Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016)

# Supersymmetric Particle Searches

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## SUPERSYMMETRIC MODEL ASSUMPTIONS

The exclusion of particle masses within a mass range ($m_1$, $m_2$) will be denoted with the notation "none $m_1$–$m_2$" in the VALUE column of the following Listings. The latest unpublished results are described in the "Supersymmetry: Experiment" review.

Most of the results shown below, unless stated otherwise, are based on the Minimal Supersymmetric Standard Model (MSSM), as described in the Note on Supersymmetry. Unless otherwise indicated, this includes the assumption of common gaugino and scalar masses at the scale of Grand Unification (GUT), and use of the resulting relations in the spectrum and decay branching ratios. It is also assumed that $R$-parity ($R$) is conserved. Unless otherwise indicated, the results also assume that:

1) The $\widetilde{\chi}^0_1$ is the lighest supersymmetric particle (LSP)
2) $m_{\widetilde{f}_L} = m_{\widetilde{f}_R}$, where $\widetilde{f}_{L,R}$ refer to the scalar partners of left- and right-handed fermions.

Limits involving different assumptions are identified in the Comments or in the Footnotes. We summarize here the notations used in this Chapter to characterize some of the most common deviations from the MSSM (for further details, see the Note on Supersymmetry).

Theories with $R$-parity violation ($\not{R}$) are characterized by a superpotential of the form: $\lambda_{ijk} L_i L_j e^c_k + \lambda'_{ijk} L_i Q_j d^c_k + \lambda''_{ijk} u^c_i d^c_j d^c_k$, where $i, j, k$ are generation indices. The presence of any of these couplings is often identified in the following by the symbols $LL\overline{E}$, $LQ\overline{D}$, and $\overline{U}\overline{D}\overline{D}$. Mass limits in the presence of $\not{R}$ will often refer to "direct" and "indirect" decays. Direct refers to $\not{R}$ decays of the particle in consideration. Indirect refers to cases where $\not{R}$ appears in the decays of the LSP.

In several models, most notably in theories with so-called Gauge Mediated Supersymmetry Breaking (GMSB), the gravitino ($\widetilde{G}$) is the LSP. It is usually much lighter than any other massive particle in the spectrum, and $m_{\widetilde{G}}$ is then neglected in all decay processes involving gravitinos. In these scenarios, particles other than the neutralino are sometimes considered as the next-to-lighest supersymmetric particle (NLSP), and are assumed to decay to their even-$R$ partner plus $\widetilde{G}$. If the lifetime is short enough for the decay to take place within the detector, $\widetilde{G}$ is assumed to be undetected and to give rise to missing energy ($\not{E}$) or missing transverse energy ($\not{E}_T$) signatures.

When needed, specific assumptions on the eigenstate content of $\widetilde{\chi}^0$ and $\widetilde{\chi}^\pm$ states are indicated, using the notation $\widetilde{\gamma}$ (photino), $\widetilde{H}$ (higgsino), $\widetilde{W}$ (wino), and $\widetilde{Z}$ (zino) to signal that the limit of pure states was used. The terms gaugino is also used, to generically indicate wino-like charginos and zino-like neutralinos.

## CONTENTS:

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## $\widetilde{\chi}^0_1$ (Lightest Neutralino) MASS LIMIT

$\widetilde{\chi}^0_1$ is often assumed to be the lightest supersymmetric particle (LSP). See also the $\widetilde{\chi}^0_2$, $\widetilde{\chi}^0_3$, $\widetilde{\chi}^0_4$ section below.

We have divided the $\widetilde{\chi}^0_1$ listings below into five sections:

1) Accelerator limits for stable $\widetilde{\chi}^0_1$,
2) Bounds on $\widetilde{\chi}^0_1$ from dark matter searches,
3) $\widetilde{\chi}^0_1 - p$ elastic cross section (spin-dependent, spin-independent interactions),
4) Other bounds on $\widetilde{\chi}^0_1$ from astrophysics and cosmology, and
5) Unstable $\widetilde{\chi}^0_1$ (Lightest Neutralino) mass limit.

### Accelerator limits for stable $\widetilde{\chi}^0_1$

Unless otherwise stated, results in this section assume spectra, production rates, decay modes, and branching ratios as evaluated in the MSSM, with gaugino and sfermion mass unification at the GUT scale. These papers generally study production of $\widetilde{\chi}^0_i \widetilde{\chi}^0_j$ ($i \geq 1$, $j \geq 2$), $\widetilde{\chi}^+_1 \widetilde{\chi}^-_1$, and (in the case of hadronic collisions) $\widetilde{\chi}^+_1 \widetilde{\chi}^0_2$ pairs. The mass limits on $\widetilde{\chi}^0_1$ are either direct, or follow indirectly from the constraints set by the non-observation of $\widetilde{\chi}^\pm_1$ and $\widetilde{\chi}^0_2$ states on the gaugino and higgsino MSSM parameters $M_2$ and $\mu$. In some cases, information is used from the nonobservation of slepton decays.

Obsolete limits obtained from $e^+e^-$ collisions up to $\sqrt{s}$=184 GeV have been removed from this compilation and can be found in the 2000 Edition (The European Physical Journal **C15** 1 (2000)) of this Review. $\Delta m = m_{\widetilde{\chi}^0_2} - m_{\widetilde{\chi}^0_1}$.

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| | | [1] DREINER | 09 | THEO | |
| >40 | 95 | [2] ABBIENDI | 04H | OPAL | all tan$\beta$, $\Delta m$ >5 GeV, $m_0$ >500 GeV, $A_0 = 0$ |
| >42.4 | 95 | [3] HEISTER | 04 | ALEP | all tan$\beta$, all $\Delta m$, all $m_0$ |

| | | | | |
|---|---|---|---|---|
| $>39.2$ | 95 | [4] ABDALLAH | 03M | DLPH | all tan$\beta$, $m_{\tilde{\nu}} >$500 GeV |
| **>46** | 95 | [5] ABDALLAH | 03M | DLPH | all tan$\beta$, all $\Delta m$, all $m_0$ |
| $>32.5$ | 95 | [6] ACCIARRI | 00D | L3 | tan$\beta > 0.7$, $\Delta m > 3$ GeV, all $m_0$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | | |
|---|---|---|---|---|---|
| | | [7] AAD | 14K | ATLS | |

[1] DREINER 09 show that in the general MSSM with non-universal gaugino masses there exists no model-independent laboratory bound on the mass of the lightest neutralino. An essentially massless $\chi^0_1$ is allowed by the experimental and observational data, imposing some constraints on other MSSM parameters, including $M_2$, $\mu$ and the slepton and squark masses.

[2] ABBIENDI 04H search for charginos and neutralinos in events with acoplanar leptons+jets and multi-jet final states in the 192–209 GeV data, combined with the results on leptonic final states from ABBIENDI 04. The results hold for a scan over the parameter space covering the region $0 < M_2 <$5000 GeV, $-1000 < \mu <$1000 GeV and tan$\beta$ from 1 to 40. This limit supersedes ABBIENDI 00H.

[3] HEISTER 04 data collected up to 209 GeV. Updates earlier analysis of selectrons from HEISTER 02E, includes a new analysis of charginos and neutralinos decaying into stau and uses results on charginos with initial state radiation from HEISTER 02J. The limit is based on the direct search for charginos and neutralinos, the constraints from the slepton search and the Higgs mass limits from HEISTER 02 using a top mass of 175 GeV, interpreted in a framework with universal gaugino and sfermion masses. Assuming the mixing in the stau sector to be negligible, the limit improves to 43.1 GeV. Under the assumption of MSUGRA with unification of the Higgs and sfermion masses, the limit improves to 50 GeV, and reaches 53 GeV for $A_0 = 0$. These limits include and update the results of BARATE 01.

[4] ABDALLAH 03M uses data from $\sqrt{s} = 192$–208 GeV. A limit on the mass of $\tilde{\chi}^0_1$ is derived from direct searches for neutralinos combined with the chargino search. Neutralinos are searched in the production of $\tilde{\chi}^0_1\tilde{\chi}^0_2$, $\tilde{\chi}^0_1\tilde{\chi}^0_3$, as well as $\tilde{\chi}^0_2\tilde{\chi}^0_3$ and $\tilde{\chi}^0_2\tilde{\chi}^0_4$ giving rise to cascade decays, and $\tilde{\chi}^0_1\tilde{\chi}^0_2$ and $\tilde{\chi}^0_1\tilde{\chi}^0_2$, followed by the decay $\tilde{\chi}^0_2 \rightarrow \tilde{\tau}\tau$. The results hold for the parameter space defined by values of $M_2 < 1$ TeV, $|\mu| \leq 2$ TeV with the $\tilde{\chi}^0_1$ as LSP. The limit is obtained for tan$\beta = 1$ and large $m_0$, where $\tilde{\chi}^0_2\tilde{\chi}^0_4$ and chargino pair production are important. If the constraint from Higgs searches is also imposed, the limit improves to 49.0 GeV in the $m_h^{\text{max}}$ scenario with $m_t$=174.3 GeV. These limits update the results of ABREU 00J.

[5] ABDALLAH 03M uses data from $\sqrt{s} = 192$–208 GeV. An indirect limit on the mass of $\tilde{\chi}^0_1$ is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays and $\tilde{\tau}\tau$ final states), for charginos (for all $\Delta m_+$) and for sleptons, stop and sbottom. The results hold for the full parameter space defined by values of $M_2 < 1$ TeV, $|\mu| \leq 2$ TeV with the $\tilde{\chi}^0_1$ as LSP. Constraints from the Higgs search in the $m_h^{\text{max}}$ scenario assuming $m_t$=174.3 GeV are included. The limit is obtained for tan$\beta \geq$ 5 when stau mixing leads to mass degeneracy between $\tilde{\tau}_1$ and $\tilde{\chi}^0_1$ and the limit is based on $\tilde{\chi}^0_2$ production followed by its decay to $\tilde{\tau}_1\tau$. In the pathological scenario where $m_0$ and $|\mu|$ are large, so that the $\tilde{\chi}^0_2$ production cross section is negligible, and where there is mixing in the stau sector but not in stop nor sbottom, the limit is based on charginos with soft decay products and an ISR photon. The limit then degrades to 39 GeV. See Figs. 40–42 for the dependence of the limit on tan$\beta$ and $m_{\tilde{\nu}}$. These limits update the results of ABREU 00W.

[6] ACCIARRI 00D data collected at $\sqrt{s}$=189 GeV. The results hold over the full parameter space defined by $0.7 \leq$ tan$\beta \leq 60$, $0 \leq M_2 \leq 2$ TeV, $m_0 \leq 500$ GeV, $|\mu| \leq 2$ TeV The minimum mass limit is reached for tan$\beta$=1 and large $m_0$. The results of slepton searches from ACCIARRI 99W are used to help set constraints in the region of small $m_0$.

The limit improves to 48 GeV for $m_0 \gtrsim 200$ GeV and $\tan\beta \gtrsim 10$. See their Figs. 6–8 for the $\tan\beta$ and $m_0$ dependence of the limits. Updates ACCIARRI 98F.

[7] AAD 14K sets limits on the $\chi$-nucleon spin-dependent and spin-independent cross sections out to $m_\chi = 10$ TeV.

## Bounds on $\widetilde{\chi}^0_1$ from dark matter searches

These papers generally exclude regions in the $M_2-\mu$ parameter plane assuming that $\widetilde{\chi}^0_1$ is the dominant form of dark matter in the galactic halo. These limits are based on the lack of detection in laboratory experiments, telescopes, or by the absence of a signal in underground neutrino detectors. The latter signal is expected if $\widetilde{\chi}^0_1$ accumulates in the Sun or the Earth and annihilates into high-energy $\nu$'s.

| *VALUE* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | |
| | [1] AARTSEN | 15C | ICCB |
| | [2] AARTSEN | 15E | ICCB |
| | [3] ABRAMOWSKI | 15 | HESS |
| | [4] ACKERMANN | 15 | FLAT |
| | [5] ACKERMANN | 15A | FLAT |
| | [6] ACKERMANN | 15B | FLAT |
| | [7] ADRIAN-MAR... | 15 | ANTR |
| | [8] BUCKLEY | 15 | THEO |
| | [9] CHOI | 15 | SKAM |
| | [10] ALEKSIC | 14 | MGIC |
| | [11] AVRORIN | 14 | BAIK |
| | [12] AARTSEN | 13 | ICCB |
| | [13] AARTSEN | 13C | ICCB |
| | [14] ABRAMOWSKI | 13 | HESS |
| | [15] ADRIAN-MAR... | 13 | ANTR |
| | [16] BERGSTROM | 13 | COSM |
| | [17] BOLIEV | 13 | BAKS |
| | [16] JIN | 13 | ASTR |
| | [16] KOPP | 13 | COSM |
| | [18] ABBASI | 12 | ICCB |
| | [19] ABRAMOWSKI | 11 | HESS |
| | [20] ABDO | 10 | FLAT |
| | [21] ACKERMANN | 10 | FLAT |
| | [22] ABBASI | 09B | ICCB |
| | [23] ACHTERBERG | 06 | AMND |
| | [24] ACKERMANN | 06 | AMND |
| | [25] DEBOER | 06 | RVUE |
| | [26] DESAI | 04 | SKAM |
| | [26] AMBROSIO | 99 | MCRO |
| | [27] LOSECCO | 95 | RVUE |
| | [28] MORI | 93 | KAMI |
| | [29] BOTTINO | 92 | COSM |
| | [30] BOTTINO | 91 | RVUE |
| | [31] GELMINI | 91 | COSM |
| | [32] KAMIONKOW... | 91 | RVUE |
| | [33] MORI | 91B | KAMI |
| none 4–15 GeV | [34] OLIVE | 88 | COSM |

[1] AARTSEN 15C is based on 316 live days of running with the IceCube detector. They set a limit of $1.9 \times 10^{-23}$ cm$^3$s$^{-1}$ on the annihilation cross section to $\nu\overline{\nu}$ for dark matter with masses between 700–1000 GeV annihilating in the Galactic halo.

[2] AARTSEN 15E is based on 319.7 live days of running with the IceCube 79-string detector. They set a limit of $4 \times 10^{-24}$ cm$^3$s$^{-1}$ on the annihilation cross section to $\nu\overline{\nu}$ for dark matter with masses between 30–10000 GeV annihilating in the Galactic center assuming an NFW profile.

[3] ABRAMOWSKI 15 places constraints on the dark matter annihilation cross section for annihilations in the Galactic center for masses between 300 GeV to 10 TeV.

[4] ACKERMANN 15 is based on 5.8 years of data with Fermi-LAT and search for monochromatic gamma-rays in the energy range of 0.2–500 GeV from dark matter annihilations. This updates ACKERMANN 13A.

[5] ACKERMANN 15A is based on 50 months of data with Fermi-LAT and search for dark matter annihilation signals in the isotropic gamma-ray background as well as galactic subhalos in the energy range of a few GeV to a few tens of TeV.

[6] ACKERMANN 15B is based on 6 years of data with Fermi-LAT observations of Milky Way dwarf spheroidal galaxies. Set limits on the annihilation cross section from $m_\chi =$ 2 GeV to 10 TeV. This updates ACKERMANN 14.

[7] ADRIAN-MARTINEZ 15 is based on data from the ANTARES neutrino telescope. They looked for interactions of $\nu_\mu$'s from neutralino annihilations in the galactic center over a background of atmospheric neutrinos and set 90% CL limits on the muon neutrino flux. They also set limits on the annihilation cross section for wimp masses of 25–10000 GeV.

[8] BUCKLEY 15 is based on 5 years of Fermi-LAT data searching for dark matter annihilation signals from Large Magellanic Cloud.

[9] CHOI 15 is based on 3903 days of SuperKamiokande data searching for neutrinos produced from dark matter annihilations in the sun. They place constraints on the dark matter-nucleon scattering cross section for dark matter masses between 4–200 GeV.

[10] ALEKSIC 14 is based on almost 160 hours of observations of Segue 1 satellite dwarf galaxy using the MAGIC telescopes between 2011 and 2013. Sets limits on the annihilation cross section out to $m_\chi = 10$ TeV.

[11] AVRORIN 14 is based on almost 2.76 years with Lake Baikal neutrino telescope. They derive 90% upper limits on the fluxes of muons and muon neutrinos from dark matter annihilations in the Sun.

[12] AARTSEN 13 is based on data collected during 317 effective days with the IceCube 79-string detector including the DeepCore sub-array. They looked for interactions of $\nu_\mu$'s from neutralino annihilations in the Sun over a background of atmospheric neutrinos and set 90% CL limits on the muon flux. They also obtain limits on the spin dependent and spin independent neutralino-proton cross section for neutralino masses in the range 20–5000 GeV.

[13] AARTSEN 13C is based on data collected during 339.8 effective days with the IceCube 59-string detector. They looked for interactions of $\nu_\mu$'s from neutralino annihilations in nearby galaxies and galaxy clusters. They obtain limits on the neutralino annihilation cross section for neutralino masses in the range 30–100,000 GeV.

[14] ABRAMOWSKI 13 place upper limits on the annihilation cross section with $\gamma\gamma$ final states in the energy range of 0.5–25 TeV.

[15] ADRIAN-MARTINEZ 13 is based on data from the ANTARES neutrino telescope. They looked for interactions of $\nu_\mu$'s from neutralino annihilations in the Sun over a background of atmospheric neutrinos and set 90% CL limits on the muon flux. They also obtain limits on the spin dependent and spin independent neutralino-proton cross section for neutralino masses in the range 50–10,000 GeV.

[16] BERGSTROM 13, JIN 13, and KOPP 13 derive limits on the mass and annihilation cross section using AMS-02 data. JIN 13 also sets a limit on the lifetime of the dark matter particle.

[17] BOLIEV 13 is based on data collected during 24.12 years of live time with the Bakson Underground Scintillator Telescope. They looked for interactions of $\nu_\mu$'s from neutralino

annihilations in the Sun over a background of atmospheric neutrinos and set 90% CL limits on the muon flux. They also obtain limits on the spin dependent and spin independent neutralino-proton cross section for neutralino masses in the range 10–1000 GeV.

[18] ABBASI 12 is based on data collected during 812 effective days with AMANDA II and 149 days of the IceCube 40-string detector combined with the data of ABBASI 09B. They looked for interactions of $\nu_\mu$'s from neutralino annihilations in the Sun over a background of atmospheric neutrinos and set 90% CL limits on the muon flux. No excess is observed. They also obtain limits on the spin dependent neutralino-proton cross section for neutralino masses in the range 50–5000 GeV.

[19] ABRAMOWSKI 11 place upper limits on the annihilation cross section with $\gamma\gamma$ final states.

[20] ABDO 10 place upper limits on the annihilation cross section with $\gamma\gamma$ or $\mu^+\mu^-$ final states.

[21] ACKERMANN 10 place upper limits on the annihilation cross section with $b\overline{b}$ or $\mu^+\mu^-$ final states.

[22] ABBASI 09B is based on data collected during 104.3 effective days with the IceCube 22-string detector. They looked for interactions of $\nu_\mu$'s from neutralino annihilations in the Sun over a background of atmospheric neutrinos and set 90% CL limits on the muon flux. They also obtain limits on the spin dependent neutralino–proton cross section for neutralino masses in the range 250–5000 GeV.

[23] ACHTERBERG 06 is based on data collected during 421.9 effective days with the AMANDA detector. They looked for interactions of $\nu_\mu$s from the centre of the Earth over a background of atmospheric neutrinos and set 90 % CL limits on the muon flux. Their limit is compared with the muon flux expected from neutralino annihilations into $W^+W^-$ and $b\overline{b}$ at the centre of the Earth for MSSM parameters compatible with the relic dark matter density, see their Fig. 7.

[24] ACKERMANN 06 is based on data collected during 143.7 days with the AMANDA-II detector. They looked for interactions of $\nu_\mu$s from the Sun over a background of atmospheric neutrinos and set 90 % CL limits on the muon flux. Their limit is compared with the muon flux expected from neutralino annihilations into $W^+W^-$ in the Sun for SUSY model parameters compatible with the relic dark matter density, see their Fig. 3.

[25] DEBOER 06 interpret an excess of diffuse Galactic gamma rays observed with the EGRET satellite as originating from $\pi^0$ decays from the annihilation of neutralinos into quark jets. They analyze the corresponding parameter space in a supergravity inspired MSSM model with radiative electroweak symmetry breaking, see their Fig. 3 for the preferred region in the $(m_0,\ m_{1/2})$ plane of a scenario with large tan$\beta$.

[26] AMBROSIO 99 and DESAI 04 set new neutrino flux limits which can be used to limit the parameter space in supersymmetric models based on neutralino annihilation in the Sun and the Earth.

[27] LOSECCO 95 reanalyzed the IMB data and places lower limit on $m_{\widetilde{\chi}^0_1}$ of 18 GeV if the LSP is a photino and 10 GeV if the LSP is a higgsino based on LSP annihilation in the sun producing high-energy neutrinos and the limits on neutrino fluxes from the IMB detector.

[28] MORI 93 excludes some region in $M_2$–$\mu$ parameter space depending on tan$\beta$ and lightest scalar Higgs mass for neutralino dark matter $m_{\widetilde{\chi}^0} > m_W$, using limits on upgoing muons produced by energetic neutrinos from neutralino annihilation in the Sun and the Earth.

[29] BOTTINO 92 excludes some region $M_2$-$\mu$ parameter space assuming that the lightest neutralino is the dark matter, using upgoing muons at Kamiokande, direct searches by Ge detectors, and by LEP experiments. The analysis includes top radiative corrections on Higgs parameters and employs two different hypotheses for nucleon-Higgs coupling. Effects of rescaling in the local neutralino density according to the neutralino relic abundance are taken into account.

[30] BOTTINO 91 excluded a region in $M_2 - \mu$ plane using upgoing muon data from Kamioka experiment, assuming that the dark matter surrounding us is composed of neutralinos and that the Higgs boson is not too heavy.

[31] GELMINI 91 exclude a region in $M_2 - \mu$ plane using dark matter searches.

[32] KAMIONKOWSKI 91 excludes a region in the $M_2$–$\mu$ plane using IMB limit on upgoing muons originated by energetic neutrinos from neutralino annihilation in the sun, assuming that the dark matter is composed of neutralinos and that $m_{H^0_1} \lesssim$ 50 GeV. See Fig. 8 in the paper.

[33] MORI 91B exclude a part of the region in the $M_2$–$\mu$ plane with $m_{\widetilde{\chi}^0_1} \lesssim$ 80 GeV using a limit on upgoing muons originated by energetic neutrinos from neutralino annihilation in the earth, assuming that the dark matter surrounding us is composed of neutralinos and that $m_{H^0_1} \lesssim$ 80 GeV.

[34] OLIVE 88 result assumes that photinos make up the dark matter in the galactic halo. Limit is based on annihilations in the sun and is due to an absence of high energy neutrinos detected in underground experiments. The limit is model dependent.

## $\widetilde{\chi}^0_1$-$p$ elastic cross section

Experimental results on the $\widetilde{\chi}^0_1$-$p$ elastic cross section are evaluated at $m_{\widetilde{\chi}^0_1}$=100 GeV. The experimental results on the cross section are often mass dependent. Therefore, the mass and cross section results are also given where the limit is strongest, when appropriate. Results are quoted separately for spin-dependent interactions (based on an effective 4-Fermi Lagrangian of the form $\overline{\chi}\gamma^\mu\gamma^5\chi\overline{q}\gamma_\mu\gamma^5 q$) and spin-independent interactions ($\overline{\chi}\chi\overline{q}q$). For calculational details see GRIEST 88B, ELLIS 88D, BARBIERI 89C, DREES 93B, ARNOWITT 96, BERGSTROM 96, and BAER 97 in addition to the theory papers listed in the Tables. For a description of the theoretical assumptions and experimental techniques underlying most of the listed papers, see the review on "Dark matter" in this "Review of Particle Physics," and references therein. Most of the following papers use galactic halo and nuclear interaction assumptions from (LEWIN 96).

### Spin-dependent interactions

| *VALUE* (pb) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| $< 1.4 \times 10^{-3}$ | 90 | [1] AMOLE 15 | PICO | $C_3F_8$ |
| $< 6.3 \times 10^{-3}$ | 90 | [2] FELIZARDO 14 | SMPL | $C_2ClF_5$ |
| $< 0.01$ | 90 | [3] APRILE 13 | X100 | Xe |
| $< 0.01$ | 90 | [4] AKIMOV 12 | ZEP3 | Xe |
| $< 0.07$ | 90 | [5] ARCHAMBAU..12 | PICA | F |
| $< 7 \times 10^{-3}$ | | [6] BEHNKE 12 | COUP | $CF_3I$ |
| $< 1.8$ | 90 | [7] DAW 12 | DRFT | $CS_2$; $CF_4$ |
| $< 8.5 \times 10^{-3}$ | | [8] FELIZARDO 12 | SMPL | $C_2ClF_5$ |
| $< 0.016$ | 90 | [9] KIM 12 | KIMS | CsI |
| $5 \times 10^{-10}$ to $10^{-5}$ | 95 | [10] BUCHMUEL... 11B | THEO | |
| $< 1$ | 90 | [11] ANGLE 08A | XE10 | Xe |
| $< 0.055$ | | [12] BEDNYAKOV 08 | HDMS | Ge |
| $< 0.33$ | 90 | [13] BEHNKE 08 | COUP | $CF_3I$ |
| $< 5$ | | [14] AKERIB 06 | CDMS | Ge |
| $< 2$ | | [15] SHIMIZU 06A | CNTR | $CaF_2$ |

| | | | | |
|---|---|---|---|---|
| $< 0.4$ | [16] ALNER | 05 | NAIA | NaI Spin Dep. |
| $< 2$ | [17] BARNABE-HE... | 05 | PICA | C |
| $2 \times 10^{-11}$ to $1 \times 10^{-4}$ | [18] ELLIS | 04 | THEO | $\mu > 0$ |
| $< 0.8$ | [19] AHMED | 03 | NAIA | NaI Spin Dep. |
| $< 40$ | [20] TAKEDA | 03 | BOLO | NaF Spin Dep. |
| $< 10$ | [21] ANGLOHER | 02 | CRES | Saphire |
| $8 \times 10^{-7}$ to $2 \times 10^{-5}$ | [22] ELLIS | 01C | THEO | $\tan\beta \leq 10$ |
| $< 3.8$ | [23] BERNABEI | 00D | DAMA | Xe |
| $< 0.8$ | SPOONER | 00 | UKDM | NaI |
| $< 4.8$ | [24] BELLI | 99C | DAMA | F |
| $<100$ | [25] OOTANI | 99 | BOLO | LiF |
| $< 0.6$ | BERNABEI | 98C | DAMA | Xe |
| $< 5$ | [24] BERNABEI | 97 | DAMA | F |

[1] The strongest limit is 0.001 pb and occurs at $m_\chi = 40$ GeV.

[2] The strongest limit is 0.0043 pb and occurs at $m_\chi = 35$ GeV. FELIZARDO 14 also presents limits for the scattering on neutrons. At $m_\chi = 100$ GeV, the upper limit is 0.13 pb and the strongest limit is 0.066 pb at $m_\chi = 35$ GeV.

[3] The strongest limit is 0.006 pb and occurs at $m_\chi = 60$ GeV. APRILE 13 also presents limits for the scattering on neutrons. At 100 GeV, the upper limit is $4 \times 10^{-4}$ pb and the strongest limit is $3.5 \times 10^{-4}$ pb at 45 GeV.

[4] This result updates LEBEDENKO 09A. The strongest limit is $8 \times 10^{-3}$ pb at $m_\chi = 50$ GeV. Limit applies to the neutralino neutron elastic cross section.

[5] This result updates ARCHAMBAULT 09. The strongest limit is 0.032 pb at $m_\chi = 20$ GeV.

[6] The strongest limit is $6 \times 10^{-3}$ at $m_\chi = 60$ GeV.

[7] The strongest limit is 1.8 pb and occurs at $m_\chi = 100$ GeV.

[8] The strongest limit is $5.7 \times 10^{-3}$ at $m_\chi = 35$ GeV.

[9] This result updates LEE 07A. The strongest limit is at $m_\chi = 80$ GeV.

[10] Predictions for the spin-dependent elastic cross section based on a frequentist approach to electroweak observables in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry.

[11] The strongest limit is 0.6 pb and occurs at $m_\chi$= 30 GeV. The limit for scattering on neutrons is 0.01 pb at $m_\chi$= 100 GeV, and the strongest limit is 0.0045 pb at $m_\chi$= 30 GeV.

[12] Limit applies to neutron elastic cross section.

[13] The strongest upper limit is 0.25 pb and occurs at $m_\chi \simeq 40$ GeV.

[14] The strongest upper limit is 4 pb and occurs at $m_\chi \simeq 60$ GeV. The limit on the neutron spin-dependent elastic cross section is 0.07 pb. This latter limit is improved in AHMED 09, where a limit of 0.02 pb is obtained at $m_\chi = 100$ GeV. The strongest limit in AHMED 09 is 0.018 pb and occurs at $m_\chi = 60$ GeV.

[15] The strongest upper limit is 1.2 pb and occurs at $m_\chi \simeq 40$ GeV. The limit on the neutron spin-dependent cross section is 35 pb.

[16] The strongest upper limit is 0.35 pb and occurs at $m_\chi \simeq 60$ GeV.

[17] The strongest upper limit is 1.2 pb and occurs $m_\chi \simeq 30$ GeV.

[18] ELLIS 04 calculates the $\chi p$ elastic scattering cross section in the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry, but without universal scalar masses. In the case of universal squark and slepton masses, but non-universal Higgs masses, the limit becomes $2 \times 10^{-4}$, see ELLIS 03E.

[19] The strongest upper limit is 0.75 pb and occurs at $m_\chi \approx 70$ GeV.

[20] The strongest upper limit is 30 pb and occurs at $m_\chi \approx 20$ GeV.

[21] The strongest upper limit is 8 pb and occurs at $m_\chi \simeq 30$ GeV.

[22] ELLIS 01C calculates the $\chi$-$p$ elastic scattering cross section in the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry. In models with nonuniversal Higgs masses, the upper limit to the cross section is $6 \times 10^{-4}$.

[23] The strongest upper limit is 3 pb and occurs at $m_\chi \simeq 60$ GeV. The limits are for inelastic scattering $X^0 + {}^{129}\mathrm{Xe} \rightarrow X^0 + {}^{129}\mathrm{Xe}^*$ (39.58 keV).

[24] The strongest upper limit is 4.4 pb and occurs at $m_\chi \simeq 60$ GeV.

[25] The strongest upper limit is about 35 pb and occurs at $m_\chi \simeq 15$ GeV.

## Spin-independent interactions

| *VALUE* (pb) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $< 6.1 \times 10^{-8}$ | 90 | AGNES | 15 | DSID | Ar |
| | 90 | [1] AGNESE | 15A | CDMS | Ge |
| $< 2.2 \times 10^{-8}$ | 90 | [2] AGNESE | 15B | CDMS | Ge |
| | | [3] AMOLE | 15 | PICO | $C_3F_8$ |
| $< 1.5 \times 10^{-8}$ | 90 | [4] XIAO | 15 | PANX | Xe |
| | | [5] AGNESE | 14 | CDMS | Ge |
| $< 1.5 \times 10^{-9}$ | 90 | [6] AKERIB | 14 | LUX | Xe |
| $10^{-11}$–$10^{-7}$ | 95 | [7] BUCHMUEL... | 14A | THEO | |
| $< 4.6 \times 10^{-6}$ | 90 | [8] FELIZARDO | 14 | SMPL | $C_2ClF_5$ |
| $10^{-11}$–$10^{-8}$ | 95 | [9] ROSZKOWSKI | 14 | THEO | |
| | | [10] AALSETH | 13 | CGNT | Ge |
| $< 2.2 \times 10^{-6}$ | 90 | [11] AGNESE | 13 | CDMS | Si |
| | | [12] LI | 13B | TEXO | Ge |
| $< 5 \times 10^{-8}$ | 90 | [13] AKIMOV | 12 | ZEP3 | Xe |
| $1.6 \times 10^{-6}$; $3.7 \times 10^{-5}$ | | [14] ANGLOHER | 12 | CRES | $CaWO_4$ |
| $< 2.6 \times 10^{-9}$ | 90 | [15] APRILE | 12 | X100 | Xe |
| | 90 | [16] ARCHAMBAU.. | 12 | PICA | $C_4F_{10}$ |
| $3 \times 10^{-12}$ to $3 \times 10^{-9}$ | 95 | [17] BECHTLE | 12 | THEO | |
| $< 1.6 \times 10^{-7}$ | | [18] BEHNKE | 12 | COUP | $CF_3I$ |
| $< 6.5 \times 10^{-6}$ | | [19] FELIZARDO | 12 | SMPL | $C_2ClF_5$ |
| $< 2.3 \times 10^{-7}$ | 90 | [20] KIM | 12 | KIMS | CsI |
| $< 3.3 \times 10^{-8}$ | 90 | [21] AHMED | 11A | | Ge |
| $< 4.4 \times 10^{-8}$ | 90 | [22] ARMENGAUD | 11 | EDE2 | Ge |
| $< 7 \times 10^{-7}$ | 90 | [23] ANGLOHER | 09 | CRES | $CaWO_4$ |
| $< 1 \times 10^{-7}$ | 90 | [24] ANGLE | 08 | XE10 | Xe |
| $< 1 \times 10^{-6}$ | 90 | BENETTI | 08 | WARP | Ar |
| $< 7.5 \times 10^{-7}$ | 90 | [25] ALNER | 07A | ZEP2 | Xe |
| $< 2 \times 10^{-7}$ | | [26] AKERIB | 06A | CDMS | Ge |
| $<90 \times 10^{-7}$ | | ALNER | 05 | NAIA | NaI Spin Indep. |
| $<12 \times 10^{-7}$ | | [27] ALNER | 05A | ZEPL | |
| $<20 \times 10^{-7}$ | | [28] ANGLOHER | 05 | CRES | $CaWO_4$ |
| $<14 \times 10^{-7}$ | | SANGLARD | 05 | EDEL | Ge |
| $< 4 \times 10^{-7}$ | | [29] AKERIB | 04 | CDMS | Ge |
| $2 \times 10^{-11}$ to $1.5 \times 10^{-7}$ | 95 | [30] BALTZ | 04 | THEO | |
| $2 \times 10^{-11}$ to $8 \times 10^{-6}$ | | [31,32] ELLIS | 04 | THEO | $\mu > 0$ |
| $< 5 \times 10^{-8}$ | | [33] PIERCE | 04A | THEO | |

| | | | | |
|---|---|---|---|---|
| $< 2 \times 10^{-5}$ | [34] AHMED | 03 | NAIA | NaI Spin Indep. |
| $< 3 \times 10^{-6}$ | [35] AKERIB | 03 | CDMS | Ge |
| $2 \times 10^{-13}$ to $2 \times 10^{-7}$ | [36] BAER | 03A | THEO | |
| $< 1.4 \times 10^{-5}$ | [37] KLAPDOR-K... | 03 | HDMS | Ge |
| $< 6 \times 10^{-6}$ | [38] ABRAMS | 02 | CDMS | Ge |
| $< 1.4 \times 10^{-6}$ | [39] BENOIT | 02 | EDEL | Ge |
| $1 \times 10^{-12}$ to $7 \times 10^{-6}$ | [31] KIM | 02B | THEO | |
| $< 3 \times 10^{-5}$ | [40] MORALES | 02B | CSME | Ge |
| $< 1 \times 10^{-5}$ | [41] MORALES | 02C | IGEX | Ge |
| $< 1 \times 10^{-6}$ | BALTZ | 01 | THEO | |
| $< 3 \times 10^{-5}$ | [42] BAUDIS | 01 | HDMS | Ge |
| $< 4.5 \times 10^{-6}$ | BENOIT | 01 | EDEL | Ge |
| $< 7 \times 10^{-6}$ | [43] BOTTINO | 01 | THEO | |
| $< 1 \times 10^{-8}$ | [44] CORSETTI | 01 | THEO | $\tan\beta \leq 25$ |
| $5 \times 10^{-10}$ to $1.5 \times 10^{-8}$ | [45] ELLIS | 01C | THEO | $\tan\beta \leq 10$ |
| $< 4 \times 10^{-6}$ | [44] GOMEZ | 01 | THEO | |
| $2 \times 10^{-10}$ to $1 \times 10^{-7}$ | [44] LAHANAS | 01 | THEO | |
| $< 3 \times 10^{-6}$ | ABUSAIDI | 00 | CDMS | Ge, Si |
| $< 6 \times 10^{-7}$ | [46] ACCOMANDO | 00 | THEO | |
| | [47] BERNABEI | 00 | DAMA | NaI |
| $2.5 \times 10^{-9}$ to $3.5 \times 10^{-8}$ | [48] FENG | 00 | THEO | $\tan\beta=10$ |
| $< 1.5 \times 10^{-5}$ | MORALES | 00 | IGEX | Ge |
| $< 4 \times 10^{-5}$ | SPOONER | 00 | UKDM | NaI |
| $< 7 \times 10^{-6}$ | BAUDIS | 99 | HDMO | $^{76}$Ge |
| $< 7 \times 10^{-6}$ | BERNABEI | 98C | DAMA | Xe |

[1] AGNESE 15A presents 90% CL limits on the elastic cross section for masses in the range 5–20 GeV, from a likelihood analysis of CDMS II data. The limit at 10 GeV is $2.5 \times 10^{-6}$ pb.

[2] AGNESE 15B result updates AHMED 10 and AHMED 09. The strongest limit is $1.8 \times 10^{-8}$ pb and occurs at $m_\chi = 60$ GeV.

[3] AMOLE 15 presents 90% CL limits on the elastic cross section for masses in the range 3–25 GeV. The strongest limit is $2 \times 10^{-6}$ pb and occurs at $m_\chi = 25$ GeV.

[4] XIAO 15 presents 90% CL limits on the elastic cross section for masses in the range 3–100 GeV. The strongest limit is $1 \times 10^{-8}$ pb and occurs at $m_\chi = 45$ GeV, using the PANDA 54 kg liquid Xenon detector over 80.1 days.

[5] AGNESE 14 presents 90% CL limits on the elastic cross section for masses in the range 3–30 GeV from 577 kg days at SuperCDMS. The strongest limit is $1 \times 10^{-7}$ pb and occurs at $m_\chi = 20$ GeV.

[6] The strongest upper limit is $7.6 \times 10^{-10}$ at $m_\chi = 33$ GeV.

[7] Predictions for the spin-independent elastic cross section based on a frequentist approach to electroweak observables in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using the 20 fb$^{-1}$ 8 TeV and the 5 fb$^{-1}$ 7 TeV LHC data and the LUX data.

[8] The strongest limit is $3.6 \times 10^{-6}$ pb and occurs at $m_\chi = 35$ GeV.

[9] Predictions for the spin-independent elastic cross section based on a Bayesian approach to electroweak observables in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using the 20 fb$^{-1}$ LHC data and LUX.

[10] AALSETH 13 presents 90% CL limits on the elastic cross section for masses in the range 4–25 GeV in addition to a region of interest at about 8 GeV. The strongest upper limit is $2 \times 10^{-5}$ pb at $m_\chi = 14$ GeV.

[11] AGNESE 13 presents 90% CL limits on the elastic cross section for masses in the range 7–100 GeV using the Si based detector. The strongest upper limit is $1.8 \times 10^{-6}$ pb at $m_\chi = 50$ GeV. This limit is improved to $7 \times 10^{-7}$ pb in AGNESE 13A.

[12] LI 13B presents 90% CL limits on the elastic cross section for masses in the range 4–40 GeV. The strongest upper limit is $4 \times 10^{-5}$ pb at $m_\chi = 14$ GeV.

[13] This result updates LEBEDENKO 09. The strongest limit is $3.9 \times 10^{-8}$ pb at $m_\chi =$ 52 GeV.

[14] ANGLOHER 12 presents results of 730 kg days from the CRESST-II dark matter detector. They find two maxima in the likelihood function corresponding to best fit WIMP masses of 25.3 and 11.6 GeV with elastic cross sections of $1.6 \times 10^{-6}$ and $3.7 \times 10^{-5}$ pb respectively, see their Table 4. The statistical significance is more than $4\sigma$.

[15] APRILE 12 updates the result of APRILE 11B. The strongest upper limit is $< 2.0 \times 10^{-9}$ pb and occurs at $m_\chi \simeq 50$ GeV.

[16] The strongest limit is $6.1 \times 10^{-5}$ pb at $m_\chi = 20$ GeV.

[17] Predictions for the spin-independent elastic cross section based on a frequentist approach to electroweak observables in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using the 5 $\text{fb}^{-1}$ LHC data and XENON100.

[18] The strongest limit is $1.4 \times 10^{-7}$ at $m_\chi = 60$ GeV.

[19] The strongest limit is $4.7 \times 10^{-6}$ at $m_\chi = 35$ GeV.

[20] This result updates LEE 07A. The strongest limit is $2.1 \times 10^{-7}$ at $m_\chi = 70$ GeV.

[21] AHMED 11A gives combined results from CDMS and EDELWEISS. The strongest limit is at $m_\chi = 90$ GeV.

[22] ARMENGAUD 11 updates result of ARMENGAUD 10. Strongest limit at $m_\chi = 85$ GeV.

[23] The strongest upper limit is $4.8 \times 10^{-7}$ pb and occurs at $m_\chi = 50$ GeV.

[24] The strongest upper limit is $5.1 \times 10^{-8}$ pb and occurs at $m_\chi \simeq 30$ GeV. The values quoted here are based on the analysis performed in ANGLE 08 with the update from SORENSEN 09.

[25] The strongest upper limit is $6.6 \times 10^{-7}$ pb and occurs at $m_\chi \simeq 65$ GeV.

[26] AKERIB 06A updates the results of AKERIB 05. The strongest upper limit is $1.6 \times 10^{-7}$ pb and occurs at $m_\chi \approx 60$ GeV.

[27] The strongest upper limit is also close to $1.0 \times 10^{-6}$ pb and occurs at $m_\chi \simeq 70$ GeV. BENOIT 06 claim that the discrimination power of ZEPLIN-I measurement (ALNER 05A) is not reliable enough to obtain a limit better than $1 \times 10^{-3}$ pb. However, SMITH 06 do not agree with the criticisms of BENOIT 06.

[28] The strongest upper limit is also close to $1.4 \times 10^{-6}$ pb and occurs at $m_\chi \simeq 70$ GeV.

[29] AKERIB 04 is incompatible with BERNABEI 00 most likely value, under the assumption of standard WIMP-halo interactions. The strongest upper limit is $4 \times 10^{-7}$ pb and occurs at $m_\chi \simeq 60$ GeV.

[30] Predictions for the spin-independent elastic cross section in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry.

[31] KIM 02 and ELLIS 04 calculate the $\chi p$ elastic scattering cross section in the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry, but without universal scalar masses.

[32] In the case of universal squark and slepton masses, but non-universal Higgs masses, the limit becomes $2 \times 10^{-6}$ ($2 \times 10^{-11}$ when constraint from the BNL $g$–2 experiment are included), see ELLIS 03E. ELLIS 05 display the sensitivity of the elastic scattering cross section to the $\pi$-Nucleon $\Sigma$ term.

[33] PIERCE 04A calculates the $\chi p$ elastic scattering cross section in the framework of models with very heavy scalar masses. See Fig. 2 of the paper.

[34] The strongest upper limit is $1.8 \times 10^{-5}$ pb and occurs at $m_\chi \approx 80$ GeV.

[35] Under the assumption of standard WIMP-halo interactions, Akerib 03 is incompatible with BERNABEI 00 most likely value at the 99.98% CL. See Fig. 4.

[36] BAER 03A calculates the $\chi p$ elastic scattering cross section in several models including the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry.

[37] The strongest upper limit is $7 \times 10^{-6}$ pb and occurs at $m_{\chi} \simeq 30$ GeV.

[38] ABRAMS 02 is incompatible with the DAMA most likely value at the 99.9% CL. The strongest upper limit is $3 \times 10^{-6}$ pb and occurs at $m_{\chi} \simeq 30$ GeV.

[39] BENOIT 02 excludes the central result of DAMA at the 99.8%CL.

[40] The strongest upper limit is $2 \times 10^{-5}$ pb and occurs at $m_{\chi} \simeq 40$ GeV.

[41] The strongest upper limit is $7 \times 10^{-6}$ pb and occurs at $m_{\chi} \simeq 46$ GeV.

[42] The strongest upper limit is $1.8 \times 10^{-5}$ pb and occurs at $m_{\chi} \simeq 32$ GeV

[43] BOTTINO 01 calculates the $\chi$-$p$ elastic scattering cross section in the framework of the following supersymmetric models: $N$=1 supergravity with the radiative breaking of the electroweak gauge symmetry, $N$=1 supergravity with nonuniversal scalar masses and an effective MSSM model at the electroweak scale.

[44] Calculates the $\chi$-$p$ elastic scattering cross section in the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry.

[45] ELLIS 01C calculates the $\chi$-$p$ elastic scattering cross section in the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry. ELLIS 02B find a range $2 \times 10^{-8}$–$1.5 \times 10^{-7}$ at tan$\beta$=50. In models with nonuniversal Higgs masses, the upper limit to the cross section is $4 \times 10^{-7}$.

[46] ACCOMANDO 00 calculate the $\chi$-$p$ elastic scattering cross section in the framework of minimal $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry. The limit is relaxed by at least an order of magnitude when models with nonuniversal scalar masses are considered. A subset of the authors in ARNOWITT 02 updated the limit to $< 9 \times 10^{-8}$ (tan$\beta$ $< 55$).

[47] BERNABEI 00 search for annual modulation of the WIMP signal. The data favor the hypothesis of annual modulation at 4$\sigma$ and are consistent, for a particular model framework quoted there, with $m_{\chi^0}=44^{+12}_{-9}$ GeV and a spin-independent $X^0$-proton cross section of $(5.4 \pm 1.0) \times 10^{-6}$ pb. See also BERNABEI 01 and BERNABEI 00C.

[48] FENG 00 calculate the $\chi$-$p$ elastic scattering cross section in the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry with a particular emphasis on focus point models. At tan$\beta$=50, the range is $8 \times 10^{-8}$–$4 \times 10^{-7}$.

## Other bounds on $\widetilde{\chi}^0_1$ from astrophysics and cosmology

Most of these papers generally exclude regions in the $M_2 - \mu$ parameter plane by requiring that the $\widetilde{\chi}^0_1$ contribution to the overall cosmological density is less than some maximal value to avoid overclosure of the Universe. Those not based on the cosmological density are indicated. Many of these papers also include LEP and/or other bounds.

| *VALUE* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|
| **>46 GeV** | [1] ELLIS 00 | RVUE | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | |
| | [2] BUCHMUEL... 14 | COSM | |
| | [3] BUCHMUEL... 14A | COSM | |

| | | | | |
|---|---|---|---|---|
| | [4] ROSZKOWSKI | 14 | COSM | |
| | [5] CABRERA | 13 | COSM | |
| | [6] ELLIS | 13B | COSM | |
| | [5] STREGE | 13 | COSM | |
| | [2] AKULA | 12 | COSM | |
| | [2] ARBEY | 12A | COSM | |
| | [2] BAER | 12 | COSM | |
| | [7] BALAZS | 12 | COSM | |
| | [8] BECHTLE | 12 | COSM | |
| | [9] BESKIDT | 12 | COSM | |
| $> 18$ GeV | [10] BOTTINO | 12 | COSM | |
| | [2] BUCHMUEL... | 12 | COSM | |
| | [2] CAO | 12A | COSM | |
| | [2] ELLIS | 12B | COSM | |
| | [11] FENG | 12B | COSM | |
| | [2] KADASTIK | 12 | COSM | |
| | [7] STREGE | 12 | COSM | |
| | [12] BUCHMUEL... | 11 | COSM | |
| | [13] ROSZKOWSKI | 11 | COSM | |
| | [14] ELLIS | 10 | COSM | |
| | [15] BUCHMUEL... | 09 | COSM | |
| | [16] DREINER | 09 | THEO | |
| | [17] BUCHMUEL... | 08 | COSM | |
| | [13] ELLIS | 08 | COSM | |
| | [18] CALIBBI | 07 | COSM | |
| | [19] ELLIS | 07 | COSM | |
| | [20] ALLANACH | 06 | COSM | |
| | [21] DE-AUSTRI | 06 | COSM | |
| | [13] BAER | 05 | COSM | |
| | [22] BALTZ | 04 | COSM | |
| $> 6$ GeV | [10,23] BELANGER | 04 | THEO | |
| | [24] ELLIS | 04B | COSM | |
| | [25] PIERCE | 04A | COSM | |
| | [26] BAER | 03 | COSM | |
| $> 6$ GeV | [10] BOTTINO | 03 | COSM | |
| | [26] CHATTOPAD... | 03 | COSM | |
| | [27] ELLIS | 03 | COSM | |
| | [13] ELLIS | 03B | COSM | |
| | [26] ELLIS | 03C | COSM | |
| | [26] LAHANAS | 03 | COSM | |
| | [28] LAHANAS | 02 | COSM | |
| | [29] BARGER | 01C | COSM | |
| | [30] ELLIS | 01B | COSM | |
| | [27] BOEHM | 00B | COSM | |
| | [31] FENG | 00 | COSM | |
| $< 600$ GeV | [32] ELLIS | 98B | COSM | |
| | [33] EDSJO | 97 | COSM | Co-annihilation |
| | [34] BAER | 96 | COSM | |
| | [13] BEREZINSKY | 95 | COSM | |
| | [35] FALK | 95 | COSM | *CP*-violating phases |
| | [36] DREES | 93 | COSM | Minimal supergravity |

| | | | | |
|---|---|---|---|---|
| | [37] FALK | 93 | COSM | Sfermion mixing |
| | [36] KELLEY | 93 | COSM | Minimal supergravity |
| | [38] MIZUTA | 93 | COSM | Co-annihilation |
| | [39] LOPEZ | 92 | COSM | Minimal supergravity, $m_0$=$A$=0 |
| | [40] MCDONALD | 92 | COSM | |
| | [41] GRIEST | 91 | COSM | |
| | [42] NOJIRI | 91 | COSM | Minimal supergravity |
| | [43] OLIVE | 91 | COSM | |
| | [44] ROSZKOWSKI | 91 | COSM | |
| | [45] GRIEST | 90 | COSM | |
| | [43] OLIVE | 89 | COSM | |
| none 100 eV – 15 GeV | SREDNICKI | 88 | COSM | $\widetilde{\gamma}$; $m_{\widetilde{f}}$=100 GeV |
| none 100 eV–5 GeV | ELLIS | 84 | COSM | $\widetilde{\gamma}$; for $m_{\widetilde{f}}$=100 GeV |
| | GOLDBERG | 83 | COSM | $\widetilde{\gamma}$ |
| | [46] KRAUSS | 83 | COSM | $\widetilde{\gamma}$ |
| | VYSOTSKII | 83 | COSM | $\widetilde{\gamma}$ |

[1] ELLIS 00 updates ELLIS 98. Uses LEP $e^+ e^-$ data at $\sqrt{s}$=202 and 204 GeV to improve bound on neutralino mass to 51 GeV when scalar mass universality is assumed and 46 GeV when Higgs mass universality is relaxed. Limits on tan$\beta$ improve to $> 2.7$ ($\mu > 0$), $> 2.2$ ($\mu < 0$) when scalar mass universality is assumed and $> 1.9$ (both signs of $\mu$) when Higgs mass universality is relaxed.

[2] Implications of the LHC result on the Higgs mass and on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry.

[3] BUCHMUELLER 14A places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches using the 20 fb$^{-1}$ 8 TeV and the 5 fb$^{-1}$ 7 TeV LHC and the LUX data.

[4] ROSZKOWSKI 14 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using Bayesian statistics and indirect experimental searches using the 20 fb$^{-1}$ LHC and the LUX data.

[5] CABRERA 13 and STREGE 13 place constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry with and without non-universal Higgs masses using the 5.8 fb$^{-1}$, $\sqrt{s} = 7$ TeV ATLAS supersymmetry searches and XENON100 results.

[6] ELLIS 13B place constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry with and without Higgs mass universality. Models with universality below the GUT scale are also considered.

[7] BALAZS 12 and STREGE 12 place constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using the 1 fb$^{-1}$ LHC supersymmetry searches, the 5 fb$^{-1}$ Higgs mass constraints, both with $\sqrt{s} = 7$ TeV, and XENON100 results.

[8] BECHTLE 12 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches, using the 5 fb$^{-1}$ LHC and XENON100 data.

[9] BESKIDT 12 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches, the 5 fb$^{-1}$ LHC and the XENON100 data.

[10] BELANGER 04 and BOTTINO 12 (see also BOTTINO 03, BOTTINO 03A and BOTTINO 04) do not assume gaugino or scalar mass unification.

[11] FENG 12B places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry and large sfermion masses using the 1 $\text{fb}^{-1}$ LHC supersymmetry searches, the 5 $\text{fb}^{-1}$ LHC Higgs mass constraints both with $\sqrt{s} = 7$ TeV, and XENON100 results.

[12] BUCHMUELLER 11 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches and including supersymmetry breaking relations between A and B parameters.

[13] Places constraints on the SUSY parameter space in the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry but non-Universal Higgs masses.

[14] ELLIS 10 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry with universality above the GUT scale.

[15] BUCHMUELLER 09 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches.

[16] DREINER 09 show that in the general MSSM with non-universal gaugino masses there exists no model-independent laboratory bound on the mass of the lightest neutralino. An essentially massless $\chi_1^0$ is allowed by the experimental and observational data, imposing some constraints on other MSSM parameters, including $M_2$, $\mu$ and the slepton and squark masses.

[17] BUCHMUELLER 08 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches.

[18] CALIBBI 07 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry with universality above the GUT scale including the effects of right-handed neutrinos.

[19] ELLIS 07 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry with universality below the GUT scale.

[20] ALLANACH 06 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry.

[21] DE-AUSTRI 06 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry.

[22] BALTZ 04 places constraints on the SUSY parameter space in the framework of $N = 1$ supergravity models with radiative breaking of the electroweak gauge symmetry.

[23] Limit assumes a pseudo scalar mass < 200 GeV. For larger pseudo scalar masses, $m_\chi > 18(29)$ GeV for $\tan\beta = 50(10)$. Bounds from WMAP, $(g-2)_\mu$, $b \to s\gamma$, LEP.

[24] ELLIS 04B places constraints on the SUSY parameter space in the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry including supersymmetry breaking relations between A and B parameters. See also ELLIS 03D.

[25] PIERCE 04A places constraints on the SUSY parameter space in the framework of models with very heavy scalar masses.

[26] BAER 03, CHATTOPADHYAY 03, ELLIS 03C and LAHANAS 03 place constraints on the SUSY parameter space in the framework of $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry based on WMAP results for the cold dark matter density.

[27] BOEHM 00B and ELLIS 03 place constraints on the SUSY parameter space in the framework of minimal $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry. Includes the effect of $\chi$-$\widetilde{t}$ co-annihilations.

[28] LAHANAS 02 places constraints on the SUSY parameter space in the framework of minimal $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry. Focuses on the role of pseudo-scalar Higgs exchange.

[29] BARGER 01C use the cosmic relic density inferred from recent CMB measurements to constrain the parameter space in the framework of minimal $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry.

[30] ELLIS 01B places constraints on the SUSY parameter space in the framework of minimal $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry. Focuses on models with large $\tan\beta$.

[31] FENG 00 explores cosmologically allowed regions of MSSM parameter space with multi-TeV masses.

[32] ELLIS 98B assumes a universal scalar mass and radiative supersymmetry breaking with universal gaugino masses. The upper limit to the LSP mass is increased due to the inclusion of $\chi - \widetilde{\tau}_R$ coannihilations.

[33] EDSJO 97 included all coannihilation processes between neutralinos and charginos for any neutralino mass and composition.

[34] Notes the location of the neutralino $Z$ resonance and $h$ resonance annihilation corridors in minimal supergravity models with radiative electroweak breaking.

[35] Mass of the bino (=LSP) is limited to $m_{\widetilde{B}} \lesssim 350$ GeV for $m_t = 174$ GeV.

[36] DREES 93, KELLEY 93 compute the cosmic relic density of the LSP in the framework of minimal $N$=1 supergravity models with radiative breaking of the electroweak gauge symmetry.

[37] FALK 93 relax the upper limit to the LSP mass by considering sfermion mixing in the MSSM.

[38] MIZUTA 93 include coannihilations to compute the relic density of Higgsino dark matter.

[39] LOPEZ 92 calculate the relic LSP density in a minimal SUSY GUT model.

[40] MCDONALD 92 calculate the relic LSP density in the MSSM including exact tree-level annihilation cross sections for all two-body final states.

[41] GRIEST 91 improve relic density calculations to account for coannihilations, pole effects, and threshold effects.

[42] NOJIRI 91 uses minimal supergravity mass relations between squarks and sleptons to narrow cosmologically allowed parameter space.

[43] Mass of the bino (=LSP) is limited to $m_{\widetilde{B}} \lesssim 350$ GeV for $m_t \leq 200$ GeV. Mass of the higgsino (=LSP) is limited to $m_{\widetilde{H}} \lesssim 1$ TeV for $m_t \leq 200$ GeV.

[44] ROSZKOWSKI 91 calculates LSP relic density in mixed gaugino/higgsino region.

[45] Mass of the bino (=LSP) is limited to $m_{\widetilde{B}} \lesssim 550$ GeV. Mass of the higgsino (=LSP) is limited to $m_{\widetilde{H}} \lesssim 3.2$ TeV.

[46] KRAUSS 83 finds $m_{\widetilde{\gamma}}$ not 30 eV to 2.5 GeV. KRAUSS 83 takes into account the gravitino decay. Find that limits depend strongly on reheated temperature. For example a new allowed region $m_{\widetilde{\gamma}} = 4$–$20$ MeV exists if $m_{\text{gravitino}} < 40$ TeV. See figure 2.

## Unstable $\widetilde{\chi}^0_1$ (Lightest Neutralino) MASS LIMIT

Unless otherwise stated, results in this section assume spectra and production rates as evaluated in the MSSM. Unless otherwise stated, the goldstino or gravitino mass $m_{\widetilde{G}}$ is assumed to be negligible relative to all other masses. In the following, $\widetilde{G}$ is assumed to be undetected and to give rise to a missing energy ($\not{E}$) signature.

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| >380 | 95 | [1] KHACHATRY...14L | CMS | $\widetilde{\chi}^0_1 \to Z\widetilde{G}$ simplified models,GMSB |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | |
|---|---|---|---|---|
| | | [2] AAD 14BH | ATLS | $2\gamma + \not{E}_T$, GMSB, SPS8 |
| | | [3] AAD 13AP | ATLS | $2\gamma + \not{E}_T$, GMSB, SPS8 |
| none 220–380 | 95 | [4] AAD 13Q | ATLS | $\gamma + b + \not{E}_T$, higgsino-like neutralino, GMSB |
| | | [5] AAD 13R | ATLS | $\tilde{\chi}^0_1 \to \mu j j$, $\not{R}$, $\lambda'_{211} \neq 0$ |
| | | [6] AALTONEN 13I | CDF | $\tilde{\chi}^0_1 \to \gamma \tilde{G}$, $\not{E}_T$, GMSB |
| >220 | 95 | [7] CHATRCHYAN 13AH | CMS | $\tilde{\chi}^0_1 \to \gamma \tilde{G}$, GMSB, SPS8, $c\tau <$ 500 mm |
| | | [8] AAD 12CP | ATLS | $2\gamma + \not{E}_T$, GMSB |
| | | [9] AAD 12CT | ATLS | $\geq 4\ell^{\pm}$, $\not{R}$ |
| | | [10] AAD 12R | ATLS | $\tilde{\chi}^0_1 \to \mu j j$, $\not{R}$, $\lambda'_{211} \neq 0$ |
| | | [11] ABAZOV 12AD | D0 | $\tilde{\chi}^0_1 \tilde{\chi}^0_1 \to \gamma Z \tilde{G} \tilde{G}$, GMSB |
| | | [12] CHATRCHYAN 12BK | CMS | $2\gamma + \not{E}_T$, GMSB |
| | | [13] CHATRCHYAN 11B | CMS | $\widetilde{W}^0 \to \gamma \tilde{G}$, $\widetilde{W}^{\pm} \to \ell^{\pm} \tilde{G}$, GMSB |
| >149 | 95 | [14] AALTONEN 10 | CDF | $p\overline{p} \to \tilde{\chi}\tilde{\chi}$, $\tilde{\chi}=\tilde{\chi}^0_2$, $\tilde{\chi}^{\pm}_1$, $\tilde{\chi}^0_1 \to \gamma \tilde{G}$, GMSB |
| >175 | 95 | [15] ABAZOV 10P | D0 | $\tilde{\chi}^0_1 \to \gamma \tilde{G}$, GMSB |
| >125 | 95 | [16] ABAZOV 08F | D0 | $p\overline{p} \to \tilde{\chi}\tilde{\chi}$, $\tilde{\chi}=\tilde{\chi}^0_2$, $\tilde{\chi}^{\pm}_1$, $\tilde{\chi}^0_1 \to \gamma \tilde{G}$, GMSB |
| | | [17] ABULENCIA 07H | CDF | $\not{R}$, $LL\overline{E}$ |
| > 96.8 | 95 | [18] ABBIENDI 06B | OPAL | $e^+e^- \to \tilde{B}\tilde{B}$, ($\tilde{B} \to \tilde{G}\gamma$) |
| | | [19] ABDALLAH 05B | DLPH | $e^+e^- \to \tilde{G}\tilde{\chi}^0_1$, ($\tilde{\chi}^0_1 \to \tilde{G}\gamma$) |
| > 96 | 95 | [20] ABDALLAH 05B | DLPH | $e^+e^- \to \tilde{B}\tilde{B}$, ($\tilde{B} \to \tilde{G}\gamma$) |

[1] KHACHATRYAN 14L searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for evidence of direct pair production of neutralinos with Higgs or $Z$-bosons in the decay chain, leading to $HH$, $HZ$ and $ZZ$ final states with missing transverse energy. The decays of 16–20. a Higgs boson to a $b$-quark pair, to a photon pair, and to final states with leptons are considered in conjunction with hadronic and leptonic decay modes of the $Z$ and $W$ bosons. No significant excesses over the expected SM backgrounds are observed. The results are interpreted in the context of GMSB simplified models where the decays $\tilde{\chi}^0_1 \to H\tilde{G}$ or $\tilde{\chi}^0_1 \to Z\tilde{G}$ take place either 100% or 50% of the time, see Figs. 16–20.

[2] AAD 14BH searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events containing non-pointing photons in a diphoton plus missing transverse energy final state. No excess is observed above the background expected from Standard Model processes. The results are used to set 95% C.L. exclusion limits in the contact of gauge-mediated supersymmetric breaking models, with the lightest neutralino being the next-to-lightest supersymmetric particle and decaying with a lifetime in the range from 0.25 ns to about 100 ns into a photon and a gravitino. For limits on the NLSP lifetime versus $\Lambda$ plane, for the SPS8 model, see their Fig. 7.

[3] AAD 13AP searched in 4.8 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events containing non-pointing photons in a diphoton plus missing transverse energy final state. No excess is observed above the background expected from Standard Model processes. The results are used to set 95% C.L. exclusion limits in the context of gauge-mediated supersymmetric breaking models, with the lightest neutralino being the next-to-lightest supersymmetric particle and decaying with a lifetime in excess of 0.25 ns into a photon and a gravitino. For limits in the NLSP lifetime versus $\Lambda$ plane, for the SPS8 model, see their Fig. 8.

[4] AAD 13Q searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events containing a high-$p_T$ isolated photon, at least one jet identified as originating from a bottom quark, and high missing transverse momentum. Such signatures may originate from supersymmetric models with gauge-mediated supersymmetry breaking in events in which one of a pair of higgsino-like neutralinos decays into a photon and a gravitino while the

other decays into a Higgs boson and a gravitino. No significant excess above the expected background was found and limits were set on the neutralino mass in a generalized GMSB model (GGM) with a higgsino-like neutralino NLSP, see their Fig. 4. Intermediate neutralino masses between 220 and 380 GeV are excluded at 95% C.L, regardless of the squark and gluino masses, purely on the basis of the expected weak production.

[5] AAD 13R looked in 4.4 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events containing new, heavy particles that decay at a significant distance from their production point into a final state containing a high-momentum muon and charged hadrons. No excess over the expected background is observed and limits are placed on the production cross-section of neutralinos via squarks for various $m_{\widetilde{q}}$, $m_{\widetilde{\chi}_1^0}$ in an R-parity violating scenario with $\lambda'_{211} \neq 0$, as a function of the neutralino lifetime, see their Fig. 6.

[6] AALTONEN 13I searched in 6.3 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV for events containing $\not\!\!E_T$ and a delayed photon that arrives late in the detector relative to the time expected from prompt production. No evidence of delayed photon production is observed.

[7] CHATRCHYAN 13AH searched in 4.9 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events containing $\not\!\!E_T$ and a delayed photon that arrives late in the detector relative to the time expected from prompt production. No significant excess above the expected background was found and limits were set on the pair production of $\widetilde{\chi}_1^0$ depending on the neutralino proper decay length, see Fig. 8. Supersedes CHATRCHYAN 12BK.

[8] AAD 12CP searched in 4.8 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with two photons and large $\not\!\!E_T$ due to $\widetilde{\chi}_1^0 \rightarrow \gamma \widetilde{G}$ decays in a GMSB framework. No significant excess above the expected background was found and limits were set on the neutralino mass in a generalized GMSB model (GGM) with a bino-like neutralino NLSP, see Figs. 6 and 7. The other sparticle masses were decoupled, $\tan\beta = 2$ and $c\tau_{NLSP} < 0.1$ mm. Also, in the framework of the SPS8 model, limits are presented in Fig. 8.

[9] AAD 12CT searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events containing four or more leptons (electrons or muons) and either moderate values of missing transverse momentum or large effective mass. No significant excess is found in the data. Limits are presented in a simplified model of *R*-parity violating supersymmetry in which charginos are pair-produced and then decay into a *W*-boson and a $\widetilde{\chi}_1^0$, which in turn decays through an RPV coupling into two charged leptons ($e^\pm e^\mp$ or $\mu^\pm \mu^\mp$) and a neutrino. In this model, limits are set on the neutralino mass as a function of the chargino mass, see Fig. 3a. Limits are also set in an *R*-parity violating mSUGRA model, see Fig. 3b.

[10] AAD 12R looked in 33 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events containing new, heavy particles that decay at a significant distance from their production point into a final state containing a high-momentum muon and charged hadrons. No excess over the expected background is observed and limits are placed on the production cross-section of neutralinos via squarks for various ($m_{\widetilde{q}}$, $m_{\widetilde{\chi}_1^0}$) in an *R*-parity violating scenario with $\lambda'_{211} \neq 0$, as a function of the neutralino lifetime, see their Fig. 8. Superseded by AAD 13R.

[11] ABAZOV 12AD looked in 6.2 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 1.96$ TeV for events with a photon, a *Z*-boson, and large $\not\!\!E_T$ in the final state. This topology corresponds to a GMSB model where pairs of neutralino NLSPs are either pair produced promptly or from decays of other supersymmetric particles and then decay to either $Z\widetilde{G}$ or $\gamma\widetilde{G}$. No significant excess over the SM expectation is observed and a limit at 95% C.L. on the cross section is derived as a function of the effective SUSY breaking scale $\Lambda$, see Fig. 3. Assuming $N_{mes} = 2$, $M_{mes} = 3\ \Lambda$, $\tan\beta = 3$, $\mu = 0.75\ M_1$, and $C_{grav} = 1$, the model is excluded at 95% C.L. for values of $\Lambda < 87$ TeV.

[12] CHATRCHYAN 12BK searched in 2.23 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with two photons and large $\not\!\!E_T$ due to $\widetilde{\chi}_1^0 \rightarrow \gamma \widetilde{G}$ decays in a GMSB framework. No significant excess above the expected background was found and limits were set on the pair production of $\widetilde{\chi}_1^0$ depending on the neutralino lifetime, see Fig. 6.

[13] CHATRCHYAN 11B looked in 35 $\mathrm{pb}^{-1}$ of $pp$ collisions at $\sqrt{s}$=7 TeV for events with an isolated lepton ($e$ or $\mu$), a photon and $\not\!\!E_T$ which may arise in a generalized gauge mediated model from the decay of Wino-like NLSPs. No evidence for an excess over the expected background is observed. Limits are derived in the plane of squark/gluino mass versus Wino mass (see Fig. 4). Mass degeneracy of the produced squarks and gluinos is assumed.

[14] AALTONEN 10 searched in 2.6 $\mathrm{fb}^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV for diphoton events with large $\not\!\!E_T$. They may originate from the production of $\widetilde{\chi}^{\pm}$ in pairs or associated to a $\widetilde{\chi}_2^0$, decaying into $\widetilde{\chi}_1^0$ which itself decays in GMSB to $\gamma\widetilde{G}$. There is no excess of events beyond expectation. An upper limit on the cross section is calculated in the GMSB model as a function of the $\widetilde{\chi}_1^0$ mass and lifetime, see their Fig. 2. A limit is derived on the $\widetilde{\chi}_1^0$ mass of 149 GeV for $\tau_{\widetilde{\chi}_1^0} \ll 1$ ns, which improves the results of previous searches.

[15] ABAZOV 10P looked in 6.3 $\mathrm{fb}^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV for events with at least two isolated $\gamma$s and large $\not\!\!E_T$. These could be the signature of $\widetilde{\chi}_2^0$ and $\widetilde{\chi}_1^{\pm}$ production, decaying to $\widetilde{\chi}_1^0$ and finally $\widetilde{\chi}_1^0 \rightarrow \gamma\widetilde{G}$ in a GMSB framework. No significant excess over the SM expectation is observed, and a limit at 95% C.L. on the cross section is derived for $N_{mes}$ = 1, $\tan\beta$ = 15 and $\mu > 0$, see their Fig. 2. This allows them to set a limit on the effective SUSY breaking scale $\Lambda > 124$ TeV, from which the excluded $\widetilde{\chi}_1^0$ mass range is obtained.

[16] ABAZOV 08F looked in 1.1 $\mathrm{fb}^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV for diphoton events with large $\not\!\!E_T$. They may originate from the production of $\widetilde{\chi}^{\pm}$ in pairs or associated to a $\widetilde{\chi}_2^0$, decaying to a $\widetilde{\chi}_1^0$ which itself decays promptly in GMSB to $\widetilde{\chi}_1^0 \rightarrow \gamma\widetilde{G}$. No significant excess was found compared to the background expectation. A limit is derived on the masses of SUSY particles in the GMSB framework for $M = 2\Lambda$, $N = 1$, $\tan\beta$ = 15 and $\mu > 0$, see Figure 2. It also excludes $\Lambda < 91.5$ TeV. Supersedes the results of ABAZOV 05A. Superseded by ABAZOV 10P.

[17] ABULENCIA 07H searched in 346 $\mathrm{pb}^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV for events with at least three leptons ($e$ or $\mu$) from the decay of $\widetilde{\chi}_1^0$ via $LL\overline{E}$ couplings. The results are consistent with the hypothesis of no signal. Upper limits on the cross-section are extracted and a limit is derived in the framework of mSUGRA on the masses of $\widetilde{\chi}_1^0$ and $\widetilde{\chi}_1^{\pm}$, see e.g. their Fig. 3 and Tab. II.

[18] ABBIENDI 06B use 600 $\mathrm{pb}^{-1}$ of data from $\sqrt{s}$ = 189–209 GeV. They look for events with diphotons + $\not\!\!E$ final states originating from prompt decays of pair-produced neutralinos in a GMSB scenario with $\widetilde{\chi}_1^0$ NLSP. Limits on the cross-section are computed as a function of m($\widetilde{\chi}_1^0$), see their Fig. 14. The limit on the $\widetilde{\chi}_1^0$ mass is for a pure Bino state assuming a prompt decay, with lifetimes up to $10^{-9}$s. Supersedes the results of ABBIENDI 04N.

[19] ABDALLAH 05B use data from $\sqrt{s}$ = 180–209 GeV. They look for events with single photons + $\not\!\!E$ final states. Limits are computed in the plane (m($\widetilde{G}$) , m($\widetilde{\chi}_1^0$)), shown in their Fig. 9b for a pure Bino state in the GMSB framework and in Fig. 9c for a no-scale supergravity model. Supersedes the results of ABREU 00Z.

[20] ABDALLAH 05B use data from $\sqrt{s}$ = 130–209 GeV. They look for events with diphotons + $\not\!\!E$ final states and single photons not pointing to the vertex, expected in GMSB when the $\widetilde{\chi}_1^0$ is the NLSP. Limits are computed in the plane (m($\widetilde{G}$), m($\widetilde{\chi}_1^0$)), see their Fig. 10. The lower limit is derived on the $\widetilde{\chi}_1^0$ mass for a pure Bino state assuming a prompt decay and $m_{\widetilde{e}_R} = m_{\widetilde{e}_L} = 2\, m_{\widetilde{\chi}_1^0}$. It improves to 100 GeV for $m_{\widetilde{e}_R} = m_{\widetilde{e}_L} = 1.1\, m_{\widetilde{\chi}_1^0}$. and the limit in the plane (m($\widetilde{\chi}_1^0$), m($\widetilde{e}_R$)) is shown in Fig. 10b. For long-lived neutralinos, cross-section limits are displayed in their Fig 11. Supersedes the results of ABREU 00Z.

# $\widetilde{\chi}^0_2$, $\widetilde{\chi}^0_3$, $\widetilde{\chi}^0_4$ (Neutralinos) MASS LIMITS

Neutralinos are unknown mixtures of photinos, z-inos, and neutral higgsinos (the supersymmetric partners of photons and of $Z$ and Higgs bosons). The limits here apply only to $\widetilde{\chi}^0_2$, $\widetilde{\chi}^0_3$, and $\widetilde{\chi}^0_4$. $\widetilde{\chi}^0_1$ is the lightest supersymmetric particle (LSP); see $\widetilde{\chi}^0_1$ Mass Limits. It is not possible to quote rigorous mass limits because they are extremely model dependent; i.e. they depend on branching ratios of various $\widetilde{\chi}^0$ decay modes, on the masses of decay products ($\widetilde{e}$, $\widetilde{\gamma}$, $\widetilde{q}$, $\widetilde{g}$), and on the $\widetilde{e}$ mass exchanged in $e^+e^- \rightarrow \widetilde{\chi}^0_i \widetilde{\chi}^0_j$. Limits arise either from direct searches, or from the MSSM constraints set on the gaugino and higgsino mass parameters $M_2$ and $\mu$ through searches for lighter charginos and neutralinos. Often limits are given as contour plots in the $m_{\widetilde{\chi}^0} - m_{\widetilde{e}}$ plane vs other parameters. When specific assumptions are made, e.g, the neutralino is a pure photino ($\widetilde{\gamma}$), pure z-ino ($\widetilde{Z}$), or pure neutral higgsino ($\widetilde{H}^0$), the neutralinos will be labelled as such.

Limits obtained from $e^+e^-$ collisions at energies up to 136 GeV, as well as other limits from different techniques, are now superseded and have not been included in this compilation. They can be found in the 1998 Edition (The European Physical Journal **C3** 1 (1998)) of this Review. Some later papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| $>$250 | 95 | [1] AAD 15BA | ATLS | $m_{\widetilde{\chi}^\pm_1} = m_{\widetilde{\chi}^0_2}$, $m_{\widetilde{\chi}^0_1} = 0$ GeV |
| $>$380 | 95 | [2] AAD 14H | ATLS | $\widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2 \rightarrow \tau^\pm \nu \widetilde{\chi}^0_1 \tau^\pm \tau^\mp \widetilde{\chi}^0_1$, simplified model, $m_{\widetilde{\chi}^\pm_1} = m_{\widetilde{\chi}^0_2}$, $m_{\widetilde{\chi}^0_1} = 0$ GeV |
| $>$700 | 95 | [2] AAD 14H | ATLS | $\widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2 \rightarrow \ell^\pm \nu \widetilde{\chi}^0_1 \ell^\pm \ell^\mp \widetilde{\chi}^0_1$, simplified model, $m_{\widetilde{\chi}^\pm_1} = m_{\widetilde{\chi}^0_2}$, $m_{\widetilde{\chi}^0_1} = 0$ GeV |
| **$>$345** | 95 | [2] AAD 14H | ATLS | $\widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2 \rightarrow W \widetilde{\chi}^0_1 Z \widetilde{\chi}^0_1$, simplified model, $m_{\widetilde{\chi}^\pm_1} = m_{\widetilde{\chi}^0_2}$, $m_{\widetilde{\chi}^0_1} = 0$ GeV |
| $>$148 | 95 | [2] AAD 14H | ATLS | $\widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2 \rightarrow W \widetilde{\chi}^0_1 H \widetilde{\chi}^0_1$, simplified model, $m_{\widetilde{\chi}^\pm_1} = m_{\widetilde{\chi}^0_2}$, $m_{\widetilde{\chi}^0_1} = 0$ GeV |
| $>$620 | 95 | [3] AAD 14X | ATLS | $\geq 4\ell^\pm$, $\widetilde{\chi}^0_{2,3} \rightarrow \ell^\pm \ell^\mp \widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1} = 0$ GeV |
| | | [4] AAD 13 | ATLS | $3\ell^\pm + \not{E}_T$, pMSSM, SMS |
| | | [5] CHATRCHYAN 12BJ | CMS | $\geq 2\ \ell$, jets $+ \not{E}_T$, $pp \rightarrow \widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| none 180–355 | 95 | [6] AAD 14G | ATLS | $\widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2 \rightarrow W \widetilde{\chi}^0_1 Z \widetilde{\chi}^0_1$, simplified model, $m_{\widetilde{\chi}^\pm_1} = m_{\widetilde{\chi}^0_2}$, $m_{\widetilde{\chi}^0_1} = 0$ GeV |
| | | [7] KHACHATRY... 14I | CMS | $\widetilde{\chi}^0_2 \rightarrow (Z,\ H) \widetilde{\chi}^0_1\ \widetilde{\ell}\ell$, simplified model |
| | | [8] AAD 12AS | ATLS | $3\ell^\pm + \not{E}_T$, pMSSM |
| | | [9] AAD 12T | ATLS | $\ell^\pm \ell^\pm + \not{E}_T$, $pp \rightarrow \widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$ |

[1] AAD 15BA searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}=8$ TeV for electroweak production of charginos and neutralinos decaying to a final state containing a $W$ boson and a 125 GeV Higgs boson, plus missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models of direct chargino and next-to-lightest neutralino production, with the decays $\widetilde{\chi}_1^\pm \rightarrow W^\pm \widetilde{\chi}_1^0$ and $\widetilde{\chi}_2^0 \rightarrow H\widetilde{\chi}_1^0$ having 100% branching fraction, see Fig. 8. A combination of the multiple final states for the Higgs decay yields the best limits (Fig. 8d).

[2] AAD 14H searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}=8$ TeV for electroweak production of charginos and neutralinos decaying to a final sate with three leptons and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models of direct chargino and next-to-lightest neutralino production, with decays to the lightest neutralino via either all three generations of leptons, staus only, gauge bosons, or Higgs bosons, see Fig. 7. An interpretation in the pMSSM is also given, see Fig. 8.

[3] AAD 14X searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}=8$ TeV for events with at least four leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the chargino mass in an R-parity conserving simplified model where the decay $\widetilde{\chi}_{2,3}^0 \rightarrow \ell^\pm \ell^\mp \widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 10.

[4] AAD 13 searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}=7$ TeV for charginos and neutralinos decaying to a final state with three leptons ($e$ and $\mu$) and missing transverse energy. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in the phenomenological MSSM, see Fig. 2 and 3, and in simplified models, see Fig. 4. For the simplified models with intermediate slepton decays, degenerate $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$ masses up to 500 GeV are excluded at 95% C.L. for very large mass differences with the $\widetilde{\chi}_1^0$. Supersedes AAD 12AS.

[5] CHATRCHYAN 12BJ searched in 4.98 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}=7$ TeV for direct electroweak production of charginos and neutralinos in events with at least two leptons, jets and missing transverse momentum. No significant excesses over the expected SM backgrounds are observed and 95% C.L. limits on the production cross section of $\widetilde{\chi}_1^\pm \widetilde{\chi}_2^0$ pair production were set in a number of simplified models, see Figs. 7 to 12. Most limits are for exactly 3 jets.

[6] AAD 14G searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}=8$ TeV for electroweak production of chargino-neutralino pairs, decaying to a final sate with two leptons ($e$ and $\mu$) and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models of chargino and next-to-lightest neutralino production, with decays to the lightest neutralino via gauge bosons, see Fig. 7. An interpretation in the pMSSM is also given, see Fig. 10.

[7] KHACHATRYAN 14I searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}=8$ TeV for electroweak production of charginos and neutralinos decaying to a final state with three leptons ($e$ or $\mu$) and missing transverse momentum, or with a $Z$-boson, dijets and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models, see Figs. 12–16.

[8] AAD 12AS searched in 2.06 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}=7$ TeV for charginos and neutralinos decaying to a final state with three leptons ($e$ and $\mu$) and missing transverse energy. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in the phenomenological MSSM, see Fig. 2 (top), and in simplified models, see Fig. 2 (bottom).

[9] AAD 12T looked in 1 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}=7$ TeV for the production of supersymmetric particles decaying into final states with missing transverse momentum and exactly two isolated leptons ($e$ or $\mu$). Same-sign dilepton events were separately studied. Additionally, in opposite-sign events, a search was made for an excess of same-flavor over different-flavor lepton pairs. No excess over the expected background is observed and limits are placed on the effective production cross section of opposite-sign dilepton events with $\not{E}_T > 250$ GeV and on same-sign dilepton events with $\not{E}_T >$

100 GeV. The latter limit is interpreted in a simplified electroweak gaugino production model.

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## $\widetilde{\chi}_1^{\pm}$, $\widetilde{\chi}_2^{\pm}$ (Charginos) MASS LIMITS

Charginos are unknown mixtures of w-inos and charged higgsinos (the supersymmetric partners of $W$ and Higgs bosons). A lower mass limit for the lightest chargino ($\widetilde{\chi}_1^{\pm}$) of approximately 45 GeV, independent of the field composition and of the decay mode, has been obtained by the LEP experiments from the analysis of the $Z$ width and decays. These results, as well as other now superseded limits from $e^+e^-$ collisions at energies below 136 GeV, and from hadronic collisions, can be found in the 1998 Edition (The European Physical Journal **C3** 1 (1998)) of this Review.

Unless otherwise stated, results in this section assume spectra, production rates, decay modes and branching ratios as evaluated in the MSSM, with gaugino and sfermion mass unification at the GUT scale. These papers generally study production of $\widetilde{\chi}_1^0\widetilde{\chi}_2^0$, $\widetilde{\chi}_1^+\widetilde{\chi}_1^-$ and (in the case of hadronic collisions) $\widetilde{\chi}_1^+\widetilde{\chi}_2^0$ pairs, including the effects of cascade decays. The mass limits on $\widetilde{\chi}_1^{\pm}$ are either direct, or follow indirectly from the constraints set by the non-observation of $\widetilde{\chi}_2^0$ states on the gaugino and higgsino MSSM parameters $M_2$ and $\mu$. For generic values of the MSSM parameters, limits from high-energy $e^+e^-$ collisions coincide with the highest value of the mass allowed by phase-space, namely $m_{\widetilde{\chi}_1^{\pm}} \lesssim \sqrt{s}/2$. The still unpublished combination of the results of the four LEP collaborations from the 2000 run of LEP2 at $\sqrt{s}$ up to $\simeq$ 209 GeV yields a lower mass limit of 103.5 GeV valid for general MSSM models. The limits become however weaker in certain regions of the MSSM parameter space where the detection efficiencies or production cross sections are suppressed. For example, this may happen when: (i) the mass differences $\Delta m_+ = m_{\widetilde{\chi}_1^{\pm}} - m_{\widetilde{\chi}_1^0}$ or $\Delta m_\nu = m_{\widetilde{\chi}_1^{\pm}} - m_{\widetilde{\nu}}$ are very small, and the detection efficiency is reduced; (ii) the electron sneutrino mass is small, and the $\widetilde{\chi}_1^{\pm}$ production rate is suppressed due to a destructive interference between $s$ and $t$ channel exchange diagrams. The regions of MSSM parameter space where the following limits are valid are indicated in the comment lines or in the footnotes.

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| >250 | 95 | [1] AAD | 15BA | ATLS | $m_{\widetilde{\chi}_1^{\pm}} = m_{\widetilde{\chi}_2^0}$, $m_{\widetilde{\chi}_1^0} = 0$ GeV |
| >590 | 95 | [2] AAD | 15CA | ATLS | $\geq 2\gamma + \not{E}_T$, GGM, bino-like NLSP, any NLSP mass |
| none 124–361 | 95 | [2] AAD | 15CA | ATLS | $\geq 1\gamma + e,\mu + \not{E}_T$, GGM, wino-like NLSP |
| >700 | 95 | [3] AAD | 14H | ATLS | $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0 \rightarrow \ell^{\pm}\nu\widetilde{\chi}_1^0\ell^{\pm}\ell^{\mp}\widetilde{\chi}_1^0$, simplified model, $m_{\widetilde{\chi}_1^{\pm}} = m_{\widetilde{\chi}_2^0}$, $m_{\widetilde{\chi}_1^0} = 0$ GeV |
| **>345** | 95 | [3] AAD | 14H | ATLS | $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0 \rightarrow W\widetilde{\chi}_1^0 Z\widetilde{\chi}_1^0$, simplified model, $m_{\widetilde{\chi}_1^{\pm}} = m_{\widetilde{\chi}_2^0}$, $m_{\widetilde{\chi}_1^0} = 0$ GeV |

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|---|---|---|---|---|---|
| >148 | 95 | [3] AAD | 14H | ATLS | $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 H\tilde{\chi}_1^0$, simplified model, $m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0}$, $m_{\tilde{\chi}_1^0} = 0$ GeV |
| >380 | 95 | [3] AAD | 14H | ATLS | $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to \tau^{\pm}\nu\tilde{\chi}_1^0\tau^{\pm}\tau^{\mp}\tilde{\chi}_1^0$, simplified model, $m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0}$, $m_{\tilde{\chi}_1^0} = 0$ GeV |
| >750 | 95 | [4] AAD | 14X | ATLS | $\geq 4\ell^{\pm}$, $\tilde{\chi}_1^{\pm} \to W^{(*)\pm}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to \ell^{\pm}\ell^{\mp}\nu$, $\not{R}$ |
| >210 | 95 | [5] KHACHATRY... | 14L | CMS | $\tilde{\chi}_2^0 \to H\tilde{\chi}_1^0$ and $\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0$ simplified models, $m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^{\pm}}$, $m_{\tilde{\chi}_1^0} = 0$ GeV |
| | | [6] AAD | 13 | ATLS | $3\ell^{\pm} + \not{E}_T$, pMSSM, SMS |
| | | [7] AAD | 13B | ATLS | $2\ell^{\pm} + \not{E}_T$, pMSSM, SMS |
| >540 | 95 | [8] AAD | 12CT | ATLS | $\geq 4\ell^{\pm}$, $\not{R}$, $m_{\tilde{\chi}_1^0} > 300$ GeV |
| | | [9] CHATRCHYAN | 12BJ | CMS | $\geq 2\ \ell$, jets + $\not{E}_T$, $pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ |
| **> 94** | 95 | [10] ABDALLAH | 03M | DLPH | $\tilde{\chi}_1^{\pm}$, $\tan\beta \leq 40$, $\Delta m_+ > 3$ GeV,all $m_0$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | | |
|---|---|---|---|---|---|
| >410 | 95 | [11] AAD | 14AV | ATLS | $\geq\ 2\ \tau + \not{E}_T$, direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ production, $m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^{\pm}}$, $m_{\tilde{\chi}_1^0} = 0$ GeV |
| >345 | 95 | [12] AAD | 14AV | ATLS | $\geq 2\ \tau + \not{E}_T$, direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ production, $m_{\tilde{\chi}_1^0} = 0$ GeV |
| none<br>100–105,<br>120–135,<br>145–160 | 95 | [13] AAD | 14G | ATLS | $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} \to W^{+}\tilde{\chi}_1^0 W^{-}\tilde{\chi}_1^0$, simplified model, $m_{\tilde{\chi}_1^0} = 0$ GeV |
| none<br>140–465 | 95 | [13] AAD | 14G | ATLS | $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} \to \ell^{+}\nu\tilde{\chi}_1^0\ell^{-}\overline{\nu}\tilde{\chi}_1^0$, simplified model, $m_{\tilde{\chi}_1^0} = 0$ GeV |
| none<br>180–355 | 95 | [13] AAD | 14G | ATLS | $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$, simplified model, $m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0}$, $m_{\tilde{\chi}_1^0} = 0$ GeV |
| >168 | 95 | [14] AALTONEN | 14 | CDF | $3\ell^{\pm}+\not{E}_T$, $\tilde{\chi}_1^{\pm} \to \ell\nu\tilde{\chi}_1^0$, mSUGRA with $m_0$=60 GeV |
| | | [15] KHACHATRY... | 14I | CMS | $\tilde{\chi}_1^{\pm} \to W\tilde{\chi}_1^0$, $\ell\tilde{\nu}$, $\tilde{\ell}\nu$, simplified model |
| | | [16] AALTONEN | 13Q | CDF | $\tilde{\chi}_1^{\pm} \to \tau X$, simplified gravity- and gauge-mediated models |
| | | [17] AAD | 12AS | ATLS | $3\ell^{\pm} + \not{E}_T$, pMSSM |
| | | [18] AAD | 12T | ATLS | $\ell^{\pm}\ell^{\mp} + \not{E}_T$, $\ell^{\pm}\ell^{\pm} + \not{E}_T$, $pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ |
| | | [19] CHATRCHYAN | 11B | CMS | $\widetilde{W}^0 \to \gamma\widetilde{G}$,$\widetilde{W}^{\pm} \to \ell^{\pm}\widetilde{G}$,GMSB |
| >163 | 95 | [20] CHATRCHYAN | 11V | CMS | $\tan\beta$=3, $m_0$=60 GeV, $A_0$=0, $\mu > 0$ |

[1] AAD 15BA searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for electroweak production of charginos and neutralinos decaying to a final state containing a $W$ boson and a 125 GeV Higgs boson, plus missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models of direct chargino and next-to-lightest neutralino production, with the decays $\widetilde{\chi}_1^\pm \rightarrow W^\pm \widetilde{\chi}_1^0$ and $\widetilde{\chi}_2^0 \rightarrow H \widetilde{\chi}_1^0$ having 100% branching fraction, see Fig. 8. A combination of the multiple final states for the Higgs decay yields the best limits (Fig. 8d).

[2] AAD 15CA searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with one or more photons and $\not{E}_T$, with or without leptons ($e$, $\mu$). No significant excess above the Standard Model expectations is observed. Limits are set on wino masses in the general gauge-mediated SUSY breaking model (GGM), for wino-like NLSP, see Fig. 9, 12

[3] AAD 14H searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for electroweak production of charginos and neutralinos decaying to a final sate with three leptons and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models of direct chargino and next-to-lightest neutralino production, with decays to the lightest neutralino via either all three generations of leptons, staus only, gauge bosons, or Higgs bosons, see Fig. 7. An interpretation in the pMSSM is also given, see Fig. 8.

[4] AAD 14X searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least four leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the wino-like chargino mass in an R-parity violating simplified model where the decay $\widetilde{\chi}_1^\pm \rightarrow W^{(*)\pm} \widetilde{\chi}_1^0$, with $\widetilde{\chi}_1^0 \rightarrow \ell^\pm \ell^\mp \nu$, takes place with a branching ratio of 100%, see Fig. 8.

[5] KHACHATRYAN 14L searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for evidence of chargino-neutralino $\widetilde{\chi}_1^\pm \widetilde{\chi}_2^0$ pair production with Higgs or $W$-bosons in the decay chain, leading to $HW$ final states with missing transverse energy. The decays of a Higgs boson to a photon pair are considered in conjunction with hadronic and leptonic decay modes of the $W$ bosons. No significant excesses over the expected SM backgrounds are observed. The results are interpreted in the context of simplified models where the decays $\widetilde{\chi}_2^0 \rightarrow H \widetilde{\chi}_1^0$ and $\widetilde{\chi}_1^\pm \rightarrow W^\pm \widetilde{\chi}_1^0$ take place 100% of the time, see Figs. 22–23.

[6] AAD 13 searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for charginos and neutralinos decaying to a final state with three leptons ($e$ and $\mu$) and missing transverse energy. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in the phenomenological MSSM, see Fig. 2 and 3, and in simplified models, see Fig. 4. For the simplified models with intermediate slepton decays, degenerate $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$ masses up to 500 GeV are excluded at 95% C.L. for very large mass differences with the $\widetilde{\chi}_1^0$. Supersedes AAD 12AS.

[7] AAD 13B searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for gauginos decaying to a final state with two leptons ($e$ and $\mu$) and missing transverse energy. No excess beyond the Standard Model expectation is observed. Limits are derived in a simplified model of wino-like chargino pair production, where the chargino always decays to the lightest neutralino via an intermediate on-shell charged slepton, see Fig. 2(b). Chargino masses between 110 and 340 GeV are excluded at 95% C.L. for $m_{\widetilde{\chi}_1^0} = 10$ GeV. Exclusion limits are also derived in the phenomenological MSSM, see Fig. 3.

[8] AAD 12CT searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events containing four or more leptons (electrons or muons) and either moderate values of missing transverse momentum or large effective mass. No significant excess is found in the data. Limits are presented in a simplified model of $R$-parity violating supersymmetry in which charginos are pair-produced and then decay into a $W$-boson and a $\widetilde{\chi}_1^0$, which in turn decays through an RPV coupling into two charged leptons ($e^\pm e^\mp$ or $e^\pm \mu^\mp$) and a neutrino. In this model, chargino masses up to 540 GeV are excluded at 95% C.L. for $m_{\widetilde{\chi}_1^0}$ above 300

GeV, see Fig. 3a. The limit deteriorates for lighter $\widetilde{\chi}^0_1$. Limits are also set in an $R$-parity violating mSUGRA model, see Fig. 3b.

[9] CHATRCHYAN 12BJ searched in 4.98 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for direct electroweak production of charginos and neutralinos in events with at least two leptons, jets and missing transverse momentum. No significant excesses over the expected SM backgrounds are observed and 95% C.L. limits on the production cross section of $\widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$ pair production were set in a number of simplified models, see Figs. 7 to 12.

[10] ABDALLAH 03M uses data from $\sqrt{s} = 192$–$208$ GeV to obtain limits in the framework of the MSSM with gaugino and sfermion mass universality at the GUT scale. An indirect limit on the mass of charginos is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays), for charginos and for sleptons. These limits are valid for values of $M_2 < 1$ TeV, $|\mu| \leq 2$ TeV with the $\widetilde{\chi}^0_1$ as LSP. Constraints from the Higgs search in the $m_h^{\text{max}}$ scenario assuming $m_t =$ 174.3 GeV are included. The quoted limit applies if there is no mixing in the third family or when $m_{\widetilde{\tau}_1} - m_{\widetilde{\chi}^0_1} > 6$ GeV. If mixing is included the limit degrades to 90 GeV. See Fig. 43 for the mass limits as a function of tan$\beta$. These limits update the results of ABREU 00W.

[11] AAD 14AV searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for the direct production of charginos, neutralinos and staus in events containing at last two hadronically decaying $\tau$-leptons, large missing transverse momentum and low jet activity. The quoted limit was derived for direct $\widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$ and $\widetilde{\chi}^\pm_1 \widetilde{\chi}^\mp_1$ production with $\widetilde{\chi}^0_2 \to \widetilde{\tau}\tau \to \tau\tau\widetilde{\chi}^0_1$ and $\widetilde{\chi}^\pm_1 \to \widetilde{\tau}\nu(\widetilde{\nu}_\tau\tau) \to \tau\nu\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_2} = m_{\widetilde{\chi}^\pm_1}$, $m_{\widetilde{\tau}} = 0.5$ ($m_{\widetilde{\chi}^\pm_1} + m_{\widetilde{\chi}^0_1}$), $m_{\widetilde{\chi}^0_1} = 0$ GeV. No excess over the expected SM background is observed. Exclusion limits are set in simplified models of $\widetilde{\chi}^\pm_1 \widetilde{\chi}^\mp_1$ and $\widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$ pair production, see their Figure 7. Upper limits on the cross section and signal strength for direct di-stau production are derived, see Figures 8 and 9. Also, limits are derived in a pMSSM model where the only light slepton is the $\widetilde{\tau}_R$, see Figure 10.

[12] AAD 14AV searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for the direct production of charginos, neutralinos and staus in events containing at last two hadronically decaying $\tau$-leptons, large missing transverse momentum and low jet activity. The quoted limit was derived for direct $\widetilde{\chi}^\pm_1 \widetilde{\chi}^\mp_1$ production with $\widetilde{\chi}^\pm_1 \to \widetilde{\tau}\nu(\widetilde{\nu}_\tau\tau) \to \tau\nu\widetilde{\chi}^0_1$, $m_{\widetilde{\tau}} = 0.5$ ($m_{\widetilde{\chi}^\pm_1} + m_{\widetilde{\chi}^0_1}$), $m_{\widetilde{\chi}^0_1} = 0$ GeV. No excess over the expected SM background is observed. Exclusion limits are set in simplified models of $\widetilde{\chi}^\pm_1 \widetilde{\chi}^\mp_1$ and $\widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$ pair production, see their Figure 7. Upper limits on the cross section and signal strength for direct di-stau production are derived, see Figures 8 and 9. Also, limits are derived in a pMSSM model where the only light slepton is the $\widetilde{\tau}_R$, see Figure 10.

[13] AAD 14G searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for electroweak production of chargino pairs, or chargino-neutralino pairs, decaying to a final sate with two leptons ($e$ and $\mu$) and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models of chargino pair production, with chargino decays to the lightest neutralino via either sleptons or gauge bosons, see Fig 5.; or in simplified models of chargino and next-to-lightest neutralino production, with decays to the lightest neutralino via gauge bosons, see Fig. 7. An interpretation in the pMSSM is also given, see Fig. 10.

[14] AALTONEN 14 searched in 5.8 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV for evidence of chargino and next-to-lightest neutralino associated production in final states consisting of three leptons (electrons, muons or taus) and large missing transverse momentum. The results are consistent with the Standard Model predictions within 1.85 $\sigma$. Limits on the chargino mass are derived in an mSUGRA model with $m_0 = 60$ GeV, tan$\beta = 3$, $A_0 =$ 0 and $\mu$ >0, see their Fig. 2.

[15] KHACHATRYAN 14I searched in 19.5 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for electroweak production of chargino pairs decaying to a final state with opposite-sign lepton pairs ($e$ or $\mu$) and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models, see Fig. 18.

[16] AALTONEN 13Q searched in 6.0 $\text{fb}^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV for evidence of chargino-neutralino associated production in like-sign dilepton final states. One lepton is identified as the hadronic decay of a tau lepton, while the other is an electron or muon. Good agreement with the Standard Model predictions is observed and limits are set on the chargino-neutralino cross section for simplified gravity- and gauge-mediated models, see their Figs. 2 and 3.

[17] AAD 12AS searched in 2.06 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for charginos and neutralinos decaying to a final state with three leptons ($e$ and $\mu$) and missing transverse energy. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in the phenomenological MSSM, see Fig. 2 (top), and in simplified models, see Fig. 2 (bottom).

[18] AAD 12T looked in 1 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for the production of supersymmetric particles decaying into final states with missing transverse momentum and exactly two isolated leptons ($e$ or $\mu$). Opposite-sign and same-sign dilepton events were separately studied. Additionally, in opposite-sign events, a search was made for an excess of same-flavor over different-flavor lepton pairs. No excess over the expected background is observed and limits are placed on the effective production cross section of opposite-sign dilepton events with $\not\!\!E_T > 250$ GeV and on same-sign dilepton events with $\not\!\!E_T > 100$ GeV. The latter limit is interpreted in a simplified electroweak gaugino production model as a lower chargino mass limit.

[19] CHATRCHYAN 11B looked in 35 $\text{pb}^{-1}$ of $pp$ collisions at $\sqrt{s}$=7 TeV for events with an isolated lepton ($e$ or $\mu$), a photon and $\not\!\!E_T$ which may arise in a generalized gauge mediated model from the decay of Wino-like NLSPs. No evidence for an excess over the expected background is observed. Limits are derived in the plane of squark/gluino mass versus Wino mass (see Fig. 4). Mass degeneracy of the produced squarks and gluinos is assumed.

[20] CHATRCHYAN 11V looked in 35 $\text{pb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with $\geq 3$ isolated leptons ($e$, $\mu$ or $\tau$), with or without jets and $\not\!\!E_T$. No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM ($m_0$, $m_{1/2}$) plane for $\tan\beta = 3$ (see Fig. 5).

## Long-lived $\widetilde{\chi}^{\pm}$ (Chargino) MASS LIMITS

Limits on charginos which leave the detector before decaying.

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| $>620$ | 95 | [1] AAD | 15AE | ATLS | stable $\widetilde{\chi}^{\pm}$ |
| $>534$ | 95 | [2] AAD | 15BM | ATLS | stable $\widetilde{\chi}^{\pm}$ |
| $>239$ | 95 | [2] AAD | 15BM | ATLS | $\widetilde{\chi}^{\pm} \to \widetilde{\chi}_1^0 \pi^{\pm}$, lifetime 1 ns, $m_{\widetilde{\chi}^{\pm}} - m_{\widetilde{\chi}_1^0} = 0.14$ GeV |
| $>482$ | 95 | [2] AAD | 15BM | ATLS | $\widetilde{\chi}^{\pm} \to \widetilde{\chi}_1^0 \pi^{\pm}$, lifetime 15 ns, $m_{\widetilde{\chi}^{\pm}} - m_{\widetilde{\chi}_1^0} = 0.14$ GeV |
| $>103$ | 95 | [3] AAD | 13H | ATLS | long-lived $\widetilde{\chi}^{\pm} \to \widetilde{\chi}_1^0 \pi^{\pm}$, mAMSB, $\Delta m_{\widetilde{\chi}_1^0} = 160$ MeV |
| $>\ 92$ | 95 | [4] AAD | 12BJ | ATLS | long-lived $\widetilde{\chi}^{\pm} \to \pi^{\pm} \widetilde{\chi}_1^0$, mAMSB |
| $>171$ | 95 | [5] ABAZOV | 09M | D0 | $\widetilde{H}$ |
| $>102$ | 95 | [6] ABBIENDI | 03L | OPAL | $m_{\widetilde{\nu}} > 500$ GeV |
| none 2–93.0 | 95 | [7] ABREU | 00T | DLPH | $\widetilde{H}^{\pm}$ or $m_{\widetilde{\nu}} > m_{\widetilde{\chi}^{\pm}}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | |
|---|---|---|---|---|
| >260 | 95 | [8] KHACHATRY...15AB | CMS | $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 \pi^{\pm}$,$\tau_{\tilde{\chi}_1^{\pm}}$=0.2ns, AMSB |
| >800 | 95 | [9] KHACHATRY...15AO | CMS | long-lived $\tilde{\chi}_1^{\pm}$, mAMSB, $\tau$ >100ns |
| >100 | 95 | [9] KHACHATRY...15AO | CMS | long-lived $\tilde{\chi}_1^{\pm}$, mAMSB, $\tau$ > 3 ns |
| | 95 | [10] KHACHATRY...15W | CMS | long-lived $\tilde{\chi}^0$, $\tilde{q} \to q\tilde{\chi}^0$, $\tilde{\chi}^0 \to \ell^+ \ell^- \nu$, $\not{R}$ |
| >270 | 95 | [11] AAD 13BD | ATLS | disappearing-track signature, AMSB |
| >278 | 95 | [12] ABAZOV 13B | D0 | long-lived $\tilde{\chi}^{\pm}$, gaugino-like |
| >244 | 95 | [12] ABAZOV 13B | D0 | long-lived $\tilde{\chi}^{\pm}$, higgsino-like |

[1] AAD 15AE searched in 19.1 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for heavy long-lived charged particles, measured through their specific ionization energy loss in the ATLAS pixel detector or their time-of-flight in the ALTAS muon system. In the absence of an excess of events above the expected backgrounds, limits are set on stable charginos, see Fig. 10.

[2] AAD 15BM searched in 18.4 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for stable and metastable non-relativistic charged particles through their anomalous specific ionization energy loss in the ATLAS pixel detector. In absence of an excess of events above the expected backgrounds, limits are set on stable charginos (see Table 5) and on metastable charginos decaying to $\tilde{\chi}_1^0 \pi^{\pm}$, see Fig. 11.

[3] AAD 13H searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for direct electroweak production of long-lived charginos in the context of AMSB scenarios. The search is based on the signature of a high-momentum isolated track with few associated hits in the outer part of the tracking system, arising from a chargino decay into a neutralino and a low-momentum pion. The $p_T$ spectrum of the tracks was found to be consistent with the SM expectations. Constraints on the lifetime and the production cross section were obtained, see Fig. 6. In the minimal AMSB framework with tan$\beta = 5$, and $\mu > 0$, a chargino having a mass below 103 (85) GeV for a chargino-neutralino mass splitting $\Delta m_{\tilde{\chi}_1^0}$ of 160 (170) MeV is excluded at the 95% C.L. See Fig. 7 for more precise bounds.

[4] AAD 12BJ looked in 1.02 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for signatures of decaying charginos resulting in isolated tracks with few associated hits in the outer region of the tracking system. The $p_T$ spectrum of the tracks was found to be consistent with the SM expectations. Constraints on the lifetime and the production cross section were obtained. In the minimal AMSB framework with $m_{3/2} < 32$ TeV, $m_0 < 1.5$ TeV, tan$\beta = 5$, and $\mu > 0$, a chargino having a mass below 92 GeV and a lifetime between 0.5 ns and 2 ns is excluded at the 95% C.L. See their Fig. 8 for more precise bounds.

[5] ABAZOV 09M searched in 1.1 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV for events with direct production of a pair of charged massive stable particles identified by their TOF. The number of the observed events is consistent with the predicted background. The data are used to constrain the production cross section as a function of the $\tilde{\chi}_1^{\pm}$ mass, see their Fig. 2. The quoted limit improves to 206 GeV for gaugino-like charginos.

[6] ABBIENDI 03L used $e^+ e^-$ data at $\sqrt{s} = $ 130–209 GeV to select events with two high momentum tracks with anomalous dE/dx. The excluded cross section is compared to the theoretical expectation as a function of the heavy particle mass in their Fig. 3. The bounds are valid for colorless fermions with lifetime longer than $10^{-6}$ s. Supersedes the results from ACKERSTAFF 98P.

[7] ABREU 00T searches for the production of heavy stable charged particles, identified by their ionization or Cherenkov radiation, using data from $\sqrt{s}$= 130 to 189 GeV. These limits include and update the results of ABREU 98P.

[8] KHACHATRYAN 15AB searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events containing tracks with little or no associated calorimeter energy deposits and with missing hits in the outer layers of the tracking system (disappearing-track signature). Such disappearing tracks can result from the decay of charginos that are nearly mass degenerate with the lightest neutralino. The number of observed events is in agreement with the background expectation. Limits are set on the cross section of electroweak chargino production in terms of the chargino mass and mean proper lifetime, see Fig. 4. In the minimal AMSB model, a chargino mass below 260 GeV is excluded at 95% C.L., see their Fig. 5.

[9] KHACHATRYAN 15O searched in 18.8 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for evidence of long-lived charginos in the context of AMSB and pMSSM scenarios. The results are based on a previously published search for heavy stable charged particles at 7 and 8 TeV. In the minimal AMSB framework with $\tan\beta = 5$ and $\mu \geq 0$, constraints on the chargino mass and lifetime were placed, see Fig. 5. Charginos with a mass below 800 (100) GeV are excluded at the 95% C.L. for lifetimes above 100 ns (3 ns). Constraints are also placed on the pMSSM parameter space, see Fig. 3.

[10] KHACHATRYAN 15W searched in up to 20.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for evidence of long-lived neutralinos produced through $\widetilde{q}$-pair production, with $\widetilde{q} \rightarrow q\widetilde{\chi}^0$ and $\widetilde{\chi}^0 \rightarrow \ell^+\ell^-\nu$ ($\not{R}$: $\lambda_{121}$, $\lambda_{122} \neq 0$). 95% C.L. exclusion limits on cross section times branching ratio are set as a function of mean proper decay length of the neutralino, see Figs. 6 and 9.

[11] AAD 13BD searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events containing tracks with no associated hits in the outer region of the tracking system resulting from the decay of charginos that are nearly mass degenerate with the lightest neutralino, as is often the case in AMSB scenarios. No significant excess above the background expectation is observed for candidate tracks with large transverse momentum. Constraints on chargino properties are obtained and in the minimal AMSB model, a chargino mass below 270 GeV is excluded at 95% C.L., see their Fig. 7.

[12] ABAZOV 13B looked in 6.3 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV for charged massive long-lived particles in events with muon-like particles that have both speed and ionization energy loss inconsistent with muons produced in beam collisions. In the absence of an excess, limits are set at 95% C.L. on gaugino- and higgsino-like charginos, see their Table 20 and Fig. 23.

## $\widetilde{\nu}$ (Sneutrino) MASS LIMIT

The limits may depend on the number, $N(\widetilde{\nu})$, of sneutrinos assumed to be degenerate in mass. Only $\widetilde{\nu}_L$ (not $\widetilde{\nu}_R$) is assumed to exist. It is possible that $\widetilde{\nu}$ could be the lightest supersymmetric particle (LSP).

We report here, but do not include in the Listings, the limits obtained from the fit of the final results obtained by the LEP Collaborations on the invisible width of the $Z$ boson ($\Delta\Gamma_{\text{inv.}} < 2.0$ MeV, LEP-SLC 06): $m_{\widetilde{\nu}} > 43.7$ GeV ($N(\widetilde{\nu})$=1) and $m_{\widetilde{\nu}} > 44.7$ GeV ($N(\widetilde{\nu})$=3) .

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| > 400 | 95 | [1] AAD 14X | ATLS | $\geq 4\ell^{\pm}$, $\widetilde{\nu} \rightarrow \nu\widetilde{\chi}_1^0$, $\widetilde{\chi}_1^0 \rightarrow \ell^{\pm}\ell^{\mp}\nu$, $\not{R}$ |
| | | [2] AAD 11Z | ATLS | $\widetilde{\nu}_\tau \rightarrow e\mu$ , $\not{R}$ |
| **> 94** | 95 | [3] ABDALLAH 03M | DLPH | $1 \leq \tan\beta \leq 40$, $m_{\widetilde{e}_R} - m_{\widetilde{\chi}_1^0}$ >10 GeV |
| > 84 | 95 | [4] HEISTER 02N | ALEP | $\widetilde{\nu}_e$, any $\Delta m$ |
| > 41 | 95 | [5] DECAMP 92 | ALEP | $\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=3 |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | | |
|---|---|---|---|---|---|
| >2000 | 95 | [6] AAD | 15O | ATLS | $\widetilde{\nu}_\tau$, $\not{R}$ ($e\mu$), $\lambda'_{311}$ = 0.11, $\lambda_{i3k}$ = 0.07 |
| >1700 | 95 | [6] AAD | 15O | ATLS | $\widetilde{\nu}_\tau$, $\not{R}$ ($\tau\mu$, $e\tau$), $\lambda'_{311}$ = 0.11, $\lambda_{i3k}$ = 0.07 |
| | | [7] AAD | 13AI | ATLS | $\widetilde{\nu}_\tau \rightarrow e\mu$, $e\tau$, $\mu\tau$, $\not{R}$ |
| | | [8] AAD | 11H | ATLS | $\widetilde{\nu}_\tau \rightarrow e\mu$, $\not{R}$ |
| | | [9] AALTONEN | 10Z | CDF | $\widetilde{\nu}_\tau \rightarrow e\mu$, $e\tau$, $\mu\tau$, $\not{R}$ |
| | | [10] ABAZOV | 10M | D0 | $\widetilde{\nu}_\tau \rightarrow e\mu$, $\not{R}$ |
| > 95 | 95 | [11] ABDALLAH | 04H | DLPH | AMSB, $\mu > 0$ |
| > 37.1 | 95 | [12] ADRIANI | 93M | L3 | $\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1 |
| > 36 | 95 | ABREU | 91F | DLPH | $\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1 |
| > 31.2 | 95 | [13] ALEXANDER | 91F | OPAL | $\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1 |

[1] AAD 14X searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events with at least four leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the sneutrino mass in an R-parity violating simplified model where the decay $\widetilde{\nu} \rightarrow \nu\widetilde{\chi}^0_1$, with $\widetilde{\chi}^0_1 \rightarrow \ell^\pm\ell^\mp\nu$, takes place with a branching ratio of 100%, see Fig. 9.

[2] AAD 11Z looked in 1.07 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with one electron and one muon of opposite charge from the production of $\widetilde{\nu}_\tau$ via an $\not{R}$ $\lambda'_{311}$ coupling and followed by a decay via $\lambda_{312}$ into $e + \mu$. No evidence for an ($e$, $\mu$) resonance over the SM expectation is observed, and a limit is derived in the plane of $\lambda'_{311}$ versus $m_{\widetilde{\nu}}$ for three values of $\lambda_{312}$, see their Fig. 2. Masses $m_{\widetilde{\nu}} < 1.32$ (1.45) TeV are excluded for $\lambda'_{311}$ = 0.10 and $\lambda_{312}$ = 0.05 ($\lambda'_{311}$ = 0.11 and $\lambda_{312}$ = 0.07).

[3] ABDALLAH 03M uses data from $\sqrt{s}$ = 192–208 GeV to obtain limits in the framework of the MSSM with gaugino and sfermion mass universality at the GUT scale. An indirect limit on the mass is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays) and for sleptons. These limits are valid for values of M$_2$ < 1 TeV, $|\mu| \leq 1$ TeV with the $\widetilde{\chi}^0_1$ as LSP. The quoted limit is obtained when there is no mixing in the third family. See Fig. 43 for the mass limits as a function of tan$\beta$. These limits update the results of ABREU 00W.

[4] HEISTER 02N derives a bound on $m_{\widetilde{\nu}_e}$ by exploiting the mass relation between the $\widetilde{\nu}_e$ and $\widetilde{e}$, based on the assumption of universal GUT scale gaugino and scalar masses $m_{1/2}$ and $m_0$ and the search described in the $\widetilde{e}$ section. In the MSUGRA framework with radiative electroweak symmetry breaking, the limit improves to $m_{\widetilde{\nu}_e}$ >130 GeV, assuming a trilinear coupling $A_0$=0 at the GUT scale. See Figs. 5 and 7 for the dependence of the limits on tan$\beta$.

[5] DECAMP 92 limit is from $\Gamma$(invisible)/$\Gamma(\ell\ell)$ = 5.91 ± 0.15 ($N_\nu$ = 2.97 ± 0.07).

[6] AAD 15O searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for evidence of heavy particles decaying into $e\mu$, $e\tau$ or $\mu\tau$ final states. No significant excess above the Standard Model expectation is observed, and 95% C.L. exclusions are placed on the cross section times branching ratio for the production of an $R$-parity-violating supersymmetric tau sneutrino, applicable to any sneutrino flavour, see their Fig. 2.

[7] AAD 13AI searched in 4.6 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for evidence of heavy particles decaying into $e\mu$, $e\tau$ or $\mu\tau$ final states. No significant excess above the Standard Model expectation is observed, and 95% C.L. exclusions are placed on the cross section times branching ratio for the production of an R-parity-violating supersymmetric tau sneutrino, see their Fig. 2. For couplings $\lambda'_{311}$ = 0.10 and $\lambda_{i3k}$ = 0.05, the lower limits on the $\widetilde{\nu}_\tau$ mass are 1610, 1110, 1100 GeV in the $e\mu$, $e\tau$, and $\mu\tau$ channels, respectively.

[8] AAD 11H looked in 35 pb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with one electron and one muon of opposite charge from the production of $\widetilde{\nu}_\tau$ via an $\not{R}$ $\lambda'_{311}$ coupling

and followed by a decay via $\lambda_{312}$ into $e +\ \mu$. No evidence for an excess over the SM expectation is observed, and a limit is derived in the plane of $\lambda'_{311}$ versus $m_{\widetilde{\nu}}$ for several values of $\lambda_{312}$, see their Fig. 2. Superseded by AAD 11Z.

[9] AALTONEN 10Z searched in 1 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV for events from the production $d\overline{d} \rightarrow\ \widetilde{\nu}_\tau$ with the subsequent decays $\widetilde{\nu}_\tau \rightarrow\ e\mu,\ \ \mu\tau,\ \ e\tau$ in the MSSM framework with $\not{R}$. Two isolated leptons of different flavor and opposite charges are required, with $\tau$s identified by their hadronic decay. No statistically significant excesses are observed over the SM background. Upper limits on $\lambda'^2_{311}$ times the branching ratio are listed in their Table III for various $\widetilde{\nu}_\tau$ masses. Limits on the cross section times branching ratio for $\lambda'_{311} = 0.10$ and $\lambda_{i3k} = 0.05$, displayed in Fig. 2, are used to set limits on the $\widetilde{\nu}_\tau$ mass of 558 GeV for the $e\mu$, 441 GeV for the $\mu\tau$ and 442 GeV for the $e\tau$ channels.

[10] ABAZOV 10M looked in 5.3 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV for events with exactly one pair of high $p_T$ isolated $e\mu$ and a veto against hard jets. No evidence for an excess over the SM expectation is observed, and a limit at 95% C.L. on the cross section times branching ratio is derived, see their Fig. 3. These limits are translated into limits on couplings as a function of $m_{\widetilde{\nu}_\tau}$ as shown on their Fig. 4. As an example, for $m_{\widetilde{\nu}_\tau}$ = 100 GeV and $\lambda_{312}\ \leq\ 0.07$, couplings $\lambda'_{311}\ >\ 7.7 \times 10^{-4}$ are excluded.

[11] ABDALLAH 04H use data from LEP 1 and $\sqrt{s}$ = 192–208 GeV. They re-use results or re-analyze the data from ABDALLAH 03M to put limits on the parameter space of anomaly-mediated supersymmetry breaking (AMSB), which is scanned in the region 1< $m_{3/2}$ <50 TeV, 0< $m_0$ <1000 GeV, 1.5<tan$\beta$ <35, both signs of $\mu$. The constraints are obtained from the searches for mass degenerate chargino and neutralino, for SM-like and invisible Higgs, for leptonically decaying charginos and from the limit on non-SM $Z$ width of 3.2 MeV. The limit is for $m_t$ = 174.3 GeV (see Table 2 for other $m_t$ values). The limit improves to 114 GeV for $\mu\ < 0$.

[12] ADRIANI 93M limit from $\Delta\Gamma(Z)$(invisible)< 16.2 MeV.

[13] ALEXANDER 91F limit is for one species of $\widetilde{\nu}$ and is derived from Γ(invisible, new)/Γ($\ell\ell$) < 0.38.

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## CHARGED SLEPTONS

This section contains limits on charged scalar leptons ($\widetilde{\ell}$, with $\ell$=$e$,$\mu$,$\tau$). Studies of width and decays of the $Z$ boson (use is made here of $\Delta\Gamma_{\text{inv}}$ < 2.0 MeV, LEP 00) conclusively rule out $m_{\widetilde{\ell}_R}$ < 40 GeV (41 GeV for $\widetilde{\ell}_L$) , independently of decay modes, for each individual slepton. The limits improve to 43 GeV (43.5 GeV for $\widetilde{\ell}_L$) assuming all 3 flavors to be degenerate. Limits on higher mass sleptons depend on model assumptions and on the mass splitting $\Delta m$= $m_{\widetilde{\ell}} - m_{\widetilde{\chi}^0_1}$. The mass and composition of $\widetilde{\chi}^0_1$ may affect the selectron production rate in $e^+ e^-$ collisions through $t$-channel exchange diagrams. Production rates are also affected by the potentially large mixing angle of the lightest mass eigenstate $\widetilde{\ell}_1$=$\widetilde{\ell}_R$ sin$\theta_\ell$ + $\widetilde{\ell}_L$ cos$\theta_\ell$. It is generally assumed that only $\widetilde{\tau}$ may have significant mixing. The coupling to the $Z$ vanishes for $\theta_\ell$=0.82. In the high-energy limit of $e^+ e^-$ collisions the interference between $\gamma$ and $Z$ exchange leads to a minimal cross section for $\theta_\ell$=0.91, a value which is sometimes used in the following entries relative to data taken at LEP2. When limits on $m_{\widetilde{\ell}_R}$ are quoted, it is understood that limits on $m_{\widetilde{\ell}_L}$ are usually at least as strong.

Possibly open decays involving gauginos other than $\widetilde{\chi}_1^0$ will affect the detection efficiencies. Unless otherwise stated, the limits presented here result from the study of $\widetilde{\ell}^+\widetilde{\ell}^-$ production, with production rates and decay properties derived from the MSSM. Limits made obsolete by the recent analyses of $e^+e^-$ collisions at high energies can be found in previous Editions of this Review.

For decays with final state gravitinos ($\widetilde{G}$), $m_{\widetilde{G}}$ is assumed to be negligible relative to all other masses.

## $\widetilde{e}$ (Selectron) MASS LIMIT

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| >410 | 95 | [1] AAD | 14X | ATLS | $\geq 4\ell^{\pm}$, $\widetilde{\ell} \rightarrow l\widetilde{\chi}_1^0$, $\widetilde{\chi}_1^0 \rightarrow \ell^{\pm}\ell^{\mp}\nu$, $\not{R}$ |
| | | [2] CHATRCHYAN | 14R | CMS | $\geq 3\ell^{\pm}$, $\widetilde{\ell} \rightarrow \ell^{\pm}\tau^{\mp}\tau^{\mp}\widetilde{G}$ simplified model, GMSB, stau (N)NLSP scenario |
| | | [3] AAD | 13B | ATLS | $2\ell^{\pm} + \not{E}_T$, SMS, pMSSM |
| **> 97.5** | | [4] ABBIENDI | 04 | OPAL | $\widetilde{e}_R$,$\Delta m >$ 11 GeV, $\lvert\mu\rvert >$100 GeV, $\tan\beta$=1.5 |
| > 94.4 | | [5] ACHARD | 04 | L3 | $\widetilde{e}_R$,$\Delta m >$ 10 GeV, $\lvert\mu\rvert >$200 GeV, $\tan\beta \geq 2$ |
| > 71.3 | | [5] ACHARD | 04 | L3 | $\widetilde{e}_R$, all $\Delta m$ |
| none 30–94 | 95 | [6] ABDALLAH | 03M | DLPH | $\Delta m >$15 GeV, $\widetilde{e}_R^+\widetilde{e}_R^-$ |
| > 94 | 95 | [7] ABDALLAH | 03M | DLPH | $\widetilde{e}_R$,$1 \leq \tan\beta \leq 40$, $\Delta m >$10 GeV |
| > 95 | 95 | [8] HEISTER | 02E | ALEP | $\Delta m >$ 15 GeV, $\widetilde{e}_R^+\widetilde{e}_R^-$ |
| > 73 | 95 | [9] HEISTER | 02N | ALEP | $\widetilde{e}_R$, any $\Delta m$ |
| **>107** | 95 | [9] HEISTER | 02N | ALEP | $\widetilde{e}_L$, any $\Delta m$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| none 90–325 | 95 | [10] AAD | 14G | ATLS | $\widetilde{\ell}\widetilde{\ell} \rightarrow \ell^+\widetilde{\chi}_1^0\ell^-\widetilde{\chi}_1^0$, simplified model, $m_{\widetilde{\ell}_L} = m_{\widetilde{\ell}_R}$, $m_{\widetilde{\chi}_1^0} = 0$ GeV |
| | | [11] KHACHATRY... | 14I | CMS | $\widetilde{\ell} \rightarrow \ell\widetilde{\chi}_1^0$, simplified model |
| > 89 | 95 | [12] ABBIENDI | 04F | OPAL | $\not{R}$, $\widetilde{e}_L$ |
| > 92 | 95 | [13] ABDALLAH | 04M | DLPH | $\not{R}$, $\widetilde{e}_R$, indirect, $\Delta m >$5 GeV |

[1] AAD 14X searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events with at least four leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the slepton mass in an R-parity violating simplified model where the decay $\widetilde{\ell} \rightarrow \ell\widetilde{\chi}_1^0$, with $\widetilde{\chi}_1^0 \rightarrow \ell^{\pm}\ell^{\mp}\nu$, takes place with a branching ratio of 100%, see Fig. 9.

[2] CHATRCHYAN 14R searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events with at least three leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the slepton mass in a stau (N)NLSP simplified model (GMSB) where the decay $\widetilde{\ell} \rightarrow \ell^{\pm}\tau^{\pm}\tau^{\mp}\widetilde{G}$ takes place with a branching ratio of 100%, see Fig. 8.

[3] AAD 13B searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for sleptons decaying to a final state with two leptons ($e$ and $\mu$) and missing transverse energy. No excess beyond

the Standard Model expectation is observed. Limits are derived in a simplified model of direct left-handed slepton pair production, where left-handed slepton masses between 85 and 195 GeV are excluded at 95% C.L. for $m_{\widetilde{\chi}^0_1} = 20$ GeV. See also Fig. 2(a). Exclusion limits are also derived in the phenomenological MSSM, see Fig. 3.

[4] ABBIENDI 04 search for $\widetilde{e}_R \widetilde{e}_R$ production in acoplanar di-electron final states in the 183–208 GeV data. See Fig. 13 for the dependence of the limits on $m_{\widetilde{\chi}^0_1}$ and for the limit at tan$\beta$=35 This limit supersedes ABBIENDI 00G.

[5] ACHARD 04 search for $\widetilde{e}_R \widetilde{e}_L$ and $\widetilde{e}_R \widetilde{e}_R$ production in single- and acoplanar di-electron final states in the 192–209 GeV data. Absolute limits on $m_{\widetilde{e}_R}$ are derived from a scan over the MSSM parameter space with universal GUT scale gaugino and scalar masses $m_{1/2}$ and $m_0$, $1 \leq \tan\beta \leq 60$ and $-2 \leq \mu \leq 2$ TeV. See Fig. 4 for the dependence of the limits on $m_{\widetilde{\chi}^0_1}$. This limit supersedes ACCIARRI 99W.

[6] ABDALLAH 03M looked for acoplanar dielectron $+\not\!\!E$ final states at $\sqrt{s} = 189$–$208$ GeV. The limit assumes $\mu$=$-200$ GeV and tan$\beta$=1.5 in the calculation of the production cross section and B($\widetilde{e} \rightarrow e \widetilde{\chi}^0_1$). See Fig. 15 for limits in the ($m_{\widetilde{e}_R}$, $m_{\widetilde{\chi}^0_1}$) plane. These limits include and update the results of ABREU 01

[7] ABDALLAH 03M uses data from $\sqrt{s} = 192$–$208$ GeV to obtain limits in the framework of the MSSM with gaugino and sfermion mass universality at the GUT scale. An indirect limit on the mass is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays) and for sleptons. These limits are valid for values of $M_2 <1$ TeV, $|\mu| \leq 1$ TeV with the $\widetilde{\chi}^0_1$ as LSP. The quoted limit is obtained when there is no mixing in the third family. See Fig. 43 for the mass limits as a function of tan$\beta$. These limits update the results of ABREU 00W.

[8] HEISTER 02E looked for acoplanar dielectron + $\not\!\!E_T$ final states from $e^+ e^-$ interactions between 183 and 209 GeV. The mass limit assumes $\mu < -200$ GeV and tan$\beta$=2 for the production cross section and B($\widetilde{e} \rightarrow e \widetilde{\chi}^0_1$)=1. See their Fig. 4 for the dependence of the limit on $\Delta m$. These limits include and update the results of BARATE 01.

[9] HEISTER 02N search for $\widetilde{e}_R \widetilde{e}_L$ and $\widetilde{e}_R \widetilde{e}_R$ production in single- and acoplanar di-electron final states in the 183–208 GeV data. Absolute limits on $m_{\widetilde{e}_R}$ are derived from a scan over the MSSM parameter space with universal GUT scale gaugino and scalar masses $m_{1/2}$ and $m_0$, $1 \leq \tan\beta \leq 50$ and $-10 \leq \mu \leq 10$ TeV. The region of small $|\mu|$, where cascade decays are important, is covered by a search for $\widetilde{\chi}^0_1 \widetilde{\chi}^0_3$ in final states with leptons and possibly photons. Limits on $m_{\widetilde{e}_L}$ are derived by exploiting the mass relation between the $\widetilde{e}_L$ and $\widetilde{e}_R$, based on universal $m_0$ and $m_{1/2}$. When the constraint from the mass limit of the lightest Higgs from HEISTER 02 is included, the bounds improve to $m_{\widetilde{e}_R}$ >77(75) GeV and $m_{\widetilde{e}_L}$ >115(115) GeV for a top mass of 175(180) GeV. In the MSUGRA framework with radiative electroweak symmetry breaking, the limits improve further to $m_{\widetilde{e}_R}$ >95 GeV and $m_{\widetilde{e}_L}$ >152 GeV, assuming a trilinear coupling $A_0$=0 at the GUT scale. See Figs. 4, 5, 7 for the dependence of the limits on tan$\beta$.

[10] AAD 14G searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for electroweak production of slepton pairs, decaying to a final sate with two leptons ($e$ and $\mu$) and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models of slepton pair production, see Fig. 8. An interpretation in the pMSSM is also given, see Fig. 10.

[11] KHACHATRYAN 14I searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for electroweak production of slepton pairs decaying to a final state with opposite-sign lepton pairs ($e$ or $\mu$) and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models, see Fig. 18.

[12] ABBIENDI 04F use data from $\sqrt{s} = 189$–$209$ GeV. They derive limits on sparticle masses under the assumption of $\not\!R$ with $L L \overline{E}$ or $L Q \overline{D}$ couplings. The results are valid for $\tan\beta = 1.5$, $\mu = -200$ GeV, with, in addition, $\Delta m$ > 5 GeV for indirect decays via $L Q \overline{D}$. The

limit quoted applies to direct decays via $LL\overline{E}$ or $LQ\overline{D}$ couplings. For indirect decays, the limits on the $\widetilde{e}_R$ mass are respectively 99 and 92 GeV for $LL\overline{E}$ and $LQ\overline{D}$ couplings and $m_{\widetilde{\chi}^0} = 10$ GeV and degrade slightly for larger $\widetilde{\chi}_1^0$ mass. Supersedes the results of ABBIENDI 00.

[13] ABDALLAH 04M use data from $\sqrt{s} = 192$–$208$ GeV to derive limits on sparticle masses under the assumption of $\not{R}$ with $LL\overline{E}$ or $\overline{U}\,\overline{D}\,\overline{D}$ couplings. The results are valid for $\mu = -200$ GeV, tan$\beta = 1.5$, $\Delta m > 5$ GeV and assuming a BR of 1 for the given decay. The limit quoted is for indirect $\overline{U}\,\overline{D}\,\overline{D}$ decays using the neutralino constraint of 39.5 GeV for $LL\overline{E}$ and of 38.0 GeV for $\overline{U}\,\overline{D}\,\overline{D}$ couplings, also derived in ABDALLAH 04M. For indirect decays via $LL\overline{E}$ the limit improves to 95 GeV if the constraint from the neutralino is used and to 94 GeV if it is not used. For indirect decays via $\overline{U}\,\overline{D}\,\overline{D}$ couplings it remains unchanged when the neutralino constraint is not used. Supersedes the result of ABREU 00U.

## $\widetilde{\mu}$ (Smuon) MASS LIMIT

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| $>410$ | 95 | [1] AAD | 14X | ATLS | $\geq 4\ell^\pm$, $\widetilde{\ell} \to \ell\widetilde{\chi}_1^0$, $\widetilde{\chi}_1^0 \to \ell^\pm\ell^\mp\nu$, $\not{R}$ |
| | | [2] CHATRCHYAN | 14R | CMS | $\geq 3\ell^\pm$, $\widetilde{\ell} \to \ell^\pm\tau^\mp\tau^\mp\widetilde{G}$ simplified model, GMSB, stau (N)NLSP scenario |
| | | [3] AAD | 13B | ATLS | $2\ell^\pm + \not{E}_T$, SMS, pMSSM |
| $>$ 91.0 | | [4] ABBIENDI | 04 | OPAL | $\Delta m$ $>3$ GeV, $\widetilde{\mu}_R^+\widetilde{\mu}_R^-$, $\lvert\mu\rvert>100$ GeV, tan$\beta$=1.5 |
| $>$ 86.7 | | [5] ACHARD | 04 | L3 | $\Delta m$ $>10$ GeV, $\widetilde{\mu}_R^+\widetilde{\mu}_R^-$, $\lvert\mu\rvert>200$ GeV, tan$\beta \geq 2$ |
| none 30–88 | 95 | [6] ABDALLAH | 03M | DLPH | $\Delta m >5$ GeV, $\widetilde{\mu}_R^+\widetilde{\mu}_R^-$ |
| **> 94** | 95 | [7] ABDALLAH | 03M | DLPH | $\widetilde{\mu}_R$,$1 \leq$ tan$\beta \leq 40$, $\Delta m > 10$ GeV |
| $>$ 88 | 95 | [8] HEISTER | 02E | ALEP | $\Delta m > 15$ GeV, $\widetilde{\mu}_R^+\widetilde{\mu}_R^-$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | | |
|---|---|---|---|---|---|
| none 90–325 | 95 | [9] AAD | 14G | ATLS | $\widetilde{\ell}\widetilde{\ell} \to \ell^+\widetilde{\chi}_1^0\ell^-\widetilde{\chi}_1^0$, simplified model, $m_{\widetilde{\ell}_L} = m_{\widetilde{\ell}_R}$, $m_{\widetilde{\chi}_1^0} = 0$ GeV |
| | | [10] KHACHATRY... | 14I | CMS | $\widetilde{\ell} \to \ell\widetilde{\chi}_1^0$, simplified model |
| $>$ 87 | 95 | [11] ABDALLAH | 04M | DLPH | $\not{R}$, $\widetilde{\mu}_R$, indirect, $\Delta m >5$ GeV |
| $>$ 81 | 95 | [12] HEISTER | 03G | ALEP | $\widetilde{\mu}_L$,$\not{R}$ decays |
| $>$ 80 | 95 | [13] ABREU | 00V | DLPH | $\widetilde{\mu}_R\widetilde{\mu}_R$ ($\widetilde{\mu}_R \to \mu\widetilde{G}$), $m_{\widetilde{G}} >8$ eV |

[1] AAD 14X searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least four leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the slepton mass in an R-parity violating simplified model where the decay $\widetilde{\ell} \to \ell\widetilde{\chi}_1^0$, with $\widetilde{\chi}_1^0 \to \ell^\pm\ell^\mp\nu$, takes place with a branching ratio of 100%, see Fig. 9.

[2] CHATRCHYAN 14R searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least three leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the slepton mass in a stau (N)NLSP simplified model (GMSB) where the decay $\widetilde{\ell} \to \ell^\pm\tau^\pm\tau^\mp\widetilde{G}$ takes place with a branching ratio of 100%, see Fig. 8.

[3] AAD 13B searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for sleptons decaying to a final state with two leptons ($e$ and $\mu$) and missing transverse energy. No excess beyond the Standard Model expectation is observed. Limits are derived in a simplified model of

direct left-handed slepton pair production, where left-handed slepton masses between 85 and 195 GeV are excluded at 95% C.L. for $m_{\widetilde{\chi}_1^0} = 20$ GeV. See also Fig. 2(a). Exclusion limits are also derived in the phenomenological MSSM, see Fig. 3.

[4] ABBIENDI 04 search for $\widetilde{\mu}_R \widetilde{\mu}_R$ production in acoplanar di-muon final states in the 183–208 GeV data. See Fig. 14 for the dependence of the limits on $m_{\widetilde{\chi}_1^0}$ and for the limit at tan$\beta$=35. Under the assumption of 100% branching ratio for $\widetilde{\mu}_R \rightarrow \mu \widetilde{\chi}_1^0$, the limit improves to 94.0 GeV for $\Delta m > 4$ GeV. See Fig. 11 for the dependence of the limits on $\mathrm{m}_{\widetilde{\chi}_1^0}$ at several values of the branching ratio. This limit supersedes ABBIENDI 00G.

[5] ACHARD 04 search for $\widetilde{\mu}_R \widetilde{\mu}_R$ production in acoplanar di-muon final states in the 192–209 GeV data. Limits on $m_{\widetilde{\mu}_R}$ are derived from a scan over the MSSM parameter space with universal GUT scale gaugino and scalar masses $m_{1/2}$ and $m_0$, $1 \leq \tan\beta \leq 60$ and $-2 \leq \mu \leq 2$ TeV. See Fig. 4 for the dependence of the limits on $m_{\widetilde{\chi}_1^0}$. This limit supersedes ACCIARRI 99W.

[6] ABDALLAH 03M looked for acoplanar dimuon $+\not{E}$ final states at $\sqrt{s}$ = 189–208 GeV. The limit assumes $\mathrm{B}(\widetilde{\mu} \rightarrow \mu \widetilde{\chi}_1^0) = 100\%$. See Fig. 16 for limits on the $(m_{\widetilde{\mu}_R}, m_{\widetilde{\chi}_1^0})$ plane. These limits include and update the results of ABREU 01.

[7] ABDALLAH 03M uses data from $\sqrt{s}$ = 192–208 GeV to obtain limits in the framework of the MSSM with gaugino and sfermion mass universality at the GUT scale. An indirect limit on the mass is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays) and for sleptons. These limits are valid for values of $\mathrm{M}_2 < 1$ TeV, $|\mu| \leq 1$ TeV with the $\widetilde{\chi}_1^0$ as LSP. The quoted limit is obtained when there is no mixing in the third family. See Fig. 43 for the mass limits as a function of tan$\beta$. These limits update the results of ABREU 00W.

[8] HEISTER 02E looked for acoplanar dimuon $+ \not{E}_T$ final states from $e^+ e^-$ interactions between 183 and 209 GeV. The mass limit assumes $\mathrm{B}(\widetilde{\mu} \rightarrow \mu \widetilde{\chi}_1^0)$=1. See their Fig. 4 for the dependence of the limit on $\Delta m$. These limits include and update the results of BARATE 01.

[9] AAD 14G searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for electroweak production of slepton pairs, decaying to a final sate with two leptons ($e$ and $\mu$) and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models of slepton pair production, see Fig. 8. An interpretation in the pMSSM is also given, see Fig. 10.

[10] KHACHATRYAN 14I searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for electroweak production of slepton pairs decaying to a final state with opposite-sign lepton pairs ($e$ or $\mu$) and missing transverse momentum. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in simplified models, see Fig. 18.

[11] ABDALLAH 04M use data from $\sqrt{s}$ = 192–208 GeV to derive limits on sparticle masses under the assumption of $\not{R}$ with $LL\overline{E}$ or $\overline{UDD}$ couplings. The results are valid for $\mu = -200$ GeV, tan$\beta$ = 1.5, $\Delta m > 5$ GeV and assuming a BR of 1 for the given decay. The limit quoted is for indirect $\overline{UDD}$ decays using the neutralino constraint of 39.5 GeV for $LL\overline{E}$ and of 38.0 GeV for $\overline{UDD}$ couplings, also derived in ABDALLAH 04M. For indirect decays via $LL\overline{E}$ the limit improves to 90 GeV if the constraint from the neutralino is used and remains at 87 GeV if it is not used. For indirect decays via $\overline{UDD}$ couplings it degrades to 85 GeV when the neutralino constraint is not used. Supersedes the result of ABREU 00U.

[12] HEISTER 03G searches for the production of smuons in the case of $\not{R}$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$ or $\overline{UDD}$ couplings at $\sqrt{s}$ = 189–209 GeV. The search is performed for direct and indirect decays, assuming one coupling at a time to be non-zero. The limit holds for direct decays mediated by $\not{R}$ $LQ\overline{D}$ couplings and improves to 90 GeV for indirect decays (for $\Delta m > 10$ GeV). Limits are also given for $LL\overline{E}$ direct ($m_{\widetilde{\mu}R} > 87$ GeV) and indirect decays ($m_{\widetilde{\mu}R} > 96$ GeV for $m(\widetilde{\chi}_1^0) > 23$ GeV from BARATE 98S) and for $\overline{UDD}$ indirect decays ($m_{\widetilde{\mu}R} > 85$ GeV for $\Delta m > 10$ GeV). Supersedes the results from BARATE 01B.

[13] ABREU 00V use data from $\sqrt{s}$= 130–189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. For limits at different $m_{\widetilde{G}}$, see their Fig. 12.

## $\widetilde{\tau}$ (Stau) MASS LIMIT

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| $>85.2$ | | [1] ABBIENDI | 04 | OPAL | $\Delta m > 6$ GeV, $\theta_{\tau}=\pi/2$, $\lvert\mu\rvert >$ 100 GeV, $\tan\beta=1.5$ |
| $>78.3$ | | [2] ACHARD | 04 | L3 | $\Delta m > 15$ GeV, $\theta_{\tau}=\pi/2$, $\lvert\mu\rvert >200$ GeV,$\tan\beta \geq 2$ |
| **>81.9** | 95 | [3] ABDALLAH | 03M | DLPH | $\Delta m >15$ GeV, all $\theta_{\tau}$ |
| $>79$ | 95 | [4] HEISTER | 02E | ALEP | $\Delta m > 15$ GeV, $\theta_{\tau}=\pi/2$ |
| $>76$ | 95 | [4] HEISTER | 02E | ALEP | $\Delta m > 15$ GeV, $\theta_{\tau}=0.91$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| | | [5] AAD | 12AF | ATLS | $2\tau$ + jets + $\not\!\!E_T$, GMSB |
| | | [6] AAD | 12AG | ATLS | $\geq 1\tau_h$ + jets + $\not\!\!E_T$, GMSB |
| | | [7] AAD | 12CM | ATLS | $\geq 1\tau$ + jets + $\not\!\!E_T$, GMSB |
| $>87.4$ | 95 | [8] ABBIENDI | 06B | OPAL | $\widetilde{\tau}_R \rightarrow \tau\widetilde{G}$, all $\tau(\widetilde{\tau}_R)$ |
| $>74$ | 95 | [9] ABBIENDI | 04F | OPAL | $\not{R}$, $\widetilde{\tau}_L$ |
| $>68$ | 95 | [10] ABDALLAH | 04H | DLPH | AMSB, $\mu > 0$ |
| $>90$ | 95 | [11] ABDALLAH | 04M | DLPH | $\not{R}$, $\widetilde{\tau}_R$, indirect, $\Delta m >5$ GeV |
| none $m_{\tau}-$ 26.3 | 95 | [3] ABDALLAH | 03M | DLPH | $\Delta m > m_{\tau}$, all $\theta_{\tau}$ |

[1] ABBIENDI 04 search for $\widetilde{\tau}\widetilde{\tau}$ production in acoplanar di-tau final states in the 183–208 GeV data. See Fig. 15 for the dependence of the limits on $m_{\widetilde{\chi}^0_1}$ and for the limit at $\tan\beta$=35. Under the assumption of 100% branching ratio for $\widetilde{\tau}_R \rightarrow \tau\widetilde{\chi}^0_1$, the limit improves to 89.8 GeV for $\Delta m > 8$ GeV. See Fig. 12 for the dependence of the limits on $m_{\widetilde{\chi}^0_1}$ at several values of the branching ratio and for their dependence on $\theta_{\tau}$. This limit supersedes ABBIENDI 00G.

[2] ACHARD 04 search for $\widetilde{\tau}\widetilde{\tau}$ production in acoplanar di-tau final states in the 192–209 GeV data. Limits on $m_{\widetilde{\tau}_R}$ are derived from a scan over the MSSM parameter space with universal GUT scale gaugino and scalar masses $m_{1/2}$ and $m_0$, $1 \leq \tan\beta \leq 60$ and $-2 \leq \mu \leq 2$ TeV. See Fig. 4 for the dependence of the limits on $m_{\widetilde{\chi}^0_1}$.

[3] ABDALLAH 03M looked for acoplanar ditaus $+\not\!\!E$ final states at $\sqrt{s}$ = 130–208 GeV. A dedicated search was made for low mass $\widetilde{\tau}$s decoupling from the $Z^0$. The limit assumes B($\widetilde{\tau} \rightarrow \tau\widetilde{\chi}^0_1$) = 100%. See Fig. 20 for limits on the ($m_{\widetilde{\tau}}$,$m_{\widetilde{\chi}^0_1}$) plane and as function of the $\widetilde{\chi}^0_1$ mass and of the branching ratio. The limit in the low-mass region improves to 29.6 and 31.1 GeV for $\widetilde{\tau}_R$ and $\widetilde{\tau}_L$, respectively, at $\Delta m > m_{\tau}$. The limit in the high-mass region improves to 84.7 GeV for $\widetilde{\tau}_R$ and $\Delta m > 15$ GeV. These limits include and update the results of ABREU 01.

[4] HEISTER 02E looked for acoplanar ditau + $\not\!\!E_T$ final states from $e^+e^-$ interactions between 183 and 209 GeV. The mass limit assumes B($\widetilde{\tau} \rightarrow \tau\widetilde{\chi}^0_1$)=1. See their Fig. 4 for the dependence of the limit on $\Delta m$. These limits include and update the results of BARATE 01.

[5] AAD 12AF searched in 2 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with two tau leptons, jets and large $\not{E}_T$ in a GMSB framework. No significant excess above the expected background was found and an upper limit on the visible cross section for new phenomena is set. A 95% C.L. lower limit of 32 TeV on the mGMSB breaking scale $\Lambda$ is set for $M_{mess}$ = 250 TeV, $N_S$ = 3, $\mu$ > 0 and $C_{grav}$ = 1, independent of tan$\beta$.

[6] AAD 12AG searched in 2.05 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with at least one hadronically decaying tau lepton, jets, and large $\not{E}_T$ in a GMSB framework. No significant excess above the expected background was found and an upper limit on the visible cross section for new phenomena is set. A 95% C.L. lower limit of 30 TeV on the mGMSB breaking scale $\Lambda$ is set for $M_{mess}$ = 250 TeV, $N_S$ = 3, $\mu$ > 0 and $C_{grav}$ = 1, independent of tan$\beta$. For large values of tan$\beta$, the limit on $\Lambda$ increases to 43 TeV.

[7] AAD 12CM searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$=7 TeV for events with at least one tau lepton, zero or one additional light lepton ($e/\mu$) jets, and large $\not{E}_T$ in a GMSB framework. No significant excess above the expected background was found and an upper limit on the visible cross section for new phenomena is set. A 95% C. L. lower limit of 54 TeV on the mGMSB breaking scale $\Lambda$ is set for $M_{mess}$ = 250 TeV, $N_S$ = 3, $\mu$ > 0 and $C_{grav}$ = 1, for tan$\beta$ > 20. Here the $\widetilde{\tau}_1$ is the NLSP.

[8] ABBIENDI 06B use 600 pb$^{-1}$ of data from $\sqrt{s}$ = 189–209 GeV. They look for events from pair-produced staus in a GMSB scenario with $\widetilde{\tau}$ NLSP including prompt $\widetilde{\tau}$ decays to ditaus + $\not{E}$ final states, large impact parameters, kinked tracks and heavy stable charged particles. Limits on the cross-section are computed as a function of m($\widetilde{\tau}$) and the lifetime, see their Fig. 7. The limit is compared to the $\sigma \cdot BR^2$ from a scan over the GMSB parameter space.

[9] ABBIENDI 04F use data from $\sqrt{s}$ = 189–209 GeV. They derive limits on sparticle masses under the assumption of $\not{R}$ with $LL\overline{E}$ or $LQ\overline{D}$ couplings. The results are valid for tan$\beta$ = 1.5, $\mu$ = −200 GeV, with, in addition, $\Delta m$ > 5 GeV for indirect decays via $LQ\overline{D}$. The limit quoted applies to direct decays with $LL\overline{E}$ couplings and improves to 75 GeV for $LQ\overline{D}$ couplings. The limit on the $\widetilde{\tau}_R$ mass for indirect decays is 92 GeV for $LL\overline{E}$ couplings at $m_{\widetilde{\chi}^0}$ = 10 GeV and no exclusion is obtained for $LQ\overline{D}$ couplings. Supersedes the results of ABBIENDI 00.

[10] ABDALLAH 04H use data from LEP 1 and $\sqrt{s}$ = 192–208 GeV. They re-use results or re-analyze the data from ABDALLAH 03M to put limits on the parameter space of anomaly-mediated supersymmetry breaking (AMSB), which is scanned in the region 1< $m_{3/2}$ <50 TeV, 0< $m_0$ <1000 GeV, 1.5<tan$\beta$ <35, both signs of $\mu$. The constraints are obtained from the searches for mass degenerate chargino and neutralino, for SM-like and invisible Higgs, for leptonically decaying charginos and from the limit on non-SM $Z$ width of 3.2 MeV. The limit is for $m_t$ = 174.3 GeV (see Table 2 for other $m_t$ values). The limit improves to 75 GeV for $\mu$ < 0.

[11] ABDALLAH 04M use data from $\sqrt{s}$ = 192–208 GeV to derive limits on sparticle masses under the assumption of $\not{R}$ with $LL\overline{E}$ couplings. The results are valid for $\mu$ = −200 GeV, tan$\beta$ = 1.5, $\Delta m$ > 5 GeV and assuming a BR of 1 for the given decay. The limit quoted is for indirect decays using the neutralino constraint of 39.5 GeV, also derived in ABDALLAH 04M. For indirect decays via $LL\overline{E}$ the limit decreases to 86 GeV if the constraint from the neutralino is not used. Supersedes the result of ABREU 00U.

## Degenerate Charged Sleptons

Unless stated otherwise in the comment lines or in the footnotes, the following limits assume 3 families of degenerate charged sleptons.

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| >93 | 95 | [1] BARATE | 01 | ALEP | $\Delta m > 10$ GeV, $\widetilde{\ell}^+_R \widetilde{\ell}^-_R$ |
| >70 | 95 | [1] BARATE | 01 | ALEP | all $\Delta m$, $\widetilde{\ell}^+_R \widetilde{\ell}^-_R$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | | |
|---|---|---|---|---|---|
| >91.9 | 95 | [2] ABBIENDI | 06B | OPAL | $\widetilde{\ell}_R \to \ell\widetilde{G}$, all $\ell(\widetilde{\ell}_R)$ |
| >88 | | [3] ABDALLAH | 03D | DLPH | $\widetilde{\ell}_R \to \ell\widetilde{G}$, all $\ell(\widetilde{\ell}_R)$ |
| >82.7 | 95 | [4] ACHARD | 02 | L3 | $\widetilde{\ell}_R$, $\not{R}$ decays, MSUGRA |
| >83 | 95 | [5] ABBIENDI | 01 | OPAL | $e^+e^- \to \widetilde{\ell}_1\widetilde{\ell}_1$, GMSB, $\tan\beta=2$ |
| | | [6] ABREU | 01 | DLPH | $\widetilde{\ell} \to \ell\widetilde{\chi}^0_2$, $\widetilde{\chi}^0_2 \to \gamma\widetilde{\chi}^0_1$, $\ell=e,\mu$ |
| >68.8 | 95 | [7] ACCIARRI | 01 | L3 | $\widetilde{\ell}_R$, $\not{R}$, $0.7 \le \tan\beta \le 40$ |
| >84 | 95 | [8] ABREU | 00V | DLPH | $\widetilde{\ell}_R\widetilde{\ell}_R$ ($\widetilde{\ell}_R \to \ell\widetilde{G}$), $m_{\widetilde{G}} > 9$ eV |

[1] BARATE 01 looked for acoplanar dilepton + $\not{E}_T$ and single electron (for $\widetilde{e}_R\widetilde{e}_L$) final states at 189 to 202 GeV. The limit assumes $\mu=-200$ GeV and $\tan\beta=2$ for the production cross section and decay branching ratios, evaluated within the MSSM, and zero efficiency for decays other than $\widetilde{\ell} \to \ell\widetilde{\chi}^0_1$. The slepton masses are determined from the GUT relations without stau mixing. See their Fig. 1 for the dependence of the limit on $\Delta m$.

[2] ABBIENDI 06B use 600 pb$^{-1}$ of data from $\sqrt{s}$ = 189–209 GeV. They look for events from pair-produced staus in a GMSB scenario with $\widetilde{\ell}$ co-NLSP including prompt $\widetilde{\ell}$ decays to dileptons + $\not{E}$ final states, large impact parameters, kinked tracks and heavy stable charged particles. Limits on the cross-section are computed as a function of m($\widetilde{\ell}$) and the lifetime, see their Fig. 7. The limit is compared to the $\sigma \cdot BR^2$ from a scan over the GMSB parameter space. The highest mass limit is reached for $\widetilde{\mu}_R$, from which the quoted mass limit is derived by subtracting $m_\tau$.

[3] ABDALLAH 03D use data from $\sqrt{s}$ = 130–208 GeV to search for tracks with large impact parameter or visible decay vertices and for heavy charged stable particles. Limits are obtained as function of m($\widetilde{G}$), after combining these results with the search for slepton pair production in the SUGRA framework from ABDALLAH 03M to cover prompt decays The above limit is reached for prompt decays and assumes the degeneracy of the sleptons. For limits at different m($\widetilde{G}$), see their Fig. 9. Supersedes the results of ABREU 01G.

[4] ACHARD 02 searches for the production of sparticles in the case of $\not{R}$ prompt decays with $LL\overline{E}$ or $\overline{UDD}$ couplings at $\sqrt{s}$=189–208 GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The MSUGRA limit results from a scan over the MSSM parameter space with the assumption of gaugino and scalar mass unification at the GUT scale and no mixing in the slepton sector, imposing simultaneously the exclusions from neutralino, chargino, sleptons, and squarks analyses. The limit holds for $LL\overline{E}$ couplings and increases to 88.7 GeV for $\overline{UDD}$ couplings. For L3 limits from $LQ\overline{D}$ couplings, see ACCIARRI 01.

[5] ABBIENDI 01 looked for final states with $\gamma\gamma\not{E}$, $\ell\ell\not{E}$, with possibly additional activity and four leptons + $\not{E}$ to search for prompt decays of $\widetilde{\chi}^0_1$ or $\widetilde{\ell}_1$ in GMSB. They derive limits in the plane ($m_{\widetilde{\chi}^0_1}$,$m_{\widetilde{\tau}_1}$), see Fig. 6, allowing either the $\widetilde{\chi}^0_1$ or a $\widetilde{\ell}_1$ to be the NLSP. Two scenarios are considered: $\tan\beta=2$ with the 3 sleptons degenerate in mass and $\tan\beta=20$ where the $\widetilde{\tau}_1$ is lighter than the other sleptons. Data taken at $\sqrt{s}$=189 GeV. For $\tan\beta=20$, the obtained limits are $m_{\widetilde{\tau}_1} > 69$ GeV and $m_{\widetilde{e}_1,\widetilde{\mu}_1} > 88$ GeV.

[6] ABREU 01 looked for acoplanar dilepton + diphoton + $\not{E}$ final states from $\widetilde{\ell}$ cascade decays at $\sqrt{s}$=130–189 GeV. See Fig. 9 for limits on the ($\mu$,$M_2$) plane for $m_{\widetilde{\ell}}$=80 GeV, $\tan\beta$=1.0, and assuming degeneracy of $\widetilde{\mu}$ and $\widetilde{e}$.

[7] ACCIARRI 01 searches for multi-lepton and/or multi-jet final states from $\not{R}$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings at $\sqrt{s}$=189 GeV. The search is performed for direct and indirect decays of neutralinos, charginos, and scalar leptons, with the $\widetilde{\chi}^0_1$ or a $\widetilde{\ell}$ as LSP and assuming one coupling to be nonzero at a time. Mass limits are derived using simultaneously the constraints from the neutralino, chargino, and slepton analyses;

and the $Z^0$ width measurements from ACCIARRI 00C in a scan of the parameter space assuming MSUGRA with gaugino and scalar mass universality. Updates and supersedes the results from ACCIARRI 99I.

[8] ABREU 00V use data from $\sqrt{s}$= 130–189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. For limits at different $m_{\widetilde{G}}$, see their Fig. 12. The above limit assumes the degeneracy of stau and smuon.

## Long-lived $\widetilde{\ell}$ (Slepton) MASS LIMIT

Limits on scalar leptons which leave detector before decaying. Limits from $Z$ decays are independent of lepton flavor. Limits from continuum $e^+e^-$ annihilation are also independent of flavor for smuons and staus. Selectron limits from $e^+e^-$ collisions in the continuum depend on MSSM parameters because of the additional neutralino exchange contribution.

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| $>$440 | 95 | [1] AAD | 15AE | ATLS | mGMSB, $M_{mess}$ = 250 TeV, $N_5$ = 3, $\mu$ $>$ 0, $C_{grav}$ = 5000, tan$\beta$ = 10 |
| $>$385 | 95 | [1] AAD | 15AE | ATLS | mGMSB, $M_{mess}$ = 250 TeV, $N_5$ = 3, $\mu$ $>$ 0, $C_{grav}$ = 5000, tan$\beta$ = 50 |
| $>$286 | 95 | [1] AAD | 15AE | ATLS | direct $\widetilde{\tau}$ production |
| none 124–309 | 95 | [2] AAIJ | 15BD | LHCB | long-lived $\widetilde{\tau}$, mGMSB, SPS7 |
| $>$ 98 | 95 | [3] ABBIENDI | 03L | OPAL | $\widetilde{\mu}_R$, $\widetilde{\tau}_R$ |
| **none 2–87.5** | 95 | [4] ABREU | 00Q | DLPH | $\widetilde{\mu}_R$, $\widetilde{\tau}_R$ |
| $>$ 81.2 | 95 | [5] ACCIARRI | 99H | L3 | $\widetilde{\mu}_R$, $\widetilde{\tau}_R$ |
| $>$ 81 | 95 | [6] BARATE | 98K | ALEP | $\widetilde{\mu}_R$, $\widetilde{\tau}_R$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $>$300 | 95 | [7] AAD | 13AA | ATLS | long-lived $\widetilde{\tau}$, GMSB, tan$\beta$ = 5–20 |
| | | [8] ABAZOV | 13B | D0 | long-lived $\widetilde{\tau}$, 100 $<m_{\widetilde{\tau}}<$300 GeV |
| $>$339 | 95 | [9,10] CHATRCHYAN | 13AB | CMS | long-lived $\widetilde{\tau}$, direct $\widetilde{\tau}_1$ pair prod., minimal GMSB, SPS line 7 |
| $>$500 | 95 | [9,11] CHATRCHYAN | 13AB | CMS | long-lived $\widetilde{\tau}$, $\widetilde{\tau}_1$ from direct pair prod. and from decay of heavier SUSY particles, minimal GMSB, SPS line 7 |
| $>$314 | 95 | [12] CHATRCHYAN | 12L | CMS | long-lived $\widetilde{\tau}$, $\widetilde{\tau}_1$ from decay of heavier SUSY particles, minimal GMSB, SPS line 7 |
| $>$136 | 95 | [13] AAD | 11P | ATLS | stable $\widetilde{\tau}$, GMSB scenario, tan$\beta$=5 |

[1] AAD 15AE searched in 19.1 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for heavy long-lived charged particles, measured through their specific ionization energy loss in the ATLAS pixel detector or their time-of-flight in the ALTAS muon system. In the absence of an excess of events above the expected backgrounds, limits are set on stable $\widetilde{\tau}$ sleptons in various scenarios, see Figs. 5-7.

[2] AAIJ 15BD searched in 3.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 and 8 TeV for evidence of Drell-Yan pair production of long-lived $\widetilde{\tau}$ particles. No evidence for such particles is observed and 95% C.L. upper limits on the cross section of $\widetilde{\tau}$ pair production are derived, see Fig. 7. In the mGMSB, assuming the SPS7 benchmark scenario $\widetilde{\tau}$ masses between 124 and 309 GeV are excluded at 95% C.L.

[3] ABBIENDI 03L used $e^+e^-$ data at $\sqrt{s}$ = 130–209 GeV to select events with two high momentum tracks with anomalous dE/dx. The excluded cross section is compared to the

theoretical expectation as a function of the heavy particle mass in their Fig. 3. The limit improves to 98.5 GeV for $\widetilde{\mu}_L$ and $\widetilde{\tau}_L$. The bounds are valid for colorless spin 0 particles with lifetimes longer than $10^{-6}$ s. Supersedes the results from ACKERSTAFF 98P.

[4] ABREU 00Q searches for the production of pairs of heavy, charged stable particles in $e^+e^-$ annihilation at $\sqrt{s}$= 130–189 GeV. The upper bound improves to 88 GeV for $\widetilde{\mu}_L$, $\widetilde{\tau}_L$. These limits include and update the results of ABREU 98P.

[5] ACCIARRI 99H searched for production of pairs of back-to-back heavy charged particles at $\sqrt{s}$=130–183 GeV. The upper bound improves to 82.2 GeV for $\widetilde{\mu}_L$, $\widetilde{\tau}_L$.

[6] The BARATE 98K mass limit improves to 82 GeV for $\widetilde{\mu}_L$,$\widetilde{\tau}_L$. Data collected at $\sqrt{s}$=161–184 GeV.

[7] AAD 13AA searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events containing long-lived massive particles in a GMSB framework. No significant excess above the expected background was found. A 95% C.L. lower limit of 300 GeV is placed on long-lived $\widetilde{\tau}$'s in the GMSB model with $M_{mess}$ = 250 TeV, $N_S$ = 3, $\mu > 0$, for tan$\beta$ = 5–20. The lower limit on the GMSB breaking scale $\Lambda$ was found to be 99–110 TeV, for tan$\beta$ values between 5 and 40, see Fig. 4 (top). Also, directly produced long-lived sleptons, or sleptons decaying to long-lived ones, are excluded at 95% C.L. up to a $\widetilde{\tau}$ mass of 278 GeV for models with slepton splittings smaller than 50 GeV.

[8] ABAZOV 13B looked in 6.3 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV for charged massive long-lived particles in events with muon-like particles that have both speed and ionization energy loss inconsistent with muons produced in beam collisions. In the absence of an excess, limits are set at 95% C.L. on the production cross section of stau leptons in the mass range 100–300 GeV, see their Table 20 and Fig. 23.

[9] CHATRCHYAN 13AB looked in 5.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV and in 18.8 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or additionally requiring that it be identified as muon in the muon chambers, from pair production of $\widetilde{\tau}_1$'s. No evidence for an excess over the expected background is observed. Supersedes CHATRCHYAN 12L.

[10] CHATRCHYAN 13AB limits are derived for pair production of $\widetilde{\tau}_1$ as a function of mass in minimal GMSB scenarios along the Snowmass Points and Slopes (SPS) line 7 (see Fig. 8 and Table 7). The limit given here is valid for direct pair $\widetilde{\tau}_1$ production.

[11] CHATRCHYAN 13AB limits are derived for the production of $\widetilde{\tau}_1$ as a function of mass in minimal GMSB scenarios along the Snowmass Points and Slopes (SPS) line 7 (see Fig. 8 and Table 7). The limit given here is valid for the production of $\widetilde{\tau}_1$ from both direct pair production and from the decay of heavier supersymmetric particles.

[12] CHATRCHYAN 12L looked in 5.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or additionally requiring that it be identified as muon in the muon chambers, from pair production of $\widetilde{\tau}_1$'s. No evidence for an excess over the expected background is observed. Limits are derived for the production of $\widetilde{\tau}_1$ as a function of mass in minimal GMSB scenarios along the Snowmass Points and Slopes (SPS) line 7 (see Fig. 3). The limit given here is valid for the production of $\widetilde{\tau}_1$ in the decay of heavier supersymmetric particles.

[13] AAD 11P looked in 37 pb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with two heavy stable particles, reconstructed in the Inner tracker and the Muon System and identified by their time of flight in the Muon System. No evidence for an excess over the SM expectation is observed. Limits on the mass are derived, see Fig. 3, for $\widetilde{\tau}$ in a GMSB scenario and for sleptons produced by electroweak processes only, in which case the limit degrades to 110 GeV.

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## $\widetilde{q}$ (Squark) MASS LIMIT

For $m_{\widetilde{q}} > $ 60–70 GeV, it is expected that squarks would undergo a cascade decay via a number of neutralinos and/or charginos rather than undergo a direct decay to photinos as assumed by some papers. Limits obtained when direct decay is assumed are usually higher than limits when cascade decays are included.

Limits from $e^+ e^-$ collisions depend on the mixing angle of the lightest mass eigenstate $\widetilde{q}_1 = \widetilde{q}_R \sin\theta_q + \widetilde{q}_L \cos\theta_q$. It is usually assumed that only the sbottom and stop squarks have non-trivial mixing angles (see the stop and sbottom sections). Here, unless otherwise noted, squarks are always taken to be either left/right degenerate, or purely of left or right type. Data from $Z$ decays have set squark mass limits above 40 GeV, in the case of $\widetilde{q} \to q\widetilde{\chi}_1$ decays if $\Delta m = m_{\widetilde{q}} - m_{\widetilde{\chi}_1^0} \gtrsim 5$ GeV. For smaller values of $\Delta m$, current constraints on the invisible width of the $Z$ ($\Delta\Gamma_{\text{inv}} < 2.0$ MeV, LEP 00) exclude $m_{\widetilde{u}_{L,R}} < 44$ GeV, $m_{\widetilde{d}_R} < 33$ GeV, $m_{\widetilde{d}_L} < 44$ GeV and, assuming all squarks degenerate, $m_{\widetilde{q}} < 45$ GeV.

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **>1450 (CL = 95%) OUR EVALUATION** | | | | |
| $>$ 850 | 95 | [1] AAD 15BV | ATLS | jets + $\not\!\!E_T$, $\widetilde{q} \to q\widetilde{\chi}_1^0$, $m_{\widetilde{\chi}_1^0} =$ 100 GeV |
| $>$ 250 | 95 | [2] AAD 15CS | ATLS | photon + $\not\!\!E_T$, $pp \to \widetilde{q}\widetilde{q}^*\gamma$, $\widetilde{q} \to q\widetilde{\chi}_1^0$, $m_{\widetilde{q}} - m_{\widetilde{\chi}_1^0} = m_c$ |
| $>$ 490 | 95 | [3] AAD 15K | ATLS | $\widetilde{c} \to c\widetilde{\chi}_1^0$, $m_{\widetilde{\chi}_1^0} < 200$ GeV |
| $>$ 875 | 95 | [4] KHACHATRY... 15AF | CMS | $\widetilde{g} \to q\widetilde{\chi}_1^0$, simplified model, 8 degenerate light $\widetilde{q}$, $m_{\widetilde{\chi}_1^0} = 0$ |
| **> 520** | 95 | [4] KHACHATRY... 15AF | CMS | $\widetilde{q} \to q\widetilde{\chi}_1^0$, simplified model, single light squark, $m_{\widetilde{\chi}_1^0} = 0$ |
| **>1450** | 95 | [4] KHACHATRY... 15AF | CMS | CMSSM, $\tan\beta = 30$, $A_0 = -2\max(m_0, m_{1/2})$, $\mu > 0$ |
| **> 850** | 95 | [5] AAD 14AE | ATLS | jets + $\not\!\!E_T$, $\widetilde{q} \to q\widetilde{\chi}_1^0$ simplified model, mass degenerate first and second generation squarks, $m_{\widetilde{\chi}_1^0} = 0$ GeV |
| $>$ 440 | 95 | [5] AAD 14AE | ATLS | jets + $\not\!\!E_T$, $\widetilde{q} \to q\widetilde{\chi}_1^0$ simplified model, single light-flavour squark, $m_{\widetilde{\chi}_1^0} = 0$ GeV |
| $>$1700 | 95 | [5] AAD 14AE | ATLS | jets + $\not\!\!E_T$, mSUGRA/CMSSM, $m_{\widetilde{q}} = m_{\widetilde{g}}$ |
| $>$ 800 | 95 | [6] CHATRCHYAN 14AH | CMS | jets + $\not\!\!E_T$, $\widetilde{q} \to q\widetilde{\chi}_1^0$ simplified model, $m_{\widetilde{\chi}_1^0} = 50$ GeV |
| $>$ 780 | 95 | [7] CHATRCHYAN 14I | CMS | multijets + $\not\!\!E_T$, $\widetilde{q} \to q\widetilde{\chi}_1^0$ simplified model, $m_{\widetilde{\chi}_1^0} < 200$ GeV |
| $>$1360 | 95 | [8] AAD 13L | ATLS | jets + $\not\!\!E_T$, CMSSM, $m_{\widetilde{g}} = m_{\widetilde{q}}$ |
| $>$1200 | 95 | [9] AAD 13Q | ATLS | $\gamma + b + \not\!\!E_T$, higgsino-like neutralino, $m_{\widetilde{\chi}_1^0} > 220$ GeV, GMSB |
| | | [10] CHATRCHYAN 13 | CMS | $\ell^\pm \ell^\mp$ + jets + $\not\!\!E_T$, CMSSM |

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|---|---|---|---|---|
| >1250 | 95 | [11] CHATRCHYAN 13G | CMS | 0,1,2, ≥ 3 *b*-jets + $\not\!\!E_T$, CMSSM, $m_{\widetilde{q}} = m_{\widetilde{g}}$ |
| >1430 | 95 | [12] CHATRCHYAN 13H | CMS | $2\gamma$ + ≥ 4 jets + low $\not\!\!E_T$, stealth SUSY model |
| > 750 | 95 | [13] CHATRCHYAN 13T | CMS | jets + $\not\!\!E_T$, $\widetilde{q} \rightarrow q\widetilde{\chi}^0_1$ simplified model, $m_{\widetilde{\chi}^0_1}$= 0 GeV |
| > 820 | 95 | [14] AAD 12AX | ATLS | $\ell$ +jets +$\not\!\!E_T$, CMSSM, $m_{\widetilde{q}}$=$m_{\widetilde{g}}$ |
| >1200 | 95 | [15] AAD 12CJ | ATLS | $\ell^{\pm}$+jets+$\not\!\!E_T$, CMSSM, $m_{\widetilde{q}}$=$m_{\widetilde{g}}$ |
| > 870 | 95 | [16] AAD 12CP | ATLS | $2\gamma$ +$\not\!\!E_T$, GMSB, bino NLSP, $m_{\widetilde{\chi}^0_1}$ > 50 GeV |
| > 950 | 95 | [17] AAD 12W | ATLS | jets + $\not\!\!E_T$, CMSSM, $m_{\widetilde{q}} = m_{\widetilde{g}}$ |
| | | [18] CHATRCHYAN 12 | CMS | $e$, $\mu$, jets, razor, CMSSM |
| > 760 | 95 | [19] CHATRCHYAN 12AE | CMS | jets + $\not\!\!E_T$, $\widetilde{q} \rightarrow q\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ < 200 GeV |
| | | [20] CHATRCHYAN 12AL | CMS | ≥ 3$\ell^{\pm}$, $\not\!R$ |
| >1110 | 95 | [21] CHATRCHYAN 12AT | CMS | jets + $\not\!\!E_T$, CMSSM |
| >1180 | 95 | [21] CHATRCHYAN 12AT | CMS | jets + $\not\!\!E_T$, CMSSM, $m_{\widetilde{q}}$=$m_{\widetilde{g}}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

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|---|---|---|---|---|
| | 95 | [22] AAD 15AI | ATLS | $\ell^{\pm}$ + jets + $\not\!\!E_T$ |
| >1650 | 95 | [1] AAD 15BV | ATLS | jets + $\not\!\!E_T$, $m_{\widetilde{g}} = m_{\widetilde{q}}$, $m_{\widetilde{\chi}^0_1}$ = 1 GeV |
| > 790 | 95 | [1] AAD 15BV | ATLS | jets + $\not\!\!E_T$, $\widetilde{q} \rightarrow qW\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ = 100 GeV |
| > 820 | 95 | [1] AAD 15BV | ATLS | 2 or 3 leptons + jets, $\widetilde{q}$ decays via sleptons, $m_{\widetilde{\chi}^0_1}$ = 100 GeV |
| > 850 | 95 | [1] AAD 15BV | ATLS | $\tau$, $\widetilde{q}$ decays via staus, $m_{\widetilde{\chi}^0_1}$ = 50 GeV |
| >1000 | 95 | [23] AAD 15CB | ATLS | jets, $\widetilde{q} \rightarrow q\widetilde{\chi}^0_1$, $\widetilde{\chi}^0_1 \rightarrow \ell qq$, RPV, $m_{\widetilde{\chi}^0_1}$ = 108 GeV and 2.5 < $c\tau_{\widetilde{\chi}^0_1}$ < 200 mm |
| > 700 | 95 | [24] KHACHATRY...15AR | CMS | $\widetilde{q} \rightarrow q\widetilde{\chi}^0_1$, $\widetilde{\chi}^0_1 \rightarrow \widetilde{S}g$, $\widetilde{S} \rightarrow S\widetilde{G}$, $S \rightarrow gg$, $m_{\widetilde{S}}$ = 100 GeV, $m_S$ = 90 GeV |
| > 550 | 95 | [24] KHACHATRY...15AR | CMS | $\ell^{\pm}$, $\widetilde{q} \rightarrow q\widetilde{\chi}^{\pm}_1$, $\widetilde{\chi}^{\pm}_1 \rightarrow \widetilde{S}W^{\pm}$, $\widetilde{S} \rightarrow S\widetilde{G}$, $S \rightarrow gg$, $m_{\widetilde{S}}$ = 100 GeV, $m_S$ = 90 GeV |
| >1500 | 95 | [25] KHACHATRY...15AZ | CMS | ≥ 2 $\gamma$, ≥ 1 jet, (Razor), bino-like NLSP, $m_{\widetilde{\chi}^0_1}$ = 375 GeV |
| >1000 | 95 | [25] KHACHATRY...15AZ | CMS | ≥ 1 $\gamma$, ≥ 2 jet, wino-like NLSP, $m_{\widetilde{\chi}^0_1}$ = 375 GeV |
| > 670 | 95 | [26] AAD 14E | ATLS | $\ell^{\pm}\ell^{\pm}(\ell^{\mp})$ + jets, $\widetilde{q} \rightarrow q'\widetilde{\chi}^{\pm}_1$, $\widetilde{\chi}^{\pm}_1 \rightarrow W^{(*)\pm}\widetilde{\chi}^0_2$, $\widetilde{\chi}^0_2 \rightarrow Z^{(*)}\widetilde{\chi}^0_1$ simplified model, $m_{\widetilde{\chi}^0_1}$ < 300 GeV |

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|---|---|---|---|---|
| > 780 | 95 | [26] AAD 14E | ATLS | $\ell^{\pm}\ell^{\pm}(\ell^{\mp})$ + jets, $\tilde{q} \rightarrow q'\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$, $\tilde{\chi}_1^{\pm} \rightarrow \ell^{\pm}\nu\tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \rightarrow \ell^{\pm}\ell^{\mp}(\nu\nu)\tilde{\chi}_1^0$ simplified model |
| > 700 | 95 | [27] CHATRCHYAN 13AO | CMS | $\ell^{\pm}\ell^{\mp}$ + jets + $\not{E}_T$, CMSSM, $m_0 < 700$ GeV |
| >1350 | 95 | [28] CHATRCHYAN 13AV | CMS | jets (+ leptons) + $\not{E}_T$, CMSSM, $m_{\tilde{g}} = m_{\tilde{q}}$ |
| > 800 | 95 | [29] CHATRCHYAN 13W | CMS | $\geq$ 1 photons + jets + $\not{E}_T$, GGM, wino-like NLSP, $m_{\tilde{\chi}_1^0}$ = 375 GeV |
| >1000 | 95 | [29] CHATRCHYAN 13W | CMS | $\geq$ 2 photons + jets + $\not{E}_T$, GGM, bino-like NLSP, $m_{\tilde{\chi}_1^0}$ = 375 GeV |
| > 340 | 95 | [30] DREINER 12A | THEO | $m_{\tilde{q}} \sim m_{\tilde{\chi}_1^0}$ |
| > 650 | 95 | [31] DREINER 12A | THEO | $m_{\tilde{q}} = m_{\tilde{g}} \sim m_{\tilde{\chi}_1^0}$ |

[1] AAD 15BV summarized and extended ATLAS searches for gluinos and first- and second-generation squarks in final states containing jets and missing transverse momentum, with or without leptons or $b$-jets in the $\sqrt{s} = 8$ TeV data set collected in 2012. The paper reports the results of new interpretations and statistical combinations of previously published analyses, as well as new analyses. Exclusion limits at 95% C.L. are set on the squark mass in several R-parity conserving models. See their Figs. 9, 11, 18, 22, 24, 27, 28.

[2] AAD 15CS searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for evidence of pair production of squarks, decaying into a quark and a neutralino, where a photon was radiated either from an initial-state quark, from an intermediate squark, or from a final-state quark. No evidence was found for an excess above the expected level of Standard Model background and a 95% C.L. exclusion limit was set on the squark mass as a function of the squark-neutralino mass difference, see Fig. 19.

[3] AAD 15K searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events containing at least two jets, where the two leading jets are each identified as originating from $c$-quarks, and large missing transverse momentum. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set on the mass of superpartners of charm quarks ($\tilde{c}$). Assuming that the decay $\tilde{c} \rightarrow c\tilde{\chi}_1^0$ takes place 100% of the time, a scalar charm mass below 490 GeV is excluded for $m_{\tilde{\chi}_1^0} < 200$ GeV. For more details, see their Fig. 2.

[4] KHACHATRYAN 15AF searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least two energetic jets and significant $\not{E}_T$, using the transverse mass variable $M_{T2}$ to discriminate between signal and background processes. No significant excess above the Standard Model expectations is observed. Limits are set on the squark mass in simplified models where the decay $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ takes place with a branching ratio of 100%, both for the case of a single light squark or 8 degenerate squarks, see Fig. 12. See also Table 5. Exclusions in the CMSSM, assuming $\tan\beta = 30$, $A_0 = -2$ max($m_0$, $m_{1/2}$) and $\mu > 0$, are also presented, see Fig. 15.

[5] AAD 14AE searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for strongly produced supersymmetric particles in events containing jets and large missing transverse momentum, and no electrons or muons. No excess over the expected SM background is observed. Exclusion limits are derived in simplified models containing squarks that decay via $\tilde{q} \rightarrow q\tilde{\chi}_1^0$, where either a single light state or two degenerate generations of squarks are assumed, see Fig. 10.

[6] CHATRCHYAN 14AH searched in 4.7 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with at least two energetic jets and significant $\not{E}_T$, using the razor variables ($M_R$ and $R^2$) to discriminate between signal and background processes. No significant excess above the Standard Model expectations is observed. Limits are set on sbottom masses in simplified models where the decay $\widetilde{q} \rightarrow q\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 28. Exclusions in the CMSSM, assuming tan$\beta$ = 10, $A_0$ = 0 and $\mu$ >0, are also presented, see Fig. 26.

[7] CHATRCHYAN 14I searched in 19.5 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events containing multijets and large $\not{E}_T$. No excess over the expected SM background is observed. Exclusion limits are derived in simplified models containing squarks that decay via $\widetilde{q} \rightarrow q\widetilde{\chi}_1^0$, where either a single light state or two degenerate generations of squarks are assumed, see Fig. 7a.

[8] AAD 13L searched in 4.7 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for the production of squarks and gluinos in events containing jets, missing transverse momentum and no high-$p_T$ electrons or muons. No excess over the expected SM background is observed. In mSUGRA/CMSSM models with tan$\beta$ = 10, $A_0$ = 0 and $\mu$ > 0, squarks and gluinos of equal mass are excluded for masses below 1360 GeV at 95% C.L. In a simplified model containing only squarks of the first two generations, a gluino octet and a massless neutralino, squark masses below 1320 GeV are excluded at 95% C.L. for gluino masses below 2 TeV. See Figures 10–15 for more precise bounds.

[9] AAD 13Q searched in 4.7 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events containing a high-$p_T$ isolated photon, at least one jet identified as originating from a bottom quark, and high missing transverse momentum. Such signatures may originate from supersymmetric models with gauge-mediated supersymmetry breaking in events in which one of a pair of higgsino-like neutralinos decays into a photon and a gravitino while the other decays into a Higgs boson and a gravitino. No significant excess above the expected background was found and limits were set on the squark mass as a function of the neutralino mass in a generalized GMSB model (GGM) with a higgsino-like neutralino NLSP, see their Fig. 4. For neutralino masses greater than 220 GeV, squark masses below 1020 GeV are excluded at 95% C.L.

[10] CHATRCHYAN 13 looked in 4.98 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with two opposite-sign leptons ($e$, $\mu$, $\tau$), jets and missing transverse energy. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in the mSUGRA/CMSSM model with tan$\beta$ = 10, $A_0$ = 0 and $\mu$ > 0, see Fig. 6.

[11] CHATRCHYAN 13G searched in 4.98 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for the production of squarks and gluinos in events containing 0,1,2, $\geq$ 3 $b$-jets, missing transverse momentum and no electrons or muons. No excess over the expected SM background is observed. In mSUGRA/CMSSM models with tan$\beta$ = 10, $A_0$ = 0, and $\mu$ > 0, squarks and gluinos of equal mass are excluded for masses below 1250 GeV at 95% C.L. Exclusions are also derived in various simplified models, see Fig. 7.

[12] CHATRCHYAN 13H searched in 4.96 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with two photons, $\geq$ 4 jets and low $\not{E}_T$ due to $\widetilde{q} \rightarrow \gamma\widetilde{\chi}_1^0$ decays in a stealth SUSY framework, where the $\widetilde{\chi}_1^0$ decays through a singlino ($\widetilde{S}$) intermediate state to $\gamma S \widetilde{G}$, with the singlet state $S$ decaying to two jets. No significant excess above the expected background was found and limits were set in a particular $R$-parity conserving stealth SUSY model. The model assumes $m_{\widetilde{\chi}_1^0}$ = 0.5 $m_{\widetilde{q}}$, $m_{\widetilde{S}}$ = 100 GeV and $m_S$ = 90 GeV. Under these assumptions, squark masses less than 1430 GeV were excluded at the 95% C.L.

[13] CHATRCHYAN 13T searched in 11.7 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events with at least two energetic jets and significant $\not{E}_T$, using the $\alpha_T$ variable to discriminate between processes with genuine and misreconstructed $\not{E}_T$. No significant excess above the Standard Model expectations is observed. Limits are set on squark masses in simplified models where the decay $\widetilde{q} \rightarrow q\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, assuming an eightfold degeneracy of the masses of the first two generation squarks, see Fig. 8 and Table 9. Also limits in the case of a single light squark are given.

[14] AAD 12AX searched in 1.04 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for supersymmetry in events containing jets, missing transverse momentum and one isolated electron or muon. No excess over the expected SM background is observed and model-independent limits are set on the cross section of new physics contributions to the signal regions. In mSUGRA/CMSSM models with tan$\beta$ = 10, $A_0$ = 0 and $\mu$ > 0, squarks and gluinos of equal mass are excluded for masses below 820 GeV at 95% C.L. Limits are also set on simplified models for squark production and decay via an intermediate chargino and on supersymmetric models with bilinear $R$-parity violation. Supersedes AAD 11G.

[15] AAD 12CJ searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events containing one or more isolated leptons (electrons or muons), jets and $\not{E}_T$. The observations are in good agreement with the SM expectations and exclusion limits have been set in number of SUSY models. In the mSUGRA/CMSSM model with tan$\beta$ = 10, $A_0$ = 0, and $\mu$ > 0, 95% C.L. exclusion limits have been derived for $m_{\widetilde{q}}$ < 1200 GeV, assuming equal squark and gluino masses. In minimal GMSB, values of the effective SUSY breaking scale $\Lambda$ < 50 TeV are excluded at 95% C.L. for tan$\beta$ < 45. Also exclusion limits in a number of simplified models have been presented, see Figs. 10 and 12.

[16] AAD 12CP searched in 4.8 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with two photons and large $\not{E}_T$ due to $\widetilde{\chi}_1^0 \rightarrow \gamma \widetilde{G}$ decays in a GMSB framework. No significant excess above the expected background was found and limits were set on the squark mass as a function of the neutralino mass in a generalized GMSB model (GGM) with a bino-like neutralino NLSP. The other sparticle masses were decoupled, tan$\beta$ = 2 and $c\tau_{NLSP}$ < 0.1 mm. Also, in the framework of the SPS8 model, a 95% C.L. lower limit was set on the breaking scale $\Lambda$ of 196 TeV.

[17] AAD 12W searched in 1.04 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for the production of squarks and gluinos in events containing jets, missing transverse momentum and no electrons or muons. No excess over the expected SM background is observed. In mSUGRA/CMSSM models with tan$\beta$ = 10, $A_0$ = 0 and $\mu$ > 0, squarks and gluinos of equal mass are excluded for masses below 950 GeV at 95% C.L. In a simplified model containing only squarks of the first two generations, a gluino octet and a massless neutralino, squark masses below 875 GeV are excluded at 95% C.L.

[18] CHATRCHYAN 12 looked in 35 pb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with $e$ and/or $\mu$ and/or jets, a large total transverse energy, and $\not{E}_T$. The event selection is based on the dimensionless razor variable $R$, related to the $\not{E}_T$ and $M_R$, an indicator of the heavy particle mass scale. No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM ($m_0$, $m_{1/2}$) plane for tan$\beta$ = 3, 10 and 50 (see Fig. 7 and 8). Limits are also obtained for Simplified Model Spectra.

[19] CHATRCHYAN 12AE searched in 4.98 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with at least three jets and large missing transverse momentum. No significant excesses over the expected SM backgrounds are observed and 95% C.L. limits on the production cross section of squarks in a scenario where $\widetilde{q} \rightarrow q\widetilde{\chi}_1^0$ with a 100% branching ratio, see Fig. 3. For $m_{\widetilde{\chi}_1^0}$ < 200 GeV, values of $m_{\widetilde{q}}$ below 760 GeV are excluded at 95% C.L. Also limits in the CMSSM are presented, see Fig. 2.

[20] CHATRCHYAN 12AL looked in 4.98 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for anomalous production of events with three or more isolated leptons. Limits on squark and gluino masses are set in $\not{R}$ SUSY models with leptonic $LL\overline{E}$couplings, $\lambda_{123}$ > 0.05, and hadronic $\overline{UDD}$ couplings, $\lambda''_{112}$ > 0.05 , see their Fig. 5. In the $\overline{UDD}$ case the leptons arise from supersymmetric cascade decays. A very specific supersymmetric spectrum is assumed. All decays are prompt.

[21] CHATRCHYAN 12AT searched in 4.73 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for the production of squarks and gluinos in events containing jets, missing transverse momentum and no electrons or muons. No excess over the expected SM background is observed. In mSUGRA/CMSSM models with tan$\beta$ = 10, $A_0$ = 0 and $\mu$ > 0, squarks with masses below 1110 GeV are excluded at 95% C.L. Squarks and gluinos of equal mass are excluded for masses below 1180 GeV at 95% C.L. Exclusions are also derived in various simplified models, see Fig. 6.

[22] AAD 15AI searched in 20 $\text{fb}^{-1}$ of $p p$ collisions at $\sqrt{s} = 8$ TeV for events containing at least one isolated lepton (electron or muon), jets, and large missing transverse momentum. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set on the squark masses in the CMSSM/mSUGRA, see Fig. 15, in the NUHMG, see Fig. 16, and in various simplified models, see Figs. 19–21.

[23] AAD 15CB searched for events containing at least one long-lived particle that decays at a significant distance from its production point (displaced vertex, DV) into two leptons or into five or more charged particles in 20.3 $\text{fb}^{-1}$ of $p p$ collisions at $\sqrt{s} = 8$ TeV. The dilepton signature is characterised by DV formed from at least two lepton candidates. Four different final states were considered for the multitrack signature, in which the DV must be accompanied by a high-transverse momentum muon or electron candidate that originates from the DV, jets or missing transverse momentum. No events were observed in any of the signal regions. Results were interpreted in SUSY scenarios involving $R$-parity violation, split supersymmetry, and gauge mediation. See their Fig. 14–20.

[24] KHACHATRYAN 15AR searched in 19.7 of $\text{fb}^{-1}$ of $p p$ collisions at $\sqrt{s} = 8$ TeV for events containing jets, either a charged lepton or a photon, and low missing transverse momentum. No significant excess above the Standard Model expectations is observed. Limits are set on the squark mass in a stealth SUSY model where the decays $\widetilde{q} \rightarrow q \widetilde{\chi}_1^{\pm}$, $\widetilde{\chi}_1^{\pm} \rightarrow \widetilde{S} W^{\pm}$, $\widetilde{S} \rightarrow S \widetilde{G}$ and $S \rightarrow g g$, with $m_{\widetilde{S}} = 100$ GeV and $m_S = 90$ GeV, take place with a branching ratio of 100%. See Fig. 6 for $\gamma$ or Fig. 7 for $\ell^{\pm}$ analyses.

[25] KHACHATRYAN 15AZ searched in 19.7 $\text{fb}^{-1}$ of $p p$ collisions at $\sqrt{s} = 8$ TeV for events with either at least one photon, hadronic jets and $\not{E}_T$ (single photon channel) or with at least two photons and at least one jet and using the razor variables. No significant excess above the Standard Model expectations is observed. Limits are set on gluino masses in the general gauge-mediated SUSY breaking model (GGM), for both a bino-like and wino-like neutralino NLSP scenario, see Fig. 8 and 9.

[26] AAD 14E searched in 20.3 $\text{fb}^{-1}$ of $p p$ collisions at $\sqrt{s} = 8$ TeV for strongly produced supersymmetric particles in events containing jets and two same-sign leptons or three leptons. The search also utilises jets originating from $b$-quarks, missing transverse momentum and other variables. No excess over the expected SM background is observed. Exclusion limits are derived in simplified models containing gluinos and squarks, see Figures 5 and 6. In the $\widetilde{q} \rightarrow q' \widetilde{\chi}_1^{\pm}$, $\widetilde{\chi}_1^{\pm} \rightarrow W^{(*)\pm} \widetilde{\chi}_2^0$, $\widetilde{\chi}_2^0 \rightarrow Z^{(*)} \widetilde{\chi}_1^0$ simplified model, the following assumptions have been made: $m_{\widetilde{\chi}_1^{\pm}} = 0.5\ m_{\widetilde{\chi}_1^0} + m_{\widetilde{g}}$, $m_{\widetilde{\chi}_2^0} = 0.5\ ( m_{\widetilde{\chi}_1^0} + m_{\widetilde{\chi}_1^{\pm}} )$. In the $\widetilde{q} \rightarrow q' \widetilde{\chi}_1^{\pm}$ or $\widetilde{q} \rightarrow q' \widetilde{\chi}_2^0$, $\widetilde{\chi}_1^{\pm} \rightarrow \ell^{\pm} \nu \widetilde{\chi}_1^0$ or $\widetilde{\chi}_2^0 \rightarrow \ell^{\pm} \ell^{\mp} (\nu \nu) \widetilde{\chi}_1^0$ simplified model, the following assumptions have been made: $m_{\widetilde{\chi}_1^{\pm}} = m_{\widetilde{\chi}_2^0} = 0.5\ ( m_{\widetilde{\chi}_1^0} + m_{\widetilde{q}} )$, $m_{\widetilde{\chi}_1^0} < 460$ GeV. Limits are also derived in the mSUGRA/CMSSM, bRPV and GMSB models, see their Fig. 8.

[27] CHATRCHYAN 2013AO searched in 4.98 $\text{fb}^{-1}$ of $p p$ collisions at $\sqrt{s} = 7$ TeV for events with two opposite-sign isolated leptons accompanied by hadronic jets and $\not{E}_T$. No significant excesses over the expected SM backgrounds are observed and 95% C.L. exclusion limits are derived in the mSUGRA/CMSSM model with $\tan\beta = 10$, $A_0 = 0$ and $\mu > 0$, see Fig. 8.

[28] CHATRCHYAN 13AV searched in 4.7 $\text{fb}^{-1}$ of $p p$ collisions at $\sqrt{s} = 7$ TeV for new heavy particle pairs decaying into jets (possibly $b$-tagged), leptons and $\not{E}_T$ using the Razor variables. No significant excesses over the expected SM backgrounds are observed and 95% C.L. exclusion limits are derived in the mSUGRA/CMSSM model with $\tan\beta = 10$, $A_0 = 0$ and $\mu > 0$, see Fig. 3. The results are also interpreted in various simplified models, see Fig. 4.

[29] CHATRCHYAN 13W searched in 4.93 $\text{fb}^{-1}$ of $p p$ collisions at $\sqrt{s} = 7$ TeV for events with one or more photons, hadronic jets and $\not{E}_T$. No significant excess above the Standard

Model expectations is observed. Limits are set on squark masses in the general gauge-mediated SUSY breaking model (GGM), for both a wino-like and bino-like neutralino NLSP scenario, see Fig. 5.

[30] DREINER 12A reassesses constraints from CMS (at 7 TeV, $\sim$ 4.4 fb$^{-1}$) under the assumption that the fist and second generation squarks and the lightest SUSY particle are quasi-degenerate in mass (compressed spectrum).

[31] DREINER 12A reassesses constraints from CMS (at 7 TeV, $\sim$ 4.4 fb$^{-1}$) under the assumption that the first and second generation squarks, the gluino, and the lightest SUSY particle are quasi-degenerate in mass (compressed spectrum).

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## Long-lived $\widetilde{q}$ (Squark) MASS LIMIT

The following are bounds on long-lived scalar quarks, assumed to hadronise into hadrons with lifetime long enough to escape the detector prior to a possible decay. Limits may depend on the mixing angle of mass eigenstates: $\widetilde{q}_1 = \widetilde{q}_L \cos\theta_q + \widetilde{q}_R \sin\theta_q$.

The coupling to the $Z^0$ boson vanishes for up-type squarks when $\theta_u$=0.98, and for down type squarks when $\theta_d$=1.17.

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| $>$ 845 | 95 | [1] AAD | 15AE | ATLS | $\widetilde{b}$ R-hadron, stable, Regge model |
| $>$ 900 | 95 | [1] AAD | 15AE | ATLS | $\widetilde{t}$ R-hadron, stable, Regge model |
| $>$1500 | 95 | [1] AAD | 15AE | ATLS | $\widetilde{g}$ decaying to 300 GeV stable sleptons, LeptoSUSY model |
| $>$ 751 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{b}$ R-hadron, stable, Regge model |
| $>$ 766 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{t}$ R-hadron, stable, Regge model |
| $>$ 525 | 95 | [3] KHACHATRY... | 15AK | CMS | $\widetilde{g}$ R-hadrons, 10 $\mu$s$< \tau <$1000 s |
| $>$ 470 | 95 | [3] KHACHATRY... | 15AK | CMS | $\widetilde{g}$ R-hadrons, 1 $\mu$s$< \tau <$1000 s |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | | |
|---|---|---|---|---|---|
| $>$ 683 | 95 | [4] AAD | 13AA | ATLS | $\widetilde{t}$, *R*-hadrons, generic interaction model |
| $>$ 612 | 95 | [5] AAD | 13AA | ATLS | $\widetilde{b}$, *R*-hadrons, generic interaction model |
| $>$ 344 | 95 | [6] AAD | 13BC | ATLS | R-hadrons, $\widetilde{t} \rightarrow b\widetilde{\chi}^0_1$, Regge model, lifetime between 10$^{-5}$ and 10$^3$ s, $m_{\widetilde{\chi}^0_1}$ = 100 GeV |
| $>$ 379 | 95 | [7] AAD | 13BC | ATLS | R-hadrons, $\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$, Regge model, lifetime between 10$^{-5}$ and 10$^3$ s, $m_{\widetilde{\chi}^0_1}$ = 100 GeV |
| $>$ 935 | 95 | [8] CHATRCHYAN | 13AB | CMS | long-lived $\widetilde{t}$ forming R-hadrons, cloud interaction model |

[1] AAD 15AE searched in 19.1 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for heavy long-lived charged particles, measured through their specific ionization energy loss in the ATLAS pixel detector or their time-of-flight in the ALTAS muon system. In the absence of an excess of events above the expected backgrounds, limits are set R-hadrons in various scenarios, see Fig. 11. Limits are also set in LeptoSUSY models where the gluino decays to stable 300 GeV leptons, see Fig. 9.

[2] AAD 15BM searched in 18.4 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for stable and metastable non-relativistic charged particles through their anomalous specific ionization energy loss in the ATLAS pixel detector. In absence of an excess of events above the expected backgrounds, limits are set on stable bottom and top squark R-hadrons, see Table 5.

[3] KHACHATRYAN 15AK looked in a data set corresponding to fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV, and a search interval corresponding to 281 h of trigger lifetime, for long-lived particles that have stopped in the CMS detector. No evidence for an excess over the expected background in a cloud interaction model is observed. Assuming the decay $\widetilde{t} \rightarrow t\widetilde{\chi}_1^0$ and lifetimes between 1 $\mu$s and 1000 s, limits are derived on $\widetilde{t}$ production as a function of $m_{\widetilde{\chi}_1^0}$, see Figs. 4 and 7. The exclusions require that $m_{\widetilde{\chi}_1^0}$ is kinematically consistent with the minimum values of the jet energy thresholds used.

[4] AAD 13AA searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events containing colored long-lived particles that hadronize forming $R$-hadrons. No significant excess above the expected background was found. Long-lived $R$-hadrons containing a $\widetilde{t}$ are excluded for masses up to 683 GeV at 95% C.L in a general interaction model. Also, limits independent of the fraction of $R$-hadrons that arrive charged in the muon system were derived, see Fig. 6.

[5] AAD 13AA searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events containing colored long-lived particles that hadronize forming $R$-hadrons. No significant excess above the expected background was found. Long-lived $R$-hadrons containing a $\widetilde{b}$ are excluded for masses up to 612 GeV at 95% C.L in a general interaction model. Also, limits independent of the fraction of $R$-hadrons that arrive charged in the muon system were derived, see Fig. 6.

[6] AAD 13BC searched in 5.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV and in 22.9 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for bottom squark R-hadrons that have come to rest within the ATLAS calorimeter and decay at some later time to hadronic jets and a neutralino. In absence of an excess of events above the expected backgrounds, limits are set on sbottom masses for the decay $\widetilde{b} \rightarrow b\widetilde{\chi}_1^0$, for different lifetimes, and for a neutralino mass of 100 GeV, see their Table 6 and Fig 10.

[7] AAD 13BC searched in 5.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV and in 22.9 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for bottom squark R-hadrons that have come to rest within the ATLAS calorimeter and decay at some later time to hadronic jets and a neutralino. In absence of an excess of events above the expected backgrounds, limits are set on stop masses for the decay $\widetilde{t} \rightarrow t\widetilde{\chi}_1^0$, for different lifetimes, and for a neutralino mass of 100 GeV, see their Table 6 and Fig 10.

[8] CHATRCHYAN 13AB looked in 5.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV and in 18.8 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or additionally requiring that it be identified as muon in the muon chambers, from pair production of $\widetilde{t}_1$'s. No evidence for an excess over the expected background is observed. Limits are derived for pair production of stops as a function of mass in the cloud interaction model (see Fig. 8 and Table 6). In the charge-suppressed model, the limit decreases to 818 GeV.

## $\widetilde{b}$ (Sbottom) MASS LIMIT

Limits in $e^+e^-$ depend on the mixing angle of the mass eigenstate $\widetilde{b}_1 = \widetilde{b}_L \cos\theta_b + \widetilde{b}_R \sin\theta_b$. Coupling to the $Z$ vanishes for $\theta_b \sim 1.17$. As a consequence, no absolute constraint in the mass region $\lesssim 40$ GeV is available in the literature at this time from $e^+e^-$ collisions. In the Listings below, we use $\Delta m = m_{\widetilde{b}_1} - m_{\widetilde{\chi}_1^0}$.

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **>600** | 95 | [1] AAD | 15CJ | ATLS | $\widetilde{b} \rightarrow b\widetilde{\chi}_1^0$, $m_{\widetilde{\chi}_1^0} < 250$ GeV |

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|---|---|---|---|---|
| >440 | 95 | [1] AAD 15CJ | ATLS | $\tilde{b} \to t\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^{(*)}\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} = 60$ GeV, $m_{\tilde{b}} - m_{\tilde{\chi}_1^\pm} < m_t$ |
| none 300–650 | 95 | [1] AAD 15CJ | ATLS | $\tilde{b} \to \tilde{b} b\tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} =$ 60 GeV, $m_{\tilde{\chi}_2^0} > 250$ GeV |
| >640 | 95 | [2] KHACHATRY... 15AF | CMS | $\tilde{b} \to b\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} = 0$ |
| **>650** | 95 | [3] KHACHATRY... 15AH | CMS | $\tilde{b} \to b\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} = 0$ |
| >250 | 95 | [3] KHACHATRY... 15AH | CMS | $\tilde{b} \to b\tilde{\chi}_1^0$, $m_{\tilde{b}} - m_{\tilde{\chi}_1^0} < 10$ GeV |
| >570 | 95 | [4] KHACHATRY... 15I | CMS | $\tilde{b} \to t\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0}$ =50 GeV, 150< $m_{\tilde{\chi}_1^\pm}$ <300 GeV |
| >255 | 95 | [5] AAD 14T | ATLS | $\tilde{b}_1 \to b\tilde{\chi}_1^0$, $m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} \approx m_b$ |
| >400 | 95 | [6] CHATRCHYAN 14AH | CMS | jets + $\not\!\!E_T$, $\tilde{b} \to b\tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^0} = 50$ GeV |
| | | [7] CHATRCHYAN 14R | CMS | $\geq 3\ell^\pm$, $\tilde{b} \to t\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^0} = 50$ GeV |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | |
|---|---|---|---|---|
| | | [8] KHACHATRY... 15AD | CMS | $\ell^\pm\ell^\mp$ + jets + $\not\!\!E_T$, $\tilde{b} \to b\ell^\pm\ell^\mp\tilde{\chi}_1^0$ |
| none 340–600 | 95 | [9] AAD 14AX | ATLS | $\geq 3$ $b$-jets + $\not\!\!E_T$, $\tilde{b} \to b\tilde{\chi}_2^0$ simplified model with $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0}$=60 GeV, $m_{\tilde{\chi}_2^0}$=300 GeV |
| >440 | 95 | [10] AAD 14E | ATLS | $\ell^\pm\ell^\pm(\ell^\mp)$ + jets, $\tilde{b}_1 \to t\tilde{\chi}_1^\pm$ with $\tilde{\chi}_1^\pm \to W^{(*)\pm}\tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^\pm} = 2\, m_{\tilde{\chi}_1^0}$ |
| >500 | 95 | [11] CHATRCHYAN 14H | CMS | same-sign $\ell^\pm\ell^\pm$, $\tilde{b} \to t\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^\pm} = 2$ GeV, $m_{\tilde{\chi}_1^0} =$ 100 GeV |
| >620 | 95 | [12] AAD 13AU | ATLS | 2 $b$-jets + $\not\!\!E_T$, $\tilde{b}_1 \to b\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} <$ 120 GeV |
| >550 | 95 | [13] CHATRCHYAN 13AT | CMS | jets + $\not\!\!E_T$, $\tilde{b} \to b\tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^0}$= 50 GeV |
| >600 | 95 | [14] CHATRCHYAN 13T | CMS | jets + $\not\!\!E_T$, $\tilde{b} \to b\tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^0}$= 0 GeV |
| >450 | 95 | [15] CHATRCHYAN 13V | CMS | same-sign $\ell^\pm\ell^\pm$ + $\geq 2$ $b$-jets, $\tilde{b} \to t\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^0} = 50$ GeV |

| | | | | | |
|---|---|---|---|---|---|
| >390 | | [16] AAD | 12AN | ATLS | $\tilde{b}_1 \to b\tilde{\chi}^0_1$, simplified model, $m_{\tilde{\chi}^0_1} < 60$ GeV |
| | | [17] CHATRCHYAN | 12AI | CMS | $\ell^\pm \ell^\pm$ + $b$-jets + $\not\!\!E_T$ |
| >410 | 95 | [18] CHATRCHYAN | 12BO | CMS | $\tilde{b}_1 \to b\tilde{\chi}^0_1$, simplified model, $m_{\tilde{\chi}^0_1} = 50$ GeV |
| >294 | 95 | [19] AAD | 11K | ATLS | stable $\tilde{b}$ |
| | | [20] AAD | 11O | ATLS | $\tilde{g} \to \tilde{b}_1 b$, $\tilde{b}_1 \to b\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1}$=60 GeV |
| | | [21] CHATRCHYAN | 11D | CMS | $\tilde{b}, \tilde{t} \to b$ |
| >230 | 95 | [22] AALTONEN | 10R | CDF | $\tilde{b}_1 \to b\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1} < 70$ GeV |
| >247 | 95 | [23] ABAZOV | 10L | D0 | $\tilde{b}_1 \to b\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1} = 0$ GeV |

[1] AAD 15CJ searched in 20 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for evidence of third generation squarks by combining a large number of searches covering various final states. Limits on the sbottom mass are shown, either assuming the $\tilde{b} \to b\tilde{\chi}^0_1$ decay, see Fig. 11, or assuming the $\tilde{b} \to t\tilde{\chi}^\pm_1$ decay, with $\tilde{\chi}^\pm_1 \to W^{(*)}\tilde{\chi}^0_1$, see Fig. 12a, or assuming the $\tilde{b} \to b\tilde{\chi}^0_2$ decay, with $\tilde{\chi}^0_2 \to h\tilde{\chi}^0_1$, see Fig. 12b. Interpretations in the pMSSM are also discussed, see Figures 13–15.

[2] KHACHATRYAN 15AF searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events with at least two energetic jets and significant $\not\!\!E_T$, using the transverse mass variable $M_{T2}$ to discriminate between signal and background processes. No significant excess above the Standard Model expectations is observed. Limits are set on the sbottom mass in simplified models where the decay $\tilde{b} \to b\tilde{\chi}^0_1$ takes place with a branching ratio of 100%, see Fig. 12. See also Table 5. Exclusions in the CMSSM, assuming $\tan\beta = 30$, $A_0 = -2$ max($m_0$, $m_{1/2}$) and $\mu > 0$, are also presented, see Fig. 15.

[3] KHACHATRYAN 15AH searched in 19.4 or 19.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events containing either a fully reconstructed top quark, or events containing dijets requiring one or both jets to originate from $b$-quarks, or events containing a mono-jet. No significant excess above the Standard Model expectations is observed. Limits are set on the sbottom mass in simplified models where the decay $\tilde{b} \to b\tilde{\chi}^0_1$ takes place with a branching ratio of 100%, see Fig. 12. Limits are also set in a simplified model where the decay $\tilde{b} \to c\tilde{\chi}^0_1$ takes place with a branching ratio of 100%, see Fig. 12.

[4] KHACHATRYAN 15I searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events in which $b$-jets and four $W$-bosons are produced. Five individual search channels are combined (fully hadronic, single lepton, same-sign dilepton, opposite-sign dilepton, multilepton). No significant excess above the Standard Model expectations is observed. Limits are set on the sbottom mass in a simplified model where the decay $\tilde{b} \to t\tilde{\chi}^\pm_1$, with $\tilde{\chi}^\pm_1 \to W^\pm\tilde{\chi}^0_1$, takes place with a branching ratio of 100%, see Fig. 7.

[5] AAD 14T searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for monojet-like events. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set on the masses of third-generation squarks in simplified models which assume that the decay $\tilde{b}_1 \to b\tilde{\chi}^0_1$ takes place 100% of the time, see Fig. 12.

[6] CHATRCHYAN 14AH searched in 4.7 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 7 TeV for events with at least two energetic jets and significant $\not{E}_T$, using the razor variables ($M_R$ and $R^2$) to discriminate between signal and background processes. A second analysis requires at least one of the jets to be originating from a $b$-quark. No significant excess above the Standard Model expectations is observed. Limits are set on sbottom masses in simplified models where the decay $\widetilde{b} \rightarrow b \widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Figs. 28 and 29. Exclusions in the CMSSM, assuming tan$\beta$ = 10, $A_0$ = 0 and $\mu$ >0, are also presented, see Fig. 26.

[7] CHATRCHYAN 14R searched in 19.5 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events with at least three leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in a simplified model where the decay $\widetilde{b} \rightarrow t \widetilde{\chi}_1^\pm$, with $\widetilde{\chi}_1^\pm \rightarrow W^\pm \widetilde{\chi}_1^0$, takes place with a branching ratio of 100%, see Fig. 11.

[8] KHACHATRYAN 15AD searched in 19.4 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events with two opposite-sign same flavor isolated leptons featuring either a kinematic edge, or a peak at the $Z$-boson mass, in the invariant mass spectrum. No evidence for a statistically significant excess over the expected SM backgrounds is observed and 95% C.L. exclusion limits are derived in a simplified model of sbottom pair production where the sbottom decays into a $b$-quark, two opposite-sign dileptons and a neutralino LSP, through an intermediate state containing either an off-shell $Z$-boson or a slepton, see Fig. 8.

[9] AAD 14AX searched in 20.1 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for the strong production of supersymmetric particles in events containing either zero or at last one high high-$p_T$ lepton, large missing transverse momentum, high jet multiplicity and at least three jets identified as originating from $b$-quarks. No excess over the expected SM background is observed. Limits are derived in mSUGRA/CMSSM models with tan$\beta$ = 30, $A_0 = -2\ m_0$ and $\mu$ > 0, see their Fig. 14. Also, exclusion limits are set in simplified models containing scalar bottom quarks, where the decay $\widetilde{b} \rightarrow b \widetilde{\chi}_2^0$ and $\widetilde{\chi}_2^0 \rightarrow h \widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see their Figures 11.

[10] AAD 14E searched in 20.3 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for strongly produced supersymmetric particles in events containing jets and two same-sign leptons or three leptons. The search also utilises jets originating from $b$-quarks, missing transverse momentum and other variables. No excess over the expected SM background is observed. Exclusion limits are derived in simplified models containing bottom, see Fig. 7. Limits are also derived in the mSUGRA/CMSSM, bRPV and GMSB models, see their Fig. 8.

[11] CHATRCHYAN 14H searched in 19.5 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events with two isolated same-sign dileptons and jets in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the sbottom mass in a simplified models where the decay $\widetilde{b} \rightarrow t \widetilde{\chi}_1^\pm$, $\widetilde{\chi}_1^\pm \rightarrow W^\pm \widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, with varying mass of the $\widetilde{\chi}_1^\pm$, for $m_{\widetilde{\chi}_1^0}$ = 50 GeV, see Fig. 6.

[12] AAD 13AU searched in 20.1 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events containing two jets identified as originating from $b$-quarks and large missing transverse momentum. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set on the masses of third-generation squarks. Assuming that the decay $\widetilde{b}_1 \rightarrow b \widetilde{\chi}_1^0$ takes place 100% of the time, a $\widetilde{b}_1$ mass below 620 GeV is excluded for $m_{\widetilde{\chi}_1^0} < 120$ GeV. For more details, see their Fig. 5.

[13] CHATRCHYAN 13AT provides interpretations of various searches for supersymmetry by the CMS experiment based on 4.73–4.98 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 7 TeV in the framework of simplified models. Limits are set on the sbottom mass in a simplified models where sbottom quarks are pair-produced and the decay $\widetilde{b} \rightarrow b \widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 4.

[14] CHATRCHYAN 13T searched in 11.7 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events with at least two energetic jets and significant $\not{E}_T$, using the $\alpha_T$ variable to discriminate

between processes with genuine and misreconstructed $\not\!\!E_T$. No significant excess above the Standard Model expectations is observed. Limits are set on sbottom masses in simplified models where the decay $\widetilde{b} \rightarrow b\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 8 and Table 9.

[15] CHATRCHYAN 13V searched in 10.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with two isolated same-sign dileptons and at least two $b$-jets in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the bottom mass in a simplified models where the decay $\widetilde{b} \rightarrow t\widetilde{\chi}_1^{\pm}$, $\widetilde{\chi}_1^{\pm} \rightarrow W^{\pm}\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, with varying mass of the $\widetilde{\chi}_1^{\pm}$, for $m_{\widetilde{\chi}_1^0} = 50$ GeV, see Fig. 4.

[16] AAD 12AN searched in 2.05 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for scalar bottom quarks in events with large missing transverse momentum and two $b$-jets in the final state. The data are found to be consistent with the Standard Model expectations. Limits are set in an $R$-parity conserving minimal supersymmetric scenario, assuming $\text{B}(\widetilde{b}_1 \rightarrow b\widetilde{\chi}_1^0) =$ 100%, see their Fig. 2.

[17] CHATRCHYAN 12AI looked in 4.98 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with two same-sign leptons ($e$, $\mu$), but not necessarily same flavor, at least 2 $b$-jets and missing transverse energy. No excess beyond the Standard Model expectation is observed. Exclusion limits are derived in a simplified model for sbottom pair production, where the sbottom decays through $\widetilde{b}_1 \rightarrow t\widetilde{\chi}_1 W$, see Fig. 8.

[18] CHATRCHYAN 12BO searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for scalar bottom quarks in events with large missing transverse momentum and two $b$-jets in the final state. The data are found to be consistent with the Standard Model expectations. Limits are set in an R-parity conserving minimal supersymmetric scenario, assuming $\text{B}(\widetilde{b}_1 \rightarrow b\widetilde{\chi}_1^0) = 100\%$, see their Fig. 2.

[19] AAD 11K looked in 34 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or time of flight in the tile calorimeter, from pair production of $\widetilde{b}$. No evidence for an excess over the SM expectation is observed and limits on the mass are derived for pair production of sbottom, see Fig. 4.

[20] AAD 11O looked in 35 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with jets, of which at least one is a $b$-jet, and $\not\!\!E_T$. No excess above the Standard Model was found. Limits are derived in the ($m_{\widetilde{g}}$, $m_{\widetilde{b}_1}$) plane (see Fig. 2) under the assumption of 100% branching ratios and $\widetilde{b}_1$ being the lightest squark. The quoted limit is valid for $m_{\widetilde{b}_1} <$ 500 GeV. A similar approach for $\widetilde{t}_1$ as the lightest squark with $\widetilde{g} \rightarrow \widetilde{t}_1 t$ and $\widetilde{t}_1 \rightarrow b\widetilde{\chi}_1^{\pm}$ with 100% branching ratios leads to a gluino mass limit of 520 GeV for $130 < m_{\widetilde{t}_1} <$ 300 GeV. Limits are also derived in the CMSSM ($m_0$, $m_{1/2}$) plane for $\tan\beta = 40$, see Fig. 4, and in scenarios based on the gauge group SO(10).

[21] CHATRCHYAN 11D looked in 35 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with $\geq$ 2 jets, at least one of which is b-tagged, and $\not\!\!E_T$, where the $b$-jets are decay products of $\widetilde{t}$ or $\widetilde{b}$. No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM ($m_0$, $m_{1/2}$) plane for $\tan\beta = 50$ (see Fig. 2).

[22] AALTONEN 10R searched in 2.65 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV for events with $\not\!\!E_T$ and exactly two jets, at least one of which is $b$-tagged. The results are in agreement with the SM prediction, and a limit on the cross section of 0.1 pb is obtained for the range of masses $80 < m_{\widetilde{b}_1} < 280$ GeV assuming that the sbottom decays exclusively to $b\widetilde{\chi}_1^0$. The excluded mass region in the framework of conserved $R_p$ is shown in a plane of ($m_{\widetilde{b}_1}$, $m_{\widetilde{\chi}_1^0}$), see their Fig.2.

[23] ABAZOV 10L looked in 5.2 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV for events with at least 2 b-jets and $\not\!\!E_T$ from the production of $\widetilde{b}_1 \widetilde{b}_1$. No evidence for an excess over the SM expectation is observed, and a limit on the cross section is derived under the assumption of 100% branching ratio. The excluded mass region in the framework of conserved $R_p$ is shown in a plane of ($m_{\widetilde{b}_1}$,$m_{\widetilde{\chi}^0_1}$), see their Fig. 3b. The exclusion also extends to $m_{\widetilde{\chi}^0_1}$ = 110 GeV for 160< $m_{\widetilde{b}_1}$ < 200 GeV.

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## $\widetilde{t}$ (Stop) MASS LIMIT

Limits depend on the decay mode. In $e^+ e^-$ collisions they also depend on the mixing angle of the mass eigenstate $\widetilde{t}_1 = \widetilde{t}_L \cos\theta_t + \widetilde{t}_R \sin\theta_t$. The coupling to the $Z$ vanishes when $\theta_t$ = 0.98. In the Listings below, we use $\Delta m \equiv m_{\widetilde{t}_1} - m_{\widetilde{\chi}^0_1}$ or $\Delta m \equiv m_{\widetilde{t}_1} - m_{\widetilde{\nu}}$, depending on relevant decay mode. See also bounds in "$\widetilde{q}$ (Squark) MASS LIMIT."

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| >250 | 95 | [1] AAD | 15CJ | ATLS | B($\widetilde{t} \rightarrow c\widetilde{\chi}^0_1$)+B($\widetilde{t} \rightarrow b f f' \widetilde{\chi}^0_1$) = 1, $m_{\widetilde{t}} - m_{\widetilde{\chi}^0_1}$ = 10 GeV |
| >270 | 95 | [1] AAD | 15CJ | ATLS | $\widetilde{t} \rightarrow c\widetilde{\chi}^0_1$, $m_{\widetilde{t}} - m_{\widetilde{\chi}^0_1}$=80 GeV |
| none, 200–700 | 95 | [1] AAD | 15CJ | ATLS | $\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ = 0 |
| >500 | 95 | [1] AAD | 15CJ | ATLS | B($\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$) + B($\widetilde{t} \rightarrow b\widetilde{\chi}^\pm_1$) = 1, $\widetilde{\chi}^\pm_1 \rightarrow W^{(*)}\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^\pm_1}$ = 2$m_{\widetilde{\chi}^0_1}$, $m_{\widetilde{\chi}^0_1}$ < 160 GeV |
| >600 | 95 | [1] AAD | 15CJ | ATLS | $\widetilde{t}_2 \rightarrow Z\widetilde{t}_1$, $m_{\widetilde{t}_1} - m_{\widetilde{\chi}^0_1}$ = 180 GeV, $m_{\widetilde{\chi}^0_1}$ = 0 |
| >600 | 95 | [1] AAD | 15CJ | ATLS | $\widetilde{t}_2 \rightarrow h\widetilde{t}_1$, $m_{\widetilde{t}_1} - m_{\widetilde{\chi}^0_1}$ = 180 GeV, $m_{\widetilde{\chi}^0_1}$ = 0 |
| none, 172.5–191 | 95 | [2] AAD | 15J | ATLS | $\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ = 1 GeV |
| >450 | 95 | [3] KHACHATRY... | 15AF | CMS | $\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ = 0, $m_{\widetilde{t}} > m_t + m_{\widetilde{\chi}^0_1}$ |
| >560 | 95 | [4] KHACHATRY... | 15AH | CMS | $\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ = 0, $m_{\widetilde{t}} > m_t + m_{\widetilde{\chi}^0_1}$ |
| >250 | 95 | [5] KHACHATRY... | 15AH | CMS | $\widetilde{t} \rightarrow c\widetilde{\chi}^0_1$, $m_{\widetilde{t}} - m_{\widetilde{\chi}^0_1}$ <10 GeV |
| none, 200–350 | 95 | [6] KHACHATRY... | 15L | CMS | $\widetilde{t} \rightarrow qq$, $\not\!R$, $\lambda''_{312} \neq 0$ |
| none, 200–385 | 95 | [6] KHACHATRY... | 15L | CMS | $\widetilde{t} \rightarrow qb$, $\not\!R$, $\lambda''_{323} \neq 0$ |
| **>730** | 95 | [7] KHACHATRY... | 15X | CMS | $\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ = 100 GeV, $m_{\widetilde{t}} > m_t + m_{\widetilde{\chi}^0_1}$ |

| | | | | | |
|---|---|---|---|---|---|
| none 400–645 | 95 | [7] KHACHATRY... | 15X | CMS | $\tilde{t} \to t\tilde{\chi}_1^0$ or $\tilde{t} \to b\tilde{\chi}_1^\pm$, $m_{\tilde{\chi}_1^0} = 100$ GeV, $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 5$ GeV |
| none 270–645 | 95 | [8] AAD | 14AJ | ATLS | $\geq$ 4 jets + $\not{E}_T$, $\tilde{t}_1 \to t\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} < 30$ GeV |
| none 250–550 | 95 | [8] AAD | 14AJ | ATLS | $\geq$ 4 jets + $\not{E}_T$, B($\tilde{t}_1 \to b\tilde{\chi}_1^\pm$) = 50 %, $m_{\tilde{\chi}_1^\pm} = 2\, m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_1^0} < 60$ GeV |
| none 210–640 | 95 | [9] AAD | 14BD | ATLS | $\ell^\pm$ + jets + $\not{E}_T$, $\tilde{t}_1 \to t\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} = 0$ GeV |
| **>500** | 95 | [9] AAD | 14BD | ATLS | $\ell^\pm$ + jets + $\not{E}_T$, $\tilde{t}_1 \to b\tilde{\chi}_1^\pm$, $m_{\tilde{\chi}_1^\pm} = 2\, m_{\tilde{\chi}_1^0}$, 100 GeV $< m_{\tilde{\chi}_1^0} <$ 150 GeV |
| none 150–445 | 95 | [10] AAD | 14F | ATLS | $\ell^\pm\ell^\mp$ final state, $\tilde{t}_1 \to b\tilde{\chi}_1^\pm$, $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^\pm} = 10$ GeV, $m_{\tilde{\chi}_1^0} = 1$ GeV |
| none 215–530 | 95 | [10] AAD | 14F | ATLS | $\ell^\pm\ell^\mp$ final state, $\tilde{t}_1 \to t\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} = 1$ GeV |
| >270 | 95 | [11] AAD | 14T | ATLS | $\tilde{t}_1 \to c\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} = 200$ GeV |
| **>240** | 95 | [11] AAD | 14T | ATLS | $\tilde{t}_1 \to c\tilde{\chi}_1^0$,$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} <$85 GeV |
| >255 | 95 | [11] AAD | 14T | ATLS | $\tilde{t}_1 \to bff'\tilde{\chi}_1^0$, $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \approx m_b$ |
| >400 | 95 | [12] CHATRCHYAN | 14AH | CMS | jets + $\not{E}_T$, $\tilde{t} \to t\tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^0} = 50$ GeV |
| | | [13] CHATRCHYAN | 14R | CMS | $\geq 3\ell^\pm$, $\tilde{t} \to (b\tilde{\chi}_1^\pm / t\tilde{\chi}_1^0)$, $\tilde{\chi}_1^\pm \to (qq'/\ell\nu)\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to (H/Z)\tilde{G}$, GMSB, natural higgsino NLSP scenario |
| >740 | 95 | [14] KHACHATRY... | 14T | CMS | $\tau$ + $b$-jets, $\not{R}$, $LQ\overline{D}$, $\lambda'_{333} \neq 0$, $\tilde{t} \to \tau b$ simplified model |
| >580 | 95 | [14] KHACHATRY... | 14T | CMS | $\tau$ + $b$-jets, $\not{R}$, $LQ\overline{D}$, $\lambda'_{3jk} \neq 0$ ($j \neq$ =3), $\tilde{t} \to \tilde{\chi}^\pm b$, $\tilde{\chi}^\pm \to qq\tau^\pm$ simplified model |

• • • We do not use the following data for averages, fits, limits, etc. • • •

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|---|---|---|---|---|---|
| >790 | 95 | [15] KHACHATRY... | 15E | CMS | $\tilde{t}_1 \to b\ell$, RPV, $c\tau = 2$ cm |
| >230 | | ROLBIECKI | 15 | THEO | $WW$ xsection, $\tilde{t}_1 \to bW\tilde{\chi}_1^0$, $m_{\tilde{t}_1} \simeq m_b + m_W + m_{\tilde{\chi}_1^0}$ |
| >600 | 95 | [16] AAD | 14B | ATLS | $Z$+$b$ $\not{E}_T$, $\tilde{t}_2 \to Z\tilde{t}_1$, $\tilde{t}_1 \to t\tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0} < 200$ GeV |

| | | | | | |
|---|---|---|---|---|---|
| >540 | 95 | [16] AAD | 14B | ATLS | $Z+b\,\not{E}_T$, $\tilde{t}_1 \to t\tilde{\chi}^0_1$, $\tilde{\chi}^0_1 \to Z\tilde{G}$, natural GMSB, 100 GeV $< m_{\tilde{\chi}^0_1} < m_{\tilde{t}_1} - 10$ GeV |
| >360 | 95 | [17] CHATRCHYAN | 14U | CMS | $\tilde{t}_1 \to b\tilde{\chi}^\pm_1$r, $\tilde{\chi}^\pm_1 \to f f' \tilde{\chi}^0_1$, $\tilde{\chi}^0_1 \to H\tilde{G}$ simplified model, $m_{\tilde{\chi}^\pm_1} - m_{\tilde{\chi}^0_1} = 5$ GeV,GMSB |
| >215 | 95 | CZAKON | 14 | | $\tilde{t} \to t\chi^0_1$, $m_{\chi^0_1} < 10$ GeV |
| | | [18] KHACHATRY... | 14C | CMS | $\tilde{t}_2 \to H\tilde{t}_1$ or $\tilde{t}_2 \to Z\tilde{t}_1$ simplified model |

[1] AAD 15CJ searched in 20 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for evidence of third generation squarks by combining a large number of searches covering various final states. Stop decays with and without charginos in the decay chain are considered and summaries of all ATLAS Run 1 searches for direct stop production can be found in Fig. 4 (no intermediate charginos) and Fig. 7 (intermediate charginos). Limits are set on stop masses in compressed mass regions regions, with $\mathrm{B}(\tilde{t} \to c\tilde{\chi}^0_1) + \mathrm{B}(\tilde{t} \to b f f' \tilde{\chi}^0_1) = 1$, see Fig. 5. Limits are also set on stop masses assuming that both the decay $\tilde{t} \to t\tilde{\chi}^0_1$ and $\tilde{t} \to b\tilde{\chi}^\pm_1$ are possible, with both their branching rations summing up to 1, assuming $\tilde{\chi}^\pm_1 \to W^{(*)}\tilde{\chi}^0_1$ and $m_{\tilde{\chi}^\pm_1} = 2\, m_{\tilde{\chi}^0_1}$, see Fig. 6. Limits on the mass of the next-to-lightest stop $\tilde{t}_2$, decaying either to $Z\tilde{t}_1$, $h\tilde{t}_1$ or $t\tilde{\chi}^0_1$, are also presented, see Figs. 9 and 10.Interpretations in the pMSSM are also discussed, see Figs 13–15.

[2] AAD 15J interpreted the measurement of spin correlations in $t\bar{t}$ production using 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV in exclusion limits on the pair production of light $\tilde{t}_1$ squarks with masses similar to the top quark mass. The $\tilde{t}_1$ is assumed to decay through $\tilde{t}_1 \to t\tilde{\chi}^0_1$ with predominantly right-handed top and a 100% branching ratio. The data are found to be consistent with the Standard Model expectations and masses between the top quark mass and 191 GeV are excluded, see their Fig. 2

[3] KHACHATRYAN 15AF searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least two energetic jets and significant $\not{E}_T$, using the transverse mass variable $M_{T2}$ to discriminate between signal and background processes. No significant excess above the Standard Model expectations is observed. Limits are set on the stop mass in simplified models where the decay $\tilde{t} \to t\tilde{\chi}^0_1$ takes place with a branching ratio of 100%, see Fig. 12. See also Table 5. Exclusions in the CMSSM, assuming $\tan\beta = 30$, $A_0 = -2\,\max(m_0,\, m_{1/2})$ and $\mu > 0$, are also presented, see Fig. 15.

[4] KHACHATRYAN 15AH searched in 19.4 or 19.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events containing either a fully reconstructed top quark, or events containing dijets requiring one or both jets to originate from $b$-quarks, or events containing a mono-jet. No significant excess above the Standard Model expectations is observed. Limits are set on the stop mass in simplified models where the decay $\tilde{t} \to t\tilde{\chi}^0_1$ takes place with a branching ratio of 100%, see Fig. 9. Limits are also set in simplified models where the decays $\tilde{t} \to t\tilde{\chi}^0_1$ and $\tilde{t} \to b\tilde{\chi}^\pm_1$, with $m_{\tilde{\chi}^\pm_1}$ - $m_{\tilde{\chi}^0_1} = 5$ GeV, each take place with a branching ratio of 50%, see Fig. 10, or with other fractions, see Fig. 11. Finally, limits are set in a simplified model where the decay $\tilde{t} \to c\tilde{\chi}^0_1$ takes place with a branching ratio of 100%, see Figs. 9, 10 and 11.

[5] KHACHATRYAN 15AH searched in 19.4 or 19.7 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events containing either a fully reconstructed top quark, or events containing dijets requiring one or both jets to originate from $b$-quarks, or events containing a mono-jet. No significant excess above the Standard Model expectations is observed. Limits are set on the stop mass in simplified models where the decay $\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$ takes place with a branching ratio of 100%, see Fig. 9. Limits are also set in simplified models where the decays $\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$ and $\widetilde{t} \rightarrow b\widetilde{\chi}^\pm_1$, with $m_{\widetilde{\chi}^\pm_1} - m_{\widetilde{\chi}^0_1}$ = 5 GeV, each take place with a branching ratio of 50%, see Fig. 10, or with other fractions, see Fig. 11. Finally, limits are set in a simplified model where the decay $\widetilde{t} \rightarrow c\widetilde{\chi}^0_1$ takes place with a branching ratio of 100%, see Figs. 9, 10, and 11.

[6] KHACHATRYAN 15L searched in 19.4 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for pair production of heavy resonances decaying to pairs of jets in four jet events. No significant excess above the Standard Model expectations is observed. Limits are set on the stop mass in $R$-parity-violating supersymmetry models where $\widetilde{t} \rightarrow q q$ ($\lambda^{''}_{312} \neq 0$), see Fig. 6 (top) and $\widetilde{t} \rightarrow q b$ ($\lambda^{''}_{323} \neq 0$), see Fig. 6 (bottom).

[7] KHACHATRYAN 15X searched in 19.3 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events with at least two energetic jets, at least one of which is required to originate from a $b$ quark, possibly a lepton, and significant $\not\!\!E_T$, using the razor variables ($M_R$ and $R^2$) to discriminate between signal and background processes. No significant excess above the Standard Model expectations is observed. Limits are set on the stop mass in simplified models where the decay $\widetilde{t} \rightarrow t\widetilde{\chi}^0_1$ and the decay $\widetilde{t} \rightarrow b\widetilde{\chi}^\pm_1$, with $m_{\widetilde{\chi}^\pm_1} - m_{\widetilde{\chi}^0_1}$ = 5 GeV, take place with branching ratios varying between 0 and 100%, see Figs. 15, 16 and 17.

[8] AAD 14AJ searched in 20.1 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events containing four or more jets and large missing transverse momentum. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set on the masses of third-generation squarks in simplified models which either assume that the decay $\widetilde{t}_1 \rightarrow t\widetilde{\chi}^0_1$ takes place 100% of the time, see Fig. 8, or that this decay takes place 50% of the time, while the decay $\widetilde{t}_1 \rightarrow b\widetilde{\chi}^\pm_1$ takes place the other 50% of the time, see Fig. 9.

[9] AAD 14BD searched in 20 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events containing one isolated lepton, jets and large missing transverse momentum. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set on the masses of third-generation squarks in simplified models which either assume that the decay $\widetilde{t}_1 \rightarrow t\widetilde{\chi}^0_1$ takes place 100% of the time, see Fig. 15, or the decay $\widetilde{t}_1 \rightarrow b\widetilde{\chi}^\pm_1$ takes place 100% of the time, see Fig. 16–22. For the mixed decay scenario, see Fig. 23.

[10] AAD 14F searched in 20.3 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for events containing two leptons ($e$ or $\mu$), and possibly jets and missing transverse momentum. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set on the masses of third-generation squarks in simplified models which either assume that the decay $\widetilde{t}_1 \rightarrow b\widetilde{\chi}^\pm_1$ takes place 100% of the time, see Figs. 14–17 and 20, or that the decay $\widetilde{t}_1 \rightarrow t\widetilde{\chi}^0_1$ takes place 100% of the time, see Figs. 18 and 19.

[11] AAD 14T searched in 20.3 fb$^{-1}$ of $p p$ collisions at $\sqrt{s}$ = 8 TeV for monojet-like and $c$-tagged events. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set on the masses of third-generation squarks in simplified models which assume that the decay $\widetilde{t}_1 \rightarrow c\widetilde{\chi}^0_1$ takes place 100% of the time, see Fig. 9 and 10. The results of the monojet-like analysis are also interpreted in terms of stop pair production in the four-body decay $\widetilde{t}_1 \rightarrow b f f' \widetilde{\chi}^0_1$, see Fig. 11.

[12] CHATRCHYAN 14AH searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with at least two energetic jets and significant $\not{E}_T$, using the razor variables ($M_R$ and $R^2$) to discriminate between signal and background processes. A second analysis requires at least one of the jets to be originating from a $b$-quark. No significant excess above the Standard Model expectations is observed. Limits are set on sbottom masses in simplified models where the decay $\widetilde{t} \rightarrow t\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Figs. 28 and 29. Exclusions in the CMSSM, assuming tan$\beta = 10$, $A_0 = 0$ and $\mu > 0$, are also presented, see Fig. 26.

[13] CHATRCHYAN 14R searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least three leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the stop mass in a natural higgsino NLSP simplified model (GMSB) where the decay $\widetilde{t} \rightarrow b\widetilde{\chi}_1^{\pm}$, with $\widetilde{\chi}_1^{\pm} \rightarrow (qq'/\ell\nu)H,\ Z\widetilde{G}$, takes place with a branching ratio of 100% (the particles between brackets have a soft $p_T$ spectrum), see Figs. 4–6.

[14] KHACHATRYAN 14T searched in 19.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with $\tau$-leptons and $b$-quark jets, possibly with extra light-flavour jets. No excess above the Standard Model expectations is observed. Limits are set on stop masses in $\not{R}$ SUSY models with $LQ\overline{D}$ couplings, in two simplified models. In the first model, the decay $\widetilde{t} \rightarrow \tau b$ is considered, with $\lambda'_{333} \neq 0$, see Fig. 3. In the second model, the decay $\widetilde{t} \rightarrow \widetilde{\chi}^{\pm} b$, with the subsequent decay $\widetilde{\chi}^{\pm} \rightarrow qq\tau^{\pm}$ is considered, with $\lambda'_{3jk} \neq 0$ and the mass splitting between the top squark and the charging chosen to be 100 GeV, see Fig. 4.

[15] KHACHATRYAN 15E searched for long-lived particles decaying to leptons in 19.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV. Events were selected with an electron and muon with opposite charges and each with transverse impact parameter values between 0.02 and 2 cm. Limits are set on SUSY benchmark models with pair production of top squarks decaying into an $e\mu$ final state via RPV interactions. See their Fig. 2

[16] AAD 14B searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events containing a $Z$ boson, with or without additional leptons, plus jets originating from $b$-quarks and significant missing transverse momentum. No excess over the expected SM background is observed. Limits are derived in simplified models featuring $\widetilde{t}_2$ production, with $\widetilde{t}_2 \rightarrow Z\widetilde{t}_1$, $\widetilde{t}_1 \rightarrow t\widetilde{\chi}_1^0$ with a 100% branching ratio, see Fig. 4, and in the framework of natural GMSB, see Fig. 6.

[17] CHATRCHYAN 14U searched in 19.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for evidence of direct pair production of top squarks, with Higgs bosons in the decay chain. The search is performed using a selection of events containing two Higgs bosons, each decaying to a photon pair, missing transverse energy and possibly $b$-quark jets. No significant excesses over the expected SM backgrounds are observed. The results are interpreted in the context of a "natural SUSY" simplified model where the decays $\widetilde{t}_1 \rightarrow b\widetilde{\chi}_1^{\pm}$, with $\widetilde{\chi}_1^{\pm} \rightarrow ff'\widetilde{\chi}_1^0$, and $\widetilde{\chi}_1^0 \rightarrow H\widetilde{G}$, all happen with 100% branching ratio, see Fig. 4.

[18] KHACHATRYAN 14C searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for evidence of direct pair production of top squarks, with Higgs or $Z$-bosons in the decay chain. The search is performed using a selection of events containing leptons and $b$-quark jets. No significant excesses over the expected SM backgrounds are observed. The results are interpreted in the context of a simplified model with pair production of a heavier top-squark mass eigenstate $\widetilde{t}_2$ decaying to a lighter top-squark eigenstate $\widetilde{t}_1$ via either $\widetilde{t}_2 \rightarrow H\widetilde{t}_1$ or $\widetilde{t}_2 \rightarrow Z\widetilde{t}_1$, followed in both cases by $\widetilde{t}_1 \rightarrow t\widetilde{\chi}_1^0$. The interpretation is performed in the region where the mass difference between the $\widetilde{t}_1$ and $\widetilde{\chi}_1^0$ is approximately equal to the top-quark mass, which is not probed by searches for direct $\widetilde{t}_1$ pair production, see Figs. 5 and 6. The analysis excludes top squarks with masses $m_{\widetilde{t}_2} < 575$ GeV and $m_{\widetilde{t}_1} < 400$ GeV at 95% C.L.

## Heavy $\tilde{g}$ (Gluino) MASS LIMIT

For $m_{\tilde{g}} > 60$–70 GeV, it is expected that gluinos would undergo a cascade decay via a number of neutralinos and/or charginos rather than undergo a direct decay to photinos as assumed by some papers. Limits obtained when direct decay is assumed are usually higher than limits when cascade decays are included.

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| $>$ 820 | 95 | [1] AAD 15BG | ATLS | GGM, $\tilde{g} \to q\tilde{q}Z\tilde{G}$, tan$\beta$ = 30, $\mu > 600$ GeV |
| $>$ 850 | 95 | [1] AAD 15BG | ATLS | GGM, $\tilde{g} \to q\tilde{q}Z\tilde{G}$, tan$\beta$ = 1.5, $\mu > 450$ GeV |
| **>1150** | 95 | [2] AAD 15BV | ATLS | general RPC $\tilde{g}$ decays, $m_{\tilde{\chi}^0_1} <$ 100 GeV |
| $>$ 700 | 95 | [3] AAD 15BX | ATLS | $\tilde{g} \to X\tilde{\chi}^0_1$, independent of $m_{\tilde{\chi}^0_1}$ |
| >1290 | 95 | [4] AAD 15CA | ATLS | $\geq 2\gamma + \not{E}_T$, GGM, bino-like NLSP, any NLSP mass |
| >1260 | 95 | [4] AAD 15CA | ATLS | $\geq 1\gamma + b$-jets $+ \not{E}_T$, GGM, higgsino-bino admix. NLSP and $\mu$ <0, m(NLSP)>450 GeV |
| >1140 | 95 | [4] AAD 15CA | ATLS | $\geq 1\gamma +$ jets $+ \not{E}_T$, GGM, higgsino-bino admixture NLSP, all $\mu$ >0 |
| **>1225** | 95 | [5] KHACHATRY... 15AF | CMS | $\tilde{g} \to q\overline{q}\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1} = 0$ |
| >1300 | 95 | [5] KHACHATRY... 15AF | CMS | $\tilde{g} \to b\overline{b}\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1} = 0$ |
| >1225 | 95 | [5] KHACHATRY... 15AF | CMS | $\tilde{g} \to t\overline{t}\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1} = 0$ |
| >1550 | 95 | [5] KHACHATRY... 15AF | CMS | CMSSM, tan$\beta$=30, $m_{\tilde{g}}=m_{\tilde{q}}$, $A_0=-2\max(m_0,m_{1/2})$, $\mu$ >0 |
| **>1150** | 95 | [5] KHACHATRY... 15AF | CMS | CMSSM, tan$\beta$=30, $A_0=-2\max(m_0,m_{1/2})$, $\mu$ >0 |
| >1280 | 95 | [6] KHACHATRY... 15I | CMS | $\tilde{g} \to t\tilde{t}\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1} = 0$ |
| >1310 | 95 | [7] KHACHATRY... 15X | CMS | $\tilde{g} \to b\overline{b}\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1} = 100$ GeV |
| >1175 | 95 | [7] KHACHATRY... 15X | CMS | $\tilde{g} \to t\overline{t}\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1} = 100$ GeV |
| >1330 | 95 | [8] AAD 14AE | ATLS | jets $+ \not{E}_T$, $\tilde{g} \to q\overline{q}\tilde{\chi}^0_1$ simplified model, $m_{\tilde{\chi}^0_1} = 0$ GeV |
| >1700 | 95 | [8] AAD 14AE | ATLS | jets $+ \not{E}_T$, mSUGRA/CMSSM, $m_{\tilde{q}} = m_{\tilde{g}}$ |
| >1090 | 95 | [9] AAD 14AG | ATLS | $\tau +$ jets $+ \not{E}_T$, natural Gauge Mediation |
| >1600 | 95 | [9] AAD 14AG | ATLS | $\tau +$ jets $+ \not{E}_T$, mGMSB, $M_{mess} = 250$ GeV, $N_5 = 3$, $\mu > 0$, $C_{grav} = 1$ |
| >1350 | 95 | [10] AAD 14X | ATLS | $\geq 4\ell^{\pm}$, $\tilde{g} \to q\overline{q}\tilde{\chi}^0_1$, $\tilde{\chi}^0_1 \to \ell^{\pm}\ell^{\mp}\nu$, $\not{R}$ |
| $>$ 640 | 95 | [11] AAD 14X | ATLS | $\geq 4\ell^{\pm}$, $\tilde{g} \to q\overline{q}\tilde{\chi}^0_1$, $\tilde{\chi}^0_1 \to \ell^{\pm}\ell^{\mp}\tilde{G}$, tan$\beta$ = 30, GGM |

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| $>1000$ | 95 | [12] CHATRCHYAN 14AH | CMS | jets + $\not\!\!E_T$, $\tilde g \to q\bar q\tilde\chi^0_1$ simplified model, $m_{\tilde\chi^0_1} = 50$ GeV |
| $>1350$ | 95 | [12] CHATRCHYAN 14AH | CMS | jets + $\not\!\!E_T$, CMSSM, $m_{\tilde g} = m_{\tilde q}$ |
| $>1000$ | 95 | [13] CHATRCHYAN 14AH | CMS | jets + $\not\!\!E_T$, $\tilde g \to b\bar b\tilde\chi^0_1$ simplified model, $m_{\tilde\chi^0_1} = 50$ GeV |
| $>1000$ | 95 | [14] CHATRCHYAN 14AH | CMS | jets + $\not\!\!E_T$, $\tilde g \to t\bar t\tilde\chi^0_1$ simplified model, $m_{\tilde\chi^0_1} = 50$ GeV |
| $>1160$ | 95 | [15] CHATRCHYAN 14I | CMS | ets + $\not\!\!E_T$, $\tilde g \to q\bar q\tilde\chi^0_1$ simplified model, $m_{\tilde\chi^0_1} < 100$ GeV |
| $>1130$ | 95 | [15] CHATRCHYAN 14I | CMS | multijets + $\not\!\!E_T$, $\tilde g \to t\bar t\tilde\chi^0_1$ simplified model, $m_{\tilde\chi^0_1} < 100$ GeV |
| $>1210$ | 95 | [15] CHATRCHYAN 14I | CMS | multijets + $\not\!\!E_T$, $\tilde g \to q\bar q W/Z\tilde\chi^0_1$ simplified model, $m_{\tilde\chi^0_1} < 100$ GeV |
| $>1260$ | 95 | [16] CHATRCHYAN 14N | CMS | $1\ell^\pm$+ jets + $\geq$ 2$b$-jets, $\tilde g \to t\bar t\chi^0_1$ simplified model, $m_{\chi^0_1}$=0 GeV, $m_{\tilde t} > m_{\tilde g}$ |
| $>$ 650 | 95 | [17] CHATRCHYAN 14P | CMS | $\tilde g \to jjj$, $\not\!R$ |
| none 200–835 | 95 | [17] CHATRCHYAN 14P | CMS | $\tilde g \to bjj$, $\not\!R$ |
| | | [18] CHATRCHYAN 14R | CMS | $\geq 3\ell^\pm$, $(\tilde g/\tilde q) \to q\ell^\pm\ell^\mp\tilde G$ simplified model, GMSB, slepton co-NLSP scenario |
| | | [19] CHATRCHYAN 14R | CMS | $\geq 3\ell^\pm$, $\tilde g \to t\bar t\tilde\chi^0_1$ simplified model |

• • • We do not use the following data for averages, fits, limits, etc. • • •

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|---|---|---|---|---|
| | 95 | [20] AAD 15AB | ATLS | $\tilde g \to \tilde S g$, $c\tau = 1$ m, $\tilde S \to S\tilde G$ and $S \to gg$, BR = 100% |
| | 95 | [21] AAD 15AI | ATLS | $\ell^\pm$ + jets + $\not\!\!E_T$ |
| $>1600$ | 95 | [2] AAD 15BV | ATLS | pMSSM, $M_1 = 60$ GeV, $m_{\tilde q} < 1500$ GeV |
| $>1280$ | 95 | [2] AAD 15BV | ATLS | mSUGRA, $m_0 > 2$ TeV |
| $>1100$ | 95 | [2] AAD 15BV | ATLS | via $\tilde\tau$, natural GMSB, all $m_{\tilde\tau}$ |
| $>1330$ | 95 | [2] AAD 15BV | ATLS | jets + $\not\!\!E_T$, $\tilde g \to q\bar q\tilde\chi^0_1$, $m_{\tilde\chi^0_1} = 1$ GeV |
| $>1500$ | 95 | [2] AAD 15BV | ATLS | jets + $\not\!\!E_T$, $\tilde g \to \tilde q q$, $\tilde q \to q\tilde\chi^0_1$, $m_{\tilde\chi^0_1} = 1$ GeV |
| $>1650$ | 95 | [2] AAD 15BV | ATLS | jets + $\not\!\!E_T$, $m_{\tilde g} = m_{\tilde q}$, $m_{\tilde\chi^0_1} = 1$ GeV |
| $>$ 850 | 95 | [2] AAD 15BV | ATLS | jets + $\not\!\!E_T$, $\tilde g \to g\tilde\chi^0_1$, $m_{\tilde\chi^0_1} < 550$ GeV |
| $>1270$ | 95 | [2] AAD 15BV | ATLS | jets + $\not\!\!E_T$, $\tilde g \to q\bar q W\tilde\chi^0_1$, $m_{\tilde\chi^0_1} = 100$ GeV |
| $>1150$ | 95 | [2] AAD 15BV | ATLS | jets + $\ell^\pm\ell^\pm$, $\tilde g \to q\bar q WZ\tilde\chi^0_1$, $m_{\tilde\chi^0_1} = 100$ GeV |

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|---|---|---|---|---|---|
| >1320 | 95 | [2] AAD | 15BV | ATLS | jets + $\ell^{\pm}\ell^{\pm}$, $\widetilde{g}$ decays via sleptons, $m_{\widetilde{\chi}^0_1} = 100$ GeV |
| >1220 | 95 | [2] AAD | 15BV | ATLS | $\tau$, $\widetilde{q}$ decays via staus, $m_{\widetilde{\chi}^0_1} = 100$ GeV |
| >1310 | 95 | [2] AAD | 15BV | ATLS | $b$-jets, $\widetilde{g} \to t\overline{t}\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1} < 400$ GeV |
| >1220 | 95 | [2] AAD | 15BV | ATLS | $b$-jets, $\widetilde{g} \to \widetilde{t}_1 t$ and $\widetilde{t}_1 \to t\widetilde{\chi}^0_1$, $m_{T_1} < 1000$ GeV |
| >1180 | 95 | [2] AAD | 15BV | ATLS | $b$-jets, $\widetilde{g} \to \widetilde{t}_1 t$ and $\widetilde{t}_1 \to b\widetilde{\chi}^{\pm}_1$, $m_{T_1} < 1000$ GeV, $m_{\widetilde{\chi}^0_1} = 60$ GeV |
| >1260 | 95 | [2] AAD | 15BV | ATLS | $b$-jets, $\widetilde{g} \to \widetilde{t}_1 t$ and $\widetilde{g} \to c\widetilde{\chi}^0_1$ |
| > 880 | 95 | [2] AAD | 15BV | ATLS | jets, $\widetilde{g} \to \widetilde{t}_1 t$ and $\widetilde{t}_1 \to sb$, RPV, $400 < m_{\widetilde{t}_1} < 1000$ GeV |
| >1200 | 95 | [2] AAD | 15BV | ATLS | $b$-jets, $\widetilde{g} \to \widetilde{b}_1 b$ and $\widetilde{b}_1 \to b\widetilde{\chi}^0_1$, $m_{\widetilde{b}_1} < 1000$ GeV |
| >1250 | 95 | [2] AAD | 15BV | ATLS | $b$-jets, $\widetilde{g} \to b\overline{b}\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1} < 400$ GeV |
| none, 750–1250 | 95 | [2] AAD | 15BV | ATLS | $b$-jets, $\widetilde{g}$ decay via offshell $\widetilde{t}_1$ and $\widetilde{b}_1$, $m_{\widetilde{\chi}^0_1} < 500$ GeV |
| | | [22] AAD | 15CB | ATLS | $\ell$, $\widetilde{g} \to (e/\mu)qq$, RPV, benchmark gluino, neutralino masses |
| > 600 | 95 | [22] AAD | 15CB | ATLS | $\ell\ell/Z$, $\widetilde{g} \to (ee/\mu\mu/e\mu)qq$, RPV, $m_{\widetilde{\chi}^0_1} = 400$ GeV and $0.7 < c\tau_{\widetilde{\chi}^0_1} < 3 \times 10^5$ mm |
| >1100 | 95 | [22] AAD | 15CB | ATLS | jets, $\widetilde{g} \to qq\widetilde{\chi}^0_1$, $\widetilde{\chi}^0_1 \to Z\widetilde{G}$, GGM, $m_{\widetilde{\chi}^0_1} = 400$ GeV and $3 < c\tau_{\widetilde{\chi}^0_1} < 500$ mm |
| >1400 | 95 | [22] AAD | 15CB | ATLS | jets or $\not{E}_T$, $\widetilde{g} \to qq\widetilde{\chi}^0_1$, Split SUSY, $m_{\widetilde{\chi}^0_1} = 100$ GeV and $15 < c\tau < 300$ mm |
| >1500 | 95 | [22] AAD | 15CB | ATLS | $\not{E}_T$, $\widetilde{g} \to qq\widetilde{\chi}^0_1$, Split SUSY, $m_{\widetilde{\chi}^0_1} = 100$ GeV and $20 < c\tau < 250$ mm |
| >1000 | 95 | [23] AAD | 15X | ATLS | $\geq 10$ jets, $\widetilde{g} \to q\overline{q}\widetilde{\chi}^0_1$, $\widetilde{\chi}^0_1 \to qqq$ (RPV), $m_{\widetilde{\chi}^0_1}$=500 GeV |
| > 917 | 95 | [23] AAD | 15X | ATLS | $\geq$ 6,7 jets, $\widetilde{g} \to qqq$, (light-quark, $\lambda''$ couplings, RPV) |
| > 929 | 95 | [23] AAD | 15X | ATLS | $\geq$ 6,7 jets, $\widetilde{g} \to qqq$, (b-quark, $\lambda''$ couplings, RPV) |
| | | [24] KHACHATRY... | 15AD | CMS | $\ell^{\pm}\ell^{\mp}$ + jets + $\not{E}_T$, GMSB, $\widetilde{g} \to q\overline{q}Z\widetilde{G}$ |
| >1300 | 95 | [25] KHACHATRY... | 15AZ | CMS | $\geq 2\ \gamma$, $\geq 1$ jet, (Razor), bino-like NLSP, $m_{\widetilde{\chi}^0_1} = 375$ GeV |

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|---|---|---|---|---|---|
| > 800 | 95 | [25] KHACHATRY... | 15AZ | CMS | ≥ 1 $\gamma$, ≥ 2 jet, wino-like NLSP, $m_{\tilde{\chi}_1^0}$ = 375 GeV |
| >1280 | 95 | [26] AAD | 14AX | ATLS | ≥ 3 $b$-jets + $\not{E}_T$, CMSSM |
| >1250 | 95 | [26] AAD | 14AX | ATLS | ≥ 3 $b$-jets + $\not{E}_T$, $\tilde{g} \rightarrow \tilde{b}_1 b \tilde{\chi}_1^0$ simplified model, $\tilde{b}_1 \rightarrow b \tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0}$ = 60 GeV, $m_{\tilde{b}_1}$ < 900 GeV |
| >1190 | 95 | [26] AAD | 14AX | ATLS | ≥ 3 $b$-jets + $\not{E}_T$, $\tilde{g} \rightarrow \tilde{t}_1 t \tilde{\chi}_1^0$ simplified model, $\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^0}$ = 60 GeV, $m_{\tilde{t}_1}$ < 1000 GeV |
| >1180 | 95 | [26] AAD | 14AX | ATLS | ≥ 3 $b$-jets + $\not{E}_T$, $\tilde{g} \rightarrow \tilde{t}_1 t \tilde{\chi}_1^0$ simplified model, $\tilde{t}_1 \rightarrow b \tilde{\chi}_1^\pm$, $m_{\tilde{\chi}_1^\pm}$=2$m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_1^0}$=60 GeV, $m_{\tilde{t}_1}$ <1000 GeV |
| >1250 | 95 | [26] AAD | 14AX | ATLS | ≥ 3 $b$-jets + $\not{E}_T$, $\tilde{g} \rightarrow b \bar{b} \tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^0}$ < 400 GeV |
| >1340 | 95 | [26] AAD | 14AX | ATLS | ≥ 3 $b$-jets + $\not{E}_T$, $\tilde{g} \rightarrow t \bar{t} \tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^0}$ < 400 GeV |
| >1300 | 95 | [26] AAD | 14AX | ATLS | ≥ 3 $b$-jets + $\not{E}_T$, $\tilde{g} \rightarrow t \bar{b} \tilde{\chi}_1^\pm$ simplified model, $\tilde{\chi}_1^\pm \rightarrow f f' \tilde{\chi}_1^0$, $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$ = 2 GeV, $m_{\tilde{\chi}_1^0}$ < 300 GeV |
| > 950 | 95 | [27] AAD | 14E | ATLS | $\ell^\pm \ell^\pm (\ell^\mp)$ + jets, $\tilde{g} \rightarrow t \bar{t} \tilde{\chi}_1^0$ simplified model |
| >1000 | 95 | [27] AAD | 14E | ATLS | $\ell^\pm \ell^\pm (\ell^\mp)$ + jets, $\tilde{g} \rightarrow t \tilde{t}_1$ with $\tilde{t}_1 \rightarrow b \tilde{\chi}_1^\pm$ simplified model, $m_{\tilde{t}_1}$ < 200 GeV, $m_{\tilde{\chi}_1^\pm}$ = 118 GeV, $m_{\tilde{\chi}_1^0}$ = 60 GeV |
| > 640 | 95 | [27] AAD | 14E | ATLS | $\ell^\pm \ell^\pm (\ell^\mp)$ + jets, $\tilde{g} \rightarrow t \tilde{t}_1$ with $\tilde{t}_1 \rightarrow c \tilde{\chi}_1^0$ simplified model, $m_{\tilde{t}_1}$ = $m_{\tilde{\chi}_1^0}$ + 20 GeV |
| > 850 | 95 | [27] AAD | 14E | ATLS | $\ell^\pm \ell^\pm (\ell^\mp)$ + jets, $\tilde{g} \rightarrow t \tilde{t}_1$ with $\tilde{t}_1 \rightarrow b s$ simplified model, $\not{R}$ |
| > 860 | 95 | [27] AAD | 14E | ATLS | $\ell^\pm \ell^\pm (\ell^\mp)$ + jets, $\tilde{g} \rightarrow q q' \tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \rightarrow W^{(*)\pm} \tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^\pm}$ = 2 $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_1^0}$ < 400 GeV |

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|---|---|---|---|---|---|
| $>1040$ | 95 | [27] AAD | 14E | ATLS | $\ell^\pm \ell^\pm (\ell^\mp)$ + jets, $\tilde{g} \to q q' \tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^{(*)\pm} \tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \to Z^{(*)} \tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^0} < 520$ GeV |
| $>1200$ | 95 | [27] AAD | 14E | ATLS | $\ell^\pm \ell^\pm (\ell^\mp)$ + jets, $\tilde{g} \to q q' \tilde{\chi}_1^\pm / \tilde{\chi}_2^0$, $\tilde{\chi}_1^\pm \to \ell^\pm \nu \tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \to \ell^\pm \ell^\mp (\nu\nu) \tilde{\chi}_1^0$ simplified model |
| $>1050$ | 95 | [28] CHATRCHYAN | 14H | CMS | same-sign $\ell^\pm \ell^\pm$, $\tilde{g} \to t \bar{t} \tilde{\chi}_1^0$ simplified model, massless $\tilde{\chi}_1^0$ |
| $>$ 900 | 95 | [29] CHATRCHYAN | 14H | CMS | same-sign $\ell^\pm \ell^\pm$, $\tilde{g} \to q q' \tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^\pm \tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^\pm} = 0.5\, m_{\tilde{g}}$, massless $\tilde{\chi}_1^0$ |
| $>1050$ | 95 | [30] CHATRCHYAN | 14H | CMS | same-sign $\ell^\pm \ell^\pm$, $\tilde{g} \to b \bar{t} \tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^\pm \tilde{\chi}_1^0$ simplified model, $m_{\tilde{\chi}_1^\pm} = 300$ GeV, $m_{\tilde{\chi}_1^0} = 50$ GeV |
| $>$ 900 | 95 | [31] CHATRCHYAN | 14H | | same-sign $\ell^\pm \ell^\pm$, $\tilde{g} \to t b s$ simplified model, $\not{R}$ |

[1] AAD 15BG searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with jets, missing $E_T$, and two opposite-sign same flavor isolated leptons featuring either a kinematic edge, or a peak at the $Z$-boson mass, in the invariant mass spectrum. No evidence for a statistically significant excess over the expected SM backgrounds are observed and 95% C.L. exclusion limits are derived in a GGM simplified model of gluino pair production where the gluino decays into quarks, a $Z$-boson, and a massless gravitino LSP, see Fig. 12. Also, limits are set in simplified models with slepton/sneutrino intermediate states, see Fig. 13.

[2] AAD 15BV summarized and extended ATLAS searches for gluinos and first- and second-generation squarks in final states containing jets and missing transverse momentum, with or without leptons or $b$-jets in the $\sqrt{s}$ =8 TeV data set collected in 2012. The paper reports the results of new interpretations and statistical combinations of previously published analyses, as well as new analyses. Exclusion limits at 95% C.L. are set on the gluino mass in several R-parity conserving models, leading to a generalized constraint on gluino masses exceeding 1150 GeV for lightest supersymmetric particle masses below 100 GeV. See their Figs. 10, 19, 20, 21, 23, 25, 26, 29–37.

[3] AAD 15BX interpreted the results of a wide range of ATLAS direct searches for supersymmetry, during the first run of the LHC using the $\sqrt{s}$ =7 TeV and $\sqrt{s} = 8$ TeV data set collected in 2012, within the wider framework of the phenomenological MSSM (pMSSM). The integrated luminosity was up to 20.3 fb$^{-1}$. From an initial random sampling of 500 million pMSSM points, generated from the 19-parameter pMSSM, a total of 310,327 model points with $\tilde{\chi}_1^0$ LSP were selected each of which satisfies constraints from previous collider searches, precision measurements, cold dark matter energy density measurements and direct dark matter searches. The impact of the ATLAS Run 1 searches on this space was presented, considering the fraction of model points surviving, after projection into two-dimensional spaces of sparticle masses. Good complementarity is observed between different ATLAS analyses, with almost all showing regions of unique sensitivity. ATLAS searches have good sensitivity at LSP mass below 800 GeV.

[4] AAD 15CA searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with one or more photons, hadronic jets or $b$-jets and $\not{E}_T$. No significant excess above the Standard Model expectations is observed. Limits are set on gluino masses in the general gauge-mediated SUSY breaking model (GGM), for bino-like or higgsino-bino admixtures NLSP, see Fig. 8, 10, 11

[5] KHACHATRYAN 15AF searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least two energetic jets and significant $\not{E}_T$, using the transverse mass variable $M_{T2}$ to discriminate between signal and background processes. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in simplified models where the decay $\widetilde{g} \rightarrow q\overline{q}\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 13(a), or where the decay $\widetilde{g} \rightarrow b\overline{b}\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 13(b), or where the decay $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 13(c). See also Table 5. Exclusions in the CMSSM, assuming $\tan\beta = 30$, $A_0 = -2\ \max(m_0,\ m_{1/2})$ and $\mu > 0$, are also presented, see Fig. 15.

[6] KHACHATRYAN 15I searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events in which $b$-jets and four $W$-bosons are produced. Five individual search channels are combined (fully hadronic, single lepton, same-sign dilepton, opposite-sign dilepton, multilepton). No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in a simplified model where the decay $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 5. Also a simplified model with gluinos decaying into on-shell top squarks is considered, see Fig. 6.

[7] KHACHATRYAN 15X searched in 19.3fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least two energetic jets, at least one of which is required to originate from a $b$ quark, and significant $\not{E}_T$, using the razor variables ($M_R$) and $R^2$) to discriminate between signal and background processes. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in simplified models where the decay $\widetilde{g} \rightarrow b\overline{b}\widetilde{\chi}_1^0$ and the decay $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$ take place with branching ratios varying between 0, 50 and 100%, see Figs. 13 and 14.

[8] AAD 14AE searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for strongly produced supersymmetric particles in events containing jets and large missing transverse momentum, and no electrons or muons. No excess over the expected SM background is observed. Exclusion limits are derived in simplified models containing gluinos and squarks, see Figures 5, 6 and 7. Limits are also derived in the mSUGRA/CMSSM with parameters $\tan\beta = 30$, $A_0 = -2\ m_0$ and $\mu > 0$, see their Fig. 8.

[9] AAD 14AG searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events containing one hadronically decaying $\tau$-lepton, zero or one additional light leptons (electrons or muons), jets and large missing transverse momentum. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set in several SUSY scenarios. For an interpretation in the minimal GMSB model, see their Fig. 8. For an interpretation in the mSUGRA/CMSSM with parameters $\tan\beta = 30$, $A_0 = -2\ m_0$ and $\mu > 0$, see their Fig. 9. For an interpretation in the framework of natural Gauge Mediation, see Fig. 10. For an interpretation in the bRPV scenario, see their Fig. 11.

[10] AAD 14X searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least four leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in an R-parity violating simplified model where the decay $\widetilde{g} \rightarrow q\overline{q}\widetilde{\chi}_1^0$, with $\widetilde{\chi}_1^0 \rightarrow \ell^\pm\ell^\mp\nu$, takes place with a branching ratio of 100%, see Fig. 8.

[11] AAD 14X searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with at least four leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in a general gauge-mediation model (GGM) where the decay $\widetilde{g} \rightarrow q\overline{q}\widetilde{\chi}_1^0$, with $\widetilde{\chi}_1^0 \rightarrow \ell^\pm\ell^\mp\widetilde{G}$, takes place with a branching ratio of 100%, for two choices of $\tan\beta = 1.5$ and 30, see Fig. 11. Also some constraints on the higgsino mass parameter $\mu$ are discussed.

[12] CHATRCHYAN 14AH searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with at least two energetic jets and significant $\not{E}_T$, using the razor variables ($M_R$ and $R^2$) to discriminate between signal and background processes. No significant excess above the Standard Model expectations is observed. Limits are set on sbottom masses in simplified models where the decay $\widetilde{g} \rightarrow q\overline{q}\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 28. Exclusions in the CMSSM, assuming tan$\beta$ = 10, $A_0$ = 0 and $\mu > 0$, are also presented, see Fig. 26.

[13] CHATRCHYAN 14AH searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with at least two energetic jets and significant $\not{E}_T$, using the razor variables ($M_R$ and $R^2$) to discriminate between signal and background processes. A second analysis requires at least one of the jets to be originating from a $b$-quark. No significant excess above the Standard Model expectations is observed. Limits are set on sbottom masses in simplified models where the decay $\widetilde{g} \rightarrow b\overline{b}\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Figs. 28 and 29. Exclusions in the CMSSM, assuming tan$\beta$ = 10, $A_0$ = 0 and $\mu > 0$, are also presented, see Fig. 26.

[14] CHATRCHYAN 14AH searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with at least two energetic jets and significant $\not{E}_T$, using the razor variables ($M_R$ and $R^2$) to discriminate between signal and background processes. A second analysis requires at least one of the jets to be originating from a $b$-quark. No significant excess above the Standard Model expectations is observed. Limits are set on sbottom masses in simplified models where the decay $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Figs. 28 and 29. Exclusions in the CMSSM, assuming tan$\beta$ = 10, $A_0$ = 0 and $\mu >$0, are also presented, see Fig. 26.

[15] CHATRCHYAN 14I searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events containing multijets and large $\not{E}_T$. No excess over the expected SM background is observed. Exclusion limits are derived in simplified models containing gluinos that decay via $\widetilde{g} \rightarrow q\overline{q}\widetilde{\chi}_1^0$ with a 100% branching ratio, see Fig. 7b, or via $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$ with a 100% branching ratio, see Fig. 7c, or via $\widetilde{g} \rightarrow q\overline{q}W/Z\widetilde{\chi}_1^0$, see Fig. 7d.

[16] CHATRCHYAN 14N searched in 19.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events containing a single isolated electron or muon and multiple jets, at least two of which are identified as originating from a $b$-quark. No significant excesses over the expected SM backgrounds are observed. The results are interpreted in three simplified models of gluino pair production with subsequent decay into virtual or on-shell top squarks, where each of the top squarks decays in turn into a top quark and a $\widetilde{\chi}_1^0$, see Fig. 4. The models differ in which masses are allowed to vary.

[17] CHATRCHYAN 14P searched in 19.4 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for three-jet resonances produced in the decay of a gluino in R-parity violating supersymmetric models. No excess over the expected SM background is observed. Assuming a 100% branching ratio for the gluino decay into three light-flavour jets, limits are set on the cross section of gluino pair production, see Fig. 7, and gluino masses below 650 GeV are excluded at 95% C.L. Assuming a 100% branching ratio for the gluino decaying to one b-quark jet and two light-flavour jets, gluino masses between 200 GeV and 835 GeV are excluded at 95% C L.

[18] CHATRCHYAN 14R searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events with at least three leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in a slepton co-NLSP simplified model (GMSB) where the decay $\widetilde{g} \rightarrow q\ell^{\pm}\ell^{\mp}\widetilde{G}$ takes place with a branching ratio of 100%, see Fig. 8.

[19] CHATRCHYAN 14R searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events with at least three leptons (electrons, muons, taus) in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in a simplified model where the decay $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$ takes place with a branching ratio of 100%, see Fig. 11.

[20] AAD 15AB searched for the decay of neutral, weakly interacting, long-lived particles in 20.3 $\text{fb}^{-1}$ of *pp* collisions at $\sqrt{s} = 8$ TeV. Signal events require at least two reconstructed vertices possibly originating from long-lived particles decaying to jets in the inner tracking detector and muon spectrometer. No significant excess of events over the expected background was found. Results were interpreted in Stealth SUSY benchmark models where a pair of gluinos decay to long-lived singlinos, $\widetilde{S}$, which in turn each decay to a low-mass gravitino and a pair of jets. The 95% confidence-level limits are set on the cross section × branching ratio for the decay $\widetilde{g} \rightarrow \widetilde{S} g$, as a function of the singlino proper lifetime ($c\tau$). See their Fig. 10(f)

[21] AAD 15AI searched in 20 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events containing at least one isolated lepton (electron or muon), jets, and large missing transverse momentum. No excess of events above the expected level of Standard Model background was found. Exclusion limits at 95% C.L. are set on the gluino mass in the CMSSM/mSUGRA, see Fig. 15, in the NUHMG, see Fig. 16, and in various simplified models, see Figs. 18–22.

[22] AAD 15CB searched for events containing at least one long-lived particle that decays at a significant distance from its production point (displaced vertex, DV) into two leptons or into five or more charged particles in 20.3 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV. The dilepton signature is characterised by DV formed from at least two lepton candidates. Four different final states were considered for the multitrak signature, in which the DV must be accompanied by a high-transverse momentum muon or electron candidate that originates from the DV, jets or missing transverse momentum. No events were observed in any of the signal regions. Results were interpreted in SUSY scenarios involving *R*-parity violation, split supersymmetry, and gauge mediation. See their Fig. 12–20.

[23] AAD 15X searched in 20.3 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events containing large number of jets, no requirements on missing transverse momentum and no isolated electrons or muons. The sensitivity of the search is enhanced by considering the number of *b*-tagged jets and the scalar sum of masses of large-radius jets in an event. No evidence was found for excesses above the expected level of Standard Model background. Exclusion limits at 95% C.L. are set on the gluino mass assuming the gluino decays to various quark flavors, and for various neutralino masses. See their Fig. 11–16.

[24] KHACHATRYAN 15AD searched in 19.4 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with two opposite-sign same flavor isolated leptons featuring either a kinematic edge, or a peak at the *Z*-boson mass, in the invariant mass spectrum. No evidence for a statistically significant excess over the expected SM backgrounds is observed and 95% C.L. exclusion limits are derived in a simplified model of gluino pair production where the gluino decays into quarks, a *Z*-boson, and a massless gravitino LSP, see Fig. 9.

[25] KHACHATRYAN 15AZ searched in 19.7 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with either at least one photon, hadronic jets and $\not\!\!E_T$ (single photon channel) or with at least two photons and at least one jet and using the razor variables. No significant excess above the Standard Model expectations is observed. Limits are set on gluino masses in the general gauge-mediated SUSY breaking model (GGM), for both a bino-like and wino-like neutralino NLSP scenario, see Fig. 8 and 9.

[26] AAD 14AX searched in 20.1 $\text{fb}^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for the strong production of supersymmetric particles in events containing either zero or at last one high high-$p_T$ lepton, large missing transverse momentum, high jet multiplicity and at least three jets identified as originating from *b*-quarks. No excess over the expected SM background is observed. Limits are derived in mSUGRA/CMSSM models with $\tan\beta = 30$, $A_0 = -2m_0$ and $\mu > 0$, see their Fig. 14. Also, exclusion limits in simplified models containing gluinos and scalar top and bottom quarks are set, see their Figures 12, 13.

[27] AAD 14E searched in 20.3 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for strongly produced supersymmetric particles in events containing jets and two same-sign leptons or three leptons. The search also utilises jets originating from $b$-quarks, missing transverse momentum and other variables. No excess over the expected SM background is observed. Exclusion limits are derived in simplified models containing gluinos and squarks, see Figures 5 and 6. In the $\tilde{g} \rightarrow q q' \tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \rightarrow W^{(*)\pm} \tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \rightarrow Z^{(*)} \tilde{\chi}_1^0$ simplified model, the following assumptions have been made: $m_{\tilde{\chi}_1^{\pm}} = 0.5\, m_{\tilde{\chi}_1^0} + m_{\tilde{g}}$, $m_{\tilde{\chi}_2^0} = 0.5\,(m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_1^{\pm}})$, $m_{\tilde{\chi}_1^0} < 520$ GeV. In the $\tilde{g} \rightarrow q q' \tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \rightarrow \ell^{\pm} \nu \tilde{\chi}_1^0$ or $\tilde{g} \rightarrow q q' \tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \rightarrow \ell^{\pm} \ell^{\mp} (\nu \nu) \tilde{\chi}_1^0$ simplified model, the following assumptions have been made: $m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0} = 0.5\,(m_{\tilde{\chi}_1^0} + m_{\tilde{g}})$, $m_{\tilde{\chi}_1^0} < 660$ GeV. Limits are also derived in the mSUGRA/CMSSM, bRPV and GMSB models, see their Fig. 8.

[28] CHATRCHYAN 14H searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with two isolated same-sign dileptons and jets in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in simplified models where the decay $\tilde{g} \rightarrow t \bar{t} \tilde{\chi}_1^0$ takes place with a branching ratio of 100%, or where the decay $\tilde{g} \rightarrow \tilde{t} t$, $\tilde{t} \rightarrow t \tilde{\chi}_1^0$ takes place with a branching ratio of 100%, with varying mass of the $\tilde{\chi}_1^0$, or where the decay $\tilde{g} \rightarrow \tilde{b} b$, $\tilde{b} \rightarrow t \tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm} \tilde{\chi}_1^0$ takes place with a branching ratio of 100%, with varying mass of the $\tilde{\chi}_1^{\pm}$, see Fig. 5.

[29] CHATRCHYAN 14H searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with two isolated same-sign dileptons and jets in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in simplified models where the decay $\tilde{g} \rightarrow q q' \tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm} \tilde{\chi}_1^0$ takes place with a branching ratio of 100%, with varying mass of the $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$, see Fig. 7.

[30] CHATRCHYAN 14H searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with two isolated same-sign dileptons and jets in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in simplified models where the decay $\tilde{g} \rightarrow b \bar{t} \tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm} \tilde{\chi}_1^0$ takes place with a branching ratio of 100%, for two choices of $m_{\tilde{\chi}_1^{\pm}}$ and fixed $m_{\tilde{\chi}_1^0}$, see Fig. 6.

[31] CHATRCHYAN 14H searched in 19.5 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for events with two isolated same-sign dileptons and jets in the final state. No significant excess above the Standard Model expectations is observed. Limits are set on the gluino mass in simplified models where the R-parity violating decay $\tilde{g} \rightarrow t b s$ takes place with a branching ratio of 100%, see Fig. 8.

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## Long-lived/light $\tilde{g}$ (Gluino) MASS LIMIT

Limits on light gluinos ($m_{\tilde{g}} < 5$ GeV), or gluinos which leave the detector before decaying.

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| $>1270$ | 95 | [1] AAD | 15AE | ATLS | $\tilde{g}$ R-hadron, generic R-hadron model |
| $>1360$ | 95 | [1] AAD | 15AE | ATLS | $\tilde{g}$ decaying to 300 GeV stable sleptons, LeptoSUSY model |
| $>1115$ | 95 | [2] AAD | 15BM | ATLS | $\tilde{g}$ R-hadron, stable |

| | | | | | |
|---|---|---|---|---|---|
| >1185 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{g} \rightarrow (g/q\overline{q})\widetilde{\chi}_1^0$, lifetime 10 ns, $m_{\widetilde{\chi}_1^0} = 100$ GeV |
| >1099 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{g} \rightarrow (g/q\overline{q})\widetilde{\chi}_1^0$, lifetime 10 ns, $m_{\widetilde{g}} - m_{\widetilde{\chi}_1^0} = 100$ GeV |
| >1182 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$, lifetime 10 ns, $m_{\widetilde{\chi}_1^0} = 100$ GeV |
| >1157 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$, lifetime 10 ns, $m_{\widetilde{g}} - m_{\widetilde{\chi}_1^0} = 480$ GeV |
| > 869 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{g} \rightarrow (g/q\overline{q})\widetilde{\chi}_1^0$, lifetime 1 ns, $m_{\widetilde{\chi}_1^0} = 100$ GeV |
| > 821 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{g} \rightarrow (g/q\overline{q})\widetilde{\chi}_1^0$, lifetime 1 ns, $m_{\widetilde{g}} - m_{\widetilde{\chi}_1^0} = 100$ GeV |
| > 836 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$, lifetime 1 ns, $m_{\widetilde{\chi}_1^0} = 100$ GeV |
| > 836 | 95 | [2] AAD | 15BM | ATLS | $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}_1^0$, lifetime 10 ns, $m_{\widetilde{g}} - m_{\widetilde{\chi}_1^0} = 480$ GeV |
| >1000 | 95 | [3] KHACHATRY... | 15AK | CMS | $\widetilde{g}$ R-hadrons, 10 $\mu$s< $\tau$ <1000 s |
| > 880 | 95 | [3] KHACHATRY... | 15AK | CMS | $\widetilde{g}$ R-hadrons, 1 $\mu$s< $\tau$ <1000 s |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | | |
|---|---|---|---|---|---|
| > 985 | 95 | [4] AAD | 13AA | ATLS | $\widetilde{g}$, *R*-hadrons, generic interaction model |
| > 832 | 95 | [5] AAD | 13BC | ATLS | R-hadrons, $\widetilde{g} \rightarrow g/q\overline{q}\widetilde{\chi}_1^0$, generic R-hadron model, lifetime between $10^{-5}$ and $10^3$ s, $m_{\widetilde{\chi}_1^0} = 100$ GeV |
| >1322 | 95 | [6] CHATRCHYAN | 13AB | CMS | long-lived $\widetilde{g}$ forming R-hadrons, f = 0.1, cloud interaction model |
| none 200–341 | 95 | [7] AAD | 12P | ATLS | long-lived $\widetilde{g} \rightarrow g\widetilde{\chi}_1^0$, $m_{\widetilde{\chi}_1^0} =$ 100 GeV |
| > 640 | 95 | [8] CHATRCHYAN | 12AN | CMS | long-lived $\widetilde{g} \rightarrow g\widetilde{\chi}_1^0$ |
| >1098 | 95 | [9] CHATRCHYAN | 12L | CMS | long-lived $\widetilde{g}$ forming *R*-hadrons, f = 0.1 |
| > 586 | 95 | [10] AAD | 11K | ATLS | stable $\widetilde{g}$ |
| > 544 | 95 | [11] AAD | 11P | ATLS | stable $\widetilde{g}$, GMSB scenario, tan$\beta$=5 |
| > 370 | 95 | [12] KHACHATRY... | 11 | CMS | long lived $\widetilde{g}$ |
| > 398 | 95 | [13] KHACHATRY... | 11C | CMS | stable $\widetilde{g}$ |

[1] AAD 15AE searched in 19.1 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for heavy long-lived charged particles, measured through their specific ionization energy loss in the ATLAS pixel detector or their time-of-flight in the ALTAS muon system. In the absence of an excess of events above the expected backgrounds, limits are set R-hadrons in various scenarios, see Fig. 11. Limits are also set in LeptoSUSY models where the gluino decays to stable 300 GeV leptons, see Fig. 9.

[2] AAD 15BM searched in 18.4 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for stable and metastable non-relativistic charged particles through their anomalous specific ionization energy loss in the ATLAS pixel detector. In absence of an excess of events above the expected backgrounds, limits are set within a generic R-hadron model, on stable gluino R-hadrons (see Table 5) and on metastable gluino R-hadrons decaying to ($g$ / $q\overline{q}$) plus a light $\widetilde{\chi}^0_1$ (see Fig. 7) and decaying to $t\overline{t}$ plus a light $\widetilde{\chi}^0_1$ (see Fig. 9).

[3] KHACHATRYAN 15AK looked in a data set corresponding to 18.6 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV, and a search interval corresponding to 281 h of trigger lifetime, for long-lived particles that have stopped in the CMS detector. No evidence for an excess over the expected background in a cloud interaction model is observed. Assuming the decay $\widetilde{g} \rightarrow g\widetilde{\chi}^0_1$ and lifetimes between 1 $\mu$s and 1000 s, limits are derived on $\widetilde{g}$ production as a function of $m_{\widetilde{\chi}^0_1}$, see Figs. 4 and 6. The exclusions require that $m_{\widetilde{\chi}^0_1}$ is kinematically consistent with the minimum values of the jet energy thresholds used.

[4] AAD 13AA searched in 4.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events containing colored long-lived particles that hadronize forming $R$-hadrons. No significant excess above the expected background was found. Long-lived $R$-hadrons containing a $\widetilde{g}$ are excluded for masses up to 985 GeV at 95% C.L in a general interaction model. Also, limits independent of the fraction of $R$-hadrons that arrive charged in the muon system were derived, see Fig. 6.

[5] AAD 13BC searched in 5.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV and in 22.9 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 8$ TeV for bottom squark R-hadrons that have come to rest within the ATLAS calorimeter and decay at some later time to hadronic jets and a neutralino. In absence of an excess of events above the expected backgrounds, limits are set on gluino masses for different decays, lifetimes, and neutralino masses, see their Table 6 and Fig. 10.

[6] CHATRCHYAN 13AB looked in 5.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV and in 18.8 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 8 TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or additionally requiring that it be identified as muon in the muon chambers, from pair production of $\widetilde{g}$'s. No evidence for an excess over the expected background is observed. Limits are derived for pair production of gluinos as a function of mass (see Fig. 8 and Table 5), depending on the fraction, f, of formation of $\widetilde{g}$−g (R-gluonball) states. The quoted limit is for f = 0.1, while for f = 0.5 it degrades to 1276 GeV. In the conservative scenario where every hadronic interaction causes it to become neutral, the limit decreases to 928 GeV for f = 0.1.

[7] AAD 12P looked in 31 pb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with pair production of long-lived gluinos. The hadronization of the gluinos leads to $R$-hadrons which may stop inside the detector and later decay via $\widetilde{g} \rightarrow g\widetilde{\chi}^0_1$ during gaps between the proton bunches. No significant excess over the expected background is observed. From a counting experiment, a limit at 95% C.L. on the cross section as a function of $m_{\widetilde{g}}$ is derived for $m_{\widetilde{\chi}^0_1}$ = 100 GeV, see Fig. 4. The limit is valid for lifetimes between $10^{-5}$ and $10^3$ seconds and assumes the *Generic* matter interaction model for the production cross section.

[8] CHATRCHYAN 12AN looked in 4.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with pair production of long-lived gluinos. The hadronization of the gluinos leads to $R$-hadrons which may stop inside the detector and later decay via $\widetilde{g} \rightarrow g\widetilde{\chi}^0_1$ during gaps between the proton bunches. No significant excess over the expected background is observed. From a counting experiment, a limit at 95% C.L. on the cross section as a function of $m_{\widetilde{g}}$ is derived, see Fig. 3. The mass limit is valid for lifetimes between $10^{-5}$ and $10^3$ seconds, for what they call "the daughter gluon energy $E_g$ >" 100 GeV and assuming the *cloud* interaction model for $R$-hadrons. Supersedes KHACHATRYAN 11.

[9] CHATRCHYAN 12L looked in 5.0 fb$^{-1}$ of $pp$ collisions at $\sqrt{s}$ = 7 TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or additionally requiring that it be identified as muon in the muon chambers, from pair production of $\widetilde{g}$'s. No evidence for an excess over the expected background is observed. Limits are

derived for pair production of gluinos as a function of mass (see Fig. 3), depending on the fraction, f, of formation of $\widetilde{g}$−g ($R$-glueball) states. The quoted limit is for f = 0.1, while for f = 0.5 it degrades to 1046 GeV. In the conservative scenario where every hadronic interaction causes it to become neutral, the limit decreases to 928 GeV for f=0.1. Supersedes KHACHATRYAN 11C.

[10] AAD 11K looked in 34 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or time of flight in the tile calorimeter, from pair production of $\widetilde{g}$. No evidence for an excess over the SM expectation is observed. Limits are derived for pair production of gluinos as a function of mass (see Fig. 4), for a fraction, f = 10%, of formation of $\widetilde{g} - g$ (R-gluonball). If instead of a phase space driven approach for the hadronic scattering of the R-hadrons, a triple-Regge model or a bag-model is used, the limit degrades to 566 and 562 GeV, respectively.

[11] AAD 11P looked in 37 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with heavy stable particles, reconstructed and identified by their time of flight in the Muon System. There is no requirement on their observation in the tracker to increase the sensitivity to cases where gluinos have a large fraction, f, of formation of neutral $\widetilde{g} - g$ (R-gluonball). No evidence for an excess over the SM expectation is observed. Limits are derived as a function of mass (see Fig. 4), for f=0.1. For fractions f = 0.5 and 1.0 the limit degrades to 537 and 530 GeV, respectively.

[12] KHACHATRYAN 11 looked in 10 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with pair production of long-lived gluinos. The hadronization of the gluinos leads to R-hadrons which may stop inside the detector and later decay via $\widetilde{g} \rightarrow g\widetilde{\chi}^0_1$ during gaps between the proton bunches. No significant excess over the expected background is observed. From a counting experiment, a limit at 95% C.L. on the cross section times branching ratio is derived for $m_{\widetilde{g}} - m_{\widetilde{\chi}^0_1} > 100$ GeV, see their Fig. 2. Assuming 100% branching ratio, lifetimes between 75 ns and $3 \times 10^5$ s are excluded for $m_{\widetilde{g}} = 300$ GeV. The $\widetilde{g}$ mass exclusion is obtained with the same assumptions for lifetimes between 10 $\mu s$ and 1000 s, but shows some dependence on the model for R-hadron interactions with matter, illustrated in Fig. 3. From a time-profile analysis, the mass exclusion is 382 GeV for a lifetime of 10 $\mu s$ under the same assumptions as above.

[13] KHACHATRYAN 11C looked in 3.1 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or additionally requiring that it be identified as muon in the muon chambers, from pair production of $\widetilde{g}$. No evidence for an excess over the expected background is observed. Limits are derived for pair production of gluinos as a function of mass (see Fig. 3), depending on the fraction, f, of formation of $\widetilde{g} - g$ (R-gluonball). The quoted limit is for f=0.1, while for f=0.5 it degrades to 357 GeV. In the conservative scenario where every hadronic interaction causes it to become neutral, the limit decreases to 311 GeV for f=0.1.

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## LIGHT $\widetilde{G}$ (Gravitino) MASS LIMITS FROM COLLIDER EXPERIMENTS

The following are bounds on light ( $\ll 1\,\mathrm{eV}$) gravitino indirectly inferred from its coupling to matter suppressed by the gravitino decay constant.

Unless otherwise stated, all limits assume that other supersymmetric particles besides the gravitino are too heavy to be produced. The gravitino is assumed to be undetected and to give rise to a missing energy ($\not{E}$) signature.

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* (eV) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | | |
|---|---|---|---|---|---|
| $> 3.5 \times 10^{-4}$ | 95 | [1] AAD | 15BH | ATLS | jet + $\not\!\!E_T$, $p p \to (\widetilde{q}/\widetilde{g})\widetilde{G}$, $m_{\widetilde{q}} = m_{\widetilde{g}} = 500$ GeV |
| $> 3 \times 10^{-4}$ | 95 | [1] AAD | 15BH | ATLS | jet + $\not\!\!E_T$, $p p \to (\widetilde{q}/\widetilde{g})\widetilde{G}$, $m_{\widetilde{q}} = m_{\widetilde{g}} = 1000$ GeV |
| $> 2 \times 10^{-4}$ | 95 | [1] AAD | 15BH | ATLS | jet + $\not\!\!E_T$, $p p \to (\widetilde{q}/\widetilde{g})\widetilde{G}$, $m_{\widetilde{q}} = m_{\widetilde{g}} = 1500$ GeV |
| $> 1.09 \times 10^{-5}$ | 95 | [2] ABDALLAH | 05B | DLPH | $e^+ e^- \to \widetilde{G}\widetilde{G}\gamma$ |
| $> 1.35 \times 10^{-5}$ | 95 | [3] ACHARD | 04E | L3 | $e^+ e^- \to \widetilde{G}\widetilde{G}\gamma$ |
| $> 1.3 \times 10^{-5}$ | | [4] HEISTER | 03C | ALEP | $e^+ e^- \to \widetilde{G}\widetilde{G}\gamma$ |
| $> 11.7 \times 10^{-6}$ | 95 | [5] ACOSTA | 02H | CDF | $p \overline{p} \to \widetilde{G}\widetilde{G}\gamma$ |
| $> 8.7 \times 10^{-6}$ | 95 | [6] ABBIENDI,G | 00D | OPAL | $e^+ e^- \to \widetilde{G}\widetilde{G}\gamma$ |

[1] AAD 15BH searched in 20.3 fb$^{-1}$ of $p p$ collisions at $\sqrt{s} = 8$ TeV for associated production of a light gravitino and a squark or gluino. The squark (gluino) is assumed to decay exclusively to a quark (gluon) and a gravitino. No evidence was found for an excess above the expected level of Standard Model background and 95% C.L. lower limits were set on the gravitino mass as a function of the squark/gluino mass, both in the case of degenerate and non-degenerate squark/gluino masses, see Figs. 14 and 15.

[2] ABDALLAH 05B use data from $\sqrt{s} = 180$–208 GeV. They look for events with a single photon + $\not\!\!E$ final states from which a cross section limit of $\sigma < 0.18$ *pb* at 208 GeV is obtained, allowing a limit on the mass to be set. Supersedes the results of ABREU 00Z.

[3] ACHARD 04E use data from $\sqrt{s} = 189$–209 GeV. They look for events with a single photon + $\not\!\!E$ final states from which a limit on the Gravitino mass is set corresponding to $\sqrt{F} > 238$ GeV. Supersedes the results of ACCIARRI 99R.

[4] HEISTER 03C use the data from $\sqrt{s} = 189$–209 GeV to search for $\gamma \not\!\!E_T$ final states.

[5] ACOSTA 02H looked in 87 $pb^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}$=1.8 TeV for events with a high-$E_T$ photon and $\not\!\!E_T$. They compared the data with a GMSB model where the final state could arise from $q\overline{q} \to \widetilde{G}\widetilde{G}\gamma$. Since the cross section for this process scales as $1/|F|^4$, a limit at 95% CL is derived on $|F|^{1/2} > 221$ GeV. A model independent limit for the above topology is also given in the paper.

[6] ABBIENDI,G 00D searches for $\gamma \not\!\!E$ final states from $\sqrt{s}$=189 GeV.

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## Supersymmetry Miscellaneous Results

Results that do not appear under other headings or that make nonminimal assumptions.

Some earlier papers are now obsolete and have been omitted. They were last listed in our PDG 14 edition: K. Olive, *et al.* (Particle Data Group), Chinese Physics C **38** 070001 (2014) (http://pdg.lbl.gov).

| *VALUE* | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| | | [1] AAD | 13P | ATLS | dark $\gamma$, hidden valley |
| | | [2] AALTONEN | 12AB | CDF | hidden-valley Higgs |
| none 100–185 | 95 | [3] AAD | 11AA | ATLS | scalar gluons |
| | | [4] CHATRCHYAN | 11E | CMS | $\mu\mu$ resonances |
| | | [5] ABAZOV | 10N | D0 | $\gamma_D$, hidden valley |

[1] AAD 13P searched in 5 fb$^{-1}$ of $p p$ collisions at $\sqrt{s} = 7$ TeV for single lepton-jets with at least four muons; pairs of lepton-jets, each with two or more muons; and pairs of lepton-jets with two or more electrons. All of these could be signatures of Hidden Valley supersymmetric models. No statistically significant deviations from the Standard Model expectations are found. 95% C.L. limits are placed on the production cross section times branching ratio of dark photons for several parameter sets of a Hidden Valley model.

[2] AALTONEN 12AB looked in 5.1 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV for anomalous production of multiple low-energy leptons in association with a $W$ or $Z$ boson. Such events may occur in hidden valley models in which a supersymmetric Higgs boson is produced in association with a $W$ or $Z$ boson, with $H \to \widetilde{\chi}^0_1 \widetilde{\chi}^0_1$ pair and with the $\widetilde{\chi}^0_1$ further decaying into a dark photon ($\gamma_D$) and the unobservable lightest SUSY particle of the hidden sector. As the $\gamma_D$ is expected to be light, it may decay into a lepton pair. No significant excess over the SM expectation is observed and a limit at 95% C.L. is set on the cross section for a benchmark model of supersymmetric hidden-valley Higgs production.

[3] AAD 11AA looked in 34 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with $\geq 4$ jets originating from pair production of scalar gluons, each decaying to two gluons. No two-jet resonances are observed over the SM background. Limits are derived on the cross section times branching ratio (see Fig. 3). Assuming 100% branching ratio for the decay to two gluons, the quoted exclusion range is obtained, except for a 5 GeV mass window around 140 GeV.

[4] CHATRCHYAN 11E looked in 35 pb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 7$ TeV for events with collimated $\mu$ pairs (leptonic jets) from the decay of hidden sector states. No evidence for new resonance production is found. Limits are derived and compared to various SUSY models (see Fig. 4) where the LSP, either the $\widetilde{\chi}^0_1$ or a $\widetilde{q}$, decays to dark sector particles.

[5] ABAZOV 10N looked in 5.8 fb$^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV for events from hidden valley models in which a $\widetilde{\chi}^0_1$ decays into a dark photon, $\gamma_D$, and the unobservable lightest SUSY particle of the hidden sector. As the $\gamma_D$ is expected to be light, it may decay into a tightly collimated lepton pair, called lepton jet. They searched for events with $\not{E}_T$ and two isolated lepton jets observable by an opposite charged lepton pair $ee$, $e\mu$ or $\mu\mu$. No significant excess over the SM expectation is observed, and a limit at 95% C.L. on the cross section times branching ratio is derived, see their Table I. They also examined the invariant mass of the lepton jets for a narrow resonance, see their Fig. 4, but found no evidence for a signal.

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| AALTONEN | 10R | PRL 105 081802 | T. Aaltonen *et al.* | (CDF Collab.) |
| AALTONEN | 10Z | PRL 105 191801 | T. Aaltonen *et al.* | (CDF Collab.) |
| ABAZOV | 10L | PL B693 95 | V.M. Abazov *et al.* | (D0 Collab.) |
| ABAZOV | 10M | PRL 105 191802 | V.M. Abazov *et al.* | (D0 Collab.) |
| ABAZOV | 10N | PRL 105 211802 | V.M. Abazov *et al.* | (D0 Collab.) |
| ABAZOV | 10P | PRL 105 221802 | V.M. Abazov *et al.* | (D0 Collab.) |
| ABDO | 10 | JCAP 1004 014 | A.A. Abdo *et al.* | (Fermi-LAT Collab.) |
| ACKERMANN | 10 | JCAP 1005 025 | M. Ackermann | (Fermi-LAT Collab.) |
| AHMED | 10 | SCI 327 1619 | Z. Ahmed *et al.* | (CDMS II Collab.) |
| ARMENGAUD | 10 | PL B687 294 | E. Armengaud *et al.* | (EDELWEISS II Collab.) |
| ELLIS | 10 | EPJ C69 201 | J. Ellis, A. Mustafayev, K. Olive | |
| ABAZOV | 09M | PRL 102 161802 | V.M. Abazov *et al.* | (D0 Collab.) |
| ABBASI | 09B | PRL 102 201302 | R. Abbasi *et al.* | (IceCube Collab.) |
| AHMED | 09 | PRL 102 011301 | Z. Ahmed *et al.* | (CDMS Collab.) |
| ANGLOHER | 09 | ASP 31 270 | G. Angloher *et al.* | (CRESST Collab.) |
| ARCHAMBAU... | 09 | PL B682 185 | S. Archambault *et al.* | (PICASSO Collab.) |
| BUCHMUEL... | 09 | EPJ C64 391 | O. Buchmueller *et al.* | (LOIC, FNAL, CERN+) |
| DREINER | 09 | EPJ C62 547 | H. Dreiner *et al.* | |
| LEBEDENKO | 09 | PR D80 052010 | V.N. Lebedenko *et al.* | (ZEPLIN-III Collab.) |
| LEBEDENKO | 09A | PRL 103 151302 | V.N. Lebedenko *et al.* | (ZEPLIN-III Collab.) |
| SORENSEN | 09 | NIM A601 339 | P. Sorensen *et al.* | (XENON10 Collab.) |
| ABAZOV | 08F | PL B659 856 | V.M. Abazov *et al.* | (D0 Collab.) |
| ANGLE | 08 | PRL 100 021303 | J. Angle *et al.* | (XENON10 Collab.) |
| ANGLE | 08A | PRL 101 091301 | J. Angle *et al.* | (XENON10 Collab.) |
| BEDNYAKOV | 08 | PAN 71 111<br>Translated from YAF 71 112. | V.A. Bednyakov, H.P. Klapdor-Kleingrothaus, I.V. Krivosheina | |
| BEHNKE | 08 | SCI 319 933 | E. Behnke | (COUPP Collab.) |
| BENETTI | 08 | ASP 28 495 | P. Benetti *et al.* | (WARP Collab.) |
| BUCHMUEL... | 08 | JHEP 0809 117 | O. Buchmueller *et al.* | |
| ELLIS | 08 | PR D78 075012 | J. Ellis, K. Olive, P. Sandick | (CERN, MINN) |
| ABULENCIA | 07H | PRL 98 131804 | A. Abulencia *et al.* | (CDF Collab.) |
| ALNER | 07A | ASP 28 287 | G.J. Alner *et al.* | (ZEPLIN-II Collab.) |
| CALIBBI | 07 | JHEP 0709 081 | L. Calibbi *et al.* | |
| ELLIS | 07 | JHEP 0706 079 | J. Ellis, K. Olive, P. Sandick | (CERN, MINN) |
| LEE | 07A | PRL 99 091301 | H.S. Lee *et al.* | (KIMS Collab.) |
| ABBIENDI | 06B | EPJ C46 307 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ACHTERBERG | 06 | ASP 26 129 | A. Achterberg *et al.* | (AMANDA Collab.) |
| ACKERMANN | 06 | ASP 24 459 | M. Ackermann *et al.* | (AMANDA Collab.) |
| AKERIB | 06 | PR D73 011102 | D.S. Akerib *et al.* | (CDMS Collab.) |
| AKERIB | 06A | PRL 96 011302 | D.S. Akerib *et al.* | (CDMS Collab.) |

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| ALLANACH | 06 | PR D73 015013 | B.C. Allanach *et al.* | |
| BENOIT | 06 | PL B637 156 | A. Benoit *et al.* | |
| DE-AUSTRI | 06 | JHEP 0605 002 | R.R. de Austri, R. Trotta, L. Roszkowski | |
| DEBOER | 06 | PL B636 13 | W. de Boer *et al.* | |
| LEP-SLC | 06 | PRPL 427 257 | ALEPH, DELPHI, L3, OPAL, SLD and working groups | |
| SHIMIZU | 06A | PL B633 195 | Y. Shimizu *et al.* | |
| SMITH | 06 | PL B642 567 | N.J.T. Smith, A.S. Murphy, T.J. Summer | |
| ABAZOV | 05A | PRL 94 041801 | V.M. Abazov *et al.* | (D0 Collab.) |
| ABDALLAH | 05B | EPJ C38 395 | J. Abdallah *et al.* | (DELPHI Collab.) |
| AKERIB | 05 | PR D72 052009 | D.S. Akerib *et al.* | (CDMS Collab.) |
| ALNER | 05 | PL B616 17 | G.J. Alner *et al.* | (UK Dark Matter Collab.) |
| ALNER | 05A | ASP 23 444 | G.J. Alner *et al.* | (UK Dark Matter Collab.) |
| ANGLOHER | 05 | ASP 23 325 | G. Angloher *et al.* | (CRESST-II Collab.) |
| BAER | 05 | JHEP 0507 065 | H. Baer *et al.* | (FSU, MSU, HAWA) |
| BARNABE-HE... | 05 | PL B624 186 | M. Barnabe-Heider *et al.* | (PICASSO Collab.) |
| ELLIS | 05 | PR D71 095007 | J. Ellis *et al.* | |
| SANGLARD | 05 | PR D71 122002 | V. Sanglard *et al.* | (EDELWEISS Collab.) |
| ABBIENDI | 04 | EPJ C32 453 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABBIENDI | 04F | EPJ C33 149 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABBIENDI | 04H | EPJ C35 1 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABBIENDI | 04N | PL B602 167 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABDALLAH | 04H | EPJ C34 145 | J. Abdallah *et al.* | (DELPHI Collab.) |
| ABDALLAH | 04M | EPJ C36 1 | J. Abdallah *et al.* | (DELPHI Collab.) |
| Also | | EPJ C37 129 (errat.) | J. Abdallah *et al.* | (DELPHI Collab.) |
| ACHARD | 04 | PL B580 37 | P. Achard *et al.* | (L3 Collab.) |
| ACHARD | 04E | PL B587 16 | P. Achard *et al.* | (L3 Collab.) |
| AKERIB | 04 | PRL 93 211301 | D. Akerib *et al.* | (CDMSII Collab.) |
| BALTZ | 04 | JHEP 0410 052 | E. Baltz, P. Gondolo | |
| BELANGER | 04 | JHEP 0403 012 | G. Belanger *et al.* | |
| BOTTINO | 04 | PR D69 037302 | A. Bottino *et al.* | |
| DESAI | 04 | PR D70 083523 | S. Desai *et al.* | (Super-Kamiokande Collab.) |
| ELLIS | 04 | PR D69 015005 | J. Ellis *et al.* | |
| ELLIS | 04B | PR D70 055005 | J. Ellis *et al.* | |
| HEISTER | 04 | PL B583 247 | A. Heister *et al.* | (ALEPH Collab.) |
| PIERCE | 04A | PR D70 075006 | A. Pierce | |
| ABBIENDI | 03L | PL B572 8 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABDALLAH | 03D | EPJ C27 153 | J. Abdallah *et al.* | (DELPHI Collab.) |
| ABDALLAH | 03M | EPJ C31 421 | J. Abdallah *et al.* | (DELPHI Collab.) |
| AHMED | 03 | ASP 19 691 | B. Ahmed *et al.* | (UK Dark Matter Collab.) |
| AKERIB | 03 | PR D68 082002 | D. Akerib *et al.* | (CDMS Collab.) |
| BAER | 03 | JCAP 0305 006 | H. Baer, C. Balazs | |
| BAER | 03A | JCAP 0309 007 | H. Baer *et al.* | |
| BOTTINO | 03 | PR D68 043506 | A. Bottino *et al.* | |
| BOTTINO | 03A | PR D67 063519 | A. Bottino, N. Fornengo, S. Scopel | |
| CHATTOPAD... | 03 | PR D68 035005 | U. Chattopadhyay, A. Corsetti, P. Nath | |
| ELLIS | 03 | ASP 18 395 | J. Ellis, K.A. Olive, Y. Santoso | |
| ELLIS | 03B | NP B652 259 | J. Ellis *et al.* | |
| ELLIS | 03C | PL B565 176 | J. Ellis *et al.* | |
| ELLIS | 03D | PL B573 162 | J. Ellis *et al.* | |
| ELLIS | 03E | PR D67 123502 | J. Ellis *et al.* | |
| HEISTER | 03C | EPJ C28 1 | A. Heister *et al.* | (ALEPH Collab.) |
| HEISTER | 03G | EPJ C31 1 | A. Heister *et al.* | (ALEPH Collab.) |
| KLAPDOR-K... | 03 | ASP 18 525 | H.V. Klapdor-Kleingrothaus *et al.* | |
| LAHANAS | 03 | PL B568 55 | A. Lahanas, D. Nanopoulos | |
| TAKEDA | 03 | PL B572 145 | A. Takeda *et al.* | |
| ABRAMS | 02 | PR D66 122003 | D. Abrams *et al.* | (CDMS Collab.) |
| ACHARD | 02 | PL B524 65 | P. Achard *et al.* | (L3 Collab.) |
| ACOSTA | 02H | PRL 89 281801 | D. Acosta *et al.* | (CDF Collab.) |
| ANGLOHER | 02 | ASP 18 43 | G. Angloher *et al.* | (CRESST Collab.) |
| ARNOWITT | 02 | hep-ph/0211417 | R. Arnowitt, B. Dutta | |
| BENOIT | 02 | PL B545 43 | A. Benoit *et al.* | (EDELWEISS Collab.) |
| ELLIS | 02B | PL B532 318 | J. Ellis, A. Ferstl, K.A. Olive | |
| HEISTER | 02 | PL B526 191 | A. Heister *et al.* | (ALEPH Collab.) |
| HEISTER | 02E | PL B526 206 | A. Heister *et al.* | (ALEPH Collab.) |
| HEISTER | 02J | PL B533 223 | A. Heister *et al.* | (ALEPH Collab.) |
| HEISTER | 02N | PL B544 73 | A. Heister *et al.* | (ALEPH Collab.) |
| KIM | 02 | PL B527 18 | H.B. Kim *et al.* | |
| KIM | 02B | JHEP 0212 034 | Y.G. Kim *et al.* | |
| LAHANAS | 02 | EPJ C23 185 | A. Lahanas, V.C. Spanos | |
| MORALES | 02B | ASP 16 325 | A. Morales *et al.* | (COSME Collab.) |
| MORALES | 02C | PL B532 8 | A. Morales *et al.* | (IGEX Collab.) |

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| ABBIENDI | 01 | PL B501 12 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABREU | 01 | EPJ C19 29 | P. Abreu *et al.* | (DELPHI Collab.) |
| ABREU | 01G | PL B503 34 | P. Abreu *et al.* | (DELPHI Collab.) |
| ACCIARRI | 01 | EPJ C19 397 | M. Acciarri *et al.* | (L3 Collab.) |
| BALTZ | 01 | PRL 86 5004 | E. Baltz, P. Gondolo | |
| BARATE | 01 | PL B499 67 | R. Barate *et al.* | (ALEPH Collab.) |
| BARATE | 01B | EPJ C19 415 | R. Barate *et al.* | (ALEPH Collab.) |
| BARGER | 01C | PL B518 117 | V. Barger, C. Kao | |
| BAUDIS | 01 | PR D63 022001 | L. Baudis *et al.* | (Heidelberg-Moscow Collab.) |
| BENOIT | 01 | PL B513 15 | A. Benoit *et al.* | (EDELWEISS Collab.) |
| BERNABEI | 01 | PL B509 197 | R. Bernabei *et al.* | (DAMA Collab.) |
| BOTTINO | 01 | PR D63 125003 | A. Bottino *et al.* | |
| CORSETTI | 01 | PR D64 125010 | A. Corsetti, P. Nath | |
| ELLIS | 01B | PL B510 236 | J. Ellis *et al.* | |
| ELLIS | 01C | PR D63 065016 | J. Ellis, A. Ferstl, K.A. Olive | |
| GOMEZ | 01 | PL B512 252 | M.E. Gomez, J.D. Vergados | |
| LAHANAS | 01 | PL B518 94 | A. Lahanas, D.V. Nanopoulos, V. Spanos | |
| ABBIENDI | 00 | EPJ C12 1 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABBIENDI | 00G | EPJ C14 51 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABBIENDI | 00H | EPJ C14 187 | G. Abbiendi *et al.* | (OPAL Collab.) |
| Also | | EPJ C16 707 (errat.) | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABBIENDI,G | 00D | EPJ C18 253 | G. Abbiendi *et al.* | (OPAL Collab.) |
| ABREU | 00J | PL B479 129 | P. Abreu *et al.* | (DELPHI Collab.) |
| ABREU | 00Q | PL B478 65 | P. Abreu *et al.* | (DELPHI Collab.) |
| ABREU | 00T | PL B485 95 | P. Abreu *et al.* | (DELPHI Collab.) |
| ABREU | 00U | PL B487 36 | P. Abreu *et al.* | (DELPHI Collab.) |
| ABREU | 00V | EPJ C16 211 | P. Abreu *et al.* | (DELPHI Collab.) |
| ABREU | 00W | PL B489 38 | P. Abreu *et al.* | (DELPHI Collab.) |
| ABREU | 00Z | EPJ C17 53 | P. Abreu *et al.* | (DELPHI Collab.) |
| ABUSAIDI | 00 | PRL 84 5699 | R. Abusaidi *et al.* | (CDMS Collab.) |
| ACCIARRI | 00C | EPJ C16 1 | M. Acciarri *et al.* | (L3 Collab.) |
| ACCIARRI | 00D | PL B472 420 | M. Acciarri *et al.* | (L3 Collab.) |
| ACCOMANDO | 00 | NP B585 124 | E. Accomando *et al.* | |
| BERNABEI | 00 | PL B480 23 | R. Bernabei *et al.* | (DAMA Collab.) |
| BERNABEI | 00C | EPJ C18 283 | R. Bernabei *et al.* | (DAMA Collab.) |
| BERNABEI | 00D | NJP 2 15 | R. Bernabei *et al.* | (DAMA Collab.) |
| BOEHM | 00B | PR D62 035012 | C. Boehm, A. Djouadi, M. Drees | |
| ELLIS | 00 | PR D62 075010 | J. Ellis *et al.* | |
| FENG | 00 | PL B482 388 | J.L. Feng, K.T. Matchev, F. Wilczek | |
| LEP | 00 | CERN-EP-2000-016 | LEP Collabs. | (ALEPH, DELPHI, L3, OPAL, SLD+) |
| MORALES | 00 | PL B489 268 | A. Morales *et al.* | (IGEX Collab.) |
| PDG | 00 | EPJ C15 1 | D.E. Groom *et al.* | (PDG Collab.) |
| SPOONER | 00 | PL B473 330 | N.J.C. Spooner *et al.* | (UK Dark Matter Col.) |
| ACCIARRI | 99H | PL B456 283 | M. Acciarri *et al.* | (L3 Collab.) |
| ACCIARRI | 99I | PL B459 354 | M. Acciarri *et al.* | (L3 Collab.) |
| ACCIARRI | 99R | PL B470 268 | M. Acciarri *et al.* | (L3 Collab.) |
| ACCIARRI | 99W | PL B471 280 | M. Acciarri *et al.* | (L3 Collab.) |
| AMBROSIO | 99 | PR D60 082002 | M. Ambrosio *et al.* | (Macro Collab.) |
| BAUDIS | 99 | PR D59 022001 | L. Baudis *et al.* | (Heidelberg-Moscow Collab.) |
| BELLI | 99C | NP B563 97 | P. Belli *et al.* | (DAMA Collab.) |
| OOTANI | 99 | PL B461 371 | W. Ootani *et al.* | |
| ABREU | 98P | PL B444 491 | P. Abreu *et al.* | (DELPHI Collab.) |
| ACCIARRI | 98F | EPJ C4 207 | M. Acciarri *et al.* | (L3 Collab.) |
| ACKERSTAFF | 98P | PL B433 195 | K. Ackerstaff *et al.* | (OPAL Collab.) |
| BARATE | 98K | PL B433 176 | R. Barate *et al.* | (ALEPH Collab.) |
| BARATE | 98S | EPJ C4 433 | R. Barate *et al.* | (ALEPH Collab.) |
| BERNABEI | 98C | PL B436 379 | R. Bernabei *et al.* | (DAMA Collab.) |
| ELLIS | 98 | PR D58 095002 | J. Ellis *et al.* | |
| ELLIS | 98B | PL B444 367 | J. Ellis, T. Falk, K. Olive | |
| PDG | 98 | EPJ C3 1 | C. Caso *et al.* | (PDG Collab.) |
| BAER | 97 | PR D57 567 | H. Baer, M. Brhlik | |
| BERNABEI | 97 | ASP 7 73 | R. Bernabei *et al.* | (DAMA Collab.) |
| EDSJO | 97 | PR D56 1879 | J. Edsjo, P. Gondolo | |
| ARNOWITT | 96 | PR D54 2374 | R. Arnowitt, P. Nath | |
| BAER | 96 | PR D53 597 | H. Baer, M. Brhlik | |
| BERGSTROM | 96 | ASP 5 263 | L. Bergstrom, P. Gondolo | |
| LEWIN | 96 | ASP 6 87 | J.D. Lewin, P.F. Smith | |
| BEREZINSKY | 95 | ASP 5 1 | V. Berezinsky *et al.* | |
| FALK | 95 | PL B354 99 | T. Falk, K.A. Olive, M. Srednicki | (MINN, UCSB) |
| LOSECCO | 95 | PL B342 392 | J.M. LoSecco | (NDAM) |
| ADRIANI | 93M | PRPL 236 1 | O. Adriani *et al.* | (L3 Collab.) |

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| DREES | 93 | PR D47 376 | M. Drees, M.M. Nojiri | (DESY, SLAC) |
| DREES | 93B | PR D48 3483 | M. Drees, M.M. Nojiri | |
| FALK | 93 | PL B318 354 | T. Falk *et al.* | (UCB, UCSB, MINN) |
| KELLEY | 93 | PR D47 2461 | S. Kelley *et al.* | (TAMU, ALAH) |
| MIZUTA | 93 | PL B298 120 | S. Mizuta, M. Yamaguchi | (TOHO) |
| MORI | 93 | PR D48 5505 | M. Mori *et al.* | (KEK, NIIG, TOKY, TOKA+) |
| BOTTINO | 92 | MPL A7 733 | A. Bottino *et al.* | (TORI, ZARA) |
| Also | | PL B265 57 | A. Bottino *et al.* | (TORI, INFN) |
| DECAMP | 92 | PRPL 216 253 | D. Decamp *et al.* | (ALEPH Collab.) |
| LOPEZ | 92 | NP B370 445 | J.L. Lopez, D.V. Nanopoulos, K.J. Yuan | (TAMU) |
| MCDONALD | 92 | PL B283 80 | J. McDonald, K.A. Olive, M. Srednicki | (LISB+) |
| ABREU | 91F | NP B367 511 | P. Abreu *et al.* | (DELPHI Collab.) |
| ALEXANDER | 91F | ZPHY C52 175 | G. Alexander *et al.* | (OPAL Collab.) |
| BOTTINO | 91 | PL B265 57 | A. Bottino *et al.* | (TORI, INFN) |
| GELMINI | 91 | NP B351 623 | G.B. Gelmini, P. Gondolo, E. Roulet | (UCLA, TRST) |
| GRIEST | 91 | PR D43 3191 | K. Griest, D. Seckel | |
| KAMIONKOW... | 91 | PR D44 3021 | M. Kamionkowski | (CHIC, FNAL) |
| MORI | 91B | PL B270 89 | M. Mori *et al.* | (Kamiokande Collab.) |
| NOJIRI | 91 | PL B261 76 | M.M. Nojiri | (KEK) |
| OLIVE | 91 | NP B355 208 | K.A. Olive, M. Srednicki | (MINN, UCSB) |
| ROSZKOWSKI | 91 | PL B262 59 | L. Roszkowski | (CERN) |
| GRIEST | 90 | PR D41 3565 | K. Griest, M. Kamionkowski, M.S. Turner | (UCB+) |
| BARBIERI | 89C | NP B313 725 | R. Barbieri, M. Frigeni, G. Giudice | |
| OLIVE | 89 | PL B230 78 | K.A. Olive, M. Srednicki | (MINN, UCSB) |
| ELLIS | 88D | NP B307 883 | J. Ellis, R. Flores | |
| GRIEST | 88B | PR D38 2357 | K. Griest | |
| OLIVE | 88 | PL B205 553 | K.A. Olive, M. Srednicki | (MINN, UCSB) |
| SREDNICKI | 88 | NP B310 693 | M. Srednicki, R. Watkins, K.A. Olive | (MINN, UCSB) |
| ELLIS | 84 | NP B238 453 | J. Ellis *et al.* | (CERN) |
| GOLDBERG | 83 | PRL 50 1419 | H. Goldberg | (NEAS) |
| KRAUSS | 83 | NP B227 556 | L.M. Krauss | (HARV) |
| VYSOTSKII | 83 | SJNP 37 948<br>Translated from YAF 37 1597. | M.I. Vysotsky | (ITEP) |