Other Particle Searches

OMITTED FROM SUMMARY TABLE

OTHER PARTICLE SEARCHES

Revised February 2018 by K. Hikasa (Tohoku University).

We collect here those searches which do not appear in any other search categories. These are listed in the following order:

- Concentration of stable particles in matter
- General new physics searches
- Limits on jet-jet resonance in hadron collisions
- Limits on neutral particle production at accelerators
- Limits on charged particles in e^+e^- collisions
- Limits on charged particles in hadron reactions
- Limits on charged particles in cosmic rays
- Searches for quantum black hole production

Note that searches appear in separate sections elsewhere for Higgs bosons (and technipions), other heavy bosons (including W_R, W', Z', leptoquarks, axigluons), axions (including pseudo-Goldstone bosons, Majorons, familons), WIMPs, heavy leptons, heavy neutrinos, free quarks, monopoles, supersymmetric particles, and compositeness.

We no longer list for limits on tachyons and centauros. See our 1994 edition for these limits.

CONCENTRATION OF STABLE PARTICLES IN MATTER

Concentration of Heavy (Charge +1) Stable Particles in Matter

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<4 \times 10^{-17}$	95	[1] YAMAGATA	93	SPEC	Deep sea water, M=5–1600m_p
$<6 \times 10^{-15}$	95	[2] VERKERK	92	SPEC	Water, M= 10^5 to 3×10^7 GeV
$<7 \times 10^{-15}$	95	[2] VERKERK	92	SPEC	Water, M= 10^4, 6×10^7 GeV
$<9 \times 10^{-15}$	95	[2] VERKERK	92	SPEC	Water, M= 10^8 GeV
$<3 \times 10^{-23}$	90	[3] HEMMICK	90	SPEC	Water, $M = 1000 m_p$

$<2 \times 10^{-21}$	90	[3] HEMMICK	90	SPEC	Water, $M = 5000 m_p$
$<3 \times 10^{-20}$	90	[3] HEMMICK	90	SPEC	Water, $M = 10000 m_p$
$<1. \times 10^{-29}$		SMITH	82B	SPEC	Water, M=30–400m_p
$<2. \times 10^{-28}$		SMITH	82B	SPEC	Water, M=12–1000m_p
$<1. \times 10^{-14}$		SMITH	82B	SPEC	Water, M >1000 m_p
$<(0.2–1.) \times 10^{-21}$		SMITH	79	SPEC	Water, M=6–350 m_p

[1] YAMAGATA 93 used deep sea water at 4000 m since the concentration is enhanced in deep sea due to gravity.

[2] VERKERK 92 looked for heavy isotopes in sea water and put a bound on concentration of stable charged massive particle in sea water. The above bound can be translated into into a bound on charged dark matter particle (5×10^6 GeV), assuming the local density, ρ=0.3 GeV/cm^3, and the mean velocity $\langle v \rangle$=300 km/s.

[3] See HEMMICK 90 Fig. 7 for other masses 100–10000 m_p.

Concentration of Heavy Stable Particles Bound to Nuclei

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<1.2 \times 10^{-11}$	95	[1] JAVORSEK	01	SPEC	Au, M= 3 GeV
$<6.9 \times 10^{-10}$	95	[1] JAVORSEK	01	SPEC	Au, M= 144 GeV
$<1 \times 10^{-11}$	95	[2] JAVORSEK	01B	SPEC	Au, M= 188 GeV
$<1 \times 10^{-8}$	95	[2] JAVORSEK	01B	SPEC	Au, M= 1669 GeV
$<6 \times 10^{-9}$	95	[2] JAVORSEK	01B	SPEC	Fe, M= 188 GeV
$<1 \times 10^{-8}$	95	[2] JAVORSEK	01B	SPEC	Fe, M= 647 GeV
$<4 \times 10^{-20}$	90	[3] HEMMICK	90	SPEC	C, $M = 100 m_p$
$<8 \times 10^{-20}$	90	[3] HEMMICK	90	SPEC	C, $M = 1000 m_p$
$<2 \times 10^{-16}$	90	[3] HEMMICK	90	SPEC	C, $M = 10000 m_p$
$<6 \times 10^{-13}$	90	[3] HEMMICK	90	SPEC	Li, $M = 1000 m_p$
$<1 \times 10^{-11}$	90	[3] HEMMICK	90	SPEC	Be, $M = 1000 m_p$
$<6 \times 10^{-14}$	90	[3] HEMMICK	90	SPEC	B, $M = 1000 m_p$
$<4 \times 10^{-17}$	90	[3] HEMMICK	90	SPEC	O, $M = 1000 m_p$
$<4 \times 10^{-15}$	90	[3] HEMMICK	90	SPEC	F, $M = 1000 m_p$
$< 1.5 \times 10^{-13}$/nucleon	68	[4] NORMAN	89	SPEC	$^{206}\mathrm{Pb} X^-$
$< 1.2 \times 10^{-12}$/nucleon	68	[4] NORMAN	87	SPEC	$^{56,58}\mathrm{Fe} X^-$

[1] JAVORSEK 01 search for (neutral) SIMPs (strongly interacting massive particles) bound to Au nuclei. Here M is the effective SIMP mass.

[2] JAVORSEK 01B search for (neutral) SIMPs (strongly interacting massive particles) bound to Au and Fe nuclei from various origins with exposures on the earth's surface, in a satellite, heavy ion collisions, etc. Here M is the mass of the anomalous nucleus. See also JAVORSEK 02.

[3] See HEMMICK 90 Fig. 7 for other masses 100–10000 m_p.

[4] Bound valid up to $m_{X^-} \sim$ 100 TeV.

GENERAL NEW PHYSICS SEARCHES

This subsection lists some of the search experiments which look for general signatures characteristic of new physics, independent of the framework of a specific model.

The observed events are compatible with Standard Model expectation, unless noted otherwise.

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] AGUILAR-AR...	20B	CONN	ν elastic scatter on nuclei
	[2] FEDDERKE	20		CHAMPs from white dwarfs
	[3] SIRUNYAN	20A	CMS	SUSY/LQ search with mT2 or long-lived charged particles
	[4] ALCANTARA	19		Auger, superheavy DM
	[5] PORAYKO	18	PPTA	pulsar timing fuzzy DM search
	[6] AAD	15AT	ATLS	$t + \not\!\!E_T$
	[7] KHACHATRY...	15F	CMS	$t + \not\!\!E_T$
	[8] AALTONEN	14J	CDF	W + 2 jets
	[9] AAD	13A	ATLS	$W W \rightarrow \ell \nu \ell' \nu$
	[10] AAD	13C	ATLS	$\gamma + \not\!\!E_T$
	[11] AALTONEN	13I	CDF	Delayed $\gamma + \not\!\!E_T$
	[12] CHATRCHYAN	13	CMS	$\ell^+ \ell^-$ + jets + $\not\!\!E_T$
	[13] AAD	12C	ATLS	$t \overline{t} + \not\!\!E_T$
	[14] AALTONEN	12M	CDF	jet + $\not\!\!E_T$
	[15] CHATRCHYAN	12AP	CMS	jet + $\not\!\!E_T$
	[16] CHATRCHYAN	12Q	CMS	Z + jets + $\not\!\!E_T$
	[17] CHATRCHYAN	12T	CMS	$\gamma + \not\!\!E_T$
	[18] AAD	11S	ATLS	jet + $\not\!\!E_T$
	[19] AALTONEN	11AF	CDF	$\ell^\pm \ell^\pm$
	[20] CHATRCHYAN	11C	CMS	$\ell^+ \ell^-$ + jets + $\not\!\!E_T$
	[21] CHATRCHYAN	11U	CMS	jet + $\not\!\!E_T$
	[22] AALTONEN	10AF	CDF	$\gamma\gamma + \ell, \not\!\!E_T$
	[23] AALTONEN	09AF	CDF	$\ell \gamma b \not\!\!E_T$
	[24] AALTONEN	09G	CDF	$\ell \ell \ell \not\!\!E_T$

[1] AGUILAR-AREVALO 20B search for light BSM mediator effect on ν elastic scatter on nuclei; no signal; limits placed in m(mediator) vs. coupling plane for two models of MeV-scale mediators.

[2] FEDDERKE 20 place limits on cosmic relic charged massive particles (CHAMPs) due to their capture and subsequent disruption of old white dwarf stars; limits placed in the m(CHAMP) vs. relic density parameter plane.

[3] SIRUNYAN 20A search for SUSY and LQ production using mT2 or presence of long-lived charged particle; no signal, limits placed in various mass planes for different BSM scenarios and various assumed lifetimes.

[4] ALCANTARA 19 place limits on m(WIMPzilla=X) vs lifetime from upper bound on ultra high energy cosmic rays at Auger experiment: e.g. $\tau(X) < 4 \times 10^{22}$ yr for m(X) = 10^{16} GeV.

[5] PORAYKO 18 search for deviations in the residuals of pulsar timing data using PPTA. No signal observed. Limits set on fuzzy DM with $3 \times 10^{-24} <$ m(DM) $< 2 \times 10^{-22}$ eV.

[6] AAD 15AT search for events with a top quark and mssing E_T in $p p$ collisions at E_{cm} = 8 TeV with L = 20.3 fb^{-1}.

[7] KHACHATRYAN 15F search for events with a top quark and mssing E_T in $p p$ collisions at E_{cm} = 8 TeV with L = 19.7 fb^{-1}.

[8] AALTONEN 14J examine events with a W and two jets in $p \overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 8.9 fb^{-1}. Invariant mass distributions of the two jets are consistent with the Standard Model expectation.

[9] AAD 13A search for resonant WW production in pp collisions at E_{cm} = 7 TeV with L = 4.7 fb^{-1}.

[10] AAD 13C search for events with a photon and missing $\not{E}_T$ in pp collisions at E_{cm} = 7 TeV with L = 4.6 fb^{-1}.

[11] AALTONEN 13I search for events with a photon and missing E_T, where the photon is detected after the expected timing, in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 6.3 fb^{-1}. The data are consistent with the Standard Model expectation.

[12] CHATRCHYAN 13 search for events with an opposite-sign lepton pair, jets, and missing E_T in pp collisions at E_{cm} = 7 TeV with L = 4.98 fb^{-1}.

[13] AAD 12C search for events with a $t\overline{t}$ pair and missing $\not{E}_T$ in pp collisions at E_{cm} = 7 TeV with L = 1.04 fb^{-1}.

[14] AALTONEN 12M search for events with a jet and missing E_T in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 6.7 fb^{-1}.

[15] CHATRCHYAN 12AP search for events with a jet and missing E_T in pp collisions at E_{cm} = 7 TeV with L = 5.0 fb^{-1}.

[16] CHATRCHYAN 12Q search for events with a Z, jets, and missing $\not{E}_T$ in pp collisions at E_{cm} = 7 TeV with L = 4.98 fb^{-1}.

[17] CHATRCHYAN 12T search for events with a photon and missing $\not{E}_T$ in pp collisions at E_{cm} = 7 TeV with L = 5.0 fb^{-1}.

[18] AAD 11S search for events with one jet and missing E_T in pp collisions at E_{cm} = 7 TeV with L = 33 pb^{-1}.

[19] AALTONEN 11AF search for high-p_T like-sign dileptons in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 6.1 fb^{-1}.

[20] CHATRCHYAN 11C search for events with an opposite-sign lepton pair, jets, and missing E_T in pp collisions at E_{cm} = 7 TeV with L = 34 pb^{-1}.

[21] CHATRCHYAN 11U search for events with one jet and missing E_T in pp collisions at E_{cm} = 7 TeV with L = 36 pb^{-1}.

[22] AALTONEN 10AF search for $\gamma\gamma$ events with e, μ, τ, or missing E_T in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 1.1–2.0 fb^{-1}.

[23] AALTONEN 09AF search for $\ell\gamma b$ events with missing E_T in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 1.9 fb^{-1}. The observed events are compatible with Standard Model expectation including $t\overline{t}\gamma$ production.

[24] AALTONEN 09G search for $\mu\mu\mu$ and $\mu\mu e$ events with missing E_T in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 976 pb^{-1}.

LIMITS ON JET-JET RESONANCES

Heavy Particle Production Cross Section

Limits are for a particle decaying to two hadronic jets.

Units(pb)	CL%	Mass(GeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
			[1] AAD 20AD	ATLS	pp at 13 TeV, dijet resonance
			[2] AAD 20T	ATLS	dijet resonance search
			[3] AAD 20W	ATLS	dijet resonance plus lepton
			[4] SIRUNYAN 20AI	CMS	dijet resonance search
			[5] AABOUD 19AJ	ATLS	$pp \rightarrow \gamma X$, $X \rightarrow jj$
			[6] SIRUNYAN 19B	CMS	$pp \rightarrow jA$, $A \rightarrow b\overline{b}$
			[7] SIRUNYAN 19CD	CMS	$pp \rightarrow Z'\gamma$, $Z' \rightarrow jj$

			[8] AABOUD	18AD	ATLS	$pp \to Y \to HX \to (bb) + (qq)$
			[9] AABOUD	18CK	ATLS	$pp \to bbb + \not{E}_T$
			[10] AABOUD	18CL	ATLS	$pp \to$ vector-like quarks
			[11] AABOUD	18N	ATLS	$pp \to jj$ resonance
			[12] SIRUNYAN	18DJ	CMS	$pp \to ZZ$ or $WZ \to \ell\overline{\ell}jj$
			[13] SIRUNYAN	18DY	CMS	$pp \to RR$; $R \to jj$
			[14] KHACHATRY...	17W	CMS	$pp \to jj$ resonance
			[15] KHACHATRY...	17Y	CMS	$pp \to$ (8–10) $j+\not{E}_T$
			[16] SIRUNYAN	17F	CMS	$pp \to jj$ angular distribution
			[17] AABOUD	16	ATLS	$pp \to b +$ jet
			[18] AAD	16N	ATLS	$pp \to$ 3 high E_T jets
			[19] AAD	16S	ATLS	$pp \to jj$ resonance
			[20] KHACHATRY...	16K	CMS	$pp \to jj$ resonance
			[21] KHACHATRY...	16L	CMS	$pp \to jj$ resonance
			[22] AAD	13D	ATLS	7 TeV $pp \to$ 2 jets
			[23] AALTONEN	13R	CDF	1.96 TeV $p\overline{p} \to$ 4 jets
			[24] CHATRCHYAN	13A	CMS	7 TeV $pp \to$ 2 jets
			[25] CHATRCHYAN	13A	CMS	7 TeV $pp \to b\overline{b}X$
			[26] AAD	12S	ATLS	7 TeV $pp \to$ 2 jets
			[27] CHATRCHYAN	12BL	CMS	7 TeV $pp \to t\overline{t}X$
			[28] AAD	11AG	ATLS	7 TeV $pp \to$ 2 jets
			[29] AALTONEN	11M	CDF	1.96 TeV $p\overline{p} \to W+$ 2 jets
			[30] ABAZOV	11I	D0	1.96 TeV $p\overline{p} \to W+$ 2 jets
			[31] AAD	10	ATLS	7 TeV $pp \to$ 2 jets
			[32] KHACHATRY...	10	CMS	7 TeV $pp \to$ 2 jets
			[33] ABE	99F	CDF	1.8 TeV $p\overline{p} \to b\overline{b}+$ anything
			[34] ABE	97G	CDF	1.8 TeV $p\overline{p} \to$ 2 jets
<2603	95	200	[35] ABE	93G	CDF	1.8 TeV $p\overline{p} \to$ 2 jets
< 44	95	400	[35] ABE	93G	CDF	1.8 TeV $p\overline{p} \to$ 2 jets
< 7	95	600	[35] ABE	93G	CDF	1.8 TeV $p\overline{p} \to$ 2 jets

[1] AAD 20AD search for weakly supervised dijet resonance in ATLAS with 139 fb^{-1} at 13 TeV; no signal; various limits placed depending on kinematics and production cross section.

[2] AAD 20T search for dijet resonance with or without b-jets at 13 TeV and 139 fb^{-1}; no signal; limits placed in $\sigma \cdot$ BF vs mass plane for various BSM models.

[3] AAD 20W search for dijet resonance plus lepton with ATLAS at 13 TeV and 139 fb^{-1}; no signal; limits placed in $\sigma \cdot$ BF vs. mass plane for various BSM models.

[4] SIRUNYAN 20AI search for dijet resonance in CMS at 13 TeV with 137 fb^{-1}; no signal; limits set in σ vs. mass plane for various BSM models .

[5] AABOUD 19AJ search for low mass dijet resonance in $pp \to \gamma X$, $X \to jj$ at 13 TeV with 79.8 fb^{-1} of data; no signal found; limits placed on Z' model in coupling vs. m(Z') plane.

[6] SIRUNYAN 19B search for low mass resonance $pp \to jA$, $A \to b\overline{b}$ at 13 TeV using 35.9 fb^{-1}; no signal; exclude resonances 50–350 GeV depending on production and decay.

[7] SIRUNYAN 19CD search for $pp \to Z'\gamma$, $Z' \to jj$ with fat jet (jj); no signal, limits placed in m(Z') vs. coupling plane for Z' masses from 10 to 125 GeV.

[8] AABOUD 18AD search for new heavy particle $Y \to HX \to (bb) + (qq)$. No signal observed. Limits set on m(Y) vs. m(X) in the ranges of m(Y) in 1–4 TeV and m(X) in 50–1000 GeV.

[9] AABOUD 18CK search for SUSY Higgsinos in gauge-mediation via $pp \to bbb + \not{E}_T$ at 13 TeV using two complementary analyses with 24.3/36.1 fb^{-1}; no signal is found

and Higgsinos with masses between 130 and 230 GeV and between 290 and 880 GeV are excluded at the 95% confidence level.

[10] AABOUD 18CL search for $pp \to$ vector-like quarks $\to$ jets at 13 TeV with 36 fb^{-1}; no signal seen; limits set on various VLQ scenarios. For pure $B \to Hb$ or $T \to Ht$, set the mass limit m > 1010 GeV.

[11] AABOUD 18N search for dijet resonance at Atlas with 13 TeV and 29.3 fb^{-1}; limits set on m(Z') in the mass range of 450–1800 GeV.

[12] SIRUNYAN 18DJ search for $pp \to ZZ$ or $WZ \to \ell\overline{\ell}jj$ resonance at 13 TeV, 35.9 fb^{-1}; no signal; limits set in the 400–4500 GeV mass range, exclusion of W' up to 2270 GeV in the HVT model A, and up to 2330 GeV for HVT model B. WED bulk graviton exclusion up to 925 GeV.

[13] SIRUNYAN 18DY search for $pp \to RR$; $R \to jj$ two dijet resonances at 13 TeV 35.9 fb^{-1}; no signal; limits placed on RPV top-squark pair production.

[14] KHACHATRYAN 17W search for dijet resonance in 12.9 fb^{-1} data at 13 TeV; see Fig. 2 for limits on axigluons, diquarks, dark matter mediators etc.

[15] KHACHATRYAN 17Y search for $pp \to$ (8–10) j in 19.7 fb^{-1} at 8 TeV. No signal seen. Limits set on colorons, axigluons, RPV, and SUSY.

[16] SIRUNYAN 17F measure $pp \to jj$ angular distribution in 2.6 fb^{-1} at 13 TeV; limits set on LEDs and quantum black holes.

[17] AABOUD 16 search for resonant dijets including one or two b-jets with 3.2 fb^{-1} at 13 TeV; exclude excited b^* quark from 1.1–2.1 TeV; exclude leptophilic Z' with SM couplings from 1.1–1.5 TeV.

[18] AAD 16N search for ≥ 3 jets with 3.6 fb^{-1} at 13 TeV; limits placed on micro black holes (Fig. 10) and string balls (Fig. 11).

[19] AAD 16S search for high mass jet-jet resonance with 3.6 fb^{-1} at 13 TeV; exclude portions of excited quarks, W', Z' and contact interaction parameter space.

[20] KHACHATRYAN 16K search for dijet resonance in 2.4 fb^{-1} data at 13 TeV; see Fig. 3 for limits on axigluons, diquarks etc.

[21] KHACHATRYAN 16L use data scouting technique to search for jj resonance on 18.8 fb^{-1} of data at 8 TeV. Limits on the coupling of a leptophobic Z' to quarks are set, improving on the results by other experiments in the mass range between 500–800 GeV.

[22] AAD 13D search for dijet resonances in pp collisions at E_{cm} = 7 TeV with L = 4.8 fb^{-1}. The observed events are compatible with Standard Model expectation. See their Fig. 6 and Table 2 for limits on resonance cross section in the range m = 1.0–4.0 TeV.

[23] AALTONEN 13R search for production of a pair of jet-jet resonances in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 6.6 fb^{-1}. See their Fig. 5 and Tables I, II for cross section limits.

[24] CHATRCHYAN 13A search for qq, qg, and gg resonances in pp collisions at E_{cm} = 7 TeV with L = 4.8 fb^{-1}. See their Fig. 3 and Table 1 for limits on resonance cross section in the range m = 1.0–4.3 TeV.

[25] CHATRCHYAN 13A search for $b\overline{b}$ resonances in pp collisions at E_{cm} = 7 TeV with L = 4.8 fb^{-1}. See their Fig. 8 and Table 4 for limits on resonance cross section in the range m = 1.0–4.0 TeV.

[26] AAD 12S search for dijet resonances in pp collisions at E_{cm} = 7 TeV with L = 1.0 fb^{-1}. See their Fig. 3 and Table 2 for limits on resonance cross section in the range m = 0.9–4.0 TeV.

[27] CHATRCHYAN 12BL search for $t\overline{t}$ resonances in pp collisions at E_{cm} = 7 TeV with L = 4.4 fb^{-1}. See their Fig. 4 for limits on resonance cross section in the range m = 0.5–3.0 TeV.

[28] AAD 11AG search for dijet resonances in pp collisions at E_{cm} = 7 TeV with L = 36 pb^{-1}. Limits on number of events for m = 0.6–4 TeV are given in their Table 3.

[29] AALTONEN 11M find a peak in two jet invariant mass distribution around 140 GeV in W + 2 jet events in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 4.3 fb^{-1}.

[30] ABAZOV 11I search for two-jet resonances in W + 2 jet events in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV with L = 4.3 fb^{-1} and give limits σ < (2.6–1.3) pb (95% CL) for m = 110–170 GeV. The result is incompatible with AALTONEN 11M.

[31] AAD 10 search for narrow dijet resonances in pp collisions at E_{cm} = 7 TeV with L = 315 nb^{-1}. Limits on the cross section in the range 10–10^3 pb is given for m = 0.3–1.7 TeV.

[32] KHACHATRYAN 10 search for narrow dijet resonances in pp collisions at E_{cm} = 7 TeV with L = 2.9 pb^{-1}. Limits on the cross section in the range 1–300 pb is given for m = 0.5–2.6 TeV separately in the final states qq, qg, and gg.

[33] ABE 99F search for narrow $b\overline{b}$ resonances in $p\overline{p}$ collisions at E_{cm}=1.8 TeV. Limits on $\sigma(p\overline{p} \rightarrow X+$ anything$)\times$B$(X \rightarrow b\overline{b})$ in the range 3–10^3 pb (95%CL) are given for m_X=200–750 GeV. See their Table I.

[34] ABE 97G search for narrow dijet resonances in $p\overline{p}$ collisions with 106 pb^{-1} of data at E_{cm} = 1.8 TeV. Limits on $\sigma(p\overline{p} \rightarrow X+$ anything$)\cdot$B$(X \rightarrow jj)$ in the range 10^4–10^{-1} pb (95%CL) are given for dijet mass m=200–1150 GeV with both jets having $|\eta|$ < 2.0 and the dijet system having $|\cos\theta^*|$ < 0.67. See their Table I for the list of limits. Supersedes ABE 93G.

[35] ABE 93G give cross section times branching ratio into light (d, u, s, c, b) quarks for Γ = 0.02 M. Their Table II gives limits for M = 200–900 GeV and Γ = (0.02–0.2) M.

LIMITS ON NEUTRAL PARTICLE PRODUCTION

Production Cross Section of Radiatively-Decaying Neutral Particle

VALUE (pb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] ALBERT	18C	HAWC	γ from Sun
		[2] KHACHATRY...	17D	CMS	$Z\gamma$ resonance
<0.0008	95	[3] AAD	16AI	ATLS	$pp \rightarrow \gamma +$ jet
		[4] KHACHATRY...	16M	CMS	$pp \rightarrow \gamma\gamma$ resonance
<(0.043–0.17)	95	[5] ABBIENDI	00D	OPAL	$e^+e^- \rightarrow X^0Y^0$, $X^0 \rightarrow Y^0\gamma$
<(0.05–0.8)	95	[6] ABBIENDI	00D	OPAL	$e^+e^- \rightarrow X^0X^0$, $X^0 \rightarrow Y^0\gamma$
<(2.5–0.5)	95	[7] ACKERSTAFF	97B	OPAL	$e^+e^- \rightarrow X^0Y^0$, $X^0 \rightarrow Y^0\gamma$
<(1.6–0.9)	95	[8] ACKERSTAFF	97B	OPAL	$e^+e^- \rightarrow X^0X^0$, $X^0 \rightarrow Y^0\gamma$

[1] ALBERT 18C search for WIMP annihilation in Sun to long-lived, radiatively decaying mediator; no signal; limits set on $\sigma^{SD}(\chi p)$ assuming long-lived mediator.

[2] KHACHATRYAN 17D search for new scalar resonance decaying to $Z\gamma$ with $Z \rightarrow e^+e^-$, $\mu^+\mu^-$ in pp collisions at 8 and 13 TeV; no signal seen.

[3] AAD 16AI search for excited quarks (EQ) and quantum black holes (QBH) in 3.2 fb^{-1} at 13 TeV of data; exclude EQ below 4.4 TeV and QBH below 3.8 (6.2) TeV for RS1 (ADD) models. The visible cross section limit was obtained for 5 TeV resonance with σ_G/M_G = 2%.

[4] KHACHATRYAN 16M search for $\gamma\gamma$ resonance using 19.7 fb^{-1} at 8 TeV and 3.3 fb^{-1} at 13 Tev; slight excess at 750 GeV noted; limit set on RS graviton.

[5] ABBIENDI 00D associated production limit is for m_{X^0}= 90–188 GeV, m_{Y^0}=0 at E_{cm}=189 GeV. See also their Fig. 9.

[6] ABBIENDI 00D pair production limit is for m_{X^0} = 45–94 GeV, m_{Y^0}=0 at E_{cm}=189 GeV. See also their Fig. 12.

[7] ACKERSTAFF 97B associated production limit is for m_{X^0} = 80–160 GeV, m_{Y^0}=0 from 10.0 pb^{-1} at E_{cm} = 161 GeV. See their Fig. 3(a).
[8] ACKERSTAFF 97B pair production limit is for m_{X^0} = 40–80 GeV, m_{Y^0}=0 from 10.0 pb^{-1} at E_{cm} = 161 GeV. See their Fig. 3(b).

Heavy Particle Production Cross Section

VALUE (cm^2/N)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] AAIJ	20AL	LHCB	pp at 13 TeV, dimuon resonance
		[2] SIRUNYAN	20AY	CMS	$\Upsilon(1S)\mu^+\mu^-$ decay states
		[3] SIRUNYAN	20Z	CMS	multilepton BSM search, 13 TeV
		[4] AABOUD	19H	ATLS	di-photon-jet resonance
		[5] AABOUD	19V	ATLS	ATLAS review, mediator-based DM
		[6] SIRUNYAN	19O	CMS	$pp \to \gamma \not{E}_T$
		[7] AABOUD	18CJ	ATLS	$pp \to VV/\ell\ell/\ell\nu$, $V = W,Z,h$
		[8] AABOUD	18CM	ATLS	$pp \to e\mu/e\tau/\mu\tau$
		[9] AAIJ	18AJ	LHCB	$pp \to A' \to \mu^+\mu^-$; dark photon
		[10] BANERJEE	18	NA64	$eZ \to eZX(A')$
		[11] BANERJEE	18A	NA64	$eZ \to eZA'$, $A' \to \chi\chi$
		[12] MARSICANO	18	E137	$e^+e^- \to A'(\gamma)$ visible decay
		[13] SIRUNYAN	18BB	CMS	$pp \to Z' \to \ell^+\ell^-$ at 13 TeV
		[14] SIRUNYAN	18DA	CMS	$pp \to$ Black Hole, string ball, sphaleron
		[15] SIRUNYAN	18DD	CMS	$pp \to jj$
		[16] SIRUNYAN	18DR	CMS	$pp \to b\mu\overline{\mu}$
		[17] SIRUNYAN	18DU	CMS	$pp \to \gamma\gamma$
		[18] SIRUNYAN	18ED	CMS	$pp \to V \to Wh$; $h \to b\overline{b}$; $W \to \ell\nu$
		[19] AABOUD	17B	ATLS	WH, ZH resonance
		[20] AAIJ	17BR	LHCB	$pp \to \pi_V\pi_V$, $\pi_V \to jj$
		[21] AAD	16O	ATLS	ℓ + (ℓs or jets)
		[22] AAD	16R	ATLS	WW, WZ, ZZ resonance
		[23] KRASZNAHO...	16		$p\,^7$Li $\to$ ^{8}Be $\to X(17)N$, $X(17) \to e^+e^-$
		[24] LEES	15E	BABR	e^+e^- collisions
		[25] ADAMS	97B	KTEV	m= 1.2–5 GeV
$< 10^{-36}$–10^{-33}	90	[26] GALLAS	95	TOF	m= 0.5–20 GeV
$<(4$–$0.3) \times 10^{-31}$	95	[27] AKESSON	91	CNTR	m = 0–5 GeV
$<2 \times 10^{-36}$	90	[28] BADIER	86	BDMP	τ = (0.05–1.) $\times 10^{-8}$s
$<2.5 \times 10^{-35}$		[29] GUSTAFSON	76	CNTR	$\tau > 10^{-7}$ s

[1] AAIJ 20AL search for dimuon resonance from promptly decaying X particle; no signal; limits placed on m(X) up to 60 GeV depending on mixing in 2HDM.
[2] SIRUNYAN 20AY measured Υ(1S) pair production cross section and searched for new states decaying into $\Upsilon(1S)\mu^+\mu^-$ at CMS with 13 TeV with 35.9 fb^{-1}. No signal is found and limits are set in $\sigma \cdot$ BF vs. mass plane for tetra-b-quarks with masses between 17.5 and 19 GeV and for generic search for narrow resonances with mass between 16.5 and 27 GeV.

[3] SIRUNYAN 20Z search for BSM physics via multilepton production with CMS at 13 TeV with 137 fb^{-1}; no signal is found and limits are set on type-III seesaw and other BSM models.
[4] AABOUD 19H searches for di-photon-jet resonance at 13 TeV and 36.7 fb^{-1} of data; no signal found and limits placed on $\sigma \cdot$ BR vs. mass plane for various simplified models.
[5] AABOUD 19V review ATLAS searches for mediator-based DM at 7, 8, and 13 TeV with up to 37 fb^{-1} of data; no signal found and limits set for wide variety of simplified models of dark matter.
[6] SIRUNYAN 19O search for $pp \rightarrow \gamma \not{E}_T$ at 13 TeV with 36.1 fb^{-1}; no signal found and limits set for various simplified models.
[7] AABOUD 18CJ make multichannel search for $pp \rightarrow VV/\ell\ell/\ell\nu$, $V = W,Z,h$ at 13 TeV, 36.1 fb^{-1}; no signal found; limits placed for several BSM models.
[8] AABOUD 18CM search for lepton-flavor violating resonance in $pp \rightarrow e\mu/e\tau/\mu\tau$ at 13 TeV, 36.1 fb^{-1}; no signal is found and limits placed for various BSM models.
[9] AAIJ 18AJ search for prompt and delayed dark photon decay $A' \rightarrow \mu^+\mu^-$ at LHCb detector using 1.6 fb^{-1} of pp collisions at 13 TeV; limits on m(A') vs. kinetic mixing are set.
[10] BANERJEE 18 search for dark photon A'/16.7 MeV boson X at NA64 via $eZ \rightarrow eZX(A')$; no signal found and limits set on the X-e^- coupling ϵ_e in the range $1.3 \times 10^{-4} \leq \epsilon_e \leq 4.2 \times 10^{-4}$ excluding part of the allowed parameter space.
[11] BANERJEE 18A search for invisibly decaying dark photons in $eZ \rightarrow eZA'$, $A' \rightarrow$ invisible; no signal found and limits set on mixing for m(A') < 1 GeV.
[12] MARSICANO 18 search for dark photon $e^+e^- \rightarrow A'(\gamma)$ visible decay in SLAC E137 e beam dump data. No signal observed and limits set in ϵ coupling vs m(A') plane, see their figure 7.
[13] SIRUNYAN 18BB search for high mass dilepton resonance; no signal found and exclude portions of p-space of Z', KK graviton models.
[14] SIRUNYAN 18DA search for $pp \rightarrow$ Black Hole, string ball, sphaleron via high multiplicity events at 13 TeV, 35.9 fb^{-1}; no signal, require e.g. m(BH) > 10.1 TeV.
[15] SIRUNYAN 18DD search for $pp \rightarrow jj$ deviations in dijet angular distribution. No signal observed. Set limits on large extra dimensions, black holes and DM mediators e.g. m(BH) $>$ 5.9–8.2 TeV.
[16] SIRUNYAN 18DR search for dimuon resonance in $pp \rightarrow b\mu\overline{\mu}$ at 8 and 13 TeV. Slight excess seen at m($\mu\overline{\mu}$) $\sim$ 28 GeV in some channels.
[17] SIRUNYAN 18DU search for high mass diphoton resonance in $pp \rightarrow \gamma\gamma$ at 13 TeV using 35.9 fb^{-1}; no signal; limits placed on RS Graviton, LED, and clockwork.
[18] SIRUNYAN 18ED search for $pp \rightarrow V \rightarrow Wh$; $h \rightarrow b\overline{b}$; $W \rightarrow \ell\nu$ at 13 TeV with 35.9 fb^{-1}; no signal; limits set on m(W') > 2.9 TeV.
[19] AABOUD 17B exclude m(W', Z') $<$ 1.49–2.31 TeV depending on the couplings and W'/Z' degeneracy assumptions via WH, ZH search in pp collisions at 13 TeV with 3.2 fb^{-1} of data.
[20] AAIJ 17BR search for long-lived hidden valley pions from Higgs decay. Limits are set on the signal strength as a function of the mass and lifetime of the long-lived particle in their Fig. 4 and Tab. 4.
[21] AAD 16O search for high E_T ℓ + (ℓs or jets) with 3.2 fb^{-1} at 13 TeV; exclude micro black holes mass $<$ 8 TeV (Fig. 3) for models with two extra dimensions.
[22] AAD 16R search for WW, WZ, ZZ resonance in 20.3 fb^{-1} at 8 TeV data; limits placed on massive RS graviton (Fig. 4).
[23] KRASZNAHORKAY 16 report pLi $\rightarrow$ Be $\rightarrow e\overline{e}N$ 5σ resonance at 16.7 MeV– possible evidence for nuclear interference or new light boson . However, such nuclear interference was ruled out already by ZANG 17.

[24] LEES 15E search for long-lived neutral particles produced in $e^+ e^-$ collisions in the Upsilon region, which decays into $e^+ e^-$, $\mu^+ \mu^-$, $e^\pm \mu^\mp$, $\pi^+ \pi^-$, $K^+ K^-$, or $\pi^\pm K^\mp$. See their Fig. 2 for cross section limits.

[25] ADAMS 97B search for a hadron-like neutral particle produced in pN interactions, which decays into a ρ^0 and a weakly interacting massive particle. Upper limits are given for the ratio to K_L production for the mass range 1.2–5 GeV and lifetime 10^{-9}–10^{-4} s. See also our Light Gluino Section.

[26] GALLAS 95 limit is for a weakly interacting neutral particle produced in 800 GeV/c pN interactions decaying with a lifetime of 10^{-4}–10^{-8} s. See their Figs. 8 and 9. Similar limits are obtained for a stable particle with interaction cross section 10^{-29}–10^{-33} cm^2. See Fig. 10.

[27] AKESSON 91 limit is from weakly interacting neutral long-lived particles produced in pN reaction at 450 GeV/c performed at CERN SPS. Bourquin-Gaillard formula is used as the production model. The above limit is for $\tau > 10^{-7}$ s. For $\tau > 10^{-9}$ s, $\sigma < 10^{-30}$ cm^{-2}/nucleon is obtained.

[28] BADIER 86 looked for long-lived particles at 300 GeV π^- beam dump. The limit applies for nonstrongly interacting neutral or charged particles with mass >2 GeV. The limit applies for particle modes, $\mu^+ \pi^-$, $\mu^+ \mu^-$, $\pi^+ \pi^- X$, $\pi^+ \pi^- \pi^\pm$ etc. See their figure 5 for the contours of limits in the mass-τ plane for each mode.

[29] GUSTAFSON 76 is a 300 GeV FNAL experiment looking for heavy (m >2 GeV) long-lived neutral hadrons in the M4 neutral beam. The above typical value is for m = 3 GeV and assumes an interaction cross section of 1 mb. Values as a function of mass and interaction cross section are given in figure 2.

Production of New Penetrating Non-ν Like States in Beam Dump

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] LOSECCO	81	CALO	28 GeV protons

[1] No excess neutral-current events leads to σ(production) × σ(interaction)×acceptance $< 2.26 \times 10^{-71}$ cm^4/nucleon^2 (CL = 90%) for light neutrals. Acceptance depends on models (0.1 to 4. × 10^{-4}).

LIMITS ON CHARGED PARTICLES IN $e^+ e^-$

Heavy Particle Production Cross Section in $e^+ e^-$

Ratio to $\sigma(e^+ e^- \rightarrow \mu^+ \mu^-)$ unless noted. See also entries in Free Quark Search and Magnetic Monopole Searches.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] KILE	18	ALEP	$e^+ e^- \rightarrow$ 4 jets
$<1 \times 10^{-3}$	90	[2] ABLIKIM	17AA	BES3	$e^+ e^- \rightarrow \ell \bar{\ell} \gamma$
		[3] ACKERSTAFF	98P	OPAL	Q=1,2/3, m=45–89.5 GeV
		[4] ABREU	97D	DLPH	Q=1,2/3, m=45–84 GeV
		[5] BARATE	97K	ALEP	Q=1, m=45–85 GeV
$<2 \times 10^{-5}$	95	[6] AKERS	95R	OPAL	Q=1, m= 5–45 GeV
$<1 \times 10^{-5}$	95	[6] AKERS	95R	OPAL	Q=2, m= 5–45 GeV
$<2 \times 10^{-3}$	90	[7] BUSKULIC	93C	ALEP	Q=1, m=32–72 GeV
$<(10^{-2}$–$1)$	95	[8] ADACHI	90C	TOPZ	Q=1, m=1–16, 18–27 GeV
$<7 \times 10^{-2}$	90	[9] ADACHI	90E	TOPZ	Q = 1, m = 5–25 GeV
$<1.6 \times 10^{-2}$	95	[10] KINOSHITA	82	PLAS	Q=3–180, m <14.5 GeV
$<5.0 \times 10^{-2}$	90	[11] BARTEL	80	JADE	Q=(3,4,5)/3 2–12 GeV

[1] KILE 18 investigate archived ALEPH $e^+ e^- \to$ 4 jets data and see 4–5 σ excess at 110 GeV.

[2] ABLIKIM 17AA search for dark photon $A \to \ell\overline{\ell}$ at 3.773 GeV with 2.93 fb^{-1}. Limits are set in ϵ vs m(A) plane.

[3] ACKERSTAFF 98P search for pair production of long-lived charged particles at E_{cm} between 130 and 183 GeV and give limits $\sigma <$(0.05–0.2) pb (95%CL) for spin-0 and spin-1/2 particles with m=45–89.5 GeV, charge 1 and 2/3. The limit is translated to the cross section at E_{cm}=183 GeV with the s dependence described in the paper. See their Figs. 2–4.

[4] ABREU 97D search for pair production of long-lived particles and give limits $\sigma <$(0.4–2.3) pb (95%CL) for various center-of-mass energies E_{cm}=130–136, 161, and 172 GeV, assuming an almost flat production distribution in cosθ.

[5] BARATE 97K search for pair production of long-lived charged particles at E_{cm} = 130, 136, 161, and 172 GeV and give limits $\sigma <$(0.2–0.4) pb (95%CL) for spin-0 and spin-1/2 particles with m=45–85 GeV. The limit is translated to the cross section at E_{cm}=172 GeV with the E_{cm} dependence described in the paper. See their Figs. 2 and 3 for limits on $J = 1/2$ and $J = 0$ cases.

[6] AKERS 95R is a CERN-LEP experiment with $W_{\text{cm}} \sim m_Z$. The limit is for the production of a stable particle in multihadron events normalized to $\sigma(e^+ e^- \to$ hadrons). Constant phase space distribution is assumed. See their Fig. 3 for bounds for $Q = \pm 2/3$, $\pm 4/3$.

[7] BUSKULIC 93C is a CERN-LEP experiment with $W_{\text{cm}} = m_Z$. The limit is for a pair or single production of heavy particles with unusual ionization loss in TPC. See their Fig. 5 and Table 1.

[8] ADACHI 90C is a KEK-TRISTAN experiment with W_{cm} = 52–60 GeV. The limit is for pair production of a scalar or spin-1/2 particle. See Figs. 3 and 4.

[9] ADACHI 90E is KEK-TRISTAN experiment with W_{cm} = 52–61.4 GeV. The above limit is for inclusive production cross section normalized to $\sigma(e^+ e^- \to \mu^+ \mu^-)\cdot\beta(3-\beta^2)/2$, where $\beta = (1 - 4m^2/W^2_{\text{cm}})^{1/2}$. See the paper for the assumption about the production mechanism.

[10] KINOSHITA 82 is SLAC PEP experiment at W_{cm} = 29 GeV using lexan and ^{39}Cr plastic sheets sensitive to highly ionizing particles.

[11] BARTEL 80 is DESY-PETRA experiment with W_{cm} = 27–35 GeV. Above limit is for inclusive pair production and ranges between 1. $\times$ 10^{-1} and 1. $\times$ 10^{-2} depending on mass and production momentum distributions. (See their figures 9, 10, 11).

Branching Fraction of Z^0 to a Pair of Stable Charged Heavy Fermions

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<5 \times 10^{-6}$	95	[1] AKERS	95R	OPAL	m= 40.4–45.6 GeV
$<1 \times 10^{-3}$	95	AKRAWY	90O	OPAL	m = 29–40 GeV

[1] AKERS 95R give the 95% CL limit $\sigma(X\overline{X})/\sigma(\mu\mu) < 1.8\times10^{-4}$ for the pair production of singly- or doubly-charged stable particles. The limit applies for the mass range 40.4–45.6 GeV for $X^{\pm}$ and < 45.6 GeV for $X^{\pm\pm}$. See the paper for bounds for $Q = \pm 2/3$, $\pm 4/3$.

LIMITS ON CHARGED PARTICLES IN HADRONIC REACTIONS

MASS LIMITS for Long-Lived Charged Heavy Fermions

Limits are for spin 1/2 particles with no color and $SU(2)_L$ charge. The electric charge Q of the particle (in the unit of e) is therefore equal to its weak hypercharge. Pair production by Drell-Yan like γ and Z exchange is assumed to derive the limits.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] SIRUNYAN	20N	CMS	disappearing track LLP
>660	95	[2] AAD	15BJ	ATLS	$\lvert Q\rvert = 2$
>200	95	[3] CHATRCHYAN	13AB	CMS	$\lvert Q\rvert = 1/3$
>480	95	[3] CHATRCHYAN	13AB	CMS	$\lvert Q\rvert = 2/3$
>574	95	[3] CHATRCHYAN	13AB	CMS	$\lvert Q\rvert = 1$
>685	95	[3] CHATRCHYAN	13AB	CMS	$\lvert Q\rvert = 2$
>140	95	[4] CHATRCHYAN	13AR	CMS	$\lvert Q\rvert = 1/3$
>310	95	[4] CHATRCHYAN	13AR	CMS	$\lvert Q\rvert = 2/3$

[1] SIRUNYAN 20N search for LLPs using disappearing track signature at CMS at 13 TeV with 101 fb^{-1}; no signal; limits placed on long-lived winos and higgsinos from SUSY depending on mass and lifetime: e.g. at 95% CL, for a purely higgsino neurtalino, m(chargino) > 750 (175) GeV for $\tau = 3$ (0.05) ns, and for a purely wino neutralino, m(chargino) > 884 (474) GeV for $\tau = 3$ (0.2) ns.

[2] AAD 15BJ use 20.3 fb^{-1} of pp collisions at $E_{cm} = 8$ TeV. See paper for limits for $\lvert Q\rvert$ = 3, 4, 5, 6.

[3] CHATRCHYAN 13AB use 5.0 fb^{-1} of pp collisions at $E_{cm} = 7$ TeV and 18.8 fb^{-1} at $E_{cm} = 8$ TeV. See paper for limits for $\lvert Q\rvert = 3, 4, \ldots, 8$.

[4] CHATRCHYAN 13AR use 5.0 fb^{-1} of pp collisions at $E_{cm} = 7$ TeV.

Heavy Particle Production Cross Section

VALUE (nb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] SIRUNYAN	20C	CMS	$4t$ search via multileptons
		[2] AABOUD	19AA	ATLS	BSM search
		[3] AABOUD	19Q	ATLS	single top +MET
		[4] AABOUD	17D	ATLS	anomalous $WWjj$, $WZjj$
		[5] AABOUD	17L	ATLS	m>870 GeV, $Z(\rightarrow \nu\nu)tX$
		[6] SIRUNYAN	17B	CMS	tH
		[7] SIRUNYAN	17C	CMS	$Z + (t$ or $b)$
		[8] SIRUNYAN	17J	CMS	$X_{5/3} \rightarrow tW$
		[9] AAIJ	15BD	LHCB	m=124–309 GeV
		[10] AAD	13AH	ATLS	$\lvert q\rvert$=(2–6)e, m=50–600 GeV
$<1.2 \times 10^{-3}$	95	[11] AAD	11I	ATLS	$\lvert q\rvert$=10e, m=0.2–1 TeV
$<1.0 \times 10^{-5}$	95	[12,13] AALTONEN	09Z	CDF	m>100 GeV, noncolored
$<4.8 \times 10^{-5}$	95	[12,14] AALTONEN	09Z	CDF	m>100 GeV, colored
$< 0.31–0.04 \times 10^{-3}$	95	[15] ABAZOV	09M	D0	pair production
<0.19	95	[16] AKTAS	04C	H1	m=3–10 GeV
<0.05	95	[17] ABE	92J	CDF	m=50–200 GeV
<30–130		[18] CARROLL	78	SPEC	m=2–2.5 GeV
<100		[19] LEIPUNER	73	CNTR	m=3–11 GeV

[1] SIRUNYAN 20C search for four top-quark production with decay to multileptons at CMS at 13 TeV with 137 fb^{-1}; no signal is found and limits are placed on the Higgs boson oblique parameter in the effective field theory framework (EFT) and the model parameters ($\tan\beta$).

[2] AABOUD 19AA search for BSM physics at 13 TeV with 3.2 fb^{-1} in $> 10^5$ regions of $>$ 700 event classes; no significant signal found.

[3] AABOUD 19Q search for single top+MET events at 13 TeV with 36.1 fb^{-1} of data; no signal found and limits set in σ or coupling vs. mass plane for variety of simplified models including DM and vector-like top quark T.

[4] AABOUD 17D search for $WWjj$, $WZjj$ in pp collisions at 8 TeV with 3.2 fb^{-1}; set limits on anomalous couplings.

[5] AABOUD 17L search for the pair production of heavy vector-like T quarks in the $Z(\rightarrow \nu\nu)tX$ final state.

[6] SIRUNYAN 17B search for vector-like quark $pp \rightarrow TX \rightarrow tHX$ in 2.3 fb^{-1} at 13 TeV; no signal seen; limits placed.

[7] SIRUNYAN 17C search for vector-like quark $pp \rightarrow TX \rightarrow Z + (t$ or $b)$ in 2.3 fb^{-1} at 13 TeV; no signal seen; limits placed.

[8] SIRUNYAN 17J search for $pp \rightarrow X_{5/3} X_{5/3} \rightarrow tWtW$ with 2.3 fb^{-1} at 13 TeV. No signal seen: m(X) $>$ 1020 (990) GeV for RH (LH) new charge 5/3 quark.

[9] AAIJ 15BD search for production of long-lived particles in pp collisions at $E_{cm} = 7$ and 8 TeV. See their Table 6 for cross section limits.

[10] AAD 13AH search for production of long-lived particles with $|q|$=(2–6)e in pp collisions at $E_{cm} = 7$ TeV with 4.4 fb^{-1}. See their Fig. 8 for cross section limits.

[11] AAD 11I search for production of highly ionizing massive particles in pp collisions at $E_{cm} = 7$ TeV with L = 3.1 pb^{-1}. See their Table 5 for similar limits for $|q| = 6e$ and $17e$, Table 6 for limits on pair production cross section.

[12] AALTONEN 09Z search for long-lived charged particles in $p\overline{p}$ collisions at $E_{cm} = 1.96$ TeV with $L = 1.0$ fb^{-1}. The limits are on production cross section for a particle of mass above 100 GeV in the region $|\eta| \lesssim 0.7$, $p_T > 40$ GeV, and $0.4 < \beta < 1.0$.

[13] Limit for weakly interacting charge-1 particle.

[14] Limit for up-quark like particle.

[15] ABAZOV 09M search for pair production of long-lived charged particles in $p\overline{p}$ collisions at $E_{cm} = 1.96$ TeV with $L = 1.1$ fb^{-1}. Limit on the cross section of (0.31–0.04) pb (95% CL) is given for the mass range of 60–300 GeV, assuming the kinematics of stau pair production.

[16] AKTAS 04C look for charged particle photoproduction at HERA with mean c.m. energy of 200 GeV.

[17] ABE 92J look for pair production of unit-charged particles which leave detector before decaying. Limit shown here is for m=50 GeV. See their Fig. 5 for different charges and stronger limits for higher mass.

[18] CARROLL 78 look for neutral, $S = -2$ dihyperon resonance in $pp \rightarrow 2K^+ X$. Cross section varies within above limits over mass range and $p_{lab} = 5.1$–5.9 GeV/c.

[19] LEIPUNER 73 is an NAL 300 GeV p experiment. Would have detected particles with lifetime greater than 200 ns.

Heavy Particle Production Differential Cross Section

VALUE ($cm^2 sr^{-1} GeV^{-1}$)	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<2.6 \times 10^{-36}$	90	[1] BALDIN	76	CNTR	$-$	Q= 1, m=2.1–9.4 GeV
$<2.2 \times 10^{-33}$	90	[2] ALBROW	75	SPEC	$\pm$	Q= $\pm$1, m=4–15 GeV
$<1.1 \times 10^{-33}$	90	[2] ALBROW	75	SPEC	$\pm$	Q= $\pm$2, m=6–27 GeV

$<8. \times 10^{-35}$	90	[3] JOVANOV...	75	CNTR	$\pm$	m=15–26 GeV
$<1.5 \times 10^{-34}$	90	[3] JOVANOV...	75	CNTR	$\pm$	$Q= \pm 2$, m=3–10 GeV
$<6. \times 10^{-35}$	90	[3] JOVANOV...	75	CNTR	$\pm$	$Q= \pm 2$, m=10–26 GeV
$<1. \times 10^{-31}$	90	[4] APPEL	74	CNTR	$\pm$	m=3.2–7.2 GeV
$<5.8 \times 10^{-34}$	90	[5] ALPER	73	SPEC	$\pm$	m=1.5–24 GeV
$<1.2 \times 10^{-35}$	90	[6] ANTIPOV	71B	CNTR	$-$	$Q=-$, m=2.2–2.8
$<2.4 \times 10^{-35}$	90	[7] ANTIPOV	71C	CNTR	$-$	$Q=-$, m=1.2–1.7, 2.1–4
$<2.4 \times 10^{-35}$	90	BINON	69	CNTR	$-$	$Q=-$, m=1–1.8 GeV
$<1.5 \times 10^{-36}$		[8] DORFAN	65	CNTR		Be target m=3–7 GeV
$<3.0 \times 10^{-36}$		[8] DORFAN	65	CNTR		Fe target m=3–7 GeV

[1] BALDIN 76 is a 70 GeV Serpukhov experiment. Value is per Al nucleus at $\theta = 0$. For other charges in range -0.5 to -3.0, CL = 90% limit is $(2.6 \times 10^{-36})/|(\text{charge})|$ for mass range (2.1–9.4 GeV) $\times$ $|(\text{charge})|$. Assumes stable particle interacting with matter as do antiprotons.

[2] ALBROW 75 is a CERN ISR experiment with $E_{cm} = 53$ GeV. $\theta = 40$ mr. See figure 5 for mass ranges up to 35 GeV.

[3] JOVANOVICH 75 is a CERN ISR 26+26 and 15+15 GeV pp experiment. Figure 4 covers ranges $Q = 1/3$ to 2 and $m = 3$ to 26 GeV. Value is per GeV momentum.

[4] APPEL 74 is NAL 300 GeV pW experiment. Studies forward production of heavy (up to 24 GeV) charged particles with momenta 24–200 GeV ($-$charge) and 40–150 GeV (+charge). Above typical value is for 75 GeV and is per GeV momentum per nucleon.

[5] ALPER 73 is CERN ISR 26+26 GeV pp experiment. $p >$0.9 GeV, $0.2 < \beta < 0.65$.

[6] ANTIPOV 71B is from same 70 GeV p experiment as ANTIPOV 71C and BINON 69.

[7] ANTIPOV 71C limit inferred from flux ratio. 70 GeV p experiment.

[8] DORFAN 65 is a 30 GeV/c p experiment at BNL. Units are per GeV momentum per nucleus.

Long-Lived Heavy Particle Invariant Cross Section

VALUE (cm^2/GeV^2/N)	*CL%*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$< 5–700 \times 10^{-35}$	90	[1] BERNSTEIN	88	CNTR		
$< 5–700 \times 10^{-37}$	90	[1] BERNSTEIN	88	CNTR		
$<2.5 \times 10^{-36}$	90	[2] THRON	85	CNTR	$-$	$Q=1$, m=4–12 GeV
$<1. \times 10^{-35}$	90	[2] THRON	85	CNTR	$+$	$Q=1$, m=4–12 GeV
$<6. \times 10^{-33}$	90	[3] ARMITAGE	79	SPEC		m=1.87 GeV
$<1.5 \times 10^{-33}$	90	[3] ARMITAGE	79	SPEC		m=1.5–3.0 GeV
		[4] BOZZOLI	79	CNTR	$\pm$	$Q = (2/3, 1, 4/3, 2)$
$<1.1 \times 10^{-37}$	90	[5] CUTTS	78	CNTR		m=4–10 GeV
$<3.0 \times 10^{-37}$	90	[6] VIDAL	78	CNTR		m=4.5–6 GeV

[1] BERNSTEIN 88 limits apply at $x = 0.2$ and $p_T = 0$. Mass and lifetime dependence of limits are shown in the regions: $m = 1.5$–7.5 GeV and $\tau = 10^{-8}$–2×10^{-6} s. First number is for hadrons; second is for weakly interacting particles.

[2] THRON 85 is FNAL 400 GeV proton experiment. Mass determined from measured velocity and momentum. Limits are for $\tau > 3 \times 10^{-9}$ s.

[3] ARMITAGE 79 is CERN-ISR experiment at $E_{cm} = 53$ GeV. Value is for $x = 0.1$ and $p_T = 0.15$. Observed particles at $m = 1.87$ GeV are found all consistent with being antideuterons.

[4] BOZZOLI 79 is CERN-SPS 200 GeV pN experiment. Looks for particle with τ larger than 10^{-8} s. See their figure 11–18 for production cross-section upper limits vs mass.

[5] CUTTS 78 is pBe experiment at FNAL sensitive to particles of $\tau > 5 \times 10^{-8}$ s. Value is for $-0.3 < x < 0$ and $p_T = 0.175$.
[6] VIDAL 78 is FNAL 400 GeV proton experiment. Value is for $x = 0$ and $p_T = 0$. Puts lifetime limit of $< 5 \times 10^{-8}$ s on particle in this mass range.

Long-Lived Heavy Particle Production (σ(Heavy Particle) / $\sigma(\pi)$)

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<10^{-8}$		[1] NAKAMURA	89	SPEC	$\pm$	$Q = (-5/3,\pm2)$
	0	[2] BUSSIERE	80	CNTR	$\pm$	$Q = (2/3,1,4/3,2)$

[1] NAKAMURA 89 is KEK experiment with 12 GeV protons on Pt target. The limit applies for mass $\lesssim$ 1.6 GeV and lifetime $\gtrsim 10^{-7}$ s.
[2] BUSSIERE 80 is CERN-SPS experiment with 200–240 GeV protons on Be and Al target. See their figures 6 and 7 for cross-section ratio vs mass.

Production and Capture of Long-Lived Massive Particles

VALUE (10^{-36} cm^2)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<20 to 800	[1] ALEKSEEV	76	ELEC	τ=5 ms to 1 day
<200 to 2000	[1] ALEKSEEV	76B	ELEC	τ=100 ms to 1 day
<1.4 to 9	[2] FRANKEL	75	CNTR	τ=50 ms to 10 hours
<0.1 to 9	[3] FRANKEL	74	CNTR	τ=1 to 1000 hours

[1] ALEKSEEV 76 and ALEKSEEV 76B are 61–70 GeV p Serpukhov experiment. Cross section is per Pb nucleus.
[2] FRANKEL 75 is extension of FRANKEL 74.
[3] FRANKEL 74 looks for particles produced in thick Al targets by 300–400 GeV/c protons.

Long-Lived Particle (LLP) Search at Hadron Collisions

Limits are for cross section times branching ratio.

VALUE (pb/nucleon)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] AAD	20D	ATLS	$pp \to$ LLPs at 13 TeV
	[2] AAD	20J	ATLS	scalar boson decay to LLPs
	[3] AAD	20M	ATLS	LLP top squark decay to μ
	[4] AAD	20P	ATLS	LLP dark photon search
	[5] AAIJ	20AL	LHCB	pp dimuon resonance
	[6] BALL	20		LLP milli-charged particles at LHC
	[7] AABOUD	19AE	ATLS	pp at 13 TeV
	[8] AABOUD	19AK	ATLS	$pp \to \Phi \to ZZ_d$
	[9] AABOUD	19AM	ATLS	DY multi-charged LLP production
	[10] AABOUD	19AO	ATLS	LLP via displaced jets
	[11] AABOUD	19AT	ATLS	heavy, charged LLPs
	[12] AABOUD	19G	ATLS	LLP decay to $\mu^+\mu^-$
	[13] SIRUNYAN	19BH	CMS	LLP via displaced jets
	[14] SIRUNYAN	19BT	CMS	LLP via displaced jets+MET
	[15] SIRUNYAN	19CA	CMS	LLP $\to \gamma$ search
	[16] SIRUNYAN	19Q	CMS	$pp \to j +$ displaced dark quark jet
	[17] SIRUNYAN	18AW	CMS	Long-lived particle search
	[18] AAIJ	16AR	LHCB	$H \to XX$ LLPs
	[19] KHACHATRY...	16BW	CMS	direct production: HSCPs
< 2 at 90%CL	[20] BADIER	86	BDMP	$\tau = (0.05–1.) \times 10^{-8}$s

[1] AAD 20D search for opposite-sign dileptons originating from long-lived particles in pp collisions at 13 Tev with 32.8 fb^{-1}; limits placed in squark cross section vs. $c\tau$ plane for RPV SUSY.

[2] AAD 20J search for scalar boson decay to two long-lived particles; no signal; limits placed in BF vs $c\tau$ plane for various mass hypotheses. This search is also combined with other ATLAS displaced-jet searches.

[3] AAD 20M search for long-lived top-squarks decay to μ and hadrons; no signal; limits placed in cross section vs. mass and mass vs. lifetime planes .

[4] AAD 20P search for long-lived dark photons produced from the decay of a scalar boson, with each dark photon decaying into displaced collimated leptons or light hadrons at 13 TeV with 36 fb^{-1}; no signal; limits placed in $\sigma \cdot$ BF vs. $c\tau$ and other planes.

[5] AAIJ 20AL search for long-lived $X \rightarrow \mu^+ \mu^-$ decays in 5.1 fb^{-1} of LHCb data at 13 TeV; no signal; limits placed on m(X) up to 3 GeV depending on kinetic mixing.

[6] BALL 20 search for long-lived milli-charged particles produced at LHC; limits placed in charge vs. mass plane (Fig. 8).

[7] AABOUD 19AE search for long-lived particles via displaced jets using 10.8 fb^{-1} or 33.0 fb^{-1} data (depending on a trigger) at 13 TeV; no signal found and limits set in branching ratio vs. decay length plane.

[8] AABOUD 19AK searches for long-lived particle Z_d via $pp \rightarrow \Phi \rightarrow Z Z_d$ at 13 TeV with 36.1 fb^{-1}; no signal found and limits set in $\sigma \times$BR vs. lifetime plane for simplified model.

[9] AABOUD 19AM search for Drell-Yan (DY) production of long-lived multi-charge particles at 13 TeV with 36.1 fb^{-1} of data; no signal found and exclude 50 GeV $<$ m(LLMCP) $<$ 980–1220 GeV for electric charge $|$q$|$ = (2–7)e.

[10] AABOUD 19AO search for neutral long-lived particles producing displaced jets at 13 TeV with 36.1 fb^{-1} of data; no signal found and exclude regions of $\sigma \cdot$ BR vs. lifetime plane for various models.

[11] AABOUD 19AT search for heavy, charged long-lived particles at 13 TeV with 36.1 fb^{-1}; no signal found and upper limits set on masses of various hypothetical particles.

[12] AABOUD 19G search for long-lived particle with decay to $\mu^+ \mu^-$ at 13 TeV with 32.9 fb^{-1}; no signal found and limits set in combinations of lifetime, mass and coupling planes for various simplified models.

[13] SIRUNYAN 19BH search for long-lived SUSY particles via displaced jets at 13 TeV with 35.9 fb^{-1}; no signal found and limits placed in mass vs lifetime plane for various hypothetical models.

[14] SIRUNYAN 19BT search for displaced jet(s)+$\not\!\!E_T$ at 13 TeV with 137 fb^{-1}; no signal found and limits placed in mass vs lifetime plane for gauge mediated SUSY breaking models.

[15] SIRUNYAN 19CA search for gluino/squark decay to long-lived neutralino, decay to γ in GMSB; no signal, limits placed in m(χ) vs. lifetime plane for SPS8 GMSB benchmark point .

[16] SIRUNYAN 19Q search for $pp \rightarrow j +$ displaced jet via dark quark with 13 TeV at 16.1 fb^{-1}; no signal found and limits set in mass vs lifetime plane for dark quark/dark pion model.

[17] SIRUNYAN 18AW search for very long lived particles (LLPs) decaying hadronically or to $\mu\overline{\mu}$ in CMS detector; none seen/limits set on lifetime vs. cross section.

[18] AAIJ 16AR search for long lived particles from $H \rightarrow XX$ with displaced X decay vertex using 0.62 fb^{-1} at 7 TeV; limits set in Fig. 7.

[19] KHACHATRYAN 16BW search for heavy stable charged particles via ToF with 2.5 fb^{-1} at 13 TeV; require stable m(gluinoball) $>$ 1610 GeV.

[20] BADIER 86 looked for long-lived particles at 300 GeV π^- beam dump. The limit applies for nonstrongly interacting neutral or charged particles with mass $>$2 GeV. The limit applies for particle modes, $\mu^+\pi^-$, $\mu^+\mu^-$, $\pi^+\pi^-$X, $\pi^+\pi^-\pi^\pm$ etc. See their figure 5 for the contours of limits in the mass-τ plane for each mode.

Long-Lived Heavy Particle Cross Section

VALUE (pb/sr)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<34	95	[1] RAM	94	SPEC	$1015 < m_{X^{++}} < 1085$ MeV
<75	95	[1] RAM	94	SPEC	$920 < m_{X^{++}} < 1025$ MeV

[1] RAM 94 search for a long-lived doubly-charged fermion X^{++} with mass between m_N and $m_N + m_\pi$ and baryon number +1 in the reaction $p p \to X^{++} n$. No candidate is found. The limit is for the cross section at 15° scattering angle at 460 MeV incident energy and applies for $\tau(X^{++}) \gg 0.1\,\mu$s.

LIMITS ON CHARGED PARTICLES IN COSMIC RAYS

Heavy Particle Flux in Cosmic Rays

VALUE ($\mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1}$)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
			[1] ALVIS	18	MAJD	Fractionally charged
$< 1 \times 10^{-8}$	90		[2] AGNESE	15	CDM2	$Q = 1/6$
$\sim 6 \times 10^{-9}$		2	[3] SAITO	90		$Q \simeq 14$, $m \simeq 370 m_p$
$< 1.4 \times 10^{-12}$	90	0	[4] MINCER	85	CALO	$m \geq 1$ TeV
			[5] SAKUYAMA	83B	PLAS	$m \sim 1$ TeV
$< 1.7 \times 10^{-11}$	99	0	[6] BHAT	82	CC	
$< 1. \times 10^{-9}$	90	0	[7] MARINI	82	CNTR	$Q = 1$, $m \sim 4.5 m_p$
$2. \times 10^{-9}$		3	[8] YOCK	81	SPRK	$Q = 1$, $m \sim 4.5 m_p$
		3	[8] YOCK	81	SPRK	Fractionally charged
3.0×10^{-9}		3	[9] YOCK	80	SPRK	$m \sim 4.5\, m_p$
$(4 \pm 1) \times 10^{-11}$		3	GOODMAN	79	ELEC	$m \geq 5$ GeV
$< 1.3 \times 10^{-9}$	90		[10] BHAT	78	CNTR	$m > 1$ GeV
$< 1.0 \times 10^{-9}$		0	BRIATORE	76	ELEC	
$< 7. \times 10^{-10}$	90	0	YOCK	75	ELEC	$Q > 7e$ or $< -7e$
$> 6. \times 10^{-9}$		5	[11] YOCK	74	CNTR	$m > 6$ GeV
$< 3.0 \times 10^{-8}$		0	DARDO	72	CNTR	
$< 1.5 \times 10^{-9}$		0	TONWAR	72	CNTR	$m > 10$ GeV
$< 3.0 \times 10^{-10}$		0	BJORNBOE	68	CNTR	$m > 5$ GeV
$< 5.0 \times 10^{-11}$	90	0	JONES	67	ELEC	$m = 5$–15 GeV

[1] ALVIS 18 search for fractional charged flux of cosmic matter at Majorana demonstrator; no signal observed and limits are set on the flux of lightly ionizing particles for charge as low as e/1000.

[2] See AGNESE 15 Fig. 6 for limits extending down to Q = 1/200.

[3] SAITO 90 candidates carry about 450 MeV/nucleon. Cannot be accounted for by conventional backgrounds. Consistent with strange quark matter hypothesis.

[4] MINCER 85 is high statistics study of calorimeter signals delayed by 20–200 ns. Calibration with AGS beam shows they can be accounted for by rare fluctuations in signals from low-energy hadrons in the shower. Claim that previous delayed signals including BJORNBOE 68, DARDO 72, BHAT 82, SAKUYAMA 83B below may be due to this fake effect.

[5] SAKUYAMA 83B analyzed 6000 extended air shower events. Increase of delayed particles and change of lateral distribution above 10^{17} eV may indicate production of very heavy parent at top of atmosphere.

[6] BHAT 82 observed 12 events with delay $> 2. \times 10^{-8}$ s and with more than 40 particles. 1 eV has good hadron shower. However all events are delayed in only one of two detectors in cloud chamber, and could not be due to strongly interacting massive particle.
[7] MARINI 82 applied PEP-counter for TOF. Above limit is for velocity = 0.54 of light. Limit is inconsistent with YOCK 80 YOCK 81 events if isotropic dependence on zenith angle is assumed.
[8] YOCK 81 saw another 3 events with $Q = \pm 1$ and m about $4.5 m_p$ as well as 2 events with $m > 5.3 m_p$, $Q = \pm 0.75 \pm 0.05$ and $m > 2.8 m_p$, $Q = \pm 0.70 \pm 0.05$ and 1 event with $m = (9.3 \pm 3.) m_p$, $Q = \pm 0.89 \pm 0.06$ as possible heavy candidates.
[9] YOCK 80 events are with charge exactly or approximately equal to unity.
[10] BHAT 78 is at Kolar gold fields. Limit is for $\tau > 10^{-6}$ s.
[11] YOCK 74 events could be tritons.

Superheavy Particle (Quark Matter) Flux in Cosmic Rays

VALUE ($cm^{-2} sr^{-1} s^{-1}$)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] ADRIANI	15	PMLA	$4 < m < 1.2 \times 10^5$ m_p
$<5 \times 10^{-16}$	90	[2] AMBROSIO	00B	MCRO	$m > 5 \times 10^{14}$ GeV
$<1.8 \times 10^{-12}$	90	[3] ASTONE	93	CNTR	$m \geq 1.5 \times 10^{-13}$gram
$<1.1 \times 10^{-14}$	90	[4] AHLEN	92	MCRO	$10^{-10} < m < 0.1$ gram
$<2.2 \times 10^{-14}$	90	[5] NAKAMURA	91	PLAS	$m > 10^{11}$ GeV
$<6.4 \times 10^{-16}$	90	[6] ORITO	91	PLAS	$m > 10^{12}$ GeV
$<2.0 \times 10^{-11}$	90	[7] LIU	88	BOLO	$m > 1.5 \times 10^{-13}$ gram
$<4.7 \times 10^{-12}$	90	[8] BARISH	87	CNTR	$1.4 \times 10^8 < m < 10^{12}$ GeV
$<3.2 \times 10^{-11}$	90	[9] NAKAMURA	85	CNTR	$m > 1.5 \times 10^{-13}$gram
$<3.5 \times 10^{-11}$	90	[10] ULLMAN	81	CNTR	Planck-mass 10^{19}GeV
$<7. \times 10^{-11}$	90	[10] ULLMAN	81	CNTR	$m \leq 10^{16}$ GeV

[1] ADRIANI 15 search for relatively light quark matter with charge $Z = 1$–8. See their Figs. 2 and 3 for flux upper limits.
[2] AMBROSIO 00B searched for quark matter ("nuclearites") in the velocity range $(10^{-5}$–$1)$ c. The listed limit is for 2×10^{-3} c.
[3] ASTONE 93 searched for quark matter ("nuclearites") in the velocity range $(10^{-3}$–$1)$ c. Their Table 1 gives a compilation of searches for nuclearites.
[4] AHLEN 92 searched for quark matter ("nuclearites"). The bound applies to velocity $< 2.5 \times 10^{-3}$ c. See their Fig. 3 for other velocity/c and heavier mass range.
[5] NAKAMURA 91 searched for quark matter in the velocity range $(4 \times 10^{-5}$–$1)$ c.
[6] ORITO 91 searched for quark matter. The limit is for the velocity range $(10^{-4}$–$10^{-3})$ c.
[7] LIU 88 searched for quark matter ("nuclearites") in the velocity range $(2.5 \times 10^{-3}$–$1)c$. A less stringent limit of 5.8×10^{-11} applies for $(1$–$2.5) \times 10^{-3} c$.
[8] BARISH 87 searched for quark matter ("nuclearites") in the velocity range $(2.7 \times 10^{-4}$–$5 \times 10^{-3})c$.
[9] NAKAMURA 85 at KEK searched for quark-matter. These might be lumps of strange quark matter with roughly equal numbers of u, d, s quarks. These lumps or nuclearites were assumed to have velocity of $(10^{-4}$–$10^{-3})$ c.
[10] ULLMAN 81 is sensitive for heavy slow singly charge particle reaching earth with vertical velocity 100–350 km/s.

Highly Ionizing Particle Flux

VALUE ($m^{-2}yr^{-1}$)	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.4	95	0	KINOSHITA 81B	PLAS	Z/β 30–100

SEARCHES FOR BLACK HOLE PRODUCTION

VALUE	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
not seen	[1] AABOUD 16P	ATLS	13 TeV $pp \rightarrow e\mu, e\tau, \mu\tau$
	[2] AAD 15AN	ATLS	8 TeV $pp \rightarrow$ multijets
	[3] AAD 14A	ATLS	8 TeV $pp \rightarrow \gamma +$ jet
	[4] AAD 14AL	ATLS	8 TeV $pp \rightarrow \ell +$ jet
	[5] AAD 14C	ATLS	8 TeV $pp \rightarrow \ell + (\ell$ or jets)
	[6] AAD 13D	ATLS	7 TeV $pp \rightarrow 2$ jets
	[7] CHATRCHYAN 13A	CMS	7 TeV $pp \rightarrow 2$ jets
	[8] CHATRCHYAN 13AD	CMS	8 TeV $pp \rightarrow$ multijets
	[9] AAD 12AK	ATLS	7 TeV $pp \rightarrow \ell + (\ell$ or jets)
	[10] CHATRCHYAN 12W	CMS	7 TeV $pp \rightarrow$ multijets
	[11] AAD 11AG	ATLS	7 TeV $pp \rightarrow 2$ jets

[1] AABOUD 16P set limits on quantum BH production in n = 6 ADD or n = 1 RS models.

[2] AAD 15AN search for black hole or string ball formation followed by its decay to multijet final states, in pp collisions at E_{cm} = 8 TeV with L = 20.3 fb^{-1}. See their Figs. 6–8 for limits.

[3] AAD 14A search for quantum black hole formation followed by its decay to a γ and a jet, in pp collisions at E_{cm} = 8 TeV with L = 20 fb^{-1}. See their Fig. 3 for limits.

[4] AAD 14AL search for quantum black hole formation followed by its decay to a lepton and a jet, in pp collisions at E_{cm} = 8 TeV with L = 20.3 fb^{-1}. See their Fig. 2 for limits.

[5] AAD 14C search for microscopic (semiclassical) black hole formation followed by its decay to final states with a lepton and $\geq$ 2 (leptons or jets), in pp collisions at E_{cm} = 8 TeV with L = 20.3 fb^{-1}. See their Figures 8–11, Tables 7, 8 for limits.

[6] AAD 13D search for quantum black hole formation followed by its decay to two jets, in pp collisions at E_{cm} = 7 TeV with L = 4.8 fb^{-1}. See their Fig. 8 and Table 3 for limits.

[7] CHATRCHYAN 13A search for quantum black hole formation followed by its decay to two jets, in pp collisions at E_{cm} = 7 TeV with L = 5 fb^{-1}. See their Figs. 5 and 6 for limits.

[8] CHATRCHYAN 13AD search for microscopic (semiclassical) black hole formation followed by its evapolation to multiparticle final states, in multijet (including γ, ℓ) events in pp collisions at E_{cm} = 8 TeV with L = 12 fb^{-1}. See their Figs. 5–7 for limits.

[9] AAD 12AK search for microscopic (semiclassical) black hole formation followed by its decay to final states with a lepton and $\geq$ 2 (leptons or jets), in pp collisions at E_{cm} = 7 TeV with L = 1.04 fb^{-1}. See their Fig. 4 and 5 for limits.

[10] CHATRCHYAN 12W search for microscopic (semiclassical) black hole formation followed by its evapolation to multiparticle final states, in multijet (including γ, ℓ) events in pp collisions at E_{cm} = 7 TeV with L = 4.7 fb^{-1}. See their Figs. 5–8 for limits.

[11] AAD 11AG search for quantum black hole formation followed by its decay to two jets, in pp collisions at E_{cm} = 7 TeV with L = 36 pb^{-1}. See their Fig. 11 and Table 4 for limits.

REFERENCES FOR Other Particle Searches

AAD	20AD	PRL 125 131801	G. Aad *et al.*	(ATLAS Collab.)
AAD	20D	PL B801 135114	G. Aad *et al.*	(ATLAS Collab.)
AAD	20J	PR D101 052013	G. Aad *et al.*	(ATLAS Collab.)
AAD	20M	PR D102 032006	G. Aad *et al.*	(ATLAS Collab.)
AAD	20P	EPJ C80 450	G. Aad *et al.*	(ATLAS Collab.)
AAD	20T	JHEP 2003 145	G. Aad *et al.*	(ATLAS Collab.)
AAD	20W	JHEP 2006 151	G. Aad *et al.*	(ATLAS Collab.)
AAIJ	20AL	JHEP 2010 156	R. Aaij *et al.*	(LHCb Collab.)
AGUILAR-AR...	20B	JHEP 2004 054	A. Aguilar-Arevalo *et al.*	(CONNIE Collab.)
BALL	20	PR D102 032002	A.H. Ball *et al.*	(milliQan)
FEDDERKE	20	PR D101 115021	M.A. Fedderke, P.W. Graham, S. Rajendran	(STAN+)
SIRUNYAN	20A	EPJ C80 3	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	20AI	JHEP 2005 033	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	20AY	PL B808 135578	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	20C	EPJ C80 75	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	20N	PL B806 135502	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	20Z	JHEP 2003 051	A.M. Sirunyan *et al.*	(CMS Collab.)
AABOUD	19AA	EPJ C79 120	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19AE	EPJ C79 481	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19AJ	PL B795 56	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19AK	PRL 122 151801	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19AM	PR D99 052003	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19AO	PR D99 052005	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19AT	PR D99 092007	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19G	PR D99 012001	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19H	PR D99 012008	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19Q	JHEP 1905 041	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19V	JHEP 1905 142	M. Aaboud *et al.*	(ATLAS Collab.)
ALCANTARA	19	PR D99 103016	E. Alcantara, L.A. Anchordoqui, J.F. Soriano	
SIRUNYAN	19B	PR D99 012005	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19BH	PR D99 032011	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19BT	PL B797 134876	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19CA	PR D100 112003	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19CD	PRL 123 231803	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19O	JHEP 1902 074	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19Q	JHEP 1902 179	A.M. Sirunyan *et al.*	(CMS Collab.)
AABOUD	18AD	PL B779 24	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18CJ	PR D98 052008	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18CK	PR D98 092002	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18CL	PR D98 092005	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18CM	PR D98 092008	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18N	PRL 121 081801	M. Aaboud *et al.*	(ATLAS Collab.)
AAIJ	18AJ	PRL 120 061801	R. Aaij *et al.*	(LHCb Collab.)
ALBERT	18C	PR D98 123012	A. Albert *et al.*	(HAWC Collab.)
ALVIS	18	PRL 120 211804	S.I. Alvis *et al.*	(MAJORANA Collab.)
BANERJEE	18	PRL 120 231802	D. Banerjee *et al.*	(NA64 Collab.)
BANERJEE	18A	PR D97 072002	D. Banerjee *et al.*	(NA64 Collab.)
KILE	18	JHEP 1810 116	J. Kile, J. von Wimmersperg-Toeller	(LISBT)
MARSICANO	18	PR D98 015031	L. Marsicano *et al.*	
PORAYKO	18	PR D98 102002	N.K. Porayako *et al.*	(PPTA Collab.)
SIRUNYAN	18AW	JHEP 1805 127	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18BB	JHEP 1806 120	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18DA	JHEP 1811 042	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18DD	EPJ C78 789	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18DJ	JHEP 1809 101	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18DR	JHEP 1811 161	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18DU	PR D98 092001	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18DY	PR D98 112014	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18ED	JHEP 1811 172	A.M. Sirunyan *et al.*	(CMS Collab.)
AABOUD	17B	PL B765 32	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	17D	PR D95 032001	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	17L	JHEP 1708 052	M. Aaboud *et al.*	(ATLAS Collab.)
AAIJ	17BR	EPJ C77 812	R. Aaij *et al.*	(LHCb Collab.)
ABLIKIM	17AA	PL B774 252	M. Ablikim *et al.*	(BESIII Collab.)
KHACHATRY...	17D	JHEP 1701 076	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	17W	PL B769 520	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	17Y	PL B770 257	V. Khachatryan *et al.*	(CMS Collab.)
SIRUNYAN	17B	JHEP 1704 136	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	17C	JHEP 1705 029	A.M. Sirunyan *et al.*	(CMS Collab.)

SIRUNYAN	17F	JHEP 1707 013	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	17J	JHEP 1708 073	A.M. Sirunyan *et al.*	(CMS Collab.)
ZANG	17	PL B773 159	X. Zang, G.A. Miller	(WASH)
AABOUD	16	PL B759 229	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	16P	EPJ C76 541	M. Aaboud *et al.*	(ATLAS Collab.)
AAD	16AI	JHEP 1603 041	G. Aad *et al.*	(ATLAS Collab.)
AAD	16N	JHEP 1603 026	G. Aad *et al.*	(ATLAS Collab.)
AAD	16O	PL B760 520	G. Aad *et al.*	(ATLAS Collab.)
AAD	16R	PL B755 285	G. Aad *et al.*	(ATLAS Collab.)
AAD	16S	PL B754 302	G. Aad *et al.*	(ATLAS Collab.)
AAIJ	16AR	EPJ C76 664	R. Aaij *et al.*	(LHCb Collab.)
KHACHATRY...	16BW	PR D94 112004	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16K	PRL 116 071801	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16L	PRL 117 031802	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16M	PRL 117 051802	V. Khachatryan *et al.*	(CMS Collab.)
KRASZNAHO...	16	PRL 116 042501	A.J. Krasznahorkay *et al.*	(HINR, ANIK+)
AAD	15AN	JHEP 1507 032	G. Aad *et al.*	(ATLAS Collab.)
AAD	15AT	EPJ C75 79	G. Aad *et al.*	(ATLAS Collab.)
AAD	15BJ	EPJ C75 362	G. Aad *et al.*	(ATLAS Collab.)
AAIJ	15BD	EPJ C75 595	R. Aaij *et al.*	(LHCb Collab.)
ADRIANI	15	PRL 115 111101	O. Adriani *et al.*	(PAMELA Collab.)
AGNESE	15	PRL 114 111302	R. Agnese *et al.*	(CDMS Collab.)
KHACHATRY...	15F	PRL 114 101801	V. Khachatryan *et al.*	(CMS Collab.)
LEES	15E	PRL 114 171801	J.P. Lees *et al.*	(BABAR Collab.)
AAD	14A	PL B728 562	G. Aad *et al.*	(ATLAS Collab.)
AAD	14AL	PRL 112 091804	G. Aad *et al.*	(ATLAS Collab.)
AAD	14C	JHEP 1408 103	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	14J	PR D89 092001	T. Aaltonen *et al.*	(CDF Collab.)
AAD	13A	PL B718 860	G. Aad *et al.*	(ATLAS Collab.)
AAD	13AH	PL B722 305	G. Aad *et al.*	(ATLAS Collab.)
AAD	13C	PRL 110 011802	G. Aad *et al.*	(ATLAS Collab.)
AAD	13D	JHEP 1301 029	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	13I	PR D88 031103	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	13R	PRL 111 031802	T. Aaltonen *et al.*	(CDF Collab.)
CHATRCHYAN	13	PL B718 815	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13A	JHEP 1301 013	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13AB	JHEP 1307 122	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13AD	JHEP 1307 178	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13AR	PR D87 092008	S. Chatrchyan *et al.*	(CMS Collab.)
AAD	12AK	PL B716 122	G. Aad *et al.*	(ATLAS Collab.)
AAD	12C	PRL 108 041805	G. Aad *et al.*	(ATLAS Collab.)
AAD	12S	PL B708 37	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	12M	PRL 108 211804	T. Aaltonen *et al.*	(CDF Collab.)
CHATRCHYAN	12AP	JHEP 1209 094	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12BL	JHEP 1212 015	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12Q	PL B716 260	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12T	PRL 108 261803	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12W	JHEP 1204 061	S. Chatrchyan *et al.*	(CMS Collab.)
AAD	11AG	NJP 13 053044	G. Aad *et al.*	(ATLAS Collab.)
AAD	11I	PL B698 353	G. Aad *et al.*	(ATLAS Collab.)
AAD	11S	PL B705 294	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	11AF	PRL 107 181801	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	11M	PRL 106 171801	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	11I	PRL 107 011804	V.M. Abazov *et al.*	(D0 Collab.)
CHATRCHYAN	11C	JHEP 1106 026	S. Chatychyan *et al.*	(CMS Collab.)
CHATRCHYAN	11U	PRL 107 201804	S. Chatychyan *et al.*	(CMS Collab.)
AAD	10	PRL 105 161801	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	10AF	PR D82 052005	T. Aaltonen *et al.*	(CDF Collab.)
KHACHATRY...	10	PRL 105 211801	V. Khachatryan *et al.*	(CMS Collab.)
Also		PRL 106 029902	V. Khachatryan *et al.*	(CMS Collab.)
AALTONEN	09AF	PR D80 011102	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	09G	PR D79 052004	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	09Z	PRL 103 021802	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	09M	PRL 102 161802	V.M. Abazov *et al.*	(D0 Collab.)
AKTAS	04C	EPJ C36 413	A. Atkas *et al.*	(H1 Collab.)
JAVORSEK	02	PR D65 072003	D. Javorsek II *et al.*	
JAVORSEK	01	PR D64 012005	D. Javorsek II *et al.*	
JAVORSEK	01B	PRL 87 231804	D. Javorsek II *et al.*	
ABBIENDI	00D	EPJ C13 197	G. Abbiendi *et al.*	(OPAL Collab.)
AMBROSIO	00B	EPJ C13 453	M. Ambrosio *et al.*	(MACRO Collab.)
ABE	99F	PRL 82 2038	F. Abe *et al.*	(CDF Collab.)

ACKERSTAFF 98P PL B433 195 K. Ackerstaff *et al.* (OPAL Collab.)
ABE 97G PR D55 5263 F. Abe *et al.* (CDF Collab.)
ABREU 97D PL B396 315 P. Abreu *et al.* (DELPHI Collab.)
ACKERSTAFF 97B PL B391 210 K. Ackerstaff *et al.* (OPAL Collab.)
ADAMS 97B PRL 79 4083 J. Adams *et al.* (FNAL KTeV Collab.)
BARATE 97K PL B405 379 R. Barate *et al.* (ALEPH Collab.)
AKERS 95R ZPHY C67 203 R. Akers *et al.* (OPAL Collab.)
GALLAS 95 PR D52 6 E. Gallas *et al.* (MSU, FNAL, MIT, FLOR)
RAM 94 PR D49 3120 S. Ram *et al.* (TELA, TRIU)
ABE 93G PRL 71 2542 F. Abe *et al.* (CDF Collab.)
ASTONE 93 PR D47 4770 P. Astone *et al.* (ROMA, ROMAI, CATA, FRAS)
BUSKULIC 93C PL B303 198 D. Buskulic *et al.* (ALEPH Collab.)
YAMAGATA 93 PR D47 1231 T. Yamagata, Y. Takamori, H. Utsunomiya (KONAN)
ABE 92J PR D46 1889 F. Abe *et al.* (CDF Collab.)
AHLEN 92 PRL 69 1860 S.P. Ahlen *et al.* (MACRO Collab.)
VERKERK 92 PRL 68 1116 P. Verkerk *et al.* (ENSP, SACL, PAST)
AKESSON 91 ZPHY C52 219 T. Akesson *et al.* (HELIOS Collab.)
NAKAMURA 91 PL B263 529 S. Nakamura *et al.*
ORITO 91 PRL 66 1951 S. Orito *et al.* (ICEPP, WASCR, NIHO, ICRR)
ADACHI 90C PL B244 352 I. Adachi *et al.* (TOPAZ Collab.)
ADACHI 90E PL B249 336 I. Adachi *et al.* (TOPAZ Collab.)
AKRAWY 90O PL B252 290 M.Z. Akrawy *et al.* (OPAL Collab.)
HEMMICK 90 PR D41 2074 T.K. Hemmick *et al.* (ROCH, MICH, OHIO+)
SAITO 90 PRL 65 2094 T. Saito *et al.* (ICRR, KOBE)
NAKAMURA 89 PR D39 1261 T.T. Nakamura *et al.* (KYOT, TMTC)
NORMAN 89 PR D39 2499 E.B. Norman *et al.* (LBL)
BERNSTEIN 88 PR D37 3103 R.M. Bernstein *et al.* (STAN, WISC)
LIU 88 PRL 61 271 G. Liu, B. Barish
BARISH 87 PR D36 2641 B.C. Barish, G. Liu, C. Lane (CIT)
NORMAN 87 PRL 58 1403 E.B. Norman, S.B. Gazes, D.A. Bennett (LBL)
BADIER 86 ZPHY C31 21 J. Badier *et al.* (NA3 Collab.)
MINCER 85 PR D32 541 A. Mincer *et al.* (UMD, GMAS, NSF)
NAKAMURA 85 PL 161B 417 K. Nakamura *et al.* (KEK, INUS)
THRON 85 PR D31 451 J.L. Thron *et al.* (YALE, FNAL, IOWA)
SAKUYAMA 83B LNC 37 17 H. Sakuyama, N. Suzuki (MEIS)
Also LNC 36 389 H. Sakuyama, K. Watanabe (MEIS)
Also NC 78A 147 H. Sakuyama, K. Watanabe (MEIS)
Also NC 6C 371 H. Sakuyama, K. Watanabe (MEIS)
BHAT 82 PR D25 2820 P.N. Bhat *et al.* (TATA)
KINOSHITA 82 PRL 48 77 K. Kinoshita, P.B. Price, D. Fryberger (UCB+)
MARINI 82 PR D26 1777 A. Marini *et al.* (FRAS, LBL, NWES, STAN+)
SMITH 82B NP B206 333 P.F. Smith *et al.* (RAL)
KINOSHITA 81B PR D24 1707 K. Kinoshita, P.B. Price (UCB)
LOSECCO 81 PL 102B 209 J.M. LoSecco *et al.* (MICH, PENN, BNL)
ULLMAN 81 PRL 47 289 J.D. Ullman (LEHM, BNL)
YOCK 81 PR D23 1207 P.C.M. Yock (AUCK)
BARTEL 80 ZPHY C6 295 W. Bartel *et al.* (JADE Collab.)
BUSSIERE 80 NP B174 1 A. Bussiere *et al.* (BGNA, SACL, LAPP)
YOCK 80 PR D22 61 P.C.M. Yock (AUCK)
ARMITAGE 79 NP B150 87 J.C.M. Armitage *et al.* (CERN, DARE, FOM+)
BOZZOLI 79 NP B159 363 W. Bozzoli *et al.* (BGNA, LAPP, SACL+)
GOODMAN 79 PR D19 2572 J.A. Goodman *et al.* (UMD)
SMITH 79 NP B149 525 P.F. Smith, J.R.J. Bennett (RHEL)
BHAT 78 PRAM 10 115 P.N. Bhat, P.V. Ramana Murthy (TATA)
CARROLL 78 PRL 41 777 A.S. Carroll *et al.* (BNL, PRIN)
CUTTS 78 PRL 41 363 D. Cutts *et al.* (BROW, FNAL, ILL, BARI+)
VIDAL 78 PL 77B 344 R.A. Vidal *et al.* (COLU, FNAL, STON+)
ALEKSEEV 76 SJNP 22 531 G.D. Alekseev *et al.* (JINR)
Translated from YAF 22 1021.
ALEKSEEV 76B SJNP 23 633 G.D. Alekseev *et al.* (JINR)
Translated from YAF 23 1190.
BALDIN 76 SJNP 22 264 B.Y. Baldin *et al.* (JINR)
Translated from YAF 22 512.
BRIATORE 76 NC 31A 553 L. Briatore *et al.* (LCGT, FRAS, FREIB)
GUSTAFSON 76 PRL 37 474 H.R. Gustafson *et al.* (MICH)
ALBROW 75 NP B97 189 M.G. Albrow *et al.* (CERN, DARE, FOM+)
FRANKEL 75 PR D12 2561 S. Frankel *et al.* (PENN, FNAL)
JOVANOV... 75 PL 56B 105 J.V. Jovanovich *et al.* (MANI, AACH, CERN+)
YOCK 75 NP B86 216 P.C.M. Yock (AUCK, SLAC)
APPEL 74 PRL 32 428 J.A. Appel *et al.* (COLU, FNAL)
FRANKEL 74 PR D9 1932 S. Frankel *et al.* (PENN, FNAL)
YOCK 74 NP B76 175 P.C.M. Yock (AUCK)

ALPER	73	PL 46B 265	B. Alper *et al.*	(CERN, LIVP, LUND, BOHR+)
LEIPUNER	73	PRL 31 1226	L.B. Leipuner *et al.*	(BNL, YALE)
DARDO	72	NC 9A 319	M. Dardo *et al.*	(TORI)
TONWAR	72	JP A5 569	S.C. Tonwar, S. Naranan, B.V. Sreekantan	(TATA)
ANTIPOV	71B	NP B31 235	Y.M. Antipov *et al.*	(SERP)
ANTIPOV	71C	PL 34B 164	Y.M. Antipov *et al.*	(SERP)
BINON	69	PL 30B 510	F.G. Binon *et al.*	(SERP)
BJORNBOE	68	NC B53 241	J. Bjornboe *et al.*	(BOHR, TATA, BERN+)
JONES	67	PR 164 1584	L.W. Jones	(MICH, WISC, LBL, UCLA, MINN+)
DORFAN	65	PRL 14 999	D.E. Dorfan *et al.*	(COLU)