Quark and Lepton Compositeness, Searches for

The latest unpublished results are described in the "Quark and Lepton Compositeness" review.

See the related review(s):

Searches for Quark and Lepton Compositeness

CONTENTS:

Scale Limits for Contact Interactions: $\Lambda(eeee)$
Scale Limits for Contact Interactions: $\Lambda(ee\mu\mu)$
Scale Limits for Contact Interactions: $\Lambda(ee\tau\tau)$
Scale Limits for Contact Interactions: $\Lambda(\ell\ell\ell\ell)$
Scale Limits for Contact Interactions: $\Lambda(eeqq)$
Scale Limits for Contact Interactions: $\Lambda(\mu\mu qq)$
Scale Limits for Contact Interactions: $\Lambda(\ell\nu\ell\nu)$
Scale Limits for Contact Interactions: $\Lambda(e\nu qq)$
Scale Limits for Contact Interactions: $\Lambda(qqqq)$
Scale Limits for Contact Interactions: $\Lambda(\nu\nu qq)$
Mass Limits for Excited e (e^*)
– Limits for Excited e (e^*) from Pair Production
– Limits for Excited e (e^*) from Single Production
– Limits for Excited e (e^*) from $e^+e^- \rightarrow \gamma\gamma$
– Indirect Limits for Excited e (e^*)
Mass Limits for Excited μ (μ^*)
– Limits for Excited μ (μ^*) from Pair Production
– Limits for Excited μ (μ^*) from Single Production
– Indirect Limits for Excited μ (μ^*)
Mass Limits for Excited τ (τ^*)
– Limits for Excited τ (τ^*) from Pair Production
– Limits for Excited τ (τ^*) from Single Production
Mass Limits for Excited Neutrino (ν^*)
– Limits for Excited ν (ν^*) from Pair Production
– Limits for Excited ν (ν^*) from Single Production
Mass Limits for Excited q (q^*)
– Limits for Excited q (q^*) from Pair Production
– Limits for Excited q (q^*) from Single Production
Mass Limits for Color Sextet Quarks (q_6)
Mass Limits for Color Octet Charged Leptons (ℓ_8)
Mass Limits for Color Octet Neutrinos (ν_8)
Mass Limits for W_8 (Color Octet W Boson)

SCALE LIMITS for Contact Interactions: $\Lambda(eeee)$

Limits are for $\Lambda^{\pm}_{LL}$ only. For other cases, see each reference.

Λ^{+}_{LL}(TeV)	Λ^{-}_{LL}(TeV)	CL%	DOCUMENT ID	TECN	COMMENT
>8.3	**>10.3**	95	[1] BOURILKOV 01	RVUE	E_{cm}= 192–208 GeV

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

>4.5	>7.0	95	[2] SCHAEL	07A	ALEP	E_{cm}= 189–209 GeV
>5.3	>6.8	95	ABDALLAH	06C	DLPH	E_{cm}= 130–207 GeV
>4.7	>6.1	95	[3] ABBIENDI	04G	OPAL	E_{cm}= 130–207 GeV
>4.3	>4.9	95	ACCIARRI	00P	L3	E_{cm}= 130–189 GeV

[1] A combined analysis of the data from ALEPH, DELPHI, L3, and OPAL.

[2] SCHAEL 07A limits are from R_c, Q_{FB}^{depl}, and hadronic cross section measurements.

[3] ABBIENDI 04G limits are from $e^+ e^- \rightarrow e^+ e^-$ cross section at $\sqrt{s} = 130$–207 GeV.

SCALE LIMITS for Contact Interactions: Λ($ee\mu\mu$)

Limits are for $\Lambda^{\pm}_{LL}$ only. For other cases, see each reference.

Λ^+_{LL}(TeV)	Λ^-_{LL}(TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>6.6	**>9.5**	95	[1] SCHAEL	07A	ALEP	E_{cm}= 189–209 GeV
> 8.5	>3.8	95	ACCIARRI	00P	L3	E_{cm}= 130–189 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
>7.3	>7.6	95	ABDALLAH	06C	DLPH	E_{cm}= 130–207 GeV
>8.1	>7.3	95	[2] ABBIENDI	04G	OPAL	E_{cm}= 130–207 GeV

[1] SCHAEL 07A limits are from R_c, Q_{FB}^{depl}, and hadronic cross section measurements.

[2] ABBIENDI 04G limits are from $e^+ e^- \rightarrow \mu\mu$ cross section at $\sqrt{s} = 130$–207 GeV.

SCALE LIMITS for Contact Interactions: Λ($ee\tau\tau$)

Limits are for $\Lambda^{\pm}_{LL}$ only. For other cases, see each reference.

Λ^+_{LL}(TeV)	Λ^-_{LL}(TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>7.9	>5.8	95	[1] SCHAEL	07A	ALEP	E_{cm}= 189–209 GeV
>7.9	>4.6	95	ABDALLAH	06C	DLPH	E_{cm}= 130–207 GeV
>4.9	**>7.2**	95	[2] ABBIENDI	04G	OPAL	E_{cm}= 130–207 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
>5.4	>4.7	95	ACCIARRI	00P	L3	E_{cm}= 130–189 GeV

[1] SCHAEL 07A limits are from R_c, Q_{FB}^{depl}, and hadronic cross section measurements.

[2] ABBIENDI 04G limits are from $e^+ e^- \rightarrow \tau\tau$ cross section at $\sqrt{s} = 130$–207 GeV.

SCALE LIMITS for Contact Interactions: Λ($\ell\ell\ell\ell$)

Lepton universality assumed. Limits are for $\Lambda^{\pm}_{LL}$ only. For other cases, see each reference.

Λ^+_{LL}(TeV)	Λ^-_{LL}(TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>7.9	**> 10.3**	95	[1] SCHAEL	07A	ALEP	E_{cm}= 189–209 GeV
>9.1	>8.2	95	ABDALLAH	06C	DLPH	E_{cm}= 130–207 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
>7.7	>9.5	95	[2] ABBIENDI	04G	OPAL	E_{cm}= 130–207 GeV
			[3] BABICH	03	RVUE	
>9.0	>5.2	95	ACCIARRI	00P	L3	E_{cm}= 130–189 GeV

[1] SCHAEL 07A limits are from R_c, Q^{depl}_{FB}, and hadronic cross section measurements.
[2] ABBIENDI 04G limits are from $e^+ e^- \rightarrow \ell^+ \ell^-$ cross section at $\sqrt{s}$ = 130–207 GeV.
[3] BABICH 03 obtain a bound -0.175 TeV^{-2} $<1/\Lambda^2_{LL} <$ 0.095 TeV^{-2} (95%CL) in a model independent analysis allowing all of Λ_{LL}, Λ_{LR}, Λ_{RL}, Λ_{RR} to coexist.

SCALE LIMITS for Contact Interactions: $\Lambda(eeqq)$

Limits are for $\Lambda^{\pm}_{LL}$ only. For other cases, see each reference.

Λ^+_{LL}(TeV)	Λ^-_{LL}(TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>24	**>37**	95	[1] AABOUD	17AT	ATLS	($eeqq$)
> 8.4	**>10.2**	95	[2] ABDALLAH	09	DLPH	($eebb$)
> 9.4	**>5.6**	95	[3] SCHAEL	07A	ALEP	($eecc$)
> 9.4	>4.9	95	[2] SCHAEL	07A	ALEP	($eebb$)
>23.3	**>12.5**	95	[4] CHEUNG	01B	RVUE	($eeuu$)
>11.1	**>26.4**	95	[4] CHEUNG	01B	RVUE	($eedd$)

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

>15.5	>19.5	95	[5] AABOUD	16U	ATLS	($eeqq$)
>13.5	>18.3	95	[6] KHACHATRY...	15AE	CMS	($eeqq$)
>16.4	>20.7	95	[7] AAD	14BE	ATLS	($eeqq$)
> 9.5	>12.1	95	[8] AAD	13E	ATLS	($eeqq$)
>10.1	>9.4	95	[9] AAD	12AB	ATLS	($eeqq$)
> 4.2	>4.0	95	[10] AARON	11C	H1	($eeqq$)
> 3.8	>3.8	95	[11] ABDALLAH	11	DLPH	($eetc$)
>12.9	>7.2	95	[12] SCHAEL	07A	ALEP	($eeqq$)
> 3.7	>5.9	95	[13] ABULENCIA	06L	CDF	($eeqq$)

[1] AABOUD 17AT limits are from pp collisions at $\sqrt{s}$ = 13 TeV. The quoted limit uses a uniform positive prior in $1/\Lambda^2$.
[2] ABDALLAH 09 and SCHAEL 07A limits are from R_b, A^b_{FB}.
[3] SCHAEL 07A limits are from R_c, Q^{depl}_{FB}, and hadronic cross section measurements.
[4] CHEUNG 01B is an update of BARGER 98E.
[5] AABOUD 16U limits are from pp collisions at $\sqrt{s}$ = 13 TeV. The quoted limit uses a uniform positive prior in $1/\Lambda^2$.
[6] KHACHATRYAN 15AE limit is from $e^+ e^-$ mass distribution in pp collisions at $E_{\rm cm}$ = 8 TeV.
[7] AAD 14BE limits are from pp collisions at $\sqrt{s}$ = 8 TeV. The quoted limit uses a uniform positive prior in $1/\Lambda^2$.
[8] AAD 13E limis are from $e^+ e^-$ mass distribution in pp collisions at $E_{\rm cm}$ = 7 TeV.
[9] AAD 12AB limis are from $e^+ e^-$ mass distribution in pp collisions at $E_{\rm cm}$ = 7 TeV.
[10] AARON 11C limits are from Q^2 spectrum measurements of $e^{\pm} p \rightarrow e^{\pm} X$.
[11] ABDALLAH 11 limit is from $e^+ e^- \rightarrow t \overline{c}$ cross section. $\Lambda_{LL} = \Lambda_{LR} = \Lambda_{RL} = \Lambda_{RR}$ is assumed.
[12] SCHAEL 07A limit assumes quark flavor universality of the contact interactions.
[13] ABULENCIA 06L limits are from $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV.

SCALE LIMITS for Contact Interactions: $\Lambda(\mu\mu qq)$

Λ^+_{LL}(TeV)	Λ^-_{LL}(TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>20	**>30**	95	[1] AABOUD	17AT	ATLS	($\mu\mu qq$)

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

>15.8	>21.8	95	[2] AABOUD	16U	ATLS	($\mu\mu q q$)
>12.0	>15.2	95	[3] KHACHATRY...	15AE	CMS	($\mu\mu q q$)
>12.5	>16.7	95	[4] AAD	14BE	ATLS	($\mu\mu q q$)
> 9.6	>12.9	95	[5] AAD	13E	ATLS	($\mu\mu q q$) (isosinglet)
> 9.5	>13.1	95	[6] CHATRCHYAN	13K	CMS	($\mu\mu q q$) (isosinglet)
> 8.0	>7.0	95	[7] AAD	12AB	ATLS	($\mu\mu q q$) (isosinglet)

[1] AABOUD 17AT limits are from pp collisions at $\sqrt{s}$ = 13 TeV. The quoted limit uses a uniform positive prior in $1/\Lambda^2$.

[2] AABOUD 16U limits are from pp collisions at $\sqrt{s}$ = 13 TeV. The quoted limit uses a uniform positive prior in $1/\Lambda^2$.

[3] KHACHATRYAN 15AE limit is from $\mu^+\mu^-$ mass distribution in pp collisions at $E_{\rm cm}$ = 8 TeV.

[4] AAD 14BE limits are from pp collisions at $\sqrt{s}$ = 8 TeV. The quoted limit uses a uniform positive prior in $1/\Lambda^2$.

[5] AAD 13E limis are from $\mu^+\mu^-$ mass distribution in pp collisions at $E_{\rm cm}$ = 7 TeV.

[6] CHATRCHYAN 13K limis are from $\mu^+\mu^-$ mass distribution in pp collisions at $E_{\rm cm}$ = 7 TeV.

[7] AAD 12AB limis are from $\mu^+\mu^-$ mass distribution in pp collisions at $E_{\rm cm}$ = 7 TeV.

SCALE LIMITS for Contact Interactions: $\Lambda(\ell\nu\ell\nu)$

VALUE (TeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>3.10	90	[1] JODIDIO	86	SPEC	$\Lambda^{\pm}_{LR}(\nu_\mu \nu_e \mu e)$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>3.8		[2] DIAZCRUZ	94	RVUE	$\Lambda^{+}_{LL}(\tau \nu_\tau e \nu_e)$
>8.1		[2] DIAZCRUZ	94	RVUE	$\Lambda^{-}_{LL}(\tau \nu_\tau e \nu_e)$
>4.1		[3] DIAZCRUZ	94	RVUE	$\Lambda^{+}_{LL}(\tau \nu_\tau \mu \nu_\mu)$
>6.5		[3] DIAZCRUZ	94	RVUE	$\Lambda^{-}_{LL}(\tau \nu_\tau \mu \nu_\mu)$

[1] JODIDIO 86 limit is from $\mu^+ \to \overline{\nu}_\mu e^+ \nu_e$. Chirality invariant interactions $L = (g^2/\Lambda^2)$ $[\eta_{LL}\ (\overline{\nu}_{\mu L}\gamma^\alpha \mu_L)\ (\overline{e}_L \gamma_\alpha \nu_{eL}) + \eta_{LR}\ (\overline{\nu}_{\mu L}\gamma^\alpha \nu_{eL})\ (\overline{e}_R \gamma_\alpha \mu_R)]$ with $g^2/4\pi = 1$ and (η_{LL},η_{LR}) = (0,±1) are taken. No limits are given for $\Lambda^{\pm}_{LL}$ with (η_{LL},η_{LR}) = (±1,0). For more general constraints with right-handed neutrinos and chirality nonconserving contact interactions, see their text.

[2] DIAZCRUZ 94 limits are from $\Gamma(\tau \to e\nu\nu)$ and assume flavor-dependent contact interactions with $\Lambda(\tau\nu_\tau e\nu_e) \ll \Lambda(\mu\nu_\mu e\nu_e)$.

[3] DIAZCRUZ 94 limits are from $\Gamma(\tau \to \mu\nu\nu)$ and assume flavor-dependent contact interactions with $\Lambda(\tau\nu_\tau \mu\nu_\mu) \ll \Lambda(\mu\nu_\mu e\nu_e)$.

SCALE LIMITS for Contact Interactions: $\Lambda(e\nu qq)$

VALUE (TeV)	*CL%*	*DOCUMENT ID*		*TECN*
>2.81	95	[1] AFFOLDER	01I	CDF

[1] AFFOLDER 00I bound is for a scalar interaction $\overline{q}_R q_L \overline{\nu} e_L$.

SCALE LIMITS for Contact Interactions: $\Lambda(qqqq)$

Λ^+_{LL}(TeV)	Λ^-_{LL}(TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>13.1 none 17.4–29.5	**>21.8**	95	[1] AABOUD	17AK	ATLS	pp dijet angl.
• • • We do not use the following data for averages, fits, limits, etc. • • •						
>11.5	>14.7	95	[2] SIRUNYAN	17F	CMS	pp dijet angl.
>12.0	>17.5	95	[3] AAD	16S	ATLS	pp dijet angl.
			[4] AAD	15AR	ATLS	$pp \to t\bar{t}t\bar{t}$
			[5] AAD	15BY	ATLS	$pp \to t\bar{t}t\bar{t}$
> 8.1	>12.0	95	[6] AAD	15L	ATLS	pp dijet angl.
> 9.0	>11.7	95	[7] KHACHATRY...	15J	CMS	pp dijet angl.
> 5		95	[8] FABBRICHESI	14	RVUE	$q\bar{q}t\bar{t}$

[1] AABOUD 17AK limit is from dijet angular distribution in pp collisions at $\sqrt{s} = 13$ TeV. u, d, and s quarks are assumed to be composite.

[2] SIRUNYAN 17F limit is from dijet angular cross sections in pp collisions at $E_{cm} = 13$ TeV. All quarks are assumed to be composite.

[3] AAD 16S limit is from dijet angular selections in pp collisions at $E_{cm} = 13$ TeV. u, d, and s quarks are assumed to be composite.

[4] AAD 15AR obtain limit on the t_R compositeness $2\pi/\Lambda^2_{RR} < 6.6$ TeV^{-2} at 95% CL from the $t\bar{t}t\bar{t}$ production in the pp collisions at $E_{cm} = 8$ TeV.

[5] AAD 15BY obtain limit on the t_R compositeness $2\pi/\Lambda^2_{RR} < 15.1$ TeV^{-2} at 95% CL from the $t\bar{t}t\bar{t}$ production in the pp collisions at $E_{cm} = 8$ TeV.

[6] AAD 15L limit is from dijet angular distribution in pp collisions at $E_{cm} = 8$ TeV. u, d, and s quarks are assumed to be composite.

[7] KHACHATRYAN 15J limit is from dijet angular distribution in pp collisions at $E_{cm} = 8$ TeV. u, d, s, c, and b quarks are assumed to be composite.

[8] FABBRICHESI 14 obtain bounds on chromoelectric and chromomagnetic form factors of the top-quark using $pp \to t\bar{t}$ and $p\bar{p} \to t\bar{t}$ cross sections. The quoted limit on the $q\bar{q}t\bar{t}$ contact interaction is derived from their bound on the chromoelectric form factor.

SCALE LIMITS for Contact Interactions: $\Lambda(\nu\nu qq)$

Limits are for $\Lambda^{\pm}_{LL}$ only. For other cases, see each reference.

Λ^+_{LL}(TeV)	Λ^-_{LL}(TeV)	CL%	DOCUMENT ID		TECN	COMMENT
>5.0	**>5.4**	95	[1] MCFARLAND	98	CCFR	νN scattering

[1] MCFARLAND 98 assumed a flavor universal interaction. Neutrinos were mostly of muon type.

MASS LIMITS for Excited e (e^*)

Most e^+e^- experiments assume one-photon or Z exchange. The limits from some e^+e^- experiments which depend on λ have assumed transition couplings which are chirality violating ($\eta_L = \eta_R$). However they can be interpreted as limits for chirality-conserving interactions after multiplying the coupling value λ by $\sqrt{2}$; see Note.

Excited leptons have the same quantum numbers as other ortholeptons. See also the searches for ortholeptons in the "Searches for Heavy Leptons" section.

Limits for Excited e (e^*) from Pair Production

These limits are obtained from $e^+ e^- \rightarrow e^{*+} e^{*-}$ and thus rely only on the (electroweak) charge of e^*. Form factor effects are ignored unless noted. For the case of limits from Z decay, the e^* coupling is assumed to be of sequential type. Possible t channel contribution from transition magnetic coupling is neglected. All limits assume a dominant $e^* \rightarrow e\gamma$ decay except the limits from $\Gamma(Z)$.

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>103.2	95	[1] ABBIENDI	02G	OPAL	$e^+ e^- \rightarrow e^* e^*$ Homodoublet type
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>102.8	95	[2] ACHARD	03B	L3	$e^+ e^- \rightarrow e^* e^*$ Homodoublet type

[1] From $e^+ e^-$ collisions at $\sqrt{s}$ = 183–209 GeV. $f = f'$ is assumed.

[2] From $e^+ e^-$ collisions at $\sqrt{s}$ = 189–209 GeV. $f = f'$ is assumed. ACHARD 03B also obtain limit for $f = -f'$: $m_{e^*} > 96.6$ GeV.

Limits for Excited e (e^*) from Single Production

These limits are from $e^+ e^- \rightarrow e^* e$, $W \rightarrow e^* \nu$, or $e p \rightarrow e^* X$ and depend on transition magnetic coupling between e and e^*. All limits assume $e^* \rightarrow e\gamma$ decay except as noted. Limits from LEP, UA2, and H1 are for chiral coupling, whereas all other limits are for nonchiral coupling, $\eta_L = \eta_R = 1$. In most papers, the limit is expressed in the form of an excluded region in the $\lambda - m_{e^*}$ plane. See the original papers.

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>3000	95	[1] AAD	15AP	ATLS	$p p \rightarrow e^{(*)} e^* X$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>2450	95	[2] KHACHATRY...	16AQ	CMS	$p p \rightarrow e e^* X$
>2200	95	[3] AAD	13BB	ATLS	$p p \rightarrow e e^* X$
>1900	95	[4] CHATRCHYAN	13AE	CMS	$p p \rightarrow e e^* X$
>1870	95	[5] AAD	12AZ	ATLS	$p p \rightarrow e^{(*)} e^* X$

[1] AAD 15AP search for e^* production in evens with three or more charged leptons in $p p$ collisions at $\sqrt{s} = 8$ TeV. The quoted limit assumes $\Lambda = m_{e^*}$, $f = f' = 1$. The contact interaction is included in the e^* production and decay amplitudes.

[2] KHACHATRYAN 16AQ search for single e^* production in $p p$ collisions at $\sqrt{s} = 8$ TeV. The limit above is from the $e^* \rightarrow e\gamma$ search channel assuming $f = f' = 1$, $m_{e^*} = \Lambda$. See their Table 7 for limits in other search channels or with different assumptions.

[3] AAD 13BB search for single e^* production in $p p$ collisions with $e^* \rightarrow e\gamma$ decay. $f = f' = 1$, and e^* production via contact interaction with $\Lambda = m_{e^*}$ are assumed.

[4] CHATRCHYAN 13AE search for single e^* production in $p p$ collisions with $e^* \rightarrow e\gamma$ decay. $f = f' = 1$, and e^* production via contact interaction with $\Lambda = m_{e^*}$ are assumed.

[5] AAD 12AZ search for e^* production via four-fermion contact interaction in $p p$ collisions with $e^* \rightarrow e\gamma$ decay. The quoted limit assumes $\Lambda = m_{e^*}$. See their Fig. 8 for the exclusion plot in the mass-coupling plane.

Limits for Excited e (e^*) from $e^+ e^- \rightarrow \gamma\gamma$

These limits are derived from indirect effects due to e^* exchange in the t channel and depend on transition magnetic coupling between e and e^*. All limits are for $\lambda_\gamma = 1$. All limits except ABE 89J and ACHARD 02D are for nonchiral coupling with $\eta_L = \eta_R = 1$. We choose the chiral coupling limit as the best limit and list it in the Summary Table.

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>356	95	[1] ABDALLAH	04N	DLPH	$\sqrt{s}$= 161–208 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>310	95	ACHARD	02D	L3	$\sqrt{s}$= 192–209 GeV

[1] ABDALLAH 04N also obtain a limit on the excited electron mass with $e e^*$ chiral coupling, $m_{e^*} > 295$ GeV at 95% CL.

Indirect Limits for Excited e (e^*)

These limits make use of loop effects involving e^* and are therefore subject to theoretical uncertainty.

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] DORENBOS...	89	CHRM	$\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$, $\nu_\mu e \rightarrow \nu_\mu e$
	[2] GRIFOLS	86	THEO	$\nu_\mu e \rightarrow \nu_\mu e$
	[3] RENARD	82	THEO	$g-2$ of electron

[1] DORENBOSCH 89 obtain the limit $\lambda_\gamma^2 \Lambda_{\text{cut}}^2 / m_{e^*}^2 < 2.6$ (95% CL), where Λ_{cut} is the cutoff scale, based on the one-loop calculation by GRIFOLS 86. If one assumes that $\Lambda_{\text{cut}} = 1$ TeV and $\lambda_\gamma = 1$, one obtains $m_{e^*} > 620$ GeV. However, one generally expects $\lambda_\gamma \approx m_{e^*}/\Lambda_{\text{cut}}$ in composite models.

[2] GRIFOLS 86 uses $\nu_\mu e \rightarrow \nu_\mu e$ and $\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$ data from CHARM Collaboration to derive mass limits which depend on the scale of compositeness.

[3] RENARD 82 derived from $g-2$ data limits on mass and couplings of e^* and μ^*. See figures 2 and 3 of the paper.

MASS LIMITS for Excited μ (μ^*)

Limits for Excited μ (μ^*) from Pair Production

These limits are obtained from $e^+ e^- \rightarrow \mu^{*+} \mu^{*-}$ and thus rely only on the (electroweak) charge of μ^*. Form factor effects are ignored unless noted. For the case of limits from Z decay, the μ^* coupling is assumed to be of sequential type. All limits assume a dominant $\mu^* \rightarrow \mu\gamma$ decay except the limits from $\Gamma(Z)$.

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>103.2	95	[1] ABBIENDI	02G	OPAL	$e^+ e^- \rightarrow \mu^* \mu^*$ Homodoublet type
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>102.8	95	[2] ACHARD	03B	L3	$e^+ e^- \rightarrow \mu^* \mu^*$ Homodoublet type

[1] From $e^+ e^-$ collisions at $\sqrt{s}$ = 183–209 GeV. $f = f'$ is assumed.

[2] From $e^+ e^-$ collisions at $\sqrt{s}$ = 189–209 GeV. $f = f'$ is assumed. ACHARD 03B also obtain limit for $f = -f'$: $m_{\mu^*} > 96.6$ GeV.

Limits for Excited μ (μ^*) from Single Production

These limits are from $e^+ e^- \to \mu^* \mu$ and depend on transition magnetic coupling between μ and μ^*. All limits assume $\mu^* \to \mu\gamma$ decay. Limits from LEP are for chiral coupling, whereas all other limits are for nonchiral coupling, $\eta_L = \eta_R = 1$. In most papers, the limit is expressed in the form of an excluded region in the $\lambda - m_{\mu^*}$ plane. See the original papers.

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>3000	95	[1] AAD	15AP	ATLS	$pp \to \mu^{(*)} \mu^* X$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>2800	95	[2] AAD	16BM	ATLS	$pp \to \mu \mu^* X$
>2470	95	[3] KHACHATRY...	16AQ	CMS	$pp \to \mu \mu^* X$
>2200	95	[4] AAD	13BB	ATLS	$pp \to \mu \mu^* X$
>1900	95	[5] CHATRCHYAN	13AE	CMS	$pp \to \mu \mu^* X$
>1750	95	[6] AAD	12AZ	ATLS	$pp \to \mu^{(*)} \mu^* X$

[1] AAD 15AP search for μ^* production in evens with three or more charged leptons in pp collisions at $\sqrt{s} = 8$ TeV. The quoted limit assumes $\Lambda = m_{\mu^*}$, $f = f' = 1$. The contact interaction is included in the μ^* production and decay amplitudes.

[2] AAD 16BM search for μ^* production in $\mu\mu jj$ events in pp collisions at $\sqrt{s} = 8$ TeV. Both the production and decay are assumed to occur via a contact interaction with $\Lambda = m_{\mu^*}$.

[3] KHACHATRYAN 16AQ search for single μ^* production in pp collisions at $\sqrt{s} = 8$ TeV. The limit above is from the $\mu^* \to \mu\gamma$ search channel assuming $f = f' = 1$, $m_{\mu^*} = \Lambda$. See their Table 7 for limits in other search channels or with different assumptions.

[4] AAD 13BB search for single μ^* production in pp collisions with $\mu^* \to \mu\gamma$ decay. $f = f' = 1$, and μ^* production via contact interaction with $\Lambda = m_{\mu^*}$ are assumed.

[5] CHATRCHYAN 13AE search for single μ^* production in pp collisions with $\mu^* \to \mu\gamma$ decay. $f = f' = 1$, and μ^* production via contact interaction with $\Lambda = m_{\mu^*}$ are assumed.

[6] AAD 12AZ search for μ^* production via four-fermion contact interaction in pp collisions with $\mu^* \to \mu\gamma$ decay. The quoted limit assumes $\Lambda = m_{\mu^*}$. See their Fig. 8 for the exclusion plot in the mass-coupling plane.

Indirect Limits for Excited μ (μ^*)

These limits make use of loop effects involving μ^* and are therefore subject to theoretical uncertainty.

VALUE (GeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] RENARD	82	THEO	$g-2$ of muon

[1] RENARD 82 derived from $g-2$ data limits on mass and couplings of e^* and μ^*. See figures 2 and 3 of the paper.

MASS LIMITS for Excited τ (τ^*)

Limits for Excited τ (τ^*) from Pair Production

These limits are obtained from $e^+ e^- \rightarrow \tau^{*+} \tau^{*-}$ and thus rely only on the (electroweak) charge of τ^*. Form factor effects are ignored unless noted. For the case of limits from Z decay, the τ^* coupling is assumed to be of sequential type. All limits assume a dominant $\tau^* \rightarrow \tau\gamma$ decay except the limits from $\Gamma(Z)$.

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>103.2	95	[1] ABBIENDI	02G	OPAL	$e^+ e^- \rightarrow \tau^* \tau^*$ Homodoublet type
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>102.8	95	[2] ACHARD	03B	L3	$e^+ e^- \rightarrow \tau^* \tau^*$ Homodoublet type

[1] From $e^+ e^-$ collisions at $\sqrt{s}$ = 183–209 GeV. $f = f'$ is assumed.

[2] From $e^+ e^-$ collisions at $\sqrt{s}$ = 189–209 GeV. $f = f'$ is assumed. ACHARD 03B also obtain limit for $f = -f'$: $m_{\tau^*} > 96.6$ GeV.

Limits for Excited τ (τ^*) from Single Production

These limits are from $e^+ e^- \rightarrow \tau^* \tau$ and depend on transition magnetic coupling between τ and τ^*. All limits assume $\tau^* \rightarrow \tau\gamma$ decay. Limits from LEP are for chiral coupling, whereas all other limits are for nonchiral coupling, $\eta_L = \eta_R = 1$. In most papers, the limit is expressed in the form of an excluded region in the $\lambda - m_{\tau^*}$ plane. See the original papers.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>2500	95	[1] AAD	15AP	ATLS	$pp \rightarrow \tau^{(*)} \tau^* X$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
> 180	95	[2] ACHARD	03B	L3	$e^+ e^- \rightarrow \tau\tau^*$
> 185	95	[3] ABBIENDI	02G	OPAL	$e^+ e^- \rightarrow \tau\tau^*$

[1] AAD 15AP search for τ^* production in events with three or more charged leptons in pp collisions at $\sqrt{s} = 8$ TeV. The quoted limit assumes $\Lambda = m_{\tau^*}$, $f = f' = 1$. The contact interaction is included in the τ^* production and decay amplitudes.

[2] ACHARD 03B result is from $e^+ e^-$ collisions at $\sqrt{s}$ = 189–209 GeV. $f = f' = \Lambda / m_{\tau^*}$ is assumed. See their Fig. 4 for the exclusion plot in the mass-coupling plane.

[3] ABBIENDI 02G result is from $e^+ e^-$ collisions at $\sqrt{s}$ = 183–209 GeV. $f = f' = \Lambda / m_{\tau^*}$ is assumed for τ^* coupling. See their Fig. 4c for the exclusion limit in the mass-coupling plane.

MASS LIMITS for Excited Neutrino (ν^*)

Limits for Excited ν (ν^*) from Pair Production

These limits are obtained from $e^+ e^- \rightarrow \nu^* \nu^*$ and thus rely only on the (electroweak) charge of ν^*. Form factor effects are ignored unless noted. The ν^* coupling is assumed to be of sequential type unless otherwise noted. All limits assume a dominant $\nu^* \rightarrow \nu\gamma$ decay except the limits from $\Gamma(Z)$.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>1600	95	[1] AAD	15AP	ATLS	$pp \rightarrow \nu^* \nu^* X$
• • • We do not use the following data for averages, fits, limits, etc. • • •					

		[2] ABBIENDI	04N	OPAL	
> 102.6	95	[3] ACHARD	03B	L3	$e^+e^- \to \nu^*\nu^*$ Homodoublet type

[1] AAD 15AP search for ν^* pair production in evens with three or more charged leptons in pp collisions at $\sqrt{s}$ = 8 TeV. The quoted limit assumes $\Lambda = m_{\nu^*}$, $f = f' = 1$. The contact interaction is included in the ν^* production and decay amplitudes.

[2] From e^+e^- collisions at $\sqrt{s}$ = 192–209 GeV, ABBIENDI 04N obtain limit on $\sigma(e^+e^- \to \nu^*\nu^*)$ $B^2(\nu^* \to \nu\gamma)$. See their Fig.2. The limit ranges from 20 to 45 fb for $m_{\nu^*} > 45$ GeV.

[3] From e^+e^- collisions at $\sqrt{s}$ = 189–209 GeV. $f = -f'$ is assumed. ACHARD 03B also obtain limit for $f = f'$: $m_{\nu^*_e} > 101.7$ GeV, $m_{\nu^*_\mu} > 101.8$ GeV, and $m_{\nu^*_\tau} > 92.9$ GeV. See their Fig. 4 for the exclusion plot in the mass-coupling plane.

Limits for Excited ν (ν*) from Single Production

These limits are from $e^+e^- \to \nu\nu^*$, $Z \to \nu\nu^*$, or $ep \to \nu^* X$ and depend on transition magnetic coupling between ν/e and ν^*. Assumptions about ν^* decay mode are given in footnotes.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>213	95	[1] AARON	08	H1	$ep \to \nu^* X$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>190	95	[2] ACHARD	03B	L3	$e^+e^- \to \nu\nu^*$
none 50–150	95	[3] ADLOFF	02	H1	$ep \to \nu^* X$
>158	95	[4] CHEKANOV	02D	ZEUS	$ep \to \nu^* X$

[1] AARON 08 search for single ν^* production in ep collisions with the decays $\nu^* \to \nu\gamma$, νZ, eW. The quoted limit assumes $f = -f' = \Lambda/m_{\nu^*}$. See their Fig. 3 and Fig. 4 for the exclusion plots in the mass-coupling plane.

[2] ACHARD 03B result is from e^+e^- collisions at $\sqrt{s}$ = 189–209 GeV. The quoted limit is for ν^*_e. $f = -f' = \Lambda/m_{\nu^*}$ is assumed. See their Fig. 4 for the exclusion plot in the mass-coupling plane.

[3] ADLOFF 02 search for single ν^* production in ep collisions with the decays $\nu^* \to \nu\gamma$, νZ, eW. The quoted limit assumes $f = -f' = \Lambda/m_{\nu^*}$. See their Fig. 1 for the exclusion plots in the mass-coupling plane.

[4] CHEKANOV 02D search for single ν^* production in ep collisions with the decays $\nu^* \to \nu\gamma$, νZ, eW. $f = -f' = \Lambda/m_{\nu^*}$ is assumed for the e^* coupling. CHEKANOV 02D also obtain limit for $f = f' = \Lambda/m_{\nu^*}$: m_{ν^*} >135 GeV. See their Fig. 5c and Fig. 5d for the exclusion plot in the mass-coupling plane.

MASS LIMITS for Excited q (q*)

Limits for Excited q (q*) from Pair Production

These limits are mostly obtained from $e^+e^- \to q^*\overline{q}^*$ and thus rely only on the (electroweak) charge of the q^*. Form factor effects are ignored unless noted. Assumptions about the q^* decay are given in the comments and footnotes.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>338	95	[1] AALTONEN	10H	CDF	$q^* \to tW^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[2] BARATE	98U	ALEP	$Z \to q^*q^*$
> 45.6	95	[3] ADRIANI	93M	L3	u or d type, $Z \to q^*q^*$

> 41.7	95	[4] BARDADIN-...	92	RVUE	u-type, $\Gamma(Z)$
> 44.7	95	[4] BARDADIN-...	92	RVUE	d-type, $\Gamma(Z)$
> 40.6	95	[5] DECAMP	92	ALEP	u-type, $\Gamma(Z)$
> 44.2	95	[5] DECAMP	92	ALEP	d-type, $\Gamma(Z)$
> 45	95	[6] DECAMP	92	ALEP	u or d type, $Z \rightarrow q^* q^*$
> 45	95	[5] ABREU	91F	DLPH	u-type, $\Gamma(Z)$
> 45	95	[5] ABREU	91F	DLPH	d-type, $\Gamma(Z)$

[1] AALTONEN 10H obtain limits on the $q^* q^*$ production cross section in $p\overline{p}$ collisions. See their Fig. 3.
[2] BARATE 98U obtain limits on the form factor. See their Fig. 16 for limits in mass-form factor plane.
[3] ADRIANI 93M limit is valid for B($q^* \rightarrow qg$)> 0.25 (0.17) for up (down) type.
[4] BARDADIN-OTWINOWSKA 92 limit based on $\Delta\Gamma(Z)$<36 MeV.
[5] These limits are independent of decay modes.
[6] Limit is for B($q^* \rightarrow qg$)+B($q^* \rightarrow q\gamma$)=1.

Limits for Excited q (q^*) from Single Production

These limits are from $e^+e^- \rightarrow q^* \overline{q}$, $p\overline{p} \rightarrow q^* X$, or $pp \rightarrow q^* X$ and depend on transition magnetic couplings between q and q^*. Assumptions about q^* decay mode are given in the footnotes and comments.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>6000	95	[1] AABOUD	17AK	ATLS	$pp \rightarrow q^* X$, $q^* \rightarrow qg$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 600–5400	95	[2] KHACHATRY...	17W	CMS	$pp \rightarrow q^* X$, $q^* \rightarrow qg$
none 1100–2100	95	[3] AABOUD	16	ATLS	$pp \rightarrow b^* X$, $b^* \rightarrow bg$
>1500	95	[4] AAD	16AH	ATLS	$pp \rightarrow b^* X$, $b^* \rightarrow tW$
>4400	95	[5] AAD	16AI	ATLS	$pp \rightarrow q^* X$, $q^* \rightarrow q\gamma$
		[6] AAD	16AV	ATLS	$pp \rightarrow q^* X$, $q^* \rightarrow Wb$
>5200	95	[7] AAD	16S	ATLS	$pp \rightarrow q^* X$, $q^* \rightarrow qg$
>1390	95	[8] KHACHATRY...	16I	CMS	$pp \rightarrow b^* X$, $b^* \rightarrow tW$
>5000	95	[9] KHACHATRY...	16K	CMS	$pp \rightarrow q^* X$, $q^* \rightarrow qg$
none 500–1600	95	[10] KHACHATRY...	16L	CMS	$pp \rightarrow q^* X$, $q^* \rightarrow qg$
>4060	95	[11] AAD	15V	ATLS	$pp \rightarrow q^* X$, $q^* \rightarrow qg$
>3500	95	[12] KHACHATRY...	15V	CMS	$pp \rightarrow q^* X$, $q^* \rightarrow qg$
>3500	95	[13] AAD	14A	ATLS	$pp \rightarrow q^* X$, $q^* \rightarrow q\gamma$
>3200	95	[14] KHACHATRY...	14	CMS	$pp \rightarrow q^* X$, $q^* \rightarrow qW$
>2900	95	[15] KHACHATRY...	14	CMS	$pp \rightarrow q^* X$, $q^* \rightarrow qZ$
none 700–3500	95	[16] KHACHATRY...	14J	CMS	$pp \rightarrow q^* X$, $q^* \rightarrow q\gamma$
>2380	95	[17] CHATRCHYAN	13AJ	CMS	$pp \rightarrow q^* X$, $q^* \rightarrow qW$
>2150	95	[18] CHATRCHYAN	13AJ	CMS	$pp \rightarrow q^* X$, $q^* \rightarrow qZ$

[1] AABOUD 17AK assume $\Lambda = m_{q^*}$, $f_s = f = f' = 1$. The contact interactions are not included in q^* production and decay amplitudes. Only the decay of $q^* \rightarrow gu$ and $q^* \rightarrow gd$ is simulated as the benchmark signals in the analysis.
[2] KHACHATRYAN 17W assume $\Lambda = m_{q^*}$, $f_s = f = f' = 1$. The contact interactions are not included in q^* production and decay amplitudes.
[3] AABOUD 16 assume $\Lambda = m_{b^*}$, $f_s = f = f' = 1$. The contact interactions are not included in the b^* production and decay amplitudes.
[4] AAD 16AH search for b^* decaying to tW in pp collisions at $\sqrt{s} = 8$ TeV. $f_g = f_L = f_R = 1$ are assumed. See their Fig. 12b for limits on $\sigma \cdot B$.

[5] AAD 16AI assume $\Lambda = m_{q^*}$, $f_s = f = f' = 1$.

[6] AAD 16AV search for single production of vector-like quarks decaying to Wb in pp collisions. See their Fig. 8 for the limits on couplings and mixings.

[7] AAD 16S assume $\Lambda = m_{q^*}$, $f_s = f = f' = 1$. The contact interactions are not included in q^* production and decay amplitudes.

[8] KHACHATRYAN 16I search for b^* decaying to tW in pp collisions at $\sqrt{s} = 8$ TeV. $\kappa_L^b = g_L = 1$, $\kappa_R^b = g_R = 0$ are assumed. See their Fig. 8 for limits on $\sigma \cdot B$.

[9] KHACHATRYAN 16K assume $\Lambda = m_{q^*}$, $f_s = f = f' = 1$. The contact interactions are not included in q^* production and decay amplitudes.

[10] KHACHATRYAN 16L search for resonances decaying to dijets in pp collisions at $\sqrt{s} = 8$ TeV using the data scouting technique which increases the sensitivity to the low mass resonances.

[11] AAD 15V assume $\Lambda = m_{q^*}$, $f_s = f = f' = 1$. The contact interactions are not included in q^* production and decay amplitudes.

[12] KHACHATRYAN 15V assume $\Lambda = m_{q^*}$, $f_s = f = f' = 1$. The contact interactions are not included in q^* production and decay amplitudes.

[13] AAD 14A assume $\Lambda = m_{q^*}$, $f_s = f = f' = 1$.

[14] KHACHATRYAN 14 use the hadronic decay of W, assuming $\Lambda = m_{q^*}$, $f_s = f = f' = 1$.

[15] KHACHATRYAN 14 use the hadronic decay of Z, assuming $\Lambda = m_{q^*}$, $f_s = f = f' = 1$.

[16] KHACHATRYAN 14J assume $f_s = f = f' = \Lambda / m_{q^*}$.

[17] CHATRCHYAN 13AJ use the hadronic decay of W.

[18] CHATRCHYAN 13AJ use the hadronic decay of Z.

MASS LIMITS for Color Sextet Quarks (q_6)

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>84	95	[1] ABE	89D	CDF	$p\overline{p} \rightarrow q_6 \overline{q}_6$

[1] ABE 89D look for pair production of unit-charged particles which leave the detector before decaying. In the above limit the color sextet quark is assumed to fragment into a unit-charged or neutral hadron with equal probability and to have long enough lifetime not to decay within the detector. A limit of 121 GeV is obtained for a color decuplet.

MASS LIMITS for Color Octet Charged Leptons (ℓ_8)

$\lambda \equiv m_{\ell_8}/\Lambda$

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>86	95	[1] ABE	89D	CDF	Stable ℓ_8: $p\overline{p} \rightarrow \ell_8 \overline{\ell}_8$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[2] ABT	93	H1	e_8: $ep \rightarrow e_8 X$

[1] ABE 89D look for pair production of unit-charged particles which leave the detector before decaying. In the above limit the color octet lepton is assumed to fragment into a unit-charged or neutral hadron with equal probability and to have long enough lifetime not to decay within the detector. The limit improves to 99 GeV if it always fragments into a unit-charged hadron.

[2] ABT 93 search for e_8 production via e-gluon fusion in ep collisions with $e_8 \rightarrow eg$. See their Fig. 3 for exclusion plot in the m_{e_8}–Λ plane for m_{e_8} = 35–220 GeV.

MASS LIMITS for Color Octet Neutrinos (ν_8)

$\lambda \equiv m_{\ell_8}/\Lambda$

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>110	90	[1] BARGER	89	RVUE	ν_8: $p\overline{p} \to \nu_8 \overline{\nu}_8$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 3.8–29.8	95	[2] KIM	90	AMY	ν_8: $e^+ e^- \to$ acoplanar jets
none 9–21.9	95	[3] BARTEL	87B	JADE	ν_8: $e^+ e^- \to$ acoplanar jets

[1] BARGER 89 used ABE 89B limit for events with large missing transverse momentum. Two-body decay $\nu_8 \to \nu g$ is assumed.

[2] KIM 90 is at E_{cm} = 50–60.8 GeV. The same assumptions as in BARTEL 87B are used.

[3] BARTEL 87B is at E_{cm} = 46.3–46.78 GeV. The limit assumes the ν_8 pair production cross section to be eight times larger than that of the corresponding heavy neutrino pair production. This assumption is not valid in general for the weak couplings, and the limit can be sensitive to its $SU(2)_L \times U(1)_Y$ quantum numbers.

MASS LIMITS for W_8 (Color Octet W Boson)

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] ALBAJAR	89	UA1	$p\overline{p} \to W_8 X$, $W_8 \to W g$

[1] ALBAJAR 89 give $\sigma(W_8 \to W + \text{jet})/\sigma(W) < 0.019$ (90% CL) for $m_{W_8} > 220$ GeV.

REFERENCES FOR Searches for Quark and Lepton Compositeness

AABOUD	17AK	PR D96 052004	M. Aaboud et al.	(ATLAS Collab.)
AABOUD	17AT	JHEP 1710 182	M. Aaboud et al.	(ATLAS Collab.)
KHACHATRY...	17W	PL B769 520	V. Khachatryan et al.	(CMS Collab.)
SIRUNYAN	17F	JHEP 1707 013	A.M. Sirunyan et al.	(CMS Collab.)
AABOUD	16	PL B759 229	M. Aaboud et al.	(ATLAS Collab.)
AABOUD	16U	PL B761 372	M. Aaboud et al.	(ATLAS Collab.)
AAD	16AH	JHEP 1602 110	G. Aad et al.	(ATLAS Collab.)
AAD	16AI	JHEP 1603 041	G. Aad et al.	(ATLAS Collab.)
AAD	16AV	EPJ C76 442	G. Aad et al.	(ATLAS Collab.)
AAD	16BM	NJP 18 073021	G. Aad et al.	(ATLAS Collab.)
AAD	16S	PL B754 302	G. Aad et al.	(ATLAS Collab.)
KHACHATRY...	16AQ	JHEP 1603 125	V. Khachatryan et al.	(CMS Collab.)
KHACHATRY...	16I	JHEP 1601 166	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.)
AAD	15AP	JHEP 1508 138	G. Aad et al.	(ATLAS Collab.)
AAD	15AR	JHEP 1508 105	G. Aad et al.	(ATLAS Collab.)
AAD	15BY	JHEP 1510 150	G. Aad et al.	(ATLAS Collab.)
AAD	15L	PRL 114 221802	G. Aad et al.	(ATLAS Collab.)
AAD	15V	PR D91 052007	G. Aad et al.	(ATLAS Collab.)
KHACHATRY...	15AE	JHEP 1504 025	V. Khachatryan et al.	(CMS Collab.)
KHACHATRY...	15J	PL B746 79	V. Khachatryan et al.	(CMS Collab.)
KHACHATRY...	15V	PR D91 052009	V. Khachatryan et al.	(CMS Collab.)
AAD	14A	PL B728 562	G. Aad et al.	(ATLAS Collab.)
AAD	14BE	EPJ C74 3134	G. Aad et al.	(ATLAS Collab.)
FABBRICHESI	14	PR D89 074028	M. Fabbrichesi, M. Pinamonti, A. Tonero	
KHACHATRY...	14	JHEP 1408 173	V. Khachatryan et al.	(CMS Collab.)
KHACHATRY...	14J	PL B738 274	V. Khachatryan et al.	(CMS Collab.)
AAD	13BB	NJP 15 093011	G. Aad et al.	(ATLAS Collab.)
AAD	13E	PR D87 015010	G. Aad et al.	(ATLAS Collab.)
CHATRCHYAN	13AE	PL B720 309	S. Chatrchyan et al.	(CMS Collab.)
CHATRCHYAN	13AJ	PL B723 280	S. Chatrchyan et al.	(CMS Collab.)
CHATRCHYAN	13K	PR D87 032001	S. Chatrchyan et al.	(CMS Collab.)

AAD	12AB	PL B712 40	G. Aad *et al.*	(ATLAS Collab.)
AAD	12AZ	PR D85 072003	G. Aad *et al.*	(ATLAS Collab.)
AARON	11C	PL B705 52	F. D. Aaron *et al.*	(H1 Collab.)
ABDALLAH	11	EPJ C71 1555	J. Abdallah *et al.*	(DELPHI Collab.)
AALTONEN	10H	PRL 104 091801	T. Aaltonen *et al.*	(CDF Collab.)
ABDALLAH	09	EPJ C60 1	J. Abdallah *et al.*	(DELPHI Collab.)
AARON	08	PL B663 382	F.D. Aaron *et al.*	(H1 Collab.)
SCHAEL	07A	EPJ C49 411	S. Schael *et al.*	(ALEPH Collab.)
ABDALLAH	06C	EPJ C45 589	J. Abdallah *et al.*	(DELPHI Collab.)
ABULENCIA	06L	PRL 96 211801	A. Abulencia *et al.*	(CDF Collab.)
ABBIENDI	04G	EPJ C33 173	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04N	PL B602 167	G. Abbiendi *et al.*	(OPAL Collab.)
ABDALLAH	04N	EPJ C37 405	J. Abdallah *et al.*	(DELPHI Collab.)
ACHARD	03B	PL B568 23	P. Achard *et al.*	(L3 Collab.)
BABICH	03	EPJ C29 103	A.A. Babich *et al.*	
ABBIENDI	02G	PL B544 57	G. Abbiendi *et al.*	(OPAL Collab.)
ACHARD	02D	PL B531 28	P. Achard *et al.*	(L3 Collab.)
ADLOFF	02	PL B525 9	C. Adloff *et al.*	(H1 Collab.)
CHEKANOV	02D	PL B549 32	S. Chekanov *et al.*	(ZEUS Collab.)
AFFOLDER	01I	PRL 87 231803	T. Affolder *et al.*	(CDF Collab.)
BOURILKOV	01	PR D64 071701	D. Bourilkov	
CHEUNG	01B	PL B517 167	K. Cheung	
ACCIARRI	00P	PL B489 81	M. Acciarri *et al.*	(L3 Collab.)
AFFOLDER	00I	PR D62 012004	T. Affolder *et al.*	(CDF Collab.)
BARATE	98U	EPJ C4 571	R. Barate *et al.*	(ALEPH Collab.)
BARGER	98E	PR D57 391	V. Barger *et al.*	
MCFARLAND	98	EPJ C1 509	K.S. McFarland *et al.*	(CCFR/NuTeV Collab.)
DIAZCRUZ	94	PR D49 2149	J.L. Diaz Cruz, O.A. Sampayo	(CINV)
ABT	93	NP B396 3	I. Abt *et al.*	(H1 Collab.)
ADRIANI	93M	PRPL 236 1	O. Adriani *et al.*	(L3 Collab.)
BARDADIN-...	92	ZPHY C55 163	M. Bardadin-Otwinowska	(CLER)
DECAMP	92	PRPL 216 253	D. Decamp *et al.*	(ALEPH Collab.)
PDG	92	PR D45 S1	K. Hikasa *et al.*	(KEK, LBL, BOST+)
ABREU	91F	NP B367 511	P. Abreu *et al.*	(DELPHI Collab.)
KIM	90	PL B240 243	G.N. Kim *et al.*	(AMY Collab.)
ABE	89B	PRL 62 1825	F. Abe *et al.*	(CDF Collab.)
ABE	89D	PRL 63 1447	F. Abe *et al.*	(CDF Collab.)
ABE	89J	ZPHY C45 175	K. Abe *et al.*	(VENUS Collab.)
ALBAJAR	89	ZPHY C44 15	C. Albajar *et al.*	(UA1 Collab.)
BARGER	89	PL B220 464	V. Barger *et al.*	(WISC, KEK)
DORENBOS...	89	ZPHY C41 567	J. Dorenbosch *et al.*	(CHARM Collab.)
BARTEL	87B	ZPHY C36 15	W. Bartel *et al.*	(JADE Collab.)
GRIFOLS	86	PL 168B 264	J.A. Grifols, S. Peris	(BARC)
JODIDIO	86	PR D34 1967	A. Jodidio *et al.*	(LBL, NWES, TRIU)
Also		PR D37 237 (erratum)	A. Jodidio *et al.*	(LBL, NWES, TRIU)
RENARD	82	PL 116B 264	F.M. Renard	(CERN)