

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

<i>VALUE</i>	<i>CL%</i>	<i>DOCUMENT ID</i>	<i>TECN</i>	<i>COMMENT</i>
• • • 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, $M = 1000m_p$

$<2 \times 10^{-21}$	90	³ HEMMICK	90	SPEC	Water, $M = 5000m_p$
$<3 \times 10^{-20}$	90	³ HEMMICK	90	SPEC	Water, $M = 10000m_p$
$<1. \times 10^{-29}$		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, $M=6-350 m_p$

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

²VERKERK 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, $\rho=0.3$ GeV/cm³, and the mean velocity $\langle v \rangle=300$ km/s.

³See 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, $M = 100m_p$
$<8 \times 10^{-20}$	90	³ HEMMICK	90	SPEC C, $M = 1000m_p$
$<2 \times 10^{-16}$	90	³ HEMMICK	90	SPEC C, $M = 10000m_p$
$<6 \times 10^{-13}$	90	³ HEMMICK	90	SPEC Li, $M = 1000m_p$
$<1 \times 10^{-11}$	90	³ HEMMICK	90	SPEC Be, $M = 1000m_p$
$<6 \times 10^{-14}$	90	³ HEMMICK	90	SPEC B, $M = 1000m_p$
$<4 \times 10^{-17}$	90	³ HEMMICK	90	SPEC O, $M = 1000m_p$
$<4 \times 10^{-15}$	90	³ HEMMICK	90	SPEC F, $M = 1000m_p$
$<1.5 \times 10^{-13}/\text{nucleon}$	68	⁴ NORMAN	89	SPEC $^{206}\text{Pb}X^-$
$<1.2 \times 10^{-12}/\text{nucleon}$	68	⁴ NORMAN	87	SPEC $^{56,58}\text{Fe}X^-$

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

²JAVORSEK 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.

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

⁴Bound 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.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
• • •	We do not use the following data for averages, fits, limits, etc. • • •		
1	PORAYKO 18	PPTA	pulsar timing fuzzy DM search
2	AAD 15AT	ATLS	$t + \cancel{E}_T$
3	KHACHATRYAN...15F	CMS	$t + \cancel{E}_T$
4	AALTONEN 14J	CDF	$W + 2$ jets
5	AAD 13A	ATLS	$W W \rightarrow \ell \nu \ell' \nu$
6	AAD 13C	ATLS	$\gamma + \cancel{E}_T$
7	AALTONEN 13I	CDF	Delayed $\gamma + \cancel{E}_T$
8	CHATRCHYAN 13	CMS	$\ell^+ \ell^- + \text{jets} + \cancel{E}_T$
9	AAD 12C	ATLS	$t \bar{t} + \cancel{E}_T$
10	AALTONEN 12M	CDF	jet + \cancel{E}_T
11	CHATRCHYAN 12AP	CMS	jet + \cancel{E}_T
12	CHATRCHYAN 12Q	CMS	$Z + \text{jets} + \cancel{E}_T$
13	CHATRCHYAN 12T	CMS	$\gamma + \cancel{E}_T$
14	AAD 11S	ATLS	jet + \cancel{E}_T
15	AALTONEN 11AF	CDF	$\ell^\pm \ell^\pm$
16	CHATRCHYAN 11C	CMS	$\ell^+ \ell^- + \text{jets} + \cancel{E}_T$
17	CHATRCHYAN 11U	CMS	jet + \cancel{E}_T
18	AALTONEN 10AF	CDF	$\gamma \gamma + \ell, \cancel{E}_T$
19	AALTONEN 09AF	CDF	$\ell \gamma b \cancel{E}_T$
20	AALTONEN 09G	CDF	$\ell \ell \ell \cancel{E}_T$

¹ PORAYKO 18 search for deviations in the residuals of pulsar timing data using PPTA. No signal observed. Limits set on fuzzy DM with $3 \times 10^{-24} < m(\text{DM}) < 2 \times 10^{-22}$ eV.

² AAD 15AT search for events with a top quark and missing E_T in pp collisions at $E_{\text{cm}} = 8$ TeV with $L = 20.3 \text{ fb}^{-1}$.

³ KHACHATRYAN 15F search for events with a top quark and missing E_T in pp collisions at $E_{\text{cm}} = 8$ TeV with $L = 19.7 \text{ fb}^{-1}$.

⁴ AALTONEN 14J examine events with a W and two jets in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 8.9 \text{ fb}^{-1}$. Invariant mass distributions of the two jets are consistent with the Standard Model expectation.

⁵ AAD 13A search for resonant $W W$ production in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.7 \text{ fb}^{-1}$.

⁶ AAD 13C search for events with a photon and missing \cancel{E}_T in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.6 \text{ fb}^{-1}$.

⁷ AALTONEN 13I search for events with a photon and missing E_T , where the photon is detected after the expected timing, in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 6.3 \text{ fb}^{-1}$. The data are consistent with the Standard Model expectation.

⁸ CHATRCHYAN 13 search for events with an opposite-sign lepton pair, jets, and missing E_T in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.98 \text{ fb}^{-1}$.

⁹ AAD 12C search for events with a $t\bar{t}$ pair and missing \cancel{E}_T in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 1.04 \text{ fb}^{-1}$.

¹⁰ AALTONEN 12M search for events with a jet and missing E_T in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 6.7 \text{ fb}^{-1}$.

¹¹ CHATRCHYAN 12AP search for events with a jet and missing E_T in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 5.0 \text{ fb}^{-1}$.

- 12 CHATRCHYAN 12Q search for events with a Z , jets, and missing \cancel{E}_T in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.98 \text{ fb}^{-1}$.
- 13 CHATRCHYAN 12T search for events with a photon and missing \cancel{E}_T in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 5.0 \text{ fb}^{-1}$.
- 14 AAD 11S search for events with one jet and missing E_T in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 33 \text{ pb}^{-1}$.
- 15 AALTONEN 11AF search for high- p_T like-sign dileptons in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 6.1 \text{ fb}^{-1}$.
- 16 CHATRCHYAN 11C search for events with an opposite-sign lepton pair, jets, and missing E_T in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 34 \text{ pb}^{-1}$.
- 17 CHATRCHYAN 11U search for events with one jet and missing E_T in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 36 \text{ pb}^{-1}$.
- 18 AALTONEN 10AF search for $\gamma\gamma$ events with e, μ, τ , or missing E_T in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 1.1\text{--}2.0 \text{ fb}^{-1}$.
- 19 AALTONEN 09AF search for $\ell\gamma b$ events with missing E_T in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 1.9 \text{ fb}^{-1}$. The observed events are compatible with Standard Model expectation including $t\bar{t}\gamma$ production.
- 20 AALTONEN 09G search for $\mu\mu\mu$ and $\mu\mu e$ events with missing E_T in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 976 \text{ pb}^{-1}$.

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 SIRUNYAN	19B CMS	$pp \rightarrow jA, A \rightarrow b\bar{b}$
			2 AABOUD	18AD ATLS	$pp \rightarrow Y \rightarrow HX \rightarrow (bb) + (qq)$
			3 AABOUD	18CK ATLS	$pp \rightarrow bbb + \cancel{E}_T$
			4 AABOUD	18CL ATLS	$pp \rightarrow$ vector-like quarks
			5 AABOUD	18N ATLS	$pp \rightarrow jj$ resonance
			6 SIRUNYAN	18DJ CMS	$pp \rightarrow ZZ$ or $WZ \rightarrow \ell\bar{\ell}jj$
			7 SIRUNYAN	18DY CMS	$pp \rightarrow RR; R \rightarrow jj$
			8 KHACHATRY...17W	CMS	$pp \rightarrow jj$ resonance
			9 KHACHATRY...17Y	CMS	$pp \rightarrow (8\text{--}10) j + \cancel{E}_T$
			10 SIRUNYAN	17F CMS	$pp \rightarrow jj$ angular distribution
			11 AABOUD	16 ATLS	$pp \rightarrow b + \text{jet}$
			12 AAD	16N ATLS	$pp \rightarrow 3$ high E_T jets
			13 AAD	16S ATLS	$pp \rightarrow jj$ resonance
			14 KHACHATRY...16K	CMS	$pp \rightarrow jj$ resonance
			15 KHACHATRY...16L	CMS	$pp \rightarrow jj$ resonance
			16 AAD	13D ATLS	7 TeV $pp \rightarrow 2$ jets
			17 AALTONEN	13R CDF	1.96 TeV $p\bar{p} \rightarrow 4$ jets
			18 CHATRCHYAN 13A	CMS	7 TeV $pp \rightarrow 2$ jets
			19 CHATRCHYAN 13A	CMS	7 TeV $pp \rightarrow b\bar{b}X$
			20 AAD	12S ATLS	7 TeV $pp \rightarrow 2$ jets

			21	CHATRCHYAN	12BL	CMS	7 TeV	$pp \rightarrow t\bar{t}X$
			22	AAD	11AG	ATLS	7 TeV	$pp \rightarrow 2$ jets
			23	AALTONEN	11M	CDF	1.96 TeV	$p\bar{p} \rightarrow W + 2$ jets
			24	ABAZOV	11i	D0	1.96 TeV	$p\bar{p} \rightarrow W + 2$ jets
			25	AAD	10	ATLS	7 TeV	$pp \rightarrow 2$ jets
			26	KHACHATRYAN	10	CMS	7 TeV	$pp \rightarrow 2$ jets
			27	ABE	99F	CDF	1.8 TeV	$p\bar{p} \rightarrow b\bar{b} + \text{anything}$
			28	ABE	97G	CDF	1.8 TeV	$p\bar{p} \rightarrow 2$ jets
<2603	95	200	29	ABE	93G	CDF	1.8 TeV	$p\bar{p} \rightarrow 2$ jets
< 44	95	400	29	ABE	93G	CDF	1.8 TeV	$p\bar{p} \rightarrow 2$ jets
< 7	95	600	29	ABE	93G	CDF	1.8 TeV	$p\bar{p} \rightarrow 2$ jets

- ¹ SIRUNYAN 19B search for low mass resonance $pp \rightarrow jA$, $A \rightarrow b\bar{b}$ at 13 TeV using 35.9 fb⁻¹; no signal; exclude resonances 50–350 GeV depending on production and decay.
- ² AABOUD 18AD search for new heavy particle $Y \rightarrow HX \rightarrow (bb) + (qq)$. 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.
- ³ AABOUD 18CK search for SUSY Higgsinos in gauge-mediation via $pp \rightarrow bbb + \cancel{E}_T$ 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.
- ⁴ AABOUD 18CL search for $pp \rightarrow$ vector-like quarks \rightarrow jets at 13 TeV with 36 fb⁻¹; no signal seen; limits set on various VLQ scenarios. For pure $B \rightarrow Hb$ or $T \rightarrow Ht$, set the mass limit $m > 1010$ GeV.
- ⁵ 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.
- ⁶ SIRUNYAN 18DJ search for $pp \rightarrow ZZ$ or $WZ \rightarrow \ell\bar{\ell}jj$ 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.
- ⁷ SIRUNYAN 18DY search for $pp \rightarrow RR$; $R \rightarrow jj$ two dijet resonances at 13 TeV 35.9 fb⁻¹; no signal; limits placed on RPV top-squark pair production.
- ⁸ 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.
- ⁹ KHACHATRYAN 17Y search for $pp \rightarrow (8-10)j$ in 19.7 fb⁻¹ at 8 TeV. No signal seen. Limits set on colorons, axigluons, RPV, and SUSY.
- ¹⁰ SIRUNYAN 17F measure $pp \rightarrow jj$ angular distribution in 2.6 fb⁻¹ at 13 TeV; limits set on LEDs and quantum black holes.
- ¹¹ 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.
- ¹² 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).
- ¹³ 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.
- ¹⁴ KHACHATRYAN 16K search for dijet resonance in 2.4 fb⁻¹ data at 13 TeV; see Fig. 3 for limits on axigluons, diquarks etc.
- ¹⁵ 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.
- ¹⁶ AAD 13D search for dijet resonances in pp collisions at $E_{\text{cm}} = 7$ 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.

- 17 AALTONEN 13R search for production of a pair of jet-jet resonances in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 6.6 \text{ fb}^{-1}$. See their Fig. 5 and Tables I, II for cross section limits.
- 18 CHATRCHYAN 13A search for qq , qg , and gg resonances in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.8 \text{ fb}^{-1}$. See their Fig. 3 and Table 1 for limits on resonance cross section in the range $m = 1.0\text{--}4.3$ TeV.
- 19 CHATRCHYAN 13A search for $b\bar{b}$ resonances in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.8 \text{ fb}^{-1}$. See their Fig. 8 and Table 4 for limits on resonance cross section in the range $m = 1.0\text{--}4.0$ TeV.
- 20 AAD 12S search for dijet resonances in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 1.0 \text{ fb}^{-1}$. See their Fig. 3 and Table 2 for limits on resonance cross section in the range $m = 0.9\text{--}4.0$ TeV.
- 21 CHATRCHYAN 12BL search for $t\bar{t}$ resonances in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.4 \text{ fb}^{-1}$. See their Fig. 4 for limits on resonance cross section in the range $m = 0.5\text{--}3.0$ TeV.
- 22 AAD 11AG search for dijet resonances in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 36 \text{ pb}^{-1}$. Limits on number of events for $m = 0.6\text{--}4$ TeV are given in their Table 3.
- 23 AALTONEN 11M find a peak in two jet invariant mass distribution around 140 GeV in $W + 2$ jet events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 4.3 \text{ fb}^{-1}$.
- 24 ABAZOV 11I search for two-jet resonances in $W + 2$ jet events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 4.3 \text{ fb}^{-1}$ and give limits $\sigma < (2.6\text{--}1.3) \text{ pb}$ (95% CL) for $m = 110\text{--}170$ GeV. The result is incompatible with AALTONEN 11M.
- 25 AAD 10 search for narrow dijet resonances in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 315 \text{ nb}^{-1}$. Limits on the cross section in the range $10\text{--}10^3 \text{ pb}$ is given for $m = 0.3\text{--}1.7$ TeV.
- 26 KHACHATRYAN 10 search for narrow dijet resonances in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 2.9 \text{ pb}^{-1}$. Limits on the cross section in the range $1\text{--}300 \text{ pb}$ is given for $m = 0.5\text{--}2.6$ TeV separately in the final states qq , qg , and gg .
- 27 ABE 99F search for narrow $b\bar{b}$ resonances in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ TeV. Limits on $\sigma(p\bar{p} \rightarrow X + \text{anything}) \times B(X \rightarrow b\bar{b})$ in the range $3\text{--}10^3 \text{ pb}$ (95%CL) are given for $m_X = 200\text{--}750$ GeV. See their Table I.
- 28 ABE 97G search for narrow dijet resonances in $p\bar{p}$ collisions with 106 pb^{-1} of data at $E_{\text{cm}} = 1.8$ TeV. Limits on $\sigma(p\bar{p} \rightarrow X + \text{anything}) \cdot B(X \rightarrow jj)$ in the range $10^4\text{--}10^{-1} \text{ pb}$ (95%CL) are given for dijet mass $m = 200\text{--}1150$ 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.
- 29 ABE 93G give cross section times branching ratio into light (d , u , s , c , b) quarks for $\Gamma = 0.02 M$. Their Table II gives limits for $M = 200\text{--}900$ GeV and $\Gamma = (0.02\text{--}0.2) M$.

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	$pp \rightarrow \gamma + \text{jet}$
		4 KHACHATRY...16M	CMS	$pp \rightarrow \gamma\gamma$ resonance

<(0.043–0.17)	95	⁵ ABBIENDI	00D	OPAL	$e^+e^- \rightarrow X^0 \Upsilon^0,$ $X^0 \rightarrow \Upsilon^0 \gamma$
<(0.05–0.8)	95	⁶ ABBIENDI	00D	OPAL	$e^+e^- \rightarrow X^0 X^0,$ $X^0 \rightarrow \Upsilon^0 \gamma$
<(2.5–0.5)	95	⁷ ACKERSTAFF	97B	OPAL	$e^+e^- \rightarrow X^0 \Upsilon^0,$ $X^0 \rightarrow \Upsilon^0 \gamma$
<(1.6–0.9)	95	⁸ ACKERSTAFF	97B	OPAL	$e^+e^- \rightarrow X^0 X^0,$ $X^0 \rightarrow \Upsilon^0 \gamma$

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 $\sigma_G/M_G = 2\%$.

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 $m_{X^0} = 90\text{--}188$ GeV, $m_{Y^0} = 0$ at $E_{\text{cm}} = 189$ GeV. See also their Fig. 9.

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

⁷ ACKERSTAFF 97B associated production limit is for $m_{X^0} = 80\text{--}160$ GeV, $m_{Y^0} = 0$ from 10.0 pb⁻¹ at $E_{\text{cm}} = 161$ GeV. See their Fig. 3(a).

⁸ ACKERSTAFF 97B pair production limit is for $m_{X^0} = 40\text{--}80$ GeV, $m_{Y^0} = 0$ from 10.0 pb⁻¹ at $E_{\text{cm}} = 161$ GeV. See their Fig. 3(b).

Heavy Particle Production Cross Section

VALUE (cm ² /N)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

¹ AABOUD	18CJ	ATLS	$pp \rightarrow VV/\ell\ell/\ell\nu, V = W, Z, h$
² AABOUD	18CM	ATLS	$pp \rightarrow e\mu/e\tau/\mu\tau$
³ AAIJ	18AJ	LHCB	$pp \rightarrow A' \rightarrow \mu^+\mu^-;$ dark photon
⁴ BANERJEE	18	NA64	$eZ \rightarrow eZX(A')$
⁵ BANERJEE	18A	NA64	$eZ \rightarrow eZA', A' \rightarrow \chi\chi$
⁶ MARSICANO	18	E137	$e^+e^- \rightarrow A'(\gamma)$ visible decay
⁷ SIRUNYAN	18BB	CMS	$pp \rightarrow Z' \rightarrow \ell^+\ell^-$ at 13 TeV
⁸ SIRUNYAN	18DA	CMS	$pp \rightarrow$ Black Hole, string ball, sphaleron
⁹ SIRUNYAN	18DD	CMS	$pp \rightarrow jj$
¹⁰ SIRUNYAN	18DR	CMS	$pp \rightarrow b\mu\bar{\nu}$
¹¹ SIRUNYAN	18DU	CMS	$pp \rightarrow \gamma\gamma$
¹² SIRUNYAN	18ED	CMS	$pp \rightarrow V \rightarrow Wh; h \rightarrow$ $b\bar{b}; W \rightarrow \ell\nu$
¹³ AABOUD	17B	ATLS	WH, ZH resonance
¹⁴ AAIJ	17BR	LHCB	$pp \rightarrow \pi_\nu \pi_\nu, \pi_\nu \rightarrow jj$
¹⁵ AAD	16O	ATLS	$\ell + (\ell s \text{ or jets})$
¹⁶ AAD	16R	ATLS	WW, WZ, ZZ resonance

		17 KRASZNAHO...16		$p^7\text{Li} \rightarrow {}^8\text{Be} \rightarrow X(17)N,$ $X(17) \rightarrow e^+e^-$
		18 LEES	15E BABR	e^+e^- collisions
		19 ADAMS	97B KTEV	$m = 1.2\text{--}5$ GeV
$< 10^{-36}\text{--}10^{-33}$	90	20 GALLAS	95 TOF	$m = 0.5\text{--}20$ GeV
$< (4\text{--}0.3) \times 10^{-31}$	95	21 AKESSON	91 CNTR	$m = 0\text{--}5$ GeV
$< 2 \times 10^{-36}$	90	22 BADIER	86 BDMP	$\tau = (0.05\text{--}1.) \times 10^{-8}\text{s}$
$< 2.5 \times 10^{-35}$		23 GUSTAFSON	76 CNTR	$\tau > 10^{-7}$ s

- ¹ 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.
- ² 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.
- ³ 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.
- ⁴ 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 $X\text{--}e^-$ 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.
- ⁵ 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.
- ⁶ 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.
- ⁷ SIRUNYAN 18BB search for high mass dilepton resonance; no signal found and exclude portions of p-space of Z' , KK graviton models.
- ⁸ 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. $m(\text{BH}) > 10.1$ TeV.
- ⁹ 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. $m(\text{BH}) > 5.9\text{--}8.2$ TeV.
- ¹⁰ SIRUNYAN 18DR search for dimuon resonance in $pp \rightarrow b\mu\bar{\mu}$ at 8 and 13 TeV. Slight excess seen at $m(\mu\bar{\mu}) \sim 28$ GeV in some channels.
- ¹¹ 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.
- ¹² SIRUNYAN 18ED search for $pp \rightarrow V \rightarrow Wh; h \rightarrow b\bar{b}; W \rightarrow \ell\nu$ at 13 TeV with 35.9 fb^{-1} ; no signal; limits set on $m(W') > 2.9$ TeV.
- ¹³ AABOUD 17B exclude $m(W', Z') < 1.49\text{--}2.31$ 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.
- ¹⁴ 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.
- ¹⁵ AAD 16O search for high $E_T \ell + (\ell\text{s or jets})$ with 3.2 fb^{-1} at 13 TeV; exclude micro black holes mass < 8 TeV (Fig. 3) for models with two extra dimensions.
- ¹⁶ 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).
- ¹⁷ KRASZNAHORKAY 16 report $p\text{Li} \rightarrow \text{Be} \rightarrow e\bar{e}N$ 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.

- ¹⁸ 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.
- ¹⁹ 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.
- ²⁰ 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} cm². See Fig. 10.
- ²¹ 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, $\sigma < 10^{-30}$ cm²/nucleon is obtained.
- ²² 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.
- ²³ 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
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- • • 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 $\sigma(\text{production}) \times \sigma(\text{interaction}) \times \text{acceptance} < 2.26 \times 10^{-71}$ cm⁴/nucleon² (CL = 90%) for light neutrals. Acceptance depends on models (0.1 to $4. \times 10^{-4}$).

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

$<1 \times 10^{-3}$	90	¹ KILE	18 ALEP	$e^+e^- \rightarrow 4$ jets
		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
$<2 \times 10^{-5}$	95	⁵ BARATE	97K ALEP	$Q=1$, $m=45-85$ GeV
		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 $e^+e^- \rightarrow 4$ jets data and see 4–5 σ excess at 110 GeV.
- ² ABLIKIM 17AA search for dark photon $A \rightarrow \ell\bar{\ell}$ 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 $\sigma < (0.05\text{--}0.2) \text{ pb}$ (95%CL) for spin-0 and spin-1/2 particles with $m=45\text{--}89.5$ GeV, charge 1 and 2/3. The limit is translated to the cross section at $E_{\text{cm}}=183$ 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 $\sigma < (0.4\text{--}2.3) \text{ pb}$ (95%CL) for various center-of-mass energies $E_{\text{cm}}=130\text{--}136, 161, \text{ and } 172$ GeV, assuming an almost flat production distribution in $\cos\theta$.
- ⁵ BARATE 97K search for pair production of long-lived charged particles at $E_{\text{cm}} = 130, 136, 161, \text{ and } 172$ GeV and give limits $\sigma < (0.2\text{--}0.4) \text{ pb}$ (95%CL) for spin-0 and spin-1/2 particles with $m=45\text{--}85$ GeV. The limit is translated to the cross section at $E_{\text{cm}}=172$ 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 $\sigma(e^+e^- \rightarrow \text{hadrons})$. 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 $W_{\text{cm}} = 52\text{--}60$ 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 $W_{\text{cm}} = 52\text{--}61.4$ GeV. The above limit is for inclusive production cross section normalized to $\sigma(e^+e^- \rightarrow \mu^+\mu^-) \cdot \beta(3 - \beta^2)/2$, where $\beta = (1 - 4m^2/W_{\text{cm}}^2)^{1/2}$. See the paper for the assumption about the production mechanism.
- ¹⁰ KINOSHITA 82 is SLAC PEP experiment at $W_{\text{cm}} = 29$ GeV using lexan and ^{39}Cr plastic sheets sensitive to highly ionizing particles.
- ¹¹ BARTEL 80 is DESY-PETRA experiment with $W_{\text{cm}} = 27\text{--}35$ 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
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$< 5 \times 10^{-6}$	95	¹ AKERS	95R OPAL	$m = 40.4\text{--}45.6$ GeV
$< 1 \times 10^{-3}$	95	AKRAWY	900 OPAL	$m = 29\text{--}40$ GeV

¹ AKERS 95R give the 95% CL limit $\sigma(X\bar{X})/\sigma(\mu\mu) < 1.8 \times 10^{-4}$ 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
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• • • We do not use the following data for averages, fits, limits, etc. • • •

>660	95	1	AAD	15BJ ATLS	$ Q = 2$
>200	95	2	CHATRCHYAN 13AB	CMS	$ Q = 1/3$
>480	95	2	CHATRCHYAN 13AB	CMS	$ Q = 2/3$
>574	95	2	CHATRCHYAN 13AB	CMS	$ Q = 1$
>685	95	2	CHATRCHYAN 13AB	CMS	$ Q = 2$
>140	95	3	CHATRCHYAN 13AR	CMS	$ Q = 1/3$
>310	95	3	CHATRCHYAN 13AR	CMS	$ Q = 2/3$

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

² CHATRCHYAN 13AB use 5.0 fb^{-1} of pp collisions at $E_{\text{cm}} = 7 \text{ TeV}$ and 18.8 fb^{-1} at $E_{\text{cm}} = 8 \text{ TeV}$. See paper for limits for $|Q| = 3, 4, \dots, 8$.

³ CHATRCHYAN 13AR use 5.0 fb^{-1} of pp collisions at $E_{\text{cm}} = 7 \text{ TeV}$.

Heavy Particle Production Cross Section

VALUE (nb)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

		1	AABOUD	17D ATLS	anomalous $W W jj, W Z jj$
		2	AABOUD	17L ATLS	$m > 870 \text{ GeV}$, $Z(\rightarrow \nu\nu) t X$
		3	SIRUNYAN	17B CMS	$t H$
		4	SIRUNYAN	17C CMS	$Z + (t \text{ or } b)$
		5	SIRUNYAN	17J CMS	$X_{5/3} \rightarrow t W$
		6	AAIJ	15BD LHCb	$m = 124\text{--}309 \text{ GeV}$
		7	AAD	13AH ATLS	$ q = (2\text{--}6)e$, $m = 50\text{--}600 \text{ GeV}$
$< 1.2 \times 10^{-3}$	95	8	AAD	11i ATLS	$ q = 10e$, $m = 0.2\text{--}1 \text{ TeV}$
$< 1.0 \times 10^{-5}$	95	9,10	AALTONEN	09Z CDF	$m > 100 \text{ GeV}$, noncolored
$< 4.8 \times 10^{-5}$	95	9,11	AALTONEN	09Z CDF	$m > 100 \text{ GeV}$, colored
$< 0.31\text{--}0.04 \times 10^{-3}$	95	12	ABAZOV	09M D0	pair production
< 0.19	95	13	AKTAS	04C H1	$m = 3\text{--}10 \text{ GeV}$
< 0.05	95	14	ABE	92J CDF	$m = 50\text{--}200 \text{ GeV}$
$< 30\text{--}130$		15	CARROLL	78 SPEC	$m = 2\text{--}2.5 \text{ GeV}$
< 100		16	LEIPUNER	73 CNTR	$m = 3\text{--}11 \text{ GeV}$

¹ AABOUD 17D search for $W W jj, W Z jj$ in pp collisions at 8 TeV with 3.2 fb^{-1} ; set limits on anomalous couplings.

² AABOUD 17L search for the pair production of heavy vector-like T quarks in the $Z(\rightarrow \nu\nu) t X$ final state.

³ SIRUNYAN 17B search for vector-like quark $pp \rightarrow TX \rightarrow t H X$ in 2.3 fb^{-1} at 13 TeV; no signal seen; limits placed.

⁴ SIRUNYAN 17C search for vector-like quark $pp \rightarrow TX \rightarrow Z + (t \text{ or } b)$ in 2.3 fb^{-1} at 13 TeV; no signal seen; limits placed.

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

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

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

⁸ AAD 11i search for production of highly ionizing massive particles in pp collisions at $E_{\text{cm}} = 7 \text{ TeV}$ with $L = 3.1 \text{ pb}^{-1}$. See their Table 5 for similar limits for $|q| = 6e$ and $17e$, Table 6 for limits on pair production cross section.

- ⁹ AALTONEN 09Z search for long-lived charged particles in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 1.0 \text{ fb}^{-1}$. 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 $0.4 < \beta < 1.0$.
- ¹⁰ Limit for weakly interacting charge-1 particle.
- ¹¹ Limit for up-quark like particle.
- ¹² ABAZOV 09M search for pair production of long-lived charged particles in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 1.1 \text{ fb}^{-1}$. 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.
- ¹³ AKTAS 04C look for charged particle photoproduction at HERA with mean c.m. energy of 200 GeV.
- ¹⁴ 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.
- ¹⁵ CARROLL 78 look for neutral, $S = -2$ dihyperon resonance in $pp \rightarrow 2K^+ X$. Cross section varies within above limits over mass range and $p_{\text{lab}} = 5.1\text{--}5.9$ GeV/ c .
- ¹⁶ 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 ($\text{cm}^2\text{sr}^{-1}\text{GeV}^{-1}$)	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	– $Q=1$, $m=2.1\text{--}9.4$ GeV
$<2.2 \times 10^{-33}$	90	² ALBROW	75	SPEC	\pm $Q=\pm 1$, $m=4\text{--}15$ GeV
$<1.1 \times 10^{-33}$	90	² ALBROW	75	SPEC	\pm $Q=\pm 2$, $m=6\text{--}27$ GeV
$<8. \times 10^{-35}$	90	³ JOVANOVO...	75	CNTR	\pm $m=15\text{--}26$ GeV
$<1.5 \times 10^{-34}$	90	³ JOVANOVO...	75	CNTR	\pm $Q=\pm 2$, $m=3\text{--}10$ GeV
$<6. \times 10^{-35}$	90	³ JOVANOVO...	75	CNTR	\pm $Q=\pm 2$, $m=10\text{--}26$ GeV
$<1. \times 10^{-31}$	90	⁴ APPEL	74	CNTR	\pm $m=3.2\text{--}7.2$ GeV
$<5.8 \times 10^{-34}$	90	⁵ ALPER	73	SPEC	\pm $m=1.5\text{--}24$ GeV
$<1.2 \times 10^{-35}$	90	⁶ ANTIPOV	71B	CNTR	– $Q=-$, $m=2.2\text{--}2.8$
$<2.4 \times 10^{-35}$	90	⁷ ANTIPOV	71C	CNTR	– $Q=-$, $m=1.2\text{--}1.7$, 2.1–4
$<2.4 \times 10^{-35}$	90	BINON	69	CNTR	– $Q=-$, $m=1\text{--}1.8$ GeV
$<1.5 \times 10^{-36}$		⁸ DORFAN	65	CNTR	Be target $m=3\text{--}7$ GeV
$<3.0 \times 10^{-36}$		⁸ DORFAN	65	CNTR	Fe target $m=3\text{--}7$ 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 $(2.1\text{--}9.4 \text{ GeV}) \times |(\text{charge})|$. Assumes stable particle interacting with matter as do antiprotons.

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

³ JOVANOVOVICH 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

<u>VALUE</u> ($\text{cm}^2/\text{GeV}^2/N$)	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>CHG</u>	<u>COMMENT</u>
● ● ● 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 $\tau = 10^{-8}-2 \times 10^{-6}$ 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 $E_{\text{cm}} = 53$ 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 $p\text{Be}$ 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
($\sigma(\text{Heavy Particle}) / \sigma(\pi)$)**

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>CHG</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
$< 10^{-8}$		¹ NAKAMURA	89	SPEC	$\pm Q = (-5/3, \pm 2)$
	0	² BUSSIÈRE	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 BUSSIÈRE 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

<u>VALUE (10^{-36}cm^2)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
< 20 to 800	¹ ALEKSEEV	76	ELEC $\tau=5$ ms to 1 day
< 200 to 2000	¹ ALEKSEEV	76B	ELEC $\tau=100$ ms to 1 day
< 1.4 to 9	² FRANKEL	75	CNTR $\tau=50$ ms to 10 hours
< 0.1 to 9	³ FRANKEL	74	CNTR $\tau=1$ 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 Search at Hadron Collisions

Limits are for cross section times branching ratio.

<u>VALUE</u> (pb/nucleon)	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		¹ SIRUNYAN	18AW CMS	Long-lived particle search
		² AAIJ	16AR LHCb	$H \rightarrow XX$ long-lived particles
		³ KHACHATRYAN	16BWCMS	direct production: HSCPs
<2	90	⁴ BADIER	86 BDMP	$\tau = (0.05-1.) \times 10^{-8}s$
¹ SIRUNYAN 18AW search for very long lived particles (LLPs) decaying hadronically or to $\mu\bar{\mu}$ in CMS detector; none seen/limits set on lifetime vs. cross section.				
² 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.				
³ KHACHATRYAN 16BW search for heavy stable charged particles via ToF with 2.5 fb^{-1} at 13 TeV; require stable $m(\text{gluinoball}) > 1610 \text{ GeV}$.				
⁴ 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 $>2 \text{ GeV}$. 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

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

<u>VALUE</u> ($\text{cm}^{-2}\text{sr}^{-1}\text{s}^{-1}$)	<u>CL%</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
< 1	$\times 10^{-8}$	90	0	¹ ALVIS	18 MAJD Fractionally charged
				² AGNESE	15 CDM2 $Q = 1/6$
~ 6	$\times 10^{-9}$		2	³ SAITO	90 $Q \simeq 14, m \simeq 370m_p$
< 1.4	$\times 10^{-12}$	90	0	⁴ MINCER	85 CALO $m \geq 1 \text{ TeV}$
				⁵ SAKUYAMA	83B PLAS $m \sim 1 \text{ TeV}$
< 1.7	$\times 10^{-11}$	99	0	⁶ BHAT	82 CC
< 1.	$\times 10^{-9}$	90	0	⁷ MARINI	82 CNTR $Q=1, m \sim 4.5m_p$
	$\times 10^{-9}$		3	⁸ YOCC	81 SPRK $Q=1, m \sim 4.5m_p$
			3	⁸ YOCC	81 SPRK Fractionally charged
3.0	$\times 10^{-9}$		3	⁹ YOCC	80 SPRK $m \sim 4.5 m_p$

$(4 \pm 1) \times 10^{-11}$		3	GOODMAN	79	ELEC	$m \geq 5 \text{ GeV}$
$< 1.3 \times 10^{-9}$	90		10 BHAT	78	CNTR	$m > 1 \text{ GeV}$
$< 1.0 \times 10^{-9}$		0	BRIATORE	76	ELEC	
$< 7. \times 10^{-10}$	90	0	YOCK	75	ELEC	$Q > 7e \text{ or } < -7e$
$> 6. \times 10^{-9}$		5	11 YOCK	74	CNTR	$m > 6 \text{ GeV}$
$< 3.0 \times 10^{-8}$		0	DARDO	72	CNTR	
$< 1.5 \times 10^{-9}$		0	TONWAR	72	CNTR	$m > 10 \text{ GeV}$
$< 3.0 \times 10^{-10}$		0	BJORNBOE	68	CNTR	$m > 5 \text{ GeV}$
$< 5.0 \times 10^{-11}$	90	0	JONES	67	ELEC	$m=5-15 \text{ GeV}$

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 $4.5m_p$ as well as 2 events with $m > 5.3m_p$, $Q = \pm 0.75 \pm 0.05$ and $m > 2.8m_p$, $Q = \pm 0.70 \pm 0.05$ 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

$\frac{VALUE}{(\text{cm}^{-2}\text{sr}^{-1}\text{s}^{-1})}$	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	$m > 5 \times 10^{14} \text{ GeV}$
$< 1.8 \times 10^{-12}$	90	3 ASTONE	93 CNTR	$m \geq 1.5 \times 10^{-13} \text{ gram}$
$< 1.1 \times 10^{-14}$	90	4 AHLEN	92 MCRO	$10^{-10} < m < 0.1 \text{ gram}$
$< 2.2 \times 10^{-14}$	90	5 NAKAMURA	91 PLAS	$m > 10^{11} \text{ GeV}$
$< 6.4 \times 10^{-16}$	90	6 ORITO	91 PLAS	$m > 10^{12} \text{ GeV}$
$< 2.0 \times 10^{-11}$	90	7 LIU	88 BOLO	$m > 1.5 \times 10^{-13} \text{ gram}$
$< 4.7 \times 10^{-12}$	90	8 BARISH	87 CNTR	$1.4 \times 10^8 < m < 10^{12} \text{ GeV}$
$< 3.2 \times 10^{-11}$	90	9 NAKAMURA	85 CNTR	$m > 1.5 \times 10^{-13} \text{ gram}$
$< 3.5 \times 10^{-11}$	90	10 ULLMAN	81 CNTR	Planck-mass 10^{19} GeV
$< 7. \times 10^{-11}$	90	10 ULLMAN	81 CNTR	$m \leq 10^{16} \text{ GeV}$

- 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 $2 \times 10^{-3}c$.
- 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

<u>VALUE</u> ($m^{-2}yr^{-1}$)	<u>CL%</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● 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

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● 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 $pp \rightarrow \ell + (\ell \text{ or jets})$
	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 $pp \rightarrow \ell + (\ell \text{ or jets})$
	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 $L = 20.3 \text{ fb}^{-1}$. 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 $L = 20 \text{ fb}^{-1}$. 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 $L = 20.3 \text{ fb}^{-1}$. 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 ≥ 2 (leptons or jets), in pp collisions at $E_{\text{cm}} = 8$ TeV with $L = 20.3 \text{ fb}^{-1}$. 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 $E_{\text{cm}} = 7$ TeV with $L = 4.8 \text{ fb}^{-1}$. 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 $E_{\text{cm}} = 7$ TeV with $L = 5 \text{ fb}^{-1}$. See their Figs. 5 and 6 for limits.
- ⁸ CHATRCHYAN 13AD search for microscopic (semiclassical) black hole formation followed by its evaporation to multiparticle final states, in multijet (including γ, ℓ) events in pp collisions at $E_{\text{cm}} = 8$ TeV with $L = 12 \text{ fb}^{-1}$. 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 ≥ 2 (leptons or jets), in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 1.04 \text{ fb}^{-1}$. See their Fig. 4 and 5 for limits.
- ¹⁰ CHATRCHYAN 12W search for microscopic (semiclassical) black hole formation followed by its evaporation to multiparticle final states, in multijet (including γ, ℓ) events in pp collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.7 \text{ fb}^{-1}$. 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 $E_{\text{cm}} = 7$ TeV with $L = 36 \text{ pb}^{-1}$. See their Fig. 11 and Table 4 for limits.

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AABOUD	18CJ	PR D98 052008	M. Aaboud <i>et al.</i>	(ATLAS Collab.)
AABOUD	18CK	PR D98 092002	M. Aaboud <i>et al.</i>	(ATLAS Collab.)
AABOUD	18CL	PR D98 092005	M. Aaboud <i>et al.</i>	(ATLAS Collab.)
AABOUD	18CM	PR D98 092008	M. Aaboud <i>et al.</i>	(ATLAS Collab.)
AABOUD	18N	PRL 121 081801	M. Aaboud <i>et al.</i>	(ATLAS Collab.)
AAIJ	18AJ	PRL 120 061801	R. Aaij <i>et al.</i>	(LHCb Collab.)
ALBERT	18C	PR D98 123012	A. Albert <i>et al.</i>	(HAWC Collab.)
ALVIS	18	PRL 120 211804	S.I. Alvis <i>et al.</i>	(MAJORANA Collab.)
BANERJEE	18	PRL 120 231802	D. Banerjee <i>et al.</i>	(NA64 Collab.)
BANERJEE	18A	PR D97 072002	D. Banerjee <i>et al.</i>	(NA64 Collab.)
KILE	18	JHEP 1810 116	J. Kile, J. von Wimmersperg-Toeller	(LISBT)
MARSICANO	18	PR D98 015031	L. Marsicano <i>et al.</i>	
PORAYKO	18	PR D98 102002	N.K. Porayako <i>et al.</i>	(PPTA Collab.)
SIRUNYAN	18AW	JHEP 1805 127	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)
SIRUNYAN	18BB	JHEP 1806 120	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)
SIRUNYAN	18DA	JHEP 1811 042	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)
SIRUNYAN	18DD	EPJ C78 789	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)
SIRUNYAN	18DJ	JHEP 1809 101	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)
SIRUNYAN	18DR	JHEP 1811 161	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)
SIRUNYAN	18DU	PR D98 092001	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)
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KHACHATRY...	17D	JHEP 1701 076	V. Khachatryan <i>et al.</i>	(CMS Collab.)
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SIRUNYAN	17F	JHEP 1707 013	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)
SIRUNYAN	17J	JHEP 1708 073	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)
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AABOUD	16	PL B759 229	M. Aaboud <i>et al.</i>	(ATLAS Collab.)
AABOUD	16P	EPJ C76 541	M. Aaboud <i>et al.</i>	(ATLAS Collab.)

AAD	16AI	JHEP 1603 041	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	16N	JHEP 1603 026	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	16O	PL B760 520	G. Aad <i>et al.</i>	(ATLAS Collab.)
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AAD	14A	PL B728 562	G. Aad <i>et al.</i>	(ATLAS Collab.)
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AAD	13AH	PL B722 305	G. Aad <i>et al.</i>	(ATLAS Collab.)
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AMBROSIO	00B	EPJ C13 453	M. Ambrosio <i>et al.</i>	(MACRO Collab.)
ABE	99F	PRL 82 2038	F. Abe <i>et al.</i>	(CDF Collab.)
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ABE	97G	PR D55 5263	F. Abe <i>et al.</i>	(CDF Collab.)
ABREU	97D	PL B396 315	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACKERSTAFF	97B	PL B391 210	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ADAMS	97B	PRL 79 4083	J. Adams <i>et al.</i>	(FNAL KTeV Collab.)

BARATE	97K	PL B405 379	R. Barate <i>et al.</i>	(ALEPH Collab.)
AKERS	95R	ZPHY C67 203	R. Akers <i>et al.</i>	(OPAL Collab.)
GALLAS	95	PR D52 6	E. Gallas <i>et al.</i>	(MSU, FNAL, MIT, FLOR)
RAM	94	PR D49 3120	S. Ram <i>et al.</i>	(TELA, TRIU)
ABE	93G	PRL 71 2542	F. Abe <i>et al.</i>	(CDF Collab.)
ASTONE	93	PR D47 4770	P. Astone <i>et al.</i>	(ROMA, ROMAI, CATA, FRAS)
BUSKULIC	93C	PL B303 198	D. Buskulic <i>et al.</i>	(ALEPH Collab.)
YAMAGATA	93	PR D47 1231	T. Yamagata, Y. Takamori, H. Utsunomiya	(KONAN)
ABE	92J	PR D46 1889	F. Abe <i>et al.</i>	(CDF Collab.)
AHLEN	92	PRL 69 1860	S.P. Ahlen <i>et al.</i>	(MACRO Collab.)
VERKERK	92	PRL 68 1116	P. Verkerk <i>et al.</i>	(ENSP, SACL, PAST)
AKESSON	91	ZPHY C52 219	T. Akesson <i>et al.</i>	(HELIOS Collab.)
NAKAMURA	91	PL B263 529	S. Nakamura <i>et al.</i>	
ORITO	91	PRL 66 1951	S. Orito <i>et al.</i>	(ICEPP, WASC, NIHO, ICRR)
ADACHI	90C	PL B244 352	I. Adachi <i>et al.</i>	(TOPAZ Collab.)
ADACHI	90E	PL B249 336	I. Adachi <i>et al.</i>	(TOPAZ Collab.)
AKRAWY	90O	PL B252 290	M.Z. Akrawy <i>et al.</i>	(OPAL Collab.)
HEMMICK	90	PR D41 2074	T.K. Hemmick <i>et al.</i>	(ROCH, MICH, OHIO+)
SAITO	90	PRL 65 2094	T. Saito <i>et al.</i>	(ICRR, KOBE)
NAKAMURA	89	PR D39 1261	T.T. Nakamura <i>et al.</i>	(KYOT, TMTC)
NORMAN	89	PR D39 2499	E.B. Norman <i>et al.</i>	(LBL)
BERNSTEIN	88	PR D37 3103	R.M. Bernstein <i>et al.</i>	(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	PR 58 1403	E.B. Norman, S.B. Gazes, D.A. Bennett	(LBL)
BADIER	86	ZPHY C31 21	J. Badier <i>et al.</i>	(NA3 Collab.)
MINCER	85	PR D32 541	A. Mincer <i>et al.</i>	(UMD, GMAS, NSF)
NAKAMURA	85	PL 161B 417	K. Nakamura <i>et al.</i>	(KEK, INUS)
THRON	85	PR D31 451	J.L. Thron <i>et al.</i>	(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 <i>et al.</i>	(TATA)
KINOSHITA	82	PRL 48 77	K. Kinoshita, P.B. Price, D. Fryberger	(UCB+)
MARINI	82	PR D26 1777	A. Marini <i>et al.</i>	(FRAS, LBL, NWES, STAN+)
SMITH	82B	NP B206 333	P.F. Smith <i>et al.</i>	(RAL)
KINOSHITA	81B	PR D24 1707	K. Kinoshita, P.B. Price	(UCB)
LOSECCO	81	PL 102B 209	J.M. LoSecco <i>et al.</i>	(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 <i>et al.</i>	(JADE Collab.)
BUSSIERE	80	NP B174 1	A. Bussiere <i>et al.</i>	(BGNA, SACL, LAPP)
YOCK	80	PR D22 61	P.C.M. Yock	(AUCK)
ARMITAGE	79	NP B150 87	J.C.M. Armitage <i>et al.</i>	(CERN, DARE, FOM+)
BOZZOLI	79	NP B159 363	W. Bozzoli <i>et al.</i>	(BGNA, LAPP, SACL+)
GOODMAN	79	PR D19 2572	J.A. Goodman <i>et al.</i>	(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 <i>et al.</i>	(BNL, PRIN)
CUTTS	78	PRL 41 363	D. Cutts <i>et al.</i>	(BROW, FNAL, ILL, BARI+)
VIDAL	78	PL 77B 344	R.A. Vidal <i>et al.</i>	(COLU, FNAL, STON+)
ALEKSEEV	76	SJNP 22 531	G.D. Alekseev <i>et al.</i>	(JINR)
ALEKSEEV	76B	Translated from YAF 22 1021.	G.D. Alekseev <i>et al.</i>	(JINR)
BALDIN	76	SJNP 23 633	G.D. Alekseev <i>et al.</i>	(JINR)
		Translated from YAF 23 1190.		
		SJNP 22 264	B.Y. Baldin <i>et al.</i>	(JINR)
		Translated from YAF 22 512.		
BRIATORE	76	NC 31A 553	L. Briatore <i>et al.</i>	(LCGT, FRAS, FREIB)
GUSTAFSON	76	PRL 37 474	H.R. Gustafson <i>et al.</i>	(MICH)
ALBROW	75	NP B97 189	M.G. Albrow <i>et al.</i>	(CERN, DARE, FOM+)
FRANKEL	75	PR D12 2561	S. Frankel <i>et al.</i>	(PENN, FNAL)
JOVANOV...	75	PL 56B 105	J.V. Jovanovich <i>et al.</i>	(MANI, AACH, CERN+)
YOCK	75	NP B86 216	P.C.M. Yock	(AUCK, SLAC)
APPEL	74	PRL 32 428	J.A. Appel <i>et al.</i>	(COLU, FNAL)
FRANKEL	74	PR D9 1932	S. Frankel <i>et al.</i>	(PENN, FNAL)
YOCK	74	NP B76 175	P.C.M. Yock	(AUCK)
ALPER	73	PL 46B 265	B. Alper <i>et al.</i>	(CERN, LIVP, LUND, BOHR+)
LEIPUNER	73	PRL 31 1226	L.B. Leipuner <i>et al.</i>	(BNL, YALE)
DARDO	72	NC 9A 319	M. Dardo <i>et al.</i>	(TORI)
TONWAR	72	JP A5 569	S.C. Tonwar, S. Naranan, B.V. Sreekantan	(TATA)
ANTIPOV	71B	NP B31 235	Y.M. Antipov <i>et al.</i>	(SERP)

ANTIPOV	71C	PL 34B 164	Y.M. Antipov <i>et al.</i>	(SERP)
BINON	69	PL 30B 510	F.G. Binon <i>et al.</i>	(SERP)
BJORNBOE	68	NC B53 241	J. Bjornboe <i>et al.</i>	(BOHR, TATA, BERN+)
JONES	67	PR 164 1584	L.W. Jones	(MICH, WISC, LBL, UCLA, MINN+)
DORFAN	65	PRL 14 999	D.E. Dorfan <i>et al.</i>	(COLU)
