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

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

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<2 \times 10^{-3}$	90		[14] BUSKULIC	93C	ALEP	Q=1, m=32–72 GeV
$<(10^{-2}$–$1)$	95		[15] ADACHI	90C	TOPZ	Q = 1, m = 1–16, 18–27 GeV
$<7 \times 10^{-2}$	90		[16] ADACHI	90E	TOPZ	Q = 1, m = 5–25 GeV
$<1.6 \times 10^{-2}$	95	0	[17] KINOSHITA	82	PLAS	Q=3–180, m <14.5 GeV
$<5.0 \times 10^{-2}$	90	0	[18] BARTEL	80	JADE	Q=(3,4,5)/3 2–12 GeV

[14] BUSKULIC 93C is a CERN-LEP experiment with $W_{cm} = m_Z$. 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.

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

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

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

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

Heavy Particle Production Cross Section in $p\overline{p}$

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. • • •						
<2603	95	200	[19] ABE	93G	CDF	1.8 TeV $p\overline{p} \rightarrow$ 2jets
< 44	95	400	[19] ABE	93G	CDF	1.8 TeV $p\overline{p} \rightarrow$ 2jets
< 7	95	600	[19] ABE	93G	CDF	1.8 TeV $p\overline{p} \rightarrow$ 2jets

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

Heavy Particle Production Cross Section

VALUE (nb)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.05	95		[20] ABE	92J	CDF	m=50–200 GeV
<30–130			[21] CARROLL	78	SPEC	m=2–2.5 GeV
<100		0	[22] LEIPUNER	73	CNTR	m=3–11 GeV

[20] 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.

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

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

Heavy Particle Production Cross Section

VALUE (cm^2/N)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$<(4$–$0.3) \times 10^{-31}$	95		[23] AKESSON	91	CNTR	0	m = 0–5 GeV
$<2.5 \times 10^{-35}$		0	[24] GUSTAFSON	76	CNTR	0	$\tau > 10^{-7}$ s

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

[24] 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.

Heavy Particle Production Differential Cross Section

VALUE (cm^{2}sr^{-1}GeV^{-1})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$<2.6 \times 10^{-36}$	90	0	[25] BALDIN	76	CNTR	$-$	Q= 1, m=2.1–9.4 GeV
$<2.2 \times 10^{-33}$	90	0	[26] ALBROW	75	SPEC	$\pm$	Q= $\pm$1, m=4–15 GeV
$<1.1 \times 10^{-33}$	90	0	[26] ALBROW	75	SPEC	$\pm$	Q= $\pm$2, m=6–27 GeV
$<8. \times 10^{-35}$	90	0	[27] JOVANOV...	75	CNTR	$\pm$	m=15–26 GeV
$<1.5 \times 10^{-34}$	90	0	[27] JOVANOV...	75	CNTR	$\pm$	Q= $\pm$2, m=3–10 GeV
$<6. \times 10^{-35}$	90	0	[27] JOVANOV...	75	CNTR	$\pm$	Q= $\pm$2, m=10–26 GeV
$<1. \times 10^{-31}$	90	0	[28] APPEL	74	CNTR	$\pm$	m=3.2–7.2 GeV
$<5.8 \times 10^{-34}$	90	0	[29] ALPER	73	SPEC	$\pm$	m=1.5–24 GeV
$<1.2 \times 10^{-35}$	90	0	[30] ANTIPOV	71B	CNTR	$-$	Q=$-$, m=2.2–2.8
$<2.4 \times 10^{-35}$	90	0	[31] ANTIPOV	71C	CNTR	$-$	Q=$-$, m=1.2–1.7, 2.1–4
$<2.4 \times 10^{-35}$	90	0	BINON	69	CNTR	$-$	Q=$-$, m=1–1.8 GeV
$<1.5 \times 10^{-36}$		0	[32] DORFAN	65	CNTR		Be target m=3–7 GeV
$<3.0 \times 10^{-36}$		0	[32] DORFAN	65	CNTR		Fe target m=3–7 GeV

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

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

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

[28] 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.

[29] ALPER 73 is CERN ISR 26+26 GeV pp experiment. p >0.9 GeV, 0.2 < β <0.65.

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

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

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

Long-Lived Heavy Particle Invariant Cross Section

VALUE (cm^2/GeV^2/N)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$< 5 \times 10^{-35}$–7×10^{-33}	90	0	[33] BERNSTEIN	88	CNTR		
$< 5 \times 10^{-37}$–7×10^{-35}	90	0	[33] BERNSTEIN	88	CNTR		
$<2.5 \times 10^{-36}$	90	0	[34] THRON	85	CNTR	$-$	Q= 1, m=4–12 GeV
$<1. \times 10^{-35}$	90	1	[34] THRON	85	CNTR	+	Q= 1, m=4–12 GeV
$<6. \times 10^{-33}$	90	0	[35] ARMITAGE	79	SPEC		m=1.87 GeV
$<1.5 \times 10^{-33}$	90	0	[35] ARMITAGE	79	SPEC		m=1.5–3.0 GeV
		0	[36] BOZZOLI	79	CNTR	$\pm$	Q = (2/3, 1, 4/3, 2)
$<1.1 \times 10^{-37}$	90	0	[37] CUTTS	78	CNTR		m=4–10 GeV
$<3.0 \times 10^{-37}$	90	0	[38] VIDAL	78	CNTR		m=4.5–6 GeV

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

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

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

[36] 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.

[37] CUTTS 78 is pBe experiment at FNAL sensitive to particles of $\tau > 5 \times 10^{-8}$ s. Value is for $-0.3 < x < 0$ and p_T = 0.175.

[38] VIDAL 78 is FNAL 400 GeV proton experiment. Value is for x = 0 and p_T = 0. Puts lifetime limit of $< 5 \times 10^{-8}$ s on particle in this mass range.

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

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<10^{-8}$		[39] NAKAMURA	89	SPEC	$\pm$	Q= ($-$5/3,$\pm$2)
	0	[40] BUSSIERE	80	CNTR	$\pm$	Q= (2/3,1,4/3,2)

[39] 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.

[40] BUSSIERE 80 is CERN-SPS experiment with 200–240 GeV protons on Be and Al target. See their figures 6 and 7 for cross-section ratio vs mass.

Production and Capture of Long-Lived Massive Particles

VALUE (10^{-36} cm^2)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<20 to 800	0	[41] ALEKSEEV	76	ELEC	τ=5 ms to 1 day
<200 to 2000	0	[41] ALEKSEEV	76B	ELEC	τ=100 ms to 1 day
<1.4 to 9	0	[42] FRANKEL	75	CNTR	τ=50 ms to 10 hours
<0.1 to 9	0	[43] FRANKEL	74	CNTR	τ=1 to 1000 hours

[41] ALEKSEEV 76 and ALEKSEEV 76B are 61–70 GeV p Serpukhov experiment. Cross section is per Pb nucleus.

[42] FRANKEL 75 is extension of FRANKEL 74.

[43] FRANKEL 74 looks for particles produced in thick Al targets by 300–400 GeV/c protons.