Free Quark Searches

NODE=S027
NODE=S027

FREE QUARK SEARCHES

Quarks are fractionally charged particles, the constituents of hadrons, with charges 1/3 e or 2/3 e. The charge of every known charged system is an integer multiple of 1/3 e. Quantum Chromodynamics predicts that quarks cannot be observed as freely propagating particles, being confined inside hadrons or deconfined in quark-gluon plasma (QGP). We observe the top quark decaying as still free, because its lifetime is too short to allow its hadronization. Experiments have produced no evidence for free propagating quarks.

Reviews can be found in Refs. 1–5.

References

1. M.L. Perl, E.R. Lee, and D. Lomba, Mod. Phys. Lett. **A19**, 2595 (2004).
2. P.F. Smith, Ann. Rev. Nucl. and Part. Sci. **39**, 73 (1989).
3. L. Lyons, Phys. Reports **129**, 225 (1985).
4. M. Marinelli and G. Morpurgo, Phys. Reports **85**, 161 (1982).
5. L.W. Jones, Rev. Mod. Phys. **49**, 717 (1977).

Quark Production Cross Section — Accelerator Searches

NODE=S027C
NODE=S027C

X-SECT (cm^2)	CHG (e/3)	MASS (GeV)	ENERGY (GeV)	BEAM	EVTS	DOCUMENT ID		TECN	
<1.7-2.3E−39	±2	100–600	7000	pp	0	[1] CHATRCHYAN	13AR	CMS	
<14-5.4E−39	±1	100–600	7000	pp	0	[1] CHATRCHYAN	13AR	CMS	OCCUR=2
<1.3E−36	±2	45–84	130–172	e^+e^-	0	ABREU	97D	DLPH	
<2.E−35	+2	250	1800	$p\overline{p}$	0	[2] ABE	92J	CDF	
<1.E−35	+4	250	1800	$p\overline{p}$	0	[2] ABE	92J	CDF	OCCUR=2
<3.8E−28			14.5A	^{28}Si–Pb	0	[3] HE	91	PLAS	
<3.2E−28			14.5A	^{28}Si–Cu	0	[3] HE	91	PLAS	OCCUR=2
<1.E−40	±1,2	<10		$p,\nu,\overline{\nu}$	0	BERGSMA	84B	CHRM	
<1.E−36	±1,2	<9	200	μ	0	AUBERT	83C	SPEC	
<2.E−10	±2,4	1–3	200	p	0	[4] BUSSIERE	80	CNTR	
<5.E−38	+1,2	>5	300	p	0	[5,6] STEVENSON	79	CNTR	
<1.E−33	±1	<20	52	pp	0	BASILE	78	SPEC	
<9.E−39	±1,2	<6	400	p	0	[5] ANTREASYAN	77	SPEC	
<8.E−35	+1,2	<20	52	pp	0	[7] FABJAN	75	CNTR	
<5.E−38	−1,2	4–9	200	p	0	NASH	74	CNTR	
<1.E−32	+2,4	4–24	52	pp	0	ALPER	73	SPEC	
<5.E−31	+1,2,4	<12	300	p	0	LEIPUNER	73	CNTR	
<6.E−34	±1,2	<13	52	pp	0	BOTT	72	CNTR	
<1.E−36	−4	4	70	p	0	ANTIPOV	71	CNTR	
<1.E−35	±1,2	2	28	p	0	[8] ALLABY	69B	CNTR	
<4.E−37	−2	<5	70	p	0	[4] ANTIPOV	69	CNTR	
<3.E−37	−1,2	2–5	70	p	0	[8] ANTIPOV	69B	CNTR	
<1.E−35	+1,2	<7	30	p	0	DORFAN	65	CNTR	
<2.E−35	−2	< 2.5–5	30	p	0	[9] FRANZINI	65B	CNTR	
<5.E−35	+1,2	<2.2	21	p	0	BINGHAM	64	HLBC	
<1.E−32	+1,2	<4.0	28	p	0	BLUM	64	HBC	
<1.E−35	+1,2	<2.5	31	p	0	[9] HAGOPIAN	64	HBC	
<1.E−34	+1	<2	28	p	0	LEIPUNER	64	CNTR	
<1.E−33	+1,2	<2.4	24	p	0	MORRISON	64	HBC	

[1] CHATRCHYAN 13AR limits assume pair-produced long-lived spin-1/2 particles neutral under $SU(3)_C$ and $SU(2)_L$. NODE=S027C;LINKAGE=G
[2] ABE 92J flux limits decrease as the mass increases from 50 to 500 GeV. NODE=S027C;LINKAGE=AA
[3] HE 91 limits are for charges of the form $N\pm1/3$ from 23/3 to 38/3. NODE=S027C;LINKAGE=QH
[4] Hadronic or leptonic quarks. NODE=S027C;LINKAGE=C
[5] Cross section cm^2/GeV^2. NODE=S027C;LINKAGE=E
[6] 3×10^{-5} <lifetime $< 1\times10^{-3}$ s. NODE=S027C;LINKAGE=F
[7] Includes BOTT 72 results. NODE=S027C;LINKAGE=D
[8] Assumes isotropic cm production. NODE=S027C;LINKAGE=B
[9] Cross section inferred from flux. NODE=S027C;LINKAGE=A

Quark Differential Production Cross Section — Accelerator Searches

NODE=S027D
NODE=S027D

X-SECT ($cm^2 sr^{-1} GeV^{-1}$)	CHG e/3	MASS (GeV)	ENERGY (GeV)	BEAM	EVTS	DOCUMENT ID		TECN
<4.E−36	−2,4	1.5–6	70	p	0	BALDIN	76	CNTR
<2.E−33	±4	5–20	52	pp	0	ALBROW	75	SPEC
<5.E−34	<7	7–15	44	pp	0	JOVANOV...	75	CNTR
<5.E−35			20	γ	0	[1] GALIK	74	CNTR
<9.E−35	−1,2		200	p	0	NASH	74	CNTR
<4.E−36	−4	2.3–2.7	70	p	0	ANTIPOV	71	CNTR
<3.E−35	±1,2	<2.7	27	p	0	ALLABY	69B	CNTR
<7.E−38	−1,2	<2.5	70	p	0	ANTIPOV	69B	CNTR

[1] Cross section in cm^2/sr/equivalent quanta. NODE=S027D;LINKAGE=A

Quark Flux — Accelerator Searches

NODE=S027FR

The definition of FLUX depends on the experiment NODE=S027FR

(a) is the ratio of measured free quarks to predicted free quarks if there is no "confinement."
(b) is the probability of fractional charge on nuclear fragments. Energy is in GeV/nucleon.
(c) is the 90%CL upper limit on fractionally-charged particles produced per interaction.
(d) is quarks per collision.
(e) is inclusive quark-production cross-section ratio to $\sigma(e^+e^- \to \mu^+\mu^-)$.
(f) is quark flux per charged particle.
(g) is the flux per ν-event.
(h) is quark yield per π^- yield.
(i) is 2-body exclusive quark-production cross-section ratio to $\sigma(e^+e^- \to \mu^+\mu^-)$.

NODE=S027FR

FLUX		CHG (e/3)	MASS (GeV)	ENRGY (GeV)	BEAM	EVTS	DOCUMENT ID		TECN	
<1.6E−3	b	see note		200	^{32}S–Pb	0	[1] HUENTRUP	96	PLAS	
<6.2E−4	b	see note		10.6	^{32}S–Pb	0	[1] HUENTRUP	96	PLAS	OCCUR=2
<0.94E−4	e	±2	2–30	88–94	e^+e^-	0	AKERS	95R	OPAL	OCCUR=2
<1.7E−4	e	±2	30–40	88–94	e^+e^-	0	AKERS	95R	OPAL	OCCUR=3
<3.6E−4	e	±4	5–30	88–94	e^+e^-	0	AKERS	95R	OPAL	OCCUR=4
<1.9E−4	e	±4	30–45	88–94	e^+e^-	0	AKERS	95R	OPAL	OCCUR=5
<2.E−3	e	+1	5–40	88–94	e^+e^-	0	[2] BUSKULIC	93C	ALEP	
<6.E−4	e	+2	5–30	88–94	e^+e^-	0	[2] BUSKULIC	93C	ALEP	OCCUR=2
<1.2E−3	e	+4	15–40	88–94	e^+e^-	0	[2] BUSKULIC	93C	ALEP	OCCUR=3
<3.6E−4	i	+4	5.0–10.2	88–94	e^+e^-	0	BUSKULIC	93C	ALEP	OCCUR=4
<3.6E−4	i	+4	16.5–26.0	88–94	e^+e^-	0	BUSKULIC	93C	ALEP	OCCUR=5
<6.9E−4	i	+4	26.0–33.3	88–94	e^+e^-	0	BUSKULIC	93C	ALEP	OCCUR=6
<9.1E−4	i	+4	33.3–38.6	88–94	e^+e^-	0	BUSKULIC	93C	ALEP	OCCUR=7
<1.1E−3	i	+4	38.6–44.9	88–94	e^+e^-	0	BUSKULIC	93C	ALEP	OCCUR=8
<1.6E−4	b	see note		see note		0	[3] CECCHINI	93	PLAS	
	b	4,5,7,8		2.1A	^{16}O	0,2,0,6	[4] GHOSH	92	EMUL	
<6.4E−5	g	1			$\nu,\overline{\nu}$	1	[5] BASILE	91	CNTR	
<3.7E−5	g	2			$\nu,\overline{\nu}$	0	[5] BASILE	91	CNTR	OCCUR=2
<3.9E−5	g	1			$\nu,\overline{\nu}$	1	[6] BASILE	91	CNTR	OCCUR=3
<2.8E−5	g	2			$\nu,\overline{\nu}$	0	[6] BASILE	91	CNTR	OCCUR=4
<1.9E−4	c			14.5A	^{28}Si–Pb	0	[7] HE	91	PLAS	
<3.9E−4	c			14.5A	^{28}Si–Cu	0	[7] HE	91	PLAS	OCCUR=2
<1.E−9	c	±1,2,4		14.5A	^{16}O–Ar	0	MATIS	91	MDRP	
<5.1E−10	c	±1,2,4		14.5A	^{16}O–Hg	0	MATIS	91	MDRP	OCCUR=2
<8.1E−9	c	±1,2,4		14.5A	Si–Hg	0	MATIS	91	MDRP	OCCUR=3

<1.7E−6	c	±1,2,4		60A	^{16}O–Hg	0	MATIS	91	MDRP	OCCUR=4
<3.5E−7	c	±1,2,4		200A	^{16}O–Hg	0	MATIS	91	MDRP	OCCUR=5
<1.3E−6	c	±1,2,4		200A	S–Hg	0	MATIS	91	MDRP	OCCUR=6
<5E−2	e	2	19–27	52–60	e^+e^-	0	ADACHI	90C	TOPZ	
<5E−2	e	4	<24	52–60	e^+e^-	0	ADACHI	90C	TOPZ	OCCUR=2
<1.E−4	e	+2	<3.5	10	e^+e^-	0	BOWCOCK	89B	CLEO	
<1.E−6	d	±1,2		60	^{16}O–Hg	0	CALLOWAY	89	MDRP	
<3.5E−7	d	±1,2		200	^{16}O–Hg	0	CALLOWAY	89	MDRP	OCCUR=2
<1.3E−6	d	±1,2		200	S–Hg	0	CALLOWAY	89	MDRP	OCCUR=3
<1.2E−10	d	±1	1	800	p–Hg	0	MATIS	89	MDRP	
<1.1E−10	d	±2	1	800	p–Hg	0	MATIS	89	MDRP	OCCUR=2
<1.2E−10	d	±1	1	800	p–N_2	0	MATIS	89	MDRP	OCCUR=3
<7.7E−11	d	±2	1	800	p–N_2	0	MATIS	89	MDRP	OCCUR=4
<6.E−9	h	−5	0.9–2.3	12	p	0	NAKAMURA	89	SPEC	
<5.E−5	g	1,2	<0.5		$\nu,\overline{\nu}d$	0	ALLASIA	88	BEBC	
<3.E−4	b	See note		14.5	^{16}O–Pb	0	[8] HOFFMANN	88	PLAS	
<2.E−4	b	See note		200	^{16}O–Pb	0	[9] HOFFMANN	88	PLAS	OCCUR=2
<8E−5	b	19,20,22,23		200A			GERBIER	87	PLAS	
<2.E−4	a	±1,2	<300	320	$\overline{p}p$	0	LYONS	87	MLEV	
<1.E−9	c	±1,2,4,5		14.5	^{16}O–Hg	0	SHAW	87	MDRP	
<3.E−3	d	−1,2,3,4,6	<5	2	Si–Si	0	[10] ABACHI	86C	CNTR	
<1.E−4	e	±1,2,4	<4	10	e^+e^-	0	ALBRECHT	85G	ARG	
<6.E−5	b	±1,2	1	540	$p\overline{p}$	0	BANNER	85	UA2	
<5.E−3	e	−4	1–8	29	e^+e^-	0	AIHARA	84	TPC	
<1.E−2	e	±1,2	1–13	29	e^+e^-	0	AIHARA	84B	TPC	
<2.E−4	b	±1		72	^{40}Ar	0	[11] BARWICK	84	CNTR	
<1.E−4	e	±2	<0.4	1.4	e^+e^-	0	BONDAR	84	OLYA	
<5.E−1	e	±1,2	<13	29	e^+e^-	0	GURYN	84	CNTR	
<3.E−3	b	±1,2	<2	540	$p\overline{p}$	0	BANNER	83	CNTR	
<1.E−4	b	±1,2		106	^{56}Fe	0	LINDGREN	83	CNTR	
<3.E−3	b	$>\lvert\pm 0.1\rvert$		74	^{40}Ar	0	[11] PRICE	83	PLAS	
<1.E−2	e	±1,2	<14	29	e^+e^-	0	MARINI	82B	CNTR	
<8.E−2	e	±1,2	<12	29	e^+e^-	0	ROSS	82	CNTR	
<3.E−4	e	±2	1.8–2	7	e^+e^-	0	WEISS	81	MRK2	
<5.E−2	e	+1,2,4,5	2–12	27	e^+e^-	0	BARTEL	80	JADE	
<2.E−5	g	1,2			ν	0	[5,6] BASILE	80	CNTR	
<3.E−10	f	±2,4	1–3	200	p	0	[12] BOZZOLI	79	CNTR	
<6.E−11	f	±1	<21	52	pp	0	BASILE	78	SPEC	
<5.E−3	g				ν_μ	0	BASILE	78B	CNTR	
<2.E−9	f	±1	<26	62	pp	0	BASILE	77	SPEC	
<7.E−10	f	+1,2	<20	52	p	0	[13] FABJAN	75	CNTR	
		+1,2	>4.5		γ	0	[5,6] GALIK	74	CNTR	
		+1,2	>1.5	12	e^-	0	[5,6] BELLAMY	68	CNTR	
		+1,2	>0.9		γ	0	[6] BATHOW	67	CNTR	
		+1,2	>0.9	6	γ	0	[6] FOSS	67	CNTR	

[1] HUENTRUP 96 quote 95% CL limits for production of fragments with charge differing by as much as ±1/3 (in units of e) for charge $6 \leq Z \leq 10$. NODE=S027FR;LINKAGE=K

[2] BUSKULIC 93C limits for inclusive quark production are more conservative if the ALEPH hadronic fragmentation function is assumed. NODE=S027FR;LINKAGE=G

[3] CECCHINI 93 limit at 90%CL for $23/3 \leq Z \leq 40/3$, for 16A GeV O, 14.5A Si, and 200A S incident on Cu target. Other limits are 2.3×10^{-4} for $17/3 \leq Z \leq 20/3$ and 1.2×10^{-4} for $20/3 \leq Z \leq 23/3$. NODE=S027FR;LINKAGE=Q1

[4] GHOSH 92 reports measurement of spallation fragment charge based on ionization in emulsion. Out of 650 measured tracks, 2 were consistent with charge $5e/3$, and 4 with $7e/3$. NODE=S027FR;LINKAGE=H

[5] Hadronic quark. NODE=S027FR;LINKAGE=B

[6] Leptonic quark. NODE=S027FR;LINKAGE=A

[7] HE 91 limits are for charges of the form $N\pm1/3$ from 23/3 to 38/3, and correspond to cross-section limits of 380μb (Pb) and 320μb (Cu). NODE=S027FR;LINKAGE=QH

[8] The limits apply to projectile fragment charges of 17, 19, 20, 22, 23 in units of $e/3$. NODE=S027FR;LINKAGE=H1

[9] The limits apply to projectile fragment charges of 16, 17, 19, 20, 22, 23 in units of $e/3$. NODE=S027FR;LINKAGE=H2

[10] Flux limits and mass range depend on charge. NODE=S027FR;LINKAGE=F

[11] Bound to nuclei. NODE=S027FR;LINKAGE=I

[12] Quark lifetimes $> 1 \times 10^{-8}$ s. NODE=S027FR;LINKAGE=D

[13] One candidate m <0.17 GeV. NODE=S027FR;LINKAGE=C

Quark Flux — Cosmic Ray Searches

NODE=S027F

Shielding values followed with an asterisk indicate altitude in km. Shielding values not followed with an asterisk indicate sea level in kg/cm^2.

NODE=S027F

NODE=S027F

FLUX ($cm^{-2}sr^{-1}s^{-1}$)	*CHG* ($e/3$)	*MASS* (GeV)	*SHIELDING*	*DOCUMENT ID*		*TECN*	
< 6.2E−10	±2			[1] ALEMANNO	22	DAMP	
< 1.E−8	±1/6–1/10			[2] AGNESE	15	CDMS	
< 9.2E−15	±1		3800	[3] AMBROSIO	00C	MCRO	
<2.1E−15	±1			MORI	91	KAM2	
<2.3E−15	±2			MORI	91	KAM2	OCCUR=2
<2.E−10	±1, 2		0.3	WADA	88	CNTR	
	±4		0.3	[4] WADA	88	CNTR	OCCUR=3
	±4		0.3	[5] WADA	86	CNTR	
<1.E−12	±2,3/2		−70.	[6] KAWAGOE	84B	PLAS	
<9.E−10	±1,2		0.3	WADA	84B	CNTR	
<4.E−9	±4		0.3	WADA	84B	CNTR	OCCUR=2
<2.E−12	±1,2,3		−0.3 *	MASHIMO	83	CNTR	
<3.E−10	±1,2		0.3	MARINI	82	CNTR	
<2.E−11	±1,2			MASHIMO	82	CNTR	
<8.E−10	±1,2		0.3	[6] NAPOLITANO	82	CNTR	
				[7] YOCK	78	CNTR	
<1.E−9				[8] BRIATORE	76	ELEC	
<2.E−11	+1			[9] HAZEN	75	CC	
<2.E−10	+1,2			KRISOR	75	CNTR	
<1.E−7	+1,2			[9,10] CLARK	74B	CC	
<3.E−10	+1	>20		KIFUNE	74	CNTR	
<8.E−11	+1			[9] ASHTON	73	CNTR	
<2.E−8	+1,2			HICKS	73B	CNTR	
<5.E−10	+4		2.8 *	BEAUCHAMP	72	CNTR	
<1.E−10	+1,2			[9] BOHM	72B	CNTR	
<1.E−10	+1,2		2.8 *	COX	72	ELEC	
<3.E−10	+2			CROUCH	72	CNTR	
<3.E−8			7	[8] DARDO	72	CNTR	
<4.E−9	+1			[9] EVANS	72	CC	
<2.E−9		>10		[8] TONWAR	72	CNTR	
<2.E−10	+1		2.8 *	CHIN	71	CNTR	
<3.E−10	+1,2			[9] CLARK	71B	CC	
<1.E−10	+1,2			[9] HAZEN	71	CC	
<5.E−10	+1,2		3.5 *	BOSIA	70	CNTR	
	+1,2	<6.5		[9] CHU	70	HLBC	
<2.E−9	+1			FAISSNER	70B	CNTR	
<2.E−10	+1,2		0.8 *	KRIDER	70	CNTR	
<5.E−11	+2			CAIRNS	69	CC	
<8.E−10	+1,2	<10		FUKUSHIMA	69	CNTR	
	+2			[9,11] MCCUSKER	69	CC	
<1.E−10		>5	1.7,3.6	[8] BJORNBOE	68	CNTR	
<1.E−8	±1,2,4		6.3,.2 *	[6] BRIATORE	68	CNTR	
<3.E−8		>2		FRANZINI	68	CNTR	
<9.E−11	±1,2			GARMIRE	68	CNTR	
<4.E−10	±1			HANAYAMA	68	CNTR	
<3.E−8		>15		KASHA	68	OSPK	
<2.E−10	+2			KASHA	68B	CNTR	
<2.E−10	+4			KASHA	68C	CNTR	
<2.E−10	+2		6	BARTON	67	CNTR	
<2.E−7	+4		0.008,0.5 *	BUHLER	67	CNTR	
<5.E−10	1,2		0.008,0.5 *	BUHLER	67B	CNTR	
<4.E−10	+1,2			GOMEZ	67	CNTR	
<2.E−9	+2			KASHA	67	CNTR	
<2.E−10	+2		220	BARTON	66	CNTR	
<2.E−9	+1,2		0.5 *	BUHLER	66	CNTR	
<3.E−9	+1,2			KASHA	66	CNTR	
<2.E−9	+1,2			LAMB	66	CNTR	
<2.E−8	+1,2	>7	2.8 *	DELISE	65	CNTR	
<5.E−8	+2	>2.5	0.5 *	MASSAM	65	CNTR	
<2.E−8	+1		2.5 *	BOWEN	64	CNTR	
<2.E−7	+1		0.8	SUNYAR	64	CNTR	

[1] ALEMANNO 22 uses data from the DAMPE satellite, with calorimetry and tracking to search for fractionally charged particles with $q = \pm 2/3e$ with a exposure time of 2.3×10^7 s. NODE=S027F;LINKAGE=J

[2] See AGNESE 15 Fig.6 for limits on vertical density as function of charge extending to $|q|/e < 1/10$. NODE=S027F;LINKAGE=I

[3] AMBROSIO 00C limit is below 11×10^{-15} for $0.25 < q/e < 0.5$, and is changing rapidly near q/e=2/3, where it is 2×10^{-14}. NODE=S027F;LINKAGE=MC

[4] Distribution in celestial sphere was described as anisotropic. NODE=S027F;LINKAGE=H

[5] With telescope axis at zenith angle 40° to the south. NODE=S027F;LINKAGE=G

[6] Leptonic quarks. NODE=S027F;LINKAGE=C

[7] Lifetime $> 10^{-8}$ s; charge ±0.70, 0.68, 0.42; and mass >4.4, 4.8, and 20 GeV, respectively. NODE=S027F;LINKAGE=F

[8] Time delayed air shower search. NODE=S027F;LINKAGE=A

[9] Prompt air shower search. NODE=S027F;LINKAGE=B

[10] Also $e/4$ and $e/6$ charges. NODE=S027F;LINKAGE=E

[11] No events in subsequent experiments. NODE=S027F;LINKAGE=D

Quark Density — Matter Searches

NODE=S027RHO
NODE=S027RHO

QUARKS/ NUCLEON	CHG (e/3)	MASS (GeV)	MATERIAL/METHOD	EVTS	DOCUMENT ID	
<1.17E−22			silicone oil drops	0	[1] LEE 02	
<4.71E−22			silicone oil drops	1	[2] HALYO 00	
<4.7E−21	±1,2		silicone oil drops	0	MAR 96	
<8.E−22	+2		Si/infrared photoionization	0	PERERA 93	
<5.E−27	±1,2		sea water/levitation	0	HOMER 92	
<4.E−20	±1,2		meteorites/mag. levitation	0	JONES 89	
<1.E−19	±1,2		various/spectrometer	0	MILNER 87	
<5.E−22	±1,2		W/levitation	0	SMITH 87	
<3.E−20	+1,2		org liq/droplet tower	0	VANPOLEN 87	
<6.E−20	−1,2		org liq/droplet tower	0	VANPOLEN 87	OCCUR=2
<3.E−21	±1		Hg drops-untreated	0	SAVAGE 86	
<3.E−22	±1,2		levitated niobium	0	SMITH 86	
<2.E−26	±1,2		^{4}He/levitation	0	SMITH 86B	
<2.E−20	>±1	0.2–250	niobium+tungs/ion	0	MILNER 85	
<1.E−21	±1		levitated niobium	0	SMITH 85	
	+1,2	<100	niobium/mass spec	0	KUTSCHERA 84	
<5.E−22			levitated steel	0	MARINELLI 84	
<9.E−20	± <13		water/oil drop	0	JOYCE 83	
<2.E−21	$> \lvert \pm 1/2 \rvert$		levitated steel	0	LIEBOWITZ 83	
<1.E−19	±1,2		photo ion spec	0	VANDESTEEG 83	
<2.E−20			mercury/oil drop	0	[3] HODGES 81	
1.E−20	+1		levitated niobium	4	[4] LARUE 81	
1.E−20	−1		levitated niobium	4	[4] LARUE 81	OCCUR=2
<1.E−21			levitated steel	0	MARINELLI 80B	
<6.E−16			helium/mass spec	0	BOYD 79	
1.E−20	+1		levitated niobium	2	[4] LARUE 79	
<4.E−28			earth+/ion beam	0	OGOROD... 79	
<5.E−15	+1		tungs./mass spec	0	BOYD 78	
<5.E−16	+3	<1.7	hydrogen/mass spec	0	BOYD 78B	
<1.E−21	±2,4		water/ion beam	0	LUND 78	
<6.E−15	>1/2		levitated tungsten	0	PUTT 78	
<1.E−22			metals/mass spec	0	SCHIFFER 78	
<5.E−15			levitated tungsten ox	0	BLAND 77	
<3.E−21			levitated iron	0	GALLINARO 77	
2.E−21	−1		levitated niobium	1	[4] LARUE 77	
4.E−21	+1		levitated niobium	2	[4] LARUE 77	OCCUR=2
<1.E−13	+3	<7.7	hydrogen/mass spec	0	MULLER 77	
<5.E−27			water+/ion beam	0	OGOROD... 77	
<1.E−21			lunar+/ion spec	0	STEVENS 76	
<1.E−15	+1	<60	oxygen+/ion spec	0	ELBERT 70	
<5.E−19			levitated graphite	0	MORPURGO 70	
<5.E−23			water+/atom beam	0	COOK 69	
<1.E−17	±1,2		levitated graphite	0	BRAGINSK 68	
<1.E−17			water+/uv spec	0	RANK 68	
<3.E−19	±1		levitated iron	0	STOVER 67	
<1.E−10			sun/uv spec	0	[5] BENNETT 66	
<1.E−17	+1,2		meteorites+/ion beam	0	CHUPKA 66	
<1.E−16	±1		levitated graphite	0	GALLINARO 66	
<1.E−22			argon/electrometer	0	HILLAS 59	
	−2		levitated oil	0	MILLIKAN 10	

[1] 95% CL limit for fractional charge particles with $0.18e \leq |Q_{residual}| \leq 0.82e$ in total of 70.1 mg of silicone oil. NODE=S027RHO;LINKAGE=LE

[2] 95% CL limit for particles with fractional charge $|Q_{residual}|$ >0.16e in total of 17.4 mg of silicone oil. NODE=S027RHO;LINKAGE=HA

[3] Also set limits for $Q = \pm e/6$. NODE=S027RHO;LINKAGE=B

[4] Note that in PHILLIPS 88 these authors report a subtle magnetic effect which could account for the apparent fractional charges. NODE=S027RHO;LINKAGE=C

[5] Limit inferred by JONES 77B. NODE=S027RHO;LINKAGE=A

REFERENCES FOR Free Quark Searches

NODE=S027

ALEMANNO	22	PR D106 063026	F. Alemanno *et al.*	(DAMPE Collab.)	REFID=61961
AGNESE	15	PRL 114 111302	R. Agnese *et al.*	(CDMS Collab.)	REFID=56445
CHATRCHYAN	13AR	PR D87 092008	S. Chatrchyan *et al.*	(CMS Collab.)	REFID=55151
Also		PR D106 099903 (errat.)	S. Chatrchyan *et al.*	(CMS Collab.)	REFID=61959
LEE	02	PR D66 012002	I.T. Lee *et al.*		REFID=48804
AMBROSIO	00C	PR D62 052003	M. Ambrosio *et al.*	(MACRO Collab.)	REFID=47695
HALYO	00	PRL 84 2576	V. Halyo *et al.*		REFID=47600
ABREU	97D	PL B396 315	P. Abreu *et al.*	(DELPHI Collab.)	REFID=45316
HUENTRUP	96	PR C53 358	G. Huentrup *et al.*	(SIEG)	REFID=44744
MAR	96	PR D53 6017	N.M. Mar *et al.*	(SLAC, SCHAF, LANL, UCI)	REFID=44785
AKERS	95R	ZPHY C67 203	R. Akers *et al.*	(OPAL Collab.)	REFID=44370
BUSKULIC	93C	PL B303 198	D. Buskulic *et al.*	(ALEPH Collab.)	REFID=43295
CECCHINI	93	ASP 1 369	S. Cecchini *et al.*		REFID=45968
PERERA	93	PRL 70 1053	A.G.U. Perera *et al.*	(PITT)	REFID=43207
ABE	92J	PR D46 1889	F. Abe *et al.*	(CDF Collab.)	REFID=42100
GHOSH	92	NC 105A 99	D. Ghosh *et al.*	(JADA, BANGB)	REFID=42041
HOMER	92	ZPHY C55 549	G.J. Homer *et al.*	(RAL, SHMP, LOQM)	REFID=42203
BASILE	91	NC 104A 405	M. Basile *et al.*	(BGNA, INFN, CERN, PLRM+)	REFID=41493
HE	91	PR C44 1672	Y.B. He, P.B. Price	(UCB)	REFID=41602
MATIS	91	NP A525 513	H.S. Matis *et al.*	(LBL, SFSU, UCI+)	REFID=41512
MORI	91	PR D43 2843	M. Mori *et al.*	(Kamiokande II Collab.)	REFID=41501
ADACHI	90C	PL B244 352	I. Adachi *et al.*	(TOPAZ Collab.)	REFID=41322
BOWCOCK	89B	PR D40 263	T.J.V. Bowcock *et al.*	(CLEO Collab.)	REFID=40872
CALLOWAY	89	PL B232 549	D. Calloway *et al.*	(SFSU, UCI, LBL+)	REFID=41274
JONES	89	ZPHY C43 349	W.G. Jones *et al.*	(LOIC, RAL)	REFID=40858
MATIS	89	PR D39 1851	H.S. Matis *et al.*	(LBL, SFSU, UCI+)	REFID=40840
NAKAMURA	89	PR D39 1261	T.T. Nakamura *et al.*	(KYOT, TMTC)	REFID=40833
ALLASIA	88	PR D37 219	D. Allasia *et al.*	(WA25 Collab.)	REFID=40486
HOFFMANN	88	PL B200 583	A. Hofmann *et al.*	(SIEG, USF)	REFID=40484
PHILLIPS	88	NIM A264 125	J.D. Phillips, W.M. Fairbank, J. Navarro	(STAN)	REFID=40738
WADA	88	NC 11C 229	T. Wada, Y. Yamashita, I. Yamamoto	(OKAY)	REFID=40726
GERBIER	87	PRL 59 2535	G. Gerbier *et al.*	(UCB, CERN)	REFID=45969
LYONS	87	ZPHY C36 363	L. Lyons *et al.*	(OXF, RAL, LOIC)	REFID=40482
MILNER	87	PR D36 37	R.E. Milner *et al.*	(CIT)	REFID=40479
SHAW	87	PR D36 3533	G.L. Shaw *et al.*	(UCI, LBL, LANL, SFSU)	REFID=40485
SMITH	87	PL B197 447	P.F. Smith *et al.*	(RAL, LOIC)	REFID=40481
VANPOLEN	87	PR D36 1983	J. van Polen, R.T. Hagstrom, G. Hirsch	(ANL+)	REFID=40483
ABACHI	86C	PR D33 2733	S. Abachi *et al.*	(UCLA, LBL, UCD)	REFID=12201
SAVAGE	86	PL 167B 481	M.L. Savage *et al.*	(SFSU)	REFID=12202
SMITH	86	PL B171 129	P.F. Smith *et al.*	(RAL, LOIC)	REFID=12203
SMITH	86B	PL B181 407	P.F. Smith *et al.*	(RAL, LOIC)	REFID=40480
WADA	86	NC 9C 358	T. Wada	(OKAY)	REFID=40725
ALBRECHT	85G	PL 156B 134	H. Albrecht *et al.*	(ARGUS Collab.)	REFID=12204
BANNER	85	PL 156B 129	M. Banner *et al.*	(UA2 Collab.)	REFID=12205
MILNER	85	PRL 54 1472	R.E. Milner *et al.*	(CIT)	REFID=12206
SMITH	85	PL 153B 188	P.F. Smith *et al.*	(RAL, LOIC)	REFID=12207
AIHARA	84	PRL 52 168	H. Aihara *et al.*	(TPC Collab.)	REFID=12208
AIHARA	84B	PRL 52 2332	H. Aihara *et al.*	(TPC Collab.)	REFID=12209
BARWICK	84	PR D30 691	S.W. Barwick, J.A. Musser, J.D. Stevenson	(UCB)	REFID=12210
BERGSMA	84B	ZPHY C24 217	F. Bergsma *et al.*	(CHARM Collab.)	REFID=12211
BONDAR	84	JETPL 40 1265	A.E. Bondar *et al.*	(NOVO)	REFID=12212
		Translated from ZETFP 40 440.			
GURYN	84	PL 139B 313	W. Guryn *et al.*	(FRAS, LBL, NWES, STAN+)	REFID=12213
KAWAGOE	84B	LNC 41 604	K. Kawagoe *et al.*	(TOKY)	REFID=12214
KUTSCHERA	84	PR D29 791	W. Kutschera *et al.*	(ANL, FNAL)	REFID=12215
MARINELLI	84	PL 137B 439	M. Marinelli, G. Morpurgo	(GENO)	REFID=11621
WADA	84B	LNC 40 329	T. Wada, Y. Yamashita, I. Yamamoto	(OKAY)	REFID=12217
AUBERT	83C	PL 133B 461	J.J. Aubert *et al.*	(EMC Collab.)	REFID=12218
BANNER	83	PL 121B 187	M. Banner *et al.*	(UA2 Collab.)	REFID=12219
JOYCE	83	PRL 51 731	D.C. Joyce *et al.*	(SFSU)	REFID=12220
LIEBOWITZ	83	PRL 50 1640	D. Liebowitz, M. Binder, K.O.H. Ziock	(UVA)	REFID=12221
LINDGREN	83	PRL 51 1621	M.A. Lindgren *et al.*	(SFSU, UCR, UCI+)	REFID=12222
MASHIMO	83	PL 128B 327	T. Mashimo *et al.*	(ICEPP)	REFID=12223
PRICE	83	PRL 50 566	P.B. Price *et al.*	(UCB)	REFID=12224
VANDESTEEG	83	PRL 50 1234	M.J.H. van de Steeg, H.W.H.M. Jongbloets, P. Wyder		REFID=12225;ERROR=1
MARINI	82	PR D26 1777	A. Marini *et al.*	(FRAS, LBL, NWES, STAN+)	REFID=12625
MARINI	82B	PRL 48 1649	A. Marini *et al.*	(FRAS, LBL, NWES, STAN+)	REFID=12226
MASHIMO	82	JPSJ 51 3067	T. Mashimo, K. Kawagoe, M. Koshiba	(INUS)	REFID=12228
NAPOLITANO	82	PR D25 2837	J. Napolitano *et al.*	(STAN, FRAS, LBL+)	REFID=12229
ROSS	82	PL 118B 199	M.C. Ross *et al.*	(FRAS, LBL, NWES, STAN+)	REFID=12230
HODGES	81	PRL 47 1651	C.L. Hodges *et al.*	(UCR, SFSU)	REFID=12231
LARUE	81	PRL 46 967	G.S. Larue, J.D. Phillips, W.M. Fairbank	(STAN)	REFID=12232
WEISS	81	PL 101B 439	J.M. Weiss *et al.*	(SLAC, LBL, UCB)	REFID=12233
BARTEL	80	ZPHY C6 295	W. Bartel *et al.*	(JADE Collab.)	REFID=12158
BASILE	80	LNC 29 251	M. Basile *et al.*	(BGNA, CERN, FRAS, ROMA+)	REFID=12235
BUSSIERE	80	NP B174 1	A. Bussiere *et al.*	(BGNA, SACL, LAPP)	REFID=10599
MARINELLI	80B	PL 94B 433	M. Marinelli, G. Morpurgo	(GENO)	REFID=12237
Also		PL 94B 427	M. Marinelli, G. Morpurgo	(GENO)	REFID=12238
BOYD	79	PRL 43 1288	R.N. Boyd *et al.*	(OSU)	REFID=12239
BOZZOLI	79	NP B159 363	W. Bozzoli *et al.*	(BGNA, LAPP, SACL+)	REFID=12240
LARUE	79	PRL 42 142	G.S. Larue, W.M. Fairbank, J.D. Phillips	(STAN)	REFID=12241
Also		PRL 42 1019	G.S. Larue, W.M. Fairbank, J.D. Phillips		REFID=12242
OGOROD...	79	JETP 49 953	D.D. Ogorodnikov, I.M. Samoilov, A.M. Solntsev		REFID=12243;ERROR=2
		Translated from ZETF 76 1881.			

STEVENSON	79	PR D20 82	M.L. Stevenson	(LBL)	REFID=12244
BASILE	78	NC 45A 171	M. Basile *et al.*	(CERN, BGNA)	REFID=12246
BASILE	78B	NC 45A 281	M. Basile *et al.*	(CERN, BGNA)	REFID=12247
BOYD	78	PRL 40 216	R.N. Boyd *et al.*	(ROCH)	REFID=12248
BOYD	78B	PL 72B 484	R.N. Boyd *et al.*	(ROCH)	REFID=12249
LUND	78	RA 25 75	T. Lund, R. Brandt, Y. Fares	(MARB)	REFID=12250
PUTT	78	PR D17 1466	G.D. Putt, P.C.M. Yock	(AUCK)	REFID=12251
SCHIFFER	78	PR D17 2241	J.P. Schiffer *et al.*	(CHIC, ANL)	REFID=12252
YOCK	78	PR D18 641	P.C.M. Yock	(AUCK)	REFID=12245
ANTREASYAN	77	PRL 39 513	D. Antreasyan *et al.*	(EFI, PRIN)	REFID=12253
BASILE	77	NC 40A 41	M. Basile *et al.*	(CERN, BGNA)	REFID=12254
BLAND	77	PRL 39 369	R.W. Bland *et al.*	(SFSU)	REFID=12255
GALLINARO	77	PRL 38 1255	G. Gallinaro, M. Marinelli, G. Morpurgo	(GENO)	REFID=12256
JONES	77B	RMP 49 717	L.W. Jones		REFID=40266
LARUE	77	PRL 38 1011	G.S. Larue, W.M. Fairbank, A.F. Hebard	(STAN)	REFID=12257
MULLER	77	SCI 196 521	R.A. Muller *et al.*	(LBL)	REFID=12258
OGOROD...	77	JETP 45 857	D.D. Ogorodnikov, I.M. Samoilov, A.M. Solntsev		REFID=12259;ERROR=3
		Translated from ZETF 72 1633.			
BALDIN	76	SJNP 22 264	B.Y. Baldin *et al.*	(JINR)	REFID=12260
		Translated from YAF 22 512.			
BRIATORE	76	NC 31A 553	L. Briatore *et al.*	(LCGT, FRAS, FREIB)	REFID=12261
STEVENS	76	PR D14 716	C.M. Stevens, J.P. Schiffer, W. Chupka	(ANL)	REFID=12262
ALBROW	75	NP B97 189	M.G. Albrow *et al.*	(CERN, DARE, FOM+)	REFID=12263
FABJAN	75	NP B101 349	C.W. Fabjan *et al.*	(CERN, MPIM)	REFID=12264
HAZEN	75	NP B95 189	W.E. Hazen *et al.*	(MICH, LEED)	REFID=12265
JOVANOV...	75	PL 56B 105	J.V. Jovanovich *et al.*	(MANI, AACH, CERN+)	REFID=12266
KRISOR	75	NC 27A 132	K. Krisor	(AACH3)	REFID=12267
CLARK	74B	PR D10 2721	A.F. Clark *et al.*	(LLL)	REFID=12268
GALIK	74	PR D9 1856	R.S. Galik *et al.*	(SLAC, FNAL)	REFID=12269
KIFUNE	74	JPSJ 36 629	T. Kifune *et al.*	(TOKY, KEK)	REFID=12270
NASH	74	PRL 32 858	T. Nash *et al.*	(FNAL, CORN, NYU)	REFID=12271
ALPER	73	PL 46B 265	B. Alper *et al.*	(CERN, LIVP, LUND, BOHR+)	REFID=12272
ASHTON	73	JP A6 577	F. Ashton *et al.*	(DURH)	REFID=12273
HICKS	73B	NC 14A 65	R.B. Hicks, R.W. Flint, S. Standil	(MANI)	REFID=12274
LEIPUNER	73	PRL 31 1226	L.B. Leipuner *et al.*	(BNL, YALE)	REFID=12275
BEAUCHAMP	72	PR D6 1211	W.T. Beauchamp *et al.*	(ARIZ)	REFID=12276
BOHM	72B	PRL 28 326	A. Bohm *et al.*	(AACH)	REFID=12277
BOTT	72	PL 40B 693	M. Bott-Bodenhausen *et al.*	(CERN, MPIM)	REFID=12278
COX	72	PR D6 1203	A.J. Cox *et al.*	(ARIZ)	REFID=12279
CROUCH	72	PR D5 2667	M.F. Crouch, K. Mori, G.R. Smith	(CASE)	REFID=12280
DARDO	72	NC 9A 319	M. Dardo *et al.*	(TORI)	REFID=12281
EVANS	72	PRSE A70 143	G.R. Evans *et al.*	(EDIN, LEED)	REFID=12282
TONWAR	72	JP A5 569	S.C. Tonwar, S. Naranan, B.V. Sreekantan	(TATA)	REFID=12283
ANTIPOV	71	NP B29 374	Y.M. Antipov *et al.*	(SERP)	REFID=12284
CHIN	71	NC 2A 419	S. Chin *et al.*	(OSAK)	REFID=12285
CLARK	71B	PRL 27 51	A.F. Clark *et al.*	(LLL, LBL)	REFID=12286
HAZEN	71	PRL 26 582	W.E. Hazen	(MICH)	REFID=12287
BOSIA	70	NC 66A 167	G.F. Bosia, L. Briatore	(TORI)	REFID=12288
CHU	70	PRL 24 917	W.T. Chu *et al.*	(OSU, ROSE, KANS)	REFID=12289
Also		PRL 25 550	W.W.M. Allison *et al.*	(ANL)	REFID=12290
ELBERT	70	NP B20 217	J.W. Elbert *et al.*	(WISC)	REFID=12291
FAISSNER	70B	PRL 24 1357	H. Faissner *et al.*	(AACH3)	REFID=12292
KRIDER	70	PR D1 835	E.P. Krider, T. Bowen, R.M. Kalbach	(ARIZ)	REFID=12293
MORPURGO	70	NIM 79 95	G. Morpurgo, G. Gallinaro, G. Palmieri	(GENO)	REFID=12294
ALLABY	69B	NC 64A 75	J.V. Allaby *et al.*	(CERN)	REFID=12295
ANTIPOV	69	PL 29B 245	Y.M. Antipov *et al.*	(SERP)	REFID=12296
ANTIPOV	69B	PL 30B 576	Y.M. Antipov *et al.*	(SERP)	REFID=12297
CAIRNS	69	PR 186 1394	I. Cairns *et al.*	(SYDN)	REFID=12298
COOK	69	PR 188 2092	D.D. Cook *et al.*	(ILL)	REFID=12299
FUKUSHIMA	69	PR 178 2058	Y. Fukushima *et al.*	(TOKY)	REFID=12300
MCCUSKER	69	PRL 23 658	C.B.A. McCusker, I. Cairns	(SYDN)	REFID=12301
BELLAMY	68	PR 166 1391	E.H. Bellamy *et al.*	(STAN, SLAC)	REFID=12302
BJORNBOE	68	NC B53 241	J. Bjornboe *et al.*	(BOHR, TATA, BERN+)	REFID=12303
BRAGINSK	68	JETP 27 51	V.B. Braginsky *et al.*	(MOSU)	REFID=12304
		Translated from ZETF 54 91.			
BRIATORE	68	NC 57A 850	L. Briatore *et al.*	(TORI, CERN, BGNA)	REFID=12305
FRANZINI	68	PRL 21 1013	P. Franzini, S. Shulman	(COLU)	REFID=12306
GARMIRE	68	PR 166 1280	G. Garmire, C. Leong, V. Sreekantan	(MIT)	REFID=12307
HANAYAMA	68	CJP 46 S734	Y. Hanayama *et al.*	(OSAK)	REFID=12308
KASHA	68	PR 172 1297	H. Kasha, R.J. Stefanski	(BNL, YALE)	REFID=12309
KASHA	68B	PRL 20 217	H. Kasha *et al.*	(BNL, YALE)	REFID=12310
KASHA	68C	CJP 46 S730	H. Kasha *et al.*	(BNL, YALE)	REFID=12311
RANK	68	PR 176 1635	D. Rank	(MICH)	REFID=12312
BARTON	67	PRSL 90 87	J.C. Barton	(NPOL)	REFID=12313
BATHOW	67	PL 25B 163	G. Bathow *et al.*	(DESY)	REFID=12314
BUHLER	67	NC 49A 209	A. Buhler-Broglin *et al.*	(CERN, BGNA)	REFID=12315
BUHLER	67B	NC 51A 837	A. Buhler-Broglin *et al.*	(CERN, BGNA+)	REFID=12316
FOSS	67	PL 25B 166	J. Foss *et al.*	(MIT)	REFID=12317
GOMEZ	67	PRL 18 1022	R. Gomez *et al.*	(CIT)	REFID=12318
KASHA	67	PR 154 1263	H. Kasha *et al.*	(BNL, YALE)	REFID=12319
STOVER	67	PR 164 1599	R.W. Stover, T.I. Moran, J.W. Trischka	(SYRA)	REFID=12320
BARTON	66	PL 21 360	J.C. Barton, C.T. Stockel	(NPOL)	REFID=12321
BENNETT	66	PRL 17 1196	W.R. Bennett	(YALE)	REFID=12322
BUHLER	66	NC 45A 520	A. Buhler-Broglin *et al.*	(CERN, BGNA+)	REFID=12323
CHUPKA	66	PRL 17 60	W.A. Chupka, J.P. Schiffer, C.M. Stevens	(ANL)	REFID=12324
GALLINARO	66	PL 23 609	G. Gallinaro, G. Morpurgo	(GENO)	REFID=12325
KASHA	66	PR 150 1140	H. Kasha, L.B. Leipuner, R.K. Adair	(BNL, YALE)	REFID=12326
LAMB	66	PRL 17 1068	R.C. Lamb *et al.*	(ANL)	REFID=12327
DELISE	65	PR 140 B458	D.A. de Lise, T. Bowen	(ARIZ)	REFID=12331
DORFAN	65	PRL 14 999	D.E. Dorfan *et al.*	(COLU)	REFID=12330
FRANZINI	65B	PRL 14 196	P. Franzini *et al.*	(BNL, COLU)	REFID=12329
MASSAM	65	NC 40A 589	T. Massam, T. Muller, A. Zichichi	(CERN)	REFID=12328
BINGHAM	64	PL 9 201	H.H. Bingham *et al.*	(CERN, EPOL)	REFID=12332
BLUM	64	PRL 13 353A	W. Blum *et al.*	(CERN)	REFID=12333
BOWEN	64	PRL 13 728	T. Bowen *et al.*	(ARIZ)	REFID=12334
HAGOPIAN	64	PRL 13 280	V. Hagopian *et al.*	(PENN, BNL)	REFID=12335
LEIPUNER	64	PRL 12 423	L.B. Leipuner *et al.*	(BNL, YALE)	REFID=12336
MORRISON	64	PL 9 199	D.R.O. Morrison	(CERN)	REFID=12337
SUNYAR	64	PR 136 B1157	A.W. Sunyar, A.Z. Schwarzschild, P.I. Connors	(BNL)	REFID=12338
HILLAS	59	NAT 184 B92	A.M. Hillas, T.E. Cranshaw	(AERE)	REFID=12339
MILLIKAN	10	Phil Mag 19 209	R.A. Millikan	(CHIC)	REFID=12340

OTHER RELATED PAPERS

LYONS	85	PRPL C129 225	L. Lyons	(OXF)	REFID=12341
Review					
MARINELLI	82	PRPL 85 161	M. Marinelli, G. Morpurgo	(GENO)	REFID=12342
Review					