<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	[12,13] BASILE 80	CNTR
<3.E−10	f	±2,4	1–3	200	p	0	[19] 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	[20] FABJAN 75	CNTR
		+1,2	>4.5		γ	0	[12,13] GALIK 74	CNTR
		+1,2	>1.5	12	e^-	0	[12,13] BELLAMY 68	CNTR
		+1,2	>0.9		γ	0	[13] BATHOW 67	CNTR
		+1,2	>0.9	6	γ	0	[13] FOSS 67	CNTR

[10] BUSKULIC 93C limits for inclusive quark production are more conservative if the ALEPH hadronic fragmentation function is assumed.

[11] 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 $7e/3$.

[12] Hadronic quark.

[13] Leptonic quark.

[14] 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).

[15] The limits apply to projectile fragment charges of 17, 19, 20, 22, 23 in units of $e/3$.

[16] The limits apply to projectile fragment charges of 16, 17, 19, 20, 22, 23 in units of $e/3$.

[17] Flux limits and mass range depend on charge.

[18] Bound to nuclei.

[19] Quark lifetimes $> 1 \times 10^{-8}$ s.

[20] One candidate m <0.17 GeV.

Quark Flux — Cosmic Ray Searches

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

FLUX (cm^{-2}sr^{-1}s^{-1})	CHG (e/3)	MASS (GeV)	SHIELDING	EVTS	DOCUMENT ID	TECN
<2.1E−15	±1			0	MORI 91	KAM2
<2.3E−15	±2			0	MORI 91	KAM2
<2.E−10	±1,2		0.3	0	WADA 88	CNTR
	±4		0.3	12	[21] WADA 88	CNTR
	±4		0.3	9	[22] WADA 86	CNTR
<1.E−12	±2,3/2		−70.	0	[23] KAWAGOE 84B	PLAS
<9.E−10	±1,2		0.3	0	WADA 84B	CNTR
<4.E−9	±4		0.3	7	WADA 84B	CNTR
<2.E−12	±1,2,3		−0.3 ∗	0	MASHIMO 83	CNTR
<3.E−10	±1,2		0.3	0	MARINI 82	CNTR
<2.E−11	±1,2			0	MASHIMO 82	CNTR
<8.E−10	±1,2		0.3	0	[23] NAPOLITANO 82	CNTR
				3	[24] YOCK 78	CNTR
<1.E−9				0	[25] BRIATORE 76	ELEC
<2.E−11	+1			0	[26] HAZEN 75	CC
<2.E−10	+1,2			0	KRISOR 75	CNTR
<1.E−7	+1,2			0	[26,27] CLARK 74B	CC
<3.E−10	+1	>20		0	KIFUNE 74	CNTR
<8.E−11	+1			0	[26] ASHTON 73	CNTR
<2.E−8	+1,2			0	HICKS 73B	CNTR
<5.E−10	+4		2.8 ∗	0	BEAUCHAMP 72	CNTR
<1.E−10	+1,2			0	[26] BOHM 72B	CNTR
<1.E−10	+1,2		2.8 ∗	0	COX 72	ELEC
<3.E−10	+2			0	CROUCH 72	CNTR
<3.E−8			7	0	[25] DARDO 72	CNTR
<4.E−9	+1			0	[26] EVANS 72	CC
<2.E−9		>10		0	[25] TONWAR 72	CNTR
<2.E−10	+1		2.8 ∗	0	CHIN 71	CNTR
<3.E−10	+1,2			0	[26] CLARK 71B	CC
<1.E−10	+1,2			0	[26] HAZEN 71	CC
<5.E−10	+1,2		3.5 ∗	0	BOSIA 70	CNTR
	+1,2	<6.5		1	[26] CHU 70	HLBC
<2.E−9	+1			0	FAISSNER 70B	CNTR
<2.E−10	+1,2		0.8 ∗	0	KRIDER 70	CNTR
<5.E−11	+2			4	CAIRNS 69	CC
<8.E−10	+1,2	<10		0	FUKUSHIMA 69	CNTR
	+2			1	[26,28] MCCUSKER 69	CC
<1.E−10		>5	1.7,3.6	0	[25] BJORNBOE 68	CNTR
<1.E−8	±1,2,4		6.3,.2 ∗	0	[23] BRIATORE 68	CNTR
<3.E−8		>2		0	FRANZINI 68	CNTR
<9.E−11	±1,2			0	GARMIRE 68	CNTR
<4.E−10	±1			0	HANAYAMA 68	CNTR
<3.E−8		>15		0	KASHA 68	OSPK
<2.E−10	+2			0	KASHA 68B	CNTR
<2.E−10	+4			0	KASHA 68C	CNTR
<2.E−10	+2		6	0	BARTON 67	CNTR
<2.E−7	+4		0.008,0.5 ∗	0	BUHLER 67	CNTR
<5.E−10	1,2		0.008,0.5 ∗	0	BUHLER 67B	CNTR
<4.E−10	+1,2			0	GOMEZ 67	CNTR
<2.E−9	+2			0	KASHA 67	CNTR
<2.E−10	+2		220	0	BARTON 66	CNTR
<2.E−9	+1,2		0.5 ∗	0	BUHLER 66	CNTR
<3.E−9	+1,2			0	KASHA 66	CNTR
<2.E−9	+1,2			0	LAMB 66	CNTR
<2.E−8	+1,2	>7	2.8 ∗	0	DELISE 65	CNTR
<5.E−8	+2	>2.5	0.5 ∗	0	MASSAM 65	CNTR
<2.E−8	+1		2.5 ∗	0	BOWEN 64	CNTR
<2.E−7	+1		0.8	0	SUNYAR 64	CNTR

[21] Distribution in celestial sphere was described as anisotropic.

[22] With telescope axis at zenith angle 40° to the south.

[23] Leptonic quarks.

[24] Lifetime $> 10^{-8}$ s; charge ±0.70, 0.68, 0.42; and mass >4.4, 4.8, and 20 GeV, respectively.

[25] Time delayed air shower search.

[26] Prompt air shower search.

[27] Also $e/4$ and $e/6$ charges.

[28] No events in subsequent experiments.

Quark Density — Matter Searches

For a recent review, see SMITH 89.

QUARKS/ NUCLEON	CHG (e/3)	MASS (GeV)	MATERIAL/METHOD	EVTS	DOCUMENT ID
<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
<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	> |± 1/2|		levitated steel	0	LIEBOWITZ 83
<1.E−19	±1,2		photo ion spec	0	VANDESTEEG 83
<2.E−20			mercury/oil drop	0	[29] HODGES 81
1.E−20	+1		levitated niobium	4	[30] LARUE 81
1.E−20	−1		levitated niobium	4	[30] LARUE 81
<1.E−21			levitated steel	0	MARINELLI 80B
<6.E−16			helium/mass spec	0	BOYD 79
1.E−20	+1		levitated niobium	2	[30] 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	[30] LARUE 77
4.E−21	+1		levitated niobium	2	[30] LARUE 77
<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	[31] 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

[29] Also set limits for $Q = \pm e/6$.

[30] Note that in PHILLIPS 88 these authors report a subtle magnetic effect which could account for the apparent fractional charges.

[31] Limit inferred by JONES 77B.

REFERENCES FOR Free Quark Searches

BUSKULIC 93C PL B303 198 +Decamp, Goy, Lees, Minard+ (ALEPH Collab.)
PERERA 93 PRL 70 1053 +Betarbet, Byungsung, Coon (PITT)
ABE 92J PR D46 R1889 +Amidei, Anway-Weiss+ (CDF Collab.)
GHOSH 92 NC 105A 99 +Roy, Ghosh, Ghosh, Basu (JADA, BANGB)
HOMER 92 ZPHY C55 549 +Smith, Lewin, Robertson+ (RAL, SHMP, LOQM)
BASILE 91 NC 104A 405 +Berbiers, Cara Romeo+ (BGNA, INFN, CERN, PLRM+)
HE 91 PR C44 1672 +Price (UCB)
MATIS 91 NP A525 513c +Pugh, Alba, Bland, Calloway+ (LBL, SFSU, UCI, LANL)
MORI 91 PR D43 2843 +Oyama, Suzuki, Takahashi+ (Kamiokande II Collab.)
ADACHI 90C PL B244 352 +Aihara, Doser, Enomoto+ (TOPAZ Collab.)
BOWCOCK 89B PR D40 263 +Kinoshita, Mauskopf, Pipkin+ (CLEO Collab.)
CALLOWAY 89 PL B232 549 +Alba, Bland, Dickson, Hodges+ (SFSU, UCI, LBL, LANL)
JONES 89 ZPHY C43 349 +Smith, Homer, Lewin, Walford (LOIC, RAL)
MATIS 89 PR D39 1851 +Pugh, Bland, Calloway+ (LBL, SFSU, UCI, FNAL, LANL)
NAKAMURA 89 PR D39 1261 +Kobayashi, Konaka, Imai, Masaike+ (KYOT, TMTC)
SMITH 89 ARNPS 39 73 (RAL)
ALLASIA 88 PR D37 219 +Angelini, Baldini+ (WA25 Collab.)