Citation: K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014) (URL: http://pdg.lbl.gov)

# Free Quark Searches

A REVIEW GOES HERE – Check our WWW List of Reviews

## Quark Production Cross Section — Accelerator Searches

| 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 |
| <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 |
| <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 |
| <1.E−40 | ±1,2 | <10 | | $p,\nu,\overline{\nu}$ | 0 | BERGSMA | 84B | CHRM |
| <1.E−36 | ±1,2 | <9 | 200 | $\mu$ | 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)$_L$.
[2] ABE 92J flux limits decrease as the mass increases from 50 to 500 GeV.
[3] HE 91 limits are for charges of the form $N\pm1/3$ from 23/3 to 38/3.
[4] Hadronic or leptonic quarks.
[5] Cross section cm$^2$/GeV$^2$.
[6] $3\times10^{-5}$ <lifetime $< 1\times10^{-3}$ s.
[7] Includes BOTT 72 results.
[8] Assumes isotropic cm production.
[9] Cross section inferred from flux.

## Quark Differential Production Cross Section — Accelerator Searches

| *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 | $\gamma$ | 0 | [10] 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 |

[10] Cross section in $cm^2$/sr/equivalent quanta.

## Quark Flux — Accelerator Searches

The definition of FLUX depends on the experiment

(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 $\nu$-event.
(h) is quark yield per $\pi^-$ yield.
(i) is 2-body exclusive quark-production cross-section ratio to $\sigma(e^+ e^- \to \mu^+ \mu^-)$.

| *FLUX* | | *CHG* (e/3) | *MASS* (GeV) | *ENRGY* (GeV) | *BEAM* | *EVTS* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|---|---|
| <1.6E−3 | b | see note | | 200 | $^{32}$S–Pb | 0 | [11] HUENTRUP | 96 | PLAS |
| <6.2E−4 | b | see note | | 10.6 | $^{32}$S–Pb | 0 | [11] HUENTRUP | 96 | PLAS |
| <0.94E−4 | e | ±2 | 2–30 | 88–94 | $e^+ e^-$ | 0 | AKERS | 95R | OPAL |
| <1.7E−4 | e | ±2 | 30–40 | 88–94 | $e^+ e^-$ | 0 | AKERS | 95R | OPAL |
| <3.6E−4 | e | ±4 | 5–30 | 88–94 | $e^+ e^-$ | 0 | AKERS | 95R | OPAL |
| <1.9E−4 | e | ±4 | 30–45 | 88–94 | $e^+ e^-$ | 0 | AKERS | 95R | OPAL |
| <2.E−3 | e | +1 | 5–40 | 88–94 | $e^+ e^-$ | 0 | [12] BUSKULIC | 93C | ALEP |
| <6.E−4 | e | +2 | 5–30 | 88–94 | $e^+ e^-$ | 0 | [12] BUSKULIC | 93C | ALEP |
| <1.2E−3 | e | +4 | 15–40 | 88–94 | $e^+ e^-$ | 0 | [12] BUSKULIC | 93C | ALEP |
| <3.6E−4 | i | +4 | 5.0–10.2 | 88–94 | $e^+ e^-$ | 0 | BUSKULIC | 93C | ALEP |
| <3.6E−4 | i | +4 | 16.5–26.0 | 88–94 | $e^+ e^-$ | 0 | BUSKULIC | 93C | ALEP |
| <6.9E−4 | i | +4 | 26.0–33.3 | 88–94 | $e^+ e^-$ | 0 | BUSKULIC | 93C | ALEP |
| <9.1E−4 | i | +4 | 33.3–38.6 | 88–94 | $e^+ e^-$ | 0 | BUSKULIC | 93C | ALEP |
| <1.1E−3 | i | +4 | 38.6–44.9 | 88–94 | $e^+ e^-$ | 0 | BUSKULIC | 93C | ALEP |
| <1.6E−4 | b | see note | | see note | | 0 | [13] CECCHINI | 93 | PLAS |
| | b | 4,5,7,8 | | 2.1A | $^{16}$O | 0,2,0,6 | [14] GHOSH | 92 | EMUL |
| <6.4E−5 | g | 1 | | | $\nu,\overline{\nu}$ | 1 | [15] BASILE | 91 | CNTR |
| <3.7E−5 | g | 2 | | | $\nu,\overline{\nu}$ | 0 | [15] BASILE | 91 | CNTR |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| <3.9E−5 | g | 1 | | | $\nu,\overline{\nu}$ | 1 | [16] BASILE | 91 | CNTR |
| <2.8E−5 | g | 2 | | | $\nu,\overline{\nu}$ | 0 | [16] BASILE | 91 | CNTR |
| <1.9E−4 | c | | | 14.5A | $^{28}$Si–Pb | 0 | [17] HE | 91 | PLAS |
| <3.9E−4 | c | | | 14.5A | $^{28}$Si–Cu | 0 | [17] HE | 91 | PLAS |
| <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 |
| <8.1E−9 | c | ±1,2,4 | | 14.5A | Si–Hg | 0 | MATIS | 91 | MDRP |
| <1.7E−6 | c | ±1,2,4 | | 60A | $^{16}$O–Hg | 0 | MATIS | 91 | MDRP |
| <3.5E−7 | c | ±1,2,4 | | 200A | $^{16}$O–Hg | 0 | MATIS | 91 | MDRP |
| <1.3E−6 | c | ±1,2,4 | | 200A | S–Hg | 0 | MATIS | 91 | MDRP |
| <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 |
| <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 |
| <1.3E−6 | d | ±1,2 | | 200 | S–Hg | 0 | CALLOWAY | 89 | MDRP |
| <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 |
| <1.2E−10 | d | ±1 | 1 | 800 | $p$–$N_2$ | 0 | MATIS | 89 | MDRP |
| <7.7E−11 | d | ±2 | 1 | 800 | $p$–$N_2$ | 0 | MATIS | 89 | MDRP |
| <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 | [18] HOFFMANN | 88 | PLAS |
| <2.E−4 | b | See note | | 200 | $^{16}$O–Pb | 0 | [19] HOFFMANN | 88 | PLAS |
| <8E−5 | b | 19,20,22,23 | | 200*A* | | | 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 | [20] 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 | [21] 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 | [21] 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 | | | $\nu$ | 0 | [15,16] BASILE | 80 | CNTR |
| <3.E−10 | f | ±2,4 | 1–3 | 200 | $p$ | 0 | [22] BOZZOLI | 79 | CNTR |
| <6.E−11 | f | ±1 | <21 | 52 | $pp$ | 0 | BASILE | 78 | SPEC |
| <5.E−3 | g | | | | $\nu_\mu$ | 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 | [23] FABJAN | 75 | CNTR |
| | | +1,2 | >4.5 | | $\gamma$ | 0 | [15,16] GALIK | 74 | CNTR |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| +1,2 | >1.5 | 12 | $e^-$ | 0 | [15,16] BELLAMY | 68 | CNTR |
| +1,2 | >0.9 | | $\gamma$ | 0 | [16] BATHOW | 67 | CNTR |
| +1,2 | >0.9 | 6 | $\gamma$ | 0 | [16] FOSS | 67 | CNTR |

[11] HUENTRUP 96 quote 95% CL limits for production of fragments with charge differing by as much as $\pm 1/3$ (in units of e) for charge $6 \leq Z \leq 10$.

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

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

[14] 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 $7e/3$.

[15] Hadronic quark.

[16] Leptonic quark.

[17] HE 91 limits are for charges of the form $N \pm 1/3$ from 23/3 to 38/3, and correspond to cross-section limits of 380$\mu$b (Pb) and 320$\mu$b (Cu).

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

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

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

[21] Bound to nuclei.

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

[23] 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* |
|---|---|---|---|---|---|---|---|
| < 9.2E−15 | ±1 | | 3800 | 0 | [24] AMBROSIO | 00C | MCRO |
| <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 | [25] WADA | 88 | CNTR |
| | ±4 | | 0.3 | 9 | [26] WADA | 86 | CNTR |
| <1.E−12 | ±2,3/2 | | −70. | 0 | [27] 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 | [27] NAPOLITANO | 82 | CNTR |
| | | | | 3 | [28] YOCK | 78 | CNTR |
| <1.E−9 | | | | 0 | [29] BRIATORE | 76 | ELEC |
| <2.E−11 | +1 | | | 0 | [30] HAZEN | 75 | CC |
| <2.E−10 | +1,2 | | | 0 | KRISOR | 75 | CNTR |
| <1.E−7 | +1,2 | | | 0 | [30,31] CLARK | 74B | CC |
| <3.E−10 | +1 | >20 | | 0 | KIFUNE | 74 | CNTR |
| <8.E−11 | +1 | | | 0 | [30] 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 | [30] 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 | [29] DARDO | 72 | CNTR |
| $<4.E-9$ | $+1$ | | | 0 | [30] EVANS | 72 | CC |
| $<2.E-9$ | | $>10$ | | 0 | [29] TONWAR | 72 | CNTR |
| $<2.E-10$ | $+1$ | | 2.8 * | 0 | CHIN | 71 | CNTR |
| $<3.E-10$ | $+1,2$ | | | 0 | [30] CLARK | 71B | CC |
| $<1.E-10$ | $+1,2$ | | | 0 | [30] HAZEN | 71 | CC |
| $<5.E-10$ | $+1,2$ | | 3.5 * | 0 | BOSIA | 70 | CNTR |
| | $+1,2$ | $<6.5$ | | 1 | [30] 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 | [30,32] MCCUSKER | 69 | CC |
| $<1.E-10$ | | $>5$ | 1.7,3.6 | 0 | [29] BJORNBOE | 68 | CNTR |
| $<1.E-8$ | $\pm1,2,4$ | | 6.3,.2 * | 0 | [27] BRIATORE | 68 | CNTR |
| $<3.E-8$ | | $>2$ | | 0 | FRANZINI | 68 | CNTR |
| $<9.E-11$ | $\pm1,2$ | | | 0 | GARMIRE | 68 | CNTR |
| $<4.E-10$ | $\pm1$ | | | 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 |

[24] AMBROSIO 00C limit is below $11 \times 10^{-15}$ for $0.25 < q/e < 0.5$, and is changing rapidly near $q/e$=2/3, where it is $2 \times 10^{-14}$.

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

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

[27] Leptonic quarks.

[28] Lifetime $> 10^{-8}$ s; charge $\pm0.70$, 0.68, 0.42; and mass $>$4.4, 4.8, and 20 GeV, respectively.

[29] Time delayed air shower search.

[30] Prompt air shower search.

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

[32] No events in subsequent experiments.

## Quark Density — Matter Searches

| QUARKS/ NUCLEON | CHG (e/3) | MASS (GeV) | MATERIAL/METHOD | EVTS | DOCUMENT ID | |
|---|---|---|---|---|---|---|
| <1.17E−22 | | | silicone oil drops | 0 | [33] LEE | 02 |
| <4.71E−22 | | | silicone oil drops | 1 | [34] 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 |
| <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 | [35] HODGES | 81 |
| 1.E−20 | +1 | | levitated niobium | 4 | [36] LARUE | 81 |
| 1.E−20 | −1 | | levitated niobium | 4 | [36] 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 | [36] 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 | [36] LARUE | 77 |
| 4.E−21 | +1 | | levitated niobium | 2 | [36] 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 | [37] 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 |

[33] 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.

[34] 95% CL limit for particles with fractional charge $|Q_{residual}| > 0.16e$ in total of 17.4 mg of silicone oil.

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

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

[37] Limit inferred by JONES 77B.

## REFERENCES FOR Free Quark Searches


| | | | | |
|---|---|---|---|---|
| CHATRCHYAN | 13AR | PR D87 092008 | S. Chatrchyan *et al.* | (CMS Collab.) |
| LEE | 02 | PR D66 012002 | I.T. Lee *et al.* | |
| AMBROSIO | 00C | PR D62 052003 | M. Ambrosio *et al.* | (MACRO Collab.) |
| HALYO | 00 | PRL 84 2576 | V. Halyo *et al.* | |
| ABREU | 97D | PL B396 315 | P. Abreu *et al.* | (DELPHI Collab.) |
| HUENTRUP | 96 | PR C53 358 | G. Huentrup *et al.* | (SIEG) |
| MAR | 96 | PR D53 6017 | N.M. Mar *et al.* | (SLAC, SCHAF, LANL, UCI) |
| AKERS | 95R | ZPHY C67 203 | R. Akers *et al.* | (OPAL Collab.) |
| BUSKULIC | 93C | PL B303 198 | D. Buskulic *et al.* | (ALEPH Collab.) |
| CECCHINI | 93 | ASP 1 369 | S. Cecchini *et al.* | |
| PERERA | 93 | PRL 70 1053 | A.G.U. Perera *et al.* | (PITT) |
| ABE | 92J | PR D46 R1889 | F. Abe *et al.* | (CDF Collab.) |
| GHOSH | 92 | NC 105A 99 | D. Ghosh *et al.* | (JADA, BANGB) |
| HOMER | 92 | ZPHY C55 549 | G.J. Homer *et al.* | (RAL, SHMP, LOQM) |
| BASILE | 91 | NC 104A 405 | M. Basile *et al.* | (BGNA, INFN, CERN, PLRM+) |
| HE | 91 | PR C44 1672 | Y.B. He, P.B. Price | (UCB) |
| MATIS | 91 | NP A525 513c | H.S. Matis *et al.* | (LBL, SFSU, UCI+) |
| MORI | 91 | PR D43 2843 | M. Mori *et al.* | (Kamiokande II Collab.) |
| ADACHI | 90C | PL B244 352 | I. Adachi *et al.* | (TOPAZ Collab.) |
| BOWCOCK | 89B | PR D40 263 | T.J.V. Bowcock *et al.* | (CLEO Collab.) |
| CALLOWAY | 89 | PL B232 549 | D. Calloway *et al.* | (SFSU, UCI, LBL+) |
| JONES | 89 | ZPHY C43 349 | W.G. Jones *et al.* | (LOIC, RAL) |
| MATIS | 89 | PR D39 1851 | H.S. Matis *et al.* | (LBL, SFSU, UCI+) |
| NAKAMURA | 89 | PR D39 1261 | T.T. Nakamura *et al.* | (KYOT, TMTC) |
| ALLASIA | 88 | PR D37 219 | D. Allasia *et al.* | (WA25 Collab.) |
| HOFFMANN | 88 | PL B200 583 | A. Hofmann *et al.* | (SIEG, USF) |
| PHILLIPS | 88 | NIM A264 125 | J.D. Phillips, W.M. Fairbank, J. Navarro | (STAN) |
| WADA | 88 | NC 11C 229 | T. Wada, Y. Yamashita, I. Yamamoto | (OKAY) |
| GERBIER | 87 | PRL 59 2535 | G. Gerbier *et al.* | (UCB, CERN) |
| LYONS | 87 | ZPHY C36 363 | L. Lyons *et al.* | (OXF, RAL, LOIC) |
| MILNER | 87 | PR D36 37 | R.E. Milner *et al.* | (CIT) |
| SHAW | 87 | PR D36 3533 | G.L. Shaw *et al.* | (UCI, LBL, LANL, SFSU) |
| SMITH | 87 | PL B197 447 | P.F. Smith *et al.* | (RAL, LOIC) |
| VANPOLEN | 87 | PR D36 1983 | J. van Polen, R.T. Hagstrom, G. Hirsch | (ANL+) |
| ABACHI | 86C | PR D33 2733 | S. Abachi *et al.* | (UCLA, LBL, UCD) |
| SAVAGE | 86 | PL 167B 481 | M.L. Savage *et al.* | (SFSU) |
| SMITH | 86 | PL B171 129 | P.F. Smith *et al.* | (RAL, LOIC) |
| SMITH | 86B | PL B181 407 | P.F. Smith *et al.* | (RAL, LOIC) |
| WADA | 86 | NC 9C 358 | T. Wada | (OKAY) |
| ALBRECHT | 85G | PL 156B 134 | H. Albrecht *et al.* | (ARGUS Collab.) |
| BANNER | 85 | PL 156B 129 | M. Banner *et al.* | (UA2 Collab.) |
| MILNER | 85 | PRL 54 1472 | R.E. Milner *et al.* | (CIT) |
| SMITH | 85 | PL 153B 188 | P.F. Smith *et al.* | (RAL, LOIC) |
| AIHARA | 84 | PRL 52 168 | H. Aihara *et al.* | (TPC Collab.) |
| AIHARA | 84B | PRL 52 2332 | H. Aihara *et al.* | (TPC Collab.) |
| BARWICK | 84 | PR D30 691 | S.W. Barwick, J.A. Musser, J.D. Stevenson | (UCB) |
| BERGSMA | 84B | ZPHY C24 217 | F. Bergsma *et al.* | (CHARM Collab.) |
| BONDAR | 84 | JETPL 40 1265 | A.E. Bondar *et al.* | (NOVO) |
| | | Translated from ZETFP 40 440. | | |

GURYN 84 PL 139B 313 W. Guryn *et al.* (FRAS, LBL, NWES, STAN+)
KAWAGOE 84B LNC 41 604 K. Kawagoe *et al.* (TOKY)
KUTSCHERA 84 PR D29 791 W. Kutschera *et al.* (ANL, FNAL)
MARINELLI 84 PL 137B 439 M. Marinelli, G. Morpurgo (GENO)
WADA 84B LNC 40 329 T. Wada, Y. Yamashita, I. Yamamoto (OKAY)
AUBERT 83C PL 133B 461 J.J. Aubert *et al.* (EMC Collab.)
BANNER 83 PL 121B 187 M. Banner *et al.* (UA2 Collab.)
JOYCE 83 PRL 51 731 D.C. Joyce *et al.* (SFSU)
LIEBOWITZ 83 PRL 50 1640 D. Liebowitz, M. Binder, K.O.H. Ziock (UVA)
LINDGREN 83 PRL 51 1621 M.A. Lindgren *et al.* (SFSU, UCR, UCI+)
MASHIMO 83 PL 128B 327 T. Mashimo *et al.* (ICEPP)
PRICE 83 PRL 50 566 P.B. Price *et al.* (UCB)
VANDESTEEG 83 PRL 50 1234 M.J.H. van de Steeg, H.W.H.M. Jongbloets, P. Wyder
MARINI 82 PR D26 1777 A. Marini *et al.* (FRAS, LBL, NWES, STAN+)
MARINI 82B PRL 48 1649 A. Marini *et al.* (FRAS, LBL, NWES, STAN+)
MASHIMO 82 JPSJ 51 3067 T. Mashimo, K. Kawagoe, M. Koshiba (INUS)
NAPOLITANO 82 PR D25 2837 J. Napolitano *et al.* (STAN, FRAS, LBL+)
ROSS 82 PL 118B 199 M.C. Ross *et al.* (FRAS, LBL, NWES, STAN+)
HODGES 81 PRL 47 1651 C.L. Hodges *et al.* (UCR, SFSU)
LARUE 81 PRL 46 967 G.S. Larue, J.D. Phillips, W.M. Fairbank (STAN)
WEISS 81 PL 101B 439 J.M. Weiss *et al.* (SLAC, LBL, UCB)
BARTEL 80 ZPHY C6 295 W. Bartel *et al.* (JADE Collab.)
BASILE 80 LNC 29 251 M. Basile *et al.* (BGNA, CERN, FRAS, ROMA+)
BUSSIERE 80 NP B174 1 A. Bussiere *et al.* (BGNA, SACL, LAPP)
MARINELLI 80B PL 94B 433 M. Marinelli, G. Morpurgo (GENO)
Also PL 94B 427 M. Marinelli, G. Morpurgo (GENO)
BOYD 79 PRL 43 1288 R.N. Boyd *et al.* (OSU)
BOZZOLI 79 NP B159 363 W. Bozzoli *et al.* (BGNA, LAPP, SACL+)
LARUE 79 PRL 42 142 G.S. Larue, W.M. Fairbank, J.D. Phillips (STAN)
Also PRL 42 1019 G.S. Larue, W.M. Fairbank, J.D. Phillips
OGOROD... 79 JETP 49 953 D.D. Ogorodnikov, I.M. Samoilov, A.M. Solntsev
Translated from ZETF 76 1881.
STEVENSON 79 PR D20 82 M.L. Stevenson (LBL)
BASILE 78 NC 45A 171 M. Basile *et al.* (CERN, BGNA)
BASILE 78B NC 45A 281 M. Basile *et al.* (CERN, BGNA)
BOYD 78 PRL 40 216 R.N. Boyd *et al.* (ROCH)
BOYD 78B PL 72B 484 R.N. Boyd *et al.* (ROCH)
LUND 78 RA 25 75 T. Lund, R. Brandt, Y. Fares (MARB)
PUTT 78 PR D17 1466 G.D. Putt, P.C.M. Yock (AUCK)
SCHIFFER 78 PR D17 2241 J.P. Schiffer *et al.* (CHIC, ANL)
YOCK 78 PR D18 641 P.C.M. Yock (AUCK)
ANTREASYAN 77 PRL 39 513 D. Antreasyan *et al.* (EFI, PRIN)
BASILE 77 NC 40A 41 M. Basile *et al.* (CERN, BGNA)
BLAND 77 PRL 39 369 R.W. Bland *et al.* (SFSU)
GALLINARO 77 PRL 38 1255 G. Gallinaro, M. Marinelli, G. Morpurgo (GENO)
JONES 77B RMP 49 717 L.W. Jones
LARUE 77 PRL 38 1011 G.S. Larue, W.M. Fairbank, A.F. Hebard (STAN)
MULLER 77 SCI 196 521 R.A. Muller *et al.* (LBL)
OGOROD... 77 JETP 45 857 D.D. Ogorodnikov, I.M. Samoilov, A.M. Solntsev
Translated from ZETF 72 1633.
BALDIN 76 SJNP 22 264 B.Y. Baldin *et al.* (JINR)
Translated from YAF 22 512.
BRIATORE 76 NC 31A 553 L. Briatore *et al.* (LCGT, FRAS, FREIB)
STEVENS 76 PR D14 716 C.M. Stevens, J.P. Schiffer, W. Chupka (ANL)
ALBROW 75 NP B97 189 M.G. Albrow *et al.* (CERN, DARE, FOM+)
FABJAN 75 NP B101 349 C.W. Fabjan *et al.* (CERN, MPIM)
HAZEN 75 NP B95 189 W.E. Hazen *et al.* (MICH, LEED)
JOVANOV... 75 PL 56B 105 J.V. Jovanovich *et al.* (MANI, AACH, CERN+)
KRISOR 75 NC 27A 132 K. Krisor (AACH3)
CLARK 74B PR D10 2721 A.F. Clark *et al.* (LLL)
GALIK 74 PR D9 1856 R.S. Galik *et al.* (SLAC, FNAL)
KIFUNE 74 JPSJ 36 629 T. Kifune *et al.* (TOKY, KEK)
NASH 74 PRL 32 858 T. Nash *et al.* (FNAL, CORN, NYU)
ALPER 73 PL 46B 265 B. Alper *et al.* (CERN, LIVP, LUND, BOHR+)
ASHTON 73 JP A6 577 F. Ashton *et al.* (DURH)
HICKS 73B NC 14A 65 R.B. Hicks, R.W. Flint, S. Standil (MANI)
LEIPUNER 73 PRL 31 1226 L.B. Leipuner *et al.* (BNL, YALE)
BEAUCHAMP 72 PR D6 1211 W.T. Beauchamp *et al.* (ARIZ)
BOHM 72B PRL 28 326 A. Bohm *et al.* (AACH)
BOTT 72 PL 40B 693 M. Bott-Bodenhausen *et al.* (CERN, MPIM)
COX 72 PR D6 1203 A.J. Cox *et al.* (ARIZ)

| | | | | |
|---|---|---|---|---|
| CROUCH | 72 | PR D5 2667 | M.F. Crouch, K. Mori, G.R. Smith | (CASE) |
| DARDO | 72 | NC 9A 319 | M. Dardo *et al.* | (TORI) |
| EVANS | 72 | PRSE A70 143 | G.R. Evans *et al.* | (EDIN, LEED) |
| TONWAR | 72 | JP A5 569 | S.C. Tonwar, S. Naranan, B.V. Sreekantan | (TATA) |
| ANTIPOV | 71 | NP B29 374 | Y.M. Antipov *et al.* | (SERP) |
| CHIN | 71 | NC 2A 419 | S. Chin *et al.* | (OSAK) |
| CLARK | 71B | PRL 27 51 | A.F. Clark *et al.* | (LLL, LBL) |
| HAZEN | 71 | PRL 26 582 | W.E. Hazen | (MICH) |
| BOSIA | 70 | NC 66A 167 | G.F. Bosia, L. Briatore | (TORI) |
| CHU | 70 | PRL 24 917 | W.T. Chu *et al.* | (OSU, ROSE, KANS) |
| Also | | PRL 25 550 | W.W.M. Allison *et al.* | (ANL) |
| ELBERT | 70 | NP B20 217 | J.W. Elbert *et al.* | (WISC) |
| FAISSNER | 70B | PRL 24 1357 | H. Faissner *et al.* | (AACH3) |
| KRIDER | 70 | PR D1 835 | E.P. Krider, T. Bowen, R.M. Kalbach | (ARIZ) |
| MORPURGO | 70 | NIM 79 95 | G. Morpurgo, G. Gallinaro, G. Palmieri | (GENO) |
| ALLABY | 69B | NC 64A 75 | J.V. Allaby *et al.* | (CERN) |
| ANTIPOV | 69 | PL 29B 245 | Y.M. Antipov *et al.* | (SERP) |
| ANTIPOV | 69B | PL 30B 576 | Y.M. Antipov *et al.* | (SERP) |
| CAIRNS | 69 | PR 186 1394 | I. Cairns *et al.* | (SYDN) |
| COOK | 69 | PR 188 2092 | D.D. Cook *et al.* | (ILL) |
| FUKUSHIMA | 69 | PR 178 2058 | Y. Fukushima *et al.* | (TOKY) |
| MCCUSKER | 69 | PRL 23 658 | C.B.A. McCusker, I. Cairns | (SYDN) |
| BELLAMY | 68 | PR 166 1391 | E.H. Bellamy *et al.* | (STAN, SLAC) |
| BJORNBOE | 68 | NC B53 241 | J. Bjornboe *et al.* | (BOHR, TATA, BERN+) |
| BRAGINSK | 68 | JETP 27 51 | V.B. Braginsky *et al.* | (MOSU) |
| | | Translated from ZETF 54 91. | | |
| BRIATORE | 68 | NC 57A 850 | L. Briatore *et al.* | (TORI, CERN, BGNA) |
| FRANZINI | 68 | PRL 21 1013 | P. Franzini, S. Shulman | (COLU) |
| GARMIRE | 68 | PR 166 1280 | G. Garmire, C. Leong, V. Sreekantan | (MIT) |
| HANAYAMA | 68 | CJP 46 S734 | Y. Hanayama *et al.* | (OSAK) |
| KASHA | 68 | PR 172 1297 | H. Kasha, R.J. Stefanski | (BNL, YALE) |
| KASHA | 68B | PRL 20 217 | H. Kasha *et al.* | (BNL, YALE) |
| KASHA | 68C | CJP 46 S730 | H. Kasha *et al.* | (BNL, YALE) |
| RANK | 68 | PR 176 1635 | D. Rank | (MICH) |
| BARTON | 67 | PRSL 90 87 | J.C. Barton | (NPOL) |
| BATHOW | 67 | PL 25B 163 | G. Bathow *et al.* | (DESY) |
| BUHLER | 67 | NC 49A 209 | A. Buhler-Broglin *et al.* | (CERN, BGNA) |
| BUHLER | 67B | NC 51A 837 | A. Buhler-Broglin *et al.* | (CERN, BGNA+) |
| FOSS | 67 | PL 25B 166 | J. Foss *et al.* | (MIT) |
| GOMEZ | 67 | PRL 18 1022 | R. Gomez *et al.* | (CIT) |
| KASHA | 67 | PR 154 1263 | H. Kasha *et al.* | (BNL, YALE) |
| STOVER | 67 | PR 164 1599 | R.W. Stover, T.I. Moran, J.W. Trischka | (SYRA) |
| BARTON | 66 | PL 21 360 | J.C. Barton, C.T. Stockel | (NPOL) |
| BENNETT | 66 | PRL 17 1196 | W.R. Bennett | (YALE) |
| BUHLER | 66 | NC 45A 520 | A. Buhler-Broglin *et al.* | (CERN, BGNA+) |
| CHUPKA | 66 | PRL 17 60 | W.A. Chupka, J.P. Schiffer, C.M. Stevens | (ANL) |
| GALLINARO | 66 | PL 23 609 | G. Gallinaro, G. Morpurgo | (GENO) |
| KASHA | 66 | PR 150 1140 | H. Kasha, L.B. Leipuner, R.K. Adair | (BNL, YALE) |
| LAMB | 66 | PRL 17 1068 | R.C. Lamb *et al.* | (ANL) |
| DELISE | 65 | PR 140B 458 | D.A. de Lise, T. Bowen | (ARIZ) |
| DORFAN | 65 | PRL 14 999 | D.E. Dorfan *et al.* | (COLU) |
| FRANZINI | 65B | PRL 14 196 | P. Franzini *et al.* | (BNL, COLU) |
| MASSAM | 65 | NC 40A 589 | T. Massam, T. Muller, A. Zichichi | (CERN) |
| BINGHAM | 64 | PL 9 201 | H.H. Bingham *et al.* | (CERN, EPOL) |
| BLUM | 64 | PRL 13 353A | W. Blum *et al.* | (CERN) |
| BOWEN | 64 | PRL 13 728 | T. Bowen *et al.* | (ARIZ) |
| HAGOPIAN | 64 | PRL 13 280 | V. Hagopian *et al.* | (PENN, BNL) |
| LEIPUNER | 64 | PRL 12 423 | L.B. Leipuner *et al.* | (BNL, YALE) |
| MORRISON | 64 | PL 9 199 | D.R.O. Morrison | (CERN) |
| SUNYAR | 64 | PR 136 B1157 | A.W. Sunyar, A.Z. Schwarzschild, P.I. Connors | (BNL) |
| HILLAS | 59 | NAT 184 B92 | A.M. Hillas, T.E. Cranshaw | (AERE) |
| MILLIKAN | 10 | Phil Mag 19 209 | R.A. Millikan | (CHIC) |


## OTHER RELATED PAPERS


| | | | | |
|---|---|---|---|---|
| LYONS | 85 | PRPL C129 225 | L. Lyons | (OXF) |
| Review | | | | |
| MARINELLI | 82 | PRPL 85 161 | M. Marinelli, G. Morpurgo | (GENO) |
| Review | | | | |