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Magnetic Monopole Searches

MAGNETIC MONOPOLE SEARCHES

Revised December 1997 by D.E. Groom (LBNL).

"At the present time (1975) there is no experimental evidence for the existence of magnetic charges or monopoles, but chiefly because of an early, brilliant theoretical argument by Dirac, the search for monopoles is renewed whenever a new energy region is opened up in high energy physics or a new source of matter, such as rocks from the moon, becomes available [1]." Dirac argued that a monopole anywhere in the universe results in electric charge quantization everywhere, and leads to the prediction of a least magnetic charge $g = e/2\alpha$, the Dirac charge [2]. Recently monopoles have become indispensable in many gauge theories, which endow them with a variety of extraordinarily large masses. The discovery by a candidate event in a single superconducting loop in 1982 [6] stimulated an enormous experimental effort to search for supermassive magnetic monopoles [3,4,5].

Monopole detectors have predominantly used either induction or ionization. Induction experiments measure the monopole magnetic charge and are independent of monopole electric charge, mass, and velocity. Monopole candidate events in single semiconductor loops [6,7] have been detected by this method, but no two-loop coincidence has been observed. Ionization experiments rely on a magnetic charge producing more ionization than an electrical charge with the same velocity. In the case of supermassive monopoles, time-of-flight measurements indicating $v \ll c$ has also been a frequently sought signature.

Cosmic rays are the most likely source of massive monopoles, since accelerator energies are insufficient to produce them. Evidence for such monopoles may also be obtained from astrophysical observations.

Jackson's 1975 assessment remains true. The search is somewhat abated by the lack of success in the 1980's and the decrease of interest in grand unified gauge theories.

References

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Monopole Production Cross Section — Accelerator Searches

X-SECT (cm^2)	*MASS* (GeV)	*CHG* (g)	*ENERGY* (GeV)	*BEAM*	*EVTS*	*DOCUMENT ID*		*TECN*
<0.65E−33	<3.3	≥ 2	11A	^{197}Au	0	[1] HE	97	
<1.90E−33	<8.1	≥ 2	160A	^{208}Pb	0	[1] HE	97	
<3.E−37	<45.0	1.0	88–94	e^+e^-	0	PINFOLD	93	PLAS
<3.E−37	<41.6	2.0	88–94	e^+e^-	0	PINFOLD	93	PLAS
<7.E−35	<44.9	0.2–1.0	89–93	e^+e^-	0	KINOSHITA	92	PLAS
<2.E−34	<850	≥ 0.5	1800	$p\overline{p}$	0	BERTANI	90	PLAS
<1.2E−33	<800	≥ 1	1800	$p\overline{p}$	0	PRICE	90	PLAS
<1.E−37	<29	1	50–61	e^+e^-	0	KINOSHITA	89	PLAS
<1.E−37	<18	2	50–61	e^+e^-	0	KINOSHITA	89	PLAS
<1.E−38	<17	<1	35	e^+e^-	0	BRAUNSCH...	88B	CNTR
<8.E−37	<24	1	50–52	e^+e^-	0	KINOSHITA	88	PLAS
<1.3E−35	<22	2	50–52	e^+e^-	0	KINOSHITA	88	PLAS
<9.E−37	<4	<0.15	10.6	e^+e^-	0	GENTILE	87	CLEO
<3.E−32	<800	≥ 1	1800	$p\overline{p}$	0	PRICE	87	PLAS
<3.E−38		<3	29	e^+e^-	0	FRYBERGER	84	PLAS
<1.E−31		1,3	540	$p\overline{p}$	0	AUBERT	83B	PLAS
<4.E−38	<10	<6	34	e^+e^-	0	MUSSET	83	PLAS
<8.E−36	<20		52	pp	0	[2] DELL	82	CNTR

<9.E−37	<30	<3	29	e^+e^-	0	KINOSHITA	82	PLAS
<1.E−37	<20	<24	63	pp	0	CARRIGAN	78	CNTR
<1.E−37	<30	<3	56	pp	0	HOFFMANN	78	PLAS
			62	pp	0	[2] DELL	76	SPRK
<4.E−33			300	p	0	[2] STEVENS	76B	SPRK
<1.E−40	<5	<2	70	p	0	[3] ZRELOV	76	CNTR
<2.E−30			300	n	0	[2] BURKE	75	OSPK
<1.E−38			8	ν	0	[4] CARRIGAN	75	HLBC
<5.E−43	<12	<10	400	p	0	EBERHARD	75B	INDU
<2.E−36	<30	<3	60	pp	0	GIACOMELLI	75	PLAS
<5.E−42	<13	<24	400	p	0	CARRIGAN	74	CNTR
<6.E−42	<12	<24	300	p	0	CARRIGAN	73	CNTR
<2.E−36		1	0.001	γ	0	[3] BARTLETT	72	CNTR
<1.E−41	<5		70	p	0	GUREVICH	72	EMUL
<1.E−40	<3	<2	28	p	0	AMALDI	63	EMUL
<2.E−40	<3	<2	30	p	0	PURCELL	63	CNTR
<1.E−35	<3	<4	28	p	0	FIDECARO	61	CNTR
<2.E−35	<1	1	6	p	0	BRADNER	59	EMUL

[1] HE 97 used a lead target and barium phosphate glass detectors. Cross-section limits are well below those predicted via the Drell-Yan mechanism.

[2] Multiphoton events.

[3] Cherenkov radiation polarization.

[4] Re-examines CERN neutrino experiments.

Monopole Production — Other Accelerator Searches

MASS (GeV)	*CHG (g)*	*SPIN*	*ENERGY (GeV)*	*BEAM*	*DOCUMENT ID*		*TECN*
> 610	≥ 1	0	1800	$p\overline{p}$	[5] ABBOTT	98K	D0
> 870	≥ 1	1/2	1800	$p\overline{p}$	[5] ABBOTT	98K	D0
>1580	≥ 1	1	1800	$p\overline{p}$	[5] ABBOTT	98K	D0
> 510			88–94	e^+e^-	[6] ACCIARRI	95C	L3

[5] ABBOTT 98K search for heavy pointlike Dirac monopoles via central production of a pair of photons with high transverse energies.

[6] ACCIARRI 95C finds a limit $B(Z \rightarrow \gamma\gamma\gamma) < 0.8 \times 10^{-5}$ (which is possible via a monopole loop) at 95% CL and sets the mass limit via a cross section model.

Monopole Flux — Cosmic Ray Searches

FLUX ($cm^{-2}sr^{-1}s^{-1}$)	*MASS* (GeV)	*CHG* (*g*)	*COMMENTS* ($\beta = v/c$)	*EVTS*	*DOCUMENT ID*		*TECN*
<1E−15		**1**	**1.1×10^{-4}–0.1**	0	[7] AMBROSIO	97	MCRO
<4.1E−15		1	(0.18–2.7)E−3	0	[8] AMBROSIO	97	MCRO
<1.0E−15		1	0.0012–0.1	0	[9] AMBROSIO	97	MCRO
<0.87E−15			(0.11–5)E−3	0	[10] AMBROSIO	97	MCRO
<6.8E−15		1	4.0E−5	0	[11] AMBROSIO	97	MCRO
<2.8E−15		1	0.1–1	0	[12] AMBROSIO	97	MCRO
<4.4E−15		1	0.1–1	0	[13] AMBROSIO	97	MCRO
<5.6E−15		1	(0.18–3.0)E−3	0	[14] AHLEN	94	MCRO
<2.7E−15		1	$\beta \sim 1 \times 10^{-3}$	0	[15] BECKER-SZ...	94	IMB
<8.7E−15		1	>2.E−3	0	THRON	92	SOUD
<4.4E−12		1	all β	0	GARDNER	91	INDU

<7.2E−13		1	all β	0	HUBER	91	INDU
<3.7E−15	>E12	1	β=1.E−4	0	[16] ORITO	91	PLAS
<3.2E−16	>E10	1	$\beta > 0.05$	0	[16] ORITO	91	PLAS
<3.2E−16	>E10–E12	2, 3		0	[16] ORITO	91	PLAS
<3.8E−13		1	all β	0	BERMON	90	INDU
<5.E−16		1	β <1.E−3	0	[15] BEZRUKOV	90	CHER
<1.8E−14		1	β >1.1E−4	0	[17] BUCKLAND	90	HEPT
<1E−18			3.E−4 < β <1.5E−3	0	[18] GHOSH	90	MICA
<7.2E−13		1	all β	0	HUBER	90	INDU
<5.E−12	>E7	1	3.E−4 < β <5.E−3	0	BARISH	87	CNTR
<1.E−13			1.E−5 < β <1	0	[15] BARTELT	87	SOUD
<1.E−10		1	all β	0	EBISU	87	INDU
<2.E−13			1.E−4 < β <6.E−4	0	MASEK	87	HEPT
<2.E−14			4.E−5 < β <2.E−4	0	NAKAMURA	87	PLAS
<2.E−14			1.E−3 < β <1	0	NAKAMURA	87	PLAS
<5.E−14			9.E−4 < β <1.E−2	0	SHEPKO	87	CNTR
<2.E−13			4.E−4 < β <1	0	TSUKAMOTO	87	CNTR
<5.E−14		1	all β	1	[19] CAPLIN	86	INDU
<5.E−12		1		0	CROMAR	86	INDU
<1.E−13		1	7.E−4 < β	0	HARA	86	CNTR
<7.E−11		1	all β	0	INCANDELA	86	INDU
<1.E−18			4.E−4 < β <1.E−3	0	[18] PRICE	86	MICA
<5.E−12		1		0	BERMON	85	INDU
<6.E−12		1		0	CAPLIN	85	INDU
<6.E−10		1		0	EBISU	85	INDU
<3.E−15			5.E−5 $\leq \beta \leq$ 1.E−3	0	[15] KAJITA	85	KAMI
<2.E−21			β <1.E−3	0	[15,20] KAJITA	85	KAMI
<3.E−15			1.E−3 < β <1.E−1	0	[15] PARK	85B	CNTR
<5.E−12		1	1.E−4 < β <1	0	BATTISTONI	84	NUSX
<7.E−12		1		0	INCANDELA	84	INDU
<7.E−13		1	3.E−4 < β	0	[17] KAJINO	84	CNTR
<2.E−12		1	3.E−4 < β <1.E−1	0	KAJINO	84B	CNTR
<6.E−13		1	5.E−4 < β <1	0	KAWAGOE	84	CNTR
<2.E−14			1.E−3 < β	0	[15] KRISHNA...	84	CNTR
<4.E−13		1	6.E−4 < β <2.E−3	0	LISS	84	CNTR
<1.E−16			3.E−4 < β <1.E−3	0	[18] PRICE	84	MICA
<1.E−13		1	1.E−4 < β	0	PRICE	84B	PLAS
<4.E−13		1	6.E−4 < β <2.E−3	0	TARLE	84	CNTR
				7	[21] ANDERSON	83	EMUL
<4.E−13		1	1.E−2 < β <1.E−3	0	BARTELT	83B	CNTR
<1.E−12		1	7.E−3 < β <1	0	BARWICK	83	PLAS
<3.E−13		1	1.E−3 < β <4.E−1	0	BONARELLI	83	CNTR
<3.E−12			5.E−4 < β <5.E−2	0	[15] BOSETTI	83	CNTR
<4.E−11		1		0	CABRERA	83	INDU
<5.E−15		1	1.E−2 < β <1	0	DOKE	83	PLAS
<8.E−15			1.E−4 < β <1.E−1	0	[15] ERREDE	83	IMB
<5.E−12		1	1.E−4 < β <3.E−2	0	GROOM	83	CNTR
<2.E−12			6.E−4 < β <1	0	MASHIMO	83	CNTR
<1.E−13		1	β=3.E−3	0	ALEXEYEV	82	CNTR

<2.E−12		1	7.E−3 $< \beta <$6.E−1	0	BONARELLI 82	CNTR
6.E−10		1	all β	1	[22] CABRERA 82	INDU
<2.E−11			1.E−2 $< \beta <$1.E−1	0	MASHIMO 82	CNTR
<2.E−15			concentrator	0	BARTLETT 81	PLAS
<1.E−13	>1		1.E−3 $< \beta$	0	KINOSHITA 81B	PLAS
<5.E−11	<E17		3.E−4 $< \beta <$1.E−3	0	ULLMAN 81	CNTR
<2.E−11			concentrator	0	BARTLETT 78	PLAS
1.E−1	>200	2		1	[23] PRICE 75	PLAS
<2.E−13		>2		0	FLEISCHER 71	PLAS
<1.E−19		>2	obsidian, mica	0	FLEISCHER 69C	PLAS
<5.E−15	<15	<3	concentrator	0	CARITHERS 66	ELEC
<2.E−11		<1–3	concentrator	0	MALKUS 51	EMUL

[7] AMBROSIO 97 global MACRO 90%CL is 0.78×10^{-15} at β=1.1×10^{-4}, goes through a minimum at 0.61×10^{-15} near β=(1.1–2.7) $\times 10^{-3}$, then rises to 0.84×10^{-15} at β=0.1. The global limit in this region is below the Parker bound at 10^{-15}. Less stringent limits are established for $4 \times 10^{-5} < \beta < 1$. Limits set by various triggers in the detector are listed below. All limits assume a catalysis cross section smaller than 10 mb.

[8] AMBROSIO 97 "Scintillator D" (low velocity) 90%CL increases from 4.1×10^{-15} at β=2.7×10^{-3} to 14.6×10^{-15} at β=0.006.

[9] AMBROSIO 97 "Scintillator B" 90%CL (single medium-velocity trigger with two analysis criteria).

[10] AMBROSIO 97 streamer tube 90%CL. Tubes contain helium, and hence trigger is sensitive via the atomic induction mechanism.

[11] AMBROSIO 97 CR39 90%CL improves to 4.3×10^{-15} at β=1.0×10^{-4}. CR39 is sensitive for $4 \times 10^{-5} < \beta < 1$ except for a window at $0.25 \times 10^{-3} < \beta < 2.1 \times 10^{-3}$. In the middle region other triggers set better limits.

[12] AMBROSIO 97 CR39 90%CL falls to 2.7×10^{-15} at β=1 and increases at lower velocities. Provides better limit than "Scintillator C" for $0.1 < \beta < 1.0$.

[13] AMBROSIO 97 "Scintillator C" 90%CL, based on high absolute energy loss in two scintillator layers.

[14] AHLEN 94 limit for dyons extends down to β=0.9E−4 and a limit of 1.3E−14 extends to β = 0.8E−4. Also see comment by PRICE 94 and reply of BARISH 94. One loophole in the AHLEN 94 result is that in the case of monopoles catalyzing nucleon decay, relativisitic particles could veto the events. See AMBROSIO 97 for additional results.

[15] Catalysis of nucleon decay; sensitive to assumed catalysis cross section.

[16] ORITO 91 limits are functions of velocity. Lowest limits are given here.

[17] Used DKMPR mechanism and Penning effect.

[18] Assumes monopole attaches fermion nucleus.

[19] Limit from combining data of CAPLIN 86, BERMON 85, INCANDELA 84, and CABRERA 83. For a discussion of controversy about CAPLIN 86 observed event, see GUY 87. Also see SCHOUTEN 87.

[20] Based on lack of high- energy solar neutrinos from catalysis in the sun.

[21] Anomalous long-range α (^{4}He) tracks.

[22] CABRERA 82 candidate event has single Dirac charge within ±5%.

[23] ALVAREZ 75, FLEISCHER 75, and FRIEDLANDER 75 explain as fragmenting nucleus. EBERHARD 75 and ROSS 76 discuss conflict with other experiments. HAGSTROM 77 reinterprets as antinucleus. PRICE 78 reassesses.

Monopole Flux — Astrophysics

FLUX (cm^{-2}sr^{-1}s^{-1})	*MASS* (GeV)	*CHG* (g)	*COMMENTS* ($\beta = v/c$)	*EVTS*	*DOCUMENT ID*		*TECN*
<1.3E−20			faint white dwarf		[24] FREESE	99	ASTR
<1.E−16	E17	1	galactic field	0	[25] ADAMS	93	COSM
<1.E−23			Jovian planets		[24] ARAFUNE	85	ASTR
<1.E−16	E15		solar trapping	0	BRACCI	85B	ASTR
<1.E−18		1		0	[24] HARVEY	84	COSM
<3.E−23			neutron stars		KOLB	84	ASTR
<7.E−22			pulsars	0	[24] FREESE	83B	ASTR
<1.E−18	<E18	1	intergalactic field	0	[24] REPHAELI	83	COSM
<1.E−23			neutron stars	0	[24] DIMOPOUL...	82	COSM
<5.E−22			neutron stars	0	[24] KOLB	82	COSM
<5.E−15	>E21		galactic halo		SALPETER	82	COSM
<1.E−12	E19	1	β=3.E−3	0	[26] TURNER	82	COSM
<1.E−16		1	galactic field	0	PARKER	70	COSM

[24] Catalysis of nucleon decay.

[25] ADAMS 93 limit based on "survival and growth of a small galactic seed field" is 10^{-16} ($m/10^{17}$ GeV) cm^{-2} s^{-1} sr^{-1}. Above 10^{17} GeV, limit 10^{-16} (10^{17} GeV$/m$) cm^{-2} s^{-1} sr^{-1} (from requirement that monopole density does not overclose the universe) is more stringent.

[26] Re-evaluates PARKER 70 limit for GUT monopoles.

Monopole Density — Matter Searches

DENSITY	*CHG* (g)	*MATERIAL*	*EVTS*	*DOCUMENT ID*		*TECN*
<6.9E−6/gram	>1/3	Meteorites and other	0	JEON	95	INDU
<2.E−7/gram	>0.6	Fe ore	0	[27] EBISU	87	INDU
<4.6E−6/gram	> 0.5	deep schist	0	KOVALIK	86	INDU
<1.6E−6/gram	> 0.5	manganese nodules	0	[28] KOVALIK	86	INDU
<1.3E−6/gram	> 0.5	seawater	0	KOVALIK	86	INDU
>1.E+14/gram	>1/3	iron aerosols	>1	MIKHAILOV	83	SPEC
<6.E−4/gram		air, seawater	0	CARRIGAN	76	CNTR
<5.E−1/gram	>0.04	11 materials	0	CABRERA	75	INDU
<2.E−4/gram	>0.05	moon rock	0	ROSS	73	INDU
<6.E−7/gram	<140	seawater	0	KOLM	71	CNTR
<1.E−2/gram	<120	manganese nodules	0	FLEISCHER	69	PLAS
<1.E−4/gram	>0	manganese	0	FLEISCHER	69B	PLAS
<2.E−3/gram	<1–3	magnetite, meteor	0	GOTO	63	EMUL
<2.E−2/gram		meteorite	0	PETUKHOV	63	CNTR

[27] Mass 1×10^{14}–1×10^{17} GeV.

[28] KOVALIK 86 examined 498 kg of schist from two sites which exhibited clear minearalogic evidence of haivng been buried at least 20 km deep and held below the Curie temperature.

Monopole Density — Astrophysics

DENSITY	*CHG (g)*	*MATERIAL*	*EVTS*	*DOCUMENT ID*		*TECN*
$<1.E-9$/gram	1	sun, catalysis	0	[29] ARAFUNE	83	COSM
$<6.E-33$/nucl	1	moon wake	0	SCHATTEN	83	ELEC
$<2.E-28$/nucl		earth heat	0	CARRIGAN	80	COSM
$<2.E-4$/prot		42cm absorption	0	BRODERICK	79	COSM
$<2.E-13/m^3$		moon wake	0	SCHATTEN	70	ELEC

[29] Catalysis of nucleon decay.

REFERENCES FOR Magnetic Monopole Searches

FREESE	99	PR D59 063007	K. Freese, E. Krasteva	
ABBOTT	98K	PRL 81 524	B. Abbott *et al.*	(D0 Collab.)
AMBROSIO	97	PL B406 249	M. Ambrosio *et al.*	(MACRO Collab.)
HE	97	PRL 79 3134	Y.D. He	(UCB)
ACCIARRI	95C	PL B345 609	M. Acciarri *et al.*	(L3 Collab.)
JEON	95	PRL 75 1443	H. Jeon, M.J. Longo	(MICH)
Also	96	PRL 76 159 (errata)		
AHLEN	94	PRL 72 608	S.P. Ahlen *et al.*	(MACRO Collab.)
BARISH	94	PRL 73 1306	B.C. Barish, G. Giacomelli, J.T. Hong	(CIT+)
BECKER-SZ...	94	PR D49 2169	R.A. Becker-Szendy *et al.*	(IMB Collab.)
PRICE	94	PRL 73 1305	P.B. Price	(UCB)
ADAMS	93	PRL 70 2511	F.C. Adams *et al.*	(MICH, FNAL)
PINFOLD	93	PL B316 407	J.L. Pinfold *et al.*	(ALBE, HARV, MONT+)
KINOSHITA	92	PR D46 R881	K. Kinoshita *et al.*	(HARV, BGNA, REHO)
THRON	92	PR D46 4846	J.L. Thron *et al.*	(SOUDAN-2 Collab.)
GARDNER	91	PR D44 622	R.D. Gardner *et al.*	(STAN)
HUBER	91	PR D44 636	M.E. Huber *et al.*	(STAN)
ORITO	91	PRL 66 1951	S. Orito *et al.*	(ICEPP, WASCR, NIHO, ICRR)
BERMON	90	PRL 64 839	S. Bermon *et al.*	(IBM, BNL)
BERTANI	90	EPL 12 613	M. Bertani *et al.*	(BGNA, INFN)
BEZRUKOV	90	SJNP 52 54 Translated from YAF 52 86.	L.B. Bezrukov *et al.*	(INRM)
BUCKLAND	90	PR D41 2726	K.N. Buckland *et al.*	(UCSD)
GHOSH	90	EPL 12 25	D.C. Ghosh, S. Chatterjea	(JADA)
HUBER	90	PRL 64 835	M.E. Huber *et al.*	(STAN)
PRICE	90	PRL 65 149	P.B. Price, J. Guiru, K. Kinoshita	(UCB, HARV)
KINOSHITA	89	PL B228 543	K. Kinoshita *et al.*	(HARV, TISA, KEK+)
BRAUNSCH...	88B	ZPHY C38 543	R. Braunschweig *et al.*	(TASSO Collab.)
KINOSHITA	88	PRL 60 1610	K. Kinoshita *et al.*	(HARV, TISA, KEK+)
BARISH	87	PR D36 2641	B.C. Barish, G. Liu, C. Lane	(CIT)
BARTELT	87	PR D36 1990	J.E. Bartelt *et al.*	(Soudan Collab.)
Also	89	PR D40 1701 erratum	J.E. Bartelt *et al.*	(Soudan Collab.)
EBISU	87	PR D36 3359	T. Ebisu, T. Watanabe	(KOBE)
Also	85	JPG 11 883	T. Ebisu, T. Watanabe	(KOBE)
GENTILE	87	PR D35 1081	T. Gentile *et al.*	(CLEO Collab.)
GUY	87	Nature 325 463	J. Guy	(LOIC)
MASEK	87	PR D35 2758	G.E. Masek *et al.*	(UCSD)
NAKAMURA	87	PL B183 395	S. Nakamura *et al.*	(INUS, WASCR, NIHO)
PRICE	87	PRL 59 2523	P.B. Price, R. Guoxiao, K. Kinoshita	(UCB, HARV)
SCHOUTEN	87	JPE 20 850	J.C. Schouten *et al.*	(LOIC)
SHEPKO	87	PR D35 2917	M.J. Shepko *et al.*	(TAMU)
TSUKAMOTO	87	EPL 3 39	T. Tsukamoto *et al.*	(ICRR)
CAPLIN	86	Nature 321 402	A.D. Caplin *et al.*	(LOIC)
Also	87	JPE 20 850	J.C. Schouten *et al.*	(LOIC)
Also	87	Nature 325 463	J. Guy	(LOIC)
CROMAR	86	PRL 56 2561	M.W. Cromar, A.F. Clark, F.R. Fickett	(NBSB)
HARA	86	PRL 56 553	T. Hara *et al.*	(ICRR, KYOT, KEK, KOBE+)
INCANDELA	86	PR D34 2637	J. Incandela *et al.*	(CHIC, FNAL, MICH)
KOVALIK	86	PR A33 1183	J.M. Kovalik, J.L. Kirschvink	(CIT)
PRICE	86	PRL 56 1226	P.B. Price, M.H. Salamon	(UCB)
ARAFUNE	85	PR D32 2586	J. Arafune, M. Fukugita, S. Yanagita	(ICRR, KYOTU+)
BERMON	85	PRL 55 1850	S. Bermon *et al.*	(IBM)
BRACCI	85B	NP B258 726	L. Bracci, G. Fiorentini, G. Mezzorani	(PISA+)
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CAPLIN	85	Nature 317 234	A.D. Caplin *et al.*	(LOIC)

EBISU	85	JPG 11 883	T. Ebisu, T. Watanabe	(KOBE)
KAJITA	85	JPSJ 54 4065	T. Kajita *et al.*	(ICRR, KEK, NIIG)
PARK	85B	NP B252 261	H.S. Park *et al.*	(IMB Collab.)
BATTISTONI	84	PL 133B 454	G. Battistoni *et al.*	(NUSEX Collab.)
FRYBERGER	84	PR D29 1524	D. Fryberger *et al.*	(SLAC, UCB)
HARVEY	84	NP B236 255	J.A. Harvey	(PRIN)
INCANDELA	84	PRL 53 2067	J. Incandela *et al.*	(CHIC, FNAL, MICH)
KAJINO	84	PRL 52 1373	F. Kajino *et al.*	(ICRR)
KAJINO	84B	JPG 10 447	F. Kajino *et al.*	(ICRR)
KAWAGOE	84	LNC 41 315	K. Kawagoe *et al.*	(TOKY)
KOLB	84	APJ 286 702	E.W. Kolb, M.S. Turner	(FNAL, CHIC)
KRISHNA...	84	PL 142B 99	M.R. Krishnaswamy *et al.*	(TATA, OSKC+)
LISS	84	PR D30 884	T.M. Liss, S.P. Ahlen, G. Tarle	(UCB, IND+)
PRICE	84	PRL 52 1265	P.B. Price *et al.*	(ROMA, UCB, IND+)
PRICE	84B	PL 140B 112	P.B. Price	(CERN)
TARLE	84	PRL 52 90	G. Tarle, S.P. Ahlen, T.M. Liss	(UCB, MICH+)
ANDERSON	83	PR D28 2308	S.N. Anderson *et al.*	(WASH)
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AUBERT	83B	PL 120B 465	B. Aubert *et al.*	(CERN, LAPP)
BARTELT	83B	PRL 50 655	J.E. Bartelt *et al.*	(MINN, ANL)
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ALEXEYEV	82	LNC 35 413	E.N. Alekseev *et al.*	(INRM)
BONARELLI	82	PL 112B 100	R. Bonarelli *et al.*	(BGNA)
CABRERA	82	PRL 48 1378	B. Cabrera	(STAN)
DELL	82	NP B209 45	G.F. Dell *et al.*	(BNL, ADEL, ROMA)
DIMOPOUL...	82	PL 119B 320	S. Dimopoulos, J. Preskill, F. Wilczek	(HARV+)
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KOLB	82	PRL 49 1373	E.W. Kolb, S.A. Colgate, J.A. Harvey	(LASL, PRIN)
MASHIMO	82	JPSJ 51 3067	T. Mashimo, K. Kawagoe, M. Koshiba	(INUS)
SALPETER	82	PRL 49 1114	E.E. Salpeter, S.L. Shapiro, I. Wasserman	(CORN)
TURNER	82	PR D26 1296	M.S. Turner, E.N. Parker, T.J. Bogdan	(CHIC)
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ULLMAN	81	PRL 47 289	J.D. Ullman	(LEHM, BNL)
CARRIGAN	80	Nature 288 348	R.A. Carrigan	(FNAL)
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