

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
< 0.6E-36	>265	1	1800	$p\bar{p}$	0	¹ KALBFLEISCH 04	INDU
< 0.2E-36	>355	2	1800	$p\bar{p}$	0	¹ KALBFLEISCH 04	INDU
< 0.07E-36	>410	3	1800	$p\bar{p}$	0	¹ KALBFLEISCH 04	INDU
< 0.2E-36	>375	6	1800	$p\bar{p}$	0	¹ KALBFLEISCH 04	INDU
< 0.7E-36	>295	1	1800	$p\bar{p}$	0	^{2,3} KALBFLEISCH 00	INDU
< 7.8E-36	>260	2	1800	$p\bar{p}$	0	^{2,3} KALBFLEISCH 00	INDU
< 2.3E-36	>325	3	1800	$p\bar{p}$	0	^{2,4} KALBFLEISCH 00	INDU
< 0.11E-36	>420	6	1800	$p\bar{p}$	0	^{2,4} KALBFLEISCH 00	INDU
<0.65E-33	<3.3	≥ 2	11A	¹⁹⁷ Au	0	⁵ HE	97
<1.90E-33	<8.1	≥ 2	160A	²⁰⁸ Pb	0	⁵ 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	$p\bar{p}$	0	BERTANI	90 PLAS
<1.2E-33	<800	≥ 1	1800	$p\bar{p}$	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	$p\bar{p}$	0	PRICE	87 PLAS

<3.E-38	<3	29	e^+e^-	0	FRYBERGER	84	PLAS
<1.E-31		1,3	$p\bar{p}$	0	AUBERT	83B	PLAS
<4.E-38	<10	<6	e^+e^-	0	MUSSET	83	PLAS
<8.E-36	<20		pp	0	⁶ DELL	82	CNTR
<9.E-37	<30	<3	e^+e^-	0	KINOSHITA	82	PLAS
<1.E-37	<20	<24	pp	0	CARRIGAN	78	CNTR
<1.E-37	<30	<3	pp	0	HOFFMANN	78	PLAS
			pp	0	⁶ DELL	76	SPRK
<4.E-33			p	0	⁶ STEVENS	76B	SPRK
<1.E-40	<5	<2	p	0	⁷ ZRELOV	76	CNTR
<2.E-30			n	0	⁶ BURKE	75	OSPK
<1.E-38			ν	0	⁸ CARRIGAN	75	HLBC
<5.E-43	<12	<10	p	0	EBERHARD	75B	INDU
<2.E-36	<30	<3	pp	0	GIACOMELLI	75	PLAS
<5.E-42	<13	<24	p	0	CARRIGAN	74	CNTR
<6.E-42	<12	<24	p	0	CARRIGAN	73	CNTR
<2.E-36		1	0.001 γ	0	⁷ BARTLETT	72	CNTR
<1.E-41	<5		p	0	GUREVICH	72	EMUL
<1.E-40	<3	<2	p	0	AMALDI	63	EMUL
<2.E-40	<3	<2	p	0	PURCELL	63	CNTR
<1.E-35	<3	<4	p	0	FIDECARO	61	CNTR
<2.E-35	<1	1	p	0	BRADNER	59	EMUL

¹ KALBFLEISCH 04 reports searches for stopped magnetic monopoles in Be, Al, and Pb samples obtained from discarded material from the upgrading of DØ and CDF. A large-aperture warm-bore cryogenic detector was used. The approach was an extension of the methods of KALBFLEISCH 00. Results are model dependent.

² KALBFLEISCH 00 used an induction method to search for stopped monopoles in pieces of the DØ (FNAL) beryllium beam pipe and in extensions to the drift chamber aluminum support cylinder. Results are model dependent.

³ KALBFLEISCH 00 result is for aluminum.

⁴ KALBFLEISCH 00 result is for beryllium.

⁵ HE 97 used a lead target and barium phosphate glass detectors. Cross-section limits are well below those predicted via the Drell-Yan mechanism.

⁶ Multiphoton events.

⁷ Cherenkov radiation polarization.

⁸ 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	$p\bar{p}$	⁹ ABBOTT	98K D0
> 870	≥ 1	1/2	1800	$p\bar{p}$	⁹ ABBOTT	98K D0
>1580	≥ 1	1	1800	$p\bar{p}$	⁹ ABBOTT	98K D0
> 510			88-94	e^+e^-	¹⁰ ACCIARRI	95C L3

⁹ ABBOTT 98K search for heavy pointlike Dirac monopoles via central production of a pair of photons with high transverse energies.

¹⁰ 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

“Caty” in the charge column indicates a search for monopole-catalyzed nucleon decay.
 The absence of an entry usually means a track-etch experiment.

<u>FLUX</u> ($\text{cm}^{-2}\text{sr}^{-1}\text{s}^{-1}$)	<u>MASS</u> (GeV)	<u>CHG</u> (g)	<u>COMMENTS</u> ($\beta = v/c$)	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<1.4E-16		1	$1.1\text{E}-4 < \beta < 1$	0	11 AMBROSIO	02B MCRO
<3E-16		Caty	$1.1\text{E}-4 < \beta < 5\text{E}-3$	0	12 AMBROSIO	02C MCRO
<1.5E-15		1	$5\text{E}-3 < \beta < 0.99$	0	13 AMBROSIO	02D MCRO
<1E-15		1	$1.1 \times 10^{-4} - 0.1$	0	14 AMBROSIO	97 MCRO
<5.6E-15		1	$(0.18-3.0)\text{E}-3$	0	15 AHLEN	94 MCRO
<2.7E-15		Caty	$\beta \sim 1 \times 10^{-3}$	0	16 BECKER-SZ...	94 IMB
<8.7E-15		1	$>2.\text{E}-3$	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	$\beta = 1.\text{E}-4$	0	17 ORITO	91 PLAS
<3.2E-16	>E10	1	$\beta > 0.05$	0	17 ORITO	91 PLAS
<3.2E-16	>E10-E12	2,3		0	17 ORITO	91 PLAS
<3.8E-13		1	all β	0	BERMON	90 INDU
<5.E-16		Caty	$\beta < 1.\text{E}-3$	0	16 BEZUKOV	90 CHER
<1.8E-14		1	$\beta > 1.1\text{E}-4$	0	18 BUCKLAND	90 HEPT
<1E-18			$3.\text{E}-4 < \beta < 1.5\text{E}-3$	0	19 GHOSH	90 MICA
<7.2E-13		1	all β	0	HUBER	90 INDU
<5.E-12	>E7	1	$3.\text{E}-4 < \beta < 5.\text{E}-3$	0	BARISH	87 CNTR
<1.E-13		Caty	$1.\text{E}-5 < \beta < 1$	0	16 BARTELT	87 SOUD
<1.E-10		1	all β	0	EBISU	87 INDU
<2.E-13			$1.\text{E}-4 < \beta < 6.\text{E}-4$	0	MASEK	87 HEPT
<2.E-14			$4.\text{E}-5 < \beta < 2.\text{E}-4$	0	NAKAMURA	87 PLAS
<2.E-14			$1.\text{E}-3 < \beta < 1$	0	NAKAMURA	87 PLAS
<5.E-14			$9.\text{E}-4 < \beta < 1.\text{E}-2$	0	SHEPKO	87 CNTR
<2.E-13			$4.\text{E}-4 < \beta < 1$	0	TSUKAMOTO	87 CNTR
<5.E-14		1	all β	1	20 CAPLIN	86 INDU
<5.E-12		1		0	CROMAR	86 INDU
<1.E-13		1	$7.\text{E}-4 < \beta$	0	HARA	86 CNTR
<7.E-11		1	all β	0	INCANDELA	86 INDU
<1.E-18			$4.\text{E}-4 < \beta < 1.\text{E}-3$	0	19 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		Caty	$5.\text{E}-5 \leq \beta \leq 1.\text{E}-3$	0	16 KAJITA	85 KAMI
<2.E-21		Caty	$\beta < 1.\text{E}-3$	0	16,21 KAJITA	85 KAMI
<3.E-15		Caty	$1.\text{E}-3 < \beta < 1.\text{E}-1$	0	16 PARK	85B CNTR
<5.E-12		1	$1.\text{E}-4 < \beta < 1$	0	BATTISTONI	84 NUSX
<7.E-12		1		0	INCANDELA	84 INDU
<7.E-13		1	$3.\text{E}-4 < \beta$	0	18 KAJINO	84 CNTR
<2.E-12		1	$3.\text{E}-4 < \beta < 1.\text{E}-1$	0	KAJINO	84B CNTR
<6.E-13		1	$5.\text{E}-4 < \beta < 1$	0	KAWAGOE	84 CNTR
<2.E-14			$1.\text{E}-3 < \beta$	0	16 KRISHNA...	84 CNTR
<4.E-13		1	$6.\text{E}-4 < \beta < 2.\text{E}-3$	0	LISS	84 CNTR
<1.E-16			$3.\text{E}-4 < \beta < 1.\text{E}-3$	0	19 PRICE	84 MICA
<1.E-13		1	$1.\text{E}-4 < \beta$	0	PRICE	84B PLAS
<4.E-13		1	$6.\text{E}-4 < \beta < 2.\text{E}-3$	0	TARLE	84 CNTR
				7	22 ANDERSON	83 EMUL

<4.E-13	1	$1.E-2 < \beta < 1.E-3$	0	BARTELT	83B	CNTR
<1.E-12	1	$7.E-3 < \beta < 1$	0	BARWICK	83	PLAS
<3.E-13	1	$1.E-3 < \beta < 4.E-1$	0	BONARELLI	83	CNTR
<3.E-12	Caty	$5.E-4 < \beta < 5.E-2$	0	¹⁶ BOSETTI	83	CNTR
<4.E-11	1		0	CABRERA	83	INDU
<5.E-15	1	$1.E-2 < \beta < 1$	0	DOKE	83	PLAS
<8.E-15	Caty	$1.E-4 < \beta < 1.E-1$	0	¹⁶ ERREDE	83	IMB
<5.E-12	1	$1.E-4 < \beta < 3.E-2$	0	GROOM	83	CNTR
<2.E-12		$6.E-4 < \beta < 1$	0	MASHIMO	83	CNTR
<1.E-13	1	$\beta=3.E-3$	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	²³ 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	²⁴ 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

¹¹ AMBROSIO 02B direct search final result for $m \geq 10^{17}$ GeV, based upon 4.2 to 9.5 years of running, depending upon the subsystem. Limit with CR39 track-etch detector extends the limit from $\beta=4 \times 10^{-5}$ ($3.1 \times 10^{-16} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$) to $\beta=1 \times 10^{-4}$ ($2.1 \times 10^{-16} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$). Limit curve in paper is piecewise continuous due to different detection techniques for different β ranges.

¹² AMBROSIO 02C limit for catalysis of nucleon decay with catalysis cross section of ≈ 1 mb. The flux limit increases by ~ 3 at the higher β limit, and increases to $1 \times 10^{-14} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$ if the catalysis cross section is 0.01 mb. Based upon 71193 hr of data with the streamer detector, with an acceptance of $4250 \text{ m}^2 \text{ sr}$.

¹³ AMBROSIO 02D result for "more than two years of data." Ionization search using several subsystems. Limit curve as a function of β not given. Included in AMBROSIO 02B.

¹⁴ AMBROSIO 97 global MACRO 90%CL is 0.78×10^{-15} at $\beta=1.1 \times 10^{-4}$, goes through a minimum at 0.61×10^{-15} near $\beta=(1.1-2.7) \times 10^{-3}$, then rises to 0.84×10^{-15} at $\beta=0.1$. The global limit in this region is below the Parker bound at 10^{-15} . Less stringent limits are established for $4 \times 10^{-5} < \beta < 1 \times 10^{-4}$. Limits set by various triggers and different subdetectors are given in the paper. All limits assume a catalysis cross section smaller than a few mb.

¹⁵ AHLEN 94 limit for dyons extends down to $\beta=0.9E-4$ and a limit of $1.3E-14$ extends to $\beta=0.8E-4$. 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, relativistic particles could veto the events. See AMBROSIO 97 for additional results.

¹⁶ Catalysis of nucleon decay; sensitive to assumed catalysis cross section.

¹⁷ ORITO 91 limits are functions of velocity. Lowest limits are given here.

¹⁸ Used DKMPR mechanism and Penning effect.

¹⁹ Assumes monopole attaches fermion nucleus.

²⁰ 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.

²¹ Based on lack of high-energy solar neutrinos from catalysis in the sun.

²² Anomalous long-range α (^4He) tracks.

²³ CABRERA 82 candidate event has single Dirac charge within $\pm 5\%$.

²⁴ 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

<u>FLUX</u> ($\text{cm}^{-2}\text{sr}^{-1}\text{s}^{-1}$)	<u>MASS</u> (GeV)	<u>CHG</u> (g)	<u>COMMENTS</u> ($\beta = v/c$)	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<1.3E-20			faint white dwarf		25 FREESE 99	ASTR
<1.E-16	E17	1	galactic field	0	26 ADAMS 93	COSM
<1.E-23			Jovian planets		25 ARAFUNE 85	ASTR
<1.E-16	E15		solar trapping	0	BRACCI 85B	ASTR
<1.E-18		1		0	25 HARVEY 84	COSM
<3.E-23			neutron stars		KOLB 84	ASTR
<7.E-22			pulsars	0	25 FREESE 83B	ASTR
<1.E-18	<E18	1	intergalactic field	0	25 REPHAELI 83	COSM
<1.E-23			neutron stars	0	25 DIMOPOUL... 82	COSM
<5.E-22			neutron stars	0	25 KOLB 82	COSM
<5.E-15	>E21		galactic halo		SALPETER 82	COSM
<1.E-12	E19	1	$\beta=3.E-3$	0	27 TURNER 82	COSM
<1.E-16		1	galactic field	0	PARKER 70	COSM

²⁵ Catalysis of nucleon decay.

²⁶ ADAMS 93 limit based on "survival and growth of a small galactic seed field" is $10^{-16} (m/10^{17} \text{ GeV}) \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. Above 10^{17} GeV , limit $10^{-16} (10^{17} \text{ GeV}/m) \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ (from requirement that monopole density does not overclose the universe) is more stringent.

²⁷ Re-evaluates PARKER 70 limit for GUT monopoles.

Monopole Density — Matter Searches

<u>DENSITY</u>	<u>CHG</u> (g)	<u>MATERIAL</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<6.9E-6/gram	>1/3	Meteorites and other	0	JEON 95	INDU
<2.E-7/gram	>0.6	Fe ore	0	28 EBISU 87	INDU
<4.6E-6/gram	> 0.5	deep schist	0	KOVALIK 86	INDU
<1.6E-6/gram	> 0.5	manganese nodules	0	29 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

²⁸ Mass 1×10^{14} - $1 \times 10^{17} \text{ GeV}$.

²⁹ KOVALIK 86 examined 498 kg of schist from two sites which exhibited clear minearalogic evidence of having been buried at least 20 km deep and held below the Curie temperature.

Monopole Density — Astrophysics

<u>DENSITY</u>	<u>CHG</u> (g)	<u>MATERIAL</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<1.E-9/gram	1	sun, catalysis	0	³⁰ 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

³⁰ Catalysis of nucleon decay.

REFERENCES FOR Magnetic Monopole Searches

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AMBROSIO 02C	EPJ C26 163	M. Ambrosio <i>et al.</i>	(MACRO Collab.)
AMBROSIO 02D	ASP 18 27	M. Ambrosio <i>et al.</i>	(MACRO Collab.)
KALBFLEISCH 00	PRL 85 5292	G.R. Kalbfleisch <i>et al.</i>	
FREESE 99	PR D59 063007	K. Freese, E. Krasteva	
ABBOTT 98K	PRL 81 524	B. Abbott <i>et al.</i>	(D0 Collab.)
AMBROSIO 97	PL B406 249	M. Ambrosio <i>et al.</i>	(MACRO Collab.)
HE 97	PRL 79 3134	Y.D. He	(UCB)
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JEON 95	PRL 75 1443	H. Jeon, M.J. Longo	(MICH)
Also 96	PRL 76 159 (errata)	H. Jeon, M.J. Longo	
AHLEN 94	PRL 72 608	S.P. Ahlen <i>et al.</i>	(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 <i>et al.</i>	(IMB Collab.)
PRICE 94	PRL 73 1305	P.B. Price	(UCB)
ADAMS 93	PRL 70 2511	F.C. Adams <i>et al.</i>	(MICH, FNAL)
PINFOLD 93	PL B316 407	J.L. Pinfold <i>et al.</i>	(ALBE, HARV, MONT+)
KINOSHITA 92	PR D46 R881	K. Kinoshita <i>et al.</i>	(HARV, BGNA, REHO)
THRON 92	PR D46 4846	J.L. Thron <i>et al.</i>	(SOUDAN-2 Collab.)
GARDNER 91	PR D44 622	R.D. Gardner <i>et al.</i>	(STAN)
HUBER 91	PR D44 636	M.E. Huber <i>et al.</i>	(STAN)
ORITO 91	PRL 66 1951	S. Orito <i>et al.</i>	(ICEPP, WASCR, NIHO, ICRR)
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	Translated from YAF 52	86.	
BUCKLAND 90	PR D41 2726	K.N. Buckland <i>et al.</i>	(UCSD)
GHOSH 90	EPL 12 25	D.C. Ghosh, S. Chatterjea	(JADA)
HUBER 90	PRL 64 835	M.E. Huber <i>et al.</i>	(STAN)
PRICE 90	PRL 65 149	P.B. Price, J. Guiru, K. Kinoshita	(UCB, HARV)
KINOSHITA 89	PL B228 543	K. Kinoshita <i>et al.</i>	(HARV, TISA, KEK+)
BRAUNSCH... 88B	ZPHY C38 543	R. Braunschweig <i>et al.</i>	(TASSO Collab.)
KINOSHITA 88	PRL 60 1610	K. Kinoshita <i>et al.</i>	(HARV, TISA, KEK+)
BARISH 87	PR D36 2641	B.C. Barish, G. Liu, C. Lane	(CIT)
BARTELT 87	PR D36 1990	J.E. Bartelt <i>et al.</i>	(Soudan Collab.)
Also 89	PR D40 1701 erratum	J.E. Bartelt <i>et al.</i>	(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 <i>et al.</i>	(CLEO Collab.)
GUY 87	NAT 325 463	J. Guy	(LOIC)
MASEK 87	PR D35 2758	G.E. Masek <i>et al.</i>	(UCSD)
NAKAMURA 87	PL B183 395	S. Nakamura <i>et al.</i>	(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 <i>et al.</i>	(LOIC)
SHEPKO 87	PR D35 2917	M.J. Shepko <i>et al.</i>	(TAMU)
TSUKAMOTO 87	EPL 3 39	T. Tsukamoto <i>et al.</i>	(ICRR)
CAPLIN 86	NAT 321 402	A.D. Caplin <i>et al.</i>	(LOIC)
Also 87	JPE 20 850	J.C. Schouten <i>et al.</i>	(LOIC)
Also 87	NAT 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 <i>et al.</i>	(ICRR, KYOT, KEK, KOBE+)
INCANDELA 86	PR D34 2637	J. Incandela <i>et al.</i>	(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. Berman <i>et al.</i>	(IBM)
BRACCI	85B	NP B258 726	L. Bracci, G. Fiorentini, G. Mezzorani	(PISA+)
Also	85	LNC 42 123	L. Bracci, G. Fiorentini	(PISA)
CAPLIN	85	NAT 317 234	A.D. Caplin <i>et al.</i>	(LOIC)
EBISU	85	JPG 11 883	T. Ebisu, T. Watanabe	(KOBE)
KAJITA	85	JPSJ 54 4065	T. Kajita <i>et al.</i>	(ICRR, KEK, NIIG)
PARK	85B	NP B252 261	H.S. Park <i>et al.</i>	(IMB Collab.)
BATTISTONI	84	PL 133B 454	G. Battistoni <i>et al.</i>	(NUSEX Collab.)
FRYBERGER	84	PR D29 1524	D. Fryberger <i>et al.</i>	(SLAC, UCB)
HARVEY	84	NP B236 255	J.A. Harvey	(PRIN)
INCANDELA	84	PRL 53 2067	J. Incandela <i>et al.</i>	(CHIC, FNAL, MICH)
KAJINO	84	PRL 52 1373	F. Kajino <i>et al.</i>	(ICRR)
KAJINO	84B	JPG 10 447	F. Kajino <i>et al.</i>	(ICRR)
KAWAGOE	84	LNC 41 315	K. Kawagoe <i>et al.</i>	(TOKY)
KOLB	84	APJ 286 702	E.W. Kolb, M.S. Turner	(FNAL, CHIC)
KRISHNA...	84	PL 142B 99	M.R. Krishnaswamy <i>et al.</i>	(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 <i>et al.</i>	(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 <i>et al.</i>	(WASH)
ARAFUNE	83	PL 133B 380	J. Arafune, M. Fukugita	(ICRR, KYOTU)
AUBERT	83B	PL 120B 465	B. Aubert <i>et al.</i>	(CERN, LAPP)
BARTELT	83B	PRL 50 655	J.E. Bartelt <i>et al.</i>	(MINN, ANL)
BARWICK	83	PR D28 2338	S.W. Barwick, K. Kinoshita, P.B. Price	(UCB)
BONARELLI	83	PL 126B 137	R. Bonarelli, P. Capiluppi, I. d'Antone	(BGNA)
BOSETTI	83	PL 133B 265	P.C. Bosetti <i>et al.</i>	(AACH3, HAWA, TOKY)
CABRERA	83	PRL 51 1933	B. Cabrera <i>et al.</i>	(STAN)
DOKE	83	PL 129B 370	T. Doke <i>et al.</i>	(WASU, RIKK, TTAM, RIKEN)
ERREDE	83	PRL 51 245	S.M. Errede <i>et al.</i>	(IMB Collab.)
FREESE	83B	PRL 51 1625	K. Freese, M.S. Turner, D.N. Schramm	(CHIC)
GROOM	83	PRL 50 573	D.E. Groom <i>et al.</i>	(UTAH, STAN)
MASHIMO	83	PL 128B 327	T. Mashimo <i>et al.</i>	(ICEPP)
MIKHAILOV	83	PL 130B 331	V.F. Mikhailov	(KAZA)
MUSSET	83	PL 128B 333	P. Musset, M. Price, E. Lohrmann	(CERN, HAMB)
REPHAELI	83	PL 121B 115	Y. Rephaeli, M.S. Turner	(CHIC)
SCHATTEN	83	PR D27 1525	K.H. Schatten	(NASA)
ALEXEYEV	82	LNC 35 413	E.N. Alekseev <i>et al.</i>	(INRM)
BONARELLI	82	PL 112B 100	R. Bonarelli <i>et al.</i>	(BGNA)
CABRERA	82	PRL 48 1378	B. Cabrera	(STAN)
DELL	82	NP B209 45	G.F. Dell <i>et al.</i>	(BNL, ADEL, ROMA)
DIMOPOUL...	82	PL 119B 320	S. Dimopoulos, J. Preskill, F. Wilczek	(HARV+)
KINOSHITA	82	PRL 48 77	K. Kinoshita, P.B. Price, D. Fryberger	(UCB+)
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. Koshiha	(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)
BARTLETT	81	PR D24 612	D.F. Bartlett <i>et al.</i>	(COLO, GESG)
KINOSHITA	81B	PR D24 1707	K. Kinoshita, P.B. Price	(UCB)
ULLMAN	81	PRL 47 289	J.D. Ullman	(LEHM, BNL)
CARRIGAN	80	NAT 288 348	R.A. Carrigan	(FNAL)
BRODERICK	79	PR D19 1046	J.J. Broderick <i>et al.</i>	(VPI)
BARTLETT	78	PR D18 2253	D.F. Bartlett, D. Soo, M.G. White	(COLO, PRIN)
CARRIGAN	78	PR D17 1754	R.A. Carrigan, B.P. Strauss, G. Giacomelli	(FNAL+)
HOFFMANN	78	LNC 23 357	H. Hoffmann <i>et al.</i>	(CERN, ROMA)
PRICE	78	PR D18 1382	P.B. Price <i>et al.</i>	(UCB, HOUS)
HAGSTROM	77	PRL 38 729	R. Hagstrom	(LBL)
CARRIGAN	76	PR D13 1823	R.A. Carrigan, F.A. Nezrick, B.P. Strauss	(FNAL)
DELL	76	LNC 15 269	G.F. Dell <i>et al.</i>	(CERN, BNL, ROMA, ADEL)
ROSS	76	LBL-4665	R.R. Ross	(LBL)
STEVENS	76B	PR D14 2207	D.M. Stevens <i>et al.</i>	(VPI, BNL)
ZRELOV	76	CZJP B26 1306	V.P. Zrelov <i>et al.</i>	(JINR)
ALVAREZ	75	LBL-4260	L.W. Alvarez	(LBL)
BURKE	75	PL 60B 113	D.L. Burke <i>et al.</i>	(MICH)
CABRERA	75	Thesis	B. Cabrera	(STAN)
CARRIGAN	75	NP B91 279	R.A. Carrigan, F.A. Nezrick	(FNAL)
Also	71	PR D3 56	R.A. Carrigan, F.A. Nezrick	(FNAL)
EBERHARD	75	PR D11 3099	P.H. Eberhard <i>et al.</i>	(LBL, MPIM)
EBERHARD	75B	LBL-4289	P.H. Eberhard	(LBL)
FLEISCHER	75	PRL 35 1412	R.L. Fleischer, R.N.F. Walker	(GESG, WUSL)

FRIEDLANDER	75	PRL 35 1167	M.W. Friedlander	(WUSL)
GIACOMELLI	75	NC 28A 21	G. Giacomelli <i>et al.</i>	(BGNA, CERN, SACL+)
PRICE	75	PRL 35 487	P.B. Price <i>et al.</i>	(UCB, HOUS)
CARRIGAN	74	PR D10 3867	R.A. Carrigan, F.A. Nezrick, B.P. Strauss	(FNAL)
CARRIGAN	73	PR D8 3717	R.A. Carrigan, F.A. Nezrick, B.P. Strauss	(FNAL)
ROSS	73	PR D8 698	R.R. Ross <i>et al.</i>	(LBL, SLAC)
Also	71	PR D4 3260	P.H. Eberhard <i>et al.</i>	(LBL, SLAC)
Also	70	Science 167 701	L.W. Alvarez <i>et al.</i>	(LBL, SLAC)
BARTLETT	72	PR D6 1817	D.F. Bartlett, M.D. Lahana	(COLO)
GUREVICH	72	PL 38B 549	I.I. Gurevich <i>et al.</i>	(KIAE, NOVO, SERP)
Also	72B	JETP 34 917	L.M. Barkov, I.I. Gurevich, M.S. Zolotorev	(KIAE+)
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FLEISCHER	71	PR D4 24	R.L. Fleischer <i>et al.</i>	(GESC)
KOLM	71	PR D4 1285	H.H. Kolm, F. Villa, A. Odian	(MIT, SLAC)
PARKER	70	APJ 160 383	E.N. Parker	(CHIC)
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FLEISCHER	69B	PR 184 1393	R.L. Fleischer <i>et al.</i>	(GESC, UNCS, GSCO)
FLEISCHER	69C	PR 184 1398	R.L. Fleischer, P.B. Price, R.T. Woods	(GESC)
Also	70C	JAP 41 958	R.L. Fleischer <i>et al.</i>	(GESC)
CARITHERS	66	PR 149 1070	W.C.J. Carithers, R.J. Stefanski, R.K. Adair	
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