n

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ∗∗∗∗

We have omitted some results that have been superseded by later experiments. See our earlier editions.

Anyone interested in the neutron should look at these two review articles: D. Dubbers and M.G. Schmidt, "The neutron and its role in cosmology and particle physics," Reviews of Modern Physics **83** 1111 (2011); and F.E. Wietfeldt and G.L. Greene, "The neutron lifetime," Reviews of Modern Physics **83** 1173 (2011).

n MASS (atomic mass units u)

The mass is known much more precisely in u (atomic mass units) than in MeV. See the next data block.

VALUE (u)	*DOCUMENT ID*		*TECN*	*COMMENT*
1.00866491595±0.00000000049	TIESINGA	21	RVUE	2018 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.00866491588±0.00000000049	MOHR	16	RVUE	2014 CODATA value
1.00866491600±0.00000000043	MOHR	12	RVUE	2010 CODATA value
1.00866491597±0.00000000043	MOHR	08	RVUE	2006 CODATA value
1.00866491560±0.00000000055	MOHR	05	RVUE	2002 CODATA value
1.00866491578±0.00000000055	MOHR	99	RVUE	1998 CODATA value
1.008665904 ±0.000000014	COHEN	87	RVUE	1986 CODATA value

n MASS (MeV)

The mass is known more precisely in u (atomic mass units) than in MeV. The conversion is: 1 u = 931.494 102 42(28) MeV/c^2 (2018 CODATA value, TIESINGA 21).

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
939.56542052±0.00000054	TIESINGA	21	RVUE	2018 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
939.5654133 ±0.0000058	MOHR	16	RVUE	2014 CODATA value
939.565379 ±0.000021	MOHR	12	RVUE	2010 CODATA value
939.565346 ±0.000023	MOHR	08	RVUE	2006 CODATA value
939.565360 ±0.000081	MOHR	05	RVUE	2002 CODATA value
939.565331 ±0.000037	[1] KESSLER	99	SPEC	$np \to d\gamma$
939.565330 ±0.000038	MOHR	99	RVUE	1998 CODATA value
939.56565 ±0.00028	[2,3] DIFILIPPO	94	TRAP	Penning trap
939.56563 ±0.00028	COHEN	87	RVUE	1986 CODATA value
939.56564 ±0.00028	[3,4] GREENE	86	SPEC	$np \to d\gamma$
939.5731 ±0.0027	[3] COHEN	73	RVUE	1973 CODATA value

[1] We use the 1998 CODATA u-to-MeV conversion factor (see the heading above) to get this mass in MeV from the much more precisely measured KESSLER 99 value of 1.00866491637 ± 0.00000000082 u.

[2] The mass is known much more precisely in u: m = 1.0086649235 ± 0.0000000023 u. We use the 1986 CODATA conversion factor to get the mass in MeV.

[3] These determinations are not independent of the $m_n - m_p$ measurements below.
[4] The mass is known much more precisely in u: $m = 1.008664919 \pm 0.000000014$ u.

$\overline{n}$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
939.485±0.051	59	[1] CRESTI	86	HBC	$\overline{p}p \to \overline{n}n$

[1] This is a corrected result (see the erratum). The error is statistical. The maximum systematic error is 0.029 MeV.

$(m_n - m_{\overline{n}})/ m_n$

A test of *CPT* invariance. Calculated from the n and $\overline{n}$ masses, above.

VALUE	DOCUMENT ID
(9±6) × 10^{-5} OUR EVALUATION	

$m_n - m_p$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1.29333236±0.00000046	[1] TIESINGA	21	RVUE	2018 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.29333205±0.00000051	[2] MOHR	16	RVUE	2014 CODATA value
1.29333217±0.00000042	[3] MOHR	12	RVUE	2010 CODATA value
1.29333214±0.00000043	[4] MOHR	08	RVUE	2006 CODATA value
1.2933317 ±0.0000005	[5] MOHR	05	RVUE	2002 CODATA value
1.2933318 ±0.0000005	[6] MOHR	99	RVUE	1998 CODATA value
1.293318 ±0.000009	[7] COHEN	87	RVUE	1986 CODATA value
1.2933328 ±0.0000072	GREENE	86	SPEC	$np \to d\gamma$
1.293429 ±0.000036	COHEN	73	RVUE	1973 CODATA value

[1] The 2018 CODATA mass difference in u is $m_n - m_p = 1.388\,449\,33(49) \times 10^{-3} u$.
[2] The 2014 CODATA mass difference in u is $m_n - m_p = 1.388\,449\,00(51) \times 10^{-3} u$.
[3] The 2010 CODATA mass difference in u is $m_n - m_p = 1.388\,449\,19(45) \times 10^{-3} u$.
[4] Calculated by us from the MOHR 08 ratio $m_n/m_p = 1.00137841918(46)$. In u, $m_n - m_p = 1.38844920(46) \times 10^{-3}$ u.
[5] Calculated by us from the MOHR 05 ratio $m_n/m_p = 1.00137841870 \pm 0.00000000058$. In u, $m_n - m_p = (1.3884487 \pm 0.0000006) \times 10^{-3}$ u.
[6] Calculated by us from the MOHR 99 ratio $m_n/m_p = 1.00137841887 \pm 0.00000000058$. In u, $m_n - m_p = (1.3884489 \pm 0.0000006) \times 10^{-3}$ u.
[7] Calculated by us from the COHEN 87 ratio $m_n/m_p = 1.001378404 \pm 0.000000009$. In u, $m_n - m_p = 0.001388434 \pm 0.000000009$ u.

n MEAN LIFE

Limits on lifetimes for *bound* neutrons are given in the section "p PARTIAL MEAN LIVES."

We average eight of the best nine measurements, those made with ultra-cold neutrons (UCN's). If we include the one in-beam measurement with a comparable error (YUE 13), we get 878.6 ± 0.6 s, where the scale factor is now 2.2.

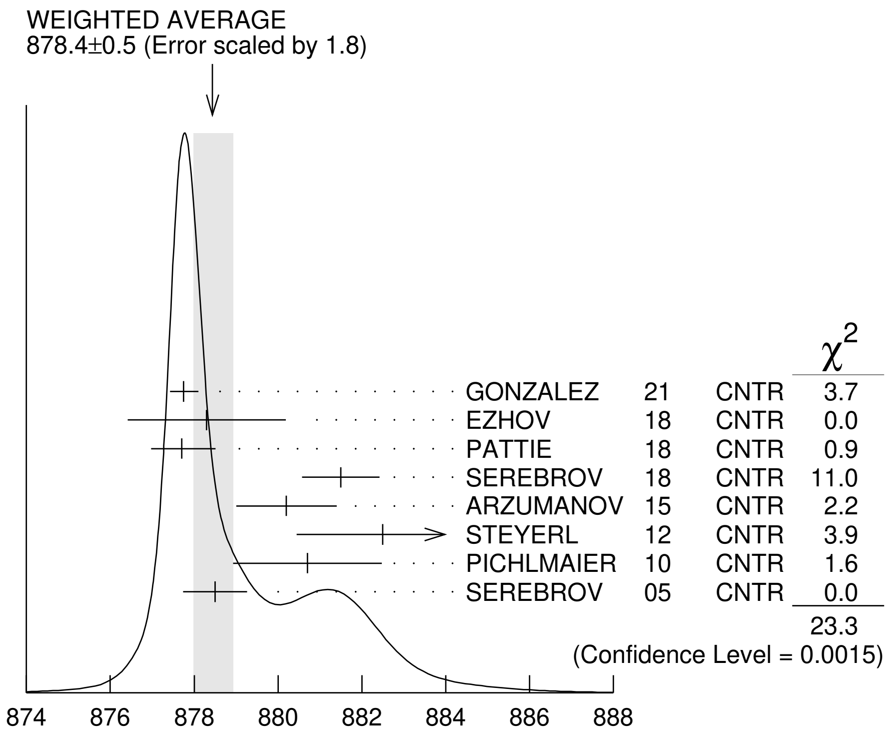
For a recent discussion of the long-standing disagreement between in-beam and UCN results, see CZARNECKI 18 (Physical Review Letters **120** 202002 (2018)). For a full review of all matters concerning the neutron lifetime until about 2010, see WIETFELDT 11, F.E. Wietfeldt and G.L. Greene, "The neutron lifetime," Reviews of Modern Physics **83** 1173 (2011).

VALUE (s)	*DOCUMENT ID*		*TECN*	*COMMENT*
878.4 ± 0.5 OUR AVERAGE	Error includes scale factor of 1.8. See the ideogram below.			
$877.75 \pm 0.28 ^{+0.22}_{-0.16}$	GONZALEZ	21	CNTR	UCN asym. magnetic trap
878.3 ± 1.6 ± 1.0	EZHOV	18	CNTR	UCN magneto-gravit. trap
$877.7 \pm 0.7 ^{+0.4}_{-0.2}$	[1] PATTIE	18	CNTR	UCN asym. magnetic trap
881.5 ± 0.7 ± 0.6	SEREBROV	18	CNTR	UCN gravitational trap
880.2 ± 1.2	[2] ARZUMANOV	15	CNTR	UCN double bottle
882.5 ± 1.4 ± 1.5	[3] STEYERL	12	CNTR	UCN material bottle
880.7 ± 1.3 ± 1.2	PICHLMAIER	10	CNTR	UCN material bottle
878.5 ± 0.7 ± 0.3	SEREBROV	05	CNTR	UCN gravitational trap
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$887 \pm 14 ^{+7}_{-3}$	[4] WILSON	21	CNTR	space-based *n* rate
887.7 ± 1.2 ± 1.9	[5] YUE	13	CNTR	In-beam *n*, trapped *p*
881.6 ± 0.8 ± 1.9	[6] ARZUMANOV	12	CNTR	See ARZUMANOV 15
886.3 ± 1.2 ± 3.2	NICO	05	CNTR	See YUE 13
886.8 ± 1.2 ± 3.2	DEWEY	03	CNTR	See NICO 05
885.4 ± 0.9 ± 0.4	ARZUMANOV	00	CNTR	See ARZUMANOV 12
889.2 ± 3.0 ± 3.8	BYRNE	96	CNTR	Penning trap
882.6 ± 2.7	[7] MAMPE	93	CNTR	UCN material bottle
888.4 ± 3.1 ± 1.1	[8] NESVIZHEV...	92	CNTR	UCN material bottle
888.4 ± 2.9	ALFIMENKOV	90	CNTR	See NESVIZHEVSKII 92
893.6 ± 3.8 ± 3.7	BYRNE	90	CNTR	See BYRNE 96
878 ±27 ±14	KOSSAKOW...	89	TPC	Pulsed beam
887.6 ± 3.0	MAMPE	89	CNTR	See STEYERL 12
877 ±10	PAUL	89	CNTR	Magnetic storage ring
876 ±10 ±19	LAST	88	SPEC	Pulsed beam
891 ± 9	SPIVAK	88	CNTR	Beam
903 ±13	KOSVINTSEV	86	CNTR	UCN material bottle
937 ±18	[9] BYRNE	80	CNTR	
875 ±95	KOSVINTSEV	80	CNTR	
881 ± 8	BONDAREN...	78	CNTR	See SPIVAK 88
918 ±14	CHRISTENSEN	72	CNTR	

[1] PATTIE 18 uses a new technique, with a semi-toroidal magneto-gravitational asymmetric trap and a novel in situ *n*-detector.

[2] ARZUMANOV 15 is a reanalysis of their 2008–2010 dataset, with improved systematic corrections of of ARZUMANOV 00 and ARZUMANOV 12.

[3] STEYERL 12 is a detailed reanalysis of neutron storage loss corrections to the raw data of MAMPE 89, and it replaces that value.
[4] WILSON 21 extract the value from the flux of *n* escaping the moon using data from the Lunar Prospector Neutron Spectrometer.
[5] YUE 13 differs from NICO 05 in that a different and better method was used to measure the neutron density in the fiducial volume. This shifted the lifetime by +1.4 seconds and reduced the previously largest source of systematic uncertainty by a factor of five.
[6] ARZUMANOV 12 reanalyzes its systematic corrections in ARZUMANOV 00 and obtains this corrected value.
[7] IGNATOVICH 95 calls into question some of the corrections and averaging procedures used by MAMPE 93. The response, BONDARENKO 96, denies the validity of the criticisms.
[8] The NESVIZHEVSKII 92 measurement has been withdrawn by A. Serebrov.
[9] The BYRNE 80 measurement has been withdrawn (J. Byrne, private communication, 1990).



neutron mean life (s)

n MAGNETIC MOMENT

See the "Quark Model" review.

VALUE (μ_N)	DOCUMENT ID		TECN	COMMENT
−1.91304273±0.00000045	TIESINGA	21	RVUE	2018 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−1.91304273±0.00000045	MOHR	16	RVUE	2014 CODATA value
−1.91304272±0.00000045	MOHR	12	RVUE	2010 CODATA value
−1.91304273±0.00000045	MOHR	08	RVUE	2006 CODATA value
−1.91304273±0.00000045	MOHR	05	RVUE	2002 CODATA value

$-1.91304272 \pm 0.00000045$		MOHR	99	RVUE	1998 CODATA value
$-1.91304275 \pm 0.00000045$		COHEN	87	RVUE	1986 CODATA value
$-1.91304277 \pm 0.00000048$	1	GREENE	82	MRS	

[1] GREENE 82 measures the moment to be $(1.04187564 \pm 0.00000026) \times 10^{-3}$ Bohr magnetons. The value above is obtained by multiplying this by $m_p/m_e = 1836.152701 \pm 0.000037$ (the 1986 CODATA value from COHEN 87).

n ELECTRIC DIPOLE MOMENT

A nonzero value is forbidden by both T invariance and P invariance. A number of early results have been omitted. See RAMSEY 90, GOLUB 94, and LAMOREAUX 09 for reviews.

The results are upper limits on $|d_n|$.

VALUE (10^{-25} *e* cm)	*CL%*		*DOCUMENT ID*		*TECN*	*COMMENT*
< 0.18	90	1	ABEL	20	MRS	UCN
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 0.22	95	2	SAHOO	17		^{199}Hg atom EDM + theory
< 0.16	95		GRANER	16	MRS	^{199}Hg atom EDM + theory
< 0.30	90	3	PENDLEBURY	15	MRS	Supersedes BAKER 06
< 0.55	90		SEREBROV	15	MRS	UCN's, $h\nu = 2\mu_n B \pm 2d_n E$
< 0.55	90	4	SEREBROV	14	MRS	See SEREBROV 15
< 0.29	90	5	BAKER	06	MRS	See PENDLEBURY 15
< 0.63	90	6	HARRIS	99	MRS	$d = (-0.1 \pm 0.36) \times 10^{-25}$
< 0.97	90		ALTAREV	96	MRS	See SEREBROV 14
< 1.1	95		ALTAREV	92	MRS	See ALTAREV 96
< 1.2	95		SMITH	90	MRS	See HARRIS 99
< 2.6	95		ALTAREV	86	MRS	$d = (-1.4 \pm 0.6) \times 10^{-25}$
0.3 ±4.8			PENDLEBURY	84	MRS	Ultracold neutrons
< 6	90		ALTAREV	81	MRS	$d = (2.1 \pm 2.4) \times 10^{-25}$
<16	90		ALTAREV	79	MRS	$d = (4.0 \pm 7.5) \times 10^{-25}$

[1] ABEL 20 reports $d = (0.0 \pm 1.1 \pm 0.2) \times 10^{-26}$ e cm value corresponding to the listed limit.
[2] SAHOO 17 develops theory to calculate this limit from the measured limit by GRANER 16 of the ^{199}Hg atom EDM.
[3] PENDLEBURY 15 reports $d = (-0.21 \pm 1.82) \times 10^{-26}$ e cm value corresponding to the listed limit.
[4] SEREBROV 14 includes the data of ALTAREV 96.
[5] LAMOREAUX 07 faults BAKER 06 for not including in the estimate of systematic error an effect due to the Earth's rotation. BAKER 07 replies (1) that the effect was included implicitly in the analysis and (2) that further analysis confirms that the BAKER 06 limit is correct as is. See also SILENKO 07.
[6] This HARRIS 99 result includes the result of SMITH 90. However, the averaging of the results of these two experiments has been criticized by LAMOREAUX 00.

n MEAN-SQUARE CHARGE RADIUS

The mean-square charge radius of the neutron, $\langle r_n^2 \rangle$, is related to the neutron-electron scattering length b_{ne} by $\langle r_n^2 \rangle = 3(m_e a_0/m_n) b_{ne}$, where m_e and m_n are the masses of the electron and neutron, and a_0 is the Bohr radius. Numerically, $\langle r_n^2 \rangle = 86.34\, b_{ne}$, if we use a_0 for a nucleus with infinite mass.

VALUE (fm^2)	DOCUMENT ID		COMMENT
−0.1155±0.0017 OUR AVERAGE			
−0.115 ±0.002 ±0.003	KOPECKY	97	ne scattering (Pb)
−0.124 ±0.003 ±0.005	KOPECKY	97	ne scattering (Bi)
−0.114 ±0.003	KOESTER	95	ne scattering (Pb, Bi)
−0.115 ±0.003	[1] KROHN	73	ne scattering (Ne, Ar, Kr, Xe)
• • • We do not use the following data for averages, fits, limits, etc. • • •			
−0.1101±0.0089	[2] HEACOCK	21	n interferometry
$-0.106\ ^{+0.007}_{-0.005}$	[3] FILIN	20	chiral EFT analysis
$-0.117\ ^{+0.007}_{-0.011}$	BELUSHKIN	07	Dispersion analysis
−0.113 ±0.003 ±0.004	KOPECKY	95	ne scattering (Pb)
−0.134 ±0.009	ALEKSANDR...	86	ne scattering (Bi)
−0.114 ±0.003	KOESTER	86	ne scattering (Pb, Bi)
−0.118 ±0.002	KOESTER	76	ne scattering (Pb)
−0.120 ±0.002	KOESTER	76	ne scattering (Bi)
−0.116 ±0.003	KROHN	66	ne scattering (Ne, Ar, Kr, Xe)

[1] KROHN 73 measured -0.112 ± 0.003 fm^2. This value is as corrected by KOESTER 76.

[2] HEACOCK 21 extract the value from Pendelloesung interferometry to measure the neutron structure factors of silicon. This value is strongly anti-correlated with the mean-square thermal atomic displacement.

[3] FILIN 20 extract the value based on their chiral-EFT calculation of the deuteron structure radius and use as input the atomic data for the difference of the deuteron and proton charge radii.

n MAGNETIC RADIUS

This is the rms magnetic radius, $\sqrt{\langle r_M^2 \rangle}$.

VALUE (fm)	DOCUMENT ID		COMMENT
$\mathbf{0.864^{+0.009}_{-0.008}}$ **OUR AVERAGE**			
0.89 ±0.03	EPSTEIN	14	Using ep, en, $\pi\pi$ data
$0.862^{+0.009}_{-0.008}$	BELUSHKIN	07	Dispersion analysis

n ELECTRIC POLARIZABILITY α_n

Following is the electric polarizability α_n defined in terms of the induced electric dipole moment by $\mathbf{D} = 4\pi\epsilon_0\alpha_n\mathbf{E}$. For a review, see SCHMIEDMAYER 89.

For a very complete reviews of the polarizability of the nucleon and Compton scattering, see SCHUMACHER 05, updated in SCHUMACHER 19, and GRIESSHAMMER 12.

VALUE (10^{-4} fm^3)	DOCUMENT ID		TECN	COMMENT
11.8 ± 1.1 OUR AVERAGE				
11.55± 1.25±0.8	MYERS	14	CNTR	$\gamma d \to \gamma d$
$12.5 \pm 1.8\ ^{+1.6}_{-1.3}$	[1] KOSSERT	03	CNTR	$\gamma d \to \gamma p n$

12.0 ± 1.5 ±2.0	SCHMIEDM...	91	CNTR	n Pb transmission
10.7 $^{+3.3}_{-10.7}$	ROSE	90B	CNTR	$\gamma d \to \gamma n p$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
8.8 ± 2.4 ±3.0	[2] LUNDIN	03	CNTR	$\gamma d \to \gamma d$
13.6	[3] KOLB	00	CNTR	$\gamma d \to \gamma n p$
0.0 ± 5.0	[4] KOESTER	95	CNTR	n Pb, n Bi transmission
11.7 $^{+4.3}_{-11.7}$	ROSE	90	CNTR	See ROSE 90B
8 ±10	KOESTER	88	CNTR	n Pb, n Bi transmission
12 ±10	SCHMIEDM...	88	CNTR	n Pb, n C transmission

[1] KOSSERT 03 gets $\alpha_n - \beta_n$ =(9.8 ± 3.6$^{+2.1}_{-1.1}$ ± 2.2) × 10^{-4} fm^3, and uses $\alpha_n + \beta_n$ = (15.2 ± 0.5) × 10^{-4} fm^3 from LEVCHUK 00. Thus the errors on α_n and β_n are anti-correlated.

[2] LUNDIN 03 measures $\alpha_N - \beta_N$ = (6.4 ± 2.4) × 10^{-4} fm^3 and uses accurate values for α_p and α_p and a precise sum-rule result for $\alpha_n + \beta_n$. The second error is a model uncertainty, and errors on α_n and β_n are anticorrelated. The data from this paper aer included in the analysis of MYERS 14.

[3] KOLB 00 obtains this value with a lower limit of 7.6 × 10^{-4} fm^3 but no upper limit from this experiment alone. Combined with results of ROSE 90, the 1-σ range is (7.6–14.0) × 10^{-4} fm^3.

[4] KOESTER 95 uses natural Pb and the isotopes 208, 207, and 206. See this paper for a discussion of methods used by various groups to extract α_n from data.

n MAGNETIC POLARIZABILITY β_n

VALUE (10^{-4} fm^3)	*DOCUMENT ID*		*TECN*	*COMMENT*
3.7 ±1.2 OUR AVERAGE				
3.65±1.25±0.8	MYERS	14	CNTR	$\gamma d \to \gamma d$
2.7 ±1.8 $^{+1.3}_{-1.6}$	[1] KOSSERT	03	CNTR	$\gamma d \to \gamma p n$
6.5 ±2.4 ±3.0	[2] LUNDIN	03	CNTR	$\gamma d \to \gamma d$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.6	[3] KOLB	00	CNTR	$\gamma d \to \gamma n p$

[1] KOSSERT 03 gets $\alpha_n - \beta_n$ =(9.8 ± 3.6$^{+2.1}_{-1.1}$ ± 2.2) × 10^{-4} fm^3, and uses $\alpha_n + \beta_n$ = (15.2 ± 0.5) × 10^{-4} fm^3 from LEVCHUK 00. Thus the errors on α_n and β_n are anti-correlated.

[2] LUNDIN 03 measures $\alpha_N - \beta_N$ = (6.4 ± 2.4) × 10^{-4} fm^3 and uses accurate values for α_p and α_p and a precise sum-rule result for $\alpha_n + \beta_n$. The second error is a model uncertainty, and errors on α_n and β_n are anticorrelated.

[3] KOLB 00 obtains this value with an upper limit of 7.6 × 10^{-4} fm^3 but no lower limit from this experiment alone. Combined with results of ROSE 90, the 1-σ range is (1.2–7.6) × 10^{-4} fm^3.

n CHARGE

See also "$|q_p + q_e|/e$" in the proton Listings.

VALUE (10^{-21} *e*)	*DOCUMENT ID*		*TECN*	*COMMENT*
− 0.2± 0.8 OUR AVERAGE				
− 0.1± 1.1	[1] BRESSI	11		Neutrality of SF_6
− 0.4± 1.1	[2] BAUMANN	88		Cold n deflection

• • • We do not use the following data for averages, fits, limits, etc. • • •

-15 ± 22		[3] GAEHLER	82	CNTR	Cold n deflection

[1] As a limit, this BRESSI 11 value is $< 1 \times 10^{-21}$ e.
[2] The BAUMANN 88 error ± 1.1 gives the 68% CL limits about the the value -0.4.
[3] The GAEHLER 82 error ± 22 gives the 90% CL limits about the the value -15.

LIMIT ON $n\overline{n}$ OSCILLATIONS

Mean Time for $n\overline{n}$ Transition

A test of ΔB=2 baryon number nonconservation. MOHAPATRA 80 and MOHAPATRA 89 discuss the theoretical motivations for looking for $n\overline{n}$ oscillations. DOVER 83 and DOVER 85 give phenomenological analyses. The best limits come from looking for the decay of neutrons bound in nuclei. However, these analyses require model-dependent corrections for nuclear effects. See KABIR 83, DOVER 89, ALBERICO 91, and GAL 00 for discussions. Direct searches for $n \to \overline{n}$ transitions using reactor neutrons are cleaner but give somewhat poorer limits. We include limits for both free and bound neutrons in the Summary Table. See MOHAPATRA 09 and PHILLIPS 16 for recent reviews.

VALUE (s)	CL%	DOCUMENT ID		TECN	COMMENT
$>4.7 \times 10^8$	90	[1] ABE	21	CNTR	n bound in oxygen
$>8.6 \times 10^7$	90	BALDO-...	94	CNTR	Reactor (free) neutrons
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>1.37 \times 10^8$	90	[2] AHARMIM	17	SNO	n bound in deuteron
$>2.7 \times 10^8$	90	ABE	15C	CNTR	n bound in oxygen
$>1.3 \times 10^8$	90	CHUNG	02B	SOU2	n bound in iron
$>1 \times 10^7$	90	BALDO-...	90	CNTR	See BALDO-CEOLIN 94
$>1.2 \times 10^8$	90	BERGER	90	FREJ	n bound in iron
$>4.9 \times 10^5$	90	BRESSI	90	CNTR	Reactor neutrons
$>4.7 \times 10^5$	90	BRESSI	89	CNTR	See BRESSI 90
$>1.2 \times 10^8$	90	TAKITA	86	CNTR	n bound in oxygen
$>1 \times 10^6$	90	FIDECARO	85	CNTR	Reactor neutrons
$>8.8 \times 10^7$	90	PARK	85B	CNTR	
$>3 \times 10^7$		BATTISTONI	84	NUSX	
$>$ 0.27–1.1 $\times 10^8$		JONES	84	CNTR	
$>2 \times 10^7$		CHERRY	83	CNTR	

[1] ABE 21 supersedes ABE 15C.
[2] The AHARMIM 17 value is an unbounded limit (it does not assume a positive lifetime). The bounded limit is 1.23×10^8 sec.

LIMIT ON nn' OSCILLATIONS

Lee and Yang (LEE 56) proposed the existence of mirror world in an attempt to restore global parity symmetry. A possible candidate for dark matter. Limits depend on assumptions about fields B and B'. See the papers for details. See BEREZHIANI 18 for a recent discussion.

VALUE (s)	CL%	DOCUMENT ID		TECN	COMMENT
>352	95	[1] ABEL	21	CNTR	UCN, scan of B field
>448	90	SEREBROV	09A	CNTR	Assumes $B' < 100$ nT

• • • We do not use the following data for averages, fits, limits, etc. • • •

		[2] ALMAZAN	22	CNTR	STEREO, hidden neutron search $\lvert m_n - m_{n'} \rvert \geq 0.$
> 17	95	[3] BEREZHIANI	18	CNTR	UCN, scan of B field
> 12	95	[4] ALTAREV	09A	CNTR	UCN, scan $0 \leq B \leq 12.5\ \mu$T
>414	90	SEREBROV	08	CNTR	UCN, B field on & off
>103	95	BAN	07	CNTR	UCN, B field on & off

[1] ABEL 21 determine several limits on the oscillation time as a function of the ratio mirror magnetic field B' to applied magnetic field B. The quoted limit of 352 s is for $B' = 0$. Lower limits on the oscillation time of 6 seconds are further obtained for any mirror field B' in the range 0.4–25.7 μT.

[2] ALMAZAN 22 reports an experimental constraint on the probability for neutron conversion into a hidden neutron, $p < 3.1 \times 10^{-11}$ at 95% CL, which may be used to set a limit on the $n n'$ oscillation time.

[3] The B field was set to (0.09, 0.12, 0.21) G. Limits on oscillation time are valid for any mirror field B' in (0.08–0.17) G, and for aligned fields B and B'. For larger values of B', the limits are significantly reduced.

[4] Losses of neutrons due to oscillations to mirror neutrons would be maximal when the magnetic fields B and B' in the two worlds were equal. Hence the scan over B by ALTAREV 09A: the limit applies for any B' over the given range. At $B' = 0$, the limit is 141 s (95% CL).

n DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Confidence level
Γ_1	$p e^- \overline{\nu}_e$		100 %	
Γ_2	$p e^- \overline{\nu}_e \gamma$		[a] (9.2±0.7) $\times 10^{-3}$	
Γ_3	hydrogen-atom $\overline{\nu}_e$		< 2.7 $\times 10^{-3}$	95%
	Charge conservation (*Q*) violating mode			
Γ_4	$p \nu_e \overline{\nu}_e$	Q	< 8 $\times 10^{-27}$	68%
	Baryon number violating decay			
Γ_5	$e^+ e^-$ invisible			

[a] This limit is for γ energies between 0.4 and 782 keV.

n BRANCHING RATIOS

$\Gamma(p e^- \overline{\nu}_e \gamma)/\Gamma_{\text{total}}$ Γ_2/Γ

VALUE (units 10^{-3})	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
9.17±0.24±0.64		[1] BALES	16	RDK2	Two different set-ups
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3.09±0.11±0.30		[2] COOPER	10	CNTR	See BALES 16
3.13±0.11±0.33		NICO	06	CNTR	See COOPER 10
<6.9	90	[3] BECK	02	CNTR	γ, p, e^- coincidence

[1] BALES 16 gets a branching fraction of $(5.82 \pm 0.23 \pm 0.62) \times 10^{-3}$ for a photon energy range 0.4 to 14.0 keV, and with a different detector array, $(3.35 \pm 0.05 \pm 0.15) \times 10^{-3}$

for 14.1 to 782 keV. Our result above is the sum; the error on the sum is completely dominated by the error on the lower range.

[2] This COOPER 10 result is for γ energies between 15 and 340 keV.

[3] This BECK 02 limit is for γ energies between 35 and 100 keV.

$\Gamma(\text{hydrogen-atom } \overline{\nu}_e)/\Gamma_{total}$ — Γ_3/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.27 × 10^{-2}	95	[1] CZARNECKI	18		Lifetime analysis
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<3 × 10^{-2}	95	[2] GREEN	90	RVUE	

[1] CZARNECKI 18 limit from an analysis of experimental discrepancies on the neutron lifetime and axial coupling applies as well to other possible exotic neutron decays.

[2] GREEN 90 infers that $\tau(\text{hydrogen-atom}\overline{\nu}_e) > 3 \times 10^4$ s by comparing neutron lifetime measurements made in storage experiments with those made in β-decay experiments. However, the result depends sensitively on the lifetime measurements, and does not of course take into account more recent measurements of same.

$\Gamma(p\nu_e\overline{\nu}_e)/\Gamma_{total}$ — Γ_4/Γ

Forbidden by charge conservation.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<8 × 10^{-27}	68	[1] NORMAN	96	RVUE	^{71}Ga → ^{71}Ge neutrals
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<9.7 × 10^{-18}	90	ROY	83	CNTR	^{113}Cd → ^{113m}In neut.
<7.9 × 10^{-21}		VAIDYA	83	CNTR	^{87}Rb → ^{87m}Sr neut.
<9 × 10^{-24}	90	BARABANOV	80	CNTR	^{71}Ga → ^{71}GeX
<3 × 10^{-19}		NORMAN	79	CNTR	^{87}Rb → ^{87m}Sr neut.

[1] NORMAN 96 gets this limit by attributing SAGE and GALLEX counting rates to the charge-nonconserving transition ^{71}Ga → ^{71}Ge+neutrals rather than to solar-neutrino reactions.

$\Gamma(e^+ e^- \text{invisible})/\Gamma_{total}$ — Γ_5/Γ

Baryon number violating decay

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.01	90	[1] KLOPF	19	CNTR	re-interpretation of MUND 13
<1 × 10^{-4}	90	[2] SUN	18	SPEC	Ultracold n, polarized

[1] KLOPF 19 value is for baryon number violating decay of neutron to electrons plus an invisible state, χ. The limit is valid for KE($e^+ e^-$) range between 32 keV and 664 keV, strengthening to few × 10^{-4} above approximately 100 keV.

[2] SUN 18 value is for baryon number violating decay of neutron to electrons plus an invisible state, χ. The limit is valid for 644 keV > KE($e^+ e^-$) > 100 keV. Assuming this decay $\chi e e$ is the only allowed χ decay channel, a 0.01 BR is ruled out for 644 keV > E($e^+ e^-$) > 100 keV at over 5σ.

See the related review(s):

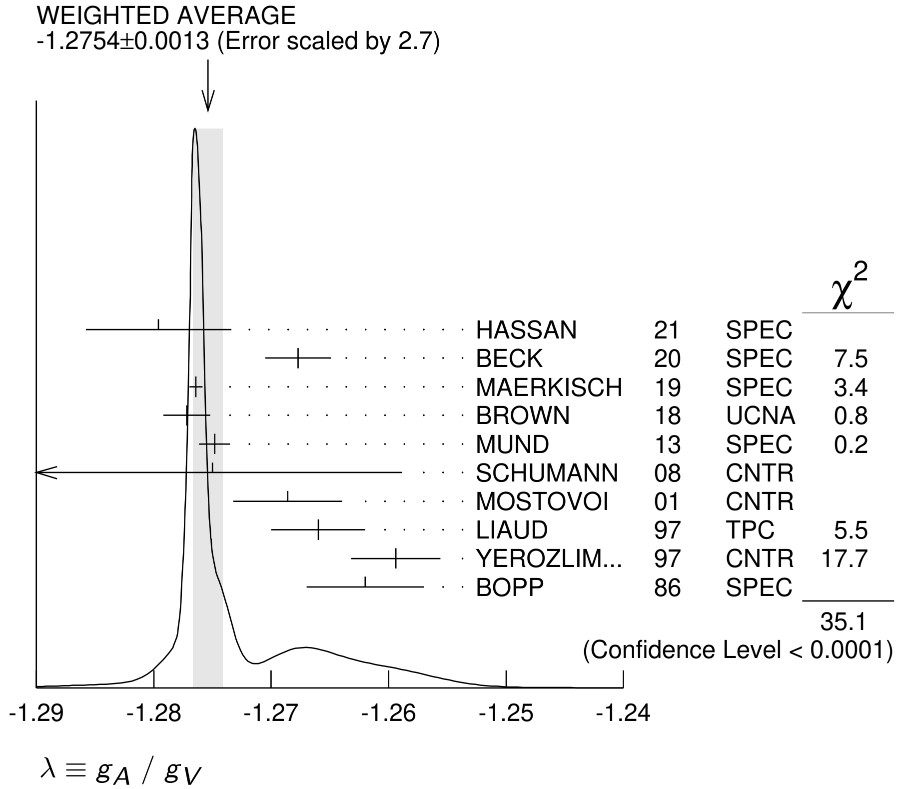
Baryon Decay Parameters

$n \to p e^- \overline{\nu}_e$ DECAY PARAMETERS

See the above "Note on Baryon Decay Parameters." For discussions of recent results, see the references cited at the beginning of the section on the neutron mean life. For discussions of the values of the weak coupling constants g_A and g_V obtained using the neutron lifetime and asymmetry parameter A, comparisons with other methods of obtaining these constants, and implications for particle physics and for astrophysics, see DUBBERS 91 and WOOLCOCK 91. For tests of the $V-A$ theory of neutron decay, see EROZOLIMSKII 91B, MOSTOVOI 96, NICO 05, SEVERIJNS 06, and ABELE 08.

$\lambda \equiv g_A / g_V$

VALUE	DOCUMENT ID		TECN	COMMENT
−1.2754 ±0.0013 OUR AVERAGE Error includes scale factor of 2.7. See the ideogram below.				
−1.2796 ±0.0062	[1] HASSAN	21	SPEC	Proton recoil spectrum
−1.2677 ±0.0028	[2] BECK	20	SPEC	Proton recoil spectrum
−1.27641 ±0.00045 ±0.00033	[3] MAERKISCH	19	SPEC	pulsed cold n, polarized
−1.2772 ±0.0020	[4] BROWN	18	UCNA	Ultracold n, polarized
−1.2748 ±0.0008 $^{+0.0010}_{-0.0011}$	[5] MUND	13	SPEC	Cold n, polarized
−1.275 ±0.006 ±0.015	SCHUMANN	08	CNTR	Cold n, polarized
−1.2686 ±0.0046 ±0.0007	[6] MOSTOVOI	01	CNTR	A and B × polarizations
−1.266 ±0.004	LIAUD	97	TPC	Cold n, polarized, A
−1.2594 ±0.0038	[7] YEROZLIM...	97	CNTR	Cold n, polarized, A
−1.262 ±0.005	BOPP	86	SPEC	Cold n, polarized, A
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−1.27607 ±0.00068	[8] SAUL	20	SPEC	Cold n, polarized, A
−1.284 ±0.014	[9] DARIUS	17	SPEC	Cold n, unpolarized
−1.2755 ±0.0030	[10] MENDENHALL	13	UCNA	See BROWN 18
−1.27590 ±0.00239 $^{+0.00331}_{-0.00377}$	[11] PLASTER	12	UCNA	See MENDENHALL 13
−1.27590 $^{+0.00409}_{-0.00445}$	LIU	10	UCNA	See PLASTER 12
−1.2739 ±0.0019	[12] ABELE	02	SPEC	See MUND 13
−1.274 ±0.003	ABELE	97D	SPEC	Cold n, polarized, A
−1.266 ±0.004	SCHRECK...	95	TPC	See LIAUD 97
−1.2544 ±0.0036	EROZOLIM...	91	CNTR	See YEROZOLIMSKY 97
−1.226 ±0.042	MOSTOVOY	83	RVUE	
−1.261 ±0.012	EROZOLIM...	79	CNTR	Cold n, polarized, A
−1.259 ±0.017	[13] STRATOWA	78	CNTR	p recoil spectrum, a
−1.263 ±0.015	EROZOLIM...	77	CNTR	See EROZOLIMSKII 79
−1.250 ±0.036	[13] DOBROZE...	75	CNTR	See STRATOWA 78
−1.258 ±0.015	[14] KROHN	75	CNTR	Cold n, polarized, A
−1.263 ±0.016	[15] KROPF	74	RVUE	n decay alone
−1.250 ±0.009	[15] KROPF	74	RVUE	n decay + nuclear ft



[1] HASSAN 21 include earlier data of DARIUS 17. The value is extracted from the angular correlation coefficient *a*.

[2] BECK 20 calculates this value from the measurement of the β-decay e–$\overline{\nu}_e$ angular correlation coefficient *a*.

[3] MAERKISCH 19 gets $A = -0.11985 \pm 0.00017 \pm 0.00012$.

[4] BROWN 18 gets $A = -0.12054 \pm 0.00044 \pm 0.00068$ and $\lambda = -1.2783 \pm 0.0022$. We quote the combined values that include the earlier UCNA measurements (MENDENHALL 13).

[5] This MUND 13 value includes earlier PERKEO II measurements (ABELE 02 and ABELE 97D).

[6] MOSTOVOI 01 measures the two *P*-odd correlations *A* and *B*, or rather *SA* and *SB*, where *S* is the *n* polarization, in free neutron decay.

[7] YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value.

[8] SAUL 20 quote this value of λ under the SM assumption of the Fierz term $b = 0$. In a combined fit authors extract a value of $\lambda = -1.2792 \pm 0.0060$.

[9] DARIUS 17 calculates this value from the measurement of the *a* parameter (see below). Data is included in HASSAN 21.

[10] MENDENHALL 13 gets $A = -0.11954 \pm 0.00055 \pm 0.00098$ and $\lambda = -1.2756 \pm 0.0030$. We quote the nearly identical values that include the earlier UCNA measurement (PLASTER 12), with a correction to that result.

[11] This PLASTER 12 value is identical with that given in LIU 10, but the experiment is now described in detail.

[12] This is the combined result of ABELE 02 and ABELE 97D.

[13] These experiments measure the absolute value of g_A/g_V only.

[14] KROHN 75 includes events of CHRISTENSEN 70.

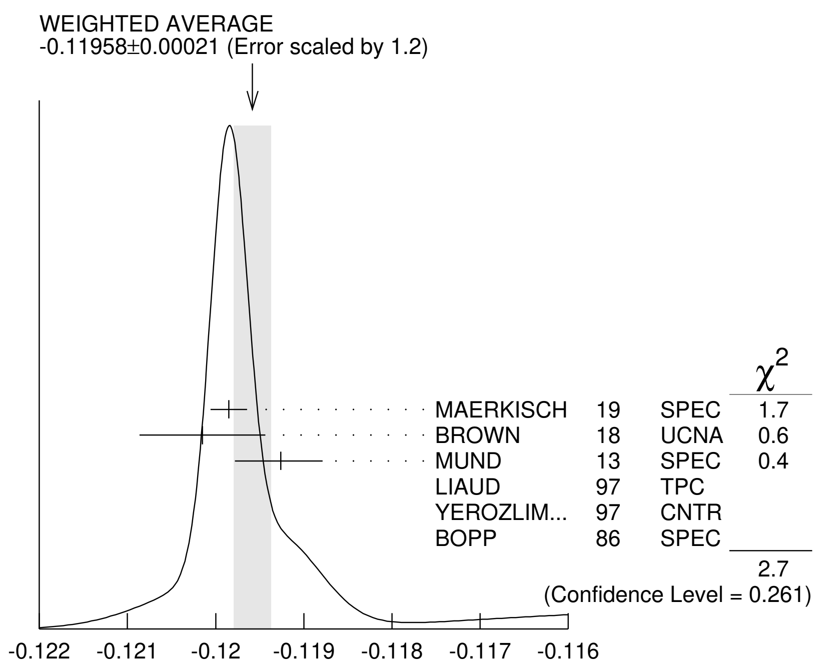
[15] KROPF 74 reviews all data through 1972.

e^- ASYMMETRY PARAMETER *A*

This is the neutron-spin electron-momentum correlation coefficient. Unless otherwise noted, the values are corrected for radiative effects and weak magnetism. In the

Standard Model, A is related to $\lambda \equiv g_A/g_V$ by $A = -2\,\lambda\,(\lambda+1)\,/\,(1+3\lambda^2)$; this assumes that g_A and g_V are real.

VALUE	DOCUMENT ID		TECN	COMMENT
−0.11958±0.00021 OUR AVERAGE Error includes scale factor of 1.2. See the ideogram below.				
−0.11985±0.00017±0.00012	[1] MAERKISCH	19	SPEC	pulsed cold n, polarized
−0.12015±0.00034±0.00063	[2] BROWN	18	UCNA	Ultracold n, polarized
$-0.11926\pm0.00031{+0.00036\atop-0.00042}$	[3] MUND	13	SPEC	Cold n, polarized
−0.1160 ±0.0009 ±0.0012	LIAUD	97	TPC	Cold n, polarized
−0.1135 ±0.0014	[4] YEROZLIM...	97	CNTR	Cold n, polarized
−0.1146 ±0.0019	BOPP	86	SPEC	Cold n, polarized
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.11972±0.00025	[5] SAUL	20	SPEC	Cold n, polarized
−0.11952±0.00110	[6] MENDENHALL	13	UCNA	See BROWN 18
$-0.11966\pm0.00089{+0.00123\atop-0.00140}$	[7] PLASTER	12	UCNA	See MENDENHALL 13
$-0.11966\pm0.00089{+0.00123\atop-0.00140}$	LIU	10	UCNA	See PLASTER 12
−0.1138 ±0.0046 ±0.0021	PATTIE	09	SPEC	Ultracold n, polarized
−0.1189 ±0.0007	[8] ABELE	02	SPEC	See MUND 13
−0.1168 ±0.0017	[9] MOSTOVOI	01	CNTR	Inferred
−0.1189 ±0.0012	ABELE	97D	SPEC	Cold n, polarized
−0.1160 ±0.0009 ±0.0011	SCHRECK...	95	TPC	See LIAUD 97
−0.1116 ±0.0014	EROZOLIM...	91	CNTR	See YEROZOLIM-SKY 97
−0.114 ±0.005	[10] EROZOLIM...	79	CNTR	Cold n, polarized
−0.113 ±0.006	[10] KROHN	75	CNTR	Cold n, polarized



e^- asymmetry parameter A

[1] MAERKISCH 19 further derive a value for the CKM-element $|V_{ud}| = 0.97351 \pm 0.00060$, using τ_n = 879.7(8) sec and the relation from CZARNECKI 18.

[2] BROWN 18 gets $A = -0.12054 \pm 0.00044 \pm 0.00068$ and $\lambda = -1.2783 \pm 0.0022$. We quote the combined values that include the earlier UCNA measurements (MENDENHALL 13).

[3] This MUND 13 value includes earlier PERKEO II measurements (ABELE 02 and ABELE 97D), with a correction to those results.

[4] YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value.

[5] Under the SM assumption that the Fierz term $b = 0$, SAUL 20 obtain the quoted asymmetry parameter A and $\lambda = -1.27607 \pm 0.00068$. In a combined fit authors extract the values $A = -0.1209 \pm 0.0015$, $\lambda = -1.2792 \pm 0.0060$, and $b = 0.017 \pm 0.021$.

[6] MENDENHALL 13 gets $A = -0.11954 \pm 0.00055 \pm 0.00098$ and $\lambda = -1.2756 \pm 0.0030$. We quote the nearly identical values that include the earlier UCNA measurement (PLASTER 12), with a correction to that result.

[7] This PLASTER 12 value is identical with that given in LIU 10, but the experiment is now described in detail.

[8] This is the combined result of ABELE 02 and ABELE 97D.

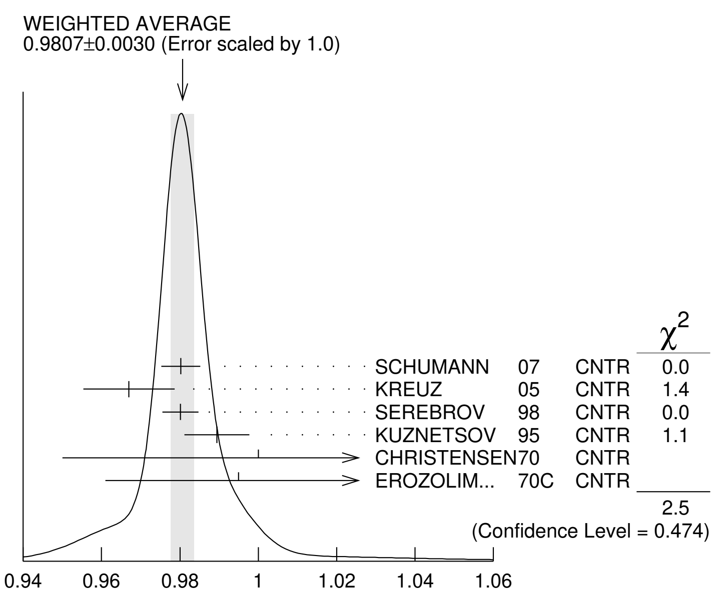
[9] MOSTOVOI 01 calculates this from its measurement of $\lambda = g_A/g_V$ above.

[10] These results are not corrected for radiative effects and weak magnetism, but the corrections are small compared to the errors.

$\overline{\nu}_e$ ASYMMETRY PARAMETER B

This is the neutron-spin antineutrino-momentum correlation coefficient. In the Standard Model, B is related to $\lambda \equiv g_A/g_V$ by $B = 2\lambda(\lambda - 1) / (1 + 3\lambda^2)$; this assumes that g_A and g_V are real.

VALUE	DOCUMENT ID		TECN	COMMENT
0.9807±0.0030 OUR AVERAGE	See the ideogram below.			
0.9802±0.0034±0.0036	SCHUMANN	07	CNTR	Cold *n*, polarized
0.967 ±0.006 ±0.010	KREUZ	05	CNTR	Cold *n*, polarized
0.9801±0.0046	SEREBROV	98	CNTR	Cold *n*, polarized
0.9894±0.0083	KUZNETSOV	95	CNTR	Cold *n*, polarized
1.00 ±0.05	CHRISTENSEN	70	CNTR	Cold *n*, polarized
0.995 ±0.034	EROZOLIM...	70C	CNTR	Cold *n*, polarized
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.9876±0.0004	[1] MOSTOVOI	01	CNTR	Inferred



$\overline{\nu}_e$ ASYMMETRY PARAMETER B

[1] MOSTOVOI 01 calculates this from its measurement of $\lambda = g_A/g_V$ above.

PROTON ASYMMETRY PARAMETER *C*

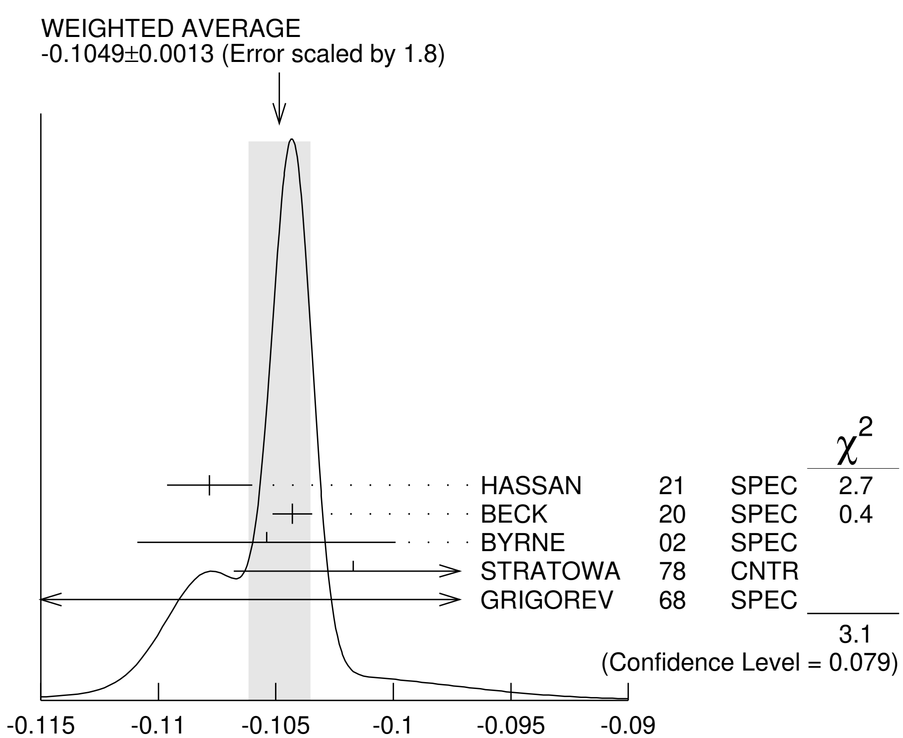
Describes the correlation between the neutron spin and the proton momentum. In the Standard Model, C is related to $\lambda \equiv g_A/g_V$ by $C = -x_c\ (A + B) = x_c\ 4\lambda/(1 + 3\lambda^2)$, where $x_c = 0.27484$ is a kinematic factor; this assumes that g_A and g_V are real.

VALUE	DOCUMENT ID		TECN	COMMENT
−0.2377±0.0010±0.0024	SCHUMANN	08	CNTR	Cold n, polarized

e-$\overline{\nu}_e$ ANGULAR CORRELATION COEFFICIENT *a*

For a review of past experiments and plans for future measurements of the a parameter, see WIETFELDT 05. In the Standard Model, a is related to $\lambda \equiv g_A/g_V$ by $a = (1 - \lambda^2)\ /\ (1 + 3\lambda^2)$; this assumes that g_A and g_V are real.

VALUE	DOCUMENT ID		TECN	COMMENT
−0.1049 ±0.0013 OUR AVERAGE Error includes scale factor of 1.8. See the ideogram below.				
−0.10782±0.00124±0.00133	[1] HASSAN	21	SPEC	Proton recoil spectrum
−0.10430±0.00084	BECK	20	SPEC	Proton recoil spectrum
−0.1054 ±0.0055	BYRNE	02	SPEC	Proton recoil spectrum
−0.1017 ±0.0051	STRATOWA	78	CNTR	Proton recoil spectrum
−0.091 ±0.039	GRIGOREV	68	SPEC	Proton recoil spectrum
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.1090 ±0.0030 ±0.0028	[2] DARIUS	17	SPEC	Cold n, unpolarized
−0.1045 ±0.0014	[3] MOSTOVOI	01	CNTR	Inferred



e-$\overline{\nu}_e$ Angular correlation coefficient a

[1] The result of HASSAN 21 includes the data of DARIUS 17, and thus supersedes those entries. HASSAN 21 uses the asymmetry in time-of-flight between the beta electron and recoil proton in delayed coincidence.

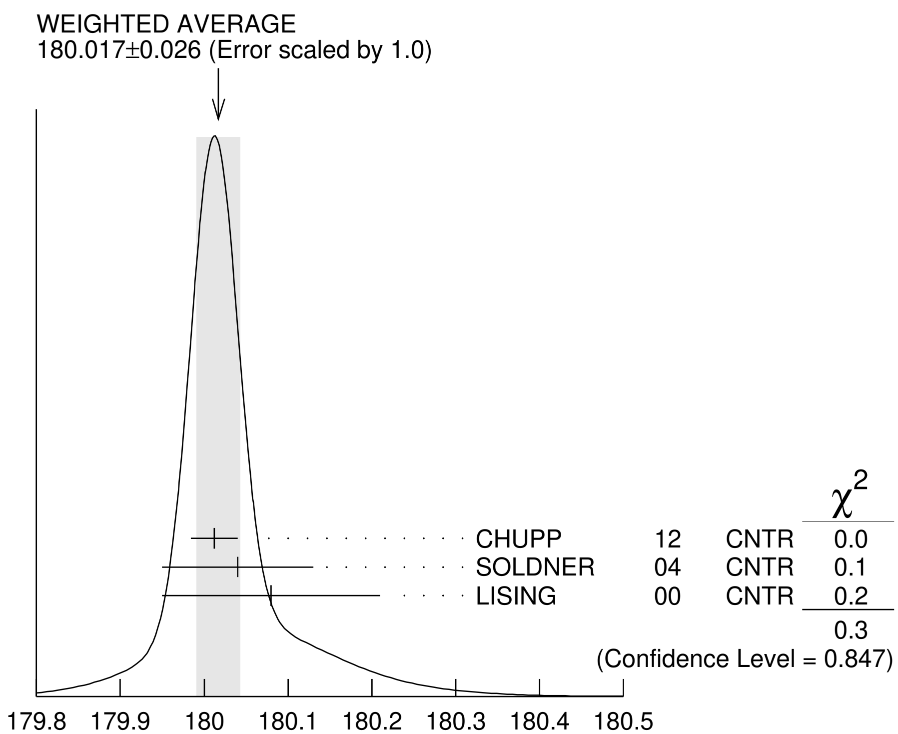
[2] DARIUS 17 exploits a "wishbone" correlation, where the p time of flight is correlated with the momentum of the electron in delayed coincidence. Data is included in HASSAN 21.

[3] MOSTOVOI 01 calculates this from its measurement of $\lambda = g_A/g_V$ above.

ϕ_{AV}, PHASE OF g_A RELATIVE TO g_V

Time reversal invariance requires this to be 0 or 180°. This is related to D given in the next data block and $\lambda \equiv g_A/g_V$ by $\sin(\phi_{AV}) \equiv D(1+3\lambda^2)/2|\lambda|$; this assumes that g_A and g_V are real.

VALUE (°)	CL%	DOCUMENT ID		TECN	COMMENT
180.017±0.026 OUR AVERAGE		See the ideogram below.			
180.012±0.028	68	CHUPP	12	CNTR	Cold n, polarized > 91%
180.04 ±0.09		SOLDNER	04	CNTR	Cold n, polarized
180.08 ±0.13		LISING	00	CNTR	Polarized > 93%
• • • We do not use the following data for averages, fits, limits, etc. • • •					
180.013±0.028		MUMM	11	CNTR	See CHUPP 12
179.71 ±0.39		EROZOLIM...	78	CNTR	Cold n, polarized
180.35 ±0.43		EROZOLIM...	74	CNTR	Cold n, polarized
181.1 ±1.3		[1] KROPF	74	RVUE	n decay
180.14 ±0.22		STEINBERG	74	CNTR	Cold n, polarized



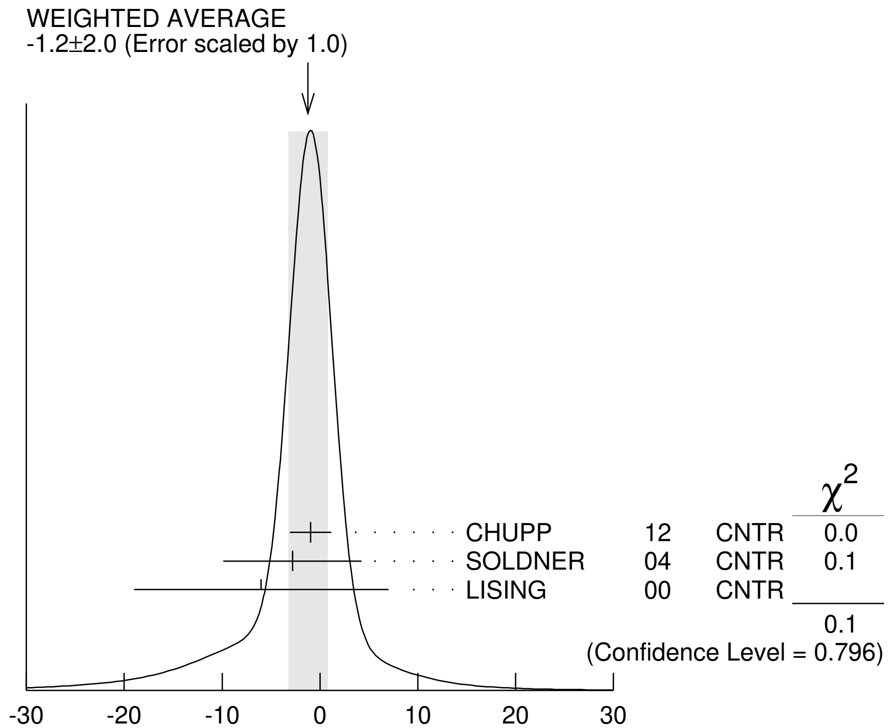
ϕ_{AV}, PHASE OF g_A RELATIVE TO g_V (°)

[1] KROPF 74 reviews all data through 1972.

TRIPLE CORRELATION COEFFICIENT *D*

These are measurements of the component of *n* spin perpendicular to the decay plane in β decay. Should be zero if *T* invariance is not violated.

VALUE (units 10^{-4})	*DOCUMENT ID*		*TECN*	*COMMENT*
− 1.2 ± 2.0 OUR AVERAGE	See the ideogram below.			
− 0.94± 1.89±0.97	CHUPP	12	CNTR	Cold *n*, polarized > 91%
− 2.8 ± 6.4 ±3.0	SOLDNER	04	CNTR	Cold *n*, polarized
− 6 ±12 ±5	LISING	00	CNTR	Polarized > 93%
• • • We do not use the following data for averages, fits, limits, etc. • • •				
− 0.96± 1.89±1.01	MUMM	11	CNTR	See CHUPP 12
+22 ±30	EROZOLIM...	78	CNTR	Cold *n*, polarized
−27 ±50	[1] EROZOLIM...	74	CNTR	Cold *n*, polarized
−11 ±17	STEINBERG	74	CNTR	Cold *n*, polarized



TRIPLE CORRELATION COEFFICIENT *D* (units 10^{-4})

[1] EROZOLIMSKII 78 says asymmetric proton losses and nonuniform beam polarization may give a systematic error up to 30×10^{-4}, thus increasing the EROZOLIMSKII 74 error to 50×10^{-4}. STEINBERG 74 and STEINBERG 76 estimate these systematic errors to be insignificant in their experiment.

TRIPLE CORRELATION COEFFICIENT *R*

Another test of time-reversal invariance. *R* measures the polarization of the electron in the direction perpendicular to the plane defined by the neutron spin and the electron momentum. $R = 0$ for T invariance.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
+0.004±0.012±0.005	[1] KOZELA	12	CNTR	Mott polarimeter

• • • We do not use the following data for averages, fits, limits, etc. • • •

$+0.008 \pm 0.015 \pm 0.005$	KOZELA	09	CNTR	See KOZELA 12

[1] KOZELA 12 also measures the polarization of the electron along the direction of the neutron spin. This is nonzero in the Standard Model; the correlation coefficient is $N = +0.067 \pm 0.011 \pm 0.004$.

FIERZ INTERFERENCE TERM *b*

The coefficient of the Fierz interference term, *b*, probes additional contributions to the differential decay rate of the neutron from scalar or tensor current interactions, beyond the Standard Model.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.017±0.020±0.003	[1] SAUL	20	SPEC	Cold *n*, polarized

[1] In a combined fit SAUL 20 extract this best fit value of the Fierz interference term *b* and the values $A = -0.1209 \pm 0.0015$ and $\lambda = -1.2792 \pm 0.0060$. For *b* it translates into a 90% CL region of $-0.018 \leq b \leq 0.052$ as a function of *A*.

n REFERENCES

We have omitted some papers that have been superseded by later experiments. See our earlier editions.

ALMAZAN	22	PRL 128 061801	H. Almazan *et al.*	(STEREO Collab.)
ABE	21	PR D103 012008	K. Abe *et al.*	(Super-Kamiokande Collab.)
ABEL	21	PL B812 135993	C. Abel *et al.*	(nEDM Collab.)
GONZALEZ	21	PRL 127 162501	F.M. Gonzalez *et al.*	(UCNtau Collab.)
HASSAN	21	PR C103 045502	M.T. Hassan *et al.*	(aCORN Collab)
HEACOCK	21	SCI 373 1239	B. Heacock *et al.*	(NIST, RIKEN, NAGO+)
TIESINGA	21	RMP 93 025010	E. Tiesinga *et al.*	(NIST)
WILSON	21	PR C104 045501	J.T. Wilson *et al.*	(JHU, DURH)
ABEL	20	PRL 124 081803	C. Abel *et al.*	(nEDM Collab.)
BECK	20	PR C101 055506	M. Beck *et al.*	(aSPECT Collab.)
FILIN	20	PRL 124 082501	A.A. Filin *et al.*	
SAUL	20	PRL 125 112501	H. Saul *et al.*	(PERKEO III Collab.)
KLOPF	19	PRL 122 222503	M. Klopf *et al.*	(PERKEO II Collab.)
MAERKISCH	19	PRL 122 242501	B. Maerkisch *et al.*	(TUM, ILL, +)
SCHUMACHER	19	LHEP 4 4	M. Schumacher	(GOET)
BEREZHIANI	18	EPJ C78 717	Z. Berezhiani *et al.*	(AQUI, INFN, ILLG+)
BROWN	18	PR C97 035505	M.A.-P. Brown *et al.*	(UCNA Collab.)
CZARNECKI	18	PRL 120 202002	A. Czarnecki, W.J. Marciano, A. Sirlin	(ALBE+)
EZHOV	18	JETPL 107 671	V.F. Ezhov *et al.*	(PNPI, LENSU, CAEN+)
PATTIE	18	SCI 360 627	R.W. Pattie Jr. *et al.*	(LASL, IND, NCSU+)
SEREBROV	18	PR C97 055503	A.P. Serebrov *et al.*	(PNPI, ILLG, RAL)
Also		JETPL 106 623	A.P. Serebrov *et al.*	(PNPI, ILLG, RAL)
SUN	18	PR C97 052501	X. Sun *et al.*	(UCNA Collab.)
AHARMIM	17	PR D96 092005	B. Aharmin *et al.*	(SNO Collab.)
DARIUS	17	PRL 119 042502	G. Darius *et al.*	(aCORN at NIST)
SAHOO	17	PR D95 013002	B.K. Sahoo	(AHMEB)
BALES	16	PRL 116 242501	M.J. Bales *et al.*	(RDK II Collab.)
GRANER	16	PRL 116 161601	B. Graner *et al.*	(WASH)
Also		PRL 119 119901 (errat.)	B. Graner *et al.*	(WASH)
MOHR	16	RMP 88 035009	P.J. Mohr, D.B. Newell, B.N. Taylor	(NIST)
PHILLIPS	16	PRPL 612 1	D.G. Phillips II *et al.*	
ABE	15C	PR D91 072006	K. Abe *et al.*	(Super-Kamiokande Collab.)
ARZUMANOV	15	PL B745 79	S. Arzumanov *et al.*	(ILLG, KIAE)
PENDLEBURY	15	PR D92 092003	J.M. Pendlebury *et al.*	(ETHZ, PSI, SUSS)
SEREBROV	15	PR C92 055501	A.P. Serebrov *et al.*	(PNPI, ILLG, IOFF)
EPSTEIN	14	PR D90 074027	Z. Epstein, G. Paz, J. Roy	(UMD, WAYN)
MYERS	14	PRL 113 262506	L.S. Myers *et al.*	(COMPTON/MAX-lab Collab.)
SEREBROV	14	JETPL 99 4	A.P. Serebrov *et al.*	(PNPI, ILL, IOFF)
MENDENHALL	13	PR C87 032501	M.P. Mendenhall *et al.*	(UCNA Collab.)
MUND	13	PRL 110 172502	D. Mund *et al.*	(HEID, ILLG)
YUE	13	PRL 111 222501	A.T. Yue *et al.*	(UMD, NIST, TENN, ORNL+)
ARZUMANOV	12	JETPL 95 224	S.S. Arzumanov *et al.*	(KIAE)
		Translated from ZETFP 95 248.		

CHUPP	12	PR C86 035505	T.E. Chupp *et al.*	(MICH, UCB, WASH+)
GRIESSHAM...	12	PPNP 67 841	H.W. Griesshammer *et al.*	(GWU, MCHS+)
KOZELA	12	PR C85 045501	A. Kozela *et al.*	(nTRV Collab.)
MOHR	12	RMP 84 1527	P.J. Mohr, B.N. Taylor, D.B. Newell	(NIST)
PLASTER	12	PR C86 055501	B. Plaster *et al.*	(UCNA Collab.)
STEYERL	12	PR C85 065503	A. Steyerl *et al.*	(URI, SUSS)
BRESSI	11	PR A83 052101	G. Bressi *et al.*	(LEGN, PAVII, PADO, TRST+)
DUBBERS	11	RMP 83 1111	D. Dubbers, M.G. Schmidt	(HEID)
MUMM	11	PRL 107 102301	H.P. Mumm *et al.*	(NIST, WASH, MICH, LBL+)
WIETFELDT	11	RMP 83 1173	F.E. Wietfeldt, G.L. Greene	(TULA, TENN)
COOPER	10	PR C81 035503	R.L. Cooper *et al.*	(MICH, NIST, TULA+)
LIU	10	PRL 105 181803	J. Liu *et al.*	(UCNA Collab.)
Also		PRL 105 219903 (errat.)	J. Liu *et al.*	(UCNA Collab.)
PICHLMAIER	10	PL B693 221	A. Pichlmaier *et al.*	(TUM, PNPI, ILLG)
ALTAREV	09A	PR D80 032003	I. Altarev *et al.*	(TUM, RAL, CAEN+)
KOZELA	09	PRL 102 172301	A. Kozela *et al.*	(JAGL, CRAC, PSI, CAEN+)
LAMOREAUX	09	JP G36 104002	S.K. Lamoreaux, R. Golub	(YALE, NCSU)
MOHAPATRA	09	JP G36 104006	R.N. Mohapatra	(UMD)
PATTIE	09	PRL 102 012301	R.W. Pattie Jr. *et al.*	(Los Alamos UCNA Collab.)
SEREBROV	09A	NIM A611 137	A.P. Serebrov *et al.*	(PNPI, IOFF, ILLG+)
ABELE	08	PPNP 60 1	H. Abele	(HEID)
MOHR	08	RMP 80 633	P.J. Mohr, B.N. Taylor, D.B. Newell	(NIST)
SCHUMANN	08	PRL 100 151801	M. Schumann *et al.*	(HEID, ILLG, KARL+)
SEREBROV	08	PL B663 181	A.P. Serebrov *et al.*	(PNPI, IOFF, ILLG+)
BAKER	07	PRL 98 149102	C.A. Baker *et al.*	(RAL, SUSS, ILLG)
BAN	07	PRL 99 161603	G. Ban *et al.*	(CAEN, JAGL, PSI, JINR+)
BELUSHKIN	07	PR C75 035202	M.A. Belushkin, H.W. Hammer, U.-G. Meissner	(BONN+)
LAMOREAUX	07	PRL 98 149101	S.K. Lamoreaux, R. Golub	(YALE, NCSU)
SCHUMANN	07	PRL 99 191803	M. Schumann *et al.*	(HEID, ILLG, KARL+)
SILENKO	07	PPNL 4 468	A.Ya. Silenko	(Belarussian U.)
		Translated from PFECAY 6 784.		
BAKER	06	PRL 97 131801	C.A. Baker *et al.*	(RAL, SUSS, ILLG)
NICO	06	NAT 444 1059	J.S. Nico *et al.*	(NIST, TULN, MICH, UMD+)
SEVERIJNS	06	RMP 78 991	N. Severijns, M. Beck, O. Naviliat-Cuncic	(LEUV+)
KREUZ	05	PL B619 263	M. Kreuz *et al.*	(HEID, ILLG, MAINZ, KARL+)
MOHR	05	RMP 77 1	P.J. Mohr, B.N. Taylor	(NIST)
NICO	05	PR C71 055502	J.S. Nico *et al.*	(NIST, TULN, IND, TENN+)
SCHUMACHER	05	PPNP 55 567	M. Schumacher	(GOET)
SEREBROV	05	PL B605 72	A.P. Serebrov *et al.*	(PNPI, JINR, ILLG)
Also		SPU 48 867	A.P. Serebrov *et al.*	(PPNI, JINR, ILLG)
		Translated from UFN 175 905.		
WIETFELDT	05	MPL A20 1783	F.E. Wietfeldt	(TULN)
SOLDNER	04	PL B581 49	T. Soldner *et al.*	(ILLG, TUM)
DEWEY	03	PRL 91 152302	M.S. Dewey *et al.*	(NIST, TULN, IND+)
KOSSERT	03	EPJ A16 259	K. Kossert *et al.*	(Mainz MAMI Collab.)
Also		PRL 88 162301	K. Kossert *et al.*	(Mainz MAMI Collab.)
LUNDIN	03	PRL 90 192501	M. Lundin *et al.*	
ABELE	02	PRL 88 211801	H. Abele *et al.*	(PERKEO-II Collab.)
BECK	02	JETPL 76 332	M. Beck *et al.*	(LEUV, SUSS, KIAE, PNPI)
		Translated from ZETFP 76 392.		
BYRNE	02	JP G28 1325	J. Byrne *et al.*	
CHUNG	02B	PR D66 032004	J. Chung *et al.*	(SOUDAN-2 Collab.)
MOSTOVOI	01	PAN 64 1955	Yu.A. Mostovoi *et al.*	
		Translated from YAF 64 2040.		
ARZUMANOV	00	PL B483 15	S. Arzumanov *et al.*	
GAL	00	PR C61 028201	A. Gal	
KOLB	00	PRL 85 1388	N.R. Kolb *et al.*	
LAMOREAUX	00	PR D61 051301	S.K. Lamoreaux, R. Golub	
LEVCHUK	00	NP A674 449	M.I. Levchuk, A.I. L'vov	(BELA, LEBD)
LISING	00	PR C62 055501	L.J. Lising *et al.*	(NIST emiT Collab.)
HARRIS	99	PRL 82 904	P.G. Harris *et al.*	
KESSLER	99	PL A255 221	E.G. Kessler Jr *et al.*	
MOHR	99	JPCRD 28 1713	P.J. Mohr, B.N. Taylor	(NIST)
Also		RMP 72 351	P.J. Mohr, B.N. Taylor	(NIST)
SEREBROV	98	JETP 86 1074	A.P. Serebrov *et al.*	
		Translated from ZETF 113 1963.		
ABELE	97D	PL B407 212	H. Abele *et al.*	(HEIDP, ILLG)
KOPECKY	97	PR C56 2229	S. Kopecky *et al.*	
LIAUD	97	NP A612 53	P. Liaud *et al.*	(ILLG, LAPP)
YEROZLIM...	97	PL B412 240	B.G. Erozolimsky *et al.*	(HARV, PNPI, KIAE)
ALTAREV	96	PAN 59 1152	I.S. Altarev *et al.*	(PNPI)
		Translated from YAF 59 1204.		

BONDAREN...	96	JETPL 64 416	L.N. Bondarenko *et al.*	(KIAE)
		Translated from ZETFP 64 382.		
BYRNE	96	EPL 33 187	J. Byrne *et al.*	(SUSS, ILLG)
MOSTOVOI	96	PAN 59 968	Y.A. Mostovoy	(KIAE)
		Translated from YAF 59 1013.		
NORMAN	96	PR D53 4086	E.B. Norman, J.N. Bahcall, M. Goldhaber	(LBL+)
IGNATOVICH	95	JETPL 62 1	V.K. Ignatovich	(JINR)
		Translated from ZETFP 62 3.		
KOESTER	95	PR C51 3363	L. Koester *et al.*	(TUM, JINR, LATV)
KOPECKY	95	PRL 74 2427	S. Kopecky *et al.*	
KUZNETSOV	95	PRL 75 794	I.A. Kuznetsov *et al.*	(PNPI, KIAE, HARV+)
SCHRECK...	95	PL B349 427	K. Schreckenbach *et al.*	(TUM, ILLG, LAPP)
BALDO-...	94	ZPHY C63 409	M. Baldo-Ceolin *et al.*	(HEID, ILLG, PADO+)
DIFILIPPO	94	PRL 73 1481	F. DiFilippo *et al.*	(MIT)
Also		PRL 71 1998	V. Natarajan *et al.*	(MIT)
GOLUB	94	PRPL 237C 1	R. Golub, K. Lamoreaux	(HAHN, WASH)
MAMPE	93	JETPL 57 82	B. Mampe *et al.*	(KIAE)
		Translated from ZETFP 57 77.		
ALTAREV	92	PL B276 242	I.S. Altarev *et al.*	(PNPI)
NESVIZHEV...	92	JETP 75 405	V.V. Nesvizhevsky *et al.*	(PNPI, JINR)
		Translated from ZETF 102 740.		
ALBERICO	91	NP A523 488	W.M. Alberico, A. de Pace, M. Pignone	(TORI)
DUBBERS	91	NP A527 239c	D. Dubbers	(ILLG)
Also		EPL 11 195	D. Dubbers, W. Mampe, J. Dohner	(ILLG, HEID)
EROZOLIM...	91	PL B263 33	B.G. Erozolimsky *et al.*	(PNPI, KIAE)
Also		SJNP 52 999	B.G. Erozolimsky *et al.*	(PNPI, KIAE)
		Translated from YAF 52 1583.		
EROZOLIM...	91B	SJNP 53 260	B.G. Erozolimsky, Y.A. Mostovoy	(KIAE)
		Translated from YAF 53 418.		
SCHMIEDM...	91	PRL 66 1015	J. Schmiedmayer *et al.*	(TUW, ORNL)
WOOLCOCK	91	MPL A6 2579	W.S. Woolcock	(CANB)
ALFIMENKOV	90	JETPL 52 373	V.P. Alfimenkov *et al.*	(PNPI, JINR)
		Translated from ZETFP 52 984.		
BALDO-...	90	PL B236 95	M. Baldo-Ceolin *et al.*	(PADO, PAVI, HEIDP+)
BERGER	90	PL B240 237	C. Berger *et al.*	(FREJUS Collab.)
BRESSI	90	NC 103A 731	G. Bressi *et al.*	(PAVI, ROMA, MILA)
BYRNE	90	PRL 65 289	J. Byrne *et al.*	(SUSS, NBS, SCOT, CBNM)
GREEN	90	JP G16 L75	K. Green, D. Thompson	(RAL)
RAMSEY	90	ARNPS 40 1	N.F. Ramsey	(HARV)
ROSE	90	PL B234 460	K.W. Rose *et al.*	(GOET, MPCM, MAINZ)
ROSE	90B	NP A514 621	K.W. Rose *et al.*	(GOET, MPCM)
SMITH	90	PL B234 191	K.F. Smith *et al.*	(SUSS, RAL, HARV+)
BRESSI	89	ZPHY C43 175	G. Bressi *et al.*	(INFN, MILA, PAVI, ROMA)
DOVER	89	NIM A284 13	C.B. Dover, A. Gal, J.M. Richard	(BNL, HEBR+)
KOSSAKOW...	89	NP A503 473	R. Kossakowski *et al.*	(LAPP, SAVO, ISNG+)
MAMPE	89	PRL 63 593	W. Mampe *et al.*	(ILLG, RISL, SUSS, URI)
MOHAPATRA	89	NIM A284 1	R.N. Mohapatra	(UMD)
PAUL	89	ZPHY C45 25	W. Paul *et al.*	(BONN, WUPP, MPIK, ILLG)
SCHMIEDM...	89	NIM A284 137	J. Schmiedmayer, H. Rauch, P. Riehs	(WIEN)
BAUMANN	88	PR D37 3107	J. Baumann *et al.*	(BAYR, MUNI, ILLG)
KOESTER	88	ZPHY A329 229	L. Koester, W. Waschkowski, J. Meier	(MUNI, TUM)
LAST	88	PRL 60 995	I. Last *et al.*	(HEIDP, ILLG, ANL)
SCHMIEDM...	88	PRL 61 1065	J. Schmiedmayer, H. Rauch, P. Riehs	(TUW)
Also		PRL 61 2509 (erratum)	J. Schmiedmayer, H. Rauch, P. Riehs	(TUW)
SPIVAK	88	JETP 67 1735	P.E. Spivak	(KIAE)
		Translated from ZETF 94 1.		
COHEN	87	RMP 59 1121	E.R. Cohen, B.N. Taylor	(RISC, NBS)
ALEKSANDR...	86	SJNP 44 900	Yu.A. Aleksandrov *et al.*	
		Translated from YAF 44 1384.		
ALTAREV	86	JETPL 44 460	I.S. Altarev *et al.*	(PNPI)
		Translated from ZETFP 44 360.		
BOPP	86	PRL 56 919	P. Bopp *et al.*	(HEIDP, ANL, ILLG)
Also		ZPHY C37 179	E. Klempt *et al.*	(HEIDP, ANL, ILLG)
CRESTI	86	PL B177 206	M. Cresti *et al.*	(PADO)
Also		PL B200 587 (erratum)	M. Cresti *et al.*	(PADO)
GREENE	86	PRL 56 819	G.L. Greene *et al.*	(NBS, ILLG)
KOESTER	86	Physica B137 282	L. Koester *et al.*	
KOSVINTSEV	86	JETPL 44 571	Y.Y. Kosvintsev, V.I. Morozov, G.I. Terekhov	(KIAE)
		Translated from ZETFP 44 444.		

TAKITA	86	PR D34 902	M. Takita *et al.*	(KEK, TOKY+)
DOVER	85	PR C31 1423	C.B. Dover, A. Gal, J.M. Richard	(BNL)
FIDECARO	85	PL 156B 122	G. Fidecaro *et al.*	(CERN, ILLG, PADO+)
PARK	85B	NP B252 261	H.S. Park *et al.*	(IMB Collab.)
BATTISTONI	84	PL 133B 454	G. Battistoni *et al.*	(NUSEX Collab.)
JONES	84	PRL 52 720	T.W. Jones *et al.*	(IMB Collab.)
PENDLEBURY	84	PL 136B 327	J.M. Pendlebury *et al.*	(SUSS, HARV, RAL+)
CHERRY	83	PRL 50 1354	M.L. Cherry *et al.*	(PENN, BNL)
DOVER	83	PR D27 1090	C.B. Dover, A. Gal, J.M. Richard	(BNL)
KABIR	83	PRL 51 231	P.K. Kabir	(HARV)
MOSTOVOY	83	JETPL 37 196	Y.A. Mostovoy	(KIAE)
		Translated from ZETFP 37 162.		
ROY	83	PR D28 1770	A. Roy *et al.*	(TATA)
VAIDYA	83	PR D27 486	S.C. Vaidya *et al.*	(TATA)
GAEHLER	82	PR D25 2887	R. Gahler, J. Kalus, W. Mampe	(BAYR, ILLG)
GREENE	82	Metrologia 18 93	G.L. Greene *et al.*	(YALE, HARV, ILLG+)
ALTAREV	81	PL 102B 13	I.S. Altarev *et al.*	(PNPI)
BARABANOV	80	JETPL 32 359	I.R. Barabanov *et al.*	(PNPI)
		Translated from ZETFP 32 384.		
BYRNE	80	PL 92B 274	J. Byrne *et al.*	(SUSS, RL)
KOSVINTSEV	80	JETPL 31 236	Y.Y. Kosvintsev *et al.*	(JINR)
		Translated from ZETFP 31 257.		
MOHAPATRA	80	PRL 44 1316	R.N. Mohapatra, R.E. Marshak	(CUNY, VPI)
ALTAREV	79	JETPL 29 730	I.S. Altarev *et al.*	(PNPI)
		Translated from ZETFP 29 794.		
EROZOLIM...	79	SJNP 30 356	B.G. Erozolimsky *et al.*	(KIAE)
		Translated from YAF 30 692.		
NORMAN	79	PRL 43 1226	E.B. Norman, A.G. Seamster	(WASH)
BONDAREN...	78	JETPL 28 303	L.N. Bondarenko *et al.*	(KIAE)
		Translated from ZETFP 28 328.		
Also		Smolenice Conf.	P.G. Bondarenko	(KIAE)
EROZOLIM...	78	SJNP 28 48	B.G. Erozolimsky *et al.*	(KIAE)
		Translated from YAF 28 98.		
STRATOWA	78	PR D18 3970	C. Stratowa, R. Dobrozemsky, P. Weinzierl	(SEIB)
EROZOLIM...	77	JETPL 23 663	B.G. Erozolimsky *et al.*	(KIAE)
		Translated from ZETFP 23 720.		
KOESTER	76	PRL 36 1021	L. Koester *et al.*	
STEINBERG	76	PR D13 2469	R.I. Steinberg *et al.*	(YALE, ISNG)
DOBROZE...	75	PR D11 510	R. Dobrozemsky *et al.*	(SEIB)
KROHN	75	PL 55B 175	V.E. Krohn, G.R. Ringo	(ANL)
EROZOLIM...	74	JETPL 20 345	B.G. Erozolimsky *et al.*	
		Translated from ZETFP 20 745.		
KROPF	74	ZPHY 267 129	H. Kropf, E. Paul	(LINZ)
Also		NP A154 160	H. Paul	(VIEN)
STEINBERG	74	PRL 33 41	R.I. Steinberg *et al.*	(YALE, ISNG)
COHEN	73	JPCRD 2 664	E.R. Cohen, B.N. Taylor	(RISC, NBS)
KROHN	73	PR D8 1305	V.E. Krohn, G.R. Ringo	
CHRISTENSEN	72	PR D5 1628	C.J. Christensen *et al.*	(RISO)
CHRISTENSEN	70	PR C1 1693	C.J. Christensen, V.E. Krohn, G.R. Ringo	(ANL)
EROZOLIM...	70C	PL 33B 351	B.G. Erozolimsky *et al.*	(KIAE)
GRIGOREV	68	SJNP 6 239	V.K. Grigoriev *et al.*	(ITEP)
		Translated from YAF 6 329.		
KROHN	66	PR 148 1303	V.E. Krohn, G.R. Ringo	
LEE	56	PR 104 254	T.D. Lee, C.N. Yang	(COLU, BNL)