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We have omitted some results that have been superseded by later experiments.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 new 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*
1.00866491600±0.00000000043	MOHR	12	RVUE	2010 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
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 much more precisely in u (atomic mass units) than in MeV. The conversion from u to MeV, 1 u = 931.494 061(21) MeV/c^2 (MOHR 12, the 2010 CODATA value), involves the relatively poorly known electronic charge.

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
939.565379±0.000021	MOHR	12	RVUE	2010 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
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	$np \rightarrow d\gamma$
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	$np \rightarrow d\gamma$
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 ± 0.000000014 u.

$\overline{n}$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
939.485±0.051	59	[5] CRESTI	86	HBC	$\overline{p}p \to \overline{n}n$

[5] 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
$(9\pm6)\times10^{-5}$ OUR EVALUATION	

$m_n - m_p$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1.29333217±0.00000042	[6] MOHR	12	RVUE	2010 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.29333214±0.00000043	[7] MOHR	08	RVUE	2006 CODATA value
1.2933317 ±0.0000005	[8] MOHR	05	RVUE	2002 CODATA value
1.2933318 ±0.0000005	[9] MOHR	99	RVUE	1998 CODATA value
1.293318 ±0.000009	[10] 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

[6] The 2010 CODATA mass difference in *u* is $m_n - m_p = 1.388\,449\,19(45)\times10^{-3}u$.

[7] Calculated by us from the MOHR 08 ratio $m_n/m_p = 1.00137841918(46)$. In u, $m_n - m_p = 1.38844920(46)\times10^{-3}$ u.

[8] Calculated by us from the MOHR 05 ratio $m_n/m_p = 1.00137841870 \pm 0.00000000058$. In u, $m_n - m_p = (1.3884487 \pm 0.0000006)\times10^{-3}$ u.

[9] Calculated by us from the MOHR 99 ratio $m_n/m_p = 1.00137841887 \pm 0.00000000058$. In u, $m_n - m_p = (1.3884489 \pm 0.0000006)\times10^{-3}$ u.

[10] 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."

The mean life of the neutron, 878.5 ± 0.8 s, obtained by SEREBROV 05 (for a more detailed account, see SEREBROV 08A; and for comments on the systematic error for this result, see STEYERL 10) was so far from our average of seven other measurements, 885.7 ± 0.8 s, that it made no sense to include it in our average. Thus our 2006, 2008, and 2010 *Reviews* stayed with 885.7 ± 0.8 s; but we noted that in light of SEREBROV 05 our value should be regarded as suspect until further experiments clarified matters.

However, after our 2010 *Review*, PICHLMAIER 10 obtained a mean life of 880.7 ± 1.8 s, and we averaged the best seven results to get 881.5 ± 1.5 s for our 2011 off-year web update. Since then, ARZUMANOV 12, responding to comments of SEREBROV 10B, recalculated the systematic corrections to its 2000 measurement (ARZUMANOV 00) and lowered its value from 885.4 ± 0.9 ± 0.4 s to 881.6 ± 0.8 ± 1.9 s. And STEYERL 12 reanalyzed systematic corrections to MAMPE 89 and lowered its value from 887.6 ± 3.0 to 882.5 ± 1.4 ± 1.5 s. Thus the trend is definitely toward a shorter lifetime.

There seems little better to do than to again average the best seven measurements. The result, 880.3 ± 1.1 s (including a scale factor of 1.9), is 5.4 seconds lower than the value we gave in 2010—a drop of 6.8 old and 4.9 new standard deviations.

For a full review of all matters concerning the neutron lifetime, see F.E. Wietfeldt and G.L. Greene, "The neutron lifetime," Reviews of Modern Physics **83** 1173 (2011). In particular, there is a full discussion of the experimental methods and results; and an average lifetime is obtained making several different selections of those results. (The revised ARZUMANOV 12 mean life was not yet available.)

VALUE (s)	*DOCUMENT ID*		*TECN*	*COMMENT*
880.3± 1.1 OUR AVERAGE	Error includes scale factor of 1.9. See the ideogram below.			
887.7± 1.2± 1.9	[11] YUE	13	CNTR	In-beam n, trapped p
881.6± 0.8± 1.9	[12] ARZUMANOV	12	CNTR	UCN double bottle
882.5± 1.4± 1.5	[13] 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
889.2± 3.0± 3.8	BYRNE	96	CNTR	Penning trap
882.6± 2.7	[14] MAMPE	93	CNTR	UCN material bottle
• • • We do not use the following data for averages, fits, limits, etc. • • •				
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
888.4± 3.1± 1.1	[15] 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	[16] BYRNE	80	CNTR	
875 ±95	KOSVINTSEV	80	CNTR	
881 ± 8	BONDAREN...	78	CNTR	See SPIVAK 88
918 ±14	CHRISTENSEN	72	CNTR	

[11] 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.

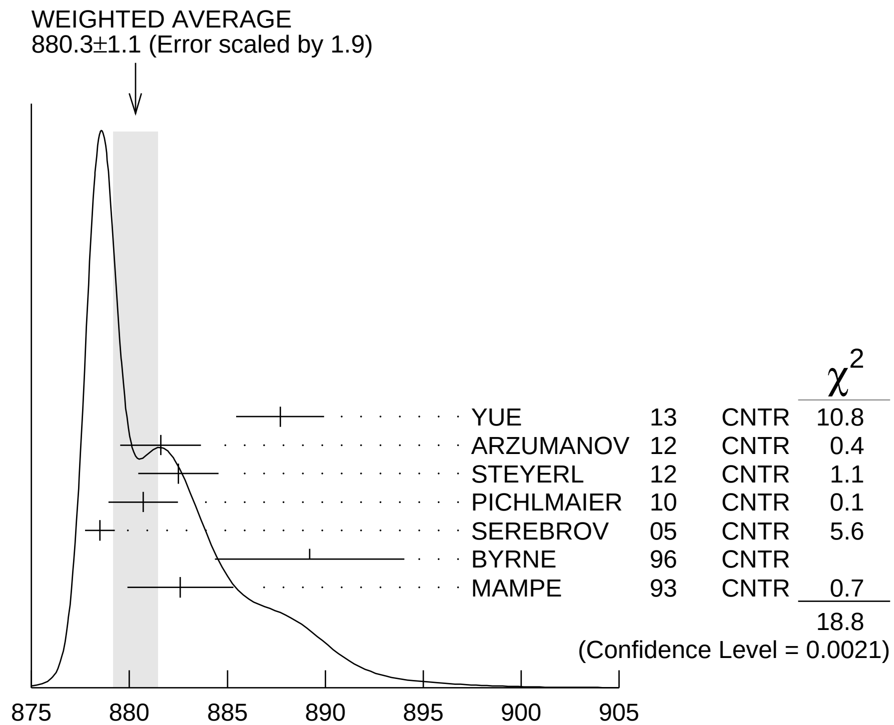
[12] ARZUMANOV 12 reanalyzes its systematic corrections in ARZUMANOV 00 and obtains this corrected value.

[13] STEYERL 12 is a detailed reanalysis of neutron storage loss corrections to the raw data of MAMPE 89, and it replaces that value.

[14] 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.

[15] The NESVIZHEVSKII 92 measurement has been withdrawn by A. Serebrov.

[16] The BYRNE 80 measurement has been withdrawn (J. Byrne, private communication, 1990).



neutron mean life (s)

n MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" in the Λ Listings.

VALUE (μ_N)	*DOCUMENT ID*		*TECN*	*COMMENT*
−1.91304272±0.00000045	MOHR	12	RVUE	2010 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−1.91304273±0.00000045	MOHR	08	RVUE	2006 CODATA value
−1.91304273±0.00000045	MOHR	05	RVUE	2002 CODATA value
−1.91304272±0.00000045	MOHR	99	RVUE	1998 CODATA value
−1.91304275±0.00000045	COHEN	87	RVUE	1986 CODATA value
−1.91304277±0.00000048	[17] GREENE	82	MRS	

[17] 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.

VALUE (10^{-25} e cm)	CL%	DOCUMENT ID		TECN	COMMENT
< 0.29	90	[18] BAKER	06	MRS	UCN's, $h\nu = 2\mu_n B \pm 2d_n E$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 0.63	90	[19] HARRIS	99	MRS	$d = (-0.1 \pm 0.36) \times 10^{-25}$
< 0.97	90	ALTAREV	96	MRS	$(+0.26 \pm 0.40 \pm 0.16) \times 10^{-25}$
< 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	$d = (4.0 \pm 7.5) \times 10^{-25}$

[18] 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.

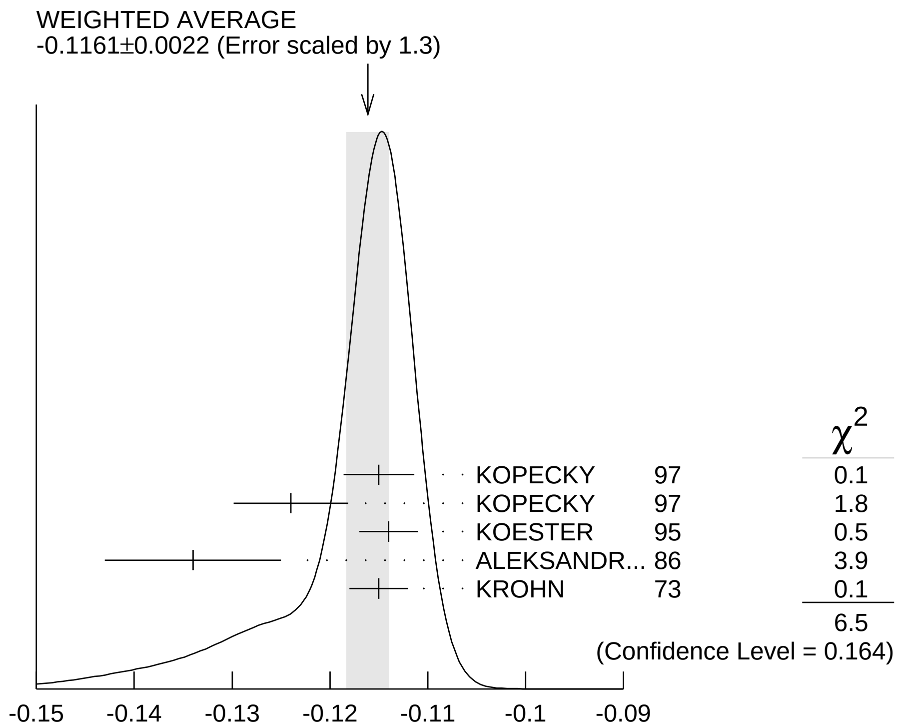
[19] This HARRIS 99 result includes the result of SMITH 90. However, the averaging of the results of these two experiments has been criticized by LAMOREAUX 00.

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
−0.1161±0.0022 OUR AVERAGE	Error includes scale factor of 1.3. See the ideogram below.		
−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)
−0.134 ±0.009	ALEKSANDR...	86	ne scattering (Bi)
−0.115 ±0.003	[20] KROHN	73	ne scattering (Ne, Ar, Kr, Xe)
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$-0.117\ ^{+0.007}_{-0.011}$	BELUSHKIN	07	Dispersion analysis
−0.113 ±0.003 ±0.004	KOPECKY	95	ne scattering (Pb)
−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)

[20] This value is as corrected by KOESTER 76.



n mean-square charge radius

n MAGNETIC RADIUS

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

VALUE (fm)	*DOCUMENT ID*		*COMMENT*
$\mathbf{0.862^{+0.009}_{-0.008}}$	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 review of the "polarizability of the nucleon and Compton scattering," see SCHUMACHER 05. His recommended values for the neutron are $\alpha_n = (12.5 \pm 1.7) \times 10^{-4}$ fm^3 and $\beta_n = (2.7 \mp 1.8) \times 10^{-4}$ fm^3, which agree with our averages within errors.

VALUE (10^{-4} fm^3)	*DOCUMENT ID*		*TECN*	*COMMENT*
11.6± 1.5 OUR AVERAGE				
$12.5 \pm 1.8^{+1.6}_{-1.3}$	[21] KOSSERT	03	CNTR	$\gamma d \to \gamma p n$
$8.8 \pm 2.4 \pm 3.0$	[22] LUNDIN	03	CNTR	$\gamma d \to \gamma d$
$12.0 \pm 1.5 \pm 2.0$	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. • • •

13.6	[23] KOLB	00	CNTR	$\gamma d \rightarrow \gamma n p$
0.0± 5.0	[24] 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

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

[22] LUNDIN 03 measures $\alpha_N - \beta_N = (6.4 \pm 2.4) \times 10^{-4}$ 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.

[23] 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) $\times 10^{-4}$ fm^3.

[24] 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±2.0 OUR AVERAGE				
$2.7 \pm 1.8^{+1.3}_{-1.6}$	[25] KOSSERT	03	CNTR	$\gamma d \rightarrow \gamma p n$
6.5±2.4±3.0	[26] LUNDIN	03	CNTR	$\gamma d \rightarrow \gamma d$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.6	[27] KOLB	00	CNTR	$\gamma d \rightarrow \gamma n p$

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

[26] LUNDIN 03 measures $\alpha_N - \beta_N = (6.4 \pm 2.4) \times 10^{-4}$ 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.

[27] 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) $\times 10^{-4}$ 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	[28] BRESSI	11		Neutrality of SF_6
− 0.4± 1.1	[29] BAUMANN	88		Cold n deflection
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−15 ±22	[30] GAEHLER	82	CNTR	Cold n deflection

[28] As a limit, this BRESSI 11 value is $< 1 \times 10^{-21}$ e.

[29] The BAUMANN 88 error ±1.1 gives the 68% CL limits about the the value −0.4.

[30] 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 in Vacuum

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 $n \rightarrow \overline{n}$ 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 for a recent review.

VALUE (s)	CL%	DOCUMENT ID		TECN	COMMENT
$>1.3 \times 10^8$	90	CHUNG	02B	SOU2	n bound in iron
$>8.6 \times 10^7$	90	BALDO-...	94	CNTR	Reactor (free) neutrons
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>1 \times 10^7$	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	
$> 2.7 \times 10^7$–1.1×10^8		JONES	84	CNTR	
$>2 \times 10^7$		CHERRY	83	CNTR	

LIMIT ON nn' OSCILLATIONS

Lee and Yang (LEE 56) proposed the existence of mirror world in an attempt to restore global parity symmetry. See BEREZHIANI 06 for a recent discussion.

VALUE (s)	CL%	DOCUMENT ID		TECN	COMMENT
>414	90	SEREBROV	08	CNTR	UCN, B field on & off
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>12	95	[31] ALTAREV	09A	CNTR	UCN, scan $0 \leq B \leq 12.5\ \mu$T
>103	95	BAN	07	CNTR	UCN, B field on & off

[31] 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]	$(3.09 \pm 0.32) \times 10^{-3}$	
Γ_3	hydrogen-atom $\overline{\nu}_e$			

Charge conservation (Q) violating mode

Γ_4	$p \nu_e \overline{\nu}_e$	Q	$< 8 \times 10^{-27}$	68%

[a] This limit is for γ energies between 15 and 340 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
3.09±0.11±0.30		[32] COOPER	10	CNTR	γ, p, e^- coincidence
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3.13±0.11±0.33		NICO	06	CNTR	See COOPER 10
<6.9	90	[33] BECK	02	CNTR	γ, p, e^- coincidence

[32] This COOPER 10 result is for γ energies between 15 and 340 keV.
[33] This BECK 02 limit is for γ energies between 35 and 100 keV.

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

VALUE	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<3 \times 10^{-2}$	95	[34] GREEN	90	RVUE

[34] 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.

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

Forbidden by charge conservation.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<8 \times 10^{-27}$	68	[35] NORMAN	96	RVUE	^{71}Ga → ^{71}Ge neutrals
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<9.7 \times 10^{-18}$	90	ROY	83	CNTR	^{113}Cd → ^{113m}In neut.
$<7.9 \times 10^{-21}$		VAIDYA	83	CNTR	^{87}Rb → ^{87m}Sr neut.
$<9 \times 10^{-24}$	90	BARABANOV	80	CNTR	^{71}Ga → ^{71}GeX
$<3 \times 10^{-19}$		NORMAN	79	CNTR	^{87}Rb → ^{87m}Sr neut.

[35] 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.

A REVIEW GOES HERE – Check our WWW List of Reviews

$n \rightarrow p e^- \overline{\nu}_e$ 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
−1.2723	**±0.0023**	**OUR AVERAGE**	Error includes scale factor of 2.2. See the ideogram below.			
−1.2755	±0.0030		[36] MENDENHALL	13	UCNA	Ultracold n, polarized
−1.2748	±0.0008	$^{+0.0010}_{-0.0011}$	[37] MUND	13	SPEC	Cold n, polarized
−1.275	±0.006	±0.015	SCHUMANN	08	CNTR	Cold n, polarized
−1.2686	±0.0046	±0.0007	[38] MOSTOVOI	01	CNTR	A and $B \times$ polarizations
−1.266	±0.004		LIAUD	97	TPC	Cold n, polarized, A
−1.2594	±0.0038		[39] 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. • • •						
−1.27590	±0.00239	$^{+0.00331}_{-0.00377}$	[40] PLASTER	12	UCNA	See MENDENHALL 13
−1.27590	$^{+0.00409}_{-0.00445}$		LIU	10	UCNA	See PLASTER 12
−1.2739	±0.0019		[41] 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		[42] STRATOWA	78	CNTR	p recoil spectrum, a
−1.263	±0.015		EROZOLIM...	77	CNTR	See EROZOLIMSKII 79
−1.250	±0.036		[42] DOBROZE...	75	CNTR	See STRATOWA 78
−1.258	±0.015		[43] KROHN	75	CNTR	Cold n, polarized, A
−1.263	±0.016		[44] KROPF	74	RVUE	n decay alone
−1.250	±0.009		[44] KROPF	74	RVUE	n decay + nuclear ft

[36] 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.

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

[38] 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.

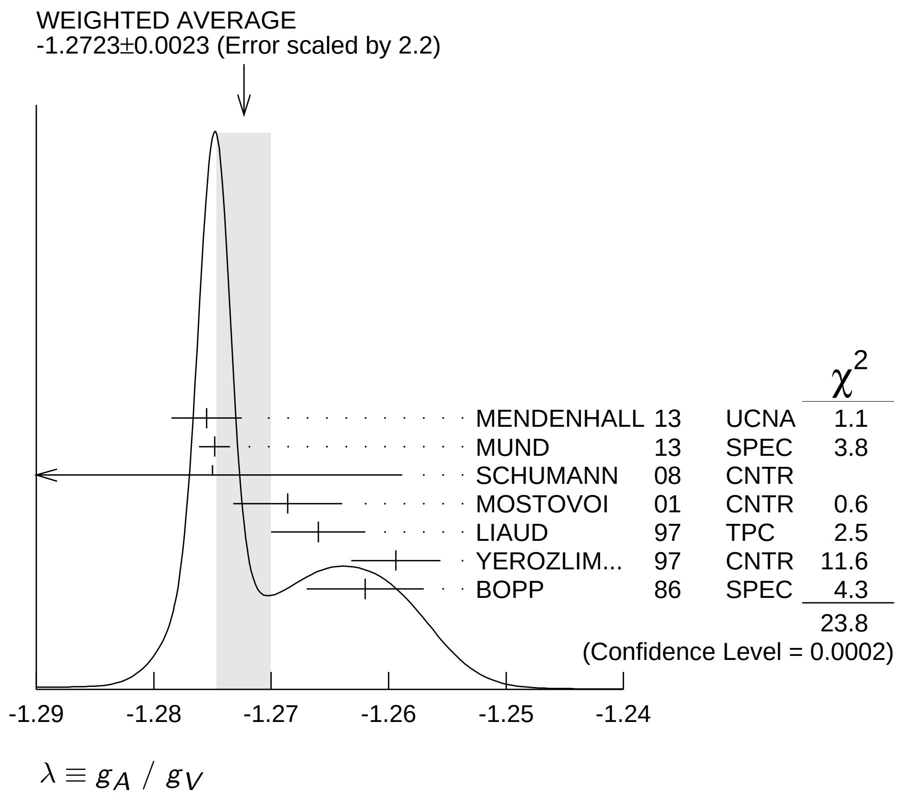
[39] YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value.

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

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

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

[43] KROHN 75 includes events of CHRISTENSEN 70.
[44] 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
−0.1184 ±0.0010 OUR AVERAGE Error includes scale factor of 2.4. See the ideogram below.			
-0.11952 ± 0.00110	[45] MENDENHALL13	UCNA	Ultracold n, polarized
$-0.11926 \pm 0.00031 {}^{+0.00036}_{-0.00042}$	[46] MUND 13	SPEC	Cold n, polarized
$-0.1160 \pm 0.0009 \pm 0.0012$	LIAUD 97	TPC	Cold n, polarized
-0.1135 ± 0.0014	[47] 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. • • •			
$-0.11966 \pm 0.00089 {}^{+0.00123}_{-0.00140}$	[48] PLASTER 12	UCNA	See MENDENHALL 13
$-0.11966 \pm 0.00089 {}^{+0.00123}_{-0.00140}$	LIU 10	UCNA	See PLASTER 12
$-0.1138 \pm 0.0046 \pm 0.0021$	PATTIE 09	SPEC	Ultracold n, polarized
-0.1189 ± 0.0007	[49] ABELE 02	SPEC	See MUND 13
-0.1168 ± 0.0017	[50] 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 YEROZOLIMSKY 97
-0.114 ±0.005	[51] EROZOLIM...	79	CNTR	Cold n, polarized
-0.113 ±0.006	[51] KROHN	75	CNTR	Cold n, polarized

[45] 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.

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

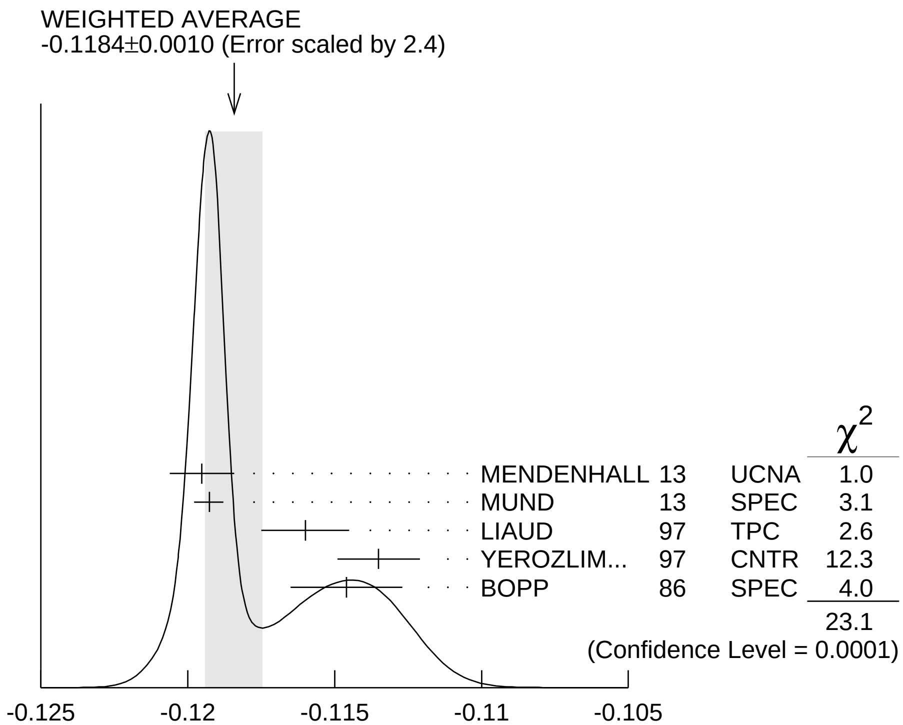
[47] YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value.

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

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

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

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



e^- asymmetry parameter A

$\overline{\nu}_e$ 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				
$0.9802\pm0.0034\pm0.0036$	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	[52] MOSTOVOI	01	CNTR	Inferred

[52] 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
−0.103 ±0.004 OUR AVERAGE				
−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. • • •				
−0.1045±0.0014	[53] MOSTOVOI	01	CNTR	Inferred

[53] 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					
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		[54] KROPF	74	RVUE	n decay
180.14 ±0.22		STEINBERG	74	CNTR	Cold n, polarized

[54] 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				
− 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	[55] EROZOLIM...	74	CNTR	Cold *n*, polarized
−11 ±17	STEINBERG	74	CNTR	Cold *n*, polarized

[55] 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	[56] KOZELA	12	CNTR	Mott polarimeter
• • • We do not use the following data for averages, fits, limits, etc. • • •				
+0.008±0.015±0.005	KOZELA	09	CNTR	See KOZELA 12

[56] 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 $N = +0.067 \pm 0.011 \pm 0.004$.

n REFERENCES

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

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+)
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.*	(MUNT, PNPI, ILLG)
SEREBROV	10B	PR C82 035501	A.P. Serebrov, A.K. Fomin	(PNPI)
Also		JETPL 92 271	A.P. Serebrov, A.K. Fomin	(PNPI)
STEYERL	10	PR C81 055505	A. Steyerl *et al.*	(URI)
ALTAREV	09A	PR D80 032003	I. Altarev *et al.*	(MUNT, 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.)
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+)
SEREBROV	08A	PR C78 035505	A.P. Serebrov *et al.*	(PNPI, JINR, 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)
BEREZHIANI	06	PRL 96 081801	Z. Berezhiani, L. Bento	(Aguila U., LISB)
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, MANZ, 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. 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, MUNT)
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)
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		Translated from ZETF 113 1963.		
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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.*	(+)
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.*	(MUNT, 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)
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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)
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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)
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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, MANZ)
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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, MPIH, 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, MUNT)
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)