



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

We have omitted some results that have been superseded by later experiments.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.

<u>VALUE (<i>u</i>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>1.00866491595 ± 0.0000000049</b>	TIESINGA	21	RVUE 2018 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •			
1.00866491588 ± 0.0000000049	MOHR	16	RVUE 2014 CODATA value
1.00866491600 ± 0.0000000043	MOHR	12	RVUE 2010 CODATA value
1.00866491597 ± 0.0000000043	MOHR	08	RVUE 2006 CODATA value
1.00866491560 ± 0.0000000055	MOHR	05	RVUE 2002 CODATA value
1.00866491578 ± 0.0000000055	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*<sup>2</sup> (2018 CODATA value, TIESINGA 21).

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>939.56542052 ± 0.00000054</b>	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	<sup>1</sup> KESSLER	99	SPEC <i>np</i> → <i>d</i> γ
939.565330 ± 0.000038	MOHR	99	RVUE 1998 CODATA value
939.56565 ± 0.00028	<sup>2,3</sup> DIFILIPPO	94	TRAP Penning trap
939.56563 ± 0.00028	COHEN	87	RVUE 1986 CODATA value
939.56564 ± 0.00028	<sup>3,4</sup> GREENE	86	SPEC <i>np</i> → <i>d</i> γ
939.5731 ± 0.0027	<sup>3</sup> COHEN	73	RVUE 1973 CODATA value

<sup>1</sup>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 ± 0.0000000082 *u*.

<sup>2</sup>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.

<sup>3</sup> These determinations are not independent of the  $m_n - m_p$  measurements below.

<sup>4</sup> The mass is known much more precisely in  $u$ :  $m = 1.008664919 \pm 0.000000014 u$ .

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### $\bar{n}$ MASS

<u>VALUE (MeV)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>939.485 ± 0.051</b>	59	<sup>1</sup> CRESTI	86	HBC $\bar{p}p \rightarrow \bar{n}n$

<sup>1</sup> This is a corrected result (see the erratum). The error is statistical. The maximum systematic error is 0.029 MeV.

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### $(m_n - m_{\bar{n}}) / m_n$

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

<u>VALUE</u>	<u>DOCUMENT ID</u>
<b><math>(9 \pm 5) \times 10^{-5}</math> OUR EVALUATION</b>	

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### $m_n - m_p$

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

<sup>1</sup> The 2018 CODATA mass difference in  $u$  is  $m_n - m_p = 1.388\,449\,33(49) \times 10^{-3} u$ .

<sup>2</sup> The 2014 CODATA mass difference in  $u$  is  $m_n - m_p = 1.388\,449\,00(51) \times 10^{-3} u$ .

<sup>3</sup> The 2010 CODATA mass difference in  $u$  is  $m_n - m_p = 1.388\,449\,19(45) \times 10^{-3} u$ .

<sup>4</sup> Calculated by us from the MOHR 08 ratio  $m_n/m_p = 1.00137841918(46)$ . In  $u$ ,  $m_n - m_p = 1.38844920(46) \times 10^{-3} u$ .

<sup>5</sup> Calculated by us from the MOHR 05 ratio  $m_n/m_p = 1.00137841870 \pm 0.00000000058$ . In  $u$ ,  $m_n - m_p = (1.3884487 \pm 0.0000006) \times 10^{-3} u$ .

<sup>6</sup> Calculated by us from the MOHR 99 ratio  $m_n/m_p = 1.00137841887 \pm 0.00000000058$ . In  $u$ ,  $m_n - m_p = (1.3884489 \pm 0.0000006) \times 10^{-3} u$ .

<sup>7</sup> Calculated by us from the COHEN 87 ratio  $m_n/m_p = 1.001378404 \pm 0.000000009$ . In  $u$ ,  $m_n - m_p = 0.001388434 \pm 0.000000009 u$ .

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***n* MEAN LIFE**

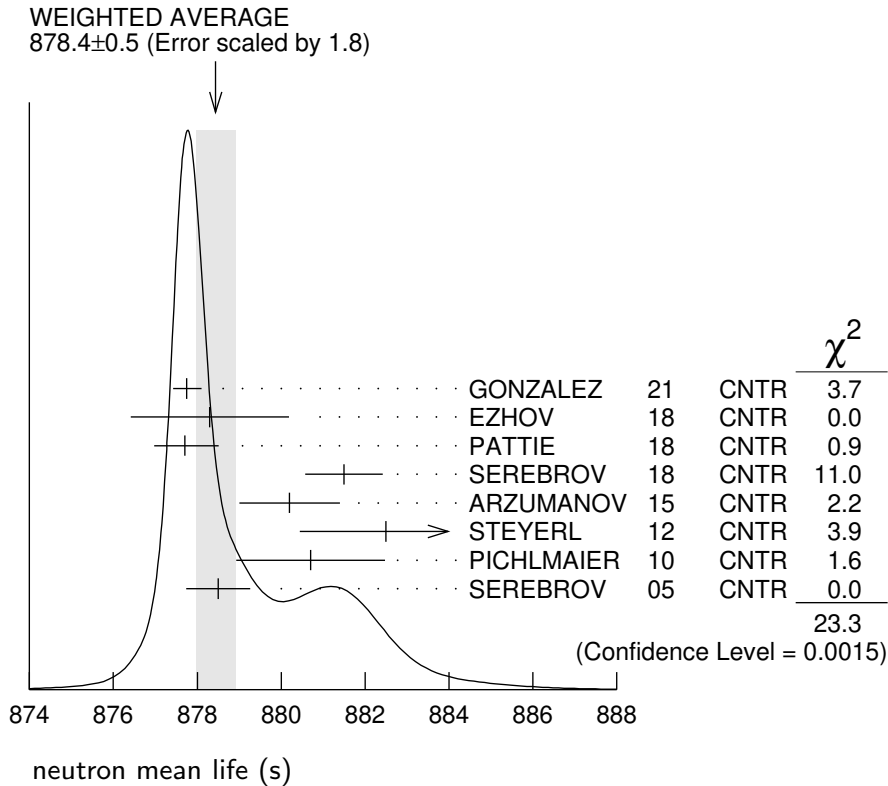
Limits on lifetimes for *bound* neutrons are given in the section “p PARTIAL MEAN LIVES.”

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  $878.6 \pm 0.6$  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).

<u>VALUE (s)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>878.4 ± 0.5 OUR AVERAGE</b>	Error includes scale factor of 1.8. See the ideogram below.		
877.75 ± 0.28 <sup>+</sup> <sub>-0.16</sub>	GONZALEZ	21	CNTR UCN asym. magnetic trap
878.3 ± 1.6 ± 1.0	EZHOV	18	CNTR UCN magneto-gravit. trap
877.7 ± 0.7 <sup>+</sup> <sub>-0.2</sub>	<sup>1</sup> PATTIE	18	CNTR UCN asym. magnetic trap
881.5 ± 0.7 ± 0.6	SEREBROV	18	CNTR UCN gravitational trap
880.2 ± 1.2	<sup>2</sup> ARZUMANOV	15	CNTR UCN double bottle
882.5 ± 1.4 ± 1.5	<sup>3</sup> 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 ± 14 <sup>+</sup> <sub>-3</sub>	<sup>4</sup> WILSON	21	CNTR space-based <i>n</i> rate
887.7 ± 1.2 ± 1.9	<sup>5</sup> YUE	13	CNTR In-beam <i>n</i> , trapped <i>p</i>
881.6 ± 0.8 ± 1.9	<sup>6</sup> 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	<sup>7</sup> MAMPE	93	CNTR UCN material bottle
888.4 ± 3.1 ± 1.1	<sup>8</sup> 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	<sup>9</sup> BYRNE	80	CNTR
875 ± 95	KOSVINTSEV	80	CNTR
881 ± 8	BONDAREN...	78	CNTR See SPIVAK 88
918 ± 14	CHRISTENSEN72		CNTR

- <sup>1</sup> PATTIE 18 uses a new technique, with a semi-toroidal magneto-gravitational asymmetric trap and a novel in situ  $n$ -detector.
- <sup>2</sup> ARZUMANOV 15 is a reanalysis of their 2008–2010 dataset, with improved systematic corrections of of ARZUMANOV 00 and ARZUMANOV 12.
- <sup>3</sup> STEYERL 12 is a detailed reanalysis of neutron storage loss corrections to the raw data of MAMPE 89, and it replaces that value.
- <sup>4</sup> WILSON 21 extract the value from the flux of  $n$  escaping the moon using data from the Lunar Prospector Neutron Spectrometer.
- <sup>5</sup> 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.
- <sup>6</sup> ARZUMANOV 12 reanalyzes its systematic corrections in ARZUMANOV 00 and obtains this corrected value.
- <sup>7</sup> 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.
- <sup>8</sup> The NESVIZHEVSKII 92 measurement has been withdrawn by A. Serebrov.
- <sup>9</sup> The BYRNE 80 measurement has been withdrawn (J. Byrne, private communication, 1990).



## $n$ MAGNETIC MOMENT

See the “Quark Model” review.

VALUE ( $\mu_N$ )	DOCUMENT ID	TECN	COMMENT
<b><math>-1.91304273 \pm 0.00000045</math></b>	TIESINGA	21	RVUE 2018 CODATA value

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

$-1.91304273 \pm 0.00000045$	MOHR	16	RVUE	2014 CODATA value
$-1.91304272 \pm 0.00000045$	MOHR	12	RVUE	2010 CODATA value
$-1.91304273 \pm 0.00000045$	MOHR	08	RVUE	2006 CODATA value
$-1.91304273 \pm 0.00000045$	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
$-1.91304277 \pm 0.00000048$	<sup>1</sup> GREENE	82	MRS	

<sup>1</sup> 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
<b>&lt; 0.18</b>	90	<sup>1</sup> ABEL 20	MRS	UCN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
< 0.22	95	<sup>2</sup> SAHOO 17		<sup>199</sup> Hg atom EDM + theory
< 0.16	95	GRANER 16	MRS	<sup>199</sup> Hg atom EDM + theory
< 0.30	90	<sup>3</sup> 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	<sup>4</sup> SEREBROV 14	MRS	See SEREBROV 15
< 0.29	90	<sup>5</sup> BAKER 06	MRS	See PENDLEBURY 15
< 0.63	90	<sup>6</sup> 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	$d = (4.0 \pm 7.5) \times 10^{-25}$

<sup>1</sup> ABEL 20 reports  $d = (0.0 \pm 1.1 \pm 0.2) \times 10^{-26}$  e cm value corresponding to the listed limit.

<sup>2</sup> SAHOO 17 develops theory to calculate this limit from the measured limit by GRANER 16 of the <sup>199</sup>Hg atom EDM.

<sup>3</sup> PENDLEBURY 15 reports  $d = (-0.21 \pm 1.82) \times 10^{-26}$  e cm value corresponding to the listed limit.

<sup>4</sup> SEREBROV 14 includes the data of ALTAREV 96.

<sup>5</sup> 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.

<sup>6</sup> 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 <sup>2</sup> )	DOCUMENT ID	COMMENT
<b>−0.1155±0.0017 OUR AVERAGE</b>		
−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	<sup>1</sup> KROHN 73	$ne$ scattering (Ne, Ar, Kr, Xe)
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●		
−0.1101±0.0089	<sup>2</sup> HEACOCK 21	$n$ interferometry
−0.106 <sup>+0.007</sup> <sub>−0.005</sub>	<sup>3</sup> FILIN 20	chiral EFT analysis
−0.117 <sup>+0.007</sup> <sub>−0.011</sub>	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)

<sup>1</sup>KROHN 73 measured  $−0.112 ± 0.003$  fm<sup>2</sup>. This value is as corrected by KOESTER 76.

<sup>2</sup>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.

<sup>3</sup>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
<b>0.864 <sup>+0.009</sup><sub>−0.008</sub> OUR AVERAGE</b>		
0.89 ±0.03	EPSTEIN 14	Using $e p$ , $e n$ , $\pi\pi$ data
0.862 <sup>+0.009</sup> <sub>−0.008</sub>	BELUSHKIN 07	Dispersion analysis

## $n$ ELECTRIC POLARIZABILITY $\alpha_n$

Following is the electric polarizability  $\alpha_n$  defined in terms of the induced electric dipole moment by  $\mathbf{D} = 4\pi\epsilon_0\alpha_n\mathbf{E}$ . For a review, see SCHMIED-MAYER 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 ( $10^{-4} \text{ fm}^3$ )	DOCUMENT ID	TECN	COMMENT
<b>11.8 ± 1.1 OUR AVERAGE</b>			
11.55 ± 1.25 ± 0.8	MYERS	14	CNTR $\gamma d \rightarrow \gamma d$
12.5 ± 1.8 $\begin{smallmatrix} +1.6 \\ -1.3 \end{smallmatrix}$	<sup>1</sup> KOSSERT	03	CNTR $\gamma d \rightarrow \gamma pn$
12.0 ± 1.5 ± 2.0	SCHMIEDM...	91	CNTR $n$ Pb transmission
10.7 $\begin{smallmatrix} +3.3 \\ -10.7 \end{smallmatrix}$	ROSE	90B	CNTR $\gamma d \rightarrow \gamma np$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
8.8 ± 2.4 ± 3.0	<sup>2</sup> LUNDIN	03	CNTR $\gamma d \rightarrow \gamma d$
13.6	<sup>3</sup> KOLB	00	CNTR $\gamma d \rightarrow \gamma np$
0.0 ± 5.0	<sup>4</sup> KOESTER	95	CNTR $n$ Pb, $n$ Bi transmission
11.7 $\begin{smallmatrix} +4.3 \\ -11.7 \end{smallmatrix}$	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

<sup>1</sup> KOSSERT 03 gets  $\alpha_n - \beta_n = (9.8 \pm 3.6 \begin{smallmatrix} +2.1 \\ -1.1 \end{smallmatrix} \pm 2.2) \times 10^{-4} \text{ fm}^3$ , and uses  $\alpha_n + \beta_n = (15.2 \pm 0.5) \times 10^{-4} \text{ fm}^3$  from LEVCHUK 00. Thus the errors on  $\alpha_n$  and  $\beta_n$  are anti-correlated.

<sup>2</sup> LUNDIN 03 measures  $\alpha_N - \beta_N = (6.4 \pm 2.4) \times 10^{-4} \text{ fm}^3$  and uses accurate values for  $\alpha_p$  and  $\alpha_p$  and a precise sum-rule result for  $\alpha_n + \beta_n$ . The second error is a model uncertainty, and errors on  $\alpha_n$  and  $\beta_n$  are anticorrelated. The data from this paper are included in the analysis of MYERS 14.

<sup>3</sup> KOLB 00 obtains this value with a lower limit of  $7.6 \times 10^{-4} \text{ fm}^3$  but no upper limit from this experiment alone. Combined with results of ROSE 90, the  $1-\sigma$  range is  $(7.6-14.0) \times 10^{-4} \text{ fm}^3$ .

<sup>4</sup> 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  $\alpha_n$  from data.

## $n$ MAGNETIC POLARIZABILITY $\beta_n$

VALUE ( $10^{-4} \text{ fm}^3$ )	DOCUMENT ID	TECN	COMMENT
<b>3.7 ± 1.2 OUR AVERAGE</b>			
3.65 ± 1.25 ± 0.8	MYERS	14	CNTR $\gamma d \rightarrow \gamma d$
2.7 ± 1.8 $\begin{smallmatrix} +1.3 \\ -1.6 \end{smallmatrix}$	<sup>1</sup> KOSSERT	03	CNTR $\gamma d \rightarrow \gamma pn$
6.5 ± 2.4 ± 3.0	<sup>2</sup> LUNDIN	03	CNTR $\gamma d \rightarrow \gamma d$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1.6	<sup>3</sup> KOLB	00	CNTR $\gamma d \rightarrow \gamma np$
<sup>1</sup> KOSSERT 03 gets $\alpha_n - \beta_n = (9.8 \pm 3.6 \begin{smallmatrix} +2.1 \\ -1.1 \end{smallmatrix} \pm 2.2) \times 10^{-4} \text{ fm}^3$ , and uses $\alpha_n + \beta_n = (15.2 \pm 0.5) \times 10^{-4} \text{ fm}^3$ from LEVCHUK 00. Thus the errors on $\alpha_n$ and $\beta_n$ are anti-correlated.			
<sup>2</sup> LUNDIN 03 measures $\alpha_N - \beta_N = (6.4 \pm 2.4) \times 10^{-4} \text{ fm}^3$ and uses accurate values for $\alpha_p$ and $\alpha_p$ and a precise sum-rule result for $\alpha_n + \beta_n$ . The second error is a model uncertainty, and errors on $\alpha_n$ and $\beta_n$ are anticorrelated.			
<sup>3</sup> KOLB 00 obtains this value with an upper limit of $7.6 \times 10^{-4} \text{ fm}^3$ but no lower limit from this experiment alone. Combined with results of ROSE 90, the $1-\sigma$ range is $(1.2-7.6) \times 10^{-4} \text{ fm}^3$ .			

## $n$ CHARGE

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

<u>VALUE (<math>10^{-21} e</math>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
– <b>0.2 ± 0.8 OUR AVERAGE</b>			
– 0.1 ± 1.1	<sup>1</sup> BRESSI	11	Neutrality of SF <sub>6</sub>
– 0.4 ± 1.1	<sup>2</sup> BAUMANN	88	Cold $n$ deflection
• • • We do not use the following data for averages, fits, limits, etc. • • •			
– 15 ± 22	<sup>3</sup> GAEHLER	82 CNTR	Cold $n$ deflection
<sup>1</sup> As a limit, this BRESSI 11 value is $< 1 \times 10^{-21} e$ .			
<sup>2</sup> The BAUMANN 88 error $\pm 1.1$ gives the 68% CL limits about the the value $-0.4$ .			
<sup>3</sup> The GAEHLER 82 error $\pm 22$ gives the 90% CL limits about the the value $-15$ .			

## LIMIT ON $n\bar{n}$ OSCILLATIONS

### Mean Time for $n\bar{n}$ Transition

A test of  $\Delta B=2$  baryon number nonconservation. MOHAPATRA 80 and MOHAPATRA 89 discuss the theoretical motivations for looking for  $n\bar{n}$  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  $n \rightarrow \bar{n}$  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.

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

<sup>1</sup> ABE 21 supersedes ABE 15C.<sup>2</sup> The AHARMIM 17 value is an unbounded limit (it does not assume a positive lifetime). The bounded limit is  $1.23 \times 10^8$  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
<b>&gt;448</b>	90	SEREBROV	09A	CNTR Assumes $B' < 100$ nT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 1	95	<sup>1</sup> BAN	23	CNTR UCN, scan of $B$ field
		<sup>2</sup> ALMAZAN	22	CNTR STEREO, hidden neutron search $ m_n - m_{n'}  \geq 0$ .
> 9	95	<sup>3</sup> ABEL	21	CNTR UCN, scan of $B$ field
> 17	95	<sup>4</sup> BEREZHIANI	18	CNTR UCN, scan of $B$ field
> 12	95	<sup>5</sup> 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

<sup>1</sup> BAN 23 determine limits on the oscillation time for the  $|\delta m(nn')|$  range of 2–59 peV. The quoted value is  $\tau_{nn'}/\sqrt{\cos(\beta)} > 1$  sec. for  $B$  in 30–1143  $\mu$ T, for the case  $\beta = 0$ .

<sup>2</sup> 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  $nn'$  oscillation time.

<sup>3</sup> ABEL 21 determine several limits on the oscillation time as a function of the mirror magnetic field  $B'$ , and of the fixed angle,  $\beta$ , between the applied magnetic field and  $B'$ . The latter is assumed to be bound to Earth. Two values are quoted from two analysis methods: (i)  $\tau_{nn'}/\sqrt{\cos(\beta)} > 9$  sec for  $B'$  in 5–25.4  $\mu$ T, and (ii) for any angle  $\beta$ ,  $\tau_{nn'} > 6$  sec for  $B'$  in 0.4–25.7  $\mu$ T. The authors also quote a limit of 352 sec for the case  $B' = 0$  T.

<sup>4</sup> 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.

<sup>5</sup> 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 ( $\Gamma_i/\Gamma$ )	Confidence level
$\Gamma_1$ $p e^- \bar{\nu}_e$	100 %	
$\Gamma_2$ $p e^- \bar{\nu}_e \gamma$	[a] $(9.2 \pm 0.7) \times 10^{-3}$	
$\Gamma_3$ hydrogen-atom $\bar{\nu}_e$	$< 2.7 \times 10^{-3}$	95%

### Charge conservation ( $Q$ ) violating mode

$\Gamma_4$ $p \nu_e \bar{\nu}_e$	$Q$ $< 8 \times 10^{-27}$	68%
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### Baryon number violating decay

$\Gamma_5$ $e^+ e^-$ invisible		
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[a] This limit is for  $\gamma$  energies between 0.4 and 782 keV.

## $n$ BRANCHING RATIOS

### $\Gamma(p e^- \bar{\nu}_e \gamma) / \Gamma_{\text{total}}$

 $\Gamma_2 / \Gamma$ 

VALUE (units $10^{-3}$ )	CL%	DOCUMENT ID	TECN	COMMENT
<b><math>9.17 \pm 0.24 \pm 0.64</math></b>		<sup>1</sup> BALES	16	RDK2 Two different set-ups
$3.09 \pm 0.11 \pm 0.30$		<sup>2</sup> COOPER	10	CNTR See BALES 16
$3.13 \pm 0.11 \pm 0.33$		NICO	06	CNTR See COOPER 10
<6.9	90	<sup>3</sup> BECK	02	CNTR $\gamma, p, e^-$ coincidence

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

<sup>1</sup> 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.

<sup>2</sup> This COOPER 10 result is for  $\gamma$  energies between 15 and 340 keV.

<sup>3</sup> This BECK 02 limit is for  $\gamma$  energies between 35 and 100 keV.

### $\Gamma(\text{hydrogen-atom } \bar{\nu}_e) / \Gamma_{\text{total}}$

 $\Gamma_3 / \Gamma$ 

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<b><math>&lt;0.27 \times 10^{-2}</math></b>	95	<sup>1</sup> CZARNECKI	18	Lifetime analysis
<3 $\times 10^{-2}$	95	<sup>2</sup> GREEN	90	RVUE

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

<sup>1</sup> 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.

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

### $\Gamma(p \nu_e \bar{\nu}_e) / \Gamma_{\text{total}}$

 $\Gamma_4 / \Gamma$ 

Forbidden by charge conservation.

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<b><math>&lt;8 \times 10^{-27}</math></b>	68	<sup>1</sup> NORMAN	96	RVUE $^{71}\text{Ga} \rightarrow ^{71}\text{Ge}$ neutrals
$<9.7 \times 10^{-18}$	90	ROY	83	CNTR $^{113}\text{Cd} \rightarrow ^{113m}\text{In}$ neut.
$<7.9 \times 10^{-21}$		VAIDYA	83	CNTR $^{87}\text{Rb} \rightarrow ^{87m}\text{Sr}$ neut.
$<9 \times 10^{-24}$	90	BARABANOV	80	CNTR $^{71}\text{Ga} \rightarrow ^{71}\text{GeX}$
$<3 \times 10^{-19}$		NORMAN	79	CNTR $^{87}\text{Rb} \rightarrow ^{87m}\text{Sr}$ neut.

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

<sup>1</sup> NORMAN 96 gets this limit by attributing SAGE and GALLEX counting rates to the charge-nonconserving transition  $^{71}\text{Ga} \rightarrow ^{71}\text{Ge} + \text{neutrals}$  rather than to solar-neutrino reactions.

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

 $\Gamma_5 / \Gamma$ 

Baryon number violating decay

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.01	90	<sup>1</sup> KLOPF	19	CNTR re-interpretation of MUND 13
<1 $\times 10^{-4}$	90	<sup>2</sup> SUN	18	SPEC Ultracold $n$ , polarized

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

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

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

See the related review(s):  
[Baryon Decay Parameters](#)

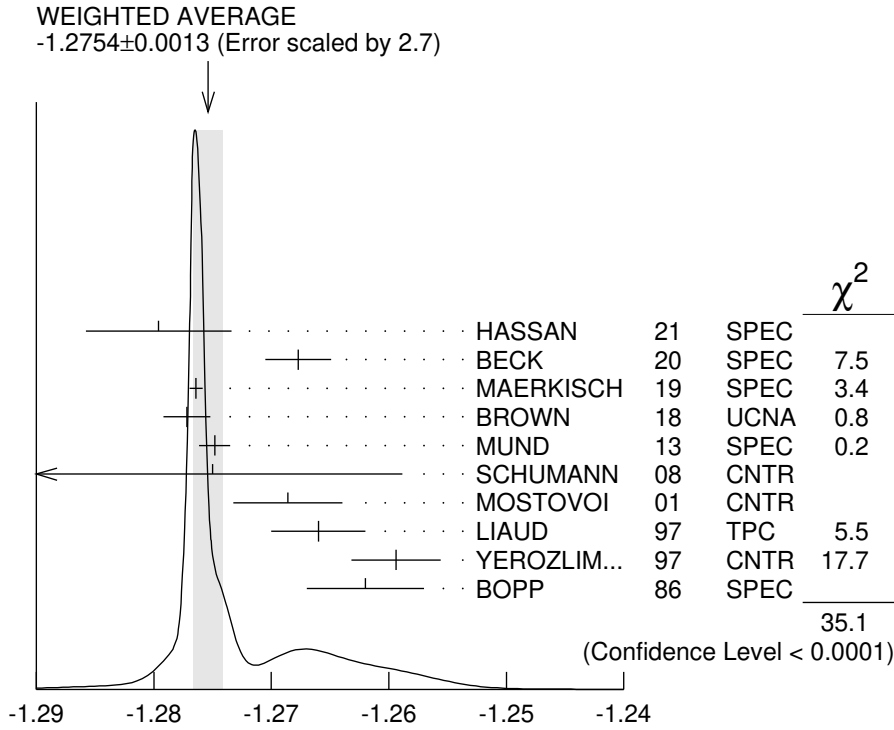
**$n \rightarrow pe^- \bar{\nu}_e$  DECAY PARAMETERS**

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
<b>-1.2754 ± 0.0013</b>	<b>OUR AVERAGE</b>		Error includes scale factor of 2.7. See the ideogram below.
-1.2796 ± 0.0062	<sup>1</sup> HASSAN 21	SPEC	Proton recoil spectrum
-1.2677 ± 0.0028	<sup>2</sup> BECK 20	SPEC	Proton recoil spectrum
-1.27641 ± 0.00045 ± 0.00033	<sup>3</sup> MAERKISCH 19	SPEC	pulsed cold $n$ , polarized
-1.2772 ± 0.0020	<sup>4</sup> BROWN 18	UCNA	Ultracold $n$ , polarized
-1.2748 ± 0.0008 <sup>+0.0010</sup> <sub>-0.0011</sub>	<sup>5</sup> MUND 13	SPEC	Cold $n$ , polarized
-1.275 ± 0.006 ± 0.015	SCHUMANN 08	CNTR	Cold $n$ , polarized
-1.2686 ± 0.0046 ± 0.0007	<sup>6</sup> MOSTOVOI 01	CNTR	$A$ and $B \times$ polarizations
-1.266 ± 0.004	LIAUD 97	TPC	Cold $n$ , polarized, $A$
-1.2594 ± 0.0038	<sup>7</sup> 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	<sup>8</sup> SAUL 20	SPEC	Cold $n$ , polarized, $A$
-1.284 ± 0.014	<sup>9</sup> DARIUS 17	SPEC	Cold $n$ , unpolarized
-1.2755 ± 0.0030	<sup>10</sup> MENDENHALL13	UCNA	See BROWN 18
-1.27590 ± 0.00239 <sup>+0.00331</sup> <sub>-0.00377</sub>	<sup>11</sup> PLASTER 12	UCNA	See MENDENHALL 13
-1.27590 <sup>+0.00409</sup> <sub>-0.00445</sub>	LIU 10	UCNA	See PLASTER 12
-1.2739 ± 0.0019	<sup>12</sup> 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 YEROZOLIM-SKY 97

-1.226 ±0.042		MOSTOVOY	83	RVUE	
-1.261 ±0.012		EROZOLIM...	79	CNTR	Cold $n$ , polarized, $A$
-1.259 ±0.017	<sup>13</sup>	STRATOWA	78	CNTR	$p$ recoil spectrum, $a$
-1.263 ±0.015		EROZOLIM...	77	CNTR	See EROZOLIMSKII 79
-1.250 ±0.036	<sup>13</sup>	DOBROZE...	75	CNTR	See STRATOWA 78
-1.258 ±0.015	<sup>14</sup>	KROHN	75	CNTR	Cold $n$ , polarized, $A$
-1.263 ±0.016	<sup>15</sup>	KROPF	74	RVUE	$n$ decay alone
-1.250 ±0.009	<sup>15</sup>	KROPF	74	RVUE	$n$ decay + nuclear ft



$$\lambda \equiv g_A / g_V$$

- <sup>1</sup> HASSAN 21 include earlier data of DARIUS 17. The value is extracted from the angular correlation coefficient  $a$ .
- <sup>2</sup> BECK 20 calculates this value from the measurement of the  $\beta$ -decay  $e-\bar{\nu}_e$  angular correlation coefficient  $a$ .
- <sup>3</sup> MAERKISCH 19 gets  $A = -0.11985 \pm 0.00017 \pm 0.00012$ .
- <sup>4</sup> 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).
- <sup>5</sup> This MUND 13 value includes earlier PERKEO II measurements (ABELE 02 and ABELE 97D).
- <sup>6</sup> 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.
- <sup>7</sup> YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value.
- <sup>8</sup> SAUL 20 quote this value of  $\lambda$  under the SM assumption of the Fierz term  $b = 0$ . In a combined fit authors extract a value of  $\lambda = -1.2792 \pm 0.0060$ .
- <sup>9</sup> DARIUS 17 calculates this value from the measurement of the  $a$  parameter (see below). Data is included in HASSAN 21.
- <sup>10</sup> 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.

- <sup>11</sup> This PLASTER 12 value is identical with that given in LIU 10, but the experiment is now described in detail.  
<sup>12</sup> This is the combined result of ABELE 02 and ABELE 97D.  
<sup>13</sup> These experiments measure the absolute value of  $g_A/g_V$  only.  
<sup>14</sup> KROHN 75 includes events of CHRISTENSEN 70.  
<sup>15</sup> 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.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b><math>-0.11958 \pm 0.00021</math> OUR AVERAGE</b>	Error includes scale factor of 1.2. See the ideogram below.		
$-0.11985 \pm 0.00017 \pm 0.00012$	<sup>1</sup> MAERKISCH 19	SPEC	pulsed cold $n$ , polarized
$-0.12015 \pm 0.00034 \pm 0.00063$	<sup>2</sup> BROWN 18	UCNA	Ultracold $n$ , polarized
$-0.11926 \pm 0.00031 \begin{smallmatrix} +0.00036 \\ -0.00042 \end{smallmatrix}$	<sup>3</sup> MUND 13	SPEC	Cold $n$ , polarized
$-0.1160 \pm 0.0009 \pm 0.0012$	LIAUD 97	TPC	Cold $n$ , polarized
$-0.1135 \pm 0.0014$	<sup>4</sup> YEROZLIM... 97	CNTR	Cold $n$ , polarized
$-0.1146 \pm 0.0019$	BOPP 86	SPEC	Cold $n$ , polarized
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$-0.11972 \pm 0.00025$	<sup>5</sup> SAUL 20	SPEC	Cold $n$ , polarized
$-0.11952 \pm 0.00110$	<sup>6</sup> MENDENHALL 13	UCNA	See BROWN 18
$-0.11966 \pm 0.00089 \begin{smallmatrix} +0.00123 \\ -0.00140 \end{smallmatrix}$	<sup>7</sup> PLASTER 12	UCNA	See MENDENHALL 13
$-0.11966 \pm 0.00089 \begin{smallmatrix} +0.00123 \\ -0.00140 \end{smallmatrix}$	LIU 10	UCNA	See PLASTER 12
$-0.1138 \pm 0.0046 \pm 0.0021$	PATTIE 09	SPEC	Ultracold $n$ , polarized
$-0.1189 \pm 0.0007$	<sup>8</sup> ABELE 02	SPEC	See MUND 13
$-0.1168 \pm 0.0017$	<sup>9</sup> MOSTOVOI 01	CNTR	Inferred
$-0.1189 \pm 0.0012$	ABELE 97D	SPEC	Cold $n$ , polarized
$-0.1160 \pm 0.0009 \pm 0.0011$	SCHRECK... 95	TPC	See LIAUD 97
$-0.1116 \pm 0.0014$	EROZOLIM... 91	CNTR	See YEROZOLIM-SKY 97
$-0.114 \pm 0.005$	<sup>10</sup> EROZOLIM... 79	CNTR	Cold $n$ , polarized
$-0.113 \pm 0.006$	<sup>10</sup> KROHN 75	CNTR	Cold $n$ , polarized

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

<sup>2</sup> 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).

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

<sup>4</sup> YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value.

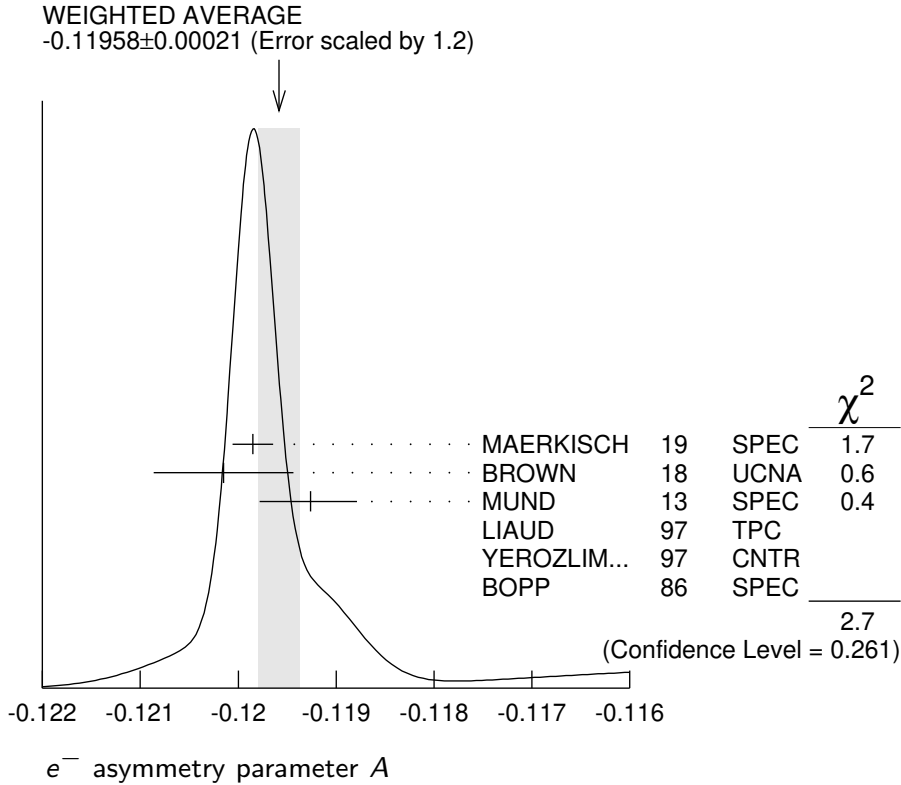
<sup>5</sup> Under the SM assumption that the Fierz term  $b = 0$ , SAUL 20 obtain the quoted asymmetry parameter  $A$  and  $\lambda = -1.27607 \pm 0.00068$ . In a combined fit authors extract the values  $A = -0.1209 \pm 0.0015$ ,  $\lambda = -1.2792 \pm 0.0060$ , and  $b = 0.017 \pm 0.021$ .

<sup>6</sup> 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.

<sup>7</sup> This PLASTER 12 value is identical with that given in LIU 10, but the experiment is now described in detail.

<sup>8</sup> This is the combined result of ABELE 02 and ABELE 97D.

- <sup>9</sup> MOSTOVOI 01 calculates this from its measurement of  $\lambda = g_A/g_V$  above.  
<sup>10</sup> These results are not corrected for radiative effects and weak magnetism, but the corrections are small compared to the errors.



### $\bar{\nu}_e$ 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
<b><math>0.9807 \pm 0.0030</math> OUR AVERAGE</b>			
$0.9802 \pm 0.0034 \pm 0.0036$	SCHUMANN 07	CNTR	Cold $n$ , polarized
$0.967 \pm 0.006 \pm 0.010$	KREUZ 05	CNTR	Cold $n$ , polarized
$0.9801 \pm 0.0046$	SEREBROV 98	CNTR	Cold $n$ , polarized
$0.9894 \pm 0.0083$	KUZNETSOV 95	CNTR	Cold $n$ , polarized
$1.00 \pm 0.05$	CHRISTENSEN70	CNTR	Cold $n$ , polarized
$0.995 \pm 0.034$	EROZOLIM... 70C	CNTR	Cold $n$ , polarized
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$0.9876 \pm 0.0004$	<sup>1</sup> MOSTOVOI 01	CNTR	Inferred

<sup>1</sup> 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
<b><math>-0.2377 \pm 0.0010 \pm 0.0024</math></b>	SCHUMANN 08	CNTR	Cold $n$ , polarized

**$e\bar{\nu}_e$  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
<b>-0.1049 ± 0.0013 OUR AVERAGE</b>	Error includes scale factor of 1.8.		
-0.10782 ± 0.00124 ± 0.00133	<sup>1</sup> 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	<sup>2</sup> DARIUS 17	SPEC	Cold $n$ , unpolarized
-0.1045 ± 0.0014	<sup>3</sup> MOSTOVOI 01	CNTR	Inferred

<sup>1</sup> 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.

<sup>2</sup> 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.

<sup>3</sup> MOSTOVOI 01 calculates this from its measurement of  $\lambda = g_A/g_V$  above.

 **$\phi_{AV}$ , 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
<b>180.017 ± 0.026 OUR AVERAGE</b>				
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		<sup>1</sup> KROPF 74	RVUE	$n$ decay
180.14 ± 0.22		STEINBERG 74	CNTR	Cold $n$ , polarized

<sup>1</sup> 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  $\beta$  decay. Should be zero if  $T$  invariance is not violated.

VALUE (units 10 <sup>-4</sup> )	DOCUMENT ID	TECN	COMMENT
<b>- 1.2 ± 2.0 OUR AVERAGE</b>			
- 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	<sup>1</sup> EROZOLIM... 74	CNTR	Cold $n$ , polarized
-11 ± 17	STEINBERG 74	CNTR	Cold $n$ , polarized

<sup>1</sup>EROZOLIMSKII 78 says asymmetric proton losses and nonuniform beam polarization may give a systematic error up to  $30 \times 10^{-4}$ , thus increasing the EROZOLIMSKII 74 error to  $50 \times 10^{-4}$ . 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.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>+0.004±0.012±0.005</b>	<sup>1</sup> 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

<sup>1</sup>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.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>0.017±0.020±0.003</b>	<sup>1</sup> SAUL	20	SPEC Cold $n$ , polarized

<sup>1</sup>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.

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ABE	21	PR D103 012008	K. Abe <i>et al.</i>	(Super-Kamiokande Collab.)
ABEL	21	PL B812 135993	C. Abel <i>et al.</i>	(nEDM Collab.)
GONZALEZ	21	PRL 127 162501	F.M. Gonzalez <i>et al.</i>	(UCNtau Collab.)
HASSAN	21	PR C103 045502	M.T. Hassan <i>et al.</i>	(aCORN Collab.)
HEACOCK	21	SCI 373 1239	B. Heacock <i>et al.</i>	(NIST, RIKEN, NAGO+)
TIESINGA	21	RMP 93 025010	E. Tiesinga <i>et al.</i>	(NIST)
WILSON	21	PR C104 045501	J.T. Wilson <i>et al.</i>	(JHU, DURH)
ABEL	20	PRL 124 081803	C. Abel <i>et al.</i>	(nEDM Collab.)
BECK	20	PR C101 055506	M. Beck <i>et al.</i>	(aSPECT Collab.)
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SCHUMACHER	19	LHEP 4 4	M. Schumacher	(GOET)
BEREZHIANI	18	EPJ C78 717	Z. Berezhiani <i>et al.</i>	(AQUI, INFN, ILLG+)
BROWN	18	PR C97 035505	M.A.-P. Brown <i>et al.</i>	(UCNA Collab.)
CZARNECKI	18	PRL 120 202002	A. Czarnecki, W.J. Marciano, A. Sirlin	(ALBE+)
EZHOF	18	JETPL 107 671	V.F. Ezhov <i>et al.</i>	(PNPI, LENSU, CAEN+)
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BALES	16	PRL 116 242501	M.J. Bales <i>et al.</i>	(RDK II Collab.)



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MOHR	16	RMP 88 035009	P.J. Mohr, D.B. Newell, B.N. Taylor	(NIST)
PHILLIPS	16	PRPL 612 1	D.G. Phillips II <i>et al.</i>	
ABE	15C	PR D91 072006	K. Abe <i>et al.</i>	(Super-Kamiokande Collab.)
ARZUMANOV	15	PL B745 79	S. Arzumanov <i>et al.</i>	(ILLG, KIAE)
PENDLEBURY	15	PR D92 092003	J.M. Pendlebury <i>et al.</i>	(ETHZ, PSI, SUSS)
SEREBROV	15	PR C92 055501	A.P. Serebrov <i>et al.</i>	(PNPI, ILLG, IOFF)
EPSTEIN	14	PR D90 074027	Z. Epstein, G. Paz, J. Roy	(UMD, WAYN)
MYERS	14	PRL 113 262506	L.S. Myers <i>et al.</i>	(COMPTON/MAX-lab Collab.)
SEREBROV	14	JETPL 99 4	A.P. Serebrov <i>et al.</i>	(PNPI, ILL, IOFF)
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MUND	13	PRL 110 172502	D. Mund <i>et al.</i>	(HEID, ILLG)
YUE	13	PRL 111 222501	A.T. Yue <i>et al.</i>	(UMD, NIST, TENN, ORNL+)
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DUBBERS	11	RMP 83 1111	D. Dubbers, M.G. Schmidt	(HEID)
MUMM	11	PRL 107 102301	H.P. Mumm <i>et al.</i>	(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 <i>et al.</i>	(MICH, NIST, TULA+)
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MOHAPATRA	09	JP G36 104006	R.N. Mohapatra	(UMD)
PATTIE	09	PRL 102 012301	R.W. Pattie Jr. <i>et al.</i>	(Los Alamos UCNA Collab.)
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ABELE	08	PPNP 60 1	H. Abele	(HEID)
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SEREBROV	08	PL B663 181	A.P. Serebrov <i>et al.</i>	(PNPI, IOFF, ILLG+)
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BAN	07	PRL 99 161603	G. Ban <i>et al.</i>	(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)
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SILENKO	07	PPNL 4 468	A.Ya. Silenko	(Belarussian U.)
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SEVERIJNS	06	RMP 78 991	N. Severijns, M. Beck, O. Naviliat-Cuncic	(LEUV+)
KREUZ	05	PL B619 263	M. Kreuz <i>et al.</i>	(HEID, ILLG, MAINZ, KARL+)
MOHR	05	RMP 77 1	P.J. Mohr, B.N. Taylor	(NIST)
NICO	05	PR C71 055502	J.S. Nico <i>et al.</i>	(NIST, TULN, IND, TENN+)
SCHUMACHER	05	PPNP 55 567	M. Schumacher	(GOET)
SEREBROV	05	PL B605 72	A.P. Serebrov <i>et al.</i>	(PNPI, JINR, ILLG)
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WIETFELDT	05	MPL A20 1783	F.E. Wietfeldt	(TULN)
SOLDNER	04	PL B581 49	T. Soldner <i>et al.</i>	(ILLG, TUM)
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ABELE	02	PRL 88 211801	H. Abele <i>et al.</i>	(PERKEO-II Collab.)
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BYRNE	02	JP G28 1325	J. Byrne <i>et al.</i>	
CHUNG	02B	PR D66 032004	J. Chung <i>et al.</i>	(SOUDAN-2 Collab.)
MOSTOVOI	01	PAN 64 1955	Yu.A. Mostovoi <i>et al.</i>	
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ARZUMANOV	00	PL B483 15	S. Arzumanov <i>et al.</i>	
GAL	00	PR C61 028201	A. Gal	

KOLB	00	PRL 85 1388	N.R. Kolb <i>et al.</i>	
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 <i>et al.</i>	(NIST emiT Collab.)
HARRIS	99	PRL 82 904	P.G. Harris <i>et al.</i>	
KESSLER	99	PL A255 221	E.G. Kessler Jr <i>et al.</i>	
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 <i>et al.</i>	
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ABELE	97D	PL B407 212	H. Abele <i>et al.</i>	(HEIDP, ILLG)
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LIAUD	97	NP A612 53	P. Liaud <i>et al.</i>	(ILLG, LAPP)
YEROZLIM...	97	PL B412 240	B.G. Erozolimsky <i>et al.</i>	(HARV, PNPI, KIAE)
ALTAREV	96	PAN 59 1152	I.S. Altarev <i>et al.</i>	(PNPI)
		Translated from YAF 59 1204.		
BONDAREN...	96	JETPL 64 416	L.N. Bondarenko <i>et al.</i>	(KIAE)
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BYRNE	96	EPL 33 187	J. Byrne <i>et al.</i>	(SUSS, ILLG)
MOSTOVOI	96	PAN 59 968	Y.A. Mostovoy	(KIAE)
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NORMAN	96	PR D53 4086	E.B. Norman, J.N. Bahcall, M. Goldhaber	(LBL+)
IGNATOVICH	95	JETPL 62 1	V.K. Ignatovich	(JINR)
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KOPECKY	95	PRL 74 2427	S. Kopecky <i>et al.</i>	
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SCHRECK...	95	PL B349 427	K. Schreckenbach <i>et al.</i>	(TUM, ILLG, LAPP)
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DIFILIPPO	94	PRL 73 1481	F. DiFilippo <i>et al.</i>	(MIT)
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GOLUB	94	PRPL 237C 1	R. Golub, K. Lamoreaux	(HAHN, WASH)
MAMPE	93	JETPL 57 82	B. Mampe <i>et al.</i>	(KIAE)
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ALTAREV	92	PL B276 242	I.S. Altarev <i>et al.</i>	(PNPI)
NESVIZHEV...	92	JETP 75 405	V.V. Nesvizhevsky <i>et al.</i>	(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 <i>et al.</i>	(PNPI, KIAE)
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SCHMIEDM...	91	PRL 66 1015	J. Schmiedmayer <i>et al.</i>	(TUW, ORNL)
WOOLCOCK	91	MPL A6 2579	W.S. Woolcock	(CANB)
ALFIMENKOV	90	JETPL 52 373	V.P. Alfimenkov <i>et al.</i>	(PNPI, JINR)
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BALDO-...	90	PL B236 95	M. Baldo-Ceolin <i>et al.</i>	(PADO, PAVI, HEIDP+)
BERGER	90	PL B240 237	C. Berger <i>et al.</i>	(FREJUS Collab.)
BRESSI	90	NC 103A 731	G. Bressi <i>et al.</i>	(PAVI, ROMA, MILA)
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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 <i>et al.</i>	(GOET, MPCM, MAINZ)
ROSE	90B	NP A514 621	K.W. Rose <i>et al.</i>	(GOET, MPCM)
SMITH	90	PL B234 191	K.F. Smith <i>et al.</i>	(SUSS, RAL, HARV+)
BRESSI	89	ZPHY C43 175	G. Bressi <i>et al.</i>	(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 <i>et al.</i>	(LAPP, SAVO, ISNG+)
MAMPE	89	PRL 63 593	W. Mampe <i>et al.</i>	(ILLG, RISL, SUSS, URI)
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BAUMANN	88	PR D37 3107	J. Baumann <i>et al.</i>	(BAYR, MUNI, ILLG)
KOESTER	88	ZPHY A329 229	L. Koester, W. Waschkowski, J. Meier	(MUNI, TUM)
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COHEN	87	RMP 59 1121	E.R. Cohen, B.N. Taylor	(RISC, NBS)

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CRESTI	86	PL B177 206	M. Cresti <i>et al.</i>	(PADO)
Also		PL B200 587 (err.)	M. Cresti <i>et al.</i>	(PADO)
GREENE	86	PRL 56 819	G.L. Greene <i>et al.</i>	(NBS, ILLG)
KOESTER	86	Physica B137 282	L. Koester <i>et al.</i>	
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 <i>et al.</i>	(KEK, TOKY+)
DOVER	85	PR C31 1423	C.B. Dover, A. Gal, J.M. Richard	(BNL)
FIDECARO	85	PL 156B 122	G. Fidencaro <i>et al.</i>	(CERN, ILLG, PADO+)
PARK	85B	NP B252 261	H.S. Park <i>et al.</i>	(IMB Collab.)
BATTISTONI	84	PL 133B 454	G. Battistoni <i>et al.</i>	(NUSEX Collab.)
JONES	84	PRL 52 720	T.W. Jones <i>et al.</i>	(IMB Collab.)
PENDLEBURY	84	PL 136B 327	J.M. Pendlebury <i>et al.</i>	(SUSS, HARV, RAL+)
CHERRY	83	PRL 50 1354	M.L. Cherry <i>et al.</i>	(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)
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ROY	83	PR D28 1770	A. Roy <i>et al.</i>	(TATA)
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GAEHLER	82	PR D25 2887	R. Gahler, J. Kalus, W. Mampe	(BAYR, ILLG)
GREENE	82	Metrologia 18 93	G.L. Greene <i>et al.</i>	(YALE, HARV, ILLG+)
ALTAREV	81	PL 102B 13	I.S. Altarev <i>et al.</i>	(PNPI)
BARABANOV	80	JETPL 32 359	I.R. Barabanov <i>et al.</i>	(PNPI)
		Translated from ZETFP 32 384.		
BYRNE	80	PL 92B 274	J. Byrne <i>et al.</i>	(SUSS, RL)
KOSVINTSEV	80	JETPL 31 236	Y.Y. Kosvintsev <i>et al.</i>	(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 <i>et al.</i>	(PNPI)
		Translated from ZETFP 29 794.		
EROZOLIM...	79	SJNP 30 356	B.G. Erokolimsky <i>et al.</i>	(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 <i>et al.</i>	(KIAE)
		Translated from ZETFP 28 328.		
Also		Smolenice Conf.	P.G. Bondarenko	(KIAE)
EROZOLIM...	78	SJNP 28 48	B.G. Erokolimsky <i>et al.</i>	(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. Erokolimsky <i>et al.</i>	(KIAE)
		Translated from ZETFP 23 720.		
KOESTER	76	PRL 36 1021	L. Koester <i>et al.</i>	
STEINBERG	76	PR D13 2469	R.I. Steinberg <i>et al.</i>	(YALE, ISNG)
DOBROZE...	75	PR D11 510	R. Dobrozemsky <i>et al.</i>	(SEIB)
KROHN	75	PL 55B 175	V.E. Krohn, G.R. Ringo	(ANL)
EROZOLIM...	74	JETPL 20 345	B.G. Erokolimsky <i>et al.</i>	
		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 <i>et al.</i>	(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 <i>et al.</i>	(RISO)
CHRISTENSEN	70	PR C1 1693	C.J. Christensen, V.E. Krohn, G.R. Ringo	(ANL)
EROZOLIM...	70C	PL 33B 351	B.G. Erokolimsky <i>et al.</i>	(KIAE)
GRIGOREV	68	SJNP 6 239	V.K. Grigoriev <i>et al.</i>	(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)