p

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

p MASS (atomic mass units u)

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

VALUE (u)	*DOCUMENT ID*		*TECN*	*COMMENT*
1.007276466621±0.000000000053 OUR EVALUATION	2018 CODATA			
1.007276466574±0.000000000010	[1] FINK	21	SPEC	Penning trap
1.007276466621±0.000000000053	[2] TIESINGA	21	RVUE	2018 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.007276466598±0.000000000033	[3] HEISSE	19	SPEC	Penning Trap
1.007276466583±0.000000000032	[4] HEISSE	17	SPEC	See HEISSE 19
1.007276466879±0.000000000091	MOHR	16	RVUE	2014 CODATA value
1.007276466812±0.000000000090	MOHR	12	RVUE	2010 CODATA value
1.00727646677 ±0.00000000010	MOHR	08	RVUE	2006 CODATA value
1.00727646688 ±0.00000000013	MOHR	05	RVUE	2002 CODATA value
1.00727646688 ±0.00000000013	MOHR	99	RVUE	1998 CODATA value
1.007276470 ±0.000000012	COHEN	87	RVUE	1986 CODATA value

[1] FINK 21 simultaneously measure the cyclotron frequencies of an H_2^+ ion and a deuteron in a coupled magnetron orbit. The proton mass is extracted using the precise deuteron mass value.

[2] The 2018 CODATA combination in TIESINGA 21 includes data from HEISSE 17, but does not include updates in HEISSE 19, which superseded HEISSE 17. Consequently, we do not average HEISSE 19 and TIESINGA 21. Updating the 2018 CODATA combination to use HEISSE 19 would shift the central value for the proton mass upwards by less than half a standard deviation. Therefore, we take the 2018 CODATA result in TIESINGA 21 as the recommended value for the proton mass.

[3] The value is an update of HEISSE 17; the result is shifted by 1.5×10^{-11} u, corresponding to 0.45 σ due to the corrected motional temperatures of the particles. The statistical and total systematic uncertainties are given as 16 and 29 in the last two digits.

[4] The statistical and systematic errors are 15 and 29 in the last two places of the value. Superseded by HEISSE 19.

p MASS (MeV)

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

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
938.27208816±0.00000029 OUR EVALUATION	2018 CODATA			
938.27208812±0.00000029	[1] FINK	21	SPEC	Penning trap
938.27208816±0.00000029	TIESINGA	21	RVUE	2018 CODATA value

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

938.2720813	±0.0000058	MOHR	16	RVUE	2014 CODATA value
938.272046	±0.000021	MOHR	12	RVUE	2010 CODATA value
938.272013	±0.000023	MOHR	08	RVUE	2006 CODATA value
938.272029	±0.000080	MOHR	05	RVUE	2002 CODATA value
938.271998	±0.000038	MOHR	99	RVUE	1998 CODATA value
938.27231	±0.00028	COHEN	87	RVUE	1986 CODATA value
938.2796	±0.0027	COHEN	73	RVUE	1973 CODATA value

[1] FINK 21 quote the more precise mass in atomic mass units.

$|m_p - m_{\overline{p}}|/m_p$

A test of *CPT* invariance. Note that the comparison of the $\overline{p}$ and p charge-to-mass ratio, given in the next data block, is much better determined.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<7 \times 10^{-10}$	90	[1] HORI	11	SPEC	$\overline{p} e^-$He atom
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<2 \times 10^{-9}$	90	[1] HORI	06	SPEC	$\overline{p} e^-$He atom
$<1.0 \times 10^{-8}$	90	[1] HORI	03	SPEC	$\overline{p} e^-\ {}^4$He, $\overline{p} e^-\ {}^3$He
$<6 \times 10^{-8}$	90	[1] HORI	01	SPEC	$\overline{p} e^-$He atom
$<5 \times 10^{-7}$		[2] TORII	99	SPEC	$\overline{p} e^-$He atom

[1] HORI 01, HORI 03, HORI 06, and HORI 11 use the more-precisely-known constraint on the $\overline{p}$ charge-to-mass ratio of GABRIELSE 99 (see below) to get their results. Their results are not independent of the HORI 01, HORI 03, HORI 06, and HORI 11 values for $|q_p + q_{\overline{p}}|/e$, below.

[2] TORII 99 uses the more-precisely-known constraint on the $\overline{p}$ charge-to-mass ratio of GABRIELSE 95 (see below) to get this result. This is not independent of the TORII 99 value for $|q_p + q_{\overline{p}}|/e$, below.

$\overline{p}/p$ CHARGE-TO-MASS RATIO, $|\frac{q_{\overline{p}}}{m_{\overline{p}}}|/(\frac{q_p}{m_p})$

A test of *CPT* invariance. Listed here are measurements involving the *inertial* masses. For a discussion of what may be inferred about the ratio of $\overline{p}$ and p *gravitational* masses, see ERICSON 90; they obtain an upper bound of 10^{-6}–10^{-7} for violation of the equivalence principle for $\overline{p}$'s.

VALUE	DOCUMENT ID		TECN	COMMENT
1.000000000003±0.000000000016 OUR AVERAGE				
1.000000000003±0.000000000016	BORCHERT	22	TRAP	Penning trap
1.000000000001±0.000000000069	ULMER	15	TRAP	Penning trap
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.99999999991 ±0.00000000009	GABRIELSE	99	TRAP	Penning trap
1.0000000015 ±0.0000000011	[1] GABRIELSE	95	TRAP	Penning trap
1.000000023 ±0.000000042	[2] GABRIELSE	90	TRAP	Penning trap

[1] Equation (2) of GABRIELSE 95 should read $M(\overline{p})/M(p)$ = 0.999 999 9985 (11) (G. Gabrielse, private communication).

[2] GABRIELSE 90 also measures $m_{\overline{p}}/m_{e^-}$ = 1836.152660 ± 0.000083 and m_p/m_{e^-} = 1836.152680 ± 0.000088. Both are completely consistent with the 1986 CODATA (COHEN 87) value for m_p/m_{e^-} of 1836.152701 ± 0.000037.

$(|\frac{q_{\overline{p}}}{m_{\overline{p}}}|-\frac{q_p}{m_p})/\frac{q_p}{m_p}$

A test of *CPT* invariance. Taken from the $\overline{p}/p$ charge-to-mass ratio, above.

VALUE	DOCUMENT ID
(0.3±1.6) × 10^{-11} OUR EVALUATION	

$|q_p + q_{\overline{p}}|/e$

A test of *CPT* invariance. Note that the comparison of the $\overline{p}$ and p charge-to-mass ratios given above is much better determined. See also a similar test involving the electron.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<7 × 10^{-10}	90	[1] HORI	11	SPEC	$\overline{p}e^-$He atom
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<2 \times 10^{-9}$	90	[1] HORI	06	SPEC	$\overline{p}e^-$He atom
$<1.0 \times 10^{-8}$	90	[1] HORI	03	SPEC	$\overline{p}e^-\ {}^4$He, $\overline{p}e^-\ {}^3$He
$<6 \times 10^{-8}$	90	[1] HORI	01	SPEC	$\overline{p}e^-$He atom
$<5 \times 10^{-7}$		[2] TORII	99	SPEC	$\overline{p}e^-$He atom
$<2 \times 10^{-5}$		[3] HUGHES	92	RVUE	

[1] HORI 01, HORI 03, HORI 06, and HORI 11 use the more-precisely-known constraint on the $\overline{p}$ charge-to-mass ratio of GABRIELSE 99 (see above) to get their results. Their results are not independent of the HORI 01, HORI 03, HORI 06, and HORI 11 values for $|m_p - m_{\overline{p}}|/m_p$, above.

[2] TORII 99 uses the more-precisely-known constraint on the $\overline{p}$ charge-to-mass ratio of GABRIELSE 95 (see above) to get this result. This is not independent of the TORII 99 value for $|m_p - m_{\overline{p}}|/m_p$, above.

[3] HUGHES 92 uses recent measurements of Rydberg-energy and cyclotron-frequency ratios.

$|q_p + q_e|/e$

See BRESSI 11 for a summary of experiments on the neutrality of matter. See also "*n* CHARGE" in the neutron Listings.

VALUE	DOCUMENT ID		COMMENT
<1 × 10^{-21}	[1] BRESSI	11	Neutrality of SF_6
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$<3.2 \times 10^{-20}$	[2] SENGUPTA	00	binary pulsar
$<0.8 \times 10^{-21}$	MARINELLI	84	Magnetic levitation
$<1.0 \times 10^{-21}$	[1] DYLLA	73	Neutrality of SF_6

[1] BRESSI 11 uses the method of DYLLA 73 but finds serious errors in that experiment that greatly reduce its accuracy. The BRESSI 11 limit assumes that $n \to p e^- \nu_e$ conserves charge. Thus the limit applies equally to the charge of the neutron.
[2] SENGUPTA 00 uses the difference between the observed rate of of rotational energy loss by the binary pulsar PSR B1913+16 and the rate predicted by general relativity to set this limit. See the paper for assumptions.

p MAGNETIC MOMENT

See the "Quark Model" review.

VALUE (μ_N)	DOCUMENT ID		TECN	COMMENT
2.79284734463±0.00000000082	TIESINGA	21	RVUE	2018 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2.79284734462±0.00000000082	SCHNEIDER	17	TRAP	Double Penning trap
2.7928473508 ±0.0000000085	MOHR	16	RVUE	2014 CODATA value
2.792847356 ±0.000000023	MOHR	12	RVUE	2010 CODATA value
2.792847356 ±0.000000023	MOHR	08	RVUE	2006 CODATA value
2.792847351 ±0.000000028	MOHR	05	RVUE	2002 CODATA value
2.792847337 ±0.000000029	MOHR	99	RVUE	1998 CODATA value
2.792847386 ±0.000000063	COHEN	87	RVUE	1986 CODATA value

$\overline{p}$ MAGNETIC MOMENT

A few early results have been omitted.

VALUE (μ_N)	DOCUMENT ID		TECN	COMMENT
−2.7928473441±0.0000000042	SMORRA	17	TRAP	Hot/cold $\overline{p}$ frequencies, Penning traps
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−2.7928465 ±0.0000023	NAGAHAMA	17	TRAP	Single $\overline{p}$, Penning trap
−2.792845 ±0.000012	DISCIACCA	13	TRAP	Single $\overline{p}$, Penning trap
−2.7862 ±0.0083	PASK	09	CNTR	$\overline{p}\,He^+$ hyperfine structure
−2.8005 ±0.0090	KREISSL	88	CNTR	$\overline{p}\,^{208}Pb$ 11→ 10 X-ray
−2.817 ±0.048	ROBERTS	78	CNTR	
−2.791 ±0.021	HU	75	CNTR	Exotic atoms

$(\mu_p + \mu_{\overline{p}}) / \mu_p$

A test of *CPT* invariance.

VALUE (units 10^{-6})	DOCUMENT ID		TECN	COMMENT
0.002±0.004	SMORRA	17	TRAP	Hot/cold $\overline{p}$ frequencies, Penning traps
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.3 ±0.8	NAGAHAMA	17	TRAP	Single $\overline{p}$, Penning trap
0 ±5	DISCIACCA	13	TRAP	Single $\overline{p}$, Penning trap

p ELECTRIC DIPOLE MOMENT

A nonzero value is forbidden by both T invariance and P invariance.

VALUE (10^{-23} e cm)	DOCUMENT ID		TECN	COMMENT
< 0.021	[1] SAHOO	17		Theory plus ^{199}Hg atom EDM
• • • We do not use the following data for averages, fits, limits, etc. • • •				
< 0.54	[1] DMITRIEV	03		Theory plus ^{199}Hg atom EDM
-3.7 ± 6.3	CHO	89	NMR	Tl F molecules
< 400	DZUBA	85	THEO	Uses ^{129}Xe moment
130 ± 200	[2] WILKENING	84		
900 ± 1400	[3] WILKENING	84		
700 ± 900	HARRISON	69	MBR	Molecular beam

[1] SAHOO 17 and DMITRIEV 03 are not direct measurements of the proton electric dipole moment. They use theory to calculate this limit from the limit on the electric dipole moment of the ^{199}Hg atom.
[2] This WILKENING 84 value includes a finite-size effect and a magnetic effect.
[3] This WILKENING 84 value is more cautious than the other and excludes the finite-size effect, which relies on uncertain nuclear integrals.

p ELECTRIC POLARIZABILITY α_p

For a very complete review of the "polarizability of the nucleon and Compton scattering," see SCHUMACHER 05, updated in SCHUMACHER 19.

See LI 22D and therein for measurements of the mean square proton electric polarizability radius.

VALUE (10^{-4} fm^3)	DOCUMENT ID		TECN	COMMENT
11.5 ± 0.4 OUR AVERAGE Error includes scale factor of 1.1.				
$12.7 \pm 0.8 \pm 0.1$	[1] MORNACCHI	22	FIT	Fit of RCS data sets
$10.65 \pm 0.35 \pm 0.36$	MCGOVERN	13	RVUE	χEFT + Compton scattering
$12.1 \pm 1.1 \pm 0.5$	[2] BEANE	03		EFT + γp
$11.82 \pm 0.98 ^{+0.52}_{-0.98}$	[3] BLANPIED	01	LEGS	$p(\vec{\gamma},\gamma)$, $p(\vec{\gamma},\pi^0)$, $p(\vec{\gamma},\pi^+)$
$11.9 \pm 0.5 \pm 1.3$	[4] OLMOSDEL...	01	CNTR	γp Compton scattering
$12.1 \pm 0.8 \pm 0.5$	[5] MACGIBBON	95	RVUE	global average
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$12.03 ^{+0.48}_{-0.54}$	[6] PASQUINI	19		fit of RCS data sets
$11.7 \pm 0.8 \pm 0.7$	[7] BARANOV	01	RVUE	Global average
$12.5 \pm 0.6 \pm 0.9$	MACGIBBON	95	CNTR	γp Compton scattering
$9.8 \pm 0.4 \pm 1.1$	HALLIN	93	CNTR	γp Compton scattering
$10.62 ^{+1.25}_{-1.19} {}^{+1.07}_{-1.03}$	ZIEGER	92	CNTR	γp Compton scattering
$10.9 \pm 2.2 \pm 1.3$	[8] FEDERSPIEL	91	CNTR	γp Compton scattering

[1] MORNACCHI 22 perform the first simultaneous extraction of the six leading-order proton polarizabilities using fixed-t subtracted dispersion relations and a bootstrap-based fitting technique.
[2] BEANE 03 uses effective field theory and low-energy γp and γd Compton-scattering data. It also gets for the isoscalar polarizabilities (see the erratum) $\alpha_N = (13.0 \pm 1.9^{+3.9}_{-1.5}) \times 10^{-4}$ fm^3 and $\beta_N = (-1.8 \pm 1.9^{+2.1}_{-0.9}) \times 10^{-4}$ fm^3.

[3] BLANPIED 01 gives $\alpha_p + \beta_p$ and $\alpha_p - \beta_p$. The separate α_p and β_p are provided to us by A. Sandorfi. The first error above is statistics plus systematics; the second is from the model.

[4] This OLMOSDELEON 01 result uses the TAPS data alone, and does not use the (re-evaluated) sum-rule constraint that $\alpha+\beta = (13.8 \pm 0.4) \times 10^{-4}$ fm^3. See the paper for a discussion.

[5] MACGIBBON 95 combine the results of ZIEGER 92, FEDERSPIEL 91, and their own experiment to get a "global average" in which model errors and systematic errors are treated in a consistent way. See MACGIBBON 95 for a discussion.

[6] PASQUINI 19 fit data sets for the unpolarized proton RCS cross section, using fixed-t subtracted dispersion relations and a bootstrap-based fitting technique.

[7] BARANOV 01 combines the results of 10 experiments from 1958 through 1995 to get a global average that takes into account both systematic and model errors and does not use the theoretical constraint on the sum $\alpha_p + \beta_p$.

[8] FEDERSPIEL 91 obtains for the (static) electric polarizability α_p, defined in terms of the induced electric dipole moment by $\mathbf{D} = 4\pi\epsilon_0\alpha_p\mathbf{E}$, the value $(7.0 \pm 2.2 \pm 1.3) \times 10^{-4}$ fm^3.

p MAGNETIC POLARIZABILITY β_p

The electric and magnetic polarizabilities are subject to a dispersion sum-rule constraint $\overline{\alpha} + \overline{\beta} = (14.2 \pm 0.5) \times 10^{-4}$ fm^3. Errors here are anticorrelated with those on $\overline{\alpha}_p$ due to this constraint.

See LI 22D and therein for measurements of the mean square proton magnetic polarizability radius.

VALUE (10^{-4} fm^3)	DOCUMENT ID		TECN	COMMENT
2.31±0.29 OUR AVERAGE	Error includes scale factor of 1.1.			
2.4 ±0.6 ±0.1	[1] MORNACCHI	22	FIT	Fit of RCS data sets
$1.77^{+0.52}_{-0.54}$	[2] PASQUINI	19	FIT	fit of RCS data sets
3.15±0.35±0.36	MCGOVERN	13	RVUE	χEFT + Compton scattering
3.4 ±1.1 ±0.1	[3] BEANE	03		EFT + γp
$1.43 \pm 0.98^{+0.52}_{-0.98}$	[4] BLANPIED	01	LEGS	$p(\vec{\gamma},\gamma)$, $p(\vec{\gamma},\pi^0)$, $p(\vec{\gamma},\pi^+)$
1.2 ±0.7 ±0.5	[5] OLMOSDEL...	01	CNTR	γp Compton scattering
2.1 ±0.8 ±0.5	[6] MACGIBBON	95	RVUE	global average
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2.3 ±0.9 ±0.7	[7] BARANOV	01	RVUE	Global average
1.7 ±0.6 ±0.9	MACGIBBON	95	CNTR	γp Compton scattering
4.4 ±0.4 ±1.1	HALLIN	93	CNTR	γp Compton scattering
$3.58^{+1.19+1.03}_{-1.25-1.07}$	ZIEGER	92	CNTR	γp Compton scattering
3.3 ±2.2 ±1.3	FEDERSPIEL	91	CNTR	γp Compton scattering

[1] MORNACCHI 22 perform the first simultaneous extraction of the six leading-order proton polarizabilities using fixed-t subtracted dispersion relations and a bootstrap-based fitting technique.

[2] PASQUINI 19 fit data sets for the unpolarized proton RCS cross section, using fixed-t subtracted dispersion relations and a bootstrap-based fitting technique.

[3] BEANE 03 uses effective field theory and low-energy γp and γd Compton-scattering data. It also gets for the isoscalar polarizabilities (see the erratum) $\alpha_N = (13.0 \pm 1.9^{+3.9}_{-1.5}) \times 10^{-4}$ fm^3 and $\beta_N = (-1.8 \pm 1.9^{+2.1}_{-0.9}) \times 10^{-4}$ fm^3.

[4] BLANPIED 01 gives $\alpha_p + \beta_p$ and $\alpha_p - \beta_p$. The separate α_p and β_p are provided to us by A. Sandorfi. The first error above is statistics plus systematics; the second is from the model.
[5] This OLMOSDELEON 01 result uses the TAPS data alone, and does not use the (re-evaluated) sum-rule constraint that $\alpha + \beta = (13.8 \pm 0.4) \times 10^{-4}$ fm^3. See the paper for a discussion.
[6] MACGIBBON 95 combine the results of ZIEGER 92, FEDERSPIEL 91, and their own experiment to get a "global average" in which model errors and systematic errors are treated in a consistent way. See MACGIBBON 95 for a discussion.
[7] BARANOV 01 combines the results of 10 experiments from 1958 through 1995 to get a global average that takes into account both systematic and model errors and does not use the theoretical constraint on the sum $\alpha_p + \beta_p$.

p SPIN POLARIZABILITY γ_{E1E1}

VALUE (10^{-4} fm^4)	*DOCUMENT ID*	*TECN*	*COMMENT*
−3.0±0.6±0.4	[1] MORNACCHI 22	FIT	Fit of RCS data sets

[1] MORNACCHI 22 perform the first simultaneous extraction of the six leading-order proton polarizabilities using fixed-t subtracted dispersion relations and a bootstrap-based fitting technique.

p SPIN POLARIZABILITY γ_{M1M1}

VALUE (10^{-4} fm^4)	*DOCUMENT ID*	*TECN*	*COMMENT*
3.7±0.5±0.1	[1] MORNACCHI 22	FIT	Fit of RCS data sets

[1] MORNACCHI 22 perform the first simultaneous extraction of the six leading-order proton polarizabilities using fixed-t subtracted dispersion relations and a bootstrap-based fitting technique.

p SPIN POLARIZABILITY γ_{E1M2}

VALUE (10^{-4} fm^4)	*DOCUMENT ID*	*TECN*	*COMMENT*
−1.2±1.0±0.3	[1] MORNACCHI 22	FIT	Fit of RCS data sets

[1] MORNACCHI 22 perform the first simultaneous extraction of the six leading-order proton polarizabilities using fixed-t subtracted dispersion relations and a bootstrap-based fitting technique.

p SPIN POLARIZABILITY γ_{M1E2}

VALUE (10^{-4} fm^4)	*DOCUMENT ID*	*TECN*	*COMMENT*
2.0±0.7±0.4	[1] MORNACCHI 22	FIT	Fit of RCS data sets

[1] MORNACCHI 22 perform the first simultaneous extraction of the six leading-order proton polarizabilities using fixed-t subtracted dispersion relations and a bootstrap-based fitting technique.

p CHARGE RADIUS

This is the rms electric charge radius, $\sqrt{\langle r_E^2 \rangle}$.

There are three kinds of measurements of the proton radius: via transitions in atomic hydrogen; via electron scattering off hydrogen; and via muonic hydrogen Lamb shift. Most measurements of the radius of the proton involve electron-proton interactions, the most recent of which is the electron scattering measurement $r_p = 0.831(14)$ fm (XIONG 19), and the atomic-hydrogen value, $r_p = 0.833(10)$ fm (BEZGINOV 19). These agree well with another recent atomic-hydrogen value r_p = 0.8335(95) fm (BEYER 17), and with the best measurement using muonic hydrogen r_p = 0.84087(39) fm (ANTOGNINI 13), that is far more precise.

The MOHR 16 value (2014 CODATA), obtained from the electronic results available at the time, was 0.8751(61) fm. This differs by 5.6 standard deviations from the muonic hydrogen value, leading to the so-called proton charge radius puzzle. See our 2018 edition (Physical Review **D98** 030001 (2018)) for a further discussion of interpretations of this puzzle. However, reflecting the new electronic measurements, the 2018 CODATA, TIESINGA 21, recommended value is 0.8414(19) fm, and the puzzle appears to be resolved.

See our 2014 edition (Chinese Physics **C38** 070001 (2014)) for values published before 2003.

VALUE (fm)				*DOCUMENT ID*		*TECN*	*COMMENT*
0.8409	**±0.0004**	**OUR AVERAGE**					
0.833	±0.010		[1]	BEZGINOV	19	LASR	2S-2P transition in H
0.831	±0.007	±0.012	[2]	XIONG	19	SPEC	$e p \rightarrow e p$ form factor
0.84087	±0.00026	±0.00029		ANTOGNINI	13	LASR	μp-atom Lamb shift
• • • We do not use the following data for averages, fits, limits, etc. • • •							
0.847	±0.008		[3]	CUI	21	FIT	use existing $e p$ data
0.878	±0.011	±0.031	[4]	MIHOVILOVIC	21		ISR $e p \rightarrow e p$ reanalysis
0.877	±0.013		[5]	FLEURBAEY	18	LASR	1S-3S transition in H
0.8335	±0.0095		[6]	BEYER	17	LASR	2S-4P transition in H
0.8751	±0.0061			MOHR	16	RVUE	2014 CODATA value
0.895	±0.014	±0.014	[7]	LEE	15	SPEC	Just 2010 Mainz data
0.916	±0.024			LEE	15	SPEC	World data, no Mainz
0.8775	±0.0051			MOHR	12	RVUE	2010 CODATA, $e p$ data
0.875	±0.008	±0.006		ZHAN	11	SPEC	Recoil polarimetry
0.879	±0.005	±0.006		BERNAUER	10	SPEC	$e p \rightarrow e p$ form factor
0.912	±0.009	±0.007		BORISYUK	10		reanalyzes old $e p$ data
0.871	±0.009	±0.003		HILL	10		z-expansion reanalysis
0.84184	±0.00036	±0.00056		POHL	10	LASR	See ANTOGNINI 13
0.8768	±0.0069			MOHR	08	RVUE	2006 CODATA value
0.844	$^{+0.008}_{-0.004}$			BELUSHKIN	07		Dispersion analysis
0.897	±0.018			BLUNDEN	05		SICK 03 + 2γ correction
0.8750	±0.0068			MOHR	05	RVUE	2002 CODATA value
0.895	±0.010	±0.013		SICK	03		$e p \rightarrow e p$ reanalysis

[1] BEZGINOV 19 measures the $2S_{1/2}$ to $2P_{1/2}$ transition frequency in atomic hydrogen using the frequency-offset separated oscillatory field (FOSOF) technique. The result agrees well with the muonic hydrogen Lamb shift value.

[2] The XIONG 19 value from $e p \rightarrow e p$ scattering and supports the muonic hydrogen Lamb shift value.

[3] CUI 21 employ a new mathematical procedure (statistical SPM, Schlessinger point method) based on form-unbiased interpolations of existing $e p$ scattering data.

[4] MIHOVILOVIC 21 reports a value of 0.878 ± 0.011 ± 0.031 ± 0.002 fm where the last uncertainty comes from the dependence on the model form factor function.

[5] FLEURBAEY 18 measures the 1S-3S transition frequency in hydrogen and in combination with the 1S-2S transition frequency deduces the proton radius and the Rydberg constant.

[6] The BEYER 17 result is 3.3 combined standard deviations below the MOHR 16 (2014 CODATA) value. The experiment measures the 2S-4P transition in hydrogen and gets the proton radius and the Rydberg constant.

[7] Authors also provide values for combinations of all available data.

p MAGNETIC RADIUS

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

VALUE (fm)	*DOCUMENT ID*		*TECN*	*COMMENT*
0.851±0.026	[1] LEE	15		Combination of world and Mainz data
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.817±0.027	[2] CUI	21B	FIT	use existing ep data
0.87 ±0.02	EPSTEIN	14		Using ep, en, $\pi\pi$ data
0.867±0.009±0.018	ZHAN	11	SPEC	Recoil polarimetry
0.777±0.013±0.010	BERNAUER	10	SPEC	$ep \to ep$ form factor
0.876±0.010±0.016	BORISYUK	10		Reanalyzes old $ep \to ep$ data
0.854±0.005	BELUSHKIN	07		Dispersion analysis

[1] In a consistent reanalysis LEE 2015 extract values separately for the Mainz 2010 data only (0.776+-0.034+-0.017) fm and for the world data without Mainz data (0.914+-0.035) fm. The quoted value is a simple combination of the two, which ignores possible discrepancies and unknown correlations and should be considered with caution.

[2] CUI 21B employ a new mathematical procedure (statistical SPM, Schlessinger point method) based on form-unbiased interpolations of existing ep scattering data.

p MEAN LIFE

A test of baryon conservation. See the "*p* Partial Mean Lives" section below for limits for identified final states. The limits here are to "anything" or are for "disappearance" modes of a bound proton (*p*) or (*n*). See also the 3ν modes in the "Partial Mean Lives" section. Table 1 of BACK 03 is a nice summary.

LIMIT (years)	*PARTICLE*	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$>0.96 \times 10^{30}$	***p***	90	[1] ALLEGA	22	SNO+	$p \to$ invisible
$>0.9 \times 10^{30}$	***n***	90	[2] ALLEGA	22	SNO+	$n \to$ invisible
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$>1.3 \times 10^{24}$	*p*	90	[3] AGOSTINI	24A	HPGE	$p \to$ invisible
$>1.5 \times 10^{24}$	*n*	90	[4] AGOSTINI	24A	HPGE	$n \to$ invisible
$>3.6 \times 10^{29}$	*p*	90	[5] ANDERSON	19A	SNO+	$p \to$ invisible
$>2.5 \times 10^{29}$	*n*	90	[5] ANDERSON	19A	SNO+	$n \to$ invisible
$>5.8 \times 10^{29}$	*n*	90	[6] ARAKI	06	KLND	$n \to$ invisible
$>2.1 \times 10^{29}$	*p*	90	[5] AHMED	04	SNO	$p \to$ invisible
$>1.9 \times 10^{29}$	*n*	90	[5] AHMED	04	SNO	$n \to$ invisible
$>1.8 \times 10^{25}$	*n*	90	[7] BACK	03	BORX	
$>1.1 \times 10^{26}$	*p*	90	[7] BACK	03	BORX	

$>3.5 \times 10^{28}$	p	90	[8] ZDESENKO	03		$p \to$ invisible
$>1 \times 10^{28}$	p	90	[9] AHMAD	02	SNO	$p \to$ invisible
$>4 \times 10^{23}$	p	95	TRETYAK	01		$d \to n + ?$
$>1.9 \times 10^{24}$	p	90	[10] BERNABEI	00B	DAMA	
$>1.6 \times 10^{25}$	p, n		[11,12] EVANS	77		
$>3 \times 10^{23}$	p		[12] DIX	70	CNTR	
$>3 \times 10^{23}$	p, n		[12,13] FLEROV	58		

[1] ALLEGA 22 look for γ rays from the de-excitation of a residual $^{15}N^*$ following the disappearance of p in ^{16}O.

[2] ALLEGA 22 look for γ rays from the de-excitation of a residual $^{15}O^*$ following the disappearance of n in ^{16}O.

[3] AGOSTINI 24A look for γ rays from the de-excitation of a residual $^{75}As^*$ following the disappearance of p in ^{76}Ge (through the transition chain $^{76}Ge \to {}^{75}Ga \to {}^{75}Ge \to {}^{75}As$).

[4] AGOSTINI 24A look for γ rays from the de-excitation of a residual $^{75}As^*$ following the disappearance of n in ^{76}Ge (through the transition chain $^{76}Ge \to {}^{75}Ge \to {}^{75}As$).

[5] AHMED 04 and ANDERSON 19A look for γ rays from the de-excitation of a residual $^{15}O^*$ or $^{15}N^*$ following the disappearance of a neutron or proton in ^{16}O.

[6] ARAKI 06 looks for signs of de-excitation of the residual nucleus after disappearance of a neutron from the s shell of ^{12}C.

[7] BACK 03 looks for decays of unstable nuclides left after N decays of parent ^{12}C, ^{13}C, ^{16}O nuclei. These are "invisible channel" limits.

[8] ZDESENKO 03 gets this limit on proton disappearance in deuterium by analyzing SNO data in AHMAD 02.

[9] AHMAD 02 (see its footnote 7) looks for neutrons left behind after the disappearance of the proton in deuterons.

[10] BERNABEI 00B looks for the decay of a $^{128}_{53}I$ nucleus following the disappearance of a proton in the otherwise-stable $^{129}_{54}Xe$ nucleus.

[11] EVANS 77 looks for the daughter nuclide ^{129}Xe from possible ^{130}Te decays in ancient Te ore samples.

[12] This mean-life limit has been obtained from a half-life limit by dividing the latter by ln(2) = 0.693.

[13] FLEROV 58 looks for the spontaneous fission of a ^{232}Th nucleus after the disappearance of one of its nucleons.

$\overline{p}$ MEAN LIFE

Of the two astrophysical limits here, that of GEER 00D involves considerably more refinements in its modeling. The other limits come from direct observations of stored antiprotons. See also "$\overline{p}$ Partial Mean Lives" after "p Partial Mean Lives," below, for exclusive-mode limits. The best (lifetime/branching fraction) limit there is 7×10^5 years, for $\overline{p} \to e^- \gamma$. We advance only the exclusive-mode limits to our Summary Tables.

LIMIT (years)	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •						
>5.0	90		SELLNER	17	TRAP	Penning trap
$>8 \times 10^5$	90		[1] GEER	00D		$\overline{p}/p$ ratio, cosmic rays
>0.28			GABRIELSE	90	TRAP	Penning trap
>0.08	90	1	BELL	79	CNTR	Storage ring
$>1 \times 10^7$			GOLDEN	79	SPEC	$\overline{p}/p$ ratio, cosmic rays
$>3.7 \times 10^{-3}$			BREGMAN	78	CNTR	Storage ring

[1] GEER 00D uses agreement between a model of galactic $\overline{p}$ production and propagation and the observed $\overline{p}/p$ cosmic-ray spectrum to set this limit.

p DECAY MODES

See the "Note on Nucleon Decay" in our 1994 edition (Phys. Rev. **D50**, 1173) for a short review.

The "partial mean life" limits tabulated here are the limits on τ/B_i, where τ is the total mean life and B_i is the branching fraction for the mode in question. For *N* decays, *p* and *n* indicate proton and neutron partial lifetimes.

	Mode	Partial mean life (10^{30} years)	Confidence level
	Antilepton + meson		
τ_1	$N \to e^+ \pi$	> 5300 (*n*), > 24000 (*p*)	90%
τ_2	$N \to \mu^+ \pi$	> 3500 (*n*), > 16000 (*p*)	90%
τ_3	$N \to \nu \pi$	> 1100 (*n*), > 390 (*p*)	90%
τ_4	$p \to e^+ \eta$	> 10000	90%
τ_5	$p \to \mu^+ \eta$	> 4700	90%
τ_6	$n \to \nu \eta$	> 158	90%
τ_7	$N \to e^+ \rho$	> 217 (*n*), > 720 (*p*)	90%
τ_8	$N \to \mu^+ \rho$	> 228 (*n*), > 570 (*p*)	90%
τ_9	$N \to \nu \rho$	> 19 (*n*), > 162 (*p*)	90%
τ_{10}	$p \to e^+ \omega$	> 1600	90%
τ_{11}	$p \to \mu^+ \omega$	> 2800	90%
τ_{12}	$n \to \nu \omega$	> 108	90%
τ_{13}	$N \to e^+ K$	> 17 (*n*), > 1000 (*p*)	90%
τ_{14}	$p \to e^+ K^0_S$		
τ_{15}	$p \to e^+ K^0_L$		
τ_{16}	$N \to \mu^+ K$	> 26 (*n*), > 4500 (*p*)	90%
τ_{17}	$p \to \mu^+ K^0_S$		
τ_{18}	$p \to \mu^+ K^0_L$		
τ_{19}	$N \to \nu K$	> 86 (*n*), > 5900 (*p*)	90%
τ_{20}	$n \to \nu K^0_S$	> 260	90%
τ_{21}	$p \to e^+ K^*(892)^0$	> 84	90%
τ_{22}	$N \to \nu K^*(892)$	> 78 (*n*), > 51 (*p*)	90%
	Antilepton + mesons		
τ_{23}	$p \to e^+ \pi^+ \pi^-$	> 82	90%
τ_{24}	$p \to e^+ \pi^0 \pi^0$	> 147	90%
τ_{25}	$n \to e^+ \pi^- \pi^0$	> 52	90%
τ_{26}	$p \to \mu^+ \pi^+ \pi^-$	> 133	90%
τ_{27}	$p \to \mu^+ \pi^0 \pi^0$	> 101	90%
τ_{28}	$n \to \mu^+ \pi^- \pi^0$	> 74	90%
τ_{29}	$n \to e^+ K^0 \pi^-$	> 18	90%

Lepton + meson

τ_{30}	$n \rightarrow e^- \pi^+$	> 65	90%
τ_{31}	$n \rightarrow \mu^- \pi^+$	> 49	90%
τ_{32}	$n \rightarrow e^- \rho^+$	> 62	90%
τ_{33}	$n \rightarrow \mu^- \rho^+$	> 7	90%
τ_{34}	$n \rightarrow e^- K^+$	> 32	90%
τ_{35}	$n \rightarrow \mu^- K^+$	> 57	90%

Lepton + mesons

τ_{36}	$p \rightarrow e^- \pi^+ \pi^+$	> 30	90%
τ_{37}	$n \rightarrow e^- \pi^+ \pi^0$	> 29	90%
τ_{38}	$p \rightarrow \mu^- \pi^+ \pi^+$	> 17	90%
τ_{39}	$n \rightarrow \mu^- \pi^+ \pi^0$	> 34	90%
τ_{40}	$p \rightarrow e^- \pi^+ K^+$	> 75	90%
τ_{41}	$p \rightarrow \mu^- \pi^+ K^+$	> 245	90%

Antilepton + photon(s)

τ_{42}	$p \rightarrow e^+ \gamma$	> 670	90%
τ_{43}	$p \rightarrow \mu^+ \gamma$	> 478	90%
τ_{44}	$n \rightarrow \nu \gamma$	> 550	90%
τ_{45}	$p \rightarrow e^+ \gamma \gamma$	> 100	90%
τ_{46}	$n \rightarrow \nu \gamma \gamma$	> 219	90%

Antilepton + single massless

τ_{47}	$p \rightarrow e^+ X$	> 790	90%
τ_{48}	$p \rightarrow \mu^+ X$	> 410	90%

Three (or more) leptons

τ_{49}	$p \rightarrow e^+ e^+ e^-$	> 34000	90%
τ_{50}	$p \rightarrow e^+ \mu^+ \mu^-$	> 9200	90%
τ_{51}	$p \rightarrow e^+ \nu \nu$	> 170	90%
τ_{52}	$n \rightarrow e^+ e^- \nu$	> 257	90%
τ_{53}	$n \rightarrow \mu^+ e^- \nu$	> 83	90%
τ_{54}	$n \rightarrow \mu^+ \mu^- \nu$	> 79	90%
τ_{55}	$p \rightarrow \mu^+ e^+ e^-$	> 23000	90%
τ_{56}	$p \rightarrow \mu^- e^+ e^+$	> 19000	90%
τ_{57}	$p \rightarrow \mu^+ \mu^+ \mu^-$	> 10000	90%
τ_{58}	$p \rightarrow \mu^+ \nu \nu$	> 220	90%
τ_{59}	$p \rightarrow e^- \mu^+ \mu^+$	> 11000	90%
τ_{60}	$n \rightarrow 3\nu$	$> 5 \times 10^{-4}$	90%
τ_{61}	$n \rightarrow 5\nu$		

Inclusive modes

τ_{62}	$N \to e^+$ anything	> 0.6 (n, p)	90%
τ_{63}	$N \to \mu^+$ anything	> 12 (n, p)	90%
τ_{64}	$N \to \nu$ anything		
τ_{65}	$N \to e^+ \pi^0$ anything	> 0.6 (n, p)	90%
τ_{66}	$N \to$ 2 bodies, ν-free		

$\Delta B = 2$ dinucleon modes

The following are lifetime limits per iron nucleus.

τ_{67}	$pp \to \pi^+ \pi^+$	> 72.2	90%
τ_{68}	$pn \to \pi^+ \pi^0$	> 170	90%
τ_{69}	$nn \to \pi^+ \pi^-$	> 0.7	90%
τ_{70}	$nn \to \pi^0 \pi^0$	> 404	90%
τ_{71}	$pp \to K^+ K^+$	> 170	90%
τ_{72}	$pp \to e^+ e^+$	> 5.8	90%
τ_{73}	$pp \to e^+ \mu^+$	> 3.6	90%
τ_{74}	$pp \to \mu^+ \mu^+$	> 1.7	90%
τ_{75}	$pn \to e^+ \overline{\nu}$	> 260	90%
τ_{76}	$pn \to \mu^+ \overline{\nu}$	> 200	90%
τ_{77}	$pn \to \tau^+ \overline{\nu}_\tau$	> 29	90%
τ_{78}	$nn \to$ invisible	> 1.4	90%
τ_{79}	$nn \to \nu_e \overline{\nu}_e$	> 1.4	90%
τ_{80}	$nn \to \nu_\mu \overline{\nu}_\mu$	> 1.4	90%
τ_{81}	$pn \to$ invisible	> 0.06	90%
τ_{82}	$pp \to$ invisible	> 0.11	90%

$\overline{p}$ DECAY MODES

	Mode	Partial mean life (years)	Confidence level
τ_{83}	$\overline{p} \to e^- \gamma$	$> 7 \times 10^5$	90%
τ_{84}	$\overline{p} \to \mu^- \gamma$	$> 5 \times 10^4$	90%
τ_{85}	$\overline{p} \to e^- \pi^0$	$> 4 \times 10^5$	90%
τ_{86}	$\overline{p} \to \mu^- \pi^0$	$> 5 \times 10^4$	90%
τ_{87}	$\overline{p} \to e^- \eta$	$> 2 \times 10^4$	90%
τ_{88}	$\overline{p} \to \mu^- \eta$	$> 8 \times 10^3$	90%
τ_{89}	$\overline{p} \to e^- K_S^0$	> 900	90%
τ_{90}	$\overline{p} \to \mu^- K_S^0$	$> 4 \times 10^3$	90%
τ_{91}	$\overline{p} \to e^- K_L^0$	$> 9 \times 10^3$	90%
τ_{92}	$\overline{p} \to \mu^- K_L^0$	$> 7 \times 10^3$	90%
τ_{93}	$\overline{p} \to e^- \gamma\gamma$	$> 2 \times 10^4$	90%
τ_{94}	$\overline{p} \to \mu^- \gamma\gamma$	$> 2 \times 10^4$	90%
τ_{95}	$\overline{p} \to e^- \omega$	> 200	90%

p PARTIAL MEAN LIVES

The "partial mean life" limits tabulated here are the limits on τ/B_i, where τ is the total mean life for the proton and B_i is the branching fraction for the mode in question.

Decaying particle: p = proton, n = bound neutron. The same event may appear under more than one partial decay mode. Background estimates may be accurate to a factor of two.

Antilepton + meson

$\tau(N \rightarrow e^+ \pi)$ τ_1

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>24000	***p***	**90**	**0**	**0.59**	[1] TAKENAKA	20	SKAM
> 5300	***n***	**90**	**0**	**0.41**	ABE	17D	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>16000	*p*	90	0	0.61	ABE	17	SKAM
> 2000	*n*	90	0	0.27	NISHINO	12	SKAM
> 8200	*p*	90	0	0.3	NISHINO	09	SKAM
> 540	*p*	90	0	0.2	MCGREW	99	IMB3
> 158	*n*	90	3	5	MCGREW	99	IMB3
> 1600	*p*	90	0	0.1	SHIOZAWA	98	SKAM
> 70	*p*	90	0	0.5	BERGER	91	FREJ
> 70	*n*	90	0	≤ 0.1	BERGER	91	FREJ
> 550	*p*	90	0	0.7	[2] BECKER-SZ...	90	IMB3
> 260	*p*	90	0	<0.04	HIRATA	89C	KAMI
> 130	*n*	90	0	<0.2	HIRATA	89C	KAMI
> 310	*p*	90	0	0.6	SEIDEL	88	IMB
> 100	*n*	90	0	1.6	SEIDEL	88	IMB
> 1.3	*n*	90	0		BARTELT	87	SOUD
> 1.3	*p*	90	0		BARTELT	87	SOUD
> 250	*p*	90	0	0.3	HAINES	86	IMB
> 31	*n*	90	8	9	HAINES	86	IMB
> 64	*p*	90	0	<0.4	ARISAKA	85	KAMI
> 26	*n*	90	0	<0.7	ARISAKA	85	KAMI
> 82	*p* (free)	90	0	0.2	BLEWITT	85	IMB
> 250	*p*	90	0	0.2	BLEWITT	85	IMB
> 25	*n*	90	4	4	PARK	85	IMB
> 15	*p*, *n*	90	0		BATTISTONI	84	NUSX
> 0.5	*p*	90	1	0.3	[3] BARTELT	83	SOUD
> 0.5	*n*	90	1	0.3	[3] BARTELT	83	SOUD
> 5.8	*p*	90	2		[4] KRISHNA...	82	KOLR
> 5.8	*n*	90	2		[4] KRISHNA...	82	KOLR
> 0.1	*n*	90			[5] GURR	67	CNTR

[1] TAKENAKA 20 includes data of ABE 17, and thus supersedes ABE 17.
[2] This BECKER-SZENDY 90 result includes data from SEIDEL 88.
[3] Limit based on zero events.
[4] We have calculated 90% CL limit from 1 confined event.
[5] We have converted half-life to 90% CL mean life.

$\tau(N \to \mu^+ \pi)$ τ_2

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>16000	***p***	**90**	**1**	**0.94**	[1] TAKENAKA	20	SKAM
> 3500	***n***	**90**	**1**	**0.77**	ABE	17D	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 7700	*p*	90	2	0.87	ABE	17	SKAM
> 1000	*n*	90	1	0.43	NISHINO	12	SKAM
> 6600	*p*	90	0	0.3	NISHINO	09	SKAM
> 473	*p*	90	0	0.6	MCGREW	99	IMB3
> 90	*n*	90	1	1.9	MCGREW	99	IMB3
> 81	*p*	90	0	0.2	BERGER	91	FREJ
> 35	*n*	90	1	1.0	BERGER	91	FREJ
> 230	*p*	90	0	<0.07	HIRATA	89C	KAMI
> 100	*n*	90	0	<0.2	HIRATA	89C	KAMI
> 270	*p*	90	0	0.5	SEIDEL	88	IMB
> 63	*n*	90	0	0.5	SEIDEL	88	IMB
> 76	*p*	90	2	1	HAINES	86	IMB
> 23	*n*	90	8	7	HAINES	86	IMB
> 46	*p*	90	0	<0.7	ARISAKA	85	KAMI
> 20	*n*	90	0	<0.4	ARISAKA	85	KAMI
> 59	*p* (free)	90	0	0.2	BLEWITT	85	IMB
> 100	*p*	90	1	0.4	BLEWITT	85	IMB
> 38	*n*	90	1	4	PARK	85	IMB
> 10	*p*, *n*	90	0		BATTISTONI	84	NUSX
> 1.3	*p*, *n*	90	0		ALEKSEEV	81	BAKS

[1] TAKENAKA 20 includes the data of ABE 17 and thus supersedes ABE 17.

$\tau(N \to \nu \pi)$ τ_3

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
> 390	***p***	**90**	**52.8**		ABE	14E	SKAM
>1100	***n***	**90**	**19.1**		ABE	14E	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 16	*p*	90	6	6.7	WALL	00B	SOU2
> 39	*n*	90	4	3.8	WALL	00B	SOU2
> 10	*p*	90	15	20.3	MCGREW	99	IMB3
> 112	*n*	90	6	6.6	MCGREW	99	IMB3
> 13	*n*	90	1	1.2	BERGER	89	FREJ
> 10	*p*	90	11	14	BERGER	89	FREJ
> 25	*p*	90	32	32.8	[1] HIRATA	89C	KAMI
> 100	*n*	90	1	3	HIRATA	89C	KAMI
> 6	*n*	90	73	60	HAINES	86	IMB
> 2	*p*	90	16	13	KAJITA	86	KAMI
> 40	*n*	90	0	1	KAJITA	86	KAMI
> 7	*n*	90	28	19	PARK	85	IMB
> 7	*n*	90	0		BATTISTONI	84	NUSX
> 2	*p*	90	≤ 3		BATTISTONI	84	NUSX
> 5.8	*p*	90	1		[2] KRISHNA...	82	KOLR
> 0.3	*p*	90	2		[3] CHERRY	81	HOME
> 0.1	*p*	90			[4] GURR	67	CNTR

[1] In estimating the background, this HIRATA 89C limit (as opposed to the later limits of WALL 00B and MCGREW 99) does not take into account present understanding that the flux of ν_μ originating in the upper atmosphere is depleted. Doing so would reduce the background and thus also would reduce the limit here.
[2] We have calculated 90% CL limit from 1 confined event.
[3] We have converted 2 possible events to 90% CL limit.
[4] We have converted half-life to 90% CL mean life.

$\tau(p \to e^+ \eta)$ τ_4

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>14000	***p***	**90**	**0**	**0.42**	[1] TANIUCHI	24	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>10000	*p*	90	0	0.78	ABE	17D	SKAM
> 4200	*p*	90	0	0.44	NISHINO	12	SKAM
> 81	*p*	90	1	1.7	WALL	00B	SOU2
> 313	*p*	90	0	0.2	MCGREW	99	IMB3
> 44	*p*	90	0	0.1	BERGER	91	FREJ
> 140	*p*	90	0	<0.04	HIRATA	89C	KAMI
> 100	*p*	90	0	0.6	SEIDEL	88	IMB
> 200	*p*	90	5	3.3	HAINES	86	IMB
> 64	*p*	90	0	<0.8	ARISAKA	85	KAMI
> 64	*p* (free)	90	5	6.5	BLEWITT	85	IMB
> 200	*p*	90	5	4.7	BLEWITT	85	IMB
> 1.2	*p*	90	2		[2] CHERRY	81	HOME

[1] TANIUCHI 24 includes the ABE 17D dataset and thus supersedes ABE 17D entries.
[2] We have converted 2 possible events to 90% CL limit.

$\tau(p \to \mu^+ \eta)$ τ_5

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>7300	***p***	**90**	**2**	**0.93**	[1] TANIUCHI	24	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>4700	*p*	90	2	0.85	ABE	17D	SKAM
>1300	*p*	90	2	0.49	NISHINO	12	SKAM
> 89	*p*	90	0	1.6	WALL	00B	SOU2
> 126	*p*	90	3	2.8	MCGREW	99	IMB3
> 26	*p*	90	1	0.8	BERGER	91	FREJ
> 69	*p*	90	1	<0.08	HIRATA	89C	KAMI
> 1.3	*p*	90	0	0.7	PHILLIPS	89	HPW
> 34	*p*	90	1	1.5	SEIDEL	88	IMB
> 46	*p*	90	7	6	HAINES	86	IMB
> 26	*p*	90	1	<0.8	ARISAKA	85	KAMI
> 17	*p* (free)	90	6	6	BLEWITT	85	IMB
> 46	*p*	90	7	8	BLEWITT	85	IMB

[1] TANIUCHI 24 includes the ABE 17D dataset and thus supersedes ABE 17D entries.

$\tau(n \to \nu\eta)$ τ_6

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>158	***n***	**90**	**0**	**1.2**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 71	*n*	90	2	3.7	WALL	00B	SOU2
> 29	*n*	90	0	0.9	BERGER	89	FREJ
> 54	*n*	90	2	0.9	HIRATA	89C	KAMI
> 16	*n*	90	3	2.1	SEIDEL	88	IMB
> 25	*n*	90	7	6	HAINES	86	IMB
> 30	*n*	90	0	0.4	KAJITA	86	KAMI
> 18	*n*	90	4	3	PARK	85	IMB
> 0.6	*n*	90	2		[1] CHERRY	81	HOME

[1] We have converted 2 possible events to 90% CL limit.

$\tau(N \to e^+\rho)$ τ_7

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>720	***p***	**90**	**2**	**0.64**	ABE	17D	SKAM
>217	***n***	**90**	**4**	**4.8**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 30	*n*	90	4	0.87	ABE	17D	SKAM
>710	*p*	90	0	0.35	NISHINO	12	SKAM
> 70	*n*	90	1	0.38	NISHINO	12	SKAM
> 29	*p*	90	0	2.2	BERGER	91	FREJ
> 41	*n*	90	0	1.4	BERGER	91	FREJ
> 75	*p*	90	2	2.7	HIRATA	89C	KAMI
> 58	*n*	90	0	1.9	HIRATA	89C	KAMI
> 38	*n*	90	2	4.1	SEIDEL	88	IMB
> 1.2	*p*	90	0		BARTELT	87	SOUD
> 1.5	*n*	90	0		BARTELT	87	SOUD
> 17	*p*	90	7	7	HAINES	86	IMB
> 14	*n*	90	9	4	HAINES	86	IMB
> 12	*p*	90	0	<1.2	ARISAKA	85	KAMI
> 6	*n*	90	2	<1	ARISAKA	85	KAMI
> 6.7	*p* (free)	90	6	6	BLEWITT	85	IMB
> 17	*p*	90	7	7	BLEWITT	85	IMB
> 12	*n*	90	4	2	PARK	85	IMB
> 0.6	*n*	90	1	0.3	[1] BARTELT	83	SOUD
> 0.5	*p*	90	1	0.3	[1] BARTELT	83	SOUD
> 9.8	*p*	90	1		[2] KRISHNA...	82	KOLR
> 0.8	*p*	90	2		[3] CHERRY	81	HOME

[1] Limit based on zero events.
[2] We have calculated 90% CL limit from 0 confined events.
[3] We have converted 2 possible events to 90% CL limit.

$\tau(N \to \mu^+\rho)$ τ_8

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>570	***p***	**90**	**1**	**1.30**	ABE	17D	SKAM
>228	***n***	**90**	**3**	**9.5**	MCGREW	99	IMB3

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

> 60	*n*	90	1	0.96	ABE	17D	SKAM
>160	*p*	90	1	0.42	NISHINO	12	SKAM
> 36	*n*	90	0	0.29	NISHINO	12	SKAM
> 12	*p*	90	0	0.5	BERGER	91	FREJ
> 22	*n*	90	0	1.1	BERGER	91	FREJ
>110	*p*	90	0	1.7	HIRATA	89C	KAMI
> 23	*n*	90	1	1.8	HIRATA	89C	KAMI
> 4.3	*p*	90	0	0.7	PHILLIPS	89	HPW
> 30	*p*	90	0	0.5	SEIDEL	88	IMB
> 11	*n*	90	1	1.1	SEIDEL	88	IMB
> 16	*p*	90	4	4.5	HAINES	86	IMB
> 7	*n*	90	6	5	HAINES	86	IMB
> 12	*p*	90	0	<0.7	ARISAKA	85	KAMI
> 5	*n*	90	1	<1.2	ARISAKA	85	KAMI
> 5.5	*p* (free)	90	4	5	BLEWITT	85	IMB
> 16	*p*	90	4	5	BLEWITT	85	IMB
> 9	*n*	90	1	2	PARK	85	IMB

$\tau(N \rightarrow \nu\rho)$ τ_9

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>162	***p***	**90**	**18**	**21.7**	MCGREW	99	IMB3
> 19	***n***	**90**	**0**	**0.5**	SEIDEL	88	IMB
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 9	*n*	90	4	2.4	BERGER	89	FREJ
> 24	*p*	90	0	0.9	BERGER	89	FREJ
> 27	*p*	90	5	1.5	HIRATA	89C	KAMI
> 13	*n*	90	4	3.6	HIRATA	89C	KAMI
> 13	*p*	90	1	1.1	SEIDEL	88	IMB
> 8	*p*	90	6	5	HAINES	86	IMB
> 2	*n*	90	15	10	HAINES	86	IMB
> 11	*p*	90	2	1	KAJITA	86	KAMI
> 4	*n*	90	2	2	KAJITA	86	KAMI
> 4.1	*p* (free)	90	6	7	BLEWITT	85	IMB
> 8.4	*p*	90	6	5	BLEWITT	85	IMB
> 2	*n*	90	7	3	PARK	85	IMB
> 0.9	*p*	90	2		[1] CHERRY	81	HOME
> 0.6	*n*	90	2		[1] CHERRY	81	HOME

[1] We have converted 2 possible events to 90% CL limit.

$\tau(p \rightarrow e^+\omega)$ τ_{10}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>1600	***p***	**90**	**1**	**1.35**	ABE	17D	SKAM

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

> 320	p	90	1	0.53	NISHINO	12	SKAM
> 107	p	90	7	10.8	MCGREW	99	IMB3
> 17	p	90	0	1.1	BERGER	91	FREJ
> 45	p	90	2	1.45	HIRATA	89C	KAMI
> 26	p	90	1	1.0	SEIDEL	88	IMB
> 1.5	p	90	0		BARTELT	87	SOUD
> 37	p	90	6	5.3	HAINES	86	IMB
> 25	p	90	1	<1.4	ARISAKA	85	KAMI
> 12	p (free)	90	6	7.5	BLEWITT	85	IMB
> 37	p	90	6	5.7	BLEWITT	85	IMB
> 0.6	p	90	1	0.3	[1] BARTELT	83	SOUD
> 9.8	p	90	1		[2] KRISHNA...	82	KOLR
> 2.8	p	90	2		[3] CHERRY	81	HOME

[1] Limit based on zero events.
[2] We have calculated 90% CL limit from 0 confined events.
[3] We have converted 2 possible events to 90% CL limit.

$\tau(p \to \mu^+ \omega)$ τ_{11}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>2800	**p**	**90**	**0**	**1.09**	ABE	17D	SKAM

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

> 780	p	90	0	0.48	NISHINO	12	SKAM
> 117	p	90	11	12.1	MCGREW	99	IMB3
> 11	p	90	0	1.0	BERGER	91	FREJ
> 57	p	90	2	1.9	HIRATA	89C	KAMI
> 4.4	p	90	0	0.7	PHILLIPS	89	HPW
> 10	p	90	2	1.3	SEIDEL	88	IMB
> 23	p	90	2	1	HAINES	86	IMB
> 6.5	p (free)	90	9	8.7	BLEWITT	85	IMB
> 23	p	90	8	7	BLEWITT	85	IMB

$\tau(n \to \nu \omega)$ τ_{12}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>108	**n**	**90**	**12**	**22.5**	MCGREW	99	IMB3

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

> 17	n	90	1	0.7	BERGER	89	FREJ
> 43	n	90	3	2.7	HIRATA	89C	KAMI
> 6	n	90	2	1.3	SEIDEL	88	IMB
> 12	n	90	6	6	HAINES	86	IMB
> 18	n	90	2	2	KAJITA	86	KAMI
> 16	n	90	1	2	PARK	85	IMB
> 2.0	n	90	2		[1] CHERRY	81	HOME

[1] We have converted 2 possible events to 90% CL limit.

$\tau(N \rightarrow e^+ K)$ τ_{13}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>1000	**p**	**90**	**6**	**4.7**	KOBAYASHI	05	SKAM
> 17	**n**	**90**	**35**	**29.4**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 85	p	90	3	4.9	WALL	00	SOU2
> 31	p	90	23	25.2	MCGREW	99	IMB3
> 60	p	90	0		BERGER	91	FREJ
> 150	p	90	0	<0.27	HIRATA	89C	KAMI
> 70	p	90	0	1.8	SEIDEL	88	IMB
> 77	p	90	5	4.5	HAINES	86	IMB
> 38	p	90	0	<0.8	ARISAKA	85	KAMI
> 24	p (free)	90	7	8.5	BLEWITT	85	IMB
> 77	p	90	5	4	BLEWITT	85	IMB
> 1.3	p	90	0		ALEKSEEV	81	BAKS
> 1.3	n	90	0		ALEKSEEV	81	BAKS

$\tau(p \rightarrow e^+ K^0_S)$ τ_{14}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>120	p	90	1	1.3	WALL	00	SOU2
> 76	p	90	0	0.5	BERGER	91	FREJ

$\tau(p \rightarrow e^+ K^0_L)$ τ_{15}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>51	p	90	2	3.5	WALL	00	SOU2
>44	p	90	0	$\leq$ 0.1	BERGER	91	FREJ

$\tau(N \rightarrow \mu^+ K)$ τ_{16}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>4500	**p**	**90**	**1**	**3.08**	[1] MATSUMOTO	22	SKAM
> 26	**n**	**90**	**20**	**28.4**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>3600	p	90	14	16.3	[2] MATSUMOTO	22	SKAM
>1600	p	90	13	13.2	REGIS	12	SKAM
>1300	p	90	3	3.9	KOBAYASHI	05	SKAM
> 120	p	90	0	<1.2	WALL	00	SOU2
> 120	p	90	4	7.2	MCGREW	99	IMB3
> 54	p	90	0		BERGER	91	FREJ
> 120	p	90	1	0.4	HIRATA	89C	KAMI
> 3.0	p	90	0	0.7	PHILLIPS	89	HPW
> 19	p	90	3	2.5	SEIDEL	88	IMB
> 1.5	p	90	0		[3] BARTELT	87	SOUD
> 1.1	n	90	0		BARTELT	87	SOUD

> 40	p	90	7	6	HAINES	86	IMB
> 19	p	90	1	<1.1	ARISAKA	85	KAMI
> 6.7	p (free)	90	11	13	BLEWITT	85	IMB
> 40	p	90	7	8	BLEWITT	85	IMB
> 6	p	90	1		BATTISTONI	84	NUSX
> 0.6	p	90	0		[4] BARTELT	83	SOUD
> 0.4	n	90	0		[4] BARTELT	83	SOUD
> 5.8	p	90	2		[5] KRISHNA...	82	KOLR
> 2.0	p	90	0		CHERRY	81	HOME
> 0.2	n	90			[6] GURR	67	CNTR

[1] MATSUMOTO 22 limit $> 4500 \times 10^{30}$ is derived from the latest dataset SKA IV phase (from 2008 to 2018) with 0.20 Mton·years of exposure.

[2] MATSUMOTO 22 limit $> 3600 \times 10^{30}$ is derived from a combination of all datasets SKA I,II, III and IV phase (from 1996 to 2018) with a total of 0.37 Mton·years of exposure. Note, the limit from only SKA IV is stronger, because there were some events observed in SKA II.

[3] BARTELT 87 limit applies to $p \rightarrow \mu^+ K^0_S$.

[4] Limit based on zero events.

[5] We have calculated 90% CL limit from 1 confined event.

[6] We have converted half-life to 90% CL mean life.

$\tau(p \rightarrow \mu^+ K^0_S)$ τ_{17}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>150	p	90	0	<0.8	WALL	00	SOU2
> 64	p	90	0	1.2	BERGER	91	FREJ

$\tau(p \rightarrow \mu^+ K^0_L)$ τ_{18}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>83	p	90	0	0.4	WALL	00	SOU2
>44	p	90	0	≤ 0.1	BERGER	91	FREJ

$\tau(N \rightarrow \nu K)$ τ_{19}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>5900	**p**	**90**	**0**	**1.0**	ABE	14G	SKAM
> 86	**n**	**90**	**0**	**2.4**	HIRATA	89C	KAMI
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 540	p	90	0	0.9	ASAKURA	15	KLND
>2300	p	90	0	1.3	KOBAYASHI	05	SKAM
> 26	n	90	16	9.1	WALL	00	SOU2
> 670	p	90			HAYATO	99	SKAM
> 151	p	90	15	21.4	MCGREW	99	IMB3
> 30	n	90	34	34.1	MCGREW	99	IMB3
> 43	p	90	1	1.54	[1] ALLISON	98	SOU2
> 15	n	90	1	1.8	BERGER	89	FREJ
> 15	p	90	1	1.8	BERGER	89	FREJ
> 100	p	90	9	7.3	HIRATA	89C	KAMI
> 0.28	p	90	0	0.7	PHILLIPS	89	HPW

> 0.3	*p*	90	0		BARTELT	87	SOUD
> 0.75	*n*	90	0		[2] BARTELT	87	SOUD
> 10	*p*	90	6	5	HAINES	86	IMB
> 15	*n*	90	3	5	HAINES	86	IMB
> 28	*p*	90	3	3	KAJITA	86	KAMI
> 32	*n*	90	0	1.4	KAJITA	86	KAMI
> 1.8	*p* (free)	90	6	11	BLEWITT	85	IMB
> 9.6	*p*	90	6	5	BLEWITT	85	IMB
> 10	*n*	90	2	2	PARK	85	IMB
> 5	*n*	90	0		BATTISTONI	84	NUSX
> 2	*p*	90	0		BATTISTONI	84	NUSX
> 0.3	*n*	90	0		[3] BARTELT	83	SOUD
> 0.1	*p*	90	0		[3] BARTELT	83	SOUD
> 5.8	*p*	90	1		[4] KRISHNA...	82	KOLR
> 0.3	*n*	90	2		[5] CHERRY	81	HOME

[1] This ALLISON 98 limit is with no background subtraction; with subtraction the limit becomes $> 46 \times 10^{30}$ years.
[2] BARTELT 87 limit applies to $n \to \nu K^0_S$.
[3] Limit based on zero events.
[4] We have calculated 90% CL limit from 1 confined event.
[5] We have converted 2 possible events to 90% CL limit.

$\tau(n \to \nu K^0_S)$ τ_{20}

LIMIT (10^{30} years)	*PARTICLE*	*CL%*	*EVTS*	*BKGD EST*	*DOCUMENT ID*		*TECN*
>260	**n**	**90**	**34**	**30**	[1] KOBAYASHI	05	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 51	*n*	90	16	9.1	WALL	00	SOU2

[1] We have doubled the $n \to \nu K^0$ limit given in KOBAYASHI 05 to obtain this $n \to \nu K^0_S$ limit.

$\tau(p \to e^+ K^*(892)^0)$ τ_{21}

LIMIT (10^{30} years)	*PARTICLE*	*CL%*	*EVTS*	*BKGD EST*	*DOCUMENT ID*		*TECN*
>84	***p***	**90**	**38**	**52.0**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>10	*p*	90	0	0.8	BERGER	91	FREJ
>52	*p*	90	2	1.55	HIRATA	89C	KAMI
>10	*p*	90	1	<1	ARISAKA	85	KAMI

$\tau(N \to \nu K^*(892))$ τ_{22}

LIMIT (10^{30} years)	*PARTICLE*	*CL%*	*EVTS*	*BKGD EST*	*DOCUMENT ID*		*TECN*
>51	***p***	**90**	**7**	**9.1**	MCGREW	99	IMB3
>78	***n***	**90**	**40**	**50**	MCGREW	99	IMB3

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

>22	n	90	0	2.1	BERGER	89	FREJ
>17	p	90	0	2.4	BERGER	89	FREJ
>20	p	90	5	2.1	HIRATA	89C	KAMI
>21	n	90	4	2.4	HIRATA	89C	KAMI
>10	p	90	7	6	HAINES	86	IMB
> 5	n	90	8	7	HAINES	86	IMB
> 8	p	90	3	2	KAJITA	86	KAMI
> 6	n	90	2	1.6	KAJITA	86	KAMI
> 5.8	p (free)	90	10	16	BLEWITT	85	IMB
> 9.6	p	90	7	6	BLEWITT	85	IMB
> 7	n	90	1	4	PARK	85	IMB
> 2.1	p	90	1		[1] BATTISTONI	82	NUSX

[1] We have converted 1 possible event to 90% CL limit.

Antilepton + mesons

$\tau(p \to e^+ \pi^+ \pi^-)$ τ_{23}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>82	***p***	**90**	**16**	**23.1**	MCGREW	99	IMB3

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

>21	p	90	0	2.2	BERGER	91	FREJ

$\tau(p \to e^+ \pi^0 \pi^0)$ τ_{24}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>147	***p***	**90**	**2**	**0.8**	MCGREW	99	IMB3

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

> 38	p	90	1	0.5	BERGER	91	FREJ

$\tau(n \to e^+ \pi^- \pi^0)$ τ_{25}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>52	***n***	**90**	**38**	**34.2**	MCGREW	99	IMB3

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

>32	n	90	1	0.8	BERGER	91	FREJ

$\tau(p \to \mu^+ \pi^+ \pi^-)$ τ_{26}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>133	***p***	**90**	**25**	**38.0**	MCGREW	99	IMB3

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

> 17	p	90	1	2.6	BERGER	91	FREJ
> 3.3	p	90	0	0.7	PHILLIPS	89	HPW

$\tau(p \to \mu^+ \pi^0 \pi^0)$ — τ_{27}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>101	***p***	**90**	**3**	**1.6**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 33	*p*	90	1	0.9	BERGER	91	FREJ

$\tau(n \to \mu^+ \pi^- \pi^0)$ — τ_{28}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>74	***n***	**90**	**17**	**20.8**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>33	*n*	90	0	1.1	BERGER	91	FREJ

$\tau(n \to e^+ K^0 \pi^-)$ — τ_{29}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>18	***n***	**90**	**1**	**0.2**	BERGER	91	FREJ

Lepton + meson

$\tau(n \to e^- \pi^+)$ — τ_{30}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>65	***n***	**90**	**0**	**1.6**	SEIDEL	88	IMB
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>55	*n*	90	0	1.09	BERGER	91B	FREJ
>16	*n*	90	9	7	HAINES	86	IMB
>25	*n*	90	2	4	PARK	85	IMB

$\tau(n \to \mu^- \pi^+)$ — τ_{31}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>49	***n***	**90**	**0**	**0.5**	SEIDEL	88	IMB
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>33	*n*	90	0	1.40	BERGER	91B	FREJ
> 2.7	*n*	90	0	0.7	PHILLIPS	89	HPW
>25	*n*	90	7	6	HAINES	86	IMB
>27	*n*	90	2	3	PARK	85	IMB

$\tau(n \to e^- \rho^+)$ — τ_{32}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>62	***n***	**90**	**2**	**4.1**	SEIDEL	88	IMB
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>12	*n*	90	13	6	HAINES	86	IMB
>12	*n*	90	5	3	PARK	85	IMB

$\tau(n \rightarrow \mu^- \rho^+)$ τ_{33}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>7	***n***	**90**	**1**	**1.1**	SEIDEL	88	IMB
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>2.6	*n*	90	0	0.7	PHILLIPS	89	HPW
>9	*n*	90	7	5	HAINES	86	IMB
>9	*n*	90	2	2	PARK	85	IMB

$\tau(n \rightarrow e^- K^+)$ τ_{34}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>32	***n***	**90**	**3**	**2.96**	BERGER	91B	FREJ
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 0.23	*n*	90	0	0.7	PHILLIPS	89	HPW

$\tau(n \rightarrow \mu^- K^+)$ τ_{35}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>57	***n***	**90**	**0**	**2.18**	BERGER	91B	FREJ
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 4.7	*n*	90	0	0.7	PHILLIPS	89	HPW

Lepton + mesons

$\tau(p \rightarrow e^- \pi^+ \pi^+)$ τ_{36}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>30	***p***	**90**	**1**	**2.50**	BERGER	91B	FREJ
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 2.0	*p*	90	0	0.7	PHILLIPS	89	HPW

$\tau(n \rightarrow e^- \pi^+ \pi^0)$ τ_{37}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>29	***n***	**90**	**1**	**0.78**	BERGER	91B	FREJ

$\tau(p \rightarrow \mu^- \pi^+ \pi^+)$ τ_{38}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>17	***p***	**90**	**1**	**1.72**	BERGER	91B	FREJ
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 7.8	*p*	90	0	0.7	PHILLIPS	89	HPW

$\tau(n \rightarrow \mu^- \pi^+ \pi^0)$ τ_{39}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>34	***n***	**90**	**0**	**0.78**	BERGER	91B	FREJ

$\tau(p \to e^- \pi^+ K^+)$ — τ_{40}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>75	**p**	**90**	**81**	**127.2**	MCGREW	99	IMB3

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

>20	p	90	3	2.50	BERGER	91B	FREJ

$\tau(p \to \mu^- \pi^+ K^+)$ — τ_{41}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>245	**p**	**90**	**3**	**4.0**	MCGREW	99	IMB3

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

> 5	p	90	2	0.78	BERGER	91B	FREJ

Antilepton + photon(s)

$\tau(p \to e^+ \gamma)$ — τ_{42}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>670	**p**	**90**	**0**	**0.1**	MCGREW	99	IMB3

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

>133	p	90	0	0.3	BERGER	91	FREJ
>460	p	90	0	0.6	SEIDEL	88	IMB
>360	p	90	0	0.3	HAINES	86	IMB
> 87	p (free)	90	0	0.2	BLEWITT	85	IMB
>360	p	90	0	0.2	BLEWITT	85	IMB
> 0.1	p	90			[1] GURR	67	CNTR

[1] We have converted half-life to 90% CL mean life.

$\tau(p \to \mu^+ \gamma)$ — τ_{43}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>478	**p**	**90**	**0**	**0.1**	MCGREW	99	IMB3

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

>155	p	90	0	0.1	BERGER	91	FREJ
>380	p	90	0	0.5	SEIDEL	88	IMB
> 97	p	90	3	2	HAINES	86	IMB
> 61	p (free)	90	0	0.2	BLEWITT	85	IMB
>280	p	90	0	0.6	BLEWITT	85	IMB
> 0.3	p	90			[1] GURR	67	CNTR

[1] We have converted half-life to 90% CL mean life.

$\tau(n \to \nu \gamma)$ — τ_{44}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>550		**90**			TAKHISTOV	15	SKAM

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

> 28	n	90	163	144.7	MCGREW	99	IMB3
> 24	n	90	10	6.86	BERGER	91B	FREJ
> 9	n	90	73	60	HAINES	86	IMB
> 11	n	90	28	19	PARK	85	IMB

$\tau(p \to e^+ \gamma\gamma)$ τ_{45}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>100	**p**	**90**	**1**	**0.8**	BERGER	91	FREJ

$\tau(n \to \nu\gamma\gamma)$ τ_{46}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>219	**n**	**90**	**5**	**7.5**	MCGREW	99	IMB3

Antilepton + single massless

$\tau(p \to e^+ X)$ τ_{47}

VALUE (10^{30} years)	CL%	DOCUMENT ID		TECN
>790	90	TAKHISTOV	15	SKAM

$\tau(p \to \mu^+ X)$ τ_{48}

VALUE (10^{30} years)	CL%	DOCUMENT ID		TECN
>410	90	TAKHISTOV	15	SKAM

Three (or more) leptons

$\tau(p \to e^+ e^+ e^-)$ τ_{49}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>34000	**p**	**90**	**0**	**0.58**	TANAKA	20	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 793	p	90	0	0.5	MCGREW	99	IMB3
> 147	p	90	0	0.1	BERGER	91	FREJ
> 510	p	90	0	0.3	HAINES	86	IMB
> 89	p (free)	90	0	0.5	BLEWITT	85	IMB
> 510	p	90	0	0.7	BLEWITT	85	IMB

$\tau(p \to e^+ \mu^+ \mu^-)$ τ_{50}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>9200	**p**	**90**	**1**	**0.27**	TANAKA	20	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 359	p	90	1	0.9	MCGREW	99	IMB3
> 81	p	90	0	0.16	BERGER	91	FREJ
> 5.0	p	90	0	0.7	PHILLIPS	89	HPW

$\tau(p \to e^+ \nu\nu)$ τ_{51}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>170	**p**	**90**			[1] TAKHISTOV	14	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 17	p	90	152	153.7	MCGREW	99	IMB3
> 11	p	90	11	6.08	BERGER	91B	FREJ

[1] Allowed events at 90% CL are 459.

$\tau(n \rightarrow e^+ e^- \nu)$ τ_{52}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>257	***n***	**90**	**5**	**7.5**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 74	*n*	90	0	< 0.1	BERGER	91B	FREJ
> 45	*n*	90	5	5	HAINES	86	IMB
> 26	*n*	90	4	3	PARK	85	IMB

$\tau(n \rightarrow \mu^+ e^- \nu)$ τ_{53}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>83	***n***	**90**	**25**	**29.4**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>47	*n*	90	0	< 0.1	BERGER	91B	FREJ

$\tau(n \rightarrow \mu^+ \mu^- \nu)$ τ_{54}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>79	***n***	**90**	**100**	**145**	MCGREW	99	IMB3
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>42	*n*	90	0	1.4	BERGER	91B	FREJ
> 5.1	*n*	90	0	0.7	PHILLIPS	89	HPW
>16	*n*	90	14	7	HAINES	86	IMB
>19	*n*	90	4	7	PARK	85	IMB

$\tau(p \rightarrow \mu^+ e^+ e^-)$ τ_{55}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>23000	***p***	**90**	**0**	**0.5**	TANAKA	20	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 529	*p*	90	0	1.0	MCGREW	99	IMB3
> 91	*p*	90	0	≤ 0.1	BERGER	91	FREJ

$\tau(p \rightarrow \mu^- e^+ e^+)$ τ_{56}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>19000	***p***	**90**	**0**	**0.5**	TANAKA	20	SKAM

$\tau(p \rightarrow \mu^+ \mu^+ \mu^-)$ τ_{57}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>10000	***p***	**90**	**1**	**0.4**	TANAKA	20	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 675	*p*	90	0	0.3	MCGREW	99	IMB3
> 119	*p*	90	0	0.2	BERGER	91	FREJ
> 10.5	*p*	90	0	0.7	PHILLIPS	89	HPW
> 190	*p*	90	1	0.1	HAINES	86	IMB
> 44	*p* (free)	90	1	0.7	BLEWITT	85	IMB
> 190	*p*	90	1	0.9	BLEWITT	85	IMB
> 2.1	*p*	90	1		[1] BATTISTONI	82	NUSX

[1] We have converted 1 possible event to 90% CL limit.

$\tau(p \to \mu^+ \nu \nu)$ τ_{58}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>220	**p**	**90**			[1] TAKHISTOV	14	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 21	p	90	7	11.23	BERGER	91B	FREJ

[1] Allowed events at 90% CL are 286.

$\tau(p \to e^- \mu^+ \mu^+)$ τ_{59}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>11000	**p**	**90**	**1**	**0.27**	TANAKA	20	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 6.0	p	90	0	0.7	PHILLIPS	89	HPW

$\tau(n \to 3\nu)$ τ_{60}

See also the "to anything" and "disappearance" limits for bound nucleons in the "p Mean Life" data block just in front of the list of possible p decay modes. Such modes could of course be to three (or five) neutrinos, and the limits are stronger, but we do not repeat them here.

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>0.00049	**n**	**90**	**2**	**2**	[1] SUZUKI	93B	KAMI
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>0.0023	n	90			[2] GLICENSTEIN	97	KAMI
>0.00003	n	90	11	6.1	[3] BERGER	91B	FREJ
>0.00012	n	90	7	11.2	[3] BERGER	91B	FREJ
>0.0005	n	90	0		LEARNED	79	RVUE

[1] The SUZUKI 93B limit applies to any of $\nu_e \nu_e \overline{\nu}_e$, $\nu_\mu \nu_\mu \overline{\nu}_\mu$, or $\nu_\tau \nu_\tau \overline{\nu}_\tau$.

[2] GLICENSTEIN 97 uses Kamioka data and the idea that the disappearance of the neutron's magnetic moment should produce radiation.

[3] The first BERGER 91B limit is for $n \to \nu_e \nu_e \overline{\nu}_e$, the second is for $n \to \nu_\mu \nu_\mu \overline{\nu}_\mu$.

$\tau(n \to 5\nu)$ τ_{61}

See the note on $\tau(n \to 3\nu)$ on the previous data block.

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>0.0017	n	90			[1] GLICENSTEIN	97	KAMI

[1] GLICENSTEIN 97 uses Kamioka data and the idea that the disappearance of the neutron's magnetic moment should produce radiation.

Inclusive modes

$\tau(N \to e^+ \text{anything})$ τ_{62}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>0.6	**p, n**	**90**			[1] LEARNED	79	RVUE

[1] The electron may be primary or secondary.

$\tau(N \to \mu^+ \text{anything})$ — τ_{63}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>12	***p, n***	**90**	**2**		[1,2] CHERRY	81	HOME
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 1.8	p, n	90			[2] COWSIK	80	CNTR
> 6	p, n	90			[2] LEARNED	79	RVUE

[1] We have converted 2 possible events to 90% CL limit.
[2] The muon may be primary or secondary.

$\tau(N \to \nu \text{anything})$ — τ_{64}

Anything = π, ρ, K, etc.

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>0.0002	p, n	90	0		LEARNED	79	RVUE

$\tau(N \to e^+ \pi^0 \text{anything})$ — τ_{65}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>0.6	***p, n***	**90**	**0**		LEARNED	79	RVUE

$\tau(N \to 2 \text{ bodies}, \nu\text{-free})$ — τ_{66}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>1.3	p, n	90	0		ALEKSEEV	81	BAKS

$\Delta B = 2$ dinucleon modes

$\tau(pp \to \pi^+ \pi^+)$ — τ_{67}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>72.2	**90**	**2**	**4.45**	GUSTAFSON	15	SKAM	per oxygen nucleus
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 0.7	90	4	2.34	BERGER	91B	FREJ	per iron nucleus

$\tau(pn \to \pi^+ \pi^0)$ — τ_{68}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>170	**90**			GUSTAFSON	15	SKAM	per oxygen nucleus
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 2.0	90	0	0.31	BERGER	91B	FREJ	per iron nucleus

$\tau(nn \to \pi^+ \pi^-)$ — τ_{69}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>0.7	**90**	**4**	**2.18**	BERGER	91B	FREJ	τ per iron nucleus

$\tau(n n \to \pi^0 \pi^0)$ — τ_{70}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>404	**90**			GUSTAFSON	15	SKAM	per oxygen nucleus
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 3.4	90	0	0.78	BERGER	91B	FREJ	per iron nucleus

$\tau(p p \to K^+ K^+)$ — τ_{71}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>170	**90**	**0**	**0.28**	LITOS	14	SKAM	τ per oxygen nucleus

$\tau(p p \to e^+ e^+)$ — τ_{72}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>5.8	**90**	**0**	**<0.1**	BERGER	91B	FREJ	τ per iron nucleus

$\tau(p p \to e^+ \mu^+)$ — τ_{73}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>3.6	**90**	**0**	**<0.1**	BERGER	91B	FREJ	τ per iron nucleus

$\tau(p p \to \mu^+ \mu^+)$ — τ_{74}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>1.7	**90**	**0**	**0.62**	BERGER	91B	FREJ	τ per iron nucleus

$\tau(p n \to e^+ \overline{\nu})$ — τ_{75}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>260	**90**			TAKHISTOV	15	SKAM	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 2.8	90	5	9.67	BERGER	91B	FREJ	τ per iron nucleus

$\tau(p n \to \mu^+ \overline{\nu})$ — τ_{76}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>200	**90**			TAKHISTOV	15	SKAM	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 1.6	90	4	4.37	BERGER	91B	FREJ	τ per iron nucleus

$\tau(p n \to \tau^+ \overline{\nu}_\tau)$ — τ_{77}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN
>29	**90**			TAKHISTOV	15	SKAM
• • • We do not use the following data for averages, fits, limits, etc. • • •						
> 1	90			[1] BRYMAN	14	CHER

[1] BRYMAN 14 uses a MCGREW 99 limit on the $p \to e^+ \nu \nu$ lifetime to extract this value.

$\tau(nn \to \text{invisible})$ τ_{78}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>1.4	**90**			[1] ARAKI	06	KLND	$nn \to$ invisible
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>0.015	90			[2,3] ALLEGA	22	SNO+	$nn \to$ invisible
>0.013	90			[2] ANDERSON	19A	SNO+	$nn \to$ invisible
>0.000042	90			[4] TRETYAK	04	CNTR	$nn \to$ invisible
>0.000049	90			[5] BACK	03	BORX	$nn \to$ invisible
>0.000012	90			[6] BERNABEI	00B	DAMA	$nn \to$ invisible

[1] ARAKI 06 looks for signs of de-excitation of the residual nucleus after disappearance of two neutrons from the s shell of ^{12}C.

[2] ALLEGA 22 and ANDERSON 19A look for γ rays from the de-excitation of a residual ^{14}O* following the disappearance of nn in ^{16}O.

[3] ALLEGA 22 replaces the previous SNO+ value of ANDERSON 19A.

[4] TRETYAK 04 uses data from an old Homestake-mine radiochemical experiment on limits for invisible decays of ^{39}K to ^{37}Ar.

[5] BACK 03 looks for decays of unstable nuclides left after NN decays of parent ^{12}C, ^{13}C, ^{16}O nuclei. These are "invisible channel" limits.

[6] BERNABEI 00B looks for the decay of a $^{127}_{54}$Xe nucleus following the disappearance of an nn pair in the otherwise-stable $^{129}_{54}$Xe nucleus. The limit here applies as well to $nn \to \nu_\mu \overline{\nu}_\mu$, $nn \to \nu_\tau \overline{\nu}_\tau$, or any "disappearance" mode.

$\tau(nn \to \nu_e \overline{\nu}_e)$ τ_{79}

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
>0.000012	**90**	**5**	**9.7**	BERGER	91B	FREJ	τ per iron nucleus

$\tau(nn \to \nu_\mu \overline{\nu}_\mu)$ τ_{80}

See the proceeding data block. "Invisible modes" would include any multi-neutrino mode.

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID		TECN	COMMENT
> 1.4 (CL=90%) OUR LIMIT							
• • • We do not use the following data for averages, fits, limits, etc. • • •							
>0.000006	90	4	4.4	BERGER	91B	FREJ	τ per iron nucleus

$\tau(pn \to \text{invisible})$ τ_{81}

This violates charge conservation as well as baryon number conservation.

VALUE (10^{30} years)	CL%	DOCUMENT ID		TECN
>0.06	90	[1,2] ALLEGA	22	SNO+
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>0.026	90	[1] ANDERSON	19A	SNO+
>0.000021	90	[3] TRETYAK	04	CNTR

[1] ALLEGA 22 and ANDERSON 19A look for γ rays from the de-excitation of a residual ^{14}N* following the disappearance of pn in ^{16}O.

[2] ALLEGA 22 replaces the previous SNO+ value of ANDERSON 19A.

[3] TRETYAK 04 uses data from an old Homestake-mine radiochemical experiment on limits for invisible decays of ^{39}K to ^{37}Ar.

$\tau(pp \to \text{invisible})$ τ_{82}

This violates charge conservation as well as baryon number conservation.

VALUE (10^{30} years)	CL%	DOCUMENT ID		TECN
>0.11	90	[1] ALLEGA	22	SNO+
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>0.047	90	[1] ANDERSON	19A	SNO+
>0.00005	90	[2] BACK	03	BORX
>0.00000055	90	[3] BERNABEI	00B	DAMA

[1] ALLEGA 22 look for γ rays from the de-excitation of a residual $^{14}C^*$ following the disappearance of pp in ^{16}O. Supersedes ANDERSON 19A result.

[2] BACK 03 looks for decays of unstable nuclides left after NN decays of parent ^{12}C, ^{13}C, ^{16}O nuclei. These are "invisible channel" limits.

[3] BERNABEI 00B looks for the decay of a $^{127}_{52}$Te nucleus following the disappearance of a pp pair in the otherwise-stable $^{129}_{54}$Xe nucleus.

$\Delta B = 1$

$\overline{p}$ PARTIAL MEAN LIVES

The "partial mean life" limits tabulated here are the limits on $\overline{\tau}/B_i$, where $\overline{\tau}$ is the total mean life for the antiproton and B_i is the branching fraction for the mode in question.

$\tau(\overline{p} \to e^- \gamma)$ τ_{83}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
> 7×10^5	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>1848	95	GEER	94	CALO	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to \mu^- \gamma)$ τ_{84}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>5×10^4	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>5.0×10^4	90	HU	98B	APEX	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to e^- \pi^0)$ τ_{85}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
> 4×10^5	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>554	95	GEER	94	CALO	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to \mu^- \pi^0)$ τ_{86}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>5×10^4	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>4.8×10^4	90	HU	98B	APEX	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to e^- \eta)$ τ_{87}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
> 2 × 10^4	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>171	95	GEER	94	CALO	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to \mu^- \eta)$ τ_{88}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>8 × 10^3	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>7.9 \times 10^3$	90	HU	98B	APEX	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to e^- K^0_S)$ τ_{89}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>900	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
> 29	95	GEER	94	CALO	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to \mu^- K^0_S)$ τ_{90}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>4 × 10^3	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>4.3 \times 10^3$	90	HU	98B	APEX	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to e^- K^0_L)$ τ_{91}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>9 × 10^3	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>9	95	GEER	94	CALO	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to \mu^- K^0_L)$ τ_{92}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>7 × 10^3	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>6.5 \times 10^3$	90	HU	98B	APEX	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to e^- \gamma\gamma)$ τ_{93}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>2 × 10^4	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to \mu^- \gamma\gamma)$ τ_{94}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>2 × 10^4	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>2.3 \times 10^4$	90	HU	98B	APEX	8.9 GeV/c $\overline{p}$ beam

$\tau(\overline{p} \to e^- \omega)$ τ_{95}

VALUE (years)	CL%	DOCUMENT ID		TECN	COMMENT
>200	90	GEER	00	APEX	8.9 GeV/c $\overline{p}$ beam

p REFERENCES

AGOSTINI	24A	EPJ C84 940	M. Agostini et al.	(GERDA Collab.)
TANIUCHI	24	PR D110 112011	N. Taniuchi et al.	(Super-Kamiokande Collab.)
ALLEGA	22	PR D105 112012	A. Allega et al.	(SNO+ Collab.)
BORCHERT	22	NAT 601 53	M.J. Borchert et al.	(BASE Collab.)
LI	22D	NAT 611 265	R. Li et al.	
MATSUMOTO	22	PR D106 072003	R. Matsumoto et al.	(Super-Kamiokande Collab.)
MORNACCHI	22	PRL 129 102501	E. Mornacchi et al.	(MAINZ, REGE, PAVI+)
CUI	21	PRL 127 092001	Z.-F. Cui et al.	(NJU, ECT, HZDR)
CUI	21B	CPL 38 121401	Z.-F. Cui et al.	(NJU, ECT, HZDR)
FINK	21	PRL 127 243001	D.J. Fink, E.G. Myers	(FSU)
MIHOVILOVIC	21	EPJ A57 107	M. Mihovilovic et al.	(LJUB, MAINZ, MIT+)
TIESINGA	21	RMP 93 025010	E. Tiesinga et al.	(NIST)
TAKENAKA	20	PR D102 112011	A. Takenaka et al.	(Super-Kamiokande Collab.)
TANAKA	20	PR D101 052011	M. Tanaka et al.	(Super-Kamiokande Collab.)
ANDERSON	19A	PR D99 032008	M. Anderson et al.	(SNO+ Collab.)
BEZGINOV	19	SCI 365 1007	N. Bezginov et al.	(YORKC, TNTO)
HEISSE	19	PR A100 022518	F. Heisse et al.	(MPIK, GSI, MAINZ)
PASQUINI	19	JP G46 104001	B. Pasquini, P. Pedroni, S. Sconfietti	(PAVI)
SCHUMACHER	19	LHEP 4 4	M. Schumacher	(GOET)
XIONG	19	NAT 575 147	W. Xiong et al.	(PRad Collab.)
FLEURBAEY	18	PRL 120 183001	H. Fleurbaey et al.	(SORB)
PDG	18	PR D98 030001	M. Tanabashi et al.	(PDG Collab.)
ABE	17	PR D95 012004	K. Abe et al.	(Super-Kamiokande Collab.)
ABE	17D	PR D96 012003	K. Abe et al.	(Super-Kamiokande Collab.)
BEYER	17	SCI 358 79	A. Beyer et al.	(MPQG Collab.)
HEISSE	17	PRL 119 033001	F. Heisse et al.	(MPIK, GSI, MAINZ, RIKEN)
NAGAHAMA	17	NATC 8 14084	H. Nagahama et al.	(RIKEN, TOKY, CERN+)
SAHOO	17	PR D95 013002	B.K. Sahoo	(AHMEB)
SCHNEIDER	17	SCI 358 1081	G. Schneider et al.	(MAINZ, RIKEN, +)
SELLNER	17	NJP 19 083023	S. Sellner et al.	(RIKEN, MPIK, +)
SMORRA	17	NAT 550 371	C. Smorra et al.	(RIKEN, CERN, +)
MOHR	16	RMP 88 035009	P.J. Mohr, D.B. Newell, B.N. Taylor	(NIST)
ASAKURA	15	PR D92 052006	K. Asakura et al.	(KamLAND Collab.)
GUSTAFSON	15	PR D91 072009	J. Gustafson et al.	(Super-Kamiokande Collab.)
LEE	15	PR D92 013013	G. Lee, J.R. Arrington, R.J. Hill	(ANL, EFI+)
TAKHISTOV	15	PRL 115 121803	V. Takhistov et al.	(Super-Kamiokande Collab.)
ULMER	15	NAT 524 196	S. Ulmer et al.	(RIKEN, CERN, MPIK, +)
ABE	14E	PRL 113 121802	K. Abe et al.	(Super-Kamiokande Collab.)
ABE	14G	PR D90 072005	K. Abe et al.	(Super-Kamiokande Collab.)
BRYMAN	14	PL B733 190	D. Bryman	(BRCO)
EPSTEIN	14	PR D90 074027	Z. Epstein, G. Paz, J. Roy	(UMD, WAYN)
LITOS	14	PRL 112 131803	M. Litos et al.	(Super-Kamiokande Collab.)
PDG	14	CP C38 070001	K. Olive et al.	(PDG Collab.)
TAKHISTOV	14	PRL 113 101801	V. Takhistov et al.	(Super-Kamiokande Collab.)
ANTOGNINI	13	SCI 339 417	A. Antognini et al.	(MPIM, ETH, UPMC+)
DISCIACCA	13	PRL 110 130801	J. DiSciacca et al.	(ATRAP Collab.)
MCGOVERN	13	EPJ A49 12	J.A. McGovern, D.R. Phillips, H.W. Griesshammer	
MOHR	12	RMP 84 1527	P.J. Mohr, B.N. Taylor, D.B. Newell	(NIST)
NISHINO	12	PR D85 112001	H. Nishino et al.	(Super-Kamiokande Collab.)
REGIS	12	PR D86 012006	C. Regis et al.	(Super-Kamiokande Collab.)
BRESSI	11	PR A83 052101	G. Bressi et al.	(LEGN, PAVII, PADO, TRST+)
HORI	11	NAT 475 484	M. Hori et al.	(MPIG, TOKY, BUDA, +)
ZHAN	11	PL B705 59	X. Zhan et al.	(JLAB-Hall A Collab.)
BERNAUER	10	PRL 105 242001	J.C. Bernauer et al.	(MAMI A1 Collab.)
Also		PR C90 015206	J.C. Bernauer et al.	(MAMI A1 Collab.)
BORISYUK	10	NP A843 59	D. Borisyuk	(KIEV)
HILL	10	PR D82 113005	R.J. Hill, G. Paz	(CHIC)
POHL	10	NAT 466 213	R. Pohl et al.	(MPIQ, ENSP, COIM, +)
NISHINO	09	PRL 102 141801	H. Nishino et al.	(Super-Kamiokande Collab.)
PASK	09	PL B678 55	T. Pask et al.	(Stefan Meyer Inst., Vienna, TOKY+)
MOHR	08	RMP 80 633	P.J. Mohr, B.N. Taylor, D.B. Newell	(NIST)
BELUSHKIN	07	PR C75 035202	M.A. Belushkin, H.W. Hammer, U.-G. Meissner	(BONN+)

ARAKI	06	PRL 96 101802	T. Araki *et al.*	(KamLAND Collab.)
HORI	06	PRL 96 243401	M. Hori *et al.*	(CERN, TOKYO+)
BLUNDEN	05	PR C72 057601	P.G. Blunden, I. Sick	(MANI, BASL)
KOBAYASHI	05	PR D72 052007	K. Kobayashi *et al.*	(Super-Kamiokande Collab.)
MOHR	05	RMP 77 1	P.J. Mohr, B.N. Taylor	(NIST)
SCHUMACHER	05	PPNP 55 567	M. Schumacher	(GOET)
AHMED	04	PRL 92 102004	S.N. Ahmed *et al.*	(SNO Collab.)
TRETYAK	04	JETPL 79 106	V.I. Tretyak, V.Yu. Denisov, Yu.G. Zdesenko	(KIEV)
		Translated from ZETFP 79 136.		
BACK	03	PL B563 23	H.O. Back *et al.*	(Borexino Collab.)
BEANE	03	PL B567 200	S.R. Beane *et al.*	
Also		PL B607 320 (errat.)	S.R. Beane *et al.*	
DMITRIEV	03	PRL 91 212303	V.F. Dmitriev, R.A. Senkov	(NOVO)
HORI	03	PRL 91 123401	M. Hori *et al.*	(CERN ASACUSA Collab.)
SICK	03	PL B576 62	I. Sick	(BASL)
ZDESENKO	03	PL B553 135	Yu.G. Zdesenko, V.I. Tretyak	(KIEV)
AHMAD	02	PRL 89 011301	Q.R. Ahmad *et al.*	(SNO Collab.)
BARANOV	01	PPN 32 376	P.S. Baranov *et al.*	
		Translated from FECAY 32 699.		
BLANPIED	01	PR C64 025203	G. Blanpied *et al.*	(BNL LEGS Collab.)
HORI	01	PRL 87 093401	M. Hori *et al.*	(CERN ASACUSA Collab.)
OLMOSDEL...	01	EPJ A10 207	V. Olmos de Leon *et al.*	(MAMI TAPS Collab.)
TRETYAK	01	PL B505 59	V.I. Tretyak, Yu.G. Zdesenko	(KIEV)
BERNABEI	00B	PL B493 12	R. Bernabei *et al.*	(Gran Sasso DAMA Collab.)
GEER	00	PRL 84 590	S. Geer *et al.*	(FNAL APEX Collab.)
Also		PR D62 052004	S. Geer *et al.*	(FNAL APEX Collab.)
Also		PRL 85 3546 (errat.)	S. Geer *et al.*	(FNAL APEX Collab.)
GEER	00D	APJ 532 648	S.H. Geer, D.C. Kennedy	
SENGUPTA	00	PL B484 275	S. Sengupta	
WALL	00	PR D61 072004	D. Wall *et al.*	(Soudan-2 Collab.)
WALL	00B	PR D62 092003	D. Wall *et al.*	(Soudan-2 Collab.)
GABRIELSE	99	PRL 82 3198	G. Gabrielse *et al.*	
HAYATO	99	PRL 83 1529	Y. Hayato *et al.*	(Super-Kamiokande Collab.)
MCGREW	99	PR D59 052004	C. McGrew *et al.*	(IMB-3 Collab.)
MOHR	99	JPCRD 28 1713	P.J. Mohr, B.N. Taylor	(NIST)
Also		RMP 72 351	P.J. Mohr, B.N. Taylor	(NIST)
TORII	99	PR A59 223	H.A. Torii *et al.*	(CERN PS-205 Collab.)
ALLISON	98	PL B427 217	W.W.M. Allison *et al.*	(Soudan-2 Collab.)
HU	98B	PR D58 111101	M. Hu *et al.*	(FNAL APEX Collab.)
SHIOZAWA	98	PRL 81 3319	M. Shiozawa *et al.*	(Super-Kamiokande Collab.)
GLICENSTEIN	97	PL B411 326	J.F. Glicenstein	(SACL)
GABRIELSE	95	PRL 74 3544	G. Gabrielse *et al.*	(HARV, MAINZ, SEOUL)
MACGIBBON	95	PR C52 2097	B.E. MacGibbon *et al.*	(ILL, SASK, INRM)
GEER	94	PRL 72 1596	S. Geer *et al.*	(FNAL, UCLA, PSU)
HALLIN	93	PR C48 1497	E.L. Hallin *et al.*	(SASK, BOST, ILL)
SUZUKI	93B	PL B311 357	Y. Suzuki *et al.*	(Kamiokande Collab.)
HUGHES	92	PRL 69 578	R.J. Hughes, B.I. Deutch	(LANL, AARH)
ZIEGER	92	PL B278 34	A. Zieger *et al.*	(MPCM)
Also		PL B281 417 (errat.)	A. Zieger *et al.*	(MPCM)
BERGER	91	ZPHY C50 385	C. Berger *et al.*	(FREJUS Collab.)
BERGER	91B	PL B269 227	C. Berger *et al.*	(FREJUS Collab.)
FEDERSPIEL	91	PRL 67 1511	F.J. Federspiel *et al.*	(ILL)
BECKER-SZ...	90	PR D42 2974	R.A. Becker-Szendy *et al.*	(IMB-3 Collab.)
ERICSON	90	EPL 11 295	T.E.O. Ericson, A. Richter	(CERN, DARM)
GABRIELSE	90	PRL 65 1317	G. Gabrielse *et al.*	(HARV, MAINZ, WASH+)
BERGER	89	NP B313 509	C. Berger *et al.*	(FREJUS Collab.)
CHO	89	PRL 63 2559	D. Cho, K. Sangster, E.A. Hinds	(YALE)
HIRATA	89C	PL B220 308	K.S. Hirata *et al.*	(Kamiokande Collab.)
PHILLIPS	89	PL B224 348	T.J. Phillips *et al.*	(HPW Collab.)
KREISSL	88	ZPHY C37 557	A. Kreissl *et al.*	(CERN PS176 Collab.)
SEIDEL	88	PRL 61 2522	S. Seidel *et al.*	(IMB Collab.)
BARTELT	87	PR D36 1990	J.E. Bartelt *et al.*	(Soudan Collab.)
Also		PR D40 1701 (errat.)	J.E. Bartelt *et al.*	(Soudan Collab.)
COHEN	87	RMP 59 1121	E.R. Cohen, B.N. Taylor	(RISC, NBS)
HAINES	86	PRL 57 1986	T.J. Haines *et al.*	(IMB Collab.)
KAJITA	86	JPSJ 55 711	T. Kajita *et al.*	(Kamiokande Collab.)
ARISAKA	85	JPSJ 54 3213	K. Arisaka *et al.*	(Kamiokande Collab.)
BLEWITT	85	PRL 55 2114	G.B. Blewitt *et al.*	(IMB Collab.)
DZUBA	85	PL 154B 93	V.A. Dzuba, V.V. Flambaum, P.G. Silvestrov	(NOVO)
PARK	85	PRL 54 22	H.S. Park *et al.*	(IMB Collab.)
BATTISTONI	84	PL 133B 454	G. Battistoni *et al.*	(NUSEX Collab.)

MARINELLI	84	PL 137B 439	M. Marinelli, G. Morpurgo	(GENO)
WILKENING	84	PR A29 425	D.A. Wilkening, N.F. Ramsey, D.J. Larson	(HARV+)
BARTELT	83	PRL 50 651	J.E. Bartelt *et al.*	(MINN, ANL)
BATTISTONI	82	PL 118B 461	G. Battistoni *et al.*	(NUSEX Collab.)
KRISHNA...	82	PL 115B 349	M.R. Krishnaswamy *et al.*	(TATA, OSKC+)
ALEKSEEV	81	JETPL 33 651	E.N. Alekseev *et al.*	(PNPI)
		Translated from ZETFP 33 664.		
CHERRY	81	PRL 47 1507	M.L. Cherry *et al.*	(PENN, BNL)
COWSIK	80	PR D22 2204	R. Cowsik, V.S. Narasimham	(TATA)
BELL	79	PL 86B 215	M. Bell *et al.*	(CERN)
GOLDEN	79	PRL 43 1196	R.L. Golden *et al.*	(NASA, PSLL)
LEARNED	79	PRL 43 907	J.G. Learned, F. Reines, A. Soni	(UCI)
BREGMAN	78	PL 78B 174	M. Bregman *et al.*	(CERN)
ROBERTS	78	PR D17 358	B.L. Roberts	(WILL, RHEL)
EVANS	77	SCI 197 989	J.C. Evans Jr., R.I. Steinberg	(BNL, PENN)
HU	75	NP A254 403	E. Hu *et al.*	(COLU, YALE)
COHEN	73	JPCRD 2 664	E.R. Cohen, B.N. Taylor	(RISC, NBS)
DYLLA	73	PR A7 1224	H.F. Dylla, J.G. King	(MIT)
DIX	70	Thesis Case	F.W. Dix	(CASE)
HARRISON	69	PRL 22 1263	G.E. Harrison, P.G.H. Sandars, S.J. Wright	(OXF)
GURR	67	PR 158 1321	H.S. Gurr *et al.*	(CASE, WITW)
FLEROV	58	DOKL 3 79	G.N. Flerov *et al.*	(ASCI)