



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

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
1.0072764665789 ± 0.000000000083	OUR EVALUATION	2022	CODATA
1.0072764665789 ± 0.000000000083	MOHR	25	RVUE 2022 CODATA value
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1.007276466574 ± 0.000000000010	¹ FINK	21	SPEC Penning trap
1.007276466621 ± 0.000000000053	² TIESINGA	21	RVUE 2018 CODATA value
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 ± 0.000000000010	MOHR	08	RVUE 2006 CODATA value
1.00727646688 ± 0.000000000013	MOHR	05	RVUE 2002 CODATA value
1.00727646688 ± 0.000000000013	MOHR	99	RVUE 1998 CODATA value
1.007276470 ± 0.0000000012	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2018 CODATA combination in TIESINGA 21 includes data from HEISSE 17, but does not include updates in HEISSE 19, which superseded HEISSE 17.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 $1.5 \times 10^{-11} u$, corresponding to 0.45σ 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 Superseded by HEISSE 19.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: $1 u = 931.494 103 72(29) \text{ MeV}/c^2$ (2022 CODATA value, MOHR 25).

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
938.27208943 ± 0.00000029	OUR EVALUATION	2022	CODATA
938.27208943 ± 0.00000029	MOHR	25	RVUE 2022 CODATA value
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
938.27208812 ± 0.00000029	FINK	21	SPEC Penning trap
938.27208816 ± 0.00000029	TIESINGA	21	RVUE 2018 CODATA value
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

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

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

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

¹HORI 01, HORI 03, HORI 06, and HORI 11 use the more-precisely-known constraint on the \bar{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 $|q_p + q_{\bar{p}}|/e$, below.

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

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

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 \bar{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 \bar{p} 's.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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. ● ● ●			
0.999999999991 ± 0.000000000009	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

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

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

$$\left(\left|\frac{q_{\bar{p}}}{m_{\bar{p}}}\right| - \frac{q_p}{m_p}\right) / \frac{q_p}{m_p}$$

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

VALUE _____ DOCUMENT ID _____
 $(0.3 \pm 1.6) \times 10^{-11}$ OUR EVALUATION

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

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

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

¹ HORI 01, HORI 03, HORI 06, and HORI 11 use the more-precisely-known constraint on the \bar{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 $|m_p - m_{\bar{p}}|/m_p$, above.

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

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>COMMENT</u>
<1 × 10⁻²¹	¹ BRESSI	11 Neutrality of SF ₆
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●		
<3.2 × 10 ⁻²⁰	² SENGUPTA	00 binary pulsar
<0.8 × 10 ⁻²¹	MARINELLI	84 Magnetic levitation
<1.0 × 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 $n \rightarrow p e^- \nu_e$ conserves charge. Thus the limit applies equally to the charge of the neutron.

² SENGUPTA 00 uses the difference between the observed rate of 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.

<u>VALUE (μ_N)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
2.79284734463 ± 0.0000000082	MOHR	25	RVUE 2022 CODATA value
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
2.79284734463 ± 0.0000000082	TIESINGA	21	RVUE 2018 CODATA value
2.79284734462 ± 0.0000000082	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

 \bar{p} MAGNETIC MOMENT

A few early results have been omitted.

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

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

A test of *CPT* invariance.

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

 p ELECTRIC DIPOLE MOMENTA nonzero value is forbidden by both *T* invariance and *P* invariance.

<u>VALUE (10^{−23} ecm)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
< 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 TI 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

¹SAHOO 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 ¹⁹⁹Hg atom.

²This WILKENING 84 value includes a finite-size effect and a magnetic effect.

³This 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 ± 0.8 ± 0.1	¹ MORNACCHI	22	FIT Fit of RCS data sets
10.65 ± 0.35 ± 0.36	MCGOVERN	13	RVUE χ EFT + Compton scattering
12.1 ± 1.1 ± 0.5	² BEANE	03	EFT + γp
11.82 ± 0.98 $\begin{smallmatrix} +0.52 \\ -0.98 \end{smallmatrix}$	³ BLANPIED	01	LEGS $p(\vec{\gamma}, \gamma)$, $p(\vec{\gamma}, \pi^0)$, $p(\vec{\gamma}, \pi^+)$
11.9 ± 0.5 ± 1.3	⁴ OLMOSDEL...	01	CNTR γp Compton scattering
12.1 ± 0.8 ± 0.5	⁵ MACGIBBON	95	RVUE global average

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

12.03 $\begin{smallmatrix} +0.48 \\ -0.54 \end{smallmatrix}$	⁶ PASQUINI	19	fit of RCS data sets
11.7 ± 0.8 ± 0.7	⁷ BARANOV	01	RVUE Global average
12.5 ± 0.6 ± 0.9	MACGIBBON	95	CNTR γp Compton scattering
9.8 ± 0.4 ± 1.1	HALLIN	93	CNTR γp Compton scattering
10.62 $\begin{smallmatrix} +1.25 + 1.07 \\ -1.19 - 1.03 \end{smallmatrix}$	ZIEGER	92	CNTR γp Compton scattering
10.9 ± 2.2 ± 1.3	⁸ FEDERSPIEL	91	CNTR γp Compton scattering

¹MORNACCHI 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.

²BEANE 03 uses effective field theory and low-energy γp and γd Compton-scattering data. It also gets for the isoscalar polarizabilities (see the erratum) $\alpha_N = (13.0 \pm 1.9 \begin{smallmatrix} +3.9 \\ -1.5 \end{smallmatrix}) \times 10^{-4}$ fm³ and $\beta_N = (-1.8 \pm 1.9 \begin{smallmatrix} +2.1 \\ -0.9 \end{smallmatrix}) \times 10^{-4}$ fm³.

³BLANPIED 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.

⁴This OLMOSDELEON 01 result uses the TAPS data alone, and does not use the (re-evaluated) sum-rule constraint that $\alpha + \beta = (13.8 \pm 0.4) \times 10^{-4}$ fm³. 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 $(7.0 \pm 2.2 \pm 1.3) \times 10^{-4} \text{ fm}^3$.

ρ MAGNETIC POLARIZABILITY β_p

The electric and magnetic polarizabilities are subject to a dispersion sum-rule constraint $\bar{\alpha} + \bar{\beta} = (14.2 \pm 0.5) \times 10^{-4} \text{ fm}^3$. Errors here are anticorrelated with those on $\bar{\alpha}_p$ 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	χ EFT + Compton scattering
3.4 ± 1.1 ± 0.1	³ BEANE 03		EFT + γp
1.43 ± 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) $\alpha_N = (13.0 \pm 1.9^{+3.9}_{-1.5}) \times 10^{-4} \text{ fm}^3$ and $\beta_N = (-1.8 \pm 1.9^{+2.1}_{-0.9}) \times 10^{-4} \text{ fm}^3$.
- 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 $\alpha + \beta = (13.8 \pm 0.4) \times 10^{-4} \text{ fm}^3$. 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 $\alpha_p + \beta_p$.

ρ SPIN POLARIZABILITY γ_{E1E1}

<u>VALUE (10^{-4} fm⁴)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$-3.0 \pm 0.6 \pm 0.4$	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.

ρ SPIN POLARIZABILITY γ_{M1M1}

<u>VALUE (10^{-4} fm⁴)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$3.7 \pm 0.5 \pm 0.1$	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.

ρ SPIN POLARIZABILITY γ_{E1M2}

<u>VALUE (10^{-4} fm⁴)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$-1.2 \pm 1.0 \pm 0.3$	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.

ρ SPIN POLARIZABILITY γ_{M1E2}

<u>VALUE (10^{-4} fm⁴)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$2.0 \pm 0.7 \pm 0.4$	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.

ρ 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 XIONG 19, and the atomic-hydrogen result BEZGINOV 19. These can be compared to another atomic-hydrogen value BEYER 17 and with the best measurement using muonic hydrogen Lamb shift ANTOGNINI 13, that is far more precise.

The latest 2022 CODATA recommendation (MOHR 25) is based on much improved theory descriptions for muonic hydrogen Lamb shift and the atomic-hydrogen transitions. MOHR 25 do not include the electron scattering data because of a lack of consensus as to how the electron-scattering

data should be analyzed, and there remains some tension between the different r_p measurements. See GAO 22A for an updated discussion.

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

<u>VALUE (fm)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
0.84075 ± 0.00064	¹ MOHR 25	RVUE	2022 CODATA
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.847 ± 0.008	² CUI 21	FIT	use existing ep data
0.878 ± 0.011 ± 0.031	³ MIHOVILOVIC 21		ISR $ep \rightarrow ep$ reanalysis
0.833 ± 0.010	⁴ BEZGINOV 19	LASR	2S-2P transition in H
0.831 ± 0.007 ± 0.012	⁵ XIONG 19	SPEC	$ep \rightarrow ep$ form factor
0.877 ± 0.013	⁶ FLEURBAEY 18	LASR	1S-3S transition in H
0.8335 ± 0.0095	⁷ BEYER 17	LASR	2S-4P transition in H
0.8751 ± 0.0061	MOHR 16	RVUE	2014 CODATA value
0.895 ± 0.014 ± 0.014	⁸ LEE 15	SPEC	Just 2010 Mainz data
0.916 ± 0.024	LEE 15	SPEC	World data, no Mainz
0.84087 ± 0.00026 ± 0.00029	ANTOIGNINI 13	LASR	μp -atom Lamb shift
0.8775 ± 0.0051	MOHR 12	RVUE	2010 CODATA, ep data
0.875 ± 0.008 ± 0.006	ZHAN 11	SPEC	Recoil polarimetry
0.879 ± 0.005 ± 0.006	BERNAUER 10	SPEC	$ep \rightarrow ep$ form factor
0.912 ± 0.009 ± 0.007	BORISYUK 10		reanalyzes old ep data
0.871 ± 0.009 ± 0.003	HILL 10		z-expansion reanalysis
0.84184 ± 0.00036 ± 0.00056	POHL 10	LASR	See ANTOIGNINI 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		$ep \rightarrow ep$ reanalysis

¹ MOHR 25 do not include the electron scattering data.

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

³ MIHOVILOVIC 21 reports a value of $0.878 \pm 0.011 \pm 0.031 \pm 0.002$ fm where the last uncertainty comes from the dependence on the model form factor function.

⁴ 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.

⁵ The XIONG 19 value from $ep \rightarrow ep$ scattering and supports the muonic hydrogen Lamb shift value.

⁶ 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.

⁷ 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.

⁸ Authors also provide values for combinations of all available data.

p MAGNETIC RADIUSThis 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	$ep \rightarrow ep$ form factor
0.876 ± 0.010 ± 0.016	BORISYUK	10	Reanalyzes old $ep \rightarrow ep$ 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 × 10³⁰	p	90	¹ ALLEGA	22 SNO+	$p \rightarrow$ invisible
>0.9 × 10³⁰	n	90	² ALLEGA	22 SNO+	$n \rightarrow$ invisible
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
>1.3 × 10 ²⁴	p	90	³ AGOSTINI	24A HPGE	$p \rightarrow$ invisible
>1.5 × 10 ²⁴	n	90	⁴ AGOSTINI	24A HPGE	$n \rightarrow$ invisible
>3.6 × 10 ²⁹	p	90	⁵ ANDERSON	19A SNO+	$p \rightarrow$ invisible
>2.5 × 10 ²⁹	n	90	⁵ ANDERSON	19A SNO+	$n \rightarrow$ invisible
>5.8 × 10 ²⁹	n	90	⁶ ARAKI	06 KLND	$n \rightarrow$ invisible
>2.1 × 10 ²⁹	p	90	⁵ AHMED	04 SNO	$p \rightarrow$ invisible
>1.9 × 10 ²⁹	n	90	⁵ AHMED	04 SNO	$n \rightarrow$ invisible
>1.8 × 10 ²⁵	n	90	⁷ BACK	03 BORX	
>1.1 × 10 ²⁶	p	90	⁷ BACK	03 BORX	
>3.5 × 10 ²⁸	p	90	⁸ ZDESENKO	03	$p \rightarrow$ invisible
>1 × 10 ²⁸	p	90	⁹ AHMAD	02 SNO	$p \rightarrow$ invisible
>4 × 10 ²³	p	95	TRETYAK	01	$d \rightarrow n + ?$
>1.9 × 10 ²⁴	p	90	¹⁰ BERNABEI	00B DAMA	
>1.6 × 10 ²⁵	p, n		^{11,12} EVANS	77	
>3 × 10 ²³	p		¹² DIX	70 CNTR	
>3 × 10 ²³	p, n		^{12,13} FLEROV	58	

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

- 2 ALLEGA 22 look for γ rays from the de-excitation of a residual $^{15}\text{O}^*$ following the disappearance of n in ^{16}O .
- 3 AGOSTINI 24A look for γ rays from the de-excitation of a residual $^{75}\text{As}^*$ following the disappearance of p in ^{76}Ge (through the transition chain $^{76}\text{Ge} \rightarrow ^{75}\text{Ga} \rightarrow ^{75}\text{Ge} \rightarrow ^{75}\text{As}$).
- 4 AGOSTINI 24A look for γ rays from the de-excitation of a residual $^{75}\text{As}^*$ following the disappearance of n in ^{76}Ge (through the transition chain $^{76}\text{Ge} \rightarrow ^{75}\text{Ge} \rightarrow ^{75}\text{As}$).
- 5 AHMED 04 and ANDERSON 19A look for γ rays from the de-excitation of a residual $^{15}\text{O}^*$ or $^{15}\text{N}^*$ 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 $^{128}_{53}\text{I}$ nucleus following the disappearance of a proton in the otherwise-stable $^{129}_{54}\text{Xe}$ 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.

\bar{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 “ \bar{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 $\bar{p} \rightarrow e^- \gamma$. We advance only the exclusive-mode limits to our Summary Tables.

<u>LIMIT</u> (years)	<u>CL%</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● 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	\bar{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 \bar{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 \bar{p} production and propagation and the observed \bar{p}/p cosmic-ray spectrum to set this limit.

ρ 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 $N \rightarrow e^+ \pi$	> 5300 (n), > 24000 (p)	90%
τ_2 $N \rightarrow \mu^+ \pi$	> 3500 (n), > 16000 (p)	90%
τ_3 $N \rightarrow \nu \pi$	> 1100 (n), > 390 (p)	90%
τ_4 $p \rightarrow e^+ \eta$	> 10000	90%
τ_5 $p \rightarrow \mu^+ \eta$	> 4700	90%
τ_6 $n \rightarrow \nu \eta$	> 158	90%
τ_7 $N \rightarrow e^+ \rho$	> 217 (n), > 720 (p)	90%
τ_8 $N \rightarrow \mu^+ \rho$	> 228 (n), > 570 (p)	90%
τ_9 $N \rightarrow \nu \rho$	> 19 (n), > 162 (p)	90%
τ_{10} $p \rightarrow e^+ \omega$	> 1600	90%
τ_{11} $p \rightarrow \mu^+ \omega$	> 2800	90%
τ_{12} $n \rightarrow \nu \omega$	> 108	90%
τ_{13} $N \rightarrow e^+ K$	> 17 (n), > 1000 (p)	90%
τ_{14} $p \rightarrow e^+ K_S^0$		
τ_{15} $p \rightarrow e^+ K_L^0$		
τ_{16} $N \rightarrow \mu^+ K$	> 26 (n), > 4500 (p)	90%
τ_{17} $p \rightarrow \mu^+ K_S^0$		
τ_{18} $p \rightarrow \mu^+ K_L^0$		
τ_{19} $N \rightarrow \nu K$	> 86 (n), > 5900 (p)	90%
τ_{20} $n \rightarrow \nu K_S^0$	> 1560	90%
τ_{21} $p \rightarrow e^+ K^*(892)^0$	> 84	90%
τ_{22} $N \rightarrow \nu K^*(892)$	> 78 (n), > 51 (p)	90%
Antilepton + mesons		
τ_{23} $p \rightarrow e^+ \pi^+ \pi^-$	> 82	90%
τ_{24} $p \rightarrow e^+ \pi^0 \pi^0$	> 147	90%
τ_{25} $n \rightarrow e^+ \pi^- \pi^0$	> 52	90%
τ_{26} $p \rightarrow \mu^+ \pi^+ \pi^-$	> 133	90%
τ_{27} $p \rightarrow \mu^+ \pi^0 \pi^0$	> 101	90%
τ_{28} $n \rightarrow \mu^+ \pi^- \pi^0$	> 74	90%
τ_{29} $n \rightarrow e^+ K^0 \pi^-$	> 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}	$n \rightarrow 3\nu$	> 5×10^{-4}	90%
τ_{61}	$n \rightarrow 5\nu$		

Inclusive modes

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

$\Delta B = 2$ dinucleon modes

The following are lifetime limits per iron nucleus.

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

\bar{p} DECAY MODES

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

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

$\tau(N \rightarrow \mu^+ \pi)$

τ_2

<i>LIMIT</i> (10^{30} years)	<i>PARTICLE</i>	<i>CL%</i>	<i>EVTS</i>	<i>BKGD EST</i>	<i>DOCUMENT ID</i>	<i>TECN</i>
>16000	<i>p</i>	90	1	0.94	¹ TAKENAKA 20	SKAM
> 3500	<i>n</i>	90	1	0.77	ABE 17D	SKAM
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
> 7700	<i>p</i>	90	2	0.87	ABE 17	SKAM
> 1000	<i>n</i>	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.

$\tau(N \rightarrow \nu\pi)$

T3

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
> 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.

$\tau(p \rightarrow e^+ \eta)$

74

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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.

$\tau(p \rightarrow \mu^+ \eta)$

75

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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.

$\tau(n \rightarrow \nu \eta)$

76

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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	<i>n</i>	90	4	3	PARK	85	IMB
> 0.6	<i>n</i>	90	2		¹ CHERRY	81	HOME

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

$\tau(N \rightarrow e^+ \rho)$

T7

<u>LIMIT</u> (10 ³⁰ years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>720	<i>p</i>	90	2	0.64	ABE	17D SKAM
>217	<i>n</i>	90	4	4.8	MCGREW	99 IMB3

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

> 30	<i>n</i>	90	4	0.87	ABE	17D SKAM
>710	<i>p</i>	90	0	0.35	NISHINO	12 SKAM
> 70	<i>n</i>	90	1	0.38	NISHINO	12 SKAM
> 29	<i>p</i>	90	0	2.2	BERGER	91 FREJ
> 41	<i>n</i>	90	0	1.4	BERGER	91 FREJ
> 75	<i>p</i>	90	2	2.7	HIRATA	89C KAMI
> 58	<i>n</i>	90	0	1.9	HIRATA	89C KAMI
> 38	<i>n</i>	90	2	4.1	SEIDEL	88 IMB
> 1.2	<i>p</i>	90	0		BARTELT	87 SOUD
> 1.5	<i>n</i>	90	0		BARTELT	87 SOUD
> 17	<i>p</i>	90	7	7	HAINES	86 IMB
> 14	<i>n</i>	90	9	4	HAINES	86 IMB
> 12	<i>p</i>	90	0	<1.2	ARISAKA	85 KAMI
> 6	<i>n</i>	90	2	<1	ARISAKA	85 KAMI
> 6.7	<i>p</i> (free)	90	6	6	BLEWITT	85 IMB
> 17	<i>p</i>	90	7	7	BLEWITT	85 IMB
> 12	<i>n</i>	90	4	2	PARK	85 IMB
> 0.6	<i>n</i>	90	1	0.3	¹ BARTELT	83 SOUD
> 0.5	<i>p</i>	90	1	0.3	¹ BARTELT	83 SOUD
> 9.8	<i>p</i>	90	1		² KRISHNA...	82 KOLR
> 0.8	<i>p</i>	90	2		³ CHERRY	81 HOME

¹Limit based on zero events.

²We have calculated 90% CL limit from 0 confined events.

³We have converted 2 possible events to 90% CL limit.

$\tau(N \rightarrow \mu^+ \rho)$

T8

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

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

> 60	<i>n</i>	90	1	0.96	ABE	17D SKAM
>160	<i>p</i>	90	1	0.42	NISHINO	12 SKAM
> 36	<i>n</i>	90	0	0.29	NISHINO	12 SKAM
> 12	<i>p</i>	90	0	0.5	BERGER	91 FREJ
> 22	<i>n</i>	90	0	1.1	BERGER	91 FREJ
>110	<i>p</i>	90	0	1.7	HIRATA	89C KAMI
> 23	<i>n</i>	90	1	1.8	HIRATA	89C KAMI
> 4.3	<i>p</i>	90	0	0.7	PHILLIPS	89 HPW
> 30	<i>p</i>	90	0	0.5	SEIDEL	88 IMB

> 11	<i>n</i>	90	1	1.1	SEIDEL	88	IMB
> 16	<i>p</i>	90	4	4.5	HAINES	86	IMB
> 7	<i>n</i>	90	6	5	HAINES	86	IMB
> 12	<i>p</i>	90	0	<0.7	ARISAKA	85	KAMI
> 5	<i>n</i>	90	1	<1.2	ARISAKA	85	KAMI
> 5.5	<i>p</i> (free)	90	4	5	BLEWITT	85	IMB
> 16	<i>p</i>	90	4	5	BLEWITT	85	IMB
> 9	<i>n</i>	90	1	2	PARK	85	IMB

$\tau(N \rightarrow \nu\rho)$

79

<i>LIMIT</i> (10 ³⁰ years)	<i>PARTICLE</i>	<i>CL%</i>	<i>EVTS</i>	<i>BKGD EST</i>	<i>DOCUMENT ID</i>	<i>TECN</i>
>162	<i>p</i>	90	18	21.7	MCGREW	99 IMB3
> 19	<i>n</i>	90	0	0.5	SEIDEL	88 IMB

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

> 9	<i>n</i>	90	4	2.4	BERGER	89 FREJ
> 24	<i>p</i>	90	0	0.9	BERGER	89 FREJ
> 27	<i>p</i>	90	5	1.5	HIRATA	89C KAMI
> 13	<i>n</i>	90	4	3.6	HIRATA	89C KAMI
> 13	<i>p</i>	90	1	1.1	SEIDEL	88 IMB
> 8	<i>p</i>	90	6	5	HAINES	86 IMB
> 2	<i>n</i>	90	15	10	HAINES	86 IMB
> 11	<i>p</i>	90	2	1	KAJITA	86 KAMI
> 4	<i>n</i>	90	2	2	KAJITA	86 KAMI
> 4.1	<i>p</i> (free)	90	6	7	BLEWITT	85 IMB
> 8.4	<i>p</i>	90	6	5	BLEWITT	85 IMB
> 2	<i>n</i>	90	7	3	PARK	85 IMB
> 0.9	<i>p</i>	90	2		¹ CHERRY	81 HOME
> 0.6	<i>n</i>	90	2		¹ CHERRY	81 HOME

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

$\tau(p \rightarrow e^+\omega)$

710

<i>LIMIT</i> (10 ³⁰ years)	<i>PARTICLE</i>	<i>CL%</i>	<i>EVTS</i>	<i>BKGD EST</i>	<i>DOCUMENT ID</i>	<i>TECN</i>
>1600	<i>p</i>	90	1	1.35	ABE	17D SKAM

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

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

¹Limit based on zero events.

²We have calculated 90% CL limit from 0 confined events.

³We have converted 2 possible events to 90% CL limit.

$\tau(p \rightarrow \mu^+ \omega)$

τ_{11}

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(n \rightarrow \nu \omega)$

τ_{12}

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

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

$\tau(N \rightarrow e^+ K)$

τ_{13}

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(p \rightarrow e^+ K_S^0)$

τ_{14}

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
● ● ● 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

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

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
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• • • 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 ≤ 0.1 BERGER 91 FREJ

$\tau(N \rightarrow \mu^+ K)$ τ_{16}

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
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>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 $p \rightarrow \mu^+ K_S^0$.

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.

$\tau(p \rightarrow \mu^+ K_S^0)$ 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

$\tau(p \rightarrow \mu^+ K_L^0)$ 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 $n \rightarrow \nu K_S^0$.

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.

$\tau(n \rightarrow \nu K_S^0)$

τ_{20}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN
>1560	n	90	198	166	¹ YAMAUCHI 25	SKAM
> 260	n	90	34	30	² KOBAYASHI 05	SKAM
> 51	n	90	16	9.1	WALL 00	SOU2

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

¹ We have doubled the $n \rightarrow \nu K_S^0$ limit given in YAMAUCHI 25 to obtain this $n \rightarrow \nu K_S^0$ limit. The result is based on the full 0.401 Mton·year exposure of all pure water phases.
² Superseded by YAMAUCHI 25. We have doubled the $n \rightarrow \nu K_S^0$ limit given in KOBAYASHI 05 to obtain this $n \rightarrow \nu K_S^0$ limit.

$\tau(p \rightarrow e^+ K^*(892)^0)$

τ_{21}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN
>84	p	90	38	52.0	MCGREW 99	IMB3
>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

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

$\tau(N \rightarrow \nu K^*(892))$

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
>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 —————

$\tau(p \rightarrow e^+ \pi^+ \pi^-)$

τ_{23}

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN
>82	p	90	16	23.1	MCGREW 99	IMB3
>21	p	90	0	2.2	BERGER 91	FREJ

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

$\tau(p \rightarrow e^+ \pi^0 \pi^0)$ **T24**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(n \rightarrow e^+ \pi^- \pi^0)$ **T25**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(p \rightarrow \mu^+ \pi^+ \pi^-)$ **T26**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(p \rightarrow \mu^+ \pi^0 \pi^0)$ **T27**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(n \rightarrow \mu^+ \pi^- \pi^0)$ **T28**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(n \rightarrow e^+ K^0 \pi^-)$ **T29**

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

————— **Lepton + meson** —————

$\tau(n \rightarrow e^- \pi^+)$ **T30**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(n \rightarrow \mu^- \pi^+)$ **T31**

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

$\tau(n \rightarrow e^- \rho^+)$ **T32**

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

$\tau(n \rightarrow \mu^- \rho^+)$ **T33**

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

$\tau(n \rightarrow e^- K^+)$ **T34**

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

$\tau(n \rightarrow \mu^- K^+)$ **T35**

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

————— **Lepton + mesons** —————

$\tau(p \rightarrow e^- \pi^+ \pi^+)$ **T36**

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

$\tau(n \rightarrow e^- \pi^+ \pi^0)$ **T37**

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

$\tau(p \rightarrow \mu^- \pi^+ \pi^+)$ **T38**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>17	<i>p</i>	90	1	1.72	BERGER	91B FREJ

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

> 7.8	<i>p</i>	90	0	0.7	PHILLIPS	89 HPW
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$\tau(n \rightarrow \mu^- \pi^+ \pi^0)$ **T39**

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

$\tau(p \rightarrow e^- \pi^+ K^+)$ **T40**

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

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

>20	<i>p</i>	90	3	2.50	BERGER	91B FREJ
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$\tau(p \rightarrow \mu^- \pi^+ K^+)$ **T41**

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

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

> 5	<i>p</i>	90	2	0.78	BERGER	91B FREJ
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————— **Antilepton + photon(s)** —————

$\tau(p \rightarrow e^+ \gamma)$ **T42**

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

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

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

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

$\tau(p \rightarrow \mu^+ \gamma)$ **T43**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>478	<i>p</i>	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

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

$\tau(n \rightarrow \nu\gamma)$

T44

<u>LIMIT</u> (10 ³⁰ years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(p \rightarrow e^+\gamma\gamma)$

T45

<u>LIMIT</u> (10 ³⁰ years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>100	p	90	1	0.8	BERGER 91	FREJ

$\tau(n \rightarrow \nu\gamma\gamma)$

T46

<u>LIMIT</u> (10 ³⁰ years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>219	n	90	5	7.5	MCGREW 99	IMB3

————— **Antilepton + single massless** —————

$\tau(p \rightarrow e^+X)$

T47

<u>VALUE</u> (10 ³⁰ years)	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>790	90	TAKHISTOV 15	SKAM

$\tau(p \rightarrow \mu^+X)$

T48

<u>VALUE</u> (10 ³⁰ years)	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>410	90	TAKHISTOV 15	SKAM

————— **Three (or more) leptons** —————

$\tau(p \rightarrow e^+e^+e^-)$

T49

<u>LIMIT</u> (10 ³⁰ years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(p \rightarrow e^+ \mu^+ \mu^-)$ **T50**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(p \rightarrow e^+ \nu \nu)$ **T51**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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.

$\tau(n \rightarrow e^+ e^- \nu)$ **T52**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(n \rightarrow \mu^+ e^- \nu)$ **T53**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(n \rightarrow \mu^+ \mu^- \nu)$ **T54**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(p \rightarrow \mu^+ e^+ e^-)$ **T55**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

$\tau(p \rightarrow \mu^- e^+ e^+)$ **T56**

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

$\tau(p \rightarrow \mu^+ \mu^+ \mu^-)$ **T57**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

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

$\tau(p \rightarrow \mu^+ \nu \nu)$ **T58**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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
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¹Allowed events at 90% CL are 286.

$\tau(p \rightarrow e^- \mu^+ \mu^+)$ **T59**

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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
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$\tau(n \rightarrow 3\nu)$ **T60**

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.

<u>LIMIT</u> (10^{30} years)	<u>PARTICLE</u>	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
>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

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

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

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

$\tau(n \rightarrow 5\nu)$

T61

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

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN
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• • • We do not use the following data for averages, fits, limits, etc. • • •

>0.0017	n	90			¹ GLICENSTEIN 97	KAMI
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¹ GLICENSTEIN 97 uses Kamioka data and the idea that the disappearance of the neutron's magnetic moment should produce radiation.

————— **Inclusive modes** —————

 $\tau(N \rightarrow e^+ \text{ anything})$

T62

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN
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>0.6	p, n	90			¹ LEARNED 79	RVUE
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¹ The electron may be primary or secondary.

 $\tau(N \rightarrow \mu^+ \text{ anything})$

T63

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN
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>12	p, n	90	2		^{1,2} CHERRY 81	HOME
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• • • We do not use the following data for averages, fits, limits, etc. • • •

> 1.8	p, n	90			² COWSIK 80	CNTR
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> 6	p, n	90			² LEARNED 79	RVUE
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¹ We have converted 2 possible events to 90% CL limit.

² The muon may be primary or secondary.

 $\tau(N \rightarrow \nu \text{ anything})$

T64

Anything = π, ρ, K , etc.

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN
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• • • We do not use the following data for averages, fits, limits, etc. • • •

>0.0002	p, n	90	0		LEARNED 79	RVUE
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 $\tau(N \rightarrow e^+ \pi^0 \text{ anything})$

T65

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN
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>0.6	p, n	90	0		LEARNED 79	RVUE
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 $\tau(N \rightarrow 2 \text{ bodies, } \nu\text{-free})$

T66

LIMIT (10^{30} years)	PARTICLE	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN
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• • • We do not use the following data for averages, fits, limits, etc. • • •

>1.3	p, n	90	0		ALEKSEEV 81	BAKS
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————— **$\Delta B = 2$ dinucleon modes** —————

 $\tau(pp \rightarrow \pi^+ \pi^+)$

T67

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

> 0.7	90	4	2.34	BERGER 91B	FREJ	per iron nucleus
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$\tau(pn \rightarrow \pi^+ \pi^0)$ **T68**

<u>LIMIT</u> (10^{30} years)	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
>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

$\tau(nn \rightarrow \pi^+ \pi^-)$ **T69**

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

$\tau(nn \rightarrow \pi^0 \pi^0)$ **T70**

<u>LIMIT</u> (10^{30} years)	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
>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

$\tau(pp \rightarrow K^+ K^+)$ **T71**

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

$\tau(pp \rightarrow e^+ e^+)$ **T72**

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

$\tau(pp \rightarrow e^+ \mu^+)$ **T73**

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

$\tau(pp \rightarrow \mu^+ \mu^+)$ **T74**

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

$\tau(pn \rightarrow e^+ \bar{\nu})$ **T75**

<u>LIMIT</u> (10^{30} years)	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
>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

$\tau(pn \rightarrow \mu^+ \bar{\nu})$ **T76**

<u>LIMIT</u> (10^{30} years)	<u>CL%</u>	<u>EVTS</u>	<u>BKGD EST</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
>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

$\tau(pn \rightarrow \tau^+ \bar{\nu}_\tau)$

T77

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

 $\tau(nn \rightarrow \text{invisible})$

T78

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN	COMMENT
>1.4	90			¹ ARAKI	06 KLND	$nn \rightarrow \text{invisible}$

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

>0.015	90			^{2,3} ALLEGA	22 SNO+	$nn \rightarrow \text{invisible}$
>0.013	90			² ANDERSON	19A SNO+	$nn \rightarrow \text{invisible}$
>0.000042	90			⁴ TRETYAK	04 CNTR	$nn \rightarrow \text{invisible}$
>0.000049	90			⁵ BACK	03 BORX	$nn \rightarrow \text{invisible}$
>0.000012	90			⁶ BERNABEI	00B DAMA	$nn \rightarrow \text{invisible}$

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

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

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

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

⁵BACK 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.

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

 $\tau(nn \rightarrow \nu_e \bar{\nu}_e)$

T79

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

 $\tau(nn \rightarrow \nu_\mu \bar{\nu}_\mu)$

T80

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
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 $\tau(pn \rightarrow \text{invisible})$

T81

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+
>0.026	90	¹ ANDERSON	19A SNO+
>0.000021	90	³ TRETYAK	04 CNTR

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

- ¹ ALLEGA 22 and ANDERSON 19A look for γ rays from the de-excitation of a residual $^{14}\text{N}^*$ following the disappearance of pn in ^{16}O .
² ALLEGA 22 replaces the previous SNO+ value of ANDERSON 19A.
³ TRETAYAK 04 uses data from an old Homestake-mine radiochemical experiment on limits for invisible decays of ^{39}K to ^{37}Ar .

$\tau(pp \rightarrow \text{invisible})$

T82

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
>0.0000055	90	³ BERNABEI 00B	DAMA

- ¹ ALLEGA 22 look for γ rays from the de-excitation of a residual $^{14}\text{C}^*$ 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 $^{127}_{52}\text{Te}$ nucleus following the disappearance of a pp pair in the otherwise-stable $^{129}_{54}\text{Xe}$ nucleus.

———— **$\Delta B = 1$** ————

\bar{p} PARTIAL MEAN LIVES

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

$\tau(\bar{p} \rightarrow e^- \gamma)$

T83

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

$\tau(\bar{p} \rightarrow \mu^- \gamma)$

T84

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
> 5×10^4	90	GEER 00	APEX	8.9 GeV/c \bar{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 \bar{p} beam

$\tau(\bar{p} \rightarrow e^- \pi^0)$

T85

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

$\tau(\bar{p} \rightarrow \mu^- \pi^0)$

T86

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
> 5×10^4	90	GEER 00	APEX	8.9 GeV/c \bar{p} beam

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

$>4.8 \times 10^4$ 90 HU 98B APEX 8.9 GeV/ c \bar{p} beam

$\tau(\bar{p} \rightarrow e^- \eta)$ T87

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

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

>171 95 GEER 94 CALO 8.9 GeV/ c \bar{p} beam

$\tau(\bar{p} \rightarrow \mu^- \eta)$ T88

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
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$>8 \times 10^3$ 90 GEER 00 APEX 8.9 GeV/ c \bar{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 \bar{p} beam

$\tau(\bar{p} \rightarrow e^- K_S^0)$ T89

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
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>900 90 GEER 00 APEX 8.9 GeV/ c \bar{p} beam

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

> 29 95 GEER 94 CALO 8.9 GeV/ c \bar{p} beam

$\tau(\bar{p} \rightarrow \mu^- K_S^0)$ T90

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
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$>4 \times 10^3$ 90 GEER 00 APEX 8.9 GeV/ c \bar{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 \bar{p} beam

$\tau(\bar{p} \rightarrow e^- K_L^0)$ T91

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
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$>9 \times 10^3$ 90 GEER 00 APEX 8.9 GeV/ c \bar{p} beam

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

>9 95 GEER 94 CALO 8.9 GeV/ c \bar{p} beam

$\tau(\bar{p} \rightarrow \mu^- K_L^0)$ T92

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
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$>7 \times 10^3$ 90 GEER 00 APEX 8.9 GeV/ c \bar{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 \bar{p} beam

$\tau(\bar{p} \rightarrow e^- \gamma\gamma)$ T93

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

$\tau(\bar{p} \rightarrow \mu^- \gamma\gamma)$ T94

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

$\tau(\bar{p} \rightarrow e^- \omega)$

795

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

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BERGER	89	NP B313 509	C. Berger <i>et al.</i>	(FREJUS Collab.)
CHO	89	PRL 63 2559	D. Cho, K. Sangster, E.A. Hinds	(YALE)
HIRATA	89C	PL B220 308	K.S. Hirata <i>et al.</i>	(Kamiokande Collab.)
PHILLIPS	89	PL B224 348	T.J. Phillips <i>et al.</i>	(HPW Collab.)
KREISSL	88	ZPHY C37 557	A. Kreissl <i>et al.</i>	(CERN PS176 Collab.)
SEIDEL	88	PRL 61 2522	S. Seidel <i>et al.</i>	(IMB Collab.)
BARTELT	87	PR D36 1990	J.E. Bartelt <i>et al.</i>	(Soudan Collab.)
Also		PR D40 1701 (errat.)	J.E. Bartelt <i>et al.</i>	(Soudan Collab.)
COHEN	87	RMP 59 1121	E.R. Cohen, B.N. Taylor	(RISC, NBS)
HAINES	86	PRL 57 1986	T.J. Haines <i>et al.</i>	(IMB Collab.)
KAJITA	86	JPSJ 55 711	T. Kajita <i>et al.</i>	(Kamiokande Collab.)
ARISAKA	85	JPSJ 54 3213	K. Arisaka <i>et al.</i>	(Kamiokande Collab.)
BLEWITT	85	PRL 55 2114	G.B. Blewitt <i>et al.</i>	(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 <i>et al.</i>	(IMB Collab.)
BATTISTONI	84	PL 133B 454	G. Battistoni <i>et al.</i>	(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 <i>et al.</i>	(MINN, ANL)
BATTISTONI	82	PL 118B 461	G. Battistoni <i>et al.</i>	(NUSEX Collab.)
KRISHNA...	82	PL 115B 349	M.R. Krishnaswamy <i>et al.</i>	(TATA, OSKC+)
ALEKSEEV	81	JETPL 33 651	E.N. Alekseev <i>et al.</i>	(PNPI)
CHERRY	81	PRL 47 1507	M.L. Cherry <i>et al.</i>	(PENN, BNL)
COWSIK	80	PR D22 2204	R. Cowsik, V.S. Narasimham	(TATA)
BELL	79	PL 86B 215	M. Bell <i>et al.</i>	(CERN)
GOLDEN	79	PRL 43 1196	R.L. Golden <i>et al.</i>	(NASA, PSSL)
LEARNED	79	PRL 43 907	J.G. Learned, F. Reines, A. Soni	(UCI)
BREGMAN	78	PL 78B 174	M. Bregman <i>et al.</i>	(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 <i>et al.</i>	(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 <i>et al.</i>	(CASE, WITW)
FLEROV	58	DOKL 3 79	G.N. Flerov <i>et al.</i>	(ASCI)