



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

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.

<u>VALUE (u)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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 ± 0.000000000010	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2018 CODATA combination in TIESINGA 21 includes data from HEISSE 17, but does not include updates in HEISSE 19, which superseded HEISSE 17.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 Superseded by HEISSE 19.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: $1 u = 931.494 102 42(28) \text{ MeV}/c^2$ (2018 CODATA value, TIESINGA 21).

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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 ± 0.0000021	MOHR	12	RVUE 2010 CODATA value
938.272013 ± 0.0000023	MOHR	08	RVUE 2006 CODATA value
938.272029 ± 0.0000080	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

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

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

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. ● ● ●			
0.99999999991 ± 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

¹Equation (2) of GABRIELSE 95 should read $M(\bar{p})/M(p) = 0.999\,999\,99\bar{5}$ (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 _____
 $(0.1 \pm 6.9) \times 10^{-11}$ 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>
$2.79284734463 \pm 0.0000000082$	TIESINGA	21	RVUE 2018 CODATA value
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$2.79284734462 \pm 0.0000000082$	SCHNEIDER	17	TRAP Double Penning trap
$2.7928473508 \pm 0.0000000085$	MOHR	16	RVUE 2014 CODATA value
$2.792847356 \pm 0.000000023$	MOHR	12	RVUE 2010 CODATA value
$2.792847356 \pm 0.000000023$	MOHR	08	RVUE 2006 CODATA value
$2.792847351 \pm 0.000000028$	MOHR	05	RVUE 2002 CODATA value
$2.792847337 \pm 0.000000029$	MOHR	99	RVUE 1998 CODATA value
$2.792847386 \pm 0.000000063$	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>
$-2.7928473441 \pm 0.0000000042$	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.

ρ ELECTRIC POLARIZABILITY α_ρ

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

VALUE (10^{-4} fm ³)	DOCUMENT ID	TECN	COMMENT
11.2 ± 0.4 OUR AVERAGE			
10.65 ± 0.35 ± 0.36	MCGOVERN	13	RVUE χ EFT + Compton scattering
12.1 ± 1.1 ± 0.5	¹ BEANE	03	EFT + γp
11.82 ± 0.98 ^{+0.52} / _{-0.98}	² BLANPIED	01	LEGS $\rho(\vec{\gamma}, \gamma)$, $\rho(\vec{\gamma}, \pi^0)$, $\rho(\vec{\gamma}, \pi^+)$
11.9 ± 0.5 ± 1.3	³ OLMOSDEL...	01	CNTR γp Compton scattering
12.1 ± 0.8 ± 0.5	⁴ MACGIBBON	95	RVUE global average

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

12.03 ^{+0.48} / _{-0.54}	⁵ PASQUINI	19	fit of RCS data sets
11.7 ± 0.8 ± 0.7	⁶ 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 ^{+1.25} / _{-1.19} ^{+1.07} / _{-1.03}	ZIEGER	92	CNTR γp Compton scattering
10.9 ± 2.2 ± 1.3	⁷ FEDERSPIEL	91	CNTR γp Compton scattering

¹BEANE 03 uses effective field theory and low-energy γp and γd Compton-scattering data. It also gets for the isoscalar polarizabilities (see the erratum) $\alpha_N = (13.0 \pm 1.9 \pm 3.9) \times 10^{-4}$ fm³ and $\beta_N = (-1.8 \pm 1.9 \pm 2.1) \times 10^{-4}$ fm³.

²BLANPIED 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.

³This 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.

⁴MACGIBBON 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.

⁵PASQUINI 19 fit data sets for the unpolarized proton RCS cross section, using fixed-t subtracted dispersion relations and a bootstrap-based fitting technique.

⁶ 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 $\alpha_p + \beta_p$.

⁷ 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 $(7.0 \pm 2.2 \pm 1.3) \times 10^{-4} \text{ fm}^3$.

p 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.

VALUE (10^{-4} fm^3)	DOCUMENT ID	TECN	COMMENT
2.5 ± 0.4 OUR AVERAGE	Error includes scale factor of 1.2.		
3.15 ± 0.35 ± 0.36	MCGOVERN	13	RVUE χ EFT + Compton scattering
3.4 ± 1.1 ± 0.1	¹ BEANE	03	EFT + γp
1.43 ± 0.98 $^{+0.52}_{-0.98}$	² BLANPIED	01	LEGS $\rho(\vec{\gamma}, \gamma)$, $\rho(\vec{\gamma}, \pi^0)$, $\rho(\vec{\gamma}, \pi^+)$
1.2 ± 0.7 ± 0.5	³ OLMOSDEL...	01	CNTR γp Compton scattering
2.1 ± 0.8 ± 0.5	⁴ MACGIBBON	95	RVUE global average
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1.77 $^{+0.52}_{-0.54}$	⁵ PASQUINI	19	fit of RCS data sets
2.3 ± 0.9 ± 0.7	⁶ 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 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 $\beta_N = (-1.8 \pm 1.9^{+2.1}_{-0.9}) \times 10^{-4} \text{ fm}^3$.

² 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.

³ 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.

⁴ 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.

⁵ PASQUINI 19 fit data sets for the unpolarized proton RCS cross section, using fixed- t subtracted dispersion relations and a bootstrap-based fitting technique.

⁶ 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 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 (ANTOIGNINI 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 $ep \rightarrow ep$ form factor
0.84087 ± 0.00026 ± 0.00029	ANTOIGNINI	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 ep data
0.878 ± 0.011 ± 0.031	⁴ MIHOVILOVIC	21	ISR $ep \rightarrow ep$ 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, 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 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 $0.878 \pm 0.011 \pm 0.031 \pm 0.002$ 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 $e p$ data
0.87 ± 0.02	EPSTEIN	14	Using $e p$, $e n$, $\pi \pi$ data
0.867 ± 0.009 ± 0.018	ZHAN	11 SPEC	Recoil polarimetry
0.777 ± 0.013 ± 0.010	BERNAUER	10 SPEC	$e p \rightarrow e p$ form factor
0.876 ± 0.010 ± 0.016	BORISYUK	10	Reanalyzes old $e p \rightarrow e p$ 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 ($0.776 \pm 0.034 \pm 0.017$) 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 $e p$ 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
>3.6 × 10²⁹	p	90	¹ ANDERSON	19A SNO+	$p \rightarrow$ invisible
>5.8 × 10²⁹	n	90	² ARAKI	06 KLND	$n \rightarrow$ invisible
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>2.5 × 10 ²⁹	n	90	¹ ANDERSON	19A SNO+	$n \rightarrow$ invisible
>2.1 × 10 ²⁹	p	90	¹ AHMED	04 SNO	$p \rightarrow$ invisible
>1.9 × 10 ²⁹	n	90	¹ AHMED	04 SNO	$n \rightarrow$ invisible
>1.8 × 10 ²⁵	n	90	³ BACK	03 BORX	
>1.1 × 10 ²⁶	p	90	³ BACK	03 BORX	
>3.5 × 10 ²⁸	p	90	⁴ ZDESENKO	03	$p \rightarrow$ invisible

>1 × 10 ²⁸	<i>p</i>	90	⁵ AHMAD	02	SNO	<i>p</i> → invisible
>4 × 10 ²³	<i>p</i>	95	TRETYAK	01		<i>d</i> → <i>n</i> + ?
>1.9 × 10 ²⁴	<i>p</i>	90	⁶ BERNABEI	00B	DAMA	
>1.6 × 10 ²⁵	<i>p, n</i>		^{7,8} EVANS	77		
>3 × 10 ²³	<i>p</i>		⁸ DIX	70	CNTR	
>3 × 10 ²³	<i>p, n</i>		^{8,9} FLEROV	58		

¹ 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 .

² ARAKI 06 looks for signs of de-excitation of the residual nucleus after disappearance of a neutron from the *s* shell of ^{12}C .

³ 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.

⁴ ZDESENKO 03 gets this limit on proton disappearance in deuterium by analyzing SNO data in AHMAD 02.

⁵ AHMAD 02 (see its footnote 7) looks for neutrons left behind after the disappearance of the proton in deuterons.

⁶ 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.

⁷ EVANS 77 looks for the daughter nuclide ^{129}Xe from possible ^{130}Te decays in ancient Te ore samples.

⁸ This mean-life limit has been obtained from a half-life limit by dividing the latter by $\ln(2) = 0.693$.

⁹ 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 × 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 × 10 ⁷			GOLDEN	79	SPEC \bar{p}/p ratio, cosmic rays
>3.7 × 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), > 16000 (p)	90%
τ_2 $N \rightarrow \mu^+ \pi$	> 3500 (n), > 7700 (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), > 1600 (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} $n \rightarrow \nu K_S^0$	> 260	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}	$p \rightarrow e^+ e^+ e^-$	> 793	90%
τ_{50}	$p \rightarrow e^+ \mu^+ \mu^-$	> 359	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}	$p \rightarrow \mu^+ e^+ e^-$	> 529	90%
τ_{56}	$p \rightarrow \mu^- e^+ e^+$	> 1.90×10^{34}	
τ_{57}	$p \rightarrow \mu^+ \mu^+ \mu^-$	> 675	90%
τ_{58}	$p \rightarrow \mu^+ \nu \nu$	> 220	90%
τ_{59}	$p \rightarrow e^- \mu^+ \mu^+$	> 6	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}	$nn \rightarrow \nu_e \bar{\nu}_e$	> 1.4	90%
τ_{79}	$nn \rightarrow \nu_\mu \bar{\nu}_\mu$	> 1.4	90%
τ_{80}	$pn \rightarrow$ invisible	$> 2.1 \times 10^{-5}$	90%
τ_{81}	$pp \rightarrow$ invisible	$> 5 \times 10^{-5}$	90%

\bar{p} DECAY MODES

	Mode	Partial mean life (years)	Confidence level
τ_{82}	$\bar{p} \rightarrow e^- \gamma$	$> 7 \times 10^5$	90%
τ_{83}	$\bar{p} \rightarrow \mu^- \gamma$	$> 5 \times 10^4$	90%
τ_{84}	$\bar{p} \rightarrow e^- \pi^0$	$> 4 \times 10^5$	90%
τ_{85}	$\bar{p} \rightarrow \mu^- \pi^0$	$> 5 \times 10^4$	90%
τ_{86}	$\bar{p} \rightarrow e^- \eta$	$> 2 \times 10^4$	90%
τ_{87}	$\bar{p} \rightarrow \mu^- \eta$	$> 8 \times 10^3$	90%
τ_{88}	$\bar{p} \rightarrow e^- K_S^0$	> 900	90%
τ_{89}	$\bar{p} \rightarrow \mu^- K_S^0$	$> 4 \times 10^3$	90%
τ_{90}	$\bar{p} \rightarrow e^- K_L^0$	$> 9 \times 10^3$	90%
τ_{91}	$\bar{p} \rightarrow \mu^- K_L^0$	$> 7 \times 10^3$	90%
τ_{92}	$\bar{p} \rightarrow e^- \gamma \gamma$	$> 2 \times 10^4$	90%
τ_{93}	$\bar{p} \rightarrow \mu^- \gamma \gamma$	$> 2 \times 10^4$	90%
τ_{94}	$\bar{p} \rightarrow e^- \omega$	> 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
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.

$\tau(N \rightarrow \mu^+ \pi)$ τ_2

<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>
>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	<i>p</i>	90	0	0.3	NISHINO 09	SKAM
> 473	<i>p</i>	90	0	0.6	MCGREW 99	IMB3
> 90	<i>n</i>	90	1	1.9	MCGREW 99	IMB3
> 81	<i>p</i>	90	0	0.2	BERGER 91	FREJ
> 35	<i>n</i>	90	1	1.0	BERGER 91	FREJ
> 230	<i>p</i>	90	0	<0.07	HIRATA 89C	KAMI
> 100	<i>n</i>	90	0	<0.2	HIRATA 89C	KAMI
> 270	<i>p</i>	90	0	0.5	SEIDEL 88	IMB
> 63	<i>n</i>	90	0	0.5	SEIDEL 88	IMB
> 76	<i>p</i>	90	2	1	HAINES 86	IMB
> 23	<i>n</i>	90	8	7	HAINES 86	IMB
> 46	<i>p</i>	90	0	<0.7	ARISAKA 85	KAMI
> 20	<i>n</i>	90	0	<0.4	ARISAKA 85	KAMI
> 59	<i>p</i> (free)	90	0	0.2	BLEWITT 85	IMB
> 100	<i>p</i>	90	1	0.4	BLEWITT 85	IMB
> 38	<i>n</i>	90	1	4	PARK 85	IMB
> 10	<i>p, n</i>	90	0		BATTISTONI 84	NUSX
> 1.3	<i>p, n</i>	90	0		ALEKSEEV 81	BAKS

¹ TAKENAKA 20 includes the data of ABE 17 and thus supersedes ABE 17. $\tau(N \rightarrow \nu \pi)$ τ_3

<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	<i>p</i>	90	52.8		ABE 14E	SKAM
>1100	<i>n</i>	90	19.1		ABE 14E	SKAM
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
> 16	<i>p</i>	90	6	6.7	WALL 00B	SOU2
> 39	<i>n</i>	90	4	3.8	WALL 00B	SOU2
> 10	<i>p</i>	90	15	20.3	MCGREW 99	IMB3
> 112	<i>n</i>	90	6	6.6	MCGREW 99	IMB3
> 13	<i>n</i>	90	1	1.2	BERGER 89	FREJ
> 10	<i>p</i>	90	11	14	BERGER 89	FREJ
> 25	<i>p</i>	90	32	32.8	¹ HIRATA 89C	KAMI
> 100	<i>n</i>	90	1	3	HIRATA 89C	KAMI
> 6	<i>n</i>	90	73	60	HAINES 86	IMB
> 2	<i>p</i>	90	16	13	KAJITA 86	KAMI
> 40	<i>n</i>	90	0	1	KAJITA 86	KAMI
> 7	<i>n</i>	90	28	19	PARK 85	IMB
> 7	<i>n</i>	90	0		BATTISTONI 84	NUSX
> 2	<i>p</i>	90	≤ 3		BATTISTONI 84	NUSX
> 5.8	<i>p</i>	90	1		² KRISHNA... 82	KOLR
> 0.3	<i>p</i>	90	2		³ CHERRY 81	HOME
> 0.1	<i>p</i>	90			⁴ GURR 67	CNTR

¹In 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.

²We have calculated 90% CL limit from 1 confined event.

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

⁴We have converted half-life to 90% CL mean life.

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

T4

<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	0	0.78	ABE	17D SKAM
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
> 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		¹ CHERRY	81 HOME

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

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

T5

<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>
>4700	p	90	2	0.85	ABE	17D SKAM
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
>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

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

T6

<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	<i>n</i>	90	2	3.7	WALL	00B	SOU2
> 29	<i>n</i>	90	0	0.9	BERGER	89	FREJ
> 54	<i>n</i>	90	2	0.9	HIRATA	89C	KAMI
> 16	<i>n</i>	90	3	2.1	SEIDEL	88	IMB
> 25	<i>n</i>	90	7	6	HAINES	86	IMB
> 30	<i>n</i>	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

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

τ_9

<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>
>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.

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

τ_{10}

<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>
>1600	<i>p</i>	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.

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

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

¹ We 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>
● ● ● 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>
>1600	p	90	13	13.2	REGIS 12	SKAM
> 26	n	90	20	28.4	MCGREW 99	IMB3
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
>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		¹ BARTELT 87	SOD
> 1.1	n	90	0		BARTELT 87	SOD
> 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		² BARTELT	83	SOUD
> 0.4	n	90	0		² BARTELT	83	SOUD
> 5.8	p	90	2		³ KRISHNA...	82	KOLR
> 2.0	p	90	0		CHERRY	81	HOME
> 0.2	n	90			⁴ GURR	67	CNTR

¹ BARTELT 87 limit applies to $p \rightarrow \mu^+ K_S^0$.

² Limit based on zero events.

³ We have calculated 90% CL limit from 1 confined event.

⁴ We have converted half-life to 90% CL mean life.

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

τ_{17}

<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. • • •

>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}

<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. • • •

>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}

<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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>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	<i>n</i>	90	3 5	HAINES	86	IMB
> 28	<i>p</i>	90	3 3	KAJITA	86	KAMI
> 32	<i>n</i>	90	0 1.4	KAJITA	86	KAMI
> 1.8	<i>p</i> (free)	90	6 11	BLEWITT	85	IMB
> 9.6	<i>p</i>	90	6 5	BLEWITT	85	IMB
> 10	<i>n</i>	90	2 2	PARK	85	IMB
> 5	<i>n</i>	90	0	BATTISTONI	84	NUSX
> 2	<i>p</i>	90	0	BATTISTONI	84	NUSX
> 0.3	<i>n</i>	90	0	³ BARTELT	83	SOUD
> 0.1	<i>p</i>	90	0	³ BARTELT	83	SOUD
> 5.8	<i>p</i>	90	1	⁴ KRISHNA...	82	KOLR
> 0.3	<i>n</i>	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
>260	<i>n</i>	90	34	30	¹ KOBAYASHI 05	SKAM

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

> 51	<i>n</i>	90	16	9.1	WALL	00	SOU2
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¹ We have doubled the $n \rightarrow \nu K^0$ 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	<i>p</i>	90	38	52.0	MCGREW	99	IMB3

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

>10	<i>p</i>	90	0	0.8	BERGER	91	FREJ
>52	<i>p</i>	90	2	1.55	HIRATA	89c	KAMI
>10	<i>p</i>	90	1	<1	ARISAKA	85	KAMI

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

τ_{22}

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

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

>22	<i>n</i>	90	0	2.1	BERGER	89	FREJ
>17	<i>p</i>	90	0	2.4	BERGER	89	FREJ
>20	<i>p</i>	90	5	2.1	HIRATA	89c	KAMI
>21	<i>n</i>	90	4	2.4	HIRATA	89c	KAMI
>10	<i>p</i>	90	7	6	HAINES	86	IMB
> 5	<i>n</i>	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

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

————— Antilepton + mesons —————

$\tau(p \rightarrow e^+ \pi^+ \pi^-)$ T23

<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>
>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

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

<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>
>18	<i>n</i>	90	1	0.2	BERGER	91 FREJ

Lepton + meson

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

<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>
>65	<i>n</i>	90	0	1.6	SEIDEL	88 IMB
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
>55	<i>n</i>	90	0	1.09	BERGER	91B FREJ
>16	<i>n</i>	90	9	7	HAINES	86 IMB
>25	<i>n</i>	90	2	4	PARK	85 IMB

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

<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>
>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**

<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>
>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**

<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>
>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**

<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>
>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

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

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

————— **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	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

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	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

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

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

T48

<u>VALUE (10³⁰ years)</u>	<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 (10³⁰ years)</u>	<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 (10³⁰ years)</u>	<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 (10³⁰ years)</u>	<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 (10³⁰ years)</u>	<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	<i>n</i>	90	25	29.4	MCGREW	99 IMB3
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
>47	<i>n</i>	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	<i>n</i>	90	100	145	MCGREW	99 IMB3
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
>42	<i>n</i>	90	0	1.4	BERGER	91B FREJ
> 5.1	<i>n</i>	90	0	0.7	PHILLIPS	89 HPW
>16	<i>n</i>	90	14	7	HAINES	86 IMB
>19	<i>n</i>	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	<i>p</i>	90	0	0.5	TANAKA	20 SKAM
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
> 529	<i>p</i>	90	0	1.0	MCGREW	99 IMB3
> 91	<i>p</i>	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	<i>p</i>	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	<i>p</i>	90	1	0.4	TANAKA	20 SKAM
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
> 675	<i>p</i>	90	0	0.3	MCGREW	99 IMB3
> 119	<i>p</i>	90	0	0.2	BERGER	91 FREJ
> 10.5	<i>p</i>	90	0	0.7	PHILLIPS	89 HPW
> 190	<i>p</i>	90	1	0.1	HAINES	86 IMB
> 44	<i>p</i> (free)	90	1	0.7	BLEWITT	85 IMB
> 190	<i>p</i>	90	1	0.9	BLEWITT	85 IMB
> 2.1	<i>p</i>	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	<i>p</i>	90			¹ TAKHISTOV	14 SKAM
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
> 21	<i>p</i>	90	7	11.23	BERGER	91B FREJ

¹Allowed events at 90% CL are 286.

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

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

 $\tau(n \rightarrow 3\nu)$ **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.

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 $\nu_e \nu_e \bar{\nu}_e$, $\nu_\mu \nu_\mu \bar{\nu}_\mu$, or $\nu_\tau \nu_\tau \bar{\nu}_\tau$.

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 $n \rightarrow \nu_e \nu_e \bar{\nu}_e$, 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
● ● ● 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 ————

 $\tau(N \rightarrow e^+ \text{ anything})$ **T62**

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.

 $\tau(N \rightarrow \mu^+ \text{ anything})$ **T63**

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.

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

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

> 2.0	90	0	0.31	BERGER	91B FREJ	per iron nucleus
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 $\tau(nn \rightarrow \pi^+ \pi^-)$ **T69**

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN	COMMENT
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>0.7	90	4	2.18	BERGER	91B FREJ	τ per iron nucleus
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 $\tau(nn \rightarrow \pi^0 \pi^0)$ **T70**

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

> 3.4	90	0	0.78	BERGER	91B FREJ	per iron nucleus
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 $\tau(pp \rightarrow K^+ K^+)$ **T71**

LIMIT (10^{30} years)	CL%	EVTS	BKGD EST	DOCUMENT ID	TECN	COMMENT
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>170	90	0	0.28	LITOS	14 SKAM	τ per oxygen nucleus
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$\tau(pp \rightarrow e^+ e^+)$ **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
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 $\tau(pn \rightarrow \mu^+ \bar{\nu})$ **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
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 $\tau(pn \rightarrow \tau^+ \bar{\nu}_\tau)$ **T77**

<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>
>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.

 $\tau(nn \rightarrow \nu_e \bar{\nu}_e)$ **T78**

We include "invisible" modes here.

<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>
>1.4	90			¹ ARAKI	06	KLND $nn \rightarrow$ invisible

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

>0.013	90			² ANDERSON	19A	SNO+ $nn \rightarrow$ invisible
>0.000042	90			³ TRETYAK	04	CNTR $nn \rightarrow$ invisible
>0.000049	90			⁴ BACK	03	BORX $nn \rightarrow$ invisible
>0.000012	90			⁵ BERNABEI	00B	DAMA $nn \rightarrow$ invisible
>0.000012	90	5	9.7	BERGER	91B	FREJ τ per iron nucleus

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

- ² ANDERSON 19A looks for γ rays from the de-excitation of a residual $^{14}\text{O}^*$ following the disappearance of nn in ^{16}O .
- ³ TRETAYAK 04 uses data from an old Homestake-mine radiochemical experiment on limits for invisible decays of ^{39}K to ^{37}Ar .
- ⁴ 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.
- ⁵ BERNABEI 00B looks for the decay of a $^{127}_{54}\text{Xe}$ 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.

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

779

See the preceding data block. “Invisible modes” would include any multi-neutrino mode.

<i>LIMIT</i> (10^{30} years)	<i>CL%</i>	<i>EVTS</i>	<i>BKGD EST</i>	<i>DOCUMENT ID</i>	<i>TECN</i>	<i>COMMENT</i>
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> 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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$\tau(pn \rightarrow \text{invisible})$

780

This violates charge conservation as well as baryon number conservation.

<i>VALUE</i> (10^{30} years)	<i>CL%</i>	<i>DOCUMENT ID</i>	<i>TECN</i>
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>0.026 90 ¹ ANDERSON 19A SNO+

>0.000021 90 ² TRETAYAK 04 CNTR

¹ ANDERSON 19A looks for γ rays from the de-excitation of a residual $^{14}\text{N}^*$ following the disappearance of pn in ^{16}O .

² TRETAYAK 04 uses data from an old Homestake-mine radiochemical experiment on limits for invisible decays of ^{39}K to ^{37}Ar .

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

781

This violates charge conservation as well as baryon number conservation.

<i>LIMIT</i> (10^{30} years)	<i>CL%</i>	<i>EVTS</i>	<i>BKGD EST</i>	<i>DOCUMENT ID</i>	<i>TECN</i>
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>0.047 **90** ¹ ANDERSON 19A SNO+

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

>0.00005 90 ² BACK 03 BORX

>0.0000055 90 ³ BERNABEI 00B DAMA

¹ ANDERSON 19A looks for γ rays from the de-excitation of a residual $^{14}\text{C}^*$ following the disappearance of pp in ^{16}O .

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.

\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.

 $\tau(\bar{p} \rightarrow e^- \gamma)$ T82

<u>VALUE (years)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
> 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

 $\tau(\bar{p} \rightarrow \mu^- \gamma)$ T83

<u>VALUE (years)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
> 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

 $\tau(\bar{p} \rightarrow e^- \pi^0)$ T84

<u>VALUE (years)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
> 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

 $\tau(\bar{p} \rightarrow \mu^- \pi^0)$ T85

<u>VALUE (years)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
> 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. •••				
> 4.8×10^4	90	HU 98B	APEX	8.9 GeV/c \bar{p} beam

 $\tau(\bar{p} \rightarrow e^- \eta)$ T86

<u>VALUE (years)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
> 2×10^4	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

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

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

 $\tau(\bar{p} \rightarrow e^- K_S^0)$ T88

<u>VALUE (years)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
>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

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

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
$>4 \times 10^3$	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

 $\tau(\bar{p} \rightarrow e^- K_L^0)$ **T90**

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
$>9 \times 10^3$	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

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

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
$>7 \times 10^3$	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

 $\tau(\bar{p} \rightarrow e^- \gamma \gamma)$ **T92**

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

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

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
$>2 \times 10^4$	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

 $\tau(\bar{p} \rightarrow e^- \omega)$ **T94**

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

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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)