# p

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

## p MASS (atomic mass units u)

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

| *VALUE* (u) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **1.007276466879±0.000000000091** | MOHR | 16 | RVUE | 2014 CODATA value |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 1.007276466583±0.000000000032 | [1] HEISSE | 17 | SPEC | Penning trap |
| 1.007276466812±0.000000000090 | MOHR | 12 | RVUE | 2010 CODATA value |
| 1.00727646677 ±0.00000000010 | MOHR | 08 | RVUE | 2006 CODATA value |
| 1.00727646688 ±0.00000000013 | MOHR | 05 | RVUE | 2002 CODATA value |
| 1.00727646688 ±0.00000000013 | MOHR | 99 | RVUE | 1998 CODATA value |
| 1.007276470 ±0.000000012 | COHEN | 87 | RVUE | 1986 CODATA value |

[1] The statistical and systematic errors are 15 and 29 in the last two places of the value. The value disagrees with the MOHR 16 value by over 3 standard deviations.

## p MASS (MeV)

The mass is known much more precisely in u (atomic mass units) than in MeV. The conversion from u to MeV, 1 u = 931.494 0054(57) MeV/$c^2$ (MOHR 16, the 2014 CODATA value), involves the relatively poorly known electronic charge.

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **938.2720813±0.0000058** | MOHR | 16 | RVUE | 2014 CODATA value |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 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 |

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

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

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

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

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

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

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 $\overline{p}$ and $p$ *gravitational* masses, see ERICSON 90; they obtain an upper bound of $10^{-6}$–$10^{-7}$ for violation of the equivalence principle for $\overline{p}$'s.

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

[1] Equation (2) of GABRIELSE 95 should read $M(\overline{p})/M(p) = 0.999\,999\,99\underline{8}5\,(11)$ (G. Gabrielse, private communication).

[2] GABRIELSE 90 also measures $m_{\overline{p}}/m_{e^-} = 1836.152660 \pm 0.000083$ 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 $1836.152701 \pm 0.000037$.

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

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

| *VALUE* | *DOCUMENT ID* |
|---|---|
| **$(-9\pm9)\times10^{-11}$ OUR EVALUATION** | |

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

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

| *VALUE* | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **$<7\times10^{-10}$** | 90 | [1] HORI | 11 | SPEC | $\overline{p}e^-$He atom |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $<2\times10^{-9}$ | 90 | [1] HORI | 06 | SPEC | $\overline{p}e^-$He atom |
| $<1.0\times10^{-8}$ | 90 | [1] HORI | 03 | SPEC | $\overline{p}e^-\,{}^4$He, $\overline{p}e^-\,{}^3$He |
| $<6\times10^{-8}$ | 90 | [1] HORI | 01 | SPEC | $\overline{p}e^-$He atom |
| $<5\times10^{-7}$ | | [2] TORII | 99 | SPEC | $\overline{p}e^-$He atom |
| $<2\times10^{-5}$ | | [3] HUGHES | 92 | RVUE | |

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

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

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

## $|q_p + q_e|/e$

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

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

[1] BRESSI 11 uses the method of DYLLA 73 but finds serious errors in that experiment that greatly reduce its accuracy. The BRESSI 11 limit assumes that $n \rightarrow p e^- \nu_e$ conserves charge. Thus the limit applies equally to the charge of the neutron.

[2] SENGUPTA 00 uses the difference between the observed rate of 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 "Note on Baryon Magnetic Moments" in the $\Lambda$ Listings.

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

## $\overline{p}$ MAGNETIC MOMENT

A few early results have been omitted.

| *VALUE* ($\mu_N$) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **−2.7928473441±0.0000000042** | SMORRA | 17 | TRAP | Hot/cold $\overline{p}$ frequencies, Penning traps |

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

| | | | | | |
|---|---|---|---|---|---|
| −2.7928465 | ±0.0000023 | NAGAHAMA | 17 | TRAP | Single $\overline{p}$, Penning trap |
| −2.792845 | ±0.000012 | DISCIACCA | 13 | TRAP | Single $\overline{p}$, Penning trap |
| −2.7862 | ±0.0083 | PASK | 09 | CNTR | $\overline{p}$ He$^+$ hyperfine structure |
| −2.8005 | ±0.0090 | KREISSL | 88 | CNTR | $\overline{p}$ $^{208}$Pb 11→ 10 X-ray |
| −2.817 | ±0.048 | ROBERTS | 78 | CNTR | |
| −2.791 | ±0.021 | HU | 75 | CNTR | Exotic atoms |

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

A test of *CPT* invariance.

| *VALUE* (units $10^{-6}$) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **0.3±0.8 OUR AVERAGE** | | | | |
| 0.3±0.8 | NAGAHAMA | 17 | TRAP | Single $\overline{p}$, Penning trap |
| 0 ±5 | DISCIACCA | 13 | TRAP | Single $\overline{p}$, Penning trap |

## *p* ELECTRIC DIPOLE MOMENT

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

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

[1] SAHOO 17 and DMITRIEV 03 are not direct measurements of the proton electric dipole moment. They use theory to calculate this limit from the limit on the electric dipole moment of the $^{199}$Hg atom.

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

[3] This WILKENING 84 value is more cautious than the other and excludes the finite-size effect, which relies on uncertain nuclear integrals.

## *p* ELECTRIC POLARIZABILITY $\alpha_p$

For a very complete review of the "polarizability of the nucleon and Compton scattering," see SCHUMACHER 05. His recommended values for the proton are $\alpha_p = (12.0 \pm 0.6) \times 10^{-4}$ fm$^3$ and $\beta_p = (1.9 \mp 0.6) \times 10^{-4}$ fm$^3$, almost exactly our averages.

| *VALUE* ($10^{-4}$ fm$^3$) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **11.2 ±0.4 OUR AVERAGE** | | | | |
| 10.65±0.35±0.36 | MCGOVERN | 13 | RVUE | $\chi$EFT + Compton scattering |
| 12.1 ±1.1 ±0.5 | [1] BEANE | 03 | | EFT + $\gamma p$ |
| $11.82\pm0.98^{+0.52}_{-0.98}$ | [2] BLANPIED | 01 | LEGS | $p(\vec{\gamma},\gamma)$, $p(\vec{\gamma},\pi^0)$, $p(\vec{\gamma},\pi^+)$ |
| 11.9 ±0.5 ±1.3 | [3] OLMOSDEL... | 01 | CNTR | $\gamma p$ 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. • • •

| | | | | |
|---|---|---|---|---|
| 11.7 ±0.8 ±0.7 | [5] BARANOV | 01 | RVUE | Global average |
| 12.5 ±0.6 ±0.9 | MACGIBBON | 95 | CNTR | $\gamma p$ Compton scattering |
| 9.8 ±0.4 ±1.1 | HALLIN | 93 | CNTR | $\gamma p$ Compton scattering |
| $10.62^{+1.25}_{-1.19}{}^{+1.07}_{-1.03}$ | ZIEGER | 92 | CNTR | $\gamma p$ Compton scattering |
| 10.9 ±2.2 ±1.3 | [6] FEDERSPIEL | 91 | CNTR | $\gamma p$ Compton scattering |

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

[2] BLANPIED 01 gives $\alpha_p + \beta_p$ and $\alpha_p - \beta_p$. The separate $\alpha_p$ and $\beta_p$ 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 $\alpha + \beta = (13.8 \pm 0.4) \times 10^{-4}$ 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] 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 $\alpha_p + \beta_p$.

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

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## *p* MAGNETIC POLARIZABILITY $\beta_p$

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

| *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 | $\chi$EFT + Compton scattering |
| 3.4 ±1.1 ±0.1 | [1] BEANE | 03 | | EFT + $\gamma p$ |
| $1.43 \pm 0.98^{+0.52}_{-0.98}$ | [2] BLANPIED | 01 | LEGS | $p(\vec{\gamma},\gamma)$, $p(\vec{\gamma},\pi^0)$, $p(\vec{\gamma},\pi^+)$ |
| 1.2 ±0.7 ±0.5 | [3] OLMOSDEL... | 01 | CNTR | $\gamma p$ 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. • • •

| | | | | |
|---|---|---|---|---|
| 2.3 ±0.9 ±0.7 | [5] BARANOV | 01 | RVUE | Global average |
| 1.7 ±0.6 ±0.9 | MACGIBBON | 95 | CNTR | $\gamma p$ Compton scattering |
| 4.4 ±0.4 ±1.1 | HALLIN | 93 | CNTR | $\gamma p$ Compton scattering |
| $3.58^{+1.19}_{-1.25}{}^{+1.03}_{-1.07}$ | ZIEGER | 92 | CNTR | $\gamma p$ Compton scattering |
| 3.3 ±2.2 ±1.3 | FEDERSPIEL | 91 | CNTR | $\gamma p$ Compton scattering |

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

[2] BLANPIED 01 gives $\alpha_p + \beta_p$ and $\alpha_p - \beta_p$. The separate $\alpha_p$ and $\beta_p$ 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 ± 0.4) $\times 10^{-4}$ 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] 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 $\alpha_p + \beta_p$.

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# *p* CHARGE RADIUS

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

There are in fact three kinds of measurements of the proton radius: with atomic hydrogen, with electron scattering off of hydrogen, and with muonic hydrogen. Most measurements of the radius of the proton involve electron-proton interactions, and most of those values, the most precise of which is $r_p$ = 0.879(8) fm (BERNAUER 10), agree with one another. The MOHR 16 value (2014 CODATA), obtained from the electronic results available at the time, is 0.8751(61) fm.

Compared to this MOHR 16 value, however, the best measurement using muonic hydrogen got $r_p$ = 0.84087(39) fm (ANTOGNINI 13), which is 16 times more precise but differs by 5.6 standard deviations.

The earlier face-off seemed to be between the two electronic methods and muonic hydrogen. But a purely statistical reanalysis of electron-scattering data by HIGINBOTHAM 16 found consistency with muonic hydrogen—so that (the paper claims) it "is the atomic hydrogen results that are the outliers." But still more recently there is a new atomic-hydrogen value, $r_p$ = 0.8335(95) fm (BEYER 17), that agrees with the muonic hydrogen value!

Since POHL 10 (the first $\mu p$ result), there has been a lot of discussion about the disagreement, especially concerning the modeling of muonic hydrogen. Here is an incomplete list of papers: DERUJULA 10, CLOET 11, DISTLER 11, DERUJULA 11, ARRINGTON 11, BERNAUER 11, HILL 11, LORENZ 14, KARSHENBOIM 14A, PESET 15, SICK 17, and HORBATSCH 17.

Until the differences between the three methods are resolved, it does not make sense to average the values together. For the present, we give both the 2014 CODATA value and the best $\mu p$ value. It is up to workers in the field to solve this puzzle.

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

| *VALUE* (fm) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **0.8751 ±0.0061** | MOHR | 16 | RVUE | 2014 CODATA value |
| **0.84087±0.00026±0.00029** | ANTOGNINI | 13 | LASR | $\mu p$-atom Lamb shift |

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

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.877 | ±0.013 | | [1] FLEURBAEY | 18 | LASR | 1S-3S transition in H |
| 0.8335 | ±0.0095 | | [2] BEYER | 17 | LASR | 2S-4P transition in H |
| 0.895 | ±0.014 | ±0.014 | [3] 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 | $ep \to ep$ 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 ANTOGNINI 13 |
| 0.8768 | ±0.0069 | | MOHR | 08 | RVUE | 2006 CODATA value |
| 0.844 | $^{+0.008}_{-0.004}$ | | BELUSHKIN | 07 | | Dispersion analysis |
| 0.897 | ±0.018 | | BLUNDEN | 05 | | SICK 03 + $2\gamma$ correction |
| 0.8750 | ±0.0068 | | MOHR | 05 | RVUE | 2002 CODATA value |
| 0.895 | ±0.010 | ±0.013 | SICK | 03 | | $ep \to ep$ reanalysis |

[1] 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.

[2] 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.

[3] 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. • • •

| | | | | |
|---|---|---|---|---|
| 0.87 ±0.02 | EPSTEIN | 14 | | Using *ep*, *en*, $\pi\pi$ data |
| 0.867±0.009±0.018 | ZHAN | 11 | SPEC | Recoil polarimetry |
| 0.777±0.013±0.010 | BERNAUER | 10 | SPEC | $ep \to ep$ form factor |
| 0.876±0.010±0.016 | BORISYUK | 10 | | Reanalyzes old $ep \to ep$ data |
| 0.854±0.005 | BELUSHKIN | 07 | | Dispersion analysis |

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

## *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 $3\nu$ modes in the "Partial Mean Lives" section. Table 1 of BACK 03 is a nice summary.

| *LIMIT* (years) | *PARTICLE* | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|---|
| $\mathbf{>5.8 \times 10^{29}}$ | ***n*** | 90 | [1] ARAKI | 06 | KLND | $n \to$ invisible |
| $\mathbf{>2.1 \times 10^{29}}$ | ***p*** | 90 | [2] AHMED | 04 | SNO | $p \to$ invisible |

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

| | | | | | | |
|---|---|---|---|---|---|---|
| $>1.9 \times 10^{29}$ | $n$ | 90 | [2] AHMED | 04 | SNO | $n \rightarrow$ invisible |
| $>1.8 \times 10^{25}$ | $n$ | 90 | [3] BACK | 03 | BORX | |
| $>1.1 \times 10^{26}$ | $p$ | 90 | [3] BACK | 03 | BORX | |
| $>3.5 \times 10^{28}$ | $p$ | 90 | [4] ZDESENKO | 03 | | $p \rightarrow$ invisible |
| $>1 \times 10^{28}$ | $p$ | 90 | [5] AHMAD | 02 | SNO | $p \rightarrow$ invisible |
| $>4 \times 10^{23}$ | $p$ | 95 | TRETYAK | 01 | | $d \rightarrow n + ?$ |
| $>1.9 \times 10^{24}$ | $p$ | 90 | [6] BERNABEI | 00B | DAMA | |
| $>1.6 \times 10^{25}$ | $p$, $n$ | | [7,8] EVANS | 77 | | |
| $>3 \times 10^{23}$ | $p$ | | [8] DIX | 70 | CNTR | |
| $>3 \times 10^{23}$ | $p$, $n$ | | [8,9] FLEROV | 58 | | |

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

[2] AHMED 04 looks for $\gamma$ rays from the de-excitation of a residual $^{15}O^*$ or $^{15}N^*$ following the disappearance of a neutron or proton in $^{16}$O.

[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 $^{128}_{53}$I nucleus following the disappearance of a proton in the otherwise-stable $^{129}_{54}$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.

## $\overline{p}$ MEAN LIFE

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

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

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

## *p* DECAY MODES

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

The "partial mean life" limits tabulated here are the limits on $\tau/\mathrm{B}_i$, where $\tau$ is the total mean life and $\mathrm{B}_i$ 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** |  |  |
| $\tau_1$ | $N \rightarrow e^+ \pi$ | $> 5300$ (*n*), $> 16000$ (*p*) | 90% |
| $\tau_2$ | $N \rightarrow \mu^+ \pi$ | $> 3500$ (*n*), $> 7700$ (*p*) | 90% |
| $\tau_3$ | $N \rightarrow \nu \pi$ | $> 1100$ (*n*), $> 390$ (*p*) | 90% |
| $\tau_4$ | $p \rightarrow e^+ \eta$ | $> 10000$ | 90% |
| $\tau_5$ | $p \rightarrow \mu^+ \eta$ | $> 4700$ | 90% |
| $\tau_6$ | $n \rightarrow \nu \eta$ | $> 158$ | 90% |
| $\tau_7$ | $N \rightarrow e^+ \rho$ | $> 217$ (*n*), $> 720$ (*p*) | 90% |
| $\tau_8$ | $N \rightarrow \mu^+ \rho$ | $> 228$ (*n*), $> 570$ (*p*) | 90% |
| $\tau_9$ | $N \rightarrow \nu \rho$ | $> 19$ (*n*), $> 162$ (*p*) | 90% |
| $\tau_{10}$ | $p \rightarrow e^+ \omega$ | $> 1600$ | 90% |
| $\tau_{11}$ | $p \rightarrow \mu^+ \omega$ | $> 2800$ | 90% |
| $\tau_{12}$ | $n \rightarrow \nu \omega$ | $> 108$ | 90% |
| $\tau_{13}$ | $N \rightarrow e^+ K$ | $> 17$ (*n*), $> 1000$ (*p*) | 90% |
| $\tau_{14}$ | $p \rightarrow e^+ K^0_S$ |  |  |
| $\tau_{15}$ | $p \rightarrow e^+ K^0_L$ |  |  |
| $\tau_{16}$ | $N \rightarrow \mu^+ K$ | $> 26$ (*n*), $> 1600$ (*p*) | 90% |
| $\tau_{17}$ | $p \rightarrow \mu^+ K^0_S$ |  |  |
| $\tau_{18}$ | $p \rightarrow \mu^+ K^0_L$ |  |  |
| $\tau_{19}$ | $N \rightarrow \nu K$ | $> 86$ (*n*), $> 5900$ (*p*) | 90% |
| $\tau_{20}$ | $n \rightarrow \nu K^0_S$ | $> 260$ | 90% |
| $\tau_{21}$ | $p \rightarrow e^+ K^*(892)^0$ | $> 84$ | 90% |
| $\tau_{22}$ | $N \rightarrow \nu K^*(892)$ | $> 78$ (*n*), $> 51$ (*p*) | 90% |
|  | **Antilepton + mesons** |  |  |
| $\tau_{23}$ | $p \rightarrow e^+ \pi^+ \pi^-$ | $> 82$ | 90% |
| $\tau_{24}$ | $p \rightarrow e^+ \pi^0 \pi^0$ | $> 147$ | 90% |
| $\tau_{25}$ | $n \rightarrow e^+ \pi^- \pi^0$ | $> 52$ | 90% |
| $\tau_{26}$ | $p \rightarrow \mu^+ \pi^+ \pi^-$ | $> 133$ | 90% |
| $\tau_{27}$ | $p \rightarrow \mu^+ \pi^0 \pi^0$ | $> 101$ | 90% |
| $\tau_{28}$ | $n \rightarrow \mu^+ \pi^- \pi^0$ | $> 74$ | 90% |
| $\tau_{29}$ | $n \rightarrow e^+ K^0 \pi^-$ | $> 18$ | 90% |

### Lepton + meson

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

### Lepton + mesons

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

### Antilepton + photon(s)

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

### Antilepton + single massless

| | | | |
|---|---|---|---|
| $\tau_{47}$ | $p \to e^+ X$ | $> 790$ | 90% |
| $\tau_{48}$ | $p \to \mu^+ X$ | $> 410$ | 90% |

### Three (or more) leptons

| | | | |
|---|---|---|---|
| $\tau_{49}$ | $p \to e^+ e^+ e^-$ | $> 793$ | 90% |
| $\tau_{50}$ | $p \to e^+ \mu^+ \mu^-$ | $> 359$ | 90% |
| $\tau_{51}$ | $p \to e^+ \nu \nu$ | $> 170$ | 90% |
| $\tau_{52}$ | $n \to e^+ e^- \nu$ | $> 257$ | 90% |
| $\tau_{53}$ | $n \to \mu^+ e^- \nu$ | $> 83$ | 90% |
| $\tau_{54}$ | $n \to \mu^+ \mu^- \nu$ | $> 79$ | 90% |
| $\tau_{55}$ | $p \to \mu^+ e^+ e^-$ | $> 529$ | 90% |
| $\tau_{56}$ | $p \to \mu^+ \mu^+ \mu^-$ | $> 675$ | 90% |
| $\tau_{57}$ | $p \to \mu^+ \nu \nu$ | $> 220$ | 90% |
| $\tau_{58}$ | $p \to e^- \mu^+ \mu^+$ | $> 6$ | 90% |
| $\tau_{59}$ | $n \to 3\nu$ | $> 5 \times 10^{-4}$ | 90% |
| $\tau_{60}$ | $n \to 5\nu$ | | |

### Inclusive modes

| | | | |
|---|---|---|---|
| $\tau_{61}$ | $N \to e^+$ anything | $> 0.6$ $(n,\ p)$ | 90% |
| $\tau_{62}$ | $N \to \mu^+$ anything | $> 12$ $(n,\ p)$ | 90% |
| $\tau_{63}$ | $N \to \nu$ anything | | |
| $\tau_{64}$ | $N \to e^+ \pi^0$ anything | $> 0.6$ $(n,\ p)$ | 90% |
| $\tau_{65}$ | $N \to$ 2 bodies, $\nu$-free | | |

## $\Delta B = 2$ dinucleon modes

The following are lifetime limits per iron nucleus.

| | | | |
|---|---|---|---|
| $\tau_{66}$ | $pp \to \pi^+\pi^+$ | $> 72.2$ | 90% |
| $\tau_{67}$ | $pn \to \pi^+\pi^0$ | $> 170$ | 90% |
| $\tau_{68}$ | $nn \to \pi^+\pi^-$ | $> 0.7$ | 90% |
| $\tau_{69}$ | $nn \to \pi^0\pi^0$ | $> 404$ | 90% |
| $\tau_{70}$ | $pp \to K^+K^+$ | $> 170$ | 90% |
| $\tau_{71}$ | $pp \to e^+e^+$ | $> 5.8$ | 90% |
| $\tau_{72}$ | $pp \to e^+\mu^+$ | $> 3.6$ | 90% |
| $\tau_{73}$ | $pp \to \mu^+\mu^+$ | $> 1.7$ | 90% |
| $\tau_{74}$ | $pn \to e^+\overline{\nu}$ | $> 260$ | 90% |
| $\tau_{75}$ | $pn \to \mu^+\overline{\nu}$ | $> 200$ | 90% |
| $\tau_{76}$ | $pn \to \tau^+\overline{\nu}_\tau$ | $> 29$ | 90% |
| $\tau_{77}$ | $nn \to \nu_e\overline{\nu}_e$ | $> 1.4$ | 90% |
| $\tau_{78}$ | $nn \to \nu_\mu\overline{\nu}_\mu$ | $> 1.4$ | 90% |
| $\tau_{79}$ | $pn \to$ invisible | $> 2.1 \times 10^{-5}$ | 90% |
| $\tau_{80}$ | $pp \to$ invisible | $> 5 \times 10^{-5}$ | 90% |

## $\overline{p}$ DECAY MODES

| | Mode | Partial mean life (years) | Confidence level |
|---|---|---|---|
| $\tau_{81}$ | $\overline{p} \to e^-\gamma$ | $> 7 \times 10^5$ | 90% |
| $\tau_{82}$ | $\overline{p} \to \mu^-\gamma$ | $> 5 \times 10^4$ | 90% |
| $\tau_{83}$ | $\overline{p} \to e^-\pi^0$ | $> 4 \times 10^5$ | 90% |
| $\tau_{84}$ | $\overline{p} \to \mu^-\pi^0$ | $> 5 \times 10^4$ | 90% |
| $\tau_{85}$ | $\overline{p} \to e^-\eta$ | $> 2 \times 10^4$ | 90% |
| $\tau_{86}$ | $\overline{p} \to \mu^-\eta$ | $> 8 \times 10^3$ | 90% |
| $\tau_{87}$ | $\overline{p} \to e^-K^0_S$ | $> 900$ | 90% |
| $\tau_{88}$ | $\overline{p} \to \mu^-K^0_S$ | $> 4 \times 10^3$ | 90% |
| $\tau_{89}$ | $\overline{p} \to e^-K^0_L$ | $> 9 \times 10^3$ | 90% |
| $\tau_{90}$ | $\overline{p} \to \mu^-K^0_L$ | $> 7 \times 10^3$ | 90% |
| $\tau_{91}$ | $\overline{p} \to e^-\gamma\gamma$ | $> 2 \times 10^4$ | 90% |
| $\tau_{92}$ | $\overline{p} \to \mu^-\gamma\gamma$ | $> 2 \times 10^4$ | 90% |
| $\tau_{93}$ | $\overline{p} \to e^-\omega$ | $> 200$ | 90% |

## *p* PARTIAL MEAN LIVES

The "partial mean life" limits tabulated here are the limits on $\tau/\mathrm{B}_i$, where $\tau$ is the total mean life for the proton and $\mathrm{B}_i$ 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

### $\tau(N \to e^+ \pi)$ $\tau_1$

| *LIMIT* *($10^{30}$ years)* | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **$>$16000** | ***p*** | **90** | **0** | **0.61** | ABE | 17 | SKAM |
| **$>$ 5300** | ***n*** | **90** | **0** | **0.41** | ABE | 17D | SKAM |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| $>$ 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 | $\le$ 0.1 | BERGER | 91 | FREJ |
| $>$ 550 | *p* | 90 | 0 | 0.7 | [1] 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 | [2] BARTELT | 83 | SOUD |
| $>$ 0.5 | *n* | 90 | 1 | 0.3 | [2] BARTELT | 83 | SOUD |
| $>$ 5.8 | *p* | 90 | 2 | | [3] KRISHNA... | 82 | KOLR |
| $>$ 5.8 | *n* | 90 | 2 | | [3] KRISHNA... | 82 | KOLR |
| $>$ 0.1 | *n* | 90 | | | [4] GURR | 67 | CNTR |

[1] This BECKER-SZENDY 90 result includes data from SEIDEL 88.

[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.

### $\tau(N \to \mu^+ \pi)$ $\tau_2$

| *LIMIT* *($10^{30}$ years)* | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **$>$7700** | ***p*** | **90** | **2** | **0.87** | ABE | 17 | SKAM |
| **$>$3500** | ***n*** | **90** | **1** | **0.77** | ABE | 17D | SKAM |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| $>$1000 | *n* | 90 | 1 | 0.43 | NISHINO | 12 | SKAM |
| $>$6600 | *p* | 90 | 0 | 0.3 | NISHINO | 09 | SKAM |
| $>$ 473 | *p* | 90 | 0 | 0.6 | MCGREW | 99 | IMB3 |
| $>$ 90 | *n* | 90 | 1 | 1.9 | MCGREW | 99 | IMB3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| > 81 | *p* | 90 | 0 | 0.2 | BERGER | 91 | FREJ |
| > 35 | *n* | 90 | 1 | 1.0 | BERGER | 91 | FREJ |
| > 230 | *p* | 90 | 0 | <0.07 | HIRATA | 89C | KAMI |
| > 100 | *n* | 90 | 0 | <0.2 | HIRATA | 89C | KAMI |
| > 270 | *p* | 90 | 0 | 0.5 | SEIDEL | 88 | IMB |
| > 63 | *n* | 90 | 0 | 0.5 | SEIDEL | 88 | IMB |
| > 76 | *p* | 90 | 2 | 1 | HAINES | 86 | IMB |
| > 23 | *n* | 90 | 8 | 7 | HAINES | 86 | IMB |
| > 46 | *p* | 90 | 0 | <0.7 | ARISAKA | 85 | KAMI |
| > 20 | *n* | 90 | 0 | <0.4 | ARISAKA | 85 | KAMI |
| > 59 | *p* (free) | 90 | 0 | 0.2 | BLEWITT | 85 | IMB |
| > 100 | *p* | 90 | 1 | 0.4 | BLEWITT | 85 | IMB |
| > 38 | *n* | 90 | 1 | 4 | PARK | 85 | IMB |
| > 10 | *p*, *n* | 90 | 0 | | BATTISTONI | 84 | NUSX |
| > 1.3 | *p*, *n* | 90 | 0 | | ALEKSEEV | 81 | BAKS |

## $\tau(N \to \nu\pi)$ $\tau_3$

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

[1] In estimating the background, this HIRATA 89C limit (as opposed to the later limits of WALL 00B and MCGREW 99) does not take into account present understanding that the flux of $\nu_\mu$ originating in the upper atmosphere is depleted. Doing so would reduce the background and thus also would reduce the limit here.

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

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

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

## $\tau(p \to e^+\eta)$ $\tau_4$

| LIMIT (10$^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>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 |

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

### $\tau(p \to \mu^+ \eta)$ $\tau_5$

| *LIMIT* (10$^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>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 |

### $\tau(n \to \nu \eta)$ $\tau_6$

| *LIMIT* (10$^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>158** | ***n*** | **90** | **0** | **1.2** | MCGREW | 99 | IMB3 |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $>$ 71 | *n* | 90 | 2 | 3.7 | WALL | 00B | SOU2 |
| $>$ 29 | *n* | 90 | 0 | 0.9 | BERGER | 89 | FREJ |
| $>$ 54 | *n* | 90 | 2 | 0.9 | HIRATA | 89C | KAMI |
| $>$ 16 | *n* | 90 | 3 | 2.1 | SEIDEL | 88 | IMB |
| $>$ 25 | *n* | 90 | 7 | 6 | HAINES | 86 | IMB |
| $>$ 30 | *n* | 90 | 0 | 0.4 | KAJITA | 86 | KAMI |
| $>$ 18 | *n* | 90 | 4 | 3 | PARK | 85 | IMB |
| $>$ 0.6 | *n* | 90 | 2 | | [1] CHERRY | 81 | HOME |

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

## $\tau(N \to e^+ \rho)$ $\tau_7$

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

[1] Limit based on zero events.

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

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

## $\tau(N \to \mu^+ \rho)$ $\tau_8$

| *LIMIT (10$^{30}$ years)* | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>570** | ***p*** | **90** | **1** | **1.30** | ABE | 17D | SKAM |
| **>228** | ***n*** | **90** | **3** | **9.5** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| > 60 | *n* | 90 | 1 | 0.96 | ABE | 17D | SKAM |
| >160 | *p* | 90 | 1 | 0.42 | NISHINO | 12 | SKAM |
| > 36 | *n* | 90 | 0 | 0.29 | NISHINO | 12 | SKAM |
| > 12 | *p* | 90 | 0 | 0.5 | BERGER | 91 | FREJ |
| > 22 | *n* | 90 | 0 | 1.1 | BERGER | 91 | FREJ |
| >110 | *p* | 90 | 0 | 1.7 | HIRATA | 89C | KAMI |
| > 23 | *n* | 90 | 1 | 1.8 | HIRATA | 89C | KAMI |
| > 4.3 | *p* | 90 | 0 | 0.7 | PHILLIPS | 89 | HPW |
| > 30 | *p* | 90 | 0 | 0.5 | SEIDEL | 88 | IMB |
| > 11 | *n* | 90 | 1 | 1.1 | SEIDEL | 88 | IMB |
| > 16 | *p* | 90 | 4 | 4.5 | HAINES | 86 | IMB |
| > 7 | *n* | 90 | 6 | 5 | HAINES | 86 | IMB |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| > 12 | *p* | 90 | 0 | <0.7 | ARISAKA | 85 | KAMI |
| > 5 | *n* | 90 | 1 | <1.2 | ARISAKA | 85 | KAMI |
| > 5.5 | *p* (free) | 90 | 4 | 5 | BLEWITT | 85 | IMB |
| > 16 | *p* | 90 | 4 | 5 | BLEWITT | 85 | IMB |
| > 9 | *n* | 90 | 1 | 2 | PARK | 85 | IMB |

## $\tau(N \to \nu\rho)$ $\tau_9$

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

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

## $\tau(p \to e^+\omega)$ $\tau_{10}$

| *LIMIT* ($10^{30}$ *years*) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>1600** | ***p*** | **90** | **1** | **1.35** | ABE | 17D | SKAM |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| > 320 | *p* | 90 | 1 | 0.53 | NISHINO | 12 | SKAM |
| > 107 | *p* | 90 | 7 | 10.8 | MCGREW | 99 | IMB3 |
| > 17 | *p* | 90 | 0 | 1.1 | BERGER | 91 | FREJ |
| > 45 | *p* | 90 | 2 | 1.45 | HIRATA | 89C | KAMI |
| > 26 | *p* | 90 | 1 | 1.0 | SEIDEL | 88 | IMB |
| > 1.5 | *p* | 90 | 0 | | BARTELT | 87 | SOUD |
| > 37 | *p* | 90 | 6 | 5.3 | HAINES | 86 | IMB |
| > 25 | *p* | 90 | 1 | <1.4 | ARISAKA | 85 | KAMI |
| > 12 | *p* (free) | 90 | 6 | 7.5 | BLEWITT | 85 | IMB |
| > 37 | *p* | 90 | 6 | 5.7 | BLEWITT | 85 | IMB |
| > 0.6 | *p* | 90 | 1 | 0.3 | [1] BARTELT | 83 | SOUD |
| > 9.8 | *p* | 90 | 1 | | [2] KRISHNA... | 82 | KOLR |
| > 2.8 | *p* | 90 | 2 | | [3] CHERRY | 81 | HOME |

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

## $\tau(p \rightarrow \mu^+ \omega)$ $\tau_{11}$

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

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

| *LIMIT* ($10^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | *TECN* |
|---|---|---|---|---|---|---|
| $>780$ | $p$ | 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 |

## $\tau(n \rightarrow \nu \omega)$ $\tau_{12}$

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

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

| *LIMIT* ($10^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | *TECN* |
|---|---|---|---|---|---|---|
| $>17$ | $n$ | 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.

## $\tau(N \rightarrow e^+ K)$ $\tau_{13}$

| *LIMIT* ($10^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | *TECN* |
|---|---|---|---|---|---|---|
| $\mathbf{>1000}$ | **p** | **90** | **6** | **4.7** | KOBAYASHI 05 | SKAM |
| $\mathbf{>17}$ | $\boldsymbol{n}$ | **90** | **35** | **29.4** | MCGREW 99 | IMB3 |

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

| *LIMIT* ($10^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | *TECN* |
|---|---|---|---|---|---|---|
| $>85$ | $p$ | 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 |

### $\tau(p \to e^{+} K^0_S)$ $\tau_{14}$

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

### $\tau(p \to e^{+} K^0_L)$ $\tau_{15}$

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

### $\tau(N \to \mu^{+} K)$ $\tau_{16}$

| *LIMIT* *($10^{30}$ years)* | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | *TECN* |
|---|---|---|---|---|---|---|
| **>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 | 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 | | [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 $p \to \mu^{+} K^0_S$.

[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.

### $\tau(p \to \mu^{+} K^0_S)$ $\tau_{17}$

| *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 |

## $\tau(p \to \mu^+ K^0_L)$ $\tau_{18}$

| 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 | $\leq 0.1$ | BERGER 91 | FREJ |

## $\tau(N \to \nu K)$ $\tau_{19}$

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | TECN |
|---|---|---|---|---|---|---|
| **>5900** | ***p*** | **90** | **0** | **1.0** | ABE 14G | SKAM |
| **> 86** | ***n*** | **90** | **0** | **2.4** | HIRATA 89C | KAMI |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| $>$ 540 | $p$ | 90 | 0 | 0.9 | ASAKURA 15 | KLND |
| $>$2300 | $p$ | 90 | 0 | 1.3 | KOBAYASHI 05 | SKAM |
| $>$ 26 | $n$ | 90 | 16 | 9.1 | WALL 00 | SOU2 |
| $>$ 670 | $p$ | 90 | | | HAYATO 99 | SKAM |
| $>$ 151 | $p$ | 90 | 15 | 21.4 | MCGREW 99 | IMB3 |
| $>$ 30 | $n$ | 90 | 34 | 34.1 | MCGREW 99 | IMB3 |
| $>$ 43 | $p$ | 90 | 1 | 1.54 | [1] ALLISON 98 | SOU2 |
| $>$ 15 | $n$ | 90 | 1 | 1.8 | BERGER 89 | FREJ |
| $>$ 15 | $p$ | 90 | 1 | 1.8 | BERGER 89 | FREJ |
| $>$ 100 | $p$ | 90 | 9 | 7.3 | HIRATA 89C | KAMI |
| $>$ 0.28 | $p$ | 90 | 0 | 0.7 | PHILLIPS 89 | HPW |
| $>$ 0.3 | $p$ | 90 | 0 | | BARTELT 87 | SOUD |
| $>$ 0.75 | $n$ | 90 | 0 | | [2] BARTELT 87 | SOUD |
| $>$ 10 | $p$ | 90 | 6 | 5 | HAINES 86 | IMB |
| $>$ 15 | $n$ | 90 | 3 | 5 | HAINES 86 | IMB |
| $>$ 28 | $p$ | 90 | 3 | 3 | KAJITA 86 | KAMI |
| $>$ 32 | $n$ | 90 | 0 | 1.4 | KAJITA 86 | KAMI |
| $>$ 1.8 | $p$ (free) | 90 | 6 | 11 | BLEWITT 85 | IMB |
| $>$ 9.6 | $p$ | 90 | 6 | 5 | BLEWITT 85 | IMB |
| $>$ 10 | $n$ | 90 | 2 | 2 | PARK 85 | IMB |
| $>$ 5 | $n$ | 90 | 0 | | BATTISTONI 84 | NUSX |
| $>$ 2 | $p$ | 90 | 0 | | BATTISTONI 84 | NUSX |
| $>$ 0.3 | $n$ | 90 | 0 | | [3] BARTELT 83 | SOUD |
| $>$ 0.1 | $p$ | 90 | 0 | | [3] BARTELT 83 | SOUD |
| $>$ 5.8 | $p$ | 90 | 1 | | [4] KRISHNA... 82 | KOLR |
| $>$ 0.3 | $n$ | 90 | 2 | | [5] CHERRY 81 | HOME |

[1] This ALLISON 98 limit is with no background subtraction; with subtraction the limit becomes $> 46 \times 10^{30}$ years.

[2] BARTELT 87 limit applies to $n \to \nu K^0_S$.

[3] Limit based on zero events.

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

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

## $\tau(n \rightarrow \nu K^0_S)$ $\tau_{20}$

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

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

## $\tau(p \rightarrow e^+ K^*(892)^0)$ $\tau_{21}$

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

## $\tau(N \rightarrow \nu K^*(892))$ $\tau_{22}$

| *LIMIT* (10$^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>51** | ***p*** | **90** | **7** | **9.1** | MCGREW | 99 | IMB3 |
| **>78** | ***n*** | **90** | **40** | **50** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| $>$22 | *n* | 90 | 0 | 2.1 | BERGER | 89 | FREJ |
| $>$17 | *p* | 90 | 0 | 2.4 | BERGER | 89 | FREJ |
| $>$20 | *p* | 90 | 5 | 2.1 | HIRATA | 89C | KAMI |
| $>$21 | *n* | 90 | 4 | 2.4 | HIRATA | 89C | KAMI |
| $>$10 | *p* | 90 | 7 | 6 | HAINES | 86 | IMB |
| $>$ 5 | *n* | 90 | 8 | 7 | HAINES | 86 | IMB |
| $>$ 8 | *p* | 90 | 3 | 2 | KAJITA | 86 | KAMI |
| $>$ 6 | *n* | 90 | 2 | 1.6 | KAJITA | 86 | KAMI |
| $>$ 5.8 | *p* (free) | 90 | 10 | 16 | BLEWITT | 85 | IMB |
| $>$ 9.6 | *p* | 90 | 7 | 6 | BLEWITT | 85 | IMB |
| $>$ 7 | *n* | 90 | 1 | 4 | PARK | 85 | IMB |
| $>$ 2.1 | *p* | 90 | 1 | | [1] BATTISTONI | 82 | NUSX |

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

### Antilepton + mesons

## $\tau(p \rightarrow e^+ \pi^+ \pi^-)$ $\tau_{23}$

| *LIMIT* (10$^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>82** | ***p*** | **90** | **16** | **23.1** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| $>$21 | *p* | 90 | 0 | 2.2 | BERGER | 91 | FREJ |

### $\tau(p \rightarrow e^+\pi^0\pi^0)$ $\tau_{24}$

| *LIMIT (10^30 years)* | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>147** | **$p$** | **90** | **2** | **0.8** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| > 38 | $p$ | 90 | 1 | 0.5 | BERGER | 91 | FREJ |

### $\tau(n \rightarrow e^+\pi^-\pi^0)$ $\tau_{25}$

| *LIMIT (10^30 years)* | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>52** | **$n$** | **90** | **38** | **34.2** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| >32 | $n$ | 90 | 1 | 0.8 | BERGER | 91 | FREJ |

### $\tau(p \rightarrow \mu^+\pi^+\pi^-)$ $\tau_{26}$

| *LIMIT (10^30 years)* | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>133** | **$p$** | **90** | **25** | **38.0** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| > 17 | $p$ | 90 | 1 | 2.6 | BERGER | 91 | FREJ |
| > 3.3 | $p$ | 90 | 0 | 0.7 | PHILLIPS | 89 | HPW |

### $\tau(p \rightarrow \mu^+\pi^0\pi^0)$ $\tau_{27}$

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

### $\tau(n \rightarrow \mu^+\pi^-\pi^0)$ $\tau_{28}$

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

### $\tau(n \rightarrow e^+K^0\pi^-)$ $\tau_{29}$

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

## Lepton + meson

### $\tau(n \rightarrow e^-\pi^+)$ $\tau_{30}$

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

### $\tau(n \to \mu^- \pi^+)$ $\tau_{31}$

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>49** | ***n*** | **90** | **0** | **0.5** | SEIDEL | 88 | IMB |

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

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| >33 | *n* | 90 | 0 | 1.40 | BERGER | 91B | FREJ |
| > 2.7 | *n* | 90 | 0 | 0.7 | PHILLIPS | 89 | HPW |
| >25 | *n* | 90 | 7 | 6 | HAINES | 86 | IMB |
| >27 | *n* | 90 | 2 | 3 | PARK | 85 | IMB |

### $\tau(n \to e^- \rho^+)$ $\tau_{32}$

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>62** | ***n*** | **90** | **2** | **4.1** | SEIDEL | 88 | IMB |

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

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| >12 | *n* | 90 | 13 | 6 | HAINES | 86 | IMB |
| >12 | *n* | 90 | 5 | 3 | PARK | 85 | IMB |

### $\tau(n \to \mu^- \rho^+)$ $\tau_{33}$

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>7** | ***n*** | **90** | **1** | **1.1** | SEIDEL | 88 | IMB |

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

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| >2.6 | *n* | 90 | 0 | 0.7 | PHILLIPS | 89 | HPW |
| >9 | *n* | 90 | 7 | 5 | HAINES | 86 | IMB |
| >9 | *n* | 90 | 2 | 2 | PARK | 85 | IMB |

### $\tau(n \to e^- K^+)$ $\tau_{34}$

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>32** | ***n*** | **90** | **3** | **2.96** | BERGER | 91B | FREJ |

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

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| > 0.23 | *n* | 90 | 0 | 0.7 | PHILLIPS | 89 | HPW |

### $\tau(n \to \mu^- K^+)$ $\tau_{35}$

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>57** | ***n*** | **90** | **0** | **2.18** | BERGER | 91B | FREJ |

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

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| > 4.7 | *n* | 90 | 0 | 0.7 | PHILLIPS | 89 | HPW |

## Lepton + mesons

### $\tau(p \to e^- \pi^+ \pi^+)$ $\tau_{36}$

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>30** | ***p*** | **90** | **1** | **2.50** | BERGER | 91B | FREJ |

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

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| > 2.0 | *p* | 90 | 0 | 0.7 | PHILLIPS | 89 | HPW |

### $\tau(n \to e^- \pi^+ \pi^0)$ $\tau_{37}$

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

### $\tau(p \to \mu^- \pi^+ \pi^+)$ $\tau_{38}$

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

### $\tau(n \to \mu^- \pi^+ \pi^0)$ $\tau_{39}$

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

### $\tau(p \to e^- \pi^+ K^+)$ $\tau_{40}$

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>75** | ***p*** | **90** | **81** | **127.2** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| >20 | *p* | 90 | 3 | 2.50 | BERGER | 91B | FREJ |

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

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>245** | ***p*** | **90** | **3** | **4.0** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| > 5 | *p* | 90 | 2 | 0.78 | BERGER | 91B | FREJ |

## Antilepton + photon(s)

### $\tau(p \to e^+ \gamma)$ $\tau_{42}$

| LIMIT ($10^{30}$ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>670** | ***p*** | **90** | **0** | **0.1** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| >133 | *p* | 90 | 0 | 0.3 | BERGER | 91 | FREJ |
| >460 | *p* | 90 | 0 | 0.6 | SEIDEL | 88 | IMB |
| >360 | *p* | 90 | 0 | 0.3 | HAINES | 86 | IMB |
| > 87 | *p* (free) | 90 | 0 | 0.2 | BLEWITT | 85 | IMB |
| >360 | *p* | 90 | 0 | 0.2 | BLEWITT | 85 | IMB |
| > 0.1 | *p* | 90 | | | [1] GURR | 67 | CNTR |

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

### $\tau(p \to \mu^+ \gamma)$ $\tau_{43}$

| *LIMIT* ($10^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>478** | **p** | **90** | **0** | **0.1** | MCGREW | 99 | IMB3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| >155 | *p* | 90 | 0 | 0.1 | BERGER | 91 | FREJ |
| >380 | *p* | 90 | 0 | 0.5 | SEIDEL | 88 | IMB |
| > 97 | *p* | 90 | 3 | 2 | HAINES | 86 | IMB |
| > 61 | *p* (free) | 90 | 0 | 0.2 | BLEWITT | 85 | IMB |
| >280 | *p* | 90 | 0 | 0.6 | BLEWITT | 85 | IMB |
| > 0.3 | *p* | 90 | | | [1] GURR | 67 | CNTR |

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

### $\tau(n \to \nu \gamma)$ $\tau_{44}$

| *LIMIT* ($10^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>550** | | **90** | | | TAKHISTOV | 15 | SKAM |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| > 28 | *n* | 90 | 163 | 144.7 | MCGREW | 99 | IMB3 |
| > 24 | *n* | 90 | 10 | 6.86 | BERGER | 91B | FREJ |
| > 9 | *n* | 90 | 73 | 60 | HAINES | 86 | IMB |
| > 11 | *n* | 90 | 28 | 19 | PARK | 85 | IMB |

### $\tau(p \to e^+ \gamma\gamma)$ $\tau_{45}$

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

### $\tau(n \to \nu \gamma\gamma)$ $\tau_{46}$

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

## Antilepton + single massless

### $\tau(p \to e^+ X)$ $\tau_{47}$

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

### $\tau(p \to \mu^+ X)$ $\tau_{48}$

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

## Three (or more) leptons

### $\tau(p \to e^+ e^+ e^-)$ $\tau_{49}$

| *LIMIT* ($10^{30}$ years) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>793** | **p** | **90** | **0** | **0.5** | MCGREW | 99 | IMB3 |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $>147$ | *p* | 90 | 0 | 0.1 | BERGER | 91 | FREJ |
| $>510$ | *p* | 90 | 0 | 0.3 | HAINES | 86 | IMB |
| $>$ 89 | *p* (free) | 90 | 0 | 0.5 | BLEWITT | 85 | IMB |
| $>510$ | *p* | 90 | 0 | 0.7 | BLEWITT | 85 | IMB |

## $\tau(p \to e^+ \mu^+ \mu^-)$ $\tau_{50}$

| *LIMIT* (*$10^{30}$ years*) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>359** | ***p*** | **90** | **1** | **0.9** | MCGREW | 99 | IMB3 |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $>$ 81 | *p* | 90 | 0 | 0.16 | BERGER | 91 | FREJ |
| $>$ 5.0 | *p* | 90 | 0 | 0.7 | PHILLIPS | 89 | HPW |

## $\tau(p \to e^+ \nu \nu)$ $\tau_{51}$

| *LIMIT* (*$10^{30}$ years*) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>170** | ***p*** | **90** | | | [1] TAKHISTOV | 14 | SKAM |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $>$ 17 | *p* | 90 | 152 | 153.7 | MCGREW | 99 | IMB3 |
| $>$ 11 | *p* | 90 | 11 | 6.08 | BERGER | 91B | FREJ |

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

## $\tau(n \to e^+ e^- \nu)$ $\tau_{52}$

| *LIMIT* (*$10^{30}$ years*) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>257** | ***n*** | **90** | **5** | **7.5** | MCGREW | 99 | IMB3 |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $>$ 74 | *n* | 90 | 0 | $< 0.1$ | BERGER | 91B | FREJ |
| $>$ 45 | *n* | 90 | 5 | 5 | HAINES | 86 | IMB |
| $>$ 26 | *n* | 90 | 4 | 3 | PARK | 85 | IMB |

## $\tau(n \to \mu^+ e^- \nu)$ $\tau_{53}$

| *LIMIT* (*$10^{30}$ years*) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>83** | ***n*** | **90** | **25** | **29.4** | MCGREW | 99 | IMB3 |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $>47$ | *n* | 90 | 0 | $< 0.1$ | BERGER | 91B | FREJ |

## $\tau(n \to \mu^+ \mu^- \nu)$ $\tau_{54}$

| *LIMIT* (*$10^{30}$ years*) | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>79** | ***n*** | **90** | **100** | **145** | MCGREW | 99 | IMB3 |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $>42$ | *n* | 90 | 0 | 1.4 | BERGER | 91B | FREJ |
| $>$ 5.1 | *n* | 90 | 0 | 0.7 | PHILLIPS | 89 | HPW |
| $>16$ | *n* | 90 | 14 | 7 | HAINES | 86 | IMB |
| $>19$ | *n* | 90 | 4 | 7 | PARK | 85 | IMB |

## $\tau(p \to \mu^+ e^+ e^-)$ $\tau_{55}$

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

## $\tau(p \to \mu^+ \mu^+ \mu^-)$ $\tau_{56}$

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

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

## $\tau(p \to \mu^+ \nu \nu)$ $\tau_{57}$

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

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

## $\tau(p \to e^- \mu^+ \mu^+)$ $\tau_{58}$

| *LIMIT (10^30 years)* | *PARTICLE* | *CL%* | *EVTS* | *BKGD EST* | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|---|---|---|---|
| **>6.0** | ***p*** | **90** | **0** | **0.7** | PHILLIPS | 89 | HPW |

## $\tau(n \to 3\nu)$ $\tau_{59}$

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

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

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

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

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

### $\tau(n \to 5\nu)$ $\tau_{60}$

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

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

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

## Inclusive modes

### $\tau(N \to e^+ \text{anything})$ $\tau_{61}$

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

[1] The electron may be primary or secondary.

### $\tau(N \to \mu^+ \text{anything})$ $\tau_{62}$

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

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

[2] The muon may be primary or secondary.

### $\tau(N \to \nu \text{anything})$ $\tau_{63}$

Anything = $\pi$, $\rho$, $K$, etc.

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

### $\tau(N \to e^+ \pi^0 \text{anything})$ $\tau_{64}$

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

### $\tau(N \to 2 \text{ bodies}, \nu\text{-free})$ $\tau_{65}$

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

## $\Delta B = 2$ dinucleon modes

### $\tau(pp \to \pi^+ \pi^+)$ $\tau_{66}$

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

## $\tau(pn \to \pi^+\pi^0)$ $\tau_{67}$

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

## $\tau(nn \to \pi^+\pi^-)$ $\tau_{68}$

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

## $\tau(nn \to \pi^0\pi^0)$ $\tau_{69}$

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

## $\tau(pp \to K^+K^+)$ $\tau_{70}$

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

## $\tau(pp \to e^+e^+)$ $\tau_{71}$

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

## $\tau(pp \to e^+\mu^+)$ $\tau_{72}$

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

## $\tau(pp \to \mu^+\mu^+)$ $\tau_{73}$

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

## $\tau(pn \to e^+\overline{\nu})$ $\tau_{74}$

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

## $\tau(pn \to \mu^+\overline{\nu})$ $\tau_{75}$

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

### $\tau(p n \rightarrow \tau^{+} \overline{\nu}_{\tau})$ $\Gamma_{76}$

| 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. • • •

| LIMIT (10$^{30}$ years) | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|
| > 1 | 90 | | | [1] BRYMAN | 14 | CHER |

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

### $\tau(n n \rightarrow \nu_{e} \overline{\nu}_{e})$ $\Gamma_{77}$

We include "invisible" modes here.

| LIMIT (10$^{30}$ years) | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|---|
| **>1.4** | **90** | | | [1] ARAKI | 06 | KLND | $n n \rightarrow$ invisible |

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

| LIMIT (10$^{30}$ years) | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|---|
| >0.000042 | 90 | | | [2] TRETYAK | 04 | CNTR | $n n \rightarrow$ invisible |
| >0.000049 | 90 | | | [3] BACK | 03 | BORX | $n n \rightarrow$ invisible |
| >0.000012 | 90 | | | [4] BERNABEI | 00B | DAMA | $n n \rightarrow$ invisible |
| >0.000012 | 90 | 5 | 9.7 | BERGER | 91B | FREJ | $\tau$ per iron nucleus |

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

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

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

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

### $\tau(n n \rightarrow \nu_{\mu} \overline{\nu}_{\mu})$ $\Gamma_{78}$

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

| LIMIT (10$^{30}$ years) | CL% | EVTS | BKGD EST | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|---|---|
| **>1.4** | **(CL = 90%) OUR LIMIT** | | | | | | | |

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

| LIMIT (10$^{30}$ years) | CL% | EVTS | BKGD EST | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|---|---|
| >0.000006 | 90 | 4 | 4.4 | | BERGER | 91B | FREJ | $\tau$ per iron nucleus |

### $\tau(p n \rightarrow \text{invisible})$ $\Gamma_{79}$

This violates charge conservation as well as baryon number conservation.

| VALUE (10$^{30}$ years) | CL% | DOCUMENT ID | | TECN |
|---|---|---|---|---|
| **>0.000021** | 90 | [1] TRETYAK | 04 | CNTR |

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

### $\tau(p p \rightarrow \text{invisible})$ $\Gamma_{80}$

This violates charge conservation as well as baryon number conservation.

| LIMIT (10$^{30}$ years) | CL% | EVTS | BKGD EST | CL% | DOCUMENT ID | | TECN |
|---|---|---|---|---|---|---|---|
| **>0.00005** | | | | 90 | [1] BACK | 03 | BORX |

| | | | |
|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | |
| >0.00000055 | 90 | [2] BERNABEI 00B | DAMA |

[1] 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.

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

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## $\overline{p}$ PARTIAL MEAN LIVES

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

### $\tau(\overline{p} \to e^- \gamma)$ $\tau_{81}$

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

### $\tau(\overline{p} \to \mu^- \gamma)$ $\tau_{82}$

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

### $\tau(\overline{p} \to e^- \pi^0)$ $\tau_{83}$

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

### $\tau(\overline{p} \to \mu^- \pi^0)$ $\tau_{84}$

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

### $\tau(\overline{p} \to e^- \eta)$ $\tau_{85}$

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

### $\tau(\overline{p} \to \mu^- \eta)$ $\tau_{86}$

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

### $\tau(\overline{p} \to e^- K_S^0)$ $\tau_{87}$

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

### $\tau(\overline{p} \to \mu^- K_S^0)$ $\tau_{88}$

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

### $\tau(\overline{p} \to e^- K_L^0)$ $\tau_{89}$

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

### $\tau(\overline{p} \to \mu^- K_L^0)$ $\tau_{90}$

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

### $\tau(\overline{p} \to e^- \gamma\gamma)$ $\tau_{91}$

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

### $\tau(\overline{p} \to \mu^- \gamma\gamma)$ $\tau_{92}$

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

### $\tau(\overline{p} \to e^- \omega)$ $\tau_{93}$

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

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## *p* REFERENCES

| | | | | |
|---|---|---|---|---|
| FLEURBAEY | 18 | PRL 120 183001 | H. Fleurbaey *et al.* | (SORB) |
| ABE | 17 | PR D95 012004 | K. Abe *et al.* | (Super-Kamiokande Collab.) |
| ABE | 17D | PR D96 012003 | K. Abe *et al.* | (Super-Kamiokande Collab.) |
| BEYER | 17 | SCI 358 79 | A. Beyer *et al.* | (MPQG Collab.) |
| HEISSE | 17 | PRL 119 033001 | F. Heisse *et al.* | (MPIH, GSI, MANZ, RIKEN) |
| HORBATSCH | 17 | PR C95 035203 | M. Horbatsch, E.A. Hessels, A. Pineda | (YORKC+) |
| NAGAHAMA | 17 | NATC 8 14084 | H. Nagahama *et al.* | (RIKEN, TOKY, CERN+) |
| SAHOO | 17 | PR D95 013002 | B.K. Sahoo | (AHMEB) |
| SCHNEIDER | 17 | SCI 358 1081 | G. Schneider *et al.* | (MANZ, RIKEN, +) |
| SELLNER | 17 | NJP 19 083023 | S. Sellner *et al.* | (RIKEN, MPIK, +) |
| SICK | 17 | PR C95 012501 | I. Sick, D. Trautmann | (BASL) |

| | | | | |
|---|---|---|---|---|
| SMORRA | 17 | NAT 550 371 | C. Smorra *et al.* | (RIKEN, CERN, +) |
| HIGINBOTHAM | 16 | PR C93 055207 | D.W. Higinbotham *et al.* | (JLAB, KENT, +) |
| MOHR | 16 | RMP 88 035009 | P.J. Mohr, D.B. Newell, B.N. Taylor | (NIST) |
| ASAKURA | 15 | PR D92 052006 | K. Asakura *et al.* | (KamLAND Collab.) |
| GUSTAFSON | 15 | PR D91 072009 | J. Gustafson *et al.* | (Super-Kamiokande Collab.) |
| LEE | 15 | PR D92 013013 | G. Lee, J.R. Arrington, R.J. Hill | (ANL, EFI+) |
| PESET | 15 | EPJ A51 32 | C. Peset, A. Pineda | (BARC) |
| TAKHISTOV | 15 | PRL 115 121803 | V. Takhistov *et al.* | (Super-Kamiokande Collab.) |
| ULMER | 15 | NAT 524 196 | S. Ulmer *et al.* | (RIKEN, CERN, MPIH, +) |
| ABE | 14E | PRL 113 121802 | K. Abe *et al.* | (Super-Kamiokande Collab.) |
| ABE | 14G | PR D90 072005 | K. Abe *et al.* | (Super-Kamiokande Collab.) |
| BRYMAN | 14 | PL B733 190 | D. Bryman | (BRCO) |
| EPSTEIN | 14 | PR D90 074027 | Z. Epstein, G. Paz, J. Roy | (UMD, WAYN) |
| KARSHENBOI... | 14A | PR D90 053012 | S.G. Karshenboim | (MPIG) |
| LITOS | 14 | PRL 112 131803 | M. Litos *et al.* | (Super-Kamiokande Collab.) |
| LORENZ | 14 | PL B737 57 | I.T. Lorentz, U.-G. Meissner | (BONN, JULI) |
| PDG | 14 | CP C38 070001 | K. Olive *et al.* | (PDG Collab.) |
| TAKHISTOV | 14 | PRL 113 101801 | V. Takhistov *et al.* | (Super-Kamiokande Collab.) |
| ANTOGNINI | 13 | SCI 339 417 | A. Antognini *et al.* | (MPIM, ETH, UPMC+) |
| DISCIACCA | 13 | PRL 110 130801 | J. DiSciacca *et al.* | (ATRAP Collab.) |
| MCGOVERN | 13 | EPJ A49 12 | J.A. McGovern, D.R. Phillips, H.W. Griesshammer | |
| MOHR | 12 | RMP 84 1527 | P.J. Mohr, B.N. Taylor, D.B. Newell | (NIST) |
| NISHINO | 12 | PR D85 112001 | H. Nishino *et al.* | (Super-Kamiokande Collab.) |
| REGIS | 12 | PR D86 012006 | C. Regis *et al.* | (Super-Kamiokande Collab.) |
| ARRINGTON | 11 | PRL 107 119101 | J. Arrington | (ANL) |
| BERNAUER | 11 | PRL 107 119102 | J.C. Bernauer *et al.* | (MAMI A1 Collab.) |
| BRESSI | 11 | PR A83 052101 | G. Bressi *et al.* | (LEGN, PAVII, PADO, TRST+) |
| CLOET | 11 | PR C83 012201 | I.C. Cloet, G.A. Miller | (WASH) |
| DERUJULA | 11 | PL B697 26 | A. de Rujula | (MADE, BOST, CERN) |
| DISTLER | 11 | PL B696 343 | M.O. Distler, J.C. Bernauer, T. Walcher | (MANZ) |
| HILL | 11 | PRL 107 160402 | R.J. Hill, G. Paz | (EFI) |
| HORI | 11 | NAT 475 484 | M. Hori *et al.* | (MPIG, TOKY, BUDA, +) |
| ZHAN | 11 | PL B705 59 | X. Zhan *et al.* | (JLAB-Hall A Collab.) |
| BERNAUER | 10 | PRL 105 242001 | J.C. Bernauer *et al.* | (MAMI A1 Collab.) |
| Also | | PR C90 015206 | J.C. Bernauer *et al.* | (MAMI A1 Collab.) |
| BORISYUK | 10 | NP A843 59 | D. Borisyuk | (KIEV) |
| DERUJULA | 10 | PL B693 555 | A. De Rujula | (MADU, CERN) |
| HILL | 10 | PR D82 113005 | R.J. Hill, G. Paz | (CHIC) |
| POHL | 10 | NAT 466 213 | R. Pohl *et al.* | (MPIQ, ENSP, COIM, +) |
| NISHINO | 09 | PRL 102 141801 | H. Nishino *et al.* | (Super-Kamiokande Collab.) |
| PASK | 09 | PL B678 55 | T. Pask *et al.* | (Stefan Meyer Inst., Vienna, TOKY+) |
| MOHR | 08 | RMP 80 633 | P.J. Mohr, B.N. Taylor, D.B. Newell | (NIST) |
| BELUSHKIN | 07 | PR C75 035202 | M.A. Belushkin, H.W. Hammer, U.-G. Meissner | (BONN+) |
| ARAKI | 06 | PRL 96 101802 | T. Araki *et al.* | (KamLAND Collab.) |
| HORI | 06 | PRL 96 243401 | M. Hori *et al.* | (CERN, TOKYO+) |
| BLUNDEN | 05 | PR C72 057601 | P.G. Blunden, I. Sick | (MANI, BASL) |
| KOBAYASHI | 05 | PR D72 052007 | K. Kobayashi *et al.* | (Super-Kamiokande Collab.) |
| MOHR | 05 | RMP 77 1 | P.J. Mohr, B.N. Taylor | (NIST) |
| SCHUMACHER | 05 | PPNP 55 567 | M. Schumacher | (GOET) |
| AHMED | 04 | PRL 92 102004 | S.N. Ahmed *et al.* | (SNO Collab.) |
| TRETYAK | 04 | JETPL 79 106 | V.I. Tretyak, V.Yu. Denisov, Yu.G. Zdesenko | (KIEV) |
| | | Translated from ZETFP 79 136. | | |
| BACK | 03 | PL B563 23 | H.O. Back *et al.* | (Borexino Collab.) |
| BEANE | 03 | PL B567 200 | S.R. Beane *et al.* | |
| Also | | PL B607 320 (errat.) | S.R. Beane *et al.* | |
| DMITRIEV | 03 | PRL 91 212303 | V.F. Dmitriev, R.A. Senkov | (NOVO) |
| HORI | 03 | PRL 91 123401 | M. Hori *et al.* | (CERN ASACUSA Collab.) |
| SICK | 03 | PL B576 62 | I. Sick | (BASL) |
| ZDESENKO | 03 | PL B553 135 | Yu.G. Zdesenko, V.I. Tretyak | (KIEV) |
| AHMAD | 02 | PRL 89 011301 | Q.R. Ahmad *et al.* | (SNO Collab.) |
| BARANOV | 01 | PPN 32 376 | P.S. Baranov *et al.* | |
| | | Translated from FECAY 32 699. | | |
| BLANPIED | 01 | PR C64 025203 | G. Blanpied *et al.* | (BNL LEGS Collab.) |
| HORI | 01 | PRL 87 093401 | M. Hori *et al.* | (CERN ASACUSA Collab.) |
| OLMOSDEL... | 01 | EPJ A10 207 | V. Olmos de Leon *et al.* | (MAMI TAPS Collab.) |
| TRETYAK | 01 | PL B505 59 | V.I. Tretyak, Yu.G. Zdesenko | (KIEV) |
| BERNABEI | 00B | PL B493 12 | R. Bernabei *et al.* | (Gran Sasso DAMA Collab.) |
| GEER | 00 | PRL 84 590 | S. Geer *et al.* | (FNAL APEX Collab.) |
| Also | | PR D62 052004 | S. Geer *et al.* | (FNAL APEX Collab.) |
| Also | | PRL 85 3546 (errat.) | S. Geer *et al.* | (FNAL APEX Collab.) |
| GEER | 00D | APJ 532 648 | S.H. Geer, D.C. Kennedy | |

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|---|---|---|---|---|
| SENGUPTA | 00 | PL B484 275 | S. Sengupta | |
| WALL | 00 | PR D61 072004 | D. Wall *et al.* | (Soudan-2 Collab.) |
| WALL | 00B | PR D62 092003 | D. Wall *et al.* | (Soudan-2 Collab.) |
| GABRIELSE | 99 | PRL 82 3198 | G. Gabrielse *et al.* | |
| HAYATO | 99 | PRL 83 1529 | Y. Hayato *et al.* | (Super-Kamiokande Collab.) |
| MCGREW | 99 | PR D59 052004 | C. McGrew *et al.* | (IMB-3 Collab.) |
| MOHR | 99 | JPCRD 28 1713 | P.J. Mohr, B.N. Taylor | (NIST) |
| Also | | RMP 72 351 | P.J. Mohr, B.N. Taylor | (NIST) |
| TORII | 99 | PR A59 223 | H.A. Torii *et al.* | (CERN PS-205 Collab.) |
| ALLISON | 98 | PL B427 217 | W.W.M. Allison *et al.* | (Soudan-2 Collab.) |
| HU | 98B | PR D58 111101 | M. Hu *et al.* | (FNAL APEX Collab.) |
| SHIOZAWA | 98 | PRL 81 3319 | M. Shiozawa *et al.* | (Super-Kamiokande Collab.) |
| GLICENSTEIN | 97 | PL B411 326 | J.F. Glicenstein | (SACL) |
| GABRIELSE | 95 | PRL 74 3544 | G. Gabrielse *et al.* | (HARV, MANZ, SEOUL) |
| MACGIBBON | 95 | PR C52 2097 | B.E. MacGibbon *et al.* | (ILL, SASK, INRM) |
| GEER | 94 | PRL 72 1596 | S. Geer *et al.* | (FNAL, UCLA, PSU) |
| HALLIN | 93 | PR C48 1497 | E.L. Hallin *et al.* | (SASK, BOST, ILL) |
| SUZUKI | 93B | PL B311 357 | Y. Suzuki *et al.* | (Kamiokande Collab.) |
| HUGHES | 92 | PRL 69 578 | R.J. Hughes, B.I. Deutch | (LANL, AARH) |
| ZIEGER | 92 | PL B278 34 | A. Zieger *et al.* | (MPCM) |
| Also | | PL B281 417 (erratum) | A. Zieger *et al.* | (MPCM) |
| BERGER | 91 | ZPHY C50 385 | C. Berger *et al.* | (FREJUS Collab.) |
| BERGER | 91B | PL B269 227 | C. Berger *et al.* | (FREJUS Collab.) |
| FEDERSPIEL | 91 | PRL 67 1511 | F.J. Federspiel *et al.* | (ILL) |
| BECKER-SZ... | 90 | PR D42 2974 | R.A. Becker-Szendy *et al.* | (IMB-3 Collab.) |
| ERICSON | 90 | EPL 11 295 | T.E.O. Ericson, A. Richter | (CERN, DARM) |
| GABRIELSE | 90 | PRL 65 1317 | G. Gabrielse *et al.* | (HARV, MANZ, WASH+) |
| BERGER | 89 | NP B313 509 | C. Berger *et al.* | (FREJUS Collab.) |
| CHO | 89 | PRL 63 2559 | D. Cho, K. Sangster, E.A. Hinds | (YALE) |
| HIRATA | 89C | PL B220 308 | K.S. Hirata *et al.* | (Kamiokande Collab.) |
| PHILLIPS | 89 | PL B224 348 | T.J. Phillips *et al.* | (HPW Collab.) |
| KREISSL | 88 | ZPHY C37 557 | A. Kreissl *et al.* | (CERN PS176 Collab.) |
| SEIDEL | 88 | PRL 61 2522 | S. Seidel *et al.* | (IMB Collab.) |
| BARTELT | 87 | PR D36 1990 | J.E. Bartelt *et al.* | (Soudan Collab.) |
| Also | | PR D40 1701 (erratum) | J.E. Bartelt *et al.* | (Soudan Collab.) |
| COHEN | 87 | RMP 59 1121 | E.R. Cohen, B.N. Taylor | (RISC, NBS) |
| HAINES | 86 | PRL 57 1986 | T.J. Haines *et al.* | (IMB Collab.) |
| KAJITA | 86 | JPSJ 55 711 | T. Kajita *et al.* | (Kamiokande Collab.) |
| ARISAKA | 85 | JPSJ 54 3213 | K. Arisaka *et al.* | (Kamiokande Collab.) |
| BLEWITT | 85 | PRL 55 2114 | G.B. Blewitt *et al.* | (IMB Collab.) |
| DZUBA | 85 | PL 154B 93 | V.A. Dzuba, V.V. Flambaum, P.G. Silvestrov | (NOVO) |
| PARK | 85 | PRL 54 22 | H.S. Park *et al.* | (IMB Collab.) |
| BATTISTONI | 84 | PL 133B 454 | G. Battistoni *et al.* | (NUSEX Collab.) |
| MARINELLI | 84 | PL 137B 439 | M. Marinelli, G. Morpurgo | (GENO) |
| WILKENING | 84 | PR A29 425 | D.A. Wilkening, N.F. Ramsey, D.J. Larson | (HARV+) |
| BARTELT | 83 | PRL 50 651 | J.E. Bartelt *et al.* | (MINN, ANL) |
| BATTISTONI | 82 | PL 118B 461 | G. Battistoni *et al.* | (NUSEX Collab.) |
| KRISHNA... | 82 | PL 115B 349 | M.R. Krishnaswamy *et al.* | (TATA, OSKC+) |
| ALEKSEEV | 81 | JETPL 33 651 | E.N. Alekseev *et al.* | (PNPI) |
| | | Translated from ZETFP 33 664. | | |
| CHERRY | 81 | PRL 47 1507 | M.L. Cherry *et al.* | (PENN, BNL) |
| COWSIK | 80 | PR D22 2204 | R. Cowsik, V.S. Narasimham | (TATA) |
| BELL | 79 | PL 86B 215 | M. Bell *et al.* | (CERN) |
| GOLDEN | 79 | PRL 43 1196 | R.L. Golden *et al.* | (NASA, PSLL) |
| LEARNED | 79 | PRL 43 907 | J.G. Learned, F. Reines, A. Soni | (UCI) |
| BREGMAN | 78 | PL 78B 174 | M. Bregman *et al.* | (CERN) |
| ROBERTS | 78 | PR D17 358 | B.L. Roberts | (WILL, RHEL) |
| EVANS | 77 | SCI 197 989 | J.C. Evans Jr., R.I. Steinberg | (BNL, PENN) |
| HU | 75 | NP A254 403 | E. Hu *et al.* | (COLU, YALE) |
| COHEN | 73 | JPCRD 2 664 | E.R. Cohen, B.N. Taylor | (RISC, NBS) |
| DYLLA | 73 | PR A7 1224 | H.F. Dylla, J.G. King | (MIT) |
| DIX | 70 | Thesis Case | F.W. Dix | (CASE) |
| HARRISON | 69 | PRL 22 1263 | G.E. Harrison, P.G.H. Sandars, S.J. Wright | (OXF) |
| GURR | 67 | PR 158 1321 | H.S. Gurr *et al.* | (CASE, WITW) |
| FLEROV | 58 | DOKL 3 79 | G.N. Flerov *et al.* | (ASCI) |