μ

$J = \frac{1}{2}$

μ MASS (atomic mass units u)

The muon's mass is obtained from the muon-electron mass ratio as determined from the measurement of Zeeman transition frequencies in muonium ($\mu^+ e^-$ atom). Since the electron's mass is most accurately known in u, the muon's mass is also most accurately known in u. The conversion factor to MeV has approximately the same relative uncertainty as the mass of the muon in u. In this datablock we give the result in u, and in the following datablock in MeV.

VALUE (u)	*DOCUMENT ID*		*TECN*	*COMMENT*
0.1134289257±0.0000000025	MOHR	16	RVUE	2014 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.1134289267±0.0000000029	MOHR	12	RVUE	2010 CODATA value
0.1134289256±0.0000000029	MOHR	08	RVUE	2006 CODATA value
0.1134289264±0.0000000030	MOHR	05	RVUE	2002 CODATA value
0.1134289168±0.0000000034	[1] MOHR	99	RVUE	1998 CODATA value
0.113428913 ±0.000000017	[2] COHEN	87	RVUE	1986 CODATA value

[1] MOHR 99 make use of other 1998 CODATA entries below.
[2] COHEN 87 make use of other 1986 CODATA entries below.

μ MASS

2010 CODATA (MOHR 12) gives the conversion factor from u (atomic mass units, see the above datablock) to MeV as 931.494 061 (21). Earlier values use the then-current conversion factor. The conversion error contributes significantly to the uncertainty of the masses given below.

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
105.6583745±0.0000024	MOHR	16	RVUE		2014 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •					
105.6583715±0.0000035	MOHR	12	RVUE		2010 CODATA value
105.6583668±0.0000038	MOHR	08	RVUE		2006 CODATA value
105.6583692±0.0000094	MOHR	05	RVUE		2002 CODATA value
105.6583568±0.0000052	MOHR	99	RVUE		1998 CODATA value
105.658353 ±0.000016	[1] COHEN	87	RVUE		1986 CODATA value
105.658386 ±0.000044	[2] MARIAM	82	CNTR	+	
105.65836 ±0.00026	[3] CROWE	72	CNTR		
105.65865 ±0.00044	[4] CRANE	71	CNTR		

[1] Converted to MeV using the 1998 CODATA value of the conversion constant, 931.494013 ± 0.000037 MeV/u.
[2] MARIAM 82 give m_μ/m_e = 206.768259(62).
[3] CROWE 72 give m_μ/m_e = 206.7682(5).
[4] CRANE 71 give m_μ/m_e = 206.76878(85).

μ MEAN LIFE τ

Measurements with an error $> 0.001 \times 10^{-6}$ s have been omitted.

VALUE (10^{-6} s)	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
2.1969811±0.0000022 OUR AVERAGE					
2.1969803±0.0000021±0.0000007	[1] TISHCHENKO	13	CNTR	+	Surface μ^+ at PSI
2.197083 ±0.000032 ±0.000015	BARCZYK	08	CNTR	+	Muons from π^+ decay at rest
2.197013 ±0.000021 ±0.000011	CHITWOOD	07	CNTR	+	Surface μ^+ at PSI
2.197078 ±0.000073	BARDIN	84	CNTR	+	
2.197025 ±0.000155	BARDIN	84	CNTR	−	
2.19695 ±0.00006	GIOVANETTI	84	CNTR	+	
2.19711 ±0.00008	BALANDIN	74	CNTR	+	
2.1973 ±0.0003	DUCLOS	73	CNTR	+	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.1969803±0.0000022	WEBBER	11	CNTR	+	Surface μ^+ at PSI

[1] TISHCHENKO 13 uses 1.6×10^{12} μ^+ events and supersedes WEBBER 11.

$\tau_{\mu^+}/\tau_{\mu^-}$ MEAN LIFE RATIO

A test of *CPT* invariance.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
1.000024±0.000078	BARDIN	84	CNTR	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.0008 ±0.0010	BAILEY	79	CNTR	Storage ring
1.000 ±0.001	MEYER	63	CNTR	Mean life $\mu^+/\ \mu^-$

$(\tau_{\mu^+} - \tau_{\mu^-})\ /\ \tau_{\text{average}}$

A test of *CPT* invariance. Calculated from the mean-life ratio, above.

VALUE	*DOCUMENT ID*
(2±8) × 10^{-5} OUR EVALUATION	

μ/p MAGNETIC MOMENT RATIO

This ratio is used to obtain a precise value of the muon mass and to reduce experimental muon Larmor frequency measurements to the muon magnetic moment anomaly. Measurements with an error > 0.00001 have been omitted. By convention, the minus sign on this ratio is omitted. CODATA values were fitted using their selection of data, plus other data from multiparameter fits.

VALUE	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
3.183345142±0.000000071	MOHR	16	RVUE		2014 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3.183345107±0.000000084	MOHR	12	RVUE		2010 CODATA value

3.183345137±0.000000085	MOHR	08	RVUE		2006 CODATA value
3.183345118±0.000000089	MOHR	05	RVUE		2002 CODATA value
3.18334513 ±0.00000039	LIU	99	CNTR	+	HFS in muonium
3.18334539 ±0.00000010	MOHR	99	RVUE		1998 CODATA value
3.18334547 ±0.00000047	COHEN	87	RVUE		1986 CODATA value
3.1833441 ±0.0000017	KLEMPT	82	CNTR	+	Precession strob
3.1833461 ±0.0000011	MARIAM	82	CNTR	+	HFS splitting
3.1833448 ±0.0000029	CAMANI	78	CNTR	+	See KLEMPT 82
3.1833403 ±0.0000044	CASPERSON	77	CNTR	+	HFS splitting
3.1833402 ±0.0000072	COHEN	73	RVUE		1973 CODATA value
3.1833467 ±0.0000082	CROWE	72	CNTR	+	Precession phase

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μ MAGNETIC MOMENT ANOMALY

The parity-violating decay of muons in a storage ring is observed. The difference frequency ω_a between the muon spin precision and the orbital angular frequency $(e/m_\mu c)\langle B\rangle$ is measured, as is the free proton NMR frequency ω_p, thus determining the ratio $R{=}\omega_a/\omega_p$. Given the magnetic moment ratio $\lambda{=}\mu_\mu/\mu_p$ (from hyperfine structure in muonium), $(g{-}2)/2 = R/(\lambda{-}R)$.

$\mu_\mu/(e\hbar/2m_\mu){-}1 = (g_\mu{-}2)/2$

VALUE (units 10^{-10})	DOCUMENT ID		TECN	CHG	COMMENT
11659208.9± 5.4±3.3	[1] BENNETT	06	MUG2		Average μ^+ and μ^-
• • • We do not use the following data for averages, fits, limits, etc. • • •					
11659208 ± 6	BENNETT	04	MUG2		Average μ^+ and μ^-
11659214 ± 8 ±3	BENNETT	04	MUG2	−	Storage ring
11659203 ± 6 ±5	BENNETT	04	MUG2	+	Storage ring
11659204 ± 7 ±5	BENNETT	02	MUG2	+	Storage ring
11659202 ± 14 ±6	BROWN	01	MUG2	+	Storage ring
11659191 ± 59	BROWN	00	MUG2	+	
11659100 ± 110	[2] BAILEY	79	CNTR	+	Storage ring
11659360 ± 120	[2] BAILEY	79	CNTR	−	Storage ring
11659230 ± 85	[2] BAILEY	79	CNTR	±	Storage ring
11620000 ±5000	CHARPAK	62	CNTR	+	

[1] BENNETT 06 reports $(g_\mu{-}2)/2 = (11659208.0 \pm 5.4 \pm 3.3) \times 10^{-10}$. We rescaled this value using μ/p magnetic moment ratio of 3.183345137(85) from MOHR 08.

[2] BAILEY 79 values recalculated by HUGHES 99 using the COHEN 87 μ/p magnetic moment. The improved MOHR 99 value does not change the result.

$(g_{\mu^+} - g_{\mu^-})\ /\ g_{\text{average}}$

A test of *CPT* invariance.

VALUE (units 10^{-8})	DOCUMENT ID		TECN
−0.11±0.12	BENNETT	04	MUG2
• • • We do not use the following data for averages, fits, limits, etc. • • •			

-2.6 ± 1.6	BAILEY	79	CNTR	

μ ELECTRIC DIPOLE MOMENT (d)

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

VALUE (10^{-19} *e* cm)	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
-0.1 ± 0.9	[1] BENNETT	09	MUG2	$\pm$	Storage ring
• • • We do not use the following data for averages, fits, limits, etc. • • •					
-0.1 ± 1.0	BENNETT	09	MUG2	$+$	Storage ring
-0.1 ± 0.7	BENNETT	09	MUG2	$-$	Storage ring
-3.7 ± 3.4	[2] BAILEY	78	CNTR	$\pm$	Storage ring
8.6 ± 4.5	BAILEY	78	CNTR	$+$	Storage ring
0.8 ± 4.3	BAILEY	78	CNTR	$-$	Storage ring

[1] This is the combination of the two BENNETT 09 results quoted here separately for μ^+ and μ^-. BENNETT 09 uses the convention $d = 1/2 \cdot (d_{\mu^-} - d_{\mu^+})$.

[2] This is the combination of the two BAILEY 78 results quoted here separately for μ^+ and μ^-. BAILEY 78 uses the convention $d = 1/2 \cdot (d_{\mu^+} - d_{\mu^-})$ and reports 3.7 ± 3.4. We convert their result to use the same convention as BENNETT 09.

MUON-ELECTRON CHARGE RATIO ANOMALY $q_{\mu^+}/q_{e^-} + 1$

VALUE	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
$(1.1 \pm 2.1) \times 10^{-9}$	[1] MEYER	00	CNTR	$+$	1s–2s muonium interval

[1] MEYER 00 measure the 1s–2s muonium interval, and then interpret the result in terms of muon-electron charge ratio q_{μ^+}/q_{e^-}.

μ^- DECAY MODES

μ^+ modes are charge conjugates of the modes below.

	Mode			Fraction (Γ_i/Γ)	Confidence level
Γ_1	$e^- \overline{\nu}_e \nu_\mu$			$\approx 100\%$	
Γ_2	$e^- \overline{\nu}_e \nu_\mu \gamma$		[a]	(1.4 ± 0.4) %	
Γ_3	$e^- \overline{\nu}_e \nu_\mu e^+ e^-$		[b]	$(3.4 \pm 0.4) \times 10^{-5}$	
	Lepton Family number (*LF*) violating modes				
Γ_4	$e^- \nu_e \overline{\nu}_\mu$	*LF*	[c]	< 1.2 %	90%
Γ_5	$e^- \gamma$	*LF*		$< 5.7 \times 10^{-13}$	90%
Γ_6	$e^- e^+ e^-$	*LF*		$< 1.0 \times 10^{-12}$	90%
Γ_7	$e^- 2\gamma$	*LF*		$< 7.2 \times 10^{-11}$	90%

[a] This only includes events with the γ energy > 10 MeV. Since the $e^- \overline{\nu}_e \nu_\mu$ and $e^- \overline{\nu}_e \nu_\mu \gamma$ modes cannot be clearly separated, we regard the latter mode as a subset of the former.

[b] See the Particle Listings below for the energy limits used in this measurement.

[c] A test of additive vs. multiplicative lepton family number conservation.

μ^- BRANCHING RATIOS

$\Gamma(e^-\overline{\nu}_e\nu_\mu\gamma)/\Gamma_{\text{total}}$ — Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.014 ±0.004		CRITTENDEN	61	CNTR	γ KE > 10 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
	862	BOGART	67	CNTR	γ KE > 14.5 MeV
0.0033±0.0013		CRITTENDEN	61	CNTR	γ KE > 20 MeV
	27	ASHKIN	59	CNTR	

$\Gamma(e^-\overline{\nu}_e\nu_\mu e^+e^-)/\Gamma_{\text{total}}$ — Γ_3/Γ

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
3.4±0.2±0.3	7443	[1] BERTL	85	SPEC	+	SINDRUM
• • • We do not use the following data for averages, fits, limits, etc. • • •						
2.2±1.5	7	[2] CRITTENDEN	61	HLBC	+	E(e^+e^-) > 10 MeV
2	1	[3] GUREVICH	60	EMUL	+	
1.5±1.0	3	[4] LEE	59	HBC	+	

[1] BERTL 85 has transverse momentum cut p_T > 17 MeV/c. Systematic error was increased by us.

[2] CRITTENDEN 61 count only those decays where total energy of either (e^+, e^-) combination is >10 MeV.

[3] GUREVICH 60 interpret their event as either virtual or real photon conversion. e^+ and e^- energies not measured.

[4] In the three LEE 59 events, the sum of energies E(e^+) + E(e^-) + E(e^+) was 51 MeV, 55 MeV, and 33 MeV.

$\Gamma(e^-\nu_e\overline{\nu}_\mu)/\Gamma_{\text{total}}$ — Γ_4/Γ

Forbidden by the additive conservation law for lepton family number. A multiplicative law predicts this branching ratio to be 1/2. For a review see NEMETHY 81.

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
< 0.012	90	[1] FREEDMAN	93	CNTR	+	ν oscillation search
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 0.018	90	KRAKAUER	91B	CALO	+	
< 0.05	90	[2] BERGSMA	83	CALO		$\overline{\nu}_\mu e \rightarrow \mu^-\overline{\nu}_e$
< 0.09	90	JONKER	80	CALO		See BERGSMA 83
−0.001±0.061		WILLIS	80	CNTR	+	
0.13 ±0.15		BLIETSCHAU	78	HLBC	±	Avg. of 4 values
< 0.25	90	EICHTEN	73	HLBC	+	

[1] FREEDMAN 93 limit on $\overline{\nu}_e$ observation is here interpreted as a limit on lepton family number violation.

[2] BERGSMA 83 gives a limit on the inverse muon decay cross-section ratio $\sigma(\overline{\nu}_\mu e^- \rightarrow \mu^-\overline{\nu}_e)/\sigma(\nu_\mu e^- \rightarrow \mu^-\nu_e)$, which is essentially equivalent to $\Gamma(e^-\nu_e\overline{\nu}_\mu)/\Gamma_{\text{total}}$ for small values like that quoted.

$\Gamma(e^-\gamma)/\Gamma_{\text{total}}$ Γ_5/Γ

Forbidden by lepton family number conservation.

VALUE (units 10^{-11})	*CL%*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
< 0.057	90	ADAM	13B	SPEC	+	MEG at PSI
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 0.24	90	ADAM	11	SPEC	+	MEG at PSI
< 2.8	90	ADAM	10	SPEC	+	MEG at PSI
< 1.2	90	AHMED	02	SPEC	+	MEGA
< 1.2	90	BROOKS	99	SPEC	+	LAMPF
< 4.9	90	BOLTON	88	CBOX	+	LAMPF
<100	90	AZUELOS	83	CNTR	+	TRIUMF
< 17	90	KINNISON	82	SPEC	+	LAMPF
<100	90	SCHAAF	80	ELEC	+	SIN

$\Gamma(e^-e^+e^-)/\Gamma_{\text{total}}$ Γ_6/Γ

Forbidden by lepton family number conservation.

VALUE (units 10^{-12})	*CL%*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
< 1.0	90	[1] BELLGARDT	88	SPEC	+	SINDRUM
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 36	90	BARANOV	91	SPEC	+	ARES
< 35	90	BOLTON	88	CBOX	+	LAMPF
< 2.4	90	[1] BERTL	85	SPEC	+	SINDRUM
<160	90	[1] BERTL	84	SPEC	+	SINDRUM
<130	90	[1] BOLTON	84	CNTR		LAMPF

[1] These experiments assume a constant matrix element.

$\Gamma(e^-2\gamma)/\Gamma_{\text{total}}$ Γ_7/Γ

Forbidden by lepton family number conservation.

VALUE (units 10^{-11})	*CL%*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
< 7.2	90	BOLTON	88	CBOX	+	LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 840	90	[1] AZUELOS	83	CNTR	+	TRIUMF
<5000	90	[2] BOWMAN	78	CNTR		DEPOMMIER 77 data

[1] AZUELOS 83 uses the phase space distribution of BOWMAN 78.
[2] BOWMAN 78 assumes an interaction Lagrangian local on the scale of the inverse μ mass.

LIMIT ON $\mu^- \rightarrow e^-$ CONVERSION

Forbidden by lepton family number conservation.

$\sigma(\mu^- {}^{32}\text{S} \rightarrow e^- {}^{32}\text{S}) / \sigma(\mu^- {}^{32}\text{S} \rightarrow \nu_\mu {}^{32}\text{P}^*)$

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<7 \times 10^{-11}$	90	BADERT...	80	STRC	SIN
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<4 \times 10^{-10}$	90	BADERT...	77	STRC	SIN

$\sigma(\mu^- \text{Cu} \to e^- \text{Cu}) / \sigma(\mu^- \text{Cu} \to \text{capture})$

VALUE	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<1.6 \times 10^{-8}$	90	BRYMAN	72	SPEC

$\sigma(\mu^- \text{Ti} \to e^- \text{Ti}) / \sigma(\mu^- \text{Ti} \to \text{capture})$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<4.3 \times 10^{-12}$	90	[1] DOHMEN	93	SPEC	SINDRUM II
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<4.6 \times 10^{-12}$	90	AHMAD	88	TPC	TRIUMF
$<1.6 \times 10^{-11}$	90	BRYMAN	85	TPC	TRIUMF

[1] DOHMEN 93 assumes $\mu^- \rightarrow e^-$ conversion leaves the nucleus in its ground state, a process enhanced by coherence and expected to dominate.

$\sigma(\mu^- \text{Pb} \to e^- \text{Pb}) / \sigma(\mu^- \text{Pb} \to \text{capture})$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<4.6 \times 10^{-11}$	90	HONECKER	96	SPEC	SINDRUM II
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<4.9 \times 10^{-10}$	90	AHMAD	88	TPC	TRIUMF

$\sigma(\mu^- \text{Au} \to e^- \text{Au}) / \sigma(\mu^- \text{Au} \to \text{capture})$

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
$<7 \times 10^{-13}$	90	BERTL	06	SPEC	$-$	SINDRUM II

LIMIT ON $\mu^- \rightarrow e^+$ CONVERSION

Forbidden by total lepton number conservation.

$\sigma(\mu^- \, {}^{32}\text{S} \to e^+ \, {}^{32}\text{Si}^*) / \sigma(\mu^- \, {}^{32}\text{S} \to \nu_\mu \, {}^{32}\text{P}^*)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<9 \times 10^{-10}$	90	BADERT...	80	STRC	SIN
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.5 \times 10^{-9}$	90	BADERT...	78	STRC	SIN

$\sigma(\mu^- \, {}^{127}\text{I} \to e^+ \, {}^{127}\text{Sb}^*) / \sigma(\mu^- \, {}^{127}\text{I} \to \text{anything})$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<3 \times 10^{-10}$	90	[1] ABELA	80	CNTR	Radiochemical tech.

[1] ABELA 80 is upper limit for $\mu^- e^+$ conversion leading to particle-stable states of ^{127}Sb. Limit for total conversion rate is higher by a factor less than 4 (G. Backenstoss, private communication).

$\sigma(\mu^- \text{Cu} \to e^+ \text{Co}) / \sigma(\mu^- \text{Cu} \to \nu_\mu \text{Ni})$

VALUE	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<2.6 \times 10^{-8}$	90	BRYMAN	72	SPEC
$<2.2 \times 10^{-7}$	90	CONFORTO	62	OSPK

$\sigma(\mu^- \text{Ti} \to e^+ \text{Ca}) / \sigma(\mu^- \text{Ti} \to \text{capture})$

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
$<3.6 \times 10^{-11}$	90	1	[1,2] KAULARD	98	SPEC	−	SINDRUM II
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$<1.7 \times 10^{-12}$	90	1	[2,3] KAULARD	98	SPEC	−	SINDRUM II
$<4.3 \times 10^{-12}$	90		[3] DOHMEN	93	SPEC		SINDRUM II
$<8.9 \times 10^{-11}$	90		[1] DOHMEN	93	SPEC		SINDRUM II
$<1.7 \times 10^{-10}$	90		[4] AHMAD	88	TPC		TRIUMF

[1] This limit assumes a giant resonance excitation of the daughter Ca nucleus (mean energy and width both 20 MeV).
[2] KAULARD 98 obtained these same limits using the unified classical analysis of FELDMAN 98.
[3] This limit assumes the daughter Ca nucleus is left in the ground state. However, the probability of this is unknown.
[4] Assuming a giant-resonance-excitation model.

LIMIT ON MUONIUM → ANTIMUONIUM CONVERSION

Forbidden by lepton family number conservation.

$R_g = G_C \;/\; G_F$

The effective Lagrangian for the $\mu^+ e^- \to \mu^- e^+$ conversion is assumed to be

$$\mathcal{L} = 2^{-1/2}\, G_C\, [\overline{\psi}_\mu \gamma_\lambda\, (1-\gamma_5)\, \psi_e]\, [\overline{\psi}_\mu \gamma_\lambda\, (1-\gamma_5)\, \psi_e] + \text{h.c.}$$

The experimental result is then an upper limit on G_C/G_F, where G_F is the Fermi coupling constant.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
< 0.0030	90	1	[1] WILLMANN	99	SPEC	+	μ^+ at 26 GeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •							
< 0.14	90	1	[2] GORDEEV	97	SPEC	+	JINR phasotron
< 0.018	90	0	[3] ABELA	96	SPEC	+	μ^+ at 24 MeV
< 6.9	90		NI	93	CBOX		LAMPF
< 0.16	90		MATTHIAS	91	SPEC		LAMPF
< 0.29	90		HUBER	90B	CNTR		TRIUMF
<20	95		BEER	86	CNTR		TRIUMF
<42	95		MARSHALL	82	CNTR		

[1] WILLMANN 99 quote both probability $P_{M\overline{M}} < 8.3 \times 10^{-11}$ at 90%CL in a 0.1 T field and $R_g = G_C/G_F$.
[2] GORDEEV 97 quote limits on both $f = G_{MM}/GF$ and the probability $W_{MM} < 4.7 \times 10^{-7}$ (90% CL).
[3] ABELA 96 quote both probability $P_{M\overline{M}} < 8 \times 10^{-9}$ at 90% CL and $R_g = G_C/G_F$.

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μ DECAY PARAMETERS

ρ PARAMETER

($V-A$) theory predicts ρ = 0.75.

VALUE	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
0.74979±0.00026 OUR AVERAGE					
0.74977±0.00012±0.00023		[1] BAYES 11	TWST	+	Surface μ^+
0.7518 ±0.0026		DERENZO 69	RVUE		
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.75014±0.00017±0.00045		[2] MACDONALD 08	TWST	+	Surface μ^+
0.75080±0.00032±0.00100	6G	[3] MUSSER 05	TWST	+	Surface μ^+
0.72 ±0.06 ±0.08		AMORUSO 04	ICAR		Liquid Ar TPC
0.762 ±0.008	170k	[4] FRYBERGER 68	ASPK	+	25–53 MeV e^+
0.760 ±0.009	280k	[4] SHERWOOD 67	ASPK	+	25–53 MeV e^+
0.7503 ±0.0026	800k	[4] PEOPLES 66	ASPK	+	20–53 MeV e^+

[1] The quoted systematic error includes a contribution of 0.00013 (added in quadrature) from uncertainties on radiative corrections and on the Michel parameter η.

[2] The quoted systematic error includes a contribution of 0.00011 (added in quadrature) from the dependence on the Michel parameter η.

[3] The quoted systematic error includes a contribution of 0.00023 (added in quadrature) from the dependence on the Michel parameter η.

[4] η constrained = 0. These values incorporated into a two parameter fit to ρ and η by DERENZO 69.

η PARAMETER

($V-A$) theory predicts η = 0.

VALUE	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
0.057 ±0.034 OUR AVERAGE					
0.071 ±0.037 ±0.005	30M	DANNEBERG 05	CNTR	+	7–53 MeV e^+
0.011 ±0.081 ±0.026	5.3M	[1] BURKARD 85B	CNTR	+	9–53 MeV e^+
−0.12 ±0.21	6346	DERENZO 69	HBC	+	1.6–6.8 MeV e^+
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−0.0021±0.0070±0.0010	30M	[2] DANNEBERG 05	CNTR	+	7–53 MeV e^+
−0.012 ±0.015 ±0.003	5.3M	[2] BURKARD 85B	CNTR	+	9–53 MeV e^+
−0.007 ±0.013	5.3M	[3] BURKARD 85B	FIT	+	9–53 MeV e^+
−0.7 ±0.5	170k	[4] FRYBERGER 68	ASPK	+	25–53 MeV e^+
−0.7 ±0.6	280k	[4] SHERWOOD 67	ASPK	+	25–53 MeV e^+
0.05 ±0.5	800k	[4] PEOPLES 66	ASPK	+	20–53 MeV e^+
−2.0 ±0.9	9213	[5] PLANO 60	HBC	+	Whole spectrum

[1] Previously we used the global fit result from BURKARD 85B in OUR AVERAGE, we now only include their actual measurement.

[2] $\alpha = \alpha' = 0$ assumed.

[3] Global fit to all measured parameters. The fit correlation coefficients are given in BURKARD 85B.

[4] ρ constrained = 0.75.

[5] Two parameter fit to ρ and η; PLANO 60 discounts value for η.

δ PARAMETER

$(V-A)$ theory predicts $\delta = 0.75$.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.75047±0.00034 OUR AVERAGE						
0.75049±0.00021±0.00027		[1] BAYES	11	TWST	+	Surface μ^+
0.7486 ±0.0026 ±0.0028		[2] BALKE	88	SPEC	+	Surface μ^+
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.75067±0.00030±0.00067		MACDONALD	08	TWST	+	Surface μ^+
0.74964±0.00066±0.00112	6G	GAPONENKO	05	TWST	+	Surface μ^+
		[3] VOSSLER	69			
0.752 ±0.009	490k	FRYBERGER	68	ASPK	+	25–53 MeV e^+
0.782 ±0.031		KRUGER	61			
0.78 ±0.05	8354	PLANO	60	HBC	+	Whole spectrum

[1] The quoted systematic error includes a contribution of 0.00006 (added in quadrature) from uncertainties on radiative corrections and on the Michel parameter η.

[2] BALKE 88 uses $\rho = 0.752 \pm 0.003$.

[3] VOSSLER 69 has measured the asymmetry below 10 MeV. See comments about radiative corrections in VOSSLER 69.

$|(\xi$ PARAMETER)×(μ LONGITUDINAL POLARIZATION)$|$

$(V-A)$ theory predicts $\xi = 1$, longitudinal polarization = 1.

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
1.0009 $^{+0.0016}_{-0.0007}$ OUR AVERAGE					
1.00084±0.00029$^{+0.00165}_{-0.00063}$	BUENO	11	TWST		Surface μ^+ beam
1.0027 ±0.0079 ±0.0030	BELTRAMI	87	CNTR		SIN, π decay in flight
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1.0003 ±0.0006 ±0.0038	JAMIESON	06	TWST	+	surface μ^+ beam
1.0013 ±0.0030 ±0.0053	[1] IMAZATO	92	SPEC	+	$K^+ \rightarrow \mu^+ \nu_\mu$
0.975 ±0.015	AKHMANOV	68	EMUL		140 kG
0.975 ±0.030	GUREVICH	64	EMUL		See AKHMANOV 68
0.903 ±0.027	[2] ALI-ZADE	61	EMUL	+	27 kG
0.93 ±0.06	PLANO	60	HBC	+	8.8 kG
0.97 ±0.05	BARDON	59	CNTR		Bromoform target

[1] The corresponding 90% confidence limit from IMAZATO 92 is $|\xi P_\mu| > 0.990$. This measurement is of K^+ decay, not π^+ decay, so we do not include it in an average, nor do we yet set up a separate data block for K results.

[2] Depolarization by medium not known sufficiently well.

ξ × (μ LONGITUDINAL POLARIZATION) × δ / ρ

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
1.00179$^{+0.00156}_{-0.00071}$		[1] BAYES	11	TWST	+	Surface μ^+ beam
• • • We do not use the following data for averages, fits, limits, etc. • • •						
>0.99682	90	[2] JODIDIO	86	SPEC	+	TRIUMF
>0.9966	90	[3] STOKER	85	SPEC	+	μ-spin rotation
>0.9959	90	CARR	83	SPEC	+	11 kG

[1] BAYES 11 obtains the limit > 0.99909 (90% CL) with the constraint that $\xi\times(\mu$ LONGITUDINAL POLARIZATION$)\times\delta/\rho \leq 1.0$.

[2] JODIDIO 86 includes data from CARR 83 and STOKER 85. The value here is from the erratum.
[3] STOKER 85 find $(\xi P_\mu \delta/\rho)$ >0.9955 and >0.9966, where the first limit is from new μ spin-rotation data and the second is from combination with CARR 83 data. In $V-A$ theory, $(\delta/\rho) = 1.0$.

ξ' = LONGITUDINAL POLARIZATION OF e^+

$(V-A)$ theory predicts the longitudinal polarization = ±1 for $e^\pm$, respectively. We have flipped the sign for e^- so our programs can average.

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.00 ±0.04 OUR AVERAGE						
0.998±0.045	1M	BURKARD	85	CNTR	+	Bhabha + annihil
0.89 ±0.28	29k	SCHWARTZ	67	OSPK	−	Moller scattering
0.94 ±0.38		BLOOM	64	CNTR	+	Brems. transmiss.
1.04 ±0.18		DUCLOS	64	CNTR	+	Bhabha scattering
1.05 ±0.30		BUHLER	63	CNTR	+	Annihilation

ξ'' PARAMETER

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.98 ±0.04 OUR AVERAGE						
0.981±0.045±0.003	3.87M	PRIEELS	14	CNTR	+	Bhabha + annihil
0.65 ±0.36	326k	[1] BURKARD	85	CNTR	+	Bhabha + annihil

[1] BURKARD 85 measure $(\xi''-\xi\xi')/\xi$ and ξ' and set $\xi = 1$.

TRANSVERSE e^+ POLARIZATION IN PLANE OF μ SPIN, e^+ MOMENTUM

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
7 ± 8 OUR AVERAGE						
6.3± 7.7± 3.4	30M	DANNEBERG	05	CNTR	+	7–53 MeV e^+
16 ±21 ±10	5.3M	BURKARD	85B	CNTR	+	Annihil 9–53 MeV

TRANSVERSE e^+ POLARIZATION NORMAL TO PLANE OF μ SPIN, e^+ MOMENTUM

Zero if T invariance holds.

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
−2 ± 8 OUR AVERAGE						
−3.7± 7.7±3.4	30M	DANNEBERG	05	CNTR	+	7–53 MeV e^+
7 ±22 ±7	5.3M	BURKARD	85B	CNTR	+	Annihil 9–53 MeV

α/A

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.4± 4.3		[1] BURKARD	85B	FIT		
• • • We do not use the following data for averages, fits, limits, etc. • • •						
15 ±50 ±14	5.3M	BURKARD	85B	CNTR	+	9–53 MeV e^+

[1] Global fit to all measured parameters. Correlation coefficients are given in BURKARD 85B.

α'/A

Zero if T invariance holds.

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
-10 ± 20 OUR AVERAGE						
$-$ 3.4$\pm$21.3$\pm$ 4.9	30M	DANNEBERG	05	CNTR	+	7–53 MeV e^+
$-$47 $\pm$50 $\pm$14	5.3M	[1] BURKARD	85B	CNTR	+	9–53 MeV e^+
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$-$ 0.2$\pm$ 4.3		[2] BURKARD	85B	FIT		

[1] Previously we used the global fit result from BURKARD 85B in OUR AVERAGE, we now only include their actual measurement. BURKARD 85B measure e^+ polarizations P_{T_1} and P_{T_2} versus e^+ energy.

[2] Global fit to all measured parameters. The fit correlation coefficients are given in BURKARD 85B.

β/A

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
3.9$\pm$ 6.2		[1] BURKARD	85B	FIT		
• • • We do not use the following data for averages, fits, limits, etc. • • •						
2 $\pm$17 $\pm$6	5.3M	BURKARD	85B	CNTR	+	9–53 MeV e^+

[1] Global fit to all measured parameters. The fit correlation coefficients are given in BURKARD 85B.

β'/A

Zero if T invariance holds.

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
2 $\pm$ 7 OUR AVERAGE						
$-$ 0.5$\pm$ 7.8$\pm$1.8	30M	DANNEBERG	05	CNTR	+	7–53 MeV e^+
17 $\pm$17 $\pm$6	5.3M	[1] BURKARD	85B	CNTR	+	9–53 MeV e^+
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$-$ 1.3$\pm$ 3.5$\pm$0.6	30M	[2] DANNEBERG	05	CNTR	+	7–53 MeV e^+
1.5$\pm$ 6.3		[3] BURKARD	85B	FIT		

[1] Previously we used the global fit result from BURKARD 85B in OUR AVERAGE, we now only include their actual measurement. BURKARD 85B measure e^+ polarizations P_{T_1} and P_{T_2} versus e^+ energy.

[2] $\alpha = \alpha' = 0$ assumed.

[3] Global fit to all measured parameters. The fit correlation coefficients are given in BURKARD 85B.

a/A

This comes from an alternative parameterization to that used in the Summary Table (see the "Note on Muon Decay Parameters" above).

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<15.9	90	[1] BURKARD	85B	FIT

[1] Global fit to all measured parameters. Correlation coefficients are given in BURKARD 85B.

a'/A

This comes from an alternative parameterization to that used in the Summary Table (see the "Note on Muon Decay Parameters" above).

VALUE (units 10^{-3})	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
5.3 ± 4.1	[1] BURKARD	85B	FIT

[1] Global fit to all measured parameters. Correlation coefficients are given in BURKARD 85B.

$(b'+b)/A$

This comes from an alternative parameterization to that used in the Summary Table (see the "Note on Muon Decay Parameters" above).

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<1.04	90	[1] BURKARD	85B	FIT

[1] Global fit to all measured parameters. Correlation coefficients are given in BURKARD 85B.

c/A

This comes from an alternative parameterization to that used in the Summary Table (see the "Note on Muon Decay Parameters" above).

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<6.4	90	[1] BURKARD	85B	FIT

[1] Global fit to all measured parameters. Correlation coefficients are given in BURKARD 85B.

c'/A

This comes from an alternative parameterization to that used in the Summary Table (see the "Note on Muon Decay Parameters" above).

VALUE (units 10^{-3})	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
3.5 ± 2.0	[1] BURKARD	85B	FIT

[1] Global fit to all measured parameters. Correlation coefficients are given in BURKARD 85B.

$\overline{\eta}$ PARAMETER

($V-A$) theory predicts $\overline{\eta} = 0$. $\overline{\eta}$ affects spectrum of radiative muon decay.

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.02 ±0.08 OUR AVERAGE					
-0.014 ± 0.090	EICHENBER...	84	ELEC	+	ρ free
$+0.09 \pm 0.14$	BOGART	67	CNTR	+	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
-0.035 ± 0.098	EICHENBER...	84	ELEC	+	ρ=0.75 assumed

μ REFERENCES

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Accepted for publication in RMP				
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ADAM	13B	PRL 110 201801	J. Adam *et al.*	(MEG Collab.)
TISHCHENKO	13	PR D87 052003	V. Tishchenko *et al.*	(MuLan Collab.)
MOHR	12	RMP 84 1527	P.J. Mohr, B.N. Taylor, D.B. Newell	(NIST)
ADAM	11	PRL 107 171801	J. Adam *et al.*	(MEG Collab.)
BAYES	11	PRL 106 041804	R. Bayes *et al.*	(TWIST Collab.)
Also		PR D85 092013	A. Hillairet *et al.*	(TWIST Collab.)
BUENO	11	PR D84 032005	J.F. Bueno *et al.*	(TWIST Collab.)
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MOHR	08	RMP 80 633	P.J. Mohr, B.N. Taylor, D.B. Newell	(NIST)
CHITWOOD	07	PRL 99 032001	D.B. Chitwood *et al.*	(MULAN Collab.)
BENNETT	06	PR D73 072003	G.W. Bennett *et al.*	(MUG-2 Collab.)
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JAMIESON	06	PR D74 072007	B. Jamieson *et al.*	(TWIST Collab.)
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GAPONENKO	05	PR D71 071101	A. Gaponenko *et al.*	(TWIST Collab.)
MOHR	05	RMP 77 1	P.J. Mohr, B.N. Taylor	(NIST)
MUSSER	05	PRL 94 101805	J.R. Musser *et al.*	(TWIST Collab.)
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BROWN	01	PRL 86 2227	H.N. Brown *et al.*	(Muon(g-2) Collab.)
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MEYER	00	PRL 84 1136	V. Meyer *et al.*	
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ABELA	96	PRL 77 1950	R. Abela *et al.*	(PSI, ZURI, HEIDH, TBIL+)
HONECKER	96	PRL 76 200	W. Honecker *et al.*	(SINDRUM II Collab.)
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FREEDMAN	93	PR D47 811	S.J. Freedman *et al.*	(LAMPF E645 Collab.)
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IMAZATO	92	PRL 69 877	J. Imazato *et al.*	(KEK, INUS, TOKY+)
BARANOV	91	SJNP 53 802	V.A. Baranov *et al.*	(JINR)
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Also		PRL 67 932 (erratum)	B.E. Matthias *et al.*	(YALE, HEIDP, WILL+)
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Also		PRL 59 970	S. Ahmad *et al.*	(TRIU, VPI, VICT, BRCO+)
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MEYER	63	PR 132 2693	S.L. Meyer *et al.*	(COLU)
CHARPAK	62	PL 1 16	G. Charpak *et al.*	(CERN)
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		Translated from ZETF 37 318.		

PLANO	60	PR 119 1400	R.J. Plano	(COLU)
ASHKIN	59	NC 14 1266	J. Ashkin *et al.*	(CERN)
BARDON	59	PRL 2 56	M. Bardon, D. Berley, L.M. Lederman	(COLU)
LEE	59	PRL 3 55	J. Lee, N.P. Samios	(COLU)