$\Gamma(e^+\nu_e\gamma)/\Gamma_{total}$ — Γ_4/Γ

Note that measurements here do not cover the full kinematic range.

VALUE (units 10^{-8})	EVTS	DOCUMENT ID		TECN	COMMENT
16.1±2.3		[10] BOLOTOV	90B	SPEC	17 GeV $\pi^- \to e^-\overline{\nu}_e\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
5.6±0.7	226	[11] STETZ	78	SPEC	P_e > 56 MeV/c
3.0	143	DEPOMMIER	63B	CNTR	$(KE)_{e^+\gamma}$ > 48 MeV

[10] BOLOTOV 90B is for E_γ > 21 MeV, E_e > 70 − 0.8 E_γ.

[11] STETZ 78 is for an $e^-\gamma$ opening angle > 132°. Obtains 3.7 when using same cutoffs as DEPOMMIER 63B.

$\Gamma(e^+\nu_e\pi^0)/\Gamma_{total}$ — Γ_5/Γ

VALUE (units 10^{-8})	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
1.025±0.034 OUR AVERAGE						
1.026±0.039	1224	[12] MCFARLANE	85	CNTR	+	Decay in flight
$1.00\ ^{+0.08}_{-0.10}$	332	DEPOMMIER	68	CNTR	+	
1.07 ±0.21	38	[13] BACASTOW	65	OSPK	+	
1.10 ±0.26		[13] BERTRAM	65	OSPK	+	
1.1 ±0.2	43	[13] DUNAITSEV	65	CNTR	+	
0.97 ±0.20	36	[13] BARTLETT	64	OSPK	+	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.15 ±0.22	52	[13] DEPOMMIER	63	CNTR	+	See DEPOMMIER 68

[12] MCFARLANE 85 combines a measured rate (0.394 ± 0.015)/s with 1982 PDG mean life.

[13] DEPOMMIER 68 says the result of DEPOMMIER 63 is at least 10% too large because of a systematic error in the π^0 detection efficiency, and that this may be true of all the previous measurements (also V. Soergel, private communication, 1972).

$\Gamma(e^+\nu_e e^+e^-)/\Gamma(\mu^+\nu_\mu)$ — Γ_6/Γ_1

VALUE (units 10^{-9})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
3.2 ±0.5 ±0.2		98	EGLI	89	SPEC	Uses R_{PCAC} = 0.068 ± 0.004
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.46±0.16±0.07		7	[14] BARANOV	92	SPEC	Stopped π^+
< 4.8	90		KORENCHE...	76B	SPEC	
<34	90		KORENCHE...	71	OSPK	

[14] This measurement by BARANOV 92 is of the structure-dependent part of the decay. The value depends on values assumed for ratios of form factors.

$\Gamma(e^+\nu_e\nu\overline{\nu})/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN
<5	90	PICCIOTTO	88	SPEC

$\Gamma(\mu^+\overline{\nu}_e)/\Gamma_{total}$ — Γ_8/Γ

Forbidden by total lepton number conservation.

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<1.5	90	COOPER	82	HLBC	Wideband ν beam

$\Gamma(\mu^+\nu_e)/\Gamma_{total}$ — Γ_9/Γ

Forbidden by lepton family number conservation.

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<8.0	90	COOPER	82	HLBC	Wideband ν beam

$\Gamma(\mu^-e^+e^+\nu)/\Gamma_{total}$ — Γ_{10}/Γ

Forbidden by lepton family number conservation.

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN	CHG
<1.6	90	BARANOV	91B	SPEC	+
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<7.7	90	KORENCHE...	87	SPEC	+

π^+ — POLARIZATION OF EMITTED μ^+

$\pi^+ \to \mu^+\nu$

Tests the Lorentz structure of leptonic charged weak interactions.

VALUE	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<(−0.9959)	90	[15] FETSCHER	84	RVUE	+	
−0.99±0.16		[16] ABELA	83	SPEC	−	μ X-rays

[15] FETSCHER 84 uses only the measurement of CARR 83.

[16] Sign of measurement reversed in ABELA 83 to compare with μ^+ measurements.

NOTE ON $\pi^{\pm} \to \ell^{\pm}\nu\gamma$ AND $K^{\pm} \to \ell^{\pm}\nu\gamma$ FORM FACTORS

(by H.S. Pruys, Zürich University)

In the radiative decays $\pi^{\pm} \to \ell^{\pm}\nu\gamma$ and $K^{\pm} \to \ell^{\pm}\nu\gamma$, where ℓ is an e or a μ and γ is a real or virtual photon (e^+e^- pair), both the vector and the axial-vector weak hadronic currents contribute to the decay amplitude. Each current gives a structure-dependent term (SD$_V$ and SD$_A$) from virtual hadronic states, and the axial-vector current also gives a contribution from inner bremsstrahlung (IB) from the lepton and meson. The IB amplitudes are determined by the meson decay constants f_π and f_K [1]. The SD$_V$ and SD$_A$ amplitudes are parameterized in terms of the vector form factor F_V and the axial-vector form factors F_A and R [1–4]:

$$M(\mathrm{SD}_V) = \frac{-eG_F\,V_{qq'}}{\sqrt{2}\,m_P}\epsilon^\mu\,\ell^\nu\,F_V\,\epsilon_{\mu\nu\sigma\tau}\,k^\sigma\,q^\tau\ ,$$

$$M(\mathrm{SD}_A) = \frac{-ie\,G_F V_{qq'}}{\sqrt{2}\,m_P}\,\epsilon^\mu\,\ell^\nu\,\{F_A\,[(s-t)g_{\mu\nu} - q_\mu\,k_\nu] + R\,t\,g_{\mu\nu}\}\ .$$

Here $V_{qq'}$ is the Cabibbo-Kobayashi-Maskawa mixing-matrix element; $\epsilon^\mu = (e/t)\overline{u}(p_-)\gamma^\mu v(p_+)$ is the polarization vector of the photon; $\ell^\nu = \overline{u}(p_\nu)\gamma^\nu(1-\gamma_5)v(p_\ell)$ is the lepton-neutrino current; q and k are the meson and photon four-momenta, with $s = q\cdot k$ and $t = k^2$; and P stands for π or K. The s and t dependence of the form factors is neglected, which is a good approximation for pions [2] but not for kaons [4]. The pion vector form factor F_V^π is related via CVC to the π^0 lifetime, $|F_V^\pi| = (1/\alpha)\sqrt{2\Gamma_{\pi^0}/\pi m_{\pi^0}}$ [1]. PCAC relates R to the electromagnetic radius of the meson [2,4], $R^P = \frac{1}{3}m_P f_P\langle r_P^2\rangle$. The calculation of the other form factors, F_A^π, F_V^K, and F_A^K, is model dependent [1,4].

When the photon is real, the partial decay rate can be given analytically [1,5]:

$$\frac{d^2\Gamma_{P\to\ell\nu\gamma}}{dxdy} = \frac{d^2\left(\Gamma_{\mathrm{IB}} + \Gamma_{\mathrm{SD}} + \Gamma_{\mathrm{INT}}\right)}{dxdy}\ ,$$

where $\Gamma_{\mathrm{IB}}, \Gamma_{\mathrm{SD}}$, and Γ_{INT} are the contributions from inner bremsstrahlung, structure-dependent radiation, and their interference, and the Γ_{SD} term is given by

$$\frac{d^2\Gamma_{\mathrm{SD}}}{dxdy} = \frac{\alpha}{8\pi}\Gamma_{P\to\ell\nu}\,\frac{1}{r(1-r)^2}\left(\frac{m_P}{f_P}\right)^2 \times\left[(F_V+F_A)^2\,\mathrm{SD}^+ + (F_V-F_A)^2\,\mathrm{SD}^-\right]\ .$$

Here

$$\mathrm{SD}^+ = (x+y-1-r)\,[(x+y-1)(1-x)-r]\ ,$$

$$\mathrm{SD}^- = (1-y+r)\,[(1-x)(1-y)+r]\ ,$$

where $x = 2E_\gamma/m_P$, $y = 2E_\ell/m_P$, and $r = (m_\ell/m_P)^2$.

In $\pi^{\pm} \to e^{\pm}\nu\gamma$ and $K^{\pm} \to e^{\pm}\nu\gamma$ decays, the interference terms are small, and thus only the absolute values $|F_A+F_V|$ and $|F_A-F_V|$ can be obtained. In $K^{\pm} \to \mu^{\pm}\nu\gamma$ decay, the interference term is important, and thus the signs of F_V and F_A can be obtained. In $\pi^{\pm} \to \mu^{\pm}\nu\gamma$ decay, bremsstrahlung completely dominates. In $\pi^{\pm} \to e^{\pm}\nu e^+e^-$ and $K^{\pm} \to \ell^{\pm}\nu e^+e^-$ decays, all three form factors, F_V, F_A, and R, can be determined.

We give the $\pi^{\pm}$ form factors F_V, F_A, and R in the Listings below. In the $K^{\pm}$ Listings, we give the sum F_A+F_V and difference F_A-F_V.