π^0

$I^G(J^{PC}) = 1^-(0^{-+})$

We have omitted some results that have been superseded by later experiments. The omitted results may be found in our 1988 edition Physics Letters **B204** (1988).

π^0 MASS

The value is calculated from $m_{\pi^\pm}$ and $(m_{\pi^\pm} - m_{\pi^0})$. See notes under the $\pi^\pm$ Mass Listings concerning recent revision of the charged pion mass.

VALUE (MeV)	*DOCUMENT ID*
134.9764±0.0006 OUR FIT	

$m_{\pi^\pm} - m_{\pi^0}$

Measurements with an error > 0.01 MeV have been omitted.

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
4.5936 ±0.0005 OUR FIT				
4.5936 ±0.0005 OUR AVERAGE				
4.59364±0.00048	CRAWFORD	91	CNTR	$\pi^- p \to \pi^0 n$, n TOF
4.5930 ±0.0013	CRAWFORD	86	CNTR	$\pi^- p \to \pi^0 n$, n TOF
• • • We do not use the following data for averages, fits, limits, etc. • • •				
4.59366±0.00048	CRAWFORD	88B	CNTR	See CRAWFORD 91
4.6034 ±0.0052	VASILEVSKY	66	CNTR	
4.6056 ±0.0055	CZIRR	63	CNTR	

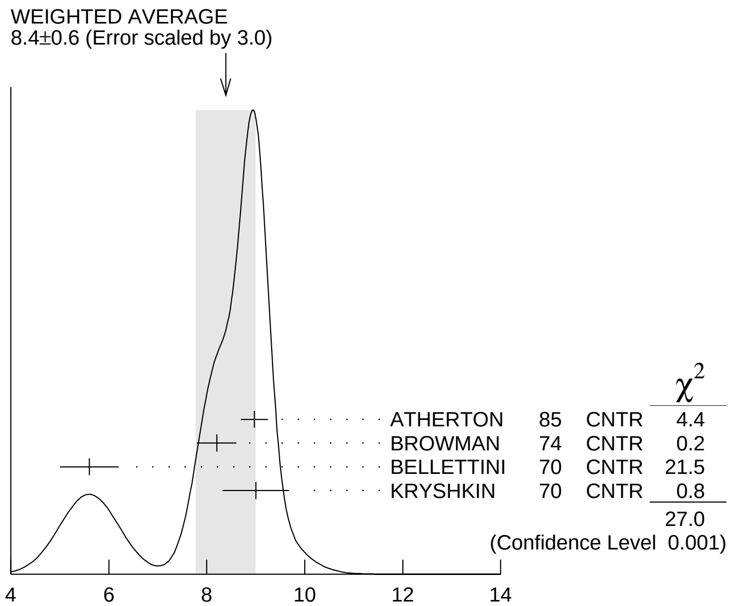
π^0 MEAN LIFE

Measurements with an error > 1×10^{-17} s have been omitted.

VALUE (10^{-17} s)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
8.4 ±0.6 OUR AVERAGE	Error includes scale factor of 3.0. See the ideogram below.				
8.97±0.22±0.17		ATHERTON	85	CNTR	
8.2 ±0.4		[1] BROWMAN	74	CNTR	Primakoff effect
5.6 ±0.6		BELLETTINI	70	CNTR	Primakoff effect
9 ±0.68		KRYSHKIN	70	CNTR	Primakoff effect
• • • We do not use the following data for averages, fits, limits, etc. • • •					
8.4 ±0.5 ±0.5	1182	[2] WILLIAMS	88	CBAL	$e^+e^- \to e^+e^-\pi^0$

[1] BROWMAN 74 gives a π^0 width $\Gamma = 8.02 \pm 0.42$ eV. The mean life is $\hbar/\Gamma$.

[2] WILLIAMS 88 gives $\Gamma(\gamma\gamma) = 7.7 \pm 0.5 \pm 0.5$ eV. We give here $\tau = \hbar/\Gamma$(total).



π^0 mean life (10^{-17} s)

π^0 DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	2γ		(98.798 ± 0.032) %	S=1.1
Γ_2	$e^+e^-\gamma$		(1.198 ± 0.032) %	S=1.1
Γ_3	γ positronium		$(1.82\pm0.29)\times10^{-9}$	
Γ_4	$e^+e^+e^-e^-$		$(3.14\pm0.30)\times10^{-5}$	
Γ_5	e^+e^-		$(7.5\pm2.0)\times10^{-8}$	
Γ_6	4γ		$<2\times10^{-8}$	CL=90%
Γ_7	$\nu\overline{\nu}$	[a]	$<8.3\times10^{-7}$	CL=90%
Γ_8	$\nu_e\overline{\nu}_e$		$<1.7\times10^{-6}$	CL=90%
Γ_9	$\nu_\mu\overline{\nu}_\mu$		$<3.1\times10^{-6}$	CL=90%
Γ_{10}	$\nu_\tau\overline{\nu}_\tau$		$<2.1\times10^{-6}$	CL=90%
	Charge conjugation (*C*) or Lepton Family number (*LF*) violating modes			
Γ_{11}	3γ	*C*	$<3.1\times10^{-8}$	CL=90%
Γ_{12}	μ^+e^-			
Γ_{13}	$\mu^+e^-+e^-\mu^+$	*LF*	$<1.72\times10^{-8}$	CL=90%

[a] Astrophysical and cosmological arguments give limits of order 10^{-13}; see the Particle Listings below.

CONSTRAINED FIT INFORMATION

An overall fit to 2 branching ratios uses 4 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2 =$ 1.9 for 2 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\text{total}}$. The fit constrains the x_i whose labels appear in this array to sum to one.

x_2	−100	
x_4	−1	0
	x_1	x_2

π^0 BRANCHING RATIOS

$\Gamma(e^+e^-\gamma)/\Gamma(2\gamma)$ — Γ_2/Γ_1

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
1.213±0.033 OUR FIT Error includes scale factor of 1.1.					
1.213±0.030 OUR AVERAGE					
1.25 ±0.04		SCHARDT	81	SPEC	$\pi^- p \to n\pi^0$
1.166±0.047	3071	[3] SAMIOS	61	HBC	$\pi^- p \to n\pi^0$
1.17 ±0.15	27	BUDAGOV	60	HBC	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1.196		JOSEPH	60	THEO	QED calculation

[3] SAMIOS 61 value uses a Panofsky ratio = 1.62.

$\Gamma(\gamma\,\text{positronium})/\Gamma(2\gamma)$ — Γ_3/Γ_1

VALUE (units 10^{-9})	EVTS	DOCUMENT ID		TECN	COMMENT
1.84±0.29	277	AFANASYEV	90	CNTR	pC 70 GeV

$\Gamma(e^+e^+e^-e^-)/\Gamma(2\gamma)$ — Γ_4/Γ_1

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN
3.18±0.30 OUR FIT				
3.18±0.30	146	[4] SAMIOS	62B	HBC

[4] SAMIOS 62B value uses a Panofsky ratio = 1.62.

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

VALUE (units 10^{-8})	EVTS	DOCUMENT ID		TECN	COMMENT
7.5±2.0 OUR AVERAGE					
6.9±2.3±0.6	21	[5] DESHPANDE	93	SPEC	$K^+ \to \pi^+\pi^0$
$8.8^{+4.5}_{-3.2}\pm0.6$	8	[6] MCFARLAND	93	SPEC	$K^0_L \to 3\pi^0$ in flight

[5] The DESHPANDE 93 result with bremsstrahlung radiative corrections is $(8.0 \pm 2.6 \pm 0.6) \times 10^{-8}$.

[6] The MCFARLAND 93 result with radiative corrections and excluding $[m_{ee}/m_{\pi^0}]^2 < 0.95$ is $(7.6^{+3.9}_{-2.8} \pm 0.5) \times 10^{-8}$.

$\Gamma(e^+e^-)/\Gamma(2\gamma)$ — Γ_5/Γ_1

VALUE (units 10^{-7})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<1.3	90		NIEBUHR	89	SPEC	$\pi^- p \to \pi^0 n$ at rest
<5.3	90		ZEPHAT	87	SPEC	$\pi^- p \to \pi^0 n$ 0.3 GeV/c
$1.7 \pm 0.6 \pm 0.3$		59	FRANK	83	SPEC	$\pi^- p \to n\pi^0$
1.8 ± 0.6		58	MISCHKE	82	SPEC	See FRANK 83
$2.23^{+2.40}_{-1.10}$	90	8	FISCHER	78B	SPRK	$K^+ \to \pi^+\pi^0$

$\Gamma(4\gamma)/\Gamma_{total}$ — Γ_6/Γ

VALUE (units 10^{-8})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 2	90		MCDONOUGH	88	CBOX	$\pi^- p$ at rest
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<160	90		BOLOTOV	86C	CALO	
<440	90	0	AUERBACH	80	CNTR	

$\Gamma(\nu\overline{\nu})/\Gamma_{total}$ — Γ_7/Γ

The astrophysical and cosmological limits are many orders of magnitude lower, but we use the best laboratory limit for the Summary Tables.

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 0.83	90		[7] ATIYA	91	B787	$K^+ \to \pi^+\nu\nu'$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$< 2.9 \times 10^{-7}$			[8] LAM	91		Cosmological limit
$< 3.2 \times 10^{-7}$			[9] NATALE	91		SN 1987A
< 6.5	90		DORENBOS...	88	CHRM	Beam dump, prompt ν
<24	90	0	[7] HERCZEG	81	RVUE	$K^+ \to \pi^+\nu\nu'$

[7] This limit applies to all possible $\nu\nu'$ states as well as to other massless, weakly interacting states.

[8] LAM 91 considers the production of right-handed neutrinos produced from the cosmic thermal background at the temperature of about the pion mass through the reaction $\gamma\gamma \to \pi^0 \to \nu\overline{\nu}$.

[9] NATALE 91 considers the excess energy-loss rate from SN 1987A if the process $\gamma\gamma \to \pi^0 \to \nu\overline{\nu}$ occurs, permitted if the neutrinos have a right-handed component. As pointed out in LAM 91 (and confirmed by Natale), there is a factor 4 error in the NATALE 91 published result (0.8×10^{-7}).

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

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN	COMMENT
<1.7	90	DORENBOS...	88	CHRM	Beam dump, prompt ν
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<3.1	90	[10] HOFFMAN	88	RVUE	Beam dump, prompt ν

[10] HOFFMAN 88 analyzes data from a 400-GeV BEBC beam-dump experiment.

$\Gamma(\nu_\mu \overline{\nu}_\mu)/\Gamma_{total}$ — Γ_9/Γ

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN	COMMENT
<3.1	90	[11] HOFFMAN	88	RVUE	Beam dump, prompt ν
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<7.8	90	DORENBOS...	88	CHRM	Beam dump, prompt ν

[11] HOFFMAN 88 analyzes data from a 400-GeV BEBC beam-dump experiment.

$\Gamma(\nu_\tau \overline{\nu}_\tau)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN	COMMENT
<2.1	90	[12] HOFFMAN	88	RVUE	Beam dump, prompt ν
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<4.1	90	DORENBOS...	88	CHRM	Beam dump, prompt ν

[12] HOFFMAN 88 analyzes data from a 400-GeV BEBC beam-dump experiment.

$\Gamma(3\gamma)/\Gamma_{total}$ — Γ_{11}/Γ

Forbidden by *C* invariance.

VALUE (units 10^{-8})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 3.1	90		MCDONOUGH	88	CBOX	$\pi^- p$ at rest
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 38	90	0	HIGHLAND	80	CNTR	
<150	90	0	AUERBACH	78	CNTR	
<490	90	0	[13] DUCLOS	65	CNTR	
<490	90		[13] KUTIN	65	CNTR	

[13] These experiments give $B(3\gamma/2\gamma) < 5.0 \times 10^{-6}$.

$\Gamma(\mu^+ e^-)/\Gamma_{total}$ — Γ_{12}/Γ

Forbidden by lepton family number conservation.

VALUE (units 10^{-9})	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<16	90	LEE	90	SPEC	$K^+ \to \pi^+ \mu^+ e^-$
<78	90	CAMPAGNARI	88	SPEC	See LEE 90

$\left[\Gamma(\mu^+ e^-) + \Gamma(e^- \mu^+)\right]/\Gamma_{total}$ — Γ_{13}/Γ

Forbidden by lepton family number conservation.

VALUE (units 10^{-9})	CL%	DOCUMENT ID		TECN	COMMENT
< 17.2	90	KROLAK	94	E799	In $K_L^0 \to 3\pi^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<140		HERCZEG	84	RVUE	$K^+ \to \pi^+ \mu e$
< 2 $\times 10^{-6}$		HERCZEG	84	THEO	$\mu^- \to e^-$ conversion
< 70	90	BRYMAN	82	RVUE	$K^+ \to \pi^+ \mu e$

π^0 ELECTROMAGNETIC FORM FACTOR

The amplitude for the process $\pi^0 \rightarrow e^+ e^- \gamma$ contains a form factor F(x) at the $\pi^0 \gamma\gamma$ vertex, where $x = [m_{e^+ e^-}/m_{\pi^0}]^2$. The parameter a in the linear expansion F(x) = 1 + ax is listed below.

All the measurements except that of BEHREND 91 are in the time-like region of momentum transfer.

LINEAR COEFFICIENT OF π^0 ELECTROMAGNETIC FORM FACTOR

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.032 ±0.004 OUR AVERAGE					
+0.026 ±0.024 ±0.048	7548	FARZANPAY	92	SPEC	$\pi^- p \rightarrow \pi^0 n$ at rest
+0.025 ±0.014 ±0.026	54k	MEIJERDREES	92B	SPEC	$\pi^- p \rightarrow \pi^0 n$ at rest
+0.0326±0.0026±0.0026	127	[14] BEHREND	91	CELL	$e^+ e^- \rightarrow e^+ e^- \pi^0$
−0.11 ±0.03 ±0.08	32k	FONVIEILLE	89	SPEC	Radiation corr.
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.12\ ^{+0.05}_{-0.04}$		[15] TUPPER	83	THEO	FISCHER 78 data
+0.10 ±0.03	31k	[16] FISCHER	78	SPEC	Radiation corr.
+0.01 ±0.11	2200	DEVONS	69	OSPK	No radiation corr.
−0.15 ±0.10	7676	KOBRAK	61	HBC	No radiation corr.
−0.24 ±0.16	3071	SAMIOS	61	HBC	No radiation corr.

[14] BEHREND 91 estimates that their systematic error is of the same order of magnitude as their statistical error, and so we have included a systematic error of this magnitude. The value of a is obtained by extrapolation from the region of large space-like momentum transfer assuming vector dominance.

[15] TUPPER 83 is a theoretical analysis of FISCHER 78 including 2-photon exchange in the corrections.

[16] The FISCHER 78 error is statistical only. The result without radiation corrections is +0.05 ± 0.03.

π^0 REFERENCES

We have omitted some papers that have been superseded by later experiments. The omitted papers may be found in our 1988 edition Physics Letters **B204** (1988).

KROLAK 94 PL B320 407 + (EFI, UCLA, COLO, ELMT, FNAL, ILL, OSAK, RUTG)
DESHPANDE 93 PRL 71 27 +Alliegro, Chaloupka+ (BNL E851 Collab.)
MCFARLAND 93 PRL 71 31 + (EFI, UCLA, COLO, ELMT, FNAL, ILL, OSAK, RUTG)
FARZANPAY 92 PL B278 413 + (ORST, TRIU, BRCO, QUKI, LBL, BIRM, OXF)
MEIJERDREES 92B PR D45 1439 Meijer Drees, Waltham+ (PSI SINDRUM-I Collab.)
ATIYA 91 PRL 66 2189 +Chiang, Frank, Haggerty+ (BNL, LANL, PRIN, TRIU)
BEHREND 91 ZPHY C49 401 +Criegee, Field, Franke+ (CELLO Collab.)
CRAWFORD 91 PR D43 46 +Daum, Frosch, Jost, Kettle+ (VILL, VIRG)
LAM 91 PR D44 3345 +Ng (AST)
NATALE 91 PL B258 227 (SPIFT)
AFANASYEV 90 PL B236 116 +Chvyrov, Karpukhin+ (JINR, MOSU, SERP)
Also 90B SJNP 51 664 Afanasyev, Gorchakov, Karpukhin, Komarov+ (JINR)
Translated from YAF 51 1040.

LEE	90	PRL 64 165	+Alliegro, Campagnari+	(BNL, FNAL, VILL, WASH, YALE)
FONVIEILLE	89	PL B233 65	+Bensayah, Berthot, Bertin+	(CLER, LYON, SACL)
NIEBUHR	89	PR D40 2796	+Eichler, Felawka, Kozlowski+	(SINDRUM Collab.)
CAMPAGNARI	88	PRL 61 2062	+Alliegro, Chaloupka+	(BNL, FNAL, PSI, WASH, YALE)
CRAWFORD	88B	PL B213 391	+Daum, Frosch, Jost, Kettle, Marshall+	(PSI, VIRG)
DORENBOS...	88	ZPHY C40 497	Dorenbosch, Allaby, Amaldi, Barbiellini+	(CHARM Collab.)
HOFFMAN	88	PL B208 149		(LANL)
MCDONOUGH	88	PR D38 2121	+Highland, McFarlane, Bolton+	(TEMP, LANL, CHIC)
PDG	88	PL B204	Yost, Barnett+	(LBL+)
WILLIAMS	88	PR D38 1365	+Antreasyan, Bartels, Besset+	(Crystal Ball Collab.)
ZEPHAT	87	JPG 13 1375	+Playfer, van Doesburg, Bressani+	(OMICRON Collab.)
BOLOTOV	86C	JETPL 43 520	+Gninenko, Dzhilkibaev, Isakov	(INRM)
		Translated from ZETFP 43 405.		
CRAWFORD	86	PRL 56 1043	+Daum, Frosch, Jost, Kettle+	(SIN, VIRG)
ATHERTON	85	PL 158B 81	+Bovet, Coet+	(CERN, ISU, LUND, CURIN, EFI)
HERCZEG	84	PR D29 1954	+Hoffman	(LANL)
FRANK	83	PR D28 423	+Hoffman, Mischke, Moir+	(LANL, ARZS)
TUPPER	83	PR D28 2905	+Grose, Samuel	(OKSU)
BRYMAN	82	PR D26 2538		(TRIU)
MISCHKE	82	PRL 48 1153	+Frank, Hoffman, Moir, Sarracino+	(LANL, ARZS)
HERCZEG	81	PL 100B 347	+Hoffman	(LANL)
SCHARDT	81	PR D23 639	+Frank, Hoffmann, Mischke, Moir+	(ARZS, LANL)
AUERBACH	80	PL 90B 317	+Haik, Highland, McFarlane, Macek+	(TEMP, LASL)
HIGHLAND	80	PRL 44 628	+Auerbach, Haik, McFarlane, Macek+	(TEMP, LASL)
AUERBACH	78	PRL 41 275	+Highland, Johnson+	(TEMP, LASL)
FISCHER	78	PL 73B 359	+Extermann, Guisan, Mermod+	(GEVA, SACL)
FISCHER	78B	PL 73B 364	+Extermann, Guisan, Mermod+	(GEVA, SACL)
BROWMAN	74	PRL 33 1400	+Dewire, Gittelman, Hanson+	(CORN, BING)
BELLETTINI	70	NC 66A 243	+Bemporad, Lubelsmey+	(PISA, BONN)
KRYSHKIN	70	JETP 30 1037	+Sterligov, Usov	(TMSK)
		Translated from ZETF 57 1917.		
DEVONS	69	PR 184 1356	+Nemethy, Nissim-Sabat, Capua+	(COLU, ROMA)
VASILEVSKY	66	PL 23 281	+Vishnyakov, Dunaitsev+	(JINR)
DUCLOS	65	PL 19 253	+Freytag, Heintze+	(CERN, HEID)
KUTIN	65	JETPL 2 243	+Petrukhin, Prokoshkin	(JINR)
		Translated from unknown journal.		
CZIRR	63	PR 130 341		(LRL)
SAMIOS	62B	PR 126 1844	+Plano, Prodell+	(COLU, BNL)
KOBRAK	61	NC 20 1115		(EFI)
SAMIOS	61	PR 121 275		(COLU, BNL)
BUDAGOV	60	JETP 11 755	+Viktor, Dzhelepov, Ermolov+	(JINR)
		Translated from ZETF 38 1047.		
JOSEPH	60	NC 16 997		(EFI)