



$$I(J^P) = \frac{1}{2}(0^-)$$

K_S^0 MEAN LIFE

For earlier measurements, beginning with BOLDT 58B, see our 1986 edition, Physics Letters **170B** 130 (1986).

OUR FIT is described in the note on “*CP* violation in K_L^0 decays” in the K_L^0 Particle Listings. The result labeled “OUR FIT Assuming *CPT*” [“OUR FIT Not assuming *CPT*”] includes all measurements except those with the comment “Not assuming *CPT*” [“Assuming *CPT*”]. Measurements with neither comment do not assume *CPT* and enter both fits.

VALUE (10^{-10} s)	EVTS	DOCUMENT ID	TECN	COMMENT
0.8954 ± 0.0004 OUR FIT				Error includes scale factor of 1.1. Assuming <i>CPT</i>
0.89564 ± 0.00033 OUR FIT				Not assuming <i>CPT</i>
0.89589 ± 0.00070		^{1,2} ABOUZAID	11	KTEV Not assuming <i>CPT</i>
0.89623 ± 0.00047		^{1,3} ABOUZAID	11	KTEV Assuming <i>CPT</i>
0.89562 ± 0.00029 ± 0.00043	20M	⁴ AMBROSINO	11	KLOE Not assuming <i>CPT</i>
0.89598 ± 0.00048 ± 0.00051	16M	LAI	02C	NA48
0.8971 ± 0.0021		BERTANZA	97	NA31
0.8941 ± 0.0014 ± 0.0009		SCHWINGEN...	95	E773 Assuming <i>CPT</i>
0.8929 ± 0.0016		GIBBONS	93	E731 Assuming <i>CPT</i>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
0.8965 ± 0.0007		⁵ ALAVI-HARATI03	KTEV	Assuming <i>CPT</i>
0.8958 ± 0.0013		⁶ ALAVI-HARATI03	KTEV	Not assuming <i>CPT</i>
0.8920 ± 0.0044	214k	GROSSMAN	87	SPEC
0.905 ± 0.007		⁷ ARONSON	82B	SPEC
0.881 ± 0.009	26k	ARONSON	76	SPEC
0.8926 ± 0.0032 ± 0.0002		⁸ CARITHERS	75	SPEC
0.8937 ± 0.0048	6M	GEWENIGER	74B	ASPK
0.8958 ± 0.0045	50k	⁹ SKJEGGEST...	72	HBC
0.856 ± 0.008	19994	¹⁰ DONALD	68B	HBC
0.872 ± 0.009	20000	^{9,10} HILL	68	DBC

¹ The two ABOUZAID 11 values use the same full KTeV dataset from 1996, 1997, and 1999. The first enters the “assuming *CPT*” fit and the second enters the “not assuming *CPT*” fit.

² ABOUZAID 11 fit has Δm , τ_S , ϕ_ϵ , $\text{Re}(\epsilon'/\epsilon)$, and $\text{Im}(\epsilon'/\epsilon)$ as free parameters. See $\text{Im}(\epsilon'/\epsilon)$ in the “ K_L^0 *CP* violation” section for correlation information.

³ ABOUZAID 11 fit has Δm and τ_S free but constrains ϕ_ϵ to the Superweak value, i.e. assumes *CPT*. This τ_S value is correlated with their $\Delta m = m_{K_L^0} - m_{K_S^0}$ measurement in the K_L^0 listings. The correlation coefficient $\rho(\tau_S, \Delta m) = -0.670$.

⁴ Fit to the proper time distribution.

⁵ This ALAVI-HARATI 03 fit has Δm and τ_S free but constrains ϕ_{+-} to the Superweak value, i.e. assumes *CPT*. This τ_S value is correlated with their $\Delta m = m_{K_L^0} - m_{K_S^0}$ measurement in the K_L^0 listings. The correlation coefficient $\rho(\tau_S, \Delta m) = -0.396$. Superseded by ABOUZAID 11.

- ⁶This ALAVI-HARATI 03 fit has Δm , ϕ_{+-} , and τ_{K_S} free. See ϕ_{+-} in the “ K_L CP violation” section for correlation information. Superseded by ABOUZAIID 11.
- ⁷ARONSON 82 find that K_S^0 mean life may depend on the kaon energy.
- ⁸CARITHERS 75 measures the Δm dependence of the total decay rate (inverse mean life) to be $\Gamma(K_S^0) = [(1.122 \pm 0.004) + 0.16(\Delta m - 0.5348)/\Delta m] 10^{10}/s$, or, in terms of mean life, CARITHERS 75 measures $\tau_S = (0.8913 \pm 0.0032) - 0.238 [\Delta m - 0.5348] (10^{-10} s)$. We have adjusted the measurement to use our best values of ($\Delta m = 0.5293 \pm 0.0009$) ($10^{10} \hbar s^{-1}$). Our first error is their experiment's error and our second error is the systematic error from using our best values.
- ⁹HILL 68 has been changed by the authors from the published value (0.865 ± 0.009) because of a correction in the shift due to η_{+-} . SKJEGGESTAD 72 and HILL 68 give detailed discussions of systematics encountered in this type of experiment.
- ¹⁰Pre-1971 experiments are excluded from the average because of disagreement with later more precise experiments.

K_S^0 DECAY MODES

Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Hadronic modes		
Γ_1 $\pi^0 \pi^0$	$(30.69 \pm 0.05) \%$	
Γ_2 $\pi^+ \pi^-$	$(69.20 \pm 0.05) \%$	
Γ_3 $\pi^+ \pi^- \pi^0$	$(3.5^{+1.1}_{-0.9}) \times 10^{-7}$	
Modes with photons or $\ell\bar{\ell}$ pairs		
Γ_4 $\pi^+ \pi^- \gamma$	[a,b] $(1.79 \pm 0.05) \times 10^{-3}$	
Γ_5 $\pi^+ \pi^- e^+ e^-$	$(4.79 \pm 0.15) \times 10^{-5}$	
Γ_6 $\pi^0 \gamma \gamma$	[a] $(4.9 \pm 1.8) \times 10^{-8}$	
Γ_7 $\gamma \gamma$	$(2.63 \pm 0.17) \times 10^{-6}$	S=3.0
Semileptonic modes		
Γ_8 $\pi^\pm e^\mp \nu_e$	[c] $(7.04 \pm 0.08) \times 10^{-4}$	
Γ_9 $\pi^\pm \mu^\mp \nu_\mu$	[c,d] $(4.69 \pm 0.05) \times 10^{-4}$	
CP violating (CP) and $\Delta S = 1$ weak neutral current (S1) modes		
Γ_{10} $3\pi^0$	CP $< 2.6 \times 10^{-8}$	CL=90%
Γ_{11} $\mu^+ \mu^-$	S1 $< 8 \times 10^{-10}$	CL=90%
Γ_{12} $e^+ e^-$	S1 $< 9 \times 10^{-9}$	CL=90%
Γ_{13} $\pi^0 e^+ e^-$	S1 [a] $(3.0^{+1.5}_{-1.2}) \times 10^{-9}$	
Γ_{14} $\pi^0 \mu^+ \mu^-$	S1 $(2.9^{+1.5}_{-1.2}) \times 10^{-9}$	

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

[b] Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ 's.

[c] The value is for the sum of the charge states or particle/antiparticle states indicated.

[d] Not a measurement. Calculated as $0.666 \cdot B(\pi^\pm e^\mp \nu_e)$.

CONSTRAINED FIT INFORMATION

An overall fit to 4 branching ratios uses 5 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2 = 0.1$ 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_8	-6	3	
x_9	-6	3	100
	x_1	x_2	x_8

K_S^0 DECAY RATES

$\Gamma(\pi^\pm e^\mp \nu_e)$

Γ_8

<u>VALUE</u> (10^6 s^{-1})	<u>EVTs</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
8.1 ± 1.6	75	¹ AKHMETSHIN 99	CMD2	Tagged K_S^0 using $\phi \rightarrow K_L^0 K_S^0$
7.50 ± 0.08		² PDG	98	
seen		BURGUN	72	HBC $K^+ p \rightarrow K^0 p \pi^+$
9.3 ± 2.5		AUBERT	65	HLBC $\Delta S = \Delta Q$, CP cons. not assumed

¹ AKHMETSHIN 99 is from a measured branching ratio $B(K_S^0 \rightarrow \pi e \nu_e) = (7.2 \pm 1.4) \times 10^{-4}$ and $\tau_{K_S^0} = (0.8934 \pm 0.0008) \times 10^{-10}$ s. Not independent of measured branching ratio.

² PDG 98 from K_L^0 measurements, assuming that $\Delta S = \Delta Q$ in K^0 decay so that $\Gamma(K_S^0 \rightarrow \pi^\pm e^\mp \nu_e) = \Gamma(K_L^0 \rightarrow \pi^\pm e^\mp \nu_e)$.

$\Gamma(\pi^\pm \mu^\mp \nu_\mu)$

Γ_9

<u>VALUE</u> (10^6 s^{-1})	<u>DOCUMENT ID</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●	
5.25 ± 0.07	¹ PDG 98
¹ PDG 98 from K_L^0 measurements, assuming that $\Delta S = \Delta Q$ in K^0 decay so that $\Gamma(K_S^0 \rightarrow \pi^\pm \mu^\mp \nu_\mu) = \Gamma(K_L^0 \rightarrow \pi^\pm \mu^\mp \nu_\mu)$.	

K_S^0 BRANCHING RATIOS

Hadronic modes

$\Gamma(\pi^0\pi^0)/\Gamma_{\text{total}}$

Γ_1/Γ

VALUE EVTS DOCUMENT ID TECN

0.3069 ± 0.0005 OUR FIT

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

0.335 ± 0.014	1066	BROWN	63	HLBC
0.288 ± 0.021	198	CHRETIEN	63	HLBC
0.30 ± 0.035		BROWN	61	HLBC

$\Gamma(\pi^+\pi^-)/\Gamma_{\text{total}}$

Γ_2/Γ

VALUE EVTS DOCUMENT ID TECN COMMENT

0.6920 ± 0.0005 OUR FIT

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

0.670 ± 0.010	3447	DOYLE	69	HBC	$\pi^- p \rightarrow \Lambda K^0$
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$\Gamma(\pi^+\pi^-)/\Gamma(\pi^0\pi^0)$

Γ_2/Γ_1

VALUE EVTS DOCUMENT ID TECN COMMENT

2.255 ± 0.005 OUR FIT

2.2549 ± 0.0054

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

		¹ AMBROSINO	06C	KLOE	
2.2555 ± 0.0012 ± 0.0054		² AMBROSINO	06C	KLOE	
2.236 ± 0.003 ± 0.015	766k	² ALOISIO	02B	KLOE	
2.11 ± 0.09	1315	EVERHART	76	WIRE	$\pi^- p \rightarrow \Lambda K^0$
2.169 ± 0.094	16k	COWELL	74	OSPK	$\pi^- p \rightarrow \Lambda K^0$
2.16 ± 0.08	4799	HILL	73	DBC	$K^+ d \rightarrow K^0 p p$
2.22 ± 0.10	3068	³ ALITTI	72	HBC	$K^+ p \rightarrow \pi^+ p K^0$
2.22 ± 0.08	6380	MORSE	72B	DBC	$K^+ n \rightarrow K^0 p$
2.10 ± 0.11	701	⁴ NAGY	72	HLBC	$K^+ n \rightarrow K^0 p$
2.22 ± 0.095	6150	⁵ BALTAY	71	HBC	$K p \rightarrow K^0 \text{ neutrals}$
2.282 ± 0.043	7944	⁶ MOFFETT	70	OSPK	$K^+ n \rightarrow K^0 p$
2.12 ± 0.17	267	⁴ BOZOKI	69	HLBC	
2.285 ± 0.055	3016	⁶ GOBBI	69	OSPK	$K^+ n \rightarrow K^0 p$
2.10 ± 0.06	3700	MORFIN	69	HLBC	$K^+ n \rightarrow K^0 p$

¹ This result combines AMBROSINO 06C KLOE 2001-02 data with ALOISIO 02B KLOE 2000 data. $K_S^0 \rightarrow \pi^+\pi^-$ fully inclusive.

² Includes radiative decays $\pi^+\pi^-\gamma$.

³ The directly measured quantity is $K_S^0 \rightarrow \pi^+\pi^-/\text{all } K^0 = 0.345 \pm 0.005$.

⁴ NAGY 72 is a final result which includes BOZOKI 69.

⁵ The directly measured quantity is $K_S^0 \rightarrow \pi^+\pi^-/\text{all } \bar{K}^0 = 0.345 \pm 0.005$.

⁶ MOFFETT 70 is a final result which includes GOBBI 69.

$$\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\text{total}} \qquad \Gamma_3/\Gamma$$

<u>VALUE (units 10^{-7})</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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3.5^{+1.1}_{-0.9} OUR AVERAGE

4.7 ^{+2.2+1.7} _{-1.7-1.5}		¹ BATLEY	05	NA48
2.5 ^{+1.3+0.5} _{-1.0-0.6}	500k	² ADLER	97B	CPLR
4.8 ^{+2.2±1.1} _{-1.6}		³ ZOU	96	E621

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

4.1 ^{+2.5+0.5} _{-1.9-0.6}		⁴ ADLER	96E	CPLR Sup. by ADLER 97B
3.9 ^{+5.4+0.9} _{-1.8-0.7}		⁵ THOMSON	94	E621 Sup. by ZOU 96

¹ BATLEY 05 is obtained by measuring the interference parameters in $K_S, K_L \rightarrow \pi^+\pi^-\pi^0$: $\text{Re}(\lambda) = 0.038 \pm 0.008 \pm 0.006$ and $\text{Im}(\lambda) = -0.013 \pm 0.005 \pm 0.004$; the correlation coeff. between $\text{Re}(\lambda)$ and $\text{Im}(\lambda)$ is 0.66 (statistical only).

² ADLER 97B find the CP -conserving parameters $\text{Re}(\lambda) = (28 \pm 7 \pm 3) \times 10^{-3}$, $\text{Im}(\lambda) = (-10 \pm 8 \pm 2) \times 10^{-3}$. They estimate $B(K_S^0 \rightarrow \pi^+\pi^-\pi^0)$ from $\text{Re}(\lambda)$ and the K_L^0 decay parameters. See also ANGELOPOULOS 98C.

³ ZOU 96 is from the the measured quantities $|\rho_{+-0}| = 0.039^{+0.009}_{-0.006} \pm 0.005$ and $\phi_\rho = (-9 \pm 18)^\circ$.

⁴ ADLER 96E is from the measured quantities $\text{Re}(\lambda) = 0.036 \pm 0.010^{+0.002}_{-0.003}$ and $\text{Im}(\lambda)$ consistent with zero. Note that the quantity λ is the same as ρ_{+-0} used in other footnotes.

⁵ THOMSON 94 calculates this branching ratio from their measurements $|\rho_{+-0}| = 0.035^{+0.019}_{-0.011} \pm 0.004$ and $\phi_\rho = (-59 \pm 48)^\circ$ where $|\rho_{+-0}|e^{i\phi_\rho} = A(K_S^0 \rightarrow \pi^+\pi^-\pi^0, I=2)/A(K_L^0 \rightarrow \pi^+\pi^-\pi^0)$.

———— Modes with photons or $\ell\bar{\ell}$ pairs ————

$$\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-) \qquad \Gamma_4/\Gamma_2$$

<u>VALUE (units 10^{-3})</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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2.59±0.08 OUR AVERAGE

2.56±0.09	1286	RAMBERG	93	E731 $p_\gamma > 50 \text{ MeV}/c$
2.68±0.15		¹ TAUREG	76	SPEC $p_\gamma > 50 \text{ MeV}/c$
7.10±0.22	3723	RAMBERG	93	E731 $p_\gamma > 20 \text{ MeV}/c$
3.0 ±0.6	29	² BOBISUT	74	HLBC $p_\gamma > 40 \text{ MeV}/c$
2.8 ±0.6		³ BURGUN	73	HBC $p_\gamma > 50 \text{ MeV}/c$

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

¹ TAUREG 76 find direct emission contribution < 0.06 , CL = 90%.

² BOBISUT 74 not included in average because p_γ cut differs. Estimates direct emission contribution to be 0.5 or less, CL = 95%.

³ BURGUN 73 estimates that direct emission contribution is 0.3 ± 0.6 .

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

VALUE (units 10^{-5})	EVTS	DOCUMENT ID	TECN	COMMENT
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4.79 ± 0.15 OUR AVERAGE

4.83 ± 0.11 ± 0.14	23k	¹ BATLEY	11 NA48	2002 data
4.69 ± 0.30	676	² LAI	03C NA48	1998+1999 data

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

4.71 ± 0.23 ± 0.22	620	^{2,3} LAI	03C NA48	1999 data
4.5 ± 0.7 ± 0.4	56	LAI	00B NA48	1998 data

¹ BATLEY 11 reports $[\Gamma(K_S^0 \rightarrow \pi^+\pi^-e^+e^-)/\Gamma_{\text{total}}] / [B(K_L^0 \rightarrow \pi^+\pi^-\pi^0)] / [B(\pi^0 \rightarrow e^+e^-\gamma)] = (3.28 \pm 0.06 \pm 0.04) \times 10^{-2}$ which we multiply by our best values $B(K_L^0 \rightarrow \pi^+\pi^-\pi^0) = (12.54 \pm 0.05) \times 10^{-2}$, $B(\pi^0 \rightarrow e^+e^-\gamma) = (1.174 \pm 0.035) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best values. Also a limit on the absolute value of the interference between bremsstrahlung and E1 transition is given : $< 4 \times 10^{-7}$ at 90% C.L.

² Uses normalization $BR(K_L \rightarrow \pi^+\pi^-\pi^0) \cdot BR(\pi^0 \rightarrow e^+e^-) = (1.505 \pm 0.047) \times 10^{-3}$ from our 2000 Edition.

³ Second error is $0.16(\text{syst}) \pm 0.15(\text{norm})$ combined in quadrature.

$\Gamma(\pi^0\gamma\gamma)/\Gamma_{\text{total}}$ Γ_6/Γ

VALUE (units 10^{-8})	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
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4.9 ± 1.6 ± 0.9		17	¹ LAI	04 NA48	$m_{\gamma\gamma}^2/m_K^2 > 0.2$
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• • • We do not use the following data for averages, fits, limits, etc. • • •

<33	90		LAI	03B NA48	$m_{\gamma\gamma}^2/m_K^2 > 0.2$
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¹ Spectrum also measured and found consistent with the one generated by a constant matrix element.

$\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ Γ_7/Γ

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
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2.63 ± 0.17 OUR AVERAGE			Error includes scale factor of 3.0.		
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2.26 ± 0.12 ± 0.06		711	¹ AMBROSINO	08C KLOE	$\phi \rightarrow K_S^0 K_L^0$
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2.713 ± 0.063 ± 0.005		7.5k	² LAI	03 NA48	
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• • • We do not use the following data for averages, fits, limits, etc. • • •

2.58 ± 0.36 ± 0.22		149	LAI	00 NA48	
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2.2 ± 1.1		16	³ BARR	95B NA31	
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2.4 ± 0.9		35	⁴ BARR	95B NA31	
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< 13	90		BALATS	89 SPEC	
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2.4 ± 1.2		19	BURKHARDT	87 NA31	
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<133	90		BARMIN	86B XEBC	
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¹ AMBROSINO 08C reports $(2.26 \pm 0.12 \pm 0.06) \times 10^{-6}$ from a measurement of $[\Gamma(K_S^0 \rightarrow \gamma\gamma)/\Gamma_{\text{total}}] \times [B(K_S^0 \rightarrow \pi^0\pi^0)]$ assuming $B(K_S^0 \rightarrow \pi^0\pi^0) = (30.69 \pm 0.05) \times 10^{-2}$.

² LAI 03 reports $[\Gamma(K_S^0 \rightarrow \gamma\gamma)/\Gamma_{\text{total}}] / [B(K_S^0 \rightarrow \pi^0\pi^0)] = (8.84 \pm 0.18 \pm 0.10) \times 10^{-6}$ which we multiply by our best value $B(K_S^0 \rightarrow \pi^0\pi^0) = (30.69 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

³ BARR 95B result is calculated using $B(K_L \rightarrow \gamma\gamma) = (5.86 \pm 0.17) \times 10^{-4}$.

⁴ BARR 95B quotes this as the combined BARR 95B + BURKHARDT 87 result after rescaling BURKHARDT 87 to use same branching ratios and lifetimes as BARR 95B.

————— Semileptonic modes —————

$\Gamma(\pi^\pm e^\mp \nu_e)/\Gamma_{\text{total}}$ Γ_8/Γ

VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT

7.04 ± 0.08 OUR FIT

7.04 ± 0.08 OUR AVERAGE

7.046 ± 0.18 ± 0.16 ¹ BATLEY 07D NA48 $K^0(\bar{K}^0)(t) \rightarrow \pi e \nu$
 6.91 ± 0.34 ± 0.15 624 ² ALOISIO 02 KLOE Tagged K_S^0 using $\phi \rightarrow K_L^0 K_S^0$

• • • We use the following data for averages but not for fits. • • •

7.05 ± 0.09 13k ³ AMBROSINO 06E KLOE Not fitted

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

7.2 ± 1.4 75 AKHMETSHIN 99 CMD2 Tagged K_S^0 using $\phi \rightarrow K_L^0 K_S^0$

¹ Reconstructed from $K^0(\bar{K}^0)(t) \rightarrow \pi e \nu$ distributions using PDG values of $B(K_L^0 \rightarrow \pi e \nu) = 0.4053 \pm 0.0015$, $\tau_L = (5.114 \pm 0.021) \times 10^{-8}$ s and $\tau_S = (0.8958 \pm 0.0005) \times 10^{-10}$ s.

² Uses the PDG 00 value for $B(K_S^0 \rightarrow \pi^+ \pi^-)$.

³ Obtained by imposing $\sum_i B(K_S^0 \rightarrow i) = 1$, where i runs over all the four branching ratios $\pi^+ \pi^-$, $\pi^0 \pi^0$, $\pi e \nu$, and $\pi \mu \nu$. Input value of $B(K_S^0 \rightarrow \pi^+ \pi^-) / B(K_S^0 \rightarrow \pi^0 \pi^0)$ from AMBROSINO 06C is used. To derive $\Gamma(K_S^0 \rightarrow \pi^+ \mu \nu) / \Gamma(K_S^0 \rightarrow \pi^+ e \nu)$, lepton universality is assumed, radiative corrections from ANDRE 07 are used, and phase space integrals are taken from KTeV, ALEXOPOULOS 04A. This branching fraction enters our fit via their $\Gamma(\pi^\pm e^\mp \nu_e) / \Gamma(\pi^+ \pi^-)$ branching ratio measurement.

$\Gamma(\pi^\pm \mu^\mp \nu_\mu)/\Gamma_{\text{total}}$ Γ_9/Γ

The PDG 06 value below has not been measured but is computed to be 0.666 times the $K_S \rightarrow \pi^\pm e^\mp \nu_e$ branching fraction. It is included in the fit that constrains the four branching ratios $\pi^+ \pi^-$, $\pi^0 \pi^0$, $\pi e \nu$, and $\pi \mu \nu$ to sum to 1. This treatment, used by AMBROSINO 06E, is preferable to our previous practice of constraining the $\pi^+ \pi^-$ and $\pi^0 \pi^0$ modes to sum to 1. The 0.666 factor is obtained from AMBROSINO 06E and assumes lepton universality, radiative corrections from ANDRE 07, and phase space integrals from KTeV, ALEXOPOULOS 04A.

VALUE (units 10^{-4}) DOCUMENT ID COMMENT

4.69 ± 0.06 OUR FIT

4.691 ± 0.001 ± 0.056 ¹ PDG 06 calculated from $\pi^\pm e^\mp \nu_e$

¹ The PDG 06 value is computed to be $B_{\text{PDG06}}(\pi \mu \nu) = 0.666 B_{\text{FIT}}(\pi e \nu)$. The first error specifies the arbitrarily small error, 0.001×10^{-4} , on $B_{\text{PDG06}}(\pi \mu \nu)$ for fixed $B_{\text{FIT}}(\pi e \nu)$. The second error is that due to the uncertainty in $B_{\text{FIT}}(\pi e \nu)$.

$\Gamma(\pi^\pm e^\mp \nu_e)/\Gamma(\pi^+ \pi^-)$ Γ_8/Γ_2

VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN

10.18 ± 0.12 OUR FIT

10.19 ± 0.11 ± 0.07 13k AMBROSINO 06E KLOE

CP violating (CP) and $\Delta S = 1$ weak neutral current (S1) modes

 $\Gamma(3\pi^0)/\Gamma_{\text{total}}$ **Γ_{10}/Γ**
 Violates CP conservation.

VALUE (units 10^{-7})	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
< 0.26	90	590M	¹ BABUSCI	13C	KLOE $\phi \rightarrow K_L^0 K_S^0$
< 1.2	90	37.8M	AMBROSINO	05B	KLOE
< 7.4	90	4.9M	² LAI	05A	NA48
<140	90	7M	ACHASOV	99D	SND
<190	90	17300	³ ANGELOPO...	98B	CPLR
<370	90		BARMIN	83	HLBC

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

¹ BABUSCI 13C uses 1.7 fb^{-1} of data of $\phi \rightarrow K_L^0 K_S^0$ decays with K_L^0 interaction in the calorimeter, collected from 2004 to 2005. No candidate events were found in the data with an expected background of $0.04^{+0.15}_{-0.03}$ events. Upper limit is obtained by normalizing to $K_S^0 \rightarrow 2\pi^0$ decays.

² LAI 05A value is obtained from their bound on $|\eta_{000}|$ (not assuming CPT) and $B(K_L^0 \rightarrow 3\pi^0) = 0.211 \pm 0.003$, and PDG 04 values for K_L^0 and K_S^0 lifetimes. If CPT is assumed then $B(K_S^0 \rightarrow 3\pi^0)_{CPT} < 2.3 \times 10^{-7}$ at 90% CL

³ ANGELOPOULOS 98B is from $\text{Im}(\eta_{000}) = -0.05 \pm 0.12 \pm 0.05$, assuming $\text{Re}(\eta_{000}) = \text{Re}(\epsilon) = 1.635 \times 10^{-3}$ and using the value $B(K_L^0 \rightarrow \pi^0 \pi^0 \pi^0) = 0.2112 \pm 0.0027$.

 $\Gamma(\mu^+ \mu^-)/\Gamma_{\text{total}}$ **Γ_{11}/Γ**
 Test for $\Delta S = 1$ weak neutral current. Allowed by first-order weak interaction combined with electromagnetic interaction.

VALUE	CL%	DOCUMENT ID	TECN
< 8×10^{-10}	90	¹ AAIJ	17BQ LHCB
< 9×10^{-9}	90	² AAIJ	13G LHCB
< 3.2×10^{-7}	90	GJESDAL	73 ASPK
< 7×10^{-6}	90	HYAMS	69B OSPK

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

¹ AAIJ 17BQ uses 3.0 fb^{-1} of pp collisions at $\sqrt{s} = 7$ and 8 TeV. The result utilizes the normalization mode branching fraction $B(K_S^0 \rightarrow \pi^+ \pi^-) = (69.20 \pm 0.05) \times 10^{-2}$ from PDG 16. Supersedes AAIJ 13G.

² AAIJ 13G uses 1.0 fb^{-1} of pp collisions at $\sqrt{s} = 7$ TeV. They obtained $B(K_S^0 \rightarrow \mu^+ \mu^-) < 11 \times 10^{-9}$ at 95% C.L.

 $\Gamma(e^+ e^-)/\Gamma_{\text{total}}$ **Γ_{12}/Γ**
 Test for $\Delta S = 1$ weak neutral current. Allowed by first-order weak interaction combined with electromagnetic interaction.

VALUE (units 10^{-7})	CL%	DOCUMENT ID	TECN	COMMENT
< 0.09	90	¹ AMBROSINO	09A	KLOE $e^+ e^- \rightarrow \phi \rightarrow K_S^0 K_L^0$
< 1.4	90	ANGELOPO...	97	CPLR
< 28	90	BLICK	94	CNTR Hyperon facility
<100	90	BARMIN	86	XEBC

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

¹ AMBROSINO 09A reports $< 0.09 \times 10^{-7}$ from a measurement of $[\Gamma(K_S^0 \rightarrow e^+ e^-) / \Gamma_{\text{total}}] / [B(K_S^0 \rightarrow \pi^+ \pi^-)]$ assuming $B(K_S^0 \rightarrow \pi^+ \pi^-) = (69.20 \pm 0.05) \times 10^{-2}$.

$\Gamma(\pi^0 e^+ e^-)/\Gamma_{\text{total}}$ Γ_{13}/Γ

Test for $\Delta S = 1$ weak neutral current. Allowed by first-order weak interaction combined with electromagnetic interaction.

VALUE (units 10^{-9})	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
$3.0^{+1.5}_{-1.2} \pm 0.2$		7	¹ BATLEY	03 NA48	$m_{ee} > 0.165$ GeV

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

< 140	90		LAI	01 NA48
< 1100	90	0	BARR	93B NA31
< 45000	90		GIBBONS	88 E731

¹ BATLEY 03 extrapolate also to the full kinematical region using a constant form factor and a vector matrix element. The resulting branching ratio is $(5.8^{+2.9}_{-2.4}) \times 10^{-9}$.

$\Gamma(\pi^0 \mu^+ \mu^-)/\Gamma_{\text{total}}$ Γ_{14}/Γ

Test for $\Delta S = 1$ weak neutral current. Allowed by first-order weak interaction combined with electromagnetic interaction.

VALUE (units 10^{-9})	EVTS	DOCUMENT ID	TECN	COMMENT
$2.9^{+1.5}_{-1.2} \pm 0.2$	6	¹ BATLEY	04A NA48	NA48/1 K_S^0 beam

¹ Background estimate is $0.22^{+0.18}_{-0.11}$ events. Branching ratio assumes a vector matrix element and unit form factor.

K_S^0 FORM FACTORS

For discussion, see note on $K_{\ell 3}$ form factors in the K^\pm section of the Particle Listings above. Because the semileptonic branching fraction is smaller in K_S^0 than K_L^0 by the ratio of the mean lives, the K_S^0 semileptonic form factor has so far been measured only in the K_{e3} mode using the linear expansion $f_+(t) = f_+(0) (1 + \lambda_+ t / m_{\pi^+}^2)$, which gives the vector form factor $f_+(t)$ relative to its value at $t = 0$.

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN K_{e3}^0 DECAY)

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN
3.39 ± 0.41	15k	AMBROSINO 06E	KLOE

See the related review(s):

[CP Violation in \$K_S^0 \rightarrow 3\pi\$](#)

CP-VIOLATION PARAMETERS IN K_S^0 DECAY

$A_S = [\Gamma(K_S^0 \rightarrow \pi^- e^+ \nu_e) - \Gamma(K_S^0 \rightarrow \pi^+ e^- \bar{\nu}_e)] / \text{SUM}$

Such asymmetry violates CP. If CPT is assumed then $A_S = 2 \text{Re}(\epsilon)$.

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN
$-3.8 \pm 5.0 \pm 2.6$	83K	¹ ANASTASI 18A	KLOE

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

$1.5 \pm 9.6 \pm 2.9$	13k	AMBROSINO 06E	KLOE
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¹ ANASTASI 18A result is a combination of the new measurement and AMBROSINO 06E. The new ANASTASI 18A measurement using data collected from 2004–2005, which corresponds to an integrated luminosity of 1.63 fb^{-1} is $A_S = (-4.9 \pm 5.7 \pm 2.6) \times 10^{-3}$.

———— PARAMETERS FOR $K_S^0 \rightarrow 3\pi$ DECAY ————

$$\text{Im}(\eta_{+-0})^2 = \Gamma(K_S^0 \rightarrow \pi^+ \pi^- \pi^0, \text{CP-violating}) / \Gamma(K_L^0 \rightarrow \pi^+ \pi^- \pi^0)$$

CPT assumed valid (i.e. $\text{Re}(\eta_{+-0}) \simeq 0$).

VALUE	CL%	EVTS	DOCUMENT ID	TECN
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• • • We do not use the following data for averages, fits, limits, etc. • • •

<0.23	90	601	¹ BARMIN	85 HLBC
<0.12	90	384	METCALF	72 ASPK

¹ BARMIN 85 find $\text{Re}(\eta_{+-0}) = (0.05 \pm 0.17)$ and $\text{Im}(\eta_{+-0}) = (0.15 \pm 0.33)$. Includes events of BALDO-CEOLIN 75.

$$\text{Im}(\eta_{+-0}) = \text{Im}(A(K_S^0 \rightarrow \pi^+ \pi^- \pi^0, \text{CP-violating}) / A(K_L^0 \rightarrow \pi^+ \pi^- \pi^0))$$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
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-0.002 ± 0.009	$+0.002$ -0.001	500k	¹ ADLER	97B CPLR
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$-0.002 \pm 0.018 \pm 0.003$	137k	² ADLER	96D CPLR	Sup. by ADLER 97B
$-0.015 \pm 0.017 \pm 0.025$	272k	³ ZOU	94 SPEC	

¹ ADLER 97B also find $\text{Re}(\eta_{+-0}) = -0.002 \pm 0.007$ $+0.004$
 -0.001 . See also ANGELOPOU-LOS 98C.

² The ADLER 96D fit also yields $\text{Re}(\eta_{+-0}) = 0.006 \pm 0.013 \pm 0.001$ with a correlation +0.66 between real and imaginary parts. Their results correspond to $|\eta_{+-0}| < 0.037$ with 90% CL.

³ ZOU 94 use theoretical constraint $\text{Re}(\eta_{+-0}) = \text{Re}(\epsilon) = 0.0016$. Without this constraint they find $\text{Im}(\eta_{+-0}) = 0.019 \pm 0.061$ and $\text{Re}(\eta_{+-0}) = 0.019 \pm 0.027$.

$$\text{Im}(\eta_{000})^2 = \Gamma(K_S^0 \rightarrow 3\pi^0) / \Gamma(K_L^0 \rightarrow 3\pi^0)$$

CPT assumed valid (i.e. $\text{Re}(\eta_{000}) \simeq 0$). This limit determines branching ratio $\Gamma(3\pi^0) / \Gamma_{\text{total}}$ above.

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

<0.1	90	632	¹ BARMIN	83 HLBC
<0.28	90		² GJESDAL	74B SPEC Indirect meas.

¹ BARMIN 83 find $\text{Re}(\eta_{000}) = (-0.08 \pm 0.18)$ and $\text{Im}(\eta_{000}) = (-0.05 \pm 0.27)$. Assuming *CPT* invariance they obtain the limit quoted above.

² GJESDAL 74B uses $K2\pi$, $K_{\mu 3}$, and K_{e3} decay results, unitarity, and *CPT*. Calculates $|\eta_{000}| = 0.26 \pm 0.20$. We convert to upper limit.

$$\text{Im}(\eta_{000}) = \text{Im}(A(K_S^0 \rightarrow \pi^0 \pi^0 \pi^0) / A(K_L^0 \rightarrow \pi^0 \pi^0 \pi^0))$$

$K_S^0 \rightarrow \pi^0 \pi^0 \pi^0$ violates *CP* conservation, in contrast to $K_S^0 \rightarrow \pi^+ \pi^- \pi^0$ which has a *CP*-conserving part.

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
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-0.001 ± 0.016 OUR AVERAGE

$0.000 \pm 0.009 \pm 0.013$	4.9M	¹ LAI	05A NA48	Assumes <i>CPT</i>
$-0.05 \pm 0.12 \pm 0.05$	17300	² ANGELOPO...	98B CPLR	Assumes <i>CPT</i>

- ¹ LAI 05A assumes $\text{Re}(\eta_{000})=\text{Re}(\epsilon)=1.66 \times 10^{-3}$. The equivalent limit is $|\eta_{000}|_{CPT} < 0.025$ at 90% CL Without assuming *CPT* invariance, they obtain $\text{Re}(\eta_{000})=-0.002 \pm 0.011 \pm 0.015$ and $\text{Im}(\eta_{000})=-0.003 \pm 0.013 \pm 0.017$ with a statistical correlation coefficient of 0.77 and an overall correlation coefficient of 0.57 between imaginary and real part. The equivalent limit is $|\eta_{000}| < 0.045$ at 90% CL
- ² ANGELOPOULOS 98B assumes $\text{Re}(\eta_{000}) = \text{Re}(\epsilon) = 1.635 \times 10^{-3}$. Without assuming *CPT* invariance, they obtain $\text{Re}(\eta_{000}) = 0.18 \pm 0.14 \pm 0.06$ and $\text{Im}(\eta_{000}) = 0.15 \pm 0.20 \pm 0.03$.

$$|\eta_{000}| = |A(K_S^0 \rightarrow 3\pi^0)/A(K_L^0 \rightarrow 3\pi^0)|$$

A non-zero value violates CP invariance.

VALUE	CL%	EVTS	DOCUMENT ID	TECN
<0.0088	90	590M	BABUSCI	13C KLOE
••• We do not use the following data for averages, fits, limits, etc. •••				
<0.018	90	37.8M	AMBROSINO	05B KLOE
<0.045	90	4.9M	LAI	05A NA48

DECAY-PLANE ASYMMETRY IN $\pi^+\pi^-e^+e^-$ DECAYS

This is the *CP*-violating asymmetry

$$A = \frac{N_{\sin\phi\cos\phi>0.0} - N_{\sin\phi\cos\phi<0.0}}{N_{\sin\phi\cos\phi>0.0} + N_{\sin\phi\cos\phi<0.0}}$$

where ϕ is the angle between the e^+e^- and $\pi^+\pi^-$ planes in the K_S^0 rest frame.

CP asymmetry A in $K_S^0 \rightarrow \pi^+\pi^-e^+e^-$

VALUE (%)	DOCUMENT ID	TECN	COMMENT
-0.4±0.8 OUR AVERAGE			
-0.4±0.8	¹ BATLEY	11 NA48	2002 data
-1.1±4.1	LAI	03C NA48	1998+1999 data
••• We do not use the following data for averages, fits, limits, etc. •••			
0.5±4.0±1.6	LAI	03C NA48	1999 data

¹ The result is used to set the limit $A < 1.5\%$ at 90% C.L.

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