



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

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 CPT
0.89564 ± 0.00033 OUR FIT				Not assuming CPT
0.89589 ± 0.00070		^{1,2} ABOUZAID	11	KTEV Not assuming CPT
0.89623 ± 0.00047		^{1,3} ABOUZAID	11	KTEV Assuming CPT
0.89562 ± 0.00029 ± 0.00043	20M	⁴ AMBROSINO	11	KLOE Not assuming CPT
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 CPT
0.8929 ± 0.0016		GIBBONS	93	E731 Assuming CPT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
0.8965 ± 0.0007		⁵ ALAVI-HARATI03	KTEV	Assuming CPT
0.8958 ± 0.0013		⁶ ALAVI-HARATI03	KTEV	Not assuming CPT
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=3.1
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] $(4.56 \pm 0.20) \times 10^{-4}$	
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 $< 2.1 \times 10^{-10}$	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	4	
x_9	-1	-3	0
	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
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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
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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
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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. $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\text{total}}$ Γ_3/Γ

VALUE (units 10^{-7})	EVTS	DOCUMENT ID	TECN	COMMENT
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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
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$2.5^{+1.3+0.5}_{-1.0-0.6}$	500k	² ADLER	97B	CPLR
$4.8^{+2.2\pm 1.1}_{-1.6}$		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 ————

$\Gamma(\pi^+ \pi^- \gamma)/\Gamma(\pi^+ \pi^-)$ Γ_4/Γ_2

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
2.59 ± 0.08 OUR AVERAGE				
2.56 ± 0.09	1286	RAMBERG	93 E731	$p_\gamma > 50$ MeV/c
2.68 ± 0.15		¹ TAUREG	76 SPEC	$p_\gamma > 50$ MeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •				
7.10 ± 0.22	3723	RAMBERG	93 E731	$p_\gamma > 20$ MeV/c
3.0 ± 0.6	29	² BOBISUT	74 HLBC	$p_\gamma > 40$ MeV/c
2.8 ± 0.6		³ BURGUN	73 HBC	$p_\gamma > 50$ MeV/c

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

³ Second error is 0.16(syst) ± 0.15(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
4.9 ± 1.6 ± 0.9		17	¹ LAI	04 NA48	$m_{\gamma\gamma}^2 / m_K^2 > 0.2$

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

<33 90 LAI 03B NA48 $m_{\gamma\gamma}^2 / m_K^2 > 0.2$

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
2.63 ± 0.17 OUR AVERAGE			Error includes scale factor of 3.1.		
2.26 ± 0.12 ± 0.06		711	¹ AMBROSINO	08C KLOE	$\phi \rightarrow K_S^0 K_L^0$
2.713 ± 0.063 ± 0.005		7.5k	² LAI	03 NA48	

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

2.58 ± 0.36 ± 0.22 149 LAI 00 NA48
 2.2 ± 1.1 16 ³ BARR 95B NA31
 2.4 ± 0.9 35 ⁴ BARR 95B NA31
 < 13 90 BALATS 89 SPEC
 2.4 ± 1.2 19 BURKHARDT 87 NA31
 <133 90 BARMIN 86B XEBC

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

<u>VALUE (units 10^{-4})</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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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
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• • • 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 $\phi \rightarrow K_L^0 K_S^0$
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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

<u>VALUE (units 10^{-4})</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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4.56 ± 0.20 OUR FIT

4.56 ± 0.11 ± 0.17	7223	¹ BABUSCI	20 KLOE	direct measurement
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¹ Value obtained by normalizing to the KLOE measurement $B(K_S^0 \rightarrow \pi^+ \pi^-) = (69.196 \pm 0.051)\%$. Also comparison with the PDG 18 based derived value leads to a lepton flavor universality test $|V_{us} f_+(0)|_{K_S^0 \rightarrow \pi \mu \nu}^2 / |V_{us} f_+(0)|_{K_S^0 \rightarrow \pi e \nu}^2 = 0.975 \pm 0.044$.

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

<u>VALUE (units 10^{-4})</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
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10.18 ± 0.12 OUR FIT

10.19 ± 0.11 ± 0.07	13k	AMBROSINO	06E KLOE
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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.

<u>VALUE (units 10^{-7})</u>	<u>CL%</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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< 0.26	90	590M	¹ BABUSCI	13C KLOE	$\phi \rightarrow K_L^0 K_S^0$
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• • • We do not use the following data for averages, fits, limits, etc. • • •

< 1.2	90	37.8M	AMBROSINO	05B KLOE
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< 7.4	90	4.9M	² LAI	05A NA48
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< 140	90	7M	ACHASOV	99D SND
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<190	90	17300	³ ANGELOPO...	98B	CPLR
<370	90		BARMIN	83	HLBC

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
< 2.1×10^{-10}	90	¹ AAIJ	20AE LHCB

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

< 8×10^{-10}	90	² AAIJ	17BQ LHCB
< 9×10^{-9}	90	³ AAIJ	13G LHCB
< 3.2×10^{-7}	90	GJESDAL	73 ASPK
< 7×10^{-6}	90	HYAMS	69B OSPK

¹ AAIJ 20AE uses 8.6 fb^{-1} of LHCb data from 2011 to 2012 and 2016 to 2018. 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 18. Supersedes AAIJ 17BQ.

² 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.

³ 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	$e^+ e^- \rightarrow \phi \rightarrow K_S^0 K_L^0$

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

< 1.4	90	ANGELOPO...	97	CPLR
< 28	90	BLICK	94	CNTR Hyperon facility
< 100	90	BARMIN	86	XEBC

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

 CP VIOLATION IN $K_S \rightarrow 3\pi$

Written 1996 by T. Nakada (Paul Scherrer Institute) and L. Wolfenstein (Carnegie-Mellon University).

The possible final states for the decay $K^0 \rightarrow \pi^+ \pi^- \pi^0$ have isospin $I = 0, 1, 2,$ and 3 . The $I = 0$ and $I = 2$ states have $CP = +1$ and K_S can decay into them without violating CP symmetry, but they are expected to be strongly suppressed by centrifugal barrier effects. The $I = 1$ and $I = 3$ states, which

have no centrifugal barrier, have $CP = -1$ so that the K_S decay to these requires CP violation.

In order to see CP violation in $K_S \rightarrow \pi^+\pi^-\pi^0$, it is necessary to observe the interference between K_S and K_L decay, which determines the amplitude ratio

$$\eta_{+-0} = \frac{A(K_S \rightarrow \pi^+\pi^-\pi^0)}{A(K_L \rightarrow \pi^+\pi^-\pi^0)}. \quad (1)$$

If η_{+-0} is obtained from an integration over the whole Dalitz plot, there is no contribution from the $I = 0$ and $I = 2$ final states and a nonzero value of η_{+-0} is entirely due to CP violation.

Only $I = 1$ and $I = 3$ states, which are $CP = -1$, are allowed for $K^0 \rightarrow \pi^0\pi^0\pi^0$ decays and the decay of K_S into $3\pi^0$ is an unambiguous sign of CP violation. Similarly to η_{+-0} , η_{000} is defined as

$$\eta_{000} = \frac{A(K_S \rightarrow \pi^0\pi^0\pi^0)}{A(K_L \rightarrow \pi^0\pi^0\pi^0)}. \quad (2)$$

If one assumes that CPT invariance holds and that there are no transitions to $I = 3$ (or to nonsymmetric $I = 1$ states), it can be shown that

$$\begin{aligned} \eta_{+-0} &= \eta_{000} \\ &= \epsilon + i \frac{\text{Im } a_1}{\text{Re } a_1}. \end{aligned} \quad (3)$$

With the Wu-Yang phase convention, a_1 is the weak decay amplitude for K^0 into $I = 1$ final states; ϵ is determined from CP violation in $K_L \rightarrow 2\pi$ decays. The real parts of η_{+-0} and η_{000} are equal to $\text{Re}(\epsilon)$. Since currently-known upper limits on $|\eta_{+-0}|$ and $|\eta_{000}|$ are much larger than $|\epsilon|$, they can be interpreted as upper limits on $\text{Im}(\eta_{+-0})$ and $\text{Im}(\eta_{000})$ and so as limits on the CP -violating phase of the decay amplitude a_1 .

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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$-0.002 \pm 0.009 \pm 0.002$ -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 $\text{Re}(\eta_{+-0}) = -0.002 \pm 0.007 \pm 0.004$. See also ANGELOPOULOS 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 $K_{2\pi}$, $K_{\mu 3}$, and $K_{e 3}$ 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±0.009±0.013	4.9M	¹ LAI	05A NA48	Assumes CPT
-0.05 ±0.12 ±0.05	17300	² ANGELOPO...	98B CPLR	Assumes CPT

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
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<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
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-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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BATTISTON	92	PRPL 214 293	R. Battiston <i>et al.</i>	(PGIA, CERN, TRSTT)
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CRAWFORD	62	CERN Conf. 827	F.S. Crawford	(LRL)
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MULLER	60	PRL 4 418	F. Muller <i>et al.</i>	(LRL, BNL)