K^0_S

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

K^0_S 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 decays" in the K^0_L 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*
0.8953 ±0.0005 OUR FIT		Error includes scale factor of 1.1. Assuming *CPT*		
0.8958 ±0.0005 OUR FIT		Not assuming *CPT*		
0.8965 ±0.0007		[1,2] ALAVI-HARATI 03	KTEV	Assuming *CPT*
0.8958 ±0.0013		[2,3] ALAVI-HARATI 03	KTEV	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. • • •				
0.8920 ±0.0044	214k	GROSSMAN 87	SPEC	
0.905 ±0.007		[4] ARONSON 82B	SPEC	
0.881 ±0.009	26k	ARONSON 76	SPEC	
0.8926 ±0.0032 ±0.0002		[5] CARITHERS 75	SPEC	
0.8937 ±0.0048	6M	GEWENIGER 74B	ASPK	
0.8958 ±0.0045	50k	[6] SKJEGGEST... 72	HBC	
0.856 ±0.008	19994	[7] DONALD 68B	HBC	
0.872 ±0.009	20000	[7,8] HILL 68	DBC	

[1] 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 $\Delta m = m_{K^0_L} - m_{K^0_S}$ measurement in the K^0_L listings. The correlation coefficient $\rho(\tau_S, \Delta m) = -0.396$.

[2] The two ALAVI-HARATI 03 values use the same data. The first enters the "assuming *CPT*" fit and the second enters the "not assuming *CPT*" fit.

[3] This ALAVI-HARATI 03 fit has Δm, ϕ_{+-}, and τ_{K_S} free. See ϕ_{+-} in the "K_L *CP* violation" section for correlation information.

[4] ARONSON 82 find that K^0_S mean life may depend on the kaon energy.

[5] CARITHERS 75 measures the Δm dependence of the total decay rate (inverse mean life) to be $\Gamma(K^0_S) = \left[(1.122 \pm 0.004) + 0.16(\Delta m - 0.5348)/\Delta m\right] 10^{10}$/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 ($\Delta m = 0.5292 \pm 0.0009$) ($10^{10}\ \hbar\ s^{-1}$). Our first error is their experiment's error and our second error is the systematic error from using our best values.

[6] HILL 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.

[7] Pre-1971 experiments are excluded from the average because of disagreement with later more precise experiments.

[8] HILL 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.

K^0_S DECAY MODES

	Mode			Fraction (Γ_i/Γ)	Confidence level
	Hadronic modes				
Γ_1	$\pi^0\pi^0$			(30.69 ± 0.05) %	
Γ_2	$\pi^+\pi^-$			(69.20 ± 0.05) %	
Γ_3	$\pi^+\pi^-\pi^0$			$(3.5\ ^{+1.1}_{-0.9}) \times 10^{-7}$	
	Modes with photons or $\ell\overline{\ell}$ pairs				
Γ_4	$\pi^+\pi^-\gamma$		[*a*,*b*]	$(1.79\pm0.05) \times 10^{-3}$	
Γ_5	$\pi^+\pi^-e^+e^-$			$(4.69\pm0.30) \times 10^{-5}$	
Γ_6	$\pi^0\gamma\gamma$		[*b*]	$(4.9\ \pm1.8\ ) \times 10^{-8}$	
Γ_7	$\gamma\gamma$			$(2.84\pm0.07) \times 10^{-6}$	
	Semileptonic modes				
Γ_8	$\pi^\pm e^\mp \nu_e$		[*c*]	$(7.04\pm0.09) \times 10^{-4}$	
Γ_9	$\pi^\pm \mu^\mp \nu_\mu$		[*c*,*d*]	$(4.69\pm0.06) \times 10^{-4}$	
	***CP* violating (*CP*) and $\Delta S = 1$ weak neutral current (*S1*) modes**				
Γ_{10}	$3\pi^0$	*CP*		$< 1.2 \times 10^{-7}$	90%
Γ_{11}	$\mu^+\mu^-$	*S1*		$< 3.2 \times 10^{-7}$	90%
Γ_{12}	e^+e^-	*S1*		$< 1.4 \times 10^{-7}$	90%
Γ_{13}	$\pi^0e^+e^-$	*S1*	[*b*]	$(3.0\ ^{+1.5}_{-1.2}) \times 10^{-9}$	
Γ_{14}	$\pi^0\mu^+\mu^-$	*S1*		$(2.9\ ^{+1.5}_{-1.2}) \times 10^{-9}$	

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

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

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

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

CONSTRAINED FIT INFORMATION

An overall fit to 4 branching ratios uses 4 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2 =$ 0.1 for 1 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\left\langle\delta x_i \delta x_j\right\rangle/(\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{total}$. 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	−6	4	100
	x_1	x_2	x_8

K_S^0 DECAY RATES

$\Gamma(\pi^{\pm} e^{\mp} \nu_e)$ — Γ_8

VALUE (10^6 s^{-1})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
8.1 ±1.6	75	[9] AKHMETSHIN	99	CMD2	Tagged K_S^0 using $\phi \to K_L^0 K_S^0$
7.50±0.08		[10] PDG	98		
seen		BURGUN	72	HBC	$K^+ p \to K^0 p \pi^+$
9.3 ±2.5		AUBERT	65	HLBC	ΔS=ΔQ, *CP* cons. not assumed

[9] AKHMETSHIN 99 is from a measured branching ratio B($K_S^0 \to \pi e \nu_e$)= (7.2 ± 1.4) × 10^{-4} and $\tau_{K_S^0}$ = (0.8934 ± 0.0008) × 10^{-10} s. Not independent of measured branching ratio.

[10] PDG 98 from K_L^0 measurements, assuming that ΔS=ΔQ in K^0 decay so that Γ($K_S^0 \to \pi^{\pm} e^{\mp} \nu_e$)= Γ($K_L^0 \to \pi^{\pm} e^{\mp} \nu_e$).

$\Gamma(\pi^{\pm} \mu^{\mp} \nu_{\mu})$ — Γ_9

VALUE (10^6 s^{-1})	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •		
5.25±0.07	[11] PDG	98

[11] PDG 98 from K_L^0 measurements, assuming that ΔS=ΔQ in K^0 decay so that Γ($K_S^0 \to \pi^{\pm} \mu^{\mp} \nu_{\mu}$)= Γ($K_L^0 \to \pi^{\pm} \mu^{\mp} \nu_{\mu}$).

K_S^0 BRANCHING RATIOS

Hadronic modes

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

$\Gamma(\pi^+\pi^-)/\Gamma_{total}$ — 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	$\pi^- p \to \Lambda K^0$

$\Gamma(\pi^+\pi^-)/\Gamma(\pi^0\pi^0)$ — Γ_2/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
2.255 ±0.005 OUR FIT					
2.2549±0.0054		[12] AMBROSINO	06C	KLOE	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.2555±0.0012±0.0054		[13] AMBROSINO	06C	KLOE	
2.236 ±0.003 ±0.015	766k	[13] ALOISIO	02B	KLOE	
2.11 ±0.09	1315	EVERHART	76	WIRE	$\pi^- p \to \Lambda K^0$
2.169 ±0.094	16k	COWELL	74	OSPK	$\pi^- p \to \Lambda K^0$
2.16 ±0.08	4799	HILL	73	DBC	$K^+ d \to K^0 pp$
2.22 ±0.10	3068	[14] ALITTI	72	HBC	$K^+ p \to \pi^+ p K^0$
2.22 ±0.08	6380	MORSE	72B	DBC	$K^+ n \to K^0 p$
2.10 ±0.11	701	[15] NAGY	72	HLBC	$K^+ n \to K^0 p$
2.22 ±0.095	6150	[16] BALTAY	71	HBC	$K p \to K^0$ neutrals
2.282 ±0.043	7944	[17] MOFFETT	70	OSPK	$K^+ n \to K^0 p$
2.12 ±0.17	267	[15] BOZOKI	69	HLBC	
2.285 ±0.055	3016	[17] GOBBI	69	OSPK	$K^+ n \to K^0 p$
2.10 ±0.06	3700	MORFIN	69	HLBC	$K^+ n \to K^0 p$

[12] This result combines AMBROSINO 06C KLOE 2001-02 data with ALOISIO 02B KLOE 2000 data. $K^0_S \to \pi^+\pi^-$ fully inclusive.

[13] Includes radiative decays $\pi^+\pi^-\gamma$.

[14] The directly measured quantity is $K^0_S \to \pi^+\pi^-$/all $K^0 = 0.345 \pm 0.005$.

[15] NAGY 72 is a final result which includes BOZOKI 69.

[16] The directly measured quantity is $K^0_S \to \pi^+\pi^-$/all $\overline{K}^0 = 0.345 \pm 0.005$.

[17] MOFFETT 70 is a final result which includes GOBBI 69.

$\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{total}$ — Γ_3/Γ

VALUE (units 10^{-7})	EVTS	DOCUMENT ID		TECN	COMMENT
$3.5^{+1.1}_{-0.9}$ OUR AVERAGE					
$4.7^{+2.2}_{-1.7}{}^{+1.7}_{-1.5}$		[18] BATLEY	05	NA48	
$2.5^{+1.3}_{-1.0}{}^{+0.5}_{-0.6}$	500k	[19] ADLER	97B	CPLR	
$4.8^{+2.2}_{-1.6}\pm1.1$		[20] ZOU	96	E621	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$4.1^{+2.5}_{-1.9}{}^{+0.5}_{-0.6}$		[21] ADLER	96E	CPLR	Sup. by ADLER 97B
$3.9^{+5.4}_{-1.8}{}^{+0.9}_{-0.7}$		[22] THOMSON	94	E621	Sup. by ZOU 96

[18] BATLEY 05 is obtained by measuring the interference parameters in K_S, $K_L \rightarrow \pi^+\pi^-\pi^0$: Re($\lambda$) = 0.038 ± 0.008 ± 0.006 and Im(λ) = −0.013 ± 0.005 ± 0.004; the correlation coeff. between Re(λ) and Im(λ) is 0.66 (statistical only).
[19] ADLER 97B find the CP-conserving parameters Re(λ) = (28 ± 7 ± 3) × 10^{-3}, Im(λ) = (−10 ± 8 ± 2) × 10^{-3}. They estimate B($K^0_S \rightarrow \pi^+\pi^-\pi^0$) from Re($\lambda$) and the K^0_L decay parameters. See also ANGELOPOULOS 98C.
[20] ZOU 96 is from the the measured quantities $|\rho_{+-0}| = 0.039^{+0.009}_{-0.006} \pm 0.005$ and $\phi_\rho = (-9 \pm 18)^\circ$.
[21] ADLER 96E is from the measured quantities Re(λ) = $0.036 \pm 0.010^{+0.002}_{-0.003}$ and Im(λ) consistent with zero. Note that the quantity λ is the same as ρ_{+-0} used in other footnotes.
[22] 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 $|\rho_{+-0}| e^{i\phi_\rho} = A(K^0_S \rightarrow \pi^+\pi^-\pi^0, I=2)/A(K^0_L \rightarrow \pi^+\pi^-\pi^0)$.

Modes with photons or $\ell\overline{\ell}$ 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_γ >50 MeV/c
2.68±0.15		[23] TAUREG	76	SPEC	p_γ >50 MeV/c
• • • We do not use the following data for averages, fits, limits, etc. • • •					
7.10±0.22	3723	RAMBERG	93	E731	p_γ >20 MeV/c
3.0 ±0.6	29	[24] BOBISUT	74	HLBC	p_γ >40 MeV/c
2.8 ±0.6		[25] BURGUN	73	HBC	p_γ >50 MeV/c

[23] TAUREG 76 find direct emission contribution <0.06, CL = 90%.
[24] BOBISUT 74 not included in average because p_γ cut differs. Estimates direct emission contribution to be 0.5 or less, CL = 95%.
[25] BURGUN 73 estimates that direct emission contribution is 0.3 ± 0.6.

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

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	COMMENT
4.69±0.30	676	[26] 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	[26,27] LAI	03C	NA48	1999 data
4.5 ±0.7 ±0.4	56	LAI	00B	NA48	1998 data

[26] Uses normalization BR($K_L \rightarrow \pi^+\pi^-\pi^0$)*BR($\pi^0 \rightarrow e^+e^-$) = (1.505 ± 0.047) × 10^{-3} from our 2000 Edition.
[27] Second error is 0.16(syst)±0.15(norm) combined in quadrature.

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

VALUE (units 10^{-8})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
4.9±1.6±0.9		17	[28] LAI	04	NA48	$m^2_{\gamma\gamma}/m^2_K > 0.2$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<33	90		LAI	03B	NA48	$m^2_{\gamma\gamma}/m^2_K > 0.2$

[28] Spectrum also measured and found consistent with the one generated by a constant matrix element.

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

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN
2.844±0.069±0.005		7.5k	[29] 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	[30] BARR	95B	NA31
2.4 ±0.9		35	[31] BARR	95B	NA31
< 13	90		BALATS	89	SPEC
2.4 ±1.2		19	BURKHARDT	87	NA31
<133	90		BARMIN	86B	XEBC

[29] LAI 03 reports $(2.78 \pm 0.06 \pm 0.04) \times 10^{-6}$ for B($K^0_S \rightarrow \pi^0\pi^0$) = $(31.39 \pm 0.28) \times 10^{-2}$. We rescale to our best value B($K^0_S \rightarrow \pi^0\pi^0$) = $(30.69 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

[31] 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

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

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
7.04±0.09 OUR FIT					
7.04±0.09 OUR AVERAGE					
7.05±0.09	13k	[32] AMBROSINO	06E	KLOE	Not fitted
6.91±0.34±0.15	624	[33] ALOISIO	02	KLOE	Tagged K^0_S using $\phi \rightarrow K^0_L K^0_S$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
7.2 ±1.4	75	AKHMETSHIN	99	CMD2	Tagged K^0_S using $\phi \rightarrow K^0_L K^0_S$

[32] Obtained by imposing Σ_i B($K^0_S \rightarrow i$) = 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($K^0_S \rightarrow \pi^+\pi^-$) / B($K^0_S \rightarrow \pi^0\pi^0$) from AMBROSINO 06C is used. To derive Γ($K^0_S \rightarrow \pi^+ \mu \nu$) / Γ($K^0_S \rightarrow \pi^+ e \nu$), lepton universality is assumed, radiative corrections from ANDRE 04 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.

[33] Uses the PDG 00 value for B($K^0_S \rightarrow \pi^+\pi^-$).

$\Gamma(\pi^{\pm} \mu^{\mp} \nu_{\mu})/\Gamma_{total}$ — 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 04, 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±0.060	[34] PDG	06	calculated from $\pi^{\pm} e^{\mp} \nu_e$

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

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

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN
10.18±0.13 OUR FIT				
10.19±0.11±0.07	13k	AMBROSINO	06E	KLOE

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

$\Gamma(3\pi^0)/\Gamma_{total}$ — Γ_{10}/Γ

Violates *CP* conservation.

VALUE (units 10^{-7})	CL%	EVTS	DOCUMENT ID		TECN
< 1.2	90	37.8M	AMBROSINO	05B	KLOE
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 7.4	90	4.9M	[35] LAI	05A	NA48
<140	90	7M	ACHASOV	99D	SND
<190	90	17300	[36] ANGELOPO...	98B	CPLR
<370	90		BARMIN	83	HLBC

[35] LAI 05A value is obtained from their bound on $|\eta_{000}|$ (not assuming *CPT*) and B($K^0_L \to 3\pi^0$) = 0.211 ± 0.003, and PDG 04 values for K^0_L and K^0_S lifetimes. If *CPT* is assumed then B($K^0_S \to 3\pi^0)_{CPT} < 2.3 \times 10^{-7}$ at 90% CL

[36] ANGELOPOULOS 98B is from Im(η_{000}) = −0.05 ± 0.12 ± 0.05, assuming Re(η_{000}) = Re(ϵ) = 1.635×10^{-3} and using the value B($K^0_L \to \pi^0\pi^0\pi^0$) = 0.2112 ± 0.0027.

$\Gamma(\mu^{+}\mu^{-})/\Gamma_{total}$ — Γ_{11}/Γ

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

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN
<0.032	90	GJESDAL	73	ASPK
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.7	90	HYAMS	69B	OSPK

$\Gamma(e^{+}e^{-})/\Gamma_{total}$ — 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%	EVTS	DOCUMENT ID		TECN	COMMENT
< 1.4	90		ANGELOPO...	97	CPLR	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 28	90	0	BLICK	94	CNTR	Hyperon facility
<100	90		BARMIN	86	XEBC	

$\Gamma(\pi^0 e^+ e^-)/\Gamma_{total}$ — 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
$\mathbf{3.0^{+1.5}_{-1.2}\pm0.2}$		7	[37] 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	

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

$\Gamma(\pi^0 \mu^+ \mu^-)/\Gamma_{total}$ — 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
$\mathbf{2.9^{+1.5}_{-1.2}\pm0.2}$	6	[38] BATLEY	04A	NA48	NA48/1 K^0_S beam

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

K^0_S 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^0_S than K^0_L by the ratio of the mean lives, the K^0_S semileptonic form factor has so far been measured only in the K_{e3} mode using the linear expansion $f_+(t) = f_+(0)\ (1 + \lambda_+ t\ /m^2_{\pi^+})$, which gives the vector form factor $f_+(t)$ relative to its value at $t = 0$.

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

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

CP VIOLATION IN $K_S \to 3\pi$

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

The possible final states for the decay $K^0 \to \pi^+\pi^-\pi^0$ 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

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

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

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

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

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

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^0_S DECAY

$A_S = [\,\Gamma(K^0_S \to \pi^- e^+ \nu_e) - \Gamma(K^0_S \to \pi^+ e^- \overline{\nu}_e)\,]$ / SUM

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

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN
1.5± 9.6±2.9	13k	AMBROSINO	06E	KLOE

—— PARAMETERS FOR $K^0_S \to 3\pi$ DECAY ——

$\mathrm{Im}(\eta_{+-0})^2 = \Gamma(K^0_S \to \pi^+\pi^-\pi^0$, *CP*-violating) / $\Gamma(K^0_L \to \pi^+\pi^-\pi^0)$

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

VALUE	CL%	EVTS	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.23	90	601	[39] BARMIN	85	HLBC
<0.12	90	384	METCALF	72	ASPK

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

$\mathrm{Im}(\eta_{+-0}) = \mathrm{Im}(\mathrm{A}(K^0_S \to \pi^+\pi^-\pi^0$, *CP*-violating) / $\mathrm{A}(K^0_L \to \pi^+\pi^-\pi^0))$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{-0.002 \pm 0.009^{+0.002}_{-0.001}}$	500k	[40] ADLER	97B	CPLR	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-0.002 \pm 0.018 \pm 0.003$	137k	[41] ADLER	96D	CPLR	Sup. by ADLER 97B
$-0.015 \pm 0.017 \pm 0.025$	272k	[42] ZOU	94	SPEC	

[40] ADLER 97B also find $\mathrm{Re}(\eta_{+-0}) = -0.002 \pm 0.007^{+0.004}_{-0.001}$. See also ANGELOPOULOS 98C.

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

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

$\mathrm{Im}(\eta_{000})^2 = \Gamma(K^0_S \to 3\pi^0) / \Gamma(K^0_L \to 3\pi^0)$

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

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.1	90	632	[43] BARMIN	83	HLBC	
<0.28	90		[44] GJESDAL	74B	SPEC	Indirect meas.

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

[44] 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.

$\mathrm{Im}(\eta_{000}) = \mathrm{Im}(A(K^0_S \to \pi^0\pi^0\pi^0)/A(K^0_L \to \pi^0\pi^0\pi^0))$

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

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$(-0.1 \pm 1.6) \times 10^{-2}$ OUR AVERAGE					
$0.000 \pm 0.009 \pm 0.013$	4.9M	[45] LAI	05A	NA48	Assumes *CPT*
$-0.05 \pm 0.12 \pm 0.05$	17300	[46] ANGELOPO...	98B	CPLR	Assumes *CPT*

[45] LAI 05A assumes $\mathrm{Re}(\eta_{000})=\mathrm{Re}(\epsilon)=1.66 \times 10^{-3}$. The equivalent limit is $|\eta_{000}|_{CPT} <0.025$ at 90% CL Without assuming *CPT* invariance, they obtain $\mathrm{Re}(\eta_{000})=-0.002 \pm 0.011 \pm 0.015$ and $\mathrm{Im}(\eta_{000})=-0.003 \pm 0.013 \pm 0.017$ 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

[46] ANGELOPOULOS 98B assumes $\mathrm{Re}(\eta_{000}) = \mathrm{Re}(\epsilon) = 1.635 \times 10^{-3}$. Without assuming *CPT* invariance, they obtain $\mathrm{Re}(\eta_{000}) = 0.18 \pm 0.14 \pm 0.06$ and $\mathrm{Im}(\eta_{000}) = 0.15 \pm 0.20 \pm 0.03$.

$|\eta_{000}| = |A(K^0_S \to 3\pi^0)/A(K^0_L \to 3\pi^0)|$

A non-zero value violates CP invariance.

VALUE	CL%	EVTS	DOCUMENT ID		TECN
<0.018	90	37.8M	AMBROSINO	05B	KLOE
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<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^0_S rest frame.

CP asymmetry *A* in $K^0_S \to \pi^+\pi^-e^+e^-$

VALUE (%)	DOCUMENT ID		TECN	COMMENT
-1.1 ± 4.1	LAI	03C	NA48	1998+1999 data
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.5 \pm 4.0 \pm 1.6$	LAI	03C	NA48	1999 data

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