K^0_L

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

$m_{K^0_L} - m_{K^0_S}$

For earlier measurements, beginning with GOOD 61 and FITCH 61, see our 1986 edition, Physics Letters **170B** 132 (1986).

OUR FIT is described in the note on "Fits for K^0_L *CP*-Violation Parameters" in the K^0_L Particle Listings.

VALUE (10^{10} $\hbar$ s^{-1})		*DOCUMENT ID*		*TECN*	*COMMENT*
0.5303±0.0009	**OUR FIT**	Assuming *CPT*			
0.5301±0.0016	**OUR FIT**	Not assuming *CPT*			
0.5308±0.0014	**OUR AVERAGE**	Error includes scale factor of 1.1.			
0.5343±0.0063	±0.0025	[1] ANGELOPO...	01	CPLR	
0.5240±0.0044	±0.0033	APOSTOLA...	99C	CPLR	K^0-$\overline{K}^0$ to $\pi^+\pi^-$
0.5295±0.0020	±0.0003	[2] ANGELOPO...	98D	CPLR	
0.5297±0.0030	±0.0022	[3] SCHWINGEN...	95	E773	20–160 GeV *K* beams
0.5257±0.0049	±0.0021	[3] GIBBONS	93C	E731	20–160 GeV *K* beams
0.5340±0.00255	±0.0015	[4] GEWENIGER	74C	SPEC	Gap method
0.5334±0.0040	±0.0015	[4] GJESDAL	74	SPEC	Charge asymmetry in $K^0_{\ell 3}$
0.542 ±0.006		CULLEN	70	CNTR	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.5307±0.0013		[5] ADLER	96C	RVUE	
0.5274±0.0029	±0.0005	[2] ADLER	95	CPLR	Sup. by ANGELOPOULOS 98D
0.5286±0.0028		[6] GIBBONS	93	E731	20–160 GeV *K* beams
0.482 ±0.014		[7] ARONSON	82B	SPEC	*E*=30–110 GeV
0.534 ±0.007		[8] CARNEGIE	71	ASPK	Gap method
0.542 ±0.006		[8] ARONSON	70	ASPK	Gap method

[1] ANGELOPOULOS 01 uses strong interactions strangeness tagging at two different times.

[2] Uses $\overline{K}^0_{e3}$ and K^0_{e3} strangeness tagging at production and decay. Assumes *CPT* conservation on $\Delta S = -\Delta Q$ transitions.

[3] Fits Δm and ϕ_{+-} simultaneously. GIBBONS 93C systematic error is from B. Winstein via private communtication.

[4] These two experiments have a common systematic error due to the uncertainty in the momentum scale, as pointed out in WAHL 89.

[5] ADLER 96C is the result of a fit which includes nearly the same data as entered into the "OUR FIT" value above.

[6] GIBBONS 93 value assume $\phi_{+-} = \phi_{00} = \phi_{SW} = (43.7 \pm 0.2)^\circ$.

[7] ARONSON 82 find that Δm may depend on the kaon energy.

[8] ARONSON 70 and CARNEGIE 71 use K^0_S mean life $= (0.862 \pm 0.006) \times 10^{-10}$ s. We have not attempted to adjust these values for the subsequent change in the K^0_S mean life or in η_{+-}.

K^0_L MEAN LIFE

VALUE (10^{-8} s)	*EVTS*	*DOCUMENT ID*		*TECN*
5.17 ±0.04 OUR FIT	Error includes scale factor of 1.1.			
5.15 ±0.04 OUR AVERAGE				
5.154±0.044	0.4M	VOSBURGH	72	CNTR
5.15 ±0.14		DEVLIN	67	CNTR
• • • We do not use the following data for averages, fits, limits, etc. • • •				
5.0 ±0.5		[9] LOWYS	67	HLBC
6.1 $^{+1.5}_{-1.2}$	1700	ASTBURY	65C	CNTR
5.3 ±0.6		FUJII	64	OSPK
5.1 $^{+2.4}_{-1.3}$	15	DARMON	62	FBC
8.1 $^{+3.2}_{-2.4}$	34	BARDON	58	CNTR

[9] Sum of partial decay rates.

K^0_L DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Semileptonic modes			
Γ_1	$\pi^{\pm} e^{\mp} \nu_e$ Called K^0_{e3}.	[a]	(38.79 ±0.27) %	S=1.1
Γ_2	$\pi^- e^+ \nu_e$			
Γ_3	$\pi^+ e^- \overline{\nu}_e$			
Γ_4	$\pi^{\pm} \mu^{\mp} \nu_{\mu}$ Called $K^0_{\mu 3}$.	[a]	(27.18 ±0.25) %	S=1.1
Γ_5	$\pi^- \mu^+ \nu_{\mu}$			
Γ_6	$\pi^+ \mu^- \overline{\nu}_{\mu}$			
Γ_7	$(\pi \mu \text{atom})\nu$		(1.06 ±0.11) $\times 10^{-7}$	
Γ_8	$\pi^0 \pi^{\pm} e^{\mp} \nu$	[a]	(5.18 ±0.29) $\times 10^{-5}$	
	Hadronic modes, including Charge conjugation×Parity Violating (*CPV*) modes			
Γ_9	$3\pi^0$		(21.08 ±0.27) %	S=1.1
Γ_{10}	$\pi^+ \pi^- \pi^0$		(12.58 ±0.19) %	S=1.7
Γ_{11}	$\pi^+ \pi^-$	*CPV*	(2.084±0.032) $\times 10^{-3}$	S=1.1
Γ_{12}	$\pi^0 \pi^0$	*CPV*	(9.42 ±0.19) $\times 10^{-4}$	S=1.1
	Semileptonic modes with photons			
Γ_{13}	$\pi^{\pm} e^{\mp} \nu_e \gamma$	[a,b,c]	(3.53 ±0.06) $\times 10^{-3}$	
Γ_{14}	$\pi^{\pm} \mu^{\mp} \nu_{\mu} \gamma$		(5.7 $^{+0.6}_{-0.7}$) $\times 10^{-4}$	

Hadronic modes with photons or $\ell\overline{\ell}$ pairs

Γ_{15}	$\pi^0\pi^0\gamma$			$<$ 5.6	$\times 10^{-6}$	
Γ_{16}	$\pi^+\pi^-\gamma$		[*b,c*]	(4.38 $\pm$0.13)	$\times 10^{-5}$	S=1.8
Γ_{17}	$\pi^0 2\gamma$		[*c*]	(1.68 $\pm$0.10)	$\times 10^{-6}$	
Γ_{18}	$\pi^0\gamma e^+e^-$			(2.3 $\pm$0.4)	$\times 10^{-8}$	

Other modes with photons or $\ell\overline{\ell}$ pairs

Γ_{19}	2γ			(5.96 $\pm$0.15)	$\times 10^{-4}$	
Γ_{20}	3γ			$<$ 2.4	$\times 10^{-7}$	CL=90%
Γ_{21}	$e^+e^-\gamma$			(10.0 $\pm$0.5)	$\times 10^{-6}$	S=1.5
Γ_{22}	$\mu^+\mu^-\gamma$			(3.59 $\pm$0.11)	$\times 10^{-7}$	S=1.3
Γ_{23}	$e^+e^-\gamma\gamma$		[*c*]	(5.95 $\pm$0.33)	$\times 10^{-7}$	
Γ_{24}	$\mu^+\mu^-\gamma\gamma$		[*c*]	(1.0 $^{+0.8}_{-0.6}$)	$\times 10^{-8}$	

Charge conjugation × Parity (*CP*) or Lepton Family number (*LF*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes

Γ_{25}	$\mu^+\mu^-$	*S1*		(7.25 $\pm$0.16)	$\times 10^{-9}$	
Γ_{26}	e^+e^-	*S1*		(9 $^{+6}_{-4}$)	$\times 10^{-12}$	
Γ_{27}	$\pi^+\pi^-e^+e^-$	*S1*	[*c*]	(3.5 $\pm$0.6)	$\times 10^{-7}$	
Γ_{28}	$\mu^+\mu^-e^+e^-$	*S1*		(2.6 $\pm$0.4)	$\times 10^{-9}$	
Γ_{29}	$e^+e^-e^+e^-$	*S1*		(3.75 $\pm$0.27)	$\times 10^{-8}$	
Γ_{30}	$\pi^0\mu^+\mu^-$	*CP,S1*	[*d*]	$<$ 3.8	$\times 10^{-10}$	CL=90%
Γ_{31}	$\pi^0e^+e^-$	*CP,S1*	[*d*]	$<$ 5.1	$\times 10^{-10}$	CL=90%
Γ_{32}	$\pi^0\nu\overline{\nu}$	*CP,S1*	[*e*]	$<$ 5.9	$\times 10^{-7}$	CL=90%
Γ_{33}	$e^\pm\mu^\mp$	*LF*	[*a*]	$<$ 4.7	$\times 10^{-12}$	CL=90%
Γ_{34}	$e^\pm e^\pm\mu^\mp\mu^\mp$	*LF*	[*a*]	$<$ 1.23	$\times 10^{-10}$	CL=90%
Γ_{35}	$\pi^0\mu^\pm e^\mp$	*LF*	[*a*]	$<$ 6.2	$\times 10^{-9}$	CL=90%

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

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

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

[*d*] Allowed by higher-order electroweak interactions.

[*e*] Violates *CP* in leading order. Test of direct *CP* violation since the indirect *CP*-violating and *CP*-conserving contributions are expected to be suppressed.

CONSTRAINED FIT INFORMATION

An overall fit to the mean life, 3 decay rate, and 14 branching ratios uses 48 measurements and one constraint to determine 9 parameters. The overall fit has a χ^2 = 43.6 for 40 degrees of freedom.

The following *off-diagonal* array elements are the correlation coefficients $\left\langle\delta p_i \delta p_j\right\rangle/(\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i, including 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_4	−36							
x_9	−49	−37						
x_{10}	−28	−28	−19					
x_{11}	−7	−8	−12	33				
x_{12}	−6	−6	−9	25	77			
x_{16}	−3	−4	−5	15	45	35		
x_{19}	−5	−5	−7	21	63	82	28	
Γ	0	0	0	0	0	0	0	0
	x_1	x_4	x_9	x_{10}	x_{11}	x_{12}	x_{16}	x_{19}

	Mode		Rate (10^8 s^{-1})	Scale factor
Γ_1	$\pi^{\pm} e^{\mp} \nu_e$ Called K^0_{e3}.	[a]	0.0750±0.0008	1.1
Γ_4	$\pi^{\pm} \mu^{\mp} \nu_\mu$ Called $K^0_{\mu 3}$.	[a]	0.0525±0.0007	1.1
Γ_9	$3\pi^0$		0.0407±0.0006	
Γ_{10}	$\pi^+ \pi^- \pi^0$		0.0243±0.0004	1.5
Γ_{11}	$\pi^+ \pi^-$		(4.03 ±0.07) × 10^{-4}	1.1
Γ_{12}	$\pi^0 \pi^0$		(1.82 ±0.04) × 10^{-4}	1.1
Γ_{16}	$\pi^+ \pi^- \gamma$	[b,c]	(8.46 ±0.26) × 10^{-6}	1.7
Γ_{19}	2γ		(1.151 ±0.030) × 10^{-4}	1.1

K^0_L DECAY RATES

$\Gamma(\pi^+ \pi^- \pi^0)$ — Γ_{10}

VALUE (10^6 s^{-1})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.43±0.04 OUR FIT Error includes scale factor of 1.5.					
2.38±0.09 OUR AVERAGE					
$2.32^{+0.13}_{-0.15}$	192	BALDO-...	75	HLBC	Assumes *CP*
2.35±0.20	180	[10] JAMES	72	HBC	Assumes *CP*
2.71±0.28	99	CHO	71	DBC	Assumes *CP*

2.12 ± 0.33	50	MEISNER	71	HBC	Assumes *CP*
2.20 ± 0.35	53	WEBBER	70	HBC	Assumes *CP*
$2.62^{+0.28}_{-0.27}$	136	BEHR	66	HLBC	Assumes *CP*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.5 ± 0.3	98	[10] JAMES	71	HBC	Assumes *CP*
3.26 ± 0.77	18	ANDERSON	65	HBC	
1.4 ± 0.4	14	FRANZINI	65	HBC	

[10] JAMES 72 is a final measurement and includes JAMES 71.

$\Gamma(\pi^{\pm} e^{\mp} \nu_e)$ — Γ_1

VALUE (10^6 s^{-1})	EVTS	DOCUMENT ID		TECN	COMMENT
7.50 ± 0.08 OUR FIT Error includes scale factor of 1.1.					
7.7 ± 0.5 OUR AVERAGE					
7.81 ± 0.56	620	CHAN	71	HBC	
$7.52^{+0.85}_{-0.72}$		AUBERT	65	HLBC	$\Delta S = \Delta Q$, *CP* assumed

$\Gamma(\pi^{\pm} e^{\mp} \nu_e) + \Gamma(\pi^{\pm} \mu^{\mp} \nu_\mu)$ — $(\Gamma_1+\Gamma_4)$

VALUE (10^6 s^{-1})	EVTS	DOCUMENT ID		TECN	COMMENT
12.75 ± 0.12 OUR FIT Error includes scale factor of 1.1.					
11.9 ± 0.6 OUR AVERAGE Error includes scale factor of 1.2.					
12.4 ± 0.7	410	[11] BURGUN	72	HBC	$K^+ p \to K^0 p \pi^+$
13.1 ± 1.3	252	[11] WEBBER	71	HBC	$K^- p \to n \overline{K}^0$
11.6 ± 0.9	393	[11,12] CHO	70	DBC	$K^+ n \to K^0 p$
$9.85^{+1.15}_{-1.05}$	109	[11] FRANZINI	65	HBC	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
8.47 ± 1.69	126	[11] MANN	72	HBC	$K^- p \to n \overline{K}^0$
10.3 ± 0.8	335	[12] HILL	67	DBC	$K^+ n \to K^0 p$

[11] Assumes $\Delta S = \Delta Q$ rule.
[12] CHO 70 includes events of HILL 67.

K^0_L BRANCHING RATIOS

Semileptonic modes

$[\Gamma(\pi^{\pm} e^{\mp} \nu_e) + \Gamma(\pi^{\pm} \mu^{\mp} \nu_\mu)]/\Gamma_{total}$ — $(\Gamma_1+\Gamma_4)/\Gamma$

VALUE	DOCUMENT ID
0.6597 ± 0.0030 OUR FIT Error includes scale factor of 1.2.	

$\Gamma(\pi^{\pm} \mu^{\mp} \nu_\mu)/\Gamma(\pi^{\pm} e^{\mp} \nu_e)$ — Γ_4/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN
0.701 ± 0.009 OUR FIT				
$0.697^{+0.010}_{-0.009}$ OUR AVERAGE				
0.702 ± 0.011	33k	CHO	80	HBC
0.662 ± 0.037	10k	WILLIAMS	74	ASPK
0.741 ± 0.044	6700	BRANDENB...	73	HBC
0.662 ± 0.030	1309	EVANS	73	HLBC
0.71 ± 0.05	770	BUDAGOV	68	HLBC
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.68 ± 0.08	3548	BASILE	70	OSPK

$\Gamma((\pi\mu\text{atom})\nu)/\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu})$ — Γ_7/Γ_4

VALUE (units 10^{-7})	EVTS	DOCUMENT ID		TECN
3.90±0.39	155	[13] ARONSON	86	SPEC
• • • We do not use the following data for averages, fits, limits, etc. • • •				
seen	18	COOMBES	76	WIRE

[13] ARONSON 86 quote theoretical value of $(4.31 \pm 0.08) \times 10^{-7}$.

$\Gamma(\pi^0\pi^{\pm}e^{\mp}\nu)/\Gamma_{\text{total}}$ — Γ_8/Γ

VALUE (units 10^{-5})	CL%	EVTS	DOCUMENT ID		TECN
5.18±0.29 OUR AVERAGE					
5.16±0.20±0.22		729	MAKOFF	93	E731
6.2 ±2.0		16	CARROLL	80C	SPEC
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<220	90		[14] DONALDSON	74	SPEC

[14] DONALDSON 74 uses $K^0_L \rightarrow \pi^+\pi^-\pi^0/(\text{all } K^0_L)$ decays = 0.126.

Hadronic modes, including Charge conjugation×Parity Violating (*CPV*) modes

$\Gamma(3\pi^0)/\Gamma_{\text{total}}$ — Γ_9/Γ

VALUE	EVTS	DOCUMENT ID		TECN
0.2108±0.0027 OUR FIT Error includes scale factor of 1.1.				
0.2105±0.0028	38k	[15] KREUTZ	95	NA31

[15] KREUTZ 95 measure $3\pi^0$, $\pi^+\pi^-\pi^0$, and $\pi e \nu_e$ modes. They assume PDG 1992 values for $\pi\mu\nu_{\mu}$, 2π, and 2γ modes.

$\Gamma(3\pi^0)/\Gamma(\pi^{\pm}e^{\mp}\nu_e)$ — Γ_9/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN
0.543±0.009 OUR FIT Error includes scale factor of 1.1.				
0.545±0.004±0.009	38k	[16] KREUTZ	95	NA31

[16] KREUTZ 95 measurement excluded from fit because it is not independent of their $\Gamma(3\pi^0)/\Gamma_{\text{total}}$ measurement, which is in the fit.

$\Gamma(3\pi^0)/[\Gamma(\pi^{\pm}e^{\mp}\nu_e)+\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu})+\Gamma(\pi^+\pi^-\pi^0)]$ — $\Gamma_9/(\Gamma_1+\Gamma_4+\Gamma_{10})$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.268±0.004 OUR FIT Error includes scale factor of 1.1.					
0.260±0.011 OUR AVERAGE					
0.251±0.014	549	BUDAGOV	68	HLBC	ORSAY measur.
0.277±0.021	444	BUDAGOV	68	HLBC	Ecole polytec.meas
$0.31\ ^{+0.07}_{-0.06}$	29	KULYUKINA	68	CC	
0.24 ±0.08	24	ANIKINA	64	CC	

$\Gamma(3\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_9/Γ_{10}

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
1.68 ±0.04 OUR FIT Error includes scale factor of 1.3.				
1.63 ±0.05 OUR AVERAGE Error includes scale factor of 1.4.				
1.611±0.014±0.034	38k	[17] KREUTZ 95	NA31	
1.80 ±0.13	1010	BUDAGOV 68	HLBC	
2.0 ±0.6	188	ALEKSANYAN 64B	FBC	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.65 ±0.07	883	BARMIN 72B	HLBC	Error statistical only

[17] KREUTZ 95 excluded from fit because it is not independent of their $\Gamma(3\pi^0)/\Gamma_{total}$ measurement, which is in the fit.

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

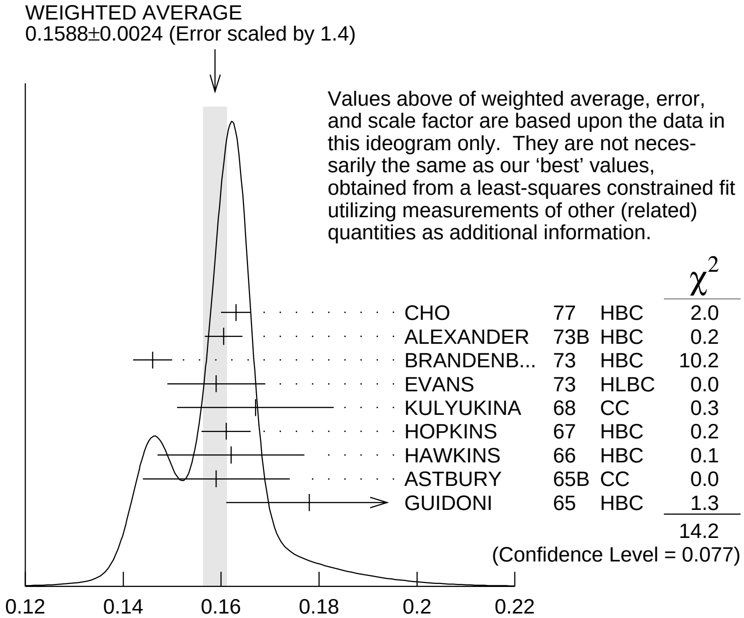
VALUE	DOCUMENT ID
0.1258±0.0019 OUR FIT Error includes scale factor of 1.7.	

$\Gamma(\pi^+\pi^-\pi^0)/\Gamma(\pi^\pm e^\mp \nu_e)$ — Γ_{10}/Γ_1

VALUE	EVTS	DOCUMENT ID	TECN
0.324±0.006 OUR FIT Error includes scale factor of 1.6.			
0.336±0.003±0.007	28k	KREUTZ 95	NA31

$\Gamma(\pi^+\pi^-\pi^0)/[\Gamma(\pi^\pm e^\mp \nu_e)+\Gamma(\pi^\pm \mu^\mp \nu_\mu)+\Gamma(\pi^+\pi^-\pi^0)]$ — $\Gamma_{10}/(\Gamma_1+\Gamma_4+\Gamma_{10})$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.1601±0.0024 OUR FIT Error includes scale factor of 1.7.				
0.1588±0.0024 OUR AVERAGE Error includes scale factor of 1.4. See the ideogram below.				
0.163 ±0.003	6499	CHO 77	HBC	
0.1605±0.0038	1590	ALEXANDER 73B	HBC	
0.146 ±0.004	3200	BRANDENB... 73	HBC	
0.159 ±0.010	558	EVANS 73	HLBC	
0.167 ±0.016	1402	KULYUKINA 68	CC	
0.161 ±0.005		HOPKINS 67	HBC	
0.162 ±0.015	126	HAWKINS 66	HBC	
0.159 ±0.015	326	ASTBURY 65B	CC	
0.178 ±0.017	566	GUIDONI 65	HBC	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.144 ±0.004	1729	HOPKINS 65	HBC	See HOPKINS 67



$\Gamma(\pi^+\pi^-\pi^0)/[\Gamma(\pi^\pm e^\mp \nu_e) + \Gamma(\pi^\pm \mu^\mp \nu_\mu) + \Gamma(\pi^+\pi^-\pi^0)]$

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

Violates *CP* conservation.

VALUE (units 10^{-3})	*DOCUMENT ID*	
2.084±0.032 OUR FIT	Error includes scale factor of 1.1.	
2.075±0.049	[18] ETAFIT	02

[18] This ETAFIT value is computed from fitted values of $|\eta_{+-}|$, the K^0_L and K^0_S lifetimes, and the $K^0_S \to \pi^+\pi^-$ branching fraction. See the discussion in the note "Fits for K^0_L *CP*-Violation Parameters."

$\Gamma(\pi^+\pi^-)/[\Gamma(\pi^\pm e^\mp \nu_e) + \Gamma(\pi^\pm \mu^\mp \nu_\mu)]$ — $\Gamma_{11}/(\Gamma_1+\Gamma_4)$

Violates *CP* conservation.

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
3.16±0.05 OUR FIT	Error includes scale factor of 1.2.				
3.08±0.10 OUR AVERAGE					
3.13±0.14	1687	COUPAL	85	SPEC	η_{+-}=2.28 ± 0.06
3.04±0.14	2703	DEVOE	77	SPEC	η_{+-}=2.25 ± 0.05
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.51±0.23	309	[19] DEBOUARD	67	OSPK	η_{+-}=2.00 ± 0.09
2.35±0.19	525	[19] FITCH	67	OSPK	η_{+-}=1.94 ± 0.08

[19] Old experiments excluded from fit. See subsection on η_{+-} in section on "PARAMETERS FOR $K^0_L \to 2\pi$ DECAY" below for average η_{+-} of these experiments and for note on discrepancy.

$\Gamma(\pi^+\pi^-)/[\Gamma(\pi^\pm e^\mp \nu_e)+\Gamma(\pi^\pm \mu^\mp \nu_\mu)+\Gamma(\pi^+\pi^-\pi^0)]$ $\Gamma_{11}/(\Gamma_1+\Gamma_4+\Gamma_{10})$

Violates *CP* conservation.

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.65±0.04 OUR FIT	Error includes scale factor of 1.1.				
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.60±0.07	4200	[20] MESSNER	73	ASPK	$\eta_{+-} = 2.23 \pm 0.05$

[20] From same data as $\Gamma(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ MESSNER 73, but with different normalization.

$\Gamma(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ Γ_{11}/Γ_{10}

Violates *CP* conservation.

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1.657±0.030 OUR FIT	Error includes scale factor of 1.2.				
1.64 ±0.04	4200	MESSNER	73	ASPK	$\eta_{+-} = 2.23$

$\Gamma(\pi^0\pi^0)/\Gamma_{total}$ Γ_{12}/Γ

Violates *CP* conservation.

VALUE (units 10^{-3})	*DOCUMENT ID*
0.942±0.019 OUR FIT Error includes scale factor of 1.1.	

$\Gamma(\pi^0\pi^0)/\Gamma(\pi^+\pi^-)$ Γ_{12}/Γ_{11}

Violates *CP* conservation.

VALUE	*DOCUMENT ID*	
0.452 ±0.006 OUR FIT		
0.4528±0.0058	[21] ETAFIT	02

[21] This ETAFIT value is computed from fitted values of $|\eta_{00} / \eta_{+-}|$ and the $\Gamma(K^0_S \to \pi^+\pi^-) / \Gamma(K^0_S \to \pi^0\pi^0)$ branching fraction. See the discussion in the note "Fits for K^0_L *CP*-Violation Parameters."

$\Gamma(\pi^0\pi^0)/\Gamma(3\pi^0)$ Γ_{12}/Γ_9

Violates *CP* conservation.

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.447±0.011 OUR FIT	Error includes scale factor of 1.1.				
0.39 ±0.06 OUR AVERAGE					
0.37 ±0.08	29	BARMIN	70	HLBC	η_{00}=2.02 ± 0.23
0.32 ±0.15	30	BUDAGOV	70	HLBC	η_{00}=1.9 ± 0.5
0.46 ±0.11	57	BANNER	69	OSPK	η_{00}=2.2 ± 0.3

Semileptonic modes with photons

$\Gamma(\pi^\pm e^\mp \nu_e \gamma)/\Gamma(\pi^\pm e^\mp \nu_e)$ Γ_{13}/Γ_1

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.910±0.014 OUR AVERAGE					
$0.908\pm0.008^{+0.013}_{-0.012}$	15k	ALAVI-HARATI	01J	KTEV	$E^*_\gamma \geq$ 30 MeV, $\theta^*_{e\gamma} \geq 20°$
$0.934\pm0.036^{+0.055}_{-0.039}$	1384	LEBER	96	NA31	$E^*_\gamma \geq$ 30 MeV, $\theta^*_{e\gamma} \geq 20°$

$\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu}\gamma)/\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu})$ — Γ_{14}/Γ_4

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
$2.08\pm0.17^{+0.16}_{-0.21}$	4261	BENDER	98	NA48	$E^*_{\gamma} \geq 30$ MeV

Hadronic modes with photons or $\ell\overline{\ell}$ pairs

$\Gamma(\pi^0\pi^0\gamma)/\Gamma_{total}$ — Γ_{15}/Γ

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN
< 5.6			BARR	94	NA31
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<230	90	0	ROBERTS	94	E799

$\Gamma(\pi^+\pi^-\gamma)/\Gamma_{total}$ — Γ_{16}/Γ

For earlier limits see our 1992 edition Physical Review **D45,** 1 June, Part II (1992).

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	COMMENT
4.38±0.13 OUR FIT	Error includes scale factor of 1.8.				
4.61±0.14 OUR AVERAGE					
4.66±0.15	3136	[22] RAMBERG	93	E731	E_{γ} >20 MeV
4.41±0.32	1062	[23] CARROLL	80B	SPEC	E_{γ} >20 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1.52±0.16	516	[24] CARROLL	80B	SPEC	E_{γ} >20 MeV
2.89±0.28	546	[25] CARROLL	80B	SPEC	

[22] RAMBERG 93 finds that fraction of Direct Emission (DE) decays with E_{γ} >20 MeV is 0.685 ± 0.041.
[23] Both components. Uses $K^0_L \to \pi^+\pi^-\pi^0$/(all K^0_L) decays = 0.1239.
[24] Internal Bremsstrahlung component only.
[25] Direct γ emission component only.

$\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-)$ — Γ_{16}/Γ_{11}

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
2.10 ±0.06 OUR FIT	Error includes scale factor of 2.1.				
2.08 ±0.02 ±0.02	8669	[26] ALAVI-HARATI	01B	KTEV	E^*_{γ} >20 MeV

[26] ALAVI-HARATI 01B includes both Direct Emission (DE) and Inner Bremstrahlung (IB) processes. THey also report DE/(DE+IB)= 0.683 ± 0.011. The paper reports results for ρ propagator, linear, and quadratic form factors.

$\Gamma(\pi^0 2\gamma)/\Gamma_{total}$ — Γ_{17}/Γ

VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
1.68±0.10 OUR AVERAGE						
1.68±0.07±0.08		884	ALAVI-HARATI	99B	KTEV	
1.7 ±0.2 ±0.2		63	[27] BARR	92	SPEC	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.86±0.60±0.60		60	PAPADIMITR...	91	E731	$m_{\gamma\gamma}$ > 280 MeV
<5.1	90		PAPADIMITR...	91	E731	$m_{\gamma\gamma}$ < 264 MeV
2.1 ±0.6		14	[28] BARR	90C	NA31	$m_{\gamma\gamma}$ > 280 MeV

[27] BARR 92 find that $\Gamma(\pi^0 2\gamma$, $m_{\gamma\gamma}$ <240 MeV)/$\Gamma(\pi^0 2\gamma)$< 0.09 (90% CL).
[28] BARR 90C superseded by BARR 92.

$\Gamma(\pi^0 \gamma e^+ e^-)/\Gamma_{total}$ — Γ_{18}/Γ

VALUE (units 10^{-8})	CL%	EVTS	DOCUMENT ID		TECN
2.34±0.35±0.13		44	ALAVI-HARATI	01E	KTEV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<71	90	0	MURAKAMI	99	SPEC

Other modes with photons or $\ell\overline{\ell}$ pairs

$\Gamma(2\gamma)/\Gamma_{total}$ — Γ_{19}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
5.96±0.15 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
4.54±0.84		[29] BANNER	72B	OSPK	
4.5 ±1.0	23	ENSTROM	71	OSPK	K^0_L 1.5–9 GeV/c
5.0 ±1.0		[30] REPELLIN	71	OSPK	
5.5 ±1.1	90	KUNZ	68	OSPK	Norm.to 3 π(C+N)

[29] This value uses $(\eta_{00}/\eta_{+-})^2 = 1.05 \pm 0.14$. In general, $\Gamma(2\gamma)/\Gamma_{total} = [(4.32 \pm 0.55) \times 10^{-4}][(\eta_{00}/\eta_{+-})^2]$.

[30] Assumes regeneration amplitude in copper at 2 GeV is 22 mb. To evaluate for a given regeneration amplitude and error, multiply by (regeneration amplitude/22mb)^2.

$\Gamma(2\gamma)/\Gamma(3\pi^0)$ — Γ_{19}/Γ_9

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.82±0.08 OUR FIT Error includes scale factor of 1.1.					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.13±0.43	28	BARMIN	71	HLBC	
2.24±0.28	115	BANNER	69	OSPK	
2.5 ±0.7	16	ARNOLD	68B	HLBC	Vacuum decay

$\Gamma(2\gamma)/\Gamma(\pi^0\pi^0)$ — Γ_{19}/Γ_{12}

VALUE	EVTS	DOCUMENT ID		TECN
0.632±0.009 OUR FIT				
0.632±0.004±0.008	110k	BURKHARDT	87	NA31

$\Gamma(3\gamma)/\Gamma_{total}$ — Γ_{20}/Γ

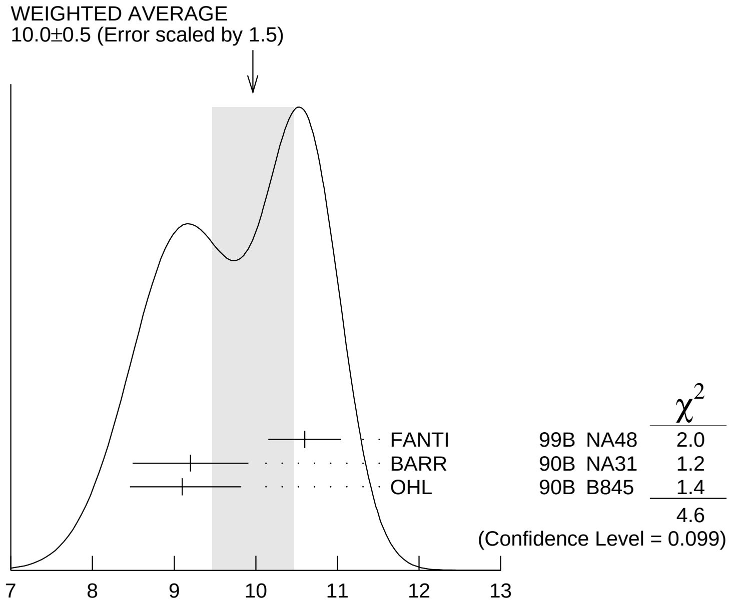
VALUE	CL%	DOCUMENT ID		TECN
$<2.4 \times 10^{-7}$	90	[31] BARR	95C	NA31

[31] Assumes a phase-space decay distribution.

$\Gamma(e^+ e^- \gamma)/\Gamma_{total}$ — Γ_{21}/Γ

VALUE (units 10^{-6})	EVTS	DOCUMENT ID		TECN
10.0±0.5 OUR AVERAGE Error includes scale factor of 1.5. See the ideogram below.				
10.6±0.2±0.4	6864	[32] FANTI	99B	NA48
9.2±0.5±0.5	1053	BARR	90B	NA31
$9.1 \pm 0.4^{+0.6}_{-0.5}$	919	OHL	90B	B845

[32] For FANTI 99B, the ± 0.4 systematic error includes for uncertainties in the calculation, primarily uncertainties in the $\pi^0 \to e^+ e^- \gamma$ and $K_L^0 \to \pi^0 \pi^0$ branching ratios, evaluated using our 1999 Web edition values.



$\Gamma\left(e^+ e^- \gamma\right)/\Gamma_{\text{total}}$ (units 10^{-6})

$\Gamma(\mu^+ \mu^- \gamma)/\Gamma_{\text{total}}$ — Γ_{22}/Γ

VALUE (units 10^{-7})	*EVTS*	*DOCUMENT ID*		*TECN*
3.59±0.11 OUR AVERAGE	Error includes scale factor of 1.3.			
3.62±0.04±0.08	9100	ALAVI-HARATI	01G	KTEV
3.4 ±0.6 ±0.4	45	FANTI	97	NA48
3.23±0.23±0.19	197	SPENCER	95	E799

$\Gamma(e^+ e^- \gamma\gamma)/\Gamma_{\text{total}}$ — Γ_{23}/Γ

VALUE (units 10^{-7})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
5.95±0.33 OUR AVERAGE					
5.84±0.15±0.32	1543	ALAVI-HARATI	01F	KTEV	$E^*_\gamma > 5$ MeV
8.0 ±1.5 $^{+1.4}_{-1.2}$	40	SETZU	98	NA31	$E_\gamma > 5$ MeV
6.5 ±1.2 ±0.6	58	NAKAYA	94	E799	$E_\gamma > 5$ MeV
6.6 ±3.2		MORSE	92	B845	$E_\gamma > 5$ MeV

$\Gamma(\mu^+ \mu^- \gamma\gamma)/\Gamma_{\text{total}}$ — Γ_{24}/Γ

VALUE (units 10^{-9})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$10.4^{+7.5}_{-5.9}\pm0.7$	4	ALAVI-HARATI	00E	KTEV	$m_{\gamma\gamma} \geq 1$ MeV/c^2

Charge conjugation × Parity (CP) or Lepton Family number (LF) violating modes, or $\Delta S = 1$ weak neutral current ($S1$) modes

$\Gamma(\mu^+\mu^-)/\Gamma(\pi^+\pi^-)$ — Γ_{25}/Γ_{11}

Test for $\Delta S = 1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10^{-6})	EVTS	DOCUMENT ID		TECN	COMMENT
3.48 ±0.05 OUR AVERAGE					
3.474±0.057	6210	AMBROSE	00	B871	
3.87 ±0.30	179	[33] AKAGI	95	SPEC	
3.38 ±0.17	707	HEINSON	95	B791	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3.9 ±0.3 ±0.1	178	[34] AKAGI	91B	SPEC	In AKAGI 95
3.45 ±0.18 ±0.13	368	[35] HEINSON	91	SPEC	In HEINSON 95
4.1 ±0.5	54	INAGAKI	89	SPEC	In AKAGI 91B
2.8 ±0.3 ±0.2	87	MATHIAZHA...	89B	SPEC	In HEINSON 91

[33] AKAGI 95 gives this number multiplied by the PDG 1992 average for $\Gamma(K^0_L \to \pi^+\pi^-)/\Gamma(\text{total})$.

[34] AKAGI 91B give this number multiplied by the 1990 PDG average for $\Gamma(K^0_L \to \pi^+\pi^-)/\Gamma(\text{total})$.

[35] HEINSON 91 give $\Gamma(K^0_L \to \mu\mu)/\Gamma_{\text{total}}$. We divide out the $\Gamma(K^0_L \to \pi^+\pi^-)/\Gamma_{\text{total}}$ PDG average which they used.

$\Gamma(e^+e^-)/\Gamma_{\text{total}}$ — Γ_{26}/Γ

Test for $\Delta S = 1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10^{-10})	CL%	EVTS	DOCUMENT ID		TECN
$0.087^{+0.057}_{-0.041}$		4	AMBROSE	98	B871
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.6	90	1	AKAGI	95	SPEC
<0.41	90	0	[36] ARISAKA	93B	B791

[36] ARISAKA 93B includes all events with <6 MeV radiated energy.

$\Gamma(\pi^+\pi^-e^+e^-)/\Gamma_{\text{total}}$ — Γ_{27}/Γ

Test for $\Delta S = 1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10^{-7})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
3.5±0.6 OUR AVERAGE						
3.2±0.6±0.4		37	ADAMS	98	KTEV	
4.4±1.3±0.5		13	TAKEUCHI	98	SPEC	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<4.6	90		NOMURA	97	SPEC	$m_{ee} > 4$ MeV

$\Gamma(\mu^+\mu^-e^+e^-)/\Gamma_{\text{total}}$ — Γ_{28}/Γ

Test for $\Delta S = 1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10^{-9})	CL%	EVTS	DOCUMENT ID		TECN
2.6 ±0.4 OUR AVERAGE					
2.62±0.40±0.17		43	ALAVI-HARATI	01H	KTEV
$2.9\ ^{+6.7}_{-2.4}$		1	GU	96	E799
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<4900	90		BALATS	83	SPEC

$\Gamma(e^+e^-e^+e^-)/\Gamma_{total}$ — Γ_{29}/Γ

Test for $\Delta S = 1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10^{-8})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
3.75±0.27 OUR AVERAGE					
3.72±0.18±0.23	441	ALAVI-HARATI	01D	KTEV	
6 ±2 ±1	18	[37] AKAGI	95	SPEC	$m_{ee} > 470$ MeV
3.96±0.78±0.32	27	GU	94	E799	
3.07±1.25±0.26	6	VAGINS	93	B845	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
7 ±3 ±2	6	[37] AKAGI	95	SPEC	$m_{ee} > 470$ MeV
10.4 ±3.7 ±1.1	8	[38] BARR	95	NA31	
6 ±2 ±1	18	AKAGI	93	CNTR	Sup. by AKAGI 95
4 ±3	2	BARR	91	NA31	Sup. by BARR 95

[37] Values are for the total branching fraction, acceptance-corrected for the m_{ee} cuts shown.
[38] Distribution of angles between two e^+e^- pair planes favors $CP = -1$ for K^0_L.

$\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{total}$ — Γ_{30}/Γ

Violates *CP* in leading order. Test for $\Delta S = 1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10^{-9})	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*
<0.38	90		ALAVI-HARATI	00D	KTEV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<5.1	90	0	HARRIS	93	E799

$\Gamma(\pi^0e^+e^-)/\Gamma_{total}$ — Γ_{31}/Γ

Violates *CP* in leading order. Direct and indirect *CP*-violating contributions are expected to be comparable and to dominate the *CP*-conserving part. Test for $\Delta S = 1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10^{-9})	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*
< 0.51	90	2	ALAVI-HARATI	01	KTEV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 4.3	90	0	HARRIS	93B	E799
< 7.5	90	0	BARKER	90	E731
< 5.5	90	0	OHL	90	B845
< 40	90		BARR	88	NA31
<320	90		JASTRZEM...	88	SPEC

$\Gamma(\pi^0\nu\overline{\nu})/\Gamma_{total}$ — Γ_{32}/Γ

Violates *CP* in leading order. Test of direct *CP* violation since the indirect *CP*-violating and *CP*-conserving contributions are expected to be suppressed. Test of $\Delta S = 1$ weak neutral current.

VALUE (units 10^{-5})	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*
< 0.059	90	0	ALAVI-HARATI	00	KTEV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 0.16	90	0	ADAMS	99	KTEV
< 5.8	90	0	WEAVER	94	E799
<22	90	0	GRAHAM	92	CNTR

$\Gamma(e^{\pm}\mu^{\mp})/\Gamma_{total}$ — Γ_{33}/Γ

Test of lepton family number conservation.

VALUE (units 10^{-11})	CL%	EVTS	DOCUMENT ID		TECN
<0.47	90		AMBROSE	98B	B871
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<9.4	90	0	AKAGI	95	SPEC
<3.9	90	0	ARISAKA	93	B791
<3.3	90	0	[39] ARISAKA	93	B791

[39] This is the combined result of ARISAKA 93 and MATHIAZHAGAN 89.

$\Gamma(e^{\pm}e^{\pm}\mu^{\mp}\mu^{\mp})/\Gamma_{total}$ — Γ_{34}/Γ

Test of lepton family number conservation.

VALUE (units 10^{-10})	CL%	EVTS	DOCUMENT ID		TECN
< 1.23	90	64	[40] ALAVI-HARATI	01H	KTEV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<61	90	0	[40] GU	96	E799

[40] Assuming uniform phase space distribution.

$\Gamma(\pi^0\mu^{\pm}e^{\mp})/\Gamma_{total}$ — Γ_{35}/Γ

Test of lepton family number conservation.

VALUE	CL%	DOCUMENT ID		TECN
$<6.2\times10^{-9}$	90	ARISAKA	98	E799

ENERGY DEPENDENCE OF K^0_L DALITZ PLOT

For discussion, see note on Dalitz plot parameters in the $K^{\pm}$ section of the Particle Listings above. For definitions of a_v, a_t, a_u, and a_y, see the earlier version of the same note in the 1982 edition of this *Review* published in Physics Letters **111B** 70 (1982).

$|\text{matrix element}|^2 = 1 + gu + hu^2 + jv + kv^2 + fuv$
where $u = (s_3 - s_0) / m^2_{\pi}$ and $v = (s_1 - s_2) / m^2_{\pi}$

LINEAR COEFFICIENT g FOR $K^0_L \rightarrow \pi^+\pi^-\pi^0$

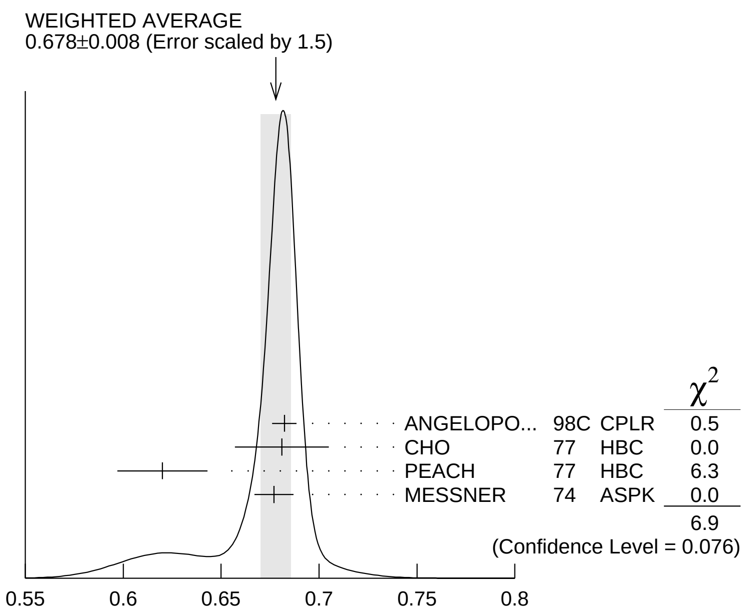
VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.678 ±0.008 OUR AVERAGE	Error includes scale factor of 1.5. See the ideogram below.				
0.6823±0.0044±0.0044	500k	ANGELOPO...	98C	CPLR	
0.681 ±0.024	6499	CHO	77	HBC	
0.620 ±0.023	4709	PEACH	77	HBC	
0.677 ±0.010	509k	MESSNER	74	ASPK	$a_y = -0.917 \pm 0.013$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.69 ±0.07	192	[41] BALDO-...	75	HLBC	
0.590 ±0.022	56k	[41] BUCHANAN	75	SPEC	$a_u = -0.277 \pm 0.010$
0.619 ±0.027	20k	[41,42] BISI	74	ASPK	$a_t = -0.282 \pm 0.011$
0.612 ±0.032		[41] ALEXANDER	73B	HBC	
0.73 ±0.04	3200	[41] BRANDENB...	73	HBC	
0.608 ±0.043	1486	[41] KRENZ	72	HLBC	$a_t = -0.277 \pm 0.018$

0.650 ±0.012	29k	[41] ALBROW	70	ASPK	$a_y = -0.858 \pm 0.015$
0.593 ±0.022	36k	[41,43] BUCHANAN	70	SPEC	$a_u = -0.278 \pm 0.010$
0.664 ±0.056	4400	[41] SMITH	70	OSPK	$a_t = -0.306 \pm 0.024$
0.400 ±0.045	2446	[41] BASILE	68B	OSPK	$a_t = -0.188 \pm 0.020$
0.649 ±0.044	1350	[41] HOPKINS	67	HBC	$a_t = -0.294 \pm 0.018$
0.428 ±0.055	1198	[41] NEFKENS	67	OSPK	$a_u = -0.204 \pm 0.025$

[41] Quadratic dependence required by some experiments. (See sections on "QUADRATIC COEFFICIENT *h*" and "QUADRATIC COEFFICIENT *k*" below.) Correlations prevent us from averaging results of fits not including *g*, *h*, and *k* terms.

[42] BISI 74 value comes from quadratic fit with quad. term consistent with zero. *g* error is thus larger than if linear fit were used.

[43] BUCHANAN 70 result revised by BUCHANAN 75 to include radiative correlations and to use more reliable K^0_L momentum spectrum of second experiment (had same beam).



Linear coeff. *g* for $K^0_L \rightarrow \pi^+\pi^-\pi^0$ matrix element squared

QUADRATIC COEFFICIENT *h* FOR $K^0_L \rightarrow \pi^+\pi^-\pi^0$

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*
0.076±0.006 OUR AVERAGE				
0.061±0.004±0.015	500k	ANGELOPO...	98C	CPLR
0.095±0.032	6499	CHO	77	HBC
0.048±0.036	4709	PEACH	77	HBC
0.079±0.007	509k	MESSNER	74	ASPK
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.011±0.018	29k	[44] ALBROW	70	ASPK
0.043±0.052	4400	[44] SMITH	70	OSPK

See notes in section "LINEAR COEFFICIENT *g* FOR $K^0_L \rightarrow \pi^+\pi^-\pi^0$ |MATRIX ELEMENT|^2" above.

[44] Quadratic coefficients h and k required by some experiments. (See section on "QUADRATIC COEFFICIENT k" below.) Correlations prevent us from averaging results of fits not including g, h, and k terms.

QUADRATIC COEFFICIENT k FOR $K_L^0 \rightarrow \pi^+\pi^-\pi^0$

VALUE	EVTS	DOCUMENT ID		TECN
0.0099±0.0015 OUR AVERAGE				
0.0104±0.0017±0.0024	500k	ANGELOPO...	98C	CPLR
0.024 ±0.010	6499	CHO	77	HBC
−0.008 ±0.012	4709	PEACH	77	HBC
0.0097±0.0018	509k	MESSNER	74	ASPK

LINEAR COEFFICIENT j FOR $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ (*CP*-VIOLATING TERM)

Listed in *CP*-violation section below.

QUADRATIC COEFFICIENT f FOR $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ (*CP*-VIOLATING TERM)

Listed in *CP*-violation section below.

QUADRATIC COEFFICIENT h FOR $K_L^0 \rightarrow \pi^0\pi^0\pi^0$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN
−5.0±1.4 OUR AVERAGE Error includes scale factor of 1.7.				
−6.1±0.9±0.5	14.7M	LAI	01B	NA48
−3.3±1.1±0.7	5M	[45] SOMALWAR	92	E731

[45] SOMALWAR 92 chose m_{π^+} as normalization to make it compatible with the Particle Data Group $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ definitions.

K^0_L FORM FACTORS

For discussion, see note on form factors in the $K^{\pm}$ section of the Particle Listings above.

In the form factor comments, the following symbols are used.

f_+ and f_- are form factors for the vector matrix element.

f_S and f_T refer to the scalar and tensor term.

$f_0 = f_+ + f_- t/(m^2_K - m^2_\pi)$.

λ_+, λ_-, and λ_0 are the linear expansion coefficients of f_+, f_-, and f_0.

λ_+ refers to the $K^0_{\mu 3}$ value except in the K^0_{e3} sections.

$d\xi(0)/d\lambda_+$ is the correlation between $\xi(0)$ and λ_+ in $K^0_{\mu 3}$.

$d\lambda_0/d\lambda_+$ is the correlation between λ_0 and λ_+ in $K^0_{\mu 3}$.

t = momentum transfer to the π in units of m^2_π.

DP = Dalitz plot analysis.

PI = π spectrum analysis.

MU = μ spectrum analysis.

POL= μ polarization analysis.

BR = $K^0_{\mu 3}/K^0_{e3}$ branching ratio analysis.

E = positron or electron spectrum analysis.

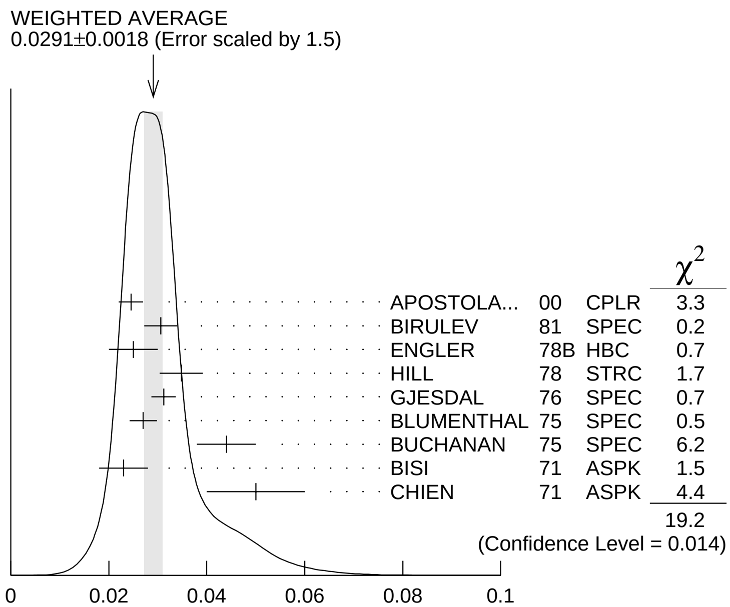
RC = radiative corrections.

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

For radiative correction of K^0_{e3} DP, see GINSBERG 67 and BECHERRAWY 70. Results labeled OUR FIT are discussed in the review "$K^{\pm}_{\ell 3}$ and $K^0_{\ell 3}$ Form Factors" in the $K^{\pm}$ Listings.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0300±0.0020 OUR FIT	Error includes scale factor of 2.0. Assumes μ-e universality.				
0.0291±0.0018 OUR AVERAGE	Error includes scale factor of 1.5. See the ideogram below.				
0.0245±0.0012±0.0022	366k	APOSTOLA...	00	CPLR	DP
0.0306±0.0034	74k	BIRULEV	81	SPEC	DP
0.025 ±0.005	12k	[46] ENGLER	78B	HBC	DP
0.0348±0.0044	18k	HILL	78	STRC	DP
0.0312±0.0025	500k	GJESDAL	76	SPEC	DP
0.0270±0.0028	25k	BLUMENTHAL	75	SPEC	DP
0.044 ±0.006	24k	BUCHANAN	75	SPEC	DP
0.023 ±0.005	42k	BISI	71	ASPK	DP
0.05 ±0.01	16k	CHIEN	71	ASPK	DP, no RC
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.029 ±0.005	19k	[46] CHO	80	HBC	DP
0.040 ±0.012	2171	WANG	74	OSPK	DP
0.045 ±0.014	5600	ALBROW	73	ASPK	DP
0.019 ±0.013	1871	BRANDENB...	73	HBC	PI transv.
0.022 ±0.014	1910	NEUHOFER	72	ASPK	PI
0.02 ±0.013	1000	ARONSON	68	OSPK	PI
+0.023 ±0.012	4800	BASILE	68	OSPK	DP, no RC

[46] ENGLER 78B uses an unique K_{e3} subset of CHO 80 events and is less subject to systematic effects.



λ_+ (Linear energy dependence of f_+, K_{e3} decay)

$\xi_A = f_-/f_+$ (determined from $K^0_{\mu3}$ spectra)

Results labeled OUR FIT are discussed in the review "$K^{\pm}_{\ell3}$ and $K^0_{\ell3}$ Form Factors" in the $K^{\pm}$ Listings. ξ_A is $\xi(0)$ determined by Method A of that review. The parameter $\xi(0)$ is redundant with λ_0 below and is not put into the Meson Summary Table.

VALUE	*dξ(0)/dλ₊*	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
−0.01±0.06 OUR FIT Error includes scale factor of 2.0. Correlation is $d\xi(0)/d\lambda_+ = -13.2$. Assumes μ-e universality.						
−0.08±0.09 OUR FIT Error includes scale factor of 2.3. Correlation is $d\xi(0)/d\lambda_+ = -13.7$.						
−0.10±0.09	−12	150k	[47] BIRULEV	81	SPEC	DP
+0.26±0.16	−13	14k	[48] CHO	80	HBC	DP
+0.13±0.23	−20	16k	[48] HILL	79	STRC	DP
−0.25±0.22	−5.9	32k	[49] BUCHANAN	75	SPEC	DP
−0.11±0.07	−17	1.6M	[50] DONALDSON	74B	SPEC	DP
• • • We do not use the following data for averages, fits, limits, etc. • • •						
−1.00±0.45	−20	1385	[51] PEACH	73	HLBC	DP
−1.5 ±0.7	−28	9086	[52] ALBROW	72	ASPK	DP
+0.50±0.61	unknown	16k	[53] DALLY	72	ASPK	DP
−3.9 ±0.4		3140	[54] BASILE	70	OSPK	DP, indep of λ_+
$-0.68^{+0.12}_{-0.20}$	−26	16k	[53] CHIEN	70	ASPK	DP
+1.2 ±0.8	−18	1341	[55] CARPENTER	66	OSPK	DP

[47] BIRULEV 81 error, $d\xi(0)/d\lambda_+$ calculated by us from λ_0, λ_+. $d\lambda_0/d\lambda_+ = 0$ used.

[48] HILL 79 and CHO 80 calculated by us from λ_0, λ_+, and $d\lambda_0/d\lambda_+$.

[49] BUCHANAN 75 is calculated by us from λ_0, λ_+ and $d\lambda_0/d\lambda_+$ because their appendix A value -0.20 ± 22 assumes $\xi(t)$ constant, i.e. $\lambda_- = \lambda_+$.

[50] DONALDSON 74B gives $\xi = -0.11 \pm 0.02$ not including systematics. Above error and $d\xi(0)/d\lambda_+$ were calculated by us from λ_0 and λ_+ errors (which include systematics) and $d\lambda_0/d\lambda_+$.

[51] PEACH 73 gives $\xi(0) = -0.95 \pm 0.45$ for $\lambda_+ = \lambda_- = 0.025$. The above value is for $\lambda_- = 0$. K.Peach, private communication (1974).

[52] ALBROW 72 fit has λ_- free, gets $\lambda_- = -0.030 \pm 0.060$ or $\Lambda = +0.15^{+0.17}_{-0.11}$.

[53] CHIEN 70 errors are statistical only. $d\xi(0)/d\lambda_+$ from figure 4. DALLY 72 is a reanalysis of CHIEN 70. The DALLY 72 result is not compatible with assumption $\lambda_- = 0$ so not included in our fit. The nonzero λ_- value and the relatively large λ_+ value found by DALLY 72 come mainly from a single low t bin (figures 1,2). The (f_+,ξ) correlation was ignored. We estimate from figure 2 that fixing $\lambda_- = 0$ would give $\xi(0) = -1.4 \pm 0.3$ and would add 10 to χ^2. $d\xi(0)/d\lambda_+$ is not given.

[54] BASILE 70 is incompatible with all other results. Authors suggest that efficiency estimates might be responsible.

[55] CARPENTER 66 $\xi(0)$ is for $\lambda_+ = 0$. $d\xi(0)/d\lambda_+$ is from figure 9.

$\xi_B = f_-/f_+$ (determined from $K^0_{\mu 3}/K^0_{e3}$)

The $K^0_{\mu 3}/K^0_{e3}$ branching ratio fixes a relationship between $\xi(0)$ and λ_+ if μ-e universality is assumed. We quote the author's $\xi(0)$ and associated λ_+ but do not average because the λ_+ values differ. The result labeled OUR FIT below does not use these ξ_b values. Instead it uses the authors $K^0_{\mu 3}/K^0_{e3}$ branching ratios to obtain the fitted $K^0_{\mu 3}/K^0_{e3}$ ratio which is then converted to the KL3FIT value below, as discussed in the review "$K^\pm_{\ell 3}$ and $K^0_{\ell 3}$ Form Factors" in the $K^\pm$ Listings. ξ_B is $\xi(0)$ determined by Method B of that review. The parameter $\xi(0)$ is redundant with λ_0 below and is not put into the Meson Summary Table.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.01±0.06 OUR FIT Error includes scale factor of 2.0. Correlation is $d\xi/d\lambda_+ = -13.2$. Assumes μ-e universality.					
0.12±0.07		[56] KL3FIT	02	RVUE	$\lambda_+ = 0.030$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.5 ±0.4	6700	BRANDENB...	73	HBC	BR, λ_+=0.019 ± 0.013
−0.08±0.25	1309	[57] EVANS	73	HLBC	BR, λ_+=0.02
−0.5 ±0.5	3548	BASILE	70	OSPK	BR, λ_+=0.02
+0.45±0.28	569	BEILLIERE	69	HLBC	BR, λ_+=0
−0.22±0.30	1309	[57] EVANS	69	HLBC	
$+0.2^{+0.8}_{-1.2}$		KULYUKINA	68	CC	BR, λ_+=0
+1.1 ±1.1	389	ADAIR	64	HBC	BR, λ_+=0
$+0.66^{+0.9}_{-1.3}$		LUERS	64	HBC	BR, λ_+=0

[56] KL3FIT value is from fitted $K^0_{\mu 3}/K^0_{e3}$ branching ratio. $d\xi(0)/d\lambda_+ = -10.2$.

[57] EVANS 73 replaces EVANS 69.

$\xi_C = f_-/f_+$ (determined from μ polarization in $K^0_{\mu 3}$)

The μ polarization is a measure of $\xi(t)$. No assumptions on λ_{+-} are necessary, but t (weighted by sensitivity to $\xi(t)$) should be specified. In λ_+, $\xi(0)$ parametrization this is $\xi(0)$ for $\lambda_+ = 0$. $d\xi/d\lambda = \xi t$. For radiative correction to μ polarization in $K^0_{\mu 3}$, see GINSBERG 73. Results labeled OUR FIT are discussed in the review "$K^\pm_{\ell 3}$ and $K^0_{\ell 3}$ Form Factors" in the $K^\pm$ Listings. ξ_C is $\xi(0)$ determined by Method C of that review. The parameter $\xi(0)$ is redundant with λ_0 below and is not put into the Meson Summary Table.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.01 ±0.06 OUR FIT Error includes scale factor of 2.0. Correlation is $d\xi(0)/d\lambda_+ = -13.2$. Assumes μ-e universality.					
−0.08 ±0.09 OUR FIT Error includes scale factor of 2.3. Correlation is $d\xi(0)/d\lambda_+ = -13.7$.					
+0.178±0.105	207k	[58] CLARK	77	SPEC	POL, $d\xi(0)/d\lambda_+ = +0.68$
−0.385±0.105	2.2M	[59] SANDWEISS	73	CNTR	POL, $d\xi(0)/d\lambda_+ = -6$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-1.81\ ^{+0.50}_{-0.26}$		[60] LONGO	69	CNTR	POL, t=3.3
−1.6 ±0.5	638	[61] ABRAMS	68B	OSPK	Polarization
−1.2 ±0.5	2608	[61] AUERBACH	66B	OSPK	Polarization

[58] CLARK 77 $t = +3.80$, $d\xi(0)/d\lambda_+ = \xi(t)t = 0.178\times3.80 = +0.68$.

[59] SANDWEISS 73 is for $\lambda_+ = 0$ and $t = 0$.

[60] LONGO 69 $t = 3.3$ calculated from $d\xi(0)/d\lambda_+ = -6.0$ (table 1) divided by $\xi = -1.81$.

[61] t value not given.

Im(ξ) in $K^0_{\mu 3}$ DECAY (from transverse μ pol.)

Test of T reversal invariance.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.007±0.026 OUR AVERAGE					
0.009±0.030	12M	MORSE	80	CNTR	Polarization
0.35 ±0.30	207k	[62] CLARK	77	SPEC	POL, t=0
−0.085±0.064	2.2M	[63] SANDWEISS	73	CNTR	POL, t=0
−0.02 ±0.08		LONGO	69	CNTR	POL, t=3.3
−0.2 ±0.6		ABRAMS	68B	OSPK	Polarization
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.012±0.026		SCHMIDT	79	CNTR	Repl. by MORSE 80

[62] CLARK 77 value has additional $\xi(0)$ dependence $+0.21\mathrm{Re}[\xi(0)]$.

[63] SANDWEISS 73 value corrected from value quoted in their paper due to new value of Re(ξ). See footnote 4 of SCHMIDT 79.

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN $K^0_{\mu 3}$ DECAY)

See also the corresponding entries and notes in section "$\xi_A = f_-/f_+$" above and section "λ_0 (LINEAR ENERGY DEPENDENCE OF f_0 IN $K^0_{\mu 3}$ DECAY)" below. For radiative correction of $K^0_{\mu 3}$ Dalitz plot see GINSBERG 70 and BECHERRAWY 70. Results labeled OUR FIT are discussed in the review "$K^\pm_{\ell 3}$ and $K^0_{\ell 3}$ Form Factors" in the $K^\pm$ Listings.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0300±0.0020 OUR FIT Error includes scale factor of 2.0. Assumes μ-e universality.					
0.033 ±0.005 OUR FIT Error includes scale factor of 2.3.					
0.0427±0.0044	150k	BIRULEV	81	SPEC	DP
0.028 ±0.010	14k	CHO	80	HBC	DP
0.028 ±0.011	16k	HILL	79	STRC	DP
0.046 ±0.030	32k	BUCHANAN	75	SPEC	DP
0.030 ±0.003	1.6M	DONALDSON	74B	SPEC	DP
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.0337±0.0033	129k	DZHORD...	77	SPEC	Repl. by BIRULEV 81
0.046 ±0.008	82k	ALBRECHT	74	WIRE	Repl. by BIRULEV 81
0.085 ±0.015	9086	ALBROW	72	ASPK	DP
0.11 ±0.04	16k	DALLY	72	ASPK	DP
0.07 ±0.02	16k	CHIEN	70	ASPK	Repl. by DALLY 72

λ_0 (LINEAR ENERGY DEPENDENCE OF f_0 IN $K^0_{\mu 3}$ DECAY)

Wherever possible, we have converted the above values of $\xi(0)$ into values of λ_0 using the associated λ^μ_+ and $d\xi(0)/d\lambda_+$. Results labeled OUR FIT are discussed in the review "$K^\pm_{\ell 3}$ and $K^0_{\ell 3}$ Form Factors" in the $K^\pm$ Listings.

VALUE	$d\lambda_0/d\lambda_+$	EVTS	DOCUMENT ID		TECN	COMMENT
0.030 ±0.005 OUR FIT Error includes scale factor of 2.0. Correlation is $d\lambda_0/d\lambda_+ = -0.12$. Assumes μ-e universality.						
0.027 ±0.006 OUR FIT Error includes scale factor of 2.3. Correlation is $d\lambda_0/d\lambda_+ = -0.17$.						
0.040 ±0.006	0.13		[64] KL3FIT	02	RVUE	$\lambda_+ = 0.030$
0.0341±0.0067	unknown	150k	[65] BIRULEV	81	SPEC	DP
+0.050 ±0.008	−0.11	14k	CHO	80	HBC	DP
+0.039 ±0.010	−0.67	16k	HILL	79	STRC	DP
+0.047 ±0.009	1.06	207k	[66] CLARK	77	SPEC	POL
+0.025 ±0.019	+0.5	32k	[67] BUCHANAN	75	SPEC	DP
+0.019 ±0.004	−0.47	1.6M	[68] DONALDSON	74B	SPEC	DP
−0.018 ±0.009	+0.49	2.2M	[66] SANDWEISS	73	CNTR	POL
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.041 ±0.008		14k	[69] CHO	80	HBC	BR, λ_+=0.028
+0.0485±0.0076		47k	DZHORD...	77	SPEC	In BIRULEV 81
+0.024 ±0.011		82k	ALBRECHT	74	WIRE	In BIRULEV 81
+0.06 ±0.03		6700	[70] BRANDENB...	73	HBC	BR, λ_+=0.019 ± 0.013
−0.060 ±0.038	−0.71	1385	[71] PEACH	73	HLBC	DP

−0.043	±0.052	−1.39	9086	[72] ALBROW	72	ASPK	DP
−0.067	±0.227	unknown	16k	[73] DALLY	72	ASPK	DP
−0.333	±0.034	+1.	3140	[74] BASILE	70	OSPK	DP
−0.140	$^{+0.043}_{-0.022}$	+0.49		[66] LONGO	69	CNTR	POL
+0.08	±0.07	−0.54	1371	[66] CARPENTER	66	OSPK	DP

[64] KL3FIT 02 value is from our fitted value of the $K^{\pm}_{\mu 3}/K^{\pm}_{e3}$ branching ratio. Assumes $\mu - e$ universality.

[65] BIRULEV 81 gives $d\lambda_0/d\lambda_+ = -1.5$, giving an unreasonably narrow error ellipse which dominates all other results. We use $d\lambda_0/d\lambda_+ = 0$.

[66] λ_0 value is for $\lambda_+ = 0.03$ calculated by us from $\xi(0)$ and $d\xi(0)/d\lambda_+$.

[67] BUCHANAN 75 value is from their appendix A and uses only $K_{\mu 3}$ data. $d\lambda_0/d\lambda_+$ was obtained by private communication, C.Buchanan, 1976.

[68] DONALDSON 74B $d\lambda_0/d\lambda_+$ obtained from figure 18.

[69] CHO 80 BR result not independent of their Dalitz plot result.

[70] Fit for λ_0 does not include this value but instead includes the $K_{\mu 3}/K_{e3}$ result from this experiment.

[71] PEACH 73 assumes $\lambda_+ = 0.025$. Calculated by us from $\xi(0)$ and $d\xi(0)/d\lambda_+$.

[72] ALBROW 72 λ_0 is calculated by us from ξ_A, λ_+ and $d\xi(0)/d\lambda_+$. They give $\lambda_0 = -0.043 \pm 0.039$ for $\lambda_- = 0$. We use our larger calculated error.

[73] DALLY 72 gives $f_0 = 1.20 \pm 0.35$, $\lambda_0 = -0.080 \pm 0.272$, $\lambda_0{}' = -0.006 \pm 0.045$, but with a different definition of λ_0. Our quoted λ_0 is his λ_0/f_0. We cannot calculate true λ_0 error without his (λ_0,f_0) correlations. See also note on DALLY 72 in section ξ_A.

[74] BASILE 70 λ_0 is for $\lambda_+ = 0$. Calculated by us from ξ_A with $d\xi(0)/d\lambda_+ = 0$. BASILE 70 is incompatible with all other results. Authors suggest that efficiency estimates might be responsible.

$|f_S/f_+|$ FOR K^0_{e3} DECAY

Ratio of scalar to f_+ couplings.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.04	68	25k	BLUMENTHAL	75	SPEC	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.095	95	18k	HILL	78	STRC	
<0.07	68	48k	BIRULEV	76	SPEC	See also BIRULEV 81
<0.19	95	5600	ALBROW	73	ASPK	
<0.15	68		KULYUKINA	67	CC	

$|f_T/f_+|$ FOR K^0_{e3} DECAY

Ratio of tensor to f_+ couplings.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.23	68	25k	BLUMENTHAL	75	SPEC	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.40	95	18k	HILL	78	STRC	
<0.34	68	48k	BIRULEV	76	SPEC	See also BIRULEV 81
<1.0	95	5600	ALBROW	73	ASPK	
<1.0	68		KULYUKINA	67	CC	

$|f_T/f_+|$ FOR $K^0_{\mu 3}$ DECAY

Ratio of tensor to f_+ couplings.

VALUE	DOCUMENT ID		TECN
0.12±0.12	BIRULEV	81	SPEC

α_{K^*} DECAY FORM FACTOR FOR $K_L \to e^+ e^- \gamma$

α_{K^*} is the constant in the model of BERGSTROM 83 which measures the relative strength of the vector-vector transition $K_L \to K^* \gamma$ with $K^* \to \rho, \omega, \phi \to \gamma^*$ and the pseudoscalar-pseudoscalar transition $K_L \to \pi, \eta, \eta' \to \gamma\gamma^*$.

VALUE	EVTS	DOCUMENT ID		TECN
−0.33 ±0.05 OUR AVERAGE				
−0.36 ±0.06 ±0.02	6864	FANTI	99B	NA48
−0.28 ±0.13		BARR	90B	NA31
$-0.280^{+0.099}_{-0.090}$		OHL	90B	B845

α_{K^*} DECAY FORM FACTOR FOR $K_L \to \mu^+ \mu^- \gamma$

α_{K^*} is the constant in the model of BERGSTROM 83 described in the previous section.

VALUE	EVTS	DOCUMENT ID		TECN
−0.158±0.027 OUR AVERAGE				
$-0.160^{+0.026}_{-0.028}$	9100	ALAVI-HARATI	01G	KTEV
$-0.04\ ^{+0.24}_{-0.21}$		FANTI	97	NA48

$\alpha^{\mathrm{eff}}_{K^*}$ DECAY FORM FACTOR FOR $K_L \to e^+ e^- e^+ e^-$

$\alpha^{\mathrm{eff}}_{K^*}$ is the parameter describing the relative strength of an intermediate pseudoscalar decay amplitude and a vector meson decay amplitude in the model of BERGSTROM 83. It takes into account both the radiative effects and the form factor. Since there are two $e^+ e^-$ pairs here compared with one in $e^+ e^- \gamma$ decays, a factorized expression is used for the $e^+ e^- e^+ e^-$ decay form factor.

VALUE	EVTS	DOCUMENT ID		TECN
−0.14±0.16±0.15	441	ALAVI-HARATI	01D	KTEV

DECAY FORM FACTORS FOR $K^0_L \to \pi^\pm \pi^0 e^\mp \nu_e$

Given in MAKOFF 93.

a_V, VECTOR MESON EXCHANGE CONTRIBUTION

VALUE	DOCUMENT ID		TECN	COMMENT
−0.72±0.07 OUR AVERAGE				
−0.67±0.21±0.12	ALAVI-HARATI	01E	KTEV	$K^0_L \to \pi^0 e^+ e^- \gamma$
−0.72±0.05±0.06	ALAVI-HARATI	99B	KTEV	$K^0_L \to \pi^0 2\gamma$

FITS FOR K^0_L CP-VIOLATION PARAMETERS

Revised May 2002 by T.G. Trippe (LBNL).

In recent years, K^0_L CP-violation experiments have improved our knowledge of CP-violation parameters and their consistency with the expectations of CPT invariance and unitarity. For definitions of K_L^0 CP-violation parameters and a brief discussion of the theory, see the article "CP Violation" by L. Wolfenstein in the *Reviews, Tables, and Plots* section of this *Review*.

This note describes our two types of fits for the CP-violation parameters in $K_L^0 \to \pi^+\pi^-$ and $\pi^0\pi^0$ decay, one for the phases ϕ_{+-} and ϕ_{00} jointly with Δm and τ_S, and the other for the amplitudes $|\eta_{+-}|$ and $|\eta_{00}|$ jointly with the $K_L^0 \to \pi\pi$ branching fractions. In this edition, phase fits are done without and with the assumption of CPT invariance, the latter giving a significant improvement in the precision of Δm and τ_S.

Fit to ϕ_{+-}, ϕ_{00}, $\Delta\phi$, Δm, and τ_S data: This is a joint fit to the data on ϕ_{+-}, ϕ_{00}, the phase difference $\Delta\phi = \phi_{00} - \phi_{+-}$, the $K_L^0 - K_S^0$ mass difference Δm, and the K_S^0 mean life τ_S, including the effects of correlations. Measurements of ϕ_{+-} and ϕ_{00} are highly correlated with Δm and τ_S. Some measurements of τ_S are correlated with Δm. The correlations are given in the footnotes of the ϕ_{+-} and ϕ_{00} sections of the K_L^0 Particle Listings and the τ_S section of the K_S^0 Particle listings. In editions of the Review prior to 1996, we adjusted the experimental values of ϕ_{+-} and ϕ_{00} to account for correlations with Δm and τ_S but did not include the effects of these correlations when evaluating Δm and τ_S. In 1996, we introduced a joint fit including these correlations. In the joint fit, the ϕ_{+-} measurements have a strong influence on the fitted value of Δm. This is because the CERN NA31 vacuum regeneration experiments (CAROSI 90 [1] and GEWENIGER 74B [2]), the Fermilab E773/E731 regenerator experiments (SCHWINGENHEUER 95 [3] and GIBBONS 93 [4]), and the CPLEAR $K^0 - \overline{K}^0$ asymmetry experiment (APOSTOLAKIS 99C [5]) have very different dependences of ϕ_{+-} on Δm, as can be seen from their diagonal bands e, d, b, c, and a, respectively, in Fig. 1.

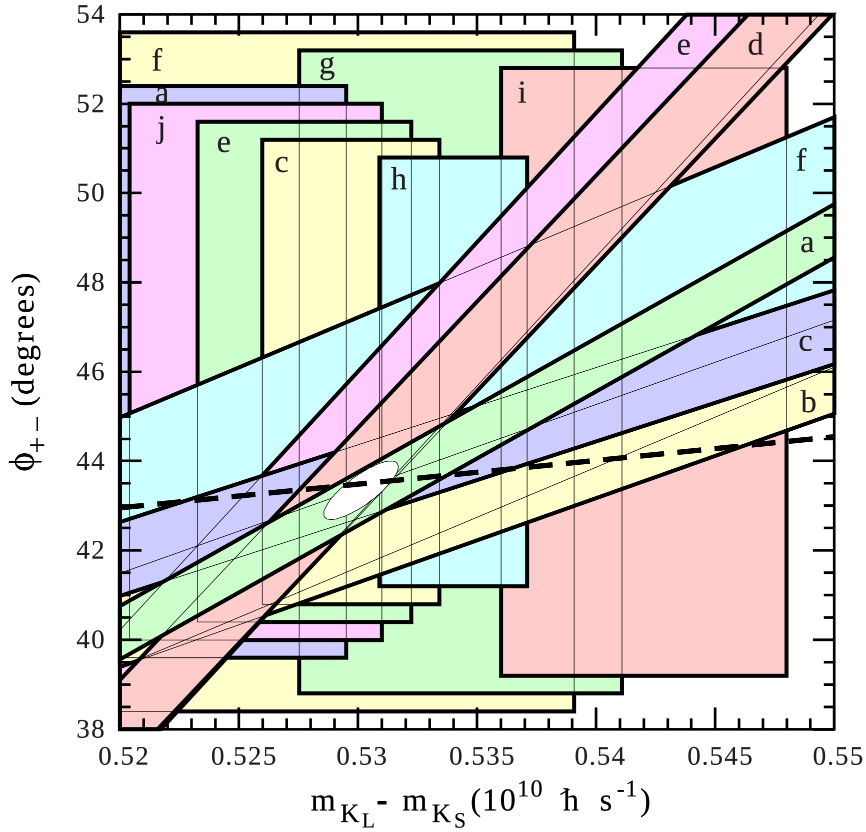


Figure 1: ϕ_{+-} vs Δm for experiments which do not assume CPT invariance. Δm measurements appear as vertical bands spanning $\Delta m \pm 1\sigma$, cut near the top and bottom to aid the eye. The ϕ_{+-} measurements appear as diagonal bands spanning $\phi_{+-} \pm \sigma_\phi$. The dashed line shows ϕ(superweak). The ellipse shows the 1σ contour of the fit result. Data are labeled by letters and cited in Table 1.

Table 1: References for data in the figures and fits. The letters in the first four columns label the bands in Fig. 1 and Fig. 2. Columns 1 and 3 label the diagonal ϕ_{+-} bands while columns 2 and 4 label the vertical Δm and τ_S bands. A check (√) in a column means that the data are excluded from the figures because they assume CPT. The data are given in the ϕ_{+-} and Δm sections of the K_L Particle Listings, and the τ_S section of the K_S Particle Listings, unless otherwise footnoted.

Location of input data					
Fig. 1		Fig. 2			
ϕ_{+-}	Δm	ϕ_{+-}	τ_S	PDG Document ID	Ref.
a	a	a		APOSTOLAKIS 99C	[5]
b		b	√	GIBBONS 93	[4]
c	c	c	√	SCHWINGENHEUER 95	[3]
d		d	d	GEWENIGER 74B	[2]
e	e*	e	e*	CAROSI 90	[1]
f	f†	f	f	CARITHERS 75	[8]
	g			ANGELOPOULOS 01	[9]
	h			GEWENIGER 74C	[7]
	i			CULLEN 70	[6]
	j			GIBBONS 93C	[10]
	√			ANGELOPOULOS 98D	[11]
	√			GJESDAL 74	[12]
			k	BERTANZA 97	[13]
			l	GROSSMAN 87	[14]
			m	SKJEGGESTAD 72	[15]

* from $\phi_{00}(\Delta m, \tau_S)$ in ϕ_{00} Particle Listings.

† from $\tau_S(\Delta m)$ in τ_S Particle Listings.

The region where the ϕ_{+-} bands from these experiments cross gives a powerful measurement of Δm which decreases the fitted Δm value relative to our pre-1996 average Δm and earlier measurements such as CULLEN 70 [6] and GEWENIGER 74C [7], i and h respectively in Fig. 1. This decrease brings the Δm-dependent ϕ_{+-} measurements into good agreement with each other and with ϕ(superweak), where

$$\phi(\text{superweak}) = \tan^{-1}\left(\frac{2\Delta m}{\Delta\Gamma}\right) = \tan^{-1}\left(\frac{2\Delta m \tau_S \tau_L}{\hbar(\tau_L - \tau_S)}\right) , \quad (1)$$

which is shown as a dashed line in Fig. 1 and Fig. 2. In this edition, we have taken care in these figures to exclude experiments which assume CPT invariance. This was not the case in the 2000 edition of the *Review* and earlier editions.

Table 2 column 2, "Fit w/o CPT," gives the resulting fitted parameters, while Table 3 gives the correlation matrix for this fit. The $\chi^2 = 1$ contour for the fit result is shown as a white ellipse in Fig. 1 and Fig. 2. The fit is seen to be consistent with the ϕ(superweak) dashed line.

For experiments which have dependencies on unseen fit parameters, that is, parameters other than those shown on the x or y axis of the figure, their band positions are evaluated using the fit results and their band widths include the fitted uncertainty in the unseen parameters.

If CPT invariance is assumed, four experimental results, those indicated by a check (✓) in column 2 or 4 of Table 1, are added to the fit. In addition, we require that $\phi_{+-} = \phi_{00} = \phi$(superweak). The result is shown in Table 2 column 3, "Fit w/ CPT," and the correlation matrix is shown in Table 4. The resulting ϕ_{+-} and ϕ_{00} are just ϕ(superweak) from Eq. (1), evaluated for Δm and τ_S from this fit. The Δm and τ_S precision are improved significantly by the CPT assumption.

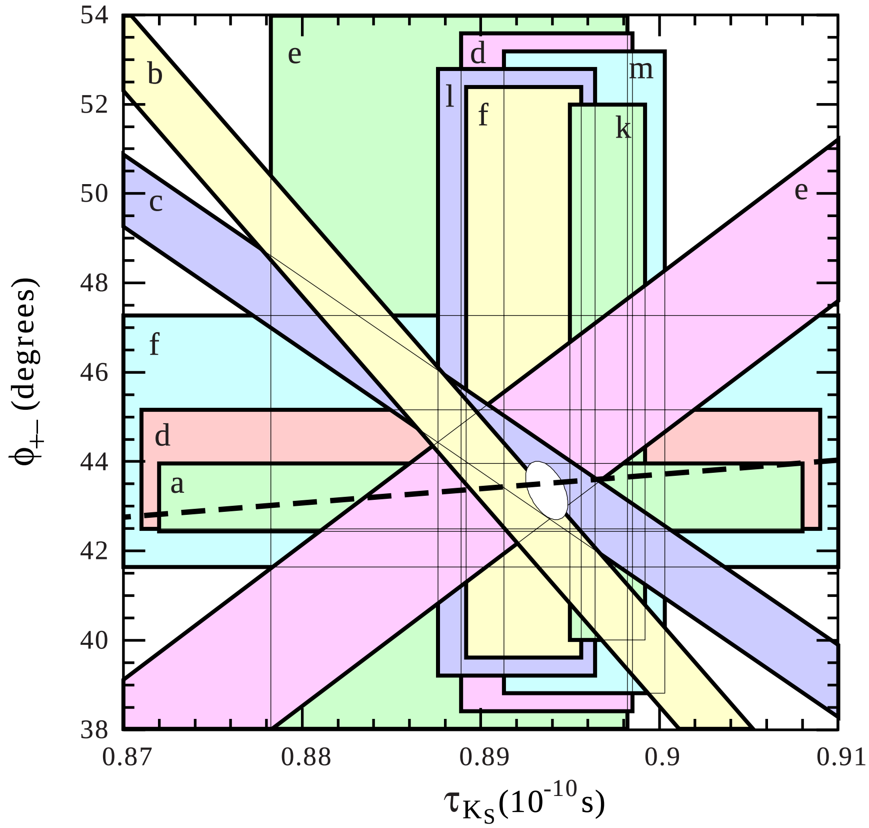


Figure 2: ϕ_{+-} vs τ_S. τ_S measurements appear as vertical bands spanning $\tau_S \pm 1\sigma$, some of which are cut near the top and bottom to aid the eye. The ϕ_{+-} measurements appear as diagonal or horizontal bands spanning $\phi_{+-} \pm \sigma_\phi$. The dashed line shows ϕ(superweak). The ellipse shows the fit result's 1σ contour. Data are labeled by letters and cited in Table 1.

Fit for ϵ'/ϵ, $|\eta_{+-}|$, $|\eta_{00}|$, and B$(K_L \rightarrow \pi\pi)$

We list measurements of $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$ and ϵ'/ϵ. Independent information on $|\eta_{+-}|$ and $|\eta_{00}|$ can be obtained

Table 2: Fit results for ϕ_{+-}, ϕ_{00}, $\phi_{00} - \phi_{+-}$, Δm, and τ_S without and with CPT assumption.

Quantity(units)	Fit w/o CPT	Fit w/ CPT
$\phi_{+-}(^\circ)$	43.4 ± 0.7	43.51 ± 0.06
$\Delta m(10^{10}\hbar\ \mathrm{s}^{-1})$	0.5301 ± 0.0016	0.5303 ± 0.0009
$\tau_S(10^{-10}\mathrm{s})$	0.8937 ± 0.0012	0.8935 ± 0.0008
$\phi_{00}(^\circ)$	43.2 ± 1.0	43.51 ± 0.06
$\Delta\phi(^\circ)$	-0.1 ± 0.8	−−−−−−−
χ^2	13.6	14.5
No. Deg. Freedom	16	21

Table 3: Correlation matrix for the results of the fit without the CPT assumption

	ϕ_{+-}	Δm	τ_S	ϕ_{00}	$\Delta\phi$
ϕ_{+-}	1.00	0.80	−0.45	0.62	−0.02
Δm	0.80	1.00	−0.33	0.54	0.04
τ_S	−0.45	−0.33	1.00	−0.25	0.05
ϕ_{00}	0.62	0.54	−0.25	1.00	0.78
$\Delta\phi$	−0.02	0.04	0.05	0.78	1.00

Table 4: Correlation matrix for the results of the fit with the CPT assumption

	ϕ_{+-}	Δm	τ_S	ϕ_{00}
ϕ_{+-}	1.00	0.90	0.49	1.00
Δm	0.90	1.00	0.06	0.90
τ_S	0.49	0.06	1.00	0.49
ϕ_{00}	1.00	0.90	0.49	1.00

from measurements of the K_L^0 and K_S^0 lifetimes (τ_L, τ_S) and branching ratios (B) to $\pi\pi$, using the relations

$$|\eta_{+-}| = \left[\frac{\mathrm{B}(K_L^0 \to \pi^+\pi^-)}{\tau_L} \; \frac{\tau_S}{\mathrm{B}(K_S^0 \to \pi^+\pi^-)}\right]^{1/2} , \qquad (2a)$$

$$|\eta_{00}| = \left[\frac{\mathrm{B}(K_L^0 \to \pi^0\pi^0)}{\tau_L} \; \frac{\tau_S}{\mathrm{B}(K_S^0 \to \pi^0\pi^0)}\right]^{1/2} . \qquad (2b)$$

For historical reasons the branching ratio fits and the CP-violation fits are done separately, but we want to include the influence of $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$, and ϵ'/ϵ measurements on $\mathrm{B}(K_L^0 \to \pi^+\pi^-)$ and $\mathrm{B}(K_L^0 \to \pi^0\pi^0)$ and vice versa. We approximate a global fit to all of these measurements by first performing two independent fits: 1) BRFIT, a fit to the K_L^0 branching ratios, rates, and mean life, and 2) ETAFIT, a fit to the $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{+-}/\eta_{00}|$, and ϵ'/ϵ measurements. The results from fit 1, along with the K_S^0 values from this edition are used to compute values of $|\eta_{+-}|$ and $|\eta_{00}|$ which are included as measurements in the $|\eta_{00}|$ and $|\eta_{+-}|$ sections with a document ID of BRFIT 02. Thus the fit values of $|\eta_{+-}|$ and $|\eta_{00}|$ given in this edition include both the direct measurements and the results from the branching ratio fit.

The process is reversed in order to include the direct $|\eta|$ measurements in the branching ratio fit. The results from fit 2 above (before including BRFIT 02 values) are used along with the K_L^0 and K_S^0 mean lives and the $K_S^0 \to \pi\pi$ branching fractions to compute the K_L^0 branching ratios $\Gamma(K_L^0 \to \pi^+\pi^-)/\Gamma(\mathrm{total})$ and $\Gamma(K_L^0 \to \pi^0\pi^0)/\Gamma(K_L^0 \to \pi^+\pi^-)$. These branching ratio values are included as measurements in the branching ratio section with a document ID of ETAFIT 02. Thus the K_L^0 branching ratio fit values in this edition include the results of direct measurements of $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$, and ϵ'/ϵ. A more detailed discussion of these fits is given in the 1990 edition of this *Review* [16].

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CP-VIOLATION PARAMETERS IN K_L^0 DECAYS

CHARGE ASYMMETRY IN $K_{\ell 3}^0$ DECAYS

Such asymmetry violates *CP*. It is related to Re(ϵ).

δ_L = weighted average of $\delta_L(\mu)$ and $\delta_L(e)$

VALUE (%)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.327±0.012 OUR AVERAGE	Includes data from the 2 datablocks that follow this one.				
0.333±0.050	33M	WILLIAMS	73	ASPK	$K_{\mu 3}$ + K_{e3}

$\delta_L(\mu) = [\Gamma(\pi^- \mu^+ \nu_\mu) - \Gamma(\pi^+ \mu^- \overline{\nu}_\mu)]/\text{SUM}$

Only the combined value below is put into the Meson Summary Table.

VALUE (%)	*EVTS*	*DOCUMENT ID*		*TECN*
The data in this block is included in the average printed for a previous datablock.				
0.304±0.025 OUR AVERAGE				
0.313±0.029	15M	GEWENIGER	74	ASPK
0.278±0.051	7.7M	PICCIONI	72	ASPK
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.60 ±0.14	4.1M	MCCARTHY	73	CNTR
0.57 ±0.17	1M	[75] PACIOTTI	69	OSPK
0.403±0.134	1M	[75] DORFAN	67	OSPK

[75] PACIOTTI 69 is a reanalysis of DORFAN 67 and is corrected for $\mu^+ \mu^-$ range difference in MCCARTHY 72.

$\delta_L(e) = [\Gamma(\pi^- e^+ \nu_e) - \Gamma(\pi^+ e^- \overline{\nu}_e)]/\text{SUM}$

Only the combined value below is put into the Meson Summary Table.

VALUE (%)	*EVTS*	*DOCUMENT ID*		*TECN*
The data in this block is included in the average printed for a previous datablock.				
0.333±0.014 OUR AVERAGE				
0.341±0.018	34M	GEWENIGER	74	ASPK
0.318±0.038	40M	FITCH	73	ASPK
0.346±0.033	10M	MARX	70	CNTR
0.246±0.059	10M	[76] SAAL	69	CNTR
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.36 ±0.18	600k	ASHFORD	72	ASPK
0.224±0.036	10M	[76] BENNETT	67	CNTR

[76] SAAL 69 is a reanalysis of BENNETT 67.

PARAMETERS FOR $K_L^0 \to 2\pi$ DECAY

η_{+-} = A($K_L^0 \to \pi^+\pi^-$) / A($K_S^0 \to \pi^+\pi^-$)
η_{00} = A($K_L^0 \to \pi^0\pi^0$) / A($K_S^0 \to \pi^0\pi^0$)

The fitted values of $|\eta_{+-}|$ and $|\eta_{00}|$ given below are the results of a fit to $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$, and Re(ϵ'/ϵ). Independent information on $|\eta_{+-}|$ and $|\eta_{00}|$ can be obtained from the fitted values of the $K_L^0 \to$

$\pi\pi$ and $K^0_S \rightarrow \pi\pi$ branching ratios and the K^0_L and K^0_S lifetimes. This information is included as data in the $|\eta_{+-}|$ and $|\eta_{00}|$ sections with a Document ID "BRFIT." See the note "Fits for K^0_L *CP*-Violation Parameters" above for details.

$|\eta_{00}| = |A(K^0_L \rightarrow 2\pi^0) / A(K^0_S \rightarrow 2\pi^0)|$

VALUE (units 10^{-3})	*DOCUMENT ID*		*TECN*	*COMMENT*
2.274±0.017 OUR FIT				
2.23 ±0.11 OUR AVERAGE				
2.12 ±0.16	[77] BRFIT	02		
2.47 ±0.31 ±0.24	ANGELOPO...	98	CPLR	
2.33 ±0.18	CHRISTENS...	79	ASPK	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2.49 ±0.40	[78] ADLER	96B	CPLR	Sup. by ANGELOPOULOS 98
2.71 ±0.37	[79] WOLFF	71	OSPK	Cu reg., 4γ's
2.95 ±0.63	[79] CHOLLET	70	OSPK	Cu reg., 4γ's

[77] This BRFIT value is computed from fitted values of the K^0_L and K^0_S lifetimes and branching fractions to $\pi\pi$. See the discussion in the note "Fits for K^0_L *CP*-Violation Parameters."

[78] Error is statistical only.

[79] CHOLLET 70 gives $|\eta_{00}|$ = (1.23 ± 0.24)×(regeneration amplitude, 2 GeV/c Cu)/10000mb. WOLFF 71 gives $|\eta_{00}|$ = (1.13 ± 0.12)×(regeneration amplitude, 2 GeV/c Cu)/10000mb. We compute both $|\eta_{00}|$ values for (regeneration amplitude, 2 GeV/c Cu) = 24 ± 2mb. This regeneration amplitude results from averaging over FAISSNER 69, extrapolated using optical-model calculations of Bohm et al., Physics Letters **27B** 594 (1968) and the data of BALATS 71. (From H. Faissner, private communication).

$|\eta_{+-}| = |A(K^0_L \rightarrow \pi^+\pi^-) / A(K^0_S \rightarrow \pi^+\pi^-)|$

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.286±0.017 OUR FIT					
2.287±0.017 OUR AVERAGE					
2.292±0.024		[80] BRFIT	02		
2.264±0.023±0.027	70M	[81] APOSTOLA...	99C	CPLR	K^0-$\overline{K}^0$ asymmetry
2.30 ±0.035		GEWENIGER	74B	ASPK	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.310±0.043±0.031		[82] ADLER	95B	CPLR	K^0-$\overline{K}^0$ asymmetry
2.32 ±0.14 ±0.03	10^5	ADLER	92B	CPLR	K^0-$\overline{K}^0$ asymmetry

[80] This BRFIT value is computed from fitted values of the K^0_L and K^0_S lifetimes and branching fractions to $\pi\pi$. See the discussion in the note "Fits for K^0_L *CP*-Violation Parameters."

[81] APOSTOLAKIS 99C report (2.264 ± 0.023 ± 0.026 + 9.1[τ_S − 0.8934]) × 10^{-3}. We evaluate for our 1998 best value τ_S= (0.8934 ± 0.0008) × 10^{-10} s.

[82] ADLER 95B report (2.312 ± 0.043 ± 0.030 −1[Δm− 0.5274] +9.1[τ_S − 0.8926]) × 10^{-3}. We evaluate for our 1996 best values Δm = (0.5304 ± 0.0014) × 10^{-10} $\hbar s^{-1}$ and τ_S = (0.8927 ± 0.0009) × 10^{-10} s. Superseded by APOSTOLAKIS 99C.

$|\eta_{00}/\eta_{+-}|$

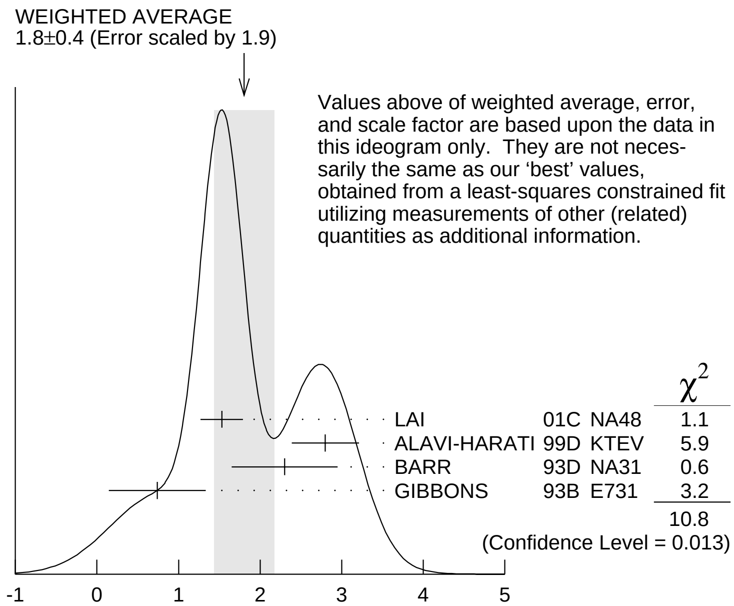
VALUE	EVTS	DOCUMENT ID		TECN
0.9946±0.0013 OUR FIT Error includes scale factor of 2.3.				
0.9930±0.0020 OUR AVERAGE				
0.9931±0.0020		[83,84] BARR	93D	NA31
0.9904±0.0084±0.0036		[85] WOODS	88	E731
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.9939±0.0013±0.0015	1M	[83] BARR	93D	NA31
0.9899±0.0020±0.0025		[83] BURKHARDT	88	NA31

[83] This is the square root of the ratio R given by BURKHARDT 88 and BARR 93D.
[84] This is the combined results from BARR 93D and BURKHARDT 88, taking into account a common systematic uncertainty of 0.0014.
[85] We calculate $|\eta_{00}/\eta_{+-}| = 1-3(\epsilon'/\epsilon)$ from WOODS 88 (ϵ'/ϵ) value.

$\mathrm{Re}(\epsilon'/\epsilon) = (1-|\eta_{00}/\eta_{+-}|)/3$

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
1.8 ±0.4 OUR FIT Error includes scale factor of 2.3.				
1.8 ±0.4 OUR AVERAGE Error includes scale factor of 1.9. See the ideogram below.				
1.53±0.26	LAI	01C	NA48	
2.80±0.30±0.28	[86] ALAVI-HARATI	99D	KTEV	
2.3 ±0.65	[87,88] BARR	93D	NA31	
0.74±0.52±0.29	GIBBONS	93B	E731	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.85±0.45±0.58	FANTI	99C	NA48	In LAI 01C
2.0 ±0.7	[89] BARR	93D	NA31	
−0.4 ±1.4 ±0.6	PATTERSON	90	E731	in GIBBONS 93B
3.3 ±1.1	[89] BURKHARDT	88	NA31	
3.2 ±2.8 ±1.2	[87] WOODS	88	E731	

[86] As part of an improved analysis of a 4 times larger data sample, KTeV has reanalyzed the data sample reported here and finds a somewhat lower value of $\mathrm{Re}(\epsilon'/\epsilon) = (2.32 \pm 0.44) \times 10^{-3}$. The new analysis, including this updated result, is being prepared for publication. See for example, GLAZOV 01 or KESSLER 01.
[87] These values are derived from $|\eta_{00}/\eta_{+-}|$ measurements. They enter the average in this section but enter the fit via the $|\eta_{00}/\eta_{+-}|$ section only.
[88] This is the combined results from BARR 93D and BURKHARDT 88, taking into account their common systematic uncertainty.
[89] These values are derived from $|\eta_{00}/\eta_{+-}|$ measurements.



$$\mathrm{Re}(\epsilon'/\epsilon) = (1-\left|\eta_{00}/\eta_{+-}\right|)/3$$

ϕ_{+-}, PHASE of η_{+-}

The dependence of the phase on Δm and τ_S is given for each experiment in the comments below, where Δm is the $K_L^0 - K_S^0$ mass difference in units $10^{10}\ \hbar\mathrm{s}^{-1}$ and τ_s is the K_S mean life in units 10^{-10} s. For the "used" data, we have evaluated these mass dependences using our 2002 values not assuming *CPT*, $\Delta m = 0.5301 \pm 0.0016$, $\tau_s = 0.8937 \pm 0.0012$ to obtain the values quoted below. We also give the regeneration phase ϕ_f in the comments below.

OUR FIT is described in the note on "Fits for K_L^0 *CP*-Violation Parameters" in the K_L^0 Particle Listings.

VALUE (°)	EVTS	DOCUMENT ID		TECN	COMMENT
43.51±0.06 OUR FIT	Assuming *CPT*				
43.4 ±0.7 OUR FIT	Not assuming *CPT*				
43.2 ±0.8	70M	[90] APOSTOLA...	99C	CPLR	K^0-$\overline{K}^0$ asymmetry
43.6 ±0.9		[91,92] SCHWINGEN...	95	E773	$CH_{1.1}$ regenerator
42.4 ±1.1		[92,93] GIBBONS	93	E731	B_4C regenerator
44.5 ±1.8		[94] CAROSI	90	NA31	Vacuum regen.
44.5 ±2.8		[95] CARITHERS	75	SPEC	C regenerator
43.8 ±1.3		[96] GEWENIGER	74B	ASPK	Vacuum regen.
• • • We do not use the following data for averages, fits, limits, etc. • • •					
43.82±0.63		[97,98] ADLER	96C	RVUE	
43.6 ±1.2		[99] ADLER	95B	CPLR	K^0-$\overline{K}^0$ asymmetry
42.3 ±4.4 ±1.4	10^5	[100] ADLER	92B	CPLR	K^0-$\overline{K}^0$ asymmetry
47.7 ±2.0 ±0.9		[92,101] KARLSSON	90	E731	

[90] APOSTOLAKIS 99C report $(43.19 \pm 0.53 \pm 0.28)^\circ + 300\ [\Delta m - 0.5301]^\circ$.

[91] SCHWINGENHEUER 95 reports $\phi_{+-} = 43.53 \pm 0.76 + 173[\Delta m - 0.5282] - 275[\tau_s - 0.8926]$.

[92] These experiments measure $\phi_{+-}-\phi_f$ and calculate the regeneration phase from the power law momentum dependence of the regeneration amplitude using analyticity and dispersion relations. SCHWINGENHEUER 95 [GIBBONS 93] includes a systematic error of 0.35° [0.5°] for uncertainties in their modeling of the regeneration amplitude. See the discussion of these systematic errors, including criticism that they could be underestimated, in the note on "C violation in K^0_L decay."

[93] GIBBONS 93 measures $\phi_{+}-\phi_f$ and calculates the regeneration phase ϕ_f from the power law momentum dependence of the regeneration amplitude using analyticity. An error of 0.6° is included for possible uncertainties in the regeneration phase. They find $\phi_{+-} = 42.21 \pm 0.9 + 189\ [\Delta m - 0.5257] - 460\ [\tau_s - 0.8922]^\circ$, as given in SCHWINGENHEUER 95, footnote 8. GIBBONS 93 reports ϕ_{+-} $(42.2 \pm 1.4)^\circ$

[94] CAROSI 90 $\phi_{+-} = 46.9 \pm 1.4 \pm 0.7 + 579\ [\Delta m - 0.5351] + 303\ [\tau_s - 0.8922]^\circ$.

[95] CARITHERS 75 $\phi_{+-} = (45.5 \pm 2.8) + 224\big[\Delta m - 0.5348\big]^\circ$. $\phi_f = -40.9 \pm 2.6^\circ$.

[96] GEWENIGER 74B $\phi_{+-} = (49.4 \pm 1.0) + 565\big[\Delta m - 0.540\big]^\circ$.

[97] ADLER 96C fit gives $(43.82 \pm 0.41)^\circ + 339(\Delta m - 0.5307)^\circ - 252(\tau_s - 0.8922)^\circ$.

[98] ADLER 96C is the result of a fit which includes nearly the same data as entered into the "OUR FIT" value in the 1996 edition of this Review (Physical Review **D54** 1 (1996)).

[99] ADLER 95B report $42.7^\circ \pm 0.9^\circ \pm 0.6^\circ + 316[\Delta m - 0.5274]^\circ + 30[\tau_s - 0.8926]^\circ$.

[100] ADLER 92B quote separately two systematic errors: ± 0.4 from their experiment and ± 1.0 degrees due to the uncertainty in the value of Δm.

[101] KARLSSON 90 systematic error does not include regeneration phase uncertainty.

ϕ_{00}, PHASE OF η_{00}

See comment in ϕ_{+-} header above for treatment of Δm and τ_s dependence.

OUR FIT is described in the note on "Fits for K^0_L CP-Violation Parameters" in the K^0_L Particle Listings.

VALUE (°)	DOCUMENT ID	TECN	COMMENT
43.51±0.06 OUR FIT Assuming CPT			
43.2 ±1.0 OUR FIT Not assuming CPT			
41.9 ±5.9	[102] ANGELOPO... 98	CPLR	
44.6 ±2.5	[103] CAROSI 90	NA31	
• • • We do not use the following data for averages, fits, limits, etc. • • •			
50.8 ±7.1 ±1.7	[104] ADLER 96B	CPLR	Sup. by ANGELOPOULOS 98
47.4 ±1.4 ±0.9	[105] KARLSSON 90	E731	

[102] ANGELOPOULOS 98 $\phi_{00} = 42.0 \pm 5.6 \pm 1.9 + 240[\Delta m - 0.5307]$ with negligible τ_s dependence.

[103] CAROSI 90 $\phi_{00} = 47.1 \pm 2.1 \pm 1.0 + 579\ [\Delta m - 0.5351] + 252\ [\tau_s - 0.8922]^\circ$.

[104] ADLER 96B identified initial neutral kaon individually as being a K^0 or a $\overline{K}^0$. The systematic uncertainty is $\pm 1.5^\circ$ combined in quadrature with $\pm 0.8^\circ$ due to Δm.

[105] KARLSSON 90 systematic error does not include regeneration phase uncertainty.

PHASE DIFFERENCE $\phi_{00} - \phi_{+-}$

Test of *CPT*.

OUR FIT is described in the note on "Fits for K^0_L *CP*-Violation Parameters" in the K^0_L Particle Listings.

VALUE (°)	DOCUMENT ID	TECN	COMMENT
0 OUR FIT Assuming *CPT*			
−0.1 ±0.8 OUR FIT Not assuming *CPT*			
−0.3 ±0.8 OUR AVERAGE			
−0.30±0.88	[106] SCHWINGEN...95		Combined E731, E773
0.2 ±2.6 ±1.2	[107] CAROSI 90	NA31	
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.62±0.71±0.75	SCHWINGEN...95	E773	
−1.6 ±1.2	[108] GIBBONS 93	E731	
−0.3 ±2.4 ±1.2	KARLSSON 90	E731	

[106] This SCHWINGENHEUER 95 values is the combined result of SCHWINGENHEUER 95 and GIBBONS 93, accounting for correlated systematic errors.

[107] CAROSI 90 is excluded from the fit because it it is not independent of ϕ_{+-} and ϕ_{00} values.

[108] GIBBONS 93 give detailed dependence of systematic error on lifetime (see the section on the K^0_S mean life) and mass difference (see the section on $m_{K^0_L} - m_{K^0_S}$).

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_L rest frame.

CP ASYMMETRY *A* in $K_L \to \pi^+\pi^-e^+e^-$

VALUE (%)	DOCUMENT ID	TECN
13.6±2.5±1.2	ALAVI-HARATI 00B	KTEV

PARAMETERS FOR $e^+e^-e^+e^-$ DECAYS

These are the *CP*-violating parameters in the ϕ distribtuion, where ϕ is the angle between the planes of the two e^+e^- paris in the kaon rest frame:

$$d\Gamma/d\phi \;\propto\; 1 + \beta_{CP}\cos(2\phi) + \gamma_{CP}\sin(2\phi)$$

β_{CP} from $K_L \to e^+e^-e^+e^-$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
−0.23±0.09±0.02	441	ALAVI-HARATI 01D	KTEV	$M_{ee} >$8 MeV/c^2

γ_{CP} from $K^0_L \to e^+e^-e^+e^-$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
−0.09±0.09±0.02	441	ALAVI-HARATI 01D	KTEV	$M_{ee} >$8 MeV/c^2

CHARGE ASYMMETRY IN $\pi^+\pi^-\pi^0$ DECAYS

These are *CP*-violating charge-asymmetry parameters, defined at beginning of section "LINEAR COEFFICIENT *g* FOR $K^0_L \rightarrow \pi^+\pi^-\pi^0$ above. See also note on Dalitz plot parameters in $K^\pm$ section and note on *CP* violation in K^0_L decay above.

LINEAR COEFFICIENT *j* FOR $K^0_L \rightarrow \pi^+\pi^-\pi^0$

VALUE	EVTS	DOCUMENT ID		TECN
0.0011±0.0008 OUR AVERAGE				
0.0010±0.0024±0.0030	500k	ANGELOPO...	98C	CPLR
0.001 ±0.011	6499	CHO	77	
−0.001 ±0.003	4709	PEACH	77	
0.0013±0.0009	3M	SCRIBANO	70	
0.0 ±0.017	4400	SMITH	70	OSPK
0.001 ±0.004	238k	BLANPIED	68	

QUADRATIC COEFFICIENT *f* FOR $K^0_L \rightarrow \pi^+\pi^-\pi^0$

VALUE	EVTS	DOCUMENT ID		TECN
0.0045±0.0024±0.0059	500k	ANGELOPO...	98C	CPLR

PARAMETERS for $K^0_L \rightarrow \pi^+\pi^-\gamma$ DECAY

$|\eta_{+-\gamma}| = |A(K^0_L \rightarrow \pi^+\pi^-\gamma$, *CP* violating$)/A(K^0_S \rightarrow \pi^+\pi^-\gamma)|$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN
2.35 ±0.07 OUR AVERAGE				
2.359±0.062±0.040	9045	MATTHEWS	95	E773
2.15 ±0.26 ±0.20	3671	RAMBERG	93B	E731

$\phi_{+-\gamma}$ = phase of $\eta_{+-\gamma}$

VALUE (°)	EVTS	DOCUMENT ID		TECN
44 ± 4 OUR AVERAGE				
43.8± 3.5± 1.9	9045	MATTHEWS	95	E773
72 ±23 ±17	3671	RAMBERG	93B	E731

$|\epsilon'_{+-\gamma}|/\epsilon$ for $K^0_L \rightarrow \pi^+\pi^-\gamma$

VALUE	CL%	EVTS	DOCUMENT ID		TECN
<0.3	90	3671	[109] RAMBERG	93B	E731

[109] RAMBERG 93B limit on $|\epsilon'_{+-\gamma}|/\epsilon$ assumes than any difference between η_{+-} and $\eta_{+-\gamma}$ is due to direct *CP* violation.

$\Delta S = \Delta Q$ IN K^0 DECAYS

The relative amount of $\Delta S \neq \Delta Q$ component present is measured by the parameter x, defined as

$$x = A(\overline{K}^0 \rightarrow \pi^-\ell^+\nu)/A(K^0 \rightarrow \pi^-\ell^+\nu)\ .$$

We list Re$\{x\}$ and Im$\{x\}$ for K_{e3} and $K_{\mu 3}$ combined.

$x = A(\overline{K}^0 \to \pi^- \ell^+ \nu)/A(K^0 \to \pi^- \ell^+ \nu) = A(\Delta S{=}-\Delta Q)/A(\Delta S{=}\Delta Q)$

REAL PART OF x

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-0.0018 \pm 0.0041 \pm 0.0045$		ANGELOPO...	98D	CPLR	K_{e3} from K^0
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.10\ {}^{+0.18}_{-0.19}$	79	SMITH	75B	WIRE	$\pi^- p \to K^0 \Lambda$
$0.04\ \pm 0.03$	4724	NIEBERGALL	74	ASPK	$K^+ p \to K^0 p \pi^+$
$-0.008\ \pm 0.044$	1757	FACKLER	73	OSPK	K_{e3} from K^0
$-0.03\ \pm 0.07$	1367	HART	73	OSPK	K_{e3} from $K^0 \Lambda$
$-0.070\ \pm 0.036$	1079	MALLARY	73	OSPK	K_{e3} from $K^0 \Lambda X$
$0.03\ \pm 0.06$	410	[110] BURGUN	72	HBC	$K^+ p \to K^0 p \pi^+$
$0.04\ {}^{+0.10}_{-0.13}$	100	[111] GRAHAM	72	OSPK	$K_{\mu 3}$ from $K^0 \Lambda$
$-0.05\ \pm 0.09$	442	[111] GRAHAM	72	OSPK	$\pi^- p \to K^0 \Lambda$
$0.26\ {}^{+0.10}_{-0.14}$	126	MANN	72	HBC	$K^- p \to n \overline{K}^0$
$-0.13\ \pm 0.11$	342	[111] MANTSCH	72	OSPK	K_{e3} from $K^0 \Lambda$
$0.04\ {}^{+0.07}_{-0.08}$	222	[110] BURGUN	71	HBC	$K^+ p \to K^0 p \pi^+$
$0.25\ {}^{+0.07}_{-0.09}$	252	WEBBER	71	HBC	$K^- p \to n \overline{K}^0$
$0.12\ \pm 0.09$	215	[112] CHO	70	DBC	$K^+ d \to K^0 p p$
$-0.020\ \pm 0.025$		[113] BENNETT	69	CNTR	Charge asym+ Cu regen.
$0.09\ {}^{+0.14}_{-0.16}$	686	LITTENBERG	69	OSPK	$K^+ n \to K^0 p$
$0.03\ \pm 0.03$		[113] BENNETT	68	CNTR	
$0.09\ {}^{+0.07}_{-0.09}$	121	JAMES	68	HBC	$\overline{p} p$
$0.17\ {}^{+0.16}_{-0.35}$	116	FELDMAN	67B	OSPK	$\pi^- p \to K^0 \Lambda$
$0.17\ \pm 0.10$	335	[112] HILL	67	DBC	$K^+ d \to K^0 p p$
$0.035\ {}^{+0.11}_{-0.13}$	196	AUBERT	65	HLBC	K^+ charge exchange
$0.06\ {}^{+0.18}_{-0.44}$	152	[114] BALDO-...	65	HLBC	K^+ charge exchange
$-0.08\ {}^{+0.16}_{-0.28}$	109	[115] FRANZINI	65	HBC	$\overline{p} p$

[110] BURGUN 72 is a final result which includes BURGUN 71.
[111] First GRAHAM 72 value is second GRAHAM 72 value combined with MANTSCH 72.
[112] CHO 70 is analysis of unambiguous events in new data and HILL 67.
[113] BENNETT 69 is a reanalysis of BENNETT 68.
[114] BALDO-CEOLIN 65 gives x and θ converted by us to Re(x) and Im(x).
[115] FRANZINI 65 gives x and θ for Re(x) and Im(x). See SCHMIDT 67.

IMAGINARY PART OF *x*

Assumes $m_{K^0_L} - m_{K^0_S}$ positive. See Listings above.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.0012±0.0019±0.0009	640k	ANGELOPO...	01B	CPLR	K_{e3} from K^0
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.0012±0.0019	640k	[116] ANGELOPO...	98E	CPLR	K_{e3} from K^0
-0.10 $^{+0.16}_{-0.19}$	79	SMITH	75B	WIRE	$\pi^- p \to K^0 \Lambda$
-0.06 ±0.05	4724	NIEBERGALL	74	ASPK	$K^+ p \to K^0 p \pi^+$
-0.017 ±0.060	1757	FACKLER	73	OSPK	K_{e3} from K^0
0.09 ±0.07	1367	HART	73	OSPK	K_{e3} from $K^0 \Lambda$
0.107 $^{+0.092}_{-0.074}$	1079	MALLARY	73	OSPK	K_{e3} from $K^0 \Lambda X$
0.07 $^{+0.06}_{-0.07}$	410	[117] BURGUN	72	HBC	$K^+ p \to K^0 p \pi^+$
0.12 $^{+0.17}_{-0.16}$	100	[118] GRAHAM	72	OSPK	$K_{\mu 3}$ from $K^0 \Lambda$
0.05 ±0.13	442	[118] GRAHAM	72	OSPK	$\pi^- p \to K^0 \Lambda$
0.21 $^{+0.15}_{-0.12}$	126	MANN	72	HBC	$K^- p \to n \overline{K}^0$
-0.04 ±0.16	342	[118] MANTSCH	72	OSPK	K_{e3} from $K^0 \Lambda$
0.12 $^{+0.08}_{-0.09}$	222	[117] BURGUN	71	HBC	$K^+ p \to K^0 p \pi^+$
0.0 ±0.08	252	WEBBER	71	HBC	$K^- p \to n \overline{K}^0$
-0.08 ±0.07	215	[119] CHO	70	DBC	$K^+ d \to K^0 p p$
-0.11 $^{+0.10}_{-0.11}$	686	LITTENBERG	69	OSPK	$K^+ n \to K^0 p$
$+0.22$ $^{+0.37}_{-0.29}$	121	JAMES	68	HBC	$\overline{p} p$
0.0 ±0.25	116	FELDMAN	67B	OSPK	$\pi^- p \to K^0 \Lambda$
-0.20 ±0.10	335	[119] HILL	67	DBC	$K^+ d \to K^0 p p$
-0.21 $^{+0.11}_{-0.15}$	196	AUBERT	65	HLBC	K^+ charge exchange
-0.44 $^{+0.32}_{-0.19}$	152	[120] BALDO-...	65	HLBC	K^+ charge exchange
$+0.24$ $^{+0.40}_{-0.30}$	109	[121] FRANZINI	65	HBC	$\overline{p} p$

[116] Superseded by ANGELOPOULOS 01B.
[117] BURGUN 72 is a final result which includes BURGUN 71.
[118] First GRAHAM 72 value is second GRAHAM 72 value combined with MANTSCH 72.
[119] Footnote 10 of HILL 67 should read +0.58, not −0.58 (private communication) CHO 70 is analysis of unambiguous events in new data and HILL 67.
[120] BALDO-CEOLIN 65 gives x and θ converted by us to Re(x) and Im(x).
[121] FRANZINI 65 gives x and θ for Re(x) and Im(x). See SCHMIDT 67.

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KARLSSON	90	PRL 64 2976	M. Karlsson *et al.*	(FNAL E731 Collab.)
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NIEBERGALL	74	PL 49B 103	F. Niebergall *et al.*	(CERN, ORSAY, VIEN)
WANG	74	PR D9 540	L. Wang *et al.*	(UMD, BNL)
WILLIAMS	74	PRL 33 240	H.H. Williams *et al.*	(BNL, YALE)
ALBROW	73	NP B58 22	M.G. Albrow *et al.*	(MCHS, DARE)
ALEXANDER	73B	NP B65 301	G. Alexander *et al.*	(TELA, HEID)
BRANDENB...	73	PR D8 1978	G.W. Brandenburg *et al.*	(SLAC)
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FACKLER	73	PRL 31 847	O. Fackler *et al.*	(MIT)
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MCCARTHY	73	PR D7 687	R.L. McCarthy *et al.*	(LBL)
Also	72	PL 42B 291	R.L. McCarthy *et al.*	(LBL)
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BARMIN	72B	SJNP 15 638	V.V. Barmin *et al.*	(ITEP)
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BURGUN	72	NP B50 194	G. Burgun *et al.*	(SACL, CERN, OSLO)
DALLY	72	PL 41B 647	E.B. Dally *et al.*	(SLAC, JHU, UCLA)
Also	70	PL 33B 627	C.Y. Chien *et al.*	(JHU, SLAC, UCLA)
Also	71	PL 35B 261	C.Y. Chien *et al.*	(JHU, SLAC, UCLA)
GRAHAM	72	NC 9A 166	M.F. Graham *et al.*	(ILL, NEAS)
JAMES	72	NP B49 1	F. James *et al.*	(CERN, SACL, OSLO)
KRENZ	72	LNC 4 213	W. Krenz *et al.*	(AACH, CERN, EDIN)
MANN	72	PR D6 137	W.A. Mann *et al.*	(MASA, BNL, YALE)
MANTSCH	72	NC 9A 160	P.M. Mantsch *et al.*	(ILL, NEAS)
MCCARTHY	72	PL 42B 291	R.L. McCarthy *et al.*	(LBL)
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PICCIONI	72	PRL 29 1412	R. Piccioni *et al.*	(SLAC)
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VOSBURGH	72	PR D6 1834	K.G. Vosburgh *et al.*	(RUTG, MASA)
Also	71	PRL 26 866	K.G. Vosburgh *et al.*	(RUTG, MASA)
BALATS	71	SJNP 13 53	M.Y. Balats *et al.*	(ITEP)
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BARMIN	71	PL 35B 604	V.V. Barmin *et al.*	(ITEP)
BISI	71	PL 36B 533	V. Bisi *et al.*	(AACH, CERN, TORI)
BURGUN	71	LNC 2 1169	G. Burgun *et al.*	(SACL, CERN, OSLO)
CARNEGIE	71	PR D4 1	R.K. Carnegie *et al.*	(PRIN)
CHAN	71	Thesis LBL-350	J.H.S. Chan	(LBL)
CHIEN	71	PL 35B 261	C.Y. Chien *et al.*	(JHU, SLAC, UCLA)
Also	72	PL 41B 647	E.B. Dally *et al.*	(SLAC, JHU, UCLA)
CHO	71	PR D3 1557	Y. Cho *et al.*	(CMU, BNL, CASE)
ENSTROM	71	PR D4 2629	J. Enstrom *et al.*	(SLAC, STAN)
Also	70	Thesis SLAC-0125	J.E. Enstrom	(STAN)
JAMES	71	PL 35B 265	F. James *et al.*	(CERN, SACL, OSLO)
MEISNER	71	PR D3 59	G.W. Meisner *et al.*	(MASA, BNL, YALE)
REPELLIN	71	PL 36B 603	J.P. Repellin *et al.*	(ORSAY, CERN)
WEBBER	71	PR D3 64	B.R. Webber *et al.*	(LRL)
Also	68	PRL 21 498	B.R. Webber *et al.*	(LRL)
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WOLFF	71	PL 36B 517	B. Wolff *et al.*	(ORSAY, CERN)
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BASILE	70	PR D2 78	P. Basile *et al.*	(SACL)
BECHERRAWY	70	PR D1 1452	T. Becherrawy	(ROCH)
BUCHANAN	70	PL 33B 623	C.D. Buchanan *et al.*	(SLAC, JHU, UCLA)
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BUDAGOV	70	PR D2 815	I.A. Budagov *et al.*	(CERN, ORSAY, EPOL)
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CHO	70	PR D1 3031	Y. Cho *et al.*	(CMU, BNL, CASE)
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SMITH	70	PL 32B 133	R.C. Smith *et al.*	(UMD, BNL)
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JAMES	68	NP B8 365	F. James, H. Briand	(IPNP, CERN)
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