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 "*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} $\hbar$ s^{-1})		*DOCUMENT ID*		*TECN*	*COMMENT*
0.5292±0.0010	**OUR FIT**	Error includes scale factor of 1.2. Assuming *CPT*			
0.5290±0.0016	**OUR FIT**	Error includes scale factor of 1.2. Not assuming *CPT*			
0.5261±0.0015		[1,2] ALAVI-HARATI	03	KTEV	Assuming *CPT*
0.5288±0.0043		[2,3] ALAVI-HARATI	03	KTEV	Not assuming *CPT*
0.5240±0.0044	±0.0033	APOSTOLA...	99C	CPLR	K^0-$\overline{K}^0$ to $\pi^+\pi^-$
0.5297±0.0030	±0.0022	[4] SCHWINGEN...	95	E773	20–160 GeV *K* beams
0.5286±0.0028		[5] GIBBONS	93	E731	Assuming *CPT*
0.5257±0.0049	±0.0021	[4] GIBBONS	93C	E731	Not assuming *CPT*
0.5340±0.00255	±0.0015	[6] GEWENIGER	74C	SPEC	Gap method
0.5334±0.0040	±0.0015	[6] GJESDAL	74	SPEC	Charge asymmetry in $K^0_{\ell 3}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.5343±0.0063	±0.0025	[7] ANGELOPO...	01	CPLR	
0.5295±0.0020	±0.0003	[8] ANGELOPO...	98D	CPLR	Assuming *CPT*
0.5307±0.0013		[9] ADLER	96C	RVUE	
0.5274±0.0029	±0.0005	[8] ADLER	95	CPLR	Sup. by ANGELOPOULOS 98D
0.482 ±0.014		[10] ARONSON	82B	SPEC	*E*=30–110 GeV
0.534 ±0.007		[11] CARNEGIE	71	ASPK	Gap method
0.542 ±0.006		[11] ARONSON	70	ASPK	Gap method
0.542 ±0.006		CULLEN	70	CNTR	

[1] ALAVI-HARATI 03 fit Δm and $\tau_{K^0_S}$ simultaneously. ϕ_{+-} is constrained to the Superweak value, i.e. *CPT* is assumed. See "K^0_S Mean Life" section for correlation information.

[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. They use 40–160 GeV *K* beams.

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

[4] Fits Δm and ϕ_{+-} simultaneously. GIBBONS 93C systematic error is from B. Winstein via private communication. 20–160 GeV *K* beams.

[5] GIBBONS 93 value assume $\phi_{+-} = \phi_{00} = \phi_{SW} = (43.7 \pm 0.2)^\circ$, i.e. assumes *CPT*. 20–160 GeV *K* beams.

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

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

[8] Uses $\overline{K}^0_{e3}$ and K^0_{e3} strangeness tagging at production and decay. Assumes CPT conservation on $\Delta S=-\Delta Q$ transitions.
[9] ADLER 96C is the result of a fit which includes nearly the same data as entered into the "OUR FIT" value above.
[10] ARONSON 82 find that Δm may depend on the kaon energy.
[11] 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*
5.18 ±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		[12] 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

[12] 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]	(38.81 ± 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]	(27.19 ± 0.25) %	S=1.1
Γ_5	$\pi^- \mu^+ \nu_\mu$				
Γ_6	$\pi^+ \mu^- \overline{\nu}_\mu$				
Γ_7	$(\pi\,\mu\,\text{atom})\nu$			$(1.06 \pm 0.11) \times 10^{-7}$	
Γ_8	$\pi^0 \pi^\pm e^\mp \nu$		[a]	$(5.18 \pm 0.29) \times 10^{-5}$	
	Hadronic modes, including Charge conjugation×Parity Violating (*CPV*) modes				
Γ_9	$3\pi^0$			(21.05 ± 0.23) %	S=1.1
Γ_{10}	$\pi^+ \pi^- \pi^0$			(12.59 ± 0.19) %	S=1.6
Γ_{11}	$\pi^+ \pi^-$	*CPV*		$(2.090 \pm 0.025) \times 10^{-3}$	S=1.1
Γ_{12}	$\pi^0 \pi^0$	*CPV*		$(9.32 \pm 0.12) \times 10^{-4}$	S=1.1

Semileptonic modes with photons

	Mode		Fraction	Scale factor / Confidence level
Γ_{13}	$\pi^{\pm} e^{\mp} \nu_e \gamma$	[*a*,*b*,*c*]	$(3.53 \pm 0.06) \times 10^{-3}$	
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

	Mode		Fraction	Scale factor / Confidence level
Γ_{15}	$\pi^0 \pi^0 \gamma$		$< 5.6 \times 10^{-6}$	
Γ_{16}	$\pi^+ \pi^- \gamma$	[*b*,*c*]	$(4.39 \pm 0.12) \times 10^{-5}$	S=1.8
Γ_{17}	$\pi^0 2\gamma$	[*c*]	$(1.41 \pm 0.12) \times 10^{-6}$	S=2.8
Γ_{18}	$\pi^0 \gamma e^+ e^-$		$(2.3 \pm 0.4) \times 10^{-8}$	

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

	Mode		Fraction	Scale factor / Confidence level
Γ_{19}	2γ		$(5.90 \pm 0.07) \times 10^{-4}$	S=1.1
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

	Mode			Fraction	Scale factor / Confidence level
Γ_{25}	$\mu^+ \mu^-$	*S1*		$(7.27 \pm 0.14) \times 10^{-9}$	
Γ_{26}	$e^+ e^-$	*S1*		$(9 {}^{+6}_{-4}) \times 10^{-12}$	
Γ_{27}	$\pi^+ \pi^- e^+ e^-$	*S1*	[*c*]	$(3.11 \pm 0.19) \times 10^{-7}$	
Γ_{28}	$\pi^0 \pi^0 e^+ e^-$	*S1*		$< 6.6 \times 10^{-9}$	CL=90%
Γ_{29}	$\mu^+ \mu^- e^+ e^-$	*S1*		$(2.69 \pm 0.27) \times 10^{-9}$	
Γ_{30}	$e^+ e^- e^+ e^-$	*S1*		$(3.75 \pm 0.27) \times 10^{-8}$	
Γ_{31}	$\pi^0 \mu^+ \mu^-$	*CP*,*S1*	[*d*]	$< 3.8 \times 10^{-10}$	CL=90%
Γ_{32}	$\pi^0 e^+ e^-$	*CP*,*S1*	[*d*]	$< 5.1 \times 10^{-10}$	CL=90%
Γ_{33}	$\pi^0 \nu \overline{\nu}$	*CP*,*S1*	[*e*]	$< 5.9 \times 10^{-7}$	CL=90%
Γ_{34}	$e^{\pm} \mu^{\mp}$	*LF*	[*a*]	$< 4.7 \times 10^{-12}$	CL=90%
Γ_{35}	$e^{\pm} e^{\pm} \mu^{\mp} \mu^{\mp}$	*LF*	[*a*]	$< 4.12 \times 10^{-11}$	CL=90%
Γ_{36}	$\pi^0 \mu^{\pm} e^{\mp}$	*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 15 branching ratios uses 50 measurements and one constraint to determine 9 parameters. The overall fit has a χ^2 = 43.7 for 42 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	−38							
x_9	−48	−37						
x_{10}	−34	−33	−5					
x_{11}	−25	−21	34	20				
x_{12}	−27	−22	42	16	86			
x_{16}	−9	−8	13	8	37	32		
x_{19}	−42	−33	86	−1	42	50	16	
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	1.1
Γ_{10}	$\pi^+ \pi^- \pi^0$		0.0243±0.0004	1.5
Γ_{11}	$\pi^+ \pi^-$		$(4.04 \pm 0.06) \times 10^{-4}$	1.1
Γ_{12}	$\pi^0 \pi^0$		$(1.800 \pm 0.027) \times 10^{-4}$	1.1
Γ_{16}	$\pi^+ \pi^- \gamma$	[b,c]	$(8.48 \pm 0.25) \times 10^{-6}$	1.7
Γ_{19}	2γ		$(1.140 \pm 0.016) \times 10^{-4}$	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	[13] 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. • • •

$2.5\ \pm0.3$	98	[13] JAMES	71	HBC	Assumes CP
3.26 ± 0.77	18	ANDERSON	65	HBC	
$1.4\ \pm0.4$	14	FRANZINI	65	HBC	

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

$\Gamma(\pi^{\pm}e^{\mp}\nu_e)$ $\qquad\qquad\Gamma_1$

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	ΔS=ΔQ,CP assumed

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

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.				
$12.4\ \pm0.7$	410	[14] BURGUN 72	HBC	$K^+p\rightarrow K^0p\pi^+$
$13.1\ \pm1.3$	252	[14] WEBBER 71	HBC	$K^-p\rightarrow n\overline{K}^0$
$11.6\ \pm0.9$	393	[14,15] CHO 70	DBC	$K^+n\rightarrow K^0p$
$9.85^{+1.15}_{-1.05}$	109	[14] FRANZINI 65	HBC	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
8.47 ± 1.69	126	[14] MANN 72	HBC	$K^-p\rightarrow n\overline{K}^0$
$10.3\ \pm0.8$	335	[15] HILL 67	DBC	$K^+n\rightarrow K^0p$

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

K^0_L BRANCHING RATIOS

Semileptonic modes

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

VALUE	DOCUMENT ID
0.6599±0.0029 OUR FIT Error includes scale factor of 1.3.	

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

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
$0.71\ \pm0.05$	770	BUDAGOV 68	HLBC
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$0.68\ \pm0.08$	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	[16] ARONSON	86	SPEC
• • • We do not use the following data for averages, fits, limits, etc. • • •				
seen	18	COOMBES	76	WIRE

[16] 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		[17] DONALDSON	74	SPEC

[17] DONALDSON 74 uses $K_L^0 \rightarrow \pi^+\pi^-\pi^0$/(all K_L^0) 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
0.2105±0.0023 OUR FIT Error includes scale factor of 1.1.				
0.2105±0.0028	38k	[18] KREUTZ	95	NA31

[18] 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
0.542±0.008 OUR FIT Error includes scale factor of 1.1.				
0.545±0.004±0.009	38k	[19] KREUTZ	95	NA31

[19] 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
1.673±0.032 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	[20] 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

[20] 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

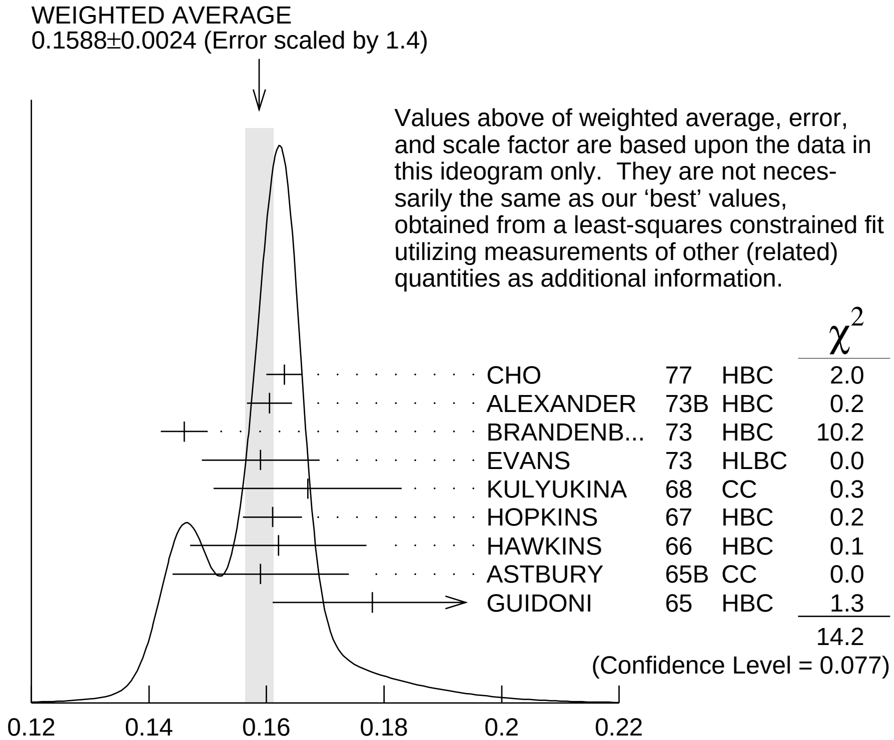
VALUE	DOCUMENT ID
0.1259±0.0019 OUR FIT Error includes scale factor of 1.6.	

$\Gamma(\pi^+\pi^-\pi^0)/\Gamma(\pi^\pm e^\mp \nu_e)$ — 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

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.1602±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



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

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

Violates *CP* conservation.

VALUE (units 10^{-3})	*DOCUMENT ID*	
2.090±0.025 OUR FIT Error includes scale factor of 1.1.		
2.081±0.048	ETAFIT	04

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

Violates *CP* conservation.

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
3.17±0.05 OUR FIT Error includes scale factor of 1.1.					
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	[21] DEBOUARD	67	OSPK	η_{+-}=2.00 ± 0.09
2.35±0.19	525	[21] FITCH	67	OSPK	η_{+-}=1.94 ± 0.08

[21] Old experiments excluded from fit. See subsection on η_{+-} in section on "PARAMETERS FOR $K^0_L \rightarrow 2\pi$ 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*
2.659±0.035 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	[22] MESSNER	73	ASPK	η_{+-} = 2.23 ± 0.05

[22] 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*
1.660±0.028 OUR FIT Error includes scale factor of 1.2.					
1.64 ±0.04	4200	MESSNER	73	ASPK	η_{+-} = 2.23

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

Violates *CP* conservation.

VALUE (units 10^{-3})	*DOCUMENT ID*
0.932±0.012 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*	
0.4458±0.0029 OUR FIT		
0.4458±0.0030	ETAFIT	04

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

Violates *CP* conservation.

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.443±0.006 OUR FIT					
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*
$\mathbf{2.08\pm0.17^{+0.16}_{-0.21}}$	252	BENDER	98	NA48	$E^*_\gamma \geq 30$ MeV

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

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

$\Gamma(\pi^+\pi^-\gamma)/\Gamma_{\text{total}}$ 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
4.39±0.12 OUR FIT	Error includes scale factor of 1.8.				
4.61±0.14 OUR AVERAGE					
4.66±0.15	3136	[23] RAMBERG	93	E731	E_γ >20 MeV
4.41±0.32	1062	[24] CARROLL	80B	SPEC	E_γ >20 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1.52±0.16	516	[25] CARROLL	80B	SPEC	E_γ >20 MeV
2.89±0.28	546	[26] CARROLL	80B	SPEC	

[23] RAMBERG 93 finds that fraction of Direct Emission (DE) decays with E_γ >20 MeV is 0.685 ± 0.041.

[24] Both components. Uses $K^0_L \rightarrow \pi^+\pi^-\pi^0$/(all K^0_L) decays = 0.1239.

[25] Internal Bremsstrahlung component only.

[26] 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 ±0.05 OUR FIT	Error includes scale factor of 2.1.				
2.08 ±0.02 ±0.02	8669	[27] ALAVI-HARATI	01B	KTEV	E^*_γ >20 MeV

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

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

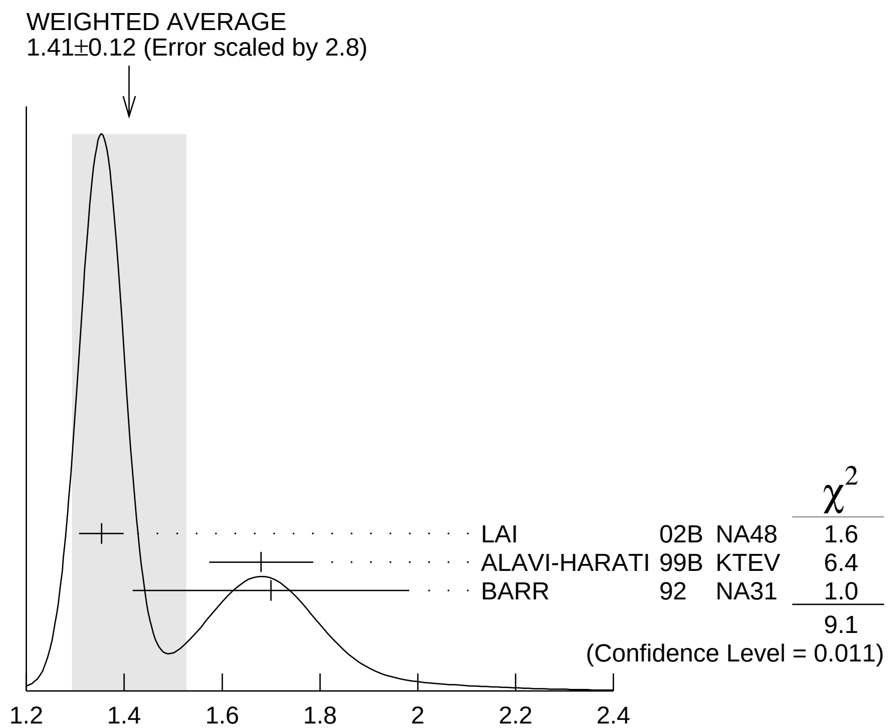
VALUE (units 10^{-6})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
1.41±0.12 OUR AVERAGE	Error includes scale factor of 2.8. See the ideogram below.					
1.35±0.04±0.02		2.5k	[28] LAI	02B	NA48	
1.68±0.07±0.08		884	[29] ALAVI-HARATI	99B	KTEV	
1.7 ±0.2 ±0.2		63	[30] BARR	92	NA31	
• • • We do not use the following 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	[31] BARR	90C	NA31	$m_{\gamma\gamma}$ > 280 MeV

[28] LAI 02B reports $1.36 \pm 0.03 \pm 0.03$ for B($K^0_L \rightarrow \pi^0\pi^0$) = 9.27×10^{-4}. We rescale to our best value B($K^0_L \rightarrow \pi^0\pi^0$) = $(9.32 \pm 0.12) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. They also find that B($\pi^0 2\gamma$, $m_{\gamma\gamma}$ <110 MeV) < 0.6×10^{-8}(90% CL).

[29] ALAVI-HARATI 99B finds that $\Gamma(\pi^0 2\gamma,\ m_{\gamma\gamma} < 240\ \text{MeV})) / \Gamma(\pi^0 2\gamma) = (17.3 \pm 1.3 \pm 1.5)\%$.

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

[31] BARR 90C superseded by BARR 92.



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

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

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

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
5.90±0.07 OUR FIT Error includes scale factor of 1.1.					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
4.54±0.84		[32] BANNER	72B	OSPK	
4.5 ±1.0	23	ENSTROM	71	OSPK	K^0_L 1.5–9 GeV/c
5.0 ±1.0		[33] REPELLIN	71	OSPK	
5.5 ±1.1	90	KUNZ	68	OSPK	Norm.to 3 π(C+N)

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

[33] 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*
2.801±0.017 OUR FIT					
2.802±0.018 OUR AVERAGE					
2.79 ±0.02 ±0.02	27k	ADINOLFI	03	KLOE	
2.81 ±0.01 ±0.02		LAI	03	NA48	
• • • 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*
0.633±0.008 OUR FIT				
0.632±0.004±0.008	110k	BURKHARDT	87	NA31

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

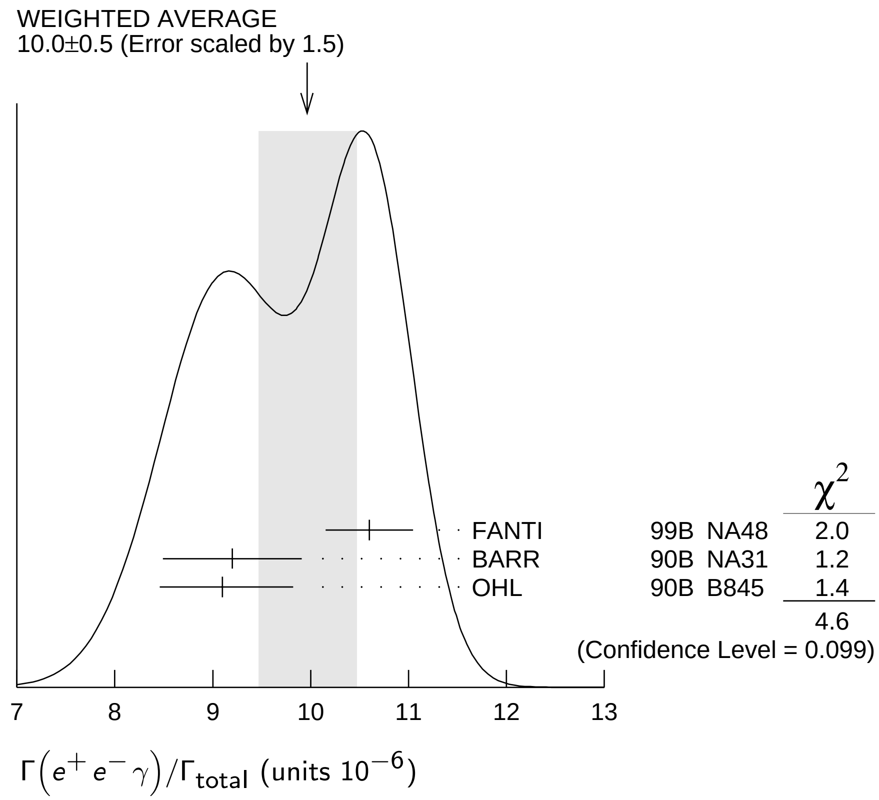
VALUE	*CL%*	*DOCUMENT ID*		*TECN*
<2.4 × 10^{-7}	90	[34] BARR	95C	NA31

[34] 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	[35] FANTI	99B	NA48
9.2±0.5±0.5	1053	BARR	90B	NA31
$9.1\pm0.4^{+0.6}_{-0.5}$	919	OHL	90B	B845

[35] 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 $K^0_L \to \pi^0\pi^0$ branching ratios, evaluated using our 1999 Web edition values.



$\Gamma(\mu^+\mu^-\gamma)/\Gamma_{total}$ 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

$\Gamma(e^+e^-\gamma\gamma)/\Gamma_{total}$ 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^*_γ >5 MeV
8.0 ±1.5 $^{+1.4}_{-1.2}$	40	SETZU	98	NA31	E_γ > 5 MeV
6.5 ±1.2 ±0.6	58	NAKAYA	94	E799	E_γ > 5 MeV
6.6 ±3.2		MORSE	92	B845	E_γ > 5 MeV

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

VALUE (units 10^{-9})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$10.4^{+7.5}_{-5.9}$±0.7	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	[36] 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	[37] AKAGI	91B	SPEC	In AKAGI 95
3.45 ±0.18 ±0.13	368	[38] 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

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

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

[38] 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	[39] ARISAKA	93B	B791

[39] 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
3.11±0.19 OUR AVERAGE						
3.08±0.09±0.18		1125	[40] LAI	03C	NA48	
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

[40] LAI 03C second error is 0.15(syst)±0.10(norm) combined in quadrature. The normalization uses BR($K_L \to \pi^+\pi^-\pi^0$) * BR($\pi^0 \to e^+e^-$) = $(1.505 \pm 0.047) \times 10^{-3}$ from our 2000 Edition.

$\Gamma(\pi^0\pi^0e^+e^-)/\Gamma_{\text{total}}$ 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
<6.6	90	1	ALAVI-HARATI	02C	E799

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

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

VALUE (units 10^{-9})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
2.69±0.27 OUR AVERAGE						
2.69±0.24±0.12		131	[41] ALAVI-HARATI	03B	KTEV	
2.9 $^{+6.7}_{-2.4}$		1	GU	96	E799	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
2.62±0.40±0.17		43	ALAVI-HARATI	01H	KTEV	Sup. by ALAVI-HARATI 03B
<4900	90		BALATS	83	SPEC	

[41] ALAVI-HARATI 03B also measures the linear slope $\alpha = -1.59 \pm 0.37$.

$\Gamma(e^+e^-e^+e^-)/\Gamma_{total}$ Γ_{30}/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	[42] 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	[42] AKAGI	95	SPEC	m_{ee} >470 MeV
10.4 ±3.7 ±1.1	8	[43] BARR	95	NA31	
6 ±2 ±1	18	AKAGI	93	CNTR	Sup. by AKAGI 95
4 ±3	2	BARR	91	NA31	Sup. by BARR 95

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

$\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{total}$ Γ_{31}/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_{32}/Γ

Violates *CP* in leading order. Direct and indirect *CP*-violating contributions are expected to be comparable and to dominate the *CP*-conserving part. LAI 02B result suggests that *CP*-violation effects dominate. Test for $\Delta S = 1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10^{-10})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 5.1	90	2	ALAVI-HARATI	01	KTEV	

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

$0.0047^{+0.0022}_{-0.0018}$			[44] LAI	02B	NA48	CP-conserving part
0.01 to 0.02			ALAVI-HARATI	99B	KTEV	CP-conserving part
< 43	90	0	HARRIS	93B	E799	
< 75	90	0	BARKER	90	E731	
< 55	90	0	OHL	90	B845	
< 400	90		BARR	88	NA31	
<3200	90		JASTRZEM...	88	SPEC	

[44] LAI 02B uses the absence of a signal in $K^0_L \to \pi^0\gamma\gamma$ with $m(\gamma\gamma)<m(\pi^0)$ and their a_V value to predict this value.

$\Gamma(\pi^0\nu\overline{\nu})/\Gamma_{total}$ — Γ_{33}/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_{34}/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	[45] ARISAKA	93	B791

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

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

Test of lepton family number conservation.

VALUE (units 10^{-11})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 4.12	90	0	ALAVI-HARATI	03B	KTEV	

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

< 12.3	90	0	[46] ALAVI-HARATI	01H	KTEV	Sup. by ALAVI-HARATI 03B
<610	90	0	[46] GU	96	E799	

[46] Assuming uniform phase space distribution.

$\Gamma(\pi^0\mu^\pm e^\mp)/\Gamma_{total}$ — Γ_{36}/Γ

Test of lepton family number conservation.

VALUE	CL%	DOCUMENT ID		TECN
$<6.2 \times 10^{-9}$	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).

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

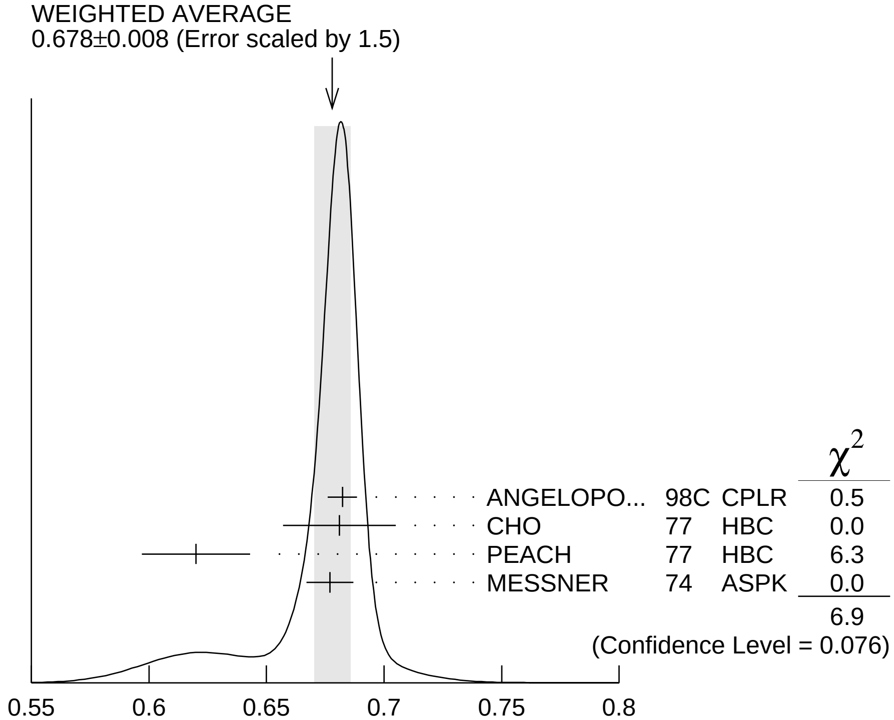
LINEAR COEFFICIENT g FOR $K^0_L \to \pi^+\pi^-\pi^0$

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	[47] BALDO-...	75	HLBC	
0.590 ±0.022	56k	[47] BUCHANAN	75	SPEC	$a_u = -0.277 \pm 0.010$
0.619 ±0.027	20k	[47,48] BISI	74	ASPK	$a_t = -0.282 \pm 0.011$
0.612 ±0.032		[47] ALEXANDER	73B	HBC	
0.73 ±0.04	3200	[47] BRANDENB...	73	HBC	
0.608 ±0.043	1486	[47] KRENZ	72	HLBC	$a_t = -0.277 \pm 0.018$
0.650 ±0.012	29k	[47] ALBROW	70	ASPK	$a_y = -0.858 \pm 0.015$
0.593 ±0.022	36k	[47,49] BUCHANAN	70	SPEC	$a_u = -0.278 \pm 0.010$
0.664 ±0.056	4400	[47] SMITH	70	OSPK	$a_t = -0.306 \pm 0.024$
0.400 ±0.045	2446	[47] BASILE	68B	OSPK	$a_t = -0.188 \pm 0.020$
0.649 ±0.044	1350	[47] HOPKINS	67	HBC	$a_t = -0.294 \pm 0.018$
0.428 ±0.055	1198	[47] NEFKENS	67	OSPK	$a_u = -0.204 \pm 0.025$

[47] 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.

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

[49] 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 $K^0_L \to \pi^+\pi^-\pi^0$ matrix element squared

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

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	[50] ALBROW	70	ASPK
0.043±0.052	4400	[50] SMITH	70	OSPK

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

[50] 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 $K^0_L \to \pi^+\pi^-\pi^0$

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 $K^0_L \to \pi^+\pi^-\pi^0$ (CP-VIOLATING TERM)

Listed in CP-violation section below.

QUADRATIC COEFFICIENT f FOR $K^0_L \to \pi^+\pi^-\pi^0$ (CP-VIOLATING TERM)

Listed in CP-violation section below.

QUADRATIC COEFFICIENT h FOR $K^0_L \to \pi^0\pi^0\pi^0$

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	[51] SOMALWAR	92	E731

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

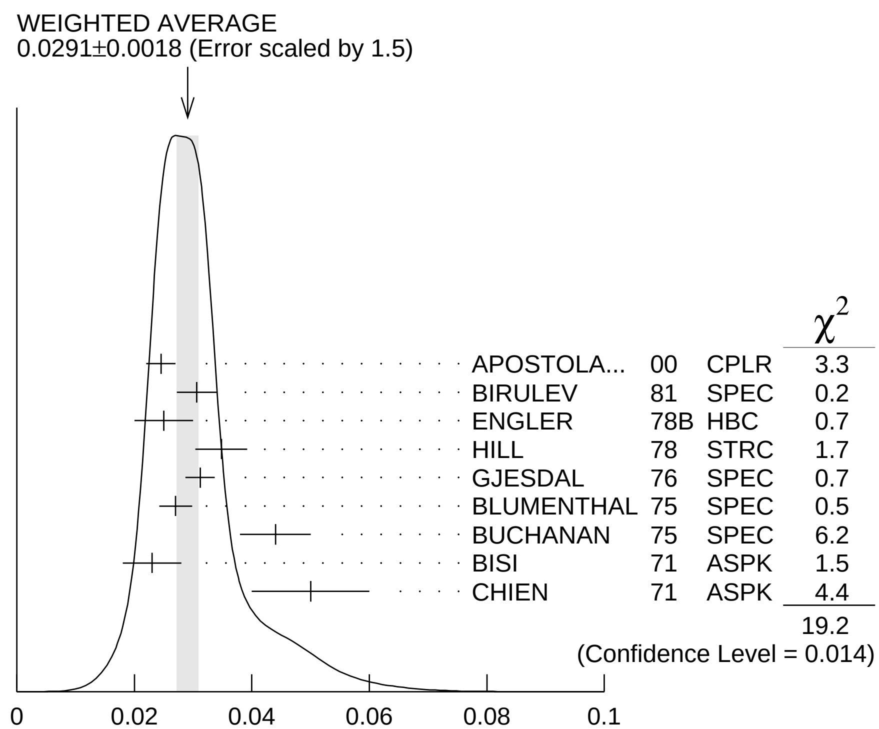
λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN K^0_{e3} DECAY)

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	[52] 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	[52] 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

[52] 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 $K^0_{\mu 3}$ spectra)

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_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	$d\xi(0)/d\lambda_+$	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	[53] BIRULEV	81	SPEC	DP
+0.26±0.16	−13	14k	[54] CHO	80	HBC	DP

$+0.13\pm0.23$	-20	16k	[54] HILL	79	STRC	DP
-0.25 ± 0.22	-5.9	32k	[55] BUCHANAN	75	SPEC	DP
-0.11 ± 0.07	-17	1.6M	[56] DONALDSON	74B	SPEC	DP
• • • We do not use the following data for averages, fits, limits, etc. • • •						
-1.00 ± 0.45	-20	1385	[57] PEACH	73	HLBC	DP
$-1.5\ \pm0.7$	-28	9086	[58] ALBROW	72	ASPK	DP
$+0.50\pm0.61$	unknown	16k	[59] DALLY	72	ASPK	DP
$-3.9\ \pm0.4$		3140	[60] BASILE	70	OSPK	DP, indep of λ_+
$-0.68^{+0.12}_{-0.20}$	-26	16k	[59] CHIEN	70	ASPK	DP
$+1.2\ \pm0.8$	-18	1341	[61] CARPENTER	66	OSPK	DP

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

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

[55] 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. $\lambda_- = \lambda_+$.

[56] 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 $d\lambda_0/d\lambda_+$.

[57] 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).

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

[59] 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.

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

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

$\xi_B = f_-/f_+$ (determined from $K^0_{\mu3}/K^0_{e3}$)

The $K^0_{\mu3}/K^0_{e3}$ 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 $K^0_{\mu3}/K^0_{e3}$ branching ratios to obtain the fitted $K^0_{\mu3}/K^0_{e3}$ ratio which is then converted to the KL3FIT value below, as discussed in the review "$K^\pm_{\ell3}$ and $K^0_{\ell3}$ 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.					
0.13 ± 0.07		[62] KL3FIT	04	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	[63] 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	[63] 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

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

[63] 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	[64] CLARK	77	SPEC	POL, $d\xi(0)/d\lambda_+$=+0.68
−0.385±0.105	2.2M	[65] SANDWEISS	73	CNTR	POL, $d\xi(0)/d\lambda_+$=−6

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

$-1.81\ ^{+0.50}_{-0.26}$		[66] LONGO	69	CNTR	POL, t=3.3
−1.6 ±0.5	638	[67] ABRAMS	68B	OSPK	Polarization
−1.2 ±0.5	2608	[67] AUERBACH	66B	OSPK	Polarization

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

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

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

[67] t value not given.

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 $d\lambda_0/d\lambda_+ = -0.17$.						
0.041 ±0.006	0.13		[68] KL3FIT	04	RVUE	$\lambda_+ = 0.030$
0.0341±0.0067	unknown	150k	[69] 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	[70] CLARK	77	SPEC	POL
+0.025 ±0.019	+0.5	32k	[71] BUCHANAN	75	SPEC	DP
+0.019 ±0.004	−0.47	1.6M	[72] DONALDSON	74B	SPEC	DP
−0.018 ±0.009	+0.49	2.2M	[70] SANDWEISS	73	CNTR	POL
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.041 ±0.008		14k	[73] 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	[74] BRANDENB...	73	HBC	BR, λ_+=0.019 ± 0.013
−0.060 ±0.038	−0.71	1385	[75] PEACH	73	HLBC	DP
−0.043 ±0.052	−1.39	9086	[76] ALBROW	72	ASPK	DP
−0.067 ±0.227	unknown	16k	[77] DALLY	72	ASPK	DP
−0.333 ±0.034	+1.	3140	[78] BASILE	70	OSPK	DP
$-0.140\ ^{+0.043}_{-0.022}$	+0.49		[70] LONGO	69	CNTR	POL
+0.08 ±0.07	−0.54	1371	[70] CARPENTER	66	OSPK	DP

[68] KL3FIT 04 value is from our fitted value of the $K^{\pm}_{\mu 3}/K^{\pm}_{e3}$ branching ratio. Assumes $\mu - e$ universality.
[69] BIRULEV 81 gives $d\lambda_0/d\lambda_+ = -1.5$, giving an unreasonably narrow error ellipse which dominates all other results. We use $d\lambda_0/d\lambda_+ = 0$.
[70] λ_0 value is for $\lambda_+ = 0.03$ calculated by us from $\xi(0)$ and $d\xi(0)/d\lambda_+$.
[71] 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.
[72] DONALDSON 74B $d\lambda_0/d\lambda_+$ obtained from figure 18.
[73] CHO 80 BR result not independent of their Dalitz plot result.
[74] Fit for λ_0 does not include this value but instead includes the $K_{\mu 3}/K_{e3}$ result from this experiment.
[75] PEACH 73 assumes $\lambda_+ = 0.025$. Calculated by us from $\xi(0)$ and $d\xi(0)/d\lambda_+$.
[76] 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.
[77] 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.
[78] 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				
$-0.36 \pm 0.06 \pm 0.02$	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

a_1/a_2 FORM FACTOR FOR M1 DIRECT EMISSION AMPLITUDE

Form factor $= \tilde{g}_{M1}\Big[1+\frac{a_1/a_2}{(M_\rho^2-M_K^2)+2M_K E_\gamma^*}\Big]$ as described in ALAVI-HARATI 00B.

VALUE (GeV^2)	EVTS	DOCUMENT ID		TECN	COMMENT
−0.734±0.022 OUR AVERAGE					
$-0.81 \ ^{+0.07}_{-0.13} \pm 0.02$		[79] LAI	03C	NA48	$\pi^+ \pi^- e^+ e^-$
$-0.737 \pm 0.026 \pm 0.022$		[80] ALAVI-HARATI	01B		$\pi^+ \pi^- \gamma$
$-0.720 \pm 0.028 \pm 0.009$	1766	[81] ALAVI-HARATI	00B	KTEV	$\pi^+ \pi^- e^+ e^-$

[79] LAI 03C also measured $\widetilde{g}_{M1} = 0.99^{+0.28}_{-0.27} \pm 0.07$.

[80] ALAVI-HARATI 01B fit gives χ^2/DOF = 38.8/27. Linear and quadratic fits give χ^2/DOF = 43.2/27 and 37.6/26 respectively.

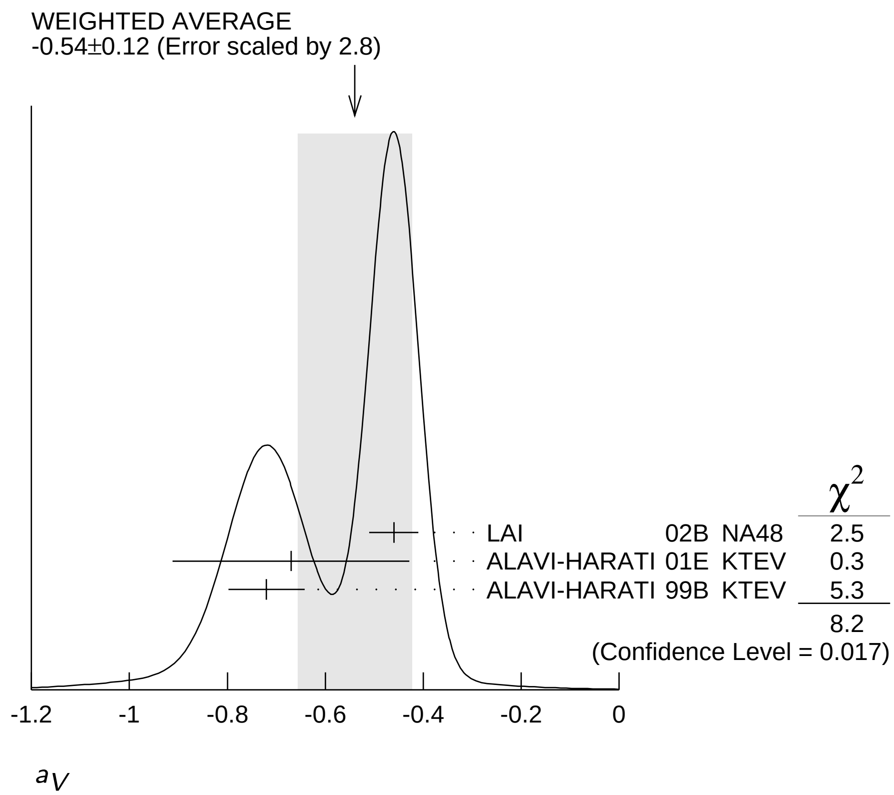
[81] ALAVI-HARATI 00B also measured $\widetilde{g}_{M1} = 1.35^{+0.20}_{-0.17} \pm 0.04$.

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
−0.54±0.12 OUR AVERAGE	Error includes scale factor of 2.8. See the ideogram below.			
−0.46±0.03±0.04	LAI	02B	NA48	$K^0_L \to \pi^0 2\gamma$
−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	$K^0_L \to \pi^0 2\gamma$



CP VIOLATION IN K_L DECAYS

Revised March 2004 by L. Wolfenstein (Carnegie-Mellon University) and T.G. Trippe (LBNL).

The symmetries C (particle-antiparticle interchange) and P (space inversion) hold for strong and electromagnetic interactions. After the discovery of large C and P violation in the weak interactions, it appeared that the product CP was a good symmetry. In 1964 CP violation was observed in K^0 decays at a level given by the parameter $\epsilon \approx 2.3 \times 10^{-3}$.

A unified treatment of CP violation in K, D, B, and B_s mesons is given in "CP Violation in Meson Decays" by

D. Kirkby and Y. Nir in this *Review.* A recent book by K. Kleinknecht [1] gives a more detailed review including a thorough discussion of the experimental techniques used to determine CP violation parameters. Here we give a concise summary of the formalism needed to define the parameters of CP violation in K_L decays and a description of our fits for the best values of these parameters.

1. Formalism for CP violation in Kaon decay:

CP violation has been observed in the semi-leptonic decays $K_L^0 \to \pi^\mp \ell^\pm \nu$ and in the nonleptonic decay $K_L^0 \to 2\pi$. The experimental numbers that have been measured are

$$\delta_L = \frac{\Gamma(K_L^0 \to \pi^- \ell^+ \nu) - \Gamma(K_L^0 \to \pi^+ \ell^- \nu)}{\Gamma(K_L^0 \to \pi^- \ell^+ \nu) + \Gamma(K_L^0 \to \pi^+ \ell^- \nu)} \qquad (1a)$$

$$\begin{aligned} \eta_{+-} &= A(K_L^0 \to \pi^+\pi^-)/A(K_S^0 \to \pi^+\pi^-) \\ &= |\eta_{+-}|\, e^{i\phi_{+-}} \qquad (1b) \\ \eta_{00} &= A(K_L^0 \to \pi^0\pi^0)/A(K_S^0 \to \pi^0\pi^0) \\ &= |\eta_{00}|\, e^{i\phi_{00}} \ . \qquad (1c) \end{aligned}$$

CP violation can occur either in the K^0–$\overline{K}^0$ mixing or in the decay amplitudes. Assuming CPT invariance, the mass eigenstates of the K^0–$\overline{K}^0$ system can be written

$$|K_S\rangle = p|K^0\rangle + q|\overline{K}^0\rangle \ , \qquad |K_L\rangle = p|K^0\rangle - q|\overline{K}^0\rangle \ . \qquad (2)$$

If CP invariance held, we would have $q = p$ so that K_S would be CP even and K_L CP odd. (We define $|\overline{K}^0\rangle$ as $CP\ |K^0\rangle$). CP violation in K^0–$\overline{K}^0$ mixing is then given by the parameter $\widetilde{\epsilon}$ where

$$\frac{p}{q} = \frac{(1+\widetilde{\epsilon})}{(1-\widetilde{\epsilon})} \ . \qquad (3)$$

CP violation can also occur in the decay amplitudes

$$A(K^0 \to \pi\pi(I)) = A_I e^{i\delta_I} \ , \qquad A(\overline{K}^0 \to \pi\pi(I)) = A_I^* e^{i\delta_I} \ , \qquad (4)$$

where I is the isospin of $\pi\pi$, δ_I is the final-state phase shift, and A_I would be real if CP invariance held. The CP-violating observables are usually expressed in terms of ϵ and ϵ' defined by

$$\eta_{+-} = \epsilon + \epsilon' \ , \qquad \eta_{00} = \epsilon - 2\epsilon' \ , \tag{5a}$$

One can then show [2]

$$\epsilon = \widetilde{\epsilon} + i \ (\text{Im}\ A_0/\text{Re}\ A_0) \ , \tag{5b}$$

$$\sqrt{2}\epsilon' = ie^{i(\delta_2-\delta_0)}(\text{Re}\,A_2/\text{Re}\,A_0) \ (\text{Im}\,A_2/\text{Re}\,A_2 - \text{Im}\,A_0/\text{Re}\ A_0) \ , \tag{5c}$$

$$\delta_L = 2\text{Re}\ \epsilon/(1+|\epsilon|^2) \approx 2\text{Re}\ \epsilon \ . \tag{5d}$$

In Eqs. (5a) small corrections of order $\epsilon' \times$ Re (A_2/A_0) are neglected and Eq. (5d) assumes the $\Delta S = \Delta Q$ rule.

The quantities Im A_0, Im A_2, and Im $\widetilde{\epsilon}$ depend on the choice of phase convention since one can change the phases of K^0 and $\overline{K}^0$ by a transformation of the strange quark state $|s\rangle \rightarrow |s\rangle \ e^{i\alpha}$; of course, observables are unchanged. It is possible by a choice of phase convention to set Im A_0 or Im A_2 or Im $\widetilde{\epsilon}$ to zero, but none of these is zero with the usual phase conventions in the Standard Model. The choice Im $A_0 = 0$ is called the Wu-Yang phase convention [3] in which case $\epsilon = \widetilde{\epsilon}$. The value of ϵ' is independent of phase convention and a nonzero value demonstrates CP violation in the decay amplitudes, referred to as direct CP violation. The possibility that direct CP violation is essentially zero and that CP violation occurs only in the mixing matrix was referred to as the superweak theory [4].

By applying CPT invariance and unitarity the phase of ϵ is given approximately by

$$\phi_\epsilon \approx \ \tan^{-1} \frac{2(m_{K_L} - m_{K_S})}{\Gamma_{K_S} - \Gamma_{K_L}} \approx 43.51 \pm 0.05^\circ \tag{6a}$$

while Eq. ($5c$) gives the phase of ϵ' to be

$$\phi_{\epsilon'} = \delta_2 - \delta_0 + \frac{\pi}{2} \approx 48 \pm 4^\circ \ , \qquad (6b)$$

where the numerical value is based on an analysis of π–π scattering [5]. The approximation in Eq. ($6a$) depends on the assumption that direct CP violation is very small in all K^0 decays. This is expected to be good to a few tenths of a degree as indicated by the small value of ϵ' and of η_{+-0}, the CP-violation parameter in the decay $K_S \to \pi^+\pi^-\pi^0$ [6], although limits on η_{000} are still poor. The relation in Eq. ($6a$) is exact in the superweak theory so this is sometimes called the superweak phase $\phi_{\rm SW}$. An important point for the analysis is that $\cos(\phi_{\epsilon'}–\phi_\epsilon) \simeq 1$. The consequence is that only two real quantities need be measured, the magnitude of ϵ and the value of (ϵ'/ϵ) including its sign. The measured quantity $|\eta_{00}/\eta_{+-}|^2$, which is very close to unity so that we can write

$$|\eta_{00}/\eta_{+-}|^2 \approx 1 - 6{\rm Re}\ (\epsilon'/\epsilon) \approx 1 - 6\epsilon'/\epsilon\ . \qquad (7a)$$

$$\mathrm{Re}(\epsilon'/\epsilon) \approx \tfrac{1}{3}(1 - |\eta_{00}/\eta_{+-}|)\ . \qquad (7b)$$

From the experimental measurements in this Edition of the *Review of Particle Physics* and the fits discussed in the next section, one finds

$$|\epsilon| = (2.284 \pm 0.014) \times 10^{-3}\ , \qquad (8a)$$

$$\phi_\epsilon = (43.5 \pm 0.7)^\circ\ , \qquad (8b)$$

$$\mathrm{Re}(\epsilon'/\epsilon) \approx \epsilon'/\epsilon = (1.67 \pm 0.26) \times 10^{-3}\ , \qquad (8c)$$

$$\phi_{+-} = (43.4 \pm 0.7)^\circ\ , \qquad (8d)$$

$$\phi_{00}–\phi_{+-} = (0.2 \pm 0.4)^\circ\ , \qquad (8e)$$

$$\delta_L = (3.27 \pm 0.12) \times 10^{-3}\ . \qquad (8f)$$

Direct CP violation, as indicated by ϵ'/ϵ, is expected in the Standard Model. However the numerical value cannot be reliably predicted because of theoretical uncertainties [7]. The value of δ_L agrees with Eq. ($5d$). The values of ϕ_{+-} and $\phi_{00} - \phi_{+-}$ are used to set limits on CPT violation. [See Tests of Conservation Laws.]

2. Fits for K_L^0 CP-violation parameters:

In recent years, K_L^0 CP-violation experiments have improved our knowledge of CP-violation parameters and their consistency with the expectations of CPT invariance and unitarity. To determine the best values of the CP-violation parameters in $K_L^0 \to \pi^+\pi^-$ and $\pi^0\pi^0$ decay, we make two types of fits, 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.

Fits to ϕ_{+-}, ϕ_{00}, $\Delta\phi$, Δm, and τ_S data: These are joint fits 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 most cases, the correlations are quoted as 100%, *i.e.*with the value and error of ϕ_{+-} or ϕ_{00} given at a fixed value of Δm and τ_S with additional terms specifying the dependence of the value on Δm and τ_S. These cases lead to diagonal bands in Figs. [1] and [2]. The KTeV experiment [8] quotes its results as values of ϕ_{+-}, Δm, and τ_S with correlations, leading to the ellipses labeled "b".

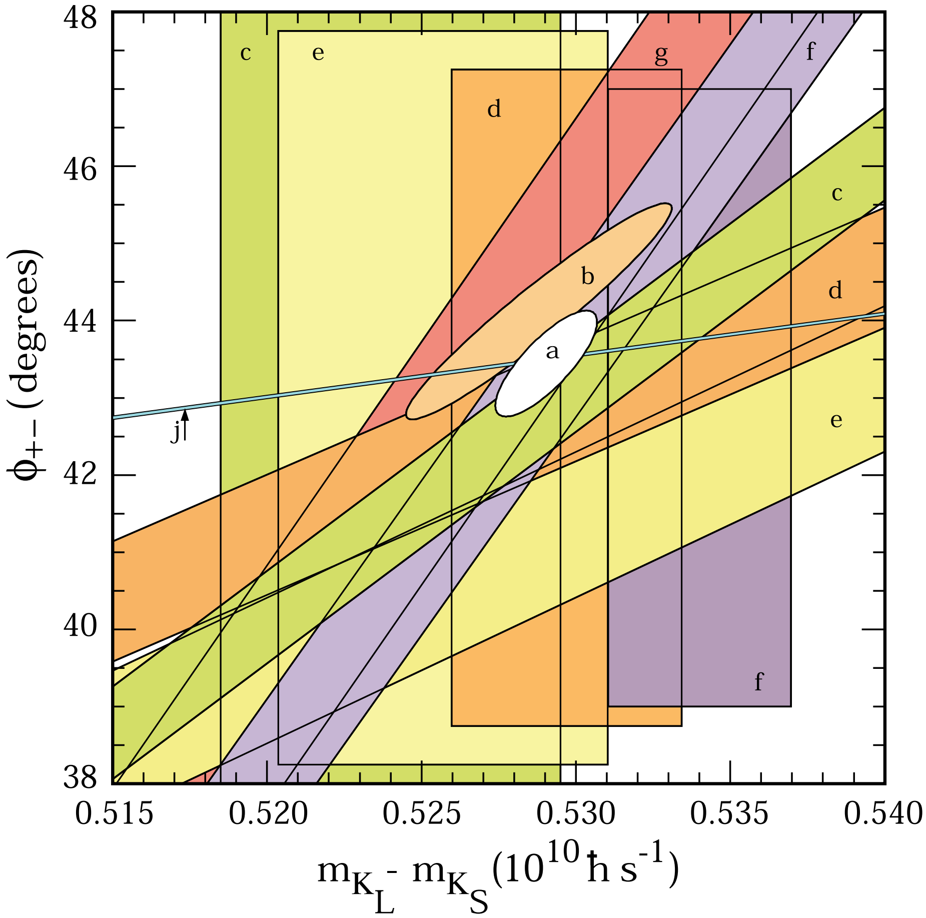


Figure 1: ϕ_{+-} vs Δm for experiments which do not assume CPT invariance. Δm measurements appear as vertical bands spanning $\Delta m \pm 1\sigma$, cut near the top and bottom to aid the eye. Most ϕ_{+-} measurements appear as diagonal bands spanning $\phi_{+-} \pm \sigma_\phi$. Data are labeled by letters: "b"–FNAL KTeV, "c"–CERN CPLEAR, "d"–FNAL E773, "e"–FNAL E731, "f"–CERN, "g"–CERN NA31, and are cited in Table 1. The narrow band "j" shows $\phi_{\rm SW}$. The ellipse "a" shows the $\chi^2 = 1$ contour of the fit result. See full-color version on color pages at end of book.

The data on τ_S, Δm, and ϕ_{+-} shown in Figs. [1] and [2]. are combined with data on ϕ_{00} and $\phi_{00} - \phi_{+-}$ in two fits, one without assuming CPT and the other with this assumption. The results without assuming CPT are shown as ellipses labeled

Table 1: References, Document ID's, and sources corresponding to the letter labels in the figures. 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.

Label	Source	PDG Document ID	Ref.
a	this review	OUR FIT	
b	FNAL KTeV	ALAVI-HARATI 03	[8]
c	CERN CPLEAR	APOSTOLAKIS 99C	[9]
d	FNAL E773	SCHWINGENHEUER 95	[10]
e	FNAL E731	GIBBONS 93,93C	[11,12]
f	CERN	GEWENIGER 74B,74C	[13,14]
g	CERN NA31	CAROSI 90	[15]
h	CERN NA48	LAI 02C	[16]
i	CERN NA31	BERTANZA 97	[17]
j	this review	SUPERWEAK 04	

"a". These ellipses are seen to be in good agreement with the superweak phase

$$\phi_{\rm SW} = \tan^{-1}\left(\frac{2\Delta m}{\Delta\Gamma}\right) = \tan^{-1}\left(\frac{2\Delta m \tau_S \tau_L}{\hbar(\tau_L - \tau_S)}\right) \ . \qquad (9)$$

In Figs. [1] and [2], $\phi_{\rm SW}$ is shown as narrow bands labeled "j".

Table 2 column 2, "Fit w/o CPT," gives the resulting fitted parameters, while Table 3 gives the correlation matrix for this fit. The white ellipses labeled "a" in Fig. 1 and Fig. 2 are the $\chi^2 = 1$ contours for this fit.

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

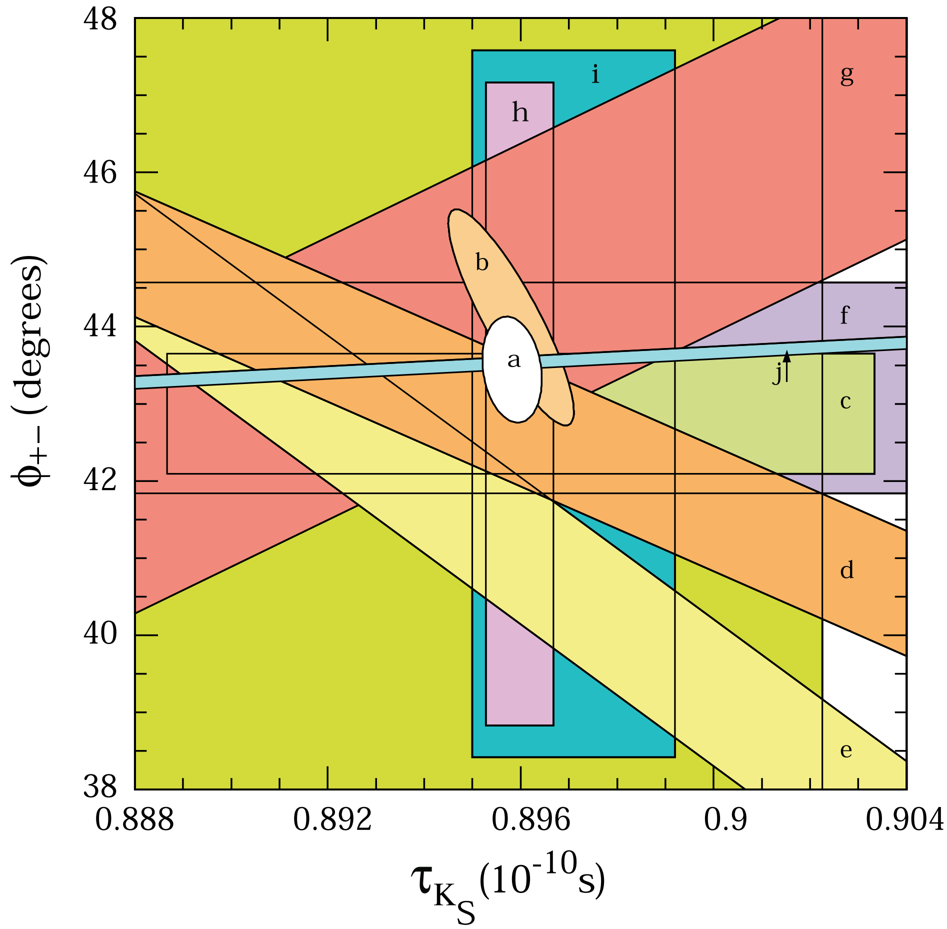


Figure 2: ϕ_{+-} vs τ_S. τ_S measurements appear as vertical bands spanning $\tau_S \pm 1\sigma$, some of which are cut near the top and bottom to aid the eye. Most ϕ_{+-} measurements appear as diagonal or horizontal bands spanning $\phi_{+-} \pm \sigma_\phi$. Data are labeled by letters: "b"–FNAL KTeV, "c"–CERN CPLEAR, "d"–FNAL E773, "e"–FNAL E731, "f"–CERN, "g"–CERN NA31, "h"–CERN NA48, "i"–CERN NA31, and are cited in Table 1. The narrow band "j" shows $\phi_{\rm SW}$. The ellipse "a" shows the fit result's $\chi^2 = 1$ contour. Color version at end of book.

uncertainty in the unseen parameters. This is also true for the $\phi_{\rm SW}$ bands.

If CPT invariance and unitarity are assumed, then by Eq. (6a), the phase of ϵ is constrained to be approximately equal to

$$\phi_{\mathrm{SW}} = (43.507 \pm 0.0004)^{\circ} + 54(\Delta m - 0.5290)^{\circ} + 32(\tau_S - 0.8958) \tag{10}$$

where we have linearized the Δm and τ_S dependence of Eq. (9). The error ± 0.0004 is due to the uncertainty in τ_L. Here Δm has units $10^{10}\,\hbar\,\mathrm{s}^{-1}$ and τ_S has units 10^{-10} s.

If in addition we use the observation that $Re(\epsilon'/\epsilon) \ll 1$ and $cos(\phi_{\epsilon'} - \phi_{\epsilon}) \simeq 1$, as well as the numerical value of $\phi_{\epsilon'} - \phi_{\epsilon}$ given in Eq. (6b), then Eqs. (5a), which are sketched in Fig. 3, lead to the constraint

$$\begin{aligned} \phi_{00} - \phi_{+-} &\approx -3\ \mathrm{Im}\left(\frac{\epsilon'}{\epsilon}\right) \\ &\approx -3\ \mathrm{Re}\left(\frac{\epsilon'}{\epsilon}\right)\tan(\phi_{\epsilon'} - \phi_{\epsilon}) \\ &\approx -0.023^{\circ} \pm 0.020^{\circ} \end{aligned} \tag{11}$$

so that $\phi_{+-} \approx \phi_{00} \approx \phi_{\epsilon} \approx \phi_{\mathrm{SW}}$.

In the fit assuming CPT we constrain $\phi_{\epsilon} = \phi_{\mathrm{SW}}$ using the linear expression in Eq. (10) and constrain $\phi_{00} - \phi_{+-}$ using Eq. (11). These constraints are inserted into the Data Listings with the Document ID of SUPERWEAK 04. Some additional data for which the authors assumed CPT are added to this fit or substitute for other less precise data for which the authors did not make this assumption. See the data listings for details.

The results of this fit are shown in Table 2, column 3, "Fit w/CPT," and the correlation matrix is shown in Table 4. The Δm precision is improved by the CPT assumption.

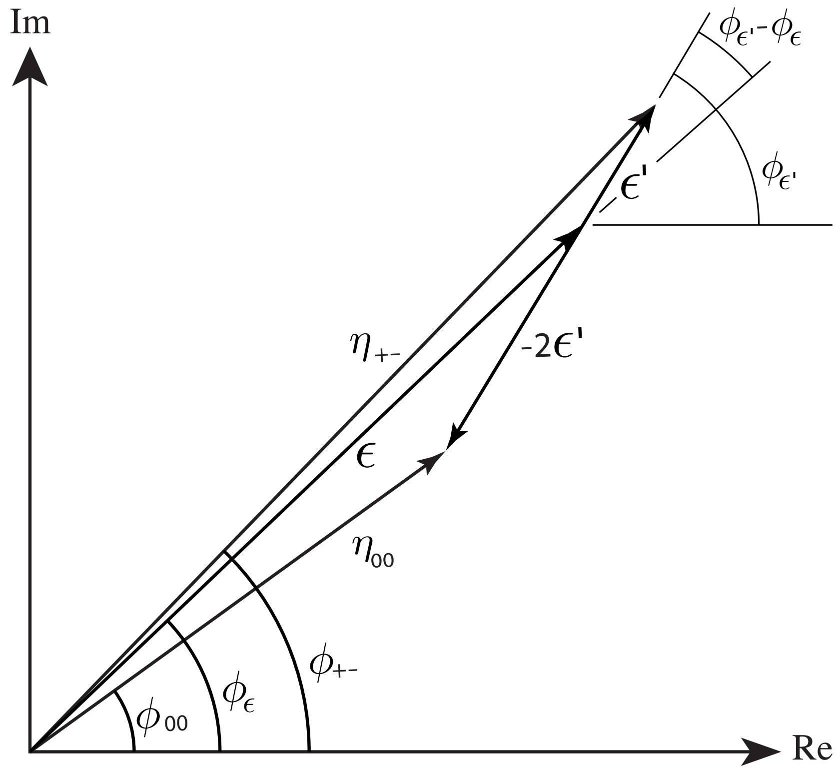


Figure 3: Sketch of Eqs. (5a). Not to scale.

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

Quantity(units)	Fit w/o CPT	Fit w/ CPT
$\phi_{+-}(^\circ)$	43.4 ± 0.7 (S=1.3)	43.52 ± 0.06 (S=1.3)
$\Delta m(10^{10}\hbar\ \mathrm{s}^{-1})$	0.5290 ± 0.0016 (S=1.2)	0.5292 ± 0.0010 (S=1.2)
$\tau_S(10^{-10}\mathrm{s})$	0.8958 ± 0.0006 (S=1.2)	0.8953 ± 0.0006 (S=1.4)
$\phi_{00}(^\circ)$	43.7 ± 0.8 (S=1.2)	43.50 ± 0.06 (S=1.3)
$\Delta\phi(^\circ)$	0.2 ± 0.4	-0.022 ± 0.041 (S=2.1)
$\phi_\epsilon(^\circ)$	43.5 ± 0.7 (S=1.3)	43.51 ± 0.05 (S=1.2)
χ^2	17.3	21.8
No. Deg. Freedom	13	17

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

	ϕ_{+-}	Δm	τ_S	ϕ_{00}	$\Delta\phi$	ϕ_ϵ
ϕ_{+-}	1.00	0.79	−0.19	0.85	0.00	0.98
Δm	0.79	1.00	−0.16	0.69	0.03	0.78
τ_S	−0.19	−0.16	1.00	−0.15	0.01	−0.18
ϕ_{00}	0.85	0.69	−0.15	1.00	0.53	0.94
$\Delta\phi$	0.00	0.03	0.01	0.53	1.00	0.21
ϕ_ϵ	0.98	0.78	−0.18	0.94	0.21	1.00

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

	ϕ_{+-}	Δm	τ_S	ϕ_{00}	$\Delta\phi$	ϕ_ϵ
ϕ_{+-}	1.00	0.92	0.32	0.76	−0.26	0.97
Δm	0.92	1.00	0.00	0.84	−0.02	0.94
τ_S	0.32	0.00	1.00	0.30	0.01	0.33
ϕ_{00}	0.76	0.84	0.30	1.00	0.44	0.89
$\Delta\phi$	−0.26	−0.02	0.01	0.44	1.00	−0.02
ϕ_ϵ	0.97	0.94	0.33	0.89	−0.02	1.00

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

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

$$|\eta_{+-}| = \left[\frac{\mathrm{B}(K_L^0 \to \pi^+\pi^-)}{\tau_L}\ \frac{\tau_S}{\mathrm{B}(K_S^0 \to \pi^+\pi^-)}\right]^{1/2} , \quad (12a)$$

$$|\eta_{00}| = \left[\frac{\mathrm{B}(K^0_L \to \pi^0\pi^0)}{\tau_L}\;\frac{\tau_S}{\mathrm{B}(K^0_S \to \pi^0\pi^0)}\right]^{1/2} . \qquad (12b)$$

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 $\mathrm{B}(K^0_L \to \pi^+\pi^-)$ and $\mathrm{B}(K^0_L \to \pi^0\pi^0)$ 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^0_L 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^0_S 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 04. 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 04 values) are used along with the K^0_L and K^0_S mean lives and the $K^0_S \to \pi\pi$ branching fractions to compute the K^0_L branching ratios $\Gamma(K^0_L \to \pi^+\pi^-)/\Gamma(\text{total})$ and $\Gamma(K^0_L \to \pi^0\pi^0)/\Gamma(K^0_L \to \pi^+\pi^-)$. These branching ratio values are included as measurements in the branching ratio section with a document ID of ETAFIT 04. Thus the K^0_L 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* [18].

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CP-VIOLATION PARAMETERS IN K_L^0 DECAYS

CHARGE ASYMMETRY IN $K^0_{\ell 3}$ 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}

$\delta_L(\mu) = [\Gamma(\pi^- \mu^+ \nu_\mu) - \Gamma(\pi^+ \mu^- \overline{\nu}_\mu)]$/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	[82] PACIOTTI	69	OSPK
0.403±0.134	1M	[82] DORFAN	67	OSPK

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

$\delta_L(e) = [\Gamma(\pi^- e^+ \nu_e) - \Gamma(\pi^+ e^- \overline{\nu}_e)]$/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	[83] 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	[83] BENNETT	67	CNTR

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

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

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

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

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

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
2.276±0.014 OUR FIT				
2.280±0.025 OUR AVERAGE				
2.278±0.025	BRFIT	04		
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	[84] ADLER	96B	CPLR	Sup. by ANGELOPOULOS 98
2.71 ±0.37	[85] WOLFF	71	OSPK	Cu reg., 4γ's
2.95 ±0.63	[85] CHOLLET	70	OSPK	Cu reg., 4γ's

[84] Error is statistical only.

[85] CHOLLET 70 gives $\left|\eta_{00}\right|$ = (1.23 ± 0.24)×(regeneration amplitude, 2 GeV/c Cu)/10000mb. WOLFF 71 gives $\left|\eta_{00}\right|$ = (1.13 ± 0.12)×(regeneration amplitude, 2 GeV/c Cu)/10000mb. We compute both $\left|\eta_{00}\right|$ 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).

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

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.288±0.014 OUR FIT					
2.286±0.017 OUR AVERAGE					
2.289±0.024		BRFIT	04		
2.264±0.023±0.027	70M	[86] 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		[87] 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

[86] 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.

[87] 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.

$\left|\epsilon\right| = (2\left|\eta_{+-}\right| + \left|\eta_{00}\right|)/3$

This expression is a very good approximation, good to about one part in 10^{-4} because of the small measured value of $\phi_{00} - \phi_{+-}$ and small theoretical ambiguities.

VALUE (units 10^{-3})	DOCUMENT ID
2.284±0.014 OUR FIT	

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

VALUE	EVTS	DOCUMENT ID		TECN
0.9950±0.0008 OUR FIT Error includes scale factor of 1.6.				
0.9930±0.0020 OUR AVERAGE				
0.9931±0.0020		[88,89] BARR	93D	NA31
0.9904±0.0084±0.0036		[90] WOODS	88	E731
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.9939±0.0013±0.0015	1M	[88] BARR	93D	NA31
0.9899±0.0020±0.0025		[88] BURKHARDT	88	NA31

[88] This is the square root of the ratio R given by BURKHARDT 88 and BARR 93D.

[89] This is the combined results from BARR 93D and BURKHARDT 88, taking into account a common systematic uncertainty of 0.0014.

[90] We calculate $|\eta_{00}/\eta_{+-}| = 1-3(\epsilon'/\epsilon)$ from WOODS 88 (ϵ'/ϵ) value.

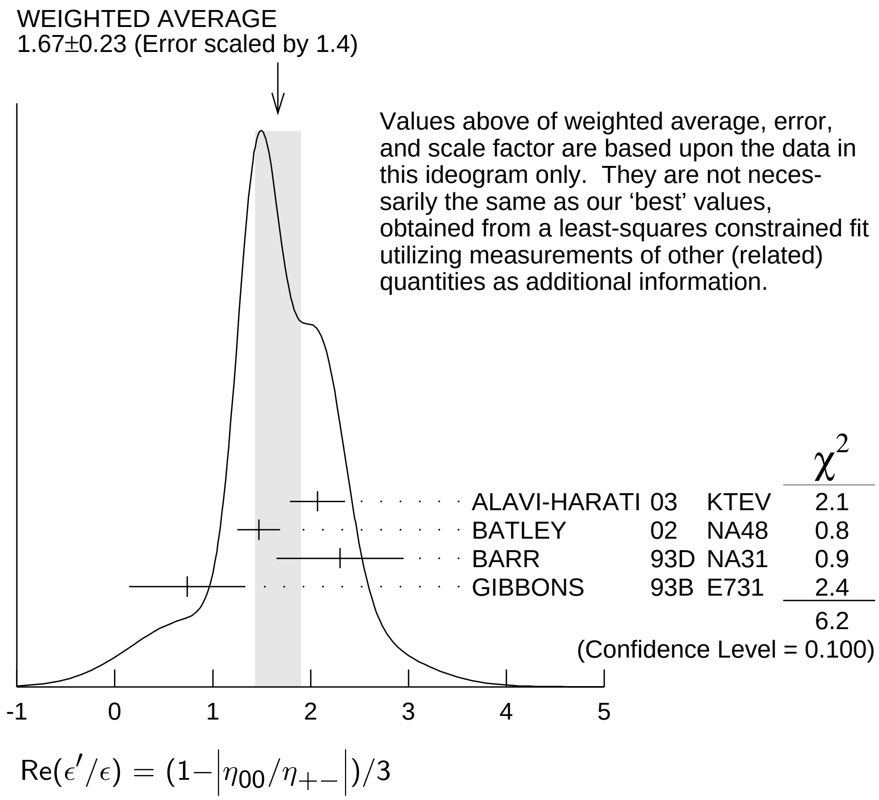
$\mathrm{Re}(\epsilon'/\epsilon) = (1-|\eta_{00}/\eta_{+-}|)/3$

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
1.67±0.26 OUR FIT Error includes scale factor of 1.6.				
1.67±0.23 OUR AVERAGE Error includes scale factor of 1.4. See the ideogram below.				
2.07±0.28	ALAVI-HARATI	03	KTEV	
1.47±0.22	BATLEY	02	NA48	
2.3 ±0.65	[91,92] BARR	93D	NA31	
0.74±0.52±0.29	GIBBONS	93B	E731	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.53±0.26	LAI	01C	NA48	Incl. in BATLEY 02
2.80±0.30±0.28	ALAVI-HARATI	99D	KTEV	In ALAVI-HARATI 03
1.85±0.45±0.58	FANTI	99C	NA48	In LAI 01C
2.0 ±0.7	[93] BARR	93D	NA31	
−0.4 ±1.4 ±0.6	PATTERSON	90	E731	in GIBBONS 93B
3.3 ±1.1	[93] BURKHARDT	88	NA31	
3.2 ±2.8 ±1.2	[91] WOODS	88	E731	

[91] These values are derived from $|\eta_{00}/\eta_{+-}|$ measurements. They enter the average in this section but enter the fit via the $|\eta_{00}/\eta_{+-}|$ only.

[92] This is the combined results from BARR 93D and BURKHARDT 88, taking into account their common systematic uncertainty.

[93] These values are derived from $|\eta_{00}/\eta_{+-}|$ measurements.



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 $K^0_L - K^0_S$ mass difference in units 10^{10} $\hbar s^{-1}$ and τ_s is the K_S mean life in units 10^{-10} s. We also give the regeneration phase ϕ_f in the comments below.

OUR FIT is described in the note on "*CP* violation in K_L decays" in the K^0_L Particle Listings. Most experiments in this section are included in both the "Not Assuming *CPT*" and "Assuming *CPT*" fits. In the latter fit, they have little direct influence on ϕ_{+-} because their errors are large compared to that assuming *CPT*, but they influence Δm and τ_s through their dependencies on these parameters, which are given in the footnotes. Only ALAVI-HARATI 03 is excluded from the "Assuming *CPT*" fit because we explicitly include their Δm and τ_s measurements which assume *CPT*.

VALUE (°)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
43.52±0.06 OUR FIT	Error includes scale factor of 1.3. Assuming *CPT*				
43.4 ±0.7 OUR FIT	Error includes scale factor of 1.3. Not assuming *CPT*				
44.12±0.72±1.20		[94] ALAVI-HARATI	03	KTEV	Not assuming *CPT*
42.9 ±0.6 ±0.3	70M	[95] APOSTOLA...	99C	CPLR	K^0-$\overline{K}^0$ asymmetry
43.0 ±0.8 ±0.2		[96,97] SCHWINGEN...	95	E773	$CH_{1.1}$ regenerator
41.4 ±0.9 ±0.3		[97,98] GIBBONS	93	E731	B_4C regenerator
44.4 ±1.6 ±0.6		[99] CAROSI	90	NA31	Vacuum regen.
43.3 ±1.0 ±0.5		[100] GEWENIGER	74B	ASPK	Vacuum regen.

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

42.5	±0.4	±0.4		[101,102] ADLER	96C	RVUE	
43.4	±1.1	±0.3		[103] ADLER	95B	CPLR	K^0-$\overline{K}^0$ asymmetry
42.3	±4.4	±1.4	10^5	[104] ADLER	92B	CPLR	K^0-$\overline{K}^0$ asymmetry
47.7	±2.0	±0.9		[97,105] KARLSSON	90	E731	
44.3	±2.8	±0.2		[106] CARITHERS	75	SPEC	C regenerator

[94] ALAVI-HARATI 03 ϕ_{+-} is correlated with their $\Delta m = m_{K^0_L} - m_{K^0_S}$ and τ_{K_S} measurements in the K^0_L and K^0_S sections respectively. The correlation coefficients are $\rho(\phi_{+-},\Delta m)$=+0.955, $\rho(\phi_{+-},\tau_S)$=−0.871, and $\rho(\tau_S,\Delta m)$=−0.840. *CPT* is not assumed. Uses scintillator Pb regenerator.

[95] APOSTOLAKIS 99C measures $\phi_{+-} = (43.19 \pm 0.53 \pm 0.28) + 300\ [\Delta m - 0.5301]$ (°). We have adjusted the measurement to use our best values of ($\Delta m = 0.5292 \pm 0.0010$) ($10^{10}$ $\hbar$ s^{-1}). Our first error is their experiment's error and our second error is the systematic error from using our best values.

[96] SCHWINGENHEUER 95 measures $\phi_{+-} = (43.53 \pm 0.76) + 173\ [\Delta m - 0.5282] - 275\ [\tau_s - 0.8926]$ (°). We have adjusted the measurement to use our best values of ($\Delta m = 0.5292 \pm 0.0010$) ($10^{10}$ $\hbar$ s^{-1}), ($\tau_s = 0.8953 \pm 0.0006$) ($10^{-10}$ s). Our first error is their experiment's error and our second error is the systematic error from using our best values.

[97] These experiments measure ϕ_{+-}−ϕ_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."

[98] GIBBONS 93 measures $\phi_{+-} = (42.21 \pm 0.9) + 189\ [\Delta m - 0.5257] - 460\ [\tau_s - 0.8922]$ (°). We have adjusted the measurement to use our best values of ($\Delta m = 0.5292 \pm 0.0010$) ($10^{10}$ $\hbar$ s^{-1}), ($\tau_s = 0.8953 \pm 0.0006$) ($10^{-10}$ s). Our first error is their experiment's error and our second error is the systematic error from using our best values. This is actually reported in SCHWINGENHEUER 95, footnote 8. GIBBONS 93 reports ϕ_{+-} $(42.2 \pm 1.4)°$. They measure ϕ_{+}−ϕ_f and calculate 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.

[99] CAROSI 90 measures $\phi_{+-} = (46.9 \pm 1.4 \pm 0.7) + 579\ [\Delta m - 0.5351] + 303\ [\tau_s - 0.8922]$ (°). We have adjusted the measurement to use our best values of ($\Delta m = 0.5292 \pm 0.0010$) ($10^{10}$ $\hbar$ s^{-1}), ($\tau_s = 0.8953 \pm 0.0006$) ($10^{-10}$ s). Our first error is their experiment's error and our second error is the systematic error from using our best values.

[100] GEWENIGER 74B measures $\phi_{+-} = (49.4 \pm 1.0) + 565\ [\Delta m - 0.540]$ (°). We have adjusted the measurement to use our best values of ($\Delta m = 0.5292 \pm 0.0010$) ($10^{10}$ $\hbar$ s^{-1}). Our first error is their experiment's error and our second error is the systematic error from using our best values.

[101] ADLER 96C measures $\phi_{+-} = (43.82 \pm 0.41) + 339\ [\Delta m - 0.5307] - 252\ [\tau_s - 0.8922]$ (°). We have adjusted the measurement to use our best values of ($\Delta m = 0.5292 \pm 0.0010$) ($10^{10}$ $\hbar$ s^{-1}), ($\tau_s = 0.8953 \pm 0.0006$) ($10^{-10}$ s). Our first error is their experiment's error and our second error is the systematic error from using our best values.

[102] 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)).

[103] ADLER 95B measures ϕ_{+-} = (42.7 ± 0.9 ± 0.6) + 316 [Δm − 0.5274] + 30 [τ_s − 0.8926] (°). We have adjusted the measurement to use our best values of (Δm = 0.5292 ± 0.0010) (10^{10} $\hbar$ s^{-1}), (τ_s = 0.8953 ± 0.0006) (10^{-10} s). Our first error is their experiment's error and our second error is the systematic error from using our best values.

[104] 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.

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

[106] CARITHERS 75 measures ϕ_{+-} = (45.5 ± 2.8) + 224 [Δm − 0.5348] (°). We have adjusted the measurement to use our best values of (Δm = 0.5292 ± 0.0010) (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. ϕ_f = −40.9 ± 2.6°.

ϕ_{00}, PHASE OF η_{00}

See comment in ϕ_{+-} header above for treatment of Δm and τ_s dependence, as well as for the inclusion of data in both the "Assuming *CPT*" and "Not Assuming *CPT*" fits.

OUR FIT is described in the note on "*CP* violation in K_L decays" in the K_L^0 Particle Listings.

VALUE (°)	*DOCUMENT ID*		*TECN*	*COMMENT*
43.50±0.06 OUR FIT	Error includes scale factor of 1.3. Assuming *CPT*			
43.7 ±0.8 OUR FIT	Error includes scale factor of 1.2. Not assuming *CPT*			
44.5 ±2.3 ±0.6	[107] CAROSI	90	NA31	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
41.6 ±5.9 ±0.2	[108] ANGELOPO...	98	CPLR	
50.8 ±7.1 ±1.7	[109] ADLER	96B	CPLR	Sup. by ANGELOPOULOS 98
47.4 ±1.4 ±0.9	[110] KARLSSON	90	E731	

[107] CAROSI 90 measures ϕ_{00} = (47.1 ± 2.1 ± 1.0) + 579 [Δm − 0.5351] + 252 [τ_s − 0.8922] (°). We have adjusted the measurement to use our best values of (Δm = 0.5292 ± 0.0010) (10^{10} $\hbar$ s^{-1}), (τ_s = 0.8953 ± 0.0006) (10^{-10} s). Our first error is their experiment's error and our second error is the systematic error from using our best values.

[108] ANGELOPOULOS 98 measures ϕ_{00} = (42.0 ± 5.6 ± 1.9) + 240 [Δm − 0.5307] (°). We have adjusted the measurement to use our best values of (Δm = 0.5292 ± 0.0010) (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. The τ_s dependence is negligible.

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

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

$\phi_\epsilon = (2\phi_{+-} + \phi_{00})/3$

This expression is a very good approximation, good to about 10^{-3} degrees because of the small measured values of $\phi_{00} - \phi_{+-}$ and Re ϵ'/ϵ, and small theoretical ambiguities.

VALUE (°)	*DOCUMENT ID*		*COMMENT*
43.51 ±0.05 OUR FIT	Error includes scale factor of 1.2. Assuming *CPT*		
43.5 ±0.7 OUR FIT	Error includes scale factor of 1.3. Not assuming *CPT*		
43.5105±0.0004±0.0548	[111] SUPERWEAK	04	Assuming *CPT*

[111] SUPERWEAK 04 is a fake measurement used to impose the CPT or Superweak constraint $\phi_{+-}=\phi_{SW} = 2\,\frac{\Delta m}{\hbar}\,(\frac{\tau_S \tau_L}{\tau_L - \tau_S})$. This "measurement" is linearized using values near the RPP 2004 edition values of Δm, τ_S and τ_L, and then adjusted to our current values as described in the following "measurement". SUPERWEAK 04 measures ϕ_ϵ = (43.5131 ± 0.0004) + 54 [$\Delta m -$ 0.5290] + 32 [$\tau_s -$ 0.8958] (°). We have adjusted the measurement to use our best values of ($\Delta m = 0.5292 \pm 0.0010$) ($10^{10}$ $\hbar$ s^{-1}), (τ_s = 0.8953 ± 0.0006) (10^{-10} s). Our first error is their experiment's error and our second error is the systematic error from using our best values.

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 $K^0_L \to \pi^+\pi^- e^+ e^-$

VALUE (%)	DOCUMENT ID		TECN
13.8±2.2 OUR AVERAGE			
14.2±3.0±1.9	LAI	03C	NA48
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 distribution, 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 $K^0_L \to e^+ e^- e^+ e^-$

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 $K^0_L \to \pi^+\pi^-\pi^0$ above.

See also note on Dalitz plot parameters in $K^\pm$ section and note on "CP violation in K_L decays" above.

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

VALUE	EVTS	DOCUMENT ID		TECN
0.0012±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 $K^0_L \to \pi^+\pi^-\pi^0$

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

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

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

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 $K^0_L \to \pi^+\pi^-\gamma$

VALUE	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*
<0.3	90	3671	[112] RAMBERG	93B	E731

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

T VIOLATION TESTS IN K^0_L DECAYS

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	[113] CLARK	77	SPEC	POL, t=0
−0.085±0.064	2.2M	[114] 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

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

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

CPT-INVARIANCE TESTS IN K^0_L DECAYS

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

Test of CPT.

OUR FIT is described in the note on "CP violation in K_L decays" in the K^0_L Particle Listings.

VALUE (°)	DOCUMENT ID	TECN	COMMENT
−0.02 ±0.04 OUR FIT	Error includes scale factor of 2.1. Assuming CPT		
0.2 ±0.4 OUR FIT	Not assuming CPT		
−0.023±0.020	[115] SUPERWEAK 04		Assuming CPT
0.39 ±0.22 ±0.45	[116] ALAVI-HARATI 03	KTEV	
−0.30 ±0.88	[117] SCHWINGEN... 95		Combined E731, E773
• • • 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	[118] GIBBONS 93	E731	
0.2 ±2.6 ±1.2	[119] CAROSI 90	NA31	
−0.3 ±2.4 ±1.2	KARLSSON 90	E731	

[115] SUPERWEAK 04 is a fake experiment to constrain ϕ_{00}-ϕ_{+-} to a small value as described in the note "CP violation in K_L decays."

[116] ALAVI-HARATI 03 fit Re(ϵ'/ϵ), Im(ϵ'/ϵ), Δm, τ_S, and ϕ_{+-} simultaneously, not assuming CPT. Phase difference is obtained from $\phi_{00} - \phi_{+-} \approx -3\mathrm{Im}(\epsilon'/\epsilon)$ for small $|\epsilon'/\epsilon|$.

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

[118] 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 $m_{K^0_L} - m_{K^0_S}$).

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

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

Test of CPT. The Superweak phase $\phi_{SW} \equiv \tan^{-1}(2\Delta m/\Delta\Gamma)$ where $\Delta m = m_{K^0_L} - m_{K^0_S}$ and $\Delta\Gamma = \hbar(\tau_L - \tau_S)/(\tau_L \tau_S)$.

VALUE (°)	DOCUMENT ID	TECN
0.61±0.62±1.01	[120] ALAVI-HARATI 03	KTEV

[120] ALAVI-HARATI 03 fit is the same as their ϕ_{+-}, τ_{K_S}, Δm fit, except that the parameter $\phi_{+-} - \phi_{SW}$ is used in place of ϕ.

$\mathrm{Re}(\frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00}) - \frac{\delta_L}{2}$

Test of CPT

VALUE (units 10^{-6})	DOCUMENT ID	TECN	COMMENT
−3±35	[121] ALAVI-HARATI 02	E799	Uses δ_L from K_{e3} decays

[121] ALAVI-HARATI 02 uses PDG 00 values of η_{+-} and η_{00}.

$\Delta S = \Delta Q$ 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.

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

REAL PART OF x

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.0018±0.0041±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	$\pi^- p \rightarrow K^0 \Lambda$
0.04 ±0.03	4724	NIEBERGALL	74	ASPK	$K^+ p \rightarrow K^0 p \pi^+$
−0.008 ±0.044	1757	FACKLER	73	OSPK	K_{e3} from K^0
−0.03 ±0.07	1367	HART	73	OSPK	K_{e3} from $K^0 \Lambda$
−0.070 ±0.036	1079	MALLARY	73	OSPK	K_{e3} from $K^0 \Lambda X$
0.03 ±0.06	410	[122] BURGUN	72	HBC	$K^+ p \rightarrow K^0 p \pi^+$
0.04 $^{+0.10}_{-0.13}$	100	[123] GRAHAM	72	OSPK	$K_{\mu 3}$ from $K^0 \Lambda$
−0.05 ±0.09	442	[123] GRAHAM	72	OSPK	$\pi^- p \rightarrow K^0 \Lambda$
0.26 $^{+0.10}_{-0.14}$	126	MANN	72	HBC	$K^- p \rightarrow n \overline{K}^0$
−0.13 ±0.11	342	[123] MANTSCH	72	OSPK	K_{e3} from $K^0 \Lambda$
0.04 $^{+0.07}_{-0.08}$	222	[122] BURGUN	71	HBC	$K^+ p \rightarrow K^0 p \pi^+$
0.25 $^{+0.07}_{-0.09}$	252	WEBBER	71	HBC	$K^- p \rightarrow n \overline{K}^0$
0.12 ±0.09	215	[124] CHO	70	DBC	$K^+ d \rightarrow K^0 p p$
−0.020 ±0.025		[125] BENNETT	69	CNTR	Charge asym+ Cu regen.
0.09 $^{+0.14}_{-0.16}$	686	LITTENBERG	69	OSPK	$K^+ n \rightarrow K^0 p$
0.03 ±0.03		[125] 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	$\pi^- p \rightarrow K^0 \Lambda$
0.17 ±0.10	335	[124] HILL	67	DBC	$K^+ d \rightarrow K^0 p p$

$0.035\ ^{+0.11}_{-0.13}$	196	AUBERT	65	HLBC	K^+ charge exchange
$0.06\ ^{+0.18}_{-0.44}$	152	[126] BALDO-...	65	HLBC	K^+ charge exchange
$-0.08\ ^{+0.16}_{-0.28}$	109	[127] FRANZINI	65	HBC	$\overline{p}p$

[122] BURGUN 72 is a final result which includes BURGUN 71.
[123] First GRAHAM 72 value is second GRAHAM 72 value combined with MANTSCH 72.
[124] CHO 70 is analysis of unambiguous events in new data and HILL 67.
[125] BENNETT 69 is a reanalysis of BENNETT 68.
[126] BALDO-CEOLIN 65 gives x and θ converted by us to Re(x) and Im(x).
[127] 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	[128] 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	[129] BURGUN	72	HBC	$K^+ p \to K^0 p \pi^+$
$0.12\ ^{+0.17}_{-0.16}$	100	[130] GRAHAM	72	OSPK	$K_{\mu 3}$ from $K^0 \Lambda$
0.05 ± 0.13	442	[130] 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	[130] MANTSCH	72	OSPK	K_{e3} from $K^0 \Lambda$
$0.12\ ^{+0.08}_{-0.09}$	222	[129] 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	[131] 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	[131] 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	[132] BALDO-...	65	HLBC	K^+ charge exchange
$+0.24\ ^{+0.40}_{-0.30}$	109	[133] FRANZINI	65	HBC	$\overline{p}p$

[128] Superseded by ANGELOPOULOS 01B.
[129] BURGUN 72 is a final result which includes BURGUN 71.
[130] First GRAHAM 72 value is second GRAHAM 72 value combined with MANTSCH 72.
[131] 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.
[132] BALDO-CEOLIN 65 gives x and θ converted by us to Re(x) and Im(x).
[133] FRANZINI 65 gives x and θ for Re(x) and Im(x). See SCHMIDT 67.

K^0_L REFERENCES

BRFIT	04	RPP 2004 edition	T.G. Trippe	(PDG Collab.)
CP violation in K_L decays				
ETAFIT	04	RPP 2004 edition	T.G. Trippe	(PDG Collab.)
CP violation in K_L decays				
KL3FIT	04	RPP 2004 edition	T.G. Trippe	(PDG Collab.)
$K^{\pm}_{\mu 3}$ and $K^0_{\mu 3}$ Form Factors review in K^+ Listings.				
SUPERWEAK	04	RPP 2004 edition	T.G. Trippe	(PDG Collab.)
CP violation in K_L decays				
ADINOLFI	03	PL B566 61	M. Adinolfi *et al.*	(KLOE Collab.)
ALAVI-HARATI	03	PR D67 012005	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
Also	04	Erratum (to be publ.)	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	03B	PRL 90 141801	A. ALavi-Harati *et al.*	(FNAL KTeV Collab.)
LAI	03	PL B551 7	A. Lai *et al.*	(CERN NA48 Collab.)
LAI	03C	EPJ C30 33	A. Lai *et al.*	(CERN NA48 Collab.)
ALAVI-HARATI	02	PRL 88 181601	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	02C	PRL 89 211801	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
BATLEY	02	PL B544 97	J.R. Batley *et al.*	(CERN NA48 Collab.)
LAI	02B	PL B536 229	A. Lai *et al.*	(CERN NA48 Collab.)
ALAVI-HARATI	01	PRL 86 397	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	01B	PRL 86 761	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	01D	PRL 86 5425	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	01E	PRL 87 021801	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	01F	PR D64 012003	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	01G	PRL 87 071801	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	01H	PRL 87 111802	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	01J	PR D64 112004	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ANGELOPO...	01	PL B503 49	A. Angelopoulos *et al.*	(CPLEAR Collab.)
ANGELOPO...	01B	EPJ C22 55	A. Angelopoulos *et al.*	(CPLEAR Collab.)
LAI	01B	PL B515 261	A. Lai *et al.*	(CERN NA48 Collab.)
LAI	01C	EPJ C22 231	A. Lai *et al.*	(CERN NA48 Collab.)
ALAVI-HARATI	00	PR D61 072006	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	00B	PRL 84 408	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	00D	PRL 84 5279	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	00E	PR D62 112001	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
AMBROSE	00	PRL 84 1389	D. Ambrose *et al.*	(BNL E871 Collab.)
APOSTOLA...	00	PL B473 186	A. Apostolakis *et al.*	(CPLEAR Collab.)
PDG	00	EPJ C15 1	D.E. Groom *et al.*	
ADAMS	99	PL B447 240	J. Adams *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	99B	PRL 83 917	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
ALAVI-HARATI	99D	PRL 83 22	A. Alavi-Harati *et al.*	(FNAL KTeV Collab.)
APOSTOLA...	99C	PL B458 545	A. Apostolakis *et al.*	(CPLEAR Collab.)
Also	00B	EPJ C18 41	A. Apostolakis *et al.*	(CPLEAR Collab.)
FANTI	99B	PL B458 553	V. Fanti *et al.*	(CERN NA48 Collab.)
FANTI	99C	PL B465 335	V. Fanti *et al.*	(CERN NA48 Collab.)
MURAKAMI	99	PL B463 333	K. Murakami *et al.*	(KEK E162 Collab.)
ADAMS	98	PRL 80 4123	J. Adams *et al.*	(FNAL KTeV Collab.)
AMBROSE	98	PRL 81 4309	D. Ambrose *et al.*	(BNL E871 Collab.)
AMBROSE	98B	PRL 81 5734	D. Ambrose *et al.*	(BNL E871 Collab.)
ANGELOPO...	98	PL B420 191	A. Angelopoulos *et al.*	(CPLEAR Collab.)
ANGELOPO...	98C	EPJ C5 389	A. Angelopoulos *et al.*	(CPLEAR Collab.)
ANGELOPO...	98D	PL B444 38	A. Angelopoulos *et al.*	(CPLEAR Collab.)
Also	01B	EPJ C22 55	A. Angelopoulos *et al.*	(CPLEAR Collab.)
ANGELOPO...	98E	PL B444 43	A. Angelopoulos *et al.*	(CPLEAR Collab.)
ARISAKA	98	PL B432 230	K. Arisaka *et al.*	(FNAL E799 Collab.)
BENDER	98	PL B418 411	M. Bender *et al.*	(CERN NA48 Collab.)
SETZU	98	PL B420 205	M.G. Setzu *et al.*	
TAKEUCHI	98	PL B443 409	Y. Takeuchi *et al.*	(KYOT, KEK, HIRO)

FANTI	97	ZPHY C76 653	V. Fanti et al.	(CERN NA48 Collab.)
NOMURA	97	PL B408 445	T. Nomura et al.	(KYOT, KEK, HIRO)
ADLER	96B	ZPHY C70 211	R. Adler et al.	(CPLEAR Collab.)
ADLER	96C	PL B369 367	R. Adler et al.	(CPLEAR Collab.)
GU	96	PRL 76 4312	P. Gu et al.	(RUTG, UCLA, EFI, COLO+)
LEBER	96	PL B369 69	F. Leber et al.	(MANZ, CERN, EDIN, ORSAY+)
PDG	96	PR D54 1	R. M. Barnett et al.	
ADLER	95	PL B363 237	R. Adler et al.	(CPLEAR Collab.)
ADLER	95B	PL B363 243	R. Adler et al.	(CPLEAR Collab.)
AKAGI	95	PR D51 2061	T. Akagi et al.	(TOHOK, TOKY, KYOT, KEK)
BARR	95	ZPHY C65 361	G.D. Barr et al.	(CERN, EDIN, MANZ, LALO+)
BARR	95C	PL B358 399	G.D. Barr et al.	(CERN, EDIN, MANZ, LALO+)
HEINSON	95	PR D51 985	A.P. Heinson et al.	(BNL E791 Collab.)
KREUTZ	95	ZPHY C65 67	A. Kreutz et al.	(SIEG, EDIN, MANZ, ORSAY+)
MATTHEWS	95	PRL 75 2803	J.N. Matthews et al.	(RUTG, EFI, ELMT+)
SCHWINGEN...	95	PRL 74 4376	B. Schwingenheuer et al.	(EFI, CHIC+)
SPENCER	95	PRL 74 3323	M.B. Spencer et al.	(UCLA, EFI, COLO+)
BARR	94	PL B328 528	G.D. Barr et al.	(CERN, EDIN, MANZ, LALO+)
GU	94	PRL 72 3000	P. Gu et al.	(RUTG, UCLA, EFI, COLO+)
NAKAYA	94	PRL 73 2169	T. Nakaya et al.	(OSAK, UCLA, EFI, COLU+)
ROBERTS	94	PR D50 1874	D. Roberts et al.	(UCLA, EFI, COLU+)
WEAVER	94	PRL 72 3758	M. Weaver et al.	(UCLA, EFI, COLU, ELMT+)
AKAGI	93	PR D47 R2644	T. Akagi et al.	(TOHOK, TOKY, KYOT, KEK)
ARISAKA	93	PRL 70 1049	K. Arisaka et al.	(BNL E791 Collab.)
ARISAKA	93B	PRL 71 3910	K. Arisaka et al.	(BNL E791 Collab.)
BARR	93D	PL B317 233	G.D. Barr et al.	(CERN, EDIN, MANZ, LALO+)
GIBBONS	93	PRL 70 1199	L.K. Gibbons et al.	(FNAL E731 Collab.)
Also	97	PR D55 6625	L.K. Gibbons et al.	(FNAL E731 Collab.)
GIBBONS	93B	PRL 70 1203	L.K. Gibbons et al.	(FNAL E731 Collab.)
GIBBONS	93C	Thesis RX-1487	L.K. Gibbons	(CHIC)
Also	97	PR D55 6625	L.K. Gibbons et al.	(FNAL E731 Collab.)
HARRIS	93	PRL 71 3914	D.A. Harris et al.	(EFI, UCLA, COLO+)
HARRIS	93B	PRL 71 3918	D.A. Harris et al.	(EFI, UCLA, COLO+)
MAKOFF	93	PRL 70 1591	G. Makoff et al.	(FNAL E731 Collab.)
Also	95	PRL 75 2069 (erratum)	G. Makoff et al.	
RAMBERG	93	PRL 70 2525	E. Ramberg et al.	(FNAL E731 Collab.)
RAMBERG	93B	PRL 70 2529	E.J. Ramberg et al.	(FNAL E731 Collab.)
VAGINS	93	PRL 71 35	M.R. Vagins et al.	(BNL E845 Collab.)
ADLER	92B	PL B286 180	R. Adler et al.	(CPLEAR Collab.)
Also	92	SJNP 55 840	R. Adler et al.	(CPLEAR Collab.)
BARR	92	PL B284 440	G.D. Barr et al.	(CERN, EDIN, MANZ, LALO+)
GRAHAM	92	PL B295 169	G.E. Graham et al.	(FNAL E731 Collab.)
MORSE	92	PR D45 36	W.M. Morse et al.	(BNL, YALE, VASS)
PDG	92	PR D45, 1 June, Part II	K. Hikasa et al.	(KEK, LBL, BOST+)
SOMALWAR	92	PRL 68 2580	S.V. Somalwar et al.	(FNAL E731 Collab.)
AKAGI	91B	PRL 67 2618	T. Akagi et al.	(TOHOK, TOKY, KYOT, KEK)
BARR	91	PL B259 389	G.D. Barr et al.	(CERN, EDIN, MANZ, LALO+)
HEINSON	91	PR D44 R1	A.P. Heinson et al.	(UCI, UCLA, LANL+)
PAPADIMITR...	91	PR D44 R573	V. Papadimitriou et al.	(FNAL E731 Collab.)
BARKER	90	PR D41 3546	A.R. Barker et al.	(FNAL E731 Collab.)
Also	88	PRL 61 2661	L.K. Gibbons et al.	(FNAL E731 Collab.)
BARR	90B	PL B240 283	G.D. Barr et al.	(CERN, EDIN, MANZ, LALO+)
BARR	90C	PL B242 523	G.D. Barr et al.	(CERN, EDIN, MANZ, LALO+)
CAROSI	90	PL B237 303	R. Carosi et al.	(CERN, EDIN, MANZ, LALO+)
KARLSSON	90	PRL 64 2976	M. Karlsson et al.	(FNAL E731 Collab.)
OHL	90	PRL 64 2755	K.E. Ohl et al.	(BNL E845 Collab.)
OHL	90B	PRL 65 1407	K.E. Ohl et al.	(BNL E845 Collab.)
PATTERSON	90	PRL 64 1491	J.R. Patterson et al.	(FNAL E731 Collab.)
INAGAKI	89	PR D40 1712	T. Inagaki et al.	(KEK, TOKY, KYOT)
MATHIAZHA...	89	PRL 63 2181	C. Mathiazhagan et al.	(UCI, UCLA, LANL+)
MATHIAZHA...	89B	PRL 63 2185	C. Mathiazhagan et al.	(UCI, UCLA, LANL+)
WAHL	89	CERN-EP/89-86	H. Wahl	(CERN)
BARR	88	PL B214 303	G.D. Barr et al.	(CERN, EDIN, MANZ, LALO+)
BURKHARDT	88	PL B206 169	H. Burkhardt et al.	(CERN, EDIN, MANZ+)
JASTRZEM...	88	PRL 61 2300	E. Jastrzembski et al.	(BNL, YALE)
WOODS	88	PRL 60 1695	M. Woods et al.	(FNAL E731 Collab.)
BURKHARDT	87	PL B199 139	H. Burkhardt et al.	(CERN, EDIN, MANZ+)
ARONSON	86	PR D33 3180	S.H. Aronson et al.	(BNL, CHIC, STAN+)
Also	82	PRL 48 1078	S.H. Aronson et al.	(BNL, CHIC, STAN+)
PDG	86C	PL 170B 132	M. Aguilar-Benitez et al.	(CERN, CIT+)
COUPAL	85	PRL 55 566	D.P. Coupal et al.	(CHIC, SACL)

BALATS	83	SJNP 38 556	M.Y. Balats *et al.*	(ITEP)
		Translated from YAF 38 927.		
BERGSTROM	83	PL 131B 229	L. Bergstrom, E. Masso, P. Singer	(CERN)
ARONSON	82	PRL 48 1078	S.H. Aronson *et al.*	(BNL, CHIC, STAN+)
ARONSON	82B	PRL 48 1306	S.H. Aronson *et al.*	(BNL, CHIC, PURD)
Also	82B	PL 116B 73	E. Fischbach *et al.*	(PURD, BNL, CHIC)
Also	83	PR D28 476	S.H. Aronson *et al.*	(BNL, CHIC, PURD)
Also	83B	PR D28 495	S.H. Aronson *et al.*	(BNL, CHIC, PURD)
PDG	82B	PL 111B 70	M. Roos *et al.*	(HELS, CIT, CERN)
BIRULEV	81	NP B182 1	V.K. Birulev *et al.*	(JINR)
Also	80	SJNP 31 622	V.K. Birulev *et al.*	(JINR)
		Translated from YAF 31 1204.		
CARROLL	80B	PRL 44 529	A.S. Carroll *et al.*	(BNL, ROCH)
CARROLL	80C	PL 96B 407	A.S. Carroll *et al.*	(BNL, ROCH)
CHO	80	PR D22 2688	Y. Cho *et al.*	(ANL, CMU)
MORSE	80	PR D21 1750	W.M. Morse *et al.*	(BNL, YALE)
CHRISTENS...	79	PRL 43 1209	J.H. Christenson *et al.*	(NYU)
HILL	79	NP B153 39	D.G. Hill *et al.*	(BNL, SLAC, SBER)
SCHMIDT	79	PRL 43 556	M.P. Schmidt *et al.*	(YALE, BNL)
ENGLER	78B	PR D18 623	A. Engler *et al.*	(CMU, ANL)
HILL	78	PL 73B 483	D.G. Hill *et al.*	(BNL, SLAC, SBER)
CHO	77	PR D15 587	Y. Cho *et al.*	(ANL, CMU)
CLARK	77	PR D15 553	A.R. Clark *et al.*	(LBL)
Also	75	Thesis LBL-4275	G. Shen	(LBL)
DEVOE	77	PR D16 565	R. Devoe *et al.*	(EFI, ANL)
DZHORD...	77	SJNP 26 478	V.P. Dzhordzhadze *et al.*	(JINR)
		Translated from YAF 26 910.		
PEACH	77	NP B127 399	K.J. Peach *et al.*	(BGNA, EDIN, GLAS+)
BIRULEV	76	SJNP 24 178	V.K. Birulev *et al.*	(JINR)
		Translated from YAF 24 340.		
COOMBES	76	PRL 37 249	R.W. Coombes *et al.*	(STAN, NYU)
GJESDAL	76	NP B109 118	G. Gjesdal *et al.*	(CERN, HEIDH)
BALDO-...	75	NC 25A 688	M. Baldo-Ceolin *et al.*	(PADO, WISC)
BLUMENTHAL	75	PRL 34 164	R.B. Blumenthal *et al.*	(PENN, CHIC, TEMP)
BUCHANAN	75	PR D11 457	C.D. Buchanan *et al.*	(UCLA, SLAC, JHU)
CARITHERS	75	PRL 34 1244	W.C.J. Carithers *et al.*	(COLU, NYU)
SMITH	75B	Thesis UCSD unpub.	J.G. Smith	(UCSD)
ALBRECHT	74	PL 48B 393	K.F. Albrecht	(JINR, BERL, BUDA, PRAG, SERP+)
BISI	74	PL 50B 504	V. Bisi, M.I. Ferrero	(TORI)
DONALDSON	74	Thesis SLAC-0184	G. Donaldson	(SLAC)
Also	76	PR D14 2839	G. Donaldson *et al.*	(SLAC)
DONALDSON	74B	PR D9 2960	G. Donaldson *et al.*	(SLAC, UCSC)
Also	73B	PRL 31 337	G. Donaldson *et al.*	(SLAC, UCSC)
GEWENIGER	74	PL 48B 483	C. Geweniger *et al.*	(CERN, HEIDH)
Also	74	Thesis CERN Int. 74-4	V. Luth	(CERN)
GEWENIGER	74B	PL 48B 487	C. Geweniger *et al.*	(CERN, HEIDH)
Also	74B	PL 52B 119	S. Gjesdal *et al.*	(CERN, HEIDH)
GEWENIGER	74C	PL 52B 108	C. Geweniger *et al.*	(CERN, HEIDH)
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MESSNER	74	PRL 33 1458	R. Messner *et al.*	(COLO, SLAC, UCSC)
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)
EVANS	73	PR D7 36	G.R. Evans *et al.*	(EDIN, CERN)
Also	69	PRL 23 427	G.R. Evans *et al.*	(EDIN, CERN)
FACKLER	73	PRL 31 847	O. Fackler *et al.*	(MIT)
FITCH	73	PRL 31 1524	V.L. Fitch *et al.*	(PRIN)
Also	72	Thesis COO-3072-13	R.C. Webb	(PRIN)
GINSBERG	73	PR D8 3887	E.S. Ginsberg, J. Smith	(MIT, STON)
HART	73	NP B66 317	J.C. Hart *et al.*	(CAVE, RHEL)
MALLARY	73	PR D7 1953	M.L. Mallary *et al.*	(CIT)
Also	70	PRL 25 1214	F.J. Sciulli *et al.*	(CIT)
MCCARTHY	73	PR D7 687	R.L. McCarthy *et al.*	(LBL)
Also	72	PL 42B 291	R.L. McCarthy *et al.*	(LBL)
Also	71	Thesis LBL-550	R.L. McCarthy	(LBL)
MESSNER	73	PRL 30 876	R. Messner *et al.*	(COLO, SLAC, UCSC)
PEACH	73	PL 43B 441	K.J. Peach *et al.*	(EDIN, CERN, AACH)
SANDWEISS	73	PRL 30 1002	J. Sandweiss *et al.*	(YALE, ANL)
WILLIAMS	73	PRL 31 1521	H.H. Williams *et al.*	(BNL, YALE)

ALBROW	72	NP B44 1	M.G. Albrow *et al.*	(MCHS, DARE)
ASHFORD	72	PL 38B 47	V.A. Ashford *et al.*	(UCSD)
BANNER	72B	PRL 29 237	M. Banner *et al.*	(PRIN)
BARMIN	72B	SJNP 15 638	V.V. Barmin *et al.*	(ITEP)
		Translated from YAF 15 1152.		
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)
NEUHOFER	72	PL 41B 642	G. Neuhofer *et al.*	(CERN, ORSAY, VIEN)
PICCIONI	72	PRL 29 1412	R. Piccioni *et al.*	(SLAC)
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BALATS	71	SJNP 13 53	M.Y. Balats *et al.*	(ITEP)
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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)
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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)
ALBROW	70	PL 33B 516	M.G. Albrow *et al.*	(MCHS, DARE)
ARONSON	70	PRL 25 1057	S.H. Aronson *et al.*	(EFI, ILLC, SLAC)
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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)
Also	68B	PL 28B 215	I.A. Budagov *et al.*	(CERN, ORSAY, EPOL)
CHIEN	70	PL 33B 627	C.Y. Chien *et al.*	(JHU, SLAC, UCLA)
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CHO	70	PR D1 3031	Y. Cho *et al.*	(CMU, BNL, CASE)
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SAAL	69	Thesis	H.J. Saal	(COLU)
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ARNOLD	68B	PL 28B 56	R.G. Arnold *et al.*	(CERN, ORSAY)
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