K^0

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

K^0 MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
497.611±0.013 OUR FIT Error includes scale factor of 1.2.					
497.611±0.013 OUR AVERAGE Error includes scale factor of 1.2.					
497.607±0.007±0.015	261k	[1] TOMARADZE	14		$\psi(2S) \to K^0_S X$
497.583±0.005±0.020	35k	AMBROSINO	07B	KLOE	$e^+e^- \to K^0_L K^0_S$
497.625±0.001±0.031	655k	LAI	02	NA48	K^0_L beam
497.661±0.033	3713	BARKOV	87B	CMD	$e^+e^- \to K^0_L K^0_S$
497.742±0.085	780	BARKOV	85B	CMD	$e^+e^- \to K^0_L K^0_S$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
497.44 ±0.50		FITCH	67	OSPK	
498.9 ±0.5	4500	BALTAY	66	HBC	K^0 from $\overline{p}p$
497.44 ±0.33	2223	KIM	65B	HBC	K^0 from $\overline{p}p$
498.1 ±0.4		CHRISTENS...	64	OSPK	

[1] Obtained by analyzing CLEO-c data but not authored by the CLEO Collaboration.

$m_{K^0} - m_{K^\pm}$

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
3.934±0.020 OUR FIT Error includes scale factor of 1.6.						
• • • We do not use the following data for averages, fits, limits, etc. • • •						
3.95 ±0.21	417	HILL	68B	DBC	+	$K^+ d \to K^0 p p$
3.90 ±0.25	9	BURNSTEIN	65	HBC	−	
3.71 ±0.35	7	KIM	65B	HBC	−	$K^- p \to n \overline{K}^0$
5.4 ±1.1		CRAWFORD	59	HBC	+	
3.9 ±0.6		ROSENFELD	59	HBC	−	

K^0 MEAN SQUARE CHARGE RADIUS

VALUE (fm^2)	EVTS	DOCUMENT ID		TECN	COMMENT
−0.077±0.010 OUR AVERAGE					
−0.077±0.007±0.011	5037	ABOUZAID	06	KTEV	$K^0_L \to \pi^+\pi^- e^+ e^-$
−0.090±0.021		LAI	03C	NA48	$K^0_L \to \pi^+\pi^- e^+ e^-$
−0.054±0.026		MOLZON	78		K_S regen. by electrons
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−0.087±0.046		BLATNIK	79		VMD + dispersion relations
−0.050±0.130		FOETH	69B		K_S regen. by electrons

T-VIOLATION PARAMETER IN K^0-$\overline{K}^0$ MIXING

The asymmetry $A_T = \frac{\Gamma(\overline{K}^0 \to K^0) - \Gamma(K^0 \to \overline{K}^0)}{\Gamma(\overline{K}^0 \to K^0) + \Gamma(K^0 \to \overline{K}^0)}$ must vanish if T invariance holds.

ASYMMETRY A_T IN K^0-$\overline{K}^0$ MIXING

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN
6.6±1.3±1.0	640k	[1] ANGELOPO... 98E	CPLR

[1] ANGELOPOULOS 98E measures the asymmetry $A_T = [\Gamma(\overline{K}^0_{t=0} \to e^+ \pi^- \nu_{t=\tau}) - \Gamma(K^0_{t=0} \to e^- \pi^+ \overline{\nu}_{t=\tau})]/[\Gamma(\overline{K}^0_{t=0} \to e^+ \pi^- \nu_{t=\tau}) + \Gamma(K^0_{t=0} \to e^- \pi^+ \overline{\nu}_{t=\tau})]$ as a function of the neutral-kaon eigentime τ. The initial strangeness of the neutral kaon is tagged by the charge of the accompanying charged kaon in the reactions $p\overline{p} \to K^- \pi^+ K^0$ and $p\overline{p} \to K^+ \pi^- \overline{K}^0$. The strangeness at the time of the decay is tagged by the lepton charge. The reported result is the average value of A_T over the interval $1\tau_S < \tau < 20\tau_S$. From this value of A_T ANGELOPOULOS 01B, assuming CPT invariance in the $e\pi\nu$ decay amplitude, determine the T-violating as ΔS=ΔS conserving parameter (for its definition, see Review below) 4Re(ϵ) = $(6.2 \pm 1.4 \pm 1.0) \times 10^{-3}$.

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CP-VIOLATION PARAMETERS

Re(ϵ)

VALUE (units 10^{-3})	DOCUMENT ID	TECN
1.596±0.013	[1] AMBROSINO 06H	KLOE
• • • We do not use the following data for averages, fits, limits, etc. • • •		
1.664±0.010	[2] LAI 05A	NA48

[1] AMBROSINO 06H uses Bell-Steinberger relations with the following measurements: B($K^0_L \to \pi^+\pi^-$) in AMBROSINO 06F, B($K^0_S \to \pi^0\pi^0\pi^0$) in AMBROSINO 05B, the K^0_S-semileptonic charge asymmetry in AMBROSINO 06E, and K^0-semileptonic results in ANGELOPOULOS 98F.

[2] LAI 05A values are obtained through unitarity (Bell-Steinberger relations), improving determination of η_{000} and combining other data from PDG 04 and APOSTOLAKIS 99B.

CPT-VIOLATION PARAMETERS

In K^0-$\overline{K}^0$ mixing, if CP-violating interactions include a T conserving part then

$$|K_S\rangle = [|K_1\rangle + (\epsilon + \delta)|K_2\rangle]/\sqrt{1+|\epsilon+\delta|^2}$$
$$|K_L\rangle = [|K_2\rangle + (\epsilon - \delta)|K_1\rangle]/\sqrt{1+|\epsilon-\delta|^2}$$

where

$$|K_1\rangle = [|K^0\rangle + |\overline{K}^0\rangle]/\sqrt{2}$$
$$|K_2\rangle = [|K^0\rangle - |\overline{K}^0\rangle]/\sqrt{2}$$

and

$$|\overline{K}^0\rangle = CP|K^0\rangle.$$

The parameter δ specifies the CPT-violating part.

Estimates of δ are given below assuming the validity of the $\Delta S = \Delta Q$ rule. See also THOMSON 95 for a test of *CPT*-symmetry conservation in K^0 decays using the Bell-Steinberger relation.

REAL PART OF δ

A nonzero value violates *CPT* invariance.

VALUE (units 10^{-4})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.51± 2.25		[1] ABOUZAID	11	KTEV	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.3 ± 2.7		[2] AMBROSINO	06H	KLOE	
2.4 ± 2.8		[3] APOSTOLA...	99B	RVUE	
2.9 ± 2.6 ±0.6	1.3M	[4] ANGELOPO...	98F	CPLR	
180 ±200	6481	[5] DEMIDOV	95		$K_{\ell 3}$ reanalysis

[1] ABOUZAID 11 uses Bell-Steinberger relations.

[2] AMBROSINO 06H uses Bell-Steinberger relations with the following measurements: B($K^0_L \rightarrow \pi^+\pi^-$) in AMBROSINO 06F, B($K^0_S \rightarrow \pi^0\pi^0\pi^0$) in AMBROSINO 05B, the K^0_S-semileptonic charge asymmetry in AMBROSINO 06E, and K^0-semileptonic results in ANGELOPOULOS 98F.

[3] APOSTOLAKIS 99B assumes only unitarity and combines CPLEAR and other results.

[4] ANGELOPOULOS 98F use $\Delta S = \Delta Q$. If $\Delta S = \Delta Q$ is not assumed, they find Re$\delta = (3.0 \pm 3.3 \pm 0.6) \times 10^{-4}$.

[5] DEMIDOV 95 reanalyzes data from HART 73 and NIEBERGALL 74.

IMAGINARY PART OF δ

A nonzero value violates *CPT* invariance.

VALUE (units 10^{-5})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
− 1.5± 1.6		[1] ABOUZAID	11	KTEV	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.4± 2.1		[2] AMBROSINO	06H	KLOE	
− 0.2± 2.0		[3] LAI	05A	NA48	
2.4± 5.0		[4] APOSTOLA...	99B	RVUE	
− 90 ± 290 ±100	1.3M	[5] ANGELOPO...	98F	CPLR	
2100 ±3700	6481	[6] DEMIDOV	95		$K_{\ell 3}$ reanalysis

[1] ABOUZAID 11 uses Bell-Steinberger relations.

[2] AMBROSINO 06H uses Bell-Steinberger relations with the following measurements: B($K^0_L \rightarrow \pi^+\pi^-$) in AMBROSINO 06F, B($K^0_S \rightarrow \pi^0\pi^0\pi^0$) in AMBROSINO 05B, the K^0_S-semileptonic charge asymmetry in AMBROSINO 06E, and K^0-semileptonic results in ANGELOPOULOS 98F.

[3] LAI 05A values are obtained through unitarity (Bell-Steinberger relations), improving determination of η_{000} and combining other data from PDG 04 and APOSTOLAKIS 99B.

[4] APOSTOLAKIS 99B assumes only unitarity and combines CPLEAR and other results.

[5] If $\Delta S = \Delta Q$ is not assumed, ANGELOPOULOS 98F finds Im$\delta = (-15 \pm 23 \pm 3) \times 10^{-3}$.

[6] DEMIDOV 95 reanalyzes data from HART 73 and NIEBERGALL 74.

Re(y)

A non-zero value would violate CPT invariance in $\Delta S = \Delta Q$ amplitude. Re(y) is the following combination of K_{e3} decay amplitudes:

$$\text{Re(y)} = \text{Re}\Big(\frac{A(\overline{K}^0 \rightarrow e^- \pi^+ \overline{\nu}_e)^* - A(K^0 \rightarrow e^+ \pi^- \nu_e)}{A(\overline{K}^0 \rightarrow e^- \pi^+ \overline{\nu}_e)^* + A(K^0 \rightarrow e^+ \pi^- \nu_e)} \Big)$$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN
0.4±2.5	13k	[1] AMBROSINO	06E	KLOE
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.3±3.1		[2] APOSTOLA...	99B	CPLR

[1] They use the PDG 04 for the K^0_L semileptonic charge asymmetry and PDG 04 (CP review, CPT NOT ASSUMED) for Re(ϵ).

[2] Constrained by Bell-Steinberger (or unitarity) relation.

Re(x_)

A non-zero value would violate CPT invariance in decay amplitudes with $\Delta S \neq \Delta Q$. x_-, used here to define Re(x_-), and x_+, used below in the $\Delta S = \Delta Q$ section are the following combinations of K_{e3} decay amplitudes:

$$x_\pm = \frac{1}{2}\Big(\frac{A(\overline{K}^0 \rightarrow \pi^- e^+ \nu_e)}{A(K^0 \rightarrow \pi^- e^+ \nu_e)} \pm \frac{A(K^0 \rightarrow \pi^+ e^- \overline{\nu}_e)^*}{A(\overline{K}^0 \rightarrow \pi^+ e^- \overline{\nu}_e)^*} \Big).$$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
−2.9± 2.0		[1] AMBROSINO	06H	KLOE	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−0.8± 2.5	13k	[2] AMBROSINO	06E	KLOE	
−0.5± 3.0		[3] APOSTOLA...	99B	CPLR	Strangeness tagged
2 ±13 ±3	650k	ANGELOPO...	98F	CPLR	Strangeness tagged

[1] AMBROSINO 06H uses Bell-Steinberger relations with the following measurements: B($K^0_L \rightarrow \pi^+\pi^-$) in AMBROSINO 06F, B($K^0_S \rightarrow \pi^0\pi^0\pi^0$) in AMBROSINO 05B, the K^0_S-semileptonic charge asymmetry in AMBROSINO 06E, and K^0-semileptonic results in ANGELOPOULOS 98F.

[2] Uses PDG 04 for the K^0_L semileptonic charge asymmetry and Re(δ) from CPLEAR, ANGELOPOULOS 98F.

[3] Constrained by Bell-Steinberger (or unitarity) relation.

$\left|m_{K^0} - m_{\overline{K}^0}\right| / m_{\text{average}}$

A test of CPT invariance. "Our Evaluation" is described in the "Tests of Conservation Laws" section. It assumes CPT invariance in the decay and neglects some contributions from decay channels other than $\pi\pi$.

VALUE	CL%	DOCUMENT ID		TECN
<6 × 10^{-19}	90	PDG	12	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$(-3 \pm 4) \times 10^{-18}$		[1] ANGELOPO...	99B	RVUE

[1] ANGELOPOULOS 99B assumes only unitarity and combines CPLEAR and other results.

$(\Gamma_{K^0} - \Gamma_{\overline{K}^0})/m_{\text{average}}$

A test of *CPT* invariance.

VALUE	*DOCUMENT ID*		*TECN*
$(7.8\pm8.4)\times10^{-18}$	[1] ANGELOPO...	99B	RVUE

[1] ANGELOPOULOS 99B assumes only unitarity and combines CPLEAR with other results. Correlated with $(m_{K^0} - m_{\overline{K}^0})$ / m_{average} with a correlation coefficient of -0.95.

TESTS OF $\Delta S = \Delta Q$ RULE

Re(x_+)

A non-zero value would violate the $\Delta S = \Delta Q$ rule in *CPT* conserving transitions. x_+ is defined above in the Re(x_-) section.

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*
$-0.9\pm$ 3.0 OUR AVERAGE				
$-2\ \pm10$		[1] BATLEY	07D	NA48
$-0.5\pm$ 3.6	13k	[2] AMBROSINO	06E	KLOE
$-1.8\pm$ 6.1		[3] ANGELOPO...	98D	CPLR

[1] Result obtained from the measurement $\Gamma(K^0_S \to \pi e \nu)$ / $\Gamma(K^0_L \to \pi e \nu) = 0.993 \pm 0.34$, neglecting possible *CPT* non-invariance and using PDG 06 values of $\text{B}(K^0_L \to \pi e \nu) = 0.4053 \pm 0.0015$, $\tau_L = (5.114 \pm 0.021) \times 10^{-8}$ s and $\tau_S = (0.8958 \pm 0.0005) \times 10^{-10}$ s.

[2] Re(x_+) can be shown to be equal to the following combination of rates:

$$\text{Re}(x_+) = \frac{1}{2}\,\frac{\Gamma(K^0_S \to \pi e \nu) - \Gamma(K^0_L \to \pi e \nu)}{\Gamma(K^0_S \to \pi e \nu) + \Gamma(K^0_L \to \pi e \nu)}$$

which is valid up to first order in terms violating *CPT* and/or the $\Delta S = \Delta Q$ rule.

[3] Obtained neglecting *CPT* violating amplitudes.

K^0 REFERENCES

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BATLEY	07D	PL B653 145	J.R. Batley *et al.*	(CERN NA48 Collab.)
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AMBROSINO	06E	PL B636 173	F. Ambrosino *et al.*	(KLOE Collab.)
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AMBROSINO	05B	PL B619 61	F. Ambrosino *et al.*	(KLOE Collab.)
LAI	05A	PL B610 165	A. Lai *et al.*	(CERN NA48 Collab.)
PDG	04	PL B592 1	S. Eidelman *et al.*	(PDG Collab.)
LAI	03C	EPJ C30 33	A. Lai *et al.*	(CERN NA48 Collab.)
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CHRISTENS...	64	PRL 13 138	J.H. Christenson *et al.*	(PRIN)
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ROSENFELD	59	PRL 2 110	A.H. Rosenfeld, F.T. Solmitz, R.D. Tripp	(LRL)