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		$\psi(2S) \rightarrow K^0_S X$
497.583±0.005±0.020	35k	AMBROSINO	07B	KLOE	$e^+ e^- \rightarrow K^0_L K^0_S$
497.625±0.001±0.031	655k	LAI	02	NA48	K^0_L beam
497.661±0.033	3713	BARKOV	87B	CMD	$e^+ e^- \rightarrow K^0_L K^0_S$
497.742±0.085	780	BARKOV	85B	CMD	$e^+ e^- \rightarrow K^0_L K^0_S$
• • • 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	+	$K^+ d \rightarrow K^0 p p$
3.90 ±0.25	9	BURNSTEIN	65	HBC	−	
3.71 ±0.35	7	KIM	65B	HBC	−	$K^- p \rightarrow n \overline{K}^0$
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	$K^0_L \rightarrow \pi^+ \pi^- e^+ e^-$
−0.090±0.021		LAI	03C	NA48	$K^0_L \rightarrow \pi^+ \pi^- e^+ e^-$
−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) = $(6.2 \pm 1.4 \pm 1.0) \times 10^{-3}$.

See the related review(s):

CPT Invariance Tests in Neutral Kaon Decay

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 Reδ=$(3.0 \pm 3.3 \pm 0.6) \times 10^{-4}$.
[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 Imδ=$(-15 \pm 23 \pm 3) \times 10^{-3}$.
[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:

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

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:

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

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($K^0_L \to \pi^+ \pi^-$) 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] 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*
$(7.8 \pm 8.4) \times 10^{-18}$	[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

$\mathrm{Re}(x_+)$

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

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*
-0.9 ± 3.0 OUR AVERAGE				
-2 ± 10		[1] BATLEY	07D	NA48
-0.5 ± 3.6	13k	[2] AMBROSINO	06E	KLOE
-1.8 ± 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 $B(K^0_L \to \pi e \nu) = 0.4053 \pm 0.0015$, $\tau_L = (5.114 \pm 0.021) \times 10^{-8}$ s and $\tau_S = (0.8958 \pm 0.0005) \times 10^{-10}$ s.

[2] $\mathrm{Re}(x_+)$ can be shown to be equal to the following combination of rates:

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

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.)
ABOUZAID	06	PRL 96 101801	E. Abouzaid *et al.*	(KTeV Collab.)
AMBROSINO	06E	PL B636 173	F. Ambrosino *et al.*	(KLOE Collab.)
AMBROSINO	06F	PL B638 140	F. Ambrosino *et al.*	(KLOE Collab.)
AMBROSINO	06H	JHEP 0612 011	F. Ambrosino *et al.*	(KLOE Collab.)
PDG	06	JP G33 1	W.-M. Yao *et al.*	(PDG Collab.)
AMBROSINO	05B	PL B619 61	F. Ambrosino *et al.*	(KLOE Collab.)
LAI	05A	PL B610 165	A. Lai *et al.*	(CERN NA48 Collab.)
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LAI	03C	EPJ C30 33	A. Lai *et al.*	(CERN NA48 Collab.)
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HILL	68B	PR 168 1534	D.G. Hill *et al.*	(BNL, CMU)
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BALTAY	66	PR 142 932	C. Baltay *et al.*	(YALE, BNL)
BURNSTEIN	65	PR 138 B895	R.A. Burnstein, H.A. Rubin	(UMD)
KIM	65B	PR 140 B1334	J.K. Kim, L. Kirsch, D. Miller	(COLU)
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CRAWFORD	59	PRL 2 112	F.S. Crawford *et al.*	(LRL)
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