



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

## $K^0$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
<b>497.611±0.013 OUR FIT</b>		Error includes scale factor of 1.2.		
<b>497.611±0.013 OUR AVERAGE</b>		Error includes scale factor of 1.2.		
497.607±0.007±0.015	261k	<sup>1</sup> TOMARADZE 14		$\psi(2S) \rightarrow K_S^0 X$
497.583±0.005±0.020	35k	AMBROSINO 07B	KLOE	$e^+e^- \rightarrow K_L^0 K_S^0$
497.625±0.001±0.031	655k	LAI 02	NA48	$K_L^0$ beam
497.661±0.033	3713	BARKOV 87B	CMD	$e^+e^- \rightarrow K_L^0 K_S^0$
497.742±0.085	780	BARKOV 85B	CMD	$e^+e^- \rightarrow K_L^0 K_S^0$
● ● ● 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 $\bar{p}p$
497.44 ±0.33	2223	KIM 65B	HBC	$K^0$ from $\bar{p}p$
498.1 ±0.4		CHRISTENS... 64	OSPK	

<sup>1</sup>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
<b>3.934±0.020 OUR FIT</b>		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	+	$K^+d \rightarrow K^0 pp$
3.90 ±0.25	9	BURNSTEIN 65	HBC	-	
3.71 ±0.35	7	KIM 65B	HBC	-	$K^-p \rightarrow n\bar{K}^0$
5.4 ±1.1		CRAWFORD 59	HBC	+	
3.9 ±0.6		ROSENFELD 59	HBC	-	

## $K^0$ MEAN SQUARE CHARGE RADIUS

VALUE (fm <sup>2</sup> )	EVTS	DOCUMENT ID	TECN	COMMENT
<b>-0.077±0.010 OUR AVERAGE</b>				
-0.077±0.007±0.011	5037	ABOUZAID 06	KTEV	$K_L^0 \rightarrow \pi^+\pi^-e^+e^-$
-0.090±0.021		LAI 03C	NA48	$K_L^0 \rightarrow \pi^+\pi^-e^+e^-$
-0.054±0.026		MOLZON 78		$K_S^0$ 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		$K_S^0$ regen. by electrons

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

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

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

VALUE (units $10^{-3}$ )	EVTS	DOCUMENT ID	TECN
<b><math>6.6 \pm 1.3 \pm 1.0</math></b>	640k	<sup>1</sup> ANGELOPO... 98E	CPLR

<sup>1</sup> ANGELOPOULOS 98E measures the asymmetry  $A_T = [\Gamma(\bar{K}_{t=0}^0 \rightarrow e^+ \pi^- \nu_{t=\tau}) - \Gamma(K_{t=0}^0 \rightarrow e^- \pi^+ \bar{\nu}_{t=\tau})] / [\Gamma(\bar{K}_{t=0}^0 \rightarrow e^+ \pi^- \nu_{t=\tau}) + \Gamma(K_{t=0}^0 \rightarrow e^- \pi^+ \bar{\nu}_{t=\tau})]$  as a function of the neutral-kaon eigentime  $\tau$ . The initial strangeness of the neutral kaon is tagged by the charge of the accompanying charged kaon in the reactions  $p\bar{p} \rightarrow K^- \pi^+ K^0$  and  $p\bar{p} \rightarrow K^+ \pi^- \bar{K}^0$ . 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  $\Delta S = \Delta S$  conserving parameter (for its definition, see Review below)  $4\text{Re}(\epsilon) = (6.2 \pm 1.4 \pm 1.0) \times 10^{-3}$ .

See the related review(s):

[CPT Invariance Tests in Neutral Kaon Decay](#)

## CP-VIOLATION PARAMETERS

### Re( $\epsilon$ )

VALUE (units $10^{-3}$ )	DOCUMENT ID	TECN
<b><math>1.596 \pm 0.013</math></b>	<sup>1</sup> AMBROSINO 06H	KLOE

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

$1.664 \pm 0.010$	<sup>2</sup> LAI	05A NA48
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<sup>1</sup> AMBROSINO 06H uses Bell-Steinberger relations with the following measurements:  $B(K_L^0 \rightarrow \pi^+ \pi^-)$  in AMBROSINO 06F,  $B(K_S^0 \rightarrow \pi^0 \pi^0 \pi^0)$  in AMBROSINO 05B, the  $K_S^0$ -semileptonic charge asymmetry in AMBROSINO 06E, and  $K^0$ -semileptonic results in ANGELOPOULOS 98F.

<sup>2</sup> LAI 05A values are obtained through unitarity (Bell-Steinberger relations), improving determination of  $\eta_{000}$  and combining other data from PDG 04 and APOSTOLAKIS 99B.

## CPT-VIOLATION PARAMETERS

In  $K^0-\bar{K}^0$  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

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

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

and

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

The parameter  $\delta$  specifies the *CPT*-violating part.

Estimates of  $\delta$  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 $\delta$

A nonzero value violates *CPT* invariance.

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

<sup>1</sup> ABOUZOID 11 uses Bell-Steinberger relations.

<sup>2</sup> AMBROSINO 06H uses Bell-Steinberger relations with the following measurements:  $B(K_L^0 \rightarrow \pi^+ \pi^-)$  in AMBROSINO 06F,  $B(K_S^0 \rightarrow \pi^0 \pi^0 \pi^0)$  in AMBROSINO 05B, the  $K_S^0$ -semileptonic charge asymmetry in AMBROSINO 06E, and  $K^0$ -semileptonic results in ANGELOPOULOS 98F.

<sup>3</sup> APOSTOLAKIS 99B assumes only unitarity and combines CPLEAR and other results.

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

<sup>5</sup> DEMIDOV 95 reanalyzes data from HART 73 and NIEBERGALL 74.

## IMAGINARY PART OF $\delta$

A nonzero value violates *CPT* invariance.

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

<sup>1</sup> ABOUZOID 11 uses Bell-Steinberger relations.

<sup>2</sup> AMBROSINO 06H uses Bell-Steinberger relations with the following measurements:  $B(K_L^0 \rightarrow \pi^+ \pi^-)$  in AMBROSINO 06F,  $B(K_S^0 \rightarrow \pi^0 \pi^0 \pi^0)$  in AMBROSINO 05B, the  $K_S^0$ -semileptonic charge asymmetry in AMBROSINO 06E, and  $K^0$ -semileptonic results in ANGELOPOULOS 98F.

<sup>3</sup> LAI 05A values are obtained through unitarity (Bell-Steinberger relations), improving determination of  $\eta_{000}$  and combining other data from PDG 04 and APOSTOLAKIS 99B.

<sup>4</sup> APOSTOLAKIS 99B assumes only unitarity and combines CPLEAR and other results.

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

<sup>6</sup> 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.  $\text{Re}(y)$  is the following combination of  $K_{e3}$  decay amplitudes:

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

<u>VALUE (units <math>10^{-3}</math>)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<b><math>0.4 \pm 2.5</math></b>	13k	<sup>1</sup> AMBROSINO 06E	KLOE

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

$0.3 \pm 3.1$		<sup>2</sup> APOSTOLA... 99B	CPLR
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<sup>1</sup> They use the PDG 04 for the  $K_L^0$  semileptonic charge asymmetry and PDG 04 ( $CPT$  review,  $CPT$  NOT ASSUMED) for  $\text{Re}(\epsilon)$ .

<sup>2</sup> Constrained by Bell-Steinberger (or unitarity) relation.

**Re(x<sub>-</sub>)**

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

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

<u>VALUE (units <math>10^{-3}</math>)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b><math>-2.9 \pm 2.0</math></b>		<sup>1</sup> AMBROSINO 06H	KLOE	

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

$-0.8 \pm 2.5$	13k	<sup>2</sup> AMBROSINO 06E	KLOE	
$-0.5 \pm 3.0$		<sup>3</sup> APOSTOLA... 99B	CPLR	Strangeness tagged
$2 \pm 13 \pm 3$	650k	ANGELOPO... 98F	CPLR	Strangeness tagged

<sup>1</sup> AMBROSINO 06H uses Bell-Steinberger relations with the following measurements:  $B(K_L^0 \rightarrow \pi^+ \pi^-)$  in AMBROSINO 06F,  $B(K_S^0 \rightarrow \pi^0 \pi^0 \pi^0)$  in AMBROSINO 05B, the  $K_S^0$ -semileptonic charge asymmetry in AMBROSINO 06E, and  $K^0$ -semileptonic results in ANGELOPOULOS 98F.

<sup>2</sup> Uses PDG 04 for the  $K_L^0$  semileptonic charge asymmetry and  $\text{Re}(\delta)$  from CPLEAR, ANGELOPOULOS 98F.

<sup>3</sup> Constrained by Bell-Steinberger (or unitarity) relation.

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

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  $\pi\pi$ .

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<b><math>&lt; 6 \times 10^{-19}</math></b>	90	PDG 12	

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

$(-3 \pm 4) \times 10^{-18}$		<sup>1</sup> ANGELOPO... 99B	RVUE
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<sup>1</sup> ANGELOPOULOS 99B assumes only unitarity and combines CPLEAR and other results.

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

A test of *CPT* invariance.

VALUE	DOCUMENT ID	TECN
$(7.8 \pm 8.4) \times 10^{-18}$	<sup>1</sup> ANGELOPO... 99B	RVUE

<sup>1</sup> ANGELOPOULOS 99B assumes only unitarity and combines CPLEAR with other results. Correlated with  $(m_{K^0} - m_{\bar{K}^0}) / m_{\text{average}}$  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
<b><math>-0.9 \pm 3.0</math> OUR AVERAGE</b>			
$-2 \pm 10$		<sup>1</sup> BATLEY 07D	NA48
$-0.5 \pm 3.6$	13k	<sup>2</sup> AMBROSINO 06E	KLOE
$-1.8 \pm 6.1$		<sup>3</sup> ANGELOPO... 98D	CPLR

<sup>1</sup> Result obtained from the measurement  $\Gamma(K_S^0 \rightarrow \pi e \nu) / \Gamma(K_L^0 \rightarrow \pi e \nu) = 0.993 \pm 0.34$ , neglecting possible *CPT* non-invariance and using PDG 06 values of  $B(K_L^0 \rightarrow \pi e \nu) = 0.4053 \pm 0.0015$ ,  $\tau_L = (5.114 \pm 0.021) \times 10^{-8}$  s and  $\tau_S = (0.8958 \pm 0.0005) \times 10^{-10}$  s.

<sup>2</sup> Re( $x_+$ ) can be shown to be equal to the following combination of rates:

$$\text{Re}(x_+) = \frac{1}{2} \frac{\Gamma(K_S^0 \rightarrow \pi e \nu) - \Gamma(K_L^0 \rightarrow \pi e \nu)}{\Gamma(K_S^0 \rightarrow \pi e \nu) + \Gamma(K_L^0 \rightarrow \pi e \nu)}$$

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

<sup>3</sup> Obtained neglecting *CPT* violating amplitudes.

## $K^0$ REFERENCES

TOMARADZE 14	PR D89 031501	A. Tomaradze <i>et al.</i>	(NWES, WAYN)
PDG 12	PR D86 010001	J. Beringer <i>et al.</i>	(PDG Collab.)
ABOUZAID 11	PR D83 092001	E. Abouzaid <i>et al.</i>	(FNAL KTeV Collab.)
AMBROSINO 07B	JHEP 0712 073	F. Ambrosino <i>et al.</i>	(KLOE Collab.)
BATLEY 07D	PL B653 145	J.R. Batley <i>et al.</i>	(CERN NA48 Collab.)
ABOUZAID 06	PRL 96 101801	E. Abouzaid <i>et al.</i>	(KTeV Collab.)
AMBROSINO 06E	PL B636 173	F. Ambrosino <i>et al.</i>	(KLOE Collab.)
AMBROSINO 06F	PL B638 140	F. Ambrosino <i>et al.</i>	(KLOE Collab.)
AMBROSINO 06H	JHEP 0612 011	F. Ambrosino <i>et al.</i>	(KLOE Collab.)
PDG 06	JP G33 1	W.-M. Yao <i>et al.</i>	(PDG Collab.)
AMBROSINO 05B	PL B619 61	F. Ambrosino <i>et al.</i>	(KLOE Collab.)
LAI 05A	PL B610 165	A. Lai <i>et al.</i>	(CERN NA48 Collab.)
PDG 04	PL B592 1	S. Eidelman <i>et al.</i>	(PDG Collab.)
LAI 03C	EPJ C30 33	A. Lai <i>et al.</i>	(CERN NA48 Collab.)
LAI 02	PL B533 196	A. Lai <i>et al.</i>	(CERN NA48 Collab.)
ANGELOPO... 01B	EPJ C22 55	A. Angelopoulos <i>et al.</i>	(CPLEAR Collab.)
ANGELOPO... 99B	PL B471 332	A. Angelopoulos <i>et al.</i>	(CPLEAR Collab.)
APOSTOLA... 99B	PL B456 297	A. Apostolakis <i>et al.</i>	(CPLEAR Collab.)
ANGELOPO... 98D	PL B444 38	A. Angelopoulos <i>et al.</i>	(CPLEAR Collab.)
Also	EPJ C22 55	A. Angelopoulos <i>et al.</i>	(CPLEAR Collab.)
ANGELOPO... 98E	PL B444 43	A. Angelopoulos <i>et al.</i>	(CPLEAR Collab.)
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DEMIDOV	95	PAN 58 968	V. Demidov, K. Gusev, E. Shabalin	(ITEP)
		From YAF 58 1041.		
THOMSON	95	PR D51 1412	G.B. Thomson, Y. Zou	(RUTG)
BARKOV	87B	SJNP 46 630	L.M. Barkov <i>et al.</i>	(NOVO)
		Translated from YAF 46 1088.		
BARKOV	85B	JETPL 42 138	L.M. Barkov <i>et al.</i>	(NOVO)
		Translated from ZETFP 42 113.		
BLATNIK	79	LNC 24 39	S. Blatnik, J. Stahov, C.B. Lang	(TUZL, GRAZ)
MOLZON	78	PRL 41 1213	W.R. Molzon <i>et al.</i>	(EFI+)
NIEBERGALL	74	PL 49B 103	F. Niebergall <i>et al.</i>	(CERN, ORSAY, VIEN)
HART	73	NP B66 317	J.C. Hart <i>et al.</i>	(CAVE, RHEL)
FOETH	69B	PL 30B 276	H. Foeth <i>et al.</i>	(AACH, CERN, TORI)
HILL	68B	PR 168 1534	D.G. Hill <i>et al.</i>	(BNL, CMU)
FITCH	67	PR 164 1711	V.L. Fitch <i>et al.</i>	(PRIN)
BALTAY	66	PR 142 932	C. Baltay <i>et al.</i>	(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)
CHRISTENS...	64	PRL 13 138	J.H. Christenson <i>et al.</i>	(PRIN)
CRAWFORD	59	PRL 2 112	F.S. Crawford <i>et al.</i>	(LRL)
ROSENFELD	59	PRL 2 110	A.H. Rosenfeld, F.T. Solmitz, R.D. Tripp	(LRL)

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