



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

## $K^0$ 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. Re(y) is the following combination of  $K_{e3}$  decay amplitudes:

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

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

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

0.3±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 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 Re( $x_-$ ), and  $x_+$ , used below in the  $\Delta S = \Delta Q$  section are the following combinations of  $K_{e3}$  decay amplitudes:

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

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

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

-0.8± 2.5	13k	<sup>2</sup> AMBROSINO 06E	KLOE	
-0.5± 3.0		<sup>3</sup> APOSTOLA... 99B	CPLR	Strangeness tagged
2 ±13 ±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 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  $\pi\pi$ .

VALUE	CL%	DOCUMENT ID	TECN
<b>&lt;6 × 10<sup>-19</sup></b>	90	PDG 12	

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

(-3 ± 4) × 10 <sup>-18</sup>		<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

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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.)
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ANGELOPO... 01B	EPJ C22 55	A. Angelopoulos <i>et al.</i>	(CPLEAR Collab.)
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APOSTOLA... 99B	PL B456 297	A. Apostolakis <i>et al.</i>	(CPLEAR Collab.)
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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)
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		Translated from YAF 46 1088.		
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		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)