The KTeV Measurement of Re(ε'/ε)

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For the KTeV Collaboration

Outline

- Introduction
- Detector and Analysis
- Important Systematics
- Results
- Improvements for Future
- Conclusion

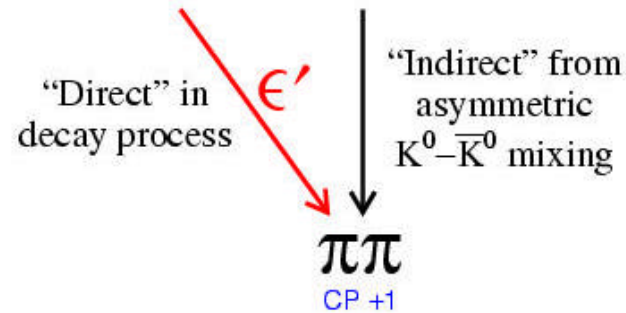
Introduction to Re(ε'/ε)

$$|K_1> \sim |K_0> - |\overline{K}_0>$$

$$|K_2> \sim |K_0> + |\overline{K}_0>$$

CP symmetry can be violated in the $K^0 - \overline{K}^0$ mixing and in the decay

$$K_L = \overset{\text{CP }-1}{K_2} + \epsilon \overset{\text{CP }+1}{K_1}$$

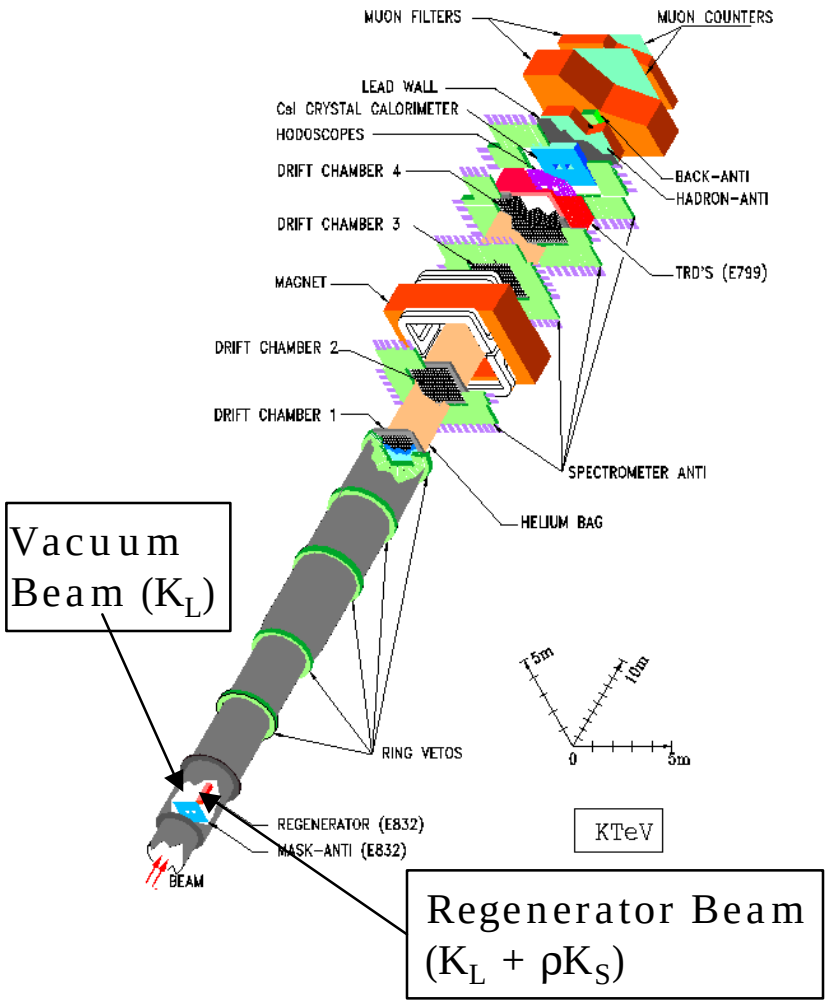


$$h_{+-} = \frac{A(K_L \to p^+p^-)}{A(K_S \to p^+p^-)} = e + e'$$

$$h_{00} = \frac{A(K_L \to p^0p^0)}{A(K_S \to p^0p^0)} = e - 2e'$$

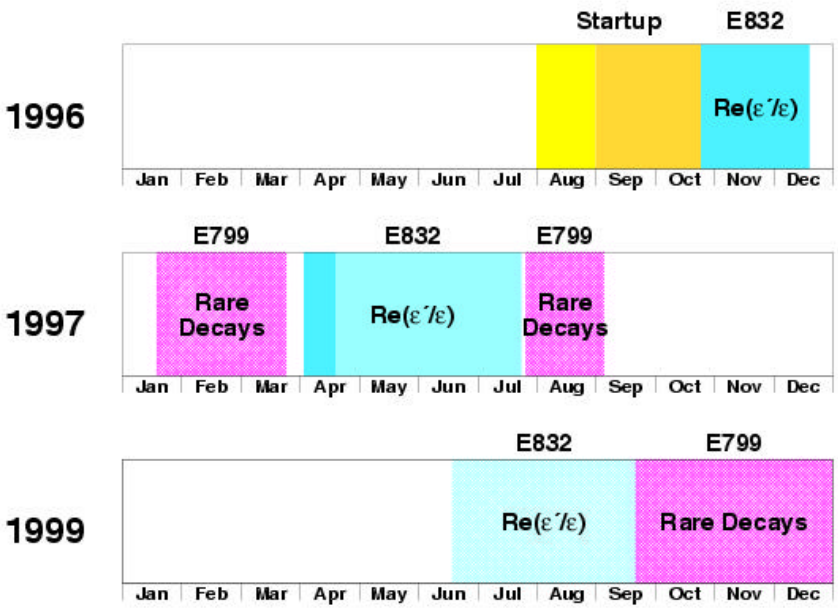
$$\Rightarrow \quad \mathrm{Re}(e'/e) \approx \frac{1}{6}\left(\left|\frac{h_{+-}}{h_{00}}\right|^2 - 1\right)$$

The KTeV Detector



- Movable active regenerator to provide a coherent mixture of K_L and K_S and to veto scattered kaons
- Charged spectrometer to reconstruct K ? $\pi^+\pi^-$ decays
- CsI calorimeter to reconstruct K ? $\pi^0\pi^0$ decays
- MC simulation used to predict acceptance

KTeV Data



- Current result based on 3.3 million K_L ? $\pi^0\pi^0$ decays from 1996 and 1997
  - $\sigma_{stat} = 1.48 \times 10^{-4}$
- 1999 dataset contains ~3.7 million K_L ? $\pi^0\pi^0$ decays
  - $\sigma_{stat} \sim 1.4 \times 10^{-4}$
- All data
  - $\sigma_{stat} \sim 1 \times 10^{-4}$

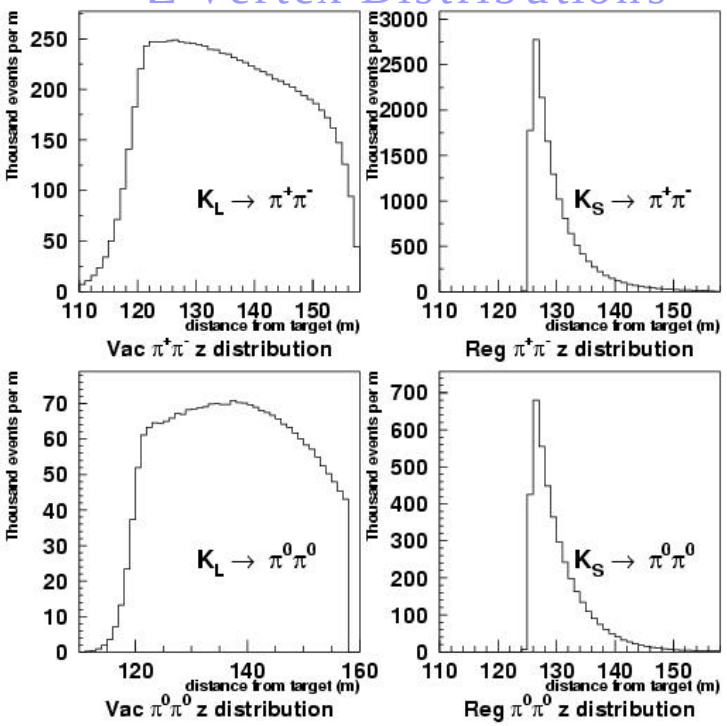
Data Analysis

- K ? $\pi^+\pi^-$
  - Momentum resolution ~0.4%
  - Z vertex resolution 5-30 cm
  - Mass resolution ~1.5 MeV
- K ? $\pi^0\pi^0$
  - $Z_{p^0} = Z_{CsI} - \frac{r_{12}\sqrt{E_1 E_2}}{m_{p^0}}$
  - Energy resolution ~0.6%
  - Z vertex resolution 20-30 cm
  - Mass resolution ~1.5 MeV

Numbers of events after background subtraction (× 10^6)

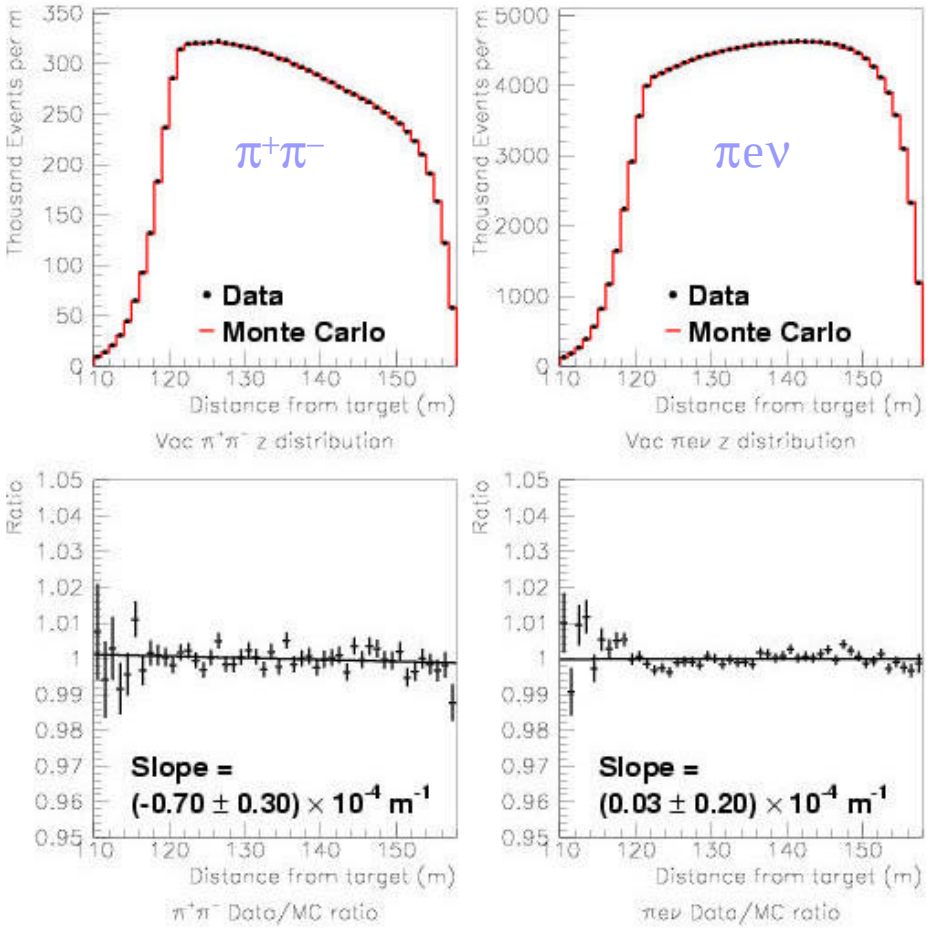
	Vacuum Beam	Regenerator Beam
K ? $\pi^+\pi^-$	11.1	19.3
K ? $\pi^0\pi^0$	3.3	5.6

Z Vertex Distributions



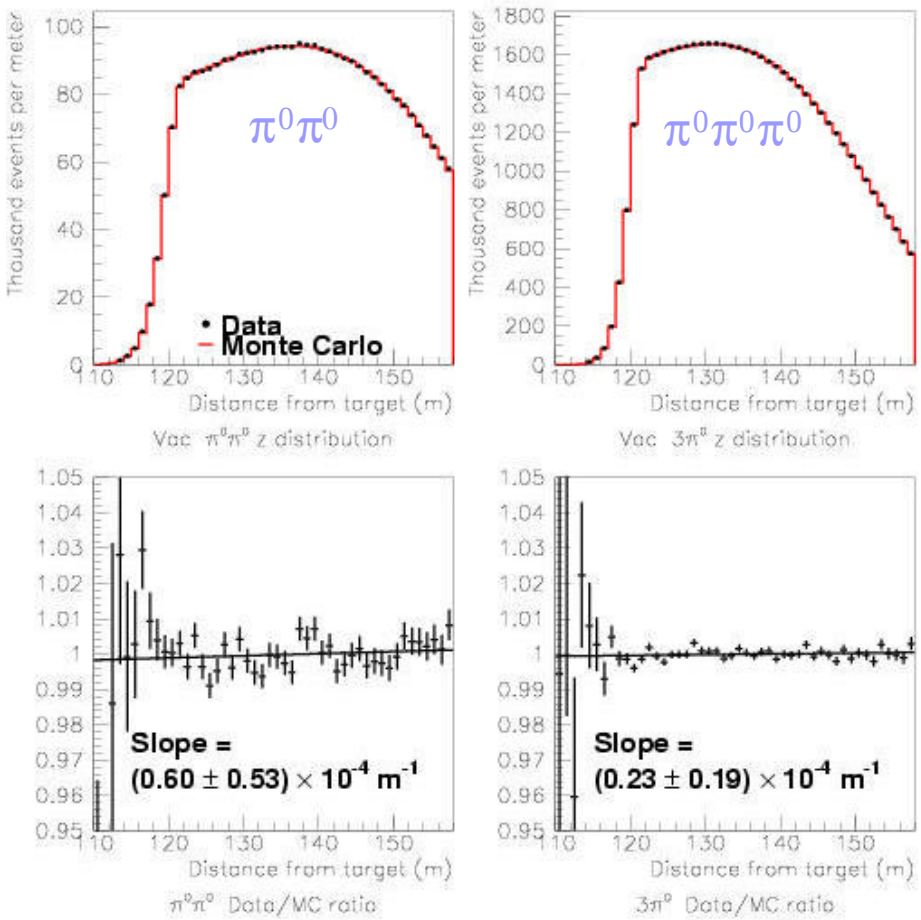
Data to MC Vertex Comparisons

Charged Mode Z Vertex



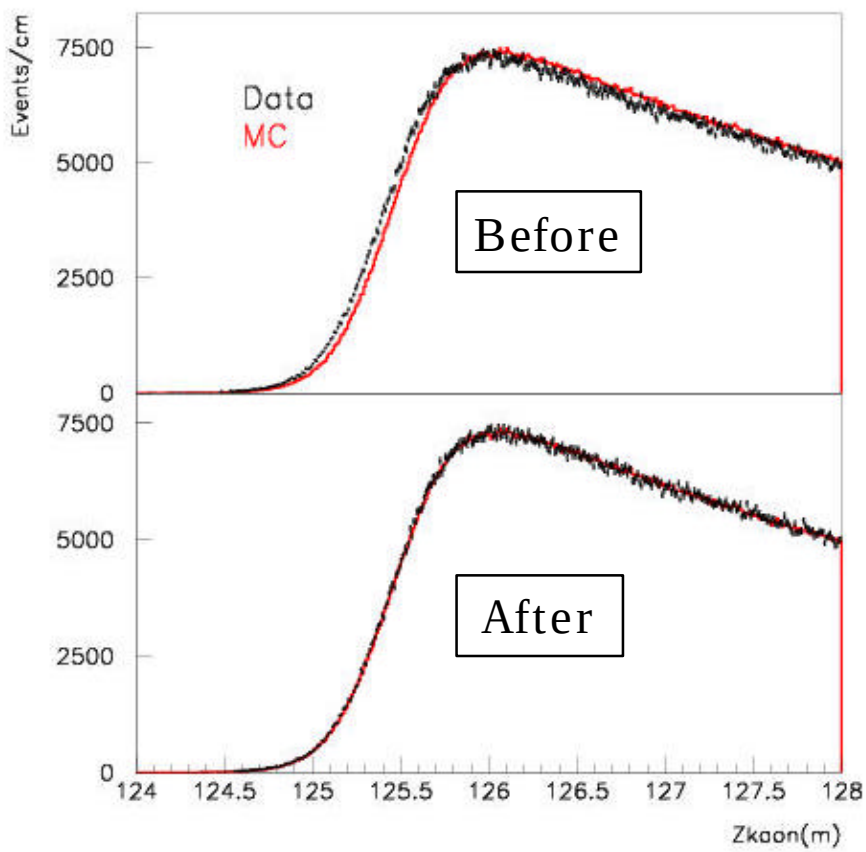
Data to MC Vertex Comparisons

Neutral Mode Z Vertex

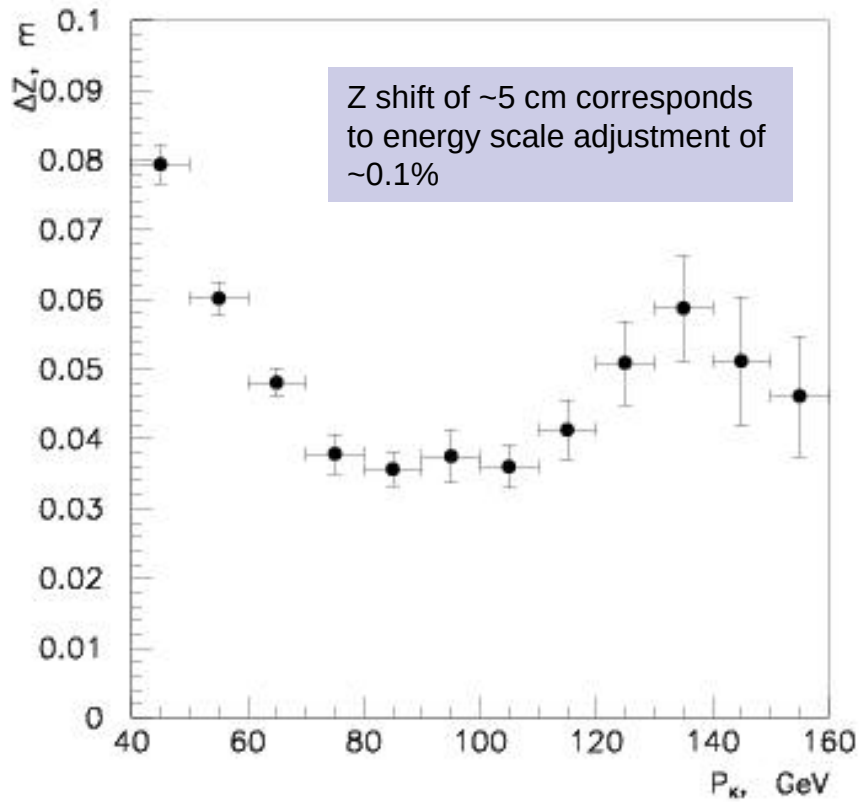


Adjustment of the Energy Scale

Z Vertex at Regenerator Edge

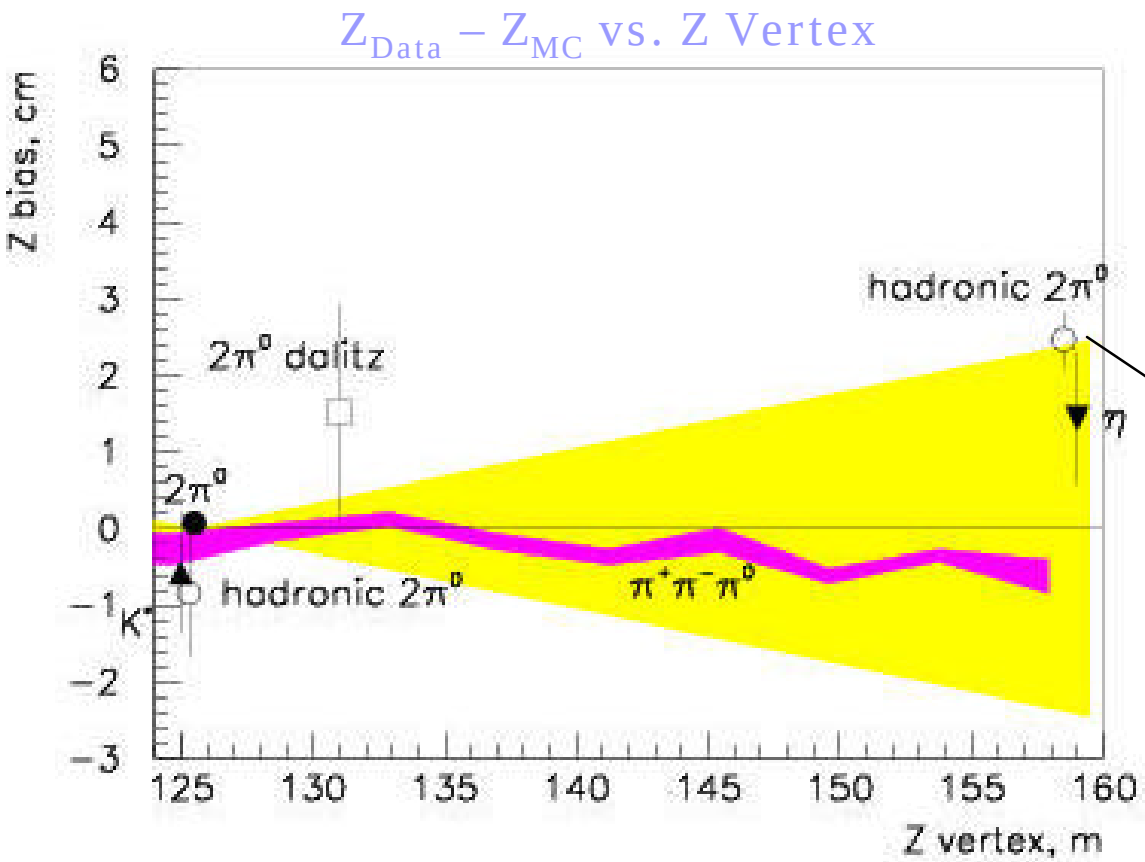


Z Shift in Kaon Momentum Bins

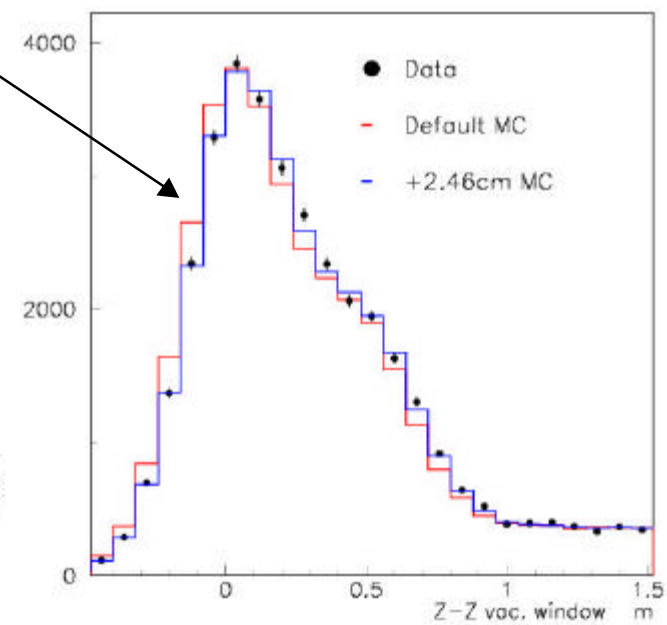


Z shift of ~5 cm corresponds to energy scale adjustment of ~0.1%

Energy Scale Crosschecks



Data-MC energy scale agreement checked along the length of the decay volume

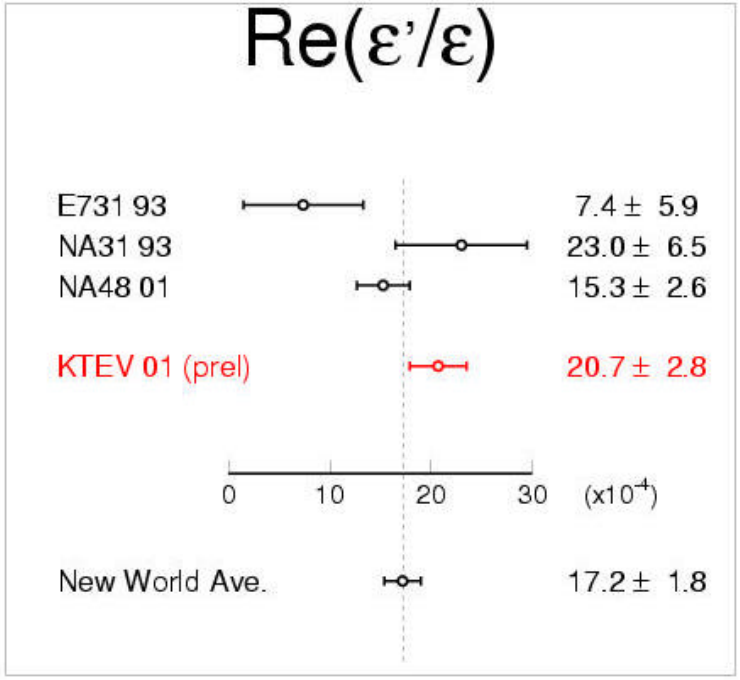


Summary of Systematics

Source of Uncertainty	Uncertainty in Re(ε'/ε) (× 10^{-4}) from	
	K_L ? $\pi^0\pi^0$	K_L ? $\pi^+\pi^-$
Trigger	0.18	0.56
CsI Energy, Position Reconstruction	1.48	-
Track Reconstruction	-	0.32
Selection Efficiency	0.37	0.44
Apertures	0.48	0.30
Background	1.07	0.20
Acceptance Correction	0.32	0.89
Monte Carlo Statistics	0.40	0.41
Fitting	0.44	
Total	2.43	

KTeV Result

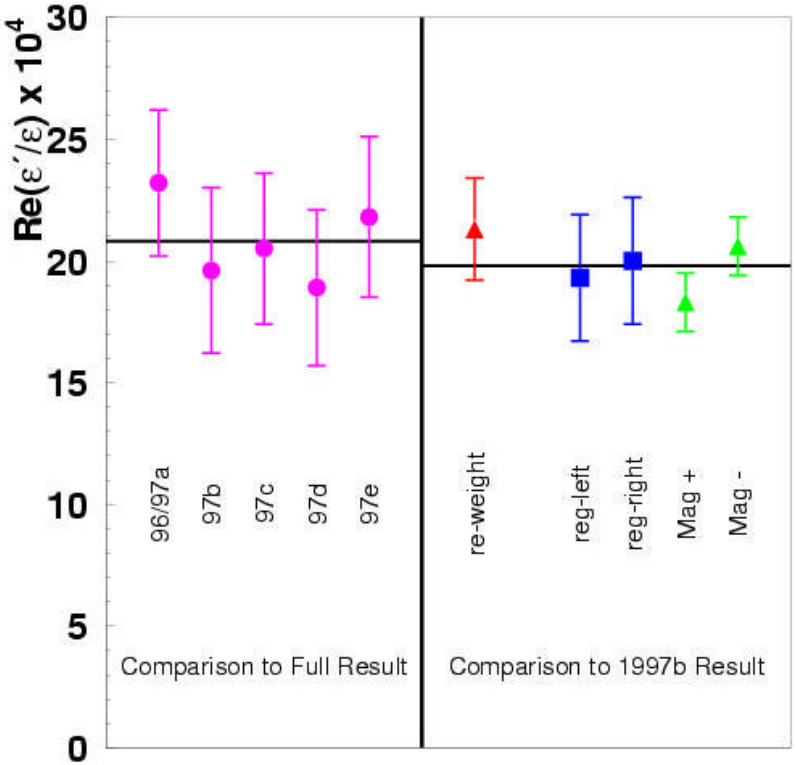
$$\mathrm{Re}(\varepsilon'/\varepsilon) = (20.7 \pm 1.5(\mathrm{stat}) \pm 2.4\ (\mathrm{syst})) \times 10^{-4}$$



World Average = $(17.2 \pm 1.8) \times 10^{-4}$

Probability = 13%

Crosschecks



- 96/97a data point is the update of the 1999 PRL result
- Re-weight data point is an NA48-style analysis

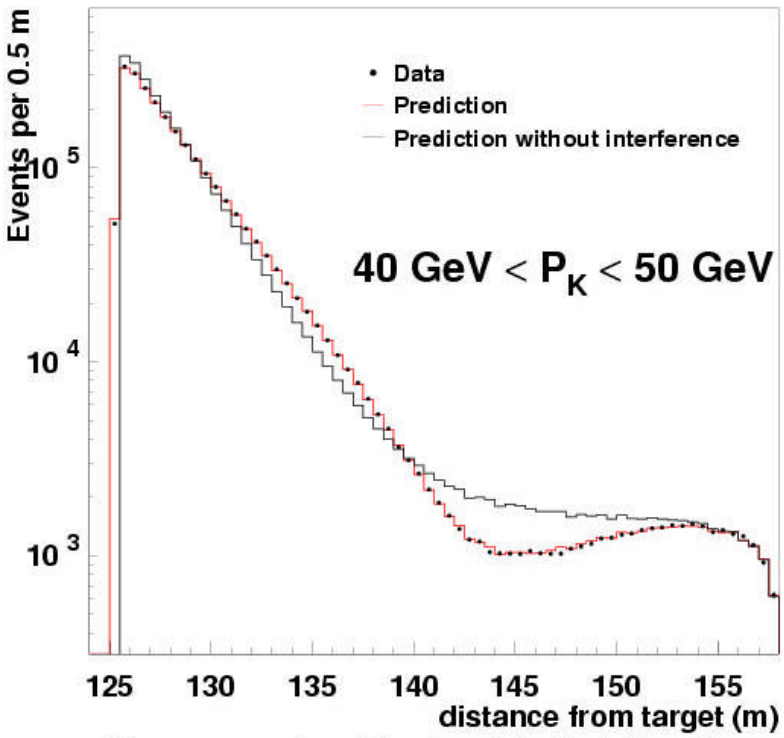
Measurement of Kaon Parameters

The regenerator beam contains a coherent mixture of K_L and K_S. Therefore, the shape of the z vertex distribution is sensitive to the kaon parameters Δm, τ_S, and the phases of η_{+-} and η_{00}.

In the absence of CPT violation:

$$f_{+-} = f_{00} = f_{SW}$$

$$\Delta\Phi \equiv f_{00} - f_{+-} = -3\,\mathrm{Im}\left(\frac{e'}{e}\right) \approx 0$$



Regenerator Vertex Z distribution

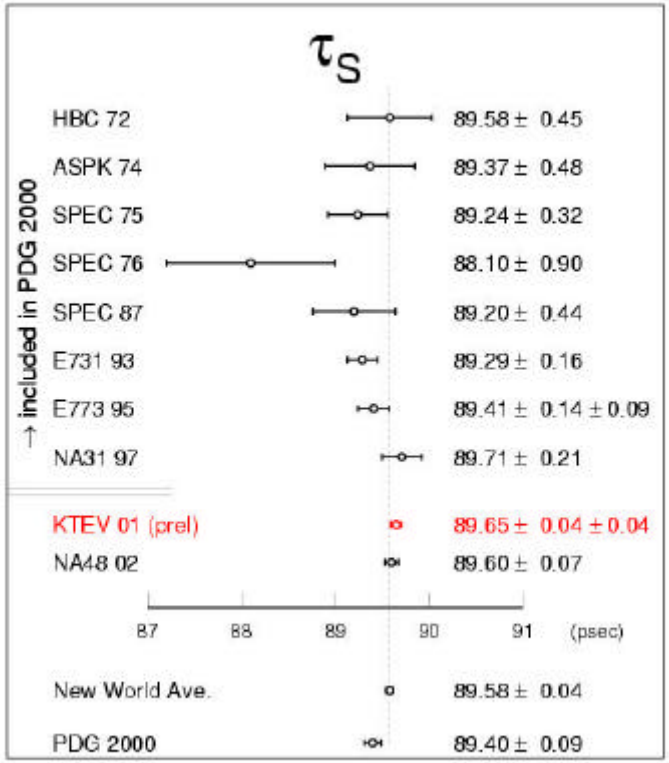
KTeV Results (Preliminary)

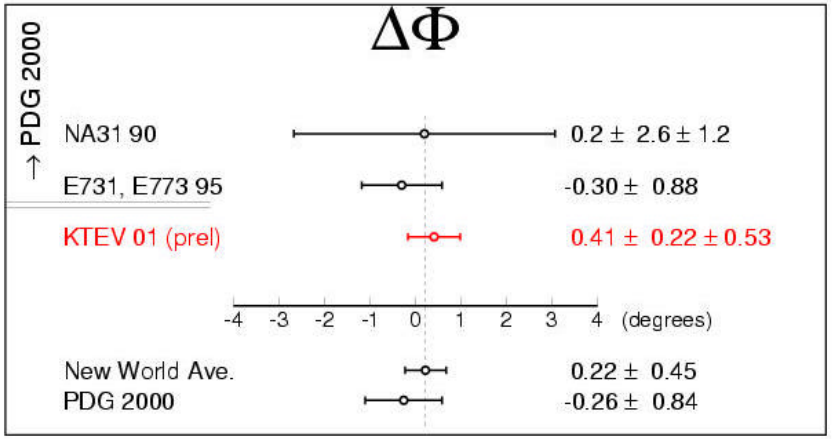
$\Delta m = (5262 \pm 7(\text{exp}) \pm 13(\text{ext})) \times 10^{6}\ \text{hs}^{-1}$
$\tau_S = (8965 \pm 4(\text{exp}) \pm 4(\text{ext})) \times 10^{-14}\ \text{s}$
$\phi_{+-} = (44.11 \pm 0.72(\text{stat}) \pm 1.14(\text{syst}))°$
$\Delta\phi = \phi_{00} - \phi_{+-} = (0.41 \pm 0.22(\text{stat}) \pm 0.48(\text{syst}))°$

Important sources of systematic uncertainty in these measurements include:

- Neutral mode analysis cuts, background subtraction, and energy scale
- Charged mode analysis cuts
- Dependence on other physics parameters

Comparison to Other Measurements





Improvements for future
(Work in progress)

- Neutral Analysis
  - Improved simulation and reconstruction of EM showers to include effects of angles
  - Improved treatment of nearby and overlapping clusters
- Charged Analysis
  - Improved treatment of fringe field
  - Improved simulation of delta rays
- 1999 Data
  - Increased statistics
  - Better drift chamber performance
  - Data at different intensities for systematic studies

Conclusions

$Re(\varepsilon'/\varepsilon) = (20.7 \pm 1.5(stat) \pm 2.4\ (syst)) \times 10^{-4}$

$\Delta m = (5262 \pm 15) \times 10^{6}\ hs^{-1}$

$\tau_S = (8965 \pm 6) \times 10^{-14}\ s$

$\phi_{+-} = (44.11 \pm 1.82)^o$

$\Delta\phi = \phi_{00} - \phi_{+-} = (0.41 \pm 0.53)^o$

- KTeV and NA48 measurements of $Re(\varepsilon'/\varepsilon)$ are consistent.
- KTeV measurements of ϕ_{+-} and ϕ_{00} show no evidence for CPT violation.
- Analysis of the 99 data and improvements to the KTeV analysis are in progress.

A PRD describing these results is in the final stages of internal review.