KTeV Results: Re(ε'/ε) & Rare Decays

XXXVIIth Rencontres de Moriond

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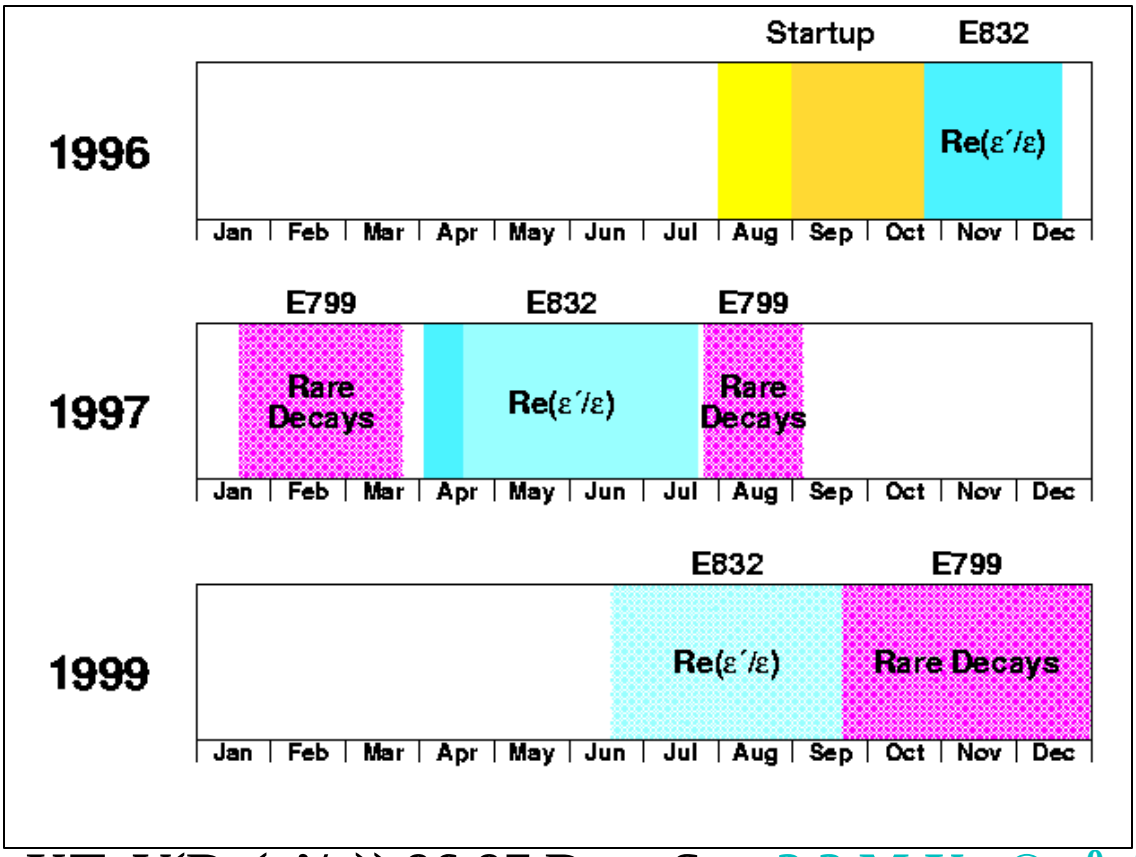
- **Overview of the KTeV experiment**
- **Re(e'/e) measurement**
- **Rare decays**
- **Summary and Future Outlook**

For the KTeV Collaboration:

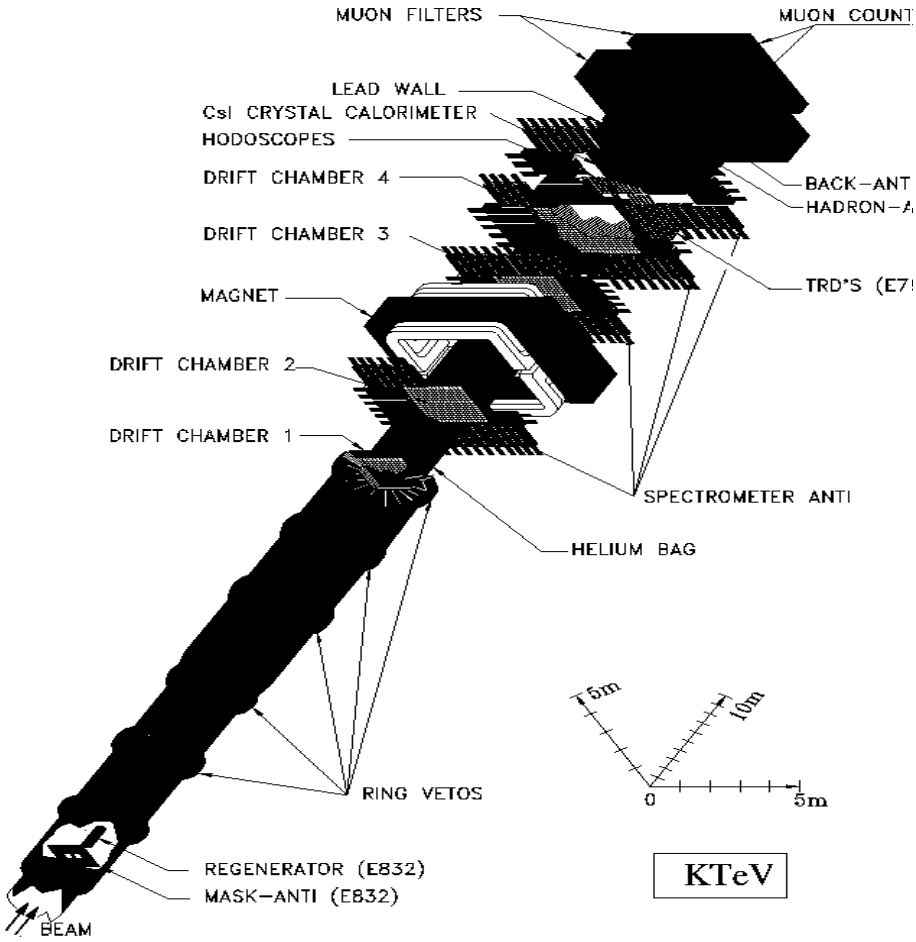
Arizona, Campinas, Chicago, Colorado, Elmhurst, Fermilab, Osaka, Rice, Rutgers, Sao Paulo, UCLA, UCSD, Virginia, Wisconsin

KTeV Fixed Target Run



- **KTeV(Re(e'/e)) 96-97 Data Set: 3.3 M K_L ® p^0p^0**
- **KTeV (Rare decays) 97 Data Set: 2.7E11 K_L Decays**
- **KTeV(Re(e'/e)) 99 Data Set: 3.7 M K_L ® p^0p^0**
- **KTeV (Rare decays) 99 Data Set: 3.6E11 K_L Decays**

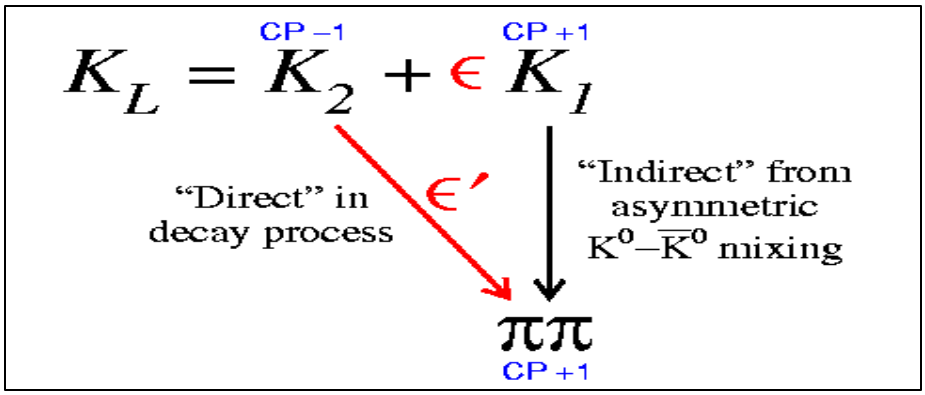
The KTeV Detector



- Pure CsI Calorimeter:
  (Energy resolution < 1% at $<E_\gamma>$ = 10GeV, π/e rejection of > 700)
- Drift chambers with resolutions (~100μm)
- Transition radiation detectors (π/e rejection of > 200) [E799]
- Clean intense beams: 5×10^{12} protons on target per spill (1min)

$$\Rightarrow 5 \times 10^{9} \text{ kaons per spill}$$

Re(ε'/ε) Measurement



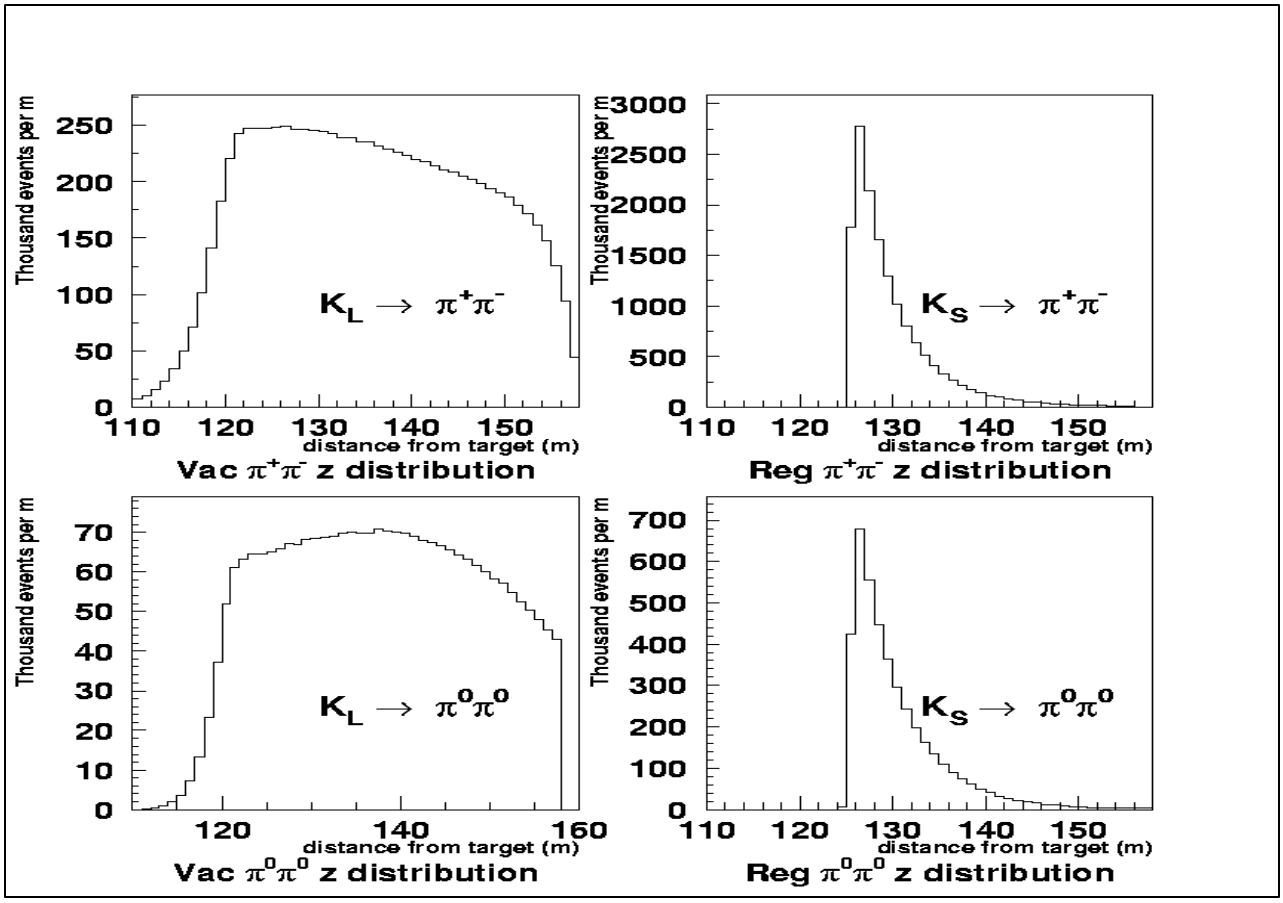
$$h_{00} \equiv \frac{A(K_L \to p^0 p^0)}{A(K_S \to p^0 p^0)} = e - 2e'$$

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

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

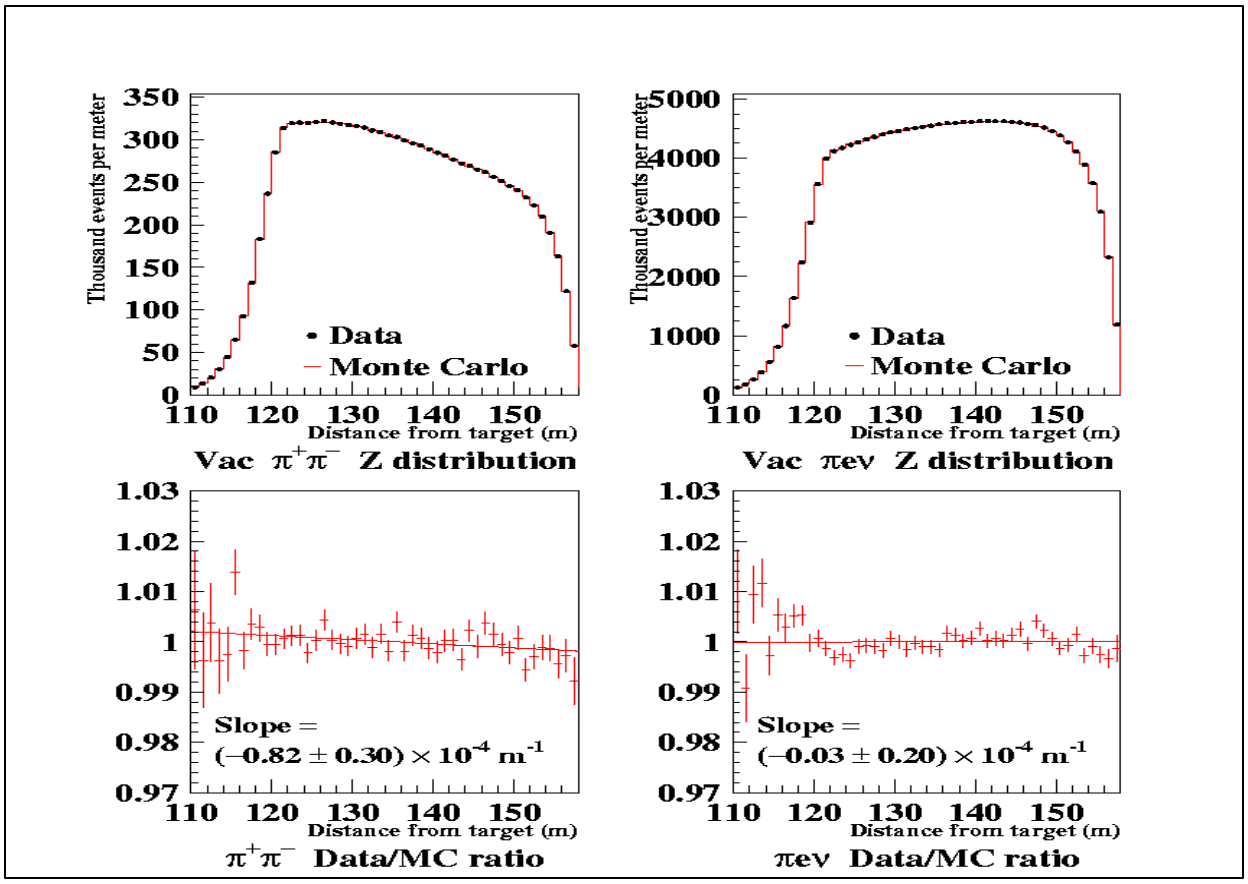
- **Regenerator beam Þ not a simple counting experiment. Fit for Re(e'/e).**

Understanding the Acceptance



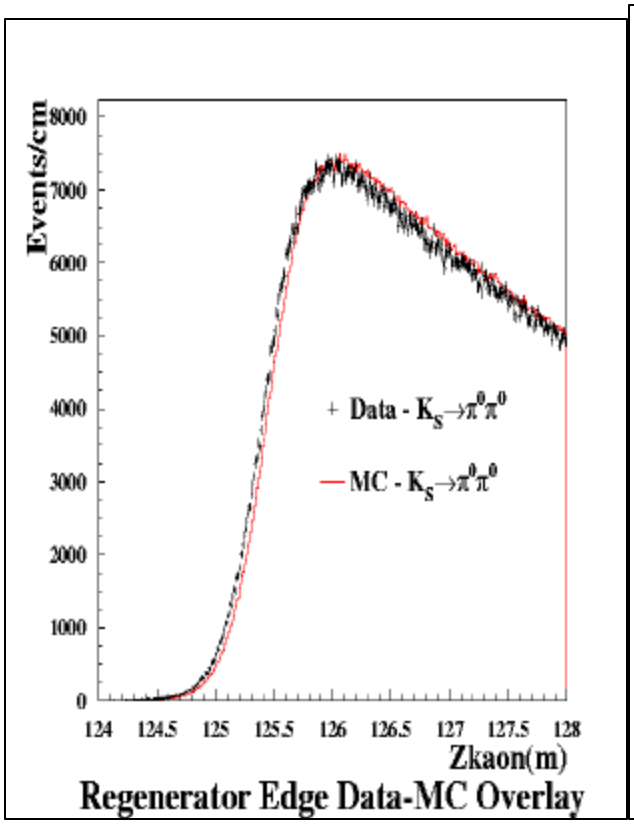
- **K_L and K_S decays have different decay distributions.**
- **Use Monte Carlo to understand acceptance correction: ~80 x 10^{-4}**
  - **~70 x 10^{-4} from geometry**
  - **~10 x 10^{-4} from resolutions and inefficiencies**

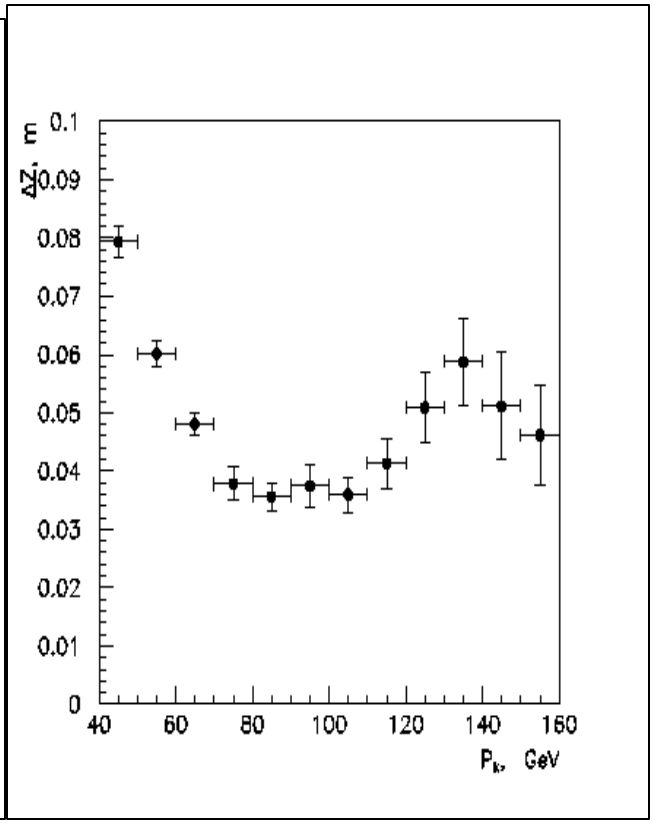
Charged Mode Z-Slope



- **Charged Acceptance Test: Data/MC Decay Vertex Z Distribution**
  - **$K_L \rightarrow p^+p^-$ and $K_L \rightarrow p$ e n**

Energy Scale Adjustment



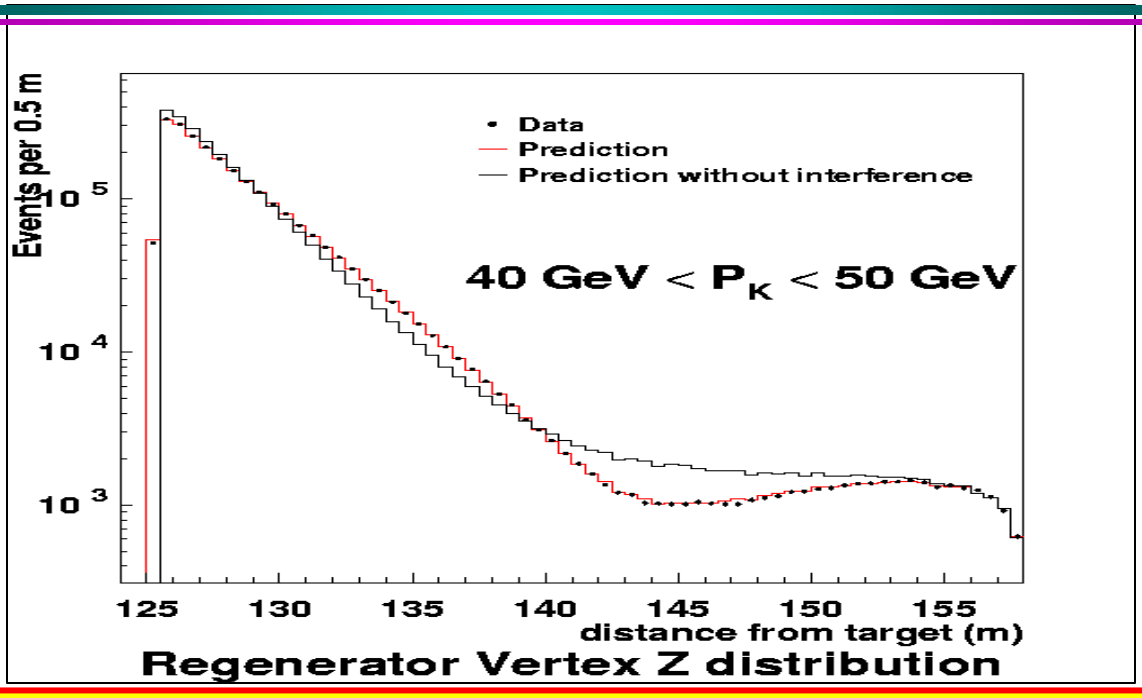


- **Correct energy scale using sharp edge of regenerator (DR(e'/e) = +2.1 x 10^{-4})**
- **Use P_K dependent correction**

Dominant Systematic Uncertainties

Source	*Contribution to error on Re(e'/e) (x 10-4)*
Neutral Energy Reconstruction	**1.5**
Neutral background from Regenerator-scatters	**1.0**
Charged Acceptance (data/MC z-slope)	**0.9**
Charged Level 3 Online Filter	**0.5**

Δm, τ_S, f_{+-} Measurements



$\Delta m = (52.62 \pm 0.15) \times 10^{8}\ \hbar s^{-1}$

$\tau_S = (89.65 \pm 0.06) \times 10^{-12} s$

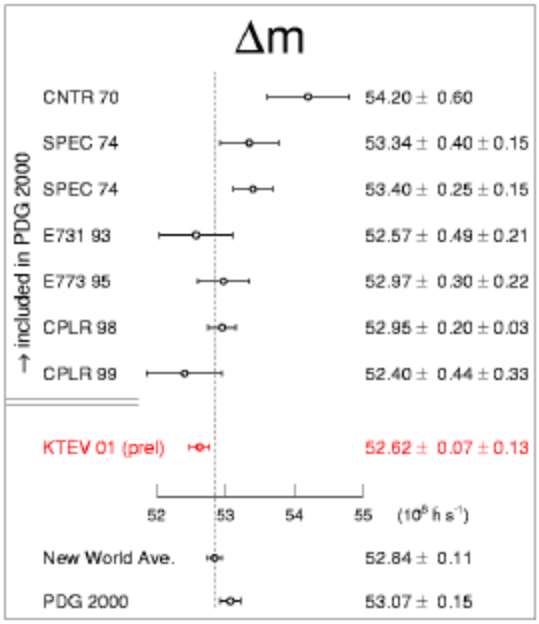
$F_{+-} = [(44.12 \pm 0.72\ (stat) \pm 1.15\ (syst)]^{o}$

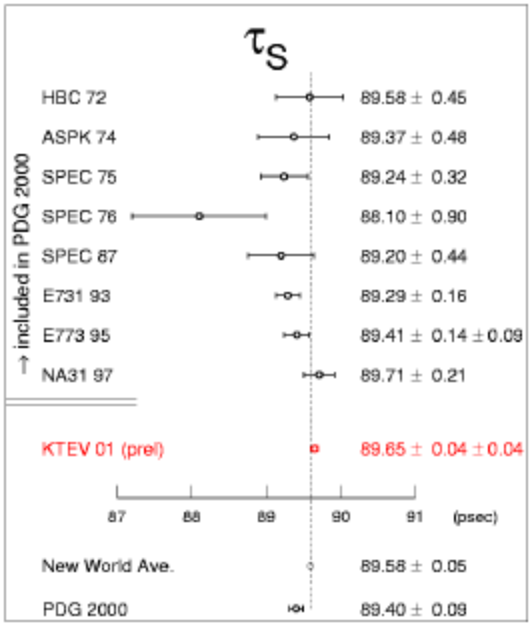
$\Delta f = [+0.41 \pm 0.22\ (stat) \pm 0.48\ (syst)]^{o}$

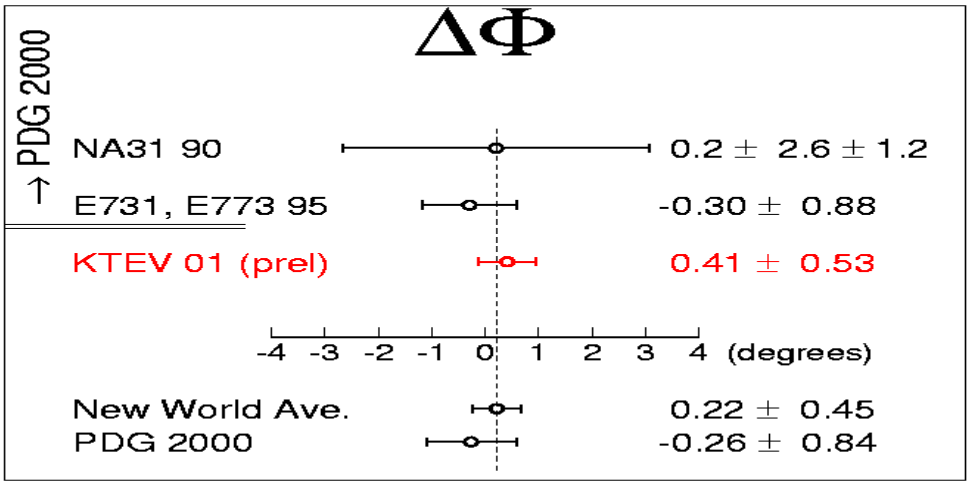
$Im(\varepsilon'/\varepsilon) = [-24 \pm 13\ (stat) \pm 28\ (syst)] \times 10^{-4}$

Preliminary

Current Status of Kaon Parameters





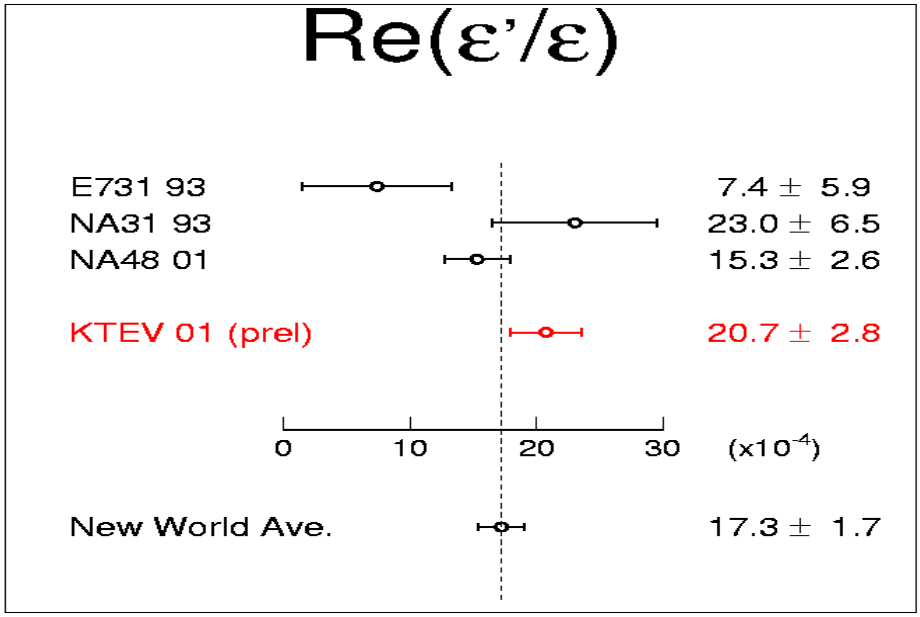


Status of Re(ε’ / ε)

Combined 96-97 Result:

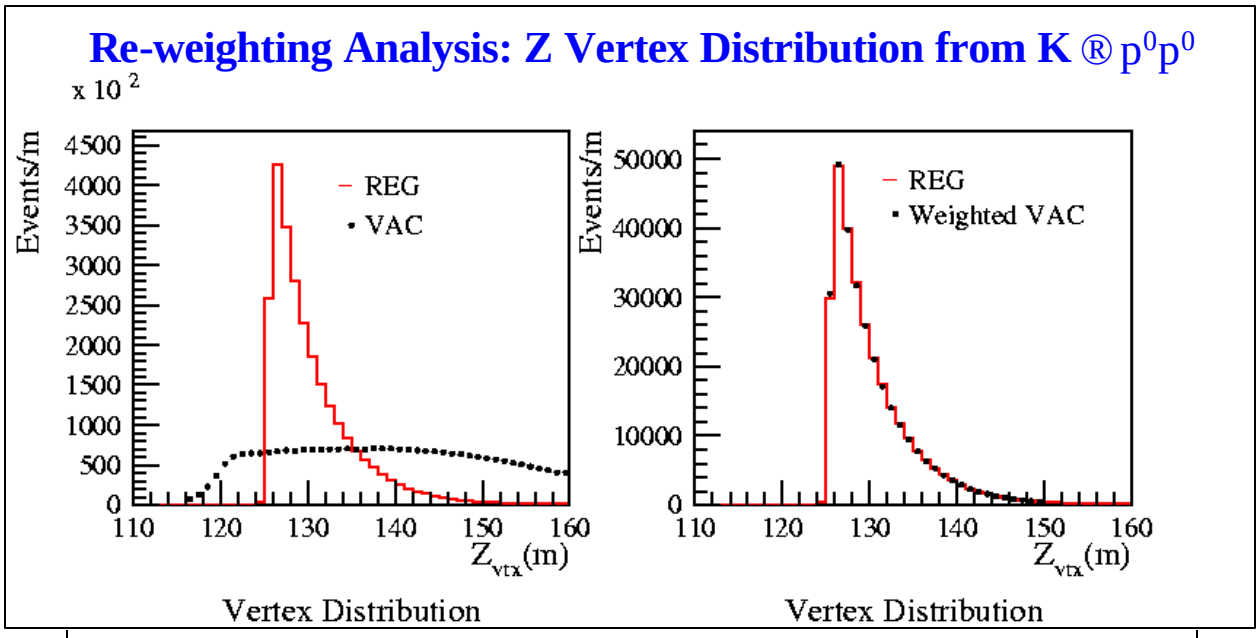
Re(e’/e) = [20.7 ± 1.5 (stat) ± 2.4 (syst)
± 0.5 (MC stat)] x 10^{-4}
= [20.7 ± 2.8 (tot)] x 10^{-4}

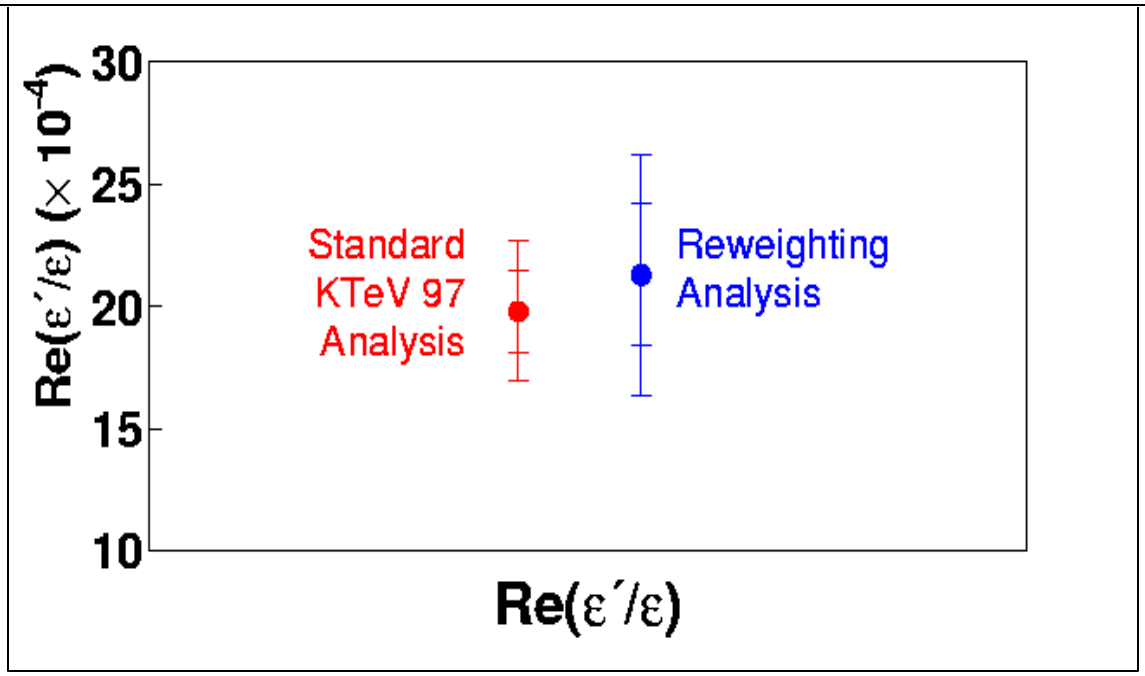
Preliminary



Probability = 13%

Cross Check of Re(ε'/ε) Measurement





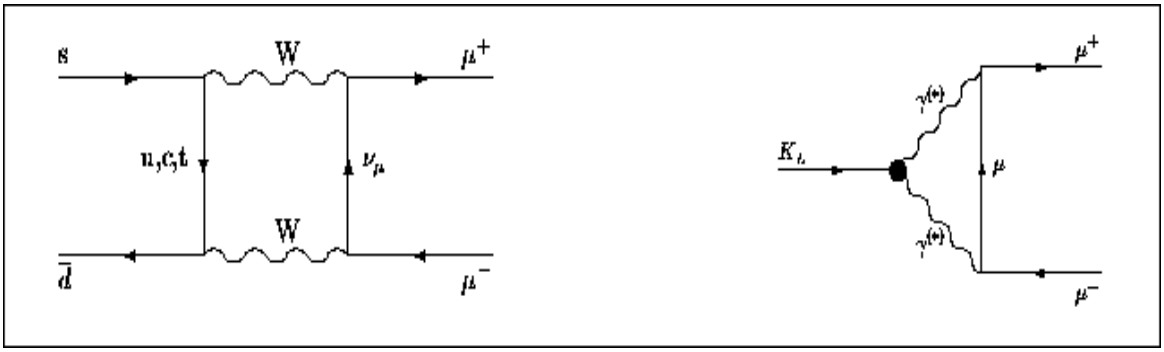
KTeV Rare Decay Program

Decay Mode	Publ.	# Events	BR
		Direct CP Violation	
$K_L \to \pi^0 e^+ e^-$	✓	2	$< 5.1 \times 10^{-10}$
$K_L \to \pi^0 \mu^+ \mu^-$	✓	2	$< 3.8 \times 10^{-10}$
$K_L \to \pi^0 \nu\bar{\nu}$	✓	0	$< 5.9 \times 10^{-7}$
		Indirect CP Violation	
$K_L \to \pi^+ \pi^- \gamma$	✓	8,669	$(2.08 \pm 0.03) \times 10^{-2}$ x $B(K_L \to \pi^+\pi^-)$
$K_L \to \pi^+ \pi^- e^+ e^-$		1,558	$(3.63 \pm 0.11 \pm 0.14) \times 10^{-7}$
		cPT and VMD	
$K_L \to \pi^0 \gamma\gamma$	✓	884	$(1.68 \pm 0.07 \pm 0.08) \times 10^{-6}$
$K_L \to \pi^0 e^+ e^- \gamma$	✓	48	$(2.34 \pm 0.35 \pm 0.13) \times 10^{-8}$
$K_L \to \pi^0 \pi^0 e^+ e^-$		1	$< 5.4 \times 10^{-9}$
		K$\gamma\gamma^*$ Vertex	
$K_L \to e^+ e^- \gamma$ *		127K	
$K_L \to \mu^+ \mu^- \gamma$ *	✓	9,327	$(3.62 \pm 0.04 \pm 0.08) \times 10^{-7}$
$K_L \to e^+ e^- \gamma\gamma$	✓	1,543	$(5.84 \pm 0.15 \pm 0.32) \times 10^{-7}$
$K_L \to \mu^+ \mu^- \gamma\gamma$	✓	4	$(1.04^{+0.75}_{-0.59} \pm 0.32) \times 10^{-8}$
		K$\gamma^*\gamma^*$ Vertex	
$K_L \to e^+ e^- e^+ e^-$	✓	441	$(3.72 \pm 0.18 \pm 0.23) \times 10^{-8}$
$K_L \to e^+ e^- \mu^+ \mu^-$ *	✓	43	$(2.62 \pm 0.40 \pm 0.17) \times 10^{-9}$
		Lepton Flavor Violation	
$K_L \to \pi^0 \mu^\pm e^\mp$		0	$< 4.4 \times 10^{-9}$

*** Covered in this talk**

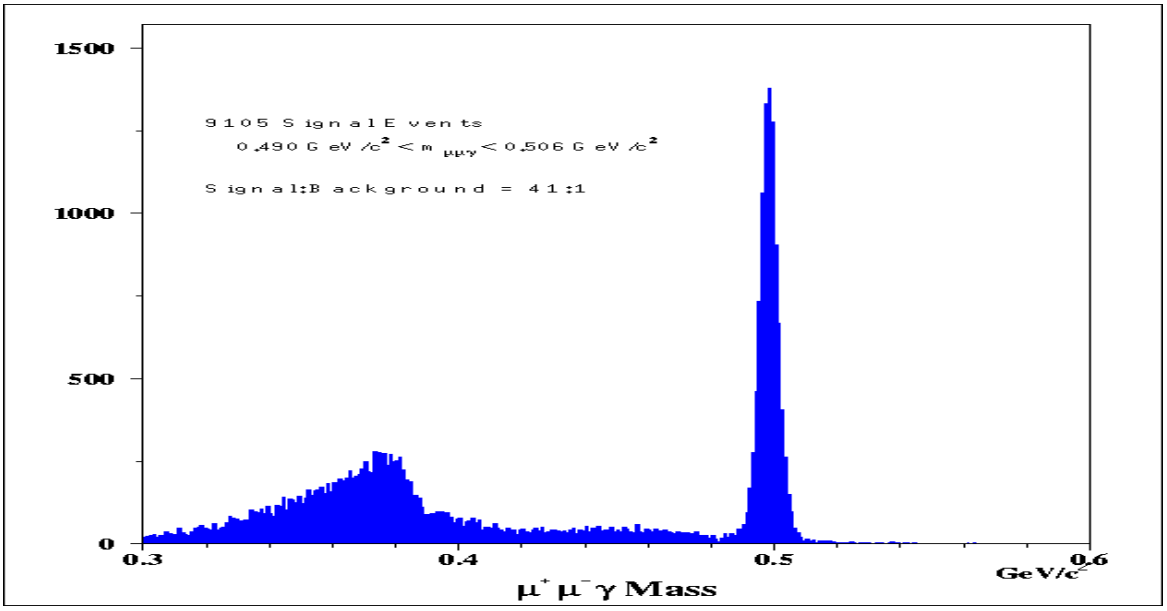
$K_L \rightarrow \mu^+\mu^-$

Short Distance **Long Distance**

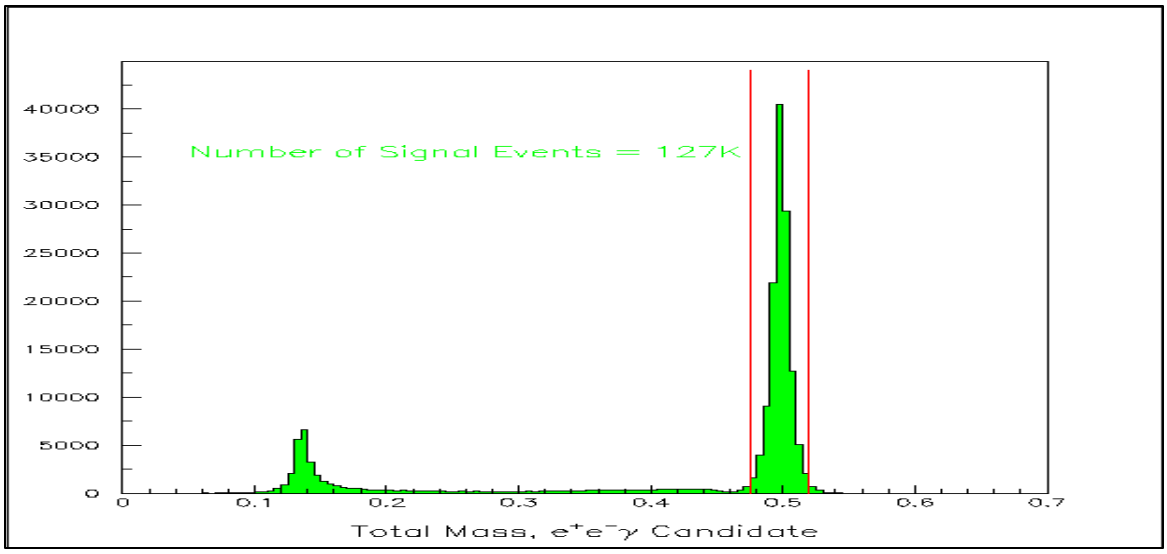


- **Short distance: Weak interactions, QCD corrections**
  - **Dominated by top quark**
  - **Sensitive to V_{td}**
- **Long distance: Low energy EM interactions**
  - **Large theoretical uncertainties**
- **Measure $K\gamma^*\gamma^*$ vertex → extract short distance contributions**
  - **Measure $K_L \to \ell^+\ell^-\gamma$: $\mu^+\mu^-\gamma$ and $e^+e^-\gamma$**
    - **$K\gamma^*\gamma$ form factor parametrized by a_{K^*}**
    - **Extrapolate to $K\gamma^*\gamma^*$**
  - **Measure $K_L \to e^+e^-\mu^+\mu^-$**
    - **Directly sensitive to $K\gamma^*\gamma^*$ vertex**
    - **DIP Model ($K\gamma^*\gamma^*$) : $1+a\,[A(q_1^2,q_2^2)]+b\,[B(q_1^2,q_2^2)]$**
    - **Low statistics (World sample: ~40 events)**

$K_L \to \mu^+\mu^-\gamma$ and $K_L \to e^+e^-\gamma$

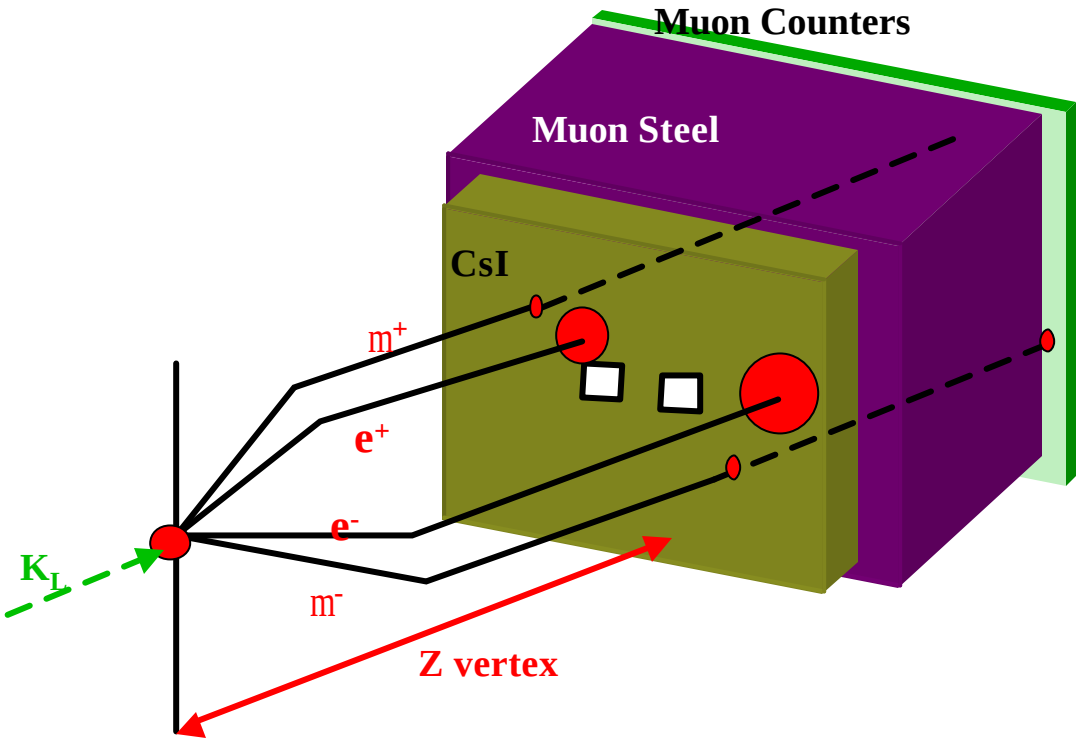


- **BR(K_L ® m^+m^-g) = (3.62 ± 0.04 ± 0.08) x 10^{-7}**
- $a_K^* = -0.160\ ^{+0.026}_{-0.028}$



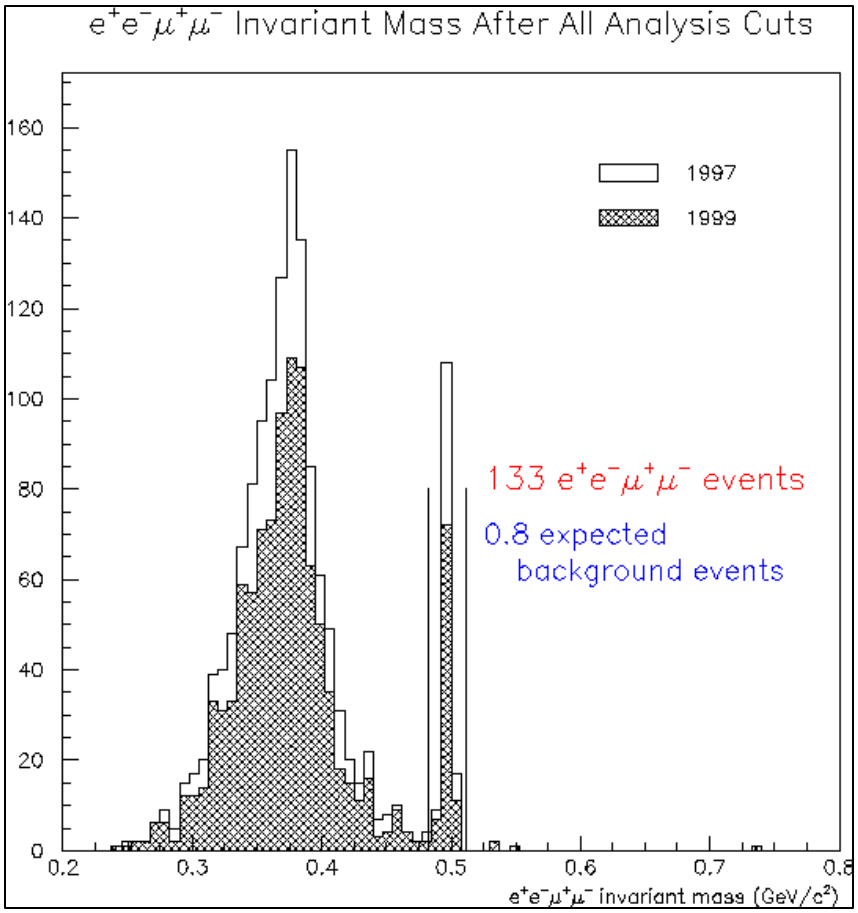
- **Coming soon! BR(K_L ® e^+e^-g) and a_K^***

$K_L \to e^+e^- \mu^+\mu^-$



- **Analysis (1997+1999 Data Sets)**
  - **Signal Selection: 4 charged tracks; 2 tracks which MIP in CsI + ID as muons; 2 tracks matched to electron-like clusters in CsI**
  - **Major background:** $\pi\mu\nu\gamma$ **with** γ **conversions**
  - **Normalize to** $K_L \to \pi^+\pi^-\pi^0$, $(\pi^0 \to e^+e^-\gamma)$
- **Form Factor: Fit simultaneously to** m_{ee} **and** $m_{\mu\mu}$ **invariant mass distributions**

$BR(K_L \rightarrow e^+e^-\mu^+\mu^-)$

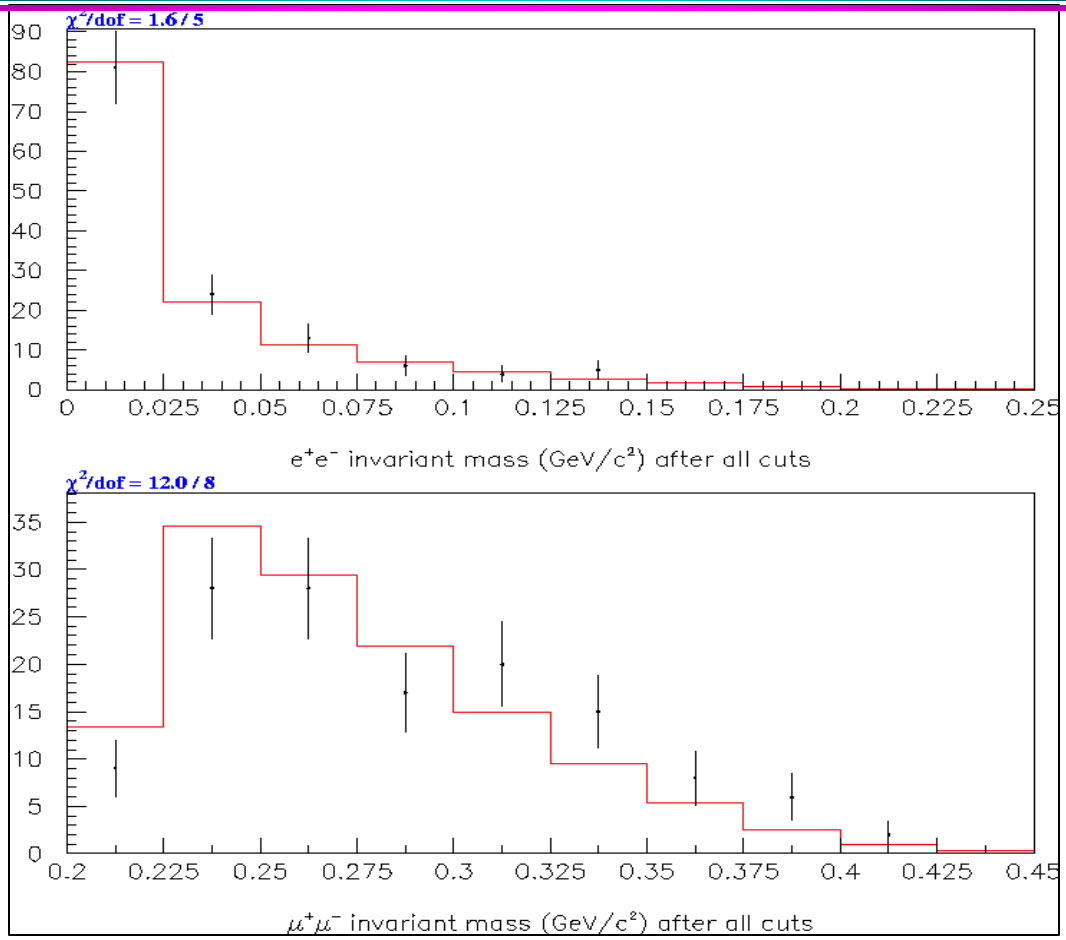


- **Combined 1997 and 1999 samples**

$$BR(K_L \rightarrow e^+e^-\mu^+\mu^-) = (2.61 \pm 0.23 \pm 0.12) \times 10^{-9}$$

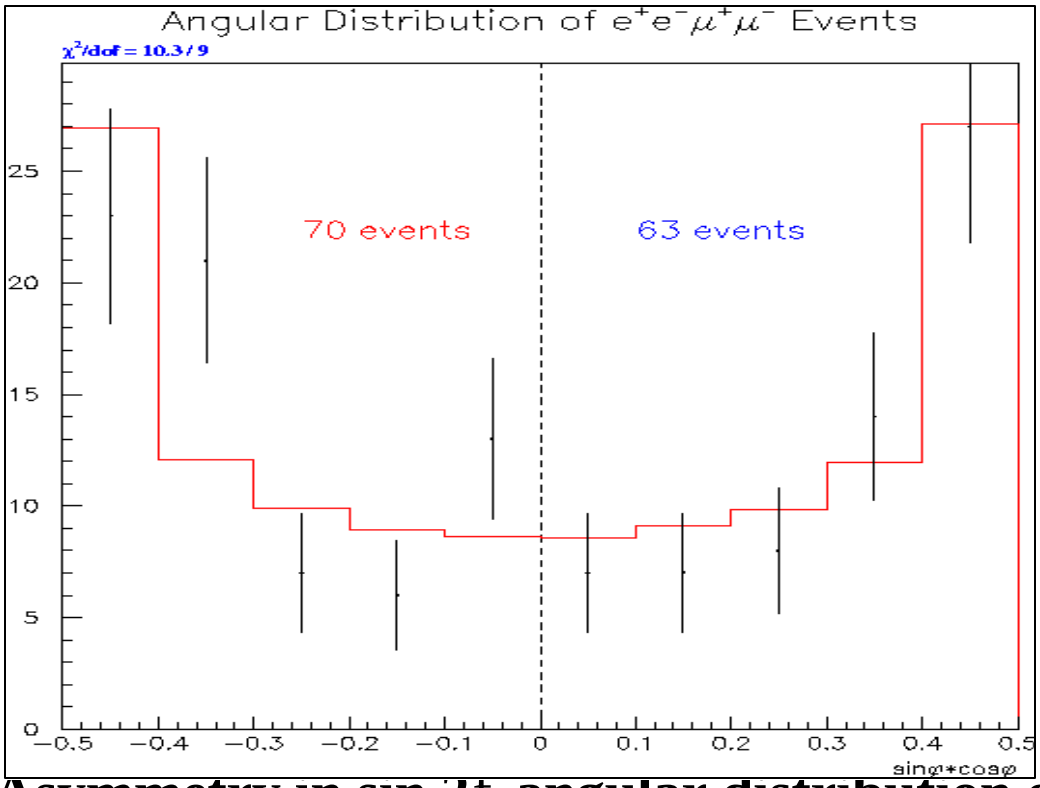
Preliminary

$K_L \rightarrow e^+e^- \mu^+\mu^-$ Form Factor



- **M_{ee} and m_{mm} mass distributions**
  - **MC shown with constant form factors.**

CP Violation in $K_L \rightarrow e^+e^- \mu^+\mu^-$



- **Asymmetry in sin 2f angular distribution of K_L ® $e^+e^-m^+m^-$ would indicate CP violation**
  - **Similar to K_L ® p^+p^- e^+e^-, but p^+p^- e^+e^- has a large effect (~14%).**
  - **Small effect expected for K_L ® $e^+e^-m^+m^-$**
- **Data/MC shows no effect**
  - **MC generated without CP violation**

Summary and Outlook

- **We are entering the realm of precision measurements of Re(e'/e)**
  - **Current World Average: 10% Measurement**
- **Currently analyzing the 1999 Re(e'/e) data set**
  - **Double the statistics of the 1996-97 result**
  - **Expected improvements in the neutral energy reconstruction should help to bring down the systematic error**
- **KTeV has also made precision measurements of the kaon parameters ($\Delta m, \tau_S, \Delta f$) and of δ**
- **New results from KTeV rare decays (combined 1997+1999) expected soon – triple the statistics of previous 1997 KTeV results**
  - **$K_L \to e^+e^-\mu^+\mu^-$ form factor**
  - **$K_L \to e^+e^-\gamma$ branching ratio and form factor**
  - **$K_L \to \pi^0 e^+\mu^-$ and $\pi^0 \to e^+\mu^-$ lepton flavor violation**
  - **$K_L \to \pi^0\pi^0\pi^0$ with $\pi^0 \to e^+e^-e^+e^-$**
  - **$K_L \to \pi^+\pi^-e^+e^-$**