Search for Lepton Flavor Violating Kaon Decays from The KTeV Experiment at Fermilab

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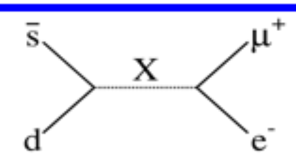
Lepton Flavor Violation

- Permitted in the *Nu* Standard Model, but suppressed beyond experimental sensitivity by small neutrino masses
- Negligible SM background means LFV decays are sensitive to new physics.
- Attainable sensitivity to $M_X > 100$ TeV, clean signatures.
- LFV in kaon decays is expected in most new physics scenarios:
  - SUSY
  - Extended Technicolor
  - Heavy neutrinos
  - Horizontal gauge bosons
  - Large extra dimensions
  - Leptoquarks
- For V-A interactions $K \to \mu e$ is the most sensitive kaon decay. If the LFV interaction is pure vector, 2 body modes would be suppressed and 3 body modes like $K \to \pi^0 \mu e$ are more promising.

Current Limit on LFV Kaon Decays

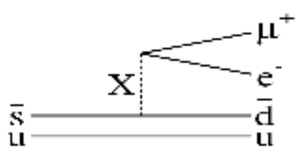
Mass scale probed by LFV kaon decays through a hypothetical LFV vector boson X. Weak coupling strength is assumed in calculating lower limit on mass scale

Branching Fraction Limit | **Mass Limit**



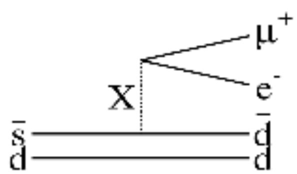
$B(K_L \to \mu e) < 4.7 \times 10^{-12}$ — $150\ \mathrm{TeV}/c^2$

PRL **81**, 5734 (1998)



$B(K^+ \to \pi^+\mu^+e^-) < 1.3 \times 10^{-11}$ — $31\ \mathrm{TeV}/c^2$

PRD **72**, 012005 (2005)



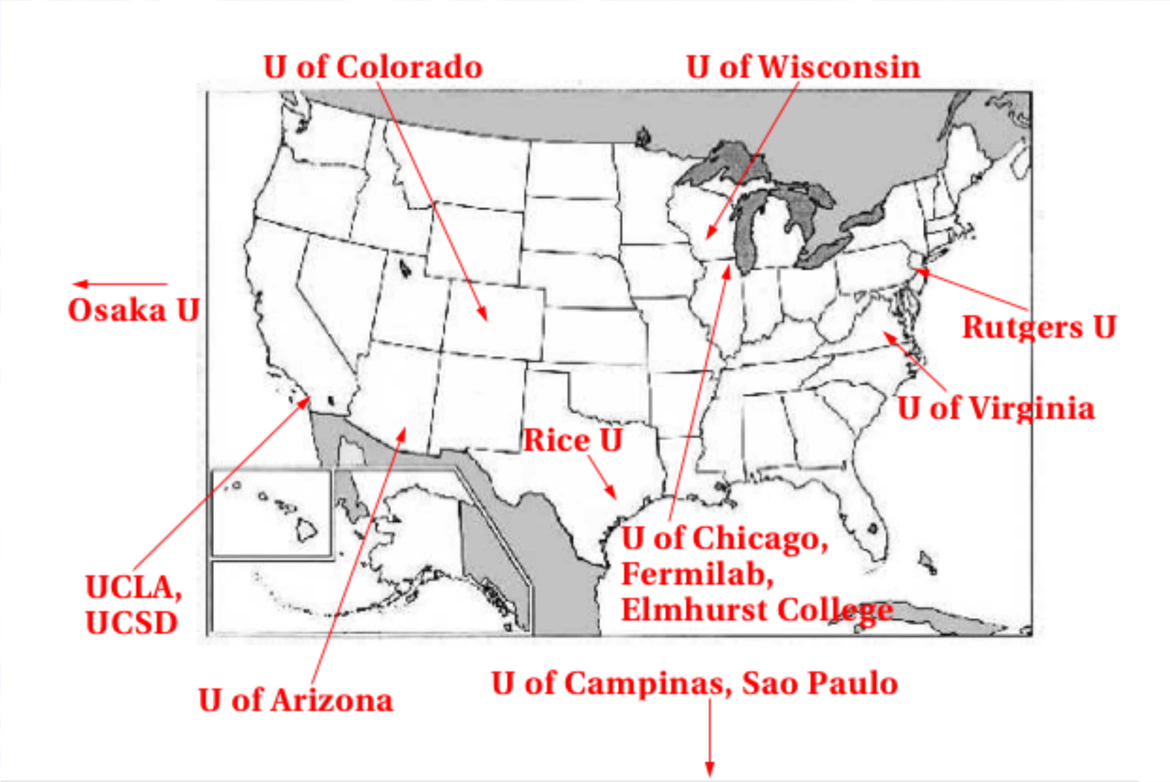
$B(K_L \to \pi^0\mu^+e^-) < 3.4 \times 10^{-10}$ — $37\ \mathrm{TeV}/c^2$

(KTeV Preliminary)

KTeV

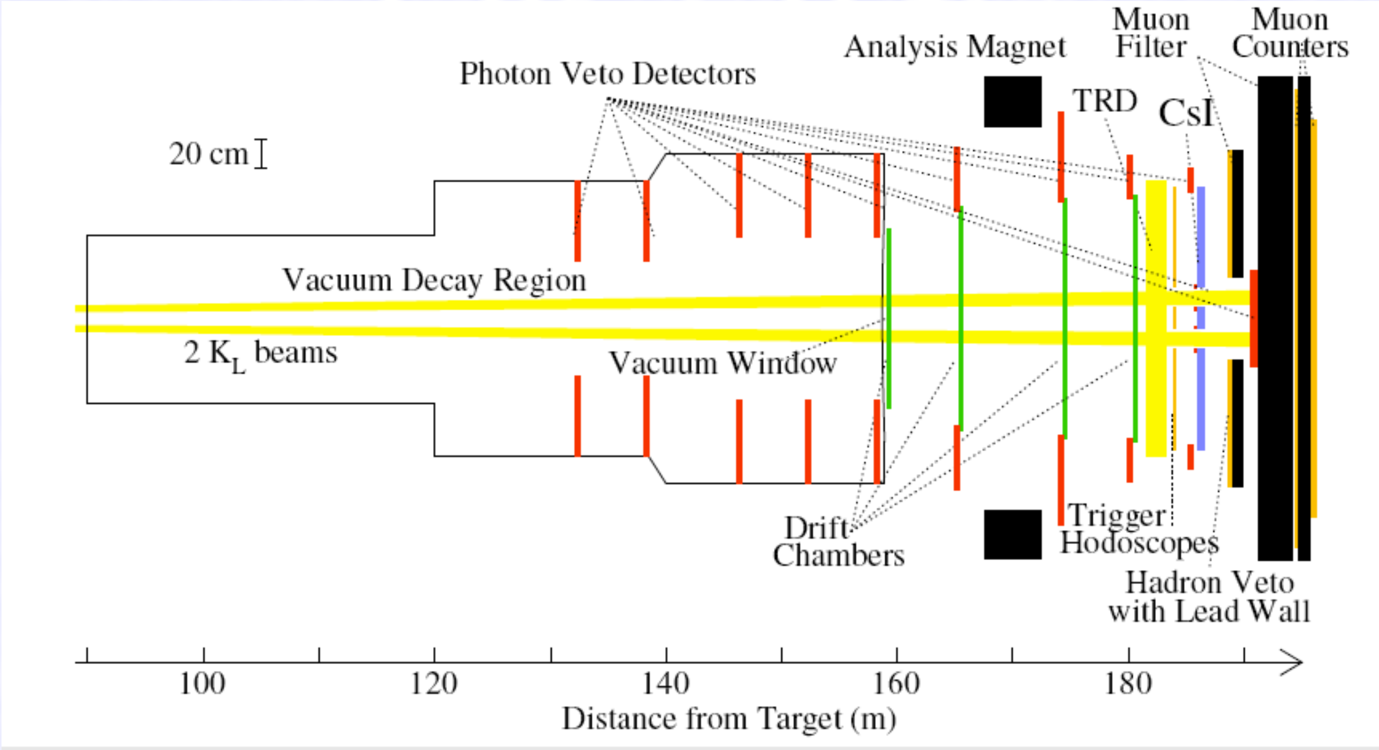
E832: measure Re(ε'/ε)
E799: rare decays

Data taken in 1996-1997 and 1999.



14 institutions
~ 80 physicists

KTeV Detector



- CsI calorimeter
- 3100 crystals
  - Energy resolution: $\sigma(E)/E = 2\%/\sqrt{E} + 0.45\%$
  - Position resolution: ~1 mm
- Clean beams
- Spectrometer
  - Better than 100 μm

LFV Decays in KTeV

- KTeV has good sensitivity to a number of LFV decays
  - $K_L \to \pi^0 \mu e$
  - $K_L \to \pi^0 \pi^0 \mu e$
  - $\pi^0 \to \mu e$ (from $K_L \to 3\pi^0$)

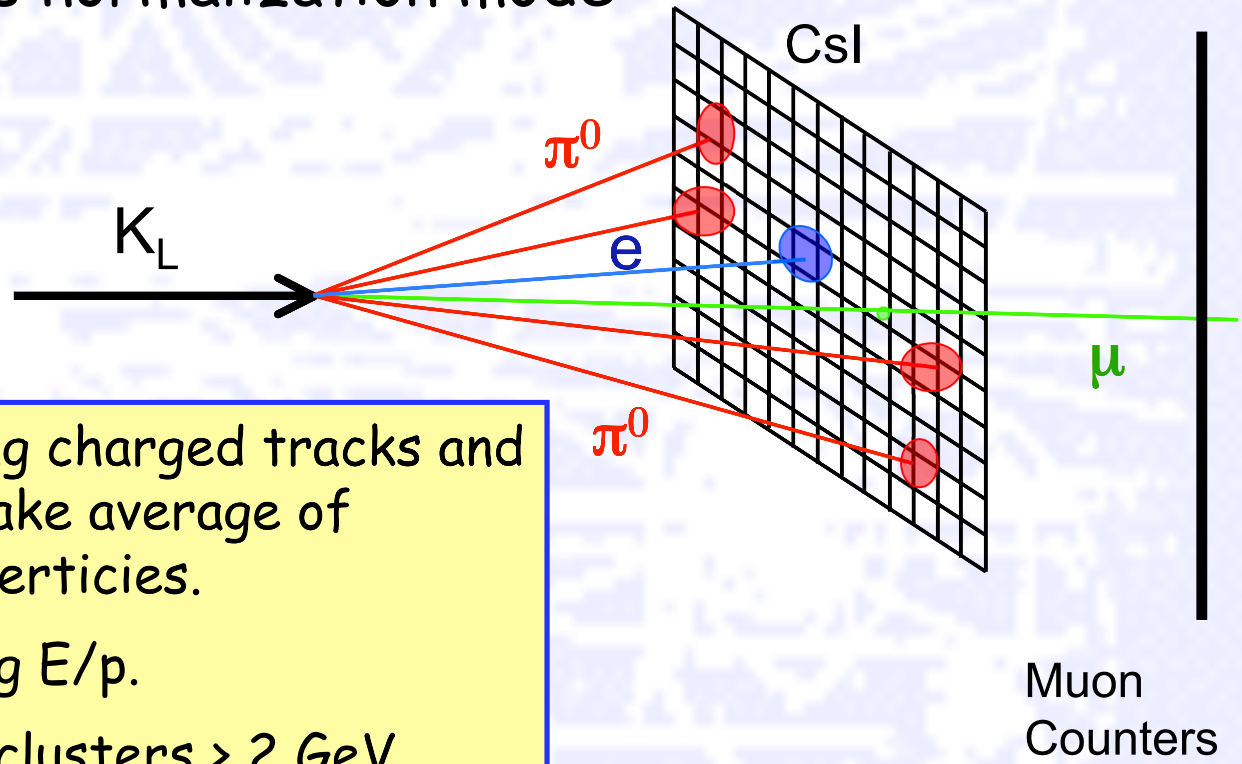
} New Preliminary Results from combined '97 and '99 runs. Boxes opened in mid Oct.

  - KTeV's large kaon flux and well understood beam and detector make this an ideal environment to search for rare decays.

$K_L \rightarrow \pi^0\pi^0\mu e$

Lower background than $K_L \rightarrow \pi^0\mu e$ due to $2\pi^0$ requirement

Use $K_L \rightarrow \pi^0\pi^0\pi^0_D$ as normalization mode



- Determine vertex using charged tracks and π^0 mass constraint. Take average of charged and neutral verticies.
- Identify electron using E/p.
- Require 5 in-time CsI clusters > 2 GeV with electromagnetic shower shape
- E_μ > 8 GeV/c with < 1 GeV in CsI and hits in μ counters

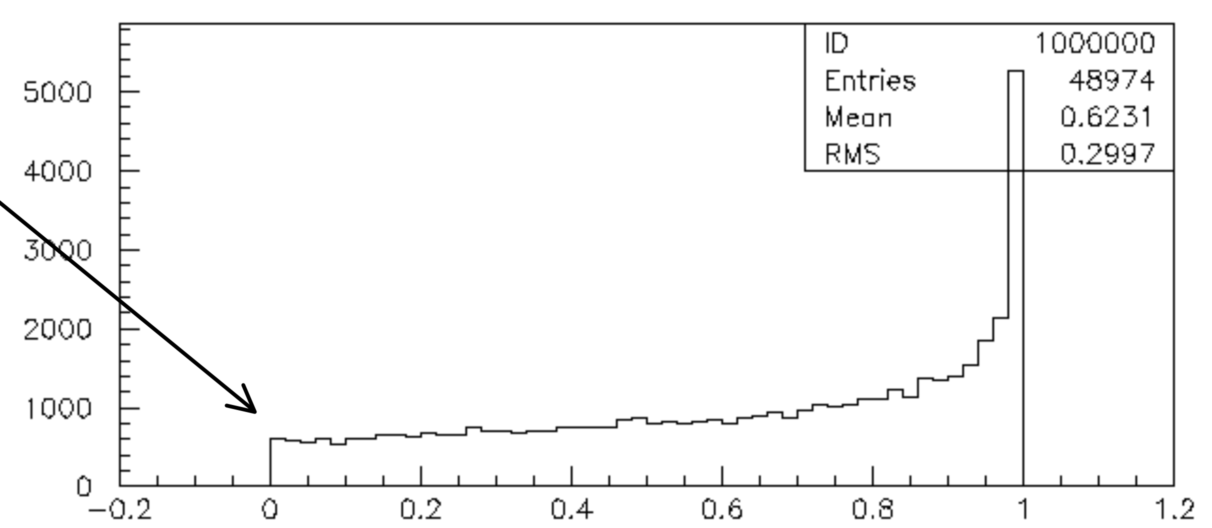
Backgrounds to $K_L \to \pi^0\pi^0\mu e$

$K_L \to \pi^0\pi^0\pi^0_D$ where an accidental muon satisfies the muon trigger and happens to be close to one of the Dalitz electrons.

This can be eliminated by making an "anti-electron" cut on the muon track using the TRDs.

Require Muon Probability > 0.015 (98% efficient for muons, eliminates 85% of electrons).

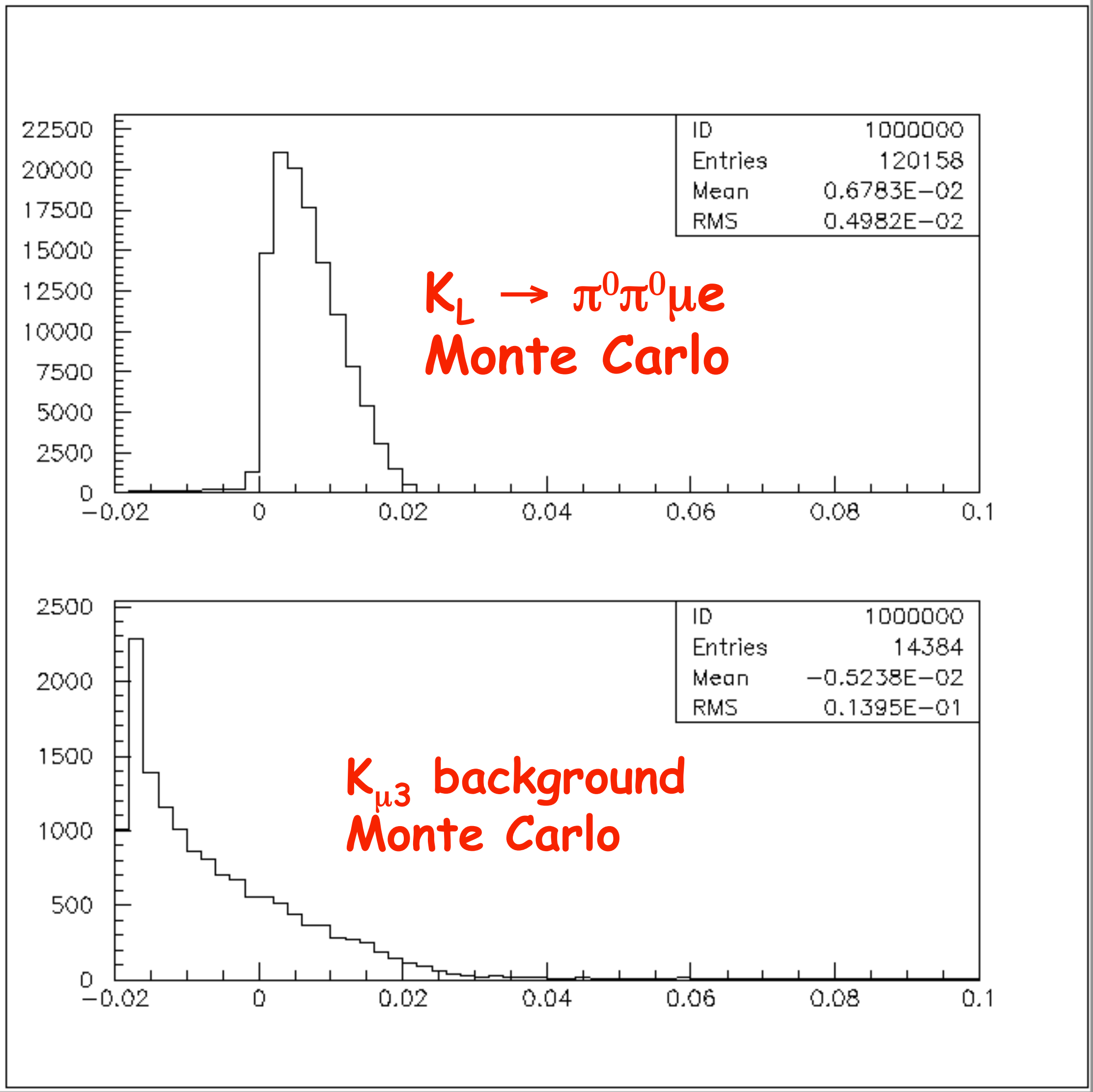
Electrons peak close to zero



TRD Muon Probability from Kμ3 data

Backgrounds to $K_L \rightarrow \pi^0\pi^0\mu e$

- $K_L \rightarrow \pi^{\pm}\mu^{\mp}\nu$ with 4 accidental photons
- $K_L \rightarrow \pi^{\pm}e^{\mp}\nu$ with 4 accidental photons and the π misidentified as a μ
- The square of the π^0 momentum in the K_L rest frame is a good discriminator against these backgrounds.
  - Calculate invariant mass of charged tracks and one π^0
  - Do for both π^0
  - For real signal events the quantity must be positive
  - Negative for many backgrounds



Square of the magnitude of π^0 momentum in K rest Frame

$K_L \rightarrow \pi^0\pi^0\mu e$ Cuts

- Z vertex between 96 and 155 m. X & Y vertex inside CsI beam holes.
- Difference between charged and neutral vertices less than 2.5 m.
- Square of π^0 momentum in K rest frame between 0 and 0.025 $(GeV/c)^2$
- π^0 masses between 0.132 and 0.138 GeV/c^2

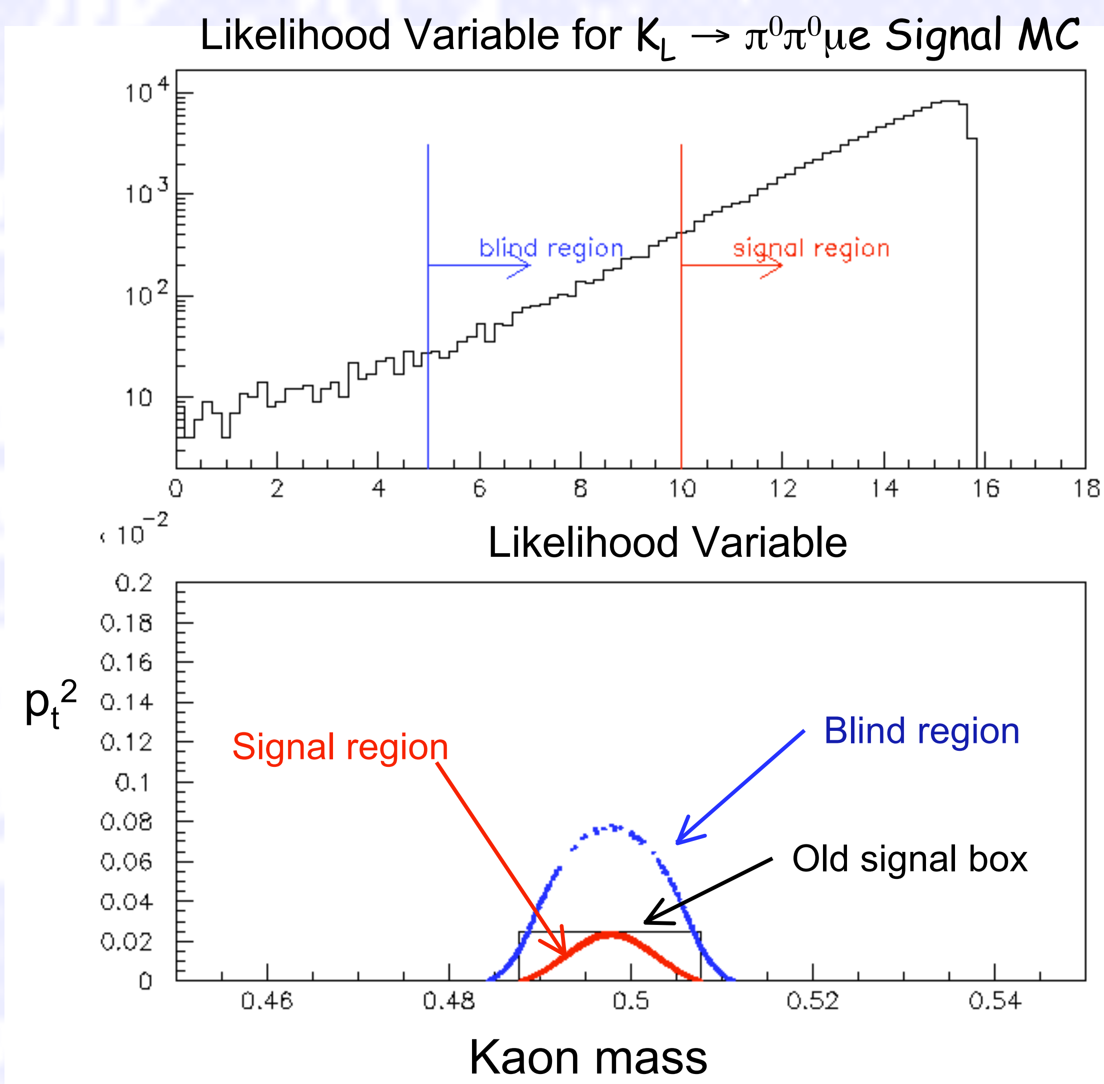
- E/p for electron between 0.95 and 1.05
- TRD signal for μ track is not consistent with electron ($prob_\mu > 0.015$)
- Fusion $\chi^2 < 10$ for electron and neutral clusters (eliminates overlapping clusters)
- μ momentum > 8 GeV. μ energy < 1 GeV in CsI.

- **Exactly 5 in-time clusters above 2 GeV in CsI.**
- **< 0.3 GeV in photon veto counters.**
- **< 15 GeV in beam veto counter.**
- **< 3 extra in-time drift chamber hit pairs.**

Kinematic cuts   Particle ID Cuts   **Accidental cuts**

Likelihood Analysis

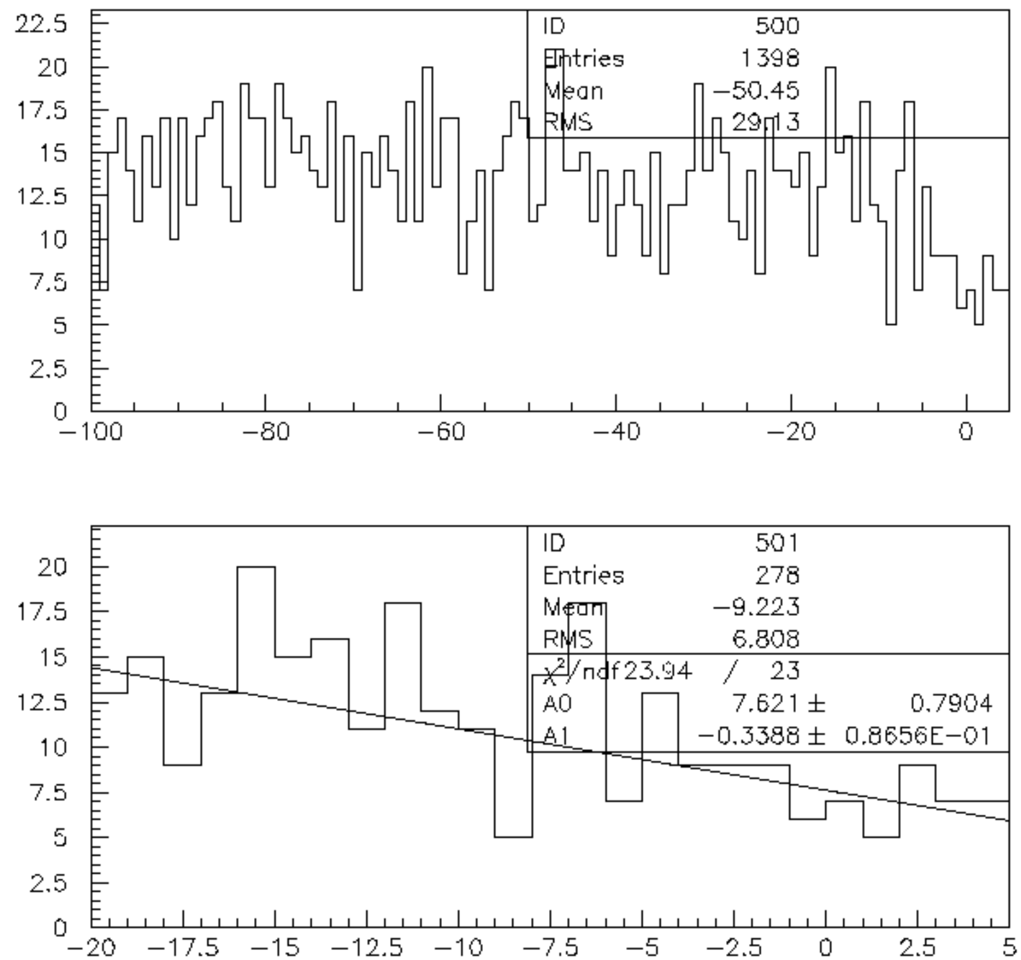
- Blind analysis
- Signal box defined by p_t^2 and kaon mass
- Fit analytical functions to p_t^2 and kaon mass.
- Normalize to form PDFs. Likelihood is product of the two PDFs.
- Signal acceptance ~2% after all cuts on previous page.
- Cut at 10 preserves 95% of the signal events remaining after all cuts.



Background Estimate

- We don't trust the MC to estimate background to 1 part in 10^{10}. Use data.
- Fit likelihood variable outside of signal region and extrapolate into signal region.
- BUT - if all cuts are in place there are not enough events!
- Solution - fit likelihood variable for data with relaxed cuts and determine suppression factors by reapplying the cuts.

Fit to Likelihood Function with Relaxed Cuts



Likelihood Variable

Signal region is for Likelihood variable > 10

Take ± 1σ on fit parameters to determine systematic error on background estimate.

Suppression Factors

Cut set	Suppression factor
Kinematic	0.092 ± 0.016 (stat)
Particle ID	0.273 ± 0.024 (stat)
Accidental	0.261 ± 0.024 (stat)
Kinematic + ID	0.012 ± 0.009
Kinematic * ID	0.025 ± 0.005
Kinematic + Accidental	0.025 ± 0.009
Kinematic * Accidental	0.024 ± 0.005
ID + Accidental	0.077 ± 0.015
ID * Accidental	0.071 ± 0.009

Sum and product of pairs of cut sets are equivalent within errors indicating that cut sets are relatively independent.

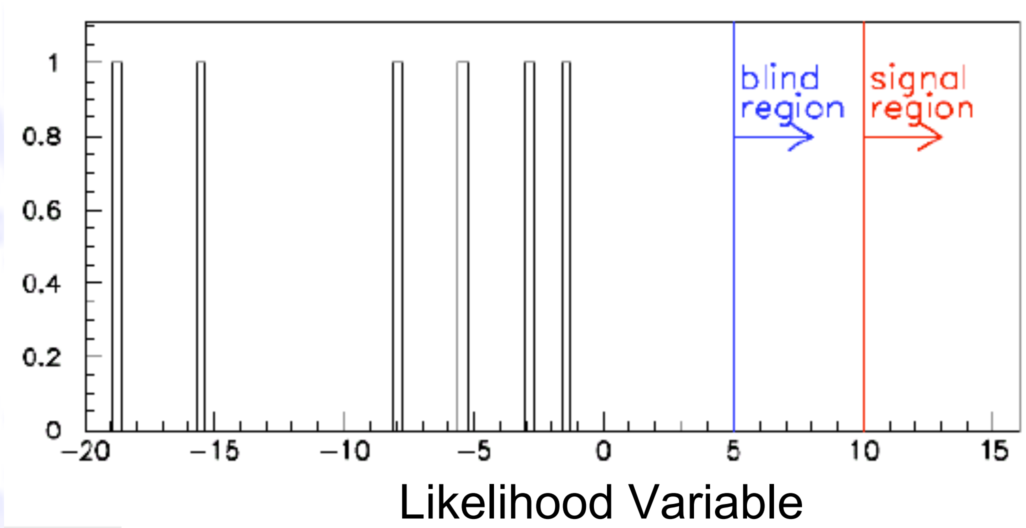
Systematic Errors

Cut variation	Var. 99 data	Var. summer 97	Var. winter 97
BA1 removed	3.7%	1.5%	0.06%
E/p (.96 to 1.04)	0.9%	1.2%	1.0%
Extra DC hits	2.0%	2.0%	1.4%
Cluster energies $>$ 3 GeV	2.0%	1.0%	1.2%
Track matching in magnet	2.3%	1.0%	1.2%
Neutral π^0 mass	0.8%	1.2%	0.7%
Charged π^0 mass	0.8%	1.5%	1.0%
Fusion χ^2	0.8%	1.1%	1.2 %
Total	4.0%	3.8%	3.0%

Result for $K_L \rightarrow \pi^0\pi^0\mu e$

Box opened

No events in signal or blind region



Expected background = 0.44 ± 0.12 events

For a kaon flux of 6.36×10^{11}

PRELIMINARY result using Feldman-Cousins method

$BR(K_L \rightarrow \pi^0\pi^0\mu e) < 1.58 \times 10^{-10}$ (90% CL)

$\pi^0 \to \mu e$ From $K_L \to \pi^0\pi^0\pi^0$

Identical to $K_L \to \pi^0\pi^0\mu e$ analysis. Just add cut on $M_{\mu e}$

Box opened. No events in signal or blind region.

Expected background = 0.03 ± 0.02 events

For a pion flux of 4.0×10^{11}

PRELIMINARY result using Feldman-Cousins method

$BR(\pi^0 \to \mu e) < 3.63 \times 10^{-10}$ (90% CL)

Previous results

$BR(\pi^0 \to \mu e) < 1.72 \times 10^{-8}$ (90% CL) E799I (PL **B320** 407 (94))
$BR(\pi^0 \to \mu^+ e^-) < 3.8 \times 10^{-10}$ (90% CL) (PRL **85** 2450 (00))
$BR(\pi^0 \to \mu^- e^+) < 3.4 \times 10^{-9}$ (90% CL) (PRL **85** 2877 (00))

Summary

KTeV has new preliminary results for 2 LFV modes.

- $BR(K_L \to \pi^0\pi^0\mu e) < 1.58 \times 10^{-10}$ (90% CL)
  - No events in signal box.
  - Background estimate of 0.44 ± 0.12 events
- $BR(\pi^0 \to \mu e) < 3.63 \times 10^{-10}$ (90% CL)
  - No events in signal box
  - Background estimate of 0.03 ± 0.02 events

New analysis combining data from 1997 and 1999 runs for $K_L \to \pi^0\mu e$ available soon.