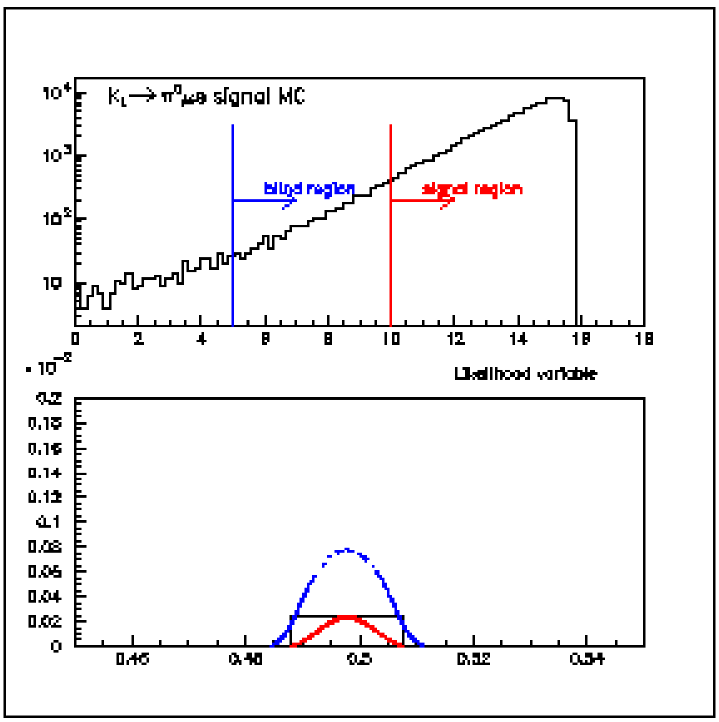
$K_L \to (\pi^0)\pi^0\mu e$ Status

MDC, KTeV meeting, Sept 9, 2006

With the agreement of the godparents, I am doing a combined analysis for $K_L \to \pi^0\pi^0\mu e$ with $\pi^0 \to \mu e$ as a subset (ie, one additional cut on $M_{\mu e}$). The $K_L \to \pi^0\mu e$ analysis will be as similar as possible.

As a reminder, I will use the likelihood variable to define the signal box in all cases.

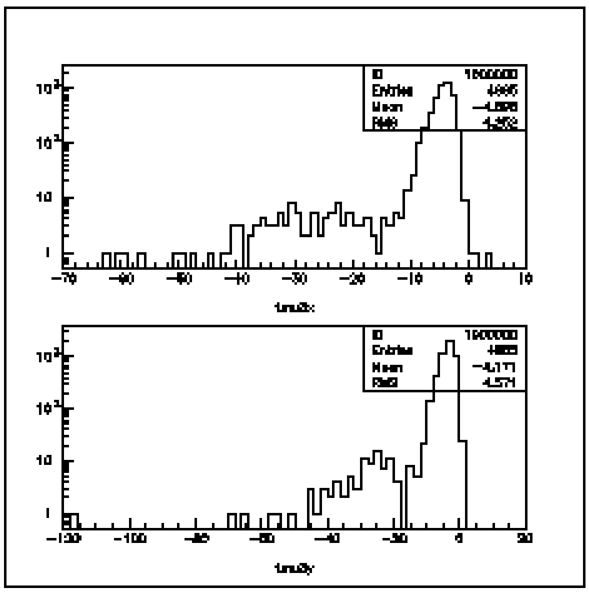


Top: Likelihood variable for signal Monte Carlo. Bottom: Comparison of the old signal box with the new signal region and blind region.

Cross Trigger Issues

The signal and normalization modes are in different triggers–consider systematics. The main difference is the MU3X,Y requirement in Trig 7.

Select $K_{\mu 3}$ decays from trigger 2. Require all three muon banks to have in-time hits which match the muon DC track. Then look at the L1 trigger TDCs, taking the hit with the best time.

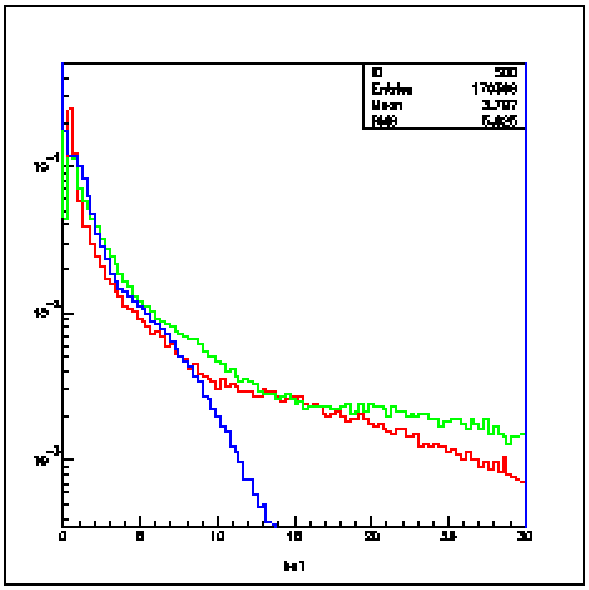


MU3X,Y L1 trigger TDC, with the requirement of in-time muon hits in all three layers of muon counters.

About 1.5% of events do not have an in-time L1 muon trigger TDC hit. Take this as a correction on acceptance, with a systematic of the same size as the correction.

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

$BA1 < 15GeV$ required for all periods, in spite of the change in configuration. Most of the benefit comes from removing events in the overflow bin.



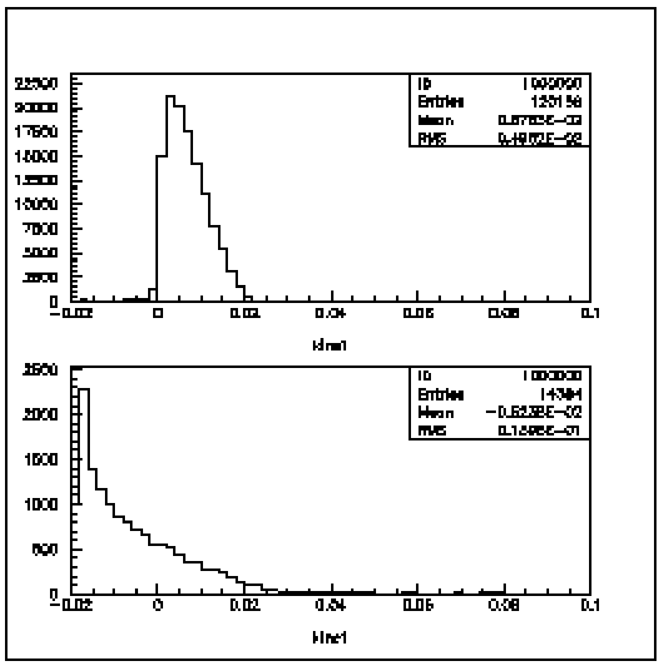
BA1 distribution. Blue=99 data, red=winter97, green=summer97.

There is a bit of a data/MC mismatch, but all two-track modes are similar, so some of the data/MC difference will cancel with the normalization mode. Also included in the cut variations.

	BA< 10 data fraction	BA < 10 MC fraction	data/MC
K_{e3}	0.838±0.008	0.896±0.008	0.935±0.012
$K_{\mu 3}$	0.835±0.012	0.898±0.011	0.930±0.018
$K3\pi^0_D$	0.848±0.005	0.907±0.032	0.935±0.033

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

$kine1$ adn $kine2$ are kinematic variable in the spirit of $pp0kine$ (one for each π^0). These variables are a good discriminator against K_{e3} and $K_{\mu3}$ backgrounds.

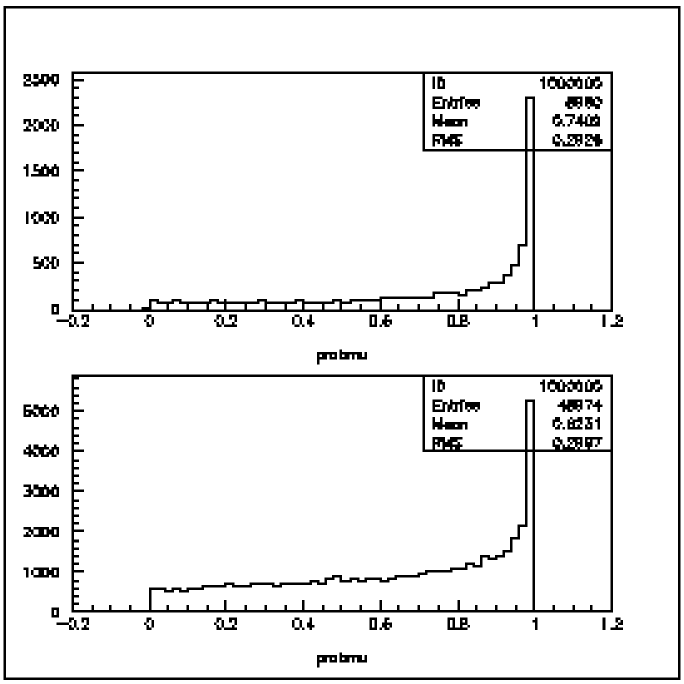


Kinematic variable (square of π^0 momenutm in K rest frame) for signal MC (top) and $K_{\mu3}$ background MC

Require $kine1$ and $kine2$ to be positive

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

One source of background is $K_L \to \pi^0\pi^0\pi^0_D$ where an accidental muon satisfies the muon trigger and happens to be close to the electron track. An anti-electron cut on the muon TRD information is effective against this background.



TRD CL that the muon track looks like a pion/muon in the TRDs. Top plot is $K_{\mu 3}$ MC, bottom plots is $K_{\mu 3}$ data.

Electrons are peaked very close to zero. Require $prob_\mu > 0.015$ (98% efficient for muons).

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

Here are the cut values:

- Track offsets in the magnet < 0.002m in all cases
- Z vertex location between 96 and 155 meters
- X and Y location of the vertex, projected to the calorimeter, is within the CsI beam holes
- 3x3 fusion $\chi^2 < 10$ for the electron and all neutral clusters
- Muon momentum > 8 GeV/c
- Energy in the calorimeter associated with the muon track < 1 GeV.
- Number of hardware clusters is exactly 5.
- Maximum energy deposited in any of the ring counters and spectrometer antis < 0.3 GeV
- Energy in BA1 < 15 GeV.
- Vertx χ^2 for the charged vertex < 20
- π^0 mass between 0.132 and 0.138 GeV for both π^0s
- Electron E/p between 0.95 and 1.05
- Projection of the muon track matches to a hit in all three muon banks
- The difference between the charged and neutral vertices is less than 2.5 meters for both neutral pions.
- Square of the magnitude of the π^0 momentum in the K rest frame ($kine1$ and $kine2$) between 0 and 0.025 $(\mathrm{GeV/c})^2$.
- The number of extra in-time drift-chamber hit pairs is < 3 for both the upstream and downstream drift chambers
- The TRD information associated with the muon track is not consistent with an electron ($prob_\mu > 0.015$).

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

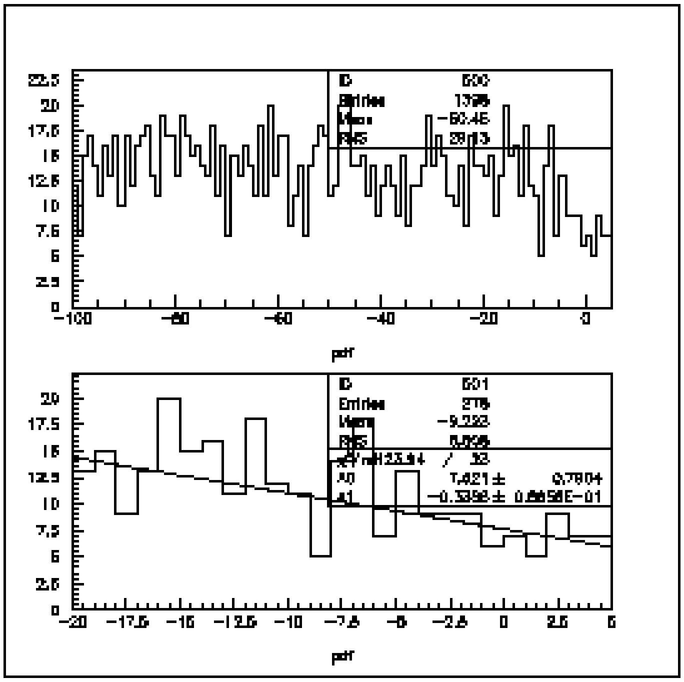
I use the data itself to estimate the background. I want to fit the *pdf* distribution outside the signal region and extrapolate into the signal region. But if all cuts are in place, there are not enough events! So define three cut sets, remove them all, than reapply one by one to get "suppression factors" for each set.

Cut set	**Suppression factor**
Kinematic	0.092 ± 0.016
Particle ID	0.273 ± 0.024
Anti-accidental	0.261 ± 0.024
Kinematic + ID	0.012 ± 0.009
Kinematic * ID	0.025 ± 0.005
Kinematic + Antiacc.	0.025 ± 0.009
Kinematic * Antiacc.	0.024 ± 0.005
ID + antiacc	0.077 ± 0.015
ID*antiacc	0.071 ± 0.009

*Effect of applying each of the three cut sets independently and applying them in pairs of two. The + symbol means both cuts have been applied to the data. The * symbol denotes the product of the two individual suppression factors. These numbers are for the 99 data and for* $-20 < pdf < 5$.

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

Remove all cuts, fit the *pdf* distribution.



Distribution of the likelihood variable for 99 data with the three cut sets removed. Top plot is $-100 < pdf < 5$, bottom plot is for $-20 < pdf < 5$, which is the range used to fit for the background.

Take $\pm 1\sigma$ on the fit parameters as the systematic on the background estimate. Project to the signal region, then reapply the suppression factors.

Background estimate in the signal region: 0.37 ± 0.11 for 99 data; 0.07 ± 0.05 for 97 data.

For $\pi^0 \to \mu e$, similar procedure, but require $0.132 < M_{\mu e} < 0.138$, background about 0.02 events for both periods.

Determine systematics by varying all the cuts:

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%

Summary of systematic errors on the apparent flux due to cut variations

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

How to combine 97/99 datasets?

$N_{tot} = BR(F_1 * \epsilon_1 + F_2 * \epsilon_2 + F_3 * \epsilon_3)$

Also add expected backgrounds.

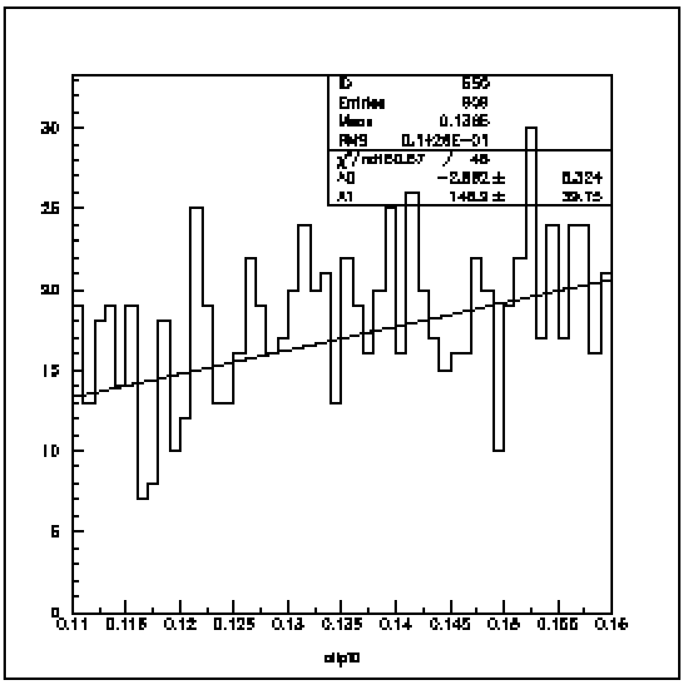
How to include systematic errors in the final limit?

- Select a trial BR
- Do several thousand MC experments at this BR. For each trial, the acceptance, flux, and background mean values are varied by their Gaussian errors and fluctuate according to Poisson stats.
- Step through many values of BR.
- The BR value for which 10% of the trials has the number of events seen in the data or less is the 90% CL limit.

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

Still working on background estimates. With the same cuts as $K_L \to \pi^0\pi^0\mu e$, several events of background are expected. Angela had additional cuts which do reduce the background.

The dominant background is K_{e3} decays with accidental photons which form a flat $M_{\gamma\gamma}$ distribution.



$M_{\gamma\gamma}$ distribution for 99 data, after all cuts except $M_{\gamma\gamma}$.

Tightening this cut reduces background but also reduces acceptance. It should be optimized $S/\sqrt{B}$ or something similar.