Lepton Flavor Violating Kaon Decays

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- Example decays and current limits
- Closer look at $K_L \rightarrow \pi^0 \mu^\pm e^\mp$
  (i.e. what I did)
- Improvement suggestions
  (i.e. what I might have done differently)

Example Lepton Flavor Violating Decays

values from 2002 PDG:

- $BR(K^+ \to \mu^+ \nu_e) < 4 \times 10^{-3}$
- $BR(K^+ \to \mu^- \nu e^+ e^+) < 2.0 \times 10^{-8}$
- $BR(K^+ \to \pi^+ \mu^- e^+) < 5.2 \times 10^{-10}$
- $BR(K^+ \to \pi^+ \mu^+ e^-) < 2.8 \times 10^{-11}$
- $BR(K_L \to \pi^0 \mu^\pm e^\mp) < 6.2 \times 10^{-9}$
- $BR(K_L \to e^\pm e^\pm \mu^\mp \mu^\mp) < 1.23 \times 10^{-10}$
- $BR(K_L \to e^\pm \mu^\mp) < 4.7 \times 10^{-12}$

Analyses in progress:

- $K_L \to \pi^\pm \pi^\pm \mu^\mp e^\mp$
- $K_L \to \pi^0 \pi^0 \mu^\pm e^\mp$

$K_L \to \pi^0 \mu^{\pm} e^{\mp}$ at KTeV

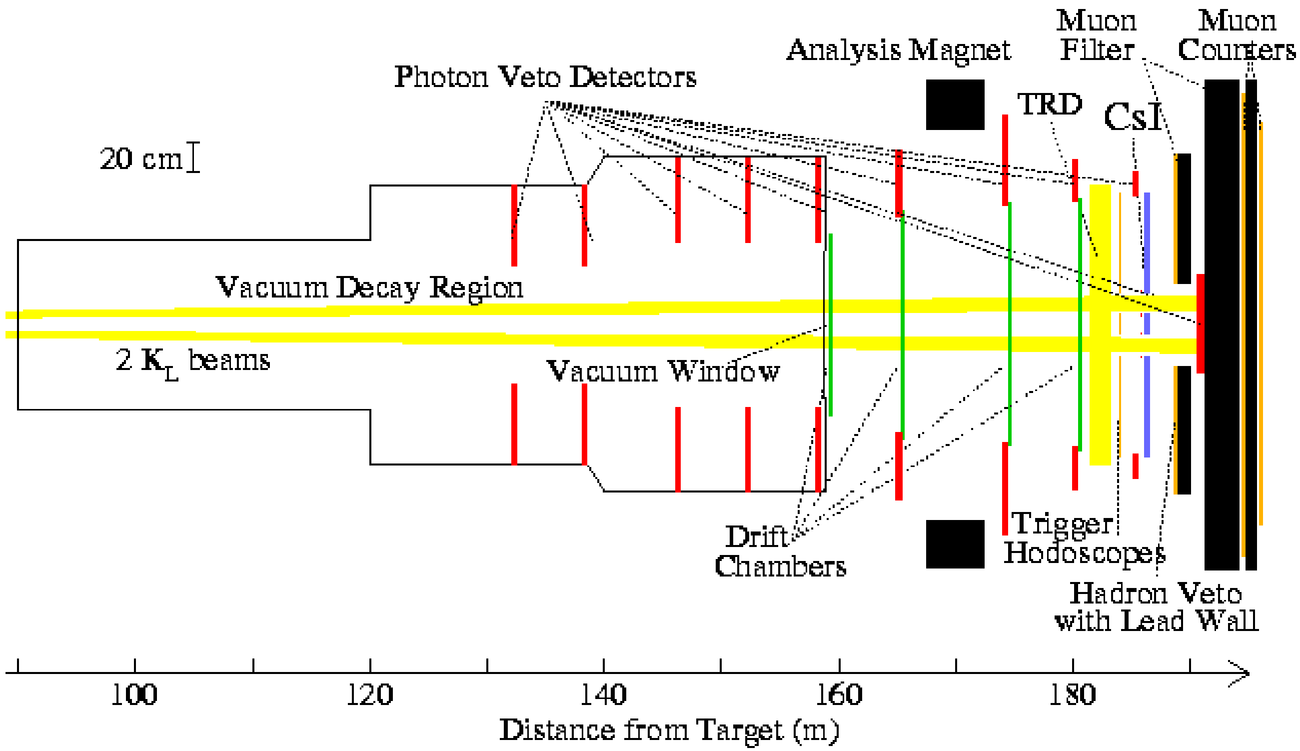
- $K_L \to \pi^0 \mu^{\pm} e^{\mp}$ was my PhD thesis topic at Rice University
- Combined 2 data sets from KTEV Kaons at the Tevatron (E799) experiment at Fermilab
  - sets referred to as "97" and "99"
- Most recent results shown at DPF 2002:

$$BR(K_L \to \pi^0 \mu^{\pm} e^{\mp}) < 3.31 \times 10^{-10}$$

90% CL, preliminary

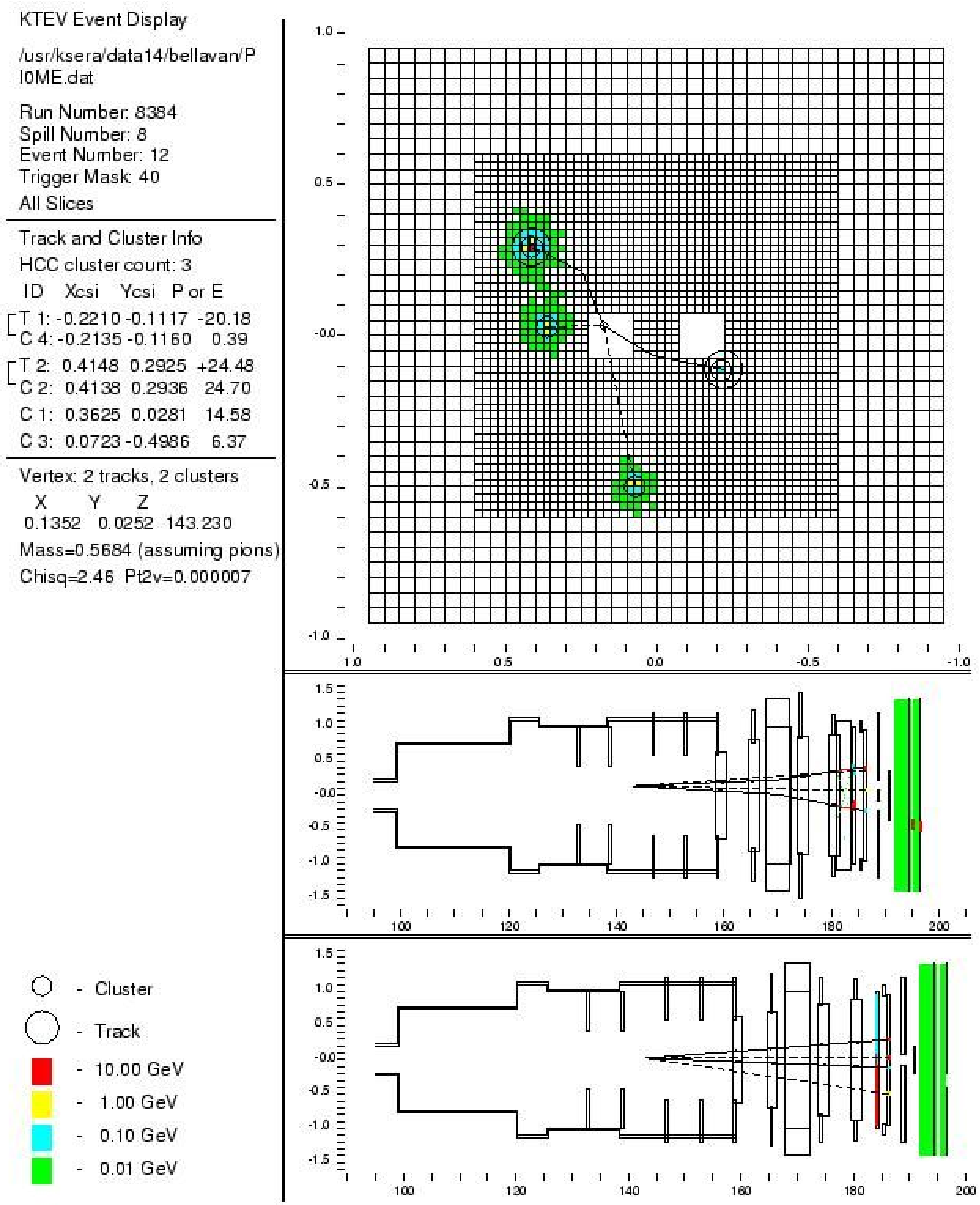
- Paper in progress

KTeV Detector



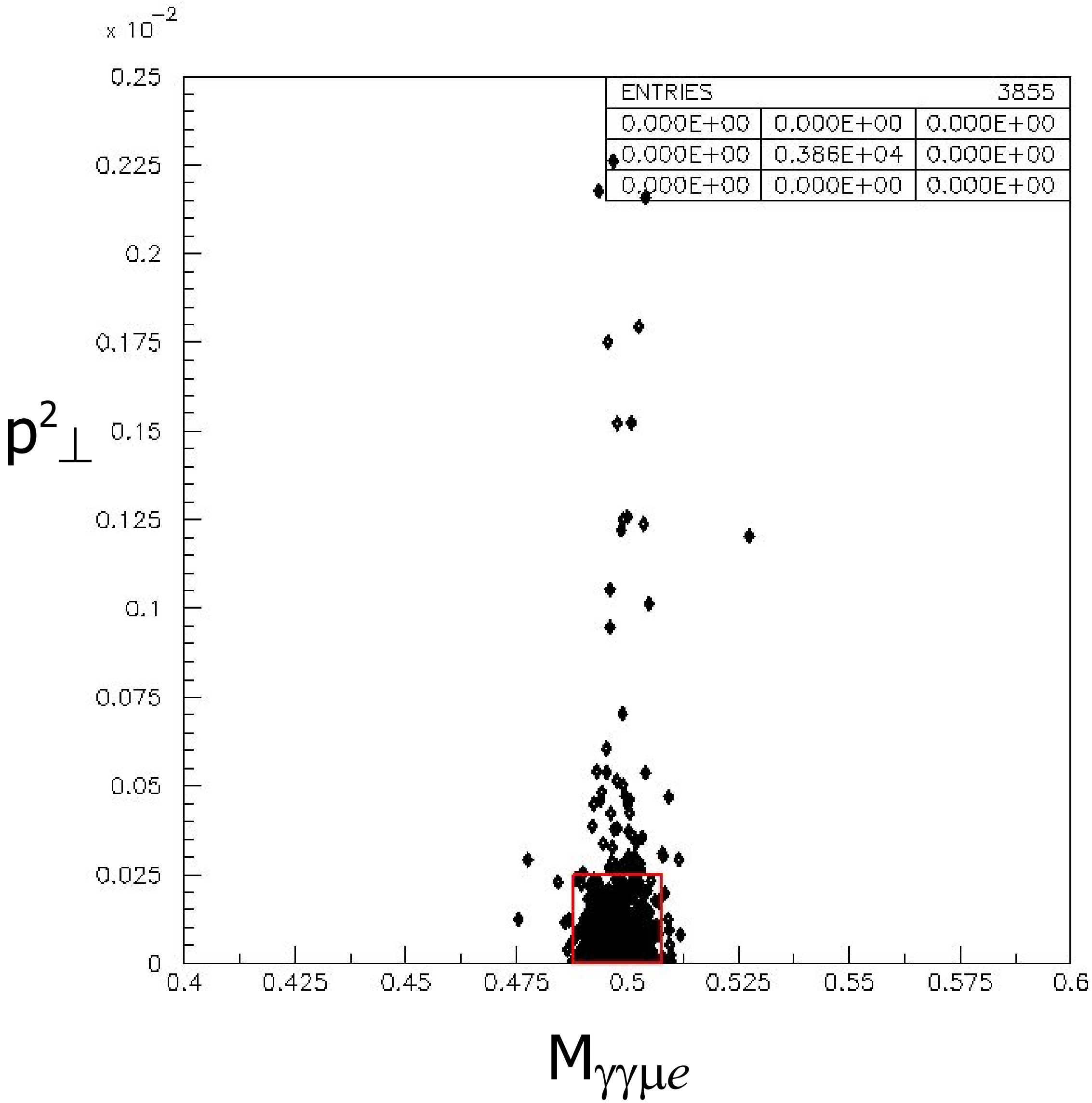
- Pure CsI calorimeter (resolution < 1% at <Eγ> = 10GeV, π/e rejection > 200)
- Transition Radiation Detectors (π/e rejection)
- Drift chamber spectrometer (100 micron resolution)
- Clean, intense beams (~5x10^{12} protons on target per minute)

$K_L \to \pi^0 \mu^\pm e^\mp$ topology (MC)



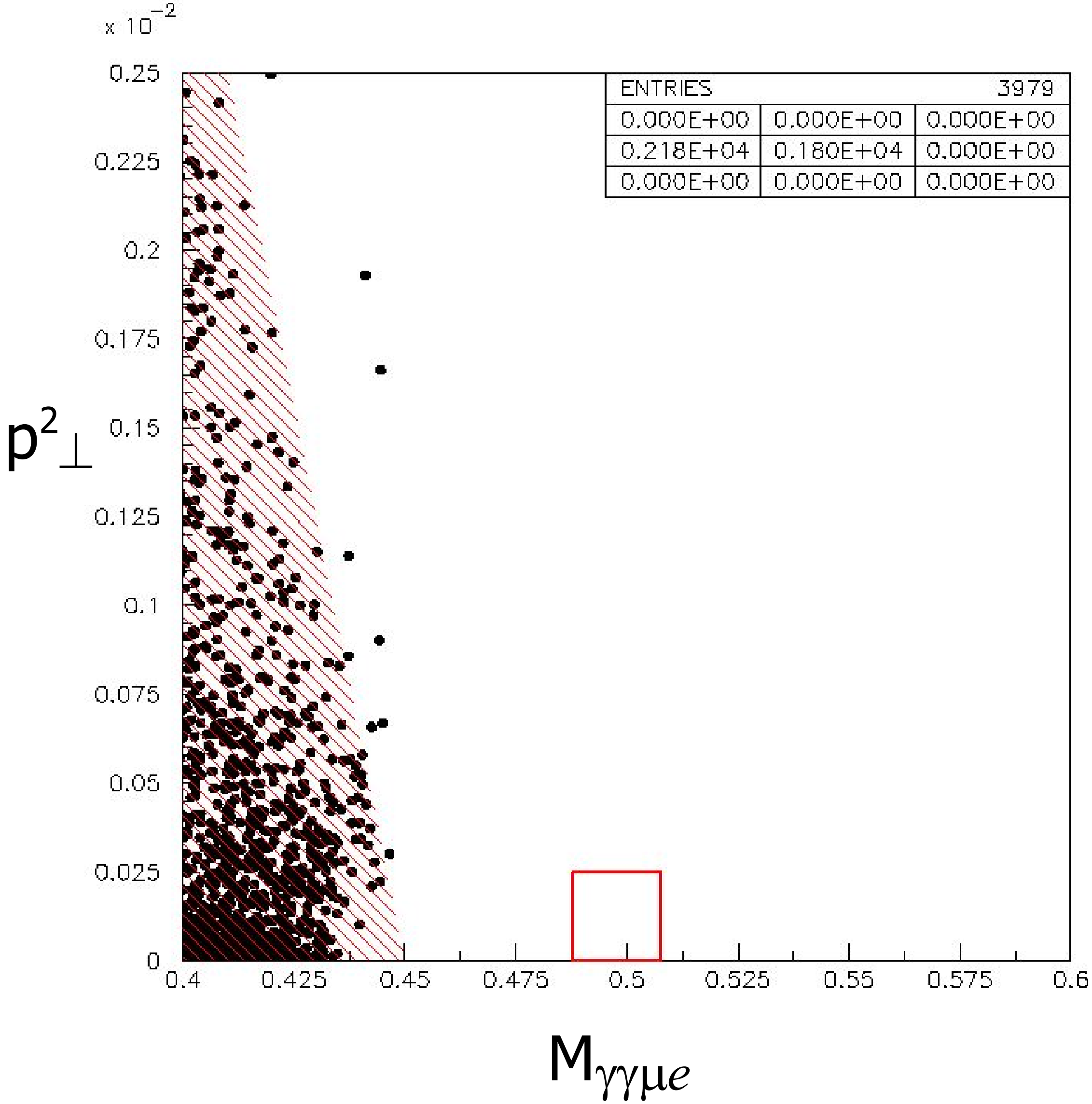
- Requirments
  - 3 EM cal. clusters
  - 2 charged tracks
  - muon ID
- Backgrounds
  - $K_L \to \pi^+\pi^-\pi^0$ (K3pi)
  - $K_L \to \pi^0\pi^\pm e^\mp \nu_e$ (Ke4)
  - $K_L \to \pi^\pm e^\mp \nu_e$ (Ke3)
- Normalization
  - $K_L \to \pi^+\pi^-\pi^0$ (K3pi)

Signal MC in "study plot"



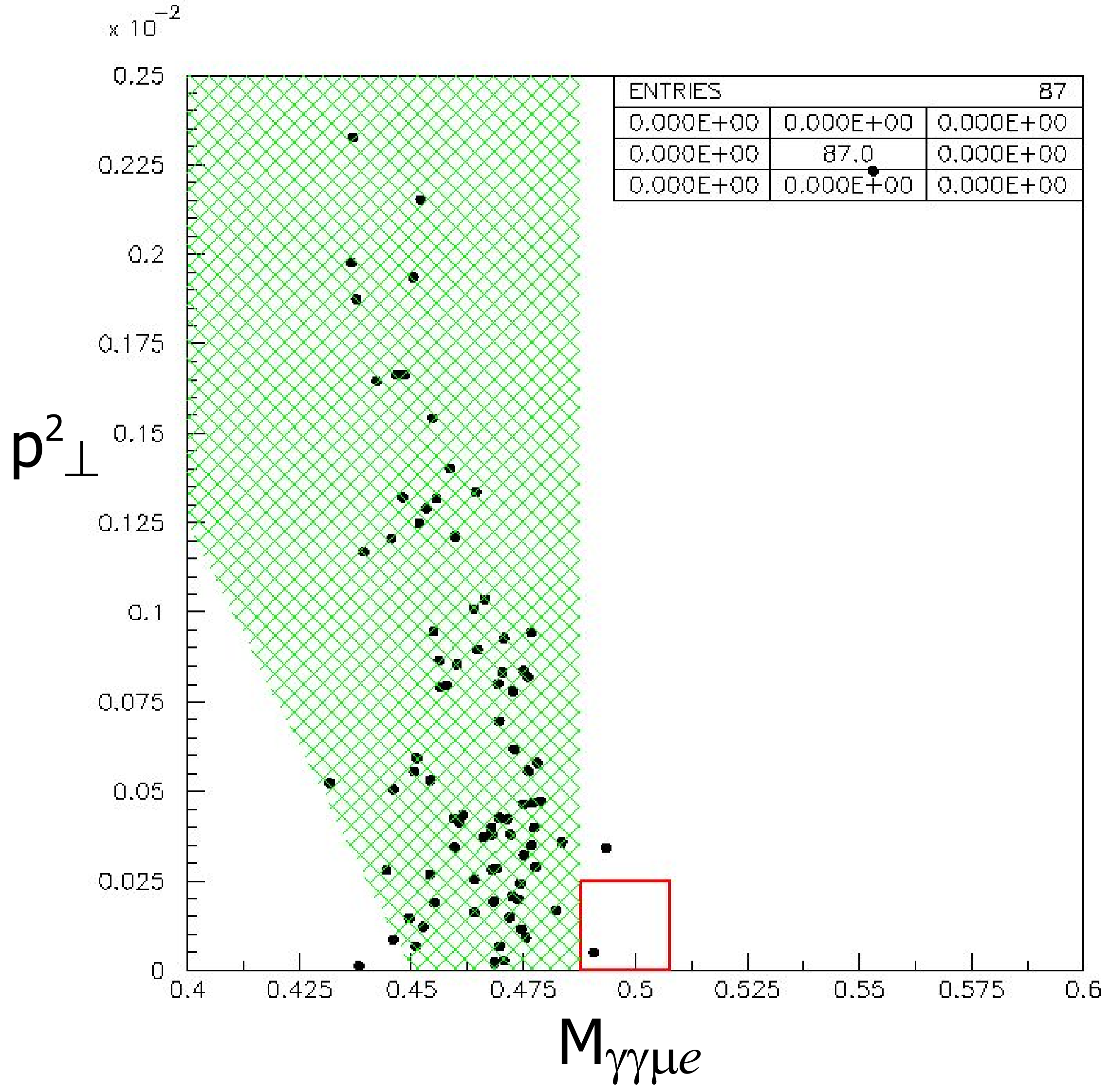
- Blind analysis done
  - "signal box" » data events within are masked until analysis complete
  - "study plot" » same parameters as signal box, but 100x's area
- Plot shows signal MC in search trigger with all cuts

Backgrounds in "study plot" - K3pi data



- Muon ID cuts removed to show more stats here
- Expected events in "97" study plot: 2.5±0.5
- Expected events in "99" study plot: 8.0±3.8

Backgrounds in “study plot” - Ke4 MC



- All cuts, but 23x's expected flux here
- Expected events in “97” study plot: 9.4±1.1
- Expected events in “99” study plot: 4.8±0.6

"Ke4 Kinematic" Cut

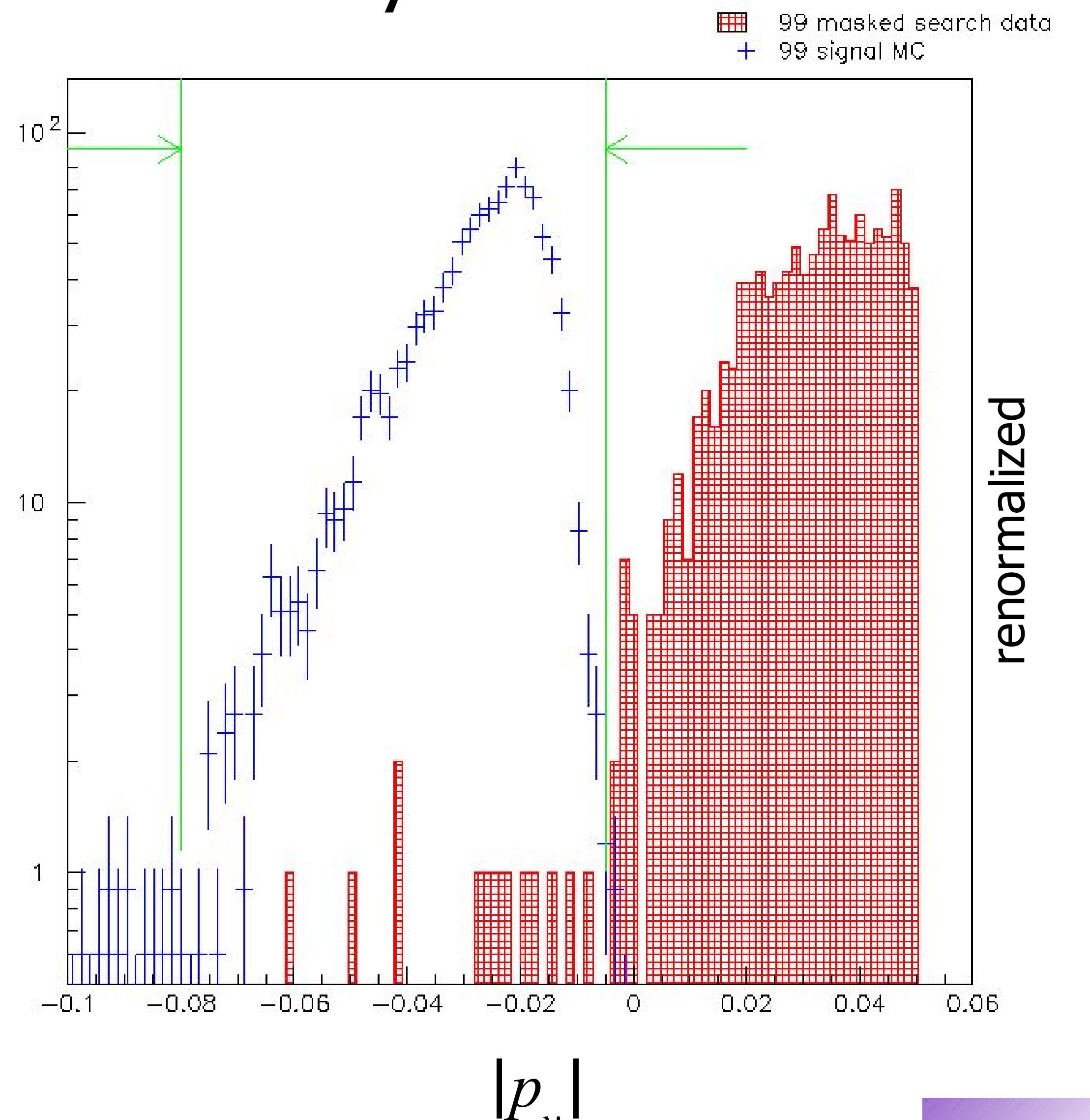
- reconstruct event as a Ke4 decay

  $(K_L \rightarrow \pi^0 \pi^{\pm} e^{\mp} \nu_e)$

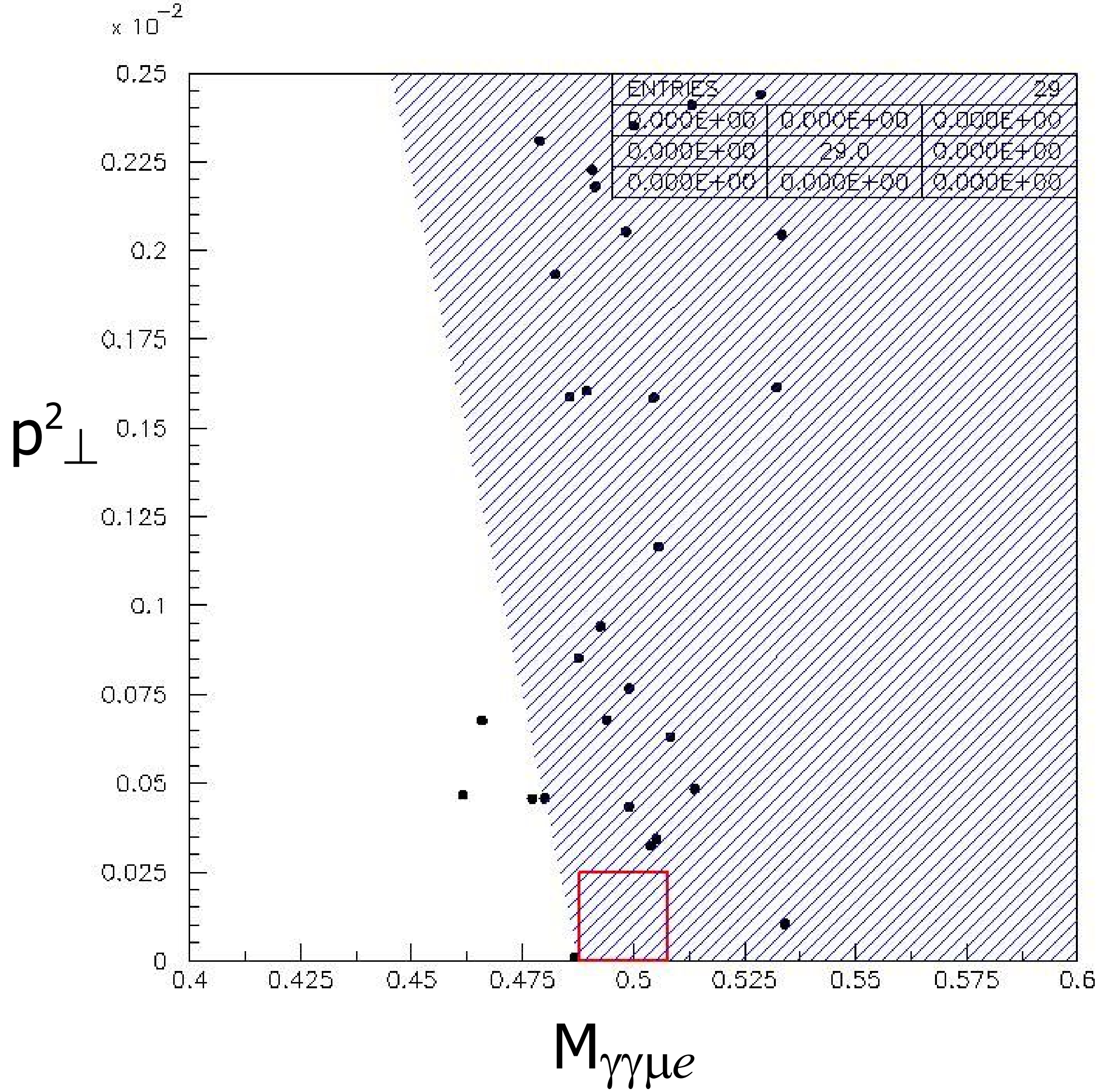
- then

$$|p_\nu| = \frac{M_K^2 - M_{\gamma\gamma\pi^\pm e^\mp}^2}{2\, M_K}$$

- red hist. = data
- blue +s. = signal MC



Backgrounds in “study plot” - Ke3 MC

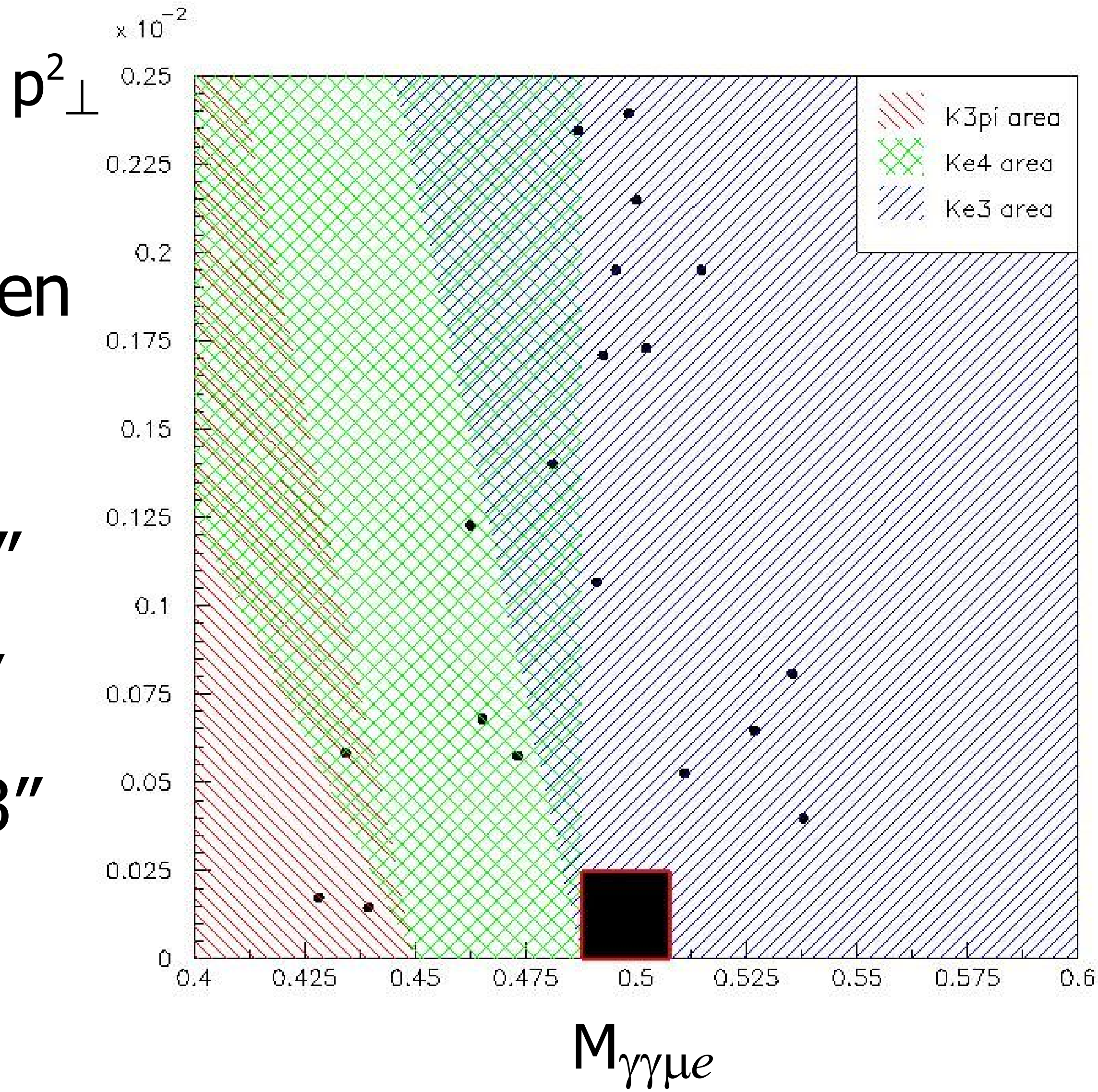


- $M_{\gamma\gamma}$ cut removed to show more stats in this plot
- expected events in “97” study plot: 10.1±8.1
- expected events in “99” study plot: 9.3±4.1

“97” results

Events seen

- 19 total
- 3 “K3pi”
- 3 “Ke4”
- 13 “Ke3”



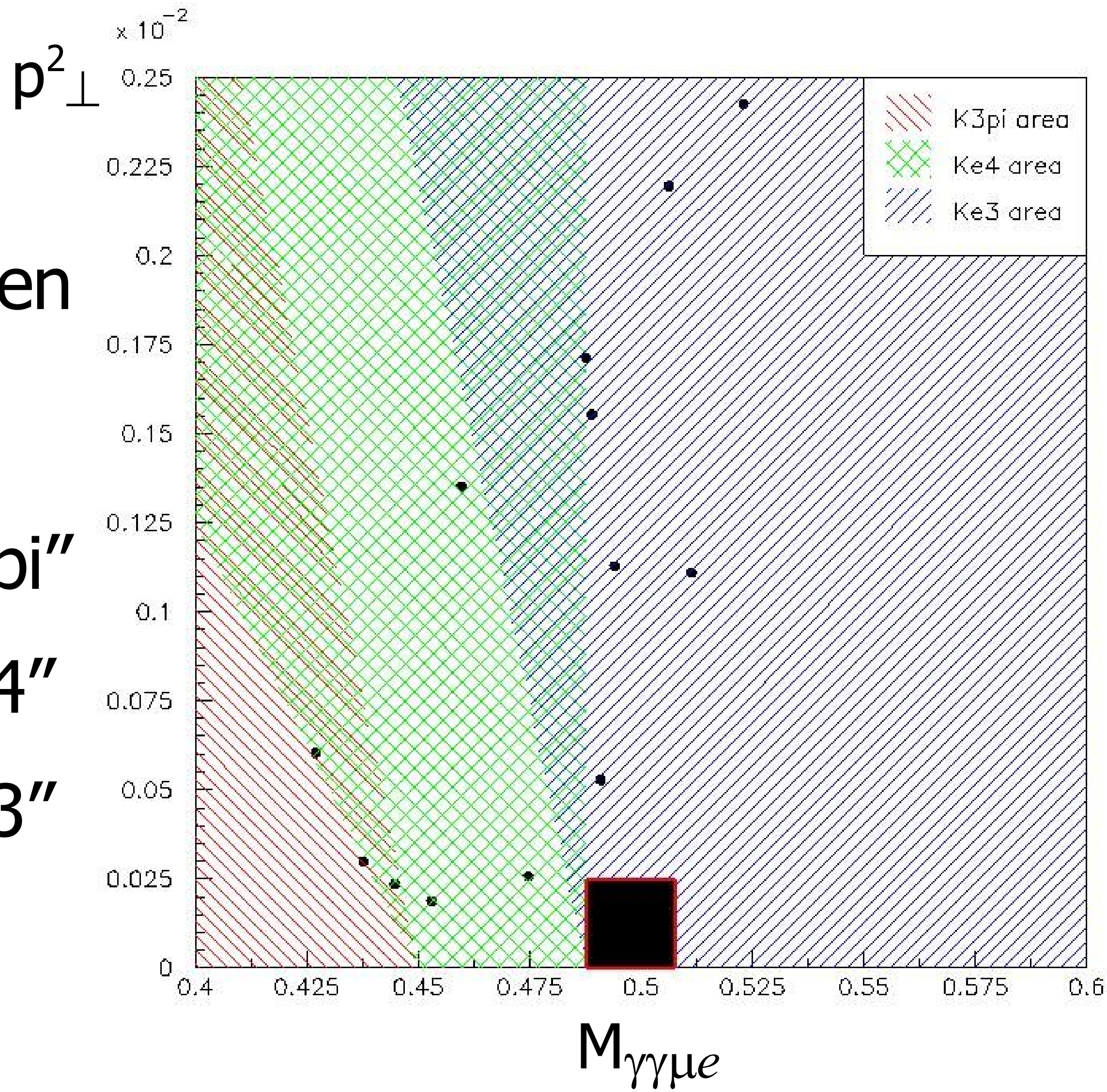
Estimated

- 22.0±8.2 total
- 2.5±0.5 “K3pi”
- 9.4±1.1 “Ke4”
- 10.1±8.1 “Ke3”

"99" results

Events seen

- 13 total
- ~3 "K3pi"
- ~3 "Ke4"
- ~7 "Ke3"

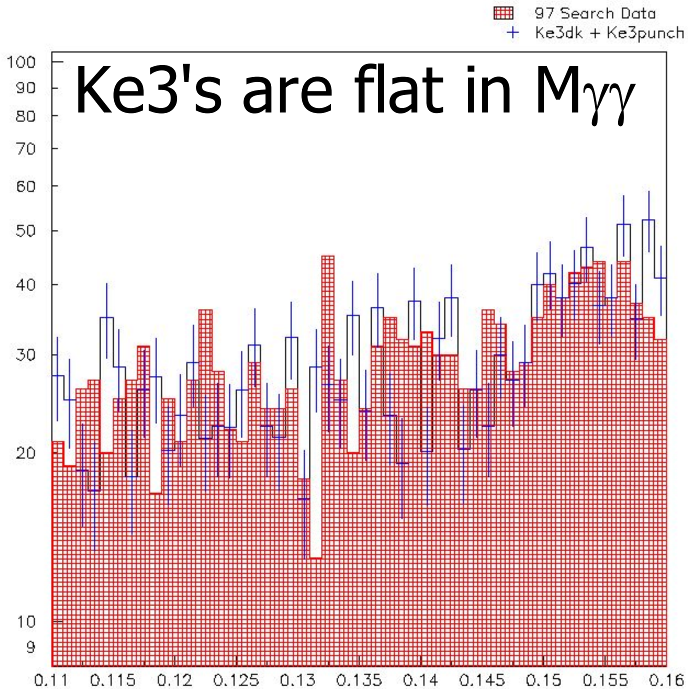


Estimated

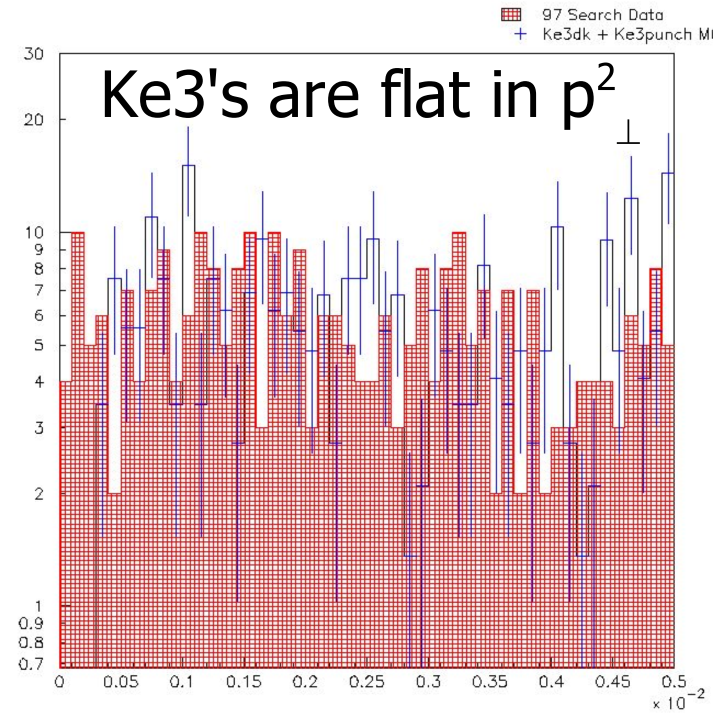
- 22.3±5.7 total
- 8.0±3.8 "K3pi"
- 4.8±0.6 "Ke4"
- 9.3±4.1 "Ke3"

Estimation of background in signal box

- Not sure can trust MC, so what can we do with data?
- Only background expected in signal box is from Ke3

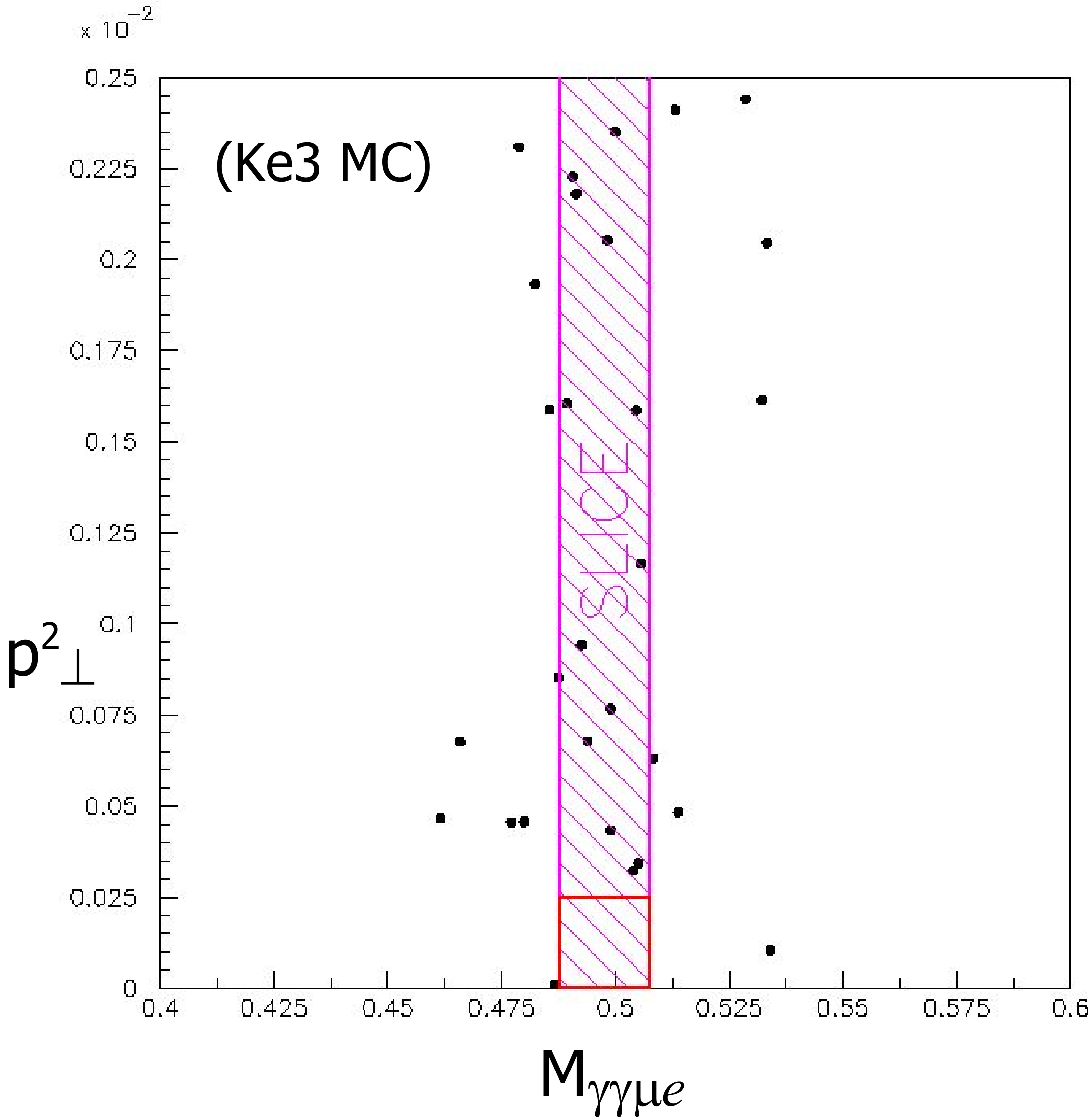


(plots renormalized)



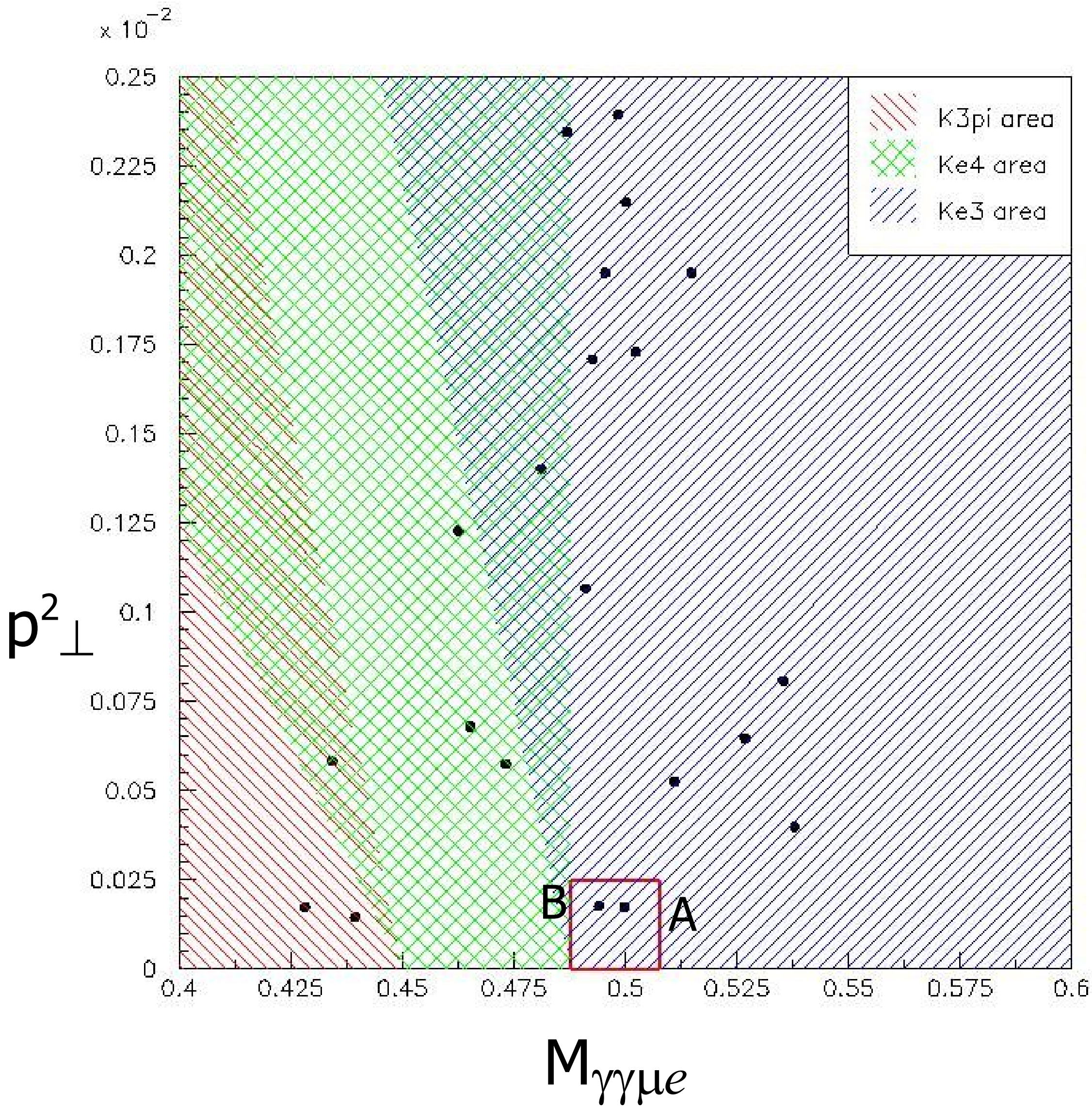
...so we can assume a uniform distribution for Ke3's in the study plot in $p^2_\perp$...

Slice Method



- Assume background is flat in $p^2_\perp$
- Remove $M_{\gamma\gamma}$ cut
- Count number of events in the slice
- Divide by area ratio and multiply by cut supression factor
- Gives box estimations of
  - 0.53±0.14 in "97"
  - 0.48±0.14 in "99"

“97” results again



- these are not signal
- look at

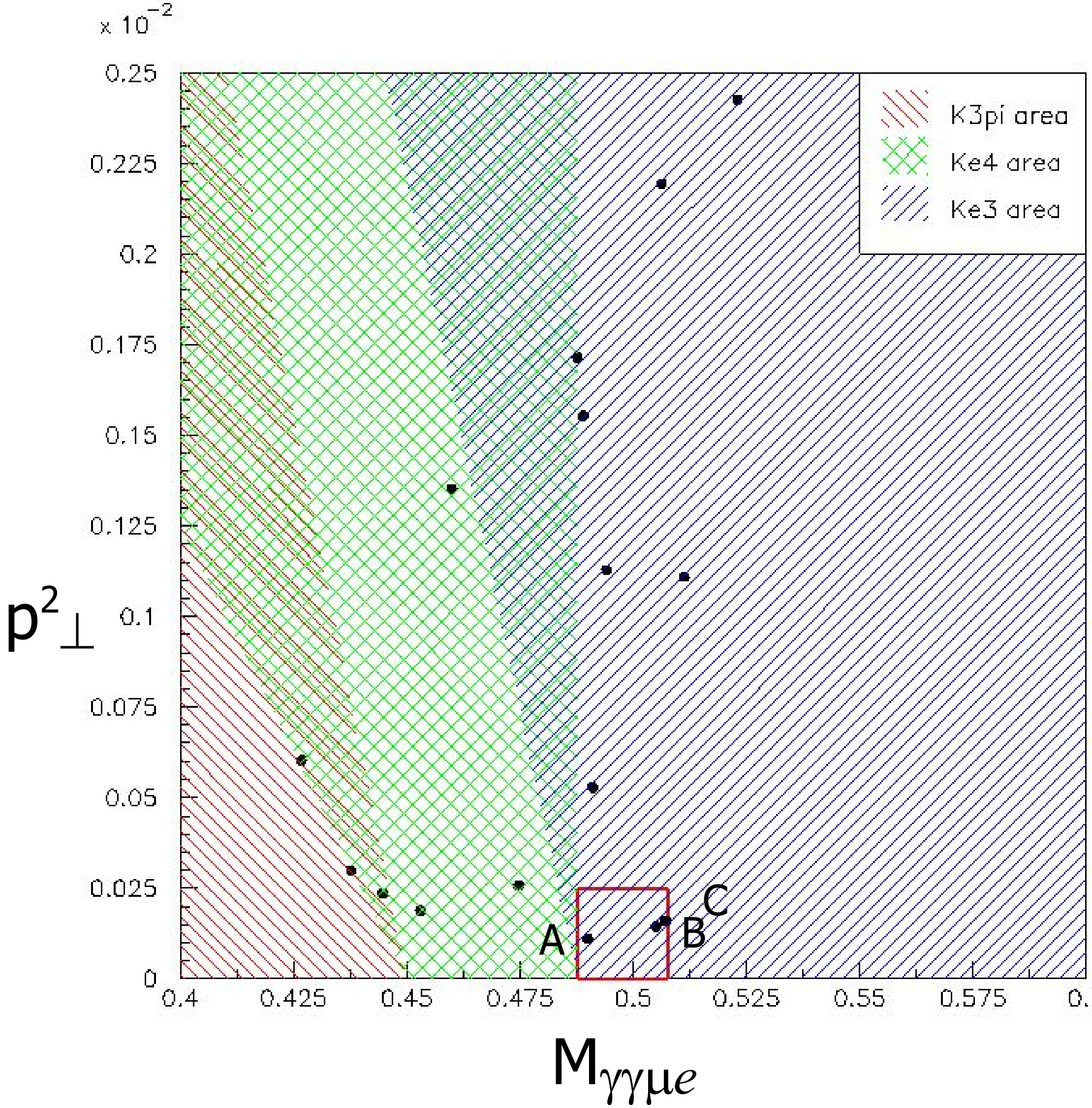
$$P(X) = |M_K - M_{\gamma\gamma\mu e}| \times p_\perp^2$$

= % of signal MC farther from M_K and/or larger in $p^2_\perp$ than data event X

A 4.3 ± 0.3%

B 2.5 ± 0.2%

"99" results again



- these are not signal either
- again, look at

$$P(X) = \left| M_K - M_{\gamma\gamma\mu e} \right| \times p_\perp^2$$

= % of signal MC farther from M_K and/or larger in $p^2_\perp$ than data event X

A 0.54 ± 0.04%

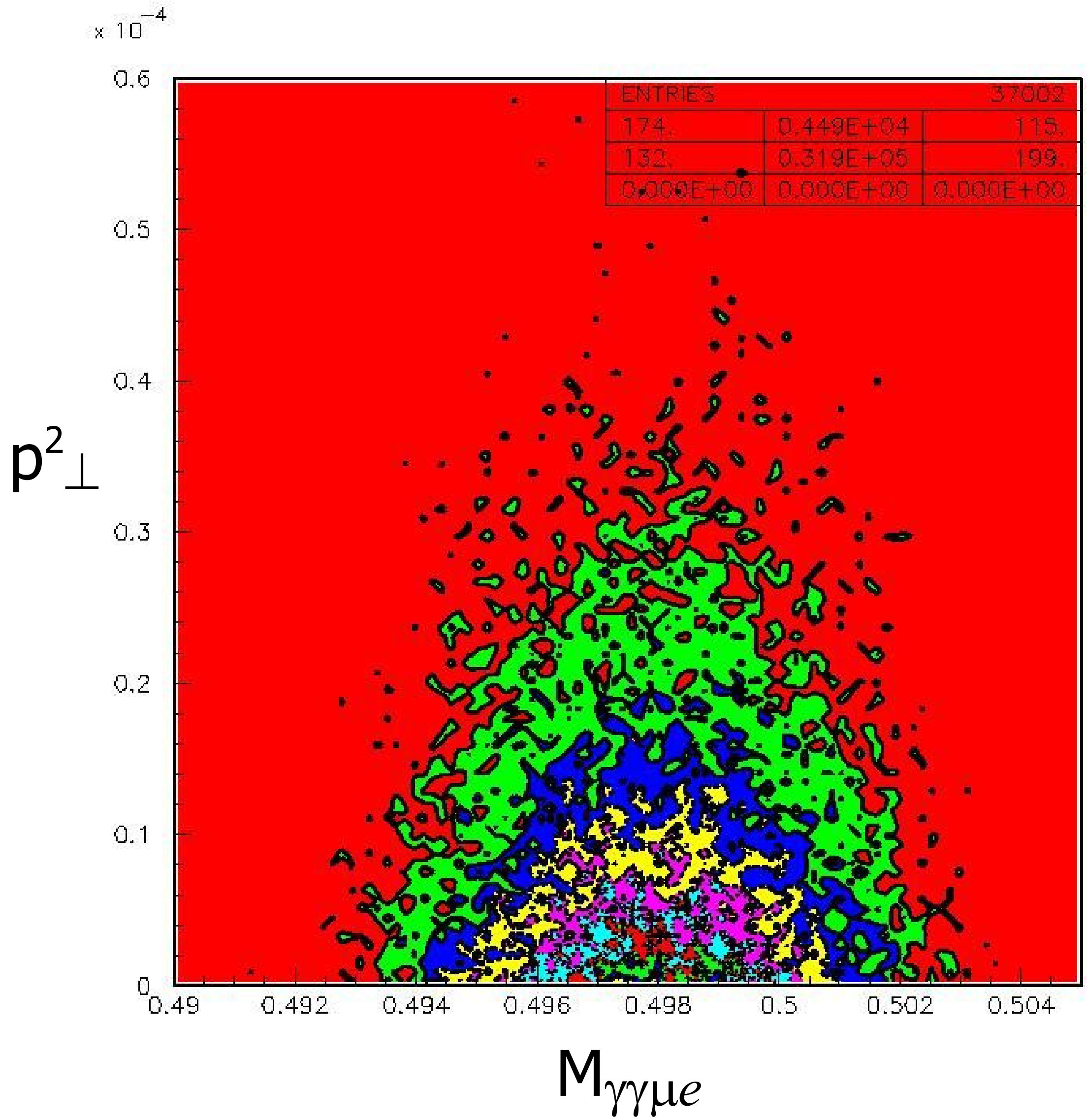
B 0.37 ± 0.03%

C 0.07 ± 0.01%

Improvments to Consider

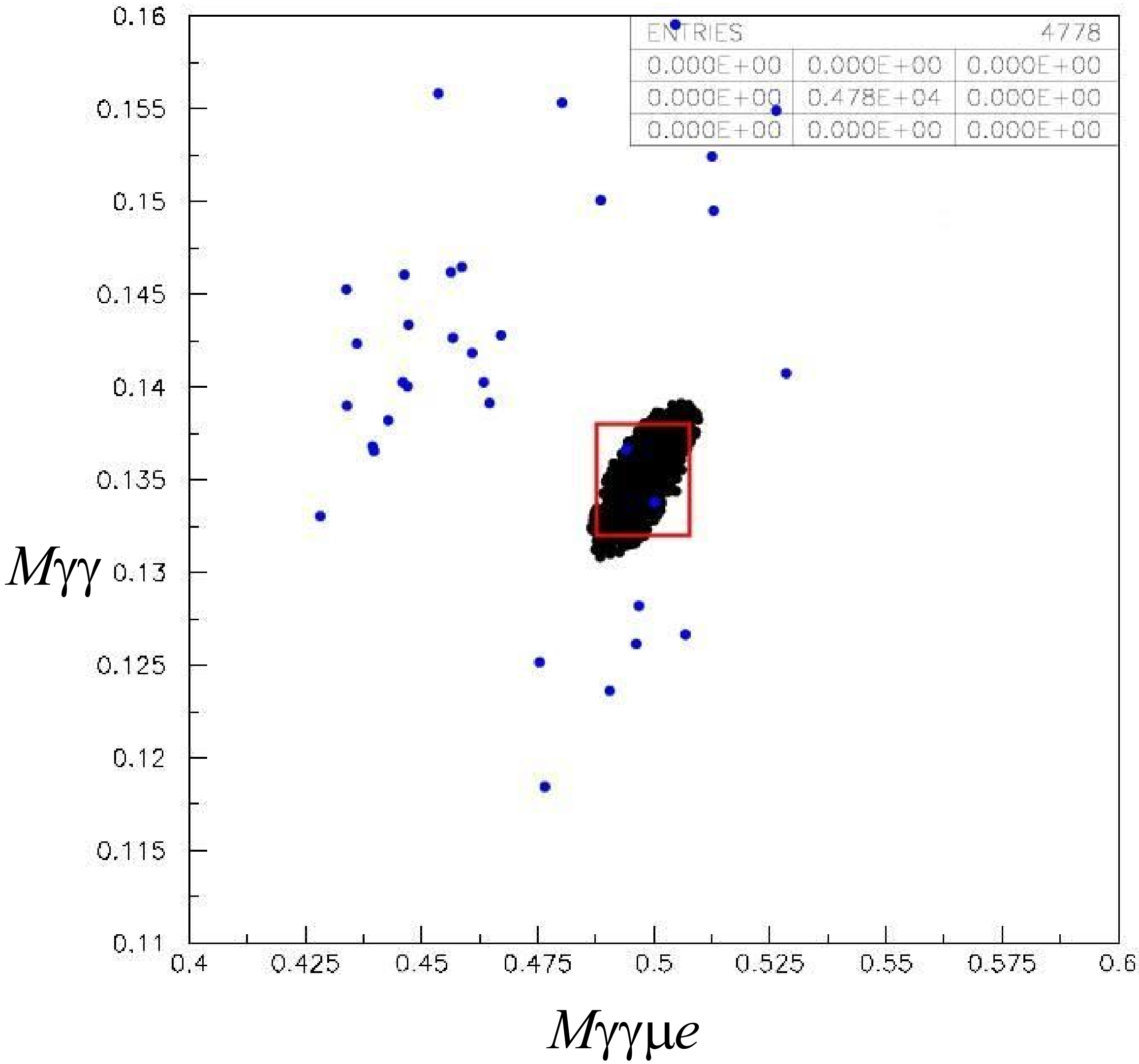
- Distribution of signal events
  - Was a box the right shape?
  - Was $p^2_\perp$ v. $M_{\gamma\gamma\mu e}$ the right plot?

Distribution of Signal Events / Box?



- Contour of signal MC looks much more like a half-circle than a box
- Events in box were **not** near the higher density areas
- Use a Probability Density Function of $p^2_\perp$ x $M_{\gamma\gamma\mu e}$ directly instead of box? $\Rightarrow$ better!

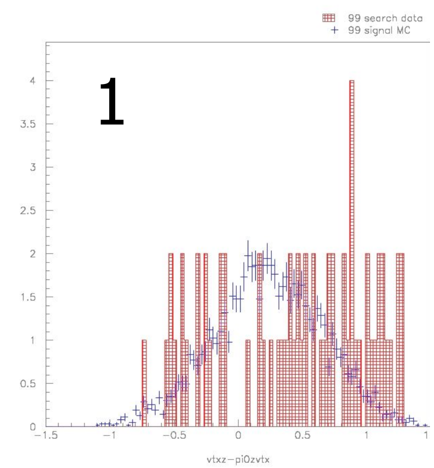
Was $p^2_\perp$ v. $M_{\gamma\gamma\mu e}$ the right plot?

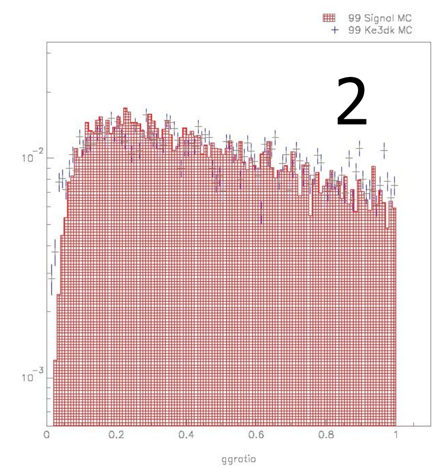


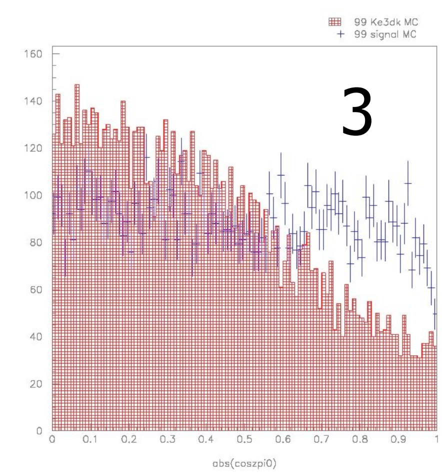
- Use $M_{\gamma\gamma}$ v. $M_{\gamma\gamma\mu e}$?
- red box = our cuts
- black = signal MC
- blue = 97 data
- not any better...

More Improvments to Consider

- Had more accidental photons in "99" than "97". Due to more protons on target?
- Is there another way to reduce accidental photons?
  1. Compare charged vertex to neutral vertex?
  2. Ratio of photon energies?
  3. Opening angle of photons?







More Improvments to Consider

- Can MC modelling be improved?
  - had to play games with forcing charged pion decay to get enough Ke3 statistics
- Could accidental vetos have been better?
- Are there backgrounds we missed?
  - ????

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