Progress & Plans for 1999 $K_L \rightarrow \pi^0\mu\mu$

- Outline
  - Overview
    - $KL \rightarrow \pi^0\mu\mu$ analysis
      - Cuts
      - Box Plot - Higher backgrounds from accidentals
  - Backgrounds estimates
      - Issues with using MC estimates
      - Data and MC background est. comparisons
  - Current issues

Analysis Cuts for $K_L \rightarrow \pi^0\mu\mu$

- No extra tracks
- Ptrk > 10 GeV/c
- Etrkclus < 1 GeV
- Offmag < 1mm (x & y)
- 97 < zvtx < 157 *
- Xvtx & yvtx in beam region at CsI
- Vtxchi2 < 10
- Trk to trk cluster position < 3.5cm
- Photon clus to trk clus > 20cm
- Exactly 2 hits in MU3X and MU3Y
- Non-adjacent mu hits in 1 plane
- RC energy < 0.2 GeV
- CA energy < 3.0 GeV
- 20 GeV < E_K < 220 GeV
- No extra HCC clusters
- Fusechi2 < 5

Signal Cuts ($K_L \rightarrow \pi^0\mu\mu$)

- Trigger 5
- Exactly 2 HCC clusters (no trk)
- $0.1315 < M\pi^0 < 0.1385$ GeV/c^2 *
- $M_{2T} < 0.350$
- -0.01 < mm0kine < 0.1
- $M3\pi < 0.460$ .or. $0.540 > M3\pi$
- $Pt^2 < 0.0001$ $(GeV/c)^2$
- $0.490 < M\pi^0\mu\mu < 0.506$ GeV/c^2

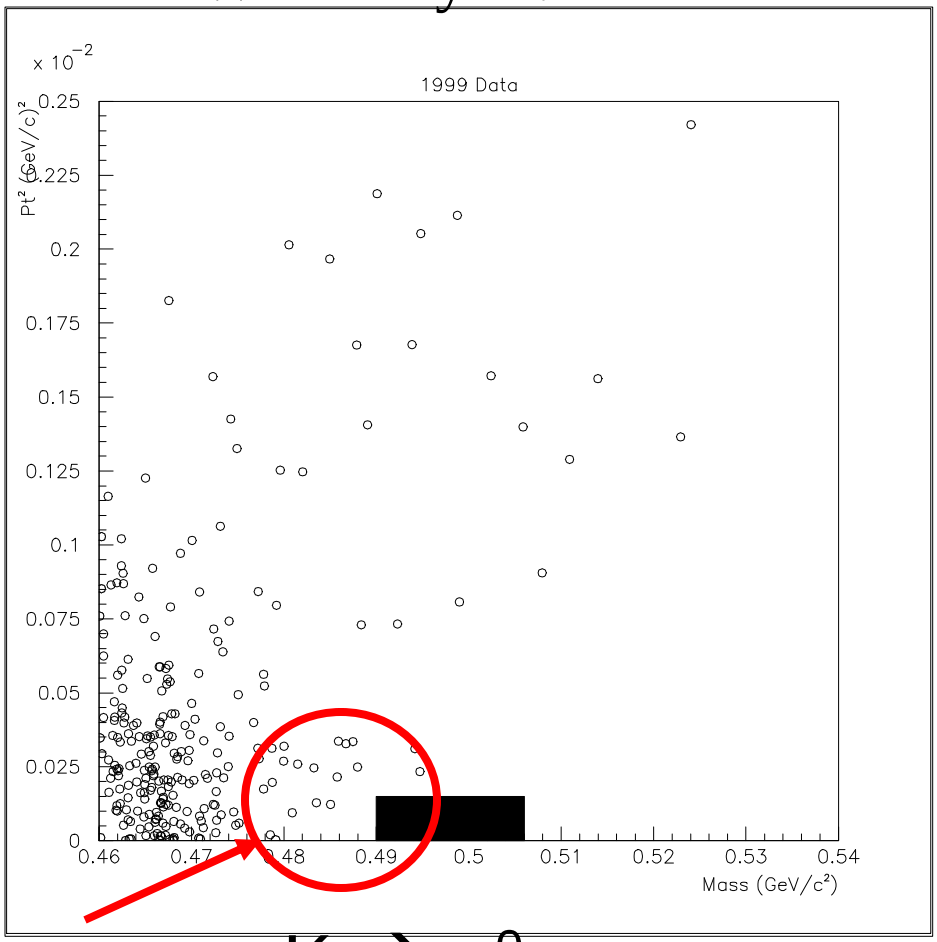
Normalization Cuts ($K_L \rightarrow \mu\mu\gamma$)

- Trigger 6
- Exactly 1 HCC cluster (no trk)
- $E\gamma > 8.0$ GeV
- $Pt^2 < 0.0001$ $(GeV/c)^2$
- $0.490 < M\pi^0\mu\mu < 0.506$ GeV/c^2

1999 Data: $K_L \rightarrow \pi^0\mu\mu$

- 1999 data
  - Signal acceptance = 3%
    - 1997 acceptance = 5%
  - Background level is higher near the box than in 1997
    - More background close to box due to lowered B-field and higher accidental rates
    - Cut on $K_L \rightarrow \pi^+\pi^-\pi^0$ inv mass to reduce backgrounds
- Largest background expected comes from $K_L \rightarrow \mu^+\mu^-\gamma\gamma$
  - Dangerous background that peaks at kaon mass

JAWS Analysis: 1999 Data



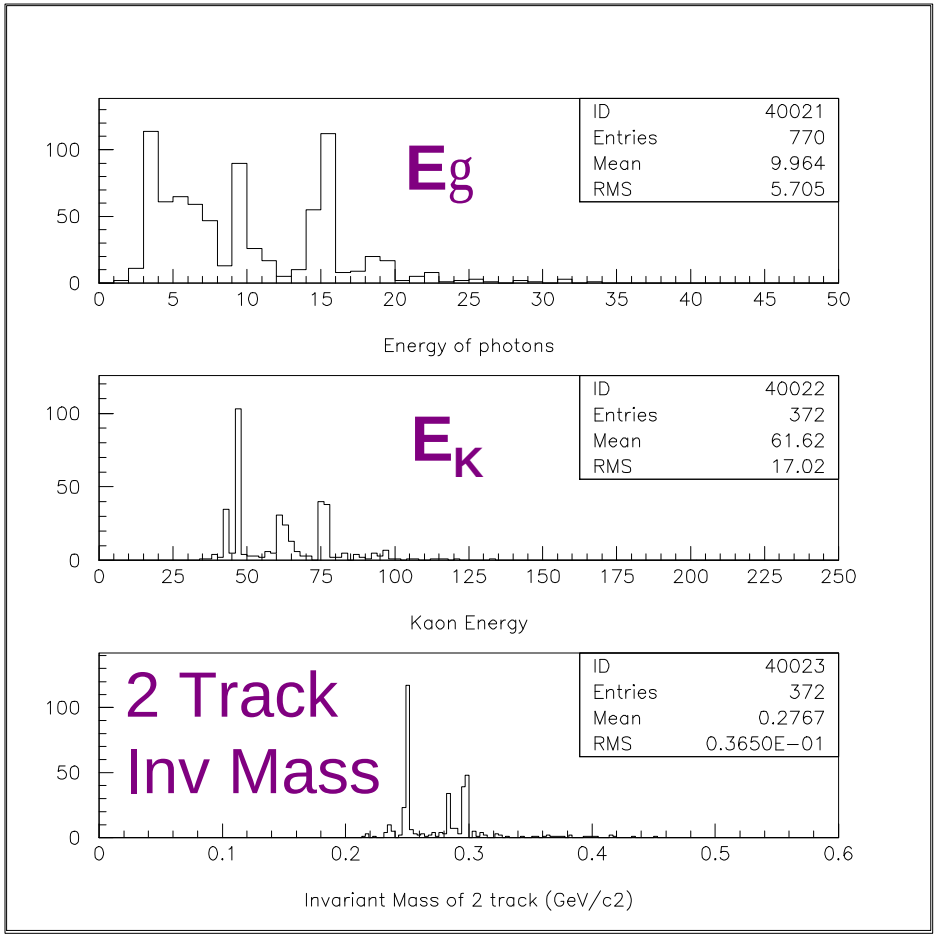
$K_L \rightarrow \pi^0\mu\mu$

Higher background levels near Box compared with 1997

Background Estimate

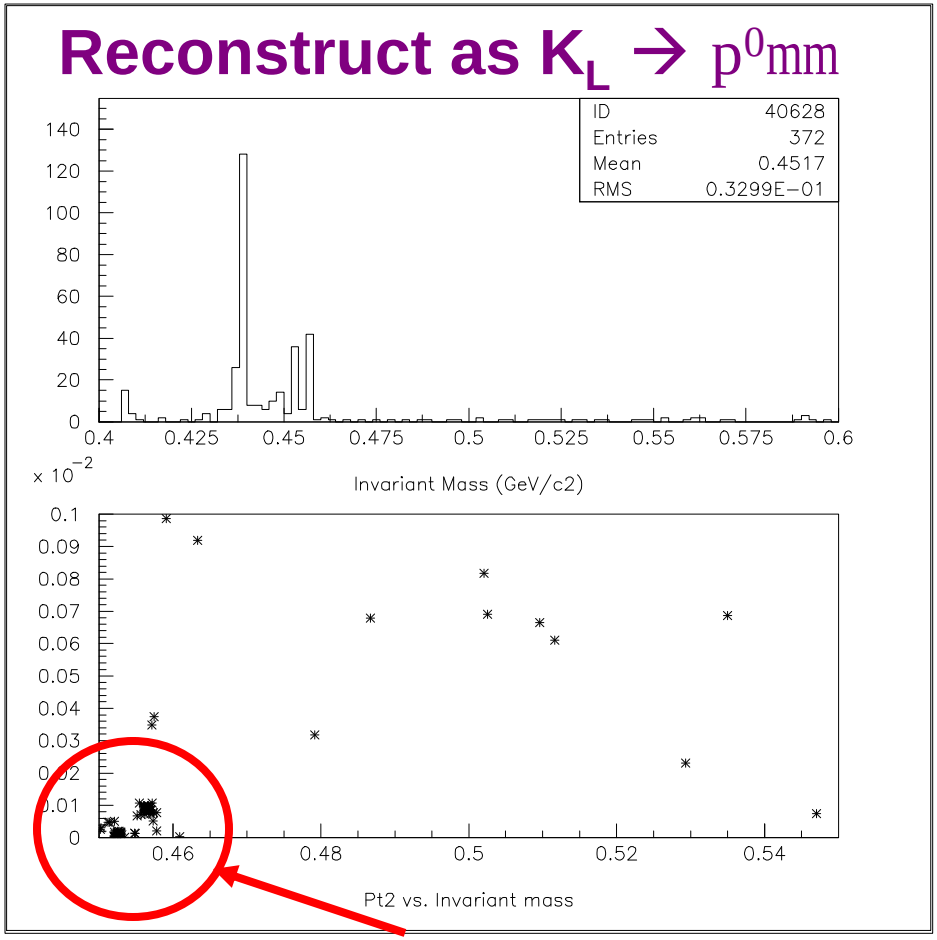
- $K_L \rightarrow \pi^+\pi^-\pi^0$
  - Estimate from "No Select" MC (Do not force pion decay or punch)
  - Estimate from Data
    - Use high pt2 region in pt2 v. inv mass plot
      - combined $K_L \rightarrow \pi\mu\nu$ and $K_L \rightarrow \pi^+\pi^-\pi^0$
- $K_L \rightarrow \pi\mu\nu$
  - Estimate with "No Select" MC and PHOTOS MC
    - Problem – Spikes in distributions from reused accidentals
    - "No Sel" MC – 56% 1999 data set + PHOTOS 11% 1999 data set
  - Estimate from Data
    - Use Sidebands of Zneut – Zcharged (ΔZ) distribution (combined $K_L \rightarrow \pi\mu\nu$ and $K_L \rightarrow \mu\mu\gamma\gamma$)
- $K_L \rightarrow \mu\mu\gamma\gamma$
  - Estimate with MC and with Data (ΔZ sideband)

Spikes in Standard $K_L \rightarrow \pi\mu\nu$ MC



Inv Mass

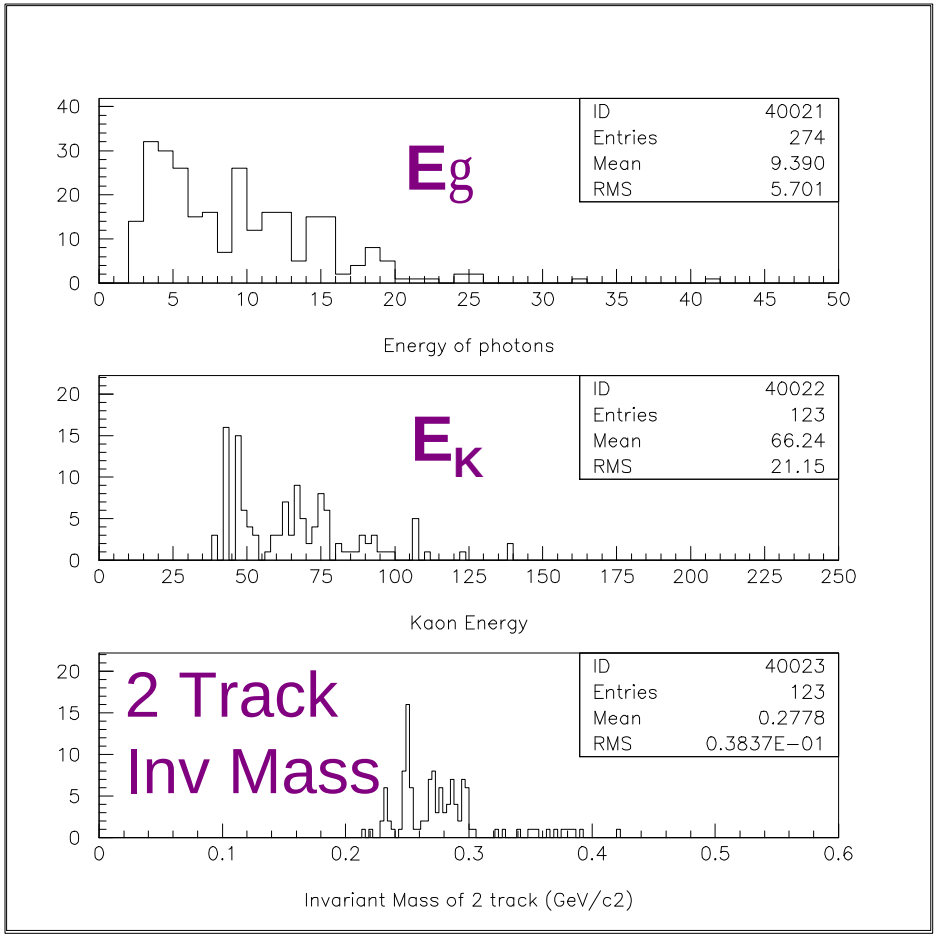
Reconstruct as $K_L \rightarrow p^0 mm$



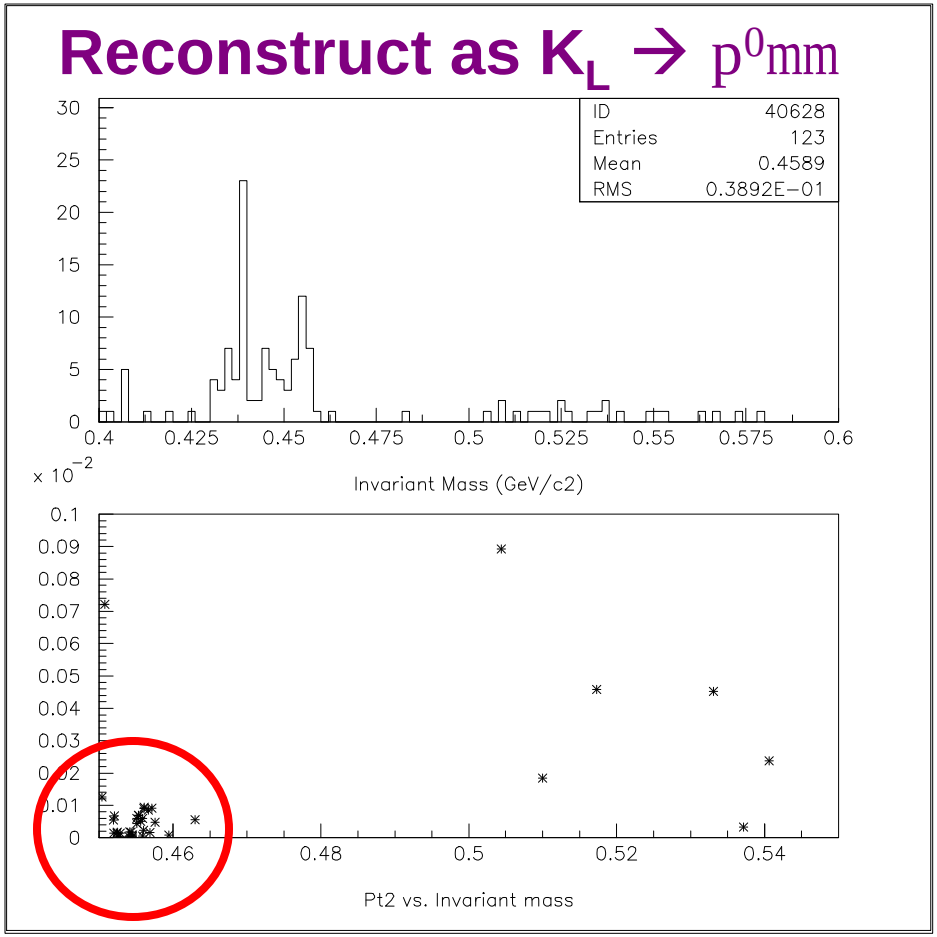
Spikes in Inv Mass Plot

$K_L \rightarrow \pi\mu\nu$ PHOTOS

Use PHOTOS and all 799 accidentals



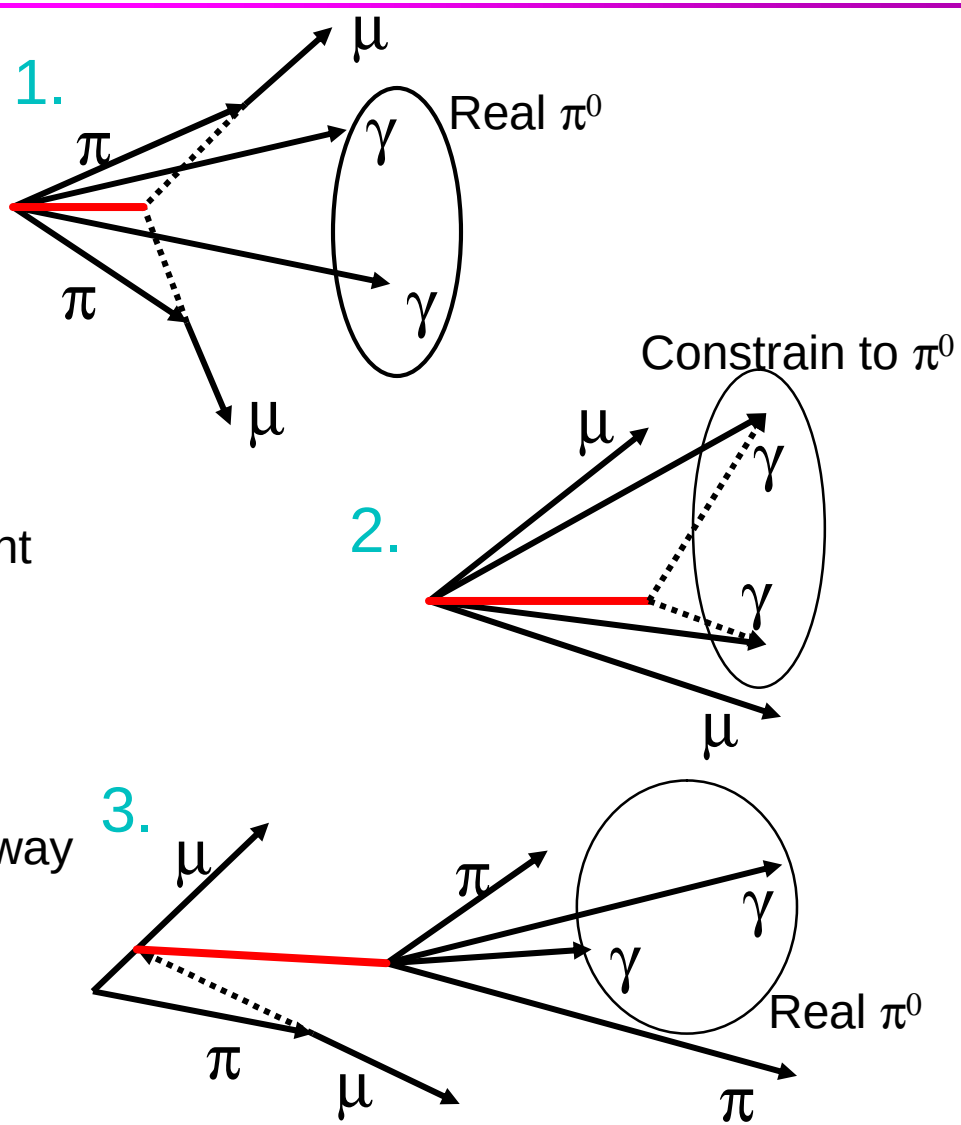
Inv Mass



Spikes Reduced but still there at some level

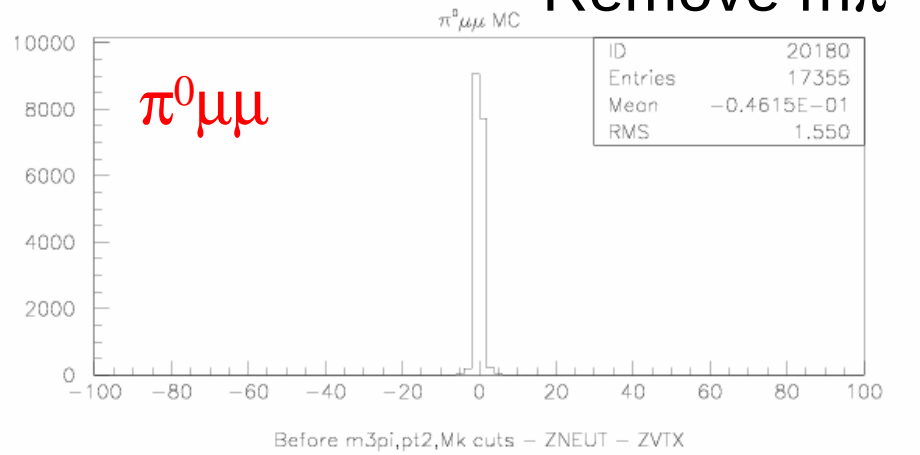
Background Estimate from Data

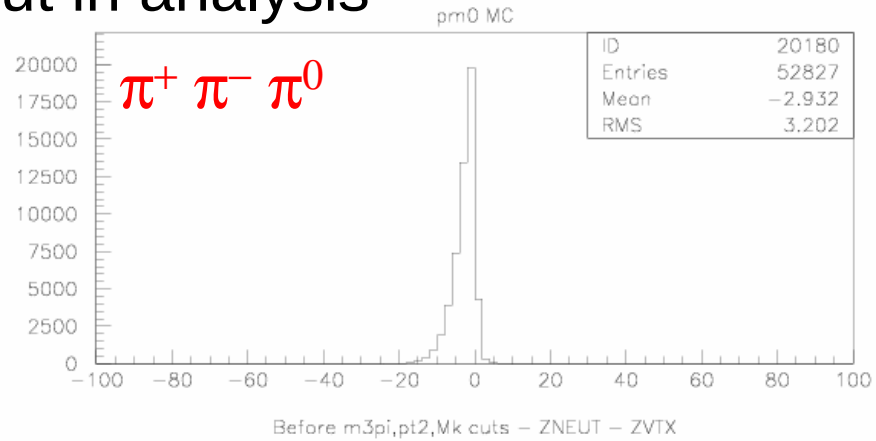
- Possible problem estimating backgrounds due to re-used accidentals in kmu3 MC
  - Signal: $K_L \rightarrow \pi^0 \mu\mu$
  - Backgrounds: kmu3,k3pi,$\mu\mu\gamma\gamma$
- Use (zneut – zchg) distribution in data to estimate background
  1. Charged vertex from decay in flight pion (muon accidental) charged vertex can reconstruct away from neutral vertex (if real π^0)
  2. Neutral vertex from 2 photons not coming from π^0 can reconstruct away from charged vertex
  3. Charged and neutral vertices can come from different kaon decays

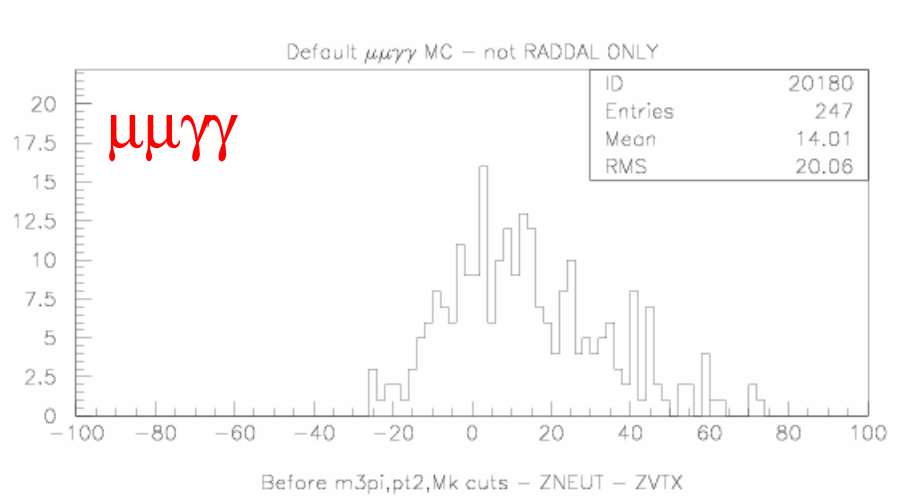


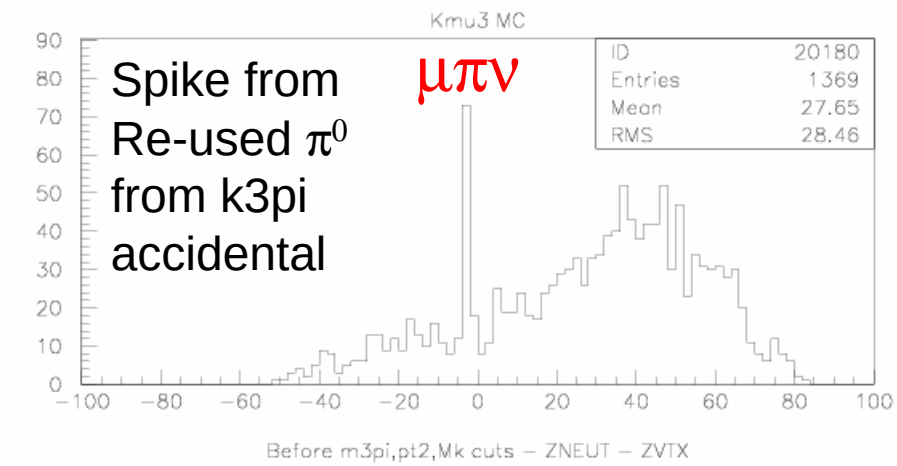
MC zneut-zchg: Before final cuts

Remove $m\pi^0$ cut in analysis



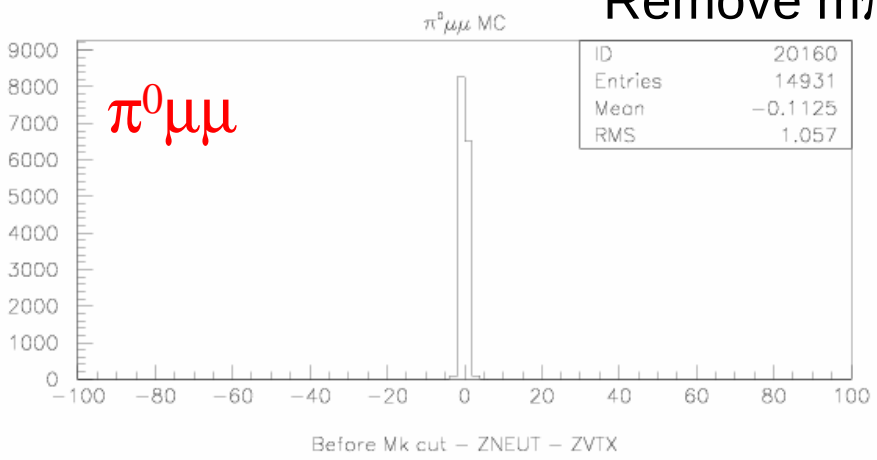


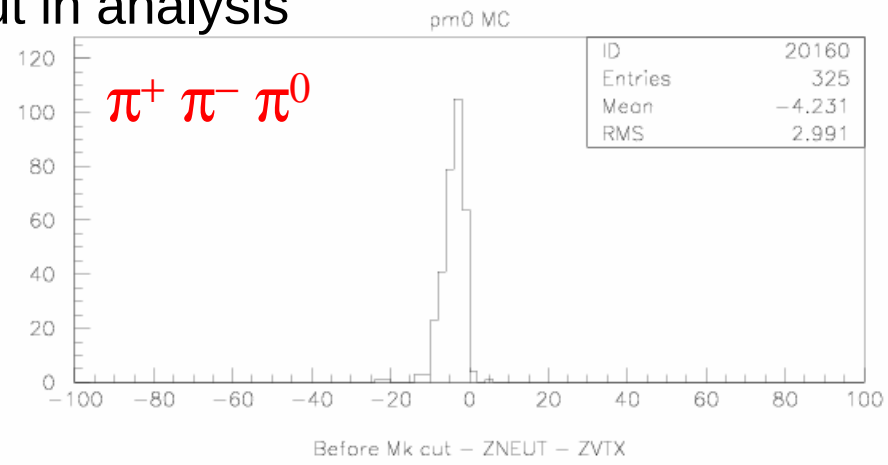


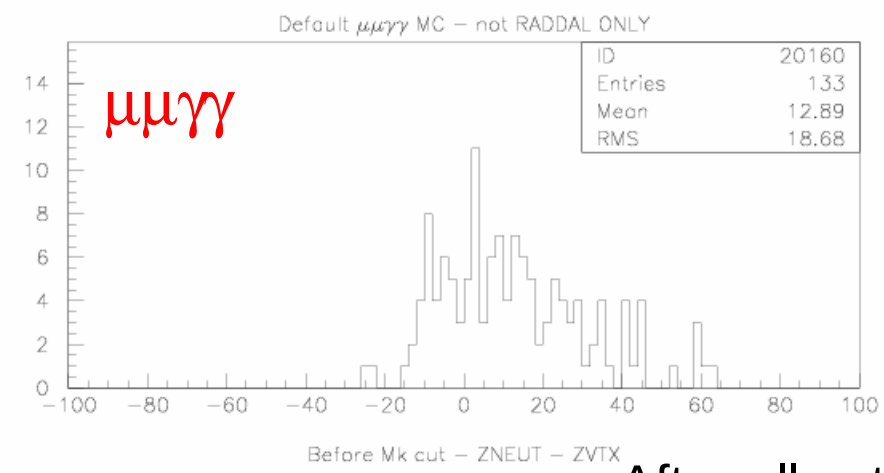


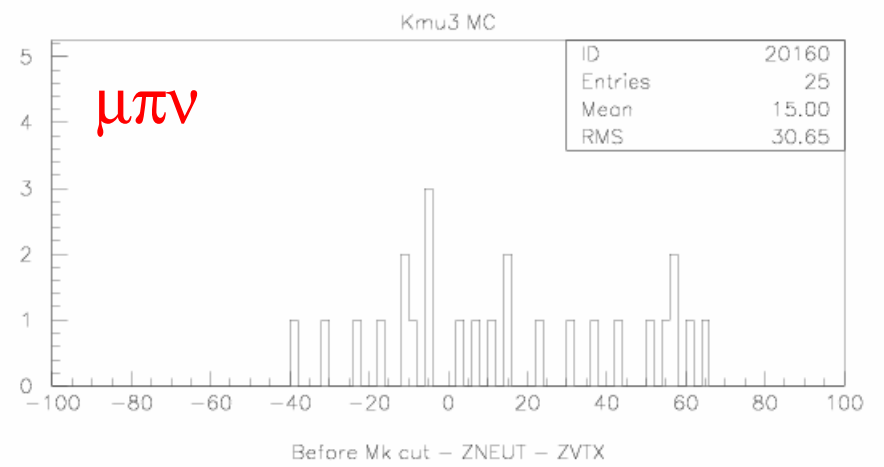
MC zneut-zchg: After all cuts

Remove $m\pi^0$ cut in analysis







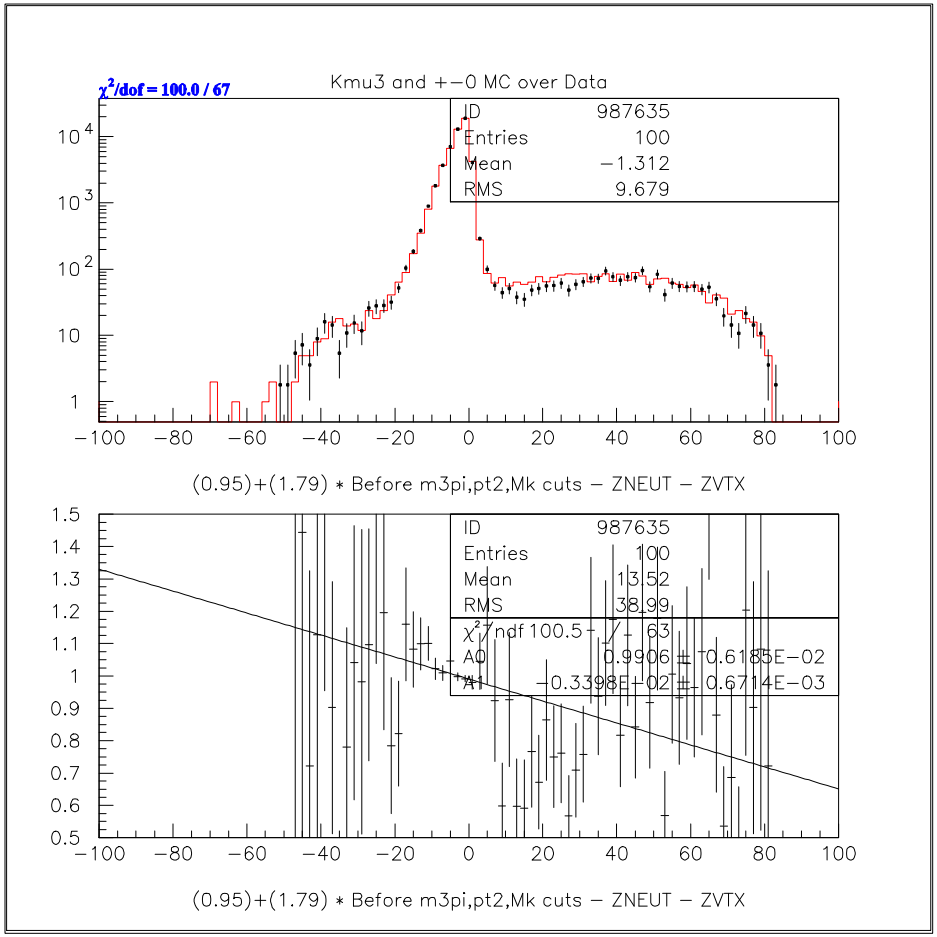


After all cuts except M_K cut

Data/MC Overlay: zneut - zchg

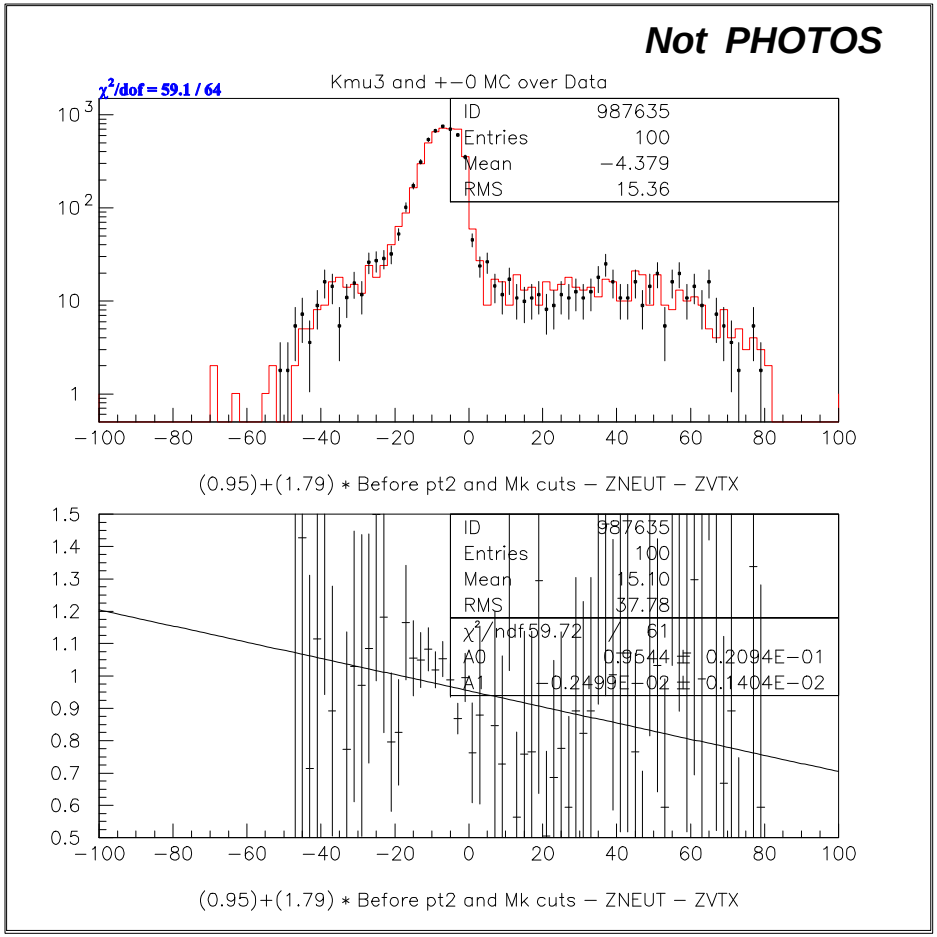
Remove $m\pi^0$ cut in analysis

MC Norm: from inv mass dist



After all cuts except M_{3pi}, pt^2, M_K cut

Not PHOTOS

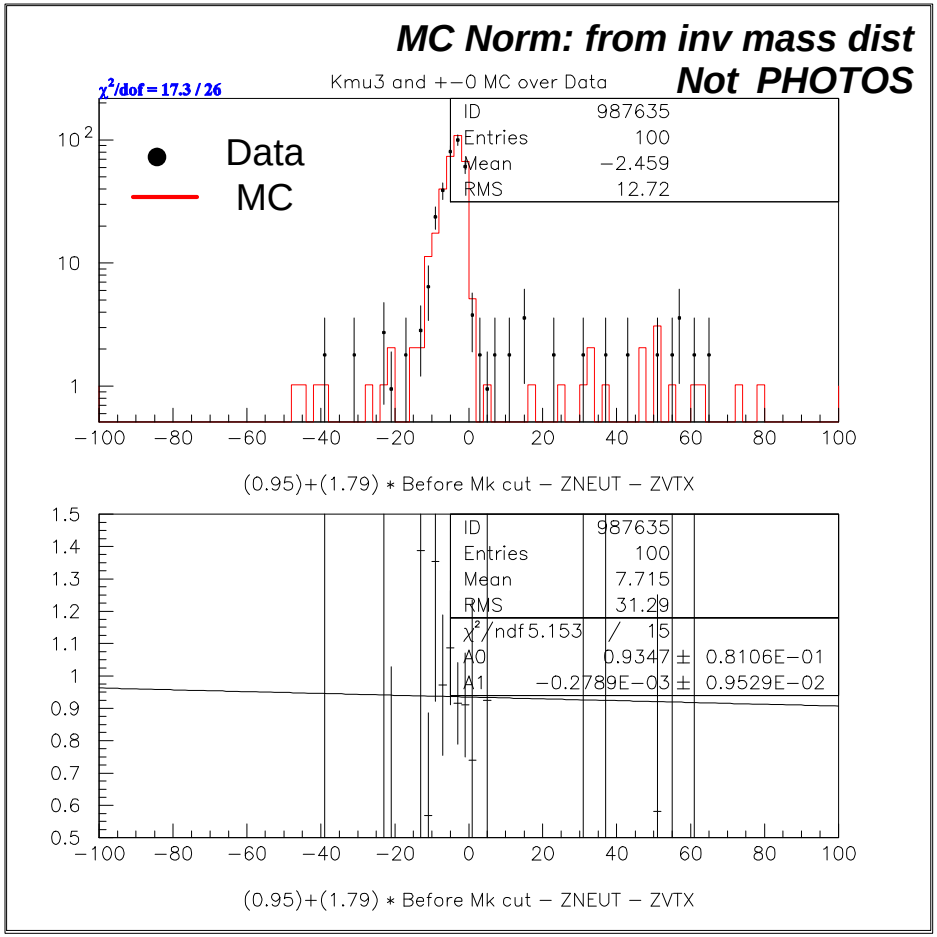


After all cuts except pt^2, M_K cut

Data Est. $K_L \rightarrow \mu\mu\gamma\gamma$ and $K_L \rightarrow \pi^+\pi^-\pi^0$

- Zdiff distribution is well modeled
- Estimate background under peak
  - Estimate background
    - Cut at -2m<zdiff<+2m (+/-2σ signal region)
    - Fit background in asymmetric region (z>10m, z<-20m)
    - Integrate in signal region
    - Data estimate from sidebands for $K_L \rightarrow \mu\mu\gamma\gamma$ + $K_L \rightarrow \pi\mu\nu$ backgrounds are 1.09 ± 0.30 evts

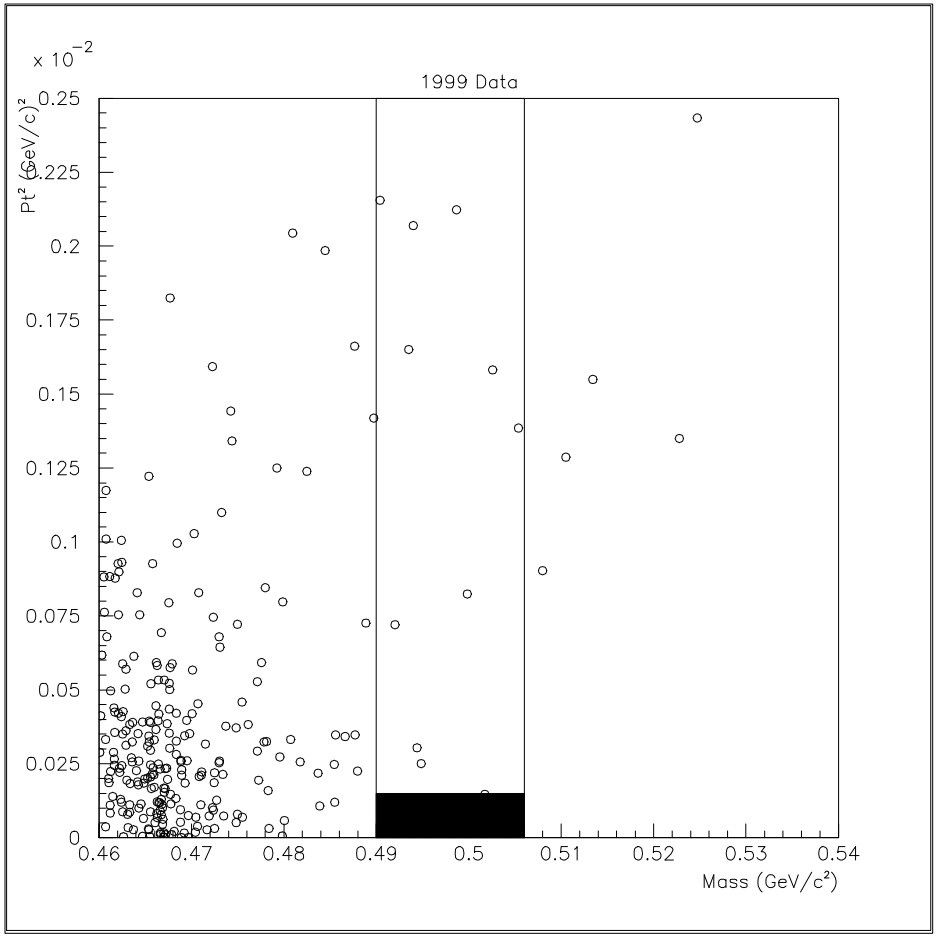
Remove $m\pi^0$ cut in analysis



After all cuts except M_K cut

Data Est. $K_L \rightarrow \pi\mu\nu$ and $K_L \rightarrow \pi^+\pi^-\pi^0$

- Estimate from data the background from $K_L \rightarrow \pi\mu\nu$ and $K_L \rightarrow \pi^+\pi^-\pi^0$ using the pt2 v. inv mass distribution
  - 12 events * 0.015/0.25 = 0.72 evts



Background Contributions - MC

Decay Mode	1997 Analysis (Acc = 5%)	Scaled to 1999 (1.33x1997)	1999 est. from MC
$K_L \rightarrow \pi\pi\pi$	0.266 ± 0.096	0.354 ± 0.128	0.16 ± 0.08
$K_L \rightarrow \pi\mu\nu$	0.225 ± 0.100	0.299 ± 0.133	0.18 ± 0.09
$K_L \rightarrow \mu\mu\gamma\gamma$	0.373 ± 0.032	0.497 ± 0.043	0.14 ± 0.06
Total	0.86 ± 0.14	1.15 ± 0.19	0.48 ± 0.13

Background Contributions MC&Data

Decay Mode	1997 MC Scaled to 1999	Est from 1999 MC	Est. from 1999 Data
$K_L \rightarrow \pi\pi\pi + K_L \rightarrow \pi\mu\nu$	0.653 ± 0.185	0.34 ± 0.12	0.72 ± 0.21
$K_L \rightarrow \mu\mu\gamma\gamma + K_L \rightarrow \pi\mu\nu$	0.796 ± 0.140	0.32 ± 0.11	1.09 ± 0.30
$K_L \rightarrow \mu\mu\gamma\gamma$ (MC) + $K_L \rightarrow \pi\pi\pi$ (Data) + $K_L \rightarrow \pi\mu\nu$ (Data) Pt2 v. Inv Mass - high pt2			0.86 ± 0.22
$K_L \rightarrow \pi\pi\pi$ (MC) + $K_L \rightarrow \mu\mu\gamma\gamma$ (Data) + $K_L \rightarrow \pi\mu\nu$ (Data) ΔZ = Zneut - Zcharged			1.25 ± 0.31
Total	1.15 ± 0.19	0.48 ± 0.13	1.06 ± 0.19 (ave)

Issues

- Why is the 1999 acceptance (3%) much lower than the 1997 acceptance (5%) when the cuts are basically the same? Can I increase the acceptance?
- Why is the 1997 background estimate for $K_L \rightarrow \mu\mu\gamma\gamma$ MC so different from 1999 estimate (1999: not dominant background)
  - Ran on 1997 MC: Background estimate in the box is 0.16 ± 0.06 compared to 1999 estimate of 0.14 ± 0.06 and rescaled 1997 estimate of 0.497 ± 0.043.
    - One possibility is an acceptance difference
    - Could be a difference in the MC that I am running compared with 1997
- Why are1999 $K_L \rightarrow 3\pi$ and $K_L \rightarrow \pi\mu\nu$ MC background estimates lower than 1997? I expected the "no-sel" MC to yield a higher background since 1997 analysis ignored acc muons.
  - Generate $K_L \rightarrow \pi\mu\nu$ with forced pion decays as cross-check