Status of $K_L \rightarrow \pi^0\mu\mu$ and $K_L \rightarrow \mu\mu\gamma\gamma$

- Outline
  - Analysis
  - Issues from last meeting
  - Results
  - Plans

1999 $K_L \rightarrow \pi^0\mu\mu / K_L \rightarrow \mu\mu\gamma\gamma$ Analysis

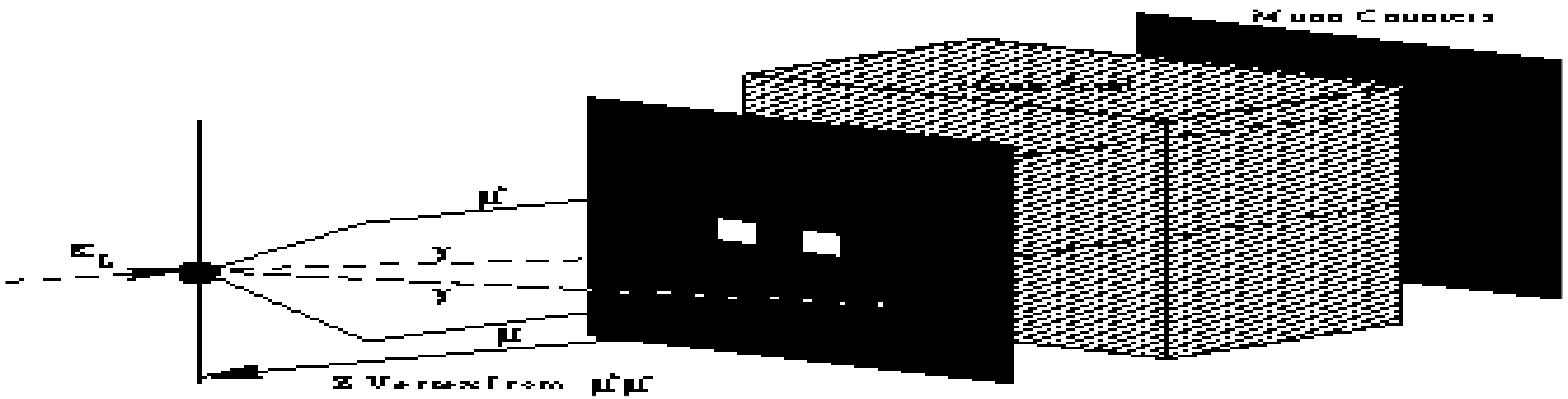
- Search for $K_L \rightarrow \pi^0\mu\mu$ but normalize to $K_L \rightarrow \mu\mu\gamma$ instead of $K_L \rightarrow \pi^+\pi^-\pi^0$ (now that $K_L \rightarrow \mu\mu\gamma$ analysis is completed)
  - Advantage: Modes are extremely similar
    - Published 1997 analysis (normalized to $K_L \rightarrow \pi^+\pi^-\pi^0$)
      - Largest uncertainty was due to energy measurement (3.30%) and particle ID (4.20%)
      - Largest bkgrnd: $\mu\mu\gamma\gamma$ (~50%), $\pi^+\pi^-\pi^0$ DD (~25%), $K\mu3+2\gamma$acc (17%)
    - For new analysis: Loosen cuts? PTRK, Photon energy cut, etc.
    - 1999 Trigger 6 prescale – 1/5 at Level 1, 1/2 at Level 3
      - Expect ~1000 events if flux is same as 1997

Prospect for 1999 $K_L \rightarrow \pi^0\mu\mu$ Limit

- Current limit based on 1997 published result
  - SES = 1 / (kaon flux x $A(K_L \rightarrow \pi^0\mu\mu)$) = 1 / (2.68E11 x 0.05)=7.46E-11
  - Assuming no events → Upper limit ~ SES * 2.31 = 1.73E-10 (90%CL)
  - Poisson probability for background 0.87±0.15 → Need 5 events for discovery
    - Observed 2 events → Upper limit ~ 5.47 * SES = 3.8E-10 (90% CL)

- Estimate of Combined Limit: 1997 + 1999 (If you assume double 1997 kaon flux + 1997 pub acceptance)
  - SES = 3.73E-11
  - Upper Limit ~ SES * 2.31 = 8.62E-11 (90% CL) (Assuming no events!)

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



- Analysis
  - Event Selection: 2 γ reconstructing as a π^0; 2 tracks which MIP in the calorimeter, 2 ID muons
  - Backgrounds from π punch-through and π decay-in-flight from $\pi^+\pi^-\pi^0$ and $K_L \rightarrow \pi\mu\nu$ (+ $2\gamma_{ACC}$);

    $K_L \rightarrow \mu\mu\gamma\gamma$ (0.373 $\pm$ 0.048 evts in 1997 published analysis)
    - Suppress with kinematic cuts on $M(\gamma\gamma)$ and $M(\mu\mu)$
    - Angular cuts on $|COS(\Theta_\pi)|$ and Cos $\Theta\gamma\gamma$ less effective than with $ee\gamma\gamma$
  - Normalize to $\mu\mu\gamma$ decays

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

- No extra tracks
- Ptrk > 10 GeV/c
- Etrkclus < 1 GeV
- Offmag < 1mm (x & y)
- 100 < zvtx < 158
- 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
- $Pt^2 < 0.0001$ $(GeV/c)^2$
- $0.492 < M\pi^0\mu\mu < 0.504$ GeV/c^2

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

- Trigger 6
- Exactly 1 HCC cluster (no trk)
- $E\gamma > 8.0$ GeV
- $Pt^2 < 0.0001$ $(GeV/c)^2$
- $0.492 < M\pi^0\mu\mu < 0.504$ GeV/c^2

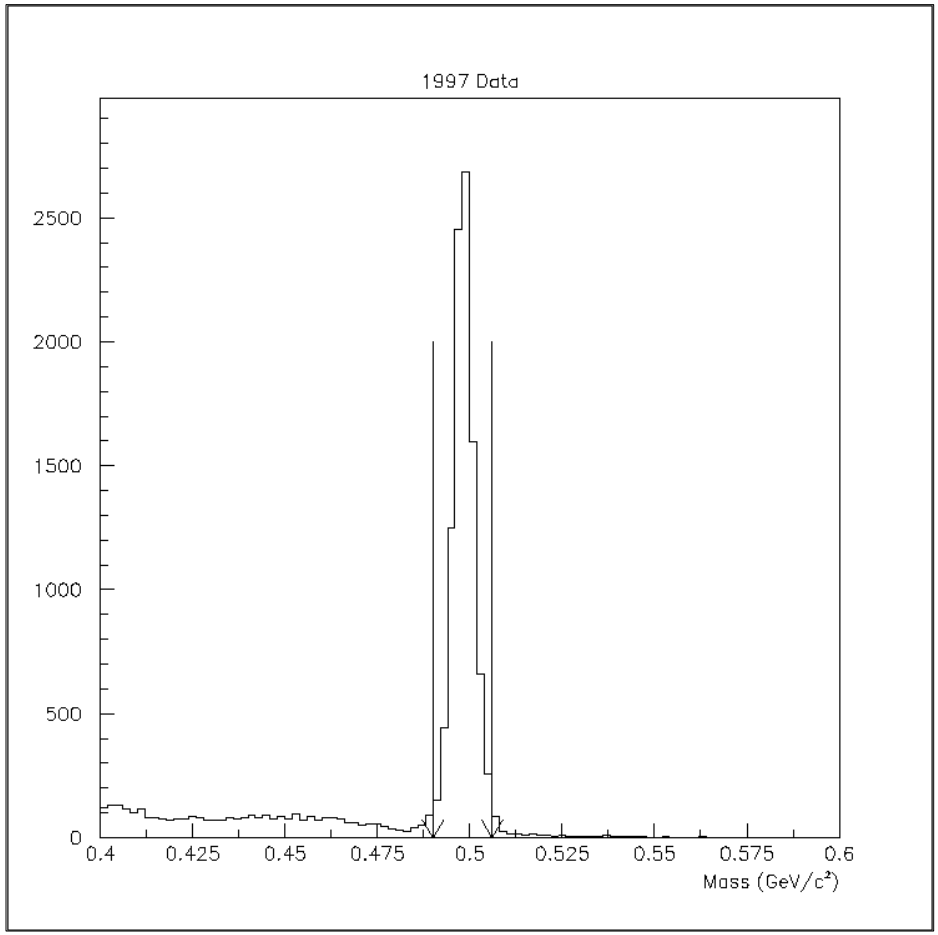
Issues

- Issues from last time….
  - 1997 $K_L \rightarrow \mu\mu\gamma\gamma$: more background than published analysis.
  - 1999 $K_L \rightarrow \mu\mu\gamma\gamma$: more background than 1997.
  - 1999 $K_L \rightarrow \pi^0\gamma\gamma$: more background close to box than 1997.

1997 Data: cross check of $K_L \rightarrow \mu\mu\gamma$

- JAWS re-analysis of 1997 data
  - Acceptance = 8.30%
  - Number of events = 9188 (not background subtracted)
  - Cuts tuned for $K_L \rightarrow \pi^0\mu\mu$ analysis
- Published 1997 result
  - Acceptance = 7.895 ± 0.018%
  - No. of events = 9327 (not background subtracted)
    - No. of events = 9105 (bkgnd sub)

JAWS re-analysis of 1997 data



1999 Data Set: $K_L \rightarrow \mu\mu\gamma$

- Normalization acceptance= 8.10%
- Number of events = 971
- What do we expect?

  1999 K_L flux = 3.6×10^{11}

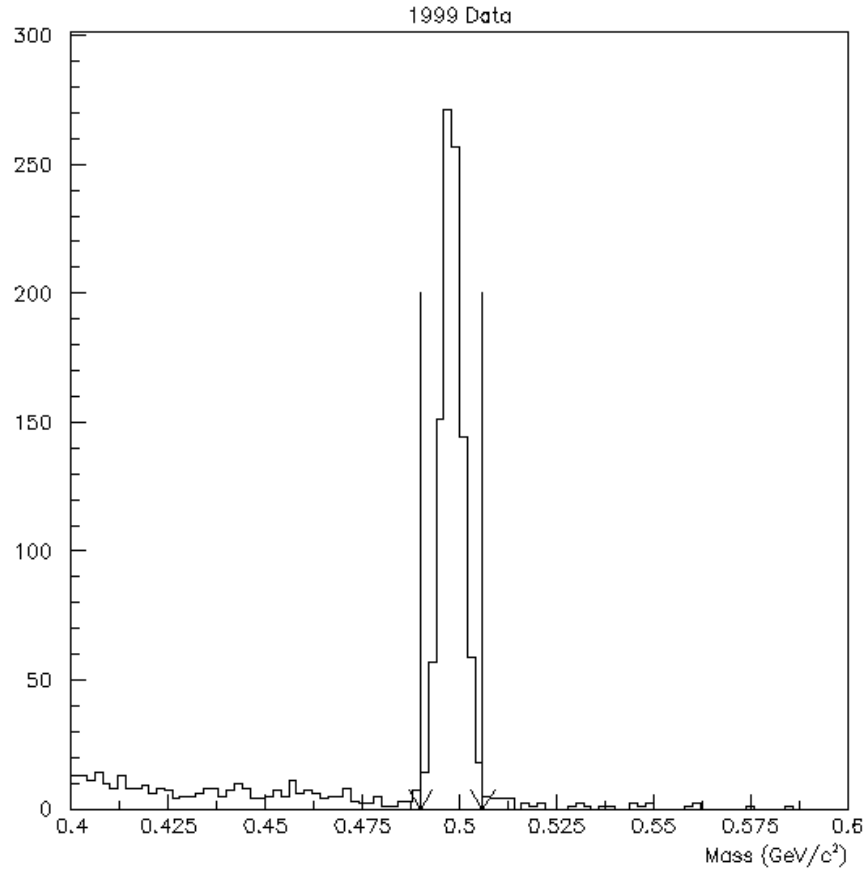
  1997 BR=$(3.62 \pm 0.04 \pm 0.08) \times 10^{-7}$

  Prescale: 5 (for some time period)

  then 10

  - Predict 1055 events + background

JAWS Analysis: 1999 Data

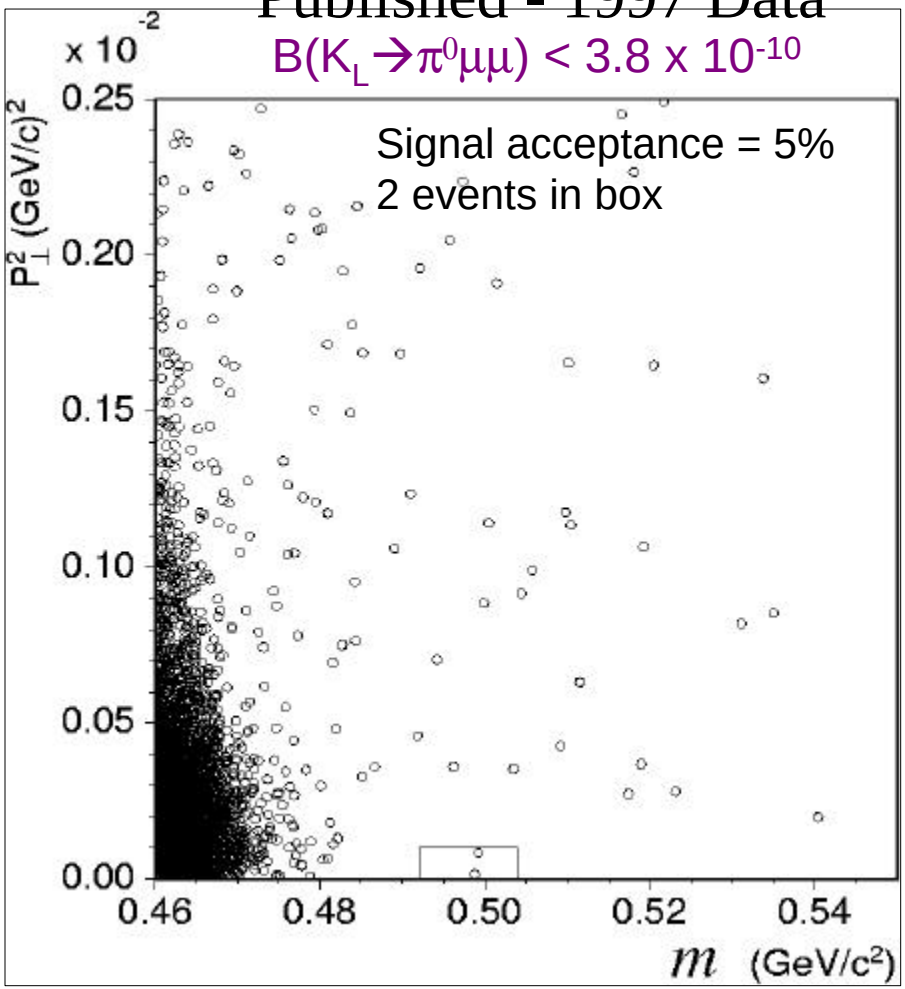


$K_L \rightarrow \mu\mu\gamma$

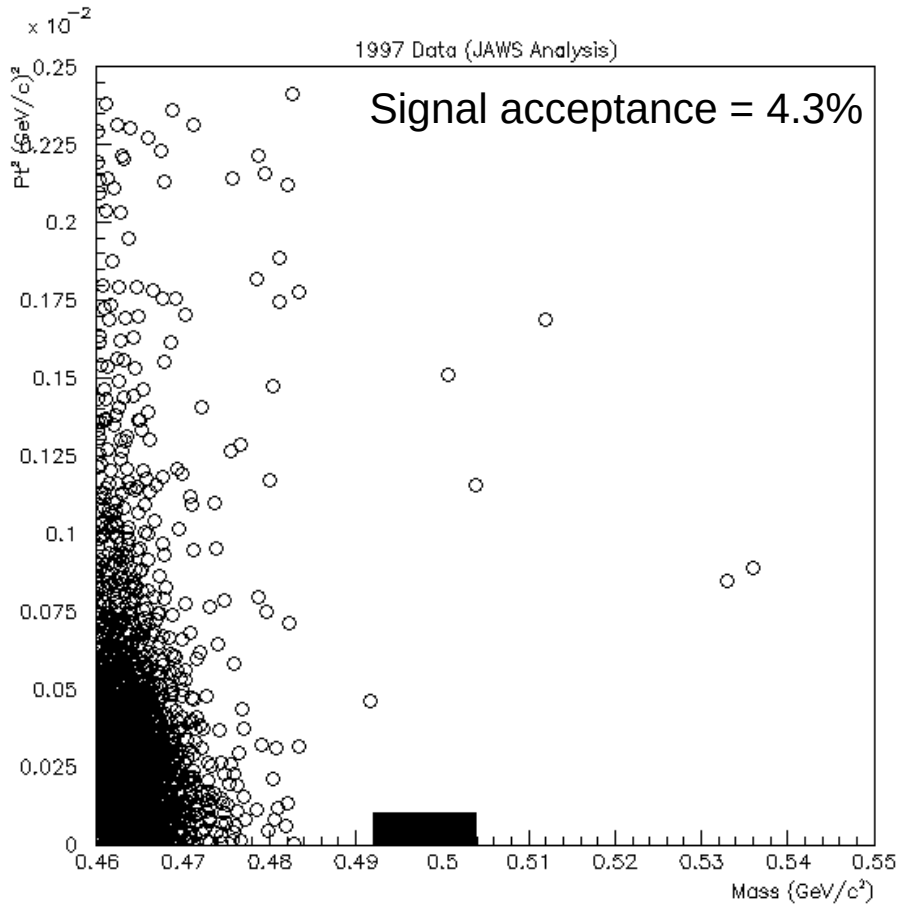
1997 Data: $K_L \rightarrow \pi^0\mu\mu$ Crosscheck

Published - 1997 Data

$B(K_L \rightarrow \pi^0\mu\mu) < 3.8 \times 10^{-10}$



JAWS Re-analysis - 1997 Data

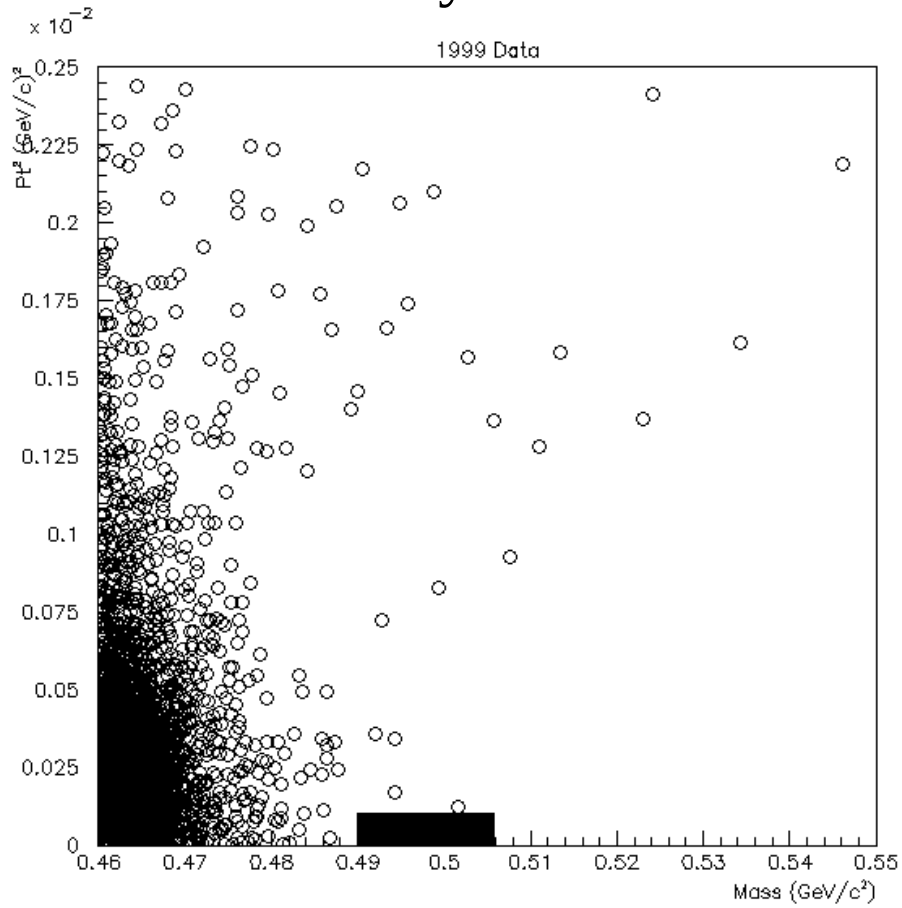


$K_L \rightarrow \pi^0\mu\mu$

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

- Apply 1997 analysis cuts to 1999 data
  - Signal acceptance = 4.5%
  - Background level is higher near the box than in either published 1997 analysis or my re-analysis
    - More background close to box due to lowered B-field
    - Low mass background is from $K_L \rightarrow \pi^+\pi^-\pi^0$
- Largest background expected comes from $K_L \rightarrow \mu^+\mu^-\gamma\gamma$
  - Dangerous background that peaks at kaon mass

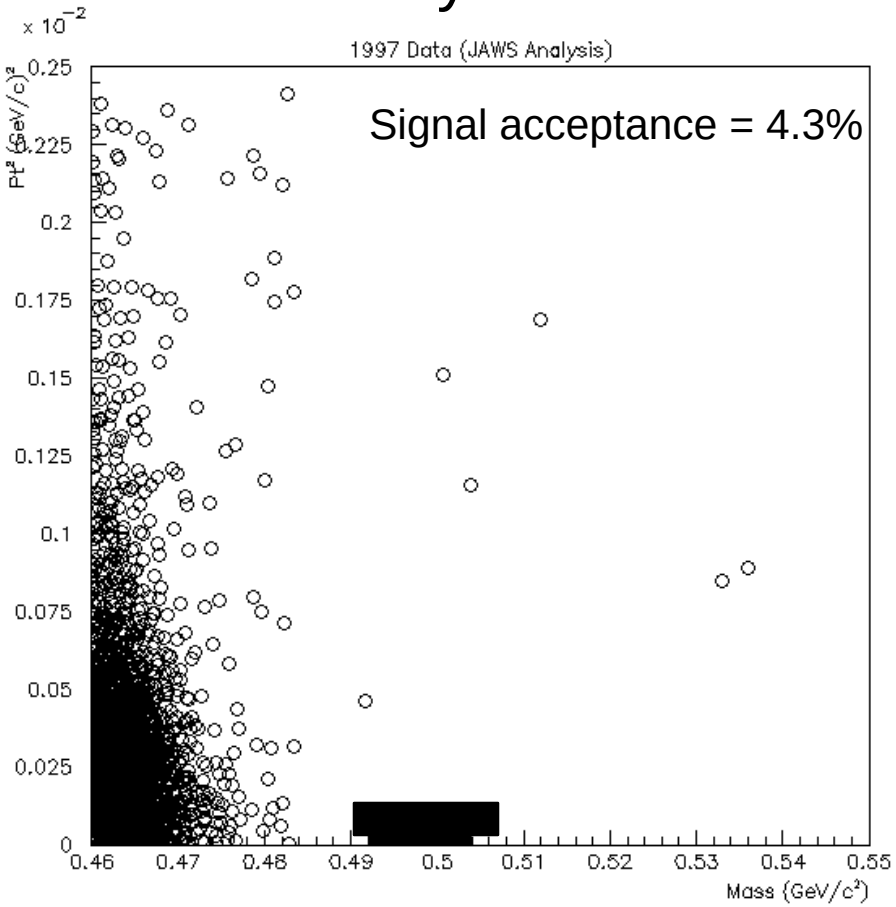
JAWS Analysis: 1999 Data



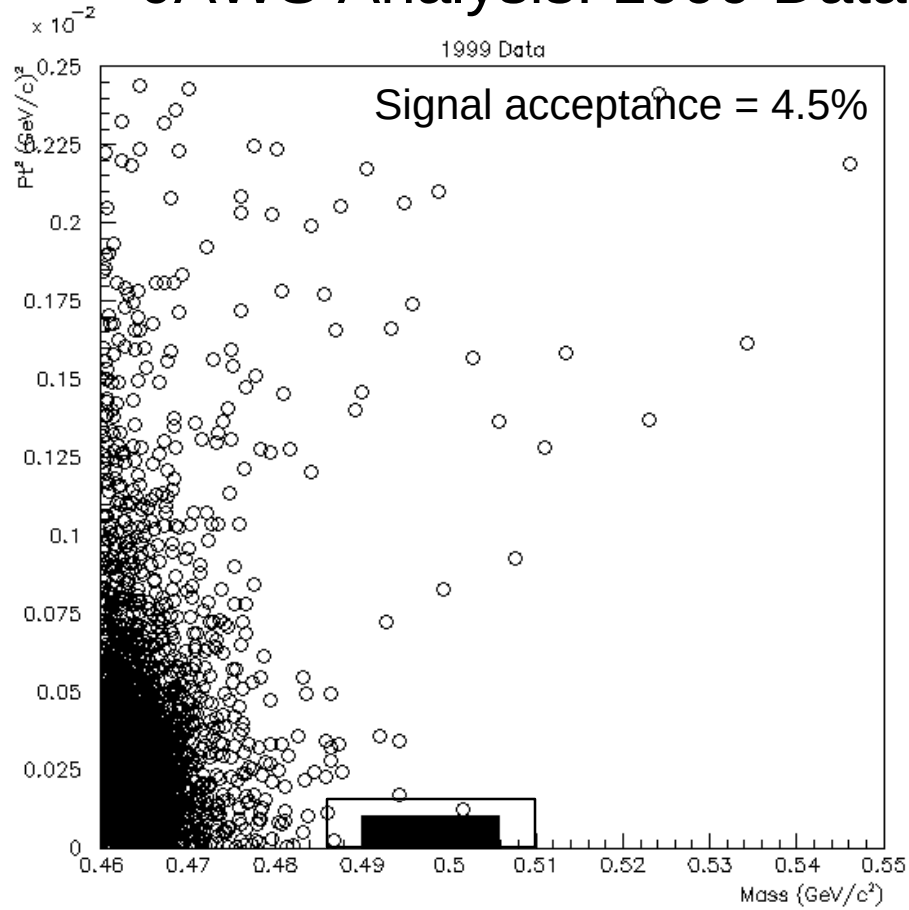
$K_L \rightarrow \pi^0\mu\mu$

$K_L \rightarrow \pi^0\mu\mu$ 1997/1999 Data Comparison

JAWS Analysis 1997 Data



JAWS Analysis: 1999 Data



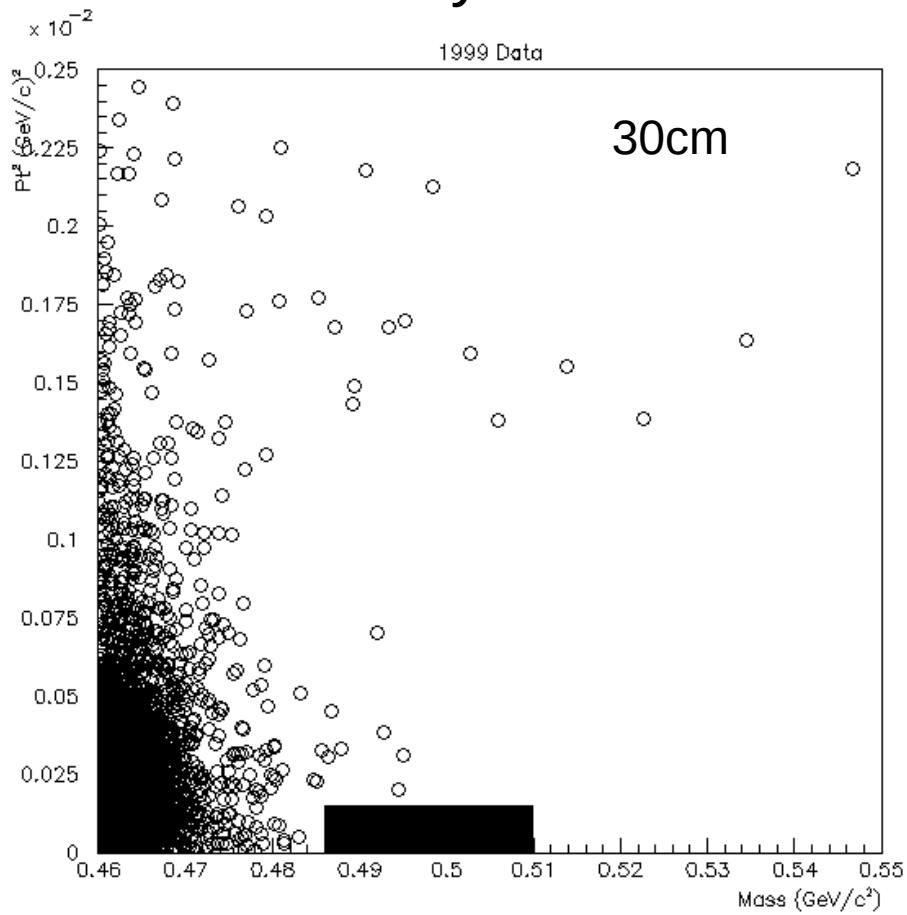
$K_L \rightarrow \pi^0\mu\mu$

Exclude events in larger box When tuning cuts

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

- Tighten cut on track matched cluster to photon distance
  - Standard cut 20cm. Tighten to 30cm.
    - Acceptance drops to 2.8%
    - 40% drop in background near box

JAWS Analysis: 1999 Data



Inceased box size during cut tuning

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

- Analysis
  - Event Selection: 2 γ which do not reconstruct as a π^0;
    2 tracks which MIP in the calorimeter, 2 ID muons
  - Backgrounds from $K_L \rightarrow \pi\mu\nu(+2\gamma_{ACC})$, $\mu\mu\gamma+\gamma_{ACC}$
    - Kinematic Cuts: $E\gamma$ (8GeV) ; Angular cuts on $COS(\Theta_{\gamma\gamma})$
    - Total Contribution (from published 1997 analysis): 0.25±0.10
  - Normalize to $K_L \rightarrow \mu\mu\gamma$

- QED Pred:$BR(K_L \rightarrow \mu^+\mu^-\gamma\gamma) = (9.1 \pm 0.78) \times 10^{-9}$
- Dangerous background for $K_L \rightarrow \pi^0\mu^+\mu^-$

Analysis Cuts for $K_L \rightarrow \mu\mu\gamma\gamma$

- No extra tracks
- 10 GeV/c < Ptrk < 100 GeV/c
- Etrkclus < 1 GeV
- Offmag < 1mm (x & y)
- 100 < zvtx < 158
- Xvtx & yvtx in beam region at CsI
- Vtxchi2 < 10
- Trk to trk cluster position < 3.5cm
- 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 ($K_L \rightarrow \mu\mu\gamma\gamma$)

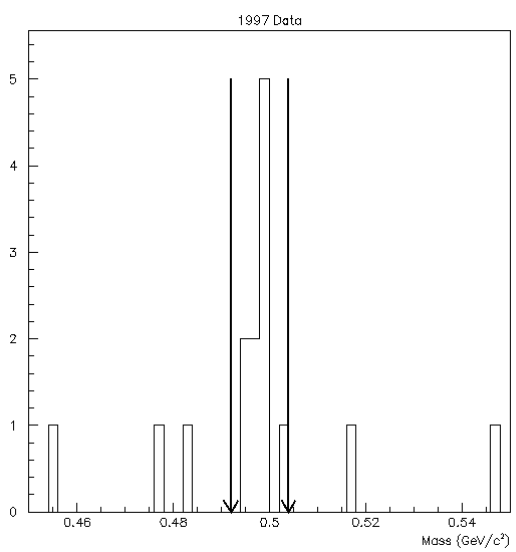
- Trigger 5
- Exactly 2 HCC clusters (no trk)
- At least 1 photon $E\gamma > 10.0$ GeV
- $M\gamma\gamma < 0.130$ GeV/c^2
- $M_{2T} < 0.340$
- -0.06 < pp0kine
- Cos $\Theta\gamma\gamma < -0.3$
- Pt2 < 0.0001 (GeV/c)^2
- $0.492 < M\mu\mu\gamma\gamma < 0.504$ GeV/c^2

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

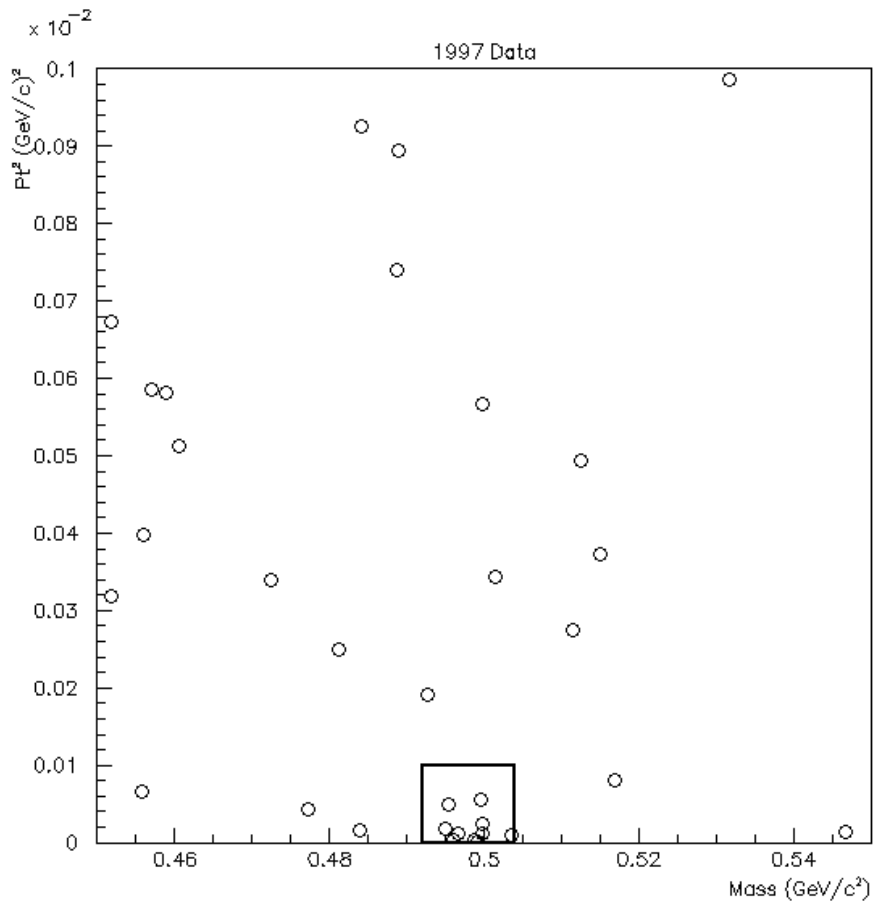
- Trigger 6
- Exactly 1 HCC cluster (no trk)
- $E\gamma > 8.0$ GeV
- Pt2 < 0.0001 (GeV/c)^2
- $0.492 < M\mu\mu\gamma\gamma < 0.504$ GeV/c^2

1997 Data: $K_L \rightarrow \mu\mu\gamma\gamma$ Crosscheck

- 10 events in the box
  - The 4 events from the 1997 published result + 6 extra
- A bit more background than published 1997 analysis, but better signal/background



JAWS Re-analysis of 1997 Data



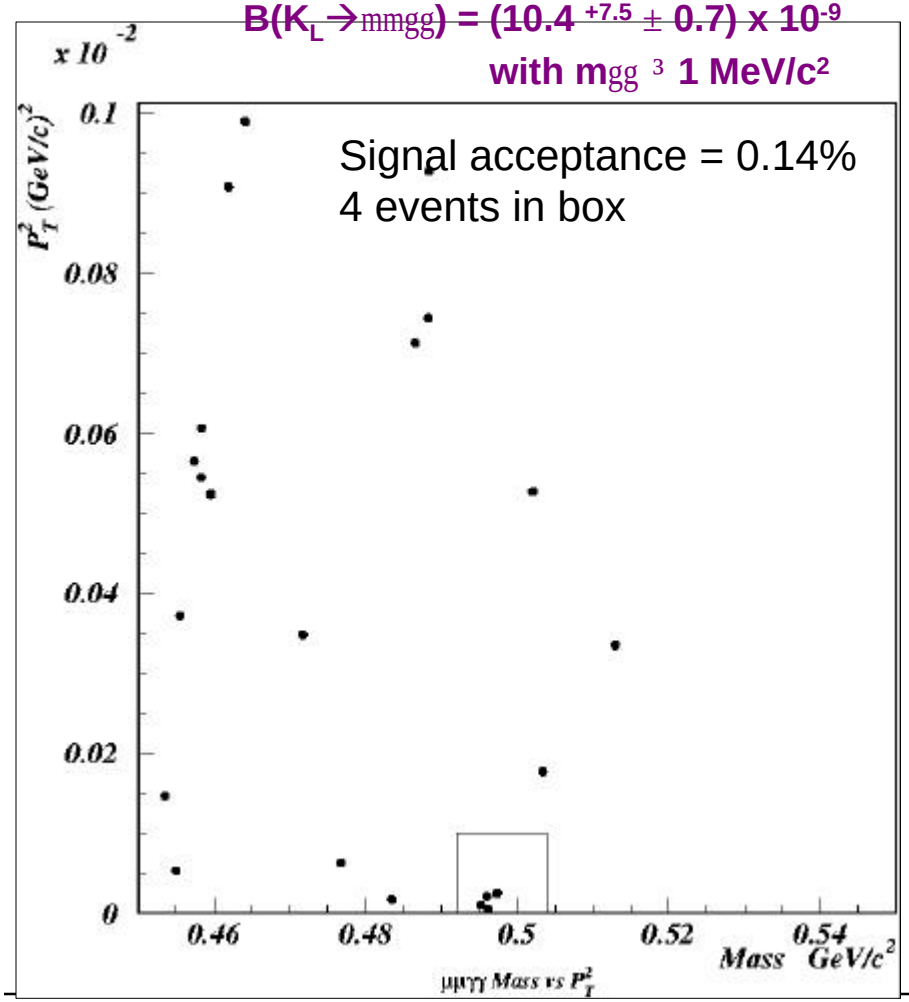
$K_L \rightarrow \mu\mu\gamma\gamma$

$K_L \rightarrow \mu\mu\gamma\gamma$: 1997 Crosscheck

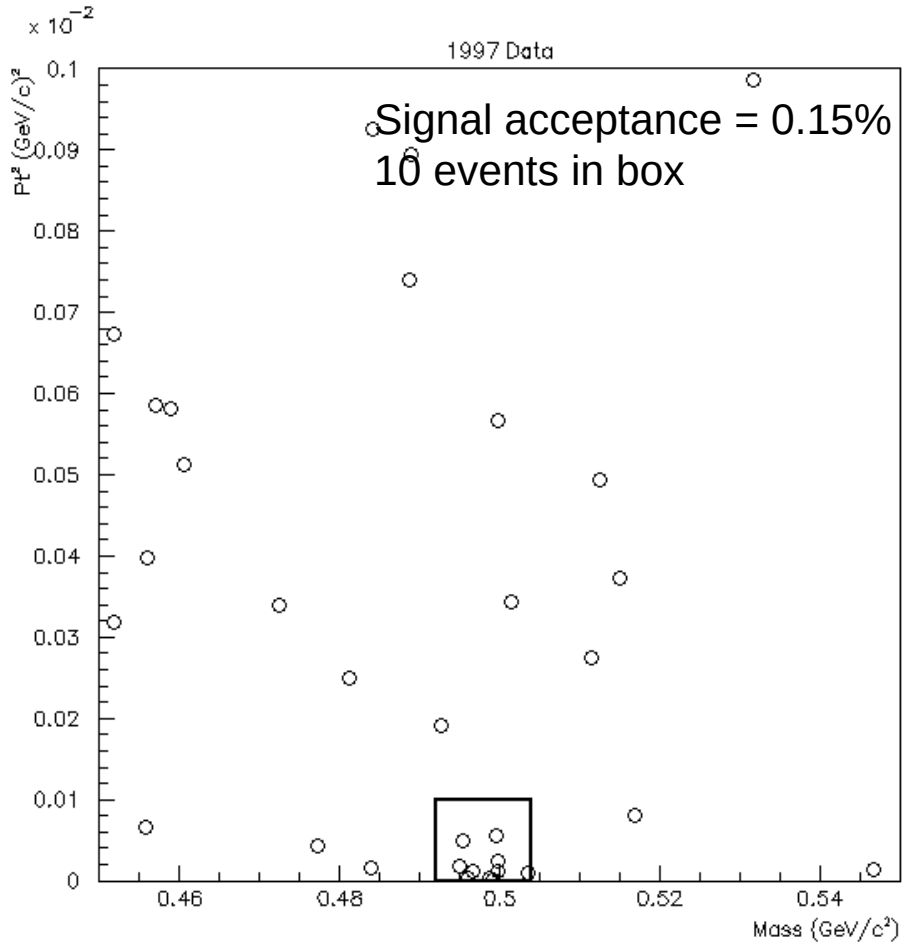
Published - 1997 Data

$B(K_L \rightarrow \mu\mu\gamma\gamma) = (10.4^{+7.5} \pm 0.7) \times 10^{-9}$

with $m_{\gamma\gamma} > 1$ MeV/c²



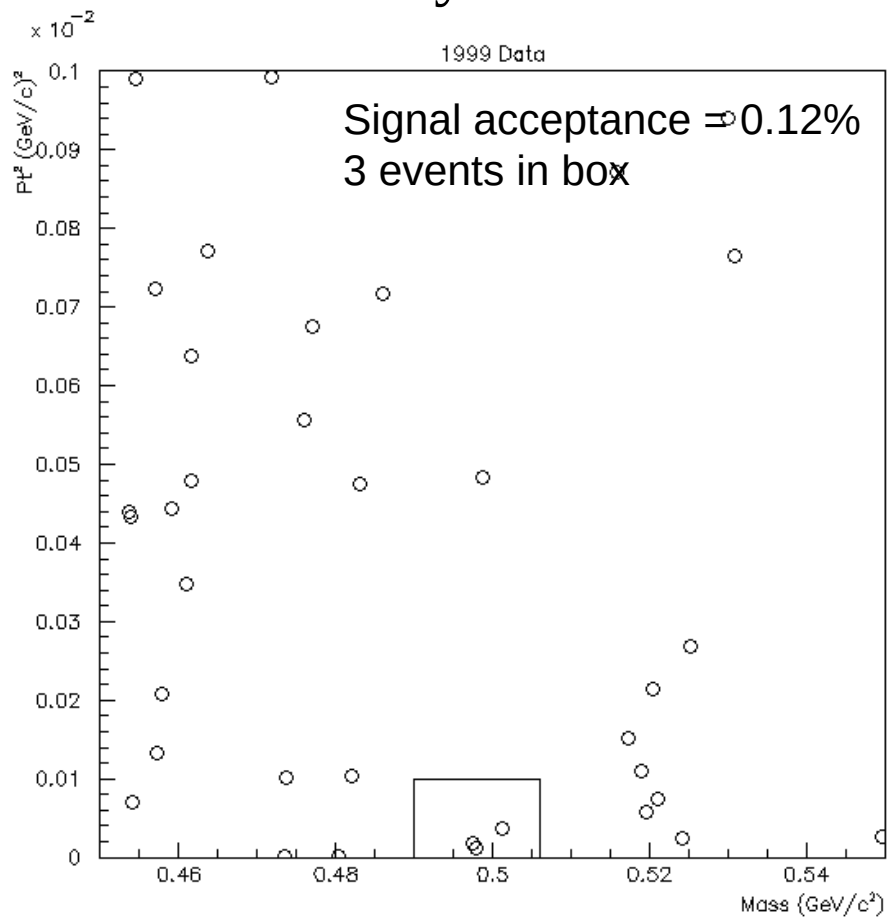
JAWS Analysis: 1997 Data



1999 Data: $K_L \rightarrow \mu\mu\gamma\gamma$

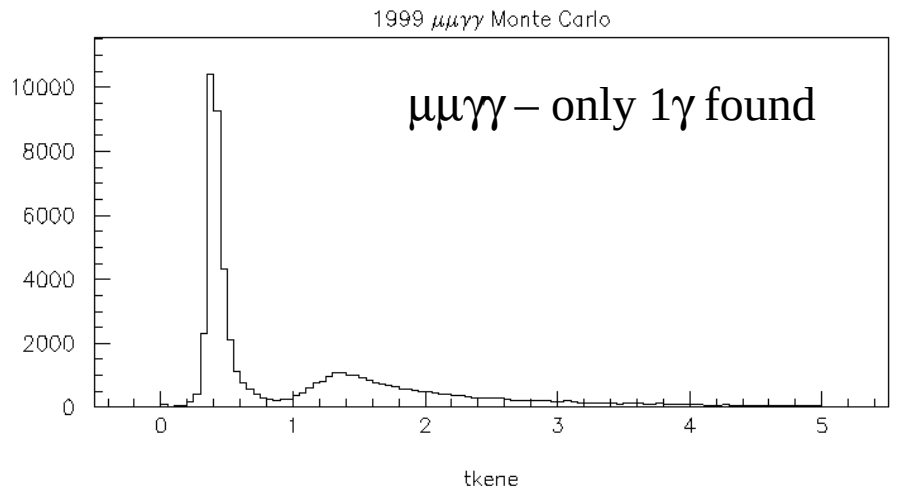
- Using cuts from 1997 published analysis
  - 1999 Signal Acceptance = 0.12%
    - (JAWS 1997 re-analysis – 0.15%)
  - 3 events in box
    - More high mass background

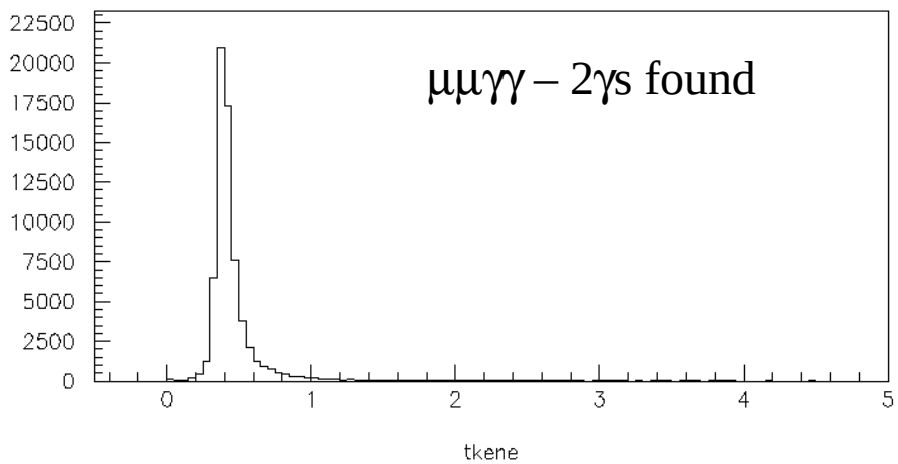
JAWS Analysis: 1999 Data



1999 Data: $K_L \rightarrow \mu\mu\gamma\gamma$

- Lower B-field in 1999
  - Significant fraction of signal events are identified as $K_L \rightarrow \mu\mu\gamma$
  - Photon shower overlaps with track matched cluster
  - Increase in acceptance for lower momentum tracks
    - Estimate the loss in acceptance
    - Tune cluster reconstruction in ktevana





Cut Tuning

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

- Investigating cuts to loosen
  - Track momentum
    (10 GeV/c → 8 GeV/c)
    Acceptance 4.3% → 5.3% (1997)
    Acceptance 4.5% → 5.6% (1999)
  - **But lets in background near box (~40% more)**
- Need to find cuts to reduce background near box
  - Cut on $E\gamma$ not effective
- Kinematic fitting?

$K_L \rightarrow \mu\mu\gamma\gamma$ analysis

- Most promising cuts to loosen
  - Track momentum
    (10 GeV/c → 8 GeV/c)
    Acceptance 0.15% → 0.17% (1997)
    Acceptance 0.12% → 0.14% (1999)
  - **Doesn't significantly increase background**

Plans

- Work on optimizing cuts
  - Can we recover $K_L \rightarrow \mu\mu\gamma\gamma$ events in 1999?
  - Can we reduce backgrounds in $K_L \rightarrow \pi^0\mu\mu$
- Generate MC ($K_L \rightarrow \pi^+\pi^-\pi^0$ DD (~Done); $K_L \rightarrow \pi\mu\nu + \gamma$acc)
- Get background estimates (MC + data)
- Combine new 1997 result + new 1999 result