# Analysis of $K_L \to \pi^0 e^+ e^- \gamma$

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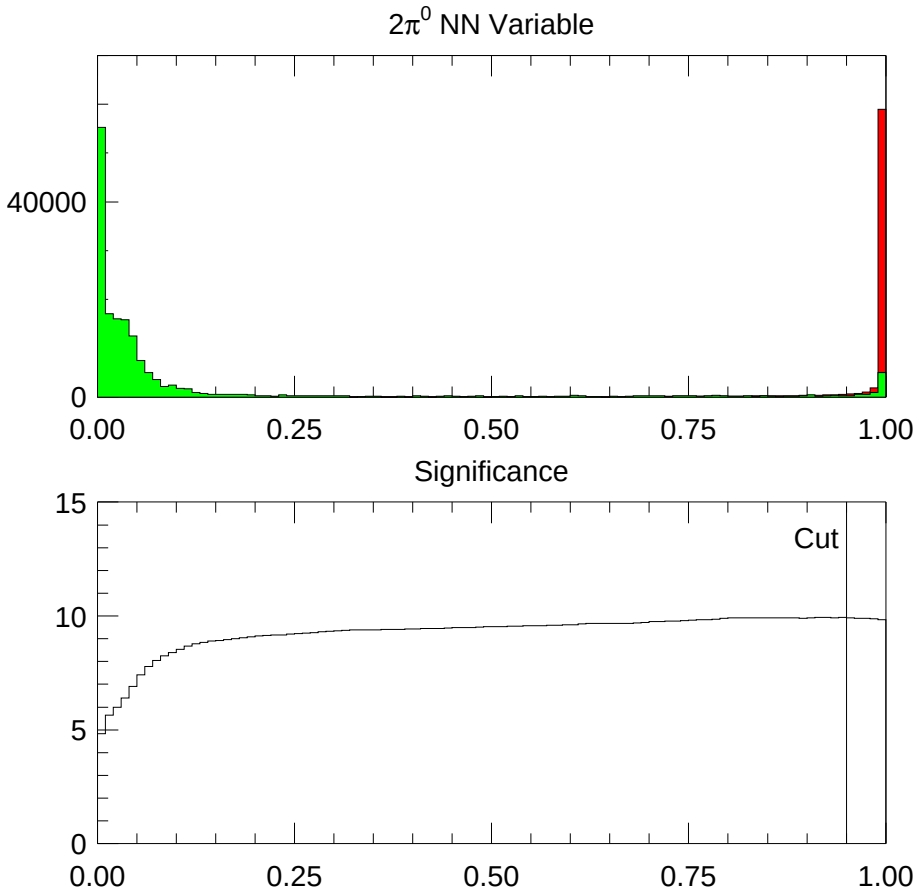
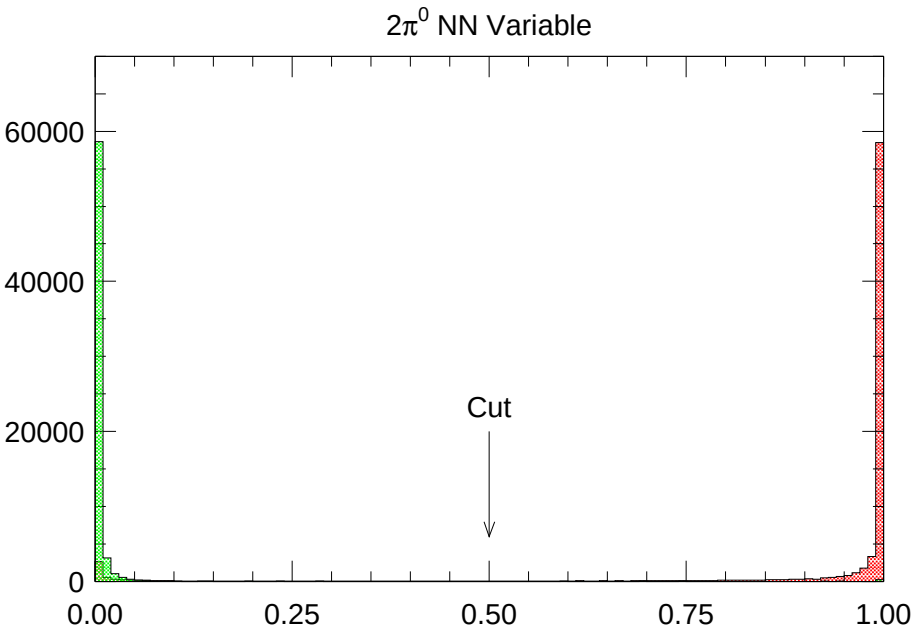
- Improved neural net variable.
- Small modification to RC cut.
- Better handling of systematics.
- $a_V$ dependence.

# $K_L \to \pi^0\pi^0$ Background

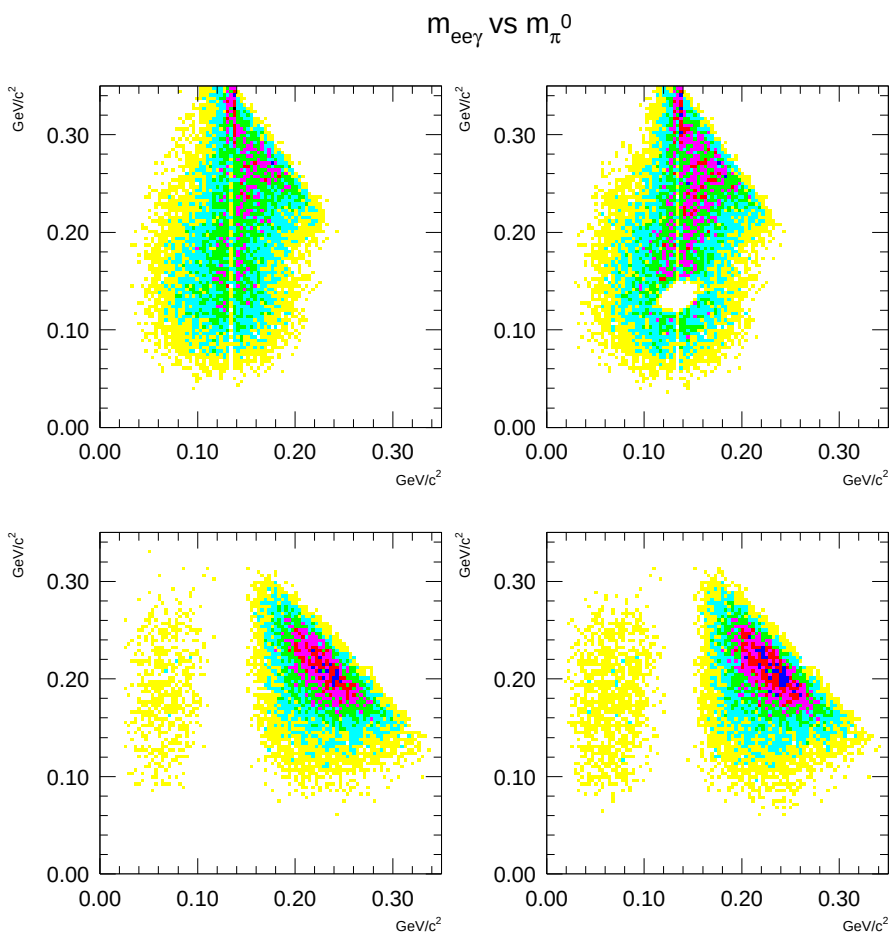
- NN variable for $2\pi^0$ (green) and $\pi^0 e^+ e^- \gamma$ (red) MC.



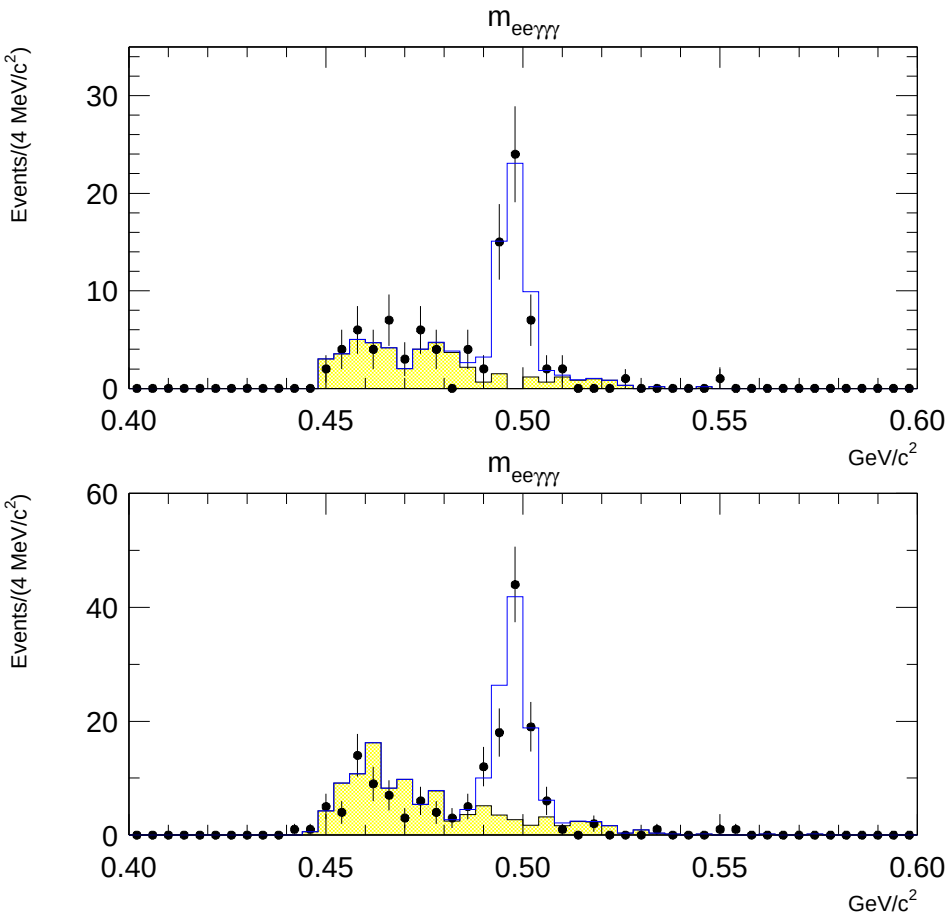
# $K_L \to \pi^0\pi^0$ Background

- Effect on $\pi^0\pi^0$ background.
  - Top plots: 2nd best combination.
  - Bottom plots: 3rd best combination.
  - LHS: Before cut.
    RHS: After cut.
- Also changed RC cut from 50 MeV $\to$ 100 MeV.



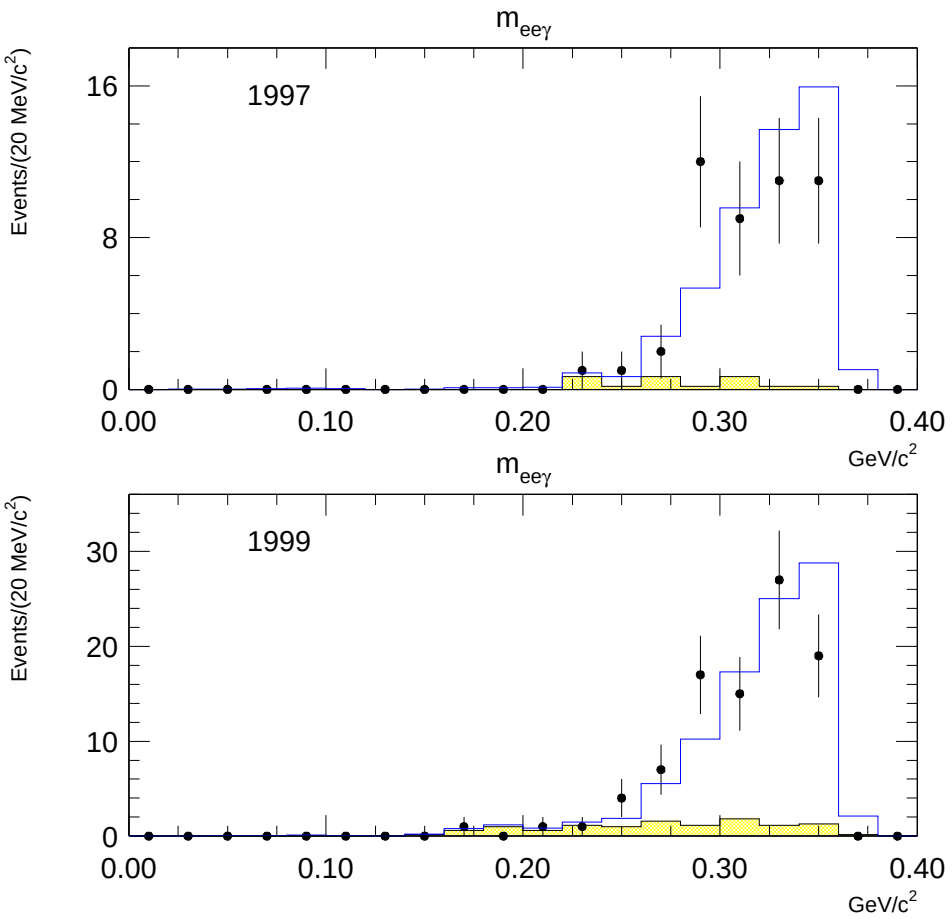
# Kaon Mass

- Mass of $e^+e^-\gamma\gamma\gamma$ system.
  - All cuts but kaon mass applied.
  - Somewhat lower background than previous result.

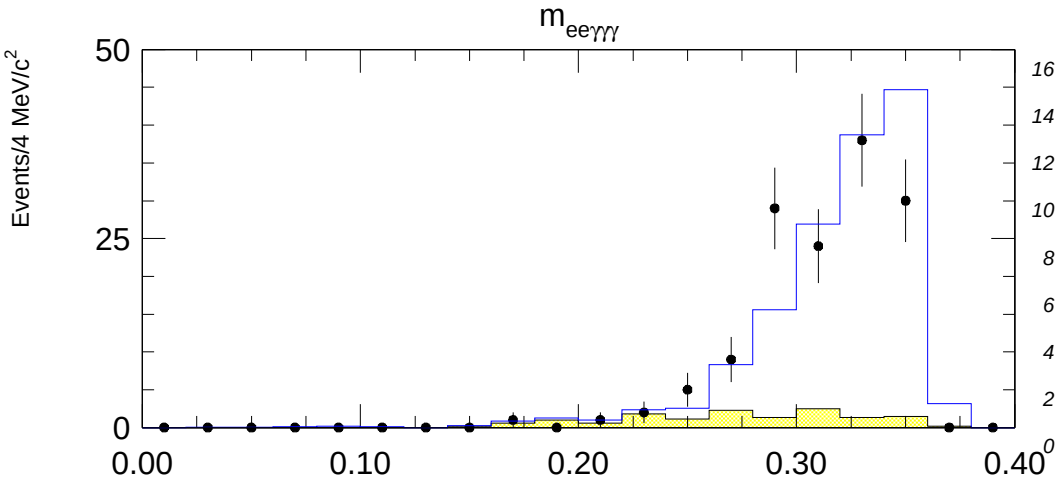


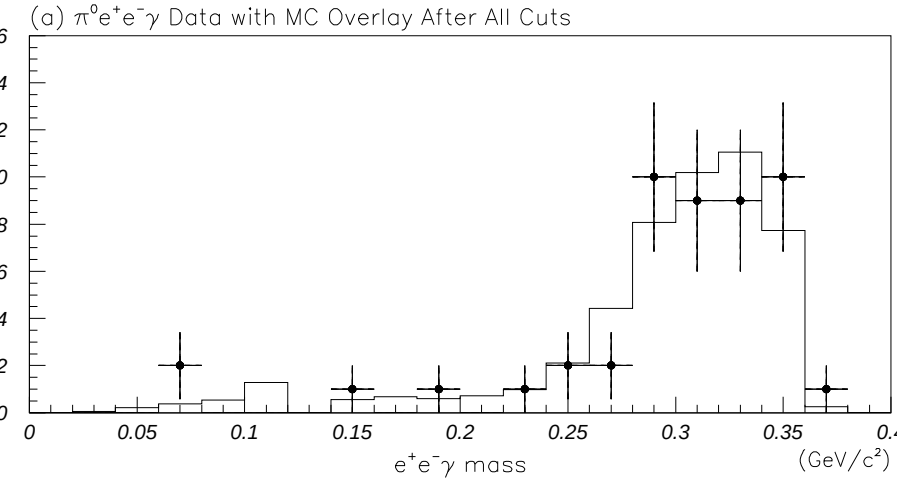
# $e^+e^-\gamma$ Mass.

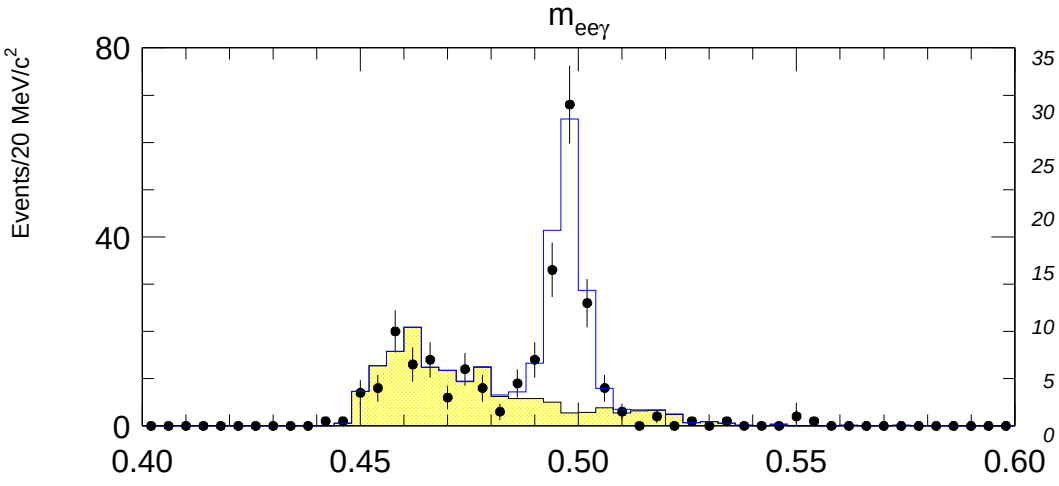
- Final sample.
  - 1997: 47 events (bkg $2.7 \pm 1.0$).
  - 1999: 85 events (bkg $11.7 \pm 2.3$).
- PRL
  - 48 events (bkg: $3.6 \pm 1.1$).

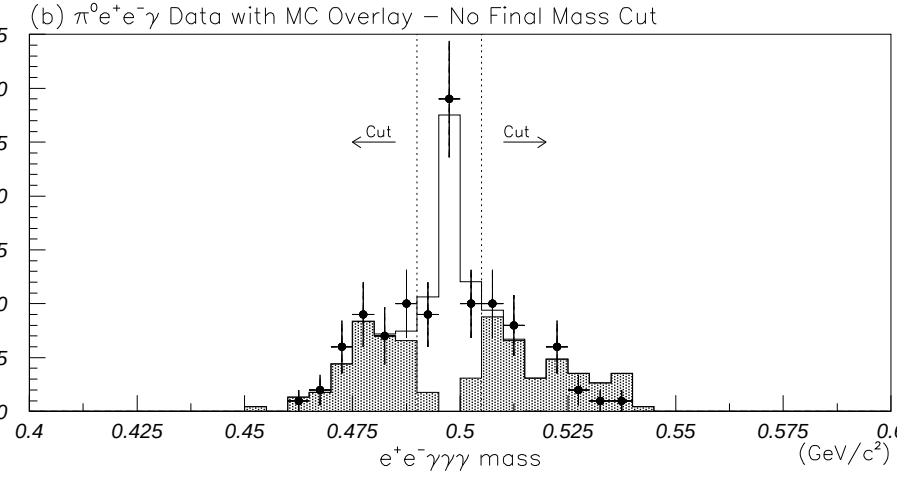


# Combined Samples



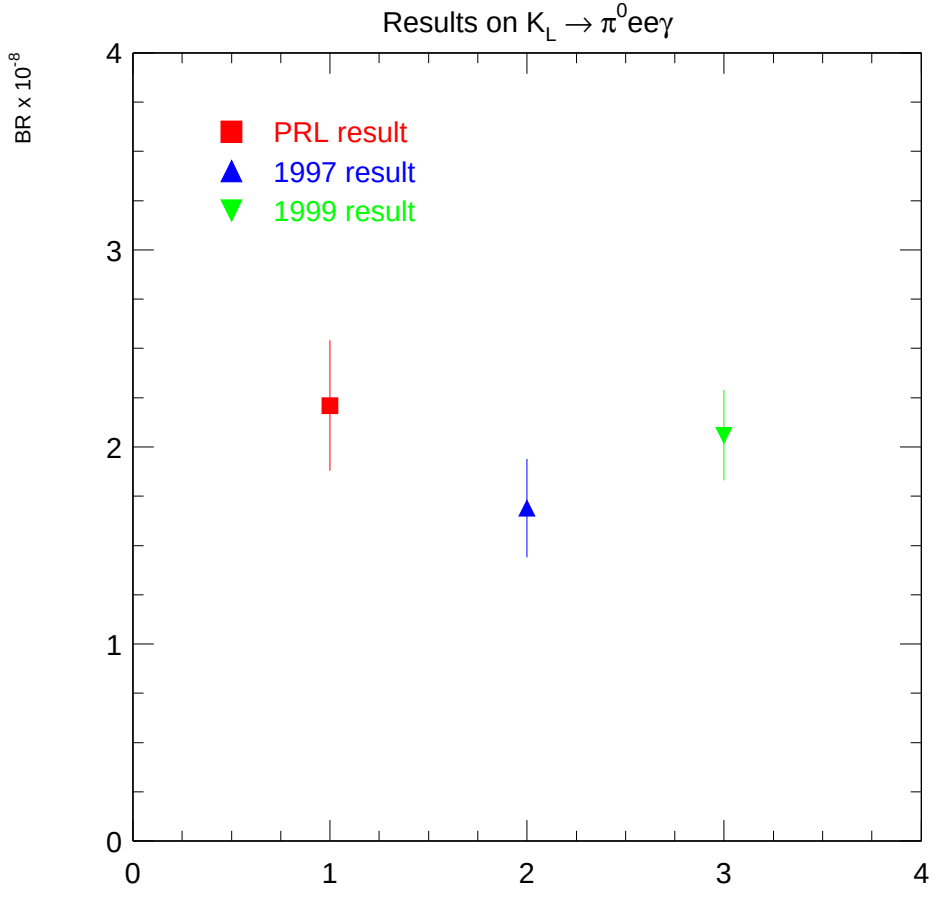



# Branching Ratio Results

- PRL: $(2.21 \pm 0.33) \times 10^{-8}$
- 1997: $(1.69 \pm 0.25) \times 10^{-8}$
- 1999: $(2.06 \pm 0.23) \times 10^{-8}$

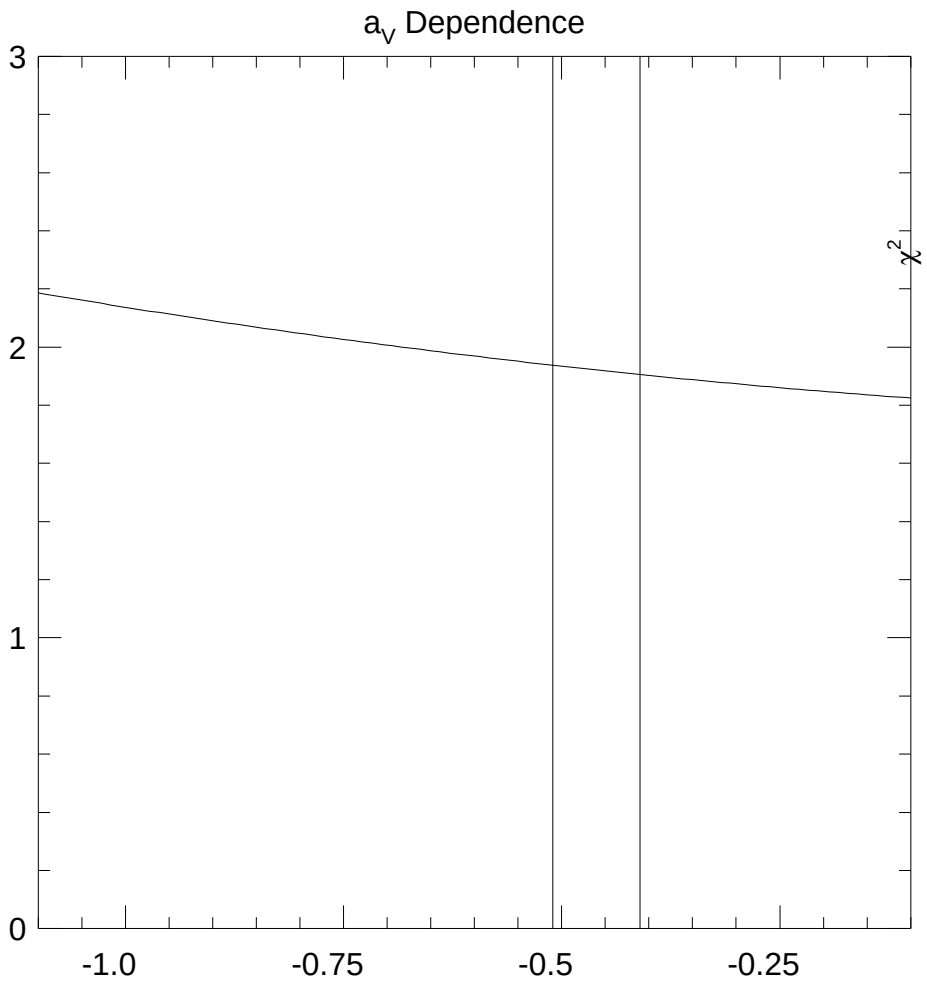


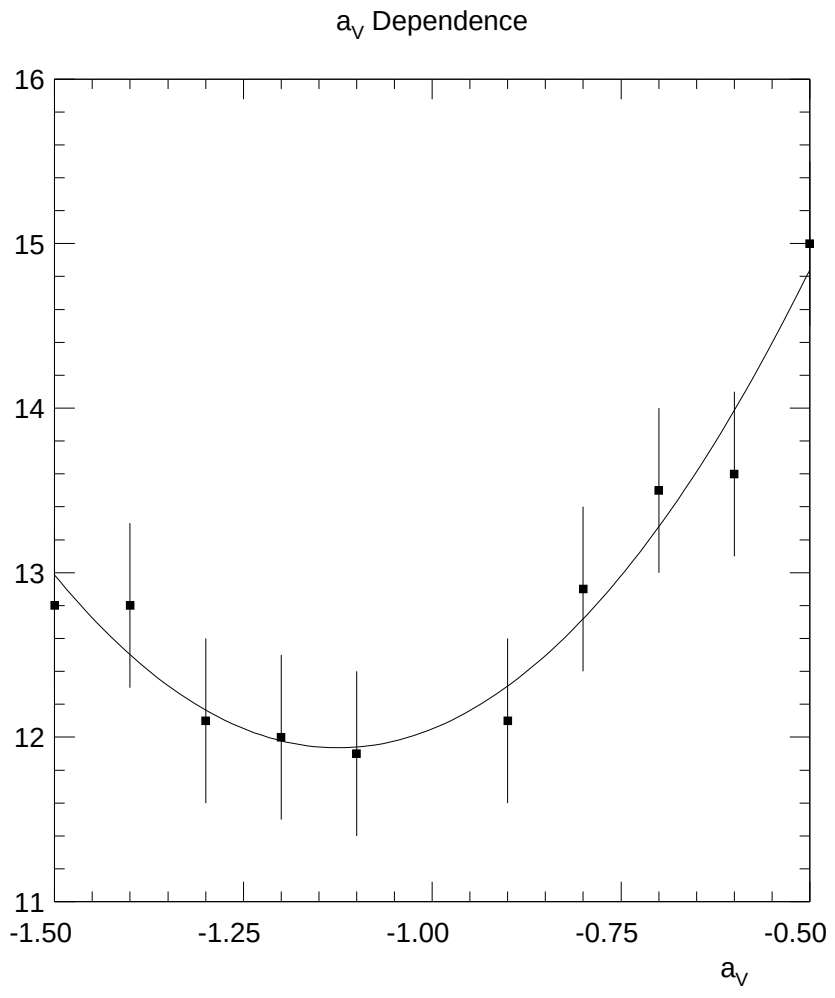
# Comparison of Results

| | PRL result | 1997 Data |
|---|---|---|
| Flux | $2.80 \times 10^{11}$ | $2.87 \times 10^{11}$ |
| Acceptance (%) | 0.72 | 0.86 |
| Signal Events | 48 | 46 |
| Background | $3.6 \pm 1.1$ | $2.7 \pm 1.49$ |
| Branching Ratio | $2.21 \times 10^{-8}$ | $1.78 \times 10^{-8}$ |

- PRL: 11 exclusive events.
- 1997 new: 13 exclusive events.
- BR difference: $(0.41 \pm 0.215) \times 10^{-8}$.

# $a_V$ Dependence



# Systematics

- Calculate systematic shifts for whole data sample.
  - Handles correlations between data sets better.

| Systematic | Error (%) |
|---|---|
| MC Statistics | 4.2 |
| $K_L$ and $\pi^0$ BR | 2.8 |
| $a_V$ dependence | 0.9 |
| $3\pi^0$ $z$ | 0.5 |
| FUSE3x3 cut | 0.4 |
| pp0kin cut | 0.3 |
| $3\pi^0$ $p$ | 0.3 |
| apertures | 0.2 |
| $p_T^2$ cut | 0.3 |
| $2\pi^0$ background | 0.1 |
| Total | 5.2 |

# Final Result

- Combine results, weighting by combined error.
- BR($K_L \to \pi^0 e^+ e^- \gamma$) = $(1.90 \pm 0.17 \pm 0.10) \times 10^{-8}$.
- Compare with $(2.21 \pm 0.33 \pm 0.12) \times 10^{-8}$ (PRL).
- Note on analysis
  - http://kpasa.fnal.gov:8080/private/ktevdoc/e799/kpi0eeg/pi0eeg_97_99.p

# Analysis of $K_L \to \pi^0\gamma\gamma$

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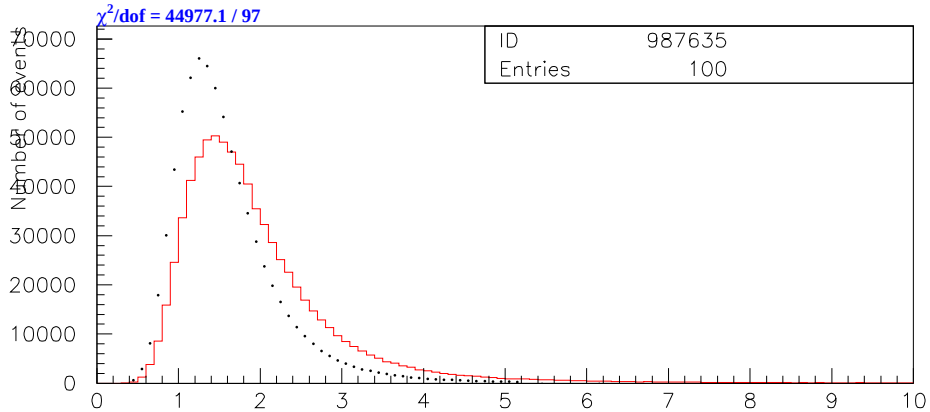
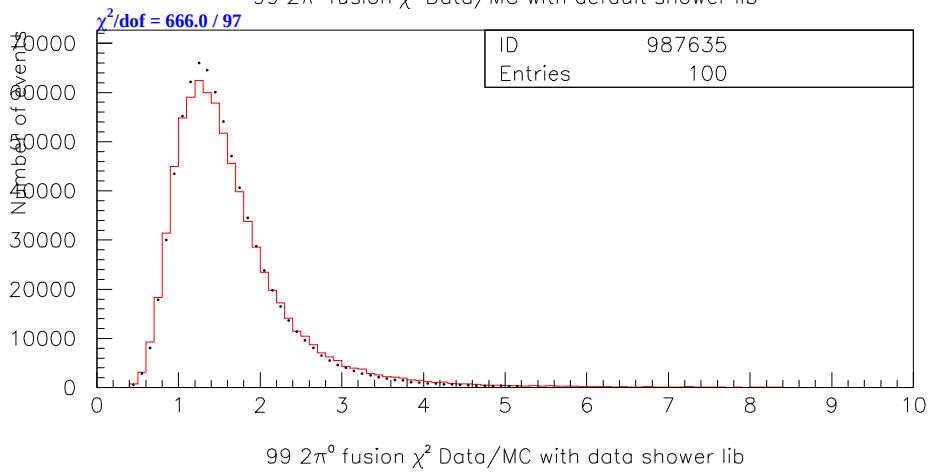
- Finalize cuts.
- Systematic studies.
- $a_V$ fits.

# Selection Criteria

| | |
|---|---|
| Level 3 $\pi^0\gamma\gamma$ tag | No extra software clusters |
| No bad spills | Cut on Vacuum window interactions |
| No unpacking errors | 40 GeV $<$ E $<$ 160 GeV |
| Four Hardware Clusters | $E_{\rm clus} > 2.0$ GeV |
| ABS(Y center of energy) $<$ 0.05 m | $E_{\rm RC} < 0.22$ GeV |
| LREGOK | $E_{\rm SA} < 0.07$ GeV |
| $\mathrm{ABS}(M_{\pi^0} - 0.135) < 0.003$ GeV/c$^2$ | $E_{\rm CA} < 2.0$ GeV |
| -0.2 $<$ X center of energy $<$ -0.1 m | $E_{\rm MA} < 0.1144$ GeV and MA source bit OFF |
| 115 m $<$ Z $<$ 130 m | $E_{\rm BA1} < 3.85$ GeV |
| No events with two $\pi^0$s | NHA (intime) $<$ 2 |
| NHIT (intime) $<$ 23 | Shape $\chi^2 <$ 2.7 |

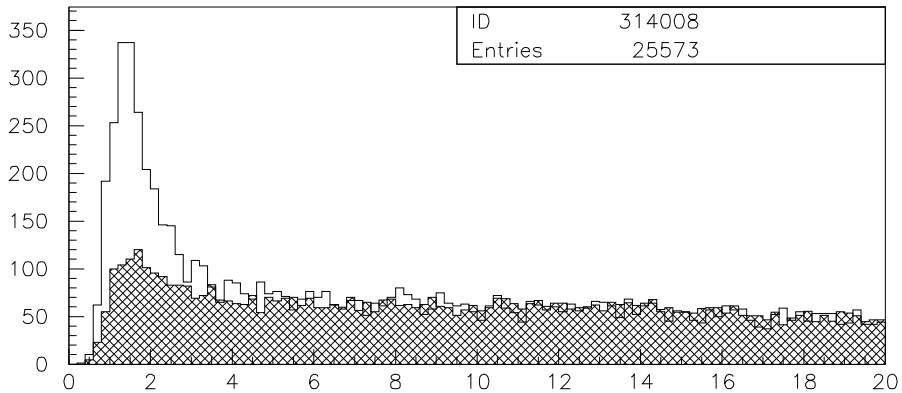
# Fusion $\chi^2$



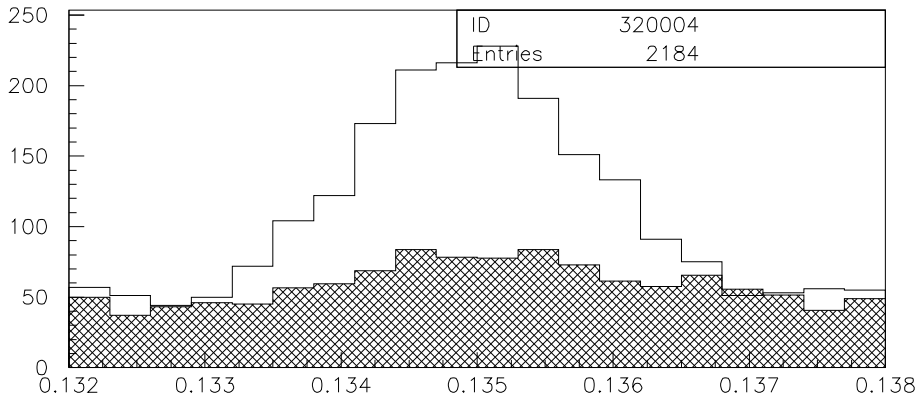




- Biggest change from previous result → larger background level.

# Background Levels

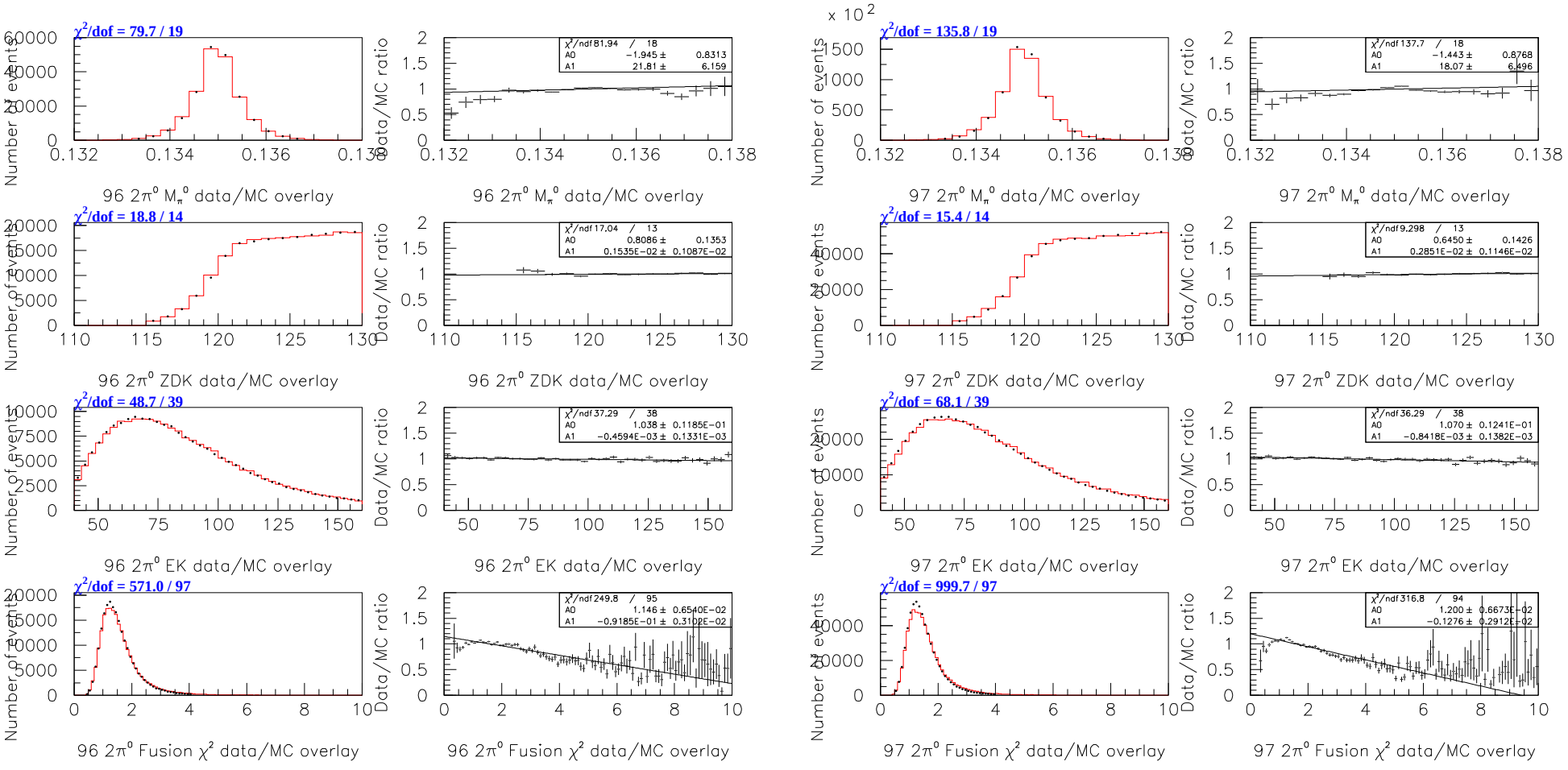



99 data Fusion $\chi^2$ after all cuts

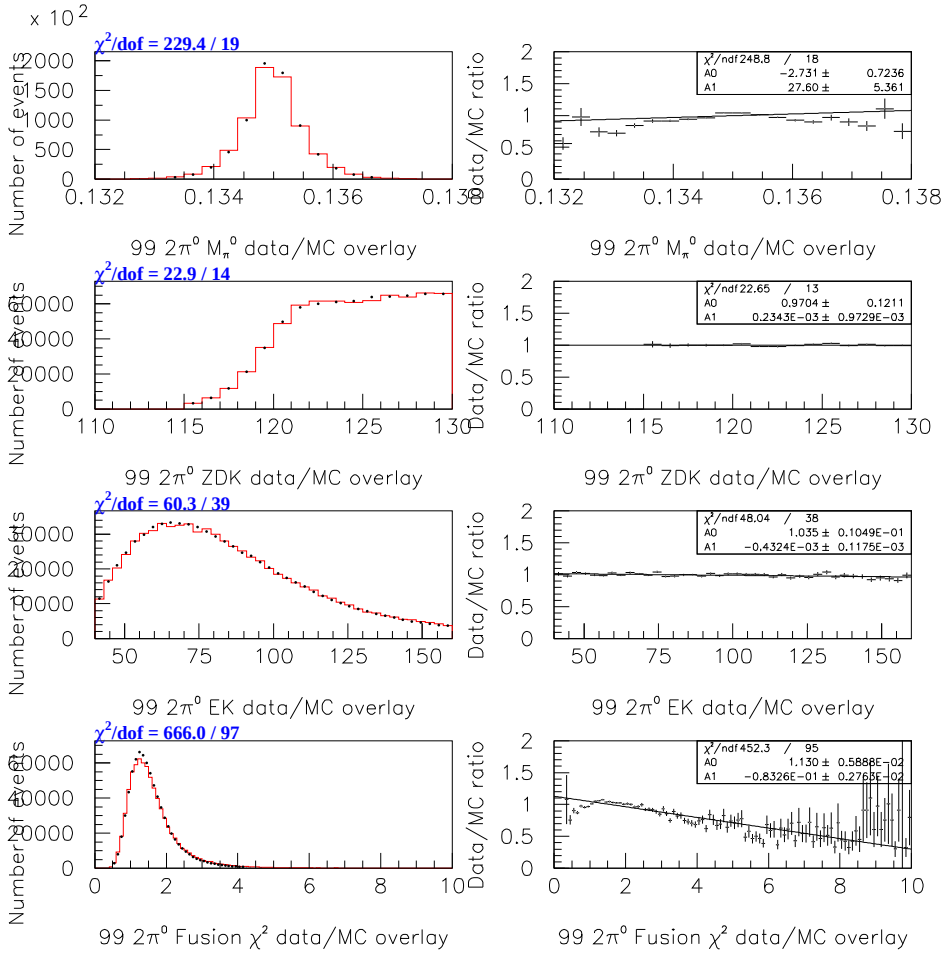



99 $M_{\pi^0}$ of $\pi^0\gamma\gamma$ after all cuts

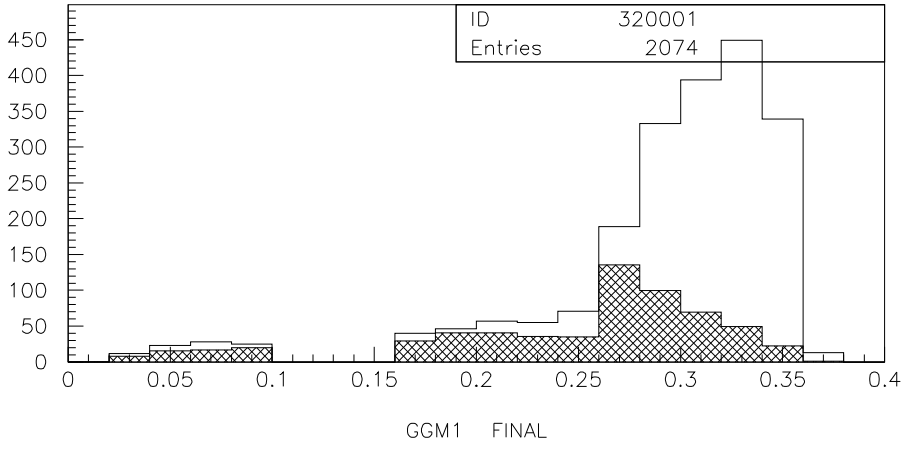
# Data/MC Comparisons (96 & 97)

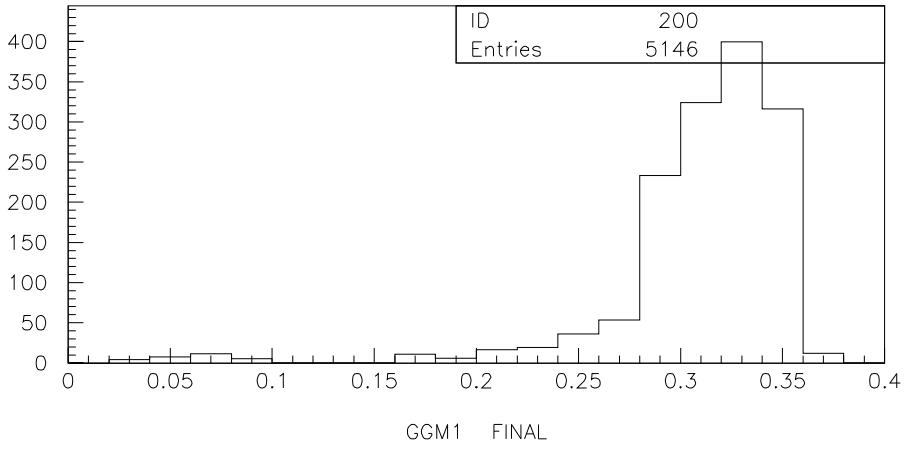


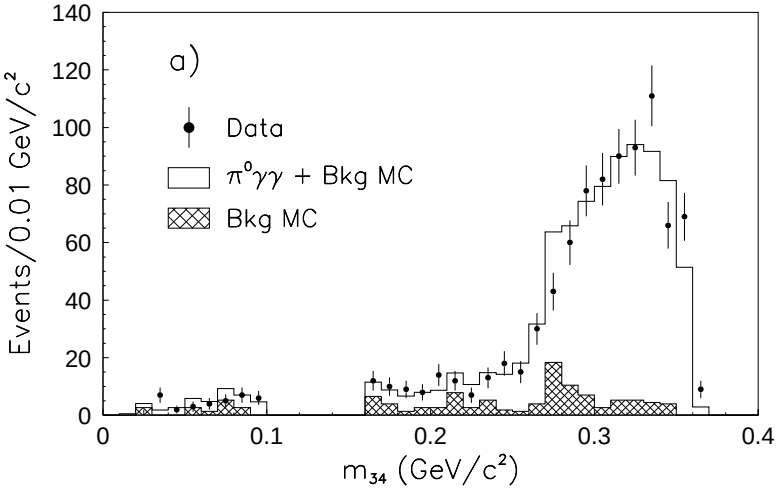
# Data/MC Comparison (99)

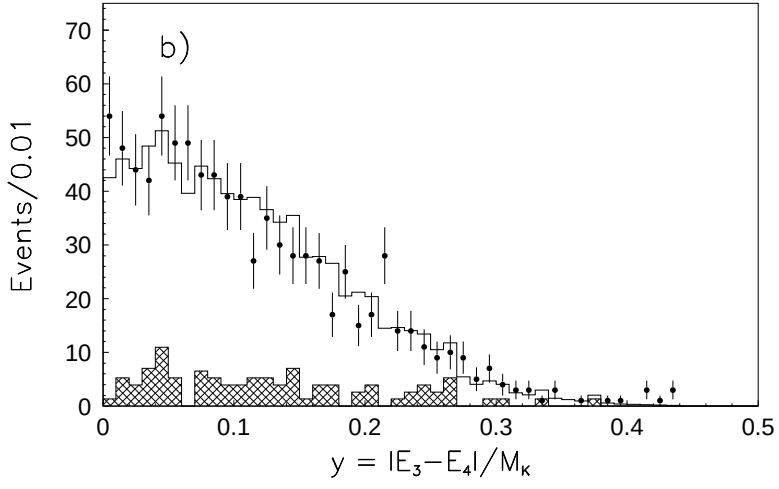


# Final $\gamma\gamma$ Mass



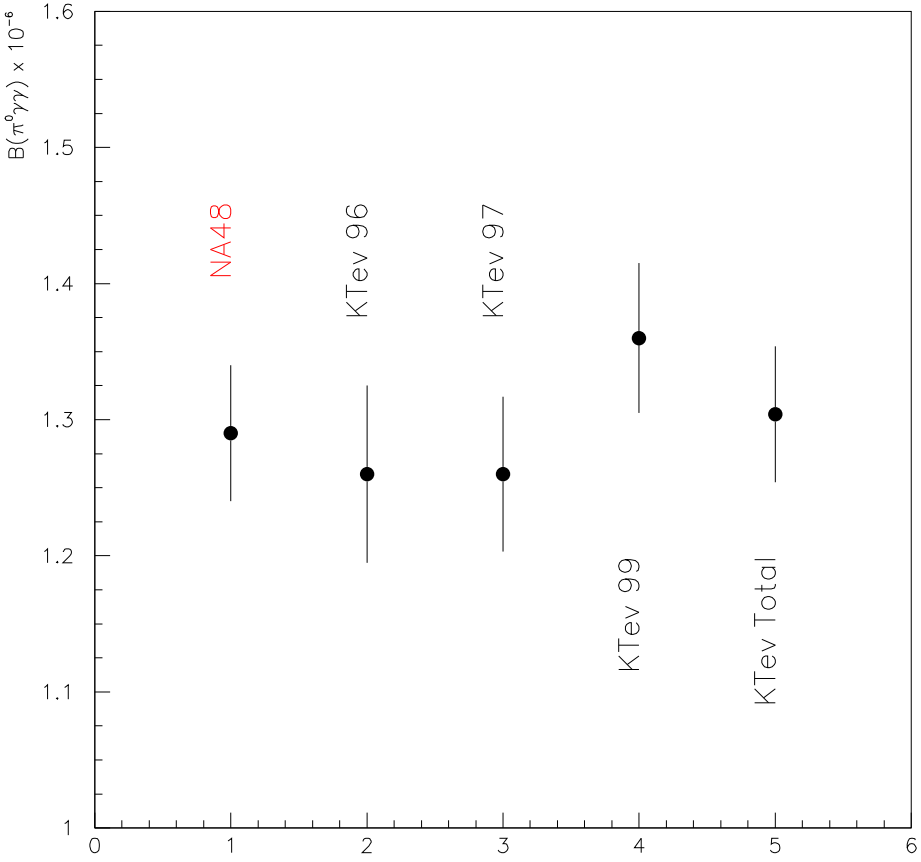



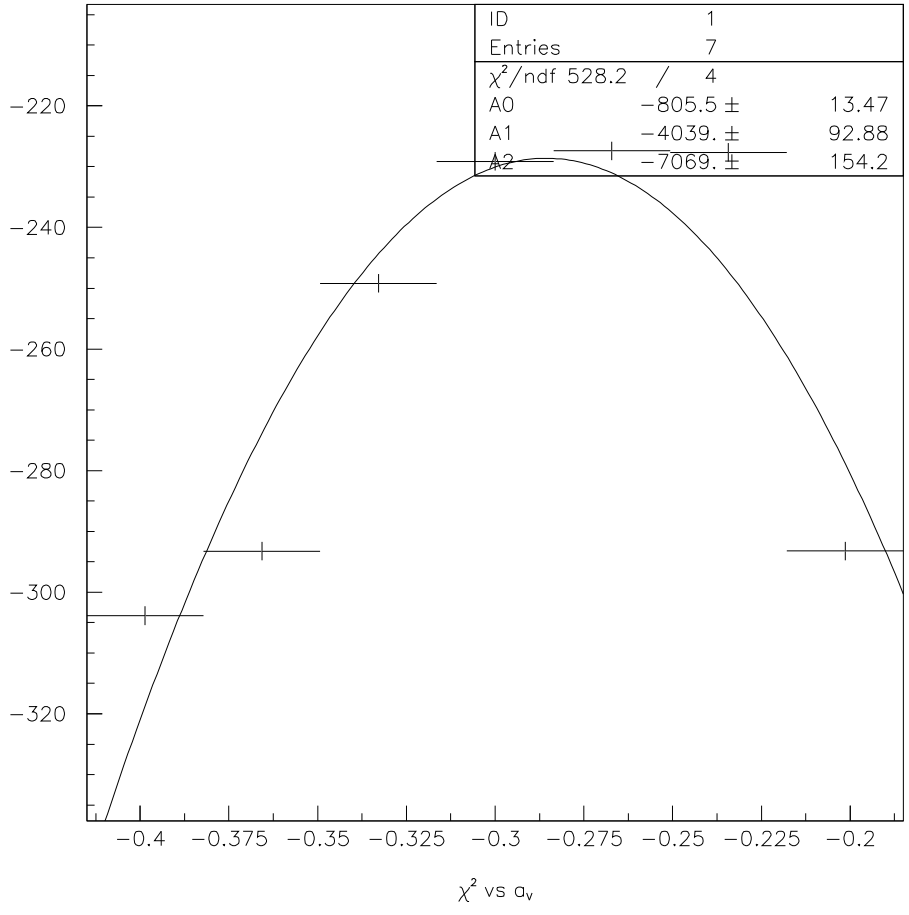
# Branching Ratio Results

- 1996: $(1.260 \pm 0.049) \times 10^{-6}$
- 1997: $(1.261 \pm 0.032) \times 10^{-6}$
- 1999: $(1.360 \pm 0.045) \times 10^{-6}$

Weighted average BR: $(1.32 \pm 0.03) \times 10^{-6}$.



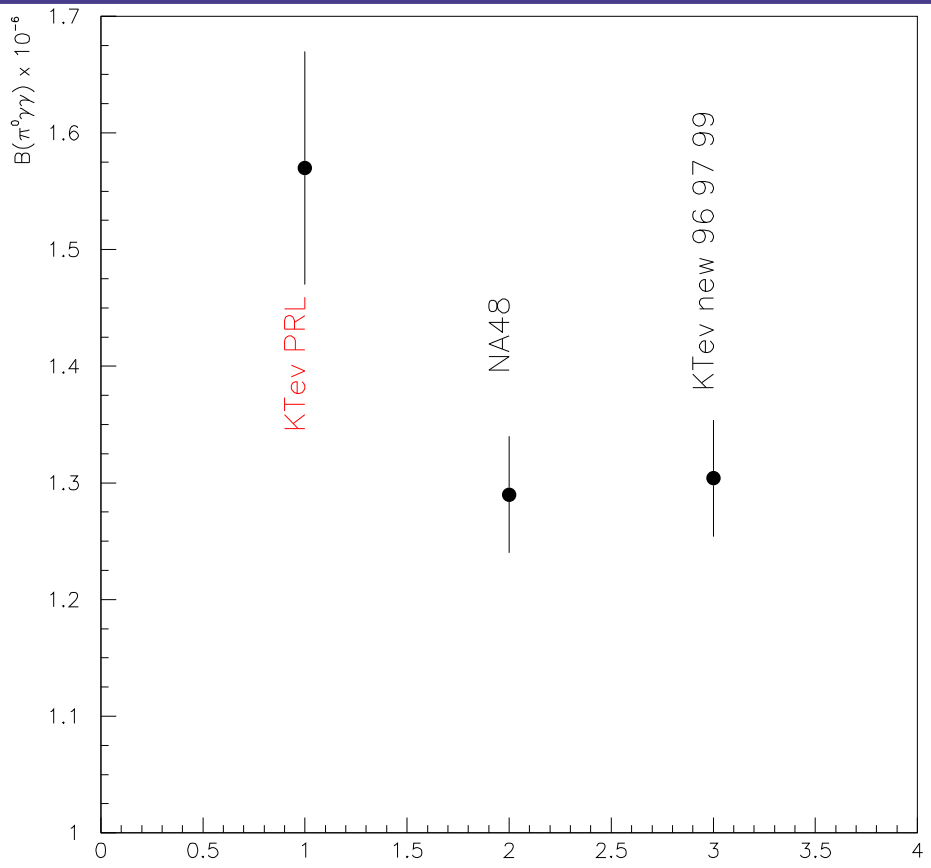
# $a_V$ Fits


ID 1
Entries 7
χ²/ndf 528.2 / 4
A0 −805.5 ± 13.47
A1 −4039. ± 92.88
A2 −7069. ± 154.2
−220
−240
−260
−280
−300
−320
−0.4
−0.375
−0.35
−0.325
−0.3
−0.275
−0.25
−0.225
−0.2
χ² vs a_V

# Systematics (1999 data only)

| Source of Uncertainty | Uncertainty (%) | |
|---|---|---|
| Decay vertex | 0.9 | |
| Mast Anti | 0.4 | |
| Ring counter | 0.3 | |
| Back Anti | 0.5 | |
| Collar Anti | 0.6 | |
| $2\pi^0$ branching ratio | 0.9 | |
| $3\pi^0$ background | 1.3 | |
| MC statistics | | 1.0 |
| Normalization | | 0.9 |
| $a_V$ dependence | 1.5 | |
| Shape $\chi^2$ ($3\pi^0$) | 0.6 | |
| Total | 2.62 | |

# Branching Ratio Results




$$\mathrm{BR}(K_L \to \pi^0\gamma\gamma) = (1.32 \pm 0.03 \pm 0.035) \times 10^{-6}$$

# Branching Ratio Results

- New combined result is consistent with NA48 result.
- Systematics done for 1999 data set.
- $a_V$ fits almost done.