Tying Up Loose Ends For The 97 Analysis of $K_L \rightarrow \pi^+\pi^-\gamma$

Michael Ronquest
mr7y@virginia.edu
University of Virginia
KTeV Collaboration Meeting
June 7 2005

Introduction

- The analysis of $K_L \rightarrow \pi^+\pi^-\gamma$ (97 data) was finished back in the fall, however a few things were left undone:
  - Calculation of < I gM1 I >, DE/(DE+IB) and r
    - These are nice for comparisons to other/old results.
  - Determination of background composition
    - John did estimate the level of the background, and he identified as well as ruled out a few sources.
- Both are done now. Here are the results....

Background

- Using the wings of the mass plot, John estimated that the background level was between 618 and 789 events, in a data sample of 112,140 events.
  - He found that $\pi^+\pi^-$ does not contribute to this background in any significant way.
  - He found that $\pi^+\pi^-\pi^0$ does (~120 events)
- He added the wings of the mass plot into his MC to treat the background systematic error.

Background Composition Study

- I looked into all of the possible sources of background.
- For each decay, I generated Monte Carlo events in order to calculate the acceptance with John's analysis cuts, and then used the total flux, as calculated from the final number of $K_L \rightarrow \pi^+\pi^-\gamma$ events, to estimate the background contribution.
- Details can be found in: ~ronquest/writeups/97pmgvacnote2.ps

Suspect Decays

- Here's a list of some possible decays that can contribute to the background:
  - K_e3+accidental photon or $K_e3\gamma$: where the electron is mistaken for a pion
  - $K_\mu3$+accidental photon: where the muon fails to fire the vetoes.
  - $\pi^+\pi^-\pi^0$: where one π^0 photon is missed
  - $\pi^+\pi^-$+accidental photon: John claims this isn't an issue(~1 event) and thus was ignored.
  - $\Lambda\rightarrow p\pi$+accidental photon: no Λ mass cut was made here, so this will look like $\pi^+\pi^-$
  - $\Xi\rightarrow\Lambda\pi^0$: where the Λ undergoes the decay above.

Background From $K_L \rightarrow \pi e \nu$

- This decay can contribute when the E/p cut at 0.85 fails to remove the electron.
- Using the acceptance for this mode as simulated in the Monte Carlo, I estimate that there are ~120 $K_L \rightarrow \pi e \nu$ events in the data after all cuts.
  - The E/p cut efficiency, as calculated from the MC, is $(1.02 \pm .05) \times 10^{-3}$. However, given that the accepted region is so far out on the E/p tail, the acceptance could be incorrect.

Background From $K_L \rightarrow \pi e \nu \gamma$

- As I originally generated non-radiative $K_L \rightarrow \pi e \nu$ events, I need to also generate $K_L \rightarrow \pi e \nu \gamma$ events to see if the acceptance may be much higher.
- I estimate that there are approximately 20 $K_L \rightarrow \pi e \nu \gamma$ events under the mass peak.

Background From $K_L \rightarrow \pi\mu\nu$

- This mode will contribute to the background when the muon fails to fire one of the μ vetoes. This happens most often when a low energy muon is absorbed in the filters in front of $\mu 2$.
- I estimate that ~3 examples of this mode are present in the data after all cuts.

Background From $K_L \rightarrow \pi^+\pi^-\pi^0$

- This mode will contribute to the background when one of the photons from the π^0 decay is paired with the other pions to form $\pi^+\pi^-\gamma$.
- A P^2_π cut is applied to suppress this mode, however, there is no cut on a reconstructed π^0.
- I estimate that there are ~130 $K_L \rightarrow \pi^+\pi^-\pi^0$ events in the final data sample.
  - This is consistent with John's estimate of 120 +/- 24 events.

Hyperon Decays

- Another possible source of background could come from hyperon decays.
- No one (that I'm aware of) has ever measured the hyperon yield in E832, so I estimated it.
  - Use the number of kaons to lambdas to cascades in E799 (500:10:1)
  - Use the kaon and hyperon transmission factors given in KTeV document 0141.
  - This yields 730:10:1 for the number of kaons to lambdas to cascades for 230GeV/c>E> 20GeV/c and 158m > z >95m.

Background from $\Lambda \rightarrow p\pi$

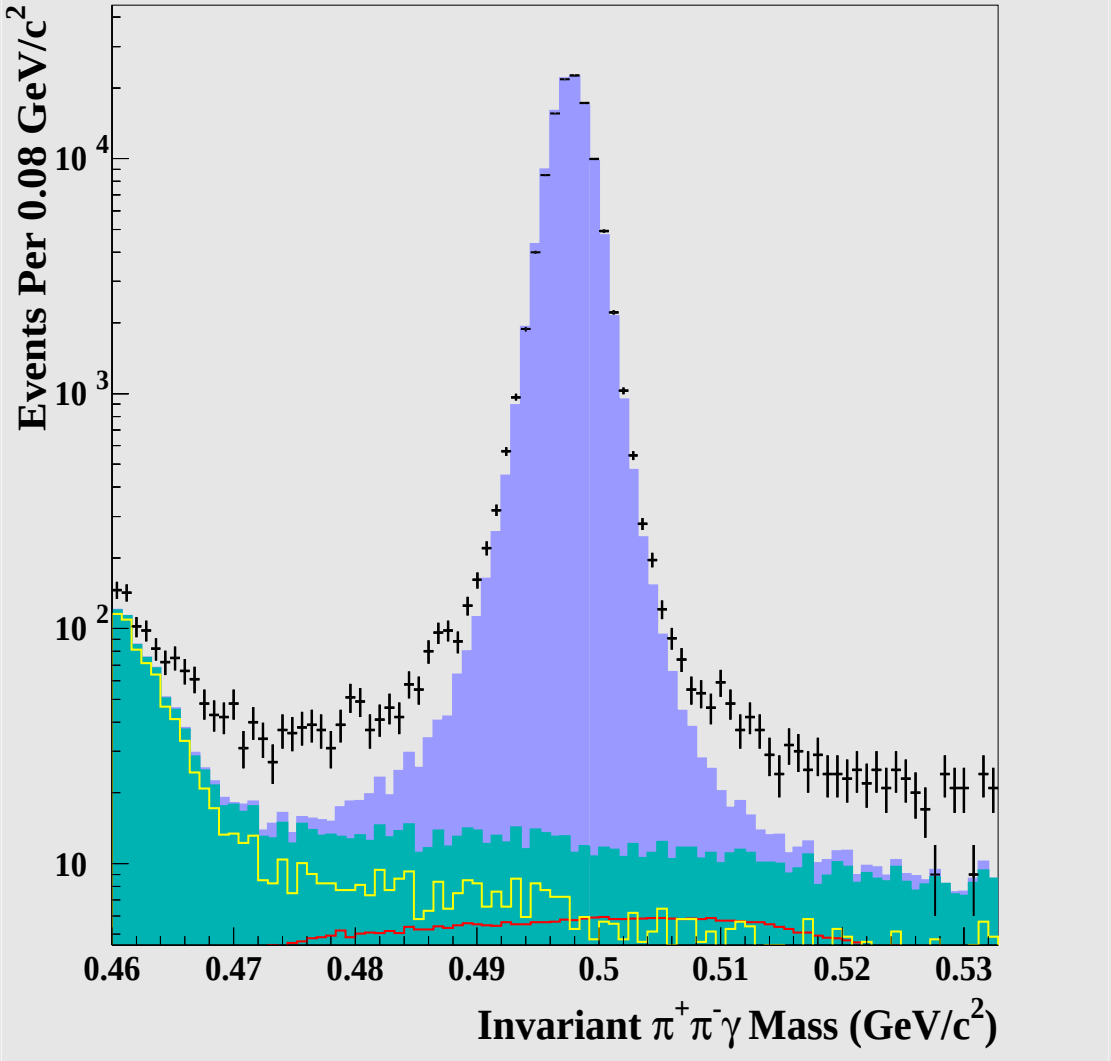
- My flux estimate is 9.019 x 10^8 decays with 230GeV/c>E_Λ> 20GeV/c and 158m > z >95m
- I estimate that ~2 of these decays are present in the data after all analysis cuts.

Background From $\Xi \rightarrow \Lambda\pi^0, \Lambda \rightarrow p\pi$

- My flux estimate is 9.019 x 10^7 for the 97 data sample, where 230GeV/c>E_{Ξ}> 20GeV/c and 158m > z >95m
- I estimate that ~5 of these decays are present in the data after all analysis cuts.

Total Background

- The picture at left shows the sum of the largest sources of background.
- The points are data, while the blue histogram is the signal+background MC. The green histogram is the total background MC. The yellow line is the shape of the $\pi^+\pi^-\pi^0$ background, while the red line is that of the $\pi\varepsilon\nu$ background.
- The sum of the background events under the mass peak is ~250.

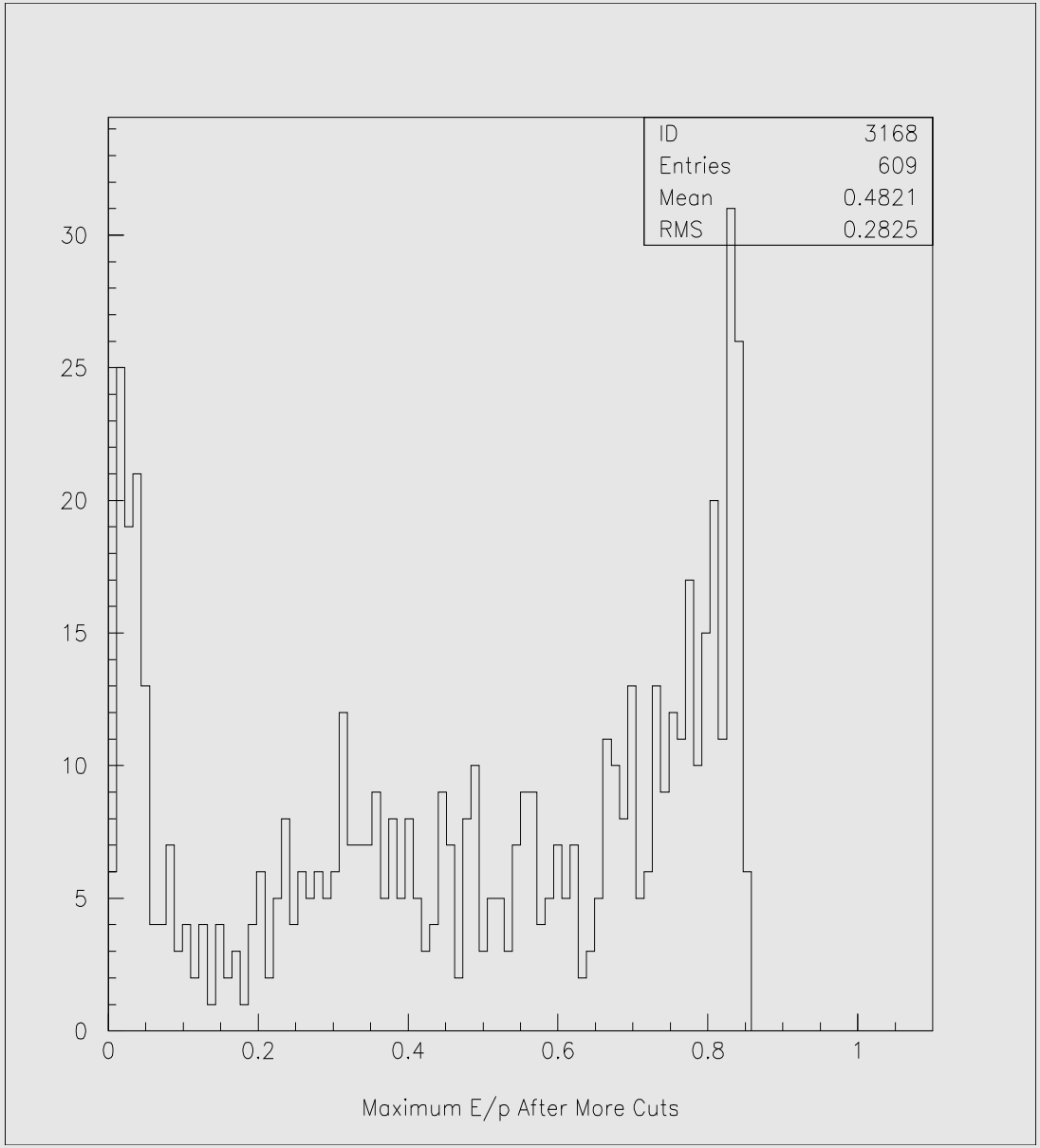


What makes up the remaining background?

- The amount of $\pi^+\pi^-\pi^0$ appears to be correctly estimated from the MC acceptance, as the data and background estimation have the same size and shape for $M_{\pi\pi\gamma}$ <0.47 GeV, where this mode is dominant.
  - For events with $M_{\pi\pi\gamma}$ >0.51 GeV, $M_{\pi\pi}$ is <u>not</u> consistent with $\pi^+\pi^-\pi^0$ decays.
- When performing the hyperon calculations, I overestimated the fluxes.
  - No spike on the Λ mass plot is visible.

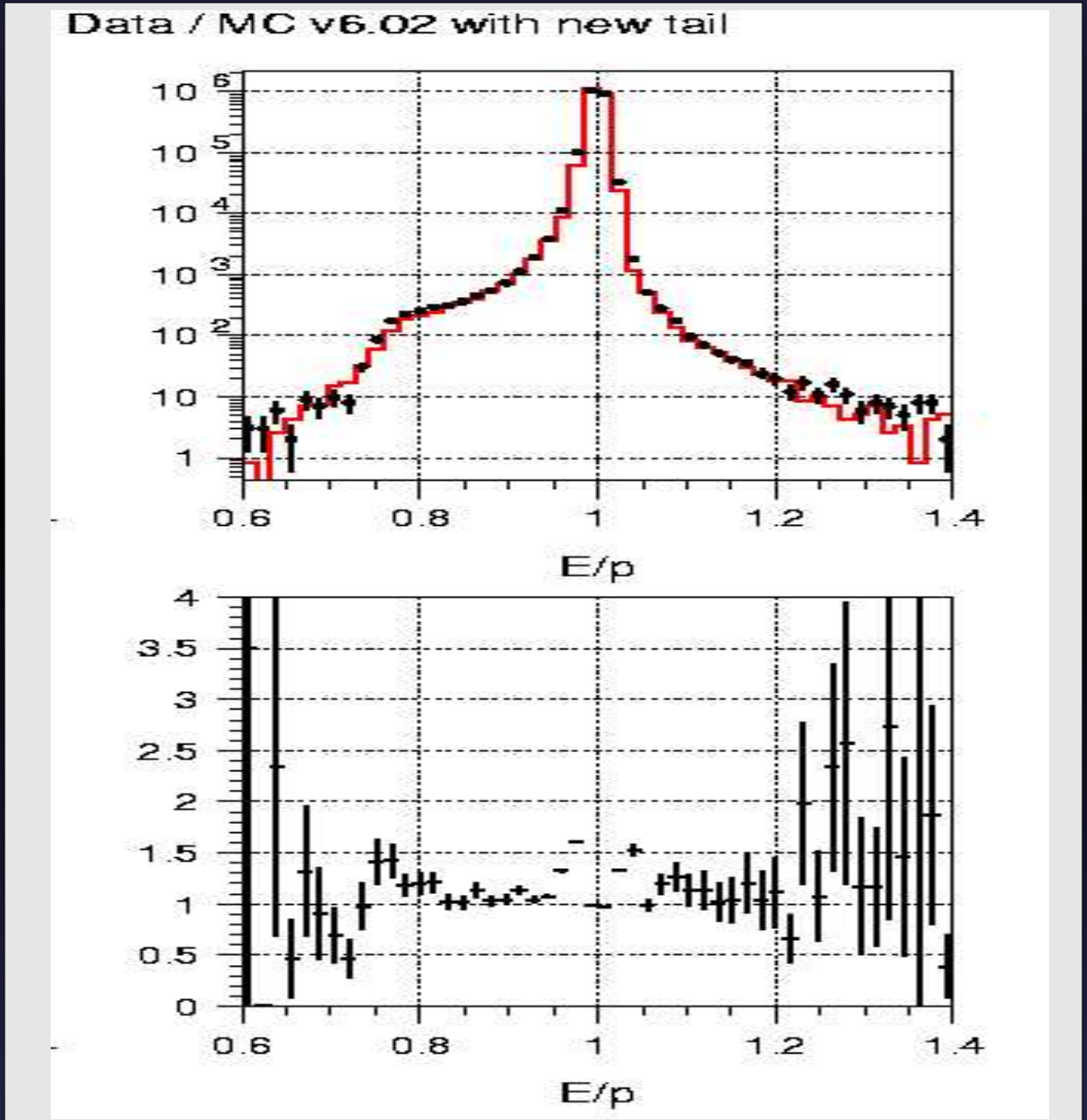
Characteristics of the remaining background

- For events with $M_{\pi\pi\gamma}$ >0.51 GeV the maximum value of E/p for each event indicates that electrons are present in a good portion of these events.
- What about the events near 0? Missed electron clusters, or something else?



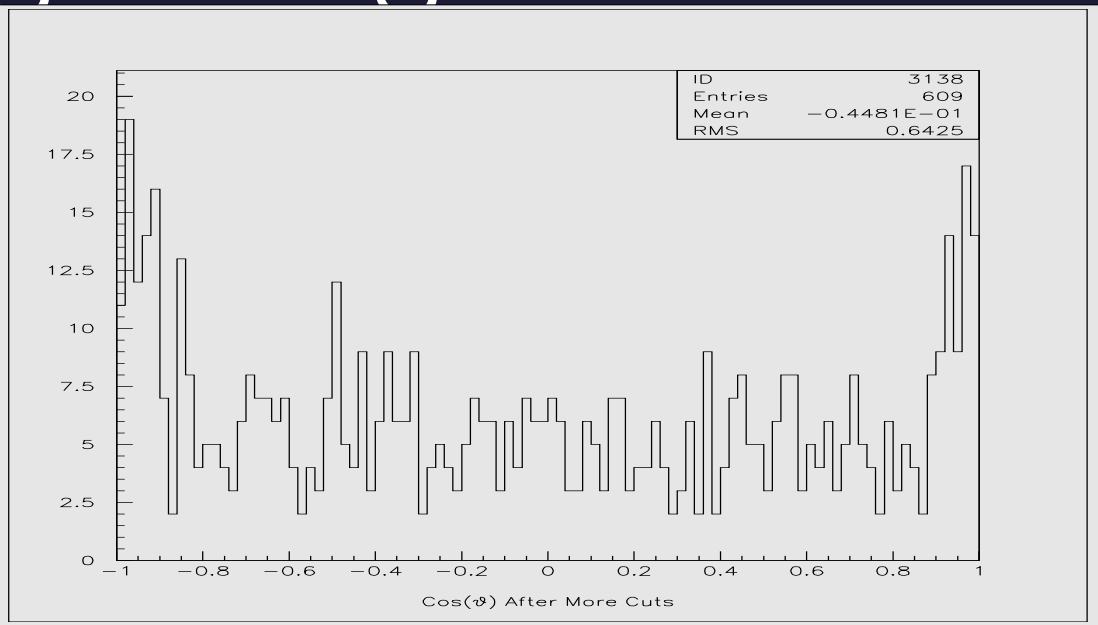
A problem with E/p?

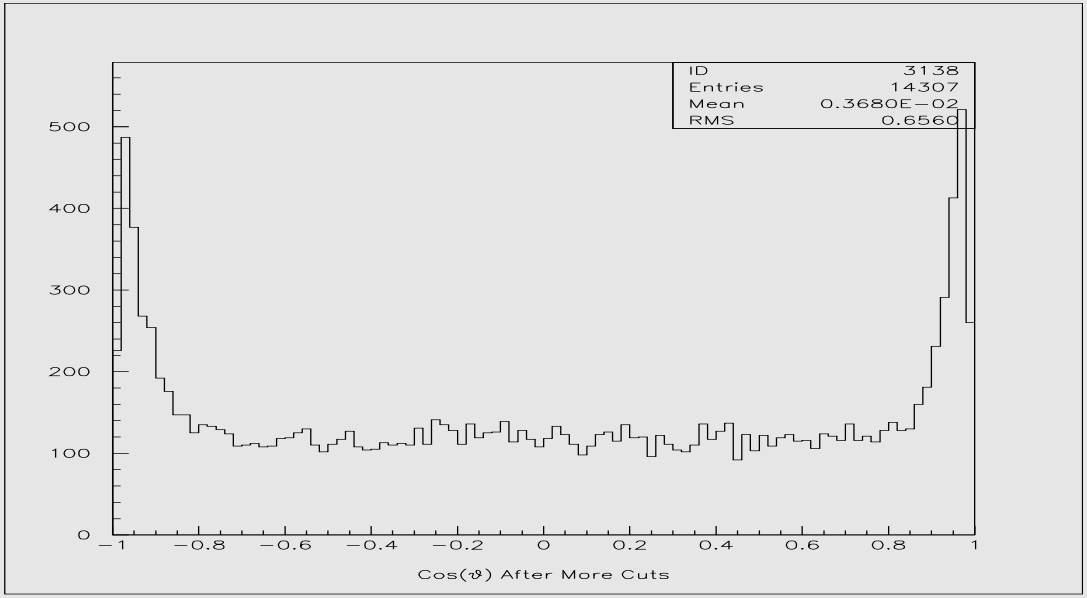
- KteVMC v6_02 and later have a much better simulation of the E/p tail, however, it still isn't perfect, as can be seen from Rick's E/p plot shown at right.
- Agreement starts to break down below E/p=0.8
- The tail isn't simulated at all past E/p=0.6!
- Small differences will results in many extra events!



Characteristics of the remaining background

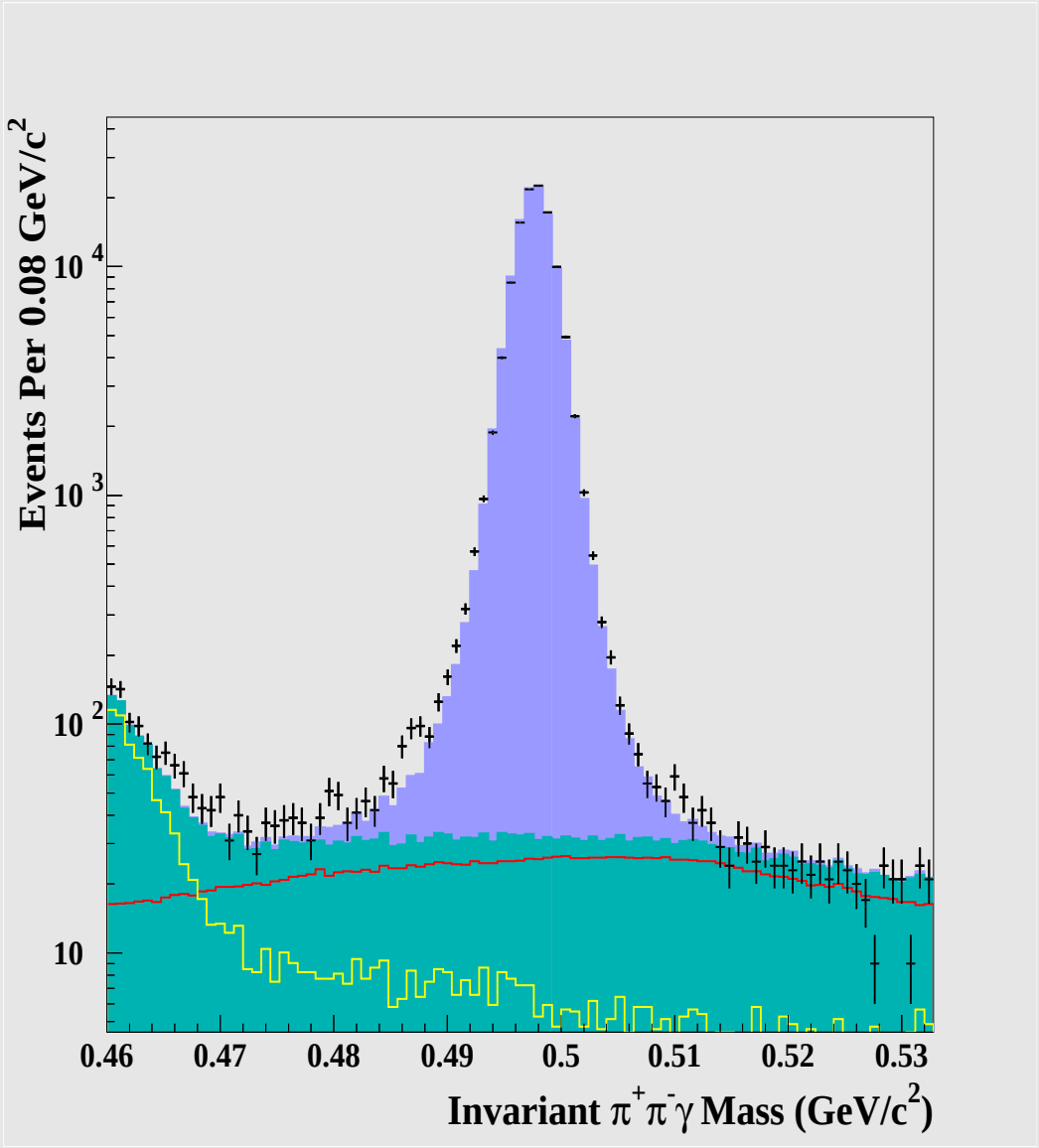
- For events with $M_{\pi\pi\gamma}$ >0.51 GeV the value of cos(θ) is strongly peaked at -1 and +1.
- K_e3 exhibits similar behavior as shown on the bottom plot.
- The missing background seems to be additional K_e3.
- Additional $K_\mu3$ can't be ruled out.





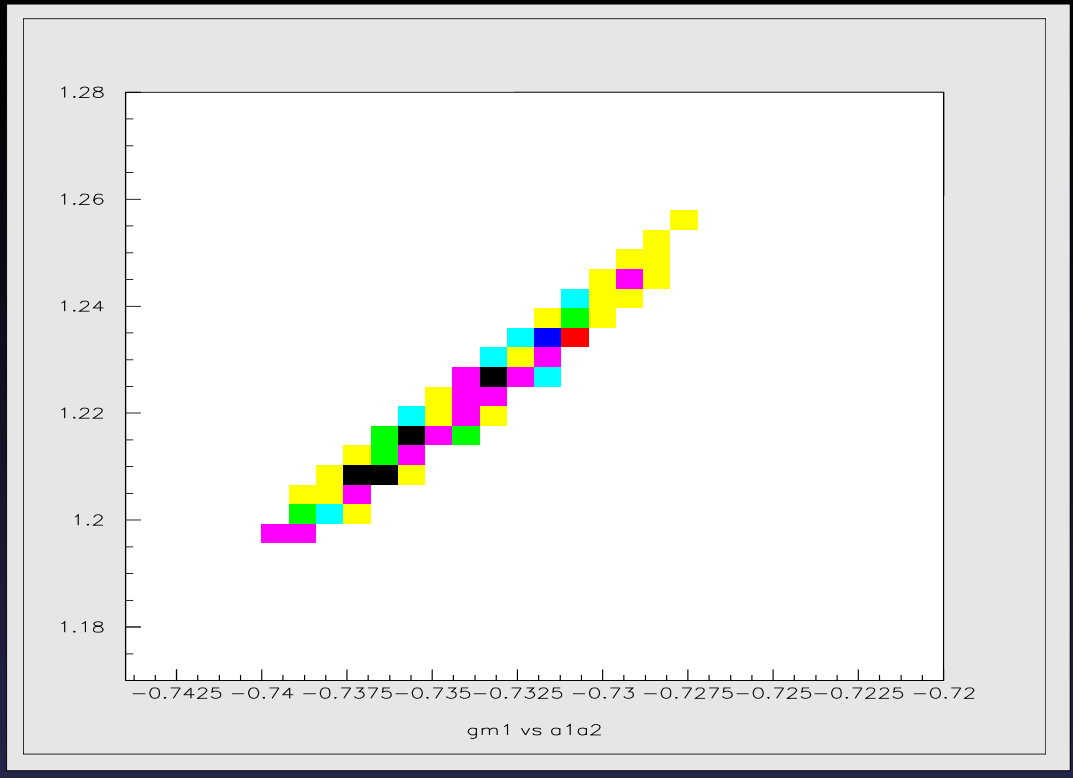
Total Corrected Background

- The picture at left shows the background estimate after Ke3 has been scaled by a factor of 4.47, that necessary to obtain a good fit to the data.
- The points are data, while the blue histogram is signal+background MC. The green histogram is the total background MC. The yellow line is the shape of the $\pi^+\pi^-\pi^0$ background, while the red line is that of the $\pi e\nu$ background.
- The sum of the background events under the mass peak is now 671 +/- 41 events, in agreement with John's estimate.



Derived Parameters for $K_L \to \pi^+\pi^-\gamma$

- The result of John's analysis was:
  - G_{M1} = 1.229 +/- 0.035(stat) +/- 0.087(syst)
  - a1/a2 = -0.733 +/- 0.007(stat) +/- 0.014(syst)
  - G_{E1} < 0.14 (90 %CL) , = 0 best fit
- The correlation between g_{M1} and a1/a2 as shown at right is approximately 0.993



Derived Parameters for $K_L \to \pi^+\pi^-\gamma$

- For the purpose of comparison against older analyses of this decay mode, it is useful to compute:
  - $< |g_{M1}| >$: the average amplitude for M1 direct photon emission (i.e. without a form factor)
  - DE/(DE+IB): total percentage of photon emission that is Direct Emission (M1).
  - R: the relative strength of M1 versus E1 emission.
- For more details, see ~ronquest/writeups/97pmgvacnote.ps

Average g_{M1}

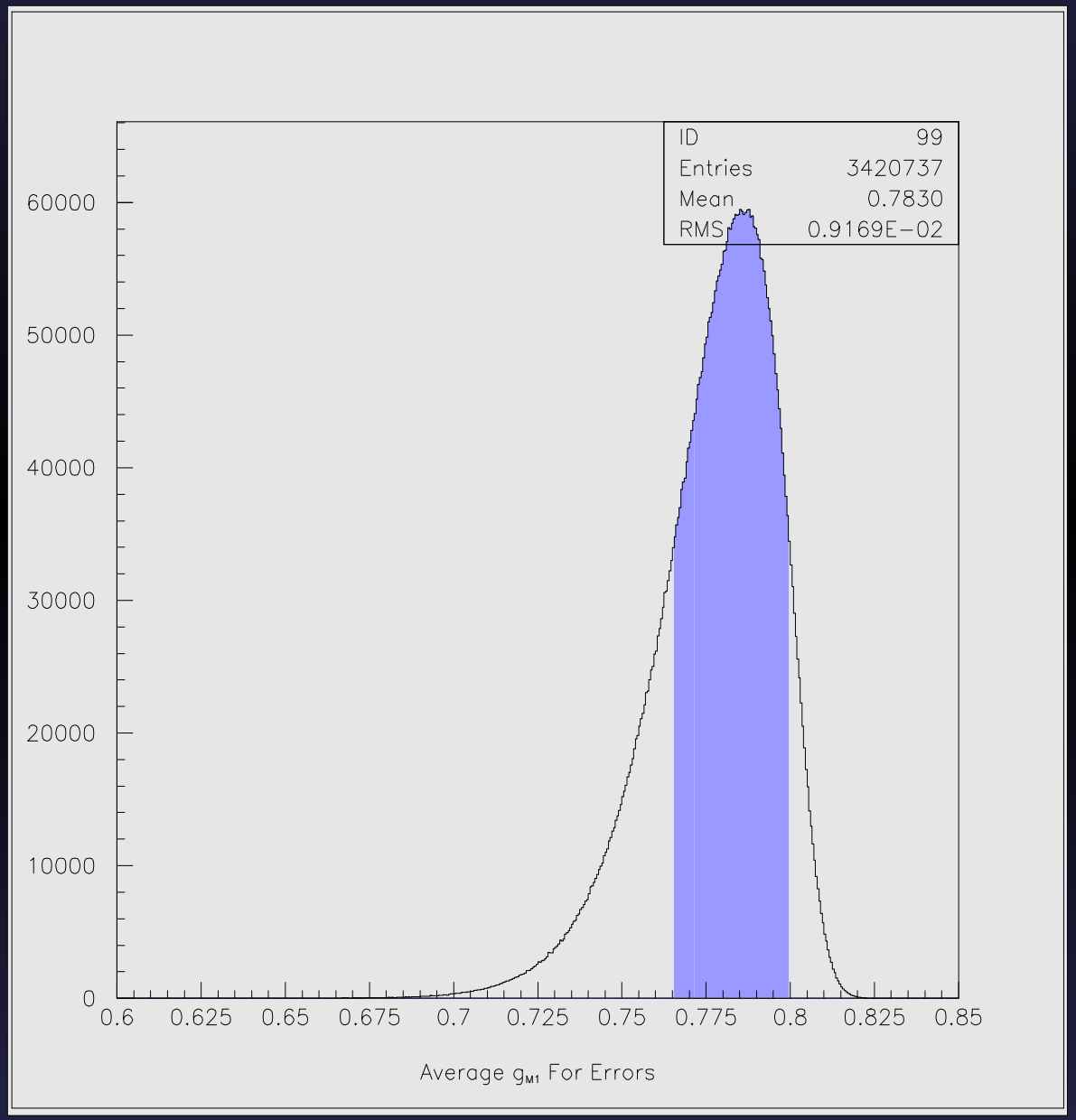
- This quantity is the magnitude of the amplitude for M1 photon emission averaged over all phase space – in this case, E_γ and $\cos(\theta)$.
- In order to find the value of $< | g_{M1} | >$ for John's numbers, I chose pairs of g_{M1} and a1/a2 according to a skewed 2D gaussian with variances equal to those of each parameter, and a correlation parameter ρ equal to 0.993.

Average g_{M1}

- After plotting the value of $< | G_{M1} | >$ for many chosen pairs of fit parameters, a distribution of $< | G_{M1} | >$ can be used to extract the central value and error bounds on $< | G_{M1} | >$.
- The central value is given by the location of the maxima on this plot.
- The error bounds are the two points of equal probability between which 68% of the area under the probability curve resides.

Average g_{M1}

- This is the probability distribution of $< | G_{M1} | >$ from which the value $0.79\ ^{+0.01}_{-0.02}$ is extracted.



M1/E1 ratio

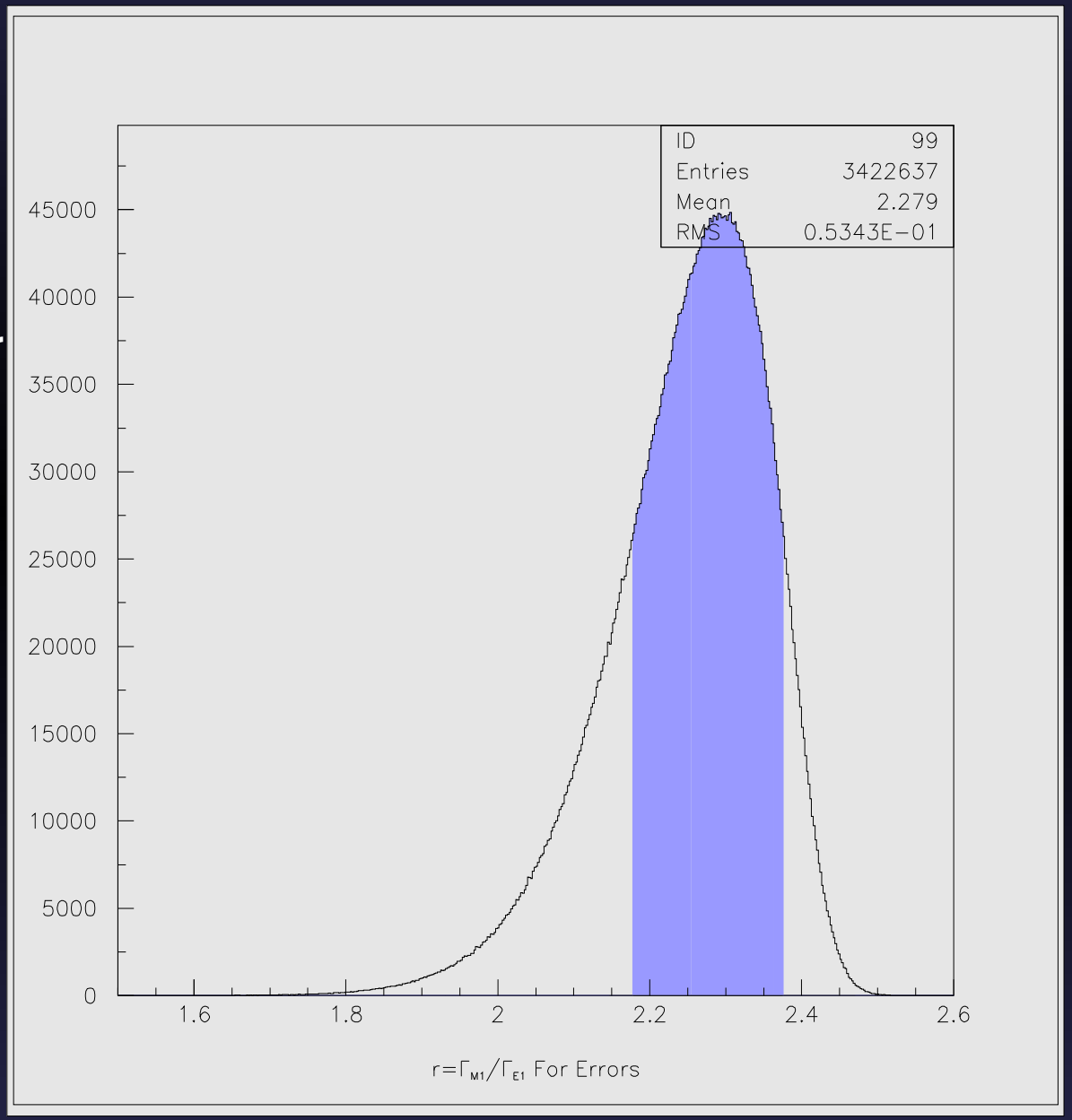
- The parameter r, which is the ratio of the partial widths of M1 and E1 photon emission,

$$r = \frac{\Gamma^{M1}_{K_L \to \pi\pi\gamma}}{\Gamma^{E1}_{K_L \to \pi\pi\gamma}} \overset{g_{E1} \to 0}{\approx} \frac{\Gamma^{M1}_{K_L \to \pi\pi\gamma}}{\Gamma^{IB}_{K_L \to \pi\pi\gamma}}$$

can be calculated in much the same way as $< I\, g_{M1}\, I >$ - by calculating the value of the partial widths using many different pairs of g_{M1} and a1/a2.

M1/E1 ratio

- This is the probability distribution of the M1/E1 ratio r from which the value $2.31\ ^{+0.07}_{-0.13}$ is extracted.
- This is valid for E_γ >20MeV



DE/(DE+IB)

- DE/(DE+IB), the ratio of the partial width for direct photon emission to the partial width of the entire decay mode can be expressed as:

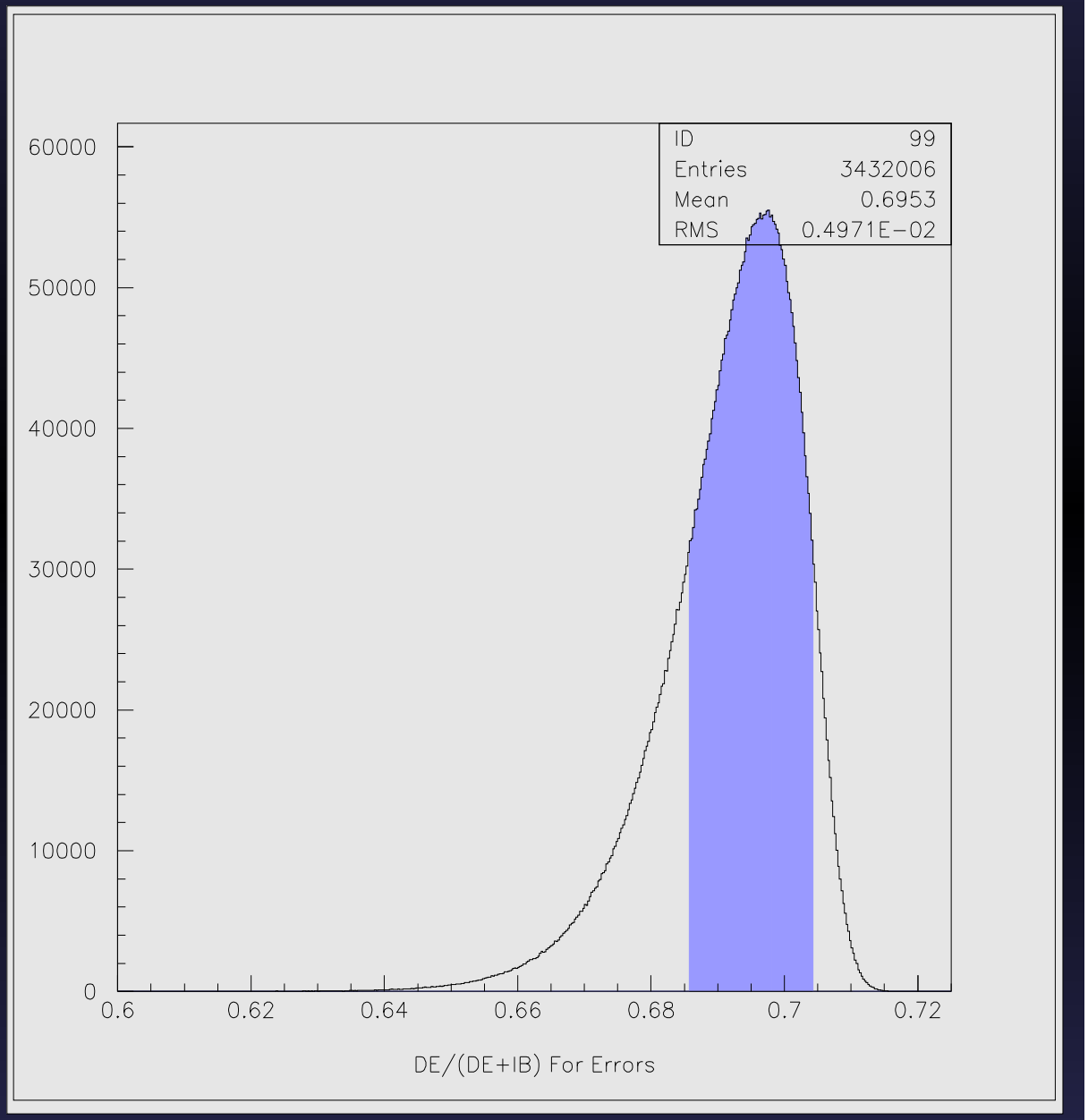
$$\frac{DE}{DE+IB}=\frac{\Gamma^{M1}_{K_L\to\pi\pi\gamma}}{\Gamma^{M1}_{K_L\to\pi\pi\gamma}+\Gamma^{IB}_{K_L\to\pi\pi\gamma}}$$

$$\overset{g_{E1}\to 0}{\approx}\frac{\Gamma^{M1}_{K_L\to\pi\pi\gamma}}{\Gamma^{M1}_{K_L\to\pi\pi\gamma}+\Gamma^{E1}_{K_L\to\pi\pi\gamma}}=\frac{r}{1+r}$$

and can be computed in the same way as the other two parameters.....

DE/(DE+IB)

- This is the probability distribution of DE/(DE+IB) from which the value $0.698\ ^{+0.007}_{-0.012}$ is extracted.
- This is valid for E_γ >20MeV

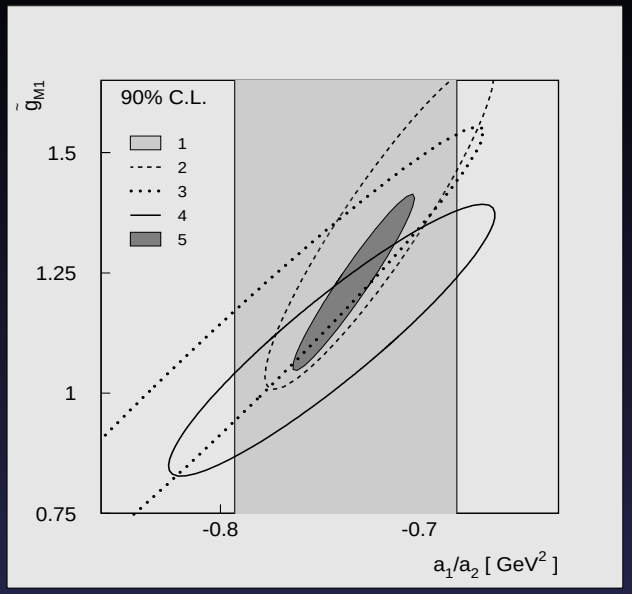


Summary I

- The background for $K_L \rightarrow \pi^+\pi^-\gamma$ has been determined to consist of
  - ~80% $K_L \rightarrow \pi\varepsilon\nu$
  - ~20% $K_L \rightarrow \pi^+\pi^-\pi^0$
- The total background under the mass peak has been estimated to be 671 +/-41 events, or ~0.6 %
  - We chose to scale up K_e3 due to the E/p and Cos(θ) distributions of the background, however, extra $K_\mu 3$ can't be ruled out-it looks similar to K_e3!

Summary II

- John measured:
  - $|g_{M1}| = 1.229 \pm 0.035 \pm 0.087$
    - Compare to $K_L \to \pi^+\pi^-e^+e^-$ (97+99): 1.11 +/- 0.12 +/- 0.08
  - a1/a2=-0.733 +/- 0.007 +/- 0.014
    - Compare to $K_L \to \pi^+\pi^-e^+e^-$ (97+99): -0.744 +/- 0.027 +/- 0.032
    - Compare to $K_L \to \pi^+\pi^-\gamma$ (96 data): -0.737 +/- 0.034
  - |gE1| < 0.14 (90% CL) , best fit =0
    - Compare to $K_L \to \pi^+\pi^-e^+e^-$ (97+99): < 0.03 (90% CL)
- Graphically:
  - $K_L \to \pi^+\pi^-\gamma$ (97): filled contour
  - $K_L \to \pi^+\pi^-e^+e^-$ (97+99):solid contour



Summary II

- Using John's results (g_{E1} was set to zero) the following have been determined:
- $< | g_{M1} | > = 0.79\ ^{+0.01}_{-0.02}$
  - Result from $K_L \to \pi^+\pi^-e^+e^-$ (97+99): 0.74 +/- 0.04
- $R = 2.31\ ^{+0.07}_{-0.13}$
- $DE/(DE+IB) = 0.698\ ^{+0.007}_{-0.012}$
  - Result from $K_L \to \pi^+\pi^-\gamma$ (96 data only): 0.683+/-0.011

Extra Slides
Notes On Analysis

Analysis cuts: $K_L \rightarrow \pi^+\pi^-\gamma$

Criterion:	Event in sample if…
• Recon832	Recon832 ok
• L1VER832	istat ≠ 0
• NTRKS	NTRKS = 2
• Clusters	1 or more non-track clusters
• Magnet offset χ^2	< 50
• Vertex χ^2	< 50
• Vertex Z	120.0 < VTXZ < 158.0
• Track X-separation in CsI	> 3 cm
• Track momentum	> 8 GeV
• π^{+-} E/p	< 0.85 GeV
• Pp0kine	< -0.0055 GeV^2
• γ energy (Lab)	> 1.5 GeV
• γ energy (Center of Mass)	> 20 MeV
• γ-track separation in CsI	> 30 cm
• Fusion χ^2	< 48
• γ CsI pipe block exclusion	smallring > 4.5 cm
• γ CsI outer fiducial cut	seedring < 18.1 cm
• $\pi^+\pi^-$ invariant mass	< 0.492 GeV
• $\pi^+\pi^-\gamma$ momentum	$25.0 < P_{\pi+\pi-\gamma} < 160.0$
• $\pi^+\pi^-\gamma$ P_T^2	$< 2.5 \times 10^{-4}$ GeV^2
• $\pi^+\pi^-\gamma$ invariant mass	$0.48967 < M_{\pi+\pi-\gamma} < 0.50567$

John's Analysis Cuts