

An Update on  
Measuring  
 $B(\pi^0 \rightarrow e^+e^-\gamma)$  using  
 $K_L \rightarrow 3\pi^0$

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9 September 2006

# Outline

- Current PDG Value
- Sample & Statistics
- Systematics
- To Do Timeline

## PDG Average for $\pi^0$ Dalitz Decay

$$\frac{\Gamma(\gamma e^+ e^-)}{\Gamma(2\gamma)} = (1.213 \pm .030)\%$$

From

$(1.25 \pm .04)\%$  Schardt 1981,  $\pi^- p \rightarrow n\pi^0$

$(1.166 \pm .047)\%$  Samios 1961, 3071 events,  
 $\pi^- p \rightarrow n\pi^0$

$(1.17 \pm .15)\%$  Budagov 1960, 27 events

No measurements of  $\pi^0$  Dalitz decay BR for  $\sim 25$  years. The 2.5% uncertainty on the current number affects many other measurements. KTeV has plenty of events to reduce the uncertainty, and this will have a broad impact on other measurements.

# Sample & Statistics

- Signal:  $K_L \rightarrow 3\pi^0$ , where one  $\pi^0 \rightarrow e^+e^-\gamma$
- Normalization:  $K_L \rightarrow 3\pi^0$  with  $\pi^0 \rightarrow \gamma\gamma$
- Ideally, use trigger 6 for both, but too restrictive (requires exactly 6 clusters at L3)

Trigger 6 for  $K_L \rightarrow 3\pi^0$  events, for normalization (prescale by 10)

## Trigger 14 for Dalitz decay events

Trigger 14: combination charged & neutral trigger; similar to trigger 1 (charged mode trigger for  $\epsilon'$ ); requires 7 or more HCC, has HA veto

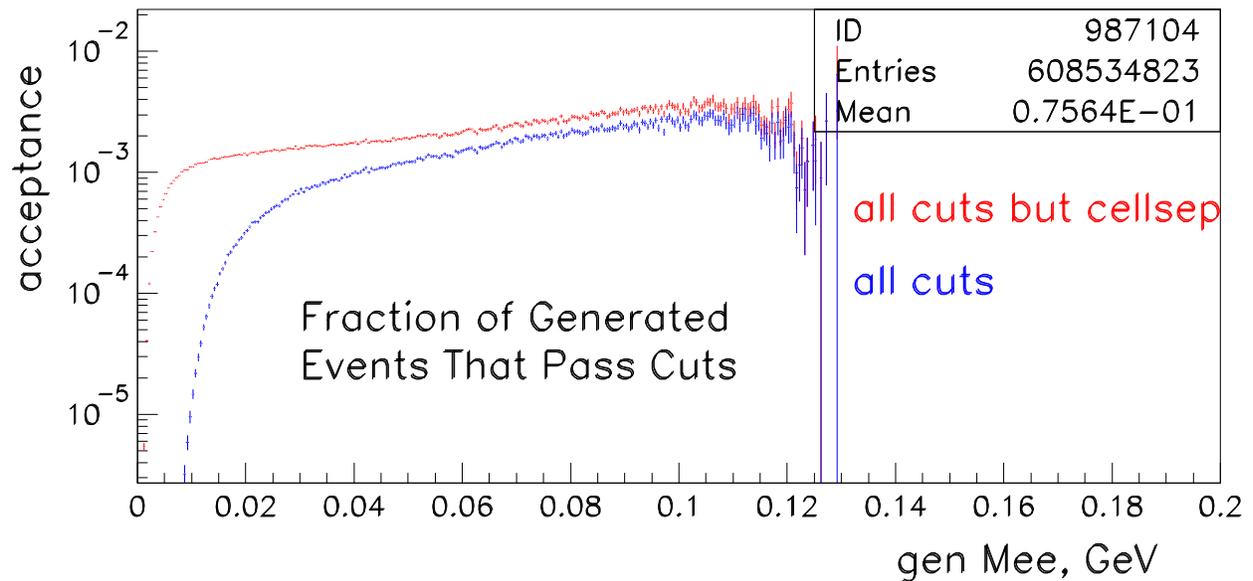
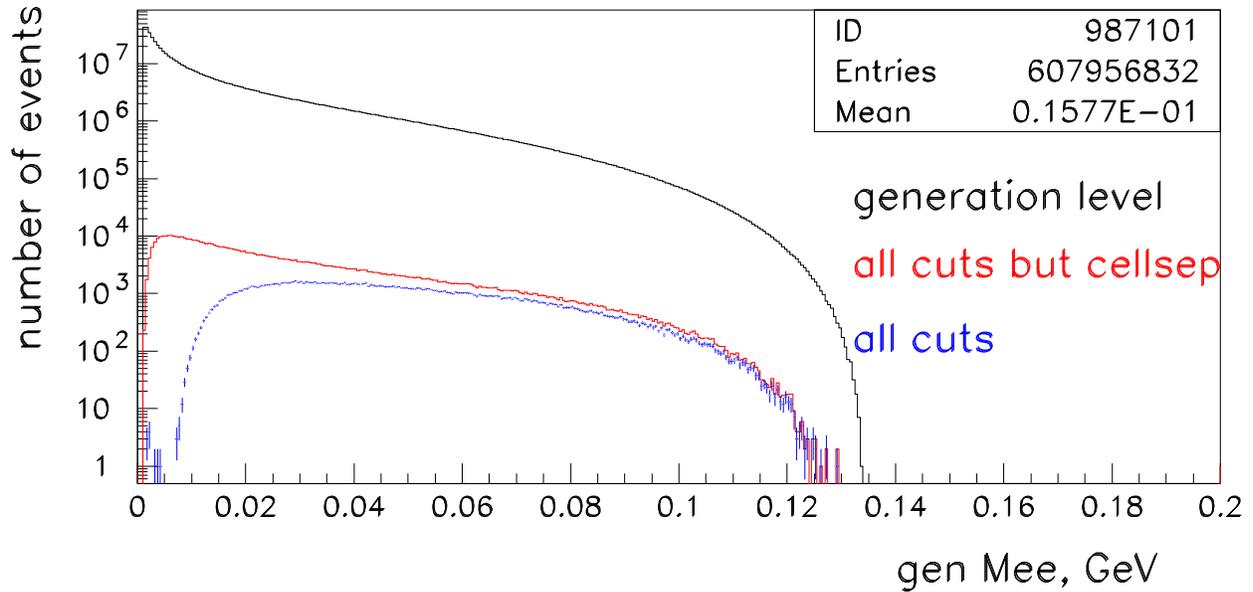
Main criteria for event selection:

- kaon mass:  $[0.490, 0.505]$  GeV/ $c^2$
- kaon z:  $[123.0, 158.0]$  m
- kaon energy:  $[40.0, 160.0]$  GeV
- min cluster energy: 3.0 GeV
- cell separation cut of 3

Cell separation cut allows us to use tracking efficiency studies from  $V_{us}$ .

Statistical uncertainty will be  $\sim 0.4\%$ .

# Cell Separation Cut and $e^+e^-$ Mass



Also, note that  $e^+e^-$  mass resolution is  $\sim 1$  MeV.

## Sample, 3pi0 and Dalitz

Number of events in data and Monte Carlo, and acceptances (with errors) for both modes, overall and broken out into intensity ranges.

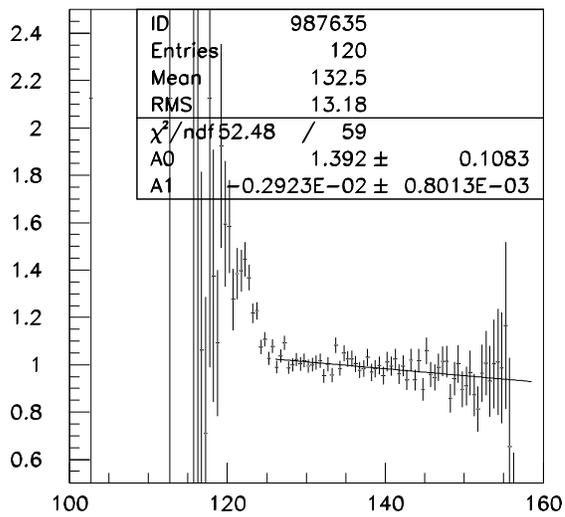
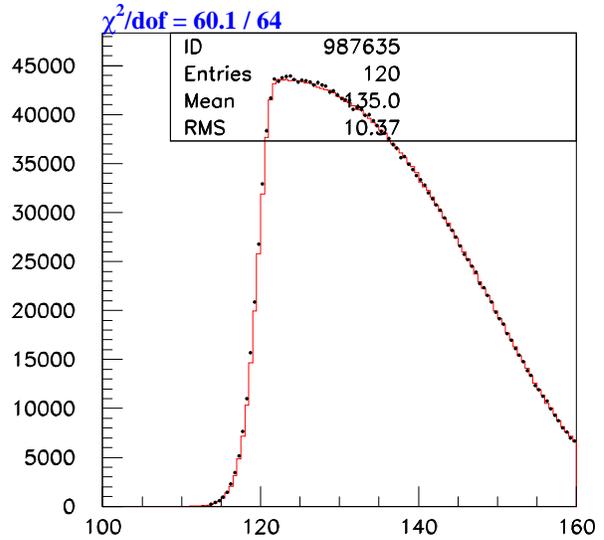
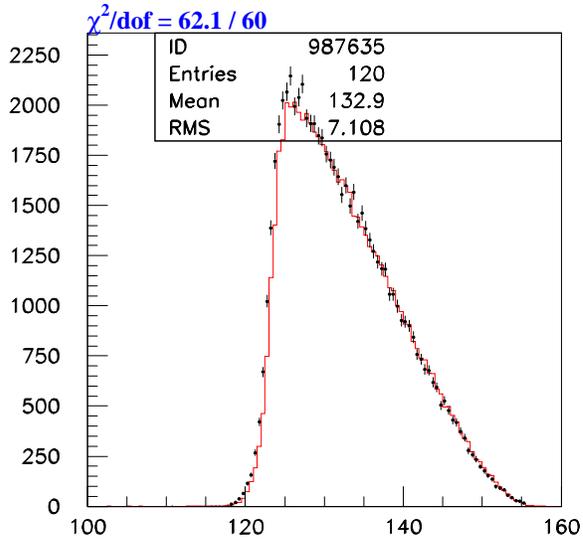
Mode	Data Events	MC Gen	MC Events
3pi0	2202500	327276652	7767562
Dalitz	68592	361114834	150610
3pi0 low	20386	62614835	1951392
dal low	623	79686461	45175
3pi0 med	997504	132643666	3500454
dal med	31581	146373771	68682
3pi0 high	1174531	189377282	4160567
dal high	35952	208946237	79957

Mode	Acceptance ( $10^{-2}$ )	Error ( $10^{-2}$ )
3pi0	2.37339326	0.00084142
Dalitz	0.04170695	0.00010745
3pi0 low	3.11650107	0.00219594
dal low	0.05669094	0.00026665
3pi0 med	2.63899069	0.00139177
dal med	0.04692234	0.00017900
3pi0 high	2.19697260	0.00106518
dal high	0.03826678	0.00013530

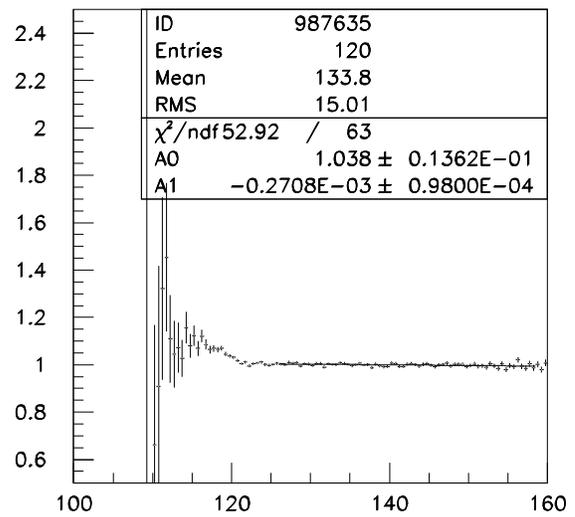
The low intensity data numbers from both modes are from runs 14090 and 14092, which were crunched from QKE tapes. The low intensity MC numbers were obtained using an accidental file containing only these two run numbers.

# Systematics: Cut Variations

## Kaon Z



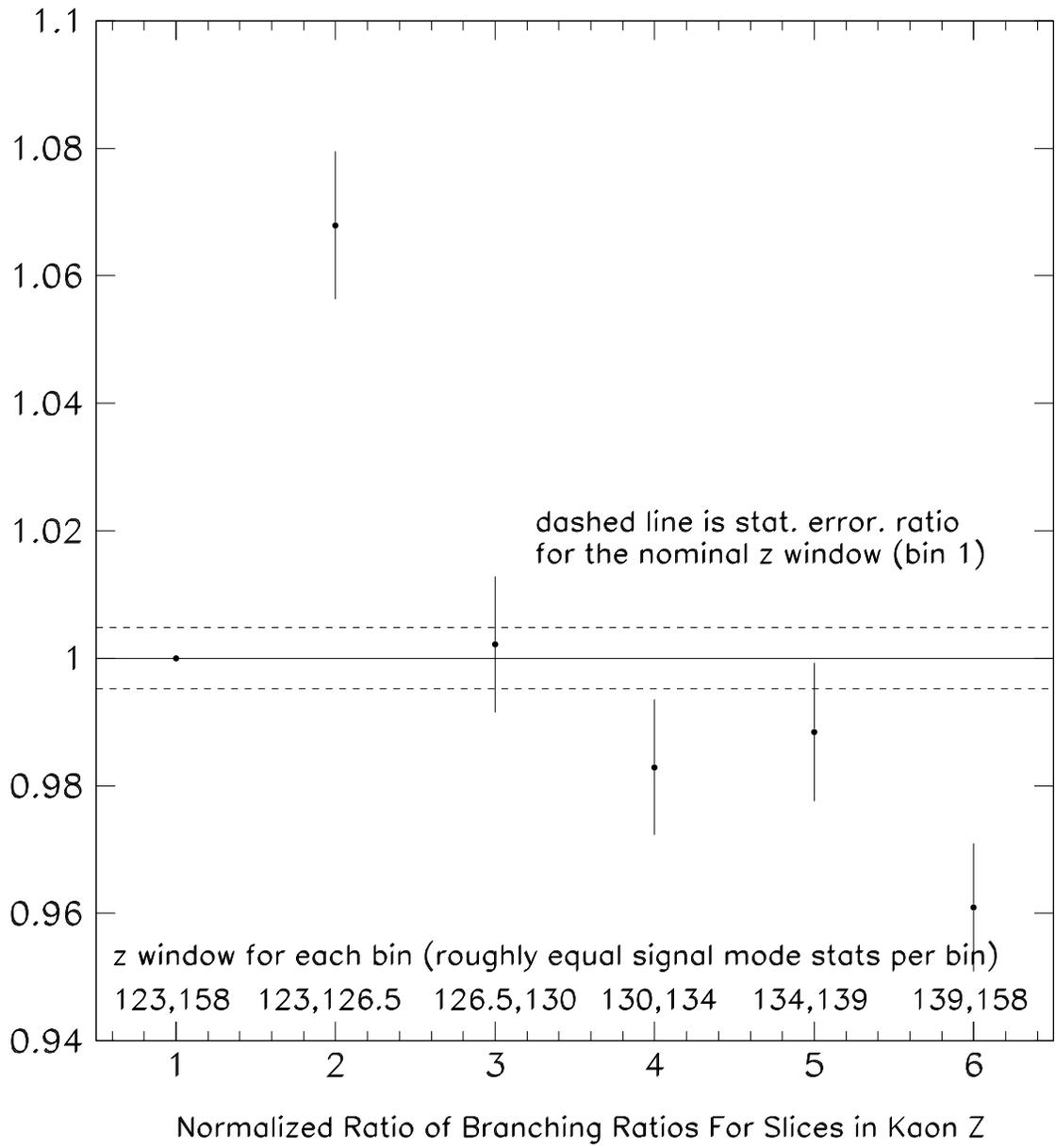
dalitz



3pi0

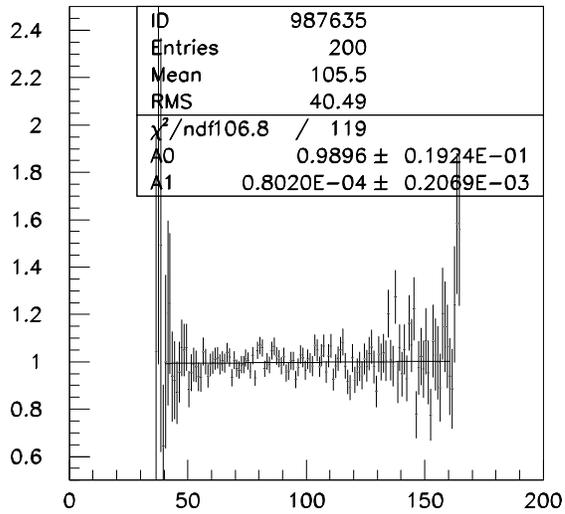
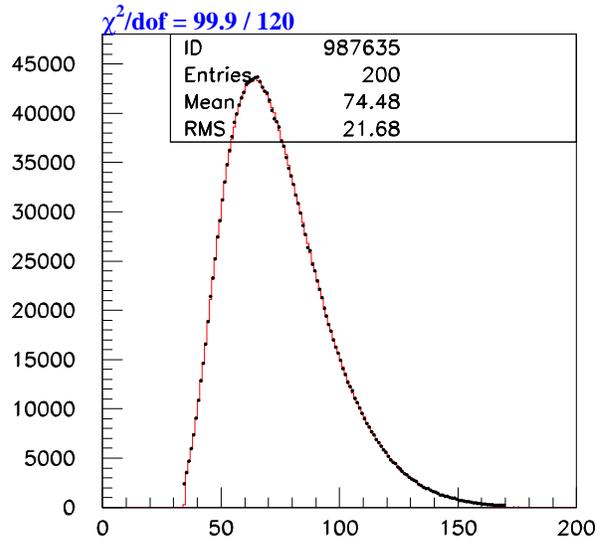
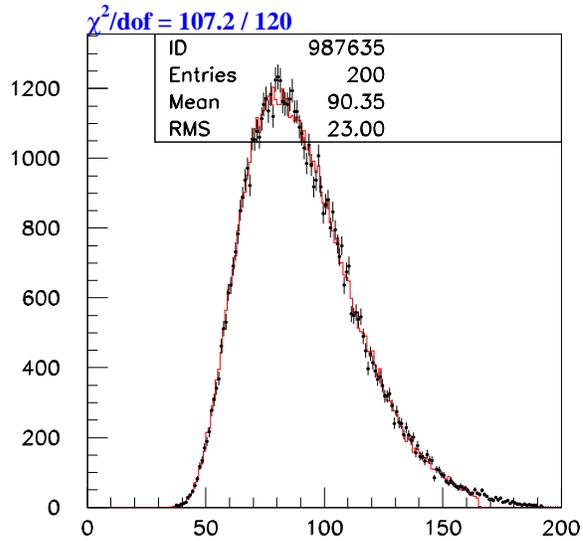
2 known items contributing to this problem - vtx z cut, energy scale

# Kaon Z

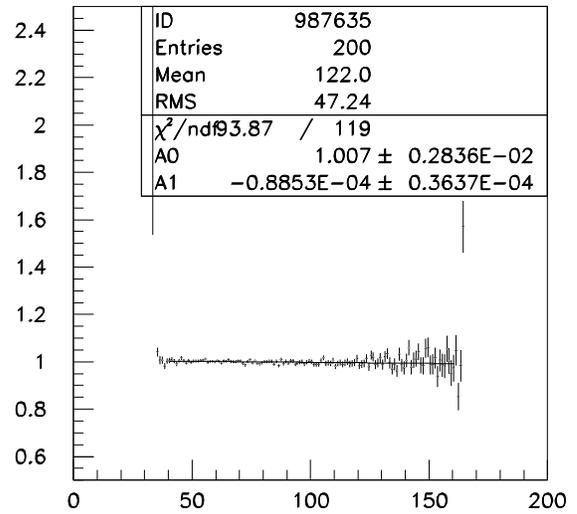


# Systematics: Cut Variations

## Kaon Energy

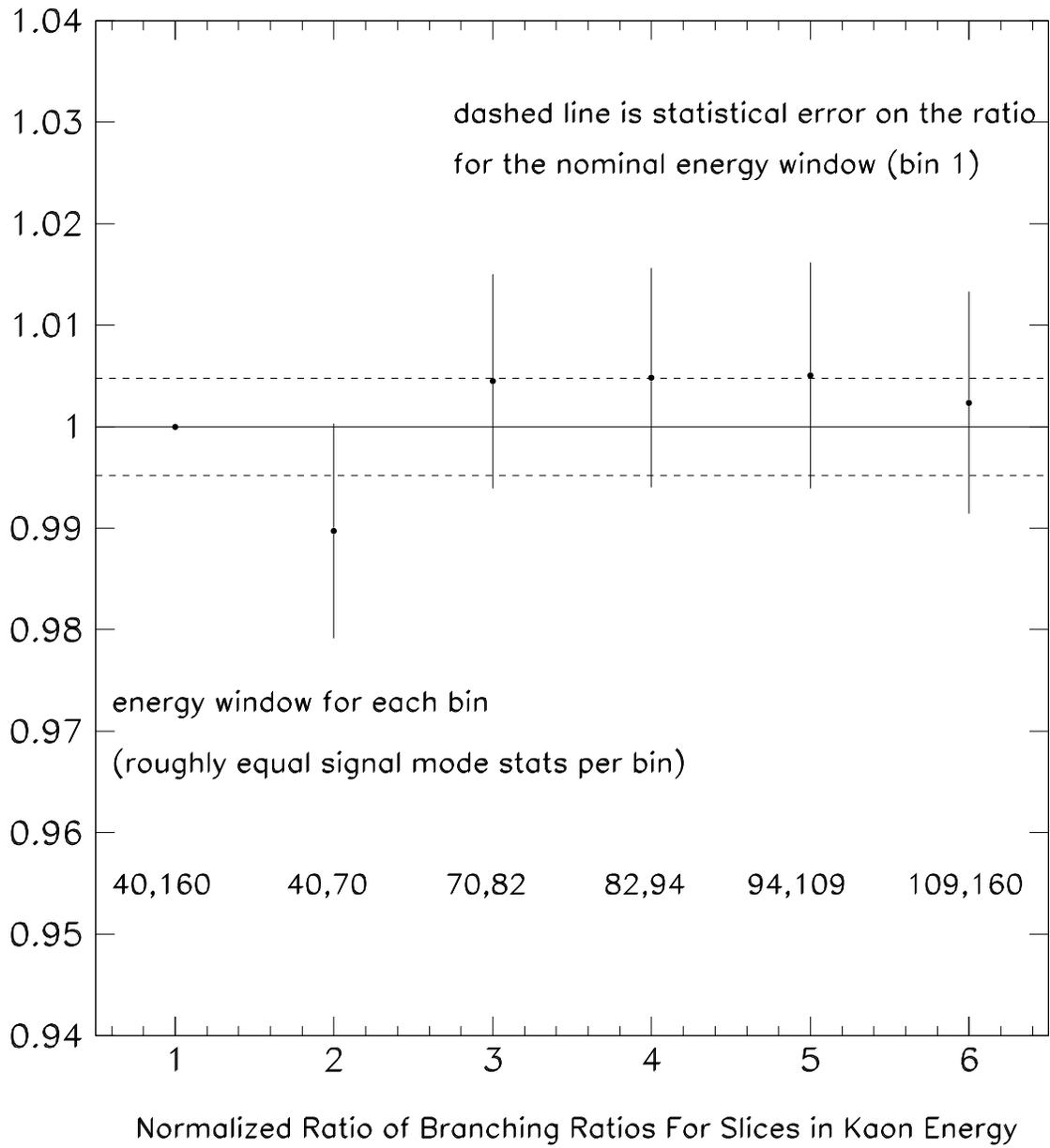


dalitz



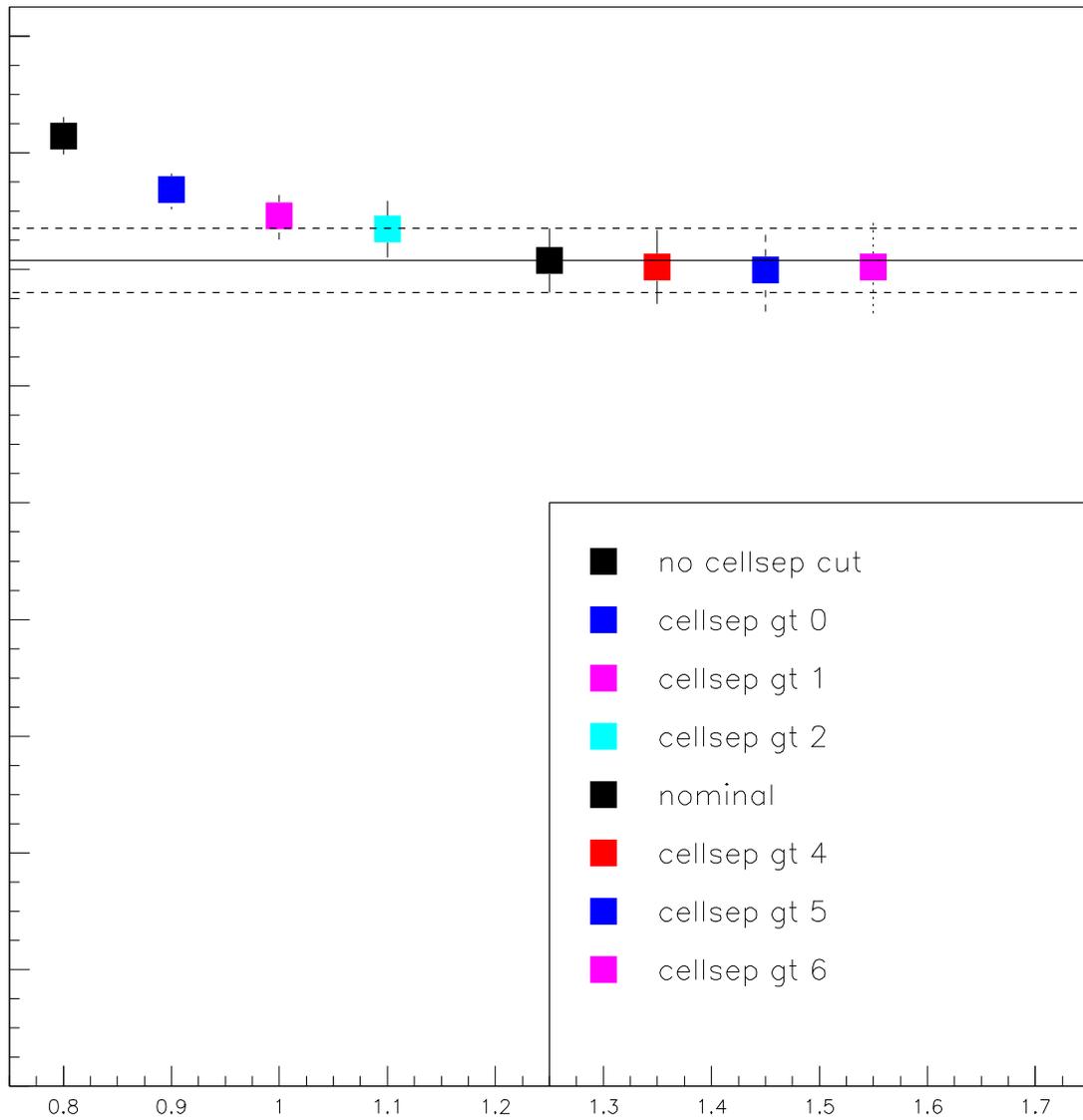
3pi0

# Kaon Energy



# Varying the Cell Separation Cut

Ratio of BR, Varying the CellSep Cut



## Systematics: Trigger Efficiency

Run dalitz analysis on random accepts from trigger 6 (QKS tapes) and check that those events that reconstruct as dalitz decays show up in trigger 14.

- Using nominal cuts, found 207 dalitz events, all of which are in trigger 14
- Remove cell separation cut – 716 dalitz events, 715 of which are in trigger 14
- This corresponds to an inefficiency of  $1/716$  (which will be a correction) and an error on that correction of  $1/716$  ( $=0.14\%$ )

## Systematics: Data Sample Integrity

Two different triggers, different data streams. Need to make sure I'm using same runs, spills in both modes.

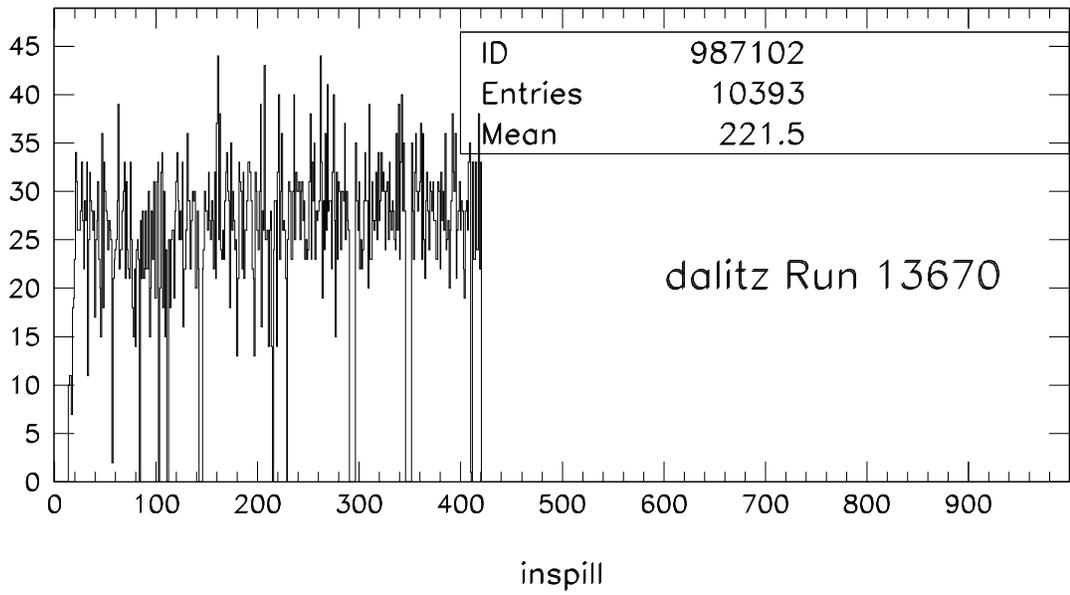
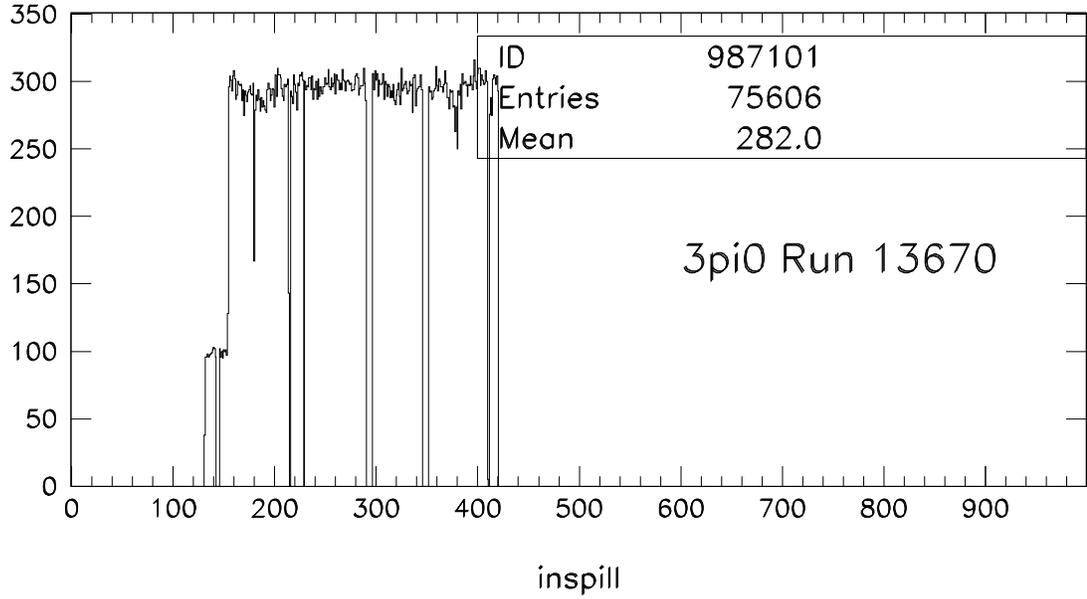
First: Use inspill distributions. Compare each run's  $3\pi^0$ :dalitz ratio to average ratio.

Found 8 runs with extremely low ratios compared to average.

- 13670
- 13834
- 13844
- 13845
- 14024
- 14292
- 14319
- 14428

These runs represent about 5% of dalitz events.

Runs 13670, 14292



Fix: Exclude the missing spills from my data sample

13834, 13844, 13845, 14024, 14319, 14428

No spills missing, but  $3\pi^0$ :dalitz ratio was about  $2/3$  the average ratio ...

One of the daq planes was missing from each of these runs.

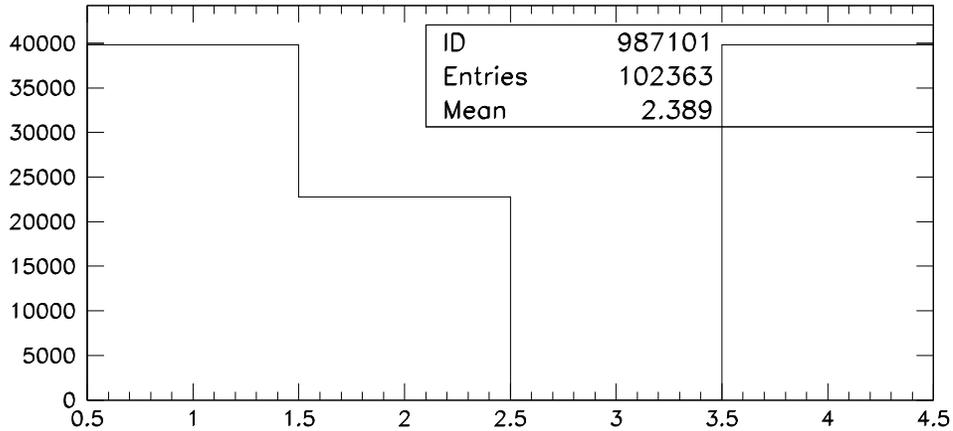
During QKT split, the QKS tape corresponding to each of these missing daq planes failed.

Tried to recover the QKS tapes from dcache (recrunched them for trigger 6).

# Recovery of QKS Tapes ultimately failed

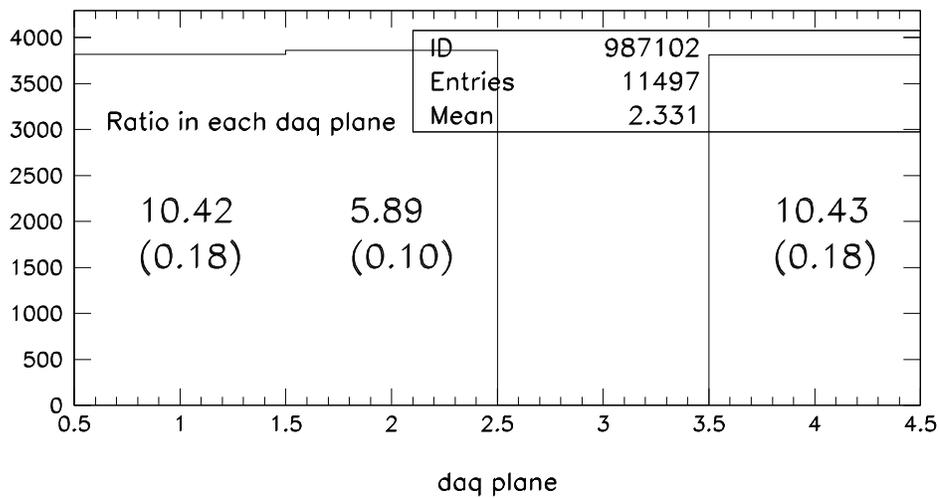
3pi0 Run 14428

Average 3pi0-dalitz ratio over all runs  
10.3203 (0.0092)



Dalitz Run 14428

daq plane

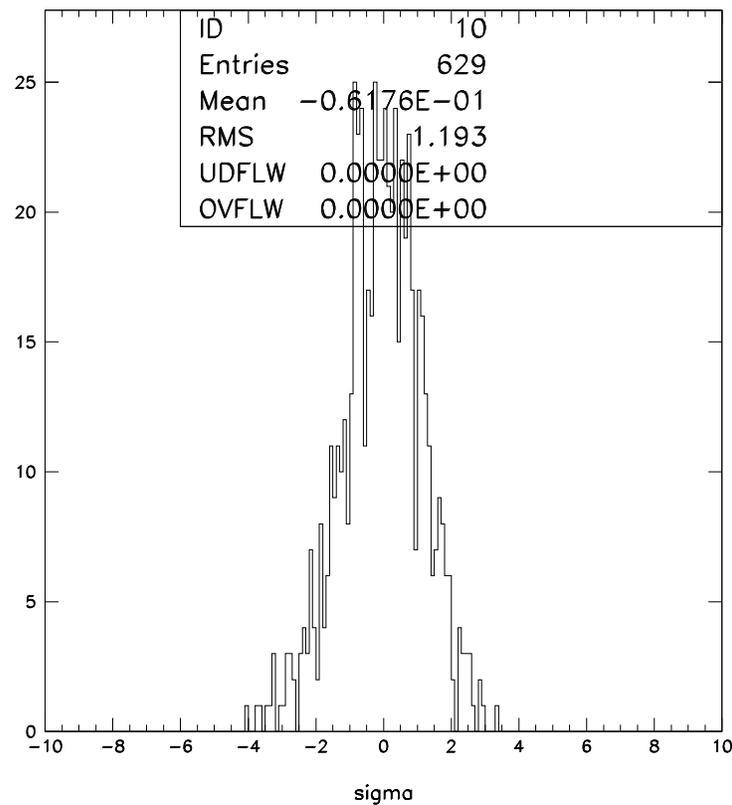


Appeared to work, but each plane from a recovered QKS tape still had a poor ratio.

Threw out these runs.

## Check Ratios Again After Removing Bad Runs and Spills

Distribution of the standard deviation from the average  $3\pi^0$ :dalitz ratio for each daq plane in each run.



$3\pi^0$  events: dalitz events 13792261 : 1321046

Average ratio 10.4404 ( $\pm 0.0095$ )

Within 1 sigma: 390 (62.0%)

Within 2 sigma: 570 (90.6%)

Within 3 sigma: 619 (98.4%)

Within 4 sigma: 628 (99.8%)

1/629 outside 4 sigma, at -4.0094 sigma

## Systematics: Form Factor

After fixing bug in which `pi0_slope_param` was never initialized in 832, ran with nominal value  $0.032 \pm 0.004$ .

Then ran with `pi0_slope_param` one sigma from nominal, 0.028.

Acceptance decreases from nominal by 0.48% ( $\pm 0.33\%$ ).

With `pi0_slope_param` uninitialized (presumably zero), the acceptance decreased from nominal by 0.73% ( $\pm 0.39\%$ ).

Next, increase MC statistics to reduce the error.

Acceptance is very insensitive to the form factor!

## Systematics: Radiative Corrections

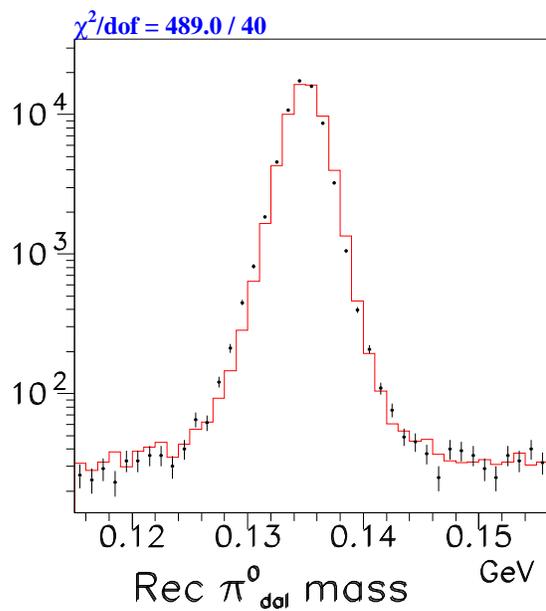
I redid the radiative corrections study after fixing the form factor bug.

Generated signal MC with no radiative corrections to compare with my nominal MC.

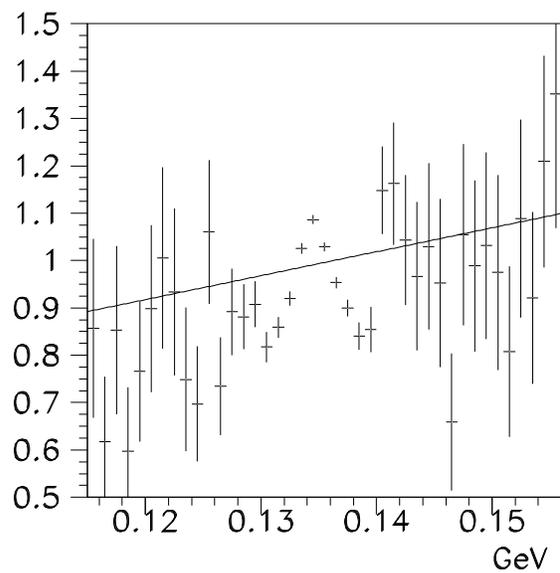
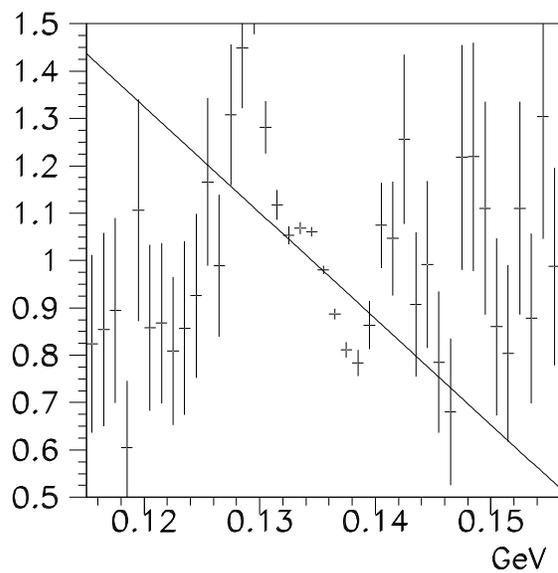
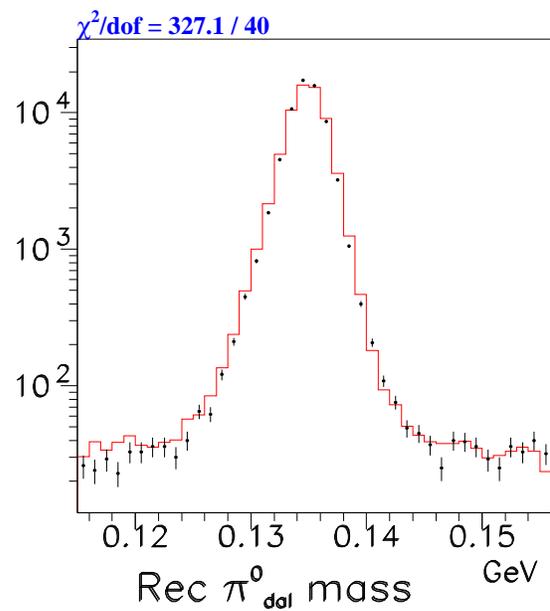
The acceptance changes by 5.28% ( $\pm 0.34\%$ ).

The  $\pi_{dalitz}^0$  mass peak shifts by  $\sim 34$  sigma, so the acceptance uncertainty due to radiative corrections is  $\sim 0.16\%$ .

MC with no  
radiative corrections

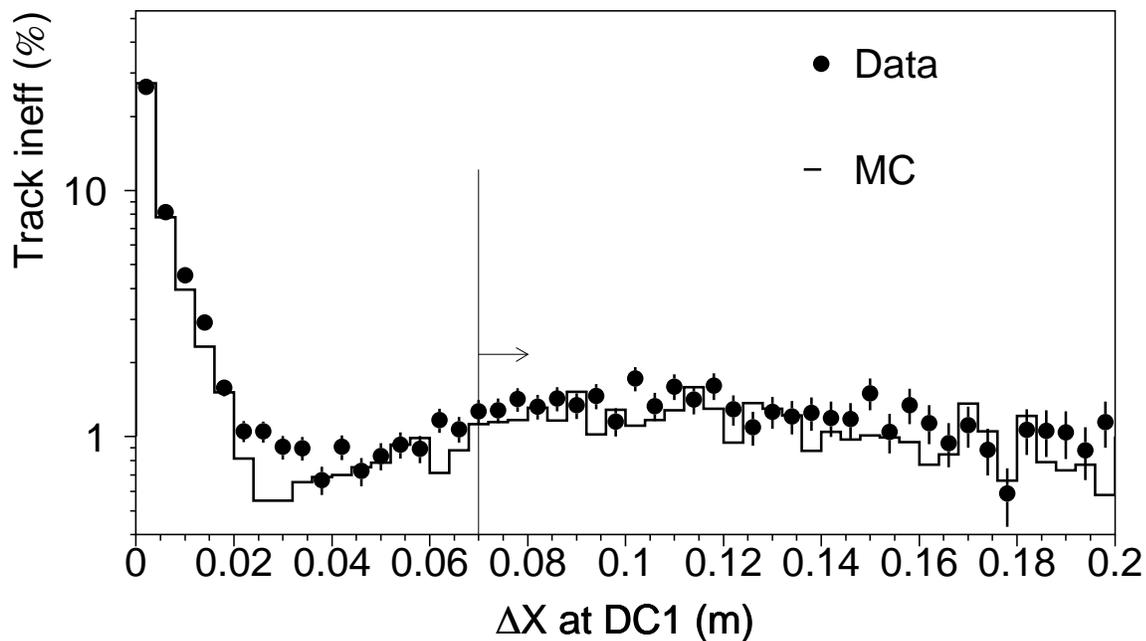


Nominal MC



## Systematics: Tracking Efficiency

Use the studies from  $V_{us}$ , which are valid when we apply a cellsep cut.



Plot from Branching Ratio paper from a study on tracking inefficiency as a function of track separation at DC1. Cell separation cut of 3 half-cells corresponds to  $\sim 2$  cm.

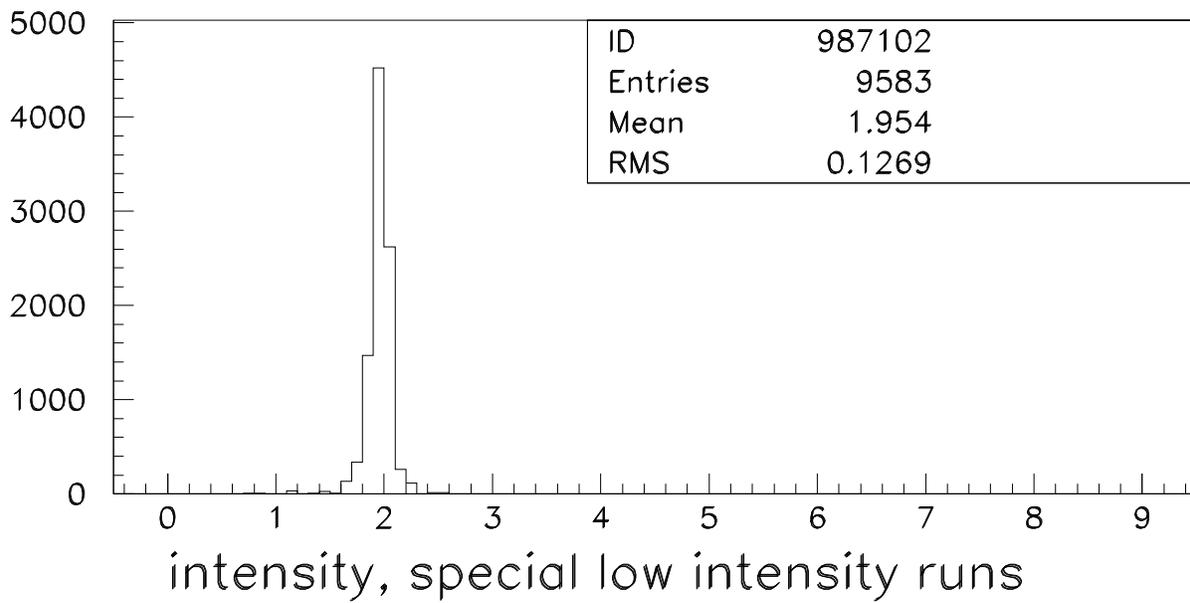
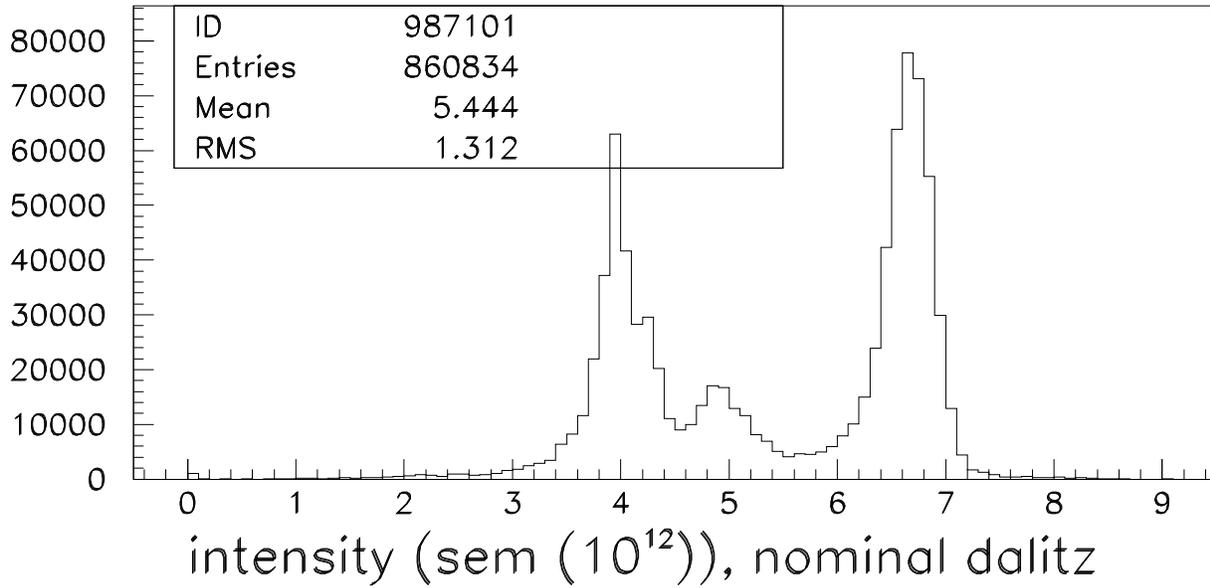
Also, I am in the process of studying tracking efficiency as a function of intensity.

## Systematics: Background

Background is very small. The main source is photon conversions at the vacuum window.

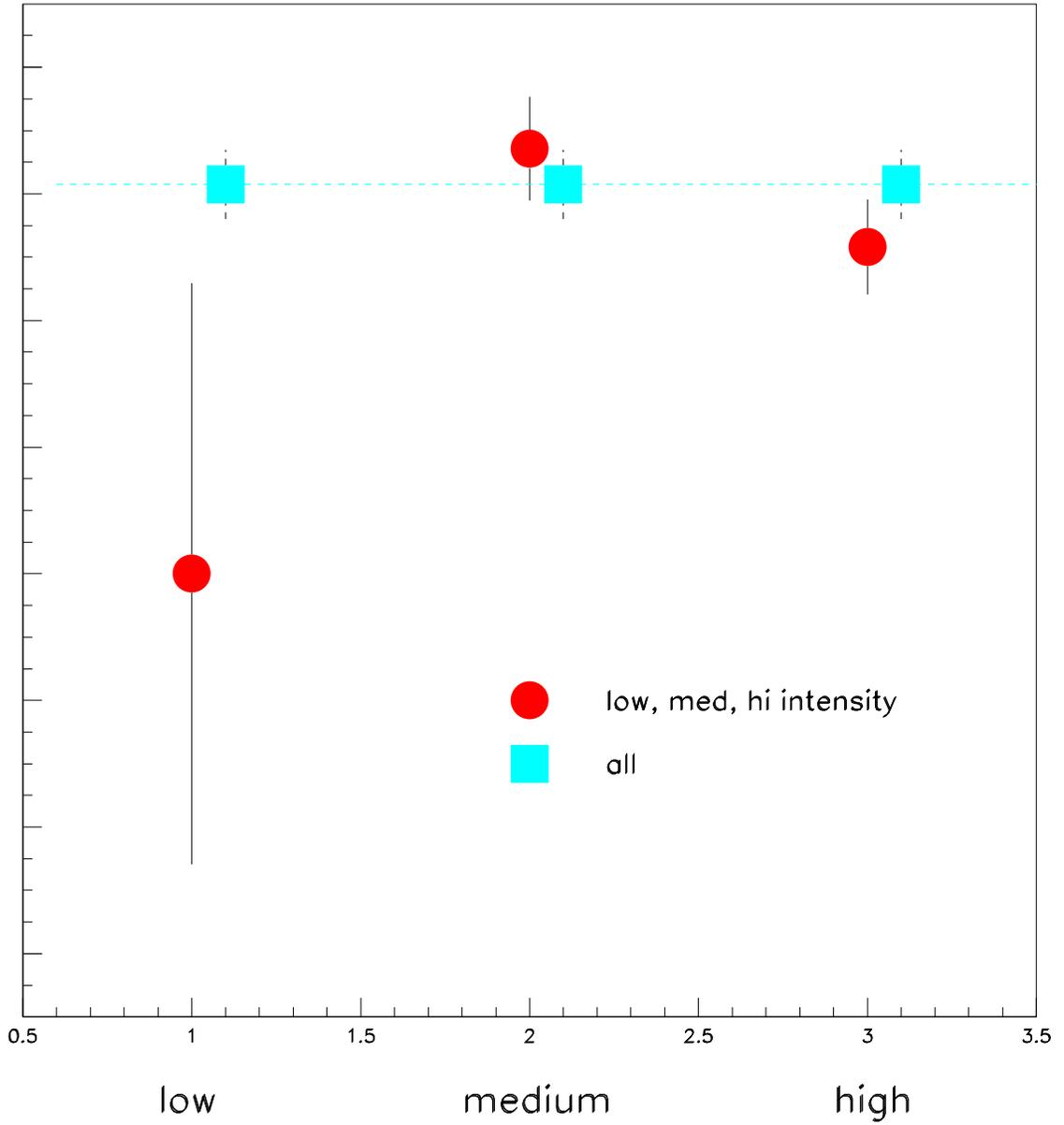
Currently generating  $3\pi^0$ s around the vacuum window in both triggers 6 and 14 to be analyzed with dalitz code.

In 99, ran with different intensities:



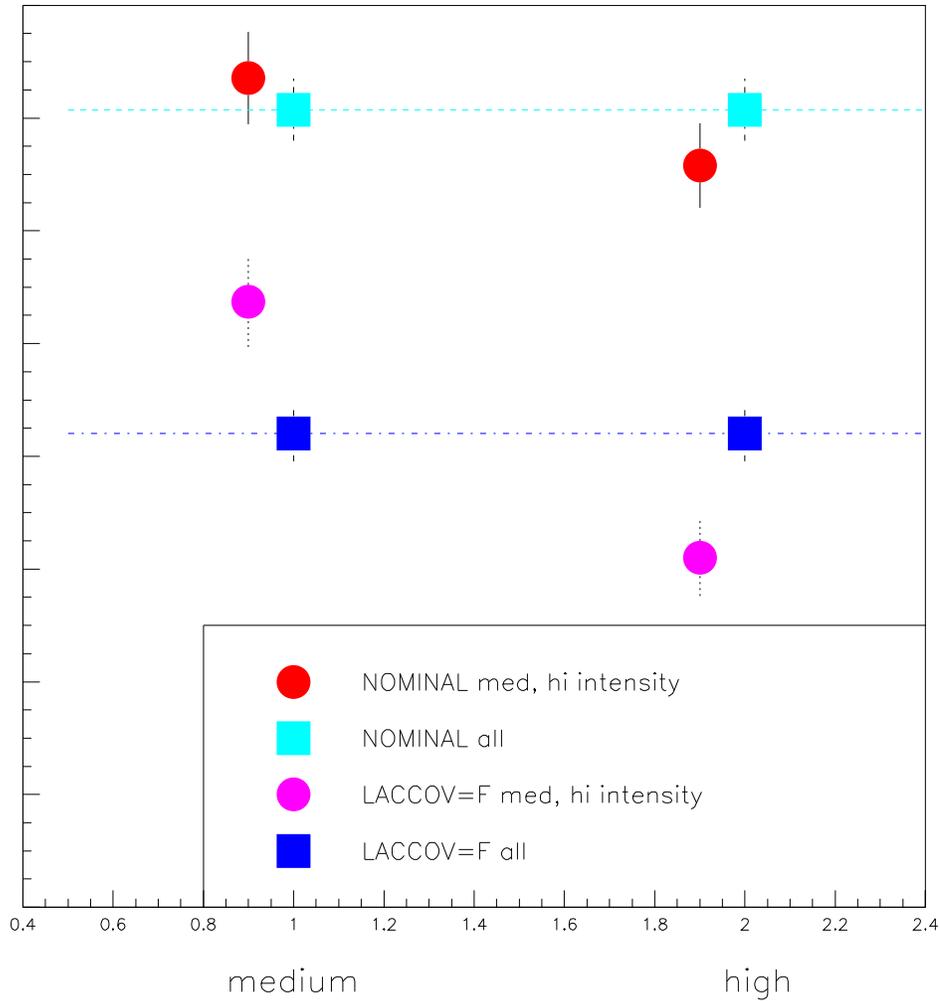
# Intensity Dependence

Ratio of BR vs Intensity



# Effect of Accidentals

Ratio of BR vs Intensity, Nominal and No Accidentals



With no accidentals, acceptance increases from nominal by  $36.2\% \pm 0.4\%$  in dalitz and 30% in  $3\pi^0$ . (recall ratio of br goes like  $\frac{dal\ data}{dal\ acc} \times \frac{3\pi^0\ acc}{3\pi^0\ events}$ )

**Notice:** With nominal MC, medium and high intensity samples give consistent results.

Several distributions are sensitive to accidentals (sod, pt, extra DC hits); error should be less than 0.5%.

# Systematics Table

Source of Systematic Error	Level of Uncertainty
Trigger Inefficiency	0.14%
Trigger 6 pre-scale	
Acceptance	
Form Factor	
Radiative Corrections	0.16%
Accidentals	
Background	
Monte Carlo Statistics	0.26%

# Cross Checks - To Do

- different time periods
- inbends/outbends
- magnet polarity

# Timeline to DPF

- Complete systematics table
- Early October: Look at the Dalitz branching ratio result
- Send around write-up of analysis
- Middle October: Phone meeting to show DPF talk
- October 29-November 3: DPF