Search for the Rare Decay $K_L^0 \to \pi^0 \nu \bar{\nu}$ at the E391a Experiment

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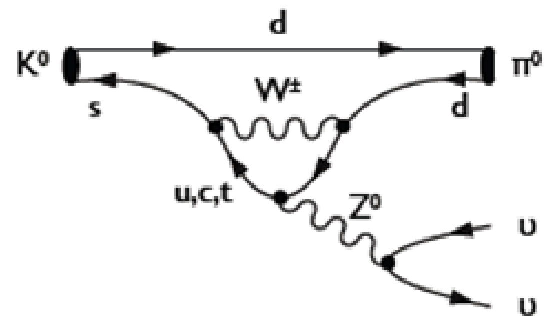
Jiasen Ma(The University of Chicago)

Outline

- Motivation
- Introduction of the Experiment
- Kaon Simulation and Flux
- Background Study
- Results and Conclusions

Why $K_L^0 \to \pi^0 \nu \bar{\nu}$

- $K_L^0 \to \pi^0 \nu \bar{\nu}$ is a direct CP violation process. Its branching ratio is directly proportional to the imaginary part of V_{td} in the CKM matrix of the Standard Model



- The theoretical uncertainty of the branching ratio is 1-2%

$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

- This makes it a powerful probe for the CP parameters in the Standard Model and possible new physics

- This decay is also sensitive to new heavy particles since it happens at the loop level.

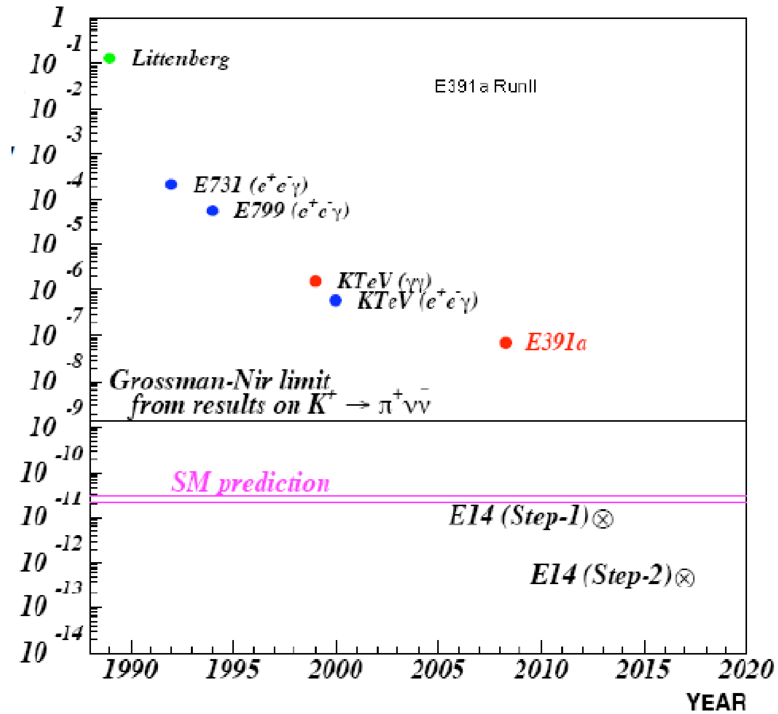
$$\mathrm{Br}(K^0_L \to \pi^0 \nu \bar{\nu})_{SM} = \kappa_L \left[\frac{\mathrm{Im}(V_{ts}^* V_{td})}{\lambda^5} X \right]^2$$

$$= (2.49 \pm 0.39) \times 10^{-11}$$

κ is related to the isospin breaking correction and X is a function of m_t and α_s

(F. Mescia and C. Smith, PRD76, 074017(2007))

The E391a Experiment



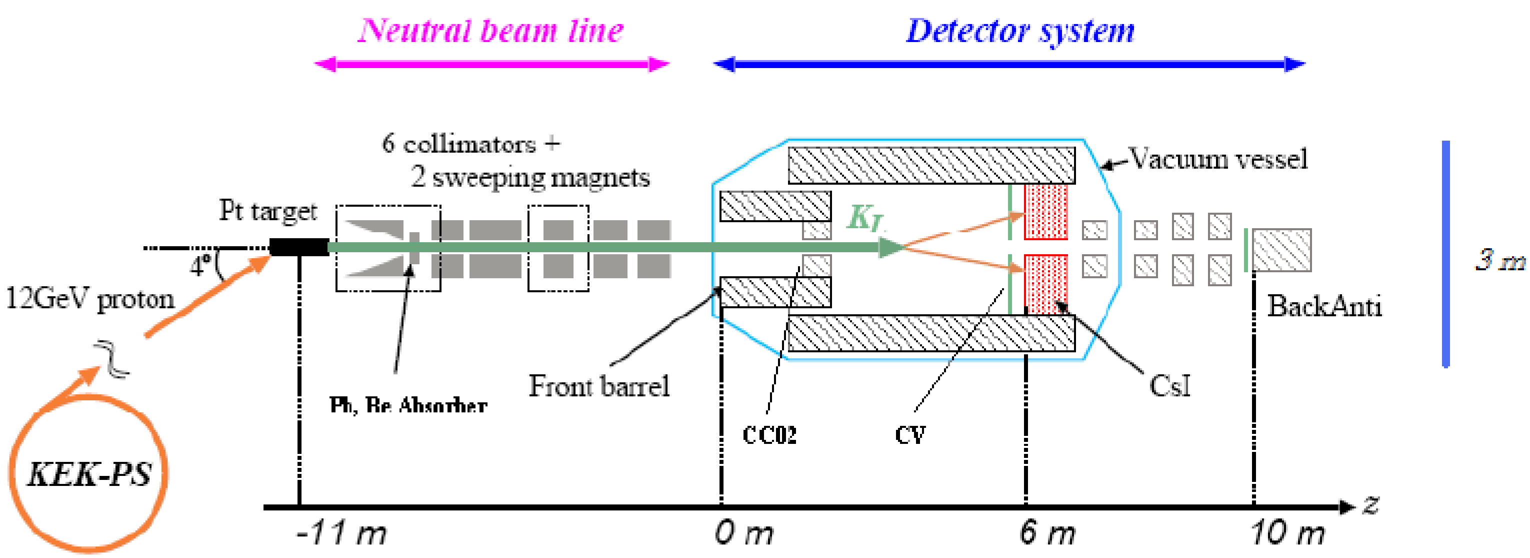
- E391a is the first dedicated experiment to search for $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$
- Three run period:

RunI	02/2004-07/2004
RunII	02/2005-04/2005
RunIII	10/2005-12/2005

- The first two Runs have improved the upper limit by a factor of 9
- This talk is focused on RunIII. The analysis goal of the last Run is to establish a better background understanding for future experiments, e.g. E14 at JParc.

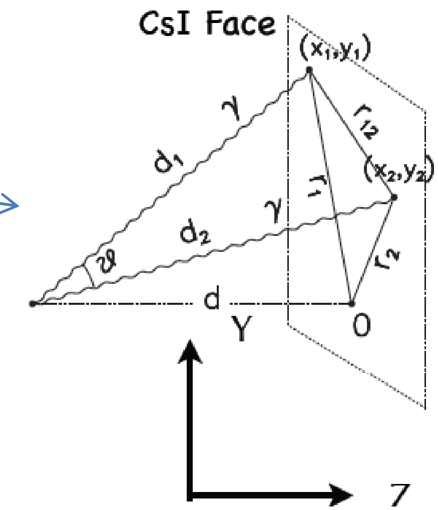
Principles of the Experiment

- The E391a experiment detects $K_L^0 \to \pi^0 \nu \bar{\nu}$ by looking for two photons with a missing transverse momentum(Pt).
- Events from the major neutral decays(Kl->3pi0, Kl->2pi0, and Kl->gg) were collected to calculate the total number of Klong.
- A pencil beam is critical for the Pt resolution and background reduction.
- The hermitic veto system is what sets this experiment apart from previous efforts



Reconstruction of Pion and Kaon

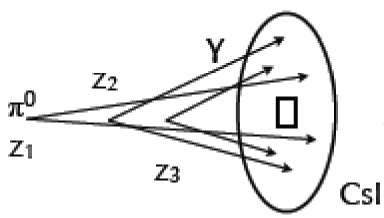
- Pi0 reconstruction:



$$m_\pi^2 = (p_{\gamma_1} + p_{\gamma_2})^2 = 2\,E_1\,E_2 \times (1 - \cos\,\theta)$$

$$r_{12}^2 = d_1^2 + d$$

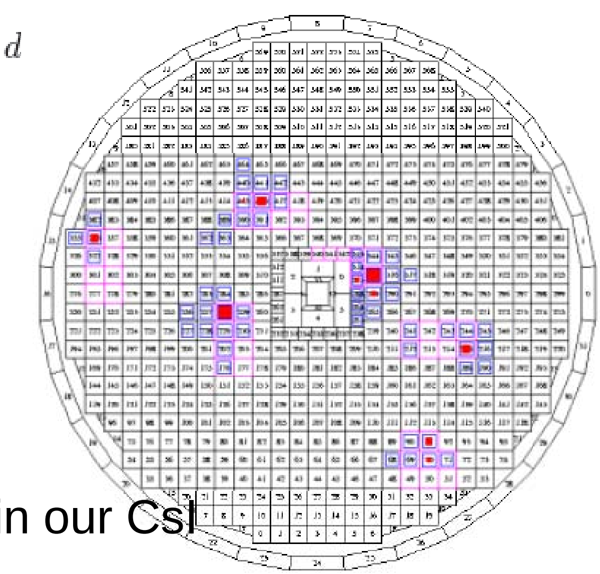
- Select the correct combination by choosing the one with small vertex dispersion among the multiple Pi0s. And use the weighted average of Pi0 z vertex as Kaon vertex.



$$\chi_z^2 = \sum_{i=1}^{n} \frac{(\bar{z} - z_i)^2}{\sigma_i^2}$$

$K \rightarrow \pi^0\pi^0\pi^0$

- Draw a line from the center of energy in the CsI face to the target, and move the Kaon vertex in the XY plane to shift it to the line.



Six clusters in our CsI

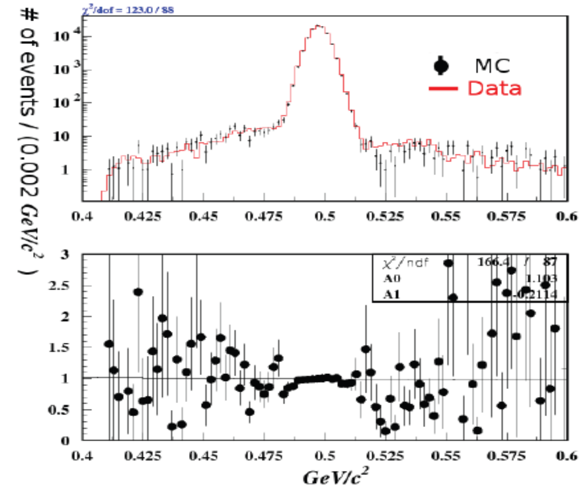
Kaon simulation and Flux

- The Kaon Monte Carlo simulation(MC) matches data well. The calculation of flux and acceptance depends on this simulation.
- Flux number:

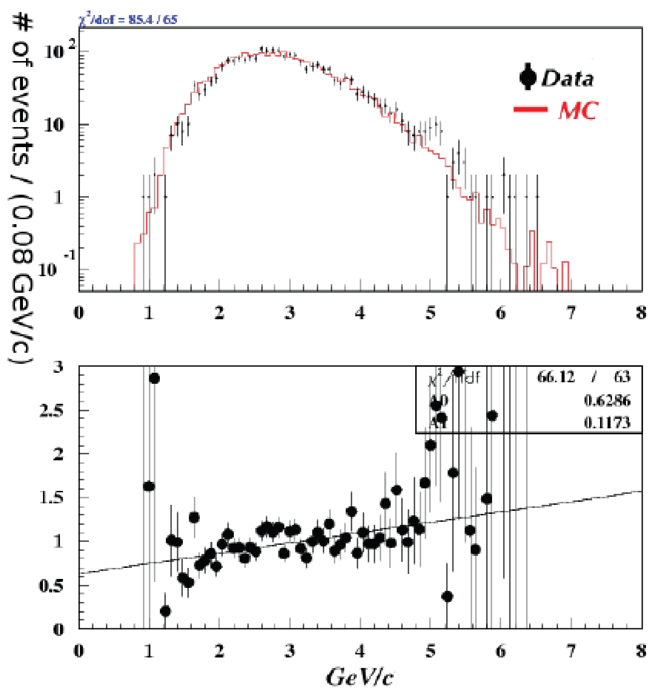
  observed # of decays in data/(observed # of decays in MC/total # of Kaon decays in MC)

  = (3.48+-0.11stat+-0.22sys)*10^9

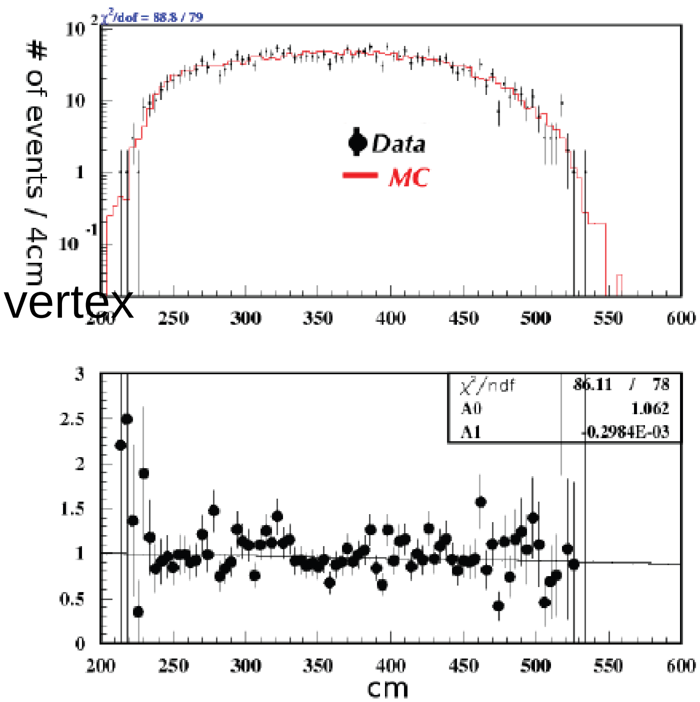
mass



Momentum

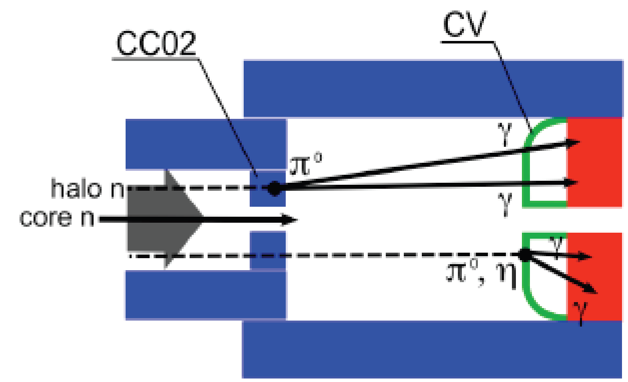


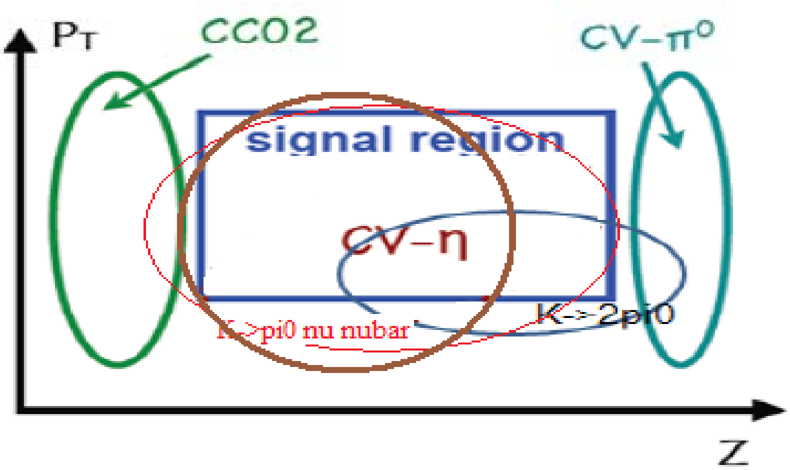
Decay z vertex

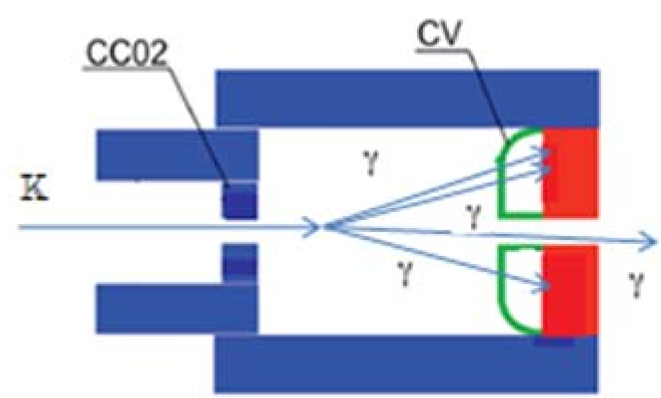


Possible Backgrounds in Search for $K_L^0 \to \pi^0 \nu \bar{\nu}$

- We often use the transverse momentum(Pt) vs. z plot to display the events.
- The signal box is defined as a simple square on the Pt vs. z plane.
- Backgrounds can come from halo neutron interaction in detectors and Kaon activities.
- Background modeling is essential.





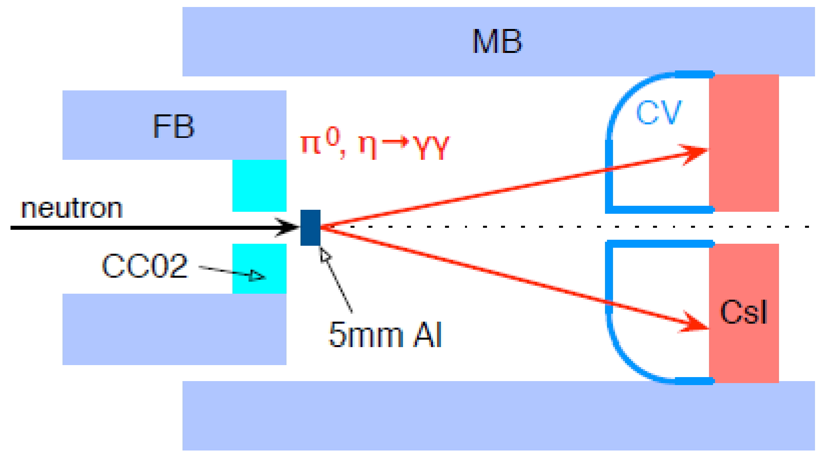


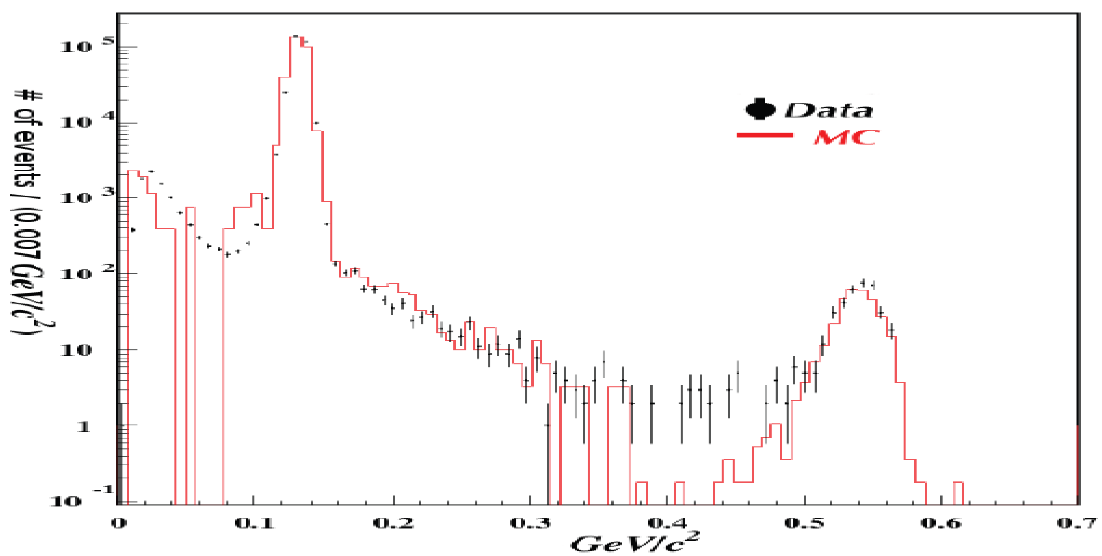
Overview of the Neutron Background Estimation

- Previous Analysis has adopted a combination of simulation and data driven method to estimate the background.
- To make a background prediction that can be useful for the future experiment, we need a simulation that starts with the physics models.
- The neutron interaction model at the energy range of a few GeV is not reliable.
- We use all possible checks for neutron interaction in our data.
- A simulation based on Fluka physics model is developed

Al target

- An Aluminum plate is placed behind CC02
- Originally, this special run is designed for CsI calibration using the known Pi0 mass and vertex.
- The huge number of core neutron interaction makes this special run an excellent test bench of the neutron interaction model in the simulation

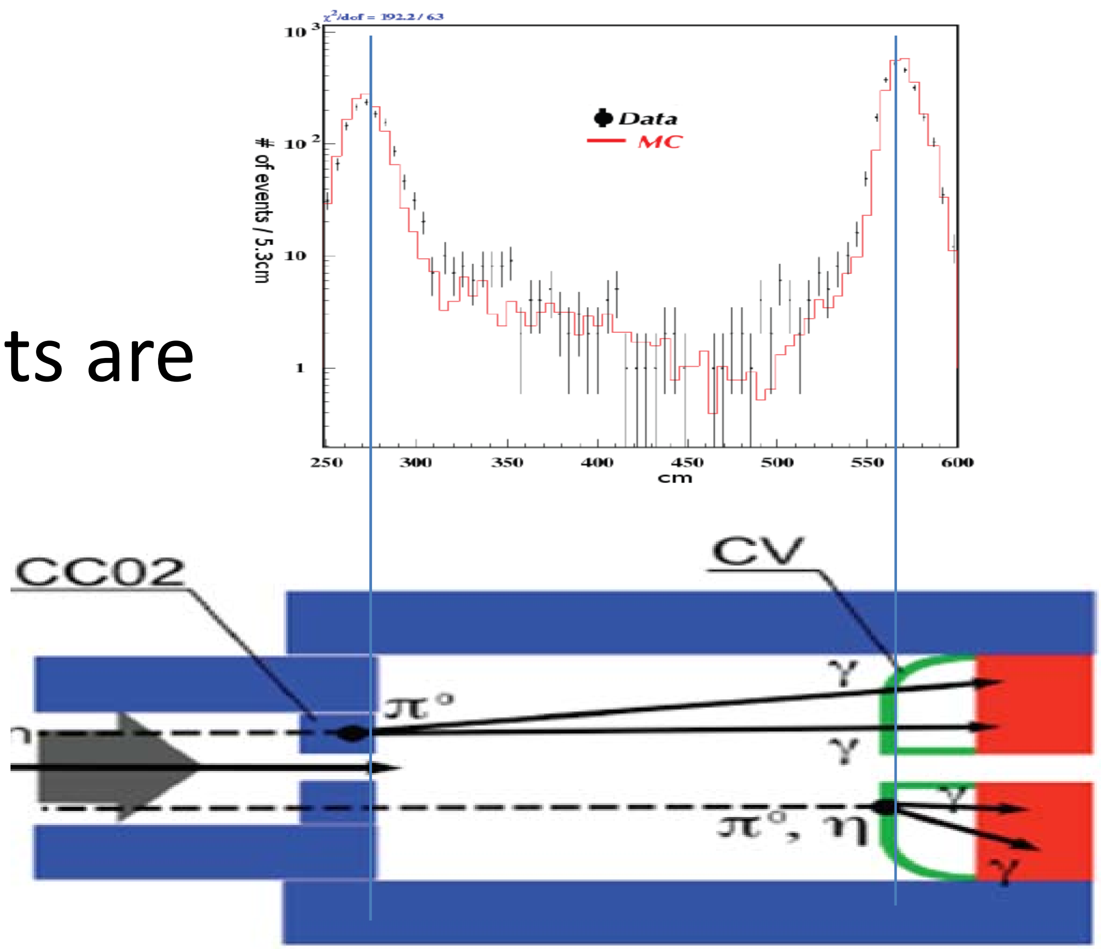




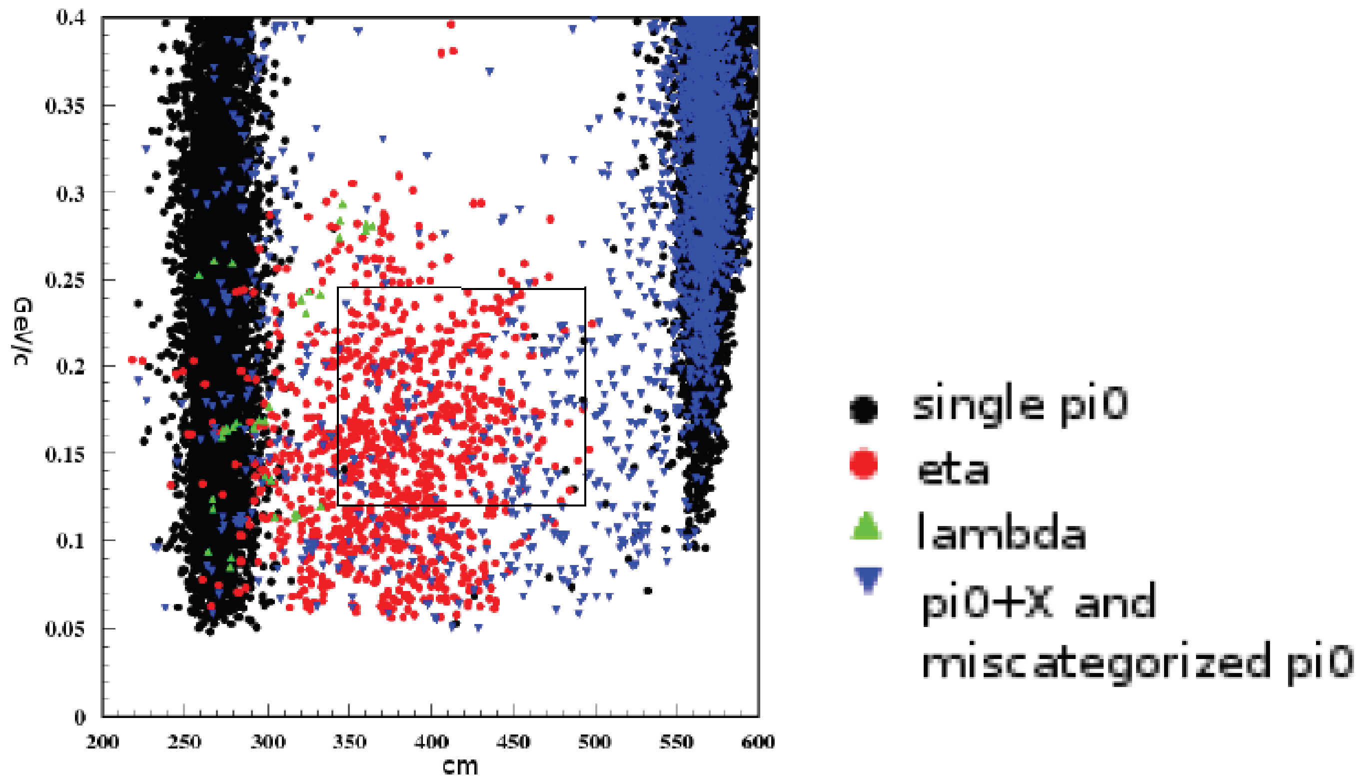
Comparison of Physics Run Data

- We compared data and MC for all events outside the signal region.
- Signal region events are excluded

Reconstructed Pi0 z distribution



Events by Secondary Particle Types in the Neutron Interaction



Event Selection

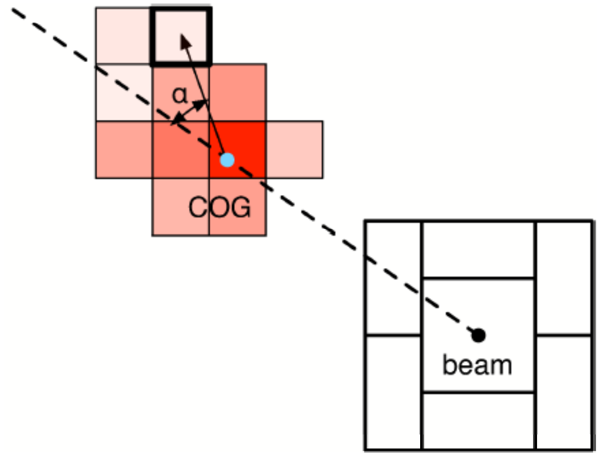
- The event selection rules are used to reduce the background while retain signal: $K_L^0 \to \pi^0 \nu \bar{\nu}$

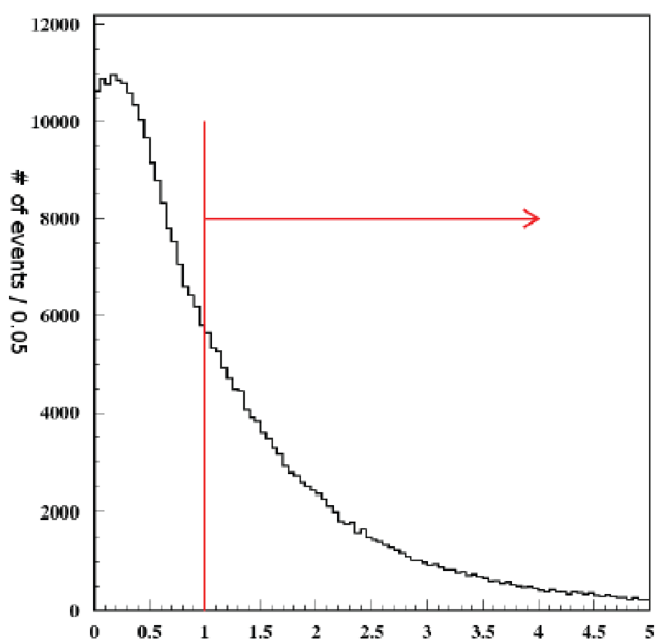
Event selection rules:
1) We require all veto detectors to be quiet.
2) Photon quality cuts to remove hadronic shower, accidental hit, and fused photons.
3) Kinematic cuts on the two photons and the relation of them.
4) We define our signal region in the phase space of pi0 z vertex and its transverse momentum.

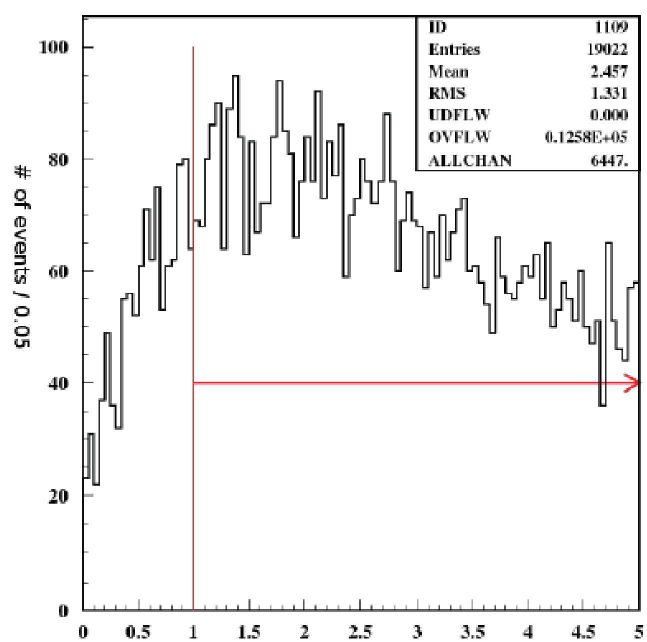
Angle Cut to Reduce Eta Background

We cut on the difference of the angle we measure from the shower radial span and the angle we get from the pi0 reconstruction.

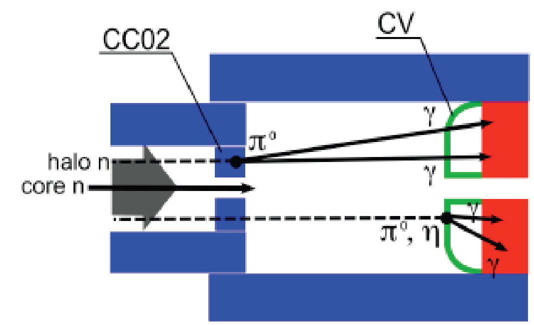
This is one powerful cut for eta background







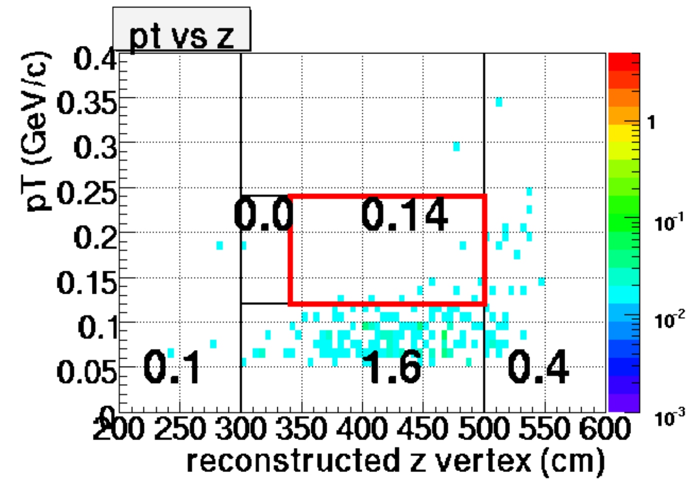
$$\Delta\theta\chi^2 \equiv \left(\frac{\theta_{r_1} - \theta_{rec.}}{\sigma_{r_1}}\right)^2$$

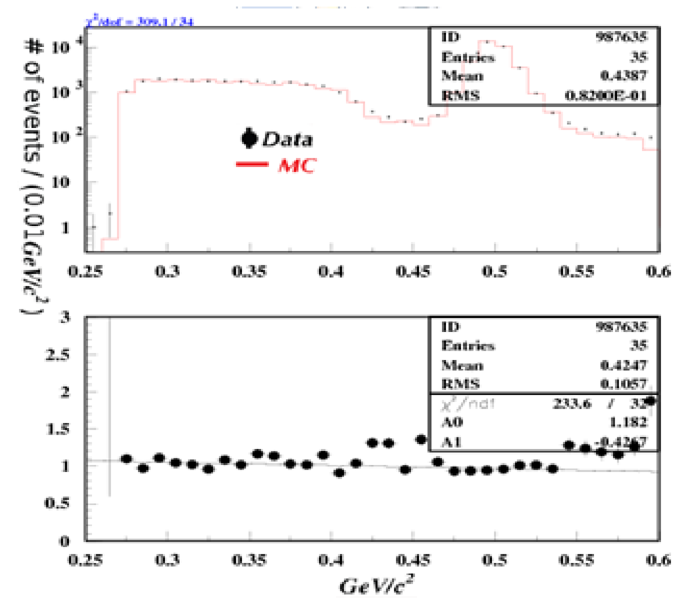


K->2pi0 Background

- We use the same MC for flux calculation to estimate this background.
- The contribution is 0.14+-0.05
- It is critical to use the low mass tail of 4 cluster events to confirm that we modeled the mechanism of this background correctly.

K->2pi0 MC



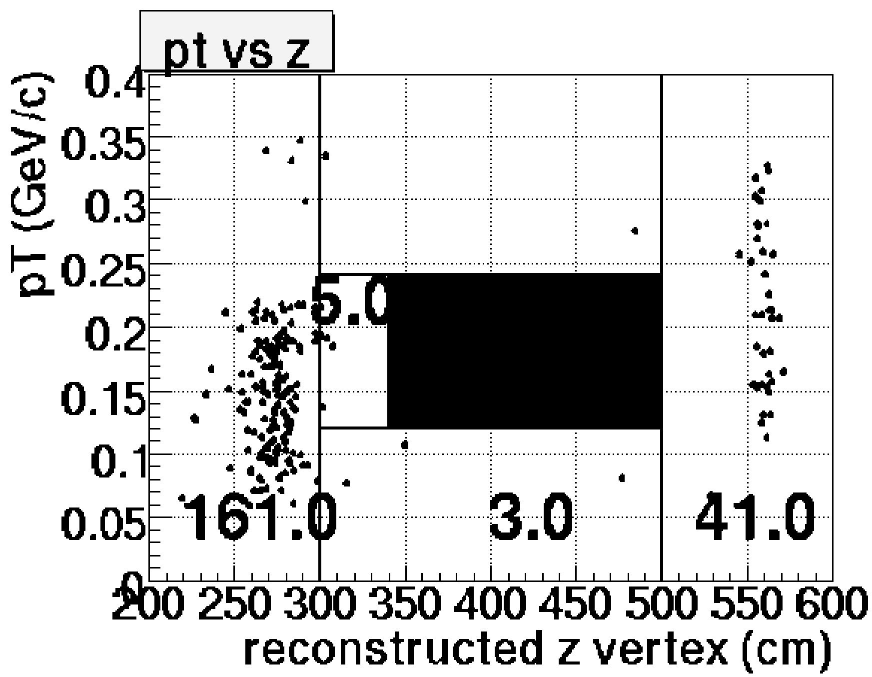


Four cluster data and MC

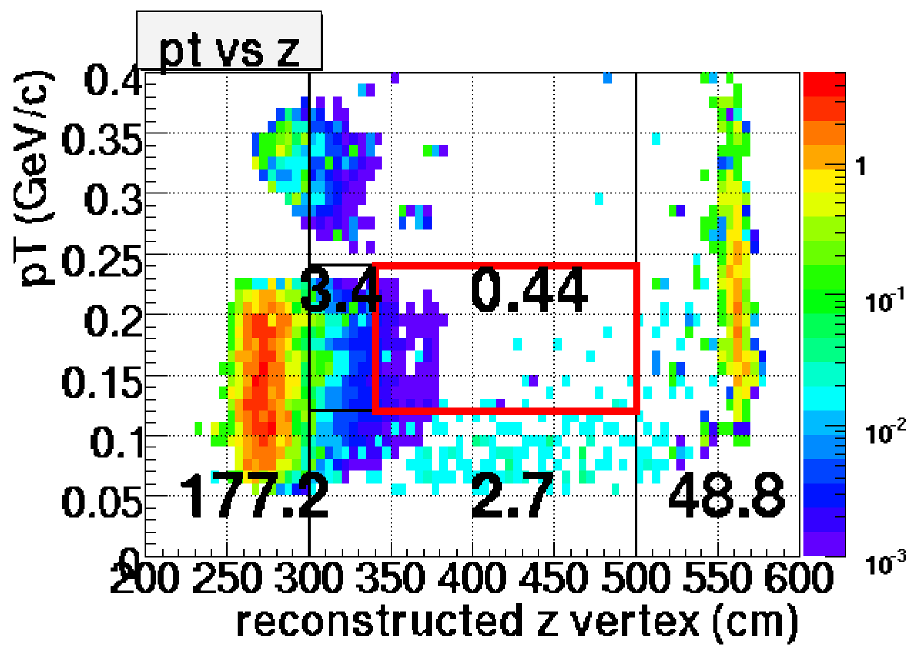
Final plots

- Applying all cuts
- The signal box was covered before we freezed the cuts.

RunIII data



Background MC



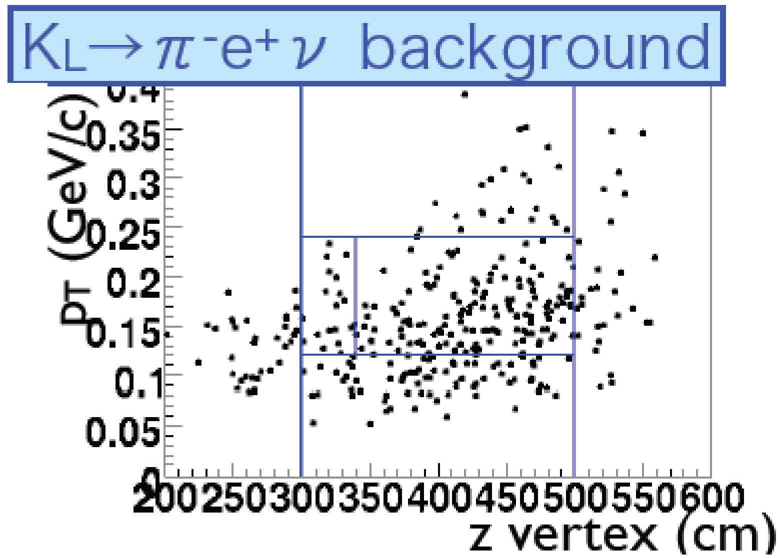
Background prediction: 0.44+-0.22stat+-0.10sys

About one third each from the CV eta, CC02 pi0(both caused by halo nuetron), and K->2pi0

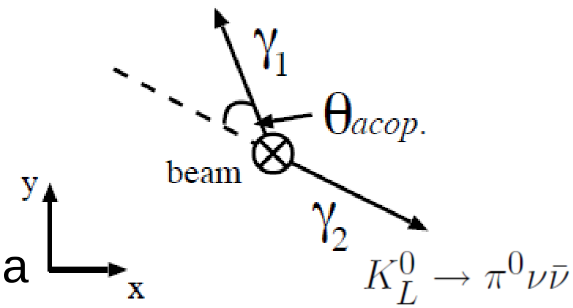
Other Negligible Background Sources

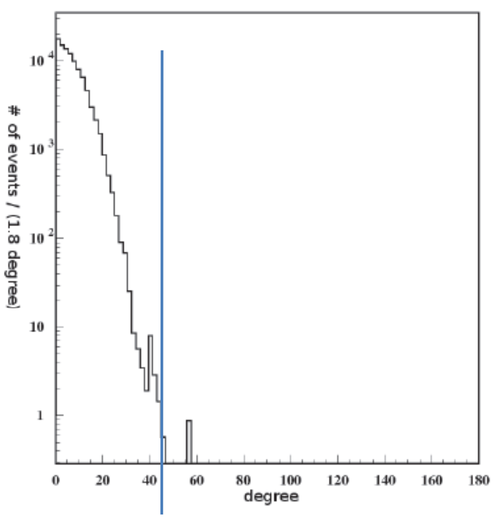
- Charged Mode
  K->pi+e+nu   5*10^-3
  k->pi+pi+pi0 <10^-4
- Backward Pi0 <0.02
- Kl->gamma+gamma <10^-5

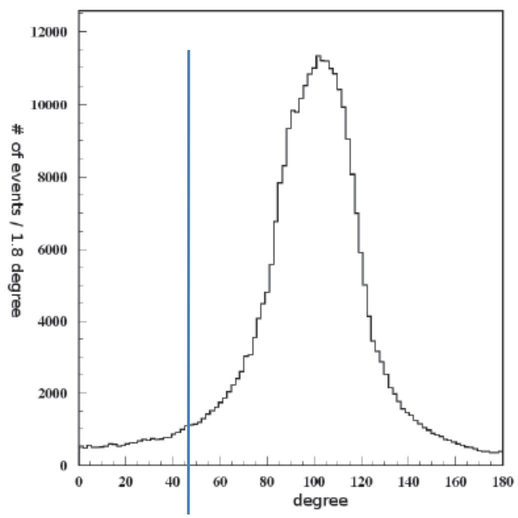
Without charged veto



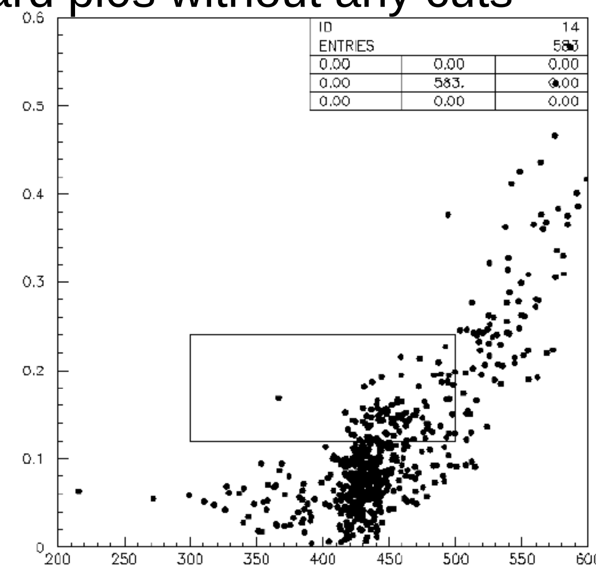
Kl->gamma+gamma





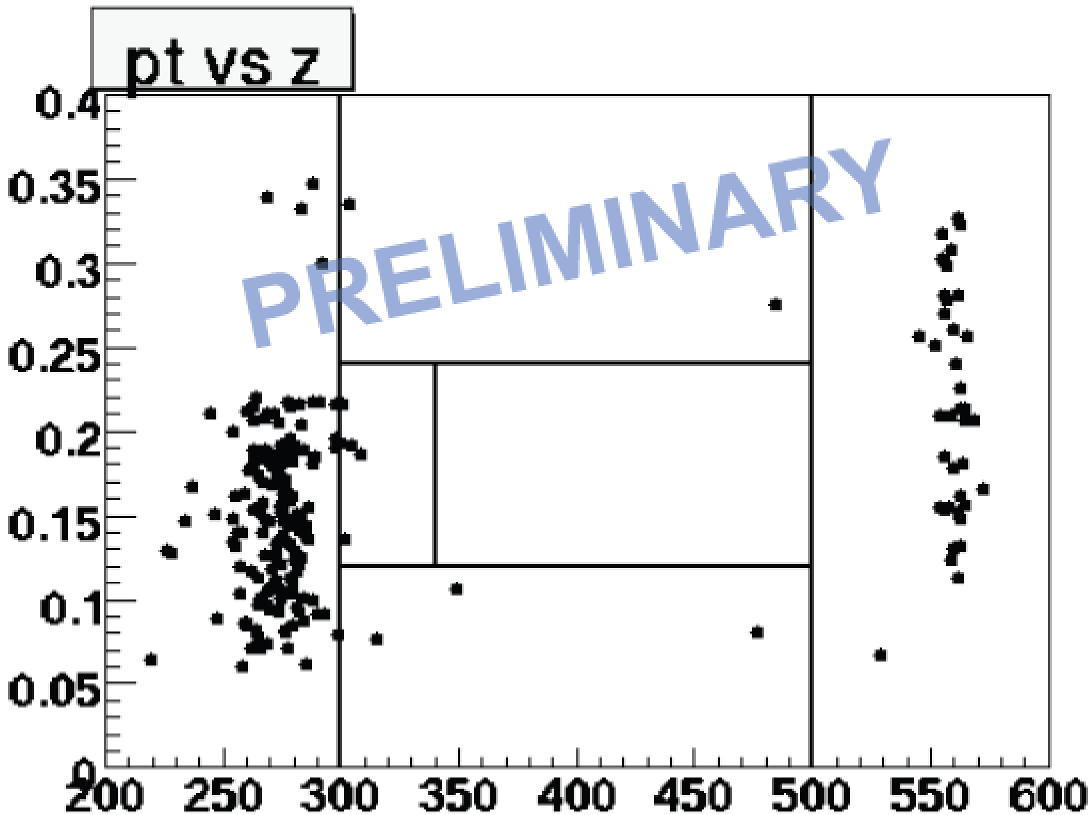


Backward pi0s without any cuts



Opening the Signal Box

- No events observed in the signal box



Acceptance with These Cuts

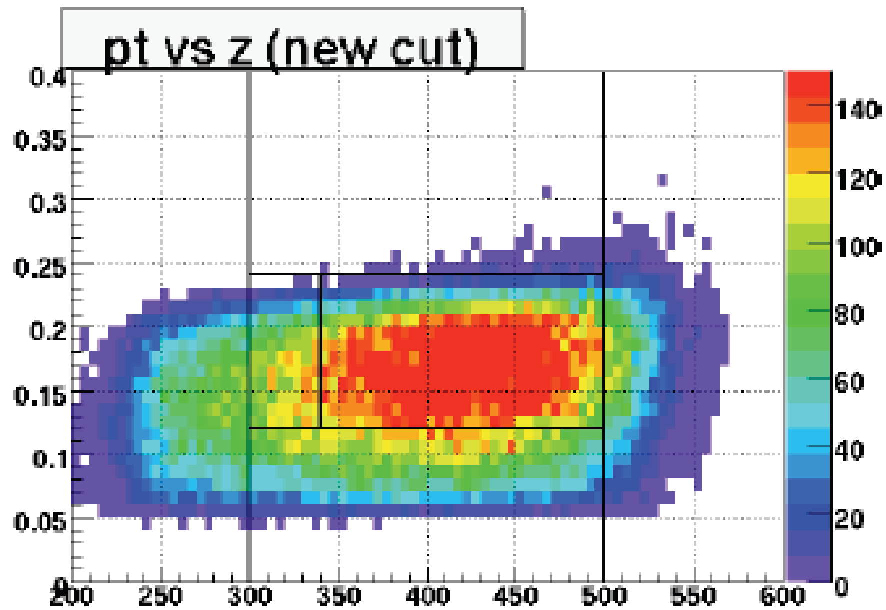
Acceptance:
(0.975+-0.005+-0.067)%

Single Event Sensitivity
(1/(flux*accptance)):
(2.95+-0.29)*10^-8

An upper limit of the decay branching ratio can be set as:
6.8*10^-8
at 90% confidence level.

A combined result together with RunII will appear soon.

The transverse momentum Versus reconstructed z plot of $K_L^0 \to \pi^0 \nu \bar{\nu}$ MC



PRELIMINARY

Conclusion

- Halo neutron related interaction and Kl->2pi0 are the dominate background sources.
- We improved the signal acceptance by 45% from the RunII result.