Study of Kaon Structure using $K_L \to \pi e \nu e e$ and $K_L \to \pi e \nu \gamma$ with external conversion

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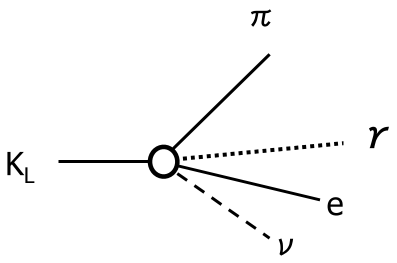
Structure dependent term in radiative Ke3

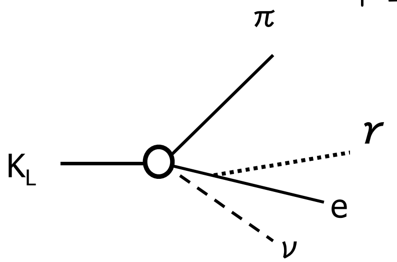
$p \quad : \pi^-$
$q \quad : \gamma$
$p_\nu \quad : \bar{\nu}$
$p_e \quad : e^-$

$$T = \frac{G_\mathrm{F}}{\sqrt{2}} e V_{us}^* \epsilon^\mu(q)^* \Big[$$



$$(\hat{V}_{\mu\nu} - A_{\mu\nu})\bar{u}(p_\nu)\gamma^\nu(1-\gamma_5)v(p_e)$$

Structure dependent

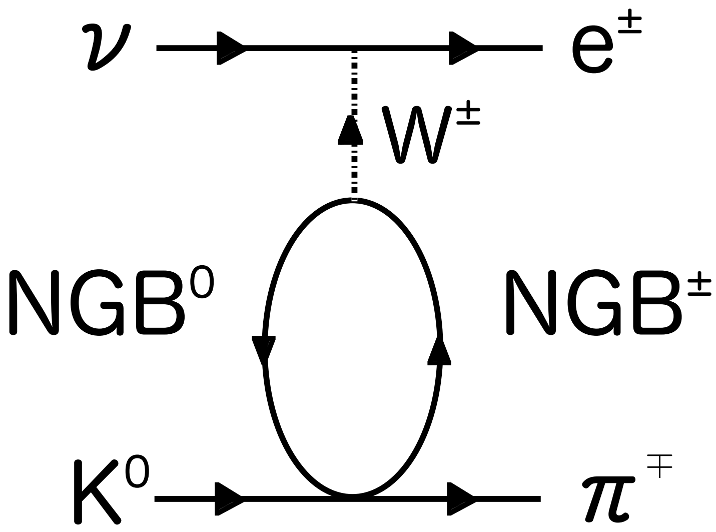


$$+F_\nu \bar{u}(p_\nu)\gamma^\nu(1-\gamma_5)\left(\frac{p_\mu}{pq} - \frac{2p_e^\mu + \not{q}\gamma^\mu}{2p_e q}\right)v(p_e)\Big]$$

Inner Brem.

F_ν : Ke3 matrix element
$\hat{V}_{\mu\nu}$: Vector amplitude
$A_{\mu\nu}$: Axial Vector amplitude

A example to calculate this is Chiral perturbation theory



NGB field of *u,d,s* symmetry

$$\begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & -\pi^+ & -K^+ \\ -\pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & -K^0 \\ K^- & -\bar{K}^0 & -\frac{2\eta_8}{\sqrt{6}} \end{pmatrix}$$

In χ PT a NGB behaves like a Gauge boson

- In the structure depending case the photon is appended on all charged NGB lines and vertices
- In the inner Brem. case the photon is appended on external lines of electron or pion

Difficulties

in the case of radiative Ke3

- Structure dependent term in radiative Ke3 is less than 1% of Inner Brem. (theoretical expectation).
- Measurement of radiative Ke3 is sensitive to accidental photons.

⇩

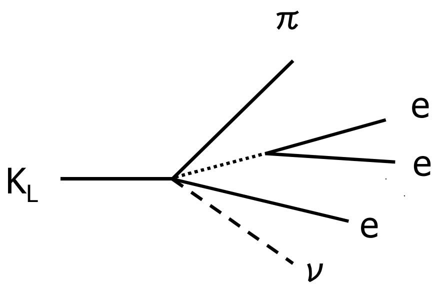
Structure dependent component in Ke3γ has not been observed yet

Experimental Br(Ke3γ) is significantly lower than theoretical predictions as far

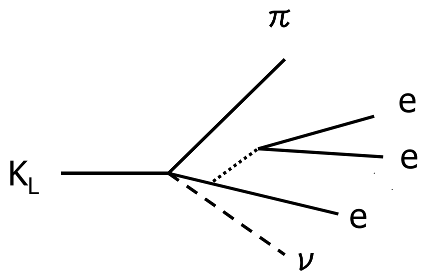
1. $K_L \to \pi e \nu ee$

- $K_L \to \pi e \nu \gamma^{*}$
  $\to e^+e^-$

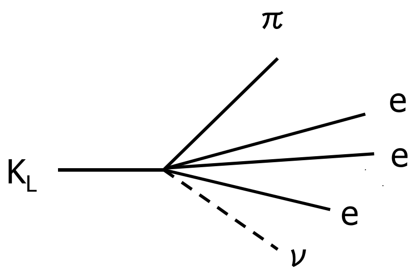
Structure dependent



Inner Brem.



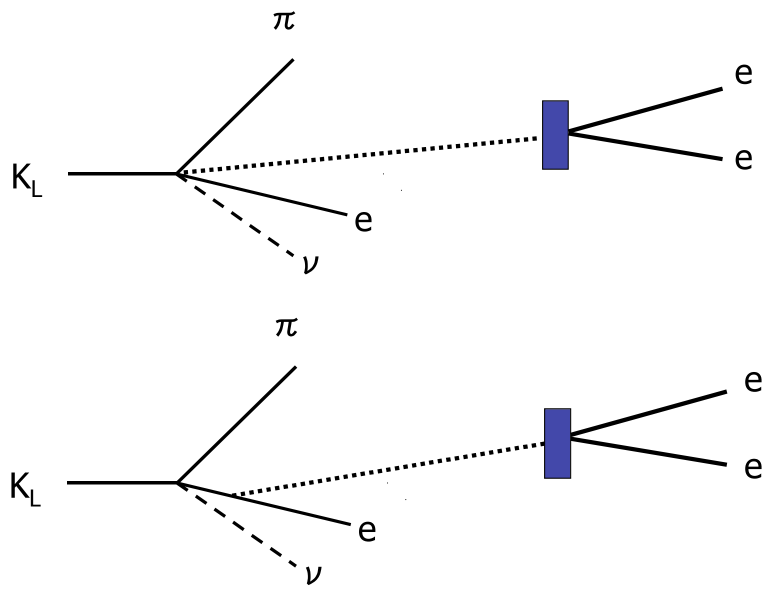
- ?



- $KL \to \pi e \nu ee$ has not been seen yet.

2. External conversion of radiative Ke3

- External conversion of real photon from radiative Ke3 can be used to reject accidental photons



Structure dependent

Inner Brem.

$K_L \to \pi e \nu ee$ and

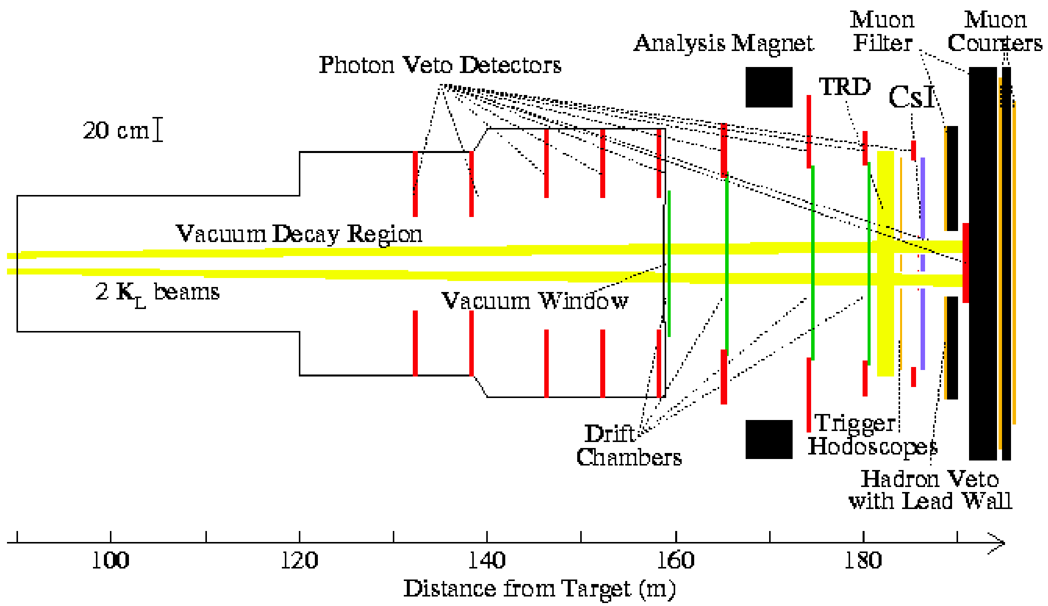
external conversion of radiative Ke3

	Probe	Inner Brem.	Structure dependent
Virtual photon	$K_L \to$ $\pi e \nu ee$	?	?
Real photon	Ext. conv. of $Ke3\gamma$	>99%	Direct emission <1%

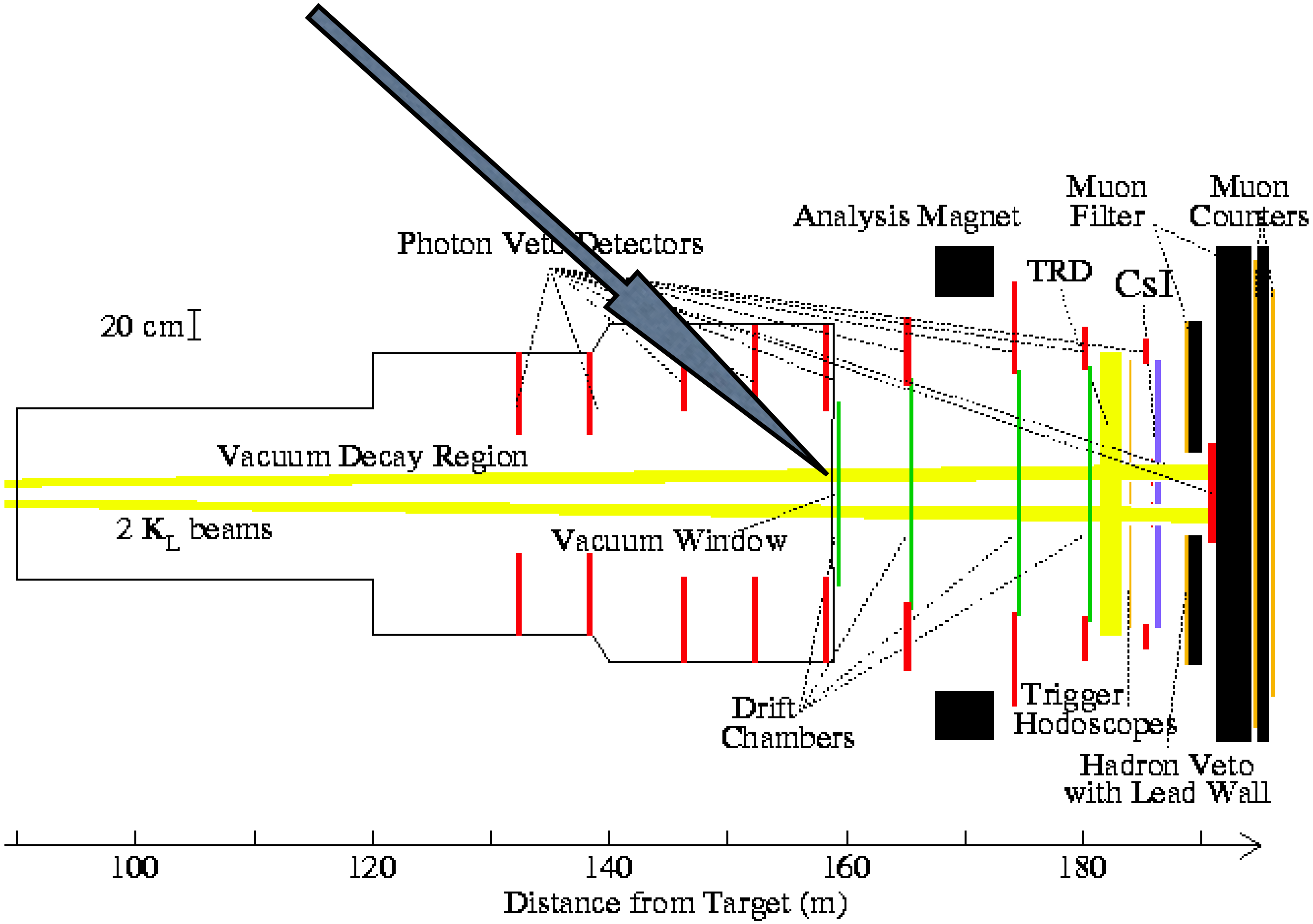
Experiment

KTeV experiment observed 2.7×10^{11} K_L in '97.

KTeV Detector, E799 Configuration



at Z=159m, Vacuum window: 0.0015 radiation length.

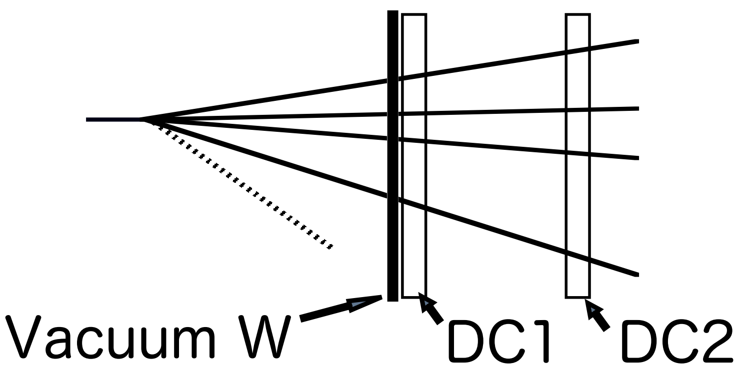


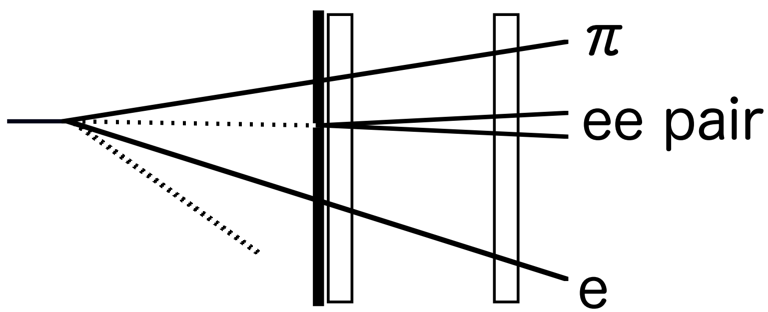
Event selection

$K_L \to \pi e \nu ee$	$K_L \to \pi e \nu \gamma$ with External Conv.
4-Track Event	
4-Track Vtx	2 x 2-Track Vtx
PID- $\pi^{\pm} e^{\mp} e^{+}e^{-}$	PID- $\pi^{\pm} e^{\mp}$, $e^{+}e^{-}$

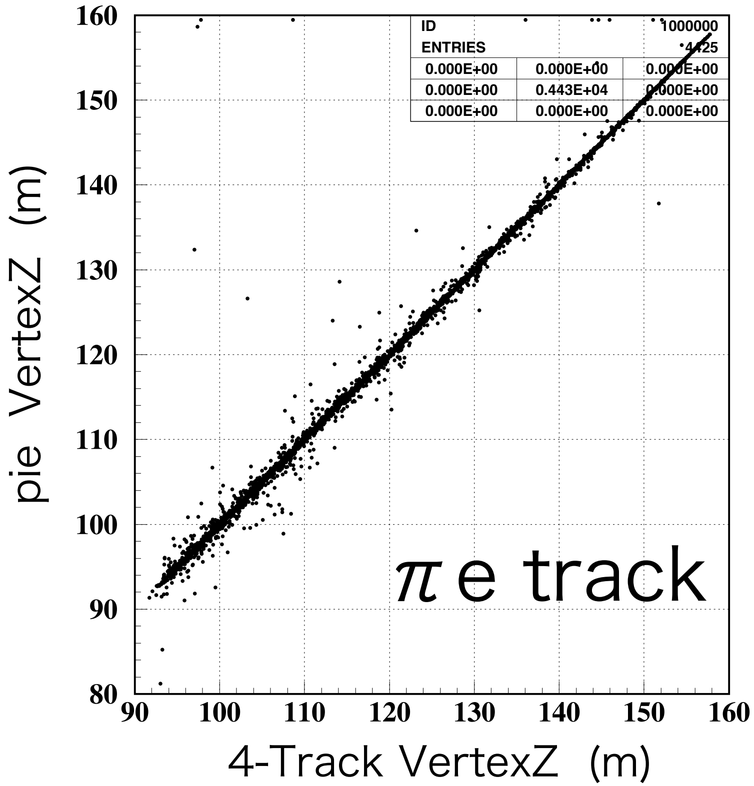
Separation of $K_L \to \pi e \nu ee$ and $K_L \to \pi e \nu \gamma$ with External Conv.

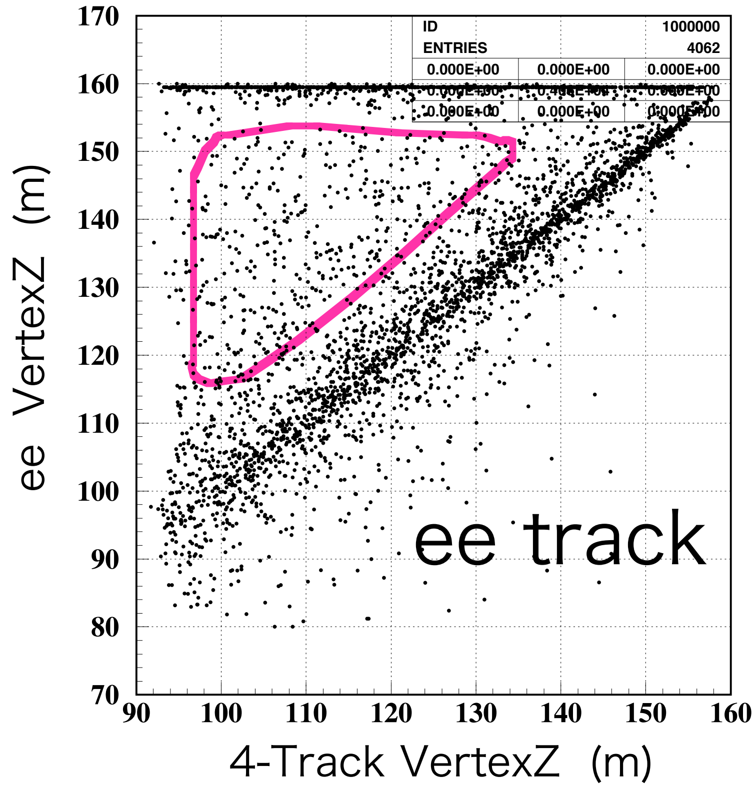
	$K_L \to \pi e \nu ee$	$K_L \to \pi e \nu \gamma$ with External Conv.
πe-Vtx & ee-Vtx	Agree	some distance
ee-Vtx	not on Vacuum window	on Vacuum window





e+e- vertices of 4-track Vtx candidates stream downward !

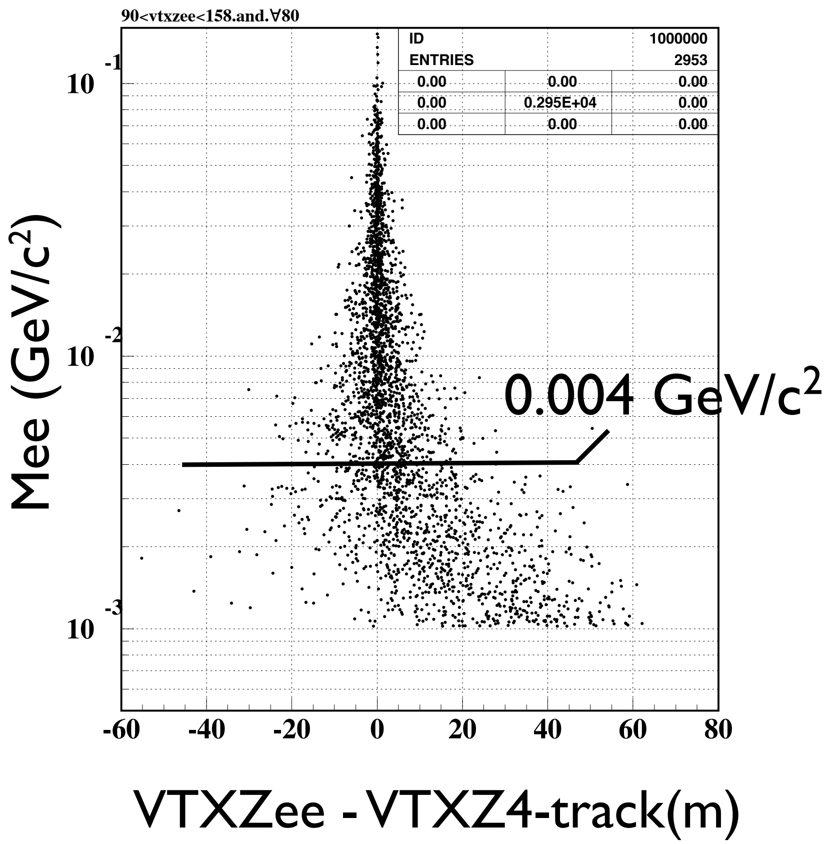


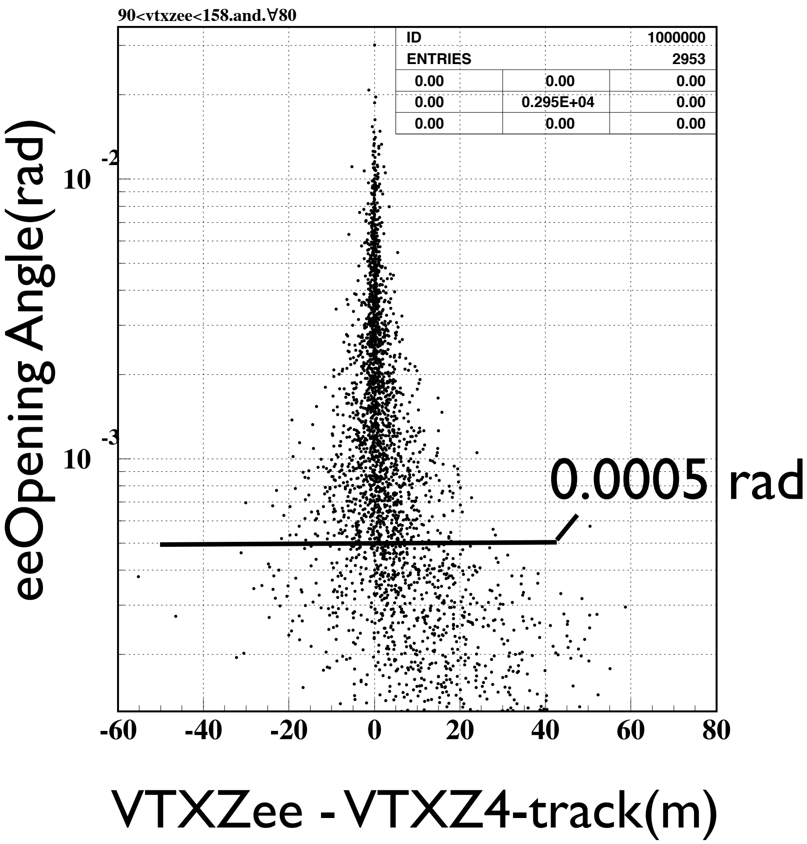


π e tracks well agree with 4track vertex

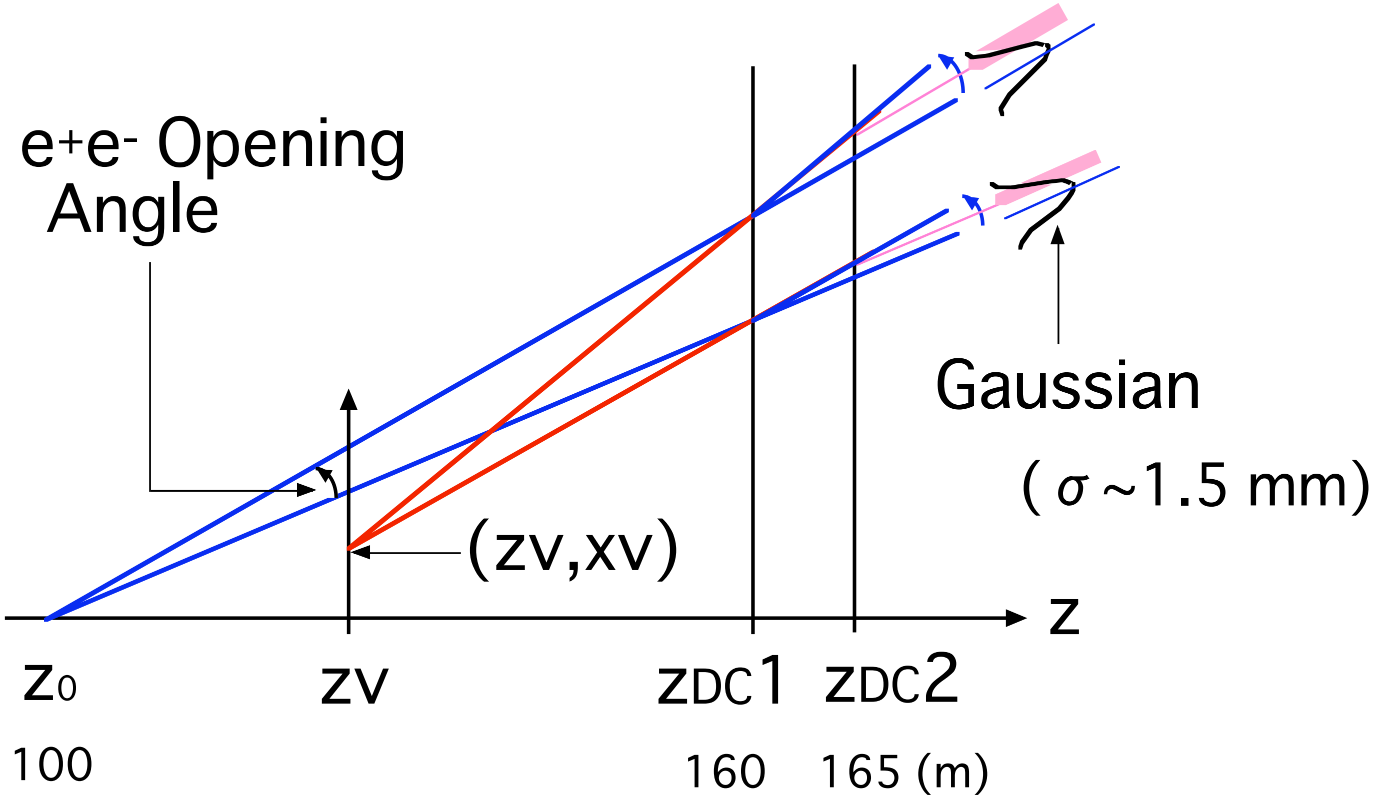
Some ee vertexZ are distributed in down stream.

Small mass pairs stream downward well too.





Between DC1 and DC2 an electron is scattered more than 1 mm at DC2



- Typical resolution of both DCs are 100 μm
- Integrated distribution of upper than Z0 and downer than Z0 must be same, but . . . .

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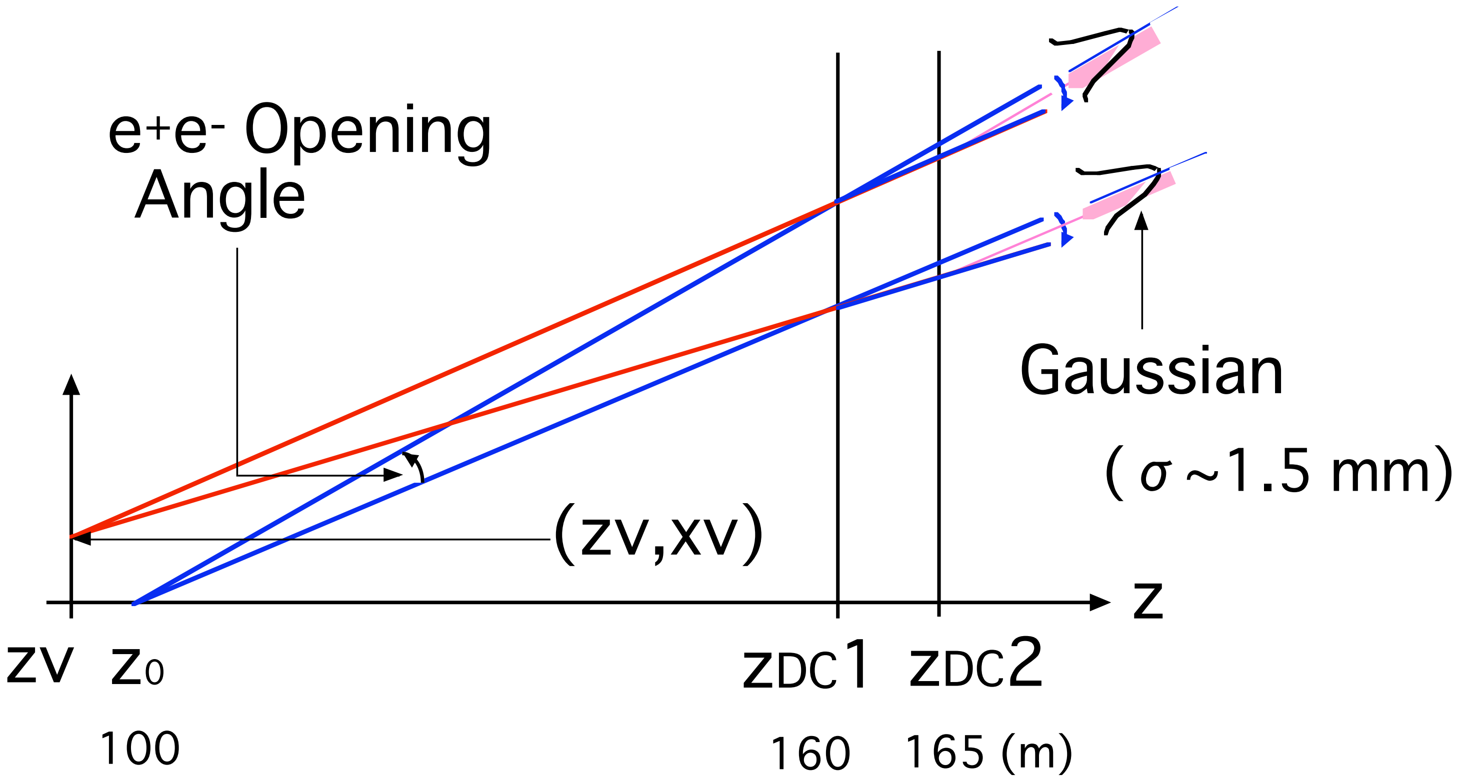

- Typical resolution of both DCs are 100 μm
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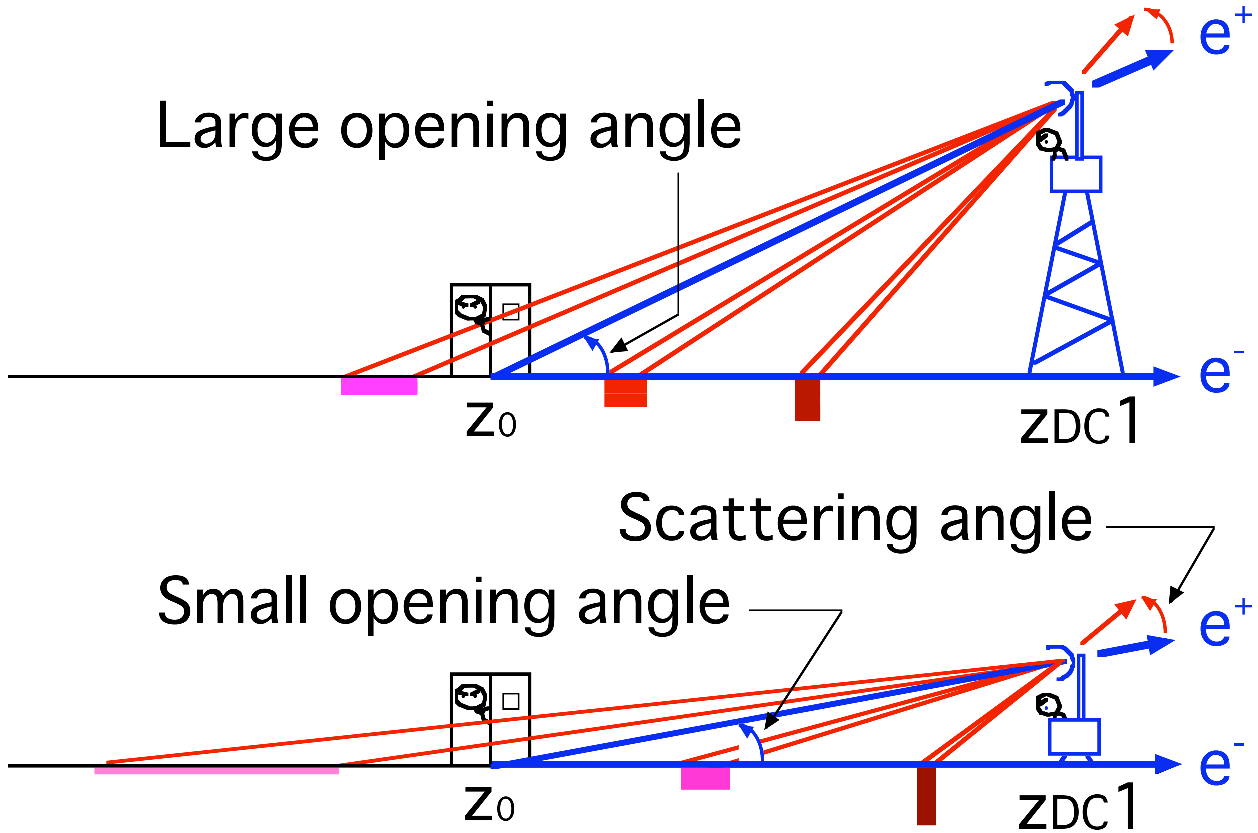
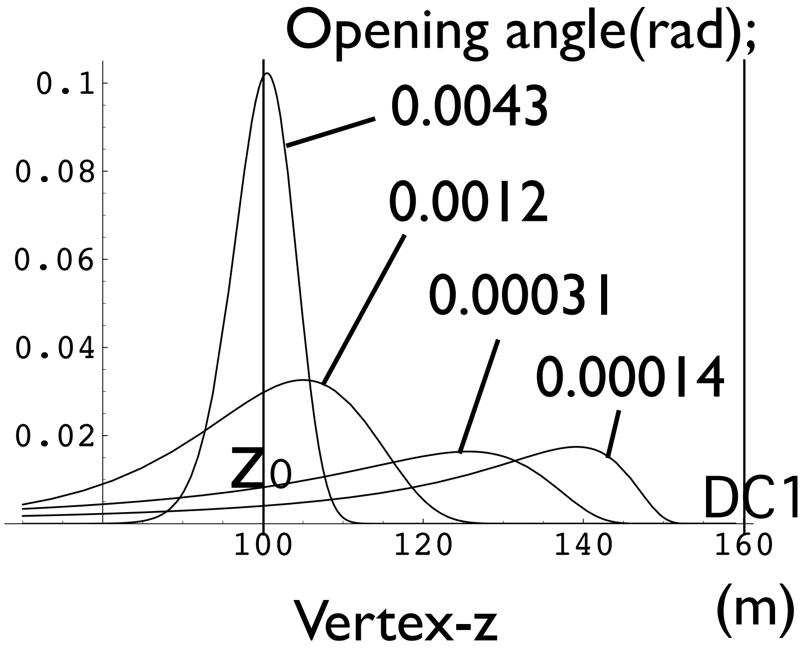
You are a sentry of a jail house searching some jail breakers



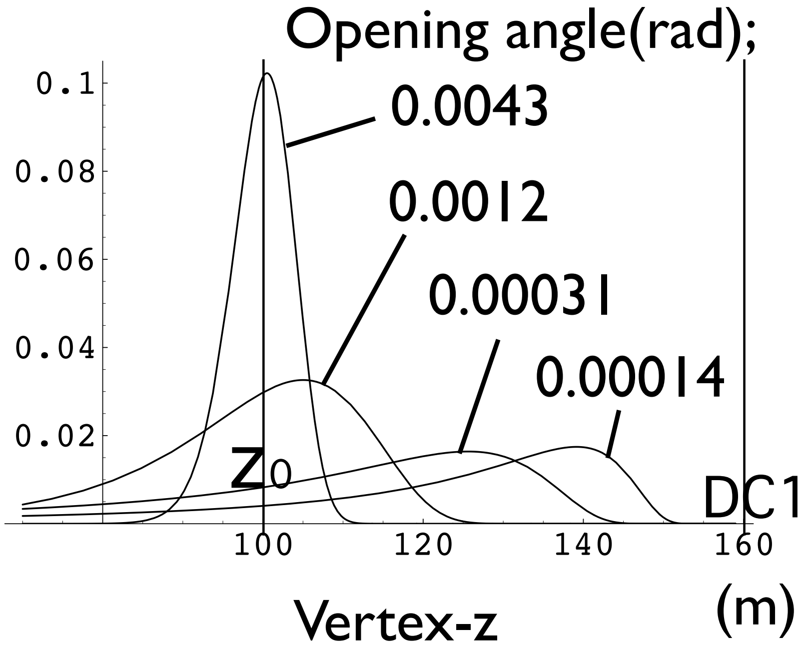
- e^+e^- opening angle at 4-track vertex is more sensitive than at e^+e^- pair track vertex.

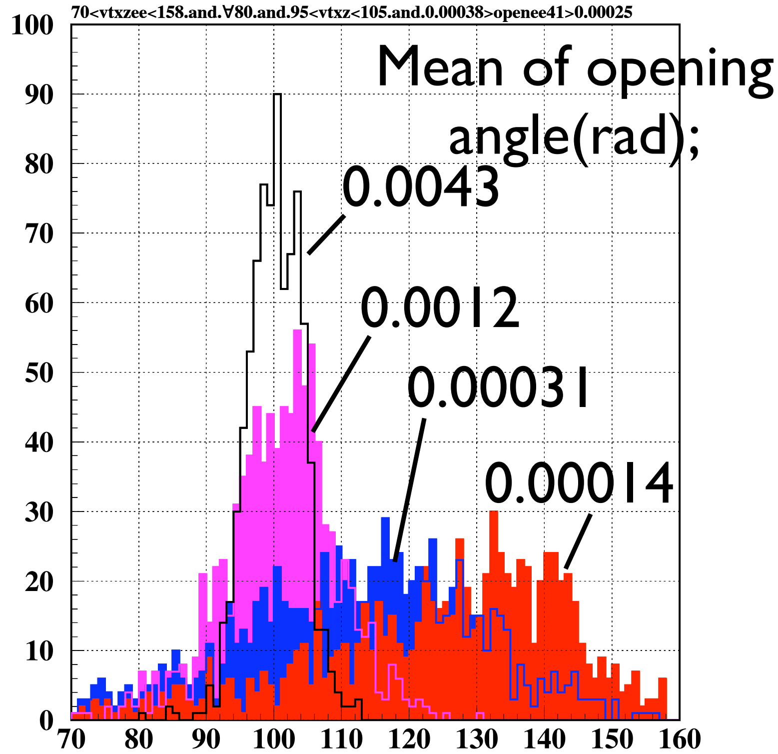
Distribution of vertex-z depending on the opening angle



- Calculated distribution of vertex-z using previous model.
- Integrated area on the upper side of Z_0(100 m) and the downer side are equal.

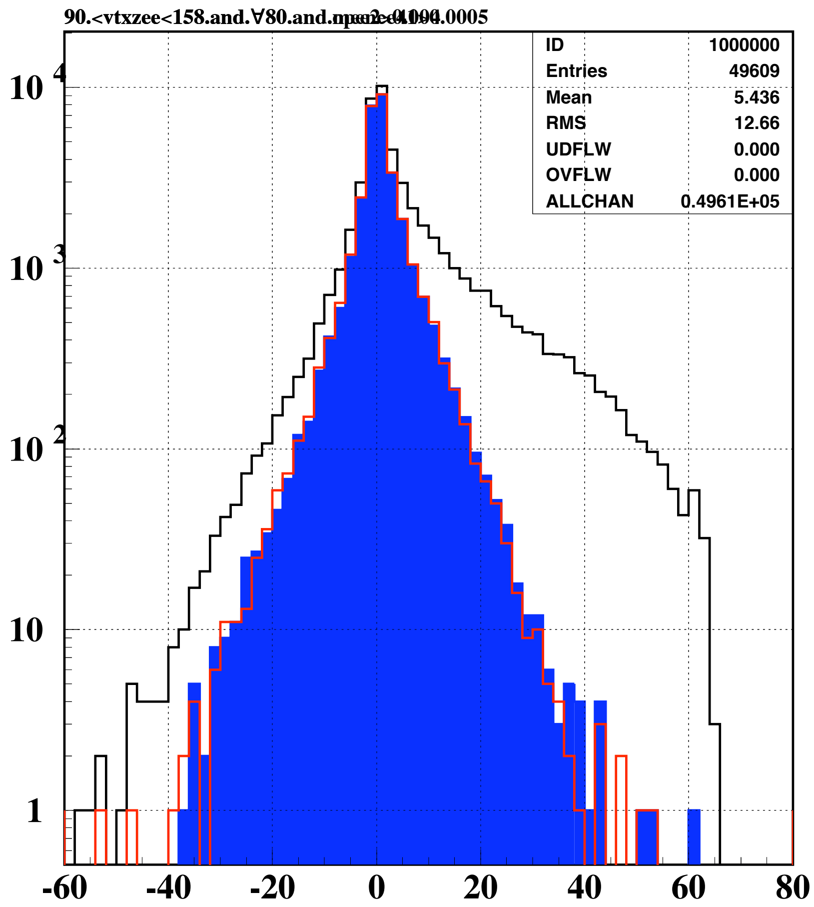
Distribution of vertex-z depending on the opening angle





- Each hisotgram(right side) is vertex-z distribution of the events which has mean of opening angle same as calculated distributions(left side).

Cut by invariantmass and opening angle of e^+e^- pair



eeVtxz - 4trackVtxz (m)

- e^+e^- opening angle >0.0005.
- $M_{e^+e^-}$>0.004 GeV/c^2
- $M_{e^+e^-}^2 \sim E_{e^+}E_{e}\,\theta_{e^+e^-}^2$

Separation of $K_L \to \pi e \nu ee$ and $K_L \to \pi e \nu \gamma$ with External Conv.

	$K_L \to \pi e \nu ee$	$K_L \to \pi e \nu \gamma$ with External Conv.
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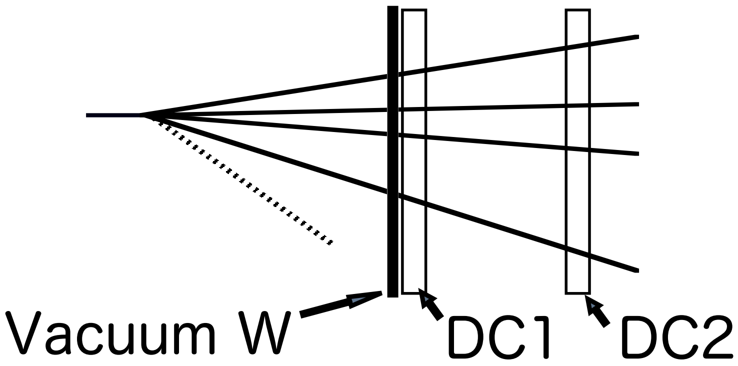
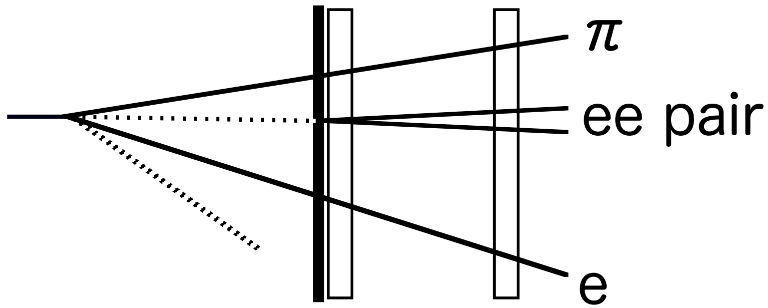
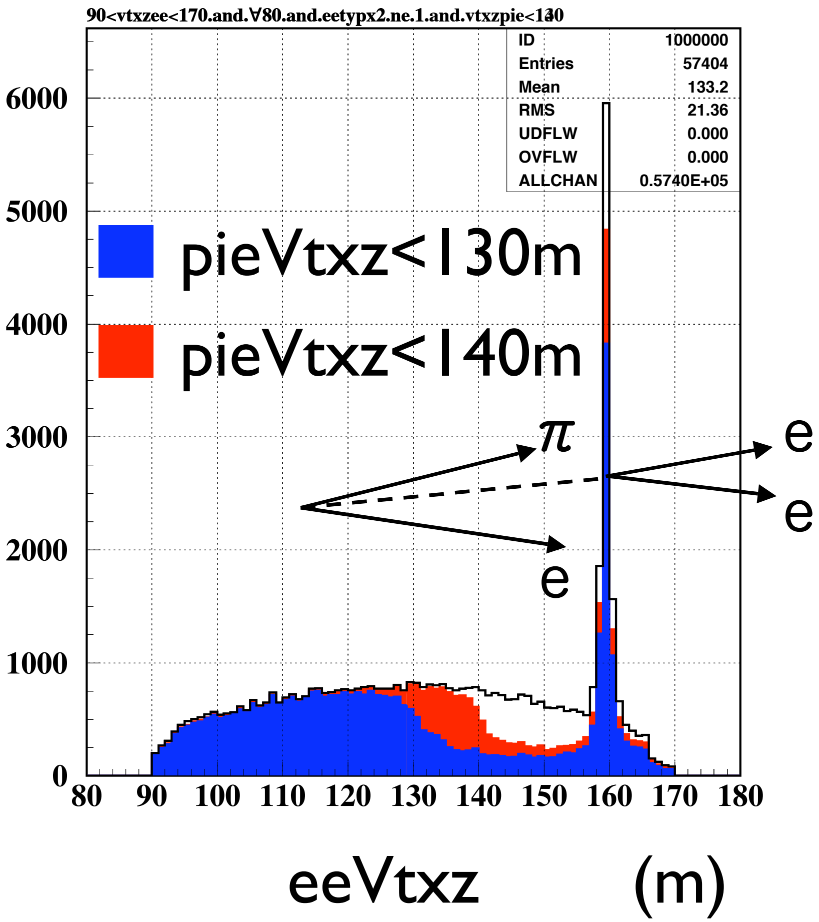


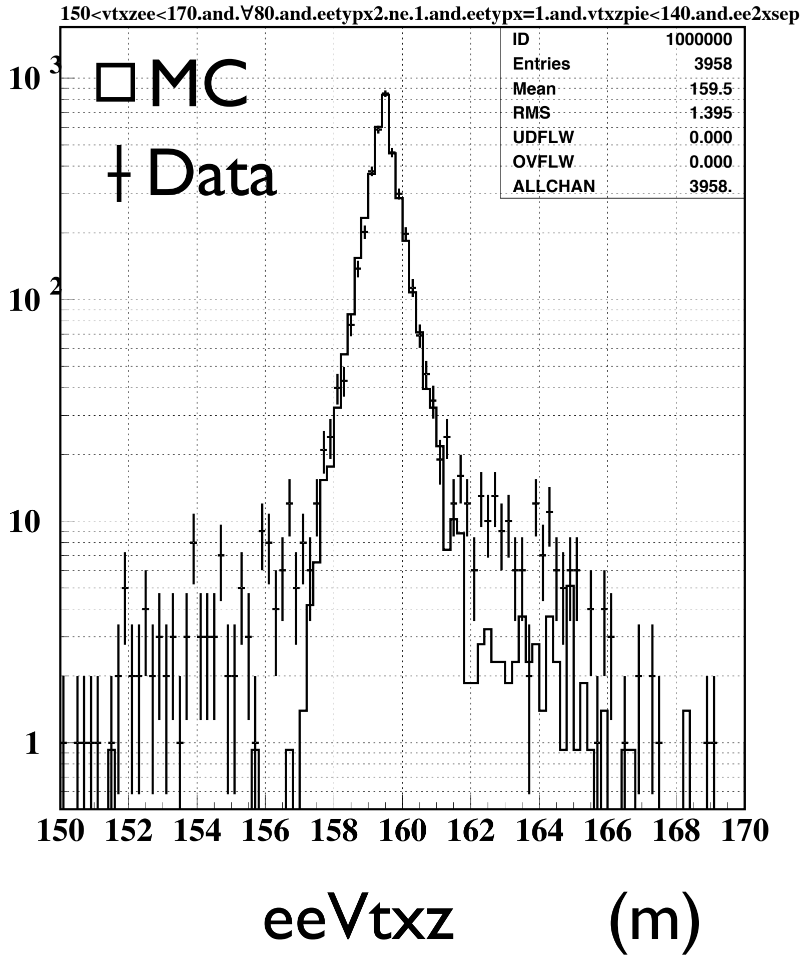


How to remove 4-track Vtx event



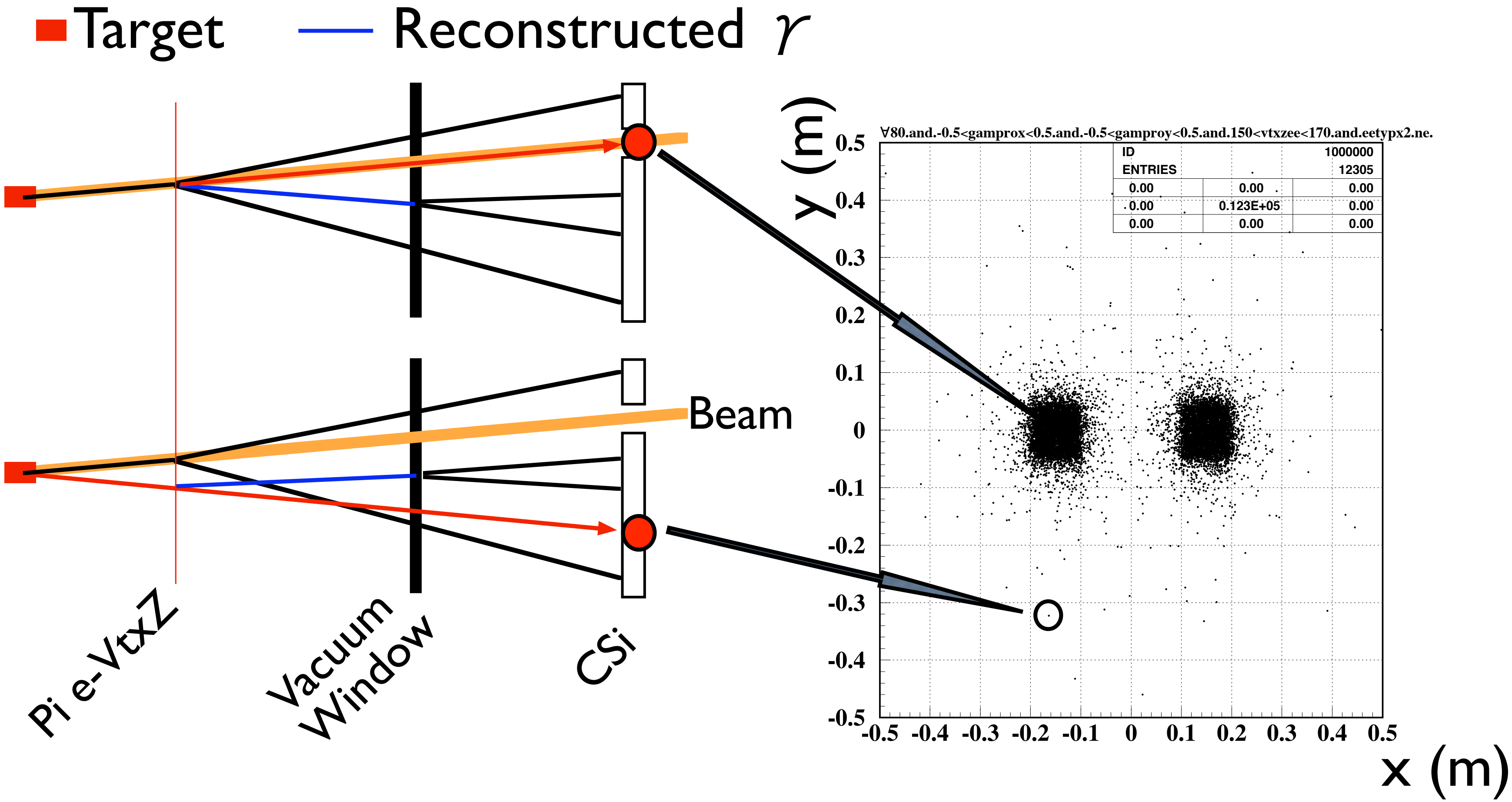
- This is not the real e^+e^- VtxZ, Because ...
- Separable distance in DC1 > 0.001 m
- Distance between DC1 and DC2 is 5 m
- If Separation at DC2 is 0.0015 m, event which has real eeVtxZ at 150 m can have eeVtxZ on DC1(Vacuum W).

Comparison with MC about eeVtxZ



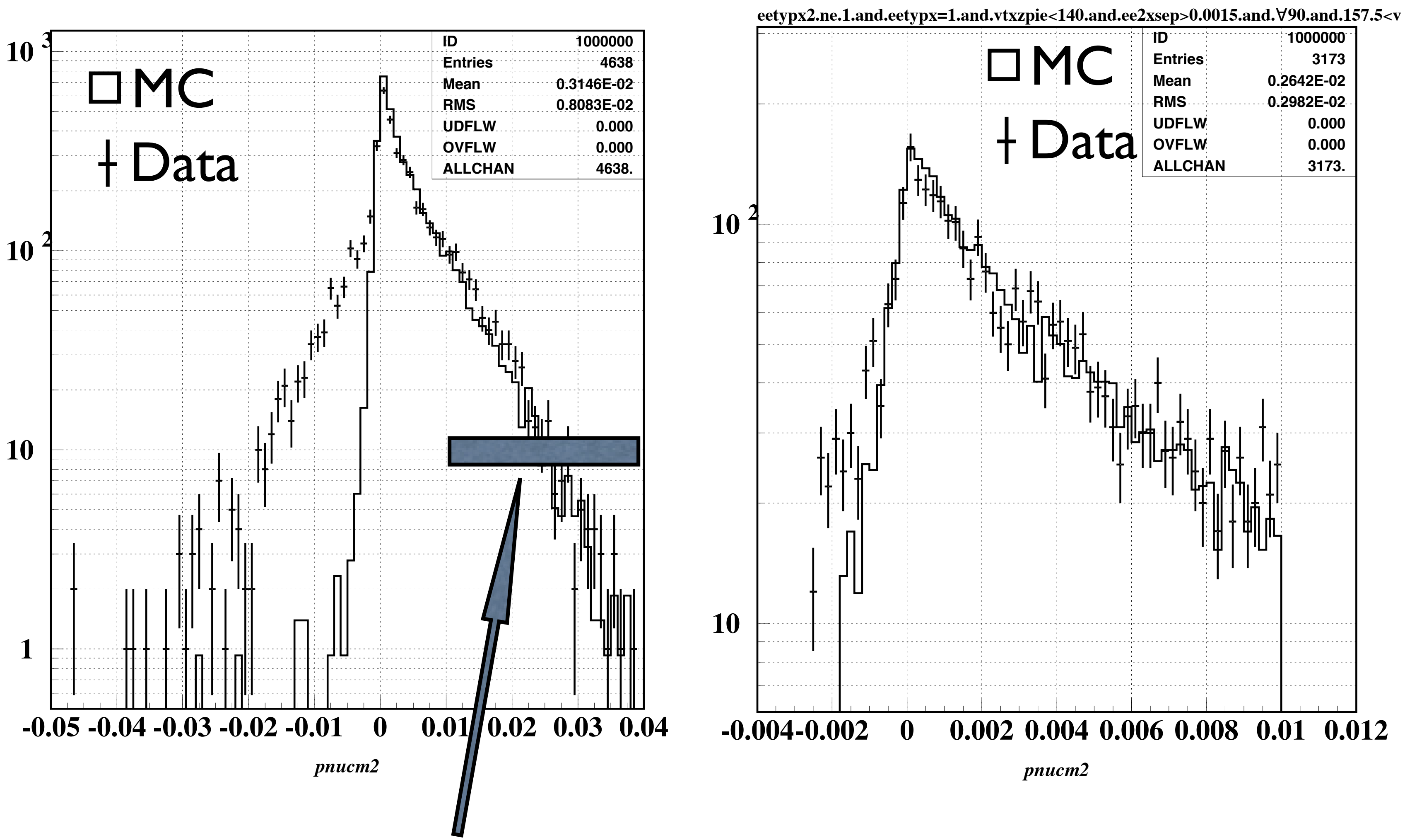
- Separation at DC2 > 0.0015 m
- PieVtxZ < 140 m
- Real Vtx proj. on CSi must be Beam hole

Reconstructed gamma must come from Kaon decay Vtx



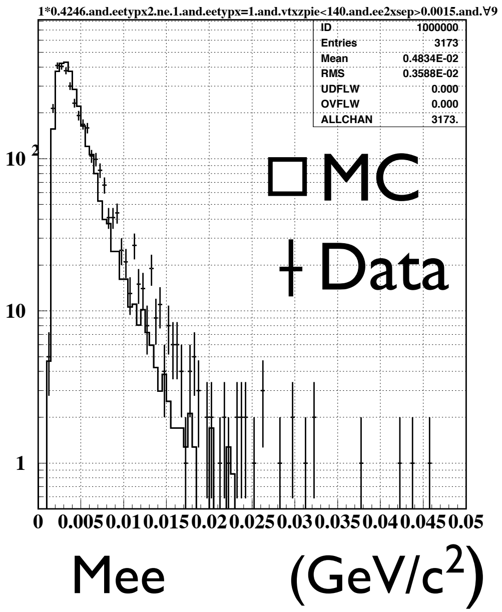
Real γ vertex proj. on CSi

$P_{\nu\parallel}{}^{*2}$

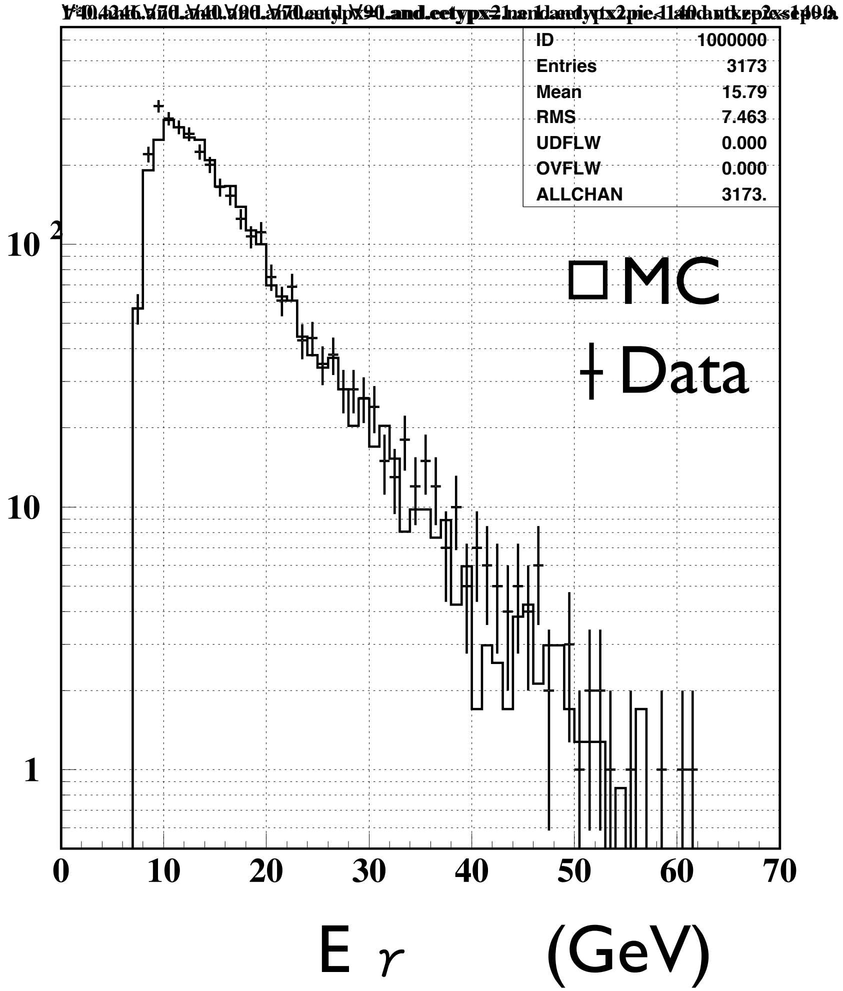


$\pi^+\pi^-\pi^0_{Dal}$ has a peak on this region.

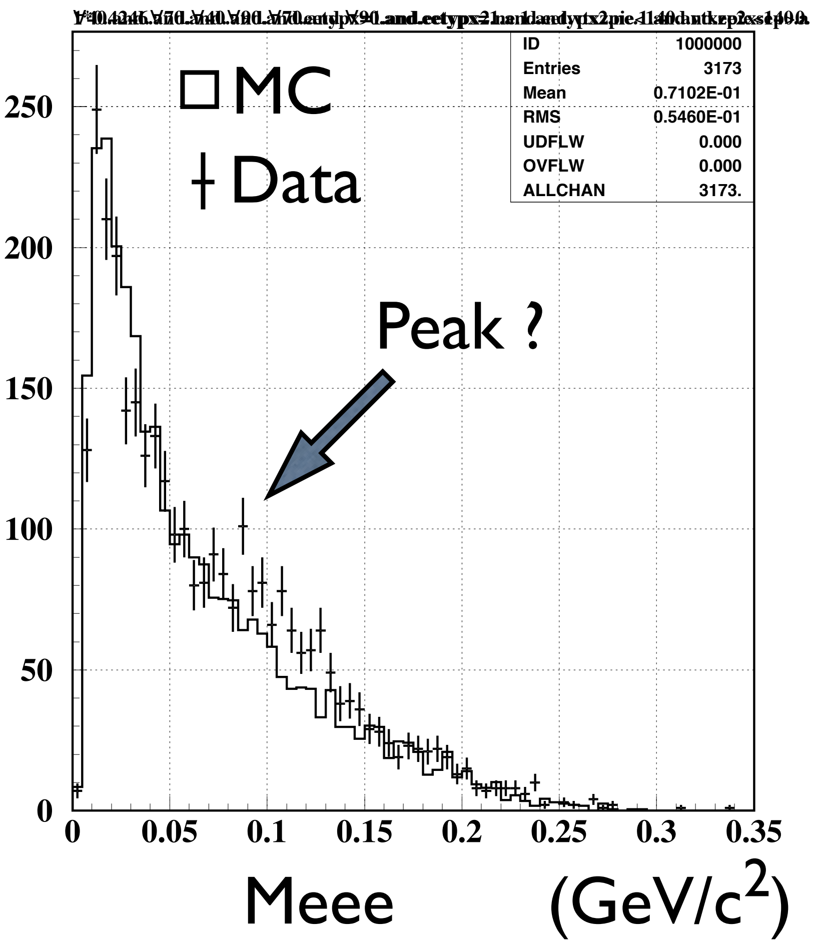
Energy of reconstructed γ



- Mee is very sensitive to manner of conversion

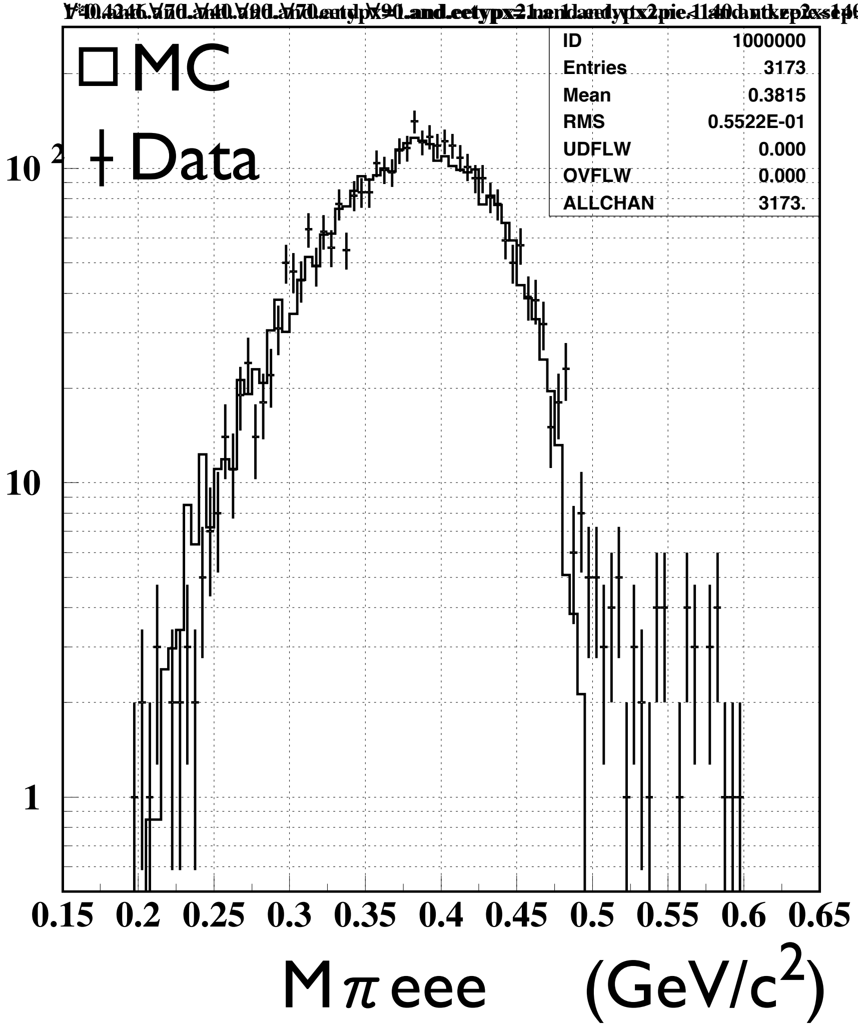


Invariant mass of three electron



- There is a peak on 80~130 MeV
- They have no relation with large invariant mass of e e pair

Invariant mass of πeee



- Agree with MC in smaller mass region than Kaon mass
- We can not use vertex χ to remove unphysical invariant mass events

Quantitative analysis of $K_L \to \pi e \nu \gamma$ with external conversion

- PDG requires that Energy of γ is greater than 30 MeV and Opening angle between electron and γ is greater than 20° in Kaon rest system
- Kaon momentum has ambiguity due to neutrino
- The way is comparison with MC
- Not yet ...

  $Br(K_{e3\gamma}$:free??$)=(7.93\pm0.17)\times10^{-2}$ (only statistical error)

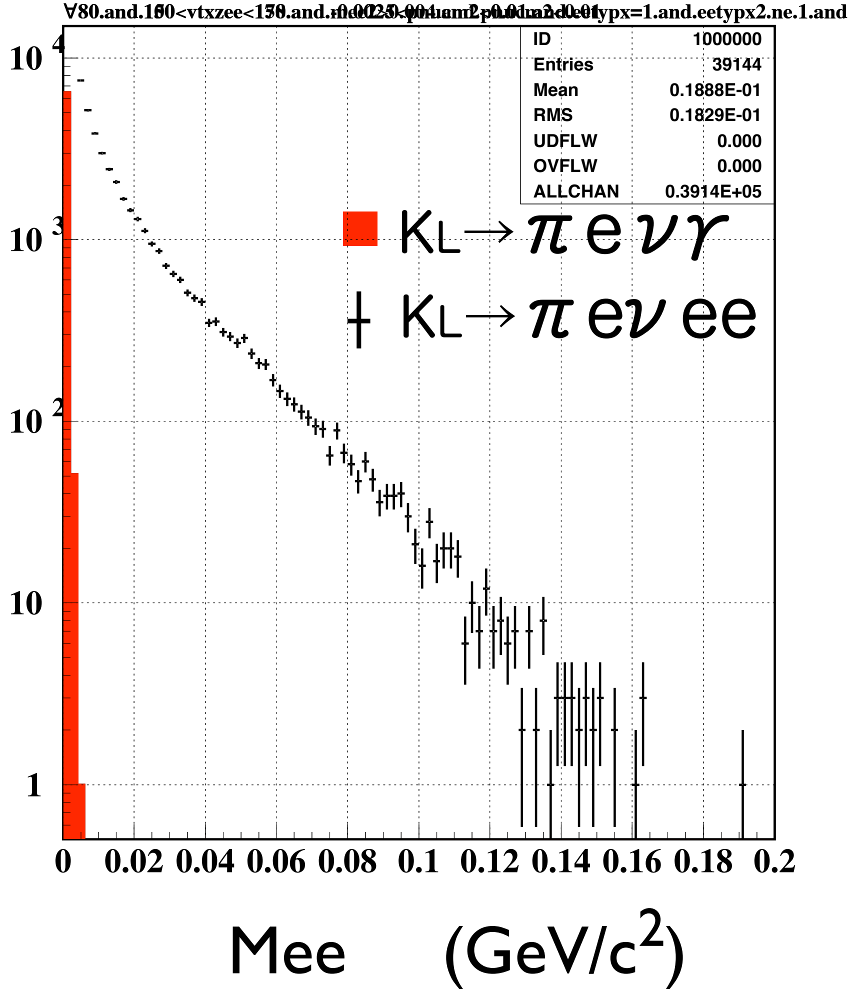
  PDG;

  $Br(K_{e3\gamma}:E_\gamma^*>30$ MeV, $\theta_\gamma^*>20°)=(3.53\pm0.06)\times10^{-3}$

Summary about $K_L \to \pi e \nu \gamma$ with external conversion

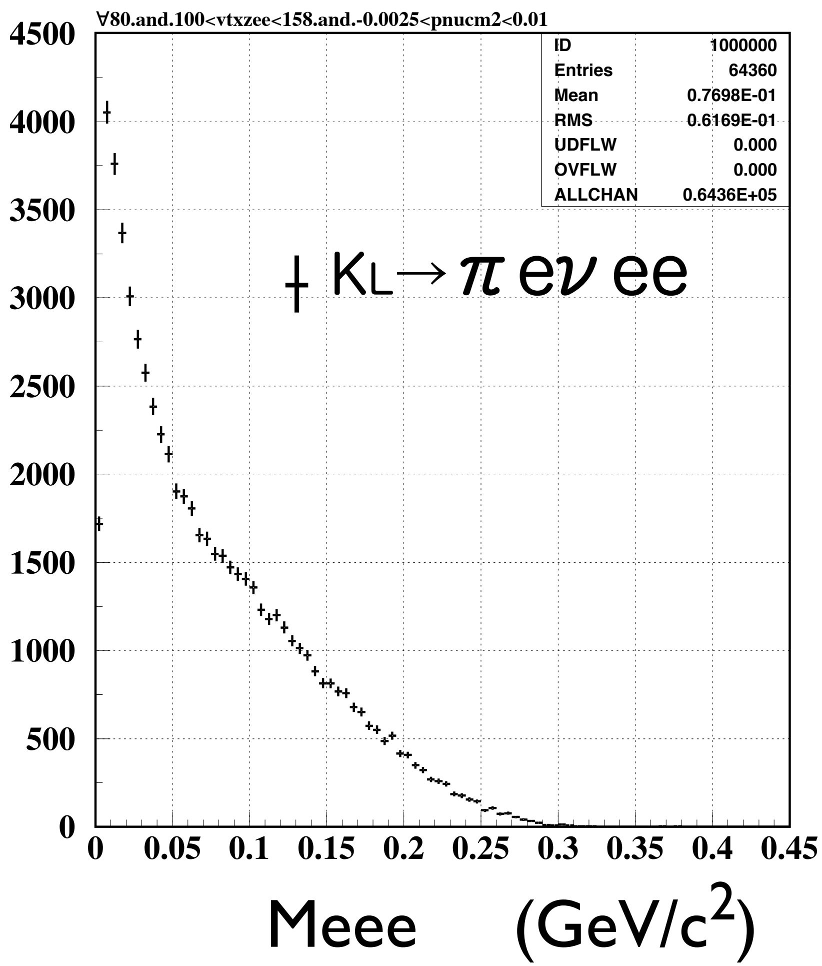
- Data has larger Mee distribution than MC
  - → Must be careful because Mee is influenced by manner of conversion directly.
- Data has a peak at 80~130 MeV in the distribution of invariant mass of three electron
- I have to determine Kaon momentum in order to make the quantitative analysis.

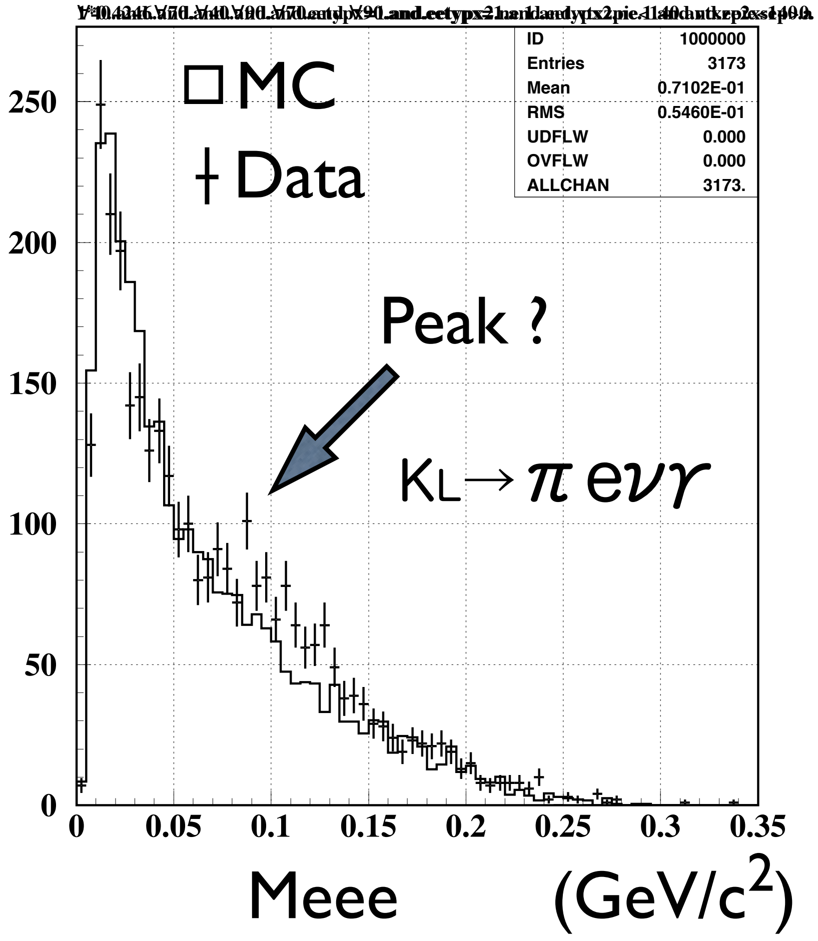
Invariant mass of ee pair comparing $K_L \to \pi e \nu \gamma$ and $K_L \to \pi e \nu ee$



- $K_L \to \pi e \nu$ ee has very large invariant mass of ee pair
- We have 6×10^4 $K_L \to \pi e \nu$ ee candidates

Invariant mass of three electron





Summary

- Conclusion
  - I am trying to study Kaon structure using $K_L \to \pi e \nu ee$ and radiative Ke3 with external conversion
  - We can separate $K_L \to \pi e \nu ee$ and Ke3γ by relation of eeVtx and pieVtex
  - We can see unknown peak in Meee distribution
  - We have $(4\sim6)\times10^4$ events of $K_L \to \pi e \nu ee$ candidates
- Plan
  - Back ground estimation more rigorous
  - Must determine Kaon 4-momentum
  - MC for $K_L \to \pi e \nu ee$