Study of $K_L \rightarrow \pi e \nu e e$

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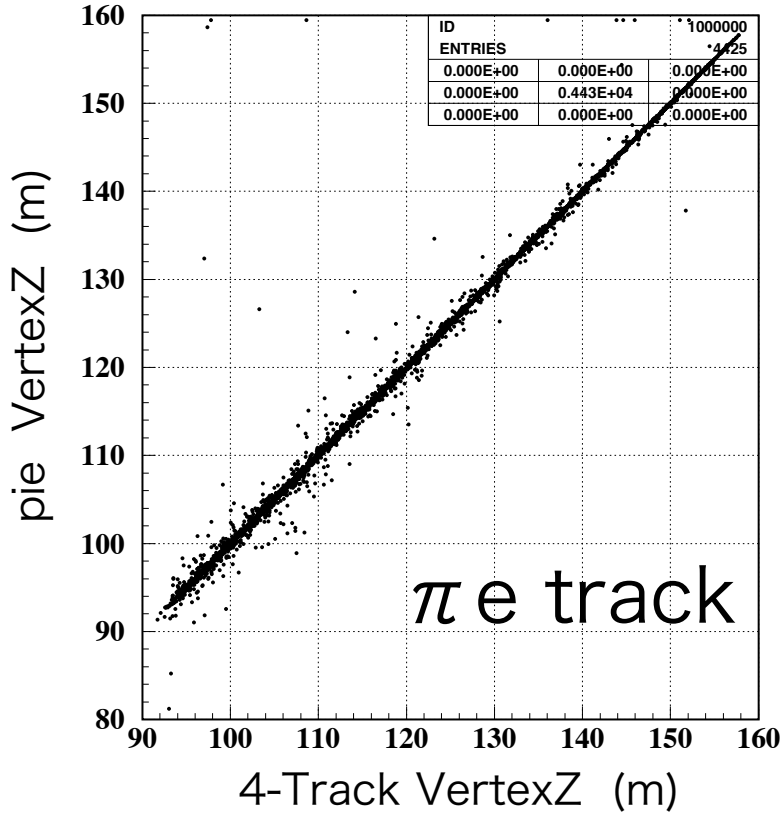
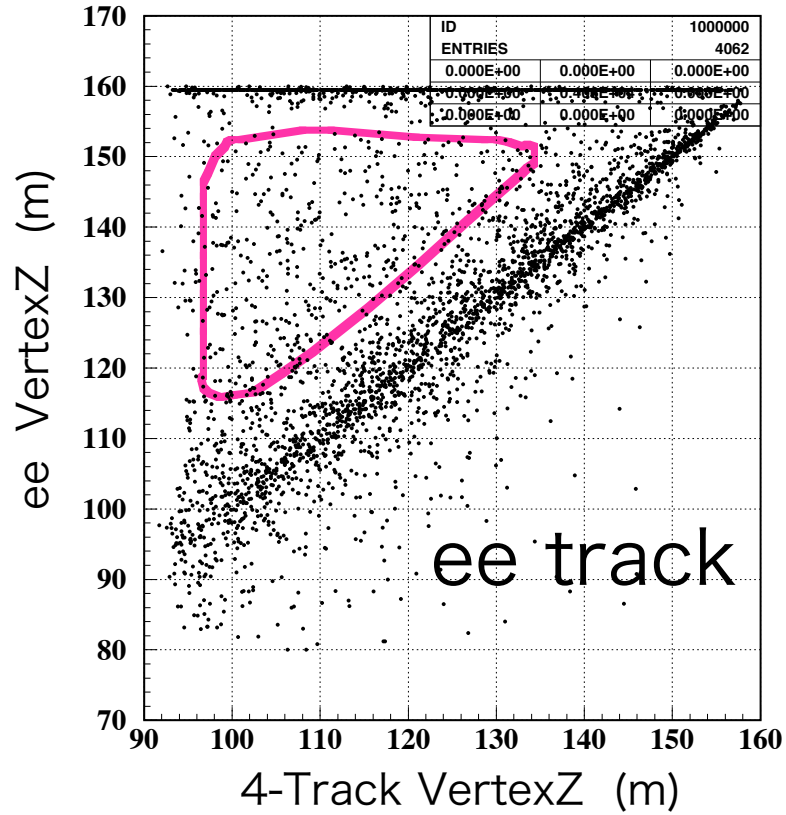
Todays talk

- Reason that VtxZ of e+e- pair reconstructed downstream from 4-track VtxZ
- Model for Monte Carlo simulation.
- Comparing Data and MC
- Summary and Plan

e+e- vertices were reconstructed downstream from 4-track Vtx

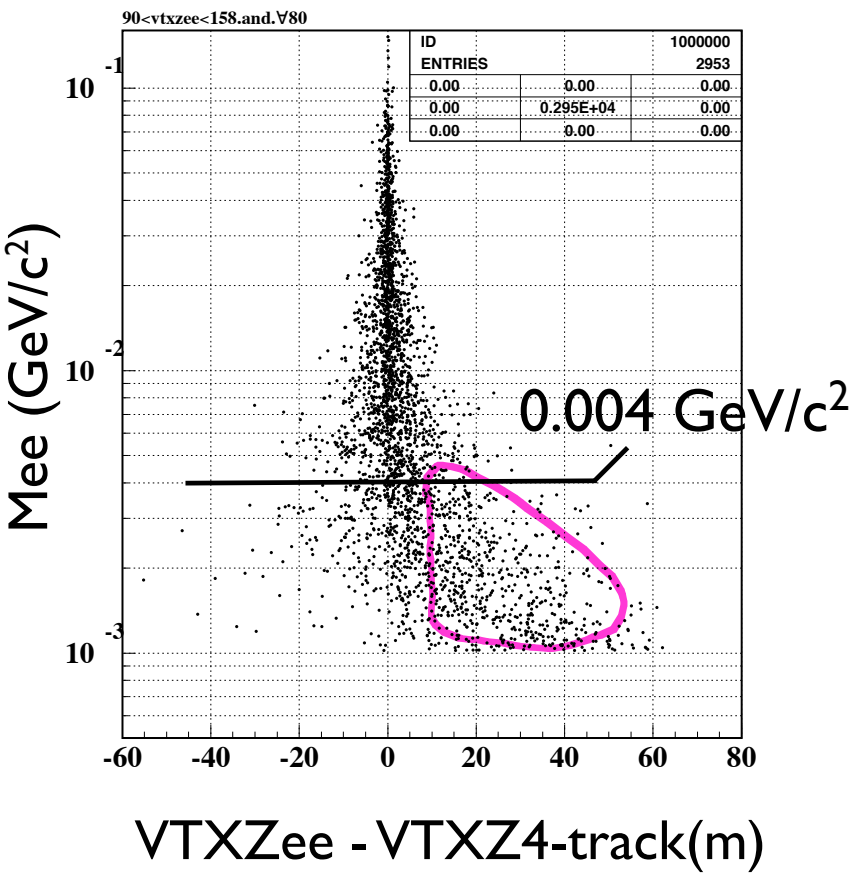


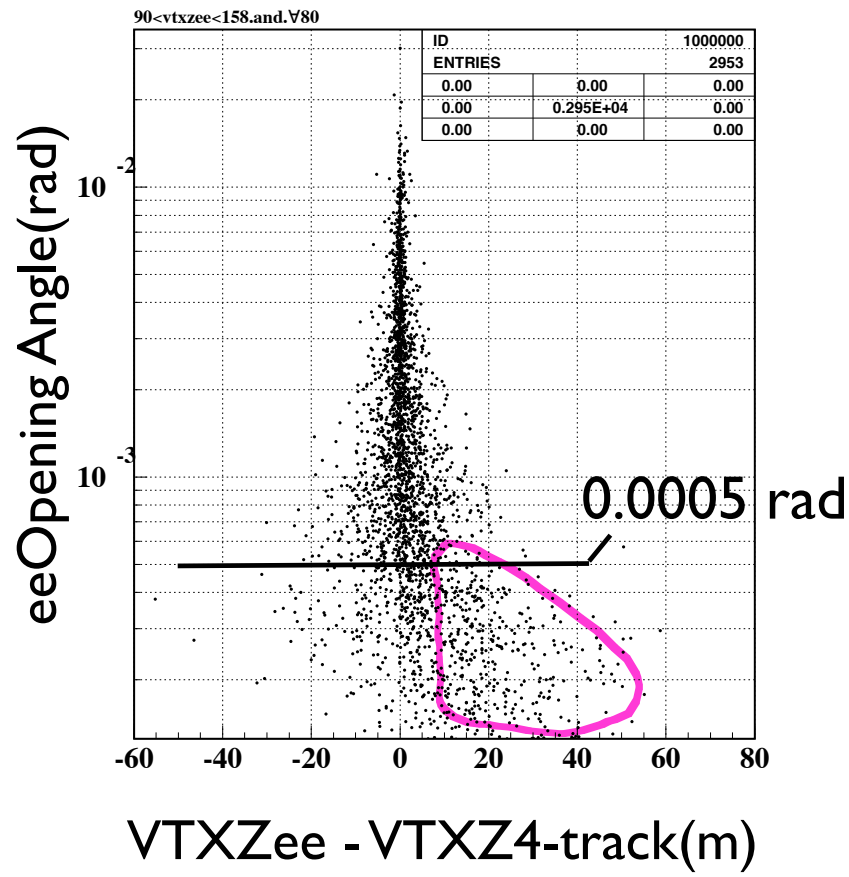


π e tracks well agree with 4track vertex

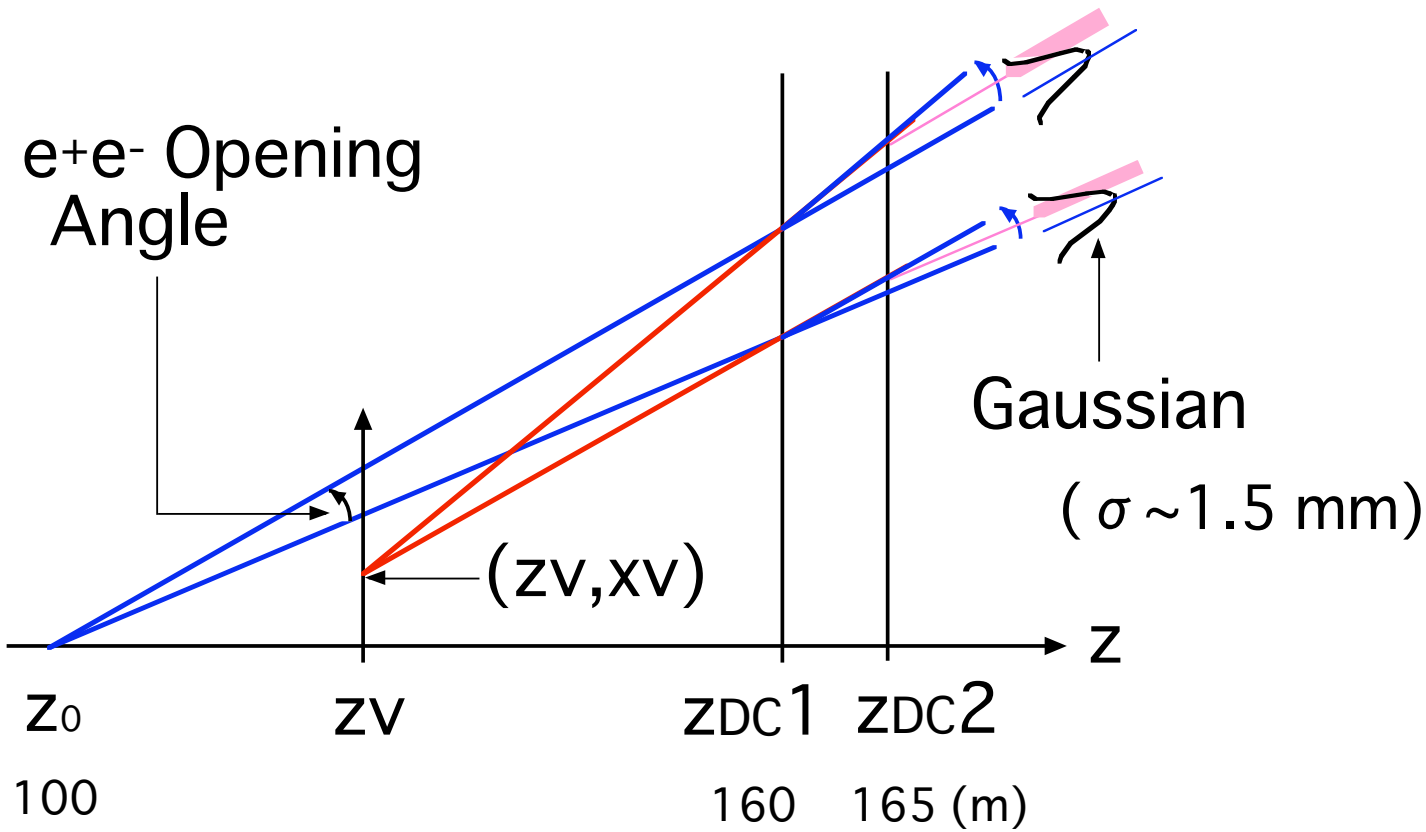
Some ee vertexZ are distributed in down stream.

Small mass and small opening angle events were reconstructed downstream from 4-TV



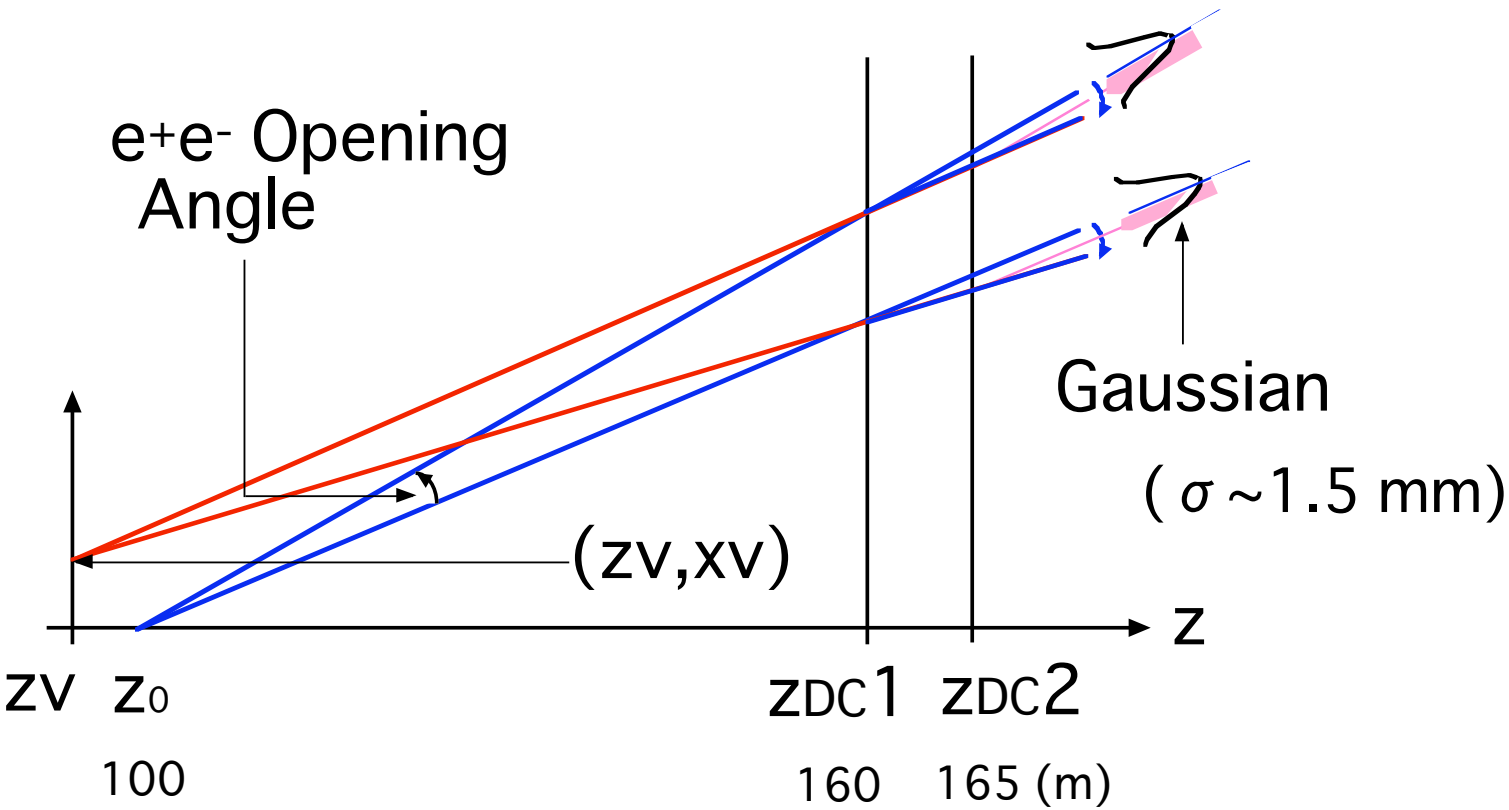


Between DC1 and DC2 an electron is scattered more than 1 mm at DC2



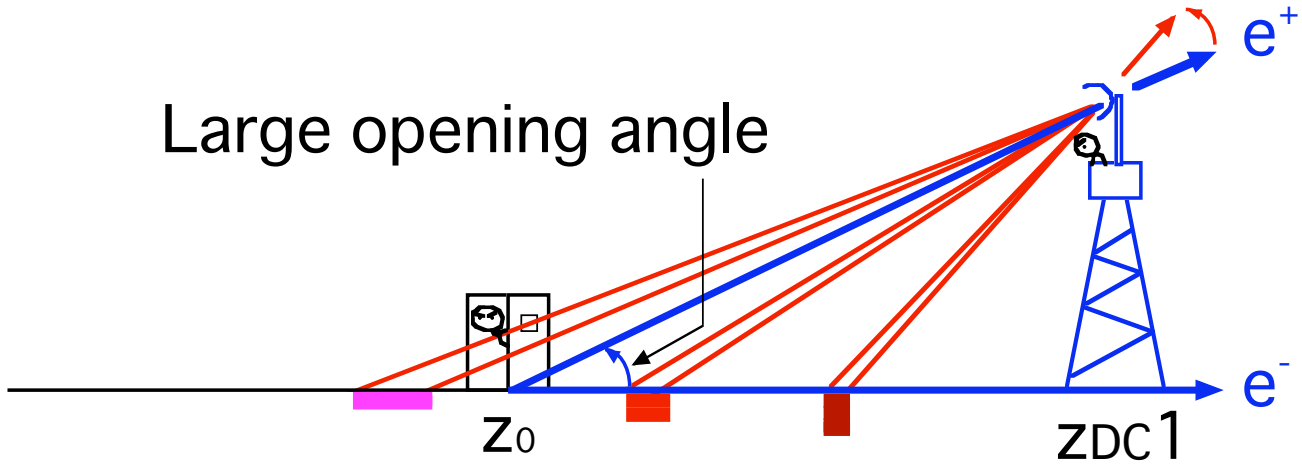
- Typical resolution of both DCs are 100 μm
- Events reconstructed upstream of Z0 and downstream of Z0 must be the same, but . . . .

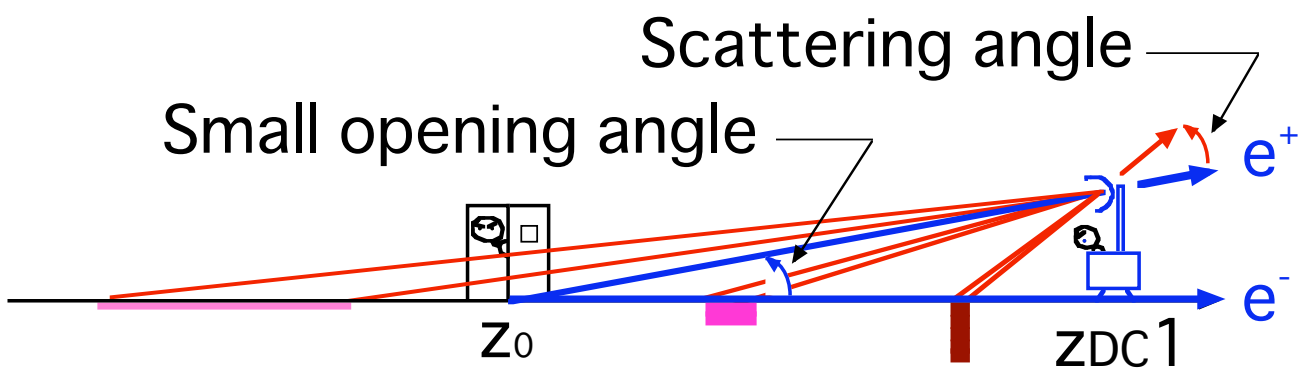
Between DC1 and DC2 an electron is scattered more than 1 mm at DC2



- Typical resolution of both DCs are 100 μm
- Events reconstructed upstream of Z0 and downstream of Z0 must be the same, but . . . .

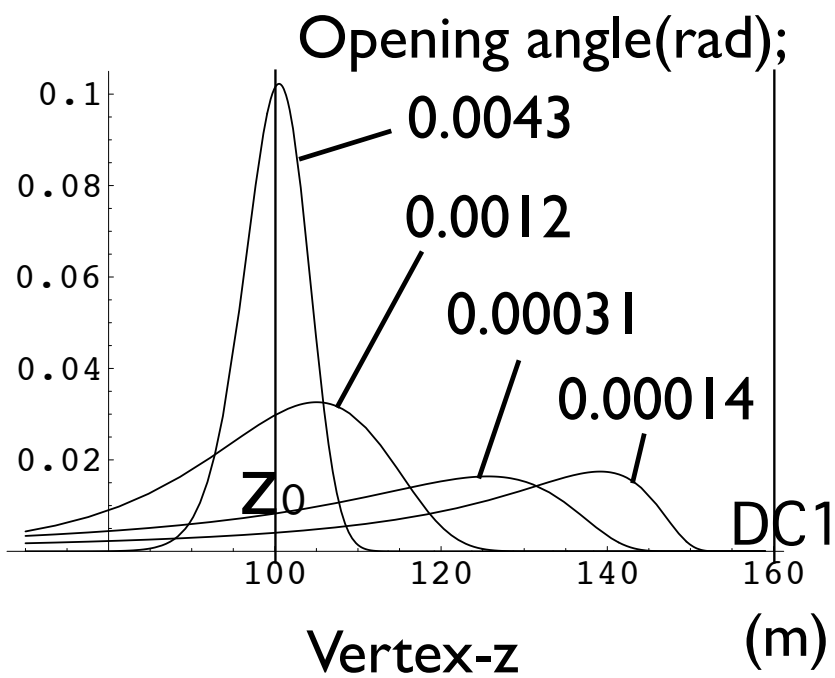
You are a guard of a jail house searching some jail breakers





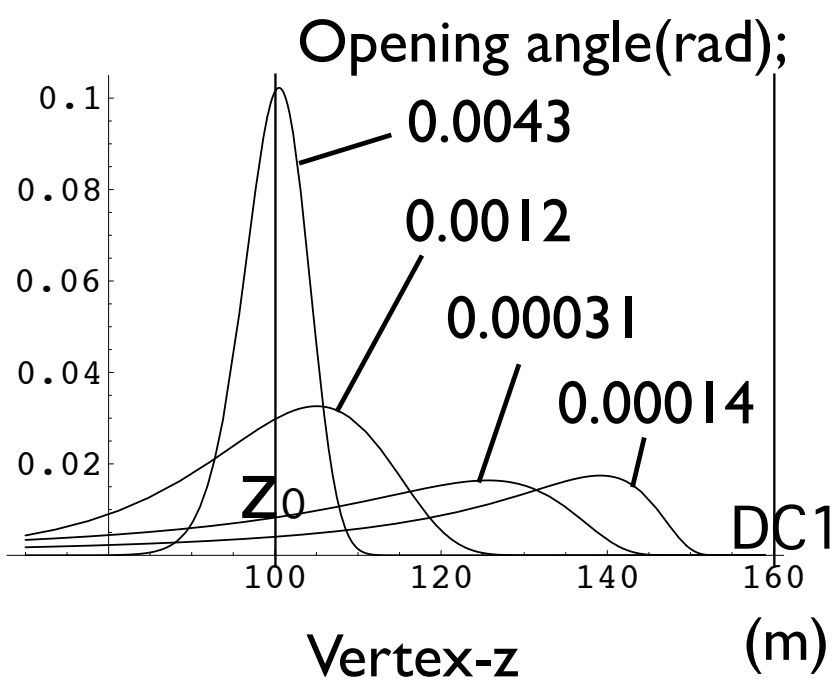
- e^+e^- opening angle at 4-track vertex is more sensitive than at e^+e^- pair track vertex.

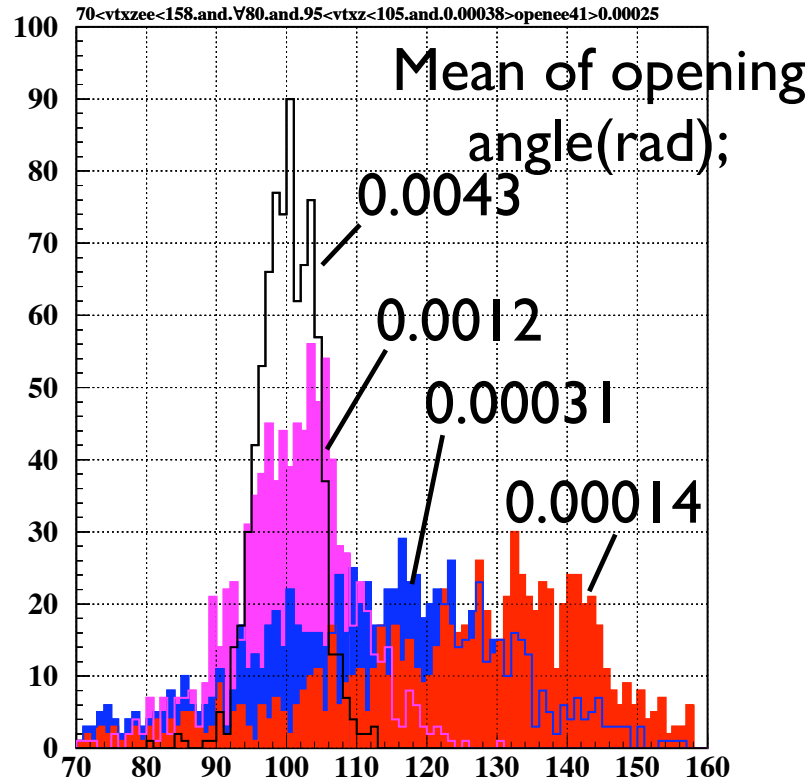
Distribution of vertex-z depending on the opening angle



- Calculated distribution of vertex-z using previous model.
- Integrated area on the upper side of Z0(100 m) and the downer side are equal.

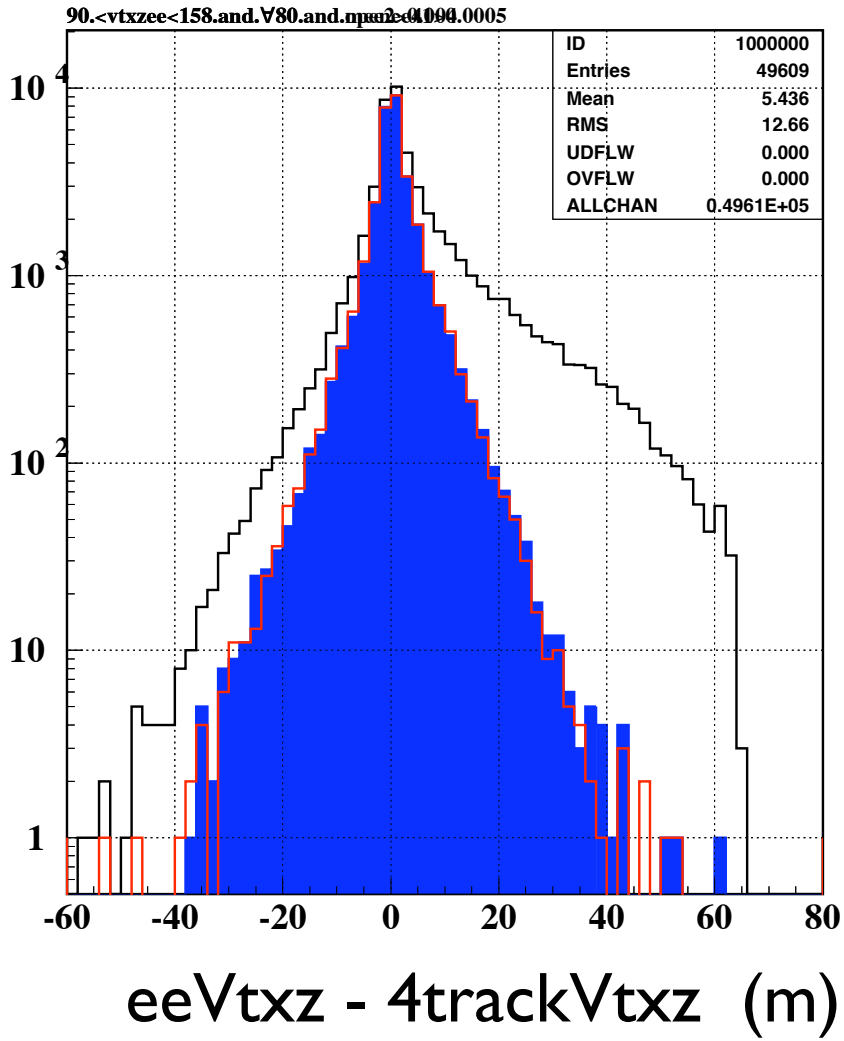
Distribution of vertex-z depending on the opening angle





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

Cut on invariant mass and opening angle of e^+e^- pair



e^+e^- opening angle >0.0005.

$M_{e^+e^-}$>0.004 GeV/c^2

- $M_{e^+e^-}^2 \sim E_{e^+}E_{e^-}\theta_{e^+e^-}^2$

Amplitude of $K_L \to \pi^{\pm} e^{\mp} \nu e^+ e^-$

Direct emission

$$T = \frac{G_F}{\sqrt{2}} e V_{us}^* \bar{\epsilon}(q)^* \Big[\cancel{(\hat{V}^0_{\mu\nu} - A^0_{\mu\nu}) \bar{u}(p_\nu) \gamma^\nu (1-\gamma_5) v(p_l)}$$
$$+ F^0_\nu \bar{u}(p_\nu) \gamma^\nu (1-\gamma_5) \left(\frac{p'_\mu + q_\mu}{p'q + q^2} - \frac{2p_{l\mu} + \not{q}\gamma_\mu}{2p_l q + q^2} \right) v(p_l) \Big]$$

Inner Brem.

$$\bar{\epsilon}(q) = \frac{e}{q^2} \bar{u}(p_2) \gamma^\mu v(p_1)$$

$$F^0_\mu = p_\mu + p'_\mu$$

p	: Kaon momentum
p'	: pion momentum
p_l	: momentum of lepton of Ke3
p_ν	: neutrino momentum
q	: momentum of virtual γ
p_1, p_2	: momentum of e^+e^-

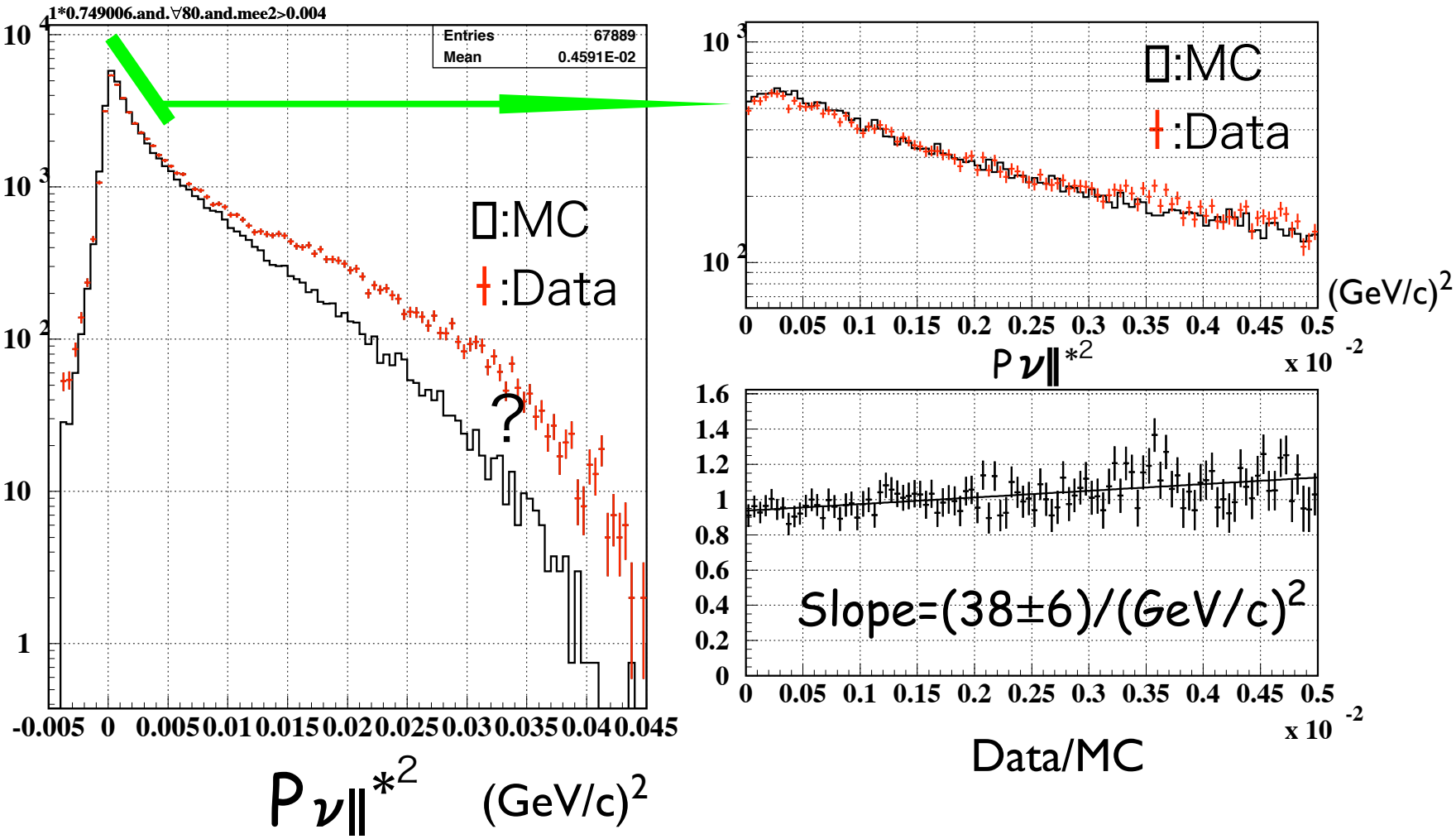
Generated events and acceptance

Generated	acceptance
4.322×10^6	1.57×10^-2

0.95 < E/p for e < 1.05
E/p for pi < 0.8
VtxChi < 40
3 ≤ number of Hclus ≤ 5
-0.001<OffMag for Pi <0.001
TRD Prob for e < 0.02
Mee > 0.004 GeV

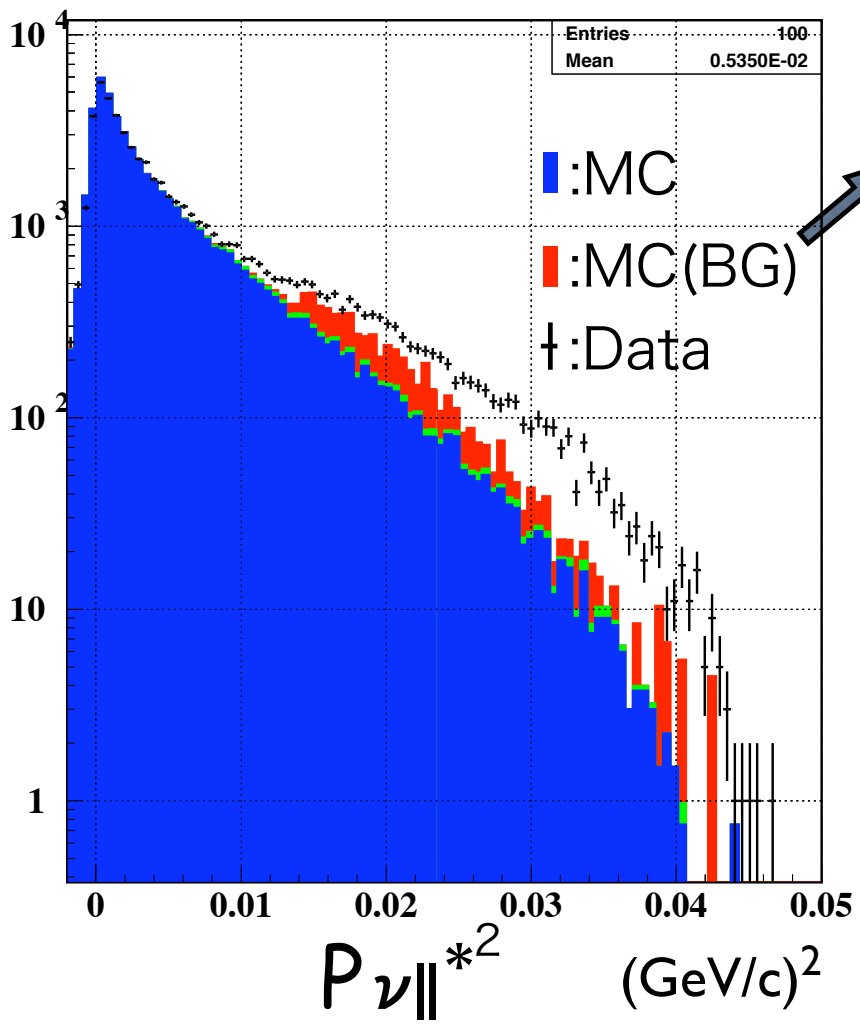
MCはMee>0.004GeVの制限を設けて行いました

Comparison of DATA to MC with only IB term of lowest order : $P_{\nu\parallel}^{*2}$



Behavior of

($K_L \to \pi^+\pi^-\pi^0$ then $\pi^0 \to e^+e^-e^+e^-$): $P_{\nu\parallel}^{*2}$



$K_L \to \pi^\pm \cancel{\pi^\mp} \pi^0$

Lost

$\pi^0 \to \cancel{e^\pm} e^\mp e^+ e^-$

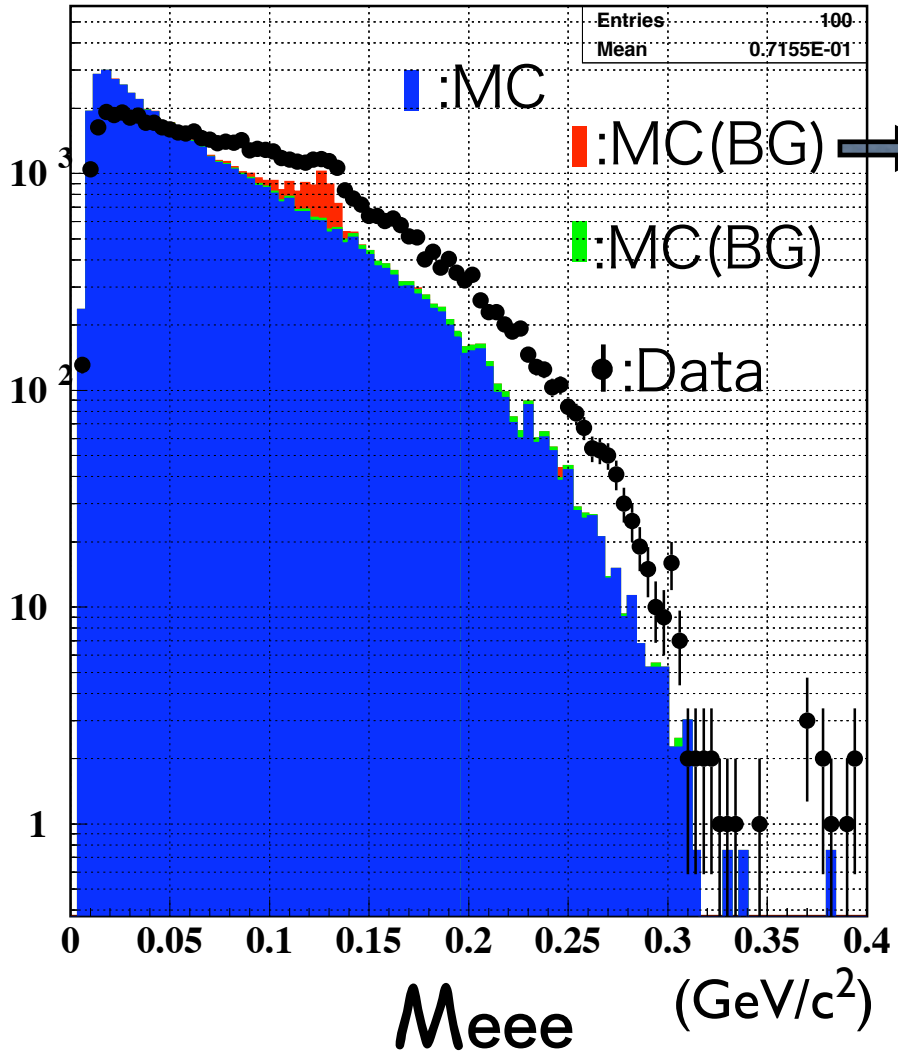
Lost

due to very small momentum, this event should have M_{π^0} as M_{eee}

- Statistics is not enough now

Behavior of

($K_L \to \pi^+\pi^-\pi^0$ then $\pi^0 \to e^+e^-e^+e^-$): M_{eee}



$K_L \to \pi^\pm \cancel{\pi^\mp} \pi^0$

Lost

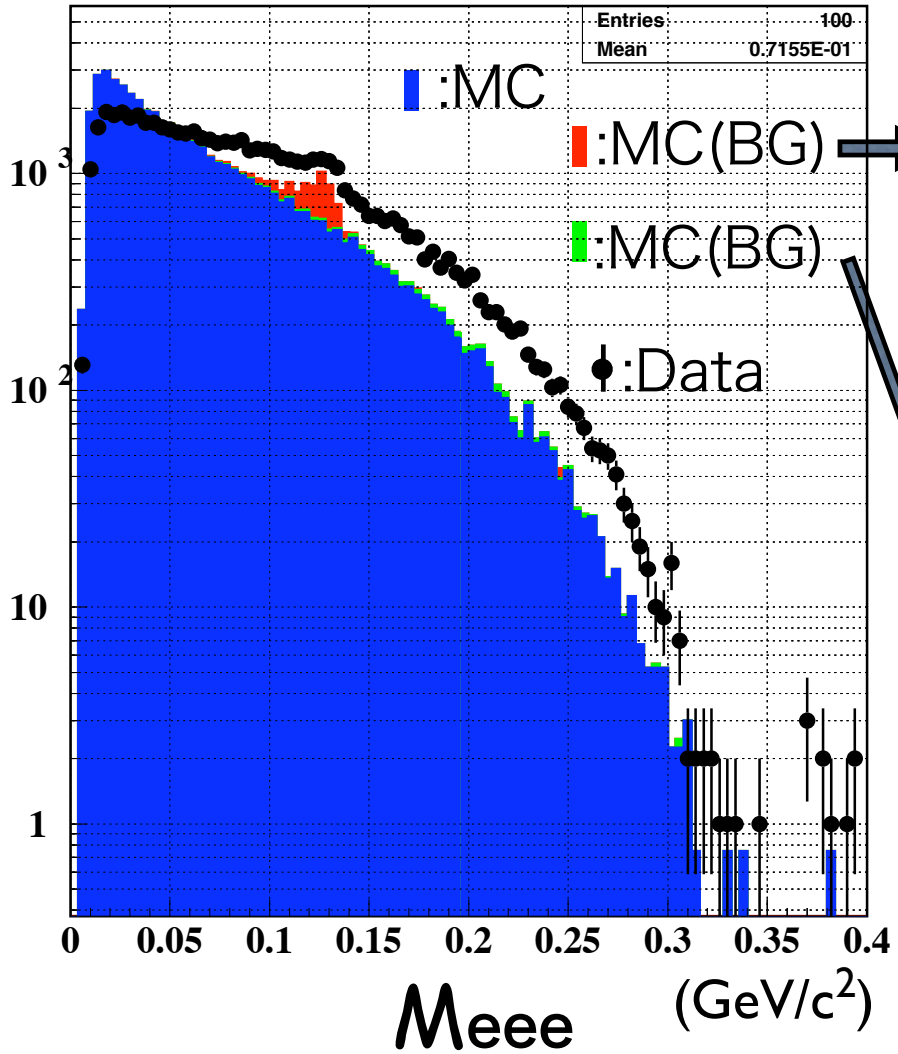
$\pi^0 \to \cancel{e^\pm} e^\mp e^+ e^-$

Lost

- Data has enhanced peak at M_{π^0} too.

Behavior of

($K_L \to \pi^+\pi^-\pi^0$ then $\pi^0 \to e^+e^-\gamma$): Meee



$K_L \to \pi^\pm \pi^\mp \pi^0$

Lost

$\pi^0 \to e^\pm e^\mp e^+ e^-$

Lost

- Data has enhanced peak at M_{π^0} too.

$K_L \to \pi^\pm \pi^\mp \pi^0$

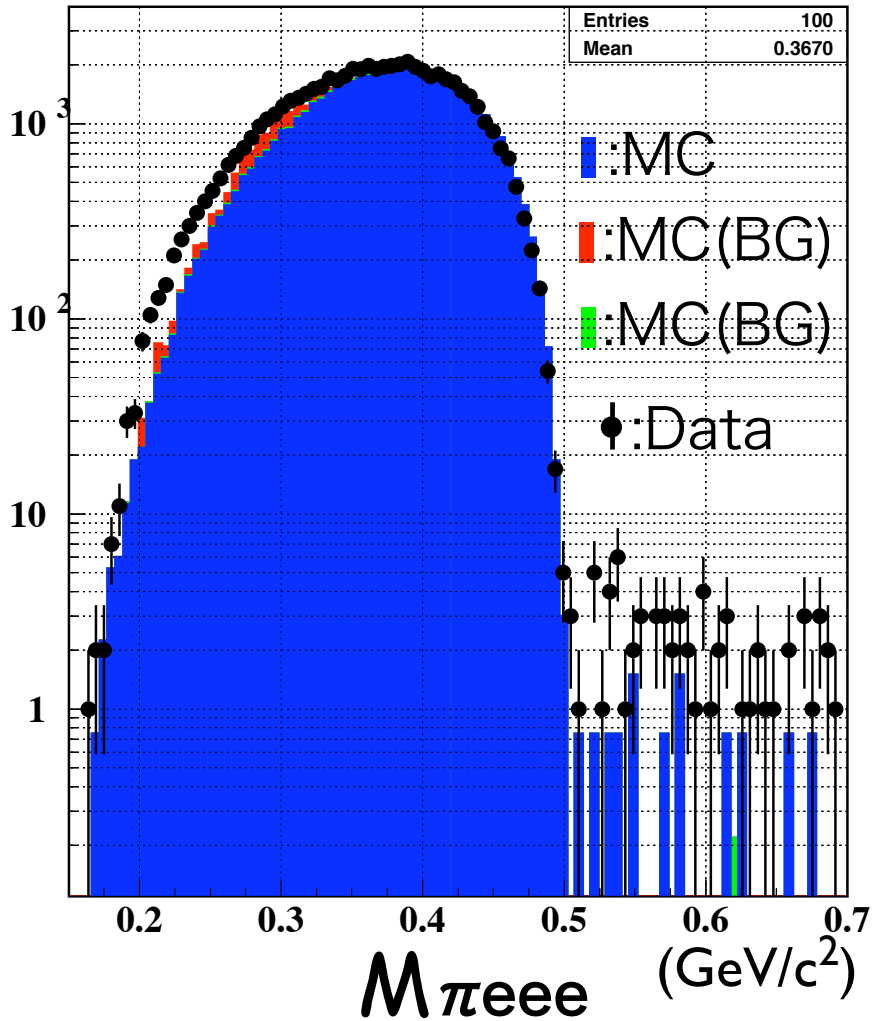
Fake

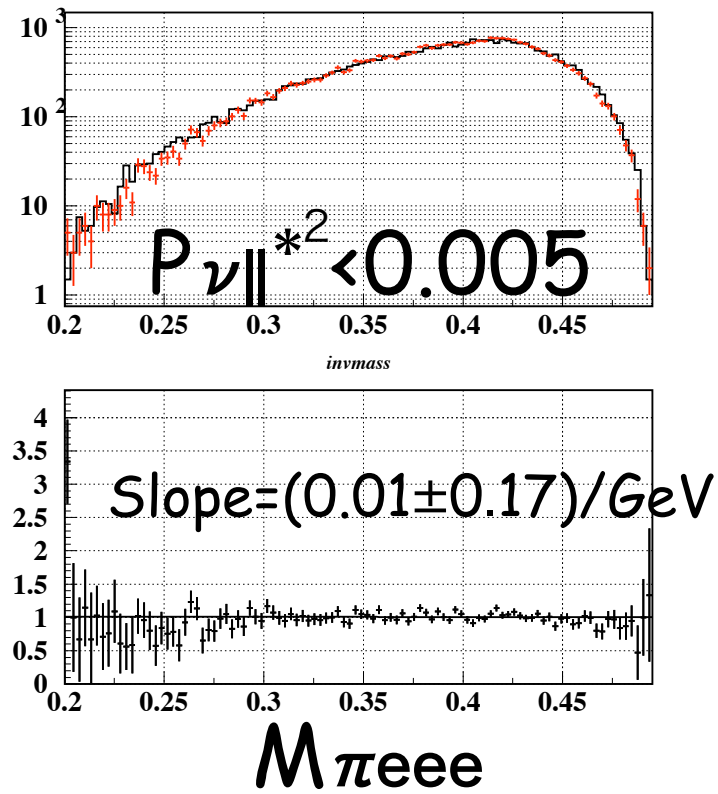
$e^\mp$

$\pi^0 \to e^+e^-\gamma$

- This BG is well removed by TRD

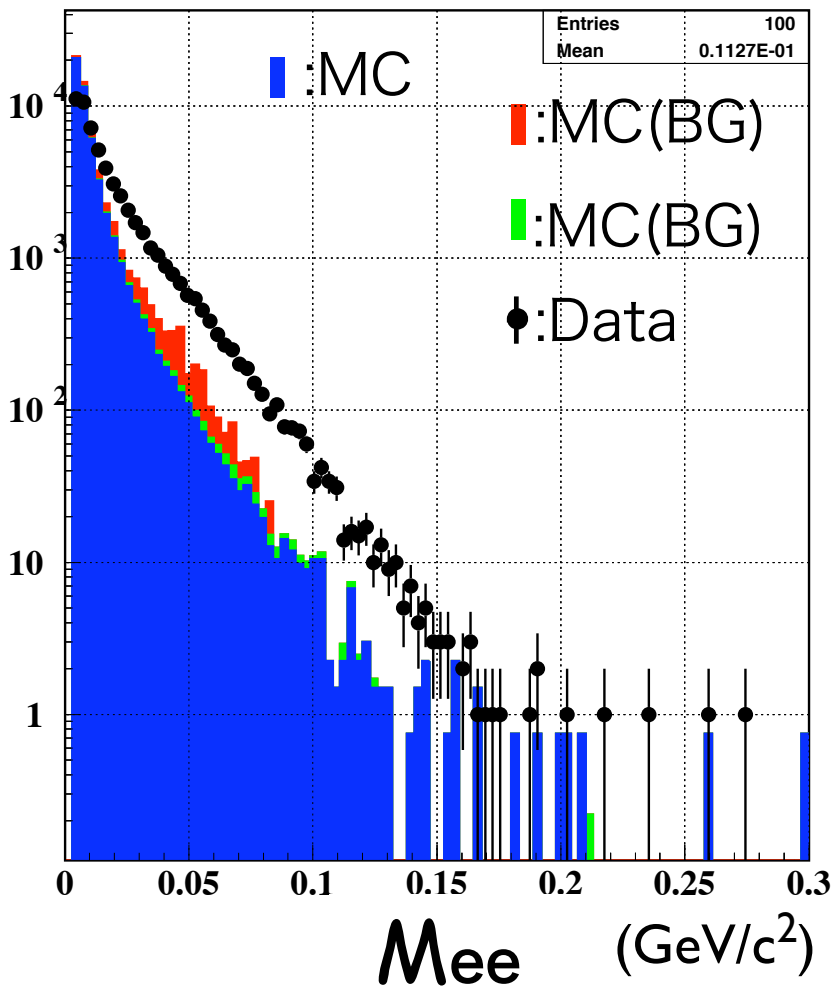
Comparison of Data and MC with only IB term of lowest order: $M_{\pi eee}$

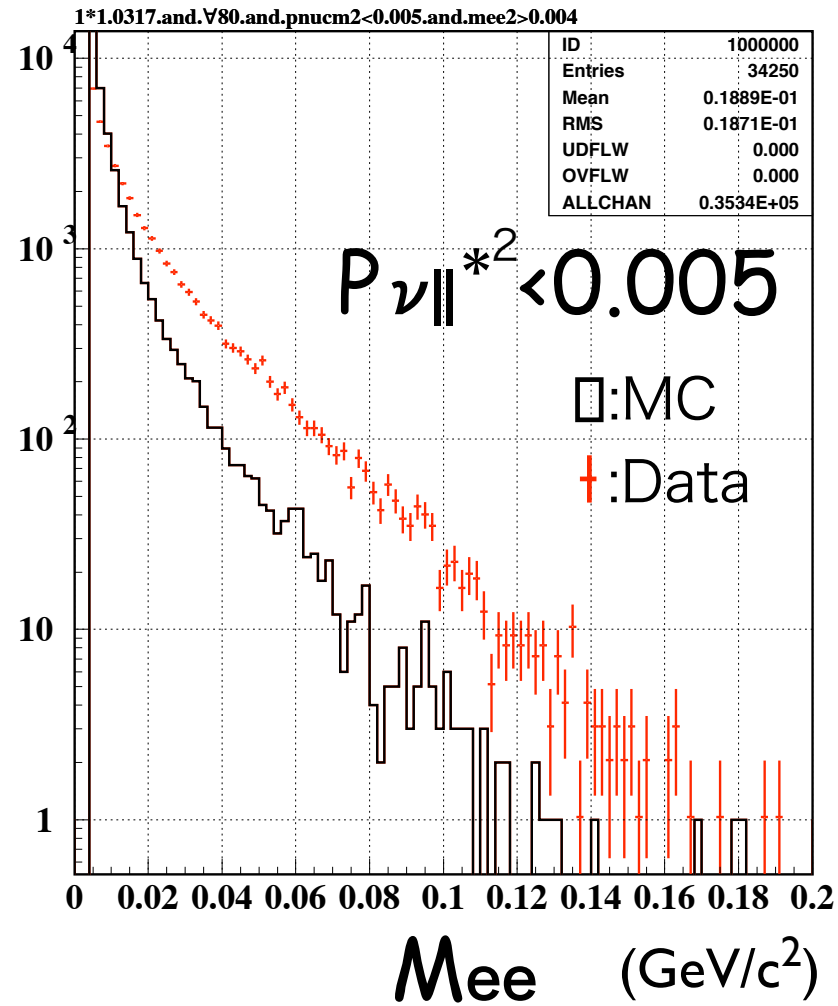




Good agreement

Comparison of Data and MC with only IB term of lowest order: Mee





Quantitative discussion

KTeV '97 winter: using K_L Yield=1.42×10^{11} by Senyo

$K_L\to\pi e\nu ee$ candidates	$0<P_{\nu//}^2<0.005$	29000
	$-0.02<P_{\nu//}^2<0.05$	57792 **
$Br(K_L\to\pi e\nu ee)$	$0<P_{\nu//}^2<0.005$	$(2.28\pm0.02)\times10^{-5}$ *
	$-0.02<P_{\nu//}^2<0.05$	$(2.59\pm0.02)\times10^{-5}$ * **
$\frac{K_L\to\pi^+\pi^-(\pi^0\text{-Dalitz})}{K_L\to\pi e\nu ee}$	$0<P_{\nu//}^2<0.005$	$(5.7\pm0.7)\times10^{-4}$ *
	$-0.02<P_{\nu//}^2<0.05$	$(1.13\pm0.13)\times10^{-2}$ * **
$\frac{K_L\to\pi^+\pi^-(\pi^0\text{-4e})}{K_L\to\pi e\nu ee}$	$0<P_{\nu//}^2<0.005$	$(5.1\pm1.8)\times10^{-4}$ *
	$-0.02<P_{\nu//}^2<0.05$	$(5.7\pm0.8)\times10^{-2}$ * **

* only statistical error

** including disagreement area

$Br(K_L\to\pi e\nu\gamma : E_\gamma^*>30\text{MeV}, \theta^*>20°) = (3.53\pm0.06)\times10^{-3}$

Conclusion

- It's reasonable that Small Mee event has e-e Vertex-Z reconstructed downstream from 4-track Vertex-Z.
- MC with lowest order amplitude without Direct Emission term agrees with data for $P_{\nu||}^{*2}$ and Mpeee if we take $P_{\nu||}^{*2} < 0.005$ $(GeV/c)^2$
- There is a large disagreement between Data and MC in Mee and Meee even with $P_{\nu||}^{*2} < 0.005$ $(GeV/c)^2$
- 130 MeV/c^2 peak on Meee is due to ($K_L \rightarrow \pi^+\pi^-\pi^0$ then $\pi^0 \rightarrow e^+e^-e^+e^-$)
- Amount of BG event ($K_L \rightarrow \pi^+\pi^-\pi^0$Dalitz) was estimated:

$K_L \rightarrow \pi^+\pi^-\pi^0$-Dalitz / $K_L \rightarrow \pi e \nu ee$ = $(5.7 \pm 0.7) \times 10^{-4}$, $P_{\nu||}^{*2} < 0.005$ $(GeV/c)^2$

$K_L \rightarrow \pi^+\pi^-\pi^0$-4e / $K_L \rightarrow \pi e \nu ee$ = $(5.1 \pm 1.8) \times 10^{-4}$, $P_{\nu||}^{*2} < 0.005$ $(GeV/c)^2$

Plan

- Analysis of Normalization Mode.
- Background estimation.
- MC with Structure dependent term.
- MC with higher order.
- Branching ratio with E_γ^*>30 MeV, θ_γ^*>20°, c.m.
  ←Determine Kaon momentum
  ←Neutrino quadratic ambiguity
- To see correlation between polarity of Pi-e and polarity of e+e- pair.