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

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Todays talk

- Background analysis.
- asymmetry of angle of ee plane and Pi-e plane
- Amplitude including Vector currents simulation.
- Summary and Plan

Background

	Branching Ratio	
$K_L \to \pi^+\pi^-(\pi^0 \to e^+e^-\gamma)$	1.507×10^{-3}	$\pi^\pm \to e^\pm$, $\cancel{\gamma}$
$K_L \to \pi^+\pi^-(\pi^0 \to e^+e^-e^+e^-)$	3.95×10^{-6}	$\cancel{\pi^\pm}, \cancel{e^\mp}$
$K_L \to \pi^\pm e^\mp \nu(\pi^0 \to e^+e^-\gamma)$	6.21×10^{-7}	$\cancel{\gamma}$
$K_L \to \pi^\pm \mu^\mp \nu e^+e^-$	?	$\mu^\mp \to e^\mp$
$K_L \to \pi^\pm e^\mp \nu(\gamma \to e^+e^-)$	$>3.5\times10^{-3}$	$\gamma \to e^+e^-$(Ext.)

Raw cuts

90 m < Z-Vertex < 158 m
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
Mee > 0.004 GeV
Energy of elec(Ke3). > 7 GeV

$$K_L \rightarrow \boxed{\pi^{\pm}}\pi^{\mp}\boxed{\pi^0}$$

$$\pi^{\pm} \rightarrow e^{\pm}$$

$$\pi^0 \rightarrow e^+e^-\not{\gamma}$$

- MC

  Generation: $\pi^+\pi^-\pi^0 \rightarrow e^+e^-\gamma$ by KTeVMC

  Force $\pi^+/\pi^- \rightarrow e^+/e^-$ (Event weight)

- Strategy

  1. pp0kine<-0.005(GeV/c)2
  2. Number of Hardware cluster = 3
  3. TRD probability

     < 0.02 for Electron track

     > 0.1 for Pion track

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

$$\pi^{\pm} \to e^{\pm}$$

$$\pi^{0} \to e^{+}e^{-}\not{\gamma}$$

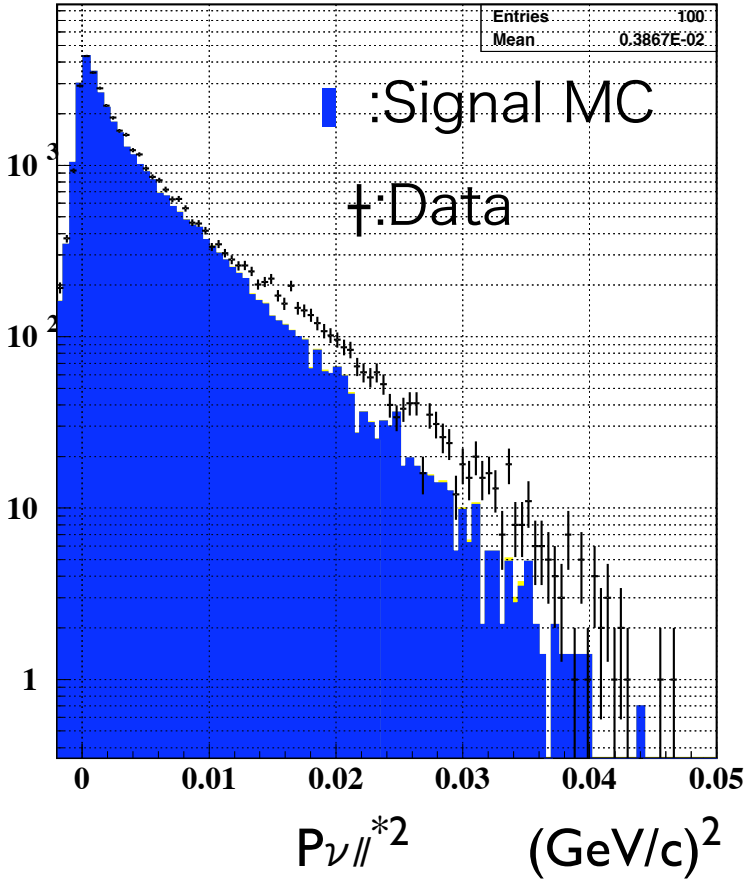
#B.G / #Signal	pp0kin	Hclus.	TRD
pp0kin	1120 / 43014 =2.60%	174 / 19516 =0.89%	40 / 33652 =0.12%
Hclus.		3360 / 23135 =14.52%	111 / 18150 =0.61%
TRD			614 / 38465 =1.60%

pp0kin × Hclus × TRD

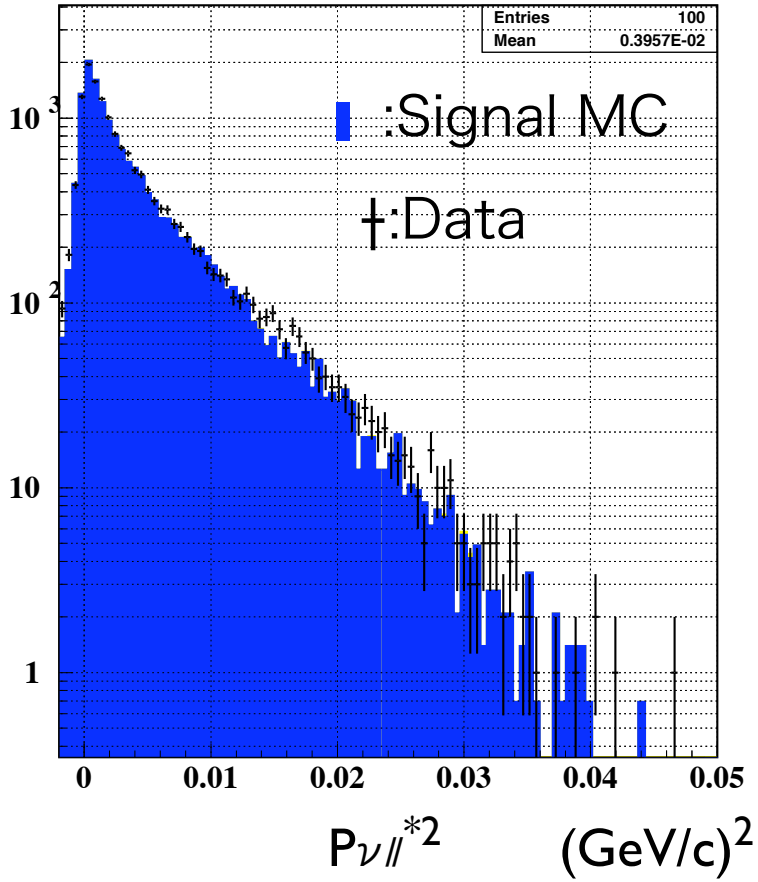
$$\frac{7.2\pm1.3}{(153.8\pm1.0)\times10^{2}}$$

$$=0.047\pm0.008\ \%$$

pp0kine × TRD × NHclus



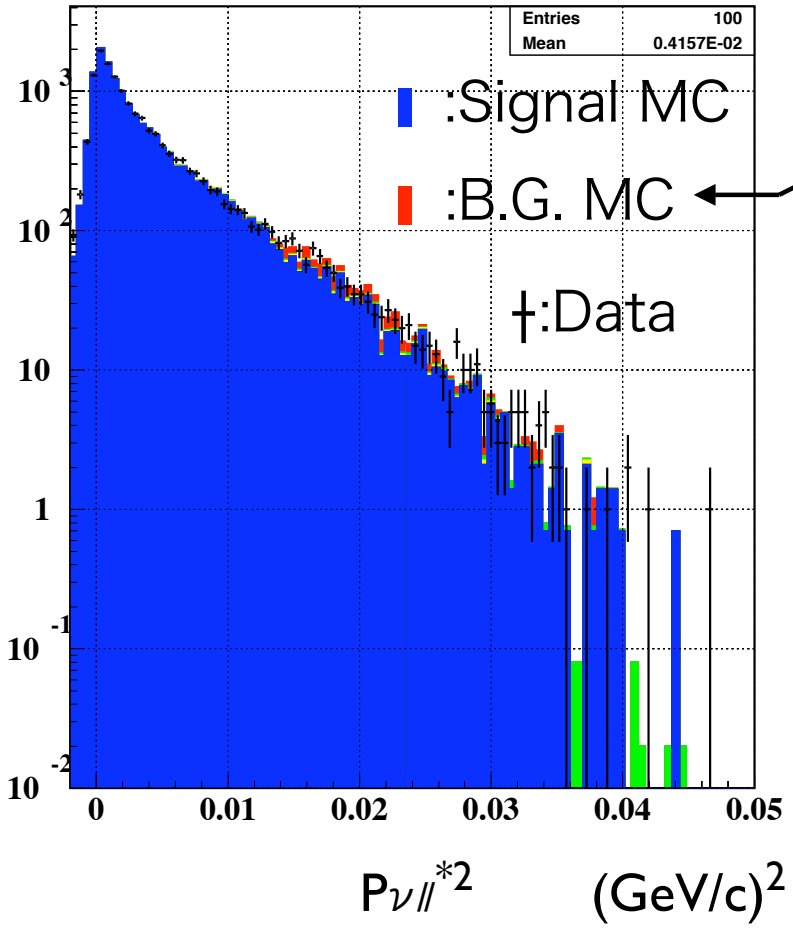
pp0kine × TRD



pp0kine × TRD × NHclus

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

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



- MC

$K_L \to \pi^+ \pi^- \pi^0$

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

by KTeVMC

$$K_L \rightarrow \cancel{\pi^{\pm}}\pi^{\mp}\boxed{\pi^0} \rightarrow \cancel{e^{\mp}}e^{\pm}e^{+}e^{-}$$

pp0kin × Hclus × TRD

$$\frac{\#B.G}{\#Signal} = \frac{157 \pm 8}{(153.8 \pm 1.0) \times 10^2}$$

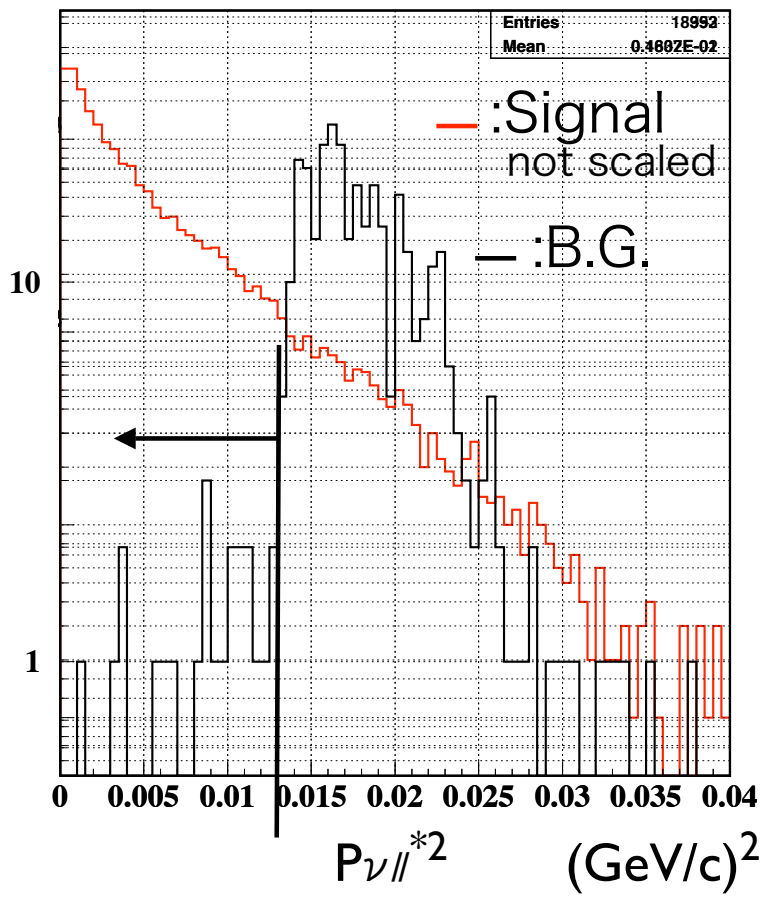
$$= 1.02 \pm 0.05\ \%$$

pp0kin × Hclus × TRD

$\boxed{\times P_{\nu//}^{*2} < 0.013\ (GeV/c)^2}$

$$\frac{\#B.G}{\#Signal} = \frac{10.2 + 2.1}{(143.7 \pm 1.0) \times 10^2}$$

$\boxed{= 0.071 \pm 0.015\ \%}$



$$K_L \to \pi^{\pm} e^{\mp} \nu \boxed{\pi^0} \to e^+ e^- \not{\gamma}$$

- MC

  Generation: $\pi^{\pm}e^{\mp}\nu\pi^0 \to e^+e^-\gamma$ by KTeVMC

- Strategy

  Number of Hardware cluster = 3

pp0kin × Hclus × TRD × ($P_{\nu//}^{*2}$ < 0.013 (GeV/c)^2)

$$\frac{\#B.G}{\#Signal} = \frac{57.1 \pm 3.0}{(143.7 \pm 1.0) \times 10^2}$$

$$= 0.397 \pm 0.021\ \%$$

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

- MC

  Generation: Modified $K_L \to \pi^+ e^- \nu e^+ e^-$ to

  $K_L \to \pi^+ \mu^- \nu e^+ e^-$

- Strategy
  1. Muon anti.
  2. Energy of electron(muon fakes) > 7GeV/c^2

$$K_L \to \pi^{\pm} e^{\mp} \nu \boxed{\gamma} \longrightarrow e^+ e^-$$ with materials

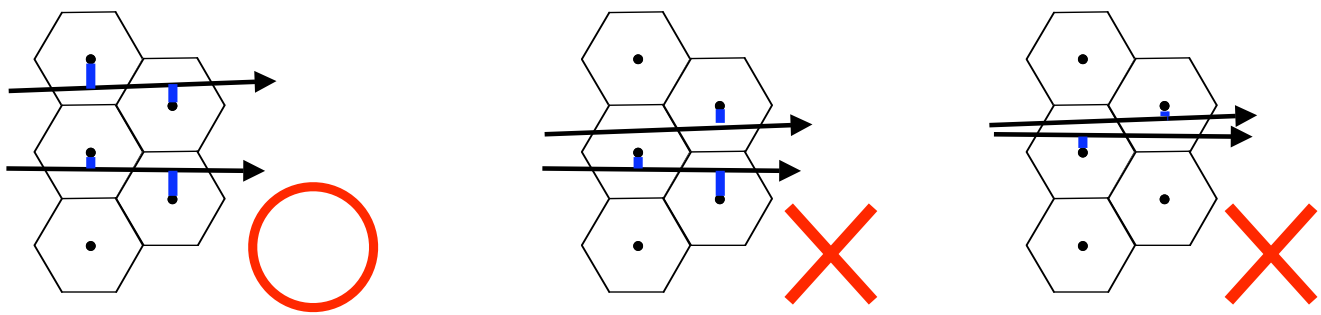
- MC

  Generation: $K_L \to \pi^{\pm} e^{\pm} \nu \gamma$ by KTeVMC

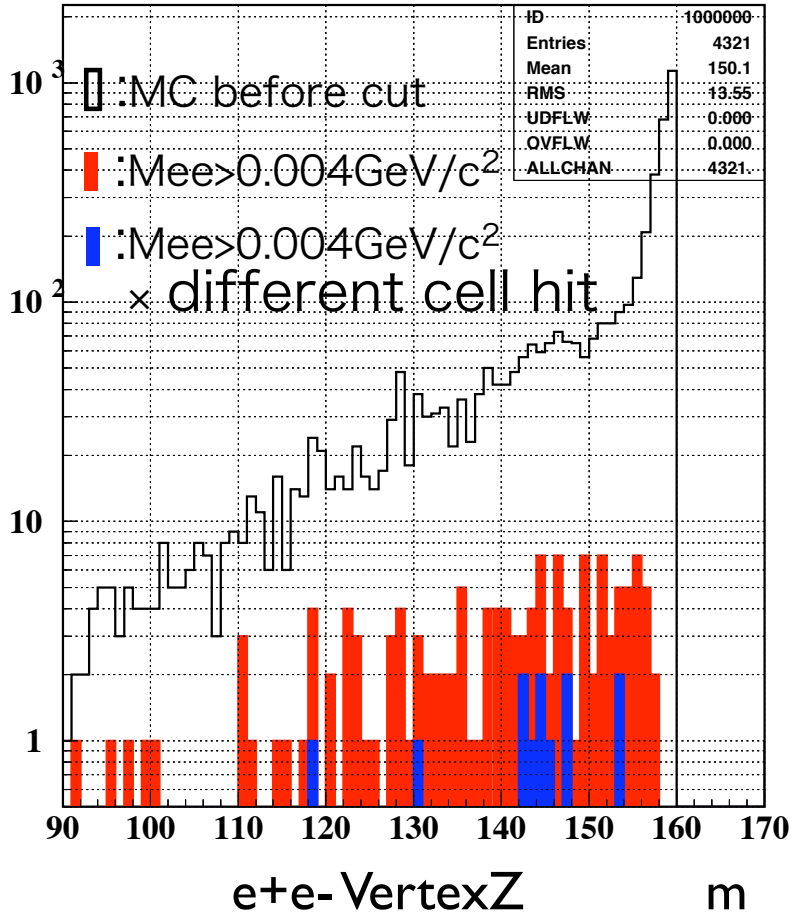
  then γ is converted at Vacuum W and DC1

- Strategy

  1. Invariant mass of ee >0.004 GeV/c2
  2. Each track goes throuh different cell at x view of DC1



$$K_L \to \pi^{\pm} e^{\mp} \nu \boxed{\gamma} \to e^+ e^-$$ with materials



- VtxZ is required to be between 90 to 158 m
- Reconstructed vtxZ of ee pair protrudes from Vacuum W to upper stream.
- 38 events remain in 11369 signal events

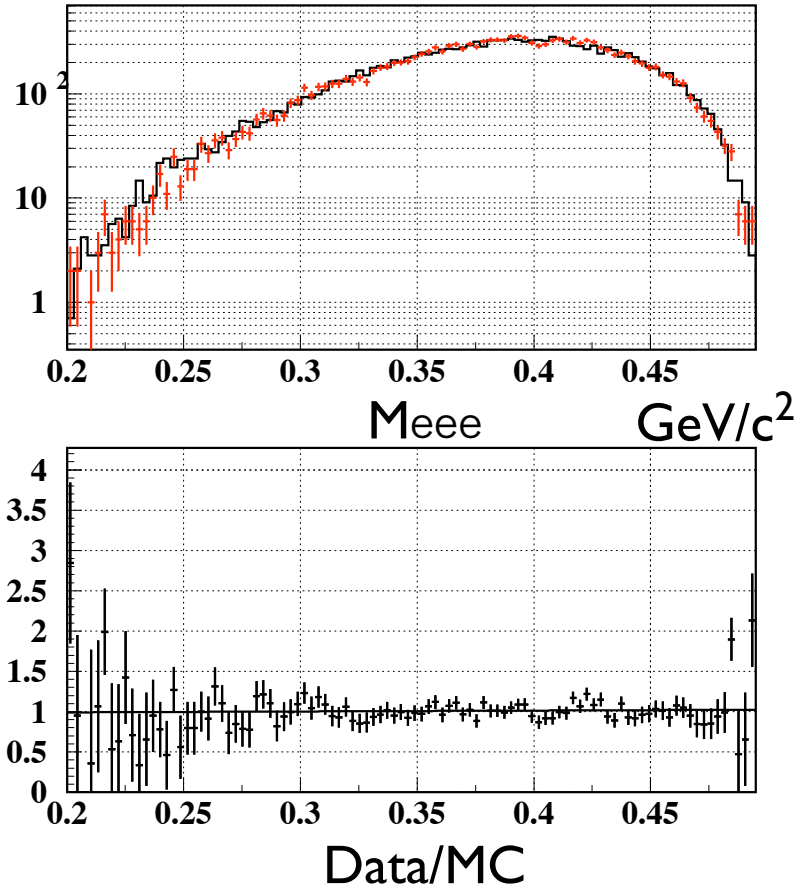
Residual Background

$K_L \to \pi^+\pi^-(\pi^0 \to e^+e^-\gamma)$	3.3±0.9±0.1	
$K_L \to \pi^+\pi^-(\pi^0 \to e^+e^-e^+e^-)$	4.9±1.5±0.5	
$K_L \to \pi^\pm e^\mp \nu(\pi^0 \to e^+e^-\gamma)$	42.6±2.6±2.6	
$K_L \to \pi^\pm \mu^\mp \nu e^+e^-$	0.0±0.4	
$K_L \to \pi^\pm e^\mp \nu(\gamma \to e^+e^-)$	(38±11)	

as we get
$(112.8 \pm 1.1) \times 10^2$ signals
in '97 winter data set

Systematic errors are from only branching ratios of B.G.

Invariant mass $M_{\pi eee}$

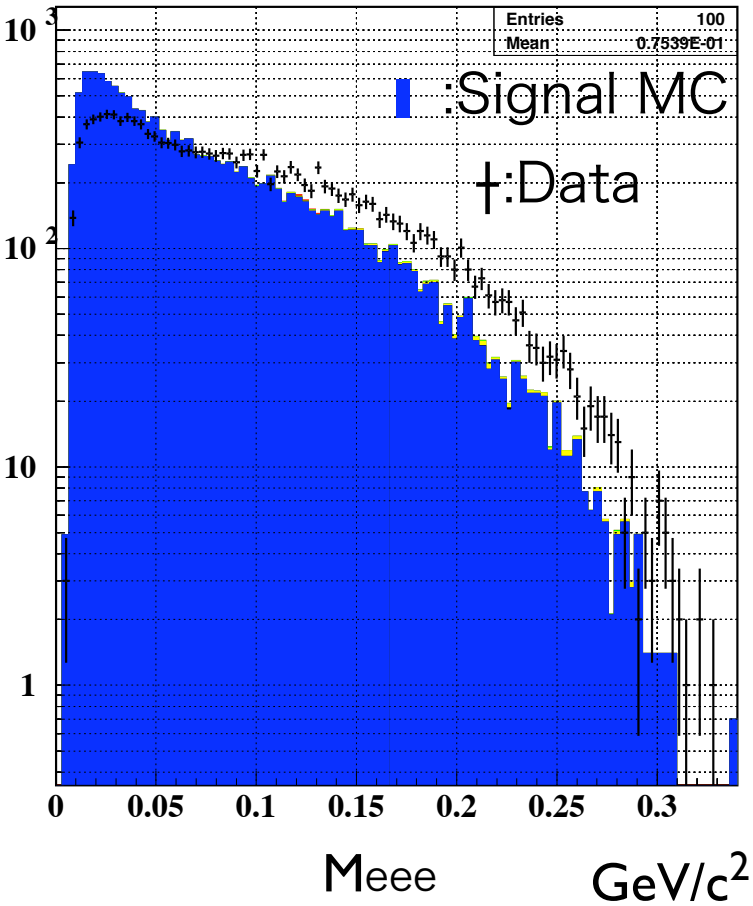


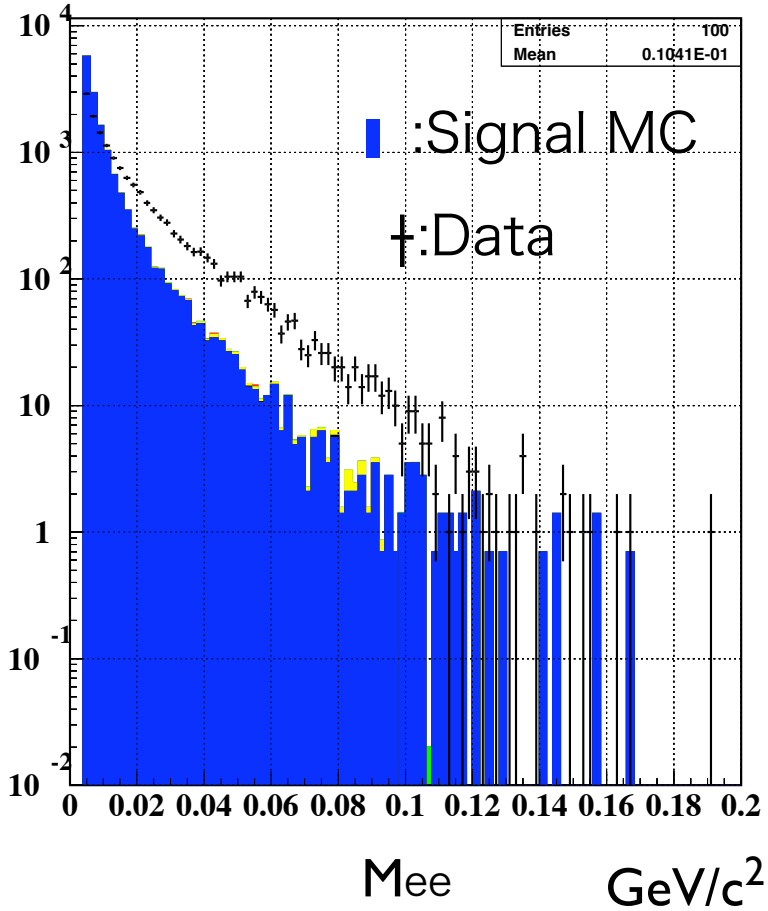
Slope=(0.11±0.23)/GeV/c^2

Intercept=(0.97±0.09)

Reduced χ^2=0.98

Invariant mass Meee and Mee





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

Direct emission

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

Inner Brem.

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

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

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 $e^+ e^-$

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

Direct emission

$$T_A = \frac{G_F}{\sqrt{2}} e V_{us}^* \bar{\epsilon}(q)^* \Big[\Big(g_{\mu\nu} - \frac{2 q_\nu p'_\mu}{p' q + q^2} \Big) \bar{u}(p_\nu) \gamma^\nu (1-\gamma_5) v(p_l)$$

$$+ F_\nu^0 \bar{u}(p_\nu) \gamma^\nu (1-\gamma_5) \Big(\frac{p'_\mu + q_\mu}{p' q + q^2} - \frac{2 p_{l\mu} + \not{q} \gamma_\mu}{2 p_l q + q^2} \Big) v(p_l) \Big]$$

Inner Brem.

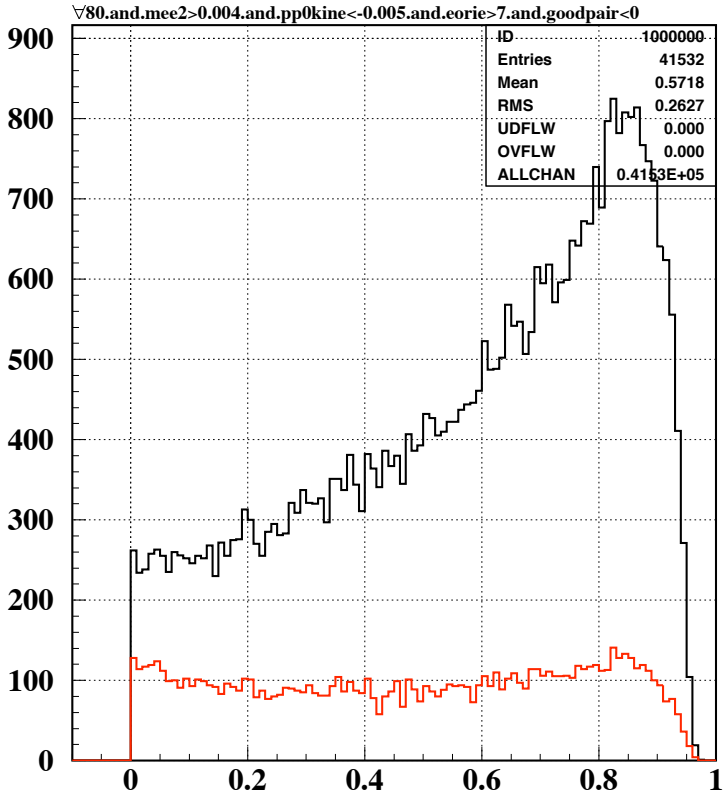
- Lacking term in the amplitude I used
  1. $e^{\pm} e^{\pm}$ exchange term
  2. Direct emission term
  3. Higher order term

$$|T_A - T_B|^2 = |T_A|^2 + |T_B|^2 - 2 Re T_A T_B$$

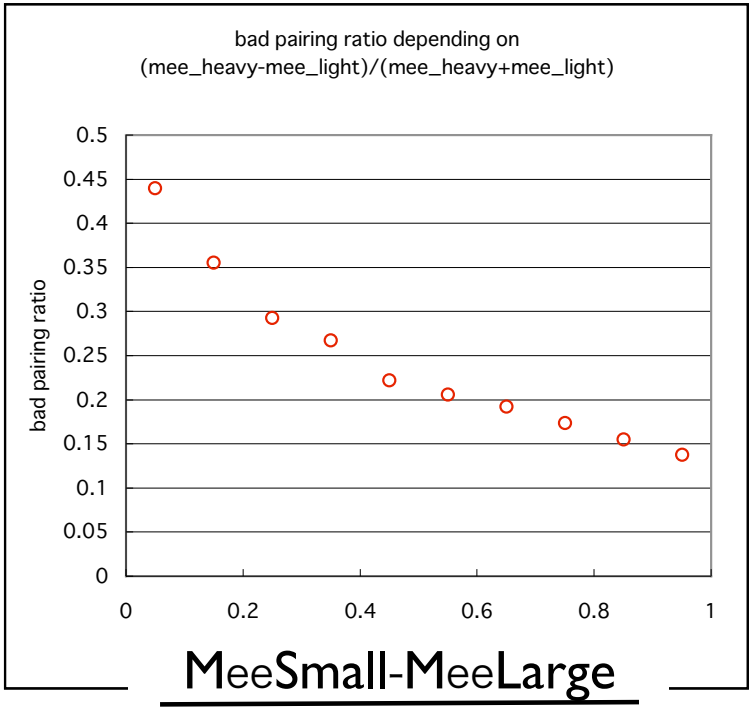
$$T_A = T(p, p', p_\nu, p_l, p_1, p_2)$$

$$T_B = T(p, p', p_\nu, p_1, p_l, p_2)$$

Asymmetry between $\pi^{\pm}e^{+}$ plane and $e^{+}e^{-}$ plane

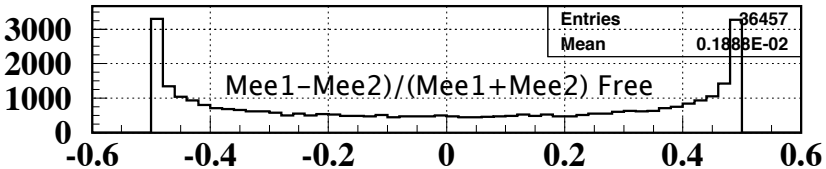


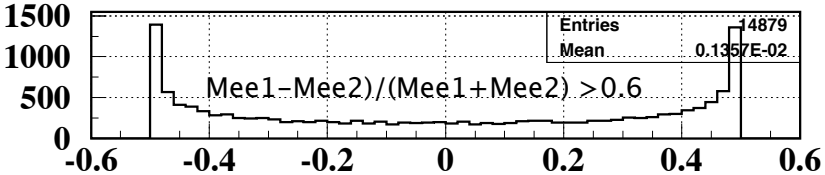
$$\frac{\text{MeeSmall-MeeLarge}}{\text{MeeSmall+MeeLarge}}$$

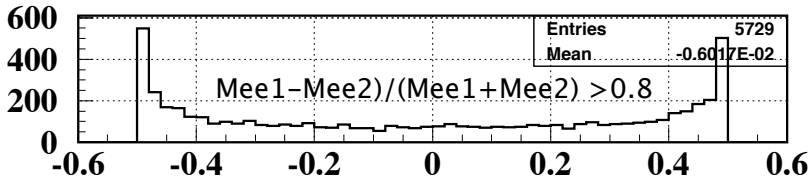


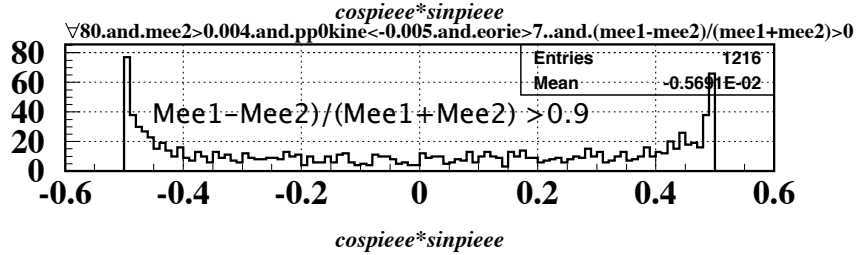
$$\frac{\text{MeeSmall-MeeLarge}}{\text{MeeSmall+MeeLarge}}$$

Asymmetry between $\pi^{\pm}e^{+}$ plane and $e^{+}e^{-}$ plane









	<0	>0	Total	Asymm	Error
0	18170	18287	36457	0.00321	0.00262
0.4	11469	11619	23088	0.0065	0.00329
0.6	7417	7462	14879	0.00302	0.0041
0.7	5209	5257	10466	0.00459	0.00489
0.8	2882	2857	5739	-0.0044	0.0066
0.9	599	617	1216	0.0148	0.01434

↑

$$\frac{\text{MeeSmall-MeeLarge}}{\text{MeeSmall+MeeLarge}}$$

Conclusion

- After all cuts $(112.8 \pm 1.1) \times 10^2$ $K_L \rightarrow \pi e \nu ee$ events remain in '97 winter data set with 88.8 back ground events
- I did not find asymmetry in between $\pi^{\pm} e^{\pm}$ plane and $e^{+} e^{-}$ plane
- The longitudinal momentum of neutrino and invariant mass of $\pi^{\pm} e^{\pm} e^{+} e^{-}$ of MC have good agreement with those of data, but invariant mass of $e^{\pm} e^{+} e^{-}$ and invariant of $e^{+} e^{-}$ do not have.

Plan

- Analysis of Normalization Mode.
- Estimation of external conversion event in data.
- MC with exchanging term
- MC with Structure dependent term.
- MC with higher order term.