The Search for $K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$

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Overview

- a preliminary KTeV study on $K_L \to \pi^0\pi^0\mu^+\mu^-$ was performed in late 2005.

- currently, there's no published calculation inside the Standard Model for $Br(K_L \to \pi^0\pi^0\mu^+\mu^-)$, although the decay is possible via γ^*.

- however, HyperCP reports a *'potential'* new neutral boson X^0 observed via $\Sigma^+ \to pX^0 \to p\mu^+\mu^-$. They determined the following branching ratios:

$$Br(\Sigma^+ \to p\mu^+\mu^-) = \left(8.6^{+6.6}_{-5.4}(stat) \pm 5.5(syst)\right) x10^{-8} \ ,$$
$$Br(\Sigma^+ \to pX^0 \to p\mu^+\mu^-) = \left(3.1^{+2.4}_{-1.9}(stat) \pm 1.5(syst)\right) x10^{-8}$$

- Hyper CP gave the mass of the *'potential'* new boson X^0 as: $(214.3 \pm 0.5)\,MeV$

- theoretical calculations of $Br(K_L \to \pi^0\pi^0X^0 \to \pi^0\pi^0\mu^+\mu^-)$ have recently been performed in a phenomenological fashion.

- Valencia *et al.* used existing constraints on pseudoscalar or axial vector X^0's to predict pseudoscalar and axial vector X^0 contributions to the $K_L \to \pi^0\pi^0\mu^+\mu^-$ decay mode:

$$Br(K_L \to \pi^0\pi^0 X^0_P \to \pi^0\pi^0\mu^+\mu^-) = \left(8.3^{+7.5}_{-6.6}\right) x10^{-9}$$

(*Valencia et al.*, 2005)

$$Br(K_L \to \pi^0\pi^0 X^0_A \to \pi^0\pi^0\mu^+\mu^-) = \left(1.0^{+0.9}_{-0.8}\right) x10^{-10}$$

- there is *no current experimental upper limit* on $K_L \to \pi^0\pi^0\mu^+\mu^-$ or $K_L \to \pi^0\pi^0 X^0 \to \pi^0\pi^0\mu^+\mu^-$.

Previous KTeV Studies

($K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$)

- the data used in the previous KTeV study was from the 1997 E799 run.

- results from that analysis include:

~acceptance of 2.73% $\rightarrow$ single event sensitivity of $1.4\, x10^{-10}$

~signal of less than 2.3 events

90% C.L. $\rightarrow$

~partial width for 'new physics' estimated to be $< 4.0\, x10^{-24}\, MeV$

$K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ Analysis Strategy

-Data Selection-

- the data to be used in this study will be from the dimuon trigger of the 1997 (1999 later on) KTeV E799 run. The tapes used were NZL001-NZL130.

- a 'crunch' has been performed on these 130 data storage tapes...these tapes contained approximately *1.73 TeraBytes* of data. KTeVana v6.04 was used on the crunch and KTeVmc v6.04 was used for MC generation.

- some other decays available from the dimuon trigger are: $K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$, $K_L \rightarrow \pi^0 \mu^+ \mu^-$, $K_L \rightarrow \mu^+ \mu^- \gamma\gamma$ and $K_L \rightarrow \mu^+ \mu^- \gamma$.

- $K_L \rightarrow \mu^+ \mu^- \gamma$ and $K_L \rightarrow \mu^+ \mu^- \gamma\gamma$ will be analyzed and considered for best *normalization* mode candidate.

TRIG5[2MU-LD] = <-'97 def'n
GATE*2V*DC12*2MU3*PHVBAR1*2HCY_LOOSE*HCC_GE1

2V = 2 hits in V view and 1 hit in V' view *OR* 2 hits in V' and 1 hit in V.

DC12 = at least 1 DCOR hit in each view of DC1 and DC2.

2MU3 = 2 or more hits in the X and Y views of MU3.

PHVBAR1: this is a veto on all RC's (except RC8), all SA's and the CIA. Specifically, this rejects events that deposit ≥ 500 MeVin the RC's and ≥ 400 MeV in the SA's and the CIA.

2HCY_LOOSE: 2+ hits in every y view of the drift chambers (by the hit counting module); however, a missing hit is allowed in the y view of chamber 1 *OR* chamber 2.

HCC_GE1: ≥ 1 hardware cluster.

(logic symbols: & or * = *AND*, | or + = *OR*, ! = *NOT*)

$K_L \to \pi^0 \pi^0 \mu^+ \mu^-$ Crunch Results

Decay	Events Generated	Acceptance After Crunch
$K_L \to \pi^0 \pi^0 \mu^+ \mu^-$	19,984,000	3.88%
$K_L \to \mu^+ \mu^- \gamma\gamma$	10,867,653	1.97%
$K_L \to \mu^+ \mu^- \gamma$	9,579,140	12.49%

- there are *three differences* in the signal and normalization mode crunches:

→ cut on the number of clusters

→ cut on the π^0 mass

→ looser cut on p_T^2 for signal than normalization

$K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ Analysis Thus Far

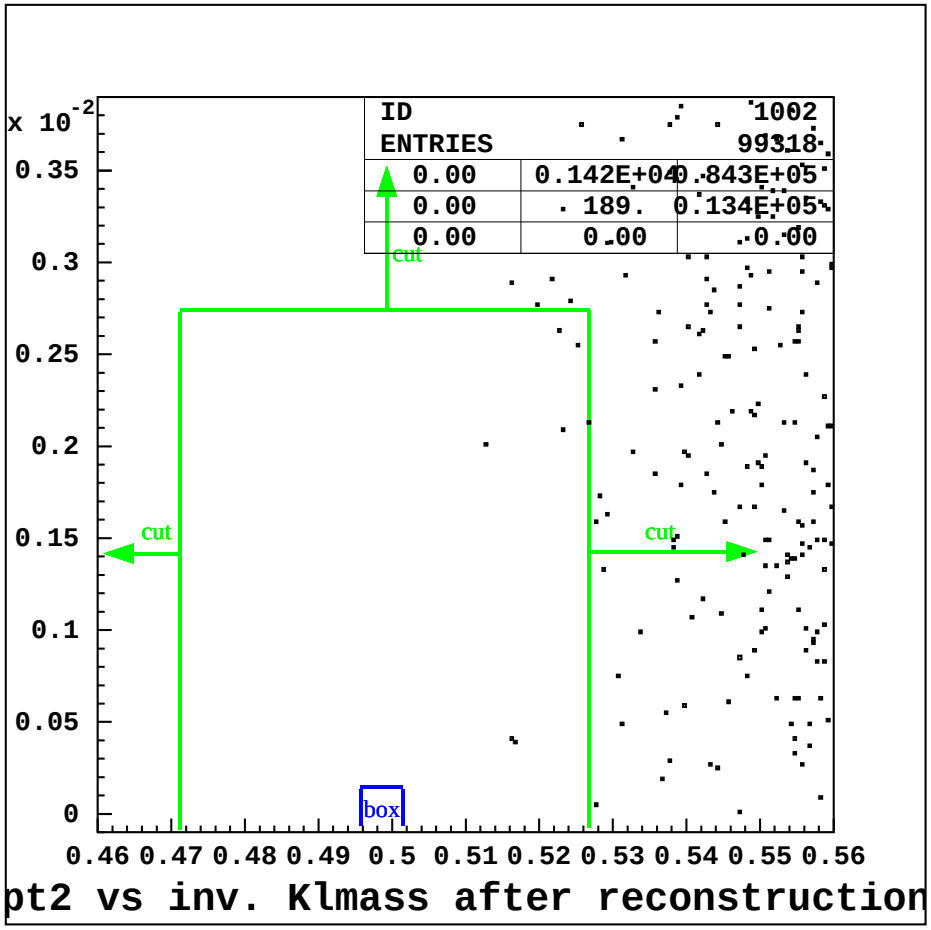
- some initial analysis cuts have already been made:

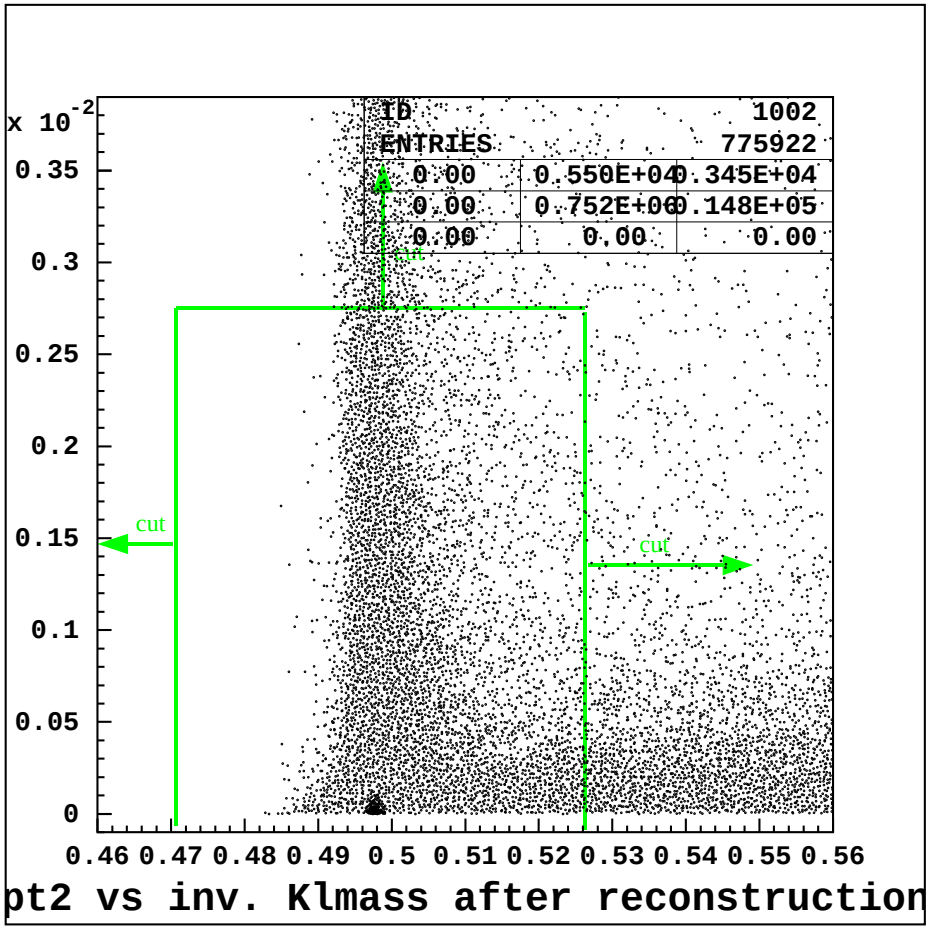
$K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ Analysis Cut	Data	MC
1) $p_T^2 \leq 0.0026\ GeV^2/c^2$	9.35%	98.4%
2) $472\ MeV \leq {}_{\mu\mu}M_K \leq 524\ MeV$	0.04%	97.1%
3) $E_{cl}(track) \leq 1.0\ GeV$	100%	95.6%
4) $p_{track} \leq 7.0\ GeV$	75.0%	99.9%
5) $\lvert M_{rec.pi0} - M_{pi0} \rvert \leq 9\ MeV$	100%	99.7%
Total Acceptance Thus Far	$1.08*10^{-6}$%	3.53%

Acceptance from Crunch included in this result!

Cut on P_T^2 and Inv. K_L Mass

($K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ Analysis - 1st and 2nd Cuts)





$K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ *Data*

~ Box Dimensions ~

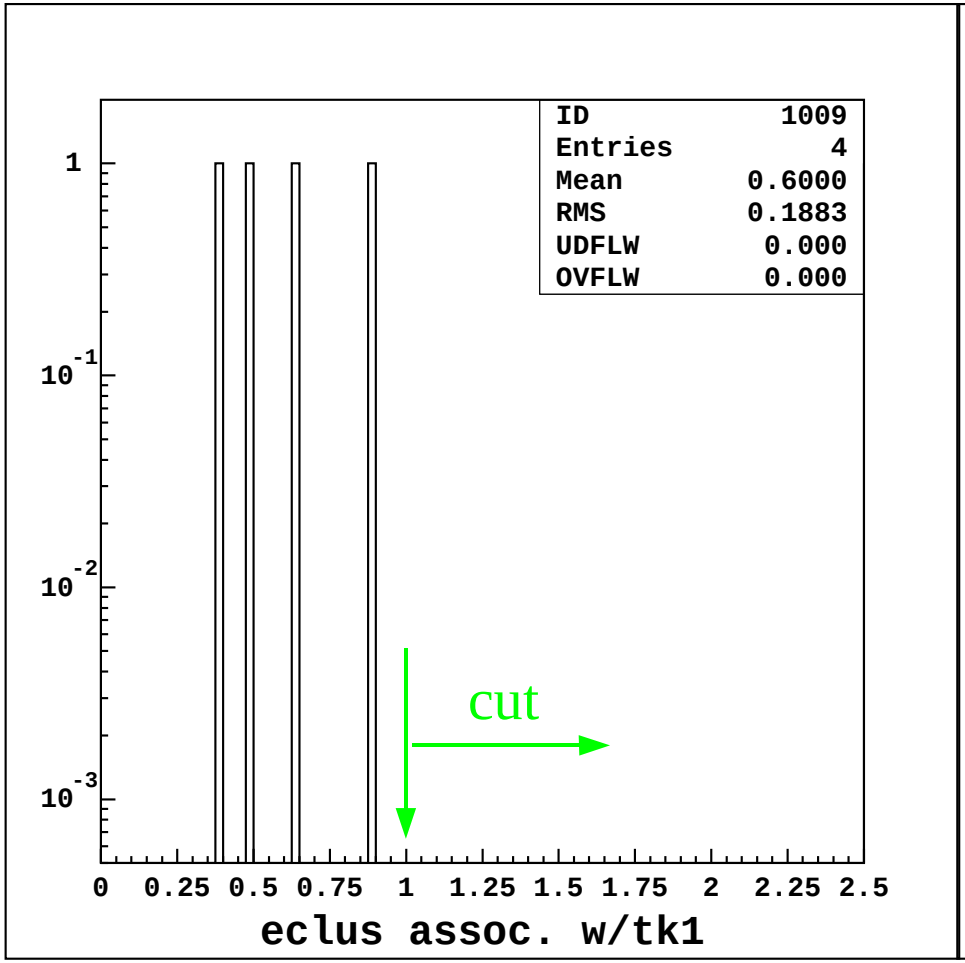
495 MeV $\leq M_K \leq$ 501 MeV

$p_T^2 \leq 130$ MeV^2

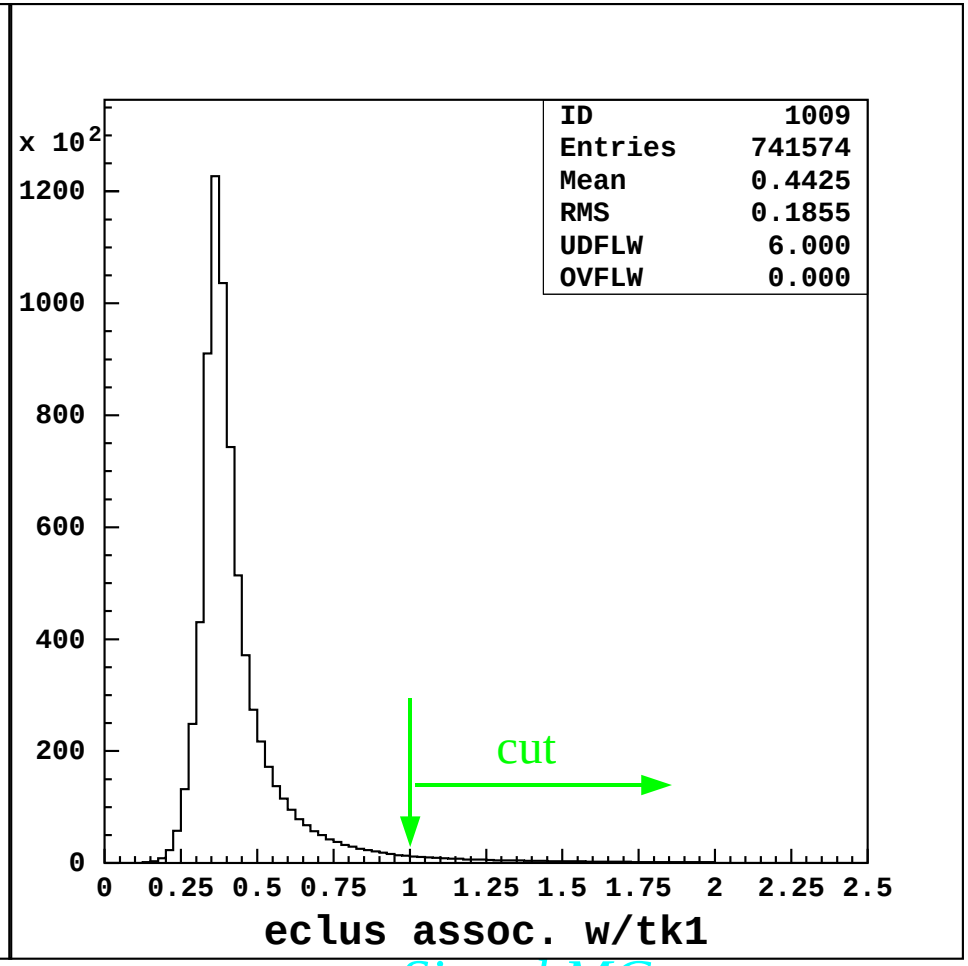
$K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ *MC*

Cut On E_{cl} Associated w/the Track

($K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ Analysis - 3rd Cut)



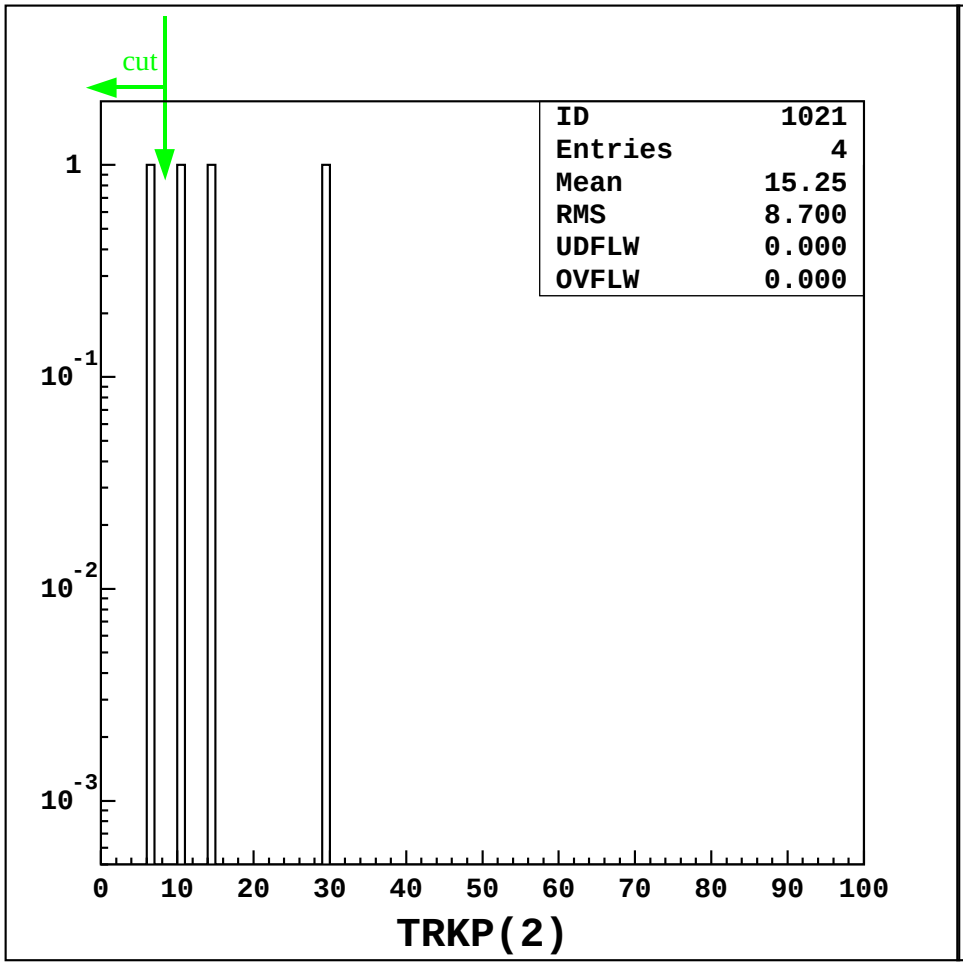
Data



Signal MC

Cut On Track Momentum

($K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ Analysis - 4th Cut)



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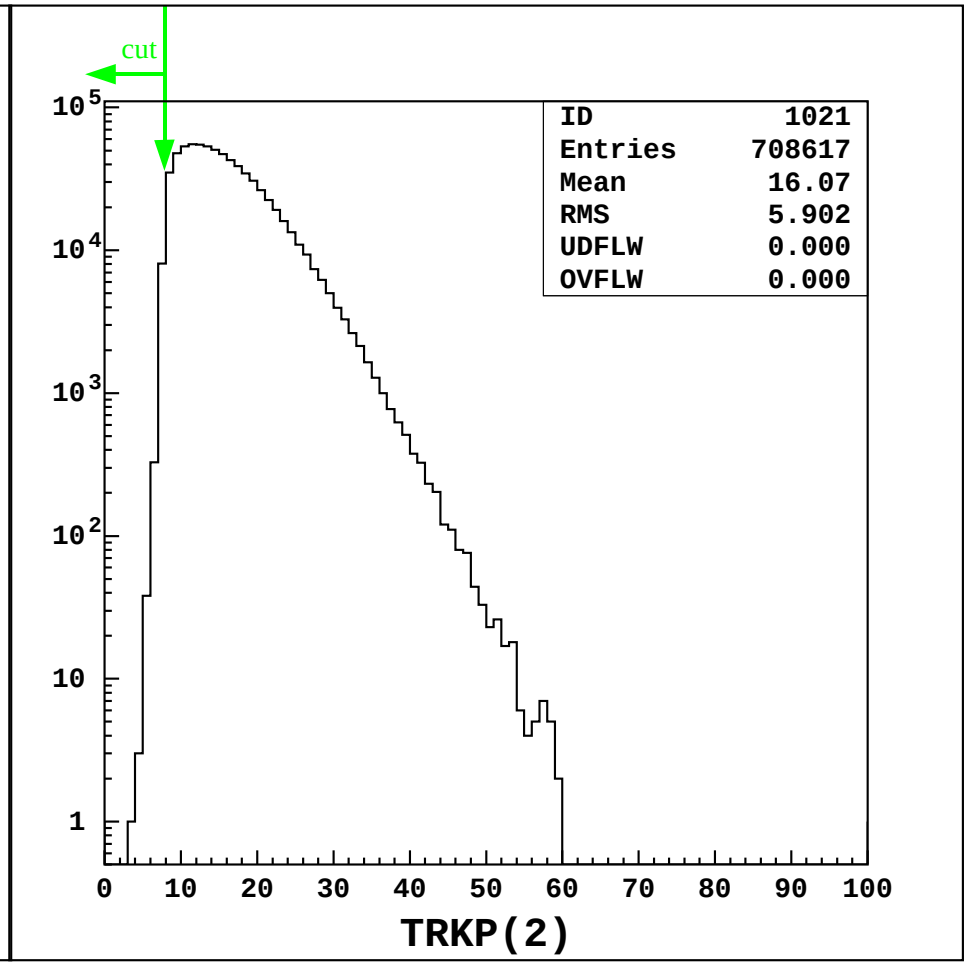
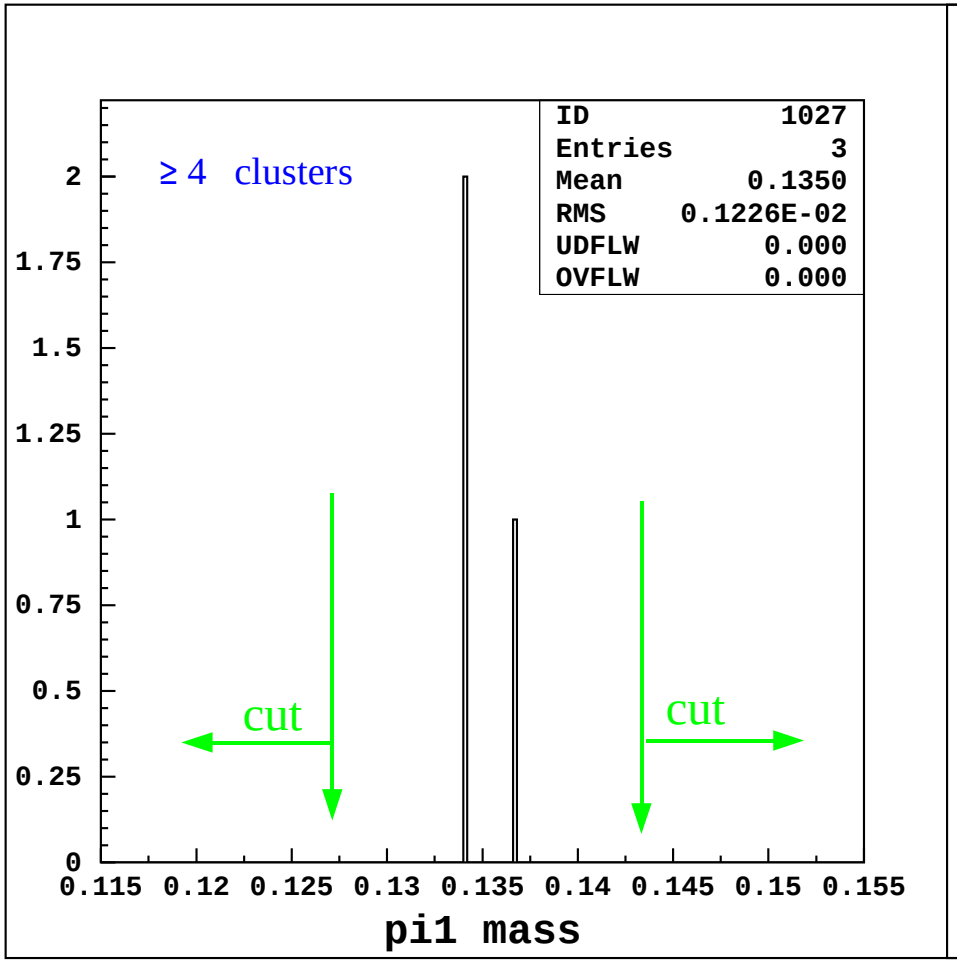


Signal MC

Cut On Reconstructed Mass of 1st π^0

($K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ Analysis - 5th Cut)



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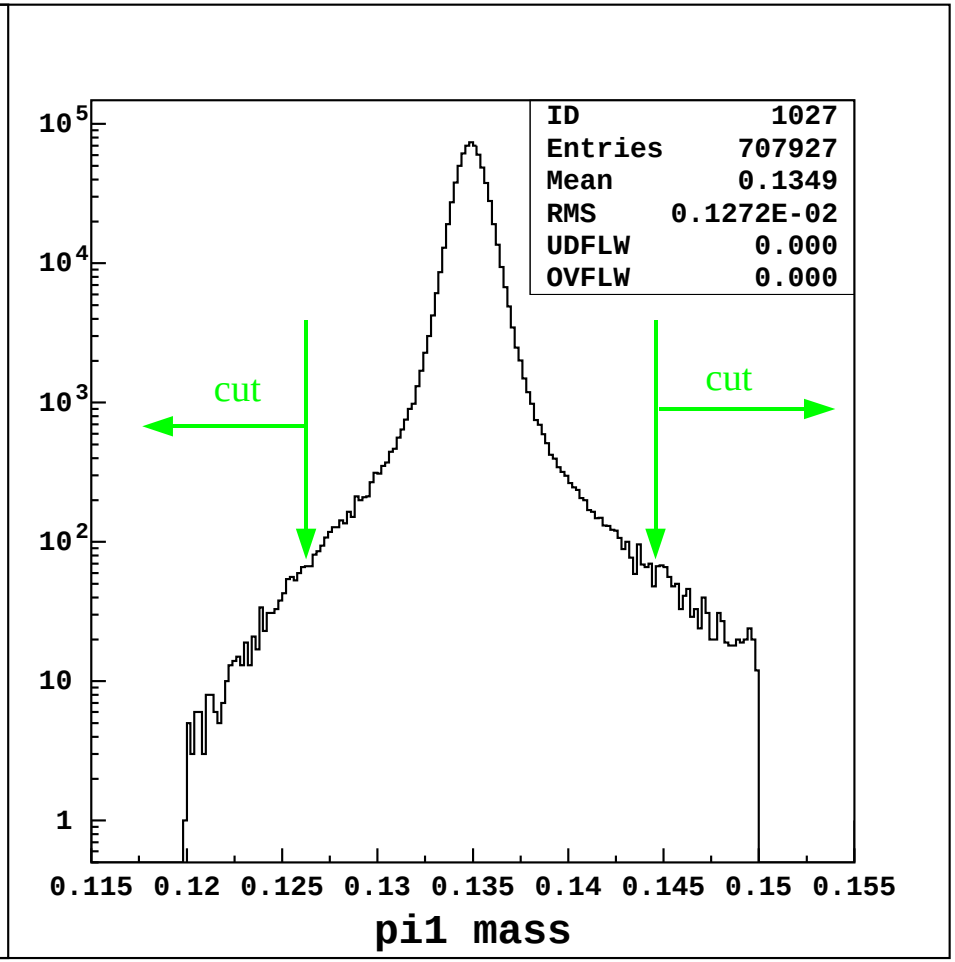
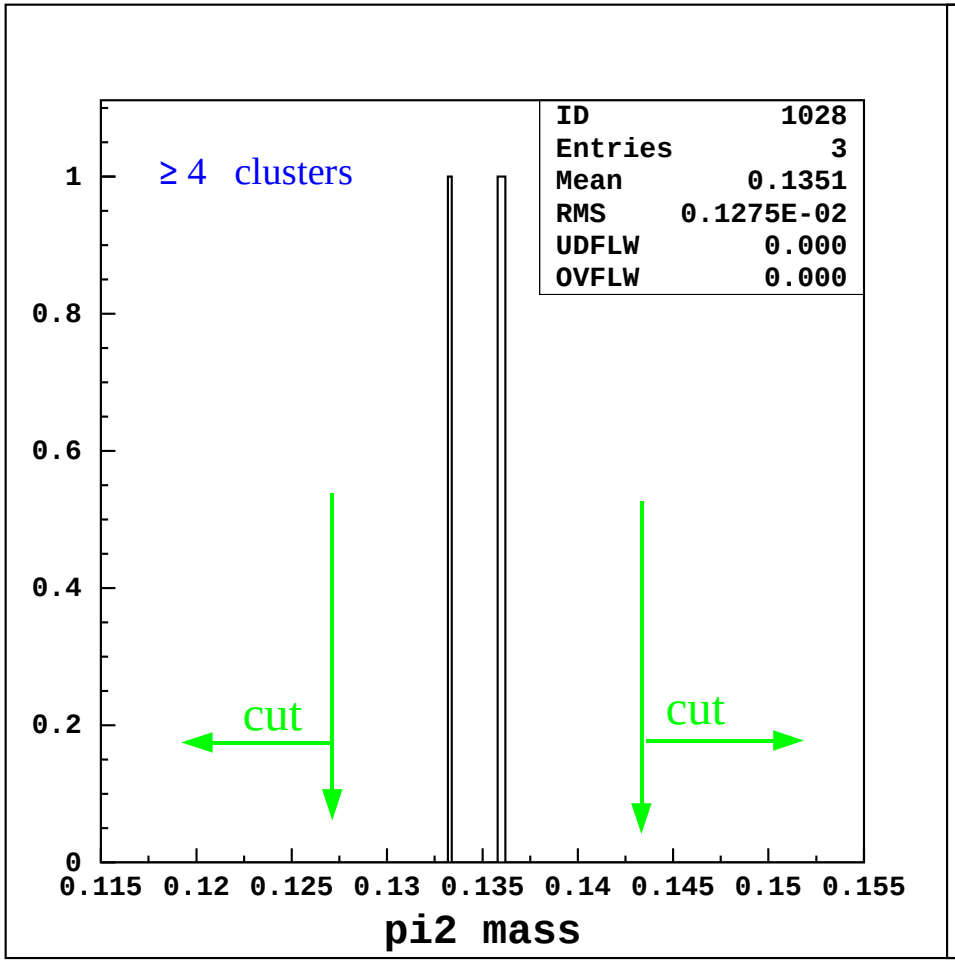


Signal MC

Cut On Reconstructed Mass of 2nd π^0

($K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ Analysis - 5th Cut)



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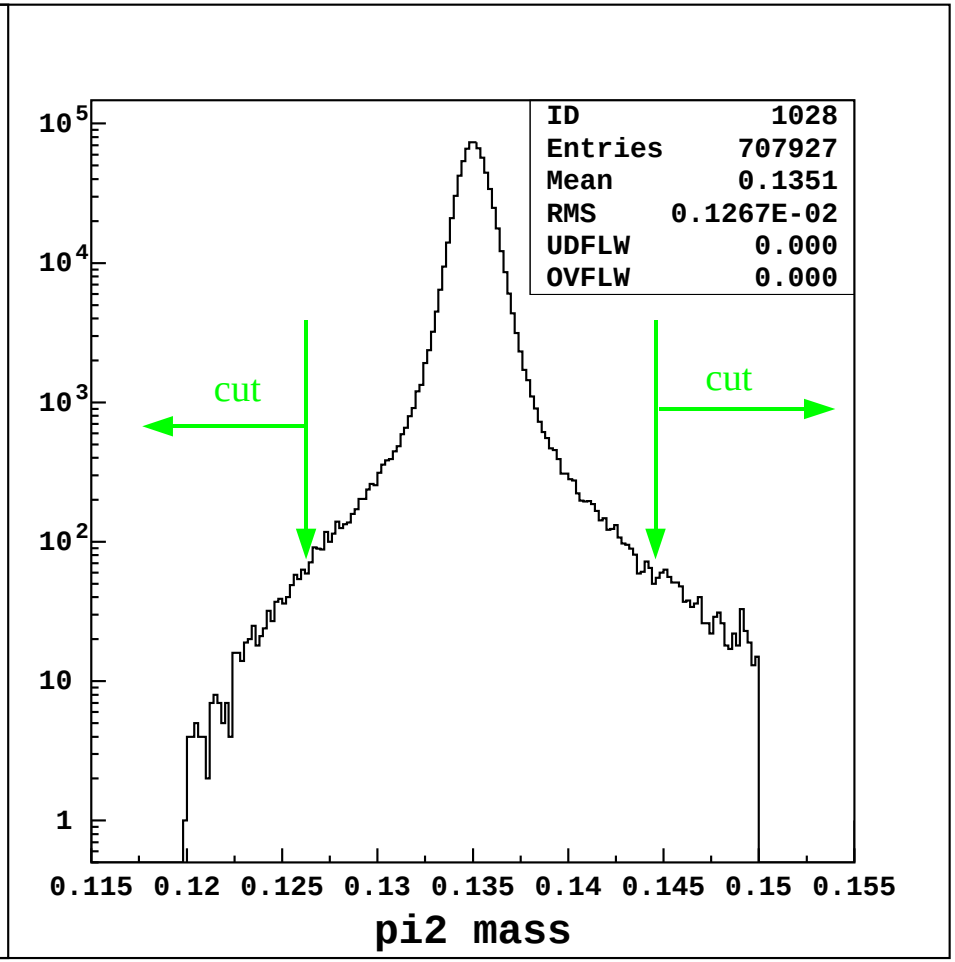
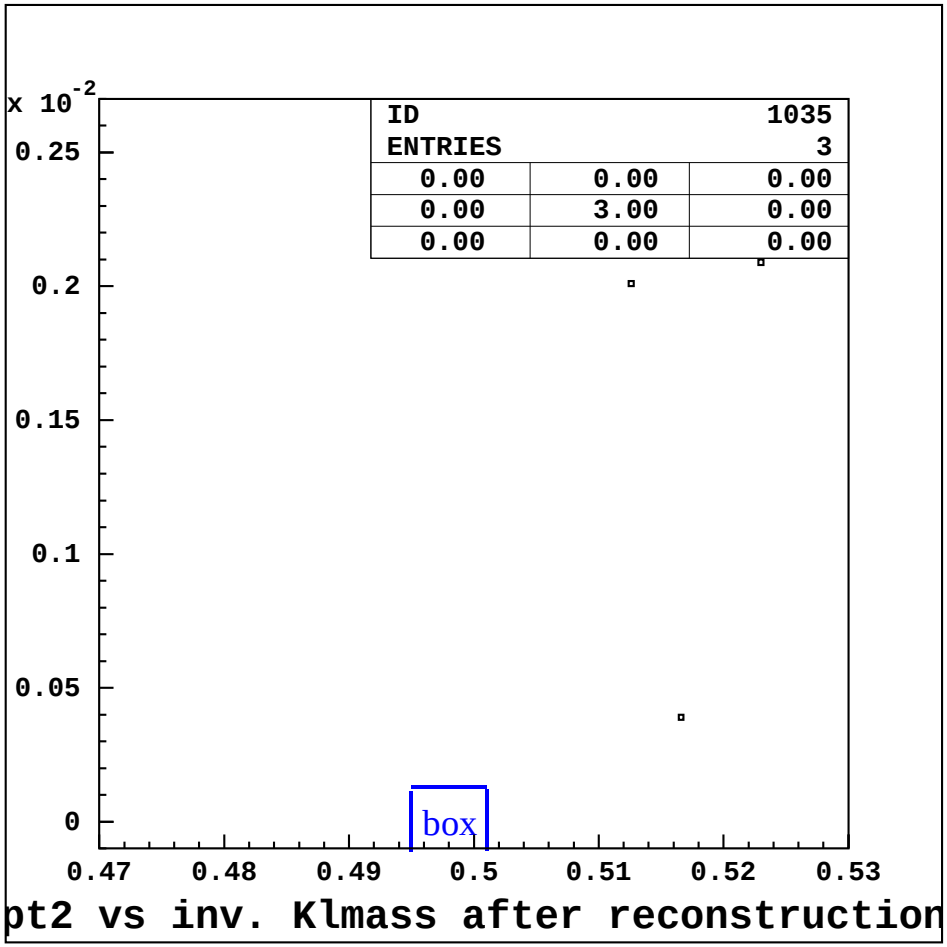
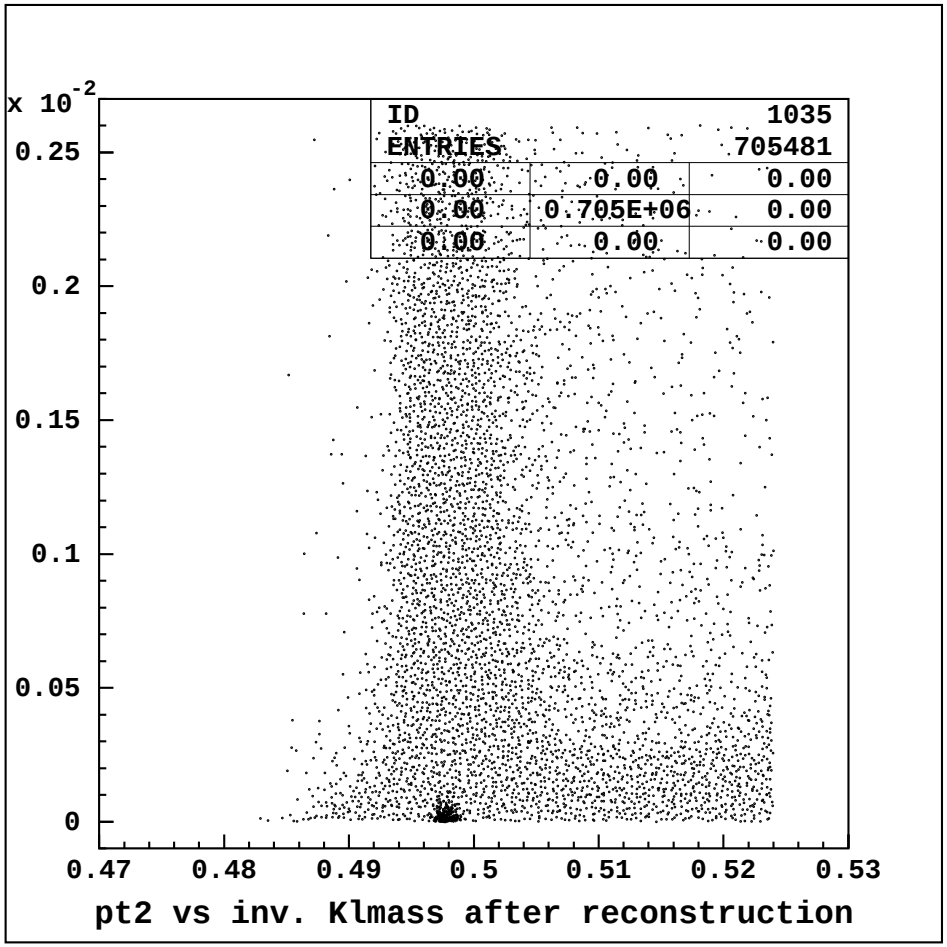


Signal MC

P_T^2 vs. Inv. K_L Mass





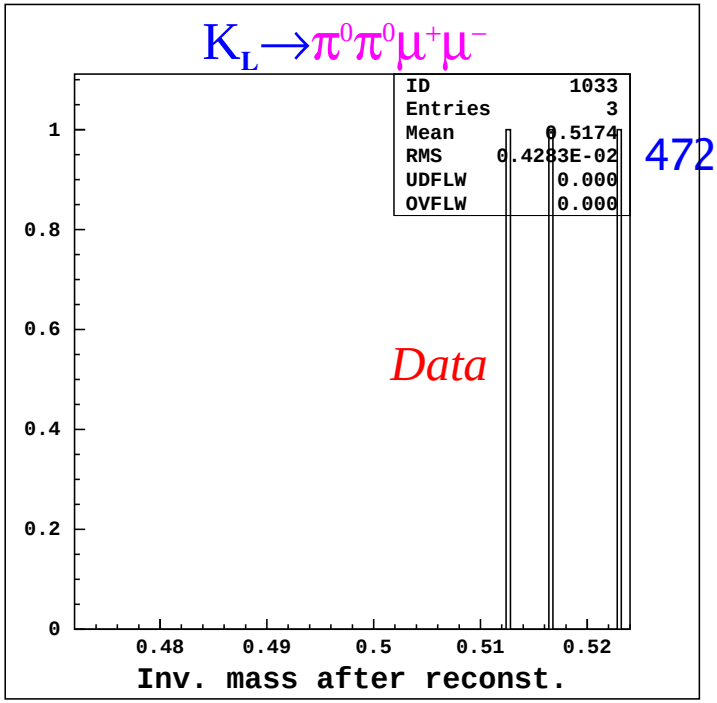
$K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ *Data*

~ Box Dimensions ~

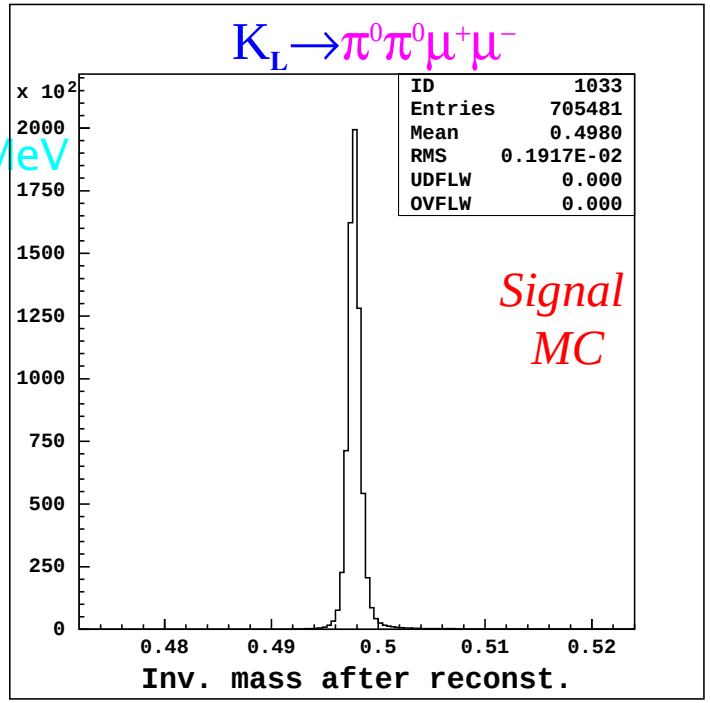
$495 \text{ MeV} \leq M_K \leq 501 \text{ MeV}$

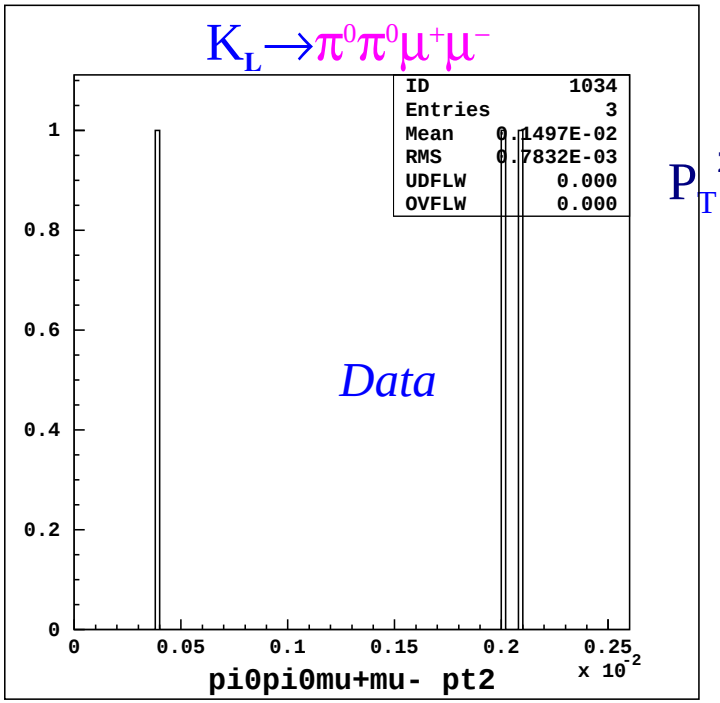
$p_T^2 \leq 130 \text{ MeV}^2$

$K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ *MC*

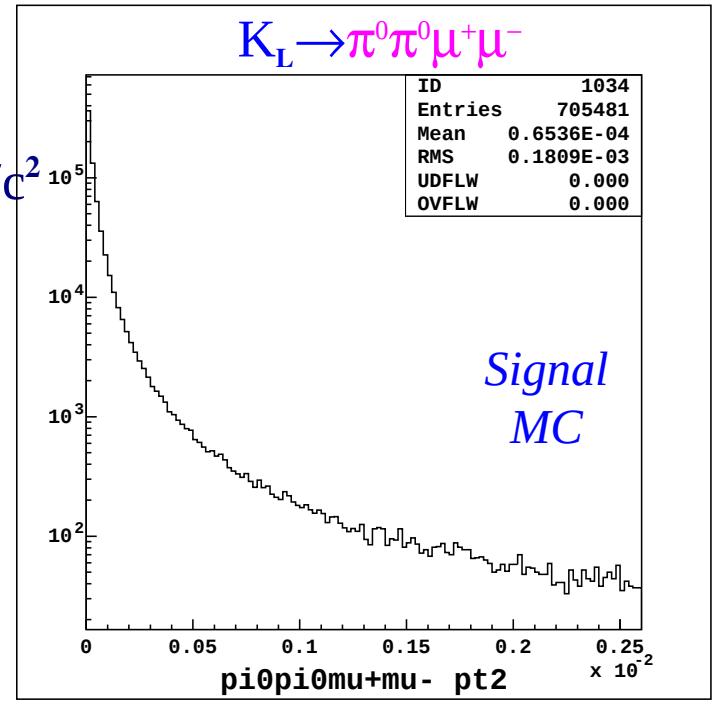


$472\ \text{MeV} \le M_K \le 524\ \text{MeV}$

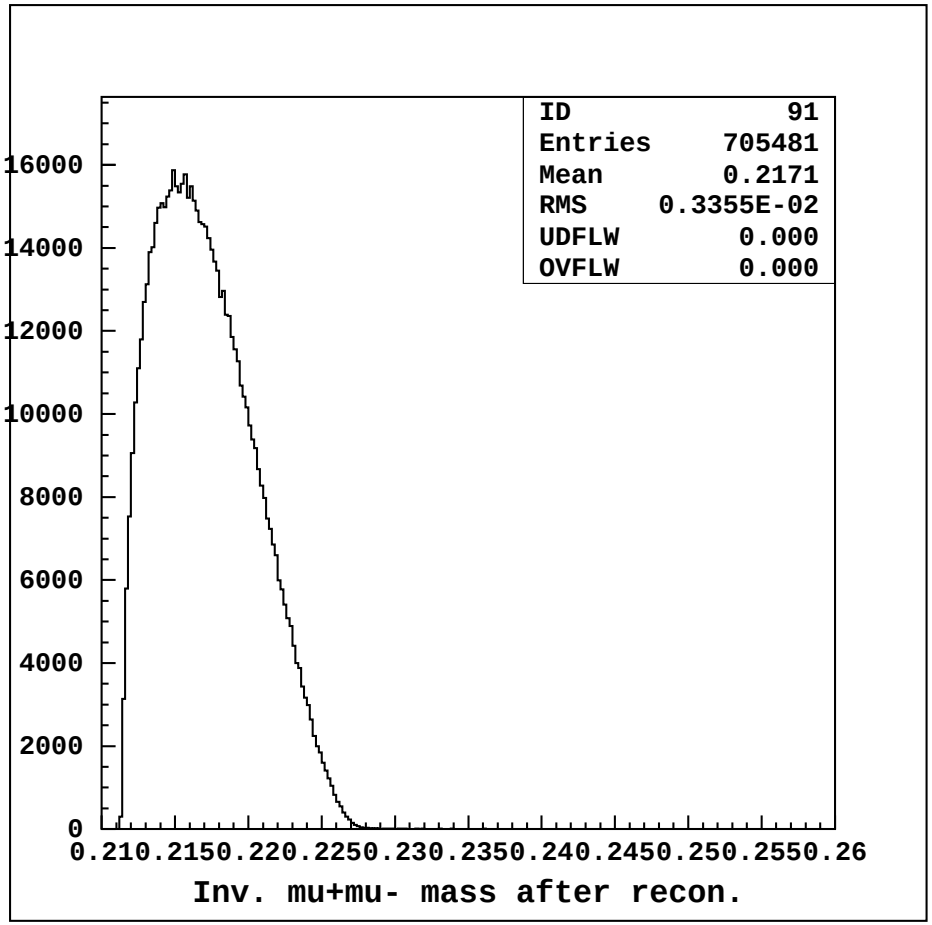




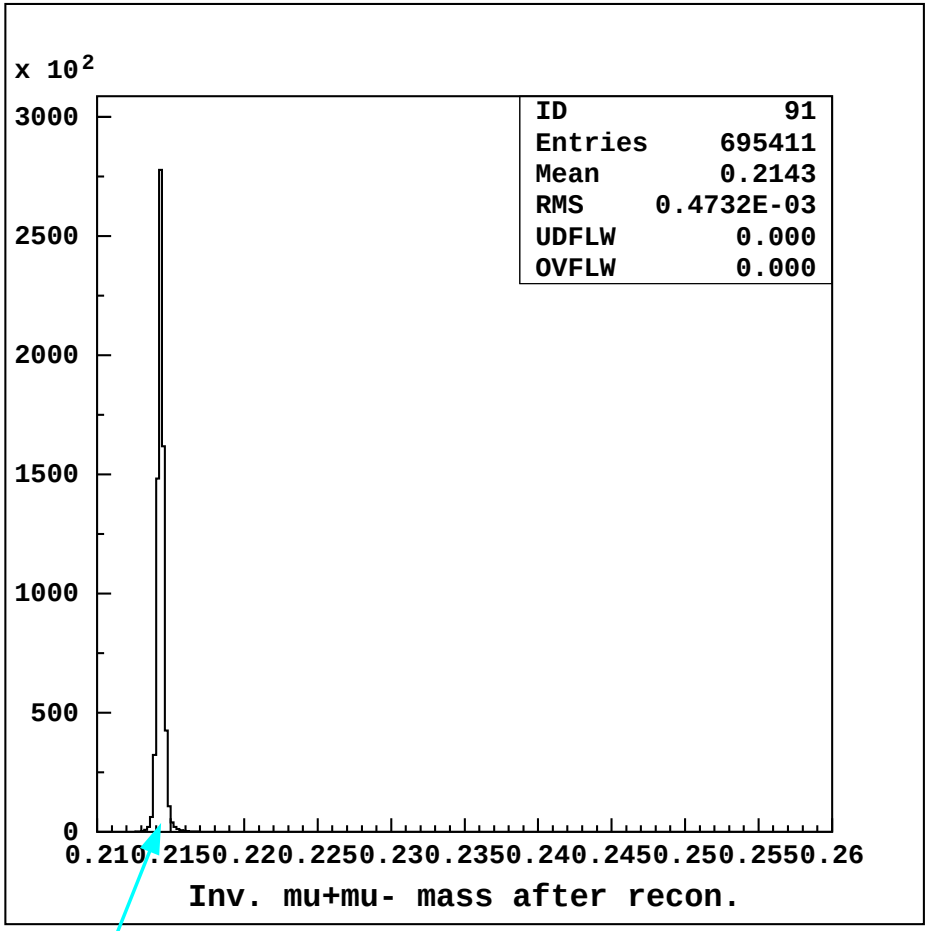
$P_T^2 \le 0.0026\ \text{GeV}^2/c^2$



Inv. $\mu^+\mu^-$ Mass



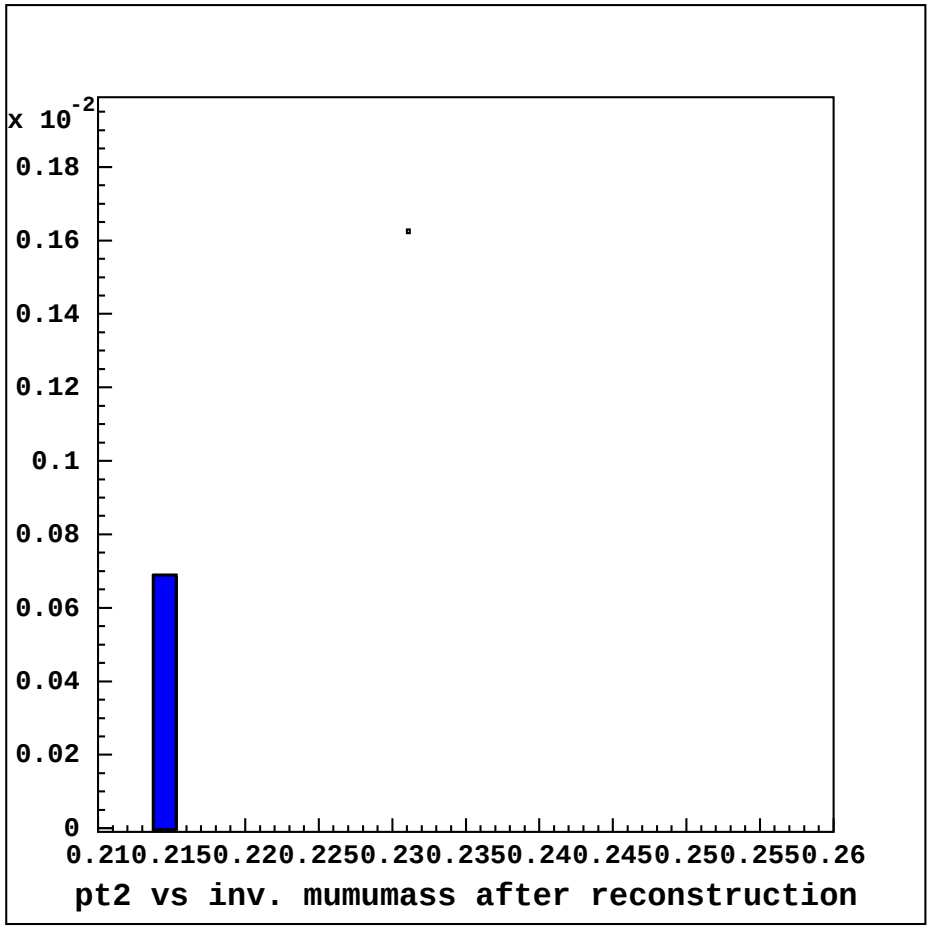
$K_L \rightarrow \pi^0\pi^0\gamma^* \rightarrow \pi^0\pi^0\mu^+\mu^-$ *MC*



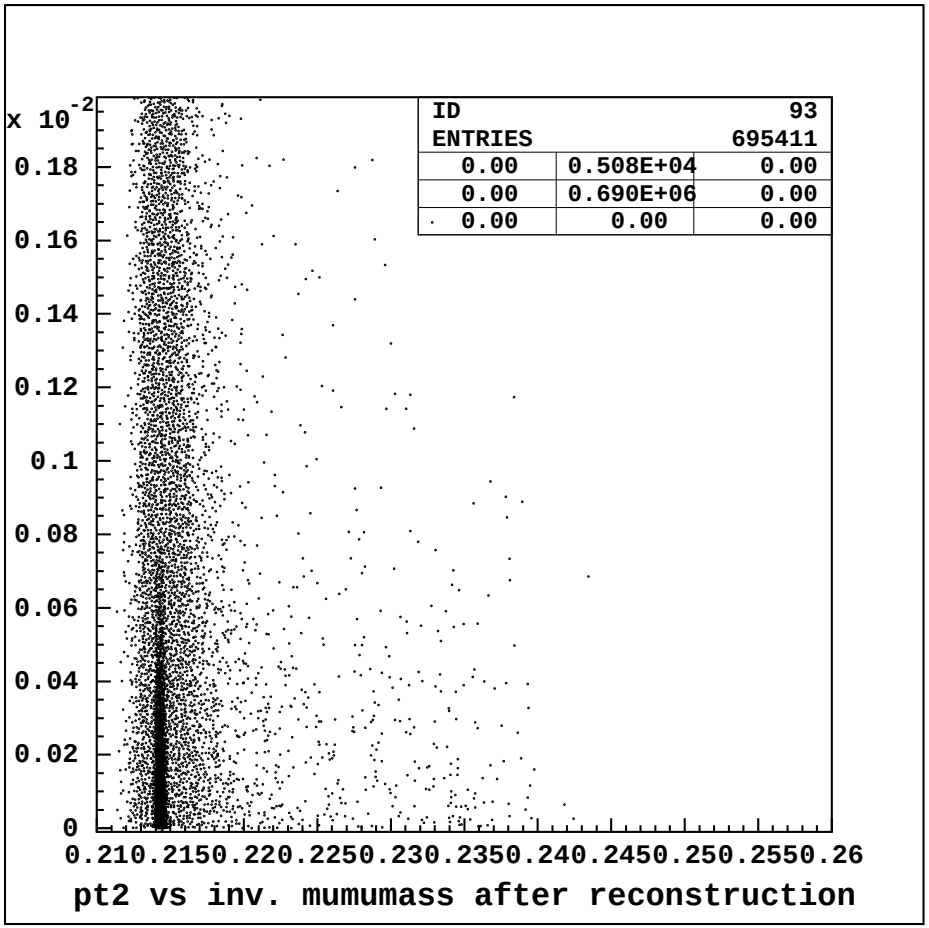
$K_L \rightarrow \pi^0\pi^0 X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-$ *MC*

In a blind analysis search for X^0,
we need to create a 2nd box!!

$[P_{T,\mu+\mu-vtx}{}^2 - P_{T,\pi0\pi0}{}^2]$ vs. Inv. $\mu^+\mu^-$ Mass



$K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ *Data*



$K_L \rightarrow \pi^0\pi^0 X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-$ *MC*

~ Box Dimensions ~

$213.8 \text{ MeV} \leq M_{\mu+\mu-} \leq 214.8 \text{ MeV}$

$p_T{}^2 \leq 700 \text{ MeV}^2$

Background Notes

- one or more than one flux of the following backgrounds have been generated and are being studied against analysis cuts:

$K_L \rightarrow \pi^0 \mu^+ \mu^-$, $K_L \rightarrow \mu^+ \mu^- \gamma\gamma$, $K_L \rightarrow \mu^+ \mu^- \gamma$, $K_L \rightarrow \mu^+ \mu^-$, $K_L \rightarrow \pi^+ \pi^- \gamma$, $K_L \rightarrow \pi^+ \pi^-$ and $K_{\mu 4}$

- all modes with charged pions involve pion punch through only.

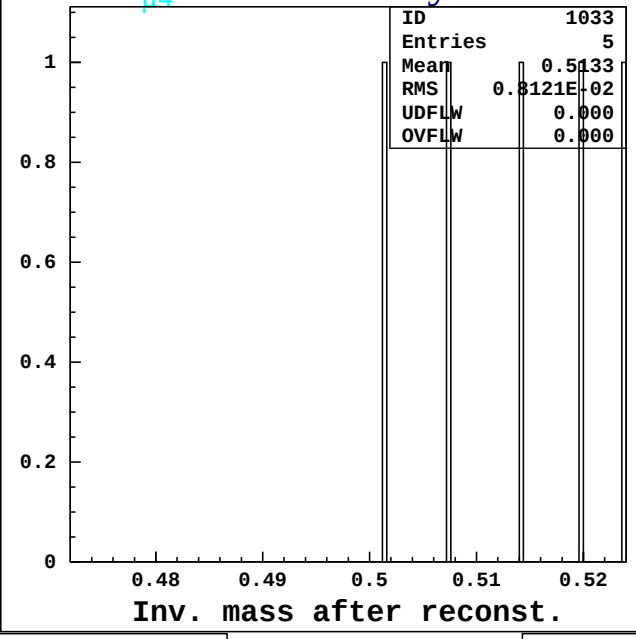
- a weighting scheme for pion to muon decays is currently being developed.

- in addition, a fraction of a flux (~5-10%) of $K_{\mu 3}\gamma$, $K_{\mu 3}$ and $K_L \rightarrow \pi^+ \pi^- \pi^0$ has been generated and is being studied against analysis cuts.

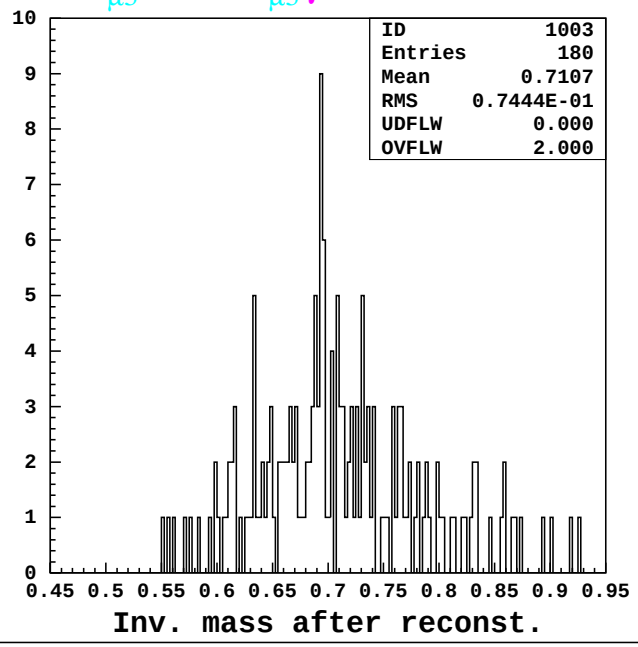
- after all analysis cuts, all backgrounds have been eliminated *except* $K_{\mu 4}$

- *however*, we have not yet come close to generating a complete flux of $K_{\mu 3}\gamma$, $K_{\mu 3}$ and $K_L \rightarrow \pi^+ \pi^- \pi^0$, so we cannot be sure that these backgrounds have actually been eliminated.

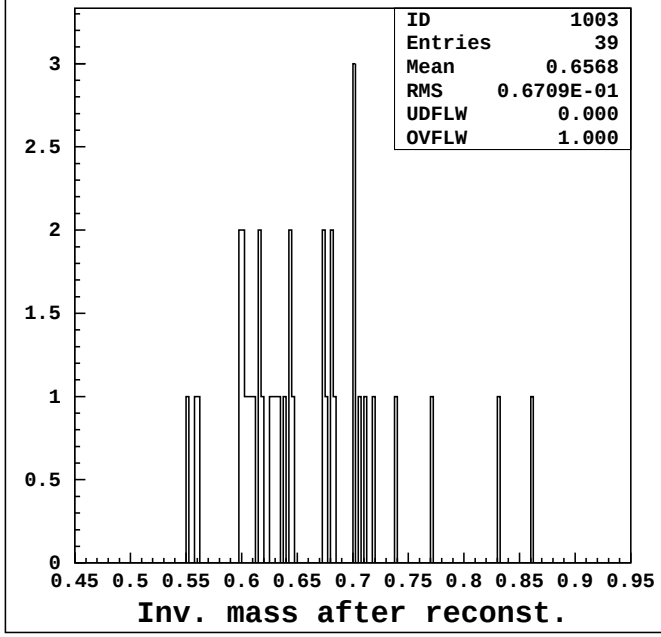
$K_{\mu 4}$ after all analysis cuts



$K_{\mu 3}$ and $K_{\mu 3}\gamma$ bef. mass cut



$K_L \rightarrow \pi^+\pi^-\pi^0$ bef. mass cut



Future Plans and Conclusions

- in short, there's still quite a bit of work to do!

- need to generate a complete flux of $K_{\mu 3}\gamma$, $K_{\mu 3}$ and $K_L \rightarrow \pi^+\pi^-\pi^0$

- need to explore more analysis cuts to beat down the aforementioned backgrounds should they sneak into the signal region.

- one potentially powerful cut that is now being explored is Kmu3KIN.

- other cuts that need to be looked at are a mumu mass cut, hits on MU3 and hit counter separation.

- need to also generate a weighting scheme to allow generation of pion punch-through and decay at the same time.

- normalization mode crunch is finished, but an analysis has to be completed for $K_L \rightarrow \mu^+\mu^-\gamma$ and $K_L \rightarrow \mu^+\mu^-\gamma\gamma$ (to see which has better statistics).