STUDY OF $K^+ \rightarrow \pi^+\pi^0$ DECAY

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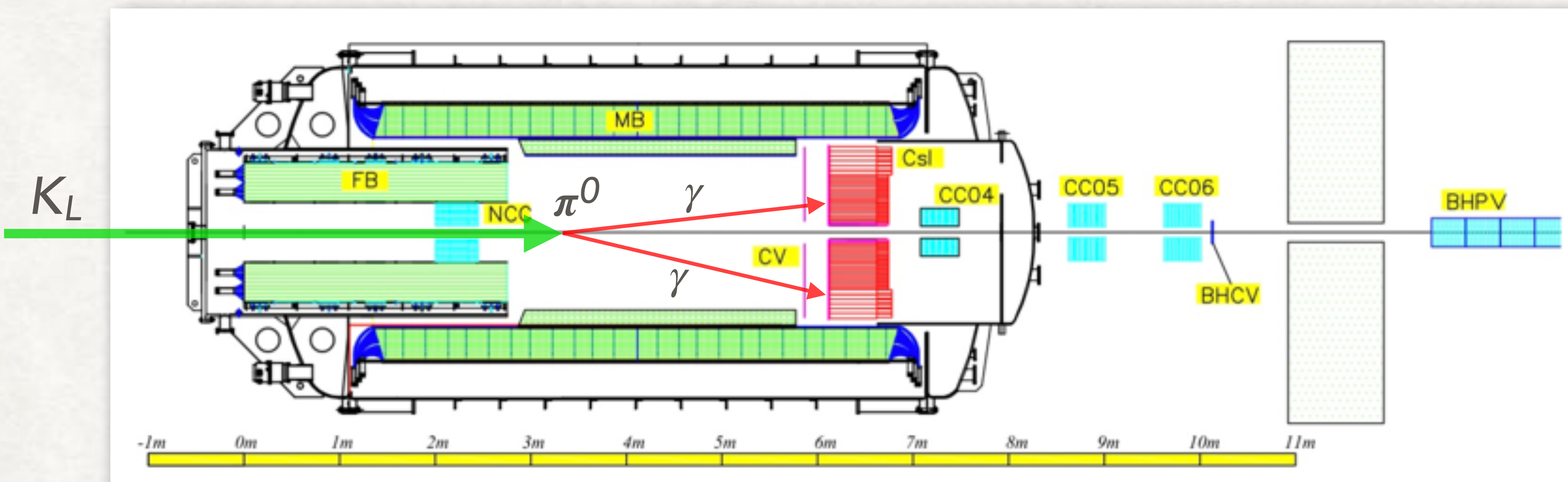
YEAR-END PRESENTATIONS 2019

THE KOTO EXPERIMENT

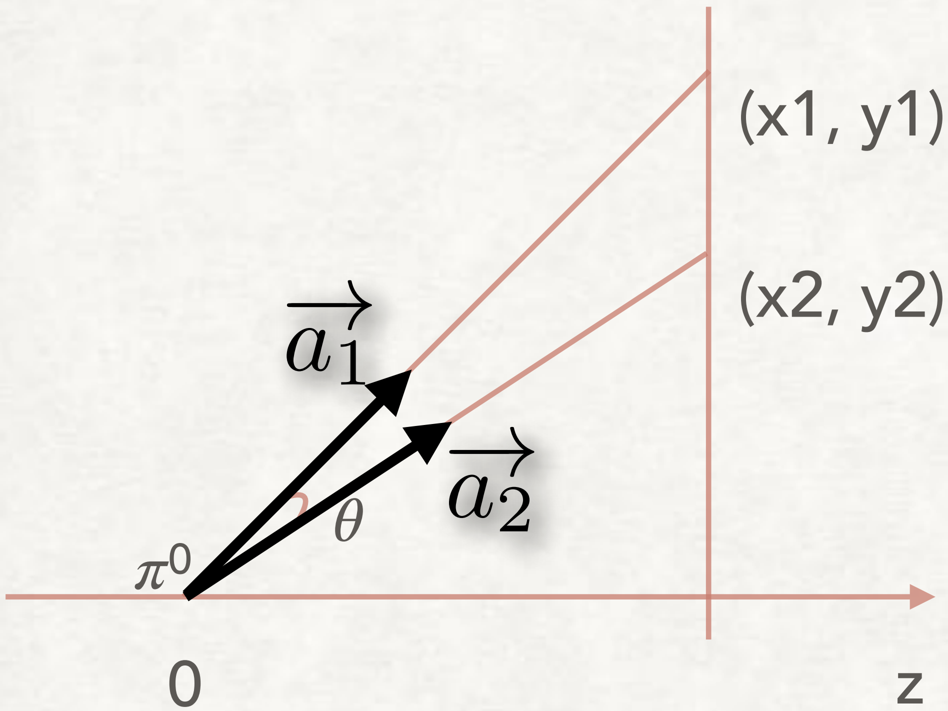
- Purpose: Search for New Physics that violates CP symmetry
- Probe: $K_L \rightarrow \pi^0 \nu \nu$
- Signature: 2 photons with π^0 invariant mass and finite pT



MOTIVATION

- Want to know if there is K^+ contamination in K_L beam
- Major decay mode: $K^+ \rightarrow \pi^+\pi^0$ (3 clusters: 2 photons from pi0 and 1 pseudo-photon pi+)
- Main background: $K_L \rightarrow \pi^+\pi^-\pi^0$ (1 charged pion escapes detection)
- Develop a new algorithm to reconstruct K^+ from 3 clusters
- Kaon mass, chi2, PT, energy, etc are reconstructed and used to evaluate the performance of new algorithm using **MC data**
- Different cut criteria are also studied

π^0 RECONSTRUCTION



- ***Position and energy info*** of the two photon clusters
- Assumption: pi0 decays on the z axis

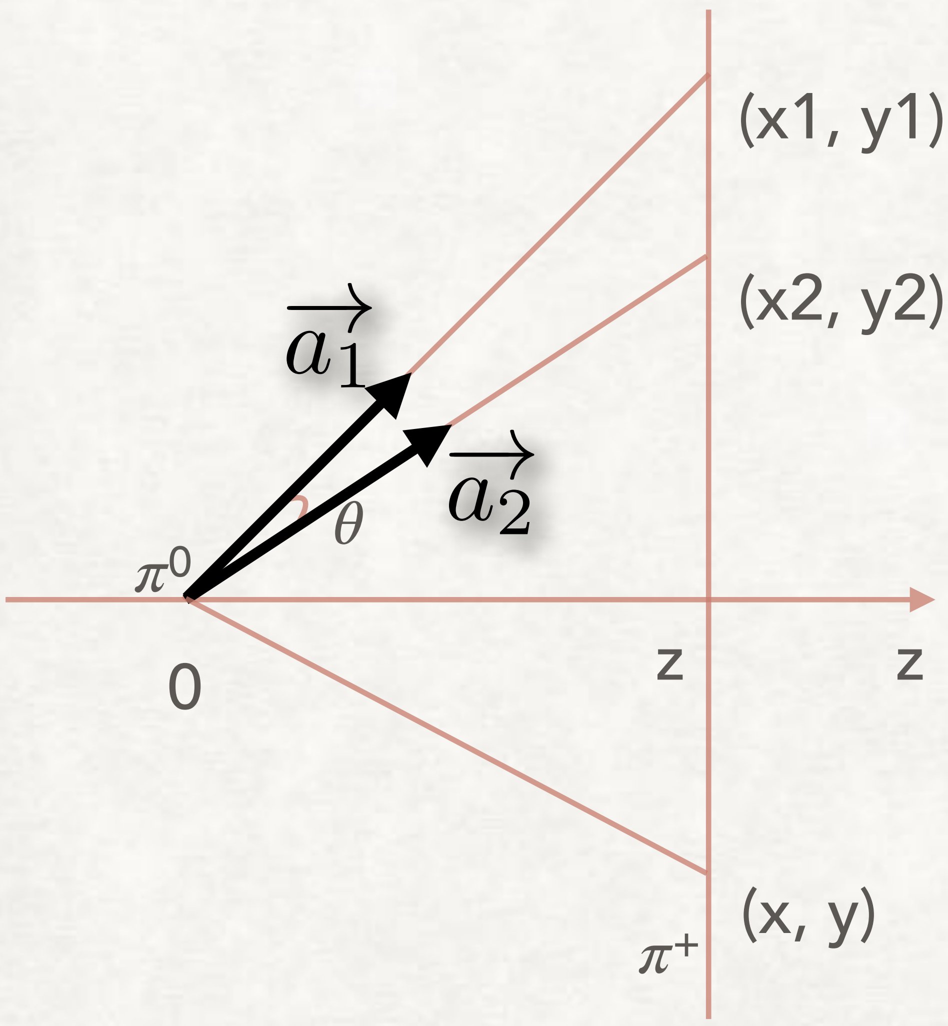
$$p_{\pi^0}^2 = (p_1 + p_2)^2$$
$$\rightarrow m_{\pi^0}^2 = 2E_1E_2(1 - cos\theta)$$

$$\overrightarrow{a_1} = (x_1, y_1, z)$$
$$\overrightarrow{a_2} = (x_2, y_2, z)$$

$$\overrightarrow{a_1}.\overrightarrow{a_2} = |\overrightarrow{a_1}||\overrightarrow{a_2}|cos\theta$$

$$\overrightarrow{p_1} = \frac{\overrightarrow{a_1}}{a_1}E_1$$
$$\overrightarrow{p_2} = \frac{\overrightarrow{a_2}}{a_2}E_2$$

π^+ RECONSTRUCTION



- Assumption: K+ decays on z axis

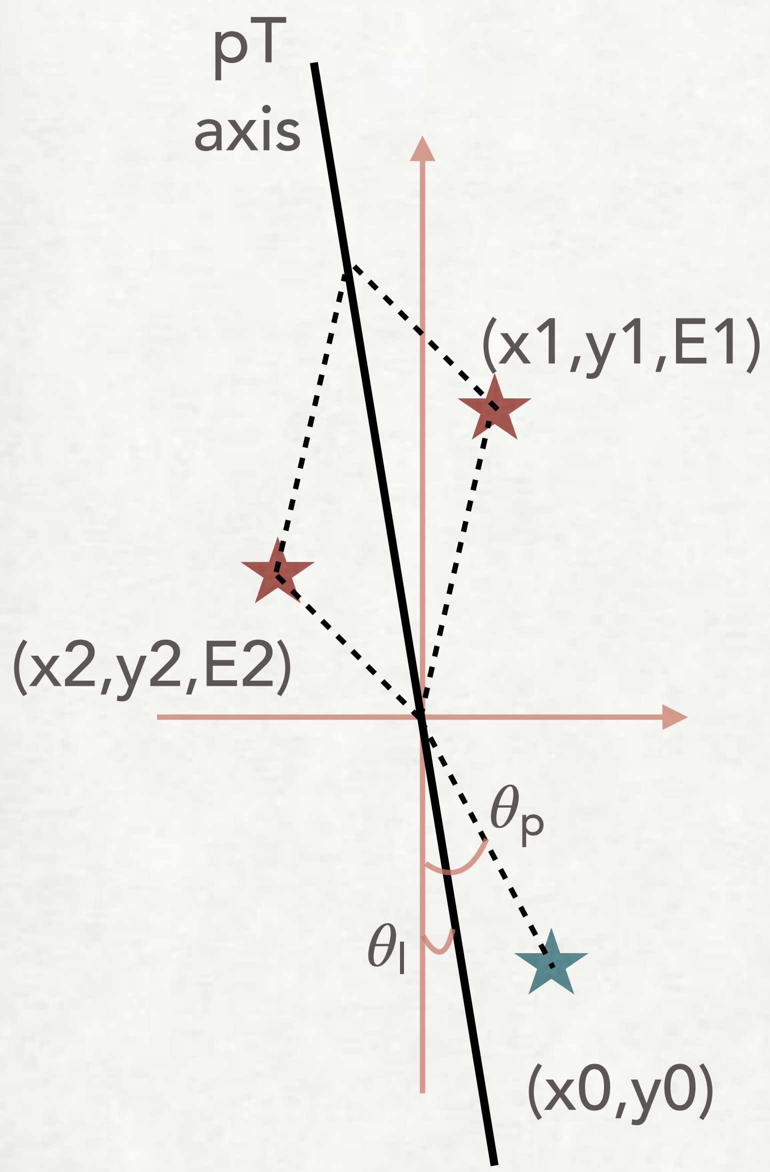
$$p_x^+ = -(p_{1x} + p_{2x})$$
$$p_y^+ = -(p_{1y} + p_{2y})$$

$$p^+ = \frac{p^{+T}}{sin(atan(\sqrt{x^2 + y^2}/z))}$$

$$E = \sqrt{{p^+}^2 - m_{\pi^+}^2}$$

=> From pi0 and pi+ 4-momenta, kaon invariant mass can be reconstructed.

THETA ANGLE



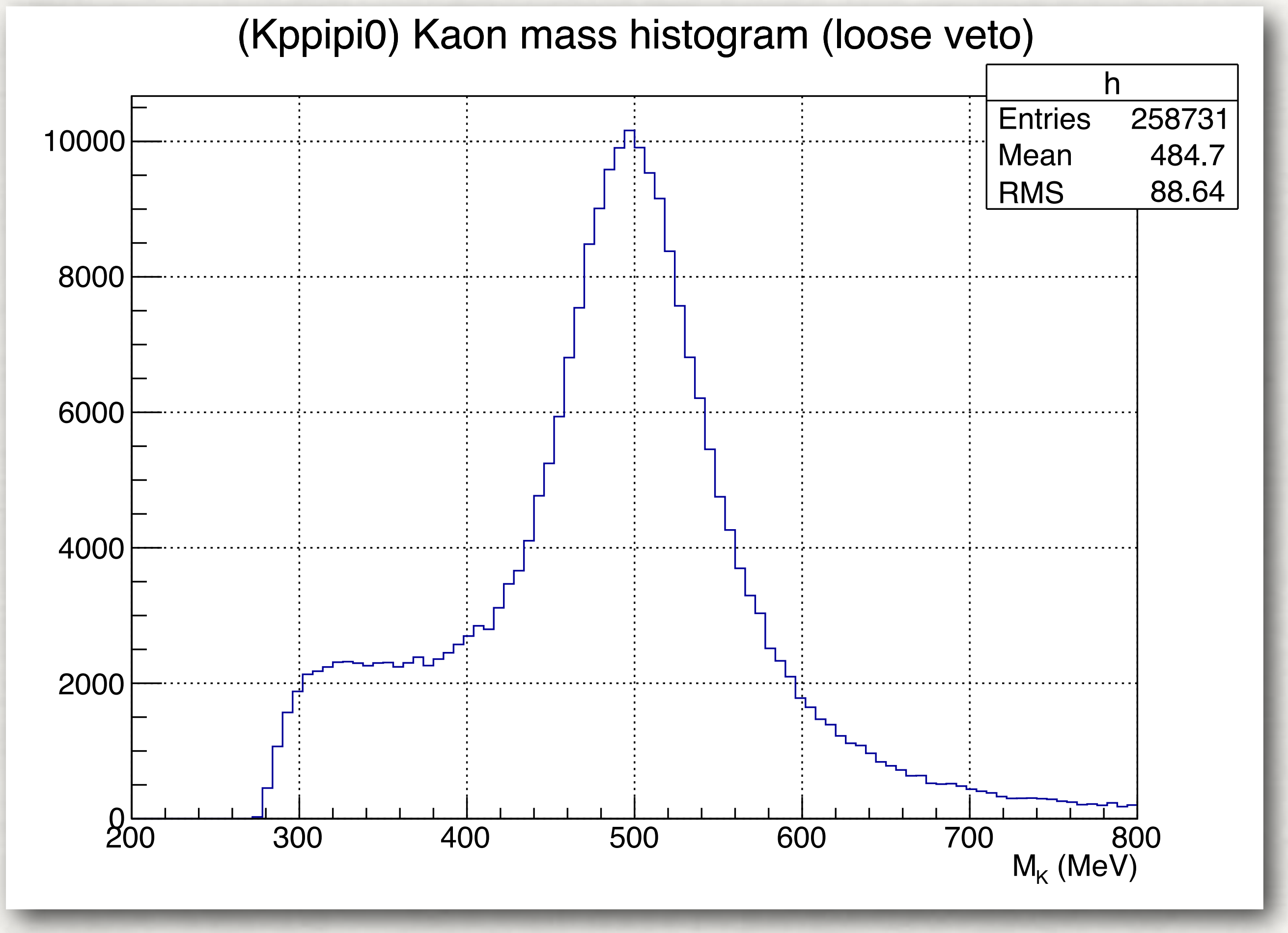
- Theta angle: Angle pi+ cluster made with pT axis (reconstructed from 2 pi0 clusters):

$$\theta = \theta_p - \theta_l$$
$$= \theta(x_1, y_1, E_1, x_2, y_2, E_2, x_0, y_0)$$

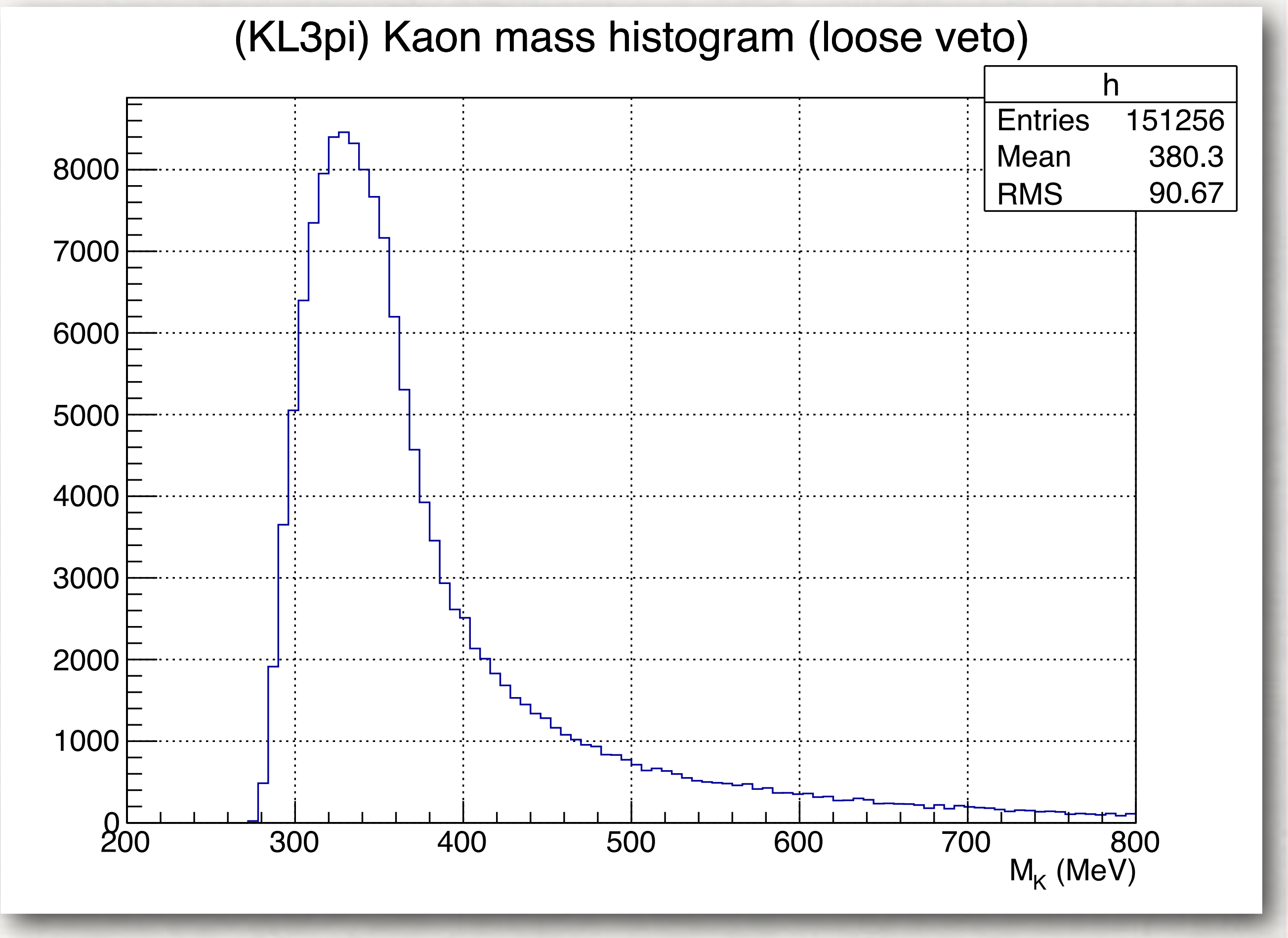
where
$$\begin{cases} \theta_l = atan\left(\dfrac{\frac{E_1 x_1}{r_1} + \frac{E_2 x_2}{r_2}}{\frac{E_1 y_1}{r_1} + \frac{E_2 y_2}{r_2}}\right) \\ \theta_p = atan\left(\dfrac{x_0}{y_0}\right) \end{cases}$$

KAON MASS

signal

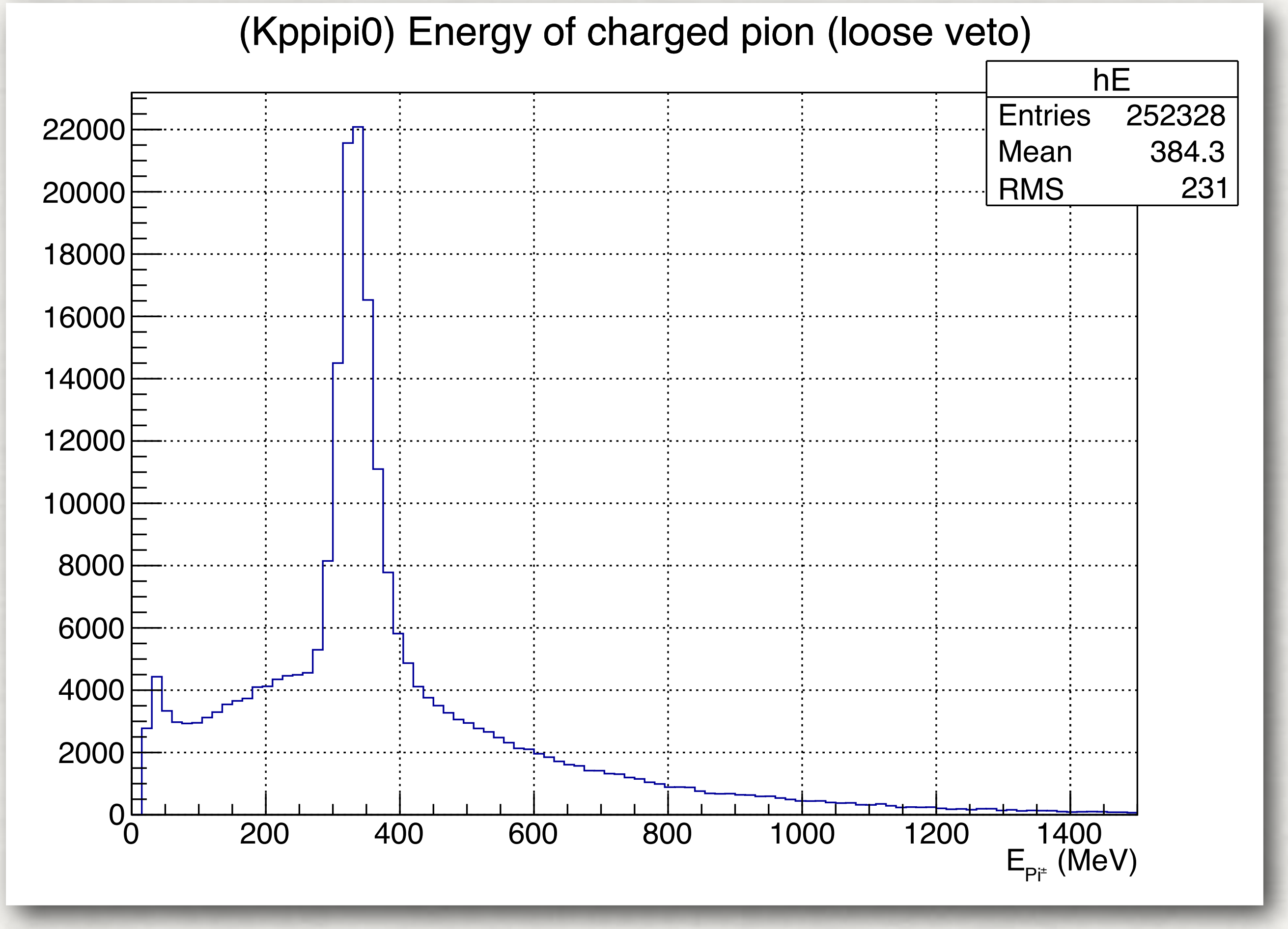


background



π+ ENERGY DEPOSIT

signal



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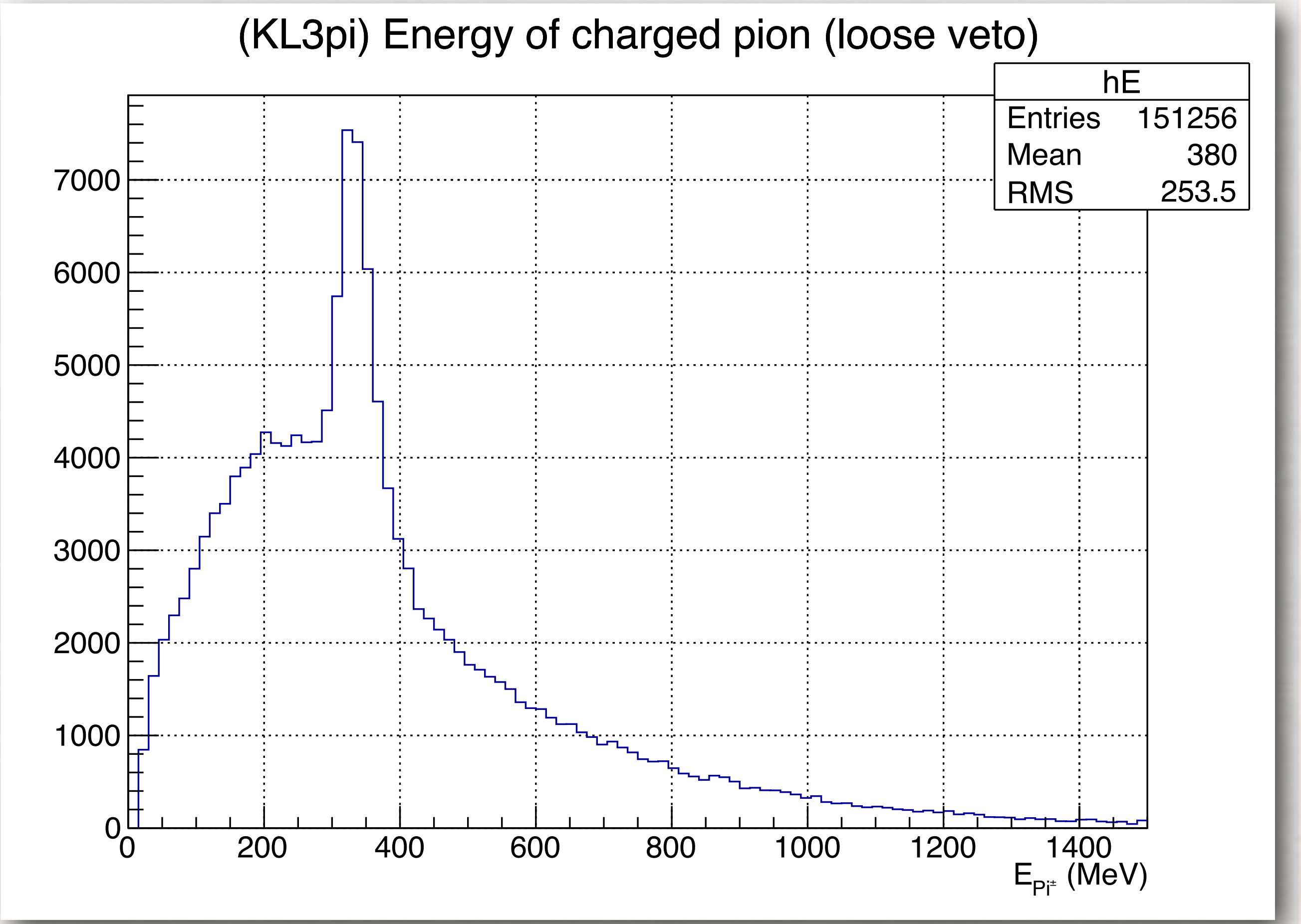
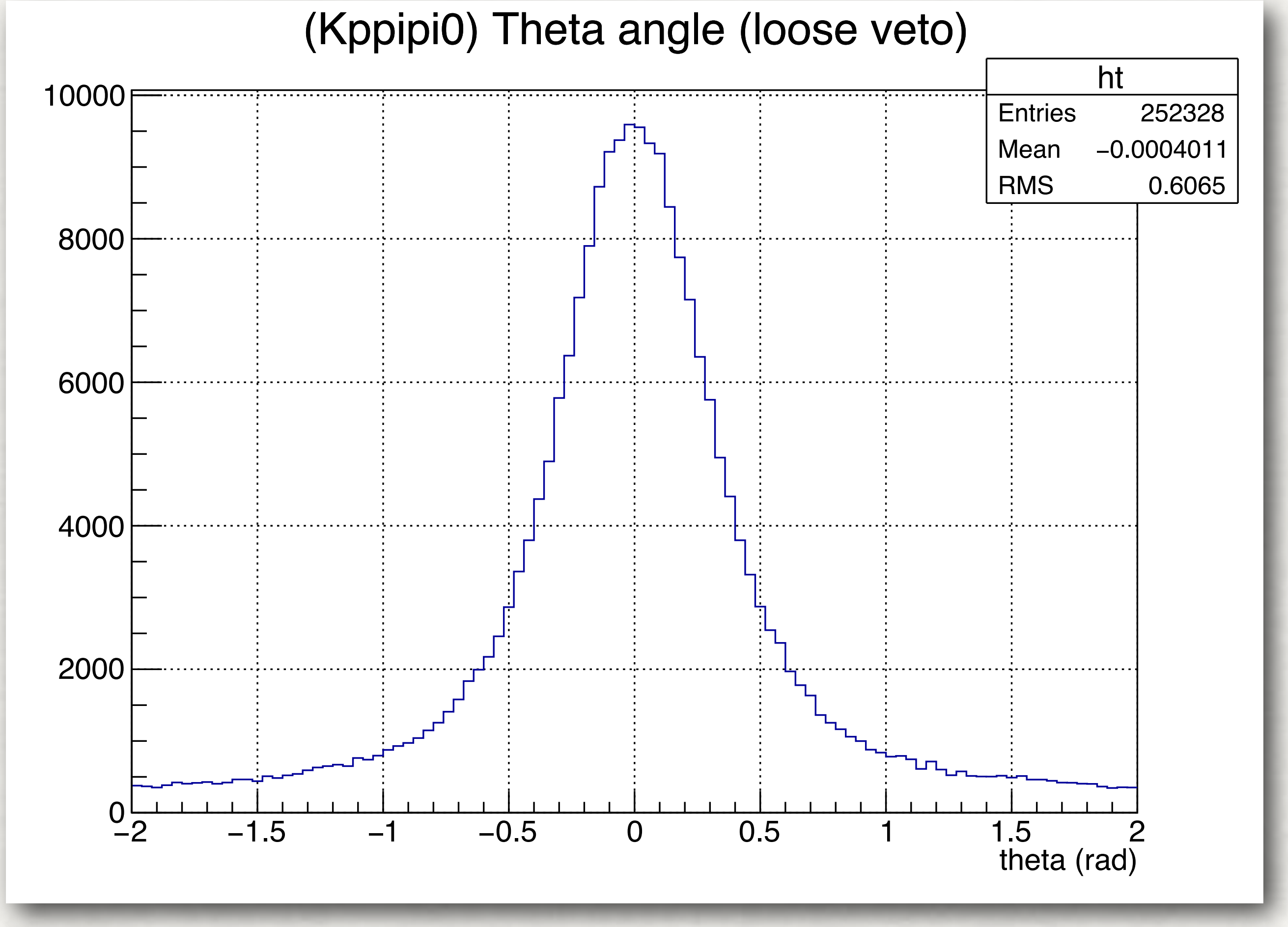
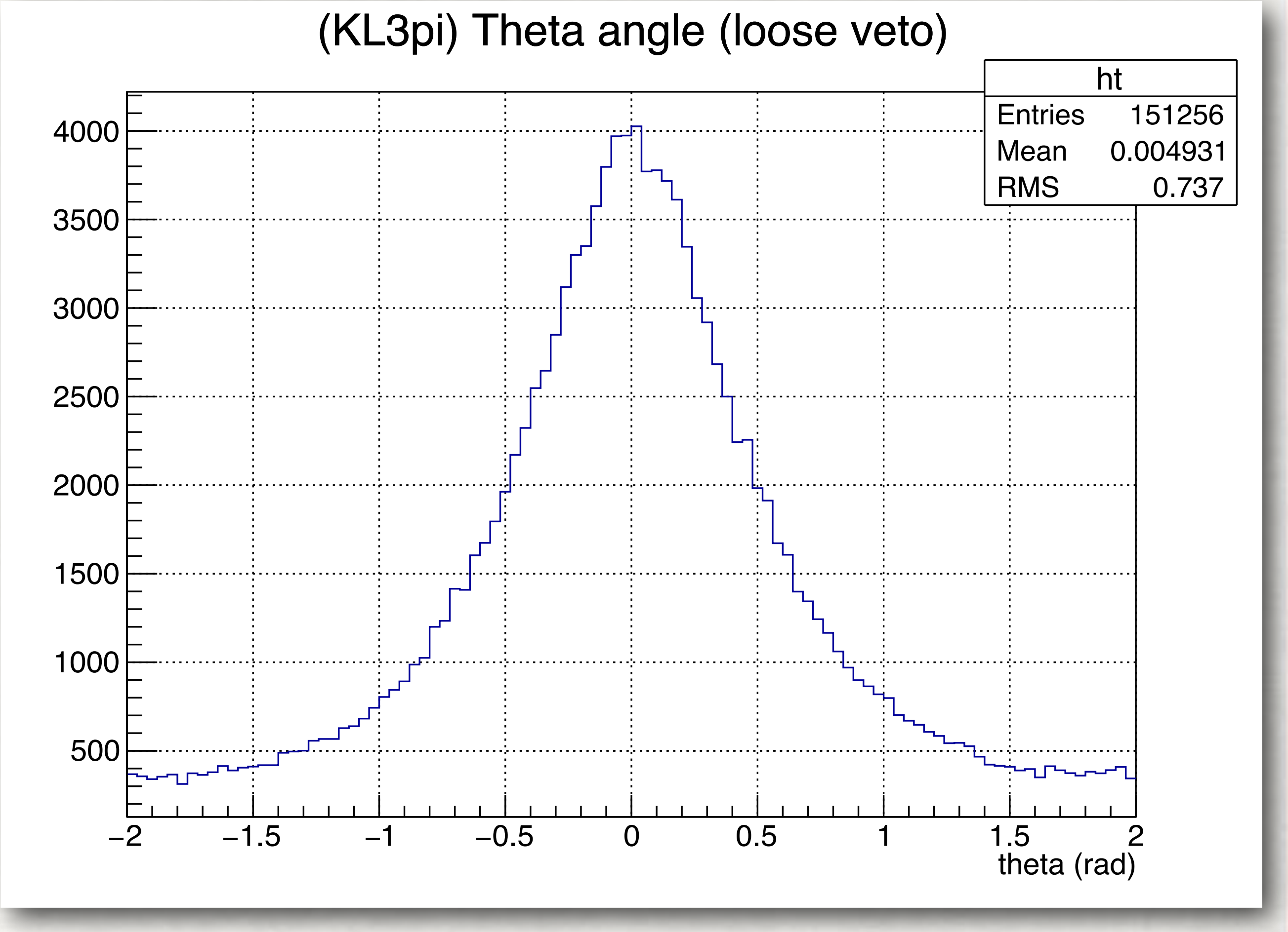


THETA ANGLE

signal

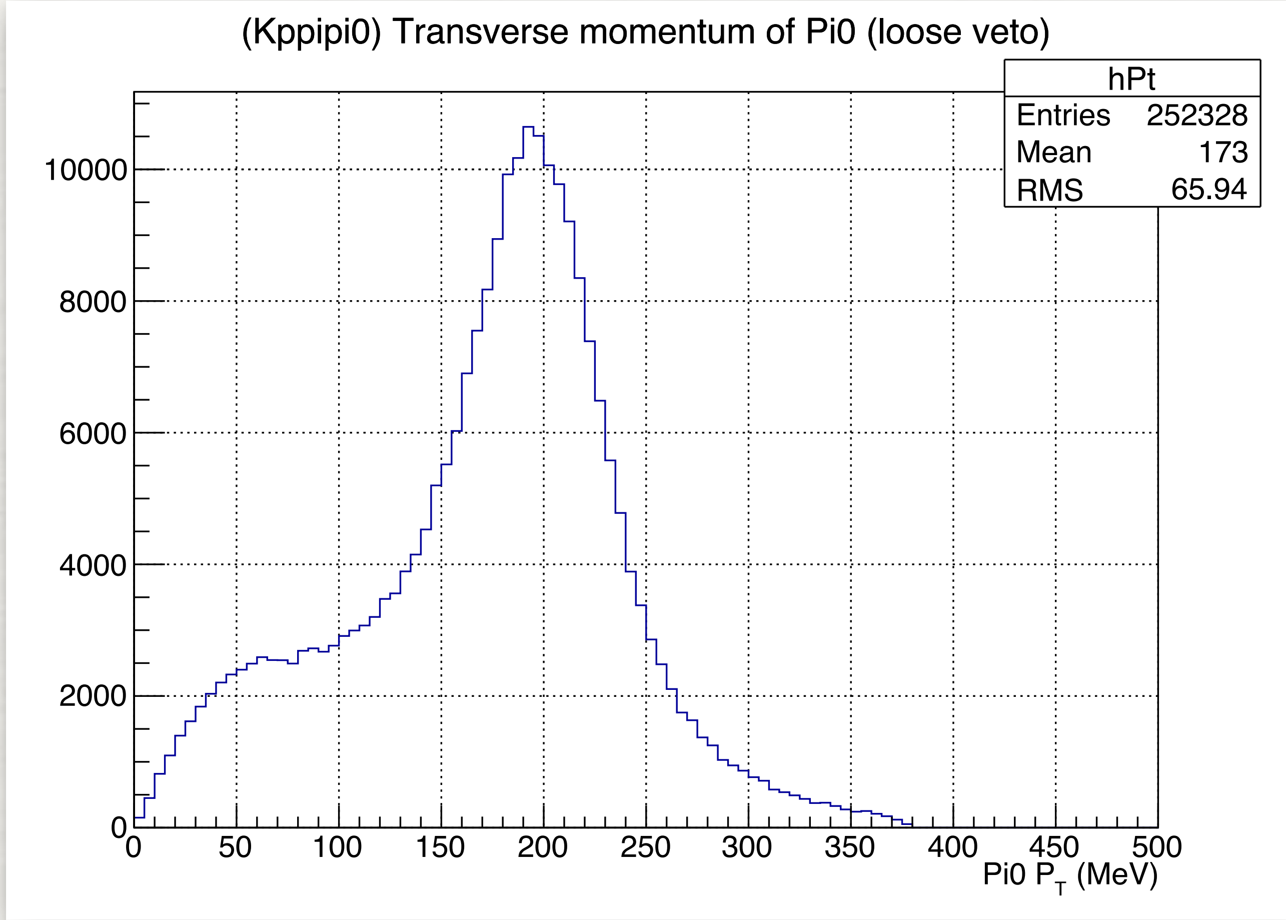
background



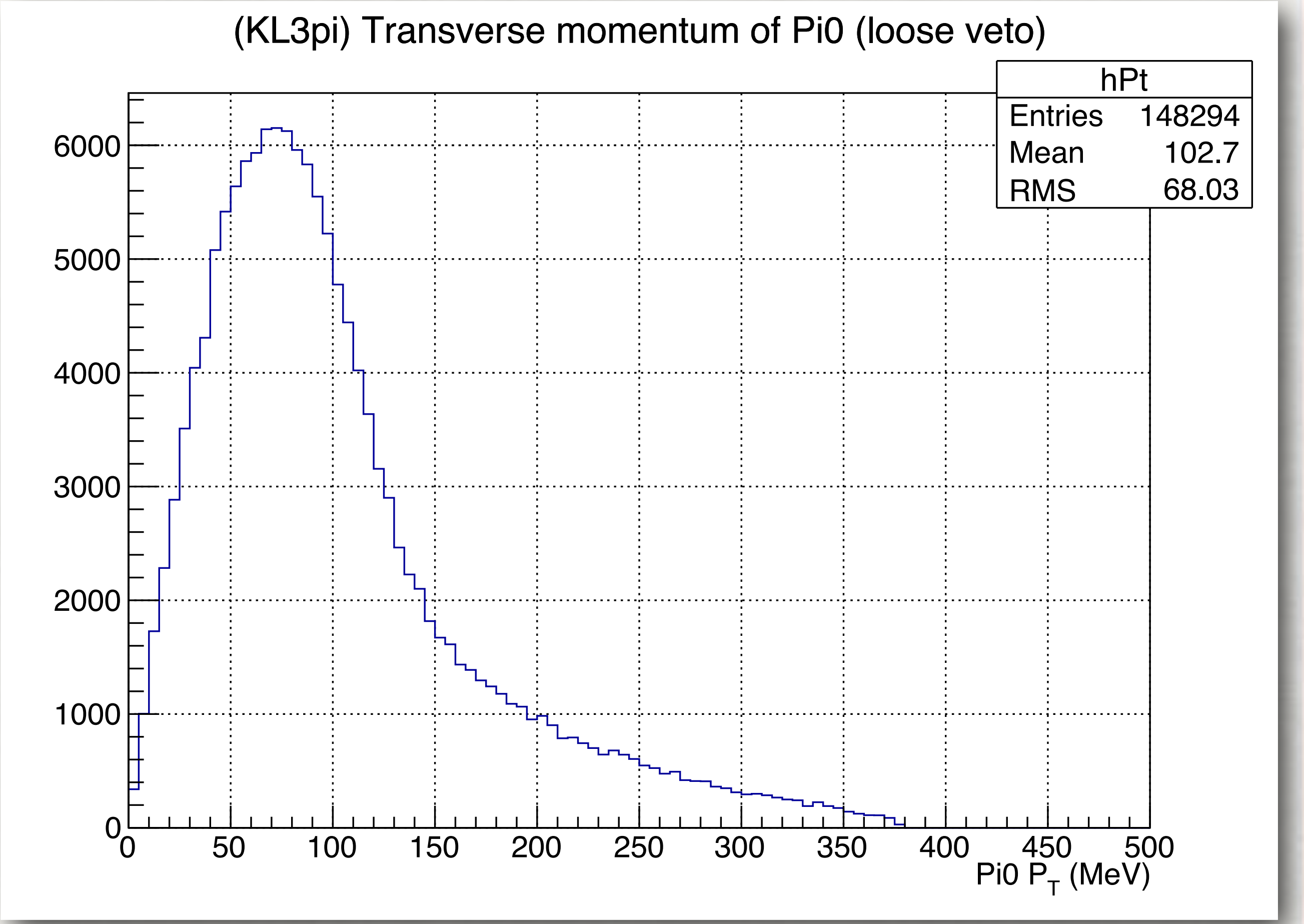


π^0 PT

signal



background



DATA

- MC events: + $K^+ \to \pi^+\pi^0$: 2E+7
  + $K_L \to \pi^+\pi^-\pi^0$: 1E+8

- Branching Ratio: + $K^+ \to \pi^+\pi^0$: ~20%
  + $K_L \to \pi^+\pi^-\pi^0$: ~10%

- Flux Ratio (Simulation): K^+/K_L~1E-5

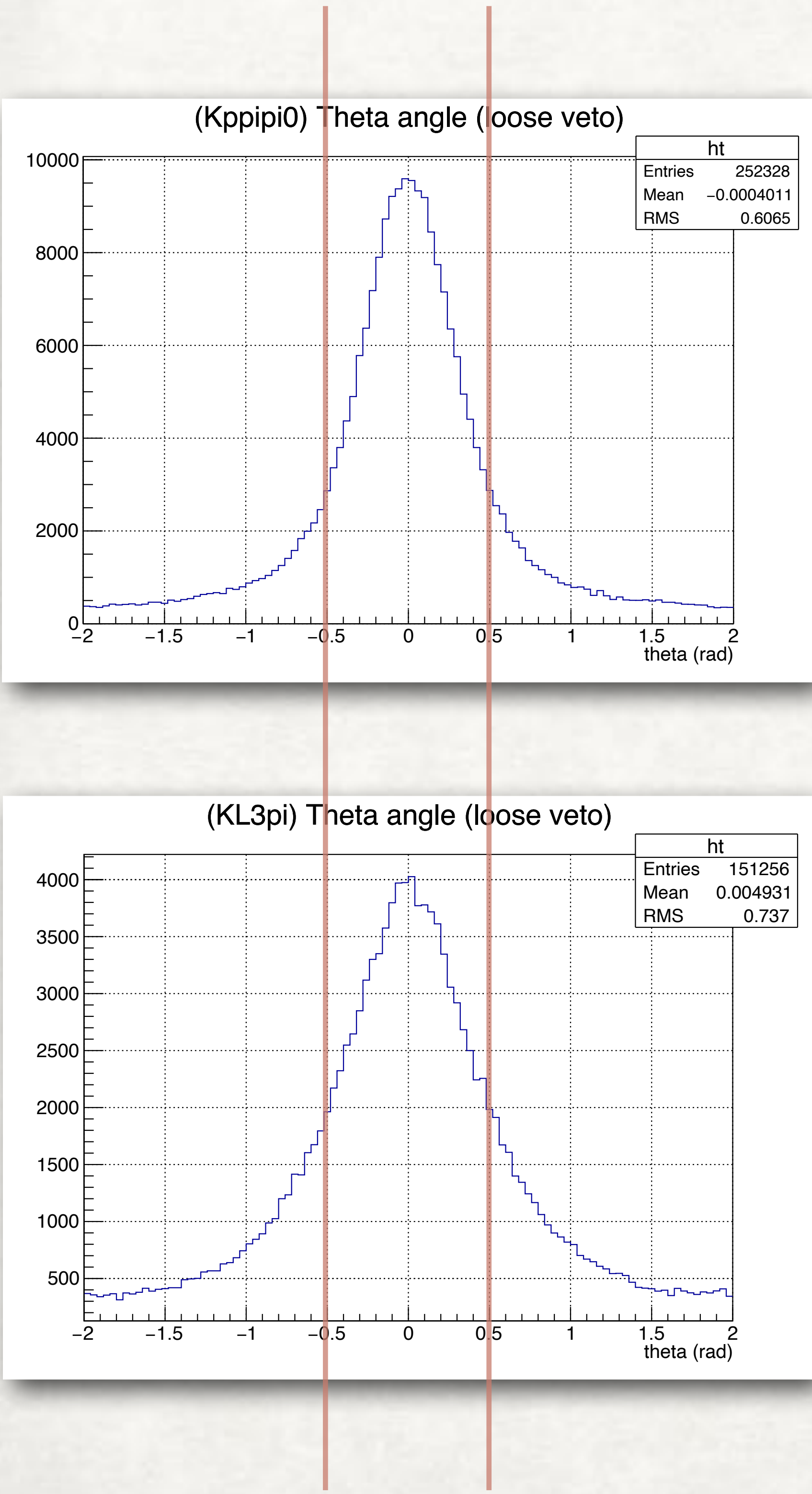
Assumption: Same amount of K^+ and K_L in the beam

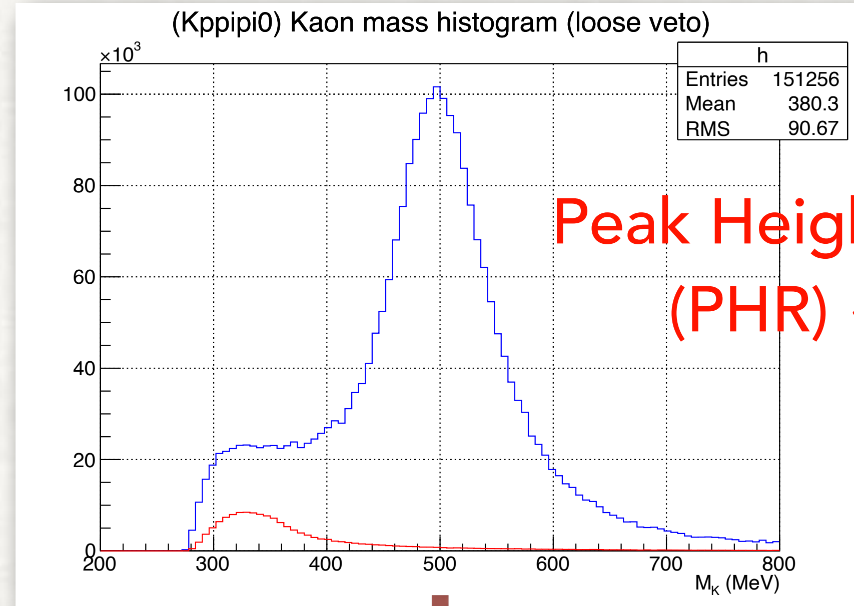
=> Scaling factor: 10

KAON MASS W CUTS

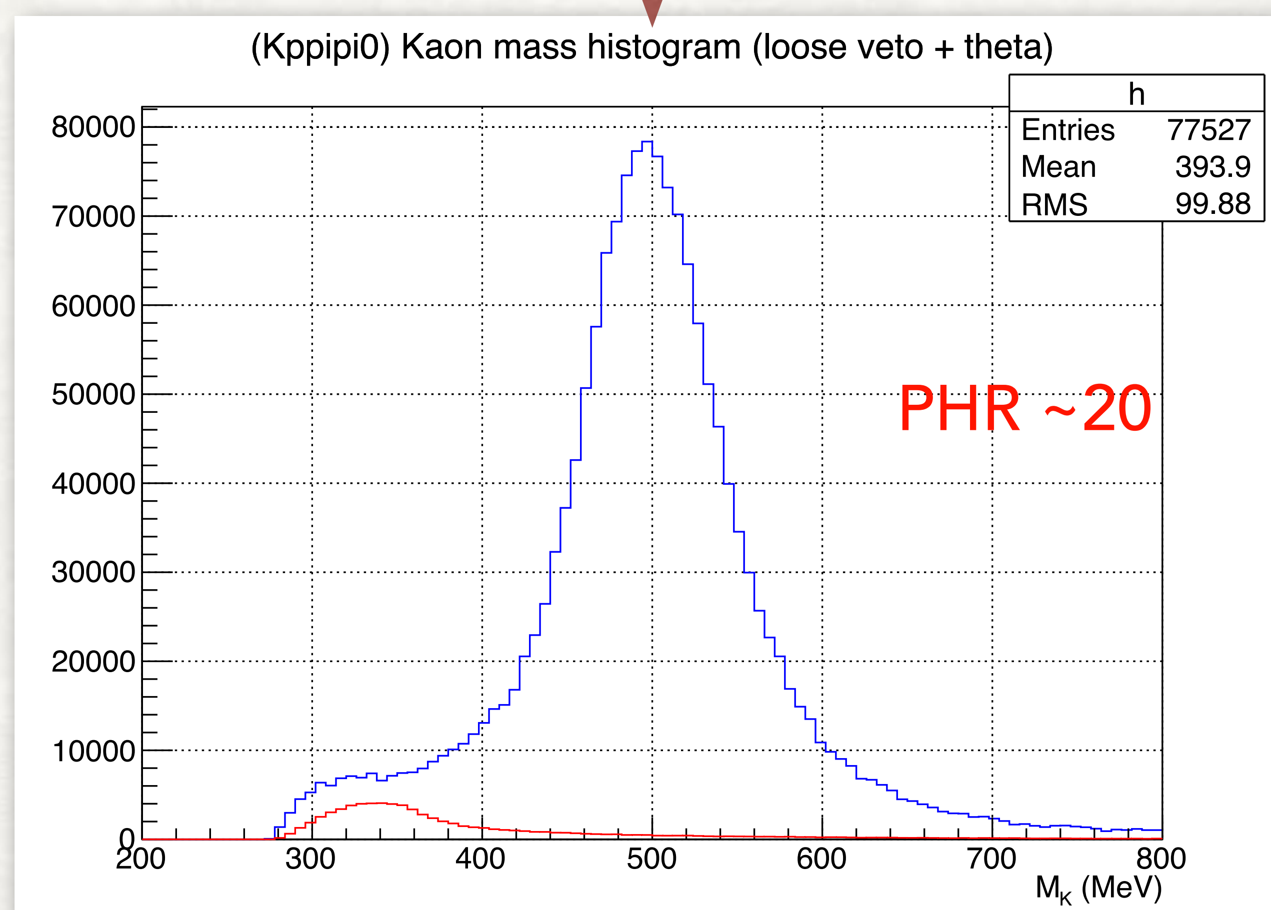
$K_L \rightarrow \pi^+\pi^-\pi^0$

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



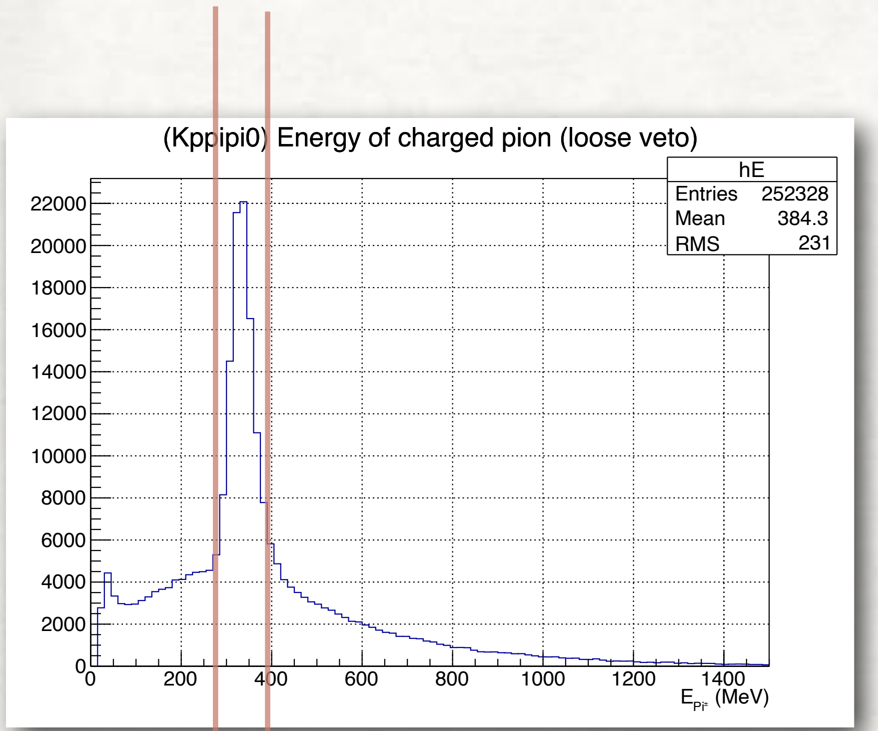


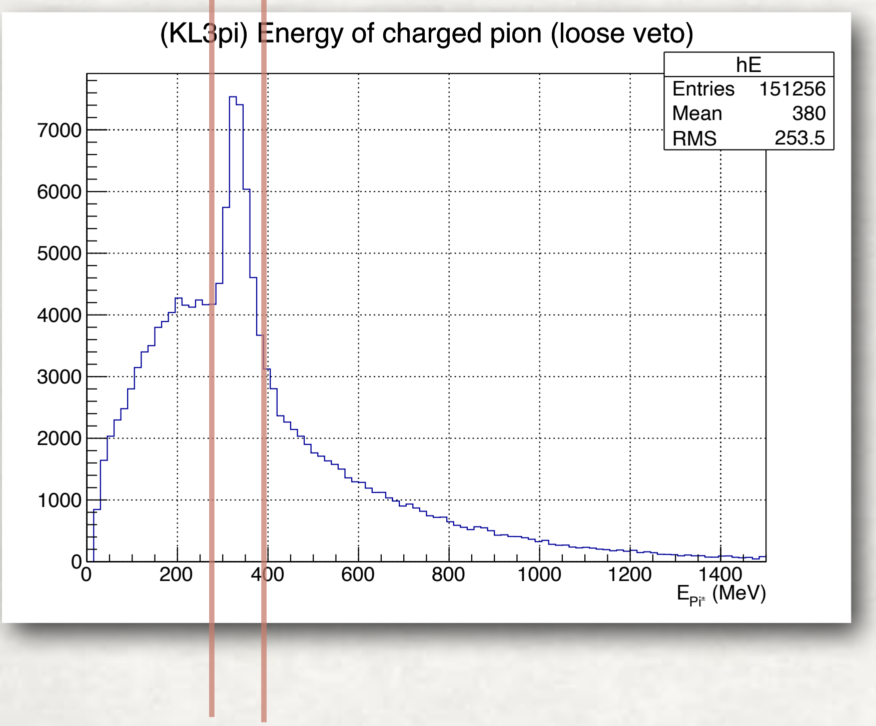
Peak Height Ratio (PHR) ~10



PHR ~20

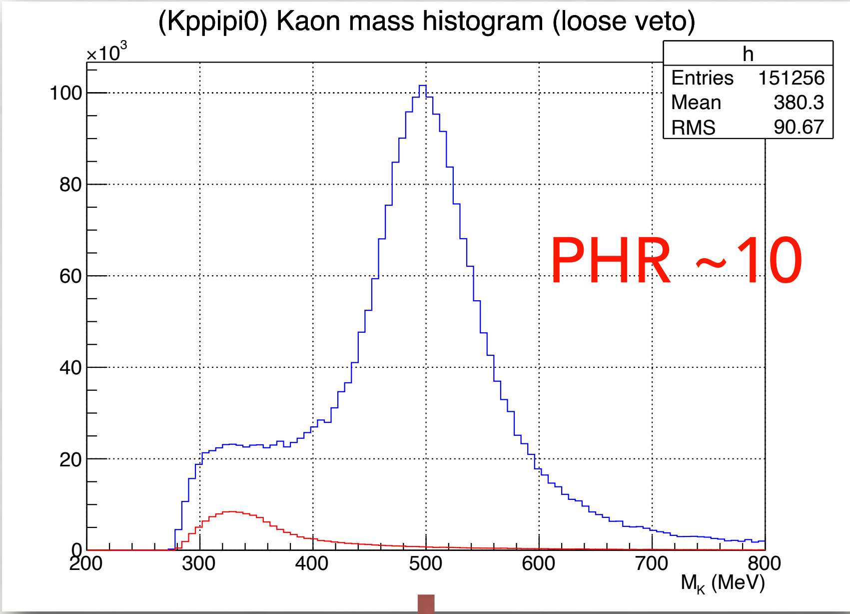
KAON MASS W CUTS

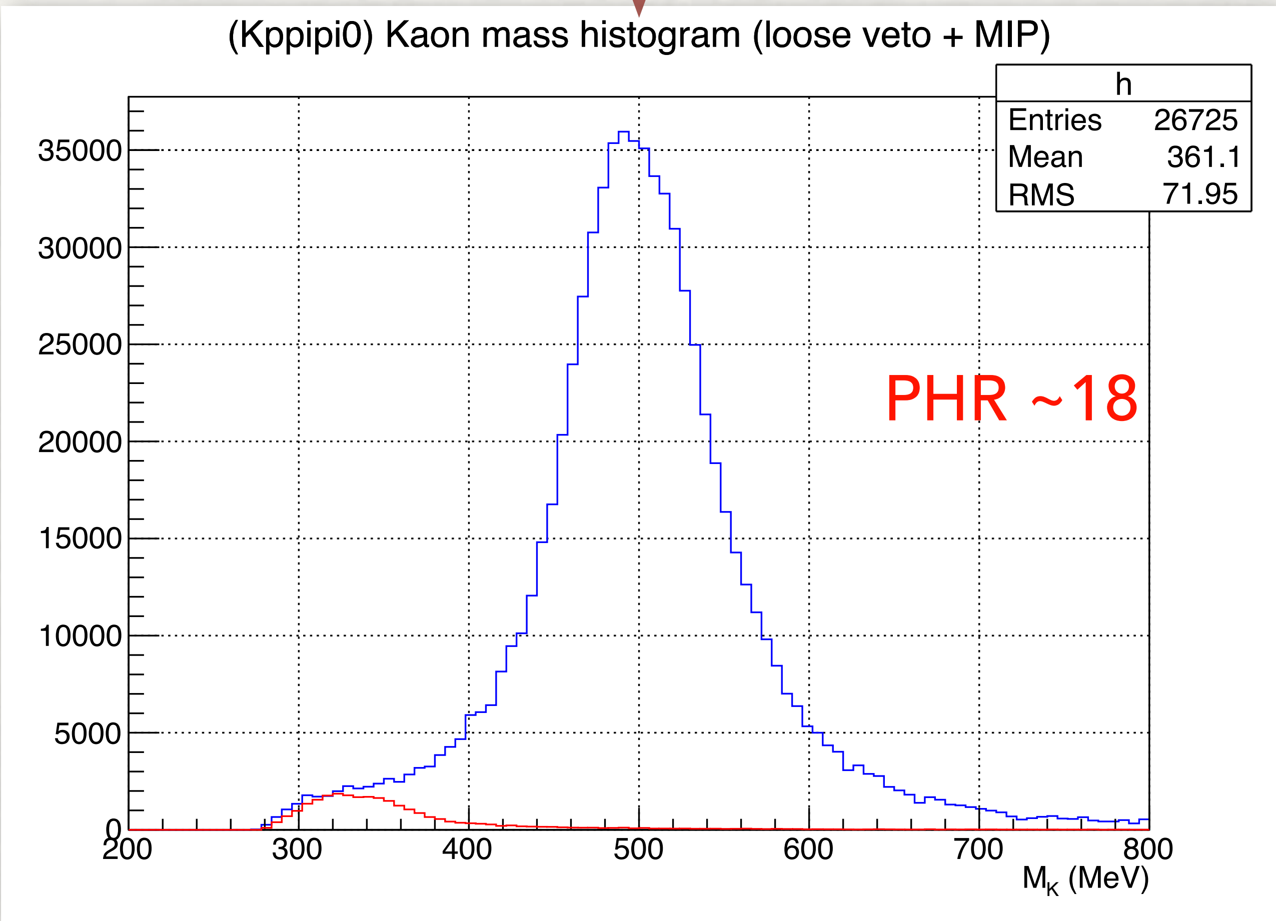




$K_L \rightarrow \pi^+\pi^-\pi^0$

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



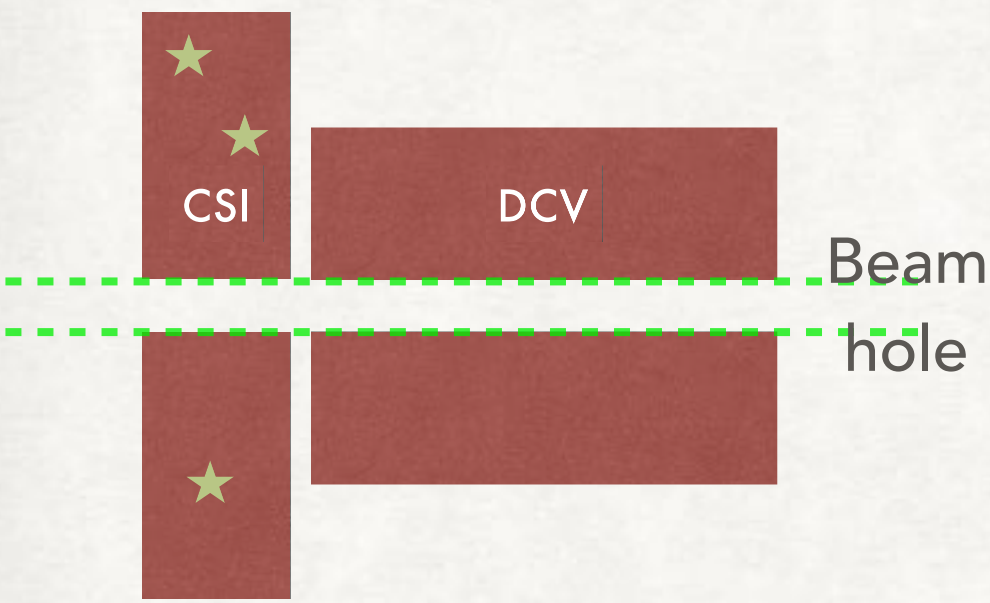


RECONSTRUCTION

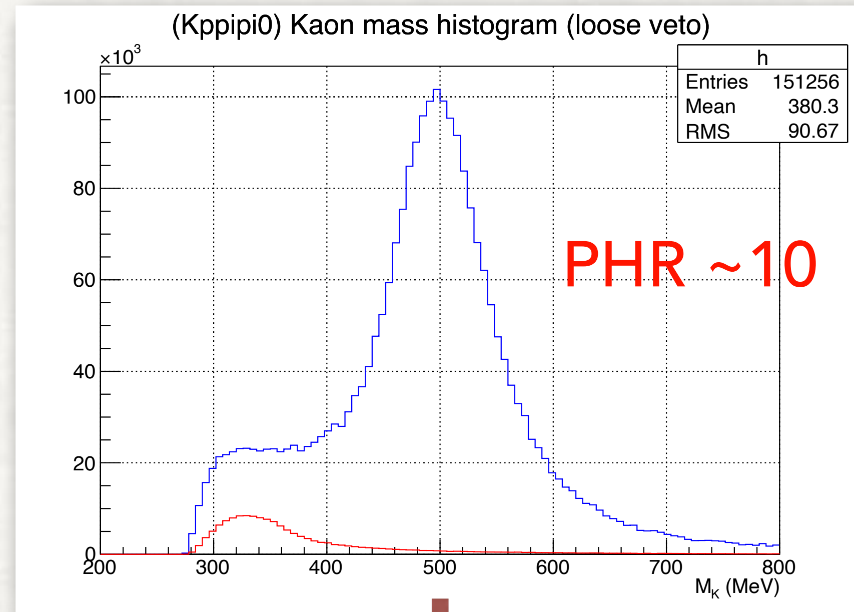
KAON MASS W CUTS

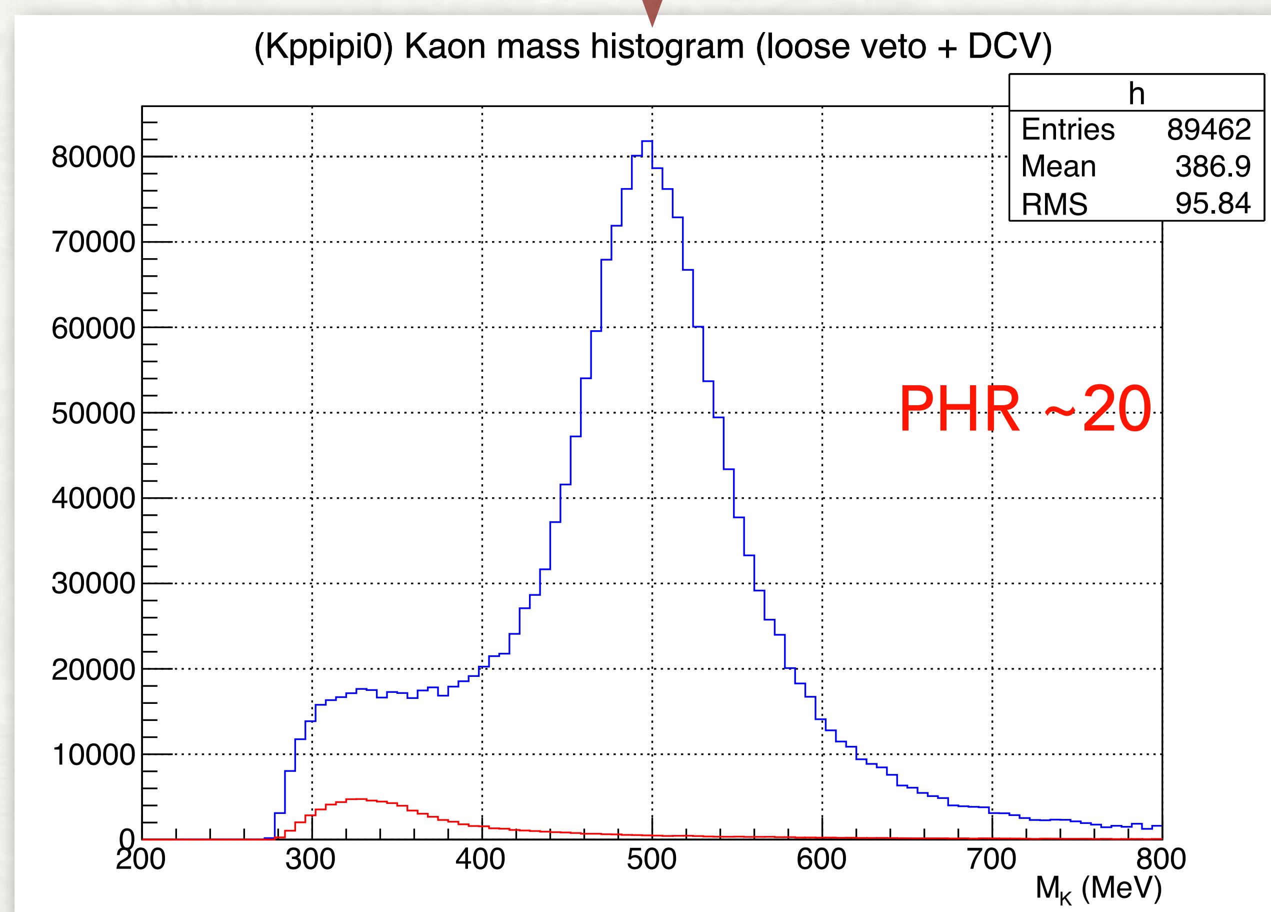
$K_L \rightarrow \pi^+\pi^-\pi^0$

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



Require no hit on DCV:
DCVVetoEne<2MeV





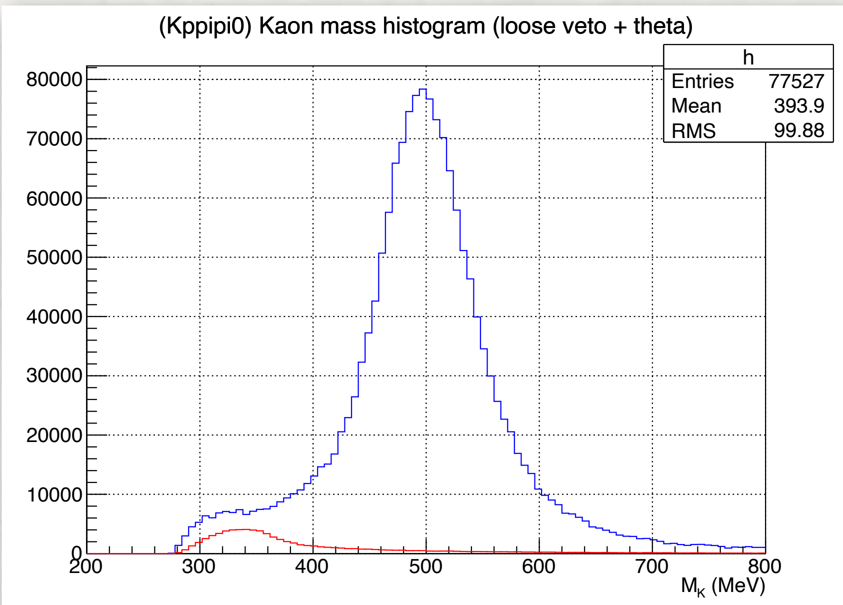
RECONSTRUCTION

KAON MASS W CUTS

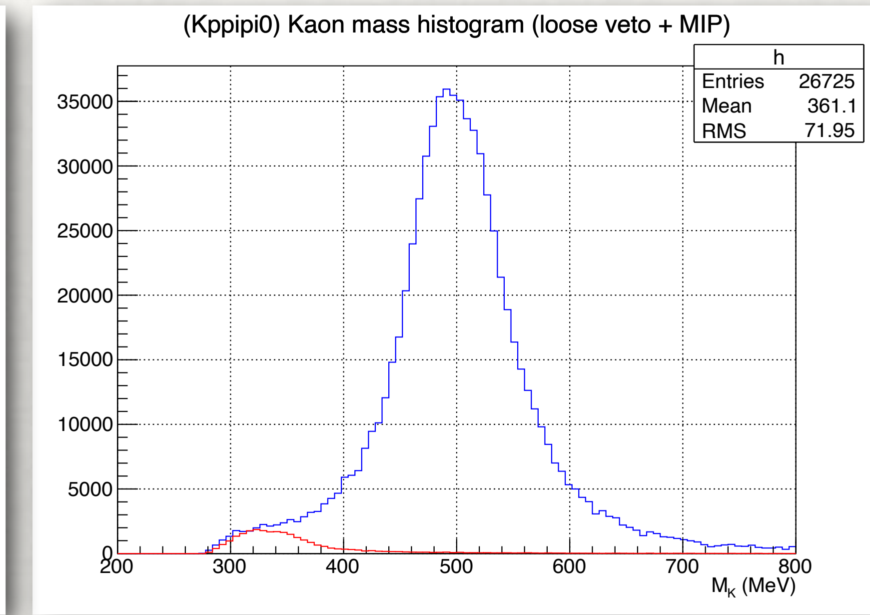
$K_L \rightarrow \pi^+\pi^-\pi^0$

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

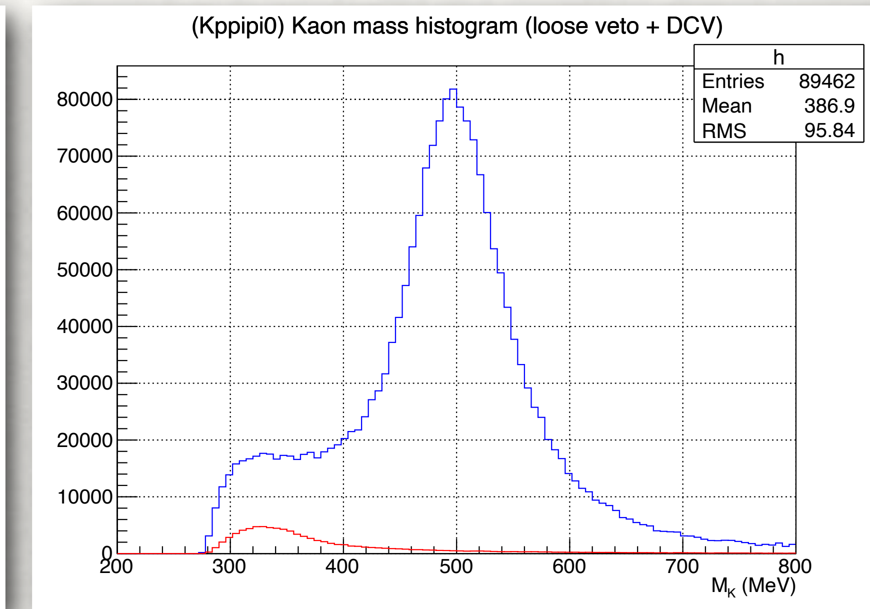
-0.5<theta<0.5

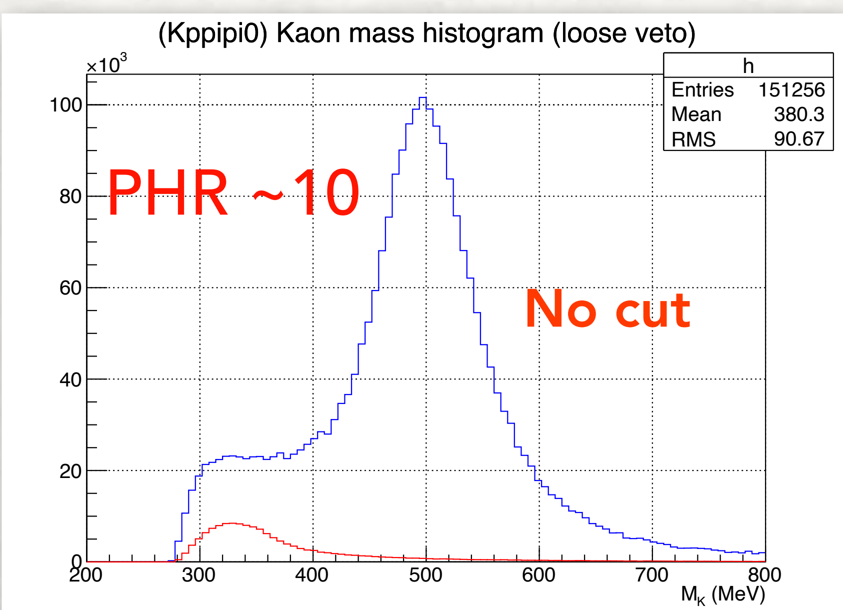


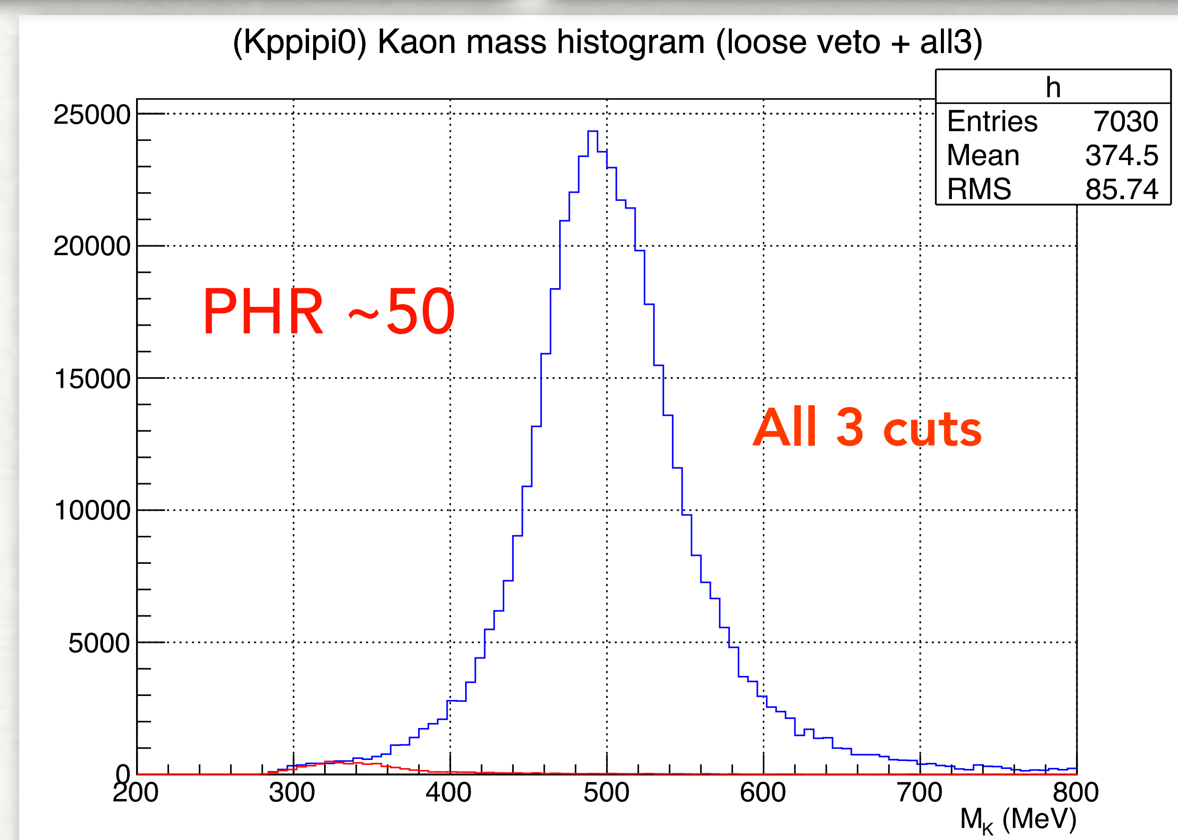
300<E pi+<360



DCVVetoEne<2







SUMMARY

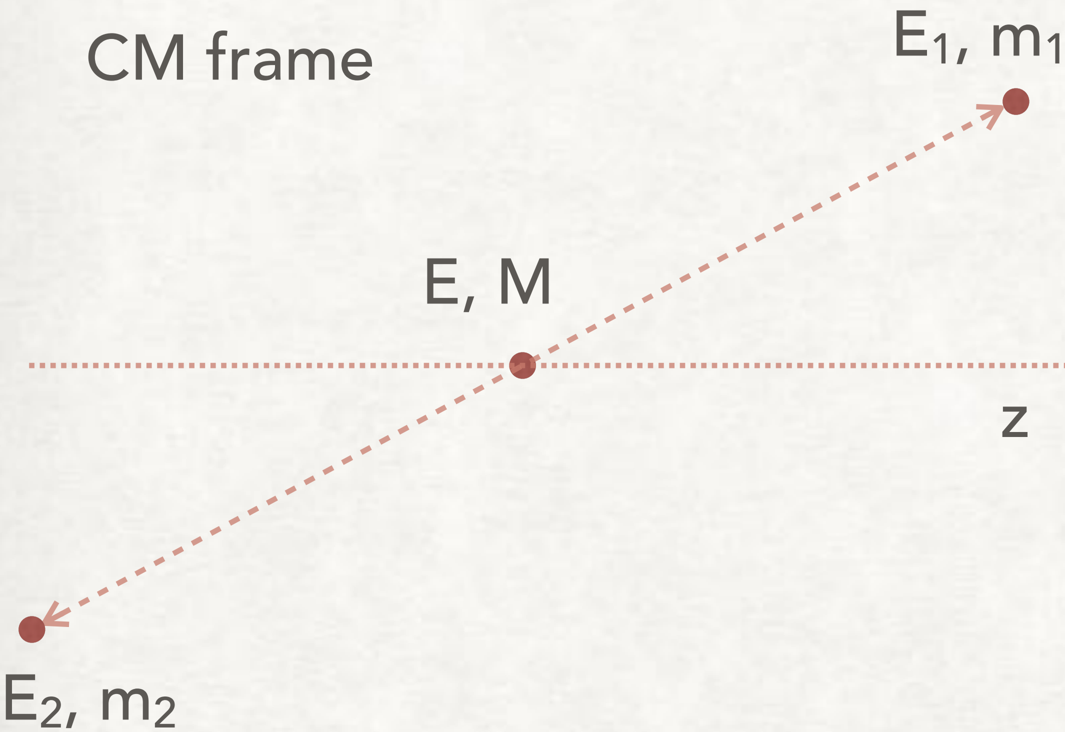
- The new algorithm can be used to discriminate between K^+ and K_L.
  However K^+ contamination is low even after cuts, more selection criteria are needed to be implemented to improve SN ratio.

- The new algorithm's results show agreement with theory.

- Next steps:
  + Apply more different cuts to improve SN ratio
  + Study a new tagging algorithm for better π^+ event selection

BACKUP

MAXIMUM PT OF PI0



$$E_1 = \frac{M^2 + m_1^2 - m_2^2}{2M}$$

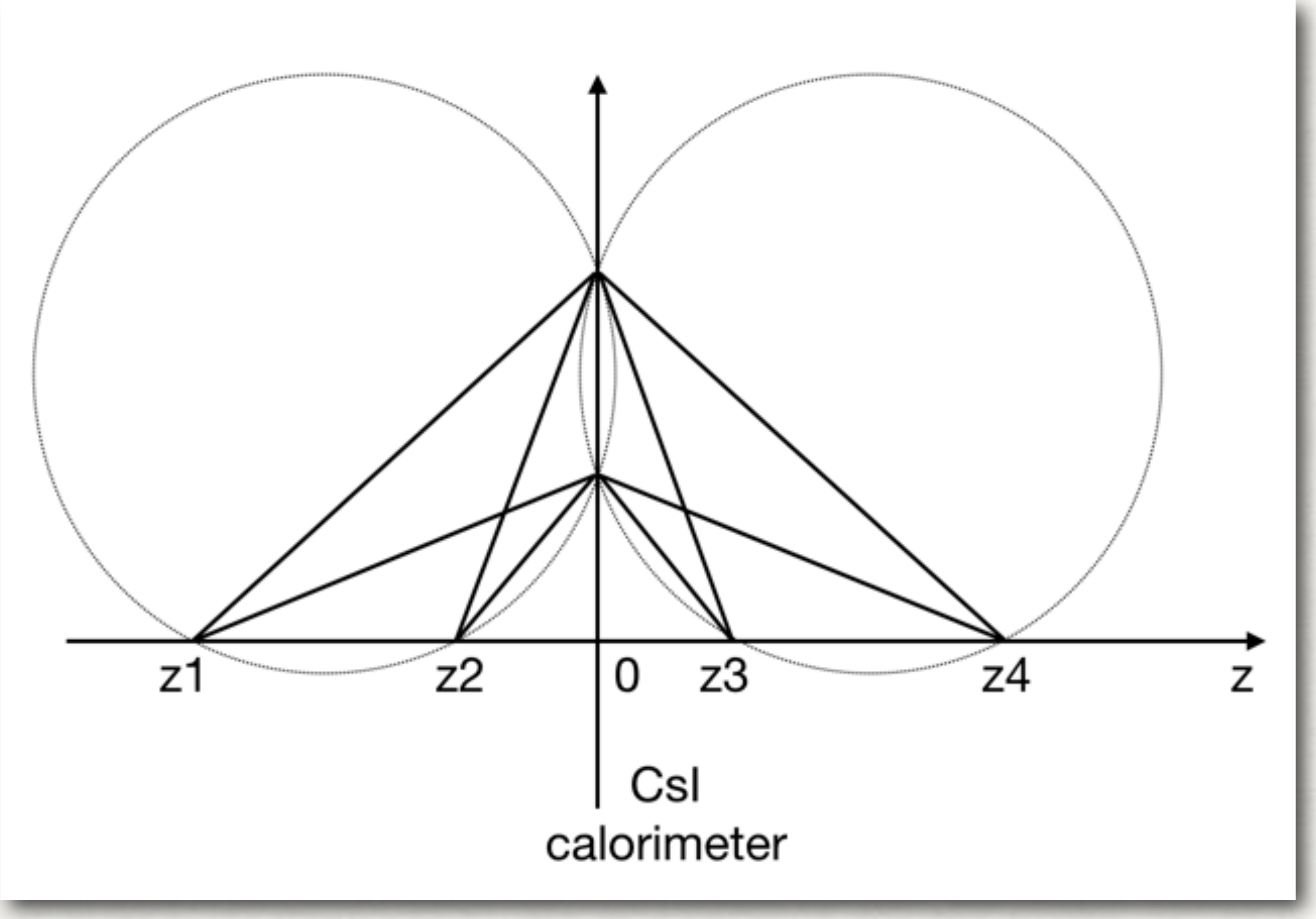
$$P_1^T \leq E_1$$

- $K^+ \to \pi^+\pi^0$: maximum $\pi^0 P^T$ can reach ~250MeV
  => large P^T distribution

- $K_L \to \pi^+\pi^-\pi^0$: maximum $\pi^0 P^T$ can't reach 250MeV
  => smaller P^T distribution

!? The large P^T tail may come from hadronic interaction

4 SOLUTIONS!?



Quadratic equation of z2 => there are 4 solutions

+ z3, z4: behind the calorimeter
+ z1, z2: possible solutions

VETO CONDITIONS

VetoCondition

CSIsingleVeto

MoreLooseVeto2017 =
" && CBARVetoEne<=5 && IBVetoEne<=5 && IBCH55VetoEne<=2.5 && (MyVetoCondition&0x100)==0 && FBARVetoEne<=5 && FBARWideRangeVetoEne<=30 && NCCVetoEne<=5 && CVVetoEne<=0.3 && IBCVVetoEne<=1 && MBCVVetoEne<=1 && !(newBHCVModHitCount>1 && newBHCVVetoEne>884.e-6/4.)"

MoreLooseVeto2015 =
" && CBARVetoEne<=5 && CSIVetoFlag==0 && FBARVetoEne<=5 && FBARWideRangeVetoEne<=30 && NCCVetoEne<=5 && CVVetoEne<=0.3 && BCVVetoEne<=1 && BHCVVetoEne<=0.3"

LooseVeto2017 =
"&& CBARVetoEne<=2 && IBVetoEne<=2 && IBCH55VetoEne<=1 && (MyVetoCondition&0x100)==0 && FBARVetoEne<=2 && FBARWideRangeVetoEne<=30 && NCCVetoEne<2 && CVVetoEne<=0.2 && IBCVVetoEne<=1 && MBCVVetoEne<=1 && !(newBHCVModHitCount>1 && newBHCVVetoEne>884.e-6/4.) && BHGCVetoEne<=2.5"

LooseVeto2015 =
&& CBARVetoEne<=2 && CSIVetoFlag==0 && FBARVetoEne<=2 && FBARNewVetoEne<=2 && FBARWideRangeVetoEne<=30 && NCCVetoEne<2 && CVVetoEne<=0.2 && BCVVetoEne<=1 && BHCVVetoEne<=0.3 && BHGCVetoEne<=2.5

TightVeto2017 =
" && CBARVetoEne<=1 && IBVetoEne<=1 && IBWideVetoEne<=2 && IBCH55VetoEne<=1 && (MyVetoCondition&0x100)==0 && FBARVetoEne<=1 && FBARNewVetoEne<=1 && FBARWideRangeVetoEne<=30 && NCCVetoEne<=1 && NCCScintiVetoEne<=1 && OEVVetoEne<=1 && CVVetoEne<=0.2 && IBCVVetoEne<=0.5 && MBCVVetoEne<=0.5 && !(newBHCVModHitCount>1 && newBHCVVetoEne>884.e-6/4.) && BHGCVetoEne<=2.5"

TightVeto2015 =
" && CBARVetoEne<=1 && CSIVetoFlag==0 && FBARVetoEne<=1 && FBARNewVetoEne<=1 && FBARWideRangeVetoEne<=30 && NCCVetoEne<=1 && NCCScintiVetoEne<=1 && OEVVetoEne<=1 && CVVetoEne<=0.2 && BCVVetoEne<=1 && BHCVVetoEne<=0.3 && BHGCVetoEne<=2.5"

VETO CONDITIONS

- ***Tight Veto Condition 2017:***
  if(***CBARVetoEne<=1*** && ***IBVetoEne<=1*** && IBWideVetoEne<=2 && IBCH55VetoEne<=1 && (MyVetoCondition&0x100)==0 && ***FBARVetoEne<=1*** && ***NCCVetoEne<=1*** && NCCScintiVetoEne<=1 && OEVVetoEne<=1 && **CVVetoEne>0.3** && ***IBCVVetoEne<=0.5*** && ***MBCVVetoEne<=0.5*** && !(newBHCVModHitCount>1 && newBHCVVetoEne>884.e-6/4.) && BHGCVetoEne<=2.5)

- ***Loose Veto Conditions 2017:***
  if(***CBARVetoEne<=2*** && ***IBVetoEne<=2*** && IBCH55VetoEne<=1 && (MyVetoCondition&0x100)==0 && ***FBARVetoEne<=2*** && ***NCCVetoEne<2*** && **CVVetoEne>0.3** && ***IBCVVetoEne<=1*** && ***MBCVVetoEne<=1*** && !(newBHCVModHitCount>1 && newBHCVVetoEne>884.e-6/4.) && BHGCVetoEne<=2.5)

CHI2 CALCULATION

$$\theta = \theta_p - \theta_l$$
$$= \theta(x_1, y_1, E_1, x_2, y_2, E_2, x_0, y_0)$$

$$\chi^2 = \frac{\theta^2}{\sigma_\theta^2}$$

$$\sigma_\theta^2 = \left(\frac{\partial\theta}{\partial x_1}\right)^2 \sigma_{x_1}^2 + \left(\frac{\partial\theta}{\partial y_1}\right)^2 \sigma_{y_1}^2 + \left(\frac{\partial\theta}{\partial E_1}\right)^2 \sigma_{E_1}^2 + \ldots$$

$$\frac{\partial\theta}{\partial x_1} = \frac{\theta(x_1 + \epsilon) - \theta(x_1)}{\epsilon}$$

Note: The dependence on x0, y0 is not taken into account because position resolution is dependent on energy of pi+ which is not known.