# Tau reconstruction in $e^+e^- \to \tau^+\tau^-$ at the ILC250

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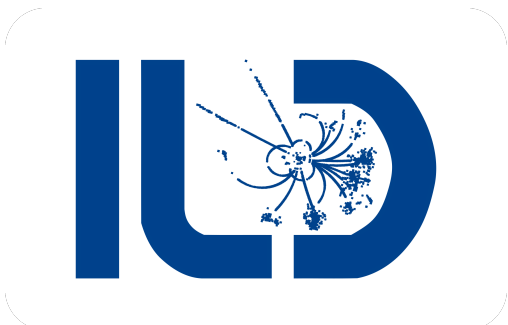

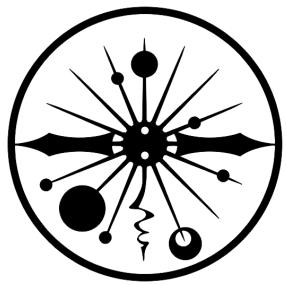



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# Introduction

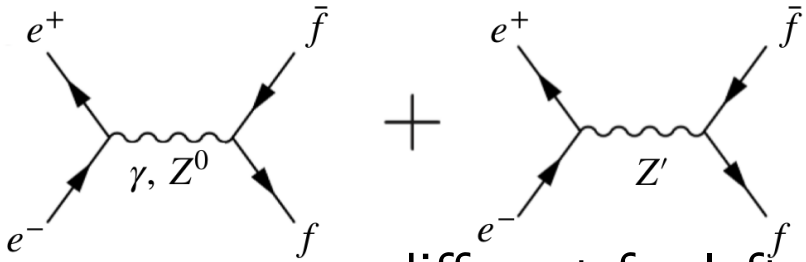
Tau is the heaviest lepton and is the only lepton that can decay to hadrons.
Collision of $e^+$ and $e^-$ generates tau lepton pair in ILC


with its rather short lifetime allows reconstruction of its spin direction by the distribution of its decay products.

Maximum sensitivity to the spin orientation requires reconstruction of the tau decay mode and the kinematics of its decay.

# Motivation 1

In the ILC, forward-backward asymmetry $A_{FB} = \frac{3}{4} A_e \cdot A_f$ can be measured




couplings to Z boson $g_R, g_L$ are different for left- and right-handed fermions and left-right polarisation asymmetry $A_f$ are expected in the Standard Model.

$$A_f = \frac{g_R^2 - g_L^2}{g_R^2 + g_L^2}$$

Thanks to ILC's polarised beams ($e^-_{L80} e^+_{R30}$) $A_e$ can be measured
$\rightarrow A_f$ can be extracted from $A_{FB}$

# Motivation 2

by measuring $A_{FB}$ precisely and looking for deviations from SM predictions it is possible to search for new physics,

such as those caused by heavy gauge boson $Z'$

$A_\tau$ can also be measured directly by using tau polarisation $P(\tau)$

$$\frac{dP(\tau)}{d\cos\theta} = \alpha A_e(1+\cos^2\theta) + \beta A_\tau \cos\theta$$

where $\alpha, \beta$: coefficients predicted by SM.

this polarisation of tau $P(\tau)$ depends on tau decay mode.

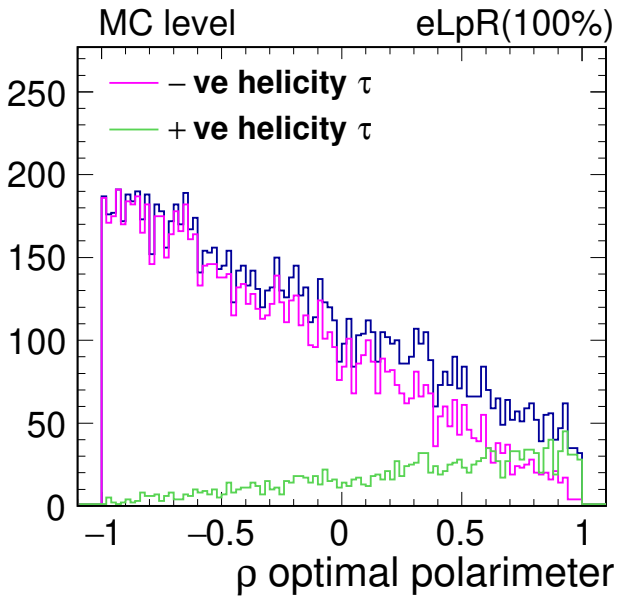
The aim of this study is reconstruction of tau spin in order to measure polarisation to investigate new physics.

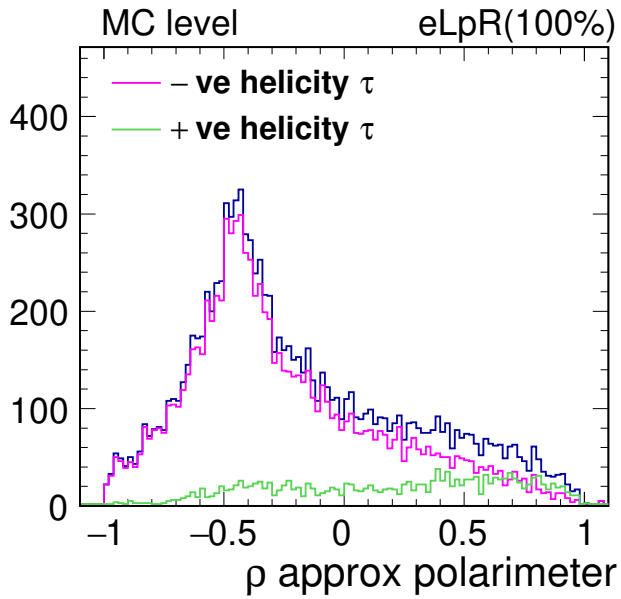
# Previous study

Polarimeter: the cosine of the angle the polarimeter vector makes to the tau flight direction.

"Approximate" polarimeter which is reconstructed based only on the momenta of visible tau decay products.

"Optimal" polarimeter is more sensitive than "Approximate".



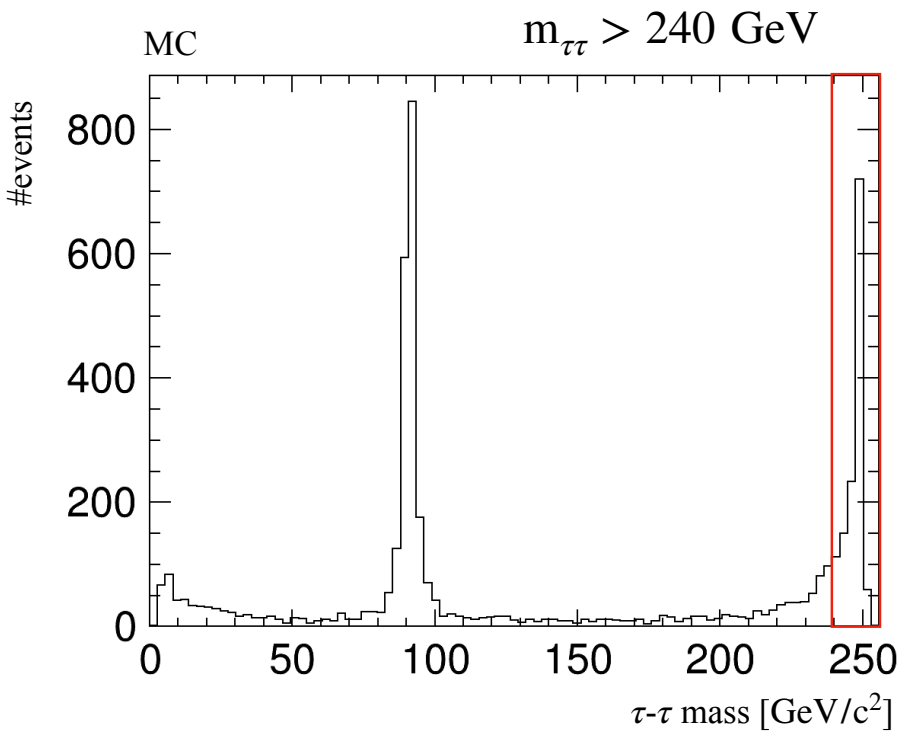

arXiv:1912.08403

In today's talk,

we explicitly extract neutrino momentum to calculate optimal polarimeters.

# Simulation setup

- Signal event sample with $100\ \%\ e^-_L e^+_R$ beam polarisations were generated using WHIZARD ver 2.8.5.
- The decay of the polarised tau was done using TAUOLA.
- ILCsoft version v02-02 was used for simulation.
- Full simulation of ILD detector based on Geant4 and realistic reconstruction were performed.



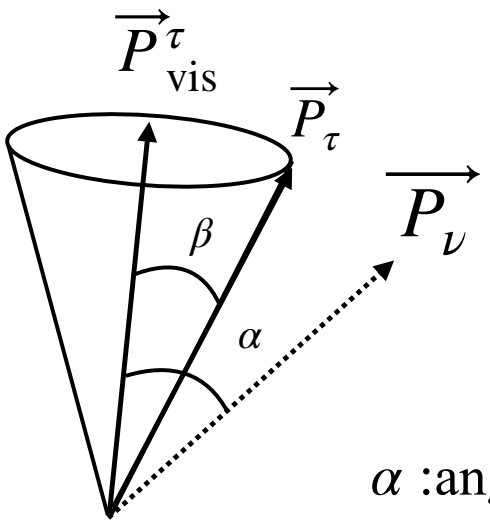

For now

- only look at
  $\tau \to \pi\nu$ and $\tau \to \rho\nu$
- $m_{\tau\tau} > 240$ GeV

# How to extract $\nu$ momentum

Assume

- 1 neutrino per tau
- $m_\tau = 1.776$ GeV
- $E_\tau = \frac{E_{cm}}{2}$




$\overrightarrow{P}^{\tau}_{\text{vis}}$ : tau visible daughter momentum

$\overrightarrow{P}_{\nu}$ : neutrino momentum

$\overrightarrow{P}_{\tau}$ : tau momentum

$\alpha$ :angle between tau visible daughter and neutrino

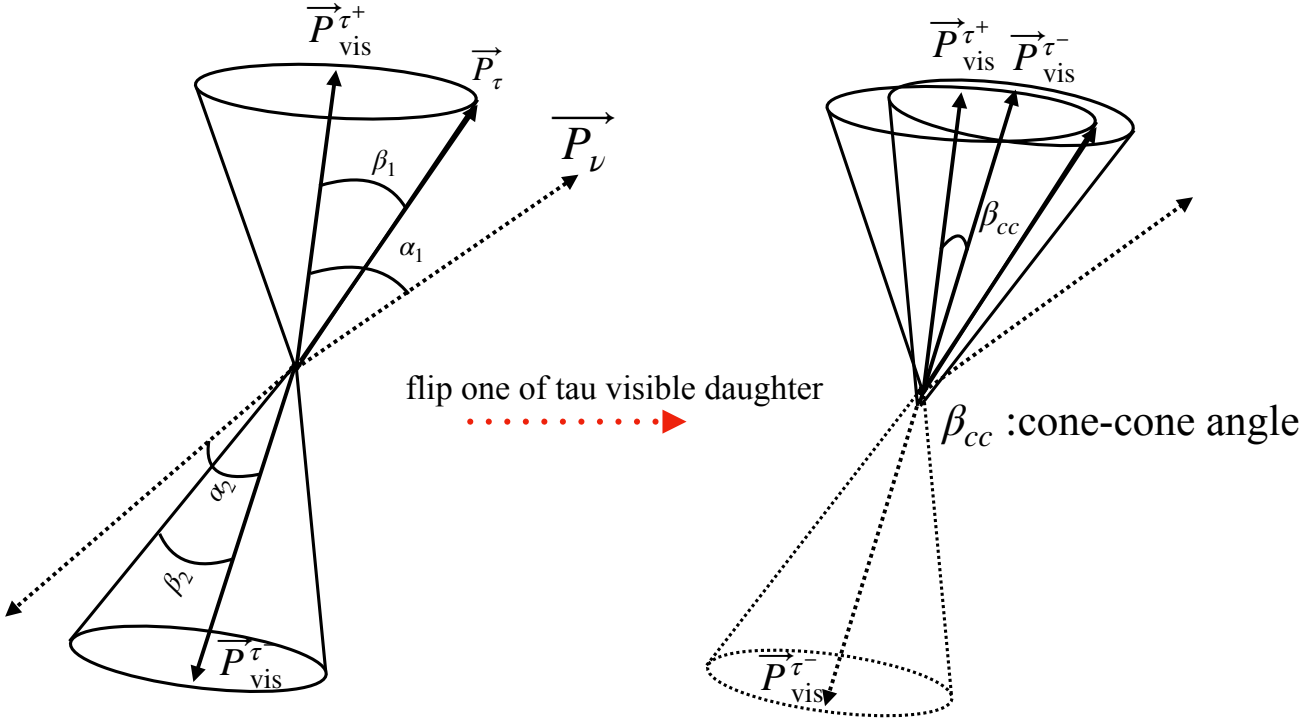
$\beta$ :angle between tau visible daughter and tau

Angle $\alpha, \beta$ can be calculated from these assumption.

# “Cone method”

Assume

- tau-tau is back-to-back



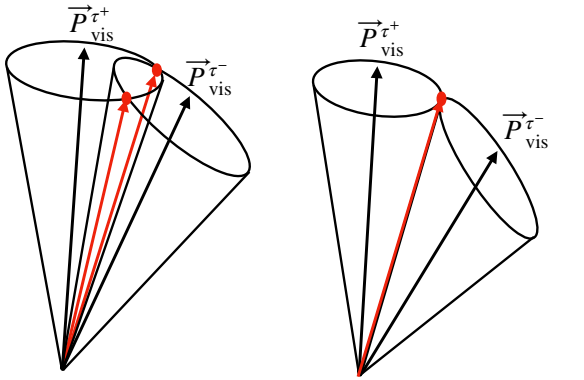

intersection of two cones are candidate tau directions consistent with assumptions.

We call this “Cone method”.

# Find solutions

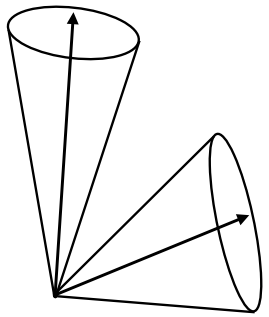
If at least one intersection point was found, there is a solution.

$\beta_1 + \beta_2 > \beta_{cc}$ $\beta_1 + \beta_2 = \beta_{cc}$

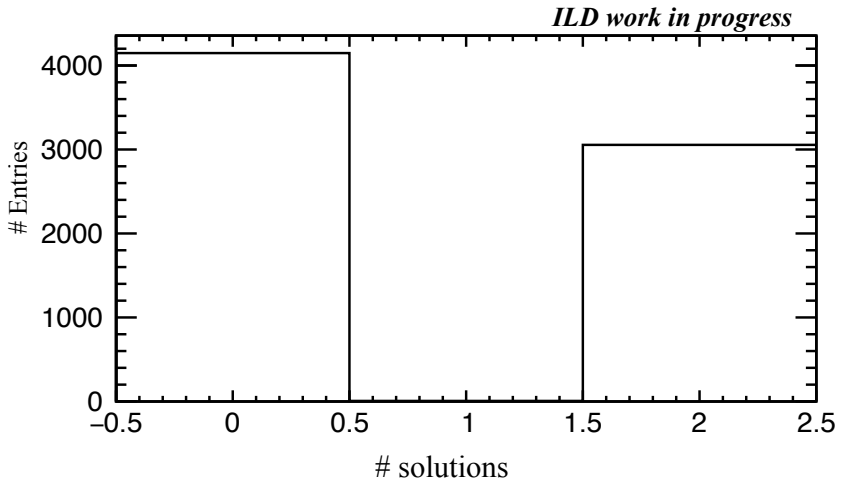



2 possible solutions 1 possible solution

$\beta_1 + \beta_2 < \beta_{cc}$



NO solutions




red line:solution = candidate tau direction

use these information to look at tau polarimeter.

# Various levels of "cheating".

3-levels of cheating

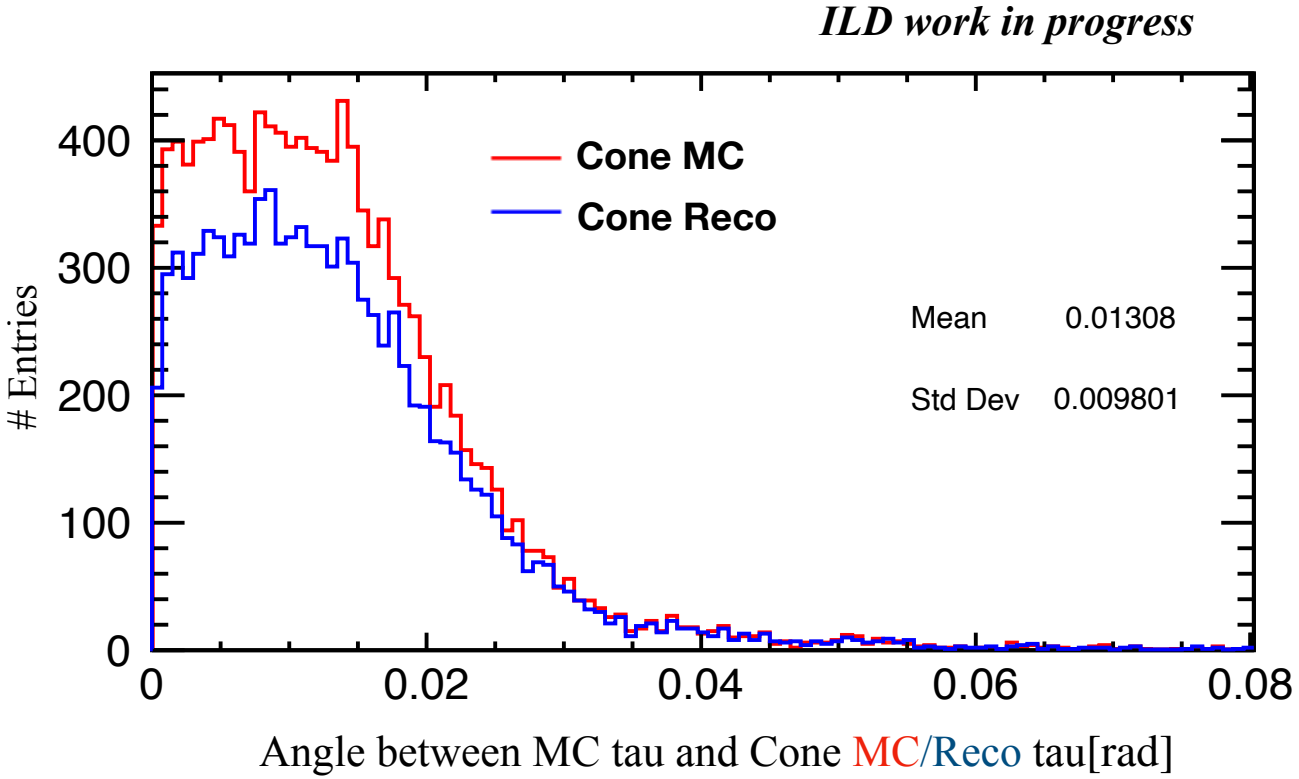
1. Using true neutrino momentum from MC.
2. "Cone method" using MC.

   using true MC visible tau daughters.
3. "Cone method" using reconstructed particle (MC linked).

   using MC linked reconstructed tau daughters.

# Angle between MC $\tau$ and Reco $\tau$

First look at angle between MC tau direction and reconstructed tau direction.



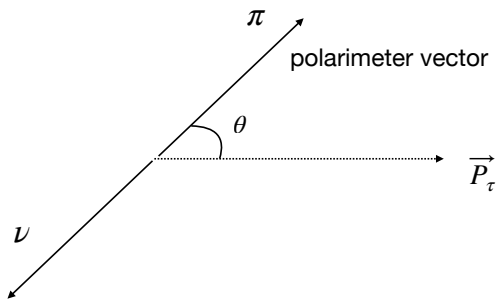

Both angles are about $\sim 0.013$ [rad] $= 0.74$ deg.
Reconstructed $\tau$ is close to MC $\tau$ direction.

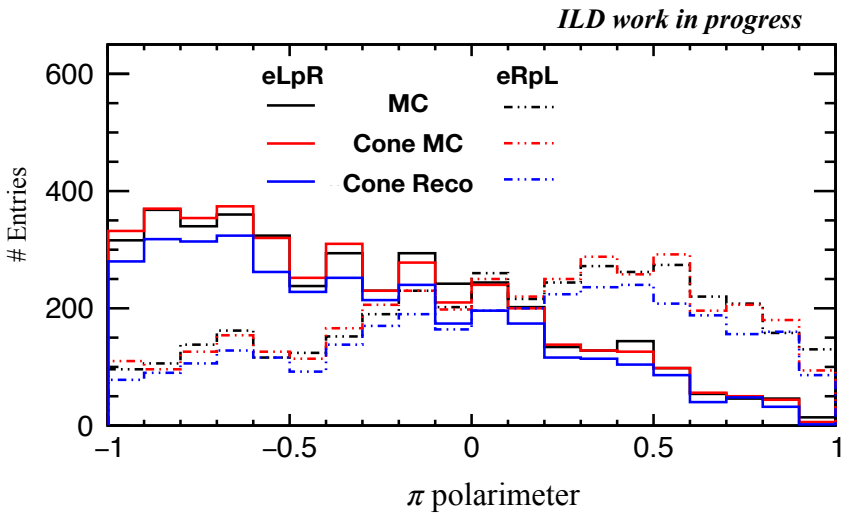
# Polarimeter:single pi decay

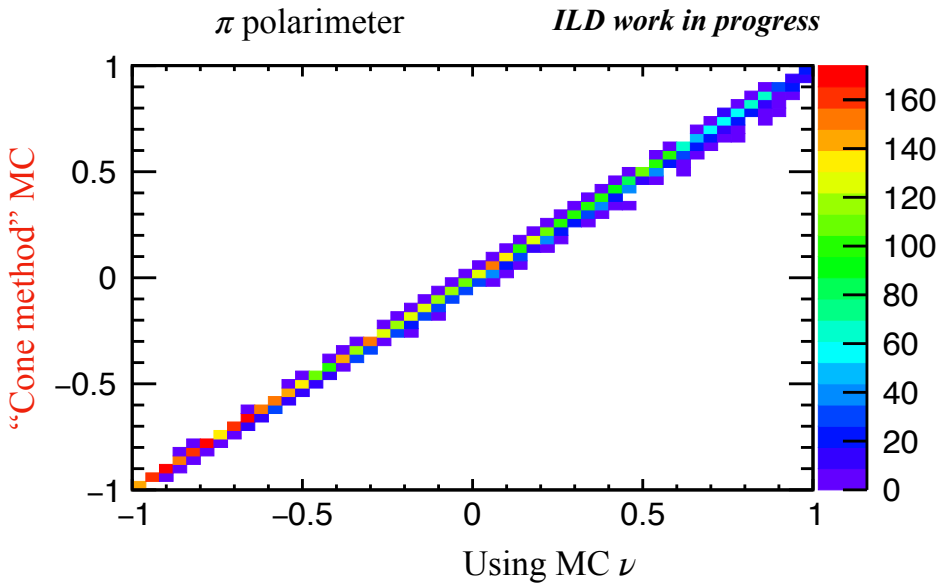
Polarimeter vectors in $\tau$ rest frame.

$\boldsymbol{h}(\tau^{\pm} \to \pi^{\pm}\nu) \propto \boldsymbol{p}_{\boldsymbol{\pi}}\pm$

polarimeter $= \cos\theta$



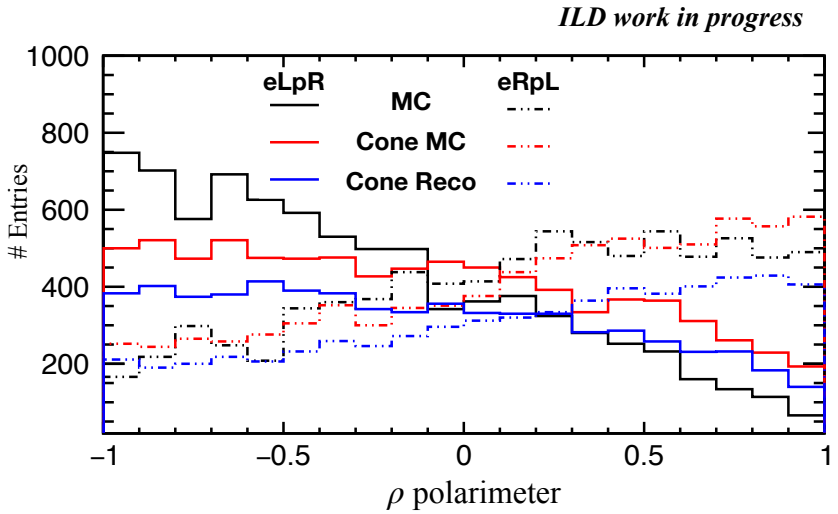

Polarimeter using reconstructed $\nu$ information is good agreement with MC one.

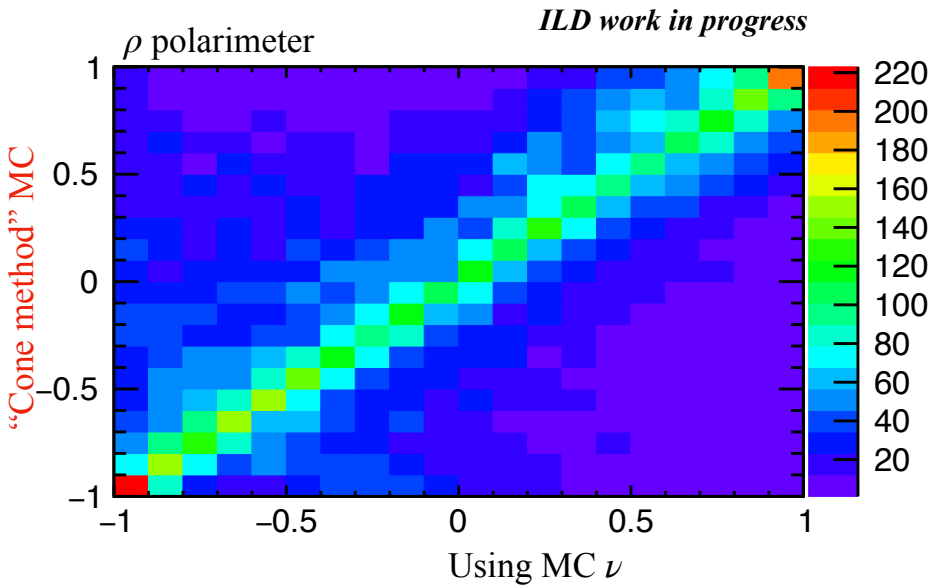
# Polarimeter:rho decay

Polarimeter vectors in $\tau$ rest frame.

$\boldsymbol{h}(\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu) \propto m_{\tau}(E_{\pi^{\pm}} - E_{\pi^{0}})(\boldsymbol{p_{\pi^{\pm}}} - \boldsymbol{p_{\pi^{0}}}) + \frac{1}{2}(p_{\pi^{\pm}} + p_{\pi^{0}})^{2}\boldsymbol{p_{\nu}}$

polarimeter $= \cos\theta$

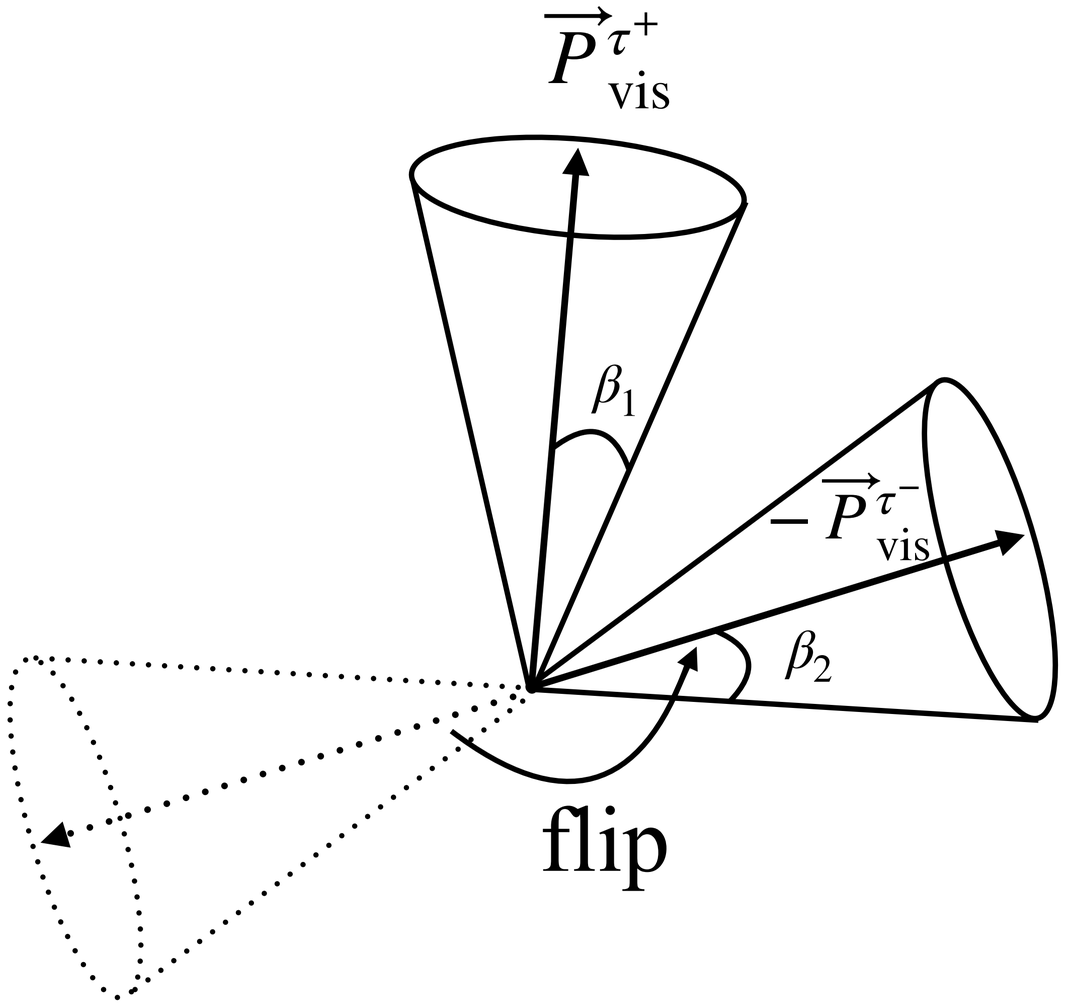


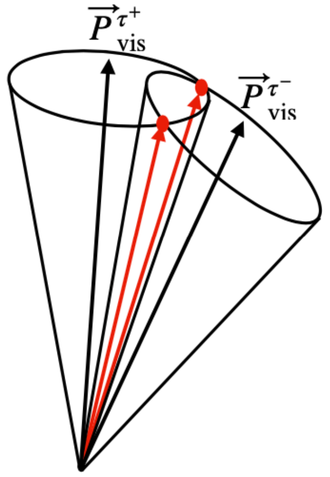

Polarimeter using reconstructed $\nu$ information sometimes far from MC one.

need further study to understand the reason.

“cone method” to reconstruct tau

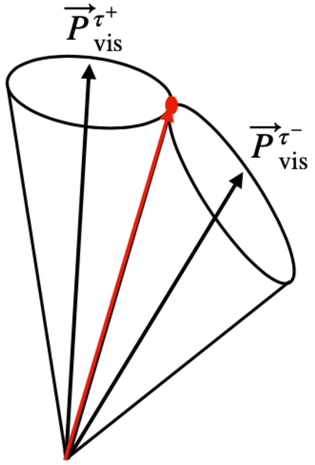



$\beta_1 + \beta_2 > \beta_{cc}$



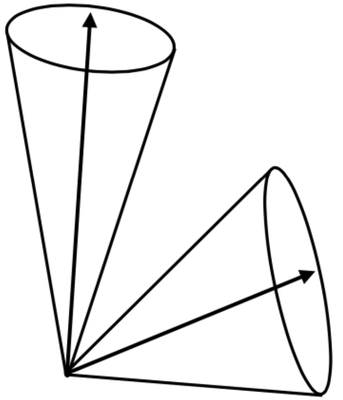

2 possible solutions

$\beta_1 + \beta_2 = \beta_{cc}$




1 possible solution

$\beta_1 + \beta_2 < \beta_{cc}$

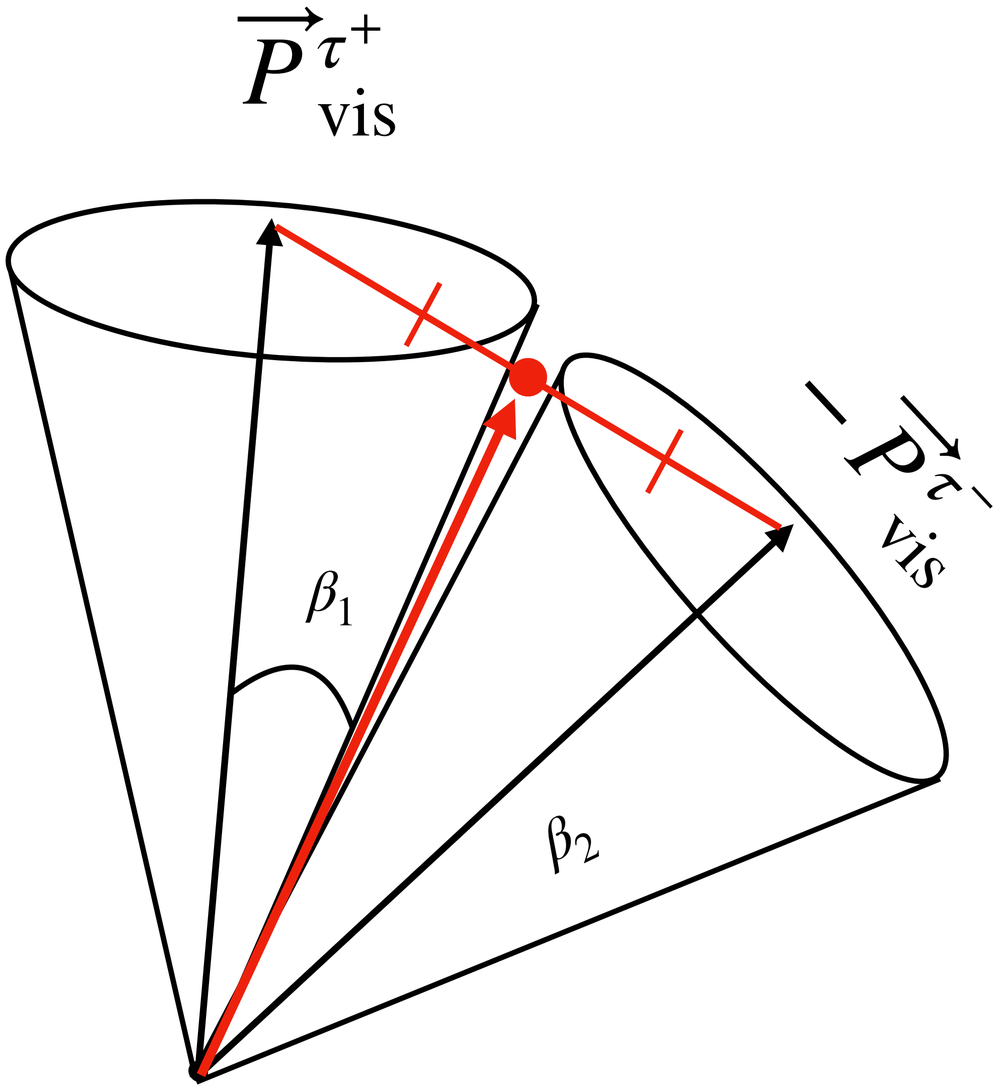


NO solutions

red line:solution = candidate tau direction

but sometimes 1 or 2 solutions can be NO solution depending on the detector resolution

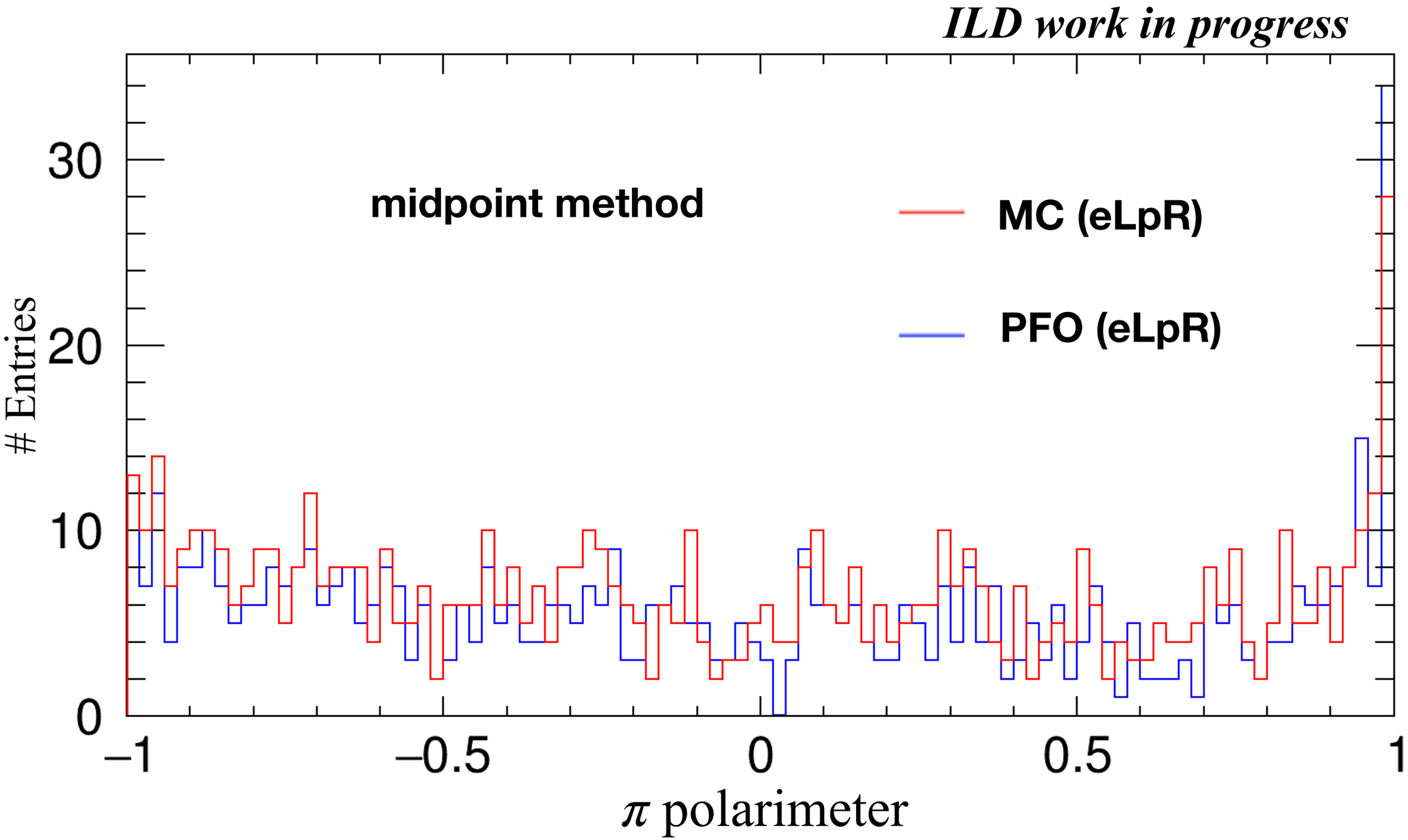
“midpoint method”




sometimes 1 or 2 solutions can be NO solution
depending on the detector resolution

→ take a midpoint of them
and use this new vector as a solution

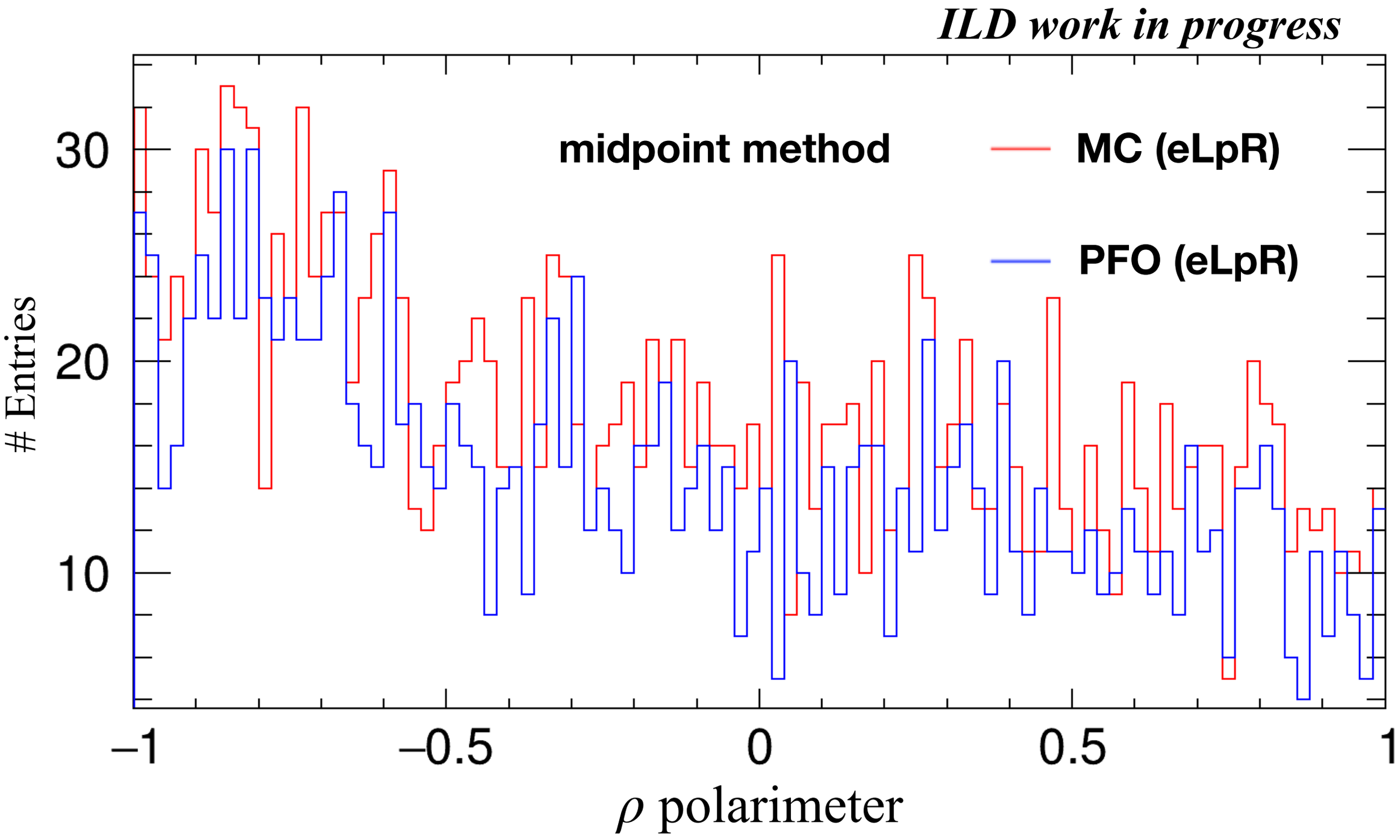
# Polarimeter: pi decay




there are few difference between MC and PFO

however, distribution is strange

# Polarimeter: rho decay



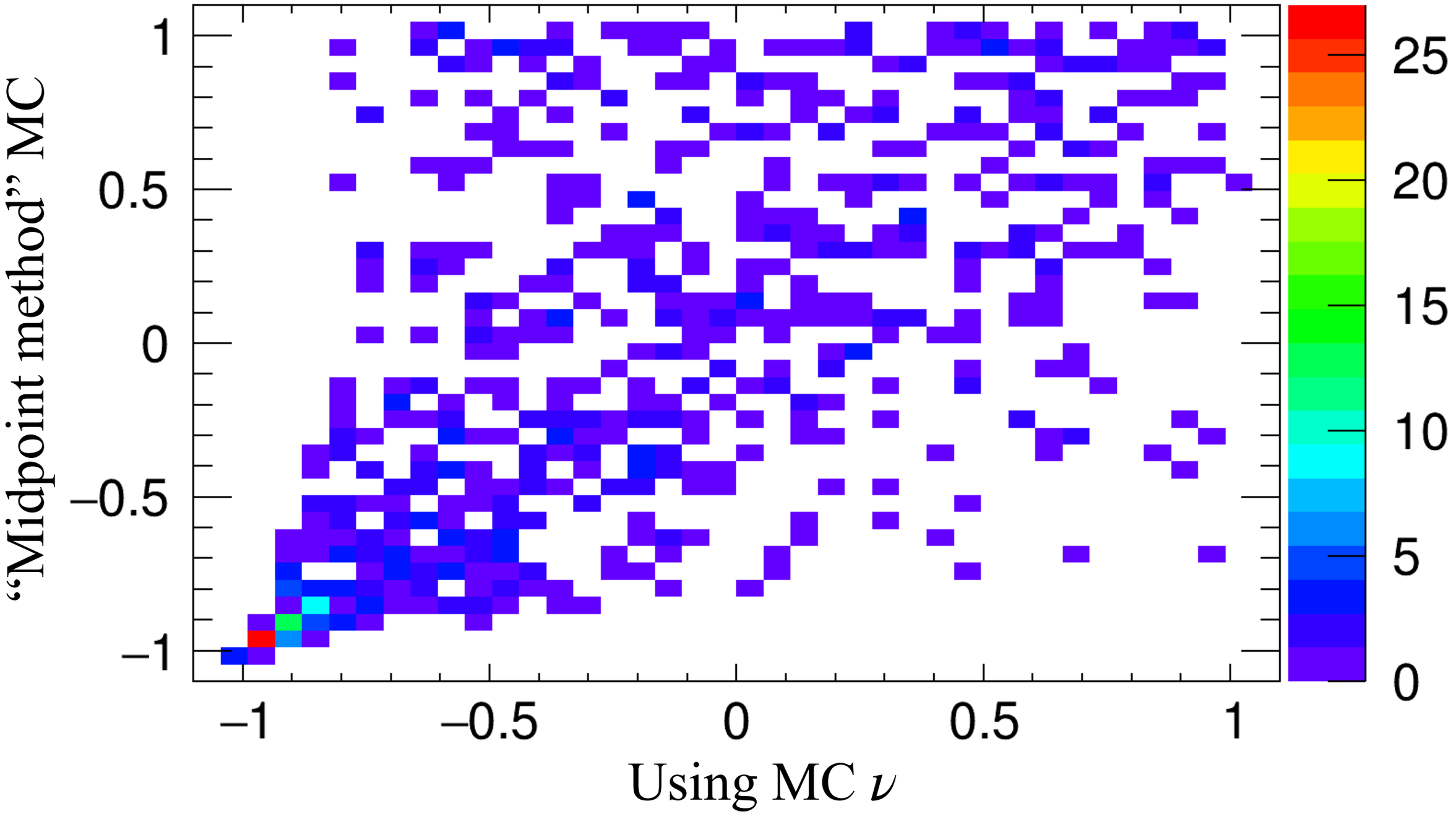

there are few difference between MC and PFO

however, they are not triangle shape

# Polarimeter: pi decay

$\pi$ polarimeter

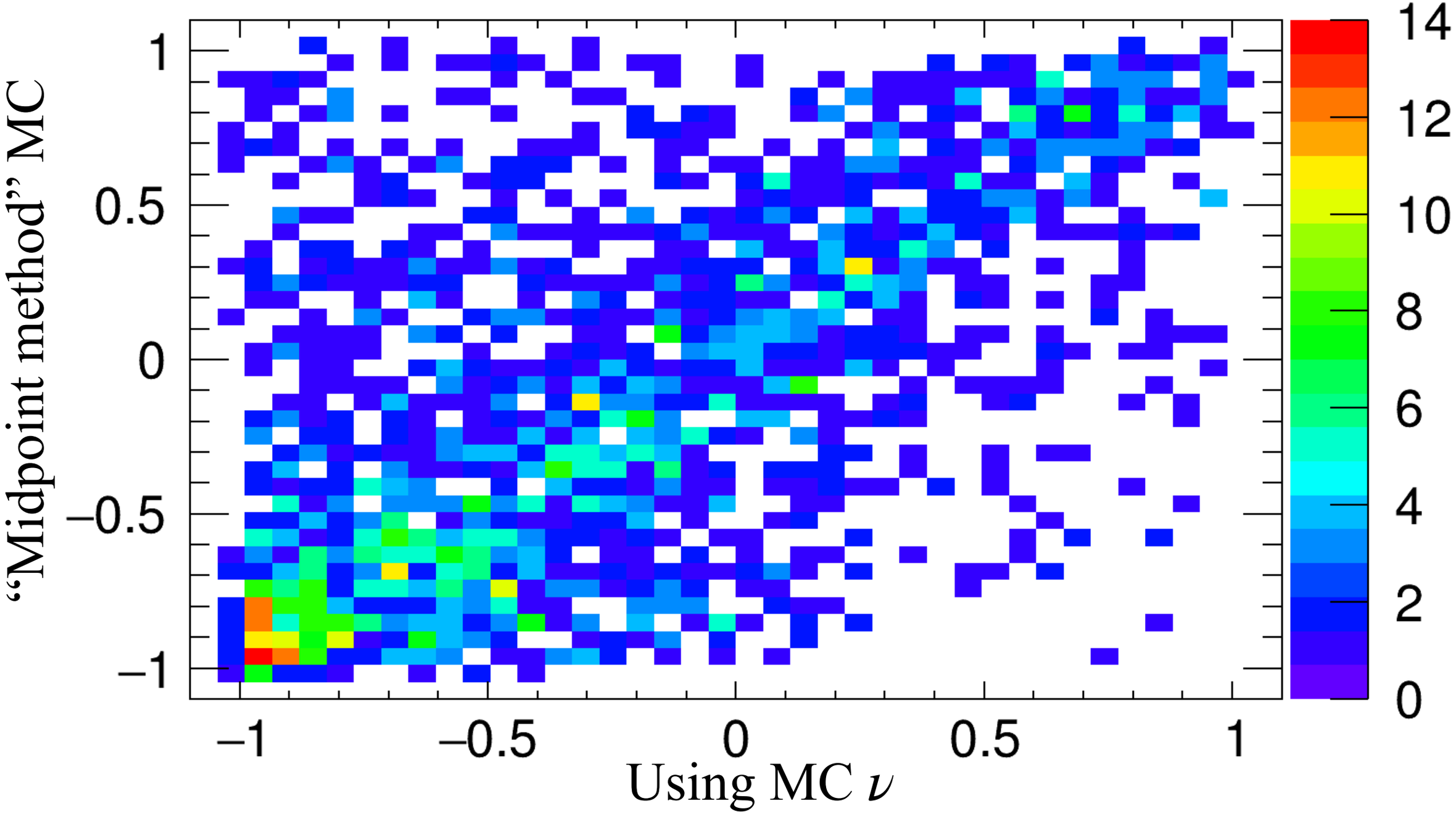
***ILD work in progress***



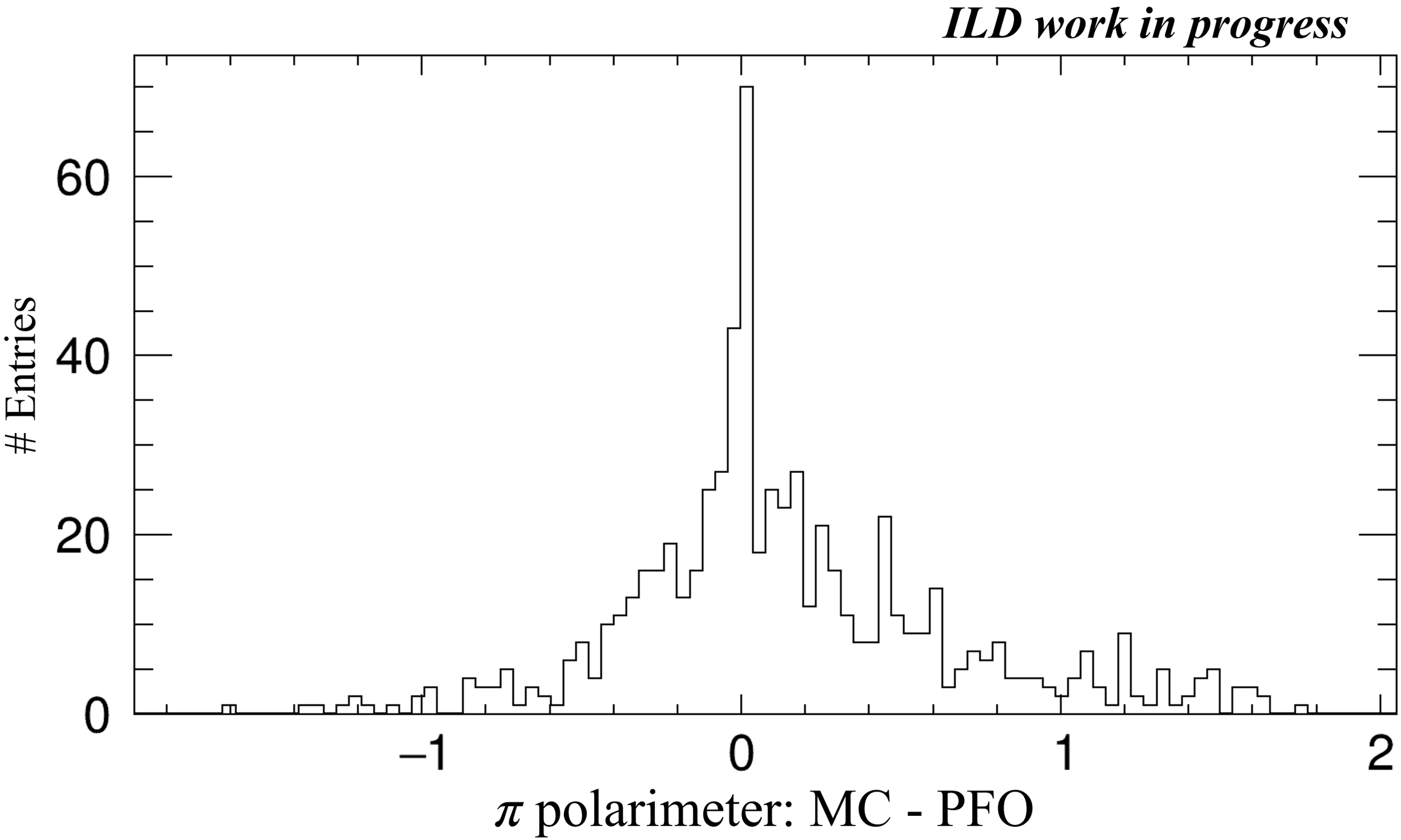
# Polarimeter: rho decay

$\rho$ polarimeter

***ILD work in progress***

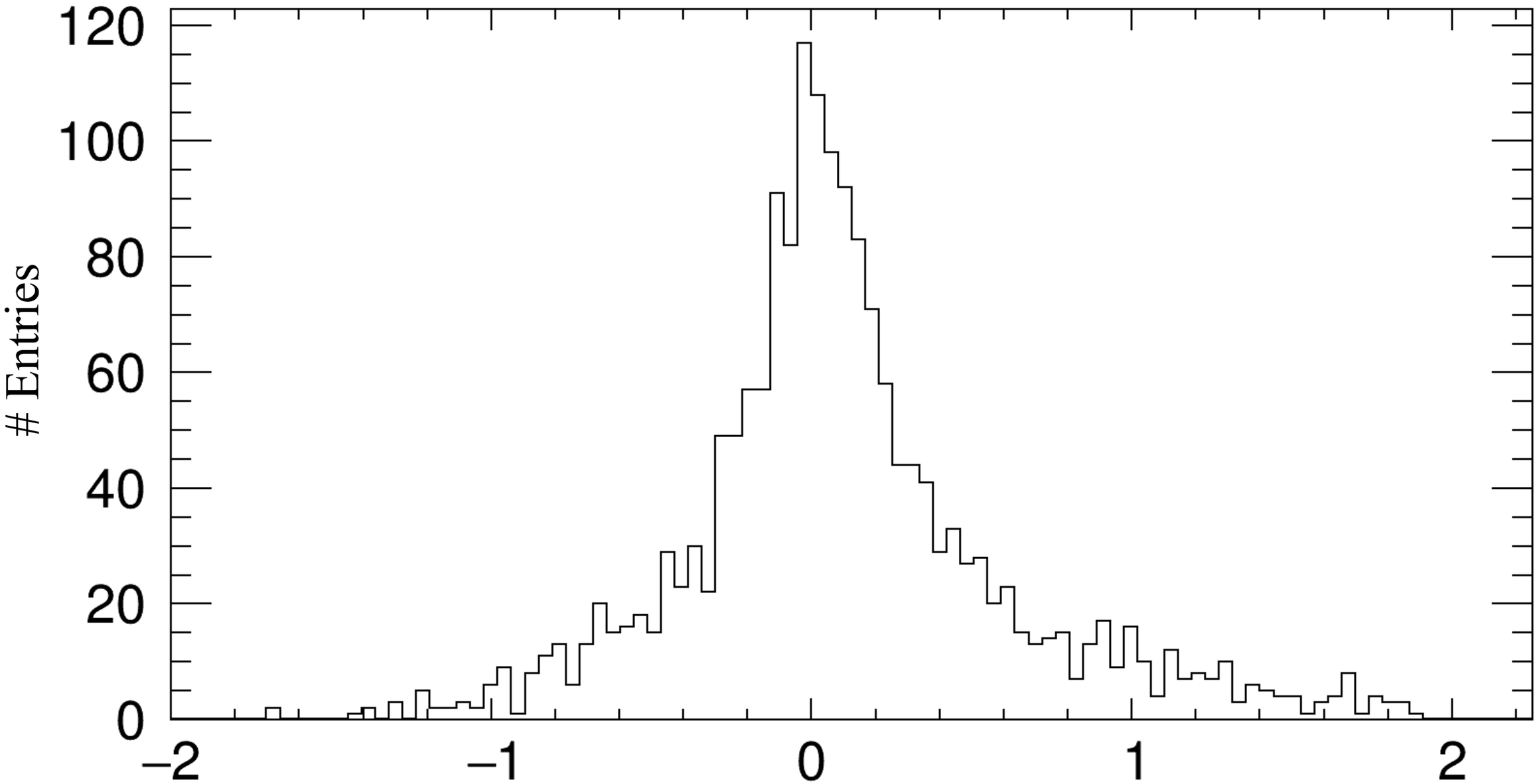


# Polarimeter: pi decay

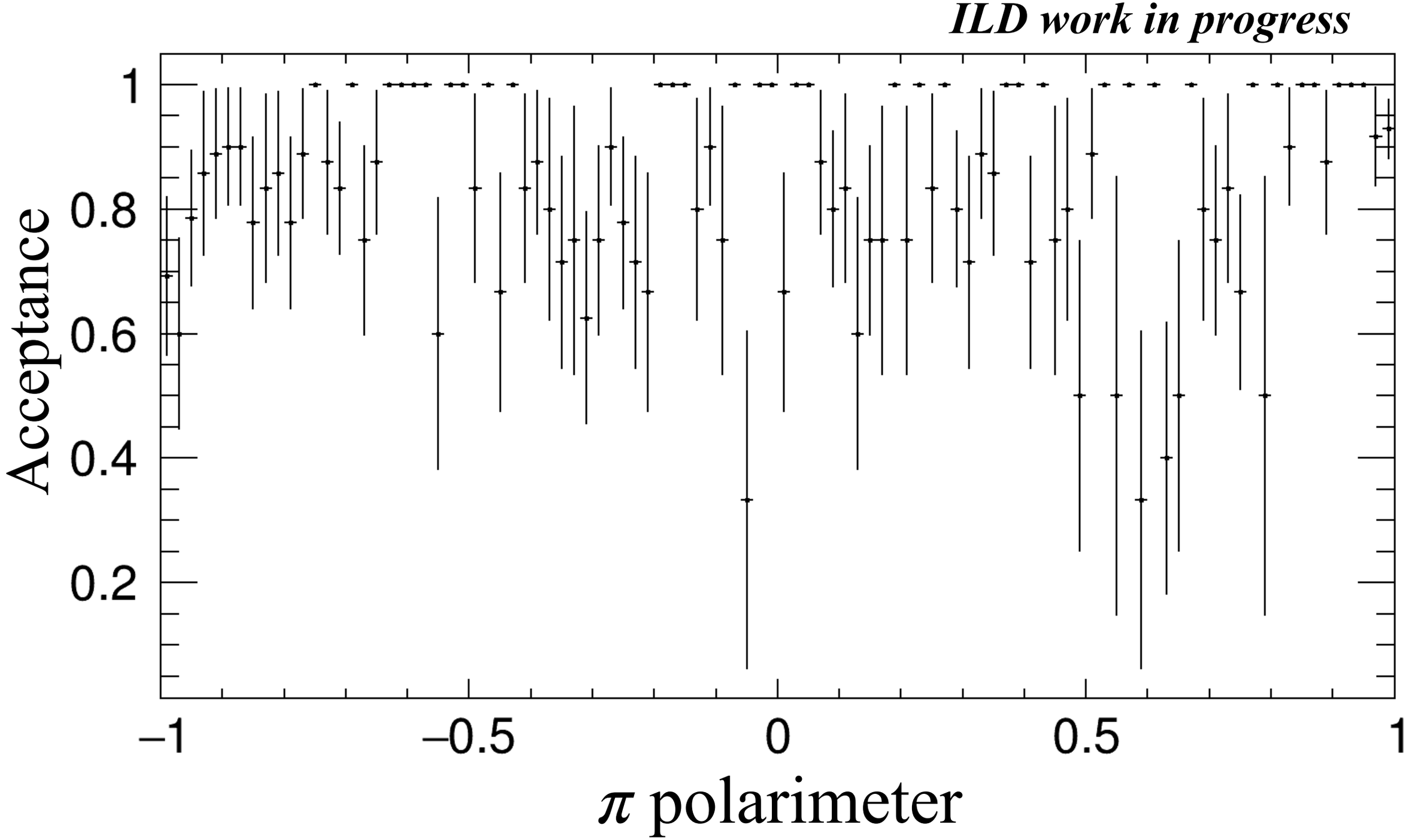


# Polarimeter: rho decay

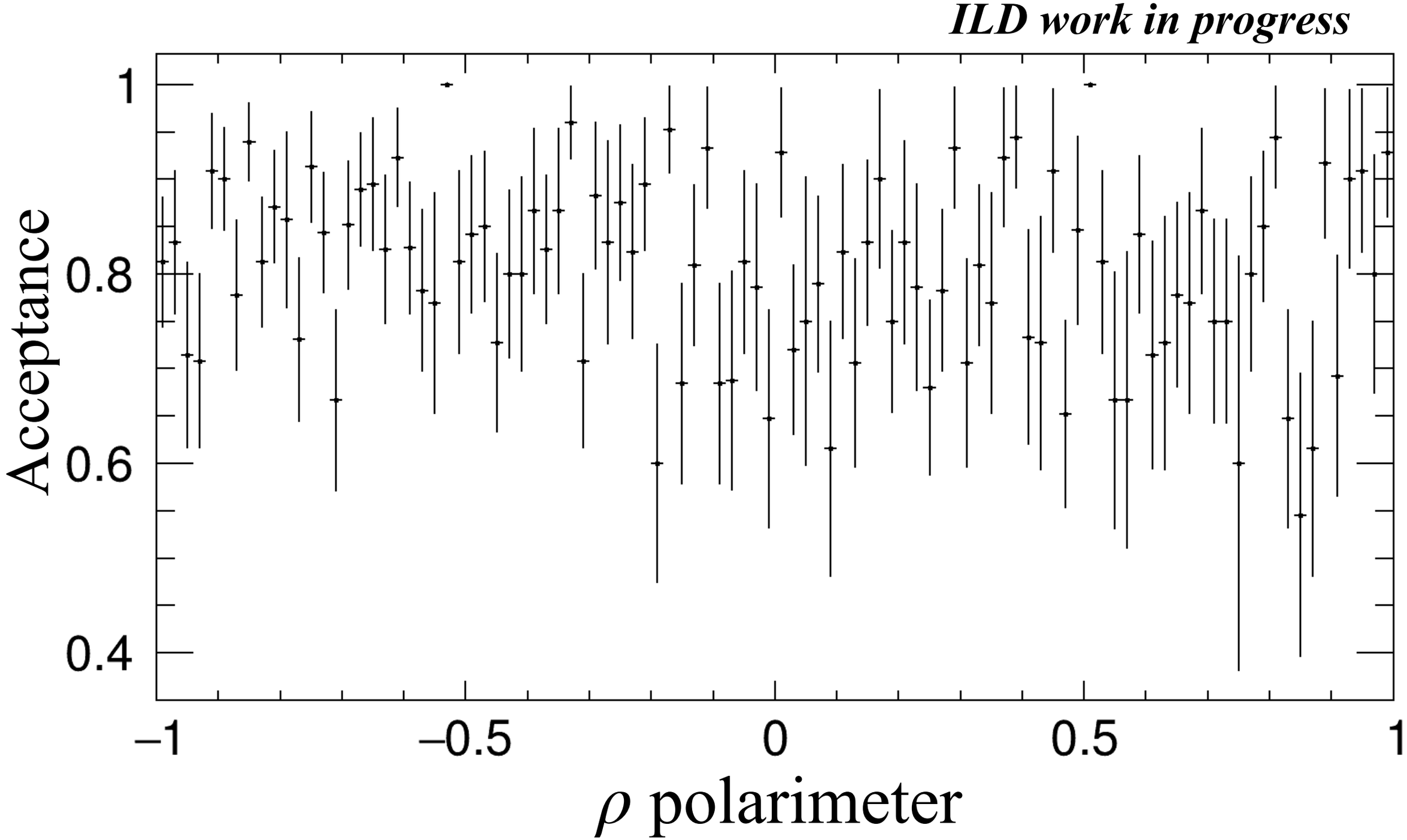
***ILD work in progress***



# Acceptance function: pi decay



# Acceptance function: rho decay



# Summary and Future plan

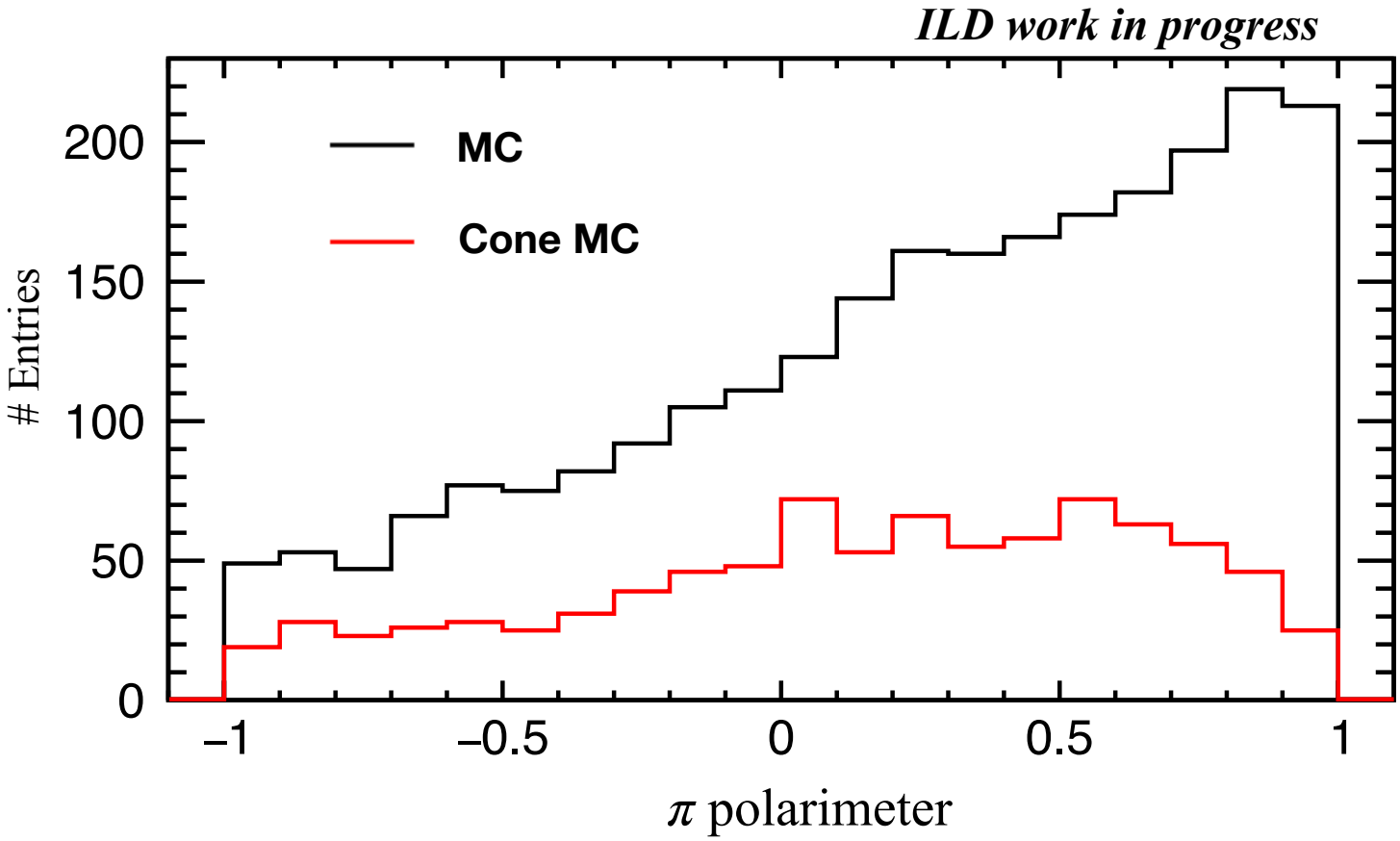
Summary

- The reconstruction of neutrino momentum in $\tau - \tau$ event at ILC-250 was investigated
- "Cone method" works well so far for $\tau \to \pi\nu$.
- Reasonable agreement between MC truth polarimeter value and the one from the cone method for $\pi\nu$ decay were found.
- In the case of $\tau \to \rho\nu$ decay, some improvements are required.

Future Plan

- ♢ Investigate the power of searching for new physics by using the tau polarisation.
- ♢ Apply method to radiative return events with visible photon.
- ♢ Also use impact parameter information for tau reconstruction.

# backup




in the region of polarimeter $= 1$, cone size will be small and less likely to find solutions.

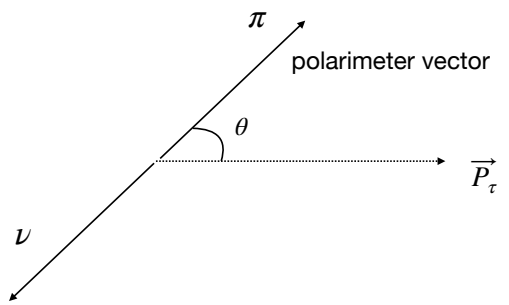
need to investigate the reason properly.

# Polarimeter:single pi decay

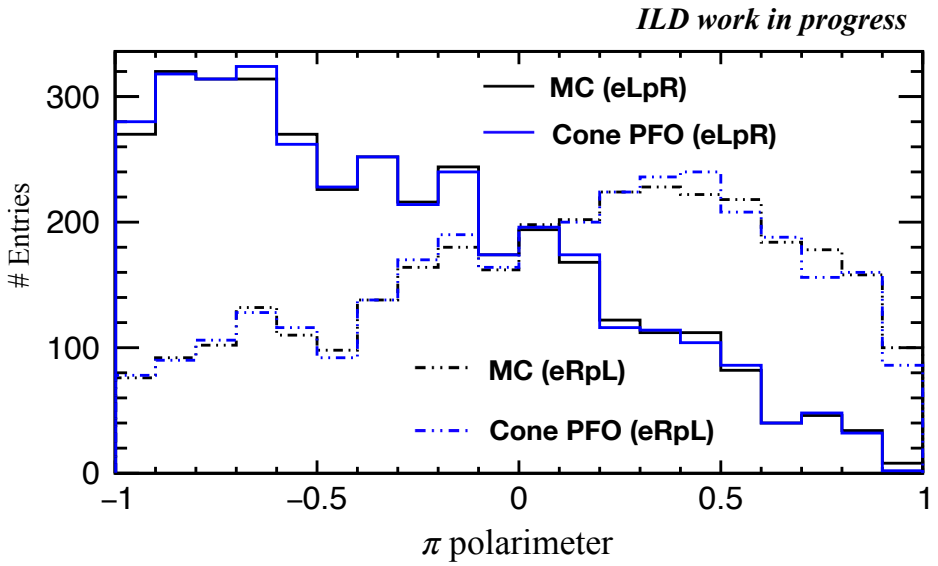
Polarimeter vectors in $\tau$ rest frame.

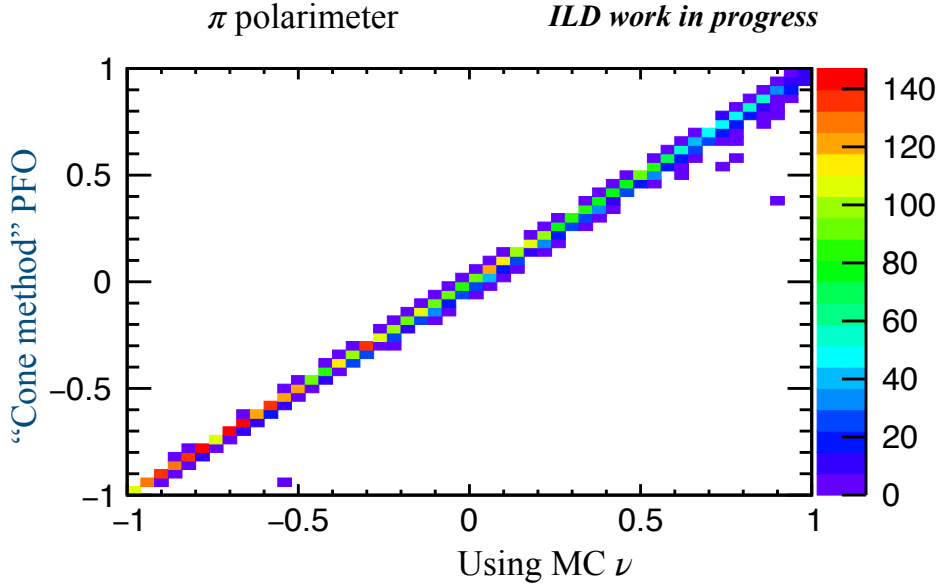
$\boldsymbol{h}(\tau^{\pm} \to \pi^{\pm}\nu) \propto \boldsymbol{p}_{\boldsymbol{\pi}}\pm$

polarimeter $= \cos\theta$




$\pi$ polarimeter



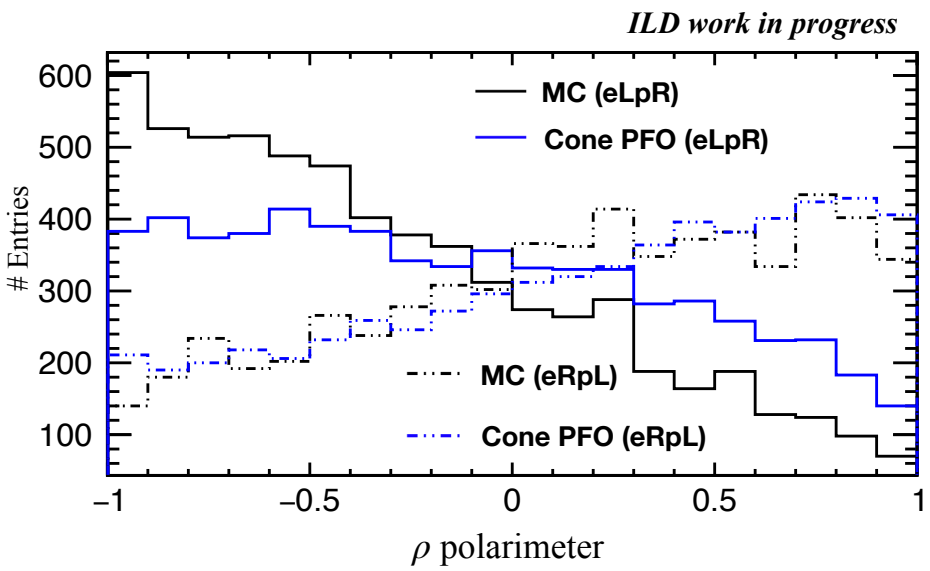

Polarimeter: "Cone method" is roughly good agreement with MC one.

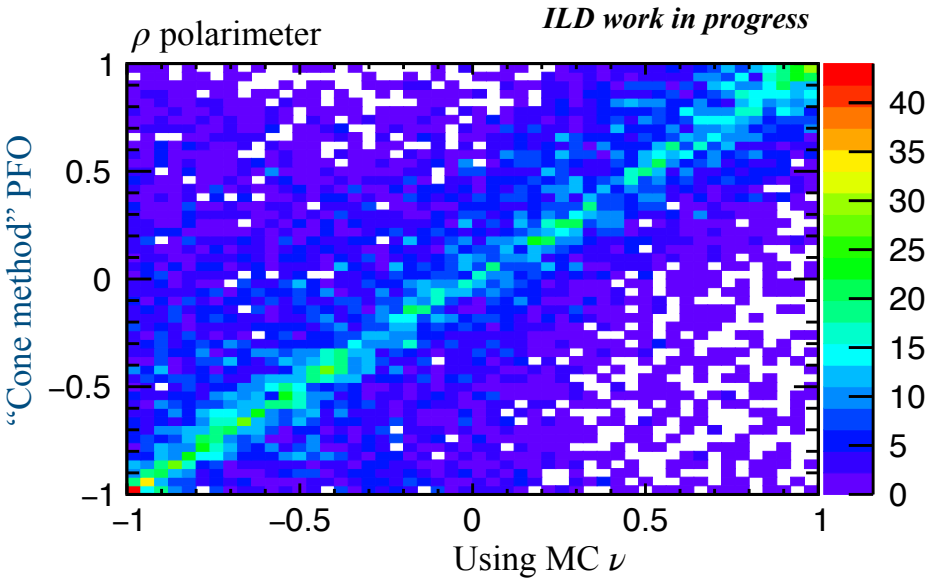
# Polarimeter:rho decay

Polarimeter vectors in $\tau$ rest frame.

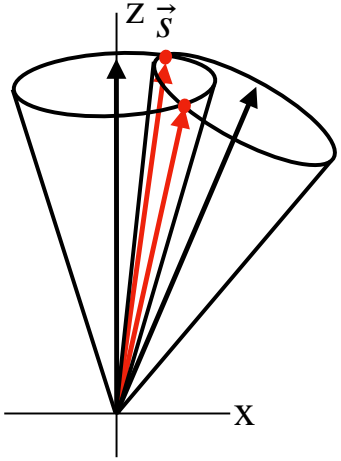
$\boldsymbol{h}(\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu) \propto m_{\tau}(E_{\pi^{\pm}} - E_{\pi^{0}})(\boldsymbol{p_{\pi^{\pm}}} - \boldsymbol{p_{\pi^{0}}}) + \frac{1}{2}(p_{\pi^{\pm}} + p_{\pi^{0}})^{2}\boldsymbol{p_{\nu}}$

polarimeter $= \cos\theta$

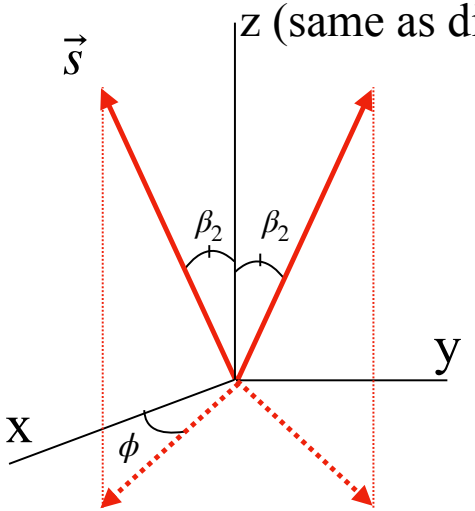


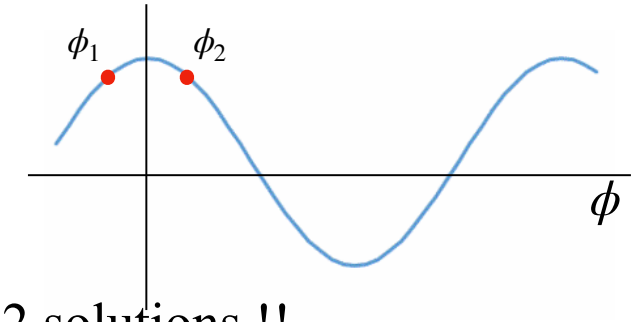

Polarimeter: "Cone method" using reconstructed $\nu$ needs to be improved.




$\vec{s}$ :possible tau direction




$$\cos\phi = \frac{(1-\cos\theta_{cc})\cos_{\beta_1}}{\sin\beta_2 \sin\theta_{cc}}$$




2 solutions !!