

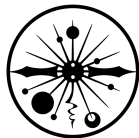
Tau reconstruction in $e^+e^- \rightarrow \tau^+\tau^-$ at the ILC250

Keita Yumino*† Daniel Jeans†

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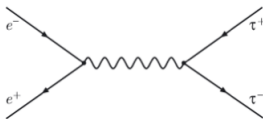
†IPNS, KEK

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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

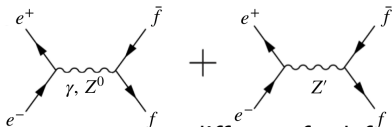


with its rather short lifetime allows reconstruction of its spin direction by the distribution of its decay products.

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_τ 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 α, β : coefficients predicted by SM.

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

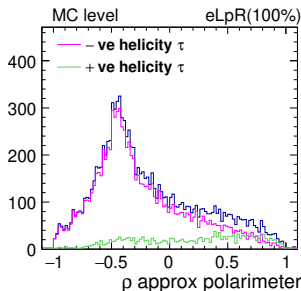
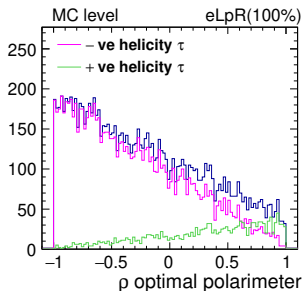
The aim of this study is reconstruction of tau spin in order to measure polarisation to investigate new physics.

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”.



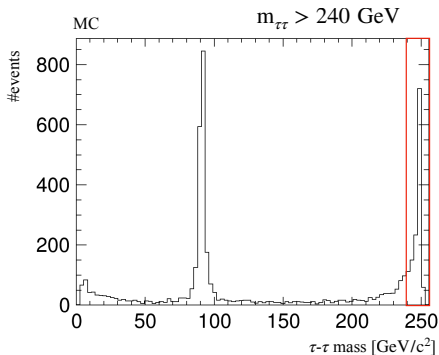
In today's talk,

we explicitly extract neutrino momentum to calculate optimal polarimeters.

arXiv:1912.08403

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.



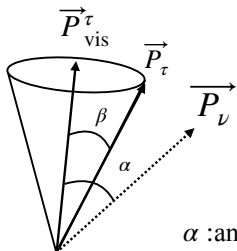
For now

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

How to extract ν momentum

Assume

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



\vec{P}_{vis}^τ : tau visible daughter momentum

\vec{P}_ν : neutrino momentum

\vec{P}_τ : tau momentum

α : angle between tau visible daughter and neutrino

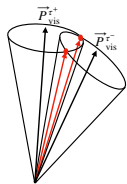
β : angle between tau visible daughter and tau

Angle α, β can be calculated from these assumption.

Find solutions

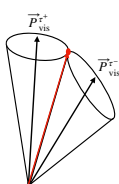
If at least one intersection point was found, there is a solution.

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



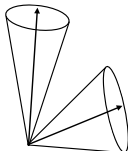
2 possible solutions

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

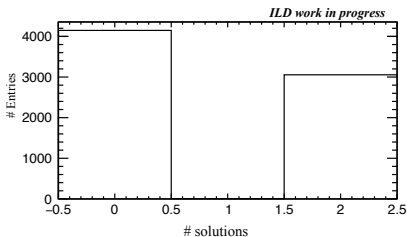


1 possible solution

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



NO solutions



red line: solution = candidate tau direction

use these information to look at tau polarimeter.

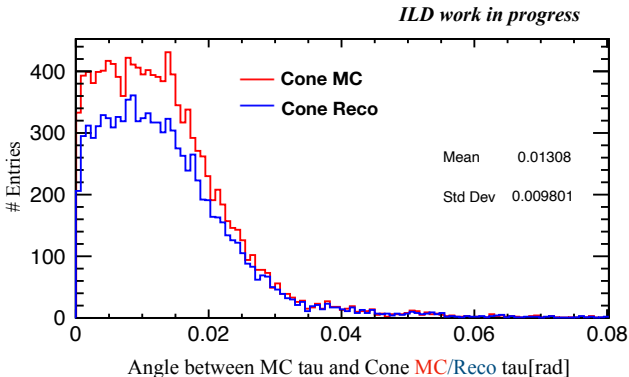
Various levels of “cheating”.

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 τ and Reco τ

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



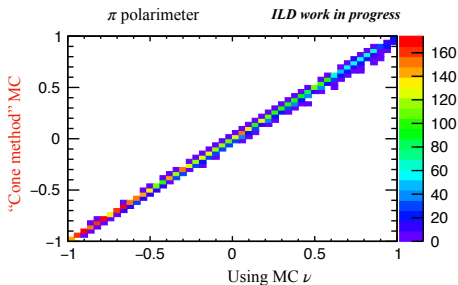
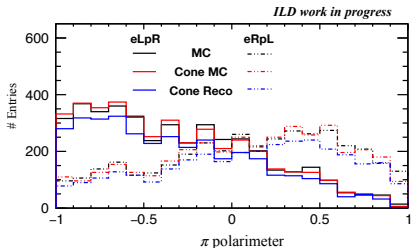
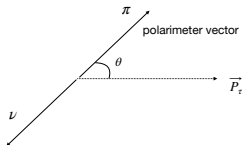
Both angles are about ~ 0.013 [rad] = 0.74 deg.
Reconstructed τ is close to MC τ direction.

Polarimeter:single pi decay

Polarimeter vectors in τ rest frame.

$$h(\tau^\pm \rightarrow \pi^\pm \nu) \propto \mathbf{p}_{\pi^\pm}$$

$$\text{polarimeter} = \cos \theta$$



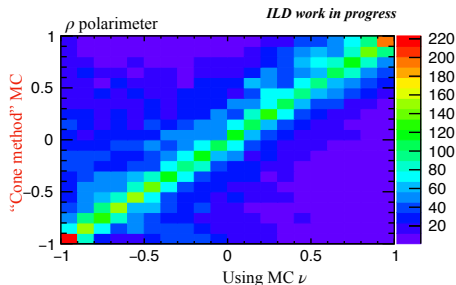
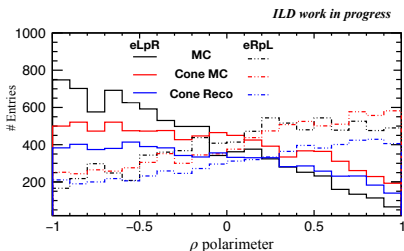
Polarimeter using reconstructed ν information is good agreement with MC one.

Polarimeter:rho decay

Polarimeter vectors in τ rest frame.

$$\mathbf{h}(\tau^\pm \rightarrow \pi^\pm \pi^0 \nu) \propto m_\tau (E_{\pi^\pm} - E_{\pi^0}) (\mathbf{p}_{\pi^\pm} - \mathbf{p}_{\pi^0}) + \frac{1}{2} (p_{\pi^\pm} + p_{\pi^0})^2 \mathbf{p}_\nu$$

polarimeter = $\cos \theta$



Polarimeter using reconstructed ν information sometimes far from MC one.

need further study to understand the reason.

Summary and Future plan

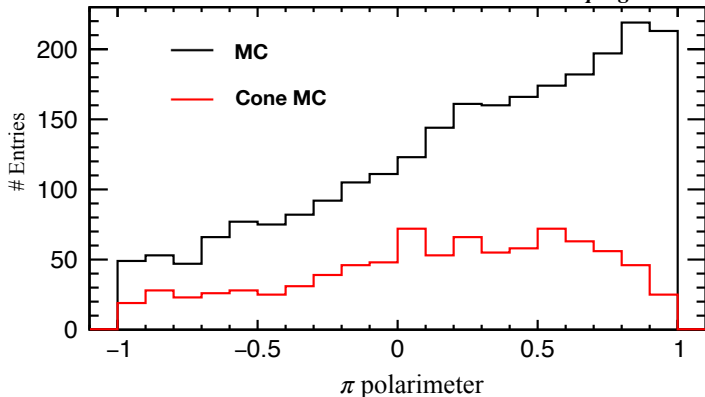
Summary

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



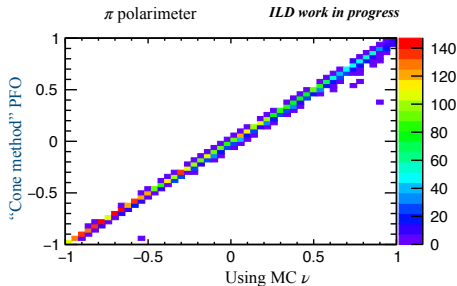
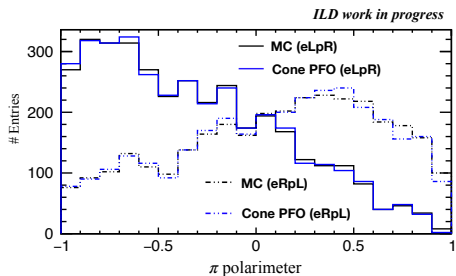
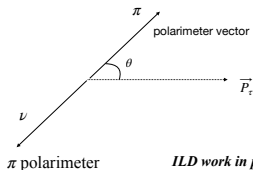
in the region of polarimeter = 1, cone size will be small and less likely to find solutions.
need to investigate the reason properly.

Polarimeter:single pi decay

Polarimeter vectors in τ rest frame.

$$h(\tau^\pm \rightarrow \pi^\pm \nu) \propto \mathbf{p}_{\pi^\pm}$$

$$\text{polarimeter} = \cos \theta$$



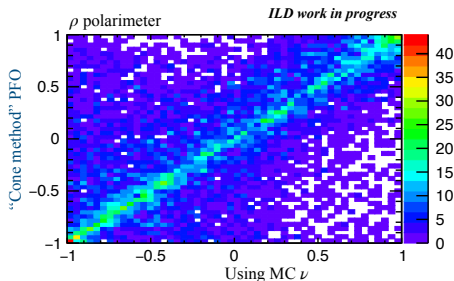
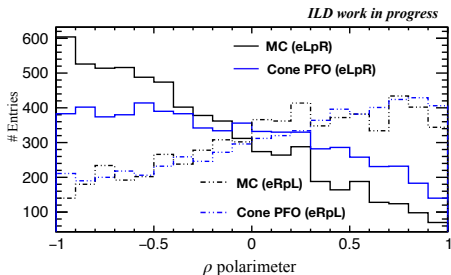
Polarimeter: "Cone method" is roughly good agreement with MC one.

Polarimeter: rho decay

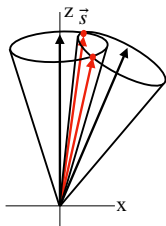
Polarimeter vectors in τ rest frame.

$$\mathbf{h}(\tau^\pm \rightarrow \pi^\pm \pi^0 \nu) \propto m_\tau (E_{\pi^\pm} - E_{\pi^0}) (\mathbf{p}_{\pi^\pm} - \mathbf{p}_{\pi^0}) + \frac{1}{2} (p_{\pi^\pm} + p_{\pi^0})^2 \mathbf{p}_\nu$$

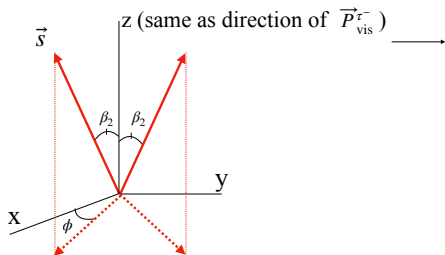
polarimeter = $\cos \theta$



Polarimeter: "Cone method" using reconstructed ν needs to be improved.



\vec{s} : possible tau direction



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

