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

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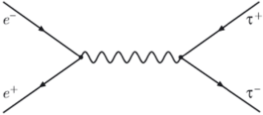
Introduction

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

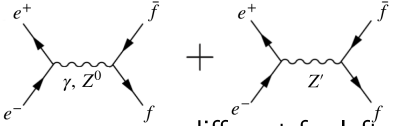


with its rather short lifetime $(2.9 \times 10^{-13}\ \mathrm{sec})$ allows reconstruction of its spin direction by the distribution of its decay products.

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'

we can also directly measure A_τ by using tau polarisation $P(\tau)$

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

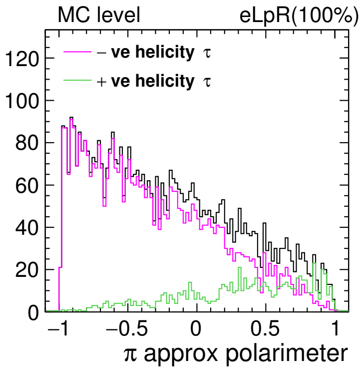
where α, β: coefficients predicted by SM.

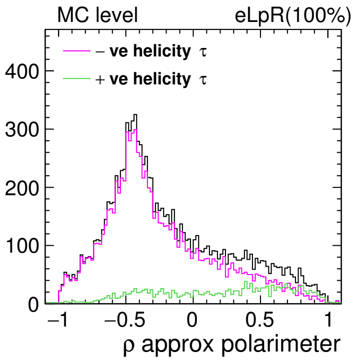
this polarisation of tau $P(\tau)$ depends on tau decay mode.

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

Previous study:look at polarimeter without using neutrino information

"Approximate" polarimeters which are reconstructed based only on the momenta of visible tau decay products.



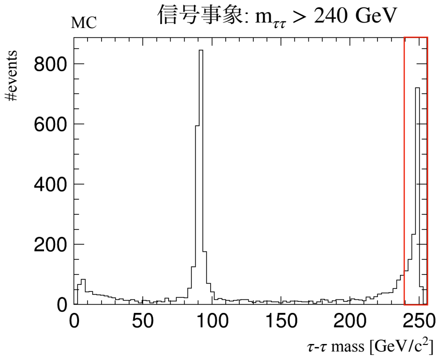


arXiv:1912.08403

In today's talk, we explicitely extract neutrino momentum and look at 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
- Full simulation of ILD detector based on Geant4 and realistic reconstruction were performed.

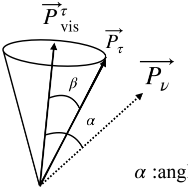


- ◇ only look at $\tau \to \pi\nu$ and $\tau \to \rho\nu$
- ◇ $m_{\tau\tau} > 240$ GeV

τ reconstruction method

we assume

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



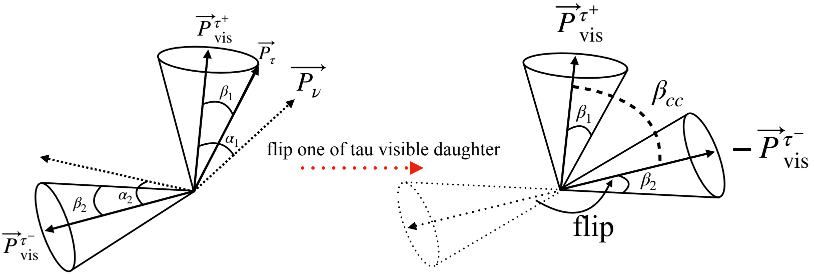
$\vec{P}^{\tau}_{\text{vis}}$: tau visible daughter momentum

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

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

α :angle between tau visible daughter and neutrino

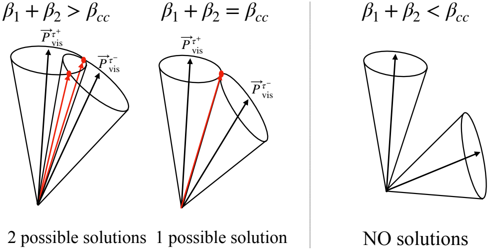
β :angle between tau visible daughter and tau

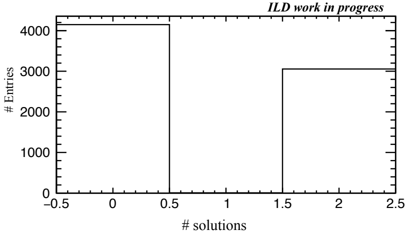


β_{cc} :cone-cone angle

Find solutions

Look at angle between tau visible daughter and candidate solution.
If at least one intersection point was found, there is a solution.





red line:solution = candidate tau direction

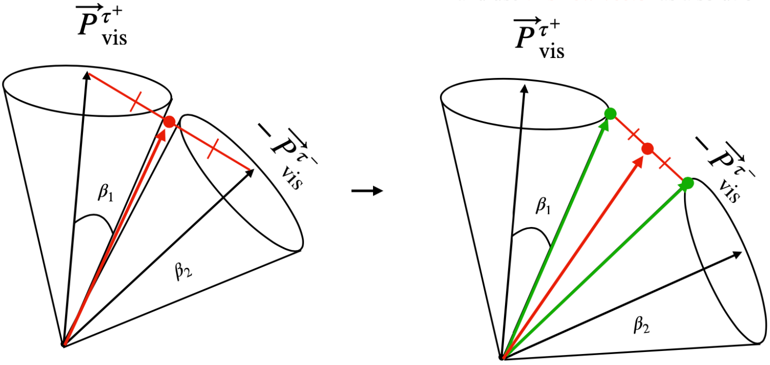
use these information to look at tau polarimeter.

Midpoint method

"Midpoint method"

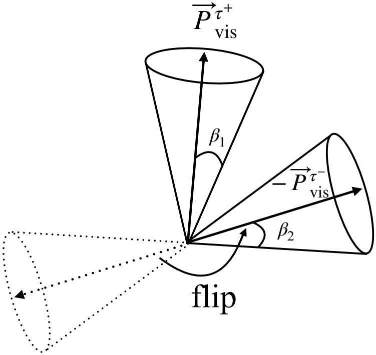
take a midpoint of visible daughters

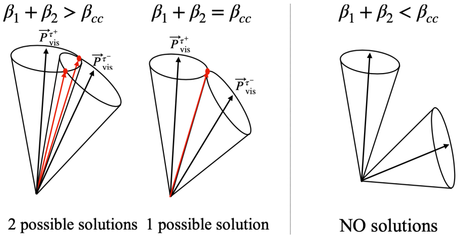
take a midpoint of cone surface
and use this new vector as a solution



Find solutions

"cone method" to reconstruct tau

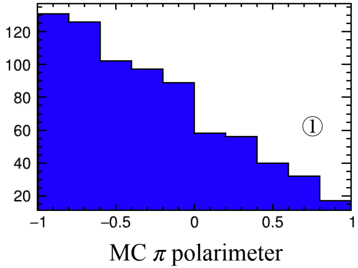


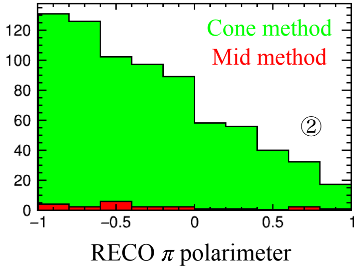


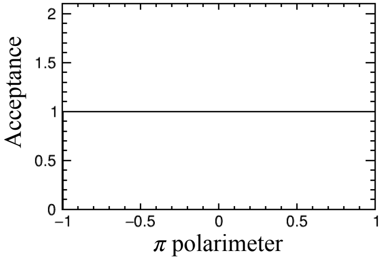
"cone method"

"Midpoint method"

Definition of acceptance function







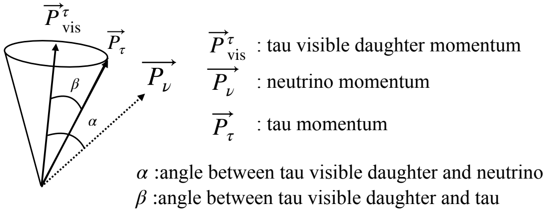
Acceptance function

$$\frac{\text{② histogram of RECO polarimeter}}{\text{① histogram of MC polarimeter}}$$

Cone method in ideal state

we assume

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

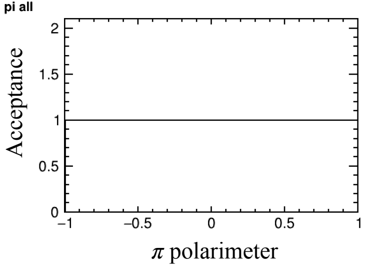


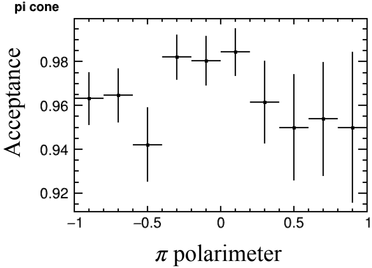
Check whether our “Cone method” is correct in the state which it should work or not.

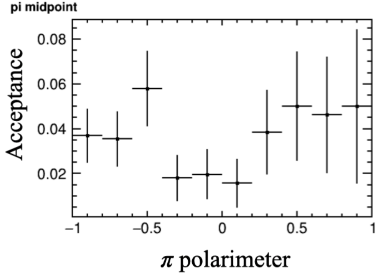
Generate events with (no ISR && no beam energy spread).

Cone method in ideal case

No FSR, single pion decay

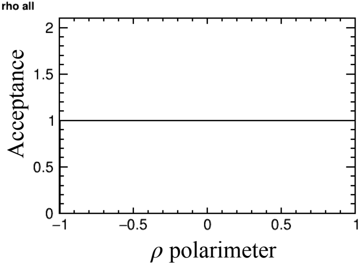


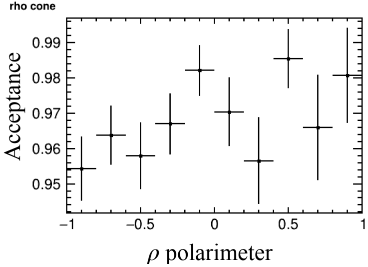


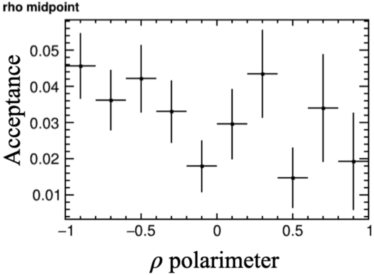


Cone method in ideal case

No FSR, rho decay

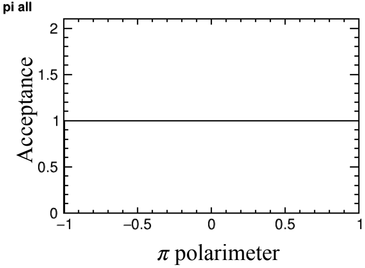


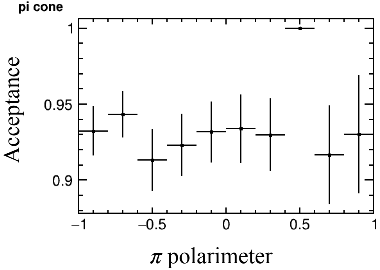


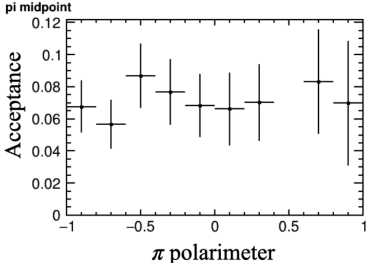


Cone method in ideal case

Include FSR, single pion decay

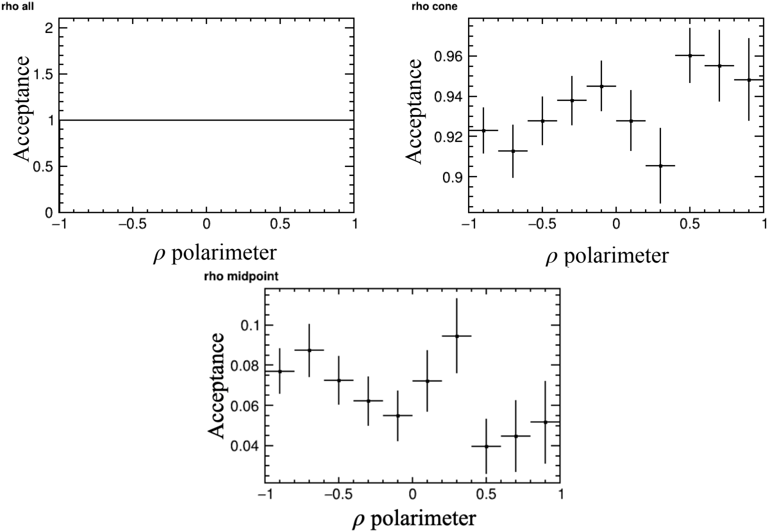






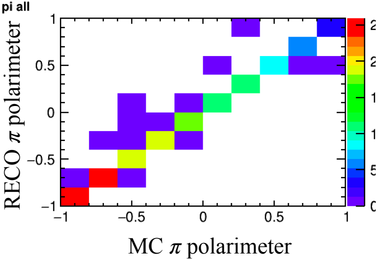
Cone method in ideal case

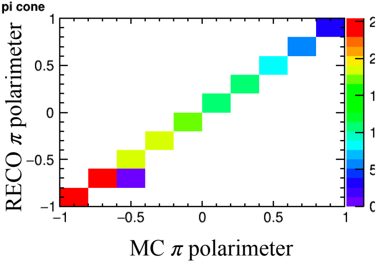
Include FSR, rho decay

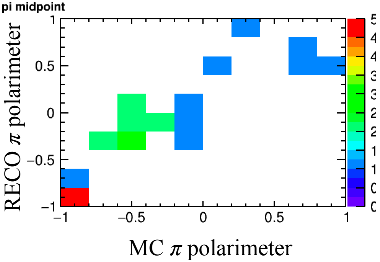


Cone method in ideal case

No FSR, single pion decay

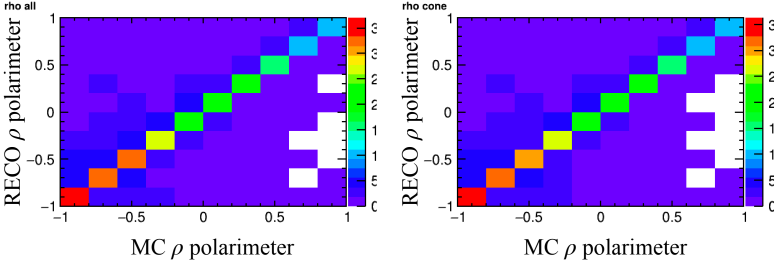


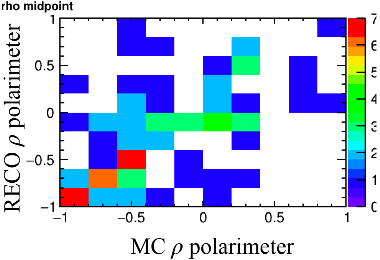




Cone method in ideal case

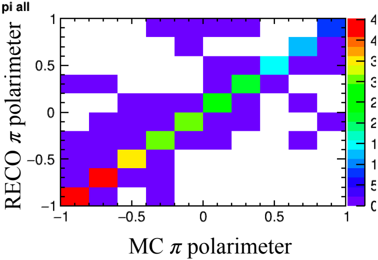
No FSR, rho decay

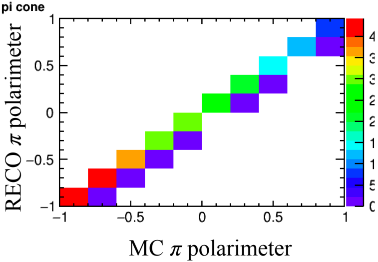


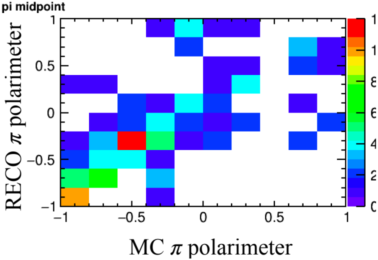


Cone method in ideal case

Include FSR, single pion decay

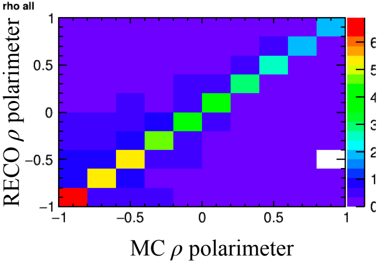


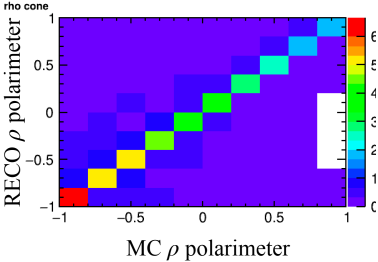


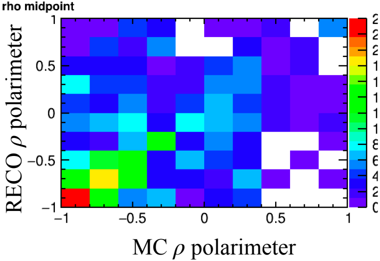


Cone method in ideal case

Include FSR, rho decay

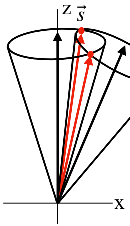




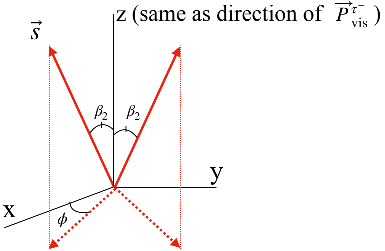


Summary

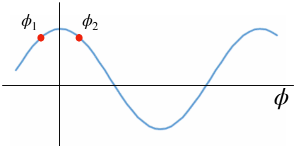
- In the event that ISR and beam energy spread are removed, the Cone method can find the solution with almost 100% probability. (It is not 100% due to the effect of numerical precision.)
- If there is an FSR photon, tau-tau is no longer back-to-back, and the "Cone method" may not be able to find a solution.
- Midpoint method can find the solution if Cone method is failed, however for now the polarimeter reconstructed using the solution found by the Midpoint method is not very accurate.
- Since Impact parameter does not assume that tau-tau is back-to-back (back-to-back in x-y plane), it could be improved by using Impact parameter.



$\vec{s}$:possible tau direction



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



2 solutions !!