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

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Motivation 1

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

Left- and right-handed coupling g_R, g_L to Z boson are different

⇒Left- and right-handed polarisation asymmetry is expected.

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

Thanks to ILC's polarised beams, A_e can be measured

⇒ A_f can be extracted from A_{FB}

By measuring A_{FB} precisely and looking for deviations from SM predictions, it is possible to search for new physics, such as heavy gauge boson Z'

Motivation 2

Tau has extra information

tau is the only particle that can measure the polarisation of the final state in the ILC250

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

$$\frac{dP(\tau)}{d\cos\theta} = \frac{3}{8}A_\tau(1+\cos^2\theta) + \frac{3}{4}A_e\cos\theta$$

The aim of this study

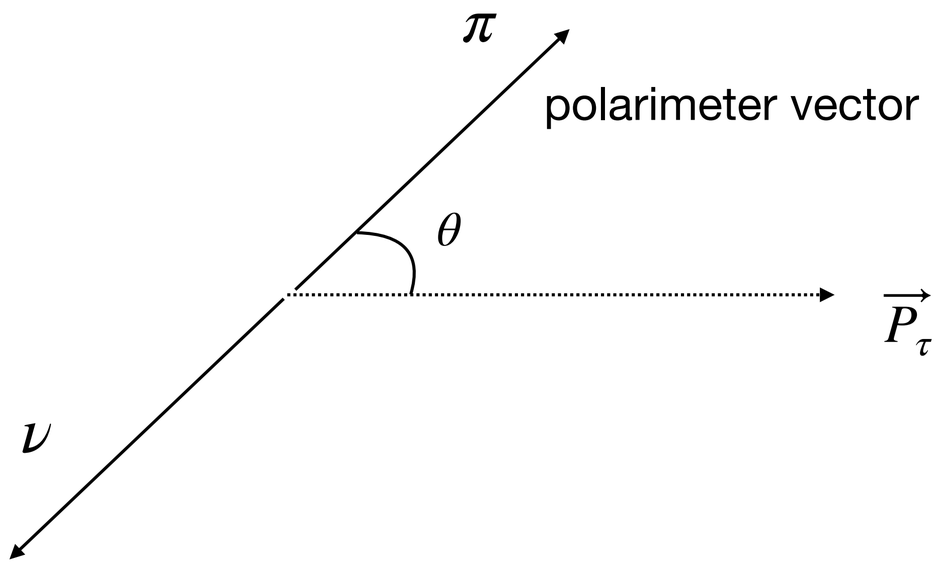
The reconstruction of tau spin orientation (“**Polarimeter**”)
in order to measure polarisation to investigate new physics.

Polarimeter

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

Polarimeter vectors of $\tau \to \pi\nu$ in τ rest frame

$$h(\tau^{\pm} \to \pi^{\pm}\nu) \propto p_{\pi^{\pm}}$$



Polarimeter vectors of $\tau \to \rho\nu$ in τ rest frame

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

"**Polarimeter**"

The cosine of the angle this polarimeter vector makes to the tau flight direction

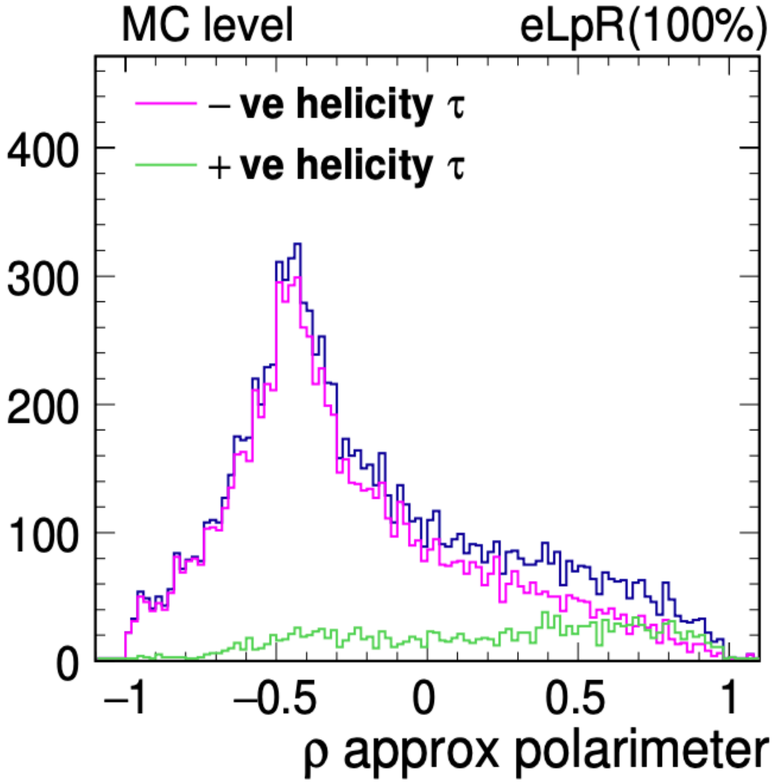
Previous study

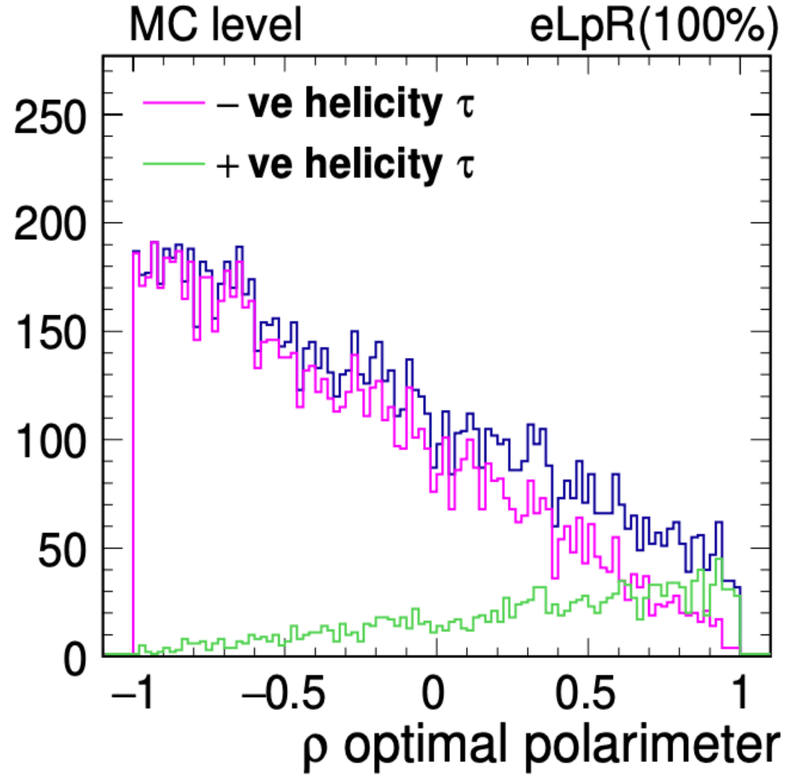
Extract polarimeter without using neutrino information

arXiv:1912.08403

"Approximate" polarimeters based only on the momenta of visible tau decay products

"Optimal" polarimeters including the neutrino component

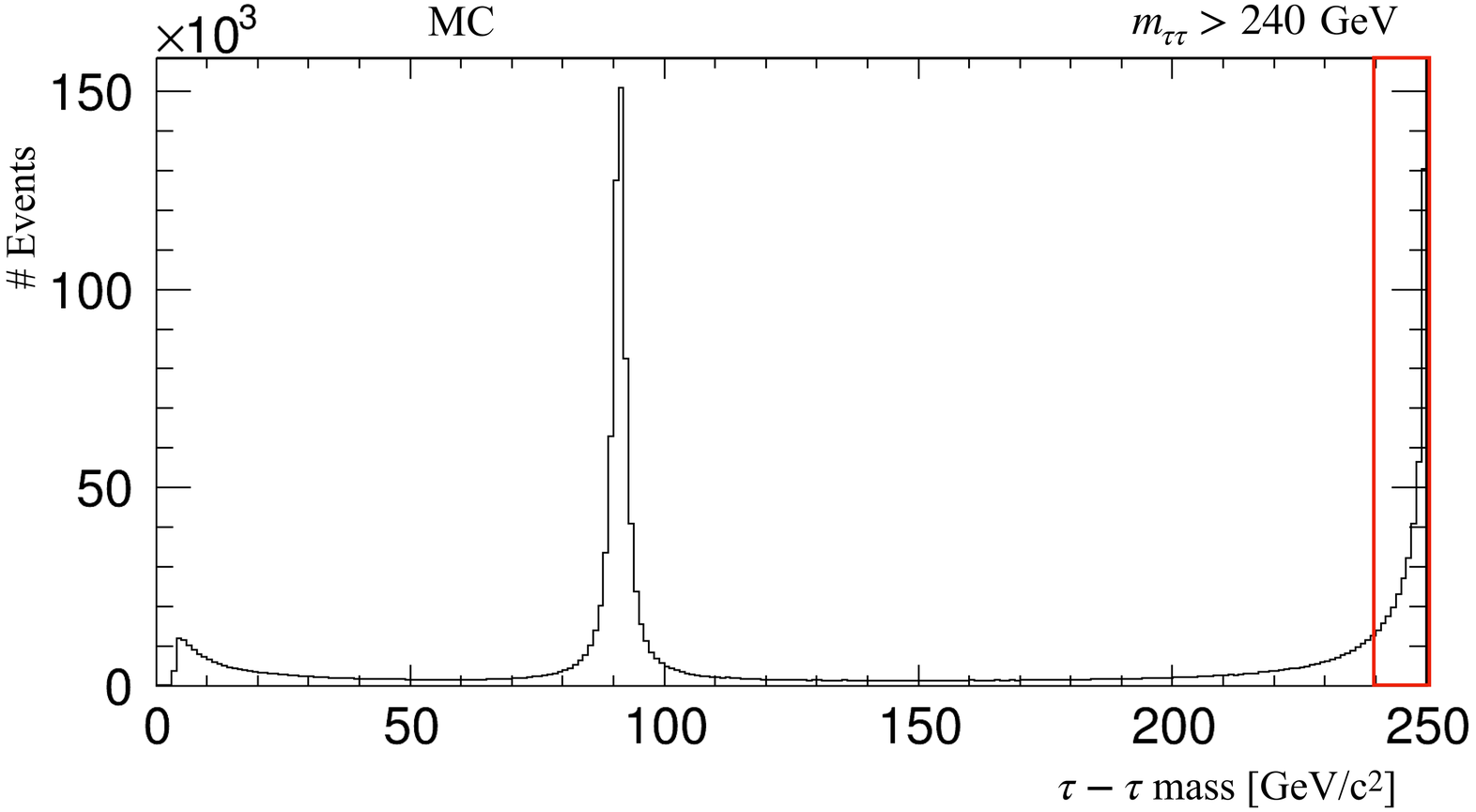




We explicitly extract the neutrino momentum and reconstruct polarimeters

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.
- MC truth information was used.



- only look at

  $\tau \to \pi\nu$ (BR ~ 10 %)

  $\tau \to \rho\nu$ (BR ~ 26 %)

  $m_{\tau\tau} > 240$ GeV

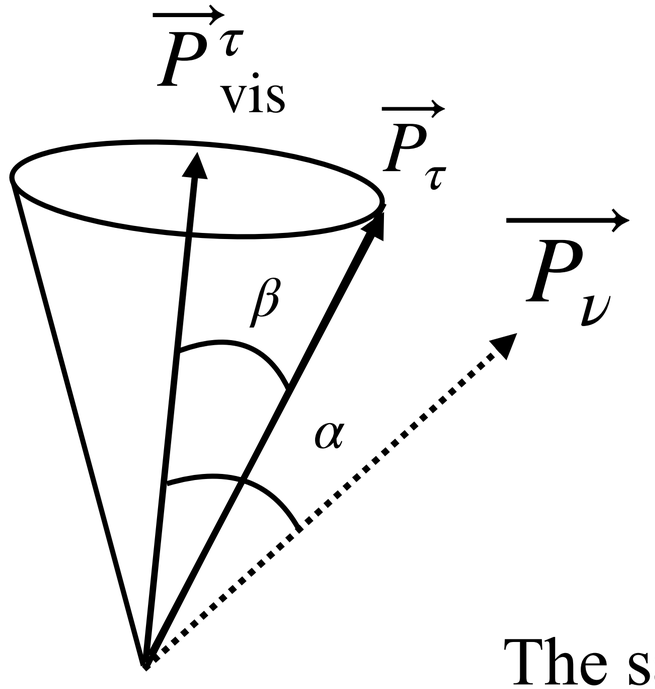
τ reconstruction method

Assume

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

from these assumptions, τ direction must make an angle β to the visible τ momentum

$$\cos\beta = f(\vec{P}^{\tau}_{\text{vis}}, m_\tau, E_\tau)$$



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

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

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

The same for the other tau

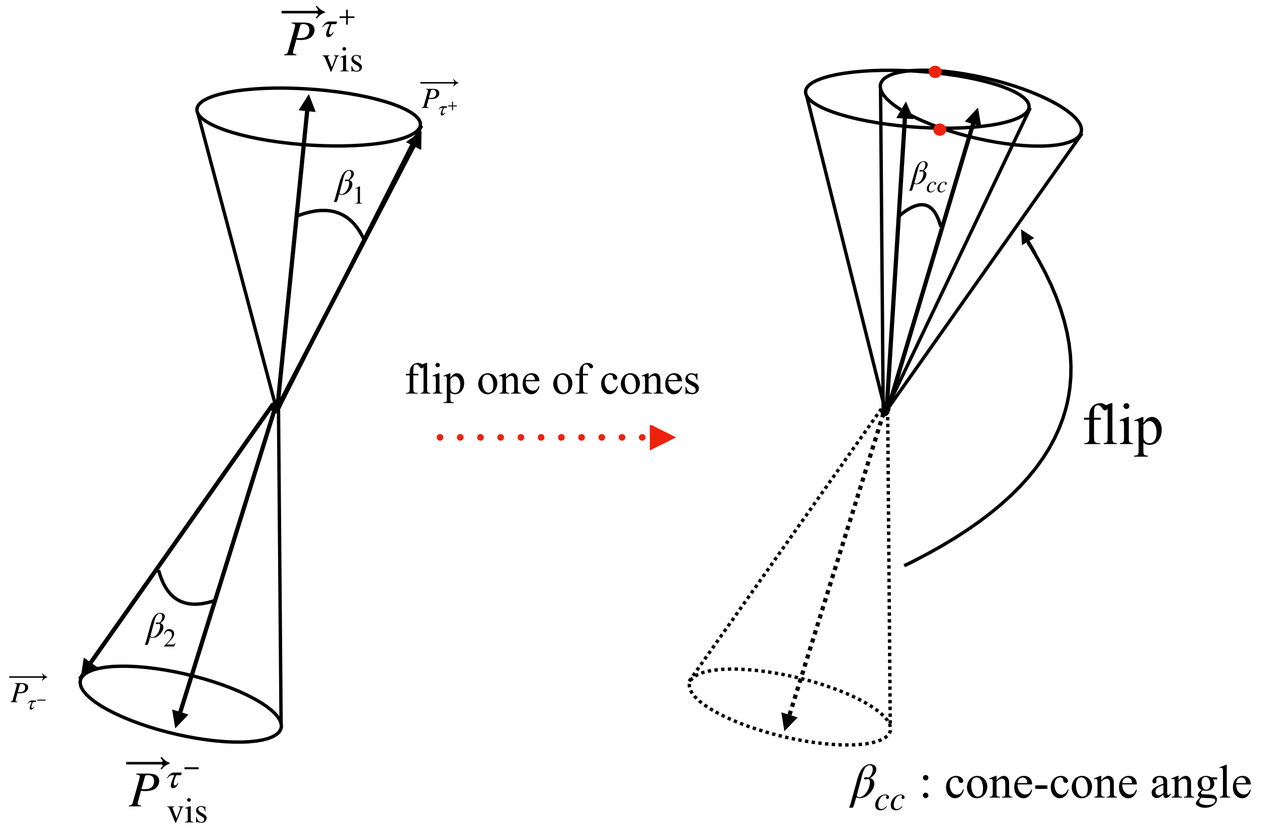
τ reconstruction method

We further assume

- two taus are back-to-back

To reconstruct tau momentum, flip one of the cones and find the intersections.

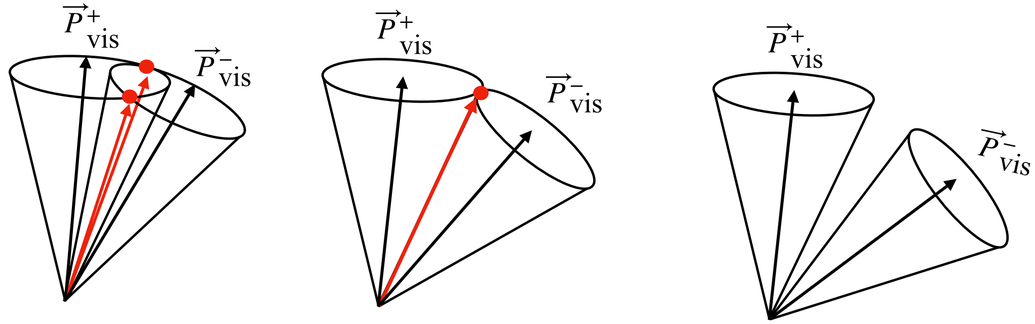
The intersection of the cones are the candidate τ momentum directions.



We call this “Cone method”

Find solutions

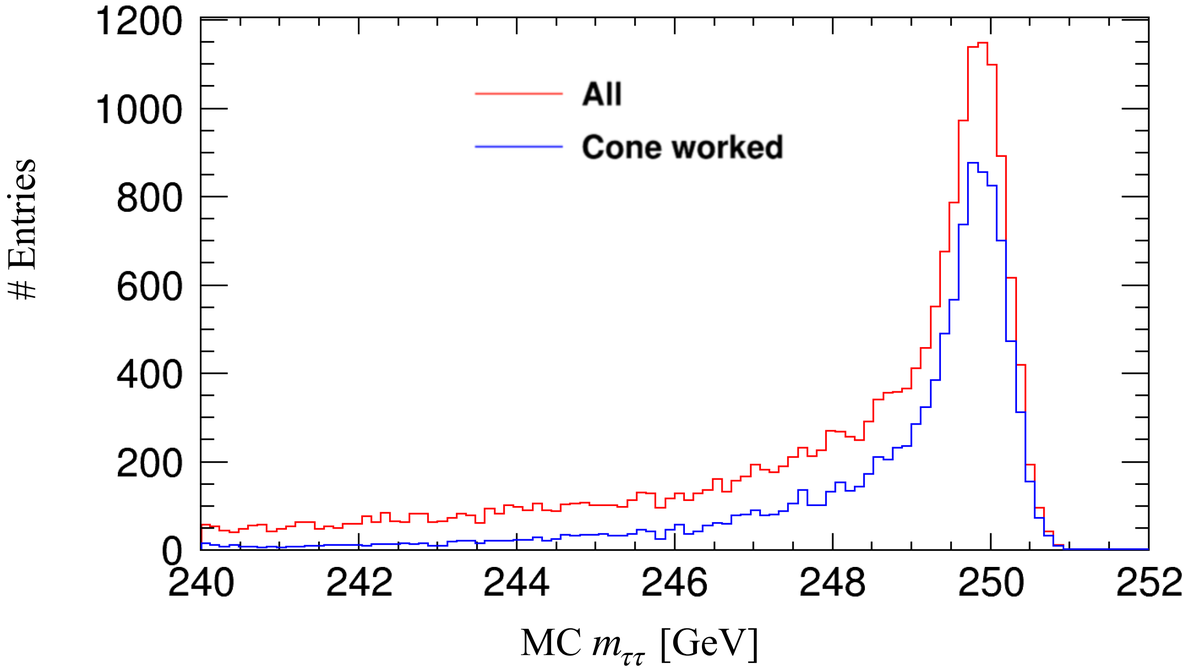
If at least one intersection point was found, there is a solution.

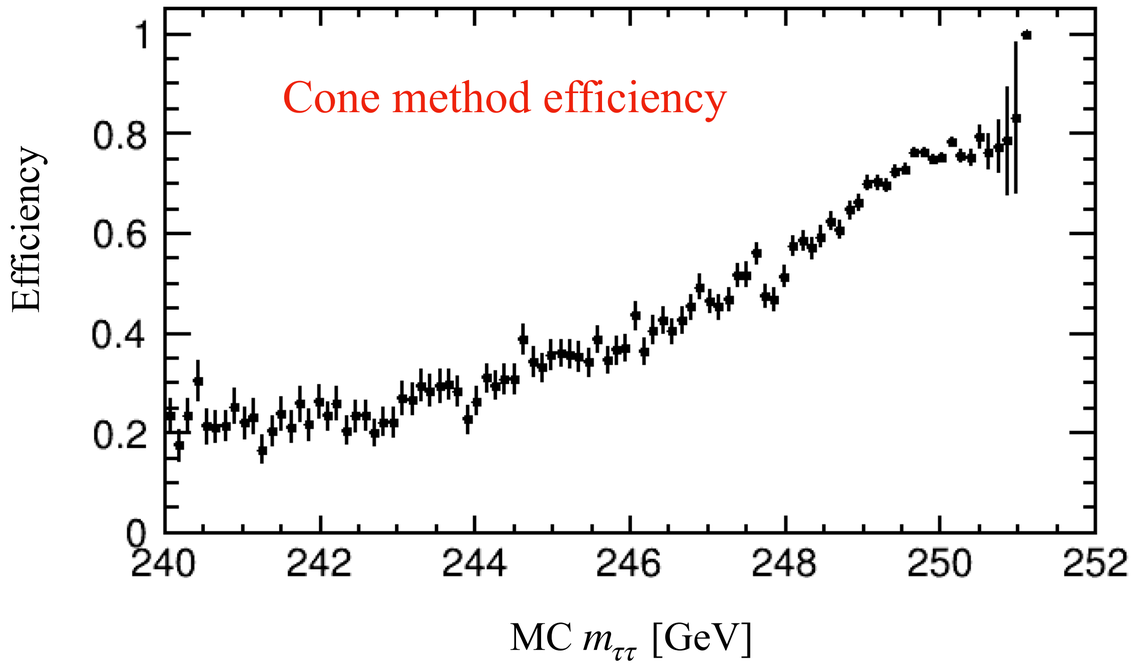


2 possible solutions

1 possible solution

NO solution

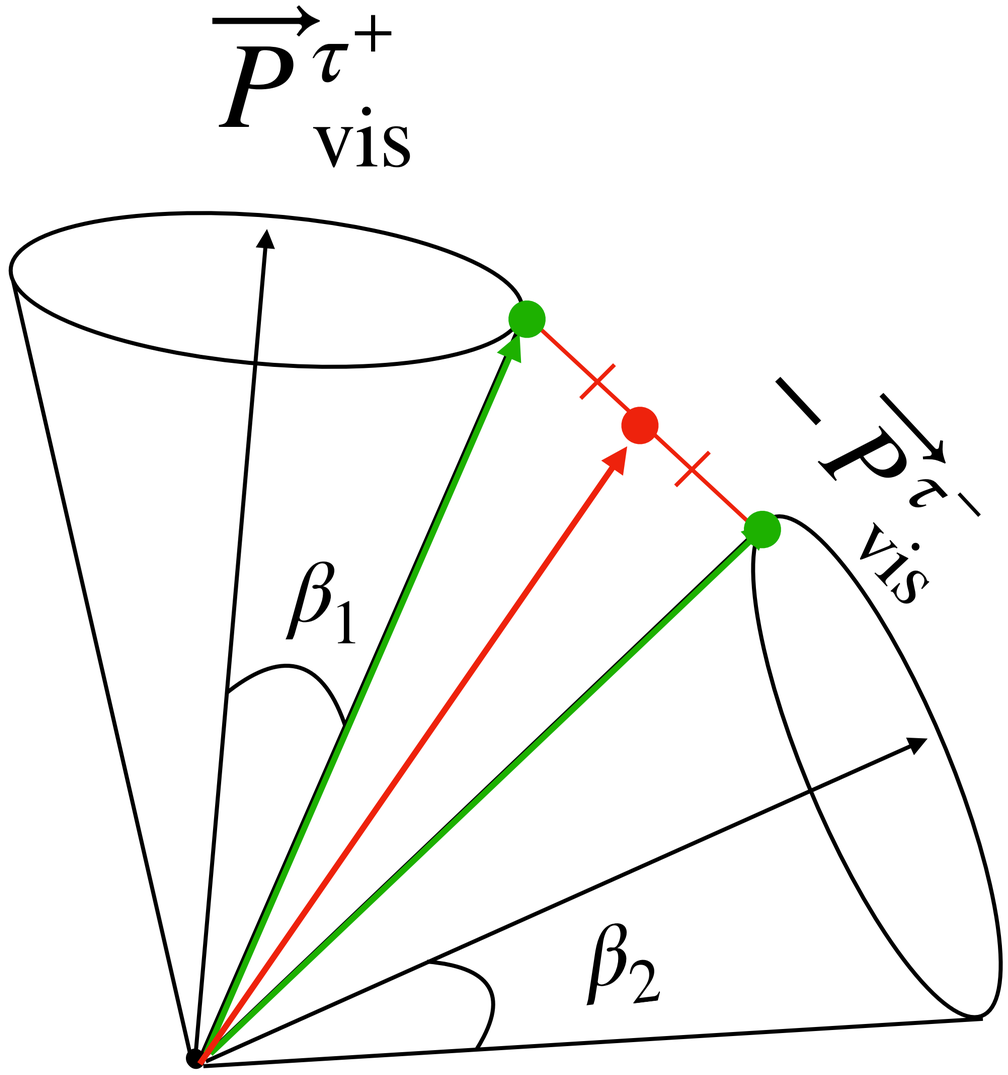




Cone method efficiency is $\sim 80\,\%$ for events with $m_{\tau\tau} \sim 250$ GeV

Midpoint method

For events for which “Cone Method” cannot find a solution



take a midpoint of the closest approach points of the two cone edges

and use this new vector as a solution

We call this “Midpoint method”

Various levels of “cheating” and methods

Two levels of cheating

1. Using true neutrino momentum from MC.
2. Using true MC visible tau daughters.

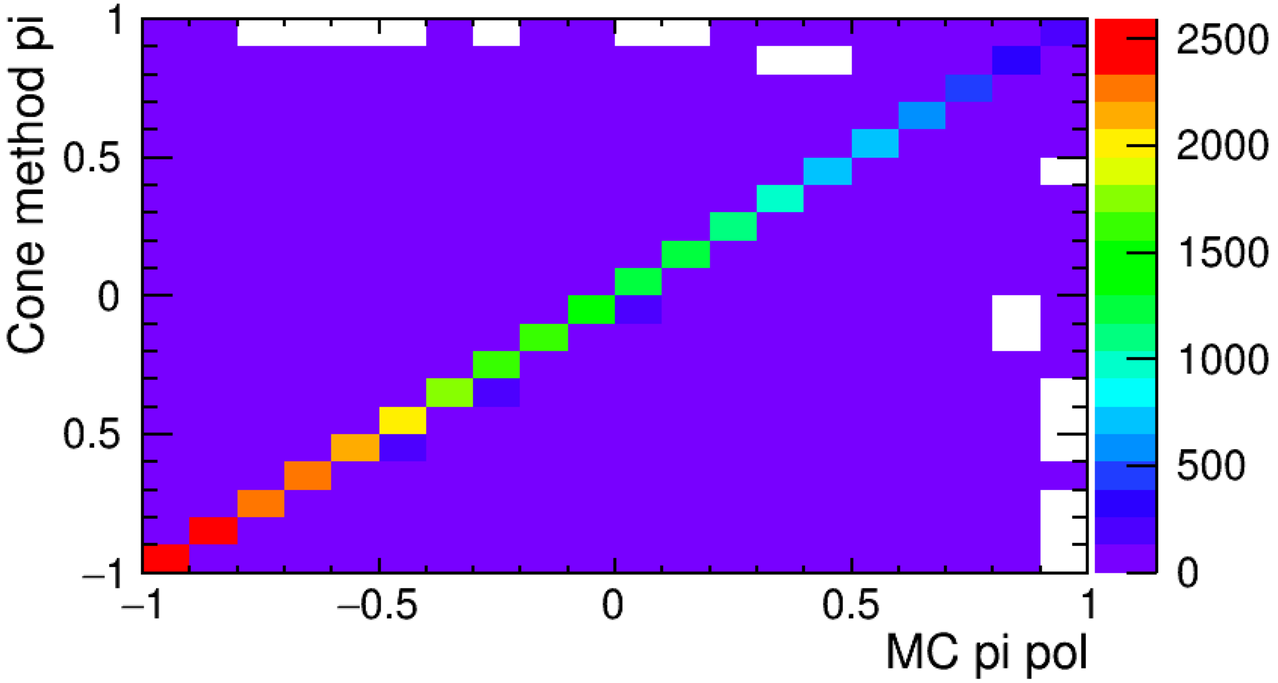
    2.1 “Cone method” to estimate the neutrino momentum.

    2.2 If Cone method fails, “Midpoint method”

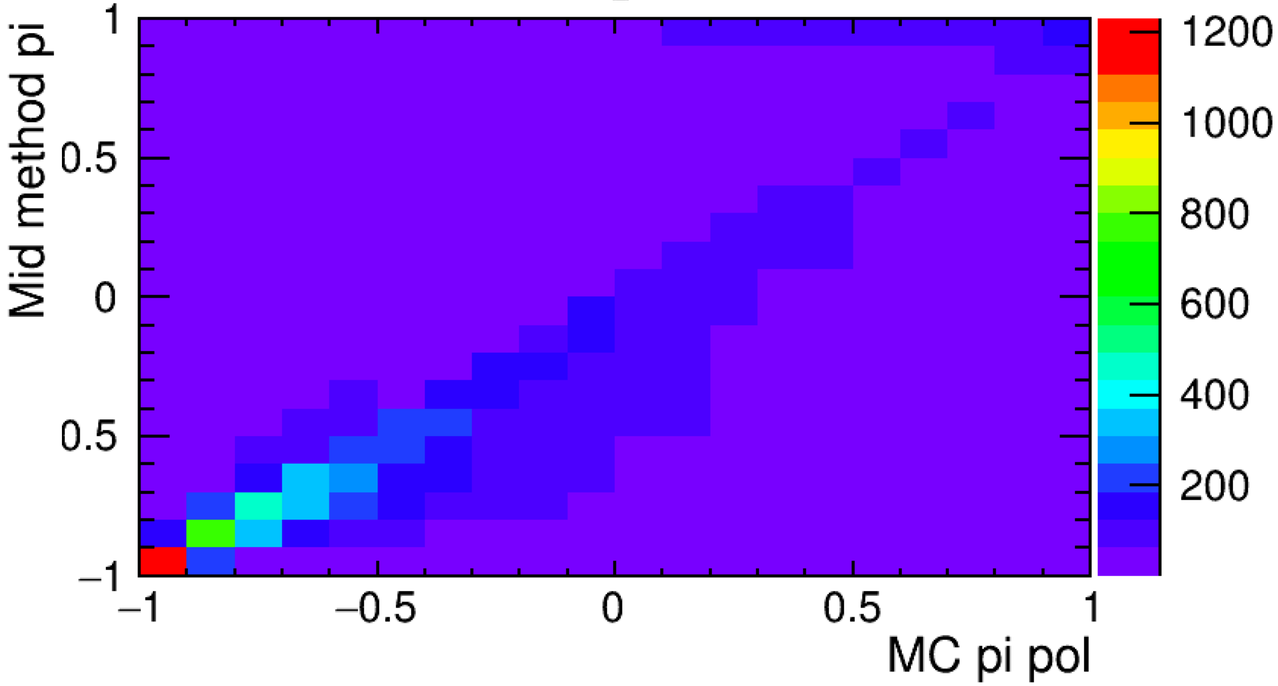
Polarimeter: single pi decay

Polarimeter vectors of $\tau \to \pi\nu$ in τ rest frame $\quad h(\tau^{\pm} \to \pi^{\pm}\nu) \propto p_{\pi^{\pm}}$

true vs Cone method



true vs Midpoint method



Polarimeter using reconstructed ν is in reasonable agreement with MC one.

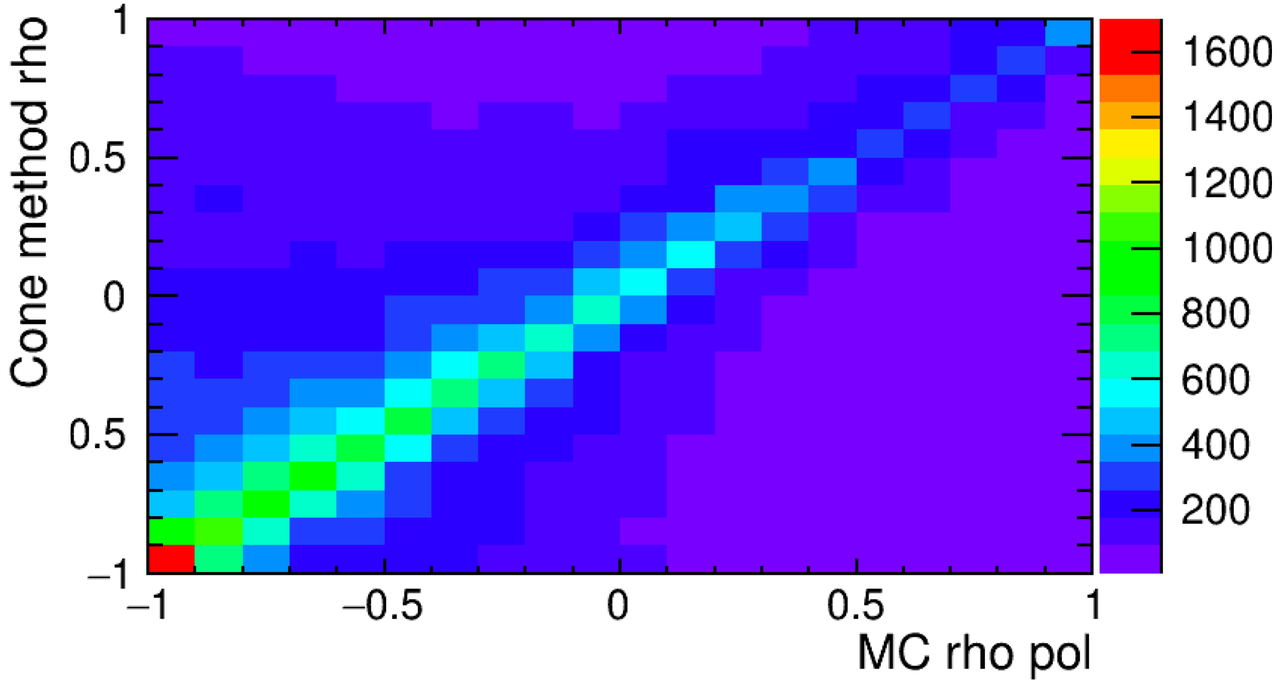
Cone method works better than Midpoint method.

Polarimeter: rho decay

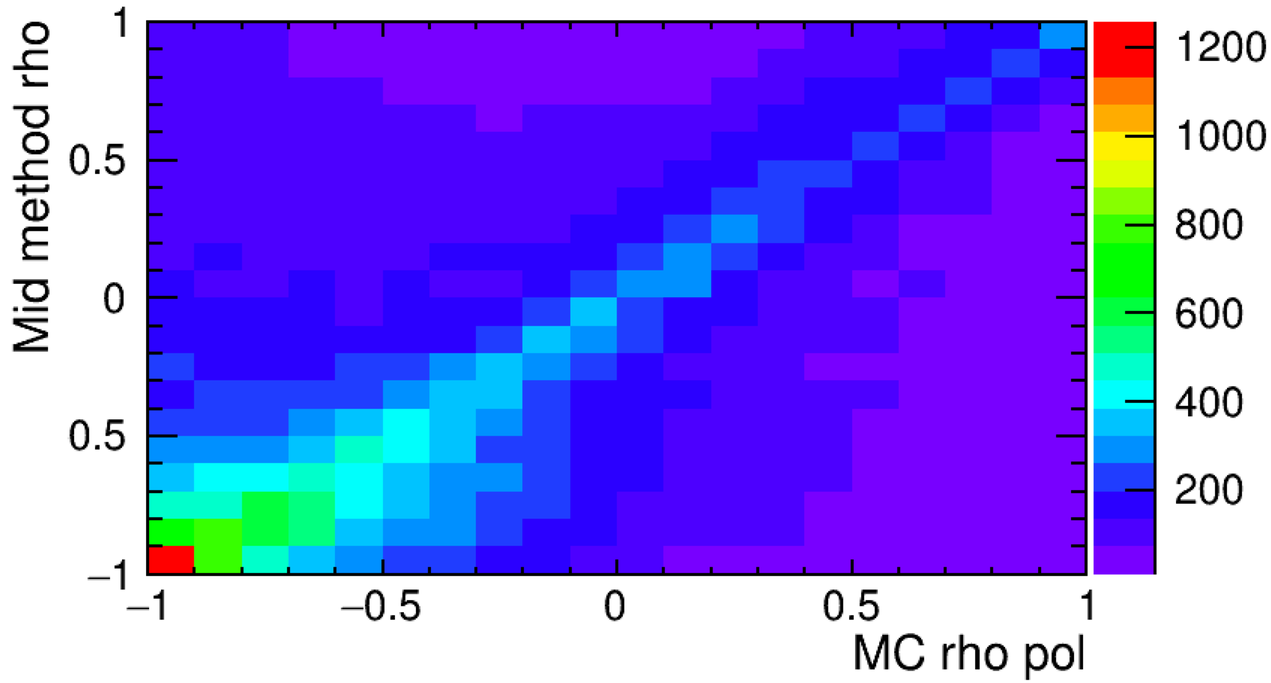
Polarimeter vectors of $\tau \to \rho\nu$ in τ rest frame

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

true vs Cone method



true vs Midpoint method



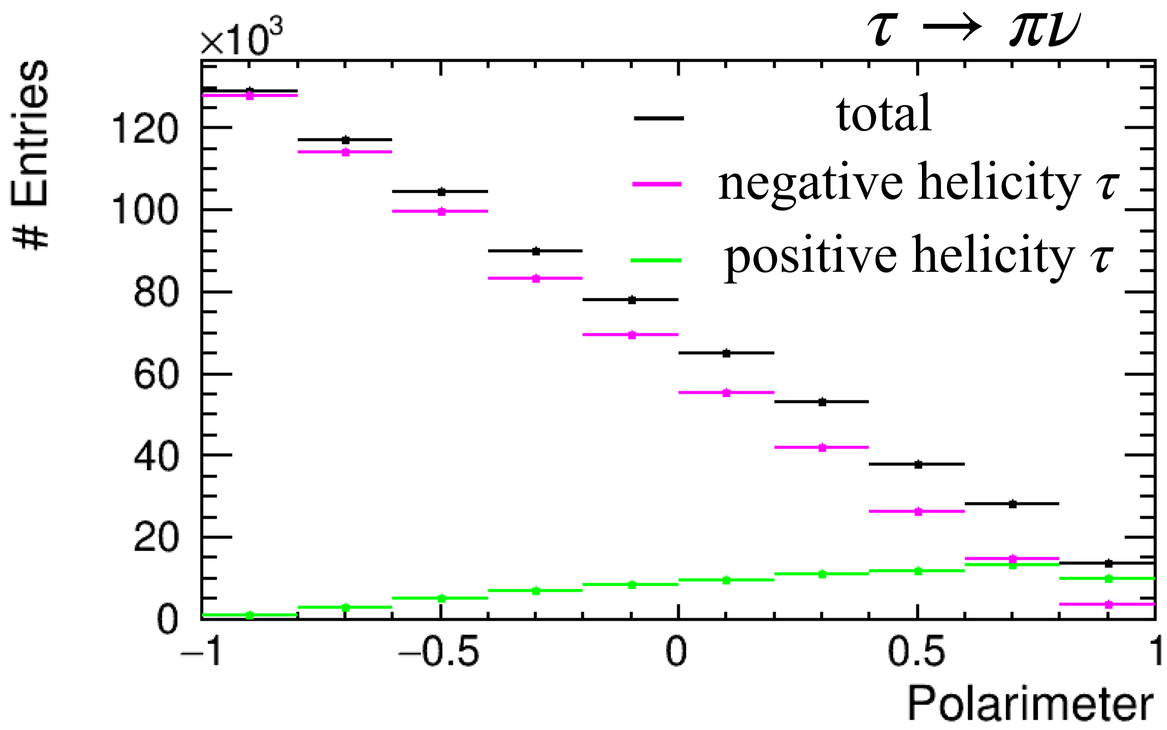
Extracted polarimeter is less precise than $\tau \to \pi\nu$

Tau Polarisation Accuracy

Q.How accurately can tau polarisation be measured?

Reconstructed polarimeter templates for $\tau \to \pi\nu$ and $\tau \to \rho\nu$ decays.

Scaled to the integrated luminosity of 1000 fb^{-1} with 100 % $e_L^- e_R^+$.



Polarisation

$$P = \frac{N_R - N_L}{N_R + N_L}$$

Use likelihood method to analytically estimate polarisation uncertainty.

Tau Polarisation Accuracy

Scaled to the luminosity of 1000 fb^{-1}

Sample with 100 % $e_L^- e_R^+$ beam polarisations

N_τ: the expected total number of taus, σ_P: the expected polarisation uncertainty

$\tau \to \pi\nu$	N_τ	σ_P
MC	0.58 M	0.27 %
Cone	0.36 M	0.35 %
Mid	0.22 M	0.55 %
Combined	0.58 M	0.30 %

$\tau \to \rho\nu$	N_τ	σ_P
MC	1.31 M	0.18 %
Cone	0.70 M	0.28 %
Mid	0.59 M	0.42 %
Combined	1.29 M	0.23 %

Precision on the polarisation σ_P of "Cone method" + "Midpoint method"

$$\tau \to \pi\nu :\sim 0.30\,\%\,, \quad \tau \to \rho\nu :\sim 0.23\,\%$$

Summary

- The reconstruction of neutrino momentum at ILC250 was investigated.
- For events with $m_{\tau\tau} \sim 250$ GeV, “Cone method” efficiency is $\sim 80\,\%$.
  - “Midpoint method” is used if “Cone method” fails.
- Polarimeters were reconstructed in the $\tau \to \pi\nu$ and $\tau \to \rho\nu$ decay modes, and used to estimate the tau polarisation.
- Reasonable agreement between MC truth polarimeter value and the one from “Cone method” for both $\tau \to \pi\nu$ and $\tau \to \rho\nu$ decay were found.
- The experimental sensitivity to the tau polarisation of “Cone method” and “Midpoint method" is around 0.18%, assuming 1000 $\text{fb}^{-1}$of 100 % $e_L^- e_R^+$ data at 250 GeV.

Future Plan

- Investigate search for new physics by using the tau polarisation.
- Apply method to radiative return events with a visible photon.
- Add impact parameter information to improve tau and polarisation reconstruction.
- Estimate the tau polarisation precision for a realistic beam polarisation and detector resolution.