Tau reconstruction for CPV measurements in Higgs to $\tau\tau$ decays at future e^+e^- collider

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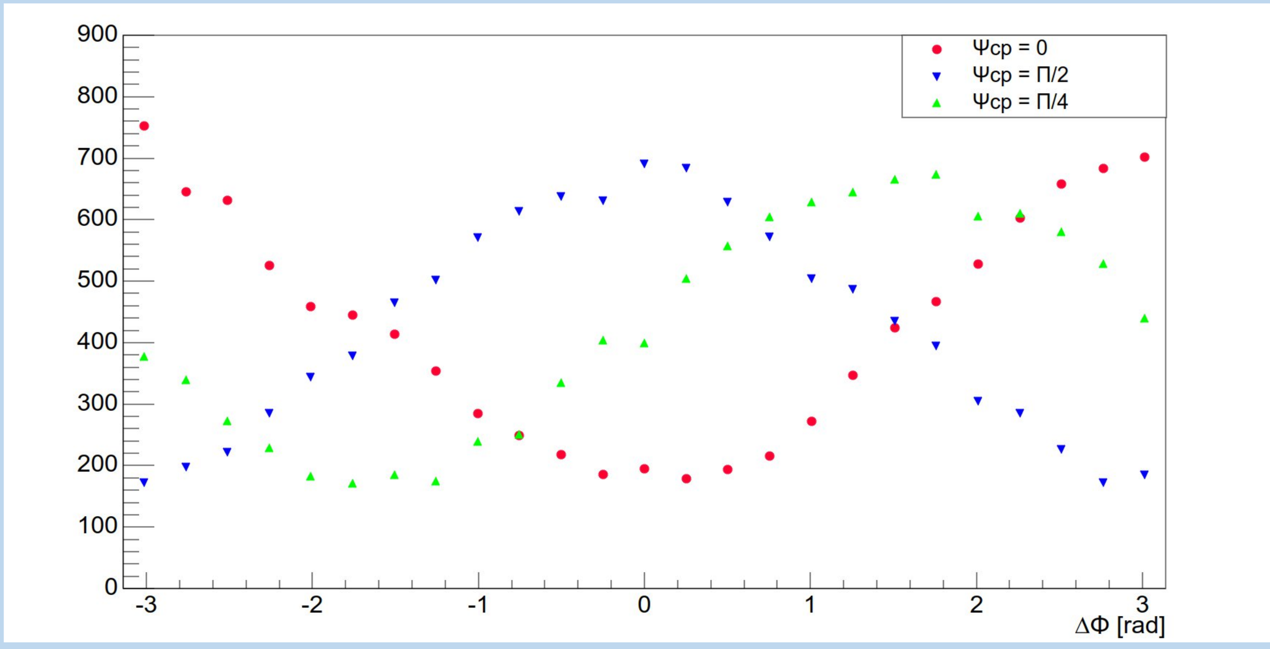


Behavior of the sensitive angular observable $\Delta\phi$ for different values of the mixing angle Ψ_{CP}.

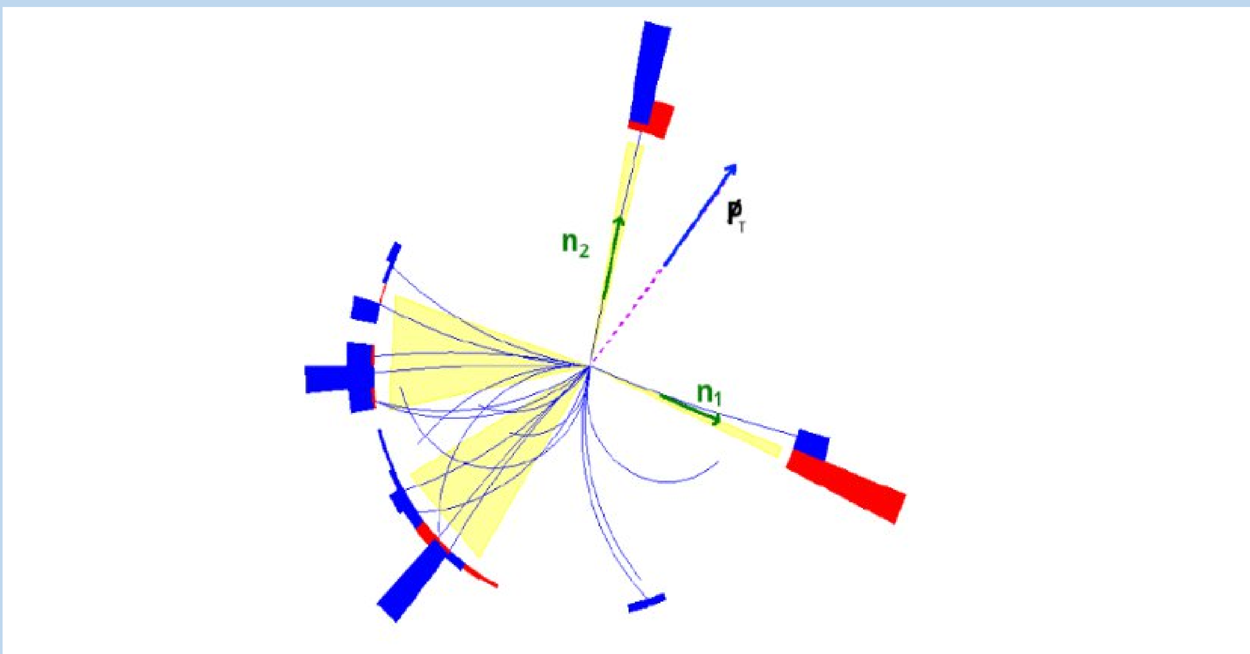
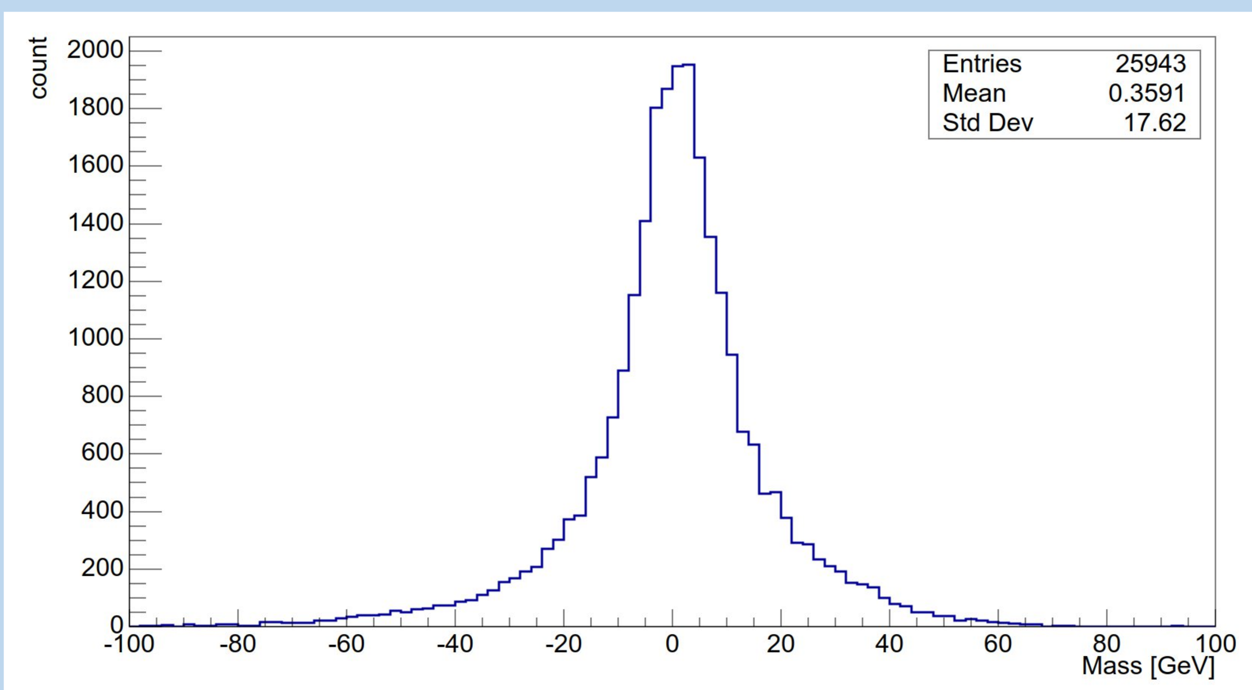


Illustration of the collinear approximation for primary Z^0 hadronic decay.



The Higgs mass resolution reconstructed from tau-pairs.

CP violation is one of the three Sakharov conditions need to explain the Baryon Asymmetry of the Universe. A few sources of CP violation exist already in the Standard Model: CKM, PMNS matrices. However, they are significantly insufficient to account for the Baryon Asymmetry.

Higgs interactions could be possible source of CPV. CP violation in the Higgs sector will be unequivocal signs of physics beyond the Standard Model.

How to look for CPV in the Higgs sector? Dedicated future e^+e^- collider experiments (Higgs factories) operating at 240 GeV center-of-mass energy should be able to probe the Higgs CP structure.

One way of doing it is by measuring the shape effects on CP-sensitive observables. In the SM, the Higgs boson is a CP even state. In more general models, a Higgs mass eigenstate h_{125} can be a superposition of a scalar (CP-even) state H and a pseudoscalar (CP-odd) state A, via a mixing angle ψ_{CP}: $h_{125} = H\cdot\cos\psi_{CP} + A\cdot\sin\psi_{CP}$

The CP mixing angle can be probed by measuring Higgs decays to τ lepton pairs. The study at the 250 GeV ILC demonstrates that the CP-mixing angle in $H \to \tau^+\tau^-$ decays can be determined with a precision of 75 mrad (4.3°) [1].

We consider Higgsstrahlung events where the Higgs boson decays to τ-lepton pairs subsequently decaying to charged pions and neutrinos (final state). Since this process is rare, ~50 events is expected with integrated luminosity of 5.6ab^{-1} estimated at 240 GeV CEPC [2].

This measurement (simulation of it) thus requires the tau-lepton reconstruction efficiency be maximized beyond the scope of the majority of the available reconstruction tools.

The collinear approximation is based on the assumption that the tau lepton and its visible decay product (a charged pion) are emitted collinearly, i.e. along the same direction in space.

This assumption, together with the conservation of the event transverse momentum, allows to determine the intensities of tau leptons' momenta.

Equations:

$$-p^x_{\bar{f}f} = p_{\tau^-}\cdot a_1 + p_{\tau^+}\cdot a_2$$

$$-p^y_{\bar{f}f} = p_{\tau^-}\cdot b_1 + p_{\tau^+}\cdot b_2$$

$$a_1 = \sin\theta_{\pi^-}\cdot\cos\phi_{\pi^-}$$
$$a_2 = \sin\theta_{\pi^+}\cdot\cos\phi_{\pi^+}$$
$$b_1 = \sin\theta_{\pi^-}\cdot\sin\phi_{\pi^-}$$
$$b_2 = \sin\theta_{\pi^+}\cdot\sin\phi_{\pi^+}$$

are resolved to give the intensity of tau momentum:

$$p_{\tau^-} = \frac{p^x_{\bar{f}f}\cdot b_2 - p^y_{\bar{f}f}\cdot a_2}{a_2\cdot b_1 - a_1\cdot b_2}$$

$$p_{\tau^+} = \frac{p^x_{\bar{f}f}\cdot a_1 - p^x_{\bar{f}f}\cdot b_1}{a_2\cdot b_1 - a_1\cdot b_2}$$

$p_{\tau^\pm}$ – momentum of reconstructed tau

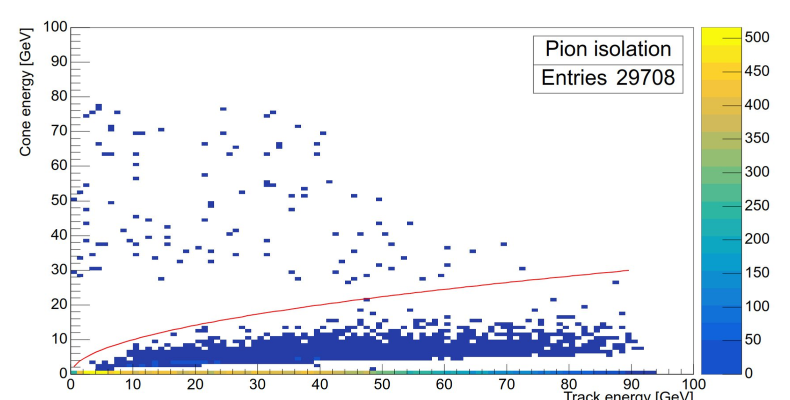
$p^{x,y}_{\bar{f}f}$ – momentum of Z^0 decay products

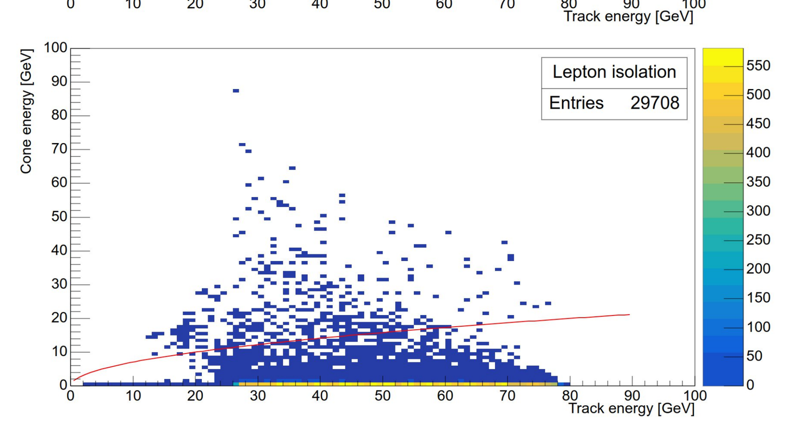
$\theta_{\pi^\pm}, \phi_{\pi^\pm}$ – polar and azimuthal angle of tau decay

Events are generated, simulated and reconstructed using WHIZARD 3.1.4 [3] event generator, PYTHIA 8.3 [4] to model τ-lepton decays and Delphes 3.5.0 [5] - a fast simulation of the CEPC detector response.

Events are preselected by requiring:

- Isolation of leptons from primary Z^0 decay;
- Pion isolation;
- Selection cuts: 60 GeV < m_{ll} < 110 GeV and 25 GeV < $p_{\tau^\pm}$ < 125 GeV





Pion isolation requires:

- 8-degree cone around the lepton:

$$E_{cone} < \sqrt{AE^2_{track} + BE_{track} + C}$$
$$m_{cone} < 2\text{ GeV}$$

E_{cone} – cone energy, E_{track} – track energy, A = 0, B = 10, C = 0 – free parameters of the fit, m_{cone} – cone invariant mass

Lepton isolation requires:

- 6-degree cone around the lepton:

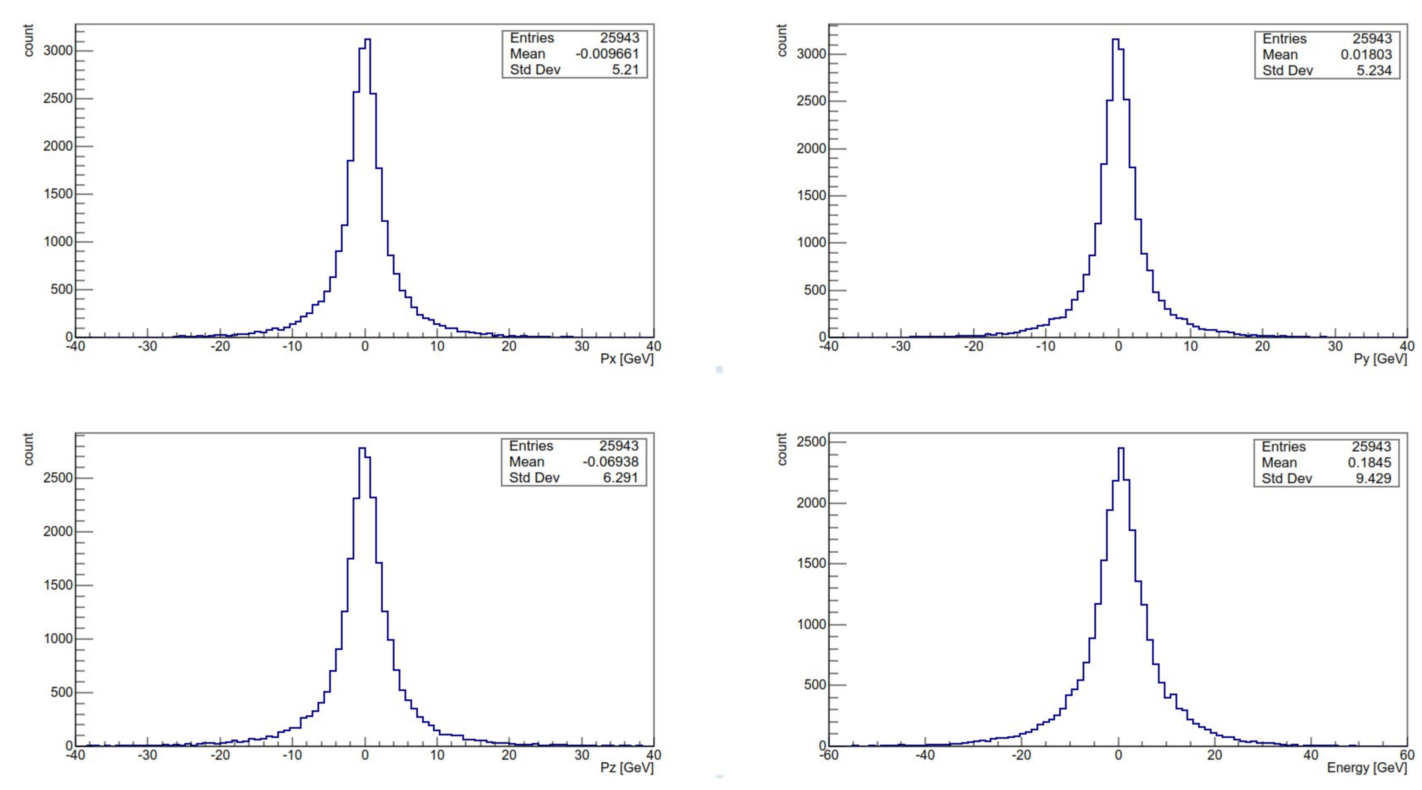
$$E_{cone} < \sqrt{AE^2_{track} + BE_{track} + C}$$

E_{cone} – cone energy, E_{track} – track energy, A = 0, B = 5, C = 0 – free parameters of the fit

Performance of τ reconstruction:

- Tau lepton reconstruction efficiency is 86% (compared to ~30% for the most tau reconstruction tools);

- Tau momentum components are reconstructed with the resolution of ~6.5 GeV;



References:

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