Decay of Z boson to a pair of τ leptons at the LHC: spin effects and New Physics

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The possible anomalous New Physics contributions to dipole and weak dipole moments of the τ lepton bring renewed interest in development and revisiting charge-parity (CP) violating signatures in the τ-pair production in Z-boson decay at energies of the LHC. Such process has been studied in the pp collisions at the LHC experiments in wide range of invariant masses of outgoing τ-lepton pair.

We study observables sensitive to New Physics effects in hadron colliders. Our approach, developed in [1-4], includes:

– electroweak radiative corrections in the Standard Model taken into account in the Improved Born Approximation [5];

– arbitrary phase-shift between vector and axial-vector couplings of Z-boson to the τ leptons;

– electromagnetic and weak anomalous magnetic and electric dipole moments of the τ lepton;

– implementation of theoretical formalism in the Monte Carlo program `TauSpinner`.

The amplitude of the process $q+\bar{q} \to \tau^- + \tau^+$ (where $q = u,\ d,\ s$) is calculated for polarized τ leptons, which decay into various channels. The cross section can be written as

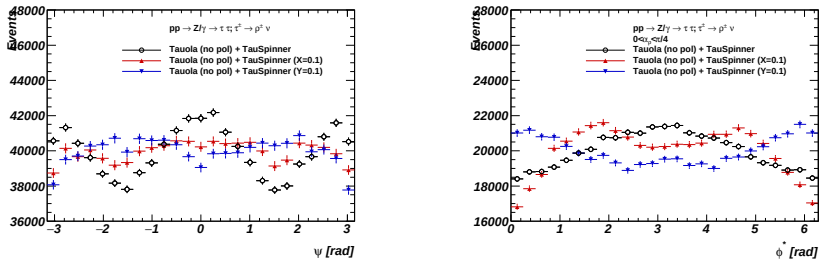
$$\frac{d\sigma}{d\Omega}(q\,\bar{q} \to \tau^-\tau^+) = \frac{\beta}{64\pi^2 s} \sum_{i,j=1}^{4} \left(R_{ij}^{(\gamma)} + R_{ij}^{(Z)} + R_{ij}^{(Z\gamma)}\right) S_i^- S_j^+,$$

where $S_i^- = (\vec{S}^-,\, 1)$, $S_j^+ = (\vec{S}^+,\, 1)$, and $\vec{S}^-$, $\vec{S}^+$ are polarization 3-vectors of τ^-, τ^+ leptons in their corresponding rest frames. The spin-correlation matrices R_{ij} carry information on mechanism of the reaction and effects of New Physics.

We include s-channel exchange of the photon γ, Z boson and their interference $Z\gamma$. The $\gamma\tau\tau$ electromagnetic vertex includes anomalous magnetic $A(s)$ and CP-violating electric $B(s)$ dipole form-factors, while $Z\tau\tau$ vertex includes weak anomalous magnetic $X(s)$ and CP-violating electric $Y(s)$ form-factors. In framework of the Improved Born Approximation the weak vector coupling of Z to τ leptons becomes complex and (s,t) dependent. On top of that we include an arbitrary phase-shift between vector and axial-vector couplings, which may reflect effect of unknown physics beyond the Standard Model.

As an example of observables, sensitive to New Physics, we show distribution of the so-called acoplanarity angles ψ and ϕ^* which can be defined for decay of τ^-, τ^+ leptons (see details in [4]):

$$\tau^- \to \rho^- + \nu_\tau \to \pi^- + \pi^0 + \nu_\tau, \qquad \tau^+ \to \rho^+ + \bar{\nu}_\tau \to \pi^- + \pi^0 + \bar{\nu}_\tau$$



Acoplanarity angle distributions for nonzero weak dipole moments in pp collisions at $\sqrt{s} = 13$ TeV.

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