Measuring $\mathcal{CP}$ properties of Higgs boson interactions with τ leptons in ATLAS detector

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Introduction

The measurement of the charge conjugation and parity ($\mathcal{CP}$) properties in the Higgs boson interaction with τ leptons. [1] The Yukawa interaction is generalized with a single mixing angle parameter ϕ_τ to describe $\mathcal{CP}$-odd interactions between the Higgs boson and τ leptons. The study is based on a measurement of $\mathcal{CP}$-sensitive angular observables defined by the visible decay products of τ lepton decays, performed using a data sample corresponding to 139 fb^{-1} of proton–proton collisions recorded at a center-of-mass energy of $\sqrt{s}$= 13 TeV with the ATLAS detector at the Large Hadron Collider. Without assuming Standard Model hypothesis for the $H \to \tau\tau$ signal strength, the mixing angle ϕ_τ is measured to be $9 \pm 16°$, with an expected value of $0 \pm 28°$ at the 68% confidence level. The pure $\mathcal{CP}$-odd hypothesis is disfavoured at 3.4 standard deviations. The results are compatible with the predictions for the Higgs boson in the Standard Model as well as $\mathcal{CP}$-violating scenarios.

Analysis Strategy

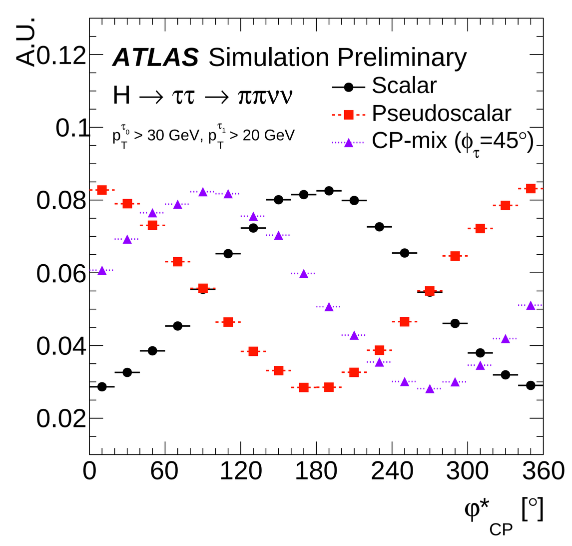
1 Motivation

$\mathcal{CP}$ properties of the fundimental particle is a very important symmetry related to the formation and the revolution of the universe. Currently we observe more matter than anti-matter in our universe known as the Baryon Asymmetry, which might be explained by the $\mathcal{CP}$ violation in the Baryogenesis. In SM the $\mathcal{CP}$ violation is explained by Kobayashi-Maskawa (KM) mechanics by introducing a non-zero phase δ_{KM} in CKM matrix, while it still does not correspond to the experiment observation.

2 Theory Predictions

In SM the Higgs boson is predictd as the $\mathcal{CP}$-even (scalar) particle, the presence of a $\mathcal{CP}$-odd (pseudoscalar) admixture has not yet been excluded. The $\mathcal{CP}$ properties of the Higgs boson can be measured via the interaction with τ lepton parameterized by the $\mathcal{CP}$-mixing angle ϕ_τ, the general effective Yukawa coupling is:

$$\mathcal{L}_{H\tau\tau} = -\frac{m_\tau}{v}\kappa_\tau(\cos\phi_\tau\bar{\tau}\tau + \sin\phi_\tau\bar{\tau}i\gamma_5\tau)H \qquad (1)$$



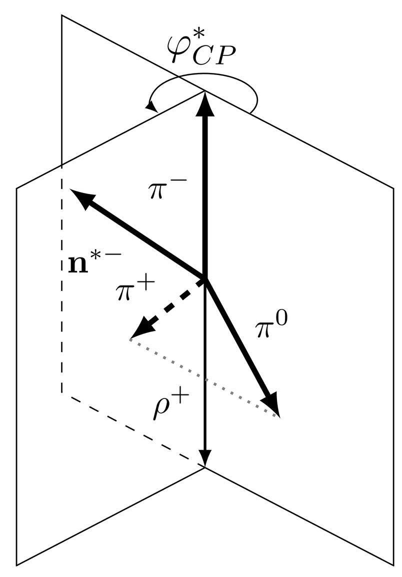
The $\mathcal{CP}$-mixing angle could be encoded in the correlations between the transverse spin co,ponents of the τ leptons then reflected in the directions of the τ lepton decay products:

$$d\Gamma_{H\to\tau\tau} \approx 1 - b(E_+)b(E_-)\frac{\pi^2}{16}\cos(\varphi^*_{CP} - 2\phi_\tau) \qquad (2)$$

3 Observable

The observable defined as the acoplanarity angle between di-τ decay planes named as φ^*_{CP}, it would be reconstructed in visible di-τ zero momentum frame by different method according to the τ decay mode:

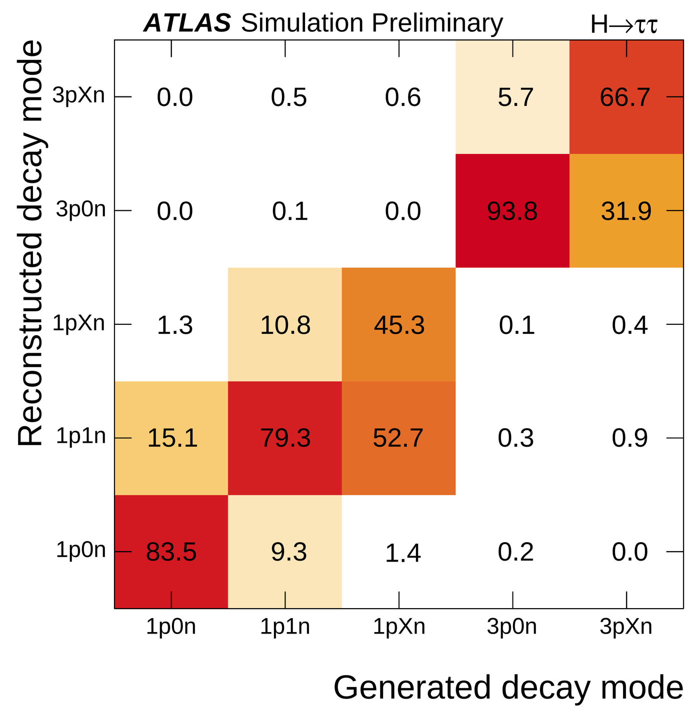
- IP method: for τ decay to only one charged particle and with no neutral visible particles, like leptonic decay and one charge and zero neutral hadronic decay, define plane spanned by charged track and its impact parameters
- ρ method: for τ decay to both charged and neutral visible particles, define plane spanned by charged track and neutral track



After the decay plane reconstruction, we can get the observable φ^*_{CP} by calculte the angle between two normal vectors of the di-τ decay planes with the direction.

τ Decay Mode Reconstruction

Hadronic decay τ is reconstructed by its visible decay products seeded by the jets reconstructed using anti-k$_t$ algorithm with a distance parameter of R=0.4. The BDT algorithm is employed to discriminate the hadronic τ decay mode.

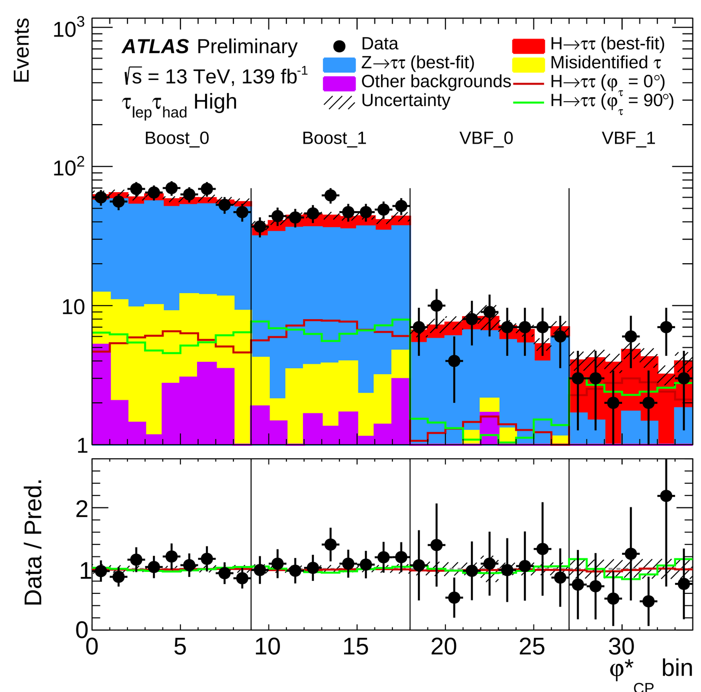


Background Estimation

Main background in this analysis are mainly from:

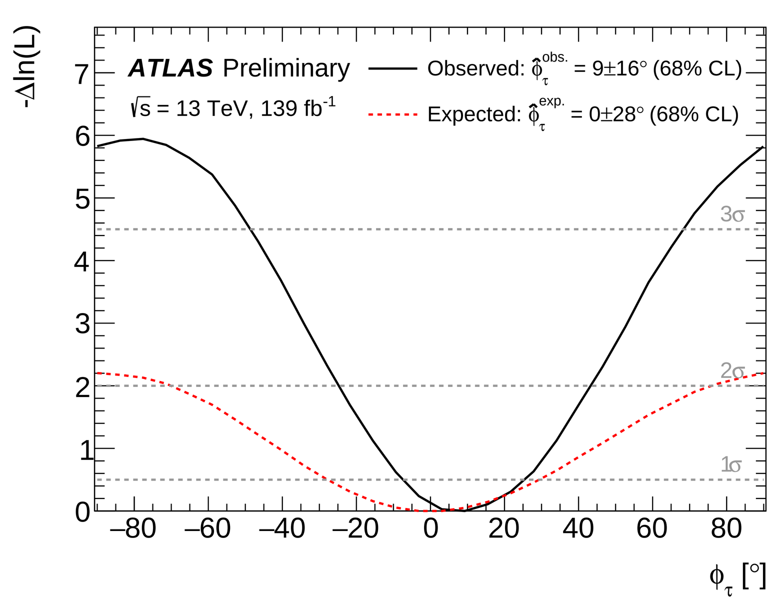
- $Z/\gamma^* \to \tau\tau$ estimated by Monte Carlo
- W+jets and QCD multijets: mis-identified as hadronic τ, estimated by data-driven method

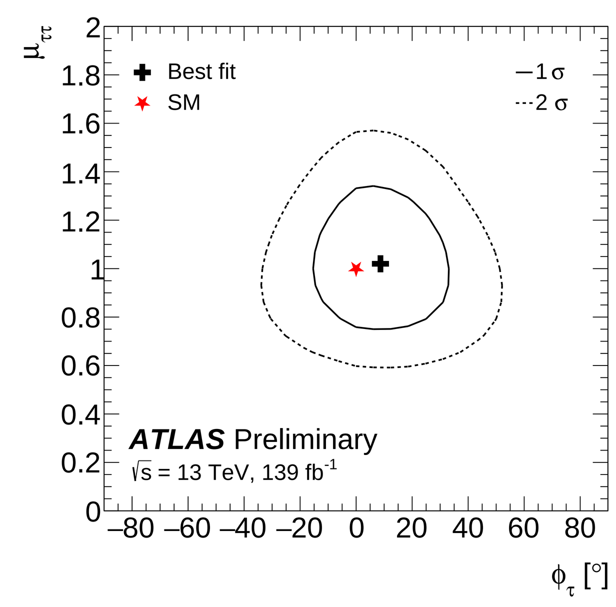
Other backgrounds are estimated by Monte Carlo samples.



Results

The observed and expected negative log-likelihood ($\Delta \ln L$) scans in ϕ_τ showed that the observed (expected) value ofϕ_τ is $9 \pm 16°$ $(0 \pm 28°)$ at the 68% confidence level (CL), and $\pm 34°$ $(^{+75°}_{-70°})$ at the 95% CL. The data disfavours the pure CP-odd hypothesis at 3.4σ, while the expected exclusion limit is at 2.1σ. The results are compatible with the SM expectation within the measured uncertainties.
A 2D scan of $\Delta \ln L$ on the signal strength $\mu_{\tau\tau}$ versus ϕ_τ showed that the 1-σ and 2-σ 2D confidence levels for $\Delta \ln L$ correspond to 1.15 and 3.09, respectively. No strong correlation is observed between $\mu_{\tau\tau}$ and ϕ_τ. The SM prediction ($\mu_{\tau\tau} = 1, \phi_\tau = 0$) of $\mu_{\tau\tau}$ is compatible with the measurement within the 1-σ confidence region.





Reference

References

[1] Measuring CP properties of Higgs boson interactions with τ leptons with the ATLAS detector. Technical report, CERN, Geneva, 2022.