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Measurement of τ Polarisation in $Z/\gamma^* \to \tau\tau$ Decays with the ATLAS Detector

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A measurement of the τ polarisation in $Z/\gamma^* \to \tau\tau$ decays is presented. The analysis is based on the 20.2 fb^{-1} of proton–proton collision data collected at a centre-of-mass energy of $\sqrt{s} = 8$ TeV by the ATLAS experiment at the CERN Large Hadron Collider in 2012. Events with one leptonic τ decay and one hadronic τ decay with a single charged particle in the final state are selected. The τ polarisation is measured using the kinematic configuration of the hadronic decay. A polarisation of $P_\tau = -0.14 \pm 0.02\,(\text{stat}) \pm 0.04\,(\text{syst})$ is measured in the mass range $66 < m_{Z/\gamma^*} < 116$ GeV. It agrees with the Standard Model prediction of $P_\tau = -0.1517 \pm 0.0014\,(\text{stat}) \pm 0.0013\,(\text{syst})$.

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1. Introduction

The τ polarisation is the asymmetry of the production cross-sections σ_+ and σ_- for τ^- leptons with positive and negative helicity, respectively

$$P_\tau = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}. \tag{1.1}$$

The positive (negative) helicity states and right-handed (left-handed) chiral states are assumed to coincide in this analysis due to the large boost of the τ leptons.

Decays of the Z boson violate parity in the Standard Model (SM), leading to a net polarisation of the decay products. Z boson decays to pairs of τ leptons provide a unique opportunity to measure the τ polarisation by using the kinematics of the subsequent τ decays, hence testing the SM predictions. The most precise result for the τ polarisation in $Z \to \tau\tau$ decays to date is the combination of the LEP experiments [1] performed in electron–positron collisions at the Z boson pole. It is presented in terms of the τ production asymmetry, A_τ, which, by convention, has reversed sign with respect to P_τ and contains small ($\mathcal{O}(0.005)$) corrections for the contribution from the interference of the Z boson and photon propagators and for the pure photon contribution. The result is $A_\tau = 0.1439 \pm 0.0043$. The measurement presented here and in Ref. [2] is based on the 20.2 fb^{-1} of proton–proton collision data collected at a centre-of-mass energy of $\sqrt{s} = 8$ TeV by the ATLAS experiment. It provides a complementary constraint of the τ polarisation in decays of Z/γ^* bosons in the mass range $66 < m_{Z/\gamma^*} < 116$ GeV that are produced in proton–proton collisions in the ATLAS detector at the LHC via a qqZ vertex. The polarisation value predicted by the SM as implemented in the ALPGEN [3] event generator interfaced with the PYTHIA6 [4] parton shower model and the TAUOLA [5] τ decay library is $P_\tau = -0.1517 \pm 0.0014\,(\text{stat}) \pm 0.0013\,(\text{syst})$. The experimental techniques pioneered in this measurement may be used to suppress SM background processes in searches for new particles, to study the Higgs boson, and to measure the τ polarisation at $\tau\tau$ invariant masses above the Z boson mass.

This document provides a brief description of the analysis highlighting the aspects that were presented in the poster [6] at the EPS conference. Further details can be found in Ref. [2].

2. Datasets and Event Selection

Samples of signal events were produced using the ALPGEN [3] event generator interfaced with the PYTHIA6 [4] parton shower model and the TAUOLA [5] τ decay library. The τ helicity was not stored during event generation, but is assigned randomly based on the kinematic configuration of the τ decays using the TAUSPINNER [7] package associated with the TAUOLA library. Additionally, the signal sample is split into events inside and outside the $66 < m_{Z/\gamma^*} < 116$ GeV range in which the τ polarisation is measured. Samples of $Z/\gamma^* \to ee$ and $Z/\gamma^* \to \mu\mu$ ($Z/\gamma^* \to \ell\ell$), as well as of $W \to e\nu$, $W \to \mu\nu$ and $W \to \tau\nu$ (W+jets) decays were produced using the ALPGEN event generator interfaced with the PYTHIA6 parton shower and TAUOLA τ decay models. A sample of top pair events was produced using the POWHEG [8, 9, 10] event generator interfaced with the PYTHIA6 parton shower model. The response of the ATLAS detector [11] was simulated [12] using the GEANT4 [13] package. Simulated events were overlaid with minimum-bias events produced with the PYTHIA8 [14] event generator to account for pile-up and were processed through the same reconstruction algorithms as the data.

Events are selected by triggers that require an electron or a muon with $p_{\mathrm{T}} > 24$ GeV. Those selected by an electron (muon) trigger are considered in the τ_e–τ_{had} (τ_μ–τ_{had}) channel. They must include exactly one electron or muon (lepton) that passes kinematic acceptance and identification criteria [15, 16] as well as isolation requirements. The flavour of the identified lepton must agree with that found at trigger level. Events also have to contain exactly one hadronic τ decay candidate (τ_{had} with visible component $\tau_{\text{had-vis}}$) that passes kinematic acceptance and identification requirements [17] and that has a single matched track in the inner detector. The lepton and τ_{had} must have opposite electric charges. The transverse mass of the lepton and the missing transverse momentum $\left(E_{\mathrm{T}}^{\mathrm{miss}}\right)$, m_{T}, must be below 30 GeV. The sum of the azimuthal angles between the lepton and the $E_{\mathrm{T}}^{\mathrm{miss}}$ and between the τ_{had} and the $E_{\mathrm{T}}^{\mathrm{miss}}$, called $\sum\Delta\phi$, must be smaller than 3.5 rad. Finally, the invariant mass of the lepton and the τ_{had} must be in the range 40–85 GeV. Events are categorised into the τ_e–τ_{had} and τ_μ–τ_{had} channels.

3. Decays of τ Leptons and Polarisation Observable

The kinematic configuration of single-prong hadronic τ decays ($\tau \to h^\pm \geq 0h^0\nu_\tau$, where $h^\pm$ denotes one $\pi^\pm$ or $K^\pm$ and h^0 denotes possible neutral hadrons which are mostly π^0 mesons) is exploited to measure the τ polarisation. It is sensitive to the polarisation because neutrinos (anti-neutrinos) are always left-handed (right-handed). In $\tau \to h^\pm\nu_\tau$ decays, the momentum fraction carried by the $h^\pm$ is larger for right-handed than for left-handed τ^-.[1] This can, however, not be observed directly, because the neutrino remains undetected. In $\tau \to h^\pm h^0\nu_\tau$ decays, the momentum–sharing of the $h^\pm$ and h^0 is preferentially symmetric (asymmetric) in decays of left-handed (right-handed) τ^-, which is characterised by the charged asymmetry observable

$$\Upsilon = \frac{p_{\mathrm{T}}^{h^\pm} - p_{\mathrm{T}}^{h^0}}{p_{\mathrm{T}}^{\tau_{\text{had-vis}}}} = 2\frac{p_{\mathrm{T}}^{\mathrm{track}}}{p_{\mathrm{T}}^{\tau_{\text{had-vis}}}} - 1 \tag{3.1}$$

(see Figure 1). A similar but less pronounced difference in the energy–sharing of the $h^\pm$ and neutral hadrons is present in the remaining single-prong hadronic τ decays.

4. Background Estimation

The dominant W+jets and multijet backgrounds are estimated using data-driven methods, while the $Z/\gamma^* \to \ell\ell$ and top pair (other) backgrounds are estimated using simulation. The subtraction of the signal and other background contributions from the control regions used in the data-driven background estimates is performed using simulation, assuming the τ polarisation from the SM. Due to the small signal contribution in these regions, the assumption has a negligible effect.

The W+jets background is estimated from a control region, called the W+jets control region, in which the $\sum\Delta\phi$ requirement is inverted and the m_{T} requirement is altered to $m_{\mathrm{T}} > 70$ GeV. The

[1] Due to nearly exact CP conservation in τ decays the distributions for right-handed (left-handed) τ^+ are identical to left-handed (right-handed) τ^-.

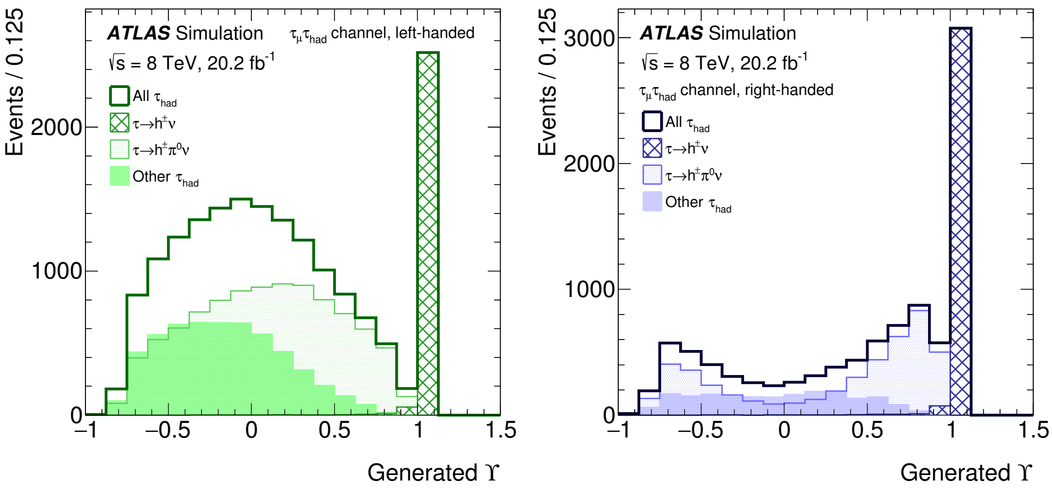

Figure 1: Charged asymmetry distributions as defined in Eq. (3.1) for left-handed (left) and right-handed (right) single-prong reconstructed τ_{had} leptons in simulated $Z/\gamma^* \to \tau\tau$ decays after the full event selection in the τ_μ–τ_{had} channel [2]. The charged asymmetry is calculated from stable-particle-level quantities. In addition to the inclusive distributions, the constituent distributions corresponding to generated τ leptons that decay in the $\tau \to h^\pm\nu$ and $\tau \to h^\pm\pi^0\nu$ ($h^\pm$ denotes $\pi^\pm$ or $K^\pm$) modes are overlaid, as well as that of the remaining decay modes. The latter mainly consist of $\tau \to h^\pm N\pi^0\nu$ decays, where $N \geq 2$. The analysis does not, however, distinguish between the decay modes. The distributions are normalised to their respective cross-sections. Here, the polarisation is taken from the simulation.

W+jets contribution in the W+jets control region is obtained by subtracting the signal and the other background contributions from the data. The multijet contribution in this region is negligible. The resulting W+jets ϒ distribution is scaled with the simulated ratio of the W+jets event yields in the signal and W+jets control regions. Afterwards, a small shape correction is applied to obtain the predicted ϒ distribution of W+jets events in the signal region.

The multijet background is estimated from a control region in which the lepton and the τ_{had} are required to have the same instead of opposite electric charges, called the same-sign region. The W+jets contribution in the same-sign region is estimated as for the signal region. The multijet ϒ distribution is obtained by subtracting the signal, W+jets and other background contributions from the data. It is scaled with the opposite-sign to same-sign ratio of multijet events found in control regions in which the lepton isolation requirements are inverted. Uncertainties in the multijet estimate are dominated by the limited size of the control regions.

5. Dominant Systematic Uncertainties

Uncertainties in the modelling of the signal process are estimated by comparing stable-particle level distributions in the nominal and alternative signal samples. Uncertainties in the splitting of the signal sample into left- and right-handed subsamples by using the TauSpinner algorithm [7] are estimated using the same methods as in Ref. [18]. The uncertainties in the modelling of the τ_{had} identification are dominated by the impact of τ_{had} identification on the shape of the signal ϒ distribution. They are estimated by extracting uncertainties on the modelling of the input variables [17] used in τ_{had} identification from the W+jets control region and a region enriched in top pair events with real τ_{had} decays. The differences observed in the input variable distributions are propagated to the signal Υ templates in the signal region and through the analysis. The τ_{had} energy scale (TES) uncertainty estimate is based on the single-hadron response studies documented in Ref. [17]. Additionally, uncertainties on the τ_{had} energy resolution (TER) are considered. They are estimated from the Υ distribution in the signal region in parallel to the τ polarisation. Uncertainties in the energy response are considered separately for π^0 mesons and other hadrons.

6. Determination of τ Polarisation

The τ polarisation is determined in an extended binned maximum-likelihood fit to the Υ distributions in the signal and same-sign regions (see Figure 2). The left- and right-handed signal templates and the contribution of $Z/\gamma^* \to \tau\tau$ decays outside the $66 < m_{Z/\gamma^*} < 116$ GeV range are taken from simulation. The templates for the other backgrounds are taken from simulation as well. The W+jets template is taken from the data-driven estimate. The multijet contribution is estimated from the same-sign region in the fit to ensure that the statistical uncertainties in the estimate are precisely accounted for. Nuisance parameters are included in the fit to steer variations of the shape and normalisation of the signal and background templates within the estimated systematic uncertainties. The τ polarisation is determined from the relative normalisation of the left- and right-handed signal templates.

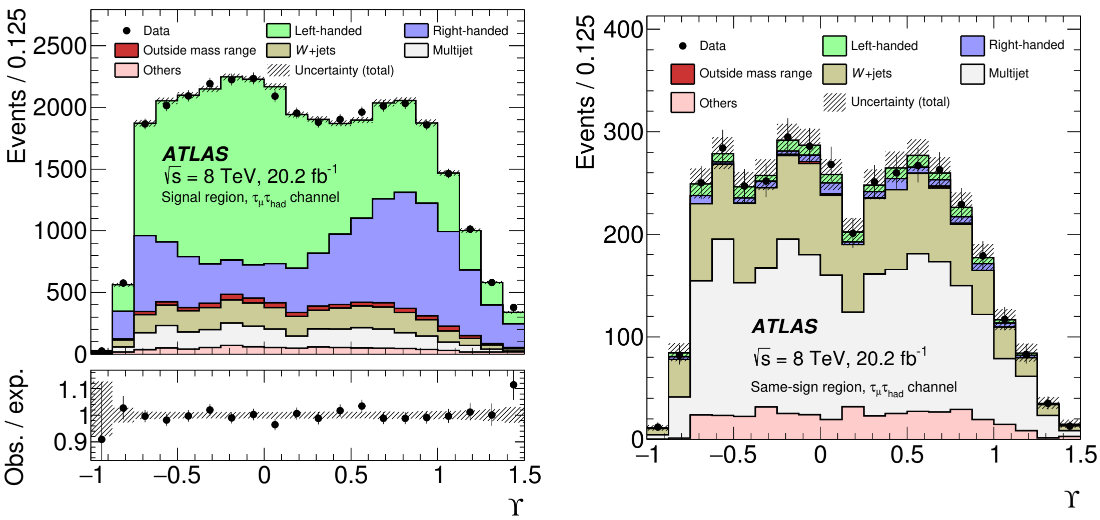

Figure 2: Post-fit Υ distributions for the τ_μ–τ_{had} channel for the signal region (left) and same-sign region (right) [2].

A value of $P_\tau = -0.14 \pm 0.02$ (stat) $\pm$ 0.04 (syst) is measured in the mass range of $66 < m_{Z/\gamma^*} < 116$ GeV. This value agrees with the SM prediction of $P_\tau = -0.1517 \pm 0.0014$ (stat) $\pm$ 0.0013 (syst).

7. Conclusions

A measurement of the τ polarisation in $Z/\gamma^* \to \tau\tau$ decays in proton–proton collisions at the LHC with the ATLAS detector is presented. The dataset recorded at a centre-of-mass energy of 8 TeV with an integrated luminosity of 20.2 fb^{-1} is used. The τ polarisation is measured in the mass range of $66 < m_{Z/\gamma^*} < 116$ GeV and a value of $P_\tau = -0.14 \pm 0.02$ (stat) $\pm$ 0.04 (syst) is found. It agrees with the SM prediction of $P_\tau = -0.1517 \pm 0.0014$ (stat) ± 0.0013 (syst), which is obtained from the ALPGEN event generator interfaced with the PYTHIA6 parton shower model and the TAUOLA τ decay library.

References

[1] The ALEPH Collaboration, The DELPHI Collaboration, The L3 Collaboration, The OPAL Collaboration, The SLD Collaboration, The LEP Electroweak Working Group, The SLD Electroweak and Heavy Flavour Groups, *Precision electroweak measurements on the Z resonance*, *Phys. Rept.* **427** (2006) 257, [hep-ex/0509008].

[2] ATLAS Collaboration, *Measurement of τ polarisation in $Z/\gamma^* \to \tau\tau$ decays in proton–proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, arXiv:1709.3490.

[3] M. L. Mangano et al., *ALPGEN, a generator for hard multiparton processes in hadronic collisions*, *JHEP* **07** (2003) 001, [hep-ph/0206293].

[4] T. Sjöstrand, S. Mrenna, and P. Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026, [hep-ph/0603175].

[5] S. Jadach, J. H. Kuhn, and Z. Was, *TAUOLA: A Library of Monte Carlo programs to simulate decays of polarized tau leptons*, *Comput. Phys. Commun.* **64** (1990) 275.

[6] Benedict Winter on behalf of the ATLAS Collaboration, *Measurement of Tau Polarisation in $Z/\gamma^* \to \tau\tau$ Decays in Proton-Proton Collisions at $\sqrt{s} = 8$ TeV with the ATLAS Detector*, ATL-PHYS-SLIDE-2017-522, 2017.

[7] Z. Czyczula, T. Przedzinski, and Z. Was, *TauSpinner Program for Studies on Spin Effect in tau Production at the LHC*, *Eur. Phys. J. C* **72** (2012) 1988, [arXiv:1201.0117].

[8] P. Nason, *A New method for combining NLO QCD with shower Monte Carlo algorithms*, *JHEP* **11** (2004) 040, [hep-ph/0409146].

[9] S. Frixione, P. Nason, and C. Oleari, *Matching NLO QCD computations with Parton Shower simulations: the POWHEG method*, *JHEP* **11** (2007) 070, [arXiv:0709.2092].

[10] S. Alioli, P. Nason, C. Oleari, and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, *JHEP* **06** (2010) 043, [arXiv:1002.2581].

[11] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

[12] ATLAS Collaboration, *The ATLAS Simulation Infrastructure*, *Eur. Phys. J. C* **70** (2010) 823, [arXiv:1005.4568].

[13] S. Agostinelli et al., *GEANT4 - a simulation toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250.

[14] T. Sjöstrand, S. Mrenna, and P. Z. Skands, *A brief introduction to PYTHIA 8.1*, *Comput. Phys. Commun.* **178** (2008) 852, [arXiv:0710.3820].

[15] ATLAS Collaboration, *Electron efficiency measurements with the ATLAS detector using the 2012 LHC proton–proton collision data*, ATLAS-CONF-2014-032, 2014.

[16] ATLAS Collaboration, *Measurement of the muon reconstruction performance of the ATLAS detector using 2011 and 2012 LHC proton–proton collision data*, *Eur. Phys. J. C* **74** (2014) 3130, [arXiv:1407.3935].

[17] ATLAS Collaboration, *Identification and energy calibration of hadronically decaying tau leptons with the ATLAS experiment in pp collisions at* $\sqrt{s} = 8$ *TeV*, *Eur. Phys. J. C* **75** (2015) 303, [arXiv:1412.7086].

[18] J. Kalinowski, W. Kotlarski, E. Richter-Was, and Z. Was, *Production of τ lepton pairs with high pT jets at the LHC and the TauSpinner reweighting algorithm*, *Eur. Phys. J. C* **76** (2016) 540, [arXiv:1604.0096].