Reconstruction of tau leptons and prospects for SUSY in ATLAS

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Abstract. Final states with tau leptons may play a special role among the broad variety of signatures for the production of supersymmetric particles at the LHC. The algorithms for tau reconstruction and identification are discussed, which are essential ingredients to reject the huge background from QCD processes. The status of analyses of SUSY tau lepton final states within the ATLAS experiment at the LHC are presented, which range from a study of semi-inclusive discovery prospects to more exclusive processes with two tau leptons from $\tilde{\chi}_2^0$ decays and their implications for the determination of SUSY parameters. Also, the prospects for exploiting tau lepton polarization are discussed.

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INTRODUCTION

Supersymmetry (SUSY) is one of the most promising extensions of the Standard Model (SM). Tau signatures are of special interest for SUSY analyses because of the large mixing of $\tilde{\tau}_L$ and $\tilde{\tau}_R$ in a large part of the SUSY parameter space. This leads to an enhancement of decays into tau leptons. Furthermore, tau mass spectra from the decay $\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1^{\pm}\tau^{\mp} \rightarrow \tilde{\chi}_1^0\tau^{\pm}\tau^{\mp}$ provide information about the $\tilde{\tau}$ masses, and tau decays offer the opportunity to measure the tau polarization, which yields information about the coupling structure of the $\tilde{\tau}$ to the neutralinos $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$. To fully exploit the possibilities offered by tau final states, a good tau identification capable of reconstructing comparatively soft tau leptons in a busy SUSY environment and of distinguishing these tau leptons from QCD jets is required.

In the following, SUSY analyses with tau final states in ATLAS [1] will be described, after an introduction to the tau reconstruction and identification algorithms [1] they depend on.

TAU RECONSTRUCTION AND IDENTIFICATION IN ATLAS

Tau leptons ($c\tau = 87\mu m$) decay within the ATLAS detector, and have to be identified by their decay characteristics. In 35% of all cases they decay into electrons or muons, which are hard to distinguish from primary leptons. Current tau reconstruction therefore focuses on the 65% hardonically decaying taus, which are further classified according to the number of charged tracks as so-called 1-prong (50%) or 3-prong (15%) decays. These decays happen predominantly via vector meson resonances, most importantly the ρ and the a_1, but finally end in pion or kaon production. Hadronically decaying taus are therefore seen as jets of charged and neutral pions or kaons. Compared to QCD jets, tau jets are more collimated, with fewer and more isolated tracks. The ratio of electromagnetic to hadronic energy is also used to distinguish taus from QCD jets, as well as the impact parameters or a displaced vertex for the 1-prong or 3-prong decays, respectively.

Two tau identification algorithms have been developed in ATLAS to reconstruct tau leptons and separate them from QCD jets:

The calorimeter-based algorithm takes calorimeter clusters as seeds, which are required to have a transverse energy of at least 10 GeV in order to form a tau candidate. Tau properties such as energy and position are calculated based on the calorimeter information. Matching tracks are then searched for, and a likelihood discriminant is formed from calorimeter and tracking information to distinguish from QCD jets.

The track-based algorithm takes a high quality leading track (p_T >6 GeV) as seed and builds a tau candidate in a narrow cone (ΔR[1] < 0.2) around it. The tau direction is calculated from tracking information, while the energy calculation uses an *energy flow* approach. Tracking and calorimeter quantities are then used to form different discriminants based on cuts, on an artificial neural network or on a PDRS[2].

To take advantage of the benefits of both algorithms, they have been combined: The track-seeded algorithm is run first, and if a matching calorimeter seed is found, both algorithms are used. In that case, the position and track multiplicity of the tau is defined by the track-based algorithm, while its transverse energy is calculated by the calorimeter cell information. After this matching procedure, a search for τ candidates is made amongst the remaining calorimeter objects. 70% of all tau candidates are found by both the track- and calorimeter-based algorithms, 5% are track-only candidates and 25% are calorimeter-only candidates.

For early data-taking, the multivariate discriminants of both algorithms are not considered reliable until the detector and the discriminating power of the complex variables entering them are well understood. Therefore, a *safe variable* approach is currently being developed, whereby a cut-based identification using a subset of variables less complex and less sensitive to detailed detector understanding will be employed.

SUSY ANALYSES WITH TAU LEPTONS

The results presented in the following are for SUSY parameters obtained with minimal supergravity (mSUGRA) examples, and assume R-parity conservation. The analyses aim at 1 fb^{-1} LHC data at 14 TeV centre-of-mass energy[3] if not stated otherwise. The combination of the two tau reconstruction algorithms had not been implemented in the software version used, therefore tau lepton identification is done by either one of the algorithms.

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[1] $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, where η is the pseudorapidity and ϕ is the azimuthal angle

[2] Probability density estimator based on range search.

[3] Signal cross-sections at 10 TeV centre-of-mass energy are about one third of those at 14 TeV.

Inclusive searches: tau mode

Since leptonic tau decays are included in the lepton mode searches, the restriction of the tau identification algorithms to hadronically decayed taus produces no loss in efficiency. The following event selection is applied:

- at least 1 τ (calorimeter-based, $\mathrm{p_T} > 40$ GeV), no isolated e,μ,
- 4 jets with $\mathrm{p_T} > 50$ GeV, leading jet: $\mathrm{p_T} > 100$ GeV,
- $\mathrm{E_T^{miss}} > 100$ GeV and $\mathrm{E_T^{miss}} > 0.2 \cdot \mathrm{M_{eff}}$ ($\mathrm{M_{eff}} = \mathrm{E_T^{miss}} + \sum_{i=1}^{4} \mathrm{p_T^{jet_i}} + \sum_{\mathrm{i=1}}^{\mathrm{N}} \mathrm{p_T^{lepton_i}}$),
- $\Delta\phi(\mathrm{jet}_{1,2,3}, \mathrm{E_T^{miss}}) > 0.2$,
- transverse mass of hardest τ (visible momentum) and $\mathrm{E_T^{miss}}$: $\mathrm{M_T} > 100$ GeV.

Events selected in this way can be triggered with approximately 97-100% efficiency by a trigger that requires one jet with $\mathrm{p_T} > 70$ GeV and $\mathrm{E_T^{miss}} > 70$ GeV.

At 1 fb^{-1}, 51 SM background events are expected to pass these cuts. The corresponding number of signal events is 259 for the ATLAS bulk region point SU3[4] and 119 for the ATLAS funnel region point SU6[5].

Exclusive studies: measurement of SUSY parameters

In an R-parity conserving scenario, no mass peaks can be measured because of the escaping lightest SUSY particle (LSP) in each decay cascade. Information about masses can be obtained by measuring the endpoints of invariant mass spectra: For the decay $\tilde{\chi}_2^0 \to \tilde{\tau}_1^{\pm}\tau^{\mp} \to \tilde{\chi}_1^0\tau^{\pm}\tau^{\mp}$, the endpoint of the $\tau\tau$ invariant mass spectrum is given by $m_{\tau\tau}^{\max} = \sqrt{\frac{(m^2_{\tilde{\chi}_2^0} - m^2_{\tilde{\tau}_1})(m^2_{\tilde{\tau}_1} - m^2_{\tilde{\chi}_1^0})}{m^2_{\tilde{\tau}_1}}}$.

Due to the escaping neutrinos in the tau decay, the characteristic triangular shape of this spectrum is lost. The trailing edge of the spectrum can be described by a log-normal function, the inflection point of which can be translated into the corresponding endpoint by a calibration. This calibration has been obtained by measuring inflection points for known SUSY masses and therefore known endpoints. The result for the SU3 point is $(102 \pm 17^{stat} \pm 5.5^{syst})$GeV. The theoretical endpoint lies at 99 GeV.

For the ATLAS coannihilation point SU1[6], a similar study has been performed, aiming at 18 fb^{-1} because of the lower signal cross-section. Due to the small mass difference between the $\tilde{\tau}_1$ and the $\tilde{\chi}_1^0$, the corresponding τ has low transverse momentum. Therefore the track-seeded tau reconstruction algorithm is used in this study, rather than the calorimeter-based approach employed in the SU3 analyses. The result obtained by using the same technique and the same calibration as the bulk region study (but different event selection) is $(70 \pm 6.5^{stat} \pm 5^{syst})$GeV, with a theoretical endpoint value of 78 GeV.

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[4] ATLAS bulk region point: $\mathrm{m_0}$ = 100 GeV, $\mathrm{m_{1/2}}$ = 300 GeV, $\mathrm{A_0}$ = -300 GeV, tanβ = 6, sgnμ: +

[5] ATLAS funnel region point: $\mathrm{m_0}$ = 320 GeV, $\mathrm{m_{1/2}}$ = 375 GeV, $\mathrm{A_0}$ = 0 GeV, tanβ = 50, sgnμ: +

[6] ATLAS coannihilation region point: $\mathrm{m_0}$ = 70 GeV, $\mathrm{m_{1/2}}$ = 350 GeV, $\mathrm{A_0}$ = 0 GeV, tanβ = 10, sgnμ: +

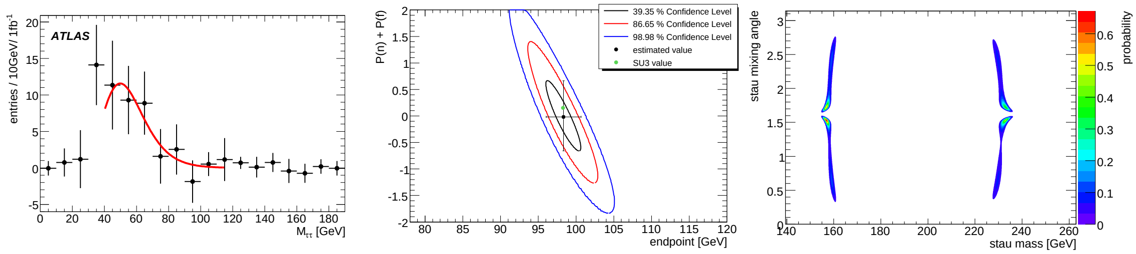

FIGURE 1. 1dim log-normal fit , 2dim fit result with CL ellipses and concluding probability for $m_{\tilde{\tau}}$, $\theta_{\tilde{\tau}}$

Polarization effects. For a single pion decay $\tau^{\pm} \to \pi^{\pm}\nu_{\tau}$, the fixed neutrino handedness gives the pion a τ-polarization dependent boost parallel or antiparallel to the tau momentum direction. Therefore, the $\tau\tau$ mass spectrum is distorted depending on the combination of tau polarizations. While the distribution depends slightly on the product of the polarisations, it is a good approximation to regard it as a function of their sum [2]. For tau decays via the ρ meson, the effect is the same as for pion decays, while the overall effect for decays via a_1 vanishes.

SUSY masses affect the shape of the spectrum predominantly in the high mass region, τ polarization near its mean value. Therefore, these influences can be disentagled by choosing two traits of the spectrum with different sensitivity to the two effects, and perform a 2-dimensional calibration [2] similar to the one described above. Measurement of those two characteristics can be translated into two equipotential lines in the plane of the sum of polarization vs. endpoint. The intersection of those lines give the measured values for both. Assuming the neutralino sector is already known from other measurements, the $\tilde{\tau}_1$ mass can be calculated from the endpoint and the stau mixing angle $\theta_{\tilde{\tau}}$ from the polarization sum. The result for 35 fb^{-1} is shown in figure 1.

This measurement could be significantly improved by considering different tau decay modes separately, and exploit the different polarization dependences. Current tau reconstruction does not offer this possibility. However, work is ongoing to improve an ansatz which makes use of the fine ATLAS calorimeter granularity to reconstruct π^0 subclusters within the tau jet, the number of which is related to the tau decay mode. By the time a sufficient amount of data has been collected to allow for a polarization study, tau reconstruction might allow for a more precise measurement by offering tau decay mode information.

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