Reconstruction and identification of hadronic tau-decays in ATLAS

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The identification of τ-jets from the hadronic τ-decay is crucial for the study of many physics channels like the production of Higgs bosons decaying to τ or SUSY. The τ-jet reconstruction in ATLAS is performed starting from the energy deposited in the calorimeters or also combining measurements from calorimeter and tracking with an energy-flow technique. Quantities built both from the calorimeters and from the inner detector are used to identify τ-jets against other jets. In the talk we will review the performance of τ-jet reconstruction and identification, showing that the excellent τ-efficiency versus the jet-rejection obtained in ATLAS will allow the study of channels where the background from jets is potentially very large.

1. Introduction

Tau leptons play an important role in the physics to be observed at LHC. They enter in electroweak measurements, studies of the top quark and are also a signature in searches for new phenomena such as Higgs, Supersymmetry and Extra Dimensions.

Tau reconstruction and identification at hadron colliders is not a simple task. The multi jet events which dominate the backgrounds have an enormous cross section. Another challenge is the hadronic τ-decay trigger.

In this contribution, we describe two methods for τ-jet reconstruction and identification studied in the ATLAS experiment.

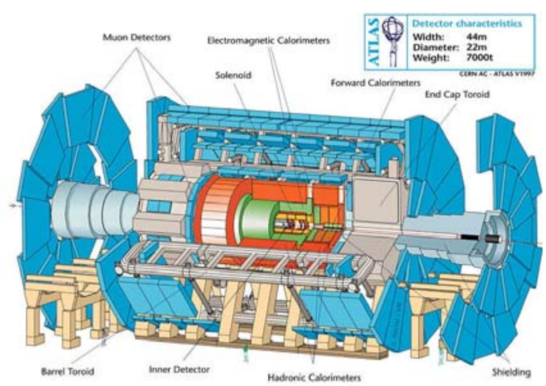

Figure 1. A schematic view of the ATLAS detector with its sub-detectors.

2. ATLAS detector

The ATLAS (A Toroidal LHC Apparatus) detector is illustred in Fig.1. It measures 22 m high, 44 m long and weighs 7000 tons. We give a brief description of the detector sub-systems used for τ jet reconstruction and identification. The ATLAS detector is composed of a tracker, a calorimeter system (electromagnetic and hadronic) and of a large muon spectrometer. More details about the detector can be found elsewhere [1].

2.1. ATLAS tracking

The precision inner tracker is constituted of pixels and of silicon strip wafers (SCT). In addition, a continuous tracking for pattern recognition and electron identification (e/π separation) is obtained with the TRT (Transition Radiation Tracker). The inner detector is inside a 2 Tesla solenoid magnet. The expected momentum resolution is :

$$\sigma_p/p = 0.05\%p\ (GeV) \oplus 1\%$$

in the range $|\eta| < 2.5$ and a pion rejection factor of $9-40$ at 90% electron efficiency.

2.2. ATLAS calorimetry

The accordion lead-liquid argon electromagnetic calorimeter is segmented longitudinally in 3 layers : Strips, Middle and Back; the first layer has thin segmentation in η : $\Delta\eta \times \Delta\phi = 0.003 \times 0.1$, $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ for the second layer and $\Delta\eta \times \Delta\phi = 0.05 \times 0.025$ for the last layer. In front of the accordion there is a presampler. The expected energy resolution is given by :

$$\sigma_E/E = 10\%\sqrt{E} \oplus 0.5E \oplus 0.7\%$$

in the range $|\eta| < 2.5$, for high luminosity and with the energy in GeV.

The scintillator-tile hadronic calorimeter has 3 longitudinal samplings but with a bigger granularity ($\Delta\eta \times \Delta\phi = 0.1 \times 0.1$, for the two first layers and $\Delta\eta \times \Delta\phi = 0.2 \times 0.1$ for the last one). The expected energy resolution is given by :

$$\sigma_E/E = 50\%\sqrt{E} \oplus 3\%$$

in the range $|\eta| < 3$ and with the energy in GeV. The aim of the calorimeters is to measure the absolute jets energy scale to the $\sim 1\%$ level.

3. Physics processes with τ leptons and their decays

A number of benchmark processes depend on the reconstruction efficiency and identification of hadronic τ : light Standard Model (SM) Higgs produced in Vector Boson Fusion (VBF) $qqH \rightarrow qq\tau\tau$, charged SUSY Higgs production $H \rightarrow \tau\nu$, neutral SUSY Higgs $H/A \rightarrow \tau\tau$ at large $tan\beta$, SUSY signatures with τ in the final state as well as Extra Dimensions [2]. We can use $Z \rightarrow \tau\tau$ and $W \rightarrow \tau$ events to understand and calibrate the calorimeters (commissioning).

Tau leptons decay to hadrons in 64.8% of the cases and to electron or muon the rest of the time. In $\sim 77\%$ of hadronic τ decays, only one charged track is produced :

$$\tau \rightarrow \nu_\tau + \pi^\pm + n\pi^0$$

and in $\sim 23\%$ we have 3 charged tracks :

$$\tau \rightarrow \nu_\tau + 3\pi^\pm + n\pi^0.$$

A τ lepton decaying hadronically will generate a small jet defined as a τ jet. With hadrons and neutrinos amongst the decay products, it is difficult to reconstruct and identify efficiently a τ jet. The background misidentified as a τ is mainly QCD multi jet events, but also electrons that shower late or with strong Bremsstrahlung, or muons interacting in the calorimeter.

4. Hadronic τ-jets reconstruction and identification

A τ-jet can be identified through the presence of a well collimated calorimeter cluster with a small number of associated charged tracks (1 to 4 tracks). In ATLAS, we are studying various methods of τ reconstruction and identification for different purposes.

The first one, TauRec (default algorithm) starts from different objects (clusters or isolated track), associates tracks and clusters to have a τ-jet candidate and then calibrates τ-jet energy using calorimeters.

The second one, Tau1P3P (new algorithm) starts from a good leading hadronic track, creates a single-prong, two-prong, three-prong or four-prong τ-jet candidate and then calibrates τ-jet energy using trackers and calorimeters.

For both algorithms we determine several discriminant variables to separate real τ jets from background which are defined using track and calorimeter informations such as :

- R_{EM} : the jet radius computed using only the electromagnetic calorimeter cells within a certain ΔR of the jet axis;
- ΔE_T^{12}: the fraction of E_T in the electromagnetic and hadronic calorimeters within an isolation region around the jet;
- N_{tr} : the number of charged tracks pointing to the cluster within a certain ΔR;
- Weighted width of the energy deposition in the strips (first layer of the electromagnetic calorimeter)

- E_T/p_T : transverse energy over transverse momentum for the highest p_T track;
- Number of strips;
- Impact parameter;
- Charge : sum of charges of the tracks associated with the τ candidate.

We calculate a likelihood or a discriminant multivariate using some discriminate variables and we apply a set of basic cuts for τ-jet identification and background rejection. Here we describe with more details TauRec and Tau1P3P.

4.1. TauRec algorithm

TauRec is the official algorithm for hadronic τ reconstruction and identification in ATLAS [3] in the range $|\eta| < 2.5$. The τ jet seed consists of a calorimeter cluster, or a jet with $p_T > 15$ GeV, or isolated tracks with $p_T > 2$ GeV. For every candidate, TauRec collects all the tracks with $p_T > 2$ GeV and with $\Delta R < 0.3$ around the center of the seed. A τ-jet candidate is defined by a deposit of energy associated to at least one track.

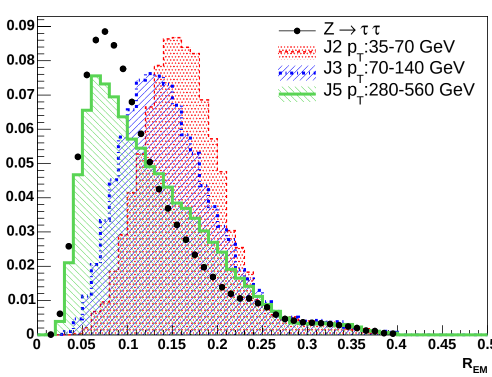

Figure 2. One example of a discriminant variable for τ reconstruction and identification from the TauRec algorithm for signal (true τ-jet) : $Z \rightarrow \tau\tau$ (black solid dots) and background (misidentified as a τ-jet) : QCD jets (color line for various p_T bins).

At a hadron collider, isolation plays an important role against QCD jets backgrounds. For all candidates we build a set of variables for τ-jet identification. The shape for some variables is p_T^τ dependent and also most τ-jet candidates contain one to three charged tracks.
For example, the electromagnetic radius R_{EM} (the jet radius computed using only the electromagnetic calorimeter cells within $\Delta R = 0.4$ of the jet axis, see Fig.2) of a τ-jet is significantly smaller than for QCD jets (only if the boost of the jet is not important), which is why a fine granularity of the electromagnetic calorimeter is important for a good τ-jet identification. Calibration of τ-jet candidates is done using only the calorimeters using a H1-Style method with weights (Monte Carlo) applied directly to cell energies depending on their E/V content (cell energy density), η and layer. This weighting method gives a good jet energy resolution of $\sim 10\%$ (see Fig.3).

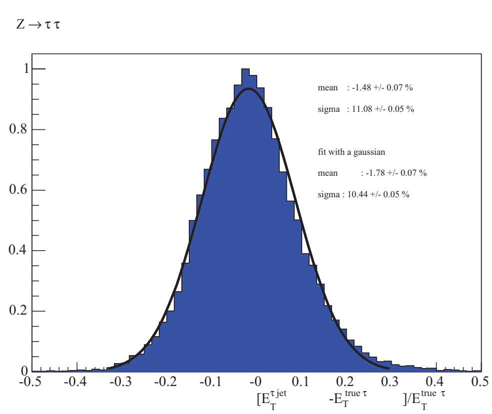

Figure 3. Energy resolution of τ-jet from the TauRec algorithm for signal ($Z \rightarrow \tau\tau$).

We calculate a likelihood using the following variables : R_{EM}, ΔE_T^{12}, $N_{track(s)}$, strips width, N_{strips}, charge, impact parameter and E_T/p_T (1^{st} track). To identify τ jets, we apply a cut on the likelihood which depends on the p_T.
The rejection factor against QCD jets versus the τ-jet reconstruction and identification efficiency [1] (see Fig.4) is illustrated for various p_T bins. A good level of background rejection is expected depending on the p_T. The efficiency of τ reconstruction and identification decreases slowly with increasing p_T, while the rejection increases by a factor 10. For a τ identification efficiency of 30%, a rejection between 400 and 10000 can be achieved for $15 < p_T < 334\ GeV$.

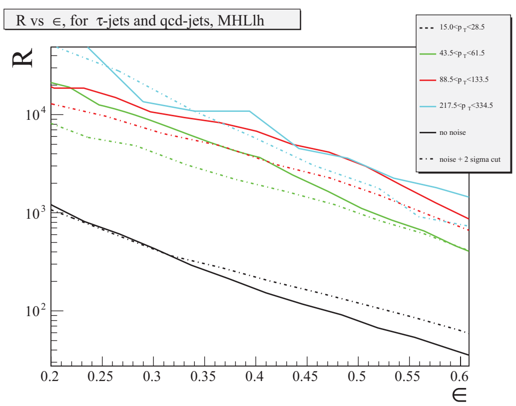

Figure 4. Rejection factor against QCD jets versus the τ-jet reconstruction and identification efficiency using cuts on the likelihood for various p_T bins, for $Z \to \tau\tau$.

The TauRec algorithm has the possibility to start with different objects, shows good efficiency for τ-jet reconstruction and identification and a good rejection against QCD jets background. We have also a good energy resolution *à la H1*.

[1]The τ efficiency is defined as the ratio of true τ jets identified as a τ over the number of true τ jets in the sample

4.2. Tau1P3P algorithm

Tau1P3P is a new and complementary algorithm aimed at soft τ reconstruction and identification [3][4]. It is seeded by a good quality track, and an energy flow approach is used to define the energy scale. The tracker transverse momentum resolution is better than the calorimetric transverse energy resolution for $E_T < 120\ GeV$. The algorithm is dedicated for τ jets with $E_T \sim 20-70\ GeV$. It can be particularly interesting for light Higgs or for soft SUSY searches.

Tau1P3P explores exclusive features of τ leptons, where a hadronic τ does not correspond to a typical jet but rather to a single charged prong or three charged prong topology : $1\ track + \sum \pi^0$ and : $3\ tracks + \sum \pi^0$. The decay products are well collimated in space and the charged tracks direction can provide a precise estimate for the true τ direction. The algorithm starts from a *good quality* hadronic track with $p_T > 9\,GeV$, then it finds nearby *good quality* tracks inside a core region of $\Delta R < 0.2$ and with $p_T > 1\,GeV$. At present, the Tau1P3P algorithm developed provides τ-jet candidates with up to 5 tracks reconstructed in the core region. For most analyses, only the following candidates should be used : single-prong τ-jet candidates (Tau1P) if there are no nearby tracks, and three-prong τ-jet candidates (Tau3P) if there are 2 nearby tracks and if the sum of the three tracks charges is consistent with Tau3P.

For all candidates (Tau1P or Tau3P), the energy scale is defined using an energy flow approach [5] where the p_T of the track is used instead of the E_T measured in the calorimeters for charged hadrons. This gives a good energy resolution for Tau1P τ-jet candidates (7.8%, see Fig.5) and for Tau3P τ-jet candidates (4.9%, see Fig.6) without additional calibration.

The Tau1P3P algorithm calculates for each τ-jet candidate several discriminant variables [3][4] using calorimetric and tracking quantities with $\Delta R < 0.2$ as a *core* and $0.2 < \Delta R < 0.4$ only for isolation. The Tau1P3P algorithm also uses a multivariant analysis [6] which samples the signal and background densities in a multi-dimensional phase-space using range-searching and probability density estimation.

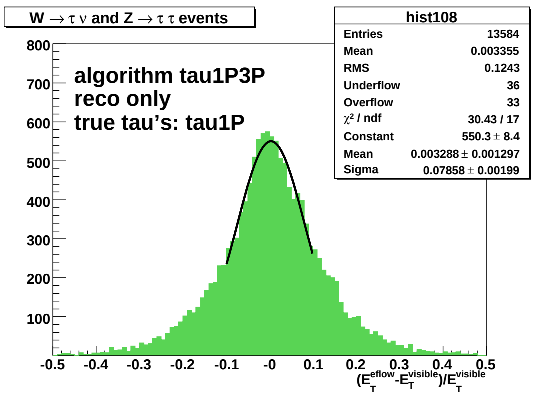

Figure 5. Energy resolution of Tau1P τ-jet candidates using Tau1P3P algorithm for signal ($Z \to \tau\tau$).

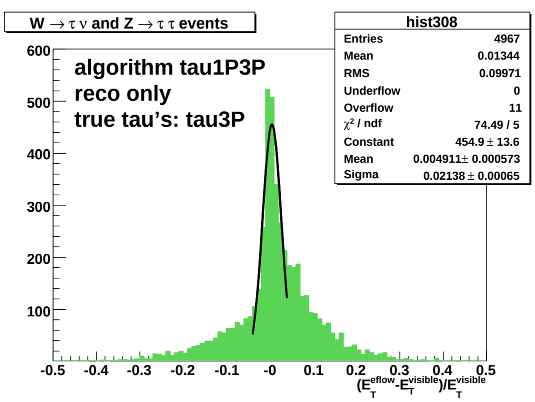

Figure 6. Energy resolution of Tau3P τ-jet candidates using Tau1P3P algorithm for signal ($Z \to \tau\tau$).

The following variables : R_{EM}, N_{strips}, strips width, ΔE_T^{12}, E_T/p_T, and the isolation criteria are combined into a single discriminant variable. To identify τ-jets, we apply a cut on this single discriminant variable. The rejection factor against QCD jets versus the τ-jet reconstruction and identification efficiency (see Fig.7) is illustrated for various p_T bins. A good level of background rejection is expected depending on the p_T. For a τ identification efficiency of 30%, a rejection between 600 and 1000 can be achieved for $15 < p_T < 60\ GeV$.

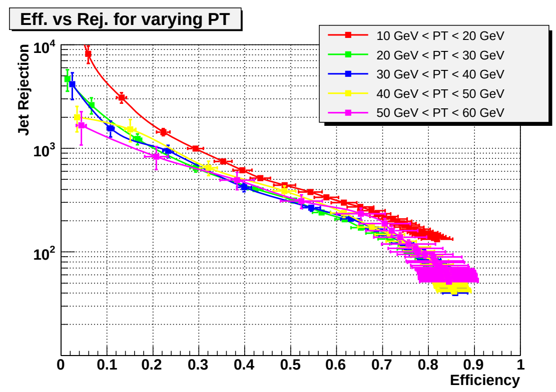

Figure 7. Rejection factor against QCD jets versus the τ-jet reconstruction and identification efficiency using cuts on the discriminant for various p_T bins, for $Z \to \tau\tau$.

The Tau1P3P algorithm which starts with a good quality track, is capable of separating a τ-jet with 1, 2, 3 and 4 tracks and shows a good efficiency for τ-jet identification and a good rejection against QCD jets background. As well, the energy flow approach gives a good energy resolution.

For both algorithms, TauRec and Tau1P3P, the performances still need detailed studies.

5. Conclusion and perspectives

The identification and reconstruction of τ-jets is crucial for several physics studies at LHC and challenging at a hadronic collider. In this contribution, a brief description of the method studied by ATLAS was presented. Hadronic τ decays can be efficiently reconstructed and identified from calorimeter and inner detector tracking with two algorithms. The energy scale is also defined with two different approaches with good results. The τ-jet identification achieved will allow the study of physics channels where the jets background is very large.

Two complementary τ-jet algorithms have been developed in ATLAS, such that robust τ-jet reconstruction and identification should be available to be checked with early data.

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