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Tau identification at ATLAS : importance, method and confrontation with Monte Carlo and test beam

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Tau identification at ATLAS : importance, method and confrontation with Monte Carlo and test beam

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Abstract. Tau jets play an important role in the physics expected at the LHC. Identification of hadronic taus will be one of the keys to beyond the Standard Model searches. We discuss the hadronic tau reconstruction and identification method studied in the ATLAS experiment at CERN. A brief discussion of the tau trigger is also included.

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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 tau trigger.

In this contribution, we describe two methods for τ identification and reconstruction studied in the ATLAS experiment, we discuss the hadronic τ trigger and present preliminary test beam results.

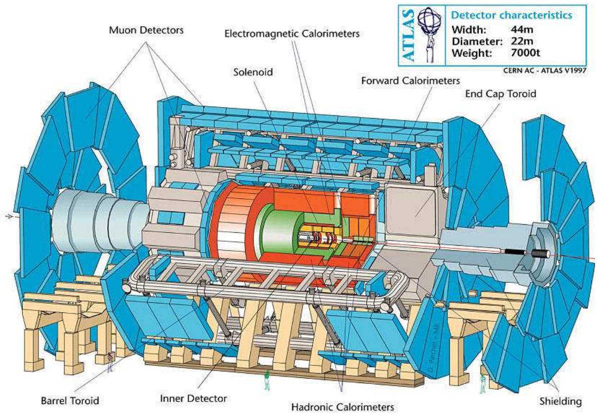

Fig. 1. A schematic view of the ATLAS detector.

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 tau reconstruction. The ATLAS detector is composed of a tracker, a calorimeter system 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. 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 transverse momentum resolution is

$$\sigma_{p_T}/p_T = 0.05\% P_T(GeV) + 1\%$$

and the electron/pion separation is good.

2.2 ATLAS calorimetry

The barrel lead-liquid argon electromagnetic calorimeter has longitudinal segmentation (3 layers : Strips, Middle and Back) with a fine granularity in η for the first layer $\Delta\eta \times \Delta\phi = 0.003 \times 0.1$, $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ for the second layer and $\Delta\eta \times \Delta\phi = 0.05 \times 0.025$ for the last layer. The expected energy resolution is given by

$$\sigma_E/E = 10\%\sqrt{E}(GeV) \oplus 500MeV/E(GeV) \oplus 0.7\%$$

in the range $|\eta| < 3.2$.

The barrel scintillator-tile hadronic calorimeter also 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

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

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

3 Physics processes with τ leptons and their decays

A number of benchmark processes depend on the reconstruction efficiency and identification of hadronic τs : 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 τs in the final state as well as Extra Dimensions. We can also use $Z \rightarrow \tau\tau$ and $W \rightarrow \tau$ events to understand and calibrate the calorimeters.

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

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

and in $\approx 23\%$ 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 tau reconstruction

A τ jet can be identified through the presence of a well collimated calorimeter cluster with a small number of associated charged tracks (1 or 3 tracks). Several discriminant variables used to separate real τ jets from background are defined using track and calorimeter information :

- R_{EM} : the jet radius computed using only the electromagnetic calorimeter cells within $\Delta R = 0.7$ of the jet;
- ΔE_T^{12}: the fraction of E_T in the electromagnetic and hadronic calorimeters within an isolation region of $0.1 < \Delta R < 0.2$ around the jet;
- N_{tr} : the number of charged tracks pointing to the cluster within $\Delta R = 0.3$;
- 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.

In ATLAS, we are studying various methods of τ identification for different purposes. Here we describe two of them.

4.1 TauRec algorithm

TauRec is the official algorithm for hadronic τ reconstruction and identification in ATLAS [2] 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 candidate is defined by a deposit of energy associated to at least one track. At a hadron collider, isolation plays an important role against QCD jets backgrounds. For all candidates we build a set of variables for τ identification (see Fig.2). We see that the shape for some variables is p_T^τ dependent and also that most τ candidates contain one to three charged tracks.

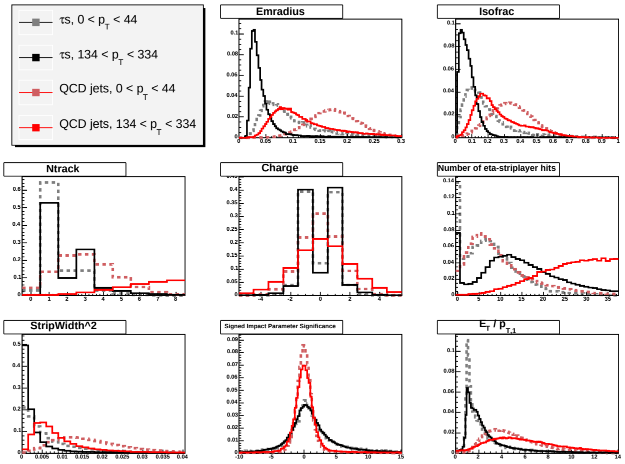

Fig. 2. Discriminant variables for τ reconstruction and identification from the TauRec algorithm for signal (true τ) : $A/H \rightarrow \tau\tau$ (red-solid line : (high p_T) and red-dashed line (low p_T)) and background : QCD jets (black-solid line : (high p_T) and black-dashed line (low p_T)).

The electromagnetic radius R_{EM} of a τ is significantly smaller than for QCD jets, which is why a fine granularity of the electromagnetic calorimeter is important for a good τ identification. Calibration of τ candidates is done using only the calorimeters using a H1-Style method with weights fitted for jets and applied directly to cell energies (depending on their E_T content, η, and layer). This weighting method gives a good jet energy resolution.

We calculate a likelihood (Fig.3) using the following variables : R_{EM}, ΔE_T^{12}, $N_{track(s)}$, strips width, N_{strips}, charge, impact parameter and E_T/p_T. To identify τ jets, we apply a cut on the likelihood which depends on the p_T.

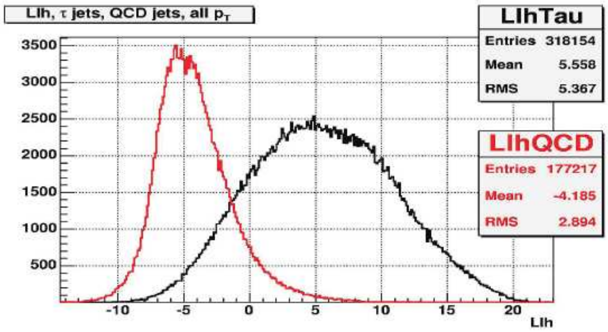

Fig. 3. Likelihood distribution from the TauRec algorithm for signal ($A/H \to \tau\tau$, reconstructed true τ in black : darkest), and for background (QCD jets in red : lightest).

Fig.4 shows the τ-jet identification efficiency [1] (left) and rejection against QCD jets (right) for various seeds versus the p_T. A good level of background rejection is expected depending of the p_T. The efficiency of τ identification decreases slowly with increasing p_T, while the rejection increases by a factor 10. For a τ identification efficiency of 50%, a rejection between 300 and 1500 can be achieved.

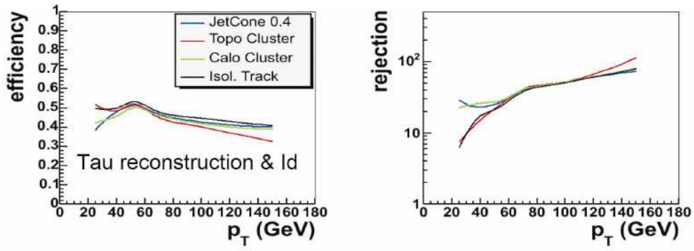

Fig. 4. Signal efficiency (left) and background rejection for an efficiency of 50% (right) obtained with TauRec using four differents seeds. The sample is $ttH \to tt\tau\tau$.

The TauRec algorithm shows good efficiency for hadronic τ jet reconstruction and identification and a good rejection against QCD jets background. We have also a good energy resolution using H1-style.

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. As can be seen in Fig.5, 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 $E_T \approx 20 - 70$ GeV. It can be particularly interesting for light Higgs or for soft SUSY searches.

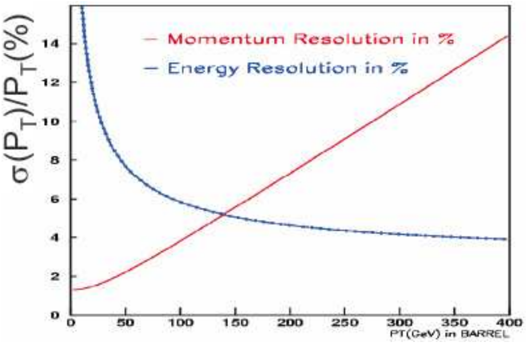

Fig. 5. Transverse momentum resolution for the tracker (red : lightest) and transverse energy resolution for the calorimeters (blue : darkest) in % versus p_T, in the barrel.

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 $\Delta R < 0.2$ and with $p_T > 2\,GeV$. It creates a single-prong candidate (Tau1P) if there are no nearby tracks. If there are 2 nearby tracks, it checks that the sum of the three tracks charges is consistent with a three-prong candidate (Tau3P).

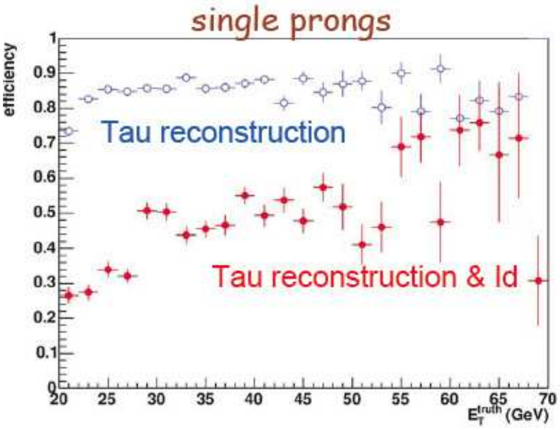

Fig. 6. Efficiency for τ reconstruction (blue circles) and for τ reconstruction and identification (red full circles) using the cut based analysis, versus the true τ transverse energy, for $Z \to \tau\tau$ events, and for $|\eta| < 1.5$.

For all candidates (Tau1P or Tau3P), the energy scale is defined using an energy flow approach [5] where tracks

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[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

within a cone of $\Delta R < 0.2$ are used. This gives a good energy resolution without additional calibration.

The Tau1P3P algorithm calculates for each candidate discriminant variables [3][4] using $\Delta R < 0.2$ as a "core" and $0.2 < \Delta R < 0.4$ only for isolation. Fig.6 shows the τ reconstruction efficiency, as well as the reconstruction and identification efficiency, using basic cuts on the tracks (i.e. p_T) for $Z \rightarrow \tau\tau$ events. The reconstruction efficiency is 82.6 % (90.3 % for single prong and 62 % for three prongs), while the reconstruction and identification efficiency, made separately for Tau1P and Tau3P using loose cuts, is 59.1 %. For QCD jets background, the efficiency of reconstruction is 2.0% for Tau1P and 4.2 % for Tau3P. For reconstructed fake candidates from QCD jets, acceptance for identification selection is 10-20% for TauP1 and 19-37% for Tau3P.

Table 1. The identification efficiency for the cut analysis [3][4] and the multivariant analysis for $Z \rightarrow \tau\tau$ signal events and for QCD jets background.

	cut analysis		multivariant analysis	
	sig	bkg	sig	bkg
$\epsilon(\%)$	58.9	14.3	58.9	9.3

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. The observables are combined into a single discriminant variable which is shown in Fig.7, for $Z \rightarrow \tau\tau$ signal events and for QCD jets background. Table 1 shows that with a multivariant analysis, the QCD jets background rejection is improved by a factor 1.5, for the same signal efficiency as the cut based analysis. As well, the energy flow approach gives a good energy resolution.

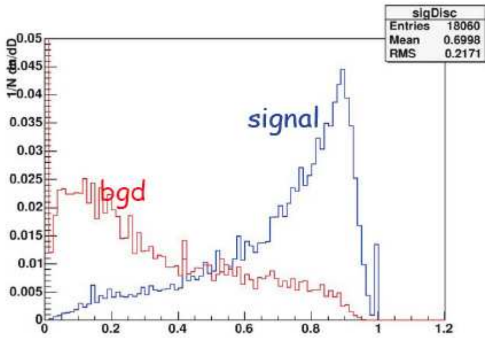

Fig. 7. Discriminant variable distribution, calculated in the Tau1P3P algorithm for $Z \rightarrow \tau\tau$ signal events (blue) and for QCD jets background (red), and for $|\eta| < 1.5$.

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

5 Tau trigger

5.1 ATLAS trigger

The ATLAS trigger system is designed to reduce the 40 MHz bunch crossing frequency to ≈ 100 Hz Fig.8. The online selection is based on three levels. The level 1 (L1) will reduce the initial event rate to ≈ 100 kHz. Then the High Level Trigger (HLT), which consists of the second level (L2) and of the Event Filter (EF), will reduce the rate further to ≈ 100 Hz before writing to mass storage. The hardware based L1 Trigger decision is made with calorimeters (coarse granularity) and muon trigger chambers information, using a defined Region of Interest (RoI). The HLT is a software selection, where the L2 uses the RoI with all detectors and full granularity information. The EF refines the selection and can perform event reconstruction with latest alignement and calibration data.

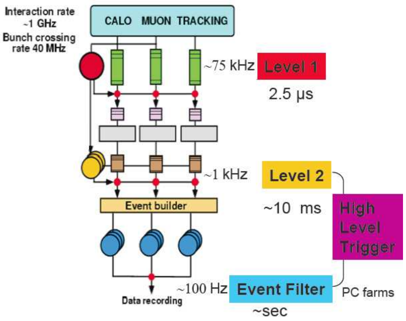

Fig. 8. A schematic view of the ATLAS trigger.

5.2 Hadronic Tau trigger

The τ leptons can be selected either by the lepton trigger (electron or muon) or by the hadronic τ trigger. Here we only discuss the hadronic τ trigger (Tau Trigger). At L1 the Tau Trigger uses 2×2 towers (1 tower : $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$) in the electromagnetic (EM) and hadronic calorimeters to define an RoI. For the isolation, 12×12 towers in the calorimeters (EM and hadronic) are used. The Tau Trigger at L2 uses both calorimeters and tracker information to evaluate offline variables and objets: EM radius of the cluster, width in energy deposition, isolation fraction and tracks. The Event Filter refines the selection based on the TauRec code. The trigger efficiency, rejection and rates for the hadronic τ trigger are presently being evaluated.

6 Experimental results from test beam

6.1 Introduction

In addition to using Monte Carlo data for a fully simulated detector, a great effort is made to study the response of all detectors to single particles in test beam. In 2004, a realistic slice of ATLAS was tested, with trackers, a module of the barrel electromagnetic Liquid Argon calorimeter, a Tile calorimeter module, as well as muon chambers, as show on Fig.9. 90 million events (e, μ, π) were taken. The main aim was to test the combined detector performance and to tune and validate Monte Carlo modelling of the detector response. For the hadronic τ reconstruction and identification, the effort is being put on the combined electromagnetic and hadronic energy resolution and on the e/π efficiency (TRT).

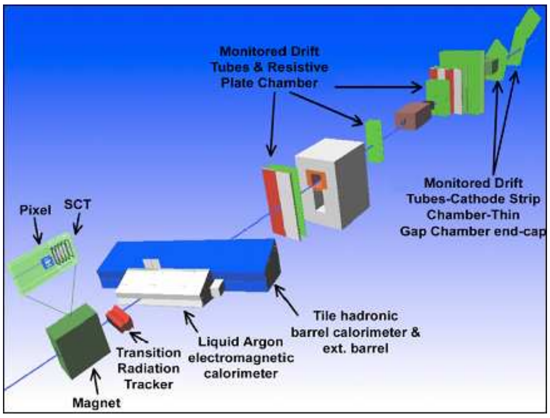

Fig. 9. Layout of the 2004 combined test beam, with a realistic slice of ATLAS.

6.2 Preliminary results

The preliminary standalone hadronic energy resolution without compensation and without correction for energy outside the hadronic calorimeter gives compatible results with previous test beam. Separation between electrons and pions is important for τ identification to reject an electron from hadronic τ candidates. The aim is to try to separate e/π by requiring a minimum number of TRT hits pers track. On Fig.10, we can see a good agreement between the data and Monte Carlo for an energy of 9 GeV and we have an efficiency of electron identification of 90 to 80% for a rejection factor for π between 50 and 250.

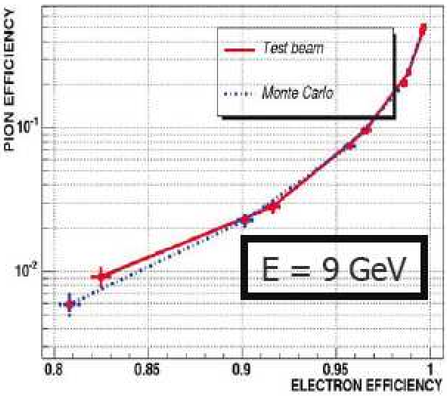

Fig. 10. Comparison between Monte Carlo and test beam data for efficiency of pions versus efficiency of electrons.

7 Conclusion

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. Work is ongoing towards a hadronic τ trigger. Preliminary results from the 2004 combined test beam show that a good energy resolution and a good e/π separation can be obtained.

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