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Particle identification for Higgs physics in the ATLAS experiment *

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ATLAS is a general purpose experiment which will operate at the LHC. In the main focus of ATLAS is the investigation of the nature of the electroweak symmetry breaking, and therefore the search for the Higgs boson. Electrons, photons, muons, tau and b-jets are important components of the possible physics signatures expected. The expected quality of particle-ID impose strong requirements upon the performance of the detector, which has to be sensitive to the Higgs boson discovery over the full range of allowed masses. In this paper, the detector performance in terms of particle identification is presented.

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1. Introduction

The experimental observation of Higgs boson(s) will be fundamental for a better understanding of the mechanism of electroweak symmetry-breaking. The design of the ATLAS experiment [1] has been optimised to cover a large spectrum of possible Higgs particle signatures. The Inner Detector (ID) consists of tracking detectors enclosed in a solenoidal magnet with 2 T field. From the inner radius (5 cm) to the outside radius (107 cm) it consists of pixel detectors, silicon strip detectors (SCT) and transition radiation drift tubes (TRT), covering the pseudo-rapidity interval $|\eta| < 2.5$. It provides an efficient tracking for lepton momentum measurement, good impact parameter resolution for b-tagging and also electron identification capability in TRT. The ID is surrounded by a highly granular liquid-argon electromagnetic sampling calorimetry (EM Calorimeter) with excellent performance in terms of e/γ identification, energy and angular resolution, response uniformity, γ/jet and γ/π^0 separation. Electromagnetic calorimetry is complemented by good jet and E_T^{miss} performance in the hadronic calorimeter

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based on LAr in the end-caps and on iron/scintillator tiles in the barrel. The global detector dimensions (diameter 22 m, length 42 m) are defined by a large air-core muon spectrometer, providing precision measurements of high-p_T muons over $|\eta| < 2.5$.

In the following, the capability of the single ATLAS subsystems as well as of their combination in identifying and measuring electrons, photons, muons, taus and b-jets will be discussed.

2. Electron identification

Events with electrons in the final state are important signatures for SM and MSSM Higgs channels: $H \to ZZ^{(*)}, WW^{(*)} \to 4l$, $l\nu l\nu$, lepton trigger for WH, ZH, ttH, b-tagging with soft electrons. Isolated high-p_T electrons ($p_T > 20$ GeV) are not easy to identify at the LHC because of large QCD background from high-p_T jets. To obtain an inclusive electron signal sample, a rejection against jets of $\sim 10^5$ is mandatory. In particular, a jet rejection of $\sim 10^6$ will be needed to extract inclusive electron signal with 90 % purity.

Electron reconstruction uses information from the EM Calorimeter and the ID systems. Electromagnetic objects can be identified in the calorimeter by looking at the transverse and longitudinal shower shapes and at isolation variables. For electrons, a track is required to match in position and energy that measured in the EM Calorimeter. Electron identification makes also use of the TRT, namely large energy depositions by electrons due to the transition radiation. For separation e/jet, cuts were developed to maintain a reasonable electron identification efficiency while removing a high fraction of jet events. They include trigger, shower shape and isolation cuts in the calorimeter, cuts on track in the ID, cuts on ID-Calo matching and TRT. The reference performance figures for efficiencies and rejection after consecutively applied above cuts are summarised in Tab. 1 for single electron and an inclusive jet samples. An electron efficiency of ~ 70 % is obtained for a QCD jet rejection above 10^5. Finally, removal of γ conversions by their direct reconstruction, would allow the identification of a pure electron

	ε_e (in %)	jet rejection ($\times 10^3$)
Calo	91.2 ± 0.4	3.01 ± 0.06
ID	81.3 ± 0.5	35.9 ± 2.5
ID-Calo	76.4 ± 0.6	103 ± 12
TRT	73.5 ± 0.6	222 ± 38

Table 1. Electron identification efficiency, ε_e, for single electrons with $p_T > 25$ GeV and jet rejection (with $p_T > 17$ GeV) at low luminosity [2].

inclusive sample with a jet rejection around 10^6.

The efficient identification of low energy electrons is an important tool for b-tagging using soft lepton technique. For electrons in jets it is difficult to recognise candidates by any unguided search in the EM Calorimeter. Instead the ID must be used to seed by tracks the calorimeter clustering. By combining various shower shape estimators, ID-Calo matching and the information from the TRT, it is possible to discriminate between e/π tracks in jet, the π rejection versus the electron efficiency is presented in Fig. 1. On average, in $WH(H \rightarrow b\bar{b})$ events, for a 80% electron efficiency, rejection of π tracks is ~ 250.

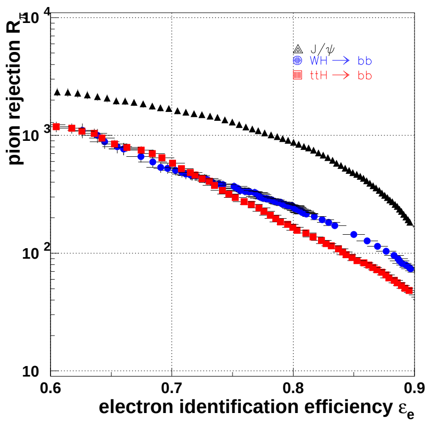

Fig. 1. π rejection vs electron identification efficiency for low-p_T electrons [3].

3. Photon identification

The identification of isolated high transverse momentum photons is essential in the search for the SM and MSSM Higgs in $H \rightarrow \gamma\gamma$ channel. A rejection factor of about 5000 is required against QCD jets in order to obtain an inclusive γ signal for 80 % γ-ID efficiency. The γ/jet separation relies on the search for electromagnetic objects, including trigger cuts, shower shape and isolation cuts in the calorimeter, and the requirement that no track is found in the ID within a $\Delta\eta \times \Delta\phi$ region of size $\pm 0.1 \times \pm 0.1$ around the calorimeter cluster. Fig. 2 shows the jet rejection after γ selection cuts as a function of the jet p_T. A rejection of better than 7000 can be obtained for $p_T > 40$ GeV, both for low and high luminosity [4].

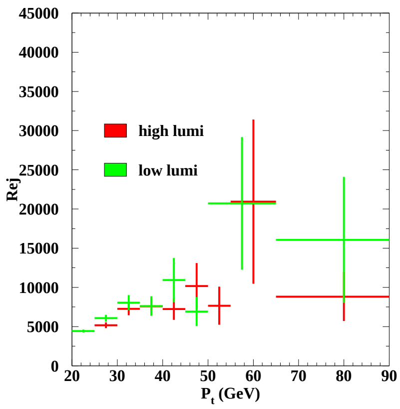

Fig. 2. The jet rejection as a function of jet p_T for events at low and high luminosity for 80% γ-ID efficiency [4].

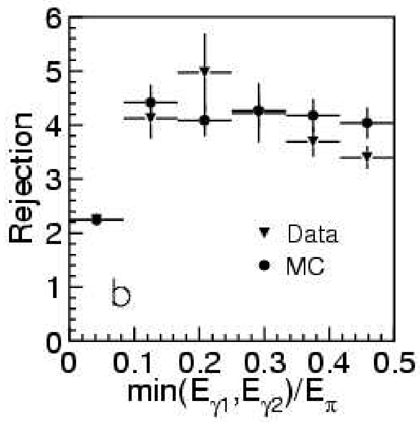

Fig. 3. π^0 rejection calculated in bins of $\min(E_{\gamma 1}, E_{\gamma 2})/E_{\pi^0}$, for data and simulation [5].

The calorimeter has to provide an additional rejection of ~ 3 against π^0 for a γ-ID efficiency of 90%, using the fine granularity in the first sampling. This has been demonstrated using specific test-beam data [5]. The agreement between simulation and data is satisfactory, and it could be shown that the required rejection factor is reached over most of the kinematical range, as shown in Fig. 3.

4. Muon identification

Muon identification and high momentum measurement accuracy is crucial to fully exploit the Higgs physics potential that will be accessible with ATLAS. In particular it will be important for SM Higgs $H \rightarrow ZZ^{(*)} \rightarrow 4l$ and MSSM Higgs $A \rightarrow \mu\mu$ searches, lepton trigger for WH, ZW, ttH and b-tagging with soft muons. The muon energy of physics interest ranges in a large interval from few GeV up to the highest values that could indicate the presence of new physics. The ATLAS Muon Spectrometer has been designed to achieve momentum measurement with high efficiency and high resolution over a wide range of p_T, η and azimuthal angle, providing at the same time stand-alone triggering capability. Momentum measurement is performed via magnetic deflection of muon tracks in a system of three large superconducting air-core toroid magnets instrumented with trigger chambers and high precision tracking chambers. The magnet configuration provides a field that is mostly orthogonal to the muon trajectories, while minimizing the degradation of resolution due to multiple scattering. By combining the Muon System and the ID measurements one improves the muon momentum resolution for track with $p_T <$ 100 GeV. Also combination of the information from the ID with that from the hadronic Tile Calorimeter leads to a good identification efficiency for muons with p_T as low as 3 GeV.

ATLAS Collaboration has developed few sophisticated algorithms [6] for reconstruction and identification of tracks inside the Muon Spectrometer alone as well as for matching tracks found in the Muon Spectrometer with the corresponding ID tracks. The average efficiency for muons in $H \to 4\mu$ ($m_H = 180$ GeV) events is $\sim 95.5\%$ which gives ~ 83 % for four muons with fake track rate < 1 % [7]. Low-p_T muons cannot be reconstructed as a track in spectrometer thus dedicated algorithm was developed [8] using matching of the ID tracks with hits in the Muon System. This method giving ~ 90 % efficiency for low-p_T muons inside b-jets with fake tracks rate $<$ 1 % can be useful for for soft lepton b-jet tagging.

5. τ-jet identification

τ-jets are originating from the hadronic decays of τ-leptons. Since there are neutrinos and hadrons among the decay products they are difficult for efficient reconstruction and identification. A number of benchmark and discovery processes depend upon the ability of τ identification: SM Higgs (VBF, ttH) $H \to \tau\tau$, MSSM Higgs $A/H \to \tau\tau$, $H^{+-} \to \tau\nu$, $W \to \tau\nu$, $Z \to \tau\tau$ (background rejection, control channel).

Since hadronic τ decays are characterised by low multiplicity particles content a τ-jet consist in general of a well-collimated calorimeter cluster with a small number of associated charged tracks (1 or 3). The main background to τ's are QCD jets. For τ efficiency ~ 30 % QCD rejection on the level at least 400 [1] is needed. Jets from hadronic τ decays and QCD jets can be distinguished by using information from the calorimeters and the Inner Detector.

There are two τ-jet reconstruction and identification algorithms developed in ATLAS. The first, base-line one [9] uses clusters as a seed for τ-candidates. For each candidate tracks near clusters are collected and ID-variables calculated. Then clusters are calibrated using the calorimeter (H1-Style method) and a likelihood is calculated. Fig. 4 demonstrates the expected QCD jet rejection as a function of τ reconstruction efficiency. Discriminating method used is a one dimensional likelihood ratio based on 8 variables. A good level of τ/jet separation can be seen over a broad E_T range. For a identification efficiency of 30% a rejection factor of 400-1000 can be achieved against QCD jets for jet E_T varying from 15 to 335 GeV.

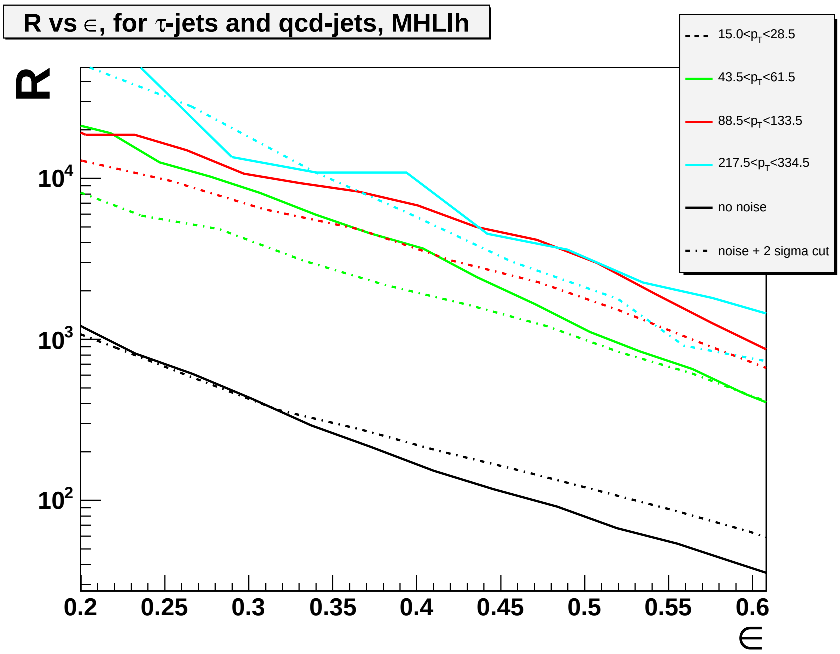

Fig. 4. Efficiency for τ's identification and rejection against QCD jets with (dashed) and without (full) noise [9].

Overall, it provides good sensitivity for the identification of τ's in many physics channels ranging from light Higgs to heavy SUSY.

The complementary algorithm [10] is dedicated for τ's with visible energy from hadronic τ decays in the range $20 - 70$ GeV. It starts from the reconstructed, good quality and relatively high p_T tracks, collects calorimetric energy deposited in the fixed cone seeded by the track and calculates ID-variables. The algorithm uses an energy-flow based approach for defining the energy scale of the reconstructed τ candidates. Using multi-variate type of discriminant (PDE-RS) for τ efficiency of 30% one may expect rejection of $600 - 10000$ for jet E_T between 15 and 60 GeV.

6. b-tagging

Tagging of b-jets is an essential tool for SM Higgs discovery channel $ttH(H \to b\bar{b})$, MSSM Higgs $h \to b\bar{b}$, rejection against $ttjj$ background and b-jet veto for tt background. For good Higgs mass resolution rejection of light jets should be > 100 and c-jets > 10 for 60 % efficiency of b-tagging at low luminosity. The most powerful method of b-tagging is the vertex

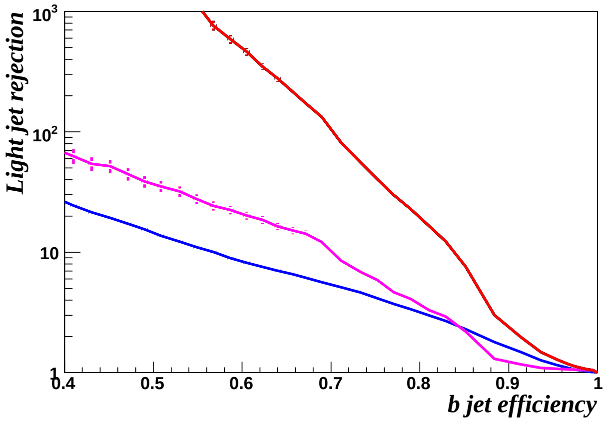

Fig. 5. Light (highest), c- and τ-jet (lowest) rejection in $t\bar{t}$ events.

method, based on the relatively long lifetime of b-hadrons [11]. Another method is tagging by low-p_T leptons, e or μ, originating from semileptonic decays of b-quarks. The basic limitation here is the branching ratio of $b \to e, \mu \sim 10$ %. Soft lepton methods will be not discussed in following.

The vertex b-tagging algorithms employed by ATLAS are based on track impact parameter significances S, defined as the distance of closest approach of a track to the primary vertex position, divided by its error. The impact parameter significance is signed using the direction of the nearest jet: positive if the track crosses the jet axis in front of the primary vertex, and negative otherwise. Tracks from light quark jets tend to have small values of $|S|$, originating mainly from resolution effects. By contrast, tracks from b decays show a large tail towards positive values, corresponding to tracks with significant impact parameters. These distributions are used to transform S into a ratio of probabilities that the track originated from a light quark jet or a b-jet. The probabilities for all tracks in the jet are combined into a jet weight which forms the main discriminating variable for distinguishing between b- and light quark jets. This procedure can be performed both in the transverse and longitudinal planes. The jet weights from both planes can be combined to give a three-dimensional b-tagging algorithm. The power of this method can be significantly improved by using additional information on the presence of secondary vertices and their properties such as mass, fit probability, multiplicity and distance from the reconstructed primary vertex, fraction of the jet energy in the secondary vertex. On Fig. 5 light, c- and τ-jet rejection factors as a function of b-tagging efficiency are presented for the method described above. Results are obtained for simulated $t\bar{t}$ events. For b-tagging efficiency of ~ 60 % light jet rejection at the level of ~ 500 and c-jet rejection at the level of ~ 10 can be achieved.

7. Summary

Particle identification is an essential ingredient for the Higgs physics in ATLAS experiment. As was shown in this paper or in the [1] the ATLAS detector has powerful particle identification capability and it is well matched to achieve the necessary requirements. Efficiencies for identification of electrons, photons, muons, tau and b-jets meet Higgs physics expectations and will allow ATLAS experiment to discover Higgs particle in the full mass range between $100 - 1000$ GeV.

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