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Object ID performance for top physics at the ATLAS detector

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Summary. — Various objects that are important for top physics at ATLAS are described. These objects include, jets, electrons, muons, and taus. Object identification methods are described, as well as the calibrations of their energies, resolutions, and reconstruction efficiencies. The reconstruction of the missing transverse energy is outlined, and algorithms to identify b-jets and their calibrations are also described.

PACS `14.65.Ha` – Top quarks.

1. – Introduction

Top-quark analyses at the ATLAS detector are performed in every final state of $t\bar{t}$ and many single-top production modes. The decay products which must be understood are therefore jets, electrons, muons, taus, and neutrinos. Neutrinos, of course, cannot be directly identified but are instead inferred by reconstructing the missing transverse energy (MET) in the detector. Identification (tagging) of jets as originating from b-quarks is also essential in order to minimize backgrounds in the single-top and the zero and one-lepton decay channels of $t\bar{t}$ production. This document will briefly describe the identification and calibration of these objects. Details relating to the detector hardware will not be discussed here. Similarly, while triggers are important for top physics, all leptonic top events in recent analyses are selected from an unprescaled single-lepton trigger, and the offline selection is chosen high enough in p_T to be in the high-efficiency plateau of the trigger with little loss of acceptance. For this reason the triggering system will not be discussed in much depth here. Interested readers can find details on the detector hardware [1] and the triggering system [2] elsewhere.

2. – Jets

Jets are reconstructed starting from topological energy clusters in the calorimeter using a cone-size of 0.4 with the anti-kt algorithm [3]. Reconstruction is initially performed using the nominal energy scale calibration appropriate for the energy deposited

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by electrons or photons. The jets are then calibrated with p_T- and η-dependent correction factors determined from simulation to restore the full hadronic energy scale. This correction factor varies from about 1.2 to 1.8 (higher for low p_T and central jets). Jets which are consistent with originating from an electron described in sect. **4** are counted as electrons instead, while the entire event is vetoed if the jet appears to have unphysical calorimeter pulse or timing characteristics to avoid biasing the reconstructed missing transverse energy of the event.

Since jets are reconstructed entirely in the calorimeter their reconstruction efficiency is determined in an independent manner by comparing jets that are fully reconstructed in the tracking system. It is found that the reconstruction efficiency is above 99% for the jets selected in top analyses. Reconstruction uncertainties therefore do not contribute a significant uncertainty to top analyses. Jet energy resolution is measured in dijet data in two different methods by comparing the reconstructed jet kinematics [4]. The two measurement results agree to within about 2%. Jet energies are smeared in the simulation to cover the range of uncertainties allowed by these measurements, but again this does not lead to a significant uncertainty for most top analyses.

The most significant uncertainty for top analyses is on the absolute calibration of the jet energy in the simulation. This uncertainty is determined as the quadrature sum of several sources of uncertainty that are determined from studies in simulation [5]. These include flavor uncertainties (b-jets, light-quark jets, and gluon jets all have different responses), uncertainties on the amount of detector material, calorimeter noise, calorimeter response (from data-driven test beam and tracking studies), pileup, and jet overlap effects. The final uncertainties per jet range from roughly 4% for low-p_T jets down to 2% for high-p_T light-quark jets for top physics. b-jets have an additional p_T-dependent uncertainty of at most 2.5% added in quadrature which is especially important for top mass analyses. These energy uncertainties are further cross-checked by measurements in photon plus jet and Z plus jet data as well as track jet measurements in dijet data [6]. They are found to be consistent with expectations within uncertainties.

2˙1. *b-tagging*. – Identification ("tagging") of b-jets significantly reduces backgrounds in top physics and is useful for properly pairing jets in zero and one lepton top decays. ATLAS has many b-taggers available. Here we only describe the most common one used in top quark physics, the "JetFitterCombNN" tagger [7]. This tagger exploits most of the characteristics of b-hadrons to make the best possible decision about whether to tag the jet. b-hadron lifetime is incorporated from the displacement of the tracks in the jet, while characteristic b-hadron mass, fragmentation and decay modes are incorporated by reconstructing one or more displaced vertices from tracks within the jet and using information about their masses, momenta, and track multiplicities. This information is incorporated into a neural network to determine a single discriminant. Analyzers can choose how tight they wish to cut on this discriminant. While tagger performance is sample dependent, in $t\bar{t}$ events where jets are selected with $p_T > 25\,\text{GeV}$ and $\eta < 2.5$ the algorithm tags b-jets with an average efficiency of 70% and a corresponding light-flavor (udsg) jet fake rate of 1%.

Uncertainties on b-tagging are significant for many analyses. The b-tagging efficiency is calibrated from measurements in dijet events which contain a muon inside of a jet. The muon transverse momentum relative to the jet axis is fit to determine the fraction of jets which are b-jets before and after tagging. The ratio of data to simulated efficiencies is usually between 0.9 and 1.0 with a roughly 10% uncertainty and is applied as a p_T-dependent scale factor to correct tagging efficiencies in simulation. The same scale factor is also applied to charm jets, but with double the uncertainty. This uncertainty is treated as fully correlated to the b-jet tagging uncertainty. Several independent calibration measurements are performed in dijet and $t\bar{t}$ events which show agreement with the primary method within uncertainties [8]. The rate of mistakenly tagging light-flavor (udsg) jets is calibrated using dijet data from two measurements. One measurement counts jets which are tagged under the unphysical assumption that jets are traveling backwards through time (tracks displaced on the unphysical side of the collision point) giving an enhanced contribution of fake tags to study. Another measurement fits the invariant mass of tagged vertices to determine the fraction of light-flavor jets. Scale factors and uncertainties for light-flavor jets are then extracted and used in analyses. In practice light-flavor fake tagging uncertainties play very little role in top analyses.

3. – Muons

Top events with muons in them are selected on a single-muon trigger. ATLAS muons are selected with $p_T > 20\,\mathrm{GeV}$ which is safely in the trigger plateau. The muons are reconstructed up to an $|\eta|$ of 2.5 by combining tracks in the inner tracking system and the muon system in a single fit [9]. In top physics it is important to separate muons from W-decays from those originating from jets (whether real muons from electroweak decays or fakes). This is primarily done by requiring the muon to be isolated from other particles in both the tracker and the calorimeter. The efficiencies of all three of these selections (trigger, reconstruction, and isolation) are calibrated separately in the data. This is done by reconstructing a $Z \to \mu\mu$ decay from a reconstructed muon and a muon candidate and then determining how often the muon candidate passes the relevant selection cuts [10]. These efficiencies agree well between data and simulation and lead to small systematics in top analyses.

Muon energies and resolutions are calibrated from fits to Z mass peaks and from $W \to \mu\nu$ decays where the inner detector and muon system tracks are compared [11]. In the most recent top results the resolution of the muons is underestimated in the simulation due to inaccuracies in the modeling of the alignment for the inner tracker and muon systems. Consequently the muon momenta in simulation is smeared and rescaled to correct the central value and apply uncertainties. Improvements of the alignment modeling are expected for future top analyses.

4. – Electrons

Electrons are selected with $p_T > 25\,\mathrm{GeV}$ in order to be in the full efficiency range of the trigger [12]. In top analyses they are accepted up to an $|\eta|$ of 2.47 with the exception of a high material transition region between $|\eta|$ of 1.37 and 1.52 where they are vetoed to maintain good resolution. Similarly to muons, electrons must be isolated in the calorimeter to suppress electrons originating from jets. They are also required to leave reasonably shaped deposits in the electromagnetic calorimeter, have minimal deposits in the hadronic calorimeter, agree reasonably in energy with the matched track momentum, and to not have their track consistent with originating from a material interaction in the inner detector. Finally, the transition radiation produced by the particle as it passes through the outermost inner tracker layer is used to suppress fake electrons.

Electron trigger and selection efficiencies are calibrated similarly to the muons, by fitting the mass peaks from $Z \to ee$ and $J/\psi \to ee$ decays [13]. Efficiencies are parameterized as a function of p_T and η, range from 75% to 85%, and agree well between data and simulation. Electron energies and momenta are also calibrated from fits to the same mass peaks as well as by comparisons between track momenta and calorimeter clusters [13]. A correction of roughly one percent for electron energy in the data is found to be necessary. In addition, the electron resolutions need to be smeared slightly in the simulation to agree with the data. In the end uncertainties on these calibrations are not very significant for most top analyses.

5. – Taus

ATLAS has one analysis measuring the $t\bar{t}$ cross section in a final state with a hadronic tau and a muon [14]. The analysis searches both for taus that decay into one track (one-prong taus) and three tracks (three-prong taus). All tau candidates are seeded from jets and are required to not have exactly two tracks. Separate boosted decision trees are used to discriminate jets from taus or electrons from one-prong taus. The decision trees use a wide variety of inputs including the tau candidate's shape in the calorimeter and the tracker and the momentum of the leading track. For one-prong taus the transition radiation in the outer tracker is used to further discriminate electrons, while for three-prong candidates a vertex is formed and the mass and displacement of the vertex are used to separate taus from jets. Further details can be found in the documentation of the analysis itself or of dedicated tau performance studies [15].

6. – Missing transverse energy

Missing transverse energy (MET) is constructed from the full momenta of all objects reconstructed in the event as well as from unclustered energy that is found in the calorimeter. It should be noted that since such a large energy-scale correction is applied to low-p_T jets (sect. **2**), mistaken identification of jets as electrons can lead to a substantial bias in the MET result. In the end, all objects used to calculate MET are defined identically to the objects used for offline analysis allowing for consistent treatment of systematic uncertainties. Additional uncertainties are applied on the modeling of the soft unclustered energy, the energies of jets which are too low in energy to be calibrated, and the simulation of energy originating from multiple collisions in the same event.

7. – Conclusion

Top analyses at ATLAS rely upon the identification and measurement of many different objects. In this note the performance and calibrations of jets, electrons, muons, taus, and b-tagging have been discussed. Uncertainties on these objects are significant for many analyses. In particular, the jet energy and b-tagging systematic uncertainties are among the largest uncertainties of many top analyses. It will be necessary to continue to improve the understanding and performance of these objects in order to improve the sensitivity of top analyses in the future.

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