Thesis outline

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2.5 Calorimeter

Calorimeters provide accurate measurements of the energies and positions of electrons, photons, and jets as well as of the missing transverse energy. Calorimetric measurements are also crucial to particle identification, serving to distinguish electrons and photons from jets, and also helping to identify hadronic decays of tau leptons. The major components are the liquid argon (LAr) barrel (EMB) and endcap (EMC) electromagnetic (EM) calorimeters covering $|\eta| < 3.2$, the tile scintillator hadronic barrel calorimeter covering $|\eta| < 1.7$, the LAr hadronic endcap calorimeter (HEC) covering $1.5 < |\eta| < 3.2$, and the LAr forward calorimeter (FCAL) covering $3.1 < |\eta| < 4.9$. The electromagnetic calorimeters use lead absorbers and a LAr ionization medium, and are contained in three separate cryostats: one for the barrel and two for the endcaps. The calorimeters have an accordion geometry that provides full symmetry without azimuthal cracks. They are segmented longitudinally into three layers (called strips, middle, and back). The middle layer contains around 80% of the energy of an electromagnetic shower. The cell size $\Delta\eta \times \Delta\phi$ is 0.025×0.025 in the middle layer and 0.003× 0.1 in the strips in the barrel calorimeter (the cells are larger at higher $|\eta|$), allowing very precise measurements of incident particles. A presampler (PS) covers the region $|\eta| < 1.8$ to improve the energy measurement for particles that start showering before entering the calorimeter. Plastic scintillator tiles are placed between the cryostats in order to recover some of the energy that is lost in dead material in this region. Wrapped around the LAr calorimeter cryostats is the barrel hadronic calorimeter. It uses iron absorbers interleaved with plastic scintillator tiles. The central barrel portion covers $|\eta| < 1.0$; two extended barrel calorimeters cover $0.8 < |\eta| < 1.7$. The 68 cm gaps between the central and extended barrels are also instrumented with plastic scintillator sheets. The endcaps of the hadronic calorimeter again use the liquid argon technology, due to the high radiation doses experienced in the forward regions. For $1.5 < |\eta| < 3.2$, copper plate absorbers are used, and the calorimeters are installed in the same cryostats as the EM endcaps. The FCAL, covering $|\eta| > 3.1$, consists of rod-shaped electrodes embedded in a tungsten matrix. The cell sizes in the hadronic calorimeters are larger than in the electromagnetic calorimeters; ranging from 0.1x0.1 to 0.2x0.2. The tile calorimeter is divided into three longitudinal layers, while the HEC has four layers. The FCAL consists of three modules in depth. Noise in the calorimeter comes from two principal sources. The first is from the readout electronics. The second is called pile-up noise, and arises from extra interactions that can either be overlaid in the same beam crossing with the primary interaction or occur during crossings that are close in time to that of the primary interaction (as the response time of the calorimeter is longer than the 25 ns interval between crossings). Incoming particles usually deposit their energy in many calorimeter cells, both in the lateral and longitudinal directions. Clustering algorithms are designed to group these cells and to sum the total deposited energy within each cluster. These energies are then calibrated to account for the energy deposited outside the cluster and in dead material. The calibration depends on the incoming particle type; the calibration for electrons and photons is described in Ref. , and the calibration for jets in Ref. .

2.6 Muon spectrometer

The MS is the outermost of the ATLAS sub-detectors: it is designed to detect charged particles in the pseudorapidity region up to $|\eta| = 2.7$, and to provide momentum measurement with a relative resolution better than 3% over a wide p_T range and up to 10% at pT $\approx$ 1 TeV. The MS consists of one barrel part (for $|\eta| < 1.05$) and two end-cap sections. A system of three large superconducting air-core toroid magnets provides a magnetic field. Triggering and η, ϕ position measurements, with typical spatial resolution of 510 mm, are provided by the Resistive Plate Chambers (RPC, three doublet layers for $|\eta| < 1.05$) and by the Thin Gap Chambers (TGC, three triplet and doublet layers for $1.0 < |\eta| < 2.4$). Precise muon momentum measurement is possible up to $|\eta| = 2.7$ and it is provided by three layers of Monitored Drift Tube Chambers (MDT), each chamber providing six to eight $|\eta|$ measurements along the muon track. For $|\eta| > 2$ the inner layer is instrumented with a quadruplet of Cathode Strip Chambers (CSC) instead of MDTs. The single hit resolution in the bending plane for the MDT and the CSC is about 80 μm and 60 μm, respectively. Tracks in the MS are reconstructed in two steps: first local track segments are sought within each layer of chambers and then local track segments from different layers are combined into full MS tracks.

2.7 Magnet system

2.8 Trigger system

2.9 Data acquisition

3 Object reconstruction

The raw output of the detector comes in the form of hits, energy deposition, times etc. These outputs are stored in Raw Data Object files (RDO). From these detector object pattern recognition algorithms produce objects that we are more familiar with, like vertices, tracks, electrons, muons, jets etc. These reconstructed events are stored in increasingly compact file formats like Event Summary Data (ESD), Analysis Object Data (AOD) and Derived Physics Data (DPD).

3.1 Vertices and pileup

Vertices are the points where some physics interaction happens. The hard interaction vertex is called the primary vertex. There may be secondary vertices in an event arising from decays and interactions of particles produced in the primary vertex. The reconstruction of vertices is dependent on reconstruction of charged particle tracks in the inner detector (ID). The high resolution pixel detector and silicon microstrip detector (SCT) are crucial for reconstructing these tracks. Additional information is provided by the transition radiation tracket (TRT). The vertex reconstruction proceeds in two stages, i) the primary vertex finding algorithm which deals with associating the tracks to a primary vertex candidate and ii) vertex fitting algorithm which reconstructs the vartex position and calculates the covariance matrix. First, the reconstructed tracks compatible with coming from the interaction region are pre-selected. A vertex seed is found by looking for the global maximum of the distribution of z co-ordinates of tracks at the point of closest approach with respect to the nominal beam spot. Taking this seed and its surrounding tracks as inputs, an adaptive χ^2-based vertex fitting algorithm is run to determine the vertex position. Each track is assigned a weight based on its compatibility with the fitted vertex position and outliers are down-weighted. Tracks that are incompatible with the vertex position by more than 7 σ are used for fitting another vertex. This procedure is continued until the list of tracks is exhausted. Secondary vertices are reconstructed using kinematic properties of the interaction likely to happen in that vertex. The displaced tracks are fitted with the secondary vertex candidate with the kinematic constraints set by the parent particle mass or the angular distribution of the daughter particles.

3.2 Electron

In ATLAS the inner detector and EM calorimeter is used for reconstructing electron objects. The inner detector tracks are matched to the energy deposits in the EM calorimeter for this purpose. The Transition Radiation Tracker (TRT) is used for electron identification. The reconstruction of electrons and photons in the region $|\eta| < 2.47$ starts from energy deposits (clusters) in the EM calorimeter. To reconstruct the EM clusters, the EM calorimeter is divided into a grid of $N_\eta \times N_\phi$ towers of size $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$. Inside each of these elements, the energy of all cells in all longitudinal (in the rho direction) layers is summed into the tower energy. These clusters are seeded by towers with total transverse energy above 2.5 GeV and searched for by a sliding-window algorithm, with a window size of 3 5 towers. Clusters matched to a well-reconstructed ID track originating from a vertex found in the beam interaction region are classified as electrons. If the matched track is consistent with originating from a photon conversion and if in addition a conversion vertex is reconstructed, the corresponding candidates are considered as converted photons. They are classified as single-track or double-track conversions depending on the number of assigned electron-tracks. Clusters without matching tracks are classified as unconverted photons. The electron cluster is then rebuilt using an area of calorimeter cells corresponding to 3×7 and 5×5 L2 cells 4 in the EMB and EMEC respectively. For converted photons, the same 3×7 cluster size is used in the barrel, while a 3×5 cluster is associated with unconverted photons due to their smaller lateral size. A 5×5 cluster size is used in the EMEC for converted and unconverted photons. These lateral cluster sizes were optimized to take into account the different overall energy distributions in the barrel and endcap calorimeters while minimizing the pile-up and noise contributions. The cluster energy is then determined by applying correction factors computed by a calibration scheme based on the full detector simulation.

Energy resolution of EM objects (electron and photon): The relative energy resolution for these EM objects can be parameterized as follows: $\sigma_E = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$, where a, b and c are η-dependent parameters; a is the sampling term, b is the noise term, and c is the constant term. The sampling term contributes mostly at low energy; its design value is $(9 \;\; 10)\%/p_E[\mathrm{GeV}]$ at low $|\eta||$, and is expected to worsen as the amount of material in front of the calorimeter increases at larger $|\eta||$. The noise term is about 350×cosh η MeV for a 3×7 cluster in $\eta \times \phi$ space in the barrel and for a mean number of interactions per bunch crossing $\mu = 20$; it is dominated by the pile-up noise at high η. At higher energies the relative energy resolution tends asymptotically to the constant term, c, which has a design value of 0.7%.

3.3 Muon

The ATLAS detector uses its Inner detector and Muon spectrometer to identify reconstruct and precisely measure the properties of muons produced in pp collisions. Muon identification is performed according to several reconstruction criteria, according to the available information from the ID, the MS, and the calorimeter sub-detector systems. The different types are: Stand-alone muons: the muon trajectory is reconstructed only in the MS. The parameters of the muon track at the interaction point are determined by extrapolating the track back to the point of closest approach to the beam line, taking into account the estimated energy loss of the muon in the calorimeters. In general the muon has to traverse at least two layers of MS chambers to provide a track measurement. SA muons are mainly used to extend the acceptance to the range $2.5 < |\eta| < 2.7$ which is not covered by the ID. MuonBoy software package is used for this reconstruction. Combined muons: track reconstruction is preformed independently for ID and MS and a combination is done to reconstruct a combined track. Segment-tagged (ST) muons: a track in the ID is classified as a muon if, once extrapolated to the MS, it is associated with at least one local track segment in the Monitored Drift Tube Chambers (MDT) or Cathode Strip Chambers (CSC). ST muons can be used to increase the acceptance in cases in which the muon crossed only one layer of MS chambers, either because of its low p_T or because it falls in regions with reduced MS acceptance; Calorimeter-tagged (CaloTag) muons: a track in the ID is identified as a muon if it could be associated to an energy deposit in the calorimeter compatible with a minimum ionizing particle. This type has the lowest purity of all the muon types but it recovers acceptance in the uninstrumented regions of the MS. The identification criteria of this muon type are optimized for a region of $|\eta| < 0.1$ and a momentum range of 25 $< p_T <$ 100 GeV.

The reconstruction of the SA, CB and ST muons (all using the MS information) has been performed using two independent reconstruction software packages, implementing different strategies (named Chains) both for the reconstruction of muons in the MS and for the ID-MS combination. For the ID-MS combination, the first chain (Chain 1 or STACO) performs a statistical combination of the track parameters of the SA and ID muon tracks using the corresponding covariance matrices. The second (Chain 2 or MUID) performs a global refit of the muon track using the hits from both the ID and MS sub-detectors. The following quality requirements are applied to the ID tracks used for CB, ST or CaloTag muons: at least 1 Pixel hit (nPix+nBadPix); at least 5 SCT hits (nSCT+nBadSCT); at most 2 active Pixel or SCT sensors traversed by the track but without hits; in the region of full TRT acceptance, $0.1 < |\eta| < 1.9$, at least 6 TRT hits. (The number of hits required in the first two points is reduced by one if the track traverses a sensor known to be inefficient according to a time-dependent database). The above requirements are dropped in the region $|\eta| > 2.5$, where short ID track segments can be matched to SA muons to form a CB muon.

3.4 Jets

Jets are collimated shower of hadrons produced in great quantity in a hadron collider. ATLAS calorimeters consist of cells which can record the signal from a particle when it traverses thorough them. The cells also record random noise from readout electronics and pileup interaction. We observe jets as a cluster of cells with energy deposition mostly in the hadronic calorimeter. To construct the jets we need to consider cells that have large signal over the random noise ratio. As a first step cells with S/N greater than 4 is used as seed for a proto-cluster. All neighboring cells with S/N $>$ 2 are iteratively added to the proto-cluster. If a cell is in the boundary of more than one proto-cluster, the proto-clusters are merged. All neighboring cells of this proto-cluster is then added irrespective of its S/N ratio. At this stage, Proto-clusters are split around the local maximas with energy E$>$ 0.5 GeV greater than any of its neighboring cell. These local maxima cells are used to seed exactly one proto-cluster consisting only those cells that were part of the initial cluster. Cells that are shared by two proto-jets contribute to each according to the proto-cluster energies and distance of the cell from the proto-cluster centers. The resulting new proto-clusters and any original proto-clusters lacking local maxima are sorted in order of E_T and called topological clusters.

These topological clusters then are fed to the jet algorithms like antikt4. d_{ij} = distance between two clusters. d_{ib} = distance between a cluster and beam.

3.5 MET

4 Monte Carlo generation

4.1 Generators

4.2 Matrix element, Parton showering, underlying events

4.3 Data and MC samples

4.4 Whizard

4.5 MC correction:

4.6 Pileup reweighting,vertex reweighting, energy correction, calibration

5 Object and Event Selection

5.1 Object selection

5.2 vertex

The vertex with the highest sum of square of transverse momentum, Σp_T^2, of the associated tracks is chosen as the primary vertex.

5.3 Electron

Electron candidates are defined as clusters of energy deposited in the electromagnetic calorimeter associated to a track reconstructed in the Inner detector. They are required to meet the ATLAS medium++ identification criteria and to have transverse energy pt $>$ 15 GeV. They need to have author =1 or 3. They also must have $|\eta| < 2.47$, excluding the crack region between barrel and end cap of the EM calorimeter, $1.37 < |\eta| < 1.52$, to avoid energy mis-measurement. For electron there is an OTx cleaning cut that require OQ&1446==0. The OTxs refer to the Optical Transmitters on the Liquid Argon Calorimeter. This cleaning cut removes electrons that fall inside cells with dead OTxs. To make sure the electron candidate is coming from the primary vertex,$|z0sin\theta|$ needs to be $<$ 0.5 mm and $|\frac{d0}{\sigma_{d0}}|$ needs to be $<$ 5 . The electron cannot be within dR =0.1 of a good muon (described later).

A tighter electron selection is also considered called the good electrons. Good electrons need to satisfy all the previous requirement. In addition it needs to pass the ATLAS tight++ identification criteria. There is also calorimeter and track isolation requirement. Calorimeter isolation $\Sigma(E_T cone30)/E_T$ <0.14 and track isolation $\Sigma(p_T cone30)/E_T$ <0.07. Monte Carlo samples fail to perfectly describe energy scale and resolution, isolation, identification, reconstruction, triggering of electrons seen in data. Correction due to these are applied to electron using the standard ATLAS egammaAnalysisUtils package.

5.4 Muon

Muons candidates are reconstructed using the STACO algorithm using both muon spectrometer (MS) and inner detector (ID) information. It has author =6. Muons are required to have pt $>$ 15 GeV and $|\eta| < 2.4$. To suppress non-prompt muons coming from hadron decay, impact parameter selections were placed, $|z0sin\theta| <$ 0.5 mm. The inner detector tracks need to satisfy the following criteria: i) Number of pixel hits + number of dead pixel sensors hits $>$ 0. ii) Number of SCT hits + number of dead SCT sensors hits $>$ 4. iii) Number of pixel holes + number of SCT holes $<$ 3. For 0.1$< |\eta| <$1.9, $n^{hits}_{TRT} + n^{outliers}_{TRT} > 5$ and $n^{outliers}_{TRT}/(n^{hits}_{TRT} + n^{outliers}_{TRT}) < 0.9$. Overlap removal A tighter muon selection is considered called the good muon where muons need to have —dosig— ¡ 3, calorimeter isolation sum(Etcone/pt) ¿ 0.07 and track isolation sum(ptcone30)/pt ¿ 0.07. Standard ATLAS muon tool is used to apply corrections due to momentum scale and resolution, trigger, reconstruction, identification efficiency. The isolation scale factor is assumed to be 1.

5.5 Jets

Jets are reconstructed from the topological clusters using the anti-kT algorithm with radius parameter R= 0.4. The jets need to have pt$>$ 30 GeV, $|\eta| <$ 4.5. To suppress pileup, for jets with pt$<$ 50 and $|\eta|$ <2.4, there is a jet vertex fraction (JVF) requirement. The JVF is defined as the ratio of pt associated with the tracks coming from the primary vertex to pt associated with all tracks. JVF needs to be > 5 for the jet to pass. Any jet that is too close to an electron pr a muon within ΔR=0.3 is removed from consideration. For the analysis we used Cambridge-Aachen R = 1.2 jets with mass-drop filtering as our merged jets. The filtering parameters are $mu_{frac} < 0.67$ and y_f needs to be > 0.09. The large-R jet needs to have pt $>$ 100GeV and $|\eta| < 1.2$ and it is removed if it is within R=1.2 of an electron or a muon.

5.6 MET

Because of the neutrino in the final state, large unbalanced "missing" momentum, $E_T^{missing}$, is expected in the transverse plane. The "RefFinal" definition of MET is used in this analysis. This definition uses the sum of calorimeter energy deposits and of the pt of muons reconstructed in the inner detector or muon spectrometer. The estimate of the energy deposited in the calorimeter is refined by associating calorimeter energy deposits with reconstructed objects (electrons, photons, jets, etc.) and replacing the calorimeter energy estimate by the calibrated object pt. For the MET calculation the MissingETUtility package has been used. The smearing, energy correction, and calibration applied to the objects are propagated to the $E_T^{missing}$ calculation.

5.7 Event selection

6 Signal and background estimation

6.1 QCD fit

text

7 Systematics

7.1 JES, JER

7.2 W+jets, ttbar, QCD etc uncertainty

7.3 Signal uncertainty

8 Fitting procedure

9 Results