PROCEEDINGS OF SCIENCE

Early material studies at the ATLAS experiment

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Crucial to numerous physics analyses at ATLAS is a detailed understanding of the material budget of the ATLAS Inner detector. This note describes three complementary studies of the material located in front of the ATLAS electromagnetic calorimeter using: converted photons, hadron interactions, and the uniformity of the energy flow in the electromagnetic calorimeter.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

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PoS(ICHEP 2010)018

1. Introduction

An accurate and high-granularity map of the ATLAS Inner Detector (ID) material is necessary for the understanding of tracking performance, as well as other objects such as electrons, photons, jets and missing energy. The material ID affects both the track trajectories (through multiple scattering and bremsstrahlung for electrons) and the electromagnetic shower development (because of the magnetic field and the energy lost in the ID material). Data collected with the ATLAS detector [1] since April 2010 at $\sqrt{s} = 7$ TeV has allowed for a range of studies, which are both complementary in their reconstruction techniques and the location of the material that is probed.

2. Studies with photon conversions

Low-p_T neutral mesons provide an abundant source of photons. The reconstruction of converted photons in the ID begins with the combination of two oppositely charged tracks with transverse momentum $p_T > 500$ MeV. These tracks are required to have a significant fraction of hits with higher than average signal in the Transition Radiation Tracker (TRT) resulting from transition radiation photons. Transition radiation photons are produced by particles with high Lorentz γ factors which in the expected momentum range are almost exclusively electrons [2].

To remove combinatorial background while maintaining a high signal efficiency, a number of geometric selection criteria and a requirement on the fit quality of the conversion vertex are imposed. To ensure a very high purity photon conversion sample, the vertices are required to have a fit $\chi^2_{vtx} < 5$, and both tracks are required to have at least 4 hits in the silicon Pixel and SemiConductor Tracker (SCT) and at least 90% probability to be electrons, as determined using high-threshold radiation in the TRT. The expected purity from simulation is well above 90% in most regions of the ID and the radial resolution for the vertex position is around 4mm.

Approximately 85000 photon conversion candidates are reconstructed in the 0.5 nb^{-1} which are used for this study. The distribution of photon conversion vertices can be used to map the distribution of material in the ID. In Figure 1 the beam pipe (R = 34.3 mm), the three barrel Pixel layers (R = (50.5, 88.5, 122.5) mm) and the first two SCT barrel layers (R = (299, 371) mm),

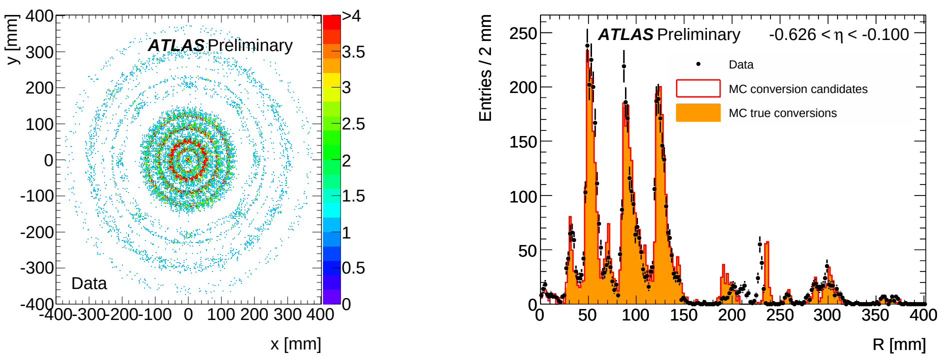

Figure 1: Distribution of reconstructed photon conversion vertices in the *xy* projection, restricted to $|\eta| < 1$, (left) and the radial distribution of conversion vertices for $-0.626 < \eta < -0.1$ (right).

together with the Pixel Support Tube (R = 229 mm) and various other support structures are clearly seen. In the *xy* projection, the cooling pipes on the Pixel detector modules and the overlap regions in the first SCT layer are visible. A clear shift in the simulated radial positions is observed for the Pixel Support Tube and global Pixel Support structure (around R = 200 mm) (see Figure 1), while the overall amount of material seems to be in good agreement.

A cross check of the material in the beam pipe using π^0 Dalitz decays utilises the well-measured branching fraction of the π^0 Dalitz decay, $\pi^0 \rightarrow \gamma e^+ e^-$. Comparing the number of photon conversions in the beam pipe with the number of π^0 Dalitz decays the amount of material in the beam pipe can be estimated. Comparisons between data and simulation will provide confidence in the description of the beam pipe in simulation. In the future, the quantitative estimation of the radiation length of the ID material will be done relative to the well known radiation length of the beam pipe.

3. Studies with hadronic interactions

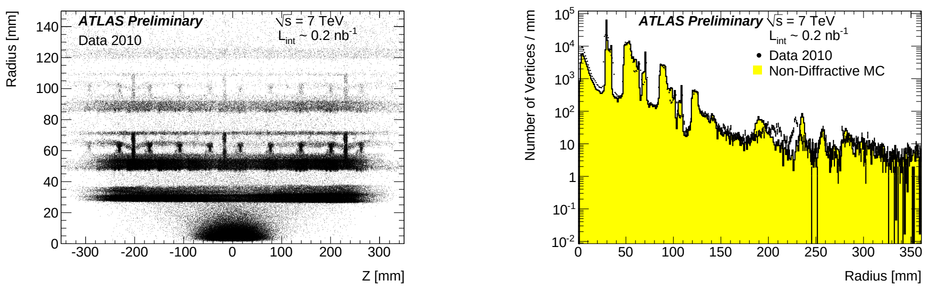

Figure 2: Left, the R vs. Z distribution of reconstructed vertices and after K_s^0 , γ and Λ vetoes. The bin width is 2 mm in Z and 0.5 mm in radius. Right, reconstructed vertices as a function of R.

This analysis [3] aims to reconstruct secondary interactions with the purpose of directly measuring the interaction lengths of material within the ID. To select well measured secondary tracks and reduce contamination from primary tracks, it is required that: (a) transverse momentum of the track > 500 MeV, (b) transverse impact parameter of the track relative to the primary vertex > 2 mm, (c) the track has at least one hit in the SCT, (d) tracks do not share hits, and (e) track fit $\chi^2/(d.o.f) < 5$. An iterative technique is used to form vertices and test which tracks should be associated to them. The expected resolution of the vertices is between 200-250 μm in both R and Z for vertices reconstructed with radii less than 100 mm.

Using data roughly corresponding to an integrated luminosity of 0.2 nb^{-1}, over 360000 vertices are reconstructed in the region $|Z| < 300$ after removing vertices associated to photon conversion, K_s^0 and Λ decays. In a similar manner to photon conversions, the distribution of hadronic interaction vertices can be used to make a detailed map of the material in the ID . Figure 2 shows clearly the beam pipe and the first three pixel layers. The material directly behind the active layers is associated to support structures and services. Comparison with simulation shows good agreement with only slight difference in the region of the beam pipe (caused by the beam pipe being displaced slightly), the pixel support structure and tube. When compared to the results from photon conversions the hadronic interaction results are, in general, in very good agreement. Specifically the position of the Pixel Support Tube and Support Structures are in excellent agreement.

4. Probing the material in front of the calorimeter using energy flow in minimum bias events

The occupancy in the electromagnetic (EM) calorimeter is sensitive to the total amount of material in front of the calorimeter. This study [4] uses about 0.1 nb^{-1} collected at $\sqrt{s} = 7$ TeV. The occupancy is defined as the fraction of events with a channel energy above a fixed threshold corresponding to about 5 times the electronic noise. In a perfectly cylindrically symmetric detector it would be expected that the occupancy would be uniform at constant η. Material localised in regions of ϕ can be seen by studying occupancy variations in ϕ at constant η. A number of service and structures run at constant ϕ making them perfect candidates for this technique. Good agreement is found between data and simulation for SCT and TRT services which amount to 0.2 X_0 and run at constant ϕ. However up to 1 X_0 of material missing in the simulation is observed in the very localised regions around the rails that support the ID, as seen in Figure 3.

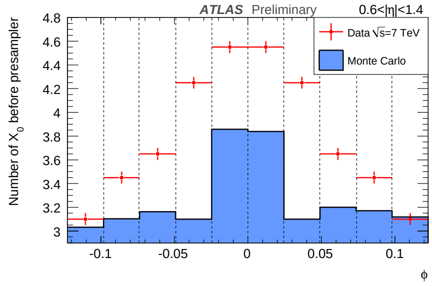

Figure 3: Average number of radiation lengths X_0 in front of the EM calorimeter in the region of the ID rails per bin in ϕ in a particular η slices of the detector ($\Delta\phi = 2\pi/256$, given by the granularity of the cells in the second layer of the EM calorimeter).

5. Conclusion

A number of complementary methods are being used to understand the material within the ATLAS Inner Detector. In general, the simulation is found to be in good agreement with the data, with only a few localised disagreements. The detector simulation will be updated to reflect the observed changes while further studies will focus on quantifying the material within the ID.

References

[1] The ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *Journal of Instrumentation* **3** (2008) S08003.

[2] The ATLAS Collaboration, *Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics*, [hep-ex/0901.0512].

[3] The ATLAS Collaboration, *Mapping the material in the ATLAS Inner Detector using secondary hadronic interactions in 7 TeV collisions*, ATLAS-CONF-2010-058.

[4] The ATLAS Collaboration, *Probing the material in front of the ATLAS electromagnetic calorimeter with energy flow from* $\sqrt{s} = 7$ *TeV minimum bias events*, ATLAS-CONF-2010-037.