# Studies of the MuGirl pattern recognition for the ATLAS upgrade

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The ATLAS detector has been designed to provide clean and efficient muon identification and precise momentum measurement over a wide range of momentum and solid angle. The spectrometer covers the pseudo-rapidity range $|\eta| < 2.7$ and allows identification of muons with momenta above 3 GeV/c and precise determination of $p_T$ to about 10% at 1 TeV[1].

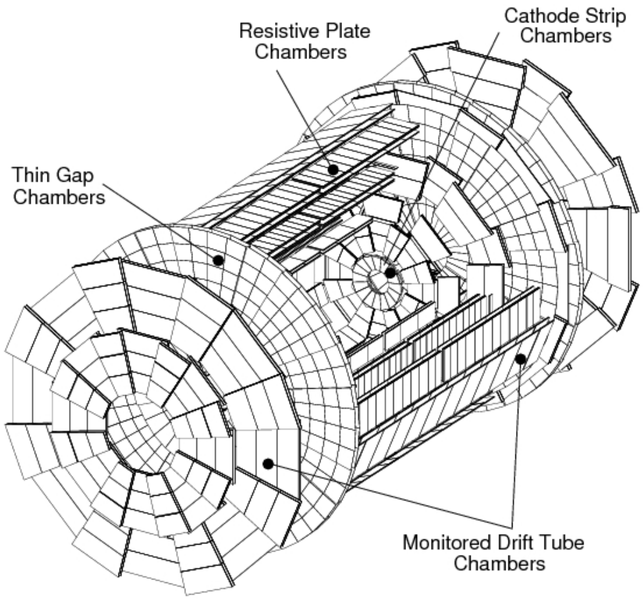


Figure 1: Layout of the Trigger Chambers (TGC and RPC) and Precision Chambers (MDT and CSC) of the ATLAS Muon Spectrometer

The muon detection system of the ATLAS detector is characterized by two high precision tracking systems, the Inner Detector (ID) and the Muon Spectrometer. The inner detector has three pixel layers, four stereo silicon microstrip layers, and, for $|\eta| < 2.0$, a straw-tube transition radiation detector that records an average of 36 additional measurements on each track. A 2 Tesla solenoidal magnet enables the inner detector to provide an independent precise momentum measurement for muons (and other charged particles) with an efficiency better than 99% and good momentum measurement up to 100 GeV.

Momentum measurement in the Muon Spectrometer is performed via the magnetic deflection of muon tracks in a system of three large superconducting air-core toroid magnets. The layout of the ATLAS Muon Spectrometer is presented in figure 1. This system is instrumented with chambers dedicated to trigger and high precision tracking. Trigger chambers consist of Resistive Plate Chambers (RPC) in the barrel and Thin Gap Chambers (TGC) in the end-cap regions. High precision tracking chambers include Monitored Drift Tubes (MDT), presented in the barrel and end-cap regions, and Cathode Strip Chambers (CSC) in the forward region.

ATLAS employs a variety of strategies for identifying and reconstructing muons. One of these, implemented by the MuGirl reconstruction program, propagates all inner detector (ID) tracks with sufficient momentum out to the muon spectrometer (MS) stations. The hits are collected within a narrow road opened around the extrapolated muon trajectory and are used to reconstruct a segment. The extrapolation is improved by using segment information for each of the stations to the next one. After the hits and segment information are collected, the final step is to do a combined fit using ID and MS hits from segments[2].

With the LHC upgrade in energy and luminosity more pileup events (number of collisions per bunch crossing) are expected. In such experimental environment the roads used for pattern recognition have to be optimized in order to cope with the increase of the background in the muon detector.

The parameter used to define the roads is the $\Delta\eta$ between the track extrapolated position and the hit. The aim of this analysis is to determine the smallest possible road size around the extrapolation to have optimum background rejection.

As part of this project we characterized the the road around the extrapolation using the RMS of the histograms of $\Delta\eta$. In figure 2 we see RMS as a function of $\eta$ for the inner and middle stations. In both cases they are symmetric with respect to zero. The RMS for the middle station is smaller, which is what we expect given that the extrapolation for the middle station comes from the inner station, being more precise than the extrapolation in the inner station, that comes from the ID. Figure 3 presents sigma as a function of $p_T$ for each technology combining all the stations. As expected, the width decreases with increasing $p_T$.

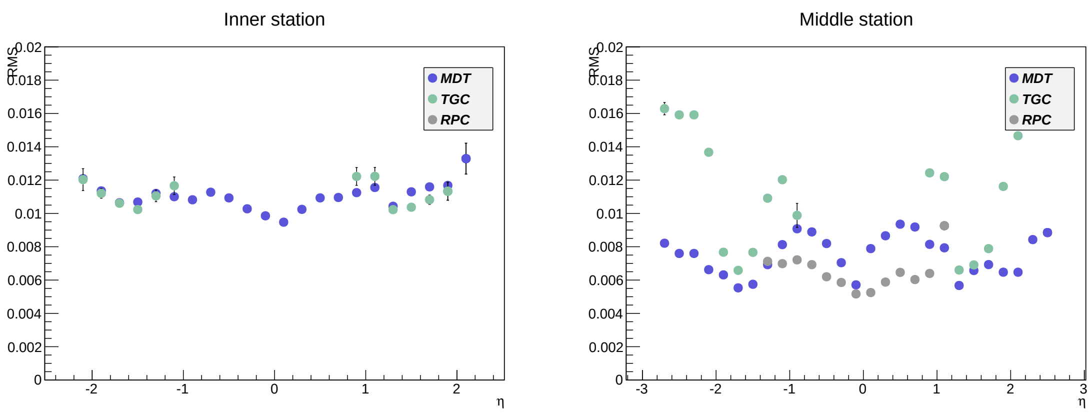


Figure 2: RMS of $\Delta\eta$ (the difference between the hit position and the extrapolated track) for the inner station (left) and middle station (right).

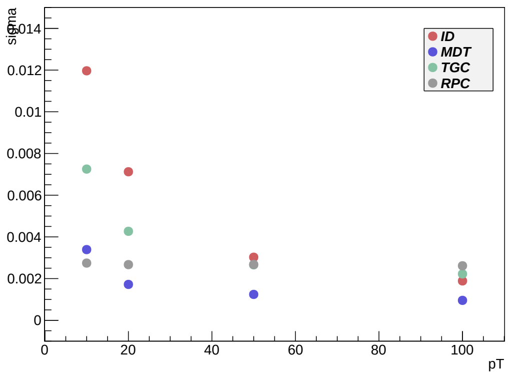


Figure 3: Sigma of $\Delta\eta$ (the difference between the hit position and the extrapolated track) as a function of $p_T$

To further improve MuGirl we are exploring new methods of pattern recognition such as the Hough transform in order to avoid having to propagate all inner detector tracks. A Hough transformation projects a point in normal $x, y$ space into a curve in $R_0, \phi$ space, called the Hough space, so straight lines in the $x, y$ plane become points in the Hough space, as can be seen in figure 4. Therefore the lines of all hits from a given line cross in one point in the Hough space. When combined with a histogramming technique (figure 5) the problem reduces to finding the bins with the highest value in the histogram [3].

This technique offers an elegant way of identifying points belonging to the same trajectory. One of the main benefits of the method is that the total CPU time is dominated by the time required to fill the Hough space, thus linear in the number of hits. Furthermore it offers good background suppression properties.

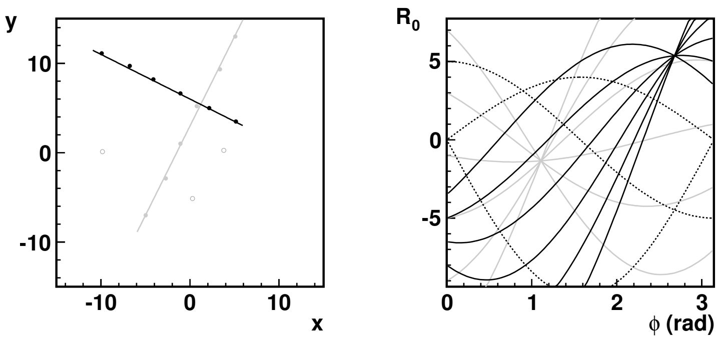


Figure 4: Set of points (left) and their representation in the Hough-space (right).

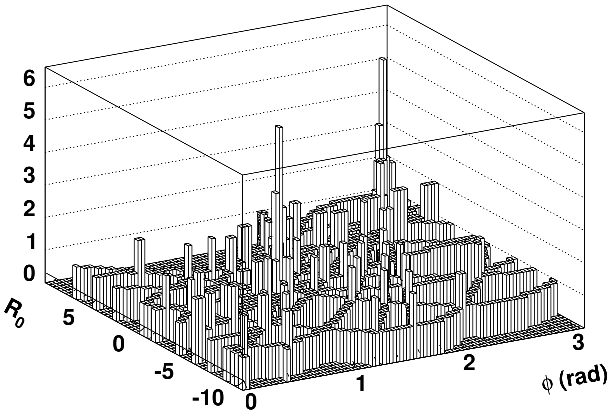


Figure 5: Representation points in binned Hough-space.

In order to characterize the Hough transform and compared it to MuGirl, we studied the road size (the $\Delta\eta$) for each technology and distance.

Also, we compared the position of the Hough maxima with the position of the truth Muon from the Monte Carlo and the same between the position of the intersection and the Monte Carlo truth. Both behaved the same, having a similar width as can be seen in figure 6.

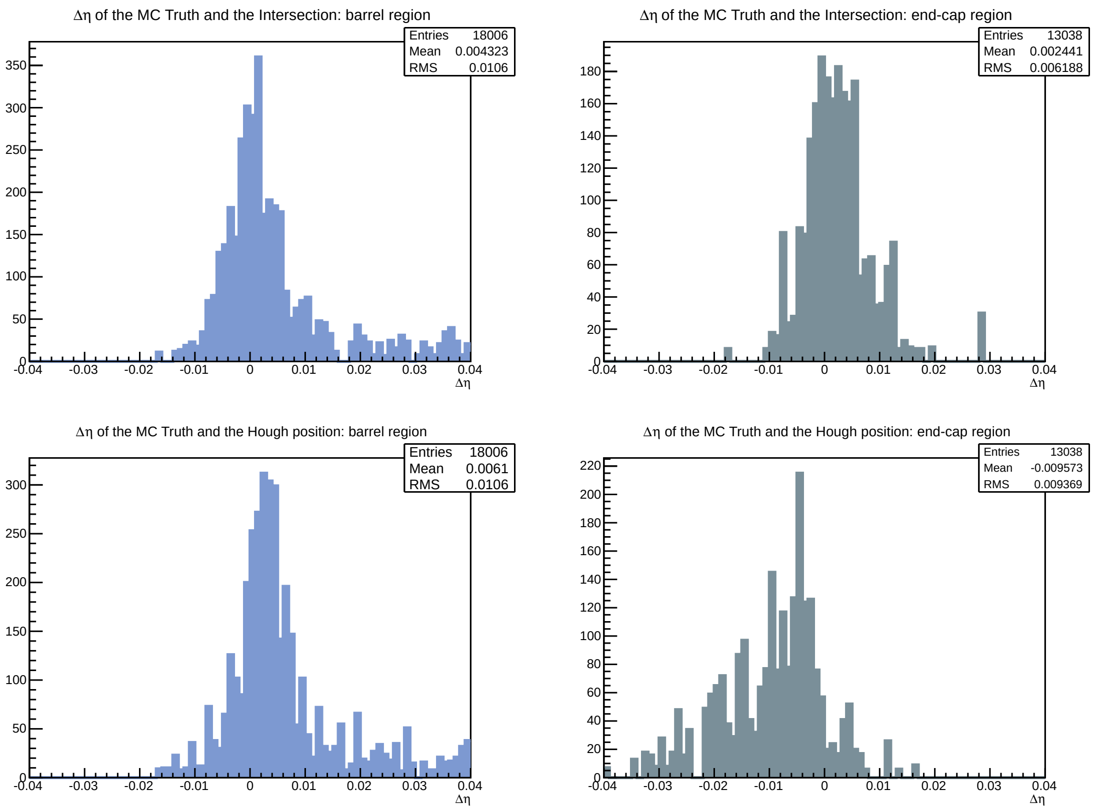


Figure 6: $\Delta\eta$ between the Intersection and the MC Truth (top) and $\Delta\eta$ between the Hough Maxima and the MC Truth.

The efficiency of the Hough transform is studied by using the number of stations in which there was a hit per candidate, doing so for the Hough and for the intersection method. Figure 7 shows the ratio between the number of hits for the Intersection/number of hits for the Hough transform. The results show the Hough transform is slightly more inefficient with respect of the extrapolation method, but this is an imprecise way of study this. The next step is to crosscheck with the efficiency to have a segment fit out of the selected hits.

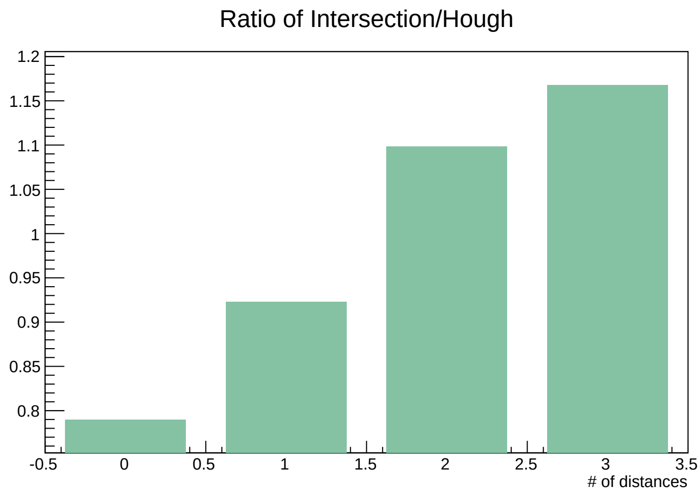


Figure 7: Ratio between the number of hits for the Intersection/number of hits for the Hough transform.

# References

[1] T. A. Collaboration”. *Expected Performance of the ATLAS Experiment: Detector, Trigger and Physics*, volume 1 (2009).

[2] S. Tarem *et al. MuGirl-Muon identification in the ATLAS detector from the inside out.* Nuclear Science Symposium Conference Record (2006).

[3] N. V. Eldik. *The ATLAS muon spectrometer: calibration and pattern recognition* (2007).