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Muon identification algorithms in ATLAS

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In the midst of the intense activity that will arise from the proton-proton collisions at the LHC, muons will be very useful to distinguish rare events of interest. Thanks to the good resolution expected for their momentum measurement, muons shall also serve as powerful tools in event reconstruction. Muon identification will thus be a crucial issue in the ATLAS experiment at the LHC. The different strategies and corresponding algorithms used for muon reconstruction are presented here: standalone reconstruction in the Muon Spectrometer only, combined reconstruction with the Inner Detector, and muon tagging of inner tracks using partially reconstructed tracks in the Muon Spectrometer or information from the Calorimeters.

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1. Introduction

The outer spectrometer of ATLAS, or Muon Spectrometer (MS) [1], is designed to detect and measure the momentum of muons with a precision of 2-3% at 10-100 GeV and 10% at 1 TeV. Precision tracking is done by 1150 stations of *Monitored Drift Tubes*, with 6 to 8 layers of tubes each, completed by 32 forward *Cathode Strip Chambers* at pseudorapidity $|\eta|>2$. High energy tracks inside the MS coverage ($|\eta|<2.7$) typically cross three precision tracking chambers. Muon triggers are provided by 606 *Resistive Plate Chambers* in the barrel region and 3588 *Thin Gap Chambers* in the endcap region, also allowing complementary tracking.

Muon identification can be performed in three ways: *standalone* reconstruction with MS information only; *combined* reconstruction, which matches and combines the standalone tracks with inner spectrometer (or Inner Detector, ID) tracks; finally, identification ("*tagging*") of ID tracks as muons with calorimetric or MS information. There are two reconstruction methods in ATLAS, each comprised of several algorithms covering all three strategies, and called "MuID" and "Staco" after the name of their respective combined reconstruction algorithms.

2. Standalone reconstruction in the Muon Spectrometer

Standalone track reconstruction in MS starts with a search for patterns among hits throughout the Spectrometer. In the selected areas, close hits in the same chamber are fitted in a straight line to produce *segments*. Segments from the three chamber stations are then used to perform a fit of the whole track with hits from all four technologies, taking into account the material and inhomogeneous magnetic field. The tracks are extrapolated back to the interaction point, through the calorimeters, taking into account energy loss and multiple scattering.

The standalone algorithm in the Muid family is called Moore. It looks for hit patterns using a Hough transform of phase space [2]: after an appropriate coordinate change, the best candidates correspond to maxima in Hough space. After the track is fit, back extrapolation to the interaction point is performed by Muid Standalone; it uses a parametrization of energy loss in the calorimeters, as well as isolated calorimetric energy measurements when available.

Muonboy performs the standalone muon reconstruction in the Staco family [3]. The track is built starting from the parameters of a segment in the outer station, then iteratively adding segments in the middle and inner layers until the full track is obtained. The track parameters are fitted and expressed at MS entrance, at calorimeter entrance, as well as at the interaction point. Back extrapolation through the calorimeters uses parametrized energy loss.

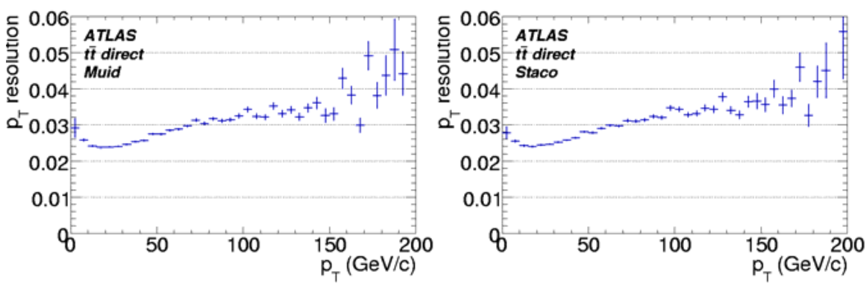

Fig. 1: Transverse momentum resolution ($\Delta p_T / p_T$) vs. p_T for combined muons; left: Muid, right: Staco.

3. Combined reconstruction

Standalone muon tracks extrapolated back to the vertex are matched to Inner Detector tracks, inside its coverage ($|\eta|<2.5$), and combined into a single track, in order to benefit from the complementary momentum sensitivities of MS and ID over the whole p_T range.

Combination of Muid Standalone tracks and ID tracks is done through a full track refit, using the original hits in both ID and MS. The transverse momentum resolution of Muid combined tracks fulfill the physics requirements of ATLAS (cf. Fig. 1 left) [4].

Staco performs a statistical combination of track vectors and covariance matrices from the Muonboy tracks at vertex and ID tracks to obtain the full track parameters. Physics requirements on resolution are also matched by Staco tracks (cf. Fig. 1 right) [4].

A third algorithm, MuGirl, creates its own segments using MS hits in the proximity of extrapolated ID tracks. It can act as a tagger (cf. below) or refit the complete combined track to improve the momentum estimate. MuGirl can also compute velocity and mass of slow particles.

4. Tagging Inner Detector tracks

Additional muon candidates are obtained by tagging ID tracks with MS or calorimeter measurements. This strategy is less sensitive to Coulomb scattering and energy loss: it can thus recover muons with low energy or in areas with limited MS coverage (such as a narrow zone at $\eta=0$), and help detector commissioning, in particular until chamber alignment becomes nominal.

MuTag is the tagger used to complement Staco in difficult areas; it tags the extrapolated ID track with the first Muonboy segment available, in the inner or middle MS layer.

MuTagIMO is an independent tagger using existing Moore segments. It performs tagging in all three stations of muon chambers, adequately resolving ambiguities for shared segments.

Finally, CaloMuonTag and CaloMuonLH look in the outermost calorimetric layers for energy deposits corresponding to the minimum-ionizing pattern of muons to tag ID tracks.

5. Performance and conclusion

Thoroughly tested with Monte Carlo simulations, the muon identification algorithms presented above satisfy the physics requirements of ATLAS. They have been successfully used to observe cosmic muons over a few years, contributing to *in situ* calibration and alignment of the MS. During first beam circulation in the LHC on September 2008, standalone reconstruction has also correctly handled the extreme conditions of beam splash events in the detector. Muon reconstruction is thus in a high level of readiness for the first LHC collisions at the end of 2009.

References

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[4] ATLAS Coll., *Expected Performance of the ATLAS Experiment*, CERN-OPEN-2008-020, arXiv:0901.0512