Muon identification for the ATLAS experiment

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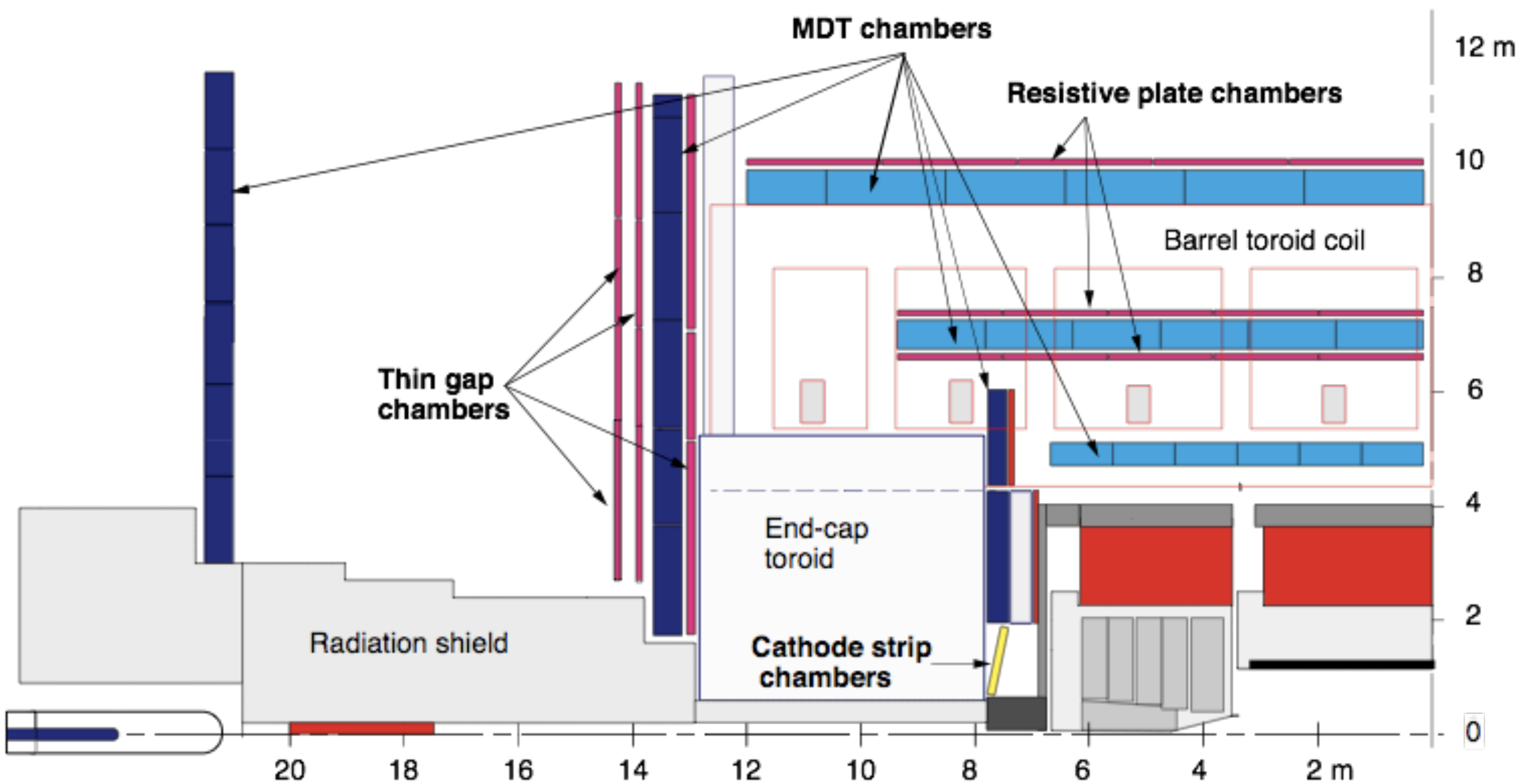
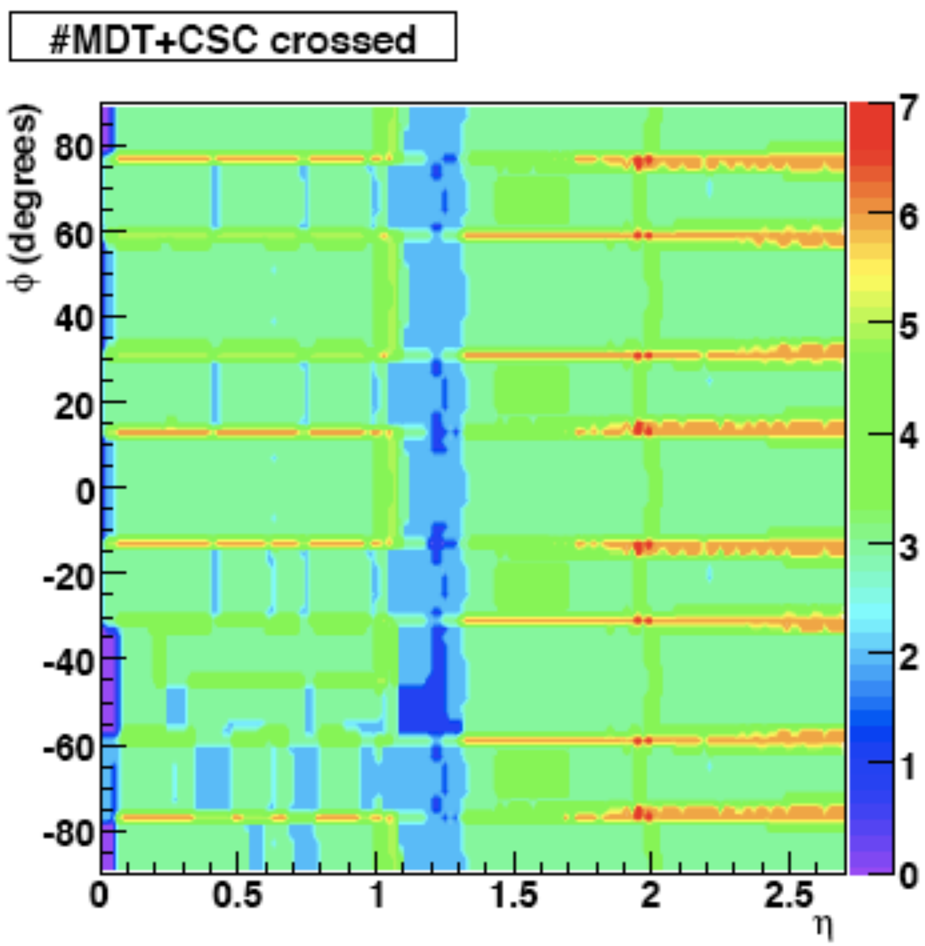
- Overview of Muon Spectrometer
- Overview and performance of stand-alone tracking algorithms
- Overview and performance of combined algorithms
- Overview and performance of tagging algorithms
- Summary

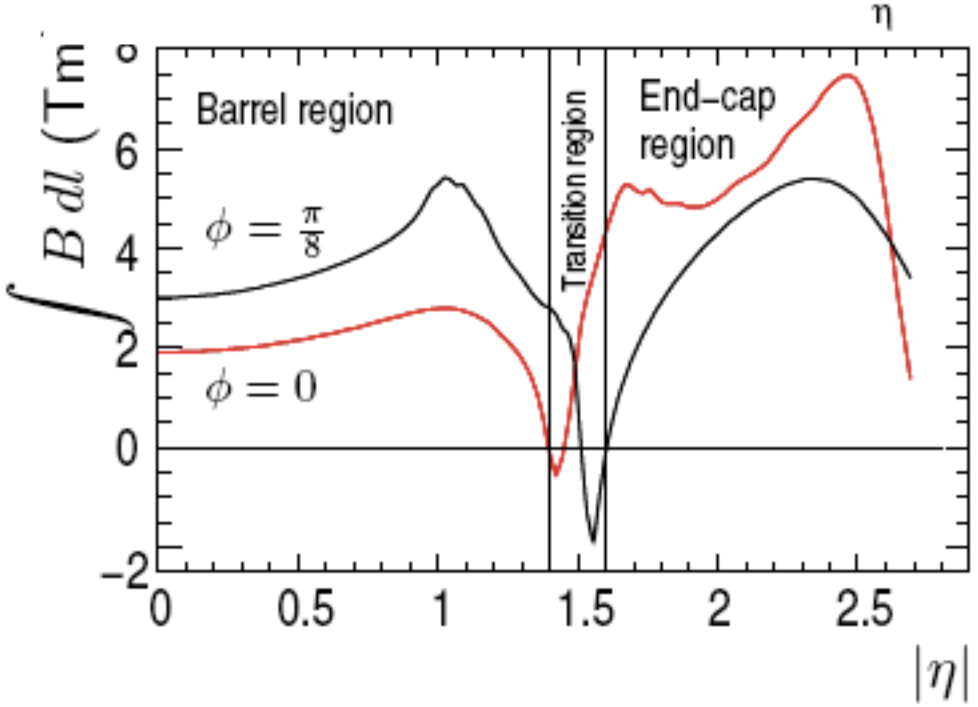
Muon Spectrometer



- Air core toroid magnet (B =0.4 T) to minimize multiple scattering.
- Three layers of precision tracking stations (MDT, CSC) for precise momentum measurement.
- Fast trigger chambers (RPC, TGC) for muon trigger.
- Large rapidity coverage: $|\eta| < 2.7$ (coverage of the inner detector: $|\eta| < 2.5$).
  - EE chambers are staged, and will be installed in 2009 (leading to an lowering of acceptance at $|\eta| \approx 1.2$). The EE chambers help cover the incomplete coverage of the EO chambers where the hole is from $1.0 \lesssim |\eta| \lesssim 1.4$.

Challenges



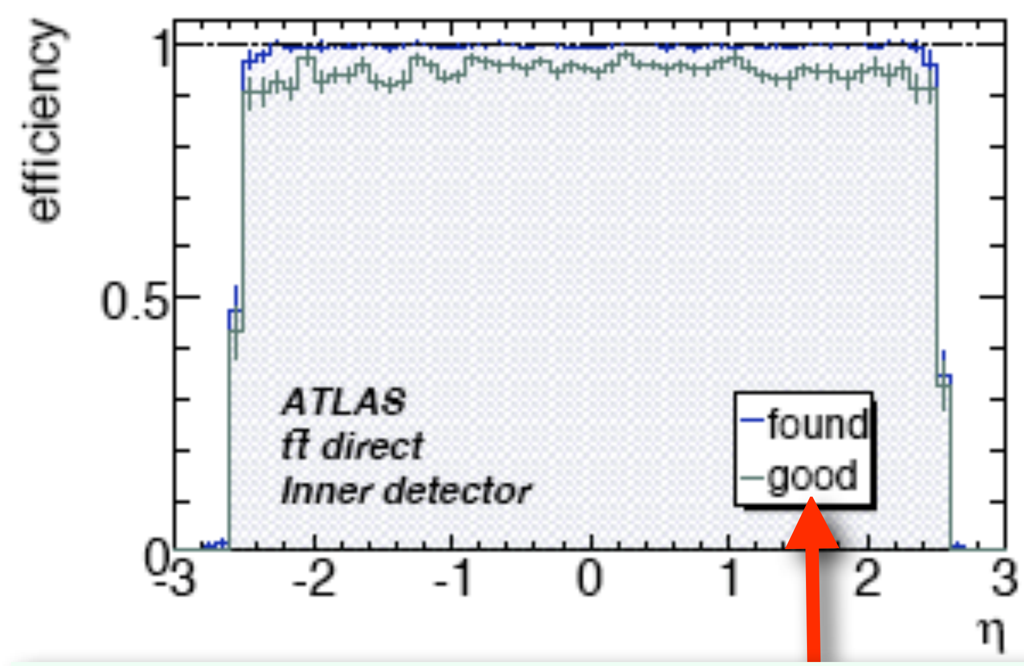


- There are some challenges to reconstructing muons with the Muon Spectrometer:
    - The large amount of dead material in ATLAS & in general, the complex geometry
    - There are regions where we have limited numbers of measurements ($|\eta|\approx1.2$, $|\eta|\approx0.0$ and near the feet)
    - ... and regions where the B field integral is small ($|\eta|\approx1.5$)
- We also need to use muon measurements from the Calorimeter and Inner Detector, in order to get the best possible performance.
    - Two approaches:
        - '*tagging*' inner detector tracks as Muons
        - Merging Inner Detector and Muon Spectrometer tracks into a '*combined*' track

Stand alone track finding

- Muon Spectrometer:
  - Measurement of the muon momentum in the muon spectrometer
    - This is done by finding ‘segments’ in stations, calculating the sagitta, and from this (& their directions) the momentum
  - The resulting track is extrapolated back to the beam, and corrected for the energy loss in the calorimeters
  - Two Algorithms:
    - Moore
    - Muonboy

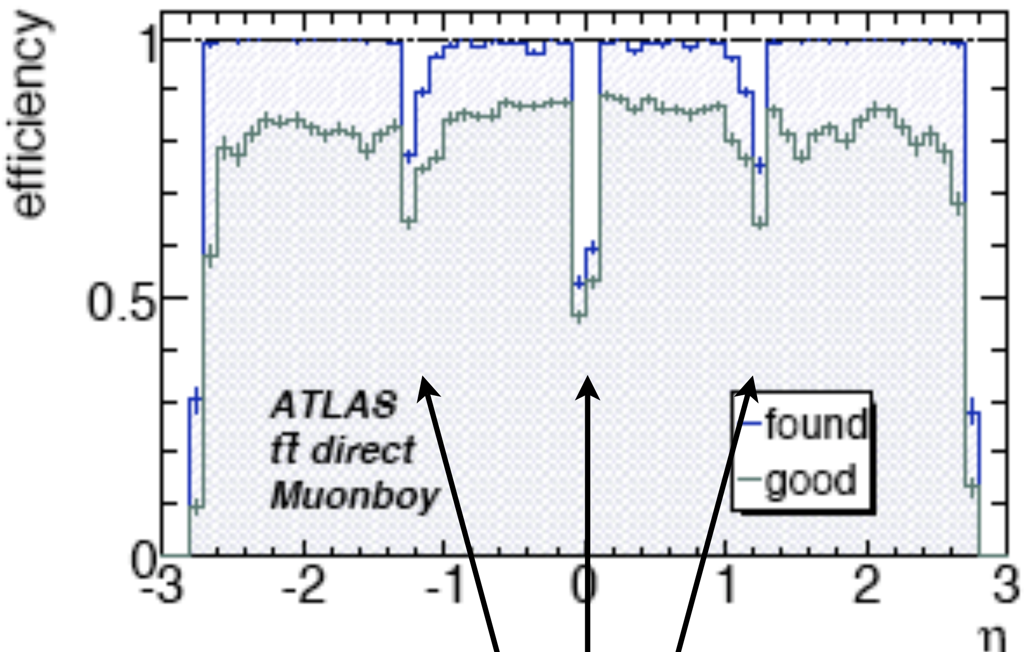
- Inner detector
  - ~100% efficient at detecting Muons:



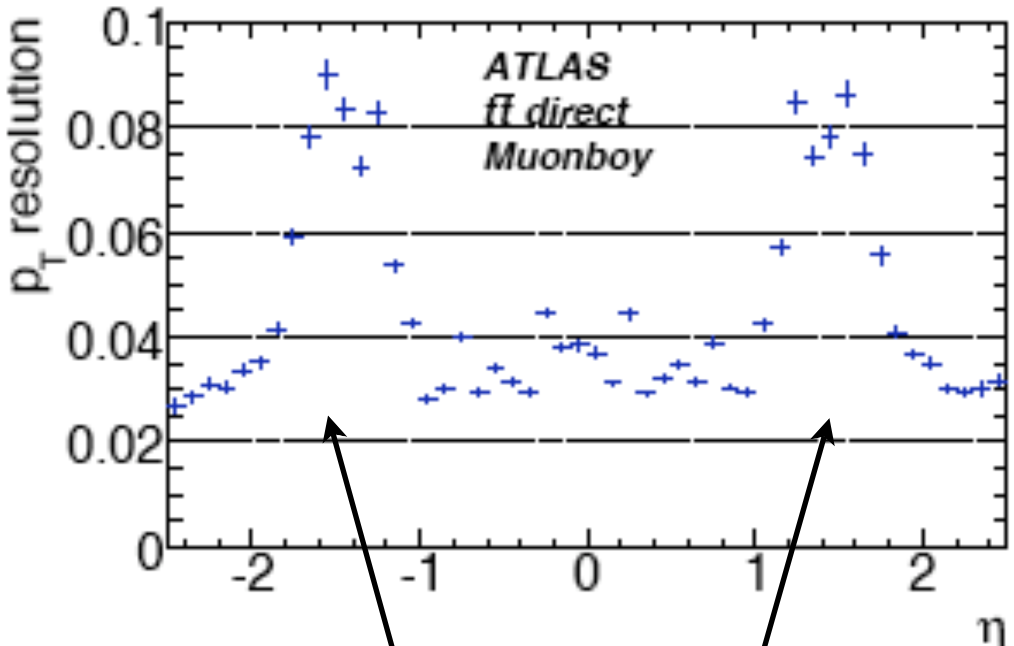
- Found : a simulated muon is considered ‘found’ if there is a reconstructed track within a specified ‘reference distance’ (corresponding to 0.5 in η and ϕ, plus a charge match)
- Good : a found muon is considered ‘good’ if the ‘evaluation distance’ (a χ^2 with 5 degrees of freedom) is <4.5

For more information : ATL-PHYS-PUB-2008-000 “Muon Reconstruction and Identification Performance in ATLAS: Studies with Simulated Monte Carlo Samples”

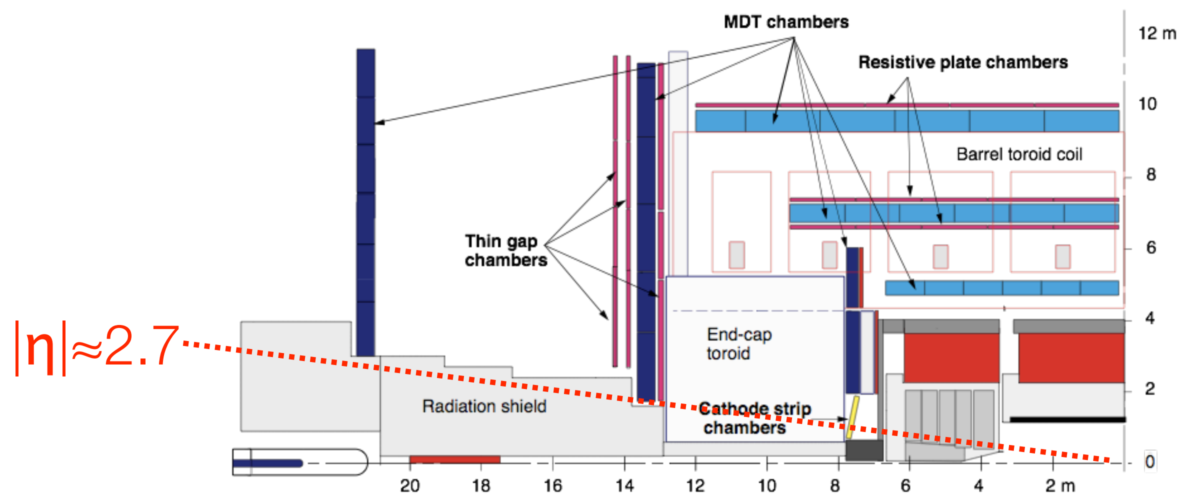
Stand alone Performance: Muon Spectrometer



Performance is good apart from regions where detector coverage is limited (|η|≈0.0 & |η|≈1.2) (the cut for ‘good’ tracks is very tight)

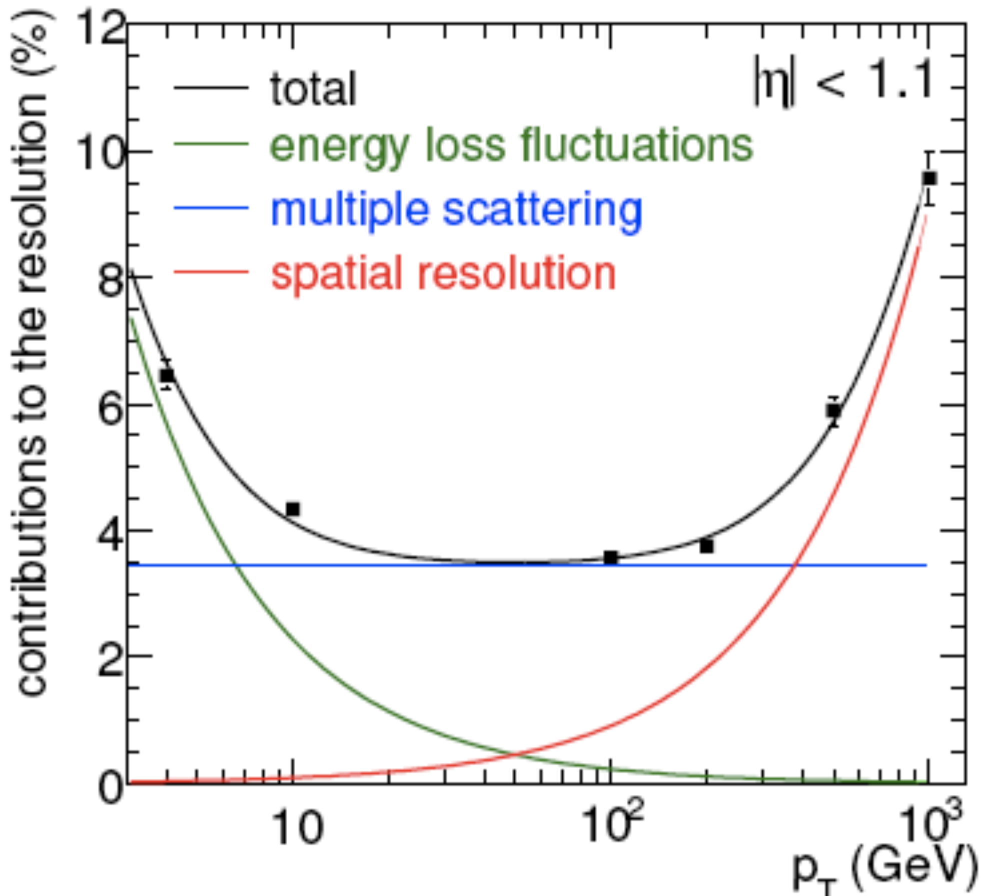


Resolution is degraded in the region 1.2<|η|<1.7 mainly due to the the low field integral , but also the limited number of measurements, and the large amount of material



(Here I only show plots for Muonboy, but Moore performance is comparable)

Stand alone Performance: Resolution

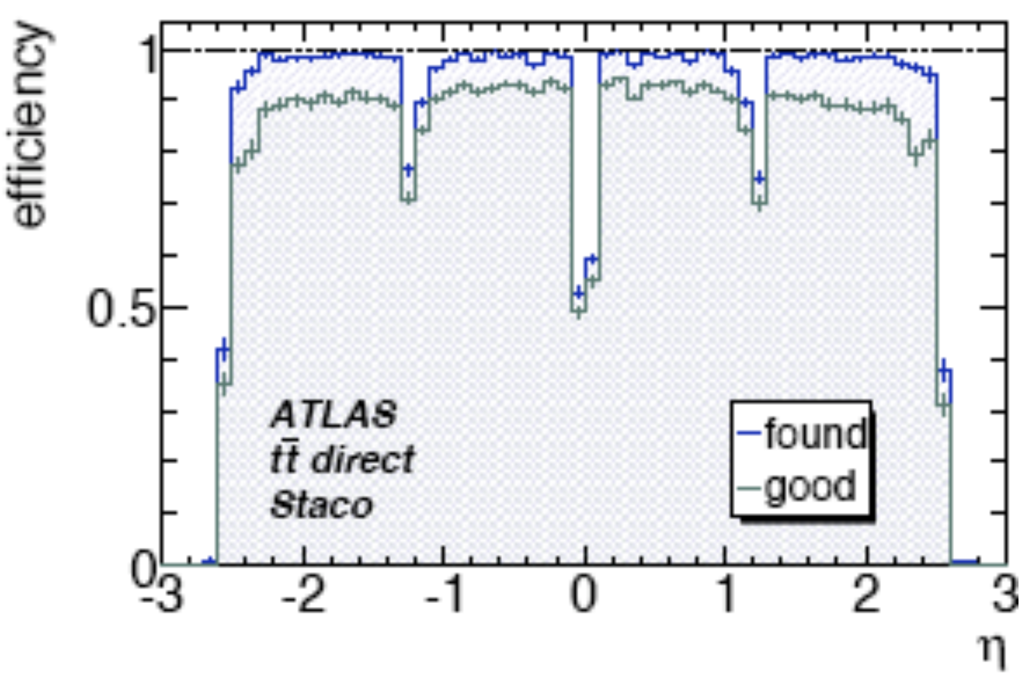


- $\frac{\delta p_T}{p_T} < 10\%$ up to p_T ≤1 TeV.
- Resolution at low p_T limited by energy loss fluctuations.
- Optimum resolution of 3.5% limited by multiple scattering in the muon spectrometer.
- Resolution at high p_T limited by the spatial resolution and alignment of the muon chambers.

Combination Algorithms

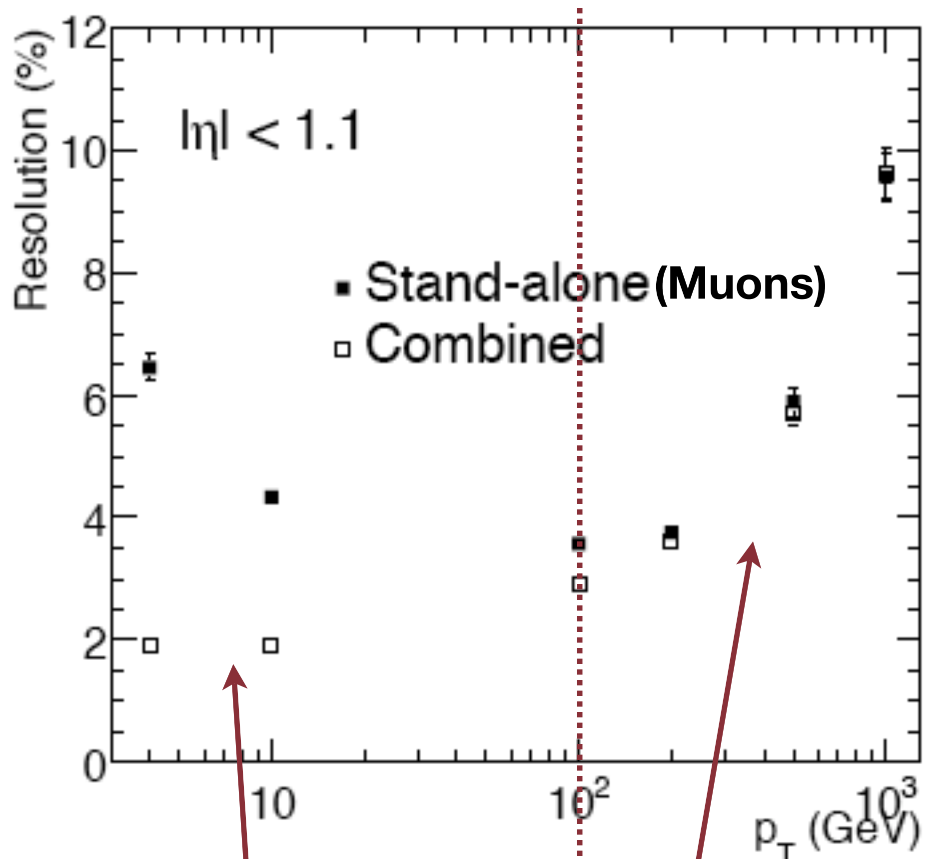
- As will be shown, we can improve the performance of our Muon identification (and correct for problems with the Muon Spectrometer) by combining measurements from all ATLAS sub-detectors
- Two Algorithms to do this: STACO and Muid
- Both muon combination algorithms create combined tracks out of pairs of muon-only and inner-detector-only tracks.
  - To do this, a match χ^2 is used.
  - Corrections are made for energy loss in the Calorimeter
- However how they handle the combined track differs slightly:
  - STACO does a statistical combination of the track vectors to obtain the combined track vector
  - Muid re-fits the combined track, starting from the ID track and then adding Muon measurements

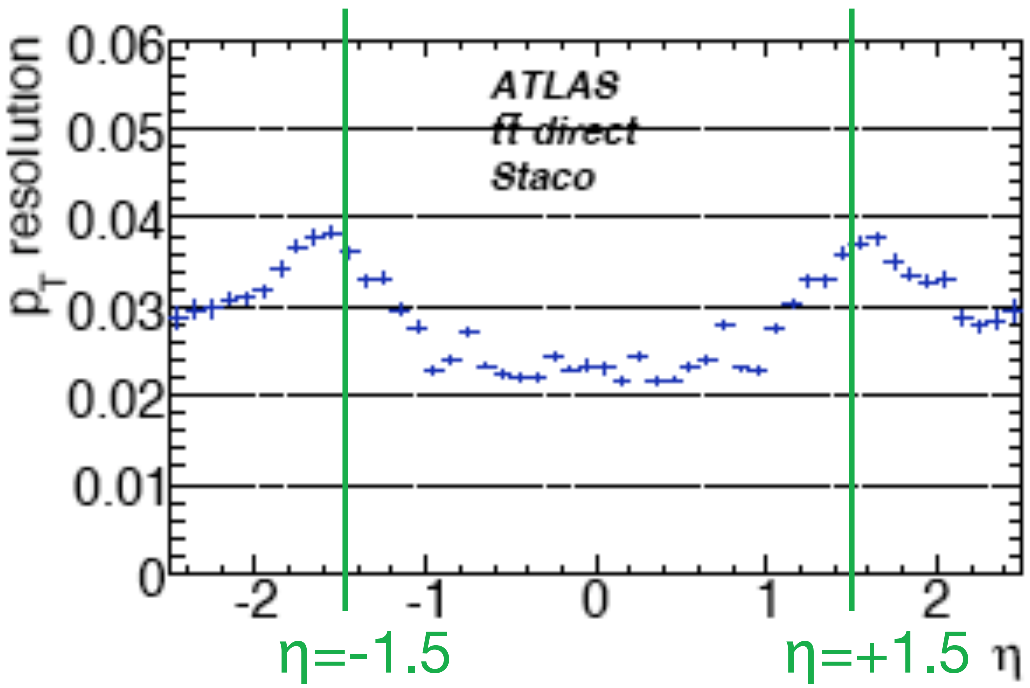
Combined Performance: Efficiency



- From the plot to the left, we can see that combined efficiency is actually slightly lower than for the standalone muon algorithms.
  - Expected, as this is the convolution of the two standalone reconstruction (ID + MS) efficiencies, plus the tracks need to be successfully combined.
- The ID significantly improves the position and direction measurement
  - Again expected: the measurements are much closer to the IP.
- In the plot you see this: the 'good' efficiency increases.
  - **Combined reco improves the 'quality'**

Combined Performance: Resolution





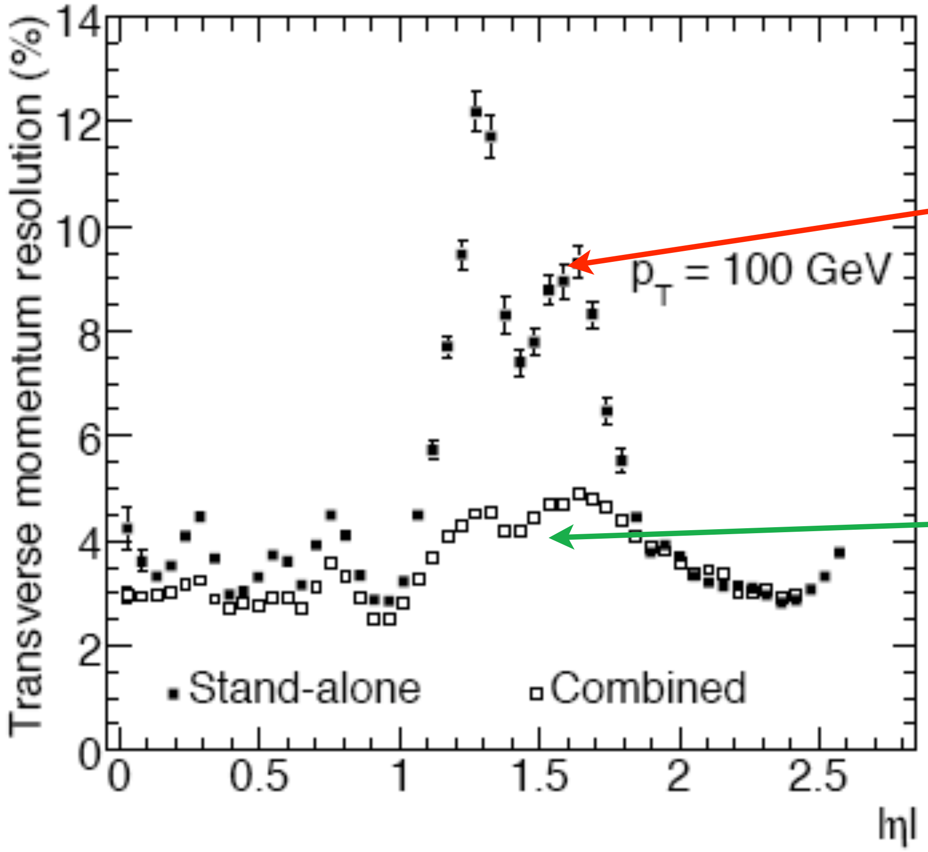
p_T < 100 GeV : Significant improvement of the resolution by the inner detector.

p_T > 100 GeV : Momentum resolution dominated by the muon spectrometer.

Resolution is significantly improved in overlap region (|η|≈1.5), and for low momentum tracks (not shown)

Muon spectrometer crucial for good momentum resolution at large pT .

Rapidity dependence of the momentum resolution

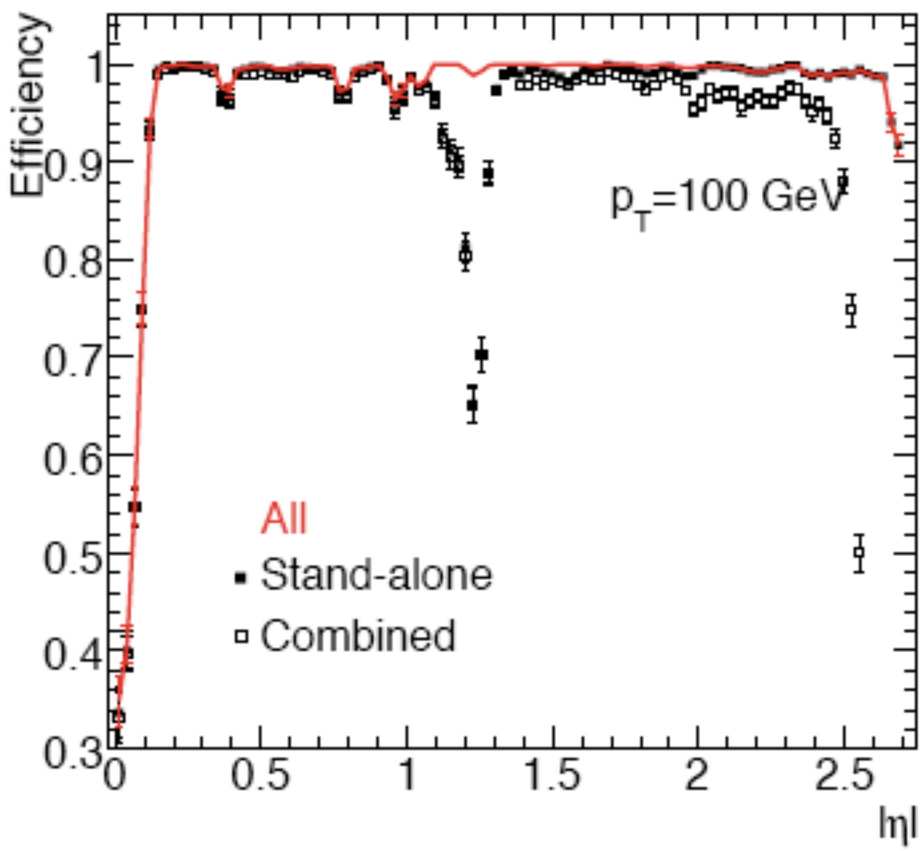


- Stand-alone p_T resolution almost independent of $|\eta|$ apart from the transition region around $|\eta| \approx 1.5$ because of the small field integration.
- Poor stand-alone resolution in the transition region recovered after the combination with the inner detector.

Muon Tagging

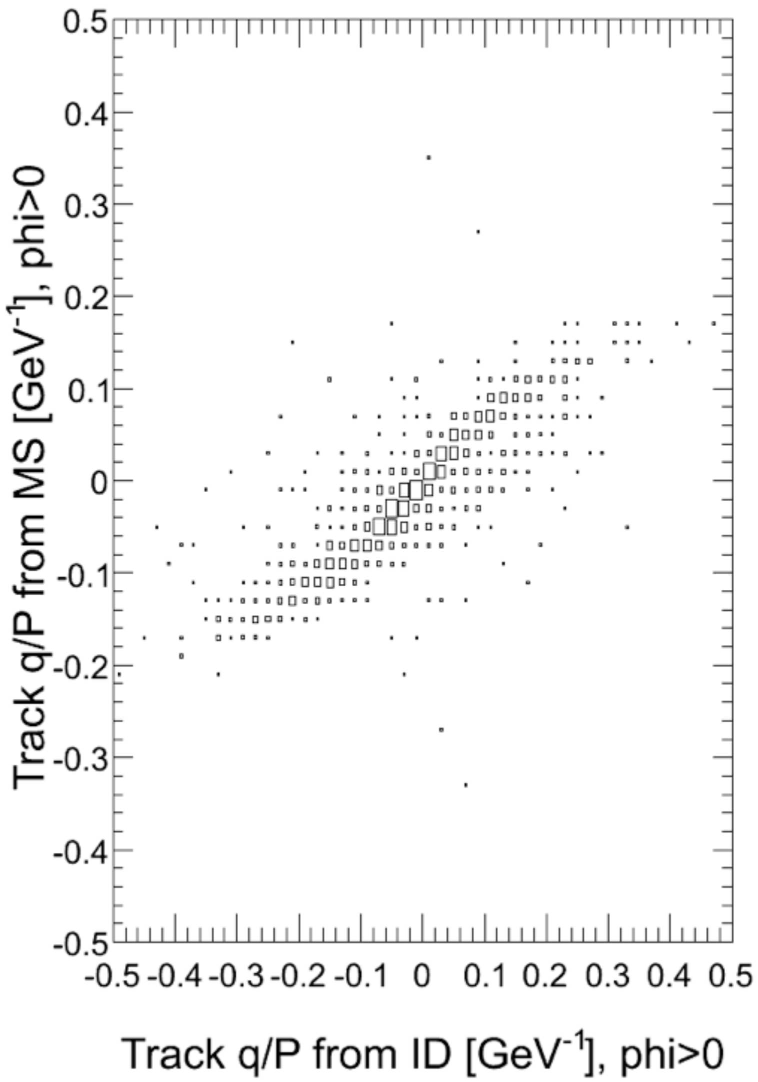
- Take an Inner Detector track and ‘tag’ it as a muon by either:
  - Finding a matched muon segment (i.e. a proto-track but in one station only)
  - Finding an appropriate energy loss measurement in the calorimeter
- Algorithms
  - MuTag, MuTagIMO
  - MuGirl
  - CaloTag, CaloTagLR
- Overview:
  - CaloTag uses cuts, whilst CaloTagLR makes use of a Likelihood ratio.
  - MuTag defines a tag χ^2, whilst MuGirl uses a neural network to define a discriminant.
  - MuGirl looks at all ID tracks and does segment finding around these tracks, whilst MuTag only uses ID tracks and segments not used by STACO.
    - (MuGirl also refits combined tracks so it could be considered a ‘combined’ algorithm too)

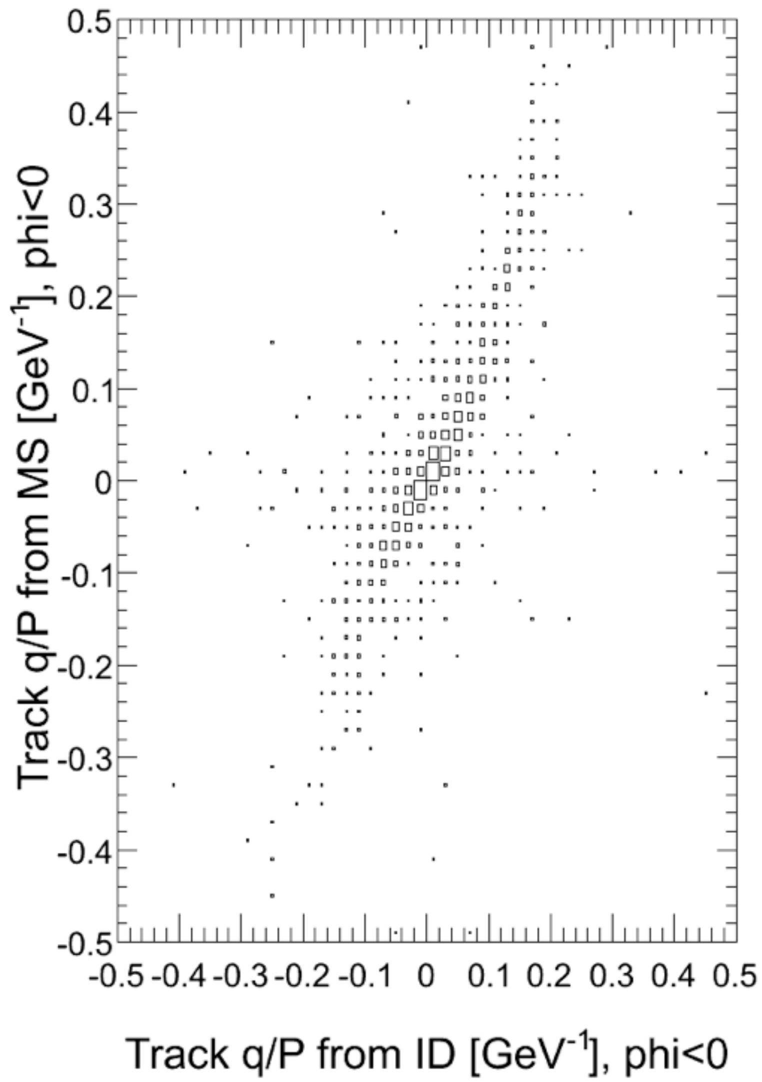
Muon Tagging: Efficiency



- Efficiency drop
  - |η|≈0 Large acceptance gap in the muon spectrometer for services of the inner detector and the calorimeters.
  - |η|≈1.2 Missing EE chambers in the spectrometer (to be installed in 2009)
- Efficiency recovery
  - |η|≈0 Tagging of inner detector tracks by calorimeter depositions (not included in the figure).
  - |η|≈1.2 Tagging of inner detector tracks by track segments in the spectrometer.

Cosmics





- ATLAS has now taken many millions of cosmic measurements
- Analysis is ongoing, but the plots to the left show a clear correlation between ID and Muon tracks.
- ATLAS is using cosmic data to study calibration and alignment, and to optimise the performance of the various algorithms.

Summary

- The ATLAS Muon Spectrometer presents some challenges to reconstructing muon tracks, notably the large dead material budget, the missing stations in the transition region, and the highly inhomogeneous magnetic field
- By using information from the Inner Detector tracking, and the calorimeters, we can recover tracks that would otherwise be lost, and improve the physics performance of ATLAS.
- The various combination and tagging algorithms that do this, have been extensively tested on simulated data, and found to perform well.
- Further optimisations are ongoing, and in particular the algorithms are now being tested with cosmic and first beam data.