Alignment of the ATLAS Muon Spectrometer with Tracks

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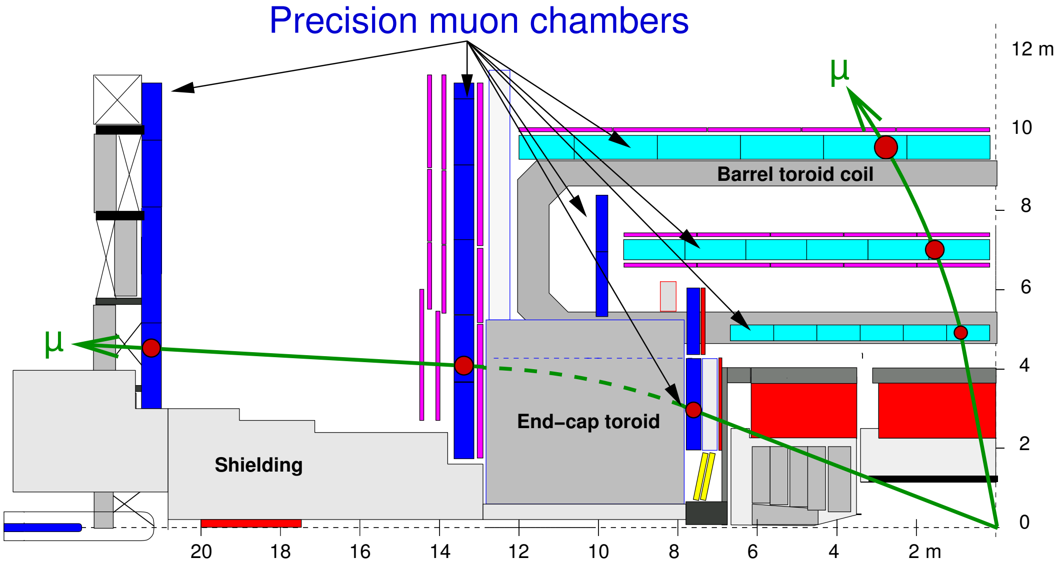
Outline

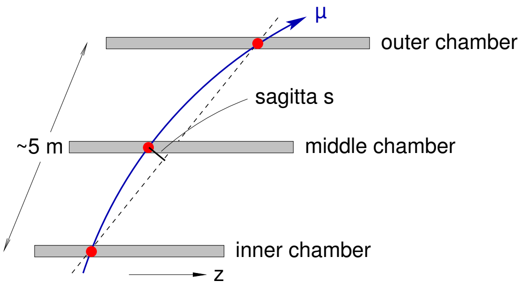
1. The ATLAS muon spectrometer.
2. Alignment strategy for the muon spectrometer.
3. Alignment with straight muon tracks.
4. Alignment with curved muon tracks.
5. Summary.

The ATLAS muon spectrometer



- ☆ Goal: Accurate momentum reconstruction up to p_T=1 TeV/c.
- Air core toroid magnet to minimize multiple scattering: 2.5-7 Tm.
- 3 layers of drift-tube chambers for accurate position measurement.

Chamber alignment requirements



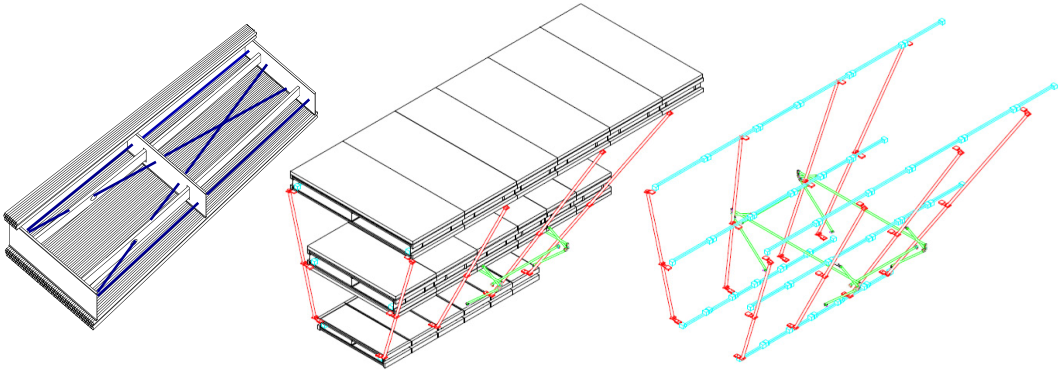
$$s \approx 500\ \mu\text{m}\frac{p}{\text{TeV}}.$$

$$\left.\frac{\delta p}{p}\right|_{p=1\ \text{TeV}} = 10\% \leftrightarrow \delta s = 50\ \mu\text{m}.$$

- Spatial resolution of the muon chambers: 35 μm. $\Rightarrow \delta s$=40 μm.

$\Rightarrow$ δs=50 μm requires 30 μm chamber alignment accuracy in sagitta direction.

The optical alignment monitoring system



Chamber geometry: 20 μm wire positioning accuracy from construction, deformations monitored by internal optical sensors.

Barrel: Alignment grid formed by four subsystems: projective, axial/praxial, reference, and chamber-to-chamber optical sensors.

End caps: High precision reference rulers (bars) form the alignment grid together with angular and proximity monitors installed on the chambers and bars.

Nonrecurring track alignment task

Calibration of the optical alignment monitoring system

- Calibrated optical system.

$\longrightarrow$ Absolute alignment accuracy $\lesssim$100 μm.

- 30 μm absolute alignment accuracy requires calibration with tracks.
- Barrel
  - Absolute optical alignment $\sim$100 μm in most of the parts.
  - Absolute optical alignment > 500 μm in some areas where platform positions are not known with sufficient accuracy.

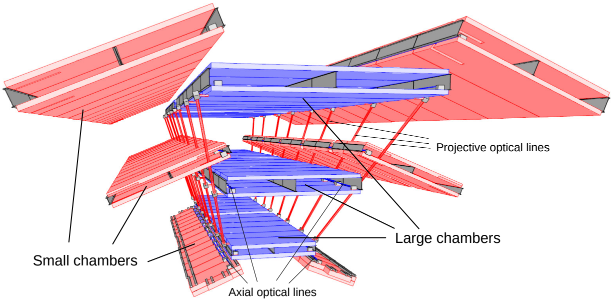
$\longrightarrow$ Alignment with straight tracks needed for 100 μm and 30 μm absolute alignment accuracy to be provided in a special run with no toroidal field.

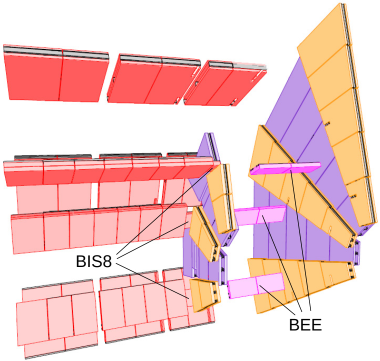
Recurring track alignment tasks

- Overlap alignment

  Alignment of barrel muon chambers with partial sets of optical sensors (small barrel, BEE, and BIS8 chambers).

  → These chambers must be aligned with respect to optically aligned chambers using muon tracks in the overlap regions.





- Barrel end-cap alignment

  Alignment of the endcaps with respect to the barrel for the muon spectrometer.

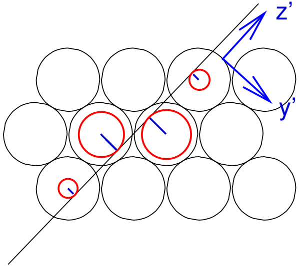
Alignment with straight tracks

- The chamber positions and orientations are determined by minimizing the sum of the track χ^2s in the chamber positions and orientations.
- Track χ^2:

$$\sum_{hits\ h} \frac{[r(t_h) - d_h]^3}{s_h^2};$$

$r(t_h)$: drift radius of the hth hit;
d_h: distance of the track from the wire of the hth hit tube.

- The Euclidian distance d_h is non-linear in the track and alignment parameters.



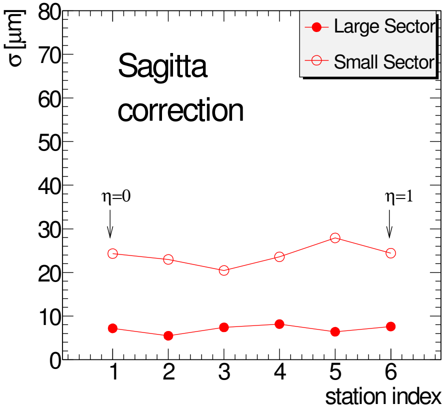
Linearization by change to track reference frame:

- $r(t_h) \to y'_h = \pm r(t_h)$.
- $d_h \to y'_h = \pm d_h$.

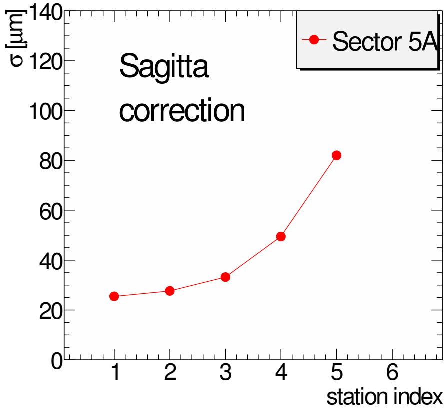
$\to$ Analytic solution of the χ^2 minimization.

Performance of the straight-track alignment method

- Successful on MC data samples of 20 GeV projective straight muon tracks and on cosmics commissioning data.
- Accuracy of the alignment correction on the sagitta



MC sample of ∼100 projective tracks



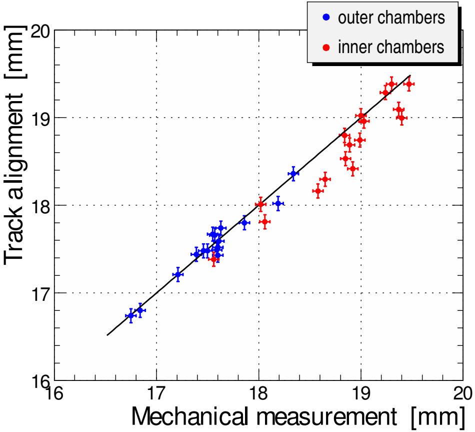
∼400 cosmic muon tracks

- Require statistics for 30 μm alignment accuracy:
  - 100,000 20 GeV projective tracks per barrel sector.
  - ∼1 million cosmic tracks for top and bottom barrel sectors.

Comparison with mechanical measurements

Interchamber distances were measured for the inner and outer chambers of the top barrel sector.

Measured distances



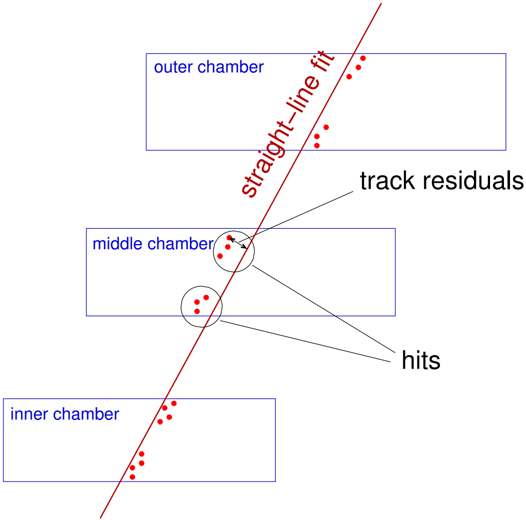
Outer chambers

- Excellent agreement of track alignment and mechanical measurements.
- $\sigma(d_{tracks} - d_{mech.})$=85 μm.

Inner chambers

- Track alignment and mechanical measurements are correlated.
- $< d_{tracks} - d_{mech.} >$=-190 μm caused, most likely, by solid spacer between innner chambers deforming tubes (remeasurement planned).

Measurement of the initial alignment accuracy



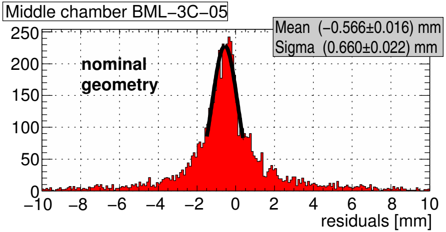
Cosmic muon track selection

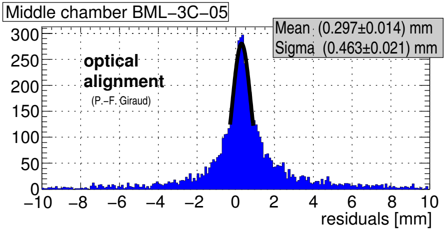
- Tracks through 3 chambers.
- Track pointing to the interaction point within 100 mrad.

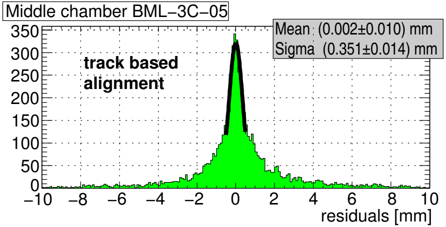
Alignment precision determination

- Straight-line fit through all hits.
- Mean value of the residual in the middle chamber $= \frac{2}{3}$ of the sagitta shift due to misalignment.

Measured initial alignment accuracy







Nominal geometry

- No alignment corrections.
- $\sim$1 mm absolute alignment accuracy.

Optical alignment

- With optical alignment corrections.
- $\sim$0.5 mm absolute alignment accuracy.

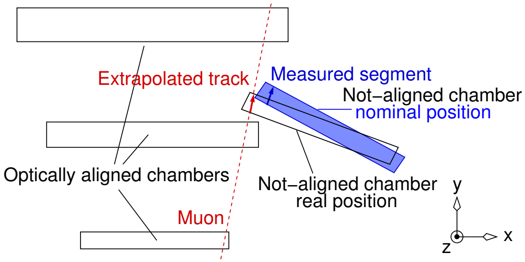
$\Rightarrow$ Significant improvement by uncalibrated optical system.

Track alignment

- With track alignment corrections.
- $\lesssim 10\ \mu m$ absolute alignment accuracy.

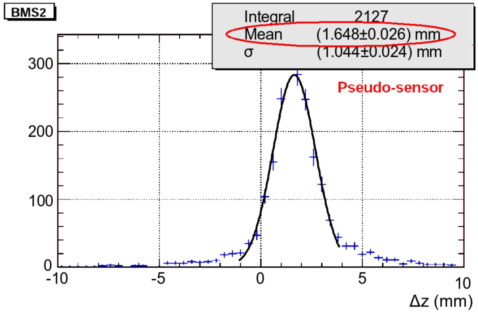
$\Rightarrow$ Required accuracy after track alignment.

Alignment with overlap tracks



- Measurement of the muon momentum with the optically aligned part of the spectrometer.
- Extrapolation of the muon trajectory to the unaligned chambers in the overlap region.
- The results of the track alignment is provided to the optical alignment system as pseudo-sensor data.

Results of a Monte-Carlo study

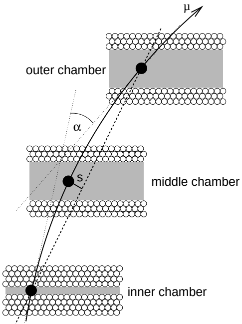


- Shifts of small chambers well monitored.
- 10,000 20 GeV overlap tracks needed for 10 μm accuracy.

$\rightarrow$ A dedicate overlap muon stream at 200 Hz will be provided at the end of the muon trigger.

Sector alignment with curved tracks

- Alignment with curved tracks difficult due to limited redundancy in the muon momentum measurement.
- Redundancy in the momentum measurement



Barrel and end caps:

- Sagitta.
- Deflection angle.

Barrel

- Curvature of muon trajectory in the middle chambers for $p_T \lesssim 6$ GeV.

- Preliminary result of Monte-Carlo studies:
  - Momentum measurement in the middle chamber of limited use due to high sensitivity to distortions of the chamber geometry and the space drift-time relationship.
  - Alignment accuracy of 30 μm hard to achieve with curved tracks.
  - 100 μm alignment accuracy seems feasible, sufficient for monitoring the geometry.
- Studies ongoing.

Summary

- The chambers of the ATLAS muon spectrometer need to be aligned with 30 μm accuracy to provide 10% momentum resolution at 1 TeV.
- Relative movements of the muon chambers are monitored by optical alignment sensors with the required accuracy for most of the spectrometer.
- Gaps in the acceptance of the optical system have to be aligned with curved muon tracks with respect to optically aligned parts of the spectrometer.
- The absolute alignment of the chambers will be determined in a special run with no magnetic field at the start of ATLAS.
- The top and bottom of the barrel muon spectrometer are well illuminated with cosmic muons which are used to align these region with the required accuracy.
- Curved alignment procedure to monitor the geometry during LHC operation are under development.