Aligment of the ATLAS Muon Spectrometer with Curved Tracks

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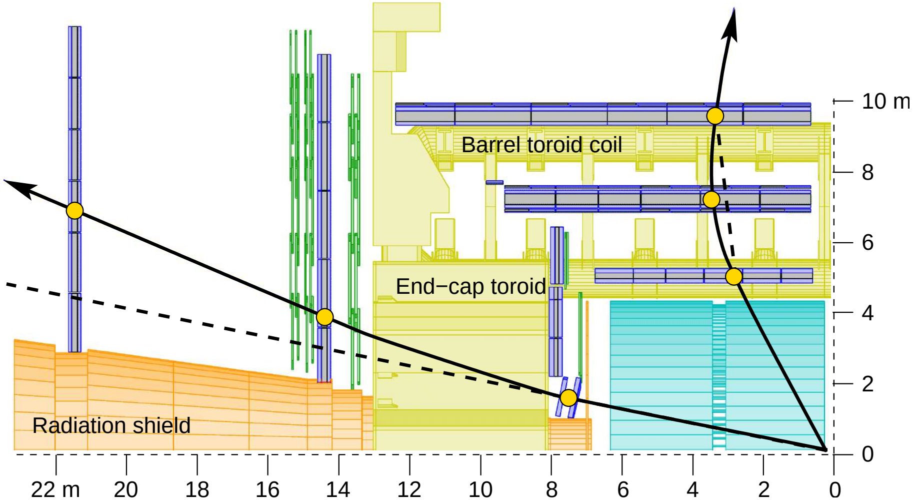
LHC Detector Alignment Workshop – II
CERN, 25.06.2007

Outline

1. Momentum measurement in the ATLAS muon spectrometer.
2. Tasks for the alignment with curved tracks.
3. Method for alignment with curved tracks.
4. Results of Monte-Carlo studies.
5. Summary.

Momentum measurement in the Atlas muon spectrometer

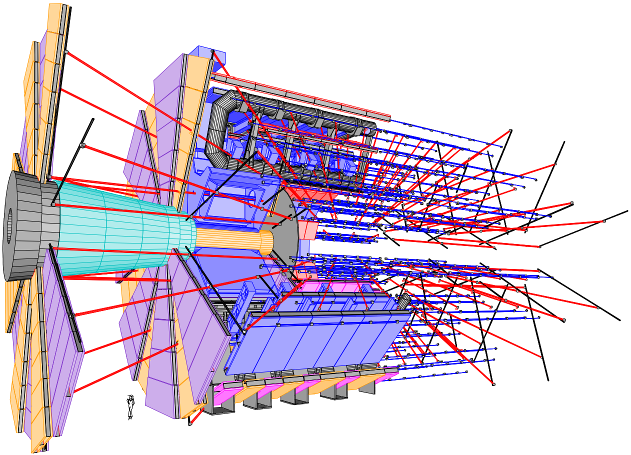


- 3 planes of precision chambers.
- Barrel: 3-point sagitta measurement.
- End cap: point-angle measurement.

- $\frac{dp_T^\mu}{p_T^\mu} = 10\%$ for $p_T^\mu = 1$ TeV/c.
  - $p_T^\mu = 1$ TeV/c: sagitta = 400-700 μm.

$\rightarrow$ 50 μm point resolution needed (including alignment across 5-10 m).

Alignment of the ATLAS muon spectrometer



Optical alignment system

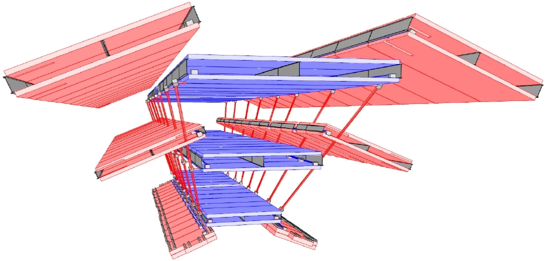
- with <30 μm accuracy
- using ~5000 light rays.

Details in Ph. Schune's and Ch. Amelung's talks.

Alignment with tracks

- Straight tracks (from cosmics and run with toroid switched off) to determine initial geometry at 30 μm level.
- Role of curved tracks see next slide.

Alignment of the barrel with curved tracks



Baseline strategy

- Absolute alignment with straight tracks.
- Large sectors: optical system for relative movements.
- Small sectors: curved tracks with overlaps with large sectors.

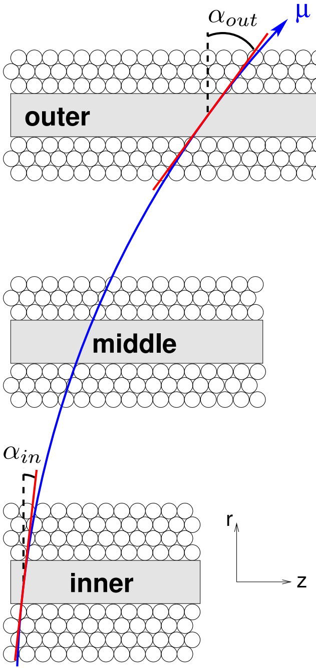
Recent feasibility study

Possibility to align the large chamber triplets with curved tracks?

- Purpose: monitoring of the optical projective alignment.
- Based on low-momentum tracks from the calibration data stream:

  $p_T > 6$ GeV/c at a rate of 2 kHz.

The alignment method



Goal

- Align the inner and outer chambers with respect to the middle chamber.

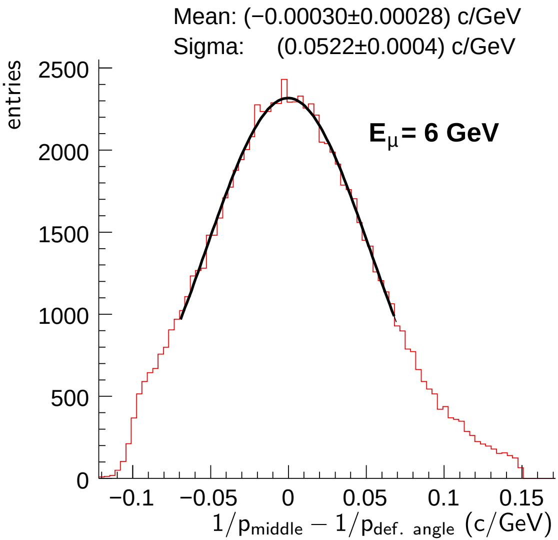
Basic idea

- Make use of the high mechanical precision and the direction capability of the chambers.
- Use an alternatives of the sagitta momentum measurement:
  - Curvature measurement in the middle chamber.
    $\rightarrow p$ unbiased, poor resolution.
  - Momentum from deflection angle:

$$\Delta\alpha = \alpha_{out} - \alpha_{in} = \frac{q}{p} \cdot \int_{\mathcal{P}} B\, dl.$$

$\rightarrow$ p potentially biased by rotation of the outer chambers, but high resolution.

Rotation between the inner and outer chamber



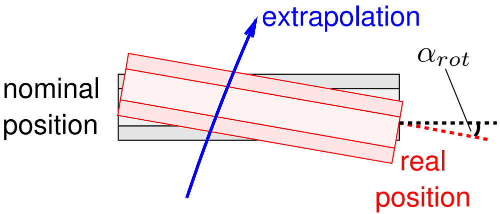
- Momentum measurement in middle chamber independent of misalignment.
- Compare $1/p_{\text{middle}}$ with $1/p_{\text{def. angle}}$ to determine the rotation between the outer chambers.
- Requirement for 30 μm alignment accuracy:
  $$\sigma_{1/p} \approx 10^{-4} \text{ c/GeV}.$$
- 30 μm accuracy: $\sim 10^6$ tracks. (100 μm accuracy: 10^5 tracks.)

Assumption on the following slides: No rotation between the outer chambers.

Determination of rotations

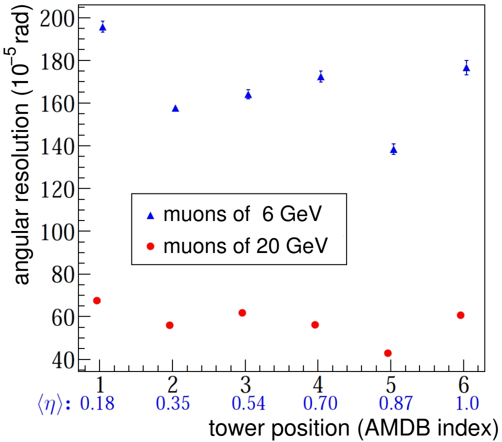
Rotations α_{rot} of the outer/inner chamber wrt. the middle chamber

- For small misalignments (translations ~1 mm), rotations can be measured independently of translations.



Rotation α_{rot} from the difference of the slopes:
$\alpha_{rot} =< \Delta m >=< m_{extr.} - m_{segment} >$.

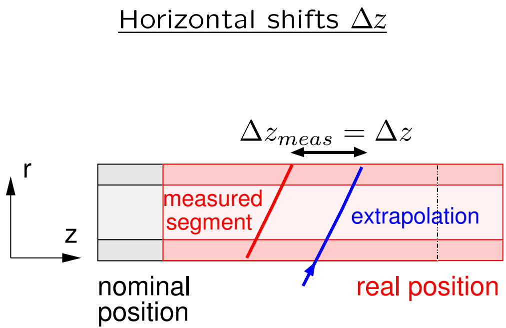
Monte-Carlo tests – rotations

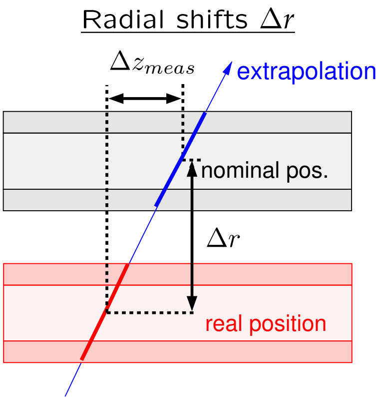


- Monte-Carlo study with 6 GeV and 20 GeV muons.
- Ideal geometry.
- Width of the Δm distribution
  $\Rightarrow$ statistical error of extrapolated angle.
- Angular resolution dominated by multiple scattering.

- Required angular resolution: 10^{-5} rad.
- Number of tracks needed for that:
  - 6 GeV: $\left(\frac{200\cdot 10^{-5}}{1\cdot 10^{-5}}\right)^2 \approx$ 40,000,
  - 20 GeV: $\left(\frac{70\cdot 10^{-5}}{1\cdot 10^{-5}}\right)^2 \approx$ 5,000.

Determination of translations





Simulataneous determination of Δz and Δr

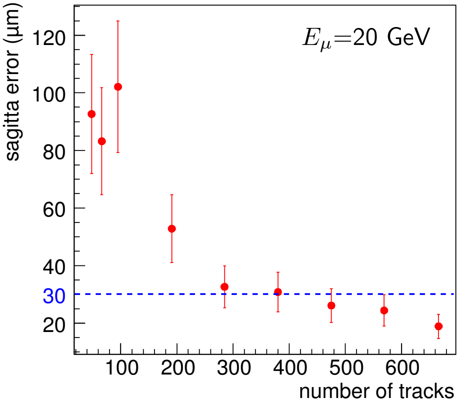
Minimization of

$$\chi^2 = \sum_{tracks} \frac{\left[\Delta z_{meas} - \left(\Delta z - \frac{1}{m}\Delta r\right)\right]^2}{\sigma^2}$$

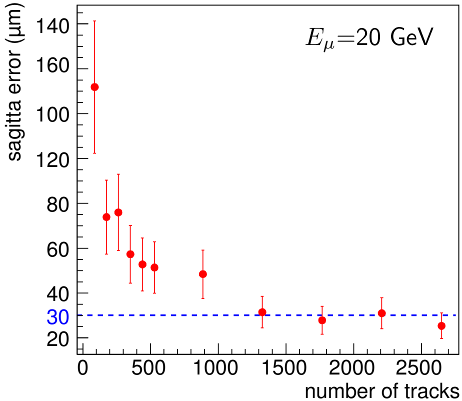
m: slope of the track.

Monte-Carlo tests – translations

Mean track angle: 10^o



Mean track angle: 35^o



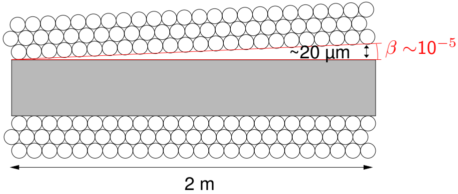
- χ^2 fit with independent data sets ("ensemble test"):
  standard deviation $\leftrightarrow$ resolution of the method.
- Δz, Δr $\rightarrow$ sagitta error (dependent on chamber position).
- 30 μm resolution: $\sim$2,000 tracks needed.

Systematic limitations

The accuracy of the method is limited by the accuracy of the momentum measurement in the middle chamber.

Limitations of the momentum measurement by the middle chamber:

- Mechanical precsion/geometry of the middle chamber.



Angle β between multilayers

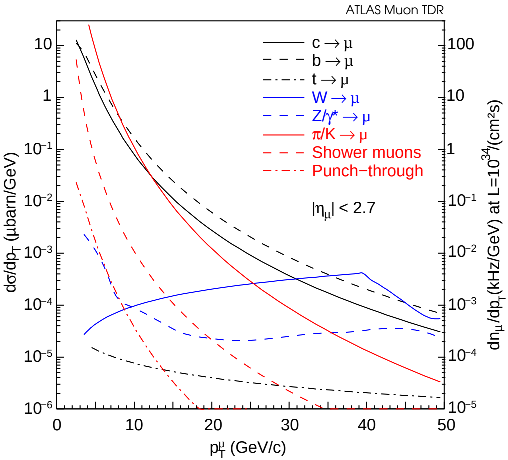
- As built: $\sim 10^{-5}$ rad.
- Required: $\sim 10^{-6}$ rad.

$\Rightarrow$ β must be determined with straight tracks ($\sim 10^6$ cosmic muon tracks).

- The magnetic field in the middle chamber must be known with $\sim 10^{-4}$ T (looks feasible from Hall probe measurements).

Requirements for the calibration stream

Inclusive muon cross sections



<u>Calibration stream:</u>

$p_T^{\mu} > 6$ GeV/c, rate: 5 Hz/tower
(prescaled trigger rate for $L > 10^{32}$ cm^{-2} s^{-1}).

→ 10^6 muons/tower
(> 1000 μ with $p_T^{\mu} > 20$ GeV/c)
after ≈3 days of data taking
➠ 30 μm alignment accuracy.

→ 10^5 muons/tower after 7 h
➠ 100 μm alignment accuracy.

Summary

- A method for the alignment of the barrel muon spectrometer with curved tracks was developed.
- Performance with the muon calibration stream of 5 Hz/tower with $p_T^{\mu} > 6$ GeV/c:
  - 100 μm alignment accuracy after 7 hours of data taking.
  - 30 μm alignment accuracy after 3 days of data taking.
- Main limitation: Mechanical precision of the chambers. Alignment accuracy < 300 μm requires measurement of the chamber geometry with straight (cosmic) muon tracks.
- The study shows that the ATLAS muon spectrometer can be aligned with tracks.
- Alignment with tracks in part complementary to "hardware" alignment, but no replacement for it.

$\rightarrow$ Plan to use track-based alignment with the Millepede approach. Prototype implementation shows promising results as expected from the presented feasibility study.