Alignment of muon chambers with tracks

Sergey Kotov, Jens Schmaler, Oliver Kortner

MPI für Physik, Munich

ATLAS-D workshop, Heidelberg, 22.09.2006
Overview of the ATLAS Muon Spectrometer alignment

Track based alignment of chambers without optical sensors

Current performance of track based alignment algorithm

A segment based approach to the muon spectrometer alignment

Conclusions and plans
Overview of the ATLAS Muon Spectrometer alignment

- Momentum measurement design goal:
  \[ \frac{\delta p_t}{p_t} = 10\% \] for 1 TeV muons ⇒ sagitta of 500 \(\mu\)m measured with 50 \(\mu\)m accuracy

- Muon chambers (\(\sim 1200\) in total) are high-precision objects by construction: sense wires are placed with 20 \(\mu\)m precision during chamber assembly

- Single muon chamber spatial resolution is \(\sim 40\mu\)m ⇒ muon chambers must be aligned to 30 \(\mu\)m accuracy in order to provide the required momentum resolution

- In the first order, only the relative alignment of triplets of chambers (towers) traversed by the same muon track is important for momentum measurement

- Optical alignment system provide this tower alignment:
  - in the barrel region 3-point straightness monitors (RASNIKs) installed on the inner/middle/outer chambers form projective lines pointing to the interaction region
  - in the endcap regions projective lines are impossible because the cryostats of endcap toroid magnets block the interaction region ⇒ the endcap alignment relies on high precision reference rulers – alignment bars which form alignment grid for the endcaps

- In principle, muon tracks can be used to align the muon spectrometer (some of these activities are being pursued by MPI MDT group)
Track based alignment of chambers without projective alignment sensors

- Many muon chambers don’t have projective optical alignment sensors $\Rightarrow$ no correction to sagitta measurement
  - small barrel chambers
  - BEE chambers
  - BIS8 chambers
- Solution: use muon tracks passing through overlaps between these chambers and optically aligned chambers to obtain their relative positions

Alignment of chambers without optical projective sensors is official responsibility of MPI MDT group and during data taking will be carried out at Munich MDT calibration and alignment center (part of Munich Tier-2)
An ATHENA package **MuonTrkAlign** for track based alignment of the muon spectrometer is being developed by MPI MDT group

- based on new common tracking EDM (uses its data objects and tools):
  - operate with tracking EDM data objects: Tracks, TrackParameters, RIO_OnTrack
  - use TrackFitters, TrackExtrapolators and other common tracking tools
  - runs on both Mounboy and MOORe output

- current results were obtained with:
  - release 12.0.1, samples of 20 GeV and 100 GeV muons
  - perfectly aligned detector geometry
  - input track container “ConvertedMooreTracks”
Check of common tracking tools: MDT residuals for refitted 20 GeV tracks

**Large chambers track**

\[ \langle \Delta \rangle = 2.8 \, \mu \text{m} \]
\[ \sigma_\Delta = 86.8 \, \mu \text{m} \]

**Small inner chamber track**

\[ \langle \Delta \rangle = 3.9 \, \mu \text{m} \]
\[ \sigma_\Delta = 54.3 \, \mu \text{m} \]

**Small middle chamber track**

\[ \langle \Delta \rangle = 0.7 \, \mu \text{m} \]
\[ \sigma_\Delta = 50.4 \, \mu \text{m} \]

**Small outer chamber track**

\[ \langle \Delta \rangle = -2.2 \, \mu \text{m} \]
\[ \sigma_\Delta = 37.1 \, \mu \text{m} \]
Check of common tracking tools: position at MS entrance for refitted tracks

![Histograms showing alignment of muon chambers with tracks](image)

Sergey Kotov, Jens Schmaler, Oliver Kortner (MPI für Physik, Munich)

Alignment of muon chambers with tracks
Check of common tracking tools: momentum at MS entrance for refitted tracks

**OrigTrkRefit-OrigTrk**

- \( \langle \Delta \rangle = -5 \ \mu \text{rad} \)
- \( \sigma_\Delta = 387 \ \mu \text{rad} \)

**LrgChmTrk-OrigTrk**

- \( \langle \Delta \rangle = -2 \ \mu \text{rad} \)
- \( \sigma_\Delta = 372 \ \mu \text{rad} \)
Extrapolation of large chambers track into small chambers: positions

Small inner chamber

X0 [mm]

D

-150 -100 -50 0 50 100 150

0

10

20

30

40

>=-2.9 mm D < 13.3 mm Ds

Small middle chamber

X0 [mm]

D

-150 -100 -50 0 50 100 150

0

10

20

30

40

>=1.2 mm D < 7.3 mm Ds

Small outer chamber

X0 [mm]

D

-150 -100 -50 0 50 100 150

0

10

20

30

40

>=-2.0 mm D < 12.9 mm Ds

Small inner chamber

Y0 [mm]

D

-150 -100 -50 0 50 100 150

0

10

20

30

40

>=-1.2 mm D < 10.5 mm Ds

Small middle chamber

Y0 [mm]

D

-150 -100 -50 0 50 100 150

0

10

20

30

40

>=0.3 mm D < 6.1 mm Ds

Small outer chamber

Y0 [mm]

D

-150 -100 -50 0 50 100 150

0

20

5

10

15

>=-0.0 mm D < 13.5 mm Ds

Small inner chamber

Z0 [mm]

D

-25 -20 -15 -10 -5 0 5 10 15 20 25

0

5

10

15

>=0.2 mm D < 3.3 mm Ds

Small middle chamber

Z0 [mm]

D

-25 -20 -15 -10 -5 0 5 10 15 20 25

0

5

10

15

>=0.1 mm D < 2.0 mm Ds

Small outer chamber

Z0 [mm]

D

-25 -20 -15 -10 -5 0 5 10 15 20 25

0

5

10

15

>=0.1 mm D < 2.0 mm Ds

Sergey Kotov, Jens Schmaler, Oliver Kortner (MPI für Physik, Munich)

Alignment of muon chambers with tracks

ATLAS-D workshop, Heidelberg, 22.09.2006
Extrapolation of large chambers track into small chambers: angles

Sergey Kotov, Jens Schmaler, Oliver Kortner (MPI für Physik, Munich)
Problems with extrapolation of large chambers track

Refitting of muon track with new common tracking tools seems to work quite well:
- MDT fit residuals are about 50 $\mu$m which corresponds to chamber spatial resolution
- differences in track perigee parameters between original and refitted tracks at MS entrance look reasonable

But extrapolation of large chambers track into small chambers does not show expected precision:
- shifts in Z-position (precision coordinate) 1-3 mm instead of expected 0.1-0.2 mm
- shifts in X- and Y-position 10-13 mm instead of $\sim$1 mm
- shifts in $\phi$ angle 30-150 mrad instead of $\sim$1 mrad
- shifts in $\theta$ angle 5-9 mrad instead of $\sim$0.4 mrad
- extrapolation to small middle chambers shows best results, extrapolation to small inner chambers is the worst

Possible reasons for under-performance of large chambers track extrapolation:
- common tracking tools were never tuned for use in muon system
  ▶ different magnetic field configuration (toroidal instead of solenoidal)
  ▶ different extrapolation step size is needed because the MS is much bigger in comparison to ID
  ▶ considerably inhomogeneous magnetic field in many chambers (this partly explains why extrapolation into small middle chambers gives better results)
- bugs in muon spectrometer part of new common tracking code (in release 12.0.1)
  ▶ MdtDriftCircle_OnTrack tracking class had bugs in \textit{localToGlobal} and \textit{associatedSurface} methods
  ▶ there were bugs in RPC digitization code

A lot of things have to be done in order to achieve the desired performance level
First look at segment based alignment of large muon chambers

- Use track segments associated with the same muon track to estimate the track momentum: $\Delta \alpha = \alpha_{out} - \alpha_{in} = \frac{q}{p_t} \int B dl$

- Start with middle chamber segment and extrapolate it to inner and outer chambers using the estimated momentum from $\Delta \alpha$ (a simple custom made segment extrapolater is used)

- Calculate relative translations and rotations of the inner and outer chambers with respect to the middle chamber from discrepancies between extrapolated and measured segments

- In the first order approximation, uncertainties in momentum determination and segment extrapolation are canceled out with enough track statistics

- Preliminary study gives the following number of tracks per $\eta$ tower needed to achieve 100 $\mu$m accuracy of relative chamber alignment:

<table>
<thead>
<tr>
<th>$p_t^{\mu}$, GeV</th>
<th>$N_{tracks}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>500k</td>
</tr>
<tr>
<td>20</td>
<td>20k</td>
</tr>
</tbody>
</table>

- For muon calibration stream with rate of 2 kHz and threshold of 20 GeV it seems doable
Common tracking tools can be used for fitting tracks in the muon spectrometer

An ATHENA package for track based alignment of small muon chambers has been written but needs considerable tuning to achieve the required alignment accuracy

Feasibility studies of segment based alignment of muon chambers have been performed and show promising results

To do list:

- run the alignment algorithm with the upcoming release 12.3.0 which has a lot of bug fixes for muon system part of common tracking code
- tune the TrkExtrapolater tool for use in the muon spectrometer
- continue studies of segment based alignment method for muon chambers
Structure of MuonTrkAlign algorithm

Steps of the MuonTrkAlign algorithm

- select an overlap region Track with associated RIOs_OnTrack collection from standard muon reconstruction
- divide this collection into four parts: RIOs_OnTrack coming from large chambers and RIOs_OnTrack coming from small inner/middle/outer chambers
- refit the “large chambers” RIOs_OnTrack collection with TrackFitter from common tracking tools, using original track as a seed
- extrapolate this “large chambers” track into small chambers with TrackExtrapolator and get track’s extrapolated parameters
- refit inner/middle/outer small chamber RIOs_OnTrack collections with TrackFitter, using extrapolated “large chambers” track parameters as seed
- differences between the refitted inner/middle/outer small chamber tracks and the extrapolated “large chambers” track are the tracking “pseudo” sensors input for ASAP
Check of common tracking tools: position at MS entrance for refitted tracks

- **OrigTrkRefit-OrigTrk**
  - $\Delta x_0$ [mm]
  - $<\Delta> = 4 \mu m$
  - $\sigma_\Delta = 160 \mu m$

- **LrgChmTrk-OrigTrk**
  - $\Delta x_0$ [mm]
  - $<\Delta> = 4 \mu m$
  - $\sigma_\Delta = 191 \mu m$

- **LrgChmTrk-OrigTrk**
  - $\Delta x_0$ [mm]
  - $<\Delta> = 2 \mu m$
  - $\sigma_\Delta = 178 \mu m$

- **LrgChmTrk-OrigTrk**
  - $\Delta y_0$ [mm]
  - $<\Delta> = 4 \mu m$
  - $\sigma_\Delta = 165 \mu m$

- **LrgChmTrk-OrigTrk**
  - $\Delta z_0$ [mm]
  - $<\Delta> = 0 \mu m$
  - $\sigma_\Delta = 24 \mu m$

- **LrgChmTrk-OrigTrk**
  - $\Delta y_0$ [mm]
  - $<\Delta> = 1 \mu m$
  - $\sigma_\Delta = 27 \mu m$

- **LrgChmTrk-OrigTrk**
  - $\Delta z_0$ [mm]
  - $<\Delta> = 1 \mu m$
  - $\sigma_\Delta = 27 \mu m$
Check of common tracking tools: momentum at MS entrance for refitted tracks

**OrigTrkRefit-OrigTrk**

- $\langle \Delta \rangle = 3 \mu \text{rad}$
- $\sigma_\Delta = 126 \mu \text{rad}$

**OrigTrkRefit-OrigTrk**

- $\langle \Delta \rangle = 0 \mu \text{rad}$
- $\sigma_\Delta = 39 \mu \text{rad}$

**OrigTrkRefit-OrigTrk**

- $\langle \Delta \rangle = -0.0$
- $\sigma_\Delta = 0.4$

**LrgChmTrk-OrigTrk**

- $\langle \Delta \rangle = 1 \mu \text{rad}$
- $\sigma_\Delta = 148 \mu \text{rad}$

**LrgChmTrk-OrigTrk**

- $\langle \Delta \rangle = 0 \mu \text{rad}$
- $\sigma_\Delta = 40 \mu \text{rad}$

**LrgChmTrk-OrigTrk**

- $\langle \Delta \rangle = -0.0$
- $\sigma_\Delta = 0.4$
Extrapolation of large chambers track into small chambers: positions

Small inner chamber

\[ \langle \Delta \rangle = -0.3 \text{ mm} \]
\[ \sigma_\langle \Delta \rangle = 9.6 \text{ mm} \]

Small middle chamber

\[ \langle \Delta \rangle = 0.3 \text{ mm} \]
\[ \sigma_\langle \Delta \rangle = 7.5 \text{ mm} \]

Small outer chamber

\[ \langle \Delta \rangle = -2.0 \text{ mm} \]
\[ \sigma_\langle \Delta \rangle = 15.2 \text{ mm} \]

Small inner chamber

\[ \langle \Delta \rangle = -0.6 \text{ mm} \]
\[ \sigma_\langle \Delta \rangle = 10.3 \text{ mm} \]

Small middle chamber

\[ \langle \Delta \rangle = -0.5 \text{ mm} \]
\[ \sigma_\langle \Delta \rangle = 7.0 \text{ mm} \]

Small outer chamber

\[ \langle \Delta \rangle = -2.0 \text{ mm} \]
\[ \sigma_\langle \Delta \rangle = 17.5 \text{ mm} \]

Small inner chamber

\[ \langle \Delta \rangle = -0.2 \text{ mm} \]
\[ \sigma_\langle \Delta \rangle = 2.4 \text{ mm} \]

Small middle chamber

\[ \langle \Delta \rangle = 0.1 \text{ mm} \]
\[ \sigma_\langle \Delta \rangle = 0.9 \text{ mm} \]

Small outer chamber

\[ \langle \Delta \rangle = -0.1 \text{ mm} \]
\[ \sigma_\langle \Delta \rangle = 1.6 \text{ mm} \]
Extrapolation of large chambers track into small chambers: angles

- Small inner chamber: $\langle \Delta \rangle = -32.8 \text{ mrad}$, $\sigma_\Delta = 200 \text{ mrad}$
- Small middle chamber: $\langle \Delta \rangle = 2.0 \text{ mrad}$, $\sigma_\Delta = 33 \text{ mrad}$
- Small outer chamber: $\langle \Delta \rangle = 0.3 \text{ mrad}$, $\sigma_\Delta = 161 \text{ mrad}$

- Small inner chamber: $\langle \Delta \rangle = -0.7 \text{ mrad}$, $\sigma_\Delta = 7.5 \text{ mrad}$
- Small middle chamber: $\langle \Delta \rangle = -0.1 \text{ mrad}$, $\sigma_\Delta = 4.8 \text{ mrad}$
- Small outer chamber: $\langle \Delta \rangle = 0.6 \text{ mrad}$, $\sigma_\Delta = 7.2 \text{ mrad}$