Impact of chamber deformations of the ATLAS New Small Wheel on muon reconstruction performance

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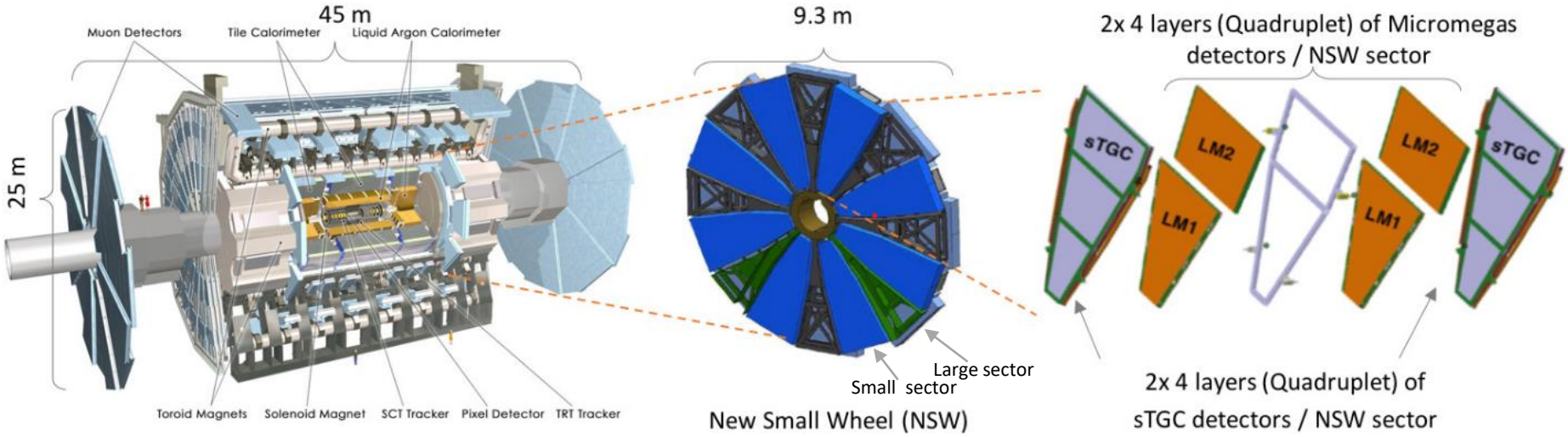
Bundesministerium für Bildung und Forschung

FSP ATLAS

The ATLAS New Small Wheels for HL-LHC



Adapted from F. Kuger 2016 *JINST* **11** C11043, *JINST* (2008) S08003, ATLAS-TDR-020

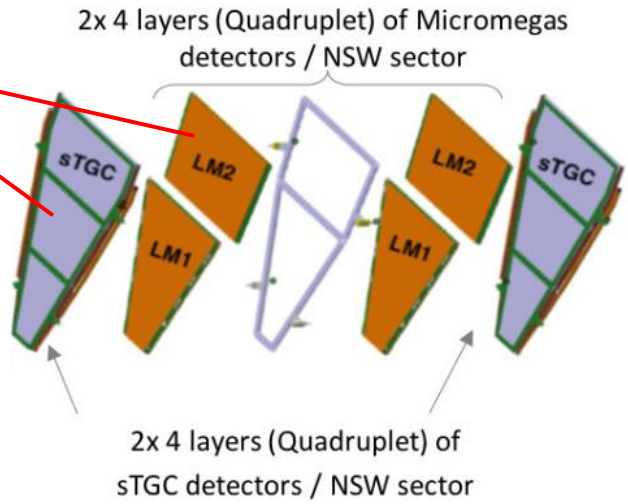
Micromegas detectors → Position measurement
sTGC → Time measurement

- The **high-luminosity** project of the CERN's Large Hadron Collider (HL-LHC) requires the **upgrade** of the ATLAS detector to maintain its performance when operating at significantly increased background rates (up to $15 - 20\ \frac{\mathrm{kHz}}{\mathrm{cm}^2}$)

Residual misalignment of the New Small Wheel

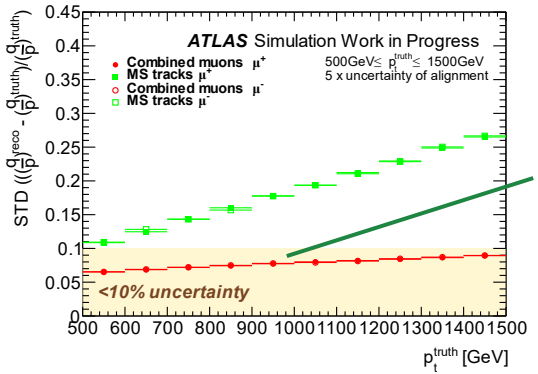
The NSW quadruplet positioning is only known up to a certain precision as caused by the measurement uncertainties of their alignment

Adapted from F. Kuger 2016 *JINST* **11** C11043, *JINST* (2008) S08003, ATLAS-TDR-020



Micromegas detectors → Position measurement
sTGC → Time measurement

Previous study



⇒ Possible residual misalignments of translations and rotations of the NSW detector modules do not affect the accuracy of the overall muon momentum measurement of the ATLAS detector within the current uncertainties for Run 3 analyses

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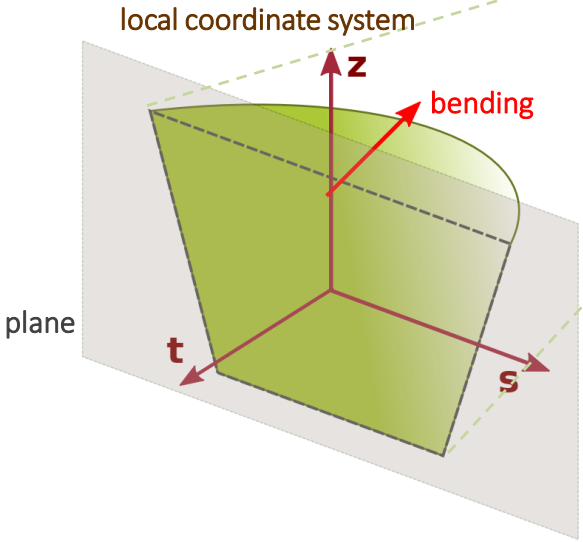
How do **deformations and expansions** account to the residual misalignment of the NSW?

Deformations and expansions

- It might not be sufficient to only consider rotations and translations as residual misalignment

- Impact of **bending** and **heat expansions** (especially of large size chambers)?



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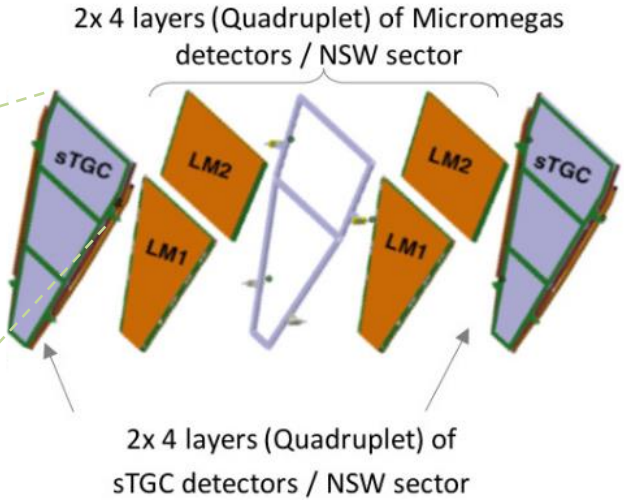


Micromegas detectors → Position measurement
sTGC → Time measurement

Set of deformation and expansion parameters

Considered deformations and expansions:

- **Anode plane bow**

$$\Phi = \tfrac{1}{2}(bp + bn) \cdot (s_{\text{rel}}^2 - 1) + \tfrac{1}{2}(bp - bn) \cdot (s_{\text{rel}}^2 - 1) \cdot z_{\text{rel}}$$
$$s \rightarrow s$$
$$t \rightarrow t + \Phi$$
$$z \rightarrow z$$

- **Spacer frame bow**

$$\Phi = \tfrac{1}{2}(sp + sn) \cdot (z_{\text{rel}}^2 - 1) + \tfrac{1}{2}(sp - sn) \cdot (z_{\text{rel}}^2 - 1) \cdot s_{\text{rel}}$$
$$s \rightarrow s$$
$$t \rightarrow t + \Phi$$
$$z \rightarrow z$$

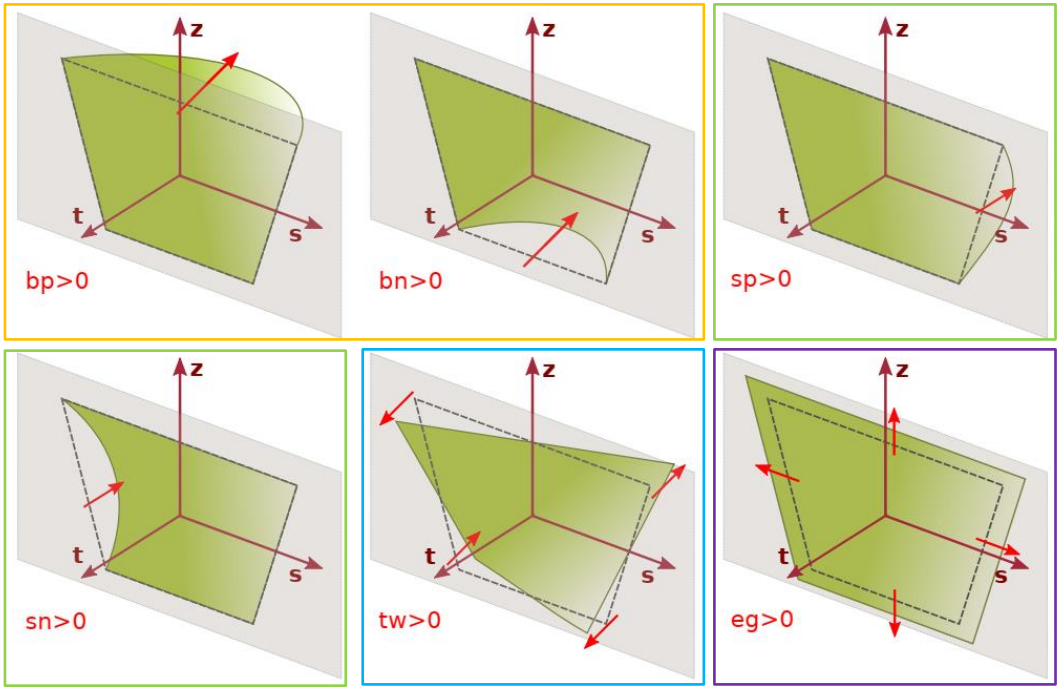
- **Twist**

$$\Phi = -tw \cdot s_{\text{rel}}$$
$$s \rightarrow s$$
$$t \rightarrow t + \Phi \cdot z_{\text{rel}}$$
$$z \rightarrow z - \Phi \cdot z_{\text{rel}} \cdot \frac{h_{\text{chamber}}}{l_{\text{chamber}}}$$

deformations/expansions relate to translational misalignment *s*, *z* and *t*

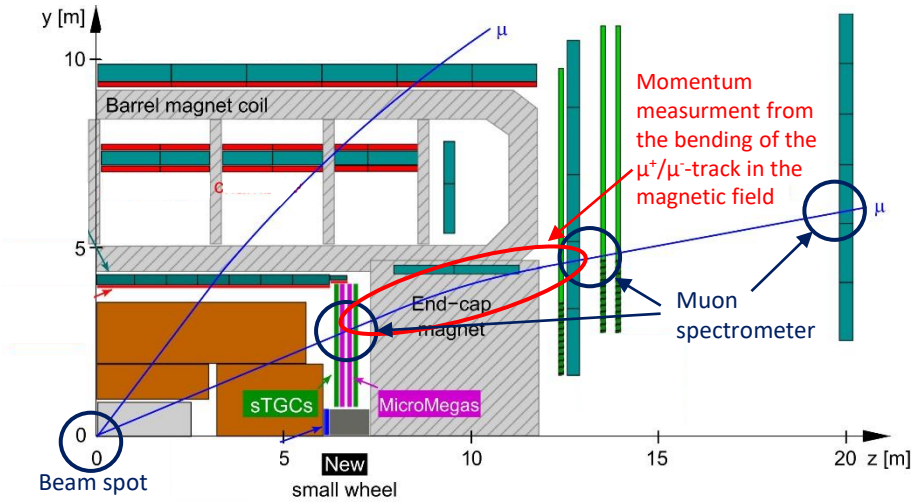
- **Global expansion**

$$\Phi = eg$$
$$s \rightarrow s \cdot (1 + \Phi)$$
$$t \rightarrow t \cdot (1 + \Phi)$$
$$z \rightarrow z \cdot (1 + \Phi)$$



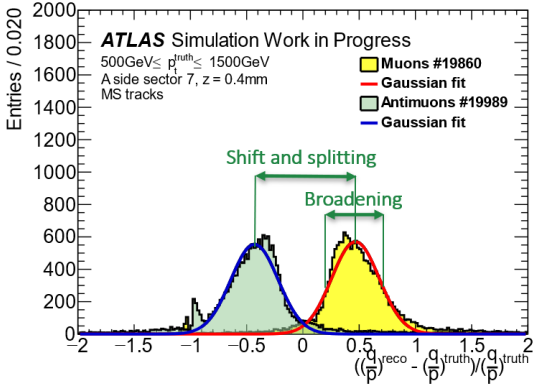
To simplify the formulas the chamber coordinate $s \in [-\frac{1}{2}w_{\text{chamber}}, +\frac{1}{2}w_{\text{chamber}}]$ was mapped onto $s_{\text{rel}} \in [-1, +1]$ and $z \in [-\frac{1}{2}l_{\text{chamber}}, +\frac{1}{2}l_{\text{chamber}}]$ onto $z_{\text{rel}} \in [-1, +1]$[2]. w_{chamber}, l_{chamber} and h_{chamber} were the chamber width, length and hight respectively.

Simulations and evaluation



Adapted from O. Kortner / Nuclear Instruments and Methods in Physics Research A 845 (2017) 241–243

- Athena (=ATLAS simulation software) simulation of the **ATLAS detector at ideal detector geometry**
- Generation of **dimuon events** in which the two muons fly to the opposite detector sides; the truth transverse muon momentum p_T is between 500GeV to 1500GeV
- Implementation of **deformations/expansions for the NSW chambers** at simulation level which are not corrected for in muon reconstructions

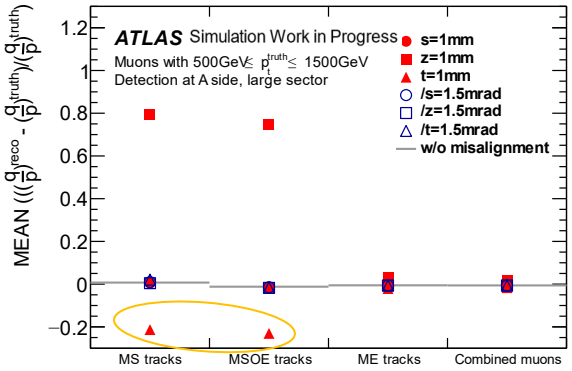


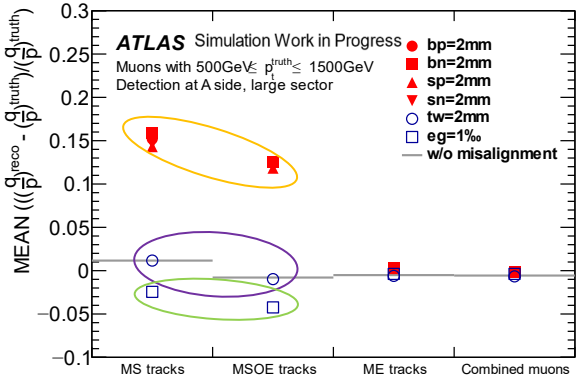
- Evaluation of the deviation of $\left(\frac{q}{p}\right)^{\text{reco}}$ from its truth value $\left(\frac{q}{p}\right)^{\text{truth}}$ by determining the mean (MEAN) and the standard deviation (STD) of **relative** $\left(\frac{q}{p}\right)$

$$\frac{\left(\frac{q}{p}\right)^{\text{reco}} - \left(\frac{q}{p}\right)^{\text{truth}}}{\left(\frac{q}{p}\right)^{\text{truth}}}$$

where q is the muon charge and p the muon momentum

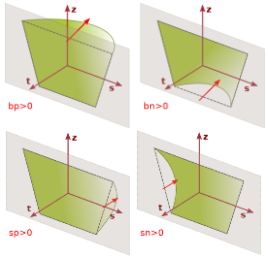
Comparison of deformations/expansions to translational misalignment



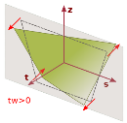


MS tracks: Reconstruction in muon spectrometer

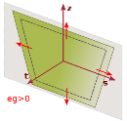
Combined muons: Combined track fit of muon spectrometer and inner detector tracks including energy loss in the calorimeter (MS track is matched to inner detector track)



t coordinate dominating



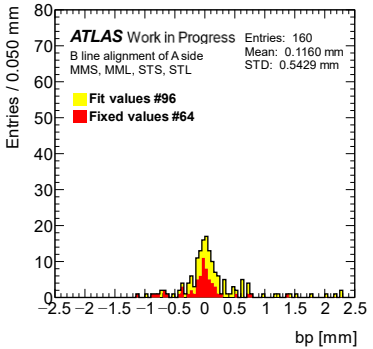
t coordinate changes compensate



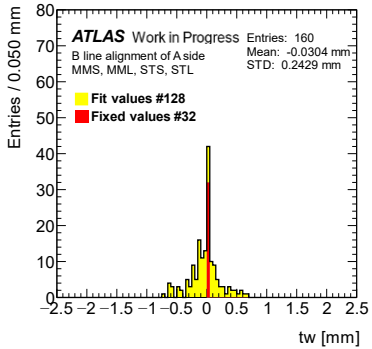
higher order effects

Realistic misalignment scenario for deformations and expansions

- The **residual misalignment** is expected to correspond to the uncertainties on the deformation parameters, which are obtained from an optical alignment sensor fit
- **Necessary assumption**: The order of the uncertainty of misalignment of the inner chambers is expected to be in the order of the misalignment of the outer chambers
- Gaussian sampling of each chamber position with parameters $\mu = 0$, $\sigma_{\mathrm{Gauss}} = \sigma_{\mathrm{fit}}$ where σ_{fit} is the **uncertainty of the alignment sensor fit** on the alignment parameter of the specific chamber; for different misalignment scenarios , σ_{Gauss} was additionally rescaled with $f = 1,2,3,4,5$



Only 96 uncertainties available for bp, bn, sp, sn



Only 128 uncertainties available for tw

Uncertainty on deformation I:

If the chamber's specific parameter uncertainty **is** available

Alignment parameter	Mean uncertainty $\overline{\sigma_{fit}}$
Tube bow bp	49 µm
Tube bow bn	49 µm
Cross plate sag sp	60 µm
Cross plate sag sn	60 µm
Twist tw	15 µm

Uncertainty on deformation II:

If the chamber's specific parameter uncertainty is **not** available

Alignment parameter	Uncertainty σ_{fit}
Tube bow bp	0.20 mm
Tube bow bn	0.14 mm
Cross plate sag sp	0.12 mm
Cross plate sag sn	0.23 mm
Twist tw	0.19 mm

Uncertainty on expansion:

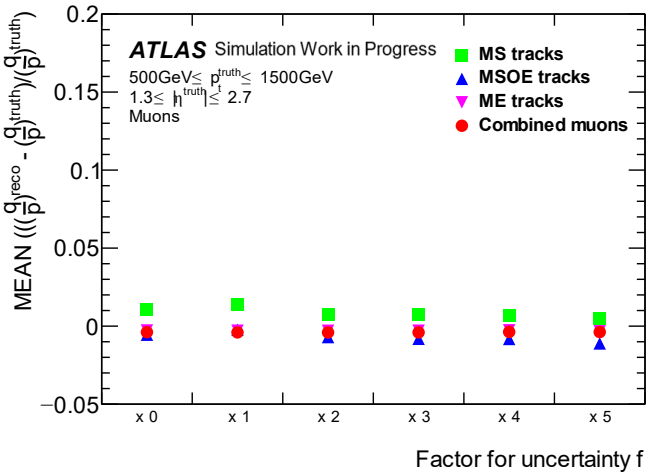
Same estimation for all chambers

Alignment parameter	Uncertainty σ_{fit}
Global expansion eg	0.015 ‰

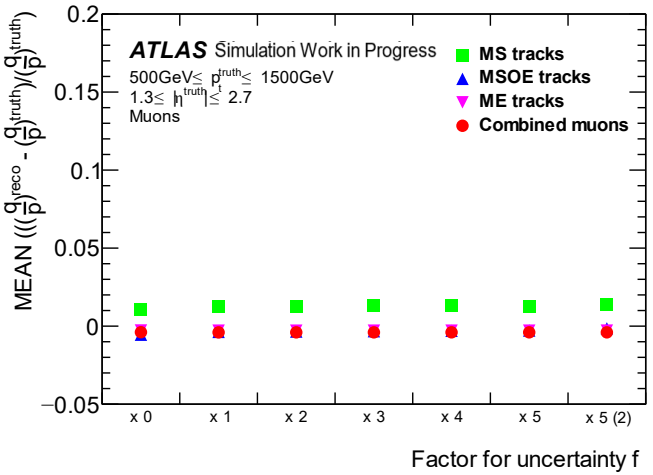
Data kindly provided by Christoph Amelung

Results for the realistic misalignment scenario I

Translations and rotations



Deformations and expansion



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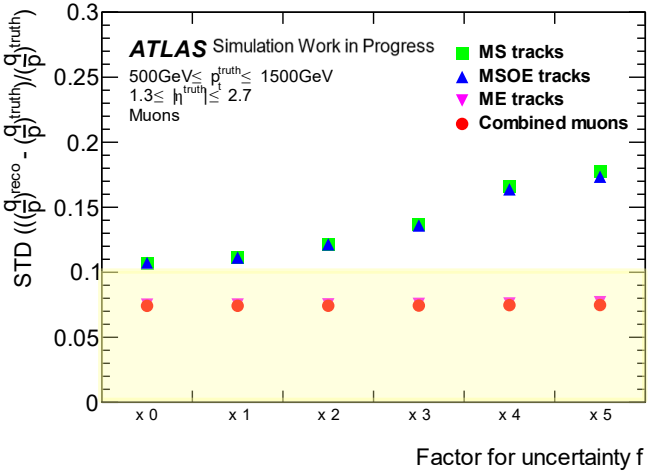
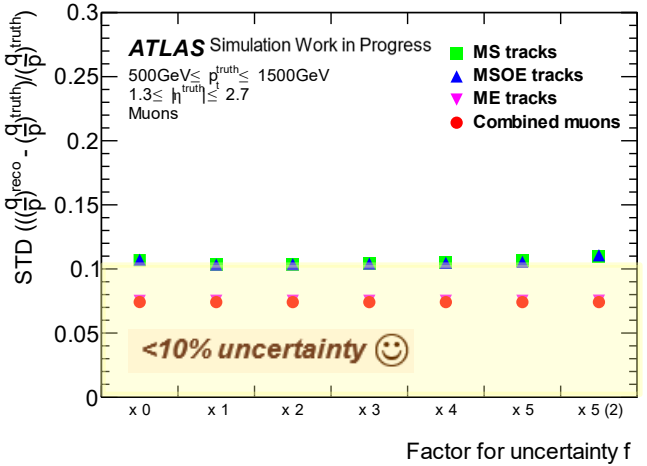
Deformation and expansion residual misalignment has almost **no impact** on mean of the relative q/p distribution

Results for the realistic misalignment scenario II

Translations and rotations



Deformations and expansion



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The impact of deformation and expansion residual misalignment is **small** compared to the uncertainties from translations and rotations

Summary

Summary:

- Possible residual misalignments of deformations and expansion of the NSW detector modules have considerable smaller impact on the accuracy of the overall muon momentum measurement of the ATLAS detector compared to translation and rotations

Further aspects:

- Study of the impact of the internal alignment of the chambers
- …

⇒ In general, detailed analysis of the alignment and more accurate determination of various impact parameters is continuously ongoing for further/future improvement of the muon momentum measurement

Thank You For Your Attention!