ATLAS Inner Detector Alignment for the LHC Run3

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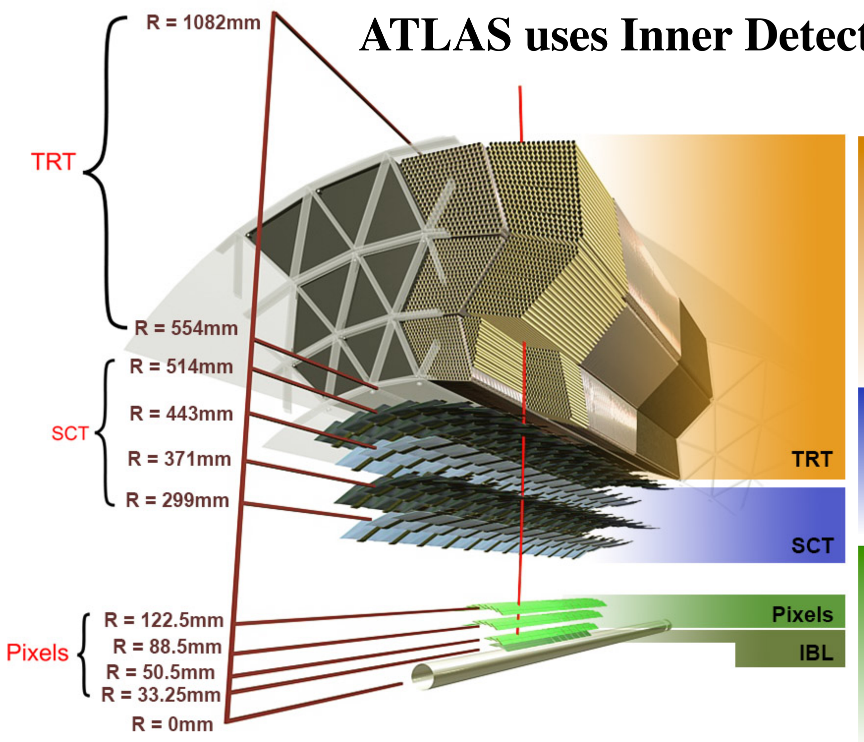
ATLAS uses Inner Detector (ID) to reconstruct trajectories of charged particles. Eur. Phys. J. C 80 (2020) 1194

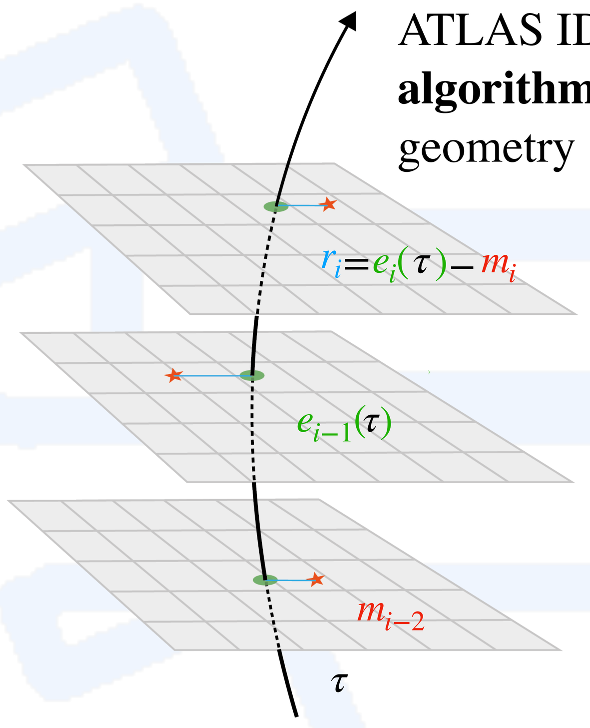


Transition Radiation Tracker (TRT) is used for the track reconstruction as well as for providing information about the particle type. It consists of 350k straw tubes and has an intrinsic resolution of 130 µm.

The Semiconductor Tracker (SCT) consists of 4088 strip modules and measures particle tracks with an intrinsic resolution of 17 µm.

The Pixel Detector has an intrinsic resolution 10 µm. It includes the insertable B-layer (IBL), with an intrinsic resolution 10 µm, which is the first point of detection in the ATLAS experiment.

ATLAS ID uses a **track-based alignment algorithm** to determine the detector's geometry



Iterative approach to find the best fit to a set of measurements of a track.

χ^2 minimisation based on distance between the fitted track point (e_i) and the measurement (m_i), residual r_i

$$\chi^2 = \mathbf{r}^T \Omega^{-1} \mathbf{r}$$

Ω being a covariance matrix of the corresponding measurements

Alignment levels

As ID consists of a large number of subsystems, each of them can be separately aligned. In total, more than **36k** degrees of freedom are considered when aligning all silicon modules and more than **700k** for the TRT. ID alignment has different hierarchical levels depending on the structures of the systems or groups of systems.

Level 1: The subsystems are aligned separately into endcaps and barrel
Level 2: Treats individual barrel layers and endcap disks as a whole
Level 3: Provides alignment for the silicon module or TRT wire

Time-dependent Alignment
- Short timescale: Single LHC fill
- Medium timescale: Days or month
- Long timescale: Several Months

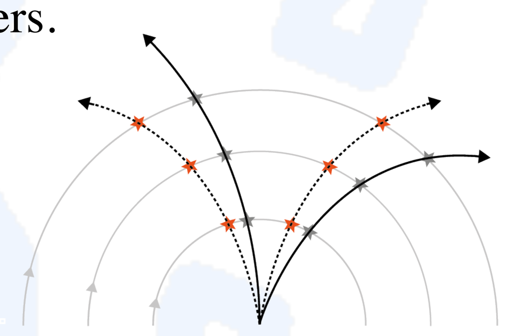
What does it take to keep the ID in perfect alignment?

Goal of the detector alignment: Determine the detector geometry as accurately as possible and correct for time-dependent movements.

Weak modes: Distortions that leave track χ^2 almost unchanged but bias the momentum and track parameters.

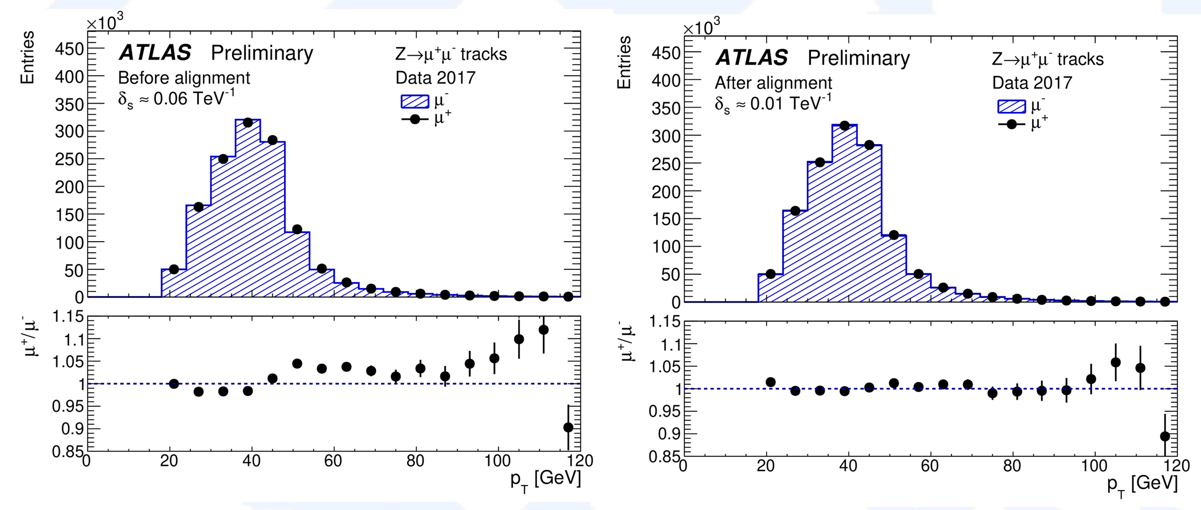
Example: Detector deformation in the bending plane of the tracks causes Sagitta distortions of the momentum

$$p = p_0(1 + qp_{0T}\delta)^{-1}$$

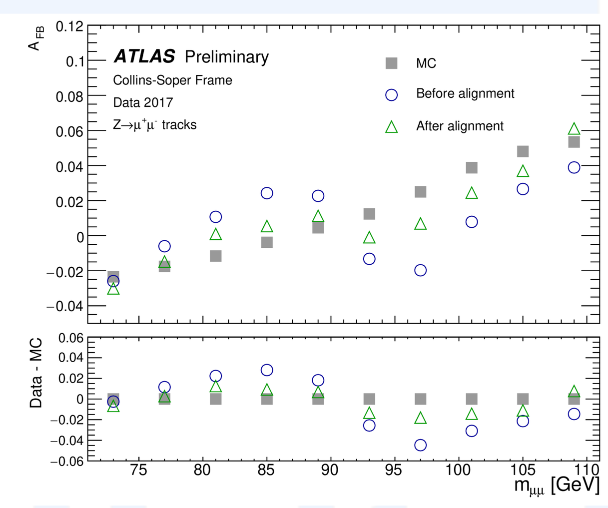


p and p_0 are reconstructed and true momentum values, q is charge, p_{0T} transverse momentum and δ sagitta bias

Poor Alignment → Worse resolution and poor reconstruction → Biased track parameters



Muon p_T distributions for the $Z \to \mu^+\mu^-$ events before and after alignment applied



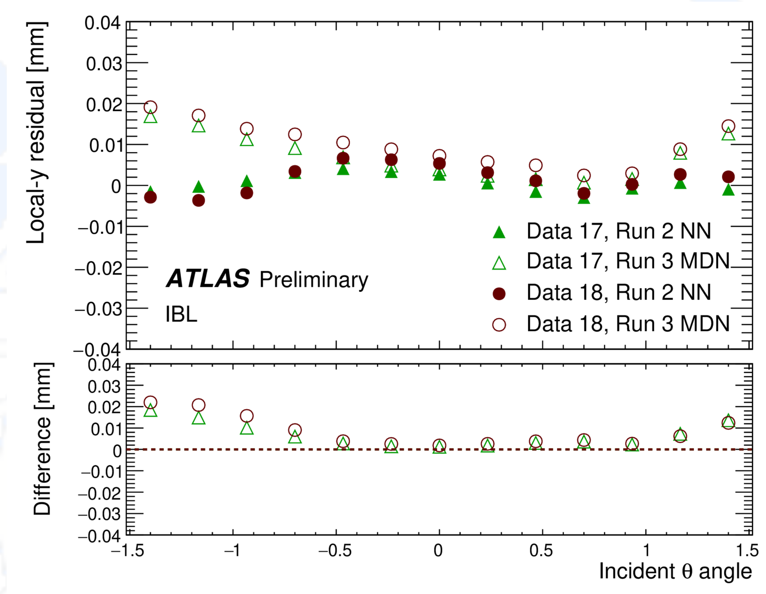
Reconstructed forward-Backward asymmetry. The values before (blue) and after (green) the alignment

Developments for the Run 3 ATL-PHYS-PUB-2022-028

New MDN (Mixture Density Network) algorithm and re-alignment

During Run2, the Pixel detector used a NN algorithm to estimate the cluster position. It provided a biased estimate of the position. This bias was compensated by the alignment

The new set of alignment constants was delivered using the MDN reconstruction algorithm (as it will be for the **Run3**) covering the whole Run2, describing the detector down to module level.



While reprocessing the Run 2 data using the MDN, unexpected biases in the track-to-hit residuals appeared.

New algorithm for Sagitta Bias measurement

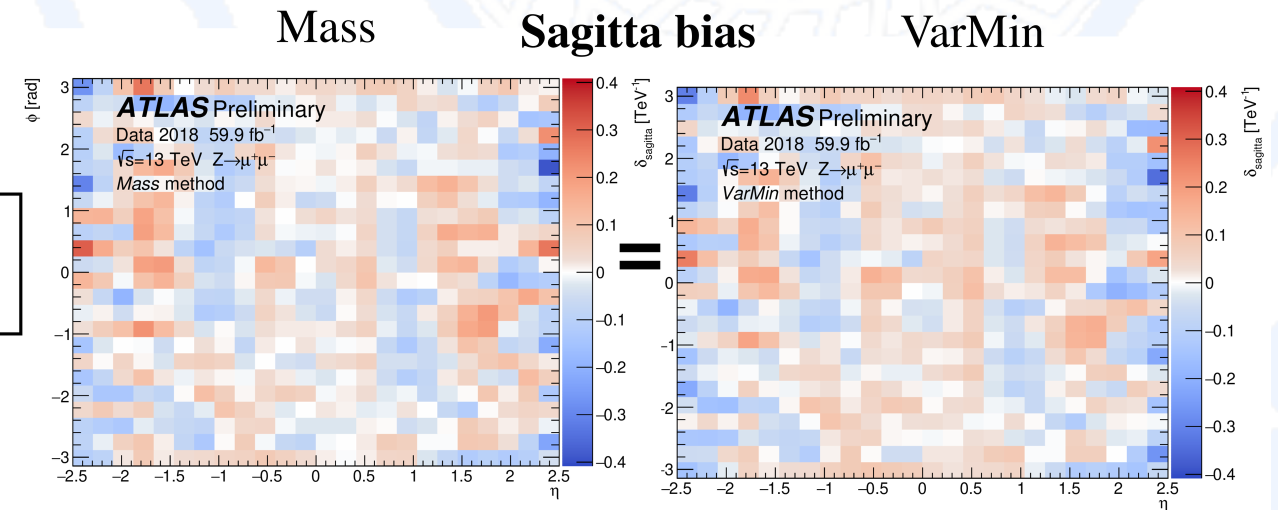
The method used for the Run2 (Mass method) is based on a difference between the reference mass (Z) and the reconstructed mass.

$$\frac{m_{\mu\mu}^2 - m_Z^2}{m_{\mu\mu}^2} = (p_T^- \delta^- - p_T^+ \delta^+) \quad \text{Global bias: } \left.\begin{array}{l}\delta_s^- = \delta_s^+ \\ p_T^+ \approx p_T^-\end{array}\right\} \Rightarrow m_{\mu\mu} \approx m_Z \Rightarrow$$

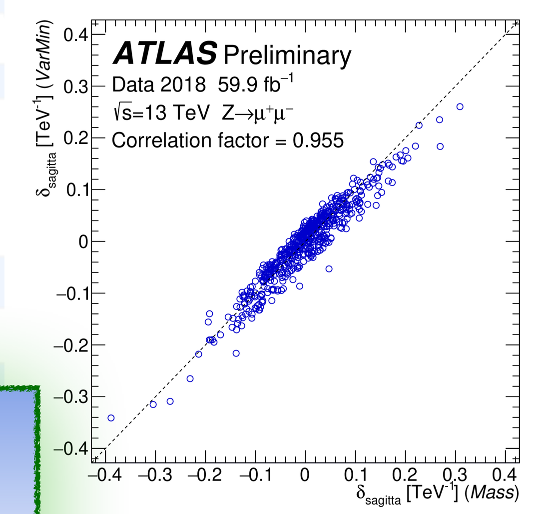
not sensitive to Global Sagitta Bias!

Where δ^- and δ^+ are sagitta bias corrections for negative and positive muons

Mass **Sagitta bias** VarMin



The two methods show similar sagitta biases meaning the global sagitta bias is smaller than the relative sagitta basis



New approach uses charge blind notion for the δ discretised with (η, ϕ)

$$m_{\mu\mu\bullet}^2 = \Delta m_{\mu\mu}^2 - \mathbf{e} \cdot \delta \qquad \text{where } \mathbf{e} = m_{\mu\mu}(0, \ldots p_T^+, \ldots p_T^-, \ldots 0)$$

- Minimises the variance of sagitta corrected reconstructed dimuon system mass

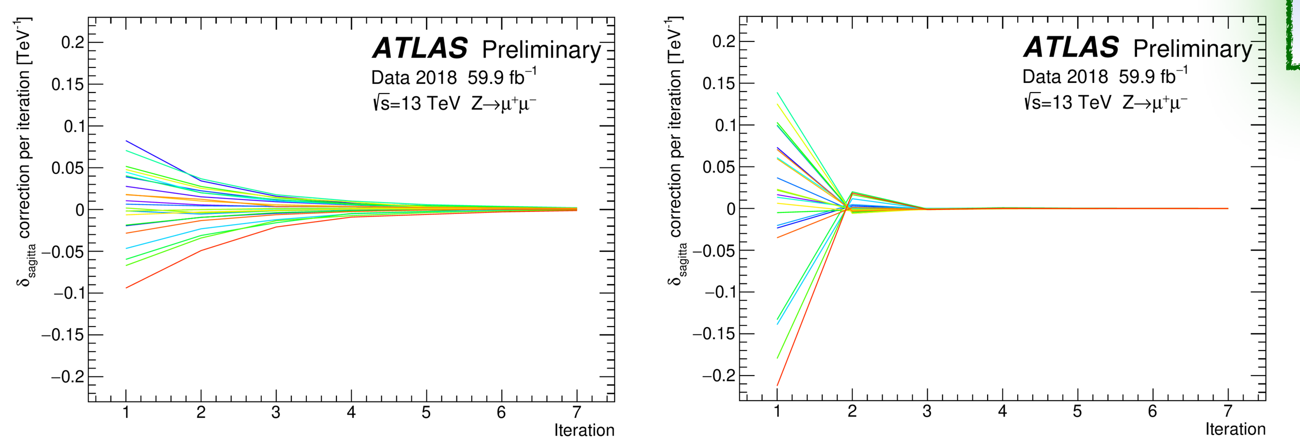
$$Var[m_{\mu\mu\bullet}^2] = Var[\Delta m_{\mu\mu}^2] + \sum_{s,t} Cov[(\mathbf{e})_s, (\mathbf{e})_t]\delta_s\delta_t - 2\sum_s Cov[\Delta m_{\mu\mu}^2, (\mathbf{e})_s]\delta_s \qquad 0 = \frac{\partial}{\partial \delta} Var[m_{\mu\mu\bullet}^2]$$

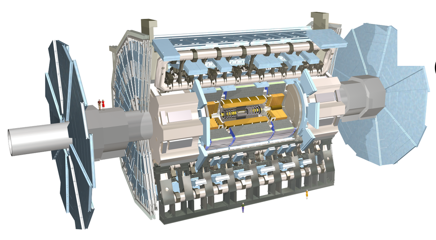
- Solves system of linear equations to find δ $\quad M\delta = \mathbf{k}$

Where $M = Cov[\Delta m_{\mu\mu}^2, \mathbf{e}_s]$; $\mathbf{k} = Cov[\mathbf{e}_s, \mathbf{e}_t]$

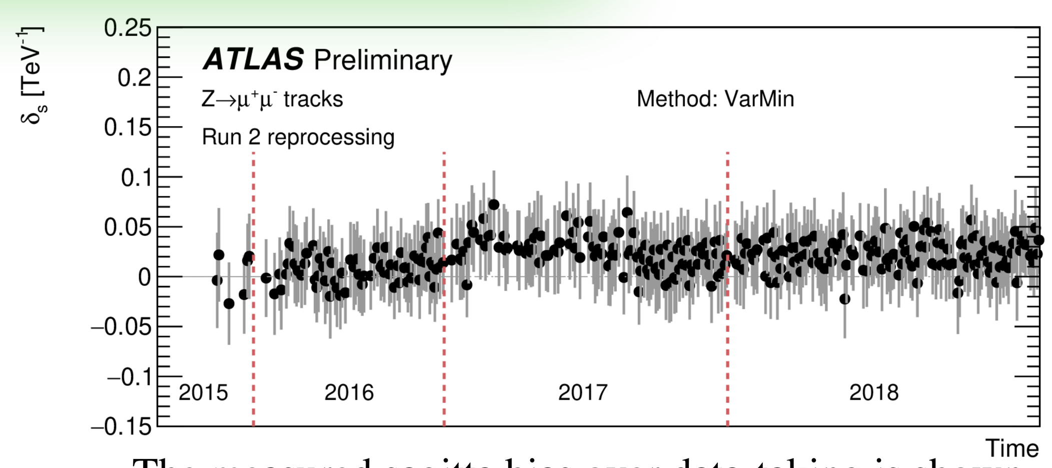
- Produce the map $\delta(\eta, \phi)$

VarMin is a great improvement for the Run 3:
Sensitivity to global bias!
Faster convergence!





Convergence for the two methods for the VarMin method (on the right-hand side), for the Mass method (on the left-hand side)



The measured sagitta bias over data-taking is shown. Level of bias is **< 0.1TeV**