THE ATLAS INNER DETECTOR TRACK BASED ALIGNMENT

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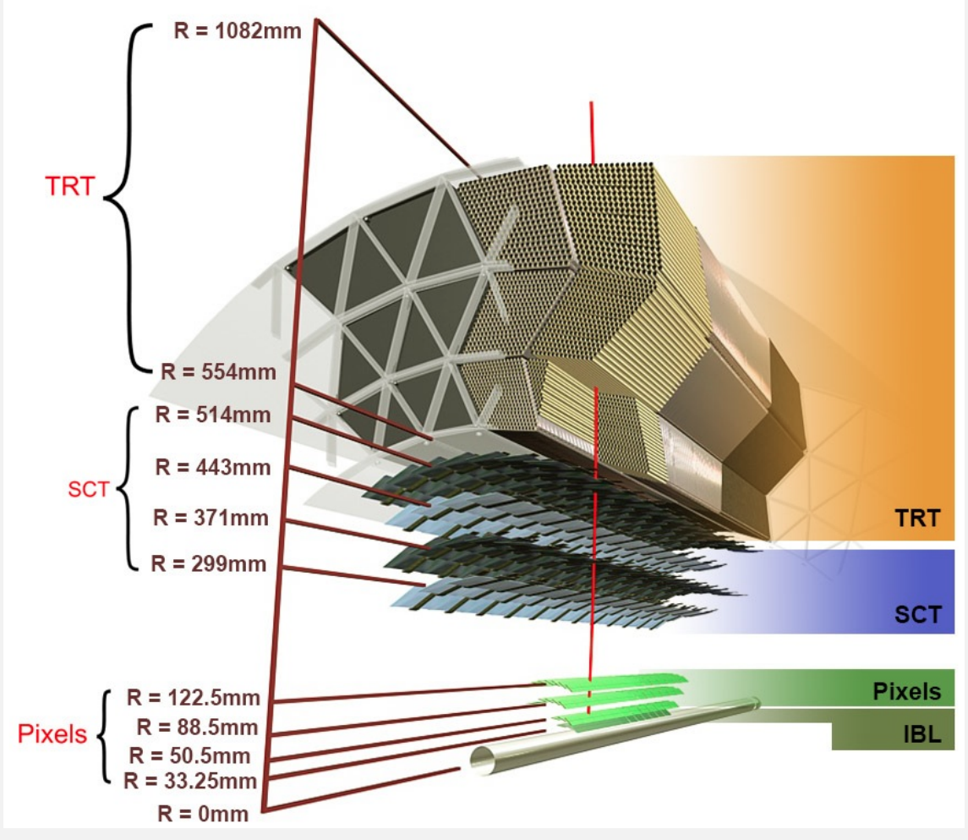
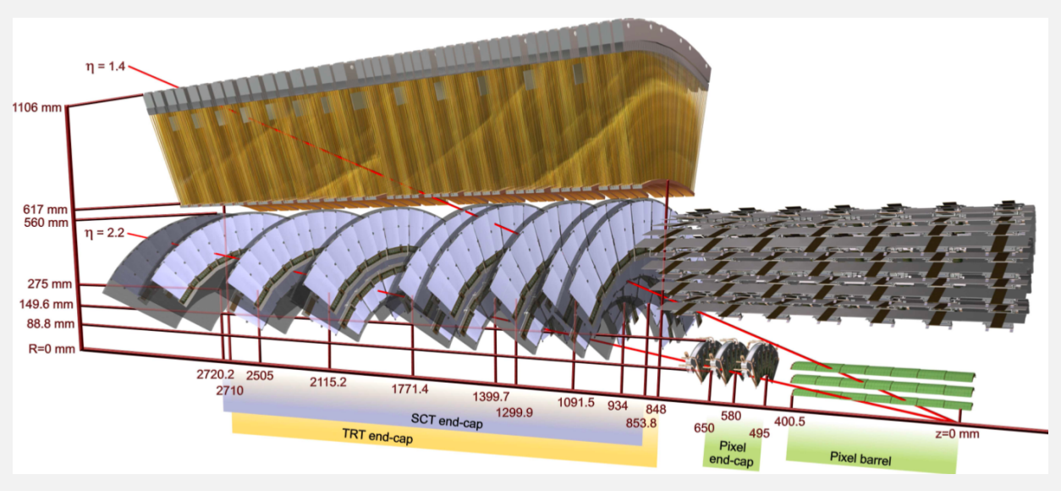
(on behalf of the ATLAS Inner Detector Alignment group)

The ATLAS Inner Detector (ID) tracking system

- The Inner Detector is the main tracking system of ATLAS. It comprises 3 subsystems embedded in a 2T axial field
  - Pixel & IBL (4 measurements/track)
  - SCT (8 measurements/track)
  - TRT (~30 measurements/track)
- Each subsystem is composed of a barrel & 2 end-caps
- Sensor dimension and resolution (100M readout channels)



Subdetector	r (cm)	Elements size	Resolution (X * Y)	hits/track (average)	channels
Pixels & IBL (silicon pads)	5 – 12.5	50 µm x 400 µm (250 IBL)	10 µm x 115 µm	1 IBL 3 Pixels	92×10^6
SCT (silicon microstrips)	30 – 52	80 µm x 12 cm (stereo)	17 µm x 580 µm	8	6.3×10^6
TRT (Transition Radiation)	56 – 107	4 mm (diameter)	130 µm	30	3.5×10^5



Inner Detector Alignment levels

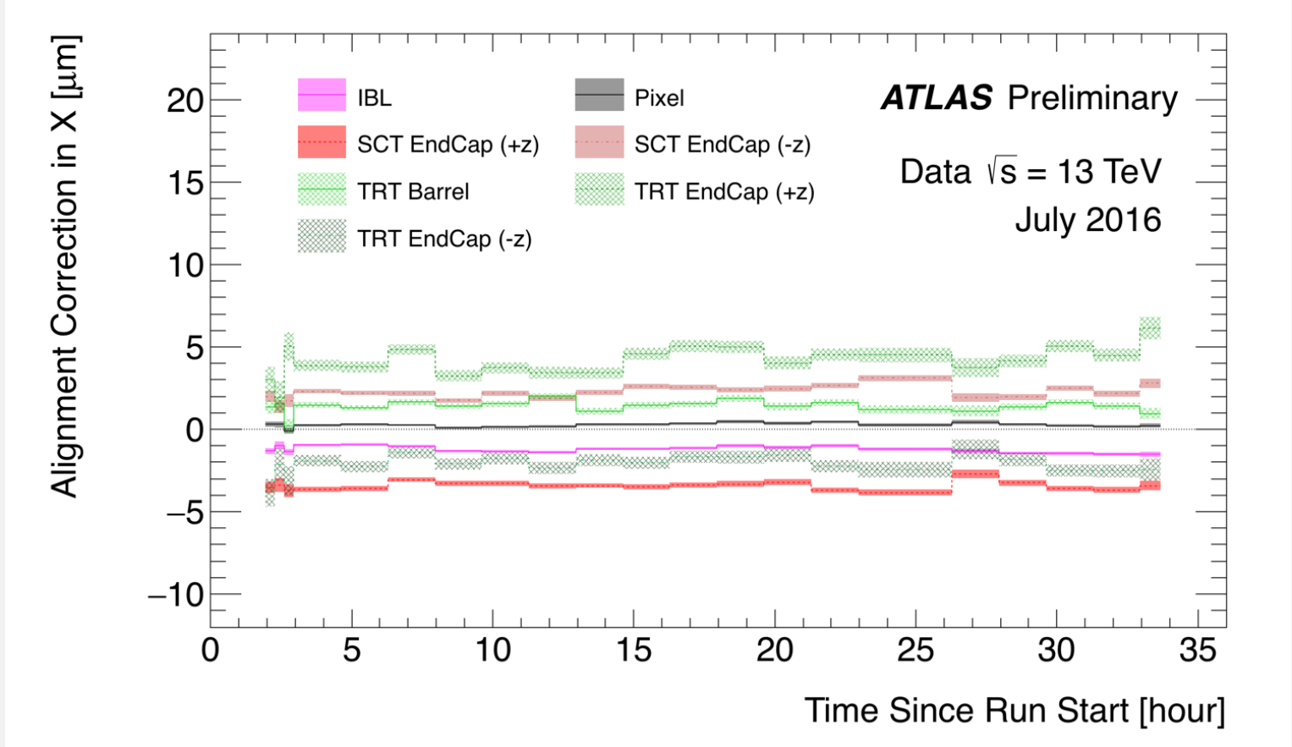
- The ID alignment proceeds from large assembly structures (barrels, end-caps, layers, etc.) to module level with increasing granularity and degrees of freedom

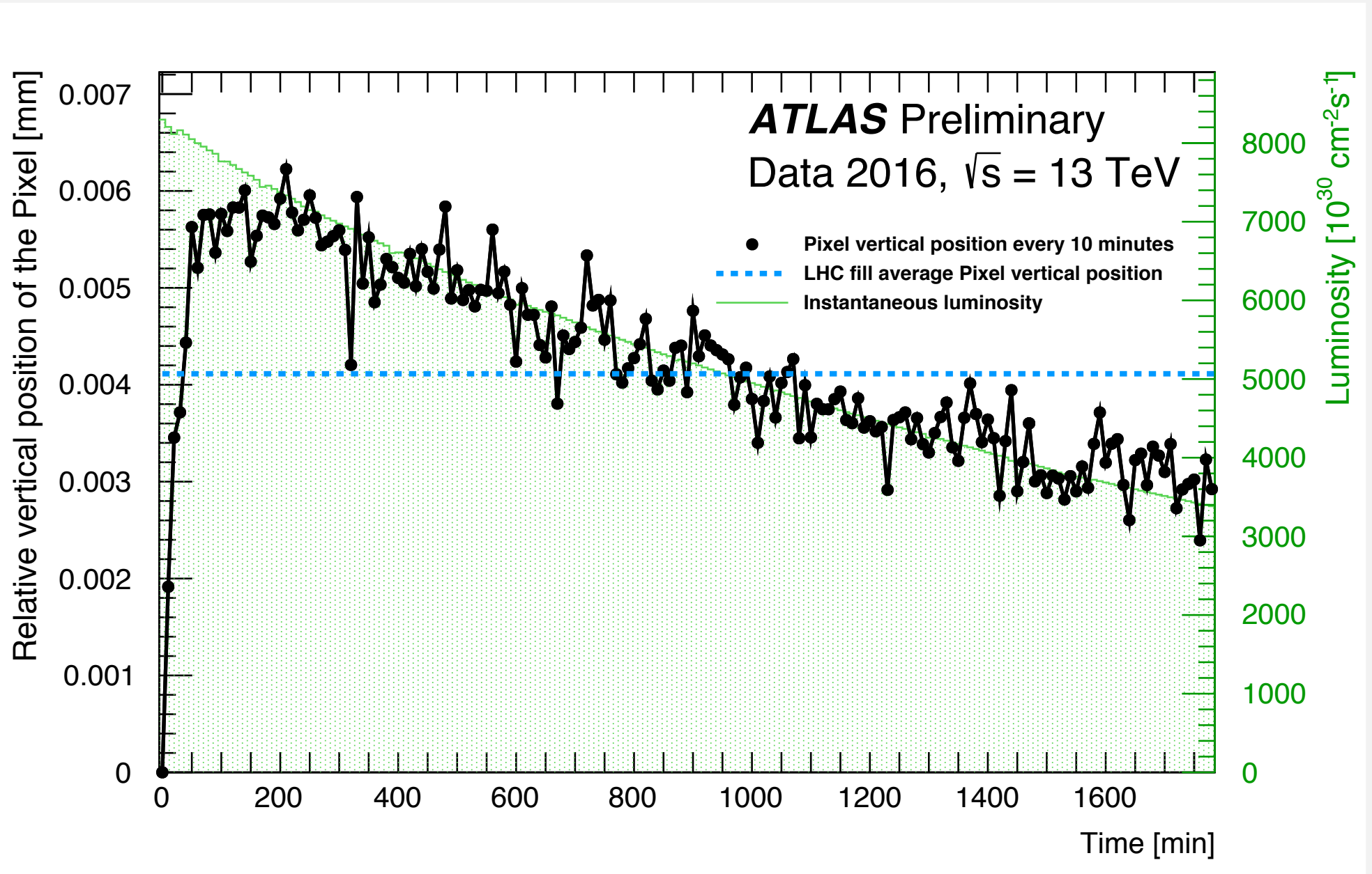
	structures			Corr. Size
	pixel	SCT	TRT	µm
Level 1	1+1	3	3	1000
Level 2	10	22	96	100
Level 3	2024	4088	350848	10

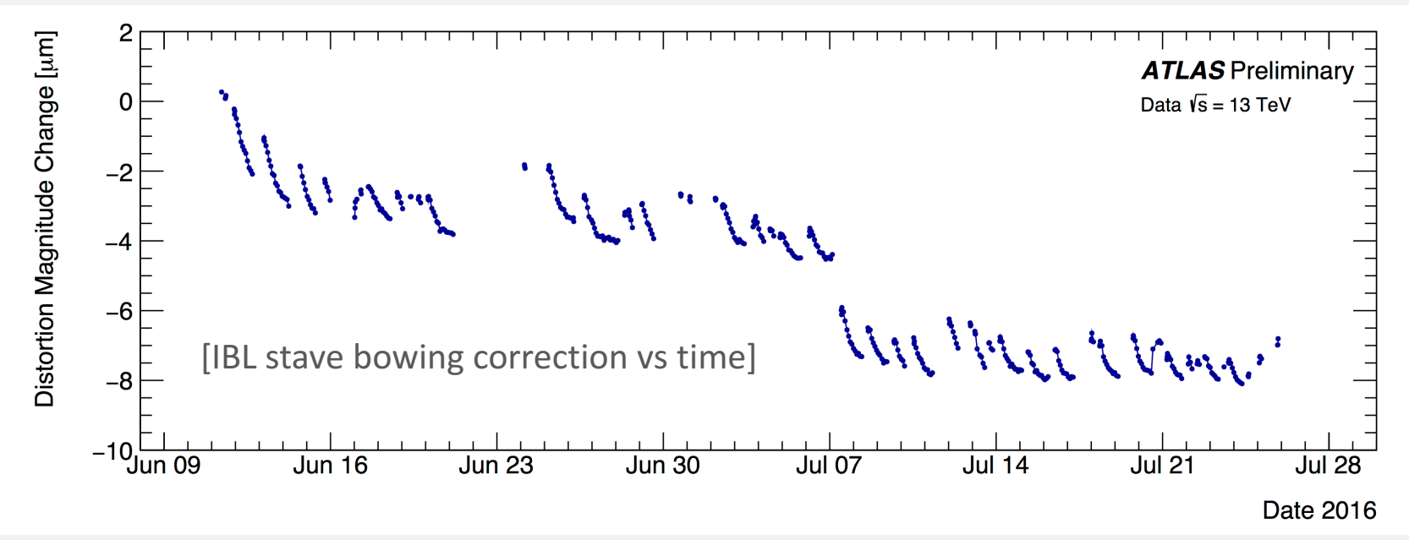
[Expected movements with respect to assembly]

Short time scale movements

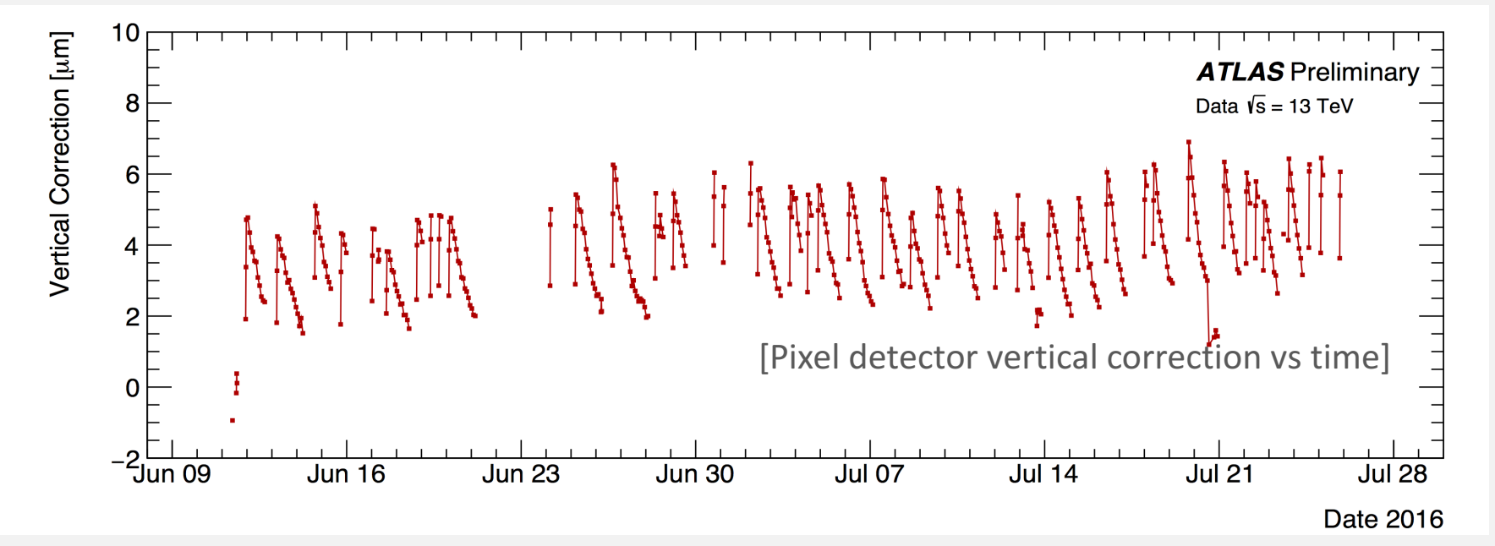
- The ID Alignment task is part of the ATLAS prompt calibration process
  - Alignment constants set must be ready within 24-hours after data taking
  - Input data set: dedicated stream of isolated tracks
- The short time scale movements of the Pixel and IBL detectors is corrected
  - First every 20 minutes. Later every 100 minutes
- Pixel detector vertical movements:
  - Initial: fast upwards, no horizontal movement seen.
  - Later: slow downwards, following LHC luminosity
- The rest of the structures are highly stable, unless a sudden change of the operational conditions occurs







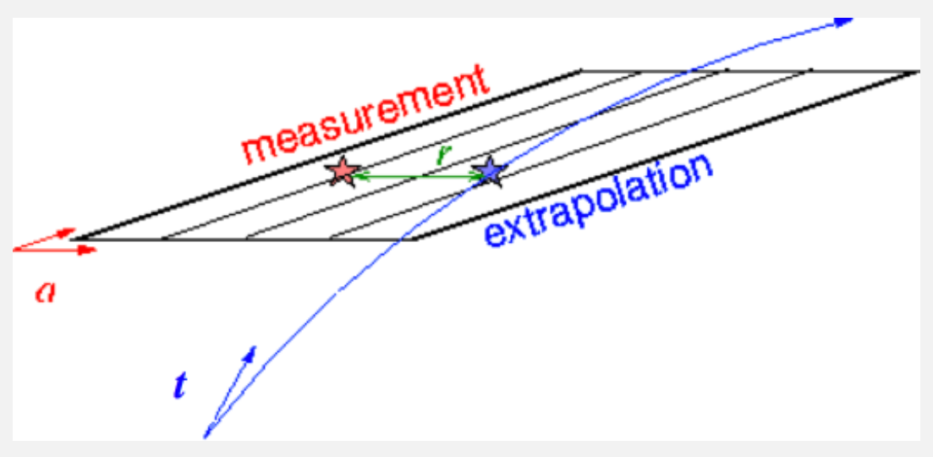
[IBL stave bowing correction vs time]

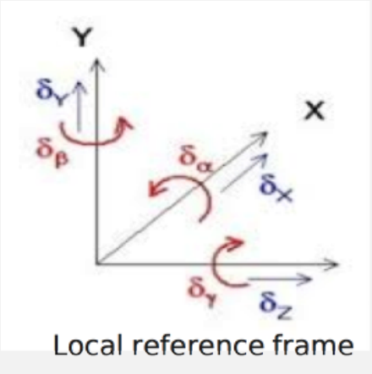


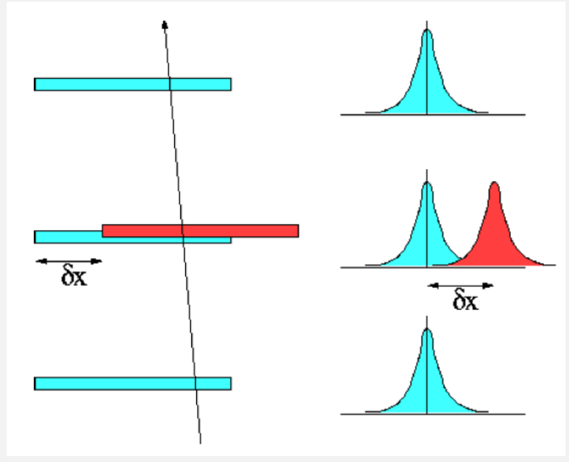
[Pixel detector vertical correction vs time]

Track based alignment

- The goal of the detector alignment is to provide an accurate description of its geometry, to allow for:
  - Precise determination of track parameters
  - Bias free
- Algorithm is based on track-hit residual minimization:







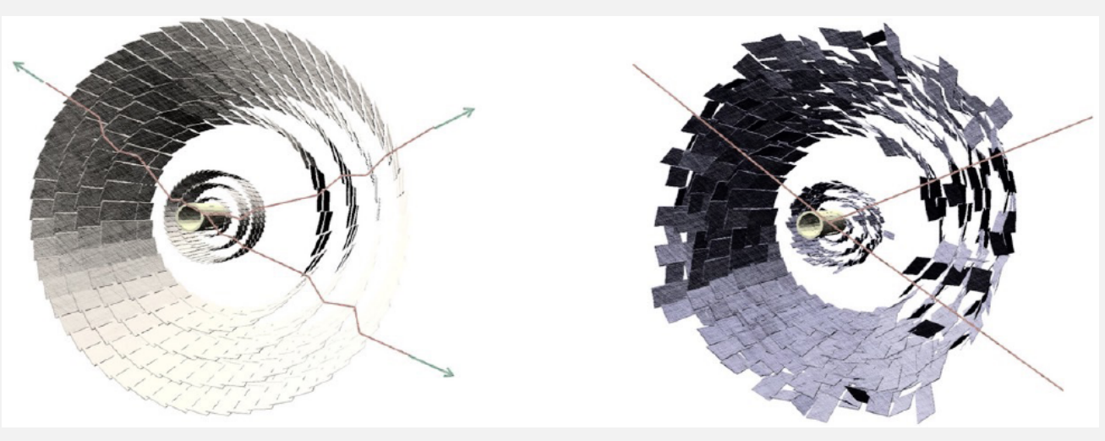
$$\chi^2=\sum_{t}\left[\boldsymbol{r}^{\boldsymbol{T}}(t,a)V^{-1}\boldsymbol{r}(t,a)\right]$$

Track parameters
$$\boldsymbol{t}=\{(d_0,z_0,\phi_0,\theta,q/p),(\theta_{scat},\ldots)\}$$

Alignment parameters
$$\boldsymbol{a}=(T_x,T_y,T_z,R_x,R_y,R_z)\times N_{struct}$$

Hit covariance matrix
$$V=\begin{pmatrix}\sigma^2_{hit} & \ldots & 0\\ \vdots & \ddots & \vdots\\ 0 & \ldots & \sigma'^2_{hit}\end{pmatrix}$$

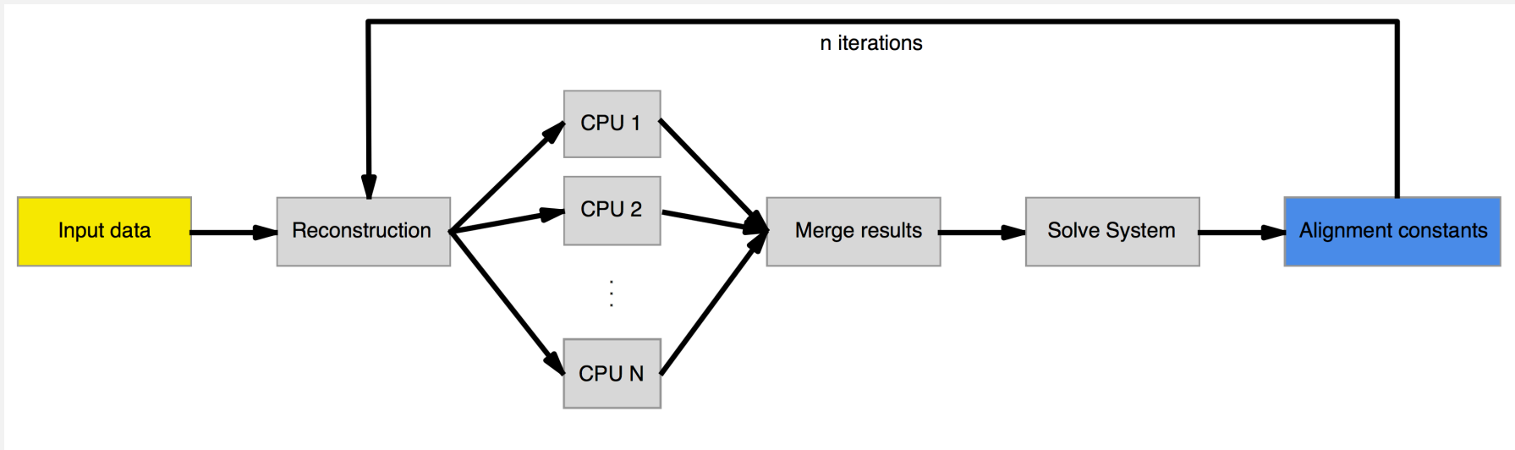
Minimization condition; N_{DoF} x N_{DoF} matrix; N_{DoF} vector
$$\frac{d\chi^2}{da}=0\quad\rightarrow\quad\sum\left[\left(\frac{d\boldsymbol{r}}{d\boldsymbol{a}}\right)^T V^{-1}\left(\frac{\partial\boldsymbol{r}}{\partial\boldsymbol{a}}\right)\right]\delta\boldsymbol{a}+\sum\left(\frac{d\boldsymbol{r}}{d\boldsymbol{a}}\right)^T V^{-1}\boldsymbol{r}=0$$



- Use of constraints on track parameters (Beam spot, E/p) and alignment corrections (assembly survey, tolerances)

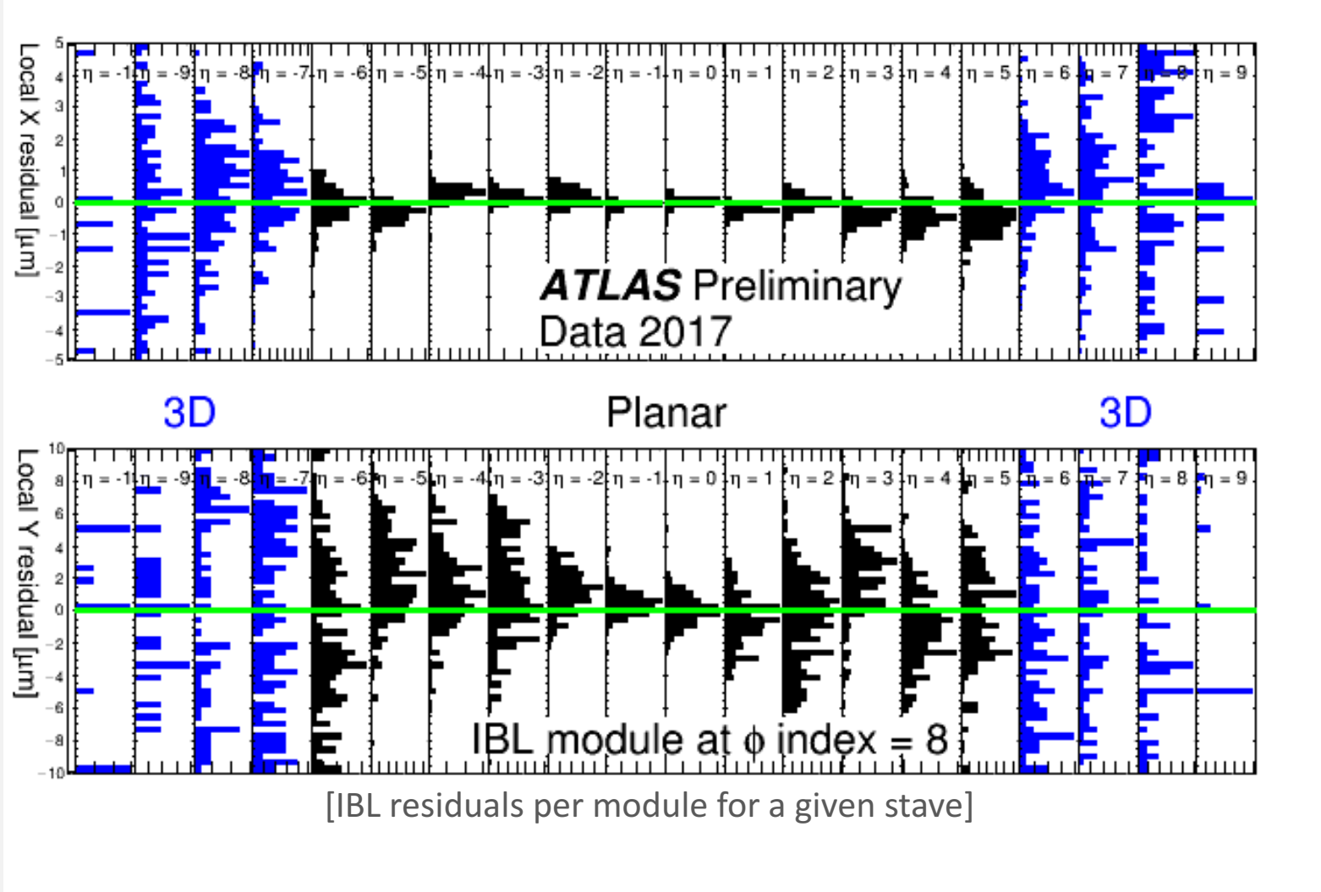
$$\chi^2=\sum_{t}\left[\boldsymbol{r}^{\boldsymbol{T}}(t,a)V^{-1}\boldsymbol{r}(t,a)+\underbrace{\boldsymbol{R}^{\boldsymbol{T}}(t)V_t^{-1}\boldsymbol{R}(t)}_{\text{Track parameter constraints}}\right]+\underbrace{\boldsymbol{R}'^T(a)V_a^{-1}\boldsymbol{R}'(a)}_{\text{Alignment parameter and tolerances constraints}}$$

- Determine $\delta\boldsymbol{a}$ iteratively
- The alignment algorithm is implemented within the ATLAS software framework
  - Reconstruction, matrix solving and calculation of alignment corrections
  - Monitoring and validation
- Executing the alignment algorithm at different stages and with different input data sets allows crosschecks and adds robustness to the result

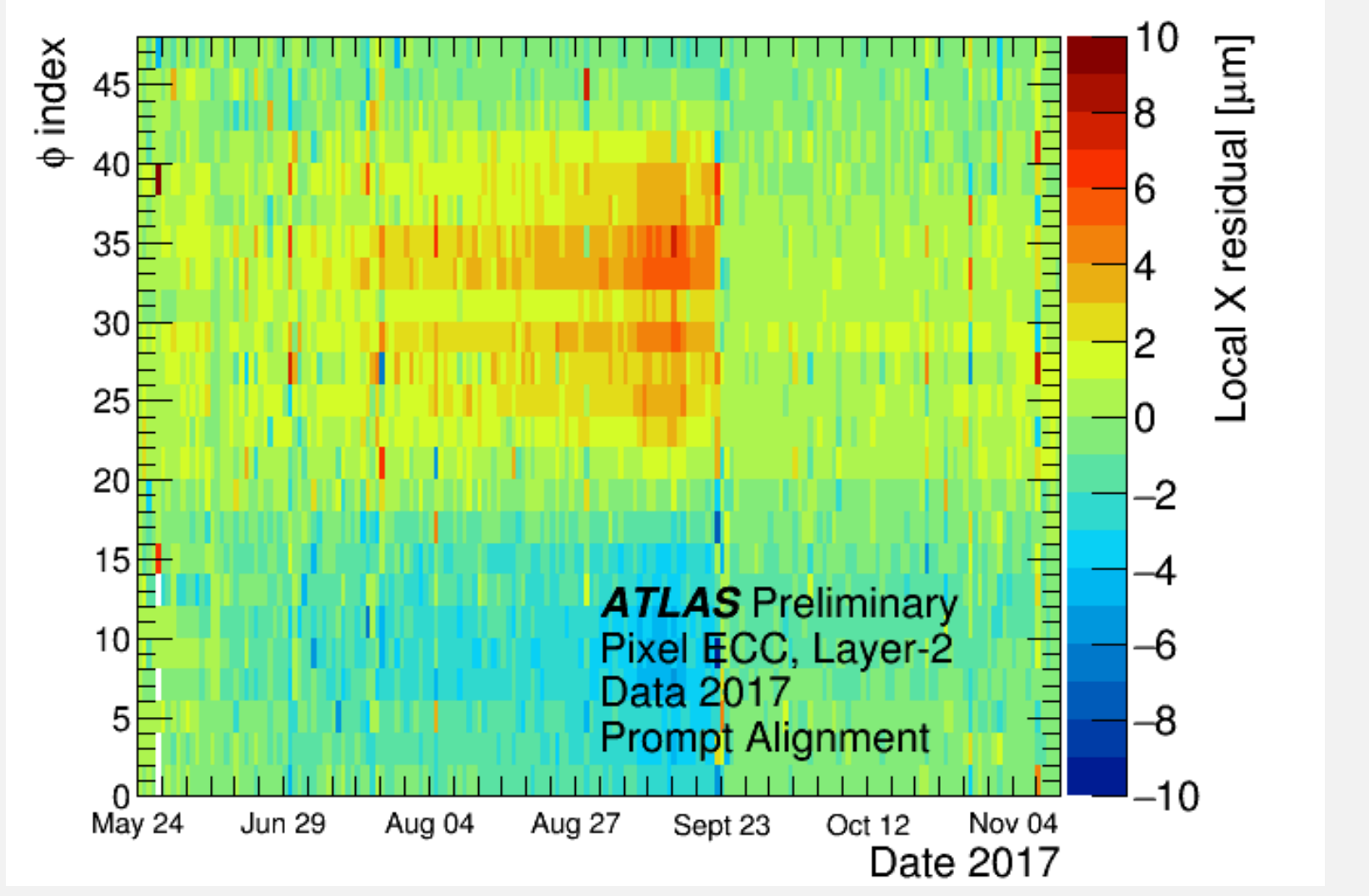


Detector alignment monitoring

- Track-hit residuals from every component are constantly monitored
  - Check if structures are either stable or drifting
  - Specially important for IBL
  - Validation of current alignment corrections & study long term trends



[IBL residuals per module for a given stave]

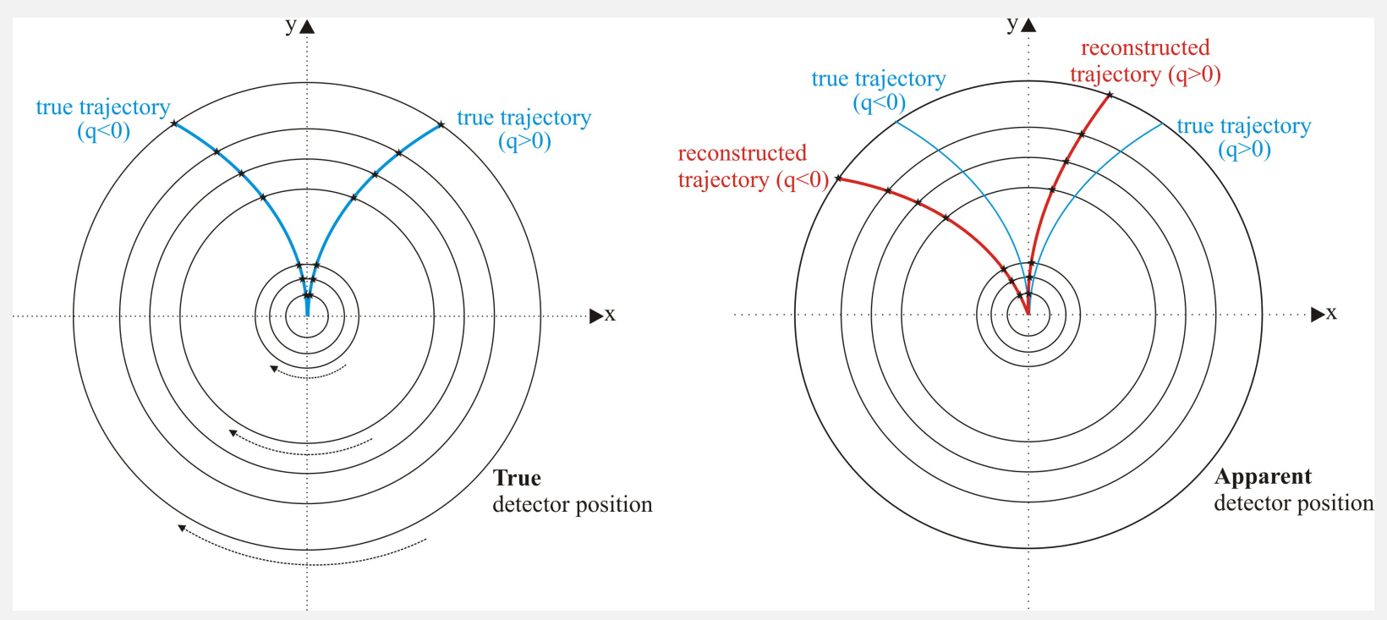


Alignment weak modes

- The main source of systematics in the alignment are geometrical distortions that preserve the helical path of the track
  - Track-hit residuals do not change significantly
  - Track χ^2 remains almost invariant
- Possible bias on track parameters from detector weak modes
  - Momentum biases: sagitta and radial distortions
  - Impact parameter
- Use constraints to detect and correct those systematic distortions
  - J/ψ, Υ, and Z decay to $\mu^+\mu^-$
    - Each μ track helps to constrain the other
  - E/p from electrons:
    - Same calorimeter response for e^+ and e^-
  - Long, complicated and time consuming procedure

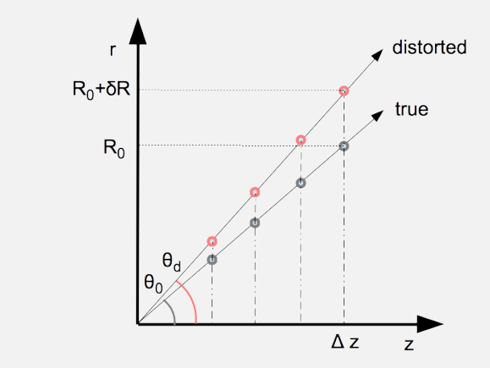
- Sagitta distortions: detector movements perpendicular to charged particle trajectories
  - Opposite effect for positive and negative charged particles

Sagitta distortion parameter: δ_s
$$\begin{aligned}p_{Td}&=p_{T0}\,(1+q\,p_{T0}\,\delta_s)^{-1}\\ p_{zd}&=p_{z0}\,(1+q\,p_{T0}\,\delta_s)^{-1}\\ \cot\theta_d&=\cot\theta_0\end{aligned}$$

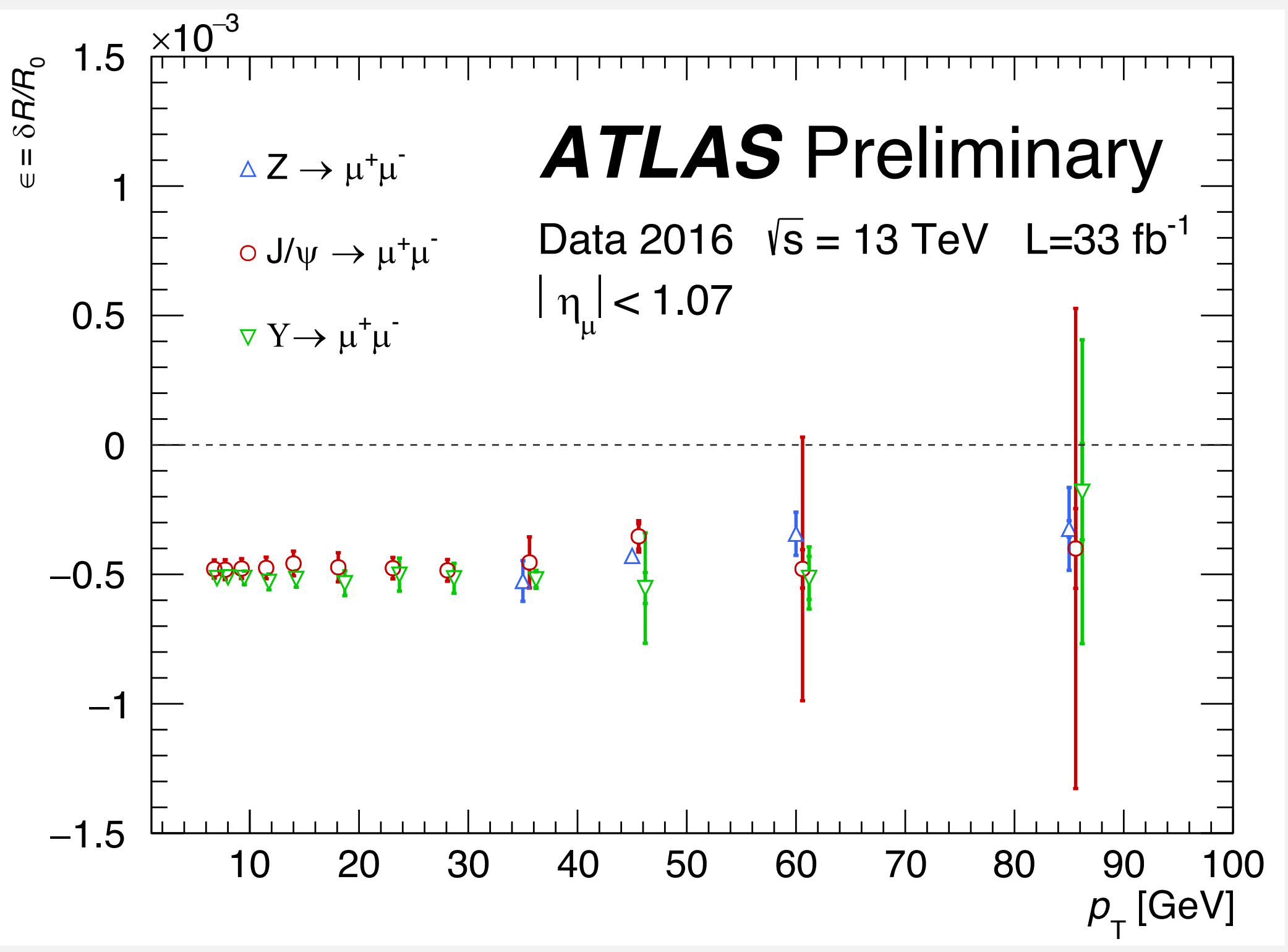


- Radial distortion: detector movements along the path of the charged particle trajectories
  - Same effect on positive and negative charged particles

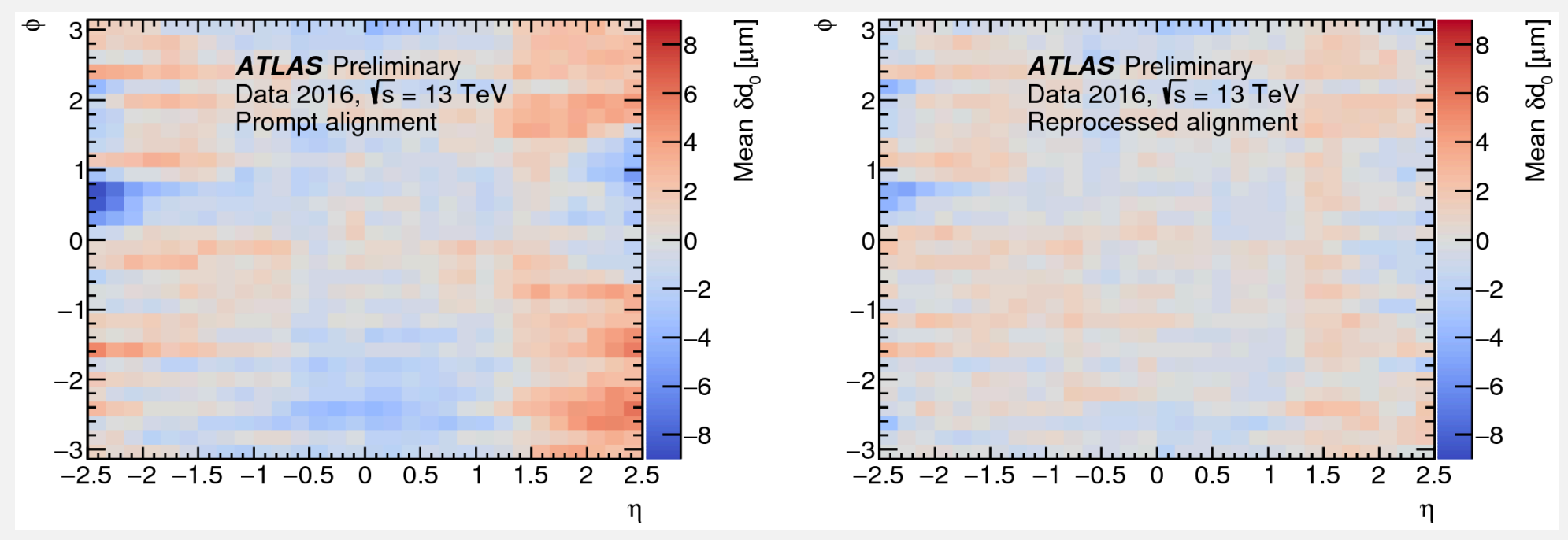
Radial distortion parameter: $\epsilon=\delta R/R_0$
$$\begin{aligned}p_{Td}&=p_{T0}\,(1+2\epsilon)\\ p_{zd}&=p_{z0}\,(1+\epsilon)\\ \cot\theta_d&=\cot\theta_0\,(1+\epsilon)^{-1}\end{aligned}$$



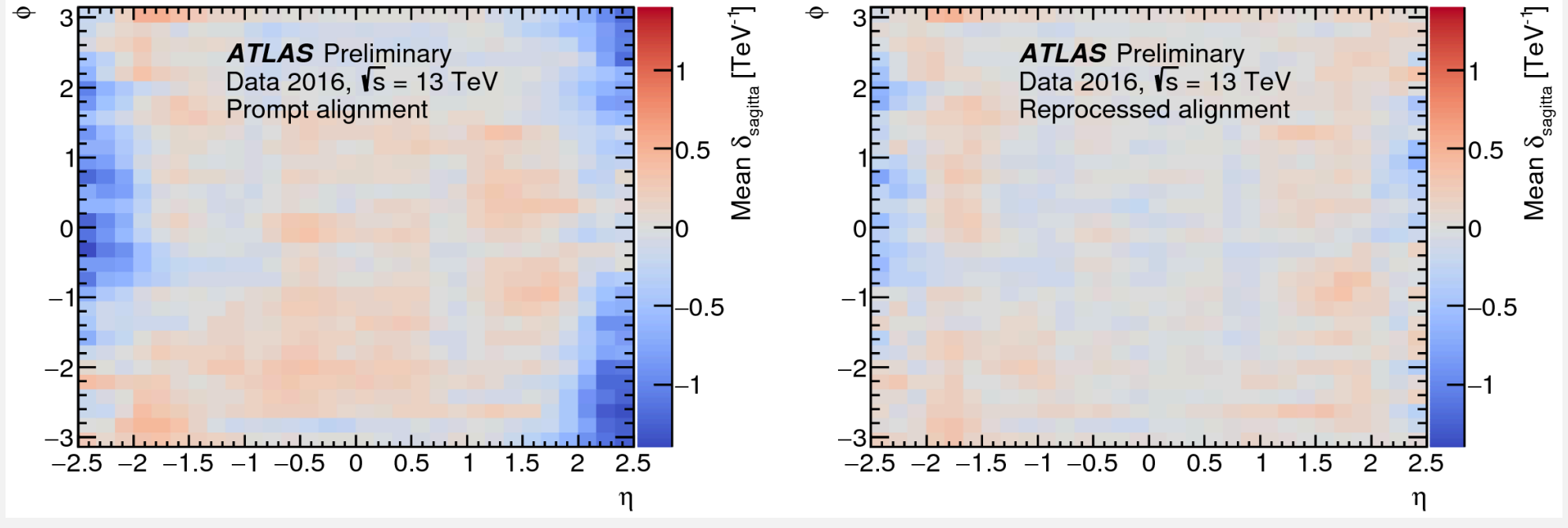
- Recent results on the detector radial distortion analizing J/ψ, Υ, and Z
  - Consistent values found
  - Effect on p_T scale is ~ 0.1%
- An improvement in the absolute momentum calibration helps to reduce the W mass uncertainty
  - Currently 19 MeV



[Impact parameter correction (δd_0) from Z → μ+μ-]



[Sagitta distortion (δ_s) correction from Z → μ+μ-]



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