Alignment of pixel sensors in ATLAS Forward Proton detectors

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New Vistas in Photon Physics in Heavy-Ion Collisions
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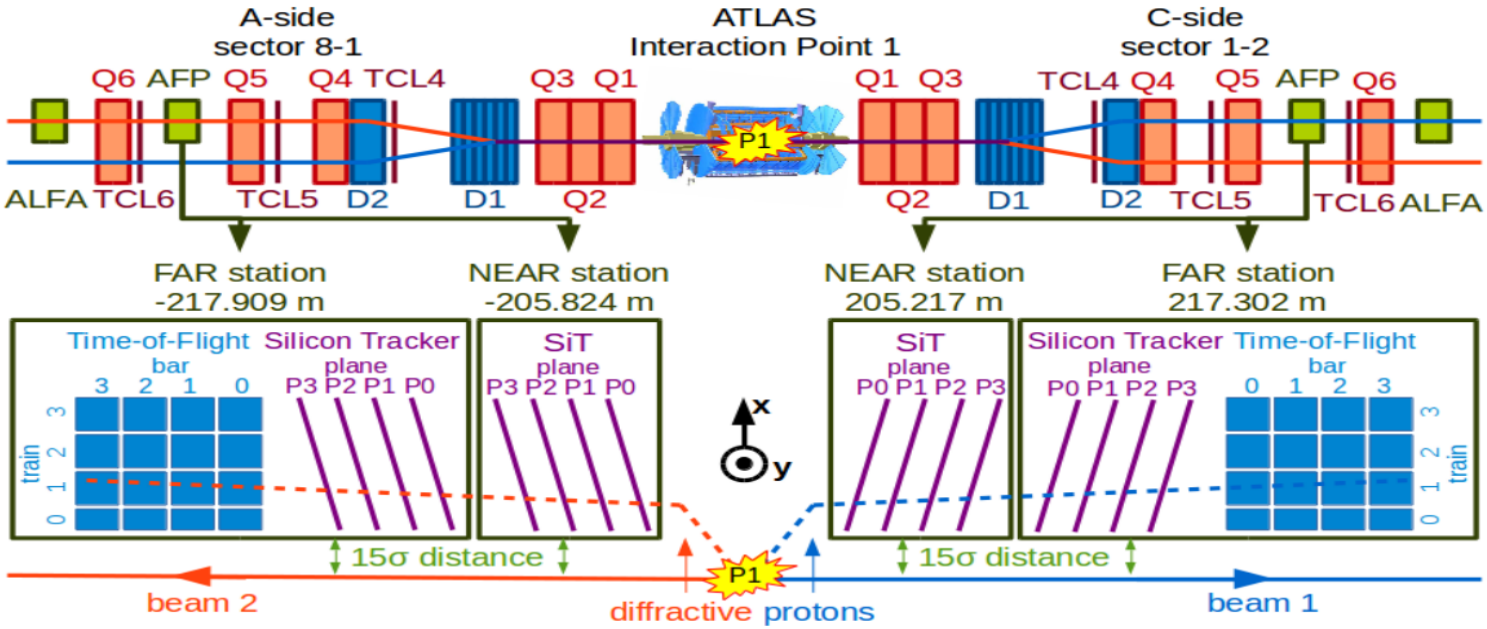
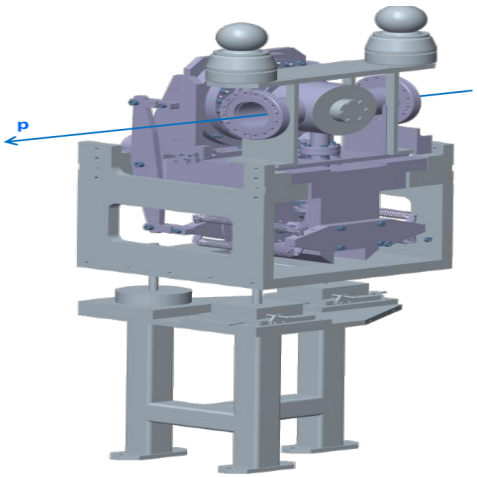
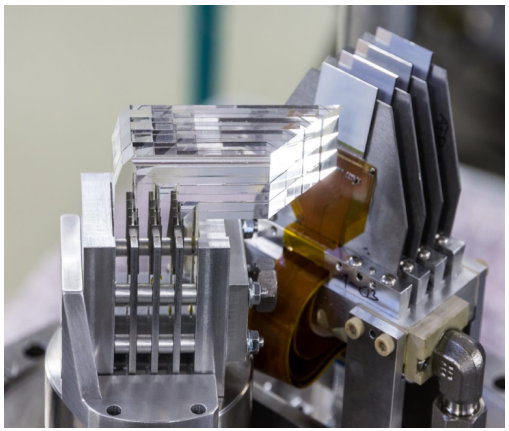
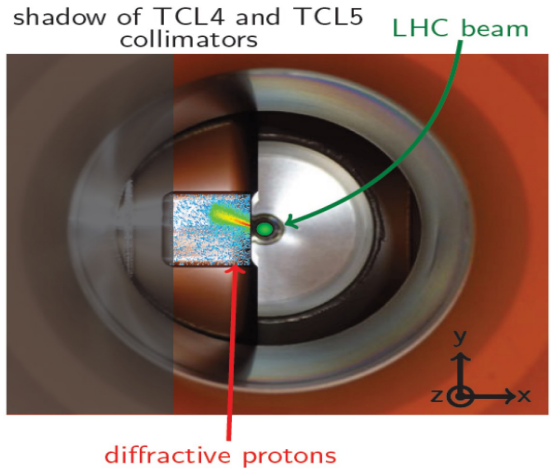
ATLAS Forward Proton Detector

The ATLAS Forward Proton (AFP) project promises to broaden ATLAS's physics reach by tagging and measuring the momentum of very forward protons in which one or both protons remain intact.



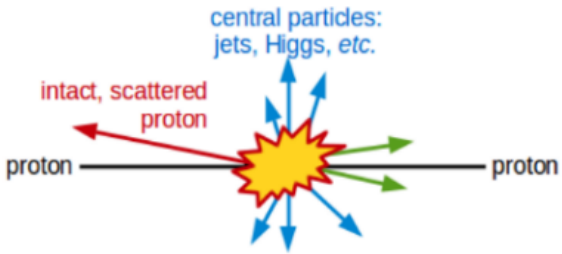


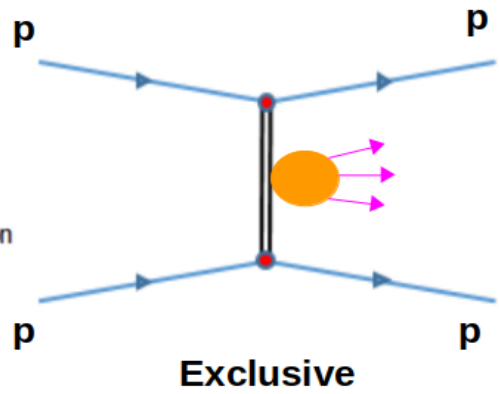


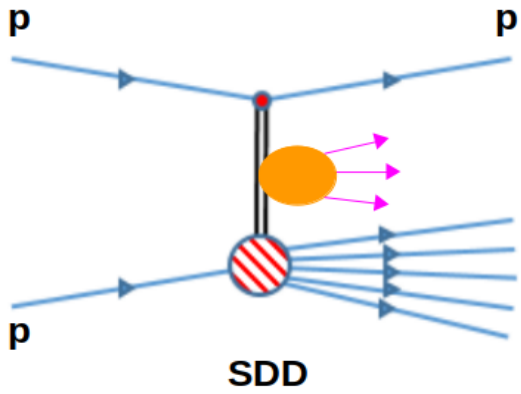


AFP Physics

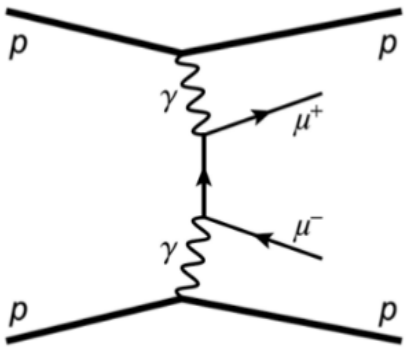
- The process where one or both protons remain intact can only happen when the object which leads the interaction doesn't change the quantum numbers of the proton:
  - Electromagnetic force: Photon
  - Strong force: Pomeron (QCD = two gluons or h.o. terms)

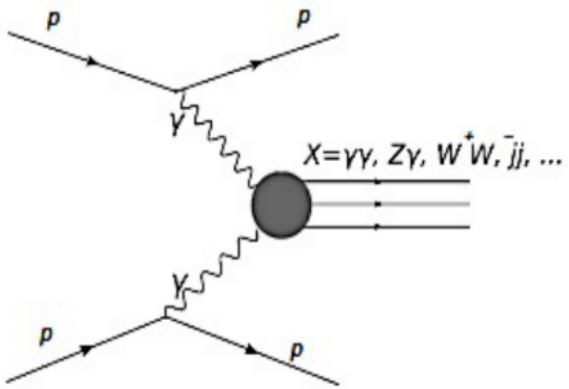






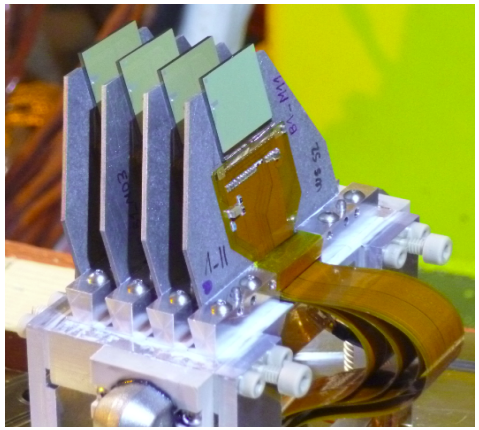
- Having the additional AFP information, the requirement of the intact protons, provides strong background reduction.
- Theoretical calculation in better control (QED processes with intact protons), not sensitive to the photon structure function





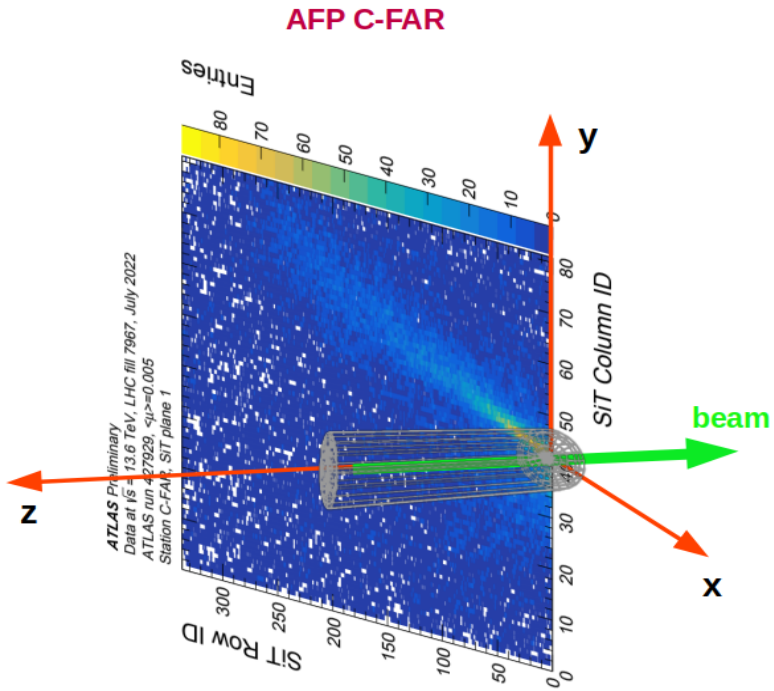
AFP Reconstruction

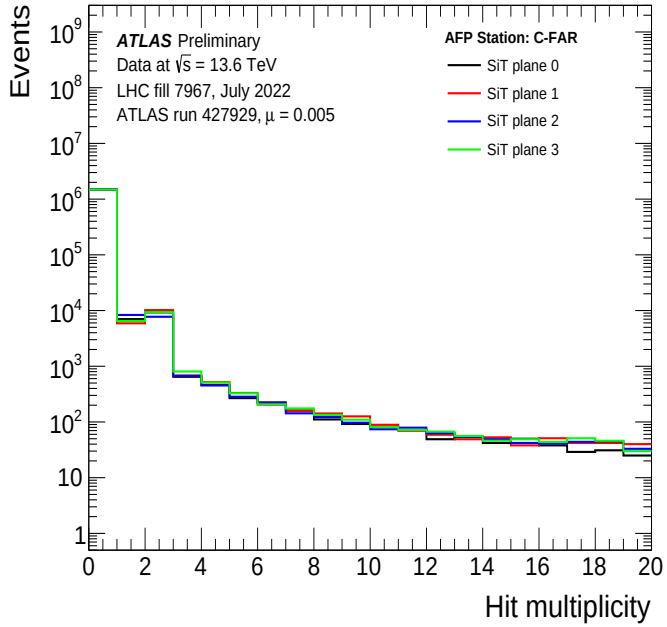
Silicon Tracker (SiT) planes



- 3D silicon pixel sensors
- 336 × 80 pixels (row × column)
- 50 µm × 250 µm and 230 µm thick
- σ_x = 6 µm and σ_y = 30 µm at 14° tilt
- FE-I4 readout chips (ATLAS IBL)

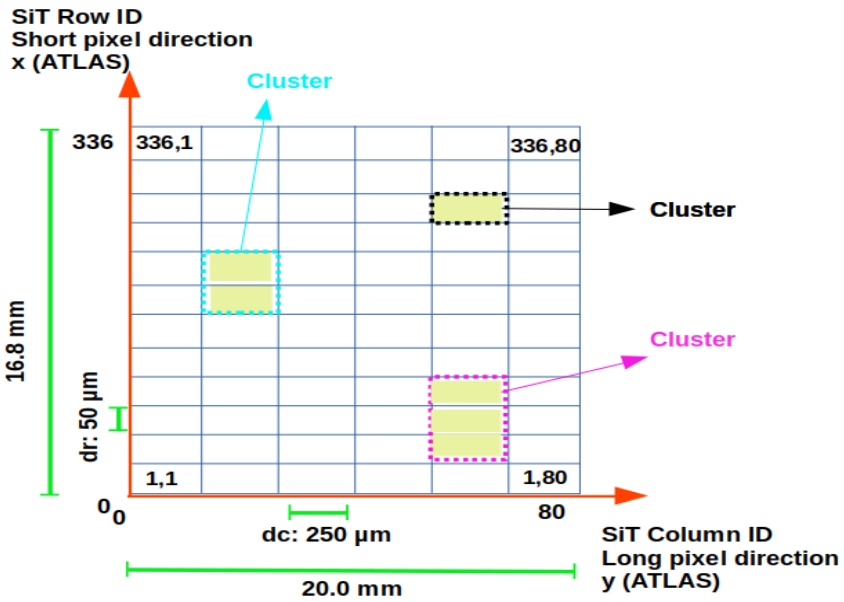
Hits recorded in a SiT plane

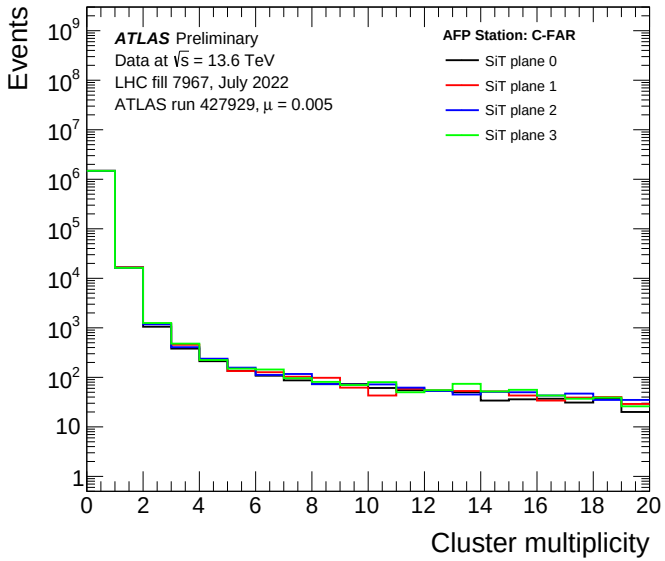




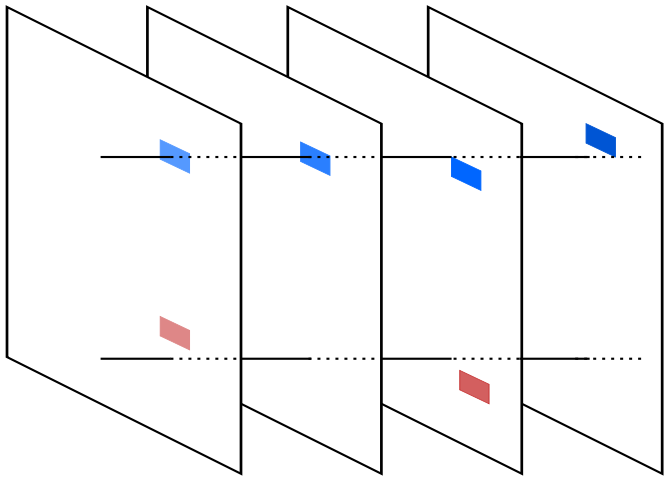
AFP Reconstruction

Cluster reconstruction

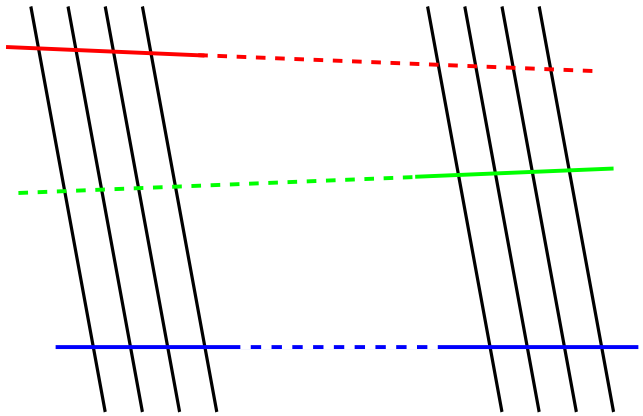




Track reconstruction

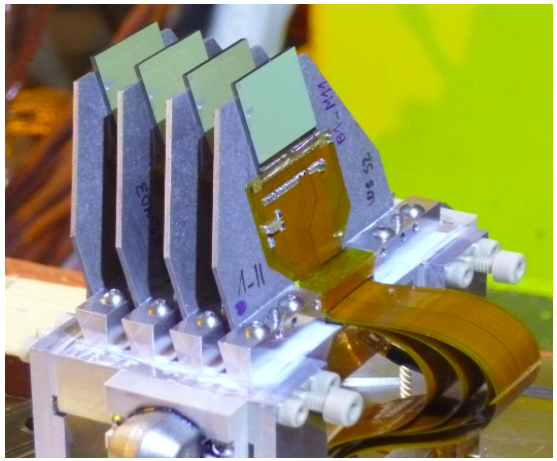


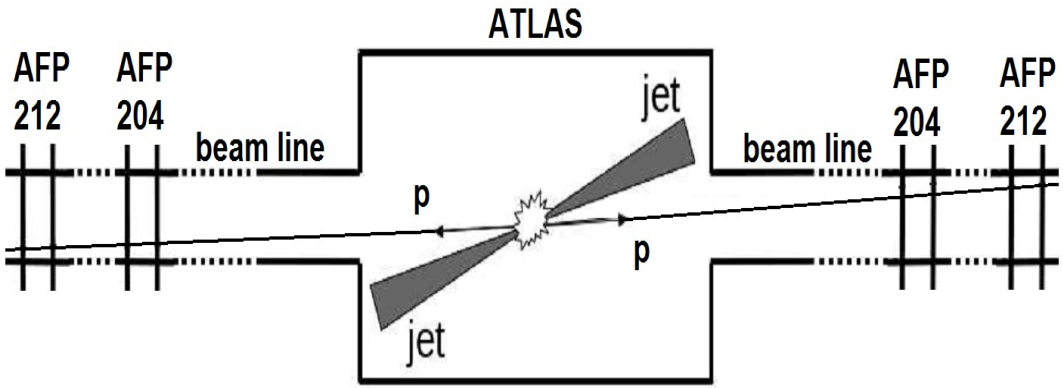
Proton reconstruction

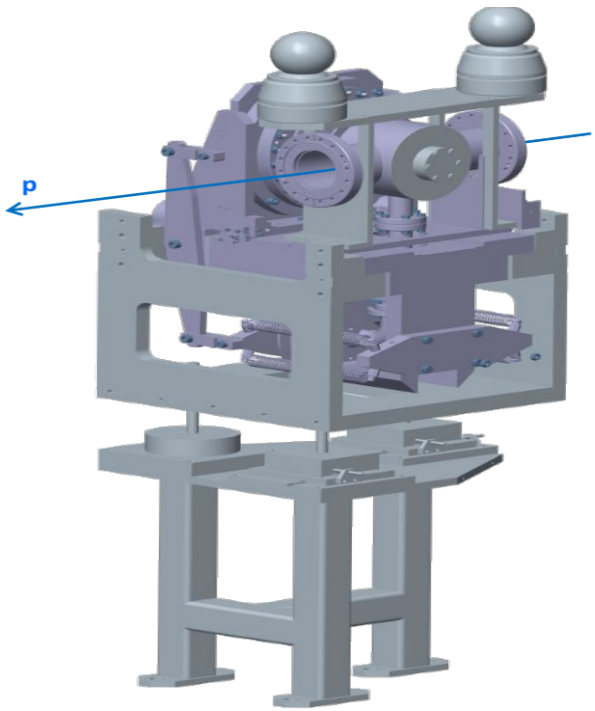


AFP Alignment

- **Inter-plane alignment**
  shift and rotation of each plane in the station
- **Global alignment**
  movement of the whole station
- **Relative alignment**
  the alignment between the Near and Far Station

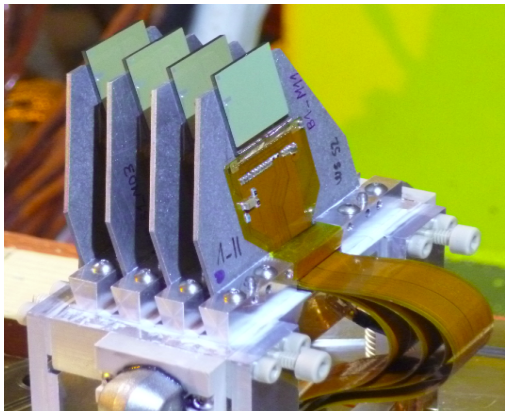


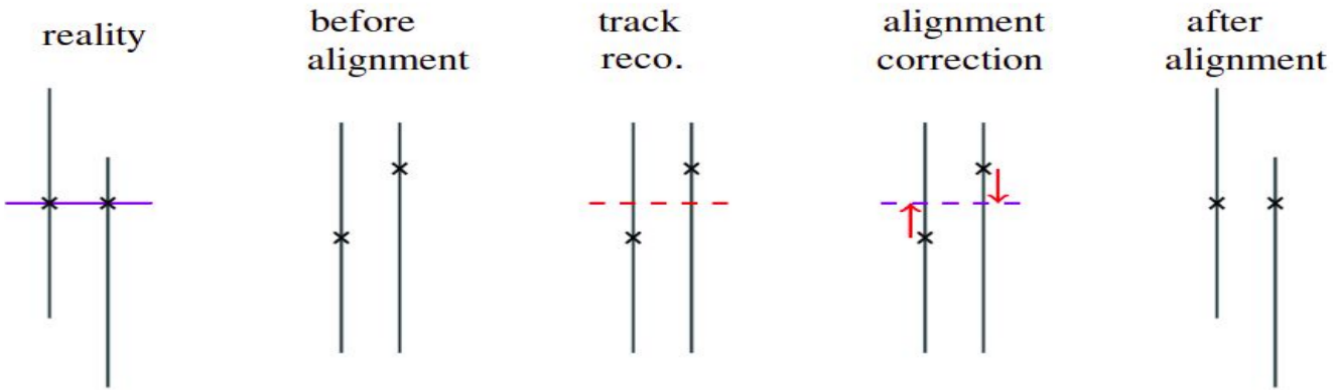




Inter-plane alignment - Method

Inter-plane alignment is a correction to reconstructed cluster positions by shifting and rotating each plane in the station.





$$\vec{r}_t = R \cdot \vec{r}_c + \delta\vec{r}$$

$$\vec{r}_t = \begin{pmatrix} 1 & -\alpha & \beta \\ \alpha & 1 & -\gamma \\ -\beta & \gamma & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} \delta x \\ \delta y \\ \delta z \end{pmatrix}$$

r_t : Track positions

r_c : Cluster positions

$\alpha,\ \beta,\ \gamma$: rotation angles about z, y, x axis

$\delta x,\ \delta y,\ \delta z$: offset values

$$\vec{r}_t - \vec{r}_c = \vec{\Delta} = (\Delta x, \Delta y, \Delta z)$$

$$\Delta x = -\alpha y + \beta z + \delta x$$

$$\Delta y = \alpha x - \gamma z + \delta y$$

$$\Delta z = -\beta x + \gamma y + \delta z$$

$$\frac{\partial \Delta x}{\partial y} = -\alpha, \quad \frac{\partial \Delta y}{\partial x} = \alpha$$

$$\frac{\partial \Delta x}{\partial z} = \beta, \quad \frac{\partial \Delta z}{\partial x} = -\beta$$

$$\frac{\partial \Delta y}{\partial z} = -\gamma, \quad \frac{\partial \Delta z}{\partial y} = \gamma$$

Alignment parameters

- Each station has 4 planes
- There are 3 rotations and 3 offsets for each plane
- 24 free parameters per station

Inter-plane alignment - Analysis

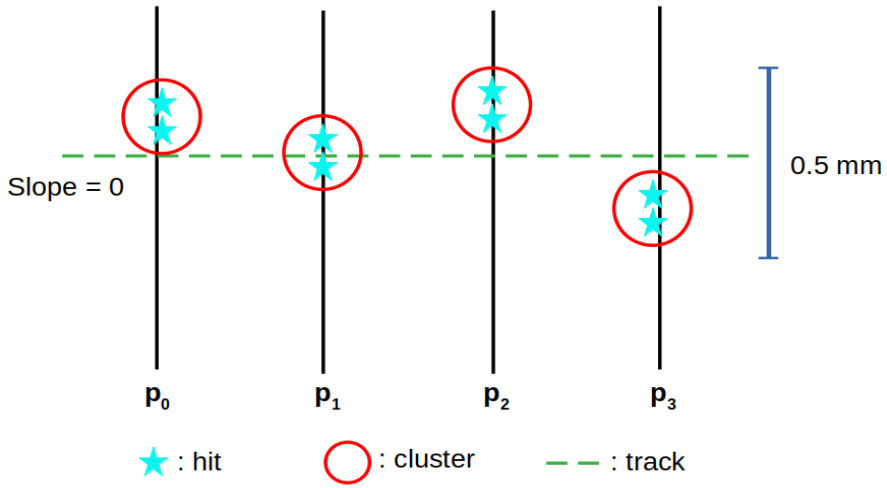
1 Event cleaning and reconstruction

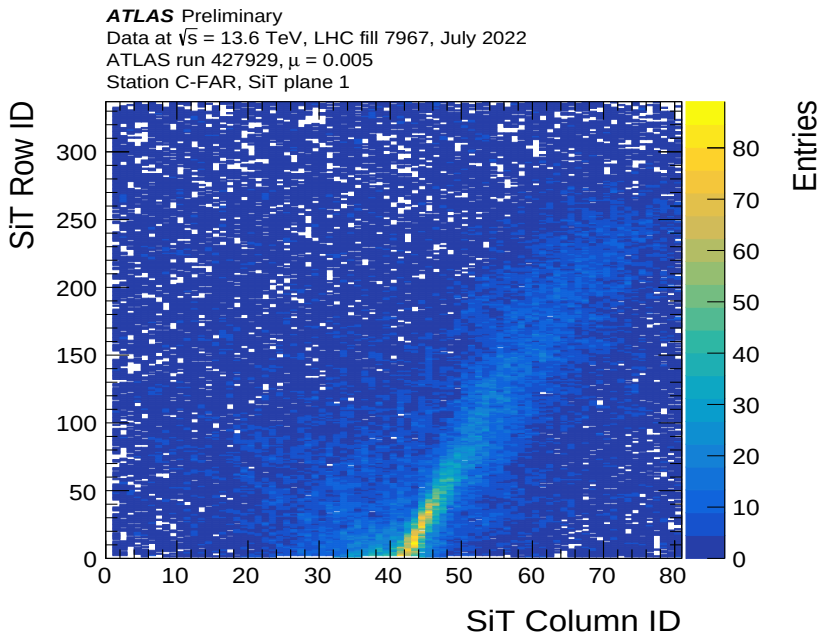
Event cleaning:

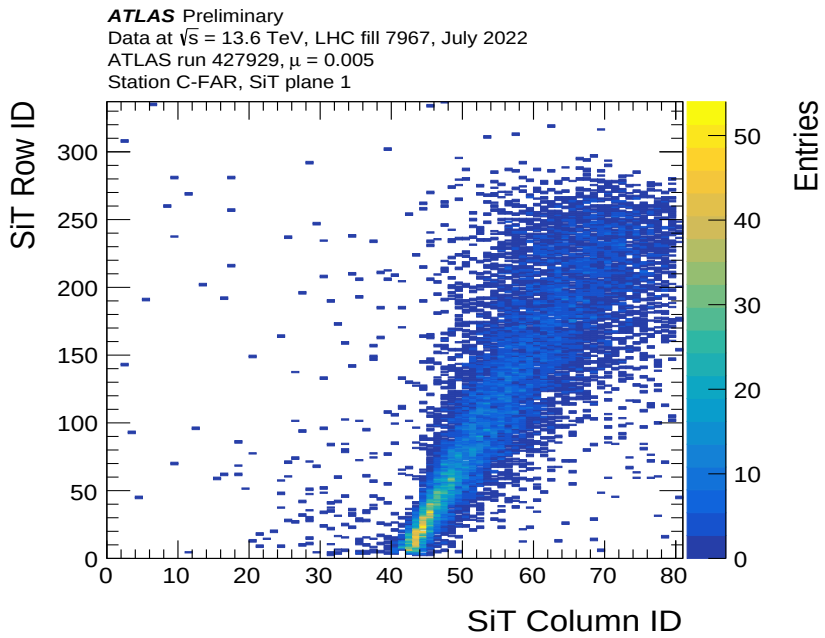
- 1 track reconstructed per station
- 1 cluster reconstructed per layer
- 1 or 2 hits recorded per layer

Event reconstruction:

- Transverse dist between clusters < 0.5 mm
- Slope of the tracks are neglected







Inter-plane alignment - Analysis

2 Calculating residuals and obtaining alignment parameters

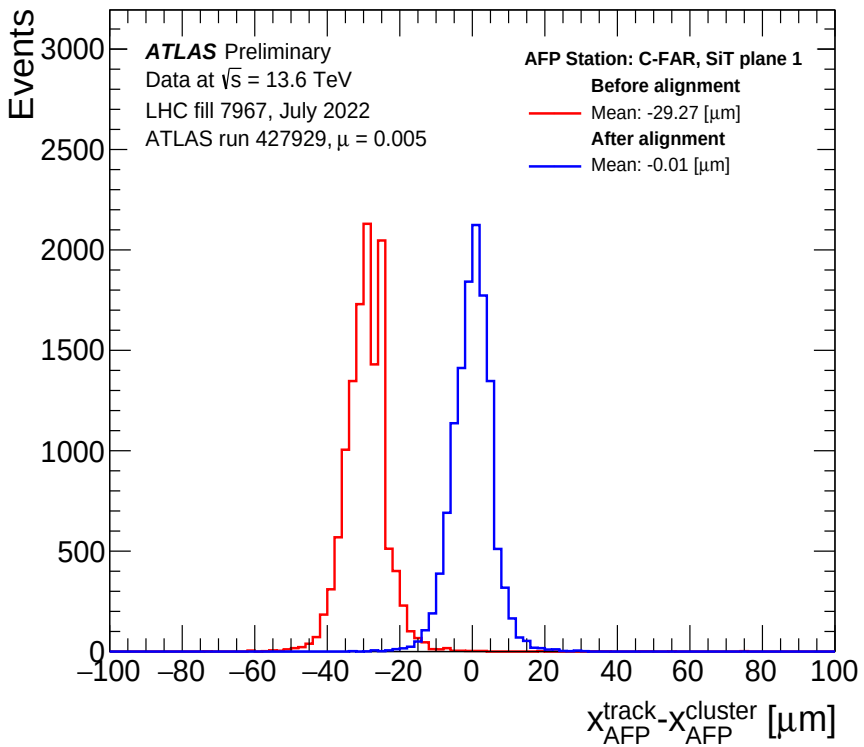
- $\delta z = 0$, $\beta = 0$, $\gamma = 0 \rightarrow$ 12 free parameters per station
- No changes in layer 0 $\rightarrow$ 9 free parameters per station
- Obtaining alignment parameters (ATLAS coordinates):

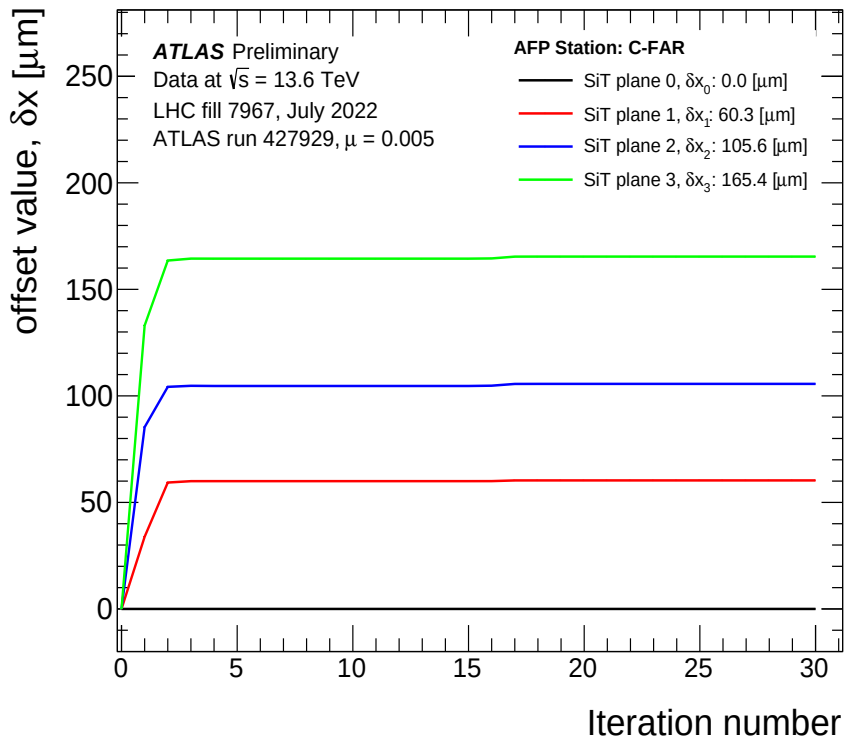
$$\Delta x = \alpha y + \delta x$$
$$\Delta y = -\alpha x + \delta y$$
$$\Delta z = 0$$
$$\frac{\partial \Delta x}{\partial y} = \alpha, \quad \frac{\partial \Delta y}{\partial x} = -\alpha$$

3 Iteration (30 times) by using previous alignment results

- Last 15 iteration with a cut on tracks' $\chi^2 < 2.0$

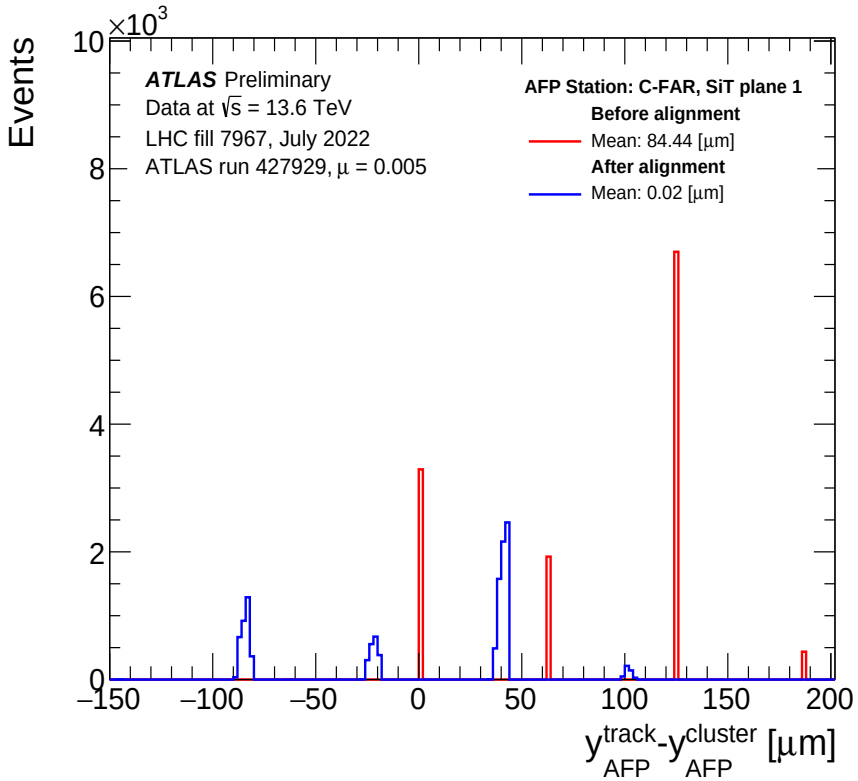
Results: Offset value δx

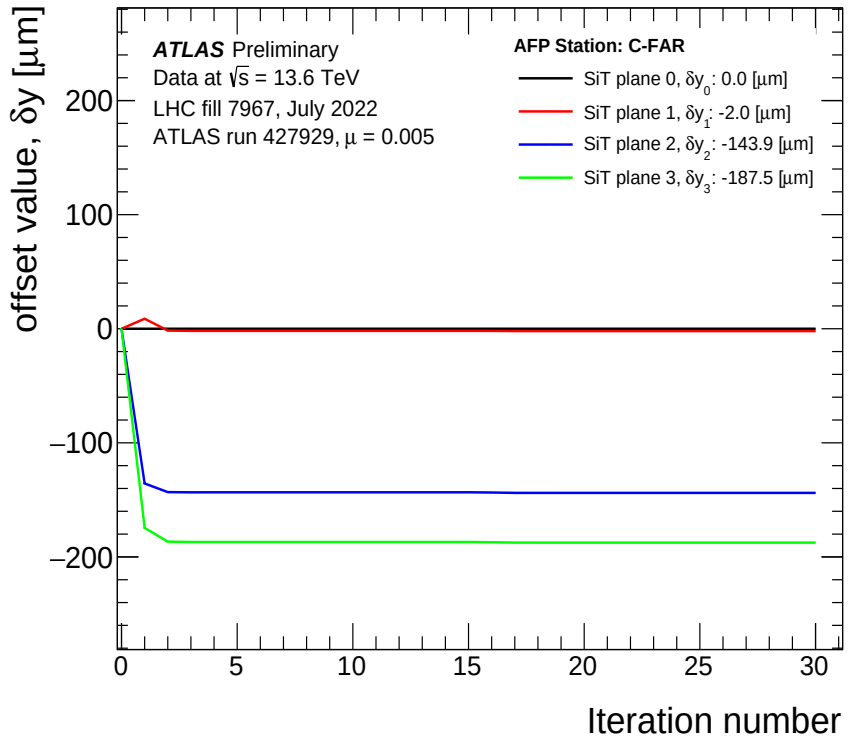




- δx is obtained from the mean value of the histogram.

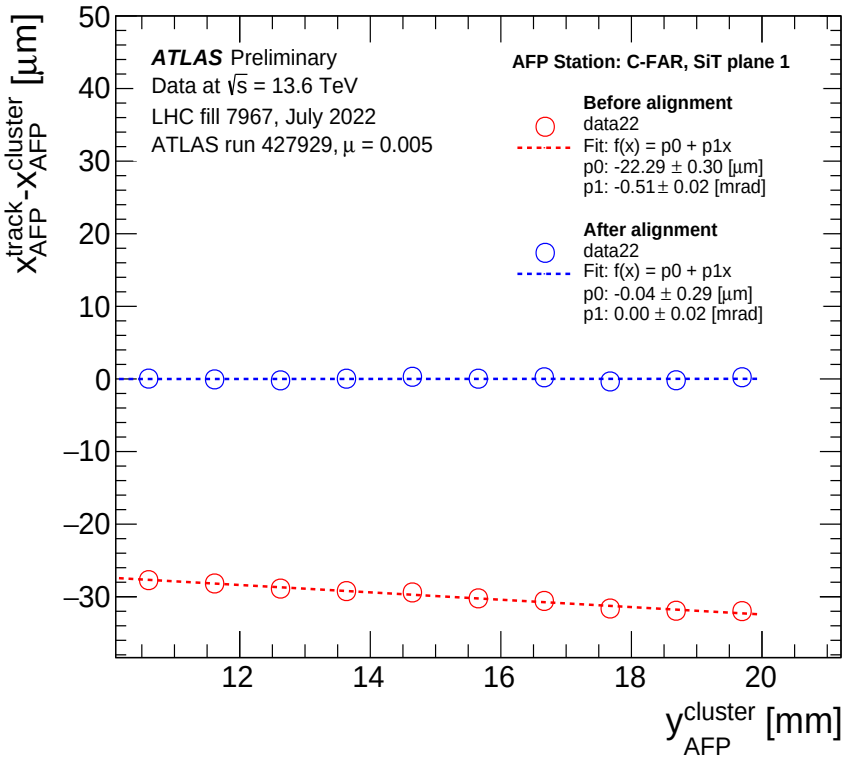
Results: Offset value δy

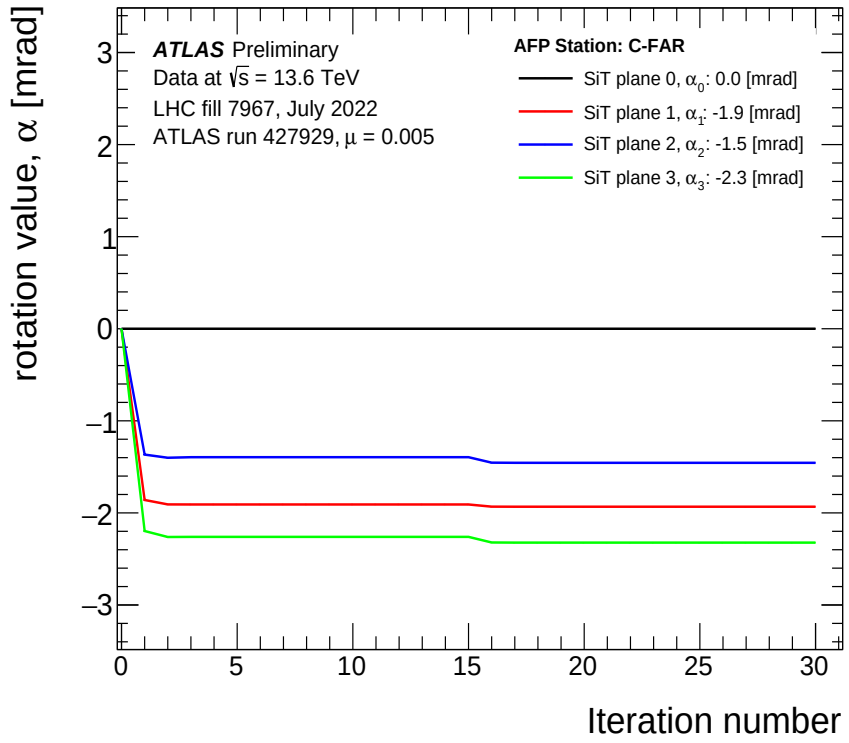




- δy is obtained from the mean value of the histogram.
- The multi-peak structure of the distribution is an effect of a low and non-Gaussian resolution in the SiT plane on the y-axis (long-pixel direction).
- The fact that red values are ”exact” while blue values are a bit ”smeared” is due to plane rotation considered in the alignment procedure.

Results: Rotation value α





- In theory, α (rotation angle about the z-axis) can be obtained from $\frac{\partial \Delta x}{\partial y} = \alpha$
- α is extracted from a linear fit applied to the data points.

Summary

- The AFP detector is important in extending ATLAS physics, where we detect protons that remain intact from the collision.
- An inter-plane alignment is required to more precisely determine the properties of the reconstructed objects in the AFP detector.
- A method for use in inter-plane alignment analysis is introduced.
- The results for alignment parameters (δx, δy, α) after 30 iterations are convergent as expected.

Thank You