Interplane alignment of SiT detector in ATLAS Forward Proton detectors

Ferhat Öztürk on behalf of ATLAS Forward Detectors

Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN), Cracow

ATLAS Forward Proton Detector

The ATLAS Forward Proton (AFP) detectors open up new possibilities to expand the ATLAS physics reach and probe unique physics processes by measuring intact protons produced in diffractive and photon-induced processes. The AFP and ATLAS detectors together provide:

- enhanced kinematic control of the final states
- significant background reduction
- various tests of the QED processes with a low but well-predicted cross-section

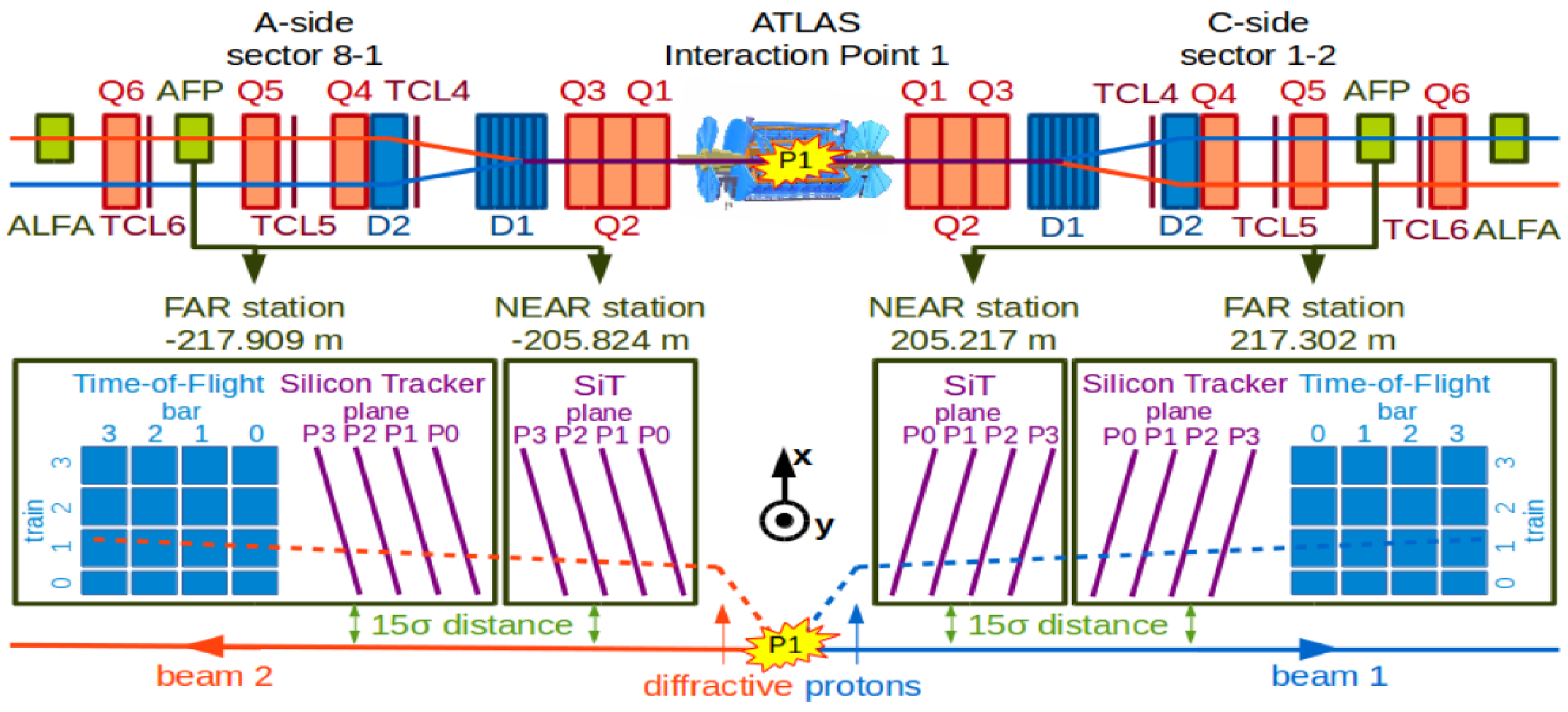

Figure 1. Schematic of AFP system, which uses devices named Roman pots to perform the measurement in the vicinity of the LHC beam [1]. The near stations consist of only 3D Silicon Tracker (SiT) detectors that measure the positions of the protons, while the far stations contain also Time-of-Flight (ToF) detectors, which measure the arrival times of the protons.

The process where one or both protons remain intact can only happen when the quantum numbers of protons do not change. The Pomeron exchange provides this in the strong interaction, and photon exchange in electromagnetic interaction.

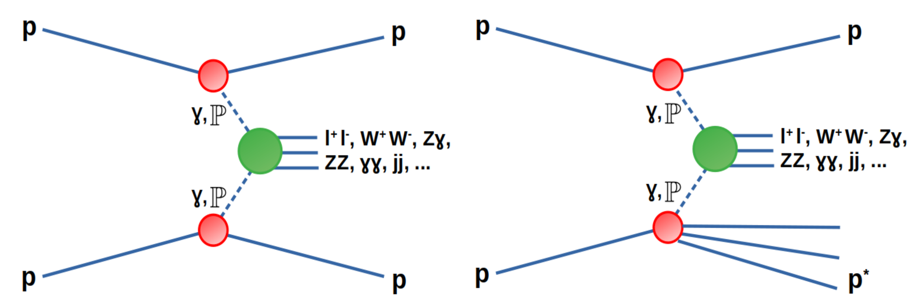

Figure 2. Feynman diagrams of exclusive production (left) and single diffractive dissociative production (right).

AFP Reconstruction

The first step is the reconstruction of clusters from hits recorded by the SiT planes. Afterwards, the tracks are reconstructed by applying a linear regression to the cluster positions. Finally, the protons are reconstructed at one or two stations using positions of the tracks.

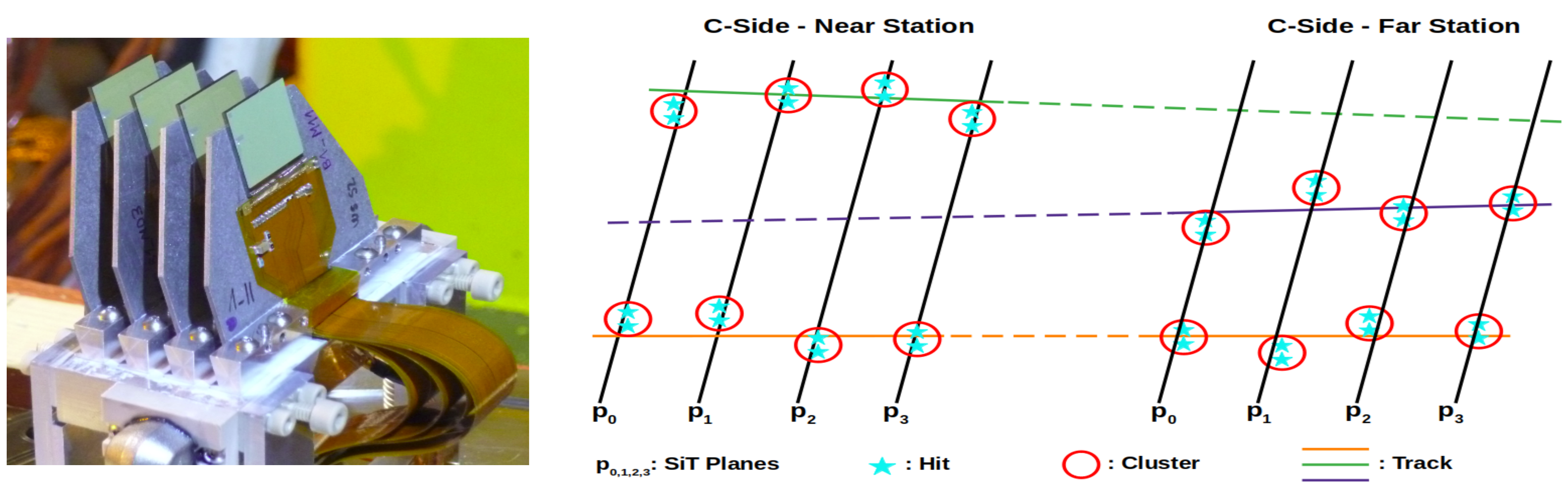

Figure 3. SiT detector with 3D silicon pixel sensors is seen on the left [1]. It consists of 336×80 pixels with the dimensions of $50\,\mu\text{m}\times250\,\mu\text{m}$. The thickness of the plane is $230\,\mu\text{m}$. The planes are tilted by 14° to achive the resolution of $6\,\mu\text{m}$ on the x-axis and $30\,\mu\text{m}$ on the y-axis [2]. A sketch of the proton reconstruction process is given on the right.

Interplane alignment of SiT detector

The aim of the interplane alignment is a precise understanding of the relative positions of the SiT planes in order to ensure the best accuracy of the measurements.

The method applied in this study uses differences between the cluster positions measured in each plane and the position of the track reconstructed from the measurement in all planes.

$$
\begin{aligned}
\vec r_t &= R\cdot\vec r_c + \delta\vec r \\
\vec r_t &= \begin{pmatrix} 1 & -\alpha & \beta \\ \alpha & 1 & -\gamma \\ -\beta & \gamma & 1 \end{pmatrix}\begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} \delta x \\ \delta y \\ \delta z \end{pmatrix} \\
\vec r_t - \vec r_c &= \Delta\vec r = (\Delta x, \Delta y, \Delta z)
\end{aligned}
\qquad (1)
$$

r_t : Track positions
r_c : Cluster positions
α, β, γ : Rotations about z, y, x
$\delta x, \delta y, \delta z$: offset values
$\Delta\vec r$: Residuals

In total, 24 parameters must be determined for the interplane alignment: 3 offsets and 3 rotation angles for each plane of each station.

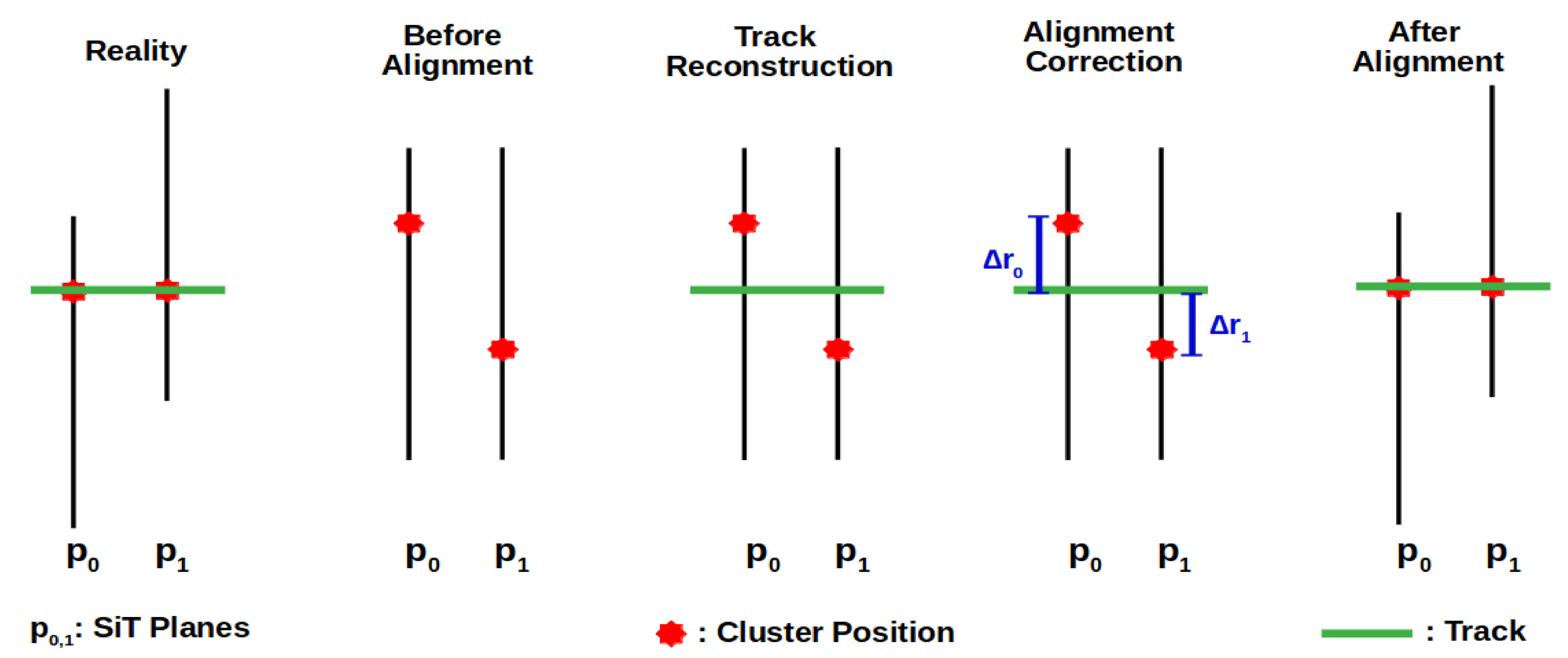

Figure 4. Simplified representation of the interplane alignment method with two planes. In reality, positions of SiT planes are unknown. The alignment process starts with "before alignment" state, where all parameters set to zero. The track with zero slope is then reconstructed from the cluster positions. The residuals ($\Delta\vec r$) on the same plane are calculated. These corrections finally are applied to cluster positions.

Analysis

At first, the event cleaning and track reconstruction are performed.

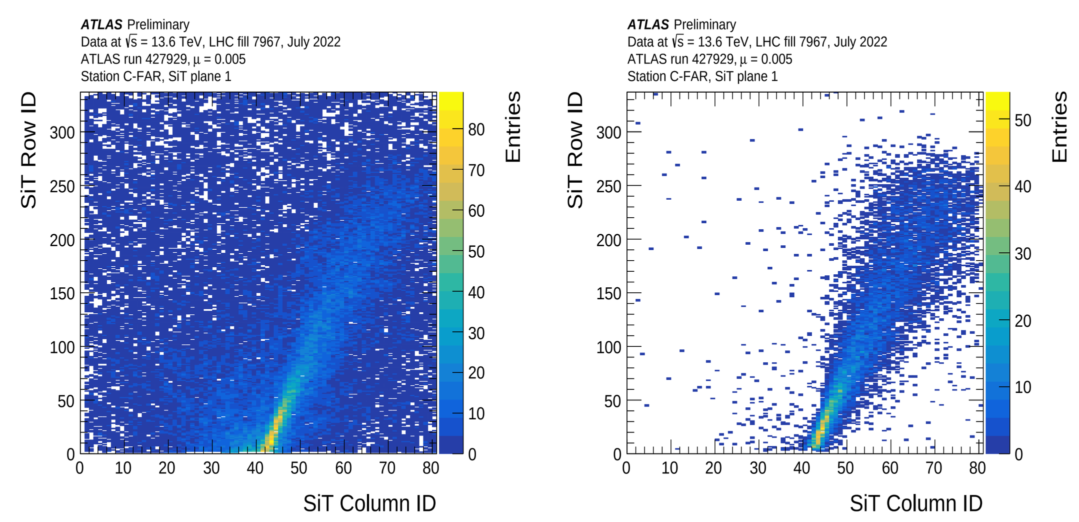

Figure 5. Distribution of hits recorded by SiT plane 1 at the AFP C-FAR station [3]. The situation with event cleaning performed is shown on the right, and initial distribution on the left. The following selection is applied: only 1 track per station, 1 cluster and 1 or 2 hits per SiT plane.

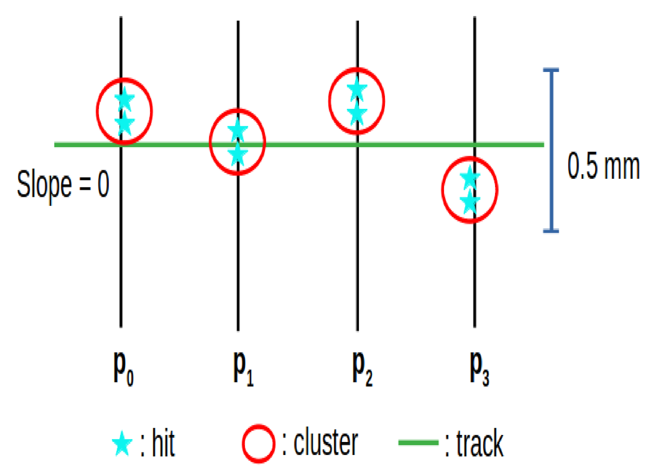

Figure 6. Illustration of track reconstruction procedure where transverse distance between clusters is less than 0.5 mm and slope of the track is neglected.

9 degrees of freedom considered in the analysis are the shifts in the x and y directions and the rotations around the z-axis. 3 degrees of freedom are eliminated by fixing the position of plane 0.

A correction to the alignment parameters is applied iteratively (30 times) until the convergence is reached. The last 15 iterations include an additional selection of events where the track χ^2 value is $\chi^2/\text{ndf} < 2.0$ in order to further clean up the sample.

Results

Obtaning corrections to the alignment parameters: δx and δy from the mean of the Δx and Δy distributions and α from the slope of the $\Delta x(y)$ dependence.

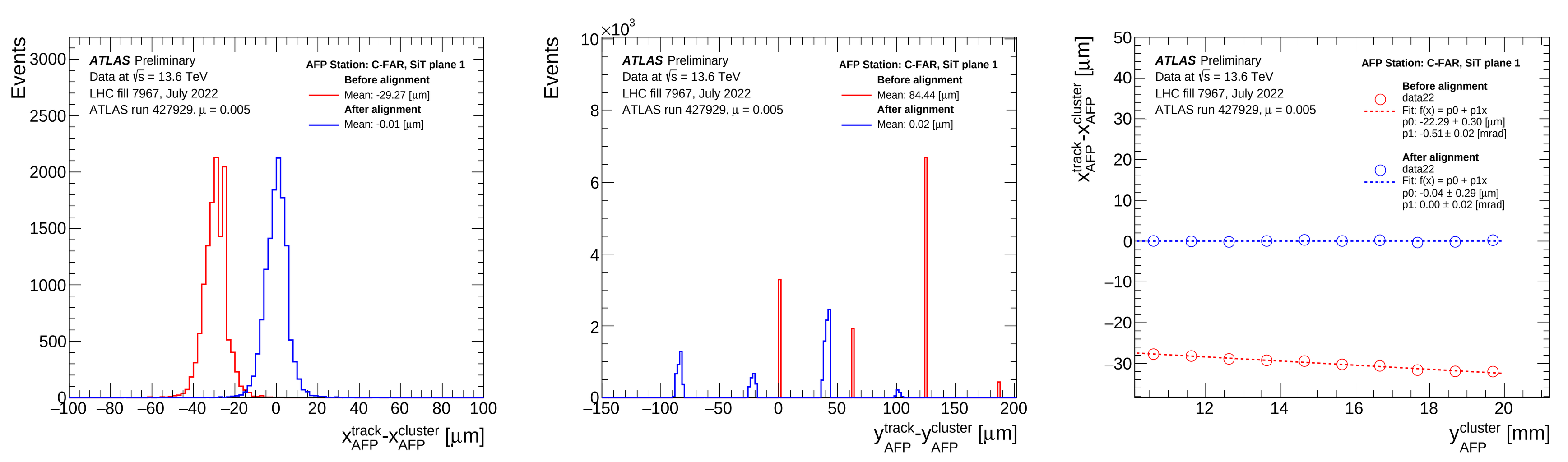

Figure 7. Position difference distribution between a reconstructed track and a cluster, of x (left) and y (middle) [3]. The average value of the difference in x-positions of the tracks and the clusters as a function y position of the clusters (right). The fits are indicated by dashed lines.

The parameter values ($\delta x, \delta y, \alpha$**)** quickly converge as expected.

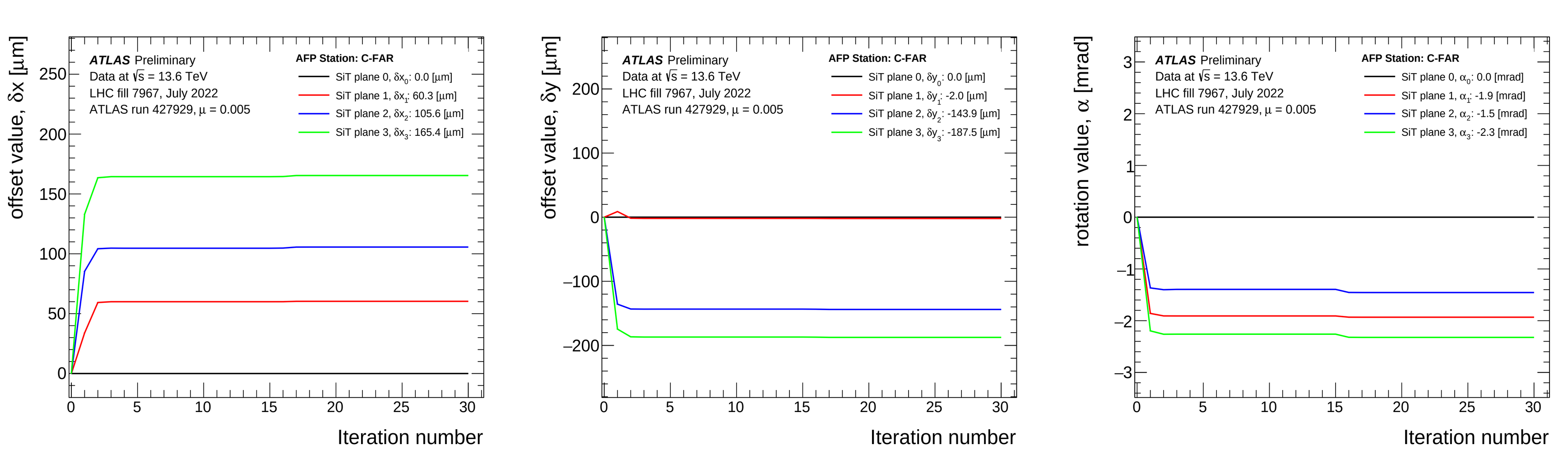

Figure 8. The evolution of the alignment parameters δx (left), δy (middle), and α (right) with iteration number [3]. The final values are given for each plane in the upper right.

[1] ATLAS Collaboration, 2022, AFP Figures, `https://twiki.cern.ch/twiki/bin/viewauth/Atlas/AFP_Figures`
[2] ATLAS Collaboration, 2015, Technical Design Report for the ATLAS Forward Proton Detect, ATLAS-TDR-024
[3] ATLAS Collaboration, 2022, AFP Performance in Run 3, ATL-COM-FWD-2022-026, `https://cds.cern.ch/record/2826256`

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