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Overview of ATLAS forward proton detectors: status, performance and new physics results

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A key focus of the physics program at the LHC is the study of head-on proton-proton collisions. However, an important class of physics can be studied for cases where the protons narrowly miss one another and remain intact. In such cases, the electromagnetic fields surrounding the protons can interact producing high-energy photon-photon collisions. Alternatively, interactions mediated by the strong force can also result in intact forward scattered protons, providing probes of quantum chromodynamics (QCD). In order to aid identification and provide unique information about these rare interactions, instrumentation to detect and measure protons scattered through very small angles is installed in the beam pipe far downstream of the interaction point. We describe the ATLAS Forward Proton AFP Detectors, including their performance to date, covering Tracking and Time-of-Flight Detectors as well as data quality monitoring. Finally, a glimpse on the newest performance results will be given.

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1. ATLAS Forward Proton (AFP) detector

The ATLAS Forward Proton (AFP) detector [1] is a forwad extension of the ATLAS [2] detector at the Large Hadron Collider (LHC), designed to detect protons undergoing small or zero angle scattering at the interaction point (IP). The AFP detector naturally provides intact proton information in both, SM processes (dileptons [3]) and BSM processes (axion-like particles [4]). The potential for other (semi)exclusive low cross-section processes with final states with high transverse momentum is large [5–7].

The AFP detector consists of four stations, which are located at approximately 205 m (NEAR) and 217 m (FAR), on anticlockwise (A) and clockwise (C) sides of the ATLAS IP.

For tracking the Silicon Tracker (SiT) is used, which consists of four layers of silicon pixel detectors. The active area of the detector is approximately 20×20 mm^2, the pixel size is 50×250 μm^2 and they form a pixel grid with a size of 336 by 80 pixels on each SiT plane. The planes of SiT are tilted by 14° providing a spatial resolution of the 10 μm in x and 30 μm in y.

The FAR stations are additionally equipped with Time-of-Flight (ToF) detectors [8], which collect Cherenkov photons created in L-shaped silica bars (LQ-bars). 16 LQ-bars grouped in 4 trains with widths of 3 mm, 3 mm, 5 mm and 5.5 mm, the first train being the closest to the beam.

When the scattered proton passes through the quartz bar, Cherenkov radiation is emitted and directed to a Micro-Channel Plate Photo-Multiplier Tube (MCP-PMT). The signal from the PMT is amplified and processed by a constant fraction discriminator (CFD), which passes it to a high performance time-to-digital converter (HPTDC) through the Digital Trigger Module (DTM).

2. Run-3 data-taking and Data Quality

AFP participates in the data-taking during standard, high pile-up (μ) LHC runs to study rare processes, and in special LHC runs with low pile-up to study processes with relatively large cross-sections. Additionally, AFP participated in special proton-Oxygen, Oxygen-Oxygen and Neon-Neon campaigns of the LHC in July 2025.

Figure 1 shows AFP recorded luminosity for the 4 years of Run-3 data-taking, calculated for two cases: both sides of AFP taking data simultaneously, and at least one side of AFP taking data. So far, AFP recorded 239.3 fb^{-1} with both arms, which corresponds to 87.5 % with respect to ATLAS recorded data.

Good Run Lists (GRLs) for AFP are based on ATLAS GRLs and are prepared separately, due to specific usage of the detector and need in more diversity of GRLs than for the ATLAS detector (possibility to use separate sides of AFP and different levels of strictness for forward analyses). AFP has 8 GRLs, based on subdetectors (SiT per side and combined, ToF) and based on strictness (at least 3/4 or 2/4 planes in each SiT detector are operational). Combined SiT loose GRLs cover from 70 to 90 % wrt. to ATLAS, depending on the year.

3. ToF detector

The ToF detector performance strongly depends on the data taking conditions. Studies based on early 2022 data taken with a very-low pile-up of $<\mu> = 0.05$ show the reconstruction efficiency on a level 95% [10]. The obtained vertex reconstruction resolution was (9.0 ± 0.1) mm.

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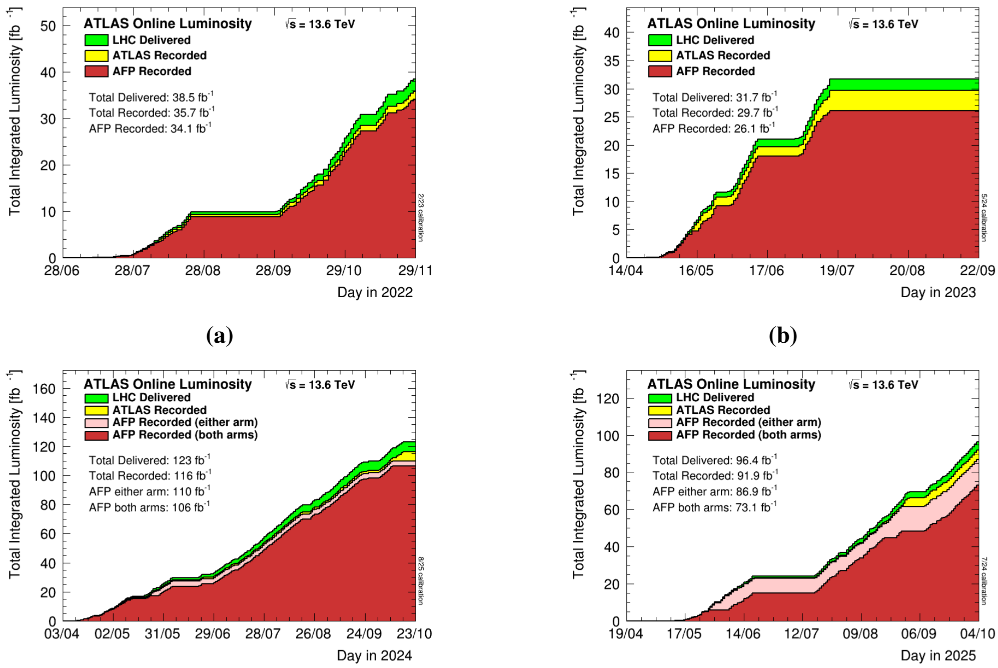

(a) (b) (c) (d)

Figure 1: Time evolution of cumulative luminosity delivered to (green), recorded by ATLAS (yellow), and recorded by AFP (red) at $\sqrt{s}$ = 13.6 TeV in (a) 2022, in (b) 2023, in (c) 2024, and in (d) 2025 [9]. Luminosity is counted as recorded by AFP if all 4 AFP stations (red) or one side stations (pink) are in physics position, AFP is included in the ATLAS data acquisition system, and the luminosity is recorded by ATLAS.

The increase of scattered proton rate in AFP cause a significant decrease of ToF reconstruction efficiency. This is clearly visible on Figure 2. The left plot shows the efficiency of ToF bars as a function of actual pile-up during in case of 386 colliding bunches. For $\mu \sim 30$, the efficiency is about 60-95%, depending on the bar. It decreases with the number of interactions, to be in range 40-60% for $\mu \sim 70$. Even bigger impact is due to number of colliding bunches (Figure 2, right plot). When LHC becomes full (reaches $\sim$ 2400 bunches), the ToF efficiency becomes very small, on a level of few %. The effect is not fully understood yet, but usually attributed to the properties of readout electronics.

4. Conclusions

The ongoing development and improvements to the AFP system increases the ratio of data useful for physics analysis. By the middle of the running period in 2025, we already recorded more than 10 times more data than in Run-2. The performance of the ToF detector was studied with 2022 low-μ data and 2024 high-μ data.

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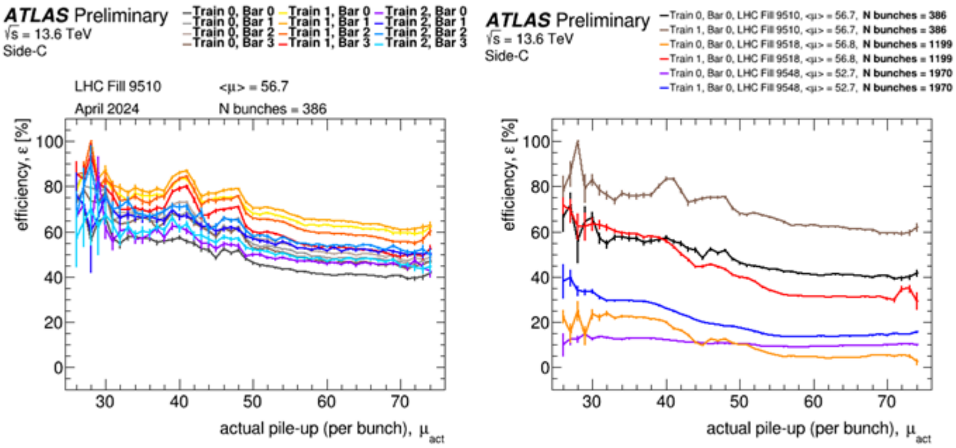

Figure 2: Efficiencies of the ToF detector channels, as a function of actual pile-up - measured per bunch - during one run (left), and for two chosen channels, as a function of actual pile-up in three high-μ LHC fills with different amount of bunches: 386, 1199 and 1970 (right) [10].

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