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Performance of ATLAS Forward Proton Detector during LHC Run 2

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Concept of ATLAS Forward Proton detectors and their active components: 3D Silicon Tracks and Time-of-Flight system is described. Performance of tracking and Time-of-Flight systems as well as studies of trigger performance and detector alignment are discussed.

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1. Introduction

Located at the Large Hadron Collider (LHC) [1], the ATLAS experiment [2] has been designed with the goal of measuring the products of proton–proton collisions. Although it has a full azimuthal angle coverage and a large acceptance in pseudorapidity, it is not fully sufficient for a certain group of physics processes, namely the diffractive physics.

Diffractive processes can be characterised by the presence of the following observables: rapidity gap (a space in rapidity where no particles are produced) and scattered protons. This is due to the nature of such interactions in which the exchanged object is a colour singlet: photon for electromagnetic or Pomeron for strong interactions.

Because of those characteristic observables one can think of two methods of detecting such processes. The first approach focus on studies of the rapidity gap. Unfortunately, the gap may be destroyed by *e.g.* particles from pile-up. The second method is based on detecting scattered protons. The advantage of this approach is that the protons are measured directly, hence it can be used in the non-zero pile-up environment. However, to measure the scattered protons the additional "forward" detectors are needed.

2. ATLAS Forward Proton Detector

The ATLAS Forward Proton detectors (AFP) [3] consist of two Roman pot stations (called Near and Far) on each side of ATLAS. They are located around 210 m from ATLAS Interaction Point (P1) and can be inserted horizontally into the LHC beam pipe. The insertion is possible due to the Roman Pot (RP) technology. In case of non-stable beams pots are in the "safe" position, which is about 40 mm from the beam. When the beam is stable, the detectors can be moved 2-3 mm close to the beam centre. Each RP consists of four Silicon Trackers (SiT) [4]. Additionally, Far stations host Time of Flight (ToF) detectors [5].

AFP is successfully taking data since 2016. In the first year AFP was only inserted during the special, low luminosity runs, but since 2017 the detector has taken data in all regular LHC fills. In 2017 AFP collected 32.0 fb^{-1}.

3. AFP Silicon Detectors Performance in Run 2

The AFP pixelated silicon tracking system provides the position measurement of the scattered protons. Each station is equipped with four SiT modules tilted by 14°. Due to this tilt it is expected to see two pixels fired per proton on average. The pixel multiplicity is shown on left plot in Figure 1. As predicted, the distribution peaks at 2. The peak at 0 is due to the proton tag on opposite side. Another contribution to zero bin comes from 1% events, in which the trigger has fired, while no hit was recorded. Differences in geometry of individual planes (*i.e.* slightly different tilt) cause migration between bins of number of hits 1 and 2.

Proton track reconstruction efficiency for different pile-up scenarios as a function of proton relative energy loss is shown on Figure 1 (right). Tracks matched between the Near and Far stations are included. In order to reduce effect of particle showers crated on upstream LHC elements, only events with track multiplicity $\leqslant 2$ in Near and track multiplicity $\leqslant 5$ in Far station are considered.

Within the AFP geometric acceptance (here taken as 0.03< ξ <0.1, where ξ is energy lost by interacting proton: 1 - E_{proton}/E_{beam}) track reconstruction stays at high level above 90% for lower pile-up scenarios. The efficiency drops slightly below the 90% only for μ = 15.

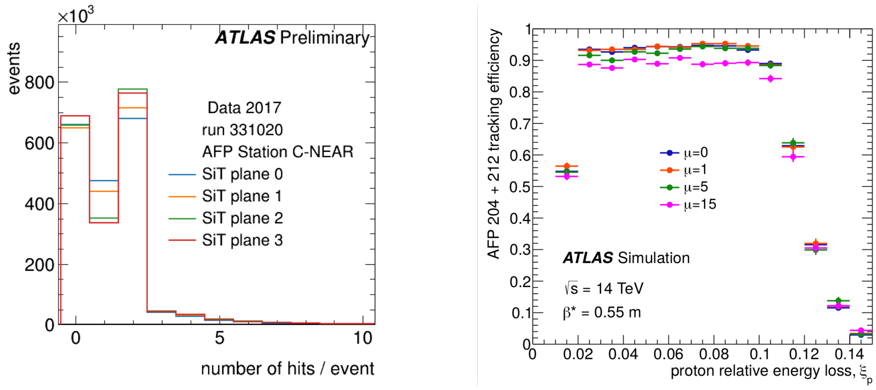

Figure 1: **Left:** number of hits per event in SiT planes in C Near station. **Right:** proton track reconstruction efficiency for different pile-up scenarios as a function of proton ξ.

4. AFP Time-of-Flight Performance in Run 2

The main backgrounds to diffractive processes is usually a non-diffractive production with soft protons originating from pile-up. These backgrounds can be significantly reduced by using the Time-of-Flight detectors. The idea is to measure difference of time of flight of scattered protons on both sides $(t_A - t_C)/2$ and compare it to the vertex reconstructed by ATLAS: $(t_A - t_C) \cdot c/2 - z_{ATLAS}$. Since several proton-proton interactions in a single bunch-crossing are expected during the regular ATLAS data-taking, a probability of combinatorial background is high. The AFP Time-of-Flight detector was designed to reduce such background by factor of few.

AFP ToF detector is composed from 16 L-shaped quartz bars (LQbar). When scattered protons hit these bars, the Cherenkov light created by protons is guided to a Micro-Channel Plate Photo-Multiplier (MCP-PMT). After the amplification, a readout is done by radiation hard electronics.

On Figure 2 the time measurement resolutions of single ToF channels extracted from AFP calibration stream for two 2017 low-μ runs are presented [5]. The error bars represent the statistical uncertainties of the resolution fits and the systematic uncertainties (time measurement correlations between channels and calibrations of the time measurement in the channels) added in quadrature. The time resolutions are extracted from the widths of the distributions of time differences $\Delta_{t_{ij}} = t_i - t_j$ within a single train, where i and j denote channel numbers. In [5] it was shown that the resolutions per bar can be as low as 20 ps (for the B, C bars). The per-proton resolution was found to be 20 ps - 26 ps for the A and C side respectively.

5. Luminosity Measurement

The issue of de-synchronisation of ATLAS and AFP readouts involving 2018 data-taking gave opportunity to measure luminosity independently from ATLAS standard measurements. The aver-

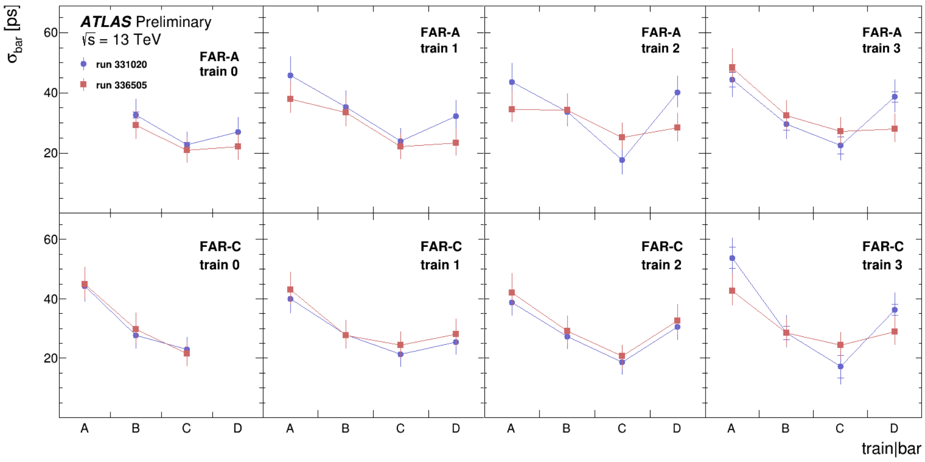

Figure 2: The time measurement resolutions of single ToF channels for A Far (top plots) and C Far (bottom plots) stations. Each plot represents different train in station. From [5].

age number of interactions per bunch crossing was determined for each luminosity block using the average number of AFP tracks.

The relation between luminosity obtained by a fit to AFP data vs calibrated LUCID data, for a chosen "calibration run" for AFP-track counting method is presented on center plot on Figure 3 (A Far station taken as an example). Calculations were done for all four stations separately and independently, using all the reconstructed tracks with no additional selection. Figure 3 shows two groups of runs, separated by an interval in which there was an LHC technical stop. The calibration run is in the second group. For the second group the agreement with LUCID is at better than 1% level. The reasons of worse results for the first group are not yet fully investigated. It has been found that the detector positions with respect to the beam were different between the two groups of runs, but further checks are to be made.

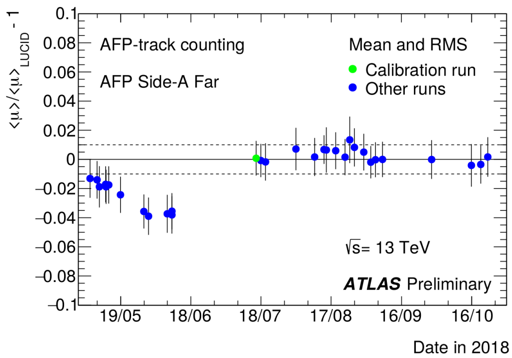

Figure 3: Luminosity calculated from 2018 AFP data. From [6].

6. Summary

AFP detectors took data in years 2016-2018 during standard and low μ runs. The 2018 data were used to calculate luminosity independently from ATLAS LUCID data.

The SiT detectors were providing expected number of hits and proton track reconstruction efficiency stayed at high level for different pile-up scenarios within AFP geometric acceptance. The studies of ToF time resolution shown that the values at around 20-26 ps per proton are achievable with the Run 2 setup.

References

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