# Backgrounds in AFP Detector Estimation

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## 1 Abstract

The ATLAS Forward Proton (AFP) [1] detectors aim to measure protons that are scattered in the ATLAS interaction point under very small angles ($90 - 160\mu rad$). The diffractive protons detected by the AFP may be accompanied by beam halo. This report presents an estimation of the beam halo backgrounds in the AFP using low pile-up data, and position distributions of the backgrounds in the AFP.

## 2 Motivation

The AFP project offers a significant extension of the ATLAS physics programme by tagging and measuring momentum and emission angles of very forward protons. This requires a detector placed very close to the beam and as such, the detector will be affected by beam halo which can make harder to study diffractive processes. The aim of this study is to find a way how to measure and suppress the halo backgrounds in the AFP. For this, we use data collected by the AFP detector during the low pile-up special run in August, 1st, 2016. A track reconstruction code and a code to read out triggers and tracks to distinguish backgrounds are used in this analysis. We use triggers based on the AFP and combined triggers with the ATLAS central detector to decide whether the event is background. This report presents an overview of the AFP detector, the way to estimate backgrounds from data and the position distributions of tracks origin from backgrounds.

## 3 Detector and Data Acquisition

The AFP proposes to install its four Roman Pot(RP) stations two on either side, denoted as the ”2+2” configuration, during the Winter 2016-2017 shutdown. As a path towards the final set-up, the AFP detectors are placed along beam line between 205 m and 217 m from the interaction point (IP) on one side early in Run2, which we call as the ”0+2” configuration. This allows performing part of the approved low-luminosity program while gaining crucial experience with and making exploratory measurements of the beam environment at higher luminosity.
The Roman Pot has been selected as the AFP beam interface with detectors placed at 205 m and 217 m from the ATLAS IP. The detector placed at 205 m is denoted as the near station, the detector placed at 217 m is denoted as the far station. AFP detector will be composed by the RP, the silicon tracker (SiT), and the time-of -flight detector (ToF). The SiT in the near station consists of 3 layers, rotated by 14 degrees around the LHC y axis. The SiT in the far station consists of 4 layers, also rotated by 14 degrees around the LHC y axis. Each layer has a sensor made of an array of $336 \times 80$ pixels of size $50\ \mu\mathrm{m} \times 250\ \mu\mathrm{m}$. The layers in each station are separated by 10 mm. Single ToF include an array of $4 \times 8$ quartz bars(in x-z plane), each of size $6\ \mathrm{mm} \times 6\ \mathrm{mm} \times 150\ \mathrm{mm}$.

The challenge of large data volumes and high trigger rates has made the Trigger and Data Acquisition (TDAQ) system a central component for generations of collider experiments. The AFP trigger system requires a first level (L1) trigger for its physics program, particularly for the process where either the backgrounds are large or the standard triggers (e.g. MBTS) are prescaled. A L1 trigger based on the HitOr from the FE-I4 chips is implemented for the AFP 0+2 configuration. The HitOr signal is formed as the logical OR of all fired pixel discriminators on the FE-I4 chip. Four FE-I4 tracker modules are located at the 205 m station, and another four modules plus a single HPTDC module for the time-of-flight digitization are in the 217 m station.
The Reconfigurable Computing Element (RCE) system is used for the readout of the AFP detectors, which shares much of the commonality for its tracking detector with the ATLAS IBL silicon tracker. The AFP High Precision

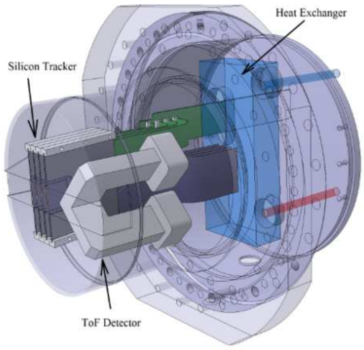

Fig 1. The model of an Roman Pot

Time-to-Digital Converter (HPTDC) chip on the 4-chip HPTDC board is interfaced with the TDAQ via an on-board Field-Programmable Gate Array (FPGA) which decodes commands and formats the HPTDC data output stream.
The data used in this analysis was taken by AFP detectors during the low pile-up special run on LHC during August, 1st, 2016.

# 4 Backgrounds Estimation

## 4.1 Signal and backgrounds kinematics

A signal in AFP detectors is represented by diffractive proton coming from the ATLAS IP. Diffractive processes exchange a strongly interacting colour-less object, so-called Pomeron. Several diffractive signatures can be distinguished, if both protons stay intact and no additional particles are produced, one deals with elastic scattering, Fig. 2(a). One or both interacting protons may not stay intact but dissociate into a higher mass, multi-particle state. Such processes are called single diffractive dissociation and double diffractive dissociation, Fig. 2(b). it is also possible to have diffractive interactions with central production of particles. Such processes are called central diffraction or double Pomeron exchange processes, Fig. 2(c). The processes that can have signals in AFP detectors are mainly single diffractive dissociation and central diffractive dissociation. These processes will have multi-particle final state, which will lead to signals in both ATLAS central detector and AFP.
A proton interacts with other proton before it being intercepted by an AFP detector. Beam halo in this sense, consists of protons/particles in the 'wings' of the beam profile distribution, and the amount of halo intercepted is strongly dependent on the distance of closest approach of the pot bottom to the circulating beam. The protons from beam halo will have signals in the AFP detectors but they wont have signals in the ATLAS central detector. This indicate a way to distinguish beam halo backgrounds from the particles detected by the AFP. An event will be identified as background if it can pass trigger in the AFP detector and cant pass triggers in the ATLAS central detector.

## 4.2 Track distributions

A particle detected by the AFP detector will create hits recorded by pixels of the the layers in silicon detectors. One hit is selected from several hits in a small region (e.g. one hit in the three hits in layer0 is selected, the other two will not be considered in the reconstruction, see Fig.3). We use a hit on the first layer (layer 0 in Fig.3) and a hit on the second layer (layer1 in Fig.3) to combine track candidate, all the combinations are track candidates, then we fit these track candidates with the hits on the remaining layers in each station using Kalman fit method [2]. If a track candidate in the near station can fit with the hits on the third layer with a result that $\chi^2 < 2$, this track candidate will be a reconstructed track. A track candidate in the far station will be a reconstructed track if it can fit with hits on either the third layer or the forth layer with a result that $\chi^2 < 2$. This requirement is not strict enough for background estimation so we have to cut on tracks. Firstly, we choose events with at least one track, and loop over the tracks in an events to choose tracks in the near station, then we consider all the combinations of the tracks in two stations and calculate the distance square between two tracks on x-y plane. The minimum distance square in a track in the near station's combinations is chosen, if the distance smaller than 2 mm, this track

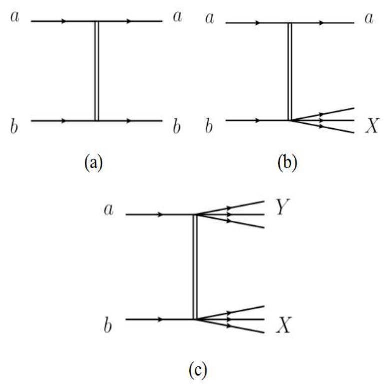


Fig 2. Feynman diagrams of diffractive processes: (a) elastic scattering, (b) single diffractive dissociation, (c) central diffractive dissociation

in the near station and the corresponding track in the far station will be selected. Track distributions are given in Fig.4, where ”2”, ”3” represent the near and far station.

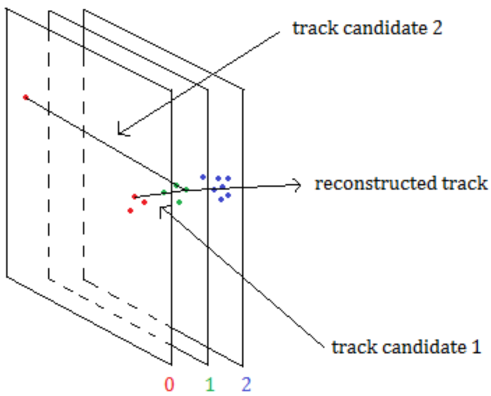


Fig 3. Reconstruction method

### 4.3 Beam halo backgrounds

The main triggers used in this analysis are L1_AFP_C_AND and L1_AFP_C_MBTS_A. L1_AFP_C_AND fires if an event has hits recorded by the AFP detector. L1_AFP_C_MBTS_A is a trigger combined the ATLAS central detector and the AFP detector. If an event can pass L1_AFP_C_AND and can't pass L1_AFP_C_ MBTS_A, it means this event has signal in the AFP detector and don't have signal in the ATLAS central detector, this is a beam halo background. However, there is a difficulty that this method can only be used on low pile-up data. In normal pile-up data, events with beam halo detected by the AFP will also have signals in the central detector.

But not all the events will cause L1_AFP_C_MBTS_A firing. We use trigger HLT_mb_sptrk_trk3_L1AFP_C_AND to estimate the fraction of diffractive protons that cant fire L1_AFP_C_MBTS_A. HLT_mb_sptrk_trk3_L1AFP_C_AND is a trigger that will be fired by three tracks with $P_T > 200MeV$ in the central detector. An event should have diffractive protons if it can pass HLT_mb_sptrk_trk3_L1AFP_C_AND and L1_AFP_C_AND, but not all of these events can pass L1_AFP_C_MBTS_A. We choose a sample with the events can pass HLT_mb_sptrk_trk3_L1AFP_C_AND and L1_AFP_C_AND. The events can't pass L1_AFP_C_MBTS_A in this sample are diffractive protons be judged as backgrounds. We count the events can pass HLT_mb_sptrk_trk3_L1AFP_C_AND and L1_AFP_C_AND, this is the number of pure signal, and count the events can't pass L1_AFP_C_MBTS_A in these events, the fraction of

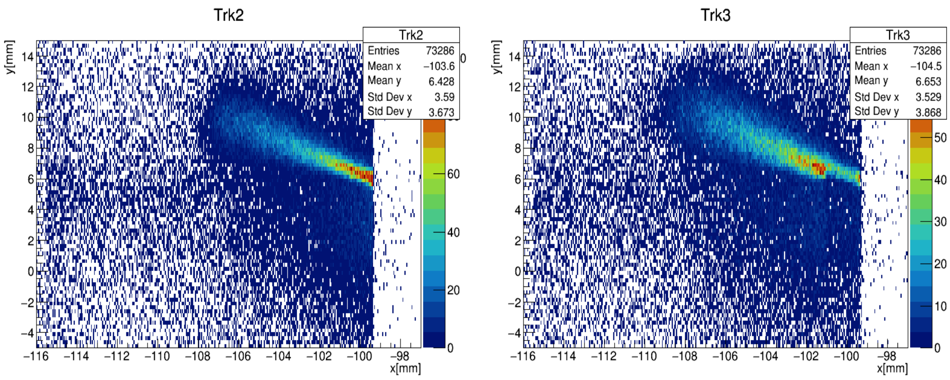


Fig 4. Track position distributions in the near station (left) and the far station (right)


Fig 5. Triggers in the ATLAS central detector and the AFP detector

diffractive protons that can't pass L1_AFP_C_MBTS_A is

$$\frac{\mathrm{N_{not\ pass\_L1\_AFP\_C\_MBTS\_A}}}{\mathrm{N_{pure\_signal}}}$$

We choose a signal sample using events can pass L1_AFP_C_AND and L1_AFP_C_MBTS_A, the background sample without correction is chosen by the events can pass L1_AFP_C_AND and can't pass L1_AFP_C_ MBTS_A.

$$\text{events pass L1\_AFP\_C\_AND} \begin{cases} \text{pass L1\_AFP\_C\_MBTS\_A} & \text{sig1 : part of sig} \\ \text{can't pass L1\_AFP\_C\_MBTS\_A} & \text{bkg1 : realbkg} + \text{sig} - \text{sig1} \end{cases}$$

The signal events mixed in the background sample are sig - sig1, it can be calculate by

$$\frac{\mathrm{N_{not\ pass\_L1\_AFP\_C\_MBTS\_A}}}{\mathrm{N_{pure\_signal}} - \mathrm{N_{not\ pass\_L1\_AFP\_C\_MBTS\_A}}}$$

The background distributions are given in Fig.6, signal distributions are given in Fig.7

# 5 Conclusion

Backgrounds distributions in the AFP detectors are achieved by an analysis of data collected by the ATLAS detector during the low pile up special run on the Large Hadron Collider during August, 1st, 2016. Fig. 8 gives the distributions of events with exactly one track, it is obvious that the distributions have similar shapes, but they are shifted about 2 mm. We know from the optics that the position of a track should be nearly the same in the two stations. The offset in our results is because the trackers' positions used in the reconstruction code don't match with the real situation. The far station is closer to the beam than the near station, $\mathrm{d_{near}}$ is about 2 mm larger than $\mathrm{d_{far}}$, as in Fig 9. But in the reconstruction program, the values of $\mathrm{d_{far}}$ and $\mathrm{d_{near}}$ are the same. It causes the tracks positions in the far station are not the real values as they are. The real values are about 2 mm smaller than the values in these distributions. The data doesn't have tracks information in the inner detector and the calorimeter.

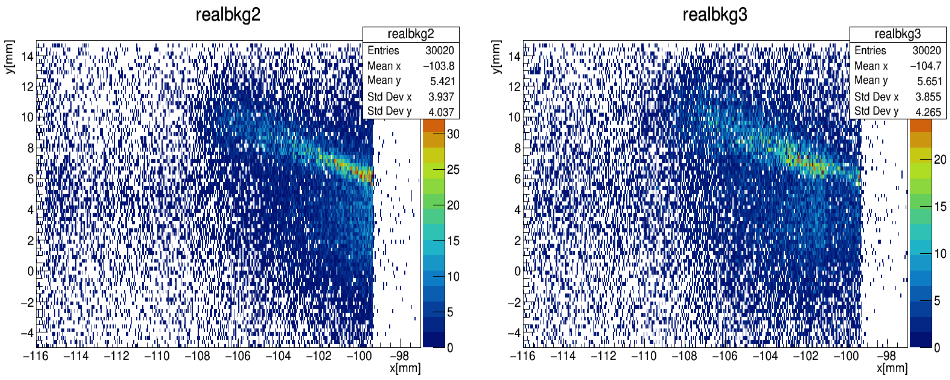


Fig 6. Backgrounds distributions in the near station (left) and the far station (right)

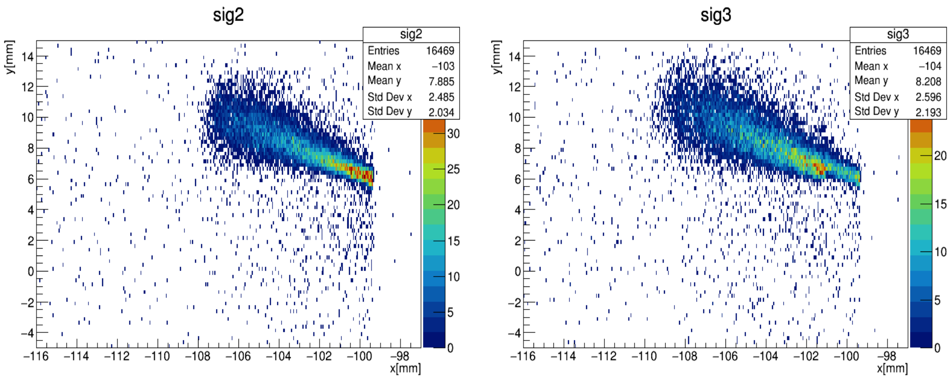


Fig 7. Signal distributions in the near station (left) and the far station (right)

We can get a purer backgrounds sample if we also require an event doesn't have signal in the inner detector and the calorimeter. The most accurate way to estimate backgrounds is to compare data with diffractive Monte Carlo samples. We use the method described in this report because of the Monte-Carlo samples are not ready for analysis. A better result could be achieved after the Monte-Carlo samples are produced.

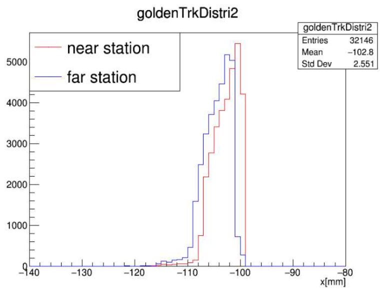


Fig 8. Distributions of events with exactly one track

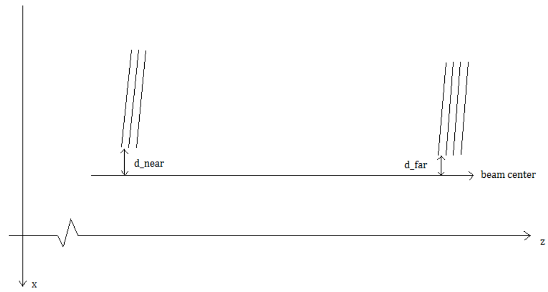


Fig 9. Station positions distribution

Reference
[1] https://cds.cern.ch/record/2017378/files/ATLAS-TDR-024.pdf
[2] https://indico.cern.ch/event/321214/contributions/744366/attachments/620295/853529/ATL-COM-FWD-2014-002.pdf