Analysis with AFP and ATLAS Detectors*

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Abstract

This paper describes the selection of Single Diffractive Jets (SD JJ) in data collected with the ATLAS Forward Protons (AFP) detectors. The method to distinguish signal events will be shown. Finally, background subtraction will be applied to reveal the presence of SD JJ in the sample.

1 Introduction

Located at the Large Hadron Collider (LHC) [2], the ATLAS experiment [4] has been designed with the goal of measuring the products of proton–proton collisions. Although its central part has a full azimuthal angle coverage and a large acceptance in pseudorapidity ($|\eta|$ <4.9), some scattered particles escape detection. This is especially unfortunate for a certain group of physics processes, in particular the diffractive physics.

Diffractive processes can be characterised by the presence of: a rapidity gap (a space in rapidity where no particles are produced) and protons scattered at very small angles. The signature is due to the nature of such interactions in which the exchanged object is a colour singlet: a Pomeron (in QCD: two gluons + h.o. terms) for the strong interactions.

Because of those characteristic observables one can think of two methods of detecting such processes. The first approach focusses on studies of the rapidity gap. It is a classical recognition method. Unfortunately, the gap may be destroyed by *e.g.* particles coming from from pile-up[1] or may be produced outside the acceptance of the ATLAS central detector. 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, it requires the additional forward detectors installed far away from the interaction point (IP). Around ATLAS IP those are: the ATLAS Forward Proton [3] system and Absolute Luminosity For ATLAS (ALFA) detectors[2].

[1]Multiple proton-proton collisions happening during the same bunch crossing. The pile-up multiplicity is indicated as μ.

[2]ALFA detectors are not topic of this note and will not be discussed further.

2 Data Sample

Single Diffractive Di-Jet[3] production (SD JJ) is characterised by the presence of two jets and forward proton as well as a rapidity gap between them. In order to prevent the gap being populated by events coming from pile-up, in this work only the periods of data taking (so-called runs) with a very small $\mu \sim 1$ were considered.

The first step of the event selection starts already during the data taking. Algorithms for very quick but crude selection are called the Level 1 (L1) triggers and are the first part of ATLAS trigger chain. After that selected events are passed to the second part called High Level Triggers (HLT). These algorithms have more time for the event selection thus tend to be more sophisticated.

In this analysis, the interest is on events with a forward proton on either side of the ATLAS detector (called A or C) and presence of at least two jets. In order to select such events the combination of triggers selecting events with jets (with minimum transverse momentum 10 or 20 GeV) and/or protons (signal in AFP detectors) were used.

3 Signal Selection

In SD JJ events it is expected to see some dependence between central system and forward proton. In order to see such relationship one can look at energy lost by proton during collision and compare it to the energy loss calculated from objects produced in the central system. Table 1 presents various possible measurements of energy losses. One can use two jets with the highest p_T, but also use response of ATLAS calorimeters (reconstructed clusters of calorimeter cells) or information from ATLAS inner detector (reconstructed tracks).

Table 1: Various definitions of energy loss. The sign in formulas indicates the side on which forward proton is produced (plus/minus is for A/C side of ATLAS). The transverse momentum of the object is denoted as p_T and its rapidity as y.

Object	Formula	Description
proton	$\xi_p^{\pm} = 1 - \frac{E_{proton}^{A/C}}{E_{beam}}$	values limited by the acceptance of AFP detectors (0.03< ξ_p <0.1)
clusters	$\xi_{cl}^{\pm} = \frac{1}{2 \cdot E_{beam}} \sum_{cl} p_T^{cl} \exp(\pm y^{cl})$	values expected to be similar to ξ_p
tracks	$\xi_{trk}^{\pm} = \frac{1}{2 \cdot E_{beam}} \sum_{trk} p_T^{trk} \exp(\pm y^{trk})$	likely to be smaller than ξ_p due to central detector acceptance ($\lvert\eta_{trk}\rvert < 2.4$)
dijet	$\xi_{dijet}^{\pm} = \exp(\pm y_{dijet}) M_{dijet} \frac{1}{2E_{beam}}$	anticipated to be smaller than ξ_p since only part of central system is taken

Selected samples contain both signal and background events (see the next section). In order to reduce the background-to-signal ratio, a few selection steps were done during this analysis. First, a very effective cut is selection of events having only one primary vertex reconstructed without any additional vertices. This significantly reduces the pile-up events. Due to the nature of the studied process, it is justified to look at the events containing exactly two jets and one reconstructed proton.

[3]Commonly di-jet is defined as two jets comming from the same vertex.

At this point in analysis the question appears if the objects used for the event selection are of good quality, *i.e.* if they are true objects and not *e.g.* noise. The presented results are based on jets, protons and clusters. The selection listed in Table 2 was used to satisfy "good" quality conditions. The cuts on quality of jets and protons influence the number of events whereas the cut on clusters only affects the distribution of ξ_{cl}. After all cuts discussed in this section, the selected events will be referred to as the "signal" sample.

Table 2: Selection applied on jets, clusters and protons.

Object	**Selection criteria**
Proton	$0.02 < \xi_p < 0.2$
Jet	being calibrated, come from the primary vertex, have p_T^{jet} >20 GeV, |timing| <12.5 ns and $\|\eta^{jet}\| < 2.4$
Cluster	p_T^{cl} >200 MeV, $\|\eta^{cl}\| < 4.8$, |timing| <12.5 ns and the most significant sampling (*i.e.* the one with the largest energy) must have $\sigma_{samplings} > 3$

4 Background Subtraction

As it was mentioned before, some dependence between the central system and the forward proton is expected. Such relationship was seen in the correlation between $\log_{10}(\xi_{cl})$ and proton x-position in a very low-μ 2016 data [1]. Therefore, it is expected to see similar dependence in studied 2017 low-μ data.

On Figure 1 (left) one can see the above-mentioned correlation from the "signal" sample. The $\log_{10}(\xi_{cl})$ is on the X axis and the forward proton x position is on the Y axis[4]. If the plotted events contain only SD JJ production the clear correlation would be visible. However, the "signal" sample is still dominated by the background.

The main background for SD JJ events comes from the Non-Diffractive jets (ND JJ). The sample containing "background" events was prepared by using random events containing two jets. There were no requirement on forward proton. Of course, it is possible to see SD JJ events with this crude selection but such an addition is negligible due to differences in cross-section.

The distributions of $\log_{10}(\xi_{cl})$ for the "signal" events (red dots, bottom plot) and "background" (black dots, bottom plot) samples are shown on the right bottom plot on Figure 1. The distributions were normalized to the integral of a 20 of last bins. It is visible that the both plots match very well for the larger ξ_{cl} values and AFP events (red) have more events in the smaller ξ_{cl} range. These additional events are expected to be the signal.

In the next step, the two plots were subtracted and the Gaussian function was fitted to it (Figure 1, right top). In addition, these events were divided according to the range of protons x position and for each considered range the Gaussian was fitted to subtracted plots. Then the mean values were drawn on the distribution 1 (red dots, left plot) and the linear function was fitted to them. It is visible that the mean values of the fits are moving from smaller values of ξ towards larger ones. This proves that there is a correlation between the central system and the forward proton, previously not visible due to background dominating the sample.

[4]For simplicity only events with proton on side C were shown.

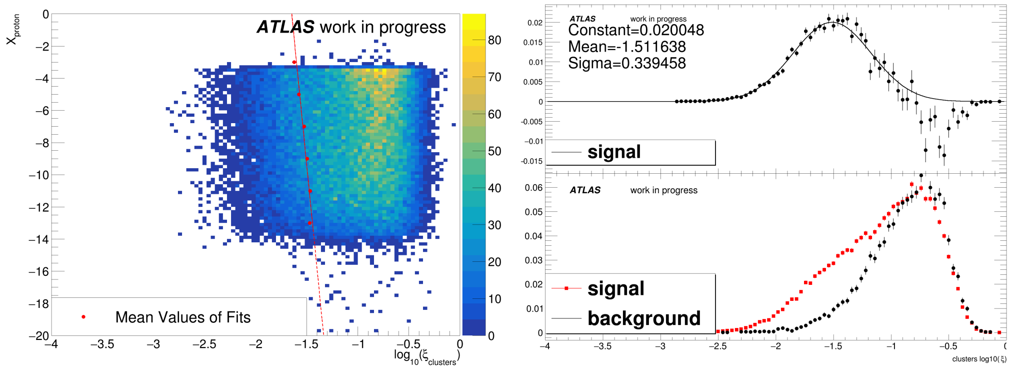

Figure 1: **Left:** correlation between $\log_{10}(\xi_{cl})$ and proton x-position. **Right:** distributions of $\log_{10}(\xi_{cl})$ for all selected "signal" events (red dots, bottom plot) and "background" events (black dots, bottom plot). Their difference (top plot) is plotted with fitted Gaussian function.

5 Summary

The analysis was done using 2017 low-μ data. The SD JJ events were selected using AFP+jet triggers with additional requirements on jets and protons and ensuring the good quality of studied objects. After such selection (described in Section 3), the background was still dominating the sample and no correlation between the central system and the forward proton was visible at first glance.

In the next step the "background" was identified by using random events without a requirement of forward proton but still requiring the presents of two jets. The "signal" events were then compared to the background distribution showing significant differences in the lower ξ_{cl} regions. The Gaussian fit to the subtracted distributions of signal and background events with different proton X_p position was calculated. This proves that there is a correlation between $\log_{10}(\xi_{cl})$ and proton x-position, however not visible due to large background.

Acknowledgements

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References

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