

EXCLUSIVE JET MEASUREMENT IN SPECIAL LHC RUNS — FEASIBILITY STUDIES* **

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Feasibility studies of the central exclusive jet production at the LHC using the proton tagging technique are presented. Three classes of the data-taking scenarios are considered: double tag at high and low pile-ups and single tag at low pile-up. Analyses were performed at the center-of-mass energy of 14 TeV for the ATLAS experiment, but are also valid for the CMS/TOTEM detectors.

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1. Introduction

The central exclusive jet events constitute a special class among diffractive jet productions. In such events, both scattered protons stay intact and all the energy lost by them is used to produce central system, see figure 1. Hence, the kinematic properties of the scattered protons are connected to those of the produced central system.

There are several theoretical descriptions of the exclusive jet production mechanisms. Here, the model of Khoze–Martin–Ryskin (KMR) [1] is used. In the KMR model, a perturbative approach is applied — the colourless exchange is represented by an exchange of two gluons: a hard and a soft one. The role of the soft gluon is to provide the colour screening that ensures that no net colour charge is exchanged between the two interacting protons.

In order to perform a fully exclusive measurement, both the jets and the intact protons have to be measured. The requirement of both protons being tagged often implies the production of a large amount of energy in the central region. In consequence, the cross section is significantly reduced and a

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large amount of data needs to be collected (high pile-up environment). Such a measurement was shown to be feasible [2] and will be discussed in detail in the next section. Since fully exclusive measurement in a high pile-up environment is very challenging, in [3], a semi-exclusive approach was proposed and shown to be feasible. Finally, for the first time, a low-luminosity measurement with both protons tagged is discussed in this publication.

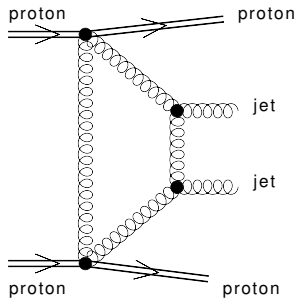


Fig. 1. Central exclusive jet production: both interacting protons stay intact and two jets are produced.

2. Experimental environment

The two-jet exclusive production can be characterised by the presence of two jets in the central rapidity region and two scattered protons. The jets are assumed to be measurable by the ATLAS central detector [4], whereas the protons need to be tagged in forward detectors. At present, ATLAS is equipped with two sets of such apparatus: ALFA [5] and AFP [6].

Diffractive protons are scattered at very low angles. Therefore, the proton detectors are located far away from the Interaction Point (IP): 205 and 217 m in the case of the AFP, and 237 and 245 m in the case of the ALFA detectors. Moreover, the proton trajectory between the IP and the location of the forward detector is not a straight line. This is due to the presence of the LHC magnets. The settings of these magnets, commonly called *machine optics*, play a key role in the exclusive analysis. In the simplest possible way, these settings could be characterized by the value of the betatron function at the IP, β^* . The studies presented in this paper focus on two such settings: $\beta^* = 0.55$ m and $\beta^* = 90$ m. The detailed description of the properties of these optics sets can be found in [7], whereas the justification of the choice is given in [3].

3. High luminosity, double tagged measurement

Feasibility studies of the exclusive jet production with forward proton tagging were performed for the ATLAS experiment, AFP detectors and $\beta^* = 0.55$ m optics [2]. They were followed by similar ones done by

CMS/TOTEM [8]. Owing to the limited acceptance, the lowest jet p_T was of about 150 GeV. This requires using high integrated luminosity which can be achieved in a high pile-up environment characterised by the average number of pp interactions per bunch crossing μ . In the analysis, two scenarios were considered: $\mu = 23$ with integrated luminosity $L = 40 \text{ fb}^{-1}$ and $\mu = 46$ with $L = 300 \text{ fb}^{-1}$. After the selection, the signal-to-background ratio was found to be 0.57 (0.16) for $\mu = 23$ (46).

For both considered scenarios, the statistical errors were found to be small. The largest systematic uncertainty was associated with modelling of the combinatorial background from non-diffractive dijet events overlapped with two protons coming from the pile-up events.

4. Low luminosity, single tagged measurement

The drawback of the studies described above is the need of collecting the data in a harsh, high pile-up environment. To address this issue, it was proposed to perform a measurement in a semi-exclusive mode, when only one of the scattered protons is tagged [3]. This allowed jets with smaller p_T values to be within the acceptance.

In the analysis, performed for $\sqrt{s} = 14 \text{ TeV}$, the following four data-taking scenarios were considered: the AFP and ALFA detectors as forward proton taggers and $\beta^* = 0.55 \text{ m}$, $\beta^* = 90 \text{ m}$ optics. After the signal selection, the signal-to-background ratio was found to vary between 5 and 10 000, depending on the considered running scenario. Moreover, it was shown that a significant measurement can be carried out for the data collection period of about 100 hours with pile-up multiplicity of $\mu \sim 1$.

5. Low luminosity, double tagged measurement

To complete the studies described above, the double tagged, low- p_T exclusive jet measurement is discussed. It can be carried out using the ALFA detectors and $\beta^* = 90 \text{ m}$ optics.

5.1. Monte Carlo generators and event reconstruction

Exclusive jets were generated accordingly to the KMR model [1] using FPMC [9]. This event generator is a modification of Herwig 6.5 [10] and uses its final state parton showering and hadronisation algorithms.

Diffractive jet backgrounds (double Pomeron exchange (DPE) and single diffractive (SD)) were also generated using FPMC, assuming the rapidity gap survival factor of 0.03 and 0.1, respectively [11]. The generation was based

on the resolved Pomeron model [12] and H1 2007 Fit B [13]. The multiparton interactions option was turned off. The non-diffractive (ND) jets and minimum-bias events were generated using PYTHIA 8 [14].

The jets were reconstructed using the anti- k_T algorithm implemented in the FastJet package [15] with the jet radius $R = 0.6$. The scattered protons were transported to the location of the considered forward detector by the FPTrack program [16]. The proton energy was reconstructed using the procedure described in [17].

5.2. Signal selection

Owing to the ATLAS jet reconstruction performance, the minimal jet transverse momentum was required to be greater than 20 GeV. An event was accepted when it contained at least two reconstructed jets and two protons detected in ALFA stations. The distance between the beam centre and the detector active area was set to 6.9 mm, which corresponds to 10 nominal beam widths plus 0.3 mm of the detector dead material.

The $\beta^* = 90$ m optics was designed to enhance the acceptance for the pp elastic scattering. Such events overlaid with non-exclusive jets will contribute as a background and need to be removed. This can be done using the elastic scattering properties. The transverse momenta of the elastically scattered protons are expected to have exactly the same value but the opposite direction. In the ALFA detector, such events are expected to have the top-bottom and left-right symmetry. Therefore, as is shown in Fig. 2, the background can be efficiently removed by requiring $|y_A^{\text{ALFA}} + y_C^{\text{ALFA}}| < 1.5$ mm, where A and C stand for the left or right side of the IP, respectively.

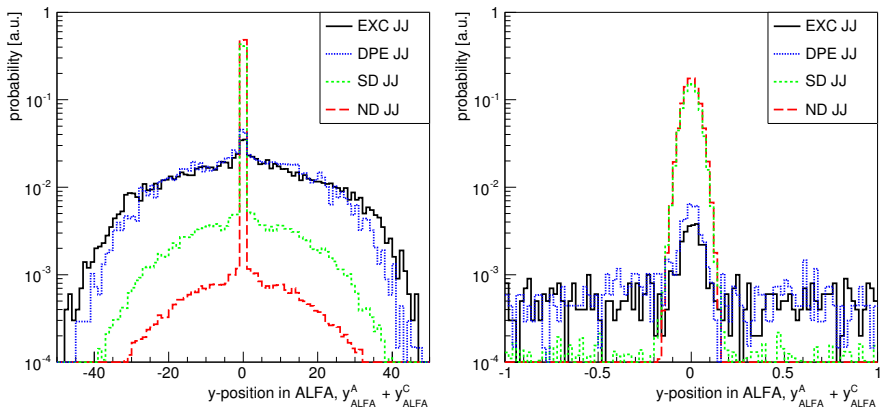


Fig. 2. Difference between y -position in ALFA stations. The peak around zero is mainly due to the jets produced together with protons scattered elastically.

To further reduce the background, exactly one vertex reconstructed in the central detector was required. Next, the energy of the scattered proton was correlated to that of the reconstructed jet system. Finally, the exclusivity criteria, such as the number of tracks reconstructed outside the jet system and the energy detected in the forward calorimeter were considered. All the above mentioned requirements were applied similarly to the procedure described in [3].

5.3. Results

The signal purity, defined as the ratio of the signal (S) to the sum of the signal and background ($S + B$) events passing the selection, is shown in Fig. 3 (left). A pure signal (purity above 90%) is expected for all considered pile-up conditions ($0.01 < \mu < 2$). The measurement quality is expressed in terms of the statistical significance, $\frac{S}{\sqrt{S+B}}$. Its distribution, after a given selection cut as a function of the pile-up, is presented in Fig. 3. The maximal significance is obtained for the pile-up of about 1. A slow decrease for $\mu < 1$ is due to the amount of data that could be collected during the fixed time, whereas the decrease for $\mu > 1$ is the consequence of the single vertex requirement.

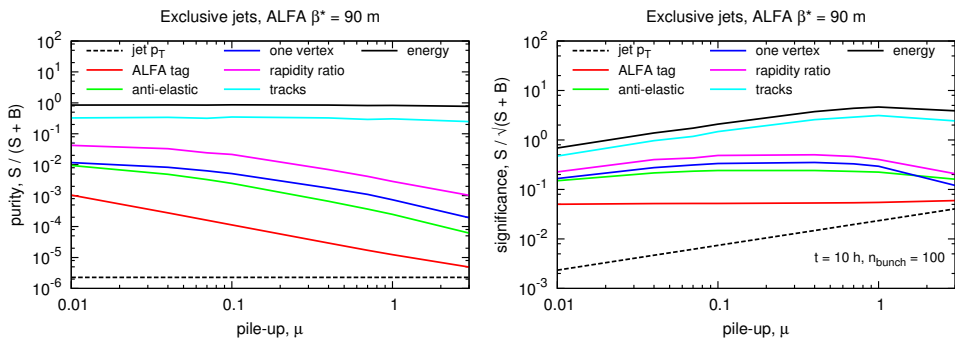


Fig. 3. Purity (left) and statistical significance (right) after a given selection as a function of pile-up.

6. Summary

Measurement of double tagged high p_T exclusive jets will be possible using the ATLAS/AFP detectors. It will be very challenging, but after the event selection, the signal-to-background ratio of 0.57 (0.16) for $\mu = 23$ (46) can be achieved.

The semi-exclusive measurement in which only one scattered proton is tagged was performed for four data-taking scenarios: the AFP and ALFA detectors and $\beta^* = 0.55$ m, $\beta^* = 90$ m optics. After the signal selection,

the signal-to-background ratio was found to range from 5 to 10^4 , depending on the considered run scenario. The significant measurement can be carried out for the data collection period of about 100 h with pile-up of about 1.

Finally, the double tagged exclusive measurement of low- p_T jets was shown to be feasible using the ALFA detectors for $\beta^* = 90$ m optics. A pure ($> 90\%$) and statistically significant signal is expected for all considered pile-up conditions ($0.01 < \mu < 2$).

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