PROCEEDINGS OF SCIENCE

Exclusive Pion Pair Production at $\sqrt{s} = 7$ TeV

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The exclusive pion pair production cross-section in diffractive proton-proton collisions ($pp \rightarrow p\pi^+\pi^- p$) was measured during the special low luminosity LHC runs at $\sqrt{s} = 7$ TeV with dedicated $\beta^* = 90$ m LHC optics. Pion pairs were detected by the ATLAS Inner Detector whereas the outgoing protons were measured by ALFA (Absolute Luminosity For ATLAS) detector situated on both sides of ATLAS forward region ~240 m from the ATLAS Interaction Point (IP). An overview of the analysis results is presented as well as a comparison of obtained measurements with relevant model predictions.

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1. Introduction

Processes of central exclusive production have gained a lot of interest in the recent years. Although nowadays the attention is paid mainly to the high-p_T processes that can be used for a new physics searches (like $\gamma\gamma$ interactions), the measurements of low-pT signals are also very important as they can help to constrain models and to understand the backgrounds for the high-p_T ones. One of such low-p_T processes is the exclusive pion pair production: $pp \to p\pi^+\pi^-p$ [1], which was measured by the ATLAS Collaboration using 80 μb^{-1} of low-luminosity data collected at $\sqrt{s}$ = 7 TeV [2]. The pion pairs were detected in the ATLAS central detector [3] while the outgoing protons were measured in the Absolute Luminosity For ATLAS (ALFA) detector system [4].

The analysis combined information from the ATLAS Inner Detector (ID) [5], the Minimum-Bias Trigger Scintillators (MBTS) [6] and the ALFA detector system. ATLAS inner detector closely surrounds the ATLAS interaction point (IP) and covers a pseudorapidity range of $|\eta| < 2.5$. MBTS is located on both sides of ATLAS between the ID and the Liquid Argon calorimeter at ±3.6 m from the IP. It covers the range of $2.1 < |\eta| < 3.8$. The ALFA detector system is located at ±240 m from ATLAS IP and consists of four Roman pot stations, containing vertically movable detectors that can approach the outgoing beams to about one millimetre. Each station is equipped with two Roman pots, each of which hosts a nearly edgeless tracking detector composed of scintillating fibres. The spatial resolution is of about 32 μm [4].

Due to the exclusivity of the process, *i.e.* the possibility to measure all final state particles, and the acceptance of the ALFA detectors, two topological configurations were considered. Elastic-like configuration happens if proton is measured in both upper(lower) stations on one side and both lower(upper) detectors on the other. Anti-elastic configuration occur if protons are tagged in all lower(upper) pots.

2. Monte Carlo and Data Samples

Two Monte Carlo (MC) signal generators, GenEx [7] and Dime [8], were used. The former for the baseline calculations of detection and reconstruction efficiency for the events and for corrections to the data. The latter for comparison and to estimate model uncertainties. Background processes (soft central diffraction) were generated by Pythia 8 [9] using the special ATLAS tune [10] and the MSTW2008lo PDF set [11].

The data were recorded at $\sqrt{s}$ = 7 TeV during a special run with β^* = 90 m optics [12] and very low pile-up, $\mu = 0.035$. The integrated delivered luminosity was $L_{int} = 78.7 \pm 0.1$ (stat) ±1.9 (syst) μb^{-1}.

3. Data Analysis

The signal topology is: two oppositely charged pions detected by the ATLAS ID and two outgoing protons measured by ALFA. Therefore, the following even selection was applied. First, the data must come from the single colliding proton bunches. Then, a trigger based on a signal in ALFA (coincidence between all four, relevant, detectors) was required. For the elastic-like events the trigger efficiency was measured to be (99.96 ± 0.10)%, while for the anti-elastic topology it was (99.02 ± 0.25)%. It should be noted that anti-elastic triggers were prescaled by a factor of 15.

Pions were defined as charged tracks reconstructed in the ATLAS ID. A special, low-p_T tracking algorithm [13] allowed to reconstruct particles with the transverse momentum $p_T > 100$ MeV. For further analysis only events with exactly two tracks having opposite-sign charges and originating from a common vertex were accepted. Due to exclusivity of the process, such events must not have any activity in the MBTS. In addition, a dedicated quality criteria were required (see Ref. [2]).

Special quality criteria were also applied for protons reconstructed in ALFA [2]. On top of that, an overall momentum balance was required. *I.e.* the transverse momentum components of the full $p\pi^+\pi^- p$ system were required to be smaller than $3.5\sigma_{x,y}$, where the resolution is approximately 60 and 20 MeV in p_x and p_y, respectively.

Application of the above selection criteria resulted in 28(3) events in the elastic-like(anti-elastic) configuration from 6 620 953 recorded ones.

It should be noted that the applied data-selection strongly suppresses the background. This can be judged from Fig. 1. On the left figure a situation after all final quality selections except "exclusivity criteria" (MBTS veto and momentum balance) were applied. After adding them (right figure), the expected background contribution is significantly lower than signal.

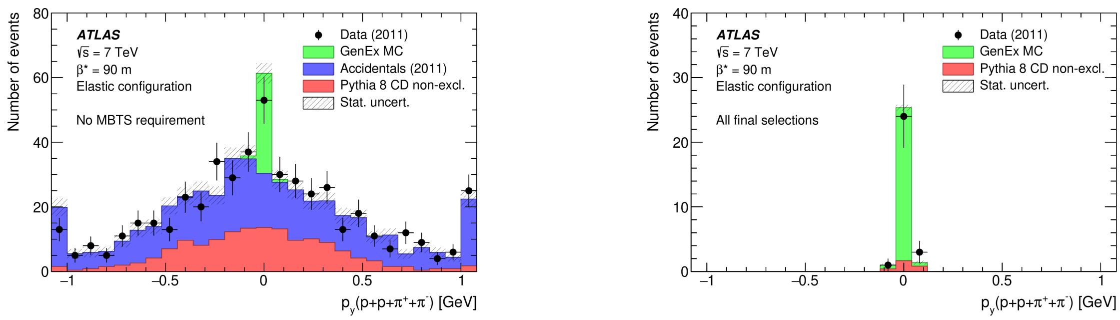

Figure 1: The summed p_y-momentum values after the pion and proton quality selection; without (**left**) and with (**right**) MBTS veto and momentum balance selection. From Ref. [2].

The overall systematic uncertainty on the exclusive pion-pair cross-section measurement was estimated to be $^{+6.4}_{-4.2}$% for the elastic-like and $^{+6.0}_{-4.4}$% for the anti-elastic configuration. The main sources of systematic uncertainties are: thickens of ID material (+4.8%/+4.1% for elastic/anti-elastic) and background determination (±3.5%). The latter one was obtained by change of the momentum balance selection criteria from 3.5 to $5\sigma_{x,y}$.

To complete, the statistical uncertainty was determined to be ±21.2% and ±61.6% for the elastic and anti-elastic signatures, respectively. The theoretical modelling, taking into account differences between GenEx and Dime, was ±2.8 and ±8.0%. Finally, the luminosity uncertainty was measured to be ±1.2%.

4. Summary

The cross-section for the exclusive pion pair production was measured to be:

- 4.8 ± 1.0 (stat) $^{+0.3}_{-0.2}$ (syst) ±0.1 (lumi) ±0.1 (model) μb for the elastic-like configuration,

- 9 ± 6 (stat) $^{+1}_{-1}$ (syst) ±1 (lumi) ±1 (model) μb for the anti-elastic configuration.

The results may be compared to the cross-sections provided by MC generators using the same fiducial region: 1.5(2) and 2(3) μb for elastic-like(anti-elastic) configuration and GenEx and Dime, correspondingly.

Finally, it is interesting to see the kinematic distributions of pion pair: rapidity (Fig. 2 left), acoplanarity (Fig. 2 right), transverse momentum (Fig. 3 left) and invariant mass (Fig. 3 right). The distributions are presented after applying all the event selections, except the background subtraction (≈ 10%). In the view of the low number of events for the anti-elastic configuration, only distributions for the elastic one are shown.

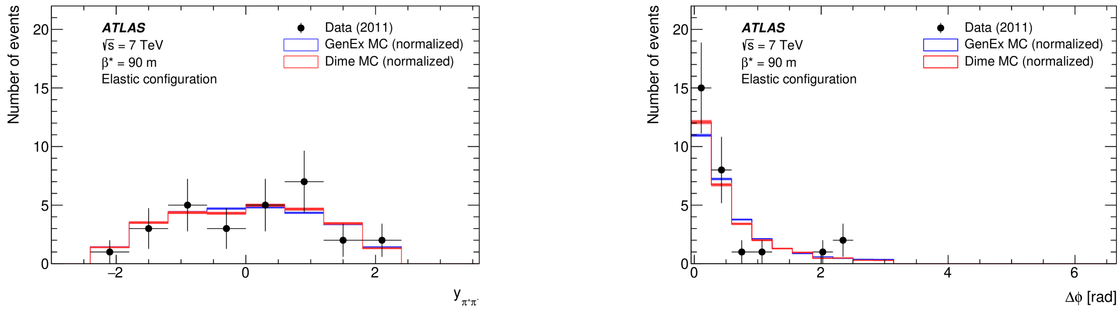

Figure 2: Distributions of pion-pair rapidity (**left**) and acoplanarity (**right**) for the data, GenEx MC and Dime MC after applying all event selections except background subtraction applied to the data. MC samples are normalized to the data. From Ref. [2].

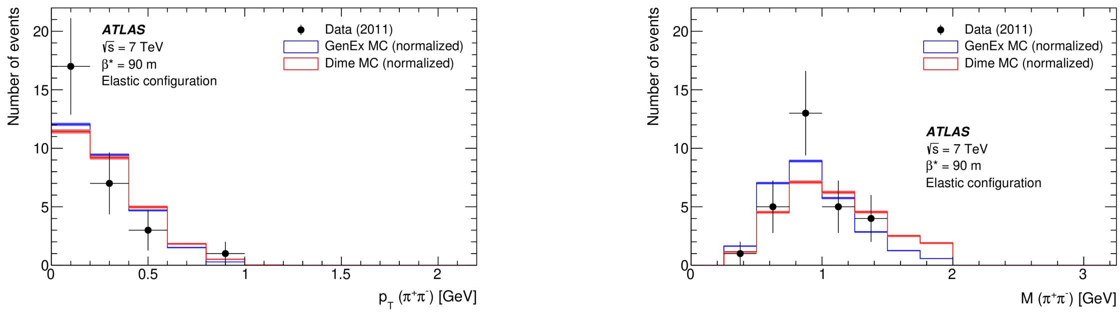

Figure 3: Distributions of pion-pair transverse momentum (**left**) and invariant mass (**right**) for the data, GenEx MC and Dime MC after applying all event selections except background subtraction applied to the data. MC samples are normalized to the data. From Ref. [2].

This measurement of exclusive pion pair production clearly demonstrates the potential to measure the exclusive hadronic processes using the forward sub-detectors in combination with the ATLAS central detector.

Acknowledgements

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