PROCEEDINGS OF SCIENCE

Measurements of single diffraction using the ALFA forward spectrometer at ATLAS

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Proton-proton collision data with low pile-up at a centre-of-mass energy $\sqrt{s} = 8$ TeV at the Large Hadron Collider with an integrated luminosity of 1.67 nb^{1} were collected by the ATLAS Collaboration and used to study inclusive single diffractive dissociation, pp $\rightarrow$ Xp. The intact forward-going proton is measured in the ALFA spectrometer, while charged particles from the dissociated system X are measured in the central ATLAS detector components. Cross sections are measured as functions of the proton fractional energy loss ξ, the squared four momentum transfer t, and the size of the visible part of the rapidity gap between the proton and the system X. The results are interpreted in the framework of Regge phenomenology.

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1. Introduction

Single Diffraction (SD) process in proton-proton (pp) collisions, $pp \to pX$ (Fig. 1 left), is characterized by an intact proton which is deflected under a very small angle with respect to the incoming proton, accompanied by a large rapidity gap, a region devoid of hadronic activity, and a central system X, originating from dissociation of the other proton. In this analysis of the LHC data collected by the ATLAS experiment [1], signal events are selected relying on tagging the intact proton in the ALFA spectrometer [2] on either side. A non-negligible background comes from processes where both protons stay intact (Central Diffraction (CD), Fig. 1 right). When overlaid with a proton from an unrelated event, Double Diffractive (DD) (Fig. 1 middle) and Non-Diffractive (ND) processes have to be considered as well. All details of this analysis can be found in Ref. [3].

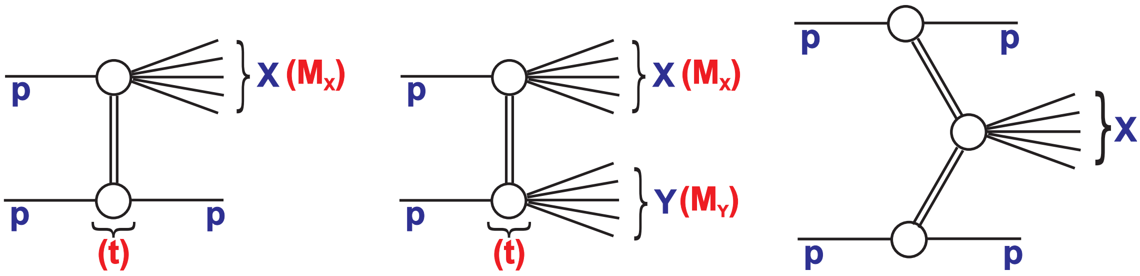

Figure 1: Schematic illustrations of (left) single-diffractive dissociation (SD), (middle) double-diffractive dissociation (DD) and (right) central diffraction (CD) and the kinematic variables used to describe them.

2. Data and MC samples

ATLAS is a multi-purpose apparatus covering almost the entire solid angle around its LHC collision point [1]. This measurement makes use of the sensitivity of the inner tracking detector (ID) and the minimum bias trigger scintillators (MBTS) to the components of the dissociating system X, and of the ALFA forward proton spectrometer to measure properties of the intact forward protons. The sample used in this analysis was taken during a special run in July 2012 where the luminosity was kept very low, such that the mean number of inelastic interactions per bunch crossing ('pile-up') is smaller than 0.08, allowing rapidity gaps to be identified and suppressing random coincidences between protons in ALFA and unrelated activity in the central detector.

Monte Carlo (MC) simulations are used for the modelling of background, unfolding of instrumental effects and comparisons of models with the hadron level cross section measurements. The Pythia 8 [4] generator is used to produce the main SD, DD, CD and ND samples. The SD, DD and CD models in Pythia 8 are based on Pomeron exchange in the 'triple Regge' [5] formalism. By default, the A3 tune [6] is used, which adopts the Donnachie-Landshoff (DL) [7] choice for the Pomeron flux factor to describe the ξ and t dependences in the diffractive channels. An alternative SD sample is produced using the A2 tune [8] and the Schuler-Sjöstrand (SS) model for the Pomeron flux factor [4]. The impact of uncertainties in the hadronisation properties of the dissociation system X is evaluated by comparison of Pythia 8 with the cluster-based approach in the Herwig 7 model [9, 10] (version 7.1.3 is used).

3. Event selection and kinematic variables

Events are required to have at least one good quality charged particle track reconstructed in the ID as well as a reconstructed primary vertex. The selection applied for the good quality tracks follows the criteria established in Ref. [11] and requires $|\eta| < 2.5$ and $p_T > 200$ MeV. The selection of proton tracks in ALFA is described in detail in Ref. [3].

The cross section measurement is performed differentially in t, which is determined from the square of the scattered proton transverse momentum, as reconstructed using ALFA. The cross section is also measured differentially in $\Delta\eta$, the size of the region in which no primary charged particles are produced with p_T >200 MeV, starting at $|\eta| = 2.5$ on the same side of the interaction point as the proton tag and extending towards the X system. The measurement is also performed as a function of ξ, determined via $\xi = M_X^2/s$ by using the charged particles reconstructed in the ID to obtain the mass of the diffractive system X, M_X. The variable ξ can also be reconstructed using the proton in ALFA via $\xi = 1 - E'_p/E_p$, where E'_p and E_p are the scattered proton energy and the beam energy, respectively. ALFA provides a powerful means of cross-checking the ID-based measurement with very different background contributions, unfolding characteristics and other systematics. After the background contributions are subtracted and the trigger and ALFA efficiencies are accounted for, the data are corrected for migrations between bins and across the fiducial boundaries of the measurement using an iterative Bayesian unfolding algorithm [12] based on the SD MC sample.

4. Backgrounds

Background in the analysis arises from non-SD pp collision processes leading to correlated signals in ALFA and the ID ('single source'), as well as from coincidences of a signal in ALFA with an uncorrelated signal in the ID ('overlay background'). The single source contribution is dominated by the CD process, which produces forward-going protons and activity in the ID. It is estimated using the MC simulation, reweighted through the comparison with data in the control sample described in Ref. [3]. The ND and DD single source contributions are negligible. In the overlay background, the signal in the central detector almost always arises from a ND, DD or SD process, whilst the ALFA signal may occur due to 'pile-up' from real forward-going protons in elastic scattering or CD process, showering in DD or ND events or from beam induced sources (dominantly beam halo). The overlay background is modelled using a data-driven technique which is described in Ref. [3]. After applying all selection cuts in the fiducial region, the overlay and CD background forms 25%, resp. 8.5% of the measured cross section. In Fig. 2 data are compared with the sum of the overlay background and the Pythia 8 A3 tune predictions for SD, DD, CD and ND processes. To match the data normalization, the SD contribution was scaled by 0.64.

5. Results

The unfolded SD cross sections correspond to the fiducial region $-4.0 < \log_{10}\xi < -1.6$ and $0.016 < |t| < 0.43$ GeV^2. The cross section differential in $\Delta\eta$ is shown in Fig. 3 (left). For gap sizes between around 1.5 and 3.5, the differential cross section exhibits the plateau that is characteristic

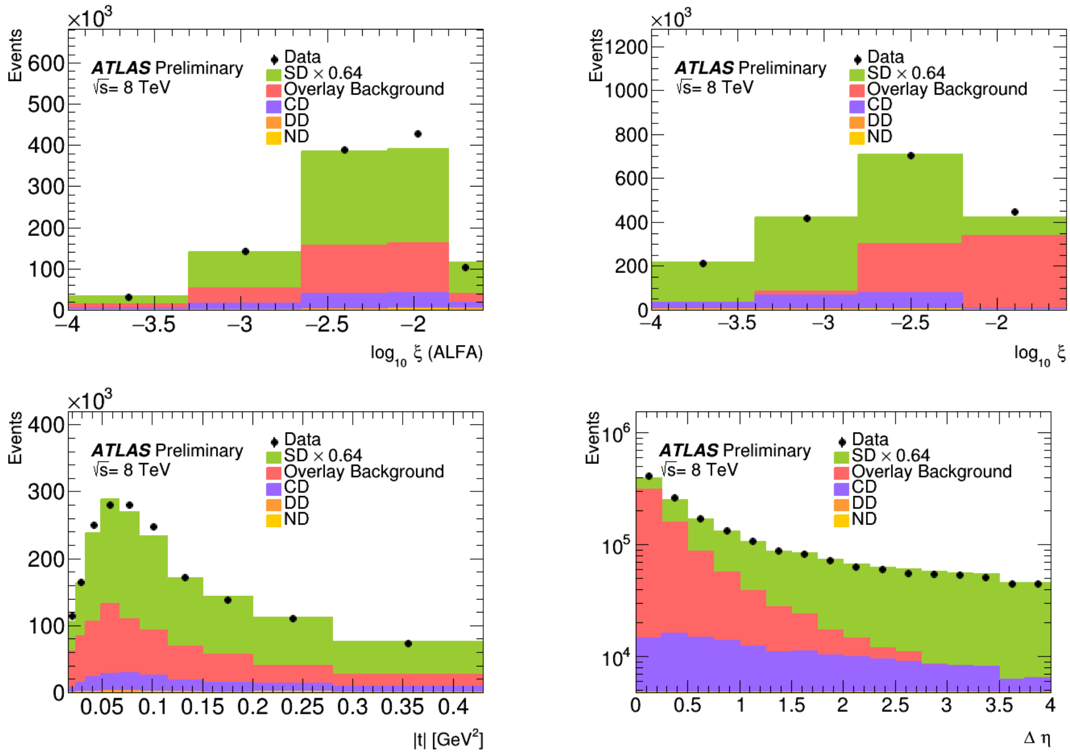

Figure 2: Uncorrected distributions of $\log_{10}\xi$ measured in ALFA (top left), $\log_{10}\xi$ measured in the ID (top right), $|t|$ (bottom left) and $\Delta\eta$ (bottom right). In all distributions, data are compared with the sum of the overlay background and the Pythia 8 A3 tune predictions for SD, DD, CD and ND processes with the SD contribution scaled by 0.64 [3].

of rapidity gap distributions in soft diffractive processes. The data are compared with the SD process simulations in the A2 and A3 tunes of Pythia 8 and with HERWIG 7, which exceed the data normalization by factors of 2.3, 1.5 and 3.0, respectively.

The cross section is shown differentially in $|t|$ in Fig. 3 (right). The differential cross section is fitted using $d\sigma/dt \approx e^{Bt}$, which is overlaid on the figure. The quality of the fit is acceptable ($\chi^2 = 8.1$ with 8 degrees of freedom, considering statistical uncertainties only). The result is $B = 7.60 \pm 0.23(\text{stat.}) \pm 0.22(\text{syst.})$ GeV^{-2} and is broadly as expected from extrapolations of lower energy measurements. It is compatible with the predictions of 7.10 GeV^{-2} from the DL flux and 7.82 GeV^{-2} from SS, contained in the Pythia 8 A3 and A2 tunes, at the 1.6 σ and 0.7 σ levels, respectively.

In Fig. 4, the cross section is shown differentially in $\log_{10}\xi$, as obtained from the charged particles reconstructed in the ID. Fully compatible results are obtained when reconstructing ξ using ALFA. The data are compatible with being flat in this variable, characteristic of the expected behaviour of the cross section roughly as $d\sigma/d\xi \approx 1/\xi$. By using the Regge framework and integrating over the fiducial t range of the measurement between $t_{\text{low}} = -0.43$ GeV^2 and $t_{\text{high}} = -0.016$ GeV^2 yields a prediction for the single differential cross section

$$\frac{d\sigma}{d\xi} \approx \left(\frac{1}{\xi}\right)^{\alpha(0)-1} \frac{e^{Bt_{\text{high}}} - e^{Bt_{\text{low}}}}{B}, \tag{5.1}$$

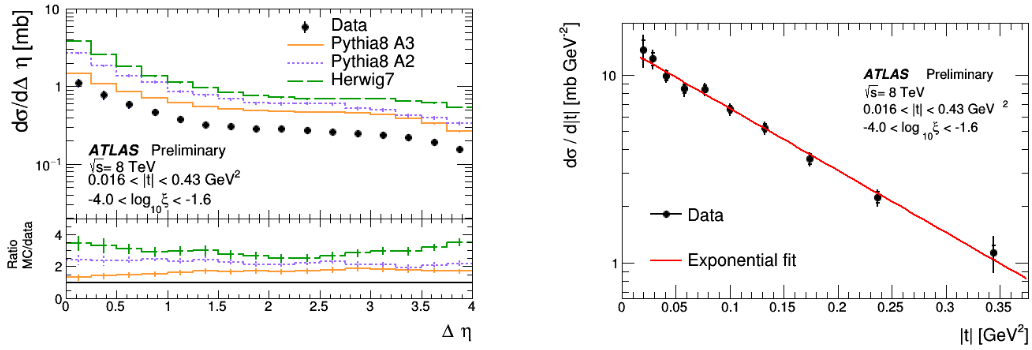

Figure 3: (left) Corrected differential cross section as a function of $\Delta\eta$, comparing the measured data with Pythia 8 and Herwig 7 predictions. The error bars display the combination of statistical and systematic uncertainties in quadrature. (right) Corrected differential cross section as a function of $|t|$ with inner error bars representing statistical uncertainties and outer error bars displaying the statistical and systematic uncertainties added in quadrature. The result of the exponential fit described in the text is overlaid [3].

where the t dependence of the Pomeron trajectory has been absorbed into $B = B_0 - 2\alpha' \ln \xi$ (B_0 characterizes the spatial size of proton and $\alpha' = 0.25$ GeV^2 corresponds to the slope of Pomeron trajectory in the DL model). A fit of the form of equation 5.1 is applied to the measured ξ distribution with $\alpha(0)$ and the overall normalisation as free parameters. This fit, displayed in Fig. 4 (left), yields a value of $\alpha(0) = 1.07 \pm 0.02(\text{stat.}) \pm 0.06(\text{syst.}) \pm 0.06(\alpha')$.

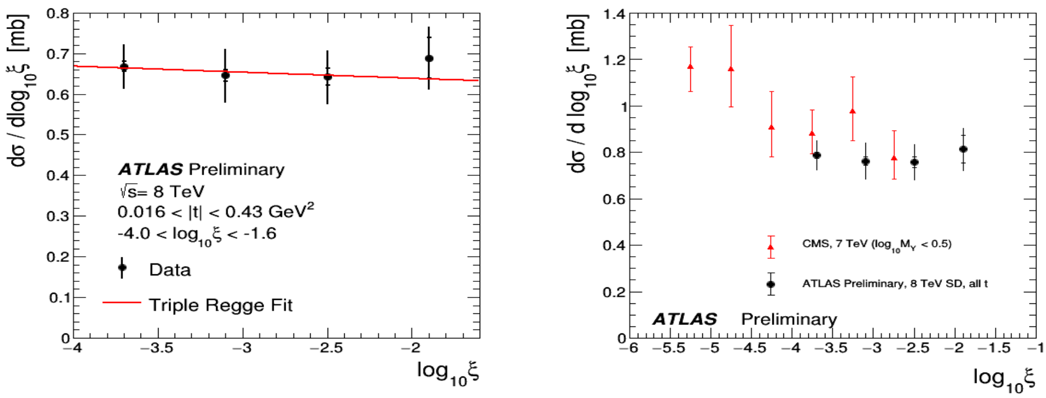

Figure 4: Corrected differential cross section as a function of $\log_{10}\xi$. (left) Data in the fiducial t range are compared with the results of the triple Regge fit described in the text. (right) ATLAS data are extrapolated to the full t range, compared with a rapidity gap-based CMS measurement [13] that contains a small DD admixture (see text). The inner error bars represent only statistical uncertainties while the outer error bars display the combination of statistical and systematic uncertainties in quadrature [3].

There are no previously published LHC results in which the pure SD differential cross section in t is measured. However, the $\log_{10}\xi$ dependence has been measured by the CMS collaboration at $\sqrt{s} = 7$ TeV in an analysis using the rapidity gap technique [13] which includes the SD process with a small DD admixture. Results from these two analyses are compared in Fig. 4 (right), after extrapolating the ATLAS results to $0 < |t| < \infty$ by applying a factor of 1.18, extracted using the measured slope parameter. The two analyses cover different but overlapping ξ regions, with a good agreement in the overlap region without subtracting any DD contribution from the CMS results or accounting for the difference between the centre-of-mass energies.

The cross section measured in the fiducial region $-4.0 < \log_{10}\xi < -1.6$ and $0.016 < |t| < 0.43$ GeV^2 is 1.59 ± 0.03(stat.) $\pm$ 0.13(syst.) mb. Extrapolating to the full t range assuming the measured slope parameter B leads to a cross section of 1.88 ± 0.15 mb integrated over $-4.0 < \log_{10}\xi < -1.6$. An extrapolation to the full ξ range is not well defined, nevertheless since the measurement of $\alpha(0)$ lies midway between the predictions of the A3 and A2 tunes of Pythia 8, the estimate is obtained by scaling the measured fiducial cross section by the average of the extrapolation factors predicted by the two tunes. Table 1 shows measured, extrapolated and predicted cross sections.

Distribution	$\sigma_{\rm SD}^{\rm fiducial(\xi,t)}$ [mb]	$\sigma_{\rm SD}^{\rm t-extrap}$ [mb]	$\sigma_{\rm SD}^{\rm t,\xi-extrap}$ [mb]
Data	1.59±0.13	1.88±0.15	6.6
PYTHIA 8 A2	3.69	4.35	12.48
PYTHIA 8 A3	2.52	2.98	12.48
HERWIG 7	4.96	6.11	24.0

Table 1: The SD cross section within the fiducial region, extrapolated across all t, and scaled to all ξ values in the context of the Pythia 8 model [3].

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