A Study of Diffractive Production in ALICE

O. Villalobos Baillie for the ALICE Collaboration

School of Physics and Astronomy, The University of Birmingham, Edgbaston, Birmingham
B15 2TT, UK
E-mail: owb@hep.ph.bham.ac.uk

Abstract. The ALICE collaboration is investigating single, double and central diffractive processes in pp interactions. The single and double diffractive cross-sections are presented at 900 GeV 2.76 TeV and 7 TeV using an analysis method based on the classification of diffractive gaps. Promising early results on central diffractive processes have motivated the use of additional diffractive counters, which are currently being installed.

1. Introduction

The study of diffractive production at the CERN LHC is of great interest, for both theoretical and practical reasons. Currently, there are several possible descriptions of the data up to Tevatron energies[1, 2, 3], all of which describe the available measurements, albeit with different treatments of the underlying mechanisms and, in particular, of the treatment of “hard” diffraction. The availability of data at much higher energies will help to disentangle these features. In addition, uncertainties over the size of the diffractive contribution are one of the principal sources of uncertainty in measurements of global variables such as the pseudorapidity density dN/dη.

Identification of diffractive events is experimentally not straightforward. At lower energies it is often possible to identify and measure the undiffracted proton, but at the LHC this becomes very challenging, so alternative methods must be considered. The principal topological signature for a diffractive process is the presence of a large rapidity gap. As discussed by Bjorken[4] and others, such gaps can be linked to Pomeron exchange. In most high energy experiments, the selection of diffractive events is made by use of this feature in different forms.

In this paper the measurements made by the ALICE collaboration[5] on single and double diffractive production will be described. The current status of studies of central production in ALICE will also be described, together with the plans for an upgrade to the apparatus to improve the detection of such processes.

2. The ALICE Detector

The ALICE detector is designed to allow a broad range of measurements in heavy-ion interactions. It allows detailed measurements of the four-momenta of identified hadrons for very high multiplicities, using detectors that measure in the central two units of pseudorapidity. As pseudorapidity is defined as

\[ \eta = -\log \tan(\theta/2) \]  

(1)
this amounts to an angular cut around production at 90°, from approximately 45° to 135°. There are in addition several detectors at forward rapidities, which allow the measurement of forward multiplicities and which can be used for triggering purposes, and a dimuon spectrometer. A full description of the detector is given in reference [6]. In this paper we concentrate on the detectors used in the current measurements. These are:

- The Silicon Pixel Detector (SPD). The Silicon Pixel Detector comprises the innermost two layers of the ALICE Inner Tracking System (ITS). Measurements consist of hits (no particle identification information) in the two layers. If the points are consistent with the trajectory of a particle coming from a common origin, i.e. the primary vertex, the points are linked to form a “tracklet”, the most basic form of track considered in ALICE. The SPD also has a trigger functionality. Each readout chip is also able to generate a trigger signal, based on the OR of the hits in the chip. A trigger processor can make programmable decisions based on the hit pattern, and thus generate a trigger inside the ALICE L0 (900 ns) latency budget.

- the V0 Detector (V0). The V0 detector consists of two 32 element scintillator hodoscopes, one on either side of the collision point, positioned at \( z = -0.9 \) m (C side) and \( z = 3.3 \) m (A side) from the centre of the interaction region. The scintillator elements are arranged in four concentric rings, each one with eight elements covering a logical wedge of arc \( \pi/4 \). The elements provide pulse-height information and timing information about the particles that pass through them. The detector can be used for triggering purposes.

- The Forward Multiplicity Detector (FMD). The Forward Multiplicity Detector consists of five rings of silicon strip detectors placed perpendicular to the beam, giving a total of 51 240 active elements. Together, these cover the pseudorapidity intervals \( -3.7 < \eta < -1.7 \) and \( 2.8 < \eta < 5.1 \).

3. Analysis Method

The analysis presented here is based on an event classification in terms of rapidity gaps[5]. For each event, the pseudorapidity gap with the largest width is found, with width \( \Delta \eta \). Also, let \( d_1 \) and \( d_2 \) be the pseudorapidity intervals from the most negative and most positive pseudorapidity track respectively to the nearest edge of the detector acceptance. (See figure 1.)

Two classes of events are defined:

(i) if the maximum gap is greater than both \( d_1 \) and \( d_2 \) then the event is classified as a “two-arm trigger” event;

(ii) if an edge of the largest gap is at \( \eta > -1 \) (\( \eta < 1 \)) and \( d_1 \) (\( d_2 \)) is larger than \( \Delta \eta \), the event is classified as a left-side (right-side) “one-arm trigger” event;

(iii) events not satisfying either of these conditions are assigned to the “two-arm trigger” category.

These definitions are made because they provide a strong separation into diffractive and non-diffractive events. In particular the “one-arm trigger” selects single diffraction. In order to test this, generated samples with varying fractions of single diffractive events were studied. It was found that the SD fraction deduced from the “one-arm triggers” is linearly related to the generated fraction, with a slope close to one.

4. Data Samples

Diffractive interactions have been studied at three pp centre-of-mass energies: 900 GeV; 2.76 TeV; 7 TeV. In order to test the sensitivity of the event classification to diffractive events, samples of events generated with the event generators PYTHIA and PHOJET were also studied at each energy. The versions used were PYTHIA 6.421 (“Perugia 0”) [7] for PYTHIA and
Figure 1. Arrangement of tracks for an event, showing definitions of largest pseudorapidity gap and the pseudorapidity intervals $d_1$ and $d_2$ to the corresponding edges of the acceptance. The grey areas indicate ranges where there are tracks.

PHOJET 1.12[8] for PHOJET. The Monte Carlo and real data distributions were compared at each energy. For the “one-arm trigger” events, the left and right edges of the gap were plotted (see figures 2a and 2b respectively for the distributions at 7 TeV; the corresponding 900 GeV and 2.76 TeV distributions are similar but are not shown) while for the “two-arm trigger” events, the centre and the width of the gap were plotted (see figures 2c and 2d for the 7 TeV distributions; the corresponding 900 GeV and 2.76 TeV distributions are similar but are not shown).

The shape of the “two-arm trigger” distribution is sensitive to the Double Diffraction fraction for large gap widths $\Delta \eta$. The fractions of Single and Double Diffraction in the Monte Carlo samples have been adjusted slightly in order to optimize the agreement between Monte Carlo and data for the Double Diffraction width distribution (2c) After the adjustment, the new default fractions for the PYTHIA and PHOJET samples are much more similar than before, and come out at around 10% at 900 GeV and 8% at 7 TeV. Note that these values are then re-assessed in the analysis in order to obtain the final measured fractions.

5. Analysis

5.1. Single Diffraction

The “one-arm trigger” selection does not select all the Single Diffraction events. At low diffractive masses there are increasingly low acceptances, and a certain fraction of the SD events satisfy the “two-arm” trigger. For this reason efficiencies are calculated at each energy based on the Monte Carlo generators and used to correct the estimate of the single diffractive fraction. In particular, the limited pseudorapidity range accessible to ALICE leads to diminishing acceptance at low diffractive masses, making the estimate of the total SD fraction dependent on model input. The estimates given in this study are based on an the yield for all diffractive masses below 200 GeV, and use the diffractive mass distribution given in reference [1]; this takes into account the reported increase in $dN/dM^2$ above a simple $1/M^2$ dependence for diffractive masses below around 4 GeV [9, 10].

A consistency check is that the acceptances and efficiencies for the two sides of the detector are different owing to the asymmetric positions of the detectors, but corrected partial cross sections for diffraction into each hemisphere should be consistent. Table 1 shows the corrected single diffraction cross-sections for left and right hemispheres as a fraction of the total inelastic...
Figure 2. Distribution of uncorrected gap parameters for 7 TeV data and for PYTHIA 6.421 and PHOJET 1.12 generated events: 2a distribution of leftmost edge of gap distribution for “one-arm trigger” events; 2b distribution of rightmost edge of gap distribution for “one-arm trigger” events; 2c centre of gap distribution for “two-arm trigger” events; 2d width of gap distribution for “two-arm trigger” events.

cross-section. Although the acceptances for the two sides are different, it can be seen that the corrected cross-sections are consistent with one another.

Table 1. Single diffraction as a fraction of the total inelastic cross-section for left and right hemispheres.

|                  | 900 GeV | 2.76 TeV | 7 TeV |
|------------------|---------|----------|-------|
| $\sigma_{SD} / \sigma_{INEL}$ left | 0.102 ± 0.019 | 0.097 ± 0.026 | 0.101 ± 0.019 |
| $\sigma_{SD} / \sigma_{INEL}$ right | 0.100 ± 0.015 | 0.090 ± 0.028 | 0.100 ± 0.020 |
| $\sigma_{SD} / \sigma_{INEL}$       | 0.202 ± 0.034 | 0.187 ± 0.054 | 0.201 ± 0.039 |

5.2. Double Diffraction
This analysis presents a new method for identifying double diffraction. It is observed that in the “two-arm trigger” sample that double diffraction becomes the dominant contribution for events with width $\Delta \eta > 3$. This suggests that measuring such events could be used as a way to estimate the double diffraction contribution to the inelastic cross-section. After a small re-adjustment of the fractions used in the model generators in order to obtain a good description of the “two-arm
Figure 3. Left panel: single diffractive cross-section as a function of centre-of-mass energy; right panel: double diffractive cross-section as a function of centre-of-mass energy. Curves correspond to estimates from models mentioned in the text.

trigger” gap distribution, these are used to correct the corresponding distribution in the real data. Double diffractive events are then defined to be those satisfying the “two-arm trigger” having a gap width $\Delta \eta > 3$. The corresponding fractions are given in Table 2.

Table 2. Double diffraction as a fraction of the total inelastic cross-section.  

| Energy  | $\sigma_{DD}/\sigma_{INEL}$ |
|---------|-----------------------------|
| 900 GeV | 0.113 ± 0.029               |
| 2.76 TeV | 0.125 ± 0.052               |
| 7 TeV | 0.122 ± 0.036               |

These fractions allow us to estimate the cross-sections for diffractive production. At centre-of-mass energies of 2.76 TeV and 7 TeV the inelastic cross-section was measured using the Van der Meer scan technique, yielding measurements of $62.1 \pm 1.6 \pm 4.3$ mb at 2.76 TeV and $72.7 \pm 1.1 \pm 5.1$ mb at 7 TeV[11]. The inelastic cross-section at 900 GeV is estimated from the measured $\sqrt{s}$ value, as no Van der Meer scan was performed at this energy. Using these values and the fraction estimates given above, the cross-section dependences for single and diffractive production, shown in figure 3 were obtained. The curves shown on the figure correspond to different models: the solid black line corresponds to reference [1], the red short-dashed line to reference [12, 13], the mauve long-dashed line to reference [14], and the blue long-short dashed line to reference [15].

6. Future Plans
The use of diffractive gaps can also be used to enhance the contribution of Central Production, i.e. of those events mediated by Double Pomeron Exchange. At present this can be enhanced using a trigger $V_0a.SPD.V_0c$. Preliminary studies using this trigger show that the shape of the two-pion spectrum changes very markedly. Whereas the minimum bias two-pion spectrum shows a prominent $\rho$ peak, in the sample taken with the “central production” trigger the $\rho$ is very much suppressed, and instead the $J^{PC} = (\text{even})^{++}$ mesons is enhanced.

The selection of diffractive events in ALICE using the original setup is limited by the range over which diffractive gaps can be verified. Better measurements can be achieved by extending the range over which particle production (or its absence) can be detected. The ALICE experiment’s capacity to detect diffraction is being enhanced in a simple but effective...
way by the addition of forward scintillator arrays which extend the range over which charged particle production (or its absence) can be detected. Figure 4 shows the rapidity coverage for the new scintillator arrays (ADA and ADD), with the aid of which ALICE can detect charged particle production over almost 16 units of pseudorapidity. Installation of these new scintillator arrays is in progress.

7. Conclusions
The ALICE collaboration has used a technique based on the measurement of rapidity gaps to estimate the fractions for single and double diffractive production in samples of minimum bias trigger events at 900 GeV, 2.76 TeV and 7 TeV. Using the inelastic cross-sections measured in Van der Meer scans at 2.76 TeV and 7 TeV, the corresponding diffractive cross sections are obtained. A sample selected to enhance central production shows features consistent with a Double Pomeron Exchange mechanism. Additional scintillator counters are being installed to improve sensitivity to these processes.

8. References
[1] Kaidalov A and Poghosyan M G 2010 Eur. Phys. J. C 67 397
[2] Harland-Long L A, Khoze V A, Stirling W J and Ryskin M G 2011 AIP Proc. Conf. 1350 187
[3] Maor U 2011 AIP Proc. Conf. 1350 191
[4] Bjorken J D 1993 Phys. Rev. D 47 101
[5] ALICE Collaboration, Poghosyan M G 2011 Journal of Physics G Nucl. Part. Phys 38 124044
[6] ALICE Collaboration, Aamodt A et al. 2008 J. Inst. 3 S08002
[7] Skands P Z Phys. Rev. D 82 074018
[8] Engel R, Ranft J and Roesler S 1995 Phys. Rev. D 52 1459
[9] UA4 Collaboration Bernard D et al. 1987 Phys. Lett B 198 583
[10] E710 Collaboration Amos N A et al. 1993 Phys. Lett B 301 313
[11] ALICE Collaboration, Oyama K 2011 Journal of Physics G Nucl. Part. Phys. 38 124131
[12] Ryskin M G, Martin A D and Khoze V A 2009 Eur. Phys. J. C 60 249
[13] Ryskin M G, Martin A D and Khoze V A 2011 Eur. Phys. J C 71 1617
[14] Ostapchenko S 2011 Phys. Rev. D 83 114018
[15] Gotsman E, Levin E and Maor U 2011 *Eur. Phys. J. C* **71** 1553