Diffraction dissociation in proton-proton collisions at $\sqrt{s} = 0.9$ TeV, 2.76 TeV and 7 TeV with ALICE at the LHC

M.G. Poghosyan for the ALICE collaboration

Universitá di Torino/INFN, 10125 Torino, Italy

E-mail: martin.poghosyan@cern.ch

Abstract. The relative rates of single- and double- diffractive processes were measured with the ALICE detector by studying properties of gaps in the pseudorapidity distribution of particles produced in proton-proton collisions at $\sqrt{s} = 0.9$ TeV, 2.76 TeV and 7 TeV. ALICE triggering efficiencies are determined for various classes of events, using a detector simulation validated with data on inclusive particle production. Cross-sections are determined using van der Meer scans to measure beam properties and obtain a measurement of the luminosity.

1. Introduction

The phenomenon of diffractive dissociation was predicted by E.L. Feinberg and I.Ya. Pomeranchuk [1] before it was observed experimentally. This process became a subject of intensive experimental studies at all hadron accelerators including the high energy facilities at CERN and FNAL (ISR, S$p\bar{p}$S and Tevatron, and now LHC).

Being diffractively produced, the system must have the same intrinsic quantum numbers as the incoming hadron while spin and parity may be different because some orbital angular momentum can be transferred to the system during the interaction. Regge theory is the main framework for describing such processes. The diffraction dissociation process is described by the phenomenology of Pomeron exchange, where the Pomeron is a color singlet with quantum numbers of the vacuum.

Experimentally, it is not possible to select from large rapidity processes those that are caused by a Pomeron exchange. Therefore, we associate the diffraction dissociation with large rapidity gap processes, considering the contribution of secondary-Reggeons as well. The separation of these processes is model dependent.

In experiments (such as ALICE at LHC) where the non-diffracted proton in single-diffraction (SD) is outside detector acceptance, the reconstruction of the characteristics of this process becomes model dependent. Therefore, the physical model which is chosen as an input for data analysis and correction, should be as close to reality as possible. By reality we mean the available data on total, elastic and diffractive interaction cross-sections of pp and $p\bar{p}$ collisions provided by experiments performed up to now.

A model based on Gribov's Regge calculus was developed [2] and was proposed to describe diffractive processes. The numerical evaluation of the model gave a good description of data on diffraction dissociation processes in pp and $p\bar{p}$ interactions over a wide energy range (from $P_{lab} = 65$ GeV/c to $\sqrt{s} = 1800$ GeV) explored with various accelerators at CERN and at Fermilab [2]. In the measurement described here the model [2] is used to provide the dependence of SD cross-section on diffracted mass in PYTHIA6 [3] and PHOJET [4] Monte Carlo (MC) generators.

2. Analysis method

A detailed description of the ALICE detector can be found in [5]. In this study we used three of its sub detectors: The Silicon Pixel Detector (SPD), the VZERO scintillator modules and the Forward Multiplicity Detector (FMD). SPD and VZERO are the main ALICE triggers for collecting minimum bias events. The FMD extends the pseudorapidity coverage to the interval from -3.7 to 5.1.

We studied, on an event per event basis, the pseudorapidity distribution of tracks made of the event vertex and a hit in either SPD, VZERO or FMD cells. For each event we found the pseudorapidity gap with the largest width and calculated the pseudorapidity distances d_1 ($\eta < 0$ side), d_2 ($\eta > 0$ side) of each edge of the measured pseudorapidity distribution from the corresponding nearest edge of the detector acceptance. After finding the widest pseudorapidity gap, we classified the events into 1-arm and 2-arm triggers as follows:

- If the maximum gap width is greater than both d_1 and d_2, the event is classified as 2-arm trigger event.
- If the edge is at $\eta > -1$ or $\eta < 1$ and d_1 or d_2 is bigger than the maximum gap width, the event is classified as Left-side or Right-side 1-arm trigger event, respectively.
- The rest of the events we considered as 2-arm trigger events.

The fraction of SD processes was measured by counting the relative rate of one-arm and two-arm triggers. MC simulations showed that masses above 200 GeV/c^2 mainly give 2-arm trigger and therefore for our measurement the $M = 200$ GeV/c^2 serves as the boundary between the SD and non-single diffractive (NSD) events.

Several tests were made to be sure that the material budget and the inefficiency of detectors do not spoil the pseudorapidity gaps. In particular, we varied the fraction of SD in MCs and studied the dependence of the measured fraction of SD vs the input fraction of SD. We found that there is one to one relation between input and output fractions and the cases with real and ideal detectors are very close to each other. We also varied the cross-section of double-diffraction (DD) in MCs to study the sensitivity of the pseudorapidity gap width distribution in 2-arm trigger events on the input fraction of DD. For this case again one to one relation was found.

A comparison with data showed that with the default DD fraction PYTHIA significantly overestimates the fraction of large pseudorapidity gaps and PHOJET significantly underestimates it. In order to have a constraint on the contribution of large rapidity gap NSD events in the one-arm triggers, the DD fraction in PYTHIA and PHOJET was varied. In PYTHIA/PHOJET the default DD fraction is 0.12/0.06 at 900 GeV and 0.13/0.05 at 7 TeV and we set it to 0.1/0.11 at 900 GeV and 0.09/0.07 at 7 TeV. For the $\sqrt{s} = 2.76$ TeV run, taken recently, the performance of FMD is not well understood yet. Therefore, we used only the SPD and VZERO detectors.

3. Results

In Table 1 we present the corrected ratios of single-diffraction over inelastic cross-sections. Statistical errors are negligible and the quoted errors are systematic. They come from the adjustment of DD in PYTHIA and PHOJET, from changing the $\sigma^{-1} d\sigma/dM$ by $\pm 50\%$ at the proton-pion mass threshold, from the uncertainty of the SD kinematic in PYTHIA and PHOJET and from the beam-gas background. Despite different acceptances and different trigger ratios of the two ALICE sides, the corrected ratios of each side are the same as expected from the symmetry of the process.

Table 1. Fractions of SD ($M < 200$ GeV/c^2) and DD ($\Delta\eta > 3$) events.

$\sqrt{s}$ (TeV)	$\sigma_{SD}^{right}/\sigma_{Inel}$	$\sigma_{SD}^{left}/\sigma_{Inel}$	$\sigma_{SD}/\sigma_{Inel}$	$\sigma_{DD}/\sigma_{Inel}$
0.9	0.100 ± 0.015	0.102 ± 0.019	0.202 ± 0.034	0.113 ± 0.029
2.76	0.090 ± 0.028	0.097 ± 0.026	0.187 ± 0.054	0.125 ± 0.052
7	0.100 ± 0.020	0.101 ± 0.019	0.201 ± 0.039	0.122 ± 0.036

After tuning MC generators for large rapidity gaps, we calculated the fraction of NSD events with pseudorapidity gap $\Delta\eta > 3$ (see Table 1). Using the obtained fractions of SD and DD, we calculated the efficiencies of detecting *pp* inelastic interactions by requiring a coincidence between the two sides of the VZERO detectors (MB_{AND}) and a logical OR between the signals from the SPD and VZERO detectors. Their ratio was compared with data and a good agreement was found. For MB_{AND} we obtained $(76.2 \pm 2)\%$ and $(74.5 \pm 1.1)\%$ at 2.76 TeV and 7 TeV, respectivelly. Using the van der Meer scans to measure the visible cross-section of the MB_{AND} trigger [6], and our simulation result for the detector acceptance, for inelastic cross-section we obtained: $\sigma_{Inel}(2.76\,TeV) = 62.1 \pm 1.6(model) \pm 4.3(luminosity)$ mb and $\sigma_{Inel}(7\,TeV) = 72.7 \pm 1.1(model) \pm 5.1(luminosity)$ mb. *pp* inelastic, SD and DD cross-sections are compared with data from other experiments and with the predictions of theoretical models from [2] and [7]-[9] in Figures 1 - 3. There is a good agreement between ALICE and UA5 for SD and DD ratios at 900 GeV and between ALICE, ATLAS and CMS for inelastic cross-section at 7 TeV. We would like to stress again that in our measurement the diffractive processes are associated with large (pseudo)rapidity gap processes. In some measurements and most theoretical models the diffraction is considered as a Pomeron exchange, excluding the contribution of Reggeons.

4. Conclusion

Fractions of SD ($M < 200$ GeV/c^2) and DD ($\Delta\eta > 3$) dissociation processes are measured at $\sqrt{s} = 0.9$, 2.76 and 7 TeV. For $\sqrt{s} = 900$ GeV a good agreement with UA5 is found. Within our accuracy, we do not observe variations of the SD fraction with energy ($\sigma_{SD}/\sigma_{Inel} \simeq 0.2$).

pp inelastic cross-section is measured at $\sqrt{s} = 2.76$ and 7 TeV. The result for 7 TeV is in a good agreement with ATLAS and CMS results.

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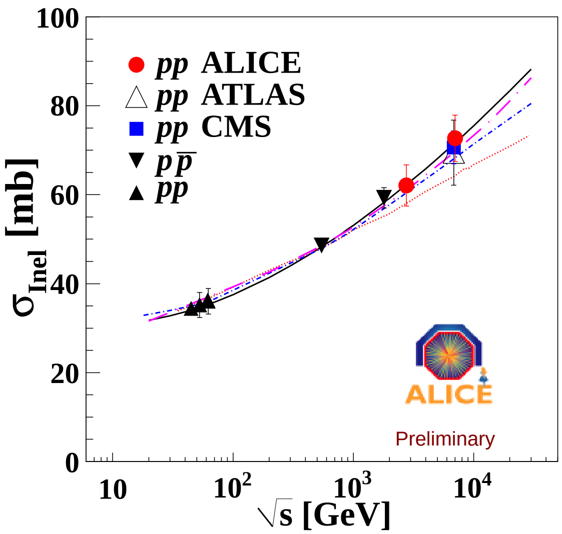

Figure 1. Inelastic cross-section as a function of collision energy. Data are compared with the predictions of [2] (solid black line), [7] (long dot-dashed pink line), [8] (short dot-dashed blue line) and [9] (dotted red line). Data from other experiments are taken from [10]

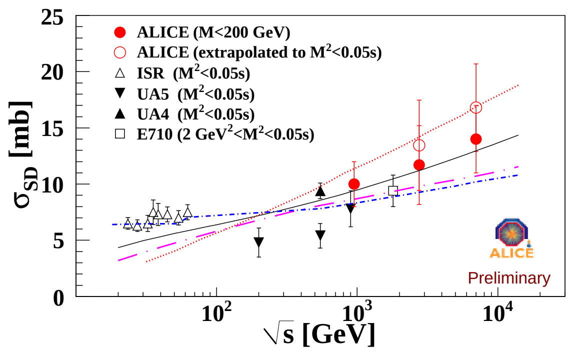

Figure 2. Single-diffractive cross-section as a function of collision energy. Data from other experiments are for $M^2 < 0.05s$ [11]. ALICE measured points are shown with full (red) circles, and in order to compare with data from other experiments were extrapolated to $M^2 < 0.05s$. The predictions of theoretical models correspond to $M^2 < 0.05s$ and are defined as in Figure 1.

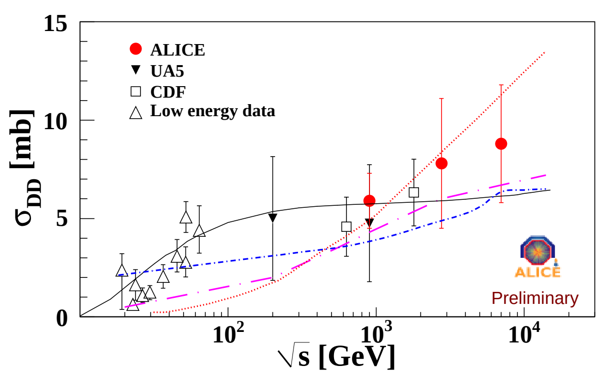

Figure 3. Double-diffractive cross-section as a function of collision energy. The theoretical model predictions are for $\Delta\eta > 3$ and are defined as in Figure 1. Data from other experiments are taken from [12].

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