Diffractive and inelastic cross-sections in proton-proton collisions at $\sqrt{s} = 0.9$ TeV, 2.76 TeV and 7 TeV with ALICE at the LHC.

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CERN
ALICE Collaboration

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Detectors used to measure pseudorapidity gaps

- Silicon Pixel Detector (SPD) corresponds to the two innermost layers of the ALICE Inner Tracking System and covers pseudorapidity range $|\eta| < 2$.
- V0 scintillator hodoscopes are placed on both sides of the interaction point covering the pseudorapidity ranges $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$.
- Forward Multiplicity Detector (FMD) is made of silicon strip sensors placed on either side of the interaction point covering the pseudo-rapidity range $-3.4 < \eta < -1.7$ and $1.7 < \eta < 5.1$.

MC generators: PYTHIA(-perugia0 tune) and PHOJET
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Right-side 1-arm trigger: no signal with $\eta < -1$
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![Diagram with pseudorapidity range and detector locations]
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Uncorrected data vs Simulation (900 GeV)

edge of left-side 1-arm trigger event

edge of right-side 1-arm trigger event

2-arm trigger event

L-side 1-arm trigger event

R-side 1-arm trigger event

2-arm trigger event

ALICE Performance 16/05/2011

data

PYTHIA

PHOJET
Uncorrected data vs Simulation (7 TeV)

- Edge of left-side 1-arm trigger event
- Edge of right-side 1-arm trigger event
- L-side 1-arm trigger event
- R-side 1-arm trigger event
- 2-arm trigger event
- Center of gap
- Gap width

- ALICE Performance 16/05/2011
- Data: PYTHIA, PHOJET
- Probabilities for different η values

- EDS11
- M. Poghosyan
Uncorrected data vs Simulation (2.76 TeV)

EDS11

M. Poghosyan
Varying the fraction of single- and double-diffractions in MC generator

900 GeV

1-arm triggers

Material budget + simulation of detector response do not spoil the sensitivity to SD

2-arm triggers

gap width distribution is sensitive to DD

Material budget + detector inefficiency

Material budget + ideal detector

pp at $\sqrt{s} = 900$ GeV

data

PYTHIA

PHOJET

PYTHIA no DD

PHOJET no DD

ADLCE

Performance

16/05/2011

pp at $\sqrt{s} = 900$ GeV

$\Delta \eta$
Fixing the fraction of DD in Monte Carlo

Use the measured width distribution from two-arm triggers to constrain the contribution of double-diffraction.

For $2.76 \text{ TeV}$ the FMD is not used and the fraction of DD is not changed.

**Fractions of DD events converging to same value in the two MC**

PYTHIA: $w_{DD} = 0.12 \rightarrow 0.1$

PHOJET: $w_{DD} = 0.06 \rightarrow 0.1$
Pileup correction

Higher luminosity
  ➔ higher pileup
  ➔ smaller rate of one-arm triggers
  ➔ underestimation of $\sigma_{SD}$ and $\sigma_{Inel}$

$$A(\mu) = \frac{\exp\{A_0 \mu\} - 1}{\exp\{\mu\} - 1}$$

$\mu$ – fraction of interactions per bunch crossing
$A_0$ – trigger rate in case of single interactions
Efficiency/Inefficiency vs mass for SD (900 GeV)

L-side SD

Performance

\( pp \) at \( \sqrt{s} = 900 \text{ GeV} \)

16/05/2011

R-side SD

Performance

\( pp \) at \( \sqrt{s} = 900 \text{ GeV} \)

16/05/2011

no trigger

1-arm trigger

2-arm trigger

opposite side 1-arm trigger
Efficiency/Inefficiency vs mass for SD (2.76 TeV)

L-side SD

R-side SD

no trigger

1-arm trigger

2-arm trigger

opposite side 1-arm trigger
$M$ [GeV/c$^2$]

**L-side SD**

**R-side SD**

no trigger

1-arm trigger

2-arm trigger

opposite side 1-arm trigger

Kaidalov et al.
A. Kaidalov et al. [arxiv:0909.5156, EPJ. C67]

Performance of the model used to parameterise SD

\[ \zeta = \frac{M^2}{s} \]
## Resulting mean efficiencies

<table>
<thead>
<tr>
<th>Process</th>
<th>900 GeV</th>
<th>2.76 TeV</th>
<th>7 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R-side SD</td>
<td>L-side SD</td>
<td>2-arm trig.</td>
</tr>
<tr>
<td>R-side 1-arm trig.</td>
<td>0.465 ± 0.031</td>
<td>0.002 ± 0.001</td>
<td>0.198 ± 0.054</td>
</tr>
<tr>
<td>L-side 1-arm trig.</td>
<td>0.004 ± 0.003</td>
<td>0.352 ± 0.014</td>
<td>0.201 ± 0.050</td>
</tr>
<tr>
<td>NSD</td>
<td>0.025 ± 0.007</td>
<td>0.012 ± 0.004</td>
<td>0.956 ± 0.014</td>
</tr>
<tr>
<td></td>
<td>R-side SD</td>
<td>L-side SD</td>
<td>2-arm trig.</td>
</tr>
<tr>
<td>R-side 1-arm trig.</td>
<td>0.395 ± 0.011</td>
<td>0.002 ± 0.001</td>
<td>0.087 ± 0.036</td>
</tr>
<tr>
<td>L-side 1-arm trig.</td>
<td>0.002 ± 0.001</td>
<td>0.301 ± 0.021</td>
<td>0.073 ± 0.027</td>
</tr>
<tr>
<td>NSD</td>
<td>0.026 ± 0.007</td>
<td>0.017 ± 0.009</td>
<td>0.946 ± 0.028</td>
</tr>
<tr>
<td></td>
<td>R-arm SD</td>
<td>L-arm SD</td>
<td>2-arm trig.</td>
</tr>
<tr>
<td>R-arm SD</td>
<td>0.333 ± 0.027</td>
<td>0.0002 ± 0.0002</td>
<td>0.038 ± 0.019</td>
</tr>
<tr>
<td>L-arm SD</td>
<td>0.0007 ± 0.0006</td>
<td>0.243 ± 0.029</td>
<td>0.041 ± 0.017</td>
</tr>
<tr>
<td>NSD</td>
<td>0.022 ± 0.006</td>
<td>0.013 ± 0.003</td>
<td>0.952 ± 0.014</td>
</tr>
</tbody>
</table>

**syst. error comes from:**
- adjustment of DD in Pythia and Phojet
- Changing $d\sigma/dM$ by ±50% at the threshold
- SD kinematic in PYTHIA and PHOJET
**Measurement of $\sigma_{SD}/\sigma_{Inel}$**

<table>
<thead>
<tr>
<th>Energy</th>
<th>Raw trigger ratios</th>
<th>Corrected ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 GeV</td>
<td>$L$-side/2-arm $= 0.0578 \pm 0.0001$ (syst.)</td>
<td>$\frac{\sigma_{SD}}{\sigma_{Inel}} = 0.215 \pm 0.030$ (syst.)</td>
</tr>
<tr>
<td></td>
<td>$R$-side/2-arm $= 0.0912 \pm 0.0001$ (syst.)</td>
<td></td>
</tr>
<tr>
<td>2.76 TeV</td>
<td>$L$-side/2-arm $= 0.0518 \pm 0.0001$ (syst.)</td>
<td>$\frac{\sigma_{SD}}{\sigma_{Inel}} = 0.187 \pm 0.055$ (syst.)</td>
</tr>
<tr>
<td></td>
<td>$R$-side/2-arm $= 0.0763 \pm 0.0001$ (syst.)</td>
<td></td>
</tr>
<tr>
<td>7 TeV</td>
<td>$L$-side/2-arm $= 0.0458 \pm 0.0001$ (syst.)</td>
<td>$\frac{\sigma_{SD}}{\sigma_{Inel}} = 0.207 \pm 0.04$ (syst.)</td>
</tr>
<tr>
<td></td>
<td>$R$-side/2-arm $= 0.0680 \pm 0.0001$ (syst.)</td>
<td></td>
</tr>
</tbody>
</table>

Despite different acceptances of the two ALICE sides, the results are symmetrical as expected from the symmetry of the physics process.
Definition of DD : all events with a gap $\Delta \eta > 3$:

$\frac{\sigma_{DD}}{\sigma_{Inel}} = 0.108 \pm 0.028$ at $900$ GeV

$\frac{\sigma_{DD}}{\sigma_{Inel}} = 0.125 \pm 0.052$ at $2.76$ TeV

$\frac{\sigma_{DD}}{\sigma_{Inel}} = 0.124 \pm 0.035$ at $7$ TeV
Van der Meer scans

A part of Inelastic cross-section is measured by requiring coincidence of V0-Left and V0-Right

\[ L = f \frac{N_1 N_2}{h_1 h_2} \]

\( f = 11245.5 \) Hz - accelerator frequency
\( N_{1,2} \) — numbers of protons per bunch
\( h_x \) and \( h_y \) — effective width and height of the collision region

\[ R_{\text{trigger}} = \sigma_{\text{visible}} L \]

<table>
<thead>
<tr>
<th>vdm scan</th>
<th>√s TeV</th>
<th>Colliding bunches</th>
<th>Crossing angle (rad)</th>
<th>β* (m)</th>
<th>Max μ</th>
<th>( h_x/2\sqrt{\pi} ) (μm)</th>
<th>( h_y/2\sqrt{\pi} ) (μm)</th>
<th>( \sigma_{\text{visible}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>7</td>
<td>1</td>
<td>280</td>
<td>2</td>
<td>0.086</td>
<td>43.8</td>
<td>46.7</td>
<td>54.21 ± 2.9</td>
</tr>
<tr>
<td>b</td>
<td>7</td>
<td>1</td>
<td>500</td>
<td>3.5</td>
<td>0.74</td>
<td>57.3</td>
<td>65.1</td>
<td>54.34 ± 1.9</td>
</tr>
<tr>
<td>c</td>
<td>2.76</td>
<td>48</td>
<td>710</td>
<td>10</td>
<td>0.12</td>
<td>164</td>
<td>166</td>
<td>47.67 ± 1.5</td>
</tr>
</tbody>
</table>
From the MC tuned with our SD and DD measurements, we can calculate the ALICE triggering efficiencies:

\( MB_{\text{OR}} = \text{V0-Left or SPD or V0-Right} \)
\( MB_{\text{AND}} = \text{V0-Left and V0-Right} \)

- **900 GeV**
  \( MB_{\text{AND}} = (76.3 \pm 1.0)\% \)
  \( MB_{\text{OR}} = (91.0 \pm 1.3)\% \)
  \( MB_{\text{AND}}/MB_{\text{OR}} = 0.838 \pm 0.005 \)

- **2.76 TeV**
  \( MB_{\text{AND}} = (76.7 \pm 2)\% \)
  \( MB_{\text{OR}} = (88.6 \pm 3)\% \)
  \( MB_{\text{AND}}/MB_{\text{OR}} = 0.866 \pm 0.007 \)

- **7 TeV**
  \( MB_{\text{AND}} = (74.2 \pm 1.1)\% \)
  \( MB_{\text{OR}} = (85.1 \pm 2.2)\% \)
  \( MB_{\text{AND}}/MB_{\text{OR}} = 0.872 \pm 0.012 \)

\[ \sigma_{\text{Inel}} (\sqrt{s} = 2.76 \text{ TeV}) = 62.2 \pm 1.7(\text{model}) \pm 2.0(\text{lumi}) \text{ mb} \]
\[ \sigma_{\text{Inel}} (\sqrt{s} = 7 \text{ TeV}) = 73.2 \pm 1.1(\text{model}) \pm 2.6(\text{lumi}) \text{ mb} \]
Comparison with other experiments and models

\[ \sigma_{\text{Inel}} \text{ at } \sqrt{s} = 7 \text{ TeV} \]

ALICE : \( 73.2 \pm 1.1^{\text{model}} \pm 2.6^{\text{lumi}} \)
ATLAS : \( 69.4 \pm 2.4^{\exp.} \pm 6.9^{\text{extrap.}} \)
CMS : \( 68.0 \pm 2.0^{\text{syst.}} \pm 2.4^{\text{lumi}} \pm 4^{\text{extrap.}} \)
TOTEM: \( 73.5 \pm 0.6^{\text{stat.}} \pm 1.8^{\text{syst.}} \)

Gotsman et al., arXiv:1010.5323, EPJ. C74, 1553 (2011)
Khoze et al., EPJ. C60 249 (2009), C71 1617 (2011)

Model predictions:
SD \( \rightarrow M^2 < 0.05\text{s} \)
DD \( \rightarrow \Delta \eta > 3 \)
Summary

Ratios of single-diffraction dissociation ($M < 200 \text{ GeV/c}^2$) to inelastic cross-sections were measured at $\sqrt{s} = 0.9$, 2.76 and 7 TeV. Within our accuracy, we do not observe variations of these ratios with energy ($\sigma_{\text{SD}}/\sigma_{\text{Inel}} \approx 0.2$).

From a determination of the inelastic cross-section (van der Meer scan) single-diffraction and double-diffraction cross-sections were obtained at $\sqrt{s} = 2.76$ and 7 TeV.

<table>
<thead>
<tr>
<th>$\sqrt{s}$ (TeV)</th>
<th>$\sigma_{\text{Inel}}$ (mb)</th>
<th>$\sigma_{\text{SD}}(M &lt; 200 \text{ GeV})/\sigma_{\text{Inel}}$</th>
<th>$\sigma_{\text{DD}}(\Delta\eta&gt;3)/\sigma_{\text{Inel}}$</th>
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<tr>
<td>0.9</td>
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<td>0.215 ± 0.030</td>
<td>0.108 ± 0.028</td>
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<td>7</td>
<td>73.2 ± 1.1 ± 2.6</td>
<td>0.207 ± 0.040</td>
<td>0.124 ± 0.035</td>
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