Predictions of Diffractive Cross Sections in Proton-Proton Collisions

Konstantin Goulianos*
The Rockefeller University


High Energy Physics - Phenomenology

MBR Monte Carlo Simulation in PYTHIA8

R. Ciesielski, K. Goulianos

(Submitted on 7 May 2012)
For details on the phenomenology of the predictions see:

DIFFRACTION 2010
“Diffractive and total $pp$ cross sections at the LHC and beyond” (KG)
http://link.aip.org/link/doi/10.1063/1.3601406

This talk: an implementation of these cross sections in PYTHIA8.
INTRODUCTION

- The RENORM (renormalization model) soft $pp$ cross sections previously used in MBR (Minimum Bias Rockefeller) simulation are adapted to PYTHIA8.
  - MBR was successful at Fermilab in fixed target and collider experiments.
- RENORM predictions are based on a parton-model approach in which diffraction is derived from inclusive PDFs and color factors.
- Diffractive cross sections and final states are both predicted:
  - Cross sections vs gap width or vs forward momentum loss of proton(s):
    - Absolute normalization!
  - Hadronization of dissociated proton:
    - A (non-perturbative) “quark string” is introduced and tuned to reproduce the MBR multiplicity and $p_T$ distributions.
    - $dN/d\eta$, $p_T$, and particle ID: new in this PYTHIA8 implementation (the original MBR simulation produced only $\pi^\pm$ and $\pi^0$).
  - Unique unitarization based on a saturated “glue-ball” exchange.
- Total Cross section $\sim \ln^2 s$ based on a glue-ball-like saturated-exchange.
  - Immune to eikonalization-model dependences.
STUDIES OF DIFFRACTION IN QCD

Non-diffractive

- color-exchange → gaps exponentially suppressed

Diffractive

- Colorless vacuum exchange
  → large-gap signature

Goal: probe the QCD nature of the diffractive exchange
1 - \( x_L \) \( \equiv \xi = \frac{M_X^2}{s} \)

\( \xi^{\text{CAL}} = \sum_{i=1}^{\text{all}} E_{\text{T}}^{i\text{-tower}} e^{-\eta_i} \)

\( s \neq E \sum_{i} \xi \eta_{\text{tower}-i} T_{\text{all}} 1^{i\text{CAL}} = \approx \frac{\ln s}{\sqrt{s}} \)

\( M_X^2 \)

since no radiation \( \rightarrow \)
no price paid for increasing diffractive gap size

\( \left( \frac{d\sigma}{d\Delta\eta} \right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \Rightarrow \frac{d\sigma}{dM^2} \propto \frac{1}{M^2} \)
Elastic scattering

$\sigma_T = \text{Im } f_{el}(t=0)$

Total cross section

**OPTICAL THEOREM**

**DIFFRACTION AT CDF**

**Single Diffraction or Single Dissociation**

**Double Diffraction or Double Dissociation**

**Double Pom. Exchange or Central Dissociation**

**Single + Double Diffraction (SDD)**

$JJ, b, J/\psi, W$

exclusive

$p \rightarrow p$

Diffraction 2012 Lanzarote  Diffractive Cross Sections in pp Collisions  K. Goulianos
Factor of ~8 (~5) suppression at $\sqrt{s} = 1800 (540) \text{ GeV}$

$diffractive$ $x$-section suppressed relative to Regge prediction as $\sqrt{s}$ increases

see KG, PLB 358, 379 (1995)
DD at CDF

\[
\frac{d^3\sigma_{DD}}{dt dM_1^2 dM_2^2} = \frac{d^2\sigma_{SD}}{dt dM_1^2} \frac{d^2\sigma_{SD}}{dt dM_2^2} \left/ \frac{d\sigma_{el}}{dt}\right.
\]

\[
= \left[ \kappa \beta_1(0) \beta_2(0) \right]^2 \frac{s^{2\epsilon} \epsilon^{b_{DD}t}}{16\pi (M_1^2 M_2^2)^{1+2\epsilon}}
\]

gap probability \quad x\text{-section}

\[
\frac{d^3\sigma_{DD}}{dt d\Delta\eta d\eta_c} = \left[ \frac{\kappa \beta^2(0)}{16\pi} e^{2[\alpha(t) - 1]\Delta\eta} \right] \left[ \kappa \beta^2(0) \left( \frac{s^\prime}{s_0} \right)^\epsilon \right]
\]

renormalized
SDD at CDF

- Excellent agreement between data and MBR (MinBiasRockefeller) MC

\[
\frac{d^5 \sigma}{dt t dtd \xi p d \Delta \eta d \eta_c} = \left[ \frac{\beta(t)}{4\sqrt{\pi}} e^{(\alpha(t)-1)\ln(1/\xi)} \right]^2 \times \kappa \left[ \frac{\beta(0)}{4\sqrt{\pi}} e^{(\alpha(t)-1)\Delta \eta} \right]^2 \kappa \left[ \beta^2(0) \left( \frac{s''}{s_o} \right)^\epsilon \right]
\]
CD (DPE) at CDF

- Excellent agreement between data and MBR
  - low and high masses are correctly implemented
Scale $s_0$ and triple-pom coupling

Pom. flux: interpret as gap probability

$\Rightarrow$ set to unity: determines $g_{PPP}$ and $s_0$

Two free parameters: $s_0$ and $g_{PPP}$

Obtain product $g_{PPP} \cdot s_0^{\epsilon/2}$ from $\sigma_{SD}$

Renormalized Pomeron flux determines $s_0$

Get unique solution for $g_{PPP}$

$g_{PPP} = 0.69 \text{ mb}^{-1/2} = 1.1 \text{ GeV}^{-1}$

$S_0 = 3.7 \pm 1.5 \text{ GeV}^2$

Slide #16

Diffractive Cross Sections in pp Collisions

K. Goulianos

Diffraction 2012 Lanzarote
Reduce the uncertainty in $s_0$

Saturation glueball?

Giant glue-ball with $f_0(980)$ and $f_0(1500)$ superimposed, interfering destructively and manifesting as dips (???)

Diffraction

$1.9 \text{ GeV}$

$\sqrt{s_0}$

Figure 8: $M_{\pi^-\pi^-}$ spectrum in DIFE at the ISR (Axial Field Spectrometer, R807 [97, 98]). Figure from Ref. [98]. See M.G.Albrow, T.D. Goughlin, J.R. Forshaw, hep-ph>arXiv:1006.1289

MIAMI 2010, Nov14-19 Diffraction, saturation, and pp cross sections at the LHC and beyond K. Goulianos 2
Cross Sections

- SD $\rightarrow$ single diffraction (single dissociation)
- DD $\rightarrow$ double dissociation (double diffraction)
- CD $\rightarrow$ central dissociation (double pomeron exchange)
Total, elastic, and inelastic $x$-sections

\[ \sigma_{ND} = (\sigma_{tot} - \sigma_{el}) - (2\sigma_{SD} + \sigma_{DD} + \sigma_{CD}) \]


\[ \sigma_{tot}^{p\pm p} = \begin{cases} 
16.79s^{0.104} + 60.81s^{-0.32} + 31.68s^{-0.54} & \text{for } \sqrt{s} < 1.8 \\
\sigma_{tot}^{CDF} + \frac{\pi}{s_0} \left[ \left( \ln \frac{s}{s_F} \right)^2 - \left( \ln \frac{s^{CDF}}{s_F} \right)^2 \right] & \text{for } \sqrt{s} \geq 1.8
\end{cases} \]


\[ \sqrt{s^{CDF}} = 1.8 \text{ TeV}, \quad \sigma_{tot}^{CDF} = 80.03 \pm 2.24 \text{ mb} \]

\[ \sqrt{s_F} = 22 \text{ GeV}, \quad s_0 = 3.7 \pm 1.5 \text{ GeV}^2 \]
Total, elastic, and inelastic $\sigma$-sections versus $\sqrt{s}$
TOTEM vs PYTHIA8-MBR

Diffraction 2012 Lanzarote  Diffractive Cross Sections in pp Collisions  K. Goulianos  16
ALICE tot-inel vs PYTHIA8-MBR

![Graph showing diffractive cross sections in pp collisions](image)
More on cross sections

Slide 12 from Uri Maor's talk at the LowX-2012

<table>
<thead>
<tr>
<th></th>
<th>7 TeV</th>
<th>14 TeV</th>
<th>57 TeV</th>
<th>100 TeV</th>
<th>1.2 x 10^{16} TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GLM</td>
<td>KMR</td>
<td>BH</td>
<td>GLM</td>
<td>KMR</td>
</tr>
<tr>
<td>$\sigma_{tot}$</td>
<td>94.2</td>
<td>97.4</td>
<td>95.4</td>
<td>104.0</td>
<td>107.5</td>
</tr>
<tr>
<td>$\sigma_{incl}$</td>
<td>71.3</td>
<td>73.6</td>
<td>69.0</td>
<td>77.9</td>
<td>80.3</td>
</tr>
<tr>
<td>$\frac{\sigma_{incl}}{\sigma_{tot}}$</td>
<td>0.76</td>
<td>0.76</td>
<td>0.72</td>
<td>0.75</td>
<td>0.75</td>
</tr>
</tbody>
</table>

MBR $\sigma_{tot}$ | 98 | 109 | 136 | 144 | 2257 |
Diffractive x-sections

\[
\frac{d^2\sigma_{SD}}{dt d\Delta y} = \frac{1}{N_{\text{gap}}(s)} \left[ \frac{\beta^2(t) e^{2[\alpha(t)-1]\Delta y}}{16\pi} \right] \cdot \left\{ \kappa \beta^2(0) \left( \frac{s'}{s_0} \right)^\epsilon \right\},
\]

\[
\frac{d^3\sigma_{DD}}{dt d\Delta y dy_0} = \frac{1}{N_{\text{gap}}(s)} \left[ \frac{\kappa \beta^2(0) e^{2[\alpha(t)-1]\Delta y}}{16\pi} \right] \cdot \left\{ \kappa \beta^2(0) \left( \frac{s'}{s_0} \right)^\epsilon \right\},
\]

\[
\frac{d^4\sigma_{DPE}}{dt_1 dt_2 d\Delta y dy_c} = \frac{1}{N_{\text{gap}}(s)} \left[ \prod_i \left[ \frac{\beta^2(t_i) e^{2[\alpha(t_i)-1]\Delta y_i}}{16\pi} \right] \right] \cdot \kappa \left\{ \kappa \beta^2(0) \left( \frac{s'}{s_0} \right)^\epsilon \right\}
\]

\[
\beta^2(t) = \beta^2(0) F^2(t)
\]

\[
F^2(t) = \left[ \frac{4m_p^2 - 2.8t}{4m_p^2 - t} \left( \frac{1}{1 - \frac{t}{0.71}} \right)^2 \right]^2 \approx a_1 e^{b_1 t} + a_2 e^{b_2 t}
\]

\[
\alpha_1 = 0.9, \alpha_2 = 0.1, b_1 = 4.6 \text{ GeV}^{-2}, b_2 = 0.6 \text{ GeV}^{-2}, s' = s e^{-\Delta y}, \kappa = 0.17, \kappa \beta^2(0) = \sigma_0, s_0 = 1 \text{ GeV}^2, \sigma_0 = 2.82 \text{ mb or } 7.25 \text{ GeV}^{-2}
\]
Supress x-sections at small gaps by a factor S using the error function with $\Delta y_S = 2$ for SD and DD, and $\Delta y = \Delta y_1 + \Delta y_2 = 2$ for CD (DPE).

$$S = \frac{1}{2} \left[ 1 + \text{erf} \left( \frac{\Delta y - \Delta y_S}{\sigma_S} \right) \right]$$
ALICE SD and DD vs PYTHIA8-MBR

Diffractive Cross Sections in pp Collisions

K. Goulianos
The differences between the PYTHIA8(4C) and MBR predictions are mainly due to the \((1/M^2)^{1+\varepsilon}\) behavior, with \(\varepsilon=1.104\) in MBR vs 1.08 in PYTHIA8(4C).
CD (DPE) x-sections at 7 TeV versus (a) $\Delta y=\Delta y_1+\Delta y_2$ and (b) $\Delta y_1$

- Both figures are MBR predictions with a $\Delta y=2$ cut-off in the error function.
- The normalization is absolute with no model uncertainty other than that due to the determination of the parameters in the formulas as determined from data.
SUMMARY introduction

- The ENORM (renormalization model) soft pp cross sections previously used in MBR (Minimum Bias Rockefeller) simulation are adapted to PYTHIA8.
  - MBR was successful at Fermilab in fixed target and collider experiments.
- RENORM predictions are based on a parton-model approach, in which diffraction is derived from inclusive PDFs and color factors.
- Diffractive cross sections and final states are both predicted:
  - Cross sections vs gap width or vs forward-momentum loss of proton(s):
    - Absolute normalization!
  - Hadronization of dissociated proton:
    - A (non-perturbative) “quark string” is introduced and tuned to reproduce the MBR multiplicity and \( p_T \) distributions.
    - \( dN/d\eta, p_T, \) and particle ID: new in this PYTHIA8 implementation (the original MBR simulation produced only \( \pi^\pm \) and \( \pi^0 \)).
  - Unique unitarization based on a saturated “glue-ball” exchange.
- Total Cross section \( \sim \ln^2 s \) based on a glue-ball-like saturated-exchange.
  - Immune to eikonalization-model dependences.

Thank you for your attention
References in arXiv:1205.1446v2 [hep-ph]


