Total, elastic and diffractive cross-sections with TOTEM

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on behalf of the TOTEM collaboration

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TOTEM physics programme

Elastic scattering

Total cross-section

Soft and hard diffraction
part I

Elastic scattering and Total cross-section
Three methods for total cross-section

elastic observables only:

\[ \sigma_{tot}^2 = \frac{16\pi}{1 + \varrho^2} \frac{1}{\mathcal{L}} \left( \frac{dN_{el}}{dt} \right)_0 \]

\( \varrho \)-independent:

\[ \sigma_{tot} = \frac{1}{\mathcal{L}} \left( N_{el} + N_{inel} \right) \]

luminosity-independent:

\[ \sigma_{tot} = \frac{16\pi}{1 + \varrho^2} \frac{dN_{el}/dt}{N_{el} + N_{inel}} \]

\begin{itemize}
  \item elastic rate
    \( \Rightarrow \) Roman Pot detectors
  \item inelastic rate
    \( \Rightarrow \) telescopes T1 and T2
  \item luminosity
    \( \Rightarrow \) provided by CMS
  \item \( \varrho \equiv \frac{\text{Re} A_{el}}{\text{Im} A_{el}} \bigg|_{t=0} \)
    \( \Rightarrow \) from COMPETE extrapolation
\end{itemize}

ingredients
Detector apparatus

- telescopes T1 and T2 charged particles from inelastic collisions
  - T1: $3.1 < |\eta| < 4.7$
  - T2: $5.3 < |\eta| < 6.5$

- Roman Pots at the LHC elastic and diffractive protons

- all detectors symmetrically on both sides of IP5
- all detectors trigger-capable
**Proton measurement with Roman Pots**

LHC magnet lattice ⇒ accelerator optics

\[ x(RP) = (\text{effective length } L_x) \cdot (\text{scattering angle } \theta_x^* ) + (\text{magnification } v_x ) \cdot (\text{vertex } x^* ) + (\text{dispersion } D_x) \cdot (\text{rel. momentum loss } \xi \equiv \Delta p/p) \]

- optics defines what and how can be observed:

the same sample of elastic events seen with different optics:

- this presentation: optics \( \beta^* = 90 \text{ m} \) used (almost) everywhere
Elastic scattering measurement

1. Kinematics reconstruction
   - proton tracks in RPs $\xrightarrow{\text{inverse optics}}$ proton kinematics at IP

2. Elastic tagging
   - elastic event = 2 anti-collinear protons from the same vertex $\Rightarrow$ compare left and right reconstructed protons
   - each proton $\xi \approx 0 \Rightarrow$ correlation hit position vs. track angle at RPs

3. Acceptance corrections
   - RP sensors have finite size, LHC apertures
   - azimuthal symmetry $\Rightarrow$ geometrical correction (+ smearing around edges)

4. Unfolding of resolution effects
   - angular resolution from data (compare left and right protons)
   - Monte Carlo $\Rightarrow$ impact on $t$-distribution

5. Inefficiency corrections
   - uncorrelated one-RP inefficiencies
   - near-far correlated RP inefficiencies
   - “pile-up” = elastic event + another track in a RP

6. Luminosity
   - from CMS (if available), uncertainty $\approx 4\%$
Elastic scattering results

√s = 7 TeV

√s = 8 TeV

Fit/extrapolation: \( e^{-B|t|} \)
\( B = (19.9 \pm 0.3) \text{ GeV}^2 \)

CMS luminosity unavailable
Total cross-section results

inelastic rate measurement: see Giuseppe Latino’s talk (on Monday)

\[ \sqrt{s} = 7 \text{ TeV} \]
[CERN-PH-EP-2012-353]

elastic observables only:

\[ \sigma_{\text{tot}} = \frac{16\pi}{1 + \varrho^2} \frac{1}{\mathcal{L}} \left. \frac{dN_{\text{el}}}{dt} \right|_0 \]

\[ \sigma_{\text{tot}} = (98.6 \pm 2.3) \text{ mb} \]

\( \varrho \)-independent:

\[ \sigma_{\text{tot}} = \frac{1}{\mathcal{L}} (N_{\text{el}} + N_{\text{inel}}) \]

\[ \sigma_{\text{tot}} = (99.1 \pm 4.4) \text{ mb} \]

\( \mathcal{L} \)-independent:

\[ \sigma_{\text{tot}} = \frac{16\pi}{1 + \varrho^2} \frac{1}{N_{\text{el}} + N_{\text{inel}}} \left. \frac{dN_{\text{el}}}{dt} \right|_0 \]

\[ \sigma_{\text{tot}} = (98.1 \pm 2.4) \text{ mb} \]

\[ \sqrt{s} = 8 \text{ TeV} \]

elastic observables only:

\[ \sigma_{\text{tot}} = \frac{16\pi}{1 + \varrho^2} \frac{1}{\mathcal{L}} \left. \frac{dN_{\text{el}}}{dt} \right|_0 \]

\[ \sigma_{\text{tot}} = (101.7 \pm 2.9) \text{ mb} \]

\( \varrho \)-independent:

\[ \sigma_{\text{tot}} = \frac{1}{\mathcal{L}} (N_{\text{el}} + N_{\text{inel}}) \]

\[ \sigma_{\text{tot}} = (101.7 \pm 2.9) \text{ mb} \]

(CMS luminosity unavailable)
**TOTEM results in context**

- outlook: successful data-taking with $\beta^* = 1000$ m optics – goal: $\varrho$ determination
part II

Diffraction

double-pomeron exchange (DPE)
  (central production)

single diffraction (SD)

double diffraction (DD)
Optics for diffractive studies

$\beta^* = 90\, \text{m}$

- optical functions at RP 220:
  $L_x \approx 0, \quad L_y \approx 260\, \text{m}, \quad D_x \approx 4\, \text{cm}$
  ↓
  diffractive protons in **vertical RPs**
  (a DPE sample)

- $|\xi|_{\text{min}} = 0\% \Rightarrow \text{low masses}$
- $\xi$-resolution
  - RPs only: (0.4 to 1)$\%$ ($t$-dependent)
  - with CMS vertex: $\approx 2\times$ better

used in 2012

- low $\beta^*$ (0.7 m here)

- optical functions at RP 220:
  $L_x \approx 1.7\, \text{m}, \quad L_y \approx 14\, \text{m}, \quad D_x \approx 8\, \text{cm}$
  ↓
  diffractive protons in **horizontal RPs**
  (a DPE sample)

- $|\xi|_{\text{min}} = 2.8\% \Rightarrow \text{higher masses}$
- $\xi$-resolution
  - RPs only: $\approx 0.2\%$

planned after long shutdown
available data
- $\sqrt{s} = 7$ TeV, $\beta^* = 90$ m, TOTEM alone: analysis ongoing
- $\sqrt{s} = 8$ TeV, $\beta^* = 90$ m, TOTEM+CMS: analysis ongoing
  (CMS trigger: di-jets with $p_T > 20$ GeV)

measurement with RPs only
- integrate over all $\xi \Rightarrow$ determine $|t|$-distribution
- extrapolate $t$-distribution $\Rightarrow$ integrated DPE cross-section

measurement with CMS
- double determination of diffractive-system mass: RPs (both sides!) and CMS
- goals: cross-sections and exceptional-event search
Single diffraction

- available data
  - $\sqrt{s} = 7$ TeV, $\beta^* = 90$ m: analysis ongoing
  - $\sqrt{s} = 8$ TeV, $\beta^* = 90$ m (TOTEM + CMS)

- event topologies $\Rightarrow$ mass classes

<table>
<thead>
<tr>
<th>mass</th>
<th>$\xi$ region</th>
<th>proton side</th>
<th>opposite side</th>
</tr>
</thead>
<tbody>
<tr>
<td>low mass</td>
<td>$\xi &lt; 10^{-6}$</td>
<td>nothing</td>
<td>T2 only</td>
</tr>
<tr>
<td>medium mass</td>
<td>$10^{-6} &lt; \xi &lt; 0.25%$</td>
<td>nothing</td>
<td>T1 and T2</td>
</tr>
<tr>
<td>high mass</td>
<td>$0.25% &lt; \xi &lt; 2.5%$</td>
<td>T1 only</td>
<td>T1 and T2</td>
</tr>
<tr>
<td>very high mass</td>
<td>$\xi &lt; 2.5%$</td>
<td>T1 and T2</td>
<td>T1 and T2</td>
</tr>
</tbody>
</table>

- double measurement of $\xi$:
  - RPs + optics
  - rapidity gap in T1/T2

- goals: integrated and differential SD cross-sections
Double diffraction

- available data
  - $\sqrt{s} = 7$ TeV, $\beta^* = 90$ m: analysis ongoing
  - $\sqrt{s} = 8$ TeV, $\beta^* = 90$ m

- trigger types
  - T1 and T2: dominated by MB $\Rightarrow$ background estimation
  - T2 but not T1: sensitive to DD

- goals
  - integral cross-section
  - differential cross-section (as function of $\eta_{\text{min}}$)