First measurement of $\sigma_{\text{tot}}$ and $\sigma_{\text{el}}$ expectations for 2011/12

LHCC
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on behalf of the TOTEM Collaboration
Elastic scattering differential cross-section

$\beta^* = 3.5 \text{ m, Oct. 2010}$  (EPL 95 2011, 41001)

Extend the measurement to lower $|t|$ values
Total Cross-Section Measurement

Optical Theorem:

\[
\sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1 + \rho^2} \cdot \left. \frac{d\sigma_{EL}}{dt} \right|_{t=0}
\]

Use \(\rho\) from COMPETE fit:

\(\rho = 0.14^{+0.01}_{-0.08}\)

Normalisation with luminosity from CMS

Uncertainty \(\pm 4\%\)

\[
\frac{d\sigma_{EL}}{dt} = \frac{1}{L} \cdot \frac{dN_{EL}}{dt}
\]

\(\Rightarrow\) Measure \(d\sigma_{el} / dt\) at lowest possible \(|t|\)
First run with the $\beta^* = 90 \text{ m}$ optics and RP insertion

- Two bunches with 1 and $2 \times 10^{10}$ protons / bunch
- Instantaneous luminosity: $8 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$
- Integrated luminosity: 1.7 $\mu$b$^{-1}$
- Estimated pile-up: $\sim 0.5 \%$
- Vertical Roman Pots at 10 $\sigma$ from beam center
- Trigger rate: $\sim 50 \text{ Hz}$
- Recorded events in vertical Roman Pots: 66950

Un-squeeze from injection optics
$\beta^* = 11 \text{m} \text{ to } 90 \text{m}$
[Helmut Burkhardt, Andre Verdier]

Very robust optics with high precision
Proton tracks of a single diagonal (left-right coincidences)

\[ \beta^* = 3.5 \text{ m} \]

\[ \beta^* = 90 \text{ m} \]

**Sector 45**

\[ x = L_x \Theta_x + \xi D + v_x x^* \]
\[ y = L_y \Theta_y + v_y y^* \]
\[ L_x \sim 0 \]

**Sector 56**

\[ t = -p^2 \theta^2 \]
\[ \xi = \Delta p/p \]

Integrated luminosity: 6.2 nbarn\(^{-1}\)

Inel. pile-up \( \sim 0.8 \text{ ev/bx} \)

Integrated luminosity: 1.65 \( \mu \text{barn}^{-1} \)

Inel. pile-up \( \sim 0.005 \text{ ev/bx} \)
Angular Correlations between outgoing protons

- Background negligible $< 1\%$
- Width of correlation band in agreement with beam divergence ($\sim 2.4 \, \mu\text{rad}$)

$L_y \sim 260 \, \text{m}$

$L_x \sim 0 - 3 \, \text{m}$
Angular difference between the two outgoing protons

\[
\frac{[\Theta_y^* (\text{proton1}) - \Theta_y^* (\text{proton2})]}{\sqrt{2}}
\]

beam divergence \(\sigma_{\Theta^*}\)

\[
\sigma_{\Theta^*} = \sqrt{\frac{\varepsilon_n}{\gamma \beta^*}} = 2.4 \mu\text{rad}
\]
Optics, t-scale and acceptance

- Perturbations: optics very robust ($L_y \sim s_{RP}$), better than:
  - $\delta \Theta_x^*/\Theta_x^* = 1.3\%_{syst}$
  - $\delta \Theta_y^*/\Theta_y^* = 0.4\%_{syst}$
- Non-linearities in $\Theta_x^*(y)$ reconstruction due to $dL_x/ds$ fixed: (checked via $L_x$)
- t systematics: $\delta t/t = 0.8\%$ (low t) up to 2.6\% (large $|t|$)
- Acceptance correction factor $< 3$ at low $|t|$, based on $\phi$ symmetry
Comparison of the two diagonals

Acceptance corrected
Efficiency Correction and Resolution Unfolding

Trigger efficiency \( \sim 99.9\% \)
Reconstruction efficiency \( \sim 91\% \)

\[ \sigma\left(\Theta_x^*\right) = \sqrt{1.7^2 \text{ (from beam div.)} + 4^2 \text{ (det. res.)}} = 4.4 \mu\text{rad} \]

\[ \sigma\left(\Theta_y^*\right) = 1.7 \mu\text{rad} \text{ (from beam div.)} \]

Unfolding correction

Effect on slope: \( \Delta B = 0.11 \text{ GeV}^{-2} \)
Final Differential Cross-Section

Extrapolation to $t = 0$:

$$\frac{d\sigma}{dt} \bigg|_{t=0} = 5.037 \times 10^2 \text{mb/GeV}^2$$

Exponential slope

$$B \bigg|_{t=0} = 20.1 \text{GeV}^{-2}$$

Good agreement with the measurement at $|t| > 0.36 \text{GeV}^2$

[EPL 95 (2011) 41001]

Total elastic cross-section:

$$\sigma_{EL} = 8.3 \text{mb}^{(\text{extrapol})} + 16.5 \text{mb}^{(\text{measured})} = 24.8 \text{mb}$$
Systematics and Statistics

- **t**: \( \pm [0.6 \div 1.8]\% \text{syst optics} \pm <1\% \text{align.} \pm [3.4 \div 11.9]\% \text{stat} \) (before unfolding)
- **d\sigma/dt**: \( \pm 4\% \text{syst lumin} \pm 1\% \text{syst (acc.+eff.+backg.+tag)} \pm 0.7\% \text{syst unfold.} \)
- **B**: \( \pm 1\% \text{stat} \pm 1\% \text{syst from } t \pm 0.7\% \text{syst from unfolding} \)
- **d\sigma/dt(t=0)**: \( \pm 0.3\% \text{stat} \pm 0.3\% \text{syst (optics)} \pm 4\% \text{syst lumin} \pm 1\% \text{syst (acc.+eff.+backg.+tag)} \)
- **\( \int d\sigma/dt \, dt $$\)**: \( \pm 4\% \text{syst lumin} \pm 1\% \text{syst (acc.+eff.+backg.+tag)} \pm 0.8\% \text{stat extrap.} \)

- **\( \sigma_{\text{TOT}} $$**: \( (+0.8\% ; -0.2\%) \text{syst } \rho \pm 0.2\% \text{stat} \pm 2.7\% \text{syst} \\
  = (+2.8\% ; -2.7\%) \text{syst } \pm 0.2\% \text{stat} \)
- **\( \sigma_{\text{EL}} $$**: \( \pm 5\% \text{syst} \pm 0.8\% \text{stat} \)
- **\( \sigma_{\text{INEL}} $$**: \( (+2.4\% ; -1.8\%) \text{syst } \pm 0.8\% \text{stat} \)
Results

Elastic exponential slope:

\[ B_{t=0} = (20.1 \pm 0.2^{(\text{stat})} \pm 0.3^{(\text{syst})}) \text{ GeV}^{-2} \]

Elastic diff. cross-section at optical point:

\[ \left. \frac{d\sigma_{el}}{dt} \right|_{t=0} = (503.7 \pm 1.5^{(\text{stat})} \pm 26.7^{(\text{syst})}) \text{ mb/GeV}^2 \]

Optical Theorem, \( \rho = 0.14^{+0.01}_{-0.08} \)

\[
\sigma_T = \left( 98.3 \pm 0.2^{(\text{stat})} \pm 2.7^{(\text{syst})} \left[ +0.8 \right]^{(\text{syst from } \rho)} \right) \text{ mb}
\]

\[
\sigma_{el} = 8.3 \text{ mb}^{(\text{extrapol.})} + 16.5 \text{ mb}^{(\text{measured})} = \left( 24.8 \pm 0.2^{(\text{stat})} \pm 2.8^{(\text{syst})} \right) \text{ mb}
\]

\[
\sigma_{inel} = \sigma_{tot} - \sigma_{el} = \left( 73.5 \pm 0.6^{(\text{stat})} \left[ +1.8 \right]^{(\text{syst})} \right) \text{ mb}
\]

\[
\sigma_{inel}^{(\text{CMS})} = (68.0 \pm 2.0^{(\text{syst})} \pm 2.4^{(\text{lumi})} \pm 4.0 \text{ (extrap)}) \text{ mb}
\]

\[
\sigma_{inel}^{(\text{ATLAS})} = (69.4 \pm 2.4^{(\text{exp})} \pm 6.9 \text{ (extrap)}) \text{ mb}
\]
Energy dependence of the exponential slope B
Energy dependence of the elastic and total cross-sections

- $\sigma_{\text{tot}}$
- $\sigma_{\text{el}}$

- $\sqrt{s}$ (GeV)

- Best COMPETE $\sigma_{\text{tot}}$ fits
- Parabolic $\sigma_{\text{el}}$ fit

- PP
- p̅p
- TOTEM
Energy dependence of inelastic cross-sections

\( \sigma_{\text{tot}} \) (red), \( \sigma_{\text{inel}} \) (blue) and \( \sigma_{\text{el}} \) (green)

- \( \bar{p}p \) (PDG)
- \( pp \) (PDG)
- Auger + Glauber
- ATLAS
- CMS
- TOTEM

best COMPETE \( \sigma_{\text{tot}} \) fits
parabolic \( \sigma_{\text{el}} \) fit

\( \sigma_{\text{tot}} \), \( \sigma_{\text{inel}} \), and \( \sigma_{\text{el}} \) (mb)

\( \sqrt{s} \) (GeV)
Running Strategy for 2011/12

RP alignment was performed at $\beta^* = 1.5$ m by approaching the RP detectors to the sharp beam edges produced by the LHC collimators. Qualification for running at $\beta^* = 1$ m, obtained via loss maps.

$\beta^* = 90$ m

29. June: machine test run and first RP insertion to $10 \sigma$ using alignment at $\beta^* = 1.5$ m
   30 min of data taking $\Rightarrow$ first measurement of $\sigma_{\text{tot}}$

August: alignment of all vertical RPs, beam lost before hor. Alignment
   No data taking

Plan for end of September:
   5 hours data taking at $5 \sigma$ (vertical RP) $\Rightarrow$ luminosity independent measurement

Horizontal alignment

October: at least one more run with 147 m alignment $\Rightarrow$ diffraction

2012:

Toward larger $\beta^* \sim 1$ km
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