PHYSICS AND STATUS OF TOTEM

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on behalf of the

TOTEM Collaboration
http://totem.web.cern.ch/Totem/
TOTEM Physics Overview

Total cross-section

Elastic Scattering

Diffraction: soft and hard

Forward physics

Physics at LHC 2008

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Current models predictions: 90-130 mb

Aim of TOTEM: ~1% accuracy

COMPETE Collaboration fits all available hadronic data and predicts:

\[ \sigma_{tot} = 111.5 \pm 1.2 \pm 4.1 \text{ mb} \]

[PRL 89 201801 (2002)]
Facts about the proton

Regge:
\[ \sigma_{\text{tot}} \sim \sum A_i s^{\alpha_i(0)-1} \quad \alpha_p = 1.08 \quad \alpha_R = 0.54 \]
\[ \sim 21.7 \quad s^{0.0808} + 56.08 \quad s^{-0.4525} \]

Geom. Scaling:
\[ \sigma_{\text{el}} \sim \sigma_{\text{tot}} \sim B(s,0) \sim R^2(s) \sim \ln^2 s \]
Elastic pp Scattering: Predictions for 14 TeV

3-gluon exchange at large $t$:

$$\frac{d\sigma}{dt} \sim C t^{-8} \quad \text{independent of } s$$

Big uncertainties at large $t$

TOTEM will measure the complete range with good statistics
Experimental layout of TOTEM

Leading Protons detectors at 147,220m from the IP

Longest experiment at the LHC (440m)
The TOTEM Detectors

Inelastic Telescopes:
- T1: $3.1 < |\eta| < 4.7$
- T2: $5.3 < |\eta| < 6.5$

Roman Pots:
- RP1
- RP2
- Cathode Strip Chambers (CSC)
- $3.1 < |\eta| < 4.7$
- 5 planes with measurement of 3 coordinates per plane
- 3 deg rotation and overlap between adjacent planes
- Primary vertex reconstruction allows background rejection
- Trigger with anode wires
Two trusses with rails will be fixed to the internal walls of CMS return yoke

Insertion and fixation test successfully done at IP5

CSC mounted on frames will slide into final position

Mounting and sliding test of “half basket” performed at Genova
T1 Telescope

Production at Gatchina (PNPI): 70 CSCs
Test and assembly done at CERN

Ageing studies at the GIF: 12-month test with ~0.07 C/cm accumulated charge on wires corresponding to ~ 5 years at $L=10^{30}\text{cm}^{-2}\text{s}^{-1}$
Cosmic Ray test set-up

15 CSCs for first ¼ telescope

Even firemen help !!
1/4 T1 Telescope complete with CSC chambers

15 CSCs mounted 3 by 3

Tilt between layers
The T2 Telescope

10 triple-GEM planes on each side of the IP to cope with high particle fluxes.

$5.3 < |\eta| < 6.6$
T2 Telescope (GEM)

- 65(φ) x 24(η) = 1560 pads
- Pads: Δη x Δφ = 0.06 x 0.015π
- 2x2 mm² – 7x7 mm²
- Strips: 256 (width: 80 μm, pitch: 400 μm)

Technology used in COMPASS
T2 and its Electronics

Lab setup:

- Beam Board
- Pad VFAT
- Strip VFAT
- GEM
- Kapton Connectors
- Adapter Card
- HorseShoe Card
- VFAT Emulator
- HorseShoe Card
T2 GEM Assembly

Production at Helsinki
Final assembly at CERN
Installation of the T2 telescope in CMS
Mechanical rigid connections between horizontal and vertical pots and BPM important for alignment
Roman pots at 220m
Roman pots at 147 m
All Roman Pots Installed at the LHC
Si Edgeless Detectors for Roman Pots

Planar technology with CTS
(Current Terminating Structure)

- Current terminating ring
- Biasing ring
- Al
- SiO₂
- p⁺
- n⁺
- Cut edge
- 50μm

[Graph showing efficiency with coordinates and dimensions]

3.5 cm

66 μm

50 μm

CTR CR Cut Edge

Physics at LHC 2008

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The Hybrid and the Assembly

Kapton hybrids laminated on CE7

Assembly of 10 detectors

“Champignon”

Motherboard
The window and the detector assembly
Level-1 Trigger Schemes at all run conditions

TOTEM trigger rate: few kHz adjusted to luminosities

- Elastic Trigger:
- Single Diffractive Trigger:
- Double Diffractive Trigger:
- Central Diffractive Trigger:
- Minimum Bias Trigger:
η–Acceptance

All detectors with trigger capability
Trigger acceptance > 95% for all inelastic events

<table>
<thead>
<tr>
<th>Process</th>
<th>σ [mb]</th>
<th>trigger loss [mb]</th>
<th>systematic error after extrapolations [mb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-diffractive inelastic</td>
<td>58</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Single diffractive</td>
<td>14</td>
<td>3</td>
<td>0.6</td>
</tr>
<tr>
<td>Double diffractive</td>
<td>7</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Double Pomeron</td>
<td>1</td>
<td>0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td>3.6</td>
<td>0.8</td>
</tr>
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</table>
• Measure $\xi$
• Compare with rap gap $\Delta \eta = -\ln \xi$
  gap suppression
• Cross-section $\sigma(\xi, t)$

\[
\left( \frac{d\sigma}{d\Delta \eta} \right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \Rightarrow \frac{d\sigma}{d\xi} \sim \frac{1}{\xi}
\]
Signatures of Single Diffractive Events

\[ \xi = \Delta p / p \]

Rapidity Gap

\[ -\ln \xi \]

\[ (M_x^2 = \xi s) \]

Typical individual cross-sections:

\[ \sigma \sim 1 - 2 \text{ mb} \]

Multiplicity distributions are difficult
Measurement of Forward Protons: the principle

Diffractive protons: hit distribution @ RP220

low $\beta = 0.5 - 2 \text{ m}$

$y \sim \Theta_y^{\text{scatt}} \sim |t_y|^{1/2}$

$x \sim \xi = \Delta p/p$

high $\beta = 90 \text{ m}$

Detect the proton via:

its momentum loss (low $\beta$)

its transverse momentum (high $\beta$)
Measurement of Forward Protons: the Acceptances

Variables in diffraction: $\xi$, $t$ and related mass $M$

Measure individual cross-sections and the correlation between the above variables

Study of the corresponding rapidity gap and its suppression
Outlook: Proton Detection at Lower $\xi$-Values

Good acceptance and momentum resolution for diffractive protons needs:
- large dispersion $D$ (few m) \( (x = \xi D) \)
- small beam width (< 1 mm)

Where in the LHC is it easy and are these requirements best fulfilled?
Proton Acceptance of a “Combined IP3 + RP220 TOTEM” Experiment

Double Pomeron Exchange

\[ M_{pp}^2 = \xi_1 \xi_2 s \]

\(\xi\)-Acceptance

DPE Mass Spectrum with Detector Acceptance

\[
\begin{align*}
\text{Beam 1} & \quad \text{Beam 2} \\
\text{IR3} & \quad \text{RP 220}
\end{align*}
\]
Running scenarios also with CMS

pp→pX                               pp→pjjX                            pp→pjjp   (bosons, heavy quarks, Higgs...)

soft diffraction              (semi)-hard diffraction                  hard diffraction

Cross section                                                                                 Luminosity

<table>
<thead>
<tr>
<th>β (m)</th>
<th>1540</th>
<th>90</th>
<th>2</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>L (cm⁻² s⁻¹)</td>
<td>10²⁹</td>
<td>10³⁰</td>
<td>10³²</td>
<td>10³⁴</td>
</tr>
</tbody>
</table>

TOTEM runs

Standard runs

Accessible physics depends on luminosity & $\beta^*$
90% (65%) of all diffractive protons are detected for $\beta^* = 1540\ (90)\ m$

$\eta = -\ln\ tg\ \theta/2$
**pp Interactions**

**Non-diffractive**
Colour exchange

\[ \frac{dN}{d\eta} = \exp(-\Delta\eta) \]

**Diffractive**
Colourless exchange with vacuum quantum numbers

\[ \frac{dN}{d\eta} = \text{const} \]

Incident hadrons acquire colour and break apart

Incident hadrons retain their quantum numbers remaining colourless

GOAL: understand the QCD nature of the diffractive exchange
will be ready for the runs in 2009

will run under all beam conditions with a complete detector in 2009

will need special high $\beta^*$ runs (hopefully in 2009) for:
  total cross-section
diffraction

will pursue a common physics program with CMS in a later stage

Diffractive scattering is a unique laboratory of confinement & QCD:
A hard scale + protons which remain intact in the scattering process