Prospects for Diffractive and Forward Physics at the LHC

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on behalf of the CMS/TOTEM Collaboration

Author List

Experimental apparatus

T1: $3.1 < \eta < 4.7$
T2: $5.3 < \eta < 6.5 = \text{Castor}$
CMS/TOTEM common physics program

Largest coverage in pseudorapidity & proton detection on both sides
Physics menu

Low Luminosity ($\leq 10^{32} \text{ cm}^{-2}\text{s}^{-1}$): low & high $\beta^*$

- Measure inclusive SD and DPE cross sections:
  - $t$, $M_x$ dependence
  - Study of topology e.g. rapidity gap
- Measure semi-hard SD and DPE:
  - Onset of jet activity
- Muller-Navelet dijets
- Forward Drell-Yan
- Validation of Cosmic Ray generators

High Luminosity ($> 10^{32} \text{ cm}^{-2}\text{s}^{-1}$) : low $\beta^*$

- Measure SD and DPE in presence of hard scales (dijets, vector bosons, heavy quarks): dPDF, GPD
- $\gamma\gamma$ and $\gamma p$ physics

High Luminosity ($> 10^{33} \text{ cm}^{-2}\text{s}^{-1}$) : low $\beta^*$

- Discovery physics in central exclusive production
  - SM or MSSM Higgs, other exotic processes
Contents of the common document

Includes important experimental issues in measuring forward and diffractive physics but not an exhaustive physics study

- Detailed studies of acceptance & resolution of the forward proton detectors
- Trigger
- Background
- Reconstruction of kinematic variables

Several exemplary processes are studied in detail

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An important milestone in the collaboration between the two experiments
X=anything : dominated by soft physics

- Measure fundamental quantities of soft QCD: SD and DPE inclusive cross sections, their $s$, $t$, $M_x$ dependences are fundamental parameters of non-perturbative QCD.

- Contributes to the pile up.

X includes jets, $W$’s, $Z$’s, Higgs (!): hard processes calculable in pQCD

- Give info on proton structure (dPDFs and GPDs), QCD at high parton densities, multi-parton interactions, discovery physics
Running scenario

- Soft diffraction: $pp \rightarrow pX$
- (Semi)-hard diffraction: $pp \rightarrow pjjX$
- Hard diffraction/exclusive processes: $pp \rightarrow pjj(X)$

Cross section vs. Luminosity

<table>
<thead>
<tr>
<th>$\sigma$ (mb)</th>
<th>$\mu$b</th>
<th>nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L (cm^{-2} s^{-1})$</td>
<td>$10^{28}$</td>
<td>$10^{30}$</td>
</tr>
<tr>
<td>$\beta (m)$</td>
<td>1540</td>
<td>90</td>
</tr>
</tbody>
</table>

TOTEM runs vs. Standard runs

The accessible physics depends on: luminosity

$\beta^*$ (different proton acceptance)
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: Acceptance (@220m)

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

- \( t(GeV^2) \)
  - \( \beta = 1540 \)
  - \( \beta = 90 \)

\( \xi = \Delta p/p \)

- \( \beta = 1540 \)
- \( \beta = 90 \)
- low \( \beta \)
Measurement of Forward Protons: Acceptance

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

\[ \beta = 1540 \]

\[ \beta = 90 \]

\[ \beta = 0.5 \]

\[ \xi = \Delta p/p \]
Measurement of Forward Protons: momentum resolution (low $\beta$)

Individual contribution to the resolution:

- Detector resolution (10$\mu$m)
- Beam position res. (50$\mu$m)
- Vertex smear. (10$\mu$m)
- relative beam energy spread ($10^{-4}$)

$\sigma(\xi)/\xi$ total

Studies available also for $\beta=1540, 90, \text{all RP stations}$
Measurement of Forward Protons: momentum resolution

\[ \frac{\Delta \xi}{\xi} \]

- \( \beta = 90, \) RP220
- low \( \beta, \) RP220
- low \( \beta, \) RP420
# Assumption on Trigger Rates

<table>
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<tr>
<th></th>
<th>L1(kHz)</th>
<th>HLT/tape (Hz)</th>
</tr>
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<tr>
<td>CMS</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>TOTEM</td>
<td>~2</td>
<td>~2000</td>
</tr>
<tr>
<td>CMS/TOTEM</td>
<td>~2</td>
<td>100</td>
</tr>
<tr>
<td>CMS/TOTEM</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Trigger rates

\[ \sigma \]

\[ L = 10^{30} \quad L = 10^{32} \]

\[ \beta = 90 \text{ m} \quad \beta = 2 \text{ m} \]

| \begin{array}{|c|c|c|}
| \hline
| 1 \text{ p} & 14 \text{ mb} & 6000 \quad 140 \times 10^3 \\
| T1/T2 & & \\
| \hline
| 2 \text{ p} & 1 \text{ mb} & 200 \quad 3.5 \times 10^3 \\
| T1/T2 & & \\
| \hline
| 1 \mu b & 0.2 & \\
| (p_T^{\text{jet}} > 20 \text{ GeV}) & & \\
| 30 \text{ nb} & 0.01 & 0.5 \\
| (p_T^{\text{jet}} > 50 \text{ GeV}) & & \\
| \hline
| 60 \text{ nb} & 10^{-3} & \\
| (p_T^{\text{jet}} > 20 \text{ GeV}) & & \\
| 1.5 \text{ nb} & 0.03 & \\
| (p_T^{\text{jet}} > 50 \text{ GeV}) & & \\
| \hline
\end{array} \]

Estimated Rates (Hz) [acceptance corrected]
Diffraction at low luminosity ($<10^{32}$ cm$^{-2}$ s$^{-1}$)

soft diffraction

Inclusive cross sections and their $t$, $M_x$ dependence

Topology of the events

Measure $\xi$ and central Mass via:

- proton(s)
- rapidity gap relation $\Delta \eta = -\ln \xi$
- calorimeters
  $$\xi = \sum_i E_i^T \exp(\mp \eta_i) / \sqrt{s}$$

Wide range $t$, $\xi$ acceptance with special optics

These processes contribute to the pile-up at high luminosity
Diffraction at low luminosity: soft diffraction (DPE)

Differential Mass distribution, acceptance corrected

Number of event collected in a few days

\[ \beta = 90 \text{m} \quad \int L dt = 0.3 (\text{pb}^{-1}) : \]

\[ 1 < M < 2000 \text{ GeV} \quad N \sim 6 \times 10^7 \]

\[ \beta = 2 \text{m} \quad \int L dt = 10 (\text{pb}^{-1}) : \]

\[ M > 300 \text{ GeV} \quad N \sim 10^8 \]
Diffraction at low luminosity: DPE Central Mass Resolution

\[ \beta = 90 \text{m} \quad \text{RP220} \]

\[ \sigma(M) \text{[GeV]} = (\xi_1 \xi_2 s)^{1/2} \]
Diffraction at low luminosity: DPE Central Mass Resolution

$\beta = 90 \text{m} \quad $ RP220

$$\xi_{\text{lower}} / \xi_{\text{higher}}$$

- $0.01-0.1$
- $0.1-0.5$
- $0.5-1.0$

$\sigma(M)[\text{GeV}]$ vs $M[\text{GeV}]$

$\sigma(M) = (\xi_1 \xi_2 s)^{1/2}$
Diffraction at low luminosity: rapidity gaps

Measure $\xi$ via rapidity gap: $\Delta \eta = -\ln \xi$

Achieved precision: $\sigma(\xi)/\xi \sim 80\%$
Diffraction at low luminosity: semi-hard diffraction

\[ \int \frac{d\sigma}{dp_T} \]

\( \beta = 90 \quad \int L dt = 0.3 \text{ (pb}^{-1}) \)

SD: \( p_T > 20 \text{ GeV} \quad 6 \times 10^4 \)

DPE: \( " \quad 2000 \)

\( \beta = 2 \quad \int L dt = 100 \text{ (pb}^{-1}) \)

SD: \( p_T > 50 \text{ GeV} \quad 5 \times 10^5 \)

DPE: \( " \quad 3 \times 10^4 \)
Diffraction at low luminosity: semi-hard diffraction

Measure the cross sections and their $t, M_X, p_T^{jet}$ dependence

Topology of the events: for example exclusive vs inclusive jet production

In addition to the previous methods, $\xi$ and central mass can be determined from calorimeter information:

$$\xi = \sum_i E_T^i e^{\eta_i}/\sqrt{s} \quad \sigma(\xi)/\xi \sim 40\%$$
Summary (Part I)

Important experimental issues have been addressed in the common document:

**Detailed studies of acceptance & resolution of the forward proton detectors for all scenarios**

**Machine induced background (not discussed, see document)**

Physics reach:

**Already at low luminosity diffractive processes, from low masses up to a few TeV, can be measured**

**The topology of the events can be studied and correlated with the forward proton**

**At medium luminosity the onset of jet activity in diffractive events can be investigated**

*Part II is now presented by M. Grothe*