Forward Physics at TOTEM

- V. Avati
  - (CERN, Case Western Reserve University)

**TOTEM**

- New Optics ($\theta = 90$ m)
- Total cross-section measurement
- Study of elastic scattering
- Soft diffraction

**CMS/TOTEM**

"Prospects for Diffractive and Forward Physics at the LHC"
- (CERN/LHCC 2006-039/G-124)

International Workshop on QCD at Cosmic Energies III
- Trieste, May 30, 2007
Physics program

Total cross-section

Elastic pp scattering in the range $10^{-3} < t = (p\Box)^2 < 10 \text{ GeV}^2$

Soft diffraction

Measurement of leading particles

Particle and energy flow in the forward direction

Soft and hard diffraction in Single and Double Pomeron Exchange
production of jets, W, heavy flavours.....

Central Exclusive Particle production

Low-x Physics

$\gamma\gamma$ and $\gamma p$ physics
TOTEM

T1: 3.1 < \eta < 4.7
T2: 5.3 < \eta < 6.5

RP (147 m)  RP (220m)
Detectors: T1/T2

T1 Telescope
3.1<\theta_{\text{V}}<4.7
CSC: 5 planes

Fully inclusive trigger inelastic events
Primary vertex reconstruction

T2 Telescope
5.3<\theta_{\text{V}}<6.5
GEM: 10 “half-”planes

Mechanical frames and CSC detectors in production; tests in progress.

75 % of GEM chambers produced and tested up to a gain of 8 x 10^4.

Installation schedule not yet defined (deadline April 08 ?)
Roman Pot & Leading Proton Detector

Each pot equipped with 10 planes “edgeless” Silicon detectors (in production)

BPM fixed to the structure (precise position of the beam)
First Roman Pot station successfully installed in the LHC tunnel !!!
Current models predict for 14 TeV: 90 – 130 mb

Aim of TOTEM: ~ 1% accuracy
First year: ~5%

Luminosity independent method:

\[
L \sigma_{tot}^2 = \left. \frac{16\pi}{1+\rho^2} \times \frac{dN}{dt} \right|_{t=0}
\]

\[
L \sigma_{tot} = N_{elastic} + N_{inelastic}
\]

\[
\sigma_{tot} = \left. \frac{16\pi}{1+\rho^2} \times \frac{(dN / dt)}{N_{el} + N_{inel}} \right|_{t=0}
\]

COMPETE Collaboration:
TOTEM needs special/independent short runs at high-$\varrho^*$ and low $M_\perp$ for precise measurement of the scattering angles of a few $\varphi$ rad

As consequence of high $\varrho^*$: large beam size at IP $\Rightarrow$ $\sqrt{M_\perp}$ $\varrho^* \sim 0.4$ mm

Require parallel-to-point focusing: trajectories of proton scattered at the same angle but at different vertex locations ($\mathcal{U}$, $y$ $\sim$ $\rightarrow$ $\mathcal{V}$)

Reduced number of bunches (43, 156) to avoid interactions further downstream

Baseline optics $\varrho^*$=1540 m: Parallel-to-point focusing in both transverse planes, allows very low-$t$ detection ($|t| \sim 2 \times 10^{-3}$ GeV$^2$)

requires special injection optics

probably not available at beginning of LHC

“Early” optics $\varrho^*$=90 m: paralle-to-point focusing only in vertical plane

$t$ detection down to $\sim 2 \times 10^{-2}$ GeV$^2$

achievable by un-squeezing the standard LHC injection optics
### Comparison of High $\mathcal{Q}$ Optics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$\beta^* \mathcal{Q}= 1540$ m (baseline optics)</th>
<th>$\beta^* \mathcal{Q}= 90$ m (early optics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossing angle</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>N of bunches</td>
<td>43</td>
<td>156</td>
</tr>
<tr>
<td>N of part./bunch</td>
<td>$3 \cdot 10^{10}$</td>
<td>$4 \cdot 10^{10}$</td>
</tr>
<tr>
<td>Emittance $\varepsilon_n$ [μm · rad]</td>
<td>1</td>
<td>3.75</td>
</tr>
<tr>
<td>RMS beam size at IP [μm]</td>
<td>450</td>
<td>200</td>
</tr>
<tr>
<td>RMS beam divergence [μrad]</td>
<td>0.29</td>
<td>2.3</td>
</tr>
<tr>
<td>$10 \sigma$ beam width at RP220 [mm]</td>
<td>0.8</td>
<td>6.25</td>
</tr>
<tr>
<td>Peak luminosity [cm$^{-2}$ s$^{-1}$]</td>
<td>$1.6 \cdot 10^{28}$</td>
<td>$5 \cdot 10^{29}$</td>
</tr>
<tr>
<td>Injection</td>
<td>special</td>
<td>standard</td>
</tr>
<tr>
<td>MD commissioning</td>
<td>more difficult</td>
<td>less difficult</td>
</tr>
</tbody>
</table>

- **$\mathcal{Q}=90$ m**
  - fits into the 2008 run scenario;
  - small integrated luminosity loss in 2008;
  - ideal for training the RP operation due to wide beams;
  - helps beam diagnostics
    - luminosity
    - beam position
    - vertex distribution

Proposal submitted to the LHCC and well received.
### Parameter Evolution and Rates

All values for nominal emittance, 7TeV and 10m $\mathcal{Q}^*$ in points 2 and 8

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Beam levels</th>
<th>Rates in 1 and 5</th>
<th>Rates in 2 (and 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_b$</td>
<td>N</td>
<td>$\beta^* 1,5$ (m)</td>
<td>$I_{\text{beam}}$ proton</td>
</tr>
<tr>
<td>43</td>
<td>4 $10^{10}$</td>
<td>11</td>
<td>$1.7 \times 10^{12}$</td>
</tr>
<tr>
<td>43</td>
<td>4 $10^{10}$</td>
<td>2</td>
<td>$1.7 \times 10^{12}$</td>
</tr>
<tr>
<td>156</td>
<td>4 $10^{10}$</td>
<td>2</td>
<td>$6.2 \times 10^{12}$</td>
</tr>
<tr>
<td>156</td>
<td>9 $10^{10}$</td>
<td>2</td>
<td>$1.4 \times 10^{13}$</td>
</tr>
<tr>
<td>936</td>
<td>4 $10^{10}$</td>
<td>11</td>
<td>$3.7 \times 10^{13}$</td>
</tr>
<tr>
<td>936</td>
<td>4 $10^{10}$</td>
<td>2</td>
<td>$3.7 \times 10^{13}$</td>
</tr>
<tr>
<td>936</td>
<td>6 $10^{10}$</td>
<td>2</td>
<td>$5.6 \times 10^{13}$</td>
</tr>
<tr>
<td>936</td>
<td>9 $10^{10}$</td>
<td>1</td>
<td>$8.4 \times 10^{13}$</td>
</tr>
<tr>
<td>2808</td>
<td>4 $10^{10}$</td>
<td>11</td>
<td>$1.1 \times 10^{14}$</td>
</tr>
<tr>
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<td>4 $10^{10}$</td>
<td>2</td>
<td>$1.1 \times 10^{14}$</td>
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<tr>
<td>2808</td>
<td>5 $10^{10}$</td>
<td>1</td>
<td>$1.4 \times 10^{14}$</td>
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<tr>
<td>2808</td>
<td>5 $10^{10}$</td>
<td>0.55</td>
<td>$1.4 \times 10^{14}$</td>
</tr>
</tbody>
</table>

R. Bailey
Optical Functions

L = (\delta \delta^*)^{1/2} \sin \Theta(s)

Idea:

L_y large \quad L_x = 0
v_y = 0
\Theta_y(220) = \sqrt{2\pi} \quad \Theta_x(220) = \square

v = (\delta \delta^*)^{1/2} \cos \Theta(s)

hit distribution (elastic)

x = L_x \square_x^* + v_x x^* + D \square
y = L_y \square_y^* + v_y y^*

(x^*, y^*): vertex position
(\square_x^*, \square_y^*): emission angle
t = t_x + t_y

\[ t \sim -(p \theta)^2 \]

\[ \sigma(t_y) / t_y \sim 0.02 \text{ GeV} / t_y^{1/2} \]

10 * beam = 0.8 mm 6.25 mm

+ 0.5 mm detector displacement

\( \delta = 1540 \)

\( \delta = 90 \)

\( \delta = 2 \)
Elastic Scattering

\[ \int L dt \quad 0.3 \text{ pb}^{-1} \quad 10 \text{ pb}^{-1} \]

\[ \delta = 90 \]

\[ \delta = 2 \]

\[ 500 \]

\[ 1 \times 10^6 \]

\[ 2 \times 10^9 \]

\[ 50 \]

\[ 10 \]

\[ 2 \]

\[ 0 \]

\[ 0 \times 10^{-10} \]

\[ 10^{-10} \]

\[ 10^{-9} \]

\[ 10^{-8} \]

\[ 10^{-7} \]

\[ 10^{-6} \]

\[ 10^{-5} \]

\[ 10^{-4} \]

\[ 10^{-3} \]

\[ 10^{-2} \]

\[ 10^{-1} \]

\[ 10^0 \]

\[ 10^1 \]

\[ 10^2 \]

squared 4-momentum transfer

\( \delta = 2 \text{ m} \)

\( \delta = 90 \text{ m} \)

\( \delta = 1540 \text{ m} \)
Elastic Scattering at low $|t|$

\[
d\sigma/dt = \exp \left[-B(t) \cdot t\right]
\]

\[\mathcal{Q}^* = 1540 \text{ m: } |t|_{\text{min}} = 0.002 \text{ GeV}^2\]

\[\mathcal{Q}^* = 90 \text{ m: } |t|_{\text{min}} = 0.04 \text{ GeV}^2\]

\[B(t) = B_0 + B_1 \cdot t + B_2 \cdot t^2\]
Extrapolation to the Optical Point \((t = 0)\)

\[
\frac{\text{extrapol.} - \text{model}}{\text{model in } d^4/\text{dt} \big|_{t=0}}
\]

**Extrapolation uncertainty**

- **Common bias due to beam divergence**: -2%
- **Spread of most of the models**: ±1%
- **Systematic error due to uncertainty of optical functions**: ±3%

\[
\int L \, dt = 2 \, \text{ nb}^{-1}
\]

(few hours running time)
Extrapolation with the Optics $\mathcal{L}^* = 1540$ m

For most models: extrapolation within $\pm 0.2\%$.
Islam model needs different treatment; to be distinguished in the visible $t$-range.

$t$-acceptance down to $0.0012$ GeV$^2$ →
good lever arm for choosing a suitable fitting function for the extrapolation to $t = 0$.

Complication:
Coulomb/nuclear interference must be included.
Measurement of the Total Cross section

Inelastic Rate (T1/T2) : Trigger Losses

<table>
<thead>
<tr>
<th></th>
<th><em>(mb)</em></th>
<th>losses</th>
<th>error after extrapolation (mb)</th>
</tr>
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<tbody>
<tr>
<td>Minimum bias</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>DPE</td>
<td>1</td>
<td>0.2</td>
<td>0.02</td>
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Total Inel. 0.8 mb

Loss at low diffractive masses M
Measurement of the Total Cross section

Inelastic Rate (T1/T2) : Trigger Losses

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Total Inel. 0.8 mb

Extrapolation of the elastic cross section to t=0

\[ \sigma = \begin{align*} 90 \ (1540) \ m b \end{align*} \leq 4\% \ (0.5\%) \]

Elastic Rate

\[ ^\bullet_{\text{tot}} / ^\bullet_{\text{tot}} \approx 5 \% \ (1\%) \]
Measurement of Beam Parameters

- Luminosity measurement (together with $\phi_{\text{tot}}$): $\pm 6\%$
- Beam profile measurement in x-projection at RP220 (elastic scattering)

===> beam position measurement at RP220 with precision $\sim 1\sigma \text{m}$ every minute to be compared with the machine’s BPMs.

===> horizontal vertex position determination: $x = v_x x^*$

===> vertex distribution (shape and width)
    ===> assuming round beams: luminosity from beam parameters
Measurement of Diffractive Protons: the principle

Diffractive protons: hit distribution @ RP220

\[ \text{low } \mathcal{Q} = 0.5 - 2 \text{ m} \]
\[ \text{high } \mathcal{Q} \leq 0 \text{ m} \]

\[ y \sim \gamma_{\text{scatt}} \sim |t_y|^{1/2} \]
\[ x \sim \frac{p}{p} \]

Detect the proton via:

its momentum loss (low \( \mathcal{Q} \))

its transverse momentum (high \( \mathcal{Q} \))
Diffractive protons detected

1-arm (incl. SD)
~50%
~90%

2-arm (incl. DPE)
~30%
~80%
Soft Diffraction

Reconstruction of \( \Box \) via protons or rapidity gap (\( \phi = -\ln(\Box) \)):
\[ \phi = 90 \text{ m}: \diamondsuit \Box \triangledown \approx 6 \times 10^{-3} \] (without vertex knowledge)

(1540 m: \( \diamondsuit \Box \triangledown \approx 9 \times 10^{-3} \))

--- various diffractive studies

(Single Diffraction and Double Pomeron Exchange)

To be extended later together with CMS
TOTEM will be ready for data-taking at the LHC start:

Measure total pp cross-section (and luminosity) with a precision of 5% \( (\delta \sigma^* = 90 \text{ m}) \)
[Ultimate precision: 1%]

Measure elastic scattering in the range \( 10^{-3} < t < 10 \text{ GeV}^2 \)

Soft Diffraction (SD, DPE)

Studies of forward particle production
Prospects for Diffractive and Forward Physics at the LHC

Author List

CMS & TOTEM & FP420

T1: $3.1 < \eta < 4.7$
T2: $5.3 < \eta < 6.5$ = Castor

RP (147 m)  RP (220m)
CMS/TOTEM common physics program

Largest coverage in pseudorapidity & proton detection on both sides

Charge particles

Energy Flux

\[ \frac{dN_c}{d\eta} \]

\[ \frac{dE}{d\eta} \]

CMS

LHC inelastic collisions

\[ -10 \quad -6.5 \quad -3 \quad 0 \quad 3 \quad 5 \quad 6.5 \quad 10 \]
Low Luminosity ($\leq 10^{32}$ cm$^{-2}$s$^{-1}$): low & high $\mathcal{L}$*
- 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 ($> 10^{32}$ cm$^{-2}$s$^{-1}$) : low $\mathcal{L}$*
- Measure SD and DPE in presence of hard scales (dijets, vector bosons, heavy quarks): dPDF, GPD
  - $\gamma p$ and $\gamma p$ physics

High Luminosity ($> 10^{33}$ cm$^{-2}$s$^{-1}$) : low $\mathcal{L}$*
- Discovery physics in central exclusive production
  - SM or MSSM Higgs, other exotic processes
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

Ch 1: Introduction
Ch 2: Experimental Set-up
Ch 3: Measurement of Forward Protons
Ch 4: Machine induced background
Ch 5: Diffraction at low and medium luminosity
Ch 6: Triggering on Diffractive Processes at High Luminosity
Ch 7: Hard diffraction at High Luminosity
Ch 8: Photon-photon and photon-proton physics
Ch 9: Low-x QCD physics
Ch 10: Validation of Hadronic Shower Models used in cosmic ray physics
**Single Diffraction**

- **Roman Pot**
- **gap**
- **central + forw. det.**

**Double Pomeron Exchange**

- **Roman Pot**
- **gap**
- **central + forw. det.**

---

**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, multiparton interactions, discovery physics
Running scenario

The accessible physics depends on: luminosity

$\mathcal{Q}^*$ (different proton acceptance)
Measurement of Forward Protons: Acceptance

![Graph showing measurement of forward protons with acceptance regions for different energies and angles.](image)
Measurement of Forward Protons: momentum resolution (low $\varrho$)

Individual contribution to the resolution:

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

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

$\phi = 90, \text{RP220}$

$\phi, \text{RP220}$

$\phi, \text{RP420}$
## Assumption on Trigger Rates

<table>
<thead>
<tr>
<th></th>
<th>L1(kHz)</th>
<th>HLT/tape (Hz)</th>
</tr>
</thead>
<tbody>
<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><strong>Common runs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMS/TOTEM</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Trigger rates

[acceptance corrected]

\( p p \to pX \)

1 p

\( T_1/T_2 \)

14 mb

6000

140 \times 10^3

\( p p \to pXp \)

2 p

\( T_1/T_2 \)

1 mb

200

3.5 \times 10^3

\( p p \to pjjX \)

1 \Omega b

(p_T^{jet}>20 GeV)

0.2

30 nb

(p_T^{jet}>50 GeV)

0.01

0.5

60 nb

jet(s)

1.5 nb

(p_T^{jet}>20 GeV)

10^{-3}

1.5 nb

(p_T^{jet}>50 GeV)

0.03

\( p p \to pjjXp \)

2 p

\( T_1/T_2 \)

jet(s)

\( L = 10^{30} \)

\( L = 10^{32} \)

\( \phi = 90 \text{ m} \)

\( \phi = 2 \text{ m} \)

------------------------------------------------------

Estimated Rates (Hz)
Diffraction at low luminosity ($<10^{32}\text{ cm}^{-2}\text{ s}^{-1}$): soft diffraction

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

Topology of the events

Measure $\square$ and central Mass via:
- proton(s)
- rapidity gap relation $\ln(\square) = -\ln(\square)$
- calorimeters

$$\square = \sum_i E_i T \exp(\mp \ln(\square)) / \sqrt{s}$$

- Wide range $t$, $\square$ 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

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

1<\(M<2000\) GeV \quad N \sim 6 \times 10^7

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

\(M>300\) GeV \quad N \sim 10^8
Diffraction at low luminosity: DPE Central Mass Resolution

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

\[ \sigma(M) \text{[GeV]} = (\xi_{\text{lower}}/\xi_{\text{higher}})^{1/2} \]

\[ \text{symmetric events} \]
Diffraction at low luminosity: DPE Central Mass Resolution

\( \xi = 90 \) m

\( \sigma(M)[GeV] \)

\[ \sigma(M)[GeV] = (\sqrt{s})^{1/2} \]

\( M[GeV] \)
Diffraction at low luminosity: rapidity gaps

Measure via rapidity gap: \( \phi_{\text{rap}} = - \ln \phi \)

Achieved precision

Gap vs \( \ln(\phi) \) - T1+T2+Calorimeters

Limit of direct measurement:

Gap meas. limit due to acceptance of T2

\( \phi \approx 2 \times 10^{-3} \)  \( 2 \times 10^{-2} \)
Diffraction at low luminosity: semi-hard diffraction

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

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

In addition to the previous methods, $\mathcal{M}$ and central mass can be determined from calorimeter information:

$$\mathcal{M} = \sum_i E_T^i e^{\frac{-\Delta \phi}{\sqrt{s}}} \sim 40\%$$
Diffraction at low luminosity: semi-hard diffraction

\[ I = \int L dt = 0.3 \text{ (pb}^{-1}) \]

\( \mathcal{Q} = 90 \)

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

N event collected [acceptance included]

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

- DPE: “
  \[ 2000 \]

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

- DPE: “
  \[ 3 \times 10^4 \]
• **Trigger** is a major limiting factor for selecting diffractive events

• Background from non-diffractive events that mimic diffractive events because of **protons from pile-up events**
CMS trigger thresholds (jets) for nominal LHC running too high for diffractive events
Use information of forward detectors to lower CMS jet trigger thresholds
The CMS trigger menus now foresee a dedicated diffractive trigger stream with 1% of the total bandwidth on L1 and HLT (1 kHz and 1 Hz)

<table>
<thead>
<tr>
<th>Luminosity [cm$^{-2}$s$^{-1}$]</th>
<th># Pile-up events per bunch crossing</th>
<th>L1 2-jet rate [kHz] for $E_T &gt; 40$GeV per jet</th>
<th>Total reduction needed</th>
<th>Reduction when requiring track in RP detectors at 220 m</th>
<th>$\xi &lt; 0.1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \times 10^{32}$</td>
<td>0</td>
<td>2.6</td>
<td>2</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>$1 \times 10^{33}$</td>
<td>3.5</td>
<td>26</td>
<td>20</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>$2 \times 10^{33}$</td>
<td>7</td>
<td>52</td>
<td>40</td>
<td>4</td>
<td>10</td>
</tr>
</tbody>
</table>

Achievable total reduction: (single-sided 220m) x 2 (jet iso) x 2 (2 jets same hemisphere as p)

L1 conditions on RP detectors provides a rate reduction sufficient to lower the 2-jet threshold to 40 GeV per jet AND being compatible with the CMS L1 bandwidth limits for luminosities up to $2 \times 10^{33}$ cm$^{-1}$ s$^{-1}$

Much less of a problem is triggering with muons, where L1 threshold for 2-muons is 3 GeV
Central exclusive production $pp \rightarrow p\phi p$ with $H(120\text{GeV}) \rightarrow b\bar{b}$

- In non-diffractive production hopeless, signal swamped with QCD dijet background
- Selection rule in CEP (central system is $J^{PC} = 0^{++}$ to good approx) improves S/B for SM Higgs dramatically
- In certain MSSM scenarios the signal cross section is three order of magnitude higher than for the SM case

**Level-1:**
- $\sim 12\%$ efficiency with 2-jets ($E_T > 40\text{GeV}$) & single-sided 220 m condition

**HLT:** Jet trigger efficiency $\sim 7\%$
To stay within 1 Hz output rate, needs to either prescale b-tag or add 420 m detectors in trigger

Additional $\sim 10\%$ efficiency by introducing a 1 jet & 1\O(40GeV, 3GeV) trigger condition
Number of PU events with protons within acceptance of near-beam detectors on either side:

~2 % with p @ 420m
~6 % with p @ 220m

Translates into a probability of obtaining a fake DPE signature caused by protons from PU:

<table>
<thead>
<tr>
<th>lumi</th>
<th>$\langle N^{PU} \rangle$</th>
<th>420+420</th>
<th>220+220</th>
<th>220+420</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \cdot 10^{33}$</td>
<td>3.5</td>
<td>0.003</td>
<td>0.019</td>
<td>0.014</td>
<td>0.032</td>
</tr>
<tr>
<td>$2 \cdot 10^{33}$</td>
<td>7.0</td>
<td>0.008</td>
<td>0.052</td>
<td>0.037</td>
<td>0.084</td>
</tr>
</tbody>
</table>

Eg at $2 \times 10^{33}$ cm$^{-2}$s$^{-1}$ -> fake DPE signature =10% -> independent of the type of signal.

Depends critically on the leading proton spectrum at the LHC which in turn depends on size of soft rescattering effects (rapidity gap survival factor)!
Can be reduced by:

**Requiring correlation** between \( \Delta t \), M measured in the central detector and \( \Delta t \), M measured by the near-beam detectors

**Fast timing detectors** that can determine whether the protons seen in the near-beam detector came from the same vertex as the hard scatter (currently R&D project)

**CEP of** \( H(120 \text{ GeV}) \rightarrow b \bar{b} \bar{b} \):**

Possible to retain \( O(10\%) \) of signal up to \( 2 \times 10^{33} \text{ cm}^2 \text{ s}^{-1} \) in a special forward detectors trigger stream

S/B in excess of unity for a SM Higgs and up to 1000 for a MSSM Higgs appears achievable
Forward particle & energy flows

Production cross sections of neutral particles

Validation of hadronic air shower models

New phenomena (DCC…?)

Low-x QCD

Proton structure at low-x, Multi-parton scattering, Parton saturation, Colour Transparency

Study of the underlying event at the LHC

(cfr P. Bartalini talk)

Multiple parton-parton interactions and rescattering effects accompanying a hard scatter
   Closely related to gap survival and factorization breaking in hard diffraction

Photon-photon and photon-proton physics
Measure:

Rapidity distribution (charged, neutral)

Energy distribution

Multiplicity & correlations

study long-range rapidity correlations and fluctuations of multiplicity

observe exotic phenomena? (DCC,....)

min bias physics

relevant for Cosmic Ray interpretation
Charged tracks in T1/T2

Energy flow in Castor

14 TeV => $10^{17}$ eV

$10^4$ CR events / km$^2$ year =>

$10^4$ events /s @ LHC (L=$10^{29}$ cm$^{-2}$ s$^{-1}$)
Quark and gluon density (PDF) at small $x_{Bj}$ (parton fractional momentum)

Pioneered by HERA, at LHC extend to lower $x$

Direct information on PDF structure and evolution provided by:

- jets (sensitive to gluon density)
- Drell-Yan pairs (sensitive to quark density)
Sensitive to low-$x_{\text{BJ}}$ quarks density in proton in case of large imbalance of fractional momenta $x_{1,2}$ of leptons, which are then boosted to large rapidities

$$M^2(\text{lepton pair}) = sx_1x_2$$

$$x_{1,2} = \frac{M}{\sqrt{(s)}} \exp(-\frac{y}{s})$$

Castor/T2 down to $x_{\text{BJ}} \sim 10^{-6}$

Measure angle of electrons with T2
Inclusive forward “low-\(E_T\)” jet (\(p_T \sim 20-100\) GeV) production:

\[ p + p \rightarrow jet1 + jet2 + X \]

- Jets in HF sensitive to \(x \sim 10^{-4}\)
- Jets in Castor \(x \sim 10^{-6}\)

**PYTHIA 6.4: \(p+p\rightarrow jet_1+jet_2, \sqrt{s} = 14\) TeV**

**jet \(_{1,2}\) in 3.0 < \(|\eta|\) < 5.0**

Large yields (~\(10^7\) at ~20 GeV)!
Provide information about the short distance quark structure
Partons inside the quarks or outside?

Estimated cross-section

\[ 3_{jets} \approx \frac{5 \text{ GeV}^8}{p_{Tmin}} \approx 10 \div 100 \text{ nb} \]

Example 3 jets at 10 GeV:
- polar angle of jets ~ 4.3 mrad \( \phi \approx 6.1 \)
- jet separation ~ 7 mrad \( \Rightarrow 10 \text{ cm in T2/Castor} \)
- jet width ~ 0.3-3 mrad \( \Rightarrow 0.4 - 4 \text{ cm in T2/Castor} \)

proton \( \Xi\Xi\Xi\Xi \) \( \Phi(p/p) \sim 10^{-6} \)

Detect the proton (@ high \( \phi \)) + jets : 10 – 100 events in 0.3 pb\(^{-1}\)
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

Trigger of diffractive events

Pile-up
Summary

**Low Luminosity (≤10^{32} cm^{-2}s^{-1}): low & high $\mathcal{L}$**

- 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
  - Inclusive Forward jets, Muller-Navelet dijets
  - Forward Drell-Yan
- Validation of Cosmic Ray generators

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

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

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

- Discovery physics in central exclusive production
  - SM or MSSM Higgs, other exotic processes

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Running with TOTEM optics: large proton acceptance

No pile-up

Trigger limiting factor

Pile-up not negligible:
  - important source of background

Need additional forward proton detector
At $2 \times 10^{33}$ cm$^{-1}$ s$^{-1}$ without any additional condition on fwd detectors:

L1 1-jet trigger threshold $O(150$ GeV$)$

L1 2-jet trigger threshold $O(100$ GeV$)$
I. Pilot physics run
   - First collisions
   - 43 bunches, no crossing angle, no squeeze, moderate intensities
   - Push performance
   - Performance limit $10^{32}$ cm$^{-2}$ s$^{-1}$ (event pileup)

II. 75ns operation
   - Establish multi-bunch operation, moderate intensities
   - Relaxed machine parameters (squeeze and crossing angle)
   - Push squeeze and crossing angle
   - Performance limit $10^{33}$ cm$^{-2}$ s$^{-1}$ (event pileup)

III. 25ns operation I
   - Nominal crossing angle
   - Push squeeze
   - Increase intensity to 50% nominal
   - Performance limit $2 \times 10^{33}$ cm$^{-2}$ s$^{-1}$

IV. 25ns operation II
   - Push towards nominal performance