The TOTEM Experiment at the LHC

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On behalf of the TOTEM Collaboration

Detector Status
Physics Program
First Results

The TOTEM Collaboration
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Detector Status
TOTEM Detectors

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

Roman Pot stations in the LHC tunnel

RP (147 m)  RP (220m)
Cathode Strip Chambers

Fully inclusive inelastic trigger
Primary Vertex Reconstruction

Both telescope arms ready for installation
Both arms are completely assembled and equipped in the test beam line H8. Successfully tested with pion and muon beams.

CSC efficiencies with muons (triple coincidences)

Longitudinal vertex

Cu target

Beam monitor frame

Transverse vertex
**TOTEM Detectors : T2**

**Gas Electron Multiplier Chambers**

- Fully inclusive inelastic trigger
- Primary vertex reconstruction
TOTEM Detectors : T2

All 4 quarters installed and operational

Present status: commissioning completed
Alignment
Data taking for Physics

Track reconstruction in a large particle density environment

Background in the very forward cone
Beam gas and halo interactions

Photon and hadron interactions producing showers

Vertex pointing / impact parameter calculation important to reject re-interactions

Trigger system:
MinBias selection
at least 5 out of 10 planes in road-coincidence

High multiplicities
TOTEM Detectors : Roman Pots

4 Stations
→ 2 Units
→ 3 pots
1 BPM
( Beam Position Monitor)

Edgeless Silicon Detectors

Roman Pot stations in the LHC tunnel
TOTEM Detectors : Roman Pots

All 12 pots at 220m are installed and operational

Present status:
commissioning completed

Alignment

Data Taking for Physics

Trigger system:

3 out of 5 planes in road-coincidence
in u & v projection
Single or Double arm
Alignment is the central problem of Roman Pot measurements: test done at 450 GeV on the 25th of June

Collimator cuts a sharp beam edge symmetrically to the centre

RP approaches this edge until it scrapes ...

... producing spike in BLM downstream

The second RP approaches

When both top and bottom pots “feel” the edge: they are at the same number of sigmas from the beam centre as the collimator and the beam centre is exactly in the middle between top and bottom pot

After this exercise the RPs have been routinely inserted at 25σ – soon at 20σ

Next: repeat the exercise at 3.5 TeV to allow insertion at nominal position (15σ)
RP Alignment wrt Beam Centre

Start with primary collimator at 4.9 $\sigma$ → beam edge at 4.9 $\sigma$

RP 4-5 (-220m)
Near – TOP @ 4.9$\sigma$

RP approach (in $\geq$100$\mu$m steps)

BLM @ 221 m
BLM @ 225 m

RP 4-5 (-220m)
Near–BOTTOM @ -4.9$\sigma$

RP trigger rate
Physics Program
TOTEM Physics Overview

Total cross-section

- best fit with stat. error band incl. both TEVATRON points
- total error band of best fit
- total error band from all models considered

Elastic Scattering

Forward physics

Diffraction: soft and hard
Current models predict for 14 TeV: $90 - 130$ mb

Aim of TOTEM: $\sim 1\%$

“First year” : $\sim 5\%$

**Luminosity independent method:**

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

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First year : ~5%

Luminosity independent method:

\[ L \sigma_{tot} = 16\pi \frac{dN}{dt} \bigg|_{t=0} \]

\[ \sigma_{tot} = \frac{16\pi}{1+\rho^2} \frac{(dN/dt)}{N_{el} + N_{inel}} \]

SPECIAL OPTICS REQUIRED!!!

T1 Installed
Optics and Forward Proton Measurement

Optical functions: $v, L, D$

$$x(s) = v_x(s, \xi) \cdot x^* + L_x(s, \xi) \cdot \Theta_x^* + \xi \cdot D(s, \xi, \theta_x^*)$$

Principle of measurements:

Hit distributions of diffractive protons in RP detectors at 220m

← low $\beta^*$ → high $\beta^*$

Optics: $\beta^*=1540m$
90m
2m, 3m
11m
Physics Program: High $\beta^*$ Optics

- **Elastic proton acceptance**
  - $\beta^* = 1540 \text{ m}$
  - $\beta^* = 90 \text{ m}$

- **Diffractive proton acceptance**

- **Total cross section measurement at $\sim 5 \%$ ($\sim 1\%$)**
- **Elastic scattering**: $0.004 < |t| < 2.5 \text{ GeV}^2$
- **Soft diffraction**: all masses - 65 % of diffractive protons seen
- **Classification of inelastic events**: rates & multiplicity

12/8/2010
Physics Program: Diffraction at low $\beta^*$

Single Diffraction

Diffractive proton in horizontal RP + diffractive system in T2
(Background: halo p + NSD)

$$d\sigma/dM : 0.025<\xi<0.15 \rightarrow 1 < M < 3 \text{ TeV} \quad \sigma(M)/M \sim 2 - 5\%$$

Hits in RP220

Acceptance

$$\text{Log}|\xi|$$

15%

2.5%

Pythia SD: $\sigma_{\text{acc, sd}} \sim 1.2 \text{ mb (x 2)} / \sigma_{\text{sd}} \sim 13.7 \text{ mb}$
Physics Program: Diffraction at low $\beta^*$

Central Diffraction

Diffractive protons in horizontal RPs + diffractive system in T2
(Background: SD+SD, SD+halo p, .....)

$\frac{d\sigma}{dM} : 200 < M < 1000$ GeV  \hspace{1cm} \sigma(M)/M \sim 2 - 5\% \hspace{1cm} \sigma(\phi) \sim 0.09/\sqrt{|t|}$

Hits in RP220

Acceptance

Phojet CD: $\sigma_{\text{acc,cd}} \sim 0.05$ mb / $\sigma_{\text{cd}} \sim 1.3$ mb

12/8/2010
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Physics Program: Elastic scattering at low $\beta^*$

Elastic protons in RP(vertical, left) & RP(vertical, right)

$$0.5 < |t| < 5 \text{ GeV}^2 \quad \sigma(|t|) \sim 0.2 \sqrt{|t|}$$

Background: Central Diffraction, SD+SD, beam halo
Physics Program: Forward Particles

Physics with T2 alone (5.3 < π < 6.5, i.e. 3 – 10 mrad)

Charged particle multiplicity distributions

Trigger on very high multiplicities in the tail of the distribution (DCC)

Multiplicity Correlations between the two forward cones
First results
T2 event at $\sqrt{s} = 7$ TeV
T2 Alignment & Vertex Reconstruction

Before

T2 Primary Vertex X
- Entries: 250019
- Mean: -0.4078
- RMS: 1.371
- RMS = 1.4 cm

T2 Primary Vertex Y
- Entries: 250019
- Mean: -0.5264
- RMS: 1.664
- RMS = 1.7 cm

T2 Primary Vertex Z
- Entries: 250019
- Mean: 81.42
- RMS: 311.6
- RMS = 3.1 m

After

T2 Primary Vertex X
- Entries: 305934
- Mean: 0.08442
- RMS: 0.8386
- RMS = 0.8 cm

T2 Primary Vertex Y
- Entries: 305934
- Mean: 0.01347
- RMS: 0.9772
- RMS = 1.0 cm

T2 Primary Vertex Z
- Entries: 305934
- Mean: -4.232
- RMS: 230.6
- RMS = 2.3 m

12/8/2010
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**T2: $\eta$ distribution**

- Pythia charged particle $\eta$
- Pythia reconstructed tracks
- Data reconstructed tracks

Tracks pointing to vertex

Statistical error only

BeamPipe cone at $\eta \sim 5.53$
**RP Alignment**

Very critical and fundamental for any physics reconstruction

- **Resolve misalignments within detector assembly** → methods: local track

- **Resolve relative positions of the pot:**
  - principal information source: motor control (→ calibration, reliability, …)
  → method: local track based (detector overlap)

- **Resolve position of beam** (uncertainties and variations of optics):
  → method: profiles from physics events, Beam Halo
  Cross-check: Beam Position Monitors ; Alignment with collimators

- **Resolve left-right position**
  → method: global (elastic) track based
RP Alignment : first time @ 25σ

Vertical alignment (sector 56)

Tracks in horizontal pot
RP Alignment : first time @ 25$\sigma$

Vertical alignment (sector 45)

Tracks in horizontal pot
RP Alignment : first time @ 25σ

Horizontal alignment

Tracks (halo protons) in vertical pot
Diffractive protons at 7 TeV!

After Alignment

Raw distributions, no selection: Diffractive protons + background

Estimated $\Delta p/p : 0.06 - 0.12$
Data taking with RP at $25\sigma$ : collected $\sim 3$ M events with RP only

$\sim 5$ M “ RP + T2

Soon : collect data at $20\sigma$ (and hopefully at $15\sigma$)

Full set of systematics sources under investigation:

- Alignment
- Beam position
- Beam divergence
- Background from the machine (halo, beam gas,.....)
- Multiple scattering and material interaction
- Optics : uncertainty on the optical functions, crossing angle, vertex....

and in addition:

- Estimate Efficiencies (trigger, track reconstruction....)
- Luminosity
- Physics Background & Pile-up
Data taking with RP at $25\sigma$ : collected ~ 3 M events with RP only
~ 5 M “ RP + T2

One elastic scattering event candidate

Run 1964.004
Event 13682
The TOTEM Detectors installed in the LHC have completed the commissioning and are presently taking data for physics.

Once that the RPs will be inserted at their nominal position, TOTEM can exploit its physics program at low $\beta^*$:

- high mass Single & Central Diffraction
- large $|t|$ elastic scattering ($0.65 < |t| < 5$ GeV$^2$)
- forward density of charged particles

Precise measurements of elastic, diffractive and total cross sections require high $\beta^*$ optics (and the installation of T1):

- Elastic scattering in a wider $|t|$ range
- Diffractive physics over a larger rapidity range $3.1 < \eta < 6.5$
- Single and Central Diffraction at any mass
- Measurement of $\sigma_{\text{tot}}$ with a precision of $\sim 5\%$ ($1\%$)