Status Report of TOTEM
and the CT-PPS Roman Pot Operations

LHCC Open Session
23rd September 2015

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on behalf of

The TOTEM Collaboration
and

The CT-PPS Project
1. Recent and upcoming physics publications

2. Beam operations in 2015
   - VdM fills at $\beta^* = 19$ m  
     done
   - Special run at $\beta^* = 90$ m  
     October
   - RP test insertions for CT-PPS at $\beta^* = 0.8$ m  
     ongoing

3. Timing detector development and testbeam characterisation
Recent and Upcoming Physics Publications

High statistics data set ($\beta^*=90\,\text{m}$, 2012): 7 M elastic events

$0.027\,\text{GeV}^2 < |t| < 0.2\,\text{GeV}^2$ dominated by hadronic interaction (Coulomb interaction neglected)

Differential Cross-Section $d\sigma/dt$

Relative deviation of $d\sigma/dt$ from exponential

Pure exponential form excluded at 7.2 $\sigma$ significance.
Upcoming: Elastic pp scattering in the Coulomb-Nuclear Interference Region

Measurement down to $|t| \sim 6 \times 10^{-4}$ GeV$^2$:

- $\beta^* = 1000$ m optics
- Roman Pot approach to $3 \sigma$ from the beam centre

\[
F_{C+H} = F_C + F_H e^{i\alpha\Psi}
\]

$|F_H|$ arg($F_H$)

\[
A e^{-B(t)|t|}
\]

hadronic phase as function of $t$:
implications on behaviour of elastic scattering in impact parameter space:
preferentially central or peripheral?

Combined $\beta^* = 1$ km & 90 m data
- exclude Simplified West & Yennie interference formula (requiring purely exponential hadronic ampl.)
- have constraining power on:
  - hadronic amplitude
  - hadronic phase $\Rightarrow$ impact parameter picture
$\rightarrow$ measurement of $\rho = \cot \arg F_H(t = 0)$
$\rightarrow$ previous $\sigma_{\text{tot}}$ measurements (that neglected CNI) are confirmed.

Results blessed, article in progress
Beam Operations in 2015

“Roman Pots” detectors (CT PPS & TOTEM) installed in LHC tunnel

CERN, 2015

Collimators TCL 4 & TCL 6
TOTEM upgraded detectors (12 RPs)
New CT-PPS detectors (12 + 2 RPs)
New BP elements: vacuum chambers, ionic pumps and cartridges, BLMs, ...
The Roman Pot System after LS1 and its Usage at High and Low $\beta^*$
(Example: Sector 5-6)

26 Roman Pots: the largest Roman Pot system ever operated at a collider

<table>
<thead>
<tr>
<th>Operation at low $\beta^*$ (0.8 m): CT-PPS</th>
<th>Operation at medium/high $\beta^*$ (19 m, 90 m)</th>
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<tbody>
<tr>
<td>14 individual pots (both sectors together)</td>
<td>18 individual pots (both sectors together)</td>
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</table>
June: LHCf Run
Data taken with T1, T2 (minimum bias) \(\rightarrow\) performance as in Run 1

August: VdM Scans
RPs inserted during all fills, even during IP5 scans:
Vertical RP: 12 \(\sigma\)
Horizontal RP: 15 \(\sigma\)

Successful data-taking with RPs, T2, and combined with CMS:
Trigger:
• RP single arm, T2 in veto
• RP double arm
• bunch crossings (zero bias)
• T2 minimum bias
• CMS: dijets, double muons

Pileup: \(\mu = 0.05\) and 0.4, Luminosity from \(9 \times 10^{28}\) to \(3 \times 10^{30}\) \(\text{cm}^{-2} \text{s}^{-1}\)
DAQ consolidation: 25 kHz rate measured: factor 25 w.r.t. Run 1

Total integrated luminosity taken: \(\sim 40 \text{nb}^{-1}\)

Offline data synchronisation and combination CMS+TOTEM in progress.

All TOTEM detectors operational and ready for the \(\beta^* = 90\) m run in October.
RP Hit Maps from the Van der Meer Runs ($\beta^* = 19 \text{ m}$)

56 RP 210 far  
(8° rotated unit)  

56 RP 220 far
Van der Meer Runs ($\beta^* = 19$ m): Elastic Events

Diagonal double-arm selection: 45 bottom – 56 top

Correlation of scattering angles in the 2 arms:

$\Theta_x^* (45)$ vs. $\Theta_x^* (56)$

$\Theta_y^* (45)$ vs. $\Theta_y^* (56)$
Scheduled for October: $\beta^* = 90 \text{ m Run}$

[see CERN-LHCC-2014-020 (TOTEM-TDR-002) 
and CERN-LHCC-2014-024 (TOTEM-TDR-002-ADD-1) ]

a) **Low-Luminosity Programme**
- for elastic scattering, total cross-section
- needs RPs very close to the beam ($\sim 5 - 6 \sigma$)
  $\Rightarrow$ use RP alignment fill (few hours of data taking after alignment)

b) **High-Luminosity Programme**
- low-mass central diffractive spectroscopy, glueball searches
- missing mass searches
in a joint run with CMS

100 ns bunch spacing $\Rightarrow$ up to 702 bunches
$\sim 700$ bunches to be reached after intensity ramp-up: 1 fill of 3–4 hours at $\sim 50$ and $\sim 250$ bunches

$\Rightarrow$ needs new version of 90 m optics with crossing angle ($\pm 50 \mu \text{rad}$):
**First optics commissioning step successfully completed on 12 September !**
**Second commissioning shift planned for today.**

bunch population $(6 - 7) \times 10^{10} \text{ p/b}$, emittance $\epsilon_n \sim 2.5 \mu \text{m rad}$
$\Rightarrow$ pileup $\mu \sim 0.1$
$\Rightarrow$ $\mathcal{L} = (0.6 - 0.8) \text{ pb}^{-1} / 24 \text{ h}$

**Common Request by CMS and TOTEM in the LPC:** $\mathcal{L}_{\text{int}} \geq 1 \text{ pb}^{-1}$
Objective:
Establish Roman Pot insertions for physics operation in all regular fills from 2016 on

Problems during first Insertion Tests in 2012:
Impedance heating combined with outgassing:
- measured temperature rise on electronics cards inside RPs despite active cooling
- traces (black spots) of metal overheating on bellow next to a ferrite fragment
- ferrite (Ferroxcube 4S60, not baked out at 1000 ºC) outgassing
  → vacuum deterioration
  → amplification of collision debris showers → dumps on BLMs
But no beam instabilities observed
Technical Improvements during LS1

- **New ferrite material** for all RPs (Transtech TT2-111R) like for collimators
  → higher Curie temperature
- **Ferrite bake-out at 1000 °C**
  → less outgassing
- **Installation of RF shields in horizontal RPs** for high-lumi operation,
  new ferrite geometry
  → significant impedance reduction
- **Cylindrical RP geometry** for new timing RPs
  → significant impedance reduction
  → but more material along the beam
  (12 cm for cylindrical pot instead of 5 cm for old box-shaped pot)
- **TCL6** to intercept showers from RPs

2015: test effectiveness of modifications by inserting RPs in all steps of intensity ramp-up
Commissioning Programme Philosophy:

- Study beam losses / showers and interplay with TCL collimator system extended BLM system: 1 monitor after **almost each RP unit**, after TCL6 and at the quadrupole Q6

- Study RP impact on impedance:
  - heating: temperature sensors on/in RPs
  - vacuum: 5 gauges in RP sector: DCS monitoring
  - beam orbit stability: monitored by impedance group

**RP Insertions in Regular Fills at Low $\beta^*$**

- Beam Loss Monitor (BLM)
- Vacuum Gauge

**Operation at low $\beta^*$**

**Operation at high $\beta^*$**
3 – 4 July: Beam-based alignment of all 14 low-beta RPs in 1½ hours, afterwards 45 minutes of diagnostic data taking in quiet beams with pots @ 6–8 σ

5 – 14 July: RP insertions in all intensity steps of 50 ns intensity ramp-up
still nominal TCL configuration: TCL5 in, TCL6 out,
very conservative RP positions due to orbit uncertainties: ~ 30 σ horizontally, ~ 20.5 σ vertically
3, 50, 152, 296, 476 bunches per beam → lumi up to 1.3 x 10^{33} cm^{-2} s^{-1}

13 – 21 August: RP insertions in first part of 25 ns intensity ramp-up
final TCL configuration: TCL5 out, TCL6 @ 25 σ
closer RP positions: ~ 25 σ horizontally, ~ 19.5 σ vertically
2, 86, 157, 219, 315 bunches per beam → lumi up to 0.7 x 10^{33} cm^{-2} s^{-1}

Technical Stop 2: Installation of Aluminium bar in cylindrical pot in 5-6 mimicking the material of a Cherenkov Quartz bar

Since 5 Sept (ongoing): RP insertions in second part of 25ns intensity ramp-up
So far: 2, 49, 219, 459, 745, 1033, 1177 bunches per beam → lumi up to 2.3 x 10^{33} cm^{-2} s^{-1}

So far: no beam instabilities due to RP insertions observed.

Aim for RP positions later this year if all insertions successful:
20.7 σ horizontally, 18.2 σ vertically
Beam Loss Monitor Response to RP Insertions
(Insertion of horizontal pots to ~25 $\sigma$ from beam centre)

- Dose rates proportional to luminosity $\Rightarrow$ showers = collision debris, not single-beam halo
- RP generating strongest shower dose rate: cylindrical pot (E6): most material
- Installation of dummy QUARTIC bar $\Rightarrow$ dose rate in BLM(E6) increases by $\sim$ factor 2
- Linear Extrapolation to $L=10^{34}$ cm$^{-2}$ s$^{-1}$: BLM(E6) = 0.47 mGy/s = 0.07 Thresh. $\Rightarrow$ no problem from BLMs expected
- Strong dose rate in BLM(TCL6), very small signals in quadrupose BLMs $\Rightarrow$ TCL6 is effective
Example fill: horizontal pots @ ~25 σ from beam centre, L ~ 1.9 x 10^{33} cm^{-2} s^{-1}

Time evolution of pressure and temperature:

- **Ramp**
- **RP insertion**

**Vacuum gauges near the most upstream RP:**
significant but unproblematic pressure rise

**Temperature sensors on cylindrical pot:**
hottest spot = pot floor (towards beam)!

Slow temperature increase approaching an equilibrium value,
moderate magnitude: up to 36 °C at RP floor 3 mm from beam centre without cooling

Comparison: 2011 in a fill without cooling: 41 °C on RP electronics card with pot retracted (4 cm from beam)
Timing detector development and testbeam characterisation
Longitudinal Vertex Reconstruction by Time Measurement

Pileup problem:
High luminosity $\rightarrow$ multiple events in 1 bunch collision!
- CMS tracker can separate multiple vertices longitudinally,
- leading proton tracks have angles in $\mu$rad range $\rightarrow$ insufficient vertex precision
$\rightarrow$ for double-arm events (CD) reconstruct vertex from time-of-flight difference

Position of Collision 1 $\sim \Delta t_{\text{Collision}1,\text{Stopwatch}1} - \Delta t_{\text{Collision}1,\text{Stopwatch}2}$
Timing Detector Development for Medium Pileup
($\beta^* = 90 \text{ m Runs}$)

Objective:
- 3 timing detector planes in 4 vertical RPs (1 pot pair per arm)
- Detector installation in Technical Stop 3 – YETS
- ~ 60 ps resolution per arm (~ 100 ps per detector) enough since at 90m the pileup $\mu < 0.6$
  (different for CT-PPS: $\beta^* = 0.8 \text{ m}: \mu \leq 50$
  $\rightarrow$ needs time resolution ~ 10 ps)

Development of Diamond Detectors:
Segmentation follows the diffractive hit distribution:
almost constant occupancy per pixel
TOTEM + CT-PPS test beam, timing detectors inside Roman Pots
- TOTEM: diamonds
- CT-PPS: QUARTIC Cherenkov detectors

Average time resolution as function of the pixel size

~100 ps goal reached for all the sizes

Room for improvement:
- diamond selection
- noise shielding
- LV optimisation

TS3: 3 planes in 1 pot → system test

Winter 2015-16 (YETS):
3 planes in 4 pots for physics in 2016
→ expected 60 ps time resolution
→ few cm vertex resolution
Conclusions, Outlook

- Several publications from run 1 upcoming (only partly covered here)
- All TOTEM detectors are operational
- Successful data taking during the VdM scans
- RP insertions in regular low-\(\beta^{*}\) fills ongoing: so far very promising
- We are ready for the special run at \(\beta^{*} = 90\) m in October
- 2016: first LHC operations with timing detectors in RPs
The End
Elastic Scattering in the Coulomb-Nuclear Interference Region

Different options for the unknown nuclear phase:

"central phase": profile function in impact parameter picture:
Elastic scattering preferentially central

\[ \arg F(t) = \frac{\pi}{2} - \tan^{-1} \frac{\cot p_0}{1 - \frac{t}{t_d}} \]

constant phase: also central behaviour
\[ \arg F(t) = p_0 \]

"peripheral phase": profile function in impact parameter picture:
Elastic scattering preferentially peripheral
\[ \arg F(t) = p_0 + \zeta \left( \frac{t}{t_0} \right)^\kappa \exp(\nu t), \quad t_0 = 1 \text{ GeV}^2 \]

Result for
\[ \rho = \frac{\Re F^H(0)}{\Im F^H(0)} = \cot \arg F^H(0) = \cot p_0 \]

is model dependent
Fit models retained for final analysis:

<table>
<thead>
<tr>
<th>Hadronic Slope</th>
<th>Constant Phase (representative for all central phases)</th>
<th>Peripheral Phase</th>
</tr>
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<tbody>
<tr>
<td>$N_B = 1$ (pure exponential)</td>
<td>excluded</td>
<td>disfavoured</td>
</tr>
<tr>
<td>$N_B = 3$ (parabolic exp. slope)</td>
<td>possible</td>
<td>possible</td>
</tr>
</tbody>
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Impact parameter picture: profile functions