TOTEM Results and Perspectives

The TOTEM Collaboration

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Elastic scattering
Total Cross-section
Inelastic cross-section
Particle Production
Diffraction
Runs with CMS
Future runs
Perspectives after the shut-down

Karsten Eggert (CWRU)
on behalf of the TOTEM collaboration

2012 LHC Days in Split, Croatia
TOTEM Physics Overview

Total cross-section

Elastic Scattering

Cosmic Ray Physics

Diffraction: soft and hard
TOTEM Detectors (T1, T2 and RP) on both sides of IP5

24 Roman Pots in the LHC tunnel on both sides of IP5
measure elastic & diffractive protons close to outgoing beam

Inelastic telescopes T1 and T2:
T1: $3.1 < \eta < 4.7$
T2: $5.3 < \eta < 6.5$
Detectors

RP 147

Vertical Pot
Horizontal Pots
Vertical Pot
Vertical Pot

Package of 10 “edgeless” Si-detectors

T1 (CSCs)

T2 (GEMs)
The Roman Pot System at 220 m

Design considerations:
Two independent detection systems with 5 m lever arm scenarios
10 Silicon detectors / RP
Reliable track reconstruction in both projections
Determine the proton angle in both projections
Approach the beam as close as possible to

Space for adding detectors for future upgrades !!!

(x*, y*): vertex position
(θx*, θy*): emission angle: \( t \approx -p^2 (\theta_x^* + \theta_y^* ) \)
ξ = Δp/p: momentum loss (diffraction)

Optimized optics

| Beam width @ vertex | Angular beam divergence | Min. reachable |t| |
|---------------------|-------------------------|---------------|-----|
| Standard optics β* ~ 1 m | σx,y* small | σ(θx,y* ) large | |t|min| ~ 0.3–1 GeV² |
| Special optics β* = 90 m | σx,y* large | σ(θx,y* ) small | |t|min| < 10⁻² GeV² |
Proton position at a given RP \((x, y)\) is a function of position \((x^*, y^*)\) and angle \((\Theta^*_x, \Theta^*_y)\) at IP5:

\[
\begin{pmatrix}
x \\
\Theta_x \\
y \\
\Theta_y \\
\Delta p/p \end{pmatrix}_{RP} = \begin{pmatrix}
v_x & L_x & 0 & 0 & D_x \\
v'_x & L'_x & 0 & 0 & D'_x \\
0 & 0 & v_y & L_y & 0 \\
0 & 0 & v'_y & L'_y & 0 \\
0 & 0 & 0 & 0 & 1
\end{pmatrix} \begin{pmatrix}
x^* \\
\Theta^*_x \\
y^* \\
\Theta^*_y \\
\Delta p/p \end{pmatrix}_{IP5}
\]

Proton transport matrix

The effective length and magnification expressed with the phase advance:

\[
L(s) = \sqrt{\beta(s)\beta^*} \sin \Delta \mu(s) \quad v(s) = \sqrt{\beta(s)\beta^{-1}} \cos \Delta \mu(s) \quad \Delta \mu(s) = \int_0^s \beta^{-1}(s') ds'
\]

Elastic proton kinematics reconstruction (simplified):

\[
\begin{align*}
\Theta^*_x &= \left( \Theta_{x,RP} - \frac{dv_x}{ds} x^* \right) \int \frac{dL_x}{ds} , & \frac{\Delta p}{p} = 0 \\
\Theta^*_y &= \left( y_{RP} - v_y y^* \right) / L_y
\end{align*}
\]

Scattering angle reconstructed in both projections

Excellent optics understanding required
Beam-Based Roman Pot Alignment (Scraping)

A primary collimator cuts a sharp edge into the beam, symmetrical to the centre.

The top RP approaches the beam until it touches the edge.

The last 10 μm step produces a spike in a Beam Loss Monitor downstream of the RP.

When both top and bottom pots are touching the beam edge:

- they are at the same number of sigmas from the beam centre as the collimator
- the beam centre is exactly in the middle between top and bottom pot

→ Alignment of the RPs relative to the beam

The RP – beam contacts are also registered as spikes in the trigger rate.

alignment is very critical and fundamental for any physics reconstruction

alignment between pots with overlapping tracks (~ few μm)

fine alignment wrt beam using elastic events
Elastic pp scattering: topology (hit map in RP detectors)

Two diagonals analysed independently

\[ t = -p^2 \theta^2 \]

\[ \xi = \Delta p/p \]
Elastic Scattering: Collinearity

Collinearity in $\theta_y^\ast$

Missing acceptance in $\theta_y^\ast$

Width in agreement with beam divergence of 17 $\mu$rad

Collinearity in $\theta_x^\ast$

Low $\zeta$, i.e. $|x| < 0.4$ mm and $2\sigma$ cut in $\Delta\theta_y^\ast$

$\Theta_x$ is measured with 5m lever arm spectrometer
Elastic pp scattering: analysis

Collinearity cut (left-right)

\[ q^*_{x,45} \leftrightarrow q^*_{x,56} \]

\[ q^*_{y,45} \leftrightarrow q^*_{y,56} \]

Background subtraction

Acceptance correction
First measurement of the elastic pp differential cross-section

2011 with $\beta^* = 3.5$ m

First published data in 2011
EPL 95 (2011) 41001
EPL 96 (2011) 21002
Comparison to some models

None of the models really fit

Better statistics at large $t$ needed (in progress)
Elastic pp Scattering at 7 TeV: Differential Cross-Section

t range : $7 \times 10^{-3}$ GeV$^2 < |t| < 3.5$ GeV$^2$

\[ d\sigma_{el}/dt = A e^{-B|t|} \]

\[ |t|_{\text{min}} = 2 \cdot 10^{-2} \text{ GeV}^2 \]

\[ |t|_{\text{min}} = 5 \cdot 10^{-3} \text{ GeV}^2 \]

\[ |t|_{\text{dip}} = 0.53 \text{ GeV}^2 \]

\[ B = 19.9 \pm 0.26^{\text{syst}} \pm 0.04^{\text{stat}} \text{ GeV}^{-2} \]

\[ A = 506 \pm 22.7^{\text{syst}} \pm 1.0^{\text{stat}} \text{ mb/GeV}^2 \]

\[ 503 \pm 26.7^{\text{syst}} \pm 1.5^{\text{stat}} \text{ mb/GeV}^2 \]

Additional data set under analysis:

$2 \text{ GeV}^2 < |t| < 3.5$ GeV$^2$

Integrated elastic cross-section:

$25.4 \pm 1.0^{lumi} \pm 0.3^{syst} \pm 0.03^{stat} \text{ mb (90\% measured)}$

$24.8 \pm 1.0^{lumi} \pm 0.2^{syst} \pm 0.2^{stat} \text{ mb (50\% measured)}$
Low t - distribution

Constant slope for $0.007 < t < 0.2 \text{ GeV}^2$

Individual errors
Slope parameter $B$ and elastic cross-section

$B$ constant in the range $0.007 < t < 0.2 \text{ GeV}^2$

$B$ increases with energy

$\sigma_{el} / \sigma_{tot}$ increases with energy
Elastic scattering – from ISR to Tevatron

**PROTON-PROTON ELASTIC SCATTERING**

- **Diffractive minimum**: analogous to Fraunhofer diffraction: \(|t| \sim p^2 \theta^2\)

- exponential slope B at low |t| increases
- minimum moves to lower |t| with increasing s → interaction region grows (as also seen from \(\sigma_{\text{tot}}\))
- depth of minimum changes → shape of proton profile changes
- depth of minimum differs between pp, p\(^-\)p → different mix of processes
Elastic Scattering and Total Cross-Section at 8 TeV

July 2012: runs at $\beta^* = 90$ m

| dataset | date               | bunches | $|t|_{\text{min}}$ (GeV$^2$) | $\mathcal{L}$ (mb$^{-1}$) |
|---------|--------------------|---------|-----------------------------|--------------------------|
| 1       | 7 July, 1st fill   | 1       | $4 \cdot 10^{-3}$          | --                       |
| 2       | 7 July, 2nd fill   | 1       | $7 \cdot 10^{-3}$          | $\approx 40$             |
| 3a      | 12–13 July         | 1       | $15 \cdot 10^{-3}$         | $\approx 30$             |
| 3b      | 12–13 July         | 2 or 3  | $15 \cdot 10^{-3}$         | $\approx 820$            |

only RP alignment, RPs moving

collinearity, low $\xi$, common vertex

<table>
<thead>
<tr>
<th>cut</th>
<th>quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>diagonal</td>
<td>4 RP hits</td>
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<tr>
<td>1</td>
<td>$\theta^<em>_x$ vs. $\theta^</em>_x^L$</td>
</tr>
<tr>
<td>2</td>
<td>$\theta^<em>_y$ vs. $\theta^</em>_y^L$</td>
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<tr>
<td>3</td>
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<td>4</td>
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<td>5</td>
<td>$\theta^*<em>y$ vs. $y</em>{R,F} - y_{R,N}$</td>
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<tr>
<td>6</td>
<td>$\theta^*<em>y$ vs. $y</em>{L,F} - y_{L,N}$</td>
</tr>
<tr>
<td>7</td>
<td>$x^<em>_R$ vs. $x^</em>_L$</td>
</tr>
</tbody>
</table>
Elastic Scattering and Total Cross-Section at 8 TeV

July 2012: runs at $\beta^* = 90$ m

| dataset | date           | bunches | RPs | $|t|_{\text{min}}$ (GeV$^2$) | $\mathcal{L}$ (mb$^{-1}$) |
|---------|----------------|---------|-----|-----------------------------|-------------------------|
| 1       | 7 July, 1st fill | 1       | $3\sigma$ | $4 \cdot 10^{-3}$ | --                       |
| 2       | 7 July, 2nd fill | 1       | $6\sigma$ | $7 \cdot 10^{-3}$ | $\approx 40$           |
| 3a      | 12–13 July         | 1       | $9.5\sigma$ | $15 \cdot 10^{-3}$ | $\approx 30$          |
| 3b      | 12–13 July         | 2 or 3  | $9.5\sigma$ | $15 \cdot 10^{-3}$ | $\approx 820$        |

only RP alignment, RPs moving

Preliminary t-distributions (unnormalised)

down to $|t| \sim 6 \times 10^{-4}$: foreseen at $\beta^* = 1$ km

larger $|t|$:  
- possible at $\beta^* = 0.6$m  
- difficult due to 2xSD and other background
Total Inelastic Cross Section Measurement at $\sqrt{s} = 7$ TeV

1. based only on elastic scattering via optical theorem
2. based on the measurement of the inelastic cross-section using charged particle detectors

Inelastic cross-section is measured with two different detectors and triggers

via elastic scattering with RP detectors
via inelastic detectors

All TOTEM detectors are used
Direct measurement of the Inelastic Cross-Section at $\sqrt{s}=7$ TeV

$T1: \, 3.1 < \eta < 4.7$

$T2: \, 5.3 < \eta < 6.5$
Inelastic Cross-Section visible in T2

Inelastic events in T2: classification

- tracks in both hemispheres
  - non-diffractive minimum bias
  - double diffraction

- tracks in a single hemisphere
  - mainly single diffraction

$M_X > 3.4\text{ GeV/c}^2$

Corrections to the T2 visible events

- Trigger Efficiency: 2.3 %
  (measured from zero bias data with respect to track multiplicity)

- Track reconstruction efficiency: 1%
  (based on MC tuned with data)

- Beam-gas background: 0.54%
  (measured with non colliding bunch data)

- Pile-up ($\mu = 0.03$): 1.5%
  (contribution measured from zero bias data)

$\sigma_{\text{inelastic, T2 visible}} = 69.7 \pm 0.1\text{ (stat)} \pm 0.7\text{ (syst)} \pm 2.8\text{ (lumi)}\text{ mb}$
Inelastic Cross-Section

\[ \sigma_{\text{inelastic}, \text{T2 visible}} \rightarrow \sigma_{\text{inelastic}} \]

Missing inelastic cross-section

- Events visible in T1 but not in T2: 2.0 %
  \textit{(estimated from zero bias data)}
- Rapidity gap in T2: 0.57 %
  \textit{(estimated from T1 gap probability transferred to T2)}
- Central Diffraction: T1 & T2 empty: 0.54%
  \textit{(based on MC, correction max \( \sim 0.25 \times \sigma_{\text{CD}} \), quoted in systematic error)}
- Low Mass Diffraction: 3.7% ± 2% (syst)
  \textit{(Several models studied, correction based on QGSJET-II-4, imposing observed 2hemisphere/1hemisphere event ratio and the effect of ‘secondaries’)}

\textbf{Possibility of measuring low mass diffraction with a single proton trigger needs clean beam conditions to avoid beam halo background}

\[ \sigma_{\text{inelastic}} = 73.7 \pm 0.1^{\text{(stat)}} \pm 1.7^{\text{(syst)}} \pm 2.9^{\text{(lumi)}} \text{ mb} \]
Inelastic Cross Section: low mass diffraction

By comparison with the measured inelastic cross-section (using the total cross-section), the low mass single diffraction can be determined:

\[ \sigma_{\text{tot}} - \sigma_{\text{el}} = 73.2 \pm 1.3 \text{ mb} \]

\[ \sigma_{Mx < 3.4 \text{ GeV}} = 2.2 \pm xx \text{ mb (preliminary)} \]

Possibility of measuring low mass diffraction with a single proton trigger needs clean beam conditions to avoid beam halo background
3 Ways to the Total Cross-Section

**elastic observables only:**

\[ \sigma_{\text{tot}}^2 = \frac{16\pi}{1 + \varrho^2} \frac{1}{\mathcal{L}} \frac{dN_{\text{el}}}{dt} \bigg|_0 \]

(p=0.14 [COMPETE])

June 2011 (EPL96): \( \sigma_{\text{tot}} = (98.3 \pm 2.8) \text{ mb} \)

Oct. 2011 (PH pre.): \( \sigma_{\text{tot}} = (98.6 \pm 2.2) \text{ mb} \)

- Different bunch intensities!

**\( \varrho \) independent:**

\[ \sigma_{\text{tot}} = \frac{1}{\mathcal{L}} (N_{\text{el}} + N_{\text{inel}}) \]

\( \sigma_{\text{tot}} = (99.1 \pm 4.3) \text{ mb} \)

**luminosity independent:**

\[ \sigma_{\text{tot}} = \frac{16\pi}{1 + \varrho^2} \frac{dN_{\text{el}}/dt}{N_{\text{el}} + N_{\text{inel}}} \bigg|_0 \]

\( \sigma_{\text{tot}} = (98.0 \pm 2.5) \text{ mb} \)

Excellent agreement between cross-section measurements at 7 TeV using
- runs with different bunch intensities,
- different methods.
Cross-sections with different methods

\[ \sigma_{\text{tot}}(\text{red}), \sigma_{\text{inel}}(\text{blue}) \text{ and } \sigma_{\text{el}}(\text{green}) \]

- \( \ddot{p}p \) (PDG)
- \( pp \) (PDG)
- Auger + Glauber
- TOTEM (\( \mathcal{L} \) indep.)
- ATLAS
- CMS

\( \sigma_{\text{tot}} \) fits:

- best COMPETE \( \sigma_{\text{tot}} \) fits

\( \rho = 0.141 \pm 0.007 \)
done before TOTEM measurement
Luminosity determination and ratios

Luminosity calibration:

\[ L = \frac{(1 + \rho^2)(N_{el} + N_{inel})^2}{16\pi (dN_{el}/dt)_{t=0}} \]

1) \( L = 82/\mu b \pm 4\% \) \( L = 83.7/\mu b \pm 3.8\% \)

2) \( L = 1.65/\mu b \pm 4\% \) \( L = 1.65/\mu b \pm 4.5\% \)

Luminosity and \( \rho \) independent ratios:

\[ \frac{\sigma_{el}}{\sigma_{tot}} = 0.257 \pm 2\% \]
\[ \frac{\sigma_{el}}{\sigma_{inel}} = 0.354 \pm 2.6\% \]

Summary:

The cross-section measurements are in excellent agreement using:
runs with different bunch luminosities
different methods
A First, Very Crude $\rho$ Estimate at 7 TeV

$$\rho = \frac{\text{Re} T(t=0)}{\text{Im} T(t=0)}$$

From optical theorem:

$$\rho^2 = 16\pi \mathcal{L}_{\text{int}} \left. \frac{dN_{\text{el}}}{dt} \right|_{t=0} \frac{1}{(N_{\text{el}} + N_{\text{inel}})^2} - 1 = 0.009 \pm 0.056$$

$\rho < 0.32$ (95% CL),
or, using Bayes’ approach (with uniform prior $|\rho|$ distribution):

$|\rho| = 0.145 \pm 0.091$ [COMPETE extrapolation: $\rho = 0.141 \pm 0.007$]

Not so exciting, but …
\[ \sigma_{\text{tot}} = \frac{4\pi}{s} \Im \left( T_{\text{elastic,nuclear}}(t = 0) \right) \]

\[ \frac{d\sigma}{dt} = \frac{4\pi\alpha^2 \left( \hbar c \right)^2 G^4(t)}{|t|^2} + \frac{\alpha(\rho - \alpha\phi)\sigma_{\text{tot}} G^2(t) e^{-B|t|/2}}{|t|} + \frac{\sigma_{\text{tot}}^2 \left( 1 + \rho^2 \right) e^{-B|t|}}{16\pi \left( \hbar c \right)^2} \]

\( \alpha \) = fine structure constant
\( \phi \) = relative Coulomb-nuclear phase
\( G(t) \) = nucleon el.-mag. form factor = \((1 + |t| / 0.71)^{-2} \)
\( \rho \) = \( \Re / \Im [T_{\text{elastic,nuclear}}(t = 0)] \)

Measurement of \( \rho \) by studying the Coulomb – Nuclear interference region down to
\[ |t| \sim 6 \times 10^{-4} \text{ GeV}^2 \]

Reachable with \( \beta^* \sim 1000 \text{ m} \) still in 2012 if RPs can approach beam centre to \( \sim 4\sigma \)
How to reach the Coulomb-Nuclear Interference Region?

$\sqrt{s} = 8 \text{ TeV}$

$\sqrt{s} = 13 \text{ TeV}$

RP window position (real $\sigma$ for $\epsilon_n = 2 \mu m$ rad)

Coulomb = nuclear

$\epsilon_n = 2 \mu m$ rad

$\epsilon_n = 1 \mu m$ rad

RP approach the beam to $\sim 4 \sigma$

Beam emittance $\epsilon_n < 2 \mu m$ rad

$\Rightarrow$ Challenging but possible

push $\beta^*$ to $> 2000$ m

good $t$-resolution needs parallel-to-point focussing in both $x$ and $y$ (phase advance $\pi/2$)

Additional magnet cables needed. To be installed during LS1
The $\beta^* = 1000$ m Optics

MD in June: first unsqueeze to 1km achieved

14 September:

- special beam optics with $\beta^* = 1000$ m fully commissioned
- collisions in IP1 and IP5 found
- vertical emittances $\varepsilon_n \sim 2 \mu$m rad
- 4 vertical TOTEM RPs (out of 8) aligned at $\sim 4 \sigma$
- time slot ended $\Rightarrow$ no physics data taken yet, diagnostic data on halo background being analysed

Physics run scheduled for October 2012
β* = 90m optics runs:
- DPE protons of \(-t > 0.02\text{GeV}^2\) detected by RP
- nearly complete \(\xi\)-acceptance

**σ_{DPE}** measurement method:

\[
\frac{d^2\sigma_{DPE}}{dt_1 dt_2} = C(\Delta \varphi_{1,2}) e^{-B_{t_1}} e^{-B_{t_2}}
\]

\[
\sigma_{DPE} = \int_0^\infty dt_1 \int_0^\infty dt_2 \frac{d^2\sigma_{DPE}}{dt_1 dt_2}
\]
Correlation between the forward proton(s) and particles in T2

sector 45  IP  sector 56
RP  T2  T2  RP

run: 37220007, event: 9904

DP

run: 37280004, event: 22784

SD (low $\xi$)
Single diffraction large $\xi$

Rapidity Gap

$\Delta \eta = -\ln \xi$

$M_x^2 = \xi s$

sector 45  IP  sector 56

$\varphi$

$\eta$

run: 37280006, event: 6074
Diffractive Analyses Ongoing

Based on $\beta^* = 90$ m (7 TeV) run in Oct. 2011 (RP @ 4.8$\sigma$ – 6.5$\sigma$):

- **Central Diffraction**
  
  \[ \frac{d^2\sigma_{DPE}}{dt_1 dt_2} , \sigma_{DPE} \]

- **Single Diffraction**
  
  \[ d\sigma_{SD}/dt , d\sigma_{SD}/d\xi , \sigma_{SD} \]

- **Double Diffraction**
  
  Select diff. masses $3.4$ GeV < M < 10 GeV
  requiring tracks in both T2s, veto on T1s

→ Extend studies over full $\eta$ range with CMS (2012 data)
Analyses in progress:

- T1 measurement at 7 TeV (3.1 < |η| < 4.7)
- **NEW**: combined analysis CMS + TOTEM (0 < |η| < 6.5) on low-pileup run of 1st May 2012 (8 TeV): common trigger (T2, bunch crossings), both experiments read out

- **NEW**: parasitical collision at $\beta^* = 90$ m (7 July 2012) → vertex at ~11m → shifted η acceptance:
Joint Data Taking with CMS

Realisation of common running much earlier than ever anticipated

1. **Hardware**: electrical from RP220 to CMS $\rightarrow$ trigger within CMS latency
2. **Trigger**: bi-directional level-1 exchange $\rightarrow$ same events taken
3. **Synchronisation**: orbit number and bunch number in data streams
4. **Offline**:
   - common repository for independently reconstructed data
   - merging procedure $\rightarrow$ common n-tuples
Joint Data Taking with CMS

May 2012: low pileup run: $\beta^* = 0.6 \text{ m}$, $\sqrt{s} = 8 \text{ TeV}$, T1 & T2 & CMS read out

<table>
<thead>
<tr>
<th>Date</th>
<th>Trigger</th>
<th>Inelastic events</th>
<th>RP position</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 1</td>
<td>T2</td>
<td></td>
<td>BX</td>
</tr>
</tbody>
</table>

July 2012: $\beta^* = 90 \text{ m}$, $\sqrt{s} = 8 \text{ TeV}$, RP & T1 & T2 & CMS read out

<table>
<thead>
<tr>
<th>Date, Set</th>
<th>Trigger</th>
<th>Inelastic events</th>
<th>RP position</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 7, DS 2</td>
<td>T2</td>
<td></td>
<td>RP_{2arms}</td>
</tr>
<tr>
<td>July 12-13, DS 3a</td>
<td>T2</td>
<td></td>
<td>RP_{2arms}</td>
</tr>
<tr>
<td>July 12-13, DS 3b</td>
<td>T2</td>
<td></td>
<td>RP_{2arms}</td>
</tr>
</tbody>
</table>

Abundant material for analysis activities throughout LS1

Analyses starting:
- hard diffraction: $p + \text{dijets}$ (90m runs)
- combined $dN_{\text{ch}} / d\eta$ and multiplicity correlations
Runs Planned for 2012 / 2013

- $\beta^* = 1000 \text{ m}$: scheduled for 24 October
  → study interference region, measure $\rho$

- RP insertions in normal physics runs ($\beta^* = 0.6 \text{ m}$)
  - hard diffraction together with CMS (high diffractive masses reachable)
  - study of closest possible approach of the horizontal RPs (i.e. acceptable beam losses)
  → essential for all near-beam detector programmes at high luminosity after LS1
  Collimators needed behind the RP to protect quadrupoles

- request a low-pileup run ($\mu \sim 5\%$) with RPs at $\beta^* = 0.6 \text{ m}$ (in May RPs were not aligned)
  → study soft central diffraction final states
    with 2 leading protons defining Pomeron-Pomeron mass $M^2 = \xi_1 \xi_2 s$
    good $\xi$ resolution at $\beta^* = 0.6 \text{ m}$ → $\sigma(M) \sim 5 \text{ GeV}$

- participation in the p-Pb runs with insertions of the RPs on the proton side
  → study diffractive/electromagnetic and quasi-elastic p-Pb scattering
  p-Pb test run in September with CMS was successful (T2 trigger given to CMS)
To be done this year

Together with CMS studies on:
- Rapidity distribution over the full acceptance range
- Diffractive di-jets
- Double Pomeron Exchange
- Single Diffraction
- Double Diffraction
- Elastic scattering and cross-sections at $\sqrt{s} = 8$ TeV
- Measurement of $\rho$ with $\beta^*=1000$ m
- Preparation for Diffractive Di-jet production at highest luminosities in view of the new forward set-up after LS1

p-A data taking in 2013
Finalize the three papers in the pipe-line
The End