Latest results of the TOTEM experiment at LHC

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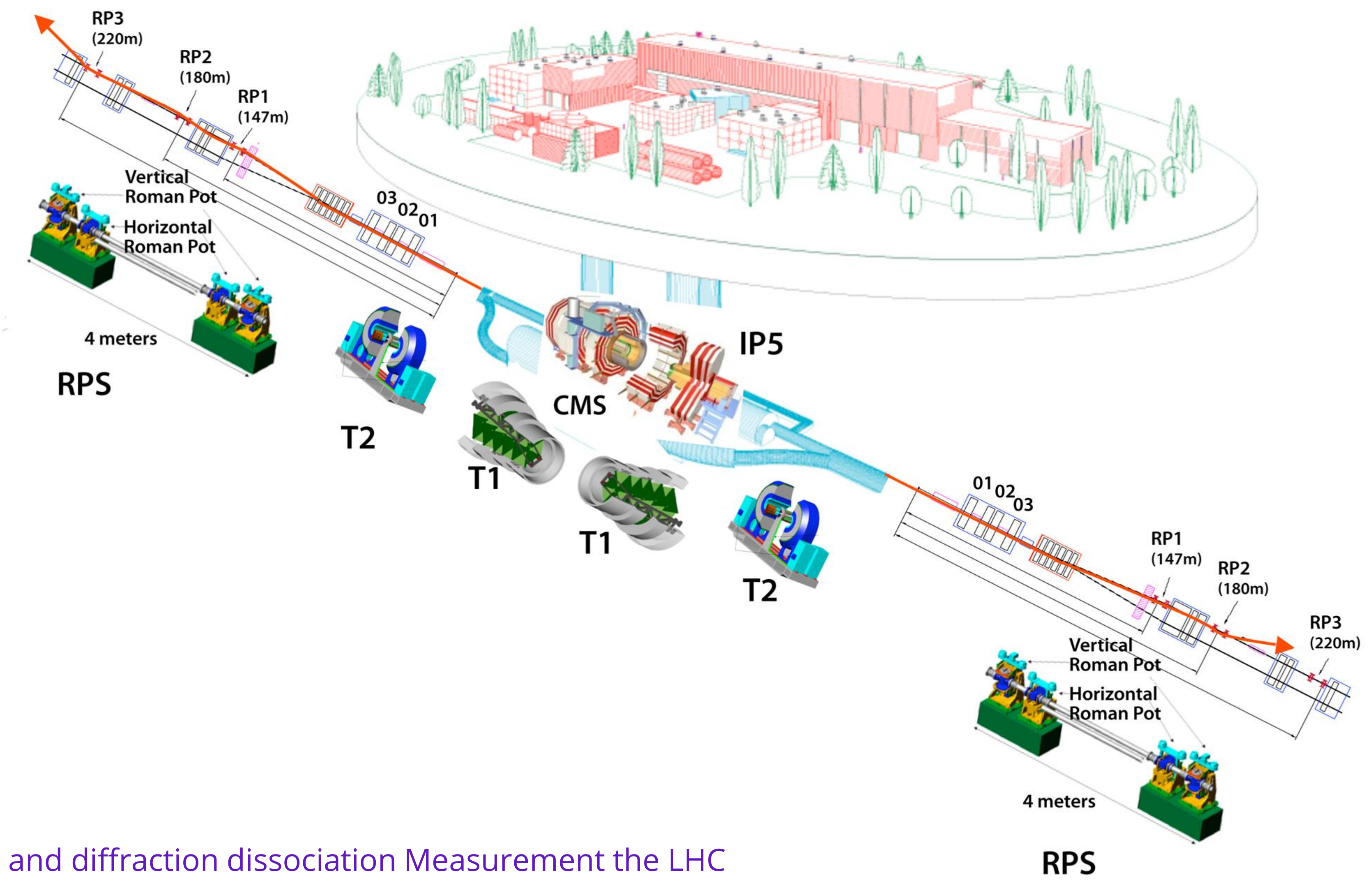
On behalf of the TOTEM Collaboration

06-11 June 2016

Outline



- TOTEM experiment at LHC
- Total cross-section
- Elastic scattering
- Diffraction dissociation

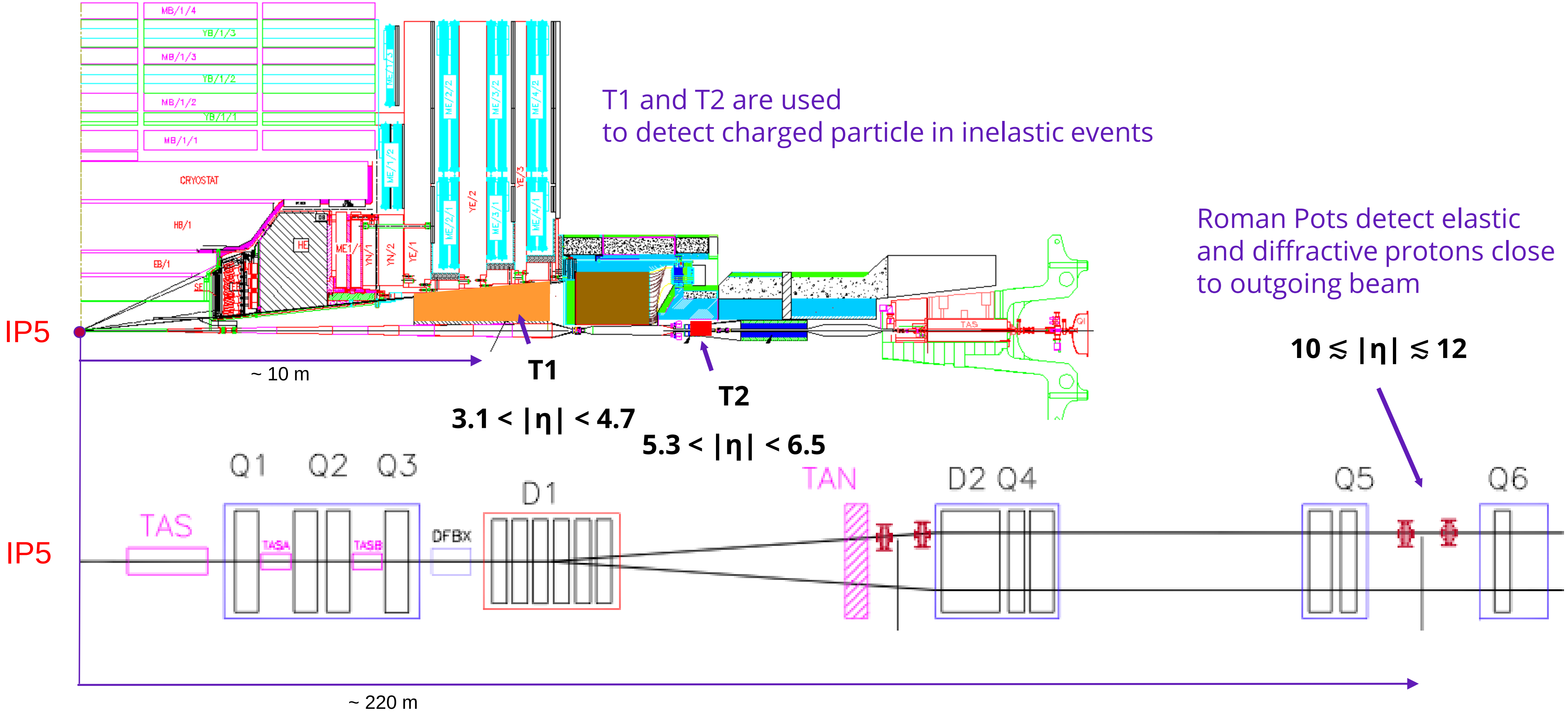
TOTal cross-section, Elastic scattering and diffraction dissociation Measurement the LHC

The TOTEM detector at the LHC

The TOTEM experimantal apparatus was designed to measure the Total Cross Section and to study Elastic Scattering and Diffraction Dissociation at the LHC

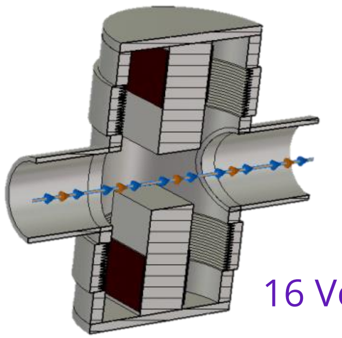
T1 and T2 are used
to detect charged particle in inelastic events

Roman Pots detect elastic
and diffractive protons close
to outgoing beam

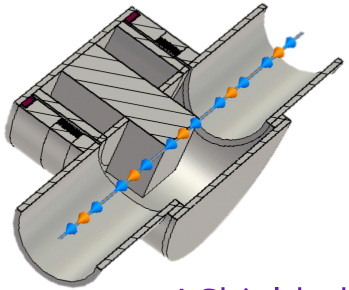


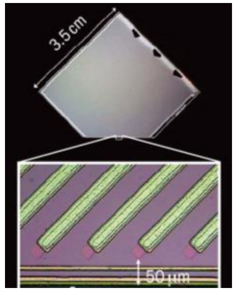
The TOTEM Roman Pot system

A Roman Pot is a movable section of the beam pipe that allows the insertion of a detector at few millimeters from the beam

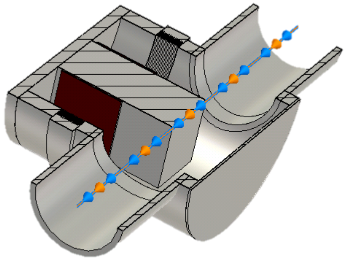


16 Vertical RPs

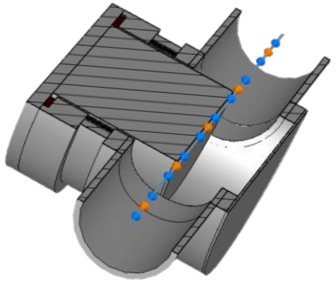


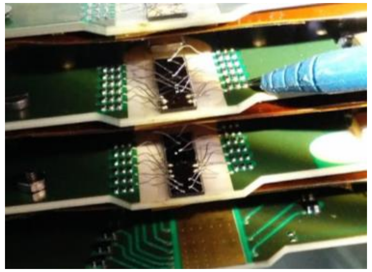


4 Shielded RPs
for high-luminosity operation



4 Horizontal RPs

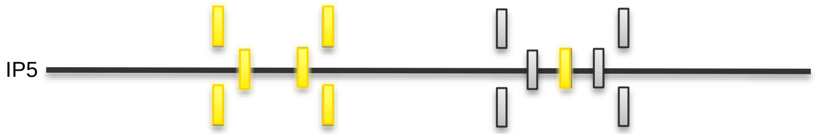




2 Cylindrical RPs
for time-of-flight detector

High intensity runs

- 4 Vertical RPs (per arm)
- 2 Shielded RPs
- Cylindrical RP



Dedicated runs

$\beta^* = 90\ m, 1\ km, 2.5\ km$

- 6 Vertical RPs
- 2 Horizontal RPs
- 1 Shielded RP

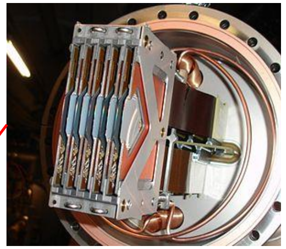
*: Si strip removed, waiting for timing detectors...

Total cross-section

Optical Theorem, Elastic $\frac{d\sigma}{dt}$ extrapolated to t = 0

$$\sigma_{\mathrm{tot}}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2} \left.\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}t}\right|_{t=0}$$

Explicit dependency on $\mathcal{L}$: $$\sigma_{\mathrm{tot}}^2 = \frac{16\pi}{1+\varrho^2}\frac{1}{\mathcal{L}}\left.\frac{\mathrm{d}N_{\mathrm{el}}}{\mathrm{d}t}\right|_0$$



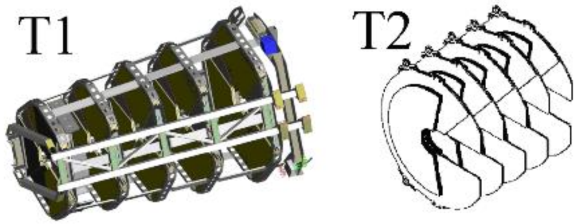
Measured using Roman Pots

$\sigma_{tot} = 98.3 \pm 2.8$ mb EPL 96(2011) 21002

$\sigma_{tot} = 98.6 \pm 2.2$ mb EPL 101(2013) 21002

Elastic + Inelastic measurement: no dependency on ρ

$$\sigma_{\mathrm{tot}} = \frac{1}{\mathcal{L}}(N_{\mathrm{el}} + N_{\mathrm{inel}})$$



Measured using T1 and T2

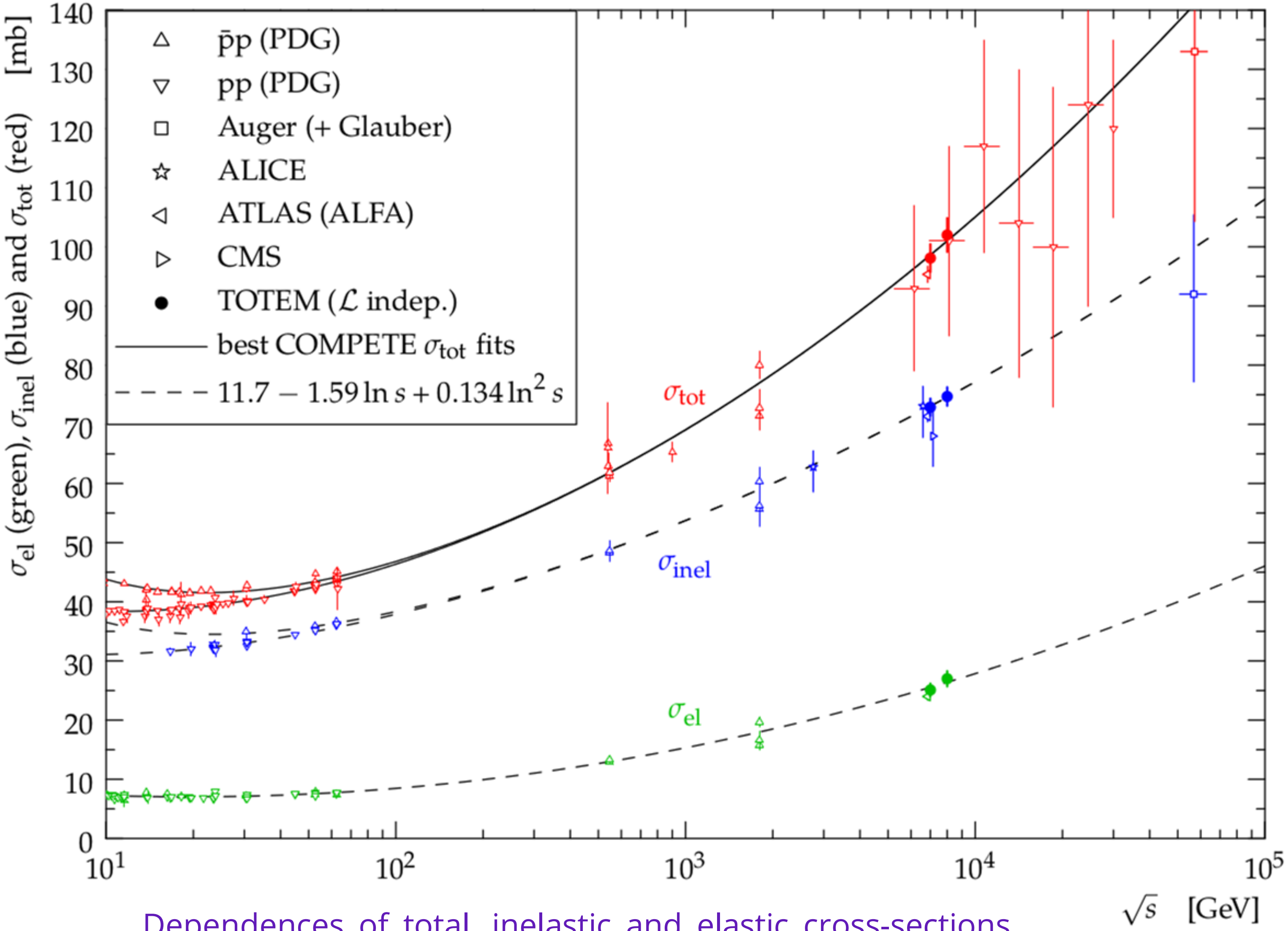
$\sigma_{tot} = 99.1 \pm 4.3$ mb EPL 101(2013) 21004

Elastic + Inelastic measurement: no dependency on $\mathcal{L}$

$$\sigma_{\mathrm{tot}} = \frac{16\pi}{1+\varrho^2}\frac{\mathrm{d}N_{\mathrm{el}}/\mathrm{d}t|_0}{N_{\mathrm{el}} + N_{\mathrm{inel}}}$$

$\sigma_{tot} = 98.0 \pm 2.5$ mb EPL 101(2013) 21004

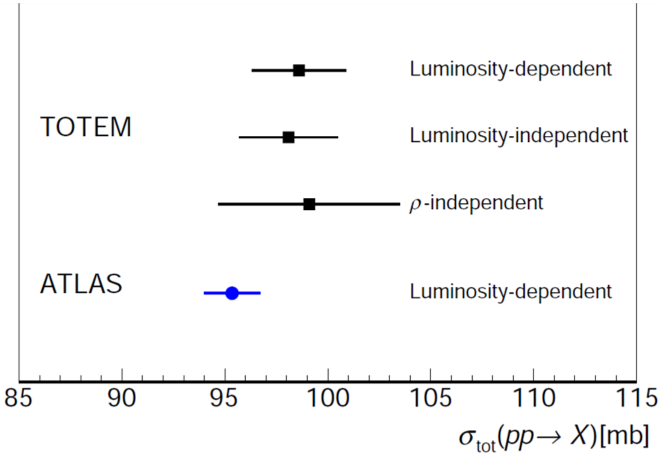
Total cross-section



Dependences of total, inelastic and elastic cross-sections on the scattering energy √s

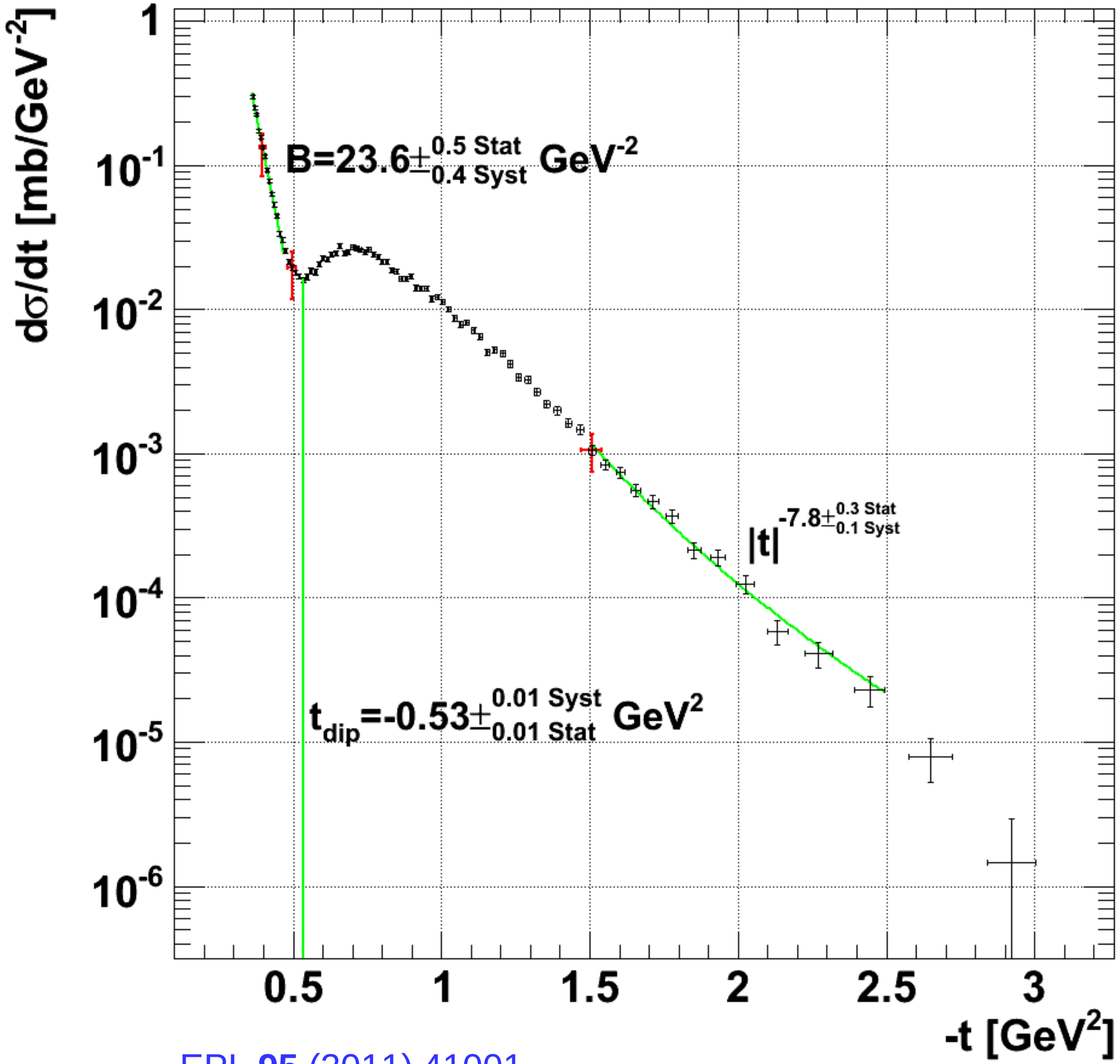
EPL 101 (2013) 21004
Phys. Rev. Lett. 111, 012001 (2013)

EPL 101 (2013) 21004 - 7 TeV
σ_{el} = 25.1 ± 1.1 mb
σ_{inel} = 72.9 ± 1.5 mb
σ_{tot} = 98.0 ± 2.5 mb
(luminosity independent)



PRL 111 (2013) 012001 - 8 TeV
σ_{el} = 27.1 ± 1.4 mb
σ_{inel} = 74.7 ± 1.7 mb
σ_{tot} = 101.7 ± 2.9 mb
(luminosity independent)

Elastic scattering at $\sqrt{s} = 7\ TeV$, $\beta^* = 3.5$ m (First measurement)



EPL **95** (2011) 41001

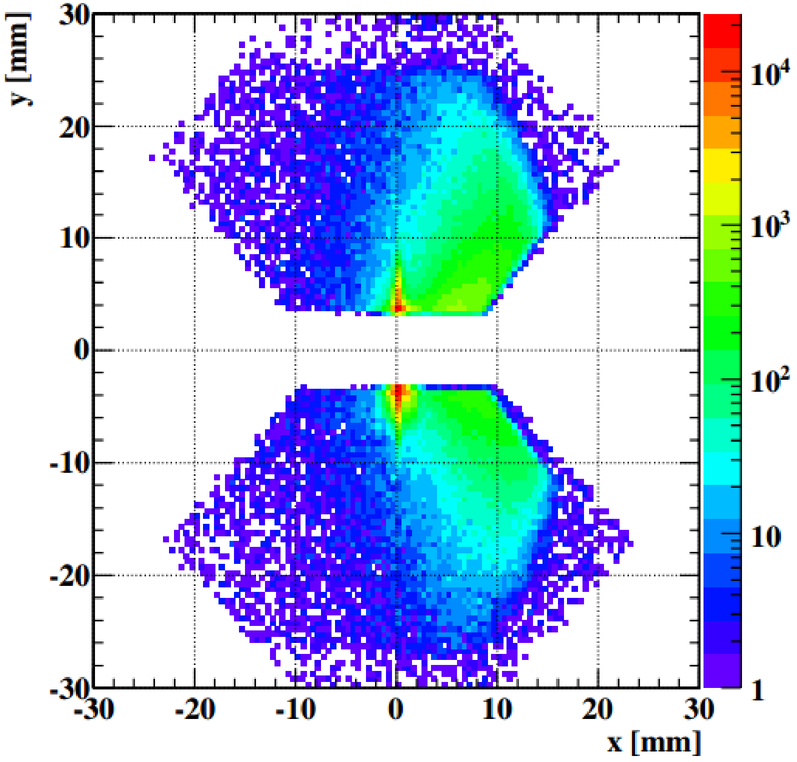
$0.36 < |t| < 2.5$ GeV²

Exponential behavior $e^{-B\,|t|}$ for $|t| < 0.47$ GeV²

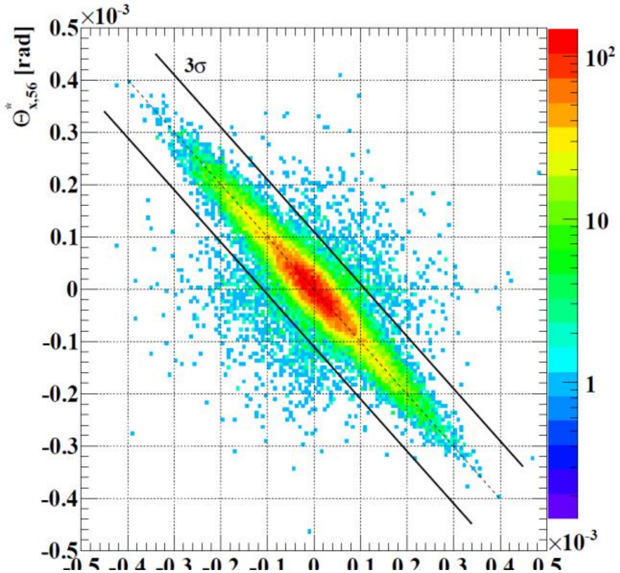
Dip moves to lower $|t|$: proton becomes "larger"

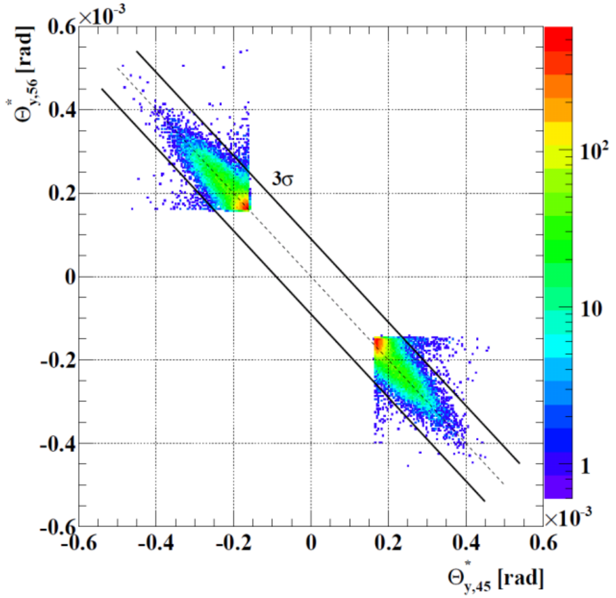
Power low behavior $|t|^{-n}$ for $1.5 < |t| < 2.5$ GeV²

Elastic scattering at $\sqrt{s} = 7\ TeV,\ \beta^* = 3.5$ m



Selected reconstructed tracks in a RP transverse to the beam at 220 m.





Correlation between the reconstructed proton scattering angles

Horizontal…

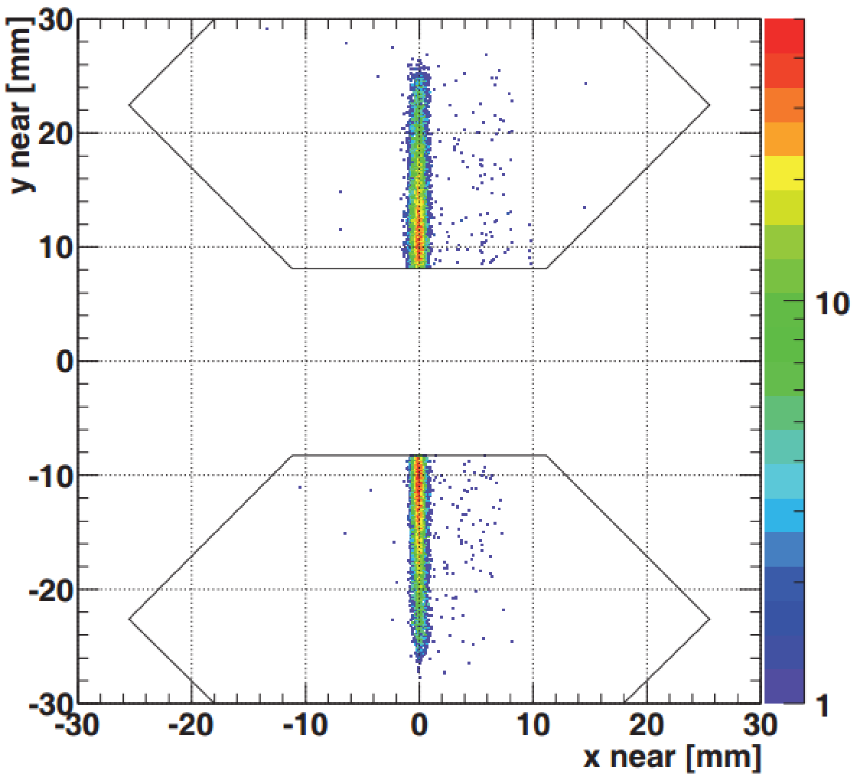
… and vertical

on both sides of the IP.

The observed spread is due to the beam divergence.

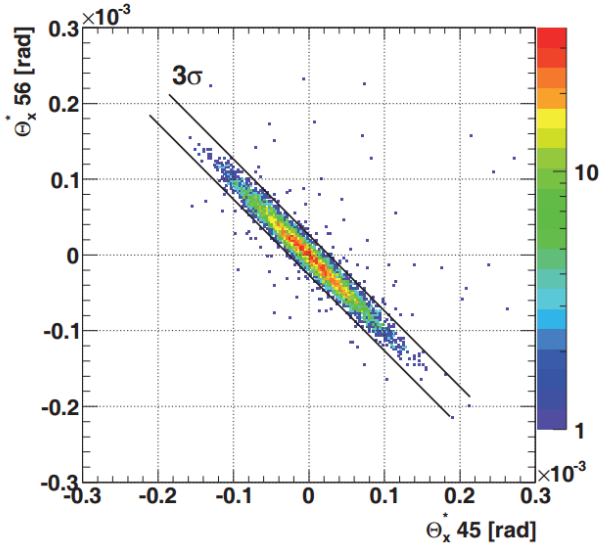
Published in EPL **95** (2011) 41001

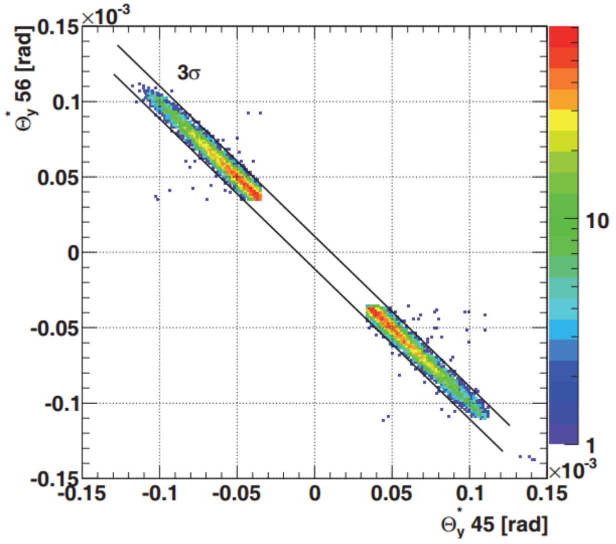
Elastic scattering at $\sqrt{s} = 7\ TeV,\ \beta^* = 90$ m



Selected reconstructed tracks in a RP transverse to the beam at 220 m.

Published in
EPL 96 (2011) 21002
EPL 101(2013) 21002





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Horizontal...

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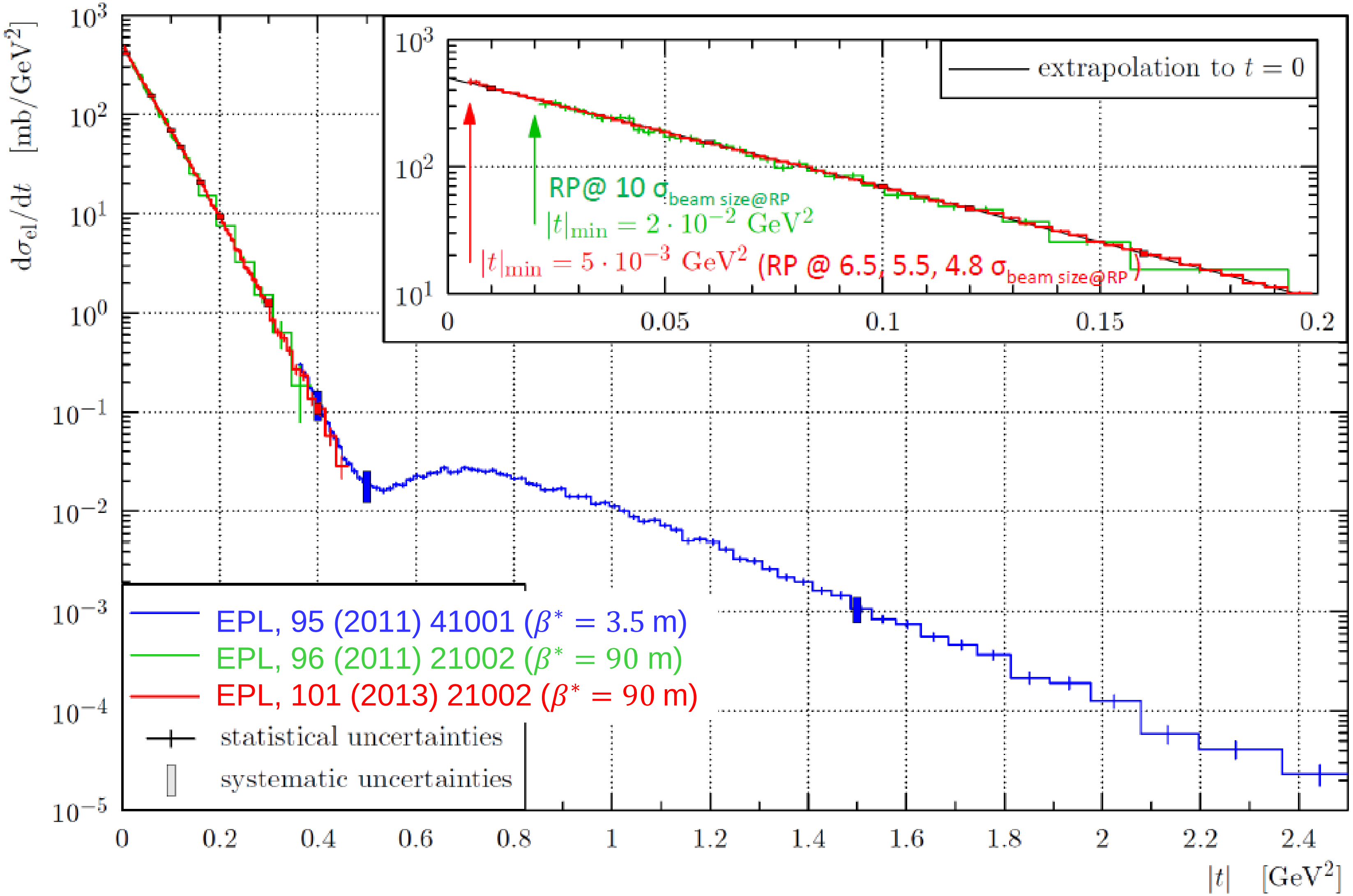
The observed spread is due to the beam divergence.

Elastic scattering at $\sqrt{s} = 7\ TeV,\ \beta^* = 90$ m



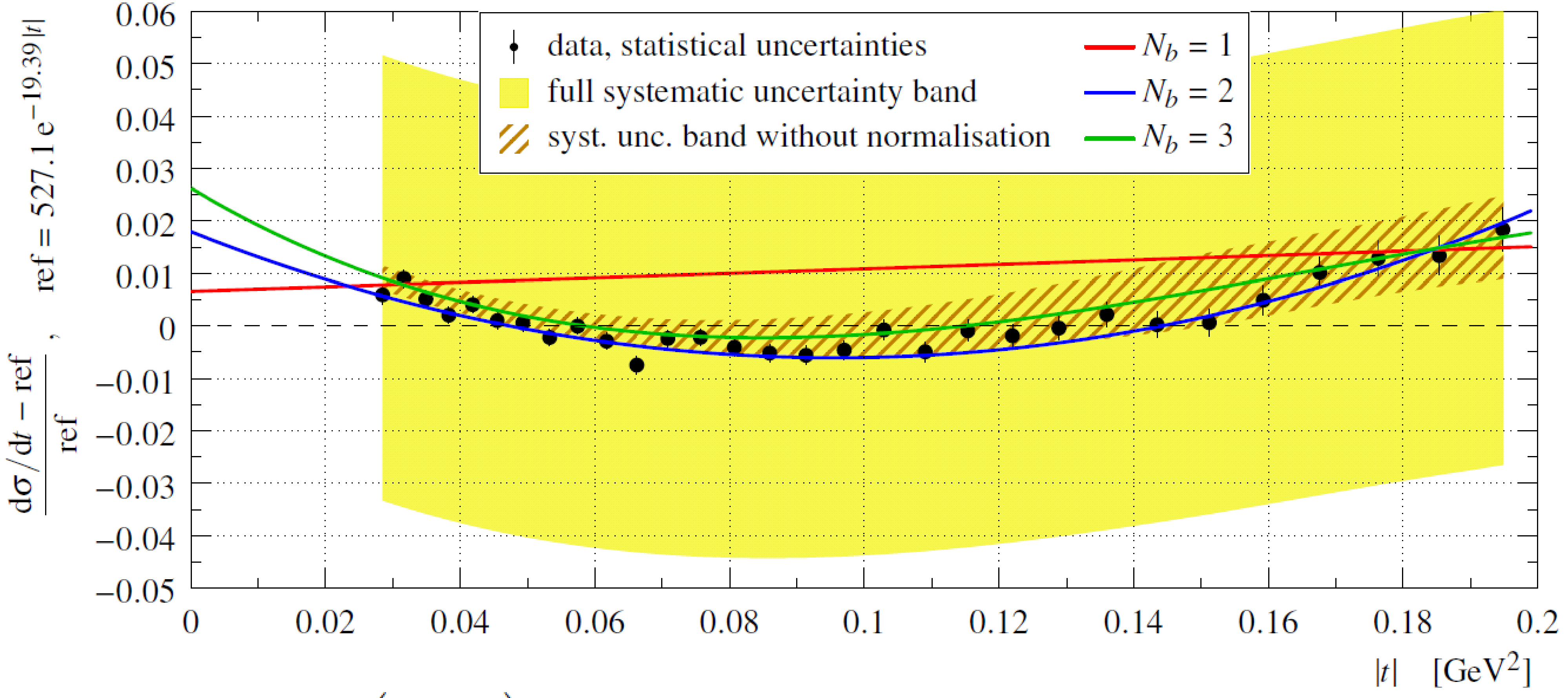
$$\sigma_{el} = \int \frac{d\sigma}{dt} dt = (24.8 \pm 0.2^{stat} \pm 1.2^{syst})\ \text{mb}$$

EPL, 96 (2011) 21002

$$\sigma_{el} = (25.43 \pm 0.03^{stat} \pm 1.07^{syst})\ \text{mb}$$

EPL, 101 (2013) 21002

Elastic scattering: non-exponentiality at low |t|



$$\frac{d\sigma}{dt}(t) = \left.\frac{d\sigma}{dt}\right|_{t=0} \exp\left(\sum_{i=1}^{N_b} b_i\, t^i\right)$$

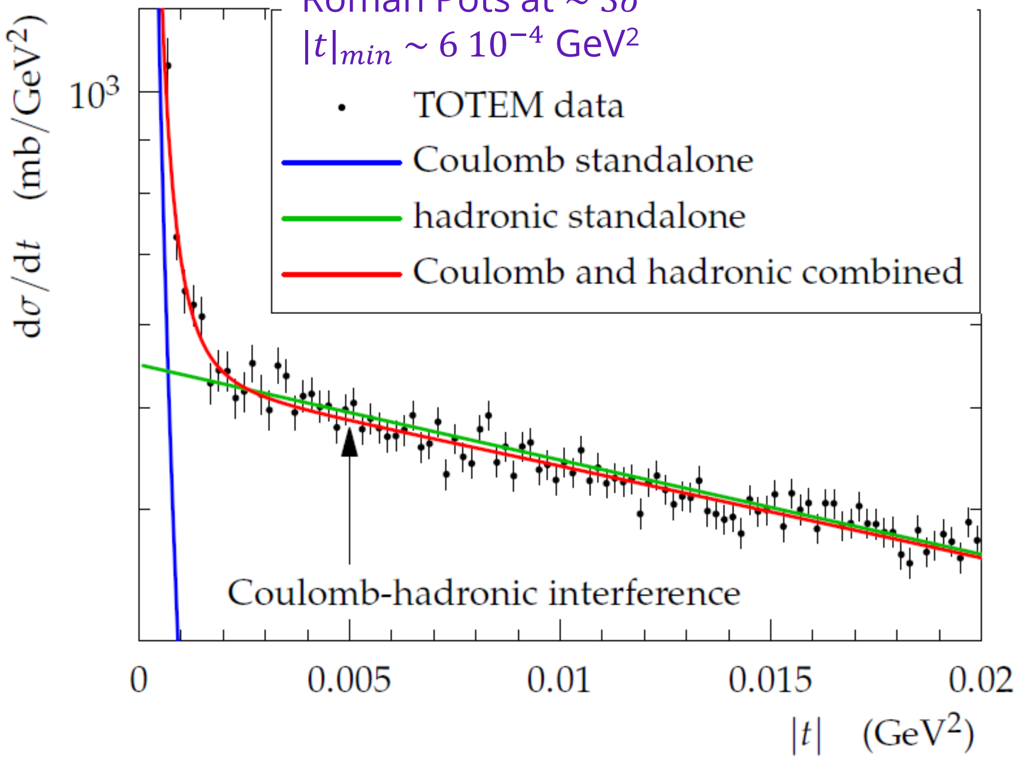
N_b = 1 excluded with 7σ significance!

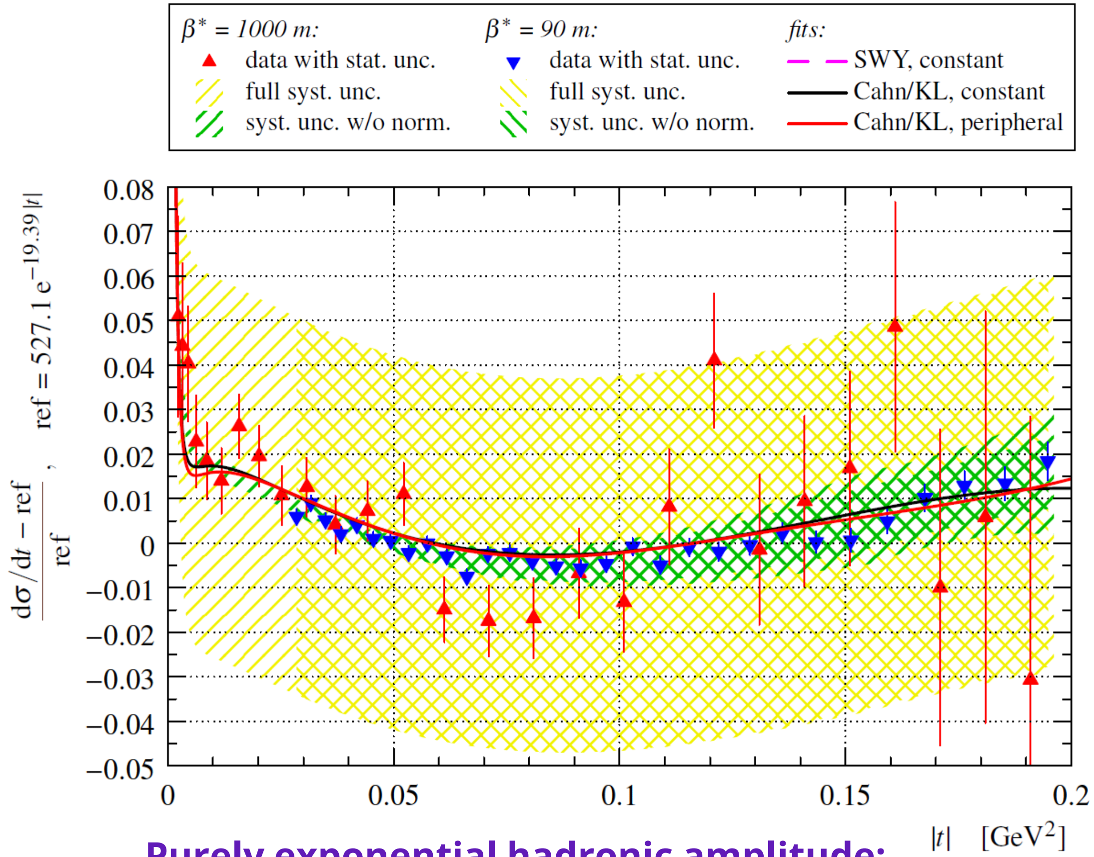
$N_b = 2 : \sigma_{tot} = (101.5 \pm 2.1)$ mb
$N_b = 3 : \sigma_{tot} = (101.9 \pm 2.1)$ mb

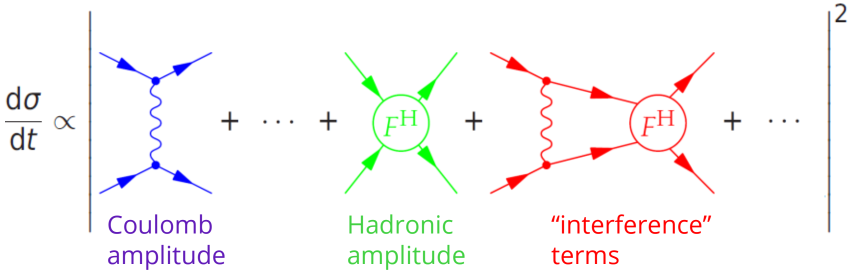
Nuclear Physics B 899 (2015) 527–546

Elastic scattering: Coulomb interference

$\sqrt{s} = 8\ \boldsymbol{TeV}$, $\boldsymbol{\beta^*} = \mathbf{1000}$ m
Roman Pots at $\sim 3\sigma$
$|t|_{min} \sim 6\ 10^{-4}$ GeV^2





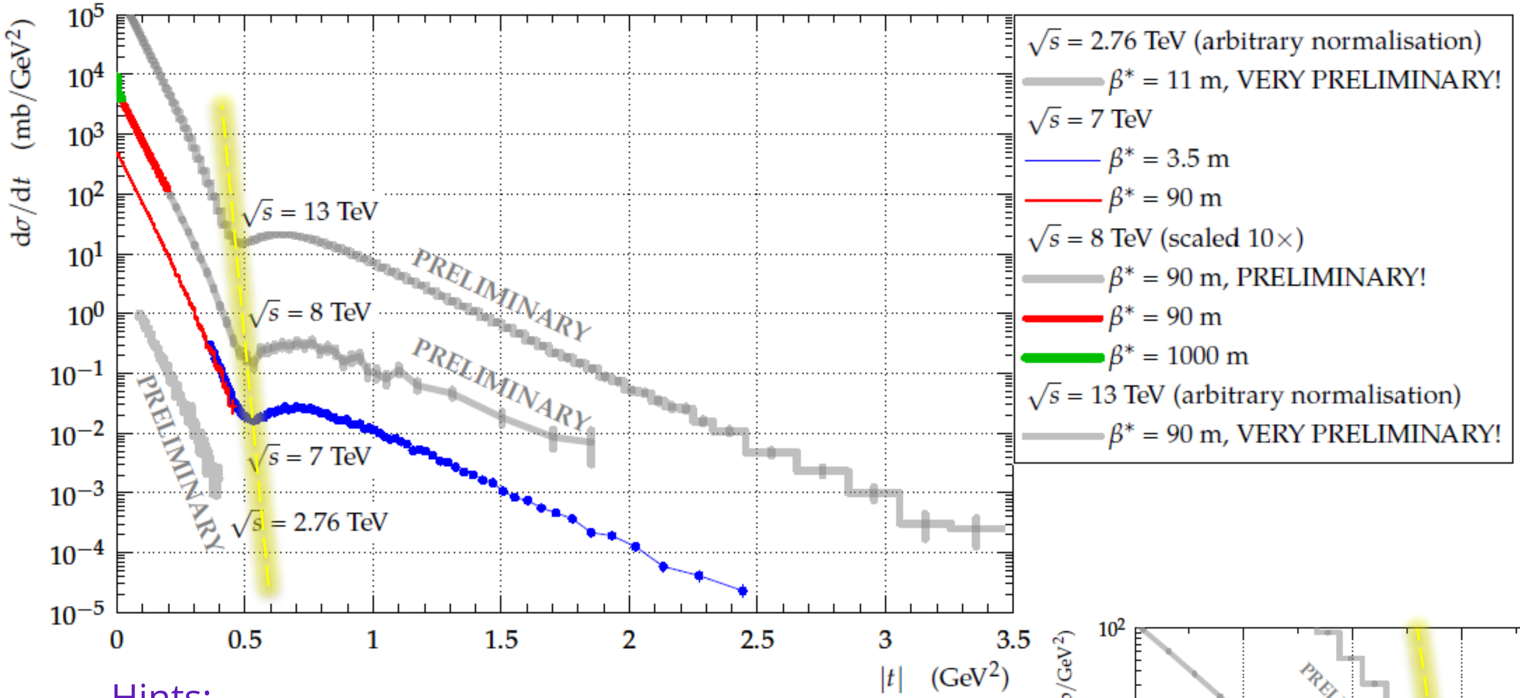


Purely exponential hadronic amplitude:
Constant phase excluded with both Simplified West-Yennie and Kundrát-Lokajicek models

Non-exponential hadronic amplitude:
Both peripheral and constant phase compatible with data

CERN-PH-EP-2015-325

Preliminary results



Different physics regimes are accessible thanks to different LHC configurations

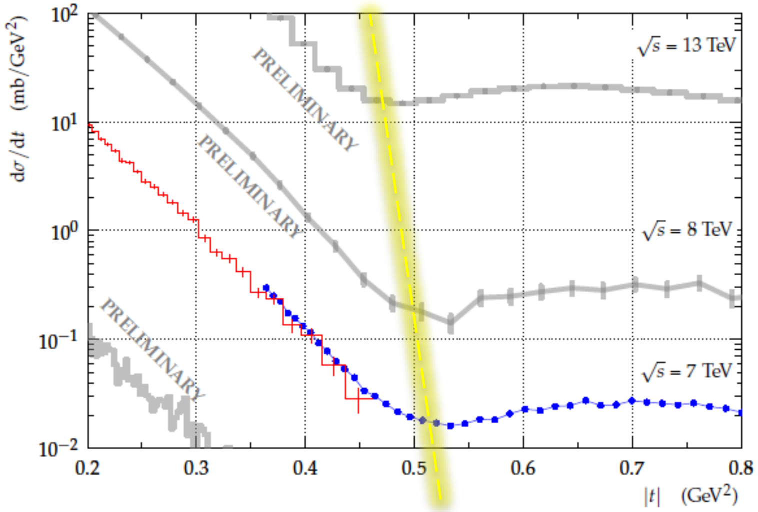
Hints:

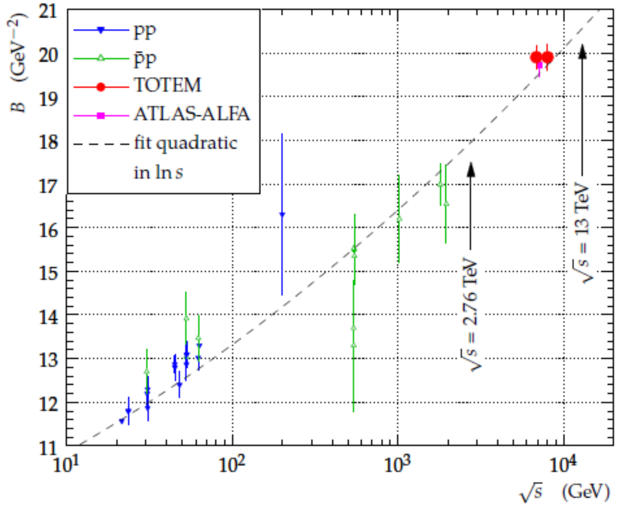
non-exponentiality confirmed at 13 TeV

$\sqrt{s}$ = 7 → 13 TeV: dip moves to lower |t|

Forward slope $B = \frac{d}{dt}\ln(\frac{d\sigma}{dt}\Big|_{t=0})$
increase wrt previous experiments

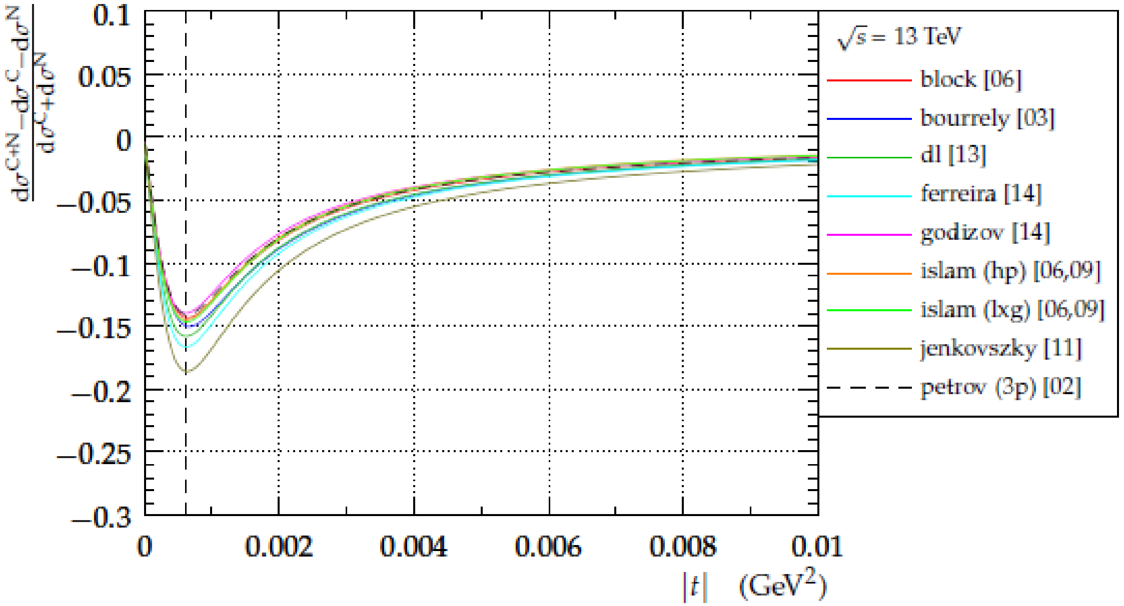
No structures at high-|t|
(rules out the "optical" models)



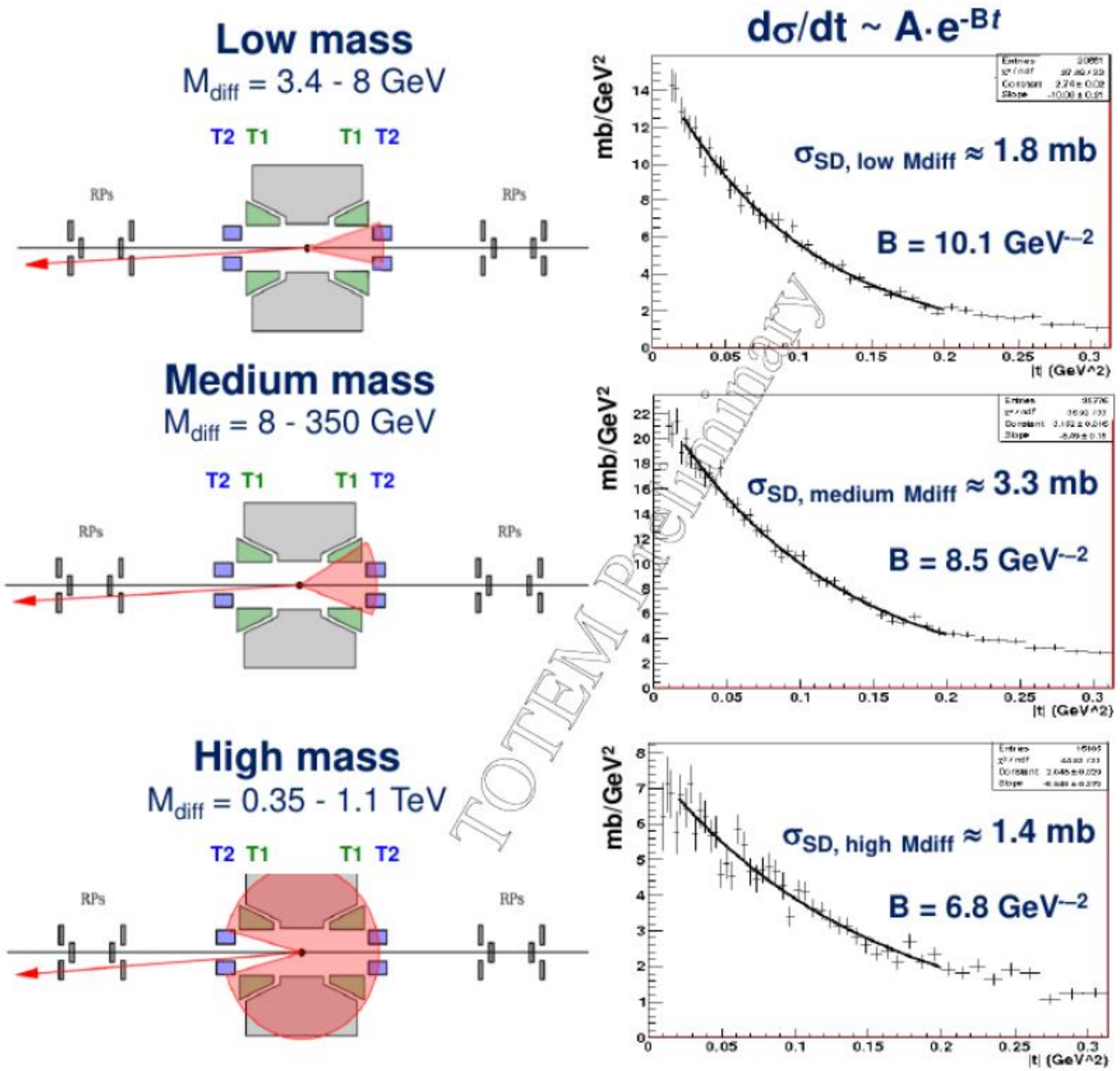


Outlook: Odderon searches

- Odderon = (hypothetical) cross-odd partner of Pomeron
- overview of past Odderon searches
  - comparison pp vs. anti-pp (dip): not applicable at LHC
  - spin analyses: not applicable at LHC
  - structures in $d\sigma/dt$: where Pomeron contribution small
    - high-$|t|$: disfavoured by 13 TeV measurements
    - low-$|t|$: shifts of ρ value $\Rightarrow$ within reach of TOTEM
- Coulomb-nuclear interference at $\sqrt{s} = 13$ TeV
  - needs special optics: $\beta^* = 2500$ m
  - $|t| = 6 \cdot 10^{-4}$ GeV^2 reachable
  - ~ 1 week data-taking time approved in 2016



Single diffraction: Preliminary results at $\sqrt{s} = 7\ TeV$



Corrections included:
- Trigger efficiency
- Proton acceptance & reconstruction efficiency
- Background subtraction
- Extrapolation to t = 0

Missing corrections:
- Class migration
- ξ resolution & beam divergence effects

Estimated uncertainties:
B ~ 15% ; σ ~ 20%

TOTEM preliminary:

σ_{SD} = 6.5 ± 1.3 mb

3.4 GeV < M_{diff} < 1.1 TeV

Analysis of very high mass SD events ongoing

courtesy of H. Saarikko

Summary

- Total cross-section measurements at $\sqrt{s}$ = 7 TeV and 8 TeV with a luminosity independent method.
- Published proton-proton elastic analysis results at $\sqrt{s}$ = 7 TeV and 8 TeV with β^* = 3.5 m, 90 m, 1000 m.
- Non-exponentiality of the differential cross-section at low-$|t|$ at $\sqrt{s}$ = 8 TeV and 13 TeV (β^* = 90 m, 1000 m).
- Hadronic-Coulomb interference at $\sqrt{s}$ = 8 TeV with β^* = 1000 m optics.
- 1st determination of the ρ parameter at the LHC with CNI.
- Ongoing analyses at $\sqrt{s}$=2.76 TeV and $\sqrt{s}$ = 13 TeV data.
- About 1 week data taking time foreseen in 2016 at 13 TeV with β^* = 2500 m.

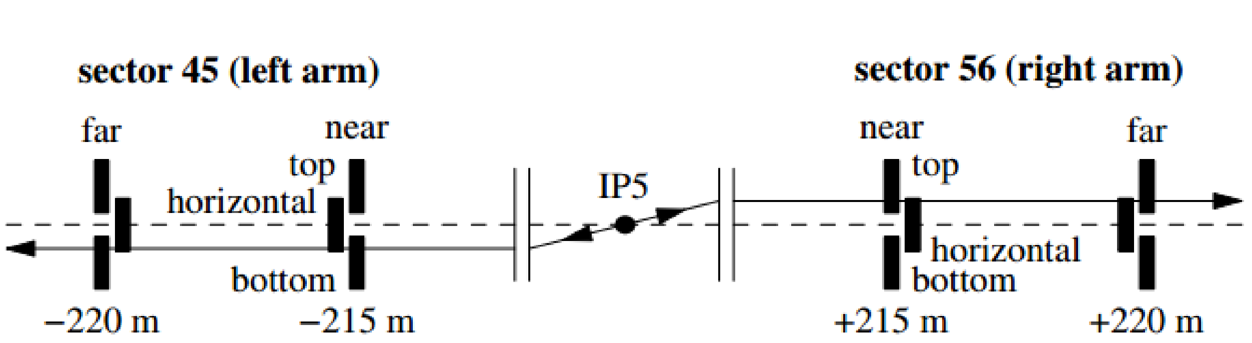
References:

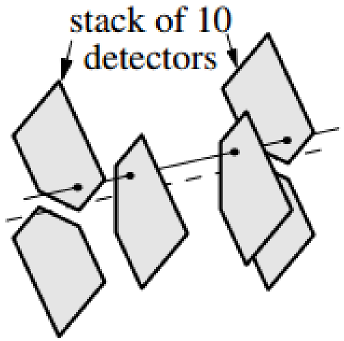
F. Nemes, TOTEM measurements of cross-sections at LHC, 3rd Elba Workshop on Forward Physics @ LHC Energy, May 2016

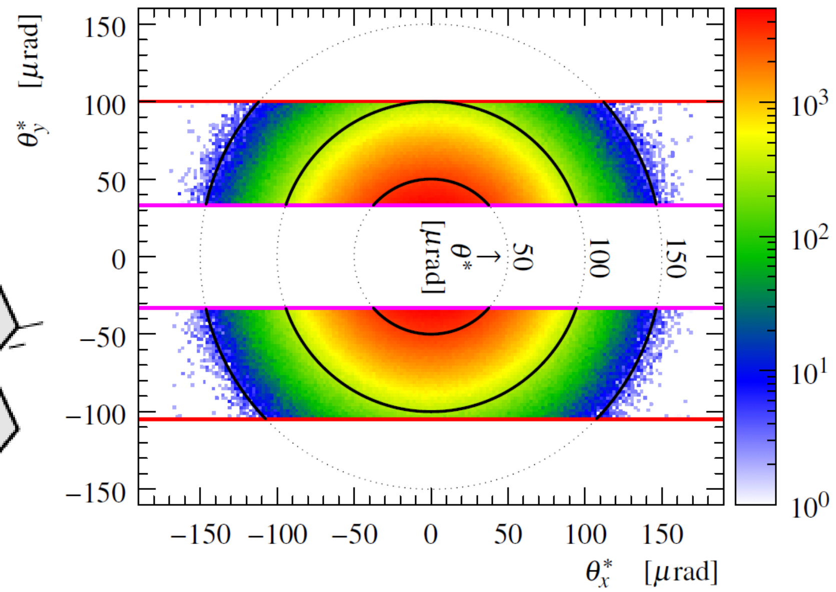
J. Kaspar, TOTEM, QCD at Cosmic Energies – VII, May 2016

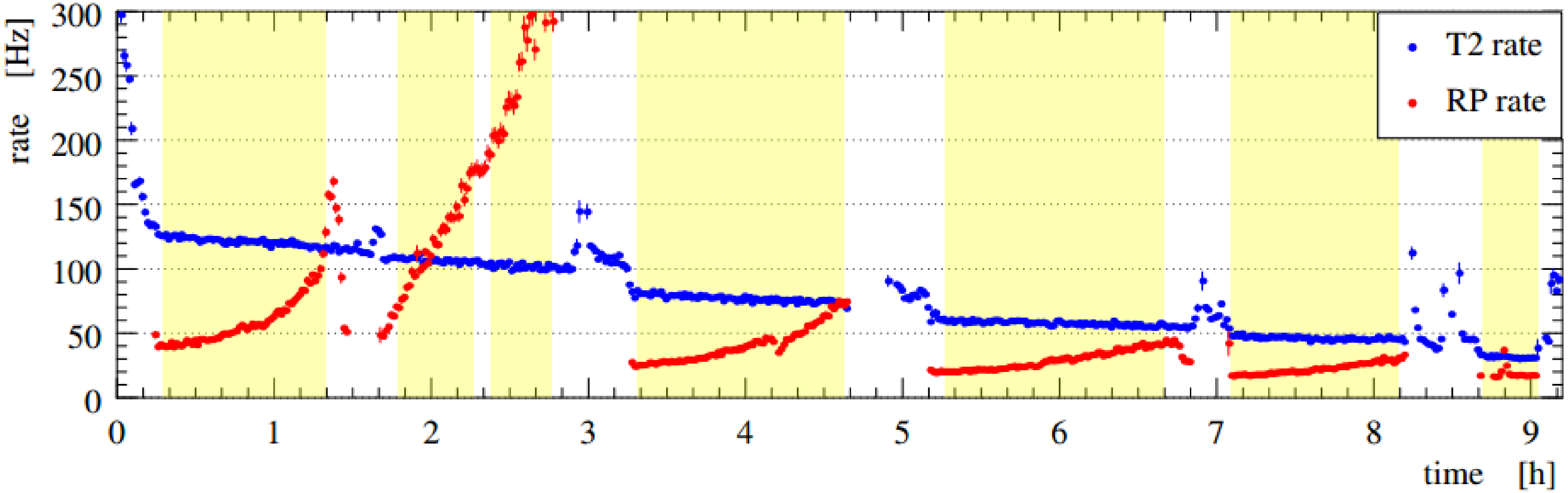
Backup slides

Tricks to obtain lower |t|

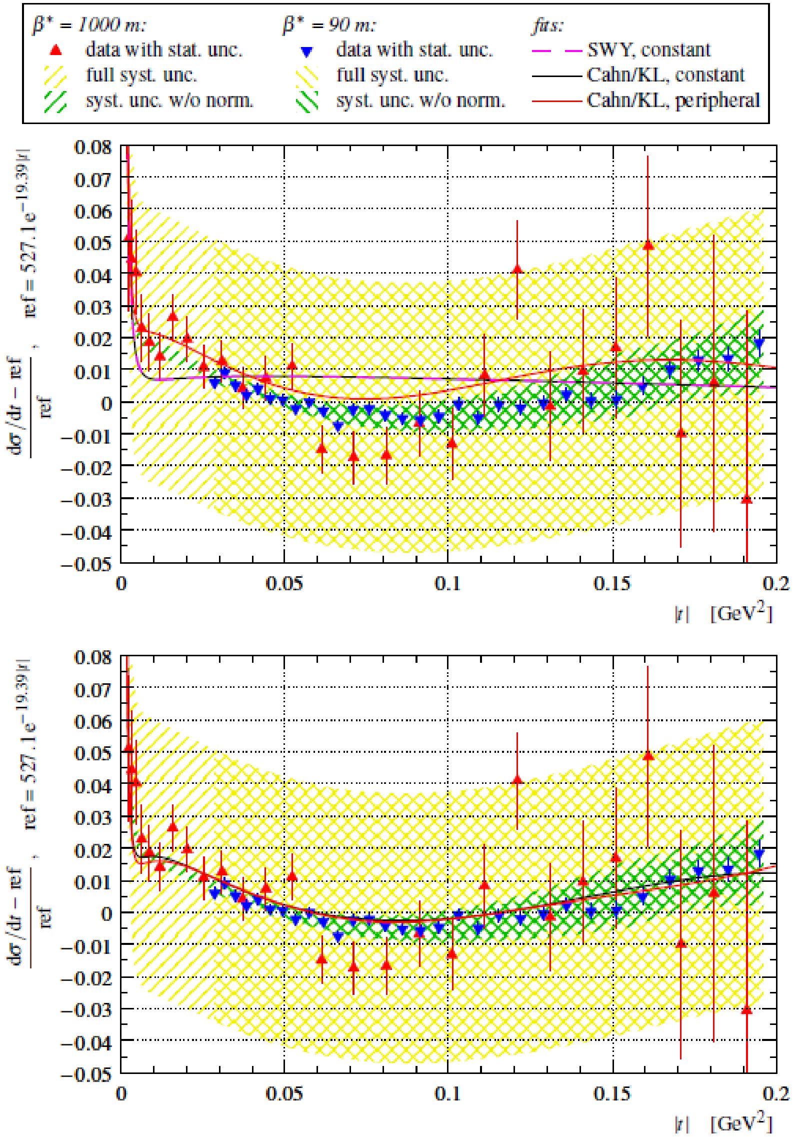








Elastic scattering : *Coulomb interference – Fits*



⇐ **purely-exponential hadronic amplitude**

- *constant phase excluded* (with both SWY and KL formulae) ⇒ application of SWY formula excluded too
- *peripheral phase* not excluded by data, but *disfavoured*
  - ρ value outside a consistent pattern of other fits and theoretical predictions
  - number of theoretical reasons for non-exponential hadronic amplitude

⇐ **non-exponential hadronic amplitude**

- both constant and peripheral phases compatible with data ⇒ *centrality not necessity*

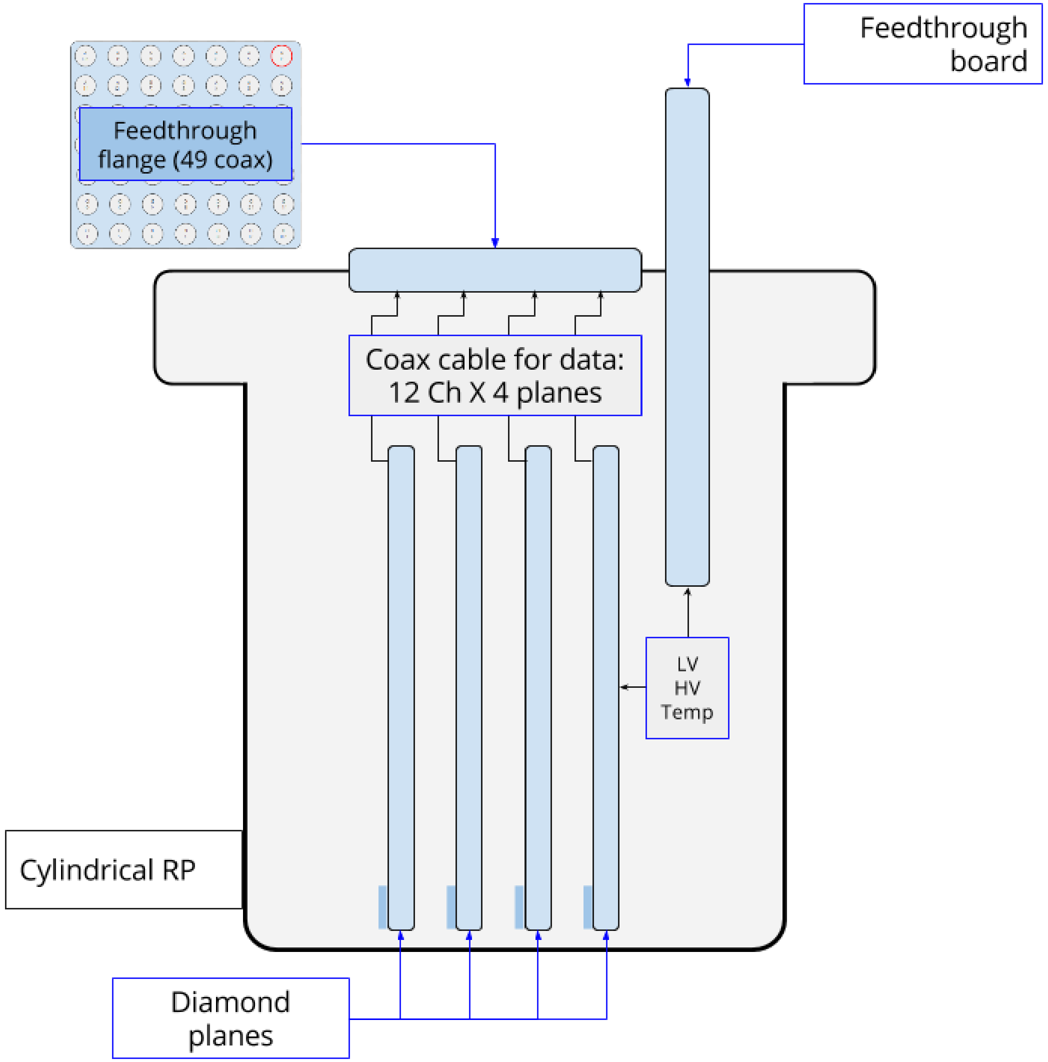
TOTEM & CMS

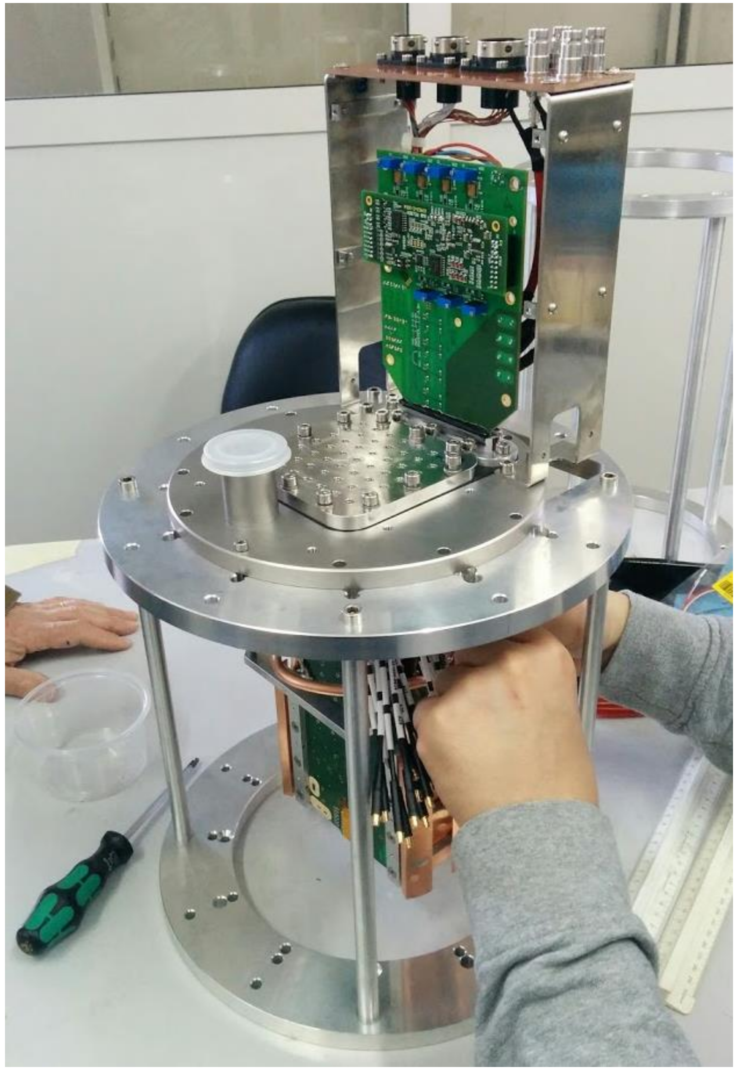
TOTEM
LHC experiment dedicated to measurement of:
total cross-section, elastic scattering and diffractive processes
Designed to study rapidity gaps, particles in very forward region, surviving protons

TOTEM + CMS
both experiments at LHC Interaction Point 5
excellent pseudorapidity coverage: optimal for hard diffraction studies
cooperation mode: independent experiments and DAQ, exchange of triggers for off-line syncronization

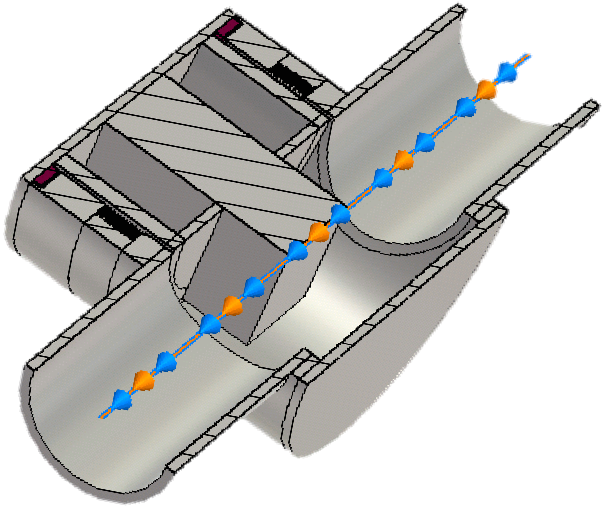
CT-PPS (CMS-TOTEM Precision Proton Spectrometer)
all sub-detectors fully integrated under CMS
Infrastructure for high luminosity and high-pileup configurations of the LHC: RF optimized RP, timing and pixel detectors

Diamond timing detector for Cylindrical RP





Roman Pot insertion in 2016

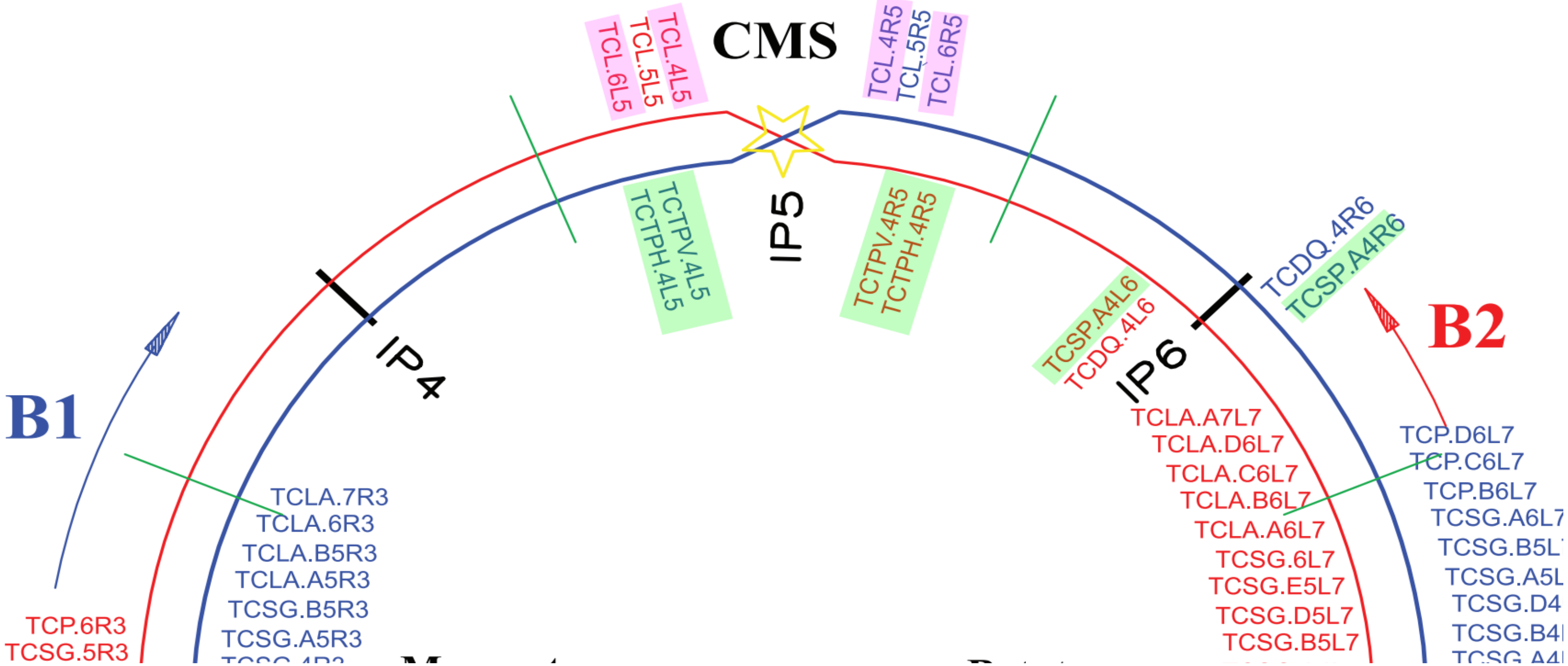


Roman Pot insertion allowed at 15 σ from June 2016!

Before:
2 hours after declaration of stable beam the RPs could be inserted at 15 σ + 0.5 mm.

The second fill of each intensity step the 0.5 mm margin was removed and then subsequent insertions were possible

Successful insertion with 2244 bunches (max in 2015)



Temperature of the Cylindrical Roman Pot