TOTEM measurements at 13 TeV and 2.76 TeV

Frigyes Nemes on behalf of the TOTEM experiment
CERN*

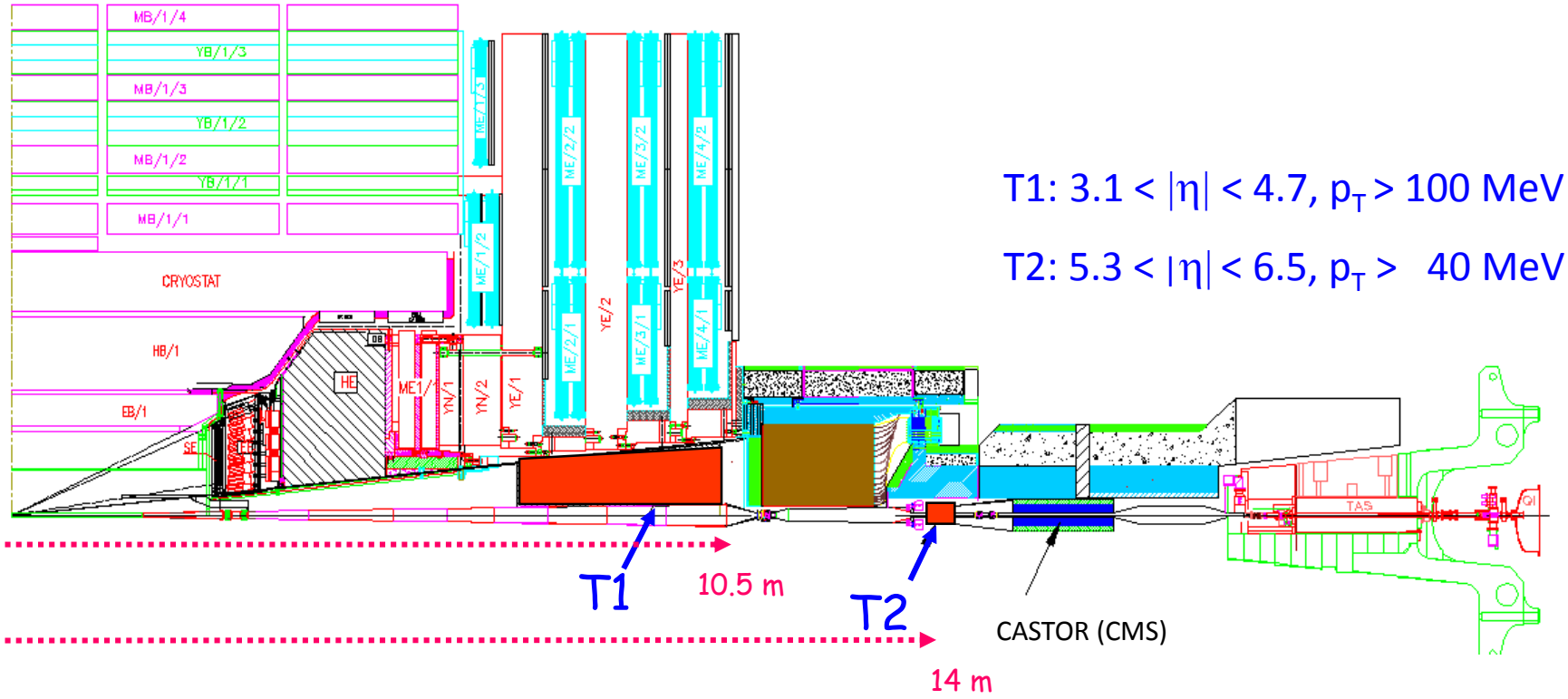
Day of Femtoscopy

Gyöngyös Károly Róbert Campus, Hungary

30 Oct 2018, 09:00 - 21:00

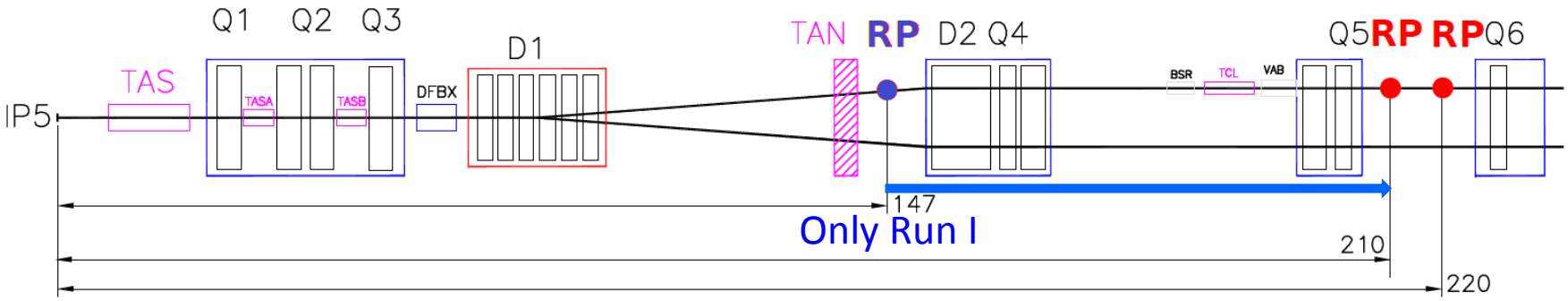
***Also at Wigner RCP, Budapest, Hungary**

Experimental layout of the TOTEM experiment (LHC Run II)



T1: $3.1 < |\eta| < 4.7$, $p_T > 100$ MeV

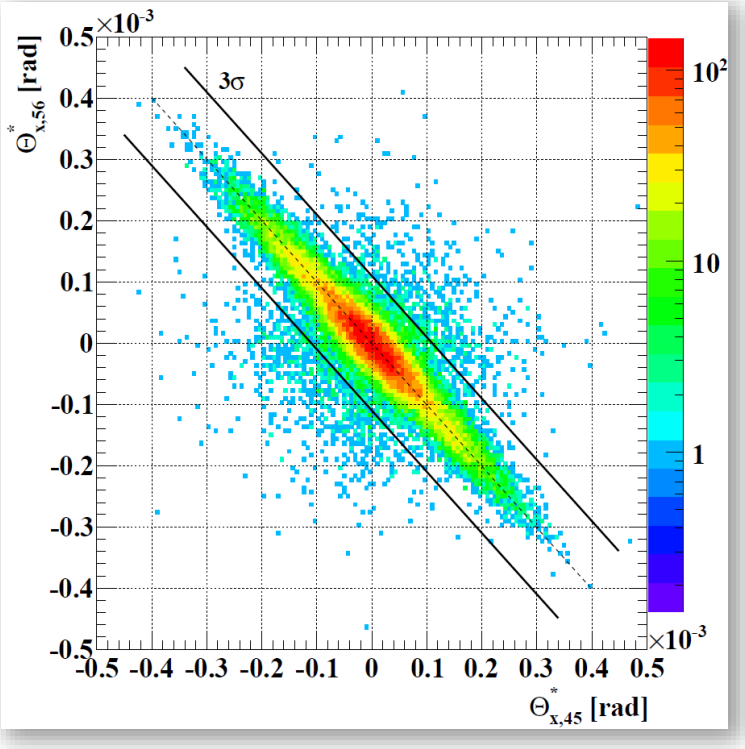
T2: $5.3 < |\eta| < 6.5$, $p_T > 40$ MeV

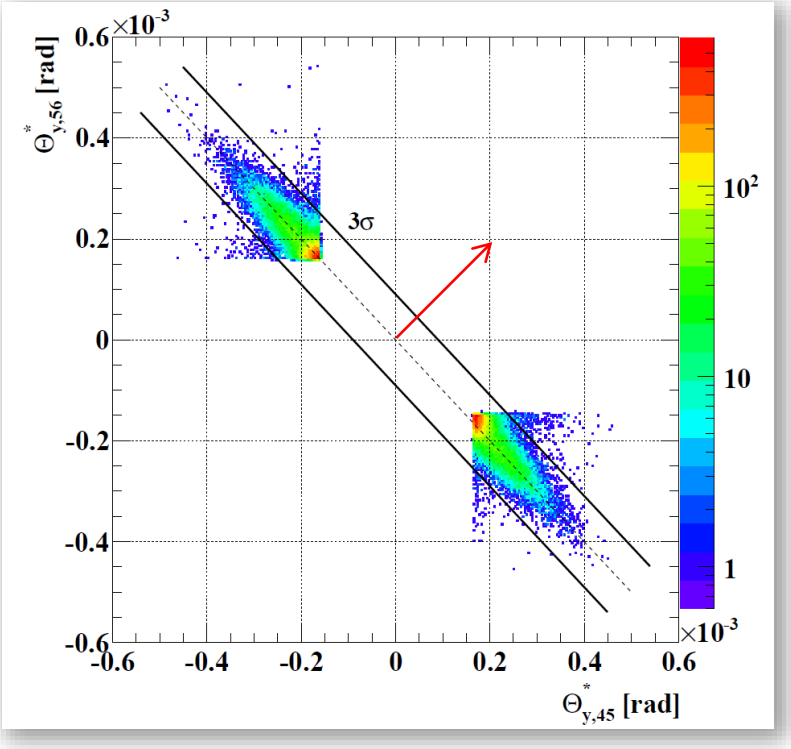


Reconstructed proton kinematics with β* = 3.5 m optics

Momentum conservation is required in elastic events:

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

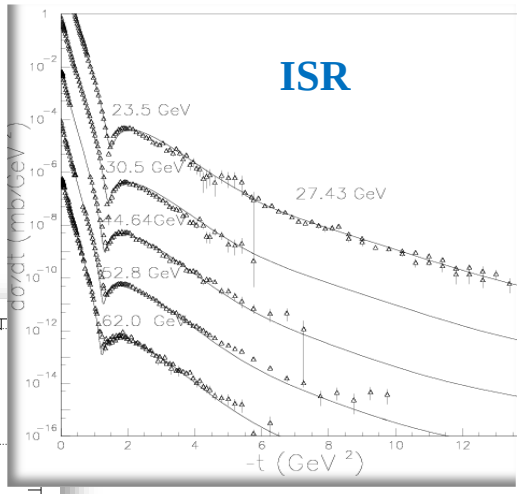


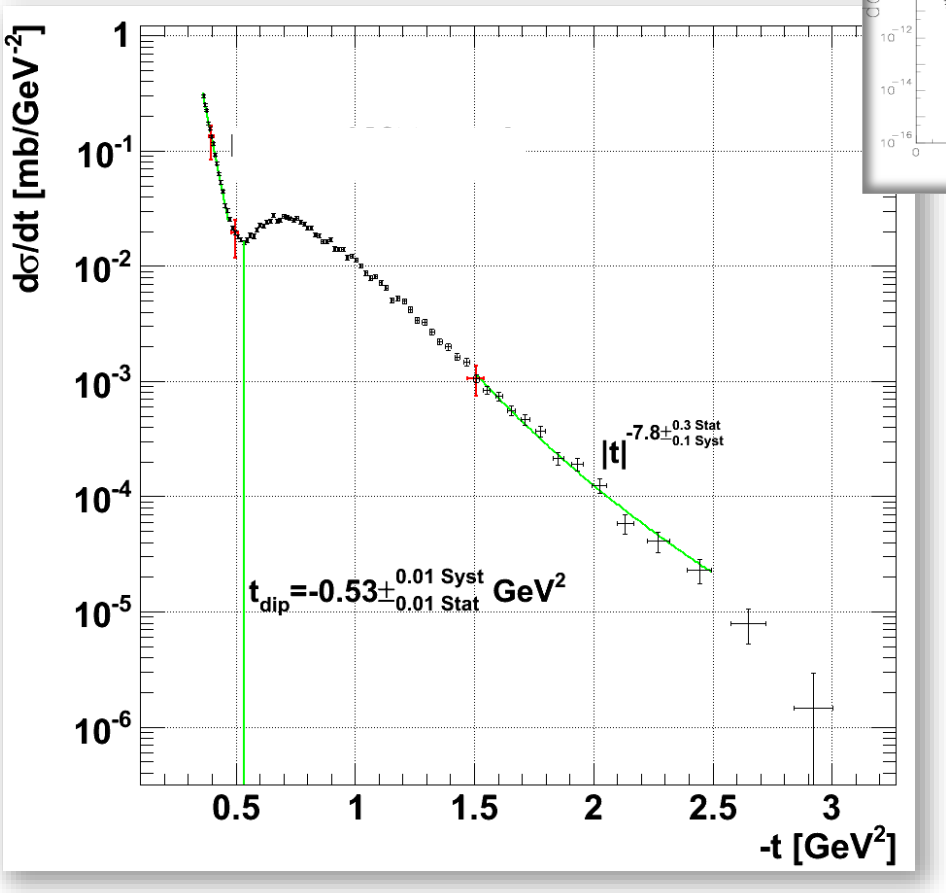


The elastic dσ/dt distribution at √s = 7 TeV (β* = 3.5 m)

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

- |t| range spans from 0.36 to 2.5 GeV^2
- Below |t| = 0.47 GeV^2 exponential $e^{-B|t|}$ behavior
- Dip moves to lower |t|, proton becomes "larger"
- 1.5 - 2.5 GeV^2 power low behavior $|t|^{-n}$





TOTEM cross-section measurement at √s = 13 TeV

$\beta^* = 90$ m, $5\sigma_{RP}$ RP distance

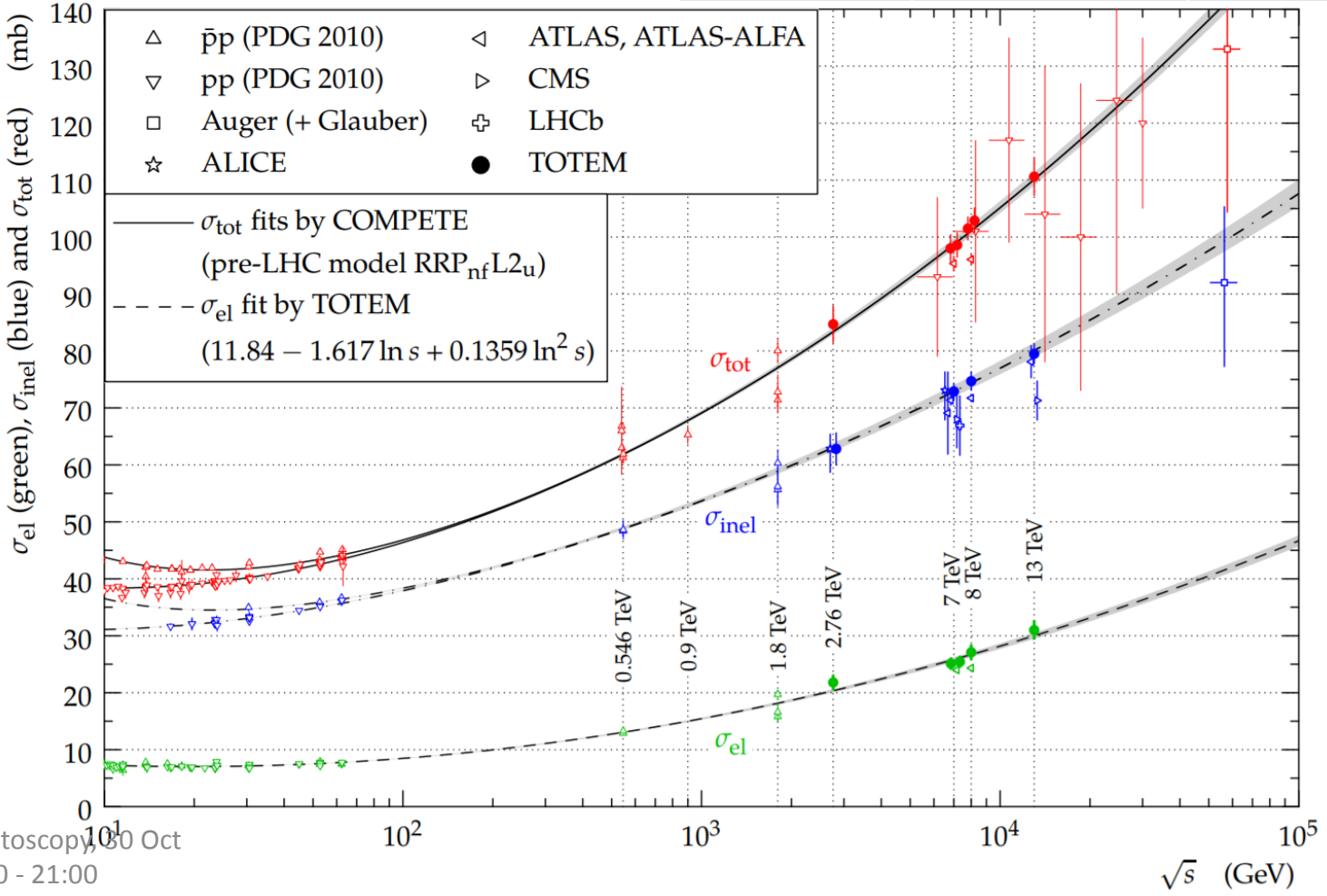
Cross sections at 13 TeV & summary plot

Provides normalization at 13 TeV to:

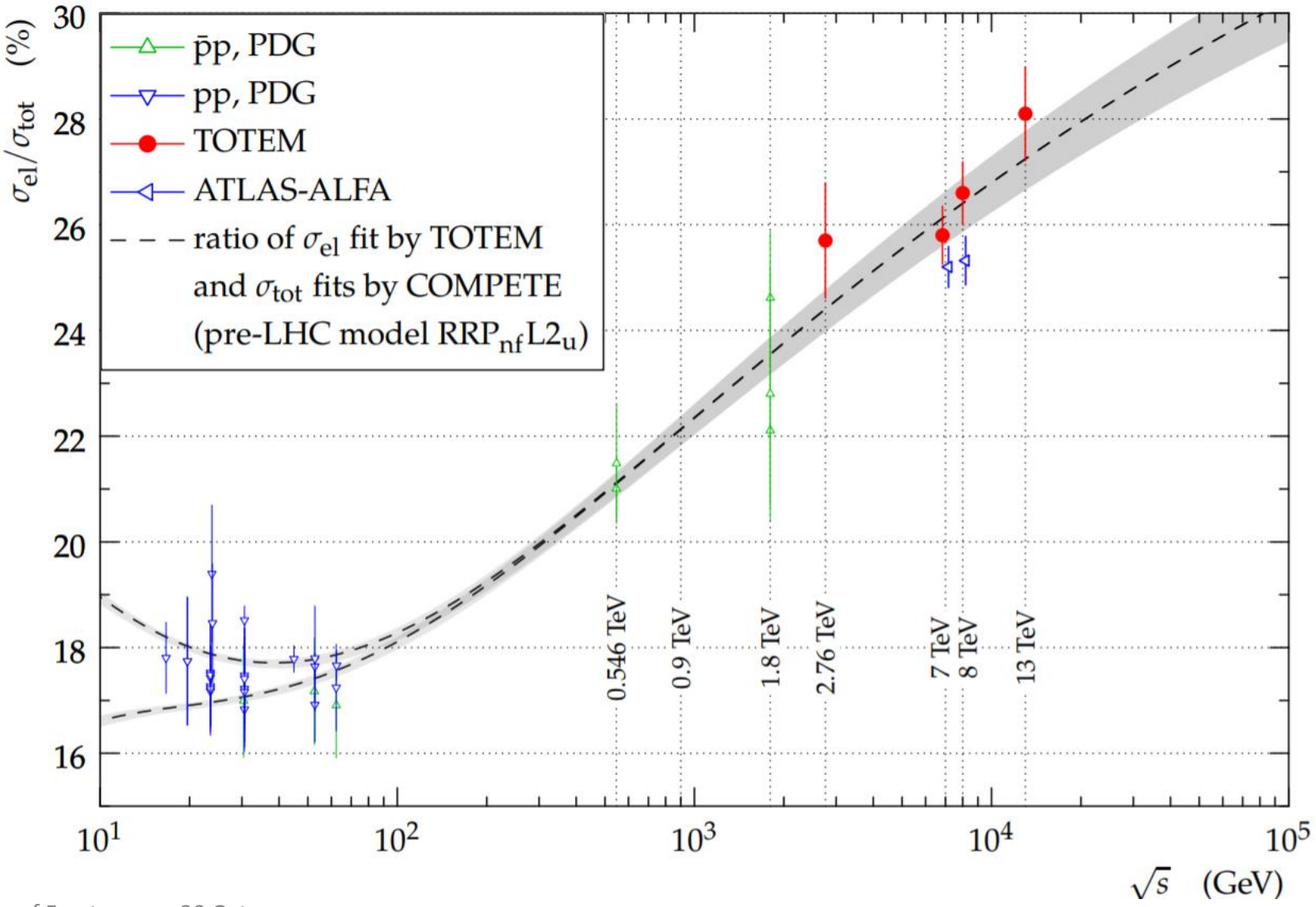
- β* = 2500 m
- β* = 90 m, 10 σ RP distance

ρ = 0.1

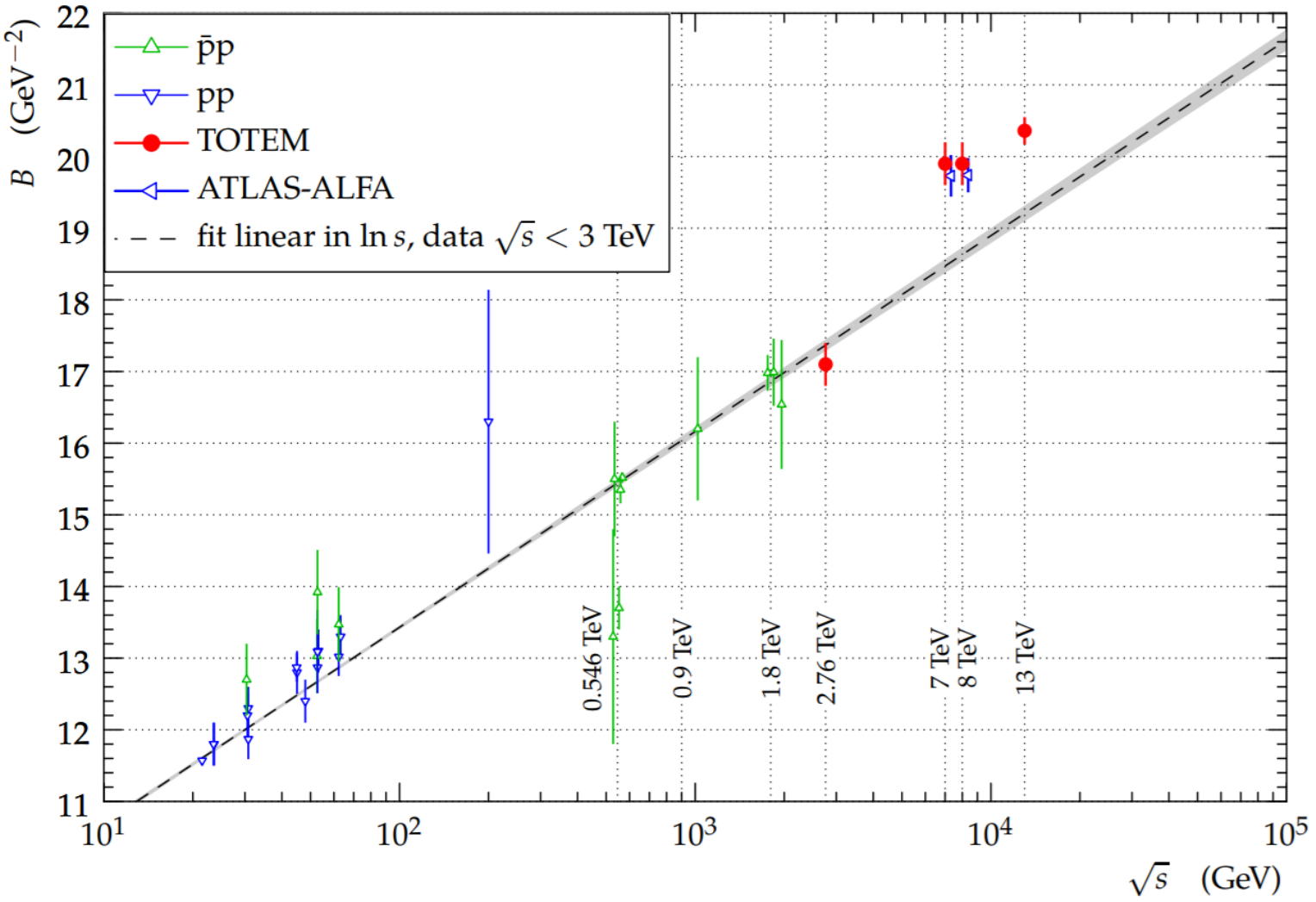
σ_{tot} [mb]	σ_{el} [mb]	σ_{inel} [mb]
110.6 ± 3.4	31.0 ± 1.7	79.5 ± 1.8



The σ_{el}/σ_{tot} ratio



Overview of the nuclear slope B evolution with energy



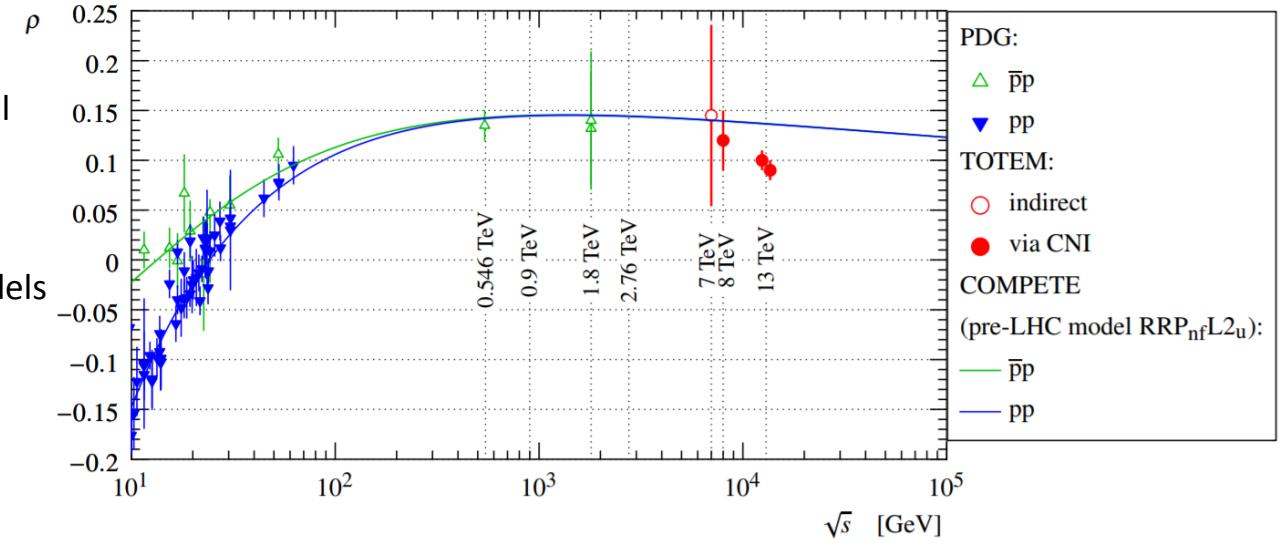
ρ measurement at √s = 13 TeV

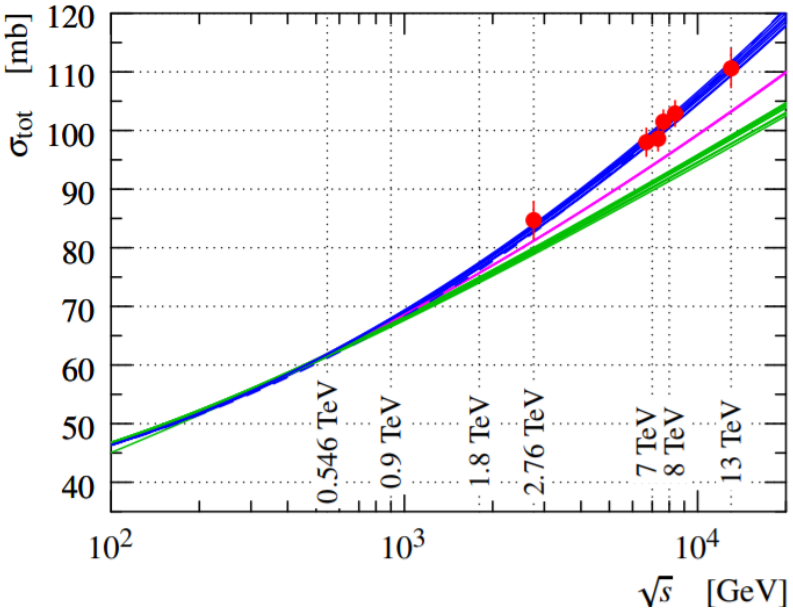
Probing the existence of colourless three-gluon bound state

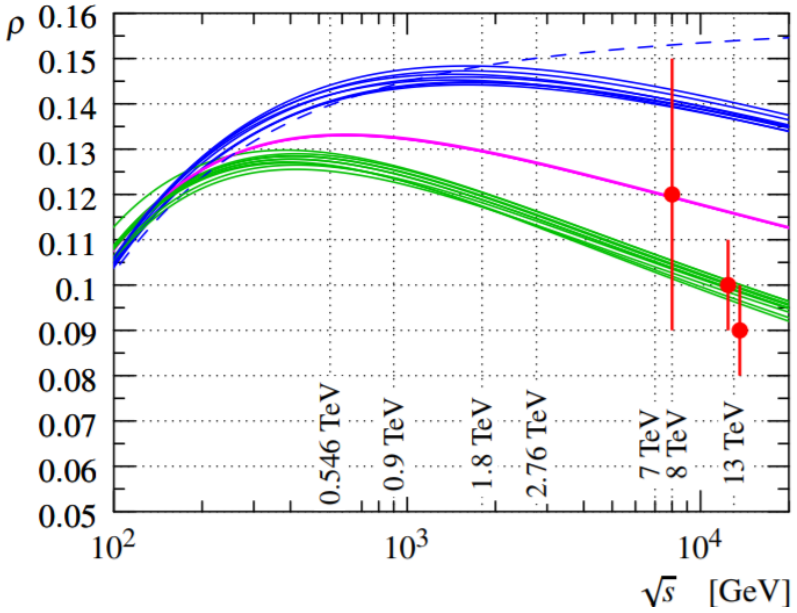
β* = 2500 m

Overview of the ρ parameter evolution with energy

- Not compatible with conventional (COMPETE) models (that doesn't include exchange of a colourless 3-gluon bound state)
- Compatibility with improved models where t-channel exchange of a colourless 3-gluon bound state $1^{PC} = 1^{--}$ is added







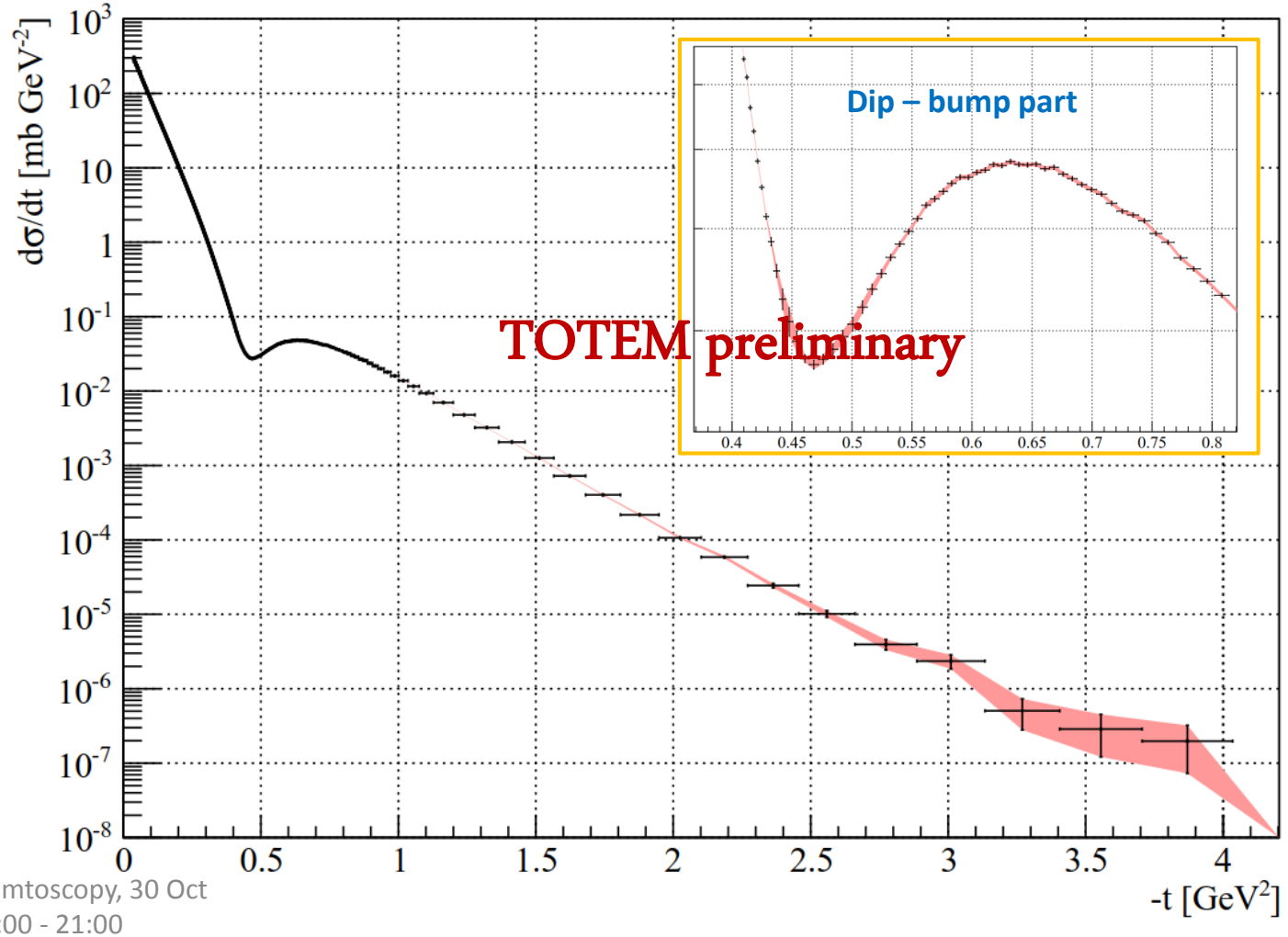
TOTEM differential cross-section measurement at √s = 13 TeV

$\beta^* = 90$ m, $10\sigma_{RP}$ RP distance

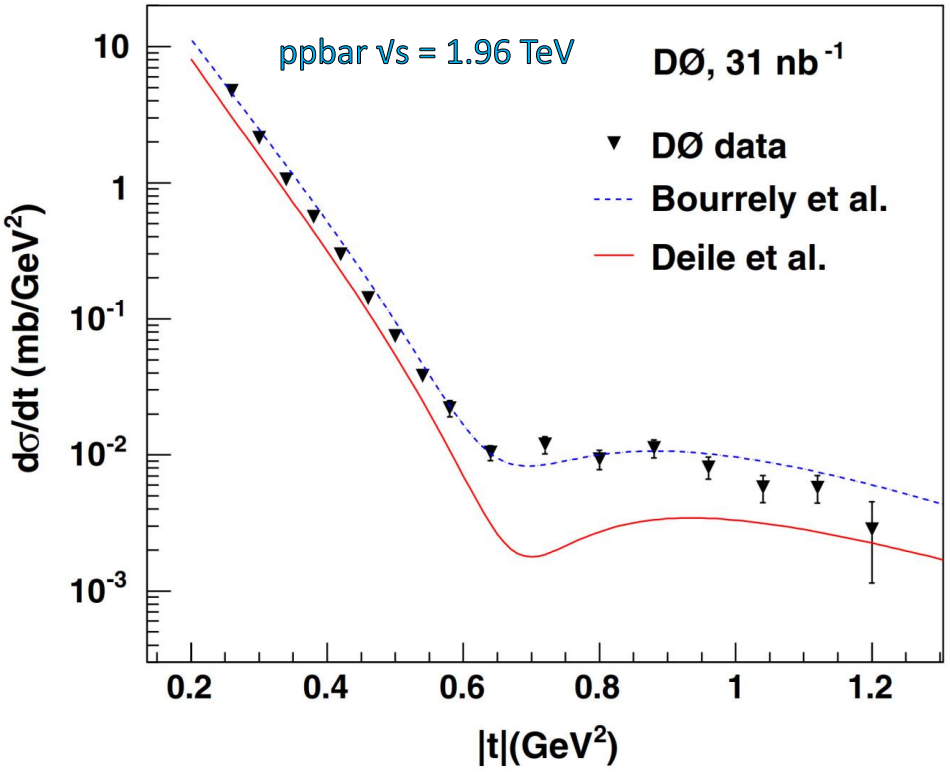
Differential cross-section (fully corrected)

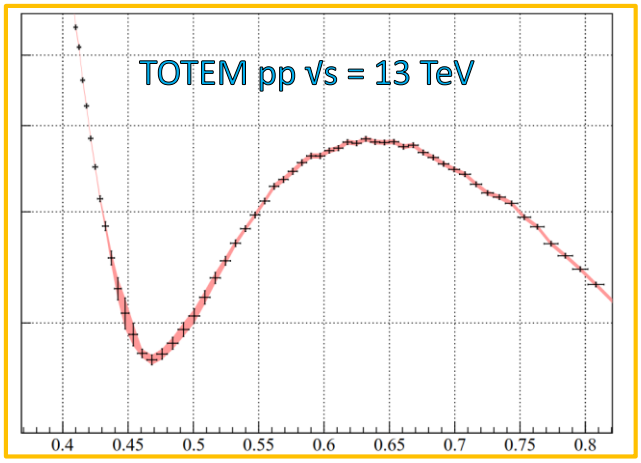
Note:

- O(10^9) observed elastic events (trigger rate **50 ×** Run I)
- Acceptance and beam divergence corrected
- 3/4 correction, matched optics
- Unfolded



The diffractive minimum in pp and ppbar collision





Note:

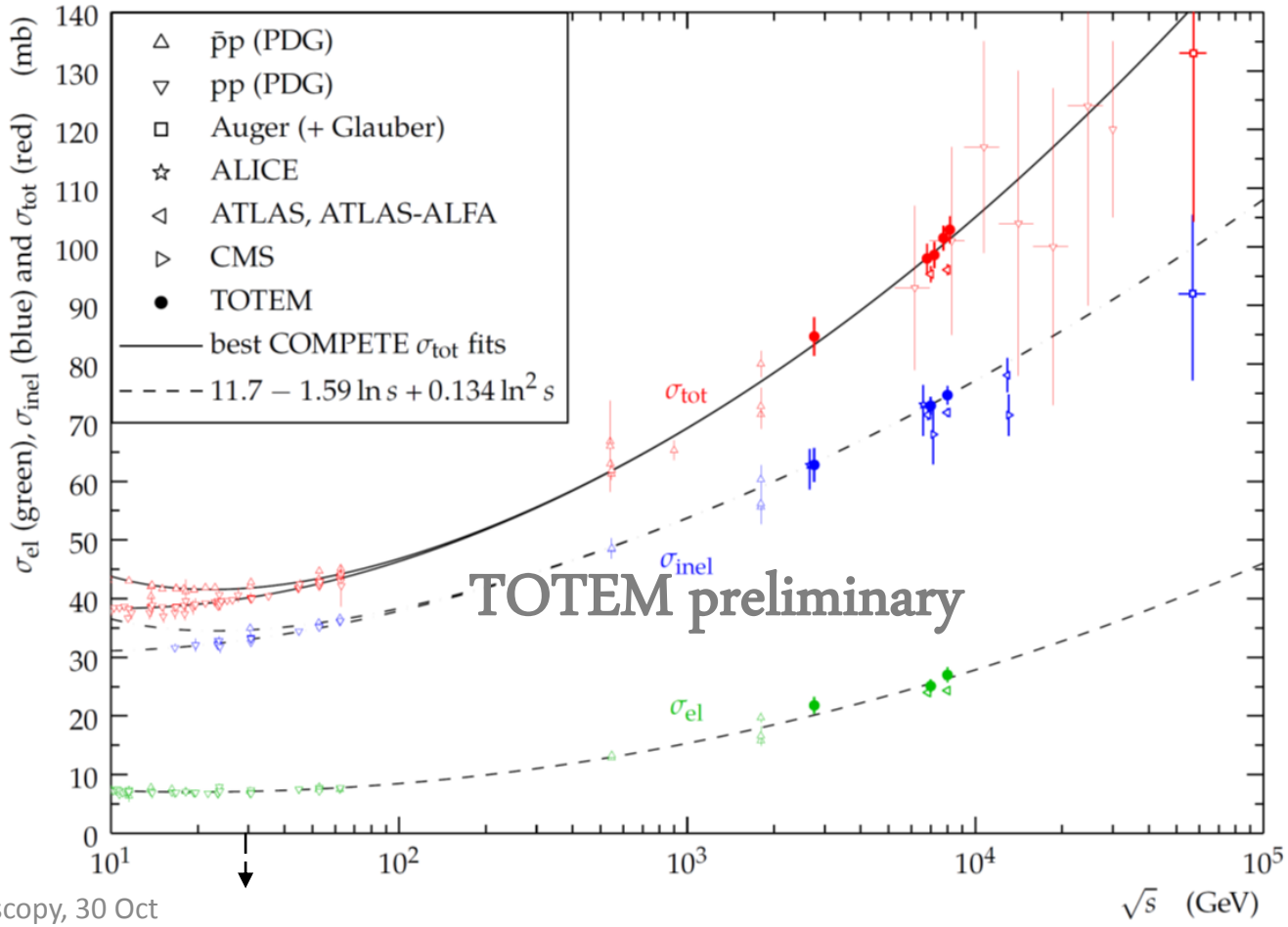
- Result confirms with unprecedented precision at the TeV scale the dip structure in elastic pp scattering (first observed at 7 TeV after the ISR) and brings to 5 sigma level the **incompatibility** at the diffractive dip between pp and ppbar, the latter measured by D0 still at the gluon-dominated TeV scale
- Not compatible with conventional (COMPETE) models (that doesn't include exchange of a colourless 3-gluon bound state)
- Compatibility with improved models where t-channel exchange of a colourless 3-gluon bound state $1^{PC} = 1^{--}$ is added

TOTEM elastic scattering measurement at √s = 2.76 TeV

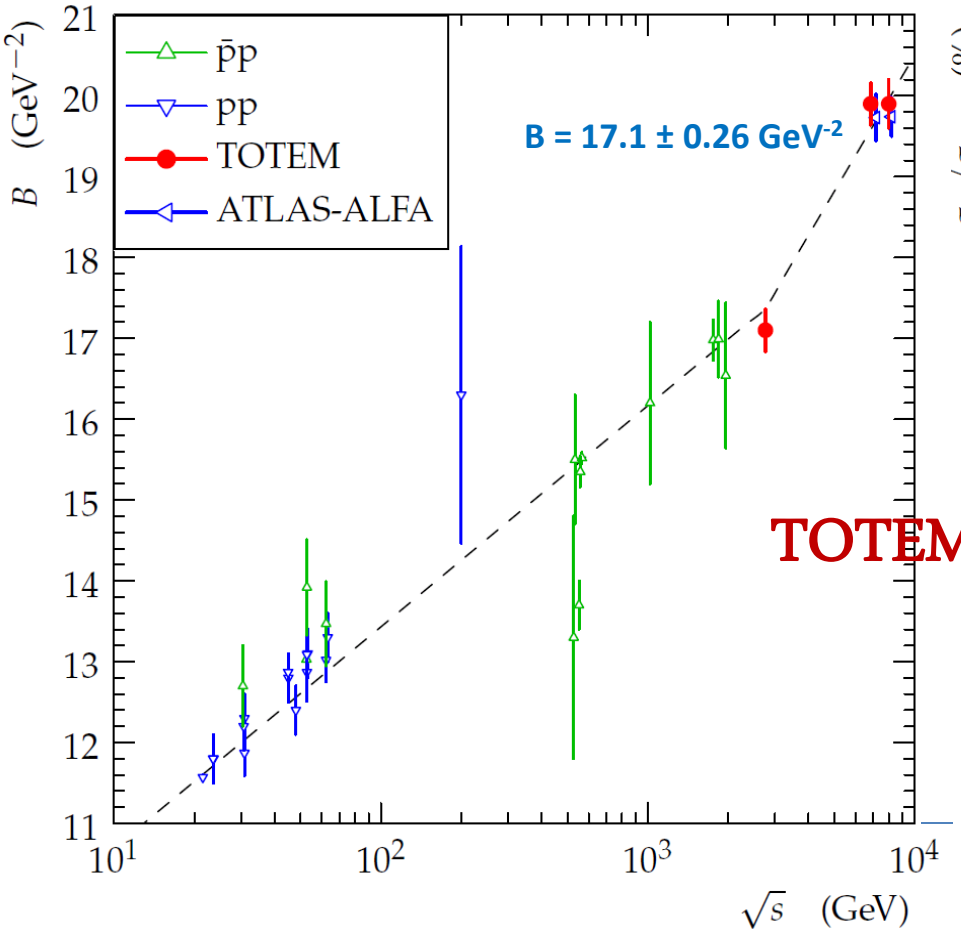
2.76 TeV luminosity independent cross-sections (β* = 11 m optics)

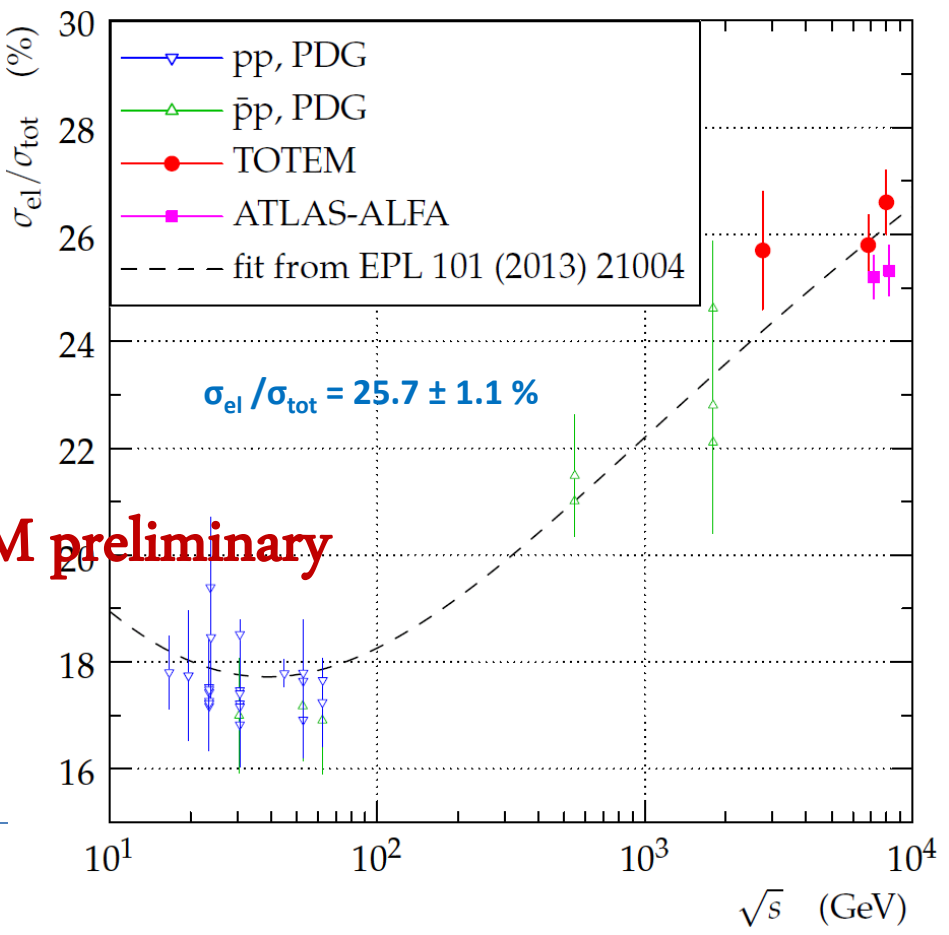
$$\sigma_{\mathrm{tot}} = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \frac{\left.\frac{dN_{\mathrm{el}}}{dt}\right|_{t=0}}{N_{\mathrm{el}} + N_{\mathrm{inel}}} \qquad \rho = \left.\frac{\mathrm{Re}\, A^H}{\mathrm{Im}\, A^H}\right|_{t=0}$$

σ_{tot} [mb]	σ_{el} [mb]	σ_{inel} [mb]
84.7 ± 3.3	21.8 ± 1.4	62.8 ± 2.9



The nuclear slope B and the σ_{el}/σ_{tot} ratio at $\sqrt{s} = 2.76$ TeV





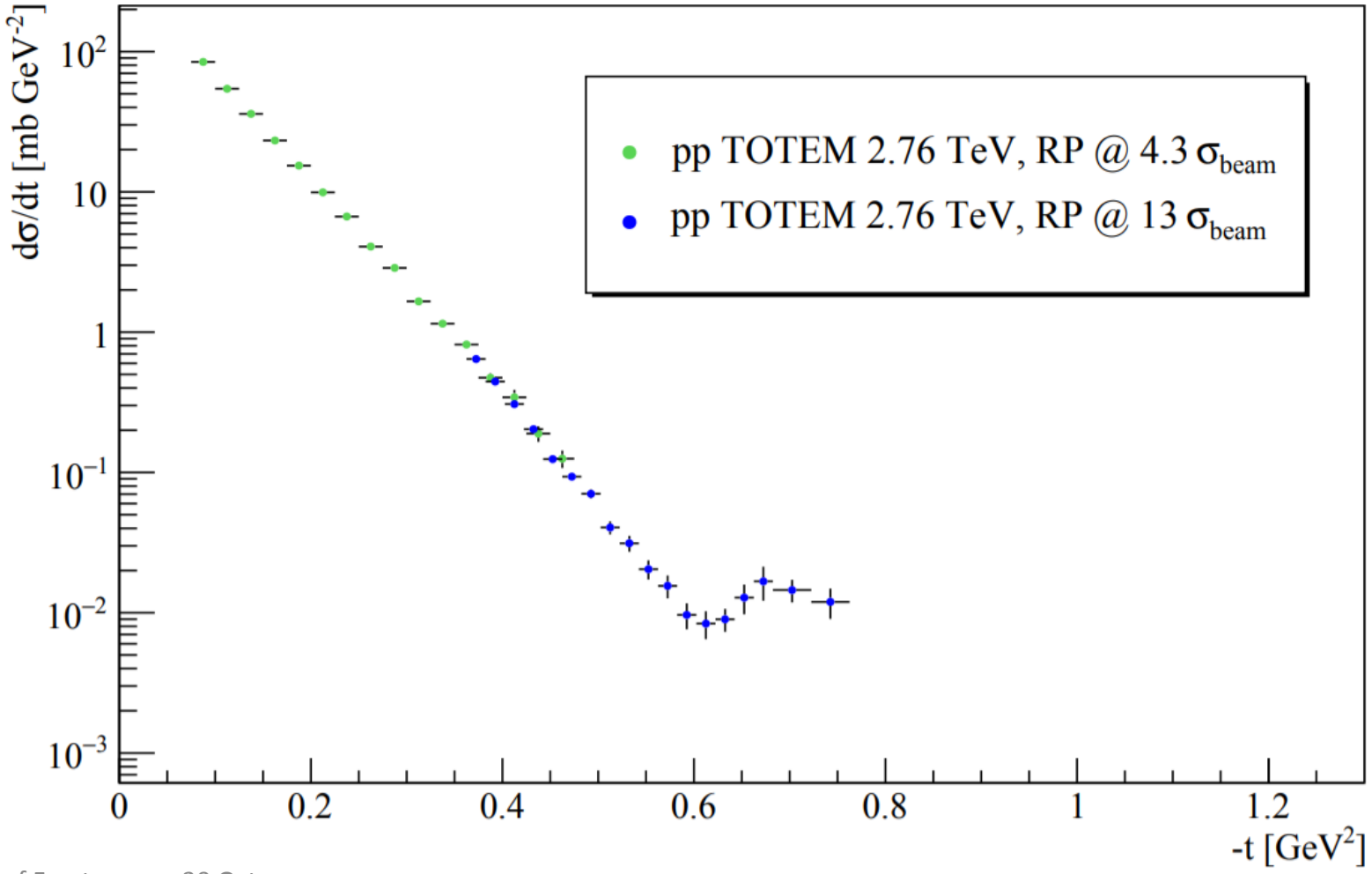
TOTEM preliminary

Differential cross-section at √s = 2.76 TeV with RPs @ 13 σ_{beam}

Differential cross-section in the dip range

Note:

- Roman Pots at 13 sigma beam
- Dip structure is observed in pp collision at 2.76 TeV



Summary

- Results at √s = 2.76 TeV
  - First total cross-section measurement
  - Change of √s behavior of slope parameter B at around 3 TeV
  - Diffractive minimum is observed and compared to D0 ppbar results
  - Data clearly favours the prediction with Odderon
- Results at √s = 13 TeV
  - **First** total cross-section measurement (http://cds.cern.ch/record/2296409)
  - **First** ρ measurement (https://cds.cern.ch/record/2298154)
  - Conventional models (COMPETE) not able to describe simultaneously TOTEM σ_{tot} & ρ measurements
  - Data compatible with t-channel exchange of a colourless QCD 3 gluon $1^{PC} = 1^{--}$ bound state
  - High-statistics differential cross-section measurement at √s = 13 TeV: confirming with unprecedented precision the dip structure in pp scattering at TeV scale: 5 σ level **incompatibility** of diffractive dip between pp and ppbar --> difference compatible with t-channel exchange of a colourless QCD 3 gluon $1^{PC} = 1^{--}$ bound state

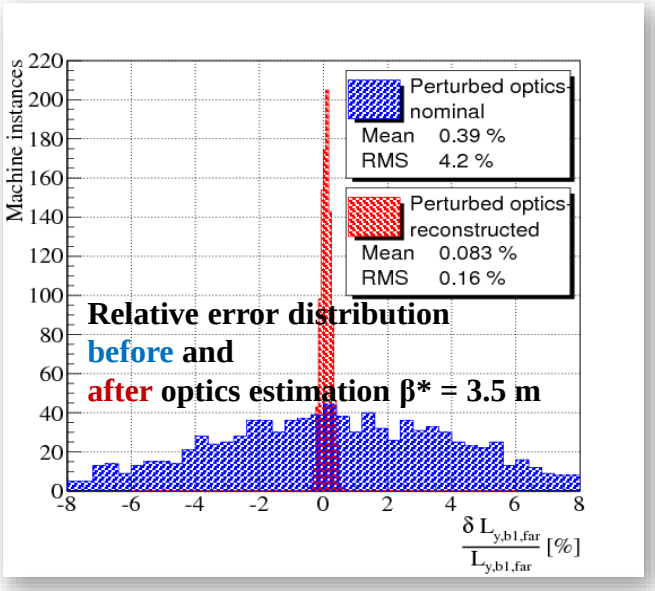
Thank you for your attention !

Backup slides

Note on proton kinematics reconstruction & optics imperfections

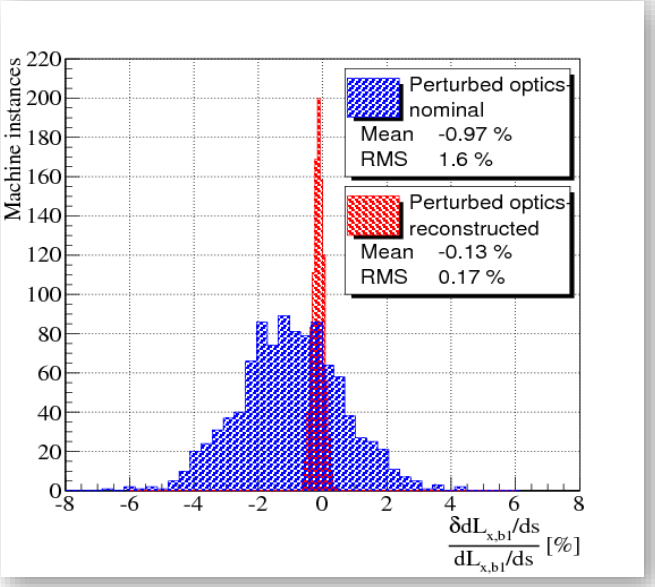
Machine imperfections alter the optics:

- **Strength conversion error, $\sigma(B)/B \approx 10^{-3}$**
- **Beam momentum offset, $\sigma(p)/p \approx 10^{-3}$**
- Magnet rotations, $\sigma(\phi) \approx 1$ mrad
- Magnetic field harmonics, $\sigma(B)/B \approx 10^{-4}$
- Power converter errors, $\sigma(I)/I \approx 10^{-4}$
- Magnet positions Δx, $\Delta y \approx 100$ µm



$$t(v_x, L_x, L_y, \ldots, p) = -p^2 \cdot \left(\Theta_x^{*2} + \Theta_y^{*2}\right)$$

→ **Precise model of the LHC optics is indispensable!**



Novel method from TOTEM:

- Use **measured** proton data from RPs
- Based on kinematics of elastic candidates
- Published in New Journal of Physics
- http://iopscience.iop.org/1367-2630/16/10/103041/