Recent results from TOTEM

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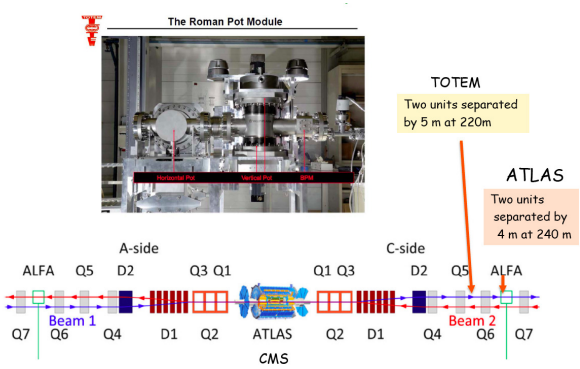
Contents

- Measurement of elastic, inelastic, total cross sections at 7, 8, 13 TeV
- Non-exponential form of $d\sigma/dt$
- Hint for Odderon (measurements of ρ and $d\sigma/dt$)?

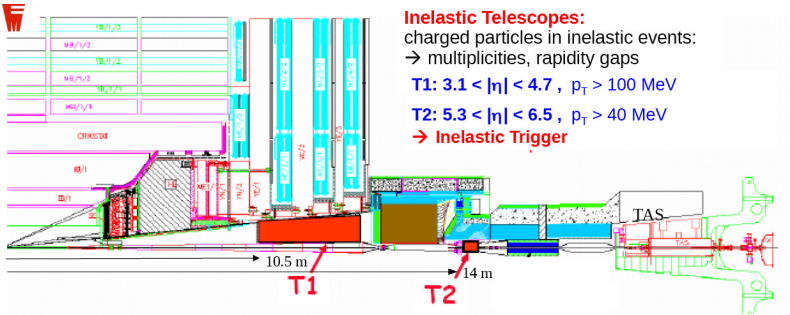
Elastic cross section measurements: detecting protons!

- Measurement of $pp \to pp$ elastic cross section by detecting intact protons and vetoing on activity in the main CMS detector
- TOTEM installed vertical roman pot detectors at 220 m from CMS; Additional horizontal detectors for hard diffraction and photon exchange measurements (see PPS talk by Justin)



- Trigger for elastics using proton in opposite configurations: Up (Down) on one side, Down (Up) on the other side

Forward coverage in CMS-TOTEM



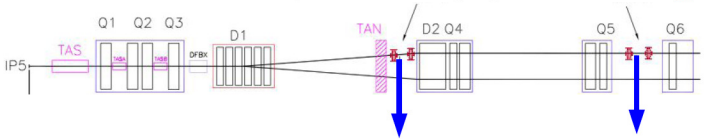
Inelastic Telescopes:
charged particles in inelastic events:
→ multiplicities, rapidity gaps

T1: 3.1 < |η| < 4.7 , p_T > 100 MeV

T2: 5.3 < |η| < 6.5 , p_T > 40 MeV

→ **Inelastic Trigger**

Roman Pots: elastic & diffractive protons close to outgoing beams → **Proton Trigger**



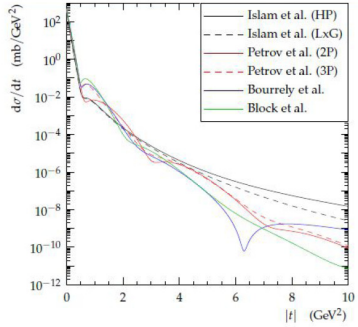
Roman Pot stations in the LHC tunnel (before LS1)

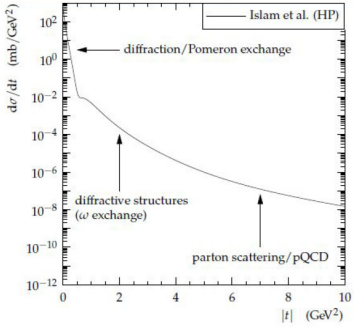
RP (147 m)

RP (220m)

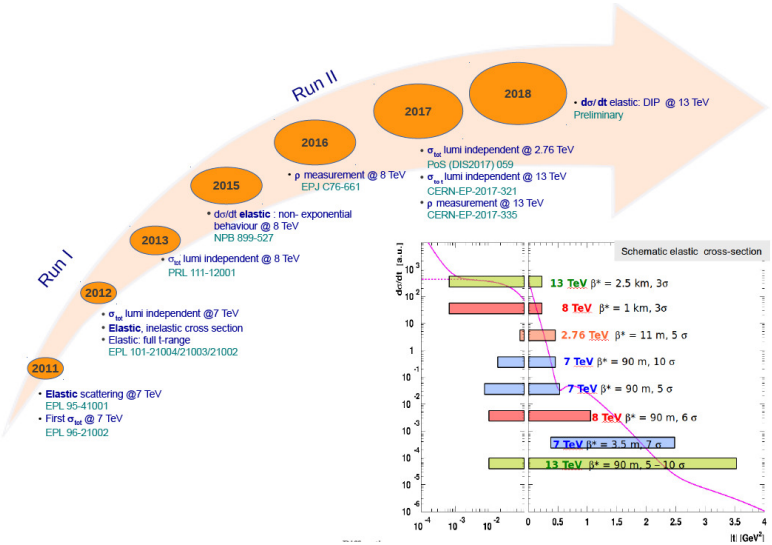
Elastic scattering at the LHC: variety of predictions before TOTEM

- Variety of models especially at high t
- Possible structures at high $|t|$?
- Regions in $|t|$ at the LHC sensitive to different kinds of physics: Diffraction/Pomeron exchange at low $|t|$, diffractive structures at medium $|t|$ and parton scattering/QCD at higher $|t|$



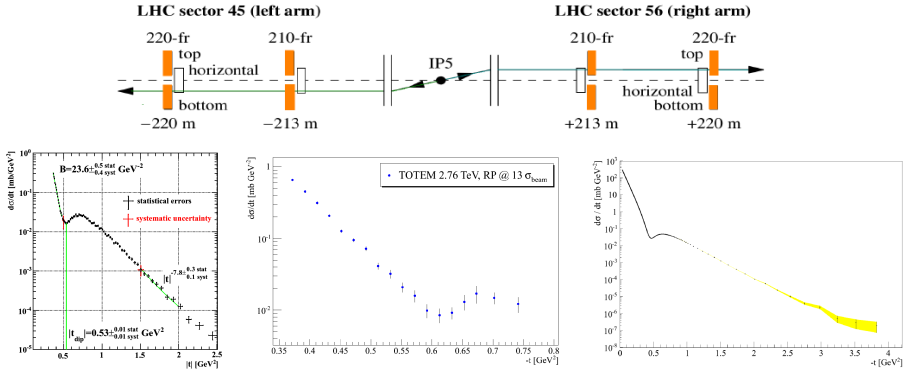


TOTEM cross section measurements



$d\sigma/dt$ measurements in TOTEM

- Elastic measurements: Use double arm roman pots (2.76/7/13 TeV)



- Inelastic measurements Use T_2 as a trigger (N_{inel} gives a signal in T_1 and/or T_2 for 92% of events)

Analysis methods in TOTEM: total cross section

- N_{inel} measured using T_1 and T_2 telescopes, and N_{el} from the roman pots
- Known equations (Optical theorem)

$$\begin{aligned} L\sigma_{tot}^2 &= \frac{16\pi}{1+\rho^2}(dN_{el}/dt)_{t=0} \\ L\sigma_{tot} &= N_{el} + N_{inel} \end{aligned} \tag{1}$$

- Different methods to measure the total cross section
  - Lumi independent measurement

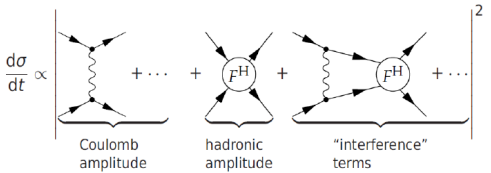
$$\sigma_{tot} = \frac{16\pi}{(1+\rho^2)} \frac{(dN_{el}/dt)_{t=0}}{(N_{el}+N_{inel})}$$

  - Lumi dependent measurement (elastic only)

$$\sigma_{tot}^2 = \frac{16\pi}{(1+\rho^2)} \frac{1}{L}(dN_{el}/dt)_{t=0}$$

  - ρ independent measurement $\sigma_{tot} = \sigma_{el} + \sigma_{inel}$

Analysis methods in TOTEM: ρ measurement

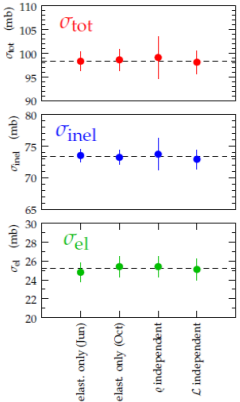


- Measure elastic scattering at very low t: Coulomb-Nuclear interference region

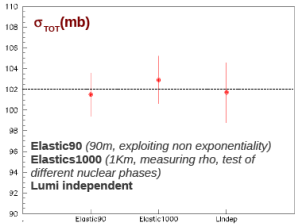
$$\frac{d\sigma}{dt} \sim |A^C + A^N(1 - \alpha G(t))|^2$$

- The differential cross section is sensitive to the phase of the nuclear amplitude
- In the CNI region, both the modulus and the phase of the nuclear amplitude can be used to determine $\rho = \frac{Re(A^N(0))}{Im(A^N(0))}$ where the modulus is constrained by the measurement in the hadronic region and the phase by the t dependence

Elastic, Inelastic and Total cross section at 7 and 8 TeV



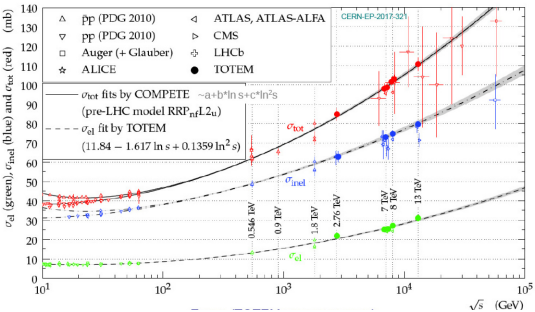
7 TeV, several methods
Same beam conditions

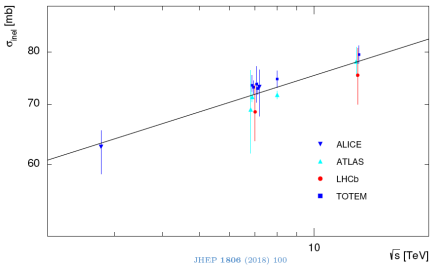


8 TeV, several methods
Different beam conditions

- Independent methods with different precision/systematics lead to similar results on elastic, inelastic and total cross sections
- In addition, at 13 TeV, total cross section using lumi independent method for $\beta^* = 90m$
- ρ measurement using $\beta^* = 2500m$ data

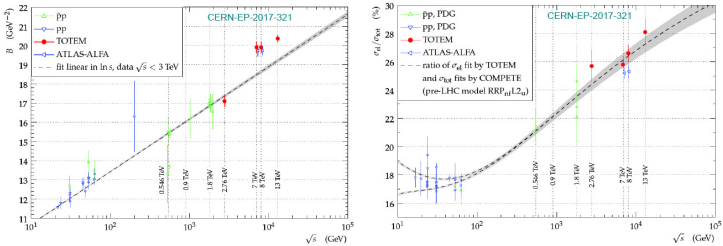
Elastic, inelastic, total cross section measurements





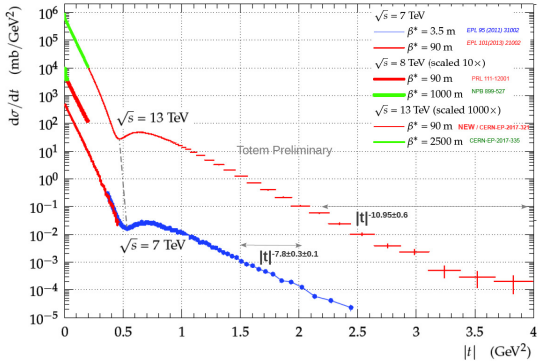
- High precision measurement of elastic, inelastic and total cross sections: new measurement by LHCb
- Measurements in agreement with cosmic-ray data (large error bars though)
- ATLAS 1.9 σ lower than TOTEM at 8 TeV

Implication of elastic cross section measurements: B slope



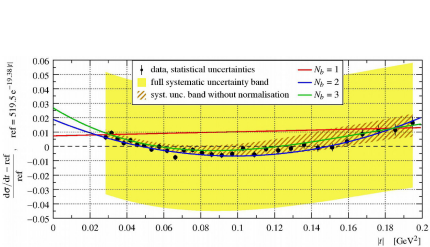
- B slope of $d\sigma/dt$: larger slope at 13 TeV
- Linear behavior (lns) compatible for $\sqrt{s} < 3$ TeV, incompatible at higher energy
- Diffraction cone shrinkage speeds up with $\sqrt{s}$
- The increase of $\sigma_{el}/\sigma tot$ with energy is confirmed at LHC

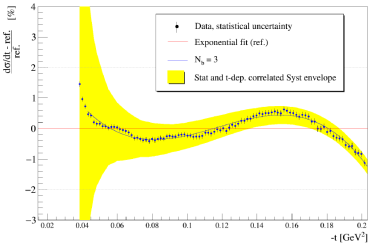
Implication of total cross section measurements: no structure at high $|t|$



- No structure seen at high $|t|$, compatible with a flat behavior
- Differences with respect to many pre-TOTEM models

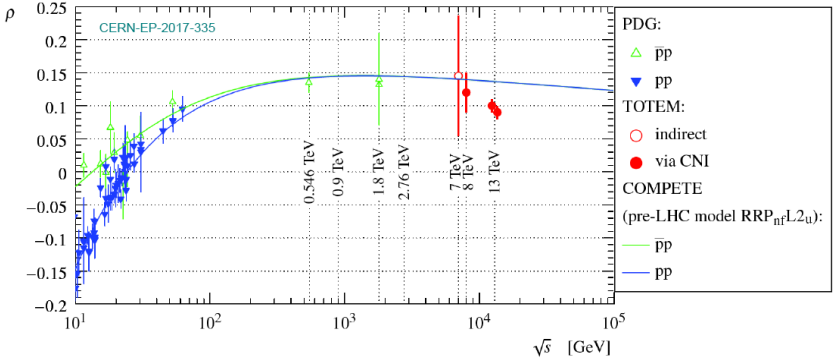
Non-exponential dependence of TOTEM elastic data





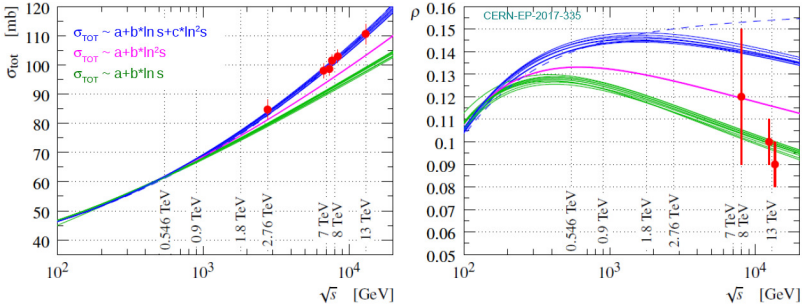
- Attempt of a usual simple exponential fit to $d\sigma/dt$ at low t
- Exponential fit: $d\sigma/dt = A\exp(-B(t)|t|)$
- Different polynomial fits of $B(t)$:
  - $N_b = 1$ $B = b_1$, reference
  - $N_b = 2$, $B = b_1 + b_2 t$
  - $N_b = 3$, $B = b_1 + b_2 t + b_3 t^2$
- Pure simple exponential form ($N_b = 1$, $B = cte$) excluded at 7.2 σ with 8 TeV data, similar results using 13 TeV data

ρ measurement at 13 TeV



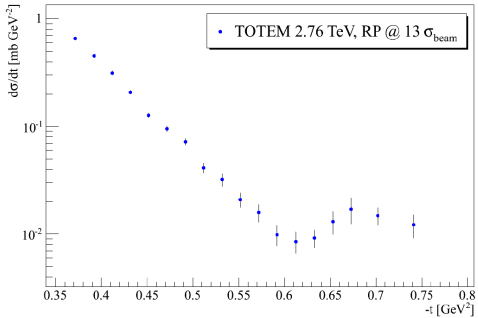
- Using low $|t|$ data, measurement of ρ at 13 TeV: $\rho = 0.09 \pm 0.01$
- High precision measurements at 13 TeV using low β^* data
- ρ value at 13 TeV clearly below expectations (COMPETE fits as an example)

ρ measurement at 13 TeV



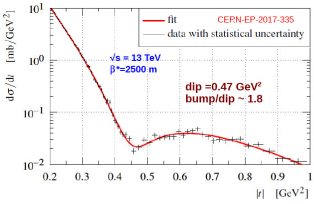
- ρ is the ratio of the imaginary and real part of the total cross section
- Using low $|t|$ data, measurement of ρ at 13 TeV: $\rho = 0.09 \pm 0.01$
- ρ value at 13 TeV clearly below expectations (COMPETE fits as an example)
- This result can be explained by the exchange of the Odderon in addition to the Pomeron, or saturation effects of σ_{tot} at high energies

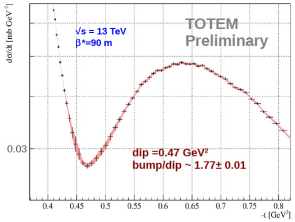
Measurements at 2.76 TeV

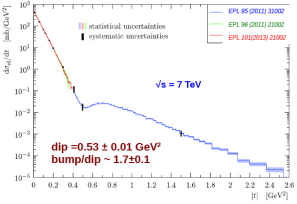


- Very recent measurement of $d\sigma/dt$ at 2.76 TeV
- Dip and bump also observed at 2.76 TeV, what about $p\bar{p}$ interactions?

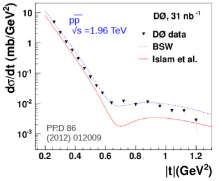
Implication of elastic cross section measurements dip position





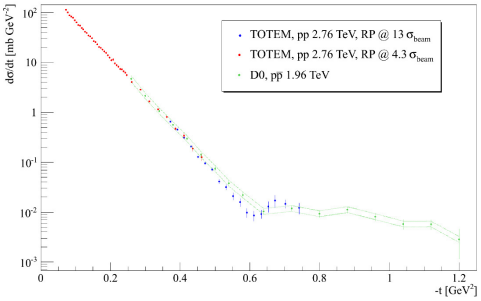


Dip is missing in pp



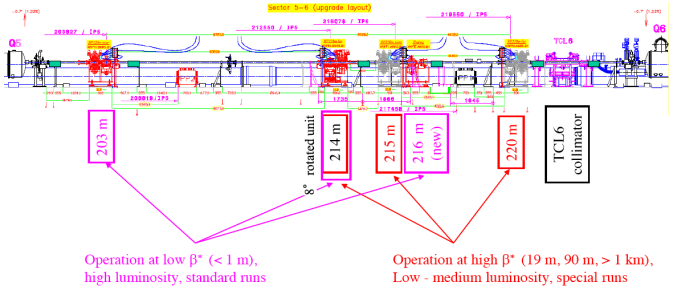
- Dip position in $|t|$ decreases with increasing $\sqrt{s}$
- Differences between pp and $p\bar{p}$ data: Dip missing in $p\bar{p}$?

$d\sigma/dt$ measurements for pp and $p\bar{p}$ interactions



- If the odderon exists, it should show up as a difference between pp and $p\bar{p}$ total cross sections
- No dip/maximum for $p\bar{p}$ cross sections (D0 at 1.96 TeV) whereas the dip/max is observed in TOTEM data at 2.76 TeV: quantitative studies in progress (D0/TOTEM)
- Clear signal of Odderon?

Running at higher luminosity: CT-PPS



- Measurements at medium luminosity (special runs): low and medium mass diffraction using high β^* runs in CMS-TOTEM: glueballs, jets, W bosons, vector mesons in SD and DPE, exclusive diffraction...
- High mass diffraction using CT-PPS: sensitivity to new physics via anomalous couplings (extra-dimensions...)
- See talk by Justin

Conclusion

- Measurements of elastic, inelastic and total cross sections at different center-of-mass energies: unprecedented precision
- B slope of $d\sigma/dt$ is larger at 13 TeV
- Dip position in $d\sigma/dt$ decreases with $\sqrt{s}$, and no structure is found at high $|t|$
- Pure exponential form of $d\sigma/dt$ is excluded
- ρ and $d\sigma/dt$ cannot be described within the same model (COMPETE): sign of Odderon or slowing down of σ_{tot} at high energy?
- Comparison between pp and $p\bar{p}$ data (TOTEM/D0) in progress