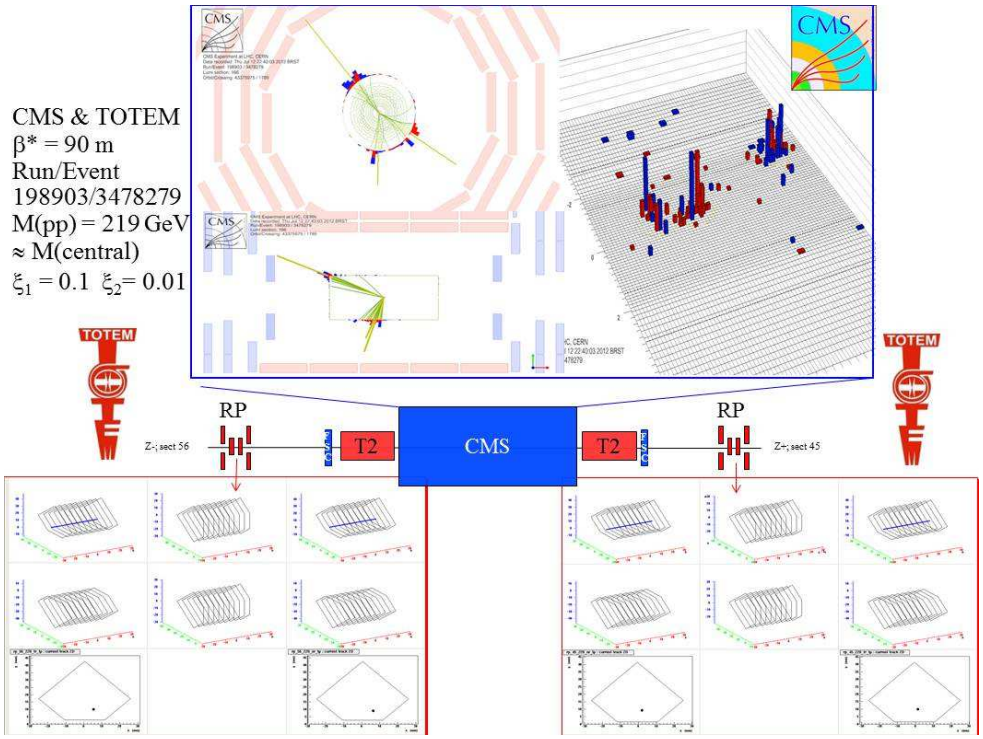
Recent results from the TOTEM collaboration

Christophe Royon
University of Kansas, Lawrence, USA

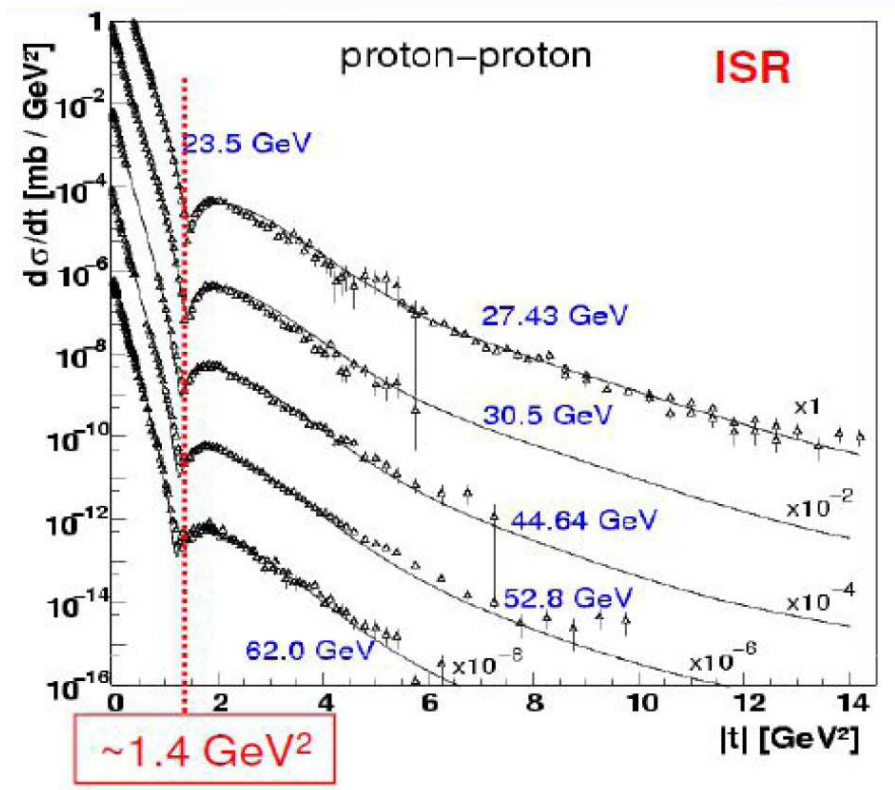
CFNS Workshop, Stony Brook, 17-19 October 2018

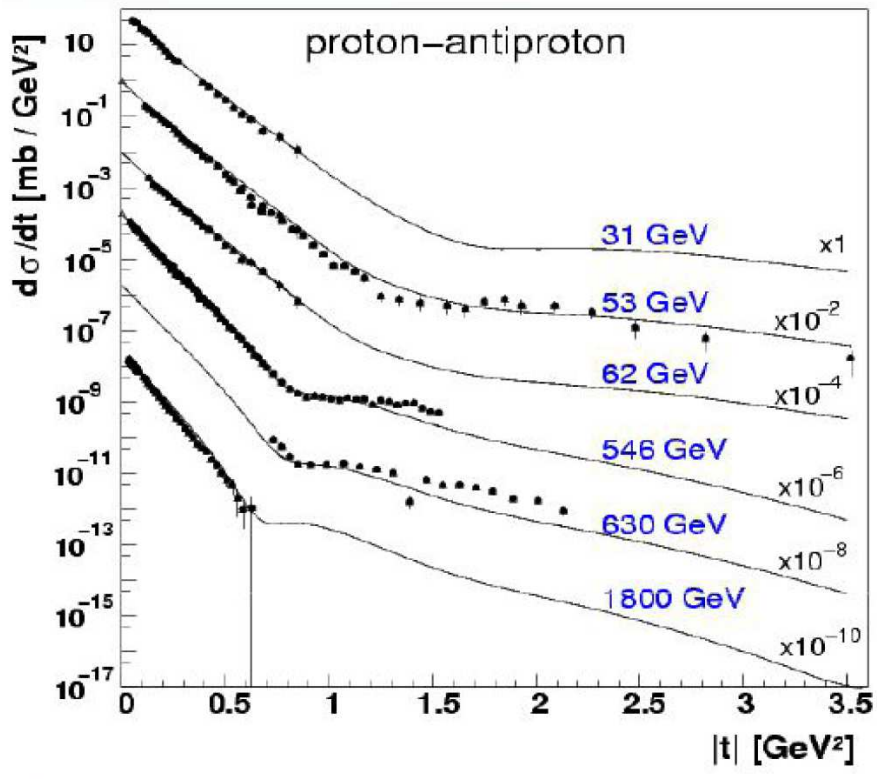
Contents:

- 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 $d\sigma/dt$)?

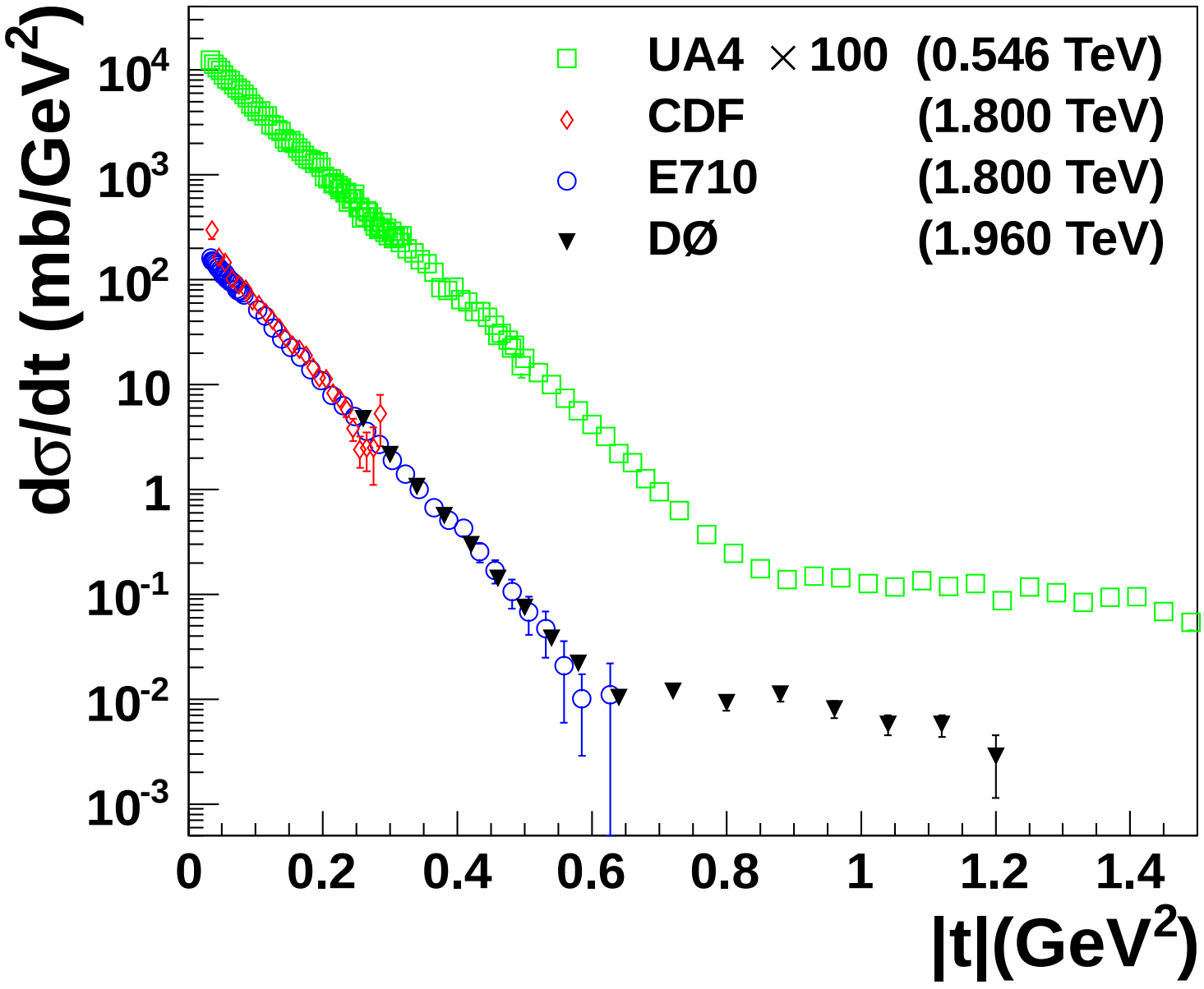


Elastic scattering: From ISR to Tevatron



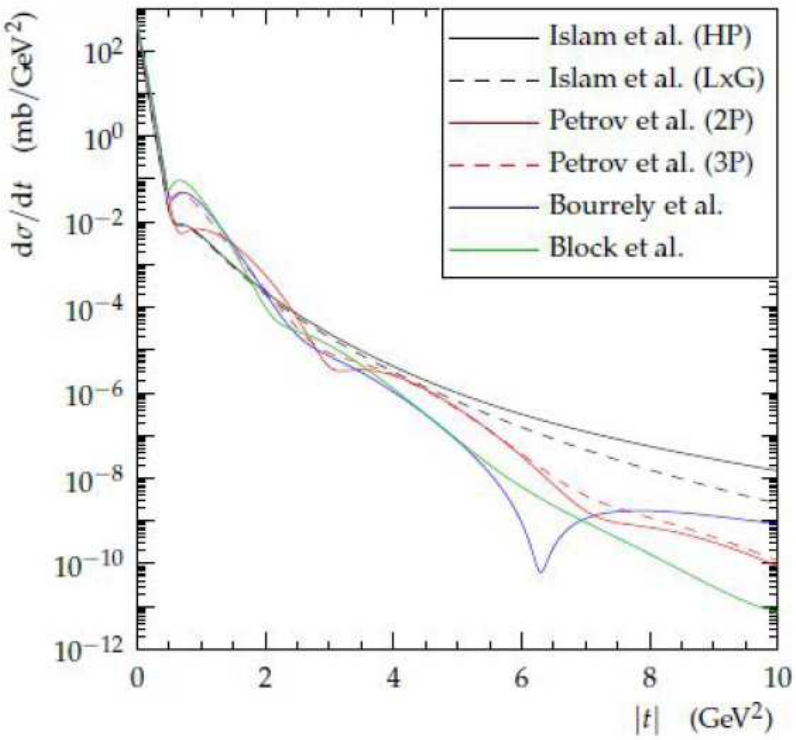


Elastic scattering: From ISR to Tevatron

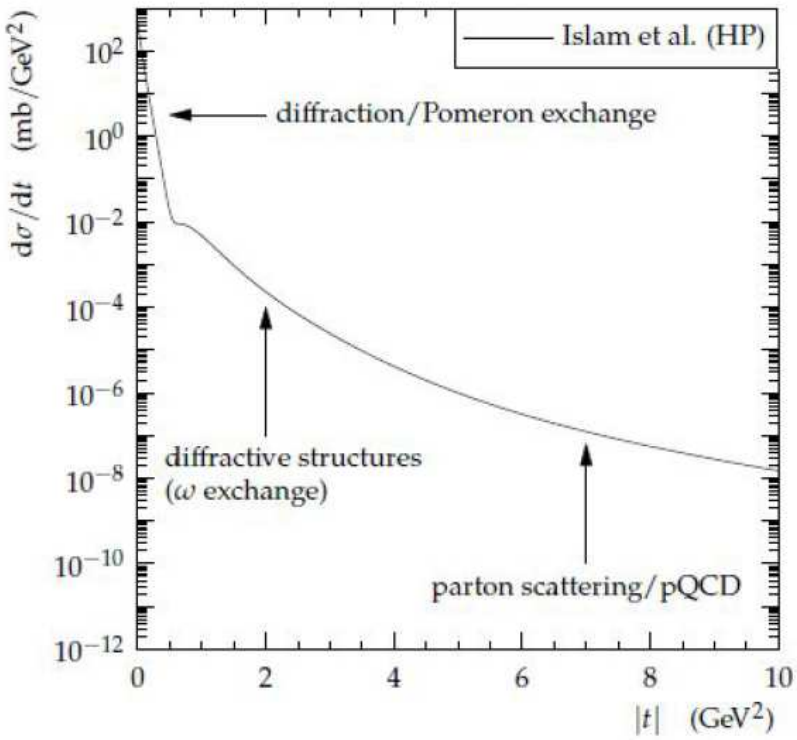


Elastic scattering at the LHC: variety of predictions before TOTEM

- 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 $|t|$



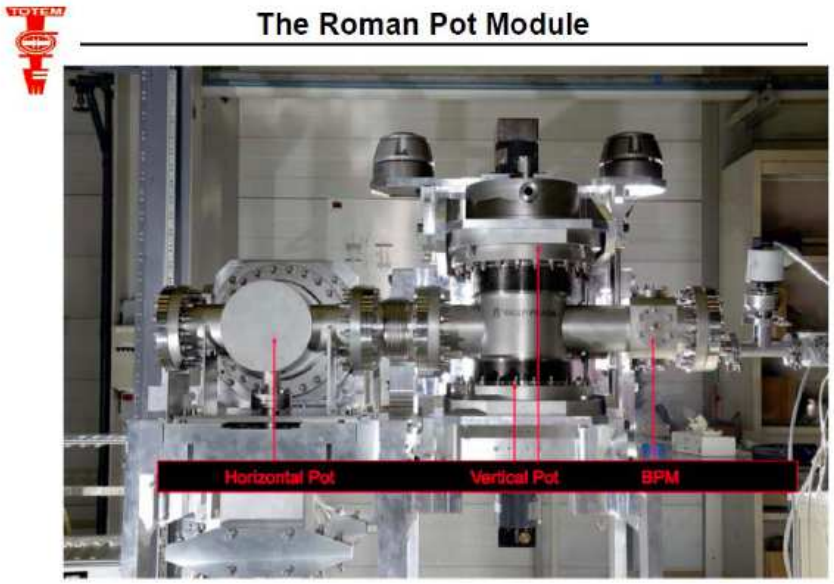
theoretical/phenomenological models: very different predictions at large |t|

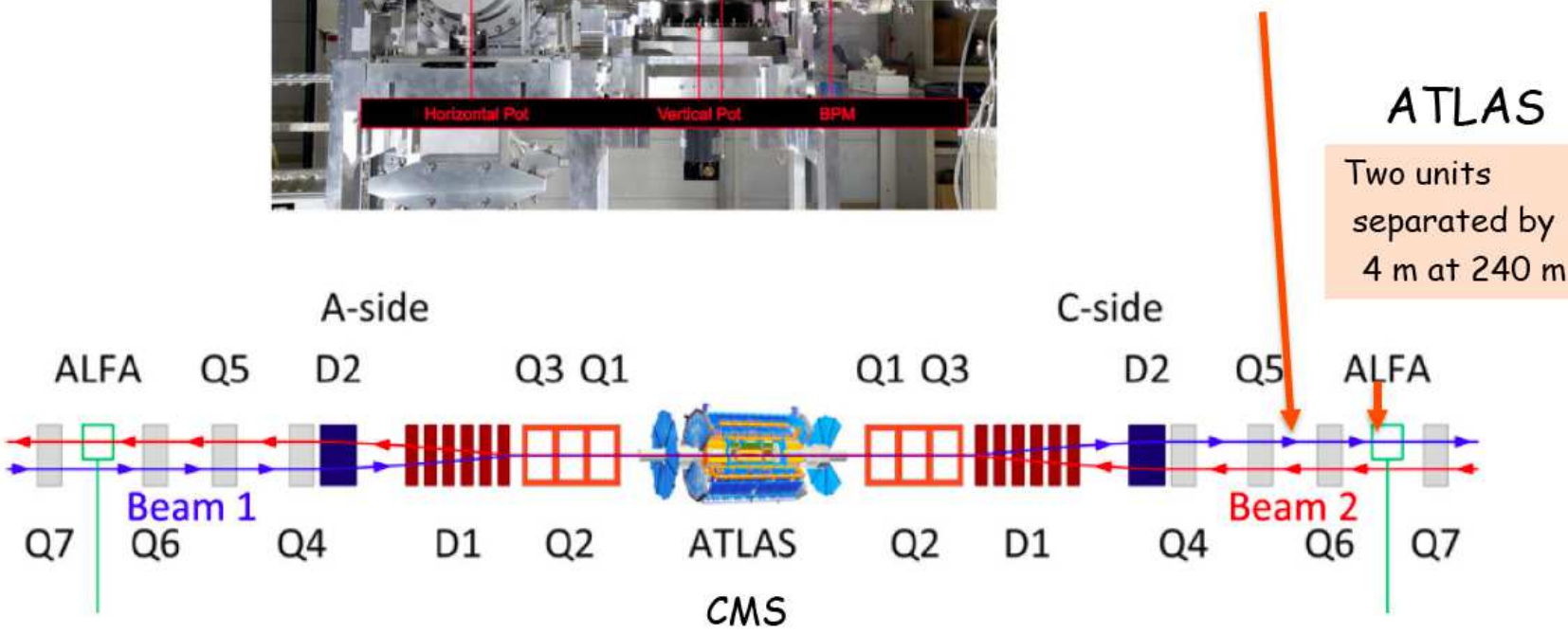


different |t| regions: different scattering mechanisms/QCD regimes

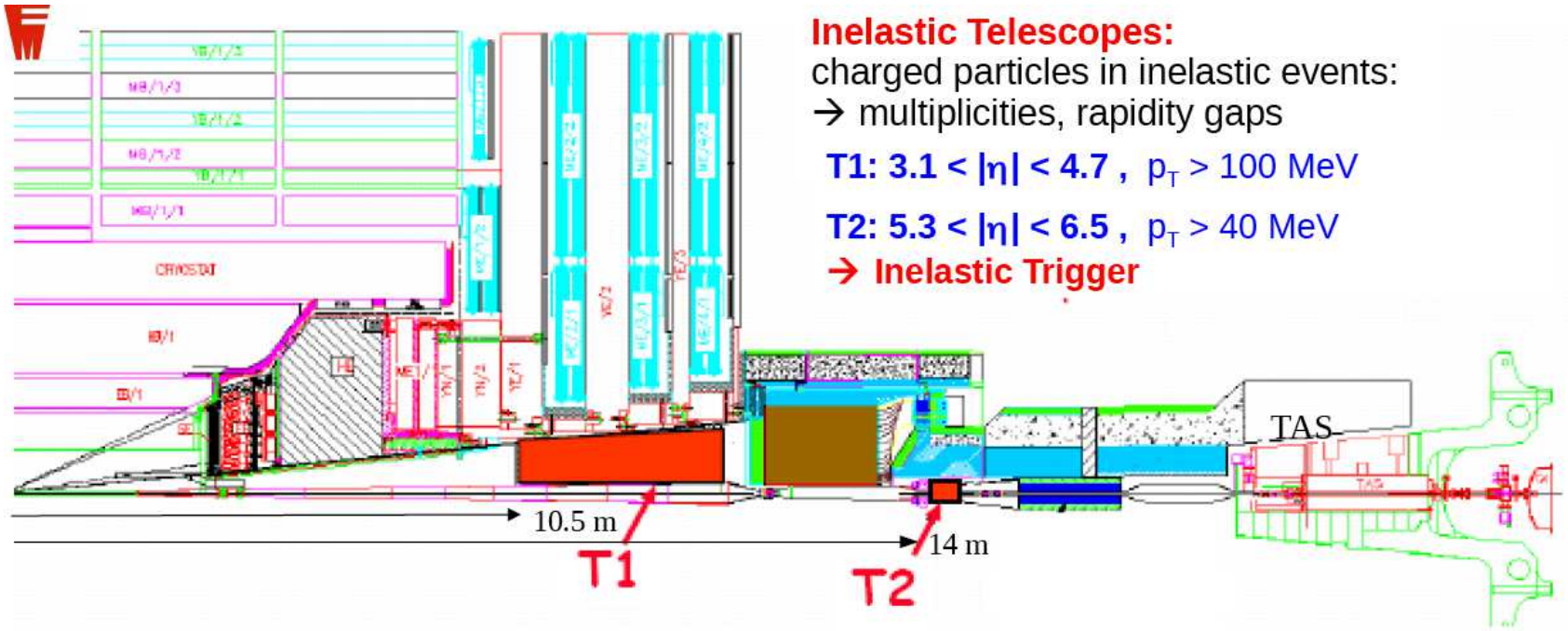
TOTEM Roman pot detectors

- For elastic measuremnts, TOTEM installed vertical roman pot detectors at 220 m from CMS (ATLAS-ALFA installed similar roman pots at 240 m)
- Trigger for elastics using proton in opposite configurations: Up (Down) on one side, Down (Up) on the other side





Forward coverage in CMS-TOTEM



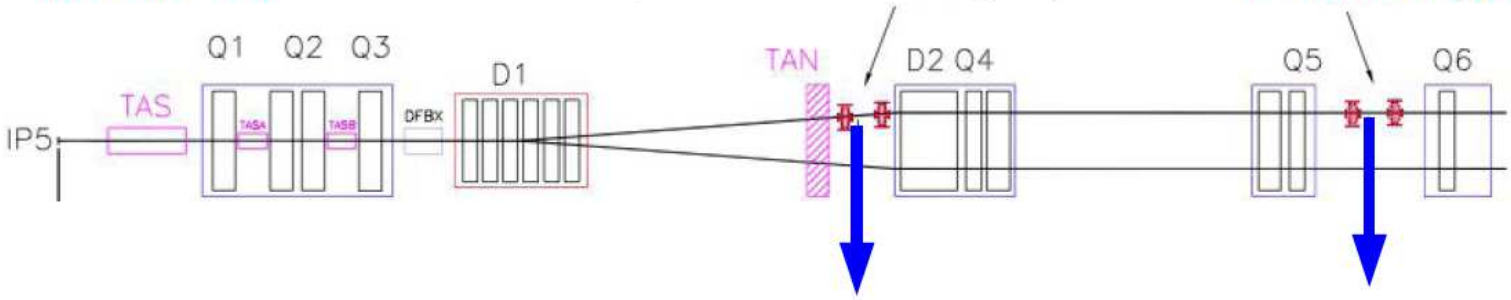
Inelastic Telescopes:
charged particles in inelastic events:
→ multiplicities, rapidity gaps

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)

TOTEM cross section measurements

Run I

2011
- **Elastic** scattering @7 TeV
  EPL 95-41001
- First σ_{tot} @ 7 TeV
  EPL 96-21002

2012
- σ_{tot} lumi independent @7 TeV
- **Elastic**, inelastic cross section
- Elastic: full t-range
  EPL 101-21004/21003/21002

2013
- σ_{tot} lumi independent @ 8 TeV
  PRL 111-12001

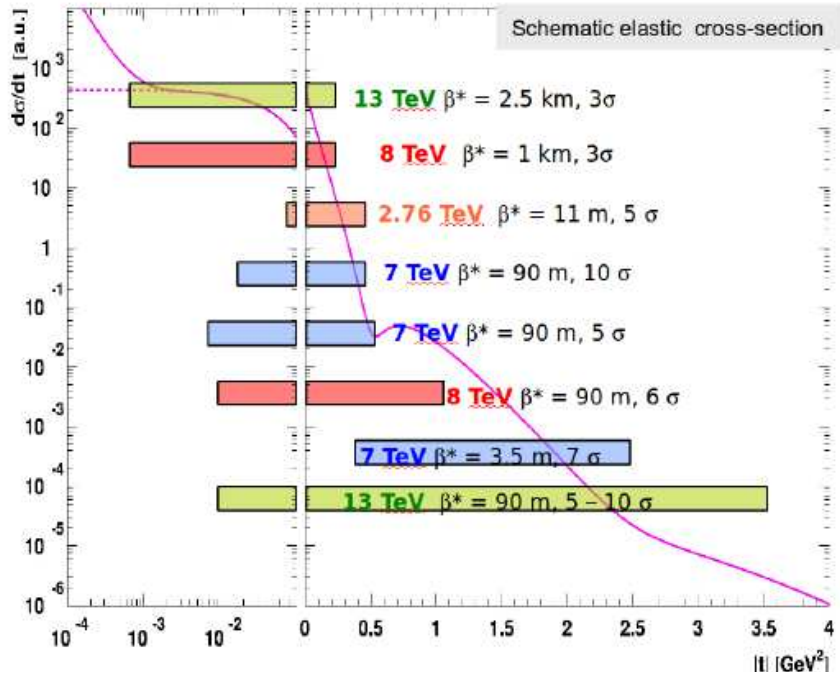
Run II

2015
- dσ/dt **elastic** : non- exponential behaviour @ 8 TeV
  NPB 899-527

2016
- ρ measurement @ 8 TeV
  EPJ C76-661

2017
- σ_{tot} lumi independent @ 2.76 TeV
  PoS (DIS2017) 059
- σ_{tot} lumi independent @ 13 TeV
  CERN-EP-2017-321
- ρ measurement @ 13 TeV
  CERN-EP-2017-335

2018
- **dσ/dt** elastic: DIP @ 13 TeV
  Preliminary



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)

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

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

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

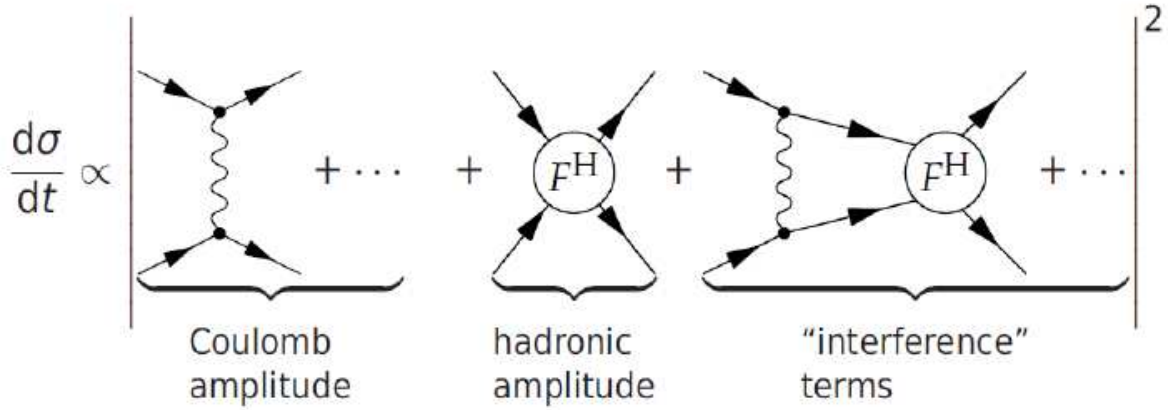
  - Lumi dependent measurement (elastic only)

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

  - 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

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

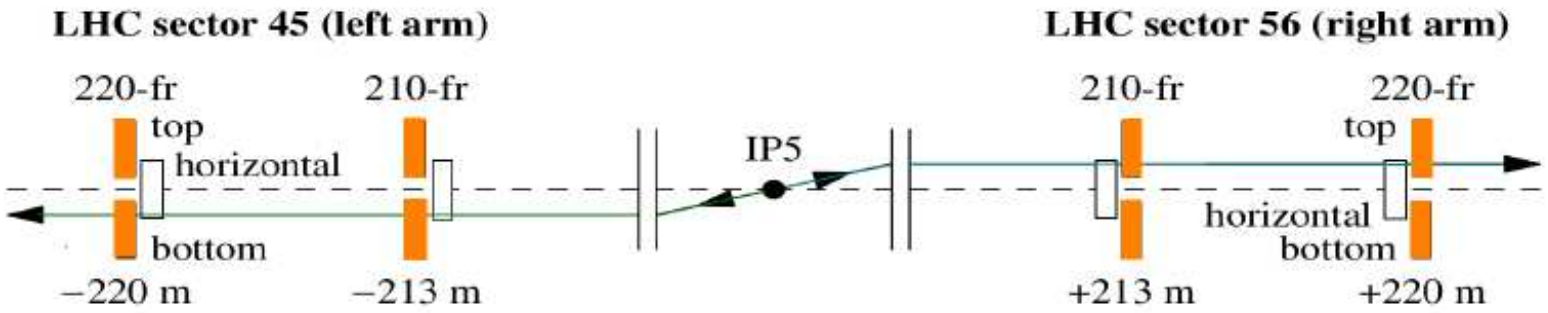
- The differential cross section is sensitive to the phase of the nuclear amplitude
- In the CNI region, both the modulus and the phase of the nuclear amplitude can be used to detrmine

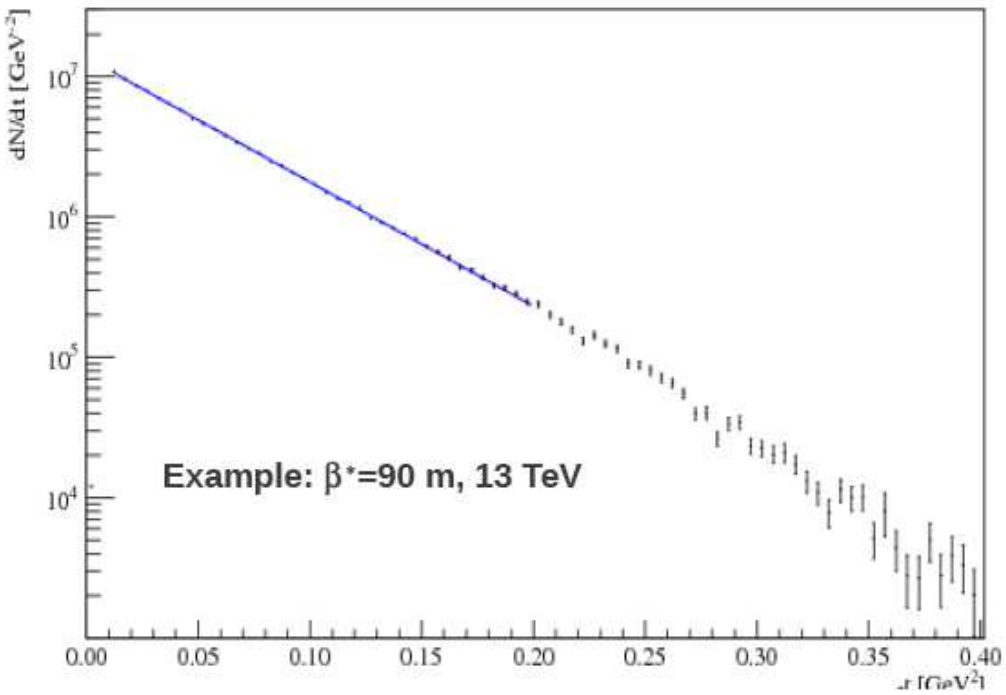
$$\rho = \frac{Re(A^N(0))}{Im(A^N(0))}$$

where the modulus is constrained by the measurement in the hadronic region and the phase by the t dependence

Elastic and inelastic measurements

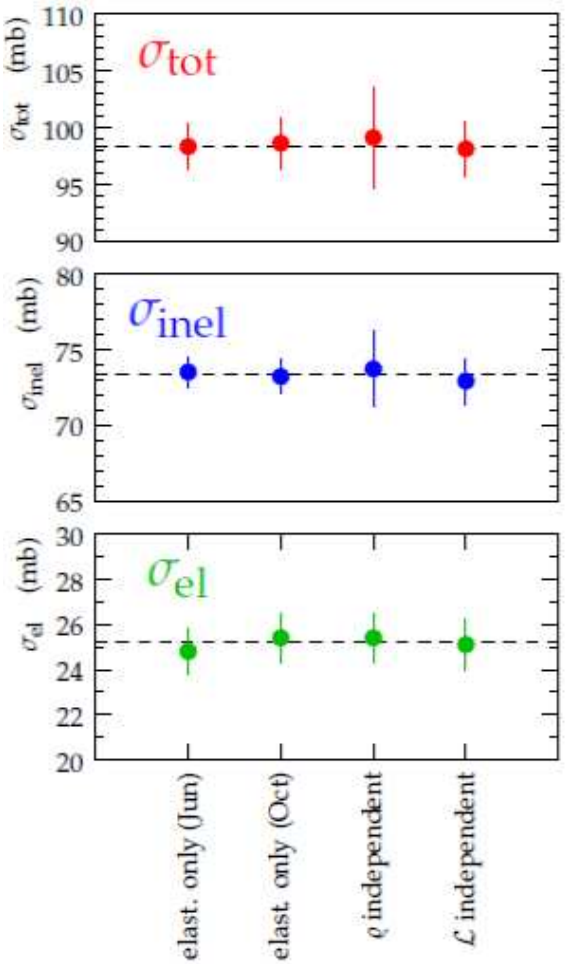
- Elastic measurements: Use double arm roman pots



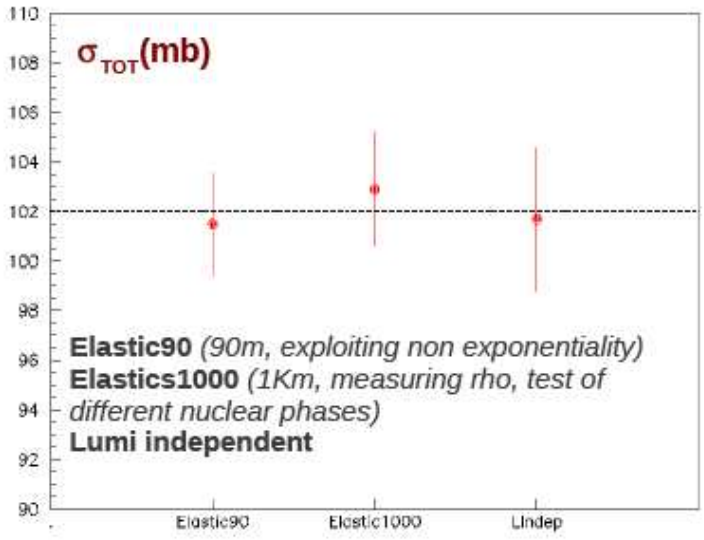


- Inelastic measurements Use T_2 as a trigger (N_{inel} gives a signal in T_1 and/or T_2 for 92% of events)
- Acceptance, efficiency corrections using data

Total cross section at 7 and 8 TeV



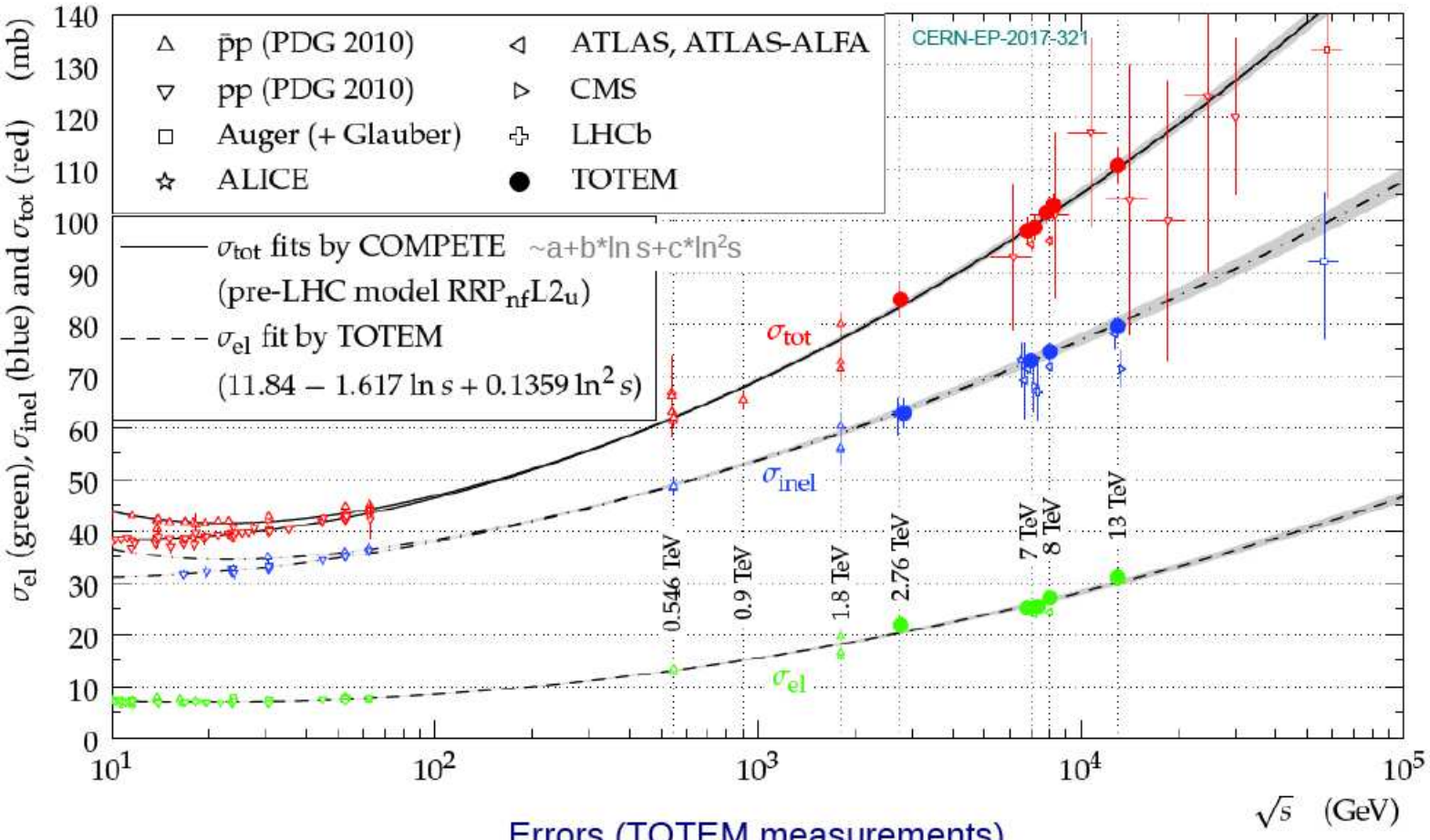
7 TeV, several methods
Same beam conditions



8 TeV, several methods
Different beam conditions

(NB: at 13 TeV, total cross section using lumi independent method for $\beta^* = 90m$, and ρ measurement using $\beta^* = 2500m$ data)

Elastic/Inelastic/Total cross section



Errors (TOTEM measurements)

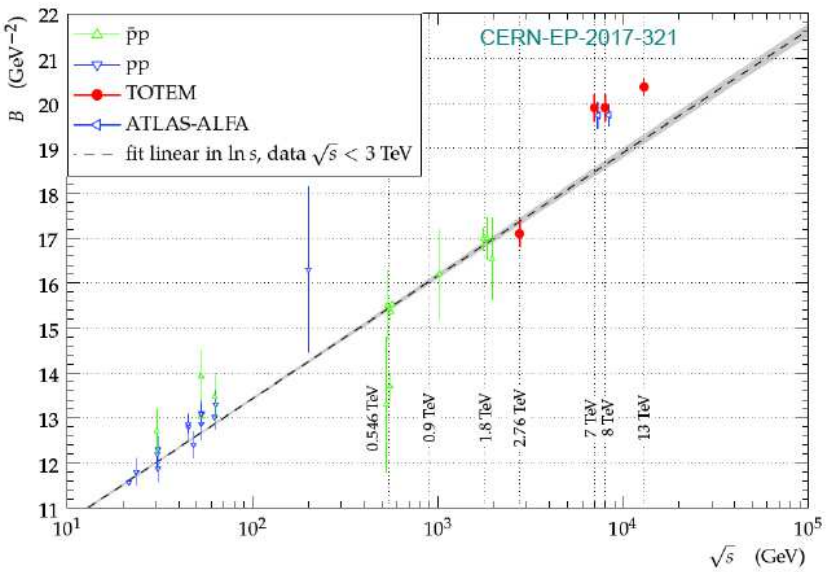
σ_{TOT} ~ 2-3 %

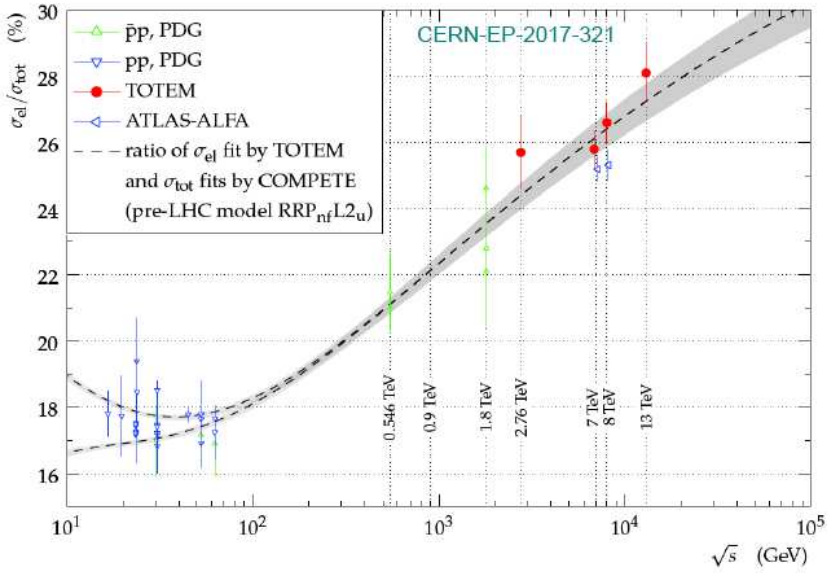
σ_{INEL} ~ 2 %

σ_{EL} ~ 2-4 %

- High precision measurement of elastic, inelastic and total cross sections
- Measurements in agreement with cosmic-ray data (large error bars though)

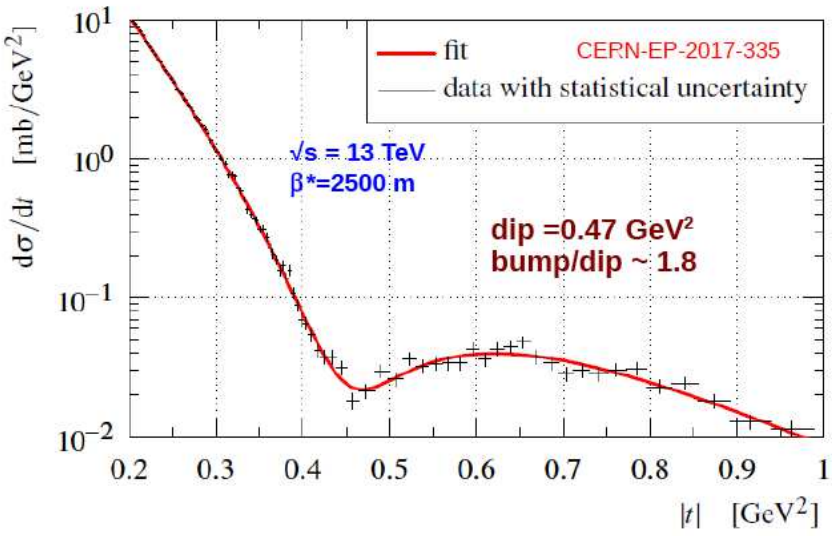
Implication of total cross section measurements I

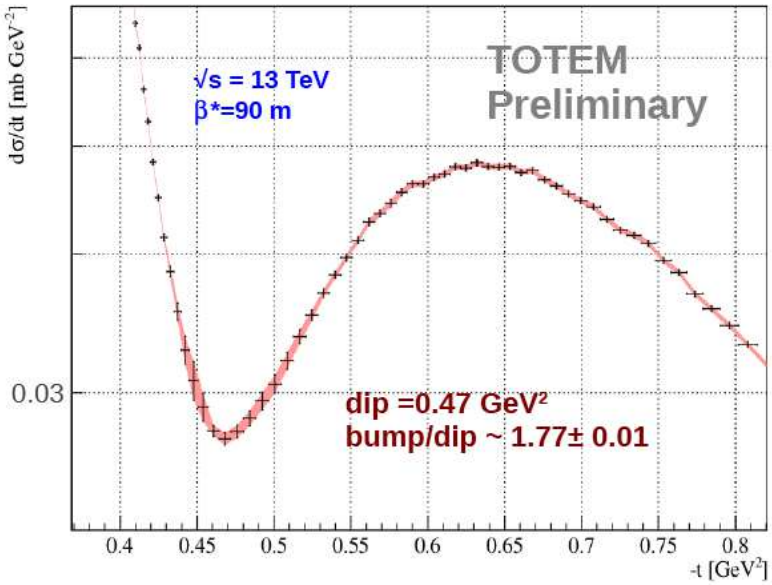


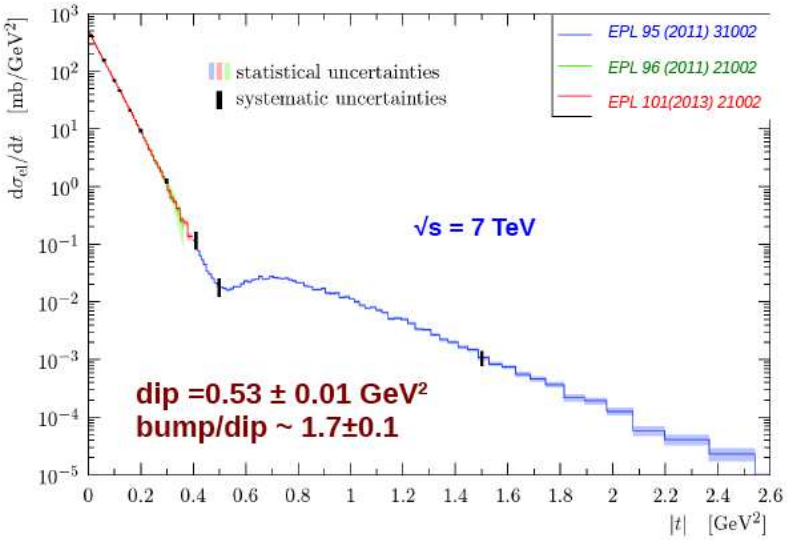


- B slope of $d\sigma/dt$: larger slope at 13 TeV
- Linear behavior (lns) compatible for $\sqrt{s} < 3$ TeV, incompatible at higher energy
- Diffraction cone shrinkage speeds up with $\sqrt{s}$
- The increase of $\sigma_{el}/\sigma tot$ with energy is confirmed at LHC

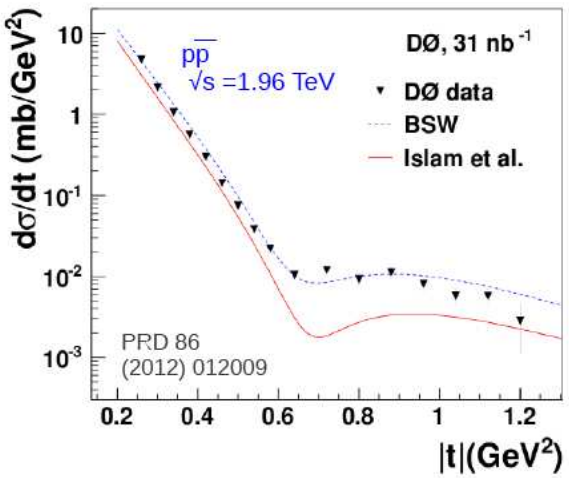
Implication of total cross section measurements II





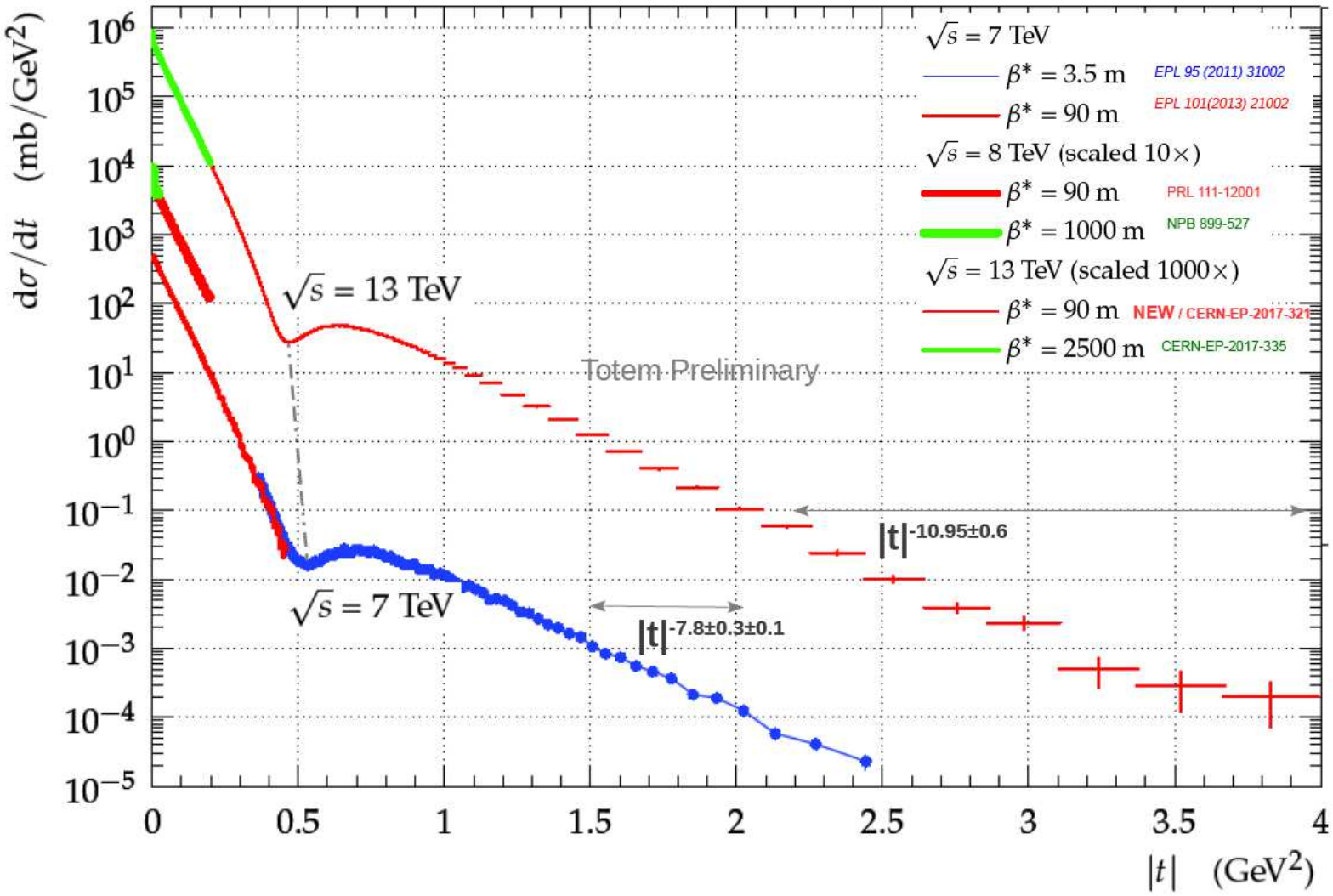


Dip is missing in $p\bar{p}$



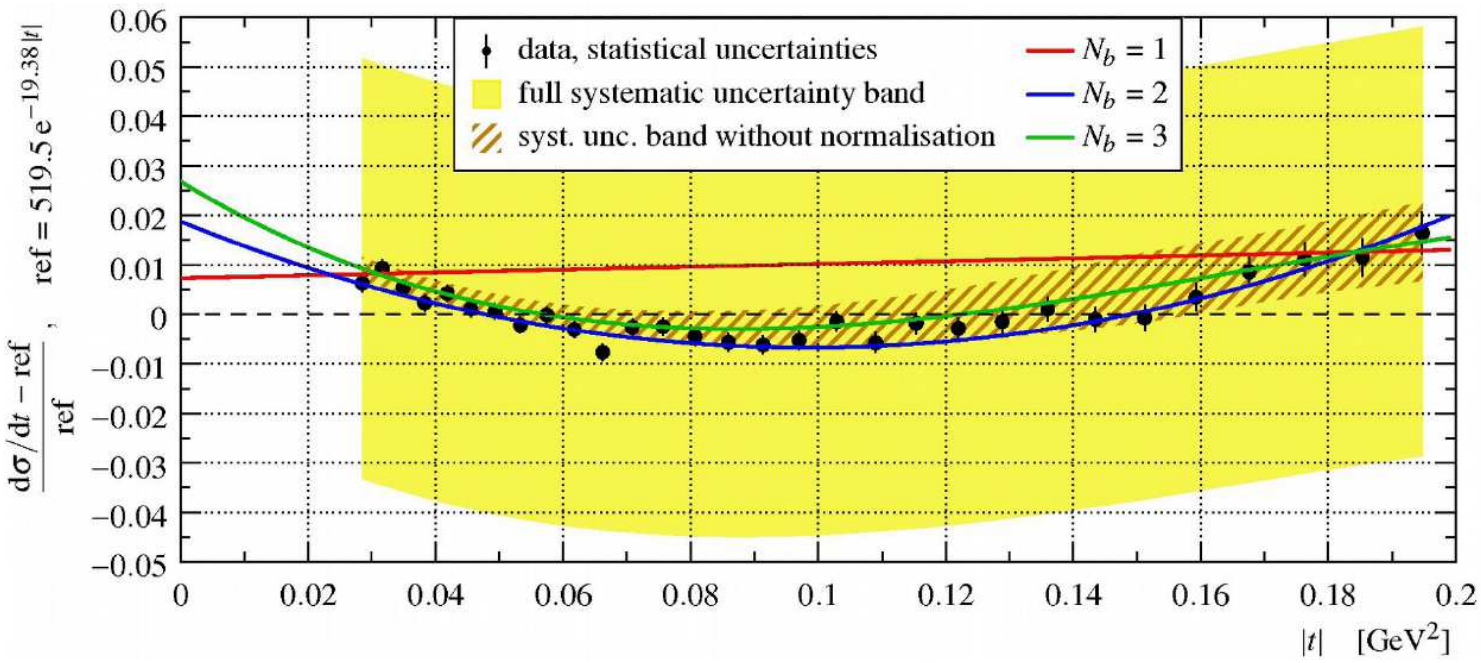
- Dip position in $|t|$ decreases with increasing $\sqrt{s}$
- Differences between pp and $p\bar{p}$ data: Dip missing in $p\bar{p}$?

Implication of total cross section measurements III



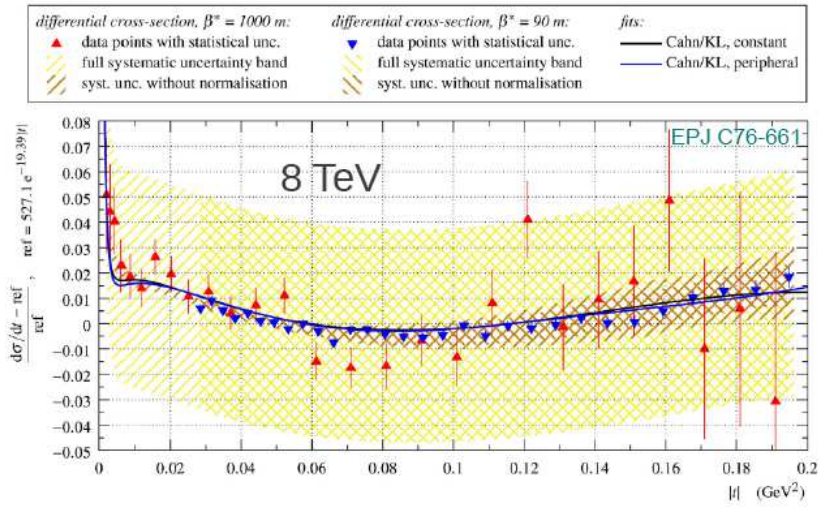
- No structure seen at high $|t|$, compatible with a flat behavior
- Differences with respect to many pre-TOTEM models

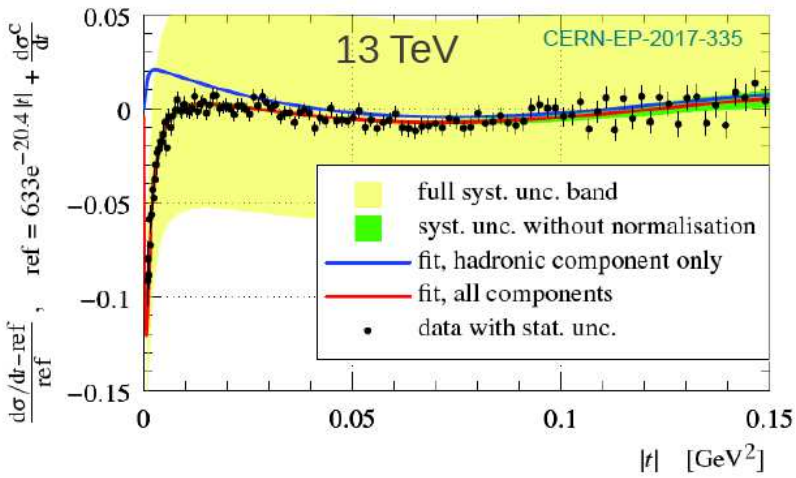
Implication of total cross section measurements IV



- 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

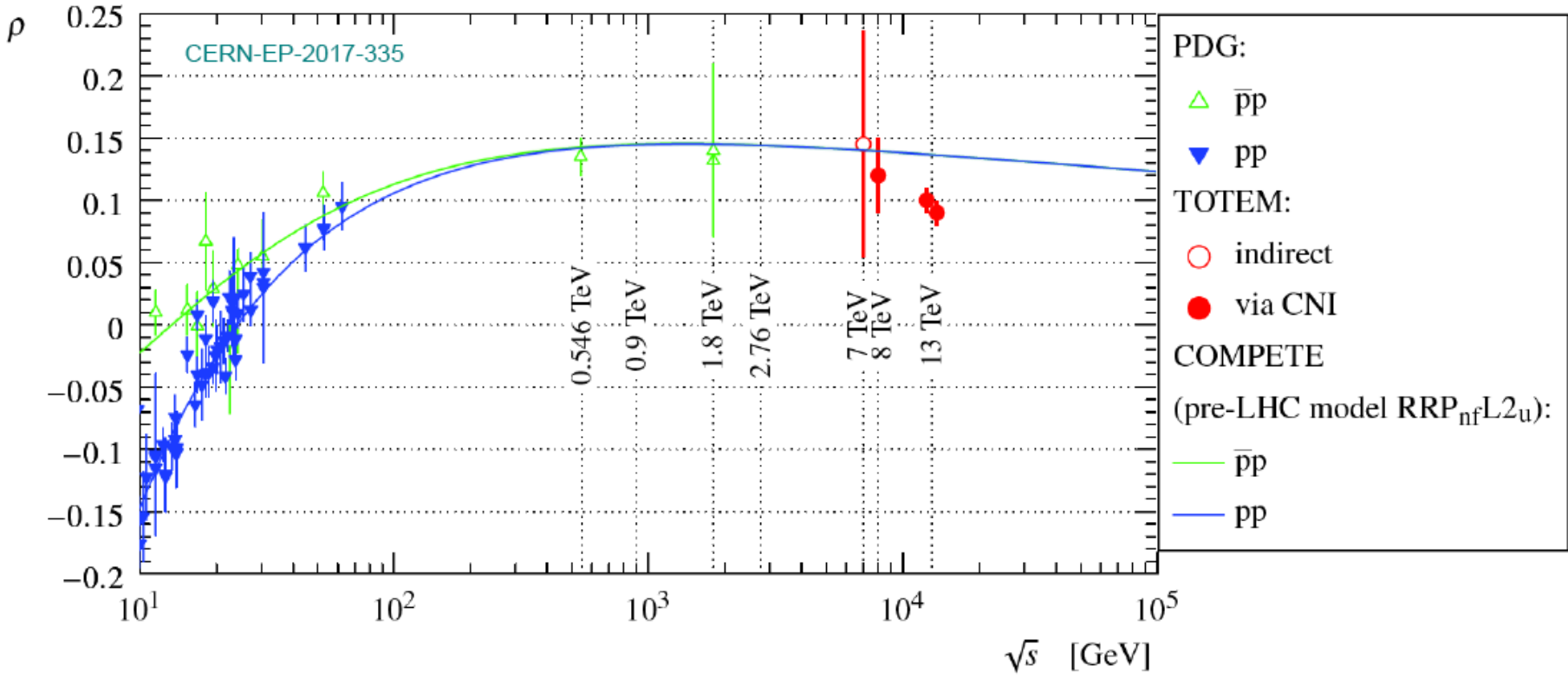
Implication of total cross section measurements V





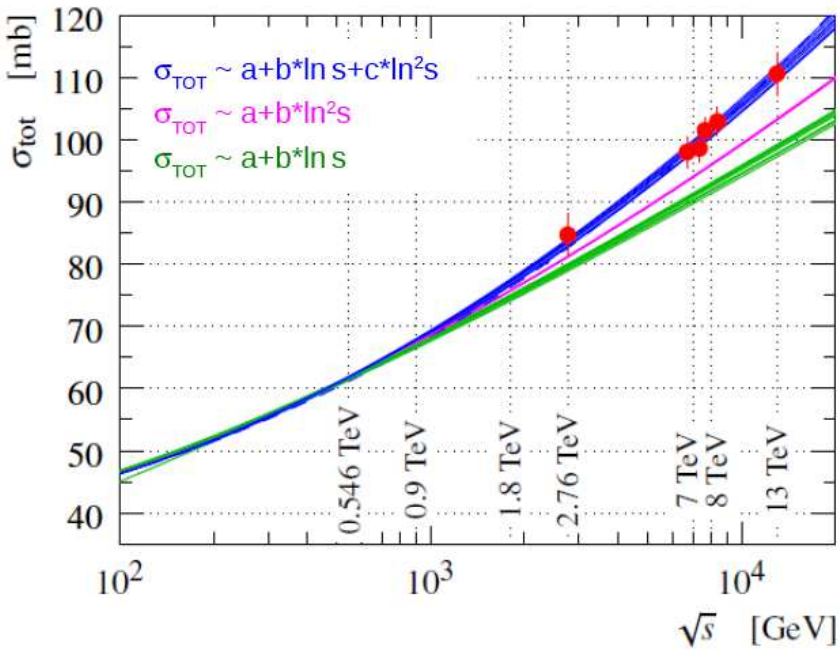
- Non-exponential behavior is confirmed at 8 and 13 TeV
- Non exponential ($n = 3$) is compatible with data

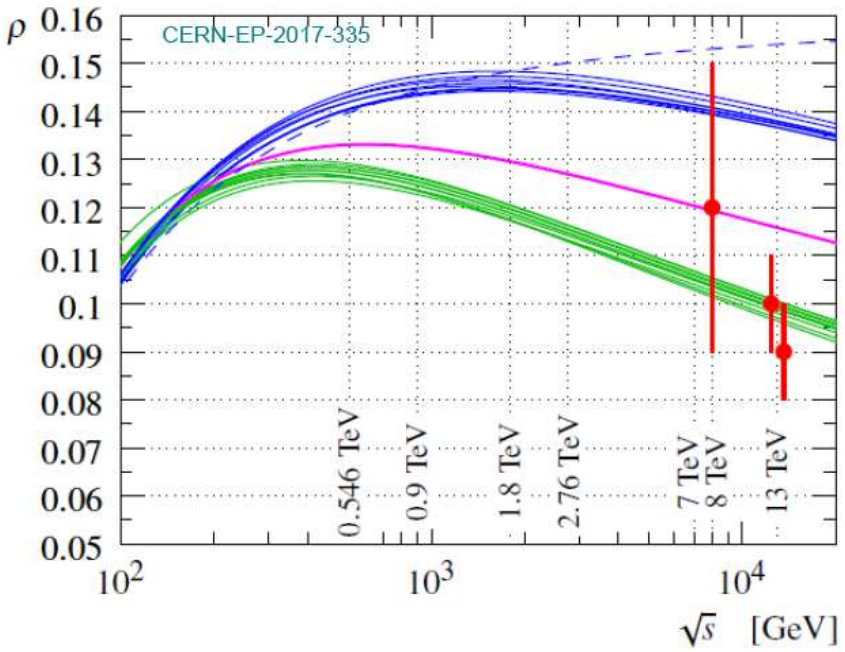
ρ measurement at 13 TeV (I)



- 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)

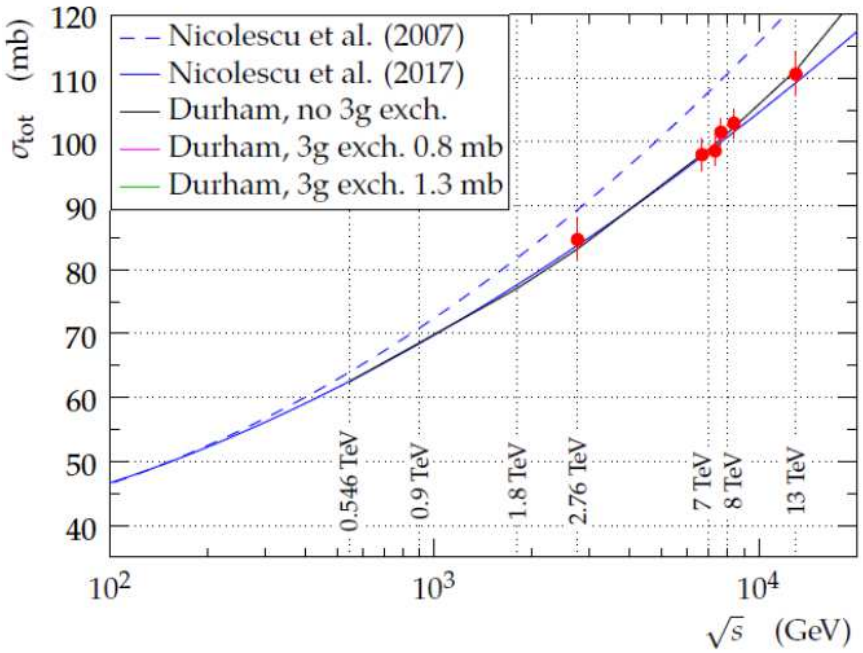
ρ measurement at 13 TeV (II)

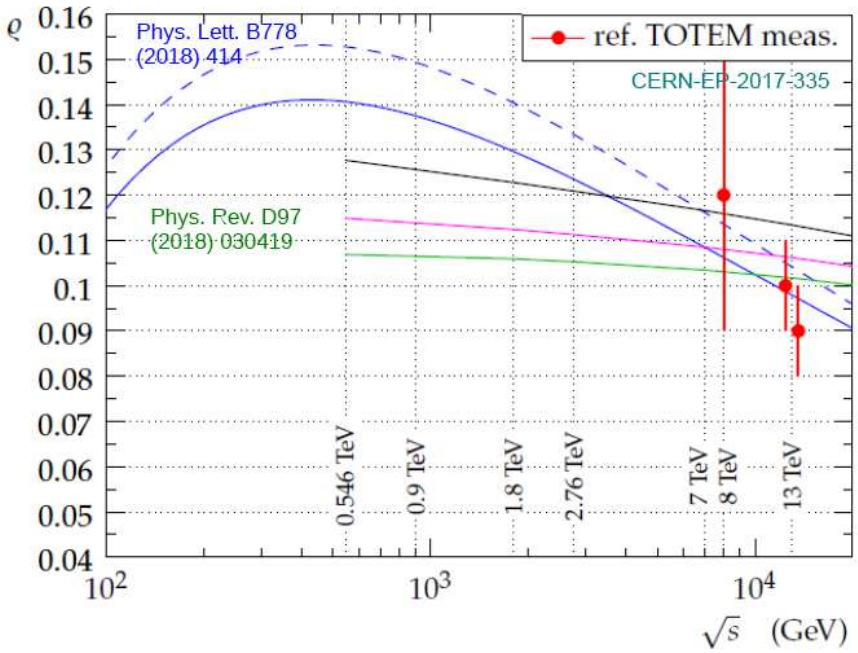




- None of COMPETE model can describe σ_{tot} and ρ at the same time!
- This result can be explained by the exchange of the Odderon in addition to the Pomeron, or saturation effects of σ_{tot} at high energies

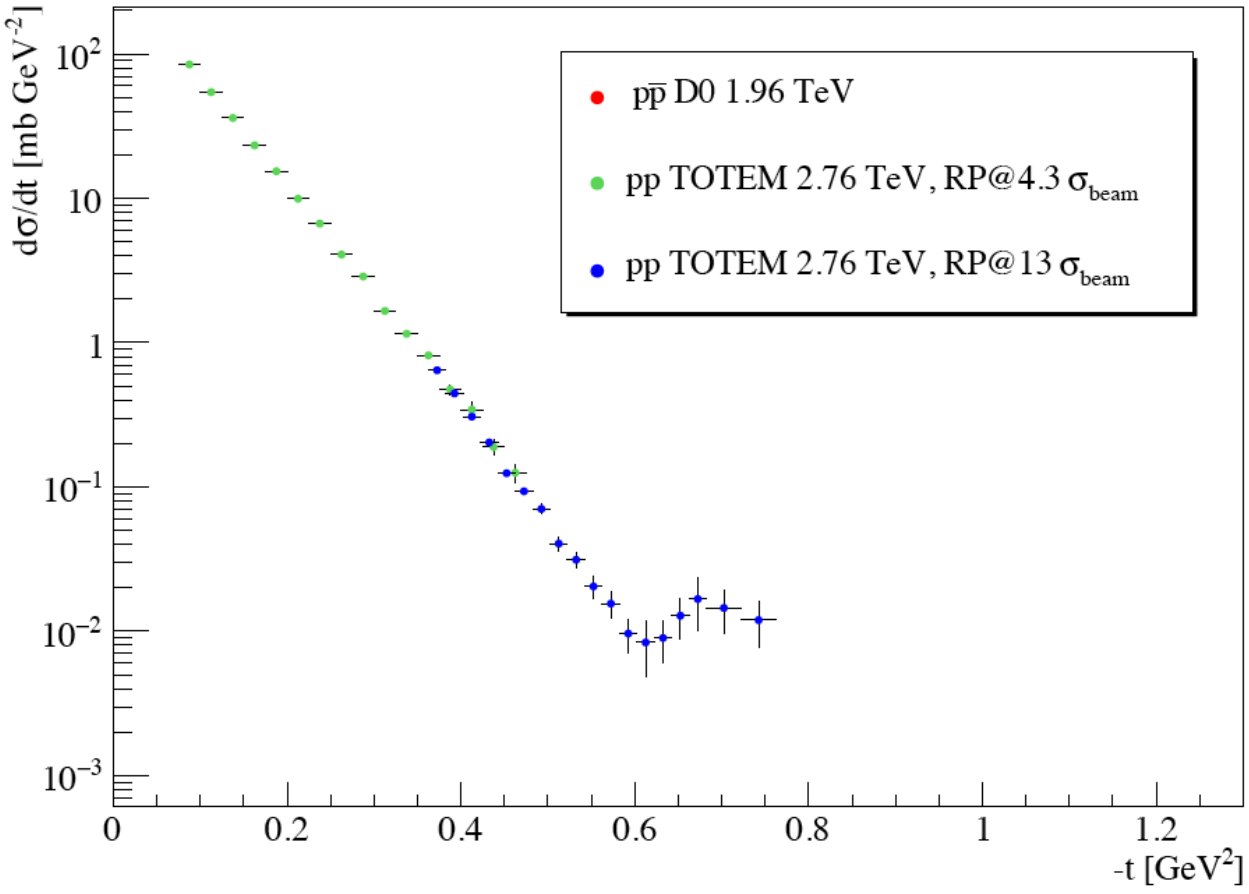
ρ measurement at 13 TeV (III)





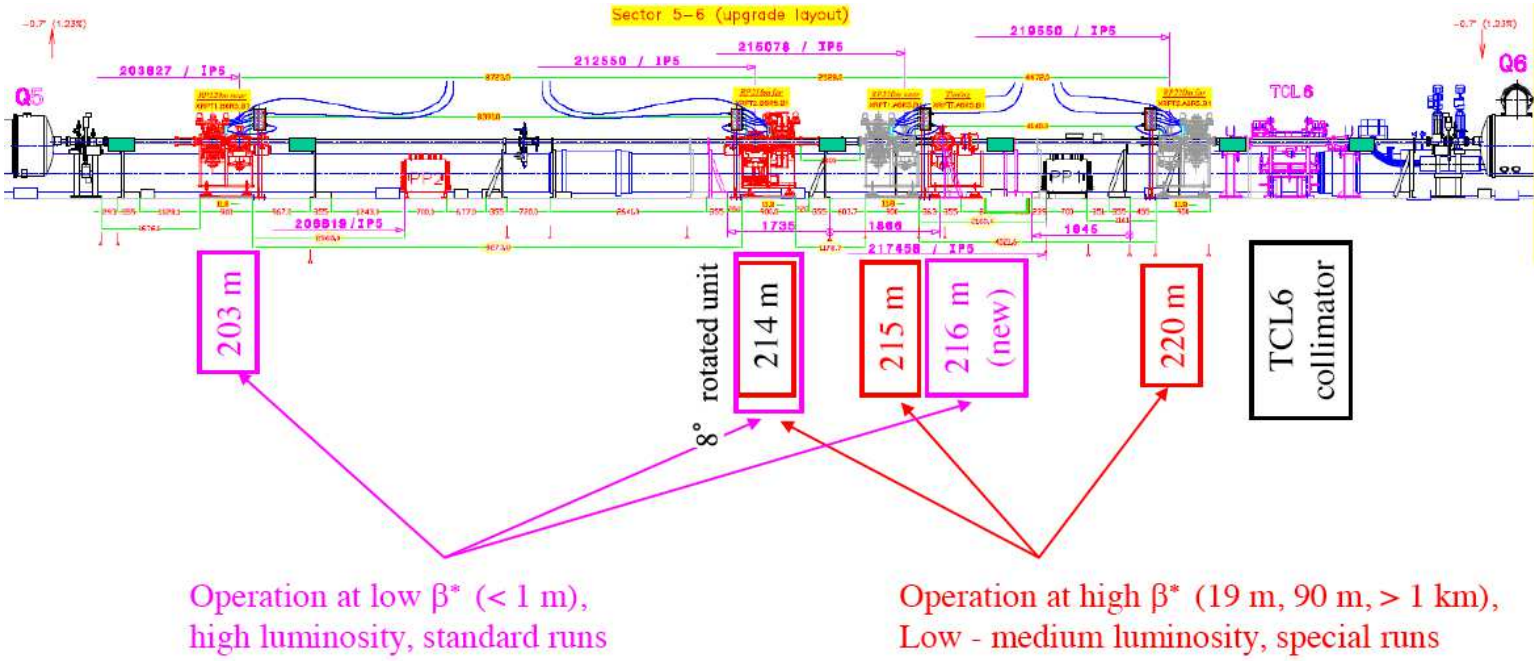
- t-channel exchange of a colorless 3-gluon bound state (Odderon) can decrease ρ at large energy
- Is it an evidence of the Odderon or the "slowing down" of σ_{tot} growth at high energy?
- Comparison between pp and $p\bar{p}$ crucial

Measurements at 2.76 TeV



- Very recent measurement of $d\sigma/dt$ at 2.76 TeV (last week)
- Data points finalized but uncertainties are not final (conservative for now)

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 Robert

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?