Recent Elastic and Total Cross-Section Measurements by TOTEM

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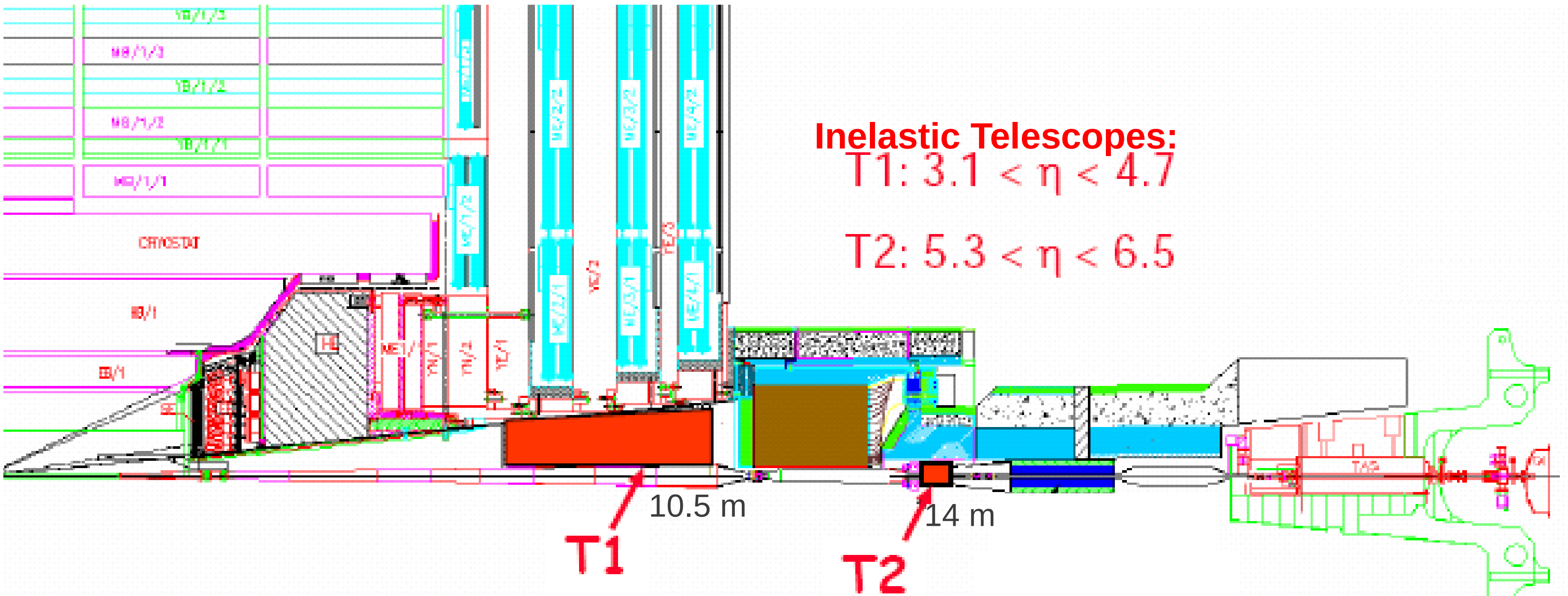
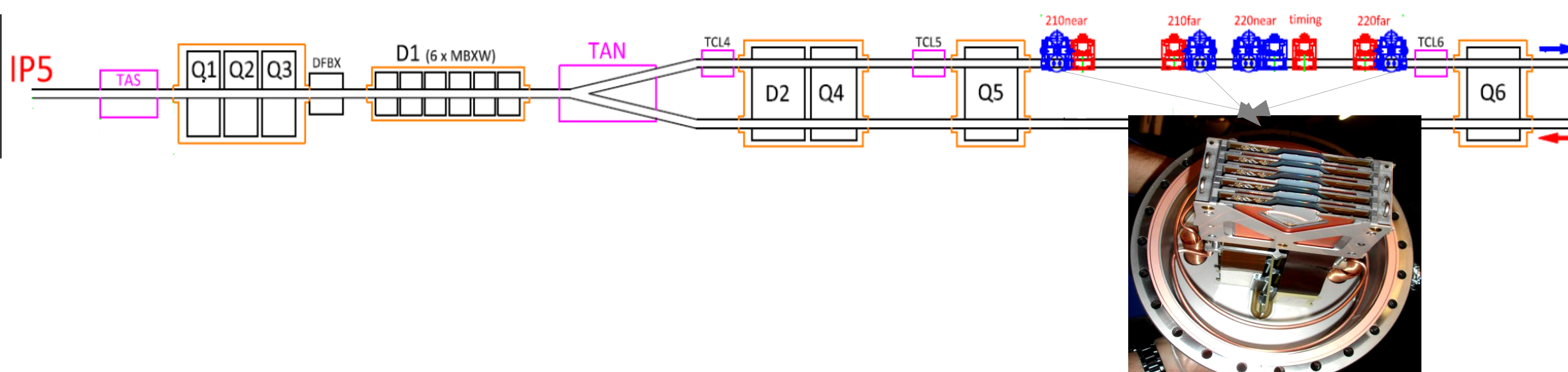
On behalf of the TOTEM Collaboration

TOTEM Detectors

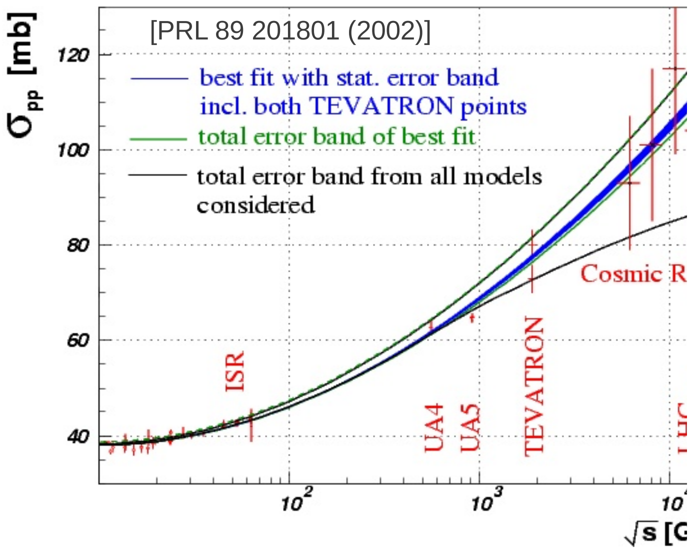


Roman Pot stations in the LHC tunnel



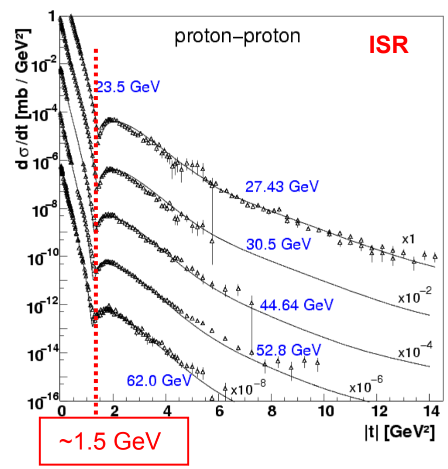
Status pre-LHC

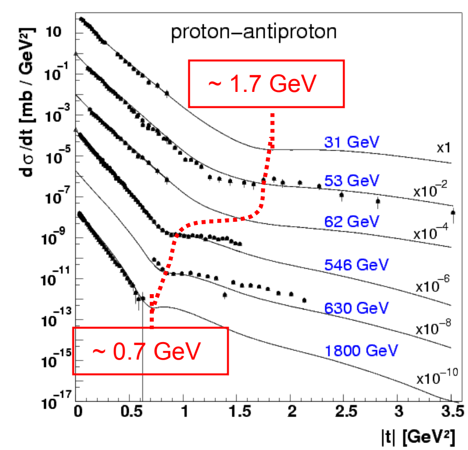
One of the physics goal of TOTEM is to measure the (elastic, inelastic, total) cross sections at LHC

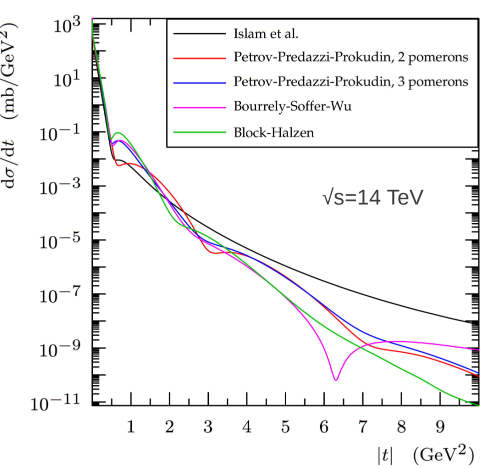


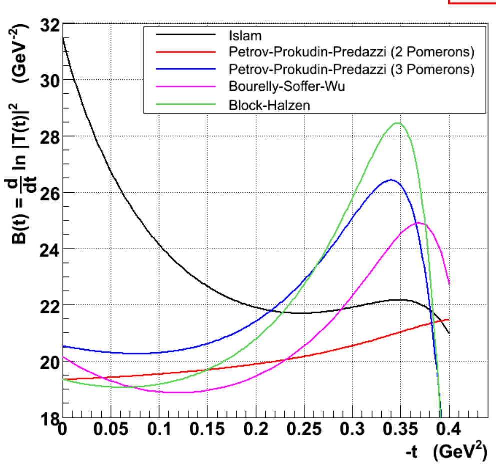
- COMPETE Collaboration fits all available hadronic data and predicts at LHC: σ_{tot} = 111.5 ± 1.2 + 4.1/-2.1 mb [PRL 89 201801 (2002)]
- Last pp data at the ISR; only ppbar at "high" energy
- Difference of σ_{pp} vs $\sigma_{\bar{p}p}$?
- σ_{TOT} (s) ~ $(\ln s)^{\gamma}$ $\gamma = 2$?
- σ_{EL}/σ_{TOT} VS energy

- Is the dip still present at high energy?
- Is the position of the dip changing?
- Large momentum transfer region: oscillations?
- Any break in the elastic slope B(t)?



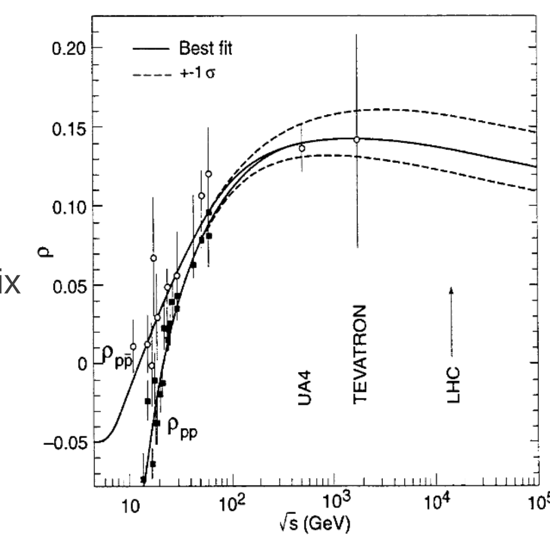






$$\rho = \Re A^N / \Im A^N |_{t=0}$$

- Foreseen to "decrease" at high energy: how fast?
- Test dispersion relation (mix real and imaginary part)



Cross section related measurements in Totem

Run I

Run II

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

2015

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

2016

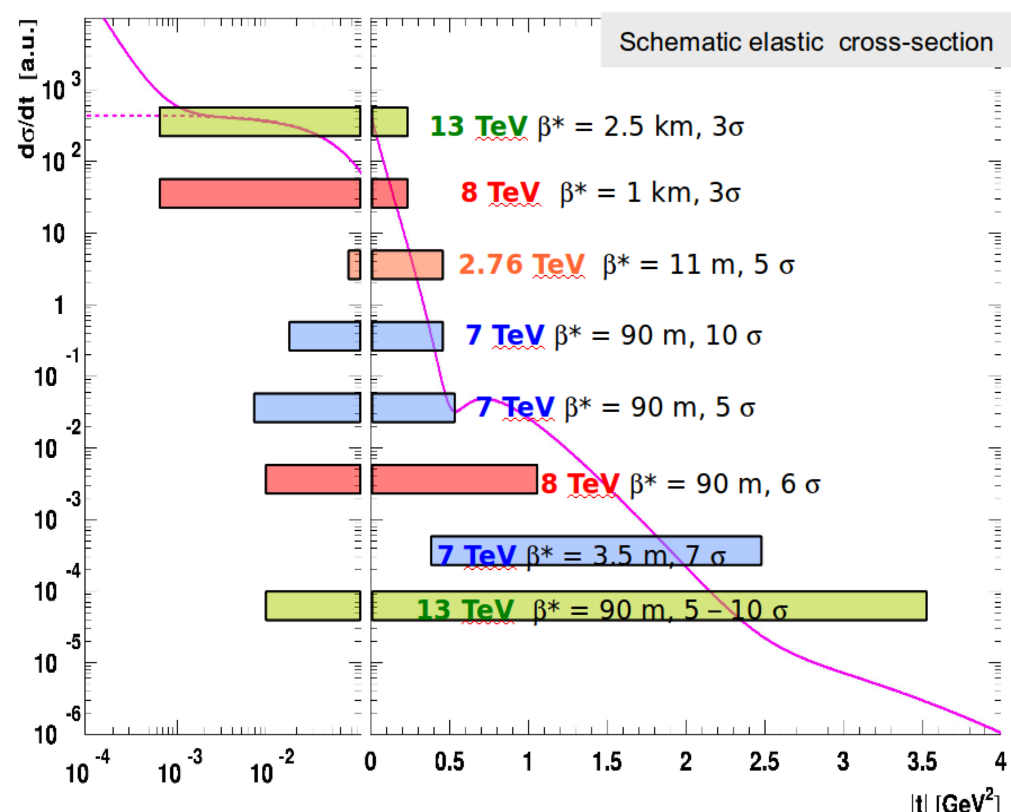
- ρ measurement @ 8 TeV
  EPJ C76-661

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



Total cross section : N_{inel} (from T1,T2 telescopes) N_{el} (from RomanPots detectors)

L independent

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

Optical Theorem

$$L\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \left.\frac{dN}{dt}\right|_{t=0}$$

$$L\sigma_{tot} = N_{elastic} + N_{inelastic}$$

But also:

L dependent/ Elastic Only

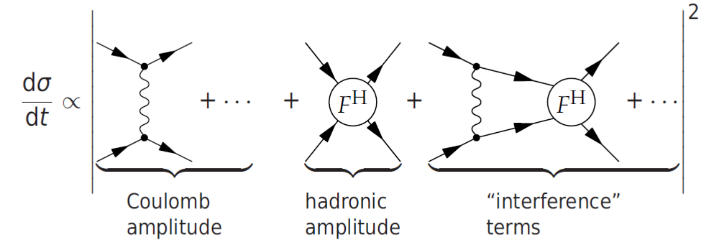
$$\sigma_{tot}^2 = \frac{16\pi}{(1+\rho^2)} \frac{1}{\mathcal{L}} \left(\frac{dN_{el}}{dt}\right)_{t=0}$$

ρ independent

$$\sigma_{tot} = \sigma_{el} + \sigma_{inel}$$

ρ measurement : elastic scattering at very low-t (Coulomb-Nuclear Interference region)

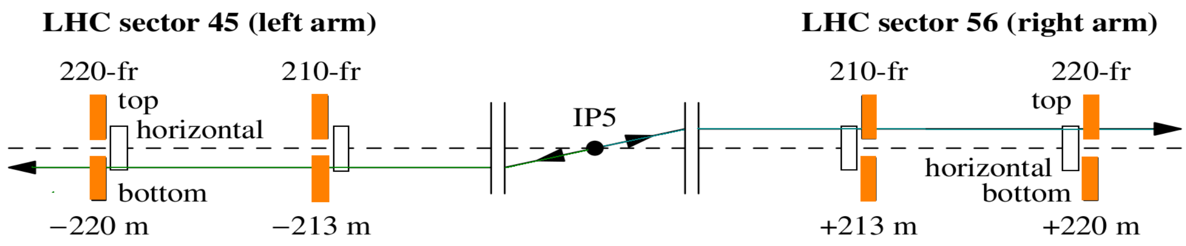
$(d\sigma/dt) \sim |A^C + A^N (1-\alpha\, G(t))|^2$



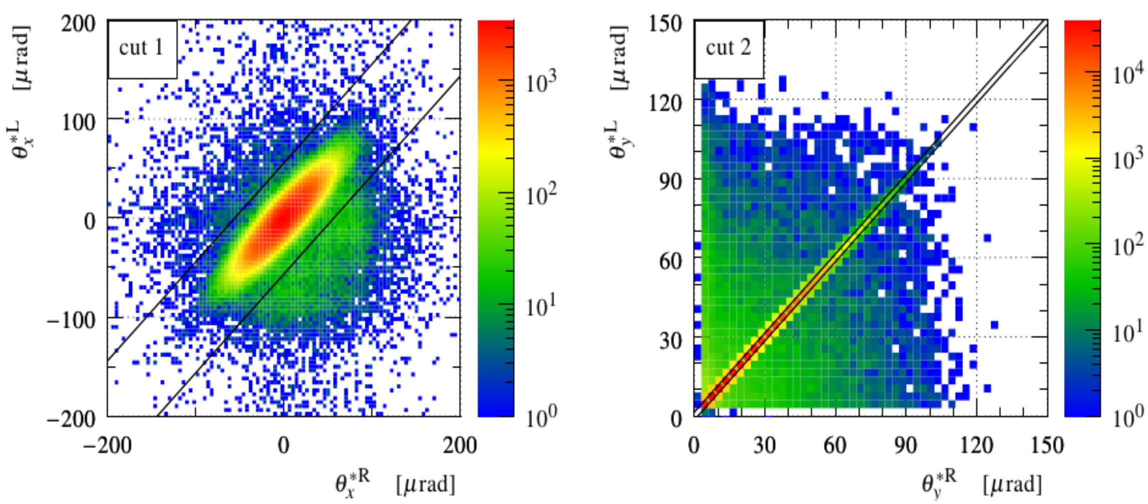
The differential cross section is sensitive to the phase of the nuclear amplitude
In the CNI both modulus (constrained by measurement in the hadronic t-region) and phase (t-dependent) of nuclear amplitude can be tested to dermine:

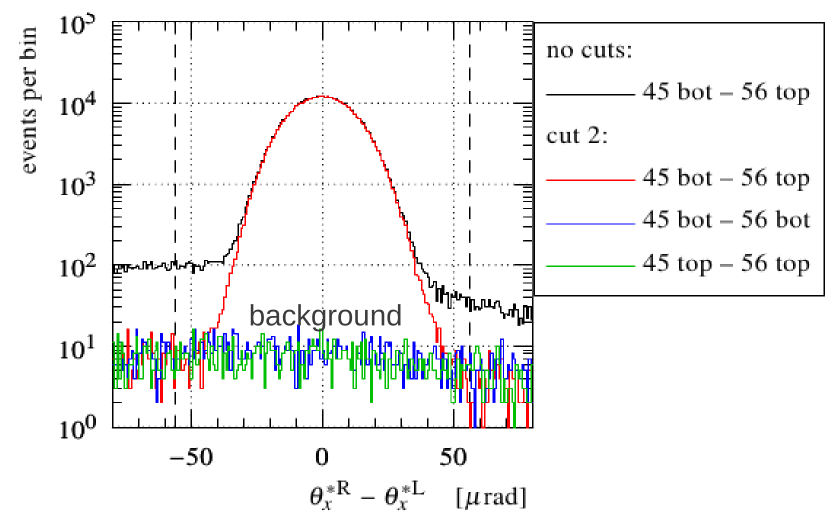
$$\rho \equiv \cot \arg \mathscr{A}^N(0) = \frac{\Re \mathscr{A}^N(0)}{\Im \mathscr{A}^N(0)}$$

Elastic measurement : method



Example: β*=2.5km, 13 TeV





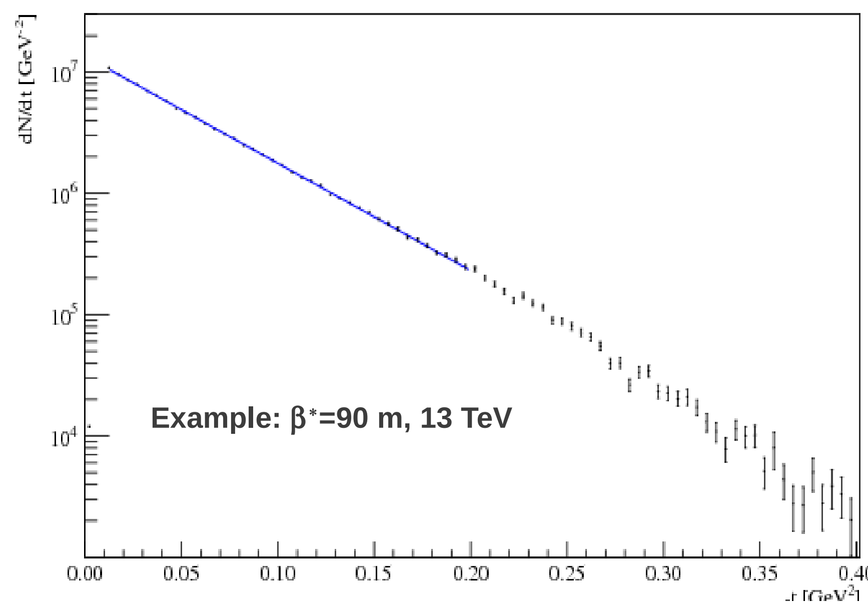
Trigger : double-arm RP
RP tracks in opposite arm in diagonal topology
Cuts: left-right correlation in several kinematic variables

Corrections to differential rate (mostly data-driven): acceptance, efficiencies (trigger, DAQ, reconstruction), smearing in |t|
Integrated rate: differential rate extrapolated to low |t| (unobserved)

@ 13 TeV

$\sigma(dN_{el}/d|t|_{t=0}) \sim 1.6$ %

$\sigma(N_{el}) \sim 2.3$ %



Inelastic measurement : method

Trigger: activity in T2 either arm

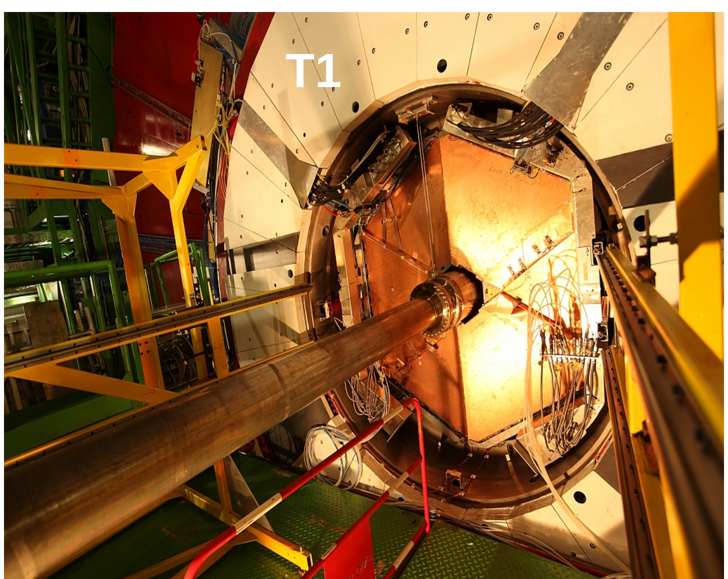
N_{ev} in T1+T2 ~ 92% of the inelastic rate

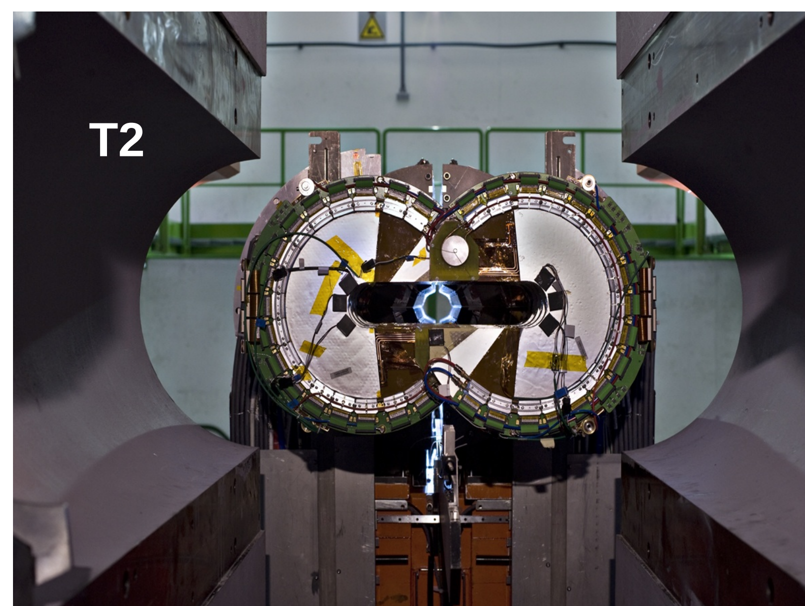
Experimental corrections (mostly data-driven): beam-gas background, trigger efficiency, pileup, T2 reconstruction e ciency, T1-only events

Corrections for final state particles outside T1/T2 acceptance (Monte-Carlo): central diffraction, rapidity gap over T2, low-mass diffraction

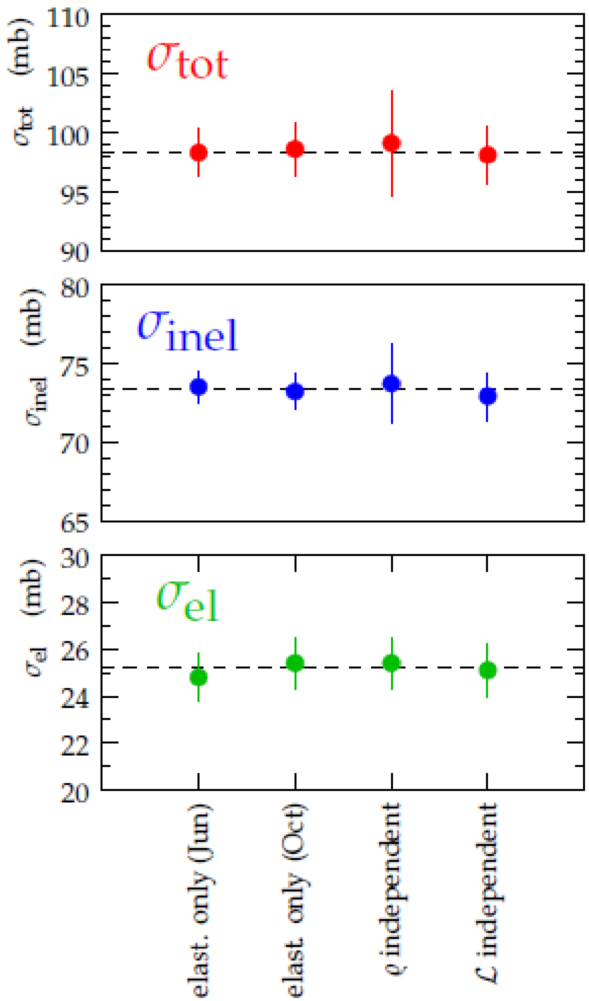
Largest contribution from low-mass diffraction (M< 4.6 GeV, $|\eta| > 6.5$)

$\sigma(N_{inel})$: 3.7% [@13 TeV]

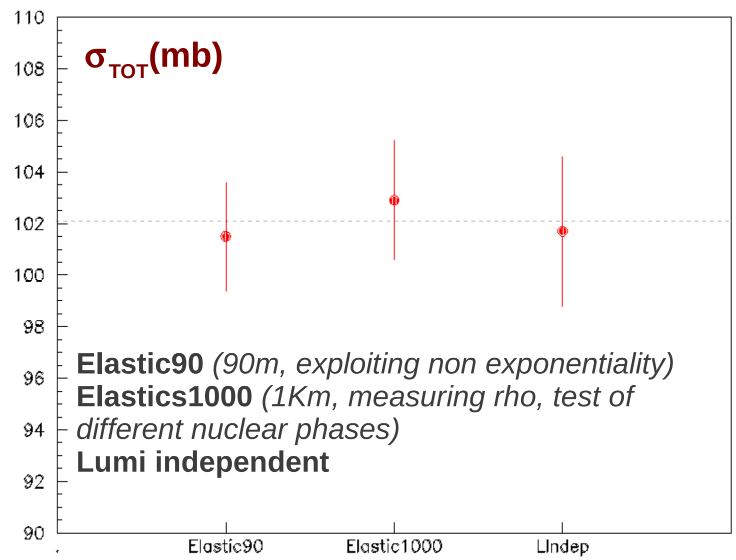




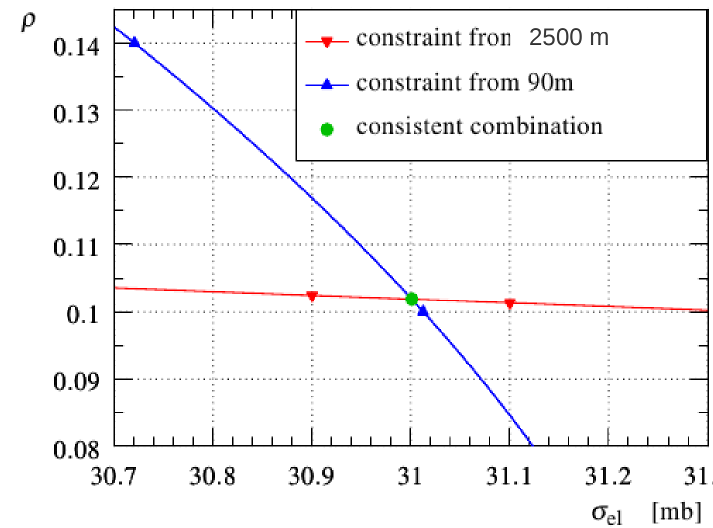
Total Cross section measurements: methods



7 TeV, several methods
Same beam conditions



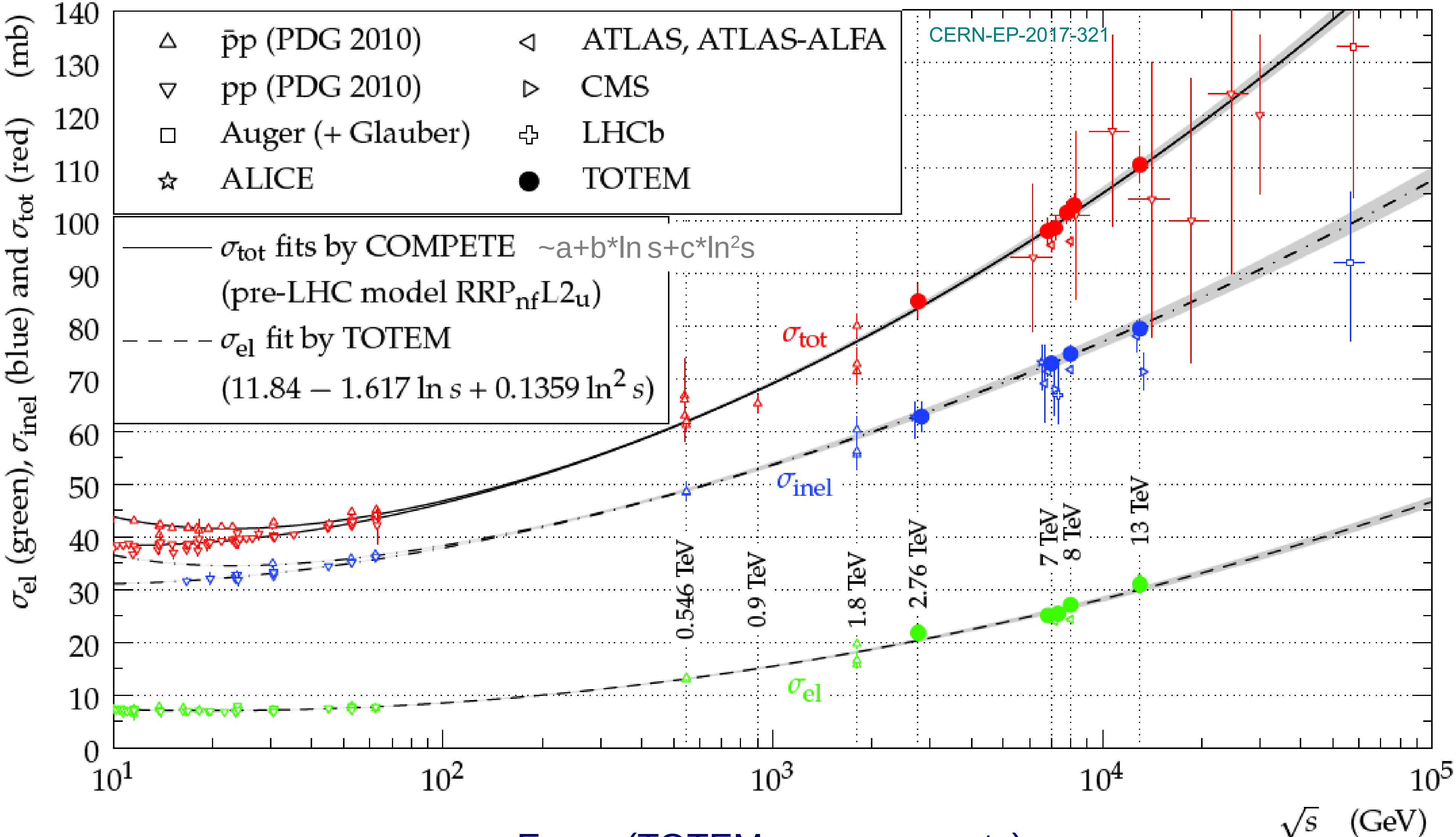
8 TeV, several methods
Different beam conditions



13 TeV
90m : lumi independent
2500m: ρ measurement

Different beam conditions

Total Cross section measurements



Errors (TOTEM measurements)

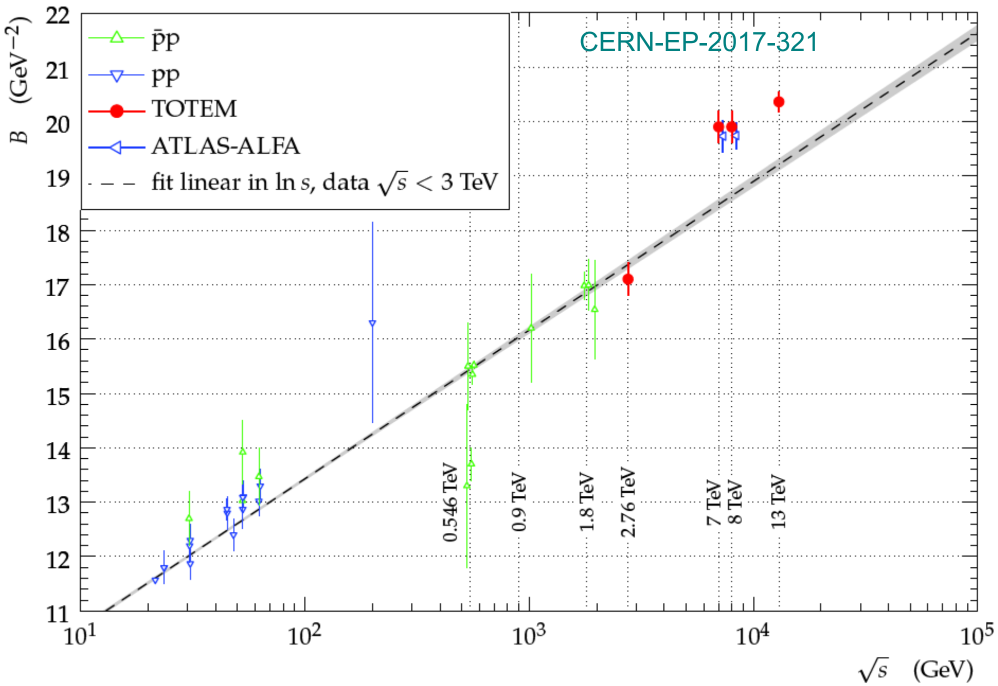
σ_{TOT} ~ 2-3 %

σ_{INEL} ~ 2 %

σ_{EL} ~ 2-4 %

Total Cross section measurements: implications

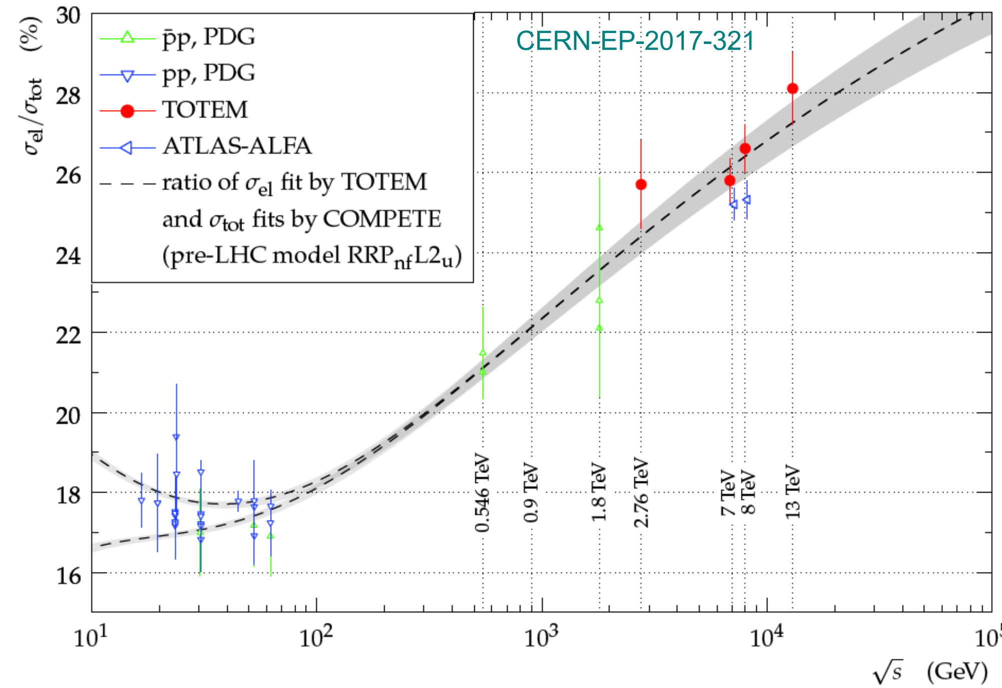
The diffraction cone shrinkage speed up with the collision energy



B=d/dn ln (ds/dt) | $_{t=0}$ increase with √s

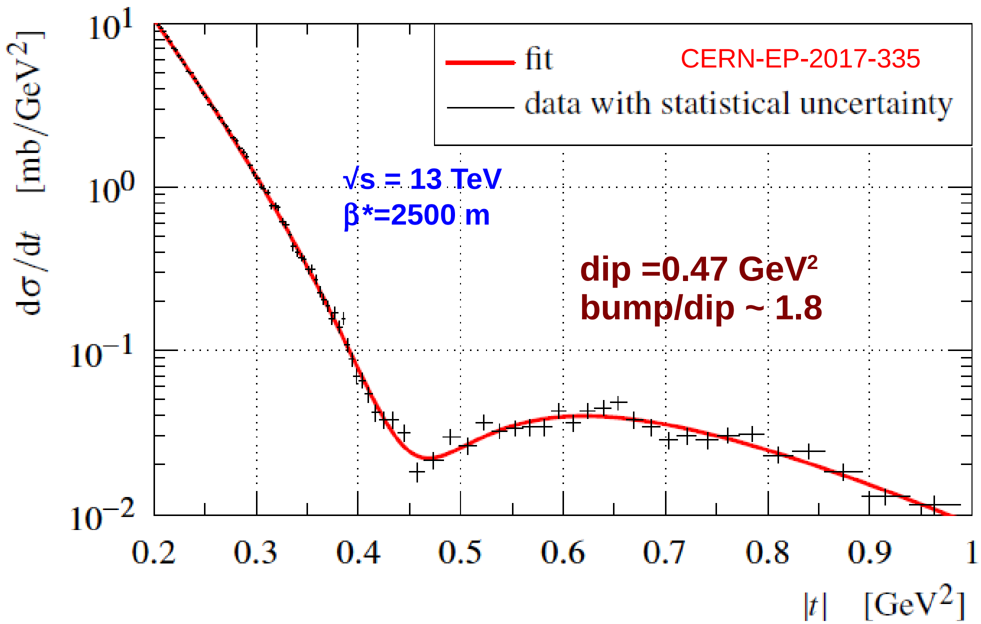
The linear (ln s) behavior is compatible for √s ≤ 3 TeV

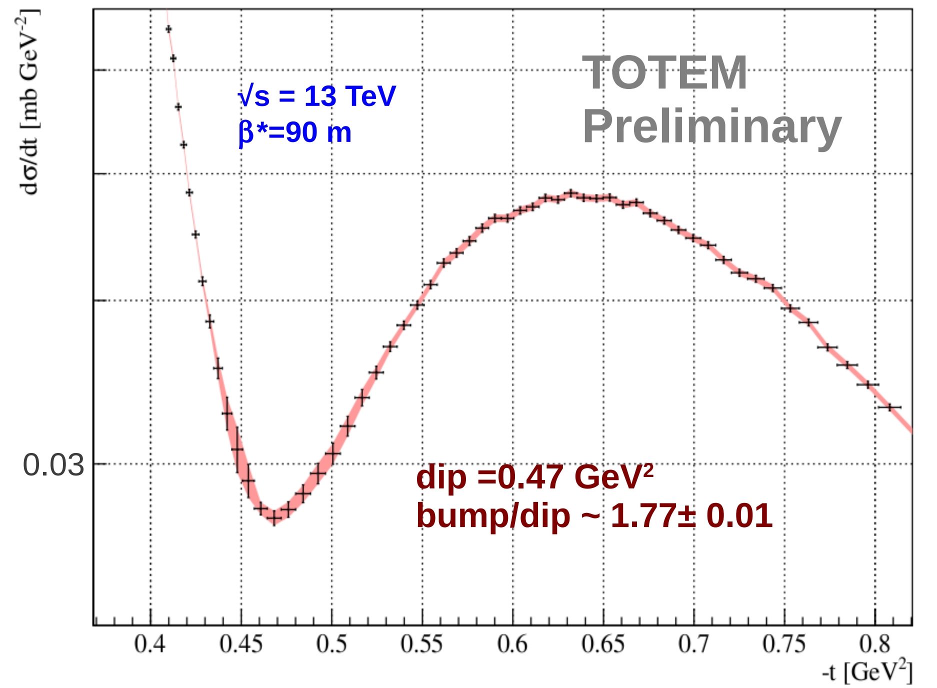
The increase of σ_{el}/σ_{TOT} with energy is confirmed also at LHC

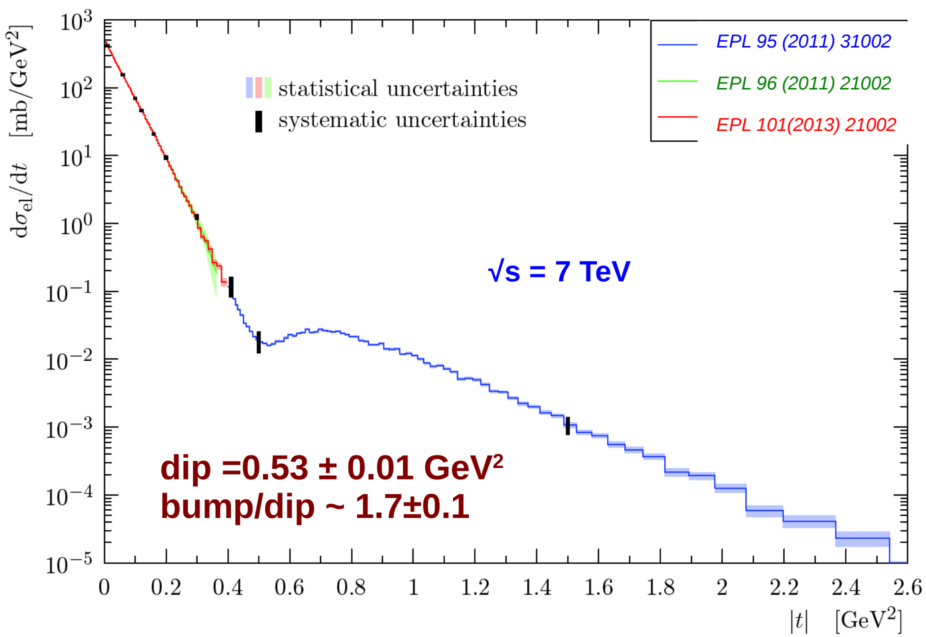


Elastic measurements: dip @ 13 TeV

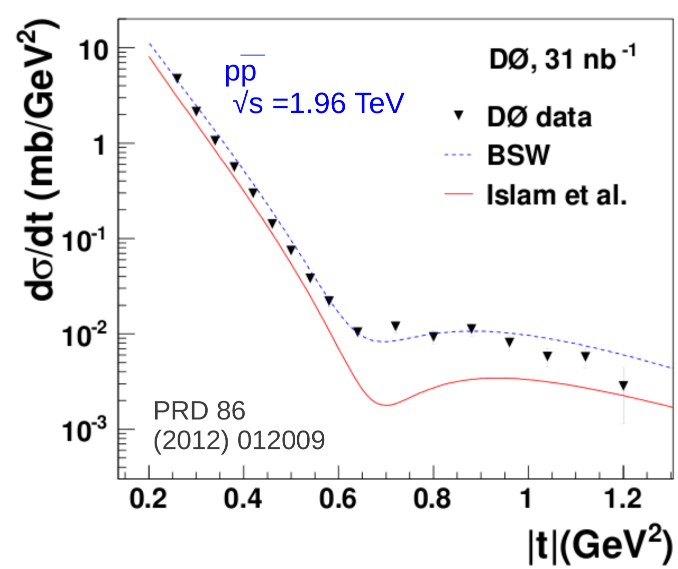
dip position in |t| decreases with increasing √s





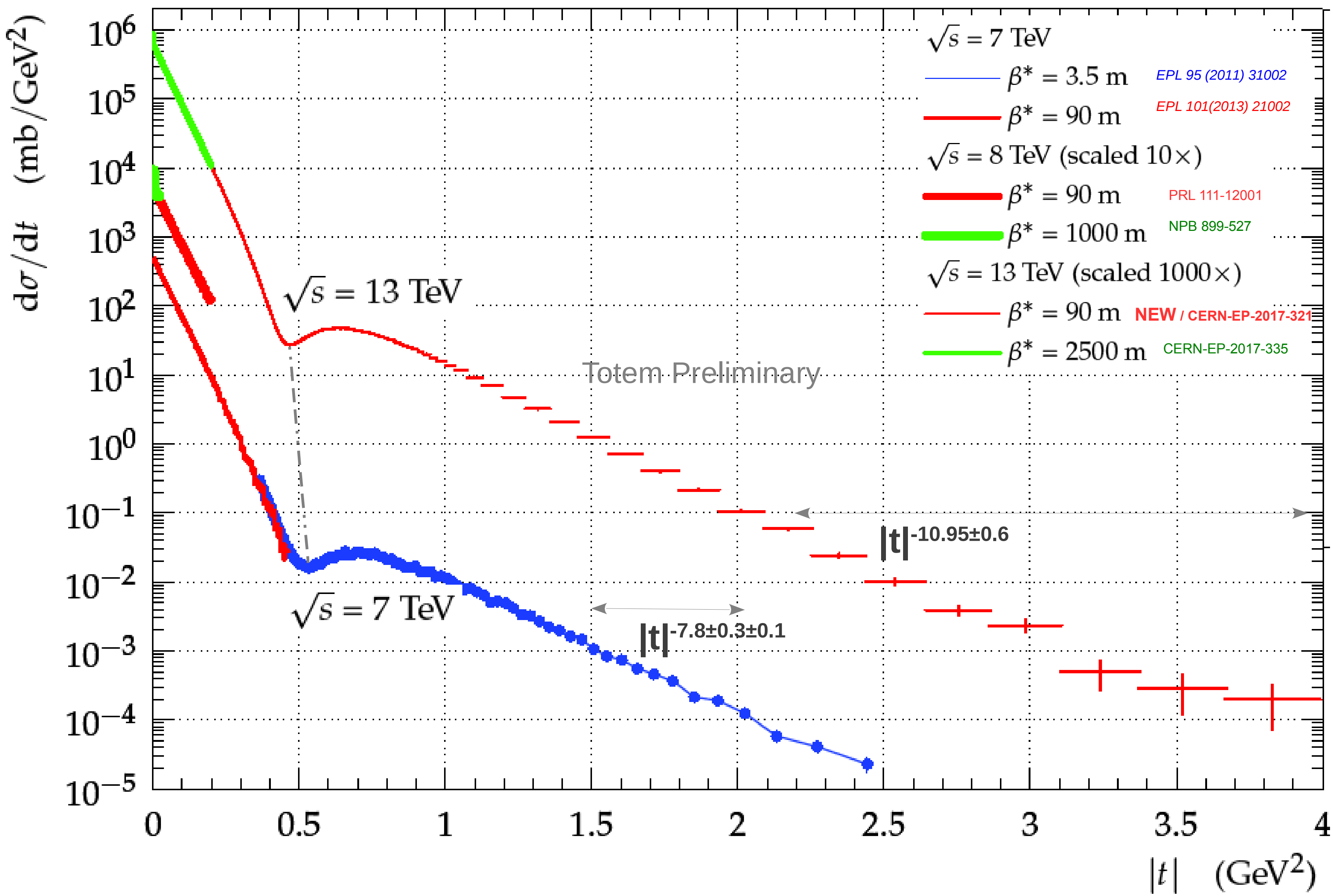


Dip is missing in $p\bar{p}$

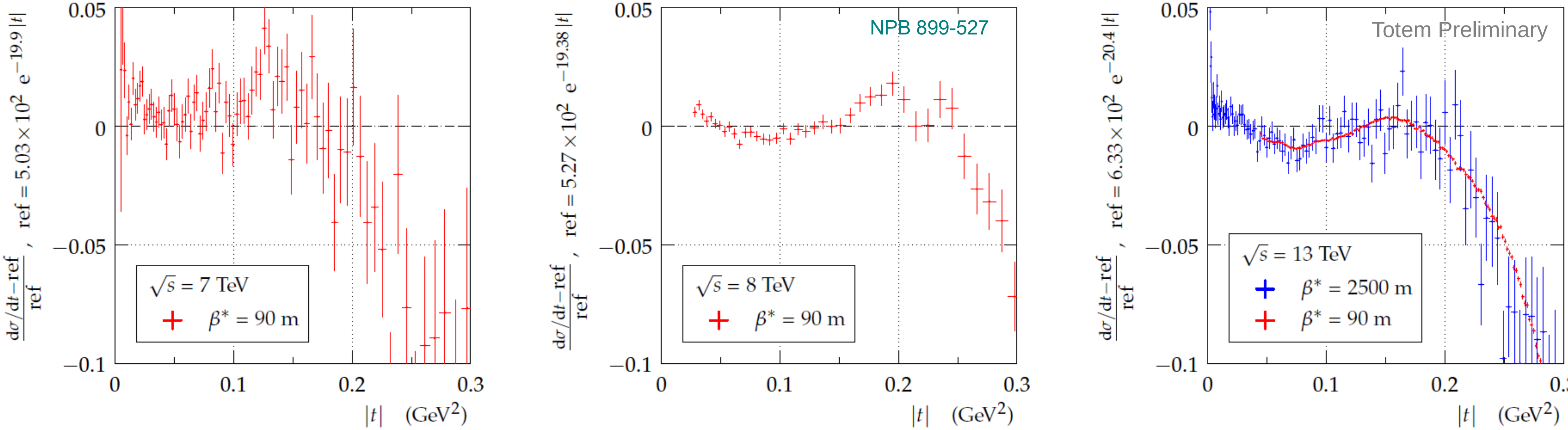


Elastic measurements: dip and structure at high-t

No structure seen at high-t



Elastic Scattering : Non-exponential behavior at low-t

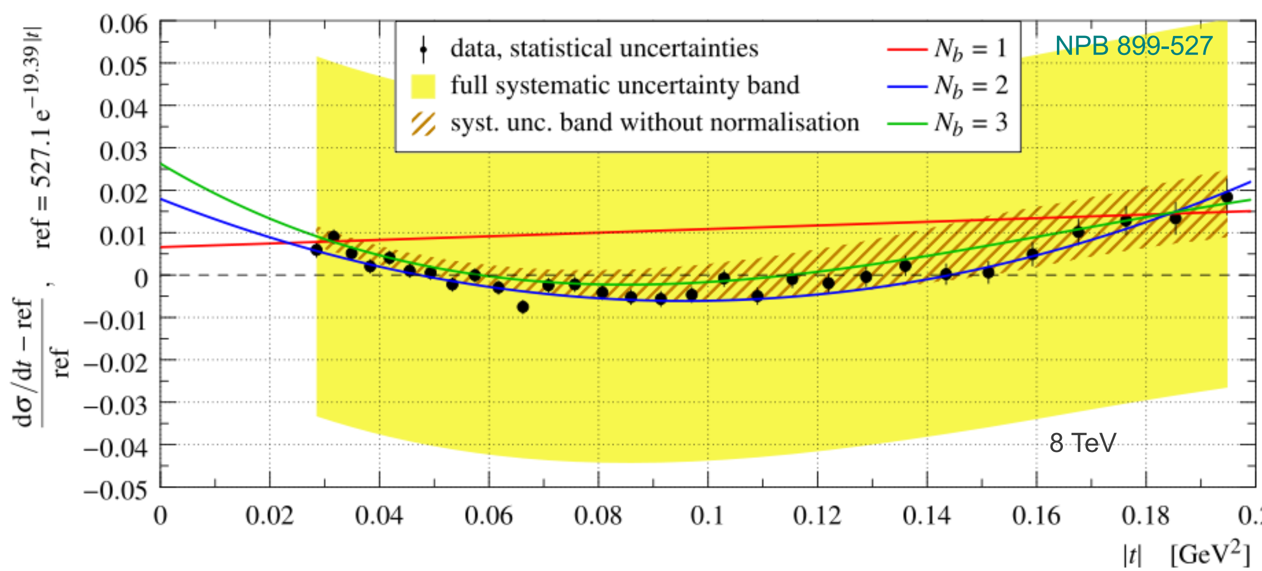


Already observed at ISR and SPS: confirmed at LHC energies

Change of slope ~ 0.1 GeV², faster decrease |t|>0.2 GeV²

Pure exponential excluded ~ 7σ significance

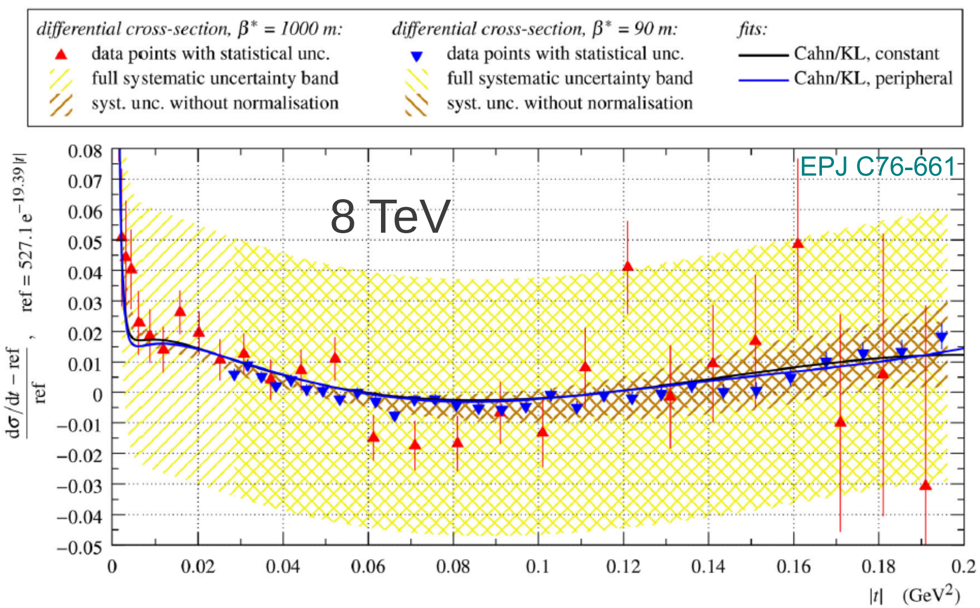
Non-exponentiality measured in the nuclear component : contribution of the Coulomb scattering or else?

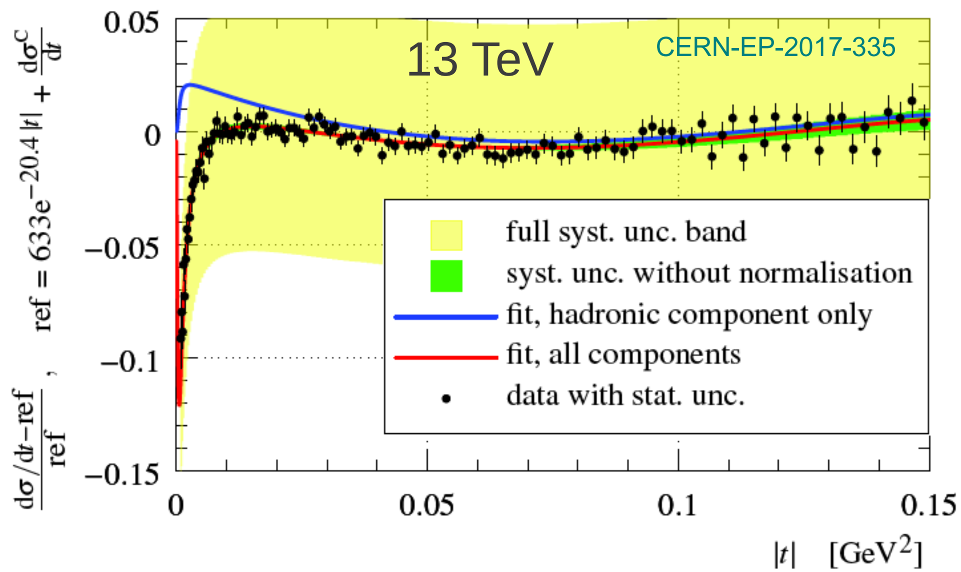


Elastic Scattering : Non-exponential behavior at low-t

Explore in very low-t region the contribution of the interference coulomb-nuclear term and of the nuclear phase

→ the pure exponential behavior of nuclear amplitude is excluded (constant phase excluded, peripheral phase disfavored)
→ Non exponential (n=3) with both constant and peripheral phase is compatible with data





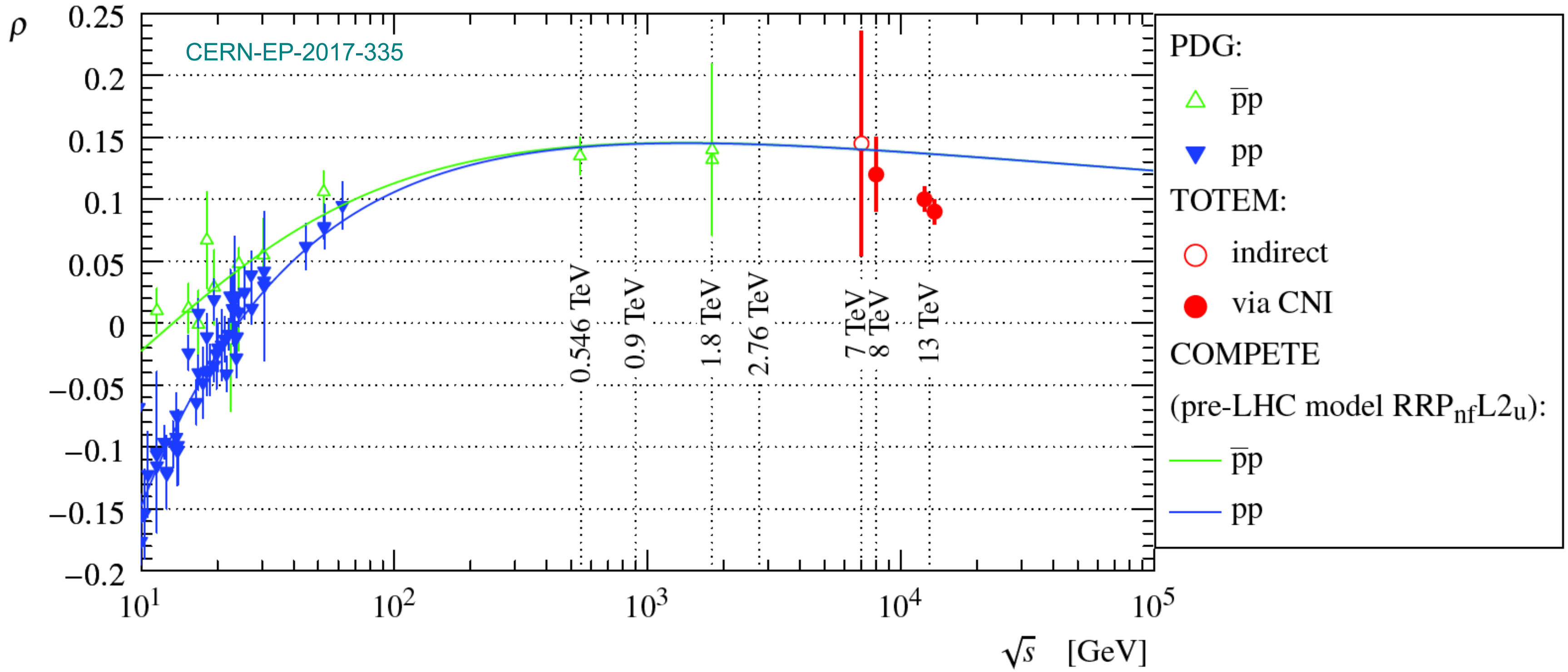
Elastic Scattering : Coulomb interference and ρ parameter

First LHC determination from Coulomb-hadronic interference at 8TeV : ρ=0.12±0.03
Uncertainty still too high (low statistics)

At 13 TeV : sample with very high statistics allows an unprecedented precision:

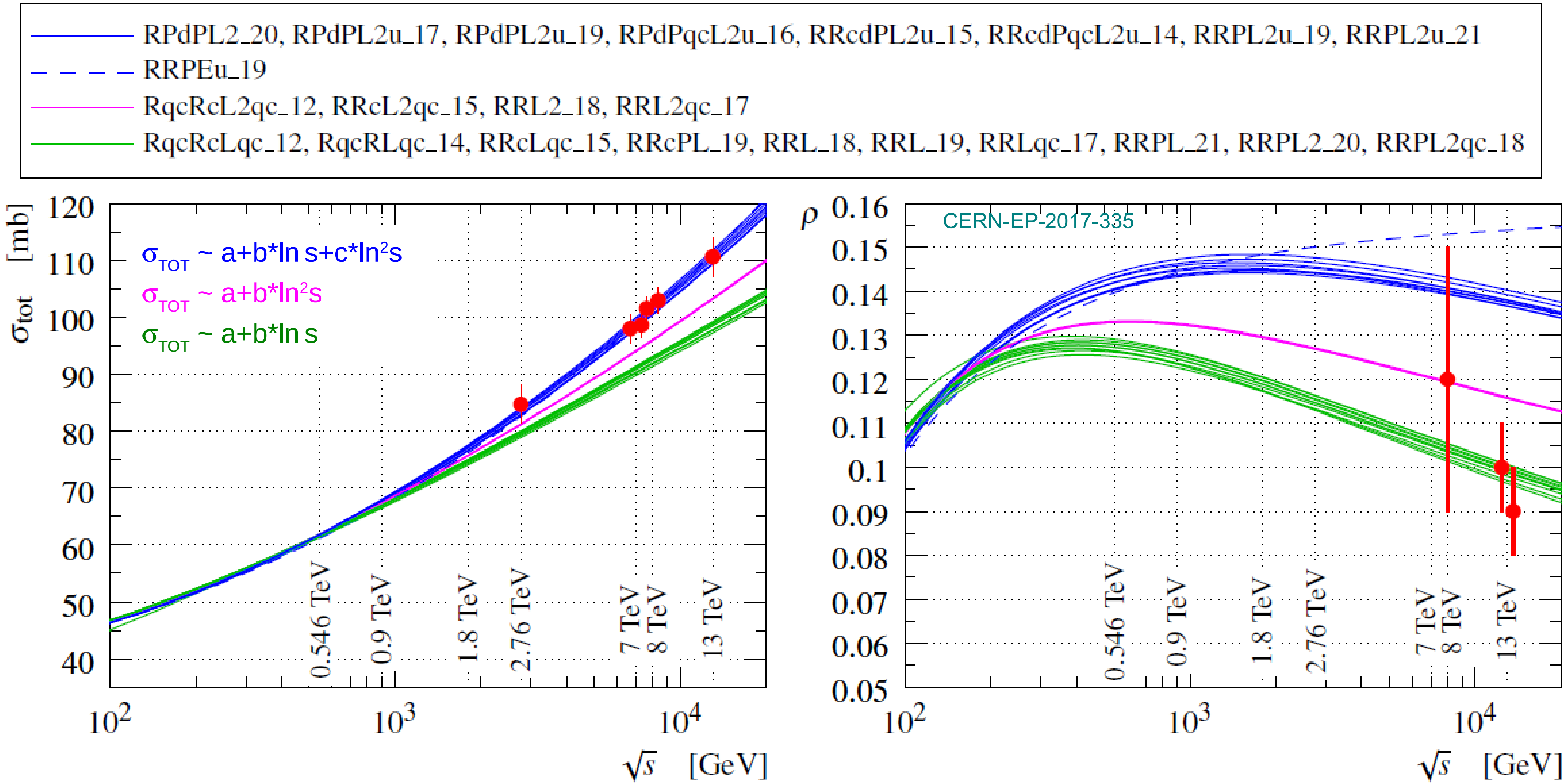
N_b	$\|t\|_{max} = 0.07\ GeV^2$ χ^2/ndf	ρ	$\|t\|_{max} = 0.15\ GeV^2$ χ^2/ndf	ρ
1	0.7	0.09 ± 0.01	2.6	–
2	0.6	0.10 ± 0.01	1.0	0.09 ± 0.01
3	0.6	0.09 ± 0.01	0.9	0.10 ± 0.01

$|t|_{max}$= 0.07 GeV2
Comparison with UA4/2
(same t-range)



The new measurement is clearly below the predictions

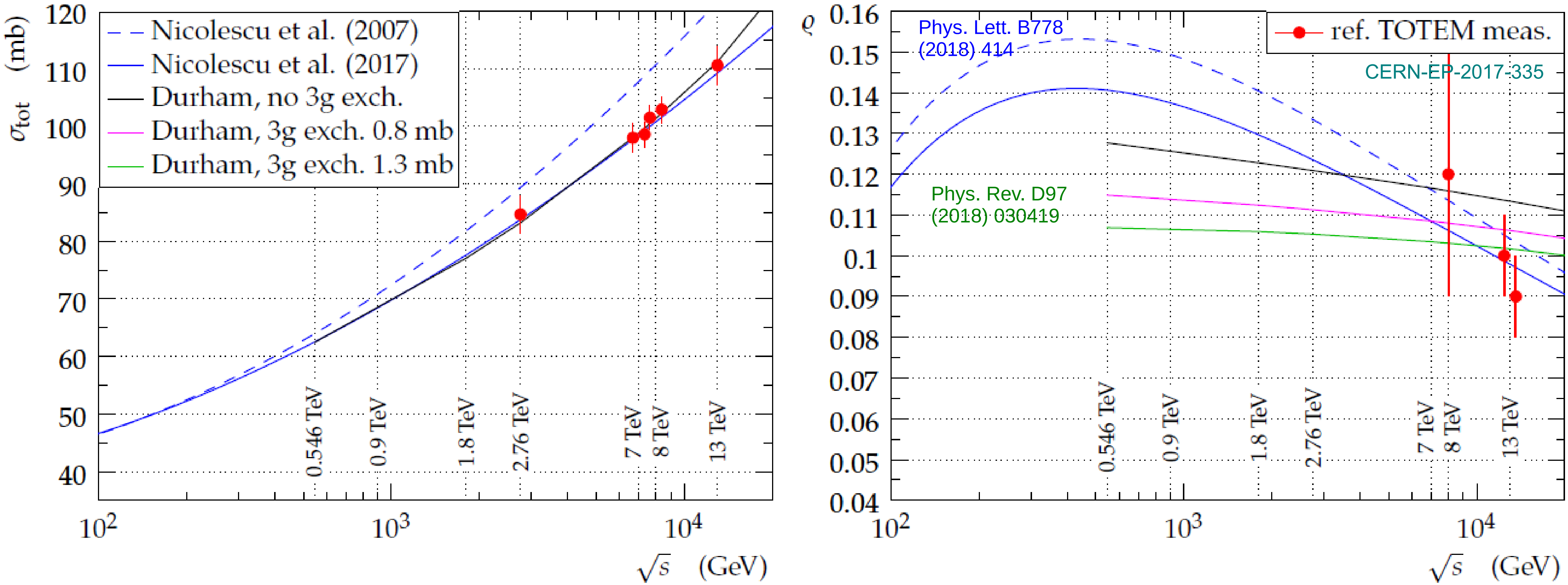
σ_{TOT} and ρ parameter : model comparison



None of COMPETE models is able to describe simultaneously σ_{TOT} and ρ

σ_{TOT} and ρ parameter : possible interpretation?

t-channel exchange of a colourless 3-gluon bound state ($J^{PC} = 1^{--}$) could decrease ρ in pp collisions at large energy



Odderon hint or first evidence of “slowing down” of σ_{TOT} growth at higher energy?

Summary

- Totem has made extensive measures related to σ_{TOT} and elastic scattering
- Some of the pre-LHC questions are nevertheless still open

- The (experimental) hints of odd-state seems confined in the sensitivity in the t-channel , although several theories predict the existence of such object (Odderon, 3g-bound state, vector glueball)

TOTEM contributions (observed/confirmed) to the predictions:

✔ decrease of ρ at high energies
✔ diffractive dip in the proton-proton elastic t-distribution
✔ the deviation of the elastic differential cross-section from a pure exponential
✔ the deviation of the elastic diffractive slope, B, from a linear log(s) dependence
✔ the variation of the nuclear phase as a function of t
✔ the large-|t | power-law behavior of the elastic t -distribution with no oscillatory behavior
✔ the growth rate of the total cross-section

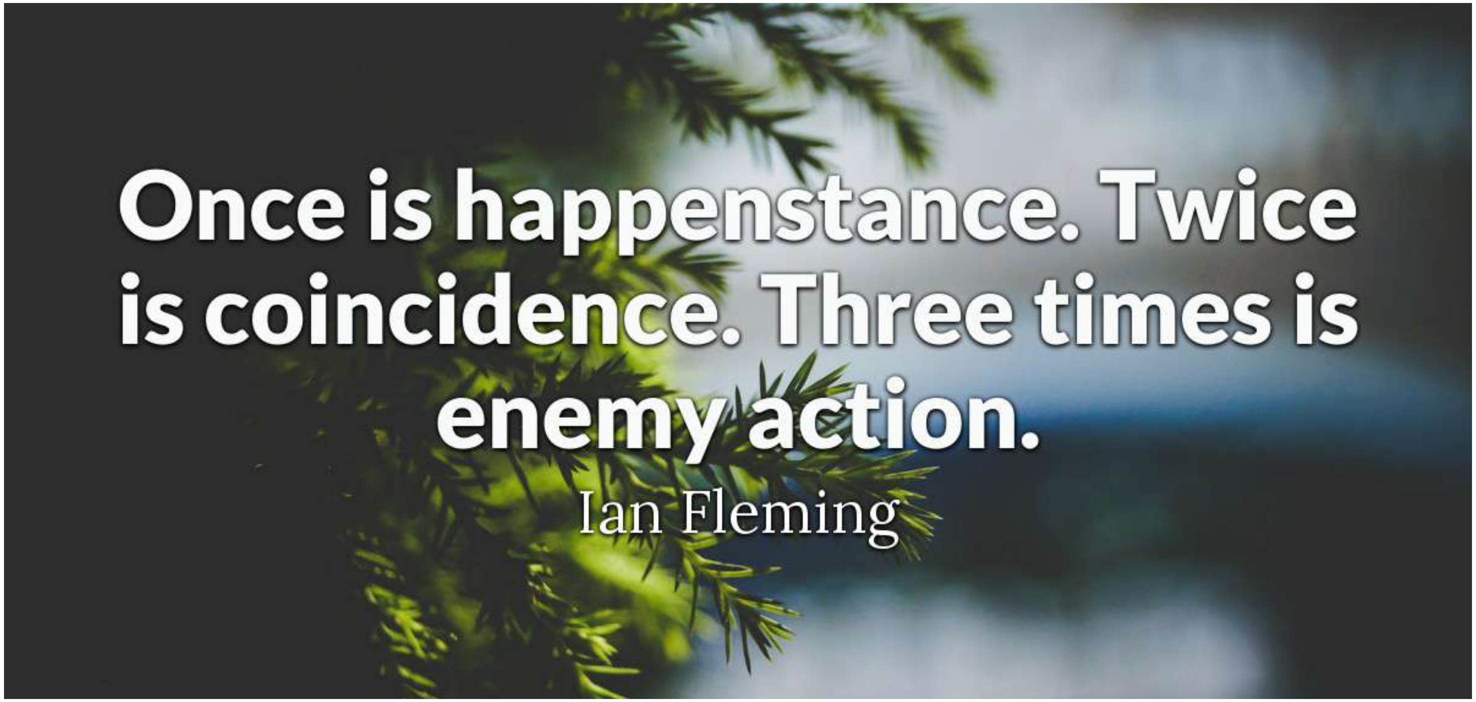
What next:

✔ Precise measurement of ρ at low energy (900 GeV)
✔ σ_{TOT} at 14 TeV

Beyond Totem:

✔ Differences between the proton-proton and proton-antiproton scattering (ISR)
LHC in p-pbar?
✗ Observation of 3g-bound state in the s-channel ?

Which could be the "three pieces of evidence"?



Thanks for your attention !

The speaker acknowledge the support from grant no. MNiSW DIR/WK/2017/07