The TOTEM Experiment : results and perspectives

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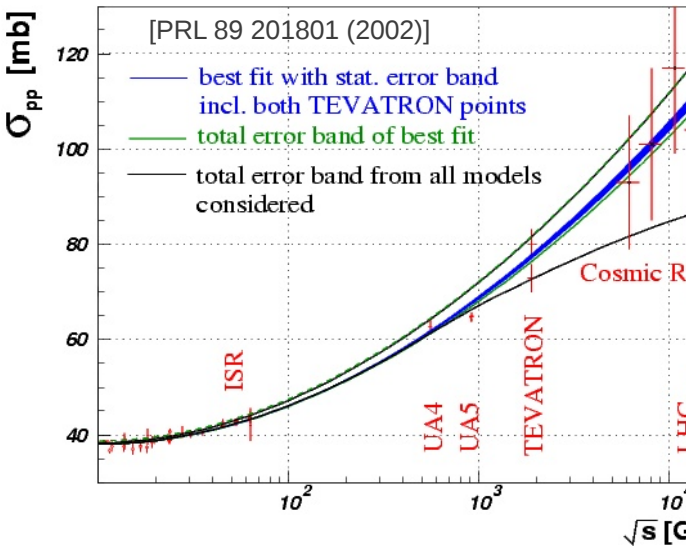
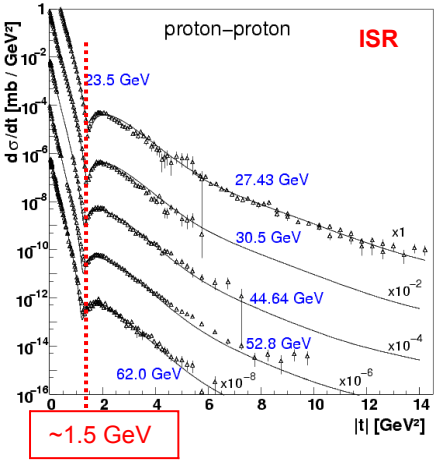
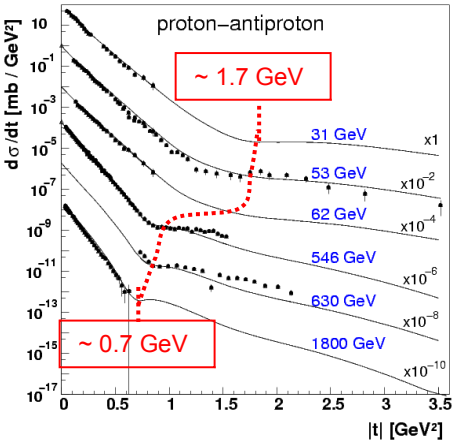
Total and Elastic cross section: pre-LHC

One of the physics goal of TOTEM was to measure the cross sections at LHC

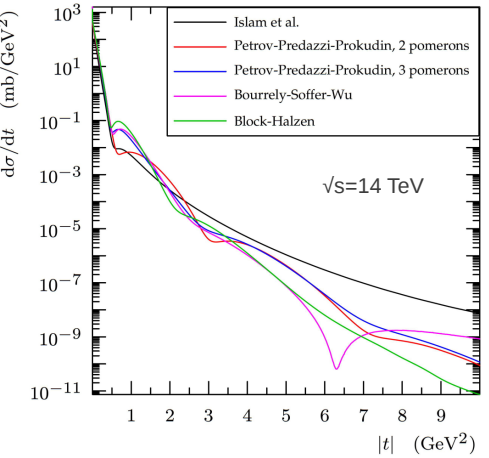


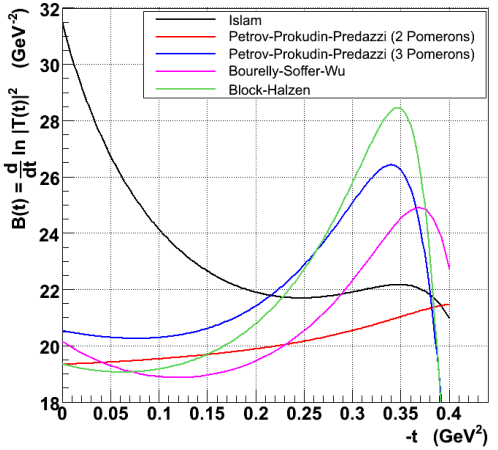
- COMPETE Collaboration fits all available hadronic data and predicts at LHC: σ_{tot} = 111.5 ± 1.2 + 4.1/-2.1 mb (14 TeV)
- Last pp data at the ISR; only ppbar at "high" energy
- Difference of σ_{pp} vs $\sigma_{\bar{p}p}$?
- σ_{TOT} (s) ~ (ln s)$^{\gamma}$ $\gamma = 2$?
- σ_{EL} / σ_{TOT} VS energy





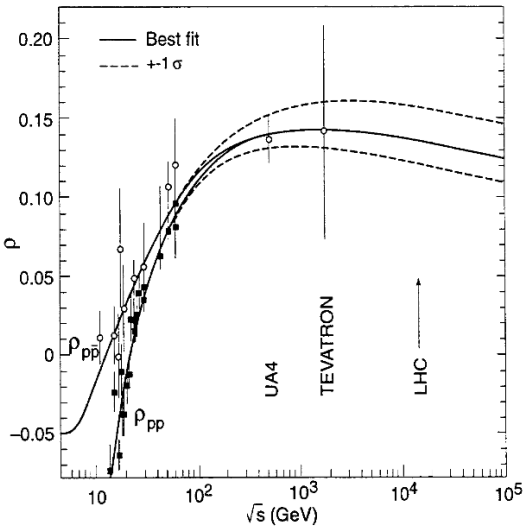
- Is the dip still present at high energy?
- Is the position of the dip changing?
- Large momentum transfer region: oscillations?
- Any break in the elastic slope B(t)?





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

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



Analysis methods

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

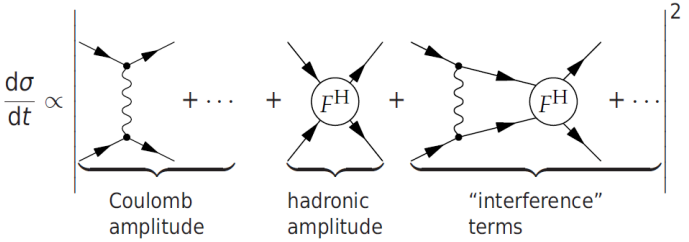
$$\sigma_{tot}^2 = \frac{16\pi}{(1+\rho^2)} \frac{1}{\mathcal{L}} \left(\frac{dN_{el}}{dt}\right)_{t=0}$$

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 varied and allow to determine:

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

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

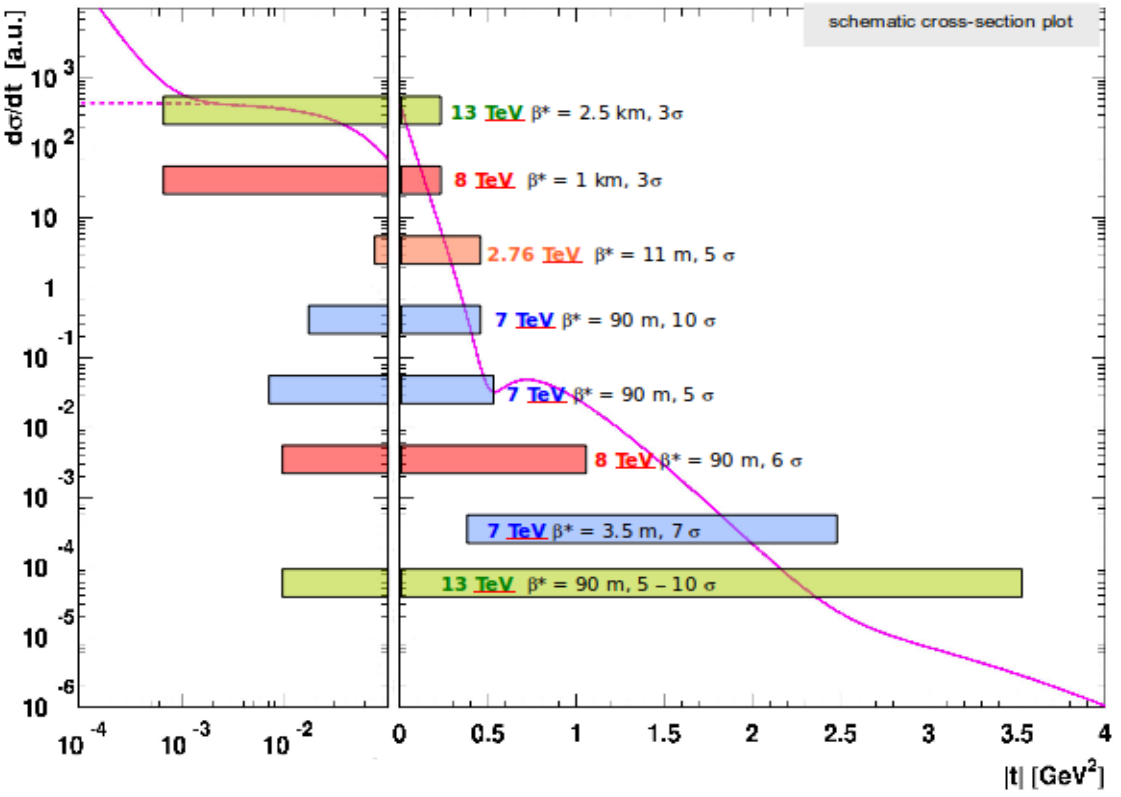
- ρ measurement @ 8 TeV
  EPJ C76-661

2017

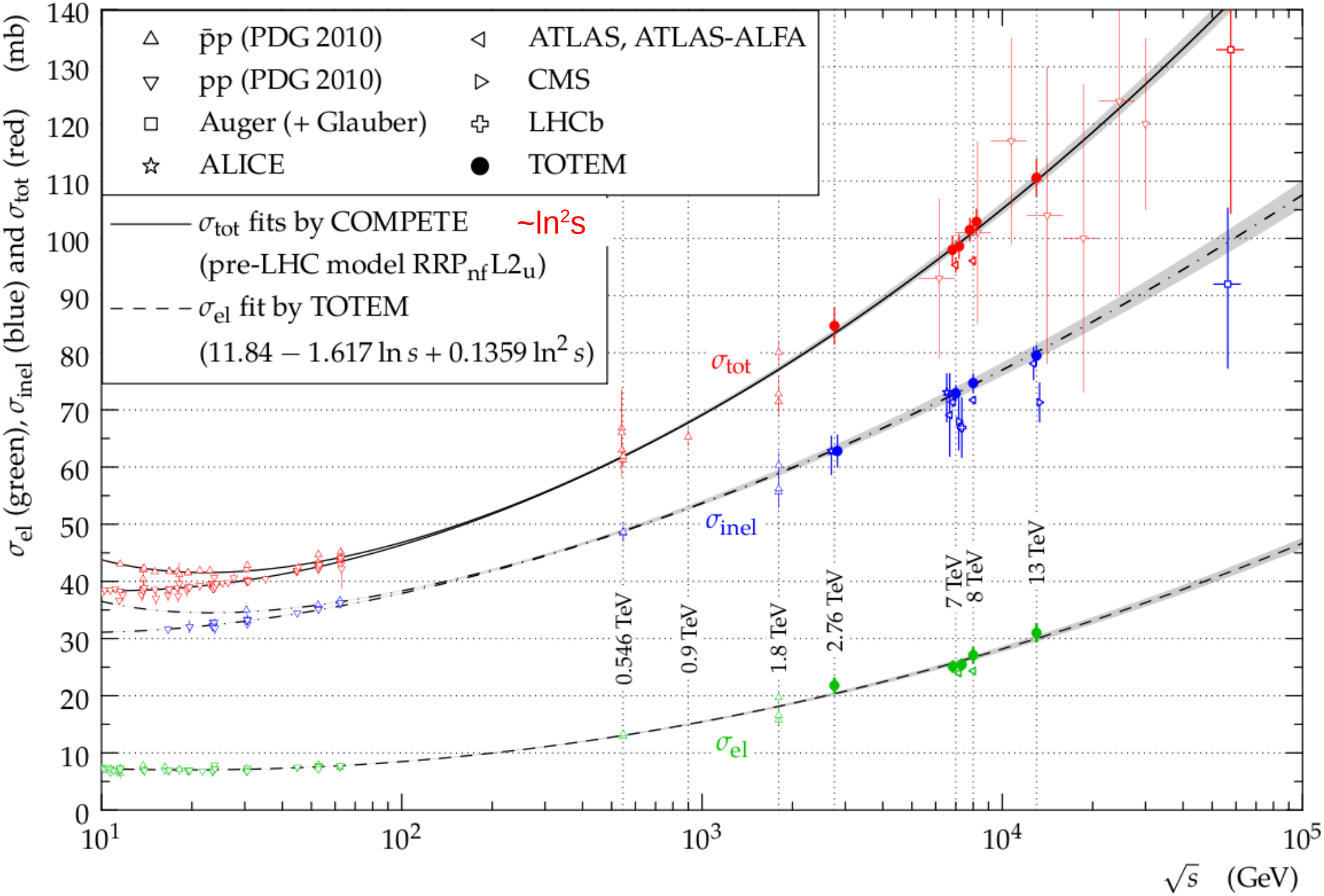
- σ_{tot} lumi independent @ 2.76 TeV
  PoS (DIS2017) 059
- σ_{tot} lumi independent @ 13 TeV
  CERN-EP-2017-321
- ρ measurement @ 13 TeV
  CERN-EP-2017-335

?

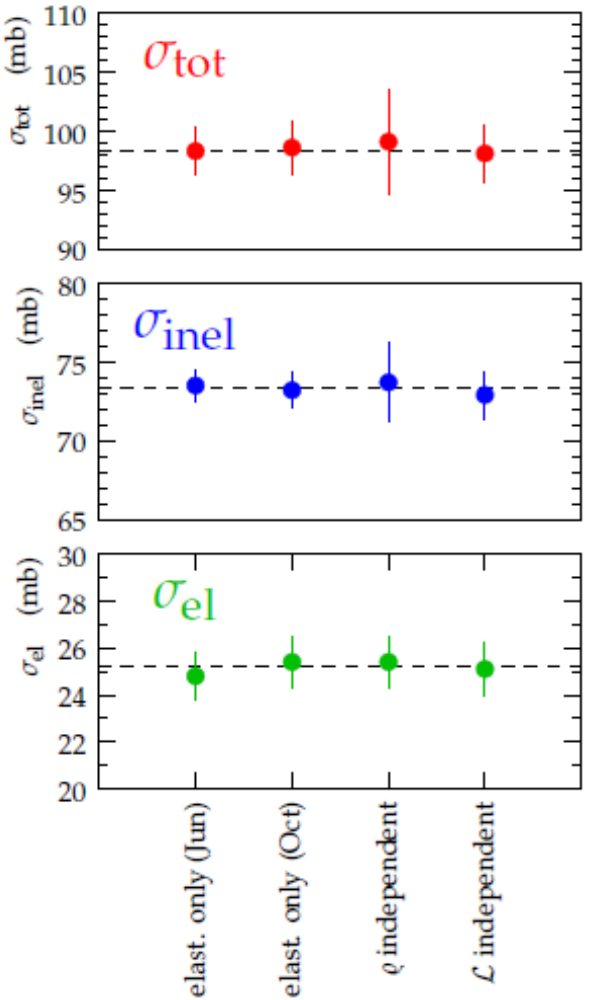
- σ_{tot} and ρ measurement @ 14 TeV
- σ_{tot} and ρ measurement @ 900GeV



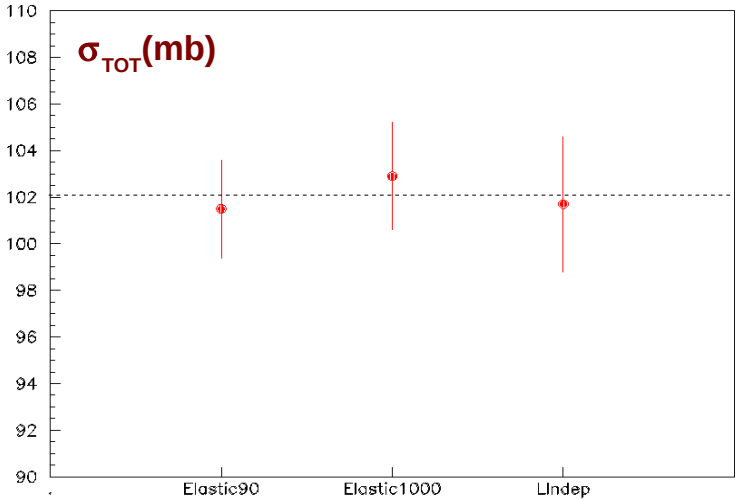
Total Cross section measurements



Total Cross section measurements: methods



7 TeV: several methods
Same beam conditions

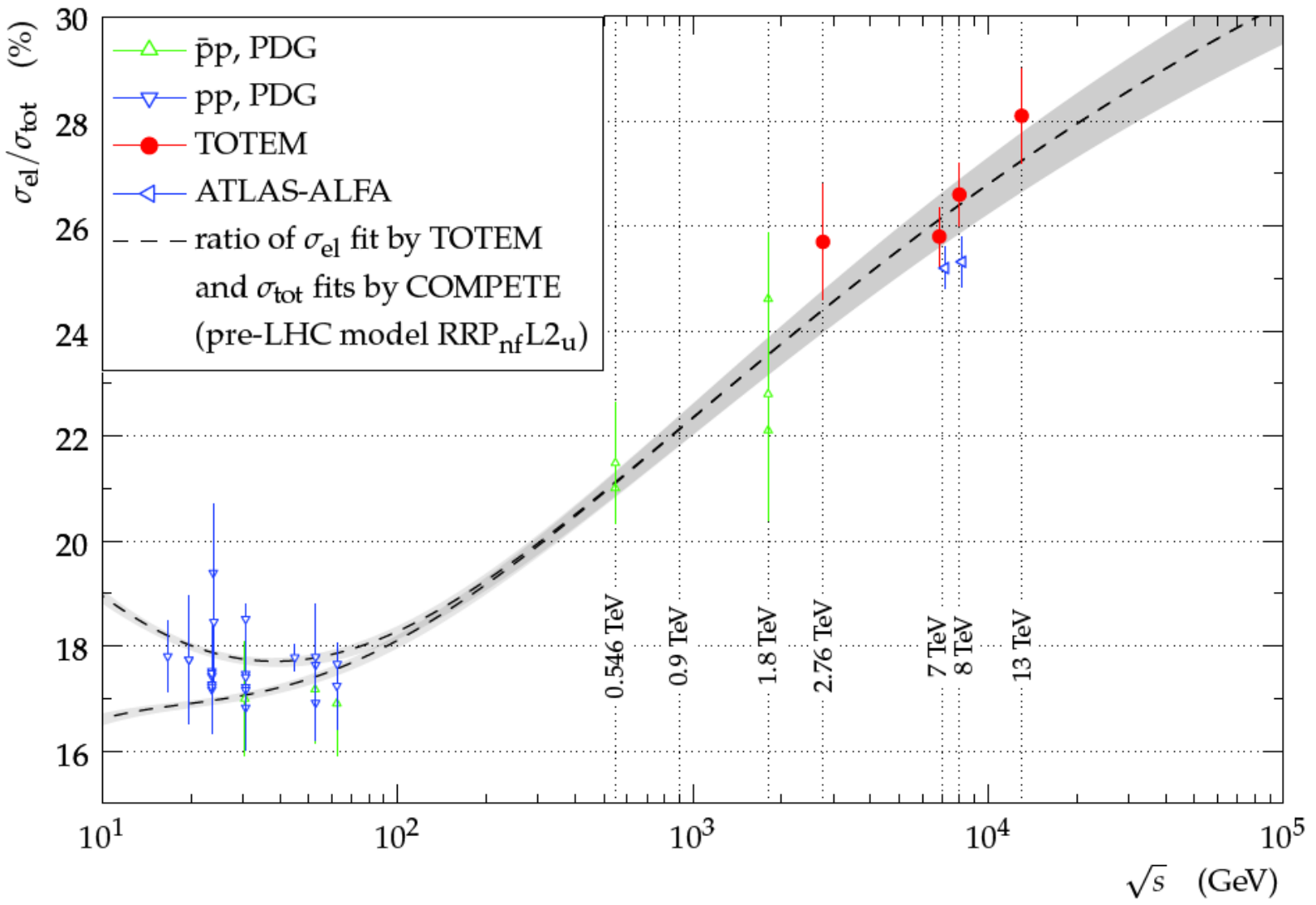


8TeV : Luminosity independent
Elastic90 (β^*=90m sample, exploiting non exponentiality of elastic distribution)
Elastic1000 (β^*=1Km, measuring rho, test of different nuclear phases)

Several methods and different beam conditions

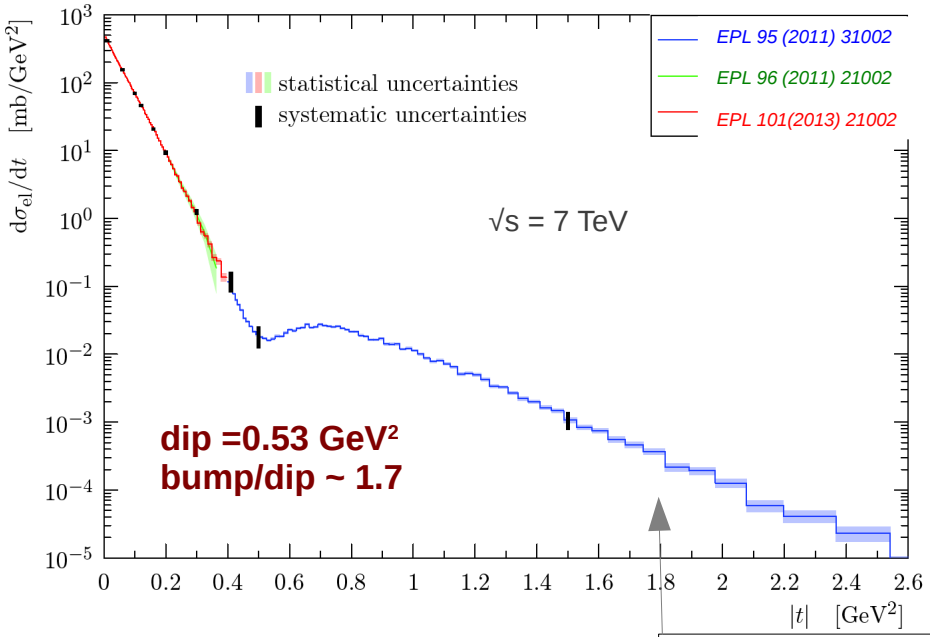
Ratio elastic – total cross section

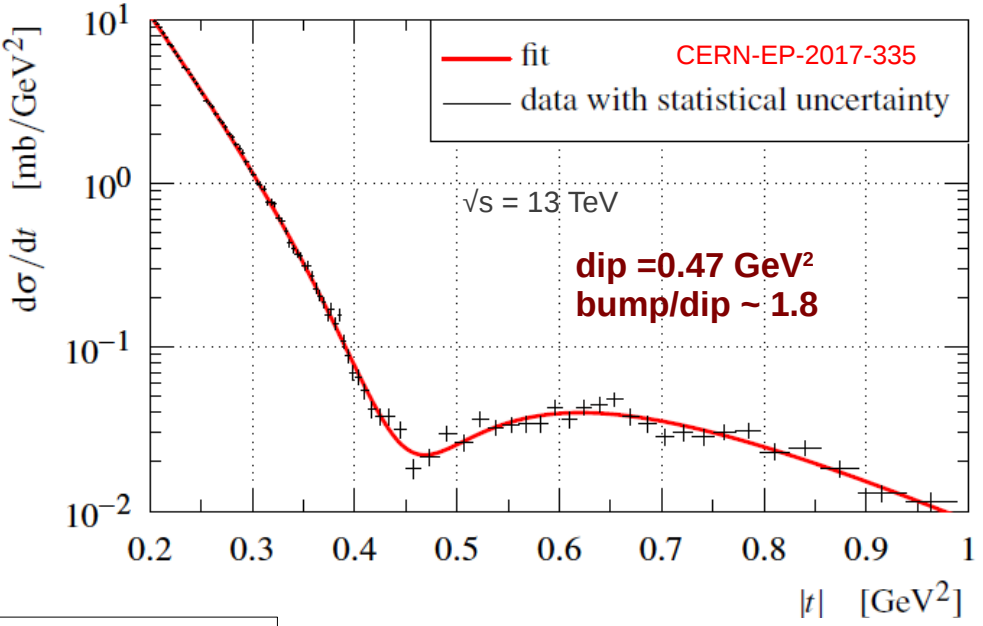
The increase of σ_{el}/σ_{TOT} with energy is confirmed also at LHC



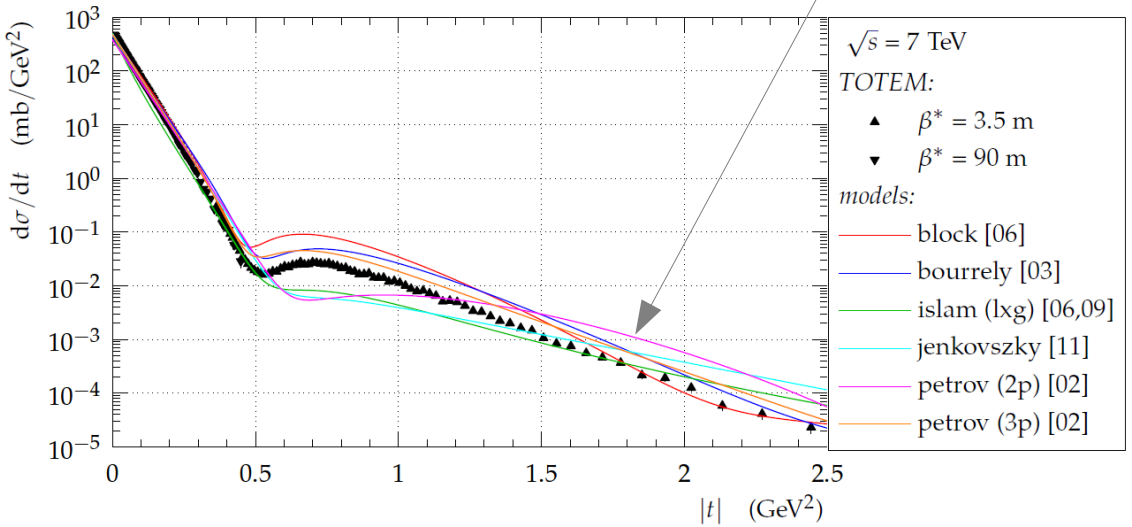
Elastic measurements: dip and structure at high-t

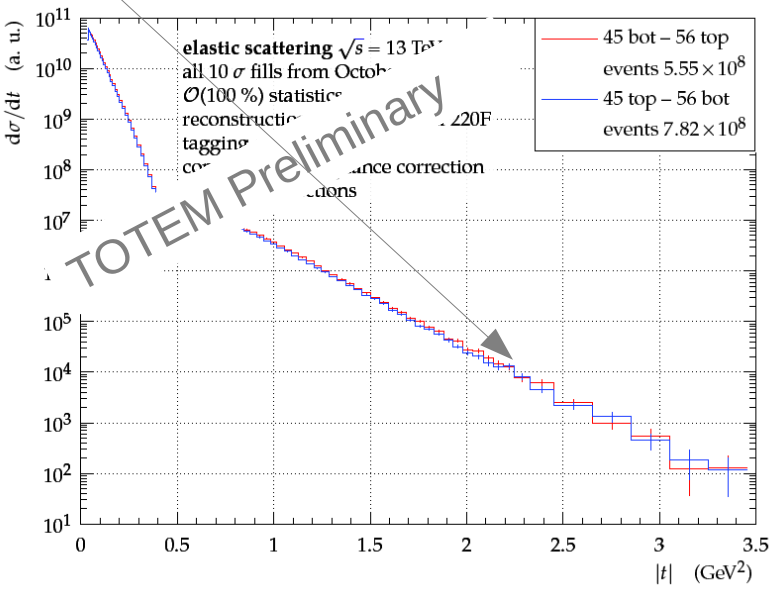
dip position in |t| decreases with increasing √s





No structure seen at high-t



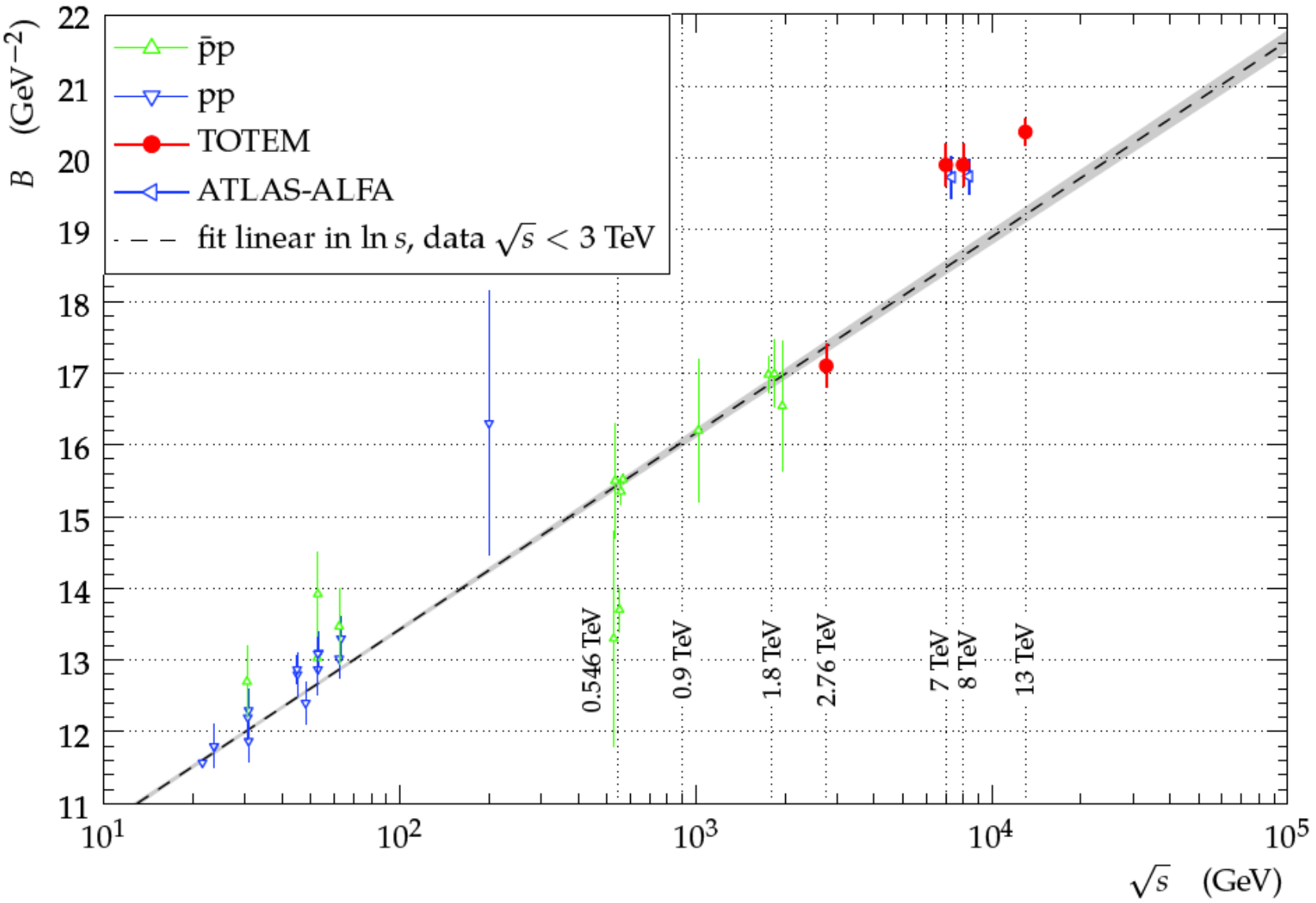


Elastic measurements: slope at low-t

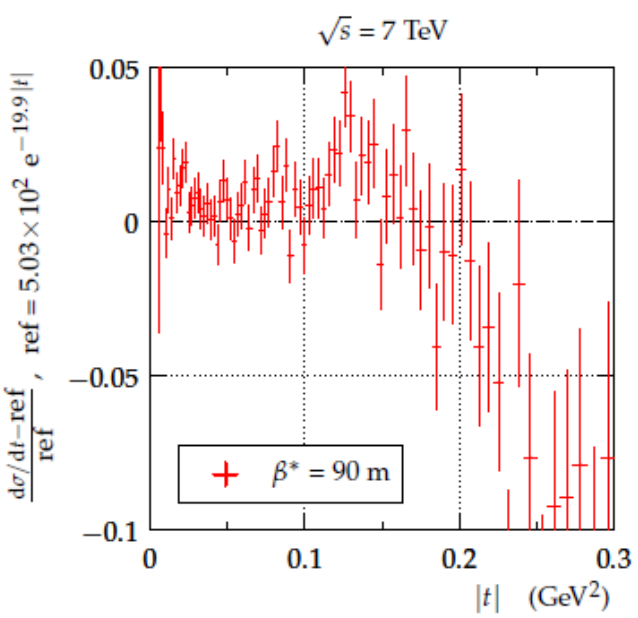
The diffraction cone shrinkage speed up with the collision energy

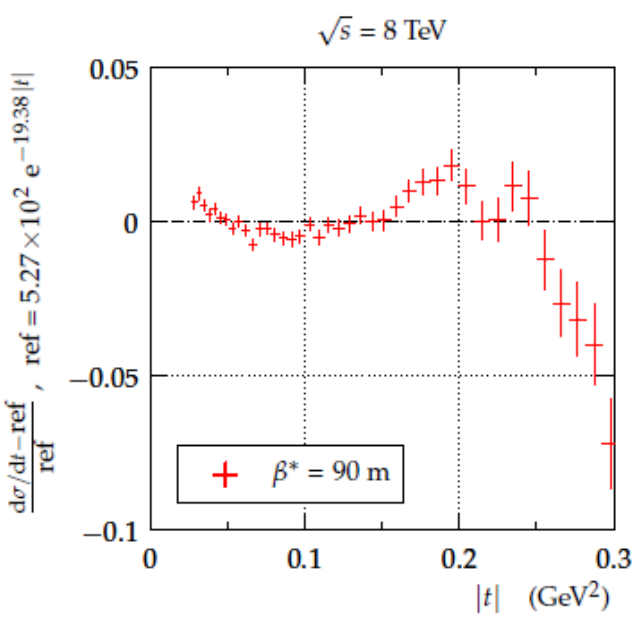
B=d/dn ln (ds/dt)$|_{t=0}$ increase with √s

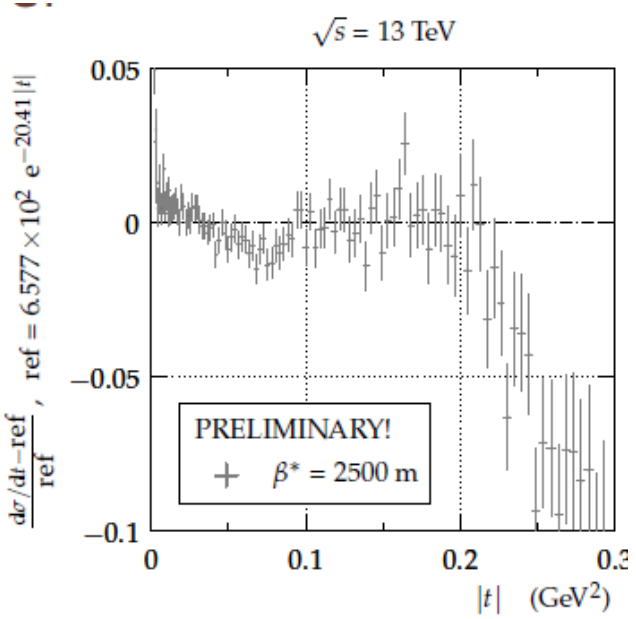
The linear (ln s) behavior changes for √s > 3 TeV



Elastic Scattering : Non-exponential behavior at low-t



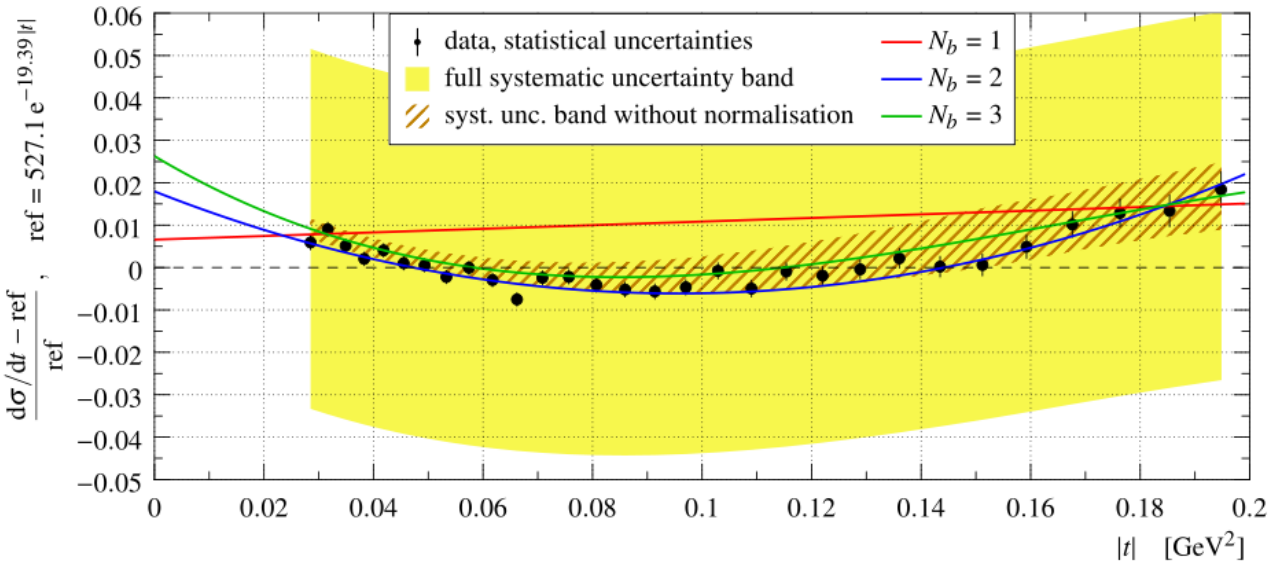




Already observed at ISR and SPS: confirmed at LHC energies
Change of slope ~ 0.1 GeV^2, faster decrease |t|>0.2 GeV^2

Pure exponential excluded ~ 7σ significance

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

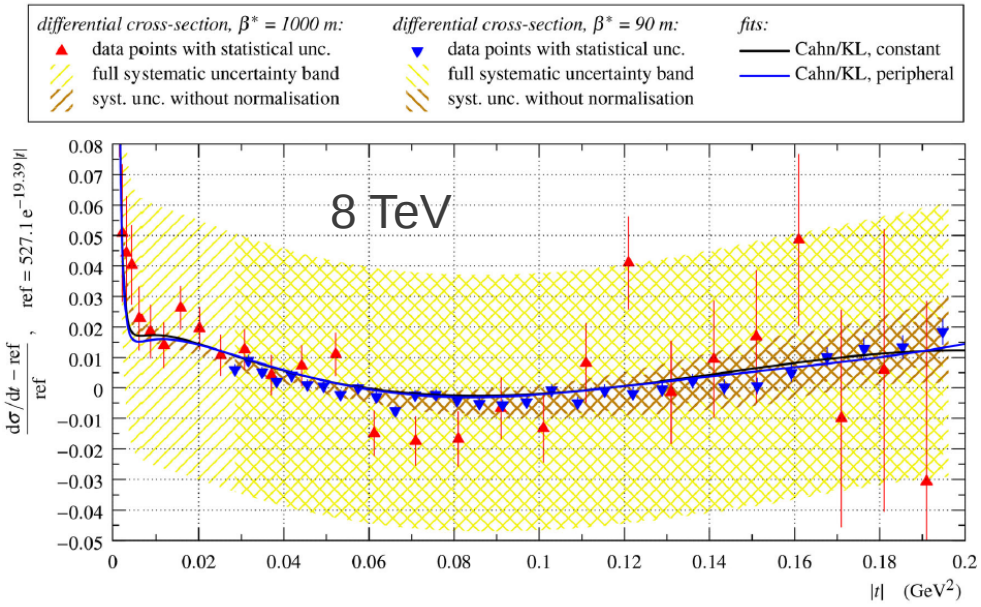


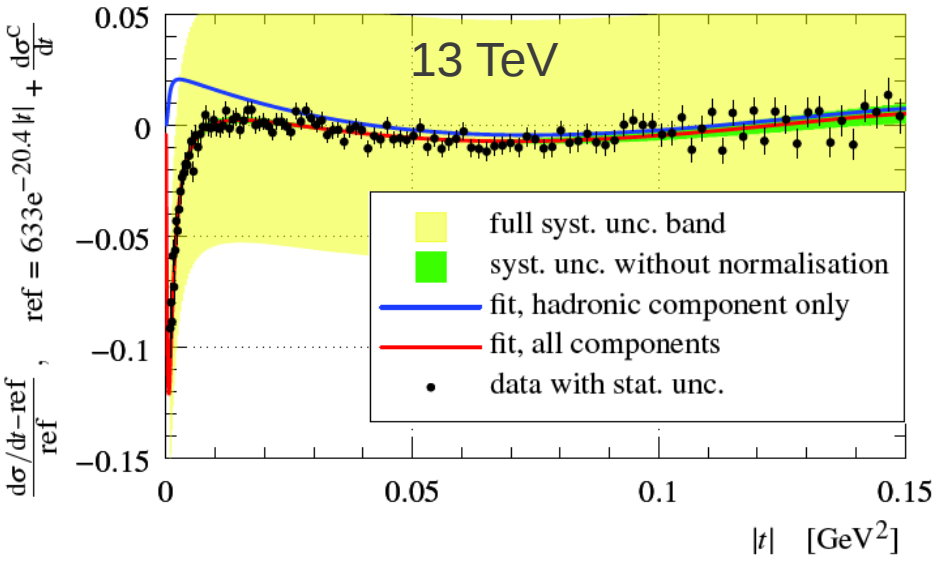
Elastic Scattering : Non-exponential behavior at low-t

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





The non exponentiality is intrinsic in the nuclear amplitude

Elastic Scattering : Coulomb interference and ρ parameter

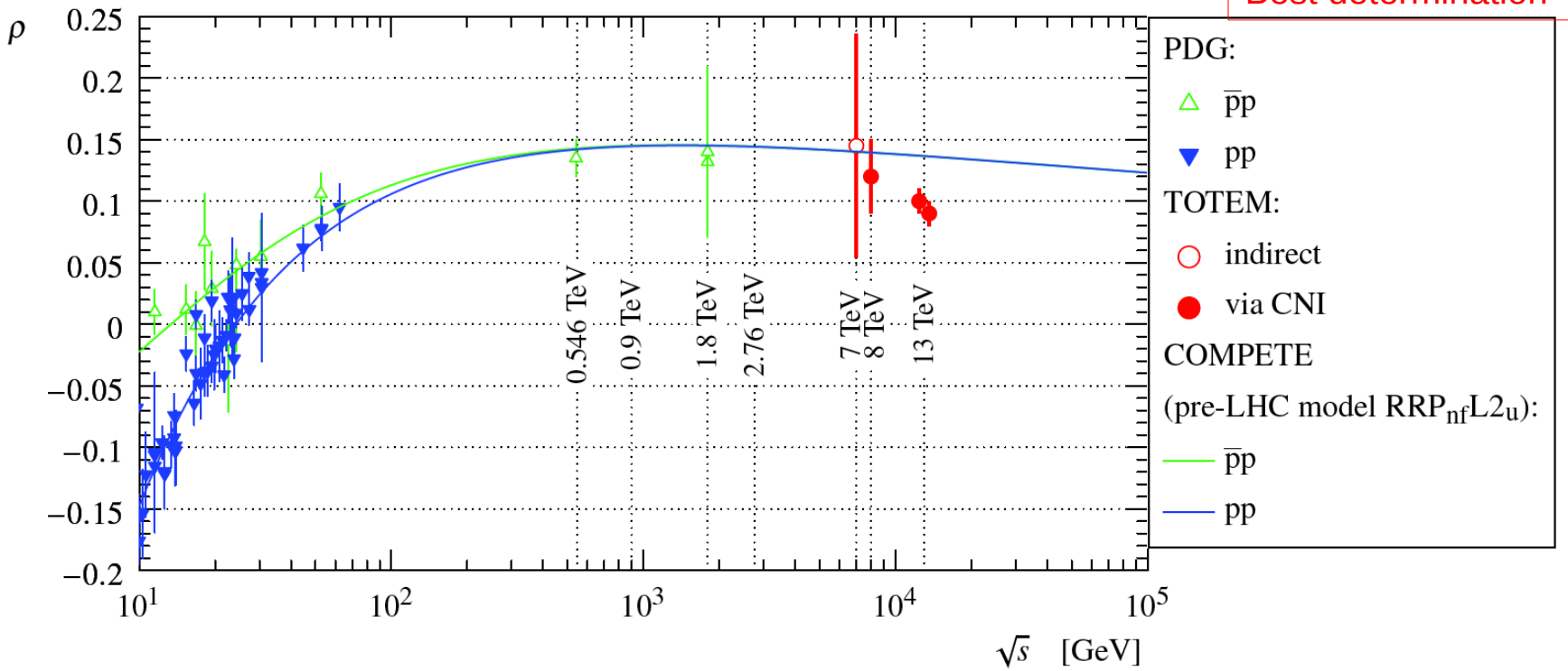
First LHC determination from Coulomb-hadronic interference at 8TeV : ρ=0.12±0.03
Uncertainty still too high (low statistics)

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

	$\|t\|_{max}$ = 0.07 GeV^2		$\|t\|_{max}$ = 0.15 GeV^2	
N_b	χ^2/ndf	ρ	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

N_b=1 & $|t|_{max}$= 0.07 GeV2
Comparison with UA4/2
(same t-range)

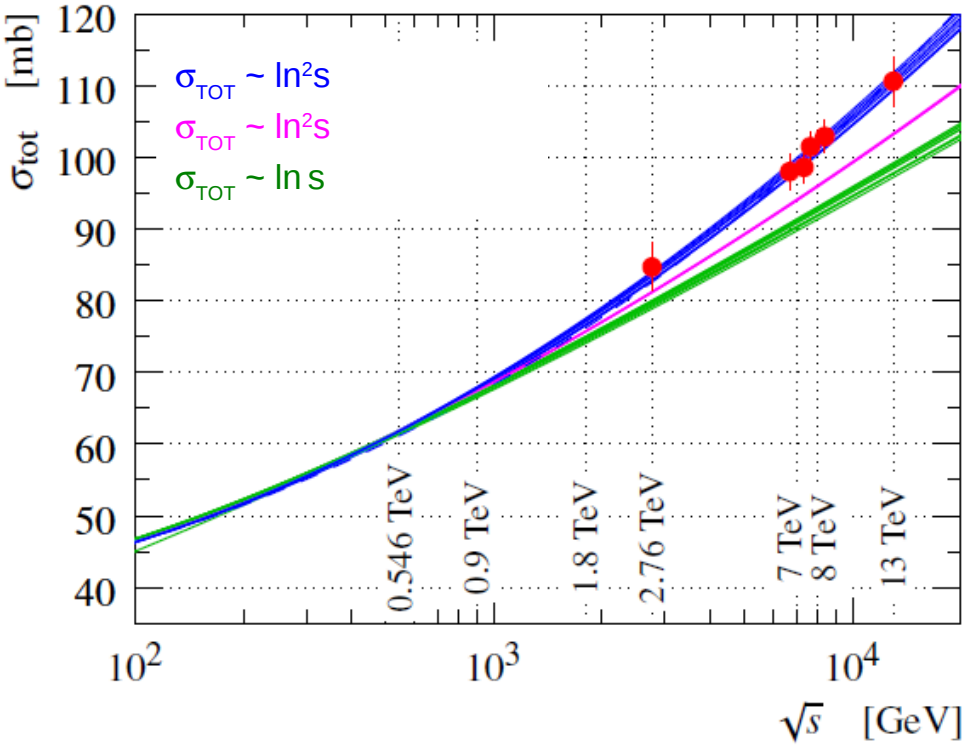
Largest |t|-range and
fit flexibility.
Best determination

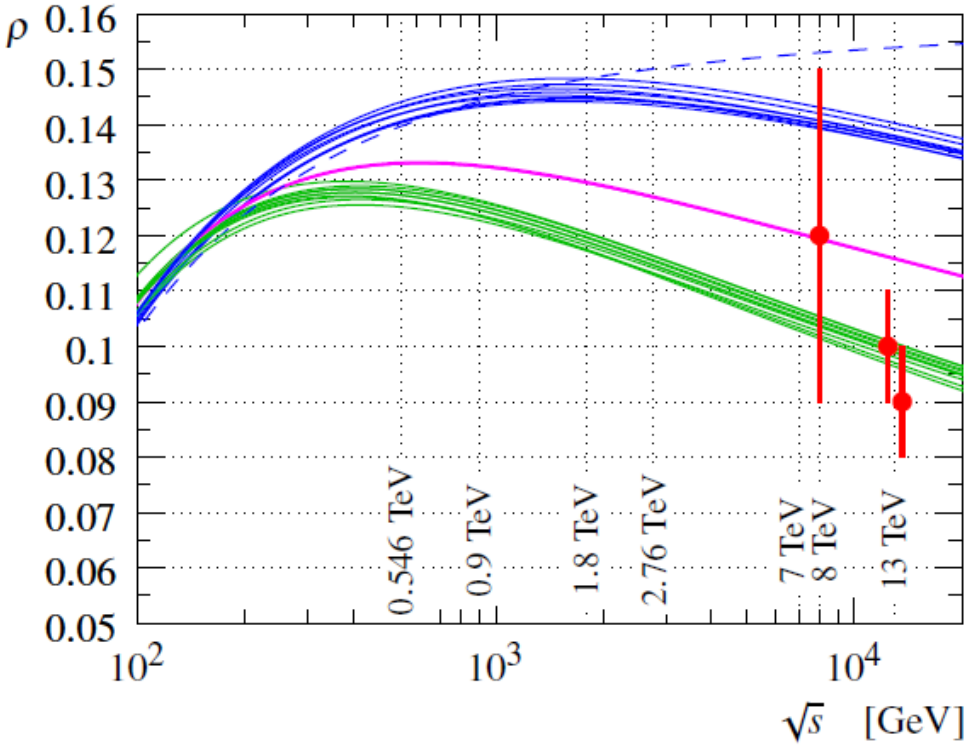


The new measurement is clearly below the predictions

σ_{TOT} and ρ parameter : model comparison

RPdPL2_20, RPdPL2u_17, RPdPL2u_19, RPdPqcL2u_16, RRcdPL2u_15, RRcdPqcL2u_14, RRPL2u_19, RRPL2u_21
RRPEu_19
RqcRcL2qc_12, RRcL2qc_15, RRL2_18, RRL2qc_17
RqcRcLqc_12, RqcRLqc_14, RRcLqc_15, RRcPL_19, RRL_18, RRL_19, RRLqc_17, RRPL_21, RRPL2_20, RRPL2qc_18

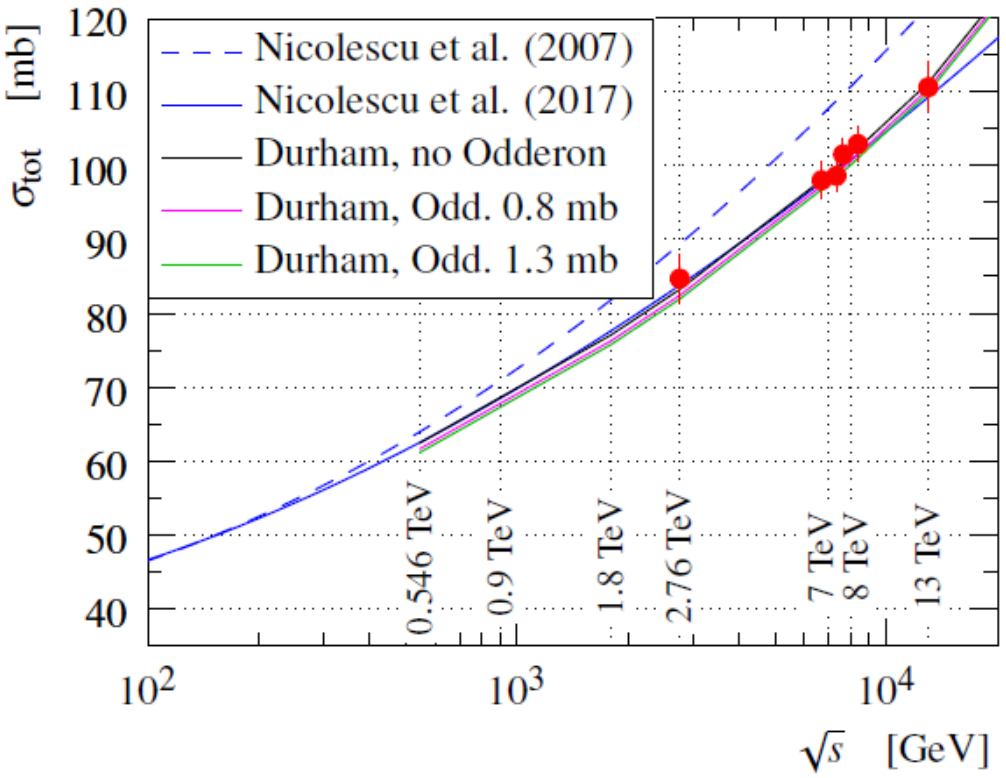


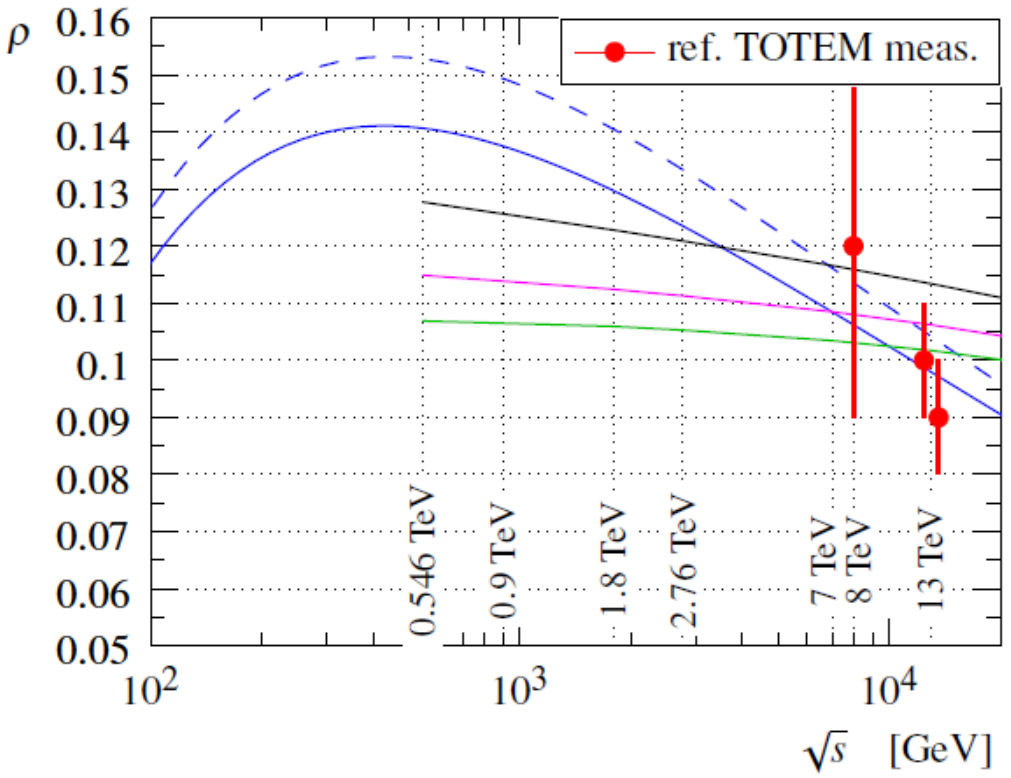


None of the models considered by COMPETE is able to describe simultaneously σ_{TOT} and ρ

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





Odd-Component (Odderon) hint or
first evidence of "slowing down" of σ_{TOT} growth at higher energy?

No conclusions, rather some hints to trigger discussion……..

Totem has made extensive measures related to σ_{TOT} and elastic scattering
...many more than it was foreseen indeed

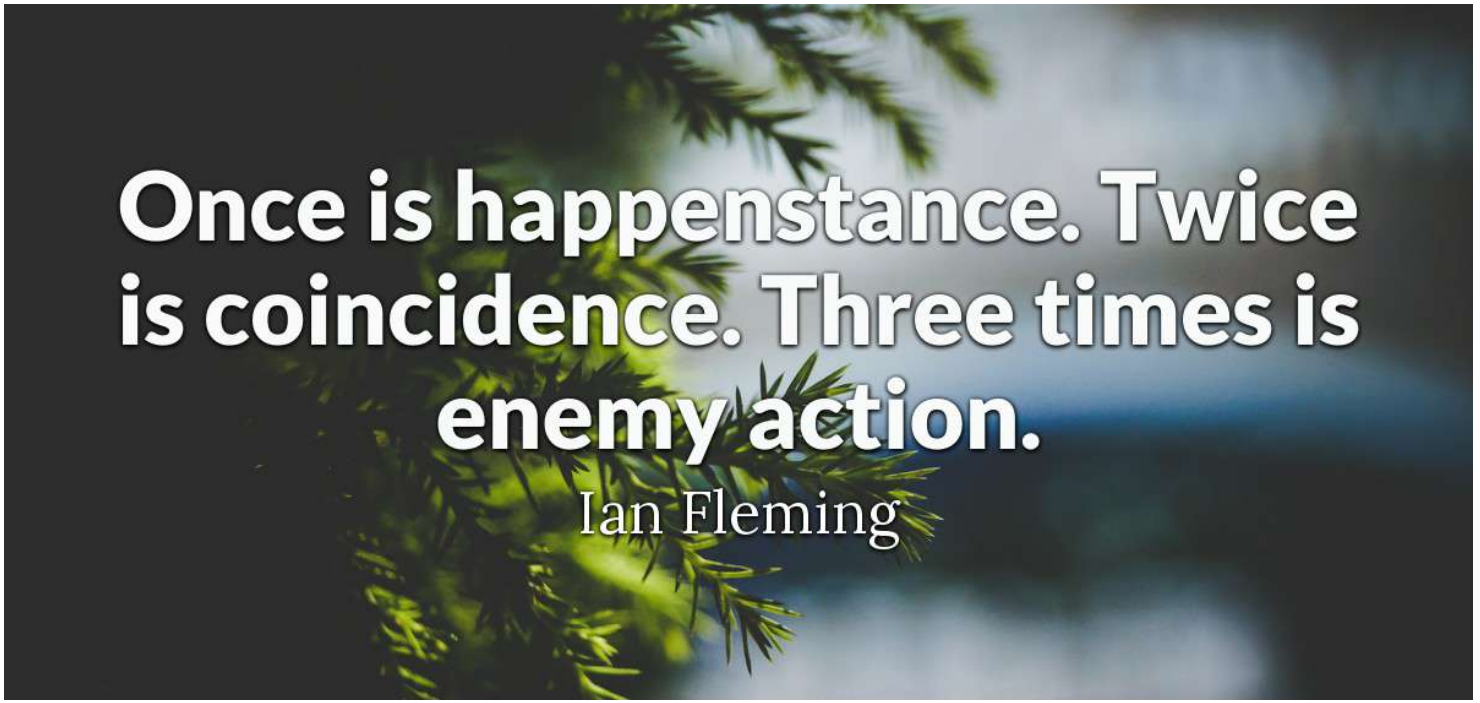
Some of the pre-LHC questions seems nevertheless still open

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 of 3g-bound state:

- ✔ decrease of ρ at high energies
- ✔ the growth rate of the total cross-section
- ✔ 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
- ✔ Precise measurement of σ_{TOT} and ρ at low energy (900 GeV) and 14 TeV
- ✔ Differences between the proton-proton and proton-antiproton scattering (“repeat” ISR)
- ✔ LHC in p-pbar?
- ✔ Exclusive vector meson production
- ✗ Observation in the s-channel (vector glueball) ?

Which could be the “three pieces of evidence” of the Odderon?


Once is happenstance. Twice is coincidence. Three times is enemy action.
Ian Fleming