TOTEM Results

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on behalf of the TOTEM collaboration

LHC Working Group on Forward Physics and Diffraction
CERN, 7 December 2017

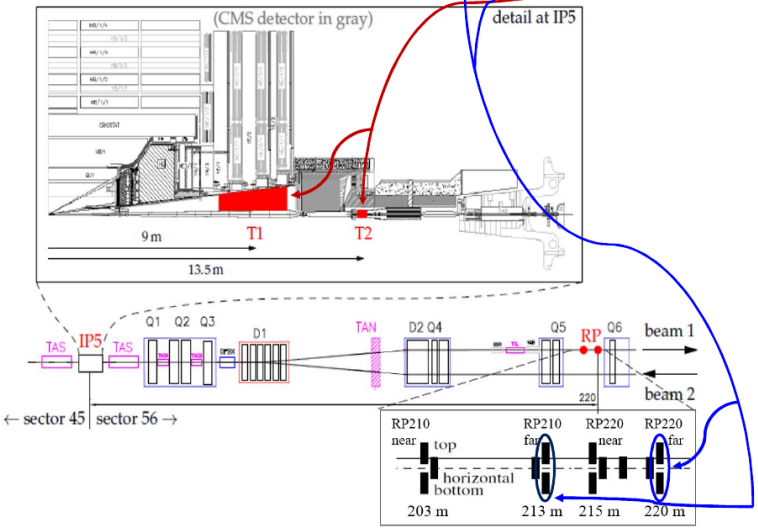
Outline – publication of two papers ongoing

- first cross-section measurement at $\sqrt{s}$ = 13 TeV
  - β^* = 90 m, October 2015

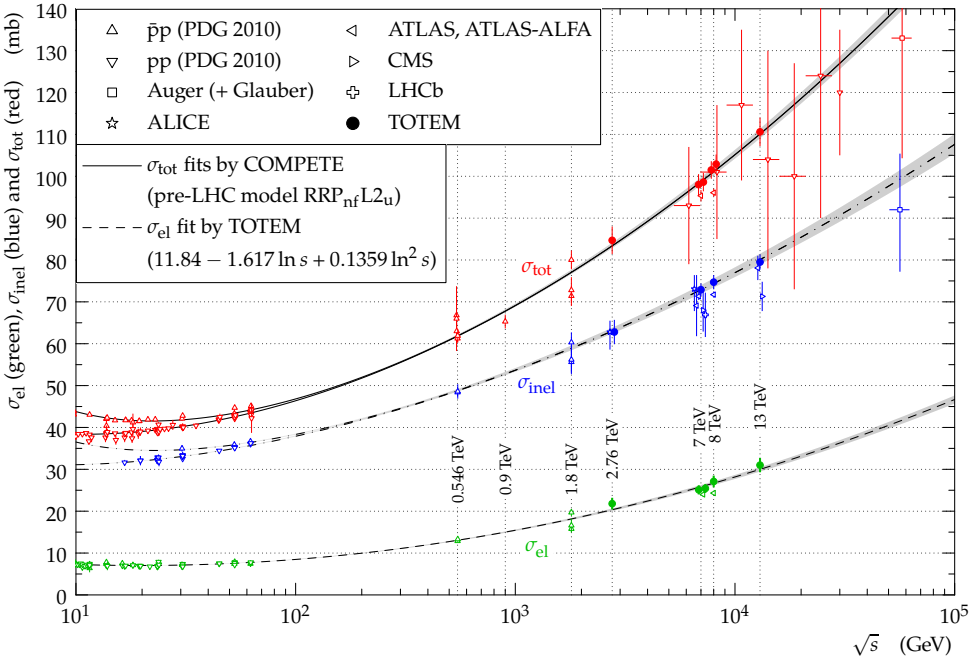
- first determination of the ρ parameter at $\sqrt{s}$ = 13 TeV
  - β^* = 2500 m, September 2016

- special run: October 2015, $\beta^* = 90$ m, $\mu \approx 0.07$, RPs at 5 σ
- luminosity-independent method

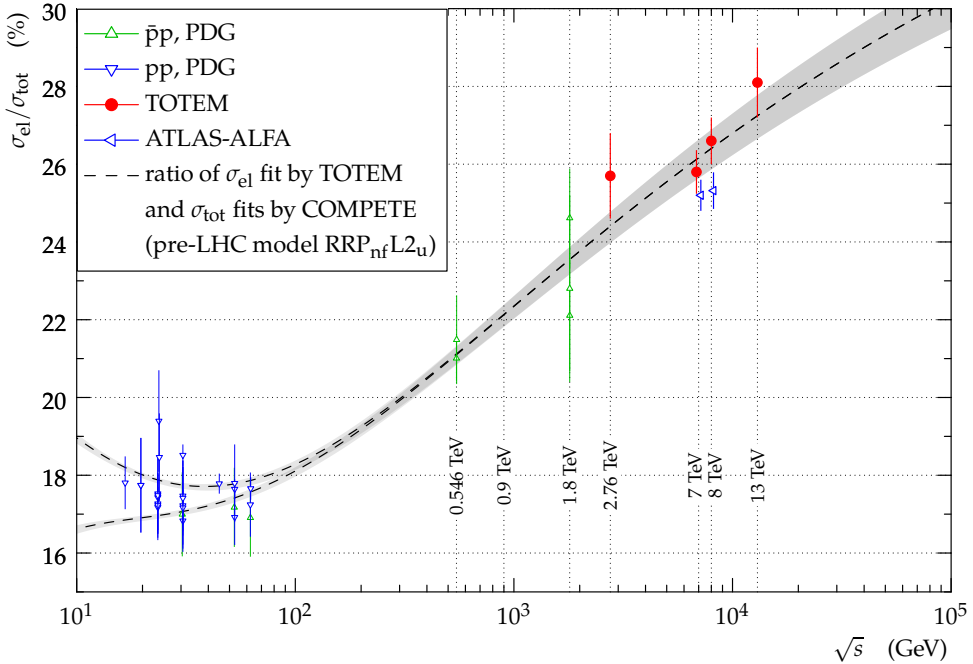
$$\sigma_{tot} = \frac{16\pi}{(1+\rho^2)} \frac{(dN_{el}/dt)_{t=0}}{(N_{el} + N_{inel})}$$



- assuming $\rho = 0.10$ (justified by the $\beta^* = 2.5$ km data):
  $\sigma_{\text{tot}} = (110.6 \pm 3.4)$ mb , $\sigma_{\text{inel}} = (79.5 \pm 1.8)$ mb , $\sigma_{\text{el}} = (31.0 \pm 1.7)$ mb

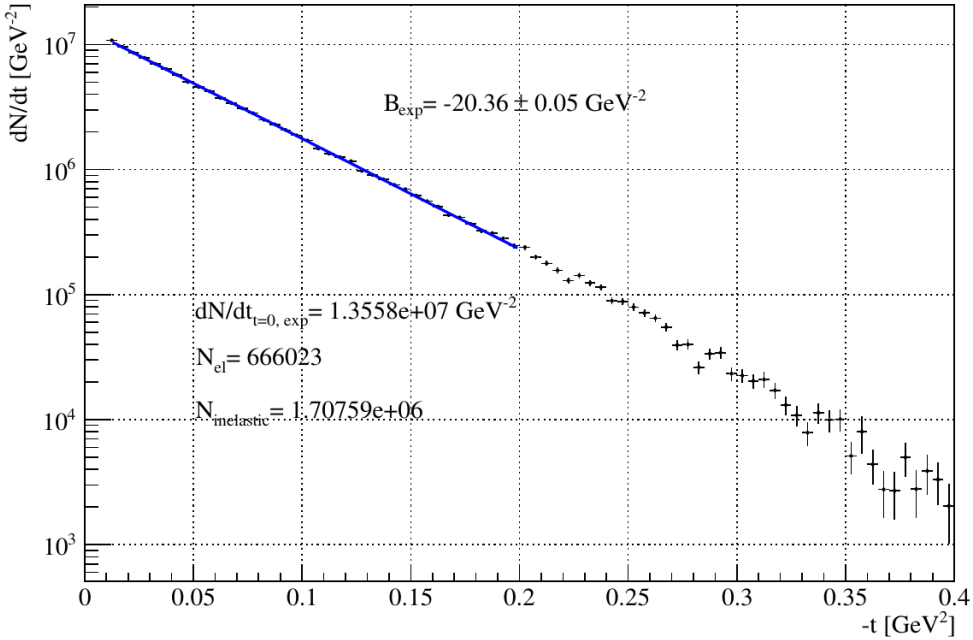


- ratio $\sigma_{el}/\sigma_{tot} = 0.281 \pm 0.009$

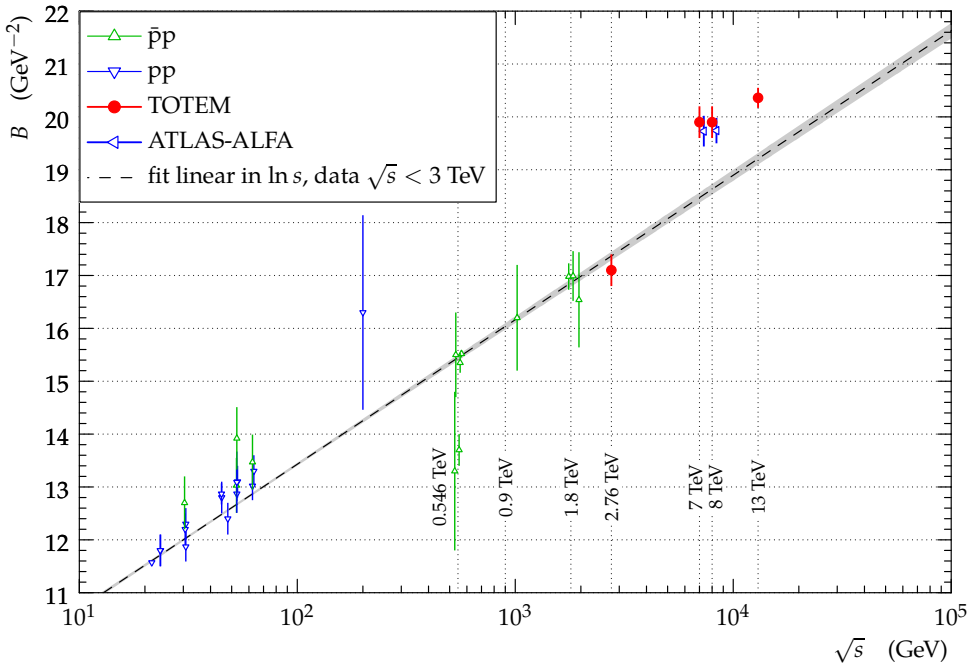


Diffractive slope at $\sqrt{s}$ = 13 TeV

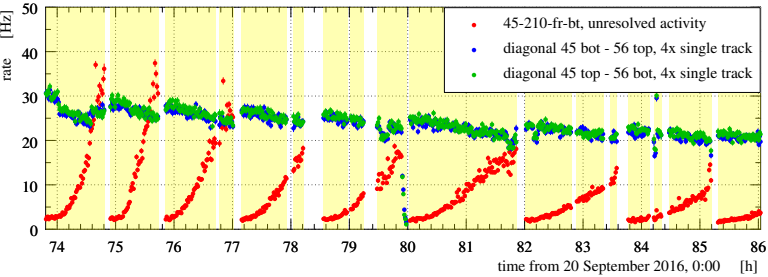
- at low $|t|$: $d\sigma/dt \approx A \exp(-B|t|)$
- at 13 TeV: $B = (20.36 \pm 0.19)$ GeV^{-2}

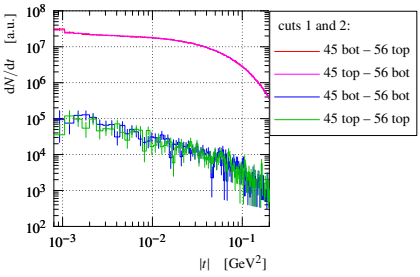


Diffractive slope at $\sqrt{s}$ = 13 TeV

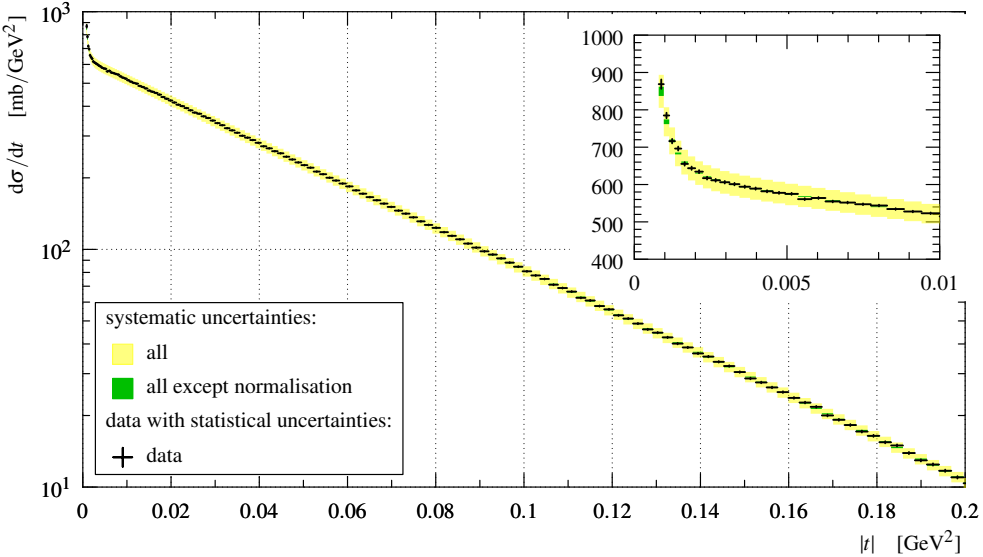


- very low $|t|$: interference between Coulomb and nuclear scattering
  - access to the phase of the nuclear amplitude, e.g. $\rho \equiv \frac{\Re \mathcal{A}^{\mathrm{N}}}{\Im \mathcal{A}^{\mathrm{N}}}|_{t=0}$
- special run in September 2016
  - RPs at 3 $\sigma \to |t|_{\mathrm{min}} \approx 8 \cdot 10^{-4}$ GeV^2
  - $\beta^* = 2.5$ km: very good angular resolution
  - 4 LHC fills: 7 M elastic candidates tagged
- background under control
  - regular "beam cleaning"
  - after selection cuts, background $\mathcal{O}(10^{-3})$

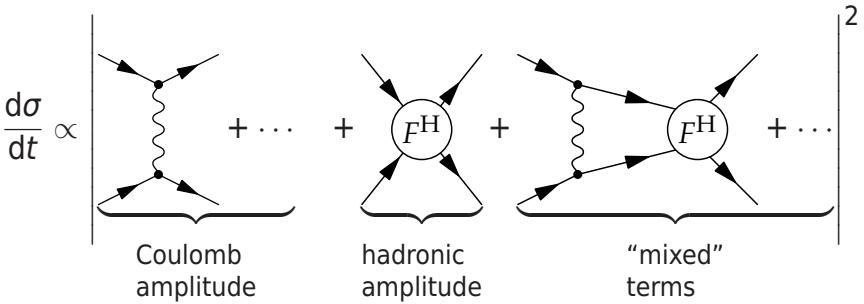




- at low $|t|$: effects due to CNI visible

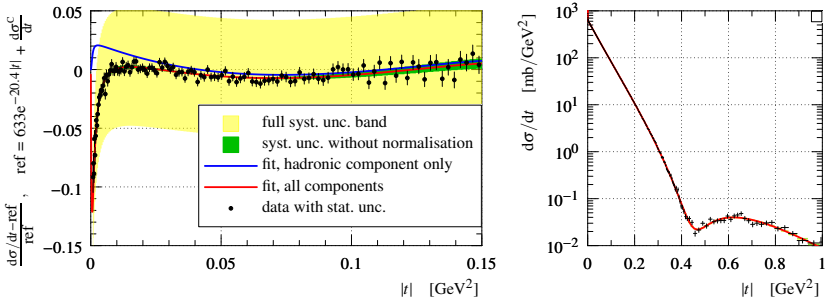


- observed cross-section

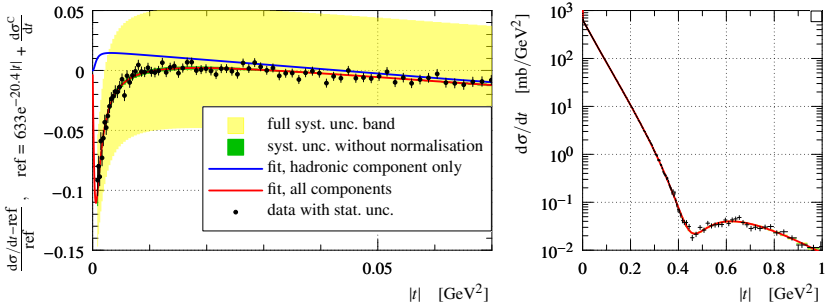


- our modelling (assumptions)
  - "interference" formula (summation for practical applications): Kundrát-Lokajíče
  - Coulomb amplitude: QED + experimental form factors
  - hadronic modulus: empirical guidance, at low $|t|$: $a \exp\left(\sum_{n=1}^{N_b} b_n t^n\right)$
  - hadronic phase: slowly varying (central behaviour), as in pre-LHC determinations
    - more exploration in a forthcoming paper

- $|t|$ ranges
  - $|t| < 0.15$ GeV^2: maximum, for higher $|t|$ faster decrease to dip
  - $|t| < 0.07$ GeV^2: $N_b = 1$ expected sufficient, equivalent to UA4
- $N_b = 3$, $|t|_{\max} = 0.15$ GeV^2



- $N_b = 1$, $|t|_{\max} = 0.07$ GeV^2

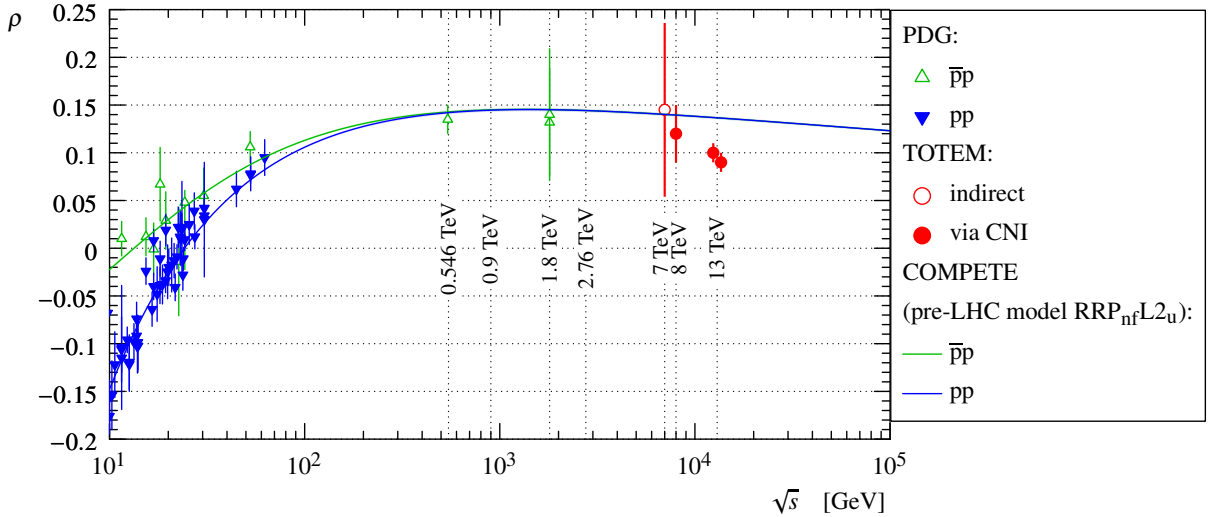


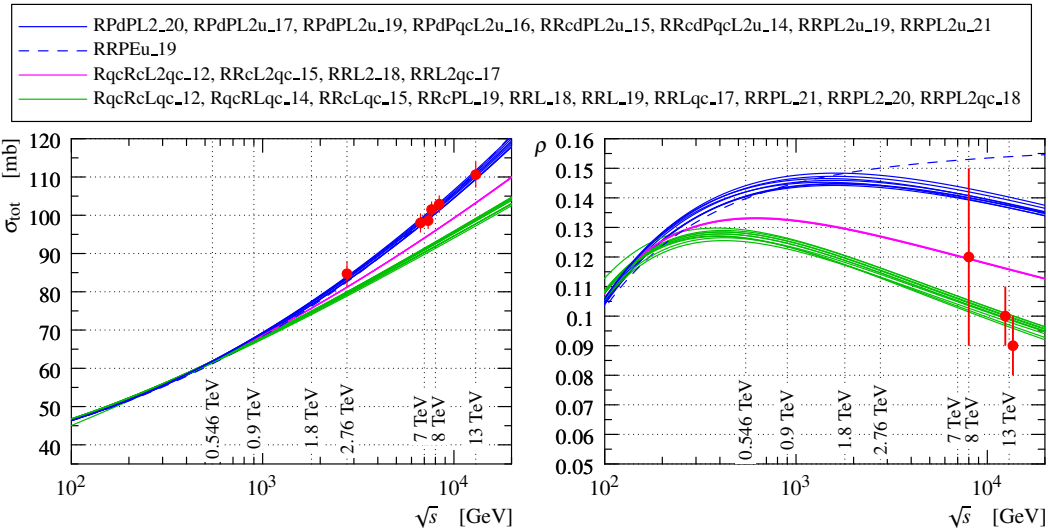
- preliminary results

	$\lvert t\rvert_{\max} = 0.07$ GeV^2		$\lvert t\rvert_{\max} = 0.15$ 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

  - data incompatible with purely-exponential hadronic component
  - ρ constrained in a narrow range
  - one of the most precise ρ determinations in history

- important fit configurations (red)
  - $N_b = 3$, $\lvert t\rvert_{\max} = 0.15$ GeV^2: “our best“ determination
  - $N_b = 1$, $\lvert t\rvert_{\max} = 0.07$ GeV^2: “most fair“ comparison to past measurements


ρ
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
10^1
10^2
10^3
10^4
10^5
√s [GeV]
0.546 TeV
0.9 TeV
1.8 TeV
2.76 TeV
7 TeV
8 TeV
13 TeV
PDG:
p̄p
pp
TOTEM:
indirect
via CNI
COMPETE
(pre-LHC model RRP_nfL2_u):
p̄p
pp



- band-data compatibility: p-values

	σ_{tot} (4 to 6 TOTEM measurements)	ρ at 13 TeV (0.09 ± 0.01)
blue	0.990 to 0.995	$3 \cdot 10^{-6}$
magenta	$4 \cdot 10^{-3}$ to $7 \cdot 10^{-5}$	$9 \cdot 10^{-3}$
green	$3 \cdot 10^{-9}$ to $2 \cdot 10^{-15}$	0.4

- t-channel exchange of a colourless 3-gluon bound state ($J^{PC} = 1^{--}$) could decrease ρ in pp collisions at large $\sqrt{s}$
  - originally predicted as "Odderon" in axiomatic theory [Lukaszuk, Nicolescu]
  - confirmed in QCD [Vacca, Braun, Lipatov et al.]: colourless 3-gluon bound state with stronger internal coupling than external
  - "vector glueball" in lattice calculations [Luscher, Morningstar et al.]
- other manifestations
  - difference of depth of "diffractive dip" between pp and $p\overline{p}$ collisions
  - faster increase of σ_{tot} with $\sqrt{s}$
  - non-constant hadronic phase and low-$|t|$ deviation from pure exponential
  - no oscillatory effects at large $|t|$
- 2 models in agreement with TOTEM data [Nicolescu, Durham]
  - *agreement improved when included exchange of 3-gluon bound state*