

TOTEM Results

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on behalf of the TOTEM collaboration

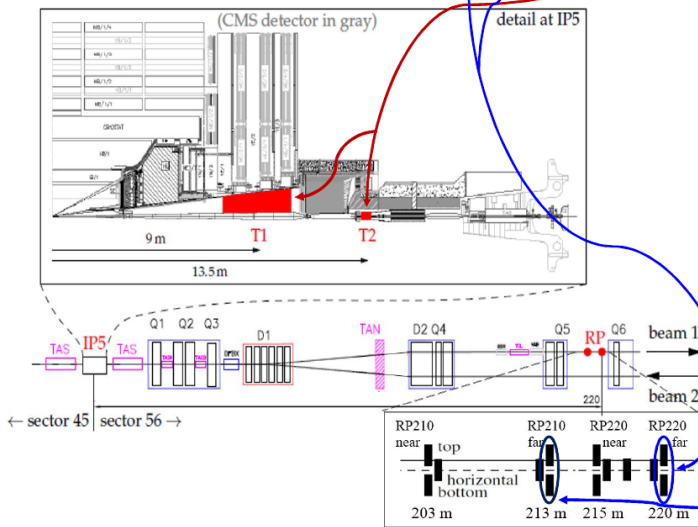


LHC Working Group on Forward Physics and Diffraction
CERN, 7 December 2017

- first cross-section measurement at $\sqrt{s} = 13$ TeV
 - $\beta^* = 90$ m, October 2015
- first determination of the ρ parameter at $\sqrt{s} = 13$ TeV
 - $\beta^* = 2500$ m, September 2016

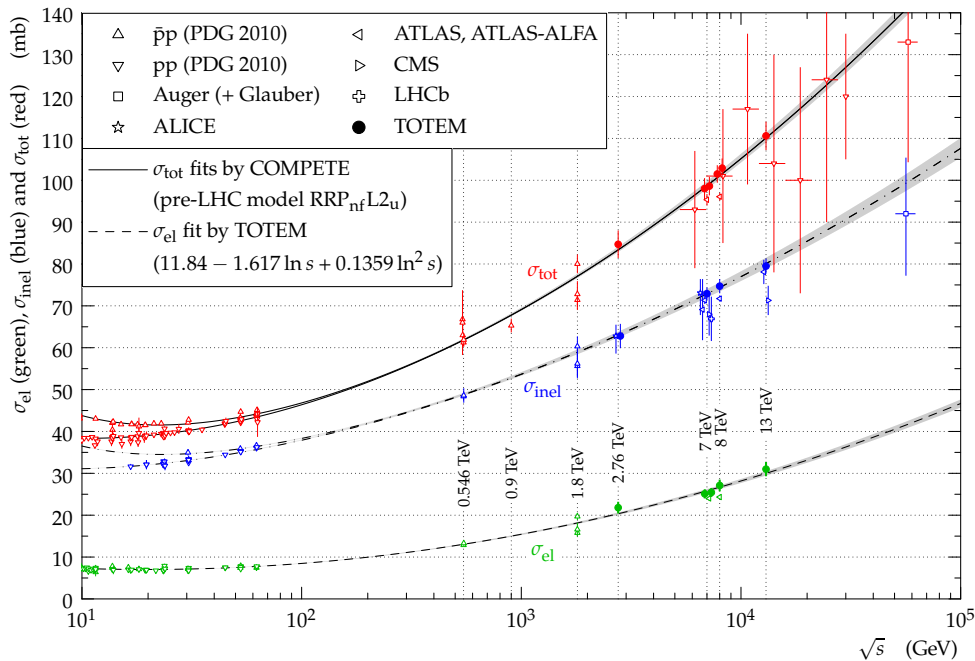
- special run: October 2015, $\beta^* = 90$ m, $\mu \approx 0.07$, RPs at 5σ
- luminosity-independent method

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

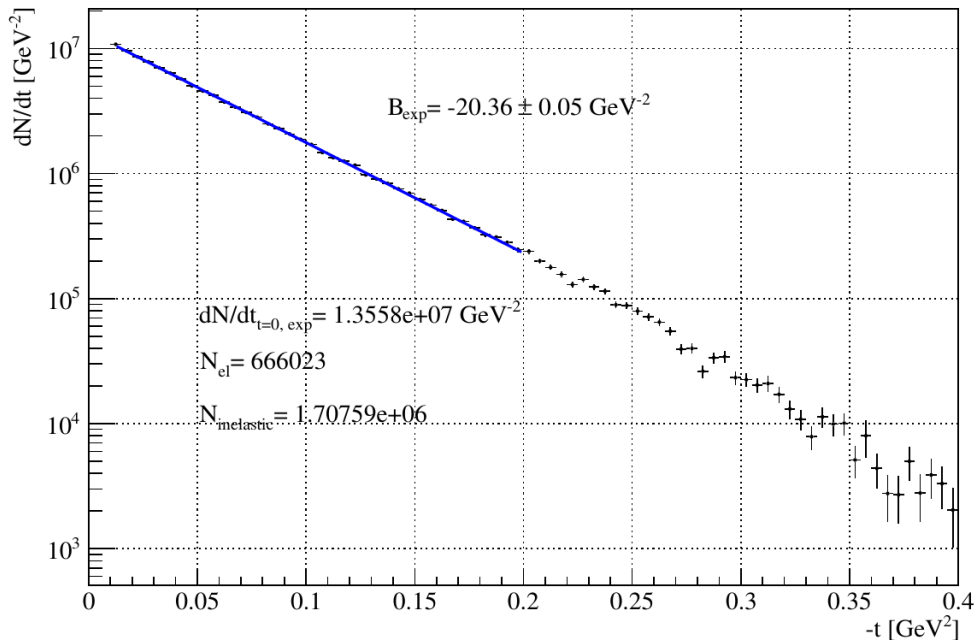


- assuming $\rho = 0.10$ (justified by the $\beta^* = 2.5$ km data):

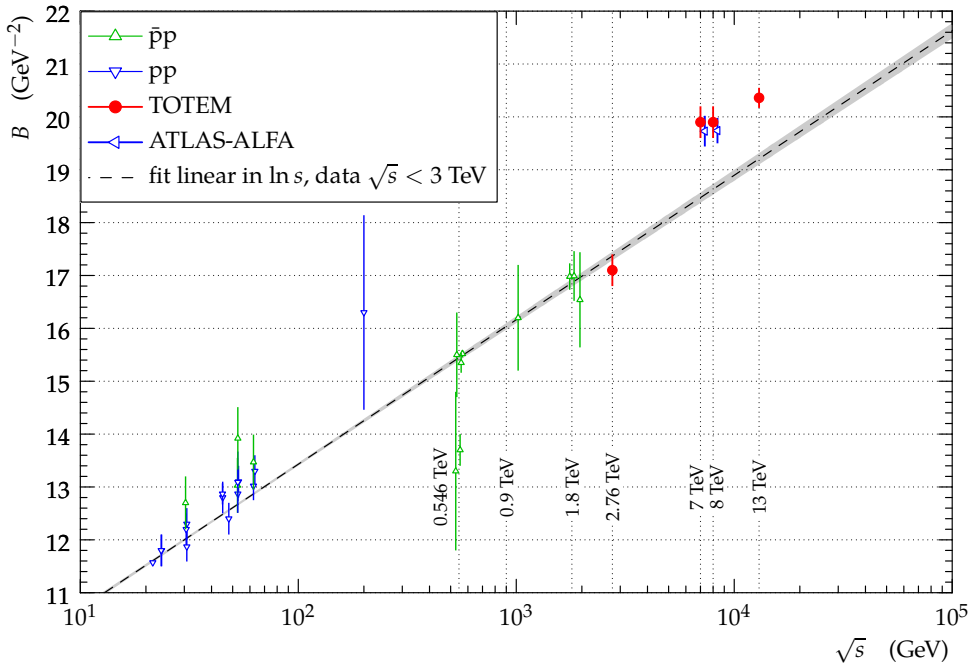
$$\sigma_{\text{tot}} = (110.6 \pm 3.4) \text{ mb}, \quad \sigma_{\text{inel}} = (79.5 \pm 1.8) \text{ mb}, \quad \sigma_{\text{el}} = (31.0 \pm 1.7) \text{ mb}$$



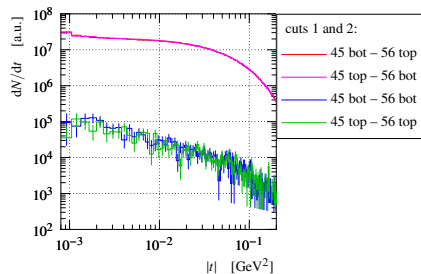
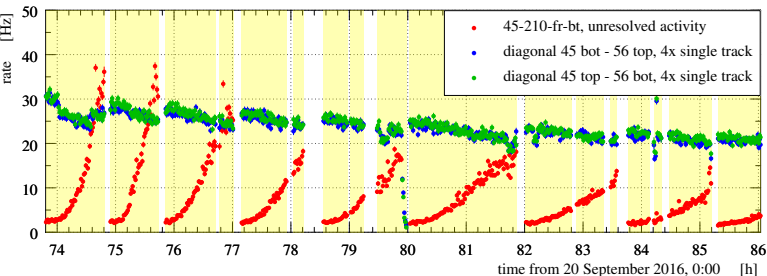
- at low $|t|$: $d\sigma/dt \approx A \exp(-B|t|)$
- at 13 TeV: $B = (20.36 \pm 0.19) \text{ GeV}^{-2}$



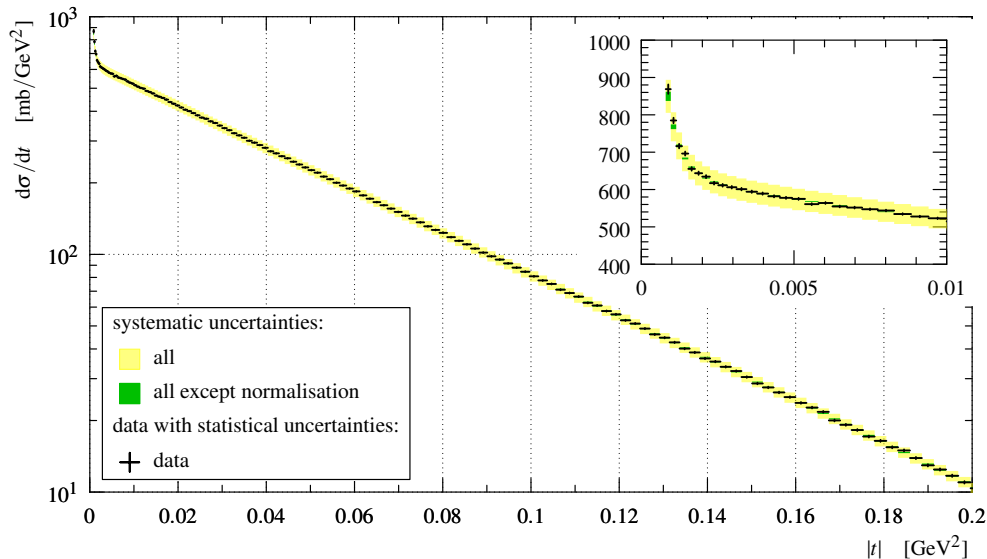
Diffractive slope at $\sqrt{s} = 13$ TeV



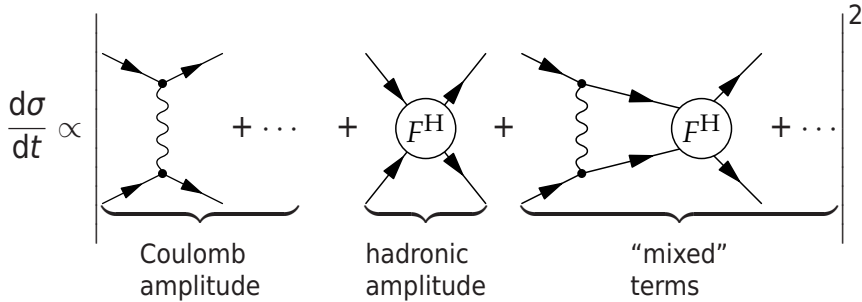
- very low $|t|$: interference between Coulomb and nuclear scattering
 - access to the phase of the nuclear amplitude, e.g. $\rho \equiv \frac{\Re A^N}{\Im A^N} |_{t=0}$
- special run in September 2016
 - RPs at $3\sigma \rightarrow |t|_{\min} \approx 8 \cdot 10^{-4} \text{ GeV}^2$
 - $\beta^* = 2.5 \text{ km}$: 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



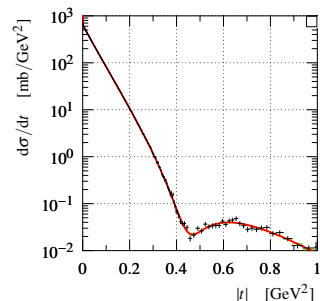
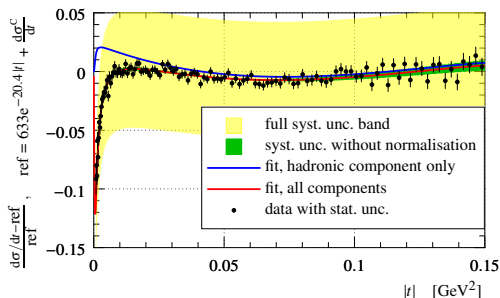
- observed cross-section



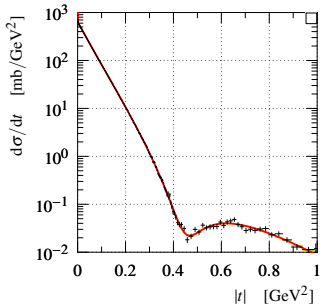
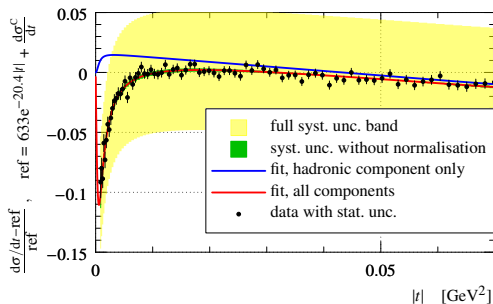
- our modelling (assumptions)

- “interference” formula (summation for practical applications): Kundrát-Lokajíč
- 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
 - $|t| < 0.15 \text{ GeV}^2$: maximum, for higher $|t|$ faster decrease to dip
 - $|t| < 0.07 \text{ GeV}^2$: $N_b = 1$ expected sufficient, equivalent to UA4
- $N_b = 3$, $|t|_{\text{max}} = 0.15 \text{ GeV}^2$



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



- preliminary results

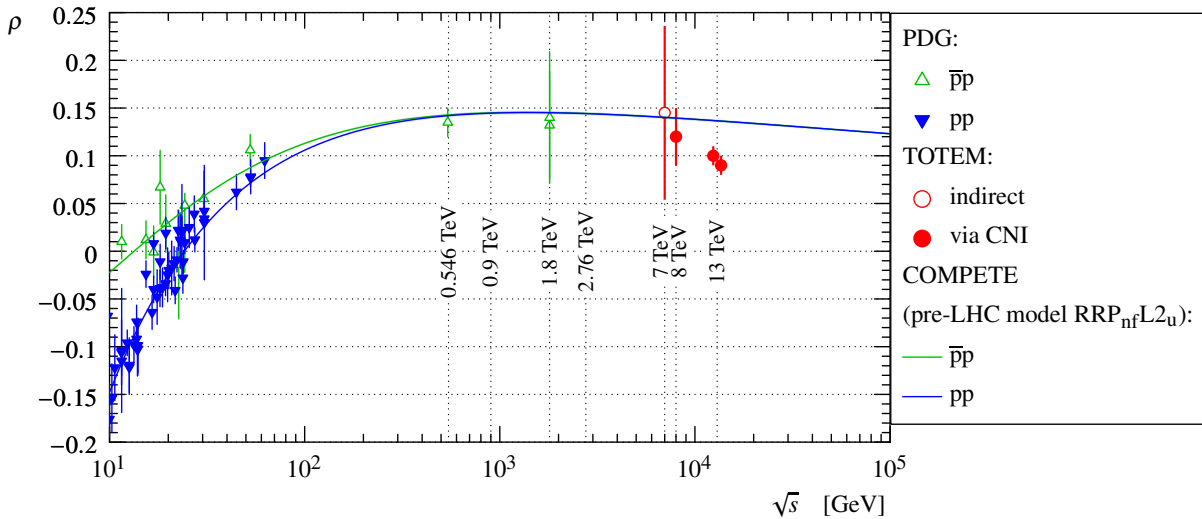
N_b	$ t _{\max} = 0.07 \text{ GeV}^2$		$ t _{\max} = 0.15 \text{ GeV}^2$	
	χ^2/ndf	ρ	χ^2/ndf	ρ
1	0.7	0.09 ± 0.01	2.6	—
2	0.6	0.10 ± 0.01	1.0	0.09 ± 0.01
3	0.6	0.09 ± 0.01	0.9	0.10 ± 0.01

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

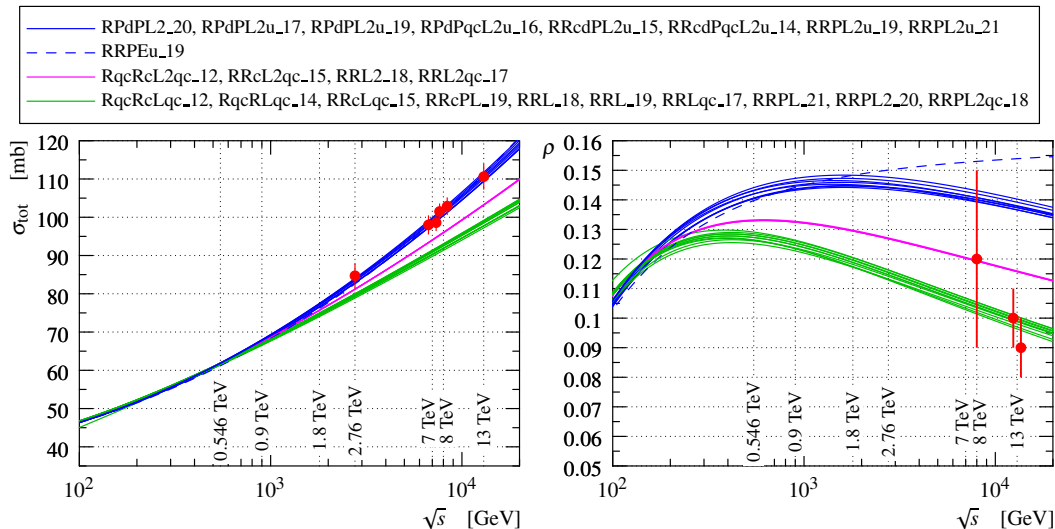
- important fit configurations (red)

- $N_b = 3$, $|t|_{\max} = 0.15 \text{ GeV}^2$: “our best” determination
- $N_b = 1$, $|t|_{\max} = 0.07 \text{ GeV}^2$: “most fair” comparison to past measurements

ρ vs. s



(In)compatibility with COMPETE



• blue-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 $p\bar{p}$ 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*