

# TOTEM Meaurement of $\rho, \, \sigma_{tot}, \, \sigma_{elastic} \\ \text{at 13TeV at LHC}$

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# The TOTEM experiment

T1&T2 Inelastic detectors **T1: 3.1 <** η < 4.7 **T2: 5.3 <** η **< 6.5** 



at ~220m from IP5 (CMS)



# Detectors technology

Silicon Strips in secondary vacuum pots

Inelastic tracking detectors: T1 (CSC) T2 (triple GEM)









# Cross section measurement





# **Differential elastic Cross Section**

In October we ran 5 days – 13Tev,  $\beta^*=90m$ , PU~0.7 ~13 billion elastics recorded

No structure was observed at large t

Soon more information on large t analysis





# **Differential Slope**





## **Differential Slope**





 $\sigma_{\rm tot}, \sigma_{\rm inel} \& \sigma_{\rm el} vs \sqrt{s}$ 



 $\sigma_{tot}$  = 110.6 ± 3.7 mb,  $\sigma_{inel}$  = 79.5 ± 2.7 mb,  $\sigma_{el}$  = 31.0 ± 2.1 mb



 $\sigma_{\rm el}/\sigma_{\rm tot}$  vs  $\sqrt{s}$ 



TOTEM @  $\sqrt{s}$  = 13 TeV:  $\sigma_{et}/\sigma_{tot}$  = 0.281 ± 0.010



# $\beta^* = 2.5 \text{ km data} @ \sqrt{s} = 13 \text{ TeV}$

Elastic scattering in Coulomb-nuclear interference (CNI) region at very low |t|:

 $\rho = \Re \left. F^{\rm H} / \Im \left. F^{\rm H} \right|_{{\rm t}=0} \right.$ 

Special run September 2016,  $\beta^*$  = 2.5 km

Vertical RPs @  $3\sigma \Rightarrow |t|_{min} \approx 8 \cdot 10^{-4} \text{ GeV}^2$  $L_{\rm int} \approx 0.4 \ \rm nb^{-1} \Rightarrow ~7 \ \rm M \ elastic$ sector 56, right side sector 45, left side station 210 station 210 station 220 station 220 Data taking: red near near near far near far RPs; optimize |t|-IP5 CMS reach  $\Rightarrow$  analysis: only RP220 far 50 (Hz) 45-210-fr-bt, unresolved activity diagonal 45 bot - 56 top, 4x single track 40 Reasonable rate diagonal 45 top - 56 bot, 4x single track background 30  $\rightarrow$  regular 20 beam cleaning 10 procedure 0 75 76 78 79 80 81 82 83 85 74 77 84 86 time from 20 September 2016, 0:00 (h)

# Elastic selection in 2.5 km data

TOTEM





## $\beta^* = 2.5 \text{ km low |t|} d\sigma_{el}/dt @ \sqrt{s} = 13 \text{ TeV}$

normalisation obtained from  $\beta^*$  = 90 m  $\sigma_{tot}$  analysis





# Interference region

observed cross-section



- our modelling (assumptions)
  - "interference" formula: Kundrát-Lokajíček
  - Coulomb amplitude: QED + experimental form factors
  - hadronic modulus: empirical guidance, at low |t|: aexp

$$\begin{pmatrix} N_b \\ \sum_{n=1}^{N_b} b_n t^n \end{pmatrix}$$

hadronic phase: slowly varying (central behaviour), as in pre-LHC determinations



# $\rho$ extraction





## ρ measurement

	$ t _{max} = 0.07 \text{ GeV}^2$		$ t _{max} = 0.15 \text{ GeV}^2$	
$N_b$	$\chi^2/ndf$	ρ	$\chi^2/ndf$	ρ
1	0.7	$0.09\pm0.01$	2.6	-
2	0.6	$0.10 \pm 0.01$	1.0	$0.09\pm0.01$
3	0.6	$0.09\pm0.01$	0.9	$0.10\pm0.01$

data incompatible with purely-exponential hadronic component

- ρ constrained in a narrow range
- $^{\circ}$  one of the most precise ho determinations in history
- important fit configurations (red)
- Nb = 3, |t|max = 0.15 GeV2: "our best" determination
- Nb = 1, |t|max = 0.07 GeV2: "most fair" comparison to past measurements



#### ρ measurement



Observe significant decrease of  $\rho$  at larger  $\sqrt{s}$ 



## Models compatibility

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 [ 4 120 110 ρ 0.16 0.15 110 0.14 נס 100 ט 0.13 90 0.12 80 0.11 0.1 70 0.09 60 TeV je, TeV 2.76 TeV 1.8 TeV eV -0.9 TeV 0.08 TeV 546 50 0.9 °. 0.07 201 Ni 0 40 0.06  $10^{2}$  $10^{3}$  $10^{3}$  $10^{4}$  $10^{4}$  $10^{2}$  $\sqrt{s}$  $\sqrt{s}$ [GeV] [GeV]

Comparison with COMPETE model predictions:

J.R. Cudell et al., PRL 89 (2002) 201801. Compatibility with COMPETE models (P-value):

	$\sigma_{ m tot}$ (6 points)	$ ho$ at 13 TeV (0.098 $\pm$ 0.01)
blue	0.99	$2 \cdot 10^{-4}$
magenta	$4 \cdot 10^{-5}$	0.11
green	$2\cdot 10^{-16}$	0.84



## Physics interpretation

- *t*-channel exchange of a colourless 3-gluon bound state (*JPC* = 1––) could decrease  $\rho$  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 p-p and p-p<sub>bar</sub> collisions
  - faster increase of  $\sigma_{\rm tot}$  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



# Conclusions

- Totem experiment made a precise measurement of the proton-proton cross section at  $\sqrt{s}=13$ TeV.
- In a special run with  $\beta^*=2500m$ , could reach the Coulomb-Nuclear Interference zone and measure the  $\rho$  parameter with unprecedented precision.
- Both measurement seems incompatible with COMPETE calculations.
- The presence of a bound 3 gluon state JPC=1– can explain such behavior.
- New data are foreseen at 14TeV after LHC Long Shutdown 2 in 2021.