

# Status of Totem Experiment

*Nicola Turini  
Department of Physics  
Università di Siena  
I-53100 Siena, ITALY*

*on behalf of the Totem experiment*

## 1 Introduction

The Totem experiment has been completed in the 2010-2011 winter shut down after the inelastic detector T1 has been inserted successful in the forward region of the CMS end cap. In the spring summer run period of the LHC the experiment has performed measurements of elastic and inelastic scattering of proton-proton collisions. In particular has been measured the elastic cross section starting from the squared four-momentum transfer  $|t| = 0.02 \text{ GeV}^2$  up to  $|t| = 2.5 \text{ GeV}^2$  [?]. In June 2011 Totem used the luminosity information of CMS in a  $B^*=90$  m run to extrapolate the  $|t| = 0$  elastic cross section and with the optical theorem could measure the total P-P cross section. Moreover inelastic scattering thopology has been studied with T2 detector to extract the  $dN/d\eta$  information in the pseudorapidity range between  $\eta = 5.3$  and  $\eta = 6.5$ .

## 2 The experiment

The Totem experiment is made by three different detectors, two inelastic detectors plus the Roman Pots for elastic and small  $\xi$  inelastic events. T1 is covering the region from  $3.1 < \eta < -4.7$ , T2 is covering the region from  $5.3 < \eta < 6.5$  [1].

The two arms of the T1 telescope, one on either side of the IP5, fit in the space between two conical surfaces, the beam pipe and the inner envelope of the flux return yoke of the CMS end-cap, at a distance between 7.5 m and 10.5 m from the interaction point. Each telescope consists of five planes of CSCs, equally spaced in z, numbered as 1 to 5 from the closest (smallest) to the farthest (largest) from the interaction point. A detector plane is composed of six CSC wire chambers covering roughly a region of  $60^\circ$  in  $\phi$  and, as mentioned above, is split in two halves and mounted on different supports. Overlap is provided between adjacent detectors (also for the ones on different supports) to cover with continuous efficiency the approximately circular

region of each telescope plane. In addition, the detector sextants in each plane are slightly rotated with respect to each other by angles varying from  $-6^\circ$  to  $+6^\circ$  in steps of  $3^\circ$ , the reference orientation being that of layer 5 [2].

The T2 telescopes are installed in the forward shielding of CMS between the vacuum chamber and the inner shielding of the HF calorimeter. There is a vacuum pump unit in front of T2 and the CMS CASTOR calorimeters behind it. In each T2 arm, 20 semi-circular GEM planes with overlapping regions are interleaved on both sides of the beam vacuum chamber to form ten detector planes of full azimuthal coverage. The GEMs are installed as pairs with a back-to-back configuration. The shape of the GEM detector used in T2 telescope is semi-circular with an active area covering an azimuthal angle of  $192^\circ$  and extending from 43 mm up to 144 mm in radius from the beam axis. The design of the T2 GEM detector is based on utilization of the standard GEM foils manufactured by the CERN-TS-DEM workshop. The foil consists of  $50\mu\text{m}$  polyimide foil (Apical) with  $5\mu\text{m}$  copper cladding on both sides. Due to the bidirectional wet etching process used by the workshop the shapes of the holes are double conical. The diameters of the holes in the middle of the foil and on the surface are 65 and  $80\mu\text{m}$ , respectively [3].

To detect leading protons scattered at very small angles, silicon sensors are placed in movable beam-pipe insertions so-called Roman Pots (RP) located symmetrically on either side of the LHC interaction point IP5 at distances of 215–220 m from the IP. Each RP station is composed of two units separated by a distance of about 5 m. A unit consists of 3 RPs, two approaching the outgoing beam vertically and one horizontally. Each RP is equipped with a stack of 10 silicon strip detectors designed with the specific objective of reducing the insensitive area at the edge facing the beam to only a few tens of micrometers [4]. The 512 strips with  $66\mu\text{m}$  pitch of each detector are oriented at an angle of  $+45^\circ$  (five u-planes) and  $-45^\circ$  (five v-planes) with respect to the detector edge facing the beam. During the measurement the detectors in the horizontal RPs overlap with the ones in the vertical RPs, enabling a precise ( $10\mu\text{m}$ ) relative alignment of all three RPs in a unit by correlating their positions via common particle tracks. The precision and the reproducibility of the alignment of all RP detector planes with respect to each other and to the position of the beam centre is one of the most delicate and difficult tasks of the experiment. In a station, the long lever arm between the near and the far RP units has two important advantages. First, the local track angles in the x- and y-projections perpendicular to the beam direction are reconstructed with a precision of 5 to  $10\mu\text{rad}$ . Second, the proton trigger selection by track angle can use all RPs independently: the stations on the opposite sides of the IP, the near and far units of each station, and the u and v planes in each unit. This redundancy can be used to obtain high trigger efficiency or purity.

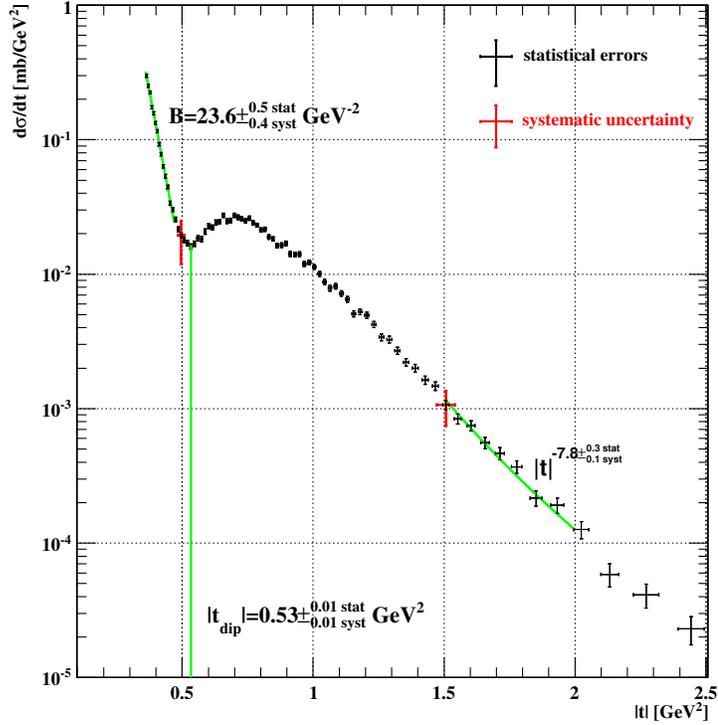


Figure 1: Differential Proton-Proton elastic cross section.

### 3 Total and elastic cross section

In october 2010 a sample of data were taken with the standard LHC 2010 optics ( $\beta^* = 3.5m$ ) during a TOTEM dedicated run with four proton bunches of nominal population ( $7 \times 10^{10}$  p/bunch) per beam with a total integrated luminosity of  $6.1nb^{-1}$  [5]. This low-luminosity configuration allowed the detectors to approach the beams to a distance as small as 7 times the transverse beam size. A reconstructed track in both projections in the near and in the far vertical RP unit is required on each side of the IP. The two diagonals *top left of IP - bottom right of IP* and *bottom left of IP - top right of IP*, tagging possible elastic candidates, are used as almost independent experiments with slightly different optics corrections, yet constrained by the alignment of the RPs. The time dependent instantaneous luminosity was taken from the CMS measurement. Its determination is based on a van der Meer scan whose uncertainty was 4%. After unfolding and inclusion of all systematic uncer-

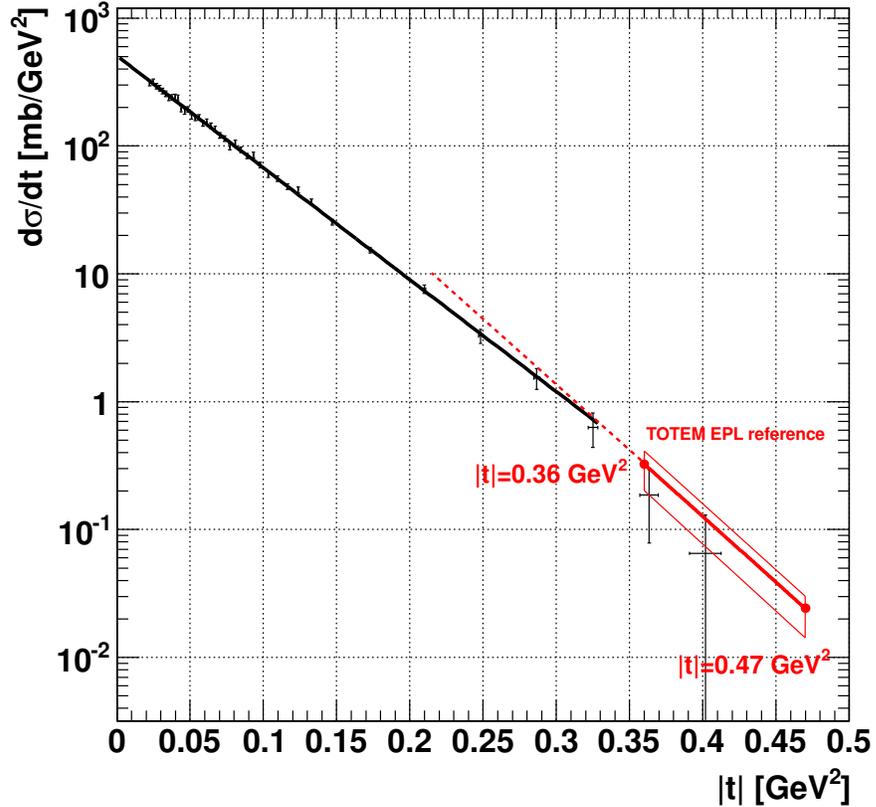


Figure 2: Differential Proton-Proton elastic cross section at small  $|t|$  .

tainties, the final differential cross-section  $d\sigma/dt$  for elastic pp scattering is given in Figure 1 covering a  $|t|$  range from  $0.36$  to  $2.5 \text{ GeV}^2$ . At  $|t|$  values below  $0.47 \text{ GeV}^2$ , the data can be described by an exponential function proportional to  $e^{-B|t|}$  with slope  $B = (23.6 \pm 0.5_{stat} \pm 0.4_{syst}) \text{ GeV}^{-2}$ .

In June 2011 data were collected in the first LHC run with the  $\beta^* = 90m$  optics [6]. Each beam had two bunches with populations of  $1 \times 10^{10}$  and  $2 \times 10^{10}$  protons. Given the normalised transverse emittances of  $(1.82.6) \mu\text{mrad}$  depending on the bunch, this filling scheme led to an instantaneous luminosity of about  $8 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$ . Thanks to the low beam intensity, the RP detectors could safely approach the beam centre to a distance of 10 times the transverse beam size. Within the running time of 33 minutes, an integrated luminosity of  $1.7 \mu\text{b}^{-1}$  was delivered, and 66950 events were recorded with a very loose trigger requiring a track segment in any of the vertical RPs in at least one of the two transverse projections  $(u, v)$ . The data sample relevant for this analysis consisted of 15973 events characterised by the elastic double-arm

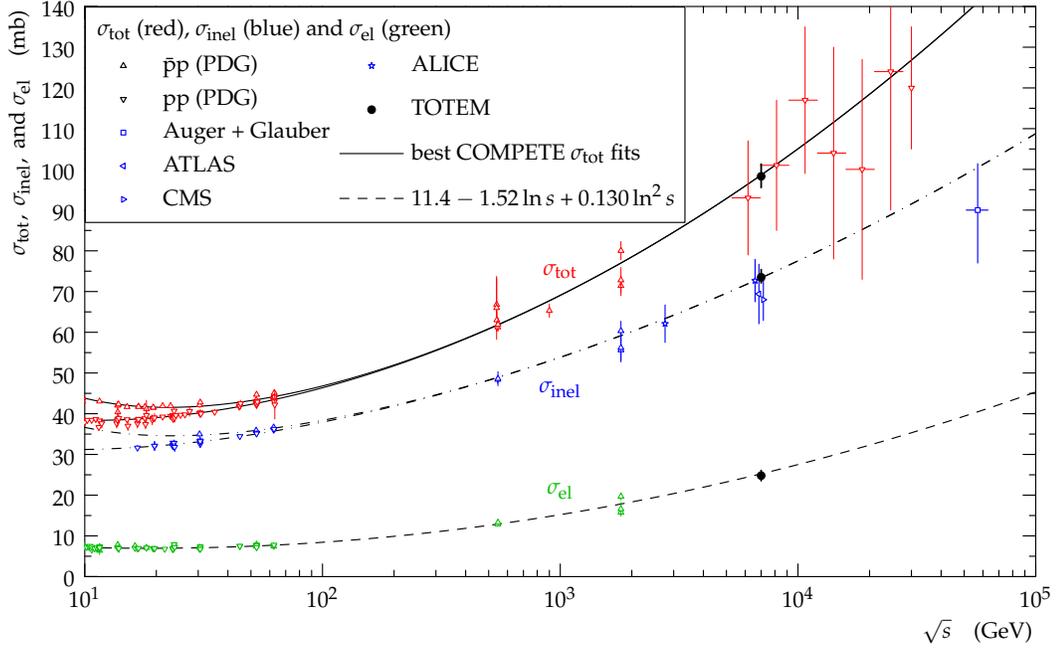


Figure 3: Total, elastic and inelastic Proton-Proton cross section .

signature in the vertical RPs. After including all the analysis corrections, the final differential cross-section for the elastic proton-proton scattering with its statistical errors is shown in Figure 2. The new data can be described by a single exponential fit ( $\chi^2/d.o.f. = 0.8$ ) over the complete  $|t|$  range of  $(0.02 - 0.33)GeV^2$  with the slope  $B = (20.1 \pm 0.2(stat) \pm 0.3(syst))GeV^{-2}$ . Assuming a constant slope  $B$  for the nuclear scattering, the differential cross-section at the optical point  $t = 0$  was determined to be  $\frac{d\sigma}{dt}|_{t=0} = (503.7 \pm 1.5(stat) \pm 26.7(syst))mb/GeV^2$ . Integrating the differential cross-section yields a total elastic scattering cross-section of  $(24.8 \pm 0.2(stat) \pm 1.2(syst))mb$ , out of which  $16.5mb$  were directly observed. The total proton-proton cross-section is related to the elastic cross-section via the optical theorem, and tacking the COMPETE prediction for the parameter  $\rho = 0.14_{-0.08}^{+0.01}$ ,  $\sigma_{tot}$  was thus determined to be  $\sigma_{tot} = 98.3 \pm 0.2(stat)_{-2.6}^{+2.8}(syst)mb$  (Figure 3). The errors are dominated by the extrapolation to  $t = 0$  and the luminosity uncertainty.

## 4 T2 $dN/d\eta$ measurement

In may 2011 data were taken with a limited luminosity of about  $10^{30}cm^{-2}s^{-1}$  with a population per bunch of about  $10^{10}$  protons. The probability of overlapping events is thus negligible, allowing the measurement of the  $dN/d\eta$  in the  $5.3 < \eta < 6.5$

region. The measurement shows a linear dependence starting from  $dN/d\eta = 3.2 \pm 10\%$  for  $\eta = 5.3$  and  $dN/d\eta = 2.4 \pm 10\%$  for  $\eta = 6.5$ . Most of the systematic errors are dominated by the extrapolation of the fraction of primary charged particles and secondary charged particles. In fact T2 has a lot of material from the vacuum chamber and vacuum ion pumps placed in front of it. The simulation of the material and the production of secondary particles is very delicate and model dependent. A detailed paper describing this measurement will follow soon.

## 5 conclusions

The Totem experiment has successfully taken data in the last LHC running year. The data taken with different beam and optics conditions has given the opportunity to measure the differential elastic cross section, total cross section and particle production in the forward region at  $5.3 < \eta < 6.5$  of pp interactions at  $\sqrt{s} = 7$  TeV. In november a dedicated run with high  $\beta$  optics has been performed although the emittancies of the beams were quite large, the RPs have been approached to the beam up to 5 times the beam size. The physics program for this run foresees the measurement of the total cross section with the luminosity independent method, requiring the measurement of the inelastic rate from T1 and T2. Single Diffraction and Double Pomeron exchange studies are also under study.

We thank our support staff and the members of various CERN groups for contributing to the construction, installation and commissioning of the detector systems.

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