

# Measurements of Proton-Proton Elastic Scattering and Total Cross-Section at the LHC by TOTEM

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**Abstract.** The TOTEM experiment at the LHC has extended the measurement of the differential cross-section for elastic proton-proton scattering at  $\sqrt{s} = 7$  TeV to four-momentum transfers  $|t|$  as low as  $5 \times 10^{-3} \text{ GeV}^2$ . The new data were collected in different dedicated runs with a special beam optics ( $\beta^* = 90$  m) and Roman Pot detectors placed as close as 4.8 times the transverse beam size from the outgoing beams. In addition, the accompanying inelastic rates were recorded with the forward telescopes T1 and T2 for  $3.1 < |\eta| < 6.5$ . Thus the first measurement of the total proton-proton cross-section with the luminosity-independent method based on the optical theorem could be performed.

Alternatively, using the CMS luminosity measurement as an input, two additional total cross-section determinations with different systematic dependences were obtained: (a) as the direct sum of the elastic and inelastic cross-sections, and (b) calculated from only the elastic cross-section extrapolated to  $t = 0$ , as published previously [1] for an earlier data set. The results from all methods and data sets agree very well within their uncertainties.

**Keywords:** elastic scattering, LHC, total cross-section, Roman Pot, TOTEM

**PACS:** 13.85.Dz, 13.85.Hd, 13.85.Lg

## SUMMARY

This conference contribution summarises the results published in three articles:

- Ref. [2]: The pp elastic scattering differential cross-section  $d\sigma/dt$  was measured down to  $|t| \sim 5 \times 10^{-3} \text{ GeV}^2$ , normalised with the luminosity from CMS. After extrapolation to  $t = 0$ , the total pp cross-section was calculated using the optical theorem

$$\sigma_{\text{tot}}^2 = \frac{16\pi (\hbar c)^2}{1 + \rho^2} \left. \frac{d\sigma_{\text{el}}}{dt} \right|_{t=0}, \quad (1)$$

with  $\rho = 0.141 \pm 0.007$  from the COMPETE [5] preferred-model extrapolation. Finally, the inelastic cross-section was obtained by subtraction:

$$\sigma_{\text{inel}} = \sigma_{\text{tot}} - \sigma_{\text{el}}. \quad (2)$$

- Ref. [3]: The inelastic pp cross-section was directly measured with the forward trackers T1 and T2, using the luminosity from CMS for normalisation. Addition of the elastic cross-section from [2] yields a  $\rho$ -independent result for the total cross-section.

- Ref. [4]: The total cross-section was obtained from the elastic and inelastic event counts, applying the luminosity-independent method:

$$\sigma_{\text{tot}} = \frac{16\pi (\hbar c)^2}{1 + \rho^2} \frac{dN_{\text{el}}/dt|_{t=0}}{N_{\text{el}} + N_{\text{inel}}}. \quad (3)$$

At the same time this method yields the integrated luminosity:

$$\mathcal{L}_{\text{int}} = \frac{1 + \rho^2}{16\pi (\hbar c)^2} \frac{(N_{\text{el}} + N_{\text{inel}})^2}{dN_{\text{el}}/dt|_{t=0}}. \quad (4)$$

The result was found to be in excellent agreement with the CMS measurement. Furthermore, the elastic and inelastic rate measurements can be combined with the CMS luminosity measurement to obtain  $\rho^2$ :

$$\rho^2 = 16\pi (\hbar c)^2 \mathcal{L}_{\text{int}} \frac{dN_{\text{el}}/dt|_{t=0}}{(N_{\text{el}} + N_{\text{inel}})^2} - 1 = 0.009 \pm 0.056 \quad (5)$$

or  $|\rho| = 0.145 \pm 0.091$ .

A numerical overview of the cross-section results is given in Table 1. The four results, having very different systematic dependences, are in excellent agreement.

**TABLE 1.** Cross-section summary. The statistical uncertainties are negligible and therefore omitted. The systematic-uncertainty contributions are grouped into several categories – *el* (from the elastic-scattering analysis), *inel* (from the inelastic-scattering analysis), *lumi* (from the 4% uncertainty of the CMS luminosity measurement) and *rho* (from the COMPETE  $\rho$  extrapolation, considering only the uncertainty of  $\pm 0.007$  related to their preferred model) – together forming the *full* systematic uncertainty (components combined in quadrature, including their correlations).

	elastic only: Eq. (1) June 2011 published in [1]	elastic only: Eq. (1) October 2011 published in [2]	$\mathcal{L}_{\text{int}}$ -independent: Eq. (3) October 2011	$\rho$ -independent (sum el. + inel.) October 2011
	full	el lumi rho $\Rightarrow$ full	el inel rho $\Rightarrow$ full	el inel lumi $\Rightarrow$ full
$\sigma_{\text{tot}}$ [mb]	98.3 $\pm$ 2.8	98.6 $\pm$ 1.0 $\pm$ 2.0 $\pm$ 0.1 $\Rightarrow$ $\pm$ 2.2	98.0 $\pm$ 1.8 $\pm$ 1.7 $\pm$ 0.2 $\Rightarrow$ $\pm$ 2.5	99.1 $\pm$ 0.3 $\pm$ 1.7 $\pm$ 4.0 $\Rightarrow$ $\pm$ 4.3
$\sigma_{\text{inel}}$ [mb]	73.5 $\pm$ 1.6	73.2 $\pm$ 0.8 $\pm$ 1.0 $\pm$ 0.1 $\Rightarrow$ $\pm$ 1.3	72.9 $\pm$ 1.1 $\pm$ 0.9 $\pm$ 0.1 $\Rightarrow$ $\pm$ 1.5	73.7 $\pm$ 1.7 $\pm$ 3.0 $\Rightarrow$ $\pm$ 3.4
$\sigma_{\text{el}}$ [mb]	24.8 $\pm$ 1.2	25.4 $\pm$ 0.3 $\pm$ 1.0 $\Rightarrow$ $\pm$ 1.1	25.1 $\pm$ 0.6 $\pm$ 0.9 $\pm$ 0.0 $\Rightarrow$ $\pm$ 1.1	25.4 $\pm$ 0.3 $\pm$ 1.0 $\Rightarrow$ $\pm$ 1.1

## ACKNOWLEDGMENTS

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## REFERENCES

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