PROCEEDINGS OF SCIENCE

First TOTEM measurement of large $|t|$ proton proton elastic scattering at the LHC energy of $\sqrt{s} = 7$ TeV

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TOTEM has measured the differential cross-section for elastic proton-proton scattering at the LHC energy of $\sqrt{s} = 7$ TeV analysing data from runs with a standard $\beta^* = 1.5$m optics. The differential cross section is measured over a $|t|$-range from 0.36 to 2.5 GeV^2. The differential cross-section shows a significant diffractive minimum at $|t| = (0.53 \pm 0.01^{\text{stat}} \pm 0.01^{\text{syst}})\,\text{GeV}^2$. For $|t|$-values larger than $\sim 1.5\,\text{GeV}^2$, the cross-section exhibits a power law behaviour with an exponent of -7.8 $\pm$ 0.3$^{\text{stat}} \pm 0.1^{\text{syst}}$. The data are compared to predictions based on different available models and show a strong discriminative power.

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1. Introduction

The TOTEM experiment[1] is designed to measure simultaneously the differential distribution of the elastic scattering and the total inelastic rate in order to measure the total proton-proton cross section with a Luminosity independent method. The experimental apparatus has two sets of different detectors to perform the simultaneous measurements: to measure elastic scattering a set of Roman Pot stations (RP) are mounted symmetrically (interaction point IP5) in the very forward region after the magnets of the long straight section insertion optics of the LHC accelerator. To measure the total interaction rate by identifying interactions with particles two telescopes of tracking detectors are installed symmetrically in the forward region of the CMS experiment to cover the rapidity range $3.1 <|\eta|< 4.7$ and $5.3<|\eta|< 6.5$. TOTEM has equipped its RP with silicon detectors of special conception[2] designed to be sensitive already 50 μm from the detector edge in order to reach the lowest value of $|t|$ by measuring elastically scattered protons as close as possible to the circulating beams. The data presented here have been collected in 2010 during the standard optics run of the LHC with a $\beta^* = 3.5\,\text{m}$.

2. The analysis

An excellent understanding of the behaviour of the optics and the alignment of the detectors with respect to the beam orbit is required to measure precisely the scattering angle: the magnetic elements of the insertion (five quadrupoles and two bending magnets on each side of the IP) can be seen as a very sophisticated magnetic spectrometer that allows the precise determination of the scattering angles of the protons interacting in IP5. Particular care was put in the fine alignment of the detectors with respect to the beam line with a special procedure[3], and to each other using tracks going through the overlap between vertical and horizontal RPs. Once reconstructed, the smearing of the angle correlation plots of single proton tracks reflects the beam angular spread. The selection of the elastic scattering events is performed applying a 3 σ collinearity cut. A fit of these distributions gives a value consistent with the beam angular divergence. The distribution of the events lying outside the 3σ cuts describe the $|t|$ dependent background evaluated to be $(8\pm1)\%$ inside the 3σ collinearity cut. The relevant optics parameters, such as magnet strengths and magnet rotations, the position of the RP and the LHC absolute momentum scale have been obtained by refitting the data within their nominal uncertainties, obtaining reasonable pull distributions. The total acceptance has been computed as a function of the vertical direction y and the azimuth ϕ. The correction factors are large at t values close to the acceptance limits at the detector edges and to avoid too large corrections the present measurement is limited to the range $0.36 < |t| < 2.5\,\text{GeV}^2$. The time dependent instantaneous luminosity was taken from the CMS measurement [4]. Its determination is based on a van der Meer scan whose uncertainty was 4 % for the data presented

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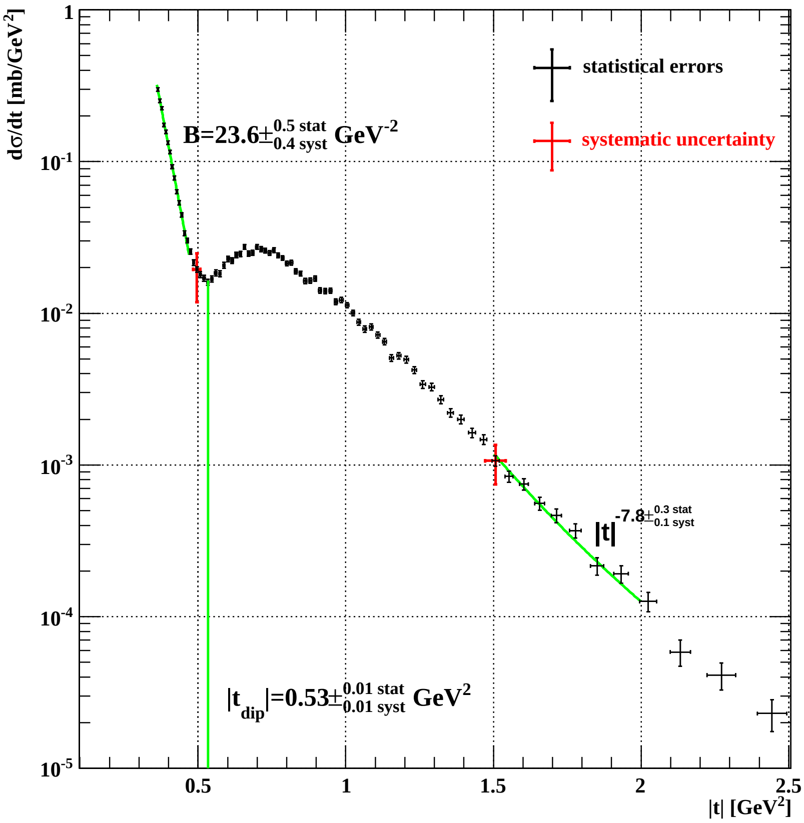

Figure 1: The measured differential cross-section $d\sigma/dt$. The superimposed fits and the parameters values are discussed in the text.

in this paper. The uncertainty in the t determination is given by the beam divergence whereas the statistical error in $d\sigma/dt$ is given by the number of events. The systematic uncertainty in t is dominated by optics and alignment. The systematic uncertainties in $d\sigma/dt$ are dominated by the uncertainty on the (t-independent) efficiency correction and on the resolution unfolding, which depends on the t measurement errors and hence on the uncertainty on the beam divergence. Both systematic uncertainties are correlated in t, therefore they mainly represent a global shift of the absolute scale of the $d\sigma/dt$ distribution. A more detailed description of the analysis can be found in reference [5].

3. Results

After unfolding and inclusion of all systematic uncertainties the final differential cross-section $d\sigma/dt$ for elastic pp scattering is given in Fig. 1 covering a $|t|$ range from 0.36 to 2.5 GeV^2.

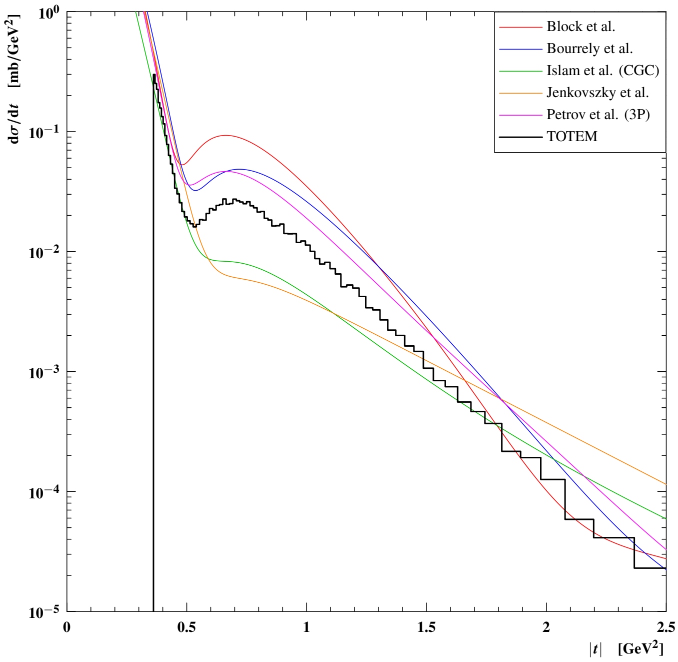

Figure 2: The measured $d\sigma/dt$ is compared to the predictions of several models (see Table 1).

An approximately exponential behaviour at small $|t|$ is followed by a diffractive minimum at $|t| = (0.53 \pm 0.01^{\text{stat}} \pm 0.01^{\text{syst}})\,\text{GeV}^2$. This pronounced dip, observed in pp but not in $\bar{\text{p}}$p scattering, moves to smaller $|t|$ values with increasing collision energy. This trend already observed at the ISR is now confirmed at $\sqrt{\text{s}} = 7\,\text{TeV}$. Above the dip structure the differential cross-section becomes flatter and can be described with a power law $|t|^{-n}$ with an exponent $n = 7.8 \pm 0.3^{\text{stat}} \pm 0.1^{\text{syst}}$ for the available $|t|$-range between $1.5\,\text{GeV}^2$ and $2.0\,\text{GeV}^2$.

4. Model comparison

In Fig. 2 the measured differential cross-section $d\sigma/dt$ is compared to the predictions from several models [6, 7, 8, 9, 10] at $\sqrt{s} = 7\,\text{TeV}$ [11]. The extracted slope parameter $B(|t| = 0.4\,\text{GeV}^2)$, the $|t|$-position of the diffractive minimum, $|t_{\text{dip}}|$, the exponent n at large t and the differential cross-section at $|t| = 0.7\text{GeV}^2$ are listed in Table 1 for a quantitative comparison. Two models [7, 10] are consistent with the data for the slope parameter B at $|t| = 0.4\,\text{GeV}^2$, the dip position, $|t_{\text{dip}}|$, and the exponent n at large $|t|$, but they both disagree with the cross-section in the measured range. The other three models [8, 6, 9] are less consistent with the data presented here.

5. Conclusion

TOTEM has measured the pp elastic scattering differential cross section at large t values at energies ≈ 100 times larger than the previous measurements at the ISR. Before the end of the year in special runs with a particular setting of the machine optics TOTEM will complete its measurement

Models' prediction	$B_{(\|t\|=0.4\ \mathrm{GeV}^2)}$ [GeV^{-2}]	$\|t_{\mathrm{dip}}\|$ [GeV^2]	n in $\|t\|^{-n}(1.5-2\,\mathrm{GeV}^2)$	$\mathrm{d}\sigma/\mathrm{d}t_{(\|t\|=0.7\ \mathrm{GeV}^2)}$ [mb/GeV^2]
M.M. Block et al. [6]	24.4	0.48	10.4	$9.1 \cdot 10^{-2}$
C. Bourrely et al. [7]	21.7	0.54	8.4	$4.8 \cdot 10^{-2}$
M.M. Islam et al. [8]	19.9	0.65	5.0	$8.2 \cdot 10^{-3}$
L.L. Jenkovszky et al. [9]	20.1	0.72	4.2	$6.1 \cdot 10^{-3}$
V.A. Petrov et al. [10]	22.7	0.52	7.0	$4.6 \cdot 10^{-2}$
This measurement	$23.6 \pm 0.5^{\mathrm{stat}} \pm 0.4^{\mathrm{syst}}$	$0.53 \pm 0.01^{\mathrm{stat}} \pm 0.01^{\mathrm{syst}}$	$7.8 \pm 0.3^{\mathrm{stat}} \pm 0.1^{\mathrm{syst}}$	$2.7 \cdot 10^{-2} + 3.7\%^{\mathrm{stat}}\ {}^{+26\%^{\mathrm{syst}}}_{-21\%^{\mathrm{syst}}}$

Table 1: The values extracted from the prediction of several models and compared to the measured values of the same quantity.

of the total pp cross-section at the present LHC center of mass energy of $\sqrt{s} = 7\,\mathrm{TeV}$. The experiment will also study in detail single diffractive and double pomeron exchange events by measuring the energy of the surviving proton(s) with the RP and looking at the particle distribution with the forward telescopes.

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