

Description of pp forward elastic scattering at 7 and 8 TeV

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We analyse the recent LHC data at 7 and 8 TeV for pp elastic scattering with special attention for the structure of the real part, which is shown to be crucial to describe the differential cross section in the forward region. We determine accurately the position of the zero of the real amplitude, which corresponds to the zero of a theorem by A. Martin.

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The elastic amplitude $T(s, t)$ is a function of only two kinematical variables, controlled by principles of analyticity and unitarity, but no fundamental solution is known for its form, and representations of the differential cross section are given in terms of models, designed and applied for restricted ranges of s and t . It is expected that at high energies the s dependence becomes relatively simple, but the enormous gaps and uncertainties in the data from CERN/ISR, Fermilab and CERN/LHC do not help in tracing the s dependence with reliability. On the other hand, for a given s , the angular dependence has not been measured with uniformity in the full t -range, and the necessary disentanglement of the real and imaginary parts of the amplitude is a hard task, with unavoidable indetermination [1, 2]. The forward t range has been measured more often. Recently Totem and Atlas groups at LHC measured $d\sigma/dt$ in forward t ranges at $\sqrt{s} = 7$ and 8 TeV [3, 4, 5, 6]. These data (Table 1) offer an opportunity to study in details several aspects of the very forward region, such as the magnitudes of the real and imaginary amplitudes, the position of the zero of the real part and the first derivatives of the amplitudes with respect to the variable t (slopes). The Coulomb-nuclear interference depends on the proton electromagnetic structure, and the relative phase requires specific assumptions for the forms of the nuclear amplitudes as described in details in our recent work [7].

In the present work we propose independent parametrizations for the real and imaginary nuclear parts, writing

$$T_R^N(t) = [1/(4\sqrt{\pi} (\hbar c)^2)] \sigma(\rho - \mu_R t) e^{B_R t/2}, \quad (1)$$

and

$$T_I^N(t) = [1/(4\sqrt{\pi} (\hbar c)^2)] \sigma(1 - \mu_I t) e^{B_I t/2}. \quad (2)$$

The parameter σ is the total cross section, ρ is the ratio of the real and imaginary parts at $|t| = 0$, B_R and B_I are the local slopes of the amplitudes and the parameters μ_R and μ_I account for the existence of zeros in the amplitudes. The zero in the real part is crucial to explain the t dependence of $d\sigma/dt$ for small $|t|$.

The good quality of Totem data at 8 TeV in the forward region confirms that the differential cross section cannot be described by a pure exponential form like $d\sigma/dt = A \exp(Bt)$. The non-exponential behaviour is obvious beforehand, since the total cross sections is a sum of squared real and imaginary amplitudes with different slopes. The zero of the real part is given by $t_R = \rho/\mu_R$. We understand that this quantity is the zero predicted in the theorem by A. Martin [8].

Data analysis at $\sqrt{s} = 7$ and 8 TeV

The analysed datasets and their t ranges are listed in Table 1, where T7, T8, A7, A8 specify Totem (T) and Atlas (A) Collaborations and center-of-mass energies 7 and 8 TeV. In the measured ranges the Coulomb effects play important role and the relative Coulomb phase is properly taken into account [7].

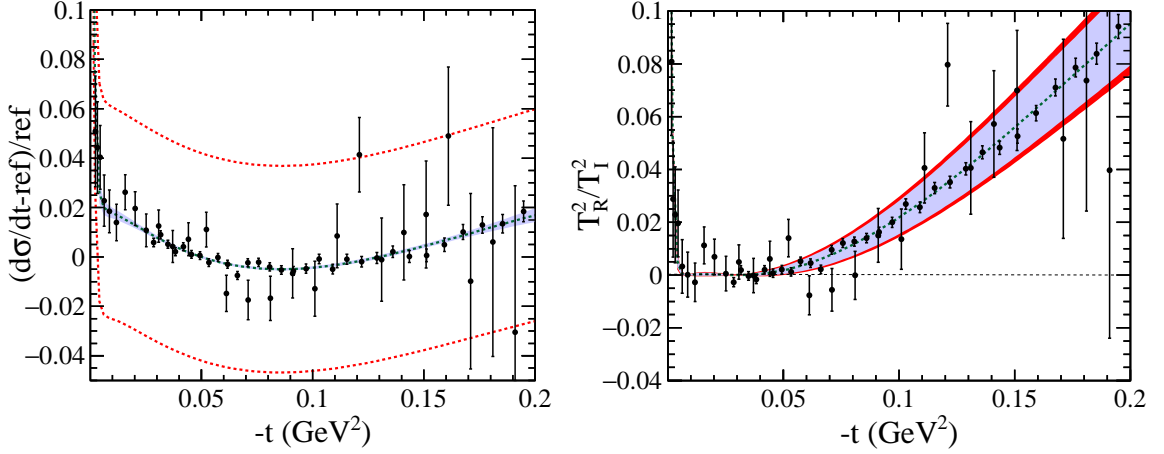


Figure 1: The left plot shows the non-exponential behaviour of the differential cross section for T8. The figure is obtained subtracting from the best fit of the differential cross section a reference function which is $d\sigma/dt$ written with a pure exponential form $ref = A \exp(Bt)$ and dividing the subtraction by this reference function. The dashed lines show the normalization error band in $d\sigma/dt$, that is quite large. The plot in the RHS shows the ratio T_R^2/T_I^2 which exhibits information of a non-exponential behaviour with advantages compared with the first plot, since σ is cancelled, and with it most of the normalization systematic error.

In order to identify values for parameters valid for all measurements, we study four different conditions in the fits: I) all six parameters are free ; II) fixing ρ at 0.14, as suggested by dispersion relations; III) fixing μ_I from the expected positions of imaginary zero [1, 2] and dip in $d\sigma/dt$; IV) fixing simultaneously ρ and μ_I at the above values. A complete table with the results can be found in ref. [7], and values obtained with Condition IV) are shown in Table 2. Fixing both ρ and μ_I at their *expected* values we obtain good modelling for all measurements, except for the total cross sections, that separate Atlas from Totem.

The regularity on the values of μ_R is remarkable. The position of the zero of the real part t_R determined by ρ/μ_R is associated with the predicted zero of A. Martin [8], is stable in all measurements with $-t_R \simeq 0.037 \text{ GeV}^2$ within the statistical errors. The position of the zero, together with the magnitude of B_R determines the structure of the amplitudes shown in Fig. 1.

The zero of the imaginary part anticipates the dip in the differential cross section that occurs beyond the range of the available data under study.

Our analysis indicates that the real amplitude plays crucial role in the description of the differential cross section in the forward region. Interference with the Coulomb interaction is properly accounted for, and use is made of information from external

\sqrt{s} (GeV)	dataset	$\Delta t $ range (GeV ²)	N points	Ref.	σ (mb)	B_I (GeV ⁻²)	ρ
7	T7	0.005149-0.3709	87	1	98.6±2.2	19.9±0.3	0.14 (fix) ^a
7	A7	0.0062-0.3636	40	2	95.35 ± 0.38	19.73 ± 0.14	0.14 (fix) ^b
8	T8	0.000741-0.19478	60	3	103.0 ± 2.3	19.56 ± 0.13	(0.12 ± 0.03) ^c
8	A8	0.0105-0.3635	39	4	96.07 ± 0.18	19.74 ± 0.05	0.1362 (fix) ^d

Table 1: Values of parameters at $\sqrt{s}=7$ and 8 TeV determined by Totem and Atlas Collaborations at LHC [3, 4, 5, 6]. Values for $\rho^{[a]}$ and $\rho^{[b]}$ are taken from COMPETE Collaboration [9]; $\rho^{[c]}$ obtained by the authors with a forward SET-I and kept fixed in a complete SET-II; $\rho^{[d]}$ is taken from [10].

Fixed Quantities : $\rho = 0.14$, $\mu_I = -2.16$ GeV ⁻² (8 TeV) [2], $\mu_I = -2.14$ GeV ⁻² (7 TeV) [1]							
	N	σ (mb)	B_I (GeV ⁻²)	B_R (GeV ⁻²)	μ_R (GeV ⁻²)	$-t_R$ (GeV ²)	χ^2/ndf
T8	60	102.40±0.15	15.27±0.39	21.15±0.39	-3.69±0.15	0.038±0.002	69.2/56
A8	39	96.82±0.11	15.26±0.06	21.65±0.24	-3.69±0.12	0.038±0.001	29.97/35
T7	87	99.80±0.21	15.71±0.14	24.26±0.47	-4.24±0.31	0.033±0.002	95.08/83
T7	87+17	99.44±0.14	15.44±0.07	22.62±0.19	-3.49±0.13	0.040±0.002	203.5/100
A7	40	95.75±0.16	15.23±0.11	21.86±0.44	-3.99±0.22	0.035±0.002	27.33/36

Table 2: Proposed values of parameters for the four datasets. The T7 data are also shown with inclusion of points at higher $|t|$ ($0.005149 < |t| < 2.443$ GeV²) that are important for confirmation of the value of μ_I [7].

sources, such as dispersion relations and predictions for the imaginary zero obtained in studies of full- t behaviour of the differential cross section [1, 2].

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References

- [1] A. Kendi Kohara, E. Ferreira, and T. Kodama, *Eur. Phys. J. C* **73**, 2326 (2013).
- [2] A. K. Kohara, E. Ferreira, and T. Kodama, *Eur. Phys. J. C* **74**, 3175 (2014) .
- [3] G. Antchev et al. (TOTEM Coll.), *Eurphys. Lett.* **101**, 21002 (2013).
- [4] G. Aad et al. (ATLAS Collaboration), *Nucl. Phys. B* **889**, 486 (2014).
- [5] G. Antchev et al. (TOTEM Coll.), *Eur. Phys. J. C.* **16**, 661 (2016) ; *Nucl. Phys. B* **899**, 527 (2015).
- [6] G. Aad et al. (ATLAS Collaboration), *Phys. Lett. B* **761** 158 (2016).
- [7] A. K. Kohara, E. Ferreira, T. Kodama and M. Rangel, arxiv.org/pdf/1709.05713.pdf, submitted to EPJC.
- [8] A. Martin, *Phys. Lett. B* **404**, 137 (1997).
- [9] J. R. Cudell et al. (COMPETE Collaboration), *Phys. Rev. Lett.* **89**, 201801 (2002)
- [10] C. Patrign *et al.* (Particle Data Group), *Chinese Physics C* **40**, 100001 (2016).