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Nuclear Physics A 922 (2014) 180–190

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Total cross sections and ρ at high energy

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Received 5 October 2013; received in revised form 5 December 2013; accepted 5 December 2013

Available online 10 December 2013

Abstract

Analysis of the new experimental data obtained by the TOTEM Collaboration at LHC at $\sqrt{s} = 7$ TeV at small momentum transfer is presented. The impact of the different assumptions on the extraction of the parameters of the elastic scattering amplitude, especially on the size of the total cross sections, is examined. It is shown that the contribution of the Coulomb amplitude and Coulomb–hadron interference term should be taken into account in the analysis of the existing experimental data at small momentum transfer. Our new method of extracting the real part of the hadron scattering amplitude from experimental data shows the inconsistency of the size of $\rho = 0.14$ to the parameters of the imaginary part of the hadron scattering amplitude obtained by the TOTEM Collaboration. The analysis of the data is compared with the similar analysis in the Regge approach for the hadron scattering amplitude.

Keywords: Hadron; Total cross sections; Elastic scattering; High energies

1. Introduction

The determination of the parameters of the elastic scattering amplitude, such as σ_{tot} – total cross sections, $\rho(s,t)$ – ratio of the real to imaginary part of the scattering amplitude, $B(s,t)$ – slopes of the imaginary and real parts of the scattering amplitude is one of the important tasks of experimental researches at the LHC. The properties of the elastic scattering amplitude at small angles are tightly connected, on the one hand, with the first principles of the theory of strong interactions and, on the other hand, with the non-perturbative properties of the hadron interaction. The knowledge of the size of the total, elastic and inelastic cross sections is important for other experimental researches at LHC. As part of the SMC Collaboration of the LHC CERN the TOTEM Collaboration (TOTal and Elastic scattering cross-section Measurement) is one of the special purpose experiments to obtain the new information about the elastic hadron scattering at LHC energies at wide momentum transfer [1]. Under various beam and background conditions, the

0375-9474/$ – see front matter
http://dx.doi.org/10.1016/j.nuclphysa.2013.12.002

differential elastic and elastic, inelastic total proton–proton cross sections have been measured. Now they published [2] the data on the differential elastic cross sections at $\sqrt{s} = 7$ TeV at the sufficiently large momentum transfer ($0.3 \leqslant |t| \leqslant 2.5$ GeV^2 and small $5 \cdot 10^{-3} \leqslant |t| \leqslant 0.4$ GeV^2 using the size of the Luminosity obtained by the SMC Collaboration. They obtained that the slope $B = 19.9 \pm 0.3$ GeV^{-2} under the assumption that the differential cross section in the region of $5 \cdot 10^{-3} \leqslant |t| \leqslant 0.2$ GeV^2 can be described by exponent with the slope independent of t. Extrapolation of the differential cross sections at $t = 0$ and the optical theorem gave the size of the total cross sections $\sigma_{tot} = 98.7$ mb. They used the size of $\rho = 0.141 \pm 0.007$ (ratio of the real to imaginary part of the elastic scattering amplitude) from the analysis carried out by the COMPETE (Computerized Models, Parameter Evaluation for Theory and Experiment) Collaboration [3] as preferred-model extrapolation. The COMPETE Collaboration considered several hundreds of possible parametrization for pp, $\bar{p}p$, $\pi^{\pm}p$, $K^{\pm}p$, γp and $\gamma\gamma$, based on simple, double or triple poles, and kept only those which had a global χ^2/point smaller than 1, for $\sqrt{s} \geqslant 5$ GeV. From these, one can predict ρ and σ_{tot} at the LHC, and estimate the error due to the extrapolation. The first results obtained by the TOTEM Collaboration [2,4] on the differential cross sections are in disfavor with practically all theoretical model predictions [2,5]. Now the models are reconstructed to obtain the coincidence with the new experimental results.

The number of elastic events is related to the total hadronic cross section through

$$\frac{dN}{dt} = \mathcal{L}\left[\frac{4\pi\alpha^2}{|t|^2}G^4(t) - \frac{2\alpha(\rho(s,t) + \phi_{CN}(s,t))\sigma_{tot}G^2(t)e^{-\frac{B(s,t)|t|}{2}}}{|t|} + \frac{\sigma_{tot}^2(1+\rho(s,t)^2)e^{-B(s,t)|t|}}{16\pi}\right] \quad (1)$$

where the three terms are due to the Coulomb scattering, Coulomb–hadron interference and hadronic interactions; $\mathcal{L}$ is the integrated luminosity, α is the electromagnetic coupling constant, $\phi_{CN}(s,t)$ is the Coulomb–hadron phase, and $G(t)$ is the electromagnetic form factor given by

$$G(t) = \frac{4m_p^2 - \mu t}{4m_p^2 - t}\frac{\Lambda^2}{(\Lambda - t)^2}, \quad (2)$$

with m_p being the proton mass, $\Lambda = 0.71$ GeV^2 and $\mu = 2.79$.

When we extract the parameters of the scattering amplitude from the experimental data, we need to use some theoretical assumption and approximations. For example, in [6,7] it was shown that the saturation regime, which can occur at the LHC energies, changes the behavior of the slope of the differential cross sections at small momentum transfer. As a result, the differential cross section cannot be described by a simple exponential form with the constant slope. Note, in (1) the assumption of the equality of the slopes of the imaginary and real parts ($B_{\mathrm{Re}}(s,t) = B_{\mathrm{Im}}(s,t)$) was used.

A remarkable example was obtained from the analysis of the experimental data at $Sp\bar{p}S$. In the proton–antiproton scattering at $\sqrt{s} = 540$ GeV there are two different measures of the size of ρ: the UA4 Collaboration ($\rho = 0.24$) and the UA4/2 Collaboration ($\rho = 0.139$). However, more careful analysis gave $\rho = 0.19$ for the data of UA4 [8] and $\rho = 0.16$ for the data UA4/2 [9]). Hence, the contradictions between the experimental data practically disappeared. In [9], it was shown that χ^2 in the fitting of the experimental data decreases by 10% if we use the slope in a more complicated form $B(t) = B_0 t + C\sqrt{t_0 - t}$. It changes the form of the differential cross section at very small momentum transfer.