Energy evolution of the large-t elastic scattering and its correlation with multiparticle production

S.M. Troshin

Institute for High Energy Physics, Protvino, Moscow Region, 142280, Russia

Abstract

It is emphasized that the collective dynamics associated with color confinement is dominating over a point-like mechanism related to a scattering of the proton constituents at the currently available values of the momentum transferred in proton elastic scattering at the LHC. Deep–elastic scattering and its role in the dissimilation of the absorptive and reflective asymptotic scattering mechanisms are discussed with emphasis on the experimental signatures associated with the multiparticle production processes.

Introduction

Studies of elastic hadron scattering where initial particles are keeping their identity can lead to a new knowledge on the nonperturbative dynamics of hadronic interactions, mechanism of confinement and asymptotic regime of strong interactions.

Concerning relation to the color confinement phenomena, it should be noted that according to the superselection rules (SSR) colored quarks and gluons live in the coherent Hilbert subspaces, and those are different from the physical Hilbert subspace populated by the white hadrons. No self-adjont operator (*related to the observable quantity*) describing transition between colored and bleached Hilbert subspaces can exist. It means that the color degrees of freedom can never be observed. It is the result of SSR for the color degrees of freedom which is combined with the non-abelian nature of QCD [1]. But it is not a proof of confinement yet — according to it, color should be confined inside hadron. There is no known dynamical mechanism providing this nowadays. Indeed, what is known is that such mechanism should be based on the collective dynamics of quarks and gluons and, as it was demonstrated in [2], the unitarity might be a consequence of the confinement.

We discuss here possible manifestations of the collective effects in hadron elastic scattering keeping in mind the connection of these effects with phenomena of color confinement.

1 Coherence in the elastic scattering

In this Section the large-t elastic scattering discussed. It should be noted that in the region of the transferred momenta beyond the second maximum in the differential cross-sections, additional dips and bumps are absent. This smooth decrease can be considered as a manifestation of the composite hadron structure, then a power-like dependence can be used as a relevant function reproducing the experimental data behavior. On the other hand, the exponential function can also be applied. Those dependencies are based on the different dynamical mechanisms, namely, power-like behavior corresponds to the composite scattering dynamics where coherence is absent and point-like constituents being independent, while the exponential form should be associated with coherent collective interactions.

The power-like parametrization $d\sigma/dt \sim |t|^{-7.8}$ has been applied for the description of the differential cross-section in the region between 1.5 (GeV)² and 2.0 (GeV)² in the paper [3]. This dependence is depicted on the Fig. 1 (red line). At the LHC energy $\sqrt{s}=7$ TeV the power-like dependence allows to fit data in the rather narrow region of the transferred momenta. At the same time the Orear

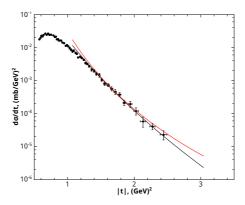


Figure 1: Dependence of the large-t elastic scattering differential cross-section.

dependence of the form [4]

$$d\sigma/dt \sim \exp(-c_{\mathbf{O}}\sqrt{-t})\tag{1}$$

can describe the experimental data better with $c_0 \simeq 12~({\rm GeV})^{-1}$, cf. Fig. 1 (solid line). The slope parameter is about twice as much bigger compared to the value of c_0 at the CERN ISR and at lower energies [5]. It is evident that the exponential dependence on $\sqrt{-t}$ describes experimental data in the wider region of -t-values and use of the power-like dependence for the data analysis seems to be premature and misleading.

Different various dynamical mechanisms can provide the Orear dependence and all of them are associted with the non-perturbative dynamics of white hadron interactions. For the first time such dependence has been obtained in the multiperipheral model [6], it has also been interpreted as a result of scattering into a classically prohibited region in [7] and as one originating from the contribution of the branching point in the complex angular momentum plane in [8]. The presence of poles in the complex impact parameter plane which can result [9] from the rational form of the scattering amplitude unitarization leads to such dependence of the scattering amplitude too. For the case of pure imaginary scattering amplitude the poles in the impact parameter plane provide the additional oscillating factors in front of the Orear exponent in the amplitude. Such oscillations are common for the picture of diffractive scattering. The absence of the oscillations at lower energies in the region of large -t can be explained by the significant role of the phase but this explanation could stop working at the LHC energies.

Alternatively, the smooth dependence of the differential cross-section observed at lower energies can be associated with the presence of the essential

¹I am indebted to S.S. Gershtein and L.N. Lipatov for bringing the papers [7] and [8], respectively, to my attention.

double helicity-flip amplitude contribution. It has been shown that the double helicity-flip amplitudes F_2 and F_4 are important at large values of -t and compensates oscillations of the helicity non-flip amplitudes [10].

If the spin effects can be neglected at the LHC energies, i.e. any helicity-flip amplitudes would not survive at such high energies, it would result in appearance of the oscillations at higher -t-values. Thus, a possible appearance of the above oscillations in the differential cross-section at higher values of -t can be interpreted in this case as an observation of the s-channel helicity conservation in pp-scattering at the LHC energies.

2 Asymptotics: reflective vs black disk

The existing experimental accelerator and cosmic rays data set for the total, elastic and total inelastic cross—sections cannot lead to the definite conclusion on the possible asymptotic hadron scattering mechanism. Therefore one should try to search for the independent experimental manifestations of the possible asymptotic mechanism. In this connection it is instrumental to consider a deep—elastic scattering. The notion of deep—elastic scattering introduced in the paper [11] uses an analogy with the deep-inelastic scattering and refers to the elastic scattering with the large transferred momenta $-t > 4~(\text{GeV/c})^2$.

With the elastic scattering amplitude being a purely imaginary function, $(f \rightarrow if)$, the function S(s,b) becomes real (S=1+2if) and can be interpreted as a survival amplitude of the prompt elastic channel. The relevant expressions for the survival amplitude S(s,b) are the following

$$S(s,b) = \pm \sqrt{1 - 4h_{inel}(s,b)},\tag{2}$$

i.e. the probability of absorptive (destructive) collisions is $1-S^2(s,b)=4h_{inel}(s,b)$ ($h_{inel}(s,b)\leq 1/4$). Simultaneous vanishing of elastic and inelastic scattering amplitudes at $b\to\infty$ should always take place and therefore only one root in Eq. (2) (with plus sign) being usually taken into account, while another one (with minus sign) is omitted as a rule. This is a well known shadow approach to elastic scattering. This is only valid in the case when $h_{inel}(s,b)$ is a monotonically decreasing function of the impact parameter and reaches its maximum value at b=0. Thus, the inelastic overlap function has a central impact parameter profile and approaches its maximum value 1/4, i.e. $h_{inel}(s,b=0)\to 1/4$ at $s\to\infty$. The survival amplitude described above, vanishes in the high energy limit in central hadron collisions, $S(s,b=0)\to 0$. However, the self-damping of inelastic channels at very high energies would lead to a peripheral dependence on the impact parameter of the inelastic overlap function $h_{inel}(s,b)$, it is vanishing at b=0 in the high energy limit $s\to\infty$. In this limit the inelastic overlap function $h_{inel}(s,b)$

reaches its maximum value at nonzero values of impact parameter b=R(s) [12]. This conclusion results from the unitarity saturation by the elastic amplitude when $f(s,b) \to 1$ at $s \to \infty$ and b=0. This saturation can be realized in the framework of the rational form of unitarization (cf. e.g. [12]). Thus, we should take $S(s,b)=-\sqrt{1-4h_{inel}(s,b)}$ when 1/2 < f(s,b) < 1. The scattering dynamics starts to be reflective in the region where very high energies combined with small and moderate values of b (it means that hard core appears) and approaches asymptotically to the completely reflecting limit (S=-1) at b=0 and $s\to\infty$ since $h_{inel}(s,b=0)\to 0$. The probability of reflective scattering at b< R(s) is to be determined then by the magnitude of $S^2(s,b)$.

Thus, the deep–elastic scattering (DES) is associated with reflective scattering at very high energies where the colliding hadrons do not suffer from absorption anymore. The DES dominates over multiparticle production (at small impact parameter values $h_{inel}(s,b=0) \rightarrow 0$). This ensures favorable conditions for the experimental measurements, since the peripheral profile of $h_{inel}(s,b)$, associated with reflective scattering, suppresses the probability of the inelastic collisions in the region of small impact parameters. The main contribution to the mean multiplicity is due to the peripheral region of $b \sim R(s)$. DES in this case is correlated with inelastic events of low cross–sections, i.e. it has a small background due to production and high experimental visibility. The reflective mechanism associated with the complete unitarity saturation will asymptotically decouple from particle production asymptotically and at finite energies it corresponds to observation of the DES with decreasing correlations with particle production. Contrary, the saturation of the black disk limit implies strong correlation of DES with multiparticle production processes [13].

Acknowledgement

I am pleased to express the gratitude to IHEP, Protvino and Organizers of Diffraction 2012 in Puerto del Carmen, Lanzarote, for the support of my participation to the Conference. The talk is based in part on the papers prepared in collaboration with N.E. Tyurin. I am grateful to him for the many useful comments and discussions. I would also like to thank L.L. Jenkovszky, U. Maor, V.A. Petrov and N.P. Zotov for the interesting remarks and discussions.

References

- [1] S. Tanimura, arXiv: 1112.5701.
- [2] S.M. Troshin, N.E. Tyurin, *Mod. Phys. Lett. A* **25**, 3363 (2010).

- [3] G. Antchev et al. (The TOTEM Collaboration), Europhys. Lett. 95, 41001 (2011).
- [4] J. Orear et al., Phys. Rev. 152, 1162 (1966).
- [5] J.L. Hartmann et al., Phys. Rev. Lett. 39, 975 (1977).
- [6] D. Amati, M. Cini, A. Stanghellini, Nuov. Cim. 30, 193 (1963).
- [7] S.P. Alliluev, S.S. Gershtein, A.A. Logunov, *Phys. Lett.* **18**, 195 (1965).
- [8] A.A. Anselm, I.T. Dyatlov, Phys. Lett. 24, 479 (1967).
- [9] V.F. Edneral, S.M. Troshin, N.E. Tyurin, *Theor. Math. Phys.* 44, 652 (1980).
- [10] V.F. Edneral, S.M. Troshin, N.E. Tyurin, *JETP Lett.* **30**, 330 (1979)
- [11] M.M. Islam, J. Kaspar, R.J. Luddy, Mod. Phys. Lett. A24, 485 (2009).
- [12] S.M. Troshin, N.E. Tyurin, Int. J. Mod. Phys. A22, 4437 (2007).
- [13] S.M. Troshin, N.E. Tyurin, Phys. Lett. B 707, 558 (2012).