Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 929 (2014) 230–245

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Cross sections, multiplicity and moment distributions at the LHC

P.C. Beggio [a,b], E.G.S. Luna [b,*]

[a] *Laboratório de Ciências Matemáticas, Universidade Estadual do Norte Fluminense Darcy Ribeiro, 28013-602, Campos dos Goytacazes, RJ, Brazil*

[b] *Instituto de Física, Universidade Federal do Rio Grande do Sul, CP 15051, 91501-970, Porto Alegre, RS, Brazil*

Received 19 March 2014; received in revised form 30 May 2014; accepted 29 June 2014

Available online 2 July 2014

Abstract

The unitarity of the S-matrix requires that the absorptive part of the elastic scattering amplitude receives contributions from both the inelastic and the elastic channels. We explore this unitarity condition in order to describe, in a connected way, hadron–hadron observables like the total and elastic differential cross sections, the ratio of the real to imaginary part of the forward scattering amplitude and the inclusive multiplicity distributions in full phase space, over a large range of energies. We introduce non-perturbative QCD effects in the forward scattering amplitude by using the infrared QCD effective charge dependent on the dynamical gluon mass. In our analysis we pay special attention to the theoretical uncertainties in the predictions due to this mass scale variation. We also present quantitative predictions for the H_q moments at high energies. Our results reproduce the moment oscillations observed in experimental data, and are consistent with the behavior predicted by QCD.

Keywords: QCD; Eikonal models; Non-perturbative QCD

1. Introduction

The study of multiple production of particles at high energies has been a subject of intense theoretical and experimental interest. Its importance lies in the fact that the multiplicity distributions of charged hadrons provide central information on the mechanism of production of the particles

* Corresponding author.

http://dx.doi.org/10.1016/j.nuclphysa.2014.06.016

[1–4]. Existing models for particle production are usually based on QCD since the production of hadrons can, at the microscopic level, be associated with the copious creation of color partons through gluon radiation. However, this approach also contains a phenomenological component as the hadronization, the transition of the quark–gluon system to hadrons, involves a soft scale, and therefore purely perturbative techniques do not apply [1–3,5,6].

The non-perturbative character of the QCD is also manifest in the elastic channel since at high energies the soft and the semihard components of the scattering amplitude are closely related [7]. Thus, in considering the forward scattering amplitude for elastic hadron–hadron collisions, it becomes important to distinguish between semihard gluons, which participate in hard parton–parton scattering, and soft gluons, emitted in any given parton–parton QCD radiation process.

Fortunately, our task of describing hadron–hadron observables in both elastic and inelastic channels, bringing up information about the infrared properties of QCD, can be properly addressed by considering the possibility that the non-perturbative dynamics of QCD generate an effective gluon mass. This dynamical gluon mass is intrinsically related to an infrared finite strong coupling constant, and its existence is strongly supported by recent QCD lattice simulations [8] as well as by phenomenological results [9–12]. More specifically, a global description of elastic and inelastic hadronic observables can succeed in a consistent way by introducing a non-perturbative QCD effective charge in the calculation of the gluon–gluon total cross section, which dominates at high energy and determines the asymptotic behavior of hadron–hadron cross sections, and by exploring the unitarity condition of the S-matrix in impact parameter space, which relates the elastic scattering amplitudes to the inelastic overlap function G_{in}.

With this background in mind, the main purpose of this paper is to explore the non-perturbative dynamics of QCD in order to describe in a connected way hadron–hadron observables in both elastic and inelastic channels, assuming the eikonal representation and the unitarity condition of the scattering matrix, and compare the results with the pp and $\bar{p}p$ experimental data of total and elastic differential cross sections, the parameter ρ and the inclusive multiplicity distributions in full phase space.

The paper is organized as follows: in the next section we introduce a QCD-based eikonal model where the onset of the dominance of semihard gluons in the interaction of high-energy hadrons is managed by the dynamical gluon mass. Motivated by the recent TOTEM measurement of the pp total cross section, σ_{tot}^{pp}, at LHC, we perform a detailed analysis of pp and $\bar{p}p$ forward scattering data and elastic differential cross sections using our eikonal model, and obtain predictions for $\sigma_{tot}^{pp,\bar{p}p}$, $\rho^{pp,\bar{p}p}$ and $d\sigma^{\bar{p}p}/dt$ at Tevatron and CERN-LHC energies. We evaluate the theoretical uncertainty associated with the dynamical mass scale and obtain predictions with uncertainty bands for $\sigma_{tot}^{pp,\bar{p}p}$ and $\rho^{pp,\bar{p}p}$. In Section 3 we present the basic formalism, as well as the underlying physical picture, of multiplicity distributions associated with charged hadron production, and introduce the theoretical prescription for connecting the elastic and inelastic channels. With the parameters of the eikonal fixed from the elastic fit, we calculate the multiplicity distribution P_n in pp and $\bar{p}p$ collisions over a large range of energies, and study the effect of the mass scale uncertainty on high multiplicities. In the sequence we calculate the H_q moments of the multiplicity distributions at high energies, where we observe that our results reproduce the oscillatory behavior predict by QCD. In Section 4 we draw our conclusions.

2. Elastic channel: the dynamical gluon mass model

QCD-inspired models are at present one of the main theoretical approaches to explain the observed increase of hadron–hadron total cross sections [10,11,13]. These models incorporate