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Gluon field fluctuations in nuclear collisions: Multiplicity and eccentricity distributions

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Abstract

We discuss different sources of fluctuations in nuclear collisions and their realization in the IP-Glasma model. We present results for multiplicity distributions in $p + p$ and $p + \mathrm{A}$ collisions and compare eccentricity (ε_2, ε_3, ε_4) distributions in $\mathrm{A} + \mathrm{A}$ collisions to the v_n distributions in 10 centrality classes measured by the ATLAS Collaboration.

Keywords: Heavy ion collisions; Particle production; Fluctuations

1. Introduction

The Color Glass Condensate (CGC) effective field theory [1] describes the generation of a dynamical transverse momentum scale $Q_s \gg \Lambda_{\mathrm{QCD}}$ at high energies, below which gluon fields saturate at occupancies of order $1/\alpha_s$. If the coupling runs as a function of this dynamical scale, $\alpha_s(Q_s) \ll 1$, weak coupling methods can be used to compute quantities that were believed previously to be intractable. This includes gluon production at low momenta where conventional perturbative methods would fail.

In this paper we use the CGC based IP-Glasma model [2,3] to compute multiplicity distributions in proton–proton, proton–lead, and lead–lead collisions, as well as the initial shape of the collision, which we characterize by its eccentricities.

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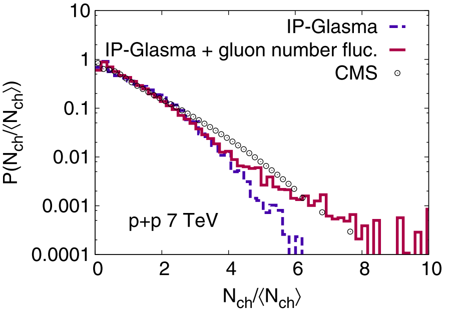

Fig. 1. Charged hadron multiplicity distribution in 7 TeV $p + p$ collisions compared to experimental data by the CMS Collaboration [8]. Result with and without additional fluctuations from fluctuating gluon numbers per flux tube.

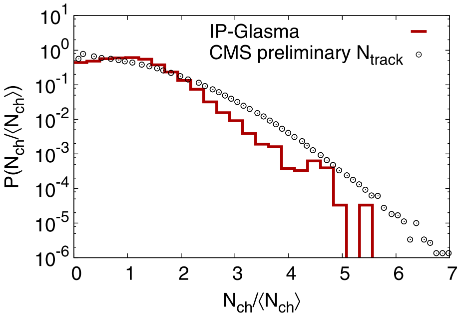

Fig. 2. Charged hadron multiplicity distribution in 5.02 TeV $p + \mathrm{Pb}$ collisions compared to uncorrected experimental data for N_{track} by the CMS Collaboration [9,10]. Result with additional fluctuations from fluctuating gluon numbers per flux tube.

2. IP-Glasma model

The IP-Glasma model is described in detail in [2,3]. It combines the IP-Sat model [4], which determines Q_s of a hadron or nucleus as a function of the gluon longitudinal momentum fraction x and the transverse spatial position in the hadron or nucleus. The parameters of the model are determined by fits to deeply inelastic scattering data from HERA [5].

The IP-Glasma model samples nucleon positions for nuclei and uses the IP-Sat Q_s distribution to compute the color charge density in the incoming hadrons/nuclei before the collision. It then samples individual color charges from this distribution. These moving color charges constitute the currents entering the classical Yang–Mills equations which determine the gluon fields within the fast moving hadrons/nuclei.

Finally, the fields at the moment of the collision are determined and evolved forward in time by means of the Yang–Mills equations. This provides the field energy–momentum tensor which can be used to generate initial conditions for hydrodynamic simulations [6]. One can further obtain gluon multiplicity distributions, which we will present in Section 3. In Section 4 we discuss how to extract the spatial energy density distribution from $T^{\mu\nu}$, determine its eccentricities ε_n,