Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 947 (2016) 142–154

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Finite numbers of sources, particle correlations and the Color Glass Condensate

Larry McLerran [a,c], Vladimir V. Skokov [b,*]

[a] Department of Physics, Brookhaven National Laboratory, Upton, NY 11973, United States
[b] RIKEN/BNL, Brookhaven National Laboratory, Upton, NY 11973, United States
[c] Physics Dept., China Central Normal University, Wuhan, China

Received 10 November 2015; received in revised form 15 December 2015; accepted 18 December 2015

Available online 23 December 2015

Abstract

We show that for a finite number of emitting sources, the Color Glass Condensate produces substantial elliptic azimuthal anisotropy, characterized by v_2, for two and four particle correlations for momentum greater than or of the order of the saturation momentum. The flow produced has the correct semi-quantitative features to describe flow seen in the LHC experiments with p–Pb and pp collisions. This flow is induced by quantum mechanical interference between the waves of produced particles, and the flow itself is coupled to fluctuations in the positions of emitting sources. We shortly discuss generalizing these results to odd v_n, to correlations involving larger number of particles, and to transverse momentum scales $\Lambda_{\mathrm{QCD}} \ll p_T \ll Q_{\mathrm{sat}}$.

Keywords: CGC; Flow; LHC; Azimuthal anisotropy

1. Introduction

It has been shown in the LHC experiments that in both pA and pp collisions, there is a substantial azimuthal anisotropy, quantified by the second Fourier harmonics also often referred to as elliptic "flow", [1–7]. This anisotropy appears in the elliptic flow coefficient v_2 for two particle correlations in $v_2\{2\}$, and for pA collisions in four particle correlations $v_2\{4\}$ and for

* Corresponding author.
E-mail address: vskokov@quark.phy.bnl.gov (V.V. Skokov).

http://dx.doi.org/10.1016/j.nuclphysa.2015.12.005

higher numbers of particles $v_2\{n\}$. There is also evidence for non-zero odd harmonics of the azimuthal anisotropy, v_3. These results suggest that a hydrodynamic treatment may be valid [8] in spite of the difficulty justifying such a description for such small systems [9]. It is nevertheless challenging to reconcile with the observation that there is little evidence for jet quenching of particles at the same transverse momentum where particles flow [2], and the fact that flow is seen at high transverse momenta where hydrodynamic descriptions are questionable.

The coefficient v_2 for two particle correlations has on the other hand been computed within the theory of the Color Glass Condensate [10–15], which for the lack of better terminology we will refer to as Glasma Graph (GG). This computation assumes a continuum of sources, and is in the limit of an infinite number of sources. The result is of order $1/N_c^2$ where N_c is the number of colors. As was later elucidated this suppression is a manifestation of Bose–Einstein enhancement of gluons in the target [16], see also discussions in Refs. [18,17]. However, it has proven difficult to use GG mechanism to extract the four particle correlation $v_2\{4\}$ since computations almost invariably lead to a four particle correlation that is positive corresponding to a complex $v_2\{4\}$, see Refs. [19–21].

One can question the CGC treatment to date as it uses a continuum of emission sources. In pA, pp and peripheral AA collisions, there is good evidence that the ellipticity that might drive hydrodynamic flow is generated by fluctuations in the emission from a finite number of sources [22–24]. Ellipticities have been calculated that semi-quantitatively agree with extraction from hydrodynamic models of experiment.

In the systems driven by fluctuations, the ellipticities that fluctuations induce vanish in the limit of an infinite number of sources. In this limit the distribution becomes uniform. Therefore the GG CGC computations will always dominate over a fluctuation induced component for sufficiently high multiplicity in the momentum domain of GG CGC applicability. Nevertheless for the multiplicities experimentally accessible, one might not be in the asymptotic limit.

The corresponding computation of the emission from the CGC for a finite number of sources is the subject of this paper. We will find that there are two effects needed to generate an acceptable $v_2\{2\}$. The first is the finite number of sources. We also find that we need to have a finite range color correlation length. This correlation length has been computed in the literature and shown to be of the order of the saturation momentum scale [25]. It arises in the evolution of gluon distribution functions. In the McLerran–Venugopalan model [27], the length is infinite, and one does not in this way generate an acceptable v_2.

Because the correlation length is of order $Q_{\rm sat}$, we will find that the characteristic momentum scale size associated with flow is the saturation momentum. Again, this is a surprise since one would have naively thought that wave interference of the emitting gluons would be on a characteristic momentum scale of the inverse source size, that is $1/R_{\rm nucleon}$ [28].

The purpose of this paper is to outline methods for the computation of $v_2\{n\}$. We explicitly compute $v_2\{2\}$, $v_4\{2\}$ and $v_2\{4\}$. We restrict our computations to transverse momentum scales greater than or of the order of that of the nuclear saturation momentum. There is no difficulty in principle computing in the extended range where $\Lambda_{\rm QCD} \ll p_\perp \ll Q_{\rm sat}$, but as a first attempt to demonstrate the method we restrict the range of momentum.

We find a semi-quantitative agreement with the experimentally measured $v_2\{2\}$. The magnitude and dependence upon $p_\perp$ appear to be roughly in agreement with experiment for reasonable choices of our parameter. We also will show that the result factorizes for momentum scales consistent with out approximation and in accord with experimental results. It is more complicated for us to compute $v_2\{n\}$ for $n \geq 4$. We can do this as an expansion in the inverse of the number of particles sources, and have done so for $v_2\{4\}$, and achieve an acceptable result. The computation