International Journal of Physics and Applications.
ISSN 0974-3103 Volume 3, Number 2 (2011), pp. 189-192

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A Numerical Analysis of Variation of Gluon-Gluon Interaction Probability $k_{GA}(x,t)$ with nuclei A in High Density QCD

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Abstract

We have studied the gluon-gluon interaction probability k_{GA} in nuclei with mass number of nuclei A. A comparative analysis of $k_{GA}(x,t)$ is made on the basis of currently available models of gluon distribution function.

Keywords: High density QCD; Gluon-gluon interaction probability; small-x physics.

PACS Nos.: 12.38.-t; 12.38.Bx; 13.60.Hb.

Introduction

Deep inelastic scattering (DIS) experiments along with high energy heavy ion collisions are furnishing crucial experimental inputs for achieving a more complete and deeper understanding of dense matter. Quantum chromodynamics (QCD) at high parton density i.e. hdQCD deals both with fundamental theoretical issues, such as unitarity of strong interactions at high energies, and with the challenge of describing experimental data coming at present from RHIC and LHC and expected exciting physics of forthcoming experiments. Over the past few years much theoretical effort has been devoted towards the understanding of the growth of the total scattering cross sections with energy [1].

While at small-x valence quarks are of little importance and the behavior of the sea is expected to follow that of the gluon distribution, which is not an observable quantity, is badly determined and represents one of the largest uncertainties in computation of cross sections both for moderate and large scales Q^2 [2]. In this situation and while waiting for new experimental data to come from lepton-ion, p-A or A-A colliders, the guidance from different theoretical models is of uttermost importance to perform safe extrapolations from the region where experimental data exist to those interesting for LHC studies [3] or physics beyond standard model.

With this aim, the present paper deals with a quantitative study of probability of gluon-gluon interaction using currently available forms of gluon distributions. We study numerically how it changes with mass number *A* of nuclei.

Formalism

The density of gluon distribution in a nucleon in high density limit is given by the solution of non-linear evolution equation which resums the power of the function [4, 5]:

$$k_g\left(x,Q^2\right)=\frac{3\pi\alpha_S\left(Q^2\right)}{2Q^2R^2}xg\left(x,Q^2\right) \tag{1}$$

which represents the probability of gluon-gluon interaction inside the parton cascade, also denoted by the packing factor of partons in a parton cascade. Here R_N is the size of the target (nucleon/nuclei) which can also be interpreted as the corelation radius between two glouns in a target at $x\approx 1$ [5]. In case of nucleons, eq.(1) is written as

$$k_{g_N}\left(x,Q^2\right)=\frac{3\pi\alpha_S\left(Q^2\right)}{2Q^2R^2}xg_N\left(x,Q^2\right) \tag{2}$$

In case of nuclei, $R_A = A^{1/3}\times R_N$ and $xg_A = A\times xg_N$ and hence this function takes the form

$$k_{g_A}\left(x,Q^2\right)=A^{1/3}\times k_{g_N}\left(x,Q^2\right) \tag{3}$$

Therefore, for the case of an interaction with nuclei, we can reach a hdQCD region at smaller parton density than in a nucleon [5]. With the introduction of our solution (22) of Ref. [6] or (13) of Ref. [7] for gluon distribution function, eq.(3) for nuclei becomes,

$$k_{G_A}\left(x,Q^2\right)=A^{1/3}\frac{3\pi\alpha_S\left(Q^2\right)}{2Q^2R^2}G(\tau)\exp\left[\begin{array}{l}\frac{(24+12k)}{(11+16k)}x\left(\frac{t}{t_0}\right)^{\frac{1}{\beta_0}(11+16k)}+\frac{(66+96k)}{\beta_0^2}\left\{\ln\left(\frac{t_0}{t}\right)\right\}^2\\ +\ln\left\{x\left(\frac{t}{t_0}\right)^{\frac{1}{\beta_0}(11+16k)}\right\}\ln\left(\frac{t_0}{t}\right)^{\frac{12}{\beta_0}}+\ln\left(\frac{t_0}{t}\right)^{\frac{1}{\beta_0}\left(\frac{2}{3}N_f+11\right)}\\ -\frac{(24+12k)}{(11+16k)}x\end{array}\right] \tag{4}$$

where τ is given by

$$\tau = x\left(\frac{t}{t_0}\right)^{\frac{1}{\beta_0}(11+16k)} \tag{5}$$

Introduction of standard DLLA (double leading logarithmic approximation) result for gluon distribution [8] in eq.(3) gives,

$$k_{G_A}^{DLLA}(x,t) = A^{1/3}\frac{3\pi\alpha_S\left(Q^2\right)}{2Q^2R^2}G\left(x,t_0\right)\exp\left[\left\{\frac{48}{\beta_0}\ln\left(\frac{t}{t_0}\right)-\ln\left(\frac{1}{x}\right)\right\}^{0.5}\right] \tag{6}$$

provided the gloun distribution is not singular at t = t_0.

Similarly, introduction of AGL [4] gluon distribution at running $\alpha_S(t)$ in eqns.(3) gives,

$$k_{G_A}^{AGL}(x,t) = A^{1/3}\frac{t}{1+t}\frac{2N_C Q^2 R_N^2}{3\pi^2}\ln\left(\frac{1}{x}\right) \tag{7}$$

Results and discussion

For quantitative analysis, we use $\alpha_S(t) = \frac{4\pi}{\beta_0 t}$, $R_N^2 = 5\ GeV^{-2}$; *A*=1 (nucleon), *A*=40 (Ca-nucleus), *A*=64 (Cu-nucleus) and *A*=197 (Au-nucleus).

Fig.1 represents variation k_{GA} with A at a fixed x = 10^{-3} and Q^2=10 GeV^2. The analysis shows that the gluon-gluon interaction probability k_{GA} increases with increase in *A* at fixed Q^2 and/or at fixed *x*; the nature of increments being different in different models; i.e., gluon-gluon interaction probability is greater in heavier nuclei.

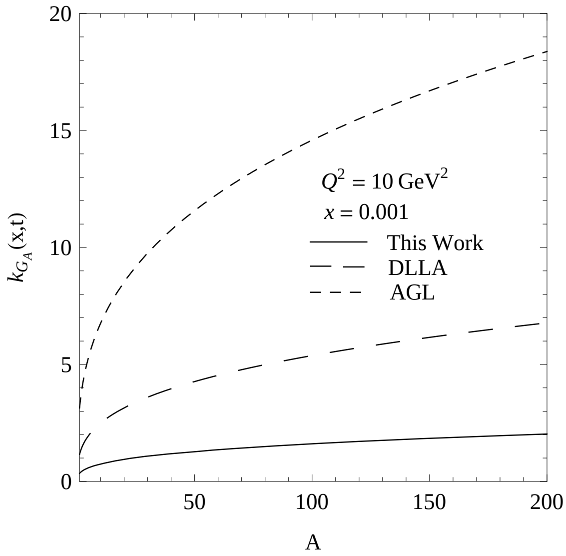

Figure 1: Variation of predicted k_{GA} with A for nuclei.

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