Fourth order corrections to the MV model, multiplicity distributions and KNO scaling

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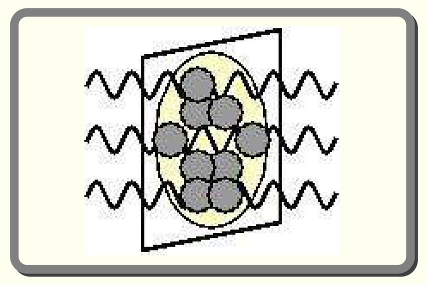
Introduction

Color Glass Condensate theory for the phenomenology of relativistic high energy collisions:

The nucleus is represented as:
Configuration of large-x sources that move ultrarelativistically + Small-x components: Gluon Color Field



McLerran-Venugopalan model ⇔ Gaussian distribution of sources

$$S_{\mathrm{MV}} = \int d^2x \frac{\delta^{ab}\rho^a\rho^b}{2\mu^2} \qquad \mu^2 \sim \frac{g^2 A}{\pi R^2}$$

Valid for a large nucleus: Mass number $A^{1/3} \to \infty$

What are the corrections for a proton?

We derive the fourth order corrections ⇔ Quartic action:

$$S[\rho(x)] \simeq \int d^2x \left[\frac{\delta^{ab}\rho^a\rho^b}{2\mu^2} - \frac{d^{abc}\rho^a\rho^b\rho^c}{\kappa_3} + \frac{\delta^{ab}\delta^{cd}+\delta^{ac}\delta^{bd}+\delta^{ad}\delta^{bc}}{\kappa_4}\rho^a\rho^b\rho^c\rho^d\right]$$

$$\kappa_3 \equiv 3\frac{g^3A^2}{(\pi R^2)^2} \qquad \kappa_4 \equiv 18\frac{g^4A^3}{(\pi R^2)^3}$$

Dipole scattering amplitude result

MV model $\quad N_{\mathrm{MV}} = 1 - \exp\left[-\frac{1}{4}r^2Q_s^2\log\left(e+\frac{1}{r\Lambda}\right)\right]$ — Overshoots the data

AAMQS fit: $\quad N_{\mathrm{AAMQS}} = 1 - \exp\left[-\frac{1}{4}\left(r^2Q_s^2\right)^\gamma\log\left(e+\frac{1}{r\Lambda}\right)\right]$ — Fit to deep inelastic scattering data with $\gamma = 1.119$ modification to the MV model

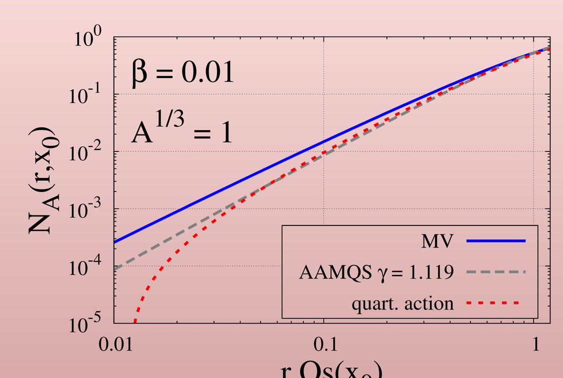
Where does the modification come from?

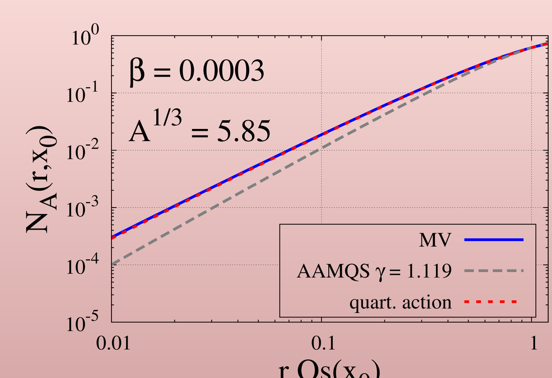
Quartic action: $$N(r) = \frac{Q_s^2r^2}{4}\log\frac{1}{r\Lambda} - \beta Q_s^2r^2\log^3\frac{1}{r\Lambda}\quad,\quad (r^2Q_s^2<1)$$

$$\beta \equiv \frac{C_F^2}{6\pi^3}\frac{g^8}{Q_s^2\kappa_4}\left[\int_{-\infty}^{\infty}dz^-\mu^4(z^-)\right]^2 \sim A^{-2/3}$$

For a proton:
The quartic action result can be matched to the AAMQS fit.

⇒ The γ modification may be due to the ρ^4 term in the action.





For a nucleus with $A = 100$:
The quartic action result overlaps with the MV model.

⇒ The γ modification should vanish for a large nucleus.

Particle multiplicity distributions result

LHC observed that multiplicities in the central region of proton-proton collisions follow a negative binomial distribution (NBD) and that they exhibit Koba-Nielsen-Olesen (KNO) scaling.

NBD: $$P(n) = \frac{\Gamma(k+n)}{\Gamma(k)\Gamma(n+1)}\frac{\bar{n}^nk^k}{(\bar{n}+k)^{n+k}}$$

$P(n)$ Probability to produce n particles
$\bar{n}$ Mean multiplicity
k Fluctuation parameter

KNO scaling: $$\bar{n}P(n) \equiv \Psi(z)$$

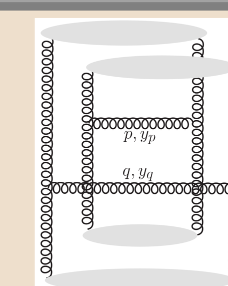
$\Psi(z)$ Energy independent function
$z \equiv \frac{n}{\bar{n}}$

NBD leads to KNO scaling for k constant and $k \ll \bar{n}$

The negative binomial distribution has been theoretically reproduced with a Gaussian MV action.

$$k = \kappa\frac{\left(N_c^2-1\right)Q_s^2S_\perp}{2\pi}$$

Calculate two-gluon production with MV.

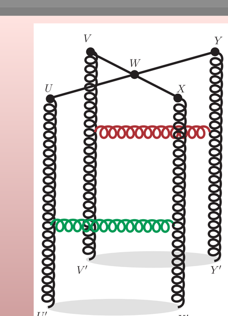


How do the corrections change the parameter k?

Quartic action $$Q_s^2S_\perp\frac{1}{k} \simeq \frac{2\pi}{N_c^2-1} - \frac{N_c^2+1}{N_c^2-1}\frac{6\pi\beta}{A^{2/3}}$$

- $\beta > 0$ makes k bigger
- To preserve KNO scaling, k has to be small

Correction diagrams:



⇒ KNO scaling constrains β i.e. the corrections to the MV model

Summary

- We derive corrections to the MV model up to fourth order in the density of color charges ρ^4;
- ρ^4 operator may explain the AAMQS model;
- KNO scaling constrains the deviation of the small-x effective action from a Gaussian.

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