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 + Small-x components:
that move ultrarelativistically
Gluon Color Field

McLerran-Venugopalan model ⇔ Gaussian distribution of sources

S_{MV} = \int d^2x \frac{\delta^2 \rho^2}{2d^2} \rho^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:

Quartic action:

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

How do the corrections change the parameter \( k \)?

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

⇒ KNO scaling constrains \( \beta \) i.e. the corrections to the MV model

Where does the modification come from?

Quartic action:

\( N(r) = \frac{Q_r^2}{4} \log \frac{1}{rA} - \beta Q_r^2 \log \frac{1}{rA} \), \( (r^2 Q_r^2 < 1) \)

\( \beta \equiv \frac{C_2^2}{6 \pi^2 \zeta_3} \left[ \int_{-1}^{\infty} dz z^2 \right] \sim A^{-2/3} \)

For a proton:

The quartic action result overlaps with the MV model.

For a nucleus with \( A = 100 \):

The quartic action result overlaps with the MV model.

⇒ The \( \gamma \) modification should vanish for a large nucleus.

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:

\[ P(n) = \frac{n^\beta}{\Gamma(n+k) \sum_k (n+k)^{n+k}} \]

\( \hat{n} \) Mean multiplicity
\( k \) Fluctuation parameter

KNO scaling:

\[ \hat{n} P(n) \equiv \Psi(z) \]

\( z \equiv \frac{1}{k} \)

NBD leads to KNO scaling for \( k \) constant and \( k \ll \hat{n} \)

Summary

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

References


Acknowledgments

We gratefully acknowledge support by the Graduate School and University Center, City University of New York, through the Doctoral Student Research Grant Program, Competition Number 7