Fluctuation Effects on R_{pA} at High Energy

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Outline

1. **Motivations**
   - QCD evolution equations at high energy
   - Effects of Pomeron Loops/Gluon Nnumber Fluctuations
2. **The ratio R_{pA} in the geometric and diffusive scaling regime**
   - R_{pA} at high energy
   - Unintegrated gluon distribution of an evolved hadron
   - R_{pA} in geometric and diffusive scaling regimes
3. **Summary**

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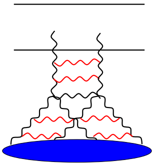
QCD evolution equations at high energy

- Kovchegov equation (***fan*** diagrams):

$$\frac{\partial}{\partial Y}\langle T\rangle_Y \quad \propto \quad \alpha_s\ [\langle T\rangle_Y - \langle T\rangle_Y \langle T\rangle_Y]$$

  - non-linear evolution, satisfies unitarity;
  - “mean field” equation;



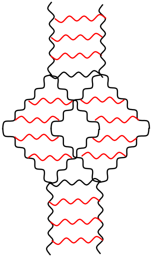
- Pomeron loop equations (***enhanced*** diagrams):
  - Langevin-type version:

$$\frac{\partial}{\partial Y} T_Y \quad \propto \quad \alpha_s \left[T_Y - T_Y\, T_Y + \sqrt{\alpha_s\, T}\ \nu\right]$$

  - Hierarchy:

$$\frac{\partial}{\partial Y}\langle T\rangle_Y \quad \propto \quad \alpha_s\ [\langle T\rangle_Y - \langle T\ T\rangle_Y]$$

$$\frac{\partial}{\partial Y}\langle T\ T\rangle_Y \quad \propto \quad \alpha_s \left[\langle T\ T\rangle_Y - \langle T\ T\ T\rangle_Y + \alpha_s^2\ \langle T\rangle_Y\right]$$

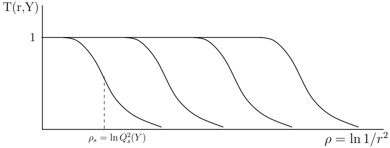


  - BFKL Pomeron Calculus, Effective Hamiltonian approach, ...
  - describe Gluon Number Fluctuations/Pomeron Loops!

Effects of Pomeron Loops/Gluon Nnumber Fluctuations

- Single events

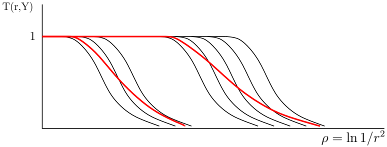
Geometric scaling



$$T(r,Y) = T(r^2 Q_s^2(Y))$$

- Average over events

Diffusive scaling



$$\langle T(r,Y)\rangle = T\left(\frac{\ln(\bar{Q}_s^2(Y)\, r^2)}{\sqrt{\alpha_s Y / \ln^3(1/\alpha_s^2)}}\right)$$

- Statistical physics $\Longleftrightarrow$ hdQCD: $\langle T(\rho-\rho_s)\rangle = \int d\rho_s\, P(\rho_s)\, T(\rho-\rho_s)$

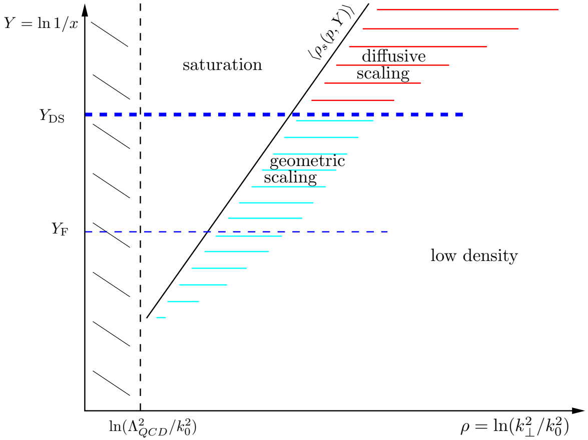
[Iancu,Mueller,Munier (2004)]

where $P(\rho_s) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp[\frac{(\rho_s - \langle\rho_s\rangle)^2}{2\sigma^2}]$, $\sigma^2 = \langle\rho_s^2\rangle - \langle\rho_s\rangle^2 = D_{dc}\alpha_s Y$

$\Longrightarrow$ shape of $\langle T\rangle$ becomes flatter with increasing Y

"Phases" of an evolved hadron

- $Y_{DS} \sim \frac{1}{D_{dc}\alpha_s} \qquad (\sigma^2 \simeq 1)$



Outline

R_{pA} at high energy

- Studied:

$$R_{pA} = \frac{h_A(k_\perp, Y)}{A^{\frac{1}{3}}\, h_p(k_\perp, Y)}\,, \qquad\qquad R_{pA} = \frac{\varphi_A(k_\perp, Y)}{A^{\frac{1}{3}}\, \varphi_p(k_\perp, Y)}$$

- "Modified" unintegrated gluon distribution:
  [Braun (2000)]

$$h_A\,(k_\perp, Y) = \frac{N_c}{(2\pi)^3\,\alpha_s} \int d^2x_\perp\, e^{ik_\perp \cdot x_\perp}\, \nabla^2_{x_\perp}\, T_A\,(x_\perp, Y)$$

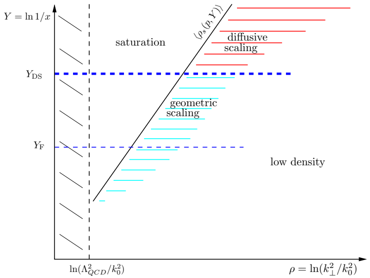
- "W-W" unintegrated gluon distribution:
  [Kovchegov, Mueller (1998)]

$$\varphi_A\,(k_\perp, Y) = \frac{N_c}{(2\pi)^3\,\alpha_s} \int \frac{d^2x_\perp}{x_\perp^2}\, e^{ik_\perp \cdot x_\perp}\, T_A\,(x_\perp, Y)$$

$\Rightarrow$ lead to the same results

- Initial conditions: Nucleus: MV-Model
  Proton: Dipole/MV-Model , $Q_s^2(A) = A^{1/3} Q_s^2(p)$

Unintegrated gluon distribution of an evolved hadron



- Geometric scaling regime (fixed α_s), $Y \ll 1/D_{dc}\alpha_s$:

$$h_A(\rho - \rho_s(A,Y)) = h_A^{\max}\ \gamma_c\ e^{-\gamma_c(\rho-\rho_s(A,Y))}\ \left(\rho - \rho_s(A,Y) + \frac{1}{\gamma_c}\right)$$

- Diffusive scaling regime (fixed α_s), $Y \gg 1/D_{dc}\alpha_s$:

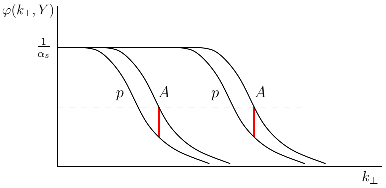
$$\langle h_A(\rho - \rho_s(A,Y))\rangle \simeq \frac{h_A^{max}}{\sqrt{2\pi\sigma^2}}\ \left(\frac{1+\gamma_c}{\gamma_c}\right)\ \exp\left[-\frac{(\rho - \langle\rho_s(A,Y)\rangle)^2}{2\sigma^2}\right]$$

- Geometric scaling regime (fixed α_s):

[Mueller (2003)], [Iancu,Itakura,Triantafyllopoulos (2004)]

$$R_{pA}(k_\perp, Y, A) \simeq \frac{1}{A^{\frac{1}{3}(1-\gamma_c)}}$$

  - partial gluon shadowing;
  - basically $k_\perp$ and Y independent;

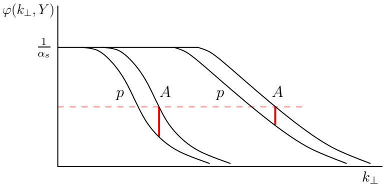


- Diffusive scaling regime (fixed α_s):

[Kozlov, Shoshi, Xiao (2006)]

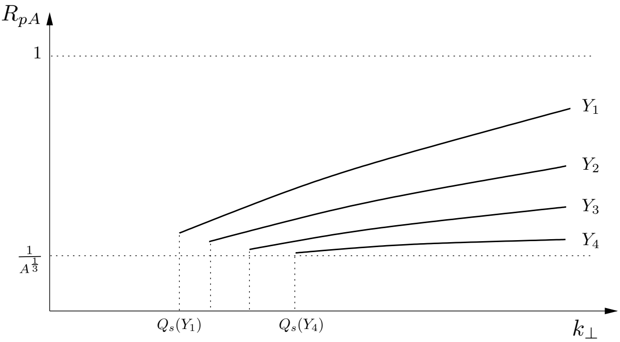
$$R_{pA} = \frac{1}{A^{\frac{1}{3}\left(1-\frac{\Delta\rho_S}{2\sigma^2}\right)}} \left[\frac{k_\perp^2}{\bar{Q}_S^2(A,Y)}\right]^{\frac{\Delta\rho_S}{\sigma^2}}$$

  - increasing gluon shadowing with Y
  - total shadowing, $R_{pA} = \frac{1}{A^{1/3}}$, for $Y \to \infty$
  - decreasing $k_\perp$ dependence with Y



General features of R_{pA} in diffusive scaling region

$Y_1 \leq Y_2 \leq Y_3 \leq Y_4$



- slope of R_{pA} becomes smaller with increasing Y
- R_{pA} goes towards $1/A^{1/3}$ with increasing Y

Outline

Summary

- LHC energy probably large enough to observe Pomeron Loops/Gluons Number Fluctuations effects
- R_{pA} is a good quantity for studying Pomeron Loops/Fluctuations effects at high energies
- With increasing rapidity, shapes of gluon distributions of nucleus and of proton become identical

For the technical details (e.g. precise form of R_{pA} for different unintegrated gluon distributions and different initial conditions):

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