Has saturation (CGC) been observed in deuteron-gold collisions at RHIC?

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Outline

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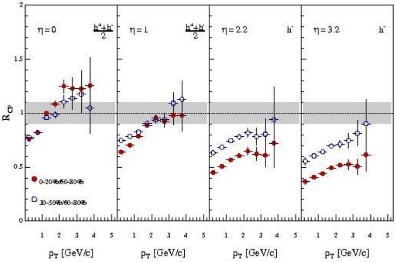
- At high density (but always in the weak coupling regime) gluons begin to overlap and the recombination is no longer negligible (non linear effects are taken into account in the BK-JIMWLK equation preserving unitarity).
- The saturation scale $Q_s(y \equiv \ln \frac{1}{x}) >> \Lambda_{QCD}$ is the relevant scale entering the description of high energy and high density systems (at RHIC $Q_s \sim 1GeV$).

BRAHMS results (2005)

The centrality dependence: C: Central, S.C: Semi-central, and P: peripheral. Black and white dots correspond respectively to C/P and S.C/P collisions.



$$R_{CP} = \frac{N^P_{coll} \frac{dN^{dA\to hX}}{d\eta d^2\mathbf{k}}|_{C(S.C)}}{N^{C(S.C)}_{coll} \frac{dN^{dA\to hX}}{d\eta d^2\mathbf{k}}|_{P}}$$

All the impact parameter dependence of the cross-section is hidden in the saturation scale.

$$Q_s^2(\mathbf{b}) \simeq Q_s^2(0) N_{part}(\mathbf{b})/N_{part}(0)$$

where **b** is the impact parameter of the collision.

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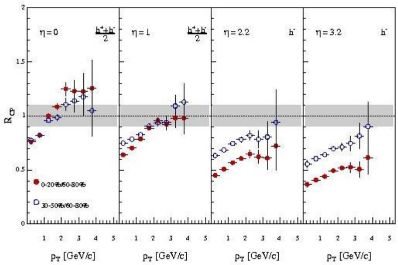

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Can one explain these results within the framework of the CGC?

Mid-rapidity hadron production in dA collisions

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- The gluon production cross-section has been calculated in the semi-classical picture of the CGC:

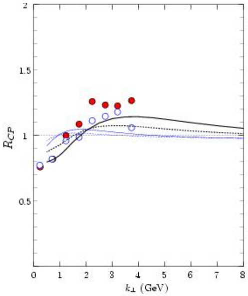
$$\frac{d\sigma}{d\eta\, d^2\mathbf{k} d^2\mathbf{b}} = \frac{C_F \alpha_s}{\pi^2} \frac{2}{\mathbf{k}^2} \int d^2\mathbf{b}' \int d^2\mathbf{r} \nabla_r^2 n_G(\mathbf{r}, \mathbf{b} - \mathbf{b}') \nabla_r^2 N_G(\mathbf{r}, \mathbf{b}) e^{i\mathbf{r}.\mathbf{k}},$$

Y. V. Kovchegov and A. H. Mueller (1998). D. Kharzeev, Y. V. Kovchegov and K. Tuchin (2003)

where $u = |\mathbf{r}|$, and the forward scattering amplitude of a gluon dipole reads (in the MV model)

$$N_G(\mathbf{r}, \mathbf{b}) = 1 - \exp[-\frac{1}{4}\mathbf{r}^2 Q_s^2(\mathbf{b}) \ln(1/|\mathbf{r}|\Lambda)]$$

Mid-rapidity hadron production in dA collisions



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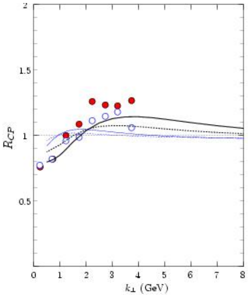

$$R^h_{CP} \sim 1 + \# \frac{\langle z^4 \rangle}{\langle z^2 \rangle} \frac{Q_s^2}{k_\perp^2} + \ldots < R^g_{CP}.$$

where

$$\langle z^n \rangle = \int_{z_0}^1 dz D_f(z, Q_f^2) z^n / \int_{z_0}^1 dz D_f(z, Q_f^2).$$

- Because of F.F's the Cronin peak gets dramatically flatted toward 1 for $Q_s^2 \sim 2$ GeV^2. To get something comparable to data one has to increase the saturation scale to a value of $Q_s^2 \sim 9$ GeV^2.

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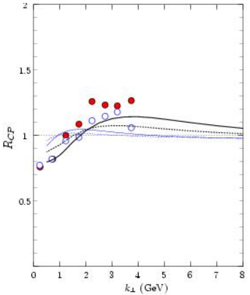

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- Intrinsic non-perturbative transverse momentum needed.

D. Kharzeev, Y. V. Kovchegov and K. Tuchin (2004). A. Accardi and M. Gyulassy (2004)
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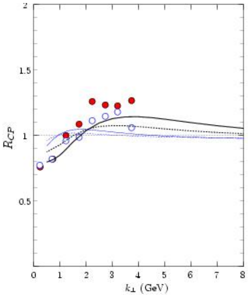

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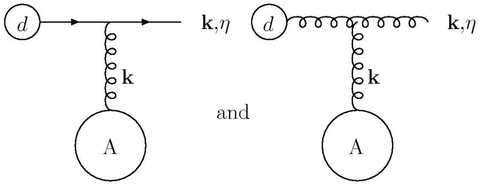
- The semi-classical picture of gluon production is not sufficient to explain the Cronin peak at RHIC.

Forward rapidity hadron production

$x_d = \frac{k_\perp}{\sqrt{s}} e^{\eta} \sim 0.2$ and $x_A = \frac{k_\perp}{\sqrt{s}} e^{-\eta} \sim 10^{-4}$.

$$\frac{d\sigma^{dA\to hX}}{d\eta d^2\mathbf{k} d^2\mathbf{b}} = \frac{\alpha_s(2\pi)}{C_F} \sum_{i=g,u,d} \int_{z_0}^{1} dz \frac{\varphi_A(x_A/z,\mathbf{b})}{\mathbf{k}^2} \times [f_i(x_d/z,\mathbf{k}^2/z^2) D_{h/i}(z,\mathbf{k}^2)]$$

where $f_{u,d}(x,\mathbf{k}^2) = (C_F/N_c) x q_{u,d}(x,\mathbf{k}^2)$ and $f_g(x,\mathbf{k}^2) = xG(x,\mathbf{k}^2)$ are the parton distributions inside the deuteron; $D_{h/i}(z,\mathbf{k})$ are F.F's of the parton i into hadron h.



- At leading twist the unintegrated gluon distribution is related to the Fourier transform of the dipole scattering amplitude:

$$\varphi_A(L,y) = \frac{4N_c}{\alpha_s(2\pi)^3}\frac{d^2}{dL^2}\tilde{N}_q(L,y).$$

where $y \equiv \ln(1/x_A)$, $L = \ln(\mathbf{k}^2/Q_s^2(\mathbf{b},y))$ and
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- The asymptotic solution of BFKL+sat ($k_\perp$ close to Q_s)

$$\tilde{N}_q(L,y) \propto \exp[-\gamma_s L - \beta(y)L^2].$$

E. Iancu, K. Itakura, L. McLerran (2002)

$\beta(y) \propto 1/y$.
$Q^2_{s.min.bias}(y) \propto A^{1/3}e^{\lambda y}$ GeV^2.
The anomalous dimension $\gamma_s = 0.628$.

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$$\tilde{N}_q(L,y) \propto L\exp[-\gamma_s L - \beta(y)L^2].$$

A. H. Mueller, D. N. Tiantafyllopoulos (2002) S. Munier, R. Peschanski (2003)

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- At $y \longrightarrow \infty$, $\tilde{N}_q$ shows an exact geometric scaling

$$\tilde{N}_q(L,y) \propto L\exp[-\gamma_s L].$$

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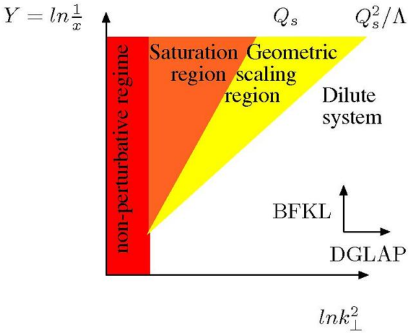
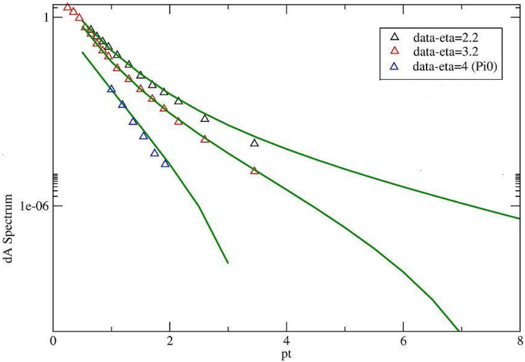
Geometric scaling region



Observables depend only on the variable $L = \ln(\mathbf{k}^2/Q_s^2(\mathbf{b}, y))$.

Data vs. theory



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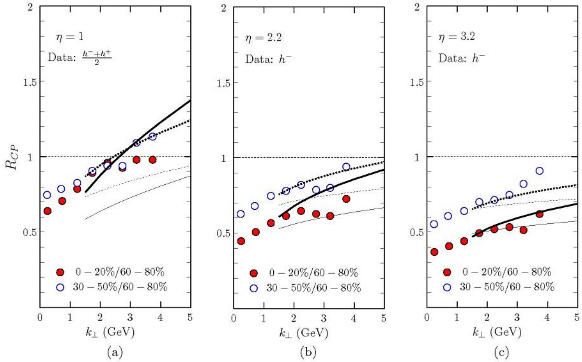
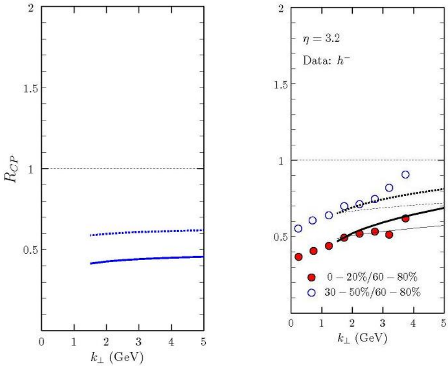


BK: thick lines. BFKL+sat: thin lines.



The exact scaling form overestimates the suppression. At larger rapidity data points should match that shape.

Interpretation

$$R_{CP} \simeq (\frac{N_{part}^{P}}{N_{part}^{C}})^{1-\gamma_{eff}}.$$

At forward rapidity $\gamma_{eff} \simeq \gamma_s + \beta(\eta)\ln(k_\perp^2/Q_s^2)$ is a decreasing function of η and an increasing function of $k_\perp$.In qualitative agreement with data. At very large η the anomalous dimension stabilizes at $\gamma_{eff} = \gamma_s$, which could be tested at the LHC.

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- Good quantitative agreement of theory with data at forward rapidity.
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- Need for higher energy data$\Rightarrow$ LHC at $\sqrt{s} = 5.5$ TeV for a crucial test. Including statistical fluctuations, predicted by the CGC, which could be relevant at such energies.