Dilepton low p_T Suppression as an Evidence of the CGC

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Talk based on work with M. A. Betemps (hep-ph/0408097 *Phys. Rev. D* in press)

Outline

- Motivation
- Color Glass Condensate
- Dilepton production in the Color Glass Condensate
- Saturation effects in the Dilepton p_T spectra
- Cronin effects in dilepton production
- Conclusions

Motivation

- Gluon High Density $\Rightarrow$ Saturation below a characteristic scale $Q_s \Rightarrow$ Color Glass Condensate (CGC).
- Search for signatures of the CGC description of the saturated regime.
- proton-nucleus collisions $\Rightarrow$ ideal experiment to investigate the saturation effects described by the CGC in the proton fragmentation region.
- Transverse momentum distribution p_T at high energies:
  - Hadron Production measured and investigated.
  - dilepton production $\Rightarrow$ sensitive probe of the perturbative shadowing and saturation dynamics in proton-proton, proton-nucleus or nucleus-nucleus scattering (needs measurements).

What we have

- Inclusive hadron production
  - To calculate the p_T and y (rapidity) distributions

$$\frac{d\sigma^{pA\to hX}}{dq_T^2 dy_h} = \frac{d\sigma^{ij\to kX}}{dq_T^2 dy_j} \otimes f_i(y_i, Q_h^2) \otimes f_j(y_j, Q_h^2) \otimes D_{k\to h}(z, Q_h^2).$$

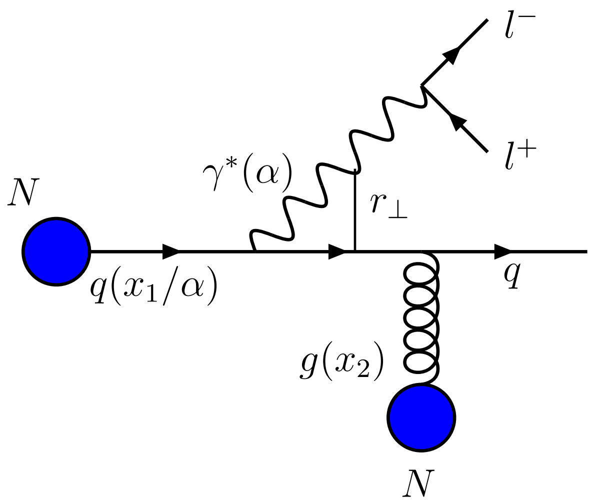
  - Needs a fragmentation function $\Rightarrow$ strongly dependent on the final state interactions
- dilepton production

$$\frac{d\sigma^{pA\to l^+ l_- X}}{dq_T^2 dy} = \frac{d\sigma^{ij\to kX}}{dq_T^2 dy} \otimes f_i(y_i, Q_h^2) \otimes f_j(y_j, Q_h^2).$$

  - Final state interactions are disregarded (eletromagnetic interaction).
  - Cleaner analysis

Perturbative Shadowing in pp collisions

Investigated in the dipole picture



Dipole ?

- $r_\perp \to$ photon-quark transverse separation,
- $\alpha r_\perp \to q\bar{q}$ (dipole) transverse separation,
- $\alpha \to$ quark light-cone momentum fraction carried by the photon,
- $x_1/\alpha \to$ projectile momentum fraction carried by the quark,
- $x_2 \to$ target momentum fraction carried by the gluon.
- $p_T \to$ tranverse momentum of the lepton pair.
- M^2 squared lepton pair mass.
- $x_F = x_1 - x_2$.

$$\frac{d\sigma_{T,L}(qN \to q\gamma^* N)}{d\ln\alpha} = \int d^2\mathbf{r}|\Psi^{T,L}_{\gamma^* q}(\alpha,\mathbf{r})|^2 \sigma^{q\bar{q}}_{dip}(x_2,\alpha\mathbf{r})$$

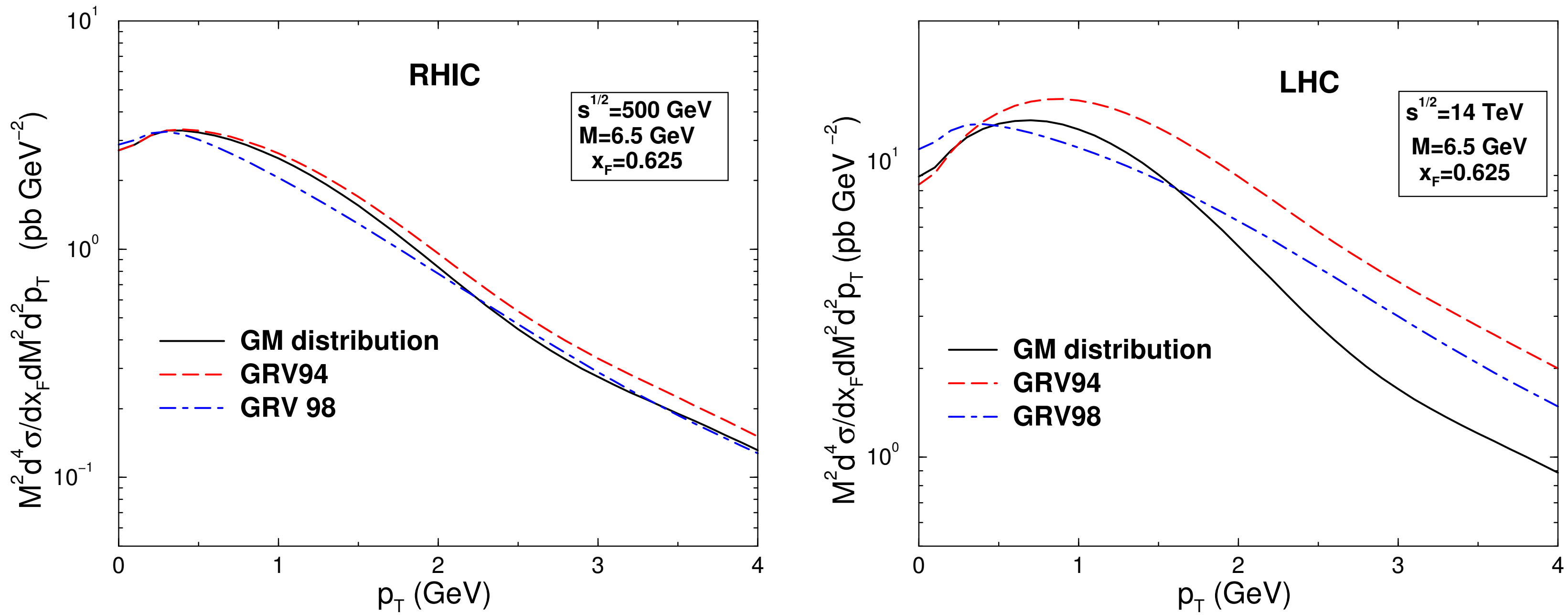
- The differential Drell-Yan cross section can be written as

$$\frac{d\,\sigma^{DY}}{dM^2 dx_F d^2p_T} = \frac{\alpha_{\mathrm{em}}}{6\,\pi M^2}\,\frac{1}{(x_1+x_2)}\int_{x_1}^{1}\frac{d\alpha}{\alpha}F_2^p\left(\frac{x_1}{\alpha}\right)\frac{d\sigma(qN\to q\gamma^* N)}{d\ln\alpha\, d^2p_T}$$

M.A. Betemps, MBGD, M. V. T. Machado,
J. Raufeisen, *Phys. Rev. D*67, n. 114008,2003

Perturbative Shadowing in pp collisions

- Perturbative corrections in the dipole cross section by Glauber-Mueller approach (AGL evolution equations)
- Comparison with the GRV predictions
- p_T distribution in pp collision (forward rapidities) at RHIC and LHC energies the DY

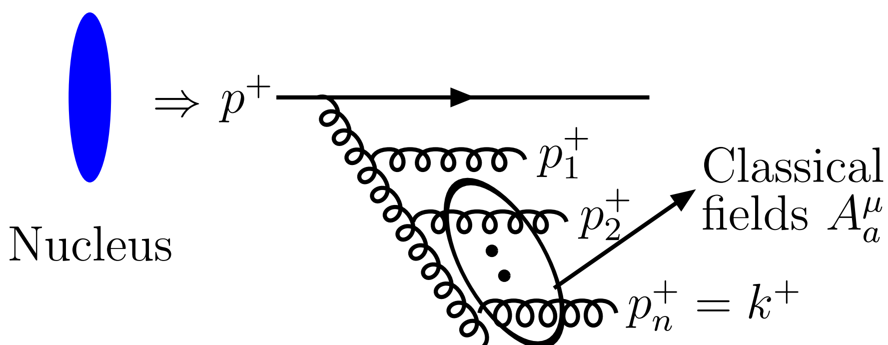


- Small corrections at RHIC energies
- Large unitarity effects at high p_T at LHC energies.
- Perturbative corrections appear at large p_T.

(Minimal) Color Glass Condensate

- Color ⇒ Gluonic field — L. McLerran, R. Venugopalan (1994)
- Glass ⇒ Internal dynamics evolves slowly
- Condensate ⇒ Dense and saturated gluon field

Use of semi-classical techniques



$p^+ > p_1^+ > p_2^+ > ... > p_n^+$

$p^+ >> p_n^+$

A_a^μ obeys Classical Yang-Mills equations,

$[D_{\mu\nu}, F_a^{\mu\nu}] = \delta^{\mu +} \rho_a(x^-, x_\perp)$.

- color charge sources density.

- x^- light-cone time.
- $\rho_a(x, x_\perp)$ stochastic variable with zero expectation value.
- average over all ρ_a configurations, with the gauge-invariant weight functional $W_{\Lambda^+}[\rho_a]$
- $p^+ > \Lambda^+$ fast gluons, $p^+ < \Lambda^+$ soft gluons.

Color Glass Condensate

- Any observable is calculated by averaging over the sources configurations by means of

$$\langle A_a^i(x^+,\vec{x})A_b^j(x^+,\vec{y})...\rangle_{\Lambda^+} = \int \mathcal{D}_\rho \, W_{\Lambda^+}[\rho] \, \mathcal{A}_a^i(\vec{x})\mathcal{A}_b^j(\vec{y}).$$

- Fundamental quantity in the CGC.
- Driven by the evolution equation JIMWLK.
- Phenomenology
  - Local Gaussian (can accommodate BFKL evolution and the gluon saturation)

$$W[x,\rho] = \exp\left\{-\int dz_\perp \frac{\rho_a(z_\perp)\rho^a(z_\perp)}{2\mu^2(x)}\right\}$$

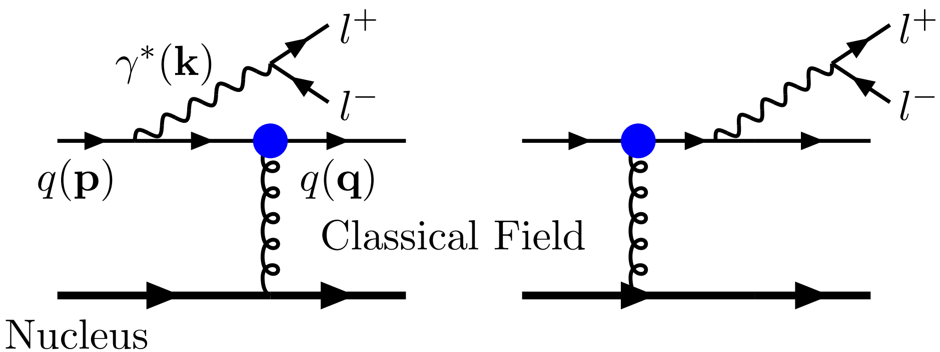
  - Non local Gaussian (Predicted by the mean field asymptotic solution of the JIMWLK evolution equations)

$$W[x,\rho] = \exp\left\{-\int dy_\perp dx_\perp \frac{\rho_a(x_\perp)\rho^a(y_\perp)}{2\mu^2(x)}\right\}$$

  - $\mu^2(x)$ is related to the average of the color charge squared.

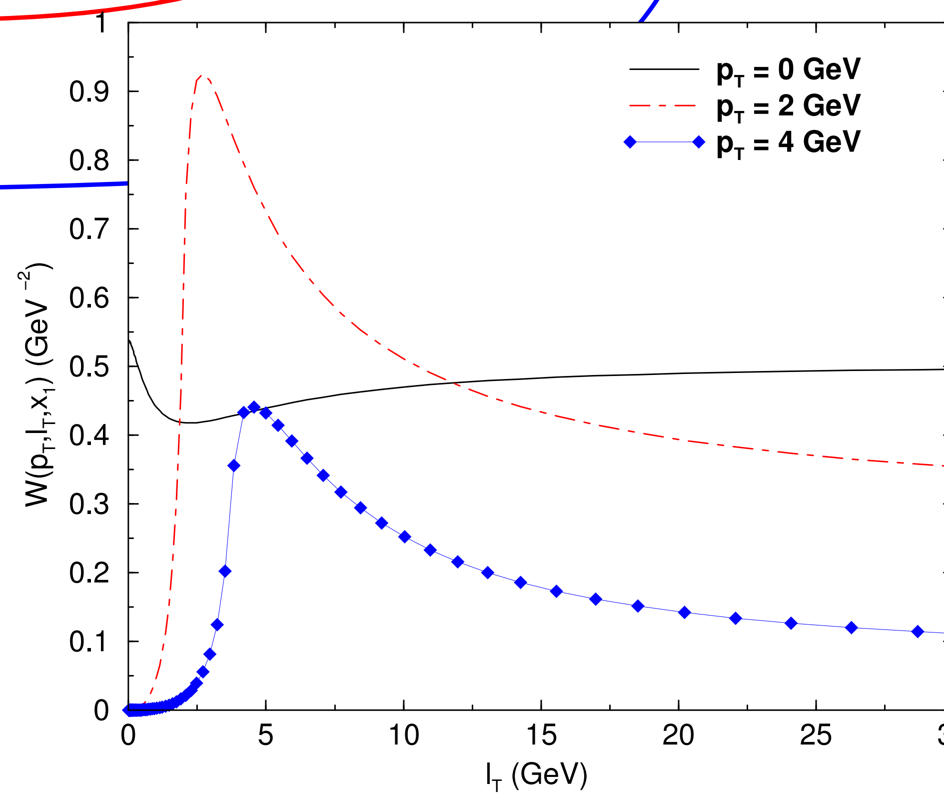
Dilepton Production in CGC

The cross section is written as



$$\frac{d\sigma^{pA\to q l^+ l^- X}}{dp_T^2\, dM\, dx_F} = \frac{4\pi^2}{M} R_A^2 \frac{\alpha_{em}^2}{3\pi} \frac{1}{x_1+x_2} \times \int \frac{dl_T}{(2\pi)^3} \quad l_T\, W(p_T, l_T, x_1)\, C(l_T, x_2, A),$$

- $W(p_T, l_T, x_1)$ analytical calculations $\Rightarrow$ select the values of l_T larger than p_T.
- $C(l_T, x_2, A)$ color field correlation $\Rightarrow$ interaction of the quark with the condensated gluonic field (Classical field).



F. Gelis, J.Jalilian-Marian, *Phys. Rev. D* 66, 094014 (2002)

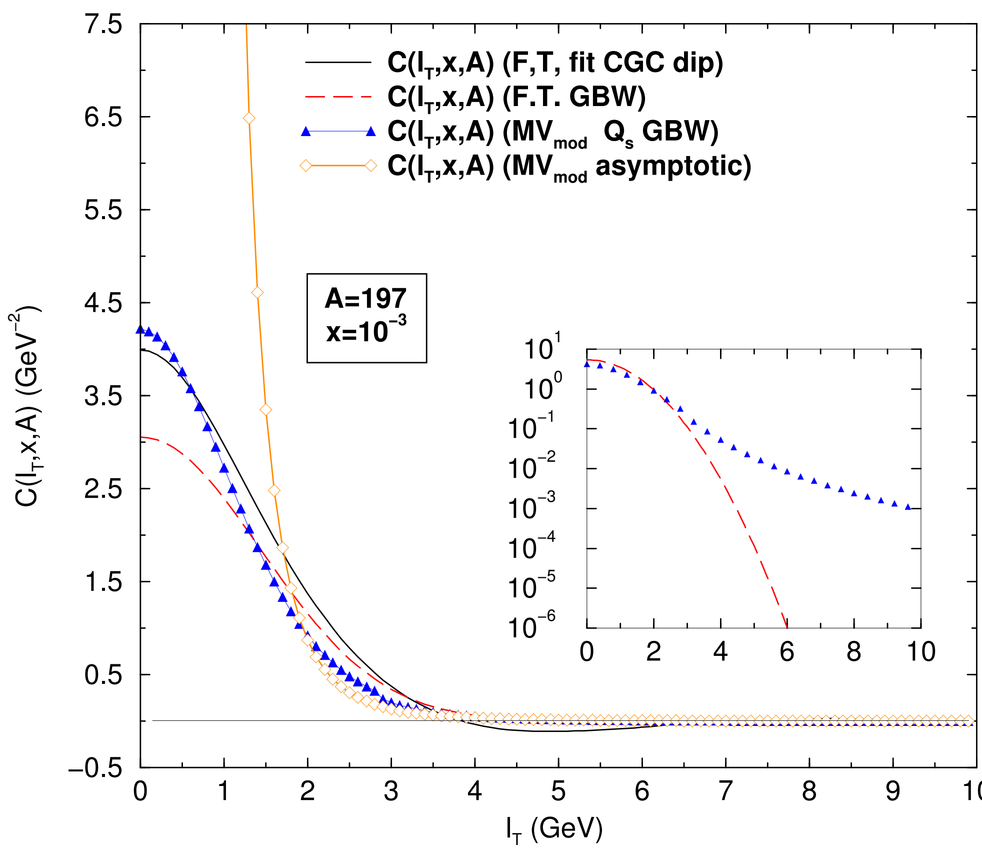
Color Field Correlation

$$C(l_T) \equiv \int d^2x_\perp e^{il_T\cdot x_\perp}\langle U(0)U^\dagger(x_\perp)\rangle_\rho,$$

- related to the Fourier transform of non-integrated gluon distribution

$$C(l_T) = \frac{1}{\sigma_0}\int d^2r e^{il_T\cdot r}[\sigma_{dip}(r\to\infty) - \sigma_{dip}(r)],$$

- We have analyzed some models for the correlation function
  - McLerran-Venugopalan
  - GBW
  - Iancu, Itakura and Munier (CGCfit)
- We use McLerran-Venugopalan



Local × Non-local

- We use McLerran-Venugopalan model with an energy dependence into the saturation scale

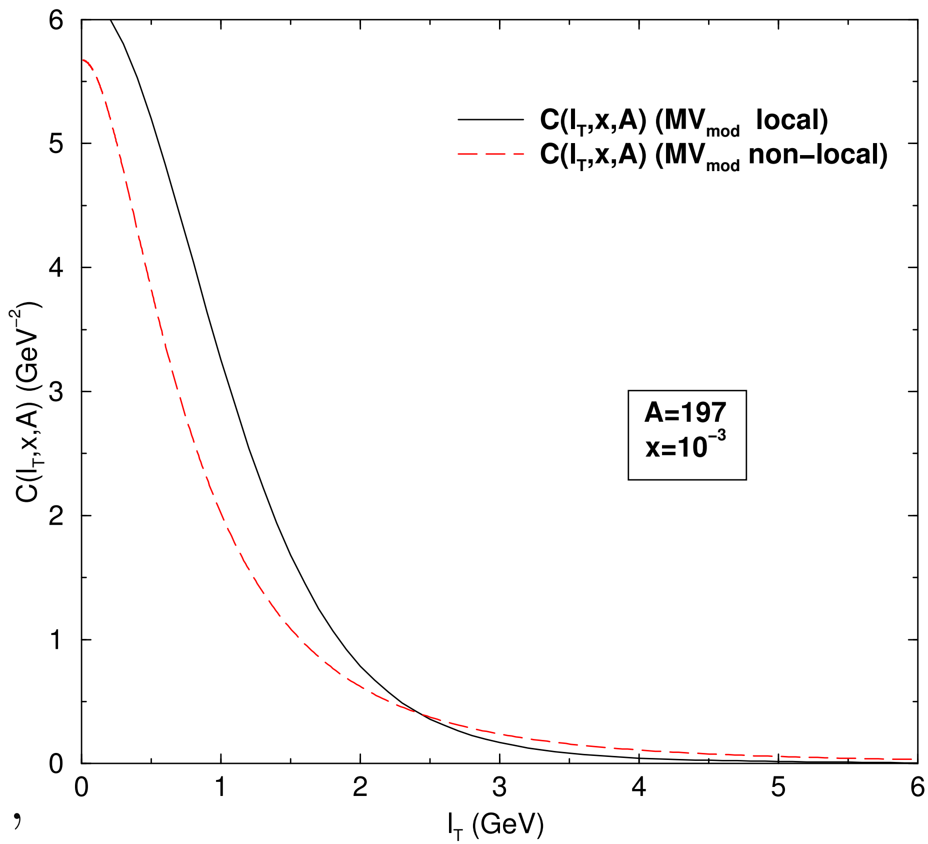
$$Q_s^2(x,A) = A^{1/3}\left(\frac{x_0}{x}\right)^{\lambda} \quad \text{parameters} \begin{cases} x_0 \\ \lambda \end{cases}$$

- Local Gaussian

$$C_{MV_{mod}}(l_T,x,A) = \int d^2x_\perp \times e^{il_T\cdot x_\perp} e^{-\frac{Q_s^2(x,A)}{\pi}\int \frac{dp}{p^3}(1-J_0(px_\perp))}.$$

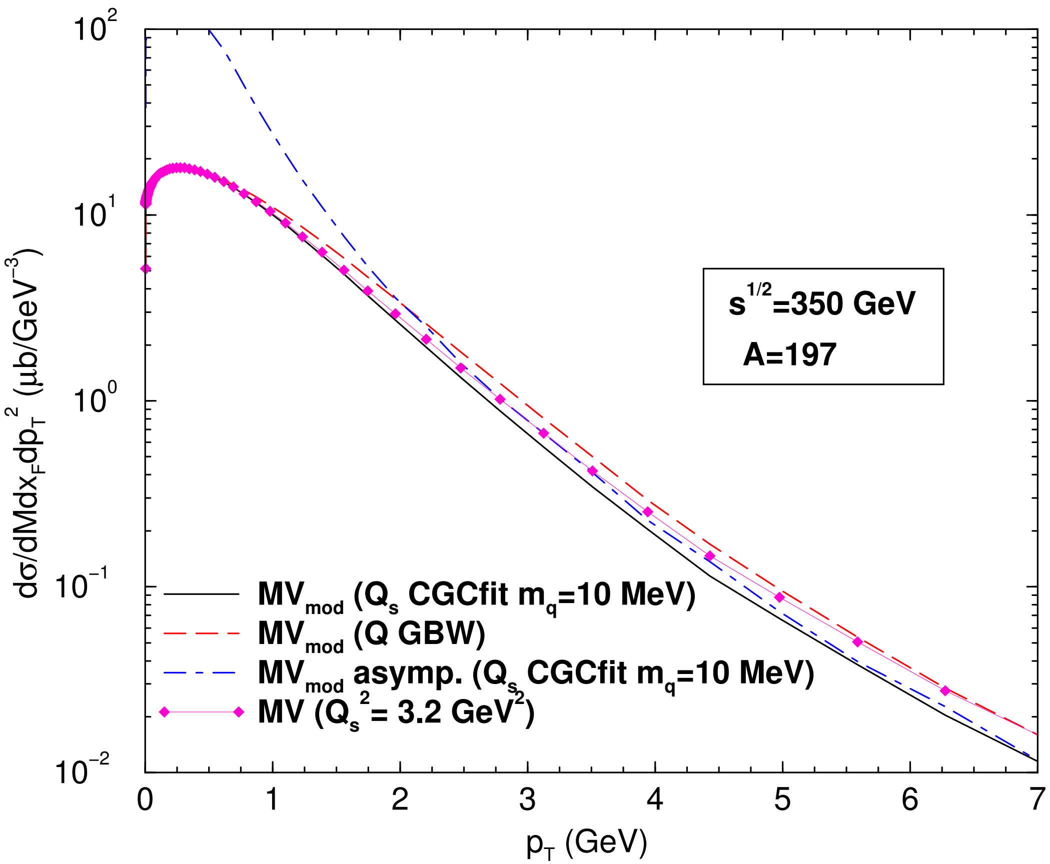
- Non-local Gaussian

$$C\ (l_T,x,A) \equiv \int d^2x_\perp e^{il_T\cdot x_\perp} \times\ e^{-\frac{2}{\gamma c}\int \frac{dp}{p}(1-J_0(x_\perp p))\ln\left(1+\left(\frac{Q_2^2(x,A)}{p^2}\right)^{\gamma}\right)},$$



Dilepton p_T spectra

RHIC



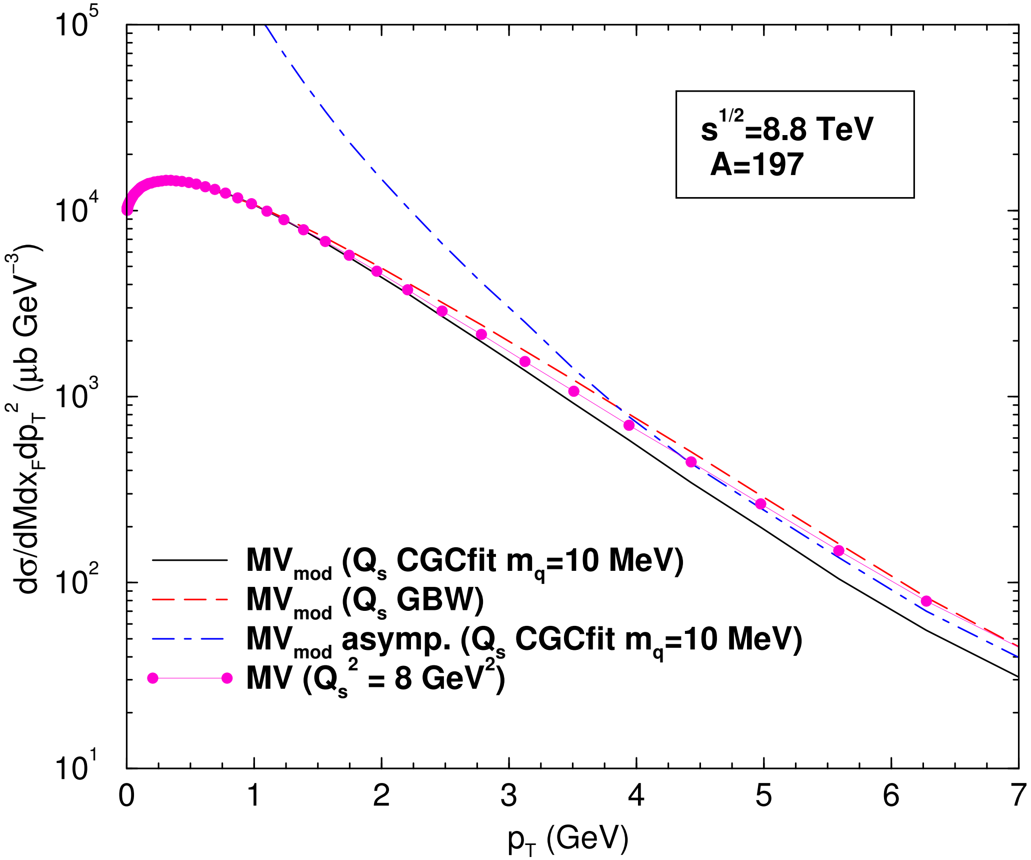
maximum RHIC energy
$M = 3$ GeV and $y = 2.2$

fits	Q_s^2 ($x = 10^{-3}$ $A = 197$)
GBW	4.114 GeV^2
CGCfit $m_q = 10$ MeV	3.069 GeV^2

- Large suppression effects at small p_T;
- Suppression below the saturation scale (Q_s);
- Dependence on the Q_s value at large p_T;
- Large value of Q_s increases the spectra at large p_T;
- Q_s x evolution yields a reduction at large p_T in comparison with the no evolution case (Magenta line).

Dilepton p_T spectra

LHC



maximum LHC energy
$M = 3$ GeV and $y = 2.2$

fits	Q_s^2 ($x = 10^{-3}$ $A = 197$)
GBW	4.114 GeV^2
CGCfit $m_q = 10$ MeV	3.069 GeV^2

- Large suppression effects at small p_T;
- Suppression below the saturation scale (larger than at RHIC energies);
- Large value of Q_s increases the spectra at large p_T;
- Q_s x evolution yields a reduction at large p_T in comparison with the no evolution case (Magenta Line).

Seeking Cronin effect in Dilepton

- Nuclear modification factor

$$R_{pA} = \frac{\frac{1}{R_A^2} \frac{d\sigma^{pA \to l^+ l + X}}{dp_T^2 dM dy}}{A^{1/3} \frac{1}{R_p^2} \frac{d\sigma^{pp \to l^+ l + X}}{dp_T^2 dM dy}}$$

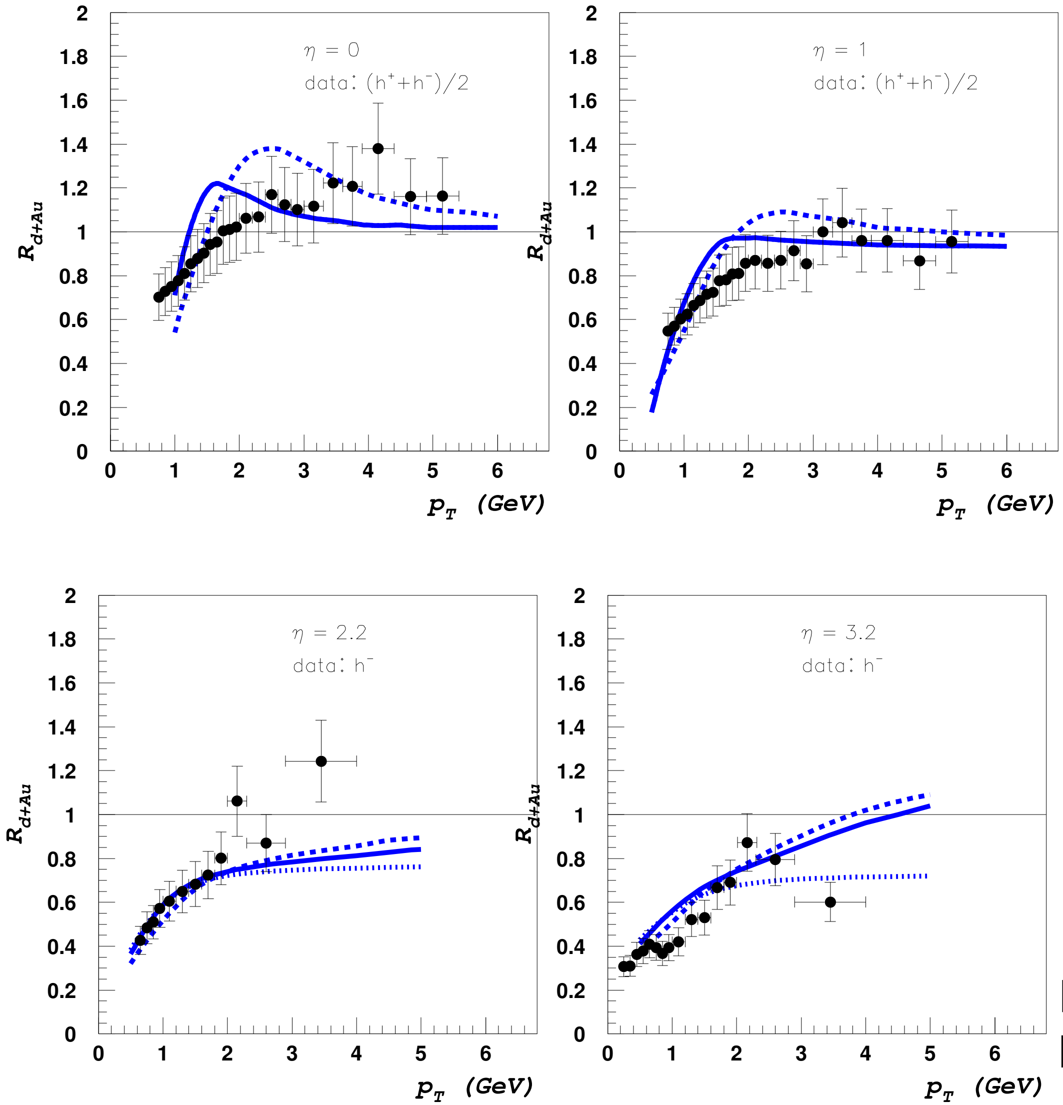
- Using the expressions to the cross section,

$$R_{pA}(y, p_T) = \frac{\int d^2 l_T W(p_T, l_T, x_1) C_A(l_T, x_2, A)}{A^{1/3} \int d^2 l_T W(p_T, l_T, x_1) C_p(l_T, x_2)},$$

- ratio between color field correlation weighted by the function $W(p_T, l_T, x_1)$;
- Similar ratio used to investigate the Cronin effect in the hadron production;

Cronin effect in the CGC approach

charged hadrons



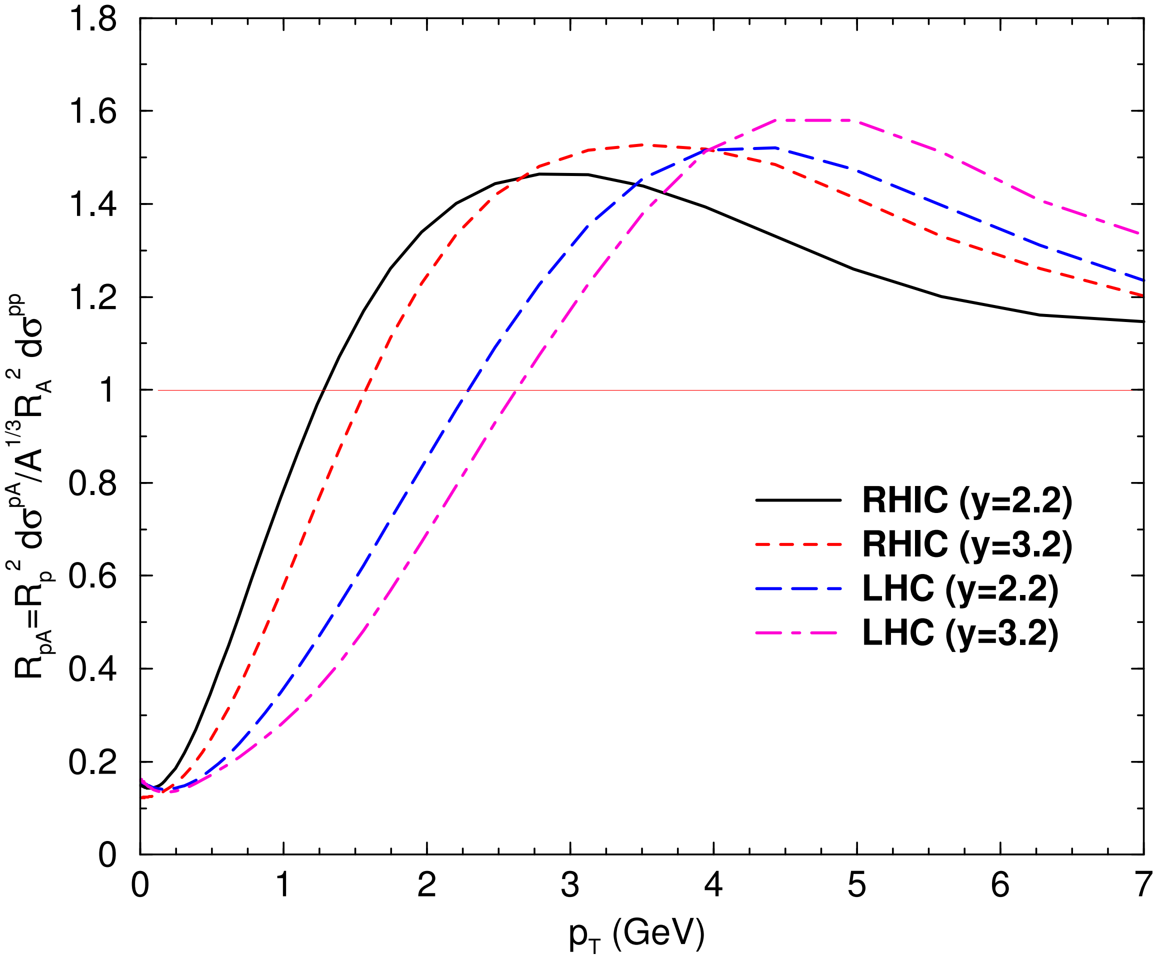
- Nuclear modification factor R_{dA}.

$$R_{dA} = \frac{\frac{d\sigma^{dA\to hX}}{dp_T^2 dy}}{\mathcal{N}_{coll} \frac{d\sigma^{pp\to hX}}{dp_T^2 dy}}$$

- data from dA collisions at $\sqrt{s} = 200$ GeV.
- BRAHMS data.
- KKP fragmentation function
- Consider valence quarks
- Introduce a functon to take into account large x gluon behavior

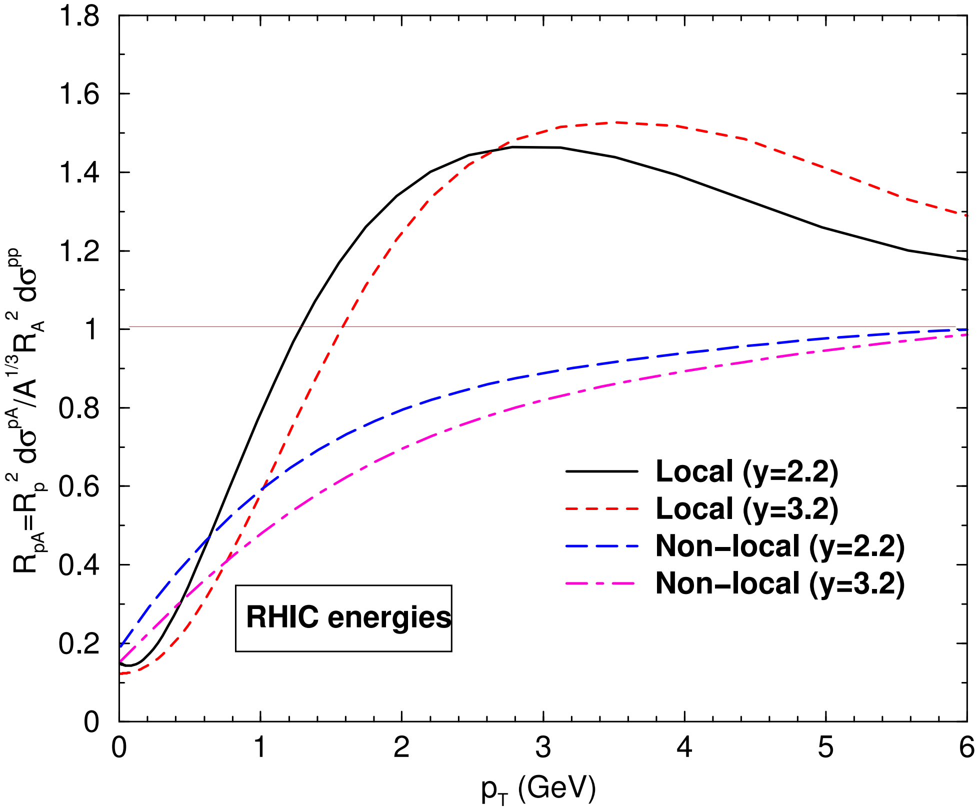
D. Kharzeev, Y. V. Kovchegov, K. Tuchin, hep-ph/0405045.

R_{pA} Local Gaussian (dileptons)



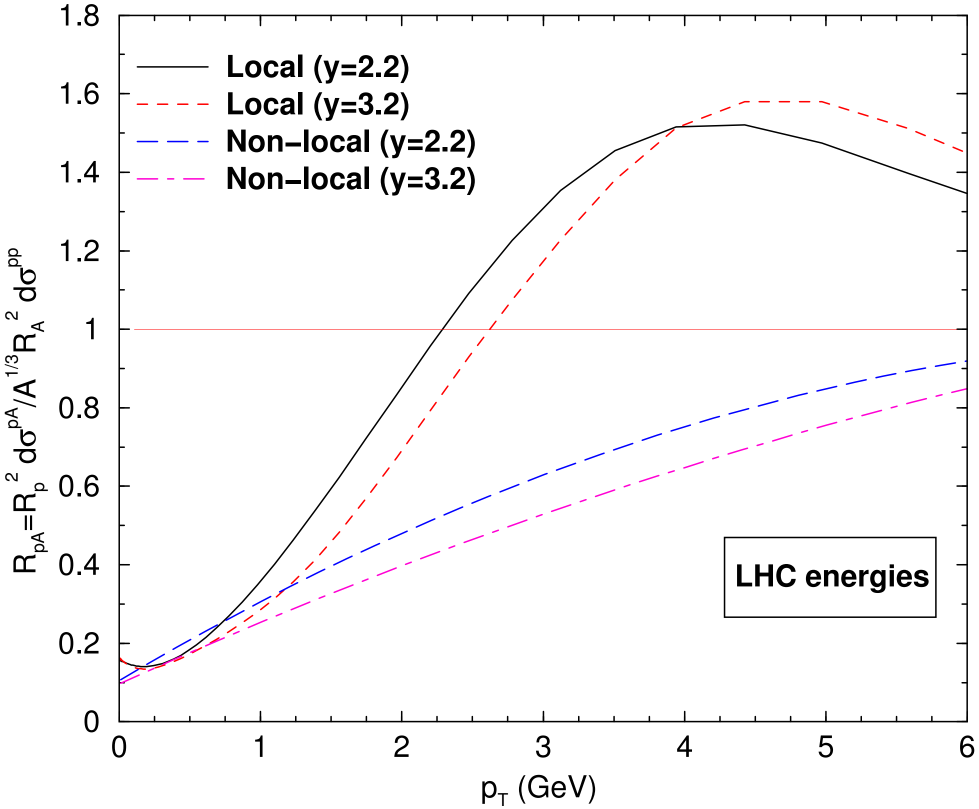
- Suppression at small p_T;
- Cronin peak appears at intermediated p_T;
- The peak increases and is shifted to large p_T with the increment in the rapidity;
- Disagreement with the suppression presented in the RHIC data on inclusive hadron sector

Local× Non-local Gaussian



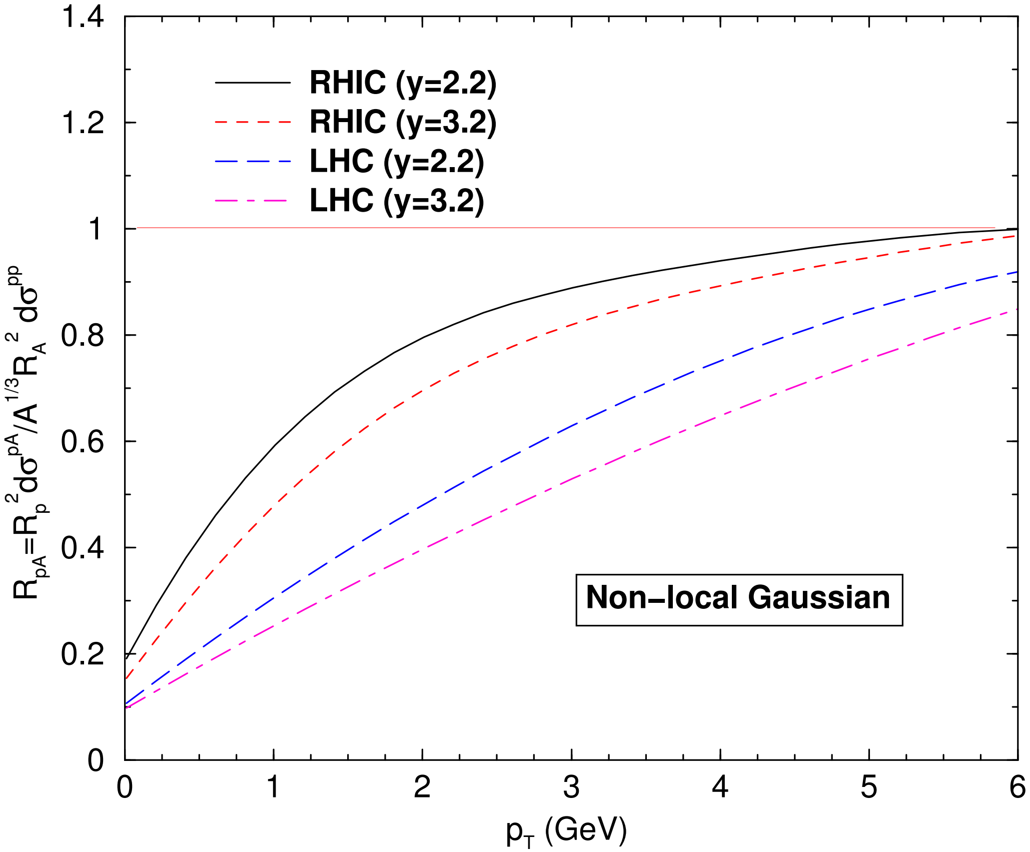
- The suppression of the Cronin peak is reached;
- The suppression is enlarged for large values of rapidity;
- RHIC data present the suppression of the Cronin peak at large rapidities;
- Effect of the evolution [Albacete, Armesto, Kovner, Salgado, Wiedemann, *Phys. Rev. D* 92, 082001 (2004)].

Local× Non-local Gaussian



- The suppression of the Cronin peak is reached;
- The suppression is intensified for large values of rapidity;
- Simulation of the quantum evolution.

Non-local Gaussian



- The suppression is intensified for large energies;
- Measurements on dilepton sector are needed.

Conclusions

- The suppression at small and moderated p_T is an evidence of the saturation effects (CGC).

- The ratio R_{pA} shows a Cronin type peak with local Gaussian and presents a suppression with a non-local Gaussian, considering the dilepton p_T spectra.

- The dilepton p_T distribution indicates the Cronin effect as an initial state effect.

- Measurements on the dilepton p_T distribution at high energies are required.