Dilepton transverse momentum in the color dipole approach

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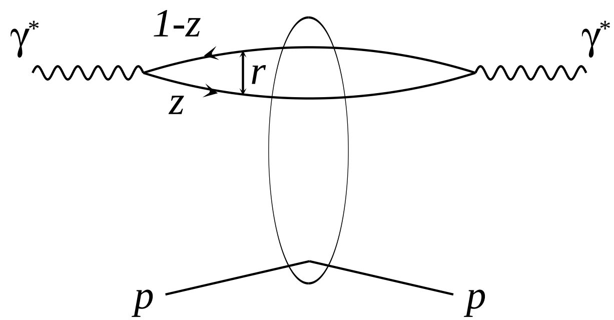
Seminar based on work with M.A. Betemps, MBGD, M.V.T. Machado and J. Raufeisen (hep-ph/0303100)

Motivations

- The Drell-Yan (DY) process can be studied similarly to the DIS through the dipole approach;
- At small-x, the dipole cross section is driven by the gluon content of the target;
- Investigation of the gluon content through the Drell-Yan process at high energies;
- The unitarity effects can be studied in the dipole cross section;
- In the dipole approach DY p_T distribution is finite for small p_T values.
- Reliable estimates for the recent experiments RHIC and LHC can be done;

Color dipole approach

- DIS in the dipole approach,



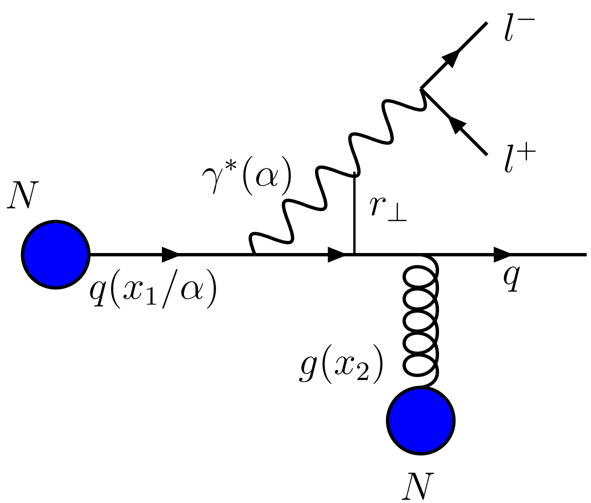
$q\bar{q}$ lifetime $>>$ interaction time $\rightarrow$ factorization of the cross section

$$\sigma_{T,L}^{\gamma^* p}(x,Q^2) = \int d^2\mathbf{r} \int dz |\Psi_{T,L}^{q\bar{q}}(z,r;Q^2)|^2 \times \sigma^{dipole}(x,r).$$

- $\sigma^{dipole}(x,r) \rightarrow$ interaction of the dipole $q\bar{q}$ with the nucleon.
- coherence length ($q\bar{q}$ lifetime)

$$l_c \approx \frac{1}{2m_N x}, \rightarrow \text{ small-}x \rightarrow \text{ high energy}$$

Drell-Yan in the dipole approach



Where is the Dipole ?

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

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

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

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

Drell-Yan in the dipole approach

- We can write such cross section as,

$$\boxed{\frac{d\,\sigma^{DY}}{dM^2\,dx_F\,d^2p_T} = \frac{\alpha_{\rm em}^2}{6\,\pi^3 M^2}\,\frac{1}{(x_1+x_2)}\int_0^\infty d\rho W(\rho,p_T)\sigma_{dip}(\rho)}$$

- Explicit dependence on the dipole cross section.
- $\rho \equiv \alpha r$ dependence of the cross section
- $$\left.\begin{array}{l} \text{large } \alpha r_\perp \Rightarrow \text{ non-perturbative sector} \\ \text{small } \alpha r_\perp \Rightarrow \text{ perturbative sector} \end{array}\right\} \Rightarrow \sigma_{dip}$$
- $W(\rho, p_T)$ should be considered as a weight function

Weight Function

$$
\begin{aligned}
W(\rho, p_T) &= \int_{x_1}^{1} \frac{d\alpha}{\alpha^2} \frac{x_1}{\alpha} F_2(x_1/\alpha, M^2) \\
&\times \left\{ [m_q^2 \alpha^4 + 2M^2(1-\alpha)^2] \left[\frac{1}{p_T^2 + \eta^2} T_1(\rho) - \frac{1}{4\eta} T_2(\rho) \right] \right. \\
&+ \left. [1 + (1-\alpha)^2] \left[\frac{\eta p_T}{p_T^2 + \eta^2} T_3(\rho) - \frac{T_1(\rho)}{2} + \frac{\eta}{4} T_2(\rho) \right] \right\}
\end{aligned}
$$

where

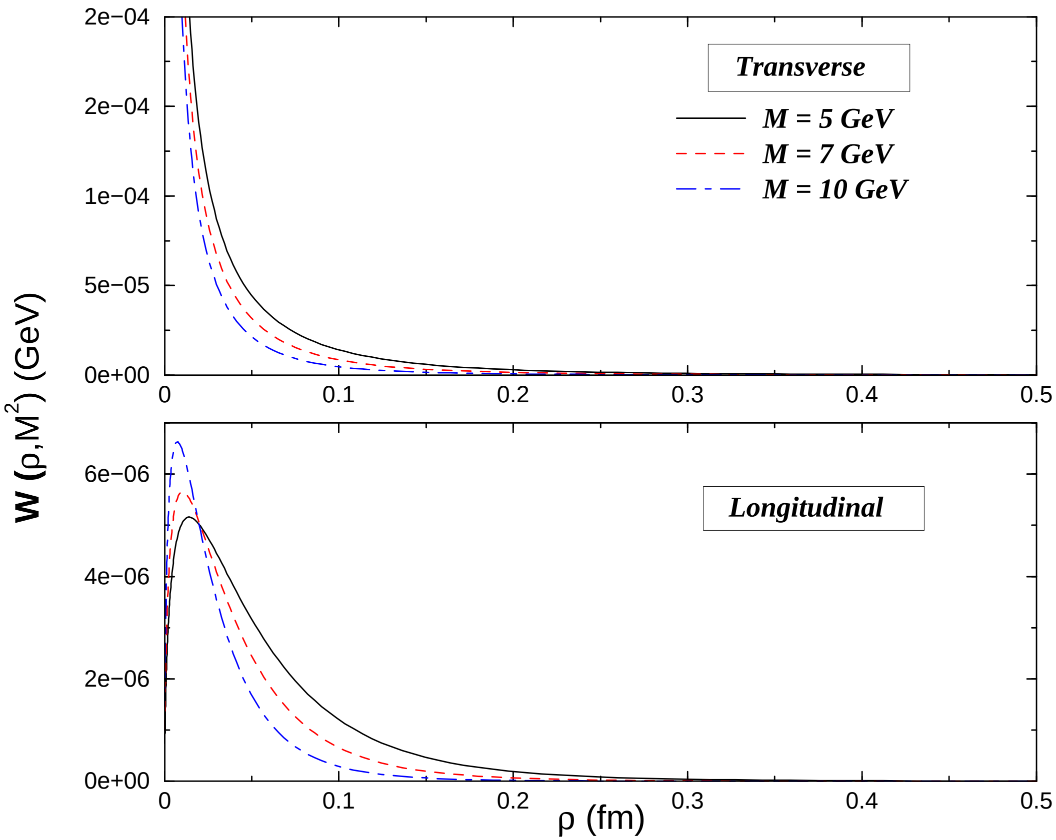
$$
\begin{aligned}
T_1(\rho) &= \rho J_0(p_T \rho/\alpha) K_0(\eta\rho/\alpha)/\alpha \\
T_2(\rho) &= \rho^2 J_0(p_T \rho/\alpha) K_1(\eta\rho/\alpha)/\alpha^2 \\
T_3(\rho) &= \rho J_1(p_T \rho/\alpha) K_1(\eta\rho/\alpha)/\alpha \,.
\end{aligned}
$$

with

$$
\eta = (1-\alpha)M^2 + \alpha^2 m_q^2
$$

Drell-Yan cross section features

- For the p_T integrated weight function we obtain

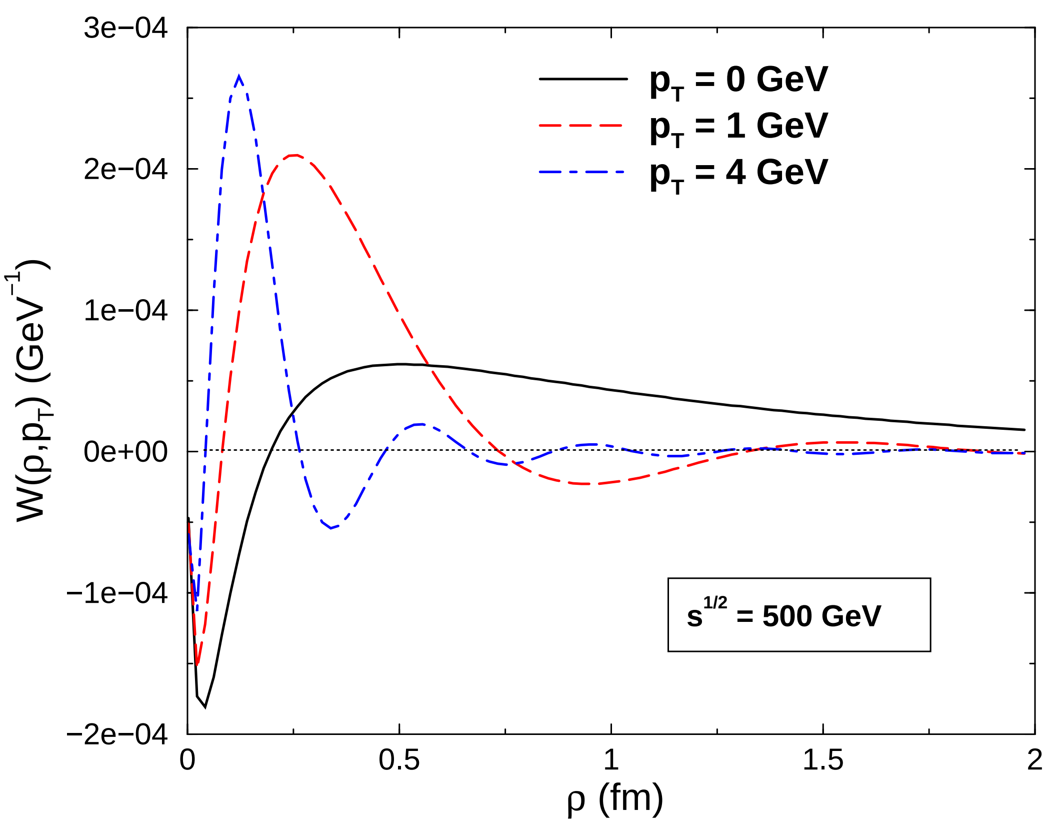


- Large ρ contribution are suppressed
- Small contribution of the non-perturbative piece [a]

[a] M.A. Betemps,MBGD, M.V.T. Machado, Phys. Rev. D66 014018 (2002)

Drell-Yan cross section features

- Concerning $W(\rho, p_T)$



- Large ρ contribution are not highly suppressed.
- Significative contribution from the non-perturbative sector.

Dipole cross section

- In the double logarithmic approximation,

$$\sigma_{dip}^{GM}(x,r) = \frac{\pi^2 \alpha_s}{3} r^2 x G^{\mathrm{GM}}(x, \tilde{Q}^2), \qquad \tilde{Q}^2 = \lambda / r^2, \qquad \lambda = 4$$

- $xG^{\mathrm{GM}}(x,\tilde{Q})$ is the Glauber-Mueller gluon distribution

$$xG^{GM}(x,Q^2) = \frac{4}{\pi^2} \int_x^1 \frac{dx'}{x'} \int_{\frac{4}{Q^2}}^{\infty} \frac{d^2 r}{\pi r^4} \int_0^{\infty} \frac{d^2 b}{\pi} \{1 - e^{-\frac{1}{2}\sigma^{GG}(x',r) S(b)}\}.$$

- $S(b)$ (Gaussian parametrization)

$$\sigma^{GG}(x,r) = \frac{3\alpha_s(4/r^2)}{4} \pi^2 r^2 \left[xG^{DGLAP}\left(x, \frac{4}{r^2}\right)\right]. \rightarrow GRV94$$

- AGL (A.L. Ayala, MBGD and E. Levin) approach [a].
- Non-perturbative sector $\rightarrow r$ freezing .

[a] Nucl. Phys. B511, 355 (1998)

Dipole cross section

- The phenomenological saturation model of Bartels et al. (BGBK) [b]

$$\sigma_{dip}(x,\rho) = \sigma_0 \left\{ 1 - \exp\left(- \frac{\pi^2 \rho^2 \alpha_s(\mu^2) x g(x,\mu^2)}{3\sigma_0} \right) \right\} ,$$

- $\mu^2 = \frac{C}{\rho^2} + \mu_0^2, \quad xg(x,Q_0^2) = A_g x^{-\lambda_g}(1-x)^{5.6}$
- There are five free parameters (σ_0, C, μ_0^2, A_g and λ_g), which have been determined by fitting ZEUS, H1 and E665 data with $x < 0.01$.
- We employ parameters from FIT 1. ($\sigma_0 = 23.03$ mb is fixed, $C = 0.26$, $\mu_0^2 = 0.52$, $A_g = 1.2$, $\lambda_g = 0.28$.)

[b] Phys. Rev. D66, 014001 (2002)

Low energy data

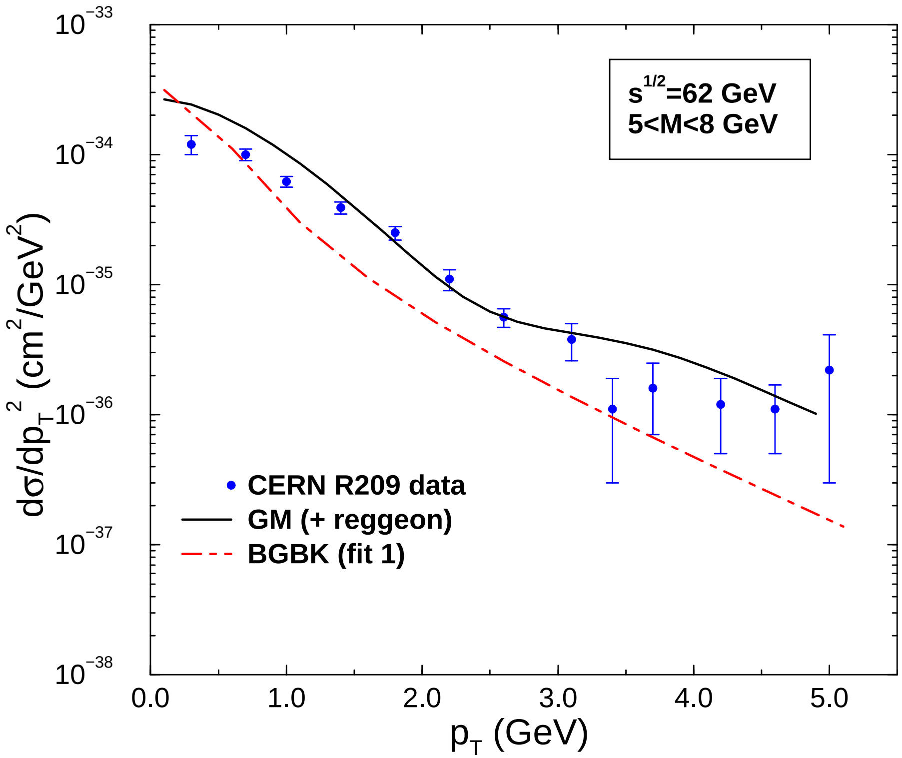
- Current data on DY reactions $\rightarrow x_2$ is around 0.1,
- Low energy$\rightarrow$ non-asymptotic quark-like content (Reggeon contribution) added to the GM dipole cross section [a]
- The suitable Reggeon parametrization for all p_T ranges is

$$\sigma_{dip}^{I\!R}(x,r) = N_{I\!R}\, r^2\, x\, q_{\text{val}}\,(x, 4/r^2)\,,$$

- Good description of the mass distribution (E772 data).
- E772 data $\rightarrow N_{IR} = 7$

[a] M.A.Betemps,MBGD, M.V.T. Machado. Phys. Rev. D66, 014018 (2002)

Low energy p_T distribution data

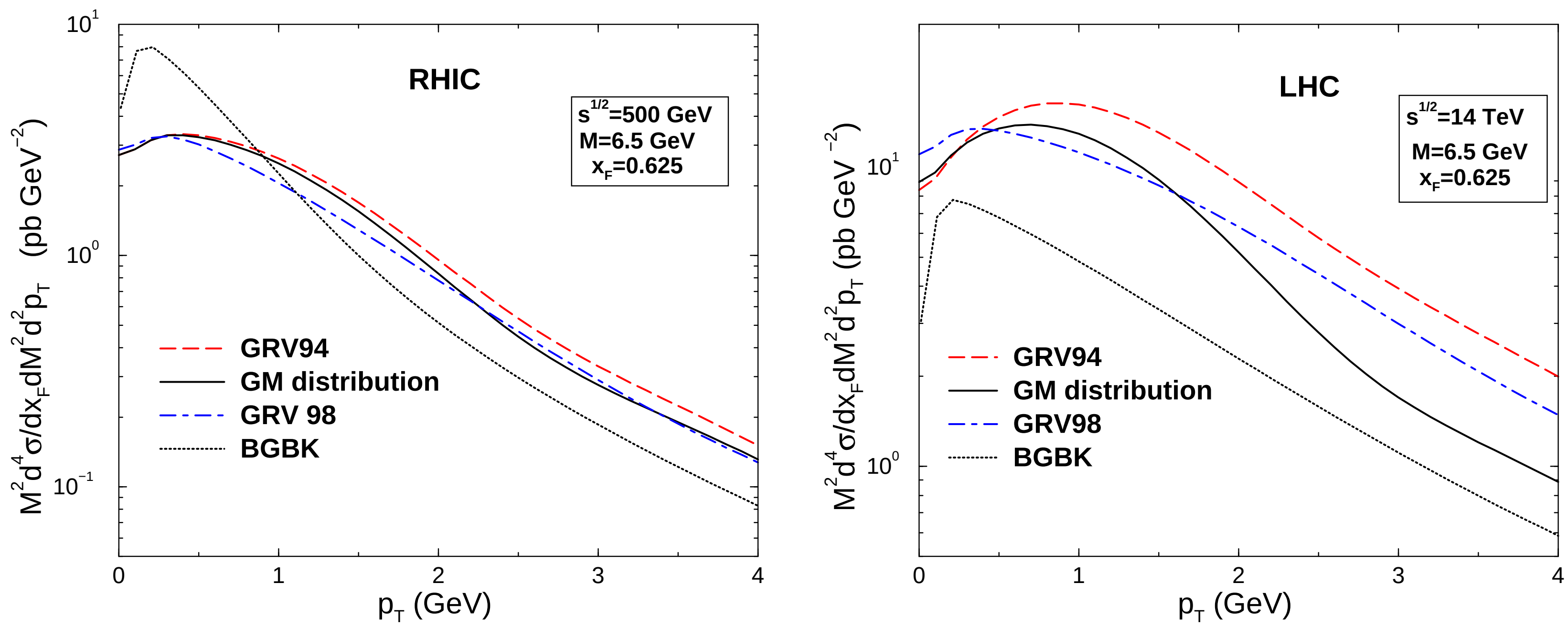


- Good agreement with the p_T distribution data $\sqrt{s} = 62$ GeV ($\sigma_0 = 7$)
- Regge contribution
- GM $\longrightarrow$ GRV94
- BGBK $\longrightarrow$ CTEQ

- At these energies, negligible unitarity corrections are in the Glauber-Mueller approach

RHIC and LHC DY p_T distribution

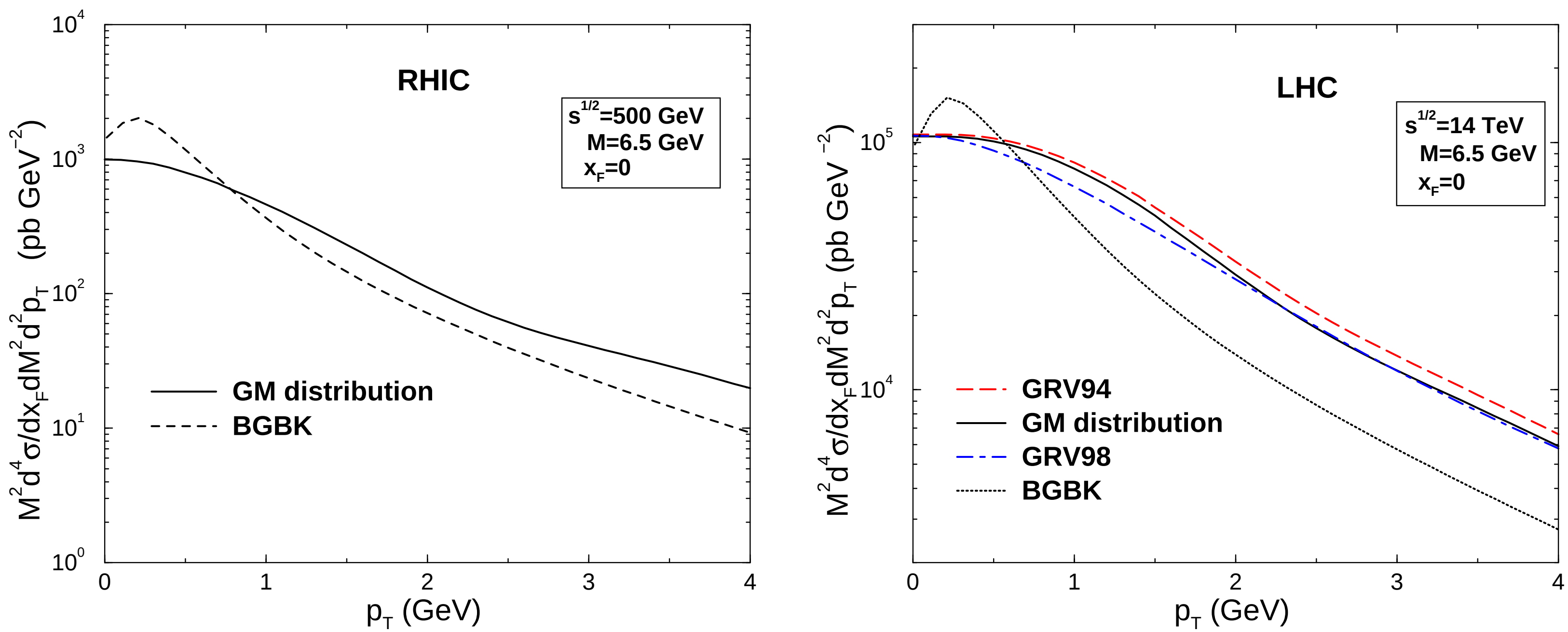
- At RHIC and LHC energies the DY p_T distribution in pp collision ($x_F = 0.625$)



- Large unitarity effects at high $p_T \Rightarrow$ small ρ.
- Negligible Regge contribution.

RHIC and LHC DY p_T distribution

- At RHIC and LHC energies the DY p_T distribution in pp collision ($x_F = 0$)



- Small unitarity effects at $x_F = 0$.
- Small Regge contribution at RHIC energies.

Conclusions

- Investigation of the gluon content through the Drell-Yan process at high energies.
- Good description of the low energy p_T data using GM + Regge (all p_T range).
- At RHIC energies the unitarity effects can be absorbed if we consider updated parametrizations ($x_2 \approx 10^{-3}$ at large x_F).
- The unitarity effects are quite sizeable at high energies (LHC), at both large p_T and x_F (rapidity).
- Unitarity corrections are not sizeable in the central rapidity region ($y = 0$) even at LHC energies.