Hadron Production at Backward Rapidities

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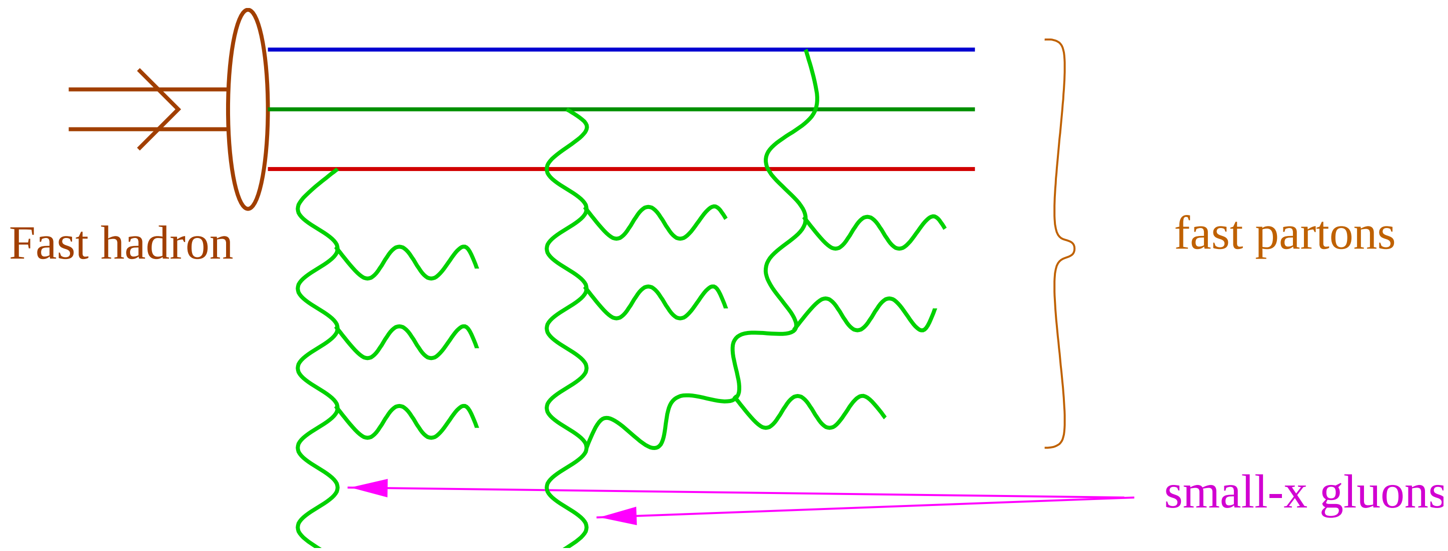
Motivation

In this work the hadron spectra is evaluated for RHIC and LHC energies considering the mixed approach: Color Glass Condensate (CGC) + Dilute System + Fragmentation function. In the forward rapidities, in deuterium-nucleus collisions, the nucleus is treated by means of the CGC. In this work, the opposing region is under investigation, and the deuterium in the dA collisions is considered as a CGC, and the nucleus treated as a diluted system.

- Forward rapidities;
  - The hadron spectra is weel described by some parametrizations, considering the Color Glass Condensate at forward rapidities;
  - The data description is performed for proton-pronton and deuterium-nucleus collisions;
  - Proton-proton collision described with the Color Glass Condensate;
  - Proton (pp collisions) and nucleus (dA collisions) can be considered by the CGC at forward rapidities.
- Backward rapidities;
  - Proton-proton spectra presents symmetry comparing backward and forward;
    - The same approach for the foward rapidities can be applied at backward.
  - Proton and deuterium can be considered by the CGC at backward rapidities;
  - Nucleus considered by the DGLAP evolution with high x nuclear effects.

The Color Glass Condensate (CGC)

- Color $\Rightarrow$ gluonic field. L. McLerran, R . Venugopalan (1994)
- Glass $\Rightarrow$ Internal dynamics evolve slowly.
- Condensate $\Rightarrow$ Dense and saturated gluon field ($\frac{1}{\alpha_s}$).
- The condensate appear below a specific scale, the saturation scale Q_s^2.
- Small x gluons are emitted by large x source (fast partons).



- All hadrons should be described in the same way at high energies.

Hadron Production in the CGC

- The cross section for hadron production in hadronic collisions was evaluated [a] at the forward rapidities region in the Color Glass Condensate theory and reads as,

$$\frac{d^2\sigma^{dA\to hX}(\text{Forw})}{dy d^2 p_T} = \frac{1}{2\pi}\int_{x_F}^{1} dx_1 \frac{x_1}{x_F}\left\{ f_{q/d}(x_1,p_T) N_F\left(\frac{x_1}{x_F}p_T, x_2\right) D_{h/q}\left(\frac{x_F}{x_1}, p_T\right) + f_{g/d}(x_1,p_T) N_A\left(\frac{x_1}{x_F}p_T, x_2\right) D_{h/g}\left(\frac{x_F}{x_1}, p_T\right)\right\}$$

- $y \Rightarrow$ Rapidity of the produced hadron.
- $p_T \Rightarrow$ Transverse momentum of the produced hadron.
- $x_F = \frac{p_T}{\sqrt{s}}\exp(y)$, $x_2 = x_1 \exp(-2y)$.
- $f(x_1, p_T) \Rightarrow$ Parton distribution function (CTEQ5L in this work).
- $D\left(\frac{x_F}{x_1}, p_T\right) \Rightarrow$ Fragmentation function (KKP in this work).
- $N_{F,A}\left(\frac{x_1}{x_F}p_T, x_2\right) \Rightarrow$ quark and gluon projectile interaction with the target (CGC) (dipole cross section).

[a] A. Dumitru, A. Hayashigaki, J. Jallilian-Marian, Nucl. Phys. A, 765, 464 (2006)

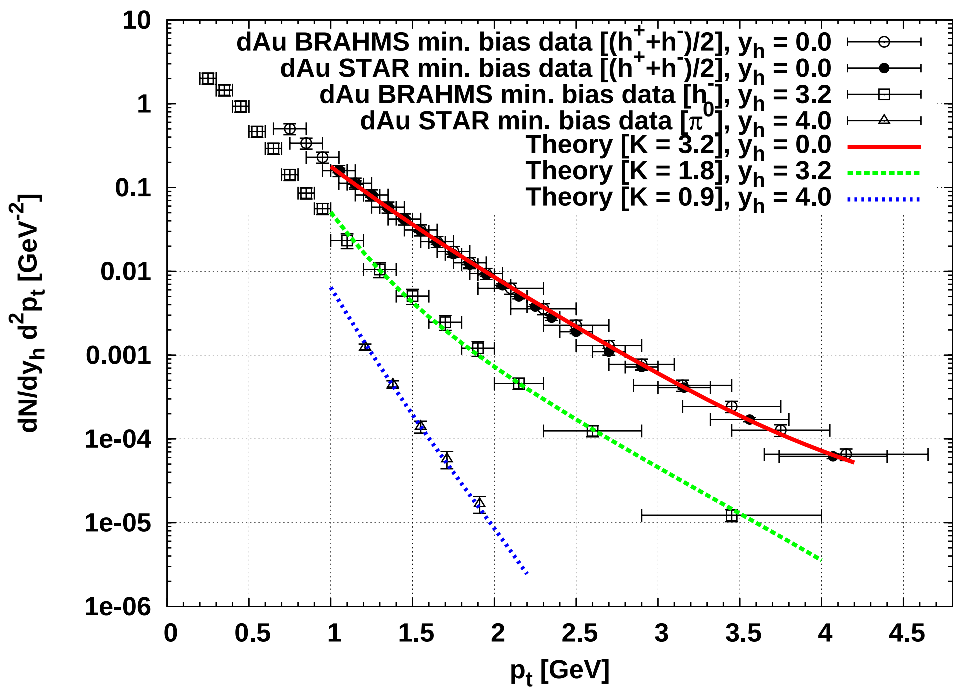
Dipole Cross Section

- The parametrization proposed by Dumitru, Hayashigaki and Jallilian-Marian (DHJ) [a] is used in this work.
- The parametrization was adjusted in order to describe the RHIC data on hadron production [a] for $\sqrt{s} = 200$ GeV.

$$N_A(r,y) = 1 - \exp\left[-\frac{1}{4}(r^2 Q_s^2(y))^{\gamma(y,r)}\right]$$

$$\gamma(y,r) = \gamma_s + (1-\gamma_s)\frac{|\log(1/r^2Q_s^2)|}{\lambda y + |\log(1/r^2Q_s^2)| + d\sqrt{y}}$$

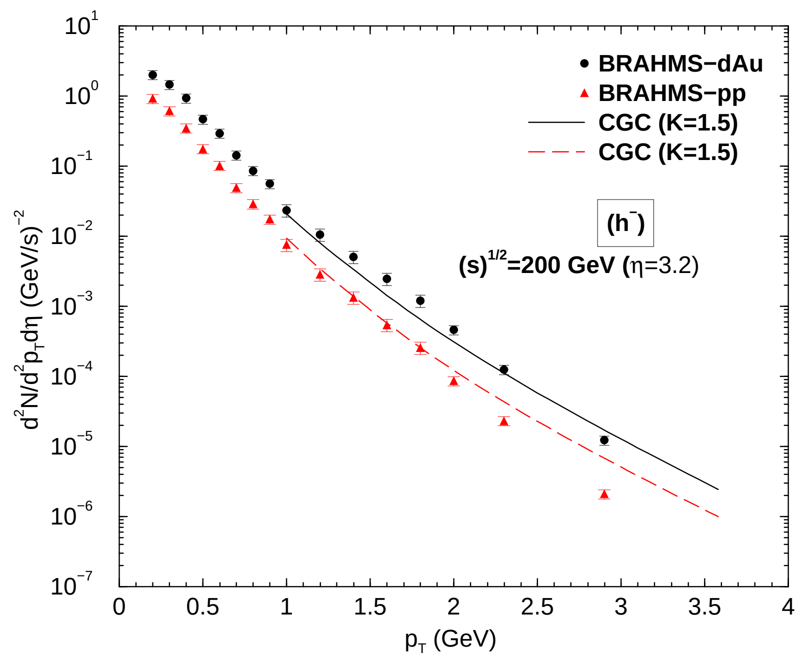
- $\lambda = 0.3$, $\gamma_s = 0.627$, $d = 1.2$.
- Need to perform Fourier transformation.
- The saturation scale $Q_s^2(x) = Q_0^2 A_{\text{eff}}^{1/3}\left(\frac{x_0}{x}\right)^{\lambda}$
- $x_0 = 3.10^{-4}$.
- A_{eff} =18.5 for A ∼200.
- Q_0^2 = 1 GeV^2.



[a] A. Dumitru, A. Hayashigaki, J. Jallilian-Marian, Nucl. Phys. A, 770, 57 (2006), extension of the parametrization proposed by Kharzeev, Kovchegov and Tuchin, Phys. Lett. B 599, 23 (2004).

Data at forward rapidities

- The formalism presented should be used in order to describe both, dAu and pp collisions,
- Data for hadron(-) from RHIC for $\sqrt{s} = 200$ GeV



- Same K factor is considered for both, pp and dA collisions.
- Reasonable description (fragmentation function for h^-?).
- Nuclear modification ratio should be evaluated and is independet of the calculation order.

Backward rapidities

- The Color Glass Condensate describe reasonably the forward data for dA and pp collisions.
- pp collisions present symmetry in rapidity (the theory should be applied at backward rapidities).
- At backward rapidities we propose exchange projectile and target, and the cross section for dA collisions should be written in the following form,

$$\frac{d^2\sigma^{dA\to hX}(\text{Back})}{dy d^2p_T} = \frac{1}{2\pi}\int_{x_F}^{1} dx_2 \frac{x_2}{x_F}\left\{f_{q/A}(x_2,p_T)N_F\left(\frac{x_2}{x_F}p_T,x_1\right)D_{h/q}(\frac{x_F}{x_2},p_T)\right.$$
$$\left. + \quad f_{g/A}(x_2,p_T)N_A\left(\frac{x_2}{x_F}p_T,x_1\right)D_{h/g}(\frac{x_F}{x_2},p_T)\right\}$$

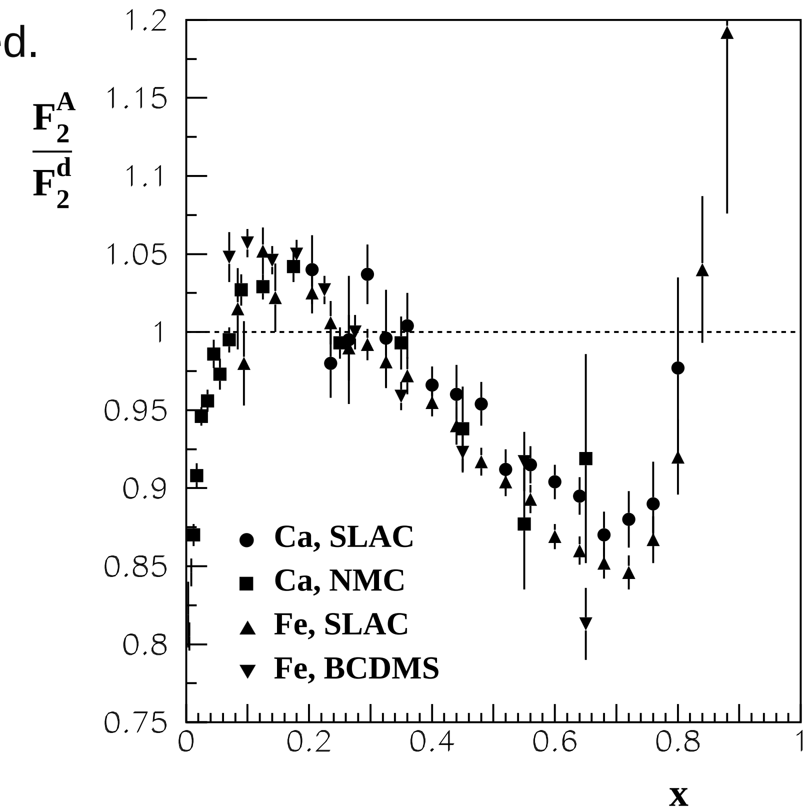
- We need to consider a nuclear parton distribution.
- In this kinematical region we have large x_2 and small x_1.
- $x_F = \frac{p_T}{\sqrt{s}}\exp(-y)$, $x_1 = x_2\exp(2y)$.

Nuclear Effects

- In the *electron-nucleus* collisions, the electron probes a structure that should present modification comparing with the *electron-proton* collisions.
- The nuclear effects in the partonic distributions are determined by means of the ratio between nuclear and proton structure function F_2.

$$R^A_{F_2} = \frac{F^A_2}{AF^{p,n,D}_2}$$

- $R^A_{F_2} = 1$ if any nuclear effect is observed.
- Four behaviors are verified:
  - $x \gtrsim 0.8 \Rightarrow$ Fermi motion.
  - $0.3 \lesssim x \lesssim 0.8 \Rightarrow$ EMC effect.
  - $0.1 \lesssim x \lesssim 0.3 \Rightarrow$ Antishadowing.
  - $0.1 \gtrsim x \Rightarrow$ Shadowing.

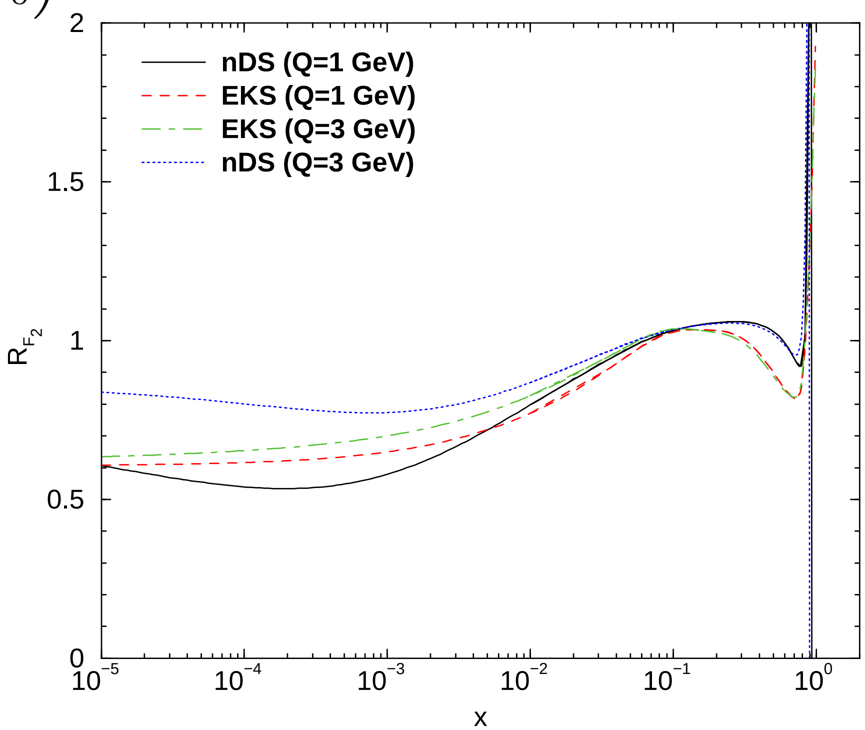


Nuclear Parton Distributions

- The nuclear structure function is obtained from the nucelar parton distributions (nPDF's):

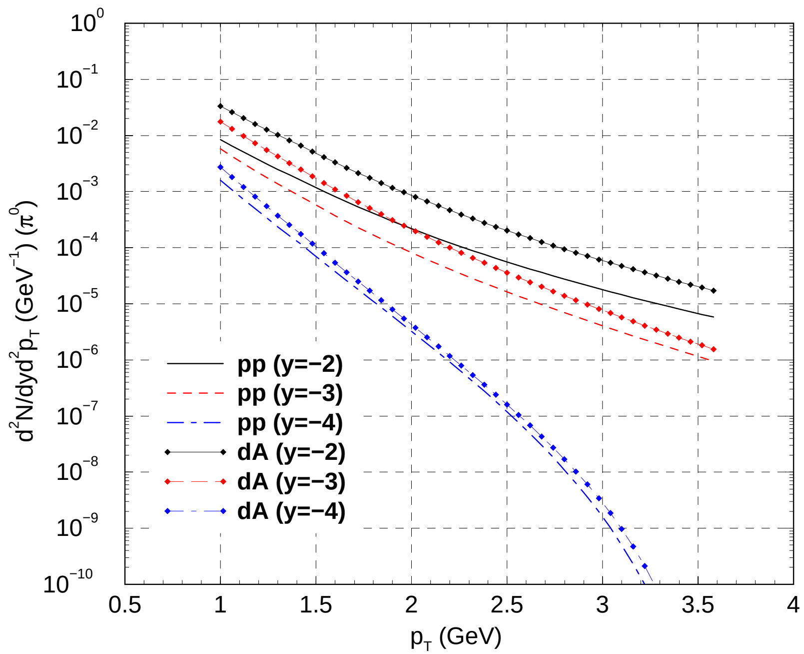
$$F_2^A(x, M^2) = \sum_q e_q^2 [x f_q^A(x, M^2) + x f_{\bar{q}}^A(x, M^2)],$$

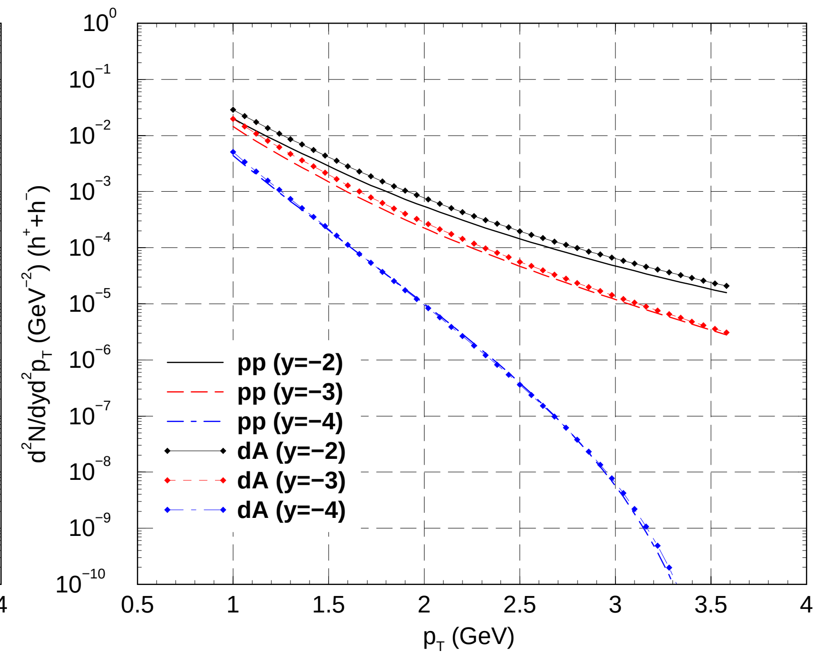
- Two approaches are studied in this work:
  - Eskola, Kolhinen and Salgado (EKS parametrization) *Eur. Phys. J. C* **9**, *61 (1999)*
    $f_q^A(x, Q_0^2) = R_q^A(x, Q_0^2) f_q^p(x, Q_0^2)$
  - D. de Florian and R. Sassot (nDS parametrization) *Phys. Rev. D* **69**, *074028 (2004)*
    $f_q^A(x, Q_0^2) = \int_x^A \frac{dy}{y} W_q(y, A) f_q^p\left(\frac{x}{y}, Q_0^2\right)$
- A proton distribution is requiered.
- EKS parametrization predicts smaller ratios comparing with the nDS results at large x.
- EKS predicts larger ratios at small x.
- nDS parametrization presents wrong behavior for x close to one.
- We consider only the EKS parametrization.



p_T spectra for π^0 and charged hadrons

- The calculation is performed considering CGC+EKS+KKP
- No K factor is considered.





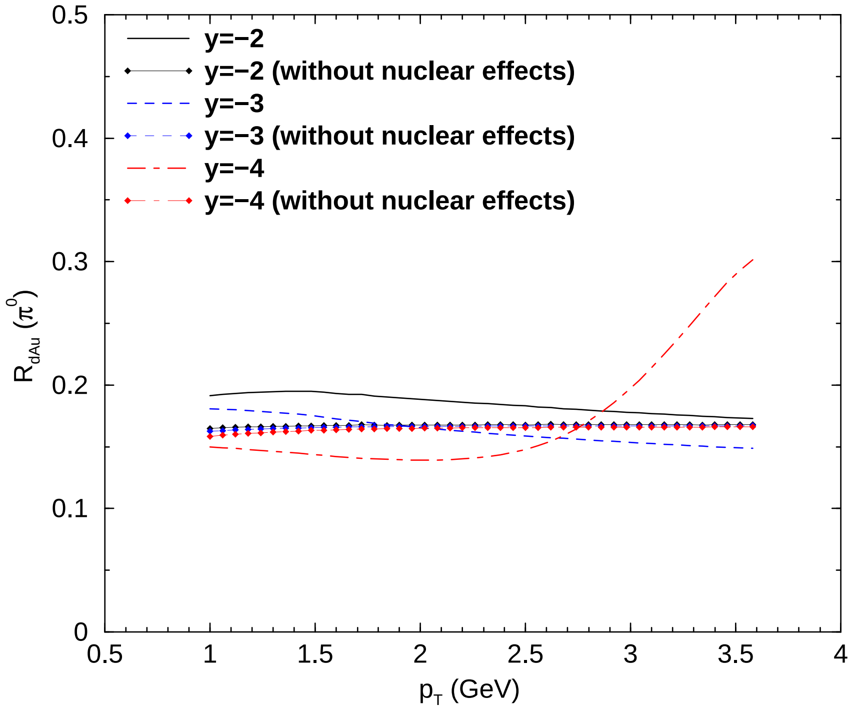
- In order to identify the effects of large x in the nucleus we evaluate the nuclear modification ratio for π^0 and charged hadrons.

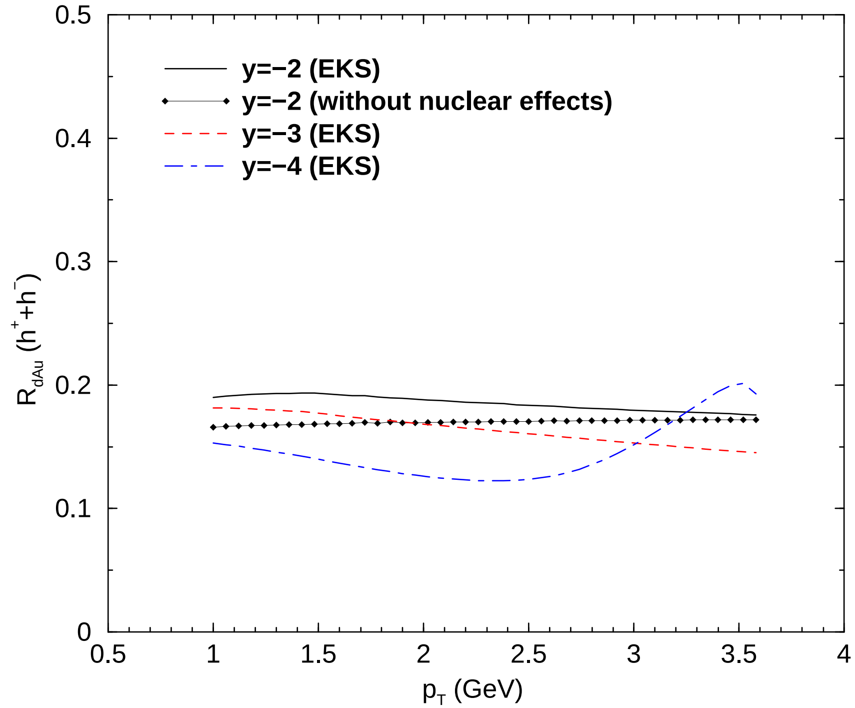
$$R_{dA} = \frac{1}{< N_{bin} >} \frac{d^2N(dA)/dyd^2p_T}{d^2N(pp)/dyd^2p_T}$$

- For RHIC the mean number of binary collisions $< N_{bin} >$=7.5$\pm$ 0.4

Nuclear modification factor

- We perform calculations with and without the nuclear effects





- x_2 integration with the limits $\int_{x_F}^{1}$ implies that distinct nuclear effects can contribute at each p_T value.
- Large $p_T \Rightarrow$ large x_F value.
- For more central rapidities, small and large x nuclear effects contribute to the ratio.
- For large p_T and more backward rapidities, the large x nuclear effects dominate.

Conclusions

- The backward region should be investigated considering the Color Glass Condensate, once the pp results in the forward rapidities should be described by the same theory.
- The integration over x, in the cross section, provide that the nuclear effects can not be analyzed separately in the nuclear modification ratio.
- The nuclear effects modify the ratio R_{dA}, mainly at more backward rapidities.
- Next steps...
  - Consider the kinematical region of the RHIC data at backward rapidites.
  - Calculations for LHC energies.