

# Nuclear suppression of charmonium at RHIC and LHC in Glauber-Gribov approach

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June 28th 2007  
“STRANGENESS IN QUARK MATTER 2007”  
Levoca, Slovakia



- 1 Introduction - why is RHIC/LHC “high energy”?
- 2 Nuclear Modification Factor
  - results for J/psi in d+Au @ RHIC
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- 3 Charmonium suppression in a final state model
- 4  $\alpha(x_F)$  dependence
  - what happens at mid-rapidity with energy?
  - scaling - breaking - appearance
- 5 Conclusions



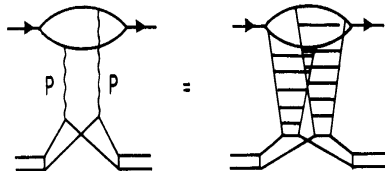
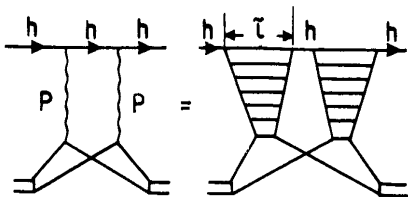
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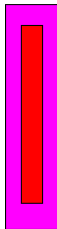
# When is energy “high”?

Coherence length in hadron-nucleus collision

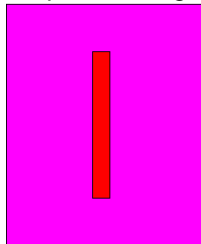
Mandelstam Nuov. Cim. **30** (1963) 1113, 1127,1148; Gribov JETP **56** (1959) 982



“Planar” diagram - Glauber model



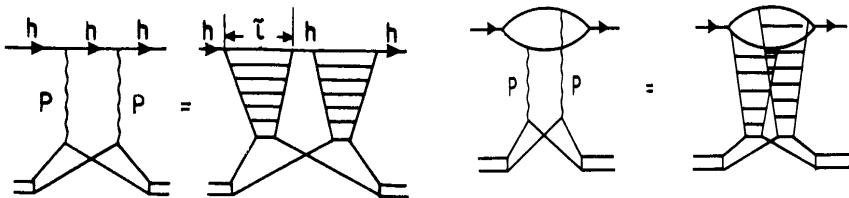
“Non-planar” diagram



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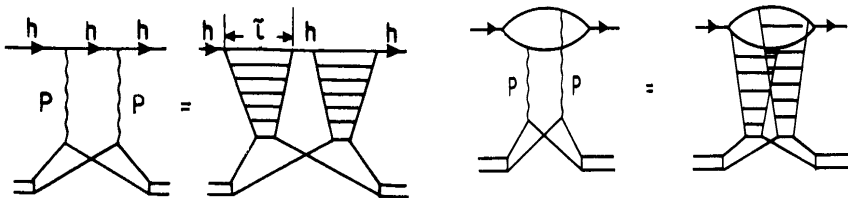
- the space-time picture does not correspond to longitudinally ordered multiple scattering
- fluctuation prepared long before collision occurs
- LHC is definitely in “high-energy regime”. **Coherent production for both light and heavy particles already at  $y=0$ !**
- is RHIC?



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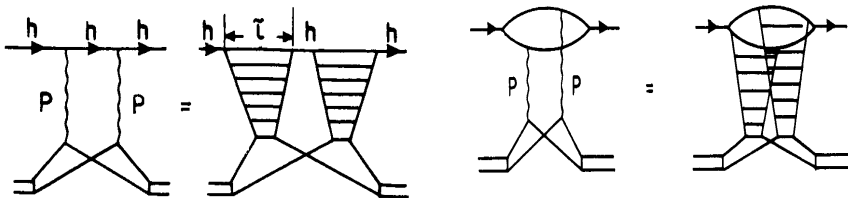
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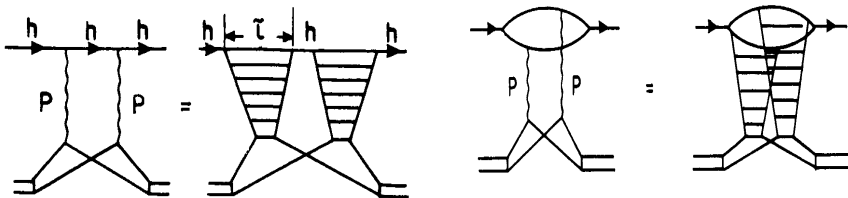
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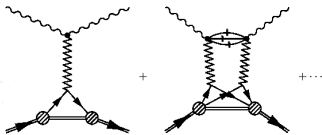
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# Calculation of total cross section

## Rescattering series



- The contribution from 1, 2... scatterings can be expanded in  $\sigma_{pA} = \sigma_{pA}^{(1)} + \sigma_{pA}^{(2)} + \dots$

$$\sigma_{pA}^{(1)} = A \cdot \sigma_{NN} ,$$

$$\sigma_{pA}^{(2)} = -4\pi A(A-1) \int d^2b T_A^2(b) \int_{M_{min}^2}^{M_{max}^2} dM^2 \left[ \frac{d\sigma_{\gamma^*N}^D(Q^2, x_P, \beta)}{dM^2 dt} \right]_{t=0} F_A^2(t_{min})$$

Karmanov, Kondratyuk, Pisma Zh.Eksp.Teor.Fiz. **18** (1973) 451

Armesto et al., Eur.Phys.J.C **29** (2003) 531

Frankfurt, Guzey, Strikman, Phys. Rev. D **71** (2005) 054001



# Hard diffraction @ HERA

## Parameterization of diffractive parton densities

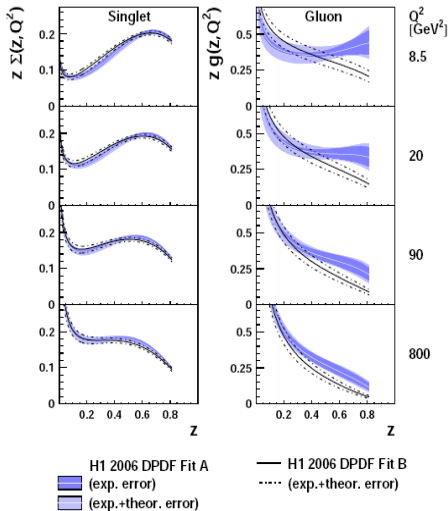
$$\left[ \frac{d\sigma_{\gamma^*N}^D}{dM^2 dt} \right]_{t=0} = \frac{4\pi^2 \alpha_{em} B}{Q^2(Q^2 + M^2)} x_P F_{2D}^{(3)}$$

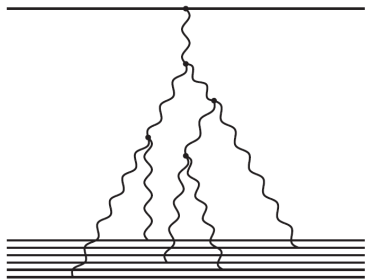
### FIT A

- parameterized at  $Q_0 = 1.75 \text{ GeV}^2$

### FIT B

- parameterized at  $Q_0 = 2.5 \text{ GeV}^2$
- maximal uncertainty in gluon dPDF due to mixing with quarks at  $\beta > 0.3$





Schwimmer Nucl.Phys.B **94** (1975) 445

- similarity to the B-K equation of dipole splitting
- relevant for hA collisions at high energies
- exact solution of the Reggeon field theory

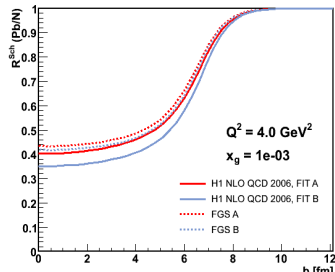
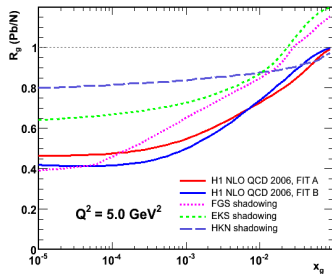
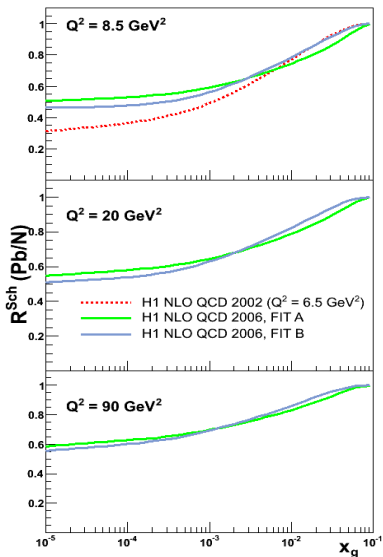
$$\sigma_{hA}^{Sch} = \sigma_{hN} \int d^2b \frac{AT_A(b)}{1 + (A-1)f(x, Q^2)T_A(b)},$$

$$f(x, Q^2) = 4\pi \int_x^{x_P^{max}} dx_P B(x_P) \frac{F_{2D}^{(3)}(x_P, Q^2, \beta)}{F_2(x, Q^2)} F_A^2(t_{min.})$$



# Results for gluon shadowing within Schwimmer model

Details - hep-ph/0705.1596



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# Production of a heavy-quark state at high-energy

Why is it important?

$J/\psi$  production in pA collisions show interesting features at different energies:

- absorption in nuclear matter ( $\sigma^{abs} \sim 5$  mb) at low energies, interpreted within a probabilistic Glauber model
- puzzle at RHIC,  $\sigma^{abs}$  much smaller (nobody expected this)
- at high energies, production of heavy state probes the very low-x distribution of the nuclear structure function

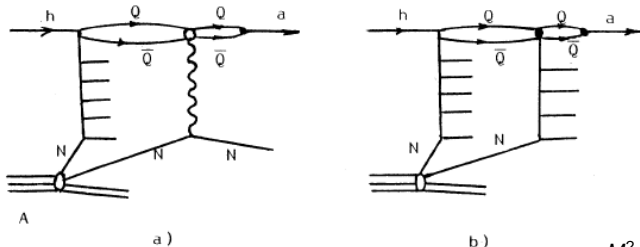
Also  $\Upsilon$  production should follow a similar pattern.

Important to understand what happens in pA to get a hold on final-state effects in AA!



# Production of a heavy-quark state at high-energy

Appearance of “high-energy regime”



Critical energy for heavy quark production  $E_C = \frac{M_{c\bar{c}}^2}{2x_+} \frac{R_A}{\sqrt{3}}$

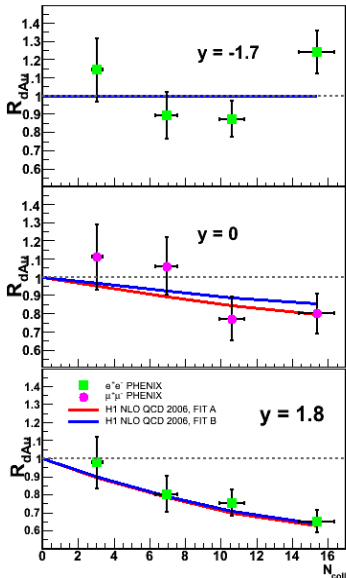
- for  $E < E_C$ : AGK cancellation is not valid and absorptive corrections are present  
→ low-energy absorption formula!
- for  $E > E_C$ : coherent production of the heavy state

Boreskov, Capella, Kaidalov, Thanh Van, PRD 47 (1993) 919

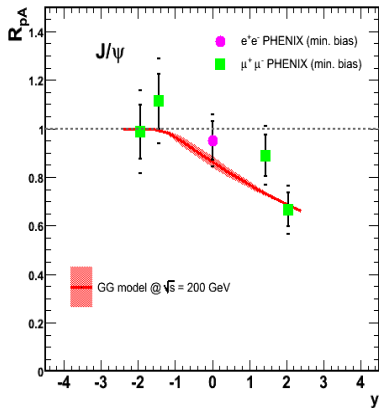


# $J/\psi$ production @ RHIC

Shadowing and  $\sigma_{abs} = 0$



$\sigma_{abs} = 0$  and shadowing reproduce the data at RHIC.

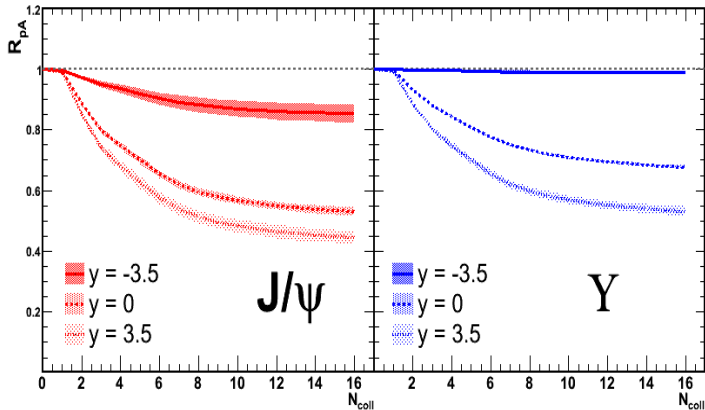


Capella, Ferreiro, hep-ph/0610313



# Predictions for p+Pb @ LHC

$J/\psi, \Upsilon$  and open heavy-flavour

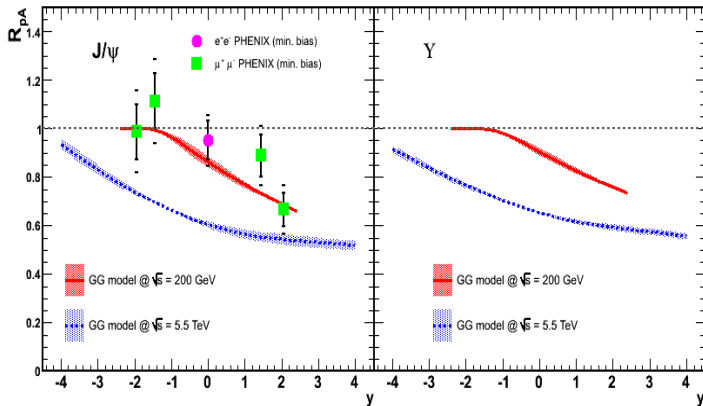


The same suppression is predicted for open heavy-flavour.



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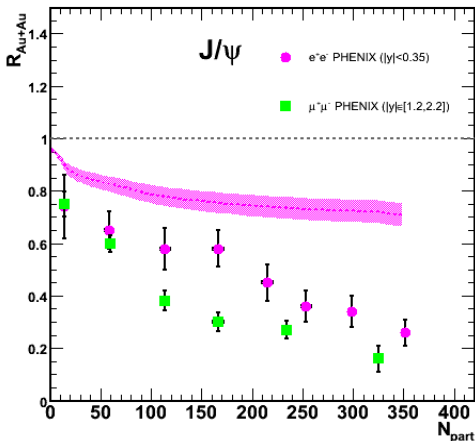


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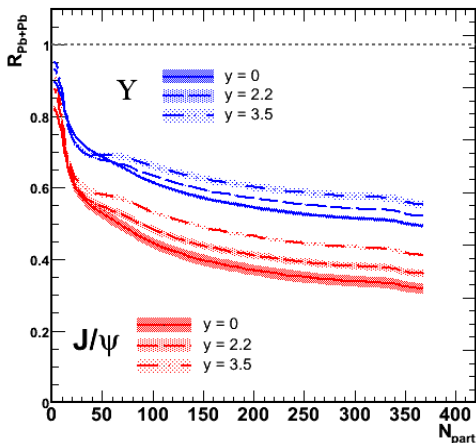
# Cold-nuclear matter effects in A+A collisions

Shadowing



- 20% suppression from CNM effects alone
- important input - suppression from co-movers alone gives too strong effect!



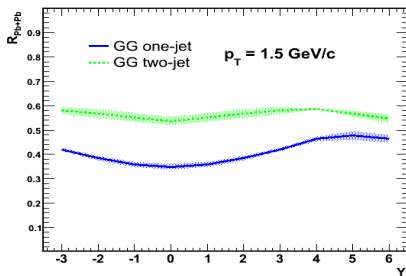
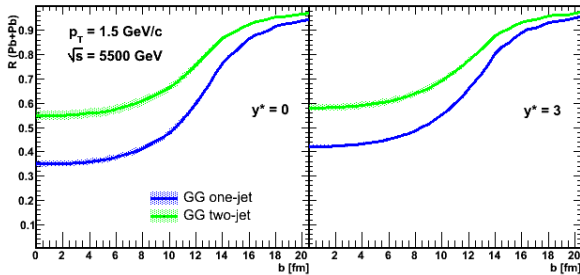


- strong shadowing effect, a factor of  $\sim 2.5$
- shadowing decreases with rapidity



# Cold-nuclear matter effects in A+A collisions

Density of produced particles



Shadowing effects are also crucial for total multiplicity and density of charged particles in the initial state of the collision.



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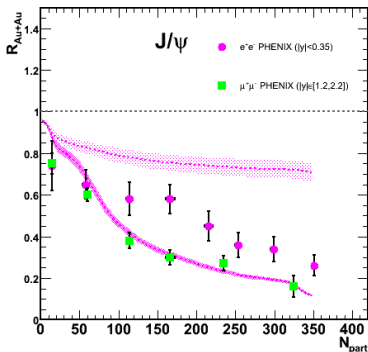


# Comovers suppression

Gain and loss equation that govern the the final-state interactions with the co-moving medium - **assuming only  $J/\psi$  dissociation**

$$\tau \frac{dN_{J/\psi}}{d\tau}(b, s, y) = -\sigma_{co} N_{J/\psi}(b, s, y) N^{co}(b, s, y)$$

$$S^{co}(b, s, y) = \exp[-\sigma_{co} N^{co}(b, sy) \ln(N^{co}(b, s, y)/N_{pp}(0))]$$



Gluon shadowing taken as before.

Shadowing + comovers suppression with  $\sigma = 0.65$  mb gives a too strong suppression.

**Recombination seems to be necessary at RHIC.**



# Comovers suppression and recombination

Estimation of recombination effect

We modify the rate equation

$$\tau \frac{dN^{J/\psi}}{d\tau} (b, s, y) = -\sigma \{ N_{J/\psi} N^{co} - N_D N_{\bar{D}} \} .$$

to incorporate the possible recombination of the abundantly produced charm to produce additional  $J/\psi$ 's. Approximately

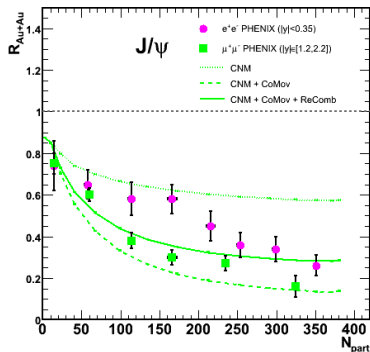
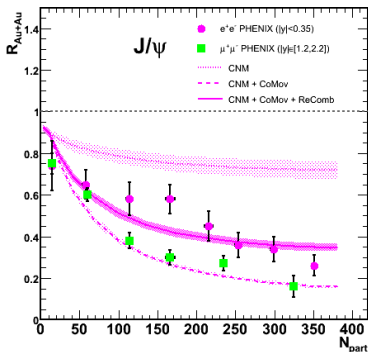
$$S^{CR}(b, s, y) = \exp \left\{ -\sigma [N^{co} - C n(b, s)] \ln \left[ \frac{N^{co}}{N_{pp}(0)} \right] \right\}$$
$$C = \frac{(dN_{pp}^D/dy)^2}{dN_{pp}^{J/\psi}/dy}$$

**C can be estimated from pp data.** Unfortunately, there are huge errorbars. First try: fit C to midrap  $R_{AA}$ !



# Comovers suppression and recombination

Estimation of recombination effect



$$C = 0.8$$

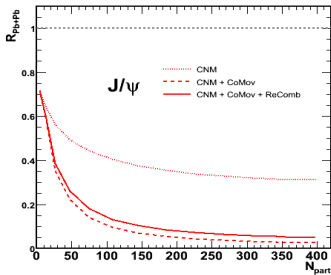
This corresponds to  $(d\sigma_{c\bar{c}}/dy)_{pp} = 0.08$  mb at midrap.

**Assumption:** C does not change much with rapidity.



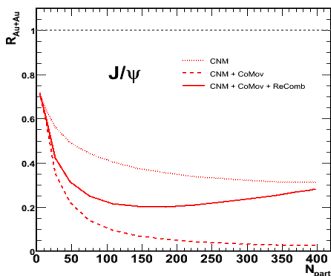
# Comovers suppression and recombination

Prediction for LHC



$C=0.8$

Recombination is negligible at LHC if the magnitude of the effect is as at RHIC.



$C = 1.6$

The total cross section of  $D\bar{D}$  grows faster than for  $J/\psi$ !

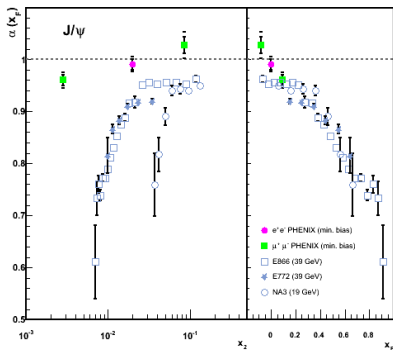
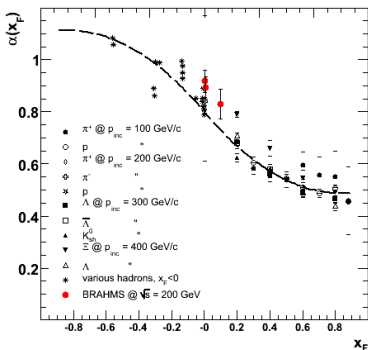


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# $\alpha(x_F)$ for light and heavy particles

Breaking of scaling! Reappearance...

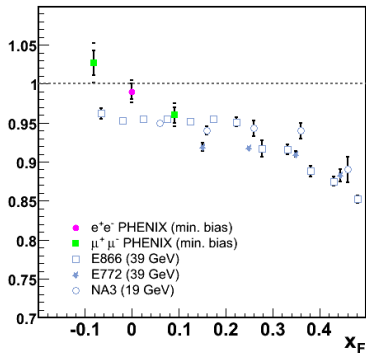
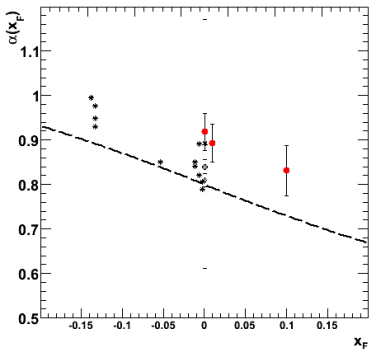


$$\frac{d\sigma_{pA}}{dy} = \frac{d\sigma_{pp}}{dy} A^{\alpha(x_F)}$$



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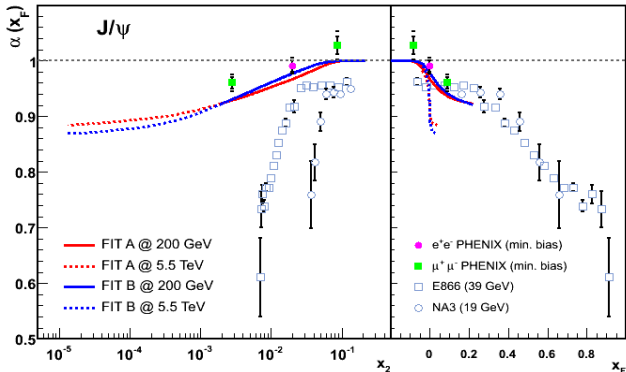


- change of behaviour of  $\alpha(x_F)$  going from low-energy to high-energy regime
- $\alpha(x_F = 0)$  sensitive to the disappearance of low-energy effects and onset of shadowing
- RHIC on the border both for light and heavy particle production



# $\alpha(x_F)$ for light and heavy particles

Breaking of scaling! Reappearance...



- scaling with  $x_F$  for low energies due to energy-momentum conservation
- scaling with  $x_2$  will appear for RHIC and higher energies



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