Nuclear shadowing and heavy ion collisions.

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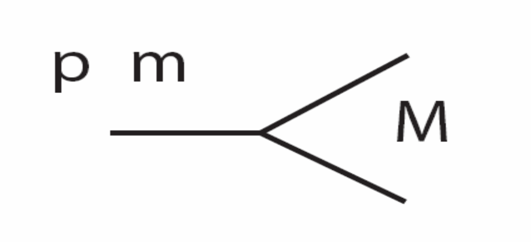
Introduction.

- Heavy ion collisions at high energies –
  a tool to study hadronic matter at extreme conditions: high density quark
  -gluon systems in deconfined phase.
- What are relevant degrees of freedom?
- Small-x DIS give an important information on properties of dense quark –gluon systems.

Space-time picture of high-energy interactions

- Large coherence length (time) of hadronic fluctuations at high energies

$$\Delta t \sim 2p/(M^2-m^2)$$



- At high energies hadronic (nuclear) fluctuations are "prepared" long before an interaction.

What are Fock state vectors of hadrons (nuclei) in the infinite momentum frame?

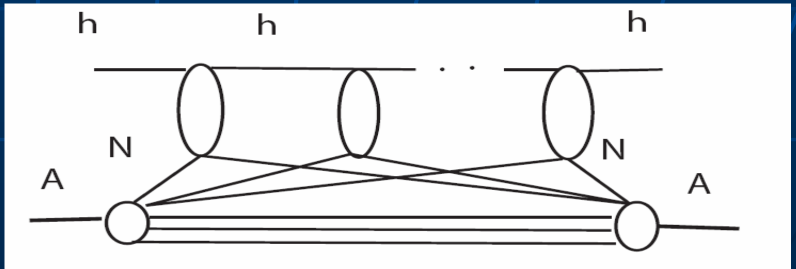
Space-time picture of high-energy interactions

- The space-time picture of hA (AB) – interaction changes at energies E_c when

  $l_{coh} \sim \Delta t \sim R_A$

  For typical interactions $E_c \sim m_N^2 R_A$

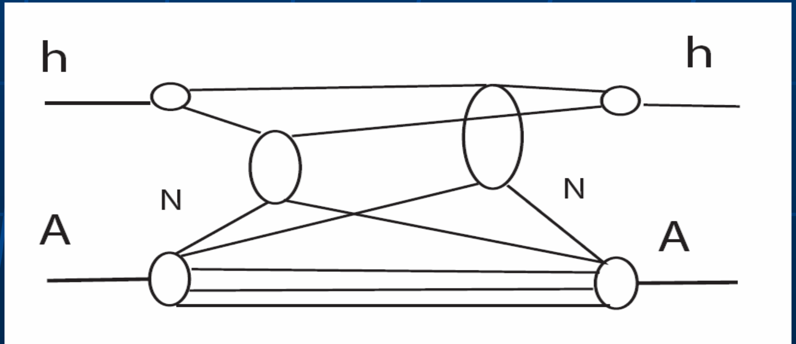
  At $E < E_c$ an elastic hA –scattering amplitude can be considered as successive rescatterings of an initial hadron on nucleons of a nucleus (Glauber model)



Space-time picture of high-energy interactions

- For $E > E_c$ there is a coherent interaction of constituents of a hadron with nucleons of a nucleus.

However hA elastic amplitude can be calculated as in the Glauber model, but with account of inelastic intermediate states ($M^2 << s$) - Gribov approach.



Shadowing of soft partons.

- Partons of a fast nucleus with small relative momenta $x < 1/m_N R_A$ overlap in longitudinal space and can interact.

For example two chains from different nucleons can fuse into a single chain (corresponds to PPP-interaction).

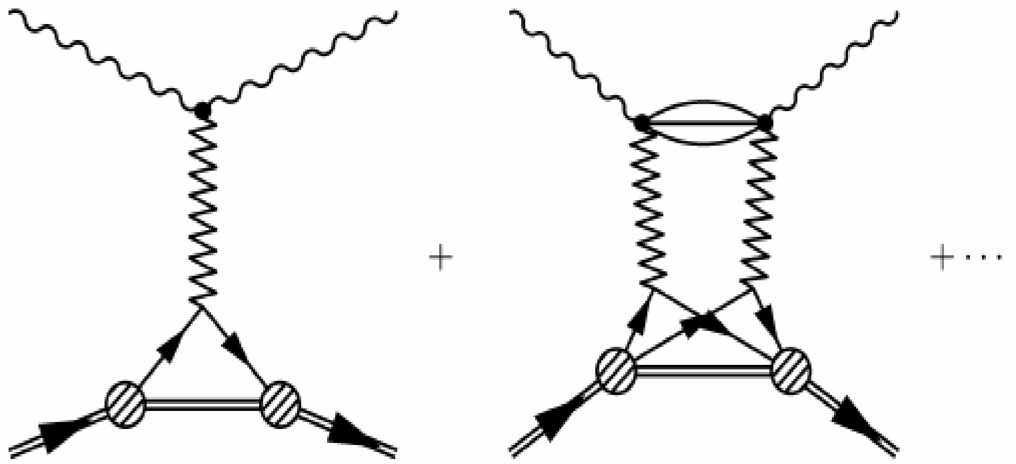
Large masses of intermediate states in Gribov approach. Couplings can be determined from diffractive production processes and turned out to be small.

Shadowing for nuclei.

The total cross section of a virtual photon (γ^*) – nucleus cross section

in the Glauber-Gribov approach

$$\sigma_{\gamma^* A} = A\sigma_{\gamma^* N} + \sigma^{(2)}_{\gamma^* A} + \ldots ,$$



Contribution of the second rescattering

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

where $T_A(b) = \int_{-\infty}^{+\infty} dz\, \rho_A(b,z)$ $\int d^2b\, T_A(b) = 1.$

The longitudinal part of nuclear form-factor

$$F_A(t_{min}) = \int d^2b\, J_0(\sqrt{-t_{min}}\, b)\, T_A(b) \,,$$

$t_{min} = -m_N^2 x_{IP}^2,$

takes into account the coherence condition: $x \ll 1/m_N R_A$

Higher order corrections

Higher order corrections are model dependent. Two models have been used in papers by A.Capella et al (1997), N.Armesto et al (2003), K.Tywoniuk et al(2006) :

a) Schwimmer model

$$\sigma^{Sch}_{\gamma^* A} = \sigma_{\gamma^* N} \int \mathrm{d}^2 b \, \frac{A\, T_A(b)}{1 + (A-1) f(x, Q^2) T_A(b)} \, ,$$

where

$$f(x, Q^2) = \frac{4\pi}{\sigma_{\gamma^* N}} \int_{M^2_{min}}^{M^2_{max}} \mathrm{d}M^2 \left[\frac{\mathrm{d}\sigma^{\mathcal{D}}_{\gamma^* N}}{\mathrm{d}M^2\, \mathrm{d}t} \right]_{t=0} F^2_A(t_{min}) \, .$$

Higher order corrections

b) Eikonal-type model

$$\sigma^{eik}_{\gamma^* A} = \sigma_{\gamma^* \mathrm{nucleon}} \int d^2 b \, \frac{A}{2(A-1) f(x,Q^2)} \left\{ 1 - \exp\left[-2(A-1) T_A(b) f(x,Q^2) \right] \right\},$$

The ratio of cross sections per nucleon for different nuclei

$$R(A/B) = \frac{B}{A} \frac{\sigma_{\gamma^* A}}{\sigma_{\gamma^* B}} .$$

In the Schwimmer model

$$R^{Sch}(A/\mathrm{nucleon}) = \int d^2 b \, \frac{T_A(b)}{1 + (A-1) f(x,Q^2) T_A(b)} ,$$

Diffractive production in γ^*p-collisions

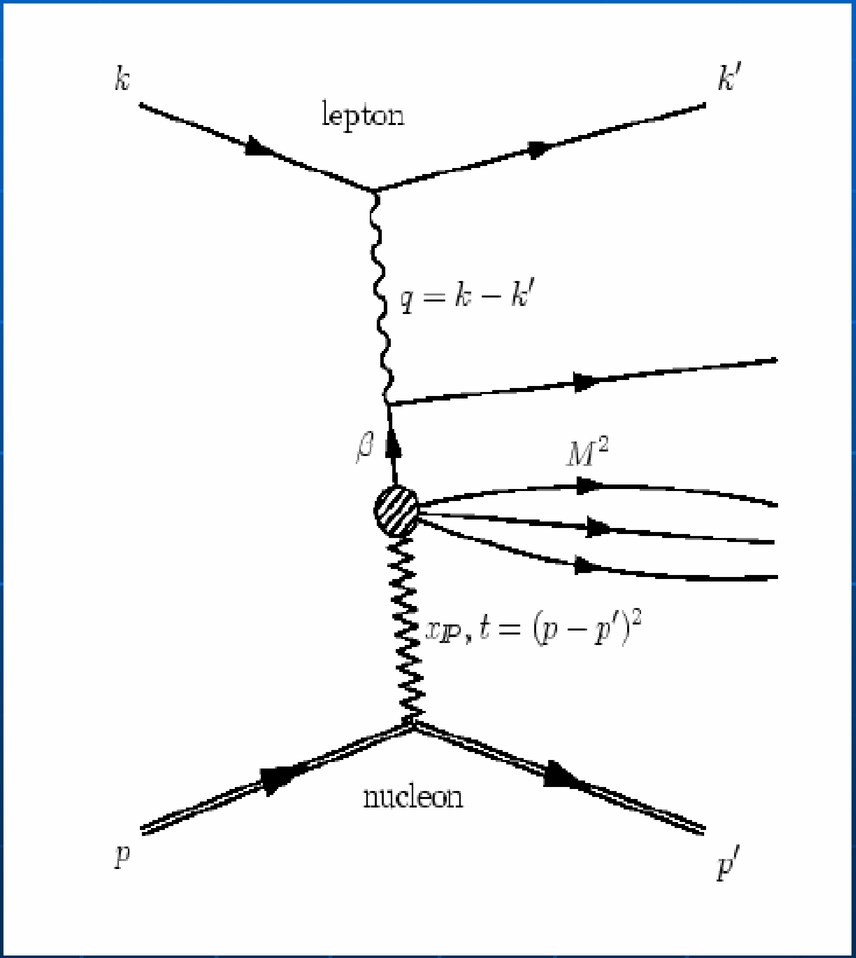
To calculate nuclear shadowing in this approach it is necessary to know diffractive dissociation of a virtual photon on a nucleon.

In paper by A.Capella et al parametrization of HERA data (with account of QCD evolution) was used to describe nuclear structure functions in the small-x region (shadowing for quarks).

Diffractive production in γ*p-collisions

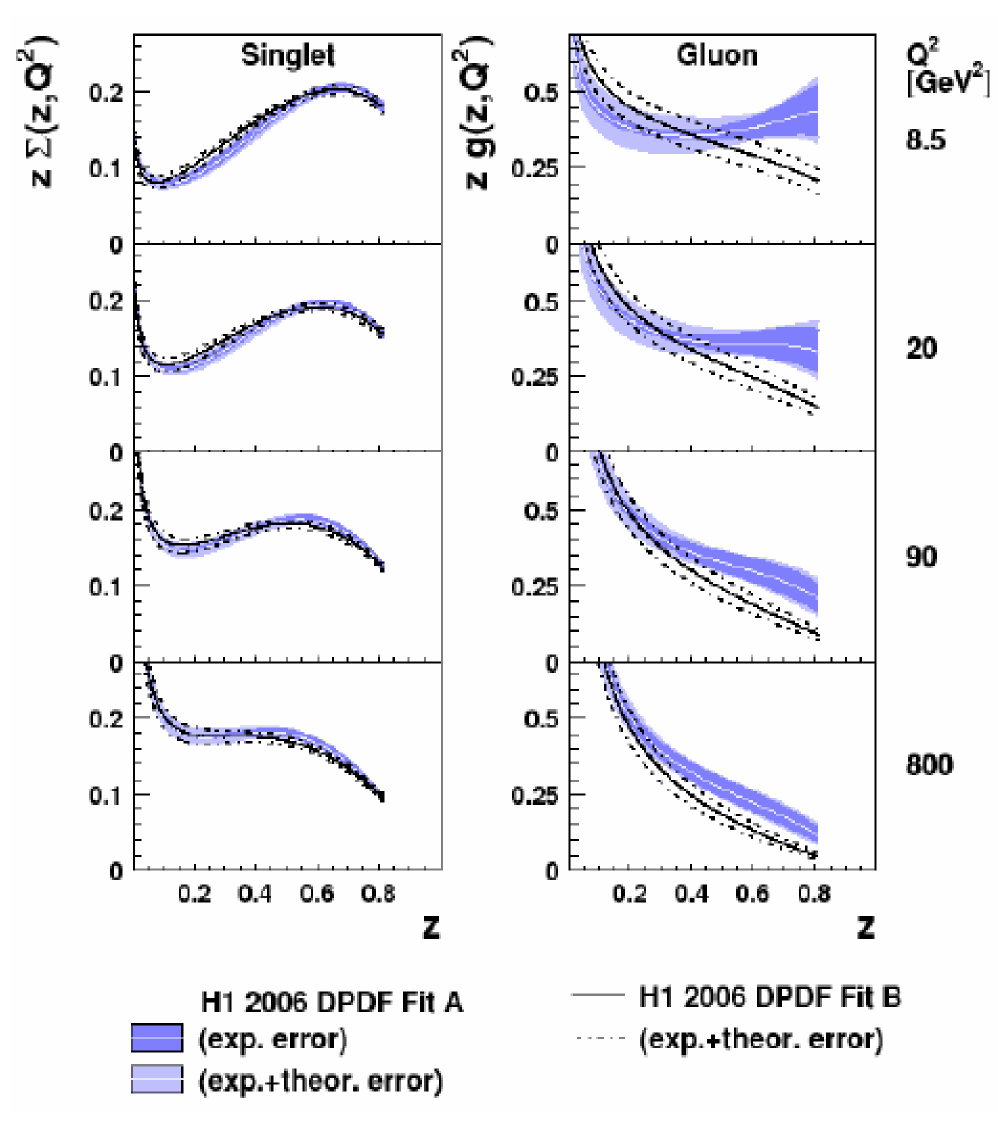
In the paper by N.Armesto et al the unitary model for γ*p-collisions valid in a broad region of Q^2 was used.

K.Tywoniuk et al used recent fits of H1 to calculate shadowing for gluons



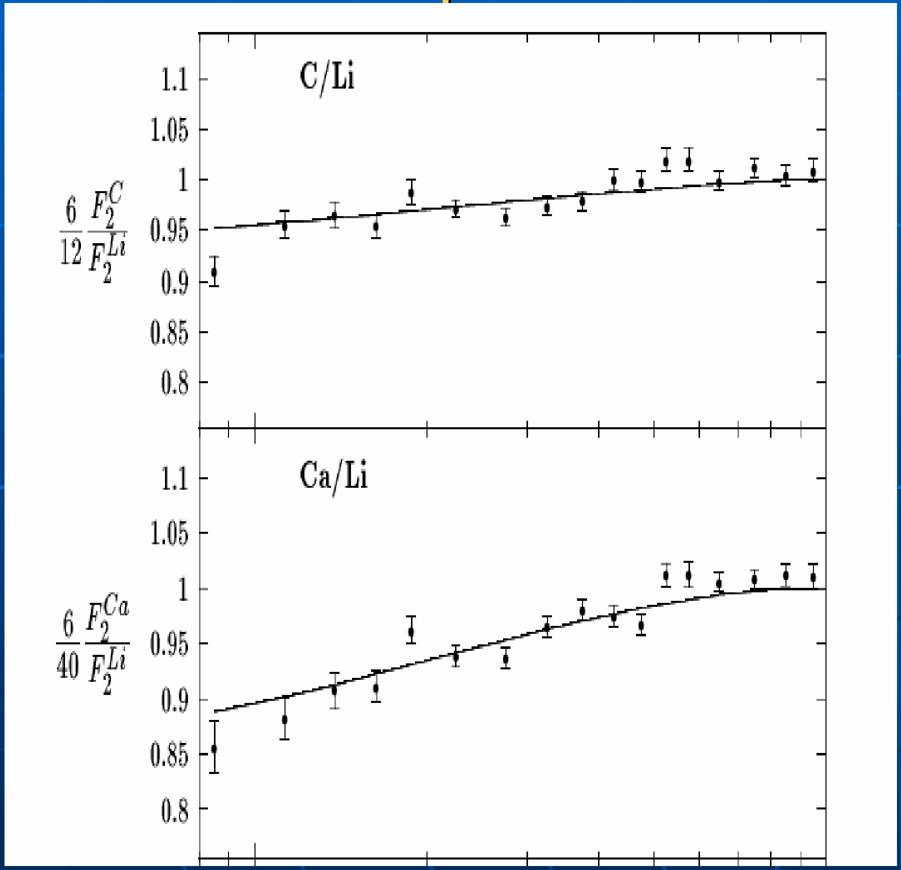
Distributions of quarks and gluons in the pomeron

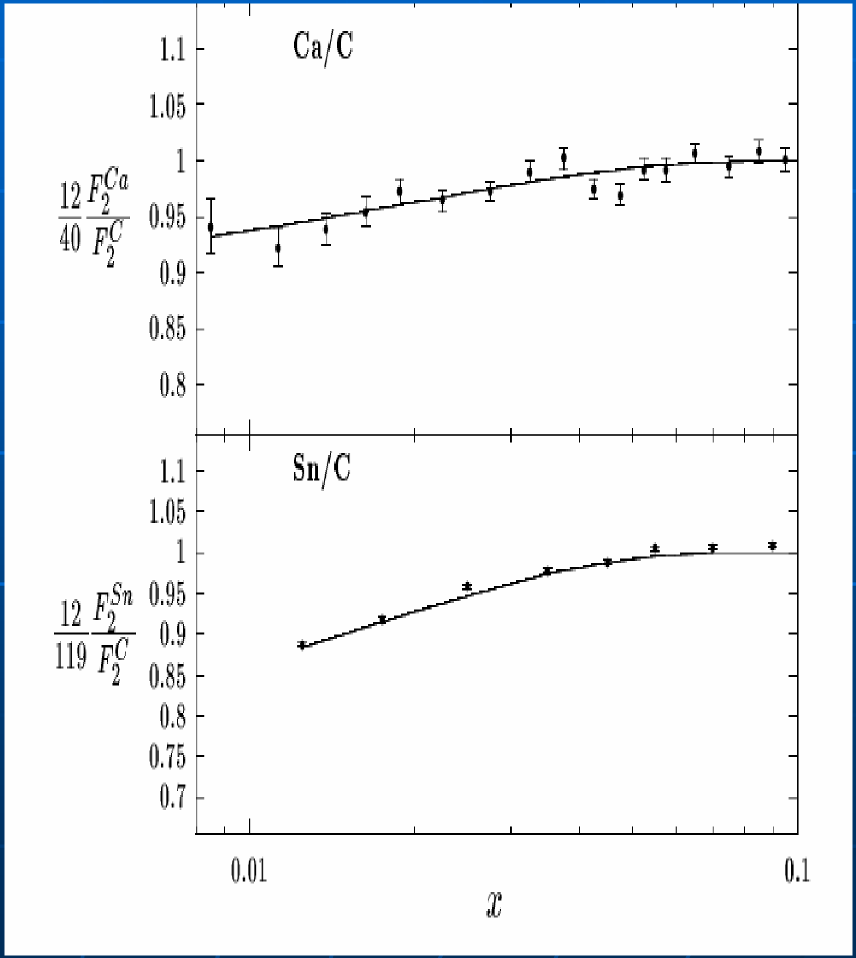
Distributions of quarks in the pomeron are known reasonably well. There are still uncertainties in distributions of gluons at β > 0.5. Fits A and B of H1 were used.



Comparison with experiment (NMC)

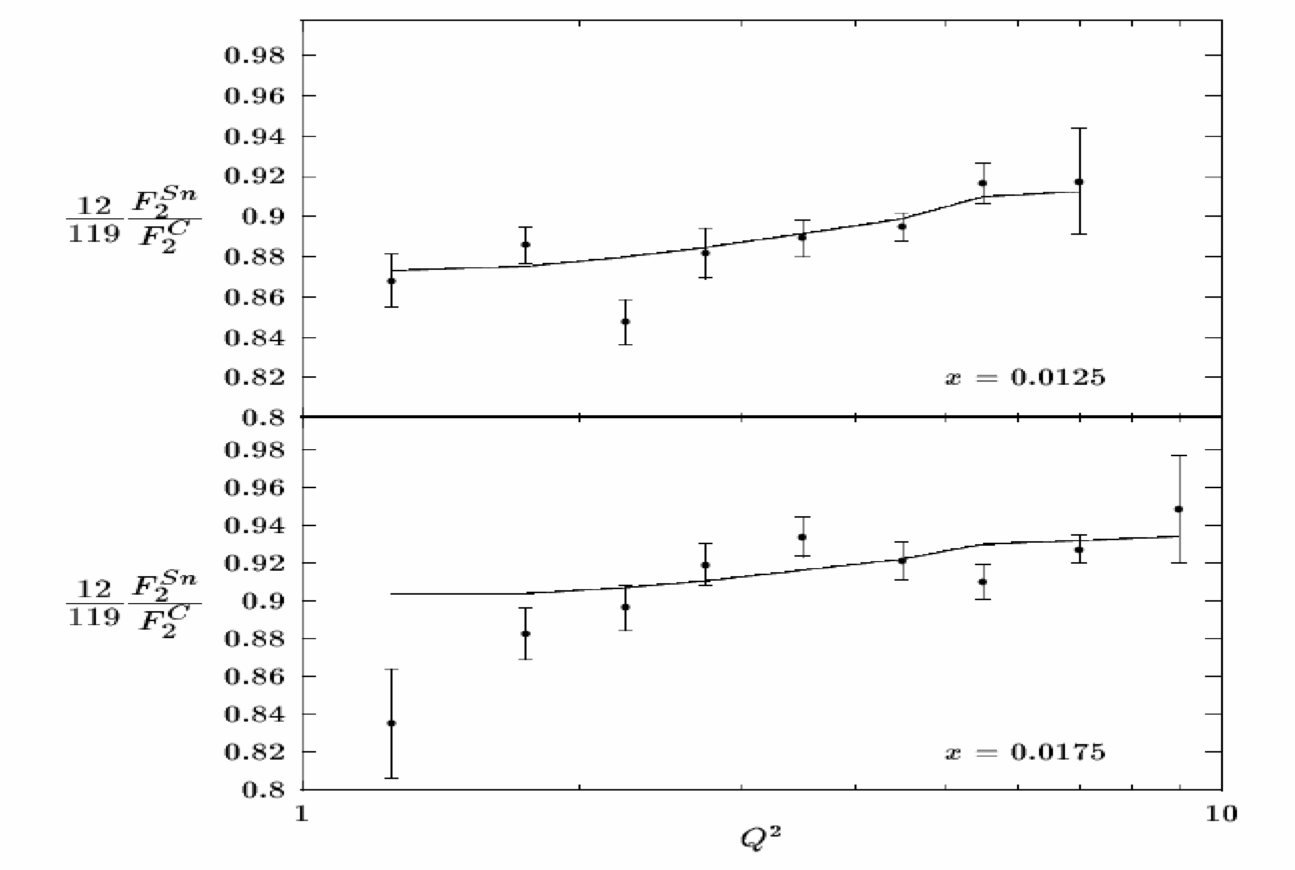
From A.Capella et al





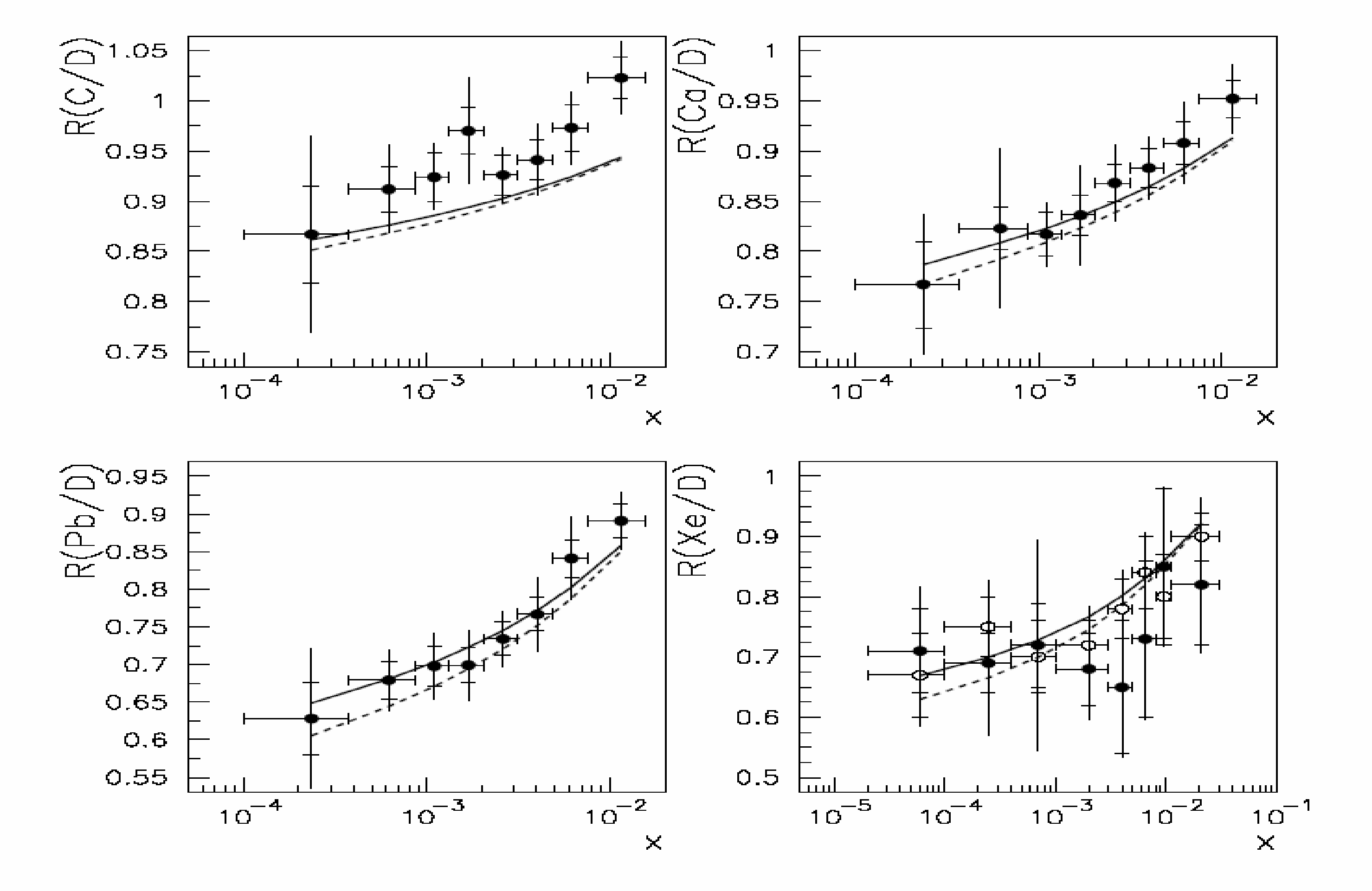
Dependence on Q^2

Weak dependence on Q^2 - leading twist effect.

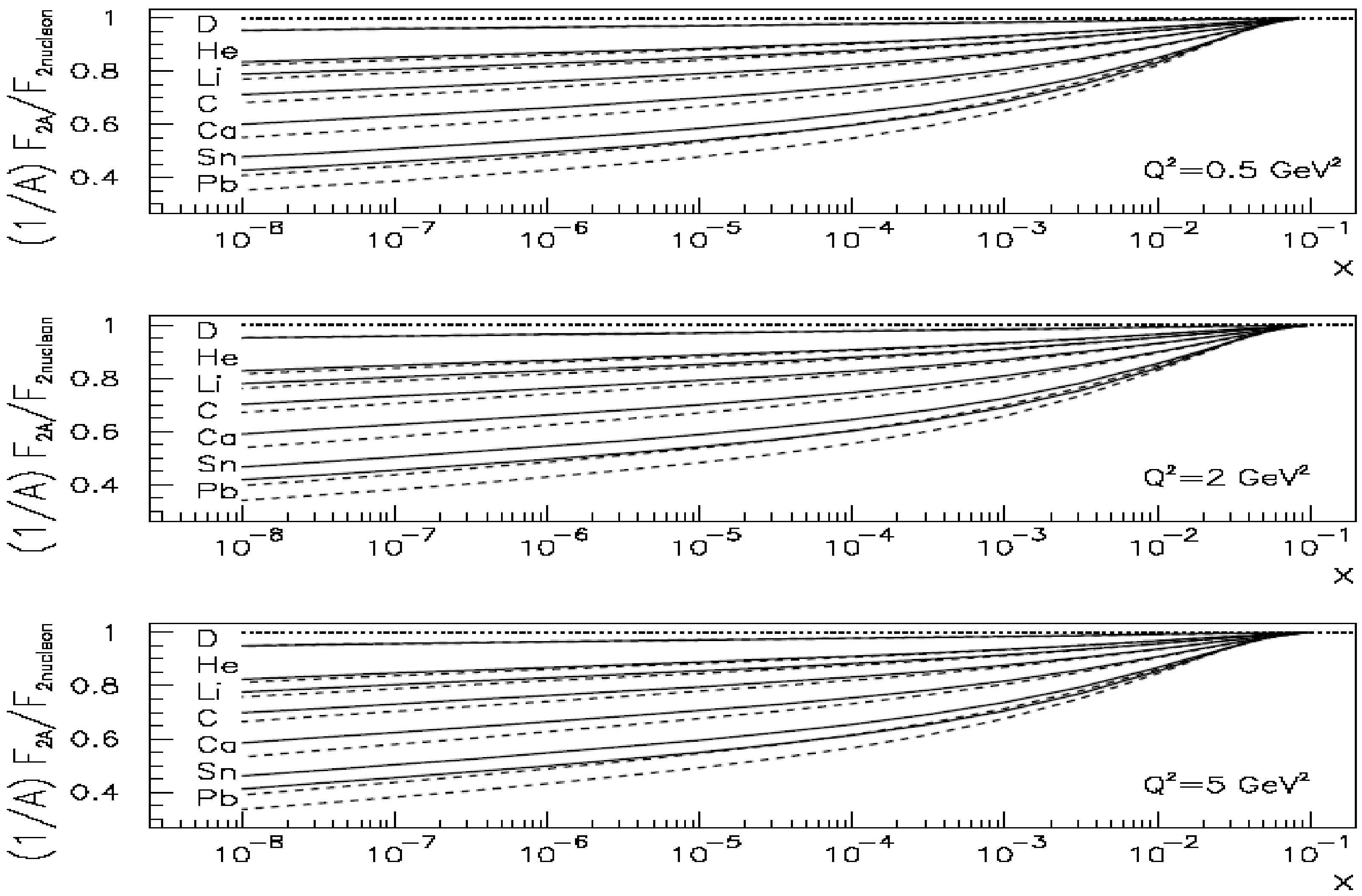


Comparison with experiment (E665)

From N.Armesto et al

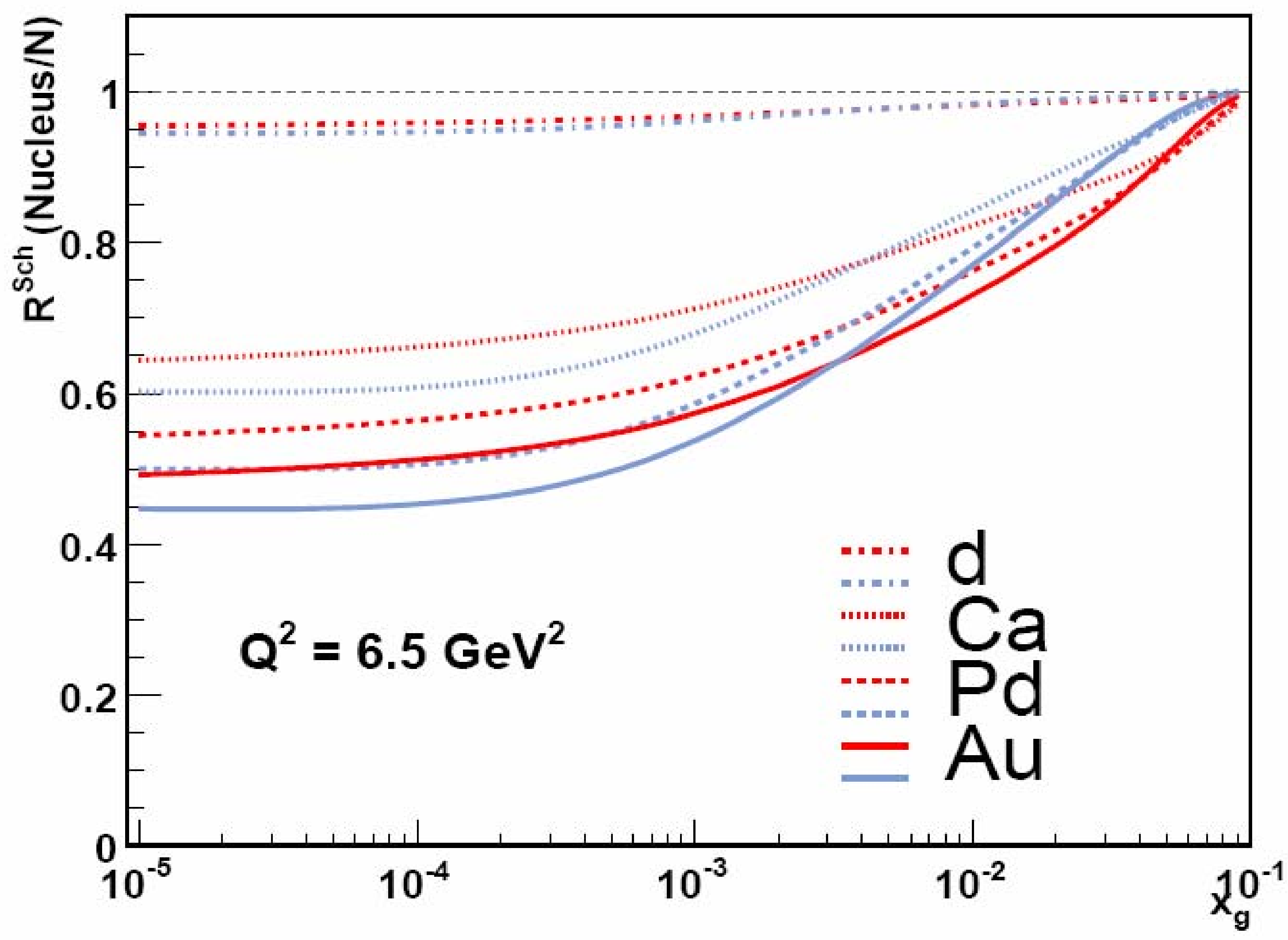


Predictions for higher energies (smaller x).

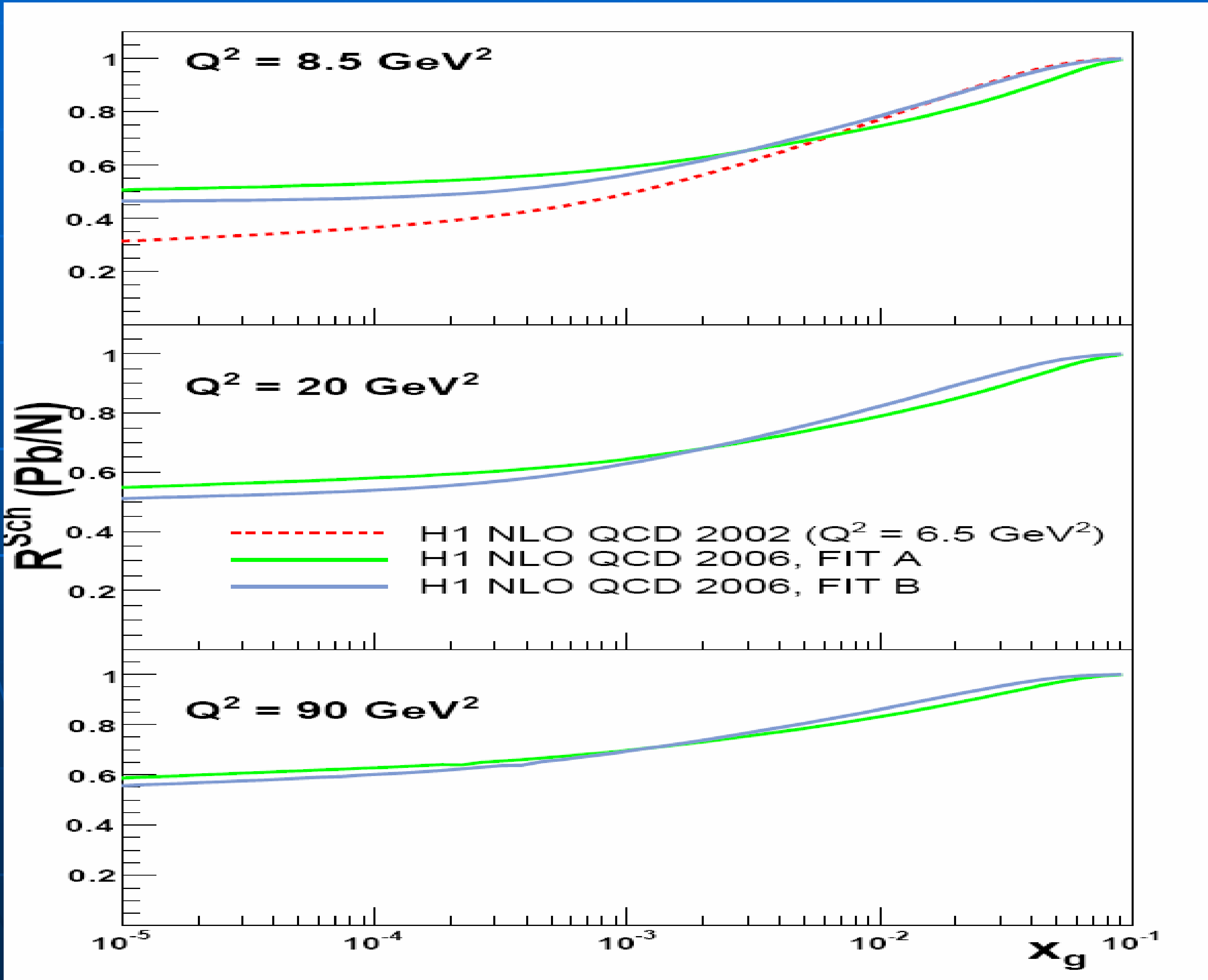


Shadowing for gluons

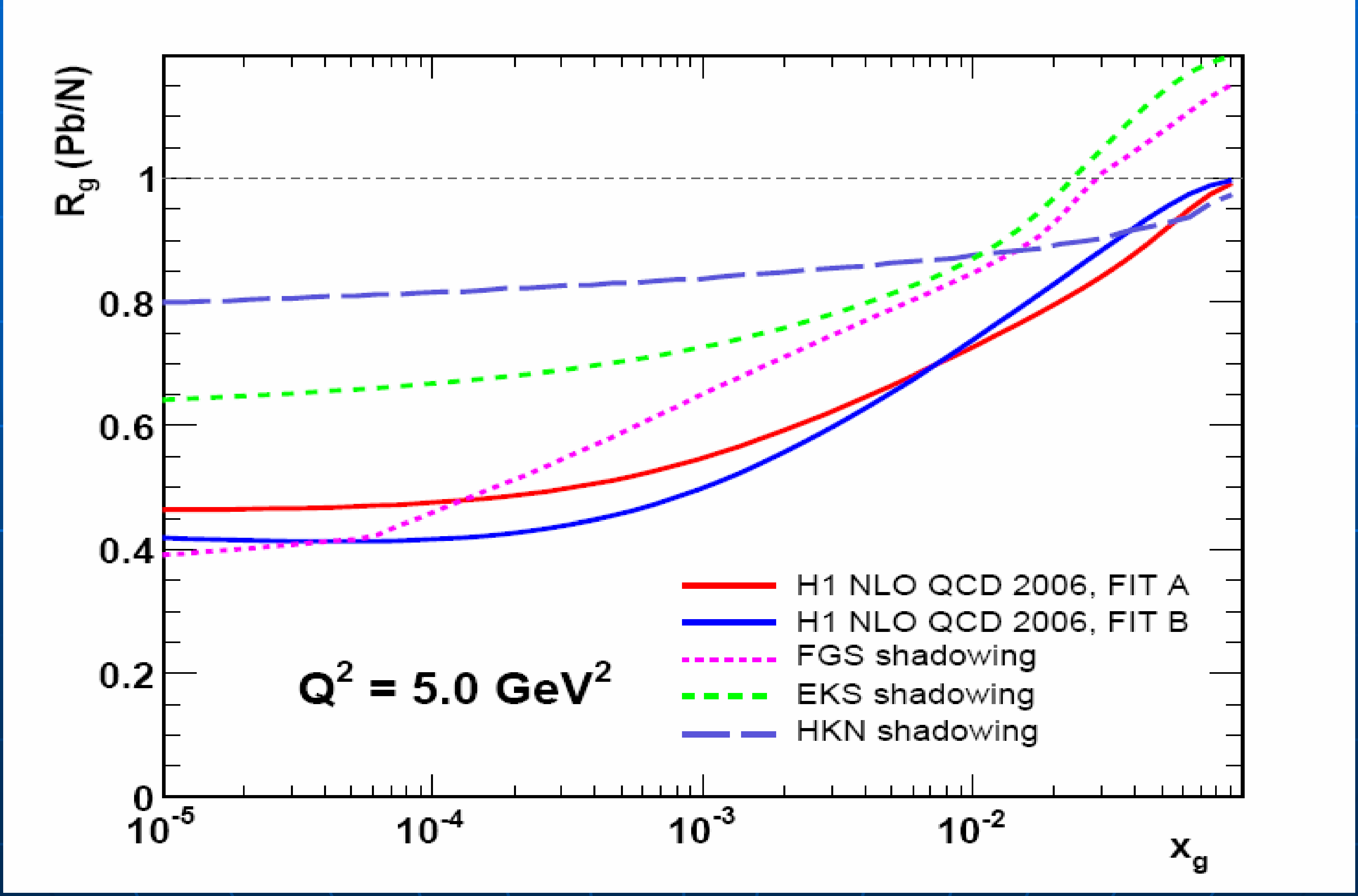
Red curves –fit A, blue ones –fit B



Q^2 -dependence



Comparison with other models



Shadowing effects in heavy ion collisions.

- Inclusive spectra and particle densities

For Glauber-type rescatterings AGK – cancellation takes place in the central rapidity region at s→ ∞

$$\frac{d\sigma_{A_1A_2}}{dy} = T_{A_1A_2}(b)\frac{d\sigma_{NN}}{dy},$$

where

$$T_{A_1A_2}(b) = \int d^2 s T_{A_1}(\mathrm{b}-\mathrm{s}) T_{A_2}(\mathrm{s}).$$

Particle densities in nucleus-nucleus collisions

For particle densities we have

$$\frac{dn_{A_1A_2}(b)}{dy} = n_{A_1A_2}(b)\frac{dn_{NN}}{dy},$$

where $n_{A_1A_2}(b) = \frac{T_{A_1A_2}(b)\sigma^{(\mathrm{tot})}_{NN}}{\sigma^{(\mathrm{tot})}_{A_1A_2}}$ is the number of collisions in the Glauber model.

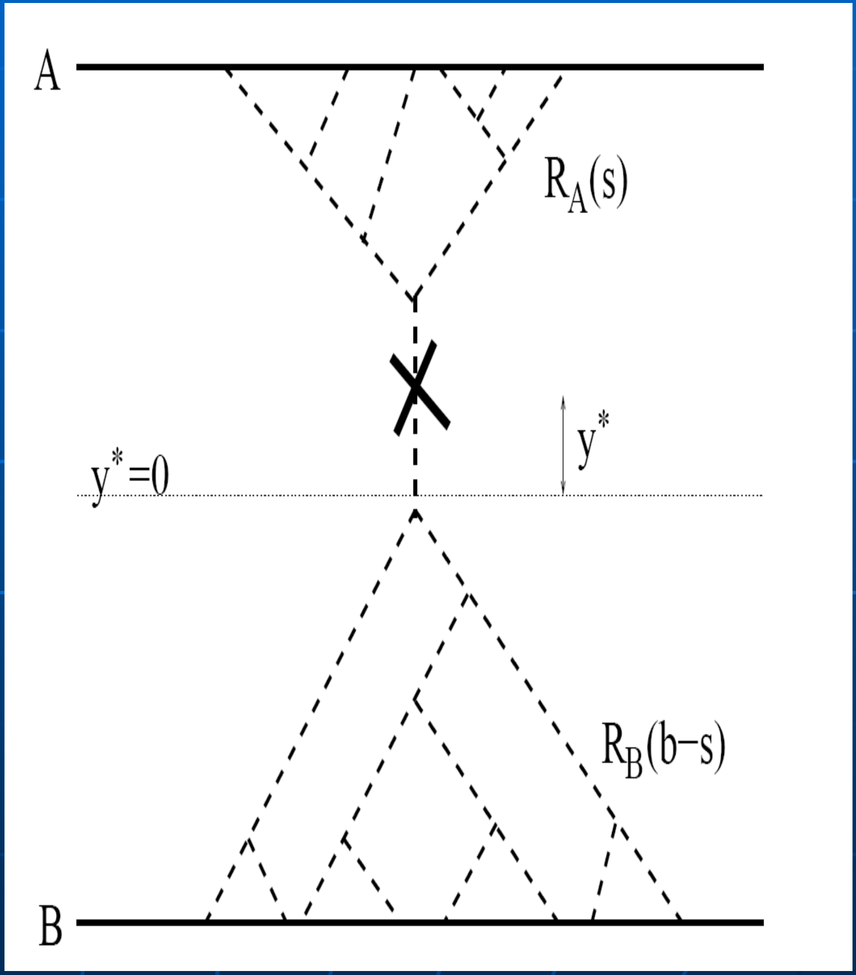
Shadowing for soft partons

- At very high energies soft partons of different nucleons overlap and can interact. This leads to shadowing effects for these partons (”saturation” for x→ 0). They are related to the shadowing for quarks and gluons in nuclei discussed above.
- ”Color glass condensate” approach in PQCD

Calculation of suppression

In the Schwimmer model the suppression for inclusive spectra is described by a simple formula

$$R_{AB}(b) = \frac{\int d^2s \; R_A(\vec{s}) R_B(\vec{b} - \vec{s})}{T_{AB}(b)} \, .$$



Calculation of nuclear suppression

Simplest partonic kinematics suggests

$$x_{A(B)} = \frac{m_T}{\sqrt{s}} e^{\pm y^*},$$

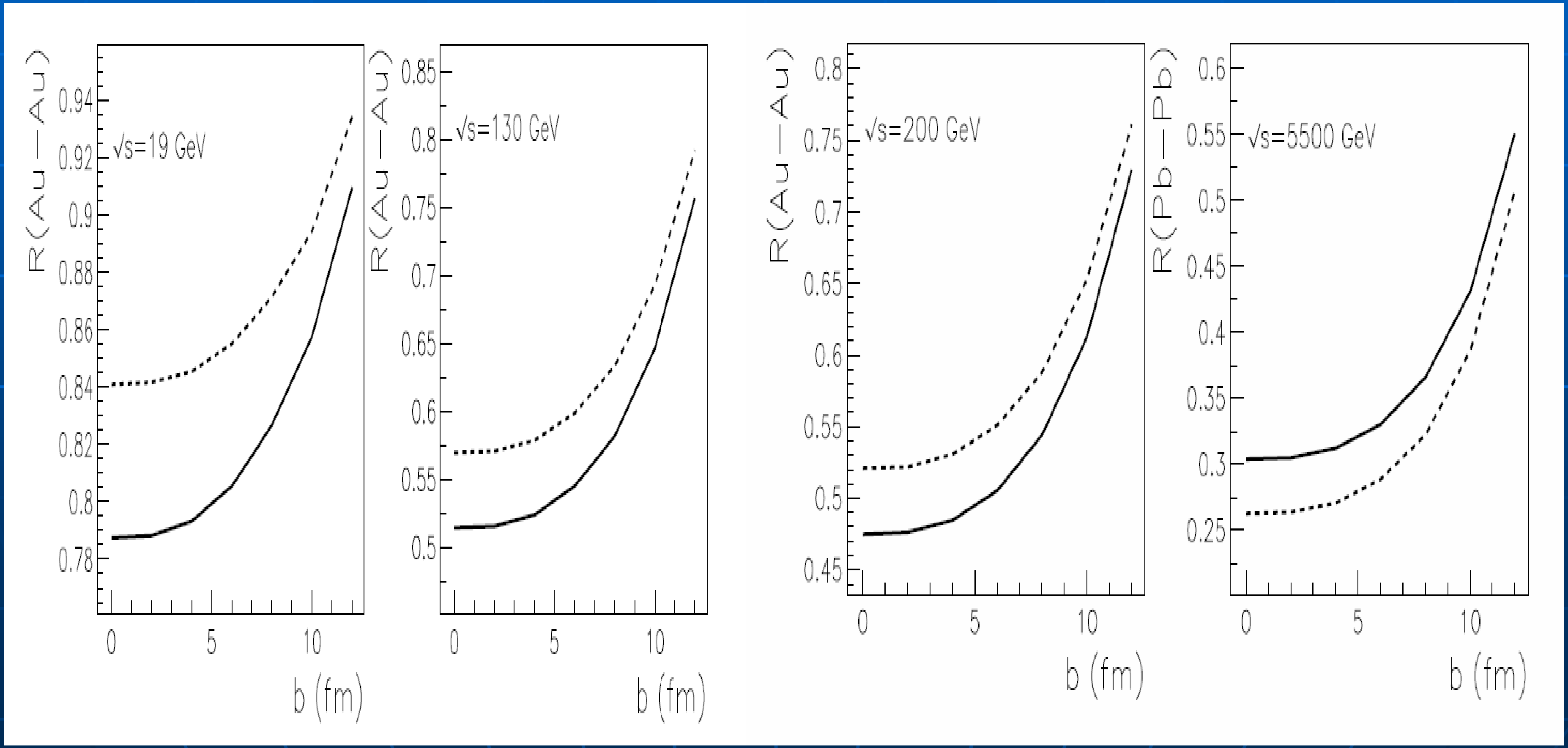
Note that these effects are important in the small-x region: $x << 1/m_N R_A$.

So they are absent for large p_T particle production at RHIC.

Suppression in this region is due to final state interactions.

Energy and impact parameter dependence of suppression

Predictions of N.Armesto et al.



Nuclear shadowing and RHIC data.

- Decrease of particle densities in comparison with Glauber model agrees with RHIC data.

  Dependence on b (N_{part}) is also reproduced.

Glauber	With account of shado-wing	Experi-ment $\sqrt{s}=$ 130 GeV
1200 ± 100	630± 120	555± 12±35 622±1 ±41

Gluon shadowing and J/ψ - production in NA-collsions.

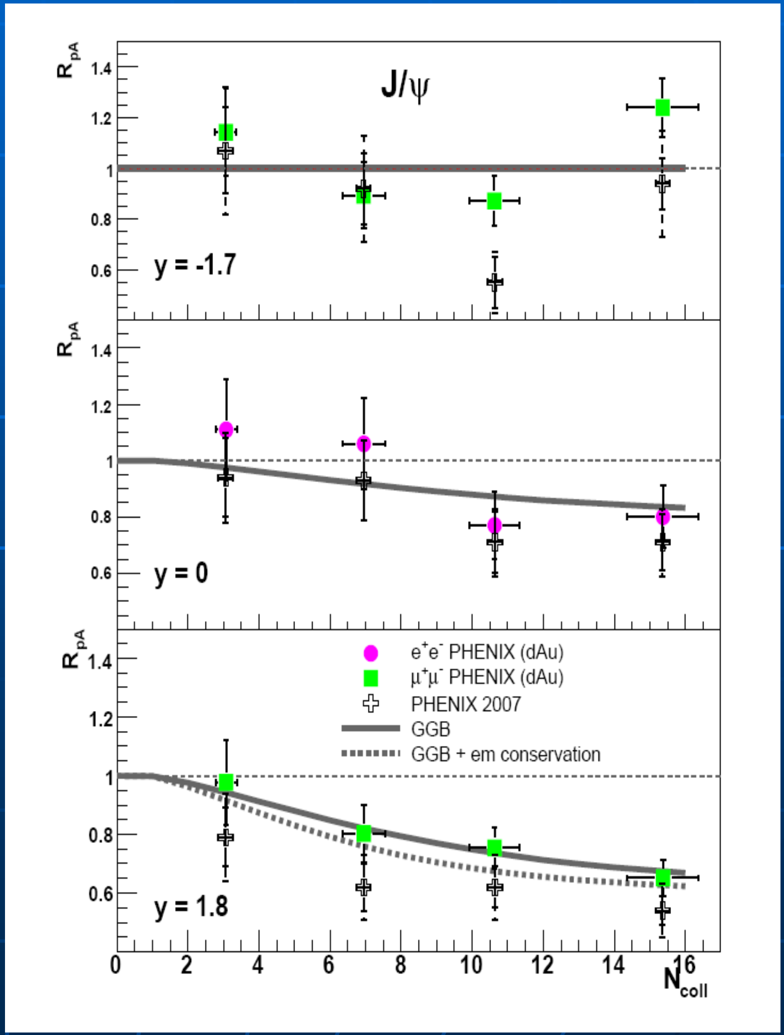
For J/psi production at $x_F=0$ in NA collisions the critical energy E_c is in the RHIC region and the “ low energy” formulas are not valid.

The Glauber-type rescatterings are very small at central rapidities in this energy region and the main mechanism of suppression is the gluon shadowing.

Gluon shadowing and J/ψ - production in NA-collsions.

Nuclear shadowing for gluons obtained from HERA data leads to a good description of RHIC results.

K.Tywoniuk et al.



J/ψ -production in NA-collsions.

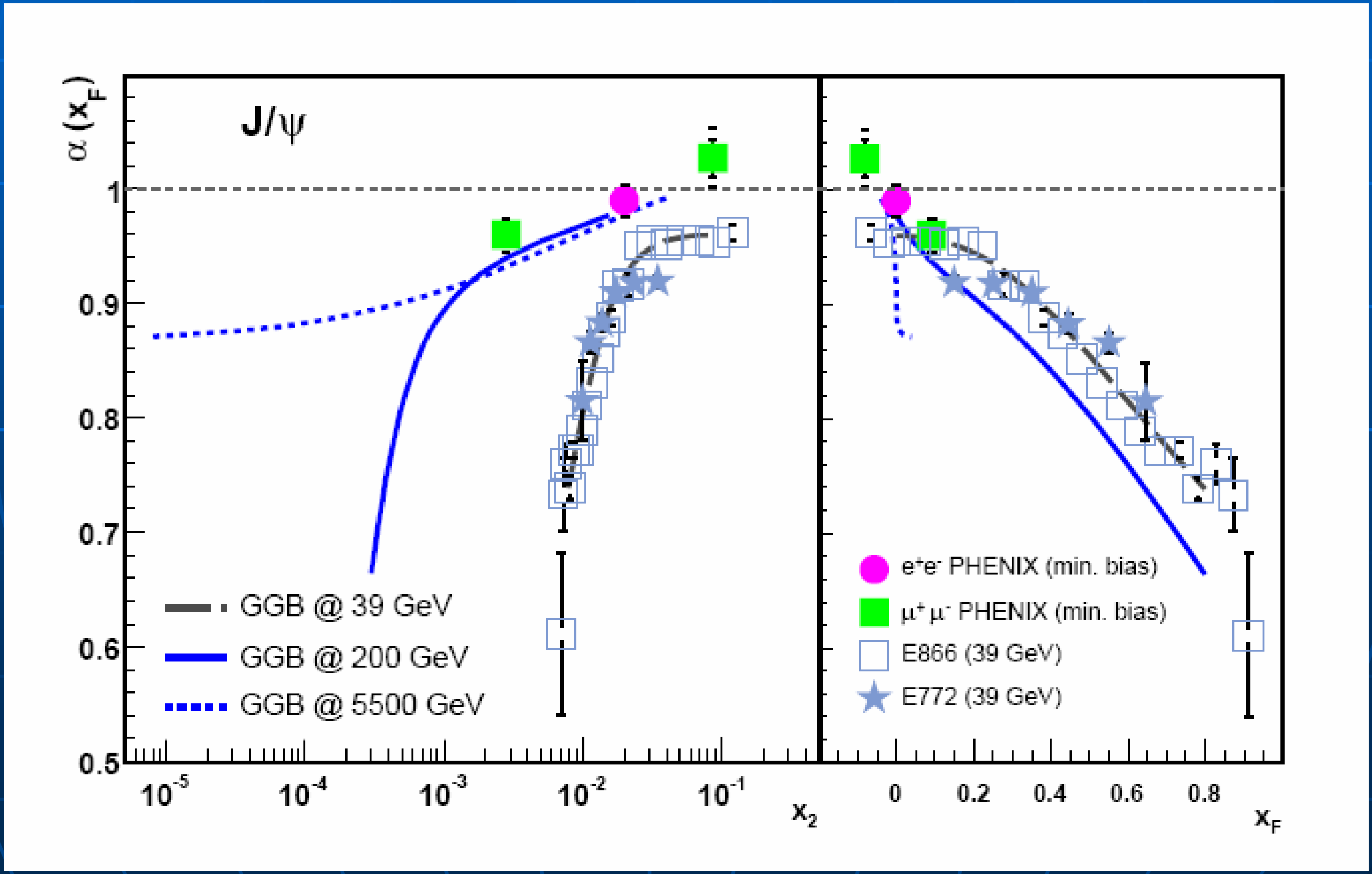
- Parameterization of inclusive cross sections

$$\frac{\mathrm{d}\sigma_{hA}^{a}}{\mathrm{d}^3p} = \frac{\mathrm{d}\sigma_{hN}^{a}}{\mathrm{d}^3p} A^{\alpha(x_F)} ,$$

- An account of change in the space-time picture of J/ψ – production gives a possibility to describe cross sections for all energies and x_F.
- Large deviations from Feynman scaling are predicted at LHC

Nuclear effects for J/ψ -production in NA-collsions.

K. Tywoniuk et al.



J/ψ -suppresion in heavy ion collisions.

J/ψ -suppression in heavy ion collisions was considered as a signal of QGP-formation.

Results from RHIC show that: suppression at $x_F=0$ is practically the

same as at SPS and

suppression at forward rapidities is stronger than at $x_F=0$.

SPS data were successfully described in the model, where J/ψ interacts with comoving particles. A. Capella et al.

J/ψ -suppresion in heavy ion collisions and comovers model.

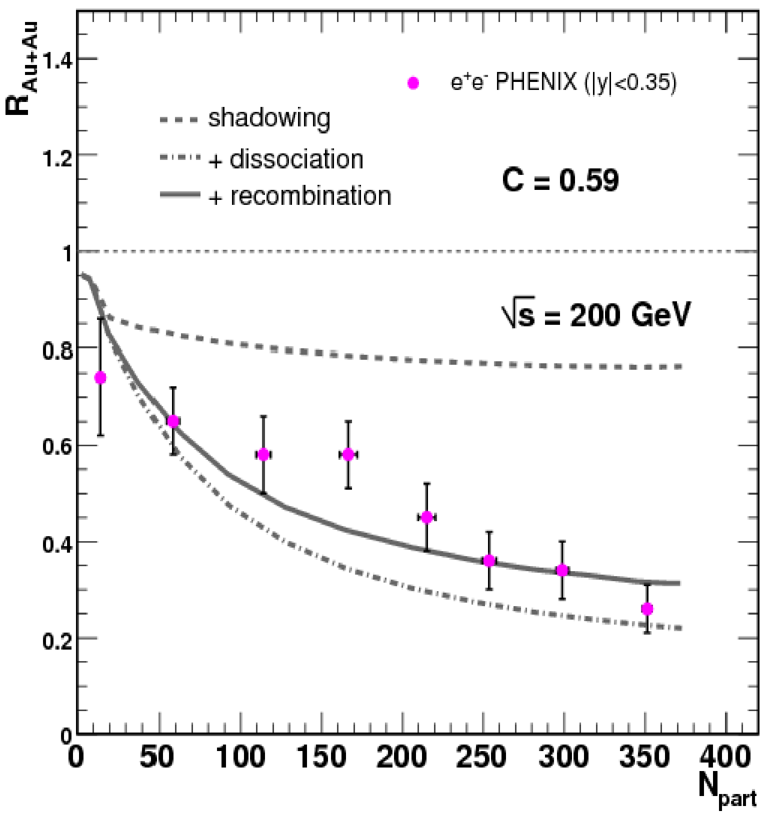
The same model, which also accounts for recombination of open charm to quarkonia well describes RHIC data.

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

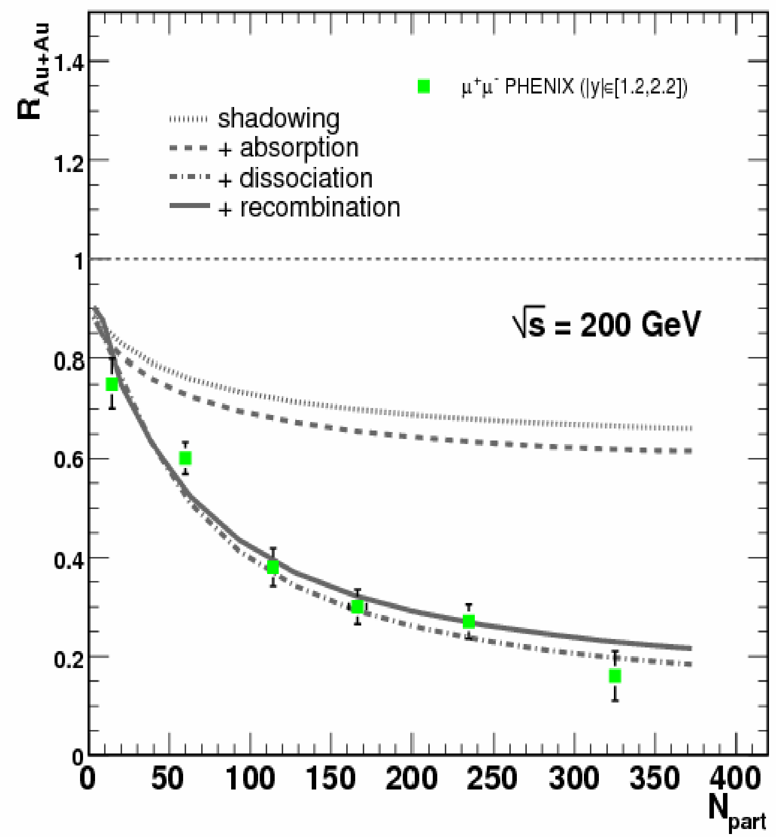
$$C = \frac{\left(dN_{pp}^{D}/dy\right)^2}{dN_{pp}^{J/\psi}/dy}$$

Comovers' suppression and recombination

Comparison to data for Au+Au and Cu+Cu @ RHIC

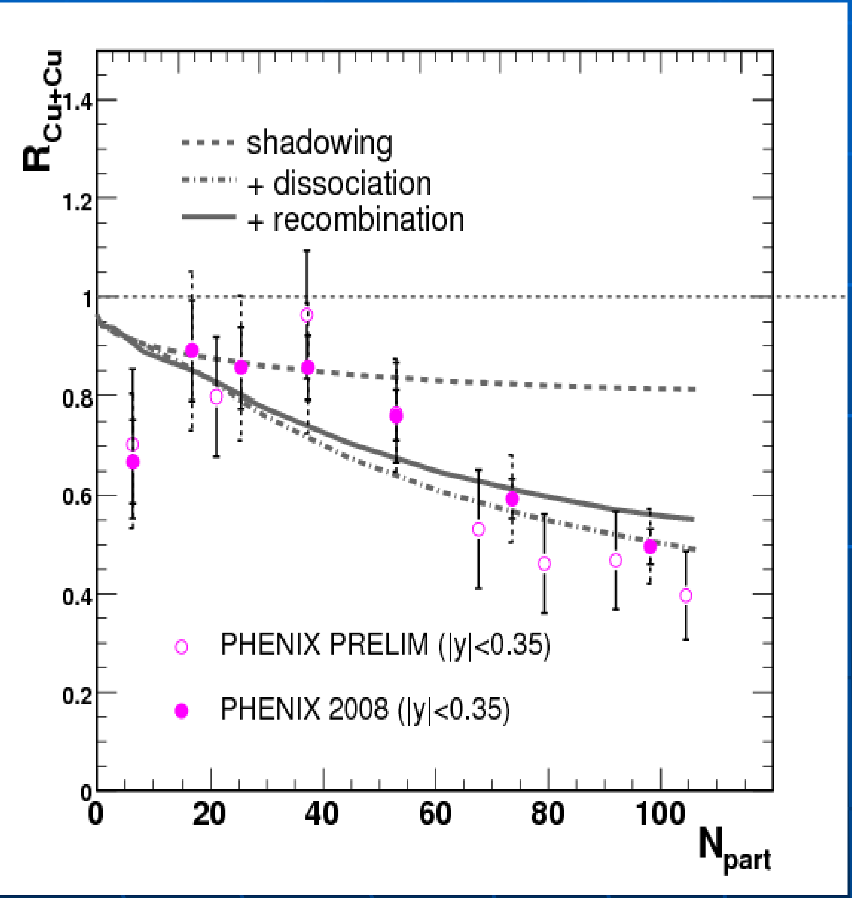


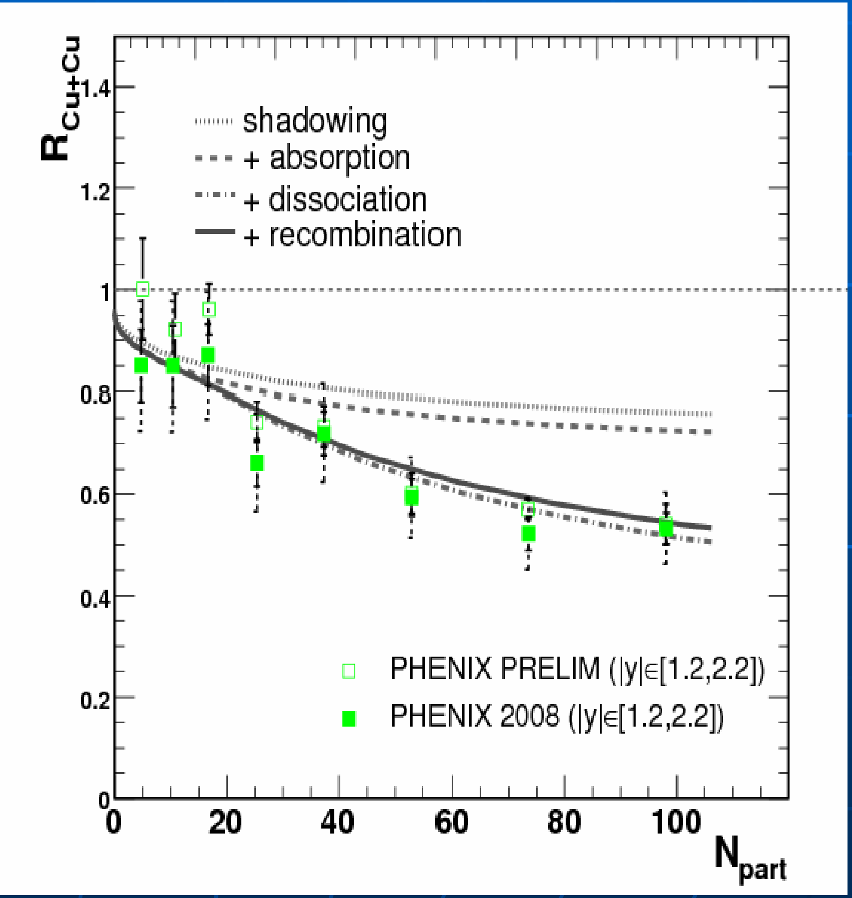
C = 0.59



Comovers' suppression and recombination

Comparison to data for Au+Au and Cu+Cu @ RHIC

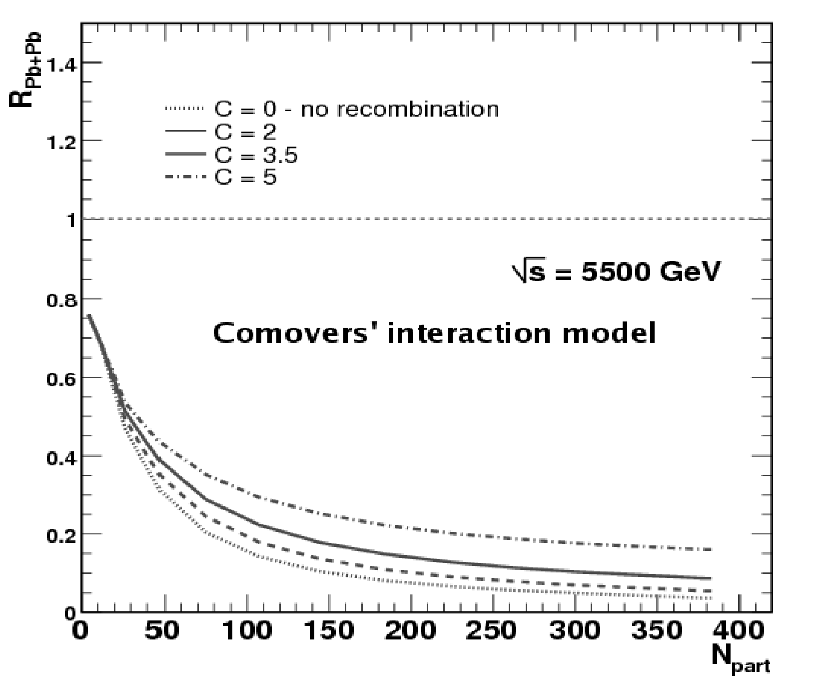




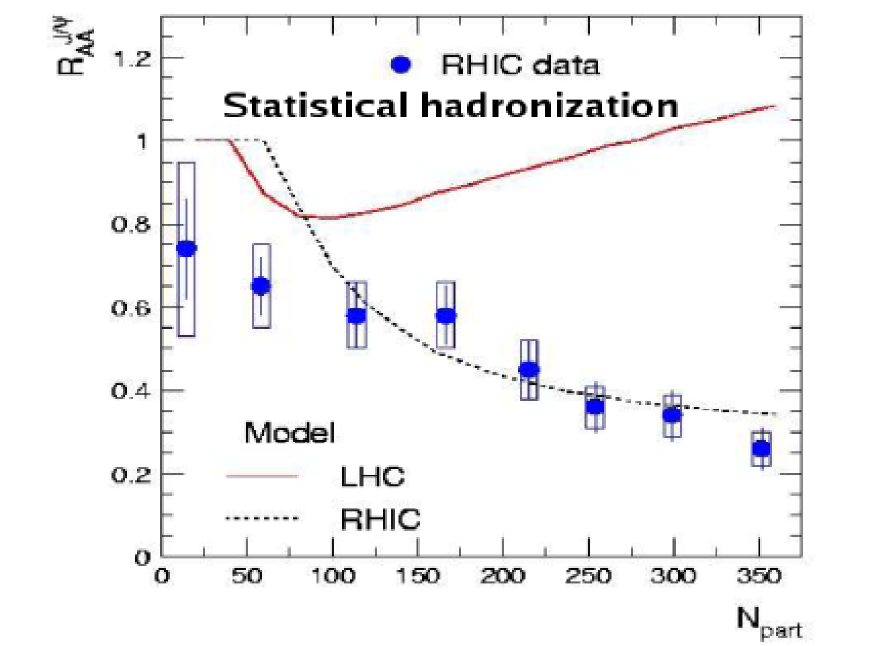
Comovers' suppression and recombination

Predictions for Pb+Pb @ LHC

- recombination a crucial effect
- strong dependence on the charm cross section
- theoretical extrapolations are very uncertain
- we assume $\sigma^{c\bar{c}} \propto s^{0.3}$



This is drastically different from statistical models



Andronic, Braun-Munzinger, Redlich, Stachel Nucl. Phys. A 789 (2007) 334

Conclusions.

- Shadowing for nuclear structure functions can be calculated using Gribov`s formalism and is related to diffractive processes.
- Interactions of soft partons play an important role in heavy ion collisions, but the ”saturation” is not achieved yet at RHIC for hard interactions.

Conclusions.

- Shadowing of gluons, calculated from diffractive data, correctly reproduces RHIC results on J/ψ-production in DA- collisions.
- Modification of nuclear distributions of gluons and account of interactions with comovers gives parameter-free description of J/ψ-suppression in heavy ion collisions at RHIC.