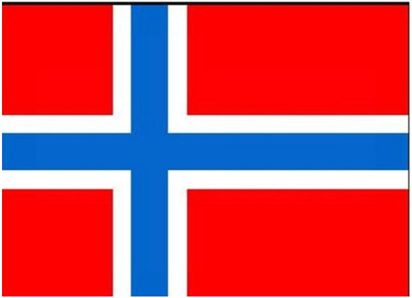
Gluon shadowing in the Glauber-Gribov model

K. Tywoniuk[1] I. C. Arsene[1] L. Bravina[1]
A. B. Kaidalov[2] E. Zabrodin[1]

[1]Department of Physics
University of Oslo

[2]Institute of Theoretical and Experimental Physics
Moscow

May 17th 2006 / Hot Quarks 2006, Villasimus

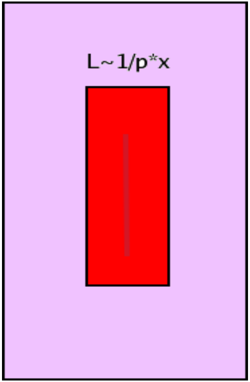


Outline

Color coherence

Space-time picture of nuclear interactions

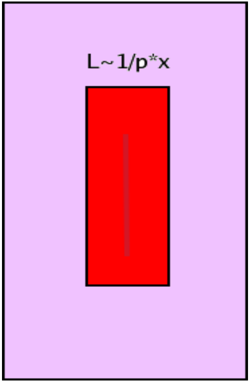
- a fast-moving hadron or nucleus can be considered as a system of coherent quark-gluon configurations of very different transverse spatial sizes.
- a content of the state is Lorentz-frame dependent.
- fast parton components of the wave function are Lorentz-contracted, while soft ones are not.



Color coherence

Space-time picture of nuclear interactions

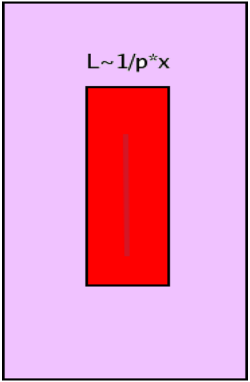
- a fast-moving hadron or nucleus can be considered as a system of coherent quark-gluon configurations of very different transverse spatial sizes.
- a content of the state is Lorentz-frame dependent.
- fast parton components of the wave function are Lorentz-contracted, while soft ones are not.



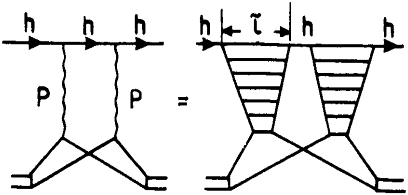
Color coherence

Space-time picture of nuclear interactions

- a fast-moving hadron or nucleus can be considered as a system of coherent quark-gluon configurations of very different transverse spatial sizes.
- a content of the state is Lorentz-frame dependent.
- fast parton components of the wave function are Lorentz-contracted, while soft ones are not.



Coherence length



"Planar" diagram for double rescattering - Glauber model.

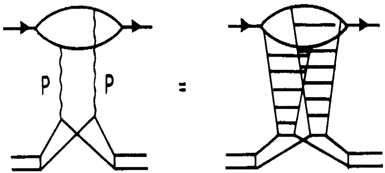
Formation time of the intermediate state

$$\tau \sim \frac{E}{m_N \mu} \, .$$

High energy: the hadronic fluctuation length can become of the order of the nuclear radius and there will be coherent interaction of constituents of the hadron with several nucleons of the nucleus.

$$l_c \approx (\Delta E)^{-1} \approx \frac{1}{2 m_N x}$$

Coherence length



“Non-planar” diagram for double rescattering.

Formation time of the intermediate state

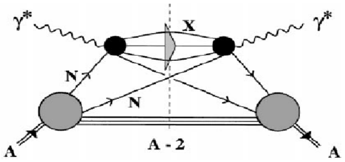
$$\tau \sim \frac{E}{m_N \mu} .$$

High energy: the hadronic fluctuation length can become of the order of the nuclear radius and there will be coherent interaction of constituents of the hadron with several nucleons of the nucleus.

$$\begin{aligned} l_c &\approx (\Delta E)^{-1} \\ &\approx \frac{1}{2m_N x} \end{aligned}$$

Nuclear shadowing

Gribov's approach

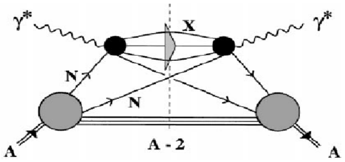


- contribution of inelastic diffractive scattering.
- space-time picture does not correspond to successive rescatterings of an initial hadron in a nucleus.
- multiparticle content of different diagrams is given by AGK cutting rules.

Gribov Sov.Phys.JETP **29** (1969) 483; Sov.Phys.JETP **30** (1970) 709
Abramovsky, Gribov, Kancheli Sov.J.Nucl.Phys **18** (1974) 308

Nuclear shadowing

Gribov's approach

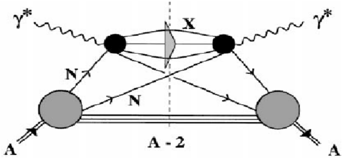


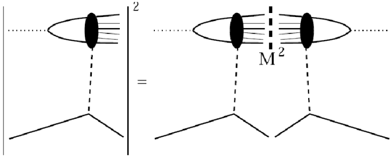
- contribution of inelastic diffractive scattering.
- space-time picture does not correspond to successive rescatterings of an initial hadron in a nucleus.
- multiparticle content of different diagrams is given by AGK cutting rules.

Gribov Sov.Phys.JETP **29** (1969) 483; Sov.Phys.JETP **30** (1970) 709
Abramovsky, Gribov, Kancheli Sov.J.Nucl.Phys **18** (1974) 308

Nuclear shadowing

Gribov's approach



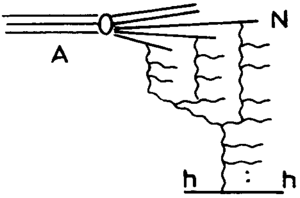


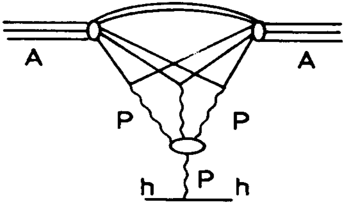
- contribution of inelastic diffractive scattering.
- space-time picture does not correspond to successive rescatterings of an initial hadron in a nucleus.
- multiparticle content of different diagrams is given by AGK cutting rules.

Gribov Sov.Phys.JETP **29** (1969) 483; Sov.Phys.JETP **30** (1970) 709
Abramovsky, Gribov, Kancheli Sov.J.Nucl.Phys **18** (1974) 308

Nuclear shadowing

Enhanced diagrams

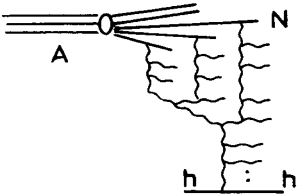


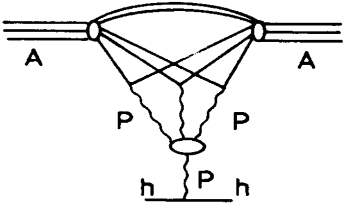


- soft partons from different ladders overlap and start to interact.
- 3IP and 4IP vertexes are rather small.
- become important for hA ($A^{1/3}$) and AB ($A^{1/3} + B^{1/3}$) collisions and at high energies.

Nuclear shadowing

Enhanced diagrams

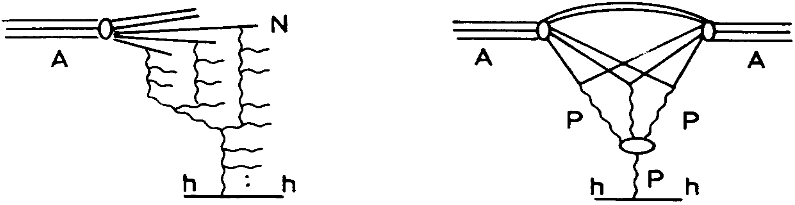




- soft partons from different ladders overlap and start to interact.
- $3\mathbb{P}$ and $4\mathbb{P}$ vertexes are rather small.
- become important for hA ($A^{1/3}$) and AB ($A^{1/3} + B^{1/3}$) collisions and at high energies.

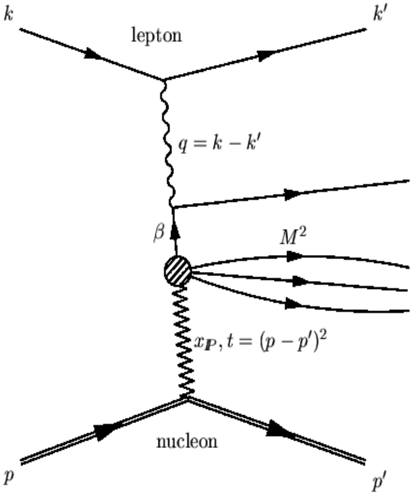
Nuclear shadowing

Enhanced diagrams



- soft partons from different ladders overlap and start to interact.
- $3\mathbb{P}$ and $4\mathbb{P}$ vertexes are rather small.
- become important for hA ($A^{1/3}$) and AB ($A^{1/3}+B^{1/3}$) collisions and at high energies.

Diffractive DIS - kinematical variables

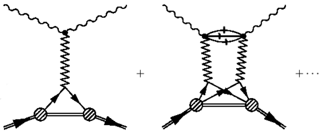


Infinite momentum frame:

- $q^2 = -Q^2$
- $x = \frac{Q^2}{2\, p \cdot q} = \frac{Q^2}{Q^2 + (p+q)^2}$
- $\beta = \frac{Q^2}{Q^2 + M^2} = \frac{x}{x_P}$

Reduction of total cross section

Rescattering series



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

$$\sigma_A^{(1)} = A \cdot \sigma_N \; ,$$

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

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

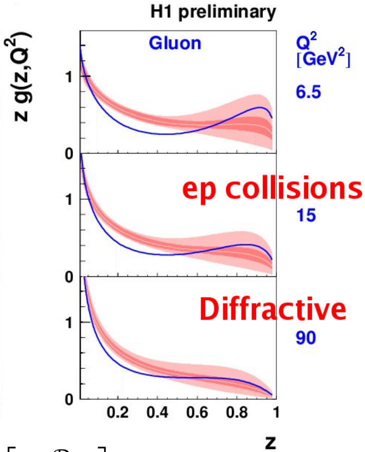
Reduction of total cross section

Relation to diffractive DIS

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

- F_A: nuclear form factor
- $T_A(b)$: nuclear density profile
- dM^2: integration over the diffractively produced hadronic system
  - M_{min}^2: minimal mass of produced system
  - M_{max}^2: large rapidity gap is required ($x_{I\!P}^{max} \ll 1$).

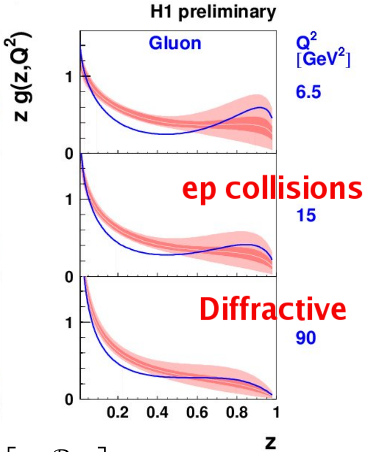
Parameterization of nuclear parton densities

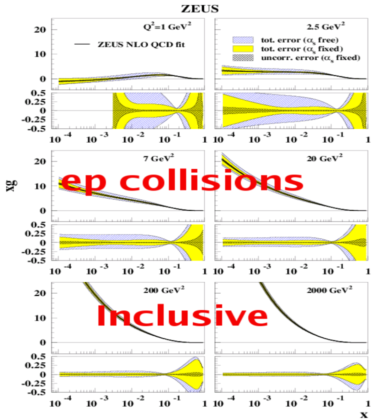


$$\left[\frac{d\sigma^{\mathcal{D}}_{\gamma^* N}}{dM^2 dt}\right]_{t=0} = \frac{4\pi^2 \alpha_{em} B}{Q^2(Q^2+M^2)} x_{I\!P} F^{(3)}_{2\mathcal{D}}$$

H1 Collaboration, paper **980** at ICHEP2002

Parameterization of nuclear parton densities





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

$$\sigma_{\gamma^* N} = \frac{4\pi^2\alpha_{em}}{Q^2} F_2(x, Q^2)$$

H1 Collaboration, paper **980** at ICHEP2002

ZEUS Collaboration, PRD **67** (2003) 012007

Parameterization of nuclear parton densities

- we assume Regge factorization and standard parameterizations as in diffractive physics.
- Pomeron parameters: $\alpha_{I\!P}(0) = 1.173$ and $\alpha'_{I\!P} = 0.26\text{GeV}^{-2}$.
- we focus on the effect of gluon shadowing.
- we put $Q^2 \approx 7\text{GeV}^2$.

Parameterization of nuclear parton densities

- we assume Regge factorization and standard parameterizations as in diffractive physics.
- Pomeron parameters: $\alpha_{I\!P}(0) = 1.173$ and $\alpha'_{I\!P} = 0.26\mathrm{GeV}^{-2}$.
- we focus on the effect of gluon shadowing.
- we put $Q^2 \approx 7\mathrm{GeV}^2$.

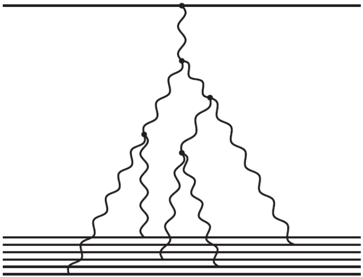
Parameterization of nuclear parton densities

- we assume Regge factorization and standard parameterizations as in diffractive physics.
- Pomeron parameters: $\alpha_{\mathbb{P}}(0) = 1.173$ and $\alpha'_{\mathbb{P}} = 0.26 \text{GeV}^{-2}$.
- we focus on the effect of gluon shadowing.
- we put $Q^2 \approx 7 \text{GeV}^2$.

Parameterization of nuclear parton densities

- we assume Regge factorization and standard parameterizations as in diffractive physics.
- Pomeron parameters: $\alpha_{I\!P}(0) = 1.173$ and $\alpha'_{I\!P} = 0.26\mathrm{GeV}^{-2}$.
- we focus on the effect of gluon shadowing.
- we put $Q^2 \approx 7\mathrm{GeV}^2$.

Schwimmer summation of fan diagrams



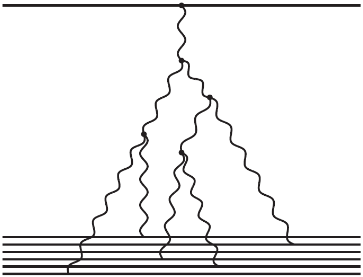
Schwimmer Nucl.Phys.B **94** (1975) 445

- splittings of Pomeron
- relevant for hA collisions at high energies
- exact solution of the Regge field theory

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

$$f(x,Q^2) = \frac{4\pi}{\sigma_{hN}} \int_{M_{min}^2}^{M_{max}^2} dM^2 \left[\frac{d\sigma_{hN}^{\mathcal{D}}}{dM^2 dt}\right]_{t=0} F_A^2(t_{min})$$

Schwimmer summation of fan diagrams



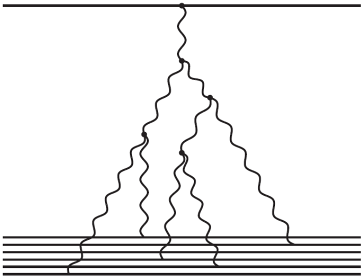
Schwimmer Nucl.Phys.B **94** (1975) 445

- splittings of Pomeron
- relevant for hA collisions at high energies
- exact solution of the Regge field theory

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

$$f(x,Q^2) = \frac{4\pi}{\sigma_{hN}} \int_{M_{min}^2}^{M_{max}^2} dM^2 \left[\frac{d\sigma_{hN}^{\mathcal{D}}}{dM^2 dt}\right]_{t=0} F_A^2(t_{min})$$

Schwimmer summation of fan diagrams



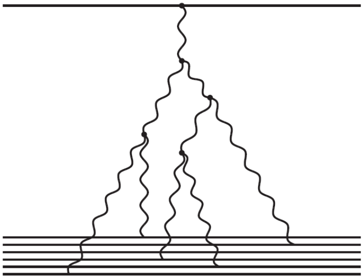
Schwimmer Nucl.Phys.B **94** (1975) 445

- splittings of Pomeron
- relevant for hA collisions at high energies
- exact solution of the Regge field theory

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

$$f(x,Q^2) = \frac{4\pi}{\sigma_{hN}} \int_{M_{min}^2}^{M_{max}^2} dM^2 \left[\frac{d\sigma_{hN}^{\mathcal{D}}}{dM^2 dt} \right]_{t=0} F_A^2(t_{min})$$

Schwimmer summation of fan diagrams



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

- splittings of Pomeron
- relevant for hA collisions at high energies
- exact solution of the Regge field theory

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

$$f(x,Q^2) = \frac{4\pi}{\sigma_{hN}} \int_{M_{min}^2}^{M_{max}^2} dM^2 \left[\frac{d\sigma_{hN}^{\mathcal{D}}}{dM^2 dt}\right]_{t=0} F_A^2(t_{min})$$

Nuclear shadowing ratio

Definition

The total hA cross section can be calculated if the total hN cross section and the differential cross section for diffractive production are known.

Nuclear shadowing is studied through the ratios of cross sections for different nuclei, defined as

$$R(A/B) = \frac{B}{A}\frac{\sigma_{hA}}{\sigma_{hB}}$$

Nuclear shadowing ratio

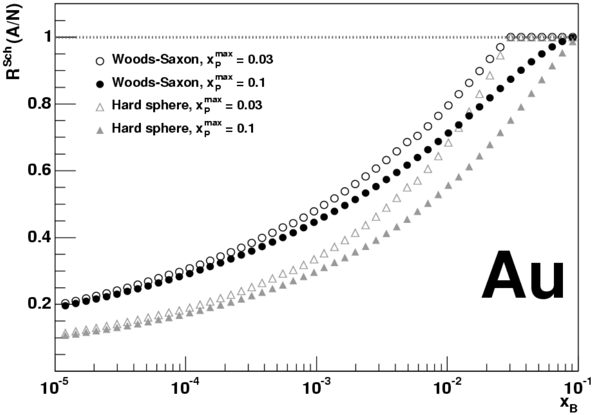
Definition

The total hA cross section can be calculated if the total hN cross section and the differential cross section for diffractive production are known.
Nuclear shadowing is studied through the ratios of cross sections for different nuclei, defined as

$$R(A/B) = \frac{B}{A}\frac{\sigma_{hA}}{\sigma_{hB}}$$

Nuclear shadowing ratio

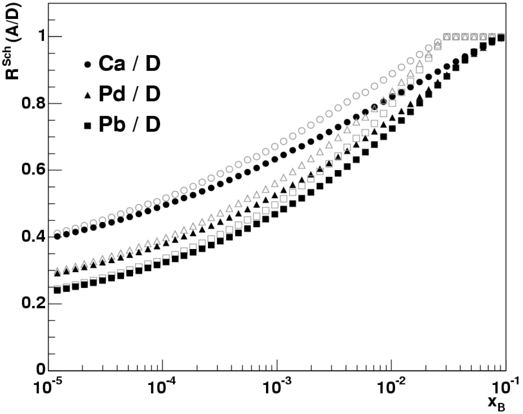
Heavy ions



Gluon shadowing for Au.

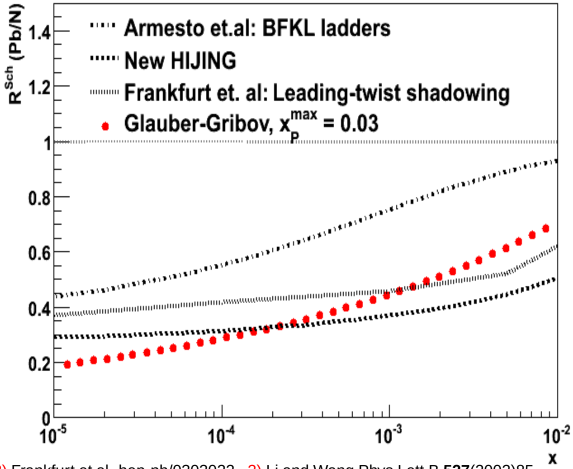
Nuclear shadowing ratio

Heavy ions



Gluon shadowing for heavy ions. Closed symbols are for $x_{I\!P}^{max} = 0.1$ while open ones are for $x_{I\!P}^{max} = 0.03$.

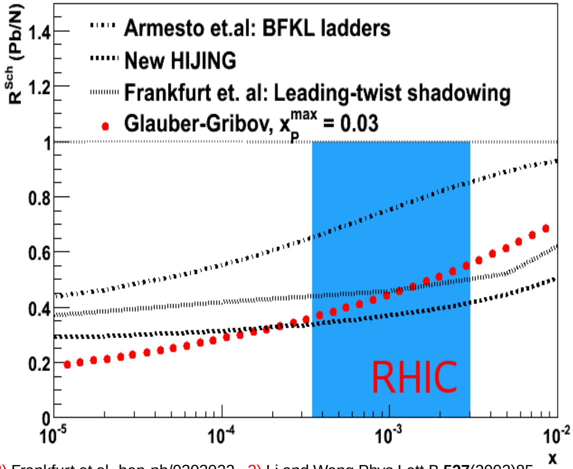
Comparison with other models - gluons



1) Armesto Eur.Phys.J.C **26**(2002)35, 2) Frankfurt et al. hep-ph/0303022, 3) Li and Wang Phys.Lett.B **527**(2002)85

Comparison with other models - gluons

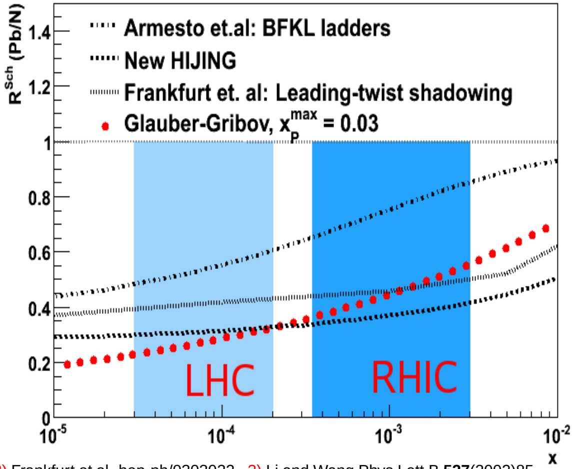
- 3 last models give similar result



1) Armesto Eur.Phys.J.C **26**(2002)35, 2) Frankfurt et al. hep-ph/0303022, 3) Li and Wang Phys.Lett.B **527**(2002)85

Comparison with other models - gluons

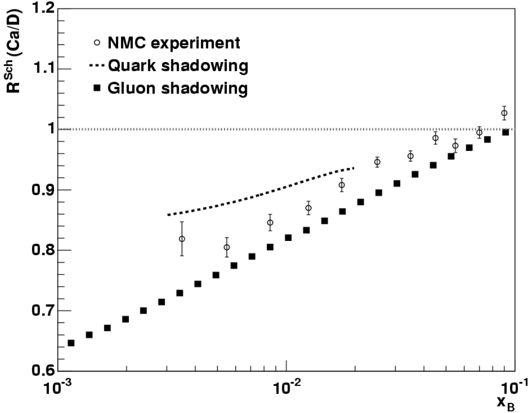
- a discrepancy of the order 2 can be disentangled experimentally



1) Armesto Eur.Phys.J.C **26**(2002)35, 2) Frankfurt et al. hep-ph/0303022, 3) Li and Wang Phys.Lett.B **527**(2002)85

Comparison with NMC experiment

Both theoretical results were calculated using the same model.



Quark shadowing: Armesto et al. Eur.Phys.J.C **29** (2003) 531

Experimental data: NMC Collaboration Nucl.Phys.B **441** (1995) 3

Unitarity effects in d-Au collisions

Corrections to the Glauber formula

$$\frac{dn_{A_1A_2}}{dy} = n_{A_1A_2}(b)\,\frac{dn_{NN}}{dy}\,R(A_1/N)R(A_2/N)$$

The theoretical prediction of the multiplicity reduction in a deuteron gold collision compared to the predictions to the simple Glauber model is based on the following formula

$$R_{dAu} = R_d(x_p)\cdot R_{Au}(x_t)$$

where $x_{p(t)} = p_T e^{\pm y^*}/\sqrt{s}$.

Capella, Kaidalov, Van; Heavy Ion Phys. **9** (1999) 169

Unitarity effects in d-Au collisions

Corrections to the Glauber formula

$$\frac{dn_{A_1A_2}}{dy} = n_{A_1A_2}(b)\,\frac{dn_{NN}}{dy}\,R(A_1/N)R(A_2/N)$$

The theoretical prediction of the multiplicity reduction in a deuteron gold collision compared to the predictions to the simple Glauber model is based on the following formula

$$R_{dAu} = R_d(x_p)\cdot R_{Au}(x_t)$$

where $x_{p(t)} = p_T e^{\pm y^*}/\sqrt{s}$.

Capella, Kaidalov, Van; Heavy Ion Phys. **9** (1999) 169

Unitarity effects in d-Au collisions

Corrections to the Glauber formula

$$\frac{dn_{A_1A_2}}{dy} = n_{A_1A_2}(b)\,\frac{dn_{NN}}{dy}\,R(A_1/N)R(A_2/N)$$

The theoretical prediction of the multiplicity reduction in a deuteron gold collision compared to the predictions to the simple Glauber model is based on the following formula

$$R_{dAu} = R_d(x_p)\cdot R_{Au}(x_t)$$

where $x_{p(t)} = c p_T e^{\pm y^*}/\sqrt{s}$.

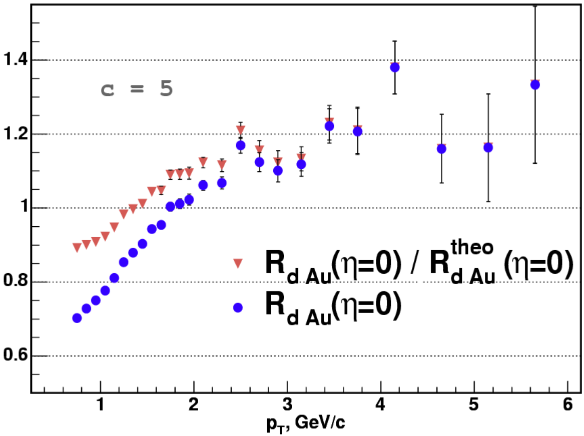
Capella, Kaidalov, Van; Heavy Ion Phys. **9** (1999) 169

Unitarity effects in d-Au collisions

Normalization of experimental data

$$R_{dAu} = \frac{1}{\langle N_{coll}\rangle} \frac{\frac{d^2N^{dAu}}{dp_T d\eta}}{\frac{d^2N^{pp}_{inel}}{dp_T d\eta}}$$

$$R^{norm}_{dAu} = \frac{R_{dAu}(\eta=0)}{R^{theo}_{dAu}(\eta=0)}$$



Experimental data: BRAHMS Collaboration Phys.Rev. Lett. **93** (2004) 242303

Unitarity effects in d-Au collisions

Nuclear modification factor at forward rapidity

We define the shadowing ratio

$$R_{d\,Au}\left(\eta\right)/R^{norm}_{d\,Au}\left(0\right)$$

- to extract the effect on shadowing at forward rapidities
- to remove other type of effects
- compare experimental data for several η's to the theoretical predictions

Unitarity effects in d-Au collisions

Nuclear modification factor at forward rapidity

We define the shadowing ratio

$$R_{d\,Au}(\eta)\,/R^{norm}_{d\,Au}(0)$$

- to extract the effect on shadowing at forward rapidities
- to remove other type of effects
- compare experimental data for several η's to the theoretical predictions

Unitarity effects in d-Au collisions

Nuclear modification factor at forward rapidity

We define the shadowing ratio

$$R_{d\,Au}\left(\eta\right)/R_{d\,Au}^{norm}\left(0\right)$$

- to extract the effect on shadowing at forward rapidities
- to remove other type of effects
- compare experimental data for several η's to the theoretical predictions

Unitarity effects in d-Au collisions

Nuclear modification factor at forward rapidity

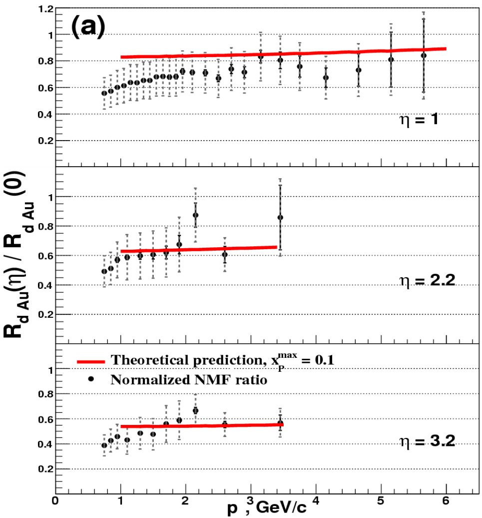
We define the shadowing ratio

$$R_{d\,Au}\left(\eta\right)/R^{norm}_{d\,Au}\left(0\right)$$

- to extract the effect on shadowing at forward rapidities
- to remove other type of effects
- compare experimental data for several η's to the theoretical predictions

Unitarity effects in d-Au collisions

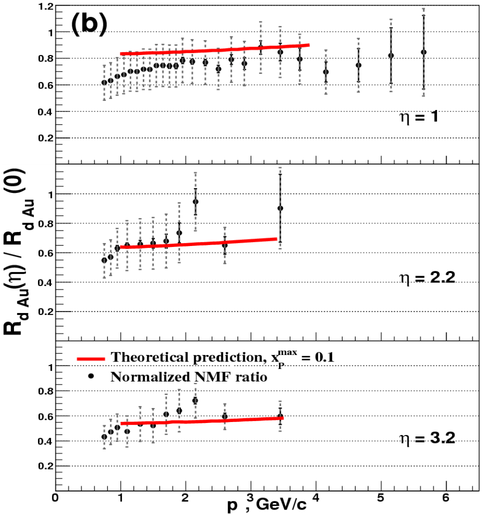
NMF - results



c = 3

Unitarity effects in d-Au collisions

NMF - results

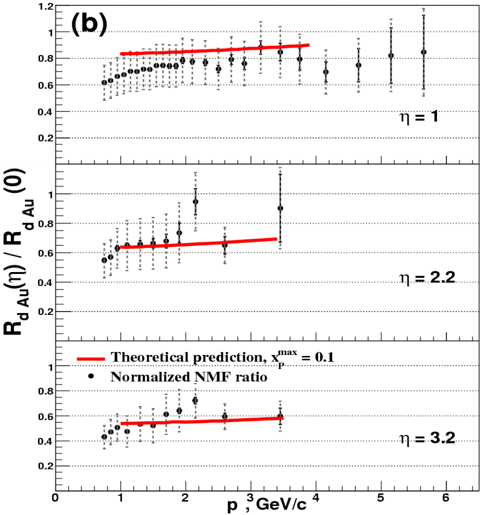


c = 5

- no dependence on parameter *c*.
- good agreement with experimental data.
- shadowing effect due to gluons more pronounced at higher rapidity.

Unitarity effects in d-Au collisions

NMF - results

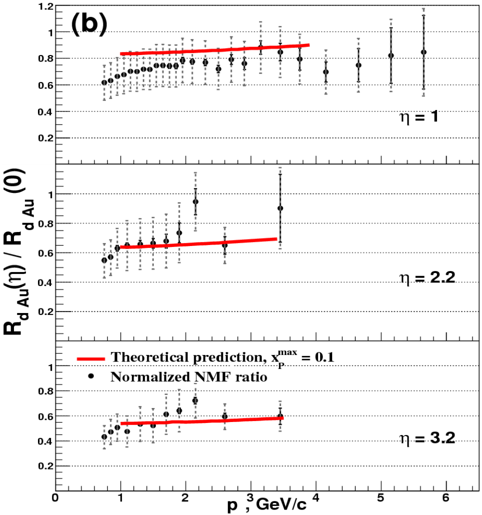


c = 5

- no dependence on parameter *c*.
- good agreement with experimental data.
- shadowing effect due to gluons more pronounced at higher rapidity.

Unitarity effects in d-Au collisions

NMF - results



c = 5

- no dependence on parameter *c*.
- good agreement with experimental data.
- shadowing effect due to gluons more pronounced at higher rapidity.

Summary

- Gluon nPDF's are extracted from recent HERA experiment data. At RHIC energies and above, the gluon shadowing strongly dominates over the quark one
- Estimation of reduction of particle multiplicity at forward rapidities is compared to BRAHMS results and agreement with experimental data is found. Gluons are responsible for the multiplicity reduction at forward rapidity.
- Agreement arises solely from the fact that unitarization is correctly accounted for; no additional effects have been added in the model.
- Outlook
  - Dependence on Q^2 - DGLAP, parameterizations....
  - Fusion of Pomerons.
  - Robustness of diffractive analysis.

Summary

- Gluon nPDF's are extracted from recent HERA experiment data. At RHIC energies and above, the gluon shadowing strongly dominates over the quark one
- Estimation of reduction of particle multiplicity at forward rapidities is compared to BRAHMS results and agreement with experimental data is found. Gluons are responsible for the multiplicity reduction at forward rapidity.
- Agreement arises solely from the fact that unitarization is correctly accounted for; no additional effects have been added in the model.
- Outlook
    - Dependence on Q^2 - DGLAP, parameterizations....
    - Fusion of Pomerons.
    - Robustness of diffractive analysis.

Summary

- Gluon nPDF's are extracted from recent HERA experiment data. At RHIC energies and above, the gluon shadowing strongly dominates over the quark one
- Estimation of reduction of particle multiplicity at forward rapidities is compared to BRAHMS results and agreement with experimental data is found. Gluons are responsible for the multiplicity reduction at forward rapidity.
- Agreement arises solely from the fact that unitarization is correctly accounted for; no additional effects have been added in the model.

- Outlook
  - Dependence on Q^2 - DGLAP, parameterizations....
  - Fusion of Pomerons.
  - Robustness of diffractive analysis.

Summary

- Gluon nPDF's are extracted from recent HERA experiment data. At RHIC energies and above, the gluon shadowing strongly dominates over the quark one
- Estimation of reduction of particle multiplicity at forward rapidities is compared to BRAHMS results and agreement with experimental data is found. Gluons are responsible for the multiplicity reduction at forward rapidity.
- Agreement arises solely from the fact that unitarization is correctly accounted for; no additional effects have been added in the model.

- Outlook
  - Dependence on Q^2 - DGLAP, parameterizations....
  - Fusion of Pomerons.
  - Robustness of diffractive analysis.

Summary

- Gluon nPDF's are extracted from recent HERA experiment data. At RHIC energies and above, the gluon shadowing strongly dominates over the quark one
- Estimation of reduction of particle multiplicity at forward rapidities is compared to BRAHMS results and agreement with experimental data is found. Gluons are responsible for the multiplicity reduction at forward rapidity.
- Agreement arises solely from the fact that unitarization is correctly accounted for; no additional effects have been added in the model.

- Outlook
  - Dependence on Q^2 - DGLAP, parameterizations....
  - Fusion of Pomerons.
  - Robustness of diffractive analysis.

Summary

- Gluon nPDF's are extracted from recent HERA experiment data. At RHIC energies and above, the gluon shadowing strongly dominates over the quark one
- Estimation of reduction of particle multiplicity at forward rapidities is compared to BRAHMS results and agreement with experimental data is found. Gluons are responsible for the multiplicity reduction at forward rapidity.
- Agreement arises solely from the fact that unitarization is correctly accounted for; no additional effects have been added in the model.
- Outlook
  - Dependence on Q^2 - DGLAP, parameterizations....
  - Fusion of Pomerons.
  - Robustness of diffractive analysis.