Nuclear shadowing in ultrarelativistic heavy ion collisions

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Outline

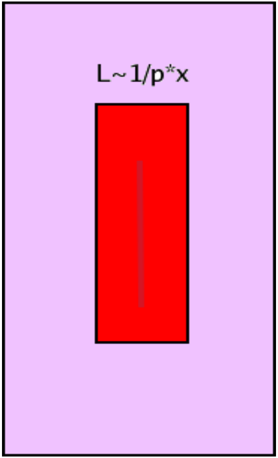
In collaboration with:

L. Bravina, E. Zabrodin, I.C. Arsene, A.B. Kaidalov

Space-time picture of nuclear interactions I

Feynman, Gribov...

- a fast-moving hadron or nucleus can be considered as a complicated fluctuation of quarks and gluons with long lifetimes
- content of the state is Lorentz-frame dependent
- fast parton components of the wave function are Lorentz-contracted, while soft ones are not



Space-time picture of nuclear interactions II

When the coherence length ("longitudinal size") of the fluctuation becomes as large as the target nucleus, the space-time picture of particle production changes. For typical processes:

Critical energy

$$E_c \sim m_N^2 R_A$$

$$\Downarrow$$

$$x < 1/(m_N R_A)$$

When $x > 1/(m_N R_A)$, the space-time picture is that of final state reinteractions of produced particles with formation time (longitudinal structure).

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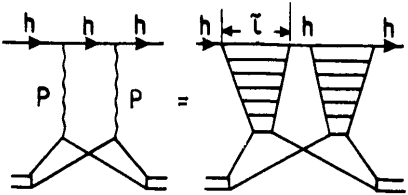
Mandelstam Nuov. Cim. **30** (1963) 1113, 1127,1148; Gribov JETP **56** (1959) 982



"Planar" diagram

- low energy scattering - longitudinal ordering
  - $\rightarrow$ Glauber multiple scattering
- high energy scattering - change in initial condition
  - $\rightarrow$ planar diagrams $\sim 1/E$
  - $\rightarrow$ fluctuation prepared long before the collision
- discontinuities of non-planar diagrams determined by AGK cutting rules

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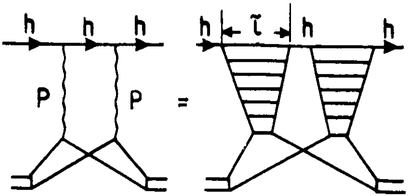

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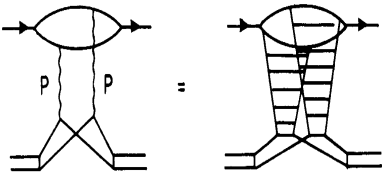

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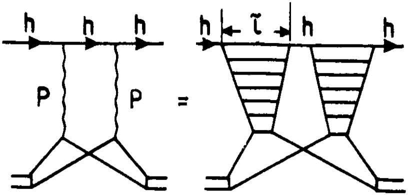

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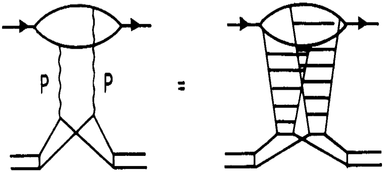

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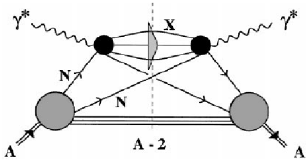
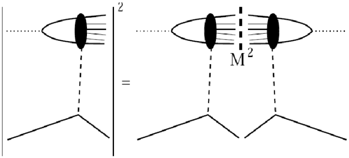
Gribov inelastic shadowing

Correction to Glauber model

We need to sum up all possible planar and non-planar diagrams, how...





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- take into account inelastic intermediate states, but..
- space-time picture does not correspond to successive rescatterings!
- AGK cuttings 1 + (-4) + 2 = -1

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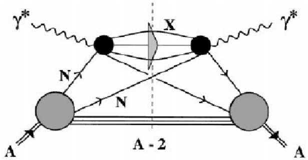

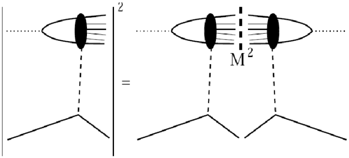

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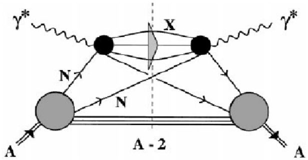

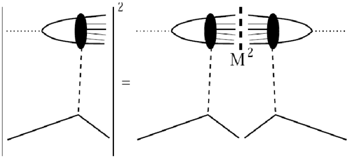

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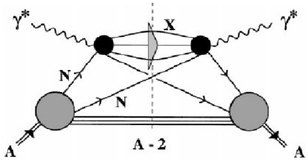

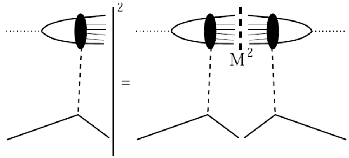

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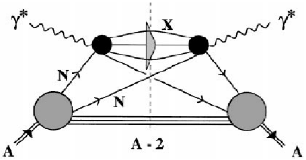

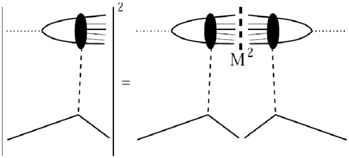

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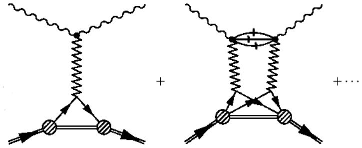
Multiple scattering series



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

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

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

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

Second order rescattering

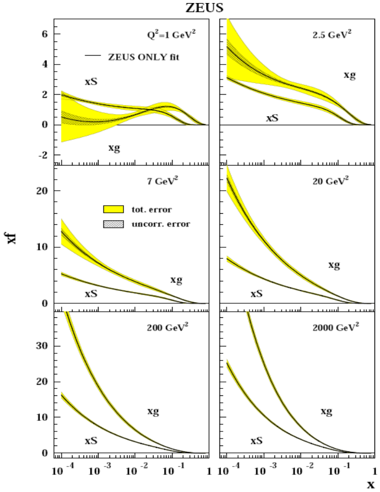
Relation to diffractive DIS

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

- 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 parton densities in proton

Inclusive cross-section



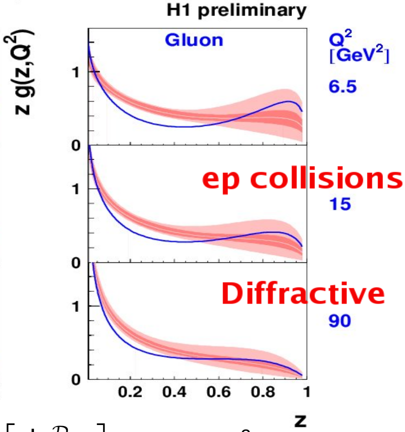
ZEUS Collaboration, PRD **67** (2003) 012007

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

- Q^2 evolution given by pQCD DGLAP
- several parameterizations on the market
- Online: `http://durpdg.dur.ac.uk/hepdata`
- we use CTEQ6

Parameterization of parton densities in the Pomeron

Diffractive cross-section



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

H1 Collaboration, paper **980** at ICHEP2002

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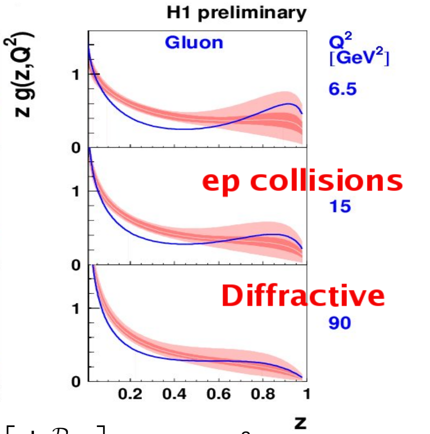

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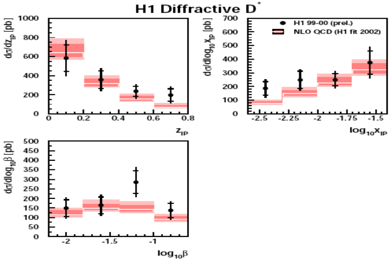

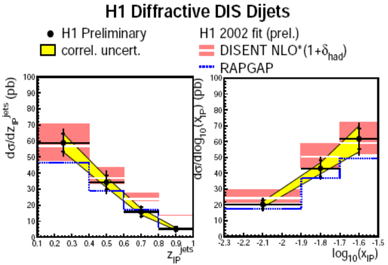

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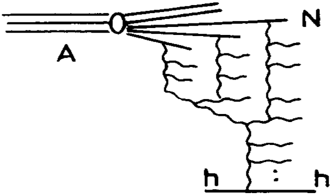
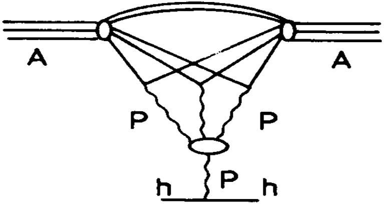
Enhanced diagrams

Interactions between parton ladders/Pomerons

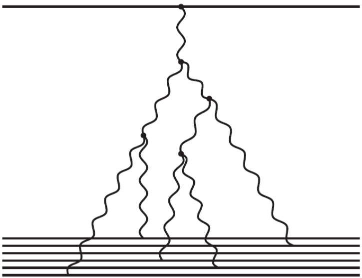




- soft partons from different ladders overlap and start to interact
- $3\mathbb{P}$ and $4\mathbb{P}$ vertexes are rather small
- become important for hA ($A^{1/3}$) and AB ($A^{1/3} + B^{1/3}$) collisions and at high energies
- related to saturation of (gluon) densities in ultrarelativistic nuclear reactions - gluon fusion, Pomeron loops

Schwimmer summation of fan diagrams

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



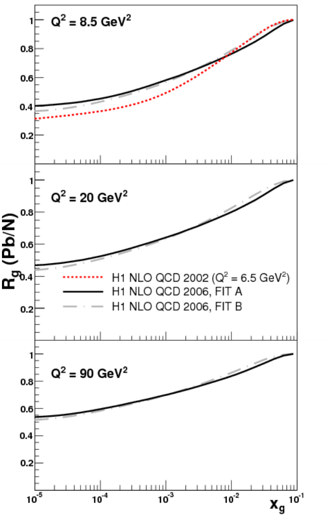
- splittings of Pomerons
- exact solution of Regge field theory
- similar results as with quasi-eikonal model
- works for hA scattering
- describes a "saturation" of the cross section

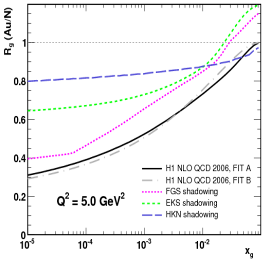
$$\sigma_{hA}^{Sch} = \sigma_{hN} \int d^2b \frac{AT_A(b)}{1+(A-1)f(x,Q^2)T_A(b)} ,$$

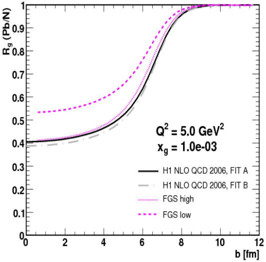
$$f(x,Q^2) = 4\pi \int_x^{x_P^{max}} dx_{I\!P} B(x_{I\!P}) \frac{F_{2\mathcal{D}}^{(3)}(x_{I\!P},Q^2,\beta)}{F_2(x,Q^2)} F_A^2(t_{min.})$$

Gluon and sea quark shadowing

Details - PLB 657 (2007) 170







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

- strong shadowing obtained
- no fitting or free parameters!

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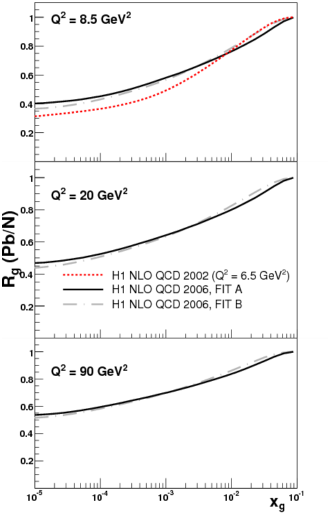

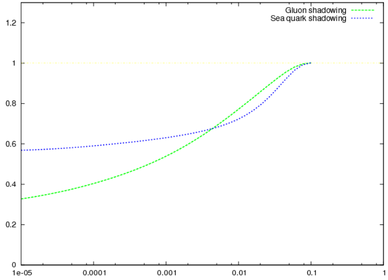

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Nuclear interactions at high energies

Corrections to the Glauber formula

Due to AGK all rescatterings cancel at mid-rapidity and $s \to \infty$!

Density of charged particles

$$\frac{dn^a_{AB}(b)}{dy} = \frac{T_{AB}(b)\,\sigma^{inel}_{pp}}{\sigma^{inel}_{AB}}\,\frac{dn^a_{NN}}{dy}$$

$\Downarrow$

Shadowing correction!

$$\frac{dn^a_{AA}(b)}{dy} = \frac{T_{AB}(b)\,\sigma^{inel}_{pp}}{\sigma^{inel}_{AB}}\,\frac{dn^a_{NN}}{dy}\,R(A/N)R(B/N)$$

For RHIC a decrease of particle denisities by a factor ~ 2, for LHC ~ 4 - agrees with experiment!

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

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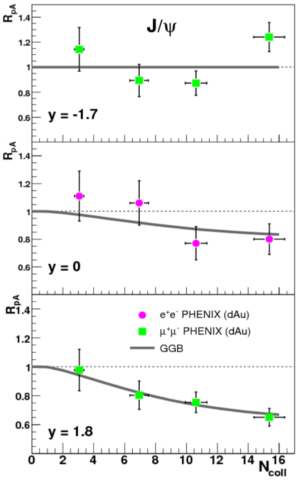
Example: J/ψ production in hA @ RHIC and LHC

arXiv:0711.4672 [hep-ph], arXiv:0708.3801 [hep-ph]



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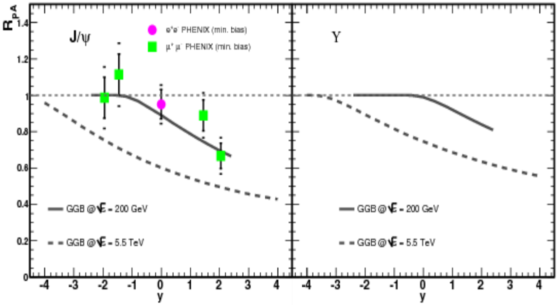
- → first signal of coherent HQ production?
- at LHC - strong IS effect!



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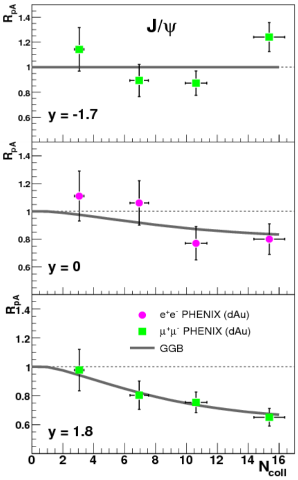

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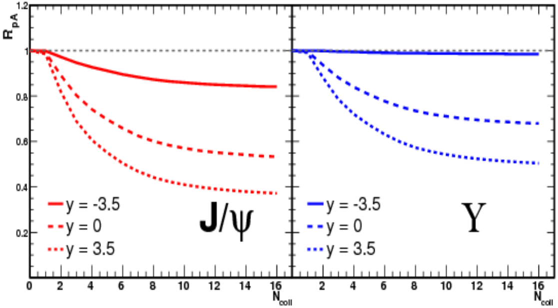

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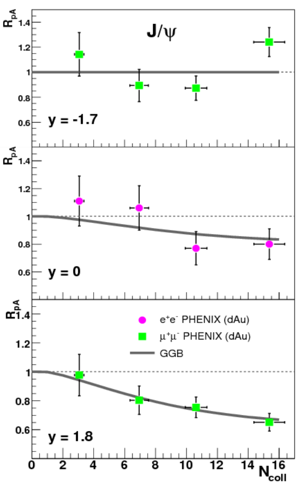

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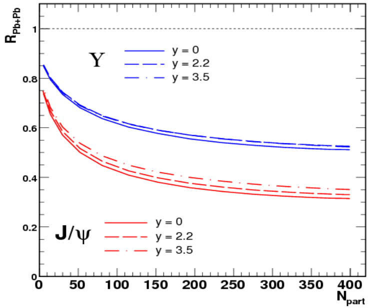
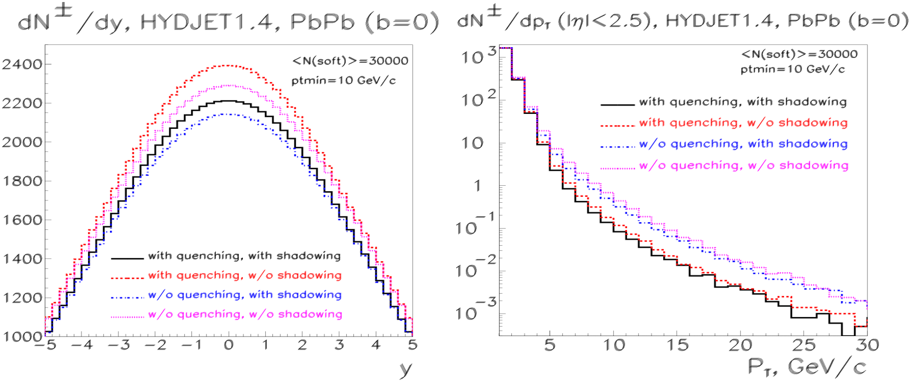


Example: Predictios for LHC

Rapidity and p_T spectra of charged particles



Rapidity and p_T spectra of charged hadrons in Pb+Pb collisions at LHC energy $\sqrt{s} = 5.5$ TeV. Quenching and shadowing is only for the hard part, $< N(soft) >$ is a free parameter.

Summary

- Nuclear shadowing was calculated in the Gribov approach
- Large shadowing corrections both for gluons and sea quarks are found from diffractive data
- No parameters were fitted in the model
- Shadowing leads to a substantial drop of particle densities in heavy-ion collisions compared to the simple Glauber model
  - $\rightarrow$ visible e.g. in d+Au collisions at RHIC (J/ψ, high-$p_\perp$ production)
  - $\rightarrow$ crucial in nucleus-nucleus collisions at RHIC and LHC!
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