ABC of Gluon Saturation and CGC

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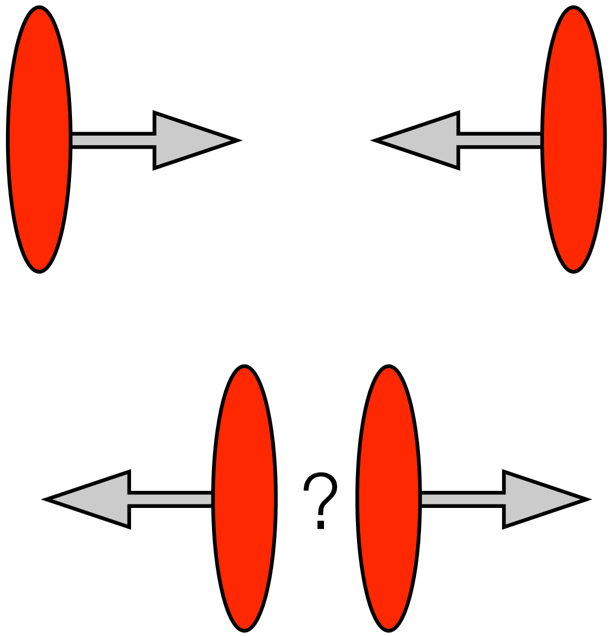
Nuclei as heavy as bulls through collision generate new states of matter

Hot Quarks 2008

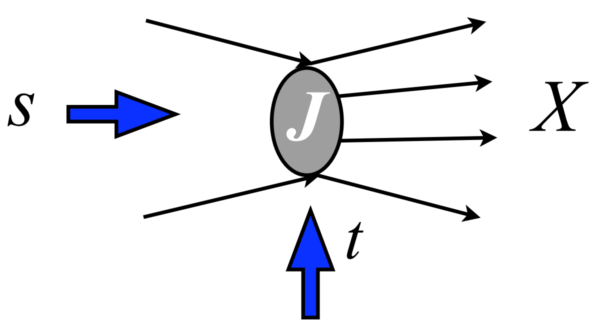


What is the distribution of nuclear matter right after the collision (before thermalization)?

First, need to understand ep, pp,eA and pA.

High energy asymptotic

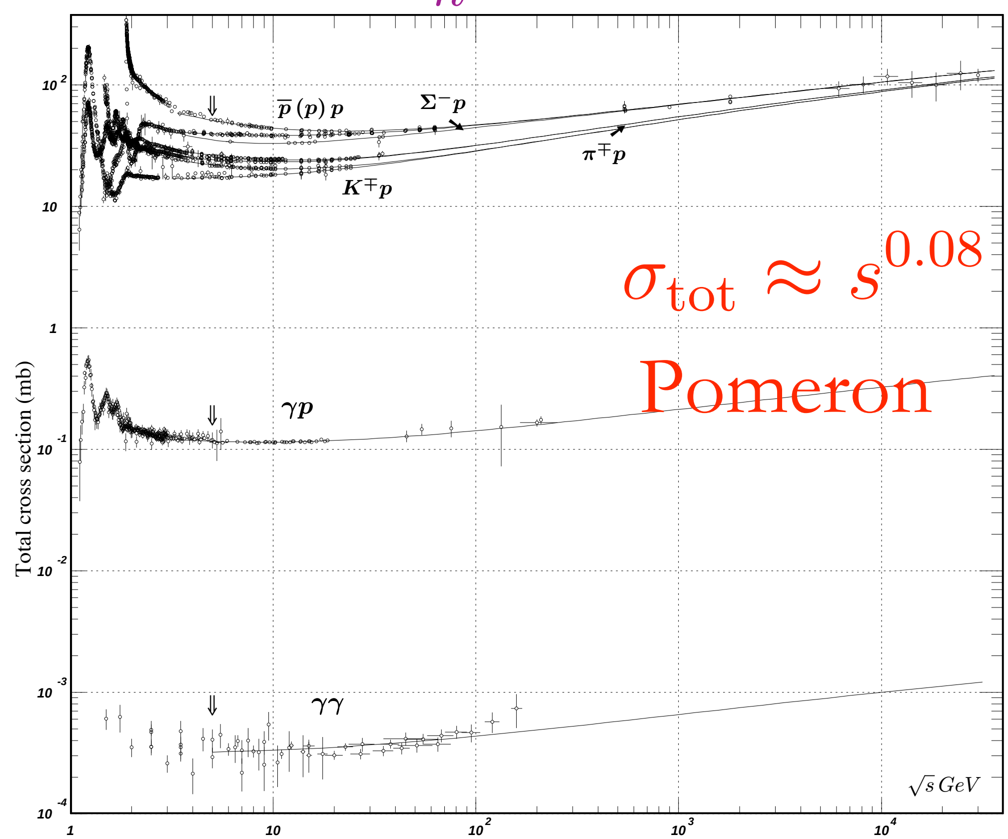
1950's



$$\sigma_{\text{tot}} = \sum_n c_n \, s^{J_n - 1}$$

Pomerantchuk Theorem:

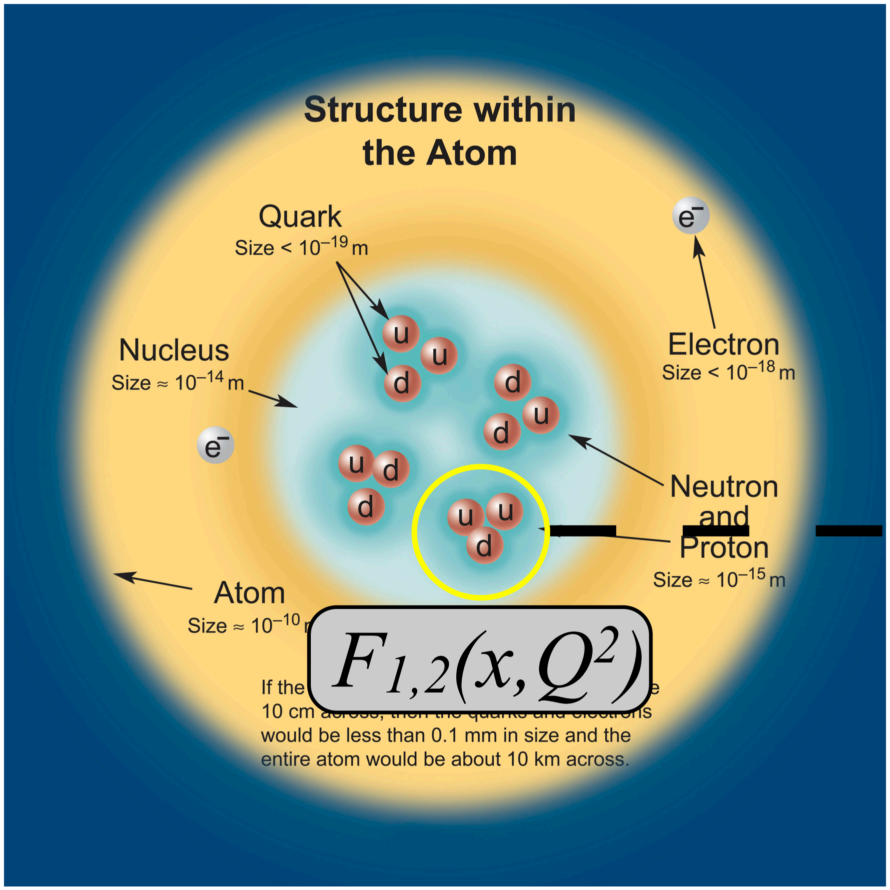
At s→∞ and t fixed, only a Reggeon with *vacuum* quantum numbers gives rising cross section.

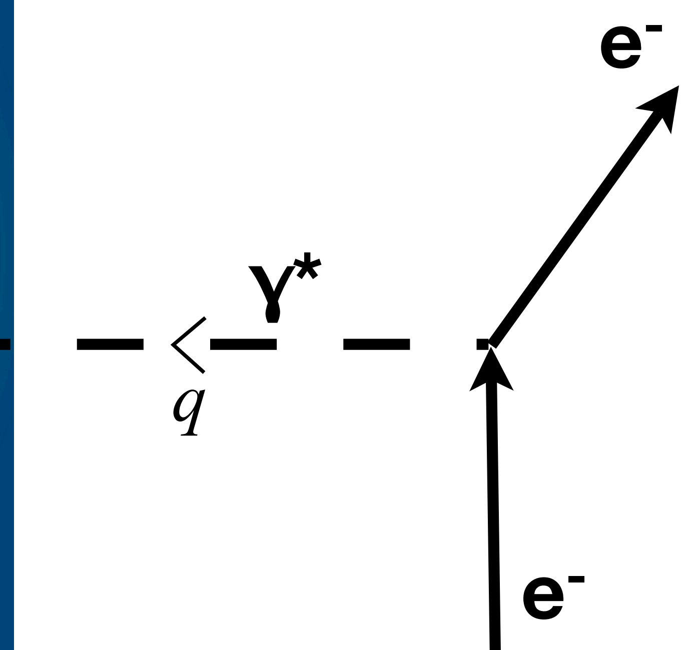


Probing proton’s content: DIS

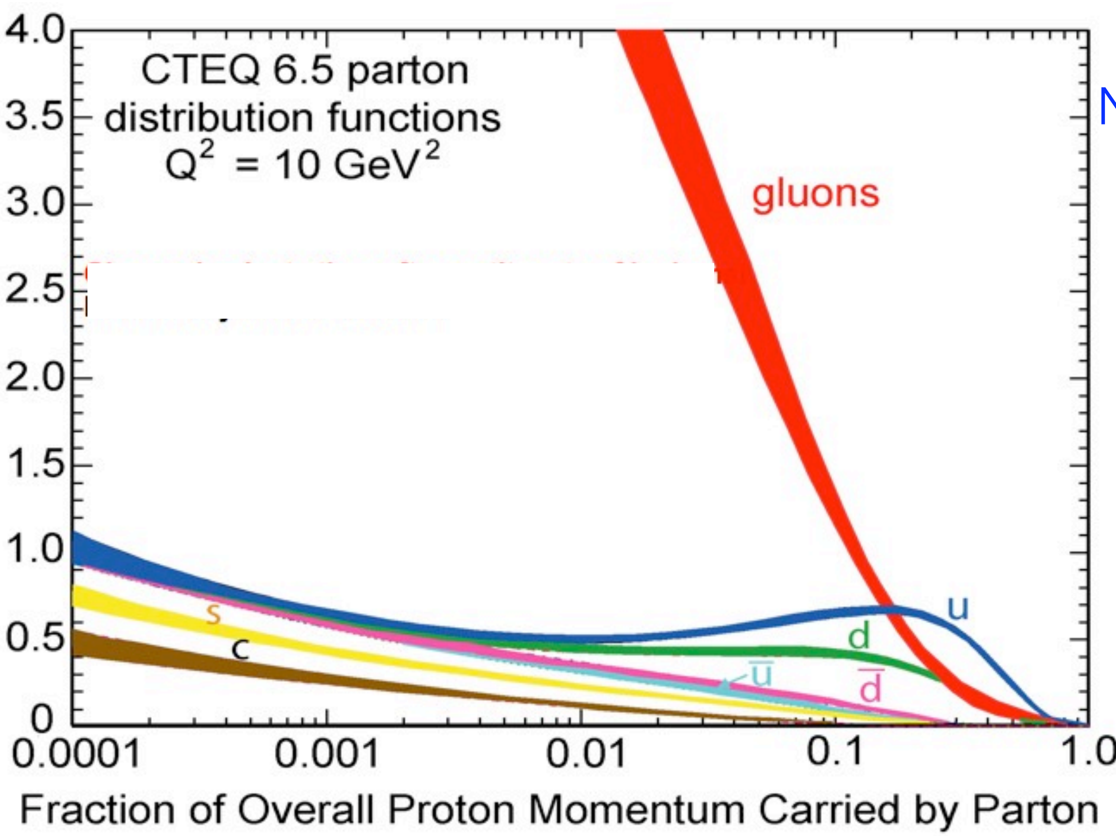
Momentum transfer $t=q^2=-Q^2$

Resolving power: $\Delta r \sim \hbar/Q$





Proton's content



$x = Q^2/s$

Energy

Number of gluons increases very fast with energy s

$$xG \sim \frac{1}{x^\lambda} \sim s^\lambda$$

Since partons are independent

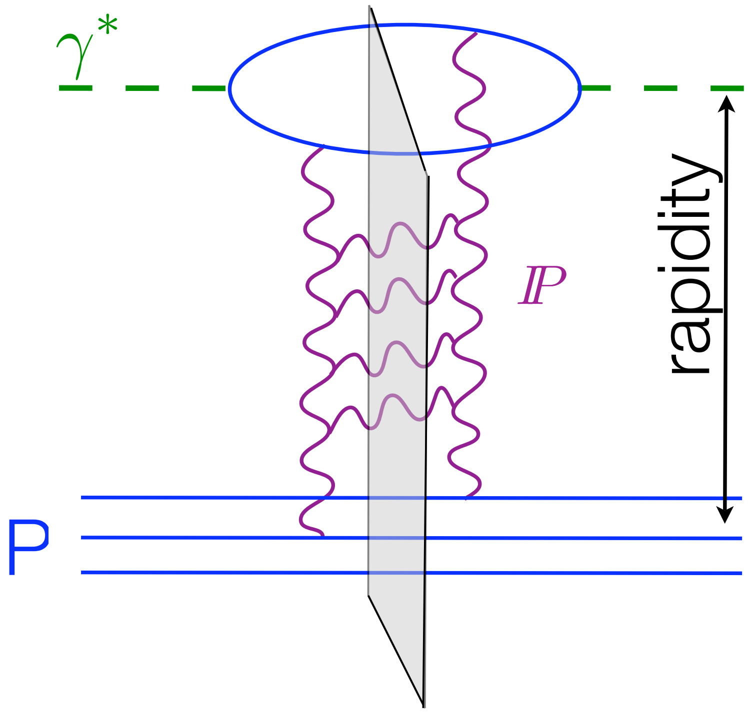
$$\sigma_{\gamma^* p} \propto s^\lambda$$

How does it happen in QCD?

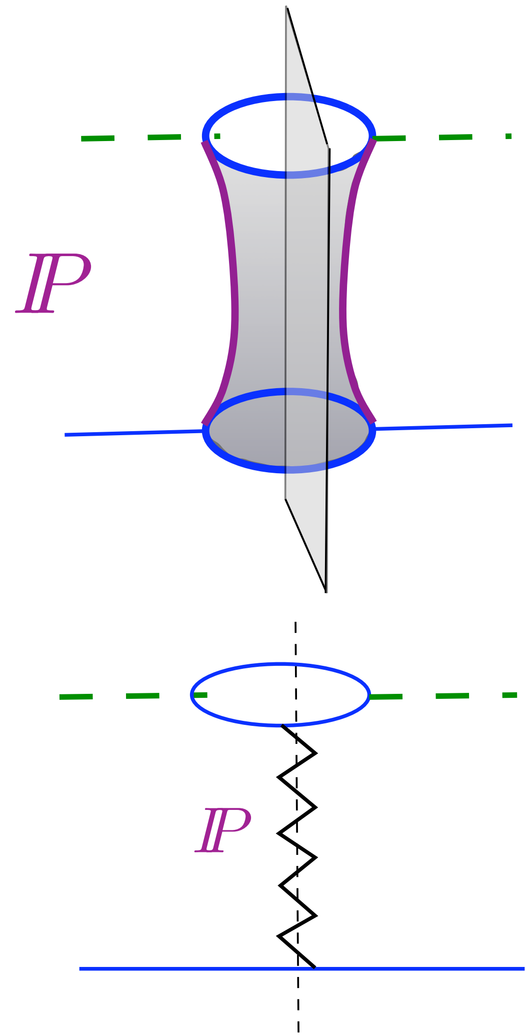
1970's

Pomeron

POMERON = QCD EVOLUTION WITH ENERGY



BFKL Pomeron



Pomeron's image: Diffraction

ep @ √s=320 GeV

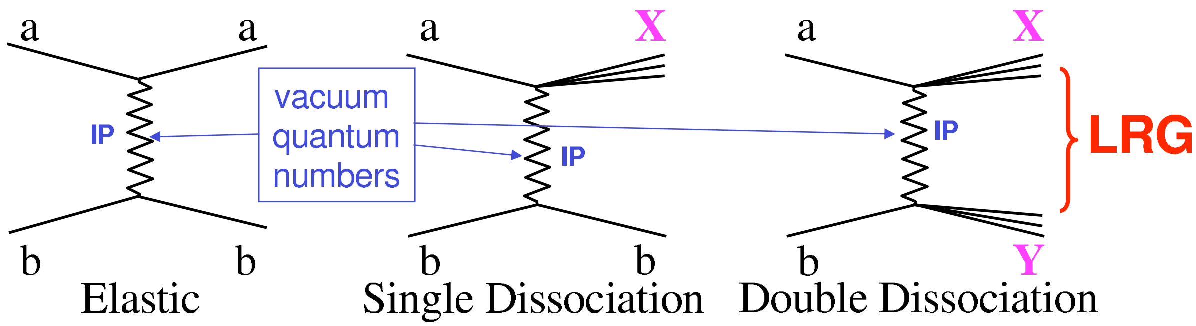
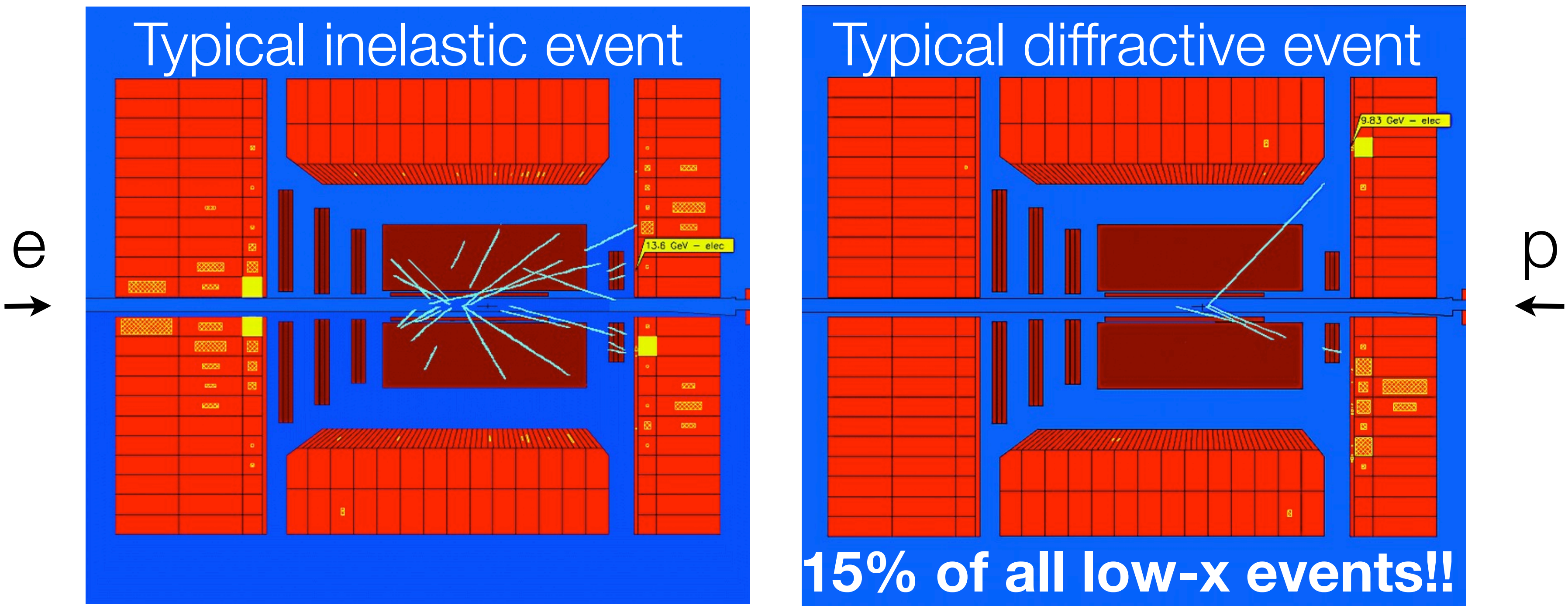
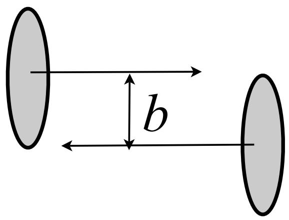


fig. courtesy by
Arneodo and Diehl



Trouble with the Pomeron

Consider a collision at a given impact parameter b



$$\sigma^{\text{tot}}_{\gamma^* p} = 2 \int d^2 b \sum_X |\mathcal{M}_{\gamma^* p \to X}(s,b)|^2$$

Total cross section ≤ 2 × interaction area

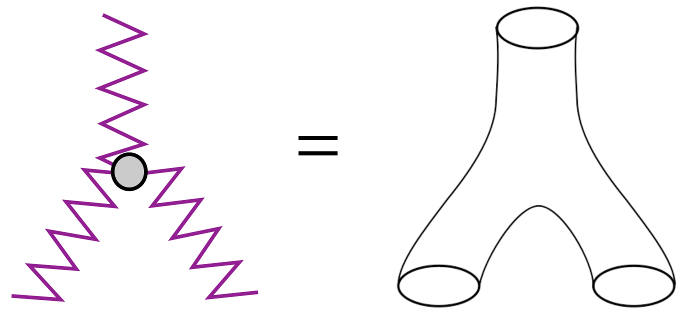
$$\sum_X |\mathcal{M}_{\gamma^* p \to X}(s,b)|^2 \leq 1$$ Unitarity (total probability = 1)

But $\sigma_{\gamma^* p} \propto s^{\lambda}$ violates this fundamental constraint!

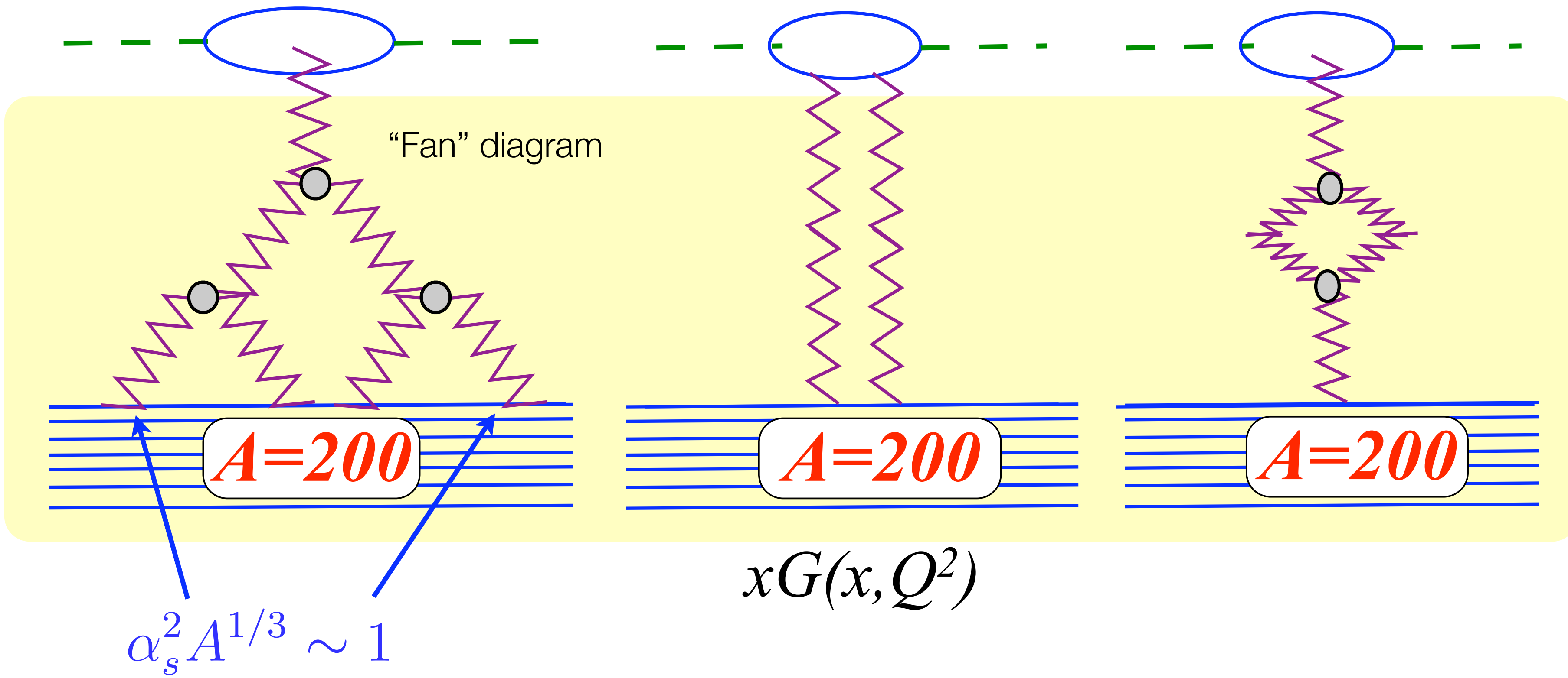
(at x≈0.01 for ep and x≈0.1 for pA)

A contribution to the sum over X is missing!

Gluon saturation



1980’s



"Quasi-classical approximation"

CGC = theory of gluon saturation 1990's

The central problem:

Given UR source of 2D density $\rho \approx \frac{A\,xG_N(x)}{S_A} \sim \frac{A\,s^{\lambda}}{A^{2/3}\,S_p}$

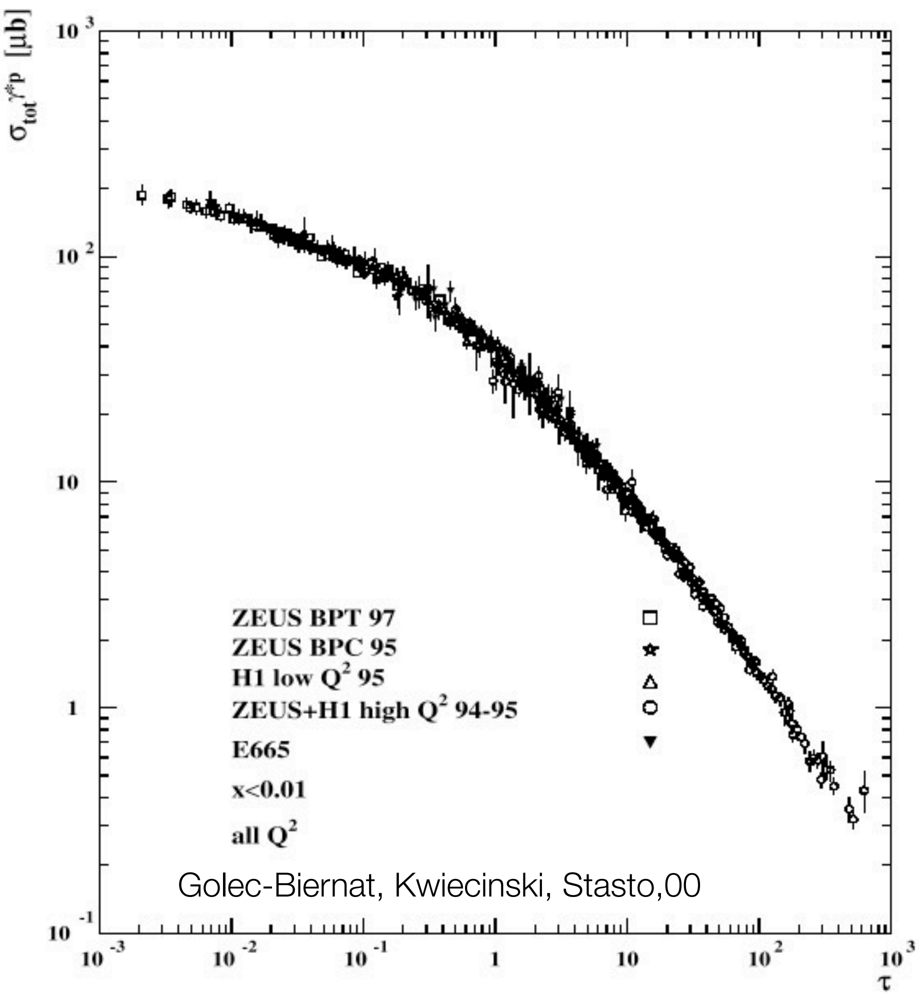
find the corresponding gluon field by solving *classical* YM.

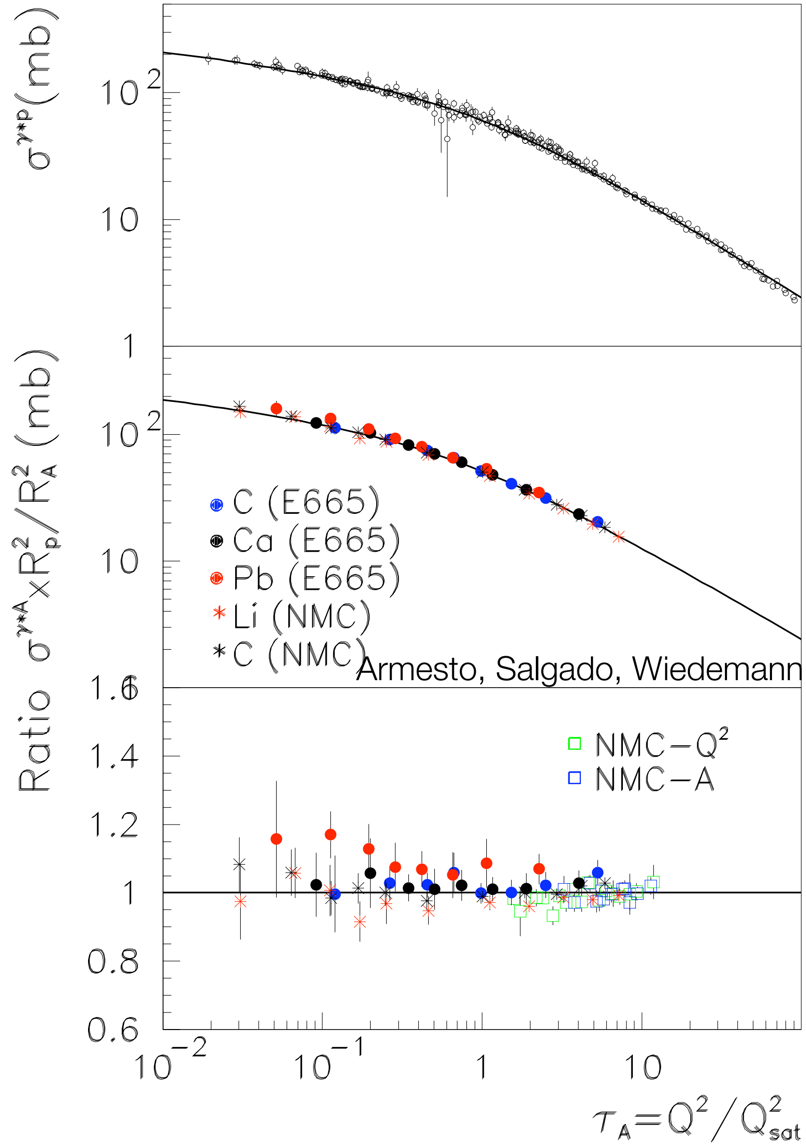
Solution: $F_{\mu\nu} \sim \frac{Q_s^2}{g}$ where $Q_s^2 \sim \rho \sim A^{1/3}\,s^{\lambda}$

Dependence on Λ_{QCD} disappears.

Asymptotic freedom: $\alpha_s(Q_s^2) << 1 \Rightarrow$ Perturbation theory is valid!

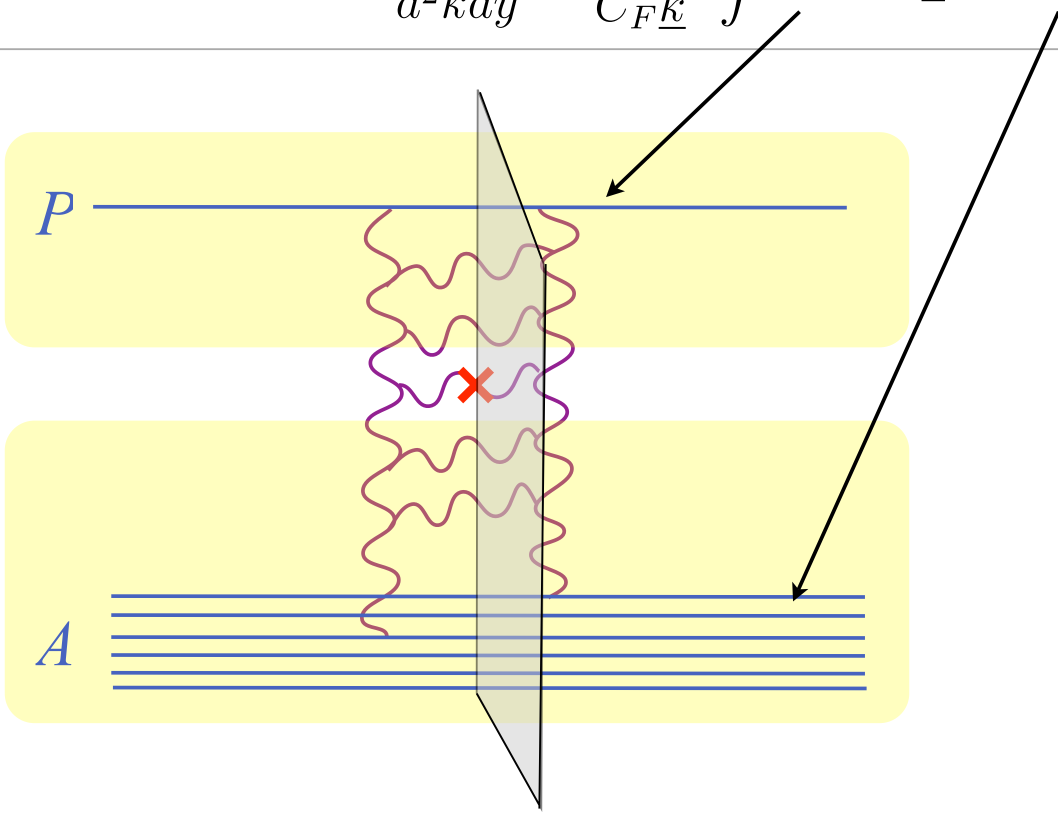
Nonlinear evolution: Geometric Scaling





Gluon production

$$\frac{d\sigma^{pA}}{d^2k\,dy} = \frac{2\,\alpha_s}{C_F \underline{k}^2} \int d^2q\, \phi_p(\underline{q}, Y-y)\, \phi_A(\underline{k}-\underline{q}, y)$$

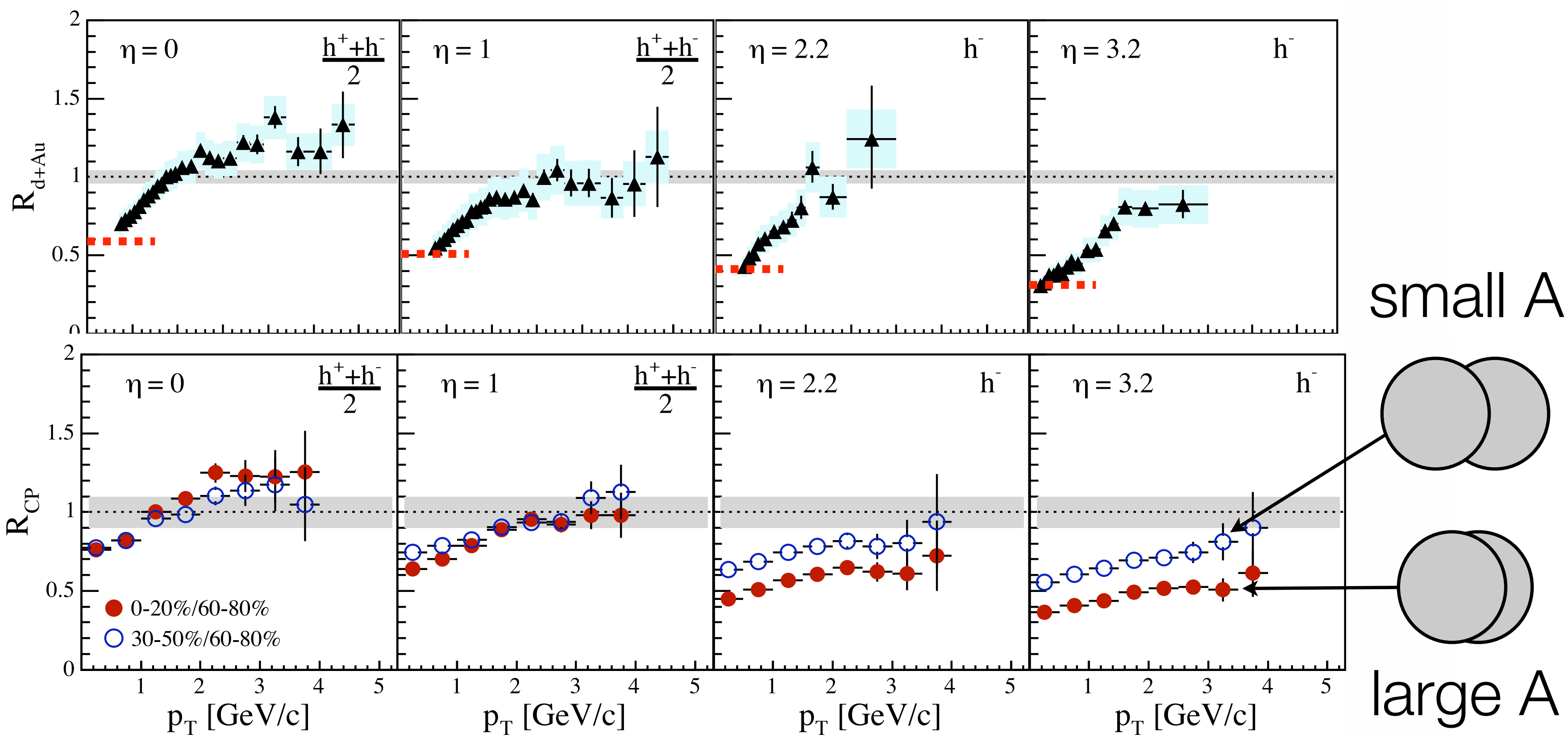


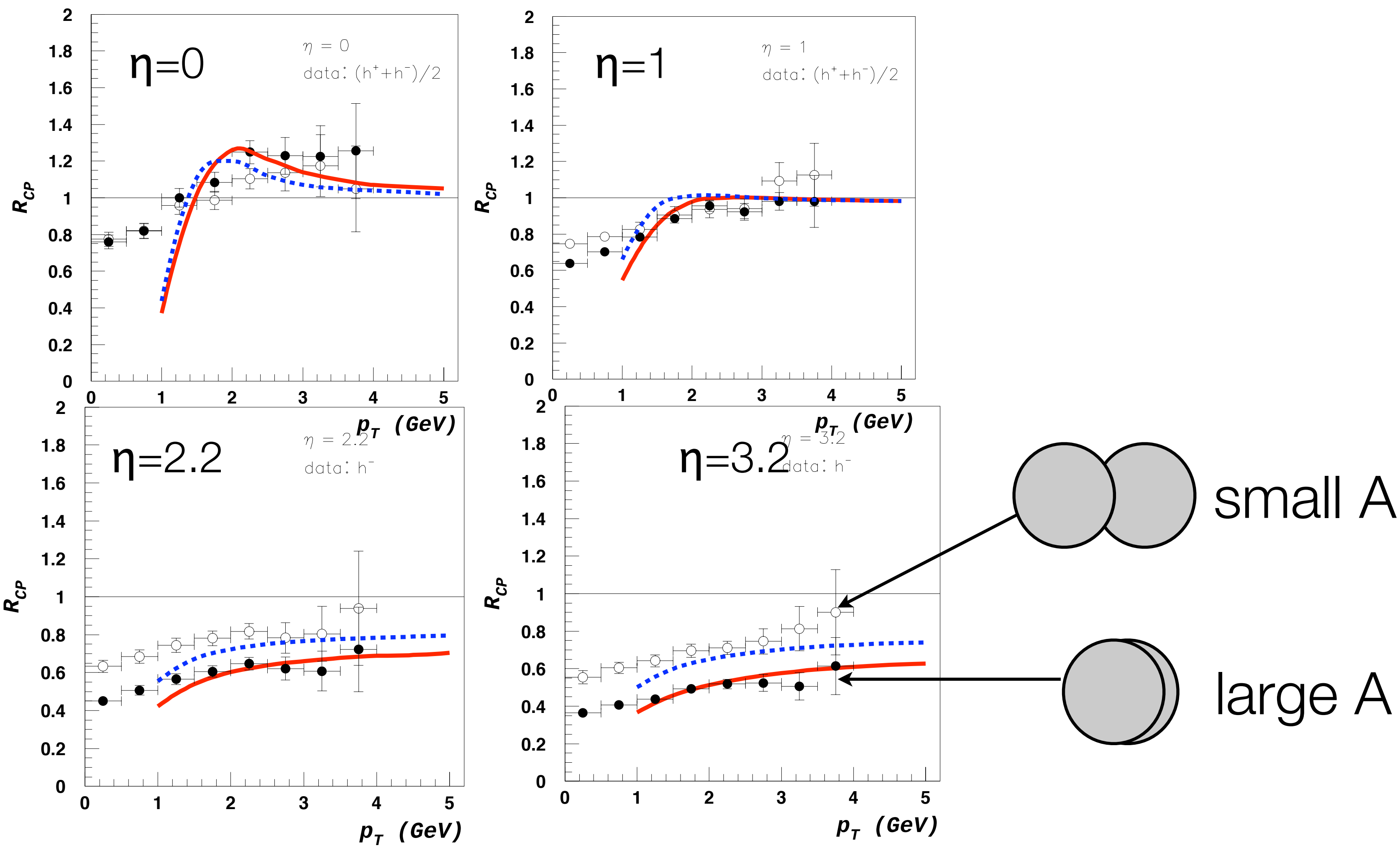
Gluon distributions can be factorized in the transverse momentum space

Kovchegov, KT, 01

Hadron spectra in dAu

$$R = \frac{\sigma(pA)}{A\,\sigma(pp)}$$

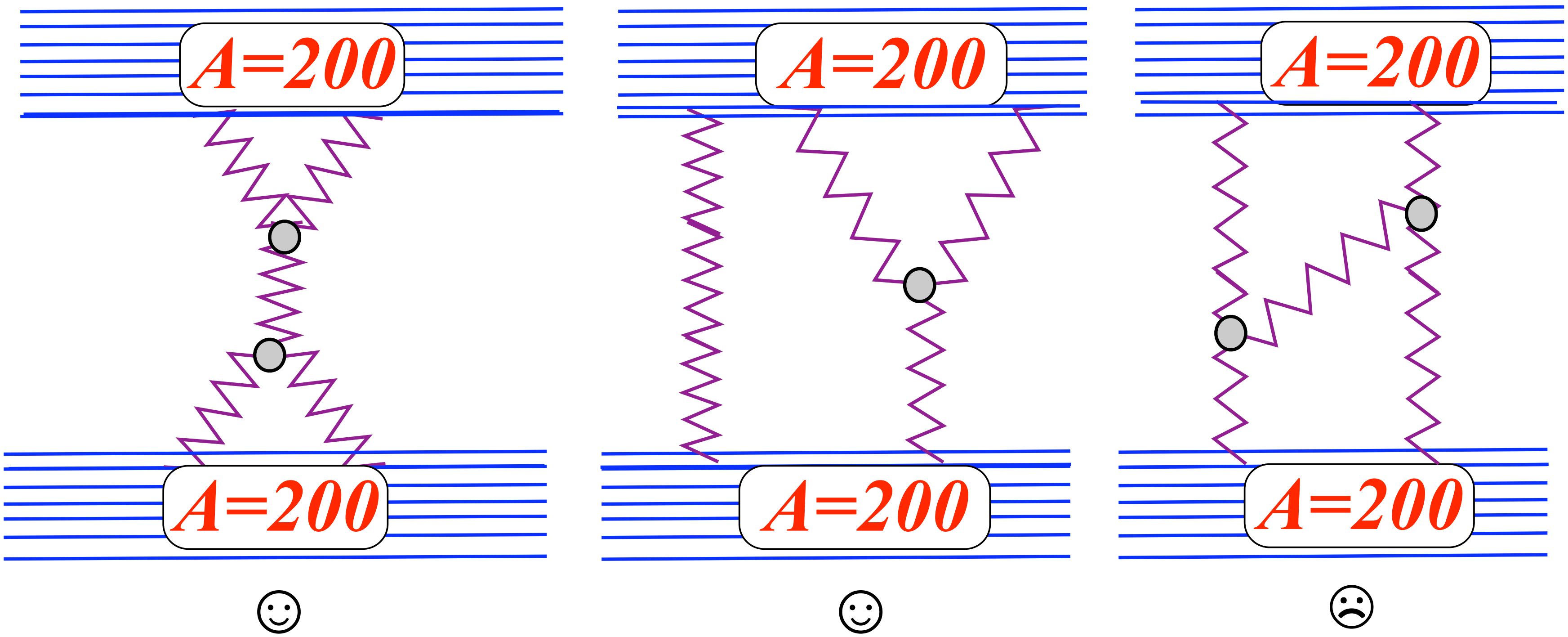



η=0
η = 0
data: (h⁺+h⁻)/2
η=1
η = 1
data: (h⁺+h⁻)/2
η=2.2
η = 2.2
data: h⁻
η=3.2
η = 3.2
data: h⁻
R_CP
p_T (GeV)
small A
large A

BRAHMS

From pA to AA

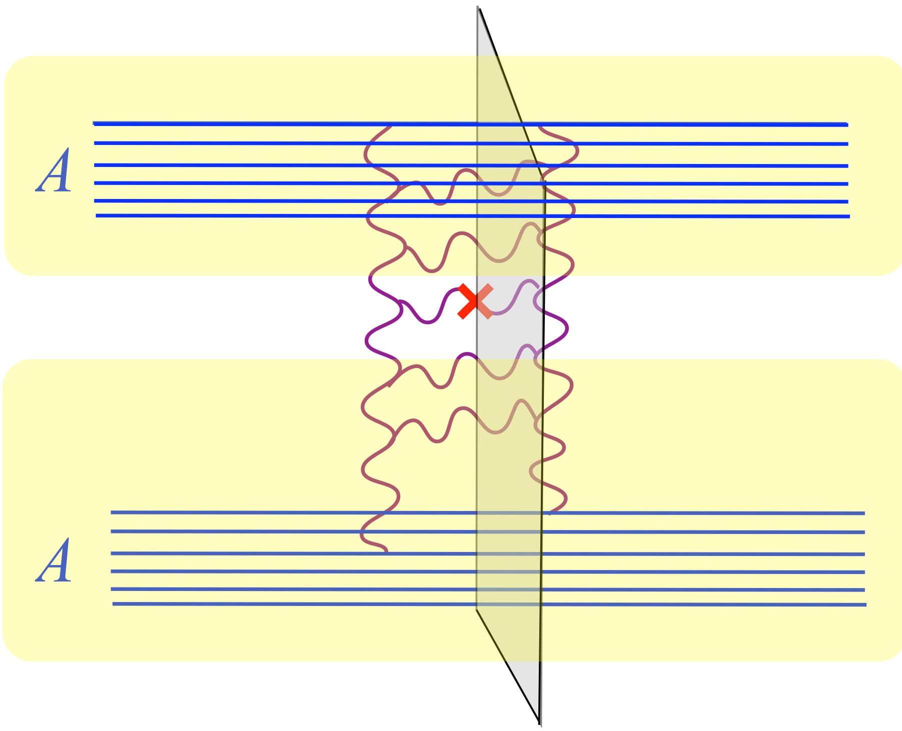
Requires solving YM for two dense systems moving in opposite directions. Remember: Huygens principle doesn't work for Non-Abelian theories!



From pA to AA

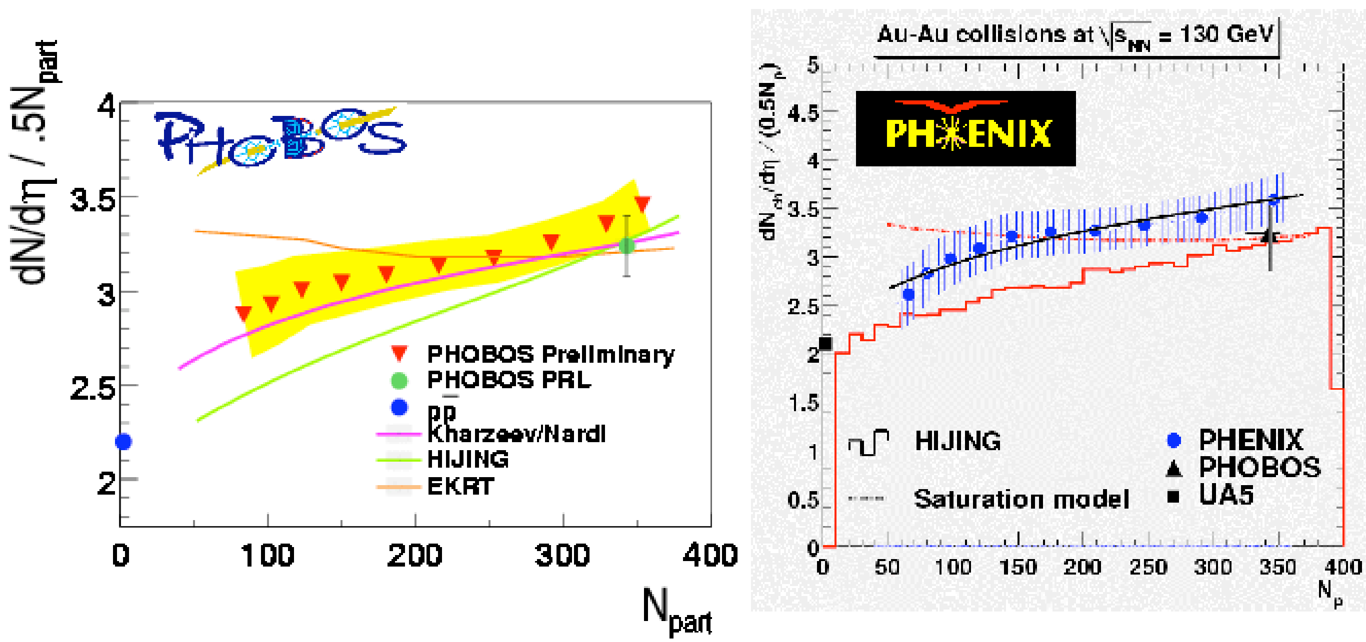
Furthest advance was made by Kovchegov who conjectured a certain factorization of the fields of the two nuclei. But we don't have a proof (Yet?)

Kharzeev - Levin - Nardi model is based to k_T-factorization (a la pQCD) and captures the essential features of hadron production:

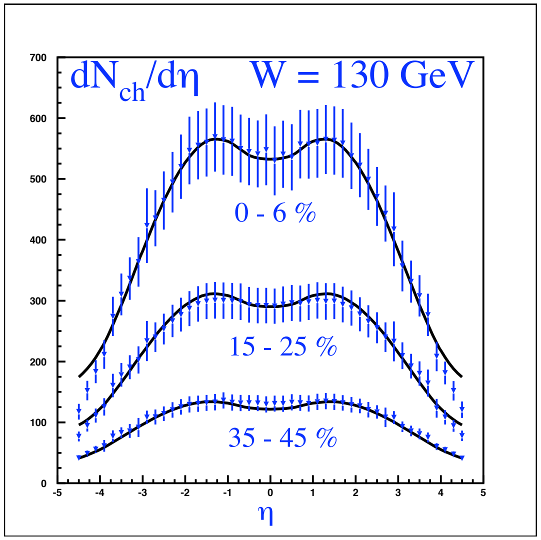


KLN model

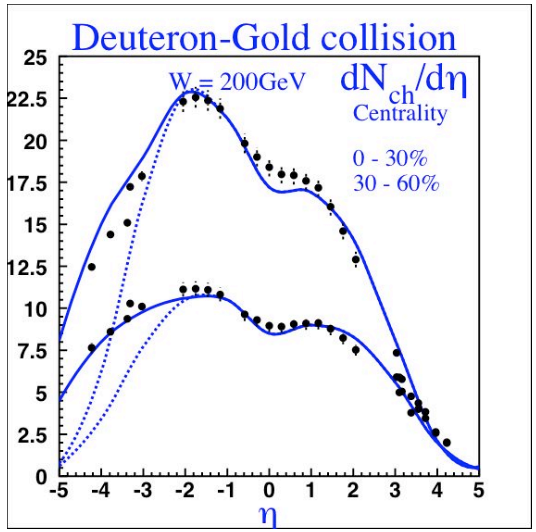
dN/dη vs Centrality at η=0



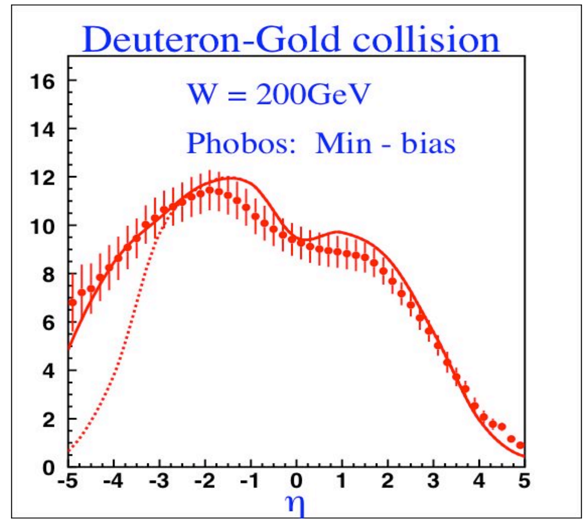
KLN model



$dN_{ch}/d\eta$ W = 130 GeV
0 - 6 %
15 - 25 %
35 - 45 %
η



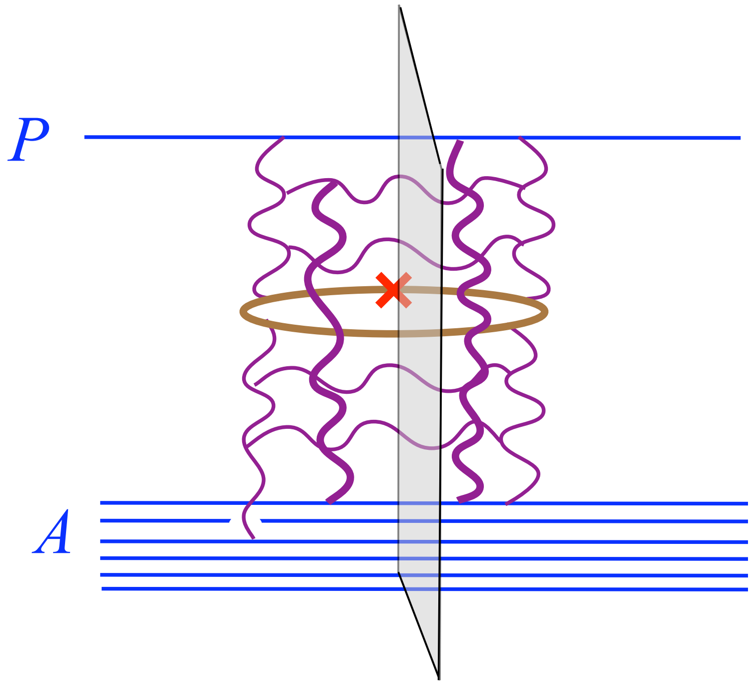
Deuteron-Gold collision
W = 200GeV
$dN_{ch}/d\eta$
Centrality
0 - 30%
30 - 60%
η

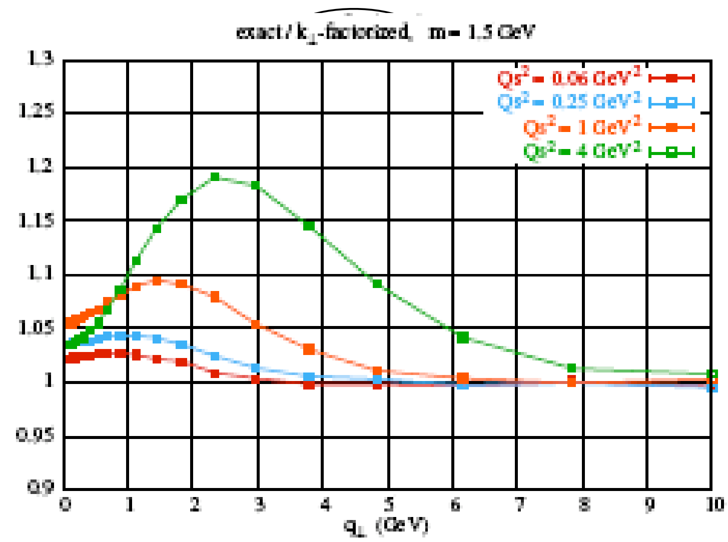


Deuteron-Gold collision
W = 200GeV
Phobos: Min - bias
η

Heavy quark production

KT, 04

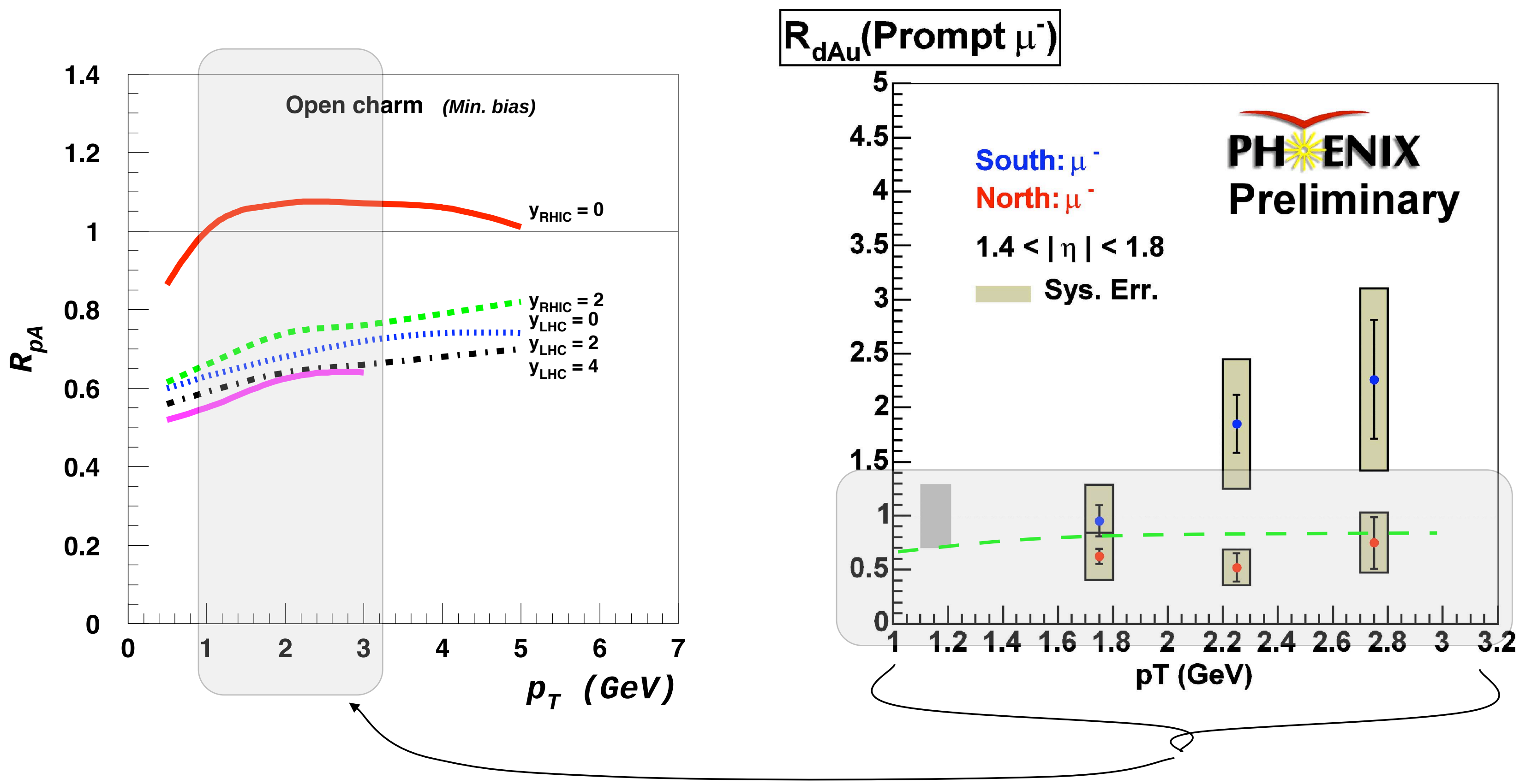




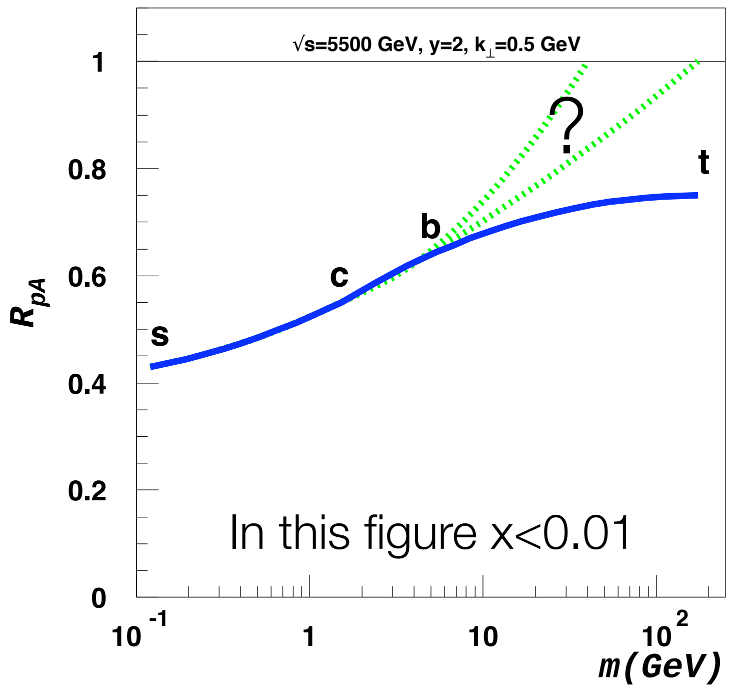
Fujii, Gelis, Venugopalan

Perturbative factorization is broken down

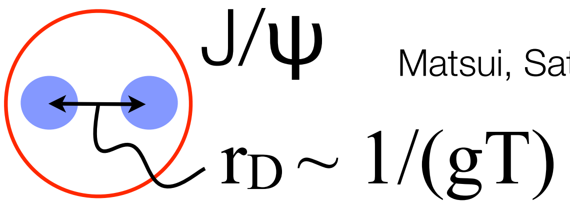
Open charm R_{pA} vs PHENIX data

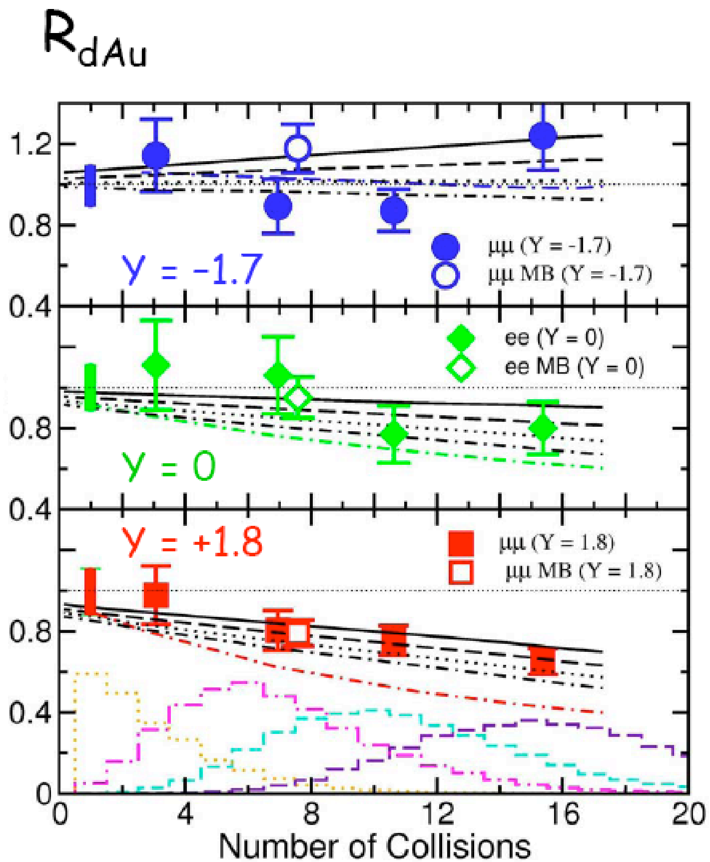


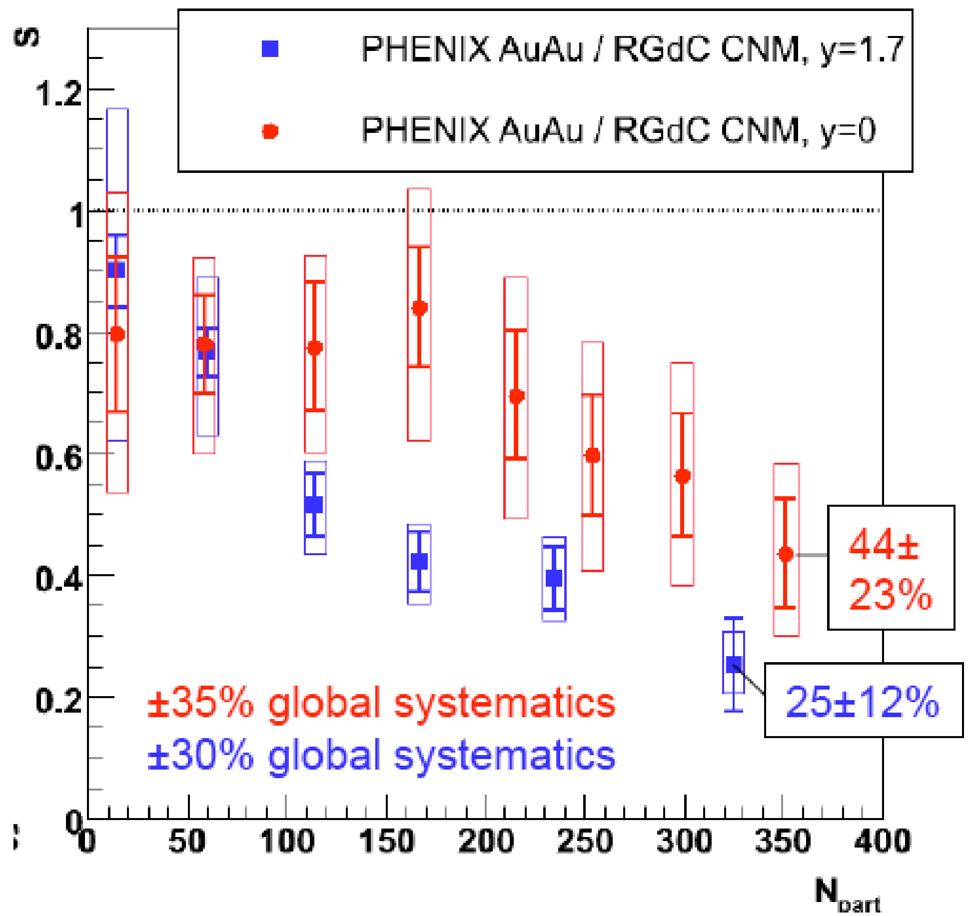
When the geometric scaling fails?



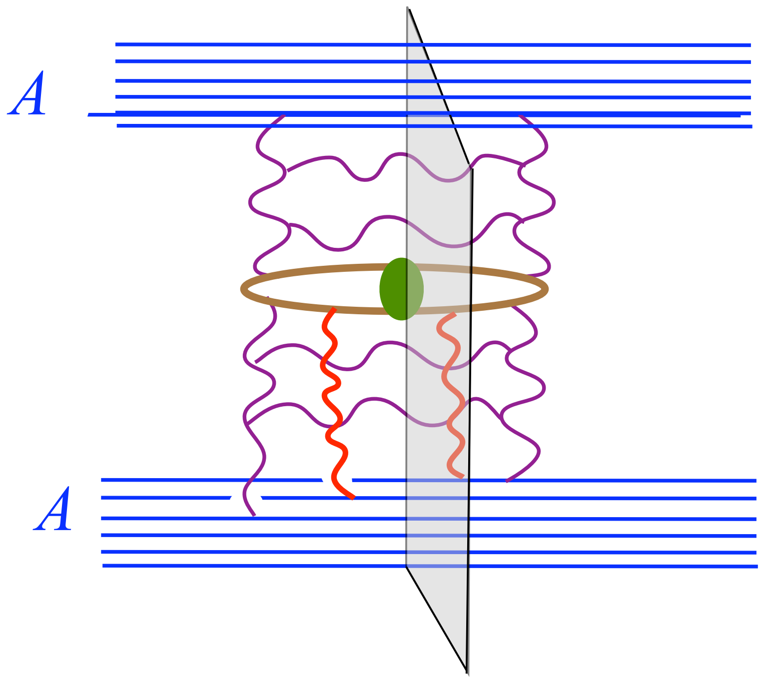
J/ψ production







J/ψ production $J^{PC}=1^{--}$



Production time

$$\tau_P = \frac{E_g}{M_\psi^2} = 7\,\mathrm{fm}$$

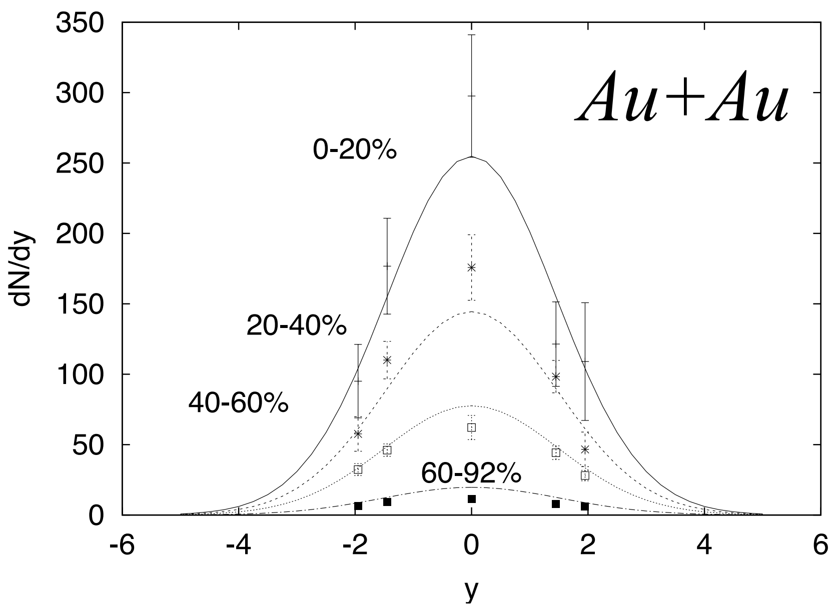
Formation time

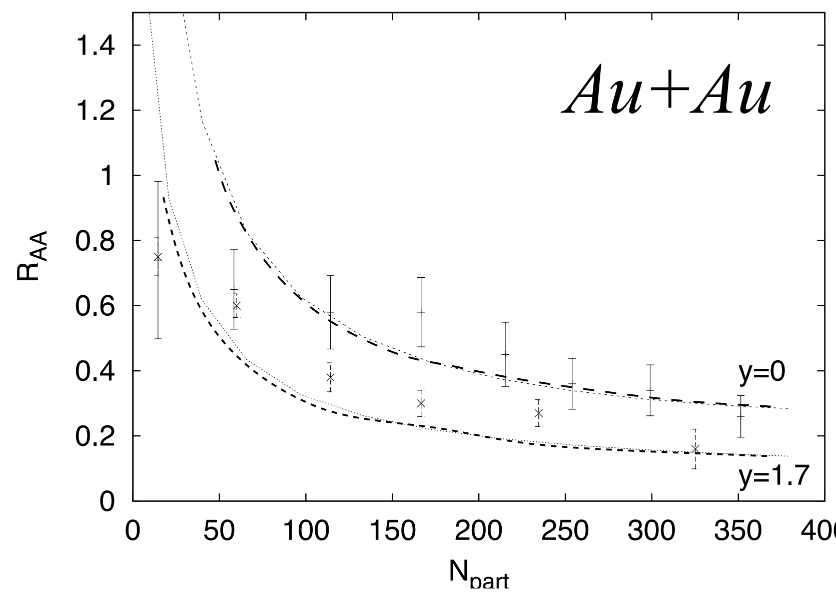
$$\tau_F = \frac{2}{M_{\psi'} - M_\psi}\frac{E_g}{M_\psi} = 42\,\mathrm{fm}$$

Number of attached gluons must be odd on each side of the cut.

J/ψ production

Kharzeev,Levin,Nardi,KT
in preparation





CGC is responsible for a significant J/ψ suppression in HIC even at $y=0$

Summary

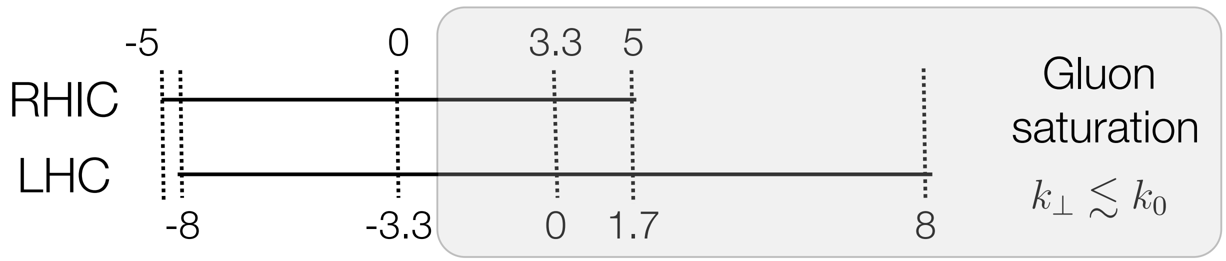
1. Cold nuclear matter at low x is dominated by high gluon densities and classical field configurations.

2. In HIC they are manifested in hadron production and correlations.

`Is most of J/ψ suppression in AA due to gluon saturation?`

3. There is a great potential to study CGC in pA and eA diffraction.

4. RHIC II and LHC will access low x and high p_T: great opportunity to study the relation between CGC and the hard perturbative theory.

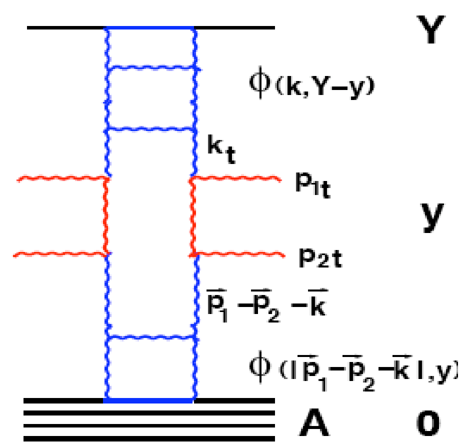


Back-up slides

Other channels of interest

1. Diffraction in pA: coherent and incoherent. Strong rapidity dependence even at LHC (where inclusive probes are saturated).

2. Correlations in pA and AA (responsible for flow at high p_T and ridge?



3. Dileptons and direct photons.

Open beauty R_{pA}