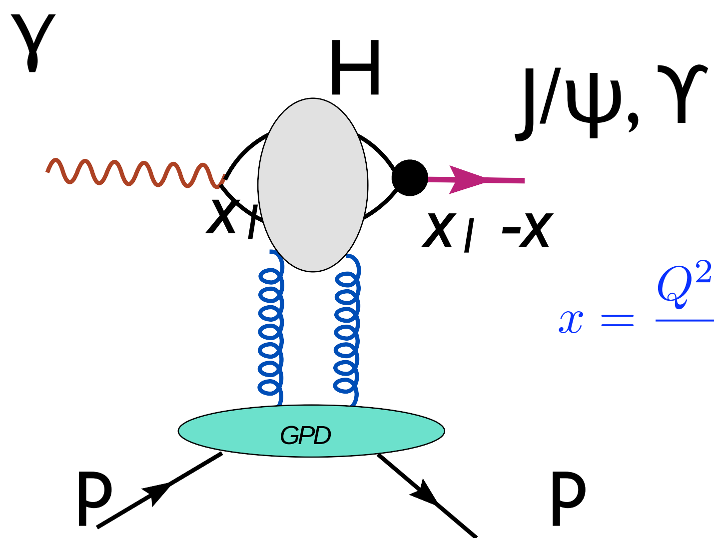
Probing high gluon densities in UPC processes with production of J/ψ

L.Frankfurt, TAU

CERN July 2009

The transverse distribution of gluons in a nucleon at small x.



$$x = \frac{Q^2 + m_V^2}{W^2}$$

$$A(\gamma^* + p \rightarrow "Onium" + p) \propto G(x_1, x1 - x, t)$$

Tool - QCD factorization theorem

Brodsky et al 04, Collins et al 07

In LT limit $x_1 - x << x_1$

however due to DGLAP evolution skewed Generalized Parton Distribution (GPD) kinematics for large Q probes diagonal GPD at Q_0 scale

$$G(x, x, t) \equiv G(x, t) = \int d^2\rho e^{-i\vec{\Delta}_\perp \rho} \boxed{G(x, \rho)}$$

← – *transverse spatial distribution of gluons*

$$\int d^2\rho G(x, \rho) = G(x)$$

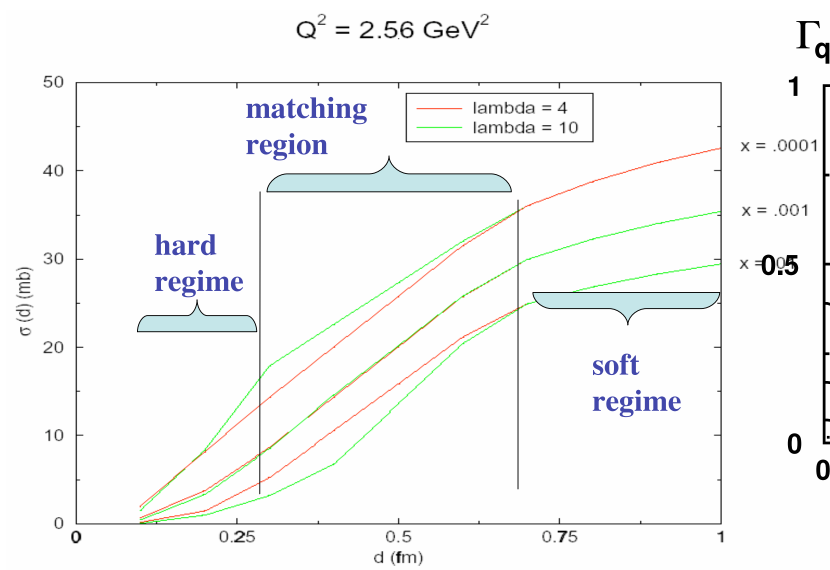
total gluon density

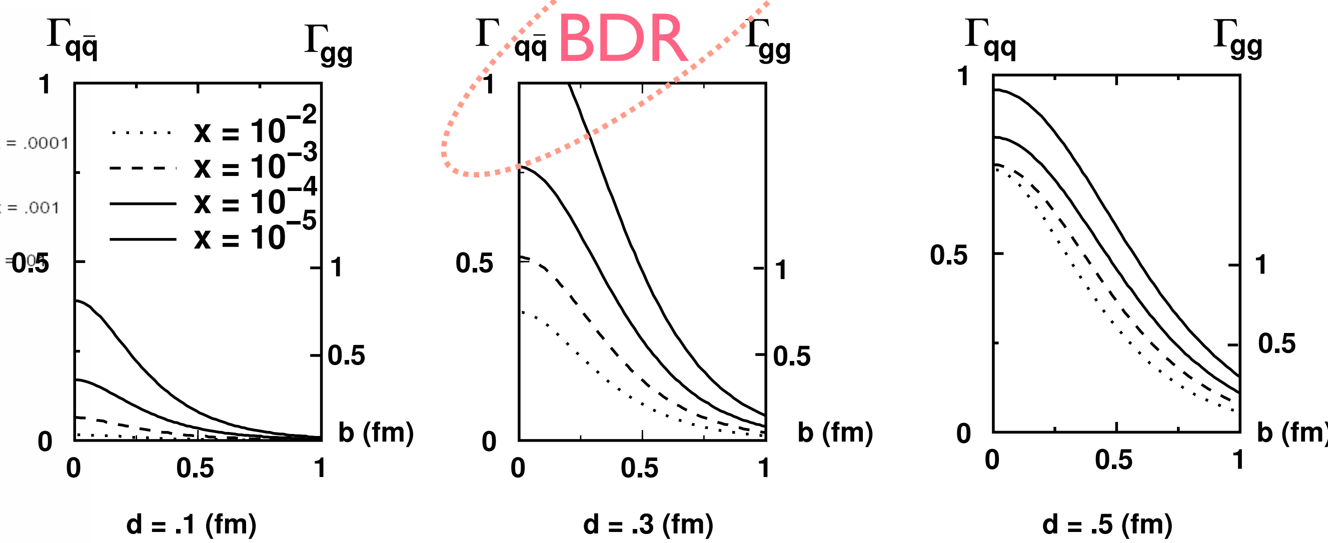
How dipole of the size d interacts with nuclear media?

small size, relatively large $x \sim 10^{-2} \div 10^{-3}$ cross section is small:

$$\sigma_{inel} = \frac{\pi^2}{3} F^2 d^2 \alpha_s(\lambda/d^2) x G_T(x.\lambda/d^2)$$

Gluon dipole interacts with 9/4 larger cross section.





studies of the "quark-antiquark dipole"(transverse size d) - nucleon cross section based pQCD and HERA data

$$\sigma_{inel}(x,b) = 1 - |1-\Gamma|^2$$

Gluon densities in nuclei and proton at b=0 are very similar!!!!

Difference is in a very different spread in b

b [fm]

How small color singlets (dipoles,...) propagate through nuclear media

*H*undred GeV (lab) - transparency of nuclei - observed at FNAL in $\pi + A \to$ 2jets + A, $\gamma + A \to J/\psi + A$,

High energies - $x_{eff}=Q^2_{eff}/s < 0.01$ - onset of color opacity regime both due to pQCD effects of LT gluon shadowing and proximity to black disk regime strong screening of total cross section of dipole -nucleus scattering

$\Rightarrow$ $\sigma_{tot}^{"dipole" A} \propto A \Longrightarrow \sigma_{tot}^{"dipole" A} \propto A^{2/3}$

coherent photoproduction of $J/\psi, \Upsilon$

survival probability, P, for propagation through the nucleus center drops to zero only rim contributes: $P \propto A \Longrightarrow P \propto A^{1/3}$

$\Rightarrow$ *quasielastic photoproduction of* $J/\psi, \Upsilon$

large t rapidity gap photoproduction of light vector mesons

diffractive (rapidity gap between VM and A) photoproduction of $J/\psi, \Upsilon$

Fundamental predictions of QCD for hard processes

- QCD predicts approximate Bjorken scaling for the cross sections of hard processes as the consequence of asymptotic freedom and transparency of hadron matter for the propagation of spatially small dipole.

- Smaller size of dipole- more rapid increase of gluon distribution with decrease of x (DGLAP): $xG(x,Q^2) \propto x^{-\delta(Q^2)}$ and $\delta(Q^2)$ increases with increase of Q. Observed at HERA.

- It follows from QCD factorization theorems that for the scattering of spatially small dipole total and elastic cross sections:

$$\sigma_{tot}(dipole + T) \propto G(x,Q^2) \qquad \sigma(el) \propto (xG(x,Q^2))^2$$

Observed at HERA in the total cross sections of DIS and in the hard diffractive electroproduction of vector mesons.

At sufficiently small x pQCD has problems with probability conservation:

$$\sigma_{el}(dipole + T) \propto (xG)^2 \geq \sigma_{tot}(dipole + T) \propto (xG)$$

This decease has been diagnosted but theoretically for the scattering of spatially small colorless gluon dipole at the energies achieved at HERA (L.F. , M.Strikman 95) Diagnostics explores or purely pQCD calculations or the fact that the ratio of elastic and total cross sections for the colorless gluon dipole scattering of a hadron target is unambigously calculable in terms of the measured at HERA gluon distribution within a proton , diffractive gluon density and the universal slope of t dependence for diffractive photoproduction of $J/\Psi, \Upsilon$ or diffractive ρ meson electroproduction of a proton target.

Constraints from the probability conservation.

Structure function of a hadron at fixed impact parameter "b" is restricted from above by 1 -the conservation of probability. Violated in pQCD at sufficiently small x because of rapid increase of xG . This observation proves existence of new nonperturbative QCD regime of strong interaction with small coupling constant .

A structure function= integral over impact parameters rapidly increases with energy forever.

Some characteristics of new QCD regime like limiting form of structure functions of hadrons and nuclei , of cross sections of hard diffractive processes, of cross sections for hadronic collisions unambigously follow from the fact that absorption is increasing with energy but can not exceed 100% and from the phenomenon of spontaneously broken chiral symmetry in QCD. (L.F. and M.Strikman 1994)

Many properties of new QCD regime like hadron distribution , flavour composition etc depend on collision energy and understood qualitatively only .

General conclusions

pQCD series diverge at sufficiently small x when $\alpha_s \ln(x_0/x)$ exceeds boundary of the region where pQCD series are asymptotic ones. In the approximation accounting for Pomeron loops this divergency is related to the tunneling transitions between two extrema in the effective Hamiltonian .(B.Blok and L.F. 2008)

Bj scaling for hard processes=dynamical conformal invariance and therefore asymptotic freedom completely disappear at sufficiently small x. Gluon distribution within a hadron achieves maximum allowed by probability conservation. Concept of parton distribution(in difference from the concept of structure functions) lost meaning at small x. In the new QCD regime σ_{DIS} does not decrease with increase of Q^2.

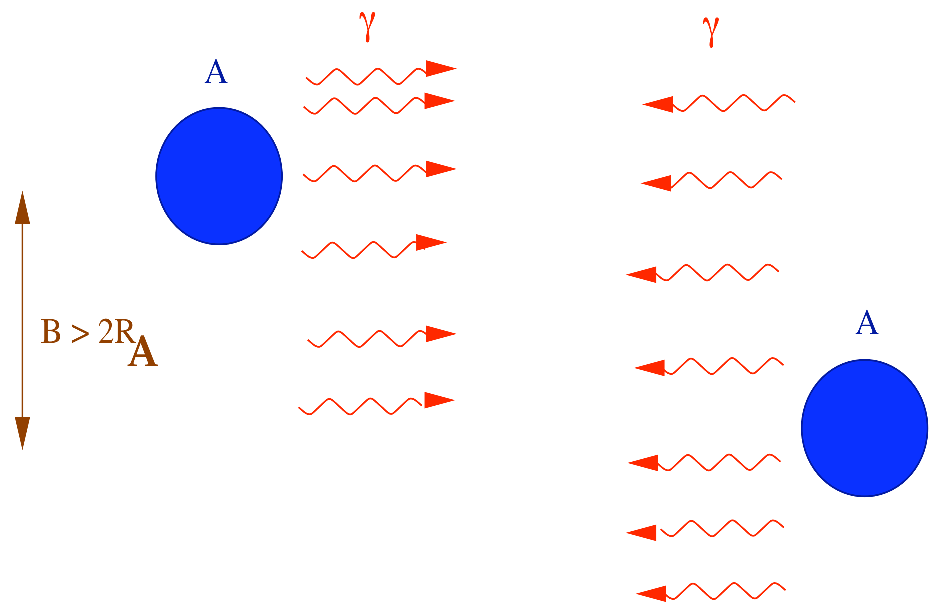
Challenge-how to investigate new QCD regime without electron accelerator?

New QCD regime of strong color fields will reveal itself in the variety of new phenomena .(L.F, M.Strikman 2000-2009)

- Complete disappearance of Bj scaling of total cross sections of DIS, of cross sections of hard processes and their rapid increase with energy.
- Hadron matter becomes nontransparent for the propagation of small colorless gluon dipole in diffractive photo(electro) production processes off nuclei and depletion of transparency for quark dipole
- Independence on Q of cross section of diffractive electroproduction of vector mesons and predicted by QCD value of this cross section .
- Dominance of hard QCD in pp collisions at central impact parameters. Dominance of soft QCD at peripheral pp collisions.
- In pp collisions at central impact parameters increase with energy of the yield of minijets, of multiparton collisions ,of the average transverse momentum of hadrons, of heavy flavour etc. Dependent on energy important part of pedestal for new particles production.

Ultraperipheral Collisions ≡ UPC

What is UPC? Collisions of nuclei (pA) at impact parameters $b \geq 2R_A$ where strong interaction between colliding particles is negligible



Ultraperipheral Nucleus–Nucleus Collision

Study of elastic dipole - nucleus scattering: exclusive vector meson production

$$\frac{d\sigma(AA \to VAA)}{dy} = N_\gamma(y)\sigma_{\gamma A \to VA}(y) + N_\gamma(-y)\sigma_{\gamma A \to VA}(-y).$$

$$rapidity \quad y = \frac{1}{2}\ln\frac{E_V - p_3^V}{E_V + p_3^V} = \ln\frac{2k}{m_V}.$$

The flux of the equivalent photons $N_\gamma(y)$ is

$$N(y) = \frac{Z^2\alpha}{\pi^2}\int d^2b\Gamma_{AA}(\vec{b})\frac{1}{b^2}X^2\left[K_1^2(X) + \frac{1}{\gamma}K_0^2(X)\right].$$

$K_0(X), K_1(X)$ – modified Bessel functions with argument $X = \frac{bm_V e^y}{2\gamma}$, γ is Lorentz factor and $\vec{b}$ is the impact parameter.

ρ, J/ψ photoproduction off nuclei is studied at RHIC - reasonable agreement with the theory(S. Klein and J.Nystrand, L.F.M.Strikman and M.Zhalov) Since cross section of such processes is rapidly increasing with energy this result means that at LHC cross sections of various photoproduction processes should have sufficient yield to be accurately measurable.

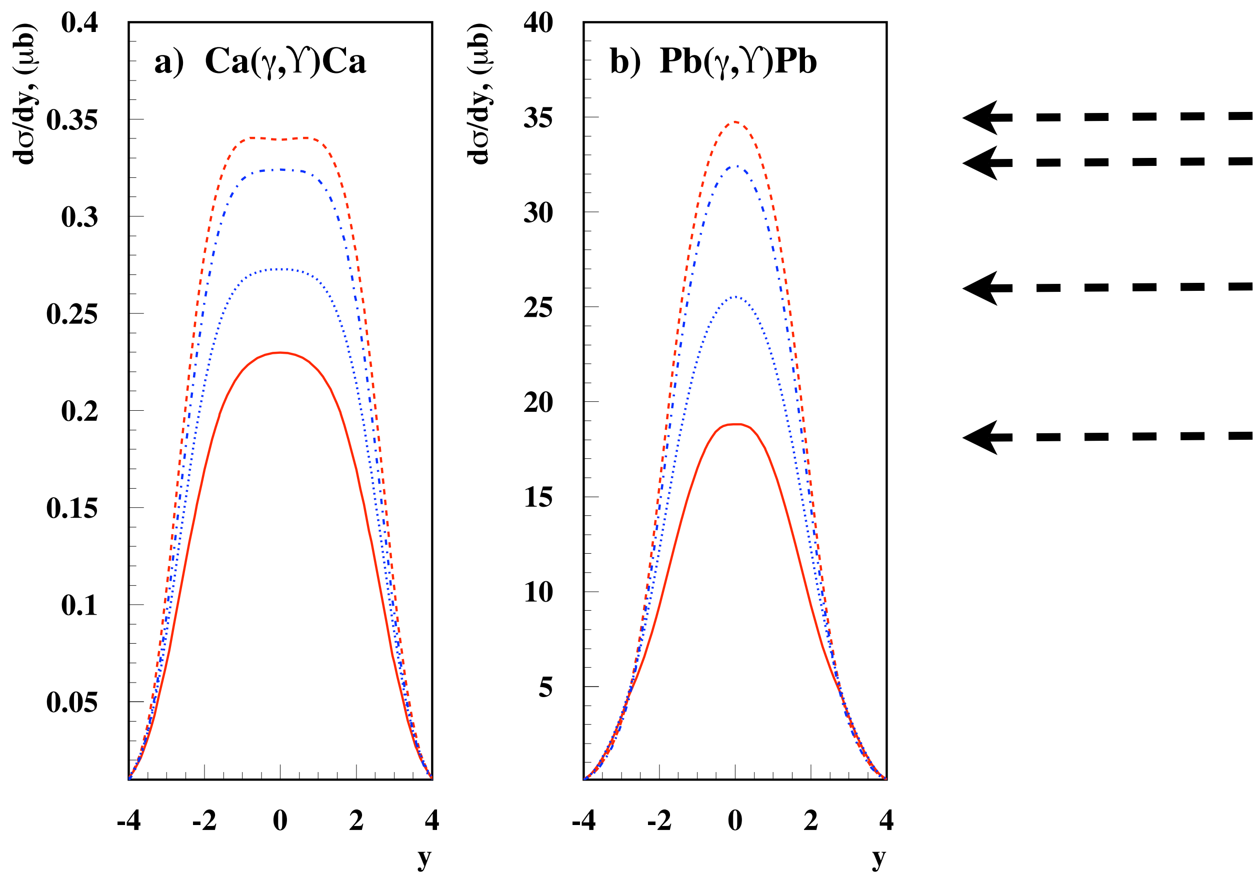
Diffractive photoproduction processes with hard probe:

$$\gamma + N(A) \rightarrow a + gap + N(A)$$

where "a" is a heavy flavour vector meson or two forward jets with large transverse momenta should be effective tool in the investigation of hard QCD phenomena

For these hard processes QCD factorization theorem has been proved (J.Collins,L.F,M. Strikman 1994). Cross sections of these processes were calculated in terms of generalized parton densities in pQCD regime (S.Brodsky et al 1994) and in the new QCD regime of large gluon densities. (L.F and M.Strikman 1994)

Thus small x hard processes can be investigated at LHC in ultraperipheral processes in three different type experiments which should give the same and complimentary information: elastic and inelastic diffractive photoproduction of vector mesons and large t elastic and inelastic diffractive vector meson production.



Imp.Approx

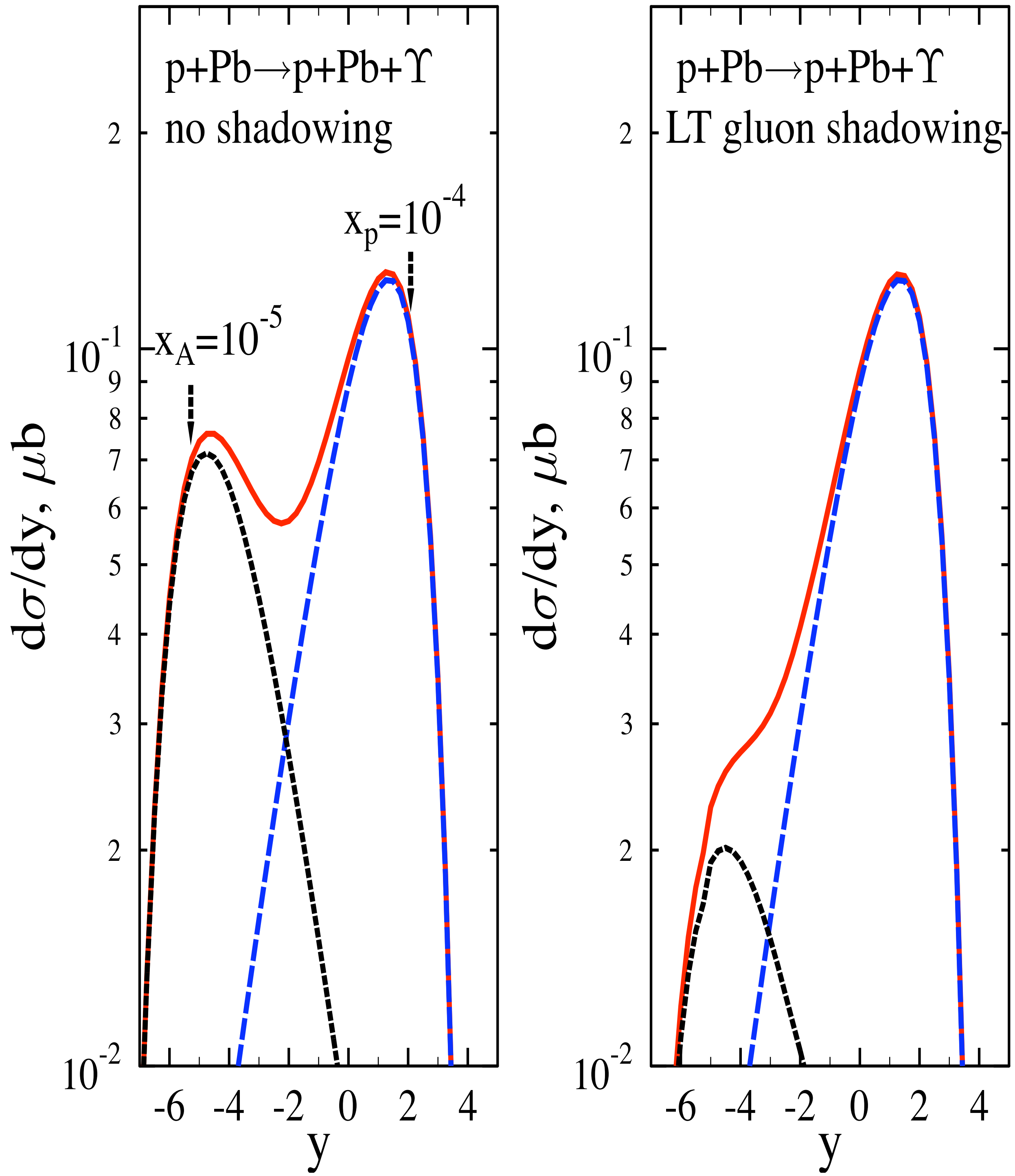
Eikonal Approx

LT shadowing using Eskola et al fit

LT shadowing using FGS 03

shadowing in b-space eikonal is small

The rapidity distribution for coherent Y production in Ca-Ca and Pb-Pb ultraperiphera collisions at the LHC. The solid curve corresponds to the calculation including leading twist nuclear shadowing using H1 diffractive pdfs of 2000; the dotted curve correspor to the calculation with the model of shadowing of Eskola et al.; the dot-dashed curve i the calculation in the eikonal dipole rescattering model; the dashed curve corresponds to the impulse approximation.



Zhalov et al 05

Sufficient to check pQCD prediction of $\sigma \sim W^{1.6}$ for Upsilon production, determination of the t-slope (best done if the protons could be detected) and measure nuclear shadowing at $Q^2=40\ GeV^2$

Production of ϒ's in pA collisions : coherent $\gamma+A \rightarrow V+A$ is shown by black lines, and $\gamma+p \rightarrow V+p$ by blue lines.

PHYSICAL REVIEW D VOLUME 54, NUMBER 5 1 SEPTEMBER 1996

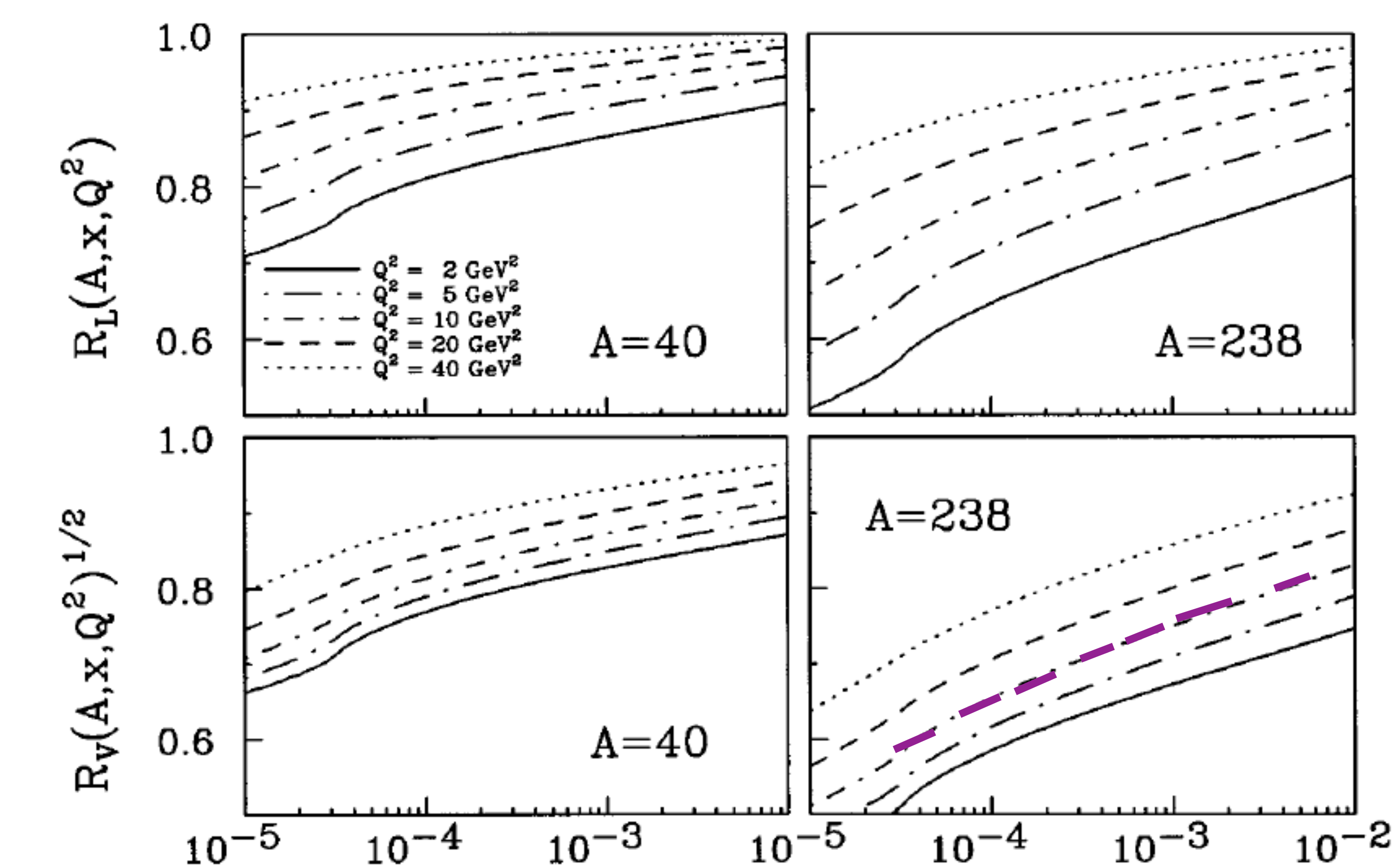
Hard diffractive electroproduction of vector mesons in QCD

Leonid Frankfurt* and Werner Koepf†
School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv, Israel

Mark Strikman‡
Pennsylvania State University, University Park, Pennsylvania

$$R_L(A,x,Q^2)=\frac{1}{A}\frac{\mathrm{Re}\left\{\int d^2b\,dz\,|\psi_{\gamma_L^*}(b,z)|^2\int d^2B\left[2-2\exp\left(-(1-i\beta)\frac{\sigma_{\rm tot}(b)T(B)}{2}\right)\right]\right\}}{\int d^2b\,dz\,|\psi_{\gamma_L^*}(b,z)|^2\sigma_{\rm tot}(b)},$$

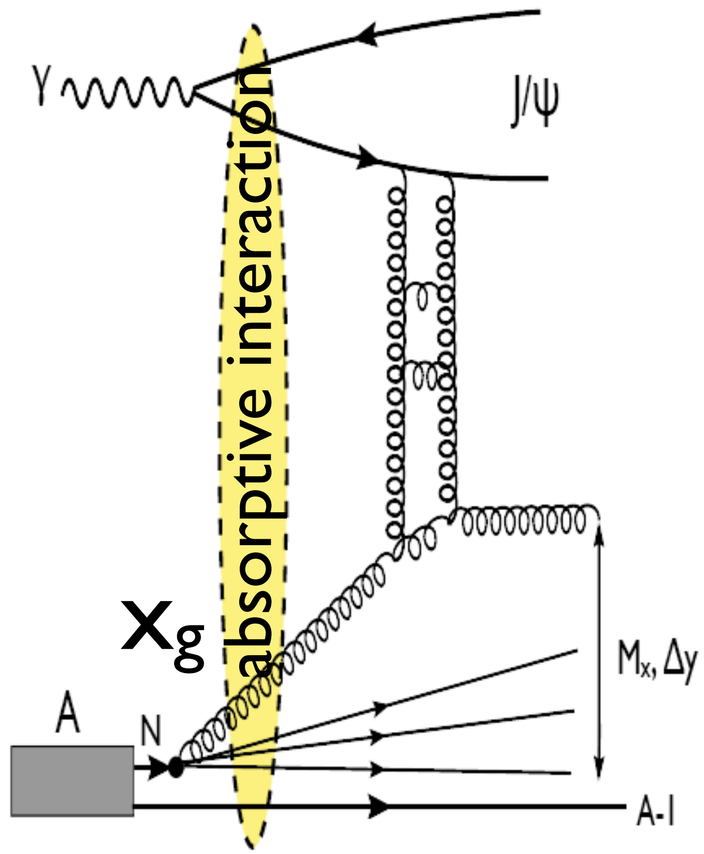
$$R_V(A,x,Q^2)=\frac{1}{A^2}\left|\frac{\int d^2b\,dz\,\psi_{\gamma_L^*}(b,z)\psi_\rho(b,z)\int d^2B\left[2-2\exp\left(-(1-i\beta)\frac{\sigma_{\rm tot}(b)T(B)}{2}\right)\right]}{\int d^2b\,dz\,\psi_{\gamma_L^*}(b,z)\psi_\rho(b,z)\sigma_{\rm tot}(b)(1-i\beta)}\right|^2.$$



Shadowing for σ_L and for coherent VM exclusive production for t=0 calculated in b-space eikonal model.

for photoproduction of J/ψ, Q^2 curve for 10 GeV^2.

The leading twist model ~ $(G_A/G_N)^2$ somewhat larger effect γ + A → J/ψ + gap + X



Ultra Peripheral Collisions [LHC]

Experimental advantages
as compared to coherent J/ψ

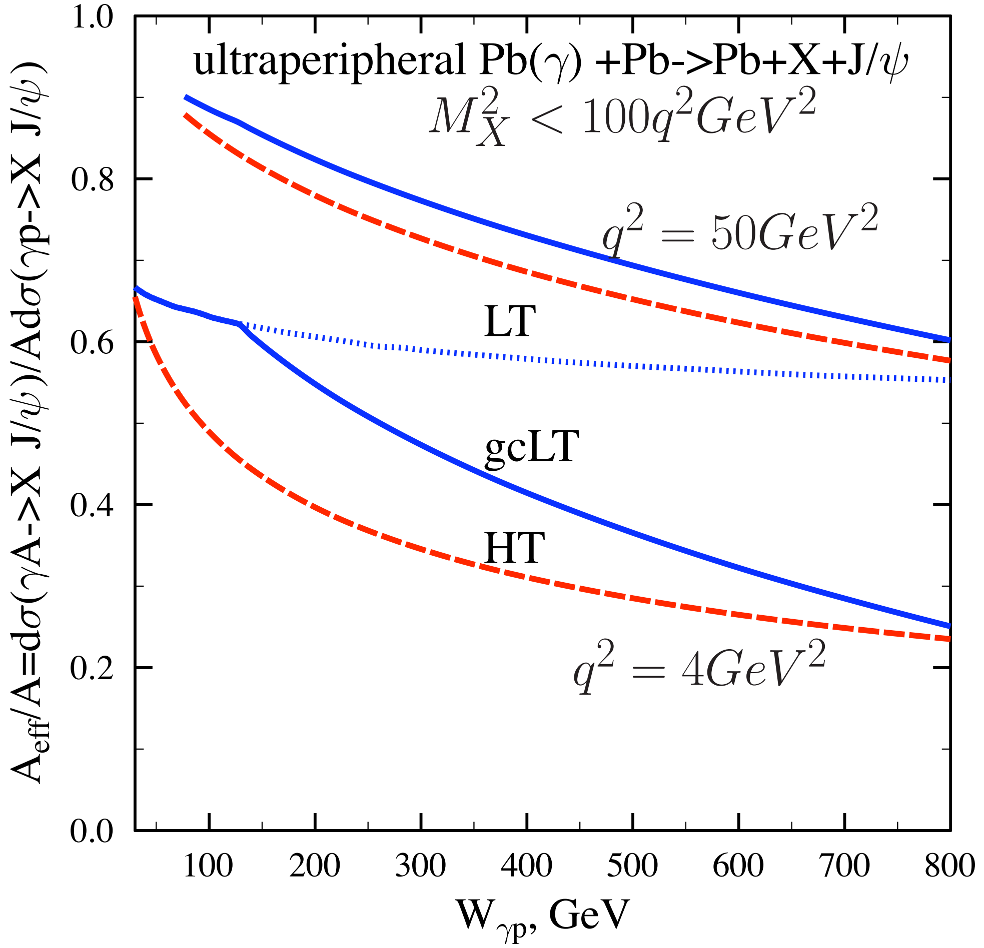
$$s' = \tilde{x} W^2_{\gamma N}$$

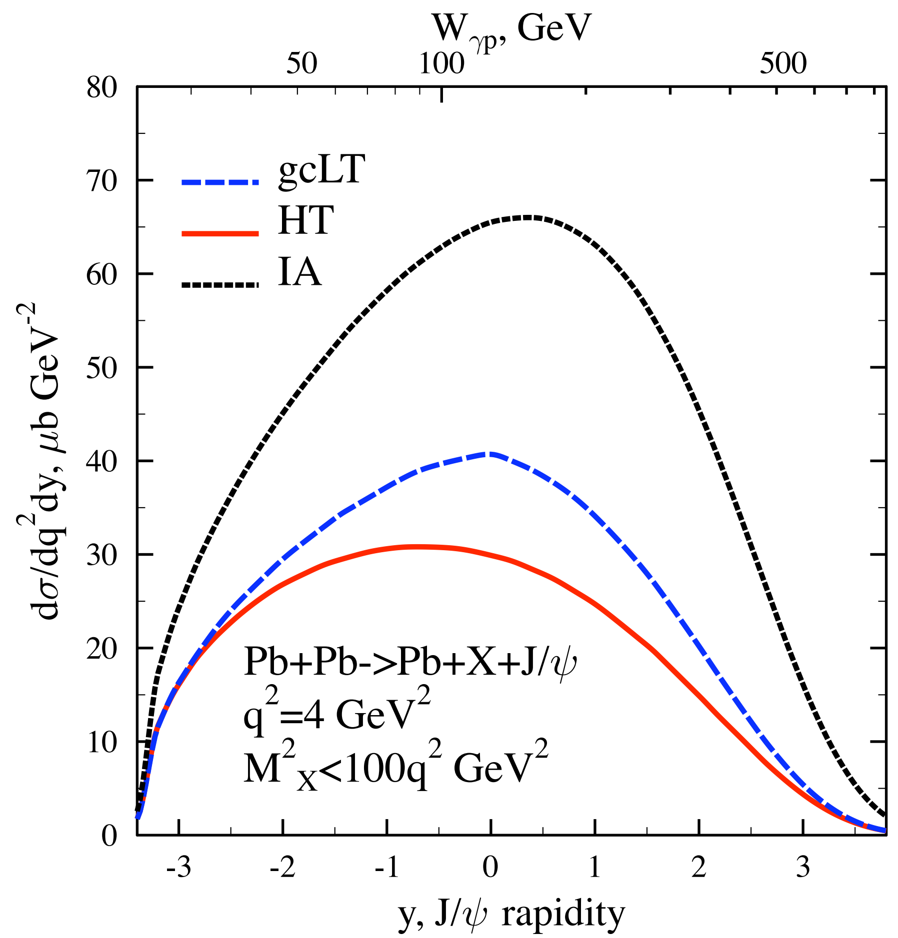
- No ambiguity which nucleus emitted photon
  - can push to higher energies
- Easier to trigger

Probes propagation of a dipole of size: $d^2(q^2)/d^2(0) \approx (1 + q^2/4m_c^2)^{-1}$

$d_0 = .25\text{fm}, m_c = 1.5\, GeV$

through ~10 fm of nuclear matter





Significant absorption is expected in the leading twist and higher twist models of dipole interaction

Cross section is high enough to perform the study during the first month of the Heavy Ion running