Probing BFKL dynamics in ep, eA scattering in large t semiexclusive rapidity gap processes

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LHeC workshop, CERN, June 24-26, 2015

Will focus on two questions which could be studied in process

$$\gamma(\gamma^*) + p(A) \rightarrow \text{"vector meson"} + \text{rapidity gap} + \text{X}$$

in ultraperipheral collisions at LHeC and ultraperipheral collisions in pA/AA at LHC

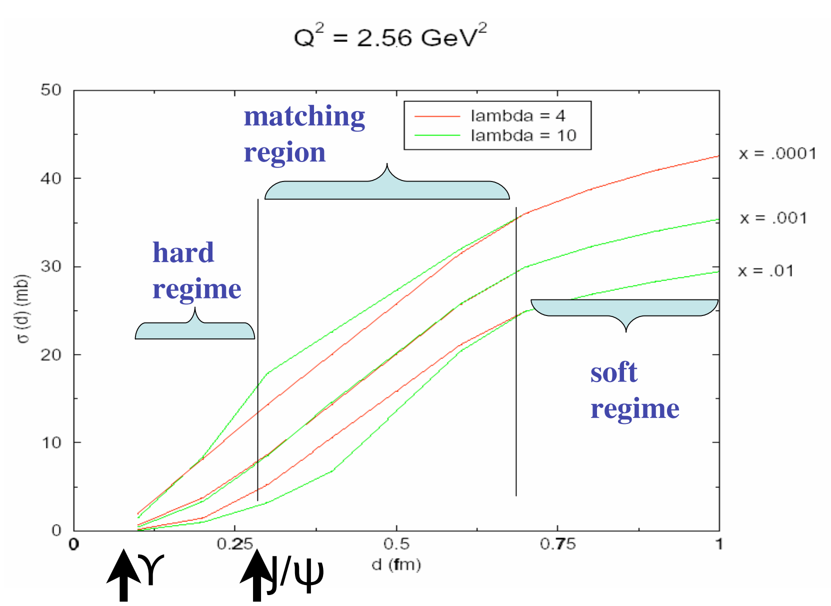
- *What is Asymptotic behavior of the amplitude of the elastic scattering of small dipoles in QCD at large t ? At what energies BFKL approximation works?*

- *How small dipoles interact with nuclear media?*

Expectations for interaction of small size dipoles:

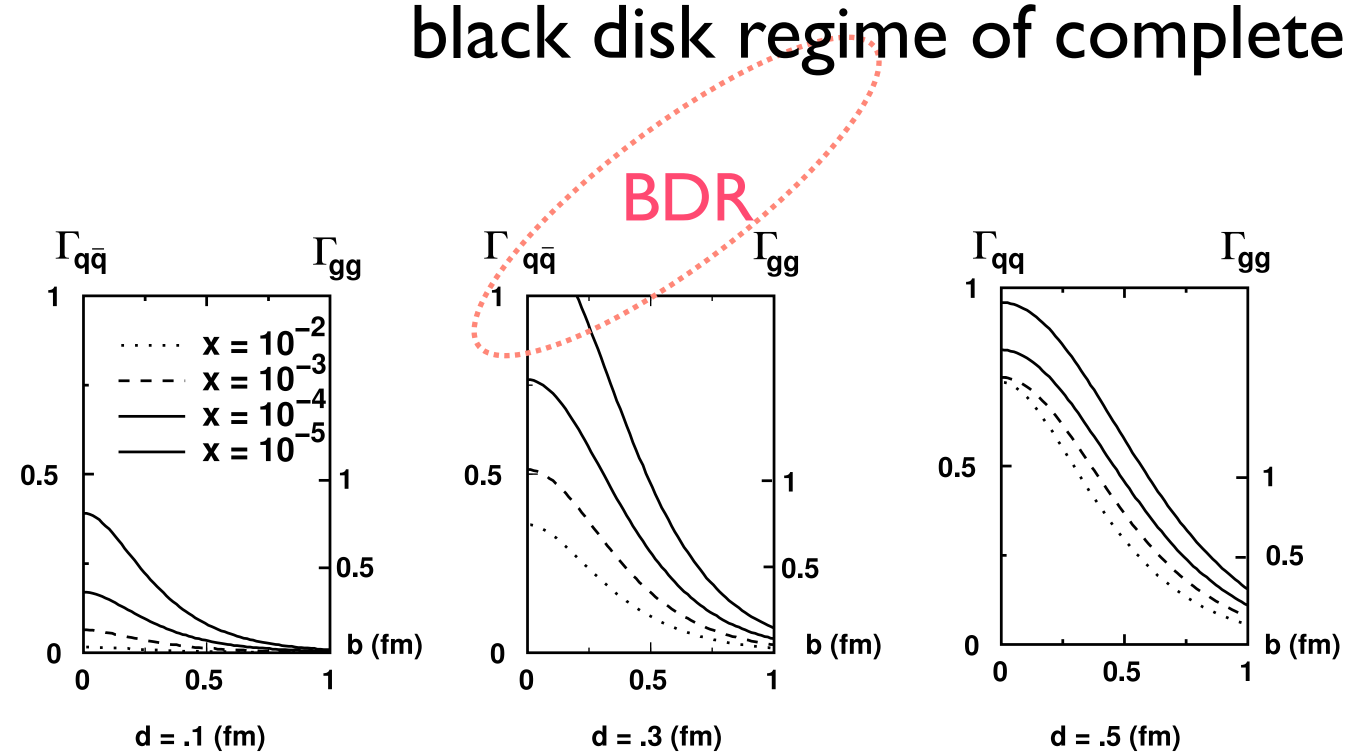
at low energies (relatively large $x \sim 10^{-2} \div 10^{-3}$) cross section is small, but rapidly grows with energy. LT shadowing slows growth.

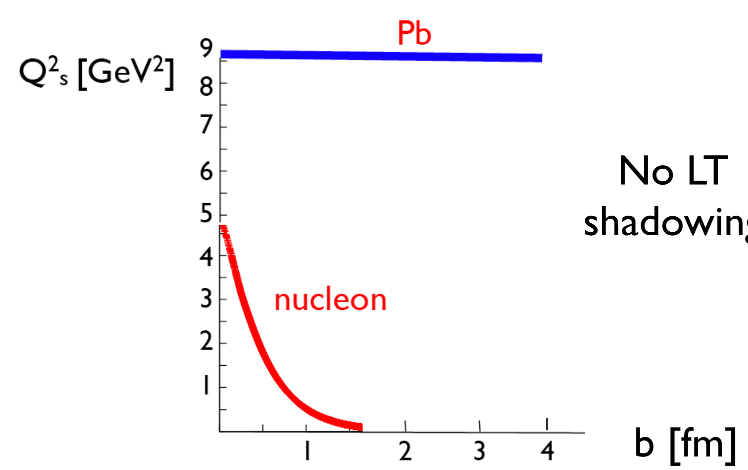
$$\sigma_{inel}^{dipole-T}(x,d) = \frac{\pi^2}{3} F^2 d^2 \alpha_s(\lambda/d^2) x G_T(x,\lambda/d^2), \lambda \sim 4 \div 8$$



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

black disk regime of complete absorption





No LT shadowing

Gluon densities in nuclei and proton at b=0 are very similar!!!! Especially if one takes into account LT nuclear shadowing (Takaki's talk)

Difference is in a very different spread in b

b - transverse distance of parton from the target center

Problems for the study - DIS two large scales Q^2 and $1/x$ (Altarelli's talk)

DGLAP emphasizes ln Q but includes ln x - double log is often a good approximation

BFKL effectively calculates amplitude f(s) of elastic scattering of two small dipoles of equal size:

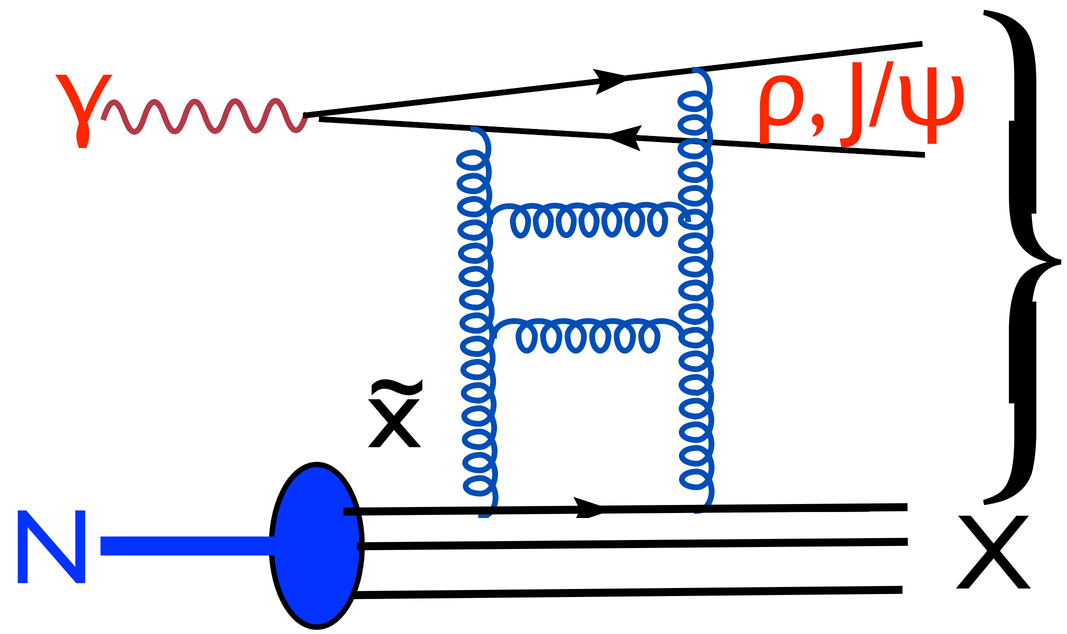
$f(s) = (s/s_0)^{1+\Delta}$

$$\Delta = a_1 \alpha_s - a_2 \alpha_s^2 + \ldots$$

leading log $\Delta \sim 0.5$, NLO ~ 0.1, resummation ~0.2

Main reason - energy conservation

Both questions can be addressed by studying rapidity gap processes at large $t=(p_\rho-p_\gamma)^2$ which were first studied at HERA



$$s' = \tilde{x} W_{\gamma p}^2$$

Elementary reaction - scattering of a hadron (γ, γ*)

off a parton of the target at large $t=(p_\gamma-p_V)^2$

$$\tilde{x} = \frac{-t}{(-t + M_X^2 - m_N^2)}$$

FS 89 (large t pp→p +gap + jet),

Mueller & Tung 91

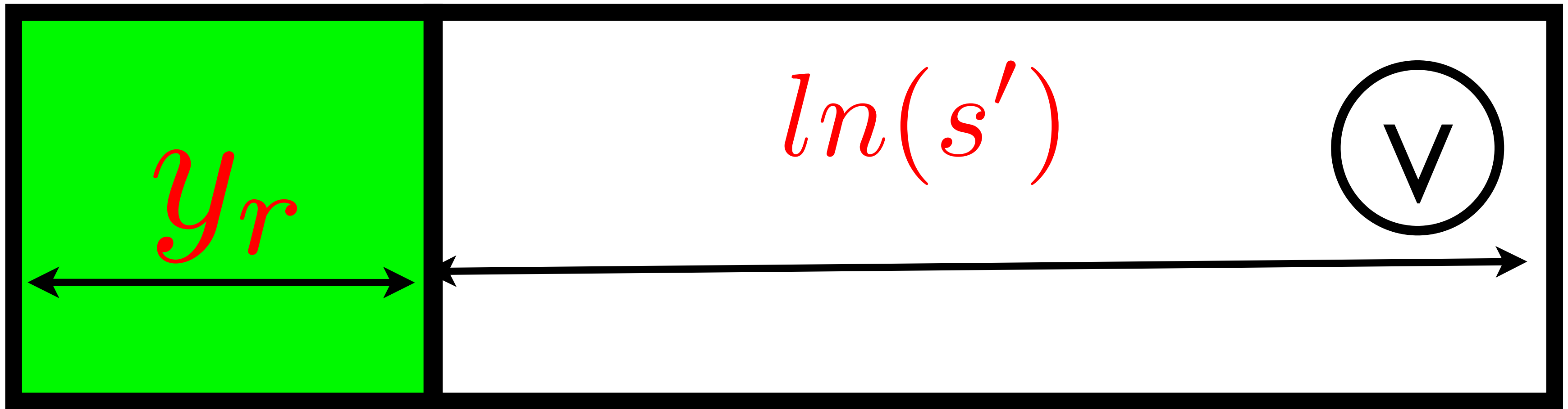
FS95

Forshaw & Ryskin 95

The rapidity gap between the produced vector meson and knocked out parton (roughly corresponding to the leading edge of the rapidity range filled by the hadronic system X) is related to $W_{\gamma p}$ and t (for large t, $W_{\gamma p}$)as

$$y_r = \ln \frac{\tilde{x} W^2_{\gamma p}}{\sqrt{(-t)(m_V^2 - t)}}$$

φ



The choice of large t ensures several important simplifications:

✳ *the parton ladder mediating quasielastic scattering is attached to the projectile via two gluons*.

✳✳ *attachment of the ladder to two partons of the target is strongly suppressed*.

✳✳✳ *the transverse size* $d_{q\bar{q}} \propto 1/\sqrt{-t} \sim 0.15\text{fm for} J/\psi \text{ for} -t \sim m^2_{J/\psi}$

$$\frac{d\sigma_{\gamma+p\to V+X}}{dt d\tilde{x}} =$$

$$= \frac{d\sigma_{\gamma+quark\to V+quark}}{dt}\left[\frac{81}{16} g_p(\tilde{x},t) + \sum_i (q_p^i(\tilde{x},t) + \bar{q}_p^i(\tilde{x},t))\right]$$

t-range for sufficient squeezing $-t \sim$ few GeV^2, For J/ψ $-t \sim 4$ -- 10 GeV^2,

Note - t-dependence is weak

$$\frac{d\sigma}{dt} \propto \frac{1}{(t+t_0)} \frac{1}{(-t+m^2_{J/\psi})^3}$$

→ Large rates up to large t

LF & MS & Zhalov 2008

HERA --Analyses with z cut, $M^2_X/s <$ const cuts are good for study of the dominance of the mechanism of scattering off single partons. However they correspond to rapidity interval between VM and jet which are typically of the order $\Delta y = 2 - 3$.

Optimal way to study BFKL dynamics is different: keep M^2_X (in practice y_r) < const and study W- dependence.

Was difficult but not impossible at HERA, natural at LHC and LHeC

At LHC one can study energy dependence of elastic qq - parton scattering at W'=20 GeV - 400 GeV, higher W' at LHeC

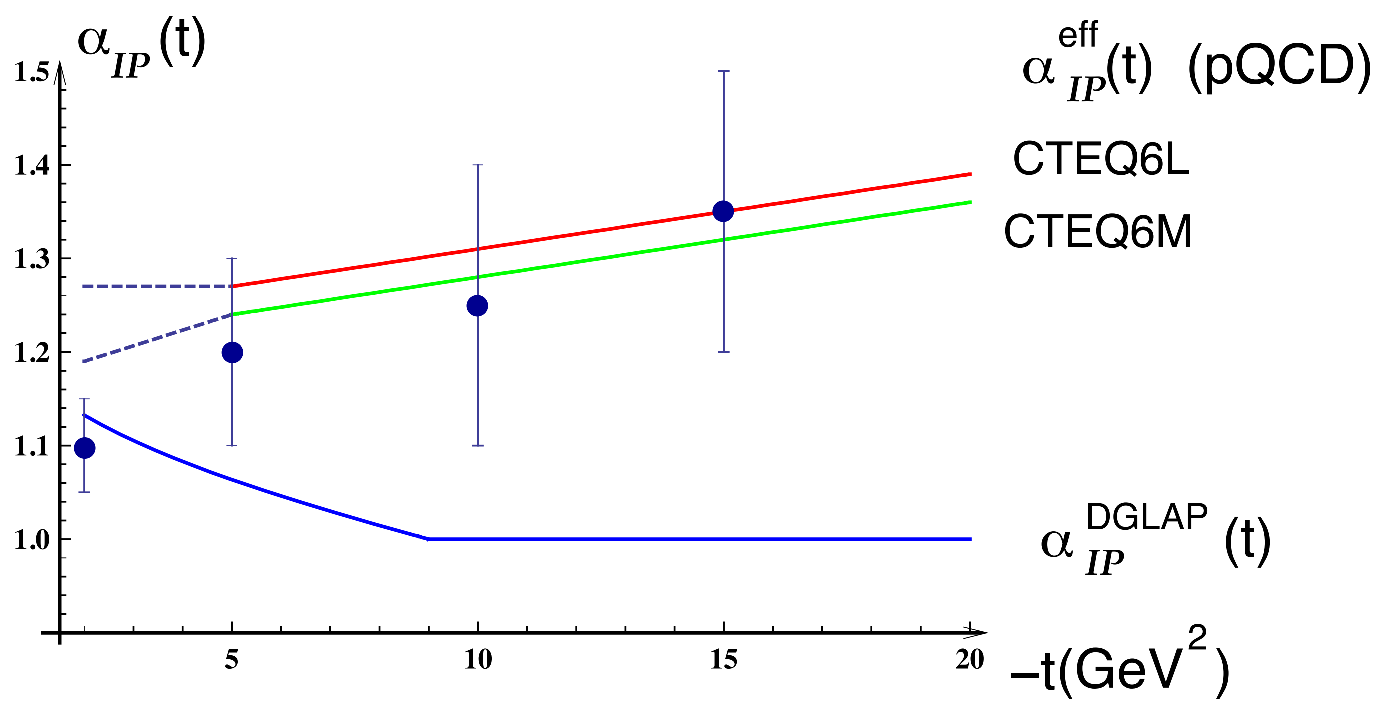
$$\sigma_{el}(q\bar{q}-q(g)(W'=400GeV)/\sigma_{el}(q\bar{q}-q(g)(W'=20GeV) \sim 10\,!!!$$

if Δ=0.2 -- NLO BFKL

$$W'^2 \equiv W^2(q\bar{q}-parton) = \tilde{x}W^2$$

better rapidity coverage of detector → larger W' range

-- J/ψ data from HERA



Large experimental value of $\alpha_{I\!P}^{eff}(t)$ is due to the dependence of cut on t in $\tilde{x}$ the HERA data. DGLAPS with $\alpha_{I\!P}^{eff}(-t \gg \text{few GeV}^2) = 1$ gives a good description of the data.

Blok, Frankfurt, MS, Phys.Lett. B690 (2010) 159-163

W' too small?

LHeC good coverage in rapidity: - 4.5 backward -- 5.1 forward

Corresponds to a range of change of s' of 10^4 is -- further veto detector closer to proton fragmentation can further increase s' range.

Guess - elastic cross section would remain constant till s'~ 10^2 GeV^2 switching to BFKL growth at s'~10^3 *Onset of BFKL dynamics only when*

$$\frac{\alpha_s(t) ln(s/s_0)}{\pi} \sim 1$$

PRL **102,** 232001 (2009) PHYSICAL REVIEW LETTERS

Tracking Fast Small Color Dipoles through Strong Gluon Fields at the LHC at large t

L. Frankfurt,[1] M. Strikman,[2] and M. Zhalov[3]

$$\gamma + A \to J/\psi(\rho, 2\pi) + \text{"gap"} + \text{X}$$

Complementary to γ+ A →J/ψ +A and has several advantages:

(i) larger W range for UPC (due to ability to determine which of nuclei generated photon)

(ii) Regulating of $\tilde{x}$ for the parton in nucleus - shadowing vs linear regime for $G_A(x,Q)$

(iii) More central collisions - larger local gluon density

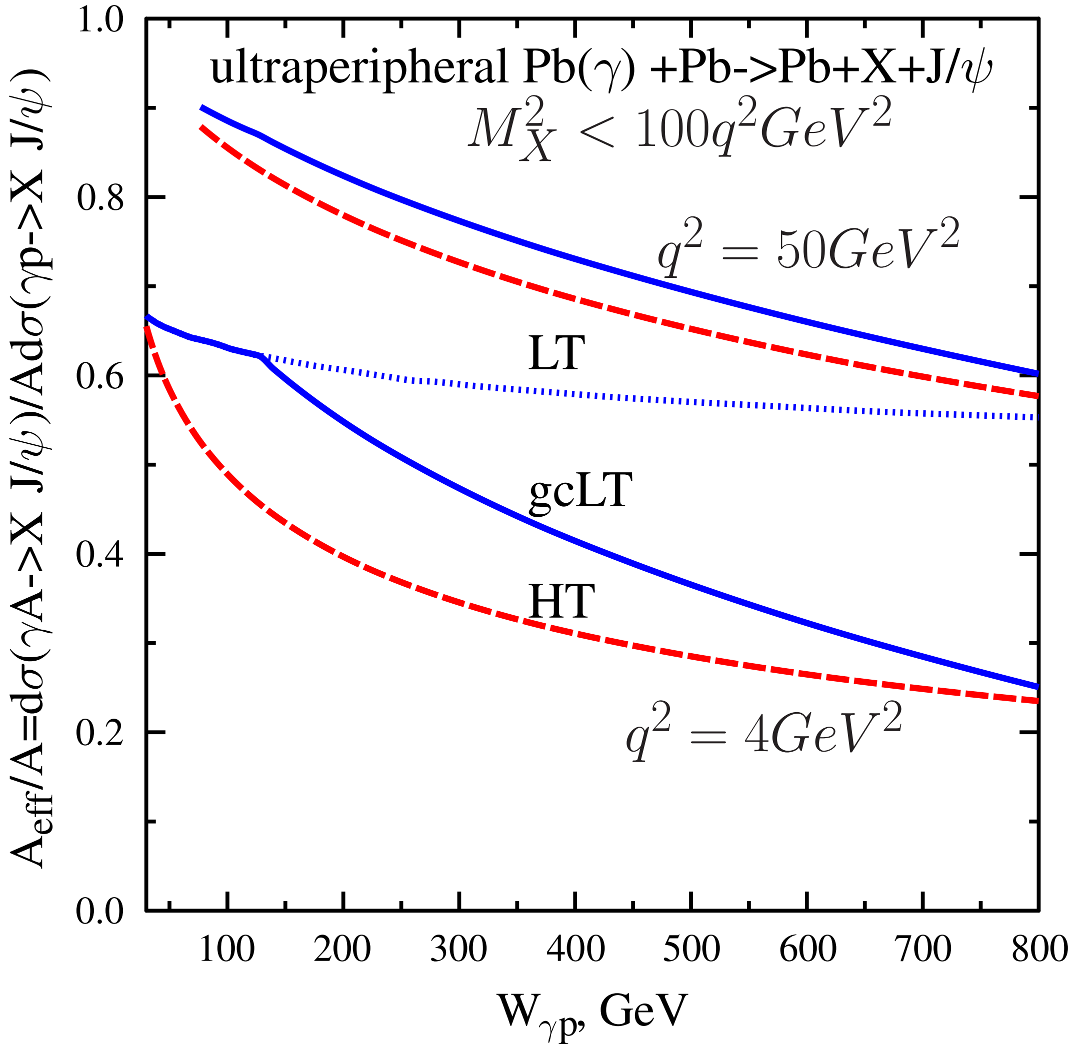
Qualitative Predictions:

- A_{eff}/A should increase with t at fixed W - smaller dipoles

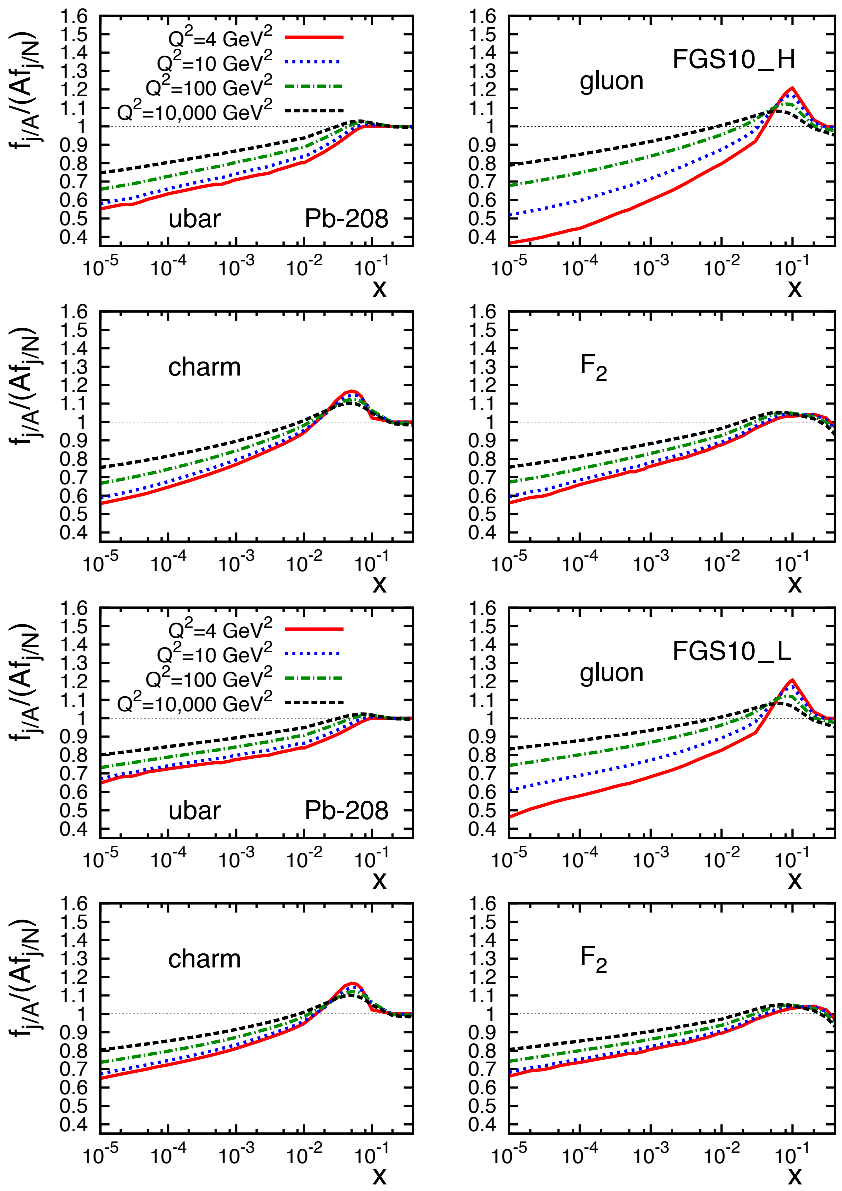
- A_{eff}/A should decrease with increase of W at fixed t - onset of black disk regime. Larger shadowing for small x (regulated by the rapidity covered by X-system)

$$P_A^{\rm gap} = \frac{1}{A}\int d^2b T(\vec{b})\left[1 - \sigma_{\rm dip-N}(x,d)\frac{g_A(x,Q^2,\vec{b})}{g_N(x,Q^2)}\right],$$

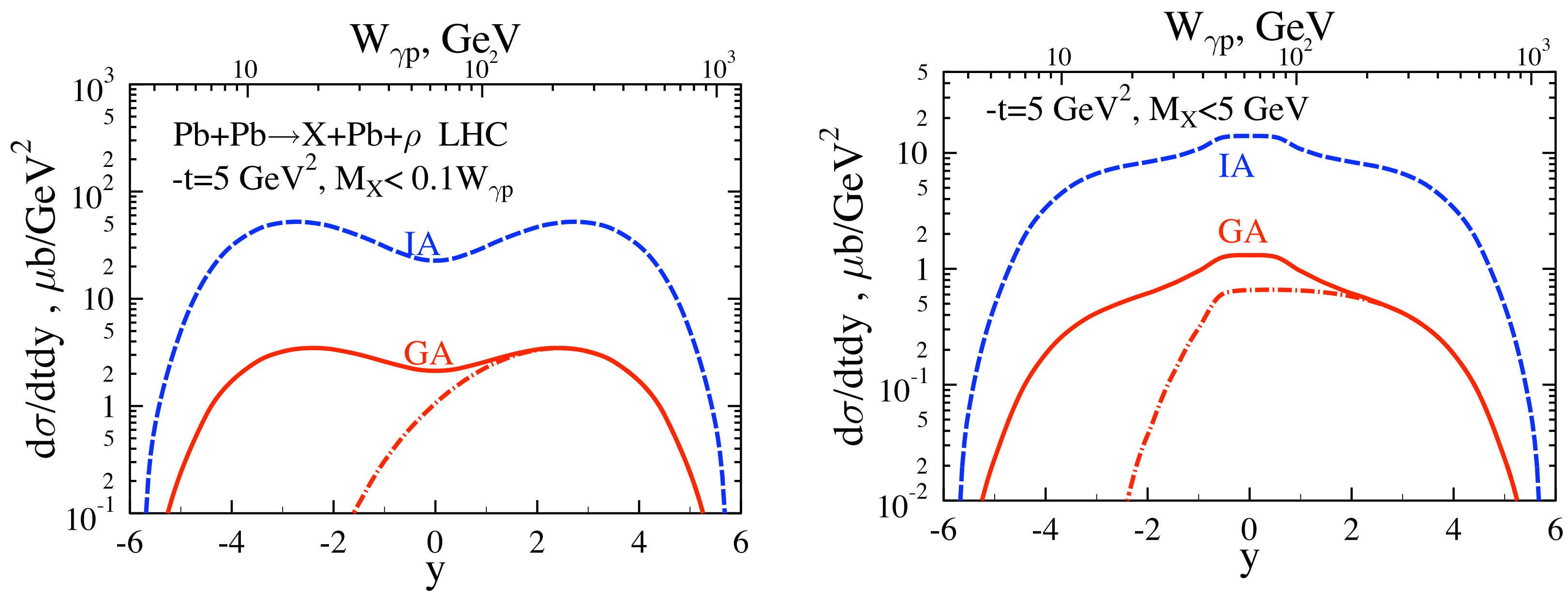
$$q^2 \equiv -t = Q^2$$



The rapidity survival probability for the J/ψ photoproduction as a function of W



Prediction for nuclear PDFs and structure functions for ^{208}Pb. The ratios R_j ($\bar{u}$ and c quarks and gluons) and R_{F_2} as functions of Bjorken x at $Q^2 = 4$, 10, 100 and 10,000 GeV^2. The four upper panels correspond to FGS10_H; the four lower panels correspond to FGS10_L.



Integrated over mass of produced system cross section of the nucleon dissociative ρ meson photoproduction at $-t=5$ GeV^2 in the ultraperipheral lead-lead collisions at LHC. The upper figure - the limit of the mass of produced system M_X is proportional to the photon-nucleon center of mass energy $M_X < 0.1 W_{\gamma p}$, in the right figure for central rapidities the limit of M_X is fixed by restriction $M_X < 5$GeV. Solid line - calculations with Glauber-Gribov screening, dashed line calculations in the leading twist approximation neglecting nuclear shadowing correction which is very small for discussed kinematics, dot-dashed line - one-side contribution when ρ meson is produced by photons emitted by only one nucleus: large positive rapidities correspond to vector mesons produced by high energy photons. The counting rate can be estimated using expected luminosity for PbPb collisions $L=10^{-3}$ μb^{-1} sec^{-1}.

Feasible to reach $W_{\gamma N}$= 1 TeV - where BDR may set in for dipole sizes 0.15 - 0.2 fm - comparable to what one can do at LHeC where precision would be better, dependence on photon virtuality can be studied, etc

Conclusions

Large t semiexclusive rapidity gap processes represent one of the best if not the best tool for study of

Energy dependence of small dipole elastic scattering, testing one scale BFKL dynamics

Propagation of the small dipoles of different size through the nuclear media regulating the role of the leading twist shadowing, providing possibility to test onset of nonlinear (black disk ?) regime

First studies - UPC in PA & AA , detailed studies LHeC