Multiparton interactions of hadrons and photons with nuclei - revealing transverse structure of nuclei and strong gluon field dynamics

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MPI @LHC 08, Perugia, 27-31 Oct.

Outline

- Main issues: correlations of partons in nuclei, onset of black regime of interaction with gluon fields - signals in parton and dipole propagation through nuclear media

- Novel phenomena:

  - Antishadowing in MPI off nuclei

  - Vector meson production in large t photoproduction (AA collisions) with rapidity gaps - propagation of small dipoles through the nucleus

  - *Fractional energy losses in parton propagation through strong gluon fields*

QCD factorization theorems for exclusive processes involving scattering or production of hadrons:

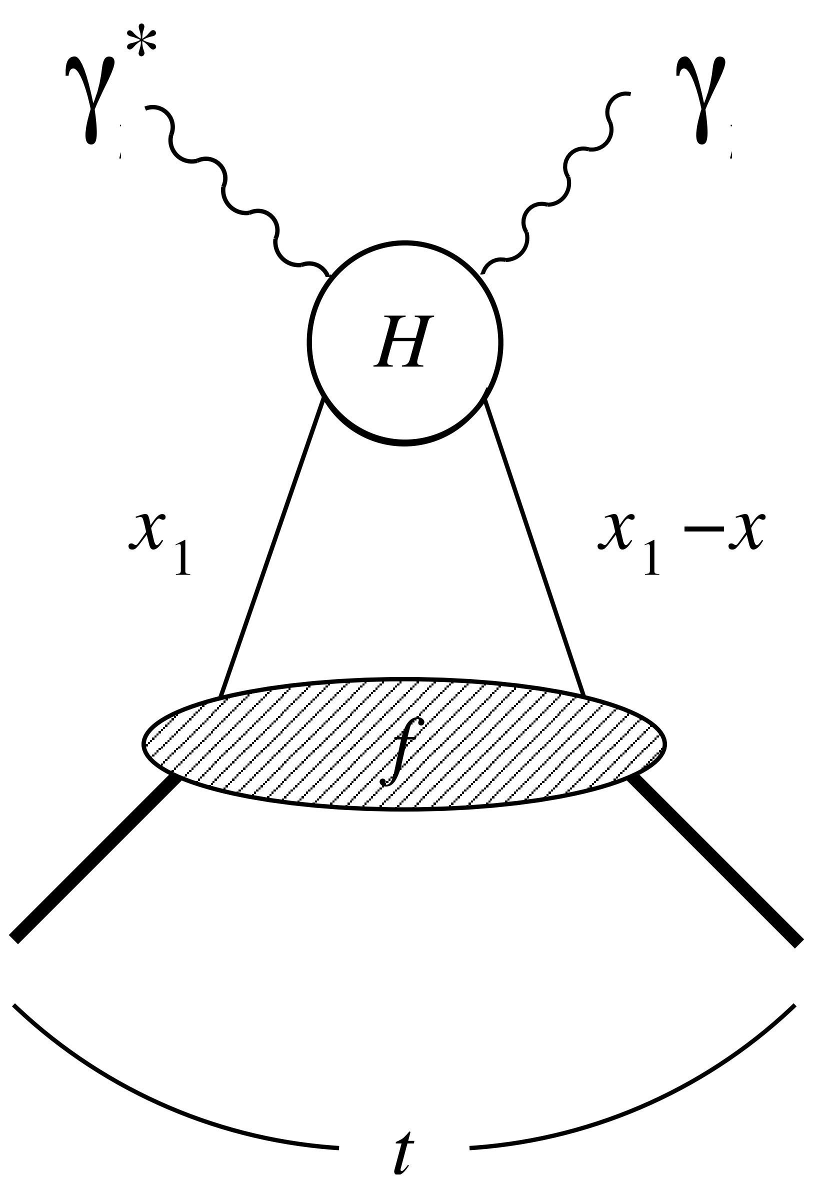
$\gamma^* + N \to \gamma + N(baryonic\, system)$ D.Muller 94 et al, Radyushkin 96, Ji 96, Collins &Freund 98

$\pi + T(A,N) \to jet_1 + jet_2 + T(A,N)$ Frankfurt, Miller, MS 93 & 03

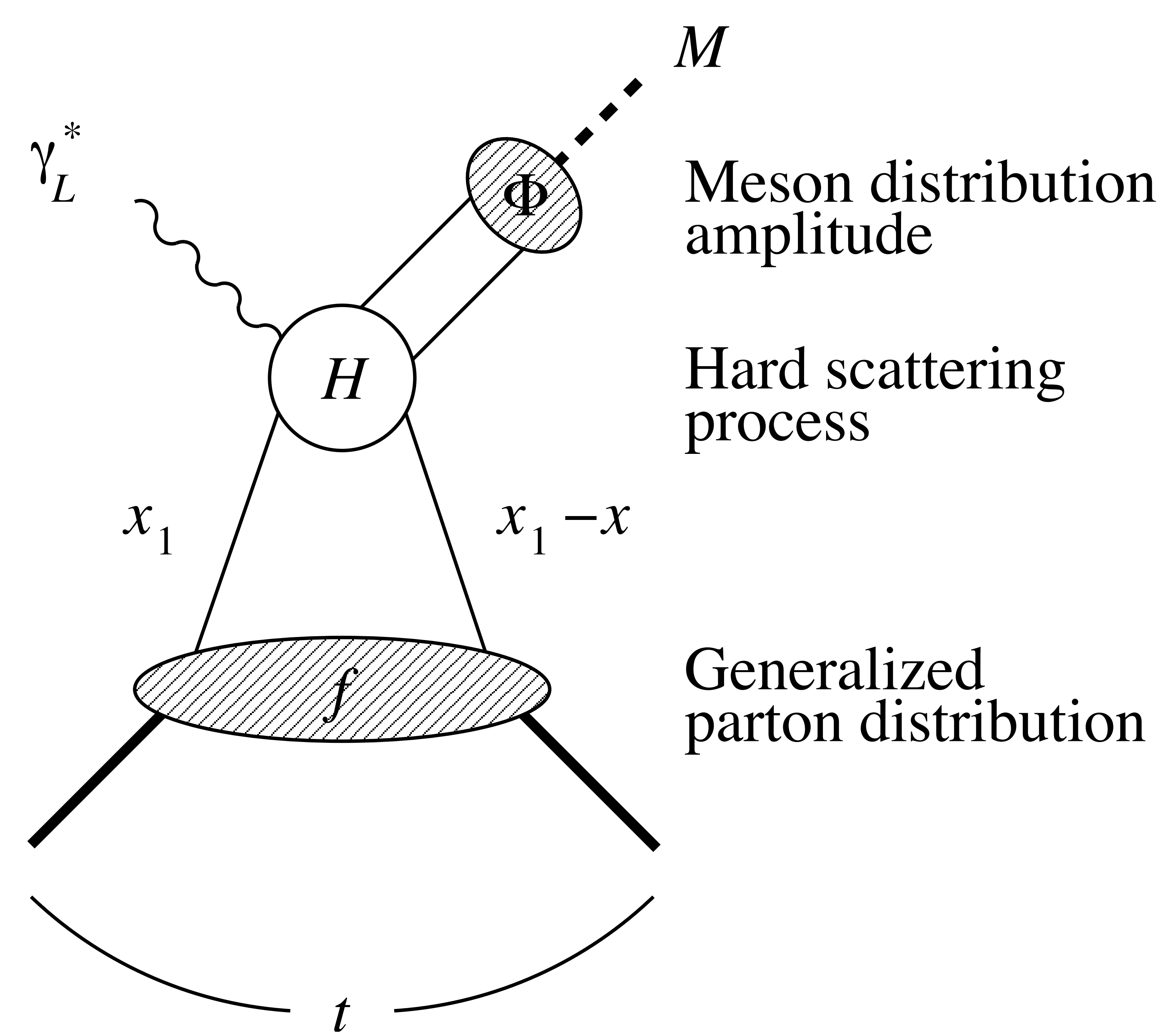
$\gamma_L^* + N \to "meson"(mesons) + N(baryonic\, system)$ Brodsky,Frankfurt, Gunion,Mueller, MS 94
- vector mesons, small x

Collins, Frankfurt, MS 97 - general case

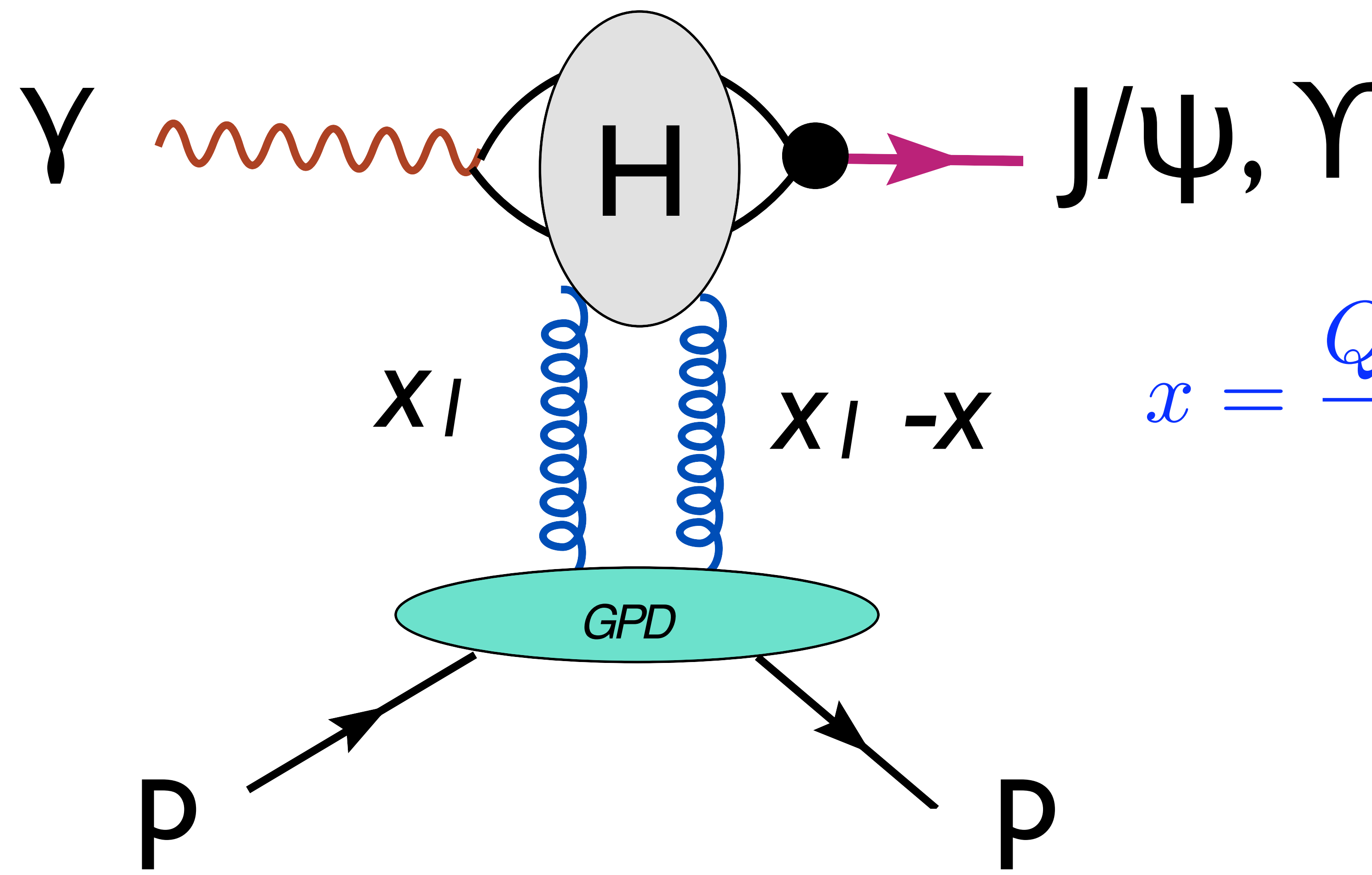
provide new effective tools for study of the 3D hadron structure, high energy color transparency and opacity and chiral dynamics



Baryo-baryonic



t-dependence only from GPD's



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

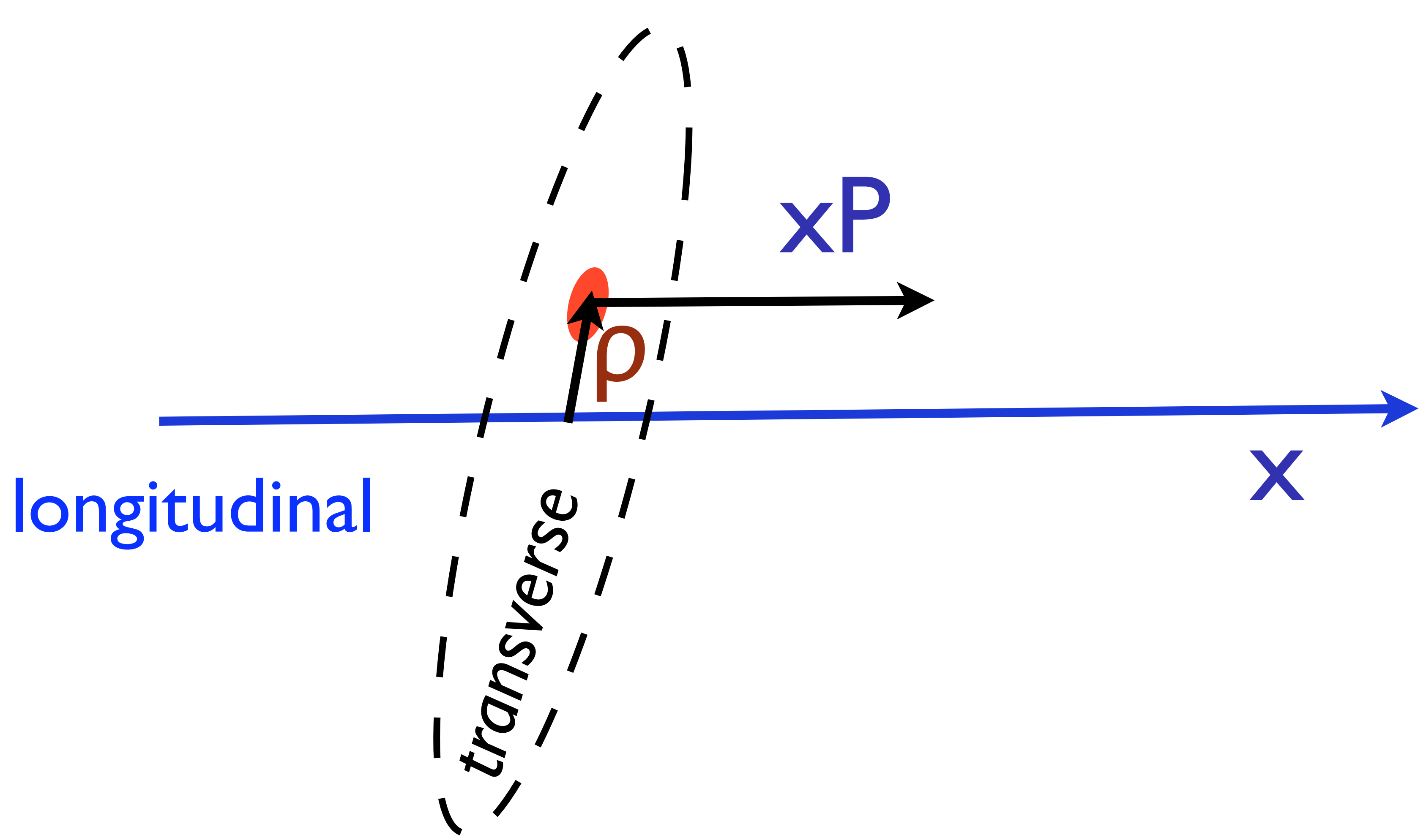
In LT limit $x_l - x << x_l$

however due to DGLAP evolution skewed GPD kinematics for large Q probes diagonal GPD at Q_0 scale

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

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

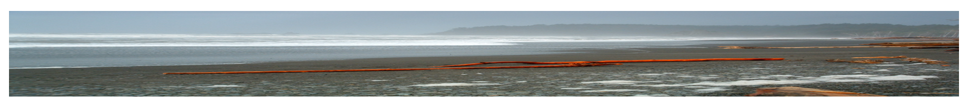
transverse spatial distribution of gluons



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

total gluon density

3 dimensional single parton distribution in nucleon



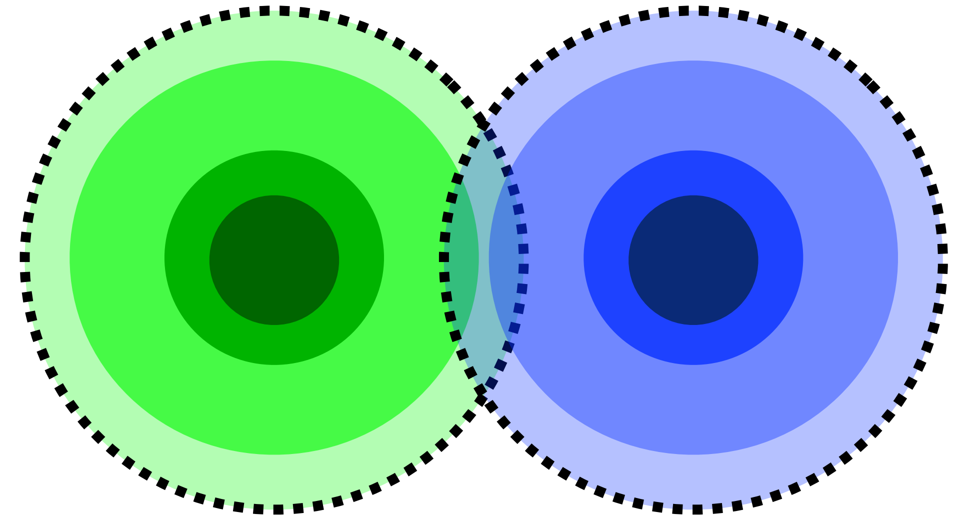
x

1D - parton distribution

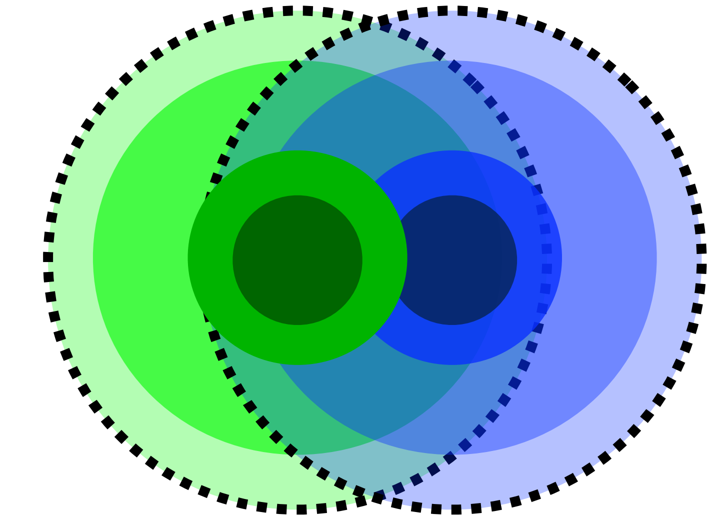
ρ- transverse coordinate

x

3D - generalized parton distribution

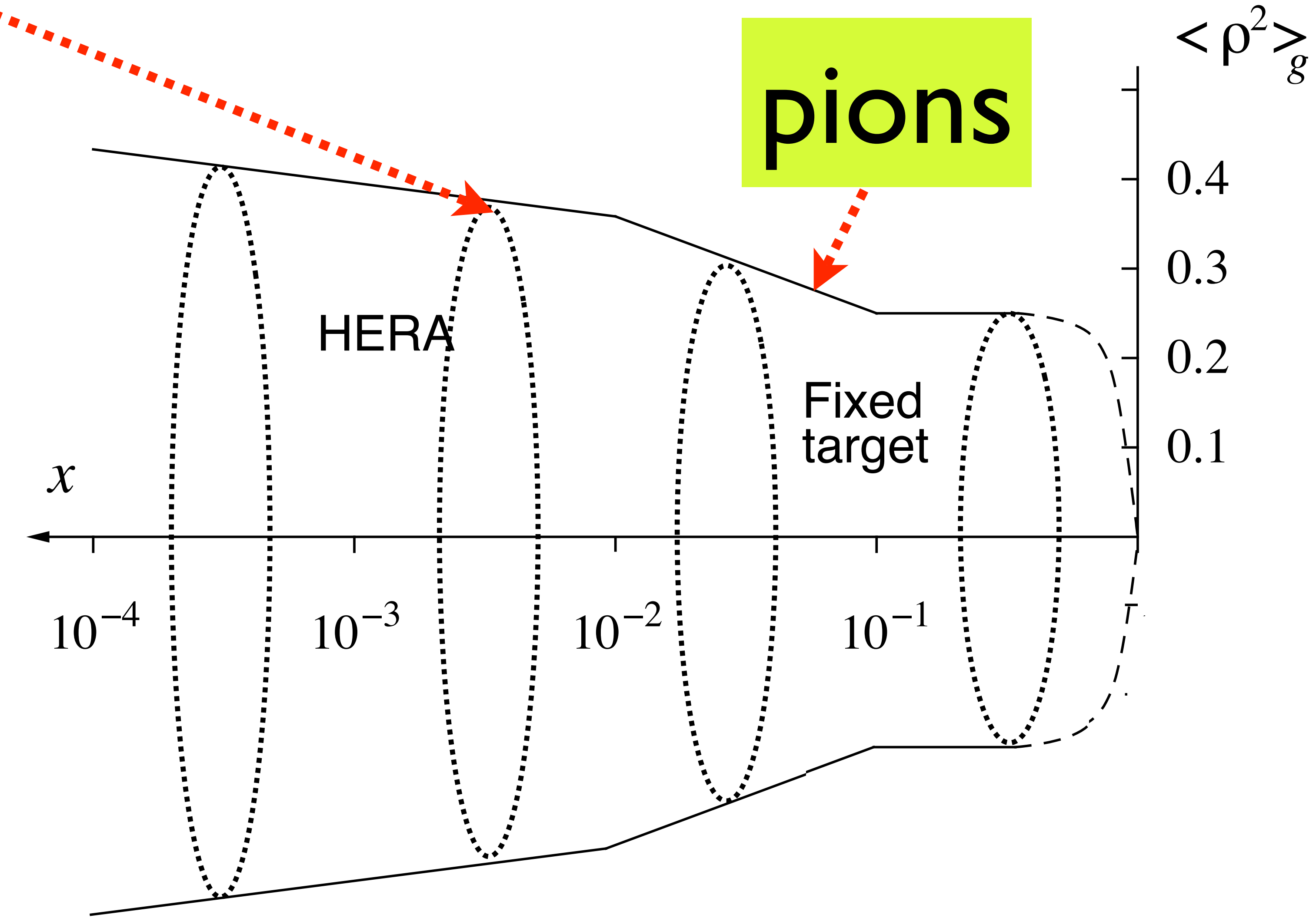


Peripheral
pp collisions



Central
pp collisions

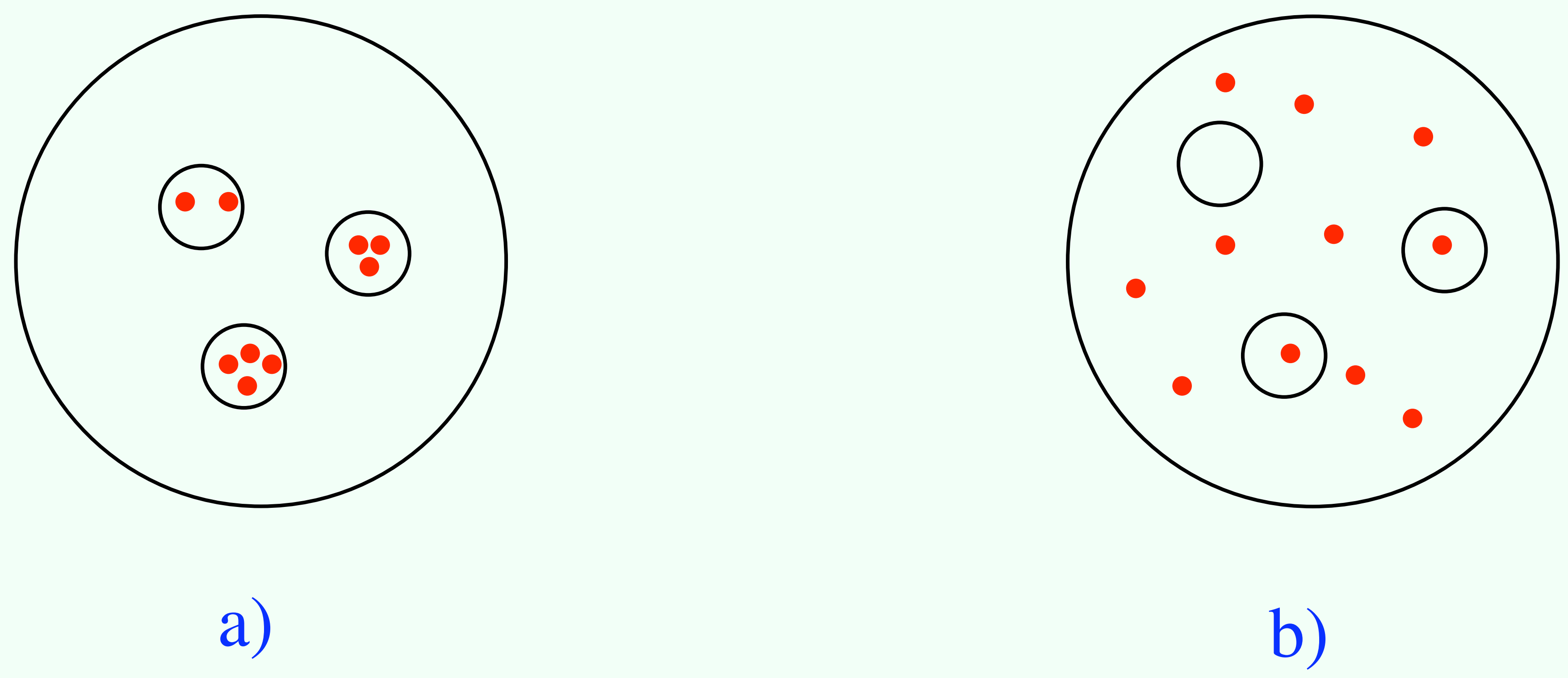
$$\langle \rho^2 \rangle_{e.m.}$$



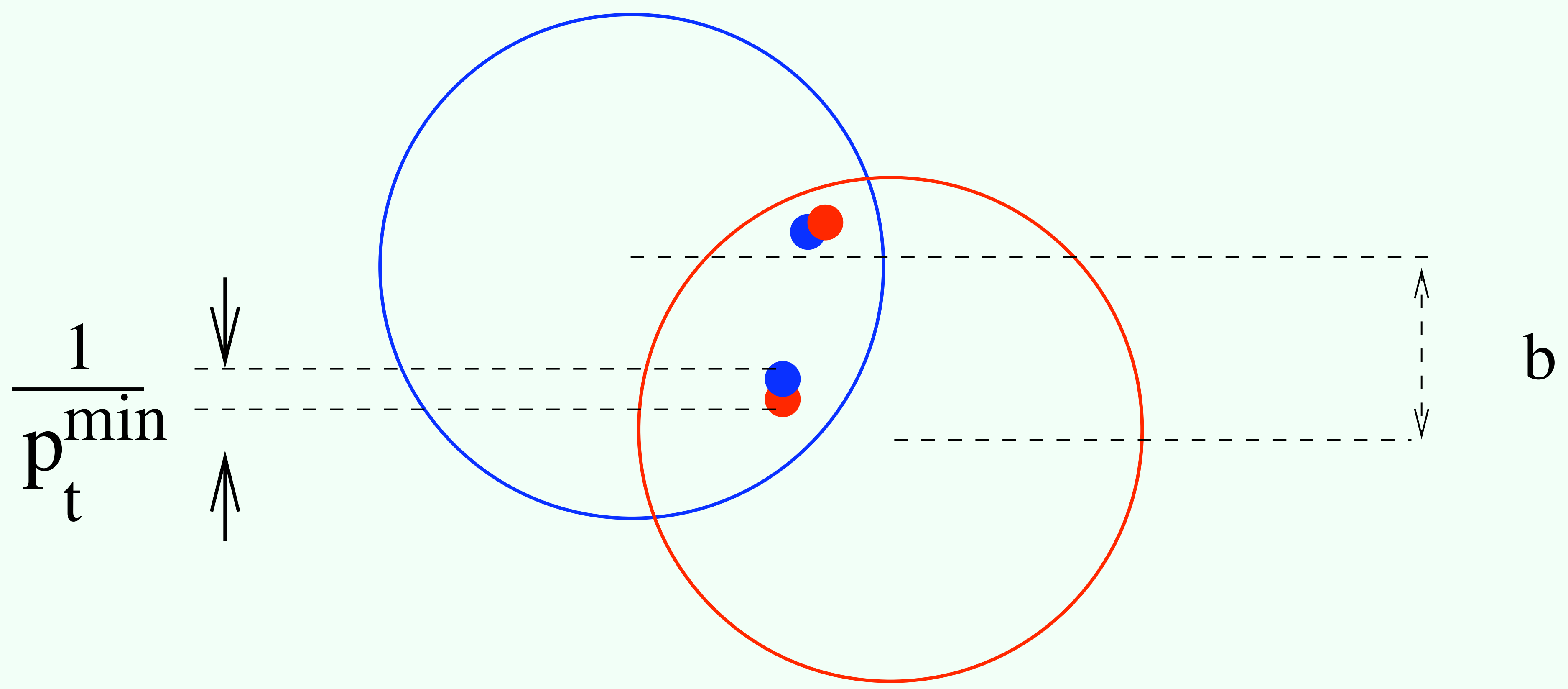
$$\langle \rho^2 \rangle_g = \frac{\partial}{\partial t} \frac{G(x.t)}{G(x,0)}$$

Interplay of hard and soft interactions in pp collisions, rate of multiple hard collisions is determined by the value of $<\rho^2_g>$ as compared to much larger radius of soft interactions. Note PYTHIA assumes $<\rho^2_g>, <\rho^2_q>$ a factor ~ 2 smaller than given by analysis of GPDs from J/ψ production- a way to mimic effects of transverse parton correlations

Multi-jet production - probe of parton correlations in nucleons



Where is the infinite number of primordial 'sea' partons in the infinite momentum state of the proton: inside the constituent quarks (a) or outside (b) ?



A view of double scattering in the transverse plane.

At high energies, two (three ...) pairs of partons can collide to produce multi-jet events which have distinctive kinematics from the process two partons → four partons.

Note - collisions at the points separated in b by ~ 0.5 fm
⇒ independent fragmentations

Evidence for transverse correlations of partons from MPI collisions

$$F_g(x,t) \equiv G(x,t)/G(x) = 1/(1-t/m_g(x)^2)$$

2 $$m_g^2(x=0.05) \sim 1GeV^2, m_g^2(x=0.001) \sim 0.6GeV^2.$$

$$F_g(x,\rho;Q^2) \equiv \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i(\Delta_\perp \rho)} F_g(x,t=-\Delta_\perp^2;Q^2)$$

$$F_g(x,\rho) = \frac{m_g^2}{2\pi} \left(\frac{m_g\rho}{2}\right) K_1(m_g\rho)$$

$$P_2(b) \equiv \int d^2\rho_1 \int d^2\rho_2\, \delta^{(2)}(\vec{b}-\vec{\rho}_1+\vec{\rho}_2)\, F_g(x_1,\rho_1)\, F_g(x_2,\rho_2) = \frac{m_g^2}{12\pi}\left(\frac{m_g b}{2}\right)^3 K_3(m_g b)$$

The rate of 4 jet production in MPI (Treleani talk) $\propto 1/\sigma_{\rm eff}$

$$\boxed{\sigma_{\rm eff} = \left[\int d^2b\, P_2^2(b)\right]^{-1} = \frac{28\pi}{m_g^2} \approx 34 \text{ mb}}$$

At least a factor of two too large as compared to CDF (probably closer to three - a flaw in the CDF procedure - Treleani's talk)

Possible sources of small σ_{eff} for CDF kinematics of x ~0.1-0.3 include:

☺ Small transverse area of the gluon field --accounts for 50 % of the enhancement $\sigma_{eff} \sim 35$ mb (F&S & Weiss 03)

☺ Constituent quarks - quark -gluon correlations (F&S&W)

If most of gluons at low Q~ 1GeV scale are in constituent quarks of radius

$r_q/r_N \sim 1/3$ found in the instanton liquid based chiral mean field model (Diakonov & Petrov)

the enhancement as compared to uncorrelated parton approximation is

$$\frac{8}{9} + \frac{1}{9}\frac{r_N^2}{r_q^2} \sim 2$$ (F&S&W)

Hence, combined these two effects are sufficient to explain CDF data for x>0.1.

<u>small x</u>

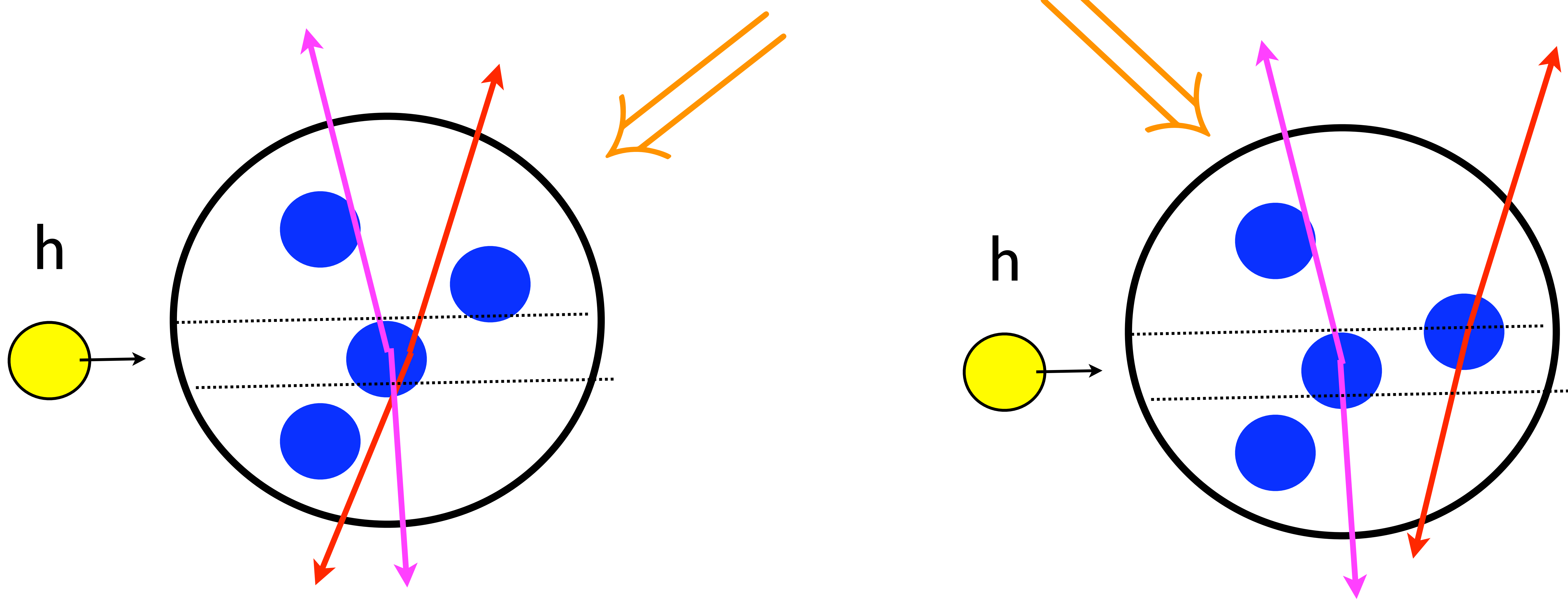
☺ Fluctuations of the transverse size of nucleons (Treleani, &F&S & W) only 20% effect

☺ QCD evolution leads to "Hot spots" in transverse plane (A.Mueller). One observes that such hot spots do enhance multijet production as well. However this effect is likely not to be relevant in the CDF kinematics as x's of colliding partons are relatively large (>0.01).

Multiparton interactions in Hadron - nucleus collisions

MS & Treleani 95 - PRL 2002

$$\sigma = \sigma_1 \cdot A + \sigma_2$$



$$R \equiv \frac{\sigma_2}{\sigma_1 \cdot A} \approx \frac{(A-1)}{A^2} \cdot \sigma_{eff} \int T^2(b)\, d^2b \approx 0.68 \cdot \left(\frac{A}{12}\right)^{0.39} \Big|_{A \geq 12, \sigma_{eff} \sim 14mb}$$

$$T(b) = \int_{-\infty}^{\infty} dz \rho_A(z,b), \int T(b) d^2b = A.$$

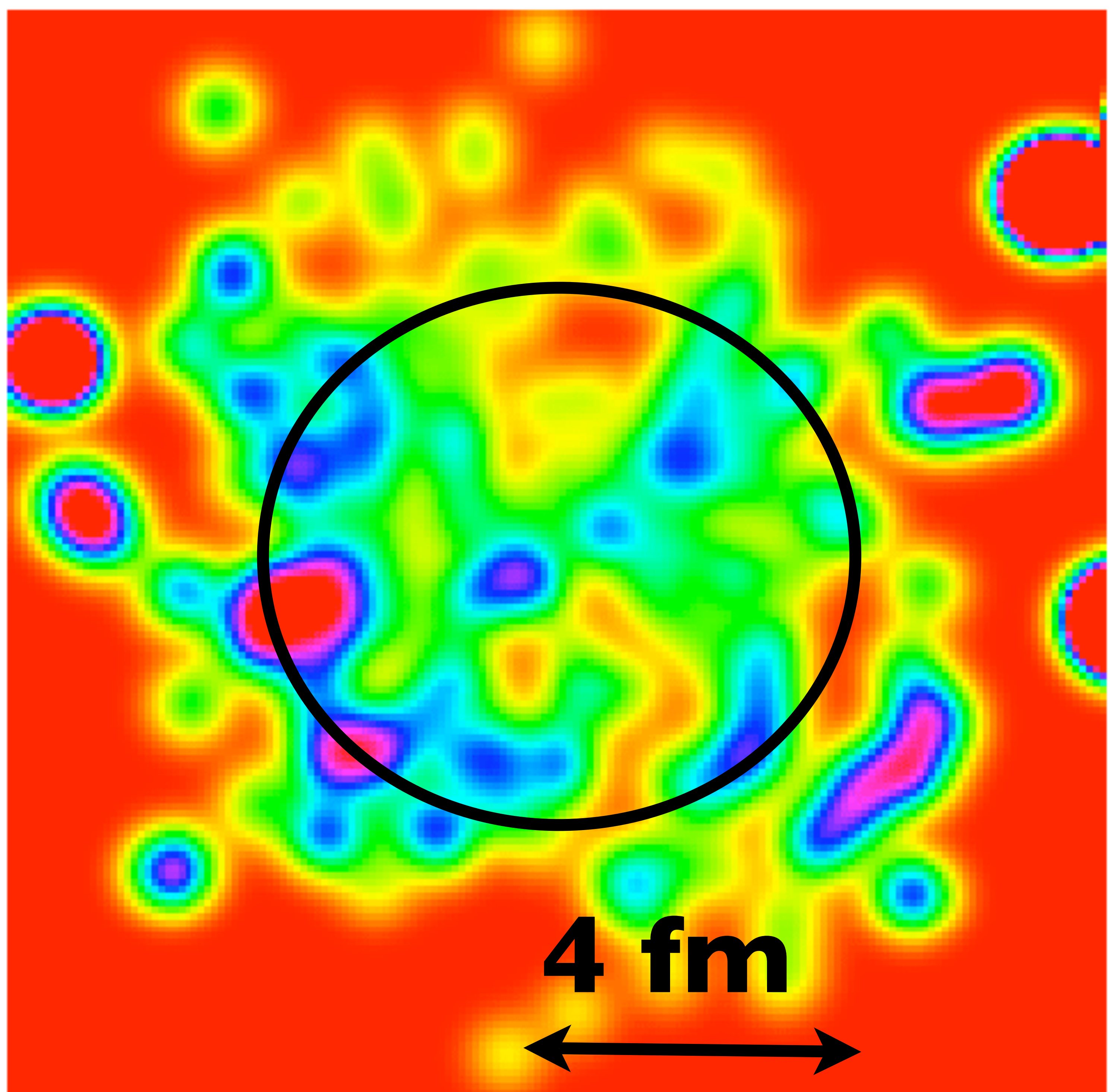
"Antishadowing effect": For A=200, and σ_{eff}=14 mb $\quad \dfrac{\sigma_{pA}}{\sigma_{pp}} \approx 4 \quad$ linear in σ_{eff} !!

Account of short-range correlations of nucleons/ finite A effects using MC (Alvioli et al):

Measurement of σ_2 allows to measure in a model independent way double parton distribution in nuclei $f(x_1,x_3)$. Especially interesting x's > 0.2 where correlation between partons should exist so that

$$f(x_1,x_3) \neq f(x_1)\, f(x_3)$$

The presented results are for $x_2,x_4 > 0.02$ where shadowing effects are negligible. Estimates of A-dependence were very recently improved using MC generator for nucleon configurations in nuclei which includes short-range correlations - M. Alvioli et al - decrease of R by 15% for A=16, and by 5% for A=208



yellow = 1
green = 2
cyan = 3
blue = 4
magenta = 5
red(top) = 6

Fluctuations of gluon density in lead on event by event basis

Measuring $f(x_1,x_3)$ from pA

⇓

model independent determination of σ_{eff}

Interesting questions - associated hadron production in central region, nuclear fragmentation.

Four jet events are due to very central collisions.

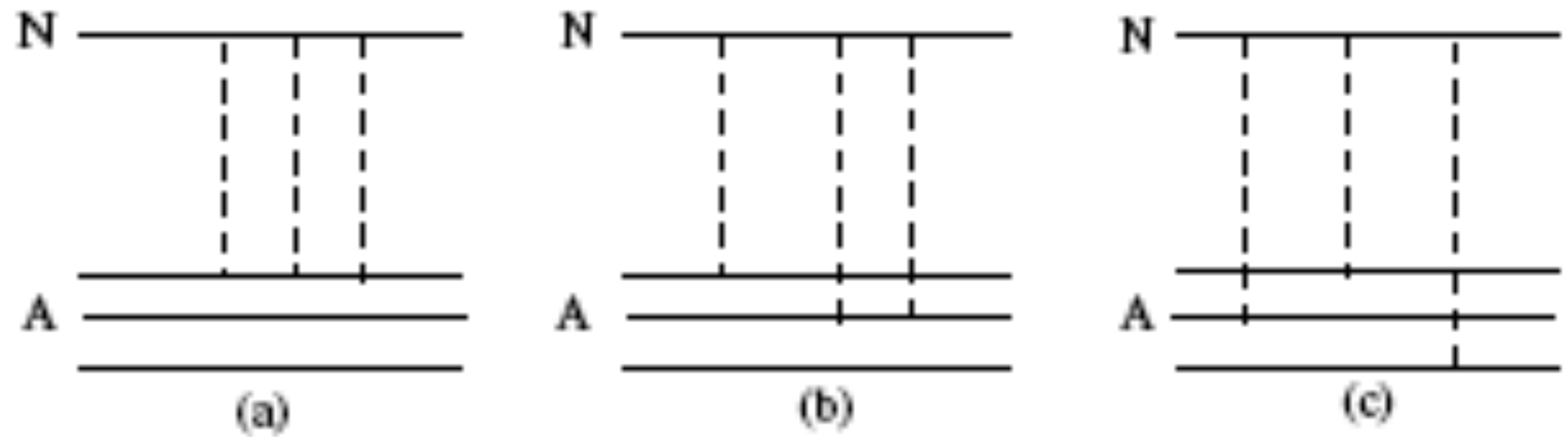
Moderate x's - increase of central multiplicity, ZDC activity, etc

New physics possible for $x_1+x_3 > 0.5$ - do we start to select configurations with few gluons and also of probably of small size?

$\Rightarrow$ Drastic change in the structure of the final state - drop in activity in $y\sim 0$, in ZDC,...

Nucleus serves as an analyzer of hadron structure

Six jet production



$$
\begin{aligned}
\sigma_1^T &= \sigma_T \int d^2 B T(B) = A\sigma_T \\
\sigma_2^T &= \frac{1}{3!}\int G(x_1,x_2,x_3)\hat{\sigma}(x_1,x_1')\hat{\sigma}(x_2,x_2')\hat{\sigma}(x_3,x_3')dx_1dx_1'dx_2dx_2'dx_3dx_3' \\
&\times\Big[G(x_1',x_2')G(x_3') + G(x_2',x_3')G(x_1') + G(x_1',x_3')G(x_2')\Big] \\
&\times \int d^2 B T^2(B)\frac{1}{\sigma'_{eff}} \\
\sigma_3^T &= \frac{1}{3!}\int G(x_1,x_2,x_3)\hat{\sigma}(x_1,x_1')G(x_1')G(x_2')G(x_3') \\
&\times\hat{\sigma}(x_2,x_2')\hat{\sigma}(x_3,x_3')dx_1dx_1'dx_2dx_2'dx_3dx_3'\int d^2 B T^3(B),
\end{aligned}
$$

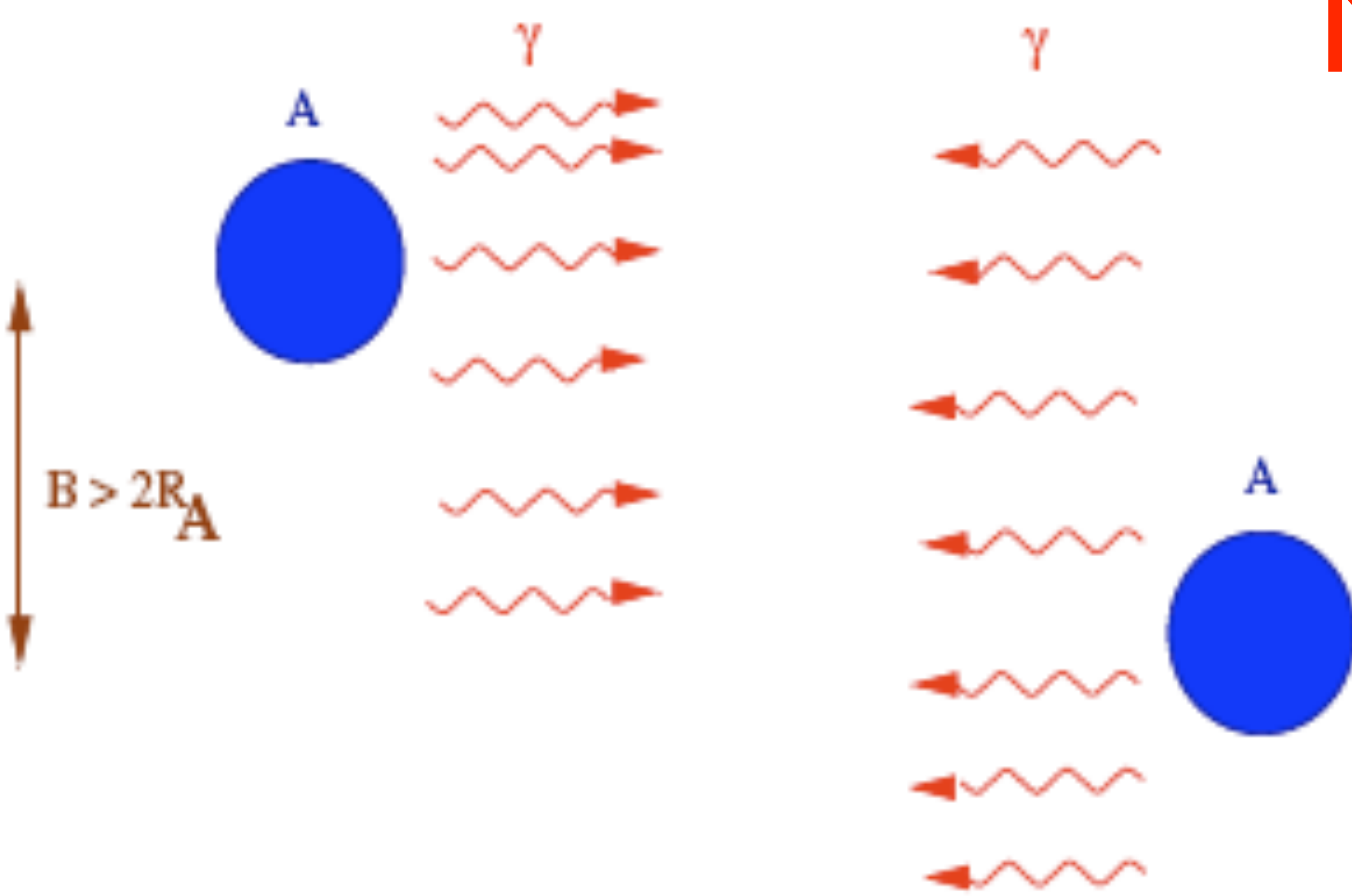
Estimate using assumption $\sigma_1 \propto \sigma_{eff}^{-2}$

$$\sigma_1 : \sigma_2 : \sigma_3 = 1 : 1.45\cdot(A/10)^{0.5} : 0.25(A/10) \rightarrow 1 : 6.5 : 5$$

A factor of 12 antishadowing

Do we have to wait 8 (?) years for pA at the LHC?

NO !!!



Ultraperipheral Nucleus–Nucleus Collision

Physics Reports 458(2008) 1 -171

The physics of ultraperipheral collisions at the LHC

A.J. Baltz[a], G. Baur[b], D. d'Enterria[c], L. Frankfurt[d], F. Gelis[e], V. Guzey[f,w], K. Hencken[g,h,1], Yu. Kharlov[i], M. Klasen[j], S.R. Klein[k], V. Nikulin[l], J. Nystrand[m], I.A. Pshenichnov[n,o], S. Sadovsky[i], E. Scapparone[p], J. Seger[q], M. Strikman[r,*,1], M. Tverskoy[l], R. Vogt[k,s,t,1], S.N. White[a], U.A. Wiedemann[u], P. Yepes[v,1], M. Zhalov[l]

$W_{\gamma N} \leq 1\,\mathrm{TeV}$ are feasible

Measure 4 jets in γA $\Rightarrow$

- measure multiparton photon wave function without need to model nucleon wave function

- determining σ_{eff} for $\gamma\ p$(*should be smaller than for pp*) interplay of soft and har components in the photon way function, gap survival.... rich physics

I will focus on related issue

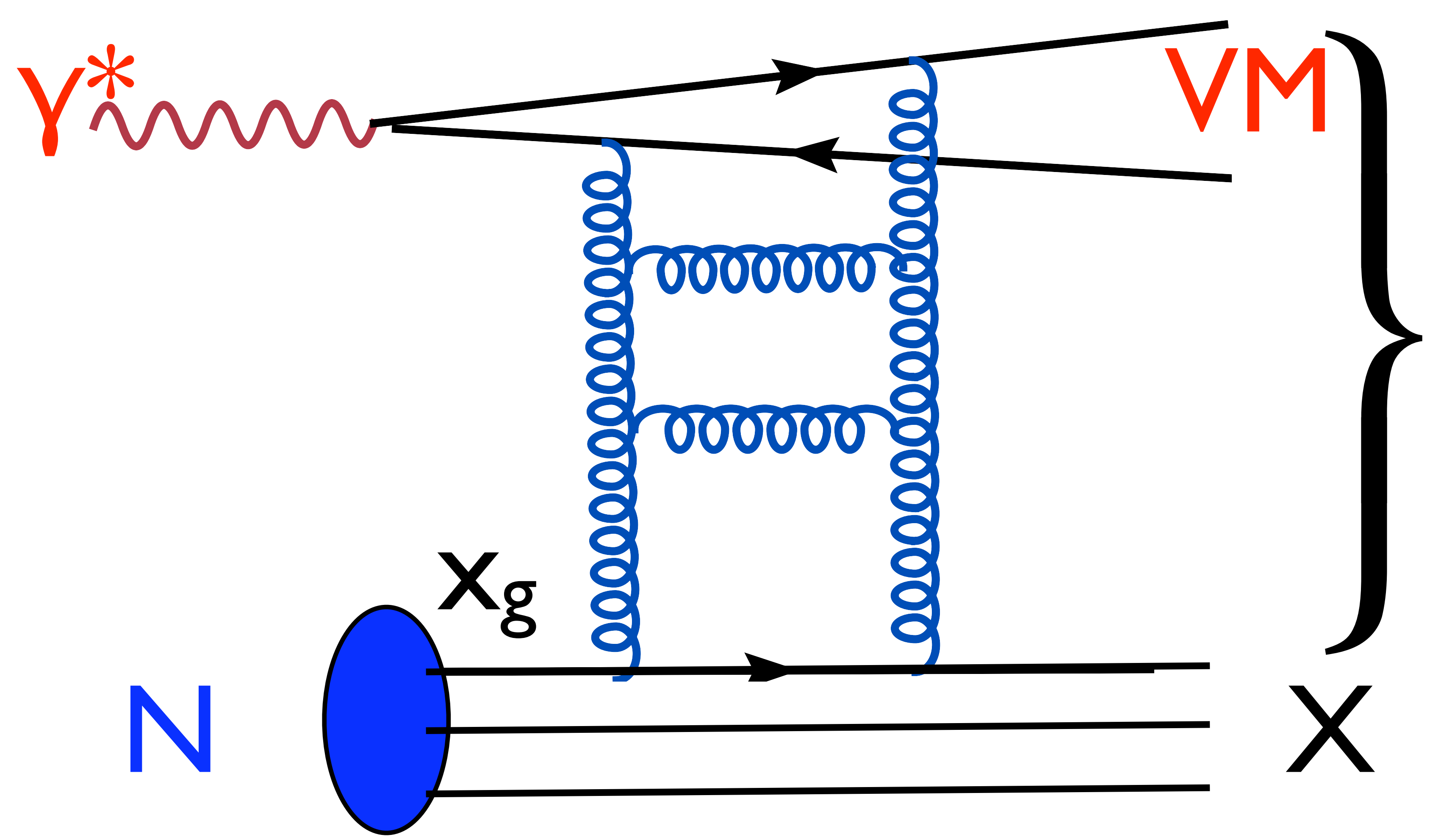
Study of energy dependence of inelastic dipole - nucleus interactions in large

$t=(p_\gamma-p_V)^2$ process $(\gamma, \gamma^*)A \to VM + gap + X$

Study of energy dependence of inelastic dipole - nucleus interactions in large $q^2=-(p_\gamma-p_V)^2$ process $(\gamma,\gamma^*)A \to VM + gap + X$

Fast track to observing the black disk regime of interaction with strong gluon fields

elementary reaction scattering of projectile off a parton of the target at large t belongs to a class of reactions with hard white exchange in t-channel



FS 89, FS95, Mueller & Tung 91

Forshaw & Ryskin 95

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

$$\tilde{x} = \frac{q^2}{(M_X^2 + q^2)}$$

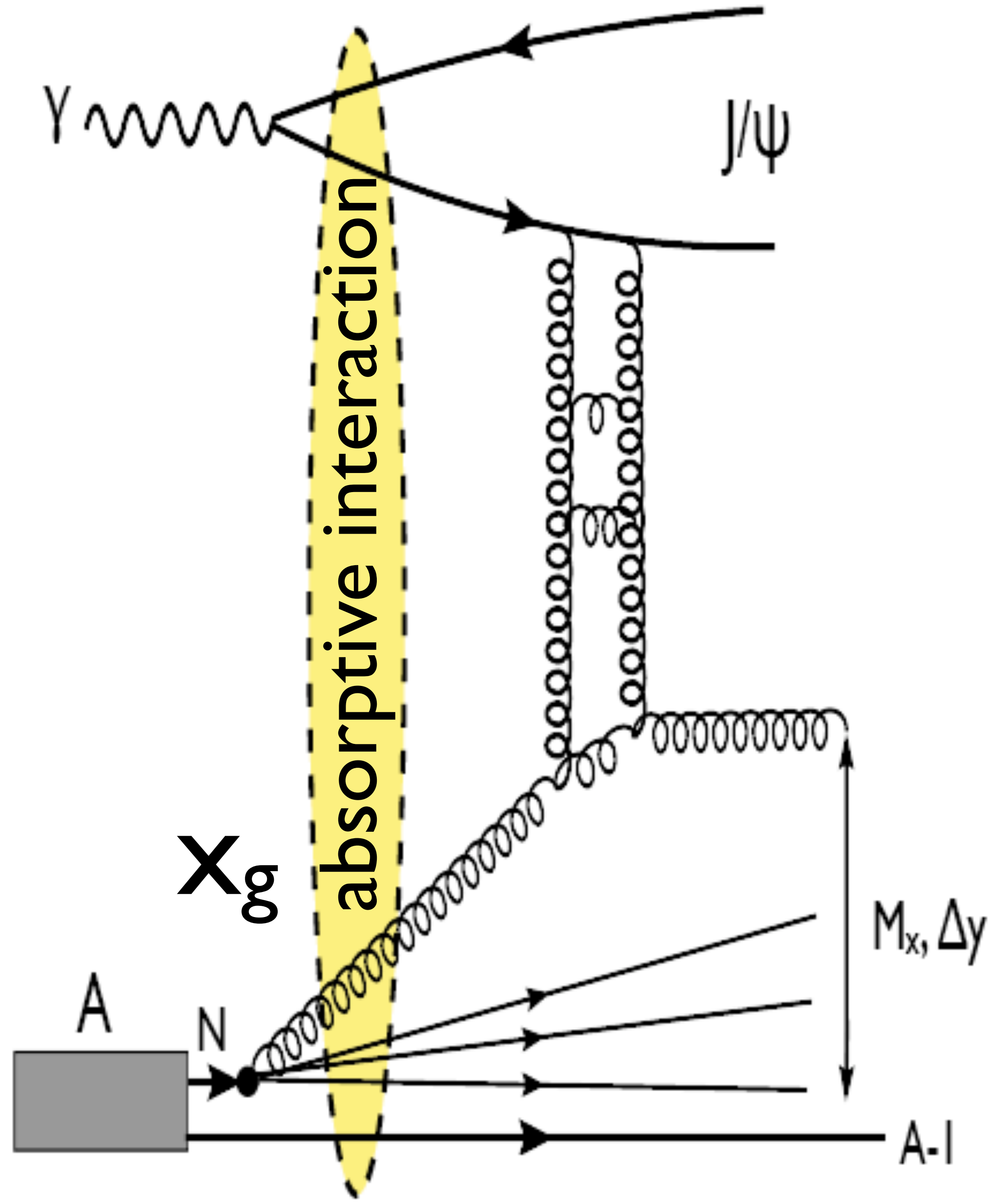
Probing BFKL like dynamics at large t - large t ensures large virtualities in the ladder and suppression of diffusion to soft physics

best way to measure of the strength of inelastic interactions of small dipole in the processes initiated by elastic small dipole - parton scattering at $[s']^{1/2}$=20 GeV - 100 GeV in pA at LHC

$\gamma + A \rightarrow \rho(J/\psi) + gap + X$

Ultra Peripheral Collisions [LHC]

FS & Zhalov 06 & 08



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

Experimental advantages as compared to coherent J/ψ

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

Consider $\tilde{x} > x_{shad} \sim 0.01$ where parton densities are linear in A

Large t selects trigger selects scattering at central impact parameters if there is no absorption.

Process involves propagation through nuclear media of $c\bar{c}$ dipole of size

$$d^2(q^2)/d^2(0) \approx (1 + q^2/4m_c^2)^{-1}$$

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

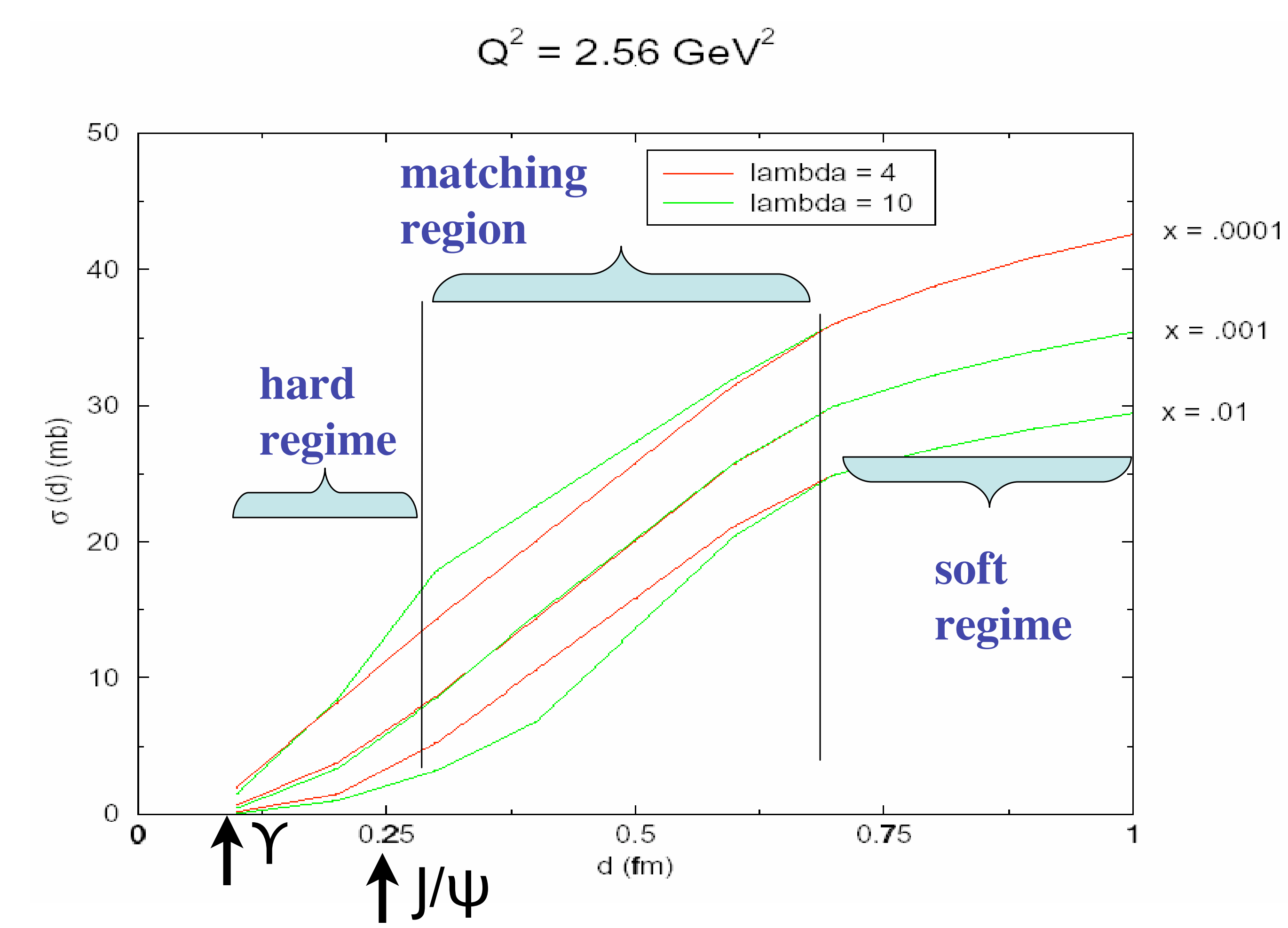
Probability not to interact inelastically is expressed through profile function Γ(b) as $|1-\Gamma(b)|^2$

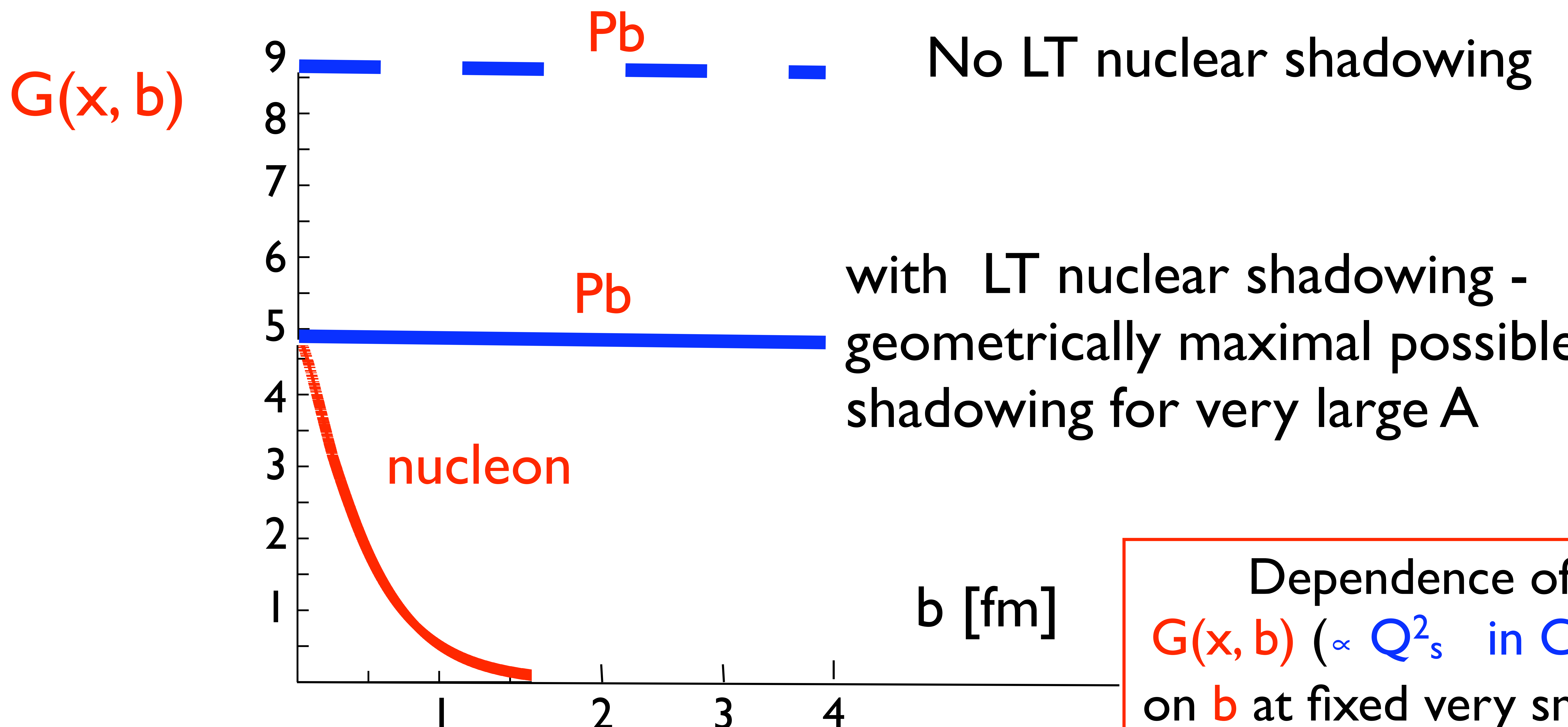
Hence $$P_A^{gap} \equiv A_{eff}/A = \int d^2b\, T(\vec{b}) \left|1-\Gamma(\vec{b})\right|^2 /A.$$

Estimate of Γ(b)   In pQCD in the LT

$$\sigma_{dip-T}(x,d) = \frac{\pi^2}{3} F^2 d^2 \alpha_s(\lambda/d^2) x G_T(x,\lambda/d^2)$$

where F^2= 3 (4/3) is the Casimir operator for the two-gluon $q\bar{q}$ dipole, and λ ~ 4 ÷ 9.

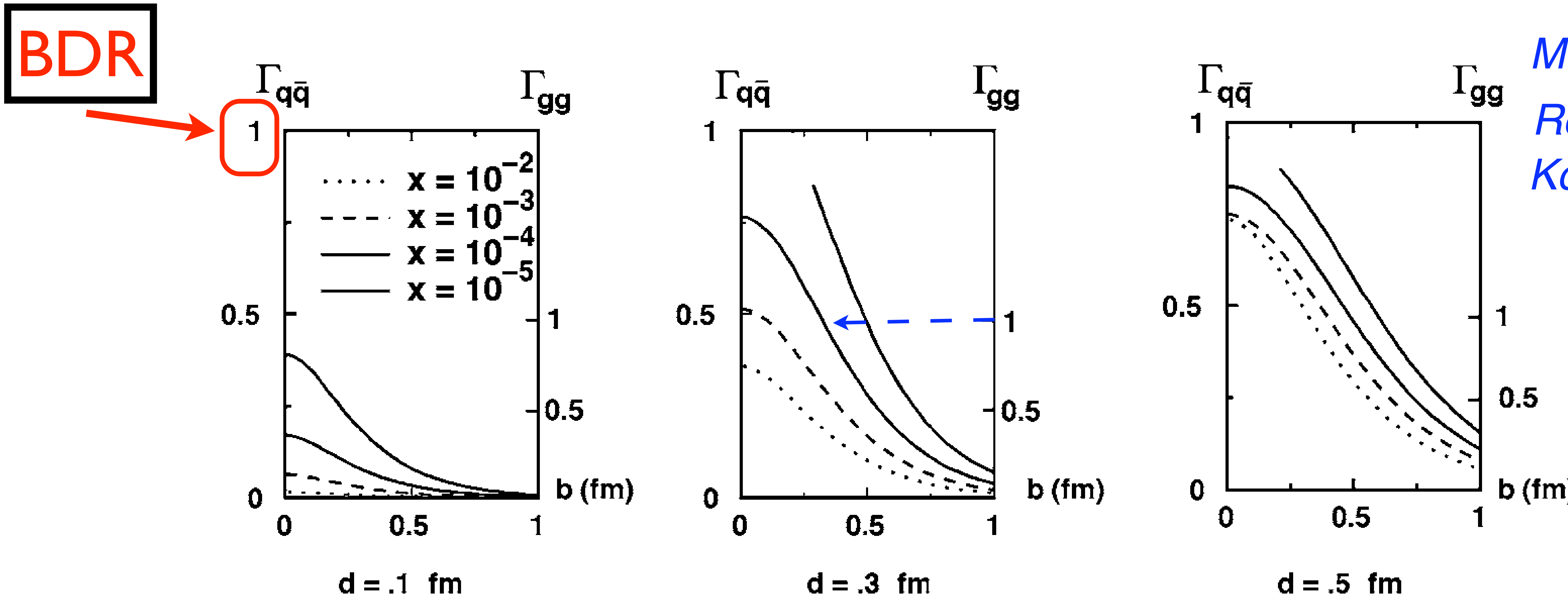




Dependence of $G(x, b)$ ($\propto Q^2_s$ in CGC) on b at fixed very small x

In the limit of $x > 10^{-3}$, and sufficiently large Q, $G_A(x,b)$ unambiguously calculable through diffractive pdfs (MS & Frankfurt 89)

Several analyses of HERA data using dipole model and information on gluon GPDs to determine how close is HERA to the regime of maximal strength of interaction - black disk regime (BDR) - with similar conclusions



Munier, Stasto, Mueller

Rogers et al

Kowalski, Motyka, Watt,

Plot from Rogers et al

$Q^2 \approx 40$ GeV^2 $\quad$ $Q^2 \approx 4$ GeV^2 $\quad$ $Q^2 \approx 1$ GeV^2

HERA just touched BDR regime for quarks at $Q^2 \sim 1$ GeV^2 and for gluons for $Q^2 \sim 4$ GeV^2 (consistent with large probability of gluon induced diffraction at HERA). If $G_A(b) \sim G_N(0)$ - expect large suppression for $x < 10^{-3} \div 10^{-4}$

Model I Eikonal - higher twist model

$$\Gamma(\vec{b}) = 1 - \exp(-\sigma_{dip-N} T(\vec{b})/2)$$

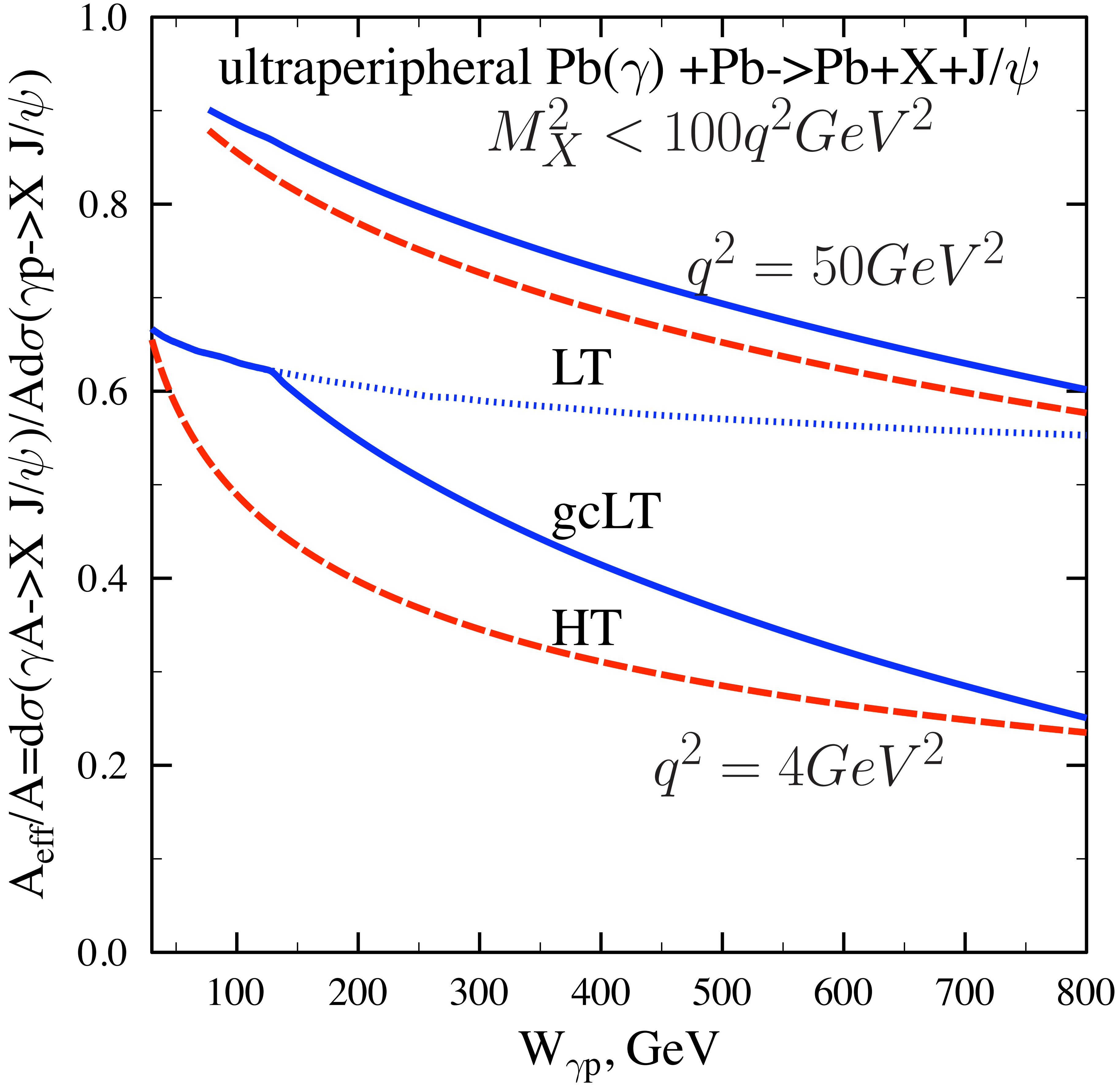
suppression factor $P_A^{gap} = \int d^2 b T(\vec{b}) \exp(-\sigma_{dip-N} T(\vec{b}))$

Model II Leading twist model

$$1 - \left|1 - \Gamma(\vec{b})\right|^2 = \sigma_{dip-N}\, g_A(x, Q^2, \vec{b})/g_N(x, Q^2)$$

where $g_A(x,Q^2,b)$ is the gluon density of the nucleus in the impact parameter space

- $\int g_A(x,Q^2,b)\, d^2b = g_A(x,Q^2)$

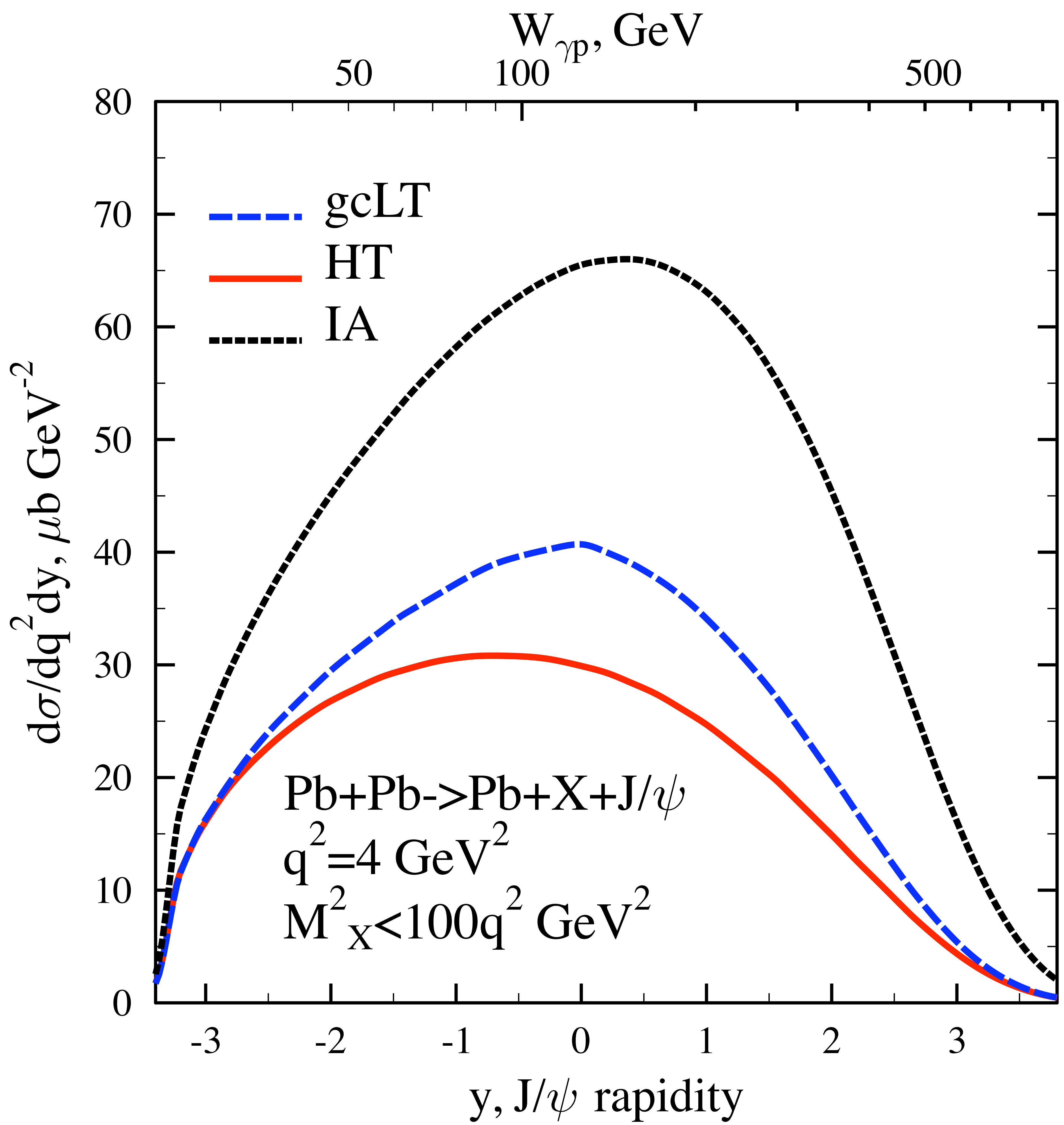


A-dependence is expected to be strong. If proper subtraction of surface is done one can look for onset of black regime where $P_A^{gap} \propto A^{-2/3}$

Note- our analysis of suppression of leading π^0 in DAu at RHIC - partons loose fraction of energy due proximity of black disk regime.

Similar effective size of dipole, x_{eff} ~ few 10^{-4} - suppression by a factor of 3

➠ The models I & II likely underestimate the effect



Contribution
from one of the nucleus

Rates are high enough to reach $W_{\gamma N}$ ~ 500 GeV in the first Pb-Pb run

Conclusions

Progress in the studies of the transverse structure of nucleon at HERA combination with MPI leads to unambigous conclusion of presence of transverse correlations between partons.

Use of nuclei in MPI allows to separate longitudinal and transverse correlations; promising direction for near future- MPI in UPC at LHC - photon - lead collisions; can be done at RHIC if acceptance of detectors is increased.

The fastest way to establish how black are interactions of small dipoles - rapidity gap events with large t in UPC heavy ion collisions

UPC will also allow a sensitive test of the finite fractional energy losses in proximity of black regime