Rapidity gaps in proton and photon induced processes at LHC

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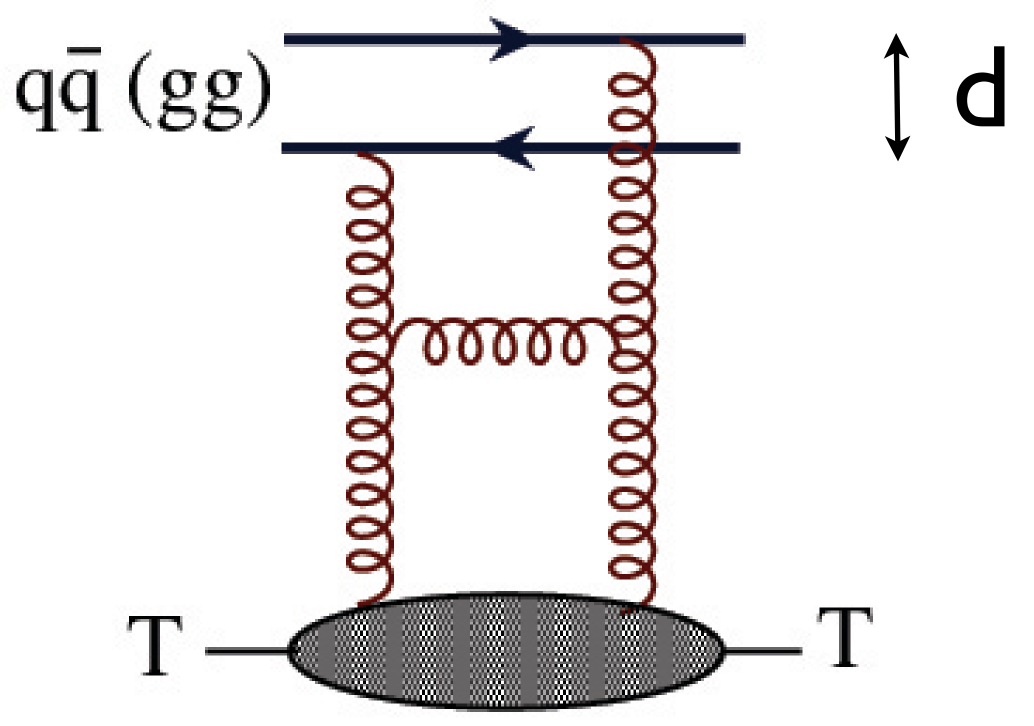
HERA-LHC workshop, March14,07

Introduction: How strong is the interaction of small dipoles?

Consider first "small dipole - hadron" cross section



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

Baym et al 93

F^2 Casimir operator of color SU(3)

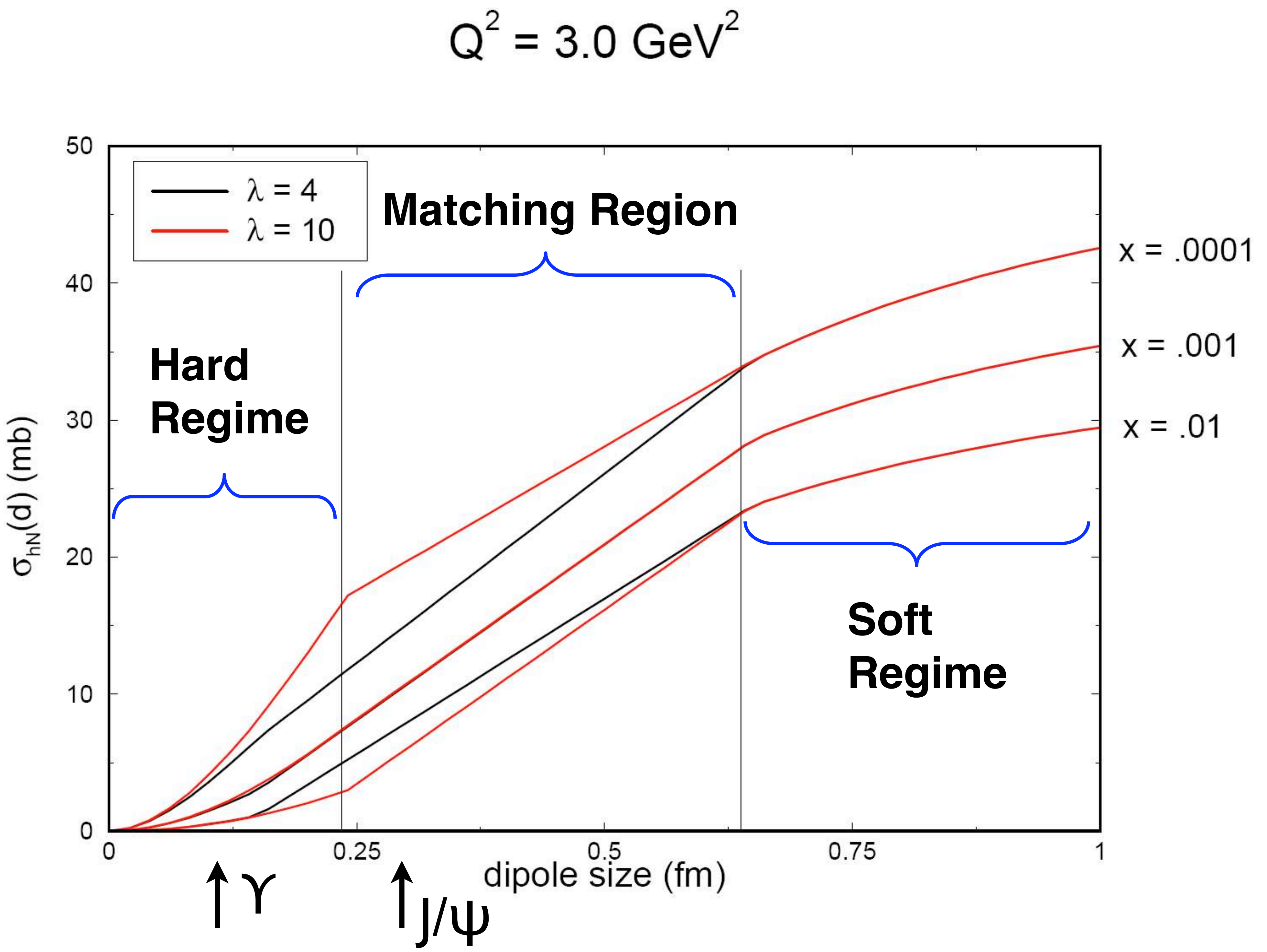
F^2 (quark) =4/3 F^2 (gluon)=3

Comment: This simple picture is valid only in LO. NLO would require introducing mixing of different components. Also, in more accurate expression there is an integral over x, and and extra term due to quark exchanges

New high energy QCD regime: regime of complete absorption for small α_s: limit - fixed Q & large energies -black disk regime (BDR)

Evidence for proximity to BDR at HERA

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



Frankfurt et al 2000-2001

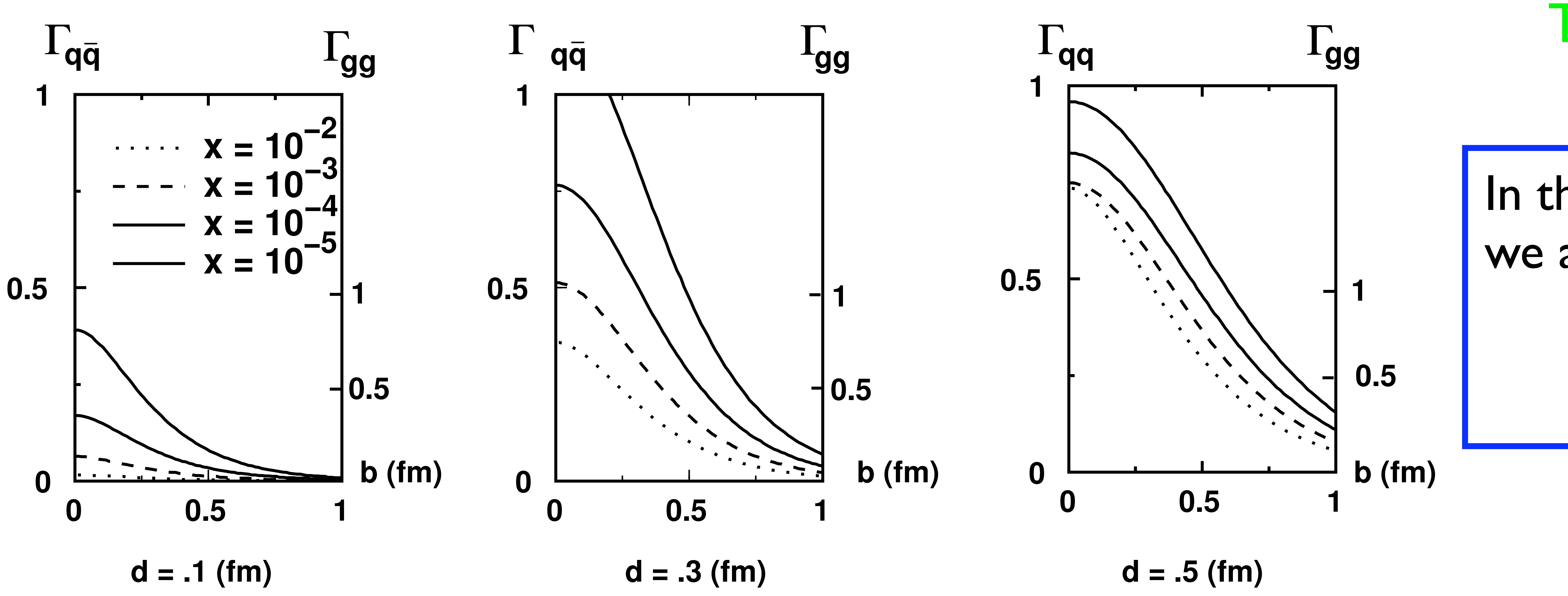
Provided a reasonable prediction for σ_L

Combine with: analysis of exclusive hard processes
(t-dependence of the dipole - nucleon scattering)

determine impact factors for elastic $q\bar{q} - N\, scattering$

$$\Gamma_h(s,b) = \frac{1}{2is}\frac{1}{(2\pi)^2}\int d^2\vec{q}\, e^{i\vec{q}\vec{b}} A_{hN}(s,t)$$

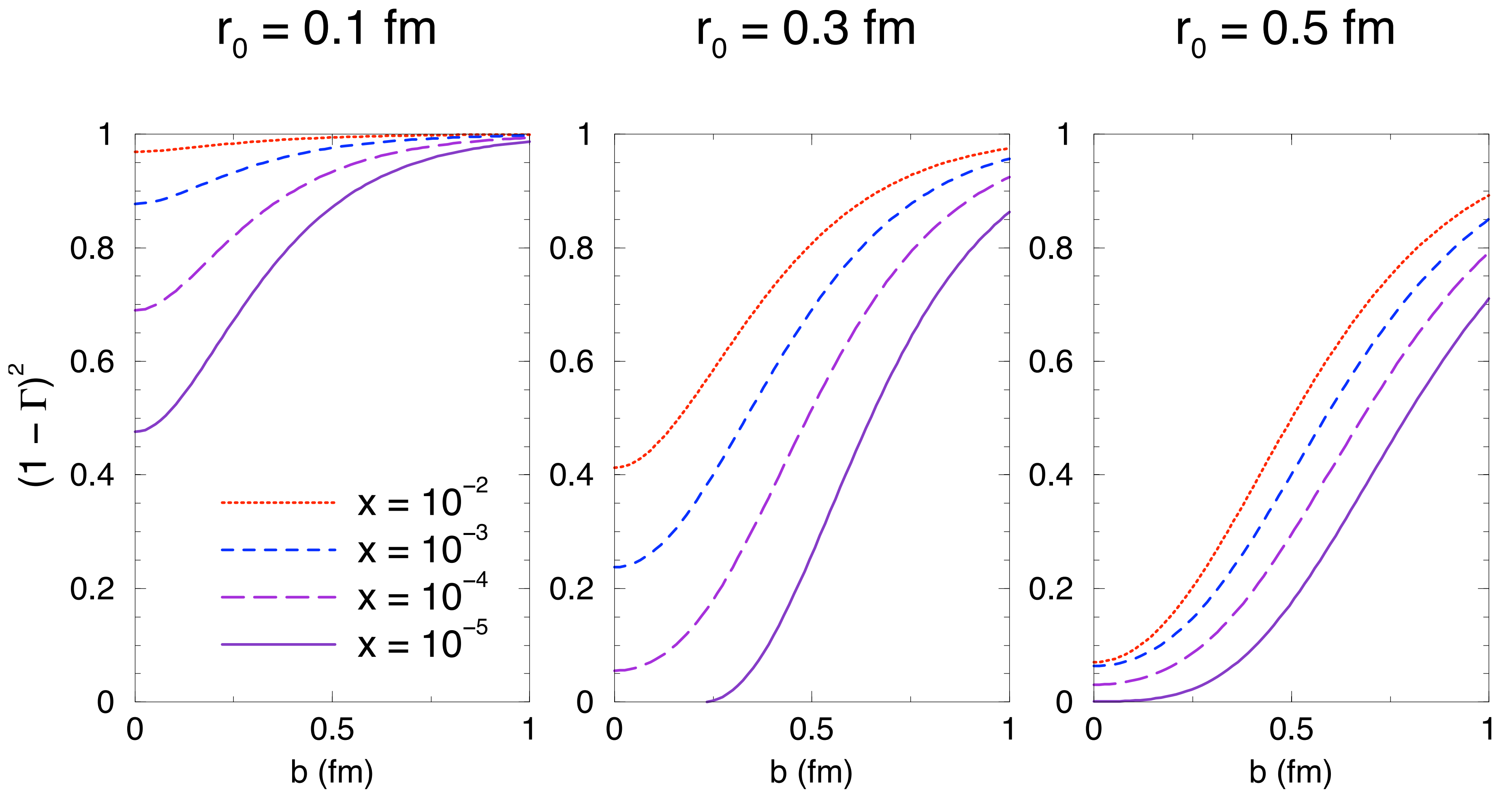
$\Gamma = 1$ *corresponds to regime of complete absorption - BDR*

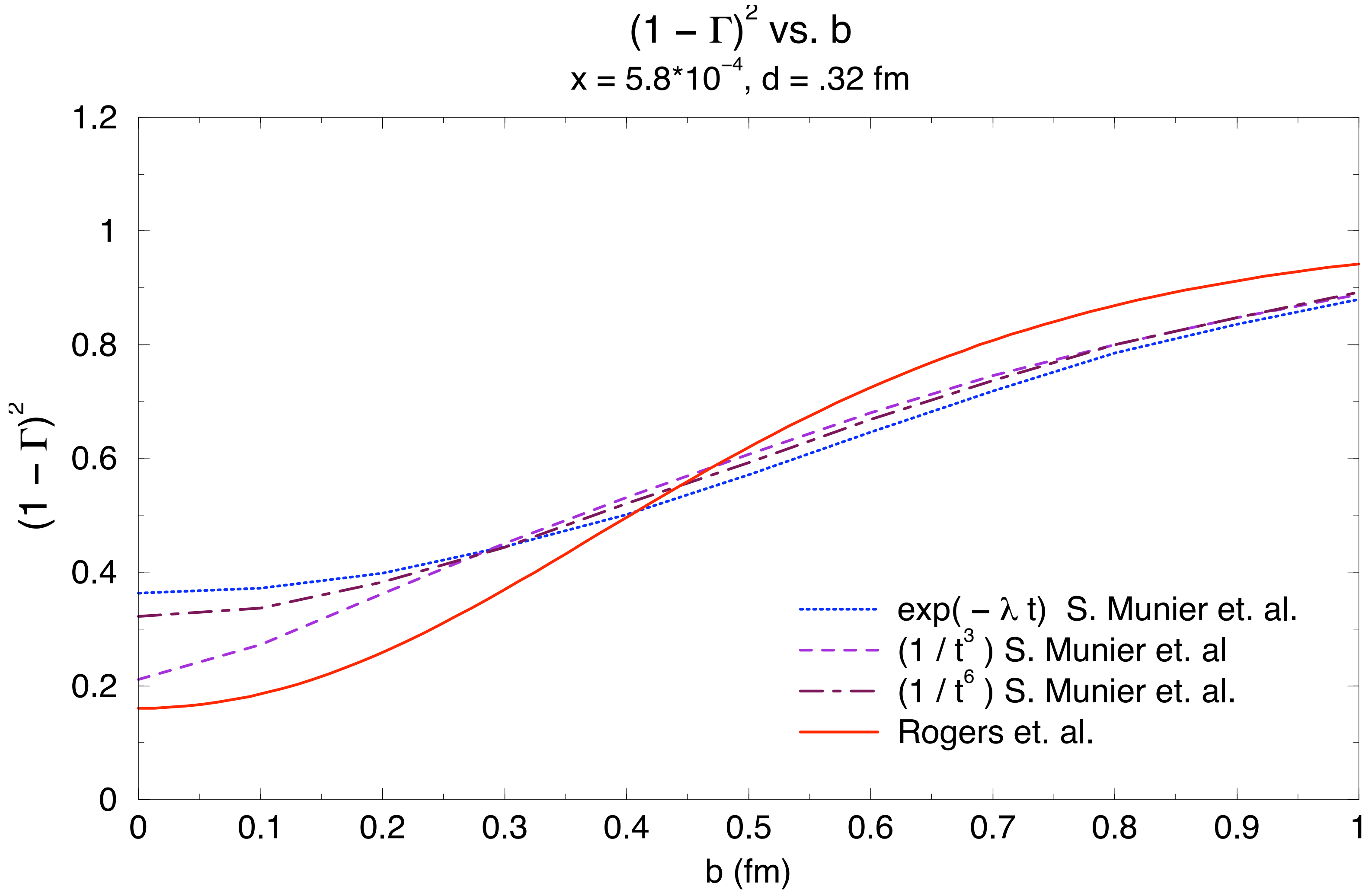


T.Rogers et al

In the case gg-N scattering we assume pQCD relation

$$\Gamma_{gg} = \frac{9}{4}\Gamma_{q\bar{q}}$$





$|1 - \Gamma(b)|^2$ -
probability not to interact at given b

gg -N interaction seems close to BDR
for $Q^2 \sim 4$ GeV^2, $x \sim 10^{-4}$

↓

for $Q^2 \sim 4$ GeV^2, $x \sim 10^{-3}$
gg - Pb interaction at b=0 is deep in BDR
$q\bar{q}$ - Pb interaction in BDR

for these x nuclear gluon shadowing effect is rather small

↓

Suppression of the leading hadron production in pA scattering at large p_t comparable to the scale of Black disk regime at given energy (FS 01-06)

⇒

Natural explanation of the BRAHMS result at RHIC, the only one consistent with the STAR data on correlations

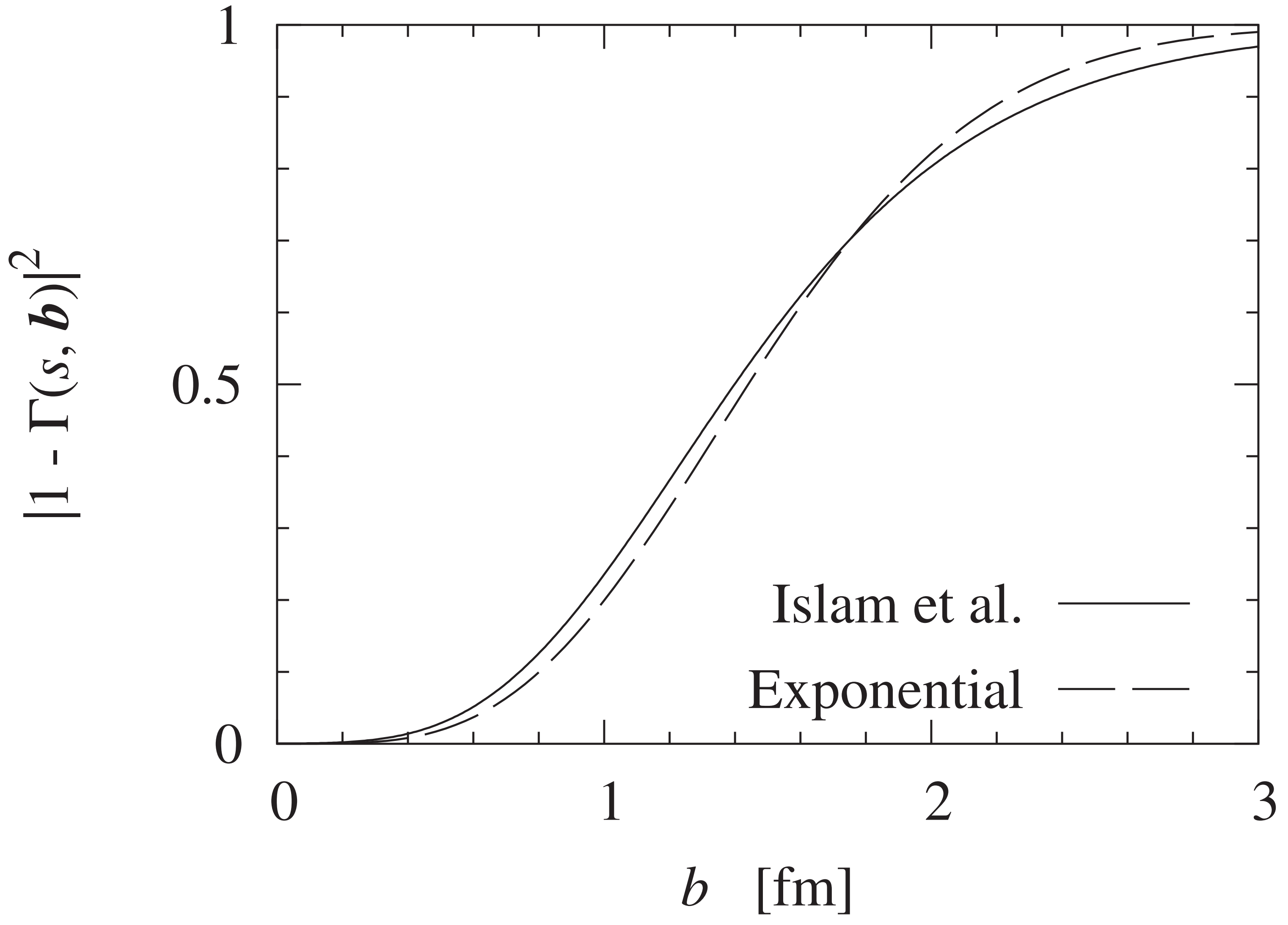
Gap suppression for pp → p+ H + p

(a) How black in pp interactions at LHC

Frankfurt, Hyde, MS, Weiss 06

$$T_{\mathrm{el}}(s, t = -\boldsymbol{\Delta}_{\perp}^2) = \frac{is}{4\pi} \int d^2 b e^{-i(\boldsymbol{\Delta}_{\perp} \boldsymbol{b})} \Gamma(s, \boldsymbol{b}),$$

$$\left.\begin{matrix} \sigma_{\mathrm{el}}(s) \\ \sigma_{\mathrm{tot}}(s) \\ \sigma_{\mathrm{inel}}(s) \end{matrix}\right\} = \int d^2 b \times \begin{cases} |\Gamma(s, \boldsymbol{b})|^2, \\ 2\,\mathrm{Re}\Gamma(s, \boldsymbol{b}), \\ [1 - |1 - \Gamma(s, \boldsymbol{b})|^2]. \end{cases}$$

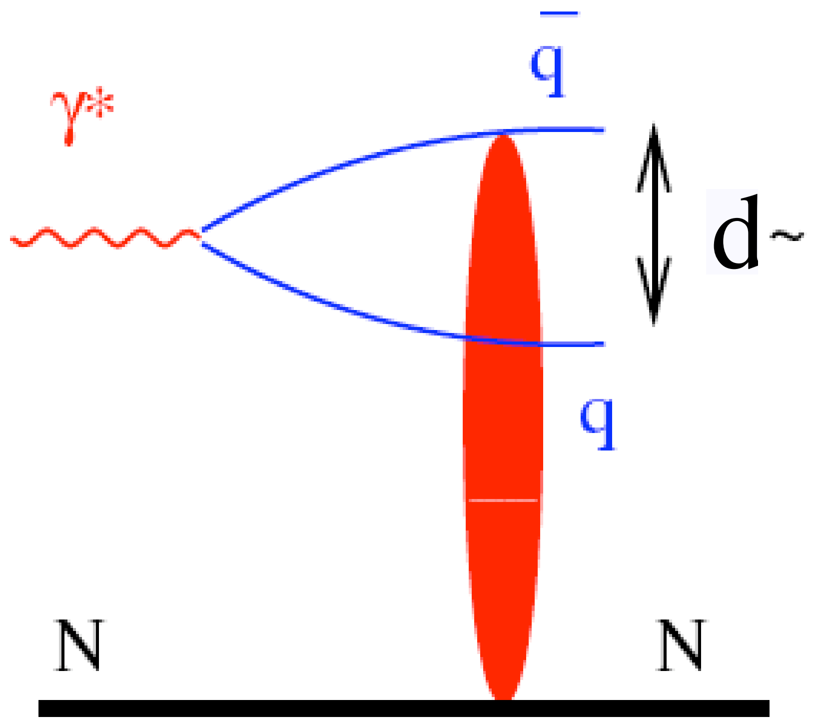


The probability distribution $|1 - \Gamma(s, \boldsymbol{b})|^2$ for no inelastic interaction, as a function of b, at the LHC energy (W=14TeV)as computed with different parametrizations of the pp elastic scattering amplitude. Solidline:parametrization of Islam et al ("diffractive part" only). Dashedline: exponential parametrization, withΓ(b=0) =1 (BLACK DISK LIMIT) and B=21.8 GeV^{-2}.

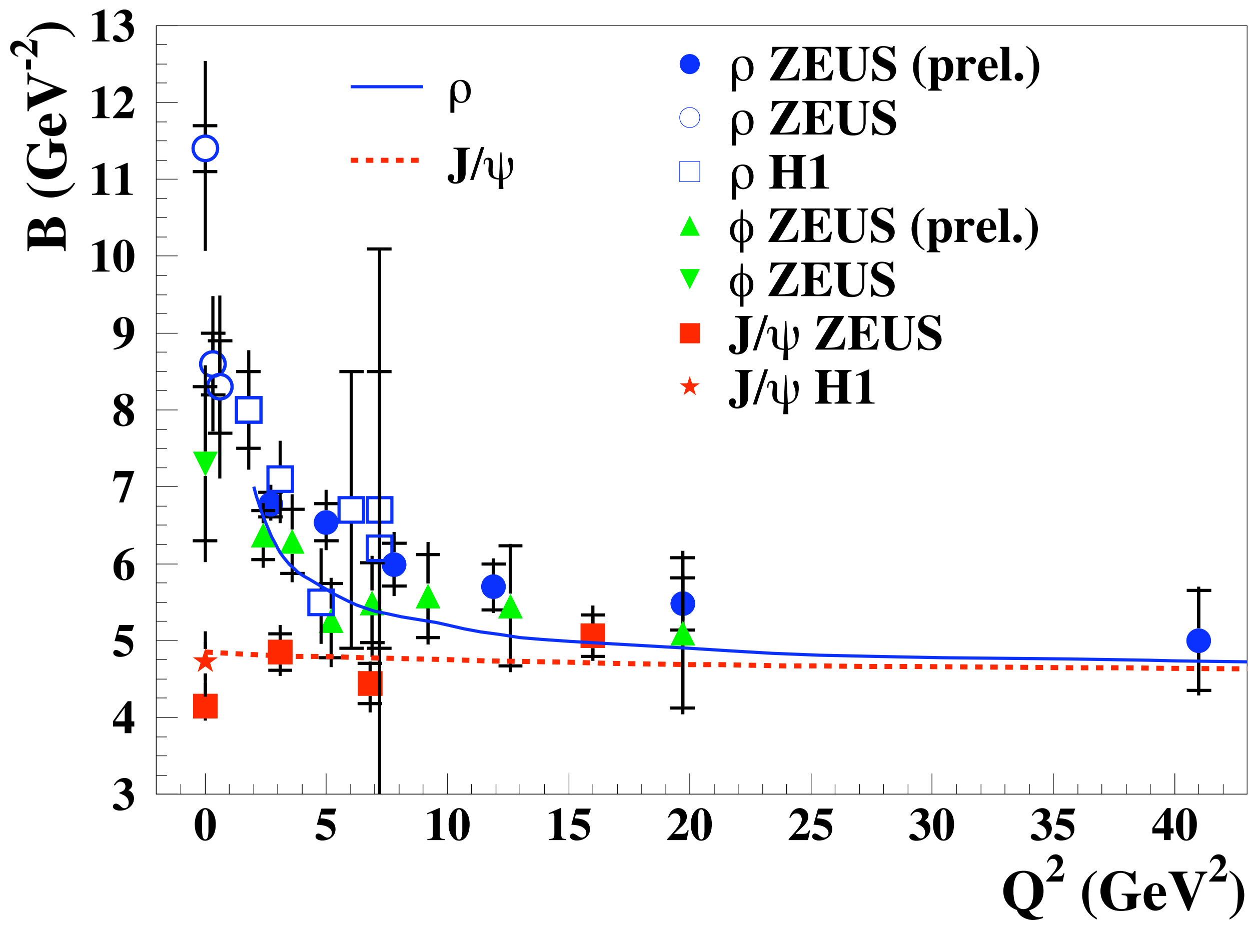
In LT in pQCD t-distribution of exclusive VM production measures transverse distribution of gluons given by the Fourier transform of the two gluon form factor

$$F_g(x,t).\ \ d\sigma/dt \propto F_g^2(x,t).$$

Onset of universal regime FKS[Frankfurt,Koepf, MS] 97.



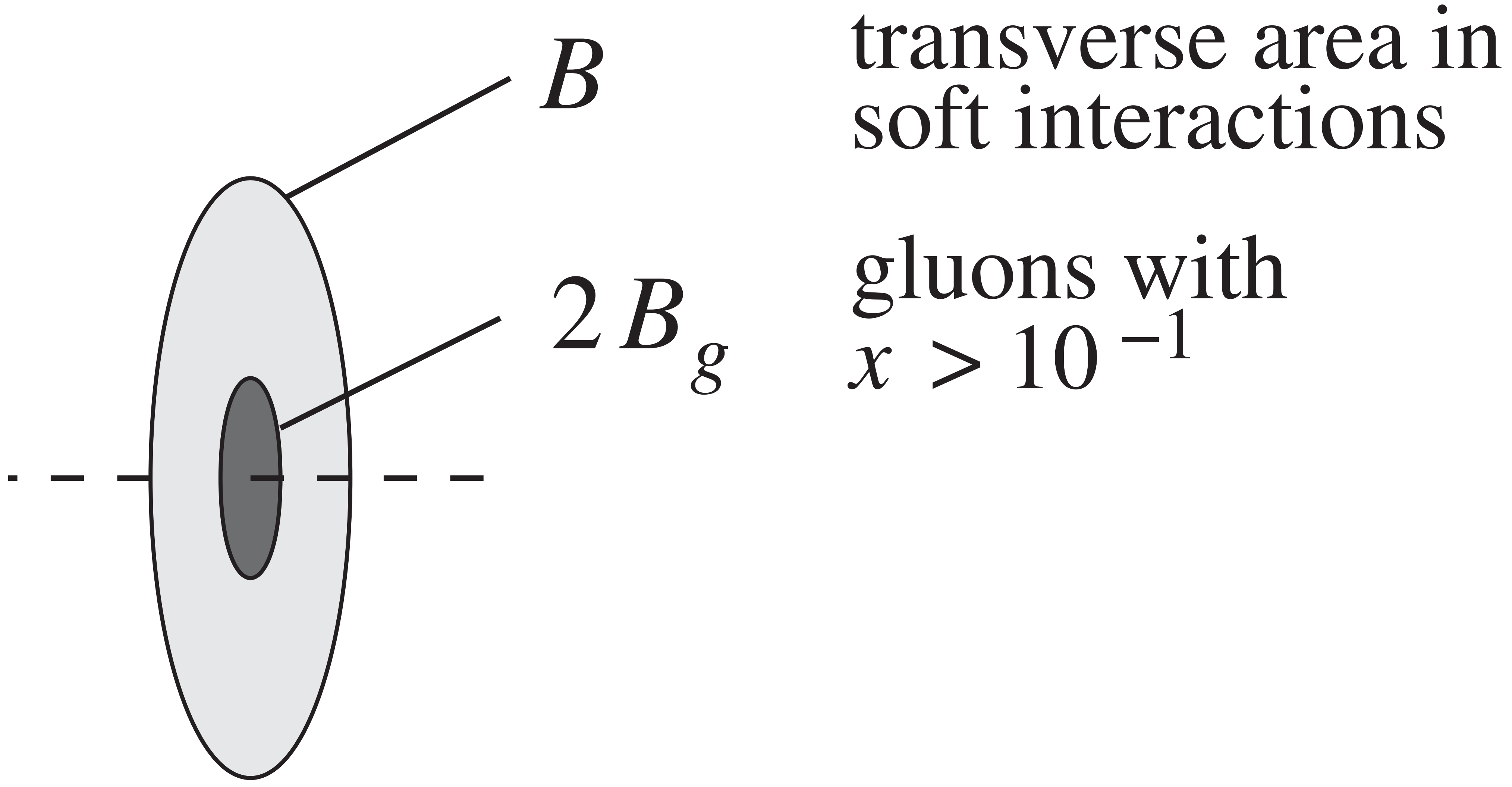
$d \sim r_T \propto \frac{1}{Q}\left(\frac{1}{m_c}\right) \ll r_N$

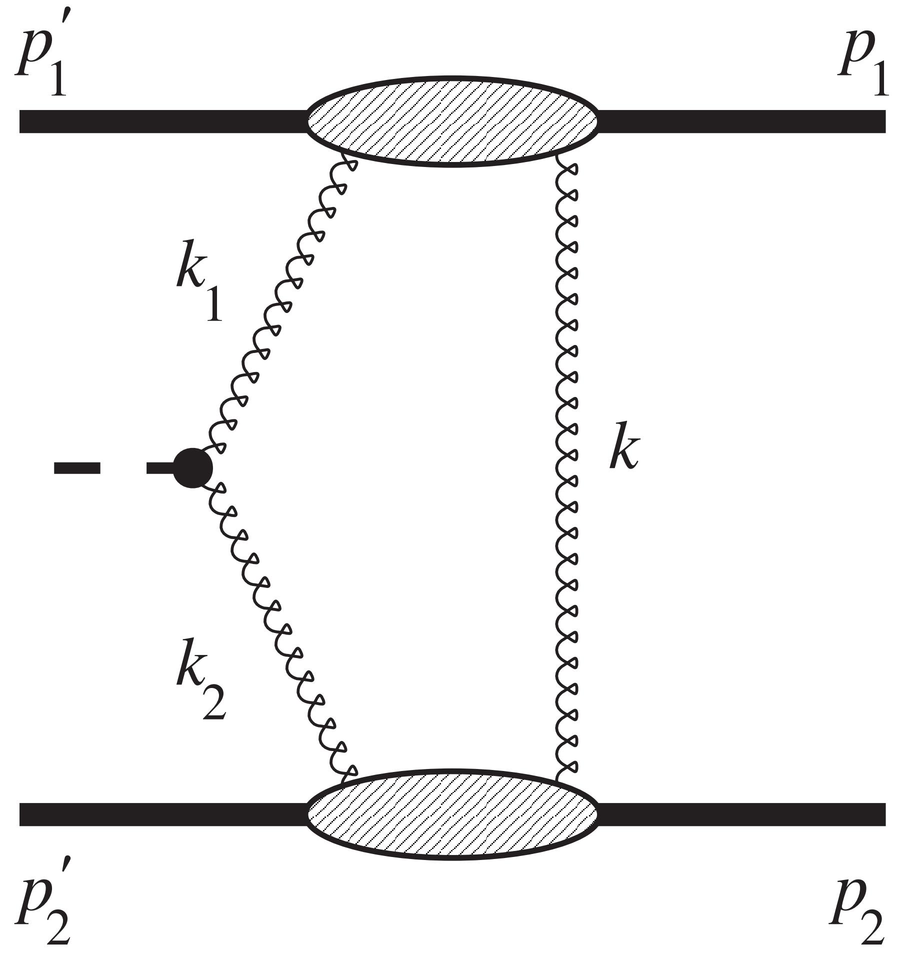


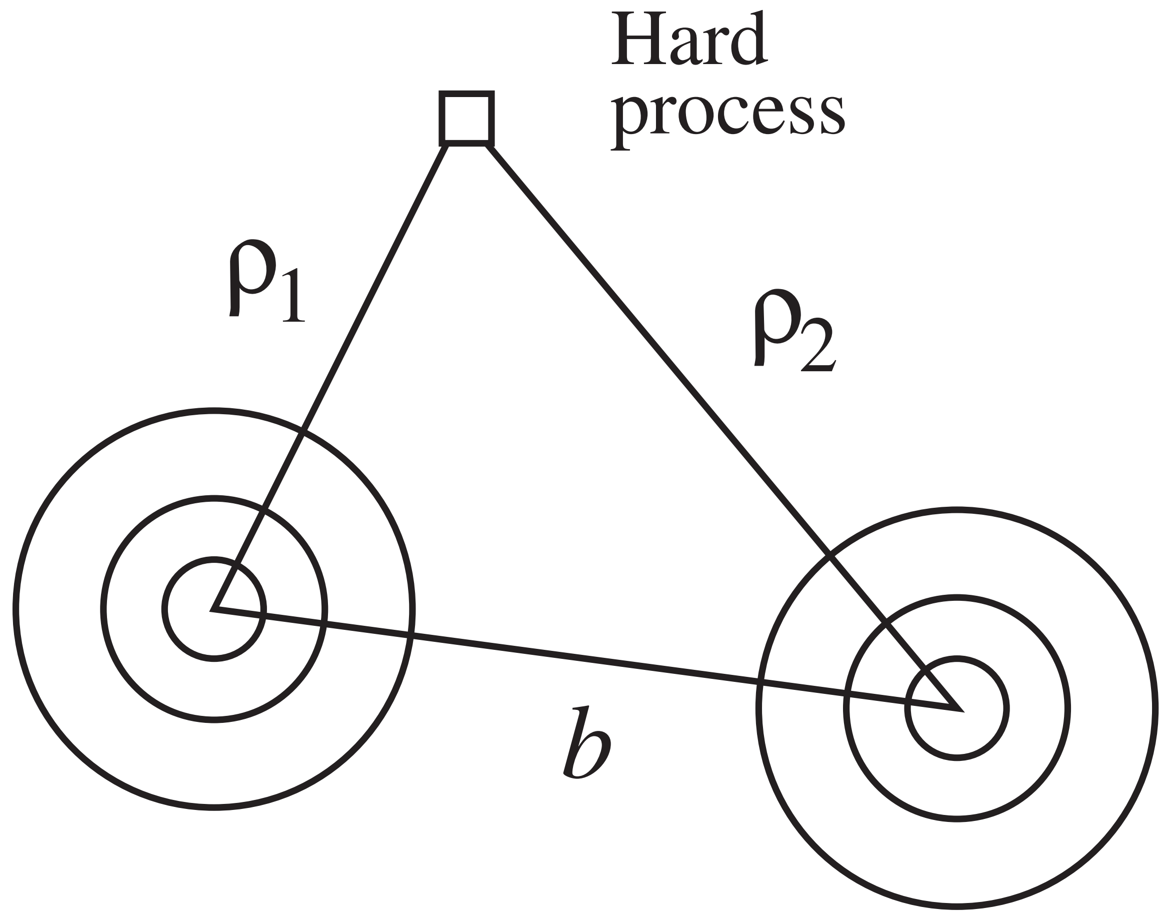
Convergence of the t-slopes, B ($\frac{d\sigma}{dt} = A\exp(Bt)$, of ρ-meson electroproduction to the slope of J/psi photo(electro)production.

Transverse distribution of gluons can be extracted from $\gamma + p \rightarrow J/\psi + N$

A crucial observation is that the transverse area occupied by partons with x > 0.05 is much smaller than the transverse area associated with the proton in soft interactions







Assuming no correlation between hard and soft interaction in impact parameter space we can derive expression for the amplitude of the process:

$$T_{\rm diff}(\boldsymbol{p}'_{1\perp}, \boldsymbol{p}'_{2\perp}) = \int d^2 b \int d\rho_1 \int d\rho_2 \delta^{(2)}(\boldsymbol{b} - \boldsymbol{\rho}_1 + \boldsymbol{\rho}_2) \; e^{-i(\boldsymbol{p}'_{1\perp}\boldsymbol{\rho}_1) - i(\boldsymbol{p}'_{2\perp}\boldsymbol{\rho}_2)} \boldsymbol{\kappa} F_g(x_1, \xi_1, \boldsymbol{\rho}_1; Q^2)$$

$$\times F_g(x_2, \xi_2, \boldsymbol{\rho}_2; Q^2)[1 - \Gamma(s, \boldsymbol{b})]$$

x $A_{\rm hard}$

Focus on the total suppression due to soft interactions

$$S^2 \equiv \frac{\sigma_{\rm diff}(\text{physical})}{\sigma_{\rm diff}(\text{no soft interactions})}$$

It is convenient to introduce a normalized impact parameter distribution

$$P_{\text{hard}}(\boldsymbol{b}) \equiv \int d^2\rho_1 \int d^2\rho_2 \delta^{(2)}(\boldsymbol{b} + \boldsymbol{\rho}_1 - \boldsymbol{\rho}_2) \frac{F_g^2(\boldsymbol{\rho}_1)}{[\int d^2\rho_1' F_g^2(\boldsymbol{\rho}_1')]} \frac{F_g^2(\boldsymbol{\rho}_2)}{[\int d^2\rho_2' F_g^2(\boldsymbol{\rho}_2')]}$$

which satisfies $\int d^2 b P_{\text{hard}}(\boldsymbol{b}) = 1.$

$$S^2 = \int d^2 b P_{\text{hard}}(\boldsymbol{b}) |1 - \Gamma(\boldsymbol{b})|^2.$$

Note that in our approach one does not need to model effects of multiPomeron exchanges, etc. Also we find that structure of diffraction in pp scattering at LHC and in gpds are so different that effects of inelastic intermediate states are very small.

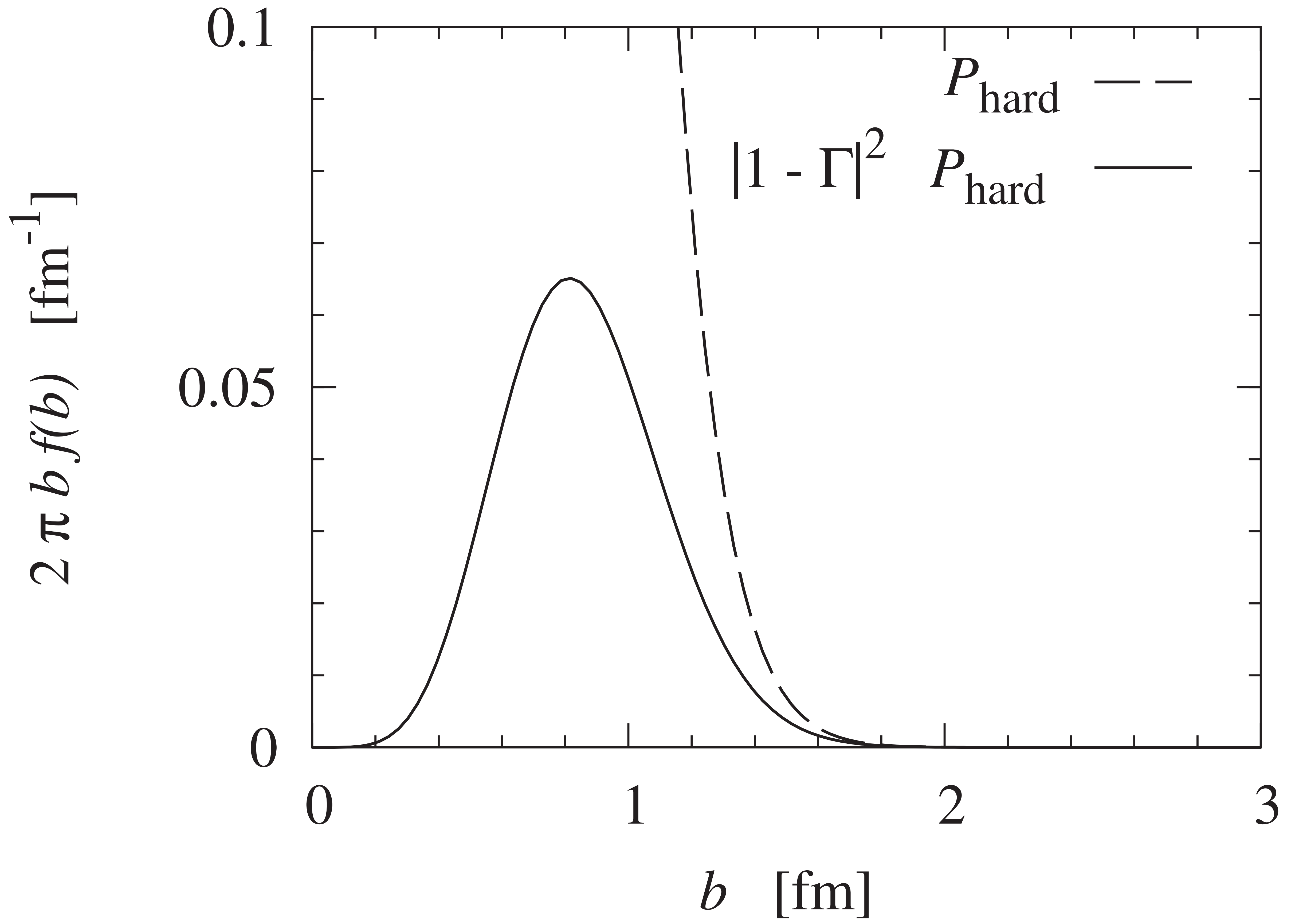
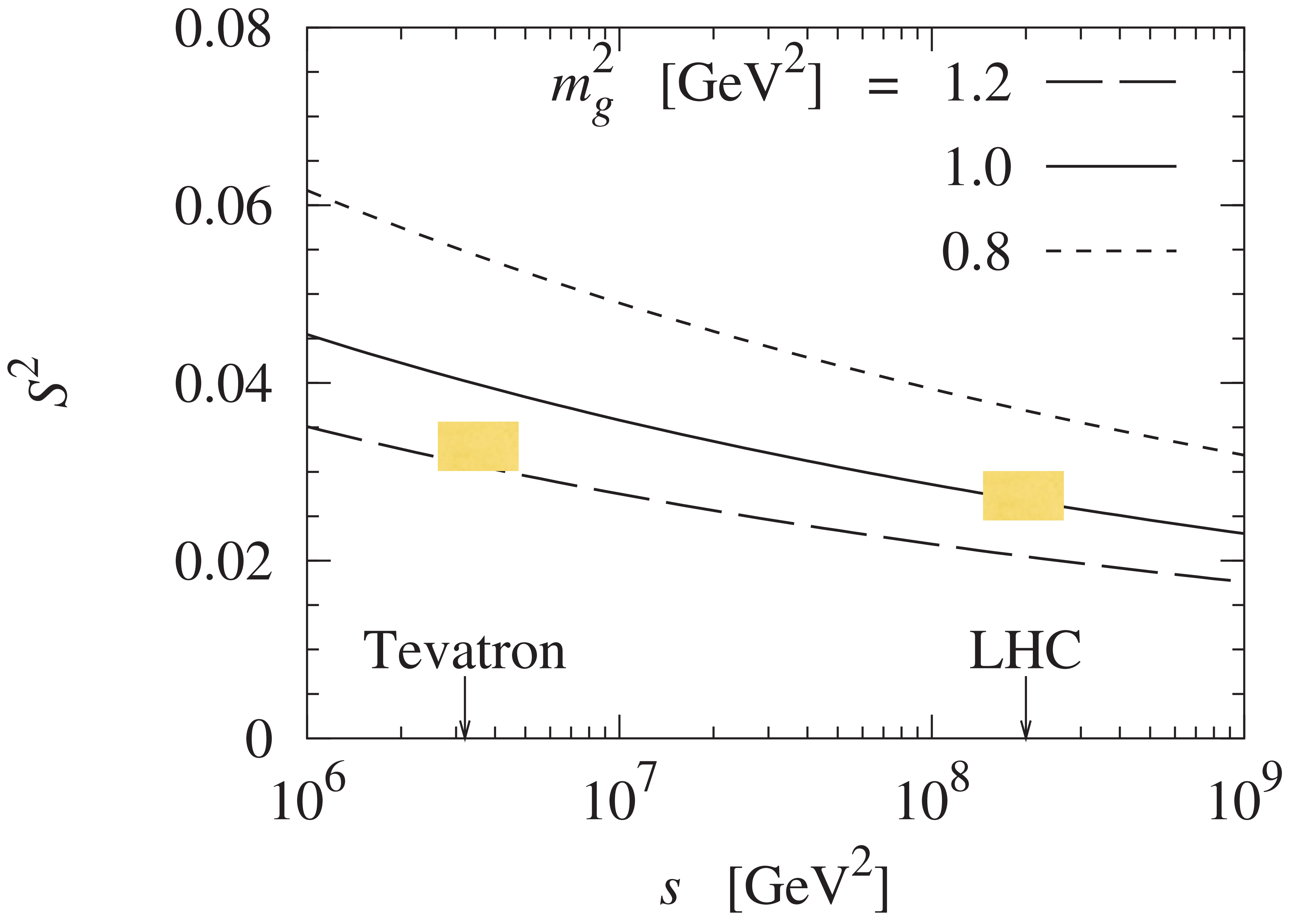


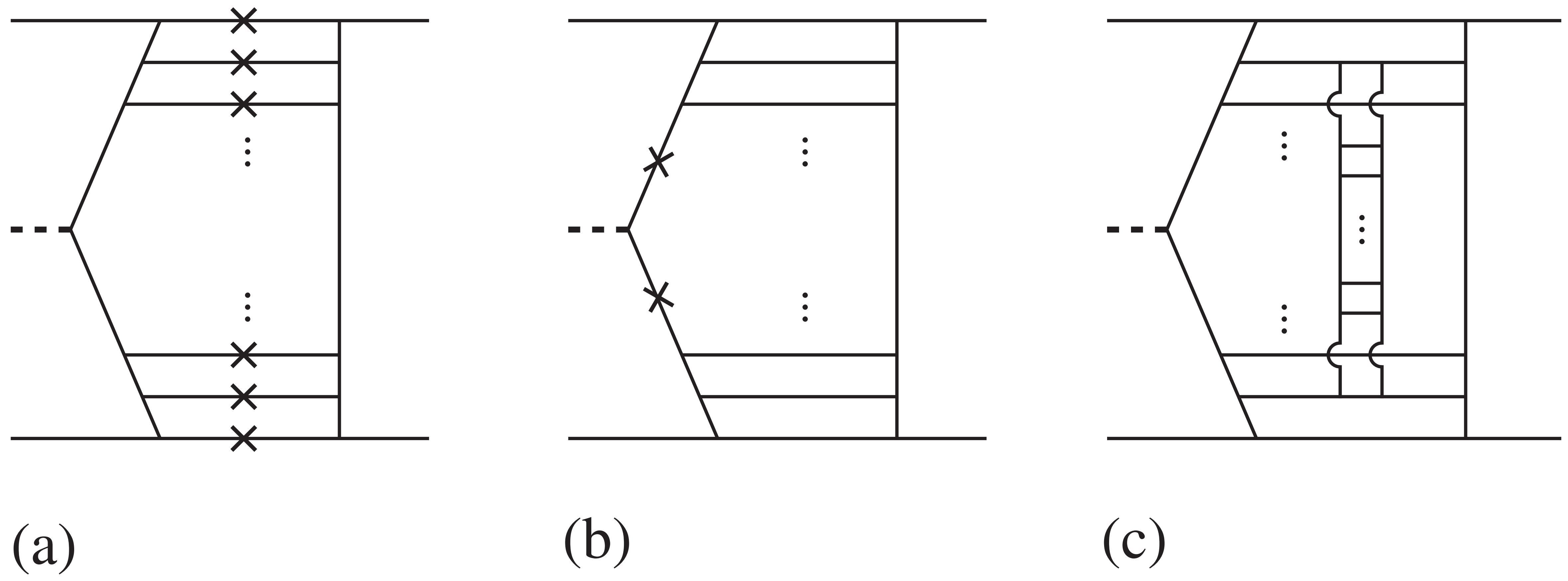
FIG. 8. The integrand (impact parameter distribution) in the RGS probability, Eq. (77), for Higgs boson production at the LHC energy. Dashed line: b distribution of the hard two-gluon exchange, $P_{\rm hard}(b)$, Eq. (75), evaluated with the exponential parametrization of the two-gluon form factor, Eq. (33) with $B_g = 3.24$ GeV^{-2}. Solid line: The product $P_{\rm hard}(b)|1 - \Gamma(\boldsymbol{b})|^2$, evaluated with the exponential parametrization, Eq. (12), with $B = 21.8$ GeV^{-2}. The vanishing of $|1 - \Gamma(\boldsymbol{b})|^2$, at small b, cf. Fig. 1, strongly suppresses contributions from small impact parameters. Note that the plot shows $2\pi b$ times the functions of impact parameter; the small-b part of the dashed curve [distribution $P_{\rm hard}(b)$] would be close to the left boundary of the plot and was omitted for better legibility. The RGS probability, S^2, is given by the area under the solid curve.

$$S^2 = 0.027$$



0.08
0.06
0.04
0.02
0
S^2
m_g^2 [GeV^2] = 1.2
1.0
0.8
Tevatron
LHC
10^6
10^7
10^8
10^9
s [GeV^2]

HARD INTERACTIONS IN THE BLACK-DISK REGIME



Modifications of the amplitude for double-gap diffraction resulting from hard interactions near the BDL.

(a) Absorption of parent partons of the gluon attached to the Higgs. The cross denotes the black interaction with the small-x
gluons in the other proton.
(b) Absorption of the hard gluons attached to the Higgs.
(c) Absorption due to local interactions within the partonic ladder.

Shown is only the generic structure of the partonic ladders; the dominant contribution comes from gluons

Let us illustrate magnitude of these effects consider the interaction of gluon from the evolution of gluon gpd with the small x gluons in the second nucleon

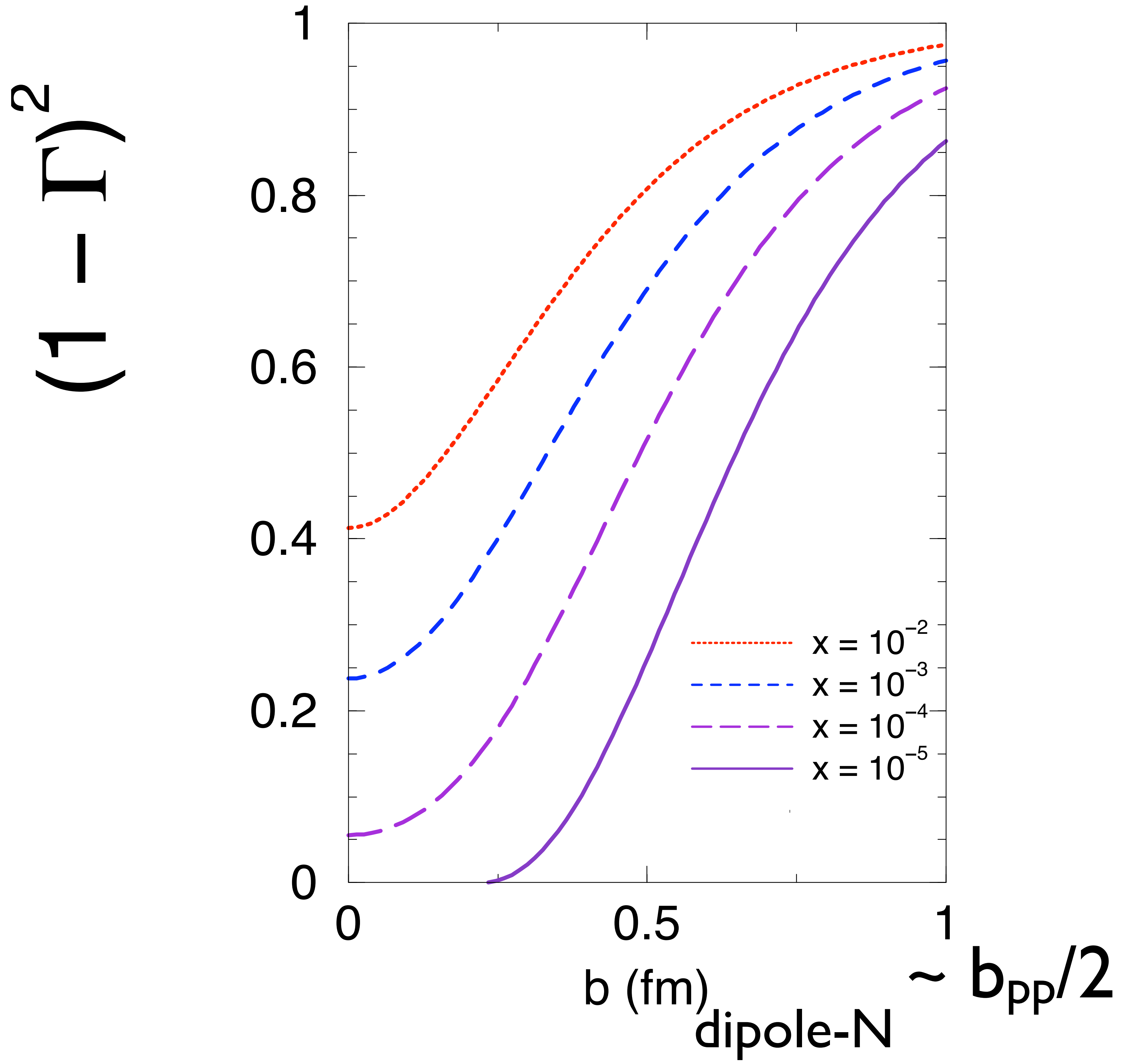
In gluon gpd for diffractive Higgs production at LHC,

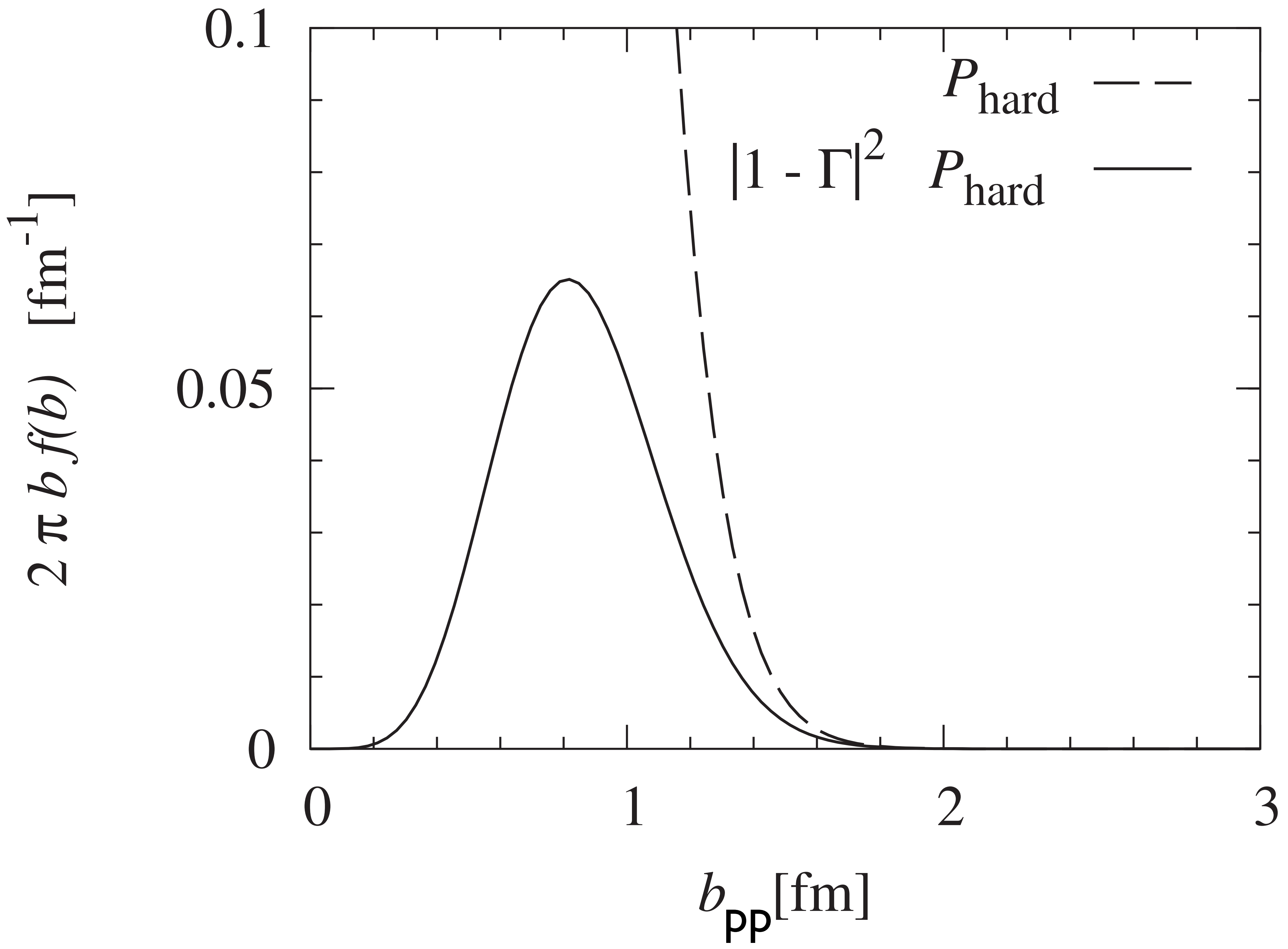
$Q^2 \sim 4\text{-}8\ \mathrm{GeV}^2$, $x \sim 10^{-2}$

backward evolution - very high probability that these gluons originated from gluons at $x \sim 10^{-1}$ and $p_t \sim 1\mathrm{GeV/c}$ - these gluons are present in the colliding nucleons and absorbed back into the final nucleon long after collisions provided they did not interact. These partons are close to the interacting partons and hence not included in the soft absorption factor.

Probability to survive - interaction of a dipole with size $d \sim \pi / 2p_t \sim .3$ fm at effective energy $s_{eff} \sim s_{LHC}/10$. $x_{eff} \sim 10^{-6} - 10^{-7}$!!!

$r_0 = 0.3$ fm



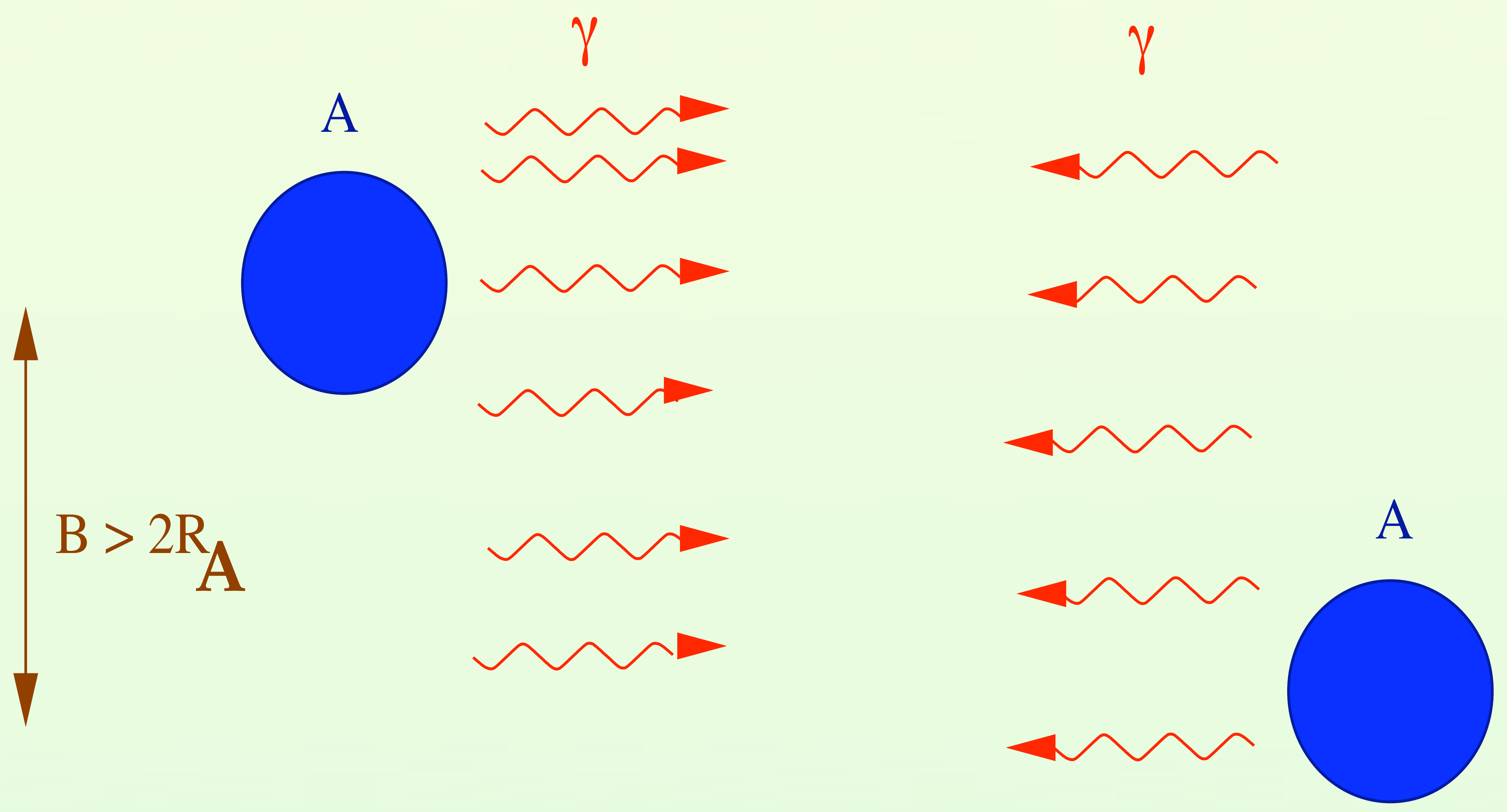


Extra suppression is roughly a square of $(1\text{-}\Gamma)^2 \rightarrow$ for $b_{pp} = 1$ fm suppression is by a factor > 5. Overall would give suppression > a factor 3-5. Only way out rare fluctuations where gluons were not emitted.

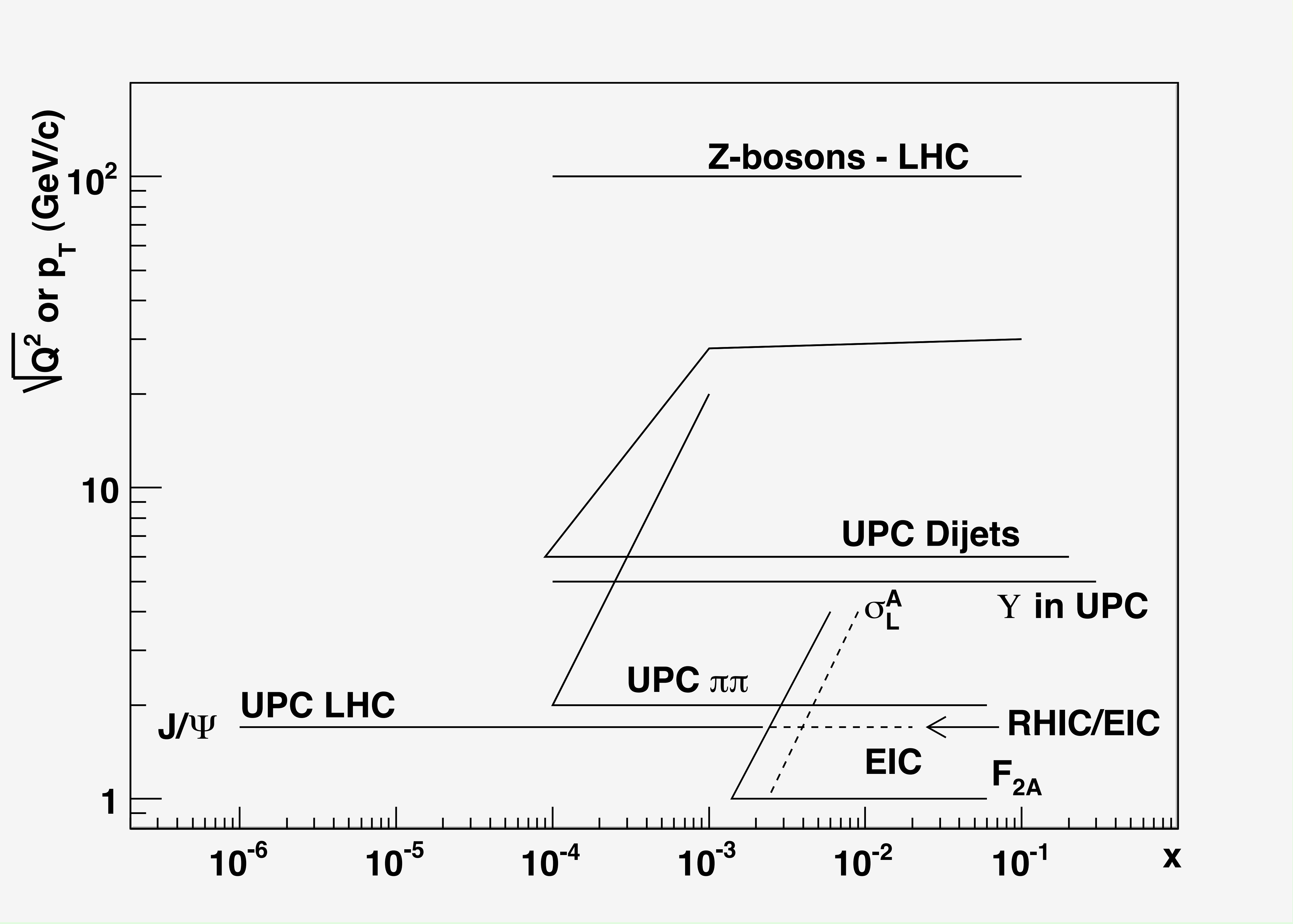
Conclusion: Suppression of exclusive Higgs production at LHC is very sensitive to onset of he black disk regime. Large suppression as compared to approximation of factorized soft and hard physics is likely to be large: $S^2 < 0.01$ Several other implications.

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

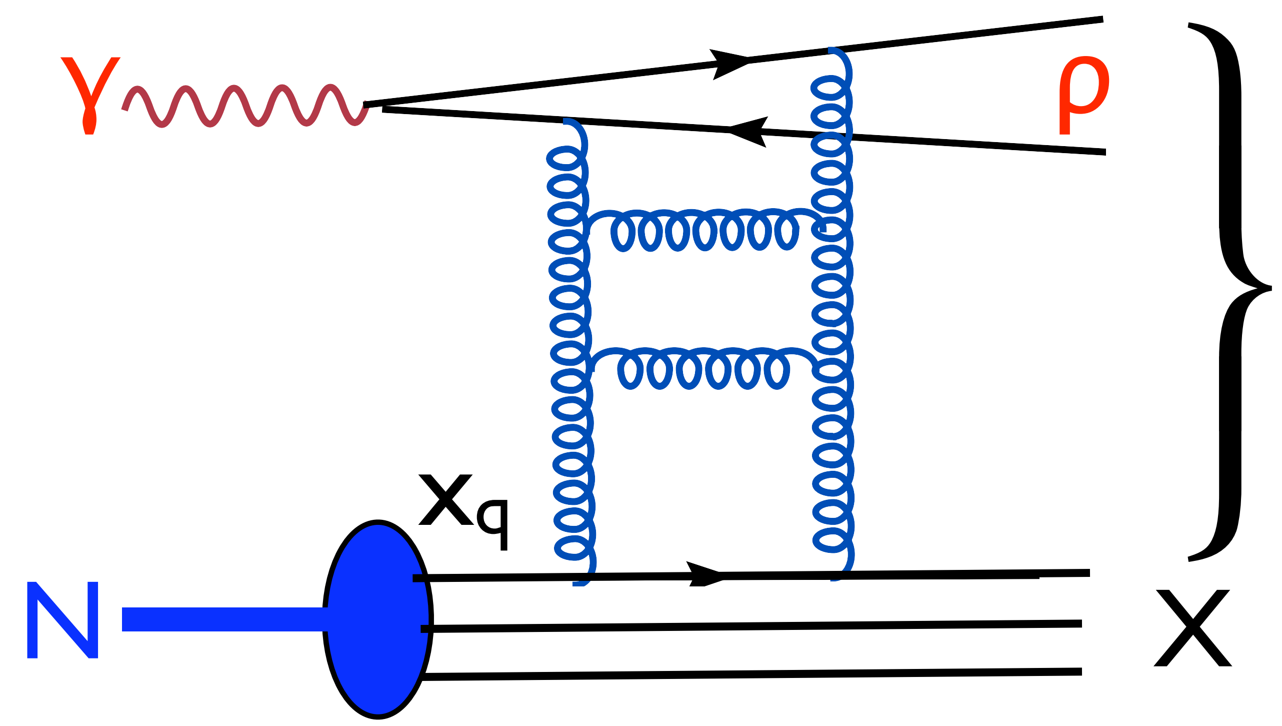


Ultraperipheral Nucleus–Nucleus Collision



minimal x are a factor of 10 smaller than at HERA

Rapidity gap processes at large $t=(p_\rho-p_\gamma)^2$: from HERA to LHC



$$s' = xW^2_{\gamma p},$$

Elementary reaction - scattering of a hadron (γ, γ*) off a parton of the target at large $t=(p_\gamma-p_V)^2$

FS 89 (large t pp→p +gap + jet), FS95
Mueller & Tung 91
Forshaw & Ryskin 95

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

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

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

The choice of large t ensures two important simplifications. First, *the parton ladder mediating quasielastic scattering is attached to the projectile via two gluons*. Second is that *attachment of the ladder to two partons of the target is strongly suppressed*. Also the transverse size $d_{q\bar{q}} \propto 1/\sqrt{-t}$

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

$$\frac{d\sigma_{N+q(g)\rightarrow N+q(g)}}{dt} \propto \frac{1}{t^6}$$

$$\frac{d\sigma_{\gamma+q(g)\rightarrow V+q(g)}}{dt} \propto \frac{1}{t^4}$$

Energy dependence of $f_q(s',t) \propto [s']^{\delta(t)}$

$\delta(-t >> 1\ GeV^2)$?

Soft QCD $\delta<-0.5$

Two gluon exchange $\delta=0$

DGLAP / resummed BFKL $\delta=0.2$ -- 0.3

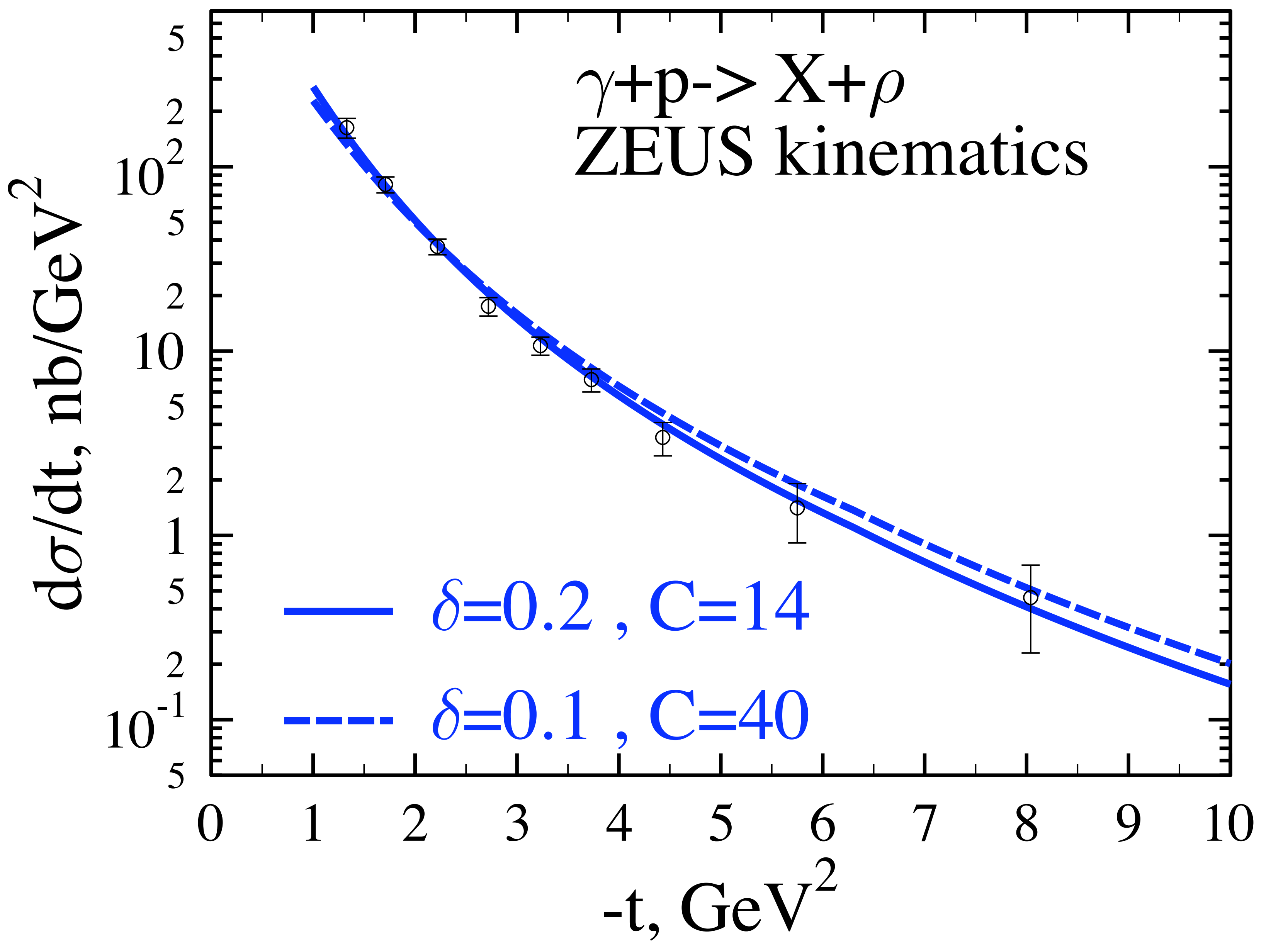
subtle points in BFKL analysis

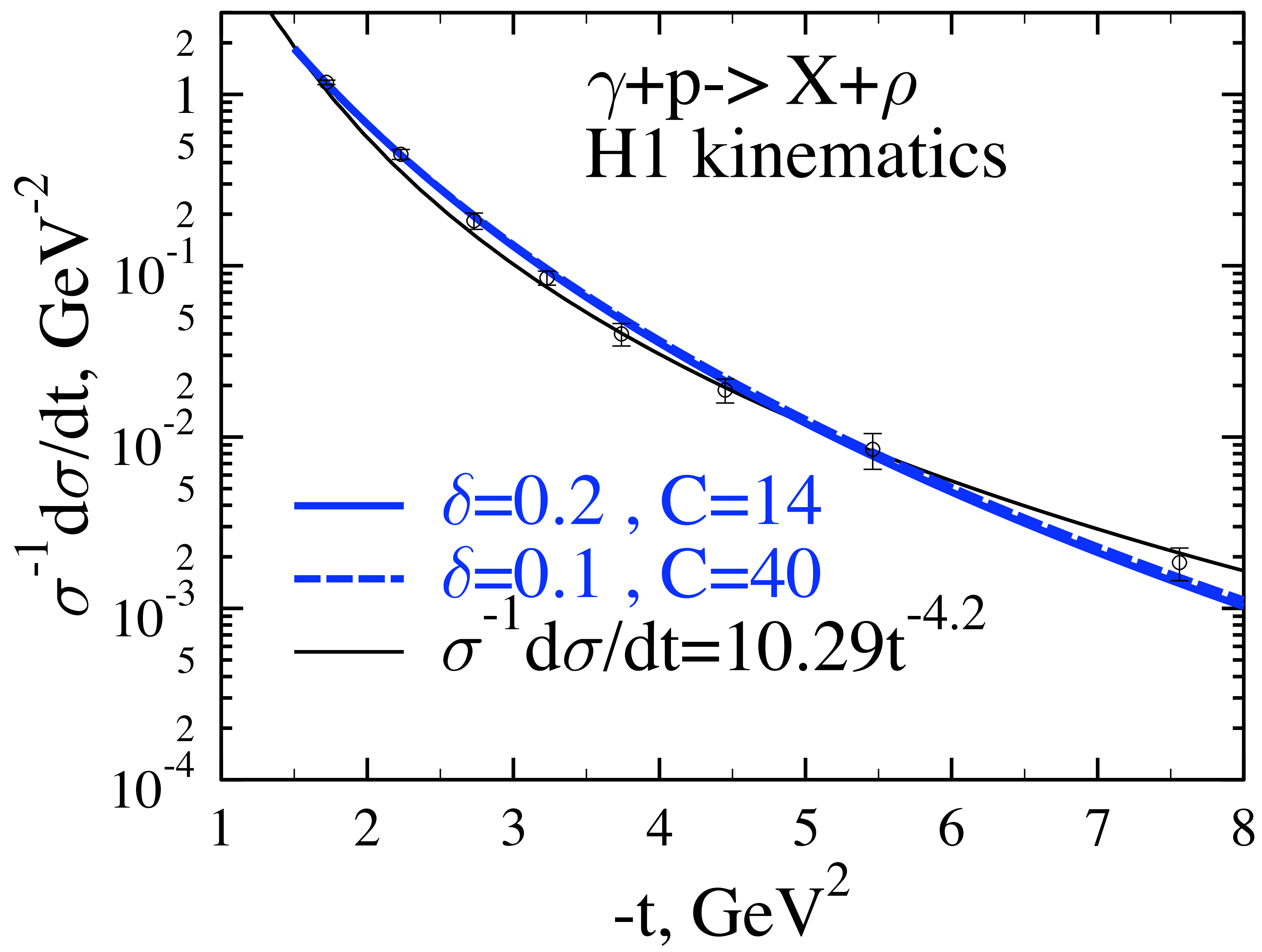
We analyzed the data using a fit

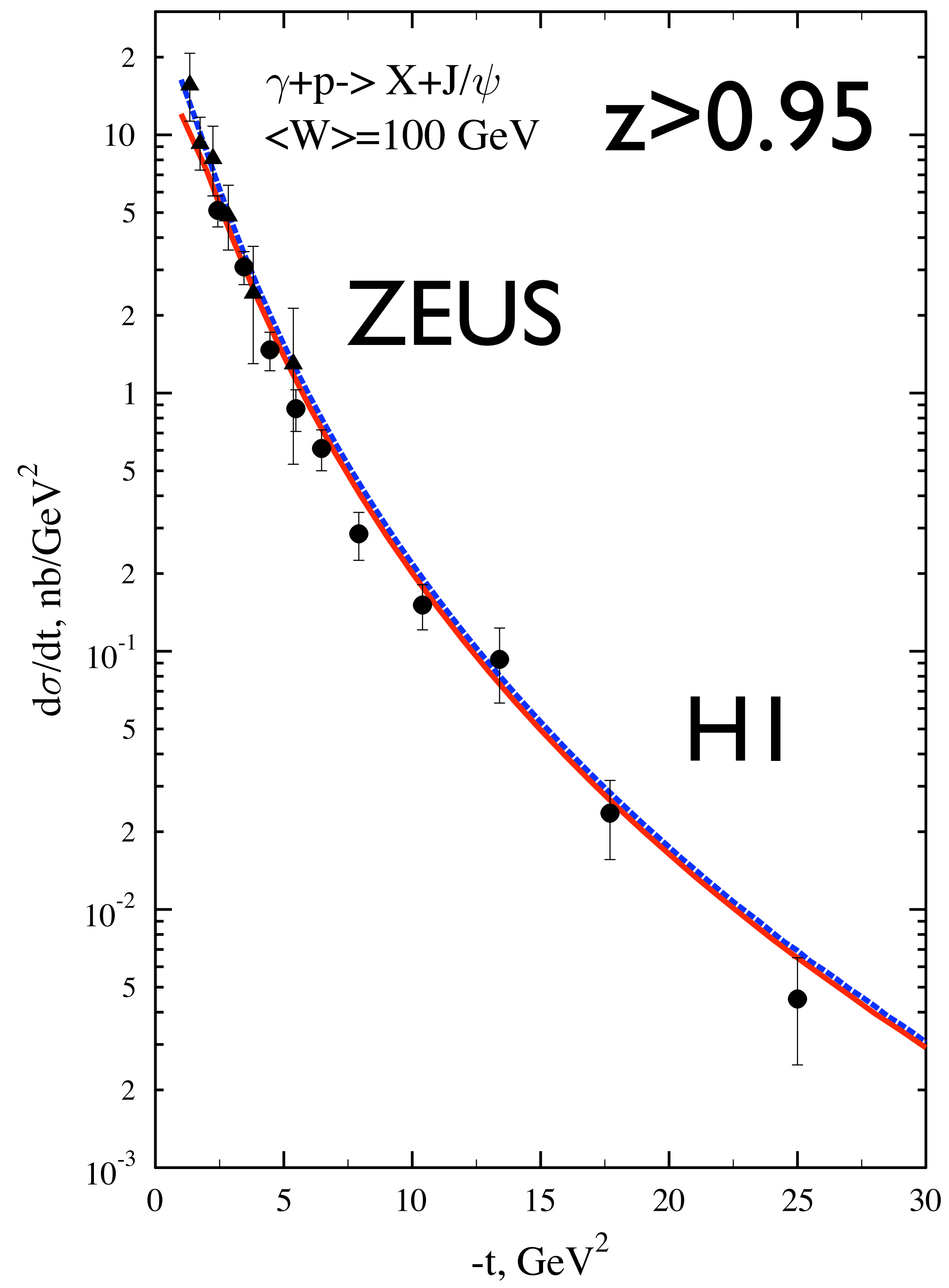
$$\frac{d\sigma_{\gamma+p\to\rho+X}}{dt} = \frac{C}{(1-t/t_0)^4}\left(\frac{s}{{m_V}^2 - t}\right)^{2\delta(t)} I(x_{min}, t)$$

$$I(x_{min}, t) = \int_{x_{min}}^{1} x^{2\delta(t)} \left[\frac{81}{16} g_p(x,t) + \sum_i [q_p^i(x,t) + \bar{q}_p^i(x,t)\right] dx$$

δ=0.1 -0.2 is consistent with the data at large t



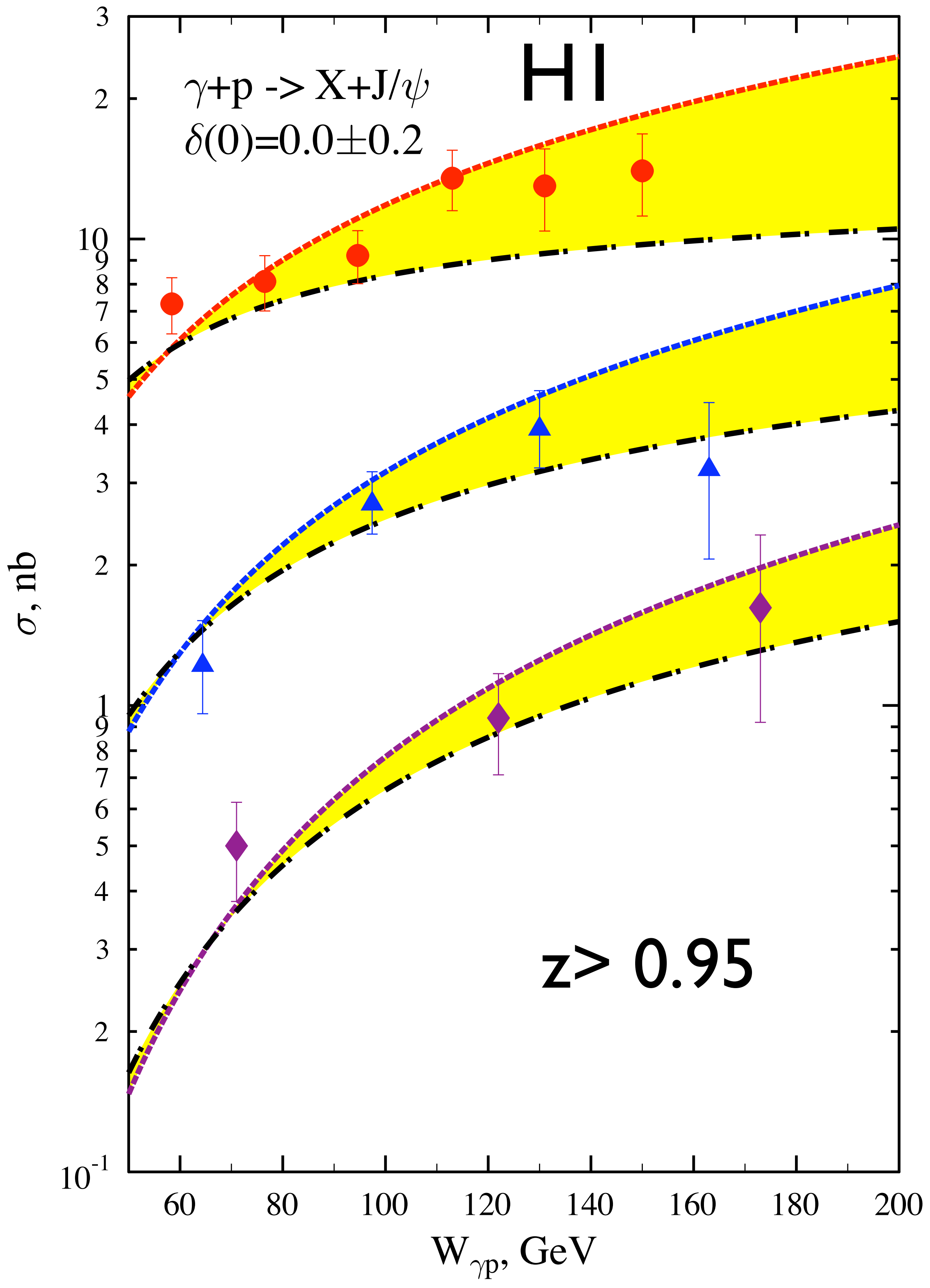


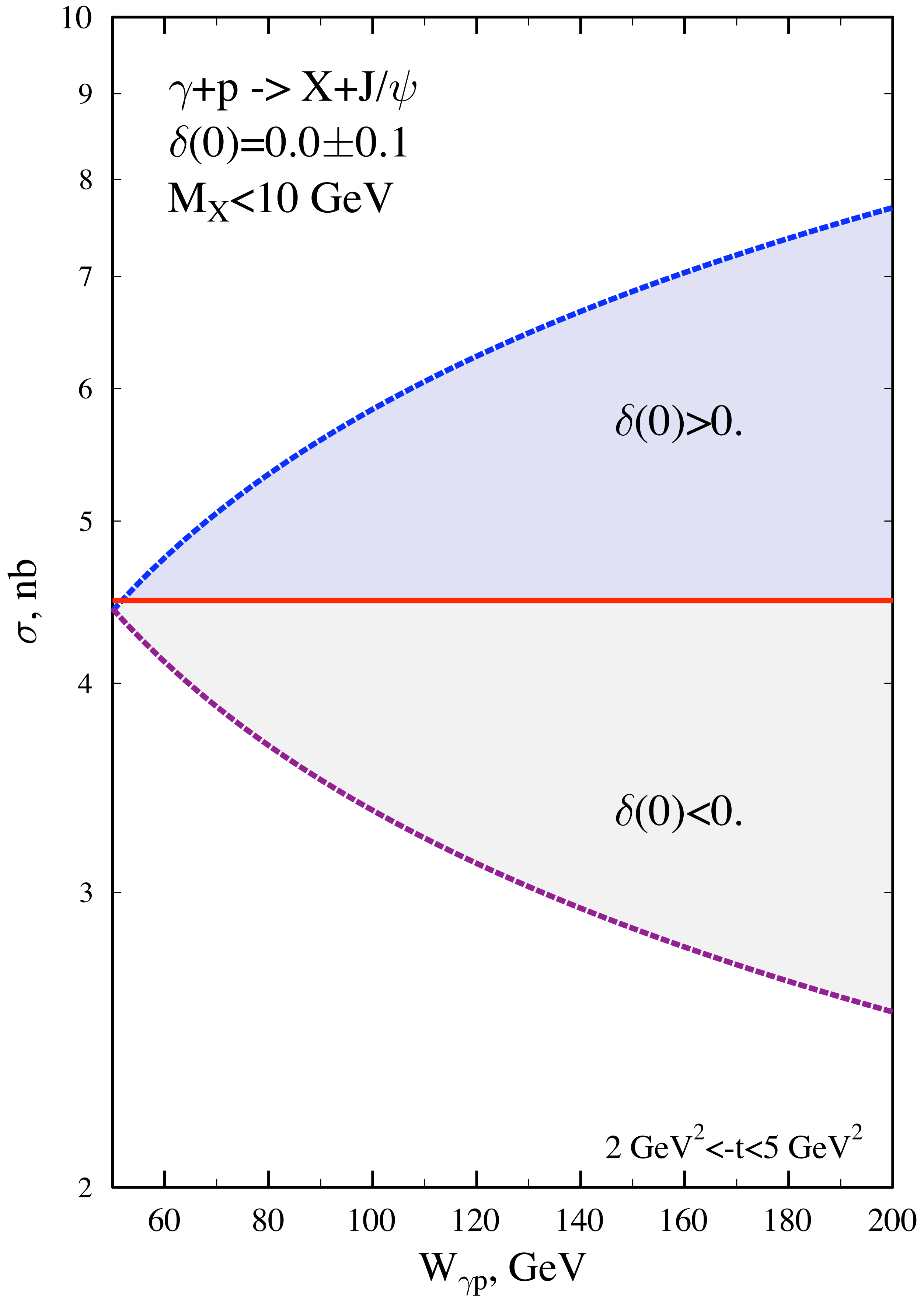


Description of ZEUS and H1 data for t-dependence of the large t and rapidity gap cross section. ZEUS data were taken at average $W_{\gamma p}$=100 GeV with fixed cut M_X < 25 GeV and additional restriction 0.01 <x< 1. The H1 data were taken at average $W_{\gamma p}$=85 GeV and cut M_X < 5 GeV.

Sensitivity to the energy dependence is weak.

t-dependence of J/psi production is consistent with dominance of hard dynamics





Study of the VM production with gaps is mostly sensitive to gluon pdfs if the cut is on z_{min} or M_X^2/W^2 is made. Sensitivity to the energy dependence of dipole - parton amplitude $f(s',t) \propto s^{\delta}$ is minor. On the contrary if the cut on $M_X <$ const is made, sensitivity to the value of δ is very high.

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 to keep

M^2_X < const and vary W

Difficult but not impossible at HERA natural at LHC

At LHC one can energy depedence of elastic $q\bar{q}$ - parton scattering at W'=20 GeV - 400 GeV

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

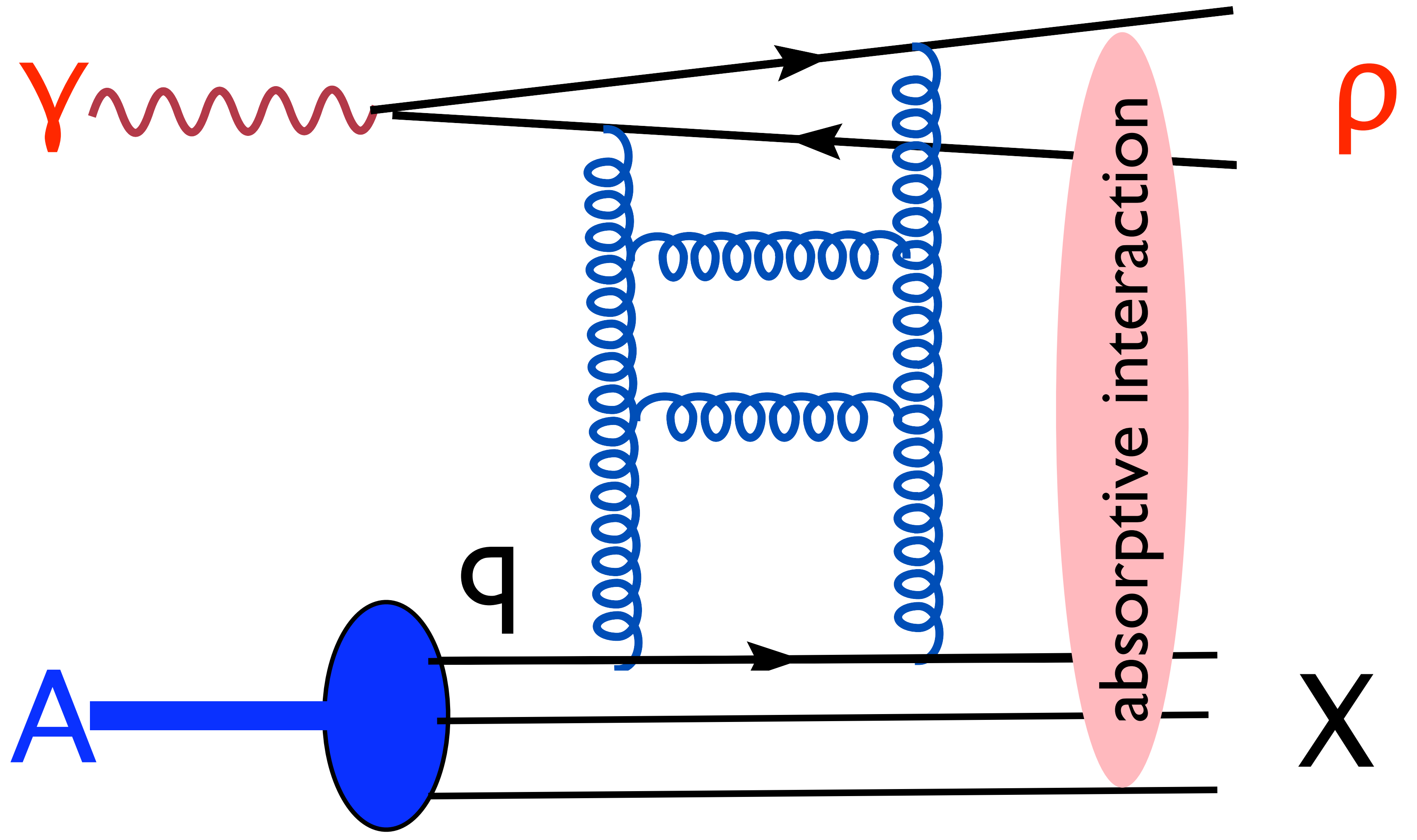
if δ=0.2

• $\gamma + A \rightarrow \rho + gap + X$

UPC [LHC & RHIC11(?)]

FS & Zhalov 06

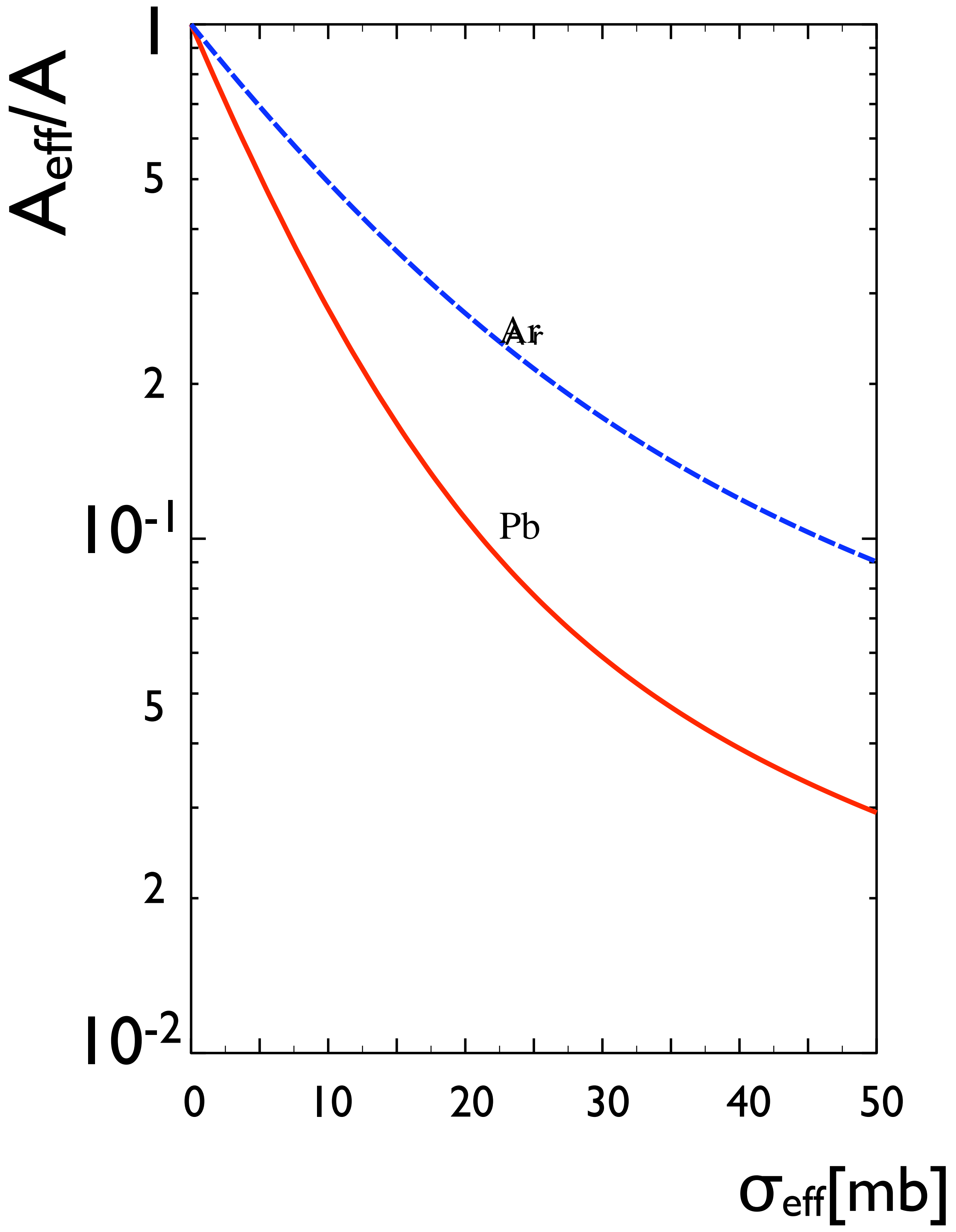
measure of the strength of inelastic interactions of small dipole in the processes initiated by BFKL elastic $q\bar{q}$ - parton scattering at W=30 GeV - 1 TeV



Advantages:

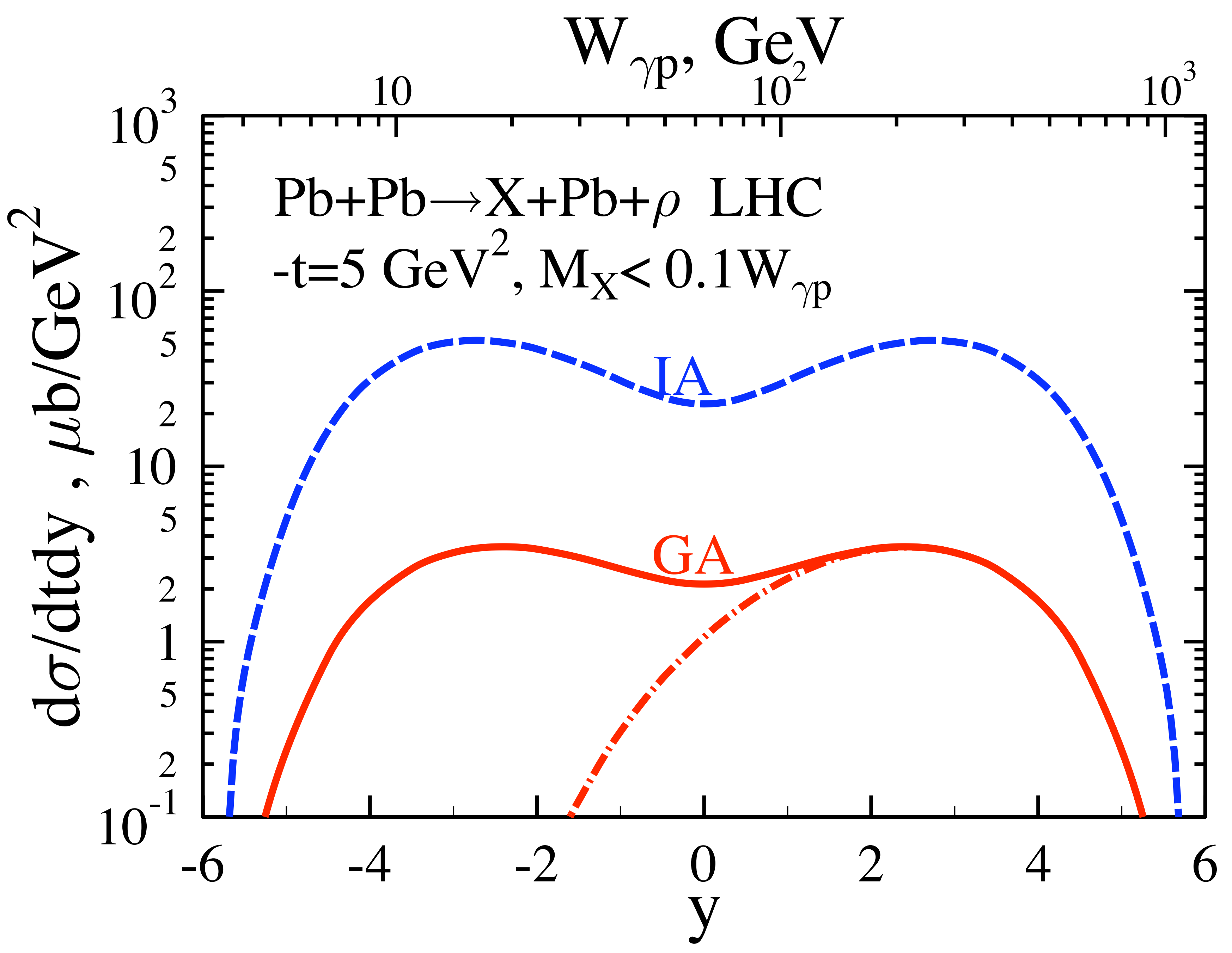
trigger on hadron production in a rapidity interval close to one of the nuclei

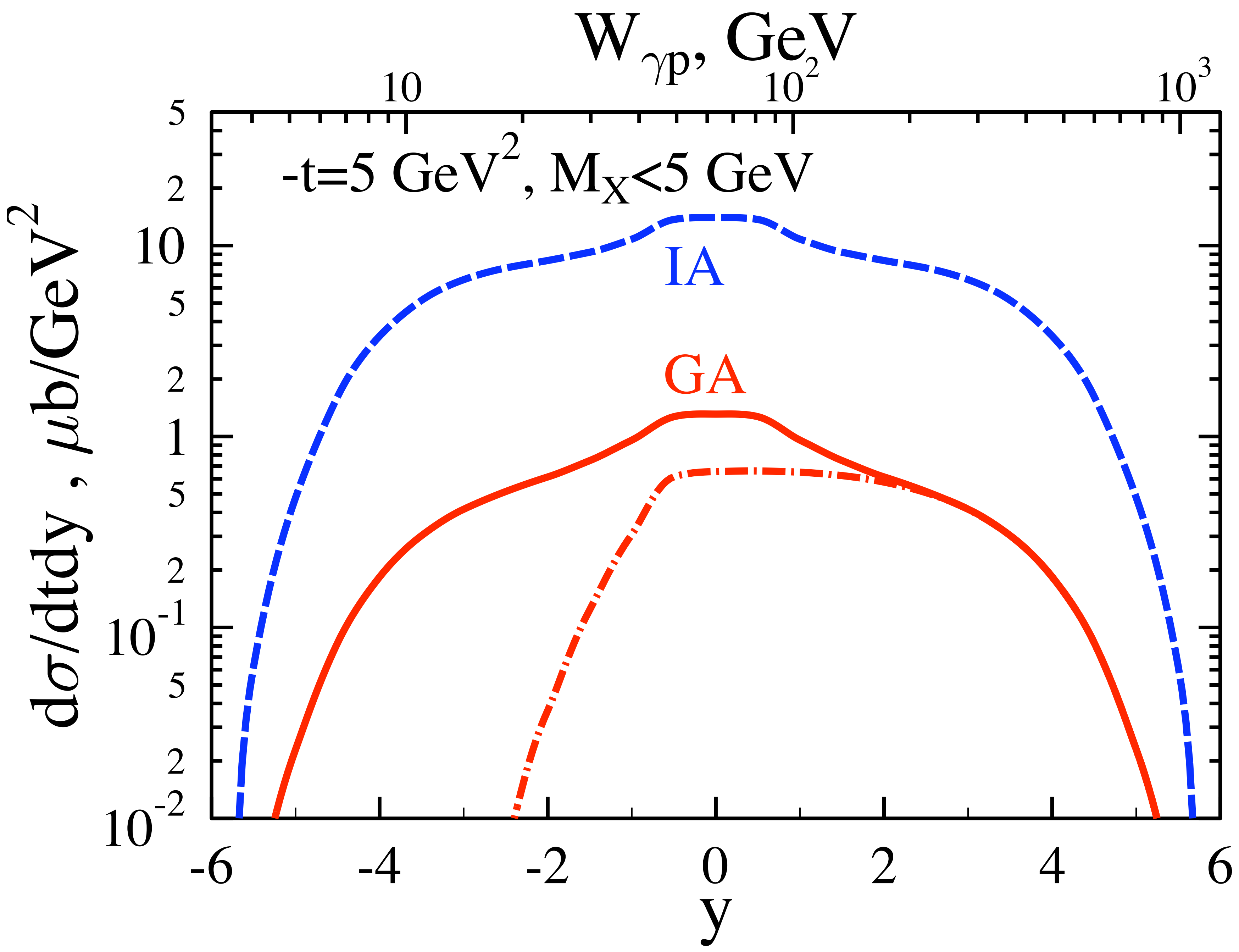
no ambiguity which of the nuclei emitted photon - Large W are possible



Strong sensitivity of A_{eff}/A to the strength of inelastic $q\bar{q}$-N interactions

Complementary to quasielastic process - no small x partons in the nucleus are involved on the trigger level





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}.

Conclusions

Gap survival probability at LHC should be much smaller than according to the models neglecting correlations of partons in transverse plane due to onset of black disk regime/ regime of high gluon fields

"No saturation without disintegration" Jonathan Mayhew, 1750

Studies of UPC at LHC will address many (though not all) of the benchmark issues of HERA III proposal including

Small x physics with protons and nuclei in **a factor of ten** *larger energy range though at higher virtualities both in inclusive and diffractive channels*

Interaction of small dipoles at ultrahigh energies - approach to regime of black disk limit, color opacity