MULTIPLE INTERACTIONS AND ENERGY LOSSES

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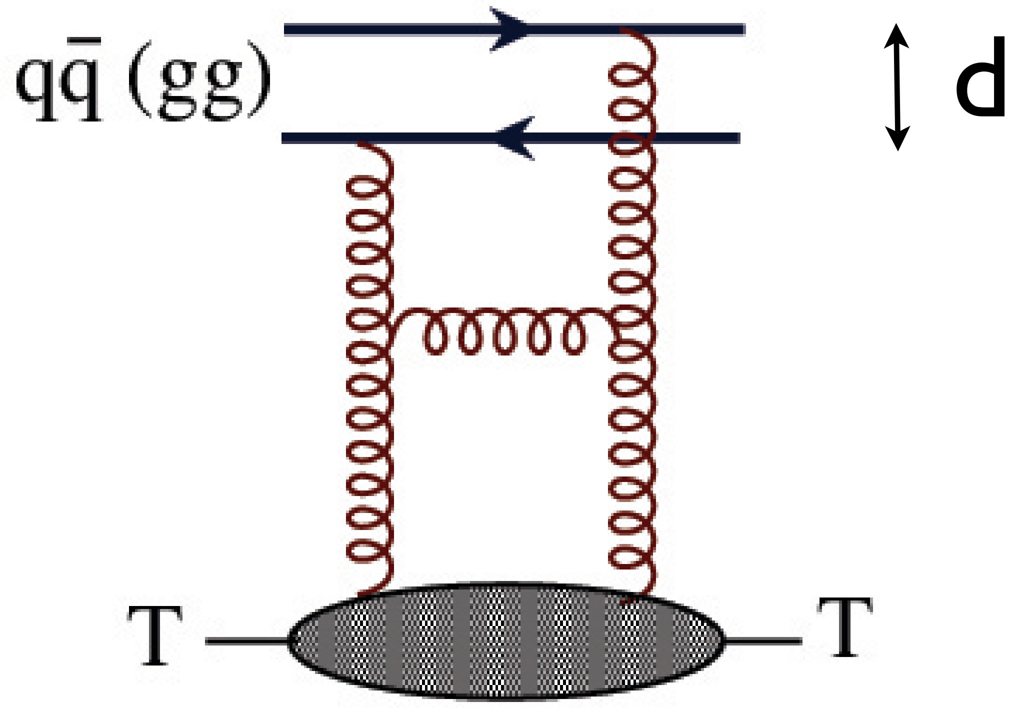
Introduction: How strong is the interaction of small dipoles?

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

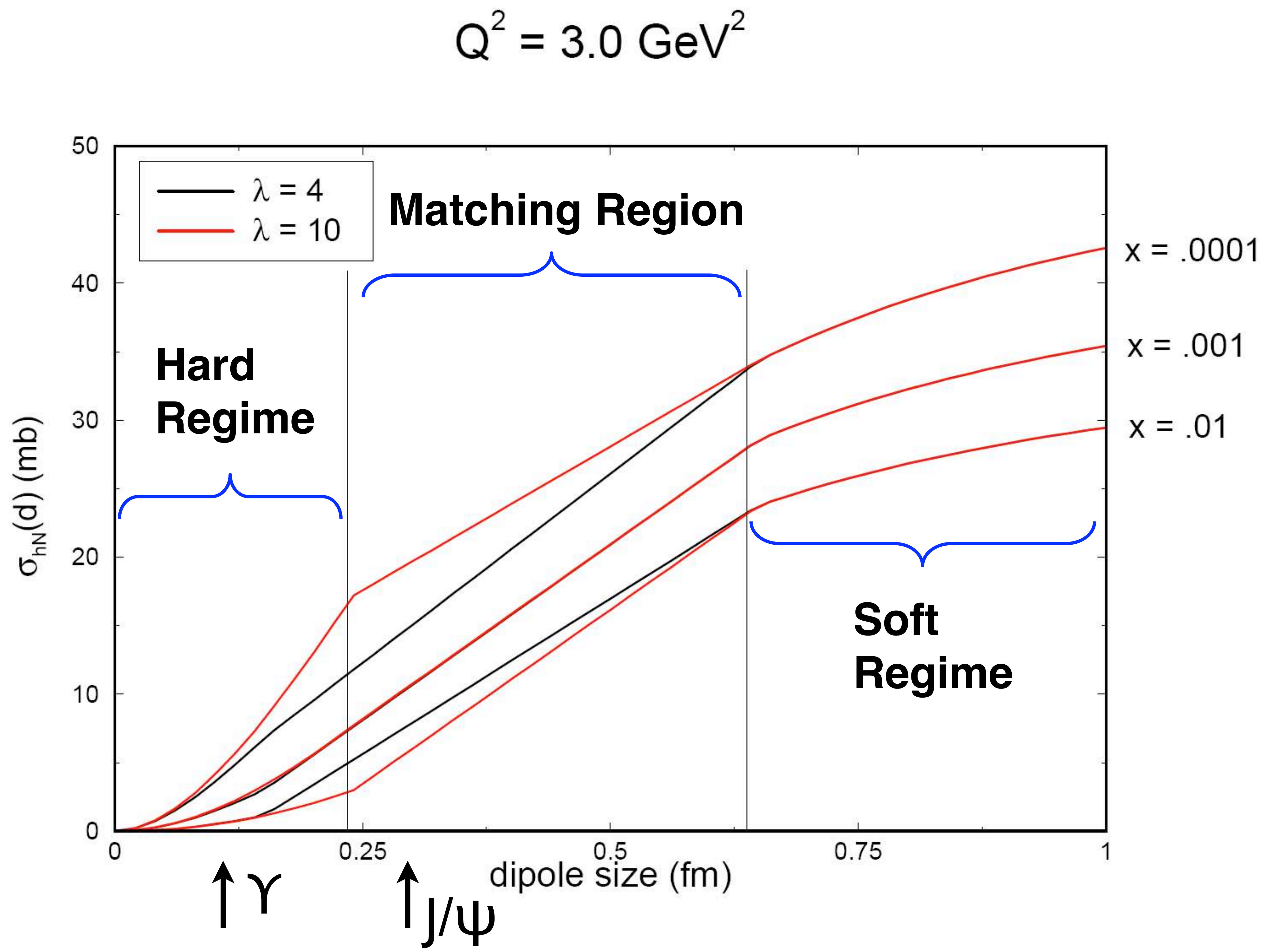
review of the most topics discussed in this talk see

& Weiss, Annual Review of Nucl. & Particle Physics 05

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

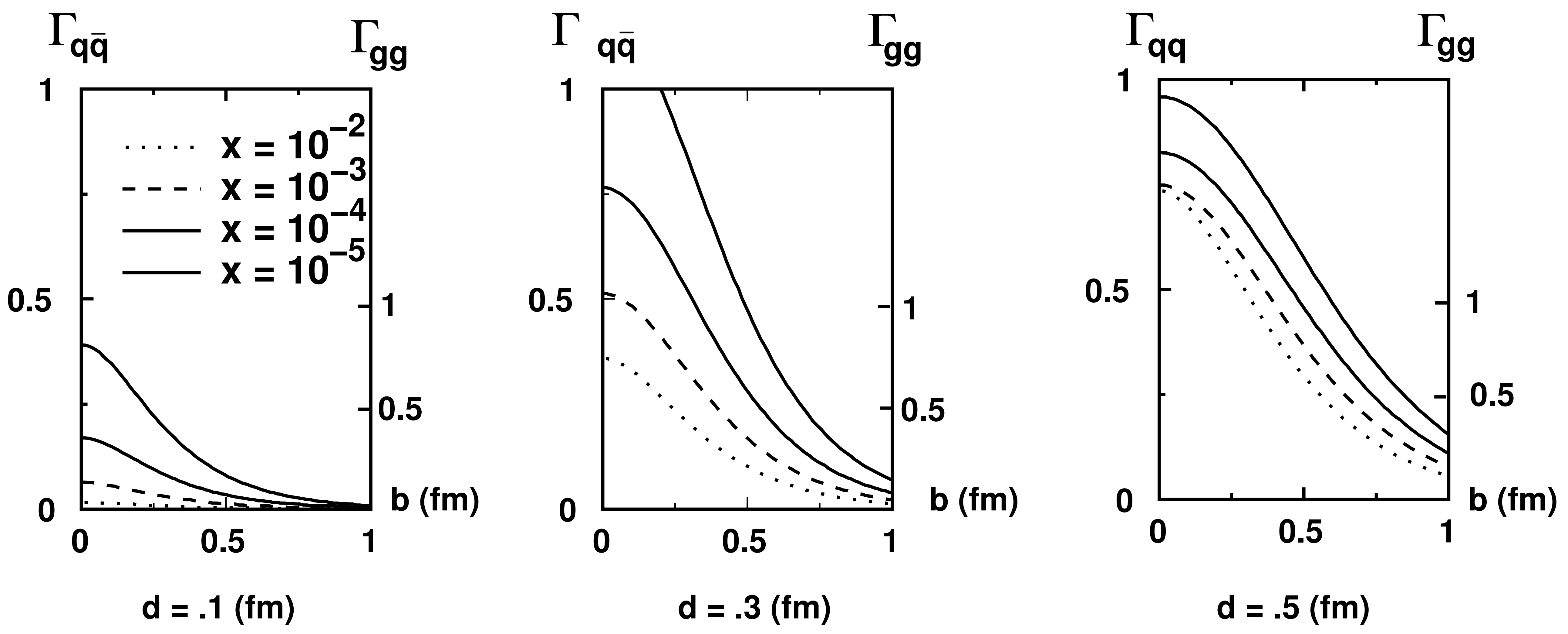
Combine with: analysis of exclusive hard processes
(t-dependence of the dipole - nucleon scattering)

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

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

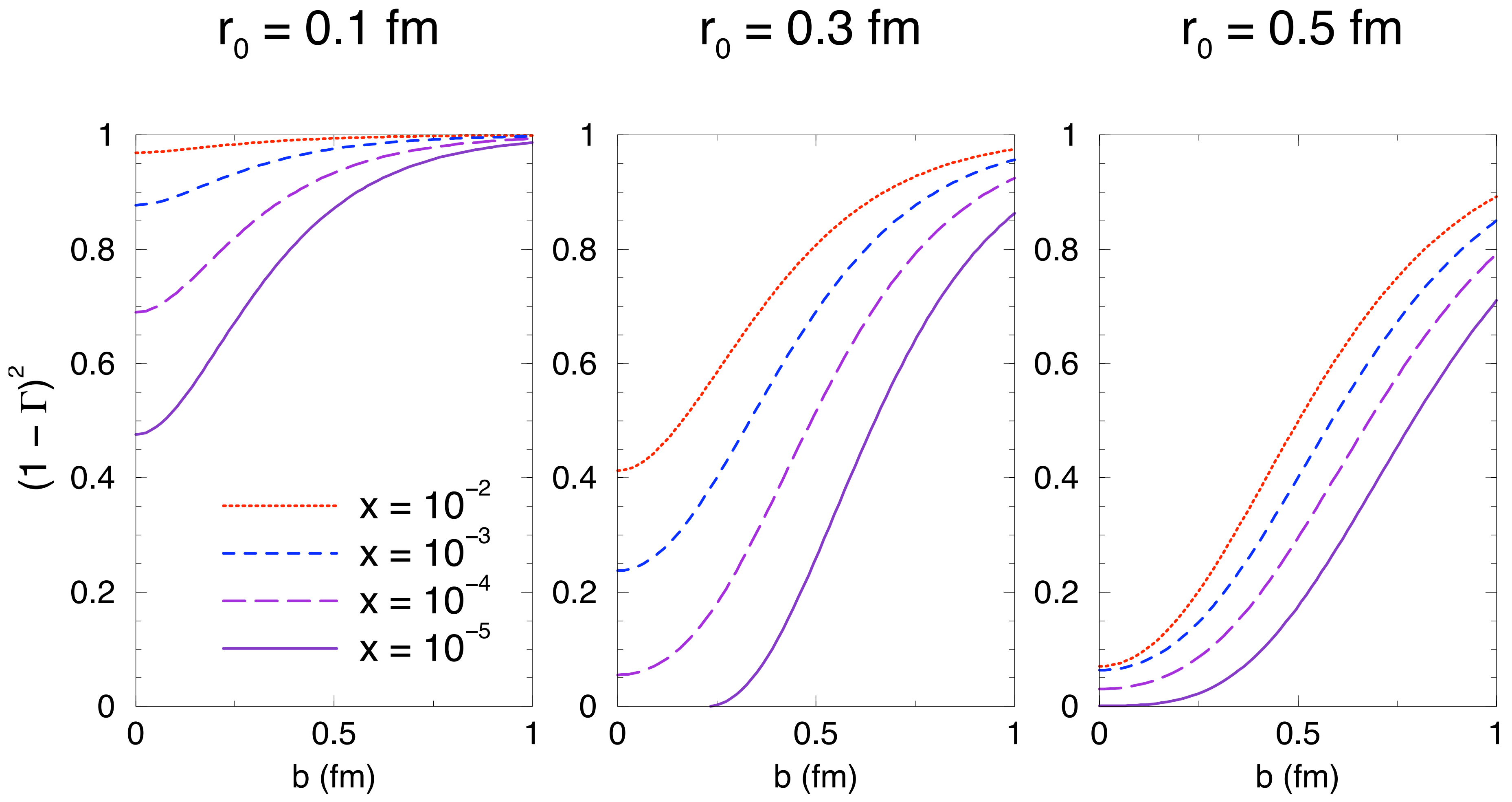
$\Gamma = 1$ *corresponds to regime of complete absorption - BDR*

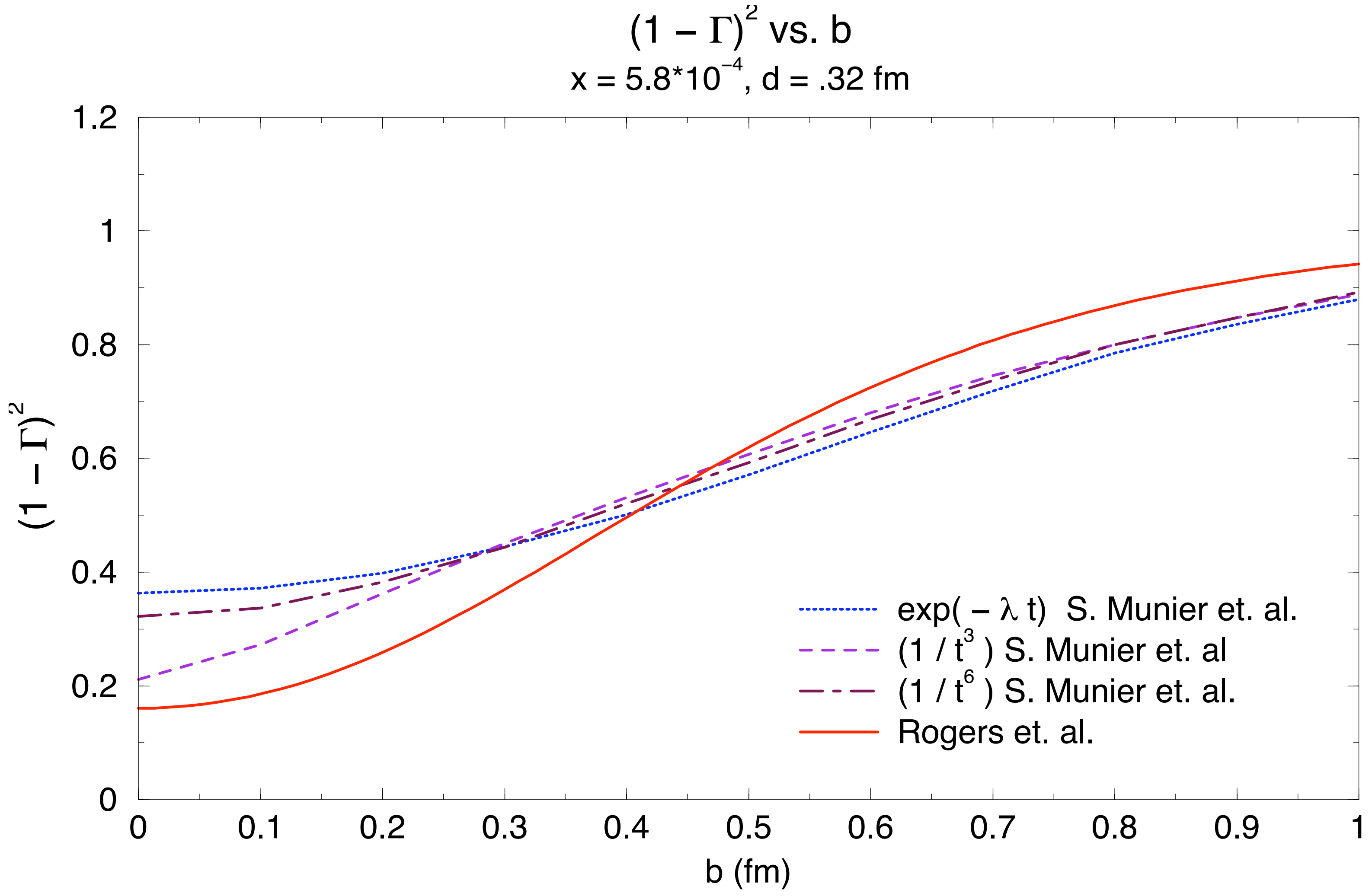
T.Rogers et al



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 leading twist gluon shadowing effect is rather small

↓

Significant fractional energy losses and p_t broadening for partons propagating through black media (FS 01-03)

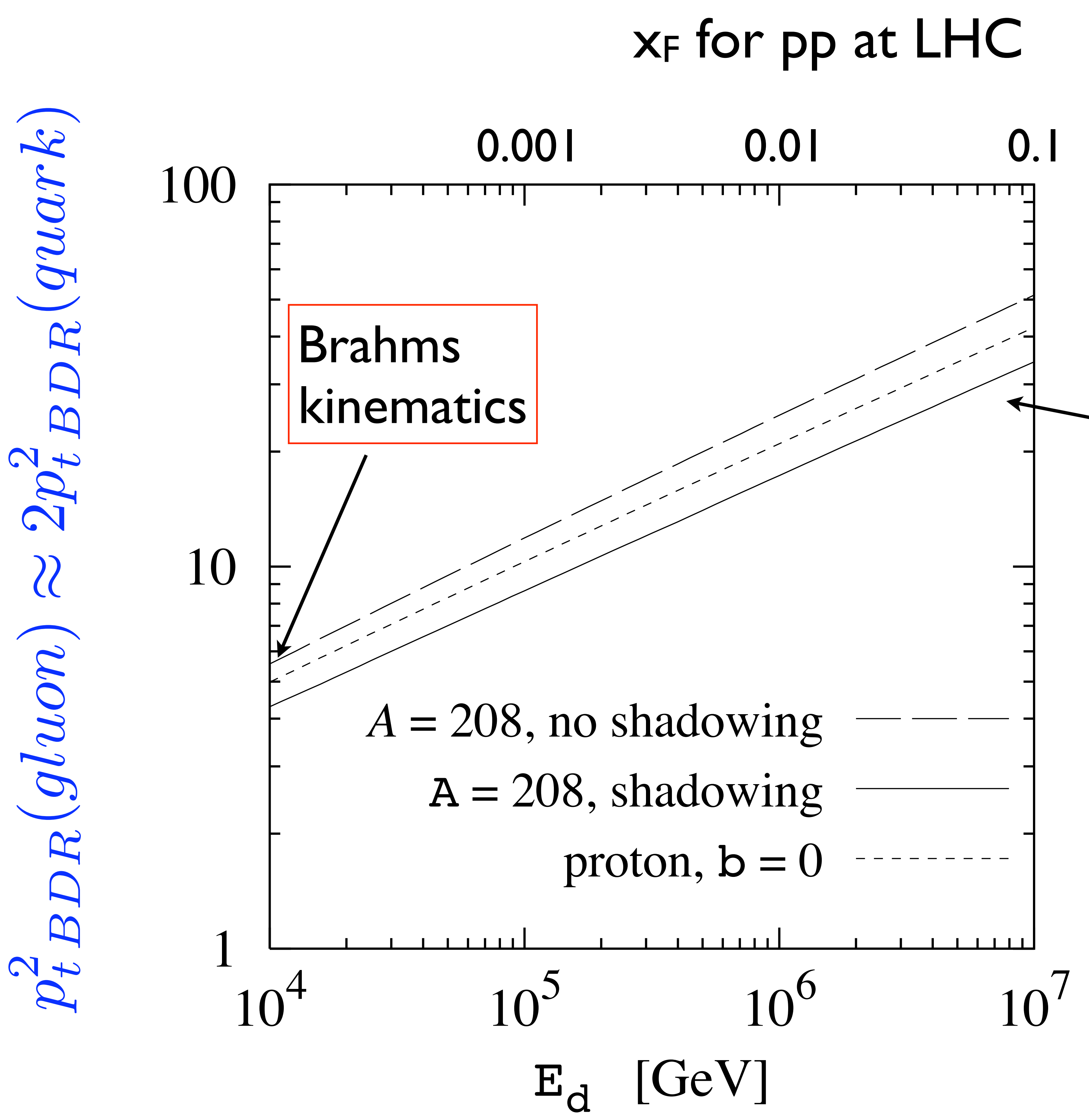
Suppression of the leading hadron production in pA scattering at large p_t comparable to the scale of Black disk regime at given energy (FS 01-06)

⇒

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

$$p_{t\,BDR} \sim \frac{\pi}{2d}$$

where d is the minimal size of the gg (qq) dipole for which $\Gamma(b=0) \geq 1$ in LT



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

Difference is in the spread in b

x-dependence of transverse distribution of gluons

can be extracted from t -dependence of the exclusive vector meson production - QCD factorization theorem for exlcusive processes, Collins &FS 97

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

For x=0.05 it is much harder than e.m. form factor (dynamical origin - chiral dynamics) $\Rightarrow$ more narrow transverse distribution of gluons than a naive expectation. (FS, Weiss -02-03)

The gluon transverse distribution is given by the Fourier transform of the two gluon form factor as

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

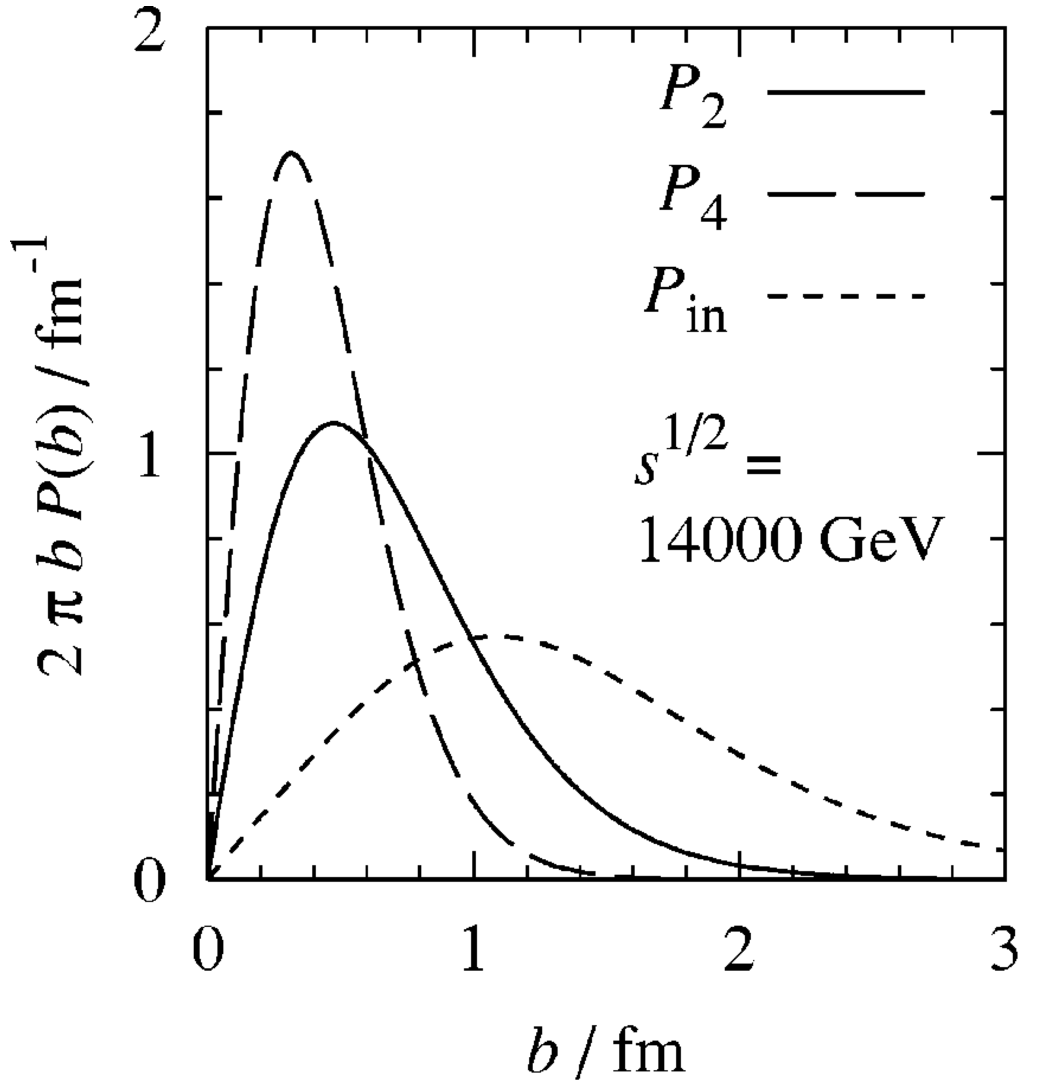
It is normalized to unit integral over the transverse plane: $\int d^2\rho \, F_g(x,\rho;Q^2) = 1.$

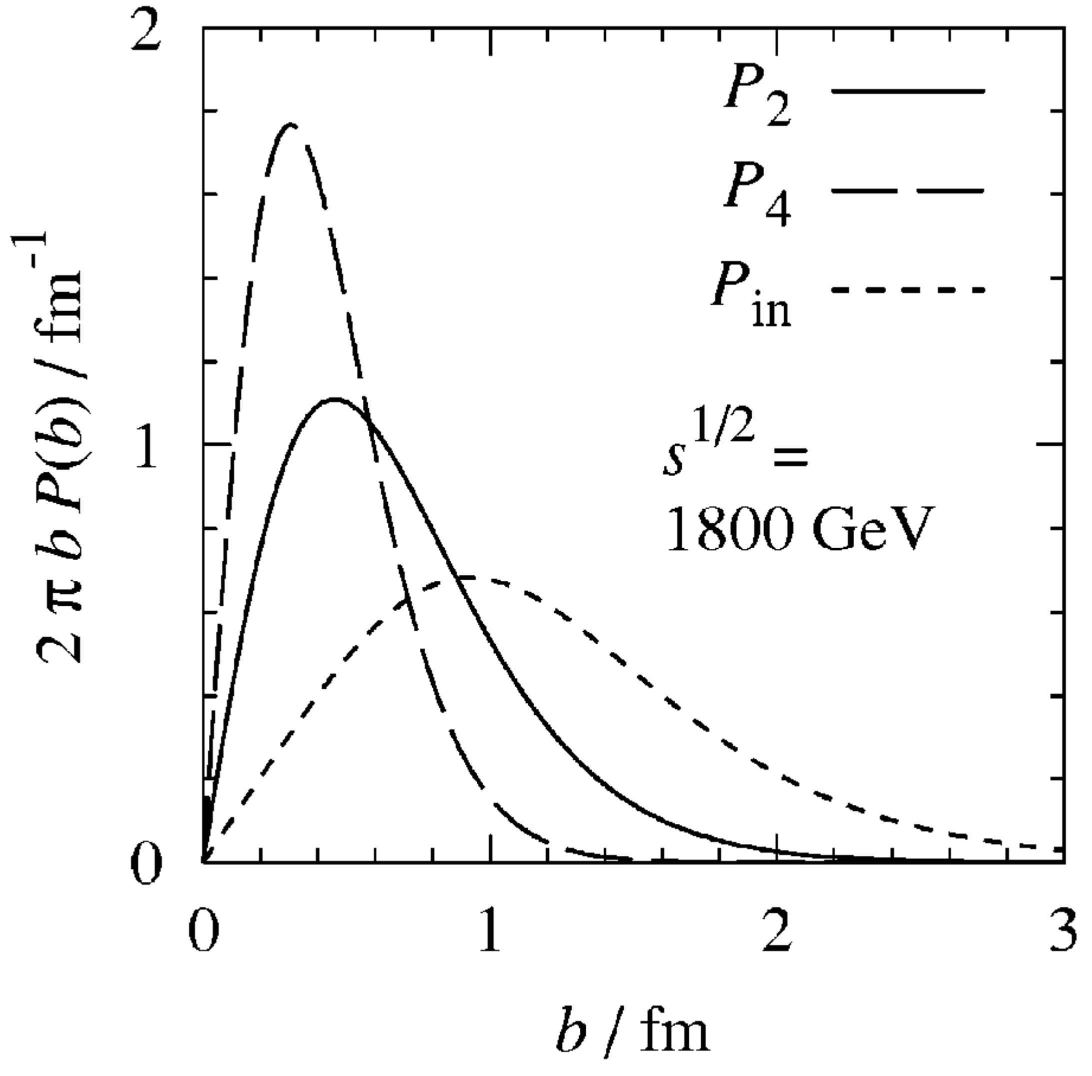
$$F_g(x,\rho) = \frac{m_g^2}{2\pi} \left(\frac{m_g\rho}{2}\right) K_1(m_g\rho)$$

The Q^2 dependence is accounted using LO DGLAP evolution at fixed ρ

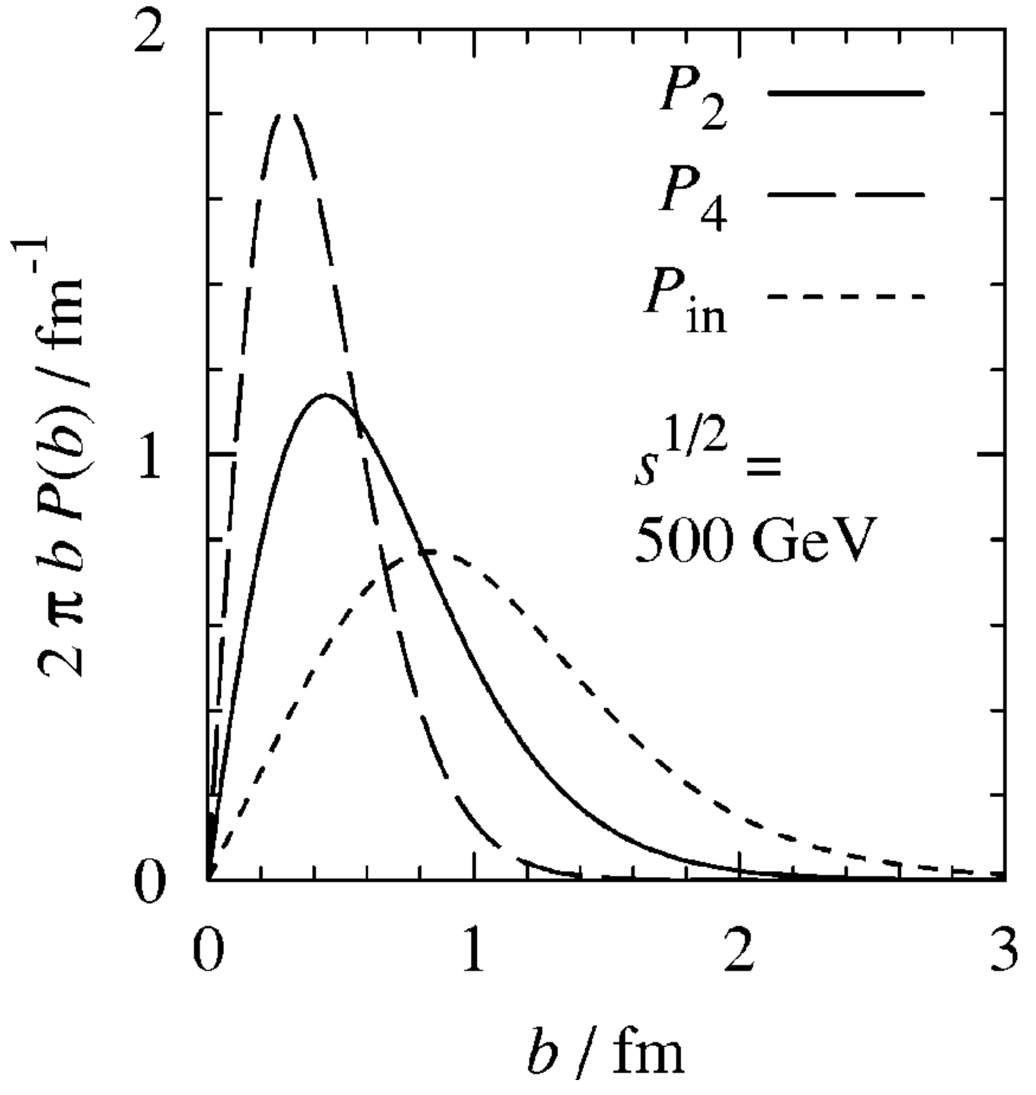
Implications for LHC - impact parameters for collisions with new particle production are much smaller than for generic inelastic collisions.

Using HERA data and fits to elastic pp data we can quantify this.





Difference between b-distributions for minimal bias and dijet, four jet events strongly increases with increase of incident energy. *Solid lines:* b–distributions for the dijet trigger, $P_2(b)$, with $q_\perp = 25\,GeV$, as obtained from the dipole–type gluon ρ–profile. *Long–dashed line:* b–distribution for double dijet events, $P_4(b)$. *Short–dashed line*: b–distribution for generic inelastic collisions.



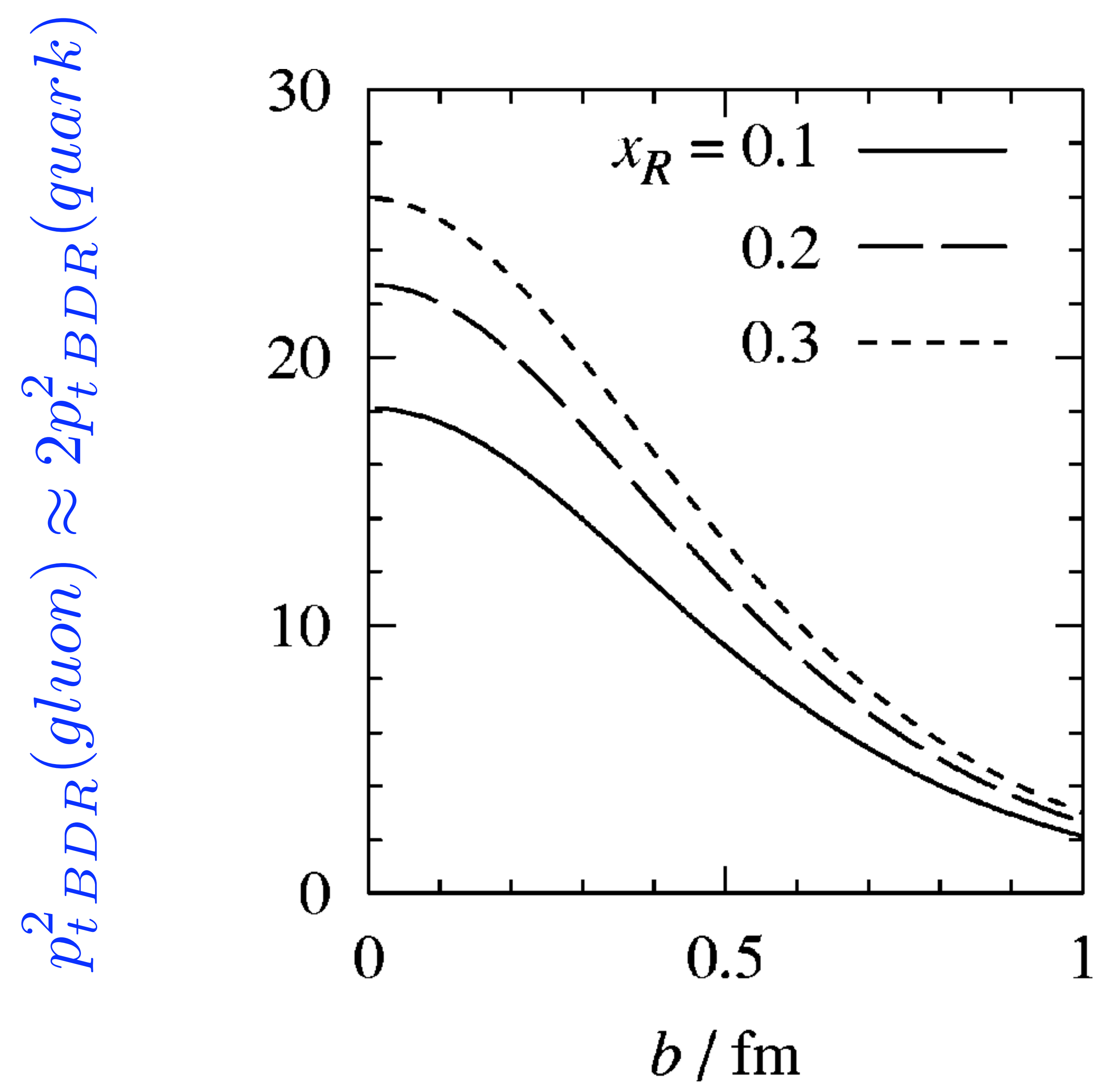
$P_2 \equiv$ 2- jet trigger

$P_4 \equiv$ 4- jet trigger

$P_{in} \equiv$ minimum bias

Distribution over b for different triggers

Warning: $P_4(b)$ is calculated assuming that there are no transverse correlations between partons, while our analysis of CDF 3jet +photon data suggests a factor of 2 enhancement due to the transverse correlations. If so, the change of b distribution between 2 jet and 4 jet trigger is a factor of 2 smaller.



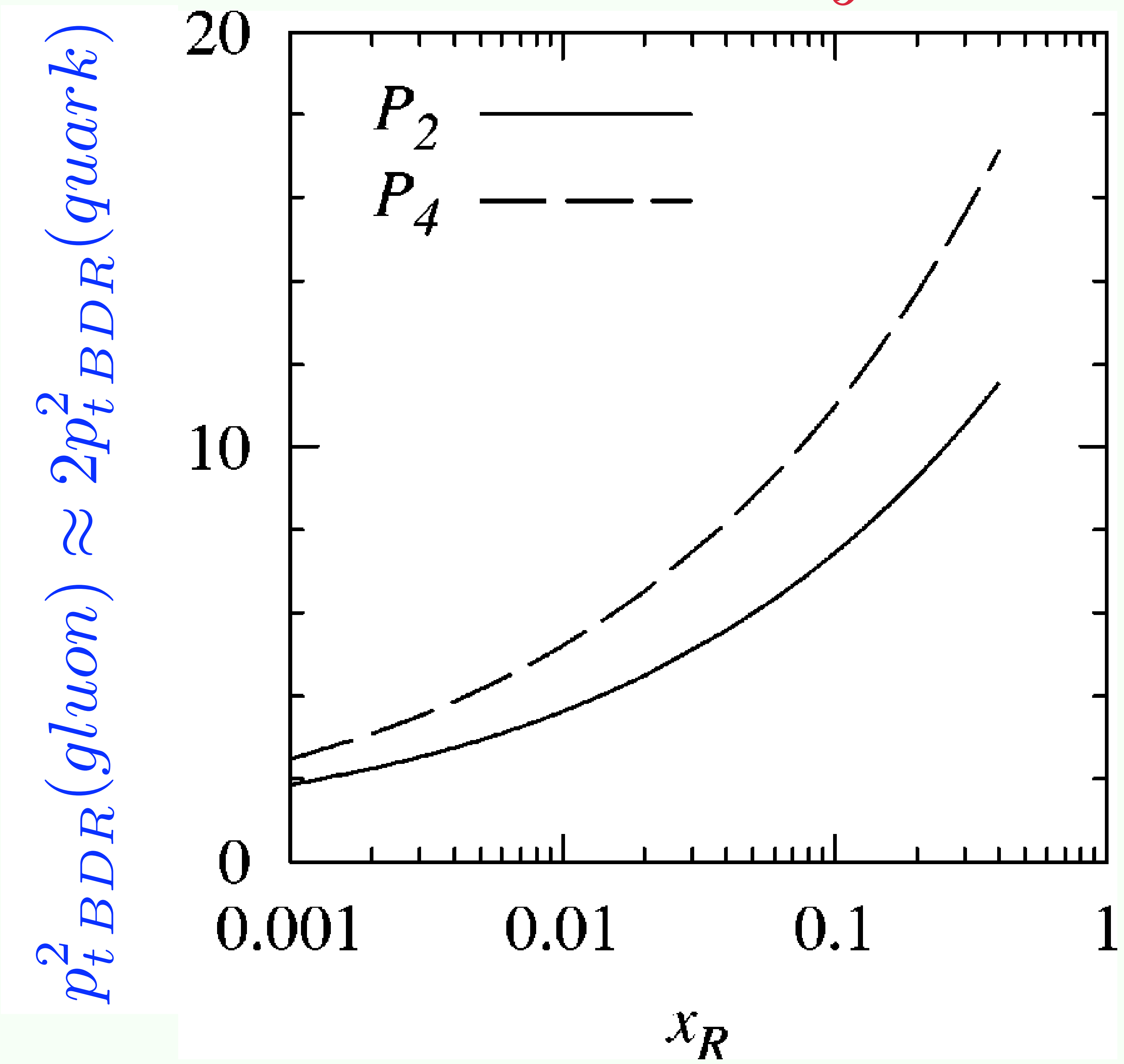
Also, a spectator parton in the BDR regime loses a significant fraction of its energy (> 10%) *similar to electron energy loss in backscattering of laser off a fast electron beam.*

For different triggers we now can take into account distribution over b.

For events with hard dijet at zero rapidity

$$\langle p^2_{\perp,\mathrm{BDR}} \rangle \equiv \int d^2b \; p^2_{\perp,\mathrm{BDR}}(b) P_2(b)$$

average with b-distribution enforced by dijet trigger



Dijet trigger allows to maximize effects of ``black interactions" of small-- x partons

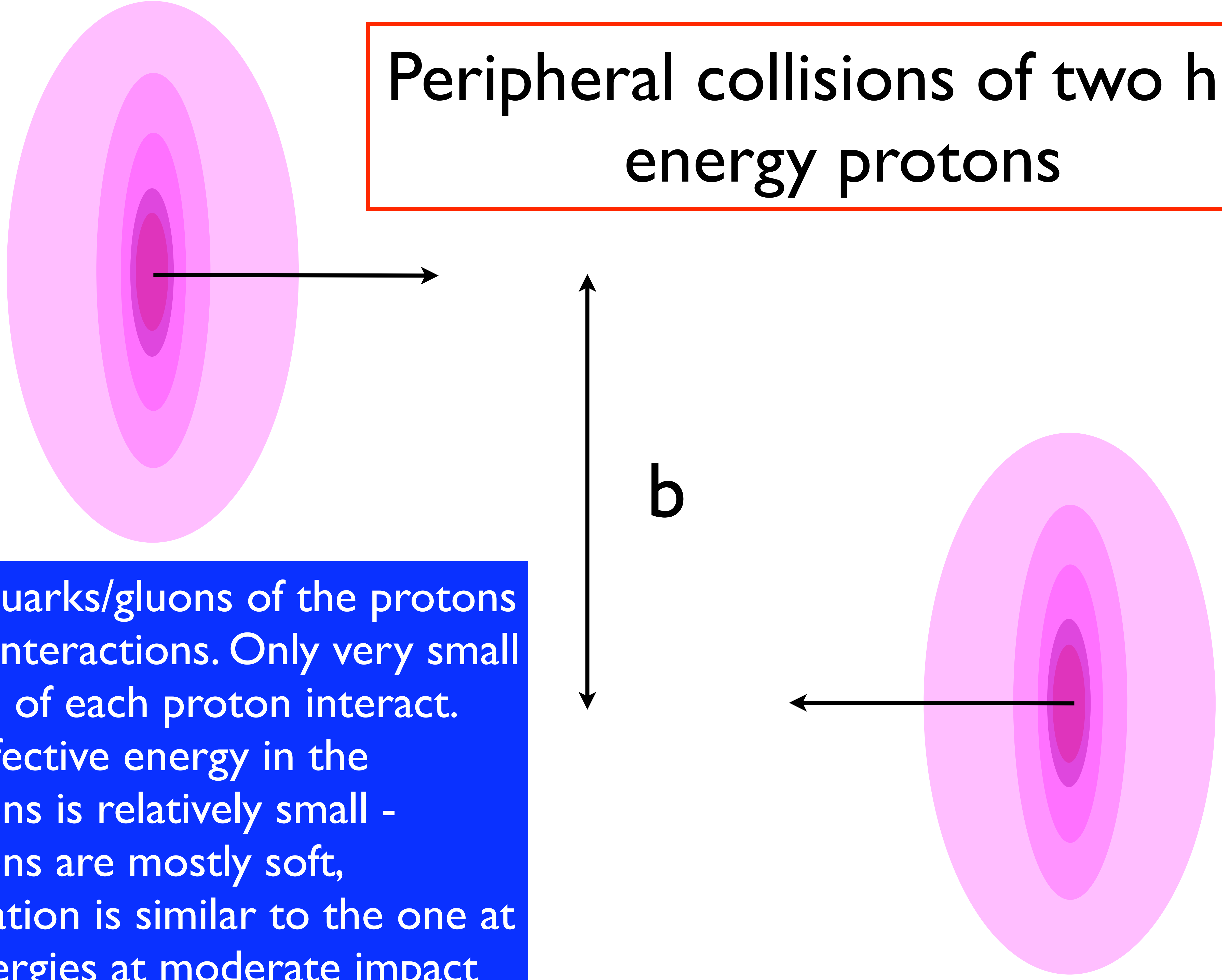
$p^2_\perp \gg \Lambda^2_{QCD} \quad \longrightarrow$ self consistent picture

Effective gluon densities ~ to central pA collisions

Warning: x>0.01 corresponds to scattering off gluons with x <10^{-5}. Our extrapolation to these x does not include possible slowdown of the increase of gluon density at these x suggested by the recent studies (Altarelli et al , Ciafaloni et al 03). In line with cosmic ray data near GZK.

Final states as a function of impact factor

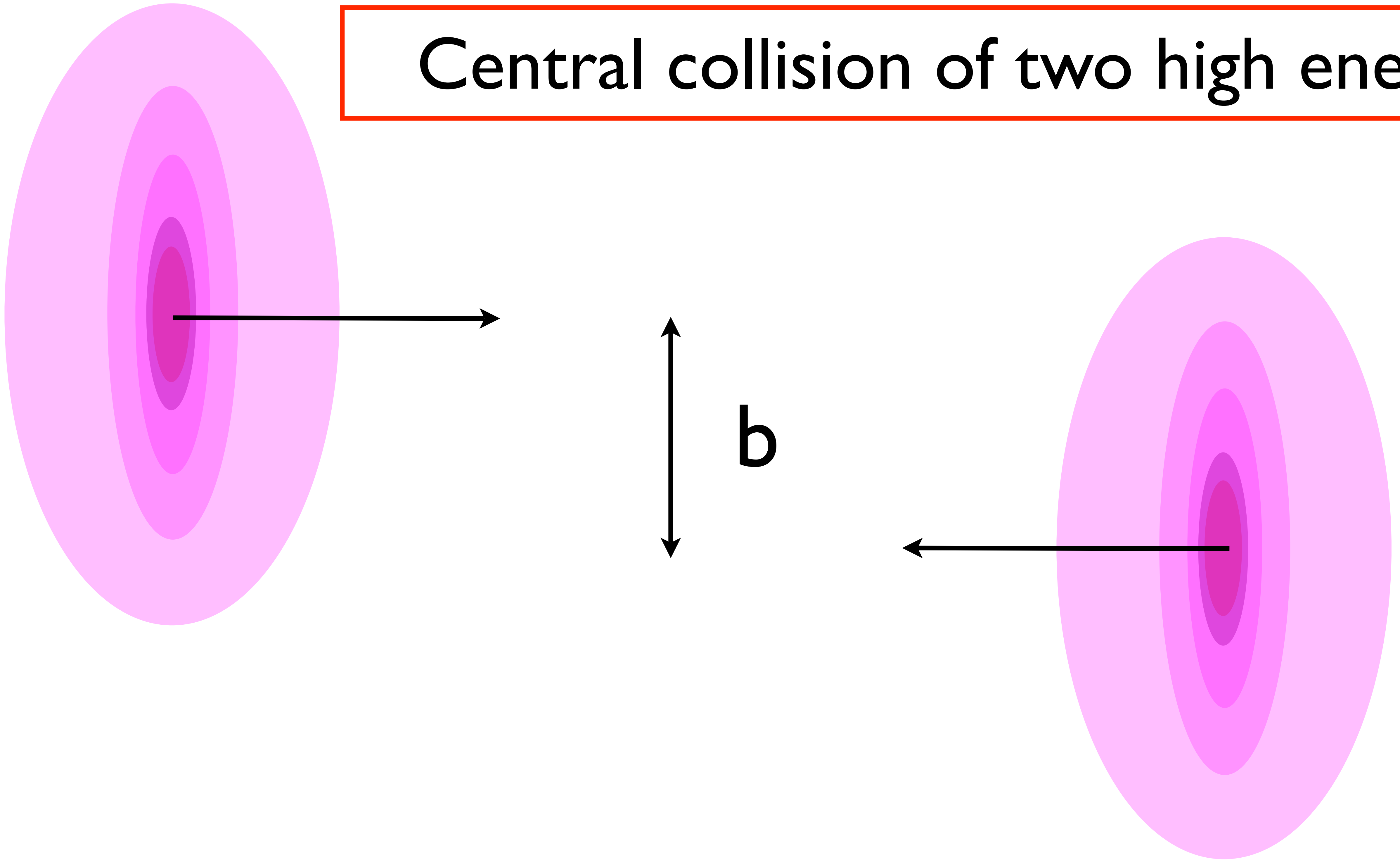
Peripheral collisions of two high energy protons



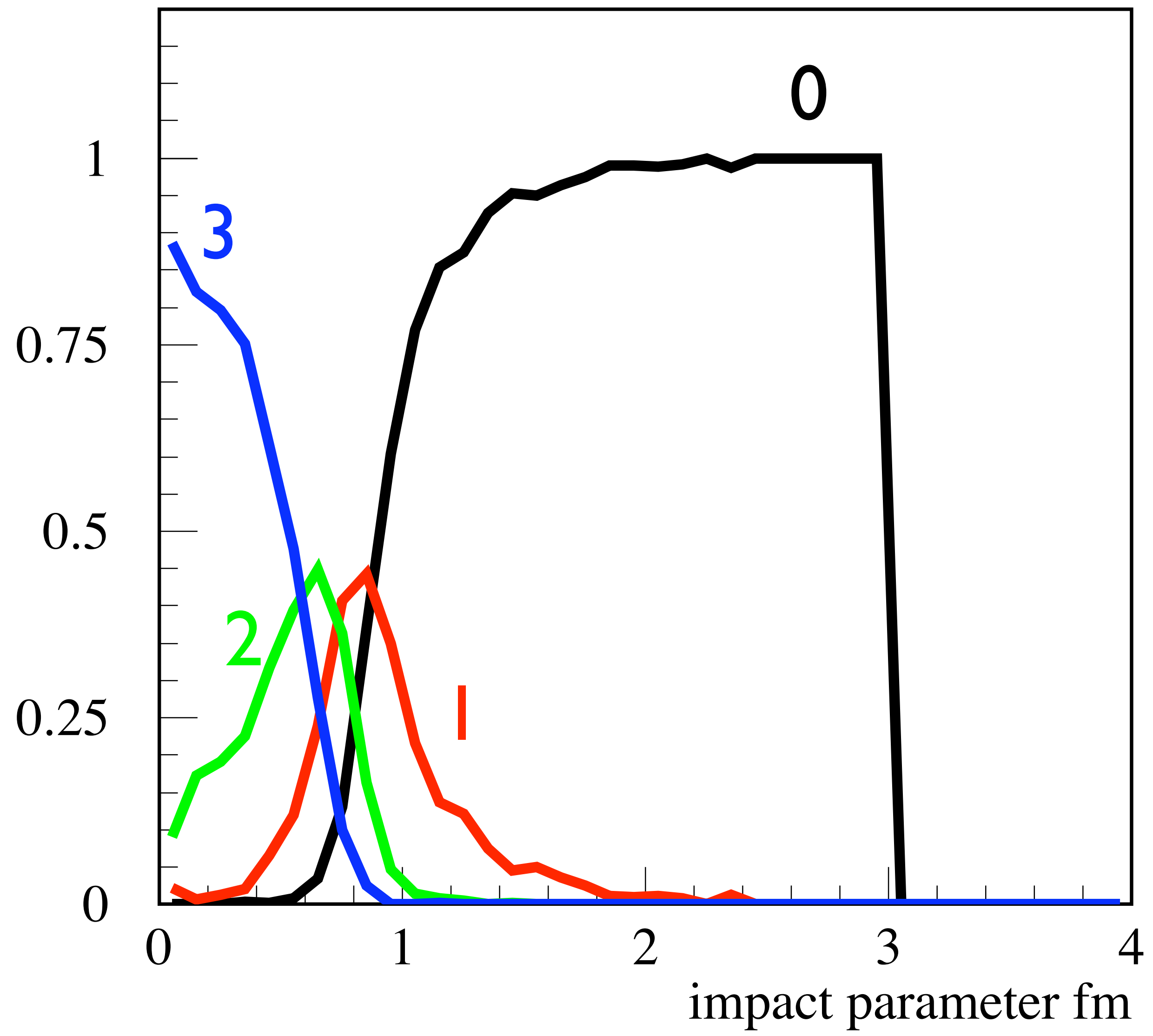
Valence quarks/gluons of the protons miss the interactions. Only very small x partons of each proton interact. Hence effective energy in the interactions is relatively small - interactions are mostly soft, fragmentation is similar to the one at lower energies at moderate impact parameters

Limiting fragmentation component of the collisions. Scaling violation due to change of the fraction of the inelastic collisions where valence quarks did not get large transverse kicks. Competition - increase on <b> vs expansion of BDR region

Central collision of two high energy protons



Valence quarks/gluons of the protons are interacting with probability ~ one, loosing energy and getting large transverse momenta growing with energy. Soft interactions are suppressed - minimal scale/virtuality of strong interaction is few GeV and growing with energy. Gross suppression of particle production in fragmentation region, much higher rate of hadron production away from the fragmentation region.



Drescher & MS 07

Number of valence quarks which received large transverse momentum in pp collision at LHC as a function of impact parameter

Qualitative predictions for properties of the final states with dijet trigger

- The leading particle spectrum will be strongly suppressed compared to minimal bias events since each parton fragments independently and splits into a couple of partons with comparable energies. The especially pronounced suppression for nucleons: for $z \geq 0.1$ the differential multiplicity of pions should exceed that of nucleons.

- A large fraction of the dijet tagged events will have no particles with $z \geq 0.02 - 0.05$. This suppression will occur simultaneously in both fragmentation regions, corresponding to the emergence of long--range rapidity correlations between the fragmentation regions ⇒ large energy release at rapidities y= 4 - 6.

- Average transverse momenta of the leading particles $\geq 1\ GeV/c$

Many similarities with expectations for spectra of leading hadrons in central pA collisions.

Conclusions

- *Many of the discussed effects are not implemented or implemented in a very rough way in the current MC's for LHC and cosmic rays*

- *Small x physics is an unavoidable component of the new particle physics production at LHC. and near GZK. Significant effects already for Tevatron.*

- *Minijet activity in events with heavy particles should be much larger than in the minimum bias events. Large uncertainties in extrapolation from Tevatron since relevant gluon fields are a factor of > 3 stronger.*

Did not have time to discuss

- *Total opacity in pp scattering at small b ($\Gamma=1$) is due transition from soft to semi hard QCD - consistent with expected changes of the inelastic events for small impact parameters.*

- *Double hard processes at Tevatron provides evidence for transverse correlations between partons. Maybe due to lumpy structure of nucleon at low scale (constituent quarks). Further studies of transverse correlations are necessary both at Tevatron and at RHIC in pp and pA scattering to improve modeling of LHC event structure.*