Transverse structure of the nucleon and onset of the black disk limit

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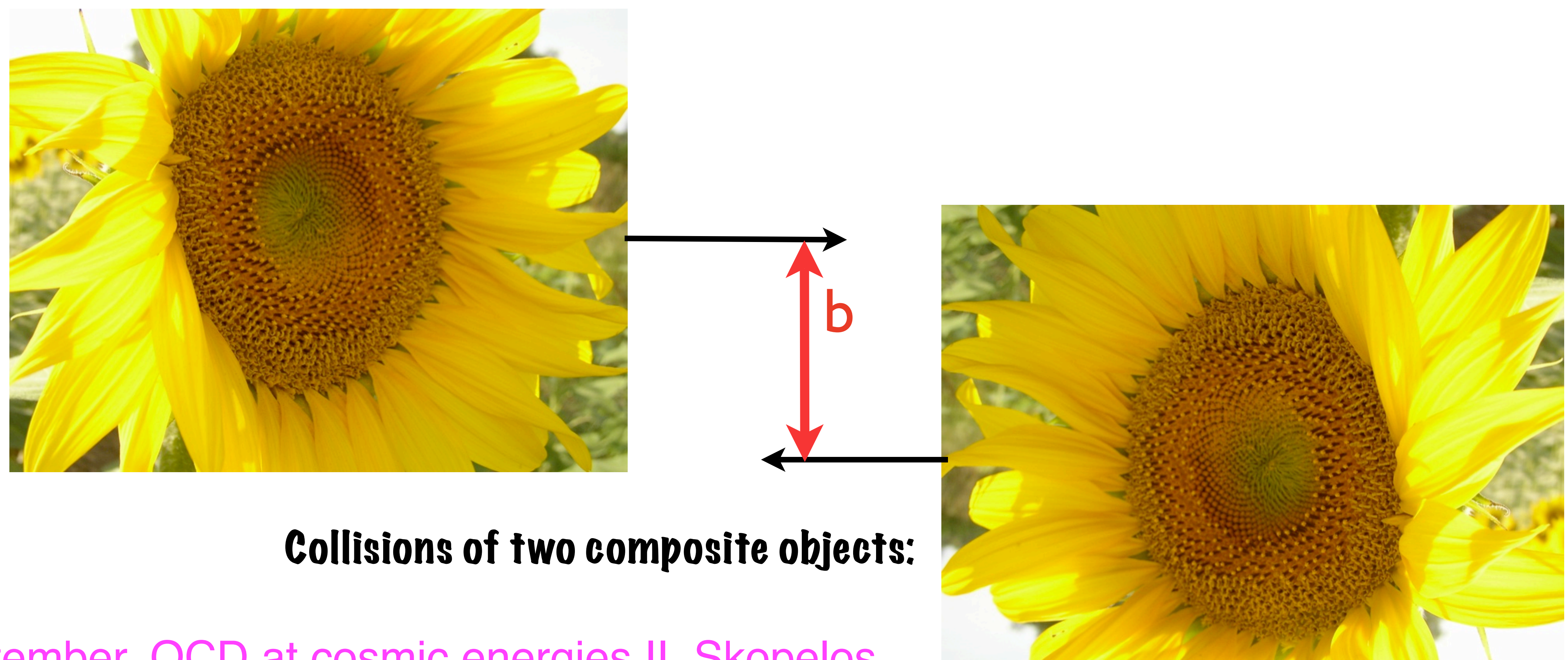


Collisions of two composite objects:

27 September, QCD at cosmic energies II, Skopelos

Outline

- *Three dimensional structure of high energy nucleon*
- *Onset of black regime of interaction for small dipoles*
- *Centrality trigger for pp collisions.*
- *Structure of inelastic final states in central pp/pA collisions & comments on peripheral collisions*
- *Implications for elastic and total cross sections - universality at asymptotic energies*

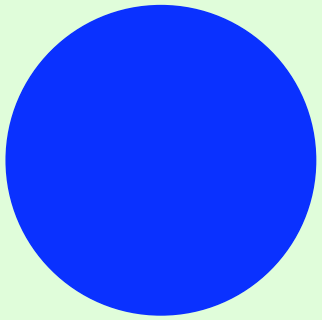
Two ingredients crucial for building a realistic description of pp/pA interactions at LHC energies and for cosmic rays:

- Realistic implementation of information about transverse structure of the parton distributions in nucleon - generalized parton distributions - studied at HERA in exclusive processes.

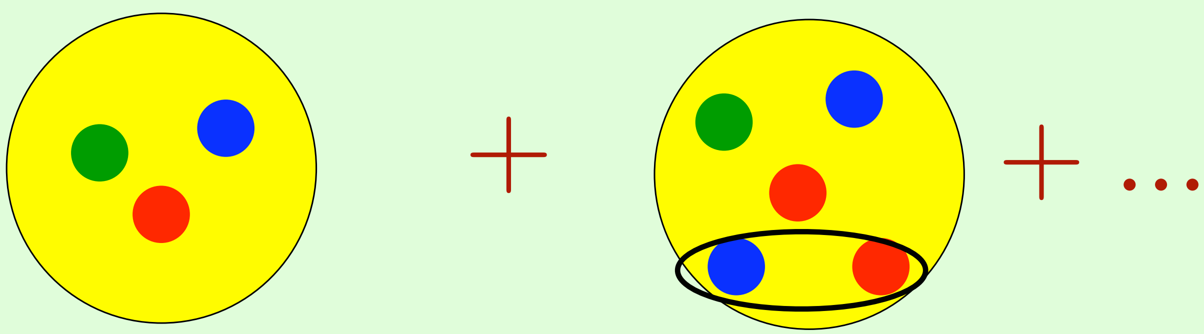
- Breakdown of the leading twist approximation for the interaction of partons up to rather large virtualities - approach to ***black disk limit***. *Problem - current MC are forced to introduce a cutoff on minimal p_t of the jets which is a strong function of pp energy but not a function of parton's x.*

- Another effect which maybe important: *transverse correlations between the partons*

Image of nucleon at different resolutions, q. Rest frame.



resolution 1 fm, $q <$ 300 MeV/c

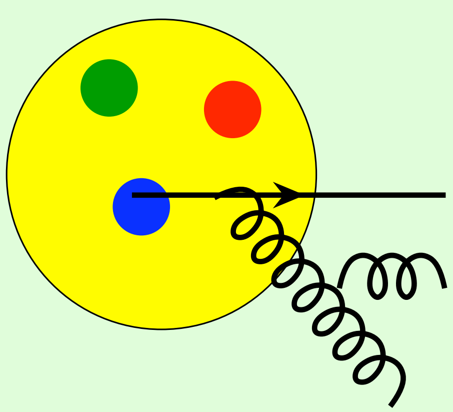


$q\bar{q}$ pair in π

resolution 1/3 fm

$1000 > q > 300$ MeV/c

Constituent quarks, pions (picture inspired by chiral QCD)



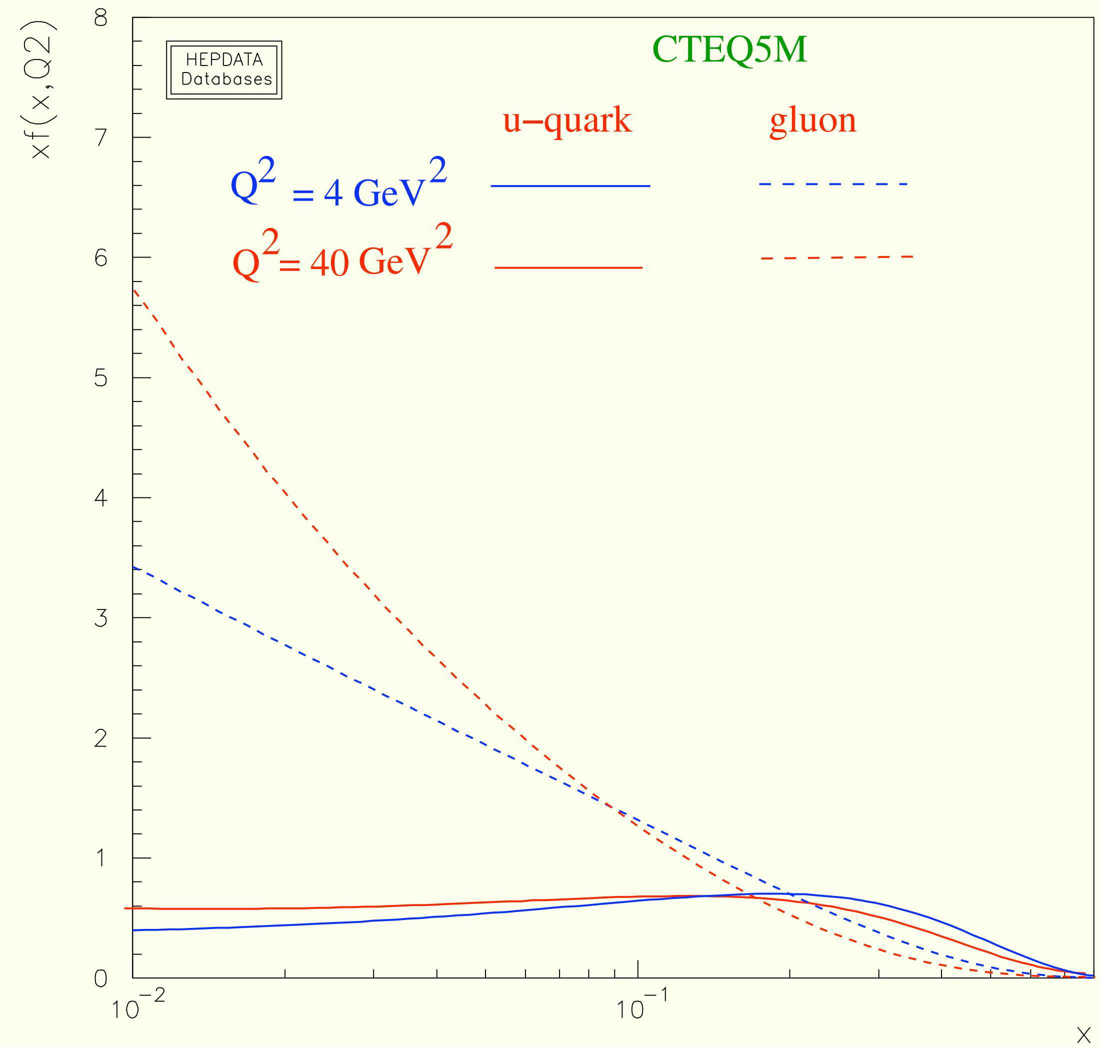
$q >$ 1000 MeV/c

pQCD evolution

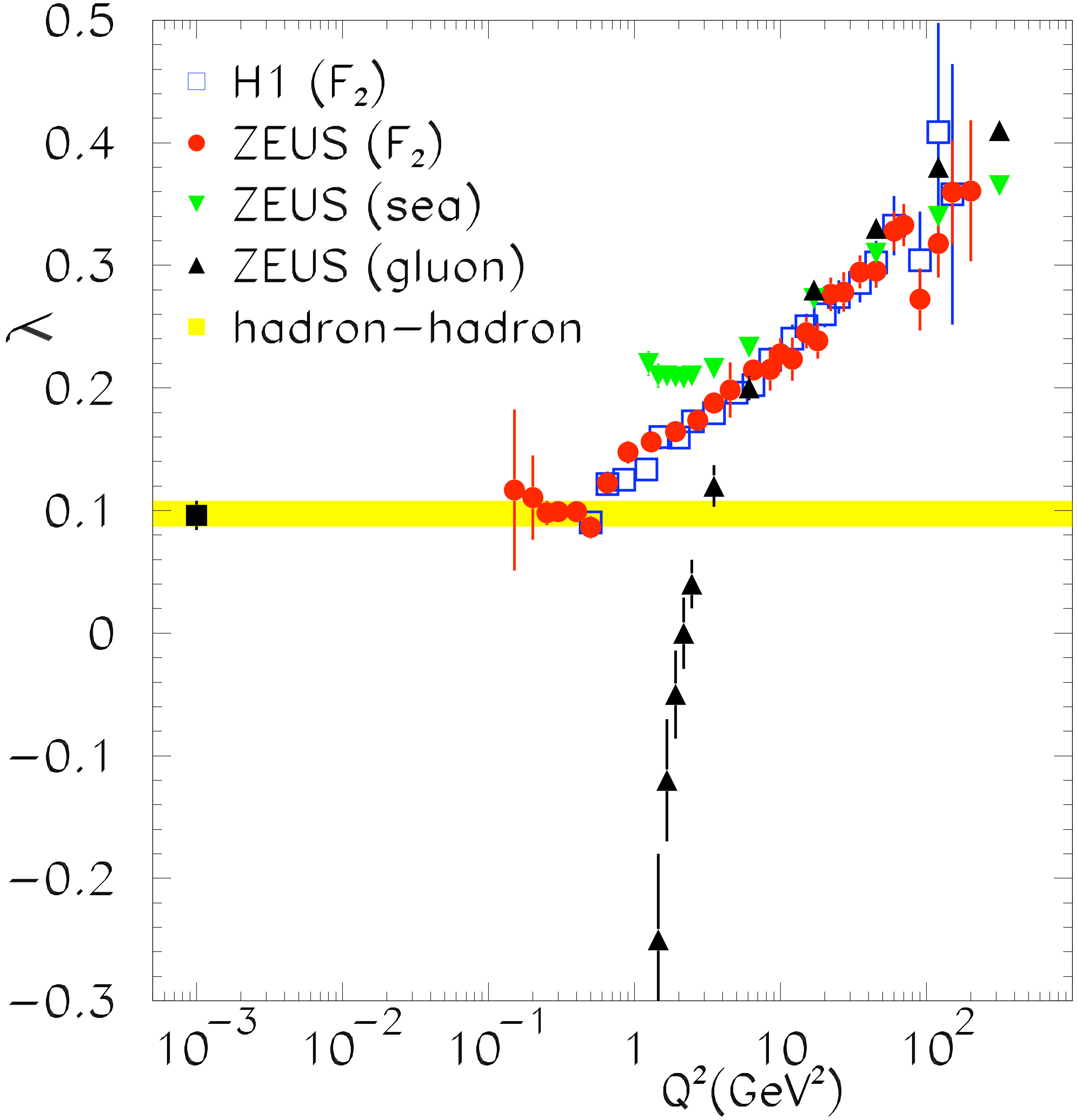
Key features of high energy QCD:

- Slow space-time evolution of the fast component of the high energy wave functions of colliding hadrons (Lorentz slow down)

- Already at a rather modest resolution of the probe, Q~ 2 GeV, nucleon consists of not simply three quarks and few gluons but of tens of constituents and the number of constituents rapidly grows with energy.

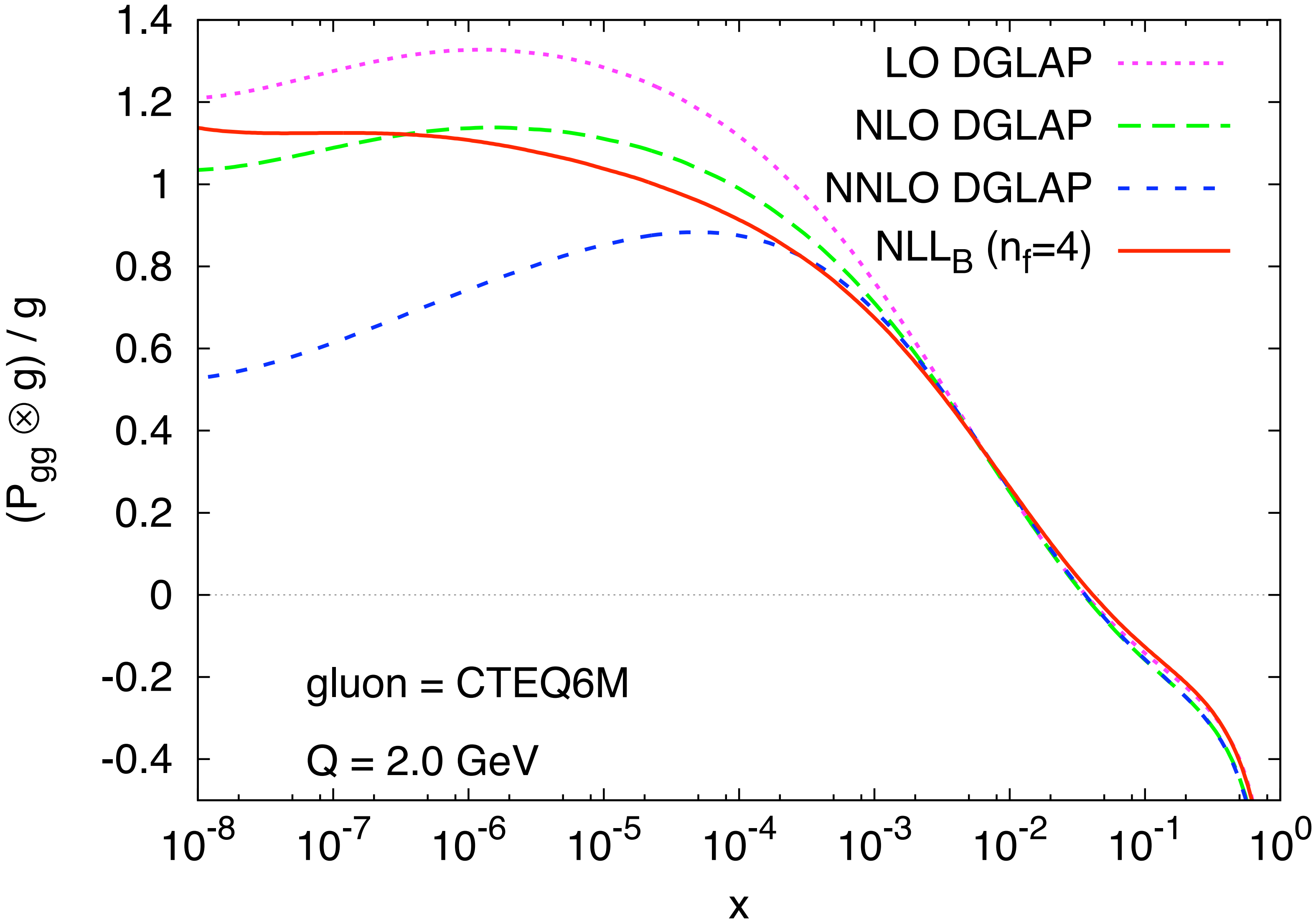


- Gluons carry ~50% of the nucleon momentum at the resolution scales as low as $Q^2 \sim m_N^2$ (nonperturbative dynamics). Speeds up generation of strong gluon fields at small x - high densities before log x effects become important



Fits: $F_{2p}(x,Q^2) \propto x^{-\lambda}$ $x\bar{q}(x,Q^2) \propto x^{-\lambda}$

$$xg(x,Q^2) \propto x^{-\lambda}$$



Scaling violation for gluons at small x
- from G.Salam study

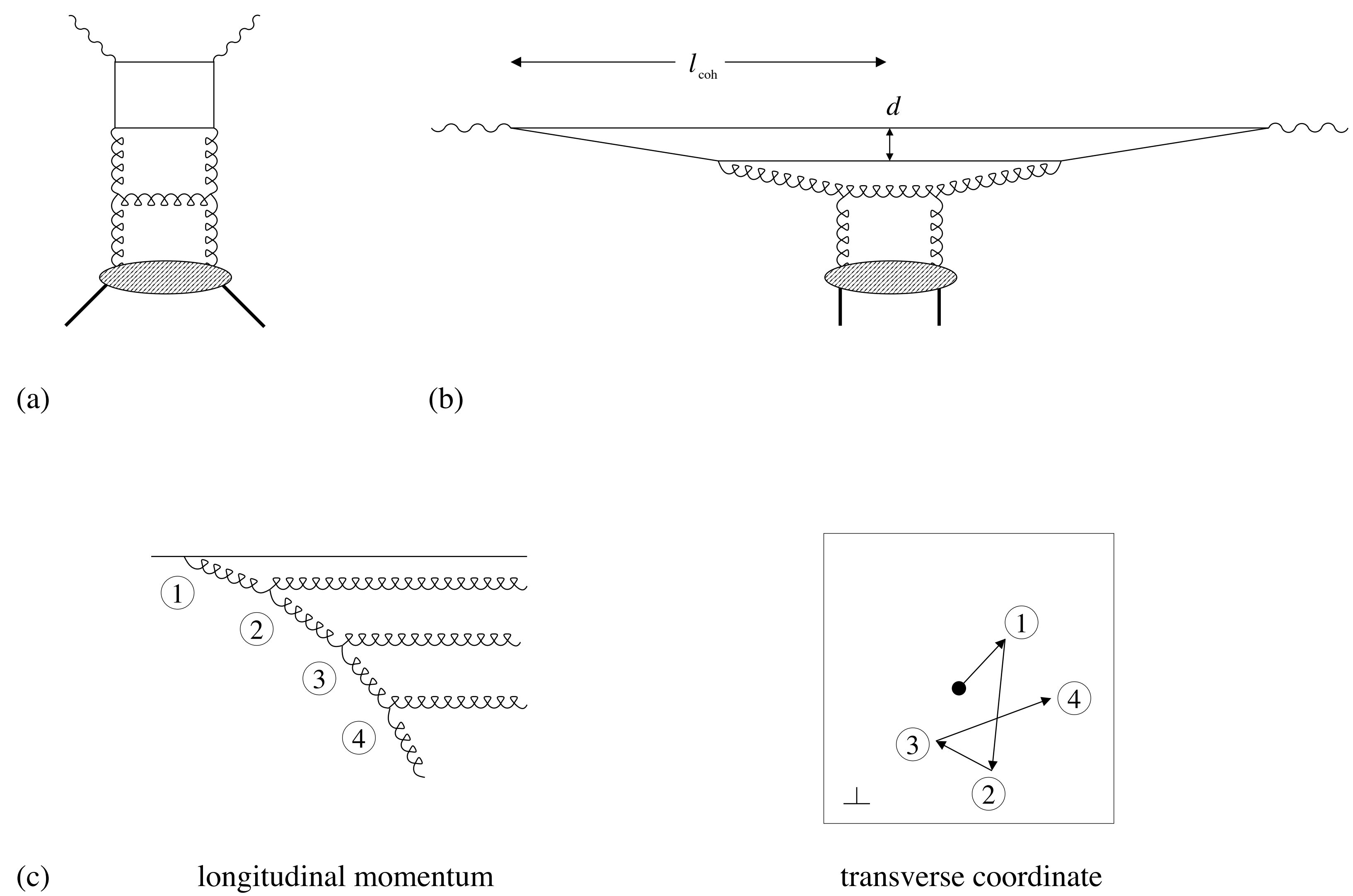
Current studies of the perturbative QCD lead to expectation that the growth of the parton densities predicted by LO DGLAP is weakly modified when NLO is included and the attempt to sum various extra terms does not modify result noticeably down to smallest x relevant for GZK.

Can we trust pQCD prediction that the growth persist down to very small x?

Depends on transverse size of the system - in practical situation answer is NO !!! already in the region where log x effects are moderate and could be delt by NLO

Image of nucleon at different resolutions, q. Fast frame.

Energy dependence of the transverse size of small x partons.



$R^2(n) \approx \frac{n}{k_{t0}^2}$ Random walk in b-space (Gribov 70). *(Drunken sailor walk)*

Length of the walk $\propto$ rapidity, y as each step a change in rapidity of few units.

$$n \propto y \implies R^2 = R_0^2 + cy \equiv R_0^2 + c' \ln s$$

Implications:

(a) The transverse size of the soft wee parton cloud should logarithmically grow with energy.

Logarithmic increase of the t-slope of the elastic hadron-hadron scattering amplitude with energy:

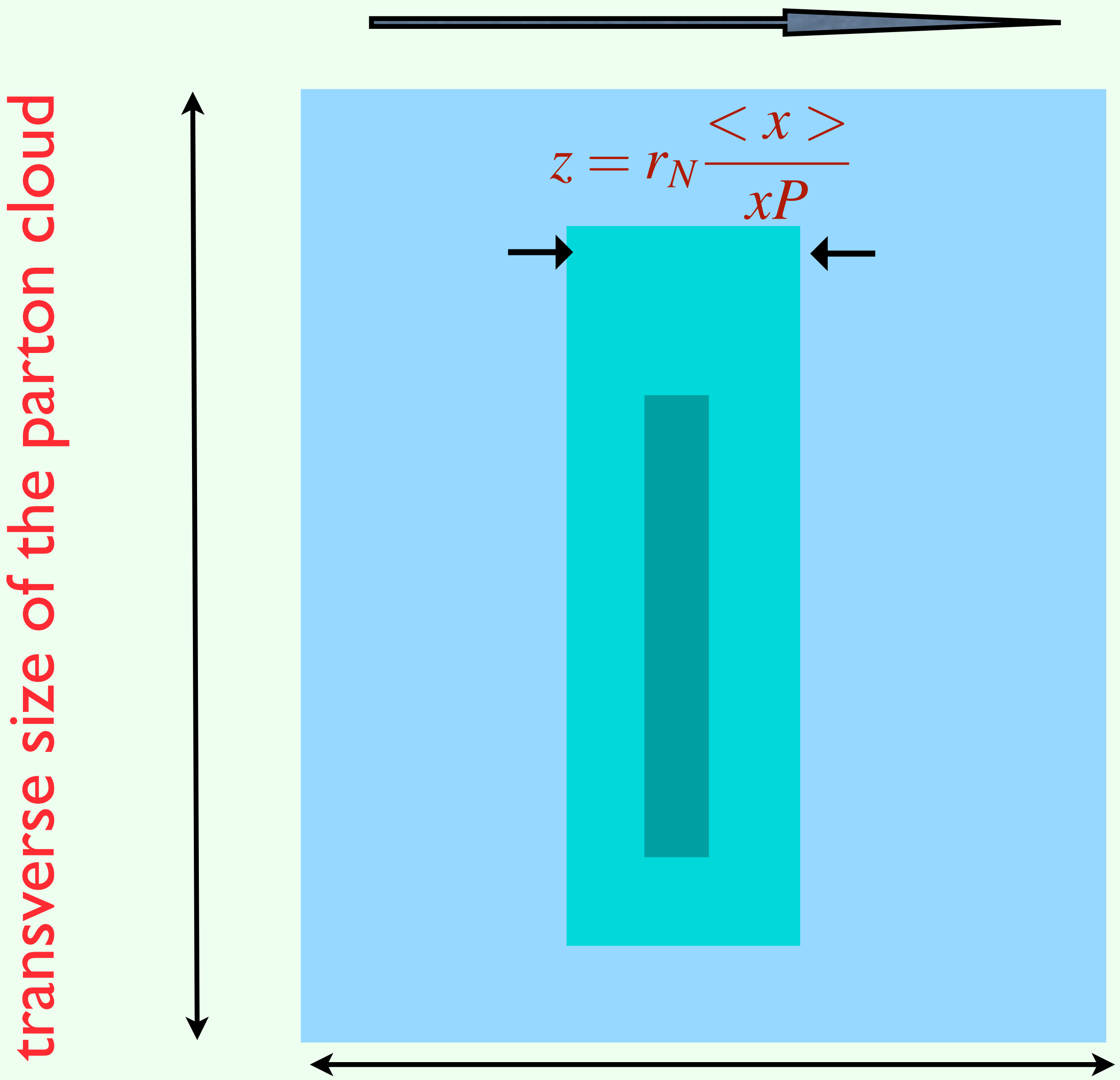
$$f(t) \propto \exp(Bt/2), \;\; B(s) = B_0 + 2\alpha' \ln(s/s_0)$$

$$\alpha' \propto 1/k_{t0}^2$$

z-x cut of the fast nucleon

the rate of increase of transverse size with x decreases with increase of the resolution scale

Momentum P in z direction



Transverse size of x>0.1 quarks and gluons is smaller than the average proton size predominantly due to the pion cloud effects - Frankfurt, MS, Weiss
- will discuss later

wee parton are spread over 1 fm even at high energies

Longitudinal momentum/transverse Image at High resolution

Implications: (b) Gribov diffusion is much weaker as the transverse momenta in most of the decay ladder are much larger than the soft scale. Transverse size shrinks with increase of resolution scale!!! *No analogous effect in classical mechanics.*

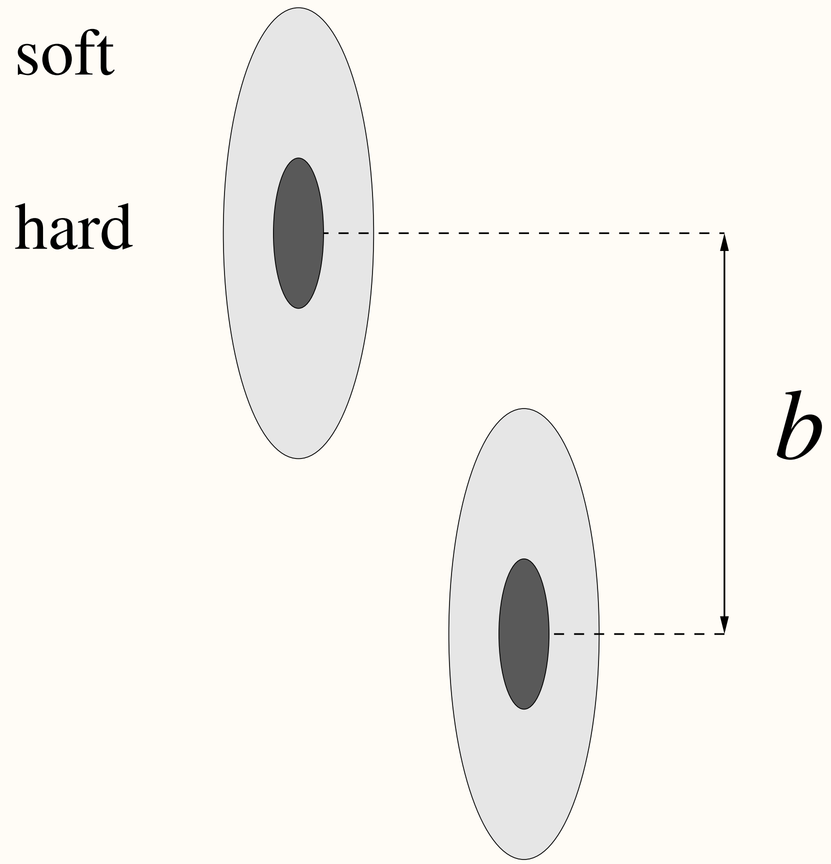
Note however - at very small x, Gribov diffusion at a soft scale generates via QCD evolution smaller increase of the radius at higher resolution scales.

Evidence for suppression of diffusion: for ZEUS and H1 observe that α' is a factor of two smaller for the process $\gamma + p \to J/\psi + p$ than for soft processes

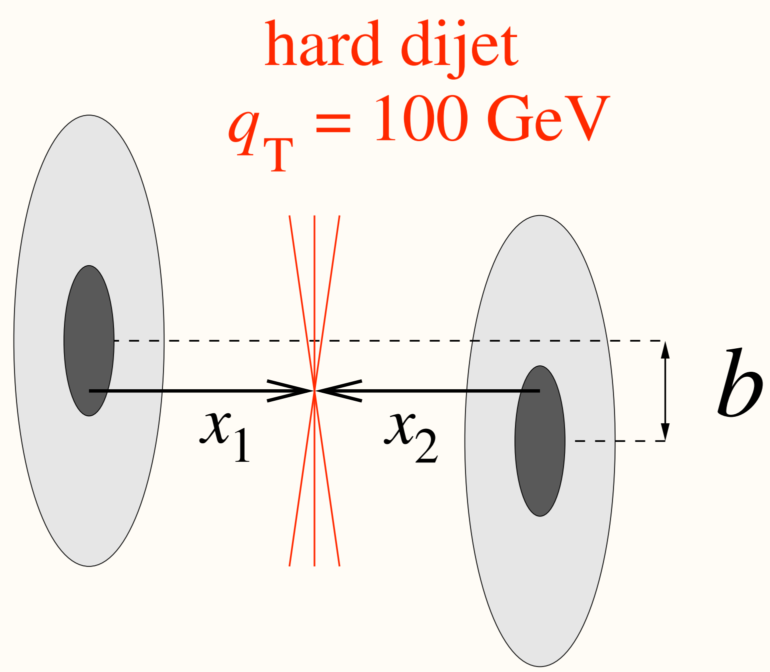
Confirms our prediction of 94 - BFGMS

Additional important effect: transverse distribution of $x \geq .05$ gluons in the nucleon is significantly smaller than a naive guess based on the e.m. radius of the nucleus.

Implication - hard processes correspond to collisions where nucleons overlap stronger & more partons hit each other - use hard collision trigger to study central collisions.



"peripheral"
(dominate total cross section)



$$x_{1,2} = 2q_T/W \sim 10^{-2}$$

"central"

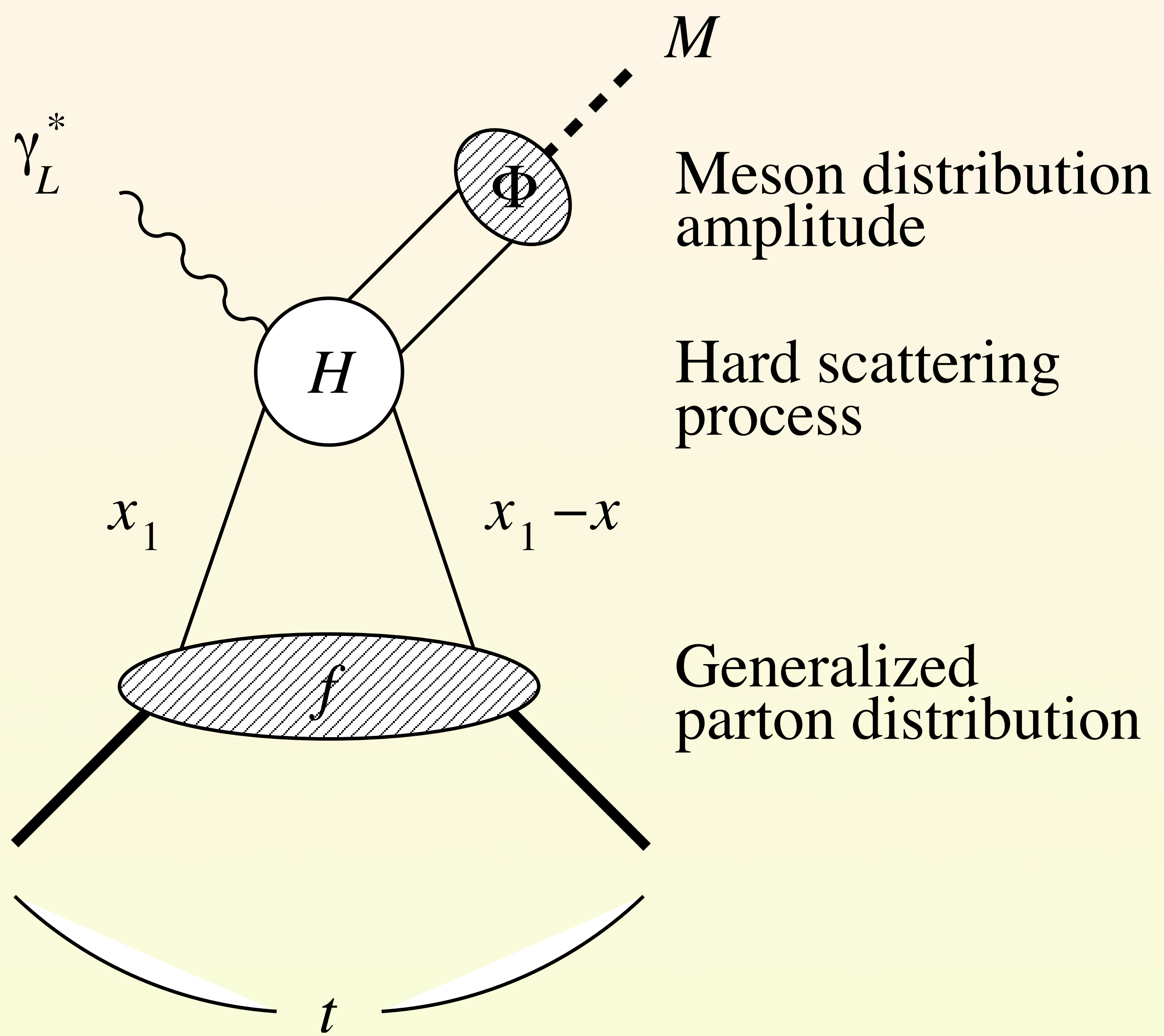
To quantify the difference of the impact parameters and the role of small x gluon field we can use theoretical analyses of the hard phenomena studied at HERA:

- Determination of the transverse distribution of gluons.

- Strength of of “small dipole”-nucleon interactions at high energies

QCD factorization theorem for DIS exclusive processes

(Brodsky,Frankfurt, Gunion,Mueller, MS 94 - vector mesons, small x; general case Collins, Frankfurt, MS 97)



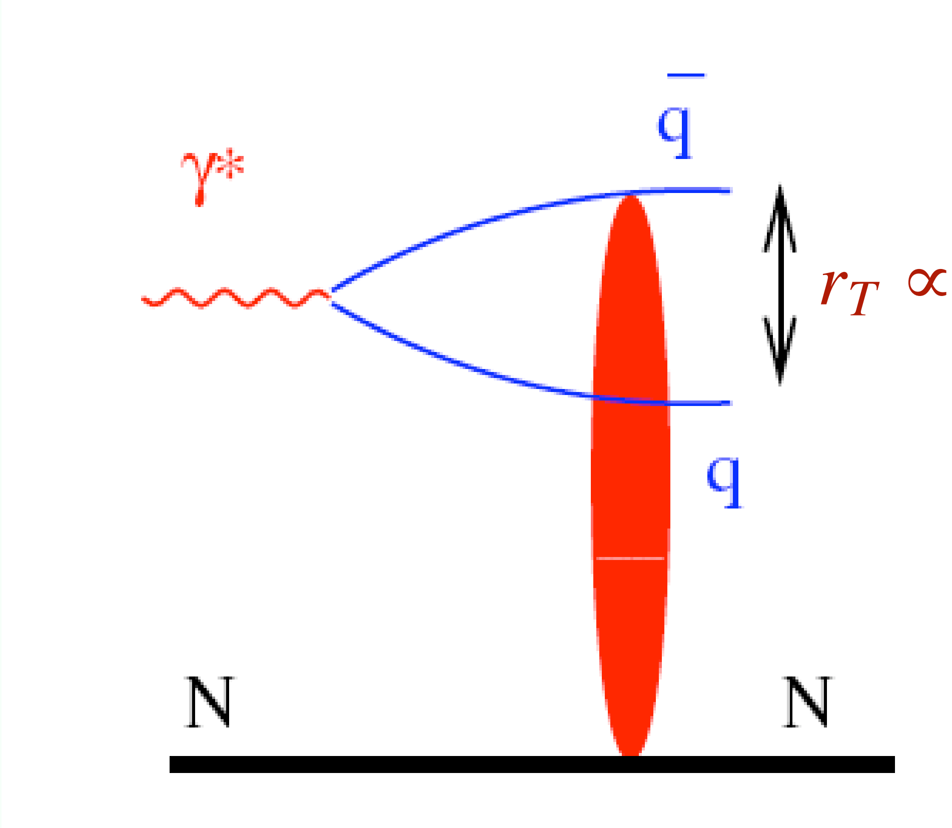
Extensive data on VM production from HERA support dominance of the pQCD dynamics. Numerical calculations including finite transverse size effects explain key elements of high Q^2 data. The most important ones are:

- Energy dependence of J/ψ production; absolute cross section of $J/\psi, \Upsilon$ production.

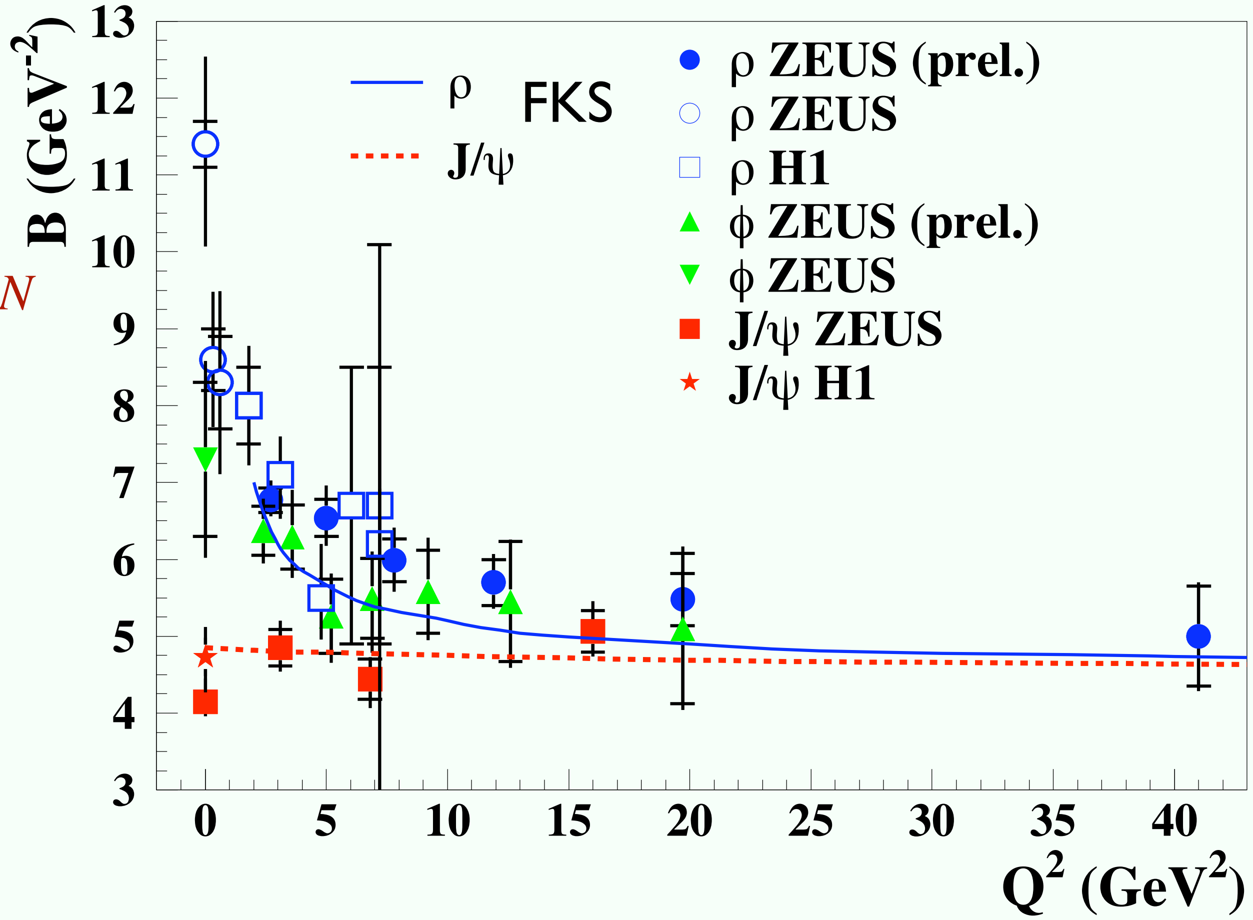
- Absolute cross section and energy dependence of ρ−meson production at $Q^2 \geq 20\ GeV^2$ Explanation of the data at lower Q^2 is more sensitive to the higher twist effects, and uncertainties of the low Q^2 gluon densities.

- Universal t-slope: process is dominated by the scattering of quark-antiquark pair in a small size configuration - t-dependence is predominantly due to the transverse spread of the gluons in the nucleon - two gluon nucleon form factor, $F_g(x,t)$. $d\sigma/dt \propto F_g^2(x,t)$.

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



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

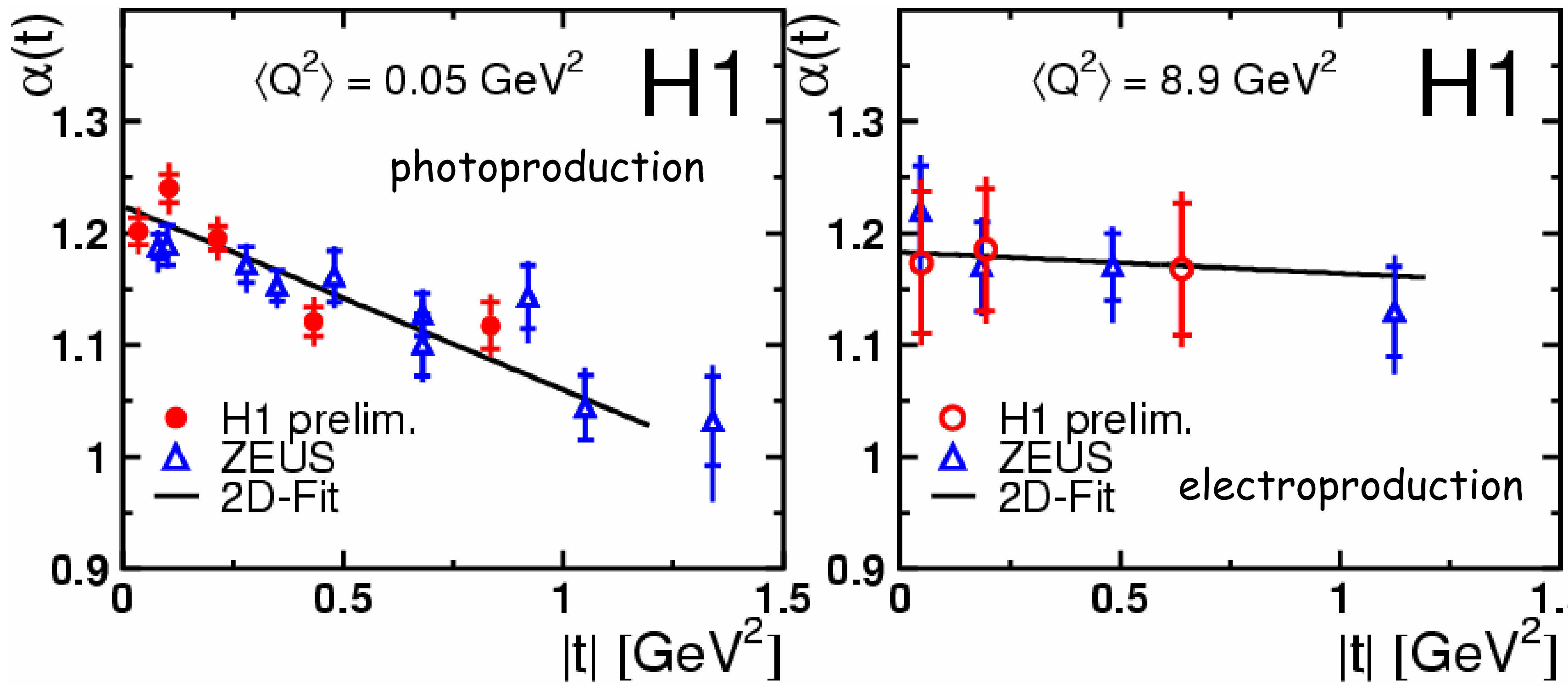


Convergence of the t-slopes, B ($\frac{d\sigma}{dt} = A\exp(Bt)$,
of ρ-meson electroproduction to the slope of J/ψ photo(electro)production.

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

Effective Pomeron Trajectory

2 dim. fit: $\alpha(t) = \alpha_0 + \alpha' t$



$$\frac{d\sigma}{dt} = f(t)\left(\frac{s}{s_0}\right)^{2\alpha(t)-1}$$

photoproduction:

$$\alpha(t) = (1.224 \pm 0.010 \pm 0.012) + (0.164 \pm 0.028 \pm 0.030)\ \text{GeV}^{-2}\ t$$

electroproduction:

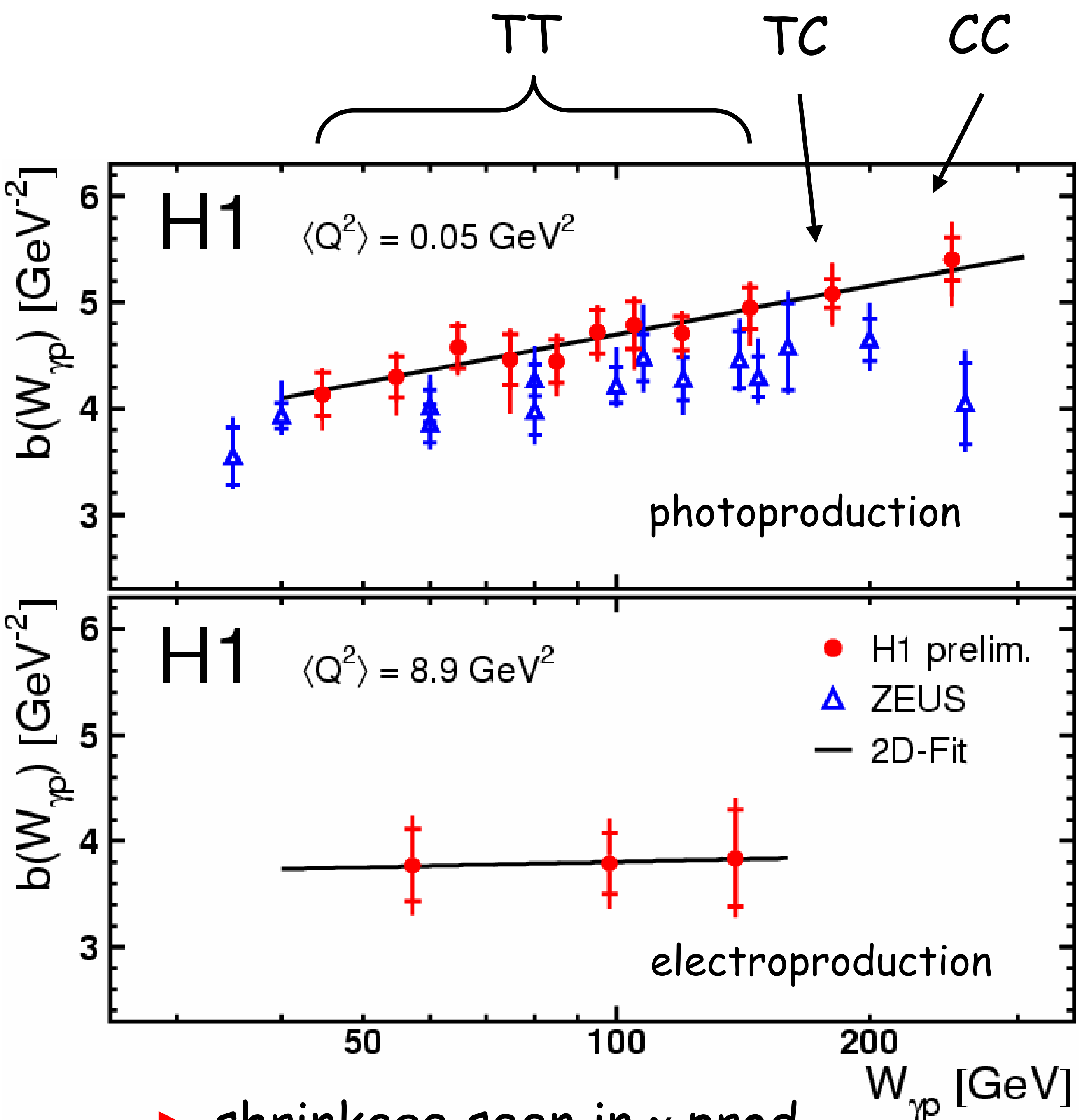
$$\alpha(t) = (1.183 \pm 0.054 \pm 0.030) + (0.019 \pm 0.139 \pm 0.076)\ \text{GeV}^{-2}\ t$$

$\rightarrow$ trajectories similar within errors

$\alpha_{I\!P} = (1.200 \pm 0.009) + (0.115 \pm 0.018)t$ ZEUS photoproduction

$\alpha_{I\!P} = (1.20 \pm 0.03) + (0.07 \pm 0.05)t$ ZEUS electroproduction

Shrinkage of the Forward Peak



→ shrinkage seen in γ prod.

data point from 1D fits to $e^{-b|t|}$

line from a 2D Fit (W and t) :

$$b(W) = b_0 + 4\alpha' \ln \frac{W}{W_0}$$

photoproduction

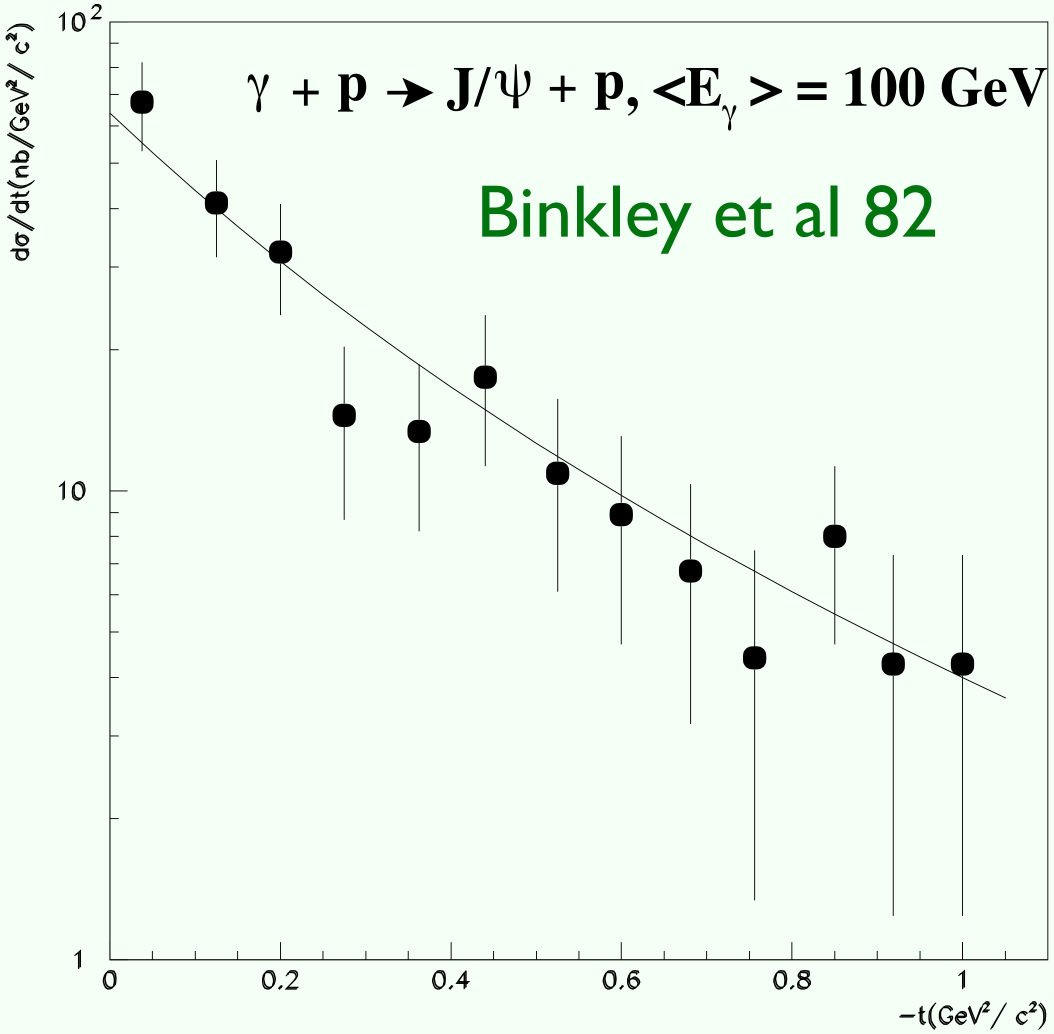
$$b_0 = 4.630 \pm 0.060 \begin{array}{l} +0.043 \\ -0.163 \end{array}$$

$$\alpha' = (0.164 \pm 0.028 \pm 0.030) \text{ GeV}^{-2}$$

electroproduction

$$b_0 = 3.86 \pm 0.13 \pm 0.31$$

$$\alpha' = (0.019 \pm 0.139 \pm 0.076) \text{ GeV}^{-2}$$



Theoretical analysis of J/ψ photoproduction at $100\ GeV \geq E_\gamma \geq 10\ GeV$ corresponds to the two-gluon form factor of the nucleon for $0.03 \leq x \leq 0.2,\ Q_0^2 \sim\ 3\ GeV^2, -t \leq 2\ GeV^2$

$$F_g(x,Q^2,t) = (1 - t/m_g^2)^{-2}.\ m_g^2 = 1.1\ GeV^2$$

which is larger than e.m. dipole mass

$$m_{e.m.}^2 = 0.7\ GeV^2. \quad \text{(FS02)}$$

The difference is likely due to the chiral dynamics - suppression of scattering off the pion field at x>0.05 (Weiss &MS 03)

Note that discussed effect in soft interactions included in the Pomeron - nucleon vertex since low energy pion-nucleon cross section is large.

☝ ☝ ☝ Large difference between impact parameters of soft interactions and hard interactions especially for $x_{parton} > 0.01$.

x-dependence of transverse distribution of gluons

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

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. (Frankfurt, MS , Weiss -02-03)

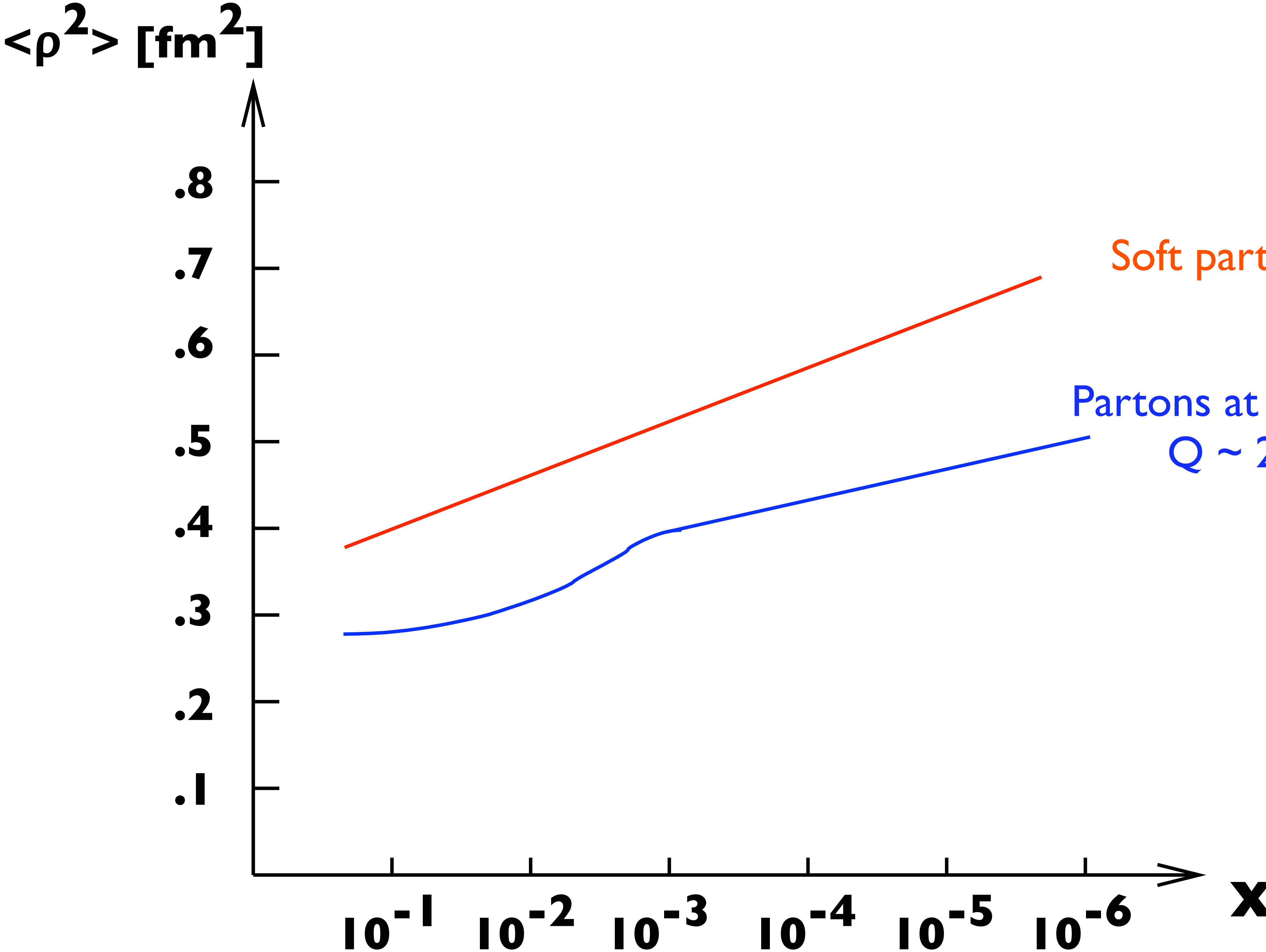
The gluon transverse distribution is given by the Fourier transform of the two gluon form factor as

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

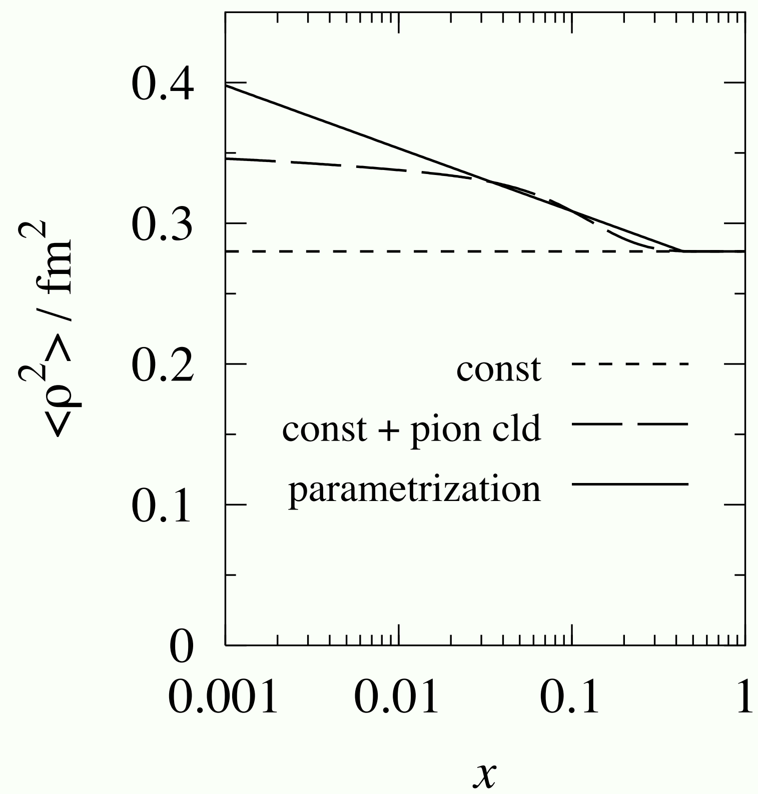
It is normalized to unit integral over the transverse plane: $\int d^2\rho\, F_g(x,\rho;Q^2) = 1.$

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

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

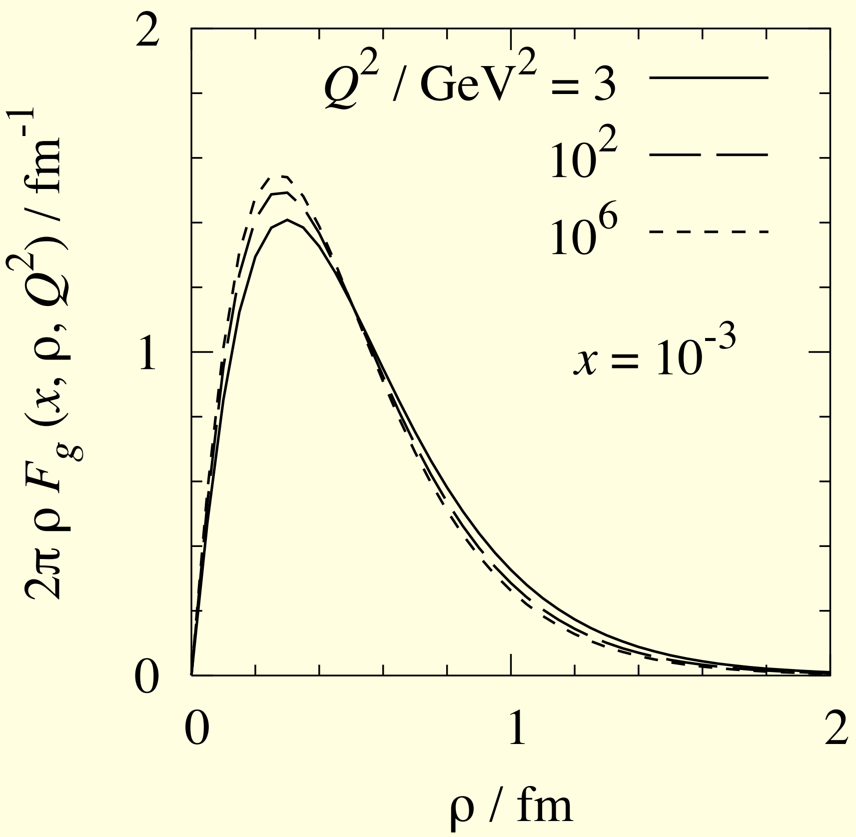


Sketch of the squared radius of the parton distribution for soft and hard regimes as a function of x.

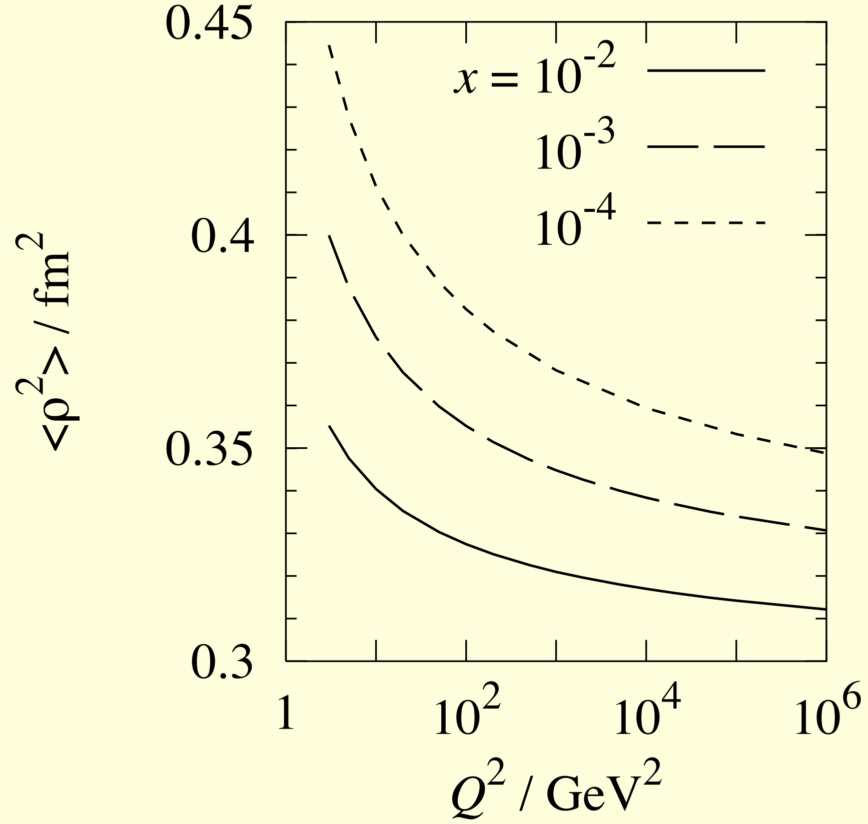


Our model for the x–dependence of the average transverse gluonic size squared of the nucleon, $\langle\rho^2\rangle$ at the scale $Q_0^2 = 2 \div 4\, GeV^2$ relevant to J/ψ production. *Short–dashed line:* $\langle\rho^2\rangle = 0.28\, fm^2$, as extracted from the t-slope of the J/ψ production cross section measured in various experiments (F& S 02) *Long–dashed line:* Sum of the constant value $\langle\rho^2\rangle = 0.28\, fm^2$ and the pion cloud contribution calculated in Strikman & Weiss, 2003 *Solid line:* The parameterization based on the experimental value of α'_{hard} as measured at HERA.

M.Strikman



The change of the normalized ρ–profile of the gluon distribution, $F_g(x, \rho; Q^2)$, with Q^2, as due to DGLAP evolution, for $x = 10^{-3}$. The input gluon distribution is the GRV 98 parameterization at $Q_0^2 = 3\,GeV^2$, with a dipole–type b–profile.

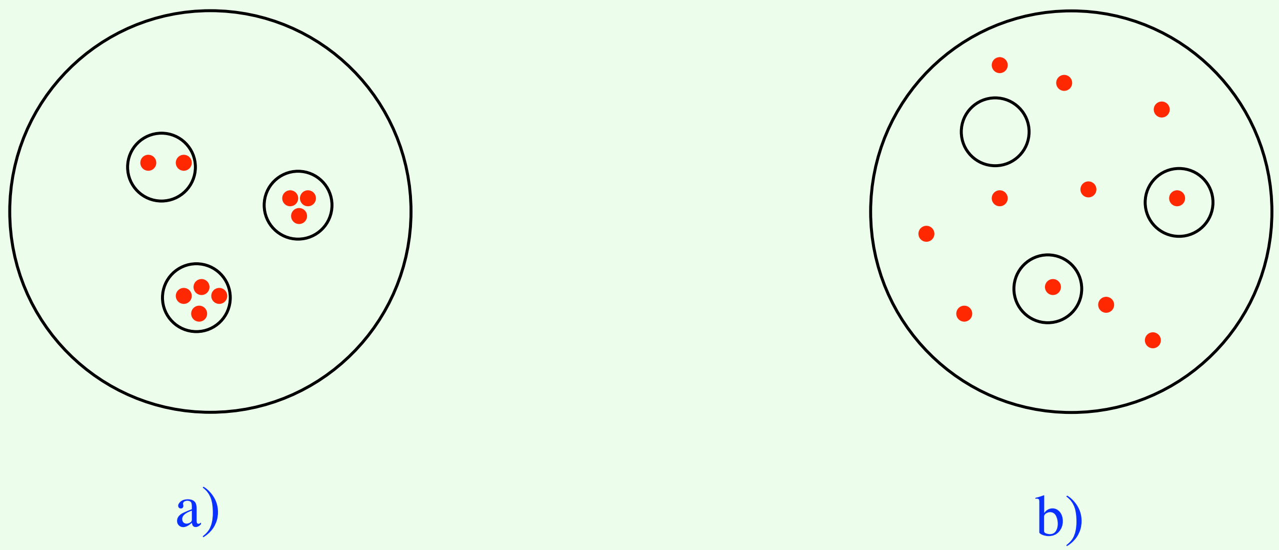


Change of $<\rho^2(Q^2)>$ with x - leads to effective α' which drops with Q but still remains finite even at very high Q.

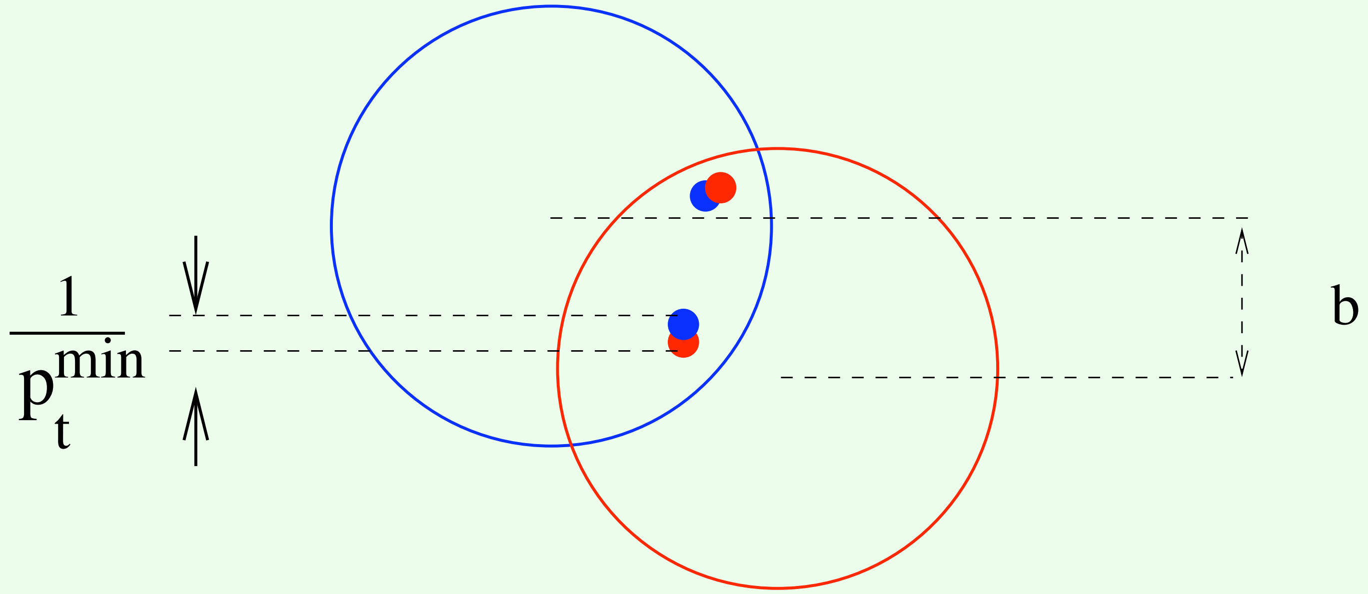
The change of the average transverse gluonic size squared, $\langle\rho^2\rangle$, due to DGLAP evolution, for $x = 10^{-2}, 10^{-3}$ and 10^{-4}.

M.Strikman

Multi-jet production - study 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 multijet events which have distinctive kinematics from the process two partons → four partons.

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

Experimentally one measures the ratio

$$\frac{\frac{d\sigma(p+\bar{p}\to jet_1+jet_2+jet_3+\gamma)}{d\Omega_{1,2,3,4}}}{\frac{d\sigma(p+\bar{p}\to jet_1+jet_2)}{d\Omega_{1,2}}\cdot\frac{d\sigma(p+\bar{p}\to jet_3+\gamma)}{d\Omega_{3,4}}}=\frac{f(x_1,x_3)f(x_2,x_4)}{\sigma_{eff}f(x_1)f(x_2)f(x_3)f(x_4)}$$

where $f(x_1,x_3), f(x_2,x_4)$ longitudinal light-cone double parton densities and

σ_{eff} is ``transverse correlation area".

CDF observed the effect in a restricted x-range: two balanced jets, and jet + photon and found $\sigma_{eff}=14.5\pm 1.7^{+\,1.7}_{-\,2.3}\,mb$ rather small - a naive expectation is σ_{eff} ~ 60 mb indicating high degree of correlations between partons in the nucleon in the transverse plane. No dependence of σ_{eff} on x_i was observed.

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 $\sigma_{eff} \sim 30$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 soliton model (Diakonov & Petrov) *the enhancement as compared to uncorrelated parton approximation is*

$$\frac{8}{9}+\frac{1}{9}\frac{r_N^2}{r_q^2}\sim 2$$

Hence, combined these two effects are sufficient to explain CDF data. (F&S&W)

☺ 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.

In order to analyze the strengths of interaction with the gluon fields at small x it is convenient to consider virtual photon - nucleon scattering in the nucleon rest frame.

Space-time picture of DIS, exclusive vector meson production - a three step process:

- transition $\gamma^* \to h$ where h are various $q\bar{q}, q\bar{q}g\ldots$ configurations long before the target:

$$l_{coh} \sim c(Q^2)q_0/Q^2, c(Q^2) \leq 1$$

Slow evolution of this wave package.

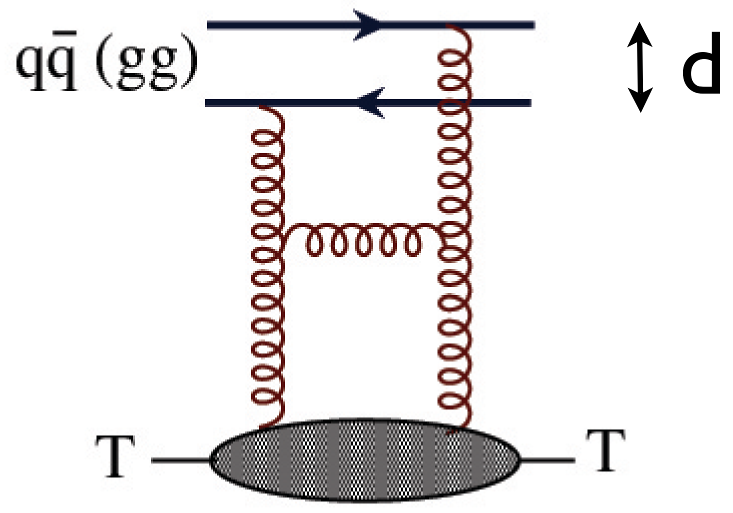
- interaction of the evolved configurations with the target,

- formation of the final state.

Convenient to introduce a notion of the cross section of the interaction of a small dipole with the nucleon. Such a cross section can be legitimately calculated in the leading log approximation. One can also try to extend it to large size dipoles hoping that a reasonably smooth matching with nonperturbative regime is possible.

A delicate point: in pQCD the cross section depends both on the transverse separation between quark and antiquark and the off-shellness (virtuality) of the probe which produced the $q\bar{q}$ pair. In most of the models on the market this is ignored.

Consider first "small dipole - hadron" cross section



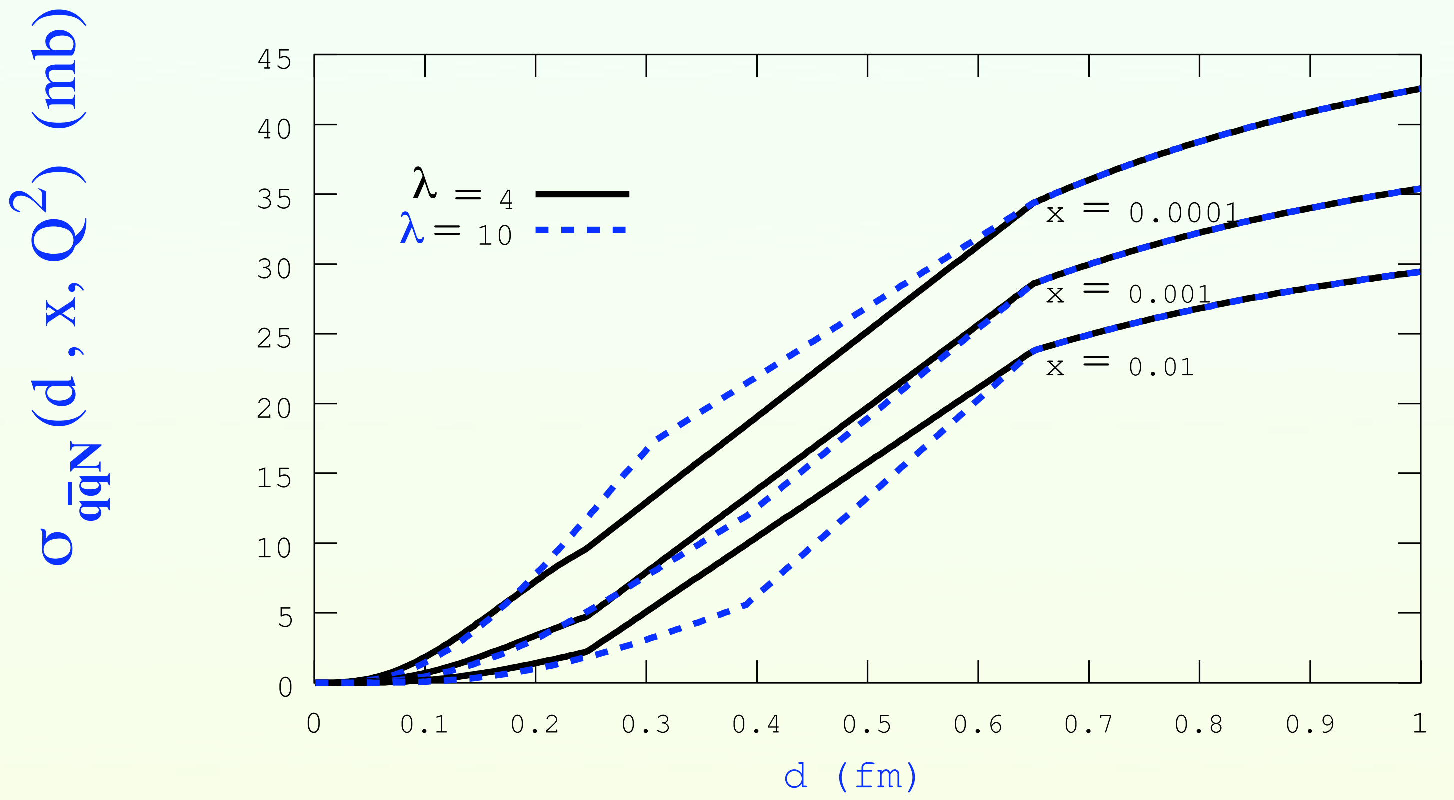
$$\sigma_{inel} = \frac{\pi^2}{3} F^2 d^2 \alpha_s(\lambda/d^2) x G_T(x.\lambda/d^2)$$

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

HERA data confirm increase of the cross sections of small dipoles predicted by pQCD



The interaction cross-section, $\hat{\sigma}$ for CTEQ4L, $x = 0.01, 0.001, 0.0001$, $\lambda = 4, 10$. Based on pQCD expression for $\hat{\sigma}$ at small d_t, soft dynamics at large b, and smooth interpolation. Provides a good description of F_{2p} at HERA and J/ψ photoproduction. Provided a reasonable prediction for σ_L

Frankfurt, Guzey, McDermott, MS 2000-2001

Impact parameter distribution in "h"(dipole)p interaction

Study of the elastic scattering allows to determine how the strength of the interaction depends on the impact parameter, b:

$$\Gamma_h(s,b) = \frac{1}{2is}\frac{1}{(2\pi)^2}\int d^2\vec{q}e^{i\vec{q}\vec{b}}A_{hN}(s,t); \;\; ImA = s\sigma_{tot}\exp(Bt/2)$$

$$\sigma_{tot} = 2\int d^2b\mathrm{Re}\Gamma(s,b)$$

$$\sigma_{el} = \int d^2b|\Gamma(s,b)|^2$$

$$\sigma_{inel} = \int d^2b(1-(1-\mathrm{Re}\Gamma(s,b))^2 - [\mathrm{Im}\Gamma(s,b)]^2)$$

$\Gamma(b) = 1 \;\equiv\; \sigma_{inel} = \sigma_{el}$

- black body limit(BBL)

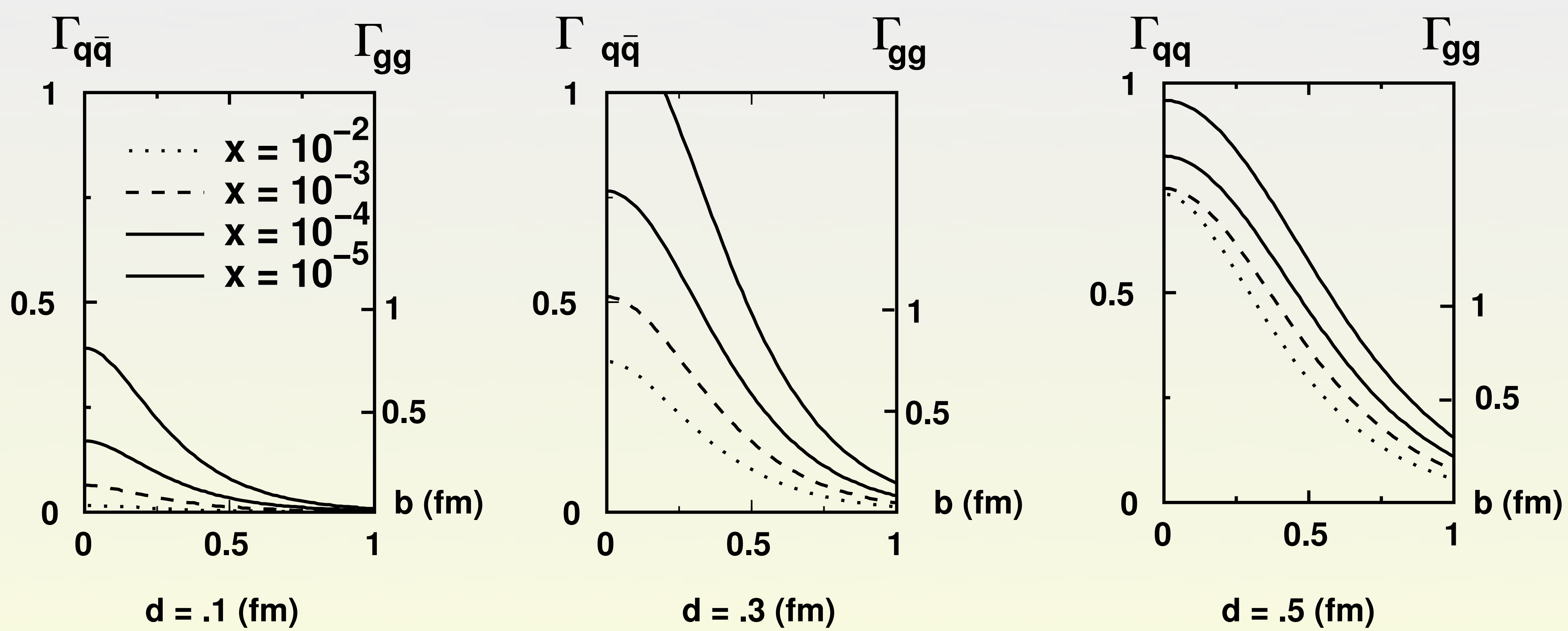
Note that elastic unitarity: $\frac{1}{2}ImA = |A|^2 + \ldots$ allows $\Gamma(b) \le 2$

Using information on the exclusive hard processes we can also estimate t-dependence of the elastic dipole-nucleon scattering and hence estimate

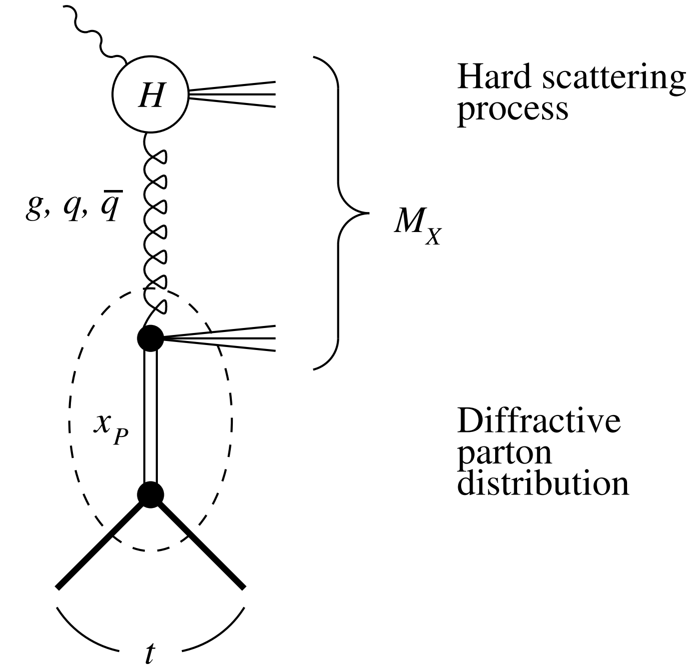
$\Gamma_{q\bar{q}}$ *from* $\sigma(q\bar{q}N)$.

In the case gg-N scattering we assume pQCD relation

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



Can use hard diffraction to check proximity to BDL



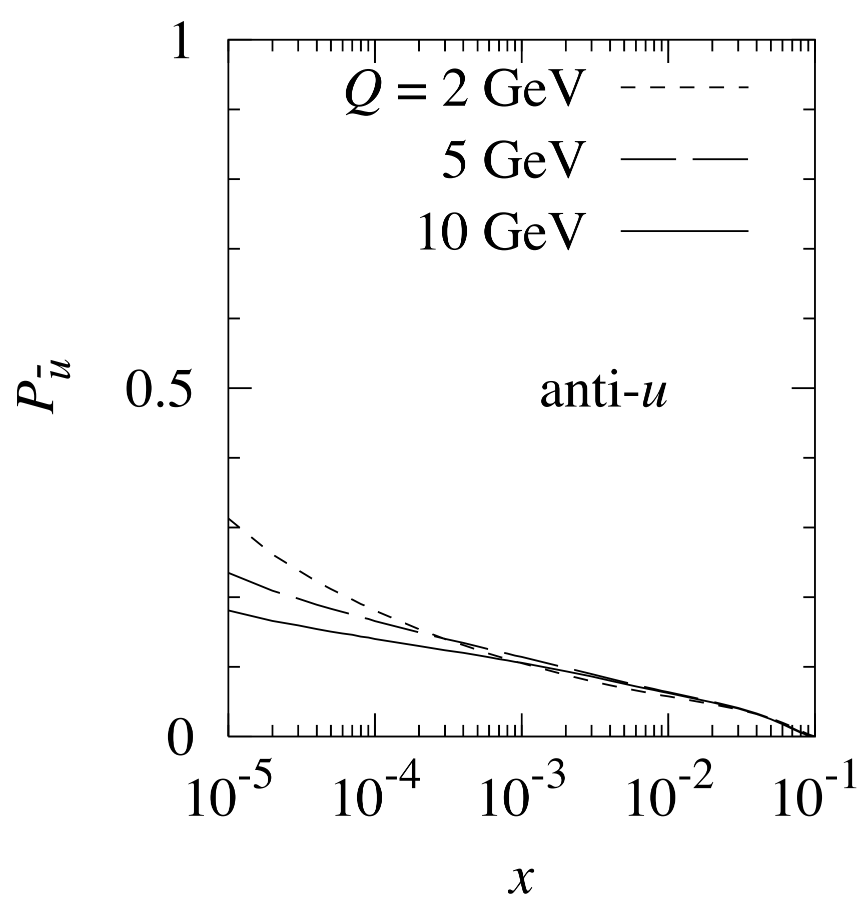
QCD factorization theorem for diffractive processes consistent with the data to define **universal** diffractive parton densities:

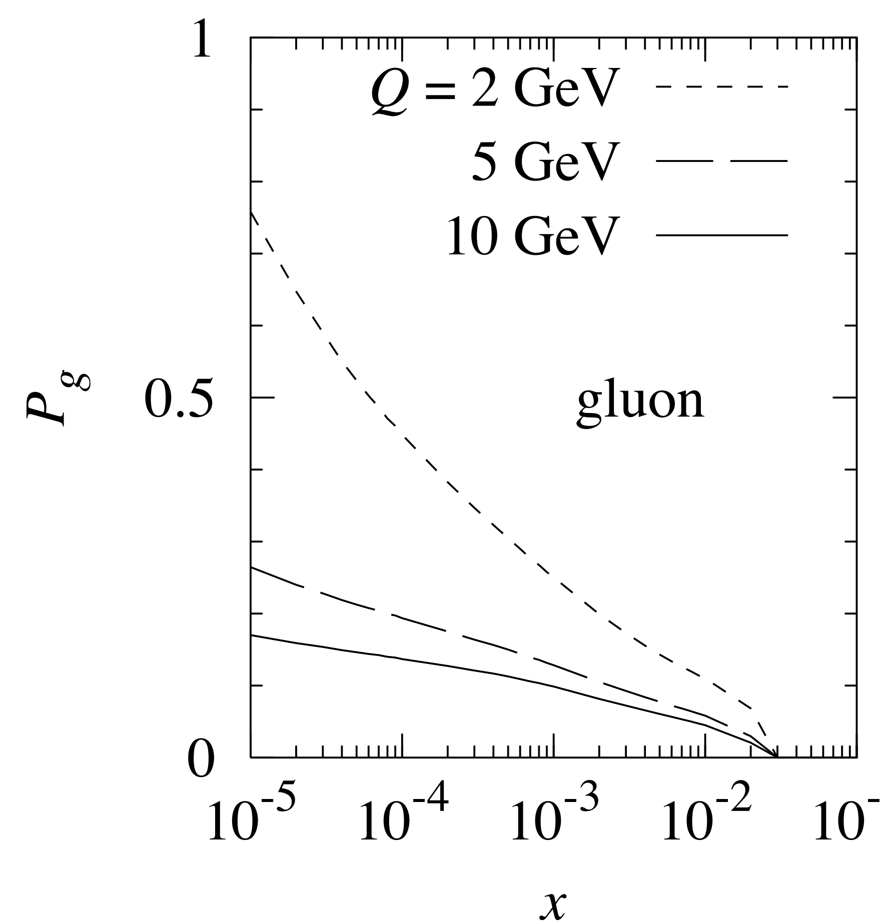
$$f_j^D\left(\frac{x}{x_{I\!P}}, Q^2, x_{I\!P}, t\right)$$

To test proximity to BDL it is useful to define and calculate the probability of diffractive scattering depending on the type of parton coupling to the hard probe

$$P_j(x,Q^2) \;=\; \int dt \int dx_{I\!P}\, f_j^D(x/x_{I\!P},Q^2,x_{I\!P},t) \Big/ f_j(x,Q^2)$$

If $P_j(x,Q^2)$ is close to 1/2 interaction of "j" parton approaches BBL





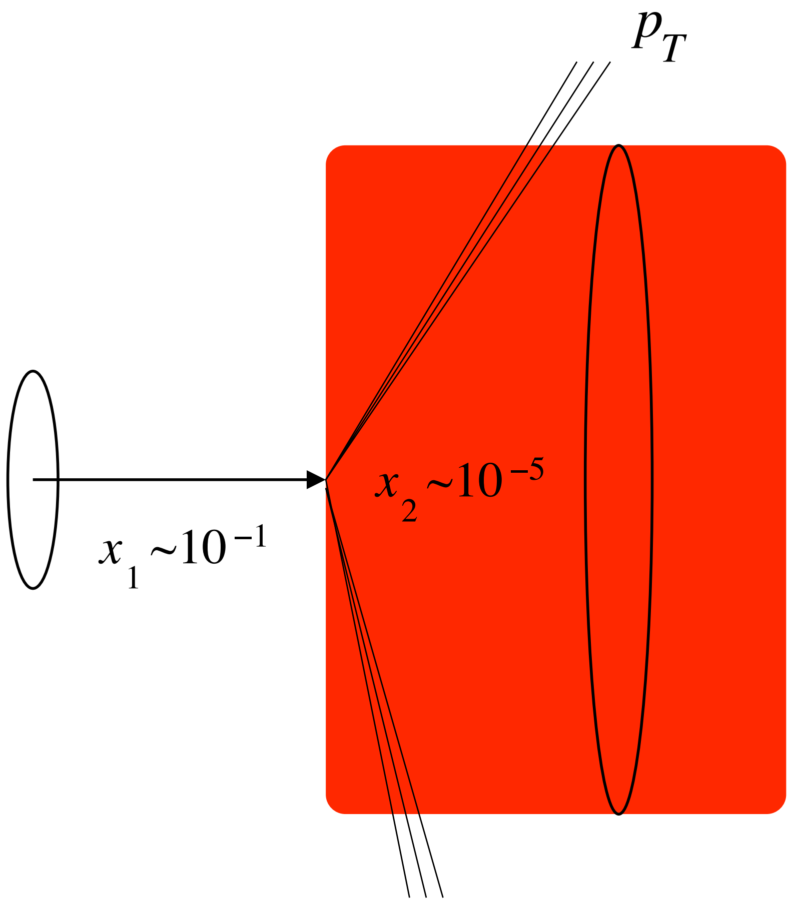
$P_g(x \le 3\cdot 10^{-4}, Q^2 = 4\,GeV^2) \ge 0.4$!!! FS98

$\Rightarrow$ *Incident partons which have large enough energies to resolve $x \sim 10^{-4}$ -- 10^{-5} in the target nucleon and which pass at impact parameters < 0.5 fm, interact with the nucleon in a regime which is close to the black disk limit.*

Implications for LHC - impact parameters for collisions with new particle production vs generic inelastic collisions

New hard dynamics for fragmentation in pA and AA collisions

First consider central pA collisions



Black disk limit in central collisions: Leading partons in the proton, x_1, interact with a dense medium of small x_2 – gluons in the nucleus (shaded area), acquiring a large transverse momentum, $p_\perp$

What happens when a parton goes through strong gluon fields? It will be resolved to its constituents if interaction is strong. To estimate the transverse momenta of the resolved system use a second parton as a regularization - consider the propagation of a small dipole of transverse size d, which interacts in LO pQCD with cross section:

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

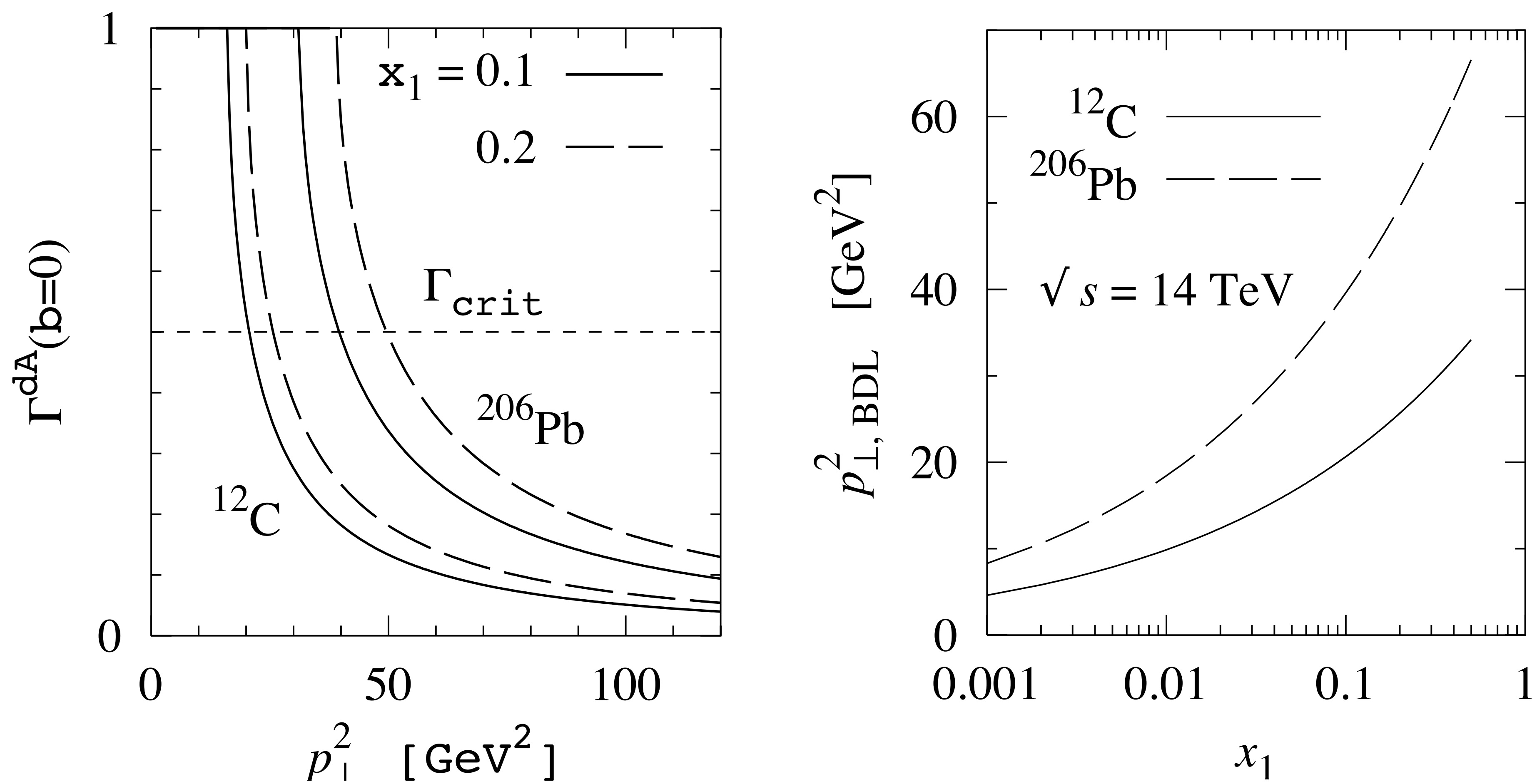
To estimate the maximum transverse momentum for interactions close to the BBL, we can treat the leading parton as one of the constituents of a small dipole scattering from the target. This “trick” allows us to apply the results of our study of the dipole –hadron scattering. In this analogy, the effective scale in the gluon distribution is $Q^2_{eff} \sim 4p^2_\perp$, corresponding to an effective dipole size of $d \approx 3/2p_\perp$

Criterion of proximity to BDL:

$$\Gamma^{\text{"}dipole\text{"}A}(b=0) \geq \Gamma_{crit} \sim 0.5$$

corresponding to probability of inelastic collision of

$$1 - |1-\Gamma|^2 \geq 0.75$$



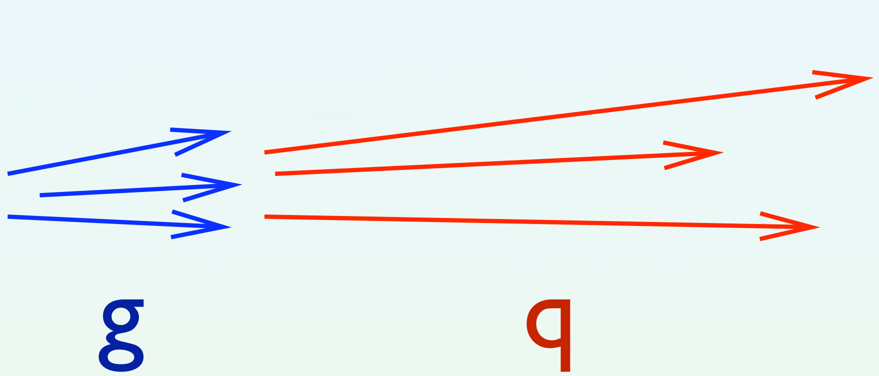
Black–disk limit in central collisions:

(a) The profile function for the scattering of a leading gluon in the proton (regarded as a constituent of a dipole) from the nucleus at zero impact parameter, , as a function of the transverse momentum squared,

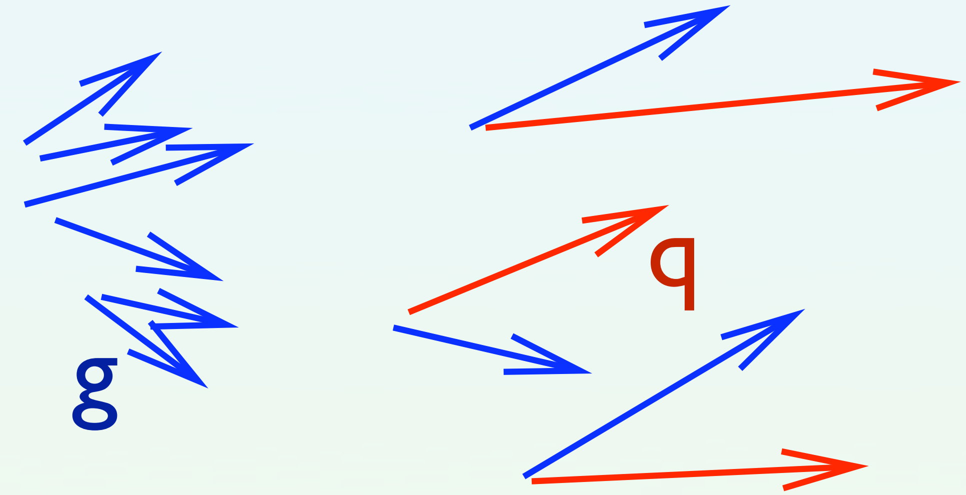
(b) The maximum transverse momentum squared, BDL, for which the interaction of the leading gluon is "black" (for quarks it is a factor of two smaller).

$p^2_{\perp,BDL}$ strongly depends on x, while cutoff in the MC's depends only on s!!!

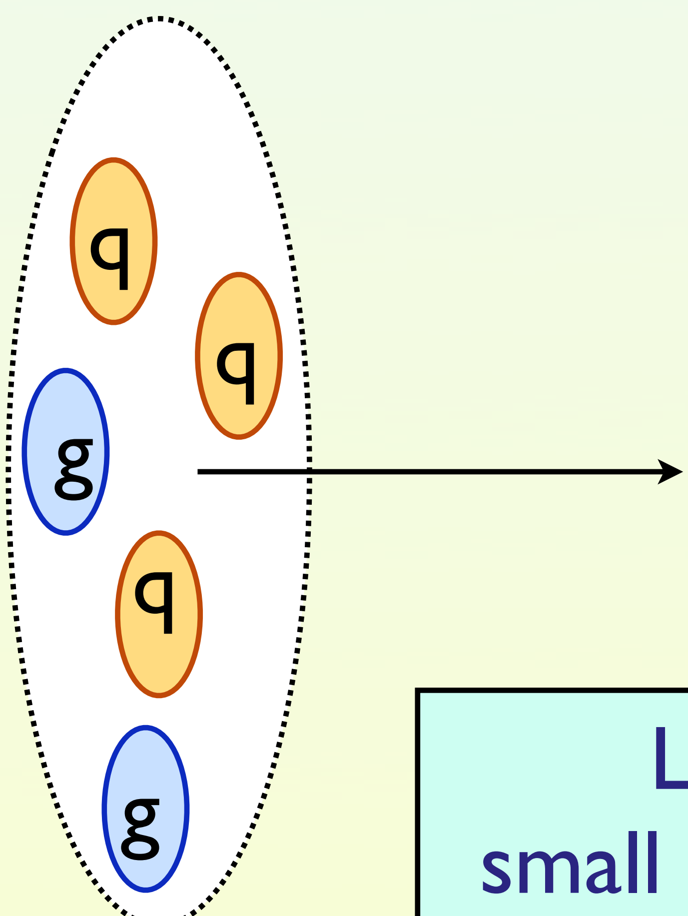
Characteristics of the final state in the central pA(pp) collisions

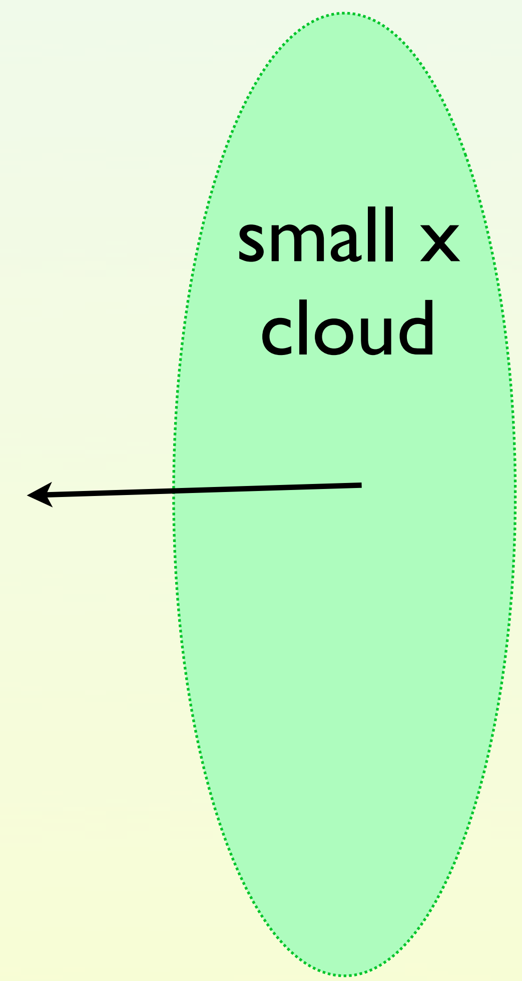


fast partons in a nucleon before collisions



fast partons in a nucleon after central collisions

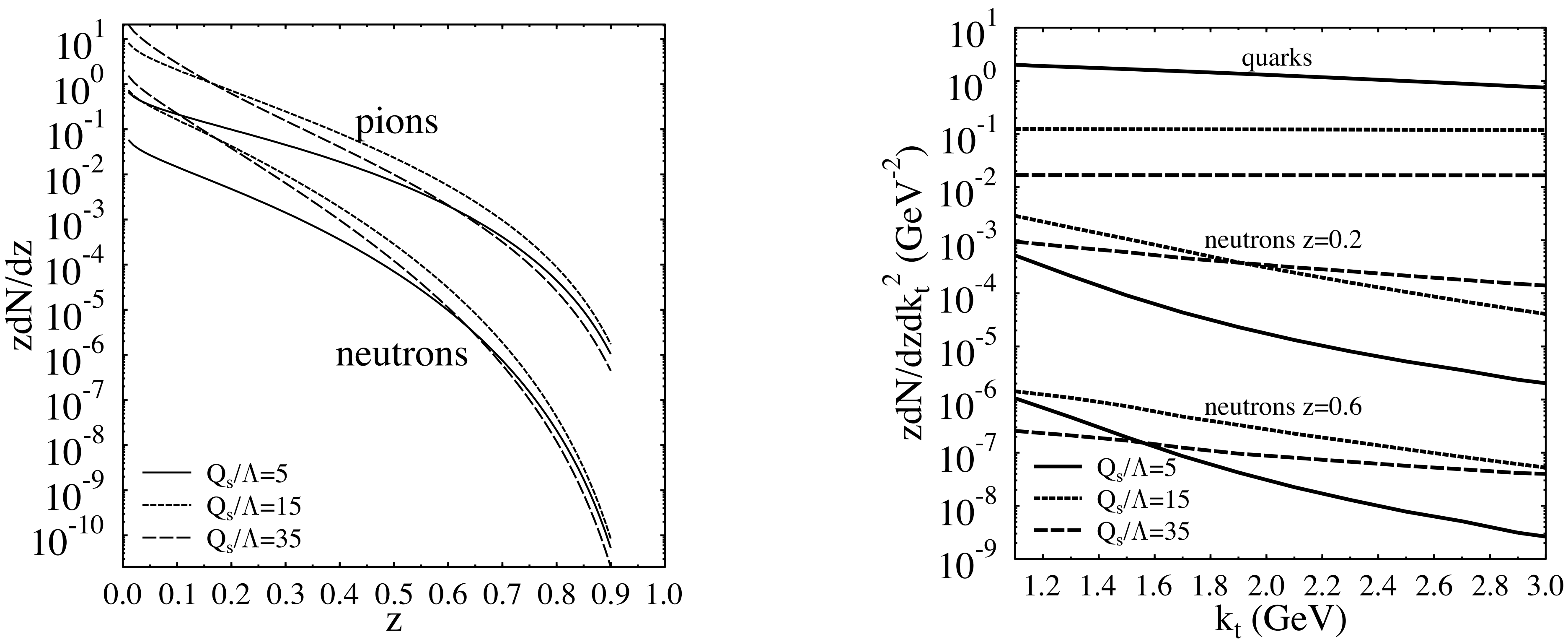




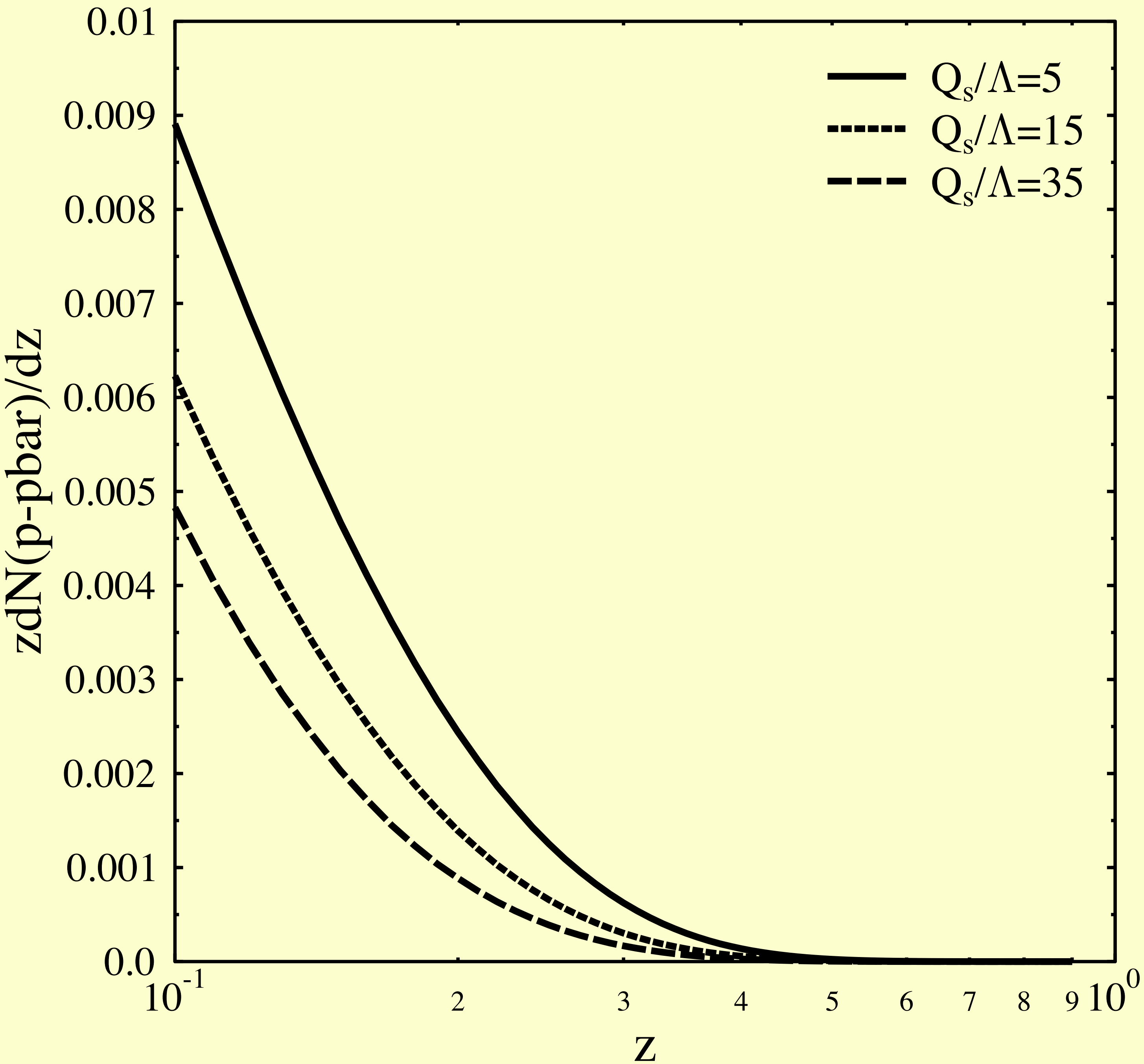
Large x partons burn
small holes in the small x cloud

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.

$$\frac{1}{N}\left(\frac{dN}{dz}\right)^{pA\to h+X} = \sum_{a=q,g}\int dx\, x f_a(x,Q^2_{eff}) D_{h/a}(z/x, Q^2_{eff})$$



Longitudinal (integrated over p_t) and transverse distributions in Color Glass Condensate model for central pA collisions. (Dumitru, Gerland, MS -PRL03). Spectra for central pp - the same trends.



Longitudinal distribution of net protons

Note for moderate Q_s coalecence becomes important for moderate z enhancing the proton yields for these z's.

Cosmic rays of ultrahigh energies: $s \leq 10^{11}\ GeV^2 = 1000\ s_{LHC}$

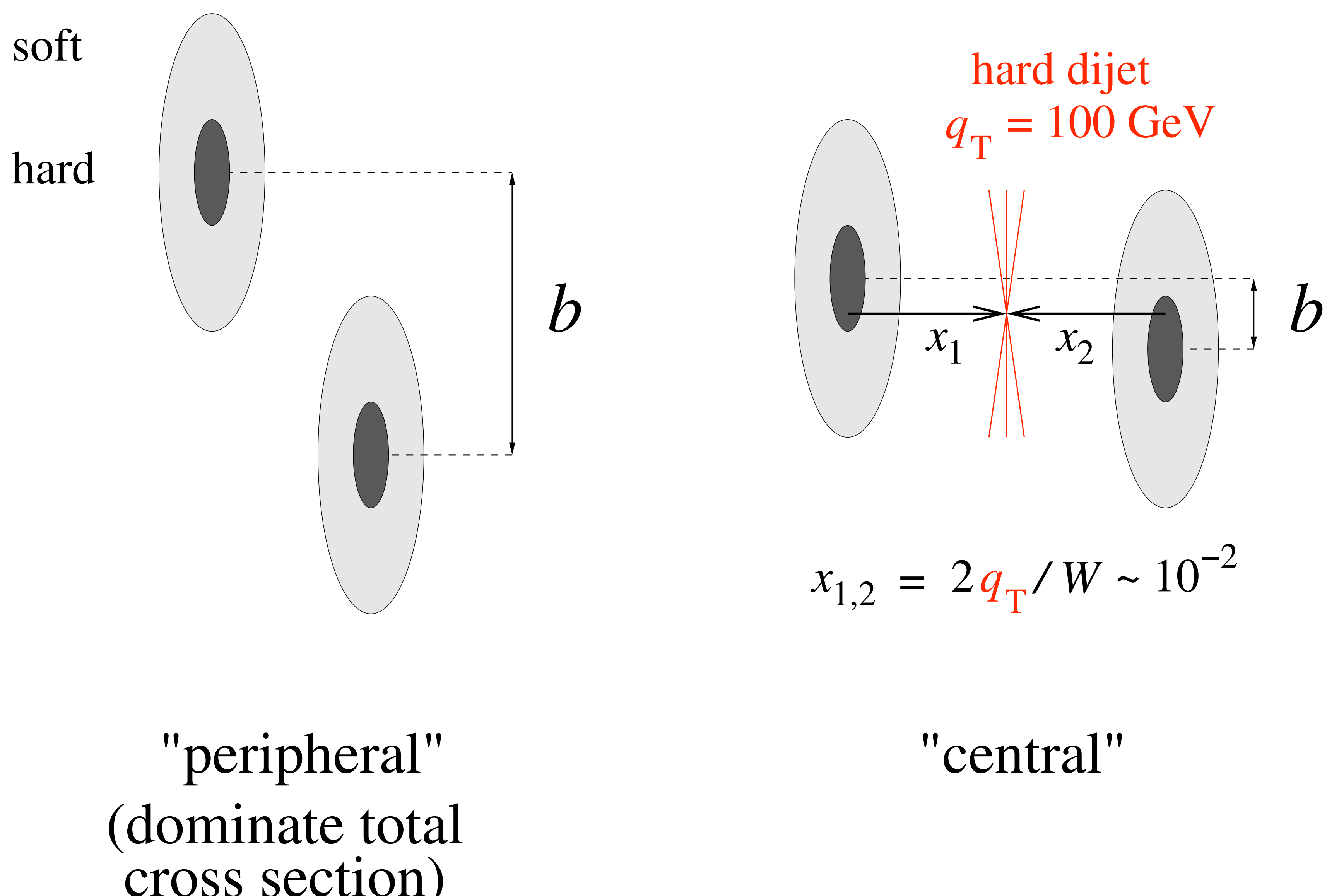
Interpretation is very sensitive to the forward physics - number of leading particles,...

A parton with a given x_1 is and resolution pt is sensitive to the partons in the target with $x \geq x_2 = 4p_t^2/s_{NN}x_1$

For $s=10^{11}$ GeV^2, $x_1=0.1$, $p_t=5$ GeV/c, $x>x_2=10^{-8}$ are resolved!!!

Can one study the same effects in pp?

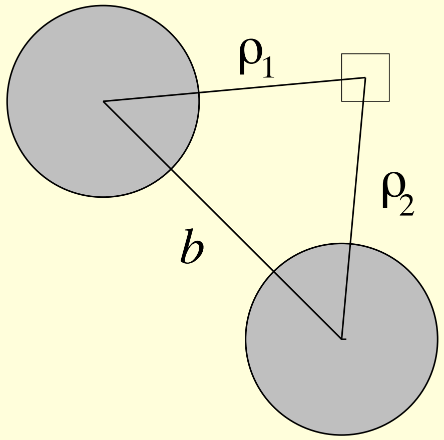
Main idea/Qualitative expectation: hard partons are more localized in transverse plane - ***gluon density in a nucleon at small impact parameters is comparable to that in heavy nuclei at small b.*** Hence in events with hard interaction trigger, spectator partons experience much stronger gluon fields.



Impact parameter distribution for a hard multijet trigger.

For simplicity take $x_1 = x_2$ for colliding partons producing two jets with $x_1 x_2 = 4q_\perp^2/s$. Answer is not sensitive to a significant variation of x_i for fixed $q_\perp$.

The overlap integral of parton distributions in the transverse plane, defining the b–distribution for binary parton collisions producing a dijet follows from the figure:



Hence the distribution of the cross section for events with dijet trigger over the impact parameter b is given by

$$P_2(b) \equiv \int d^2\rho_1 \int d^2\rho_2 \; \delta^{(2)}(\boldsymbol{b} - \boldsymbol{\rho}_1 + \boldsymbol{\rho}_2) F_g(x_1, \rho_1) \; F_g(x_1, \rho_2),$$

where $x_1 = 2q_\perp/\sqrt{s}$. Obviously $P_2(b)$ is automatically normalized to 1.

For a dipole parameterization:

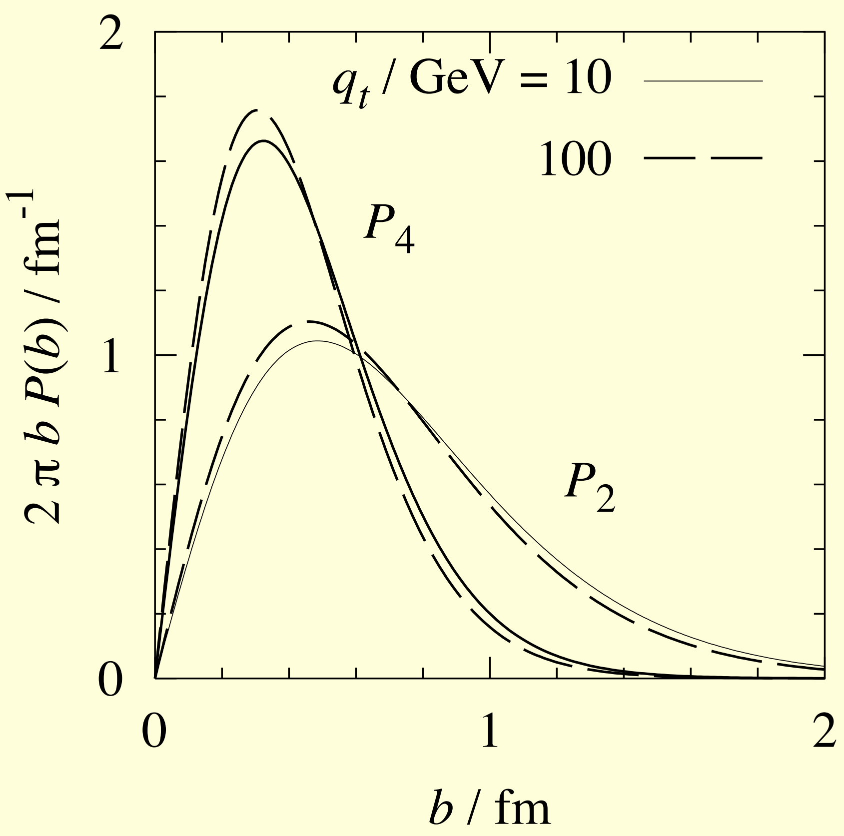
$$P_2(b) \;\; = \;\; \frac{m_g^2}{12\pi} \left(\frac{m_g b}{2}\right)^3 K_3(m_g b)$$

For two binary collisions producing four jets *assuming no correlation between gluons in the transverse plane*:

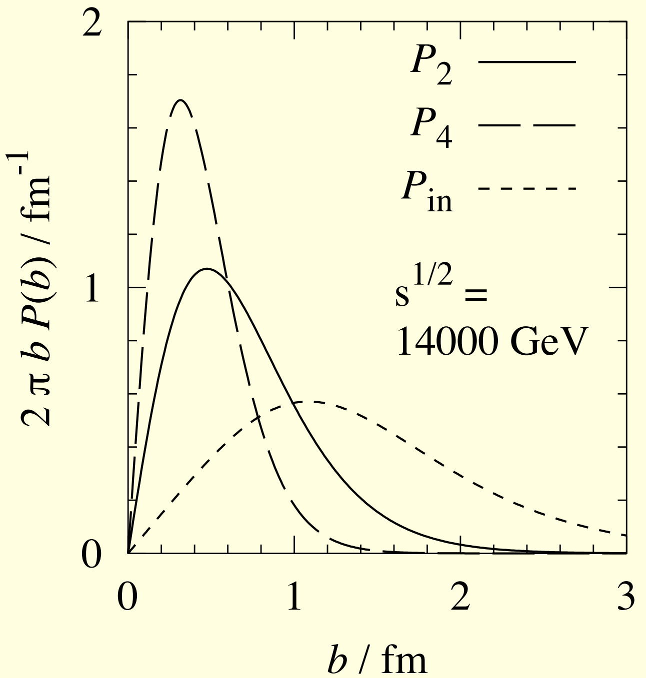
$$P_4(b) \;\; = \;\; \frac{P_2^2(b)}{\displaystyle\int d^2b \; P_2^2(b)}; P_4(b) \;\; = \;\; \frac{7\, m_g^2}{36\pi} \left(\frac{m_g b}{2}\right)^6 \left[K_3(m_g b)\right]^2 .$$

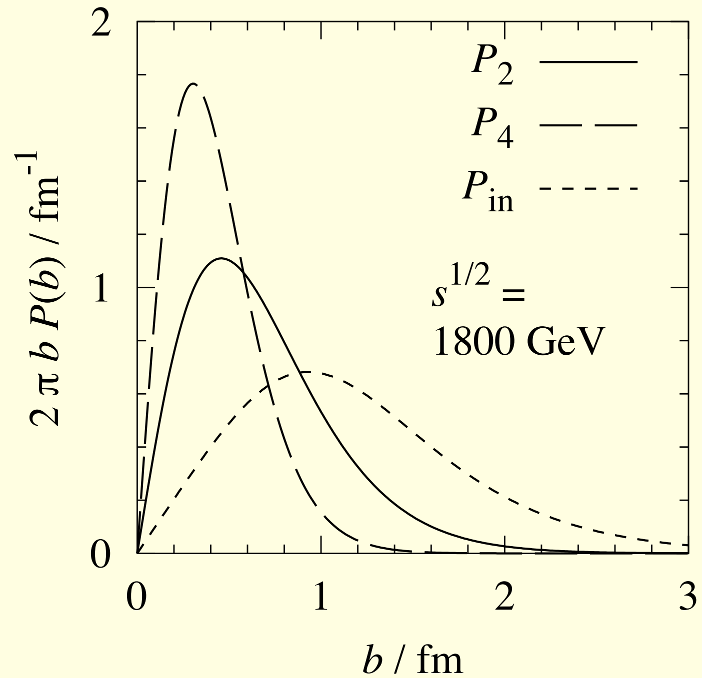
More realistic estimate for 4 jet case using information from the analysis of the CDF data gives:

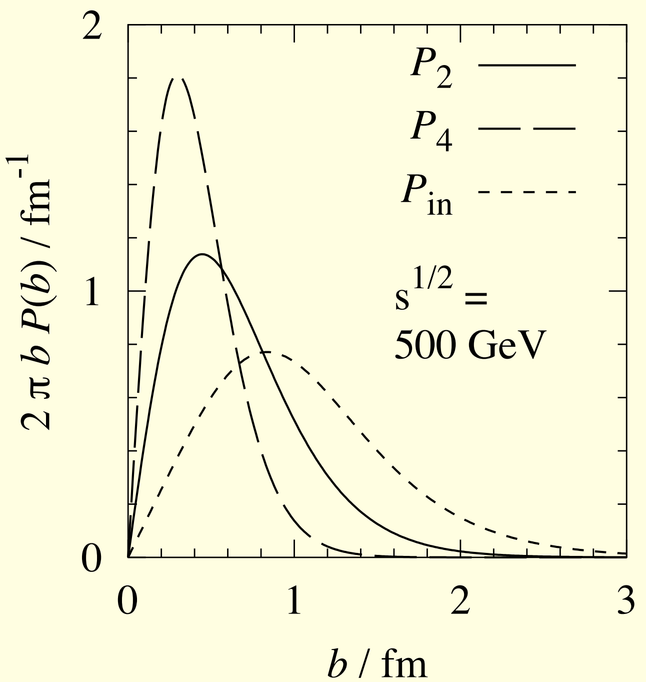
$$P_{4,corr}(b) \approx P_2(b) \, \frac{\sigma_{eff}(model) - \sigma_{eff}(CDF)}{\sigma_{eff}(model)} + P_4(b) \, \frac{\sigma_{eff}(CDF)}{\sigma_{eff}(model)}$$



The b–distribution for the trigger on hard dijet production, $P_2(b)$, obtained with the dipole form of the gluon b–profile, for $\sqrt{s} = 14000\, GeV$ and $q_\perp = 10\, GeV$ and $100\, GeV$. The plots show the "radial" distributions in the impact parameter plane, $2\pi b\, P_2(b)$. Also shown is the corresponding distribution for a trigger on double dijet production, $P_4(b)$, with the same $p_\perp$.







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.

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Let us estimate what average transverse momenta are obtained by a parton in the collision at a fixed b and next take into account distribution over b .

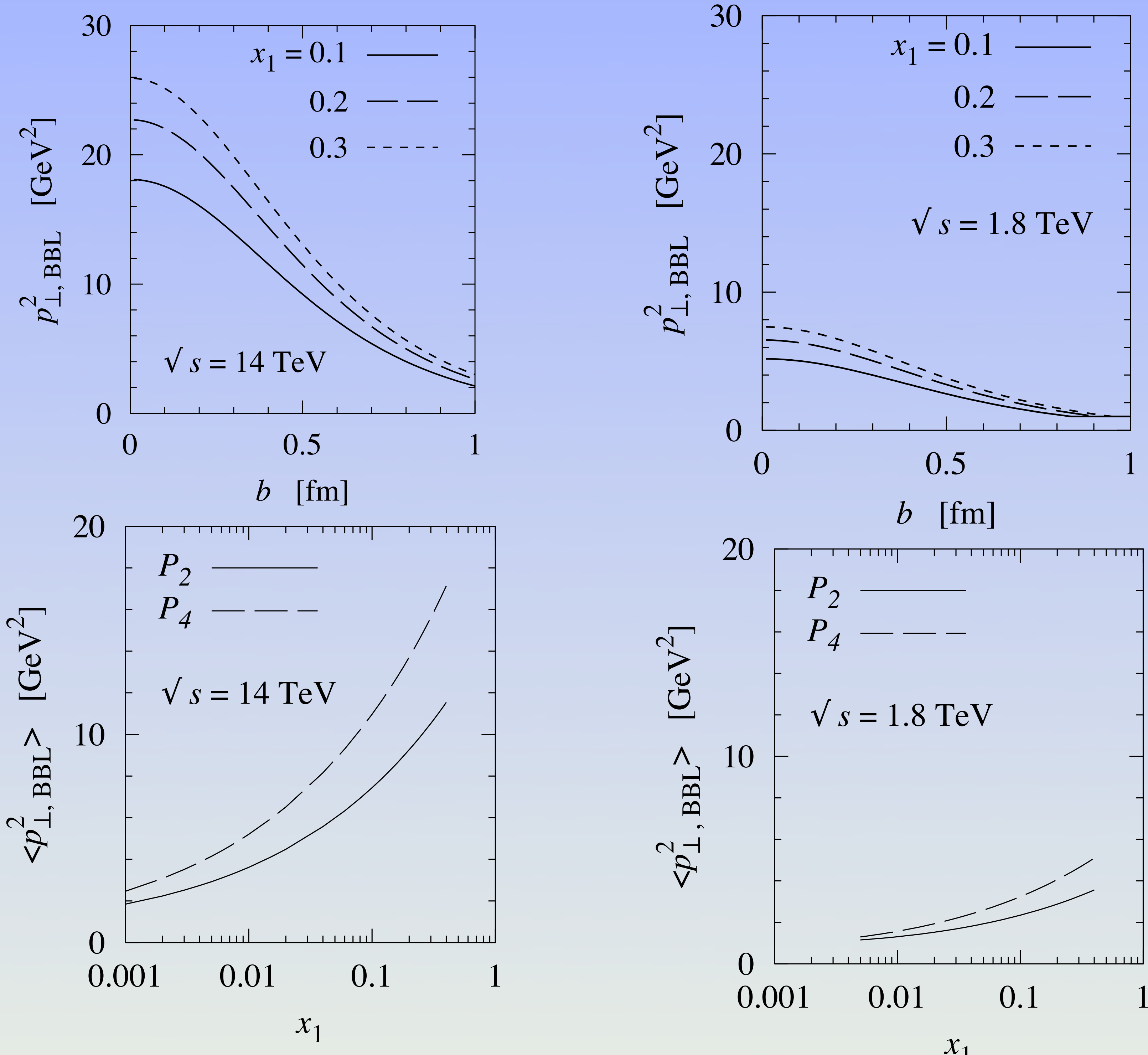
- Fixing fast parton's x (x_1) resolved by collision with partons in other proton

- Determining what minimal x are resolved in the second proton for given virtuality $x = \frac{4p_\perp^2}{x_1 s}, Q^2 = 4p_\perp^2$ $small\, x \leftrightarrow large\, x_1$

- for given ρ – distance of the parton from the center of another nucleon – determining maximum virtuality - minimal size of the dipole- d, for which Γ =0.5.

- converting from d to average $< p_\perp^2 >$

$p_\perp$ acquired by a spectator parton	$\approx$	Maximal $p_\perp$ for which interaction remains black for given x_1



The critical transverse momentum squared, below which the interaction of a leading gluon with the other proton is close to the black body limit, as a function b (x_1)

For leading quarks, the values of $p^2_{\perp,BDL}$ are about half of those for gluons.

Also, a spectator parton in the BDL regime loses a significant fraction of its energy *similar to electron energy loss in backscattering of laser off a fast electron beam. Very different from eikonal type picture (scattering off the classical field)*

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.

Implications for the searches of new heavy particles at LHC.

- Background cannot be modeled based on study of minimal bias events.

- Events with production of heavy particles should contain a significant fraction of hadrons with transverse momenta $p_\perp \sim p_{\perp,BDL}$

  originating from fragmentation of partons which passed through by the strong gluon field. Transverse momenta of these hadrons are unrelated to the transverse momenta of the jets. Strong increase of multiplicity at central rapidities: a factor ~2 increase observed at FNAL, much larger at LHC.

$\Longrightarrow$ Difficult to identify jets, isolated leptons,... unless $p_\perp(\text{jet}) \gg p_{\perp,BDL}$

$\Longrightarrow$ Significant corrections to the LT approximation results for total cross sections and small $p^2_\perp < p^2_{\perp,BDL}$ differential cross sections of new particle production.

What dynamics governs the BLACK DISK (BD) regime in hadron-hadron collisions?

In central pp collision at collider energies leading quarks get transverse momenta > 1 GeV/c

If a leading parton got a transverse momentum $p_\perp$

probability for a nucleon to remain intact is $P_q \sim F_N^2(p_\perp^2)$

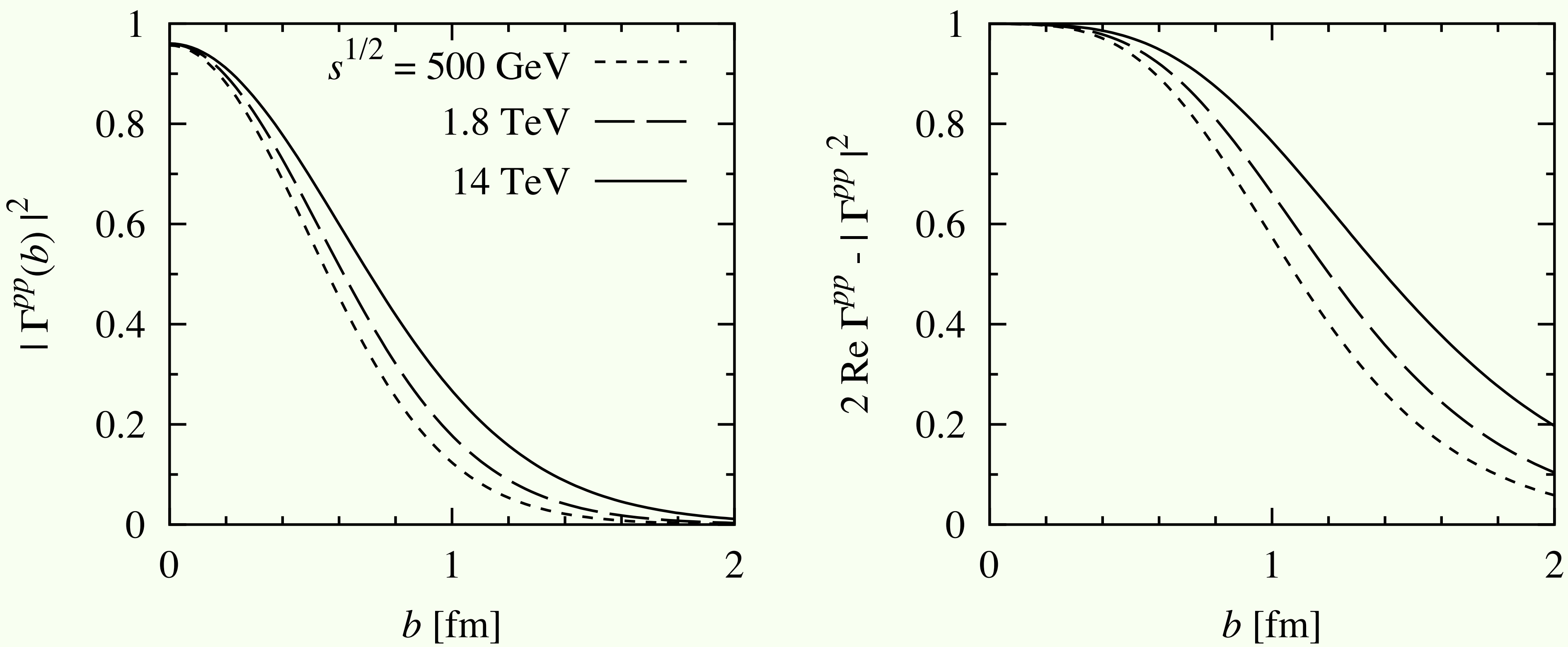
If $\langle p_\perp \rangle > 1 GeV/c \Longrightarrow P_q \ll 1/2$

However there are three leading quarks (and also leading gluons) in each nucleon.

$\Rightarrow$ Probability not to interact $\equiv |1-\Gamma(b)|^2 \leq [P_q]^6 \sim 0$

☛ $\Gamma(b \sim 0) = 1$!!!

Explains the elastic pp data for small b, predicts an increase of b range, $b<b_F$ where $\Gamma=1$, $b_F = c \ln s$ - Froissart regime.

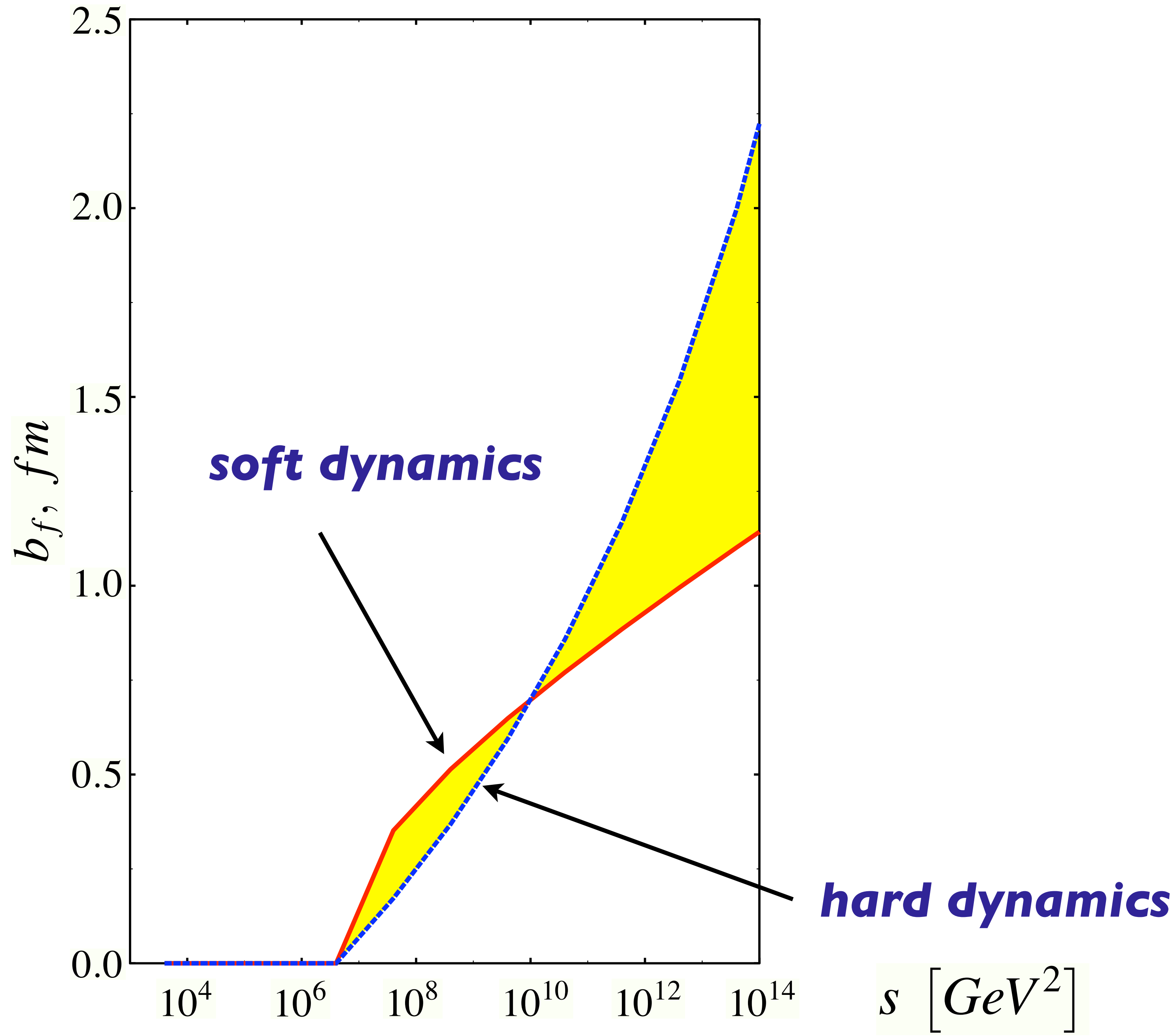


Calculation uses model of Islam et al; use of the model of Khoze et al leads to similar results.

Probability of inelastic interaction:

$$P(b) = 2\,Re\Gamma(b) - |\Gamma(b)|^2$$

Large b > 1 fm collisions generate ~ 50% of the total inelastic cross section of pp scattering. In such interactions nucleons interact mostly via their periphery - and valence quarks are likely not to be disturbed. Hence for such events - leading particle effect will survive. Challenge is to model simultaneously both small and large b collisions. Necessary for determining a fraction of events with leasding nucleons. In any case this picture leads to large fluctuations of the global stucture of the events in pp and to leasser extent in p-air interactions. At LHC look for anticorrelation between the forward protons/neutrons and activity at central rapidities.



Energy dependence of the black body regime cutoff parameter b_F estimated based on hard dynamics compared to the estimate based on soft dynamics - Landshoff - Donnachie model at large b.

Conclusions

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

★ *Minijet activity in events with heavy particles should be much larger than in the minimum bias events or if it is modeled based on soft extrapolation from Tevatron.*

★ *Significant corrects for the LT predictions especially for moderate transverse momenta.*

★ *Many of the discussed effects are not implemented or implemented in a very crude way in the current MC for LHC and cosmic rays*

★ *Forward physics for cosmic rays sensitive to small x physics - connection between pPb at LHC and GZK cosmic rays*

★ *Total opacity 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.*