Small x physics in centra
pp collisions at LHC

Mark Strikman, PSU

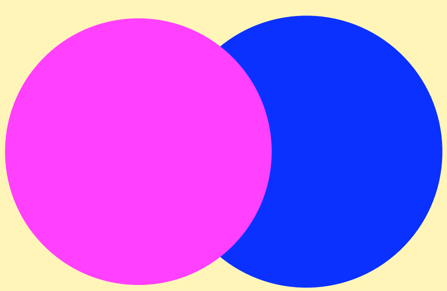
For a detailed review see Frankfurt, MS, C. Weiss - Annual Review in Nuclear and Particle Sciences, 05

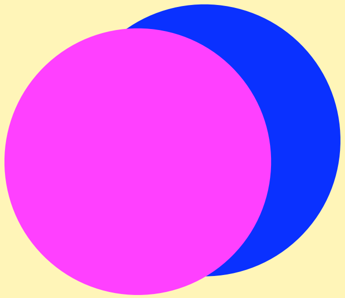
Lisbon, June 28

Aim - realistic account of the transverse structure of the nucleon and of the onset of Black Disk Limit on the global structure of the events with Higgs, SUSY,... at LHC

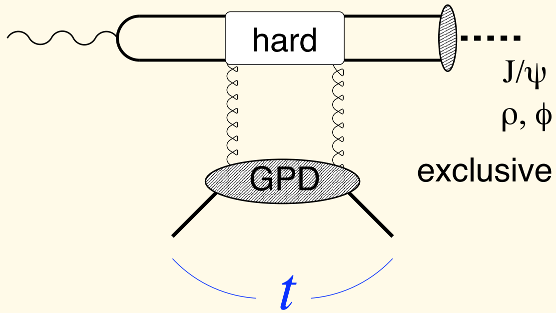
For inclusive cross section at high virtuality transverse structure does not matter - convolution of parton densities

For multiple collisions - which have large probability at LHC - *rates scale as 1/(transverse area occupied by partons), depend on the shape of the transverse distribution and on the degree of the overlap*



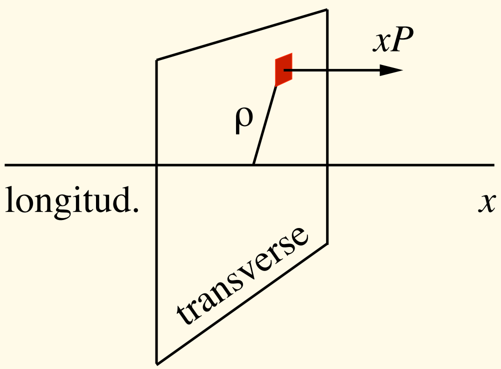


- Transverse spatial distribution of gluons



$$G(x, Q^2_{\text{eff}}; t) \;=\; G(x, Q^2_{\text{eff}}) \;\times\; F_g(x, Q^2_{\text{eff}}; t)$$

generalized gluon dist'n — two–gluon formfactor



$$F_g(x, t) \;=\; \int d^2\rho \, e^{-i\vec{\Delta}_\perp \cdot \vec{\rho}} \;\; F_g(x, \boldsymbol{\rho})$$

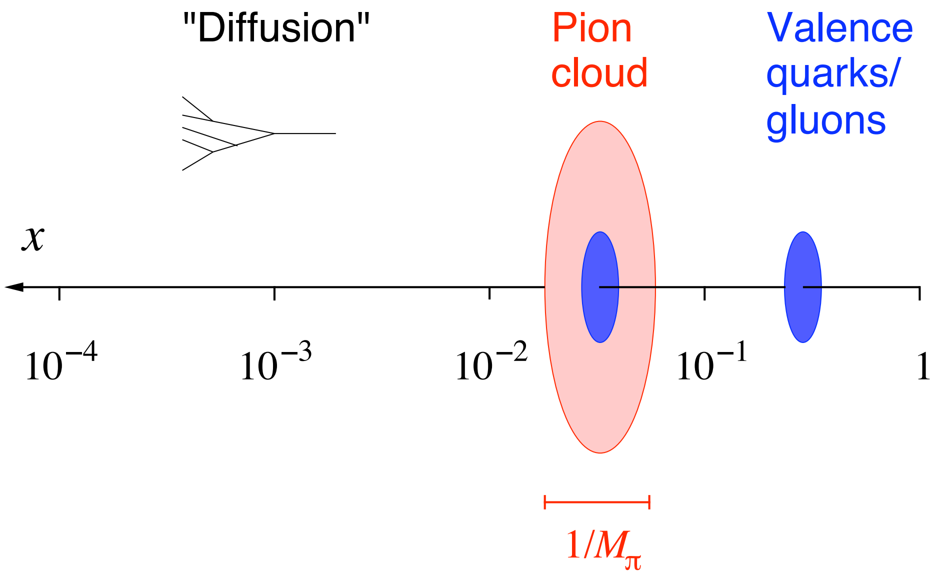
transverse spatial distribution of gluons

$$\langle \rho^2 \rangle_g \;=\; 4 \, \frac{\partial}{\partial t} \, F_g(x, t)$$

gluonic transverse size of nucleon, x–dependent!

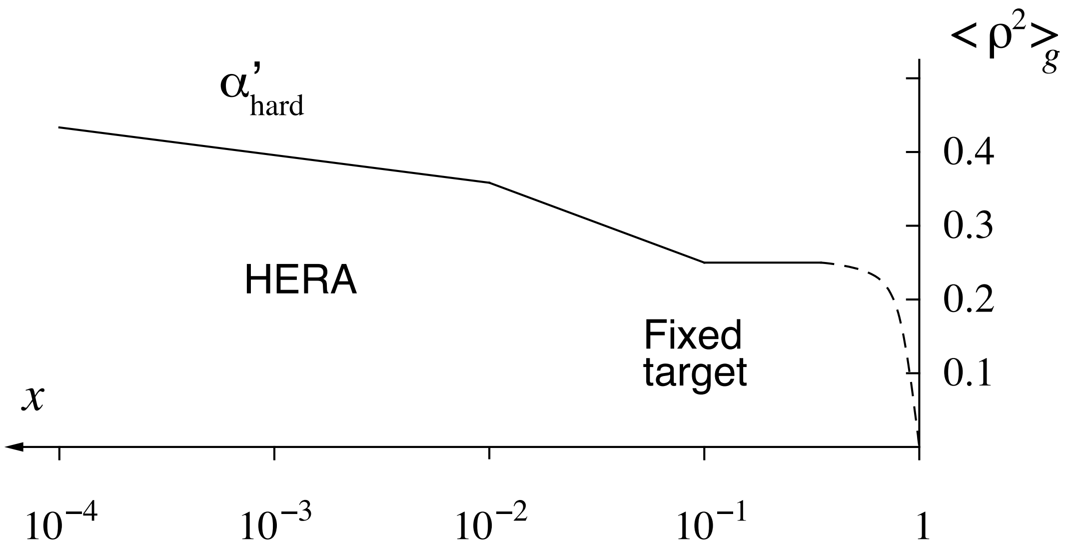
– Can be extracted from t–dependence of $\dfrac{d\sigma}{dt}(\gamma^* p \to V p)$

- Gluonic transverse size: x–dependence



Gluon transverse size decreases with increase of x

Pion cloud contributes for $x<M_\pi/M_N$ [MS &C.Weiss 03]

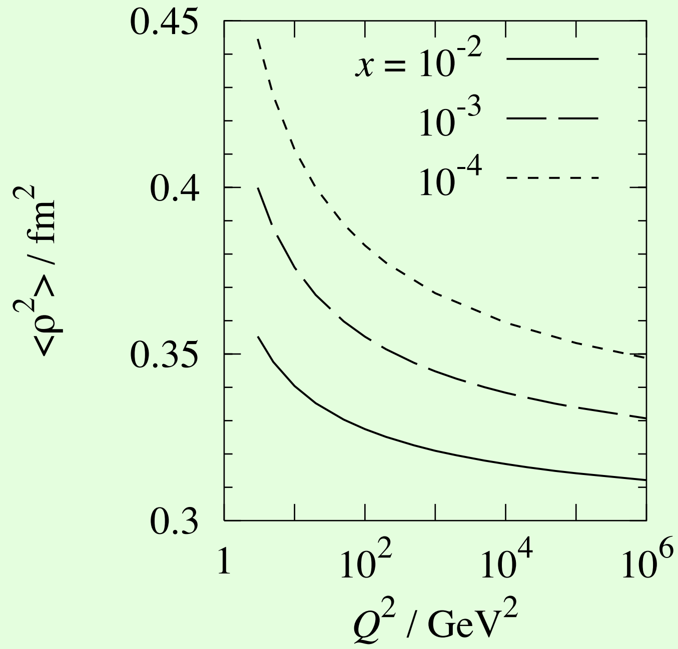


– Transverse size at large x much smaller than proton radius in soft interactions:

$$\langle\rho^2\rangle(x > 10^{-2}) \ll R^2_{\text{soft}}$$

$\Downarrow$

Two scale picture



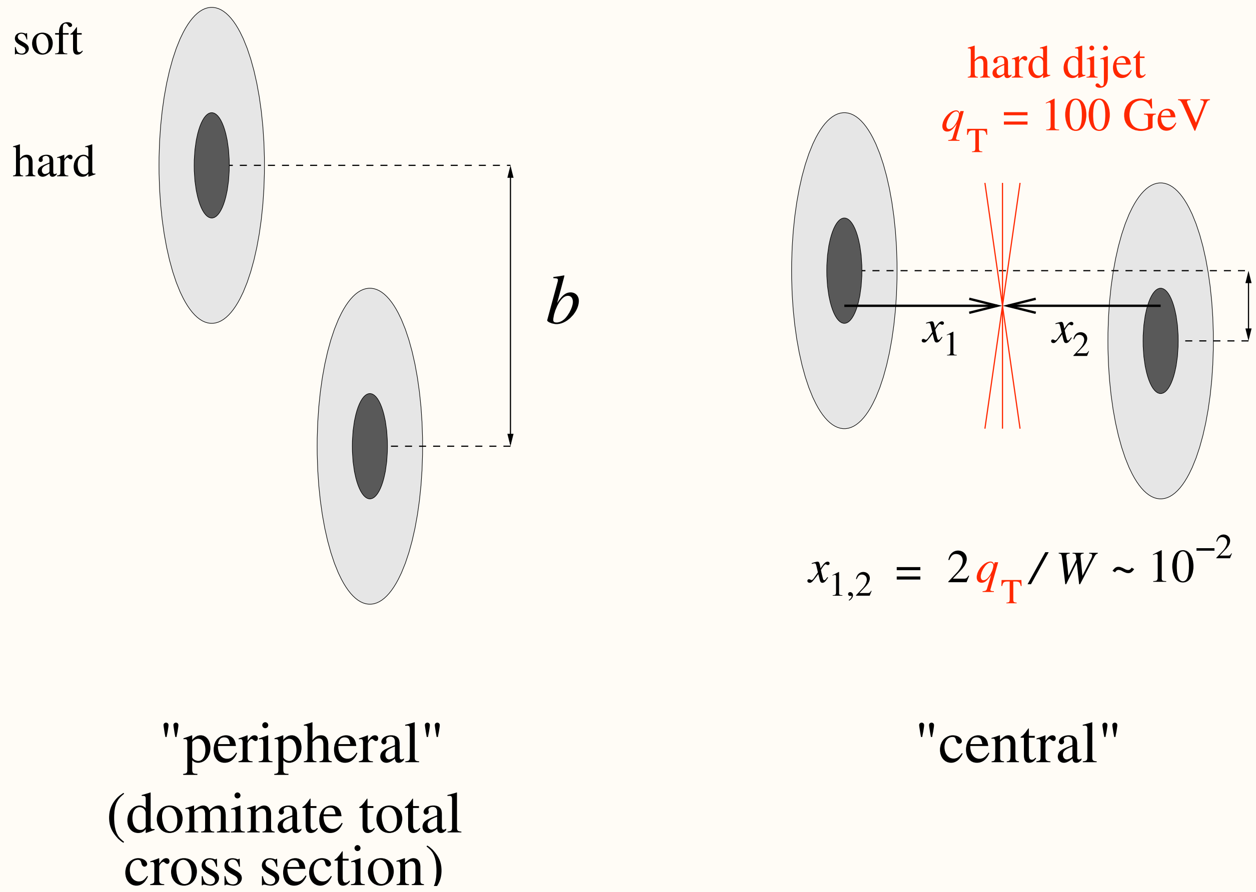
Change of $<\rho^2(Q^2)>$ with x - leads to effective α' which drops with Q but still remains finite even at very high Q.

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

Implication of the two scale picture:

hard processes between partons with moderately large $x > 0.01$ correspond to collisions where nucleons overlap much stronger

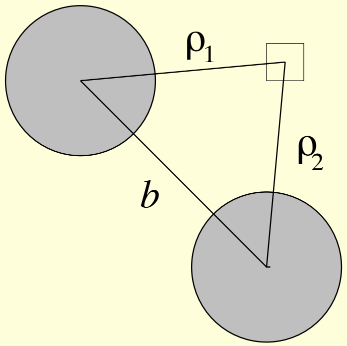


Note that a parton passing through the center of the nucleon encounters gluon density similar to that in the nuclei

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 $P_2(b)\, d^2b$

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

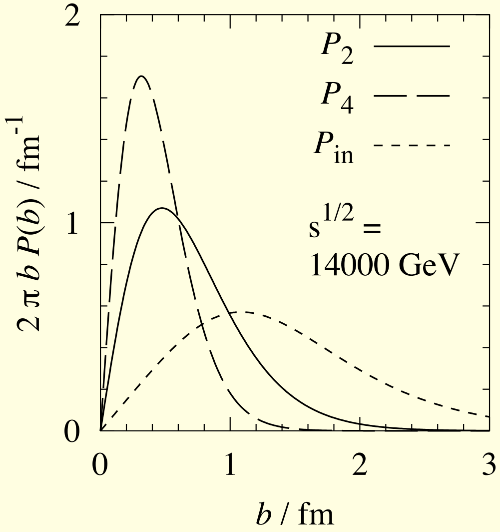
where $x_1 = 2q_\perp/\sqrt{s}$. Obviously $P_2(b)$ is automatically normalized to 1.

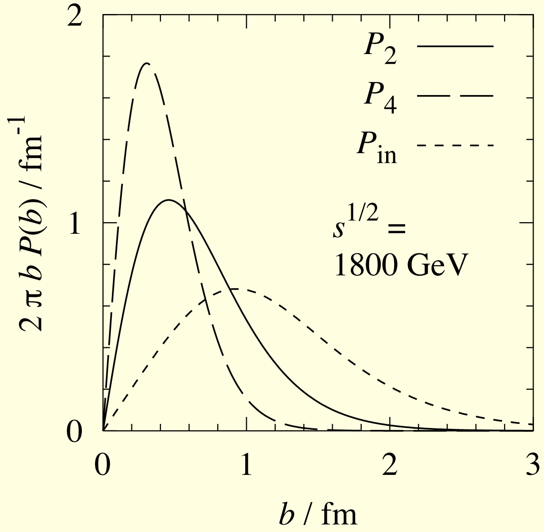
Impact parameter distribution for minimal bias inelastic interactions interactions can be extracted from the data/models of elastic scattering using S-channel unitarity relations between elastic, inelastic and total cross sections:

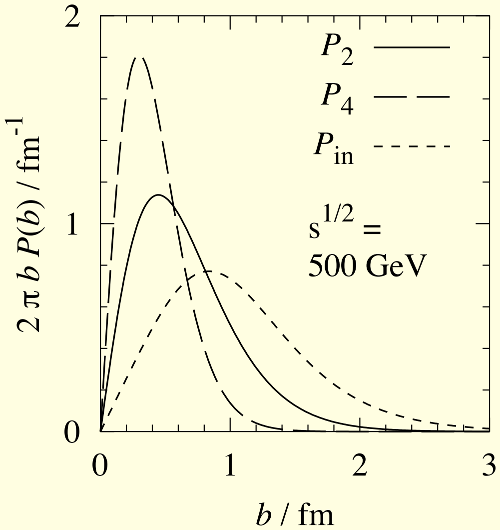
$$\Gamma_h(s,b) = \frac{1}{2is}\frac{1}{(2\pi)^2}\int d^2\vec{q}e^{i\vec{q}\vec{b}}A_{hN}(s,t) \qquad ImA(t=0) = s\sigma_{tot}$$

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

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







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.

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.

At HERA interaction of gluons is close to BDL for $Q^2 \leq 4GeV^2$

- Pattern of scaling violation for small Q and small x
- Large ratio of diffraction/ total for gluon channel
- Large value of Γ(b~0) for "gluon dipole" -nucleon interaction for d >0.3 fm, $x \sim 10^{-4}$

Based on HERA data we expect for RHIC BDL for similar virtualities for interaction of leading quarks with heavy nuclei ➣Large fractional energy losses. Explains pattern of suppression of leading pions and correlations observed at RHIC.

Hence we expect similar effects in the central pp collisions. First we 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

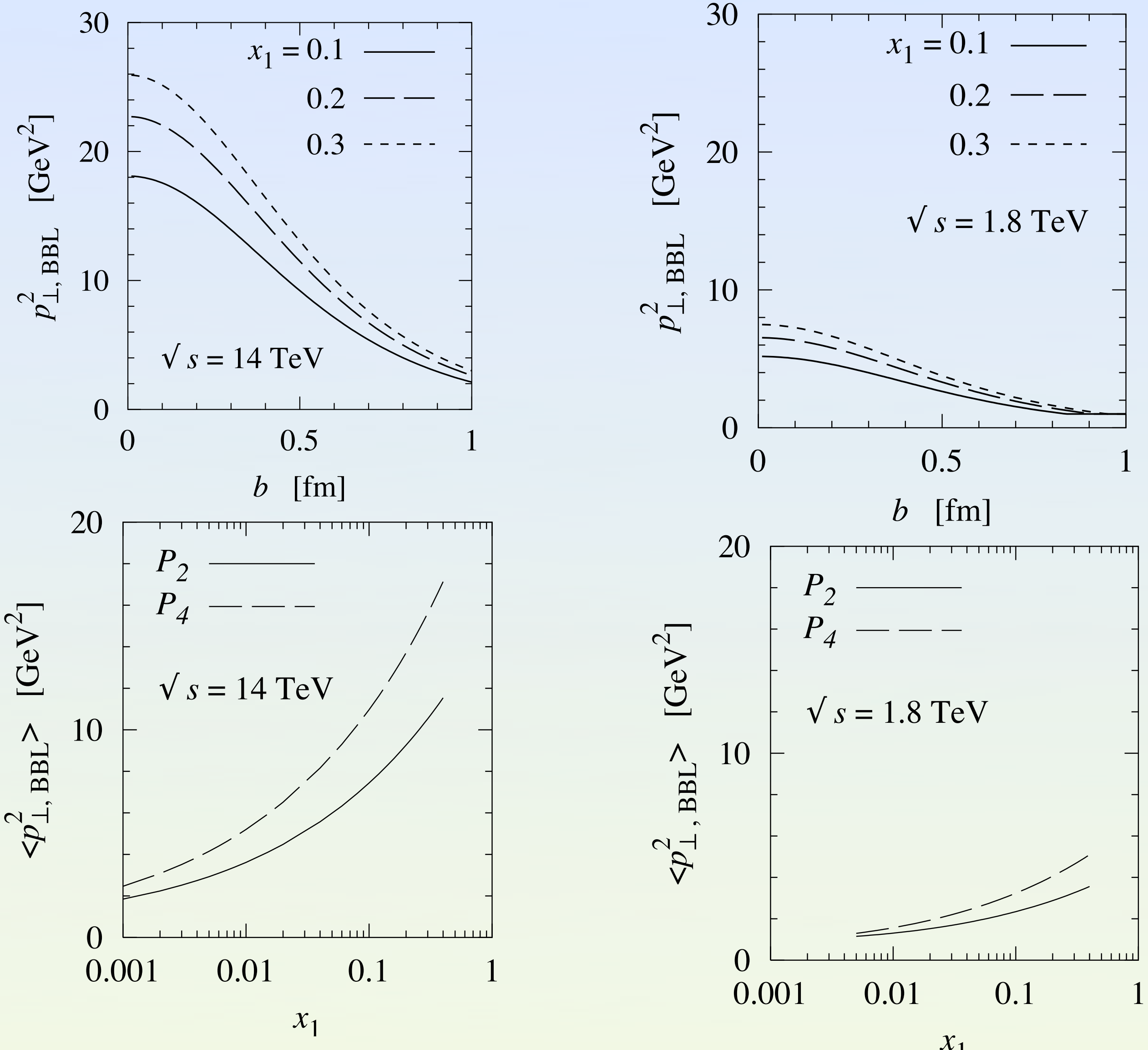
- Determining what minimal x are resolved in the second proton for given virtuality

$$x = \frac{4p_\perp^2}{x_1 s}, Q^2 = 4p_\perp^2 \qquad small\, x \leftrightarrow large\, x_1$$

- 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 $\langle p_\perp^2 \rangle \approx (3/2d)^2$

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

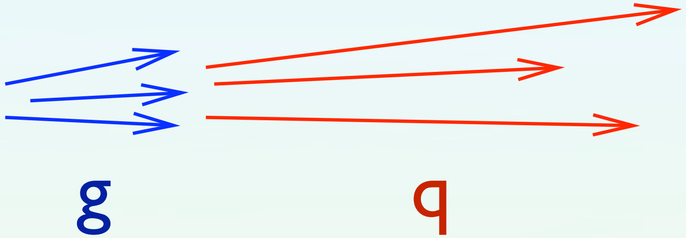


The critical transverse momentum squared, below which the interaction of a leading gluon with the other proton is close to the black disk limit, as a function of b (x_1)

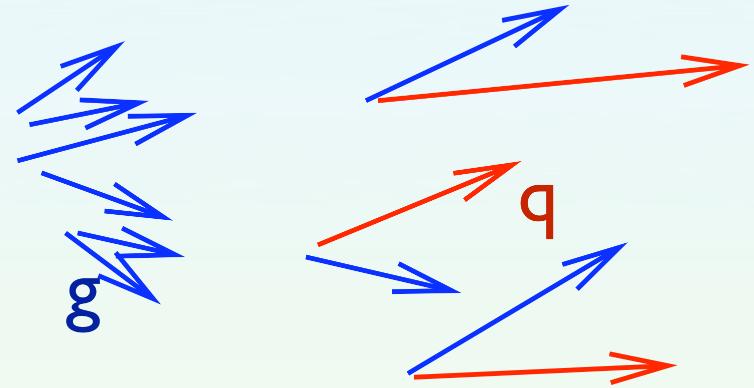
For leading quarks, the values of $p^2_{\perp,BDL}$ are about half of those for gluons.

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

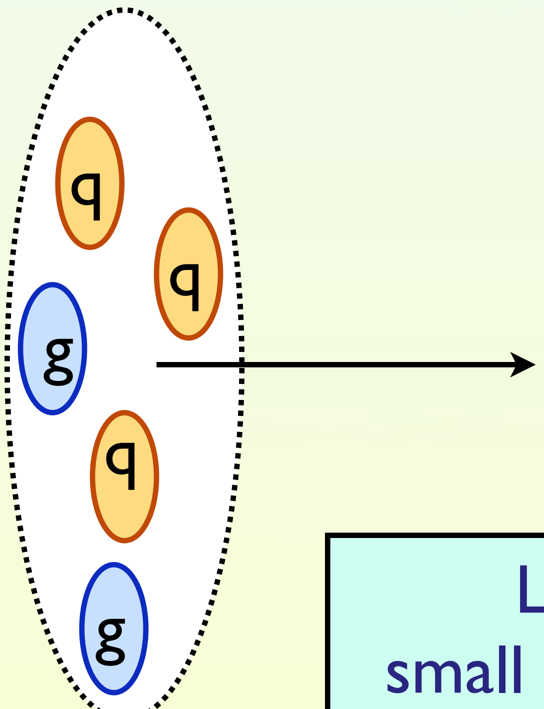
Characteristics of the final state in the central pA(pp) collisions

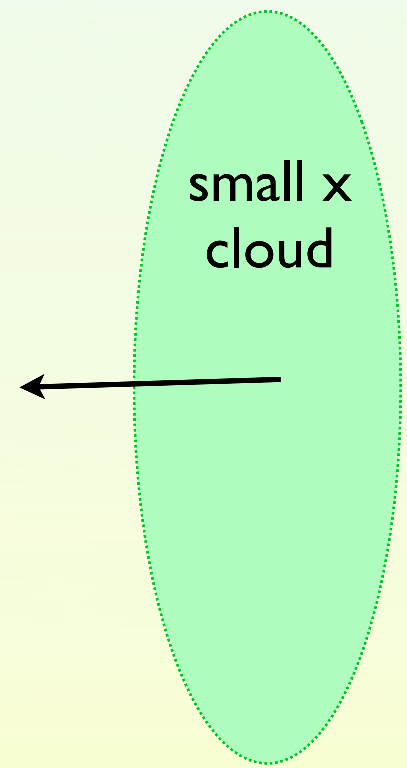


fast partons in a nucleon before collisions



fast partons in a nucleon after central collision





Large x partons burn
small holes in the small x cloud

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 also looses a fraction of its energy. 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 $z \geq 0.02 - 0.05$ 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 at LHC.

- 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

- ★ *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*

Several topics which I did not have time to mention

- ★ *Evidence for presence of transverse correlations between x>0.1 partons in the nucleon*

- ★ *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.*