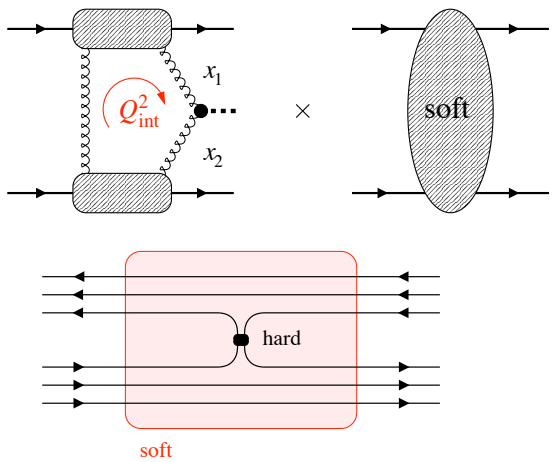
THEORETICAL EVALUATION OF GAP SURVIVAL

Leonid Frankfurt

MULTIPARTON INTERACTIONS, PERUGIA,OCTOBER 2008

Hard–soft interplay in $pp \to p + H + p$



- H produced in hard process with two–gluon exchange

  $\mu^2_{\text{soft}} \ll Q^2_{\text{int}} \ll M^2$ [Khoze et al. 97]

  $x_{1,2} \sim \frac{M}{\sqrt{s}} \sim 10^{-2}$ Higgs at LHC

- Soft spectator interactions must not produce particle

$$\sigma(pp \to p + H + p = S^2 \sigma_{hard}$$

If soft and hard phenomena would be independent the contribution of soft interactions into gap survival is unambigously calculable in terms of special QCD factorization theorem.

Different time/distance scales!

Amplitude calculable in terms of

– Gluon GPD
– pp elastic S–matrix

Outline

Some properties of high energy QCD at the LHC

Evaluation of gap survival if no correlations between hard and soft QCD

Suppression of gap survival due to onset of black pQCD regime

Color fluctuations in nucleons and gap survival

Concept of peripheral and central collisions should be well defined at the LHC.

1. In a quantum field theory -QCD transverse radius of peripheral interactions should increase with energy (V.Gribov 1963) Observed at FNAL as shrinking of diffractive cone for elastic pp interactions with increase of energy:

$$r^2 = B = B_o + 2\alpha' \ln(s/s_o)$$

2. For small impact parameters "b" hard and soft QCD compete and hard QCD probably wins at the LHC.

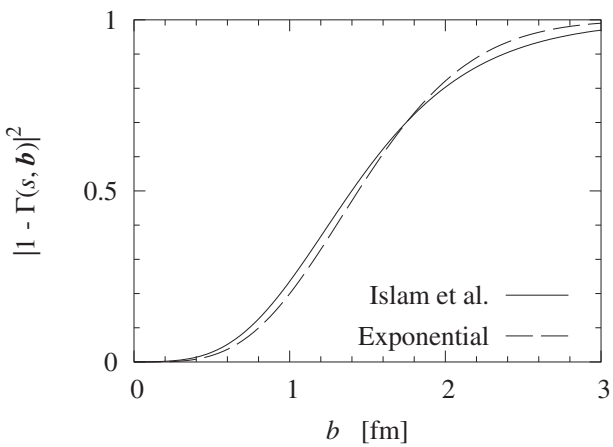
3. Hard interactions, new particle production are concentrated at central impact parameters.

How black is pp interactions at LHC

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

PHYSICAL REVIEW D **75,** 054009 (2007)

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



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. Solid line: parametrization of Islam et al("diffractive part" only). Dashed line: exponential parametrization, withΓ(b=0) =1 (BLACK DISK LIMIT) and B=21.8 GeV^{-2}.

Dominance of spin flip amplitudes for inelastic large mass diffraction at nonzero t .

Experimentally(FNAL): $d\sigma(p+p \to p+X)/dt = Aexp(Bt)$

Observed slope : $B \approx 8 \div 9GeV^{-2}$

Calculation partial wave for b=0 gives for inelastic diffraction:

$f(b=0,s)=1$

which is wrong since inelastic diffraction is peripheral process.

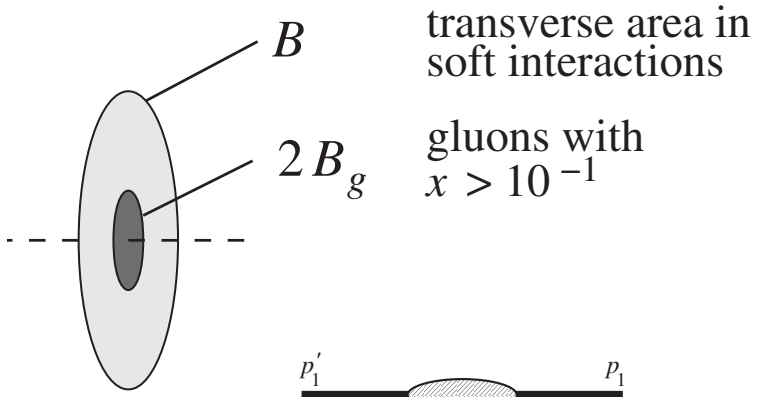
Explanation-large spin flip : $d\sigma/dt = A_1 expB_1 t - texpB_2 t$

and $B_1 \gg 9GeV^{-2}$

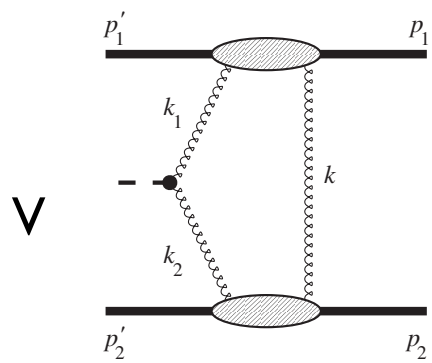
Serious technical problem for Pomeron, eikonal models.

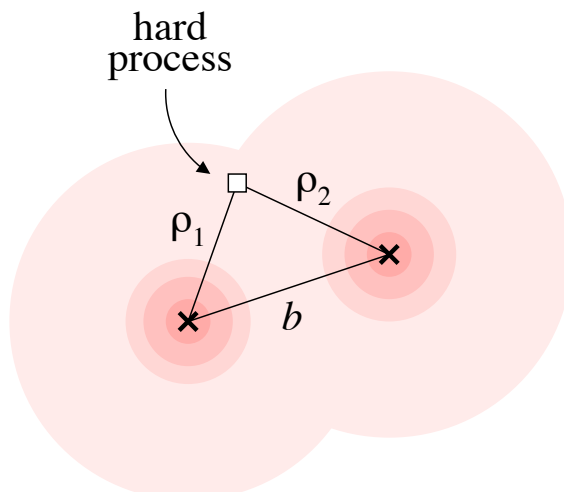
Gap suppression for pp → p+ H + p

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



Frankfurt, Hyde, MS, Weiss 06





Assuming no correlation between hard and soft interaction in impact parameter space since they occur at different space-time intervals - we derive expression for the amplitude of the process:

$$T_{\rm diff} = \langle p_1' p_2' | \hat{V}_{\rm hard} \hat{S}_{\rm soft} | p_1 p_2 \rangle.$$

S means S matrix

$$T_{\rm diff}(\boldsymbol{p}_{1\perp}', \boldsymbol{p}_{2\perp}') = \int d^2 b \int d\rho_1 \int d\rho_2 \delta^{(2)}(\boldsymbol{b} - \boldsymbol{\rho}_1 + \boldsymbol{\rho}_2)\, e^{-i(\boldsymbol{p}_{1\perp}'\boldsymbol{\rho}_1) - i(\boldsymbol{p}_{2\perp}'\boldsymbol{\rho}_2)} \kappa F_g(x_1, \xi_1, \boldsymbol{\rho}_1; Q^2) \times F_g(x_2, \xi_2, \boldsymbol{\rho}_2; Q^2)[1 - \Gamma(s, \boldsymbol{b})]$$

where $\kappa \equiv \kappa(s, \xi_1, \xi_2)$ represents the symbolic result for the absolute normalization of amplitude of the hard scattering process

It is convenient to introduce a normalized impact parameter distribution

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

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

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

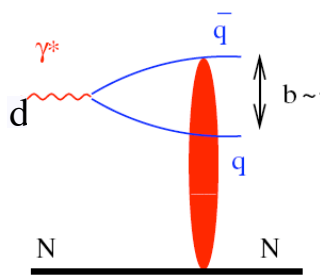
In the approach based on QCD factorization theorem no need to model effects of multi Pomeron exchanges, use eikonal approximation etc. Answer is expressed through the experimentally measured elastic amplitude of pp scattering.

Interesting that naive generalization of eikonal model which includes diffraction = the Good-Walker model approach has problems. It violates Pumplin bound and ignores dominance of spin flip in the inelastic diffraction away from t=0.

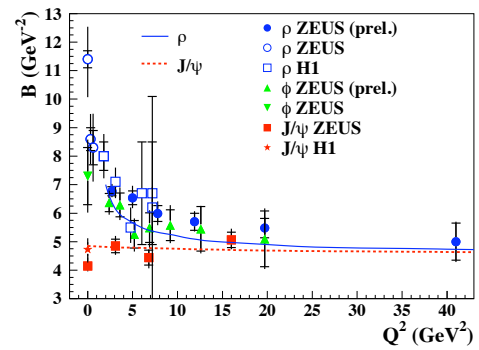
In LT in pQCD t-distribution of exclusive VM production measures transverse distribution of gluons given by the Fourier transform of the two gluon form factor $F_g(x,t)$

$$d\sigma/dt \propto F^2_g(x,t)$$

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

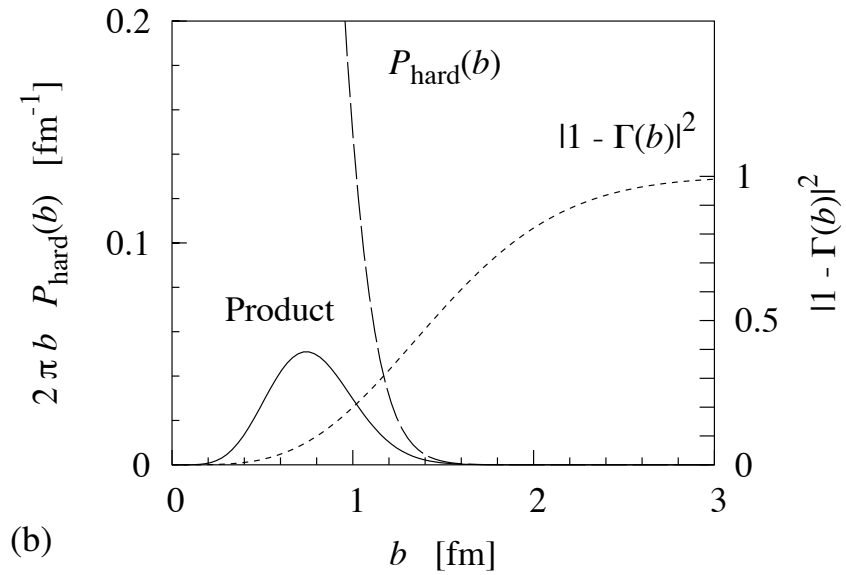


$$r_T \propto \frac{1}{Q}\left(\frac{1}{m_c}\right) \ll r_N$$

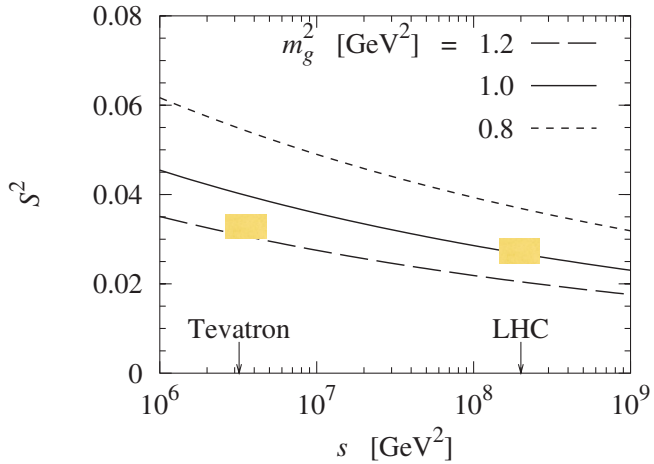


Convergence of the t-slopes, B ($\frac{d\sigma}{dt} = A\exp(Bt)$, of ρ-meson electroproduction to the slope of J/psi photo(electro)production.

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



The integrand (impact factor distribution) in the RGS probability for Higgs boson production at the LHC energy. Dashed line: b distribution of the hard two-gluon exchange, $P_{hard}(b)$ evaluated with exponential parametrization of the two-gluon form factor with B_g=3.24 GeV^{-2}. Solid line: the product $P_{hard}(b)|1-\Gamma(b)|^2$ .Vanishing of $|1-\Gamma(b)|^2$ strongly suppresses the contribution of the small impact parameters. RGS probability, S^2 is given by the area under the solid curve. Note that median of the distribution is at b~0.8 fm.



S^2(LHC)"uncorrelated approximation"≈ 0.025 is close to the "Durham" number of 2001(Khoze, Martin, Ryskin) due to accidental compensation of two effects: no suppression due to diffractive channel, but a larger suppression due to more realistic transverse distribution of gluons.

B_{2g} =3.24 GeV^{-2} for x~ 10^{-2} vs $B_{2g(HERA)}$ =5 GeV^{-2}

Triple pomeron contribution in "Durham" approach is problematic because of neglect of spin flip .

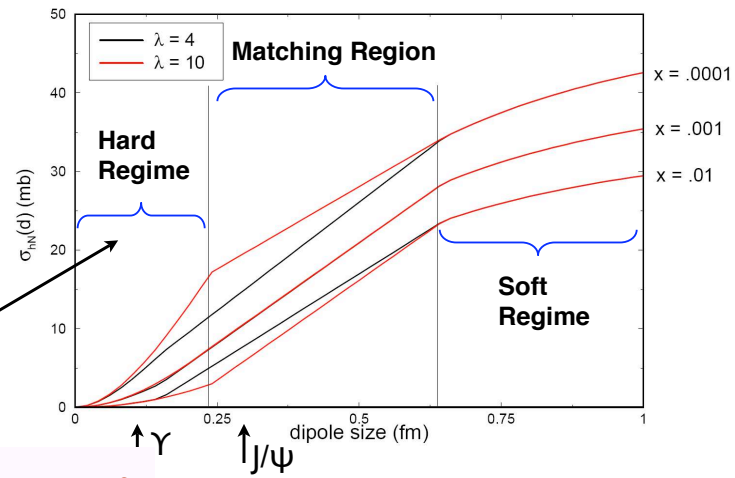
Effects of correlations:

- Local correlations induced by QCD evolution
- Correlations induced by global size fluctuations

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

$Q^2 = 3.0\ GeV^2$



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

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

Frankfurt et al 2000-2001

F^2 Casimir operator of color SU(3)

Baym et al 93

Provided a reasonable prediction for σ_L

F^2(quark) =4/3

F^2 (gluon)=3

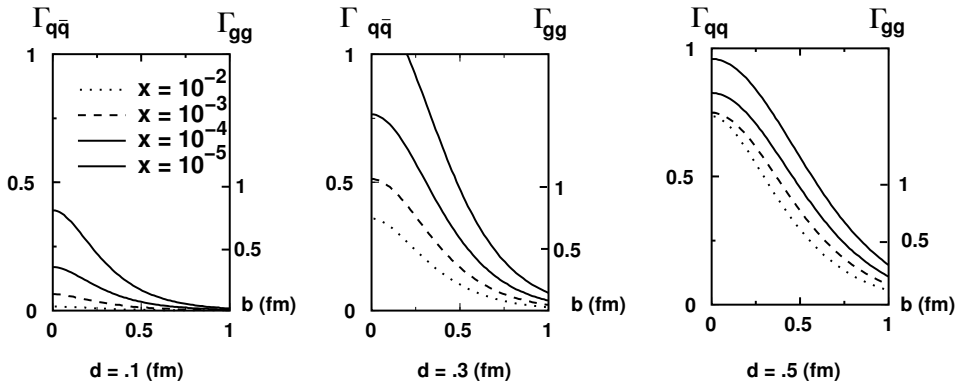
Analyze strength of interaction of small color dipoles with nucleons:

Combine study of dipole nucleon cross section (description of F_{2p} and analysis of exclusive hard processes (t-dependence of the dipole - nucleon scattering)

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

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

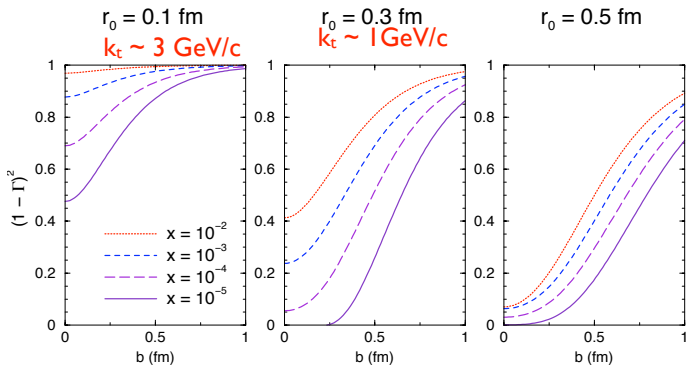
$\Gamma = 1$ *corresponds to regime of complete absorption - BDR*

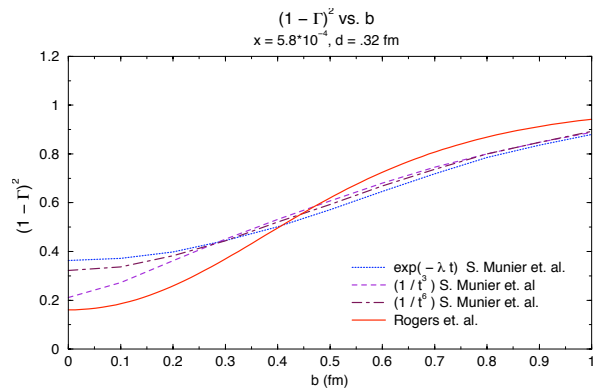


T.Rogers et al

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, $x \sim 10^{-4}$

⇒ Large probability of diffraction in gluon channel

Forward partons with p_t less than BDR scale should loose energy and p_t distribution should broaden

Test

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

Gluon densities at small x in heavy nuclei at b=0 and in the proton at b=0 are similar

⇒ In high energy pp collisions at small b no partons with p_t < few GeV can survive

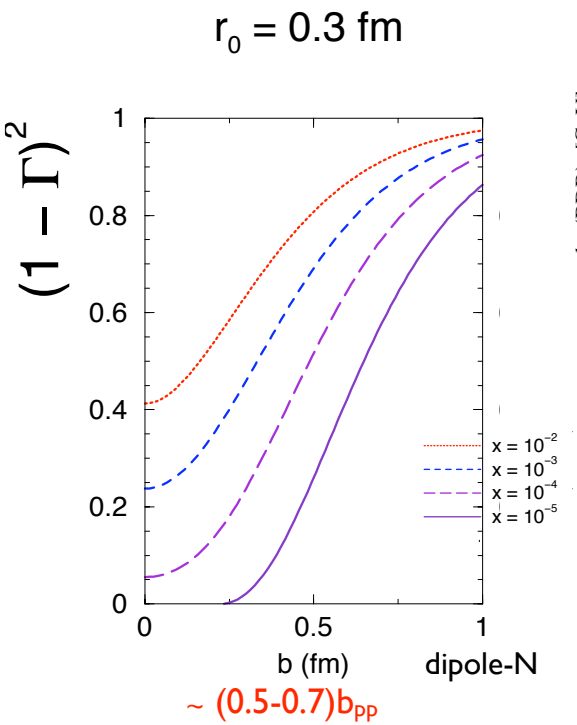
Let us illustrate magnitude of these effects consider the interaction of gluon from the evolution of gluon gpd with the small x gluons in the second nucleon

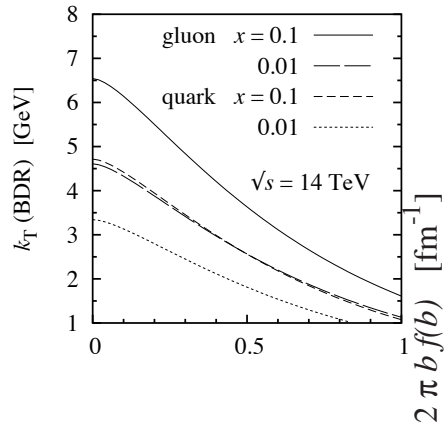
In gluon GDPs for diffractive Higgs production at LHC,

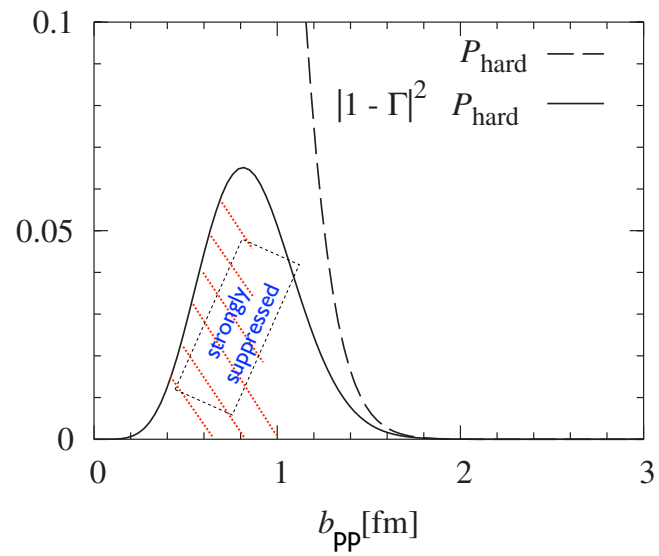
$Q^2 \sim 4\text{-}8\ \mathrm{GeV}^2,\ x \sim 10^{-2}$

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 $s_{eff} \sim s_{LHC}/10$. $x_{eff} \sim 10^{-6} - 10^{-7}$!!!



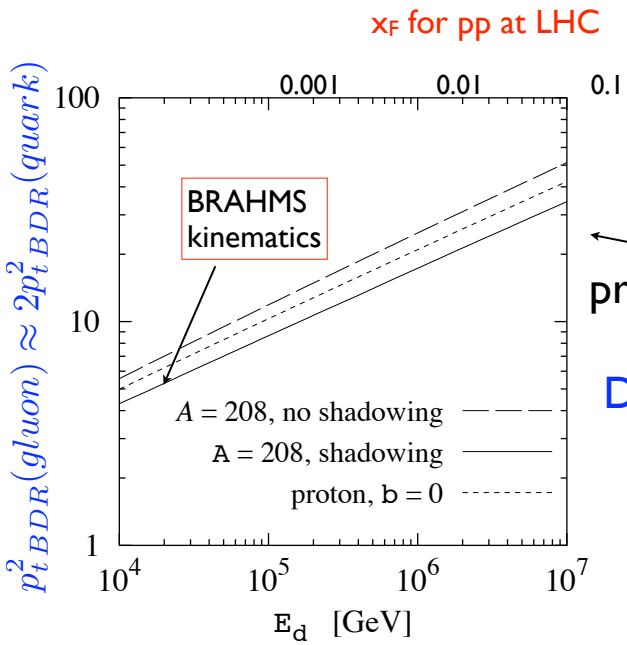




Extra suppression is roughly $|1-\Gamma_{\text{dipole N}}((0.5\text{-}0.7)b_{pp})|^4$ ➔ for b_{pp} =0.8 fm suppression is by a factor > 10. Overall would give suppression > a factor 5. If a gluon was emitted from a gluon at large x suppression is even larger.

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

where d is the minimal size of the gg (qq) dipole for which Γ(b=0)≥ 1/2 in LT



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

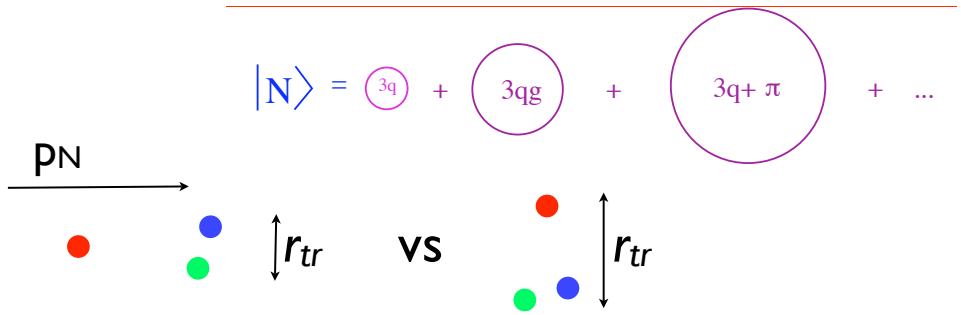
Difference is in the spread in b

Suppression of exclusive Higgs production at LHC is very sensitive to onset of the black disk regime. Large suppression as compared to approximation of factorized soft and hard physics . Black disk regime effects should suppress S^2 by at least a factor of 3 at LHC (likely a factor of 4 -5). For Tevatron this effect is much smaller since effective x are a factor of 50 larger.

$$\boxed{S^2_{\ LHC}(\text{Higgs}) < 0.01}$$

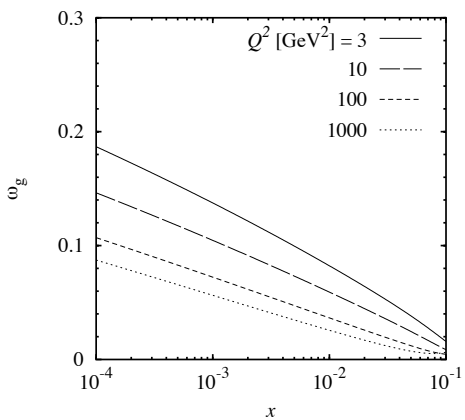
Several other implications - in particular much more narrow t - distributions for protons since b is a factor > 40% larger.

There exist global fluctuations of the strength of interaction of a fast nucleon, for example due to fluctuations of the size /orientation



Due to a slow space-time evolution of the fast nucleon wave function one can treat the interaction as a superposition of interaction of configurations of different strength - Pomeranchuk & Feinberg, Good and Walker, Pumplin &Miettinen (in QCD this is reasonable for total cross sections and for diffraction at very small t)

Fluctuations of parton density



- Fluctuations of gluon density in hard diffraction $ep \to e + V + X$

$$\omega_g = \frac{\langle G^2 \rangle - \langle G \rangle^2}{\langle G \rangle^2} = \frac{d\sigma/dt \text{ (inel)}}{d\sigma/dt \text{ (el)}}$$

"Color fluctuations"

- Correlated with soft pp cross section fluctuations

- RGS probability in pp at LHC reduced by $\sim 20\%$ (model-dep.)

[Frankfurt, Strikman, Treleani, Weiss, arXiv:0808.0182] PRL 08

LHC - strong suppression for b< 1 fm. However cross section is already killed there by BDR mechanism - no double jeopardy.

Conclusions - several mechanisms suppress rapidity gaps at LHC for b < 1 fm, leading to a strong suppression of S^2 at LHC as compared to naive uncorrelated picture.

$$S^2 < 0.01$$

Safe contribution is from b> 1.2 fm, leading to

$$S^2 \geq 0.004$$

GUESS: $0.007 \geq S^2 \geq 0.005$

Conclusions

Gap survival probability at LHC should be much smaller (<.01) than according to the models neglecting correlations of partons in transverse plane due to onset of black disk regime/ regime of high gluon fields

$\Updownarrow$

Safe contribution is from b> 1.2 fm, leading to $S^2 \geq 0.004$

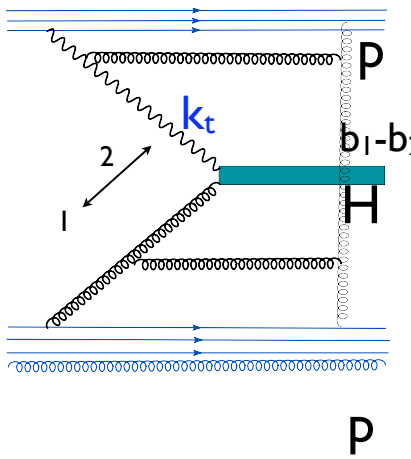
GUESS:	$0.007 \geq S^2 \geq 0.005$	2006
Levin et al	$S^2 < 0.01$	2007
Durham group	$S^2 < 0.01$	2008

ACCOUNT of CORRELATIONS between soft and hard interactions -
HARD INTERACTIONS IN THE BLACK-DISK REGIME

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

(a) Absorption of parent parton of the gluons attached to the Higgs.
(b)Absorption of the gluons which screens hard gluon attached to the Higgs.
(c) Absorption due to local interactions within the partonic ladder.

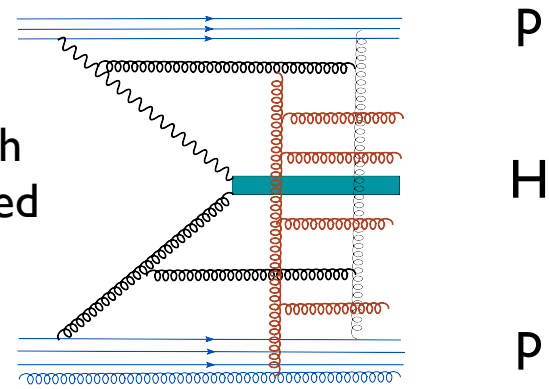
we will consider only (a) which leads to a large suppression - other may lead to further suppression



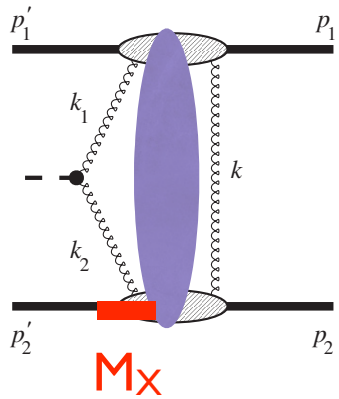
$b_1 - b_2 \sim 1/k_t << r_N$

Interactions of parton "2" with second nucleon are not included in the soft factor $|1-\Gamma|^2$

How large it is?



Inelastic diffraction screening due to inelastic two gluon GPD



We find that structure of diffraction in pp scattering at LHC and in GDPs relevant for the Higgs production is very different:

$10^{-8} \leq x_{I\!P} \leq 0.1$ generic pp diffraction vs $10^{-2} \leq x_{I\!P} \leq 0.1$ for GDPs

Overall we find effects of inelastic intermediate states, M_X, are very small when parton distributions in all configurations are the same.