
Color fluctuations and gap survival probability at the LHC energies
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Outline

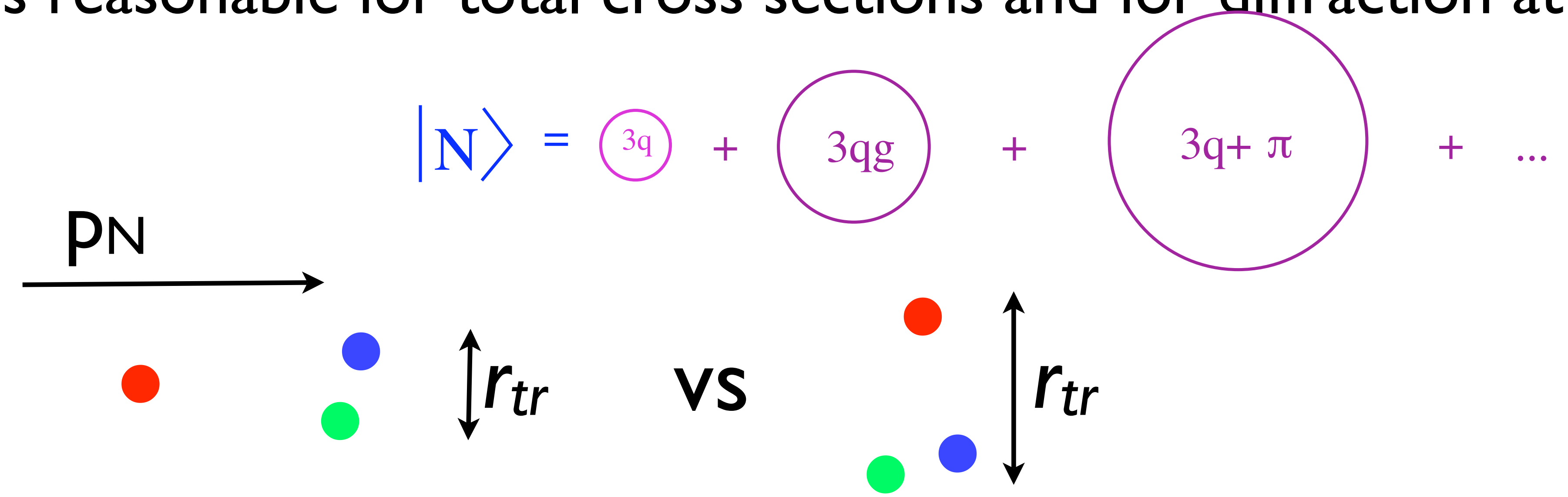
* Strength of gluon fluctuations in nucleon at small x.

* Strong gluon fields at small x - and suppression of gap survival in Higgs production at the LHC energies

Frankfurt, Hyde, Strikman, Weiss, PRD **75**:054009, 2007.
FSW + Treleani, PRL **101**:202003, 2008.

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

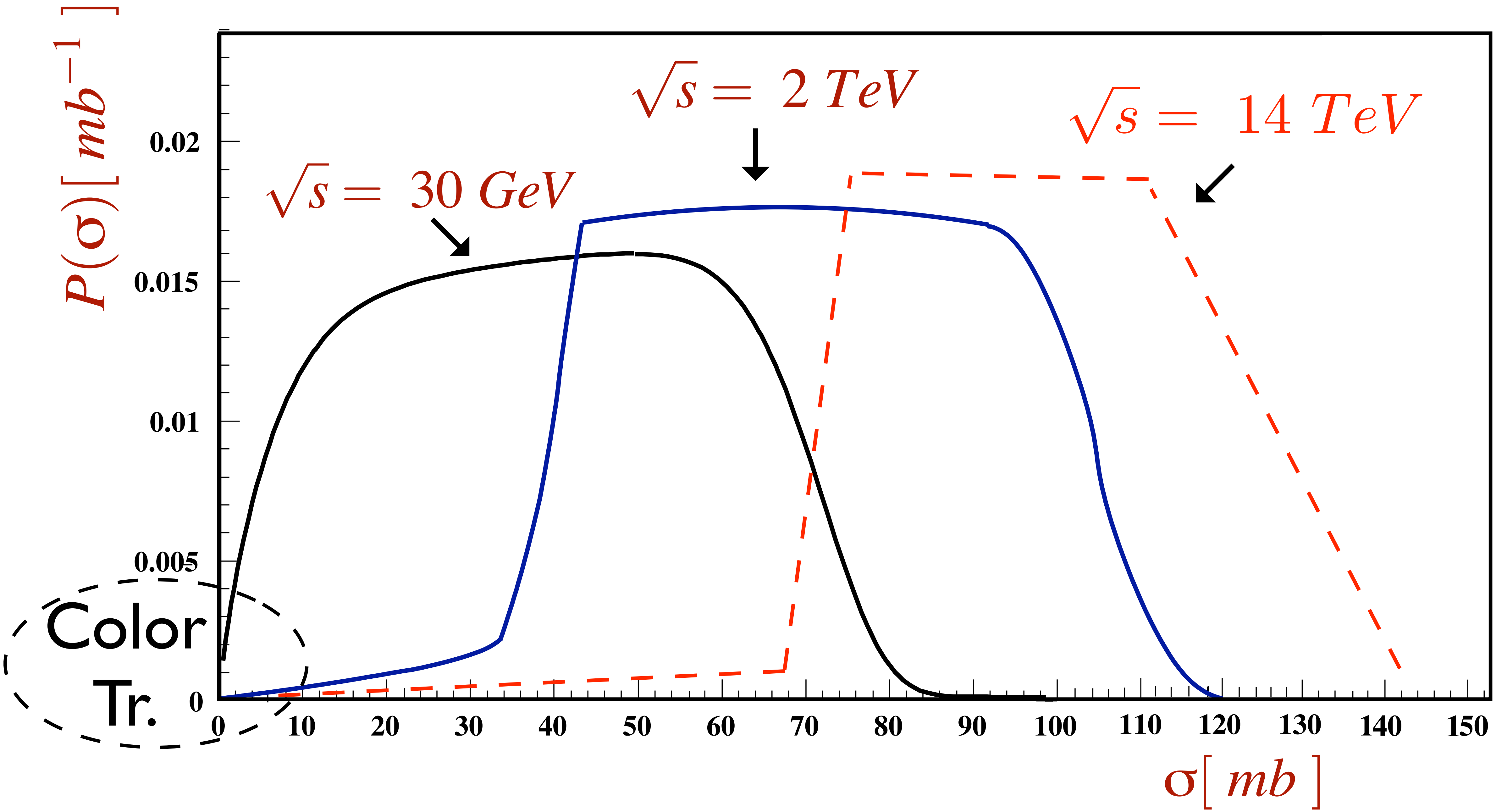
Direct measure of these fluctuation is diffraction at small t.
- Pomeranchuk & Feinberg, Good and Walker, Pumplin &Miettinen (in QCD this logic is reasonable for total cross sections and for diffraction at very small t)



Convenient quantity - $P(\sigma)$ -probability that nucleon interacts with cross section σ

If there were no fluctuations of strength - there will be no inelastic diffraction at t=0:

$$\left.\frac{\frac{d\sigma(pp\to X+p)}{dt}}{\frac{d\sigma(pp\to p+p)}{dt}}\right|_{t=0} = \frac{\int(\sigma-\sigma_{tot})^2 P(\sigma)d\sigma}{\sigma_{tot}^2} \equiv \omega_\sigma$$ variance



The 30 GeV curve is result of the analysis (Baym et al 93) of the FNAL diffractive pp and pd data which explains FNAL diffractive pA data (Frankfurt, Miller, MS 93-97). The 14 and 2TeV curves are my guess based on matching with fixed target data and collider diffractive data.

Strength of the gluon field should depend on the size of the quark configurations - for small configurations the field is strongly screened - gluon density much smaller than average.

How strong are fluctuations of the gluon field in nucleons?

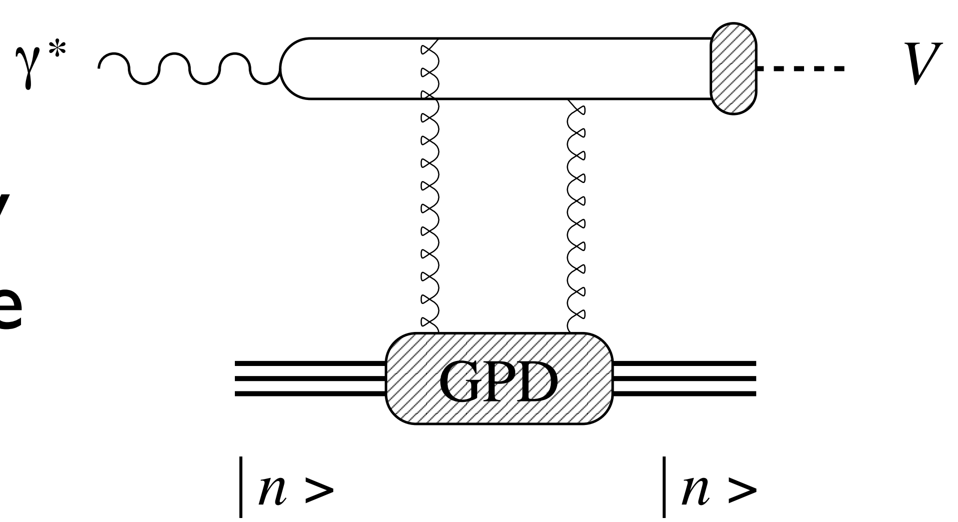
FSTW08

Consider $\gamma_L^* + p \to V + X$ for Q^2 > few GeV^2

In this limit the QCD factorization theorem (BFGMS03, CFS07) for these processes is applicable

Expand initial proton state in a set of partonic states characterized by the number of partons and their transverse positions, summarily labeled as $|n\rangle$

$$|p\rangle = \sum_n a_n |n\rangle$$



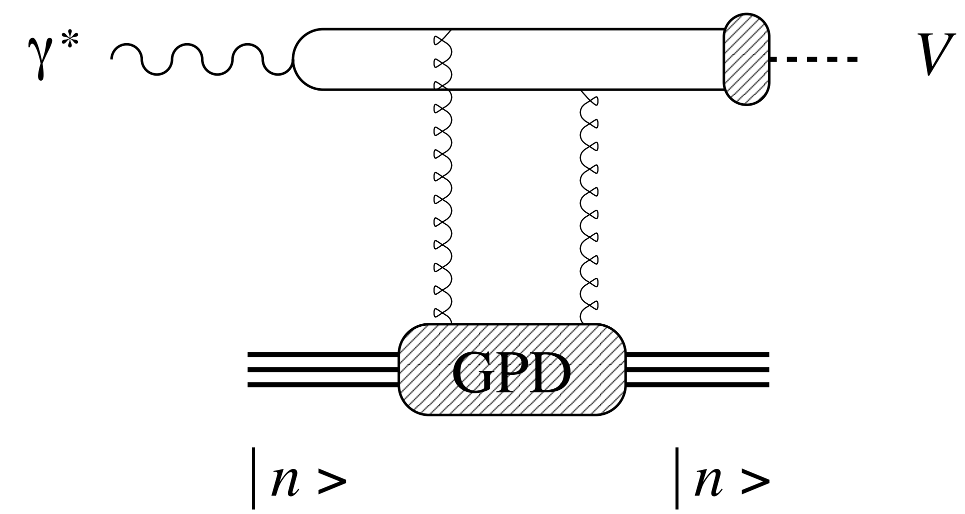
Each configuration n has a definite gluon density $G(x, Q^2| n)$ given by the expectation value of the twist--2 gluon operator in the state $|n\rangle$

$$G(x, Q^2) \;=\; \sum_n |a_n|^2 G(x, Q^2|n) \;\equiv\; \langle G \rangle$$

Making use of the completeness of partonic states, we find that the elastic(X = p) and total diffractive (X arbitrary) cross sections are proportional to

$$(d\sigma_{\rm el}/dt)_{t=0} \quad \propto \quad \left[\sum_n |a_n|^2 G(x,Q^2|n)\right]^2 \equiv \langle G\rangle^2,$$

$$(d\sigma_{\rm diff}/dt)_{t=0} \quad \propto \quad \sum_n |a_n|^2 \left[G(x,Q^2|n)\right]^2 \equiv \langle G^2\rangle.$$



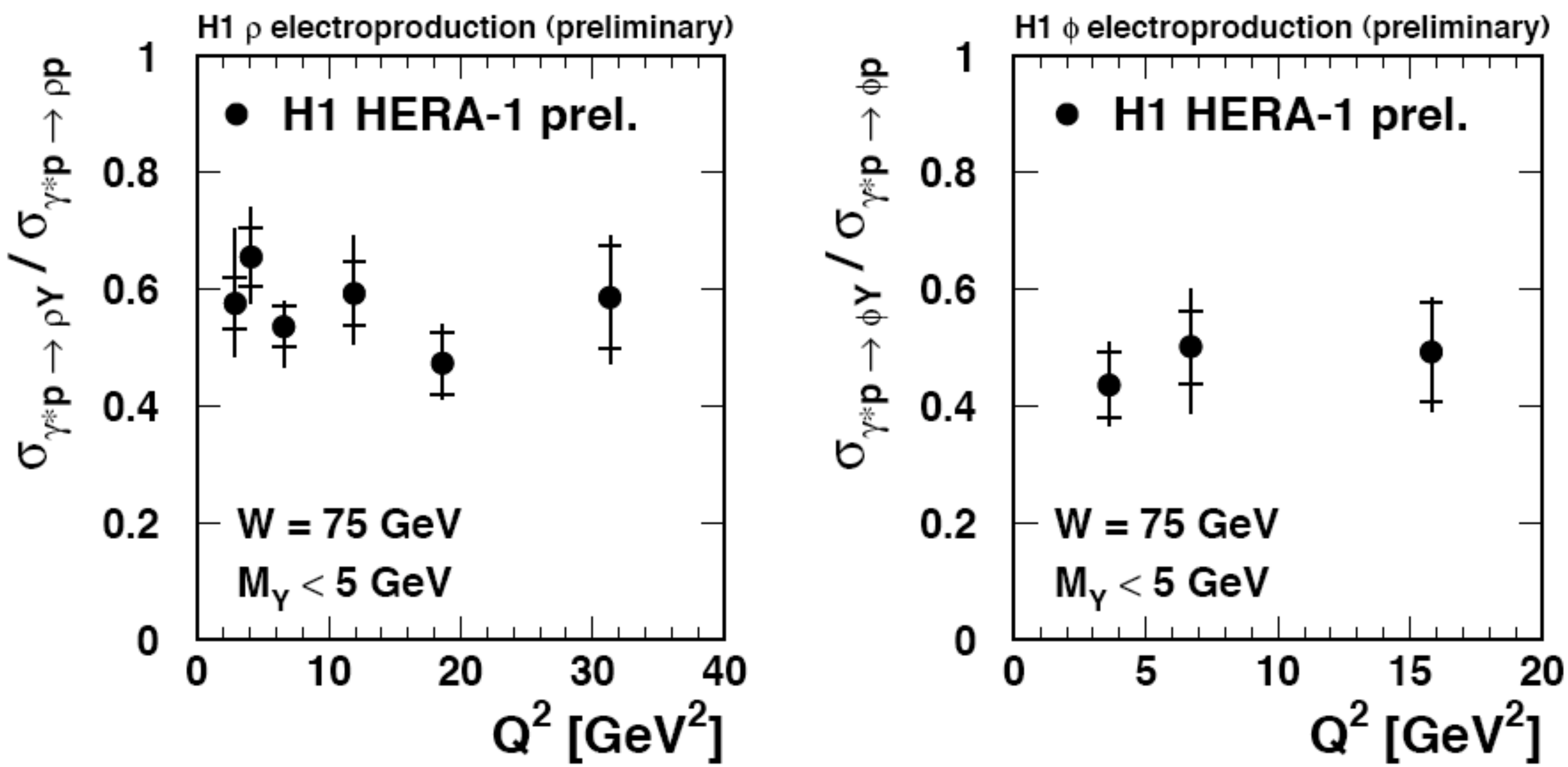
Hence cross section of inelastic diffraction is

$$\sigma_{\rm inel} = \sigma_{\rm diff} - \sigma_{\rm el}$$

$$\Rightarrow \quad \omega_g \equiv \frac{\langle G^2\rangle - \langle G\rangle^2}{\langle G\rangle^2} = \frac{d\sigma_{\gamma^*+p\to VM+X}}{dt} \Big/ \frac{d\sigma_{\gamma^*+p\to VM+p}}{dt}\Big|_{t=0}.$$

New sum rule!

p-diss. / Elastic Ratio - vs. (Q^2)



- p-diss. / elastic ratio independent of Q^2
- Similar ratio within errors for ρ and ϕ

No official numbers for t -slopes - educ. guess $B_{el} / B_{inel} \sim 3 \div 4$

$$\Rightarrow \quad \omega_g(Q^2 \sim \text{few GeV}^2, x \sim 10^{-3}) \sim 0.15 \div 0.2$$

Simple "scaling model" based on two assumptions

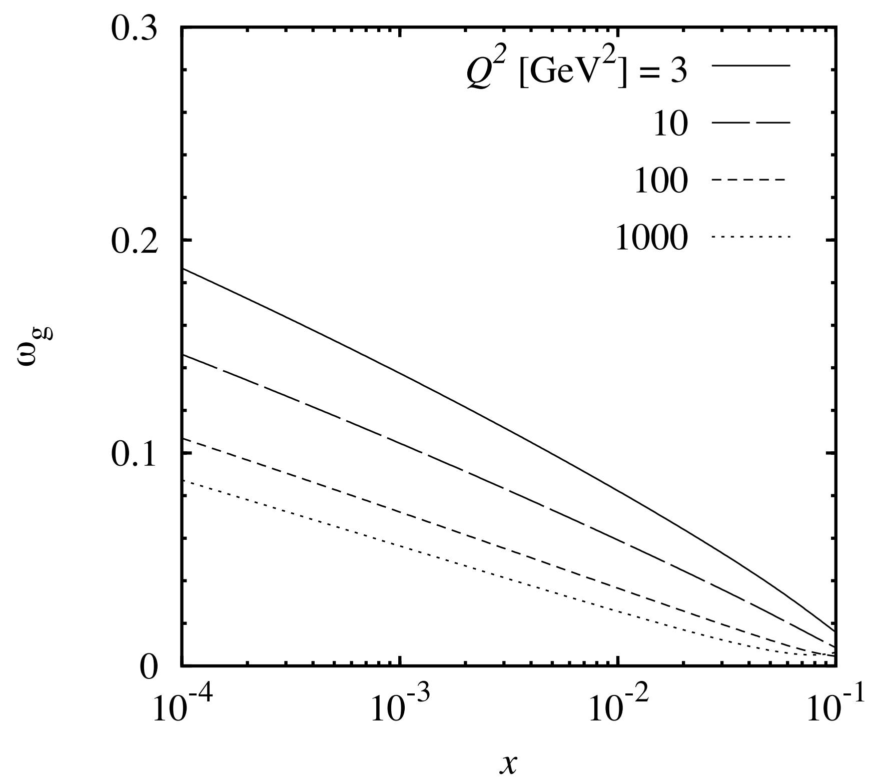
- At moderate energies $\sqrt{s}$ = 20 GeV the hadronic cross section of a configuration is proportional to the transverse area occupied by the color charges in that configuration,

$$\sigma \propto R^2_{\rm config}$$

- the normalization scale of the parton density changes proportionally to the size of the configuration $\mu^2 \propto R^{-2}_{\rm config} \propto \sigma^{-1}$ (in the spirit of Close et al 83 - EMC effect model)

$$G(x, Q^2\,|\sigma) \;=\; G(x, \xi Q^2) \qquad \xi(Q^2) \;\equiv\; (\sigma/\langle\sigma\rangle)^{\alpha_s(Q_0^2)/\alpha_s(Q^2)}$$

$$where\; Q_0^2 \sim 1\,{\rm GeV}^2$$



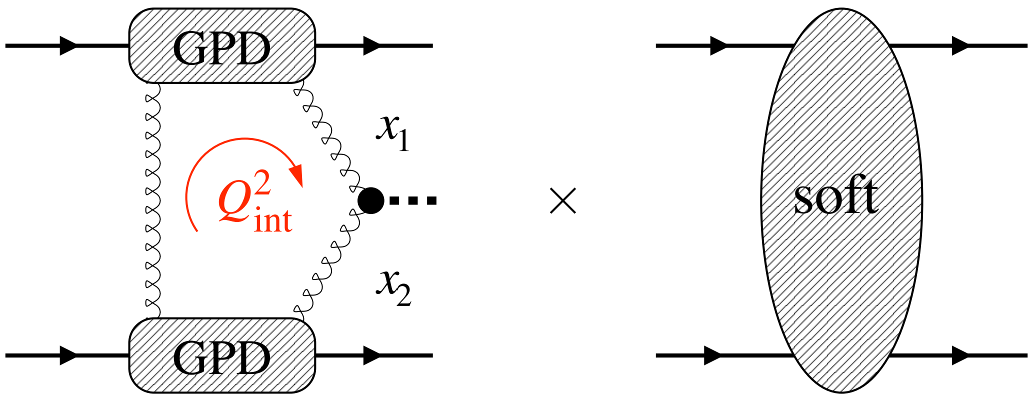
The dispersion of fluctuations of the gluon density, ω_g, as a function of x for several values of Q^2, as obtained from the scaling model

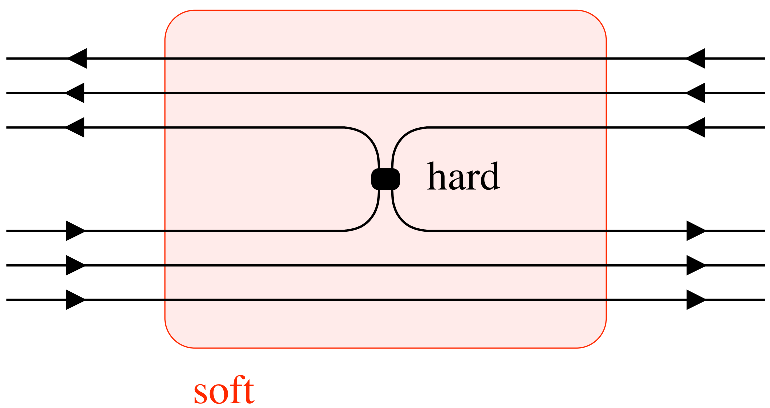
Warning: the model designed for small x < 0.01. There maybe other effects which could contribute to ω_g for large x

At the same time decrease of ω_g with Q^2 at x=const - generic effect

Gluon fluctuations have to be explored both theoretically and experimentally including implications for LHC final states

Suppression of gap survival due to interplay of soft and hard physics at large impact parameters- hard-soft interplay in pp→p+H+p





Different time/distance scales!

- H produced in hard process

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

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

- Soft spectator interactions must not produce particles $S^2 \equiv \frac{\sigma_{\text{diff}}(\text{full})}{\sigma_{\text{diff}}(\text{no soft})}$

- Mean--field approximation:

$$[V_{\text{hard}}, H_{\text{soft}}] = 0$$

independent, closure of partonic states

- Amplitude is calculable in terms of

- Gluon GPD unintegrated

- pp elastic S-matrix

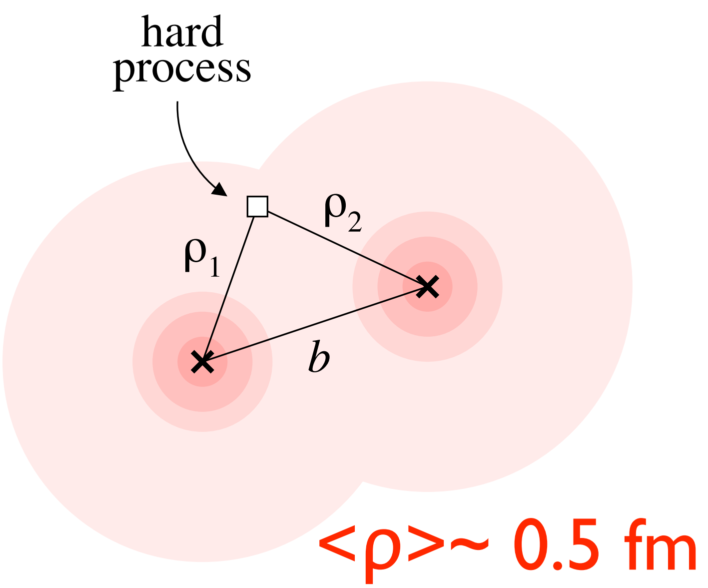
FHSW, PRD **75**:054009, 2007

S^2 in mean field approximation

probability to two partons to interact at given b

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

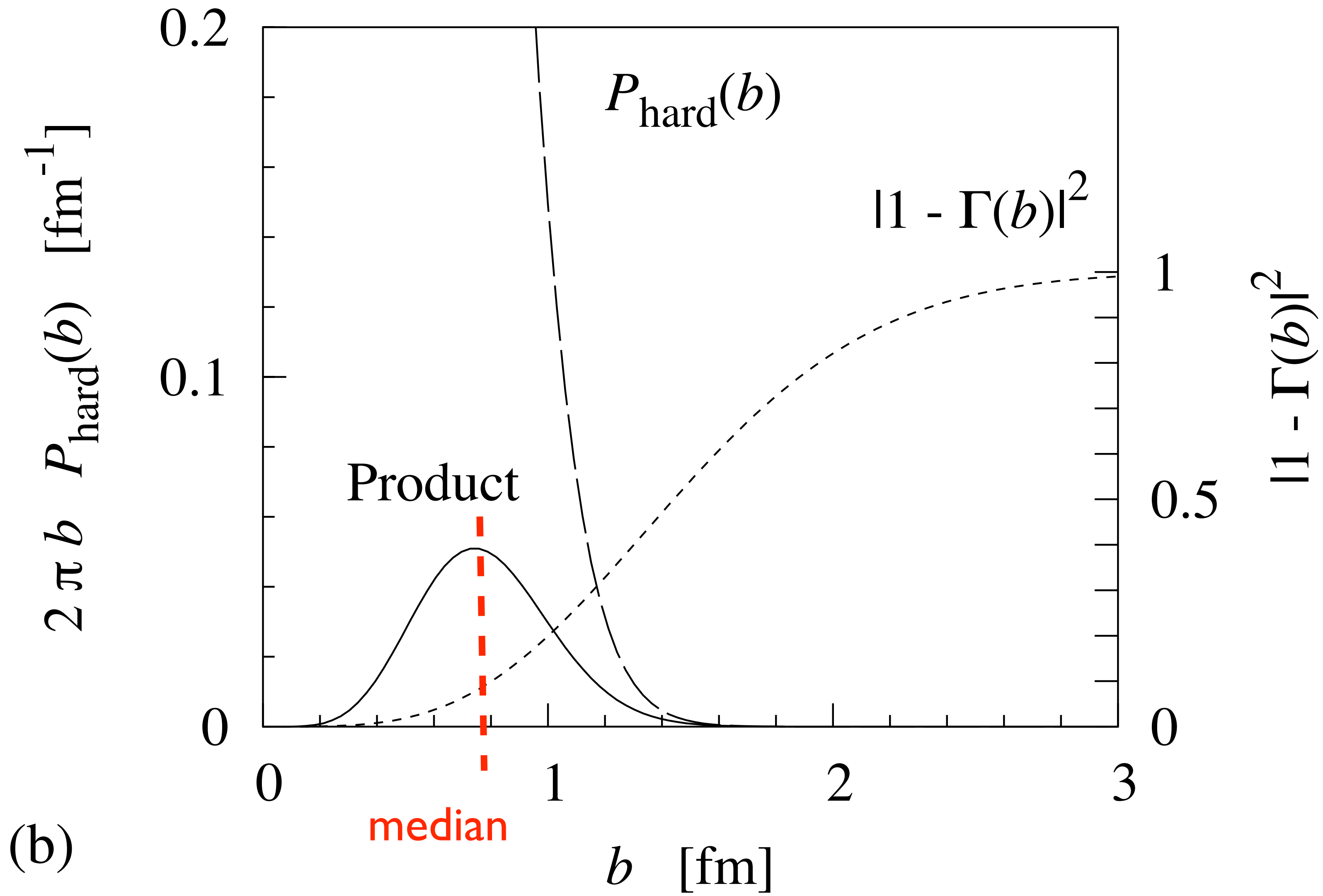
which satisfies $\int d^2 b P_{\rm hard}(\boldsymbol{b}) = 1.$



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

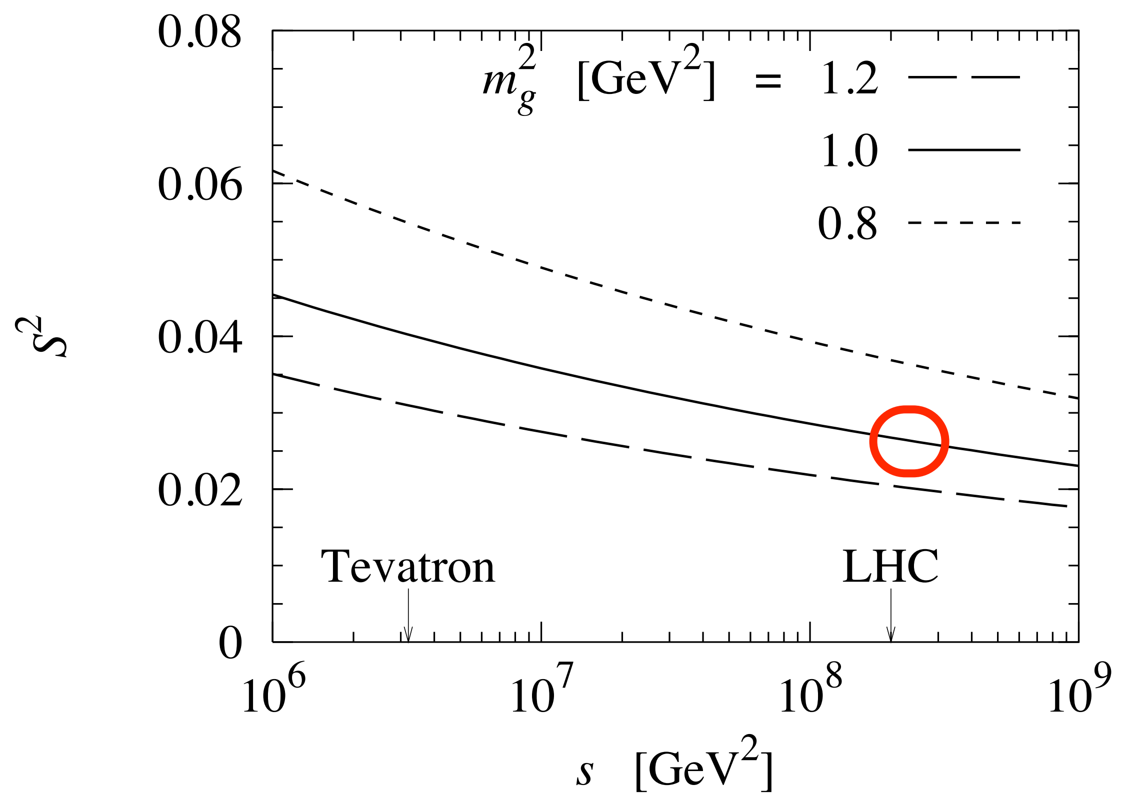
Γ(b) - impact factor for elastic pp amplitude

Answer in the mean field approximation is expressed through the experimentally measured elastic amplitude of pp scattering

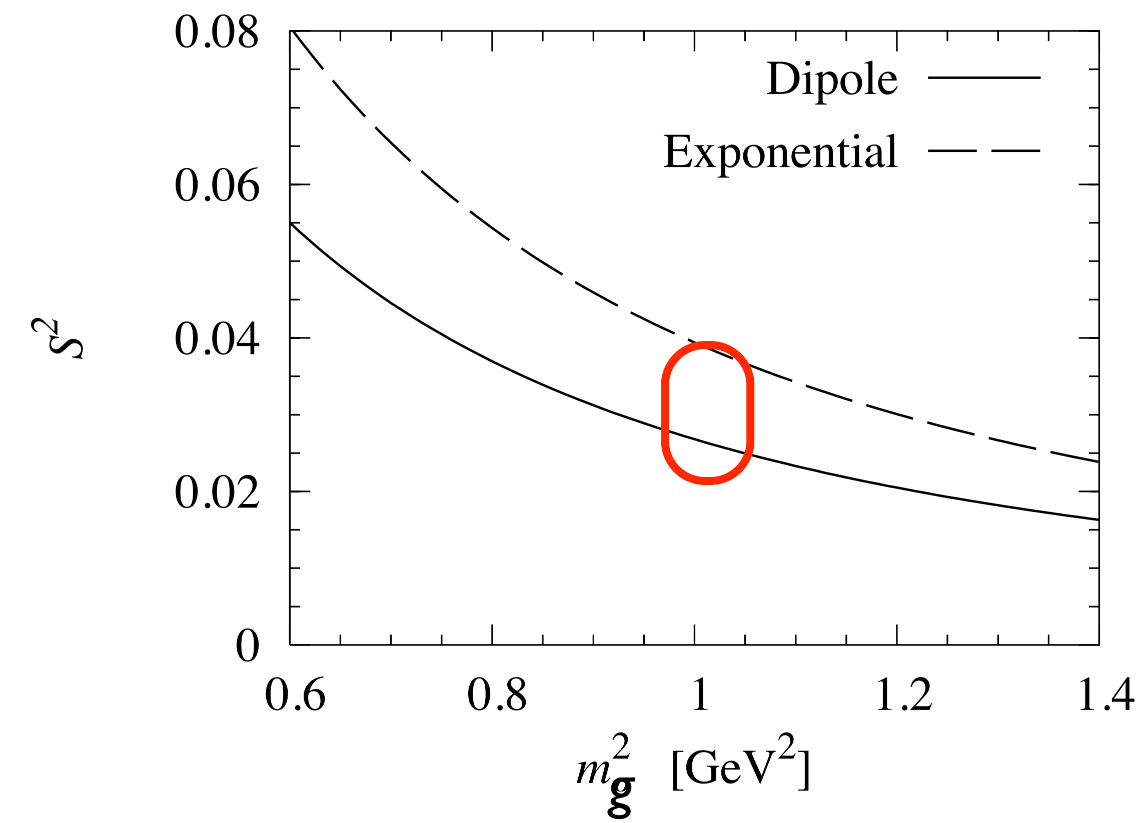


The integrand (impact factor distribution) in the RGS probability for Higgs boson production at the LHC energy. Dashed line: b distribution of the hard two-gluon exchange, $P_{hard}(b)$ evaluated with exponential parametrization of the two-gluon form factor with $B_g=3.24$ GeV^{-2}. Solid line: the product $P_{hard}(b)|1-\Gamma(b)|^2$. 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.

Sensitivity to GPD input



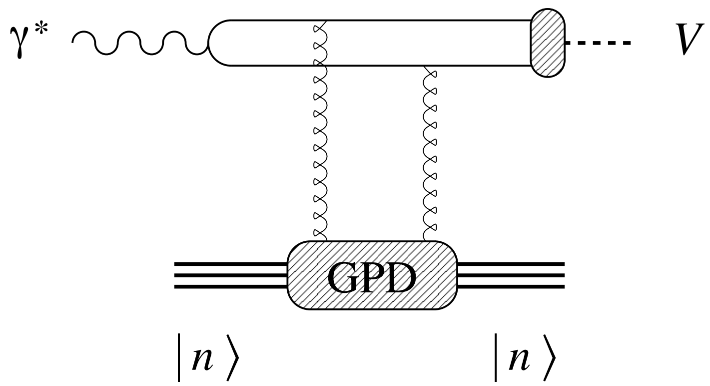
dipole t dependence of gluon GPD

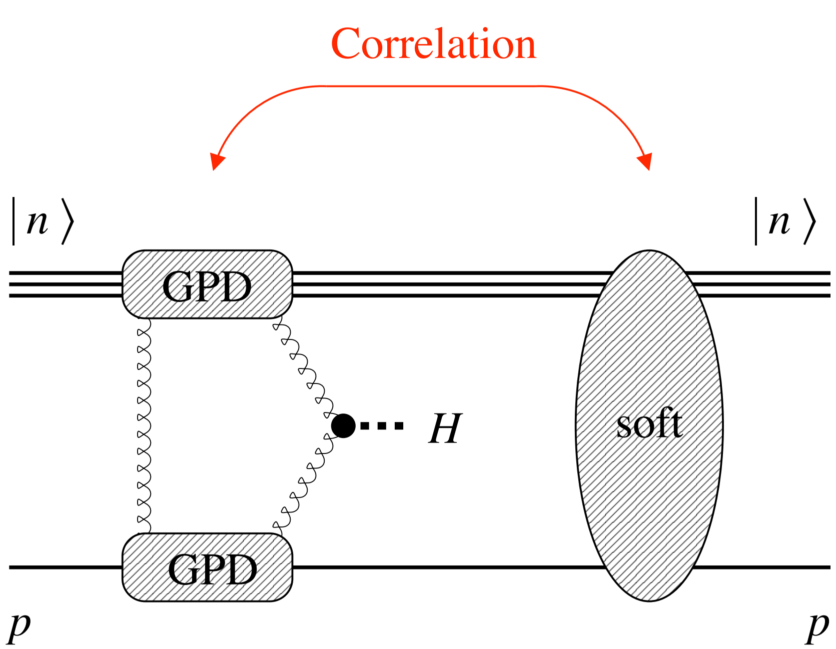


sensitivity to the shape of gluon GPD

S^2 in the mean field approximation for LHC is 3 - 4 % - close to the result of Khoze et al which however included strong reduction of S^2 due to inelastic diffraction

Hard - soft correlations

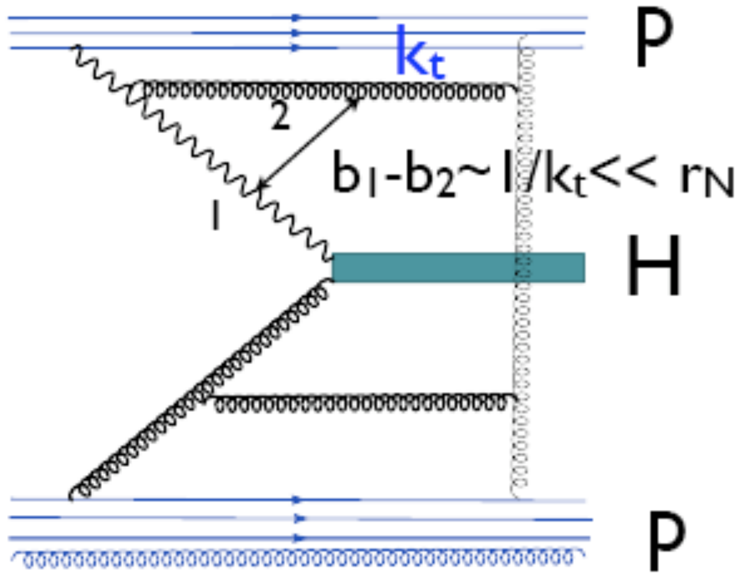




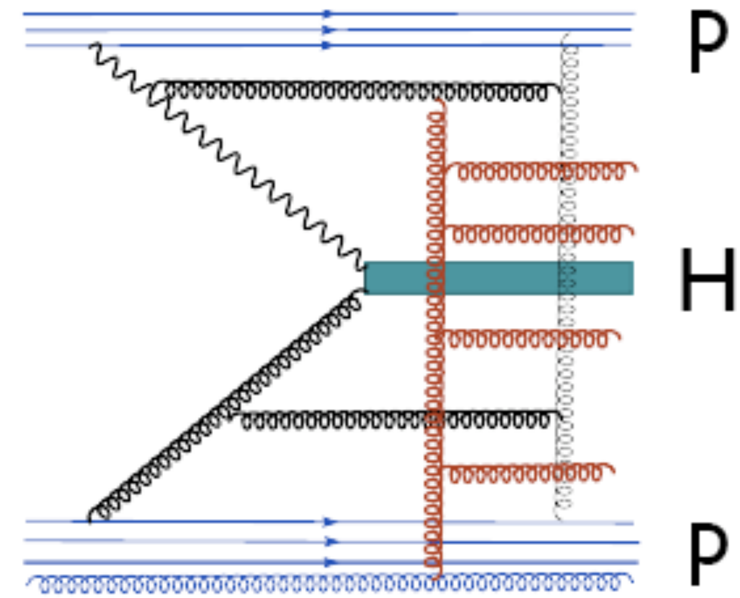
Global correlations - larger size - stronger gluon field but also stronger absorption - reduce S^2

$\omega_g \sim .2$ ➠ reduction effect is only 20%

Local correlations induced by pQCD evolution



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



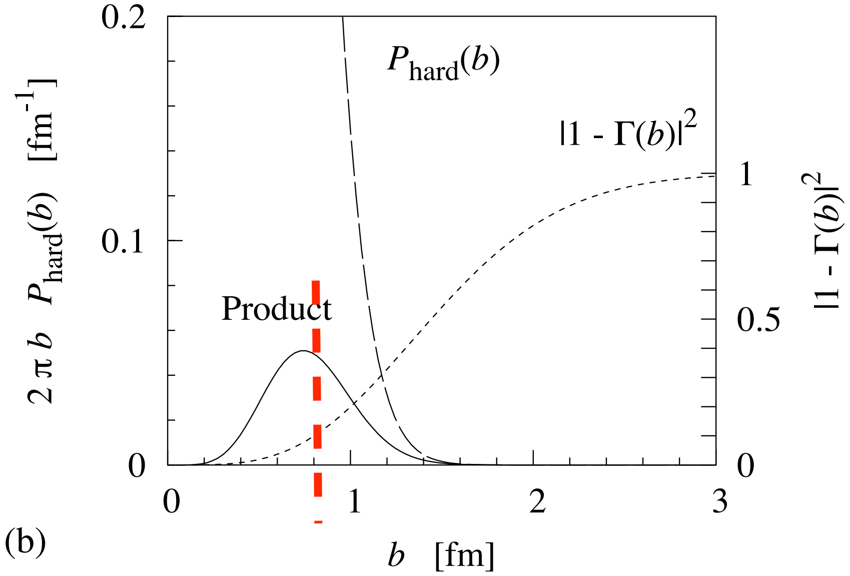
In gluon GDPs for diffractive Higgs production at LHC, $Q^2 \sim$ 4- 8 GeV^2, $x \sim 10^{-2}$

backward evolution - very high probability that these gluons originated from gluons at $x \sim 10^{-1}$ and $p_t \sim$ 1GeV/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 $s_{eff} \sim s_{LHC}/10$: $x_{eff} \sim 10^{-7}$!!!

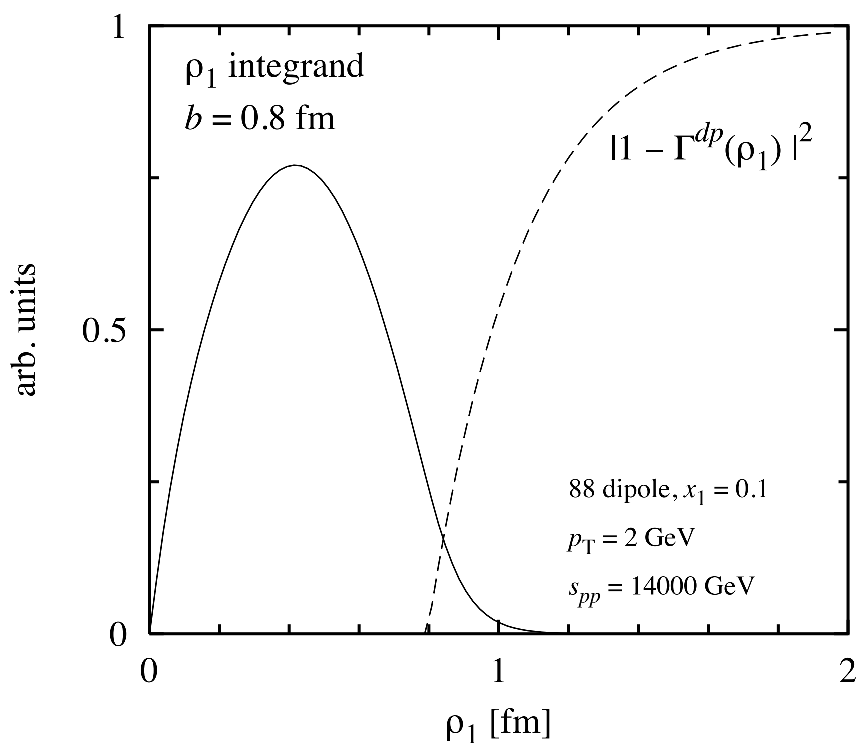
Consistent with evidence from analysis of suppression of forward pion production in deuteron- gold collisions at RHIC FS 08

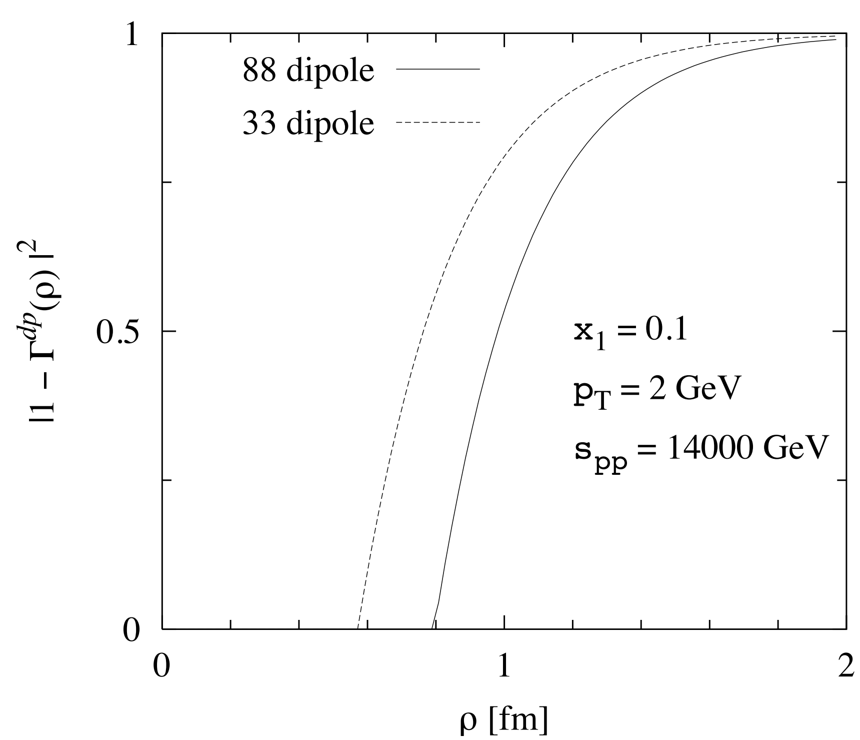
How large is reduction?

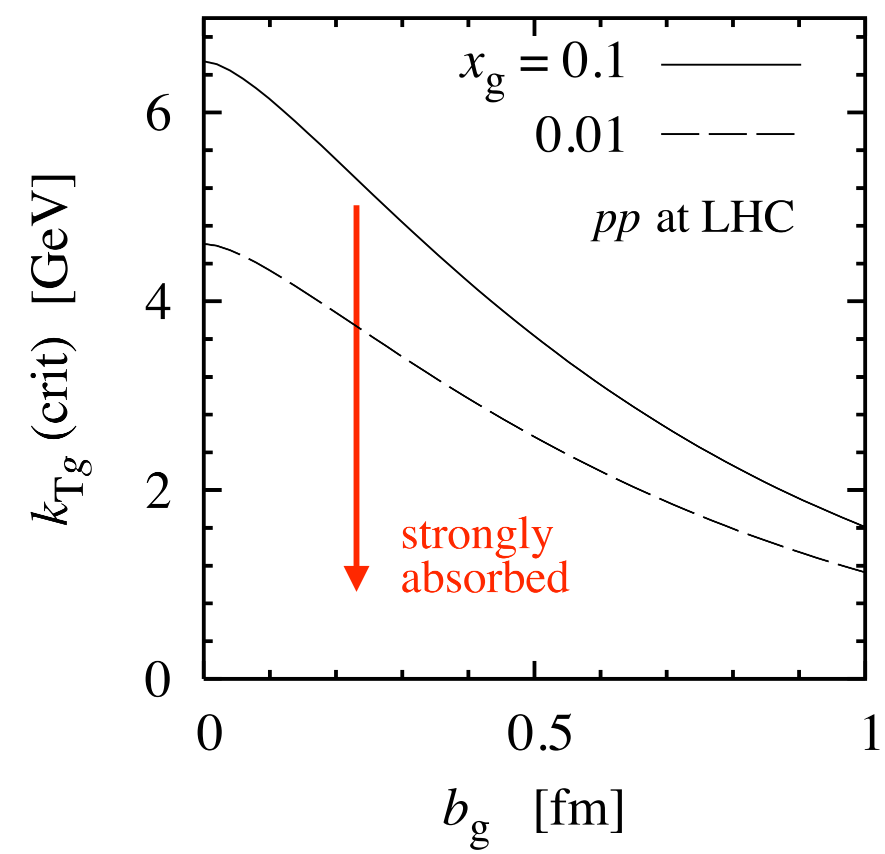


Consider b=0.8 fm - median of S^2 integral in mean field

take p_T=2 GeV to reduce effect







Contribution of average b~ 0.8 is reduced to 0 even when interaction with just extra partons of one nucleon are taken into account.

Overall extra suppression by a factor > 10.

Is there a chance to get $S^2 \sim 1\%$?

Need mechanism to generate Hard gluons not correlated with other partons

example - Sudakov form factor suppressed contribution

The probability to find a gluon at $x=10^{-2}$ at $Q^2=4\ GeV^2$ which had the same x at a soft scale of Q_0^2 is given by $C\ \delta(x-1)$ in the integral form of the evolution equation times the ratio of gluon pdfs at Q^2 and Q_0^2

$$C = \left[S_G(Q^2/Q_0^2)\right]^2 = \exp\left(-\frac{3\alpha_s}{\pi}\ln^2(Q^2/Q_0^2)\right)$$

the square of the gluon Sudakov form factor - probability not to emit a gluon in the amplitude

Hence suppression factor for this contribution is

$$R = C^2\left[\frac{g_N(x_H, Q^2)}{g_N(x_H, Q_0^2)}\right]^4$$

→ ≤ 0.02 $(Q_0^2 = 1GeV^2)$

→ ≤ 0.3 $(Q_0^2 = 2GeV^2)$ too high Q_0^2??

➠ $S^2 < 1\%$ assuming standard pattern of onset of saturation/ black disk regime and no novel parton correlation mechanisms in nucleons

Summary

☛ Dedicated experimental studies of the new color fluctuation sum rule are necessary

☛ RGS - New effect: Hard spectator interactions in black--disk regime

- *Reduces RGS probability at LHC by at least factor of 3*
- *Marginal at Tevatron --- careful with extrapolation!*

Need detailed modeling including impact parameter dependence, parton radiation ``history,'' unitarity effects, and non-perturbative parton--parton correlations in wave function