Diffraction phenomenology with massive gluons: some recent developments

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- The gluon is the fundamental particle of the Yang-Mills theory $\Rightarrow$ it is a massless particle since gauge invariance forbids a mass term in Lagrangian
- However nonperturbative effects can lead to a dynamical mass for the gluon without breaking gauge invariance
- Many recent works have show that the gluon may develop a dynamical mass $\Rightarrow$ studies of the Schwinger-Dyson equations for the gluon propagator in the Landau gauge found IR finite propagators [see the review hep-ph/0609149, and references therein]
- Recent lattice QCD simulations present clear evidence for the dynamical generation of a gluon mass [see Cornwall, hep-ph/0904.3758, for a long compilation of references about these lattice results]

The freezing of the strong coupling

- The freezing of the coupling α_s and the existence of a Dynamical Gluon Mass (DGM) are intimately connected [Aguilar, Natale, and Silva, Phys. Rev. Lett. **90** (2003) 152001]
- The possibility that the QCD coupling α_s has a IR finite behaviour has been extensively studied in recent years $\Rightarrow$ there are many phenomenological evidences in favor of coupling constant freezing at low momenta
- The freezing of the QCD running coupling at low energy scales could allow to capture at an inclusive level the nonperturbative effects in a reliable way [see, for instance, Brodsky, hep-ph/0111127; Acta Phys. Pol. B **32** (2001) 4013]
- Question: How to explore this new and promising scenario?

- One attempt to understand the effect of dinamically massive gluons was done some years ago [Forshaw, Papavassiliou and Parrinello, Phys. Rev. D **59** (1999) 074008]
$\Rightarrow$ they do introduce bare massive gluons and study the amplitude behaviour for some tree and one-loop level diagrams that could be relevant for diffractive scattering

- The calculation is instrutive but does not reproduce the high-energy limit of massless gluons with two degrees of freedom $\Rightarrow$ the massless limit of the amplitude for the tree level processes is not recovered due to the presence of a small mass independent term

$\Longrightarrow$ we cannot work with a massive Yang-Mills theory

- Solution: the sum over the polarizations should be performed as if the gluons were massless $\Rightarrow$ the effects of the DGM in the propagators and vertices are retained, and the sum of polarizations is performed for massless gluons

- In this approach the differential $gg \to gg$ cross section is given by [Luna *et al.*, Phys. Rev. D **72** (2005) 034019]:

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{9\pi\bar{\alpha}_s^2}{2\hat{s}^2}\left[3 - \frac{\hat{s}(4M_g^2 - \hat{s} - \hat{t})}{\left(\hat{t} - M_g^2\right)^2} - \frac{\hat{s}\hat{t}}{\left(3M_g^2 - \hat{s} - \hat{t}\right)^2} - \frac{\hat{t}\left(4M_g^2 - \hat{s} - \hat{t}\right)}{\left(\hat{s} - M_g^2\right)^2}\right], \tag{1}$$

where $\bar{\alpha}_s$ and M_g are the nonperturbative running coupling and the dynamical gluon mass, respectively.

Infrared mass scale

- The expressions for $\bar{\alpha}_s$ and M_g were obtained by Cornwall by means of a Schwinger-Dyson equation for the gluon propagator in the case of pure gauge QCD:

$$\bar{\alpha}_s(q^2) = \frac{4\pi}{\beta_0 \ln\left[\left(q^2 + 4M_g^2(q^2)\right)/\Lambda^2\right]},$$

$$M_g^2(q^2) = m_g^2 \left[\frac{\ln\left(\frac{q^2+4m_g^2}{\Lambda^2}\right)}{\ln\left(\frac{4m_g^2}{\Lambda^2}\right)}\right].$$

- in the limit $q^2 \gg \Lambda^2$ the dynamical mass $M_g(q^2)$ vanishes: the expression (1) reproduces its perturbative QCD counterpart

Some phenomenological applications

- fixing of the renormalization scale of the QCD coupling in exclusive hadronic amplitudes (Brodsky, Ji, Pang, Robertson)
- nonleptonic annihilation decays of B meson (Natale, Zanetti)
- calculation of the tree level gluon-gluon cross section $\Rightarrow$ determination of pp and $\bar{p}p$ total cross sections (Luna, Menon, Natale)
- calculation of the total photoproduction cross section $\sigma^{\gamma p}$ and the total hadronic cross section $\sigma^{\gamma\gamma}$ (Luna, Natale)
- determination of the survival probability of large rapidity gaps from production of Higgs boson via fusion of electroweak W bosons $\Rightarrow$ estimates are compatible with to the ones obtained by the Durham group (Luna)

Hadron-hadron total cross sections

- A consistent calculation of high-energy hadron-hadron cross section can be done using a QCD-inspired (or "mini-jet") model [see, for instance, Luna and Natale, Phys. Rev. D **73** (2006) 074019; Pancheri *et al.*, Acta Phys. Pol. B **36** (2005) 735]

- We use an eikonal approach in order to examine the relationship between the gluon-gluon scattering and the elastic pp and $\bar{p}p$ total cross sections $\Rightarrow$ we found that the dynamical gluon mass is of the same order of magnitude as the *ad hoc* infrared mass scale m_0 underlying eikonalized QCD-based models [Luna *et al.*, Phys. Rev. D **72** (2005) 034019]

  $\Longrightarrow$ the dynamical scale represents the onset of nonperturbative contributions to the elastic hadron-hadron scattering

Hadron-hadron total cross sections

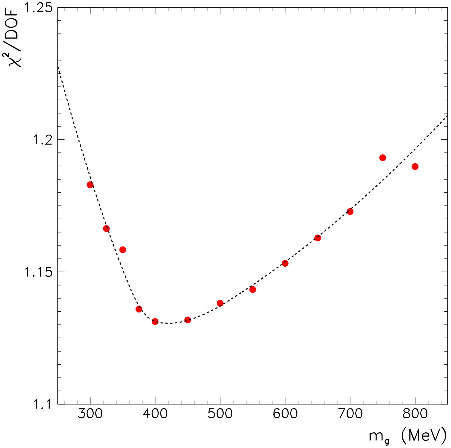


Figure I: *The* χ^2/DOF *as a function of dynamical gluon mass*

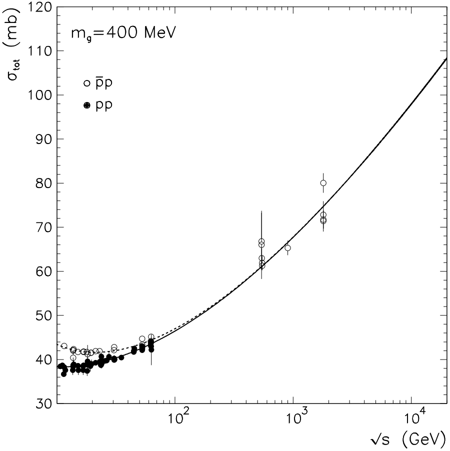


Figure II: *Total cross section for pp (solid curve) and $\bar{p}p$ (dashed curve) scattering*

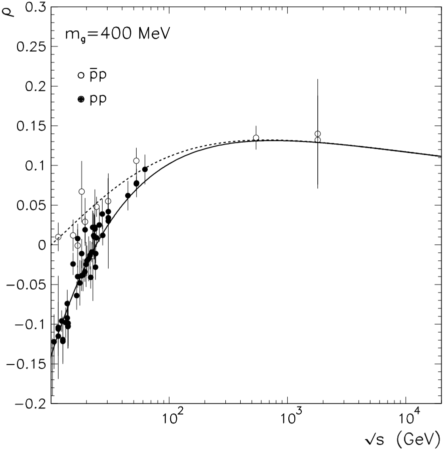


Figure III: *Ratio of the real to imaginary part of the forward scattering amplitude for pp (solid curve) and p̄p (dashed curve) scattering*

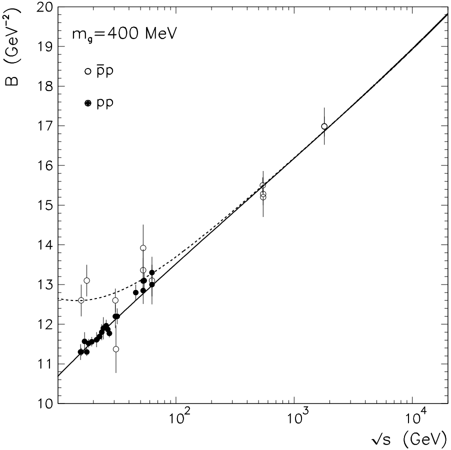


Figure IV: *Nuclear slope parameter for elastic pp (solid curve) and p̄p (dashed curve) scattering*

Hadron-hadron total cross sections

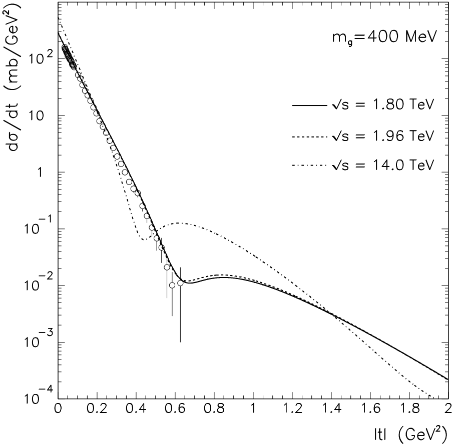


Figure V: *Predictions for the differential scattering cross sections at* $\sqrt{s} = 1.8, 1.96$ and 14 TeV

Survival probability of large rapidity gaps

- Rapidity gaps can occur in the case of Higgs boson production via fusion of electroweak bosons
- We have performed a computation of the survival probability in pp and $\bar{p}p$ channels in the framework of the QCD-based model with a DGM
[Luna, Phys. Lett. B **641** (2006) 171]

  $\Rightarrow$ we have calculated $\langle |S|^2 \rangle$, the probability that LRG survive the soft rescattering of spectator partons

  $\Rightarrow$ we have focused in processes of Higgs production through W fusion

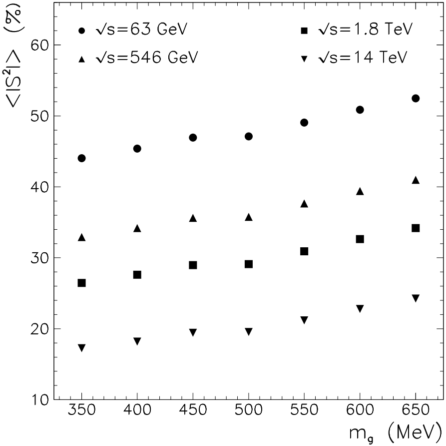


Figure VI: *The survival probability* $\langle |S|^2 \rangle$ *as a function of the dynamical gluon mass*

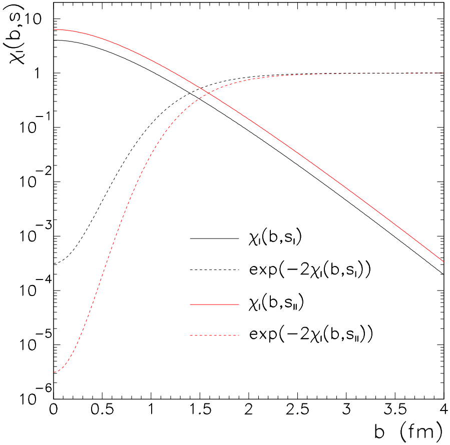


Figure VII: *The imaginary part of the eikonal and the exponential factor for pp collisions as a function of the impact parameter b. Here* $\sqrt{s_I} = 1.8$ TeV *and* $\sqrt{s_{II}} = 14$ TeV

Resummation of soft gluon radiation (WORK IN PROGRESS...)

- In QCD-based models the parton distribution is managed by an overlap function $\Rightarrow$ emissions of soft gluons break collinearity between the colliding partons $\Rightarrow$ soft gluon k_t-emission changes the overlap function $W(b,s)$

- In QED the soft photon resummation in the energy-momentum K_μ can be obtained order by order as

$$d^4P(K) = d^4K \int \frac{d^4x}{(2\pi)^4}\, e^{iK\cdot x - h(x,E)}, \quad \text{where}$$

$$h(x,E) = \int_0^E d^3\bar{n}(k)[1 - e^{-ik\cdot x}] = \int_0^E \frac{d^3k}{2k_0}\, |j_\mu(k,\{p_i\})|^2;$$

here $d^4P(K)$ is the four-dimensional probability distribution for soft massless quanta emitted by a semiclassical source, E is the maximal energy allowed to single photon emission and $\{p_i\}$ is the momenta of the emitting fields.

Resummation of soft gluon radiation

- For strong interactions the resummed transverse momentum distribution is given by

$$d^2P(\mathbf{K}_\perp) = d^2\mathbf{K}_\perp \int \frac{d^2\mathbf{b}}{(2\pi)^2}\, e^{-i\mathbf{K}_\perp\cdot\mathbf{b} - h(b,E)}, \qquad \text{where}$$

$$h(b,E) = \int_0^E \frac{d^3k}{2k_0} \sum_{colors} \left| j^{\mu,i}(k,\{p_i\}) j_{\mu,j}(k,\{p_i\}) \right|^2 .$$

- In QCD applications $h(b,E)$ can be written as (Altarelli, Dokshitzer, Dyakonov, Ellis, Martin, Parisi, Petronzio, ...):

$$h(b,E) = \frac{16}{3} \int^E \frac{dk_t}{k_t} \frac{\alpha_s(k_t^2)}{\pi} \ln\left(\frac{2E}{k_t}\right) [1 - J_0(k_t b)]$$

$\Rightarrow$ $h(b,E)$ describes the relative transverse momentum distribution induced by soft gluon emission from a pair of initially collinear partons

$\Rightarrow$ integration is downed to infrared momentum modes

- The attenuation of the rise of the total cross sections comes from soft gluon k_t-emission (Godbole, Grau, Pancheri, Srivastava, ...)
  $\Rightarrow$ the emissions break collinearity between the colliding partons and change the overlap function $W(b,s)$ (matter distribution), given by

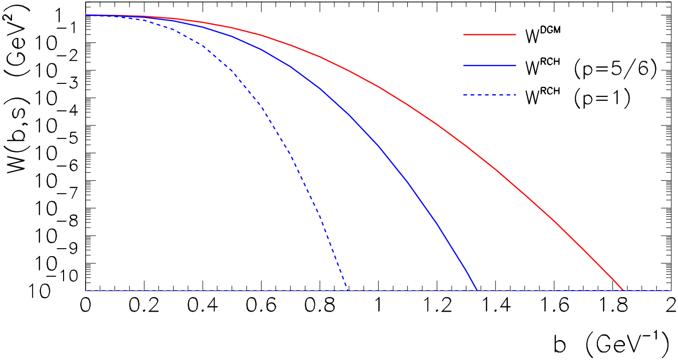
$$W(b,s) = N \int d^2\mathbf{K}_\perp \, e^{-i\mathbf{K}_\perp \cdot \mathbf{b}} \, \frac{d^2P(\mathbf{K}_\perp)}{d^2\mathbf{K}_\perp} = W_0(s)\, e^{-h(b,q_{max})}$$

  $\Rightarrow$ the high-energy dependence of the total hadronic cross section (large b value) is intrinsically related to the small k_t value of α_s
  $\Rightarrow$ the behaviour of α_s in the infrared limit plays a central role

- A phenomenological expression for α_s inspired by the Richardson potential is given by

$$\alpha_s(k_t^2) = \frac{4\pi}{\beta_0} \frac{p}{\ln\left[1 + p\left(k_t^2/\Lambda^2\right)^p\right]}.$$

$\Rightarrow$ the overlap functions $W^{DGM}(b,s)$ and $W^{RCH}(b,s)$:



Conclusions

- The Dynamical Gluon Mass (DGM) introduces a natural IR cutoff which may replace the one that is always present in many perturbative QCD calculations $\Rightarrow$ it is a natural regulator for the tree-level gluon-gluon cross section
- The DGM scheme get rid of the Landau singularity in the coupling constant $\Rightarrow$ singularities in the physical amplitudes that do not correspond to the expected physical behaviour are removed
- The DGM and $\bar{\alpha}_s$ are physically well motivated
- Recent lattice QCD simulations present clear evidence for the dynamical generation of a gluon mass
- The frozen coupling $\bar{\alpha}_s$ provides an useful phenomenological tool to the study of diffractive physics where a purely perturbative QCD method is inadequate