Non-minimal coupling contribution to DIS at low x in Holographic QCD

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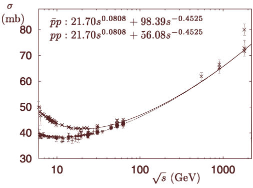
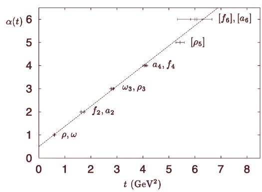
Talk plan

- Brief review of Pomeron phenomenology
- Brief review of previous work on the same line
- Motivation for the non-minimal coupling
- Holographic computation of structure function
- Results
- Future

Pomeron: a historical introduction

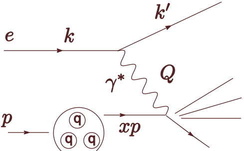




Regge Theory:

$$\mathcal{A}^{\pm}(s,t) \sim \Gamma(-\alpha^{\pm}(t))(\frac{s}{s_0})^{\alpha^{\pm}(t)}$$

Deep Inelastic Scattering



DESY

hadronic tensor:

$$\langle H, P | [J^\mu(x), J^\nu(0)] | H, P \rangle$$

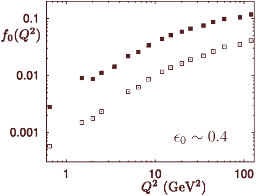
structure functions:

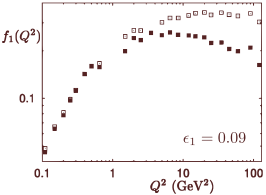
$$F_2(Q^2, x) \sim \mathrm{Im}$$ 

well known dependence on Q, small x is challenging...

New DIS data: the Hard Pomeron

$$F_2(Q^2,x) = f(Q^2)x^{-\epsilon(Q^2)} = f_0(Q^2)x^{-\epsilon_0} + f_1(Q^2)x^{-\epsilon_1} + \ldots$$

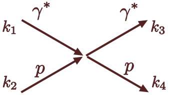




Donnachie and Landshoff
hep-ph/0105088
hep-ph/9806344

Goal

Use the gauge/string duality to compute



$$\int dx e^{ik\cdot x} \langle P | \mathcal{T}\left(J_\mu(x) J_\nu(0)\right) | P \rangle$$

in the Regge limit

$$k_1 = \left(\sqrt{s}, -\frac{Q^2}{\sqrt{s}}, 0\right)\,, \qquad -k_3 = \left(\sqrt{s}, \frac{q_\perp^2 - Q^2}{\sqrt{s}}, q_\perp\right)\,,$$

$$k_2 = \left(\frac{M^2}{\sqrt{s}}, \sqrt{s}, 0\right)\,, \qquad -k_4 = \left(\frac{M^2 + q_\perp^2}{\sqrt{s}}, \sqrt{s}, -q_\perp\right)\,.$$

Improved Holographic QCD model

$$S = M^3 N_c^2 \int d^5x \sqrt{-g_s} e^{-2\Phi} \left(4 g_s^{\mu\nu} \partial_\mu \partial_\nu + R_s + V(\Phi)\right)$$

$$ds^2 = e^{2A(z)} \left(dz^2 + \eta_{\mu\nu} dx^\mu dx^\nu\right)$$

Dictionary:

$$\log E \leftrightarrow A(z)$$

$$T_{\mu\nu} \leftrightarrow h_{\mu\nu}$$

$$\mathrm{tr} F^2 \leftrightarrow \phi$$

$$\mathrm{tr} F \wedge F \leftrightarrow a$$

Successfully explains:

-Confinement
-Asymptotic freedom
-Glueball spectrum data know from lattice computations

Building Higher Spin EOM

The EOM of the higher spin fields should satisfy:

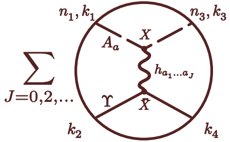
- Be compatible with graviton EOM for J=2
- The coupling with the dilaton to be the one of the closed string in the graviton's trajectory
- Reproduce known free CFT case for constant dilaton.

We propose:

$$\left(\nabla^2 - 2\,e^{-2A}\dot{\Phi}\nabla_z - \frac{\Delta(\Delta-4)}{L^2} + J\dot{A}^2 e^{-2A} + (J-2)e^{-2A}\left(a\,\ddot{\Phi} + b\left(\ddot{A} - \dot{A}^2\right) + c\,\dot{\Phi}^2\right)\right) h^{TT}_{\alpha_1 \dots \alpha_J} = 0$$

Witten diagram: minimal coupling

We consider the tree level exchange of those higher spin fields belonging to graviton Regge trajectory



Minimal coupling vertex in X:

$$\kappa_J \int d^5 X \sqrt{-g} e^{-\Phi} F_{b_1 a} D_{b_2} \dots D_{b_{J-1}} F^a_{b_J} h^{b_1 \dots b_J}$$

Non-minimal coupling motivation

For AdS or flat space, there are only two possible cubic couplings between these fields

$$F^{ac}F^{b}{}_{c}h_{ab}\,, \quad F^{ac}F^{bd}\nabla_c\nabla_d h_{ab}$$

in general this does not hold. For concreteness, we will consider the action

$$S_A = -\frac{1}{4}\int d^5X\sqrt{-g}\,e^{-\Phi}\left(F_{ab}F^{ab} + \beta R_{abcd}F^{ab}F^{cd}\right),$$

and we will find the coupling with the graviton by linearizing.

Linearizing and generalizing

$$\delta S = -\frac{1}{2}\int d^5X\sqrt{-\bar{g}}\,e^{-\Phi}\Big(F^{ab}F^{c}{}_{b}h_{ac} \longrightarrow \text{M.C.}$$

$$+\frac{\beta}{2}h_{ap}\bar{R}^{p}_{bcd}F^{ab}F^{cd} - \beta F^{ac}F^{bd}\bar{\nabla}_a\bar{\nabla}_b h_{cd}\Big) \rightarrow \text{N.M.C.}$$

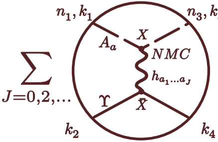
the non-minimal cubic interaction generalizes to

$$\beta_J\int d^5X\sqrt{-\bar{g}}e^{-\Phi}\Big(F^{ca_1}\bar{\nabla}^{a_2}\dots\bar{\nabla}^{a_{J-1}}F^{a_J d}\bar{\nabla}_c\bar{\nabla}_d$$

$$+\frac{1}{2}F^{a_1 b}\bar{\nabla}^{a_2}\dots\bar{\nabla}^{a_{J-1}}F^{cd}\bar{R}^{a_J}{}_{bcd}\Big)h_{a_1\dots a_J}$$

Witten diagram: non-minimal coupling

Non-minimal coupling contribution to F_2



After taking the Regge limit

$$F_2(x, Q^2) = \sum_n \left(f_n^{\rm MC}(Q^2) + f_n^{\rm NMC}(Q^2) \right) x^{1-j_n} \, ,$$

Further details

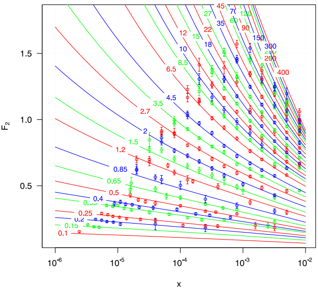
$$f_n^{\rm NMC}(Q^2) = \ \tilde{g}_n Q^{2j_n} \int dz\, e^{-\left(j_n - \frac{3}{2}\right)A} \left(f_Q^2 \tilde{\mathcal{D}}_\perp + \frac{\dot{f}_Q^2}{Q^2} \tilde{\mathcal{D}}_\parallel \right) \psi_n \,,$$

where $\tilde{g}_n \sim \beta_{j_n(0)}$ and

$$\tilde{\mathcal{D}}_\perp = e^{-2A} \left(\dot{A}\partial_z + \dot{A}^2 + \dot{A}\dot{B} \right),$$
$$\tilde{\mathcal{D}}_\parallel = e^{-2A} \left(\partial_z^2 - \big(\dot{A} - 2\dot{B}\big)\partial_z + \ddot{B} + \ddot{A} + \dot{B}^2 - \dot{A}\dot{B} \right)$$

with $B = \Phi - A/2$

Results



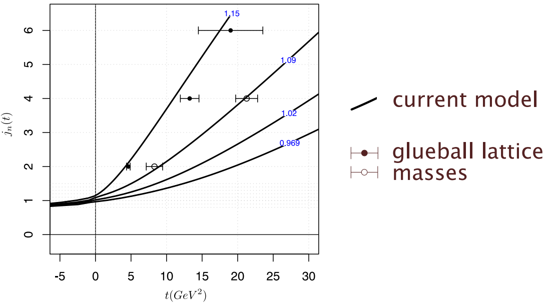
Best fit for F_2

Number of points: 249

$$\chi^2_{d.o.f} = 1.1$$

$l_s^{-1} = 6.93$	$g_0 = -0.154$	$\tilde{g}_0 = 0.0707$
a = -4.68	$g_1 = -0.424$	$\tilde{g}_1 = -0.0378$
b = 4.85	$g_2 = 2.12$	$\tilde{g}_2 = -0.248$
c = 0.665	$g_3 = -0.721$	$\tilde{g}_3 = 0.363$
d = -0.328		
$\beta = -0.026$		

Regge trajectories

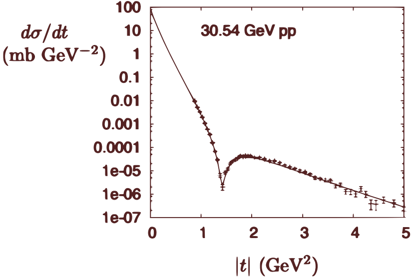


Conclusions

We considered the contribution of a non-minimal coupling in a holographic Pomeron model:

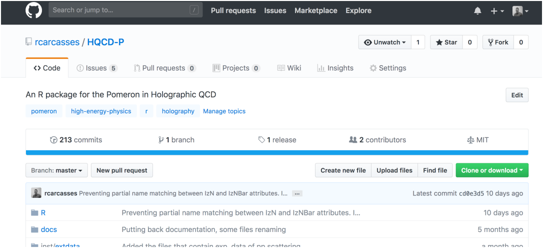
- The contribution is encoded in the operators $\tilde{\mathcal{D}}_{\perp}$ and $\tilde{\mathcal{D}}_{\parallel}$.
- Fit of $F_2(x, Q^2)$ improves, $\chi^2_{d.o.f.}$ decrease to 1.1.
- The scale of the non-minimal coupling is in the range of the mass difference between the spin 2 and spin 4 glueballs.

Future: differential cross-sections...

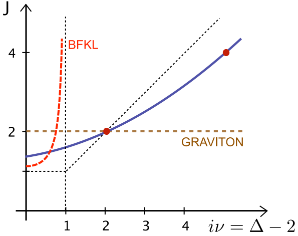


Future: HQCDP package

https://github.com/rcarcasses/HQCD-P



Diffusion limit



For the term related to the anomalous dimension of the dual operator we propose:

$$\frac{\Delta(\Delta-4)}{L^2} =$$

$$\frac{2}{l_s^2}\,(J-2)\left(1+\frac{d}{\sqrt{\lambda}}\right)+\frac{1}{\lambda^{4/3}}(J^2-4)$$