Fermionic DIS from a deformed string/ gauge correspondence model

Eduardo Folco Capossoli

Colégio Pedro II,

Rio de Janeiro - Brazil

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Miguel Angel Martín Contreras, Danning Li, Alfredo Vega and Henrique Boschi-Filho

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Summary of the talk:

- Brief Review: AdS/CFT correspondence and AdS/QCD;
- Motivations
- The deformed string/ gauge model;
- Holographic description of the DIS within the deformed string/ gauge model.
- Numerical results.

Quantum Chromodynamics - QCD

✓ used as the standard theory to explain the phenomenology of strong interactions.

❑ at the low-energy limit ($g_{YM} > 1$) the QCD cannot be treated perturbatively.

Alternative Way

AdS/CFT correspondence

AdS/CFT correspondence, J. Maldacena, 1997

(simplified version of a particular useful case)

SUPERSTRING THEORY in the $AdS_5 \times S^5$ spacetime.

⇔ DUAL

YANG-MILLS THEORY

- Supersymmetric $\mathcal{N} = 4$
- Conformal
- SU(N) symmetry, with $\mathrm{N} \rightarrow \infty$

in a 4-dimensional Minkowski spacetime ($AdS_5 \times S^5$ boundary).

At low energies string theory is represented by an effective supergravity theory → **gauge / gravity duality**

Other versions of the Correspondence: $AdS_4 \times S^7$ or $AdS_7 \times S^4$ (M-theory in 11 dimensions)

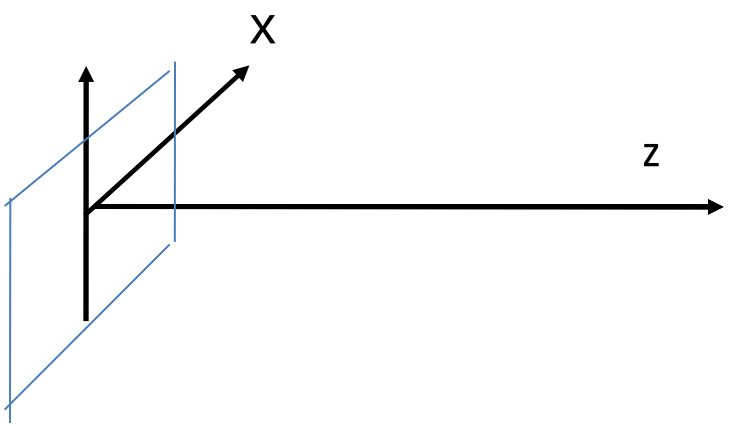
- After breaking the conformal symmetry one can build phenomenological models that describe approximately QCD. So, AdS/QCD models.
- Strong coupling theory ⇔ Weak coupling theory.

Holography in String theory

AdS Space in Poincaré coordinates

$$ds^2 = \frac{R^2}{(z)^2}(dz^2 + (d\vec{x})^2 - dt^2)$$

The 4-dim boundary is at z = 0



Fifth dimension z ~ 1 / E where E = Energy in 4-dim boundary

AdS/CFT Dictionary

Isometries in the bulk ↔ Simmetries in the boundary field theory

$$\begin{array}{ccc} \text{Field } (\phi,\ g_{\mu\nu}\ldots.) & \leftrightarrow & \text{Operator } (TrF^2,\ T_{\mu\nu}\ldots.) \\ \text{Radial distance, } u & \leftrightarrow & \text{Energy} \\ \text{Minimal area} & \leftrightarrow & \text{Wilson loop} \\ \vdots & & \vdots \\ \text{Minimal volume} & \leftrightarrow & \text{Entanglement entropy} \end{array}$$

Bulk field mass ↔ boundary operator scaling dimension

$$\phi : \quad \Delta(\Delta - d) = m^2$$

$$\psi : \quad |m| = \Delta - \frac{d}{2}$$

$$A_\mu : \quad m^2 = (\Delta - 1)(\Delta + 1 - d)$$

A Bottom-up Approach: The Softwall Model

Soft cut off (Karch, Katz, Son, Stephanov PRD 2006)

$$S = \int d^{10}x \sqrt{-g} e^{-\phi(z)} \mathcal{L}, \quad \phi(z) = kz^2,$$

With k ~$\Lambda^2{}_{QCD}$

spectrum of vector mesons $m^2_{V_n} = 4c(n+1)\,,$

Motivations

- The original softwall works for mesons, however:

→ it doesn't seem to work well for the glueball spectroscopy.;

→ it does not produce a mass gap for the fermionic sector.

→ modifications in the original softwall model.

Deformed AdS/QCD or deformed string/ gauge model

original SW: $S = \int d^5x \sqrt{-g}\, e^{-\Phi(z)} \mathcal{L}, \quad \Phi(z) = \pm k z^2$, with $k \sim \Lambda^2_{QCD}$

Deformed AdS space

$$ds^2 = g_{mn} dx^m dx^n = \frac{R^2}{z^2} e^{\Phi}(dz^2 + \eta_{\mu\nu} dx^\mu dx^\nu) = e^{2A(z)}(dz^2 + \eta_{\mu\nu} dx^\mu dx^\nu),$$

$$A(z) = -\log(z) + \frac{kz^2}{2}.$$

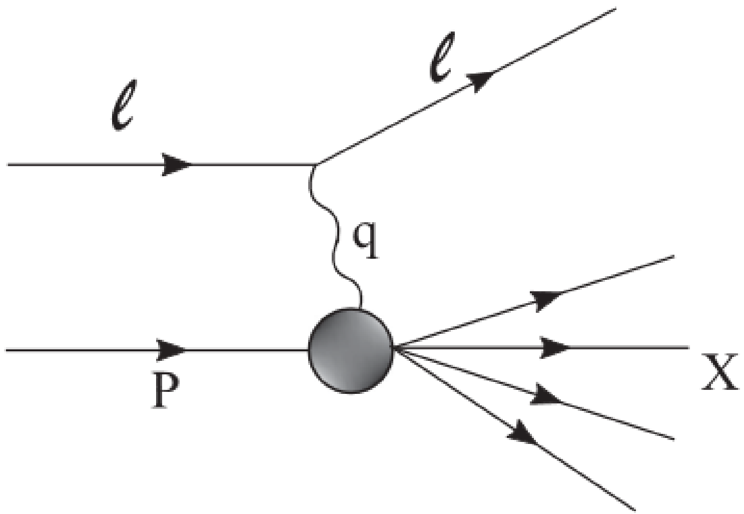
$$S = \int d^5x \sqrt{-g}\, \mathcal{L},$$

O. Andreev (PRD 2006);
O. Andreev e V. I. Zakharov (PRD 2006).

an application (for instance) of the deformed string/gauge model.

To study unpolarized spin 1/2 baryonic deep inelastic scattering (DIS) in the regime of large Bjorken parameter x and calculate the corresponding structure functions $F_{1,2}(x,q^2)$.

Deep Inelastic scattering (DIS)



$$x = -\frac{q^2}{2P \cdot q}$$ **Bjorken parameter** $0 \leq x \leq 1$

$M^2 = -P^2$: Mass/momentun (inital hadron)

$$s = -P_X^2 = -(P+q)^2$$

$$d\sigma \propto \frac{\alpha^2}{q^4} L^{\mu\nu}_{electron} W_{\mu\nu}$$

$$W^{\mu\nu} = \frac{i}{4\pi} \sum_s \int d^4y e^{iq.y} \langle P, s | T\{J^\mu(y) J^\nu(0)\} | P, s \rangle$$

$$W^{\mu\nu} = W_1 \left(\eta^{\mu\nu} - \frac{q^\mu q^\nu}{q^2} \right) + \frac{2x}{q^2} W_2 \left(P^\mu + \frac{q^\mu}{2x} \right) \left(P^\nu + \frac{q^\nu}{2x} \right)$$

$$W_2(x, q^2) \approx 2x\, W_1(x, q^2)$$

Callan-Gross relation

Holographic description of the DIS within the deformed AdS.

Polchinski e Strassler, JHEP (2003).

EFC, MAMC, DL, AV, HBF, PRD(2020).

$$\eta_\mu \langle P+q, s_X | J^\mu(0) | P, s\rangle = S_{\text{int}} \quad = g_V \int dz d^4y \sqrt{-g}\phi^\mu \bar{\Psi}_X \Gamma_\mu \Psi_i$$

Step#1: Computing the electromagnetic field

$$S = -\int d^5x \sqrt{-g}\frac{1}{4}F^{mn}F_{mn} \Longrightarrow \partial_m[\sqrt{-g}F^{mn}] = 0.$$

$$\partial_\mu \phi^\mu + e^{-A}\partial_z(e^A \phi_z) = 0$$ → **gauge fixing**

$$\Box\phi_\mu + A'\partial_z\phi_\mu + \partial_z^2\phi_\mu = 0$$

$$\Box\phi_z - \partial_z(\partial_\mu\phi^\mu) = 0,$$

$$\eta_\mu q^\mu = 0$$

$$\phi_\mu(z,y)|_{z=0} = \eta_\mu e^{iq\cdot y}$$

$$\phi_\mu(z,q) = -\frac{\eta_\mu e^{iq\cdot y}}{2} kz^2 \Gamma\left[1-\frac{q^2}{2k}\right] \mathcal{U}\left(1-\frac{q^2}{2k}; 2; -\frac{kz^2}{2}\right)$$

$$\equiv -\frac{\eta_\mu e^{iq\cdot y}}{2} B(z,q)$$

Step#2: Computing the baryonic states

$$S = \int_{AdS} d^5x \sqrt{g}\, \bar{\Psi}(\not{D} - m_5)\Psi. \quad \not{D} \equiv g^{mn} e_n^a \gamma_a \left(\partial_m + \frac{1}{2}\omega_m^{bc}\Sigma_{bc}\right)$$

$$\Rightarrow \quad (\not{D} - m_5)\Psi = 0,$$

After some algebra....

$$-\psi''_{R/L}(z) + \left[m_5^2 e^{2A(z)} \pm m_5 e^{A(z)} A'(z)\right] \psi_{R/L}(z) = M_n^2 \psi^n_{R/L}(z),$$

$$|m_5| = \Delta_{\text{can}} + \gamma - 2.$$

$$\Psi_i = e^{iP\cdot y} z^2 e^{-kz^2} \left[\left(\frac{1+\gamma_5}{2}\right)\psi_L^i(z) + \left(\frac{1-\gamma_5}{2}\right)\psi_R^i(z)\right] u_{s_i}(P)$$

$$\Psi_X = e^{iP_X\cdot y} z^2 e^{-kz^2} \left[\left(\frac{1+\gamma_5}{2}\right)\psi_L^X(z) + \left(\frac{1-\gamma_5}{2}\right)\psi_R^X(z)\right] u_{s_X}(P_X).$$

This model requires numerical solution!

Step#3: Computing S_{int}

$$\eta_\mu \langle P+q, s_X | J^\mu(0) | P, s\rangle = S_{\text{int}} = g_V \int dz d^4y \sqrt{-g}\phi^\mu \bar{\Psi}_X \Gamma_\mu \Psi_i$$

$$\eta_\mu \eta_\nu W^{\mu\nu} = \frac{g_{\text{eff}}^2}{4} \sum_{M_X^2} \delta(M_X^2 - (P+q)^2) \left\{ (\mathcal{I}_L^2 + \mathcal{I}_R^2) \left[(P\cdot\eta)^2 - \frac{1}{2}\eta\cdot\eta(P^2 + P\cdot q) \right] + \mathcal{I}_L \mathcal{I}_R M_X^2 M_0^2 \eta\cdot\eta \right\}$$

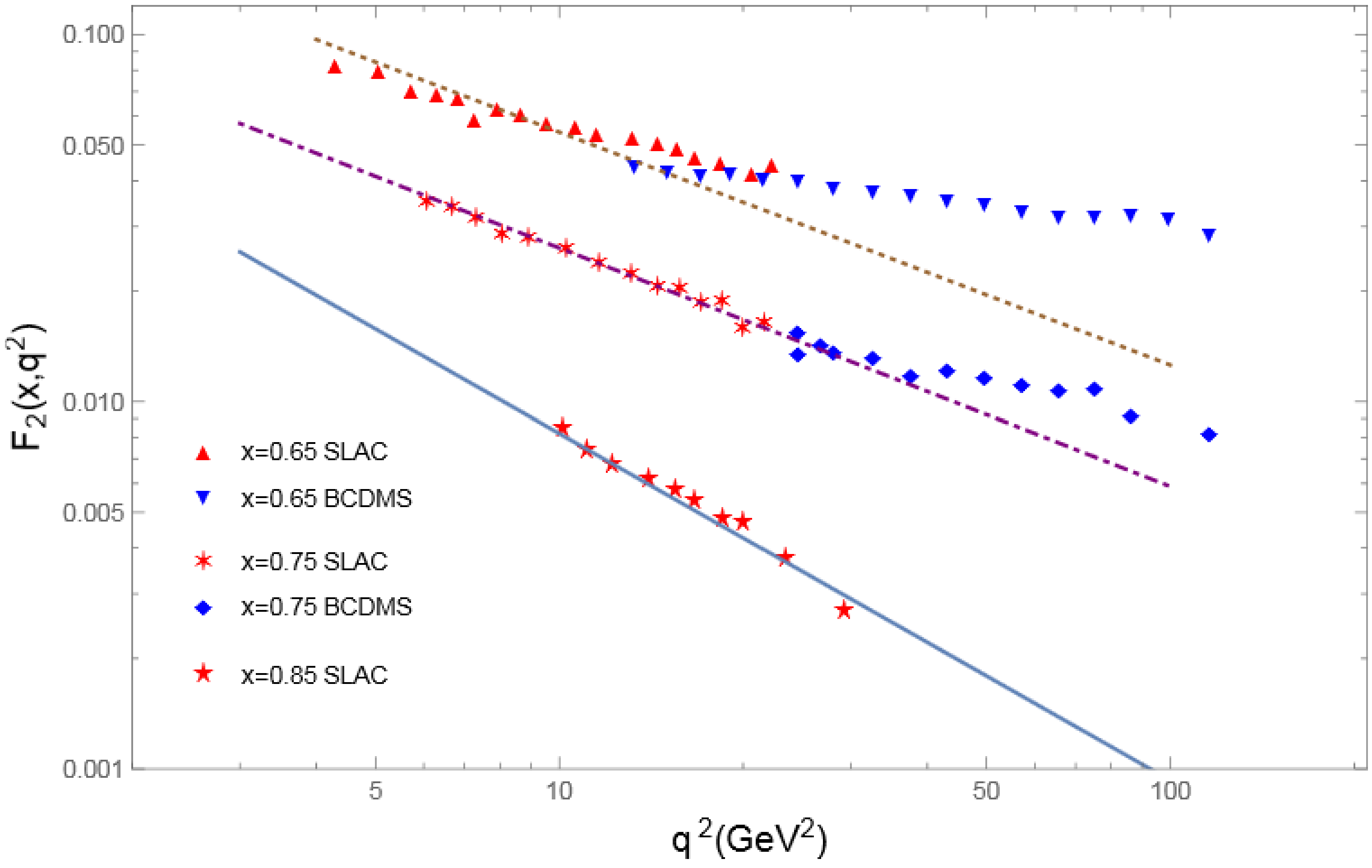
$$\mathcal{I}_{R/L} = \int dz B(z,q) \psi^X_{R/L}(z, P_X) \psi^i_{R/L}(z, P).$$

$$\eta_\mu \eta_\nu W^{\mu\nu} = \eta^2 F_1(q^2, x) + \frac{2x}{q^2}(\eta\cdot P)^2 F_2^2(q^2, x)$$

$$F_1(q^2, x) = \frac{g_{\text{eff}}^2}{4}\left[M_0 \sqrt{M_0^2 + q^2\left(\frac{1-x}{x}\right)} \mathcal{I}_L \mathcal{I}_R + (\mathcal{I}_L^2 + \mathcal{I}_R^2)\left(\frac{q^2}{4x} + \frac{M_0^2}{2}\right)\right] \frac{1}{M_X^2}$$

$$F_2(q^2, x) = \frac{g_{\text{eff}}^2}{8} \frac{q^2}{x} (\mathcal{I}_L^2 + \mathcal{I}_R^2) \frac{1}{M_X^2}$$

Numerical Resuls (1)



Thank you for your attention!
Muchas gracias!
eduardo_capossoli@cp2.g12.br