Tests of holographic approaches to QCD: anomalous AVV correlation function

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Colour meets Flavour Workshop
KhodjamirianFest
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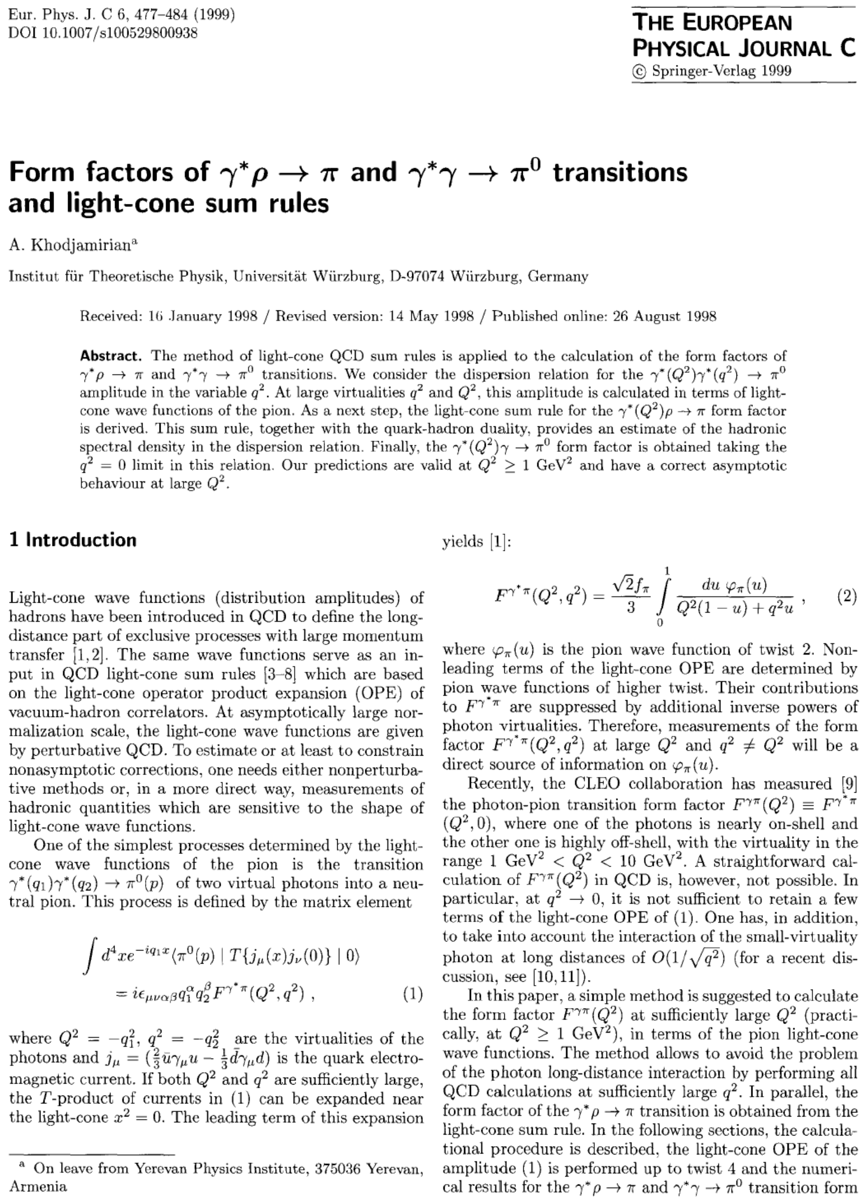
Alex's papers
about related topics in QCD



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Form factors of $\gamma^*\rho \to \pi$ and $\gamma^*\gamma \to \pi^0$ transitions and light-cone sum rules

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Abstract. The method of light-cone QCD sum rules is applied to the calculation of the form factors of $\gamma^*\rho \to \pi$ and $\gamma^*\gamma \to \pi^0$ transitions. We consider the dispersion relation for the $\gamma^*(Q^2)\gamma^*(q^2) \to \pi^0$ amplitude in the variable q^2. At large virtualities q^2 and Q^2, this amplitude is calculated in terms of light-cone wave functions of the pion. As a next step, the light-cone sum rule for the $\gamma^*(Q^2)\rho \to \pi$ form factor is derived. This sum rule, together with the quark-hadron duality, provides an estimate of the hadronic spectral density in the dispersion relation. Finally, the $\gamma^*(Q^2)\gamma \to \pi^0$ form factor is obtained taking the $q^2 = 0$ limit in this relation. Our predictions are valid at $Q^2 \geq 1$ GeV^2 and have a correct asymptotic behaviour at large Q^2.

1 Introduction

Light-cone wave functions (distribution amplitudes) of hadrons have been introduced in QCD to define the long-distance part of exclusive processes with large momentum transfer [1,2]. The same wave functions serve as an input in QCD light-cone sum rules [3–8] which are based on the light-cone operator product expansion (OPE) of vacuum-hadron correlators. At asymptotically large normalization scale, the light-cone wave functions are given by perturbative QCD. To estimate or at least to constrain nonasymptotic corrections, one needs either nonperturbative methods or, in a more direct way, measurements of hadronic quantities which are sensitive to the shape of light-cone wave functions.

One of the simplest processes determined by the light-cone wave functions of the pion is the transition $\gamma^*(q_1)\gamma^*(q_2) \to \pi^0(p)$ of two virtual photons into a neutral pion. This process is defined by the matrix element

$$\int d^4x e^{-iq_1x}\langle\pi^0(p) \mid T\{j_\mu(x)j_\nu(0)\} \mid 0\rangle$$
$$= i\epsilon_{\mu\nu\alpha\beta}q_1^\alpha q_2^\beta F^{\gamma^*\pi}(Q^2,q^2) \ , \qquad (1)$$

where $Q^2 = -q_1^2$, $q^2 = -q_2^2$ are the virtualities of the photons and $j_\mu = (\frac{2}{3}\bar{u}\gamma_\mu u - \frac{1}{3}\bar{d}\gamma_\mu d)$ is the quark electromagnetic current. If both Q^2 and q^2 are sufficiently large, the T-product of currents in (1) can be expanded near the light-cone $x^2 = 0$. The leading term of this expansion yields [1]:

$$F^{\gamma^*\pi}(Q^2,q^2) = \frac{\sqrt{2}f_\pi}{3}\int\limits_0^1 \frac{du\ \varphi_\pi(u)}{Q^2(1-u)+q^2u} \ , \qquad (2)$$

where $\varphi_\pi(u)$ is the pion wave function of twist 2. Nonleading terms of the light-cone OPE are determined by pion wave functions of higher twist. Their contributions to $F^{\gamma^*\pi}$ are suppressed by additional inverse powers of photon virtualities. Therefore, measurements of the form factor $F^{\gamma^*\pi}(Q^2,q^2)$ at large Q^2 and $q^2 \neq Q^2$ will be a direct source of information on $\varphi_\pi(u)$.

Recently, the CLEO collaboration has measured [9] the photon-pion transition form factor $F^{\gamma\pi}(Q^2) \equiv F^{\gamma^*\pi}$ $(Q^2,0)$, where one of the photons is nearly on-shell and the other one is highly off-shell, with the virtuality in the range 1 GeV^2 $< Q^2 <$ 10 GeV^2. A straightforward calculation of $F^{\gamma\pi}(Q^2)$ in QCD is, however, not possible. In particular, at $q^2 \to 0$, it is not sufficient to retain a few terms of the light-cone OPE of (1). One has, in addition, to take into account the interaction of the small-virtuality photon at long distances of $O(1/\sqrt{q^2})$ (for a recent discussion, see [10,11]).

In this paper, a simple method is suggested to calculate the form factor $F^{\gamma\pi}(Q^2)$ at sufficiently large Q^2 (practically, at $Q^2 \geq 1$ GeV^2), in terms of the pion light-cone wave functions. The method allows to avoid the problem of the photon long-distance interaction by performing all QCD calculations at sufficiently large q^2. In parallel, the form factor of the $\gamma^*\rho \to \pi$ transition is obtained from the light-cone sum rule. In the following sections, the calculational procedure is described, the light-cone OPE of the amplitude (1) is performed up to twist 4 and the numerical results for the $\gamma^*\rho \to \pi$ and $\gamma^*\gamma \to \pi^0$ transition form

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AdS/CFT inspired approaches to QCD need to be tested

successes vs drawbacks

outline:

- anomalous AVV correlation function in QCD
- an AdS/QCD determination
- comparison with QCD results, comments, perspectives

AdS/CFT correspondence

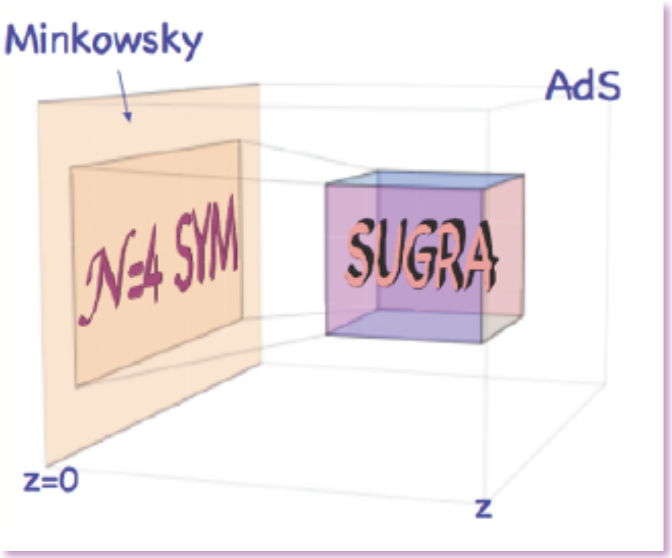
Maldacena
Gubser Klebanov Polyakov
Witten

$\mathcal{N}$=4 SYM with gauge group SU(N_c) at large N_c in 4d ⟷ d=10 Type IIB string theory in $AdS_5 \times S_5$

$g_{YM}\,,\quad N_c$

$g_s\,,\quad R/\ell_s$

R radius of AdS_5



$$ds^2 = \frac{R^2}{z^2}(dt^2 - d\vec{x}^2 - dz^2) + R^2 d\Omega_5$$

$AdS_5 \times S_5$

$x \to \lambda x$
$z \to \lambda z$

→ z-> 0: UV brane

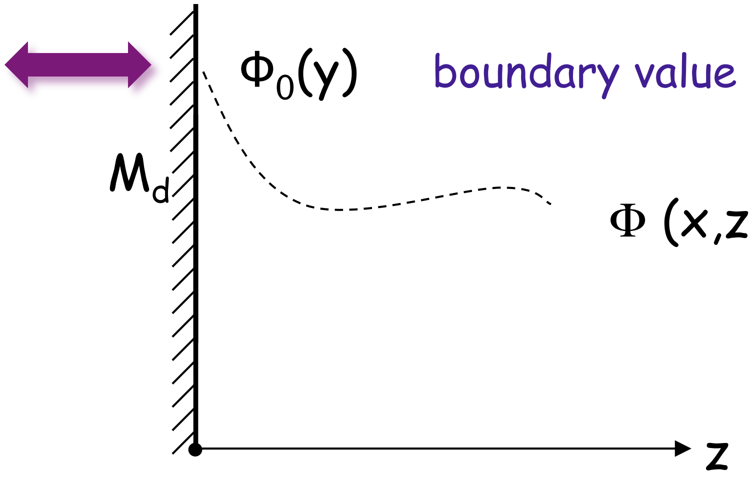
matching the parameters: $g_{YM}^2 = g_s$ $\lambda = g_{YM}^2 N_c = (R/\ell_s)^4$

$g_{YM} \to 0 \quad N_c \to \infty \quad \lambda \to \infty$ ⟷ $g_s \to 0 \quad \frac{R}{\ell_s} \to \infty$

large 't Hooft coupling ⟷ supergravity limit

dynamics of a 4d CFT encoded by classical gravity in 5d

AdS/CFT correspondence



operator O(y)
of CFT

M_d

$\Phi_0(y)$ boundary value

$\Phi\ (x,z)$ bulk field in AdS_{d+1}

z

$\Phi_0\,(y)$ coupled to O via $\int_{M_d} d^d y\, \Phi_0(y)\, O(y)$

CFT generating functional
with the source Φ_0

$$Z_{CFT}[\Phi_0] = \int dA\ \exp\left\{ -S_{CFT} + \int d^d x\, \Phi_0 O \right\}$$

gravity partition function
in $AdS_{d+1} \times C$ with boundary value Φ_0

$$Z_{grav}\left[\Phi_0\right]$$

AdS/CFT correspondence conjecture

$$Z_{CFT}\left[\Phi_0\right] = Z_{grav}\left[\Phi_0\right]$$

Gubser Klebanov Polyakov
Witten

massless QCD conformal at a classical level

QCD a candidate for a description inspired by AdS/CFT correspondence

conditions to be implemented for the geometry of the dual space:

UV -> conformal behaviour -> $AdS_5 = M_4$ + radial (holographic) coordinate z
IR -> modification (at least) of the AdS geometry of the bulk

dictionary

4d - CFT	5d - gravity
gauge invariant operator O(x)	field $\psi(x,z)$
hadron mass^2	eigenvalue of a 5d eq. of motion
conformal dimension Δ	5d mass m_5
	$m_{d+1}^2 R^2 = (\Delta - p)(\Delta + p - d)$ Δ dimension of the p-form operator
UV	small z
scale Λ_{QCD}	deformation at large z dilaton, hard-wall, ….

A test of AdS/QCD

first proposed by Son-Yamamoto arXiv:1010.0718

$$J_\mu = \bar{q}\gamma_\mu V q$$

$$J_\nu^5 = \bar{q}\gamma_\nu\gamma_5 A q$$

consider the corr. function $$T_{\mu\nu}(q,k) = i\int d^4x \langle 0|T\left[J_\mu(x)J_\nu^5(0)\right]|\gamma(k,\varepsilon)\rangle$$

$$T_{\mu\nu}(q,k) = e\varepsilon^\sigma T_{\mu\nu\sigma}(q,k)$$

weak e.m. field:

$$T_{\mu\nu\sigma}(q,k) = i^2\int d^4x\, d^4y\, \langle 0|T\left[J_\mu(x)J_\nu^5(0)J_\sigma^{em}(y)\right]|0\rangle$$

$$T_{\mu\nu}(q,k) = -\frac{i}{4\pi^2}Tr[QVA]\left\{\omega_T(q^2)\left(-q^2\tilde{f}_{\mu\nu} + q_\mu q^\lambda \tilde{f}_{\lambda\nu} - q_\nu q^\lambda \tilde{f}_{\lambda\mu}\right) + \omega_L(q^2) q_\nu q^\lambda \tilde{f}_{\lambda\mu}\right\}$$

transverse

longitudinal

$$\tilde{f}_{\mu\nu} = \frac{1}{2}\varepsilon_{\mu\nu\alpha\beta}f^{\alpha\beta}$$

$$f^{\alpha\beta} = k^\alpha\varepsilon^\beta - k^\beta\varepsilon^\alpha$$

QCD
chiral limit

$$\omega_L(Q^2) = \frac{2N_c}{Q^2}$$

Adler Bardeen
Bell Jackiw

$\omega_T(Q^2)$ dynamical quantity
no perturbative corrections to all orders

Vainshtein 2003

chiral limit:

$$\omega_L(Q^2) = \frac{2N_c}{Q^2}$$

OPE
Q^2->∞

$$\omega_T(Q^2) = \frac{N_c}{Q^2} + \frac{128\pi^3\alpha_s\chi\langle\bar{q}q\rangle^2}{9Q^6} + O\left(\frac{1}{Q^8}\right)$$

Vainshtein 2003

$$\langle 0|\bar{q}\sigma_{\mu\nu}q|\gamma\rangle = ie\chi\langle\bar{q}q\rangle f_{\mu\nu}$$

χ magnetic susceptibility
of the chiral condensate

m > 0 :

Q^2->∞

$$\omega_L(Q^2) = \frac{2N_c}{Q^2}\left[1 + \frac{2m^2}{Q^2}\ln\frac{m^2}{Q^2} - \frac{8\pi^2 m\langle\bar{q}q\rangle\chi}{N_c Q^2} + O\left(\frac{m^4}{Q^4}\right)\right]$$

$$2\omega_T(Q^2) = \frac{2N_c}{Q^2}\left[1 + \frac{2m^2}{Q^2}\ln\frac{m^2}{Q^2} - \frac{8\pi^2 m\langle\bar{q}q\rangle\chi}{N_c Q^2} + O\left(\frac{m^4}{Q^4}\right)\right]$$

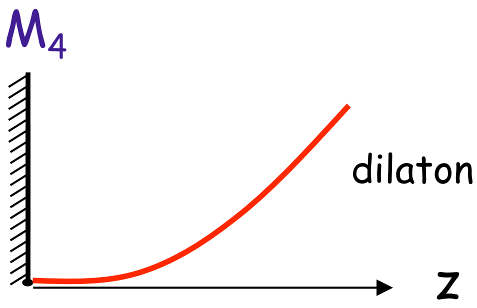
Czarnecki Marciano Vainshtein

to which extent AdS/QCD models reproduce these QCD results?

soft-wall AdS/QCD model

Karch, Katz, Son, Stephanov, Andreev, Zakharov, Radyushkin, Gorsky, Gherghetta, Brodsky, de Teramond, Lebed…

confinement provided by a background "dilaton" field in the bulk



dilaton profile $\varphi = c^2 z^2$

SU(2)$_L$xSU(2)$_R$ chiral symmetry:

- conserved currents in QCD: $J^{\mu}_{L,R} = \bar{q}\gamma^{\mu}\frac{1\mp\gamma_5}{2}q$

- bulk gauge fields in 5d : $A_{L,R}$ (x,z)

chiral symmetry breaking:

- massive scalar bulk field in 5d dual to $\bar{q}_L q_R$ X=(X$_0$(z)+S(x,z)) e$^{2i\Pi(x,z)}$

Pomarol, Da Rold, Erlich….

at small z: $X_0^{\alpha\beta} \underset{z\to 0}{\rightarrow} (m\,z + \sigma\,z^3)\frac{\delta^{\alpha\beta}}{2}$ $(\sigma \propto \langle\bar{q}q\rangle)$

5d YM action

$$S_{YM}=\frac{1}{k_{YM}}\int d^5x\sqrt{|g|}\;e^{-\varphi(z)}\;Tr\left[|DX|^2-m_5^2|X|^2-\frac{1}{4g_5^2}\left(F_L^2+F_R^2\right)\right]$$

$$D^M X=\partial^M X-iA_L^M X+iXA_R^M$$

in terms of vector and axial fields

$$V=(A_L+A_R)/2$$
$$A=(A_L-A_R)/2$$

$$S_{YM}=\frac{1}{k_{YM}}\int d^5x\sqrt{|g|}\;e^{-\varphi(z)}\;Tr\left[|DX|^2-m_5^2|X|^2-\frac{1}{2g_5^2}\left(F_V^2+F_A^2\right)\right]$$

$$D^M X=\partial^M X-i\left[V^M,X\right]-i\left\{A^M,X\right\}$$
$$F_V^{MN}=\partial^M V^N-\partial^N V^M-i\left[V^M,V^N\right]-i\left[A^M,A^N\right]$$
$$F_A^{MN}=\partial^M A^N-\partial^N A^M-i\left[V^M,A^N\right]-i\left[A^M,V^N\right]$$

Matching to QCD in SS corr. funct. → $k_{YM}=\frac{16\pi^2}{N_C}$

VV corr. funct. → $g_5^2=\frac{3}{4}$

vector meson spectrum $m^2(\rho_n)=4c^2(n+1)$

axial meson spectrum, mass of scalars, decay constants, strong couplings, …

$U(N_f)_L$x$U(N_f)_R$ to describe em interactions

Chern-Simons term

$$S_{CS} = S_{CS}(A_L) - S_{CS}(A_R)$$

$$S_{CS}(A) = k_{CS} \int d^5x \quad Tr\left[AF^2 - \frac{i}{2} A^3 F - \frac{1}{10} A^5 \right]$$

relevant term

$$S_{CS+b} = 3k_{CS}\varepsilon_{ABCDE} \int d^5x \quad Tr\left[A^A \left\{ F_V^{BC}, F_V^{DE} \right\} \right]$$

$$S_{5d}^{eff} = S_{YM} + S_{CS+b}$$

$$P_{\mu\nu}^{perp} = \eta_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}$$

$$P_{\mu\nu}^{par} = \frac{q_\mu q_\nu}{q^2}$$

$$\hat{V}_\mu^a(q,z) = V\,(q,z) P_{\mu\nu}^{perp} V_0^{av}(q)$$

$$\hat{A}_\mu^a(q,z) = A_{perp}(q,z) P_{\mu\nu}^{perp} A_0^{av}(q) + A_{par}(q,z) P_{\mu\nu}^{par} A_0^{av}(q)$$

$$\hat{A}_\mu^{apar}(q,z) = A_{par}(q,z) P_{\mu\nu}^{par} A_0^{av}(q) = iq_\mu \hat{\Phi}^a$$

$$\omega_L(Q^2) = -\frac{2N_C}{Q^2} \int_0^\infty dy\; A_{par}(Q^2,y)\; \partial_y V(Q^2,y)$$

integral over
the holographic coordinate

$$\omega_T(Q^2) = -\frac{2N_C}{Q^2} \int_0^\infty dy\; A_{perp}(Q^2,y)\; \partial_y V(Q^2,y)$$

equations of motion (eom) for V(q,z), $A_{par}(q,z)$, $A_{perp}(q,z)$ -> ω_L , ω_T

various cases investigated:

$$m = 0,\; m \neq 0$$

$$\langle \bar{q}q \rangle = 0, \quad \langle \bar{q}q \rangle \neq 0$$

De Fazio, Giannuzzi, Nicotri, Sanz-Cillero, PC

$$\left\langle e^{i\int d^4x\, 0(x)\, f_0(x)} \right\rangle_{QCD} = e^{iS_{5d}^{eff}[f(x,z)]}$$

$$d^{ab}(2\pi)^{-4}\delta^4(q_1+q_2)\langle J_\mu^V\, J_\nu^A\rangle_{\tilde F}^{\perp\perp} = \frac{\delta^2 S_{CS+b}}{\delta V_{\mu 0}^{a\perp}(q_1)\,\delta A_{\nu 0}^{b\perp}(q_2)}$$

$$d^{ab}(2\pi)^{-4}\delta^4(q_1+q_2)\langle J_\mu^V\, J_\nu^A\rangle_{\tilde F}^{\perp\|} = \frac{\delta^2 S_{CS+b}}{\delta V_{\mu 0}^{a\perp}(q_1)\,\delta A_{\nu 0}^{b\|}(q_2)} \;,$$

eqs. of motion

$$\partial_y\left(\frac{e^{-y^2}}{y}\,\partial_y V_\perp\right) - \tilde Q^2\frac{e^{-y^2}}{y}V_\perp = 0$$

$$\partial_y\left(\frac{e^{-y^2}}{y}\,\partial_y A_\perp\right) - \tilde Q^2\frac{e^{-y^2}}{y}A_\perp - \frac{g_5^2 v^2(y) e^{-y^2}}{y^3}A_\perp = 0$$

$$\partial_y\left(\frac{e^{-y^2}}{y}\,\partial_y \tilde\phi^a\right) + \frac{g_5^2 v^2(y) e^{-y^2}}{y^3}(\tilde\pi^a - \tilde\phi^a) = 0$$

$$\tilde Q^2(\partial_y\tilde\phi^a) + \frac{g_5^2 v^2(y)}{y^2}\partial_y\tilde\pi^a = 0 \;.$$

$$X_0 \to v(z)$$

boundary conds.

$$V(Q^2,0) = 1 \qquad V(Q^2,\infty) = 0$$

.....

$m = 0 \qquad \langle \bar{q} q \rangle = 0$

$$A_{par}(Q^2, y) = 1$$

$$A_{perp}(Q^2, y) = V(Q^2, y)$$

$$\omega_L(Q^2) = -\frac{2N_C}{Q^2} \int_0^\infty dy\; A_{par}(Q^2, y)\; \partial_y V(Q^2, y) = \frac{2N_C}{Q^2}$$

$$\omega_T(Q^2) = -\frac{2N_C}{Q^2} \int_0^\infty dy\; A_{perp}(Q^2, y)\; \partial_y V(Q^2, y) = \frac{N_C}{Q^2}$$

$\omega_L (Q^2) = 2\, \omega_T (Q^2)$

AdS/QCD ok

$m = 0 \quad \langle \bar{q} q \rangle \neq 0$

$A_{par}(Q^2, y) = 1$

$\omega_L(Q^2) = \frac{2N_C}{Q^2}$ → AdS/QCD fits QCD

AdS/QCD

$$\omega_T(Q^2) = \frac{N_c}{Q^2} - \tau g_5^2 \sigma^2 \frac{2N_c}{Q^8} + O\left(\frac{1}{Q^{10}}\right)$$

QCD

$$\omega_T(Q^2) = \frac{N_c}{Q^2} + \frac{128\pi^3 \alpha_s \chi \langle \bar{q} q \rangle^2}{9Q^6} + O\left(\frac{1}{Q^8}\right)$$

$Q^2 \to \infty$

$\tau = 2.472$

$\sigma \to \langle \bar{q} q \rangle$

in this AdS/QCD approach, terms governed by the magnetic susceptibility of the chiral condensate are missed in ω_T

$m \neq 0 \quad \langle \bar{q} q \rangle \neq 0$

AdS/QCD

$$\omega_T(Q^2) = \frac{N_c}{Q^2}\left[1 - \frac{g_5^2 m^2}{3Q^2} - \frac{2g_5^2 m^2 c^2}{5Q^4} + \frac{g_5^4 m^4}{6Q^4} - \frac{8 g_5^2 m \sigma}{5Q^4}\right] + O\left(\frac{1}{Q^8}\right)$$

QCD

$$\omega_T(Q^2) = \frac{N_c}{Q^2}\left[1 + \frac{2m^2}{Q^2} \ln\frac{m^2}{Q^2} - \frac{8\pi^2 m \langle \bar{q} q \rangle \chi}{N_c Q^2} + O\left(\frac{m^4}{Q^4}\right)\right]$$

AdS/QCD

$$\omega_L(Q^2) = \frac{2N_c}{Q^2} - \left[1 - \Pi(Q^2, 0)\right] N_c \left[\frac{g_5^2 m^2}{Q^4} + \frac{8 g_5^2 m \sigma}{Q^6} - \frac{2 g_5^4 m^4}{3Q^6} + O\left(\frac{1}{Q^8}\right)\right]$$

QCD

$$\omega_L(Q^2) = \frac{2N_c}{Q^2}\left[1 + \frac{2m^2}{Q^2} \ln\frac{m^2}{Q^2} - \frac{8\pi^2 m \langle \bar{q} q \rangle \chi}{N_c Q^2} + O\left(\frac{m^4}{Q^4}\right)\right]$$

structure of the power corrections not properly reproduced

Son-Yamamoto relation

Son and Yamamoto have proposed the relation

arXiv:1010.0718

$$\omega_T(Q^2) = \frac{N_c}{Q^2} + \frac{N_c}{F_\pi^2}\Pi_{LR}(Q^2)$$

$$\Pi_{LR}(Q^2) = \Pi_{VV}(Q^2) - \Pi_{AA}(Q^2)$$

AdS/QCD: the LR two point correlation function can be obtained from the fields V and A_{perp} close to the UV brane

$$\Pi_{LR}(Q^2) = -\frac{e^{-y^2}}{k_{YM}\, g_5^2\, \tilde{Q}^2}\left(V(Q^2,y)\frac{\partial_y V(Q^2,y)}{y} - A_\perp(Q^2,y)\frac{\partial_y A_\perp(Q^2,y)}{y}\right)\Bigg|_{y\to 0}$$

large Q^2 :
mismatch in
power corrections

$$\Pi_{LR}(Q^2) = -\frac{N_c\sigma}{10\pi^2 Q^6} + O\left(\frac{1}{Q^8}\right)$$

$$\sigma \to \langle \bar{q}q \rangle$$

$$\omega_T(Q^2) = \frac{N_c}{Q^2} - \tau g_5^2\sigma^2\frac{2N_c}{Q^8} + O\left(\frac{1}{Q^{10}}\right)$$

Son and Yamamoto relation not reproduced in soft-wall AdS/QCD at large Q^2

same result in the hard-wall model
in modified models, the relation holds for small Q^2 but not for large Q^2

Kiritsis et al. 2011

low energy parameters

m=0, Q^2=0: eom solved analytically

Pion decay constant

$$F_\pi^2 = -\frac{N_c}{12\pi^2} c^2 \frac{\partial_y A(0,y)}{y}\Big|_{y\to 0} \longrightarrow \boxed{F_{\pi^0} = 81.5 \text{ MeV}}$$

$$F_{\pi^0}^{\exp} = 92.2 \text{ MeV}$$

$N_C = 3$

$\langle \bar{q} q \rangle = (-0.23 \text{ GeV})^3$

$c = \frac{M_\rho}{2}$

low energy constant

Bijnens et al 2003

$$C_{22}^W = \frac{\omega_T(0)}{128\pi^2} = -\frac{N_c}{64\pi^2 c^2}\int_0^\infty dy\, A(0,y)\, f_V(y)$$

$$f_V(y) = \frac{\partial_y V(Q^2,y)}{Q^2}\Big|_{Q^2\to 0} = -\frac{y}{2} e^{y^2}\Gamma(0,y^2) \longrightarrow \boxed{C_{22}^W = 6.6\times 10^3 \text{ GeV}^{-2}}$$

from the slope of $\pi^0 \to \gamma\gamma$ form factor

$$F(Q^2) = F(0)\left(1 - \alpha \frac{Q^2}{M_{\pi^0}^2}\right)$$

$$\alpha = 0.032 \pm 0.004 \qquad C_{22}^W = \frac{\alpha N_c}{64\ \pi^2\ M_{\pi^0}^2} \longrightarrow C_{22}^W = (8.3 \pm 1.3)\times 10^{-3}\ \text{GeV}^{-2}$$

from resonance ch.theory

Kampf Novotny 2011

$$C_{22}^W = \frac{N_c}{64\ \pi^2\ M_\rho^2} \longrightarrow C_{22}^W = 7.9\times 10^{-3}\ \text{GeV}^{-2}$$

low energy parameters

m=0, $Q^2 \to \infty$

$$\Pi_{LR}(Q^2) = \frac{O_6}{Q^6} + \ldots.$$

$N_C = 3$

$\langle \bar{q}q \rangle = (-0.23\text{ GeV})^3$

$c = \frac{M_\rho}{2}$

$$O_6 = -\frac{32\pi^2}{5N_c}\langle \bar{\mathrm{q}}\mathrm{q} \rangle^2 = -3.1 \times 10^{-3}\ \mathrm{GeV}^6$$

$O_6 = (-3.9 \pm 0.8) \times 10^{-3}\ \mathrm{GeV}^6$ QCD sum rules

parameters correctly reproduced

conclusions

- $m=0 \quad \langle\bar{q}q\rangle=0$: in this AdS/QCD approach $\omega_L(Q^2) = 2\,\omega_T(Q^2) = 2\,N_c/Q^2$
- $m=0 \quad \langle\bar{q}q\rangle\neq 0$: ω_L OK , problem in ω_T
- away from the chiral limit: mismatch with QCD in power corrections
- Son-Yamamoto relation not recovered at large Q^2
- low energy parameters correctly obtained

- successes and limitations detected
- improvements seem possible (by including the dual of $\bar{q}\sigma_{\mu\nu}q$)

- the approach is useful for difficult problems (high T, high baryonic density, …), it is worth continuing to study it

- well established traditional methods are precious guides to constrain the various possible holographic versions…

well established traditional methods precious guides e.g. SVZ sum rules

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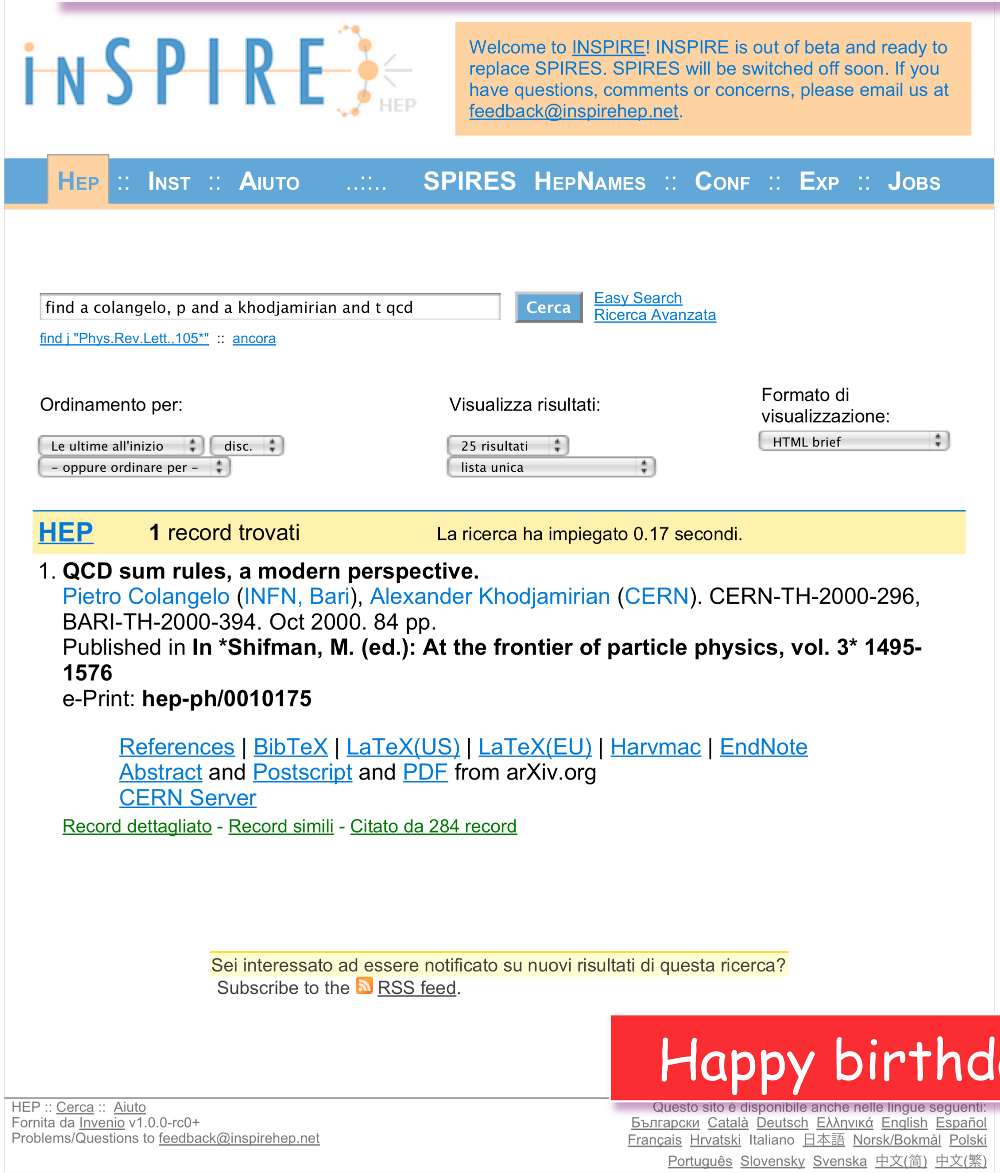

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1. **QCD sum rules, a modern perspective.**
   Pietro Colangelo (INFN, Bari), Alexander Khodjamirian (CERN). CERN-TH-2000-296, BARI-TH-2000-394. Oct 2000. 84 pp.
   Published in **In *Shifman, M. (ed.): At the frontier of particle physics, vol. 3* 1495-1576**
   e-Print: **hep-ph/0010175**

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Happy birthday, Alex !