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Exotic glueballs in AdS/QCD

based on JHEP **1510** (2015), 137

work with Pietro Colangelo and Floriana Giannuzzi

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$J^{PC}=0^{--}$ exotic glueball

- **Glueballs:** bound states of gluons.
  Elusive hadrons due to the mixing with ordinary $q\bar{q}$ configurations.

- $J^{PC}=0^{--}$ exotic in the quark model ⟶ glueballs with such quantum numbers are promising for identification.

- Odd charge conjugation glueballs must be composed by an odd number of constituent gluons ⟶ ***"oddballs"***

- The $J^{PC}=0^{--}$ glueball is described by the QCD local operator

$$J(x)=g^3_{YM}\,d_{abc}\left[\left(\eta_{\alpha\beta}-\frac{\partial_\alpha\partial_\beta}{\partial^2}\right)\tilde{G}^a_{\mu\nu}(x)\right]\left[\partial_\alpha\partial_\beta G^b_{\nu\rho}(x)\right]\left[G^c_{\rho\mu}(x)\right]$$

d_{abc}: Symmetric $SU(3)_{\text{color}}$ structure constants

$\eta_{\alpha\beta}$: Minkowski metric tensor

Gluon field strength $G^a_{\mu\nu}(x)$

$$\tilde{G}^a_{\mu\nu}(x)=\frac{1}{2}\varepsilon_{\mu\nu\rho\sigma}G^a_{\rho\sigma}(x)$$

Oddballs in holographic models

Strongly-coupled
Conformal **F**ield **T**heory
on the Minkowski space
$\mathcal{M}_4$

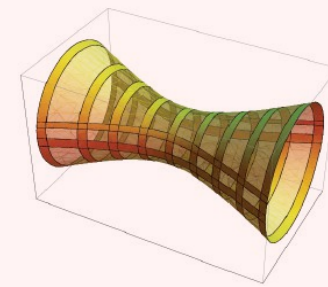
A conformal compactification gives
the **Boundary** of

duality

Wealky-coupled gravitational theory on
$$AdS_5(R) \times S^5(R)$$

Anti-de Sitter hyperboloid
R curvature radius

Bulk



Gauge-invariant scalar $J(x)$
with conformal dimension Δ

duality

Bulk field $O_0(x,z)$ with mass M_5 given by
$$M_5^2 R^2 = \Delta(\Delta - 4)$$

Three models

Mass scale breaking
conformal invariance
(QCD confinement)

duality

Action for the dual field and bulk geometry
- SOFT WALL
- HARD WALL
- EINSTEIN-DILATON

Mass spectrum

Action for the bulk field $O_0(x,z)$:

$$S=\frac{1}{k}\int d^5x\sqrt{|g|}\,\underline{a(z)}\left[g^{MN}\partial_M O_0 \partial_N O_0 - M_5^2 O_0^2\right]$$

g_{MN} 5D metric, $g \equiv det\, g_{MN}$

AdS_5 metric

$$ds^2=\frac{1}{z^2}\left(dx_0^2-d\vec{x}^2-dz^2\right),$$
$$z>0 \quad (R=1)$$

★ **HARD WALL :** sharp cutoff $z \le z_m$ (mass scale), $\underline{a(z)=1}$

MASS SPECTRUM $m_n^2 \sim n^2$ n radial quantum number

$m_0=2.80\ \text{GeV}, \quad m_1=4.14\ \text{GeV}$ $[1/z_m=346\ \text{MeV}]$

★ **SOFT WALL :** $\underline{a(z)=e^{-c^2z^2}},$ c mass scale

REGGE TRAJECTORY $m_n^2=4c^2(n+4)$

$m_0=1.55\ \text{GeV}, \quad m_1=1.74\ \text{GeV}$ $[c=m_\rho/2=388\ \text{MeV}]$

★ **EINSTEIN – DILATON :** 5D bulk geometry $ds^2_{(ED)}=\frac{e^{2\delta^2z^2-\frac{4}{3}\Phi(z)}}{z^2}\left(dx_0^2-d\vec{x}^2-dz^2\right)$

$\Phi(z)$ scalar field obtained solving the Einstein equations for the metric-dilaton system, δ mass scale, $\underline{a(z)=1}$

$m_0=2.82\ \text{GeV}, \quad m_1=4.07\ \text{GeV}$ $[\delta=0.43\ \text{GeV}]$

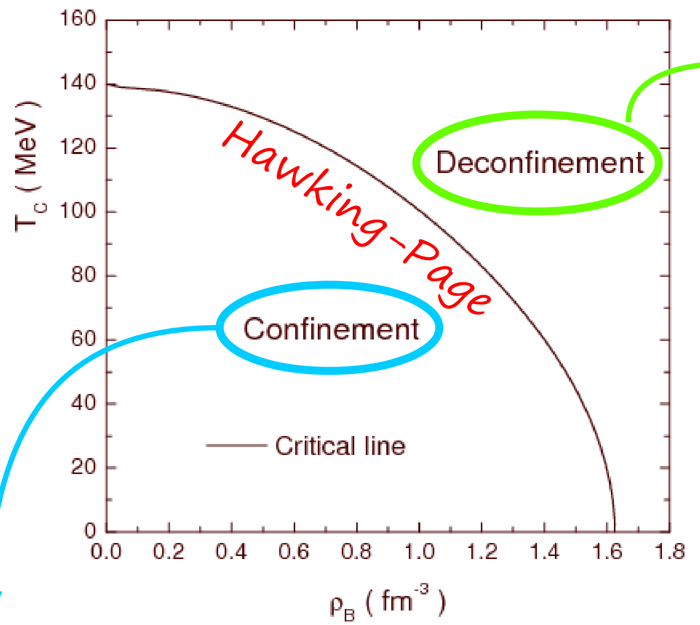
Oddballs in medium at finite T and μ

Temperature and density fluctuations in the quark medium

duality

Deformation $f(z)$ in the AdS_5 geometry

$$ds^2 = \frac{1}{z^2}\left(f(z)\, dx_0^2 - d\vec{x}^2 - \frac{dz^2}{f}(z) \right)$$



Deconfined phase:

AdS/RN metric $f(z) = 1 - \left(\frac{1}{z_h^4} + q^2 z_h^2 \right) z^4 + q^2 z^6$

Black hole with outer horizon $z = z_h$ and charge q

$$T = \frac{1}{4\pi} \left| \frac{df}{dz} \right|_{z=z_h} = \frac{1}{\pi z_h}\left(1 - \frac{Q^2}{2} \right), \quad \mu = \kappa \frac{Q}{z_h},$$

with $Q = q z_h^3$ and $0 \leq Q \leq \sqrt{2}$

Confined phase:

Thermal-charged AdS metric $f(z) = 1 + q^2 z^6$

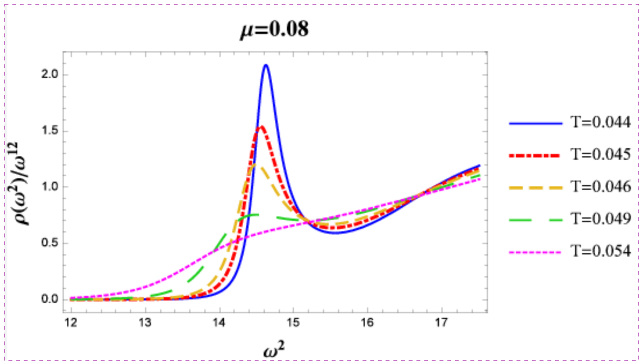
T is implemented using a periodic Eucliean time $\tau = i x_0$ with period $\beta = 1/T$, and $\mu \propto q$

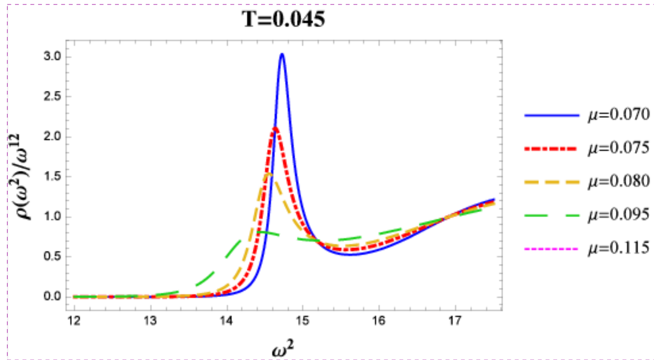
Oddballs in medium at finite T and μ

Results in the SOFT WALL MODEL (Dimensionful quantities in units of $c = m_\rho/2 = 388$ MeV)

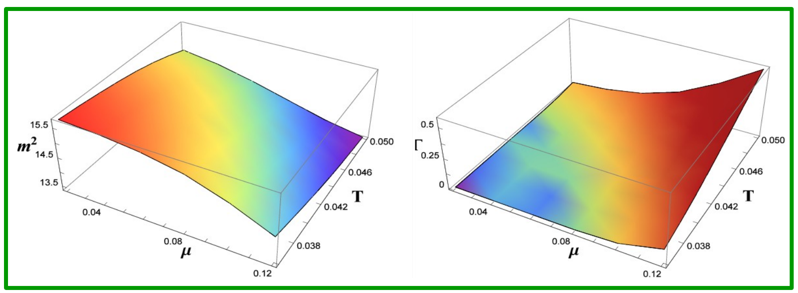
- Deconfined quark medium

Spectral function $\rho(\omega^2) = \mathrm{Im}\,\Pi^R(\omega^2)$, with Π^R the retarded Green's function of $J(x)$





Effects of temperature and density: mass reduction, broadening and melting of the bound states



(T, μ) - dependence of the lightest oddball's mass m and width Γ. At (T, μ) below the *Hawking-Page* deconfinement transition AdS/RN is metastable.

- Confined quark medium

Mass increasing with μ and independent of T