Non-singlet baryons in gauge/gravity duality

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Non-singlet baryons are predicted in N=4 SYM by the AdS/CFT correspondence.

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How:

Analyze the holographic description in various backgrounds with reduced supersymmetries and/or confining

- Reduced SUSY: $AdS_5 \times Y_5$, Lunin-Maldacena β deformed, Frolov multi-β deformed

- Confining: Maldacena-Nuñez

Results:

- Non-singlet baryons exist in all these backgrounds
- Same number of quarks in all $AdS_5 \times Y_5$ Einstein manifolds with 5-form flux, independent of SUSY
- More restricted number of quarks in MN
- Stable against fluctuations
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(Based on arXiv:1203.6817, D. Giataganas, Y.L., M. Picos, K. Siampos, JHEP)

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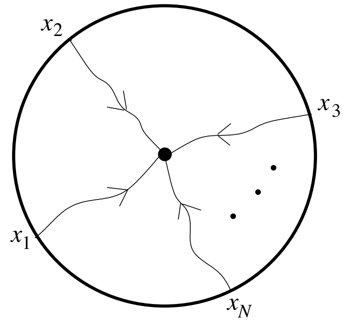

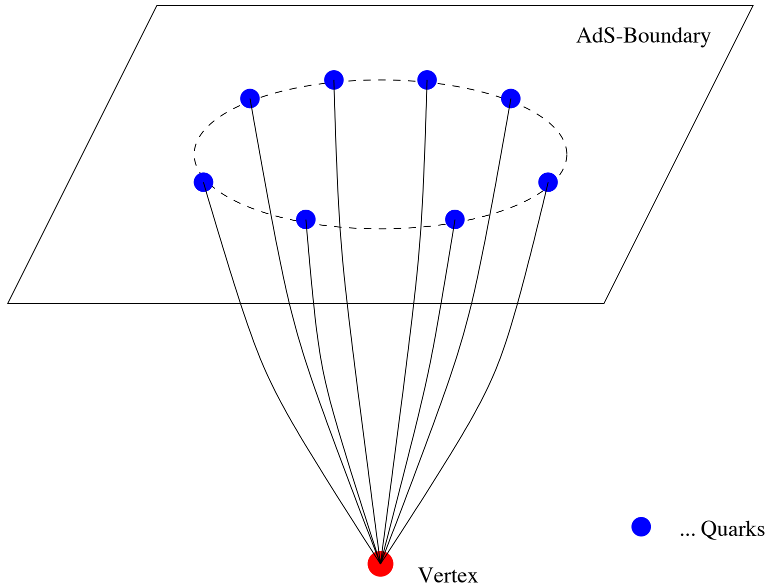

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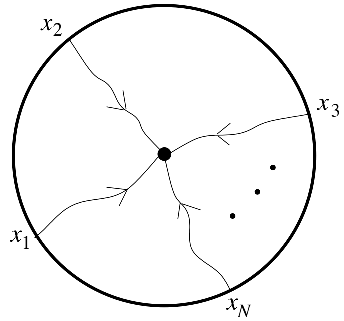

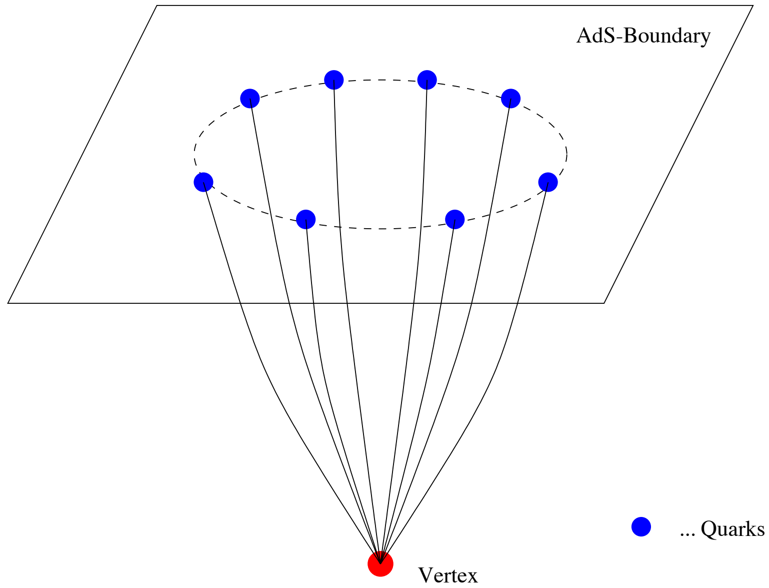

Baryon vertex in the gravity side: D5-brane wrapped on the 5-sphere (Witten'98):

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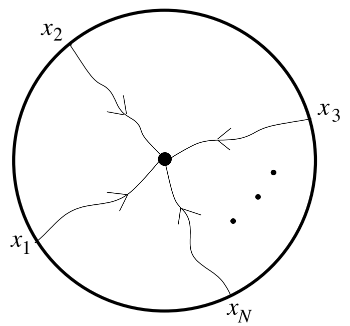

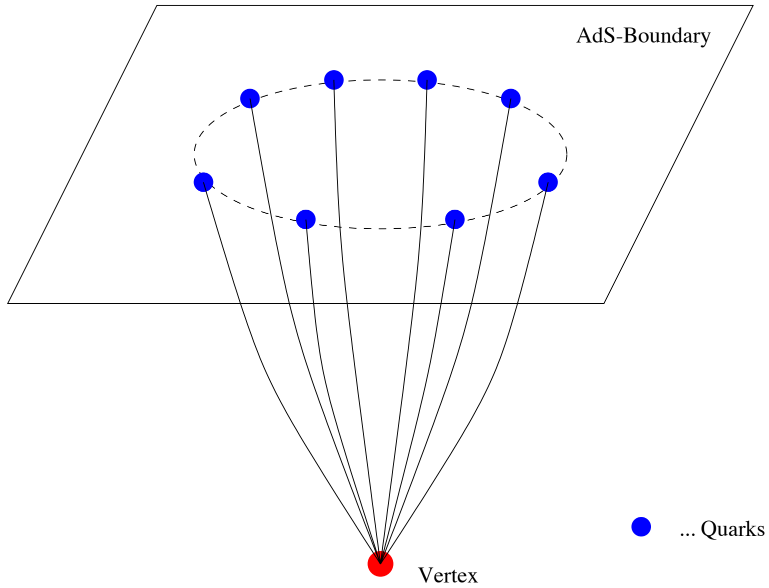

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In $AdS_5 \times S^5$: $5N/8 \leq k \leq N$

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What happens in less supersymmetric and/or confining backgrounds?

And at finite 't Hooft coupling?

2. Gauge/gravity calculation of the energy

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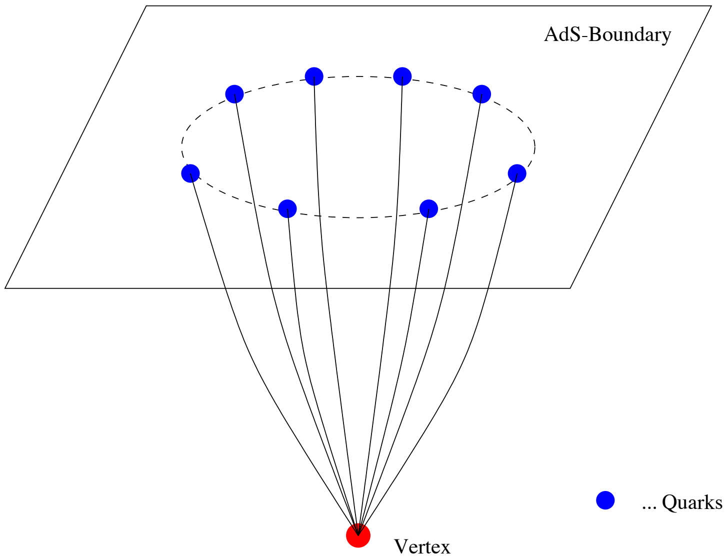

Consider a uniform distribution of strings on an $\mathbb{M}_p$ shell

Non-SUSY but we can ignore the backreaction

In the probe brane approach: $S = S_{Dp} + S_{NF1}$:

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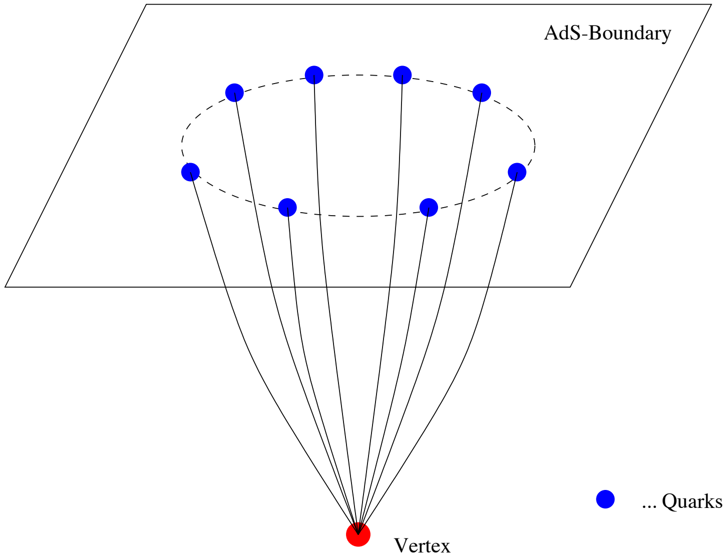

$$\rho(0) = \rho_0$$
$$\rho(L) = \infty$$

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$$S_{Dp} = -T_p \int_{\mathbb{R}\times\mathbb{M}_p} d^{p+1}\xi \sqrt{|\det P(G + 2\pi F - B)|}$$

In $AdS_5 \times Y_5$:

$$ds^2 = \frac{\rho^2}{R^2} dx^2_{1,3} + \frac{R^2}{\rho^2} d\rho^2 + R^2 ds^2_{Y_5}$$

$$R^4 = \frac{4\pi^4 N g_s}{\mathrm{Vol}(Y_5)}, \qquad F_5 = 4\, R^4 (1 + *) d\mathrm{Vol}(Y_5)$$

Bulk equation of motion: $$\frac{\rho^4}{\sqrt{\frac{\rho^4}{R^4} + \rho'^2}} = c$$

Boundary equation of motion: $$\frac{{\rho_0}'}{\sqrt{\frac{\rho_0^4}{R^4} + {\rho_0'}^2}} = \frac{T_5\, R^4\, \mathrm{Vol}(Y_5)}{N T_{F1}}$$

Define $\sqrt{1-\beta^2} = \dfrac{T_5\, R^4\, \mathrm{Vol}(Y_5)}{N T_{F1}}$ with $\beta \in [0,1]$

The two equations can be combined into:

$$\frac{\rho^4}{\sqrt{\frac{\rho^4}{R^4} + \rho'^2}} = \beta\, \rho_0^2\, R^2$$

Integrating: Size of the configuration:

$$\boxed{L = \frac{R^2}{\rho_0} \int_1^\infty dz \frac{\beta}{z^2 \sqrt{z^4 - \beta^2}}}$$

On-shell energy:

$$E = E_{Dp} + E_{NF1} = N T_{F1} \rho_0 \Big(\sqrt{1-\beta^2} + \int_1^\infty dz \frac{z^2}{\sqrt{z^4 - \beta^2}} \Big)$$

Binding energy:

$$E_{\text{bin}} = N T_{F1} \rho_0 \Big(\sqrt{1-\beta^2} + \int_1^\infty dz \Big[\frac{z^2}{\sqrt{z^4-\beta^2}} - 1 \Big] - 1 \Big)$$

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$$\boxed{E_{\rm bin} = -f(\beta)\frac{\sqrt{\lambda}}{L}}$$

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$\Rightarrow$ - The configuration is stable

- $E_{\rm bin} \sim 1/L$ dictated by conformal invariance
- $E_{\rm bin} \sim \sqrt{\lambda}$ non-trivial prediction for the non-perturbative regime of the gauge theory

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Confining background?

Maldacena-Nuñez: $E_{\rm bin} \sim L$

(Loewy, Sonnenschein'01)

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Non-singlets?

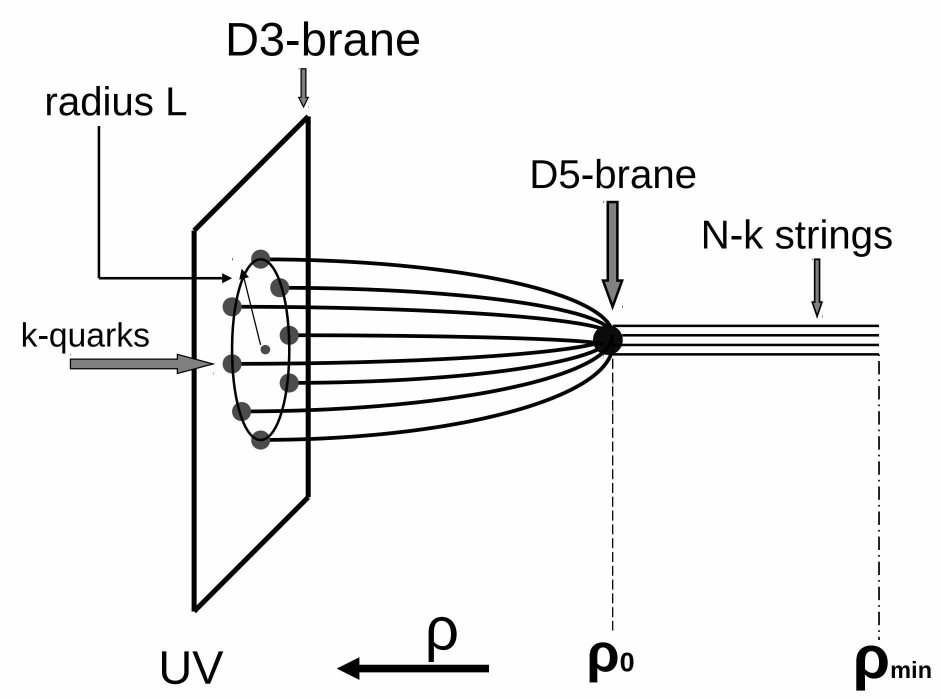
3. Reduce the number of quarks

In $AdS_5 \times S^5$: Baryon vertex classical solutions with number of quarks $5N/8 \leq k \leq N$ (non-singlet)

(Brandhuber, Itzhaki, Sonnenschein, Yankielowitz'98; Imamura'98)

Stable against fluctuations for $0.813\,N \leq k \leq N$

(Sfetsos, Siampos'08)



3.1. The classical solution

The boundary equation of motion changes:

$$\frac{\rho_0'}{\sqrt{\frac{\rho_0^4}{R^4} + {\rho_0'}^2}} = \frac{T_5\, R^4\, \mathrm{Vol}(Y_5)}{k\, T_{F1}} + \frac{N-k}{k} \leq 1$$

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$\Rightarrow$ Non-singlet states in non-SUSY or confining backgrounds

3.2. Stability analysis

Important in establishing the physical parameter space

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Expand the Nambu-Goto action to quadratic order and study the zero mode problem $\leftrightarrow$ Critical curve in the parametric space separating the stable and unstable regions

Stability reduced to an eigenvalue problem of the general Sturm-Liouville type

Instabilities emerge from longitudinal fluctuations of the strings

For $AdS_5 \times Y_5$ and beta deformed:

Bound for the number of F-strings coming from stability:

$$k \geq \frac{N}{1+\gamma_c}(1+\sqrt{1-\beta^2}) \qquad \gamma_c = 0.538$$

More restrictive than the bound imposed by the existence of a classical solution:

$$k \geq \frac{N}{2}(1+\sqrt{1-\beta^2})$$

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Can we reach the finite 't Hooft coupling region?

5. Baryons at finite 't Hooft coupling

Generalize the baryon vertex adding a magnetic flux.

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- Complementary at finite n. Should agree at large n

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$$R^4 = \frac{4\pi^4 N g_s}{\text{Vol}(Y^{p,q})} \; , \qquad ds_{Y^{p,q}}^2 = ds^2(M_4) + (\frac{1}{3} d\psi + \sigma)^2$$

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Take $F = \mathcal{N} J$ with $J = \frac{1}{2} d\sigma$ the Kähler form:

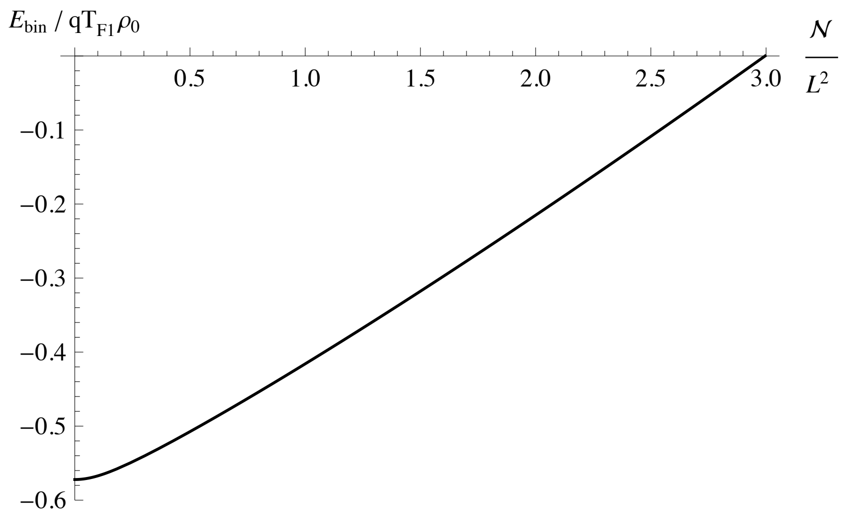
$$\sqrt{1-\beta^2} = \frac{T_5 R^4 \text{Vol}(Y^{p,q})}{N T_{F1}} (1 + \frac{4\pi^2 \mathcal{N}^2}{R^4})$$

$$\beta \leq 1 \Rightarrow \quad \mathcal{N}_{\text{max}} \leftrightarrow \beta = 0$$

Binding energy:

$$E_{\rm bin} = N T_{F1} \rho_0 \left(\sqrt{1-\beta^2} + \int_1^\infty dz \left[\frac{z^2}{\sqrt{z^4-\beta^2}} - 1 \right] - 1 \right)$$

- $E_{\rm bin}$ negative and decreases monotonically with β
- $E_{\rm bin} = 0$ for $\beta = 0$ (N free radial strings stretching from ρ_0 to ∞ plus a Dp-brane at ρ_0)



$$\mathcal{N}_{\rm max} \sim \sqrt{\lambda}$$

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Non-singlets:

The bound for the number of quarks is modified ($(k, \mathcal{N})$ parameter space bounded by the values for which the baryon vertex reduces to free quarks):

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$k_{\rm min}$ is maximum for the 5-sphere, the most SUSY case

$$\pi^3 = \mathrm{Vol}(S^5) > \frac{16}{27}\pi^3 = \mathrm{Vol}(T^{1,1}) > \mathrm{Vol}(Y^{2,1}) \approx 0.29\pi^3$$

↑ $Y^{p,q}$ with largest volume

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Spike solutions non-SUSY for $T^{1,1}$, $Y^{p,q}$ and MN

(Areán, Crooks, Ramallo'04; Canoura, Edelstein, Pando Zayas, Ramallo, Vaman'05; Imamura'04)

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Micro description:

D1’s expanding into a fuzzy M_4. Only known for the S^5 (Janssen, Y.L., Rodriguez-Gomez’06) and the $T^{1,1}$

The fuzzy $T^{1,1}$

The $T^{1,1}$ is a U(1) bundle over $S^2 \times S^2$ $\Rightarrow$ Take the D1's wrapped on the U(1) fibre and expanding into a $S^2_{\rm fuzzy} \times S^2_{\rm fuzzy}$

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Substituting in Myers action for D1-branes:

$$S_{DBI} = -\int \mathrm{STr}\Big\{ e^{-\phi} \sqrt{|\det\Big(P[E_{\mu\nu} + E_{\mu i}(Q^{-1} - \delta)^i_j E^{jk} E_{k\nu}]\Big)\det Q|}\Big\}$$

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Agreement with macro descrip. in large m

The F1 in the micro description

$$S_{CS} = \int \mathrm{STr}\Big\{ P\Big(e^{\frac{i}{2\pi}(i_X i_X)} \sum_q C_q\, e^{-B_2} \Big) e^{2\pi F} \Big\}$$

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Similar micro analysis in MN in terms of D1's expanding into a fuzzy S^2

6. Conclusions

- Non-singlet baryons are predicted by gauge/gravity duality in less supersymmetric and/or confining backgrounds

- They are stable against fluctuations

- At finite 't Hooft coupling:

  Microscopical description of the vertex

  Complete this analysis with α' corrections to the NG action of the strings (or microscopic spike), α' corrections to the background

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Thanks!