Hall Droplet Sheets in Holographic QCD

"ICTP Workshop on String Theory, Holography, and Black Holes"

Andrea Olzi

Based on:

F. Bigazzi, A. L. Cotrone, A.O. JHEP **02**, 194 (2023).

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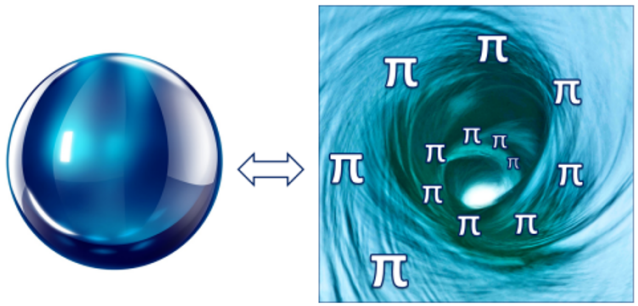
Baryons in Low-Energy QCD

Low-energy QCD $\rightarrow$ Chiral Lagrangian (pionic degrees of freedom)



Baryon $\Leftrightarrow$ Pion-field vortex

Baryon charge $\Rightarrow$ Topological charge of the Skyrmion.

No low-energy description of $N_f = 1$ Baryons

Chiral Lagrangian at Large-N $\Rightarrow$ η' phase of the chiral condensate

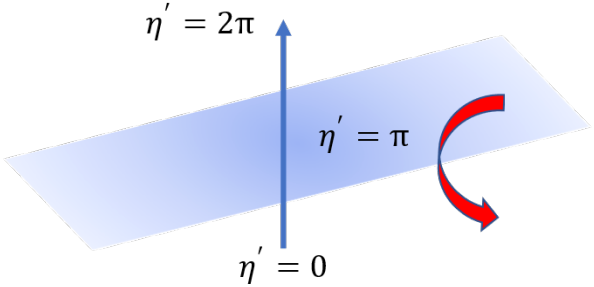
$$\mathcal{L}_{\eta'} = \frac{1}{2}(\partial\eta')^2 - \frac{1}{2}m\Lambda_{QCD}\cos(\eta') - \frac{1}{2}m_{WV}^2 \min_{k\in\mathbb{Z}}(\eta' + 2\pi k)^2.$$

One-flavored baryons require an alternative low-energy description.

Baryons as Quantum Hall droplets

Z. Komargodski, arXiv:1812.09253 [hep-th].

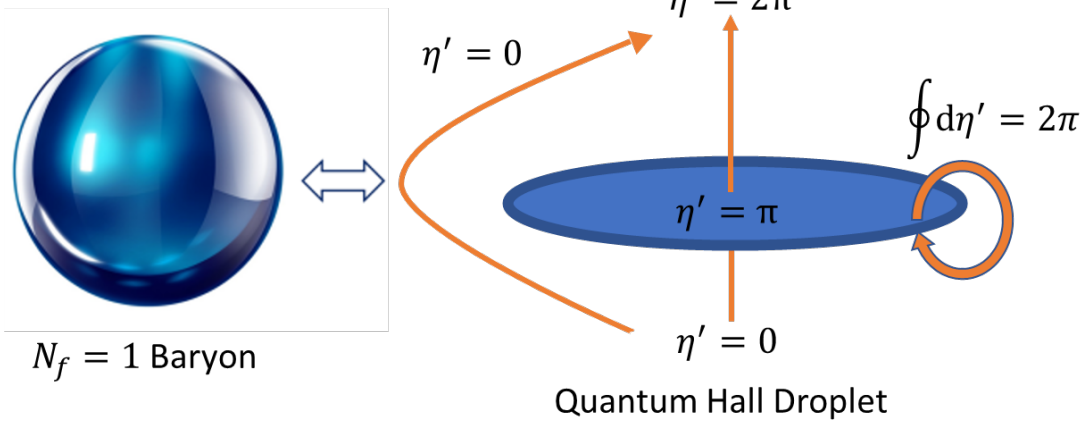
Extended excitations of the η' meson: sheets.



Effective field theory on the sheet

$\eta' = \pi \rightarrow U(1)_N$ Chern-Simons (CS) theory

$$\frac{N}{4\pi}\int a \wedge da \Rightarrow \text{Fractional Quantum Hall effect!}$$



$N_f = 1$ Baryon

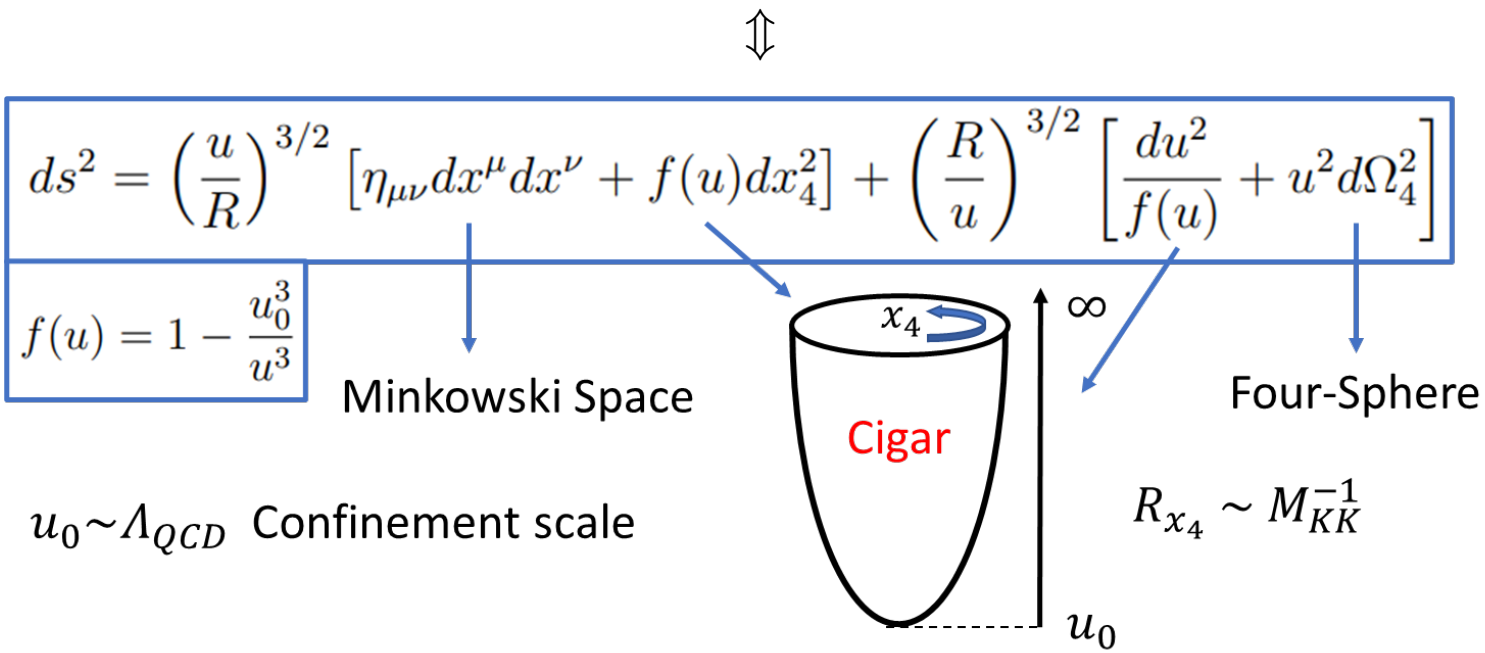
Quantum Hall Droplet

Helpful tool to study gauge theories at strong coupling $\Rightarrow$ Holography

Holographic (Witten-)Yang-Mills theory

Witten, Adv. Theor. Math. Phys. 2, 505 (1998).

4-dim. $SU(N)$ YM $N \gg 1$, $\lambda = g^2_{YM} N \gg 1$ + massive modes

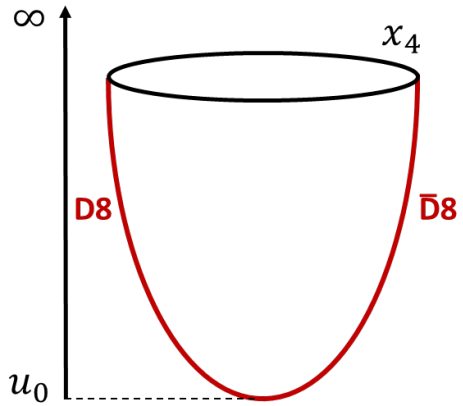


Confinement, Mass Gap.

Flavors

Sakai, Sugimoto, Prog. Theor. Phys. 113, 843 (2005).

- N_f probe D8/$\overline{\text{D8}}$ - branes (wrapped on the background four-sphere).
- $U(N_f) \otimes U(N_f) \to U(N_f)$: spontaneous symmetry breaking of chiral symmetry realized geometrically.
- Mesons arise from fluctuations of the D8-brane gauge field $\mathcal{A}$.



$$N_f = 1 \;\; \to \;\; S \sim \lambda N \int_{M_5} \mathcal{F} \wedge \star d\mathcal{F} + N \int_{M_5} \mathcal{A} \wedge \mathcal{F} \wedge \mathcal{F}.$$

Maxwell-Chern-Simons (MCS) theory in a five-dimensional curved space-time.

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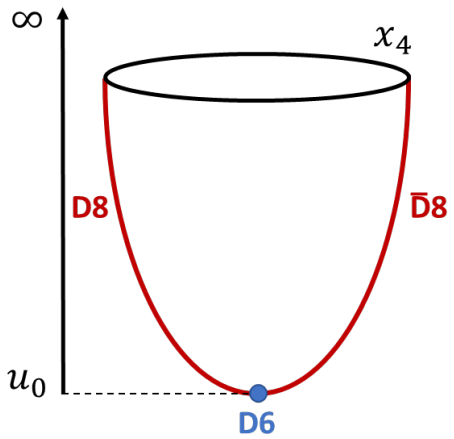
Sheet $\Leftrightarrow$ D6-brane wrapped on S^4



Effective field theory on the Holo-sheet

$U(1)_N$ CS theory D6-brane world-volume.

$$\Rightarrow \quad \frac{N}{4\pi}\int_{M_3} a \wedge da,$$

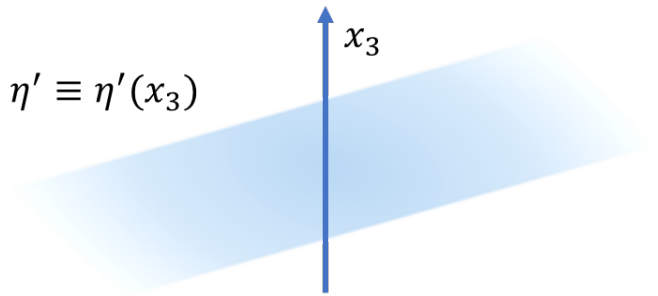
where $M_3 = (t, x_1, x_2)$.

D8-brane gauge field perspective

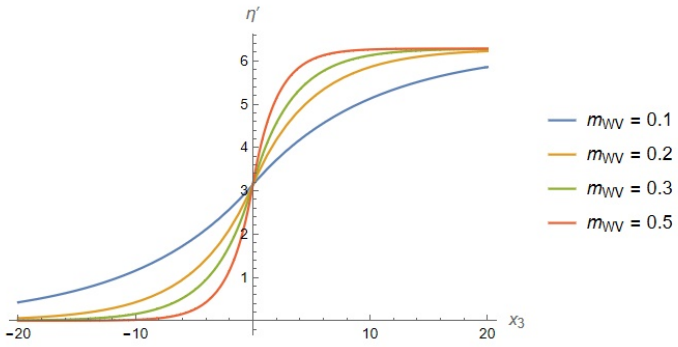
D6-brane is a source for the MCS theory $\Rightarrow$ non-trivial η' profile.

Infinite Sheet Geometry

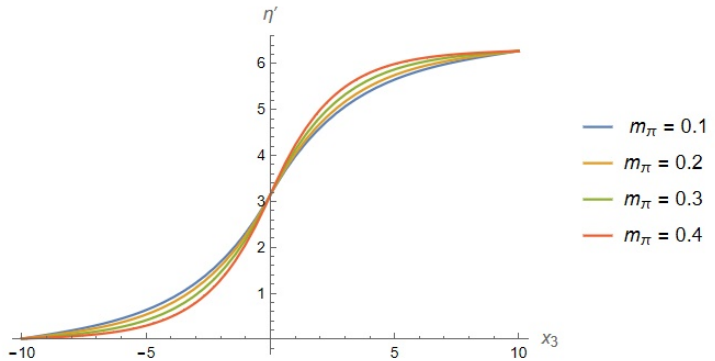
F. Bigazzi, A. L. Cotrone, A.O., JHEP 02, 194 (2023).



$$\partial^2\eta' - m_{WV}^2(\eta' - 2\pi\Theta(x_3))^2 - m_\pi^2 \sin(\eta') = 0$$



Massless quark case.



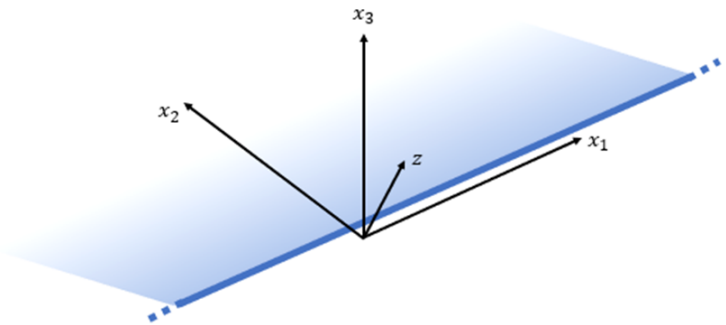
Massive quark case.

$T \sim \lambda^2 N \Lambda_{QCD}^3$ Tension of the sheet.

$\delta \sim (\Lambda_{QCD}\sqrt{\lambda})^{-1}$ Thickness of the sheet.

Semi-Infinite Sheet Geometry

F. Bigazzi, A. L. Cotrone, A.O., JHEP 02, 194 (2023).



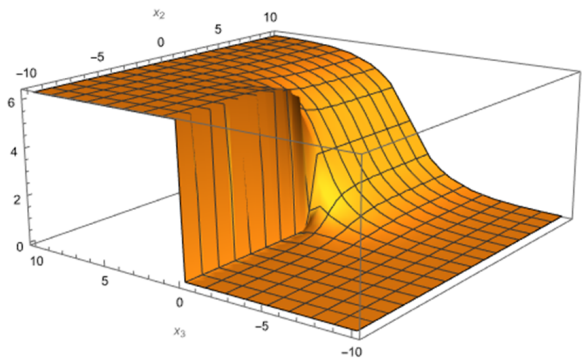
$$d\mathcal{F} = -2\pi\delta(x_2)\delta(x_3)\delta(z)dx_2 \wedge dx_3 \wedge dz.$$

z holographic coordinate.

Action for the transverse fluctuation of the boundary (Y_n mesonic modes)

$$S = -\frac{1}{2}\sum_{n=0}^{\infty}\int d^4x \left[(\partial_r Y_n)^2 + \lambda_n {Y_n}^2\right]$$

η' profile



Chiral component of the gauge field on the boundary ⇒ chiral edge mode.

Thank you for your time!