Confining Models in Holography

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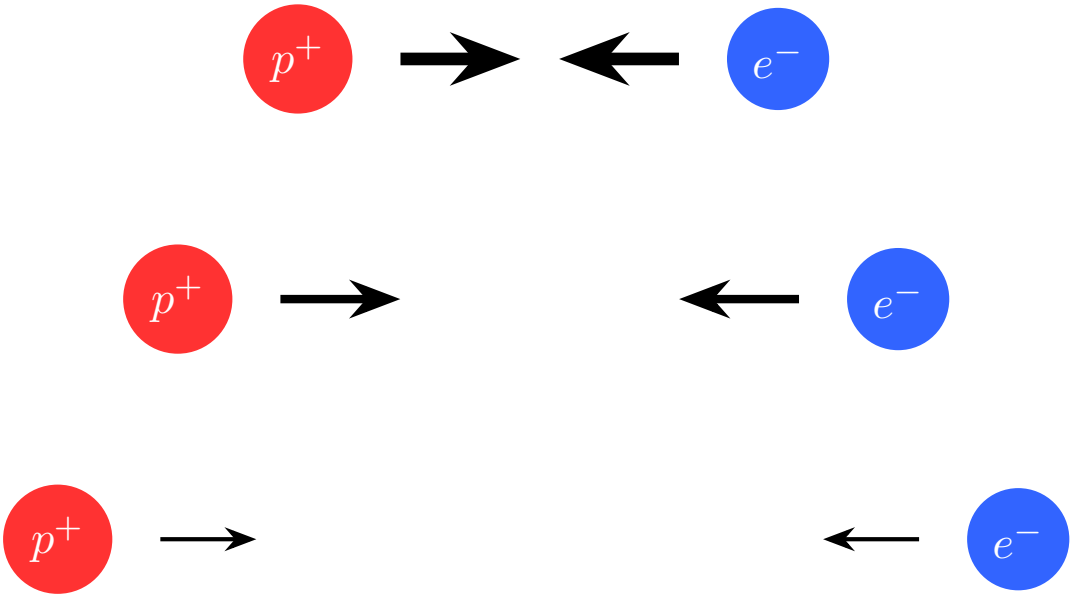
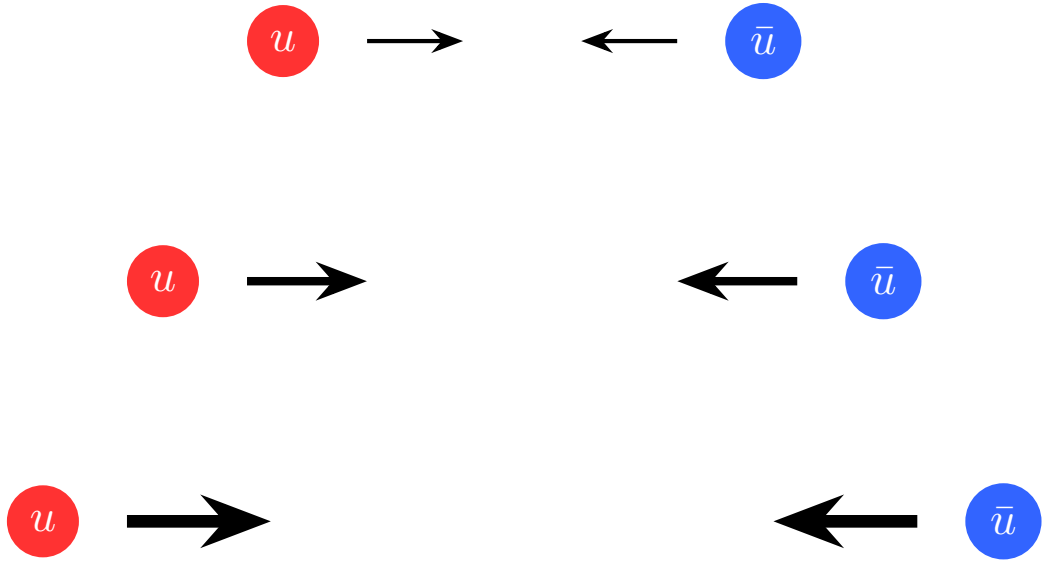
What is Confinement?

- In electromagnetism, the potential energy between a proton and an electron decreases as you separate them. So that it requires a finite amount of energy to move them away from each other.



What is Confinement?

- Quarks, the particles that make up the proton and neutron, do not behave in this way. They interact through the strong force (QCD), and the potential energy grows as you separate them, so that it requires a lot of energy to decouple two of them.



- This is a manifestation of confinement.

What is Confinement?

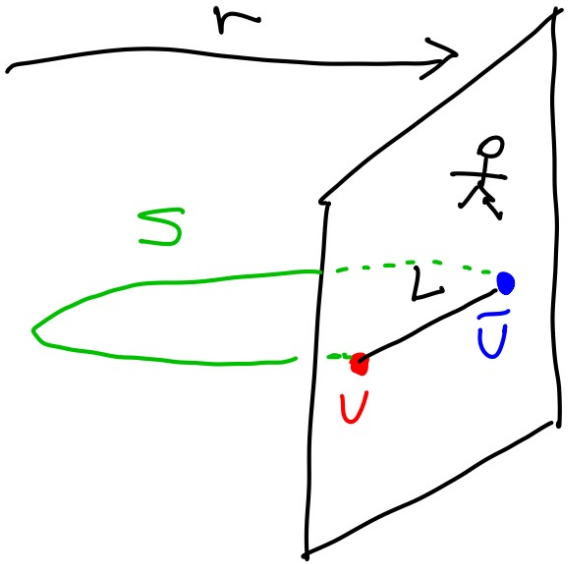
- We focus on 4D theories similar to QCD, that is, theories that have gluons (Yang-Mills theory), quarks (Weyl fermions) and scalars.
- The interaction between different fields, mediated by the gluons, is typically strong at low energies, making it hard to apply standard field theory techniques (perturbation theory, Feynman diagrams).
- A new framework needs to be developed to address this problem.

Holography

- Holographic Dualities in String Theory, known as Gauge/Gravity duality, provide a framework to study the strong couling regime of QFTs.
- The fields forming a String Theory configuration geometrically encode information about the QFT, for example: number of gluons (gauge group rank), number of fermions and scalars (global symmetries), anomalies and non-perturbative phenomena

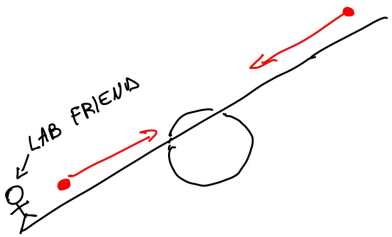
Strongly Coupled QFT in 4D $\Leftrightarrow$ Theory of gravity in more dimensions

Holography

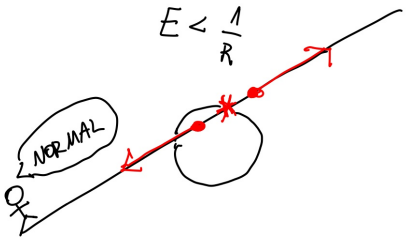


QFTs on a Circle

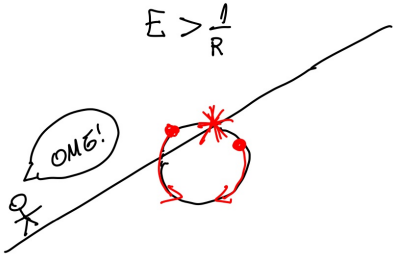
- 4D QCD-like theories: gluons, quarks, scalar particles all massless.
- As a toy model, we consider one of the space directions to be a circle.



Before Collision



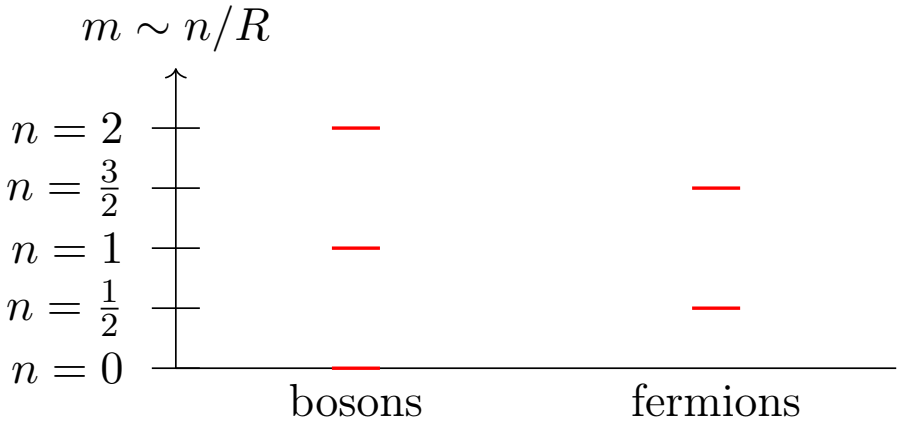
Option 1



Option 2

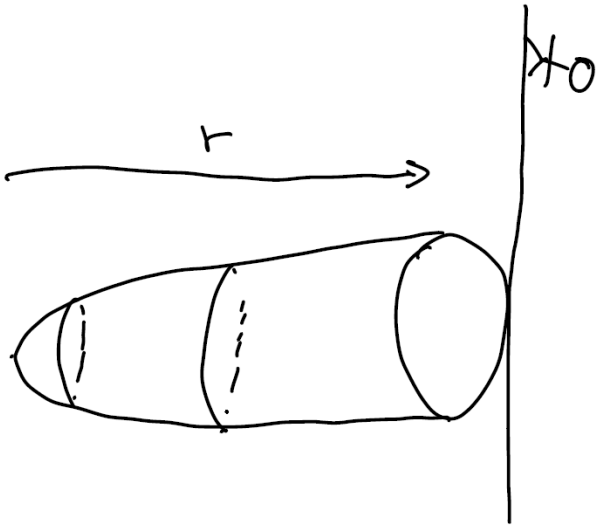
QFTs on a Circle

- Importantly, we need to specify what happens to particles when they go around this circle. Typical conditions are that gluons and scalars go back to themselves, but fermions pick-up a minus sign.
- This has important consequences for a 3D observer



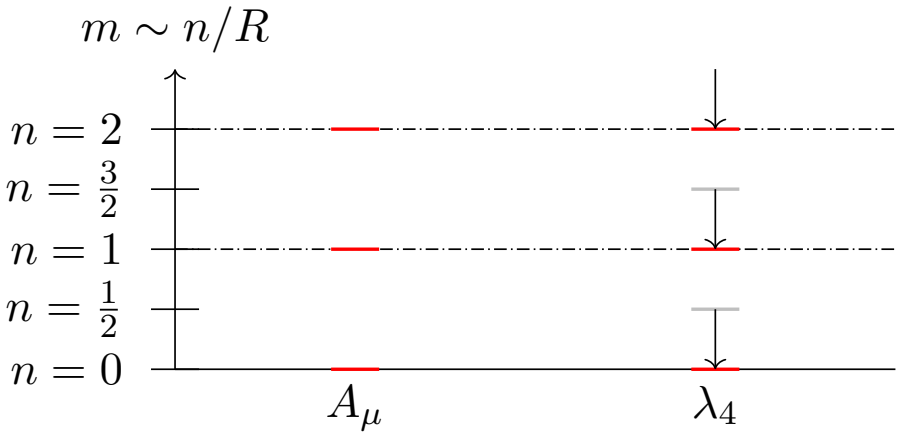
Holographic Description

- Cycle going to zero size represents going to scales below the size of the cycle



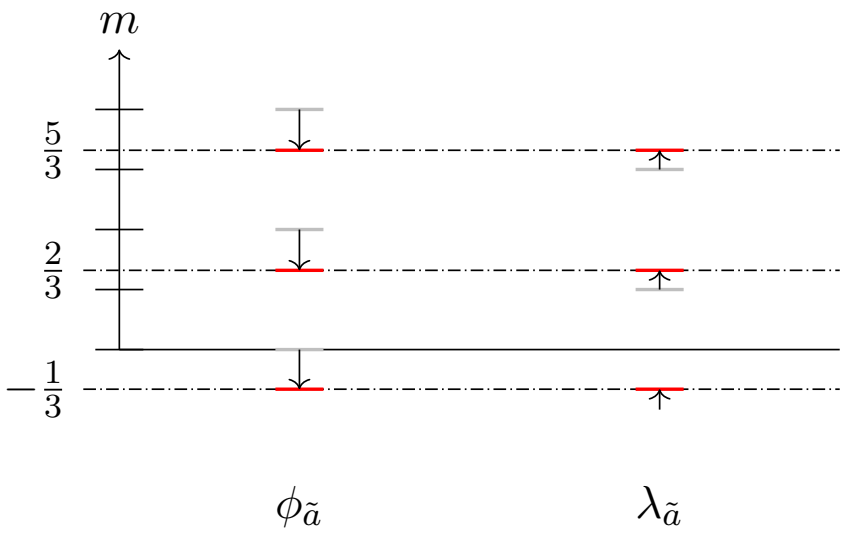
The QFTs of Interest

- Theory of gluons, fermions and scalars (all massless) on $\mathbb{R}^{2,1} \times \mathrm{S}^1$
- There is a global U(1) symmetry that rotates a pair of scalars and shifts the fermions by a phase (R-symmetry).
- It is possible to recover a massless fermions by adding a constant magnetic potential along the circle (background gauge field of the U(1) R-symmetry $\mathcal{A} = Q\, d\phi$).



The QFTs of Interest

- This also realigns the massess of the leftover fermion and scalar modes



- This can be done only if the U(1) R-symmetry is non-anomalous.
- For a 3D observer, a Chern-Simons level $k = N_c$ is generated. (This is independent of matter content)

Holographic Description

- Holographically, there has to be a cigar-like geometry realising the circle compactification.
- Furthermore, there is a mix between the circle which shrinks, and the circle that realises the U(1) global symmetry.
- There are several examples of Gravity-QFT holographic pairs that share this features: $AdS_5 \times S^5$ and 4D $\mathcal{N} = 4$ SYM, Klebanov-Witten theory, 4D $\mathcal{N} = 2$ quiver gauge theories and Gaiotto-Maldacena geometries.
- Conformal symmetry is not necessary.

4D SQCD-like theories

- We consider a particular QCD-like theory with gluons, and adjoint fermion, and N_f fermions and scalars in the fundamental representation.
- There is a non-anomalous U(1) global symmetry (R-symmetry) only when $N_f = 2N_c$.
- We further compactify the theory on as discussed before.

4D SQCD-like theories

- The cigar-like geometry exists only if $N_f = 2N_c$!. The geometric configurations "knows" about the non-anomalous condition.
- Chern-Simons level can be "measured" only at the end of the space $\sim$ end of the compactification (tip of the cigar)
- We computed a bunch of observables: Wilson Loops and central charges, signalling confinement.

Outlook

- Reductions from 5D$\rightarrow$ 4D more phenomenologically appealing scenarios.
- Extend the non-anomalous argument to other dimensions: from 6D$\rightarrow$5D , from even to odd.
- Twist with another global symmetry?

Thank You