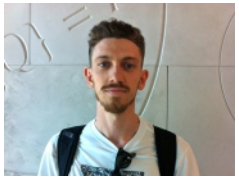
QFT/Strings panel discussion



Marco Fazzi
Milano Bicocca

FLDSTRDUAL: Field theory dualities from string dualities

Federico Galli
Firenze

HCFT: Holographic conformal field theories

Carlo Meneghelli
Parma

SSFTBM: Solving super-conformal field theories by bootstrap methods

Dave Sutherland
Trieste

EFTforBSM: Guiding the search for new fundamental physics with field theory techniques

Itamar Yaakov
Milano Bicocca

DONAGT: Constucting novel defect operators in non-abelian gauge theory

1) Introductions
2) Main discussion (10 mins per fellow)
3) General discussion

Please ask questions at any time by either raising a hand, or writing in the chat.

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FLDSTRDUAL

use dualities

(same physics, two different descriptions,
one is calculable, other isn't)

to prove / derive new dualities

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very powerful: explore otherwise-inaccessible physical observables

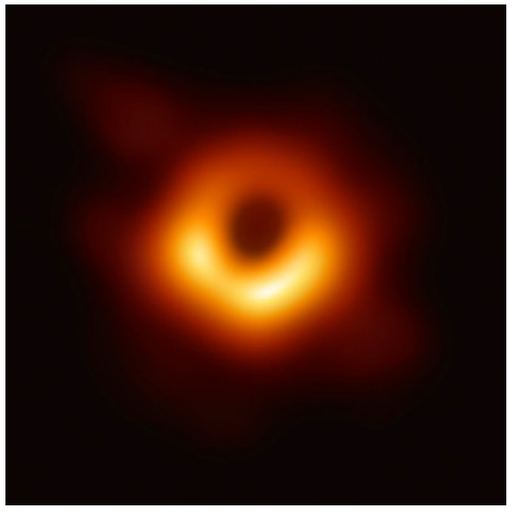
Target:

Weapon:

very powerful: explore otherwise-inaccessible physical observables

Target:

black hole microstates



Weapon:

field theory (CFT)
‘generating function’

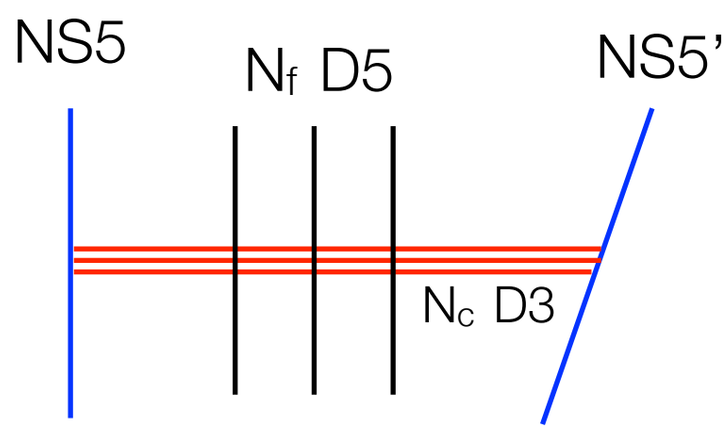
$$\oint \prod_i \frac{dz_i}{2\pi i z_i} \, e^{N_c^2 S_{\rm eff}}$$

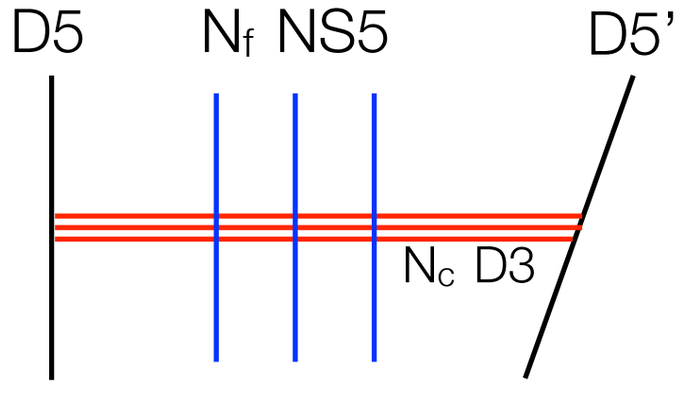
matter & gauge in 3d
(minimal to no susy)

string theory

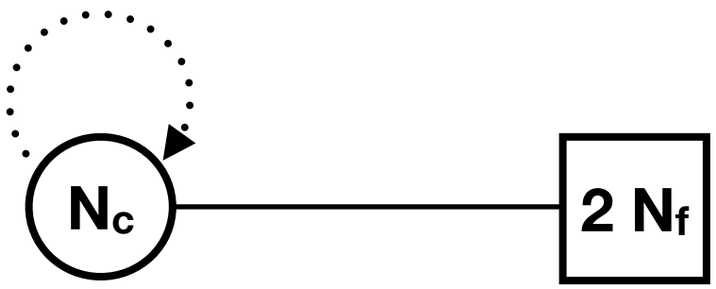
matter & gauge in 3d
(minimal to no susy)

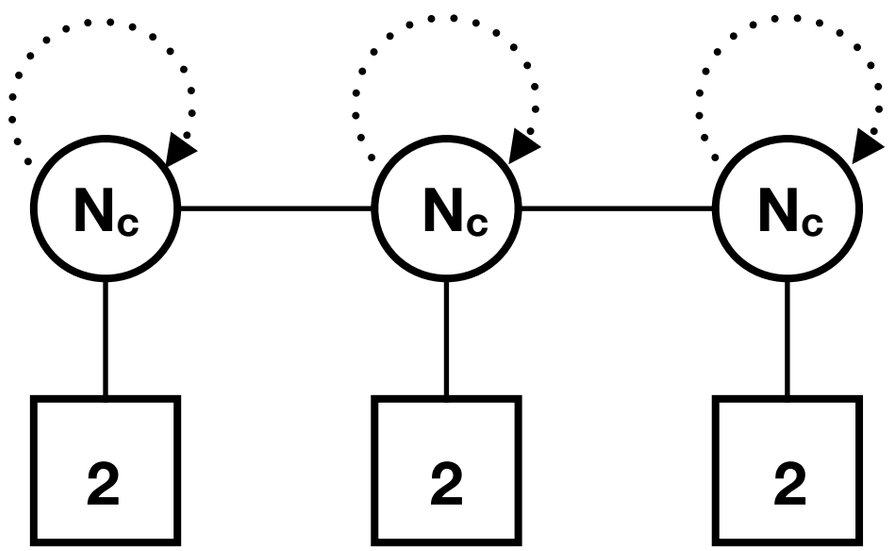
string theory



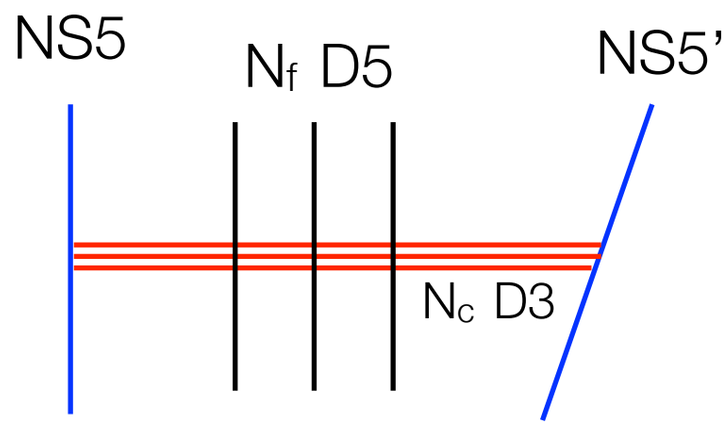


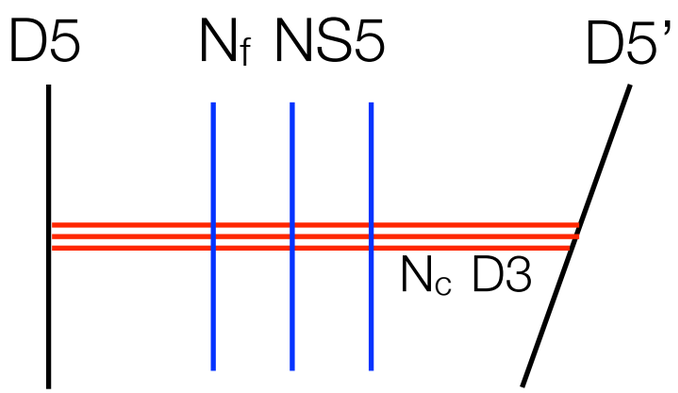
matter & gauge in 3d
(minimal to no susy)





string theory

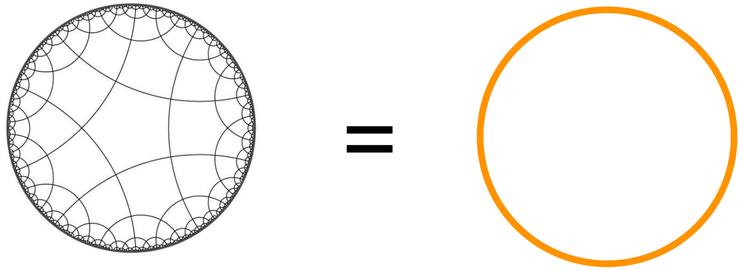




HCFT - Holographic Conformal Field Theories

Holographic principle: gravity and spacetime as emergent phenomena resulting from the collective behavior of a large number of non-gravitational degrees of freedom

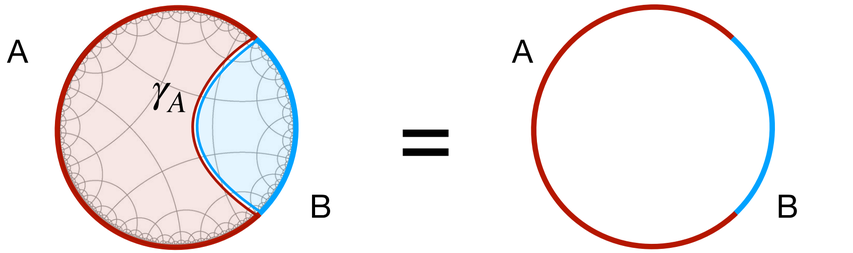
AdS/CFT:



Gravity in AdS_{d+1} = CFT_d

How gravity is encoded in the underlying holographic CFT degrees of freedom?

Quantum Information: provides a useful language and organizing principle



$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle_A|0\rangle_B + |1\rangle_A|1\rangle_B\right)$$

Entanglement Entropy

$$S(A) = -\mathrm{Tr}\rho_A \log \rho_A$$

$\Longleftrightarrow$

Holographic Entanglement Entropy

$$S(A) = \frac{\mathrm{Min}(\mathrm{Area}_{\gamma_A})}{4G_N}$$

First Law of Entanglement Entropy

$$\delta S(A) = \delta\langle H(A)\rangle$$

$\Longleftrightarrow$

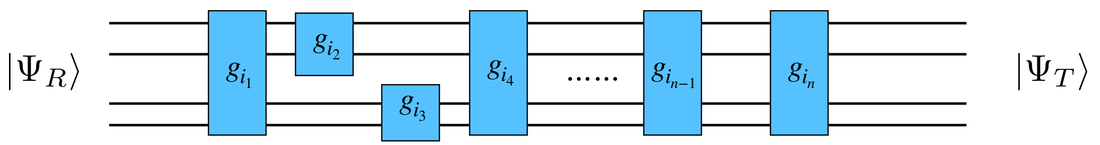
Einstein's Equations

$$G_{\mu\nu} + g_{\mu\nu}\Lambda = 8\pi G_N T_{\mu\nu}$$

Spacetime geometry ~ entanglement structure

HCFT

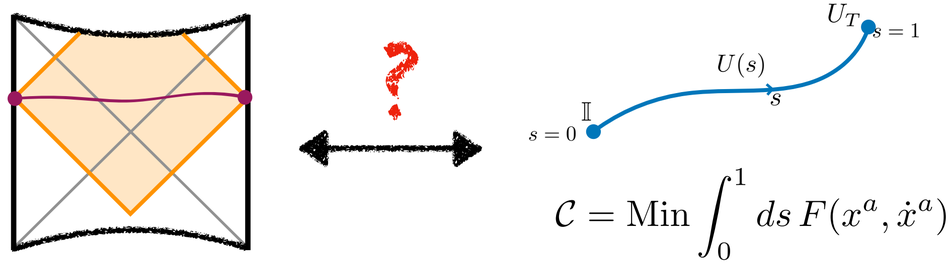
Quantum circuit complexity: cost of the optimal circuit connecting a target and reference state through the action of unitaries



$$|\Psi_T\rangle = U_T|\Psi_R\rangle = g_{i_n}\dots g_{i_1}|\Psi_R\rangle$$

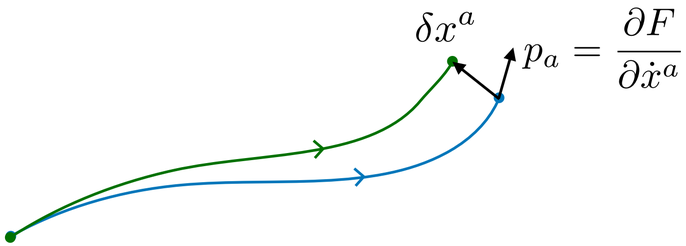
Different holographic proposals and field theory attempts, but quite disconnected.

Can we build a connection between the field theory and holographic directions?



$$\mathcal{C} = \text{Min}\int_0^1 ds\, F(x^a, \dot{x}^a)$$

First law of complexity: how complexity varies under a small change of the target state



$$\delta C = p_a \delta x^a\Big|_{s=1} + \frac{1}{2}\delta p_a \delta x^a\Big|_{s=1}$$

Vacuum perturbation by coherent scalar states

- Coherent states orthogonal to vacuum AdS circuit direction
- Restrictions on field theory proposals compatible with holography
- Guiding principle to shed light on the implicit choices in the holographic complexity measure

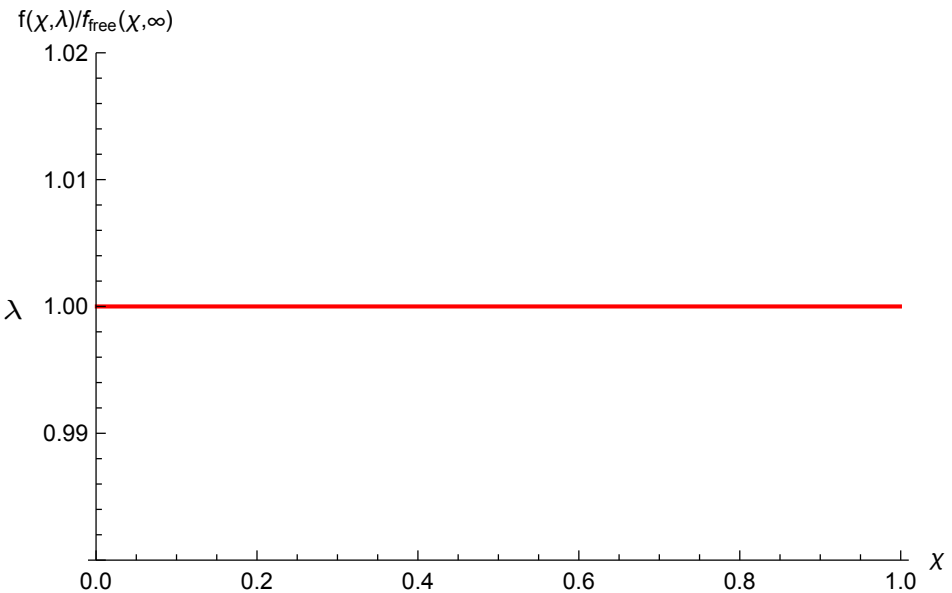
[Bernamonti, FG, Hernandez, Myers, Ruan, Simón PRL'19 & JPA'20]

Solving superconformal field theories by bootstrap methods

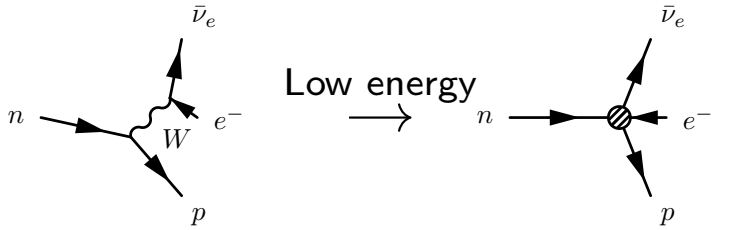
A. Conformal Perturbation Theory and S-duality in $\mathcal{N}$=4 SYM

B. Vertex Algebras and $\mathcal{N} = 2$ Superconformal Field Theories in 4d

- The simplest 1d SCFT:
  $W_{\mathcal{C}} \sim$ Tr Pexp $\int_{\mathcal{C}}(A + \phi)$
  in $\mathcal{N} = 4$ SYM
- Perturbative analytic bootstrap methods ($\lambda \sim \infty$):
  $f(\chi, \lambda) = \langle \phi(0)\phi(\chi)\phi(1)\phi(\infty)\rangle_\lambda$
- What's next?



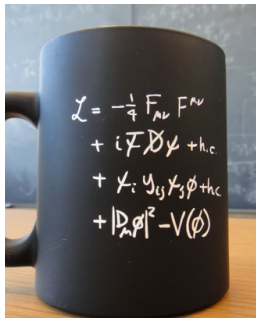
EFTs encode generic local scattering



$$\sim (\bar{p}\gamma^\mu n)(\bar{e}_L\gamma_\mu\nu_L)$$

proxy for heavy physics, e.g. Fermi theory

Simple Lagrangians belie complex calculations



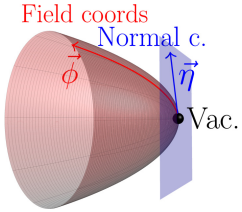
$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}_p^s e_r)(\bar{d}_s q_t^p)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^s u_r)\varepsilon_{jk}(\bar{q}_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^s T^A u_r)\varepsilon_{jk}(\bar{q}_s^k T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jm}\varepsilon_{kn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^s e_r)\varepsilon_{jk}(\bar{q}_s^k u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^s\sigma_{\mu\nu}e_r)\varepsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu}u_t)$		

SM + SMEFT

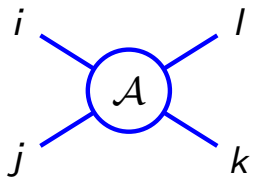
previous [2001.00017] and current work

Mapping from lagrangians to amplitudes efficiently



$$\mathcal{L}^{(\phi)} = V(\vec{\phi}) + g_{ij}(\vec{\phi})\partial\phi^i\partial\phi^j + \ldots$$

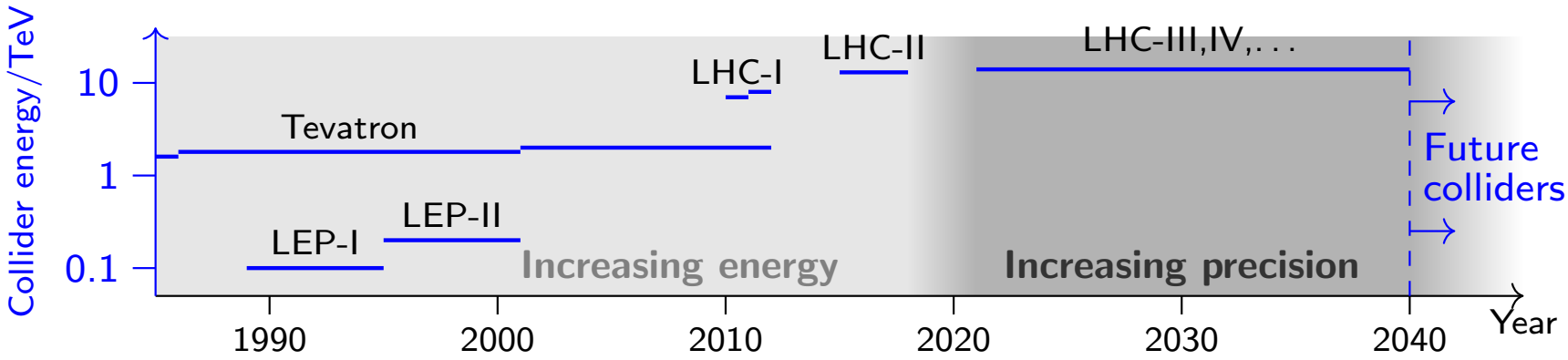
$$\mathcal{A}^{(\eta)}_{ijkl} = V_{;(ijkl)} + \tfrac{2}{3}sR_{i(kl)j} + \tfrac{2}{3}tR_{i(jl)k} + \tfrac{2}{3}uR_{i(jk)l} + \ldots$$



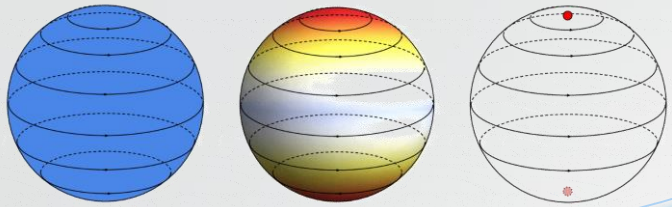
previous [2008.08597] and current work

future work

SMEFT can help organise a systematic search for BSM physics



Using localization



study twisted indices

w/ Hosseini and Zaffaroni,
w/ Griguolo and Lundberg

define defects in $\mathcal{N}=4$ SYM

in progress

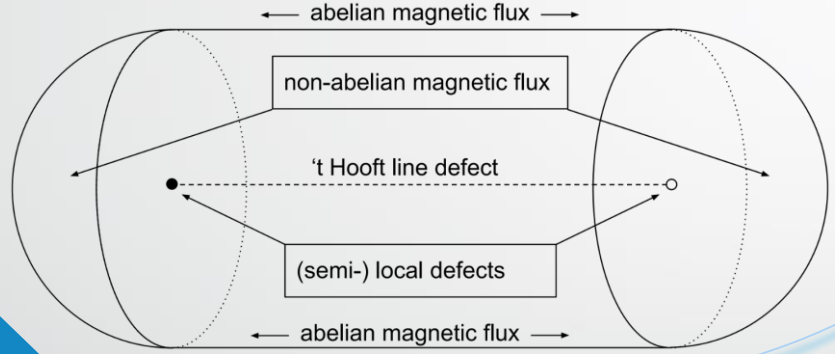
proof of concept: EM duality in $\mathcal{N}=4$ SYM

in progress

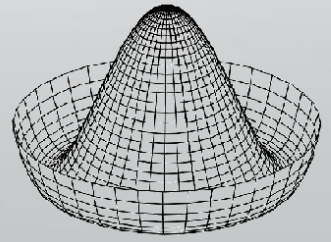
proof of concept: ABJM vs $\mathcal{N}=8$

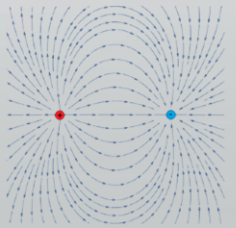
explore non-supersymmetric Yang-Mills theory and QCD

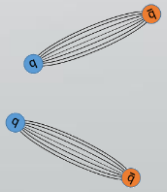
and defect operators



to study phases of gauge theories







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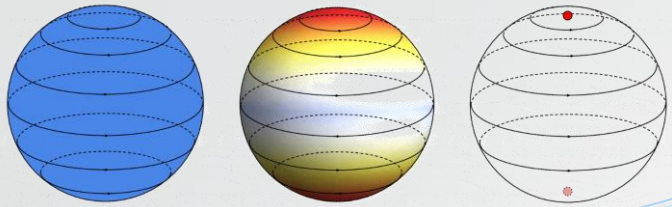
Using localization



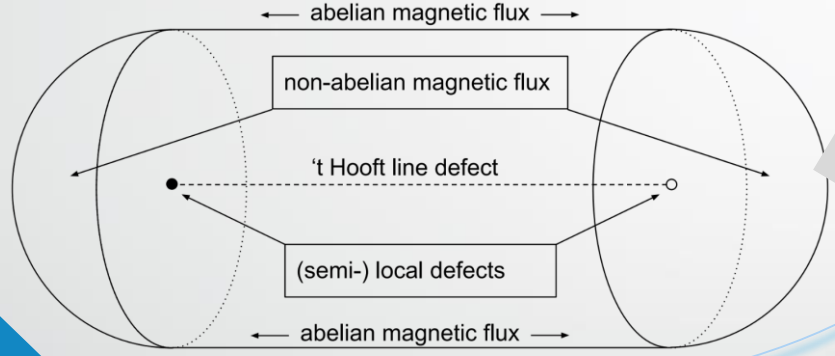
Study twisted indices

w/ Hosseini and Zaffaroni,
w/ Griguolo and Lundberg

$$\mathcal{I} = \#\langle \text{bosonic states} \rangle - \#\langle \text{fermionic states} \rangle$$

and defect operators

$$\langle \mathcal{O}_{\text{BPS}} \rangle \overset{\text{deform}}{=} \lim_{t\to\infty} \left\langle \mathcal{O}_{\text{BPS}} e^{-t\delta \int V_{\text{loc.}}} \right\rangle \overset{\text{localize}}{=} \oint_{\text{moduli}} \left(\begin{matrix} \text{one} \\ \text{loop} \end{matrix} \right) \underbrace{\mathcal{O}_{\text{BPS}} e^{-S}}_{\text{classical}}$$

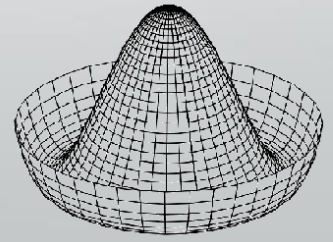


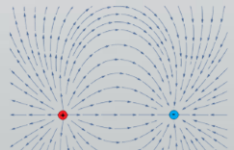
states live here

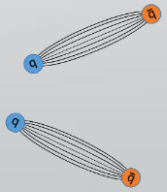
connection to black holes

$$S_{\text{BH}} = \frac{A}{4G} \overset{?}{=} \log d_{\text{micro}}$$

to study phases of gauge theories







$$\lim_{g\to\infty} \lim_{N\to\infty} \mathcal{I} = S_{\text{BH}}!$$

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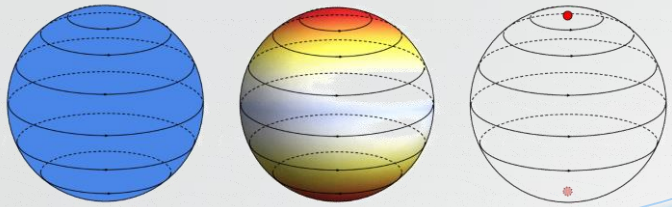
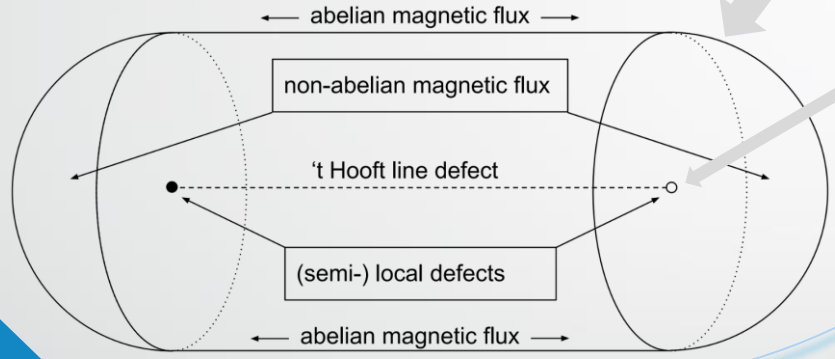
Using localization



and defect operators



Define defects in $\mathcal{N}=4$ SYM

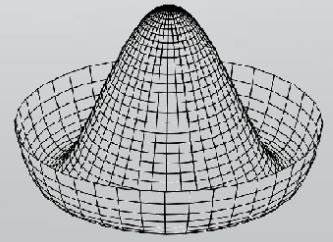
Supergravity background

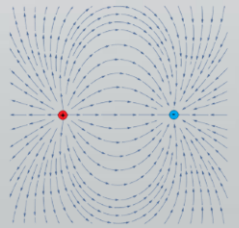
$$\frac{1}{8\pi^2}\mathrm{tr}F\wedge F=\frac{1}{2}\delta^{(4)}\left(\vec{x}\right)$$

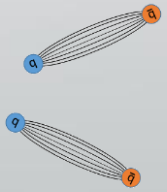
supersymmetrized version!

- ✓ scalars
- ✓ stable
- ✓ BPS

to study phases of gauge theories







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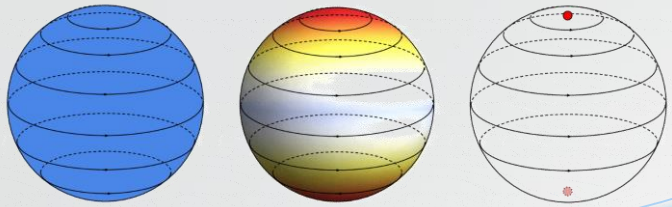
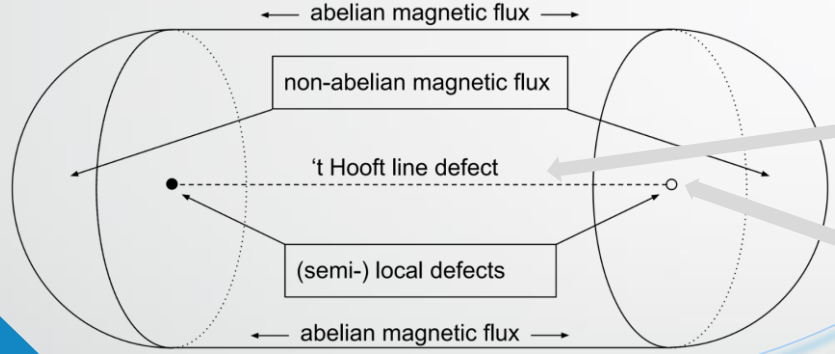
Using localization



EM duality in $\mathcal{N}=4$ SYM

$$g_{\mathrm{YM}} \quad \longleftrightarrow \quad \frac{1}{g_{\mathrm{YM}}}$$

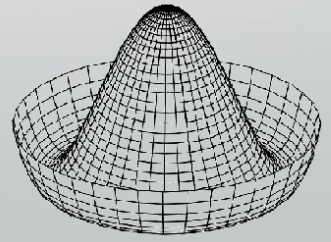
and defect operators

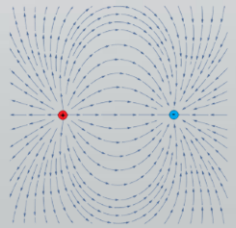


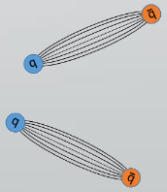
't Hooft loop ⟷ Wilson loop

local defect ⟷ squark?

to study phases of gauge theories







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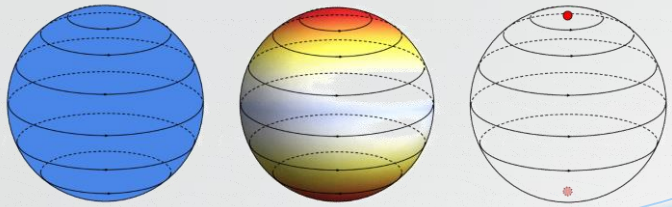
Using localization



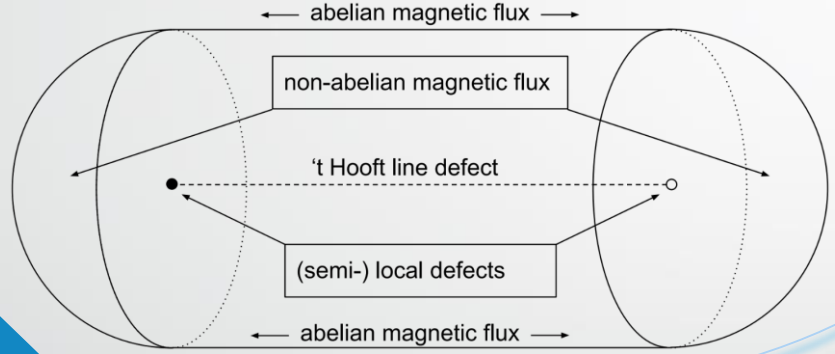
study twisted indices

w/ Hosseini and Zaffaroni,
w/ Griguolo and Lundberg

define defects in $\mathcal{N}=4$ SYM

in progress

and defect operators



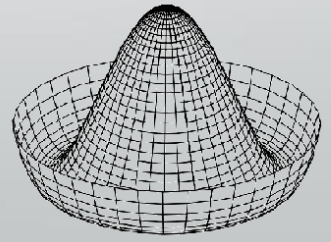
proof of concept: EM duality in $\mathcal{N}=4$ SYM

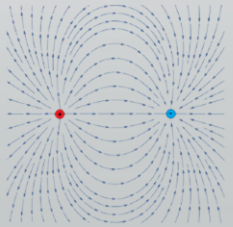
in progress

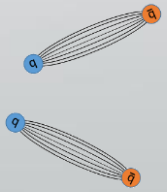
proof of concept: ABJM vs $\mathcal{N}=8$

explore non-supersymmetric Yang-Mills theory and QCD

to study phases of gauge theories







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Many unexplored examples of the following gravity/gauge duality:

AdS/CFT

Black holes:

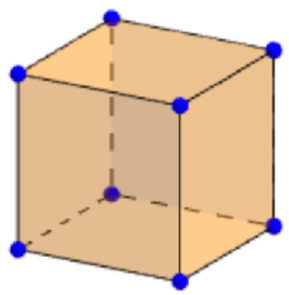
more charges,
momenta etc.

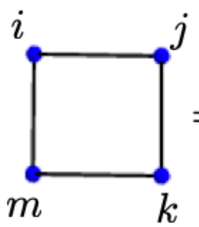
CFTs:

4d N=4 SYM
4d N=1 quivers
4d N=1 non-toric quivers

exploit algebraic topology/ML to extract quantitative statistical predictors for exotic phases of matter such as 3d fractons

Classical Spin System

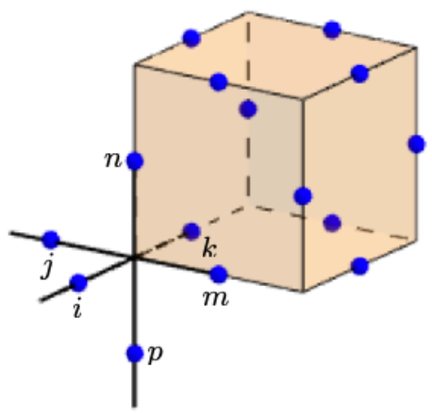




$$= \tau_i^z \tau_j^z \tau_k^z \tau_m^z$$

Plaquette Ising Model

Fracton Topological Phase



$$A_c = \prod_{n \in \partial c} \sigma_n^x$$

$$B_s^{(xz)} = \sigma_i^z \sigma_p^z \sigma_n^z \sigma_k^z$$

$$B_s^{(xy)} = \sigma_i^z \sigma_j^z \sigma_k^z \sigma_m^z$$

$$B_s^{(yz)} = \sigma_j^z \sigma_n^z \sigma_m^z \sigma_p^z$$

X-Cube Model

extract critical exponents and existence of phase transitions

derive dualities to ‘ordinary’ (tensor) gauge theories (continuum models)