Higgs phenomenon and N=3 higher spin holography

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Based on collaborations with

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Motivation (I)

- Higher spin gauge theory

$$\varphi_{\mu_1 \ldots \mu_s} \sim \varphi_{\mu_1 \ldots \mu_s} + \partial_{(\mu_1} \xi_{\mu_2 \ldots \mu_s)}$$

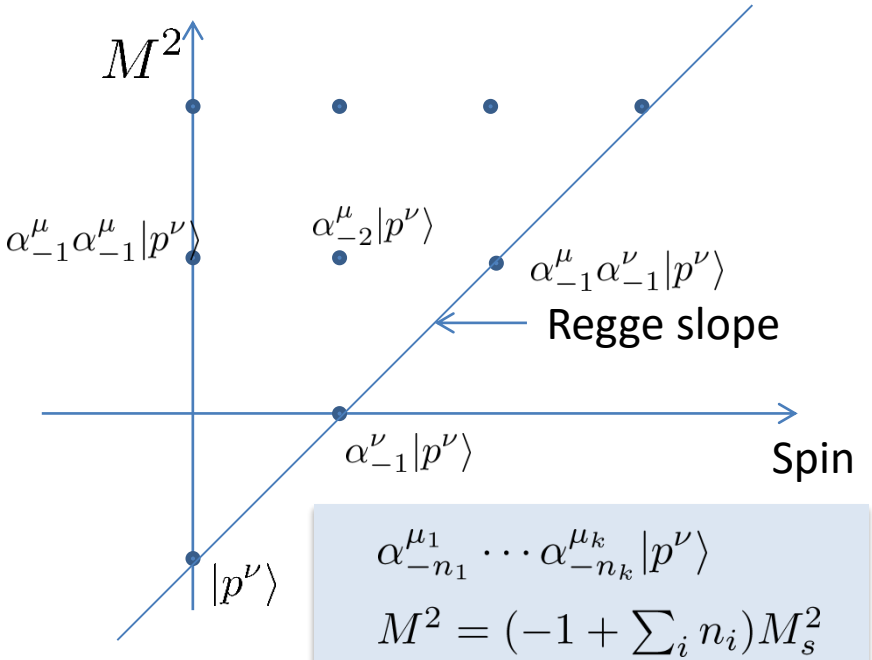
  - Natural extension of electromagnetism (s=1) and gravity (s=2)
  - A toy model for the tensionless limit of superstring theory
  - Vasiliev theory is famous as a non-trivial theory on AdS
- Application 1: AdS/CFT
  - More tractable AdS/CFT correspondence can be constructed than using superstring theory
  - Examples
    - 4d Vasiliev theory ⇔ 3d O(N) vector model [Klebanov-Polyakov '02]
    - 3d Vasiliev theory ⇔ 2d large N minimal model [Gaberdiel-Gopakumar '10]

Motivation (II)

- Application 2: Black hole
  - Chern-Simons description is possible for 3d higher spin gauge theory (c.f. for 3d pure gravity [Achucarro-Townsend ’86, Witten ’88])
  - 3d black holes with higher spin charges are constructed. Notions like horizon and singularity are NOT gauge invariant [Gutperle-Kraus ’11].
  - Holographic entanglement entropy from Wilson loop [de Boer-Jotter, Ammon-Castro-Iqbal ’13]
- Application 3: Superstring theory
  - Higher spin gauge theory is NOT just a toy model but can be an alternative description of superstring theory

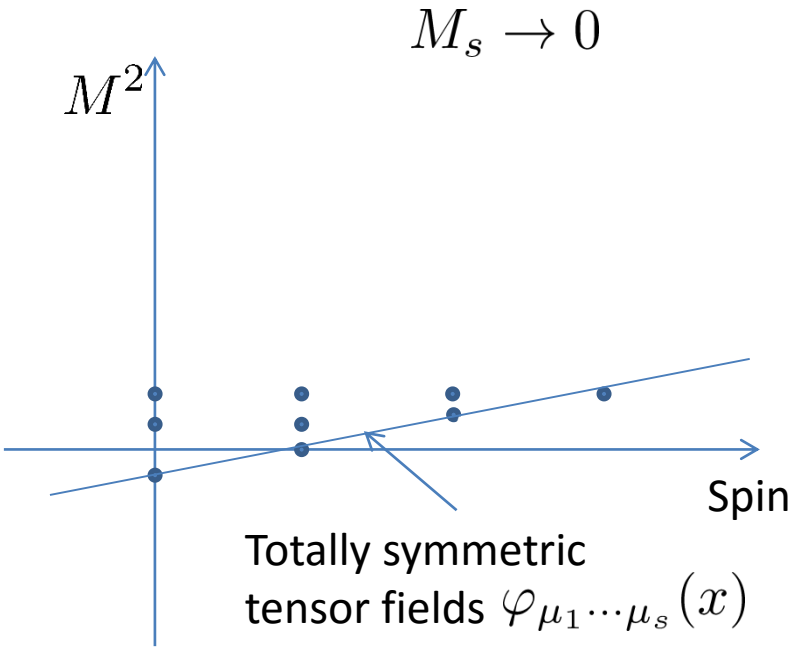
Strings from higher spin fields

- String spectrum



$$\alpha^{\mu_1}_{-n_1}\cdots\alpha^{\mu_k}_{-n_k}|p^\nu\rangle$$
$$M^2=(-1+\textstyle\sum_i n_i)M_s^2$$

- Tensionless limit



Superstring theory may be given by a broken phase of higher spin gauge theory [Gross '88]

Towards the Gross's speculation

- Backgrounds
  - No-go theorems [e.g., Weinberg '64] forbid non-trivial interactions consistent with higher spin gauge symmetry (with some assumptions)
  - Recent developments are made by working on AdS space
    - Vasiliev theory as a non-trivial higher spin gauge theory on AdS space
    - AdS/CFT correspondence utilizing the Vasiliev theory
- Concrete proposals
  - Relations between superstrings and higher spin fields via AdS/CFT
    - 4d/3d duality ➔ ABJ triality [Chang-Minwalla-Sharma-Yin '12]
    - 3d/2d duality ➔ AdS_3 versions [Gaberdiel-Gopakumar, CHR '13-'15], Higgsing [HR, CH '15, Gaberdiel-Peng-Zadeh '15]

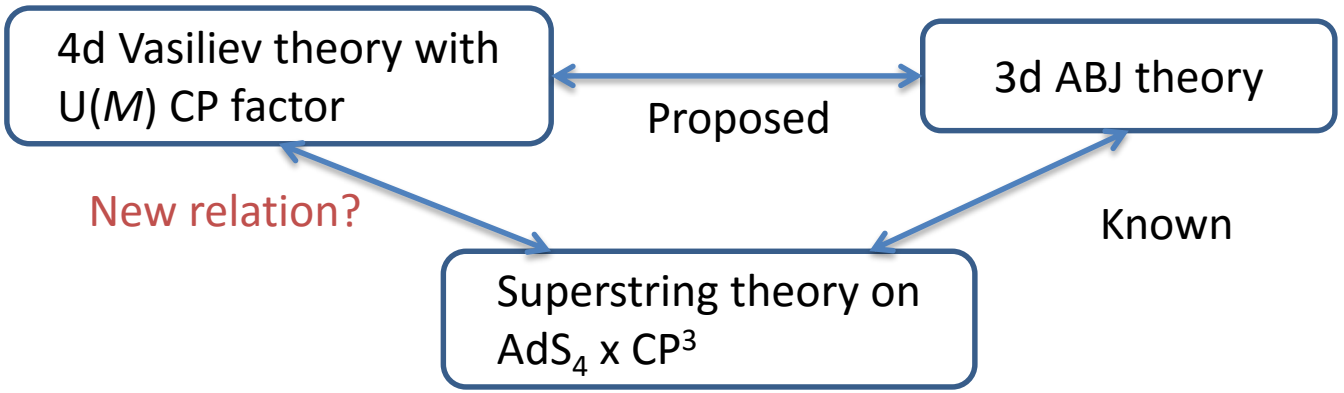
Plan of the talk

- Introduction
- Higher spin fields and strings
- Higgs phenomenon
- Conclusion

HIGHER SPIN FIELDS AND STRINGS

ABJ triality

- Klebanov-Polyakov proposal ’02
  - 4d Vasiliev theory ⇔ 3d O(*N*) vector model
- ABJ triality [Chang-Minwalla-Sharma-Yin ’12]
  - HS side: 4d Vasiliev theory with U(*M*) Chan-Paton factor
  - CFT side: 3d Aharony-Bergman-Jafferis(-Maldacena) theory
  - String side: Superstring theory on $AdS_4 \times CP^3$



Adding CP factor

- 3d ABJ theory
  - Bi-fundamentals under U(*N*) x U(*M*) gauge symmetry

$$A_i^\alpha, B_\beta^j \ (i,j=1,2,\ldots,N,\ \alpha,\beta=1,2,\ldots,M)$$

- Higher spin region: *M* << *N*
  - 't Hooft parameter is stronger for U(*N*) than U(*M*)

U(*N*) invariant currents Higher spin fields

$$[J_{\mu_1\ldots\mu_s}]^\alpha_\beta = A_i^\alpha \partial_{(\mu_1}\cdots\partial_{\mu_s)} B_\beta^i \quad \Longleftrightarrow \quad [\varphi_{\mu_1\ldots\mu_s}]^\alpha_\beta$$

- String region: *M* ≈ *N* >> 1
  - $\mathrm{tr}[ABAB\cdots AB]$ ⇔ strings
  - Single-string state ⇔ Multi-particle state of higher spin fields

Lower dimensional triality

- Gaberdiel-Gopakumar proposal ’10
  - 3d Vasiliev theory ⇔ 2d large N minimal model
- Extension [CHR ’13] (c.f. [Gaberdiel-Gopakumar ’13] for M=2)
  - HS side: 3d Vasiliev theory with U(M) CP factor
  - CFT side: 2d coset-type model
- Related superstring theory
  - N=4 holography [Gaberdiel-Gopakumar ’13-’15]
    - N=4 SUSY ➔ Superstrings on $AdS_3 \times M^7$ ($M^7 = S^3 \times S^3 \times S^1$ or $S^3 \times T^4$)
    - U(2) CP factor ➔ String bit picture is obscure
  - Holography with U(M) CP factor [CHR ’14, HR ’15]
    - N=3 SUSY ➔ M^7 = SO(5)/SO(3) (or SU(3)/U(1))??
    - BPS spectrum is shown to agree

HIGGS PHENOMENON

Marginal deformation & Higgsing

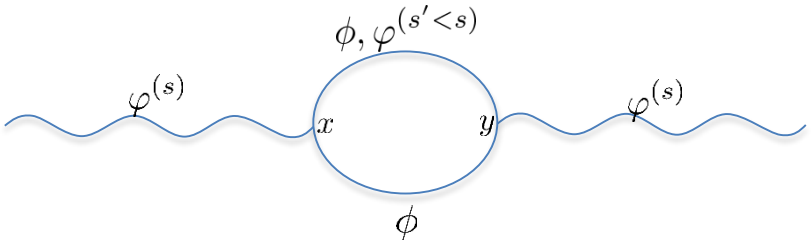
[HR ’15]

- Introduction of finite string tension

Superstring theory	CFT	Higher spin gauge theory
Tensionless limit	2d N=3 coset model	3d N=3 Vasiliev theory
With finite string tension	Double-trace type deformations	Change of boundary conditions for bulk fields

[Witten ’01]

- Higgs mass of spin s fields from one loop effects



  - Non-standard boundary conditions for ϕ induces non-trivial mass term
    - For a massive graviton [Porrati ’01, Duff-Liu-Sati ’02, Kiritsis ’06, Aharony-Clark-Karch ’06]
    - For higher spin fields on AdS_4 [Girardello-Porrati-Zaffaroni ’02]

CFT methods

- Higgs phenomenon from CFT
  - Conserved current ⇔ Higher spin fields are massless

$$\partial \cdot J^{(s)} = 0$$

  - Non-conserved current ⇔ Higher spin fields are massive

$$\partial \cdot J^{(s)} = \alpha \mathcal{O}^{(s-1)}$$

- Higgs mass from the scaling dimension
  - The scaling dimension can be computed by

$$|\partial \cdot J^{(s)}|^2 \propto (\Delta - s - d + 2)\langle J^{(s)}|J^{(s)}\rangle$$
$$= |\alpha \mathcal{O}^{(s-1)}|^2 = \alpha^2 \langle \mathcal{O}^{(s-1)}|\mathcal{O}^{(s-1)}\rangle$$

  - The AdS/CFT dictionary

$$M^2_{(s)} = \Delta(\Delta - d) - (d + s - 2)(s - 2)$$

Our results

- The masses of spin s fields
  - Leading in $1/N$ (or $1/c$) but all order in f^2 [HR, CH '15]

$$\begin{cases} M^2_{(s)} = 0 & (\mathrm{so}(3)_R \text{ singlet}) \\ M^2_{(s)} = \frac{12(s-1)}{c}\frac{f^2}{(1+f^2)^2} & (\mathrm{so}(3)_R \text{ triplet}) \end{cases}$$

- Comments

$$\left(c = \tfrac{3}{2}MN = \tfrac{3}{2G_N}\right)$$

  - $M^2 = 0$
    - Similar results were obtained at the leading order of f in [Gaberdiel-jin-Li '13]
    - Probably masses are generated at the higher order of M/N except for s=2
  - $M^2 \propto s$-1
    - Superstrings with pure NSNS-flux?? (M/N-corrections should be checked)
    - $M^2 \approx s\log(s)$ ⇔ superstrings with pure RR-flux [Gaberdiel-Peng-Zadeh '15]

CONCLUSION

Summary

- Three trialities among higher spin fields, strings and CFT

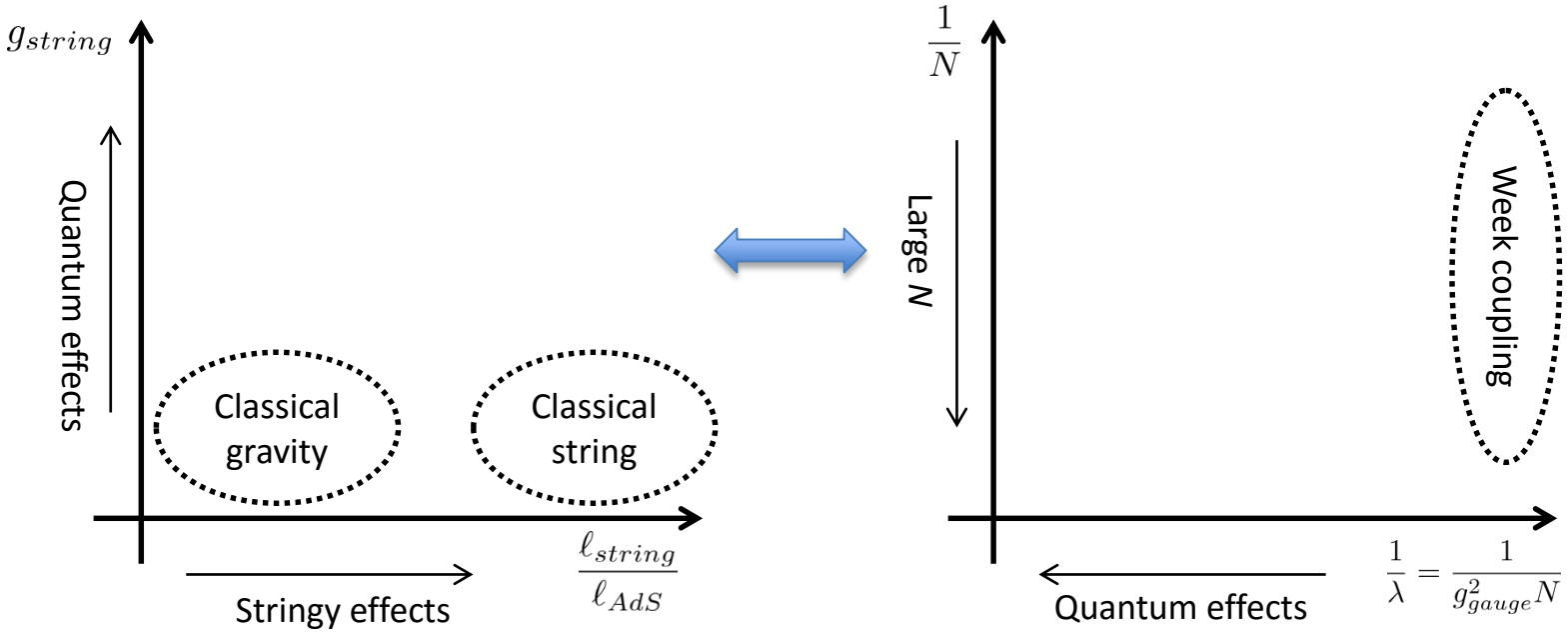
	CFT ⇔ Strings	HS⇔ Strings	Tractability
ABJ triality (AdS_4)	◯	◯	△
N=4 triality (AdS_3)	◯	△	◯
N=3 triality (AdS_3)	△	◯	◯

- Higgs masses from the symmetry breaking
  - Compare to string spectrum
    - M/N-corrections should be computed
    - Understand AdS_3/CFT_2 with N=3 SUSY
  - Generalize to the ABJ triality
    - The methods for 3d CFTs have been developed

BACKUPS

The map of AdS/CFT

- Superstrings on $AdS_5 x S^5$
- 4d U(*N*) gauge theory



- Tensionless limit of string theory (higher spin gauge theory) can be dual to a perturbative region of gauge theory
- Higher spin gauge theory is easier to solve than string theory