Higher spin holography and Higgs phenomenon

Yasuaki Hikida (Ritsumeikan University)

Ref. YH,arXiv:1601.01784

(Cf. YH-Rønne,JHEP1507(2015)125;Creutzig-YH,JHEP1510(2015)164)

July 3rd (2016)@YITP

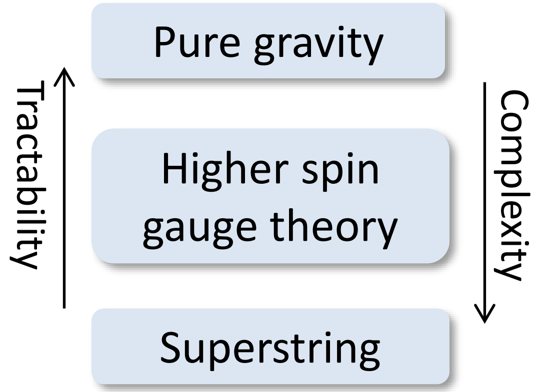
4 Day Conference ''holography and quantum information''

Higher spin gauge theory

- Higher spin gauge theory
  - A totally symmetric rank-*s* field

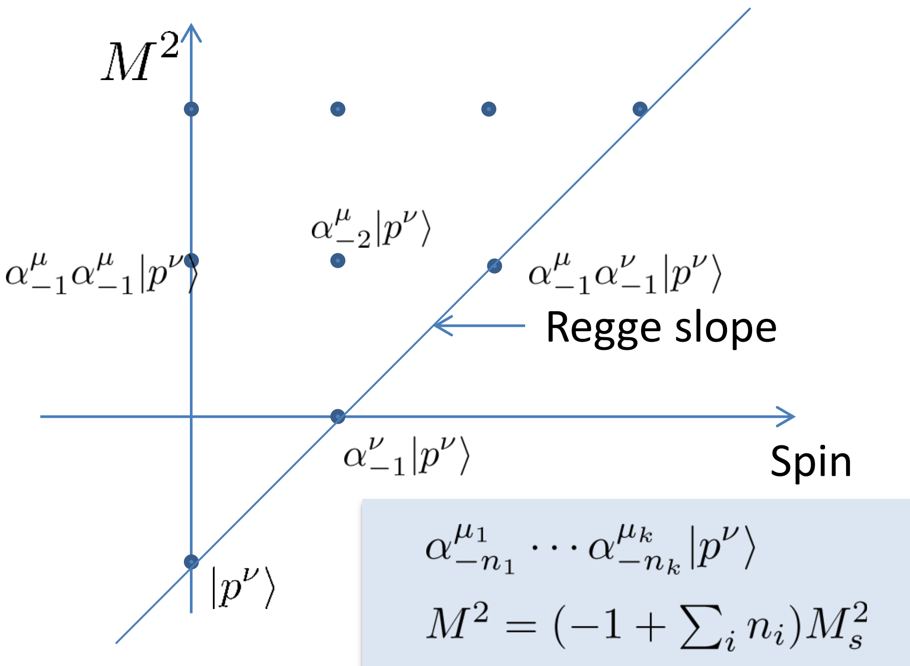
$$\varphi_{\mu_1 \dots \mu_s} \sim \varphi_{\mu_1 \dots \mu_s} + \partial_{(\mu_1} \xi_{\mu_2 \dots \mu_s)}$$

  - Natural extension of electromagnetism (*s*=1) and gravity (*s*=2)
  - Vasiliev theory is famous as a non-trivial theory on AdS
- Applications
  - Simplified version of AdS/CFT correspondence
    - More tractable than using superstring theory
  - Higher spin excitations of superstring theory
    - Higher spin gauge theory may be regarded as a toy model for superstring theory



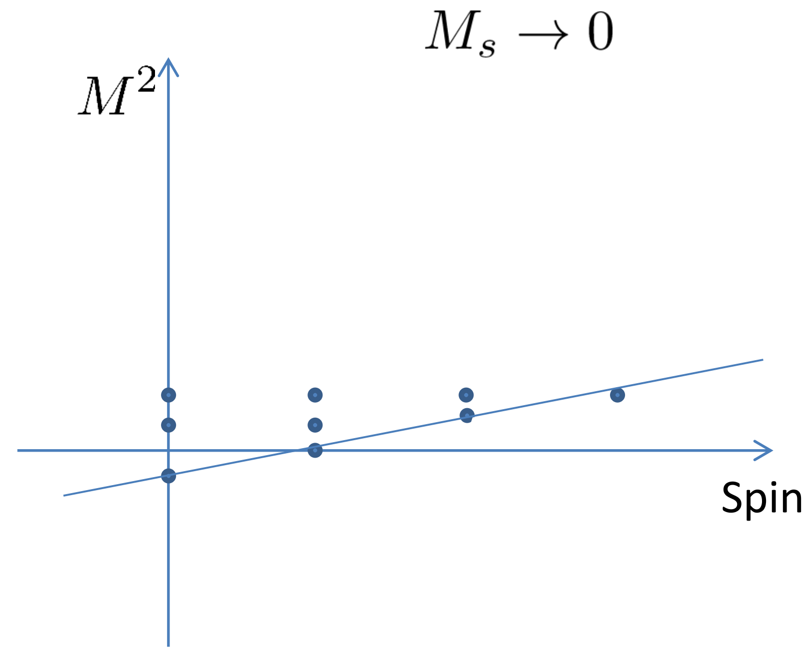
Strings ⇔ Higher spin fields

- 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



- Higher spin gauge symmetry may appear at the tensionless limit
- Superstrings could be described by breaking higher spin symmetry [Gross '88]

Higgs phenomenon

- The aim of this talk
  - To understand the mechanism of higher spin symmetry breaking as a generalization of Higgs mechanism for spin 1 gauge theory
  - To examine the relation to superstring theory
- 4d Vasiliev theory
  - We examine 4d Vasiliev theory dual to 3d critical O(N) vector model
  - The anomalous dimensions of dual higher spin currents were already computed from purely CFT method
  - We reproduce them with the bulk Witten diagram to understand the mechanism from the bulk viewpoints [YH ’16]
- 3d Vasiliev theory
  - We compute masses for 3d Vasiliev theory and discuss the relation to superstring theory [YH-Rønne, Creutzig-YH ’15]

Plan

0. Introduction

1. Higher spin holography

2. Breaking of higher spin symmetry (AdS_4)

3. Relation to superstrings (AdS_3)

4. Conclusion

1. HIGHER SPIN HOLOGRAPHY

Higher spin gauge theory

- Higher spin gauge theory
  - Higher spin gauge transformation

$$\delta\varphi_{\mu_1\ldots\mu_s} = \partial_{(\mu_1}\xi_{\mu_2\ldots\mu_s)}, \ \varphi^{\lambda\sigma}_{\lambda\sigma\mu_5\ldots\mu_s} = 0, \ \xi^{\lambda}_{\lambda\mu_3\ldots\mu_s} = 0$$

  - Equations of motion [Fronsdal '78]

$$\Box\,\varphi_{\mu_1\ldots\mu_s} - \partial_{(\mu_1|}\partial^{\lambda}\varphi_{|\mu_2\ldots\mu_s)\lambda} + \partial_{(\mu_1}\partial_{\mu_2}\varphi_{\mu_3\ldots\mu_s)\lambda}{}^{\lambda} = 0$$

  - No-go theorems [e.g. Weinberg '64] forbid non-trivial interactions consistent with higher spin gauge symmetry (with some assumptions)
- Non-trivial theories on AdS
  - Vasiliev theory: Only equations of motion are known
  - Higher spin AdS_3 gravity: Topological theory (Chern-Simons description)

Higher spin holography

- Klebanov-Polyakov proposal '02

4d Vasiliev theory	⟷	3d O(N) vector model
$\varphi_{\mu_1 \ldots \mu_s}$		$J_{a_1 \ldots a_s} = \phi_i \partial_{(a_1} \cdots \partial_{a_s)} \phi^i$

  – CFT correlators are reproduced from Vasiliev theory [Giombi-Yin '09-'10]

- Further developments
  – Role of higher spin symmetry is clarified [Maldacena-Zhiboedov '11-'12]
  – Concrete relations between superstrings and higher spin fields via AdS/CFT (ABJ triality) [Chang-Minwalla-Sharma-Yin '12]
  – Lower dimensional duality (3d Vasiliev ⇔ 2d W_N minimal model) [Gaberdiel-Gopakumar '10]

2. BREAKING OF HIGHER SPIN SYMMETRY

Symmetry breaking

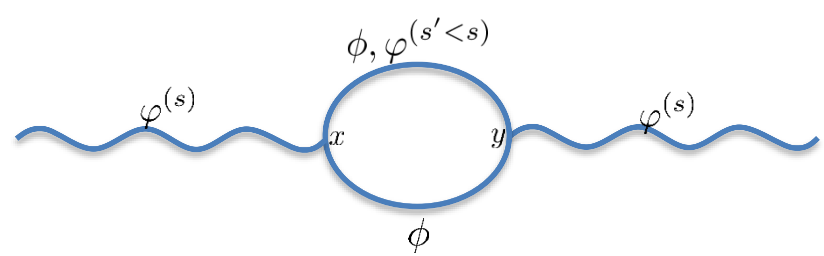
- Klebanov-Polyakov duality

4d Vasiliev with Neumann b.c. ⟷ 3d free O(*N*) boson

↓ [Witten '01] ↓ $\frac{f}{2}(\phi^i\phi_i)^2$

4d Vasiliev with Dirichlet b.c. ⟷ 3d critical O(*N*) model

- Higher spin symmetry breaking
  - CFT side: Symmetry is broken at the order of 1/*N*
  - HS side: Gauge fields become massive because of
    - The change of boundary condition for scalar field
    - One-loop effect
  - We want to confirm this bulk interpretation quantitatively



Short v.s. long multiplet

[Girardello-Porrati-Zaffaroni '02]

- Fields on AdS_4 are classified by representations of so(4,1)
  - Δ : scaling dimension, s : spin $(\Delta \geq s+1)$
- Shortening of representation

$$\lim_{\Delta \to s+1} D(\Delta, s) \to D(s+1, s) \oplus D(s+2, s-1)$$

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

- Goldstone modes from bound states with $(S, n) = (s - s' - 1, 0)$

$$D(s'+1, s') \otimes D(2, 0) = \bigoplus_{S=0}^{\infty} \bigoplus_{n=0}^{\infty} D(s'+S+n+3, s'+S)$$

  - A remark: spin 2 currents are kept conserved

Masses from anomalous dimensions

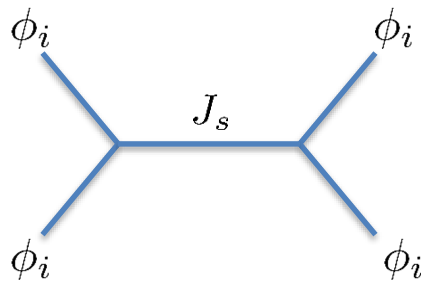
- AdS/CFT dictionary
  - The masses from the anomalous dimensions of dual currents

$$M_s^2 = \Delta_s(\Delta_s - 3) - (s+1)(s-2)$$

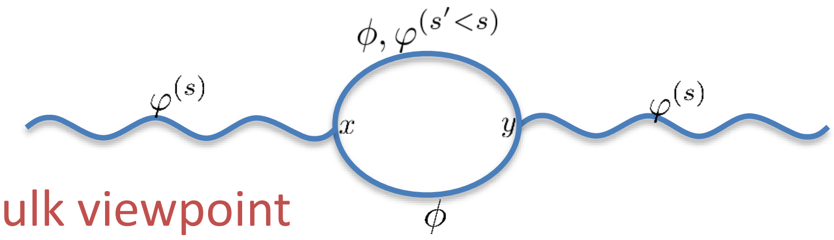
- The anomalous dimensions from the critical model
  - They were obtained purely from the CFT [Ruhl '04] (see also [Skvortsov '15, Giombi-Kirilin '16])

$$\tau_s \equiv \Delta_s - s - 1 = \frac{16(s-2)}{3\pi^2 N(2s-1)} + \mathcal{O}(\tfrac{1}{N^2})$$

$$\Rightarrow M_s^2 = \frac{16(s-2)}{3\pi^2 N} + \mathcal{O}(\tfrac{1}{N^2})$$



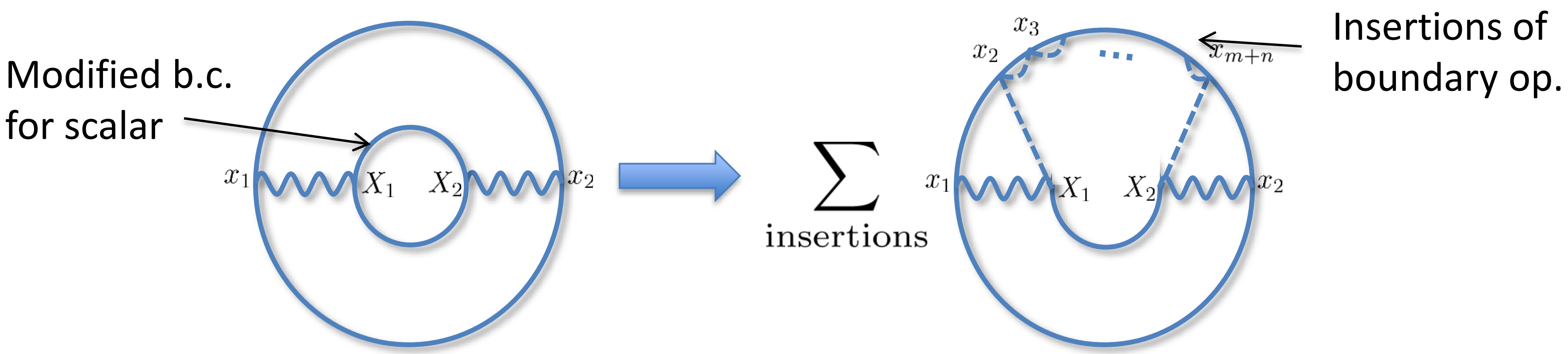
Anomalous dimensions from bulk



- Goal
  - To reproduce the masses from the bulk viewpoint
- Methods
  - Trick 1: Compute 2-pt function of currents using the bulk Witten diagram

$$\langle J_s(x_1) J_s(x_2) \rangle_{f\to\infty} = \frac{N_s P_s(x_{12})}{|x_{12}|^{2s+2+2\tau_s}}$$

  - Trick 2: Rewrite the scalar propagator with modified b.c. with the insertions of boundary operators

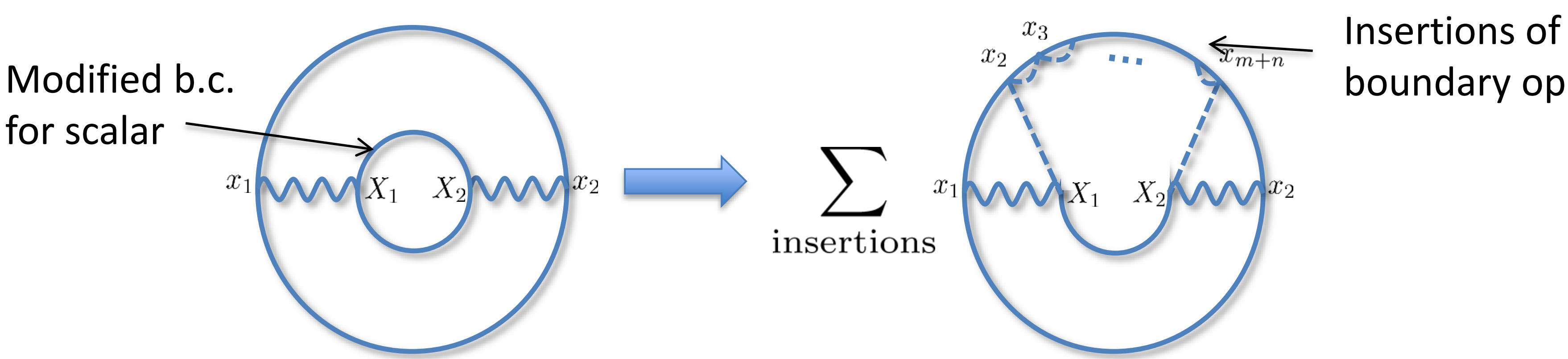


Anomalous dimensions from bulk

- Bulk Witten diagram ➔ Boundary conformal perturbation theory

$$\left\langle \prod_{i=1}^{n} \Phi_i(x_i) \right\rangle_f = \frac{\langle \prod_{i=1}^{n} \Phi_i(x_i) e^{-\Delta S} \rangle_0}{\langle e^{-\Delta S} \rangle_0}$$

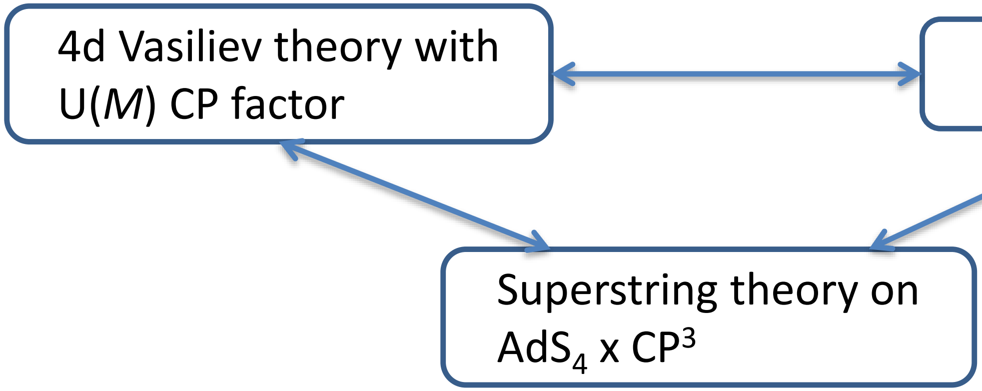
- The anomalous dimensions are reproduced in the conformal perturbation theory [YH '16]
  - The result confirm quantitatively the bulk picture that the breaking is a one loop effect and due to the change of boundary condition
  - The Goldstone modes cannot be identified with this method



3. RELATION TO SUPERSTRINGS

ABJ triality

- Klebanov-Polyakov proposal ’02
  - 4d Vasiliev theory ⇔ 3d O(N) vector model
- ABJ triality [Chang-Minwalla-Sharma-Yin ’12]
  - HS side: 4d extended Vasiliev theory with U(M) Chan-Paton factor
  - CFT side: 3d $U(N)_k \times U(M)_{-k}$ Chern-Simons-Matter theory (ABJ theory)
  - String side: Superstring theory on $AdS_4 \times CP^3$



Lower dimensional triality

- Gaberdiel-Gopakumar proposal '10
  - 3d Vasiliev theory ⇔ 2d W_N minimal model
- More degrees of freedom [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 at a large *N* limit $\frac{\mathrm{su}(N+M)_k \oplus \mathrm{so}(2NM)_1}{\mathrm{su}(N)_{k+M} \oplus \mathrm{u}(1)}$
  - Evidence: One-loop partition function agrees
- Extended supersymmetry [CHR '14, HR '15]
  - *N*=3 SUSY at *k*=*N*+*M*

    ➔ Superstrings on $AdS_3 \times M^7$ (M^7 = SO(5)/SO(3) or SU(3)/U(1))
  - Evidence: BPS spectrum agrees (cf. [Argurio-Giveon-Shomer '00])
  - Similar proposals with *N*=4 [Gaberdiel-Gopakumar '13-'15]

Symmetry breaking

- Turning on string tension
  - The 2d coset model is dual to 3d Vasiliev with exact higher spin symmetry
  - Higher spin symmetry for 2d CFT is broken by deformation preserving $\mathcal{N}$=3 superconformal symmetry
- The masses of higher spin fields
  - Leading in G_N, all order in deformation parameter f [YH-Rønne, Creutzig-YH '15]

$$\begin{cases} M^2_{(s)} = 0 & (\text{so}(3)_R \text{ singlet}) \\ M^2_{(s)} = \frac{8G_N(s-1)f^2}{(1+f^2)^2} & (\text{so}(3)_R \text{ triplet}) \end{cases}$$

  - $M^2 = 0$ (symmetry is preserved at the order)
  - $M^2 \propto s\text{-}1$ (like Regge spectrum in flat space-time)
  - Need to examine M/N-effects

4. CONCLUSION

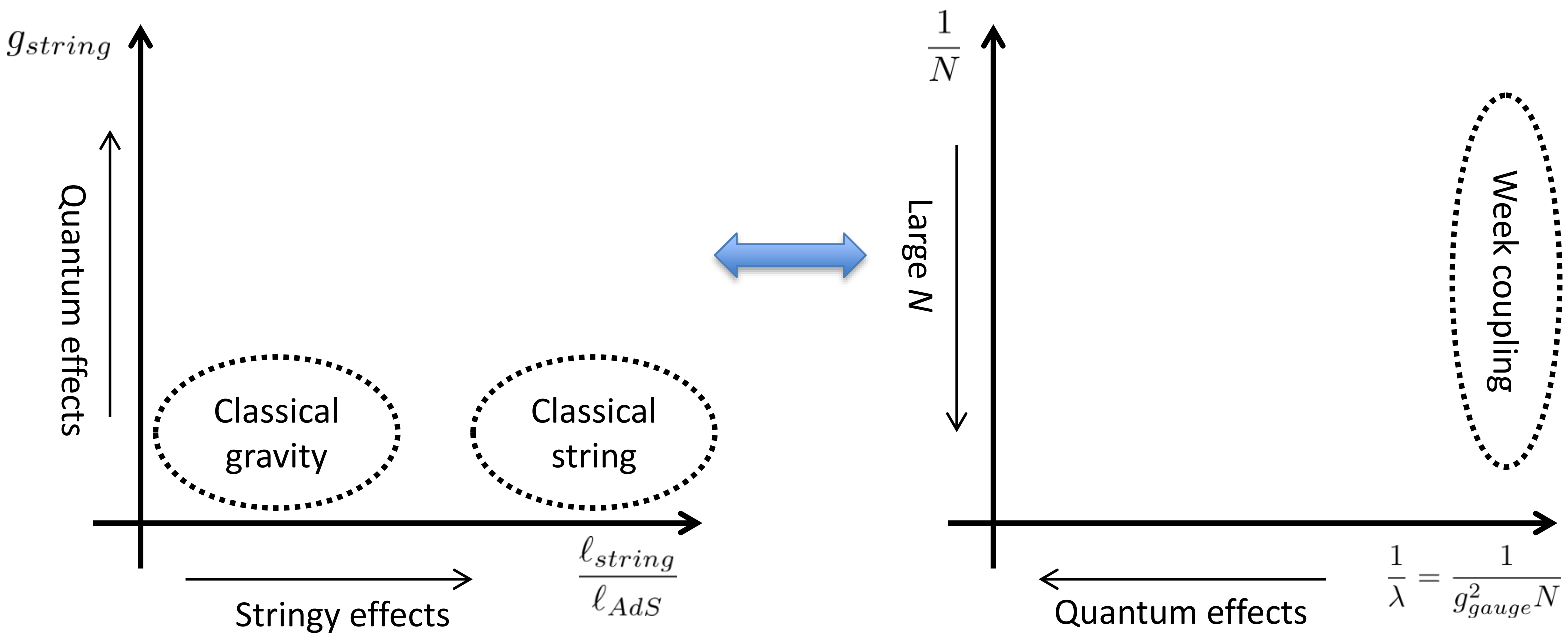
Conclusion

- The symmetry breaking in 4d Vasiliev theory
  - Masses of higher spin fields are reproduced in conformal perturbation theory
  - Bulk interpretation is (partially) confirmed via the relation between the bulk Witten diagrams and boundary conformal perturbation theory
- Relation to superstring theory
  - AdS_4: need to introduce supersymmetry and coupling to gauge fields In order to see the relation to ABJ triality
  - AdS_3: M/N-corrections should be included to relate to superstring theory
  - Other works on Higgsing for higher spin fields on AdS [Gaberdiel-Peng-Zadeh ’15, Gwak-Joung-Mkrtchyan-Rey ’15, Gwak-Kim-Rey ’16]

5. APPENDICES

The map of AdS/CFT

- Superstrings on AdS_5xS^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

ABJ triality

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

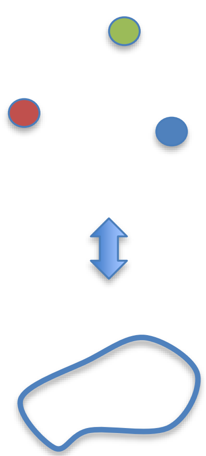
$$A_i^\alpha, B_\beta^j \ (i, j = 1, 2, \ldots, N, \ \alpha, \beta = 1, 2, \ldots, M)$$

- Higher spin region: *M* << *N*
  - ‘t Hooft parameter is stronger for U(*N*) than U(*M*)

U(*N*) invariant currents ⟺ Higher spin fields

$$[J_{a_1 \ldots a_s}]^\alpha{}_\beta = A_i^\alpha \partial_{(a_1} \cdots \partial_{a_s)} B_\beta^i \quad \Longleftrightarrow \quad [\varphi_{\mu_1 \ldots \mu_s}]^\alpha{}_\beta$$

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



Boundary condition & RG flow

- Scalar field in 4d Vasiliev theory
  - Behavior of bulk scalar near the boundary (z=0)

$$\varphi \sim az + bz^2 \Rightarrow \begin{cases} a = 0 \text{ (Dirichlet b.c.)} \Leftrightarrow \Delta_+ = 2 \\ b = 0 \text{ (Neumann b.c.)} \Leftrightarrow \Delta_- = 1 \end{cases}$$

$$\left(\Delta_\pm = \frac{3}{2} \pm \sqrt{\frac{9}{4} + m^2} = 2 \text{ or } 1 \right)$$

- RG flow by $\delta\mathcal{L} = \frac{f}{2}(\phi^i\phi_i)^2$
  - Free theory at UV fixed pt.
    - Dimension of dual scalar operator $[\phi_i\phi^i] = 1 \Leftrightarrow \text{Neumann b.c.}$
  - Critical theory at IR fixed pt.

[Witten '01]

- Deformation by double trace like op. ⇔ Change of bulk b.c.