BEING FLAT WITH NO SYMMETRIES

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arXiv:1410.2257 [hep-th]
arXiv:15xx.xxxxx [hep-th]

with Xi Dong and Daniel Z. Freedman

Goal:

Deal with (little) hierarchy problem in MSSM.

Introduce a novel SUSY breaking mechanism.

- Mass of top and stop are split.
- Coupling constants are mismatched.
- Higgs mass does not receive SUSY breaking corrections.

Toy model in AdS_3

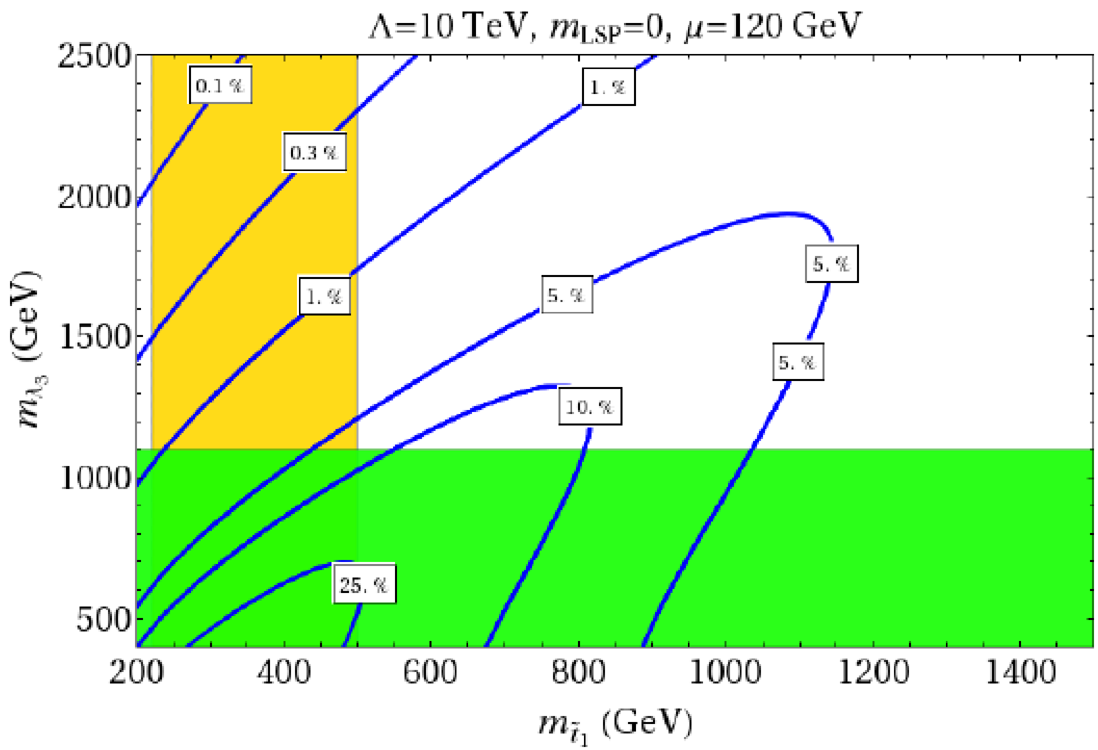
More realistic model in AdS_n :

- Flat spacetime limit of AdS_4
- RS-model in AdS5

Little hierarchy problem

The null-results of SUSY search challenge SUSY as solution of hierarchy problem:

$$\delta m_{H_u}^2 = -\frac{3y_t^2}{4\pi^2} m_{\tilde{t}}^2 \ln\left(\Lambda/m_{\tilde{t}}\right) \qquad \delta m_{\tilde{t}}^2 = \frac{2g_s^2}{3\pi^2} m_{\tilde{g}}^2 \ln\left(\Lambda/m_{\tilde{g}}\right)$$



arXiv:1210.0555
A. Arvanitaki, N. Craig,
S. Dimopoulos, G. Villadoro

Little hierarchy problem

Ways out:

- Hide SUSY through kinematics or unconventional decays
  - Stealth SUSY
  - Light or degenerate stop and top
  - R-Parity Violation
- Smart model building
  - Scherk-Schwarz SUSY breaking in 5D
  - Colorless SUSY
  - Super-soft SUSY
- Self-adjustment Mechanism/Large N (MS)SM
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-
-

Little hierarchy problem

General belief:

Scalar mass always gets sizable corrections from SUSY breaking effects through loop diagrams.

Ideal scenario:

Scalar mass does not receive any SUSY breaking effects even the scalar couples to SUSY breaking sectors.

⇓

We present a detailed toy model where the ideal scenario is realized!

AdS_3 toy model setup:

- An R-charge neutral supermultiplet

$$\Phi_m = \{\phi_m, \psi_m, ...\}$$

- A supermultiplet with non-zero R-charges

$$\Phi_c = \{\phi_c, \psi_c, ...\}$$

AdS3 toy model setup:

- Gauge R-symmetry group $U(1) \times \tilde{U}(1)$

  with R-gauge boson A and $\tilde{A}$

$$\frac{k}{8\pi} \int_{\text{bulk}} \left[A \wedge dA - \tilde{A} \wedge d\tilde{A} \right]$$

EOM in the bulk:

$$F = 0$$

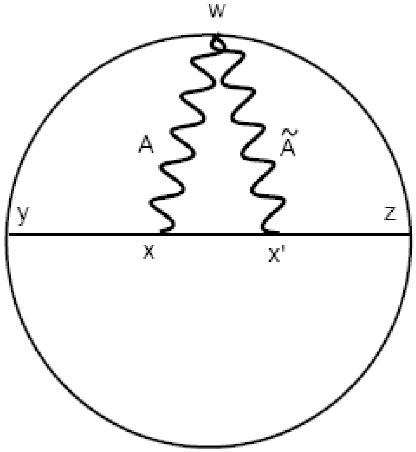
$$\Rightarrow \quad K_{\mu i}(x, \vec{w}) = \partial_\mu \Lambda_i(x, \vec{w})$$

total derivative respect to bulk coordinates

Mass shift for R-charged particle:

- Explicit SUSY breaking on the boundary of AdS3!

$$S = S_0 + \frac{h}{2}\int_{\text{bdy}} A \wedge \tilde{A}$$



SUSY: $\Delta_F = \Delta_B + \frac{1}{2}$

$$\delta_h \Delta = -2\pi h q\tilde{q}$$

R-charges are different for boson and fermion in one supermultiplet

$(q, \tilde{q})$ $(q-1, \tilde{q})$

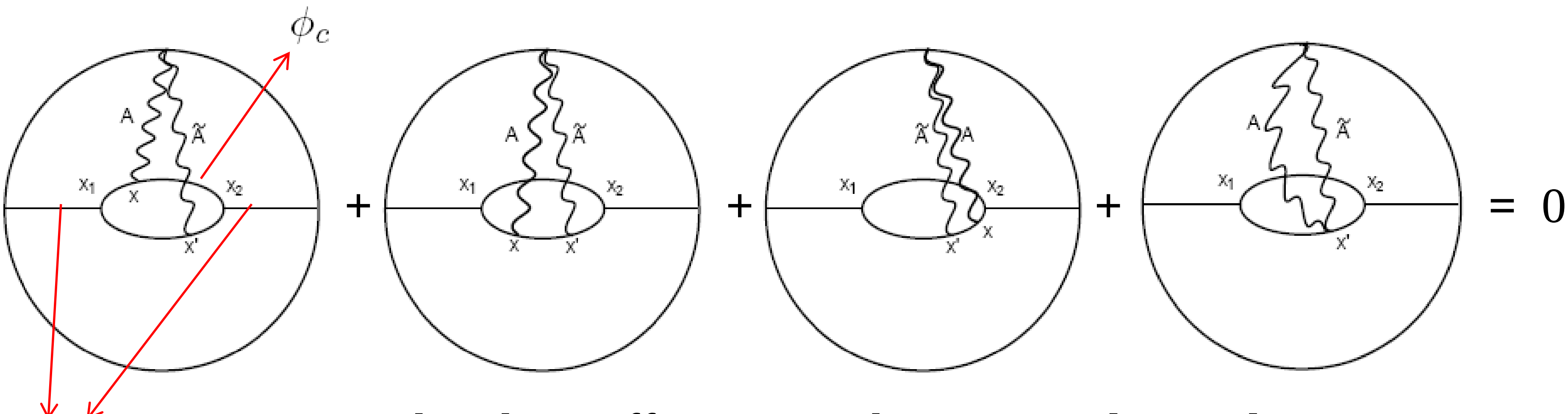
⇨ SUSY breaking effect is explicit!

No mass shift for R-neutral particle:

Suppose we have the following interaction:

$$\mathcal{L} \supset y\phi_m\phi_c^\dagger\phi_c \quad \text{or} \quad \phi_m^2\phi_c^\dagger\phi_c$$

Shift symmetry is not a good symmetry.

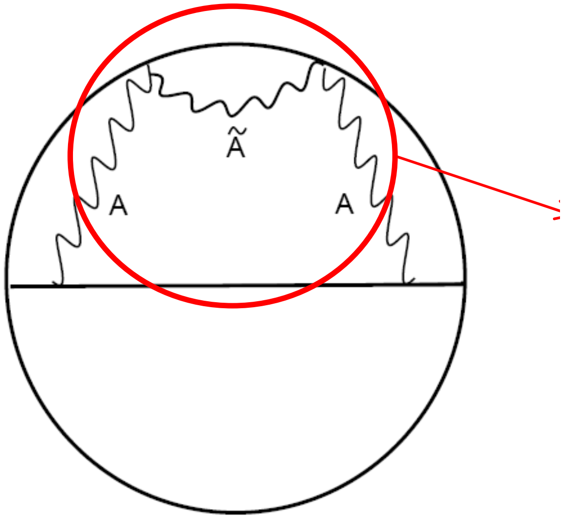


No SUSY breaking effect is seen by R-neutral particle!

$$K_{\mu i}(x, \vec{w}) = \partial_\mu \Lambda_i(x, \vec{w})$$

Ward Identity of R-symmetry guarantees the cancellation!

Singly charged particle



$$\mathscr{L}_{CFT} \sim h^2 \int dw_1^2 dw_2^2 J_z(w_1)\langle \tilde{J}_{\bar{z}}(\bar{w}_1)\tilde{J}_{\bar{z}}(\bar{w}_2)\rangle J_z(w_2)$$

$$\sim \frac{h^2 k}{2} \int dw_1^2 dw_2^2 J_z(w_1) \frac{1}{(\bar{w}_1 - \bar{w}_2)^2} J_z(w_2)$$

$$\sim \frac{h^2 k}{2} \int dw_1^2 dw_2^2 J_z(w_1) \frac{J^{zz}(\vec{w}_1, \vec{w}_2)}{(\vec{w}_1 - \vec{w}_2)^2} J_z(w_2)$$

$$\mathscr{L}_{AdS} \sim \frac{h^2 k}{2} \int d^2 w_1 d^2 w_2 A_z(w_1) \frac{J^{zz}(\vec{w}_1 - \vec{w}_2)}{(\vec{w}_1 - \vec{w}_2)^2} A_z(w_2)$$

⇩

Effectively a non-local SUSY breaking term after integrating out $\tilde{A}$.

Does not cause any unreasonable results which violate causality.

This non-local interaction term structure will be borrowed to higher dimension construction.

AdS$_n$ (n>3) generalization

Key:

Construct a theory in which $K^{A}_{\mu,i}(x,\vec{w})$ is a total derivative.

Maxwell theory with Dirichlet boundary condition is legal.

gauge field in bulk A_μ

$\Updownarrow$

conserved current operator J_i (Δ = n-2) on the boundary

AdS$_n$ (n>3) generalization

$$K^A_{\mu,i}(x,\vec{w}) = \frac{J_{\mu i}(x,\vec{w})x_0}{(x_0^2 + (\vec{x}-\vec{w})^2)^2}$$

not a total derivative

However, there is a interesting/useful identity

$$\partial_i K^A_{\mu,i}(x,\vec{w}) = 2\partial_\mu \frac{x_0^{n-1}}{(x_0^2 + (\vec{x}-\vec{w})^2)^{n-1}}$$

Can be reduced to a total derivative if there is a ∂_i acting on it

AdS$_n$ (n>3) generalization

As a direct analogue to non-local interaction from AdS$_3$ case

$$\mathscr{L}_{AdS} \sim \lim_{w_1^0, w_2^0 \to 0} h \int d^{n-1}w_1 d^{n-1}w_2 (w_1^0)^{3-n} (w_2^0)^{3-n} A_i(w_1) \frac{J^{ij}(\vec{w}_1 - \vec{w}_2)}{(\vec{w}_1 - \vec{w}_2)^2} A_j(w_2)$$

$$\mathscr{L}_{CFT} \sim h \int d^{n-1}w_1 d^{n-1}w_2 J_i(w_1) \boxed{\frac{J^{ij}(\vec{w}_1, \vec{w}_2)}{(\vec{w}_1 - \vec{w}_2)^2}} J_j(w_2)$$

$\rightarrow \partial_i \partial_j Log[(\vec{w}_1 - \vec{w}_2)^2]$

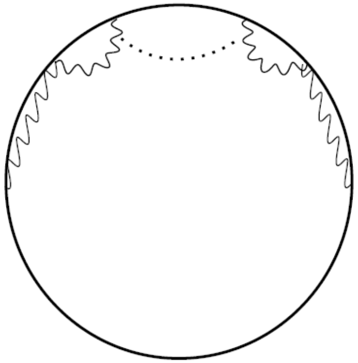
⇨ One should not integrate by parts at operator level due to the subtlety of contact terms!
(Similar subtlety happens in AdS$_3$ scenario as well.)

One can directly check the non-triviality of such operator by a properly regulated calculation.

$$\delta\Delta \sim hq^2$$

SUSY breaking mass shift

Exact marginality and all loop order results

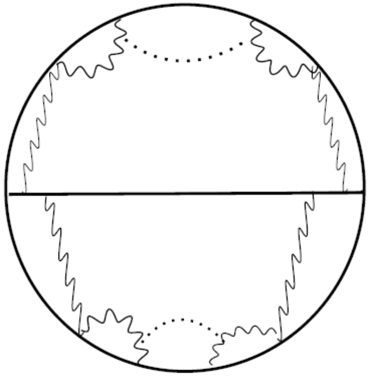


One can explicitly show that the dimension of J_i is not modified at all loop order for all dimensions.

Thus the deformation is exact marginal for any dimension AdS!

We can calculate the exact SUSY breaking corrections, which gives a precise result:

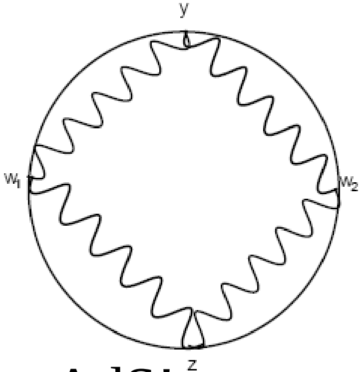
$$\text{AdS}_3: \quad \delta\Delta \sim -\frac{\pi h q\tilde{q} - \pi^2 k^2 h^2 (q^2 + \tilde{q})^2/4}{1 - \pi^2 h^2 k\tilde{k}/4}$$



Mass change can be arbitrarily large!

Exact marginality and all loop order results

One can explicitly show that the dimension of J_i is not modified at all loop order for all scenarios.

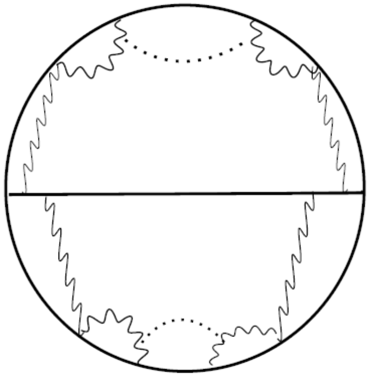


Thus the deformation is exact marginal for any dimension AdS!

We can calculate the exact SUSY breaking corrections, which gives a precise result:

$$\mathrm{AdS}_{4,5\ldots}: \quad \delta\Delta \sim hq^2$$

Only lowest order contribution is non-zero.
Mass change can be arbitrarily large.



Conclusion

We present a novel SUSY breaking mechanism.

SUSY is explicitly broken:

Mass spectrum/ Coupling constants

R-neutral particles do not feel SUSY breaking at all loop orders!

An existence proof :

smart model building can avoid any amount of fine tuning even with explicit SUSY breaking.

Concrete predictions:

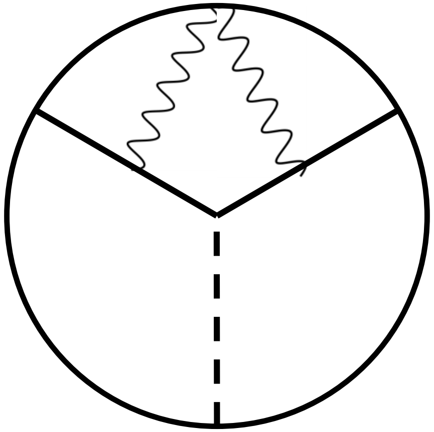
Mismatch of mass $\Longleftrightarrow$ Mismatch of coupling constants.

SUSY breaking effects on couplings:

The other way to see SUSY breaking effects

⇨ shifts of coupling constants

may lead to an intuition on how the cancellations happen

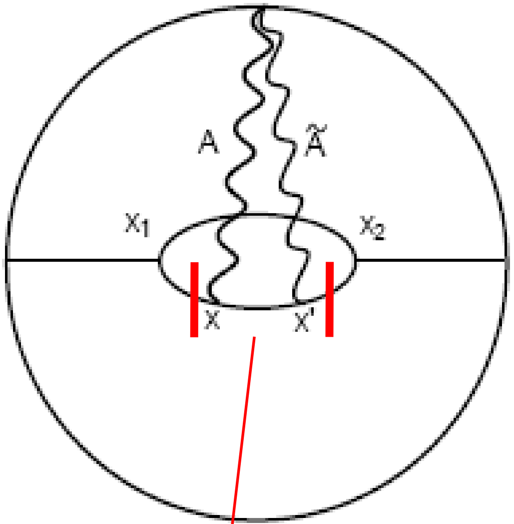


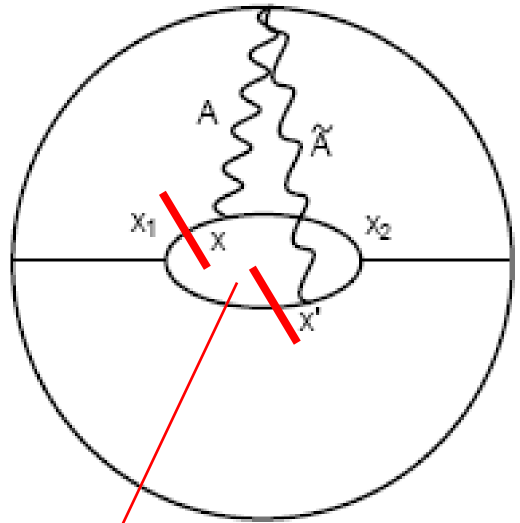
Concrete prediction in our model:

mass mismatching ⟺ coupling mismatching

SUSY breaking effects on couplings:

An ad hoc understanding on the cancellations:





change of particle mass in the internal loop

change of interacting vertex

The effects from these two kinds of changes cancel and leave the potential of the moduli fields flat.

CFT dual:

Phys. Rev. D 65, 106007 (2002)
O. Aharony, M. Berkooz and E. Silverstein

Starting from a SCFT living on 2D (the boundary of AdS_3)

Add in the following deformation:

$$S_{\rm CFT} = S_{\rm CFT,0} + \frac{h}{2}\int J \wedge \tilde{J}$$

- R-currents
- double trace deformation
- exact marginal
- explicit SUSY breaking

Mass in AdS SUGRA:

In SUGRA , a particle's mass is directly related to its R-charge!

4D example:

$$\mathcal{L}_{KIN} = \partial^\mu \bar{z}\, \partial_\mu z + \frac{i}{2}\, \bar{\psi}\, \not{D} \psi + \bar{F}F + a(\bar{z}F + z\bar{F}) + 3a^2 \bar{z}z,$$

$$\mathcal{L}_{INT} = FW' + \bar{F}\bar{W}' + 3a(W + \bar{W}) - \tfrac{1}{2}\bar{\psi}(LW'' + R\bar{W}'')\, \psi$$

$$F = -\bar{W}'(\bar{z}) - az$$

Conventional mass term in AdS3 :

$$W = \mu\phi^2/(2L)$$

$$\mathcal{L}_\mu = \frac{1}{L^2}\left[\left(-\frac{3}{4} + \mu^2\right)\phi^\dagger\phi + \mu\left(\phi^2 + \phi^{\dagger 2}\right) - \frac{\mu L}{2}\left(\chi^2 + \bar{\chi}^2\right)\right]$$

violating R-symmetry

Mass in AdS SUGRA:

In AdS, SUGRA does not allow arbitrary mass terms!

Instead, one can introduce “real mass” terms :
(arXiv:1012.3210 [hep-th], Jafferis)

$$\mathcal{L}_q = \frac{1}{L^2}\left[\left(-\frac{3}{4}+\left(q-\frac{1}{2}\right)\left(q-\frac{3}{2}\right)\right)\phi^\dagger\phi - i\left(q-\frac{1}{2}\right)L\bar{\chi}\chi\right]$$

⇨ $$\begin{cases} (m_B L)^2 = -\frac{3}{4}+\left(q-\frac{1}{2}\right)\left(q-\frac{3}{2}\right) \\ m_F L = q-\frac{1}{2} \end{cases}$$

⇨ Particle mass in AdS is closely related to its R-charge.

Existence of non-derivative cubic coupling:

Similar to mass term, the interaction terms are not arbitrary in AdS SUGRA!

$$\mathcal{K} = \Phi^\dagger \Phi + Z^\dagger Z \left(1 + \lambda(\Phi + \Phi^\dagger)\right)$$

$$\Rightarrow \mathcal{L} \supset \partial_\mu \phi^\dagger \partial^\mu \phi + D_\mu z^\dagger D^\mu z + \lambda(\phi D_\mu z^\dagger D^\mu z + \phi^\dagger D_\mu z^\dagger D^\mu z)$$
$$+\lambda(\partial_\mu \phi D^\mu z^\dagger \; z + \partial_\mu \phi^\dagger z^\dagger D^\mu z) + \ldots$$

First integrating by parts then using E.O.M. ,

$$(-\lambda\phi\Box z^\dagger \; z) \quad \Leftrightarrow \quad (\lambda m^2 \phi z^\dagger z)$$

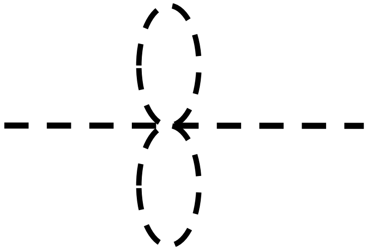
Non-Canonical Kahler potential can generically induce non-derivative cubic coupling.

(Little) hierarchy problem in 3D?

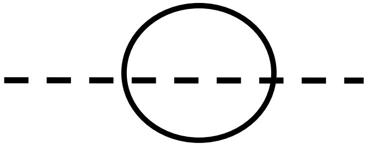
$$[\phi] = \frac{1}{2} \qquad\qquad [\psi] = 1$$

quadratic divergences :

ϕ^6

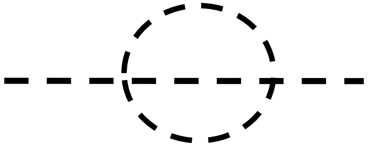


$\phi^2\psi^2$

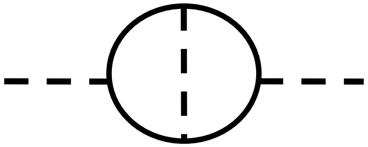


logarithmic divergences :

$v\phi^4$



$\sqrt{v}\phi\psi^2$

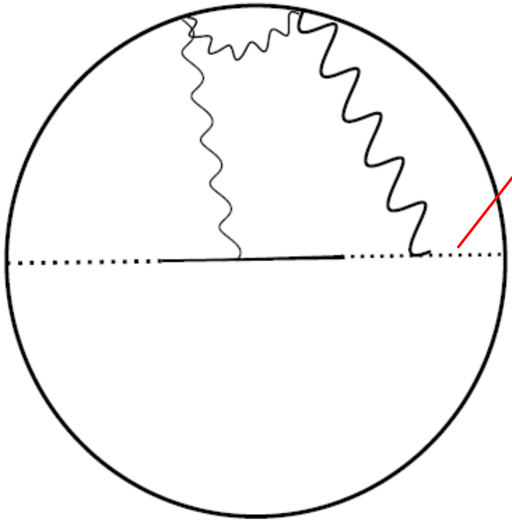


Wilson line

Consider 2-pt correlation function of 2 bulk points:

Gauge invariance requires Wilson lines attach to end points of charged particles.

Results depend on the choice of Wilson line!



Wilson line along radial direction

topologically different from the previous diagram

$$\langle O_c^\dagger(y) O_c(z) \rangle$$

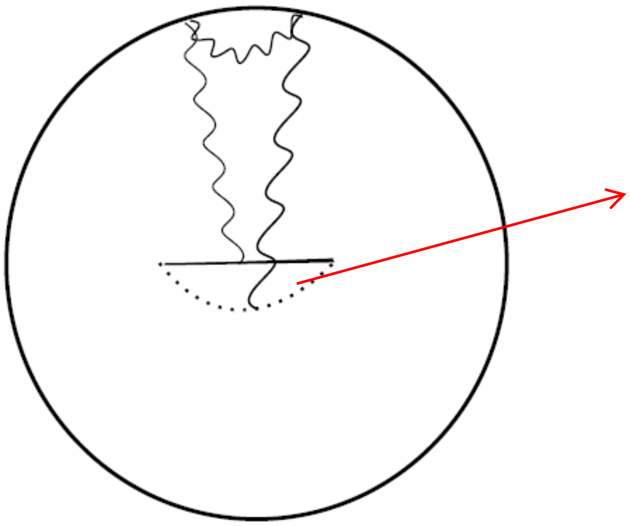
SUSY breaking effects are explicit.

Wilson line

Consider 2-pt correlation function of 2 bulk points:

Gauge invariance requires Wilson lines attach to end points of charged particles.

Results depend on the choice of Wilson line!



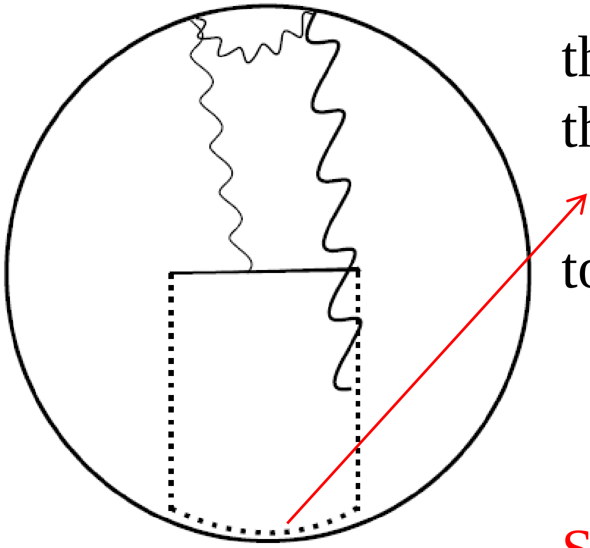
Wilson line connects back in bulk

Wilson line

Consider 2-pt correlation function of 2 bulk points:

Gauge invariance requires Wilson lines attach to end points of charged particles.

Results depend on the choice of Wilson line!



the limit of Wilson line nearby the boundary

topologically equivalent to the previous diagram

$$\langle O_c^\dagger(y) e^{q \int_y^z dx\, J} O_c(z) \rangle$$

SUSY breaking effects vanish!

Exact marginality and Cosmological Constant

Zamolodchikov c theorem for 2d CFT

⇨ The central charge of CFT is not modified by this exact marginal deformation.

⇨ The cosmological constant (R_{AdS}) in AdS_3 does not change, even SUSY is broken.

⇨ Not clear for higher dimension AdS scenario, a more detailed study is necessary.

But it is plausible/promising that the C.C. in higher dimension remains blind to SUSY breaking effects.