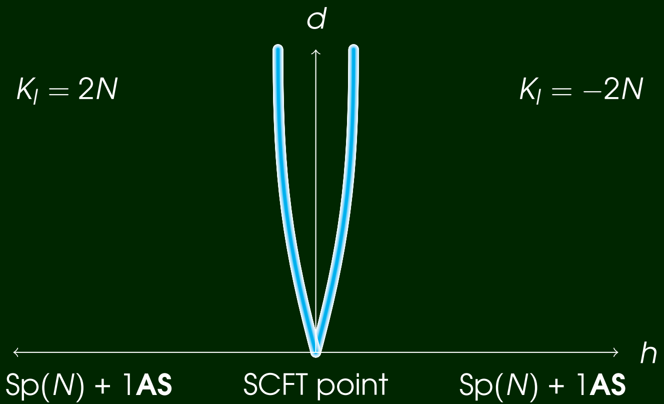
Posters at Y206

on Dec. 6 (Wed.) Tomorrow 18:00-

Mohammad Akhond - Kyoto University

2307.13724 (hep-th) with M. Honda and F. Mignosa



Zeros and factorizations of scattering amplitudes

Author:Nima Arkani-Hamed, **Qu Cao(曹趣)**, Jin Dong(董晋),Carolina Figueiredoe,Song He(何颂)

$$\mathcal{L}_{\mathrm{tr}(\phi^3)} = \mathrm{Tr}(\partial\phi)^2 + g\,\mathrm{Tr}(\phi^3)$$

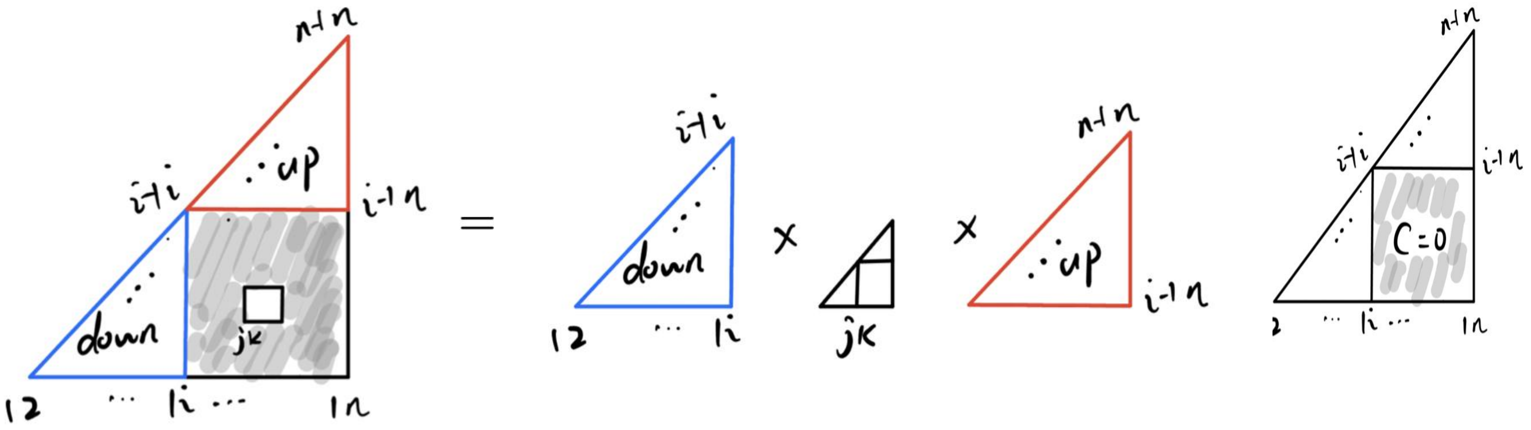
$$c_{ij} = -s_{i,j} = X_{i,j} + X_{i+1,j+1} - X_{i,j+1} - X_{i+1,j}$$

$$\mathcal{L}_{\mathrm{NLSM}} = \frac{1}{8\lambda^2}\,\mathrm{Tr}\left(\partial_\mu \mathrm{U}^\dagger \partial^\mu \mathrm{U}\right)$$

$$X_{a,b} = (p_a + p_{a+1} + \cdots + p_{b-1})^2$$

$$c_{a,b} = -s_{a,b} = -(p_a + p_b)^2$$

$$\mathcal{L}_{\mathrm{YMS}} = -\,\mathrm{Tr}\left(\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}D^\mu\phi^I D_\mu\phi^I - \frac{g_{\mathrm{YM}}^2}{4}\sum_{I\neq J}\left[\phi^I,\phi^J\right]^2\right)$$



$: c_{ab} = 0, \text{for } 1 \leq a \leq i-2, i \leq b \leq n-1.$

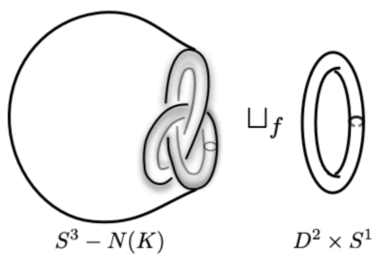
3-factorization : $\mathcal{I}_n\big|_{\text{3-fac kin.}} = \tilde{\mathcal{I}}_i^{down} \times \tilde{\mathcal{I}}_{n-i+2}^{up} \times \tilde{\mathcal{I}}_4,$

Surgery construction for 3d theories

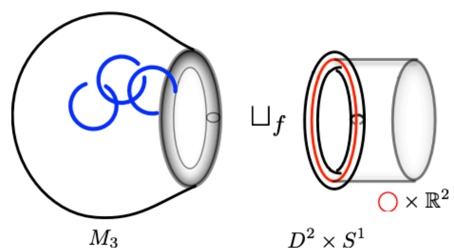
The 18th Kavli Asian Winter School, YITP

Shi Cheng, *Fudan University*, *ref:* SC 2310.07624, SC & P. Sułkowski 2302.13371

Dehn surgery construction

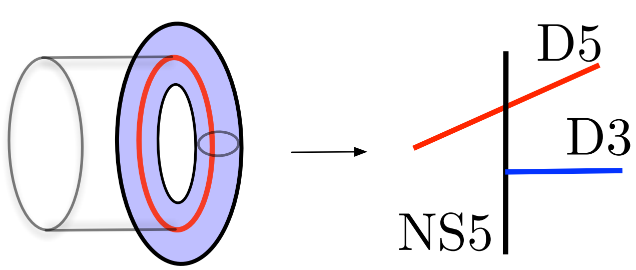


T[M_3]

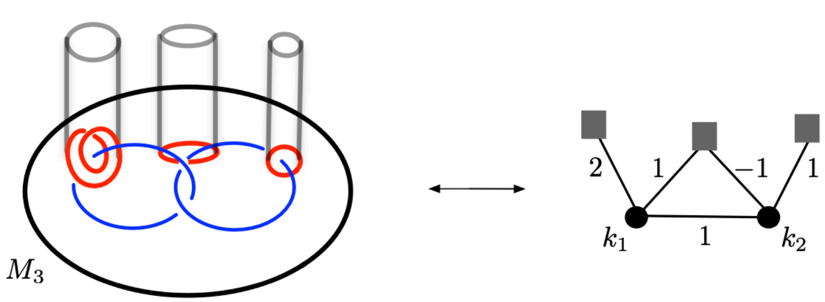


T[M_3] + matter

Dual to brane webs



Plumbing graphs, an example:



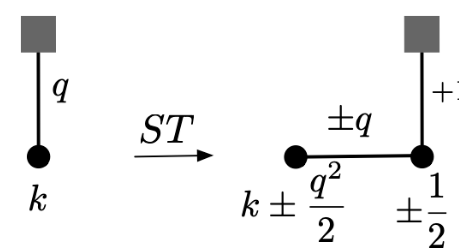
Gauge theory:

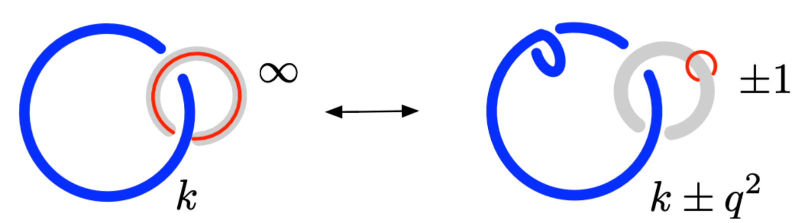
ST-moves, superpotentials

Geometry:

Kirby moves, handle-slides, rational equivalent surgeries

Dualities <—> Geometric transformations





Dictionary: 3d theories <-> 3-manifolds

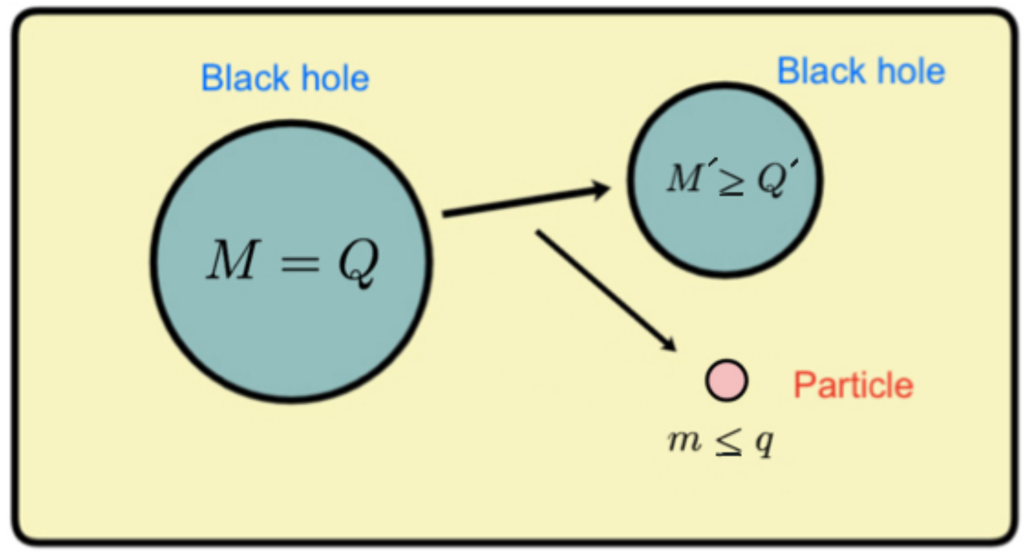
Please see my poster

Supersymmetric Cardy Formula & Weak Gravity Conjecture in AdS/CFT

Minseok Cho, Sunjin Choi, Ki-Hong Lee, Jaewon Song

JHEP11(2023)118 [2308.01717] and Work in Progress

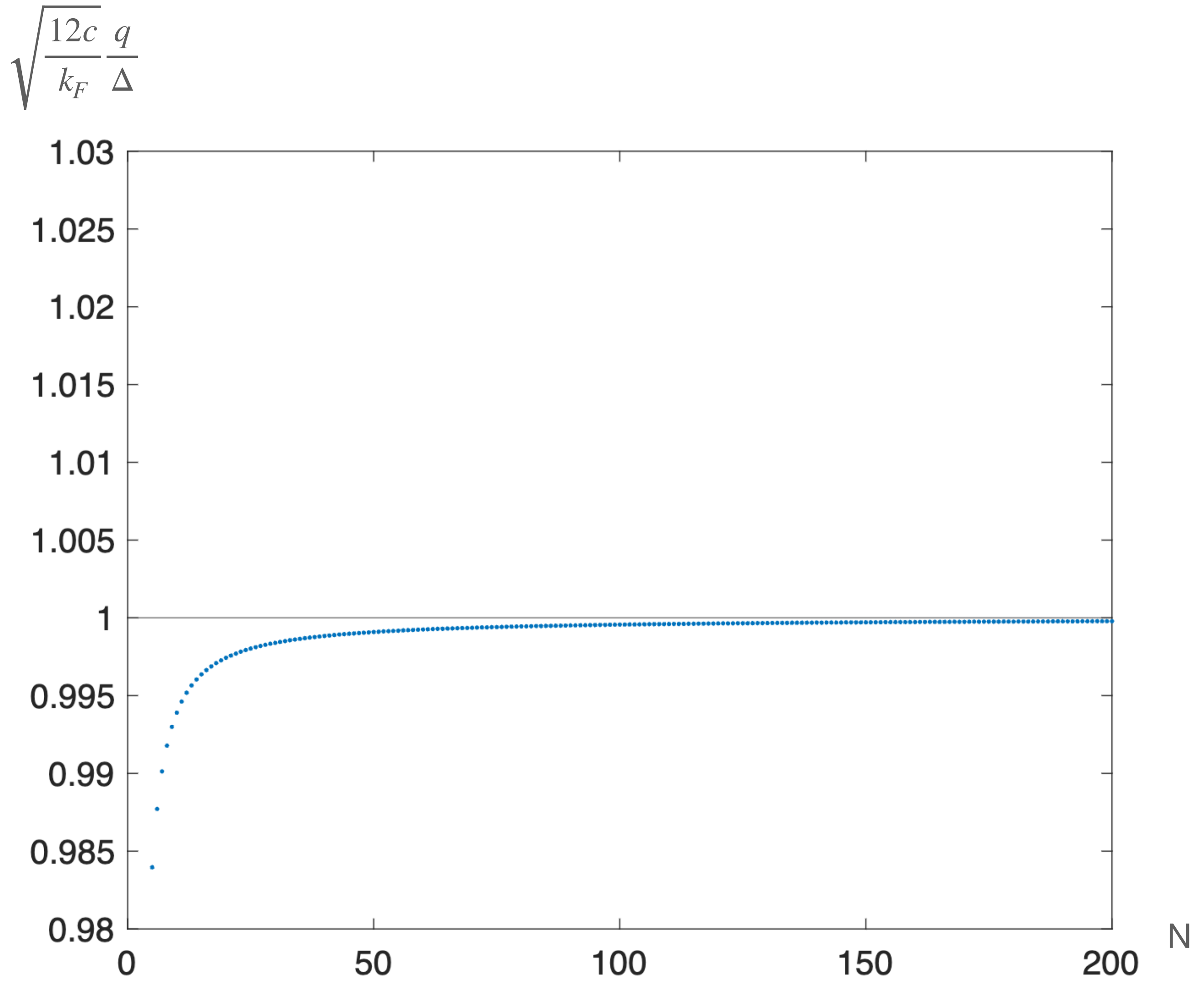
Weak Gravity Conjecture (WGC) | For an extremal BH to decay without leaving remnants, there must be sufficiently light-charged particles that extremal BH can emit.



WGC in CFT4
(∃ counter-examples)

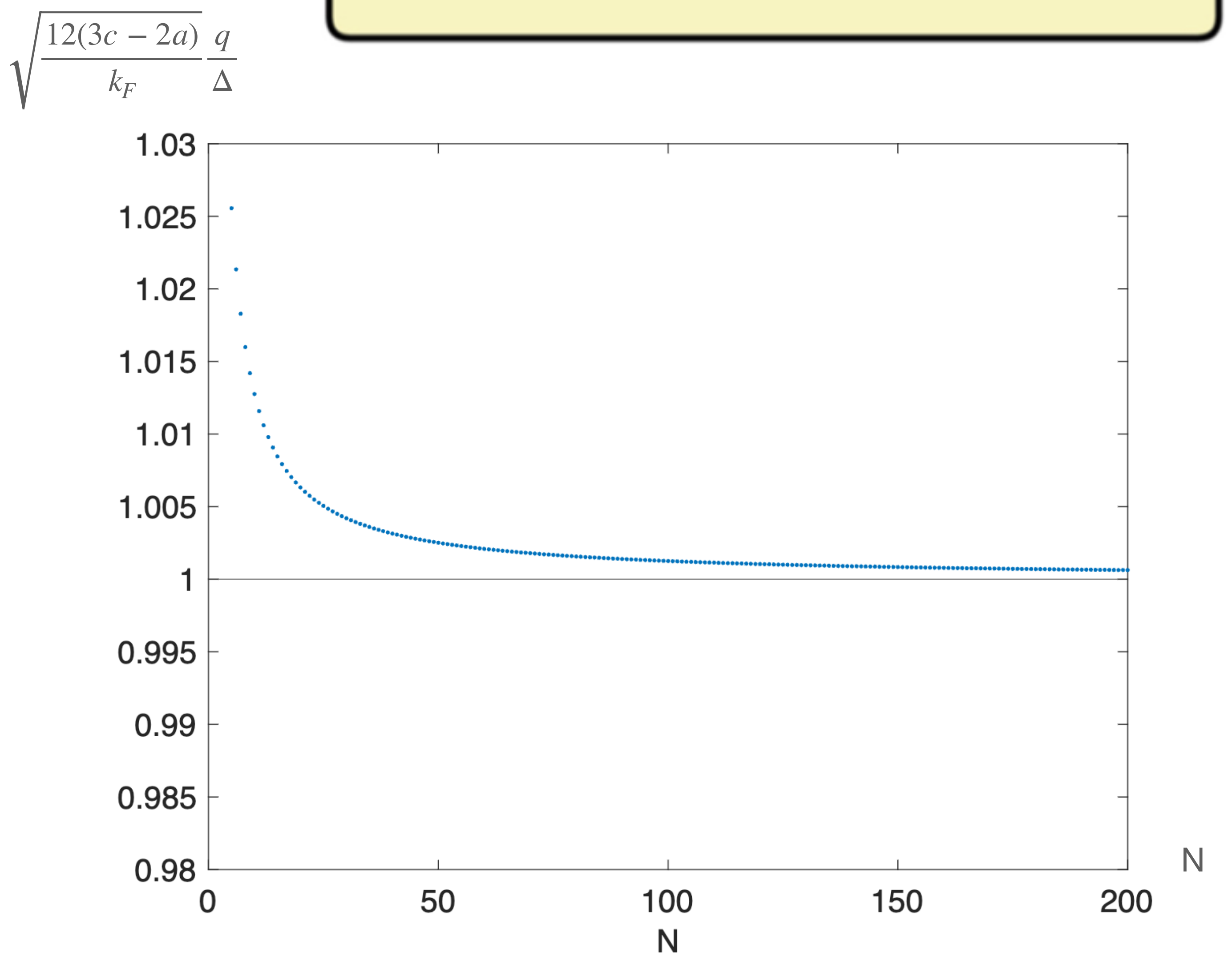
$$\frac{q}{\Delta} \geq \sqrt{\frac{k_F}{12c}}$$

Target: IR fixed points of 4d $\mathcal{N} = 1$ supersymmetric SU(N) gauge theory with particular matter fields.



Modified WGC
(∄ counter-examples)

$$\frac{q}{\Delta} \geq \sqrt{\frac{k_F}{12(3c-2a)}}$$



4d $\mathcal{N} = 1$ superconformal index

$$\mathcal{I} = \mathrm{Tr}_{\mathcal{H}}\left[e^{\pi i R} e^{-\omega_1 (J_1 + R/2)} e^{-\omega_2 (J_2 + R/2)}\right]$$

In the Cardy-like limit $\omega_1, \omega_2 \to 0$,

$$S(J) = \mathrm{Re}(\log \mathcal{I}) \sim (3c - 2a)^{1/3} \cdot J^{2/3}$$

Y206, Dec. 6

CODE STRUCTURES OF RATIONAL NARAIN CFTS

Yuma FURUTA @ RIMS, Kyoto University

arXiv: 2307.04190

Construction A

CFT on a torus $\mathbb{R}^n/\Lambda$

Error correcting code ▶ Narain CFT

Weight enumerator polynomial → Partition function

What kind of Narain CFT can be constructed by a code?

Useful for Averaging!

↓

We detected the condition for some orbifold CFTs to have a code structure.

Mass Deformations of *2d (0,2)* gauge theories and Brane Bricks

Sebastian Franco[#,◊], **Dongwook Ghim**[§], Georgios P. Goulas[#] and Rak-Kyeong Seong[♧]

[#]Physics Department, The City College of the CUNY, New York, USA [◊] Initiative for Theoretical Sciences, The City University of New York, New York, USA [§]Interdisciplinary Theoretical and Mathematical Sciences Program (iTHEMS), RIKEN, Saitama, Japan [♧] Dept. of Mathematical Sciences & Department of Physics, UNIST, Ulsan, Korea

Brane Brick Models : brane construction

- World-volume theory of D1-brane whose transverse geometry is a toric Calabi-Yau 4-fold.
- Its T-dual picture is a Type IIA brane construction which we call 'brane brick'

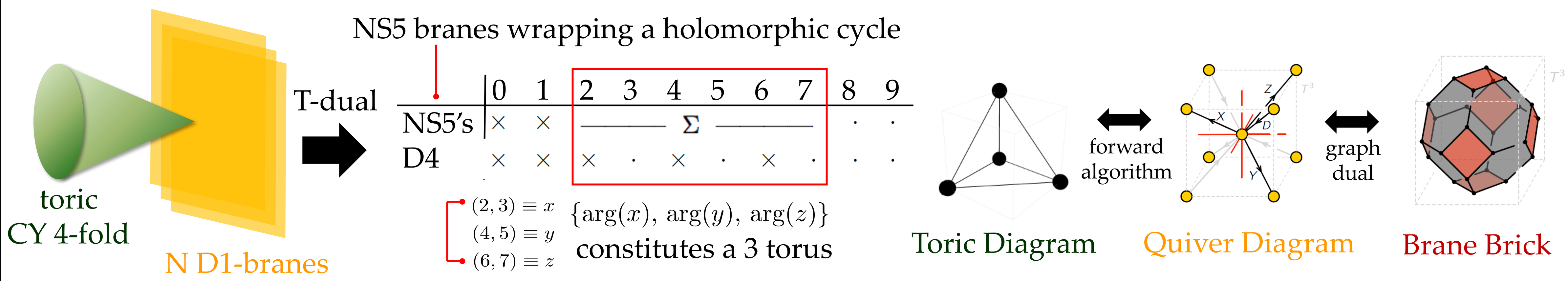


Fig. 1. Brane setup and combinatorial tools for brane brick models

Toric Diagram	(0,2) Gauge Theory	Brane Brick
combinations of connected edges	chiral multiplets	orientable faces
	Fermi multiplets	unorientable faces
volume	vector multiplets	bricks
	J- and E-terms	edges
vertices	**GLSM fields**	**brick matchings**
edges	phase boundary	

Table 1. Dictionary between gauge theory and combinatorial tools

Mass deformations of *(0,2)* quiver gauge theories

- Holomorphic interaction of 2d *(0,2)* gauge theories is given by J- and E-terms, each of which is associated with each Fermi multiplet.

$$\Lambda = \lambda_- - \theta^+ G - i\theta^+\bar{\theta}^+ D_+\lambda_- - \bar{\theta}^+ E\,, \quad \bar{\mathcal{D}}\Lambda = E(\Phi_i)$$

$$L_J = -\int d^2x d\theta^+ \sum_a (\Lambda_a\, J_a(\Phi_i)|_{\bar{\theta}^+=0}) - h.c.$$

- J- and E-terms that are linear in chiral multiplets turn on the mass
➔ A chiral-Fermi pair in the same (or opposite) gauge repre. can trigger mass deformations.

$$(\Lambda_{ij}\,, X_{ij}) \in Q: \quad J'_{ji} = J_{ji}\,,\ E'_{ij} = E_{ij} \pm m X_{ij} \qquad X_{ij} = \mp\frac{1}{m} E_{ij}$$

$$(\Lambda_{ij}\,, X_{ji}) \in Q: \quad J'_{ji} = J_{ji} \pm m X_{ji}\,,\ E'_{ij} = E_{ij} \qquad X_{ji} = \mp\frac{1}{m} J_{ji}$$

Fig. 4. (0,2) Chiral-Fermi pair in a quiver *Q*

Volume of Sasaki-Einstein 7-manifold

For a pair of *(0,2)* theories connected by mass deformation-triggered RG flow, their corresponding Sasaki-Einstein 7-manifold follows **inequality** on the minimal volume; $V_{min} < V'_{min}$.

➔ The volume quantifies **the degrees of freedom in the corresponding 2d gauge theory.**

e.g. the minimized volume of two SE 7-folds for $\mathcal{C}_{++}$ and H_4 ;

$$V_{min}^{\mathcal{C}_{++}} = \frac{8}{27} \simeq 0.296\,, \quad V_{min}^{H_4} = \frac{11+5\sqrt{5}}{64} \simeq 0.347$$

Global symmetry of *2d (0,2)* brane brick theories

$$\Lambda_{ij}: \quad E_{ij} = E^+_{ij} - E^-_{ij}$$
$$\bar{\Lambda}_{ij}: \quad J_{ji} = J^+_{ji} - J^-_{ji}$$
$$\sum_a \mathrm{tr}\,[E_a(\Phi_i) J_a(\Phi_i)] = 0\,.$$

Toric conditions on holomorphic interaction

- The toric symmetry constrains the shape of J- and E-terms ➔ **brick matching** and its correspondence with vertices in toric diagram
- The structure of brick matching and the existence of the **chiral-Fermi pair** ➔ given quiver gauge theory is mass-deformable or not.

Example : mass deformation of C_{++} theory

	J	E
Λ_{12} :	$X_{21}\cdot Y_{12}\cdot Y_{21} - Y_{21}\cdot Y_{12}\cdot X_{21}$	$-Y_{12} + Z_{13}\cdot X_{32} - X_{14}\cdot Z_{42}$
Λ_{34} :	$X_{43}\cdot Y_{34}\cdot Y_{43} - Y_{43}\cdot Y_{34}\cdot X_{43}$	$Y_{34} + Z_{31}\cdot X_{14} - X_{32}\cdot Z_{24}$
Λ_{14} :	$Y_{43}\cdot X_{32}\cdot X_{21} - X_{43}\cdot X_{32}\cdot Y_{21}$	$Z_{13}\cdot Y_{34} - Y_{12}\cdot Z_{24}$
Λ_{32} :	$Y_{21}\cdot X_{14}\cdot X_{43} - X_{21}\cdot X_{14}\cdot Y_{43}$	$Z_{31}\cdot Y_{12} - Y_{34}\cdot Z_{42}$
Λ^1_{23} :	$Y_{34}\cdot Y_{43}\cdot X_{32} - X_{32}\cdot Y_{21}\cdot Y_{12}$	$Z_{24}\cdot X_{43} - X_{21}\cdot Z_{13}$
Λ^2_{23} :	$X_{32}\cdot X_{21}\cdot Y_{12} - Y_{34}\cdot X_{43}\cdot X_{32}$	$Z_{24}\cdot Y_{43} - Y_{21}\cdot Z_{13}$
Λ^1_{41} :	$Y_{12}\cdot Y_{21}\cdot X_{14} - X_{14}\cdot Y_{43}\cdot Y_{34}$	$Z_{42}\cdot X_{21} - X_{43}\cdot Z_{31}$
Λ^2_{41} :	$X_{14}\cdot X_{43}\cdot Y_{34} - Y_{12}\cdot X_{21}\cdot X_{14}$	$Z_{42}\cdot Y_{21} - Y_{43}\cdot Z_{31}$

$$Y_{12} = Z_{13}\cdot X_{32} - X_{14}\cdot Z_{42}$$
$$Y_{34} = -Z_{31}\cdot X_{14} + X_{32}\cdot Z_{24}$$

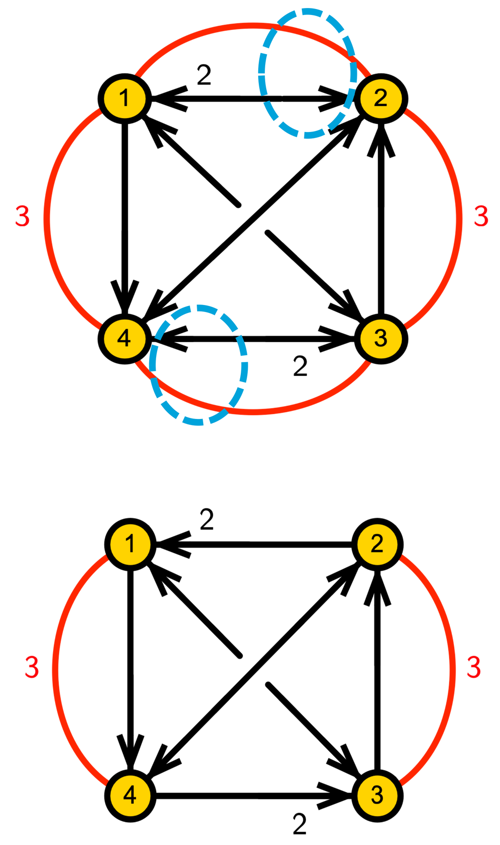


Fig. 5. Quivers of C_{++} and H_4 theory

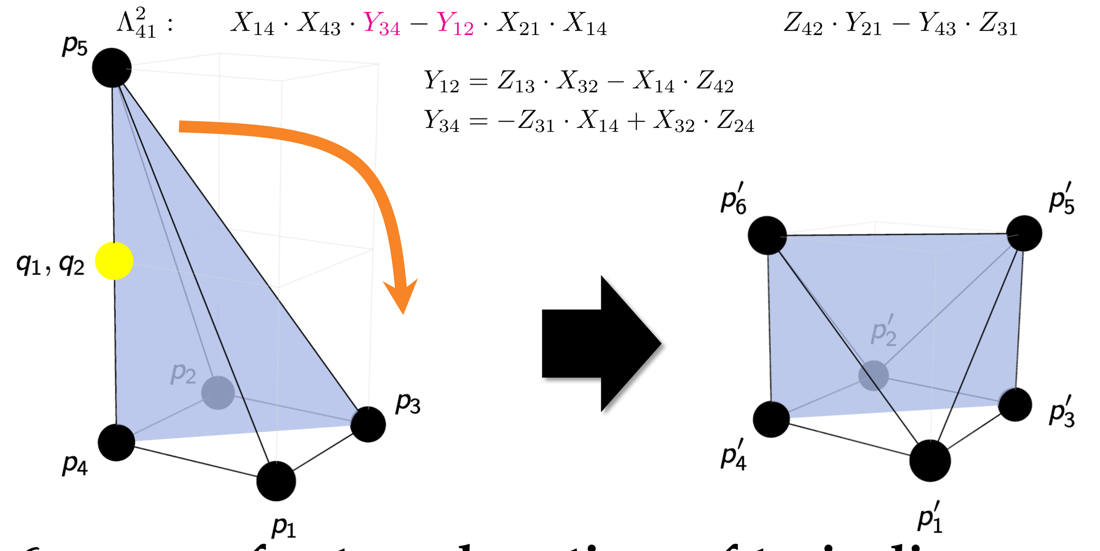


Fig. 6. move of external vertices of toric diagram under 2d mass deformation

Klebanov-Witten deformation and its generalization with Brane Tilings for *4d N=1* gauge theories

- Klebanov-Witten deformation = mass deformation from an orbifold theory $(\mathbb{C}^2/\mathbf{Z}_2 \times \mathbb{C})$ to conifold theory
= **move of vertex** in the toric diagram

$$\mathcal{W} = X_{12}Y_{21}Z_{11} - X_{21}Z_{11}Y_{12} + Z_{11}^2 + X_{21}Y_{12}Z_{22} - X_{12}Z_{22}Y_{21} - Z_{22}^2$$

$$\mathcal{W} = X_{12}Y_{21}Y_{12}X_{21} - X_{12}X_{21}Y_{12}Y_{21}$$

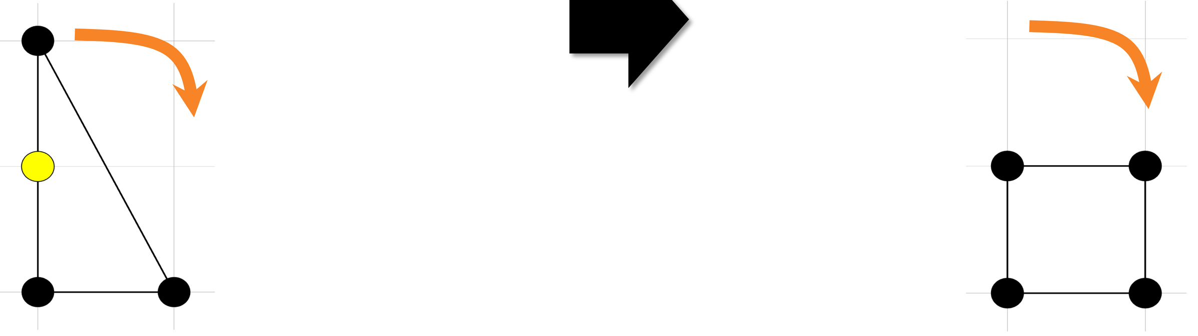


Fig. 2. Two quiver and toric diagrams of gauge theories associated with KW deformation.

- Other mass deformations among *4d N=1* gauge theories
  a. PdP_{4b} to PdP_{4a} theory

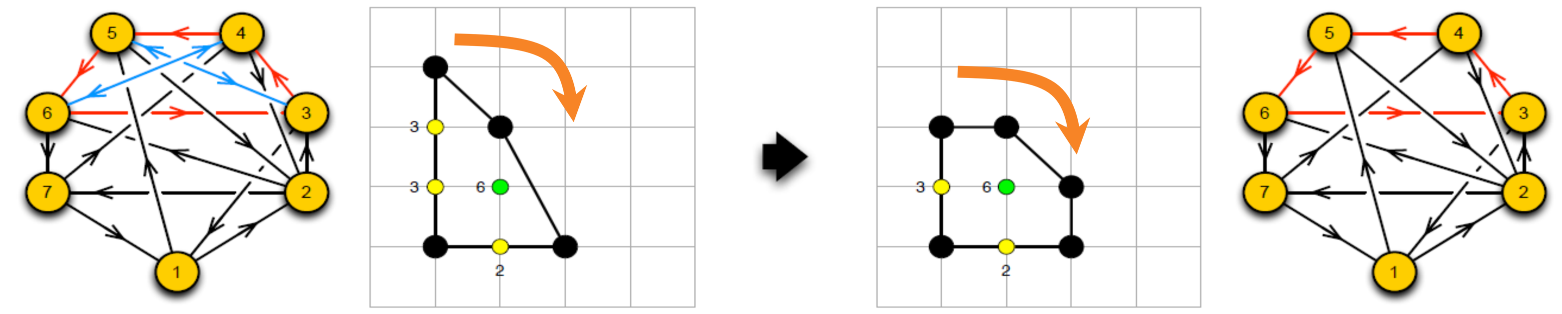


Fig. 3. Quivers of PdP_{4b} and PdP_{4a} theory and the toric diagrams of corresponding toric Calabi-Yau 3-folds*[3]

Reference

[1] S. Franco, D. Ghim, G. P. Goulas, R. -K. Seong, *Mass Deformations of Brane Brick Models*, submitted to JHEP [arXiv:2307. 03220].

[2] S. Franco, D. Ghim, S. Lee, R.-K. Seong and D. Yokoyama, *2d (0,2) Quiver Gauge Theories and D-Branes*, JHEP **09** (2015) 072, [arXiv:1506.03818].

[3] M. Bianchi, S. Cremonesi, A. Hanany, J. F. Morales, D. Ricci Pacifici and R.-K. Seong, *Mass-deformed Brane Tilings*, JHEP **10** (2014) 27, [arXiv:1408.1957].

Tensor renormalization group calculation for 2-flavor Schwinger model

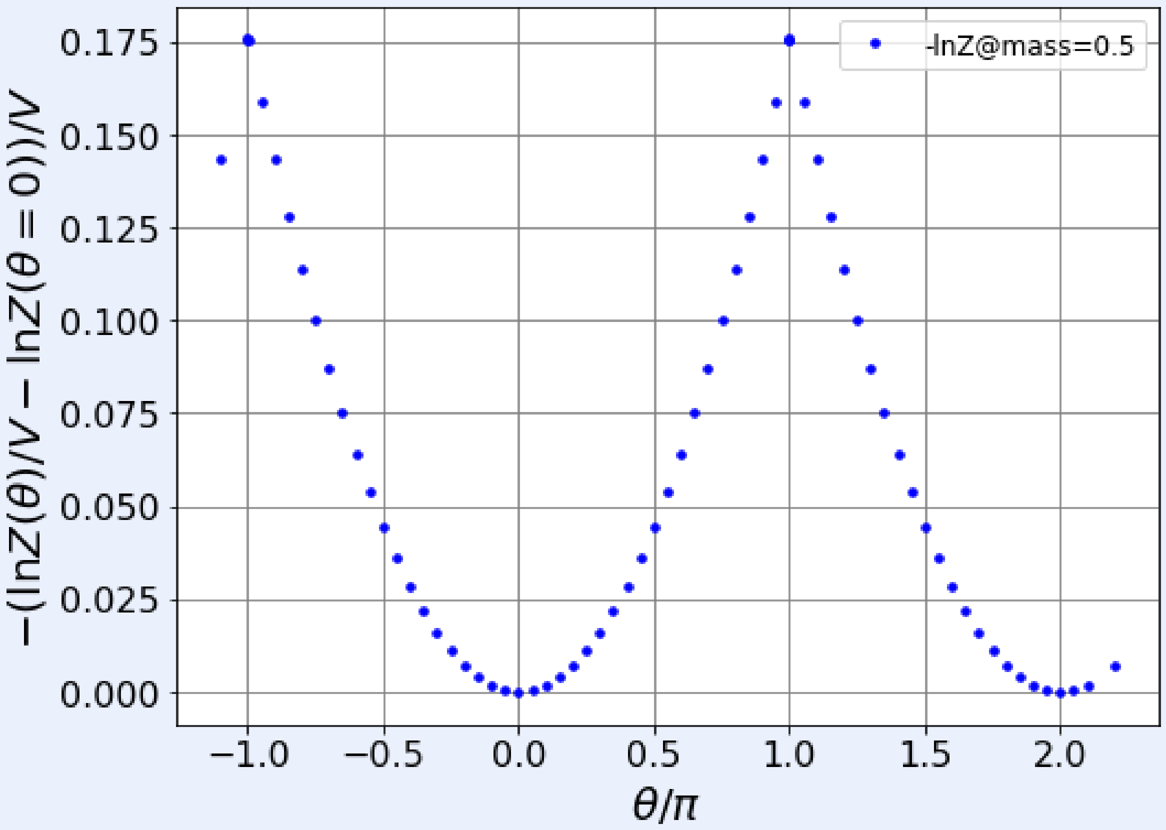
Hayato Kanno (YITP)

On-going work with Shinichiro Akiyama (U. of Tsukuba), Kotaro Murakami (Tokyo Tech.), Shinji Takeda (Kanazawa U.)

YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

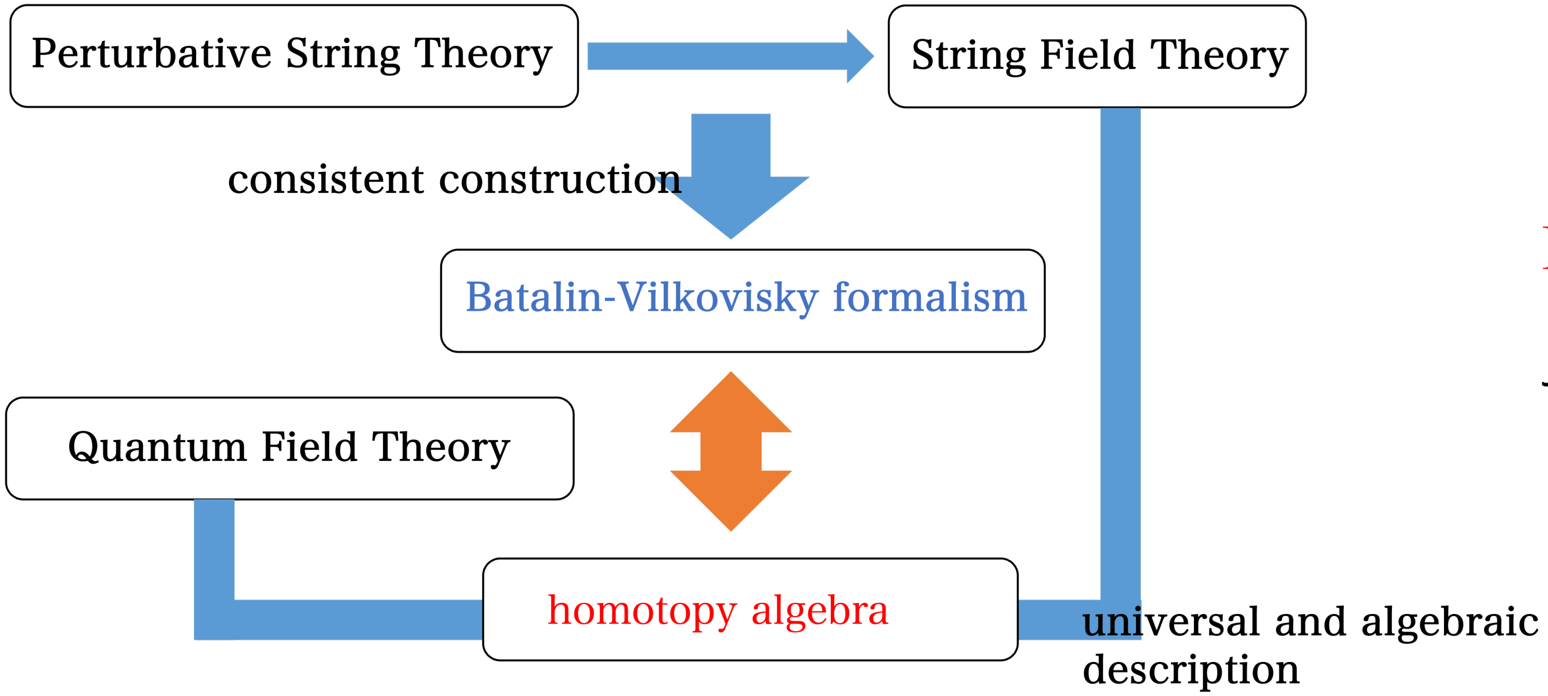
We calculate 2-flavor **Schwinger model** (a 2d toy model of QCD). We use **tensor renormalization group** (TRG), which is a kind of tensor network.

We focus on the θ dependence of Schwinger model. In particular, we respect **2π periodicity** of θ parameter in our calculation. We checked first order phase transition at $\theta = \pi$.



Correlation functions involving Dirac fields from homotopy algebras

Keisuke Konosu
Graduate School of Arts and Sciences, The University of Tokyo

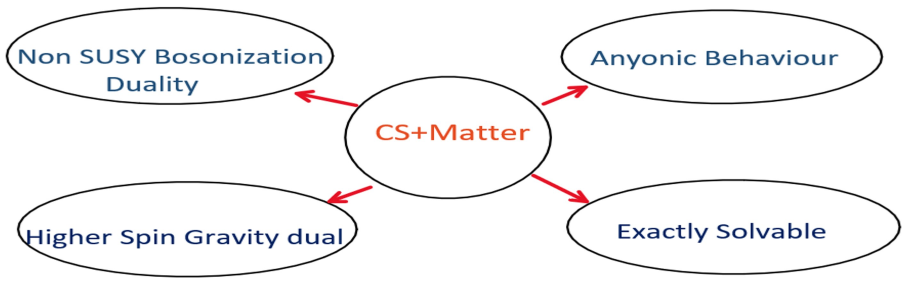


Please visit Y206 !!

Jojiro will present the related topic on Dec.11!!

Exactly Solving Chern Simons+Matter theories at large N

-Dhruva K.S (IISER Pune)



- CS+Matter theory is a Slightly Broken Higher Spin Theory.

$$\partial \cdot J_s = \mathcal{O}\left(\frac{1}{N}\right), s = 3, 4, \cdots$$

- Maldacena and Zhiboedov [1204.3882] used this to find,

$$\langle J_{s_1} J_{s_2} J_{s_3} \rangle_{\rm QF} = \frac{\tilde{N}}{1+\tilde{\lambda}^2}\left[\langle J_{s_1} J_{s_2} J_{s_3} \rangle_{\rm FF} + \tilde{\lambda}\langle J_{s_1} J_{s_2} J_{s_3} \rangle_{\rm odd} + \tilde{\lambda}^2 \langle J_{s_1} J_{s_2} J_{s_3} \rangle_{\rm FB}\right]$$

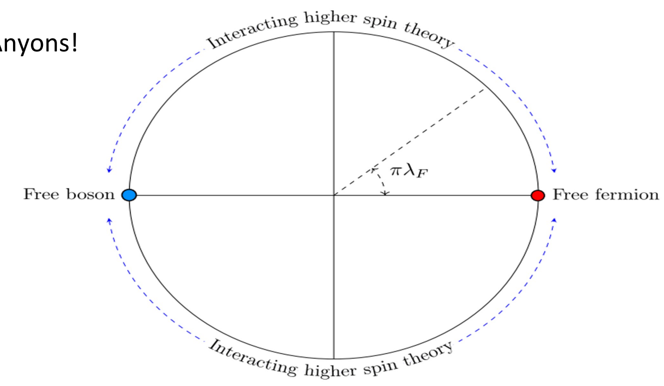
- However, it was later found by Sachin et al that the odd piece can also be obtained from free theory in fact for any CFT!

$$\langle J_{s_1} J_{s_2} J_{s_3} \rangle_{\rm odd} = \langle \epsilon \cdot J_{s_1} J_{s_2} J_{s_3} \rangle_{\rm FF\text{-}FB}$$

- Further, in spinor helicity variables we obtain,

$$\langle J_{s_1} J_{s_2} J_{s_3} \rangle_{\rm QF} = \frac{\tilde{N}}{2}\left[\langle J_{s_1} J_{s_2} J_{s_3} \rangle_{\rm FF+FB} + e^{-i\pi\lambda_f} \langle J_{s_1} J_{s_2} J_{s_3} \rangle_{\rm FF\text{-}FB}\right]$$

- Anyons!



- Similar analysis for higher point functions desirable. More difficult as conformal symmetry does not fix their structures.
- However, by working in Fourier space we were able to obtain results such as,

$$\langle TTTT \rangle_{QF} = \frac{\tilde{N}}{1+\tilde{\lambda}^2}\left(\langle TTTT \rangle_{FF} + \tilde{\lambda}\epsilon \cdot \langle TTTT \rangle_{FF-CB} + \tilde{\lambda}^2 \langle TTTT \rangle_{CB}\right)$$

- We also obtained similar results for arbitrary spin!
- Also extended to the n point case!

Reference:[2207.05101] P.J, S.J, B.S, **D K.S** and A.Z and references therein

Fermi gas formalism for $\hat{D}$-type quiver Chern-Simons theory

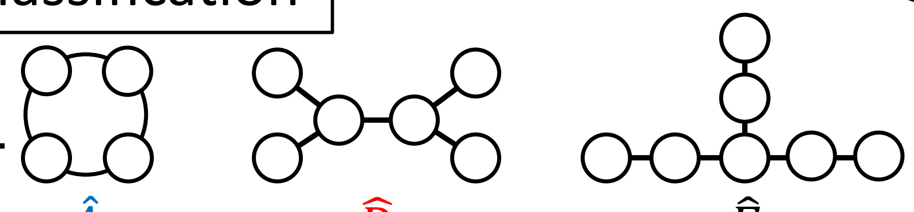
Naotaka Kubo (CJQS, Tianjin Univ.)
Based on arXiv2312.xxxx : with Tomoki Nosaka

3d SUSY Chern-Simons theories

Worldvolume theory of M2-branes

Described by quiver diagram
which determines a gauge group and a matter content.

ADE classification



The partition functions of $\hat{A}$-type quiver theories have been studied.

Z → Fermi gas formalism → $\hat{\rho}$ → ex)

A density matrix of an associated Fermi gas system

Duality: Hanany-witten transition, $SL(2,\mathbb{Z})$ transformation
Symmetry: Weyl group of E_n
Integrability: q-Painlevé equation

We studied $\hat{D}$-type quiver theories.

- We applied the Fermi gas formalism.
- Dualities and symmetries were found.

Thermal one-point functions: CFT's with fermions, large d and large spin

Srijan Kumar, IISc Bangalore.

OPE: $\langle \psi^\dagger(x)\psi(0)\rangle_\beta \sim \sum_{\mathcal{O}} C_{\psi^\dagger\psi\mathcal{O}} |x|^{\Delta_{\mathcal{O}}-2\Delta_\psi} \langle \mathcal{O}\rangle_\beta$

Thermal CFT 2-point function → OPE Inversion Formula → Thermal 1-point function of higher spin currents

For bosons: $\mathcal{O}[n,\ell] \equiv \phi\partial_{\mu_1}\cdots\partial_{\mu_\ell}\partial^{2n}\phi.$

For fermions:

$$\mathcal{O}_+[n,\ell] \equiv \psi^\dagger\gamma_{\mu_1}\partial_{\mu_2}\cdots\partial_{\mu_\ell}\partial^{2n}\psi,$$
$$\mathcal{O}_-[n,l] \equiv \psi^\dagger\gamma^\mu\partial_\mu\partial_{\mu_1}\cdots\partial_{\mu_\ell}\partial^{2n}\psi,$$
$$\mathcal{O}_0[n,\ell] \equiv \psi^\dagger\partial_{\mu_1}\cdots\partial_{\mu_\ell}\partial^{2n}\psi.$$

For **Critical Gross-Neveu model**, We find that the **1-pt functions of three different classes of fermionic operators are related to each other**, e.g.,

$$\langle \mathcal{O}_0[0,l]\rangle = \frac{m_{\text{th}}}{\ell}\langle \mathcal{O}_+[0,l]\rangle$$

where m_{th} =thermal mass,

Even though **no obvious equation of motion relates them.**

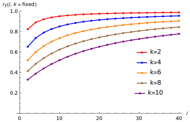
Critical Gross-Neveu model at $d = 2k+1$ dimensions:

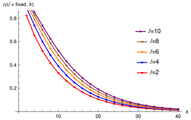
At large spin(ℓ), d =fixed,

$$r_f = \frac{\mathcal{O}_+[0,\ell]|_{\text{critical}}}{\mathcal{O}_+[0,\ell]|_{\text{free}}} \to 1$$

At large d, ℓ=fixed,

$$r_f = \frac{\mathcal{O}_+[0,\ell]|_{\text{critical}}}{\mathcal{O}_+[0,\ell]|_{\text{free}}} \to 0$$





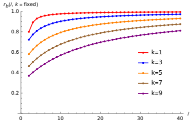
Critical O(N) model at $d = 2k+1$ dimensions:

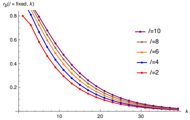
At large spin(ℓ), d =fixed,

$$r_b = \frac{\mathcal{O}[0,\ell]|_{\text{critical}}}{\mathcal{O}[0,\ell]|_{\text{free}}} \to 1$$

At large d, ℓ=fixed,

$$r_b = \frac{\mathcal{O}[0,\ell]|_{\text{critical}}}{\mathcal{O}[0,\ell]|_{\text{free}}} \to 0$$



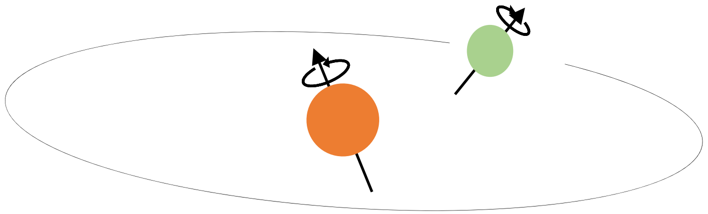


Poincaré invariance of binary dynamics in the post-Minkowskian Hamiltonian approach

Hojin Lee(SNU)

based on 2305.10739, 2307.05626 w/ Sangmin Lee(SNU) and Kanghoon Lee(APCTP)

- The two-body dynamics in GR is one of the most interesting and challenging problem and is only investigated in COM frame



- We constructed two-body Poincaré-symmetry covariant Hamiltonian and Boost Generator at 1PM exact all order in spin and 2PM without spin using Scattering Amplitude techniques

$$V(p,r) = \int \frac{d^3q}{(2\pi)^3} e^{i\vec{q}\cdot\vec{r}} \left[\mathcal{M}(p,p') - \int \frac{d^3k}{(2\pi)^3} \frac{\mathcal{M}(p,k)\mathcal{M}(k,p')}{E_p - E_k + i\epsilon} + \dots \right]$$

$$H^{[1]} = -\frac{4\pi G m_1^2 m_2^2}{E_1 E_2} \int_{\vec{q}} \frac{e^{i\vec{q}\cdot\vec{r}}}{\vec{q}^2 - (q^0)^2} \left[\frac{1}{2} \sum_{s=\pm 1} e^{2s\rho} W_1(s\tau_1) W_2(s\tau_2) \right] U_1 U_2$$

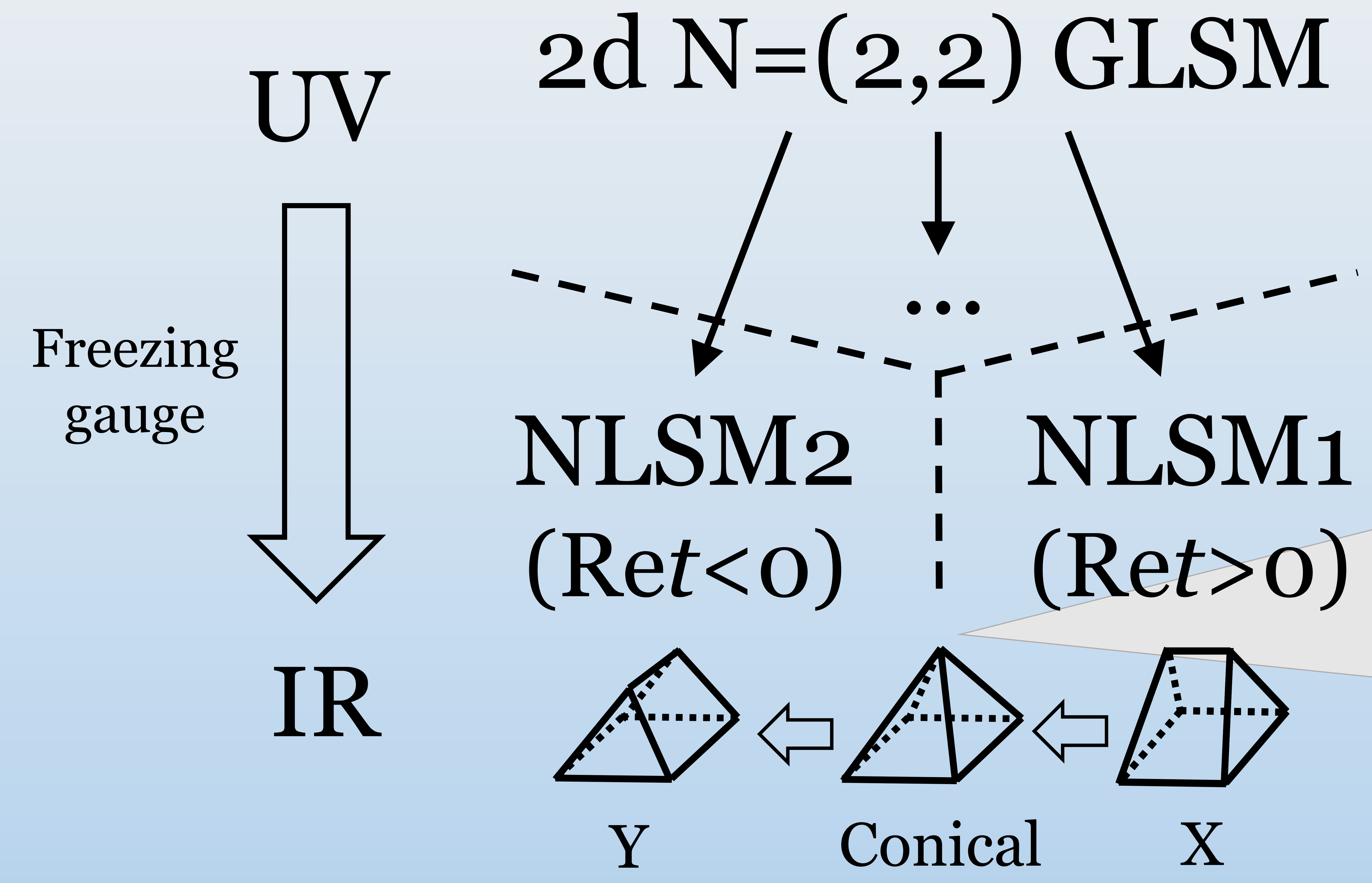
$$H^{[2]} = H_1^{[2]} + H_2^{[2]} + H_3^{[2]} + H_4^{[2]}, \quad \gamma_o = (1 - \vec{u}_c^2)^{-1/2},$$

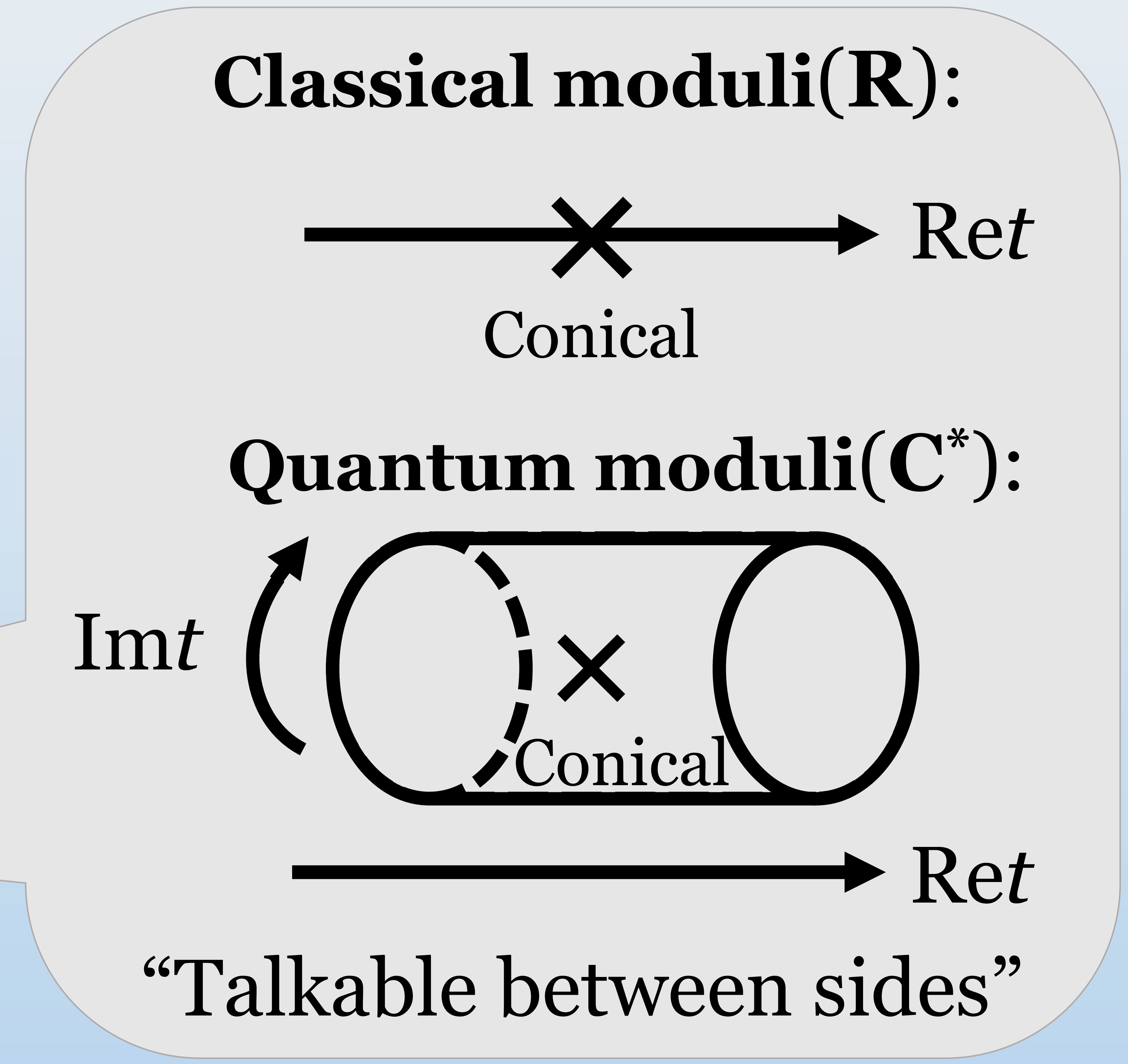
$$H_1^{[2]} = \gamma_c^2 \gamma_o^{-1} H_{1,\mathrm{b}}^{[2]} \quad H_{(2,3)}^{[2]} = \gamma_c^2 H_{(2,3),\mathrm{b}}^{[2]}, \quad H_4^{[2]} = (3\gamma_c^2 - 2\gamma_c^4) H_{4,\mathrm{b}}^{[2]}$$

Brane Transport in CY_3

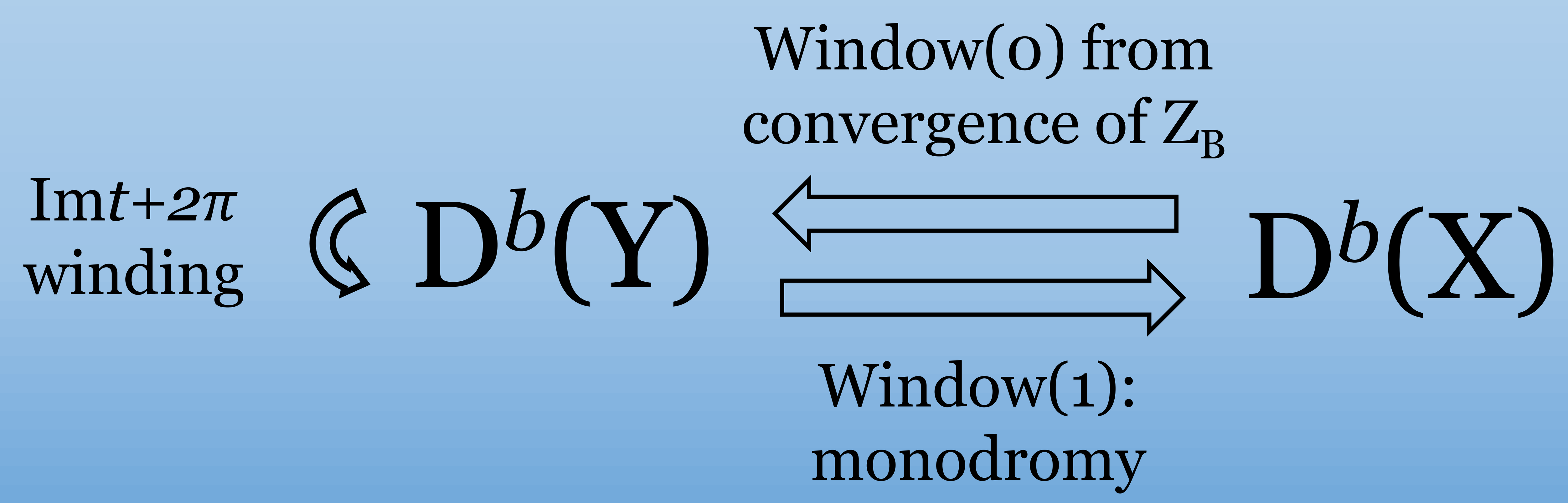
Ban Lin(林般) YMSC

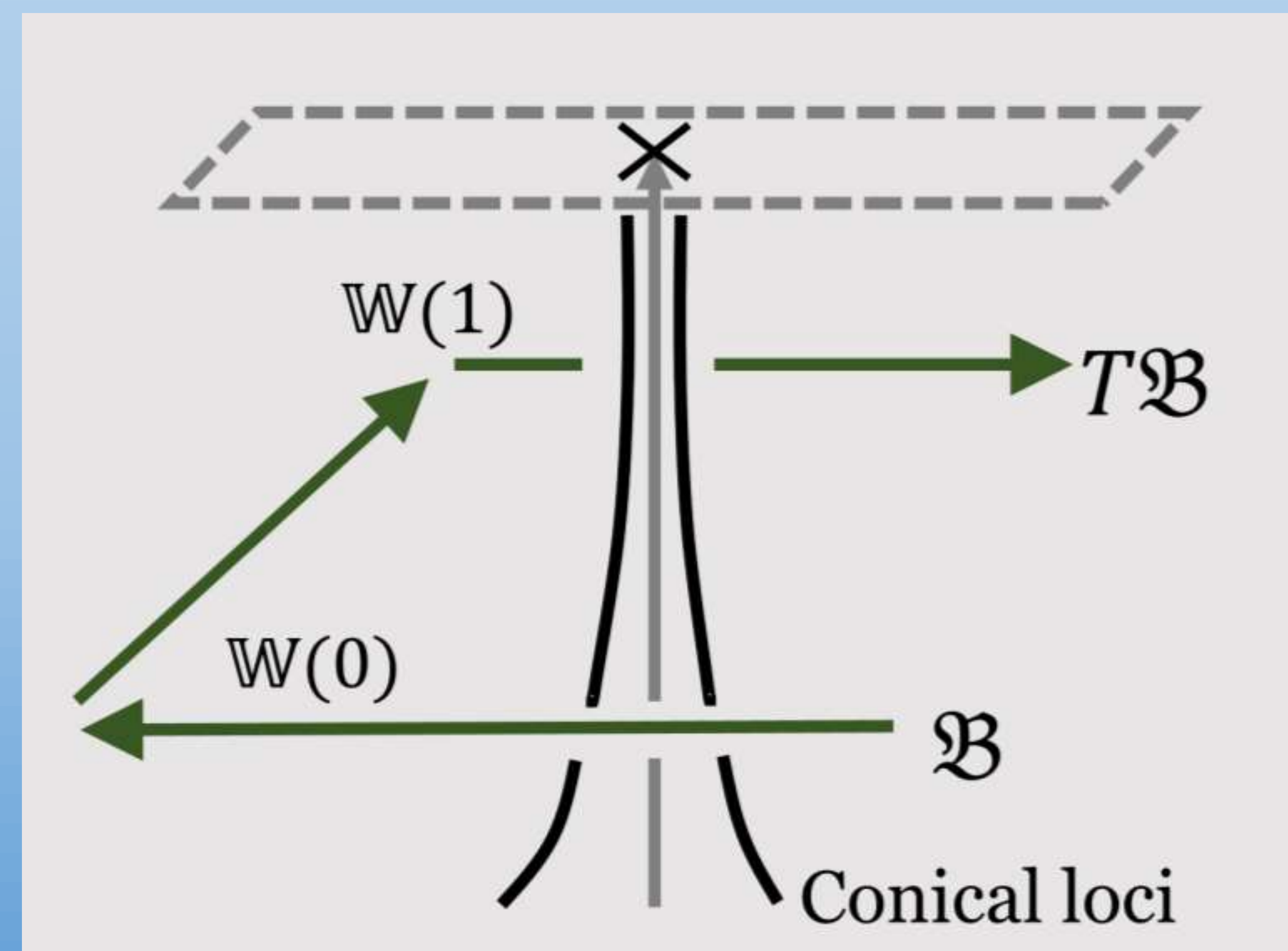
UV unification of SCFTs





Analytic continuation in moduli





Continue with my poster!

Effective gravitational couplings of higher rank supersymmetric gauge theories

Sujoy Mahato, HRI, Prayagraj, India

The 18th Kavli Asian Winter School on Strings, Particles and Cosmology, Yukawa Institute for Theoretical Physics, Kyoto University

When one places a topologically twisted Supersymmetric theories on a curved background, it couples gravitationally to the background spacetime which are topological in nature.

$$Z \sim \int [\ldots]\ \underline{\mathbf{A(u)}^{\chi}\mathbf{B(u)}^{\sigma}}$$

Euler number χ and signature σ, two topological invariants of the background manifold.

Motivation: *These two functions (A, B) are related to the SCFT central charges (c, a).*

For generic $N = 2$ gauge theories, based on the symmetry arguments, the general form of the gravitational couplings (A, B) is conjectured to be,

$$A = \alpha \left(det \frac{du_i}{da_j} \right)^{1/2} \qquad \text{and} \qquad B = \beta \Delta^{1/8}$$

u: gauge invariant coordinate on the coulomb branch and Δ: discriminant of the Seiberg-Witten curve.

One can verify the above relation by using two popular methods used to study these theories

1. Seiberg- Witten Solutions

2. Supersymmetric Localisation

Goal: *Find the constants (α, β) for different supersymmetric gauge theories.*

Posters at Y306

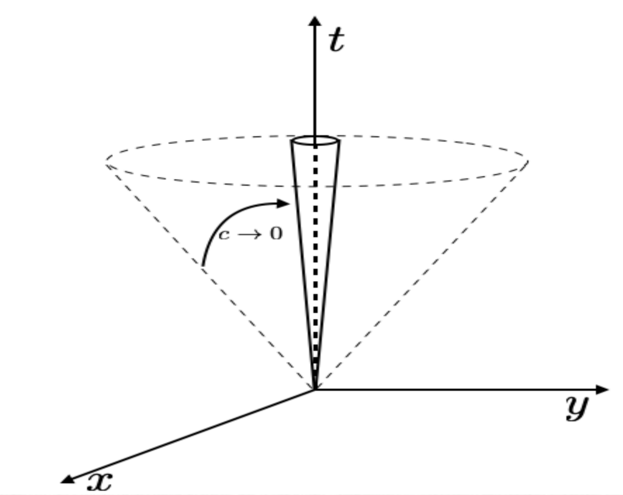
on Dec. 6 (Wed.) Tomorrow 18:00-

CARROLL FERMIONS AND FLAT BAND

SAIKAT MONDAL, ARJUN BAGCHI, RUDRANIL BASU, ARITRA BANERJEE, MINHAJUL ISLAM

Based on arXiv: 2211.11640 (JHEP 03 (2023) 227)

- We will focus on Carrollian theories and wish to build towards an understanding of fermions in Carroll spacetime.



- Carroll group arises from the Poincare group in the $c \to 0$ limit. [*Levy-Leblond, 1965*] [*Sen Gupta, 1966*]

- We propose that Carroll Clifford algebra is given by

$$\{\tilde{\gamma}_\mu, \tilde{\gamma}_\nu\} = 2h_{\mu\nu}\,, \quad \{\hat{\gamma}^\mu, \hat{\gamma}^\nu\} = 2\Theta^{\mu\nu}$$

- We construct two different actions for Carroll fermions and study their properties.

$$\mathcal{S}_1 = \int dt d^{d-1}x\, \bar{\Psi}\, \tilde{\gamma}_0\, \partial_t\, \Psi \qquad \mathcal{S}_2 = \int dt d^{d-1}x\, \bar{\Psi}\, \left(\hat{\gamma}^0\, \partial_t + \hat{\gamma}^i\, \partial_i\right)\Psi$$

- We have argued how Carrollian symmetry is connected to flat-band physics such as 1d chain and Twisted Bilayer Graphene (TBG)…

Interested ! Find Saikat Mondal @Y306 on Dec 6

Tensionless Tales of Compactification

A. Banerjee, R. Chatterjee, Priyadarshini Pandit*
Indian Institute of Technology Kanpur, India (2307.01275)

Y306, Dec 6

Objective: We study the circle compactifications of tensionless bosonic string theory

Tensionless Strings

- These are the extended analogues of massless point particles. [Schild '70s]
- Free string theory is characterized by the tension of the string.

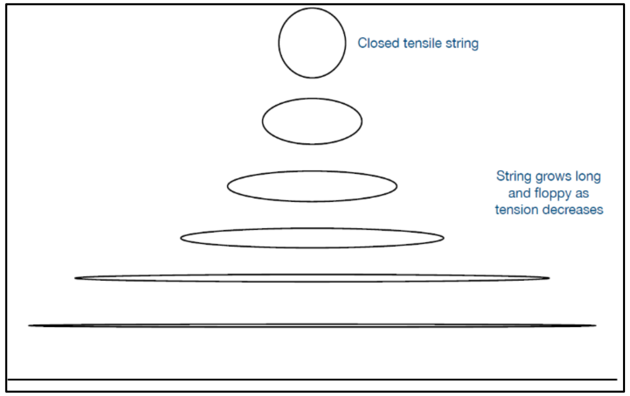
$$T = \frac{1}{2\Pi\alpha'} \quad \text{where } \alpha' = l_s^2$$

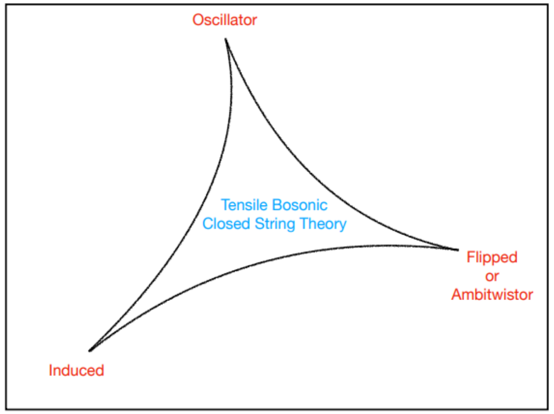
- $T \to \infty$: point particle limit (Classical gravity)
- $T \to 0$: stringy limit (ultra Quantum gravity)
- It can be realised in terms of worldsheet coordinates (τ, σ) scaling as $\{\tau \to \epsilon\tau, \sigma \to \sigma\}$ with $\epsilon \to 0$.

Under this scaling, the two copies of Virasoro algebra scales to BMS_3 algebra.

Why Tensionless Strings?

- The string scattering amplitudes becomes simpler revealing a larger symmetry in this regime.
- Closed string becomes tensionless when it falls on the event horizon of a Schwarzschild black hole.
- A novel closed-to-open transition was discovered in this limit.
- Recently these have been used to build a quantum model of black holes in AdS_3.





Non-perturbative studies of superstring theory: Emergence of expanding universe Y306

Yuhma Asano (U. of Tsukuba), Jun Nishimura (KEK, SOKENDAI), Worapat Piensuk (SOKENDAI), Naoyuki Yamamori (SOKENDAI)

IKKT matrix model — non-perturbative construction of superstring theory

(Spacetime emerges dynamically)

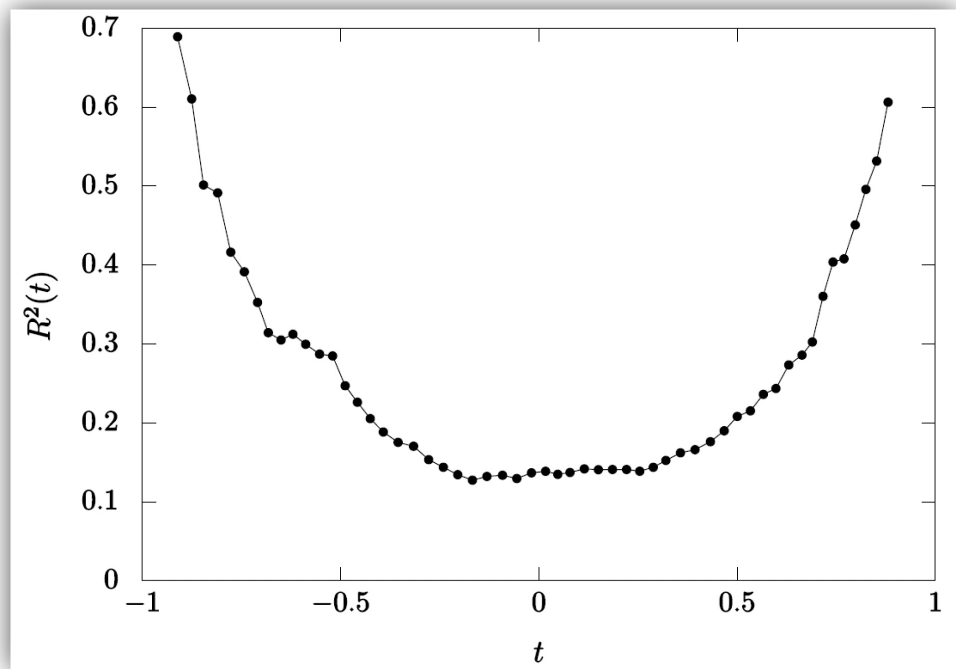
Numerical approach — Monte-Carlo method + other techniques

→ Emergent spacetime is Euclidean and complex

→ Mass term was introduced (classical solutions with expanding behaviour)

This work

- Analytical approach
- Derive all classical solutions at N=2
- Discuss the emergence of spaces



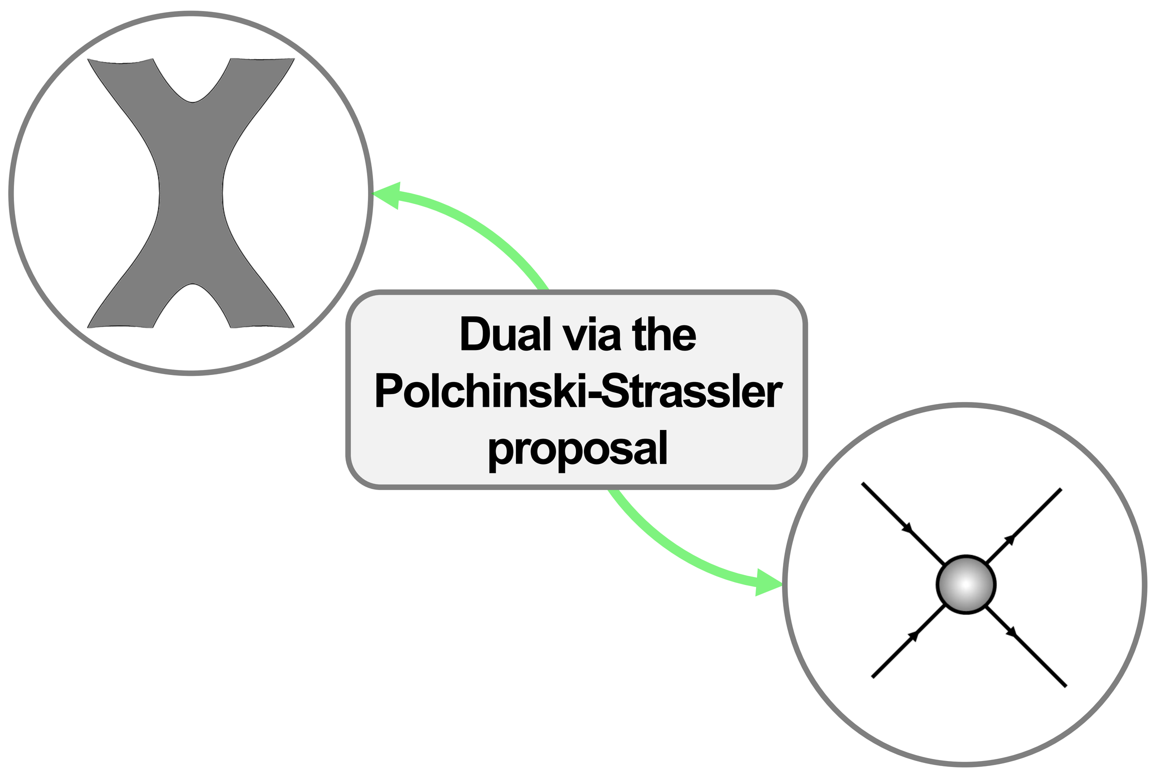
Meson Scattering in Holographic QCD via the Polchinski-Strassler Prescription

Bartosz Pyszkowski

Kyoto University, Yukawa Institute for Theoretical Physics

Synopsis of the Project

- **Outline:** using the hard-wall model [1], we study π and ϱ meson scattering in the high-energy fixed-angle regime via the Polchinski-Strassler prescription [2]
- **Aim:** develop predictions for the non-perturbative scattering of low-lying mesons, and further test our understanding of the gauge/string duality
- **Results and Prospects:** results qualitatively agree with QCD and provide further quantitative data (to be verified); we also aim to extend the proposal to a_1 meson scattering



Background Material

The Polchinski-Strassler Prescription: Statement

- The **Polchinski-Strassler (PS) proposal** argues that a stringy amplitude can be used to approx. a gauge theory amplitude
- The prescription states that in the high-energy fixed-angle regime we have

$$\mathcal{A}_{4d} \sim \int_0^{z_0} dz\sqrt{-g} \times \mathcal{M}_{5d}|_{\eta_{\mu\nu}\to g_{\mu\nu}} \times \prod_{i=1}^{n} \psi_i$$

- **Rescaling the stringy amplitude** recovers the hard scattering behaviour in the high-energy fixed-angle regime [2]
- Here, ψ_i are the wavefunctions of the states being scattered

The Polchinski-Strassler Prescription: A Simple Example

- Consider the following action with a *diagonal spacetime metric* $g^{MN} = g^{MN}(z)$

$$S = \int d^4x dz\sqrt{-g}\,\big(g^{\mu\nu}\partial_\mu\Phi\partial_\nu\Phi + g^{zz}\partial_z\Phi\partial_z\Phi - M^2\Phi^2 - \lambda\Phi^3\big)$$

- Take the following *mode expansion* for Φ (with a suitable wave equation for ϕ_n)

$$\Phi(x^\mu, z) = \sum_{n=0}^{\infty} \varphi^{(n)}(x^\mu)\phi_n(z)$$

- In the high-energy limit, the two-to-two $\varphi^{(0)}$ scattering **obeys the PS proposal**

$$A_{4d} \sim \int dz\sqrt{-g} \times A_{5d}|_{\eta_{\mu\nu}\to g_{\mu\nu}} \times \phi_0^4(z)$$

Relevant Insights From QCD and Holographic QCD

- In the high-energy fixed-angle regime, the **constituent counting rule** states that amplitudes of *low-lying hadrons* scale as

$$\sim s^{\frac{d}{2}-\frac{d-2}{4}n} \times g(\theta)$$

n is the no. of hard constituents taking part in the scattering

- In our holographic QCD setup, open strings are treated as dual to mesons
- At *low-energies*, holographic models **mimic** QCD, but **deviate** at *high-energies* due to the *large 't Hooft coupling* of the string dual

Current Results

High-Energy Behaviour

- To describe two-to-two meson scattering, we insert a **Veneziano-like** amplitude into the PS prescription

$$\mathcal{M}_{5d} \propto \frac{\Gamma(-\frac{s}{2})\,\Gamma(-\frac{t}{2})}{\Gamma(1-\frac{s}{2}-\frac{t}{2})} \times K\left(\xi_{1\sim4}, k_{1\sim4}\right)$$

- Meson wavefunctions and other details are taken from the hard-wall model [1]
- Apply the high-energy fixed-angle limit

$$\sim \int dz\, z^{-d-1} \times \Big[(z^2 s)^{q_n} e^{-f(\theta_i)\alpha' z^2 s} \times z^n s^{\frac{1}{4}(n+n_v)}\Big] \times z^{(d-3)\frac{n}{2}+\frac{n_v}{2}}$$

- Simplify to find the **expected behavior**

$$\sim s^{\frac{d}{2}-\frac{d-2}{4}n} \times \int_0^{z_0\sqrt{s}} d\tilde{z}\, F(\theta, \tilde{z}, n_a)$$

Quantitative Results

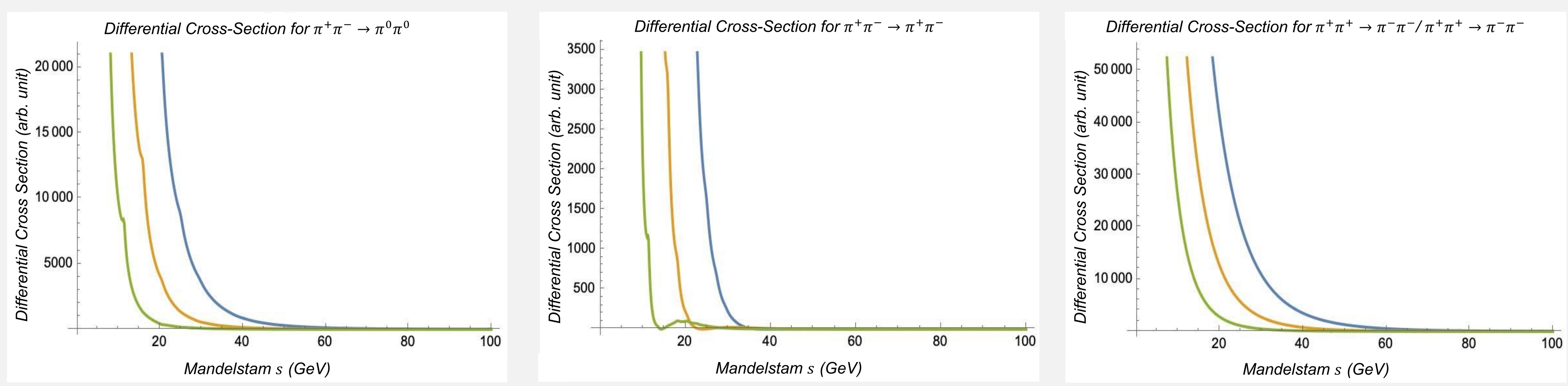


Figure 1. Differential cross-sections for the selected two-to-two $\pi\ \pi \to \pi\ \pi$ processes, where the scattering angle values were fixed. Here, the π mesons are treated as massless, and the high-energy limit was applied. Numerical analysis (not demonstrated herein) shows that the results obey to the constituent counting rules.

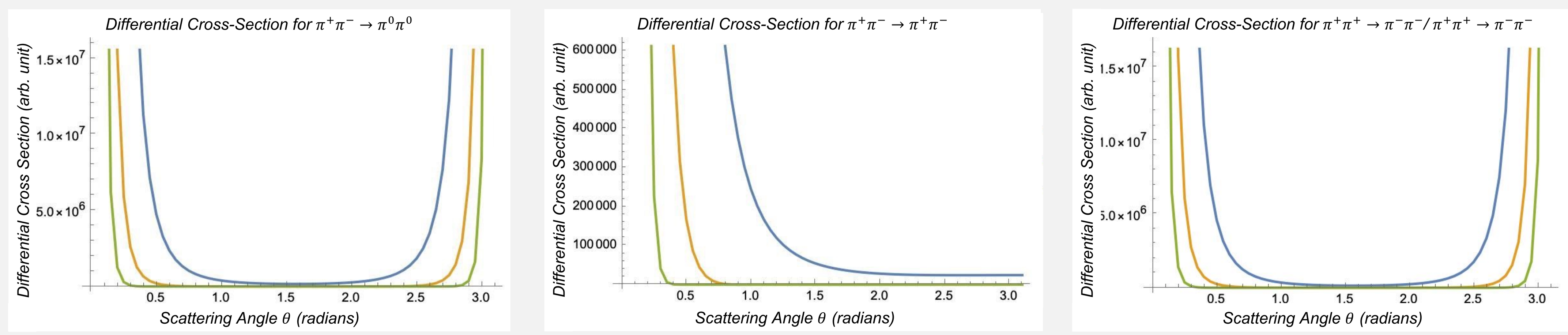


Figure 2. Differential cross-section for the selected two-to-two $\pi\ \pi \to \pi\ \pi$ processes, where Mandelstam s values were fixed. The symmetry of the differential cross-sections in the first and third graphs around the scattering angle $\theta = \pi/2$ above is an extension of the presence of identical particles in initial or final states.

Acknowledgements

The project presented herein is carried out in equal collaboration with Adi Armoni, Dorin Weissman, and Shigeki Sugimoto. BP would also like to thank Kenya Ikeda and Zongzhe Du for helpful discussions.

Bibliography

[1] J. Erlich et al., *Phys. Rev. Lett.* **95**, 261602 (2005).
[2] J. Polchinski and M. J. Strassler, *Phys. Rev. Lett.* **88**, 031601 (2002).
[3] S. J. Brodsky and G. R. Farrar, *Phys. Rev. Lett.* **31**, 1153 (1973).

Marginal deformation of $\mathcal{N} = 2$ SCFTs & Spin-2 spectrum

Sourav Roychowdhury

Indian Association for the Cultivation of Science, India

Collaboration with Dibakar Roychowdhury (IIT-Roorkee), India

Based on arXiv : 2301.12757 , JHEP

Kavli Asian Winter School 2023

Yukawa Institute for Theoretical Physics, Japan

Dec 6, 2023

Overview

- We study spin 2 spectrum associated with marginal deformation of $\mathcal{N} = 2$ SCFTs in $4d$ holographically (Gaiotto-Maldacena background).
- Analytically estimate the spectra for leading order in the deformation parameter (γ) .
- Marginal deformed Gaiotto-Maldacena backgrounds

$$
\begin{aligned}
ds^2_{10,IIA} &= 4f_1 ds^2_{AdS_5} + f_2(d\sigma^2 + d\eta^2) + f_3 d\chi^2 \\
&+ \frac{f_3 \sin^2\chi}{1 + \gamma^2 f_3 f_4 \sin^2\chi} d\xi^2 \\
&+ \frac{f_4}{1 + \gamma^2 f_3 f_4 \sin^2\chi} (d\beta - \gamma f_5 \sin\chi d\chi)^2 \ ,
\end{aligned} \tag{1}
$$

- We get a continuous spectra associated with the breaking of the spherical symmetry in the internal manifold .

Thank You !

Anisotropy in chaotic dynamics present for two different string orientations in both **String and Einstein Frame** using the Einstein-Maxwell-dilaton model.

Anisotropic and frame dependent chaos of suspended strings from a dynamical holographic QCD model with magnetic field

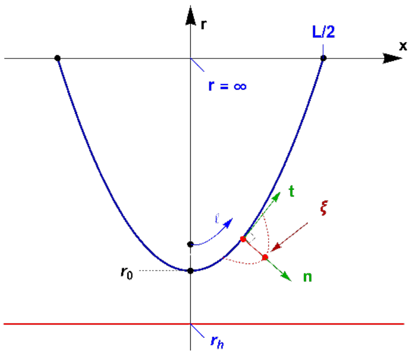
Bhaskar Shukla, David Dudal and Subhash Mahapatra

1 Introduction

- We study the string motion and its chaotic behaviour in the presence of a background magnetic field.
- The string motion is described by the NG action,

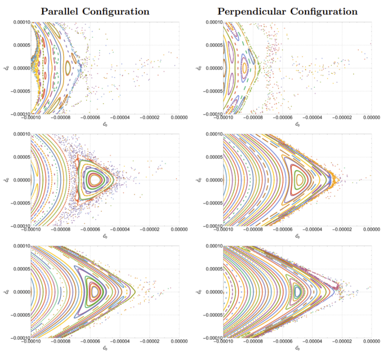
$$S = -\frac{1}{2\pi\alpha'}\int dtd\ell\sqrt{-h}$$

2 Chaos of perturbative string

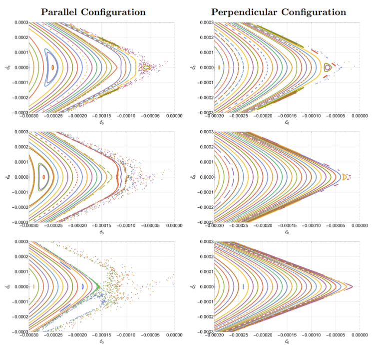


3 Poincaré Sections

3.1 String Frame

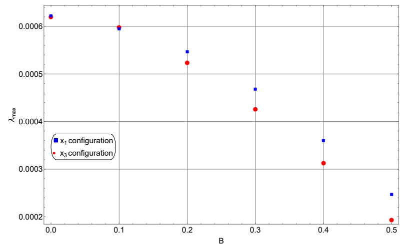


3.2 Einstein Frame

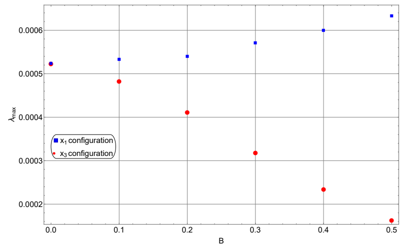


4 Lyap. Exponents

4.1 String Frame



4.2 Einstein Frame



5 MSS bound

Largest Lyapunov exponent remains below the **MSS bound** in both String and Einstein frame.

SCAN ME

← Download the paper

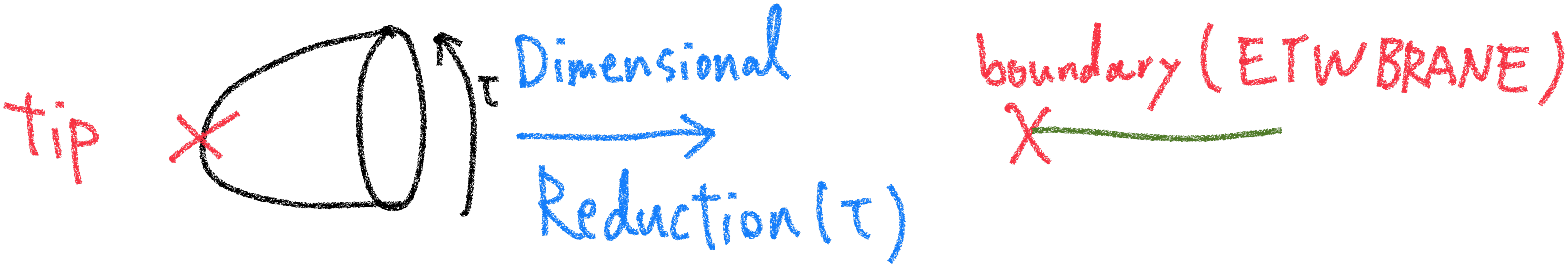
NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

YITP YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

End-of-the-world branes from Dimensional Reduction

Yu-ki Suzuki(YITP) collaboration with Shigeki Sugimoto(Kyoto University)

- The end-of-the-world brane (ETW) is a Neumann-like boundary condition brane in gravity.
- We find that through dimensional reduction of the cigar geometries the ETW branes are created and we can fix the tension of them.
- We discuss its application to string theory and holography.

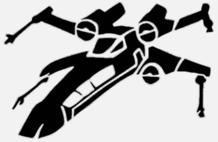


(Elliptic) Symbol Integration

Song He (何颂), <u>Yichao Tang</u> (唐一朝) from ITP, CAS, Beijing

Prequel: Attack of the MPL

$$\mathcal{I} = \int F\, \mathrm{d}\kappa, \quad DF = H\, D\varphi,$$

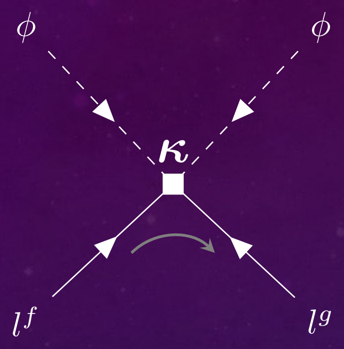


$$[D\kappa \wedge D\varphi]^{(1,1)} \xlongequal[\text{Residues}]{\text{Match}} \mathrm{d}\mu \wedge \delta w,$$

$$\mathcal{S}(\mathcal{I}) = \text{boundary} + \mathcal{S}\left(\int H\, \mathrm{d}\mu\right) \otimes w.$$

The Elliptic Strikes Back... @Y306, Dec.6

QUANTUM EFFECTS ON NEUTRINO PARAMETERS FROM A FLAVORED GAUGE BOSON



Effective operator for neutrino masses

Loop corrections? Running?

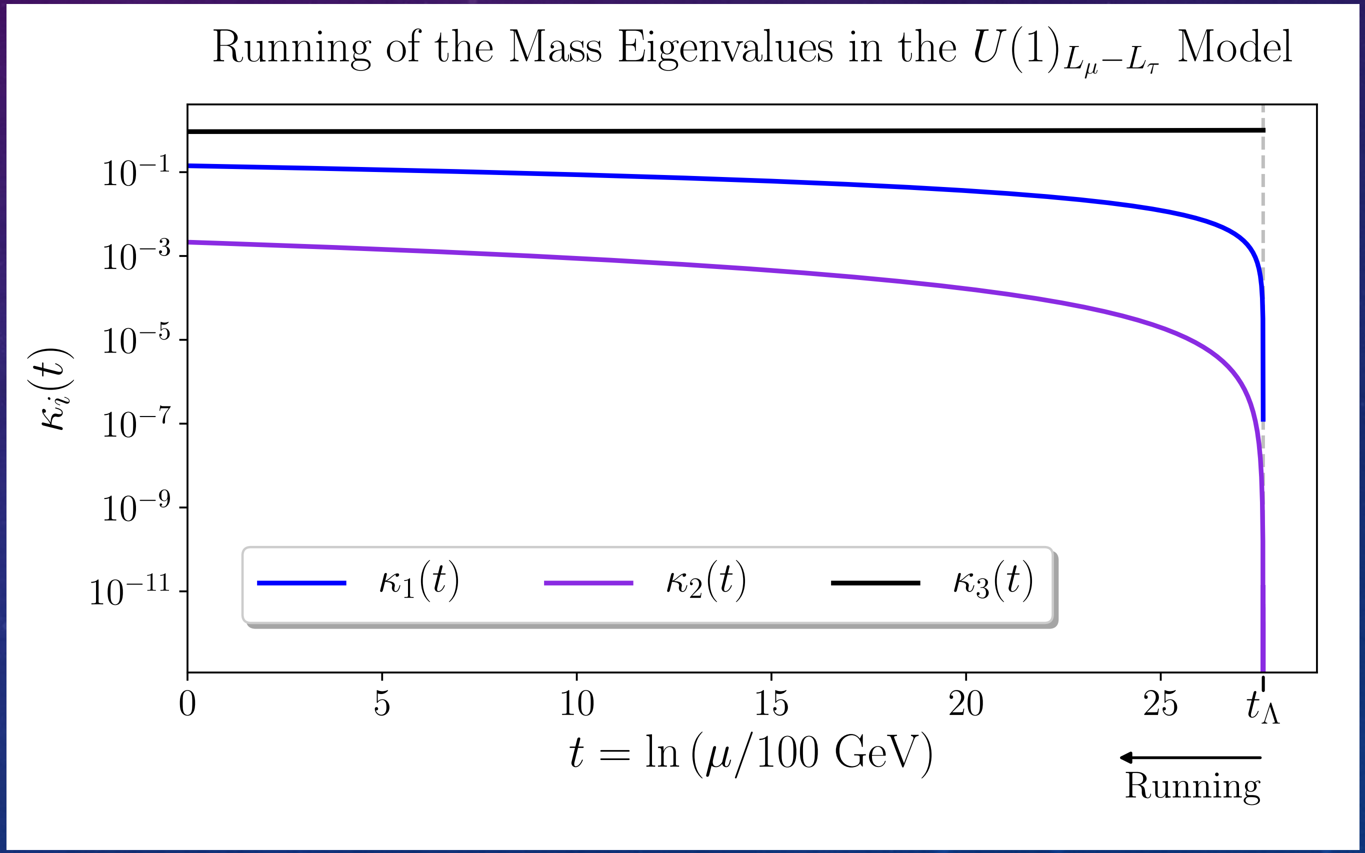
Flavor gauge extensions?

$$\mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \times \mathrm{U}(1)_{L_\mu - L_\tau}$$

$$\Downarrow$$

Special diagram!

GENERATE NEUTRINO MASSES FROM ZERO VIA ONE-LOOP RUNNING!



Lefschetz thimble analysis of the Lorentzian IKKT matrix model around its classical solutions

Ashutosh Tripathi (KEK/SOKENDAI)

On going work with Y. Asano (U. of Tsukuba), J. Nishimura (KEK), C. Y. Chou (KEK), N. Yamamori (KEK) and W. Piensuk (KEK)

(Dec 6 @ Y306)

- We numerically investigate the bosonic Lorentzian IKKT matrix model with a mass term.

$$Z = \int dA e^{i(S_b + S_m)} = \int dA e^{-S_{eff}},$$

A_μ - N×N Hermitian matrices

$$S_{eff} = \underbrace{-i\frac{N}{4}\mathrm{tr}\{[A_\mu, A_\nu][A^\mu, A^\nu]\}}_{\text{bosonic action}(S_b)} - \frac{i}{2}\underbrace{N\gamma\{e^{i\epsilon}\mathrm{tr}(A_0)^2 - e^{-i\epsilon}\mathrm{tr}(A_I)^2\}}_{\text{Lorentz invariant mass term}(S_m)\ \text{(regulator)}}$$

partition function diverges without mass term!

- complex effective action → model suffers from sign problem (simulations→difficult).
- We employ generalized Lefschetz thimble method(GTM) → to overcome the sign problem.
- Here, we simulate the N=2 case of the above model.
- Results → Surprising properties due to non-compactness of the Lorentz symmetry.
  Why is it worthwhile to study the N=2 case numerically?

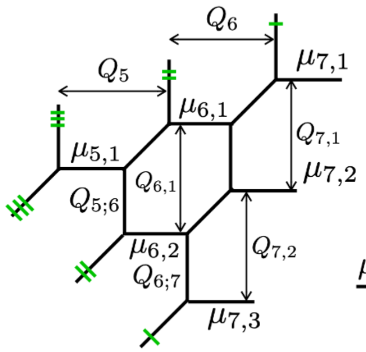
Details→ Poster!

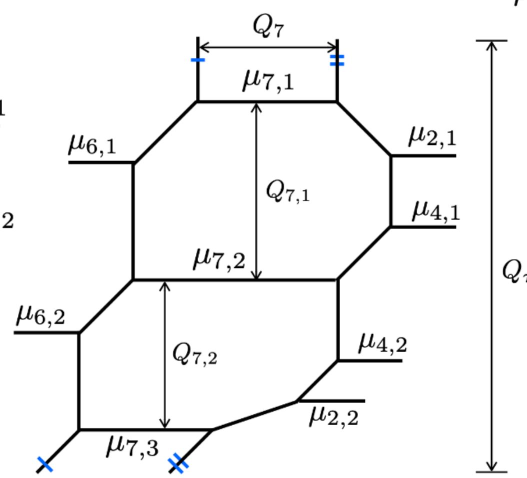
DE-type little strings from glued brane webs

18th KAWS, YITP

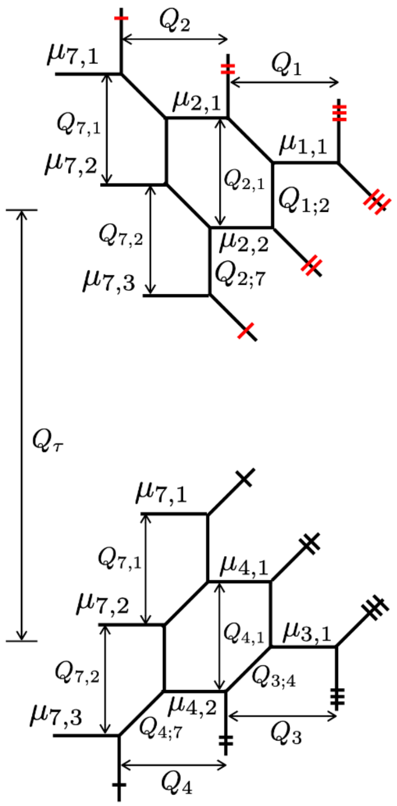
Xingyue Wei, UESTC. Based on arXiv:2212.07344, Kim, Sugimoto, W, Yagi.

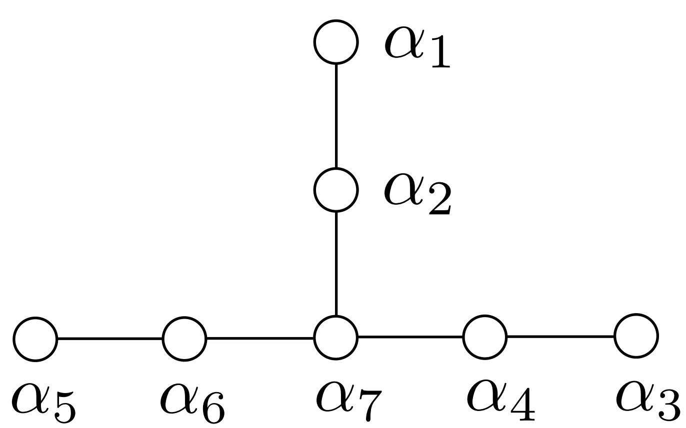
Trivalent gluing
+ Non-parallel self-gluing





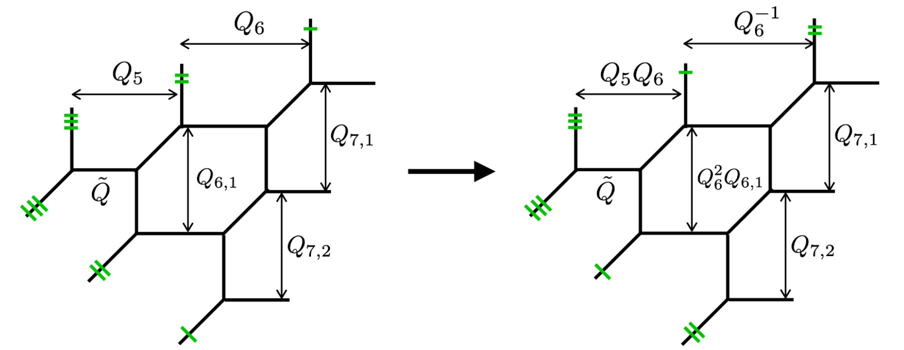
E_6-type LST

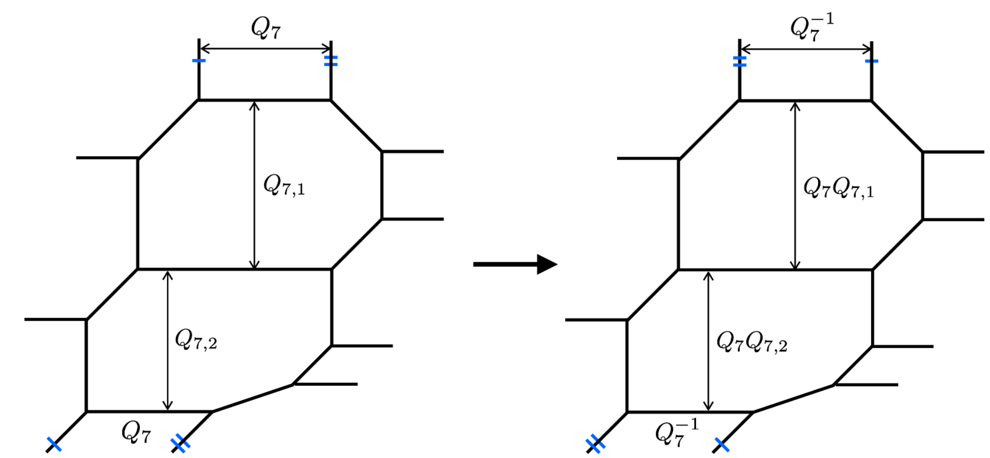




Weyl reflections:

$$\begin{cases} r_{\alpha_1}: & \alpha_1 \to \alpha_1^{-1},\ \alpha_2 \to \alpha_2\alpha_1; \\ r_{\alpha_2}: & \alpha_2 \to \alpha_2^{-1},\ \alpha_1 \to \alpha_1\alpha_2,\ \alpha_7 \to \alpha_7\alpha_2; \\ r_{\alpha_3}: & \alpha_3 \to \alpha_3^{-1},\ \alpha_4 \to \alpha_4\alpha_3; \\ r_{\alpha_4}: & \alpha_4 \to \alpha_4^{-1},\ \alpha_3 \to \alpha_3\alpha_4,\ \alpha_7 \to \alpha_7\alpha_4; \\ r_{\alpha_5}: & \alpha_5 \to \alpha_5^{-1},\ \alpha_6 \to \alpha_6\alpha_5; \\ r_{\alpha_6}: & \alpha_6 \to \alpha_6^{-1},\ \alpha_5 \to \alpha_5\alpha_6,\ \alpha_7 \to \alpha_7\alpha_6; \\ r_{\alpha_7}: & \alpha_7 \to \alpha_7^{-1},\ \alpha_2 \to \alpha_2\alpha_7,\ \alpha_4 \to \alpha_4\alpha_7,\ \alpha_6 \to \alpha_6\alpha_7. \end{cases}$$





Certain flop transitions:

$$\begin{cases} Q_1 \to Q_1^{-1},\ Q_2 \to Q_2Q_1; \\ Q_2 \to Q_2^{-1},\ Q_1 \to Q_1Q_2,\ Q_7 \to Q_7Q_2; \\ Q_3 \to Q_3^{-1},\ Q_4 \to Q_4Q_3; \\ Q_4 \to Q_4^{-1},\ Q_3 \to Q_3Q_4,\ Q_7 \to Q_7Q_4; \\ Q_5 \to Q_5^{-1},\ Q_6 \to Q_6Q_5; \\ Q_6 \to Q_6^{-1},\ Q_5 \to Q_5Q_6,\ Q_7 \to Q_7Q_6; \\ Q_7 \to Q_7^{-1},\ Q_2 \to Q_2Q_7,\ Q_4 \to Q_4Q_7,\ Q_6 \to Q_6Q_7. \end{cases}$$

The affine E_6 Weyl symmetry corresponds to exchanging external parallel NS-charged branes.

Please see my poster for more details.

Analytical study of the bosonic Lorentzian IKKT matrix model at large D

Naoyuki Yamamori (SOKENDAI)

based on collaboration with : Y. Asano (Univ. of Tsukuba), J. Nishimura (KEK,SOKENDAI) W. Piensuk (SOKENDAI)

IKKT matrix model : Non-perturbative formalism of superstring theory

bosonic Lorentzian model with Lorentz invariant mass term

$$Z = \int dA e^{i(S_b + S_m)}$$ SO(9,1) symmetry

A_μ : N×N Hermitian matrices

bosonic action

$$S_b = -\frac{N}{4}\mathrm{tr}[A_\mu, A_\nu][A^\mu, A^\nu]$$

mass term

convergence factor

$$S_m = \frac{1}{2}N\gamma\left\{e^{i\varepsilon}\mathrm{tr}(A_0)^2 + e^{-i\varepsilon}\mathrm{tr}(A_i)^2\right\}$$

1/D expansion ➡ Non-perturbative property of N=2 bosonic IKKT model at large D

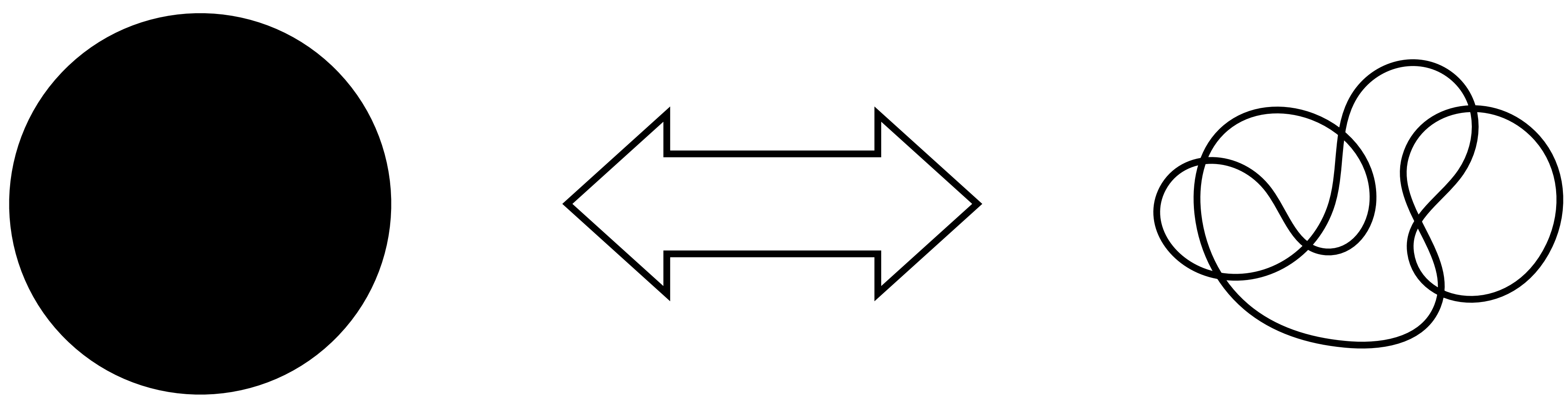
D: the number of bosonic matrices

Toward chaos in string scatterings

Takuya Yoda
Kyoto University, Japan

Black hole is chaotic

Black hole-string correspondence



Then, is string also chaotic?

京都大学
KYOTO UNIVERSITY

Kavli Asisan Winter School@YITP, 05 December 2023

Generalised Bismut-Lichnerowicz formulae and quantum corrections in string theory

Yi Zhang, Center for High Energy Physics, Peking University

Based on: [1705.04330] A. Coimbra and R. Minasian
[1304.3137], [1912.10974] J. T. Liu and R .Minasian
[2312.xxxxx] P. Cheng, A. Coimbra, R .Minasian and YZ

Standard Lichnerowicz formula [A. Lichnerowicz '63]

- A physicist familiar version is given in components as

$$\left(\nabla\!\!\!/^{2} - \nabla_\mu \nabla^\mu\right)\epsilon = -\frac{1}{4}R\epsilon\,.$$

- ∇ here is the covariant derivative with respect to the torsion free Levi-Civita connection and R is the scalar curvature.

- A version of the Lichnerowicz formula with closed three-form torsion H is found due to Bismut.

Bismut-Lichnerowicz formula [J-M. Bismut '63]

Let now B be a smooth section of $\Lambda^3(T^*M)$. Of course, ${}^cB$ acts like ${}^cB\otimes 1$ on $F\otimes\xi$. Let $\|B\|$ be the norm of B in $\Lambda^3(T^*M)$.

Theorem 1.3. *The following identity holds*

$$(D^L + {}^cB)^2 = -\sum_1^n (\nabla^L_{e_i} + {}^c(i_{e_i}B))^2 + \frac{K}{4} + {}^c((\nabla^\xi)^2) + {}^c(dB) - 2\|B\|^2\,. \qquad (1.13)$$

✦ *A local index theorem for non Kähler manifolds* [J-M. Bismut '89]

- Bismut extended Lichnerowicz's formula by including **odd-forms**.
- For instance, including closed three-from H, find a pair of operators

$$\nabla^H_\mu\epsilon = \nabla_\mu\epsilon + \frac{1}{8}H_{\mu\nu\rho}\gamma^{\nu\rho}\epsilon \quad \text{and} \quad \nabla\!\!\!/^{H}\epsilon = \nabla\!\!\!/\epsilon + \frac{1}{24}H_{\mu\nu\rho}\gamma^{\mu\nu\rho}\epsilon$$

- The difference of their squares on spinors is **tensorial (integrability)**!

$$(\nabla\!\!\!/^{H})^2 - (\nabla^H)^\mu\nabla^H_\mu\epsilon = -\frac{1}{4}R\epsilon + \frac{1}{48}H^{\mu\nu\rho}H_{\mu\nu\rho}\epsilon$$

✦ **Bismut's formula captures NS-sector (without dilation) dynamics at lowest order.**

SUGRA/M-theory as Generalised Complex Geometry [D. Waldram et al.]

✦ **The operator pairs can be identified with TYPE II SUSY variations**

$$\delta\psi_\mu = D_\mu\epsilon = \nabla_\mu\epsilon + \frac{1}{8}H_{\mu\nu\rho}\gamma^{\nu\rho}\epsilon\,,$$

$$\delta\rho = D\epsilon = \nabla\!\!\!/\epsilon + \frac{1}{24}H_{\mu\nu\rho}\gamma^{\mu\nu\rho}\epsilon - \gamma^\mu\partial_\mu\phi\epsilon\,.$$

↑ Dilaton piece

✦ **However, now the difference of operator squares does not give a tensor.**

✦ **It is the inclusion of the dilaton that requires a truly generalised treatment!**

- The operators should be seen as components of "generalised" Levi-Civita connection.
- Extend tangent bundle as $T\oplus T^*$, on which the generalised connection is defined.
- "Generalised" torsion-free condition tells the missing-piece for tensoriality and yields the bosonic NS action and Bianchi identity as a four-form $-\frac{1}{4}S\epsilon - \nabla_{[\mu}H_{\nu\rho\sigma]}\gamma^{\mu\nu\rho\sigma}\epsilon\,.$

✦ **This is precisely the generalised complex geometry proposed by mathematicians.**

- It puts diffeomorphisms and gerbe gauge transformations on equal footing:

$$(g,B,\phi) \longrightarrow (g+\mathcal{L}_v g, B+\mathcal{L}_v B, \phi+\mathcal{L}_v\phi)$$
$$(g,B,\phi) \longrightarrow (g, B-d\lambda, \phi)\,.$$

- For TYPE II SUGRAs this just geometrises the *O(d,d)* T-duality structure.
- The passage to non-closed torsion H (HET) requires a further extension $T\oplus T^*\oplus\mathfrak{g}$.
- *M*-theory has generalised tangent bundle corresponds to representation of $E_{d(d)}$ groups.

String/String duality manifest B-L formula for 16 supercharges [check my poster pls!]

✦ **In fact, generalised geometry structure is NOT the unique way out for tensoriality.**

✦ **We propose formulae as** $(D^\dagger_\mu D^\mu + D^\dagger D)\,\epsilon = (\text{tensorial supergravity quantities})\,\epsilon$

✦ **Higher derivative/string loop corrections can be computed!** [forthcoming paper]

- Dilaton/2-form completion to 8-derivative corrections [Liu and Minasian '13] can be reproduced.
- New couplings and uplift to 10d, include gauge multiplets are in considerations.

Posters at Y206

on Dec.11（Mon.） 18:00-

Lattice construction of mixed 't Hooft anomaly with $\mathbb{Z}_N$ 1-form symmetry and θ periodicity

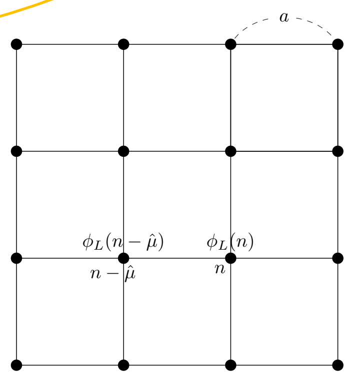
arXiv:2303.10977[hep-th]

Motokazu Abe (Kyushu U.)
Kavli Asian Winter School 2024@YITP
2023/11/30

Generalized Symmetry
→ Higher Form Symmetry
→ ‘t Hooft Anomaly

the mixed anomaly between the $\mathbb{Z}_N$ 1-form gauge and $\mathcal{T}$ symmetry in $SU(N)$ gauge theory with θ term at $\theta = \pi$

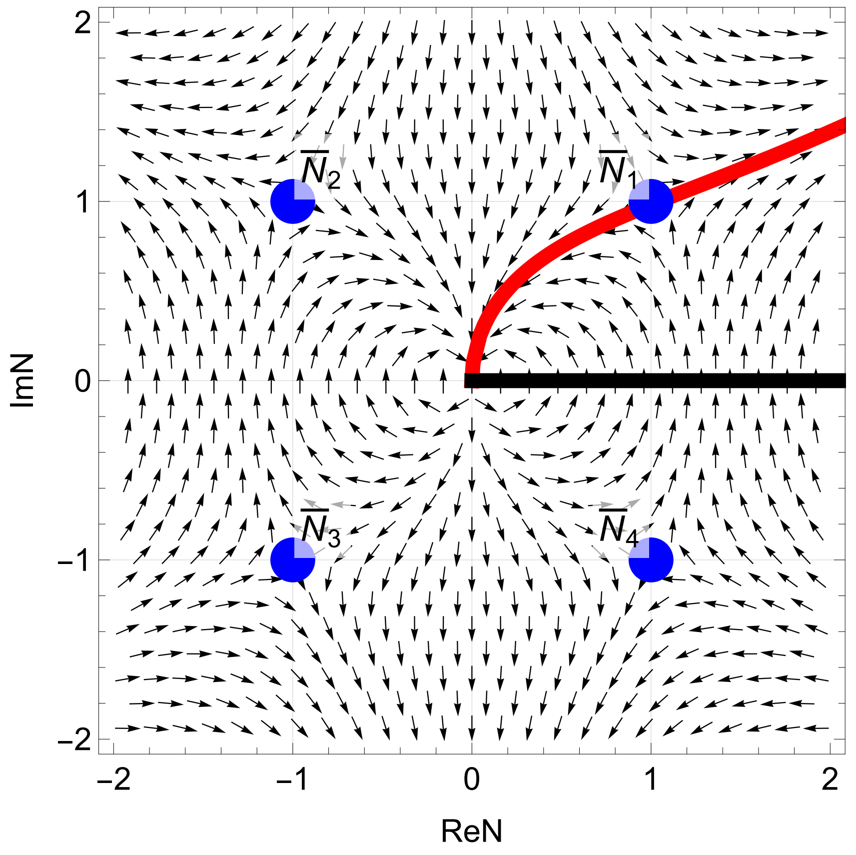
☆**Motivation : Understand ‘t Hooft anomalies in the lattice field theory**

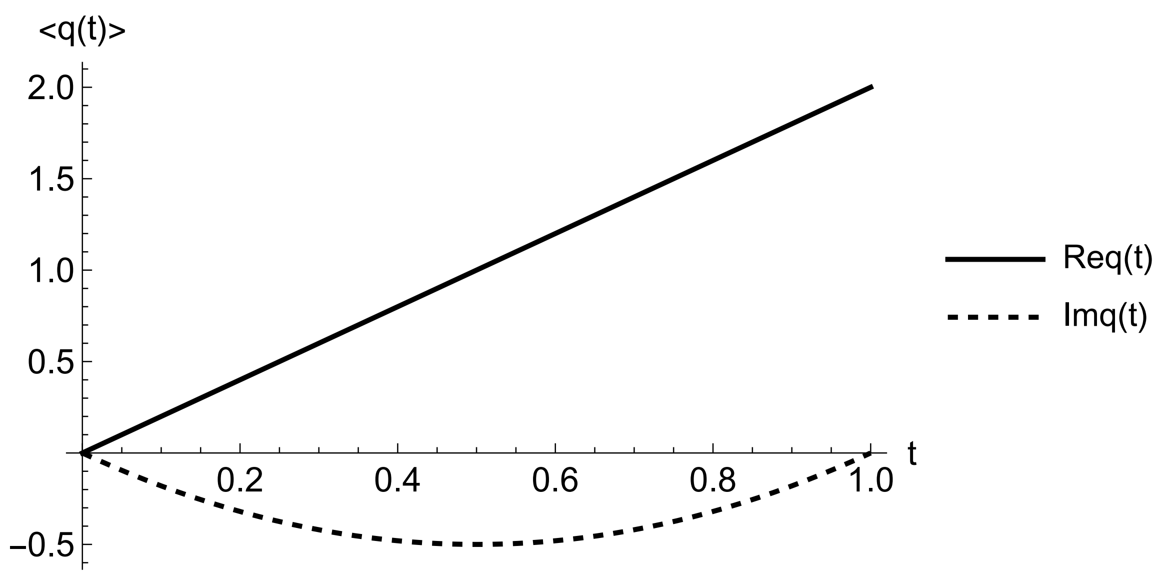


A new no-boundary proposal for smooth beginning of spacetime

Chou, Chien-Yu (Sokendai)
Upcoming work with Prof. Jun Nishimura

To define a consistent path integral for the universe to evolve from nothing to a scale q_f

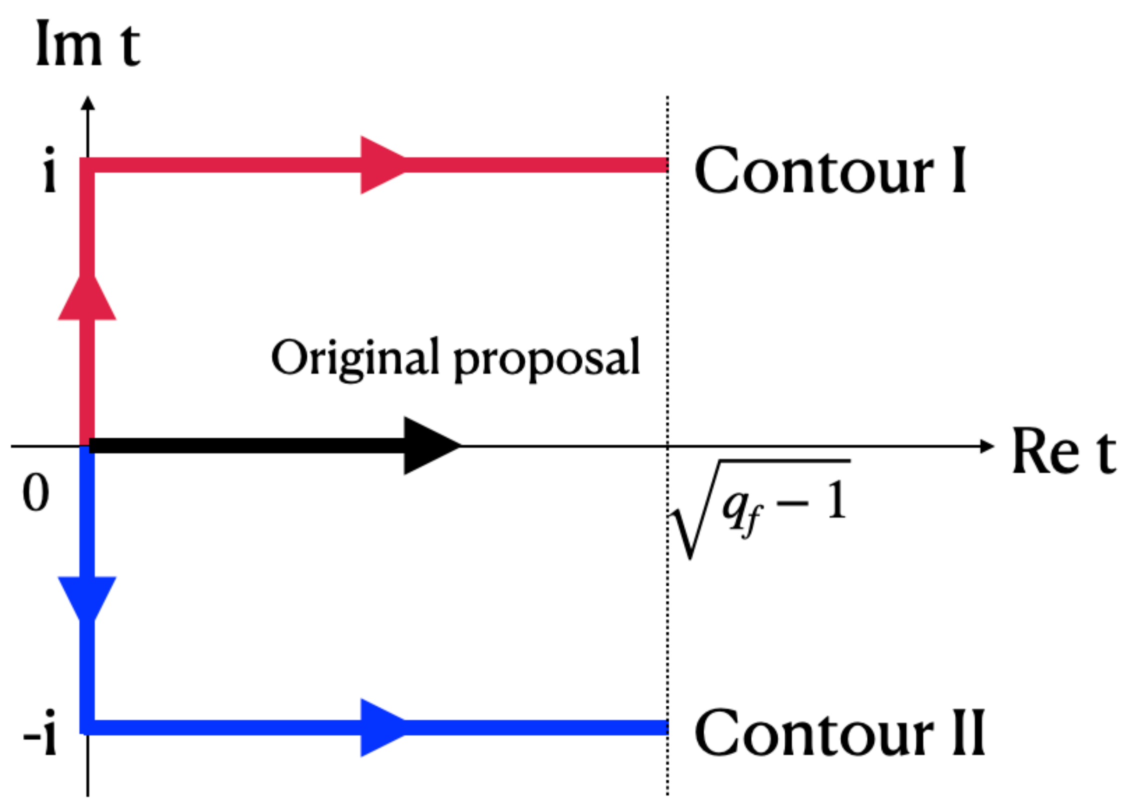




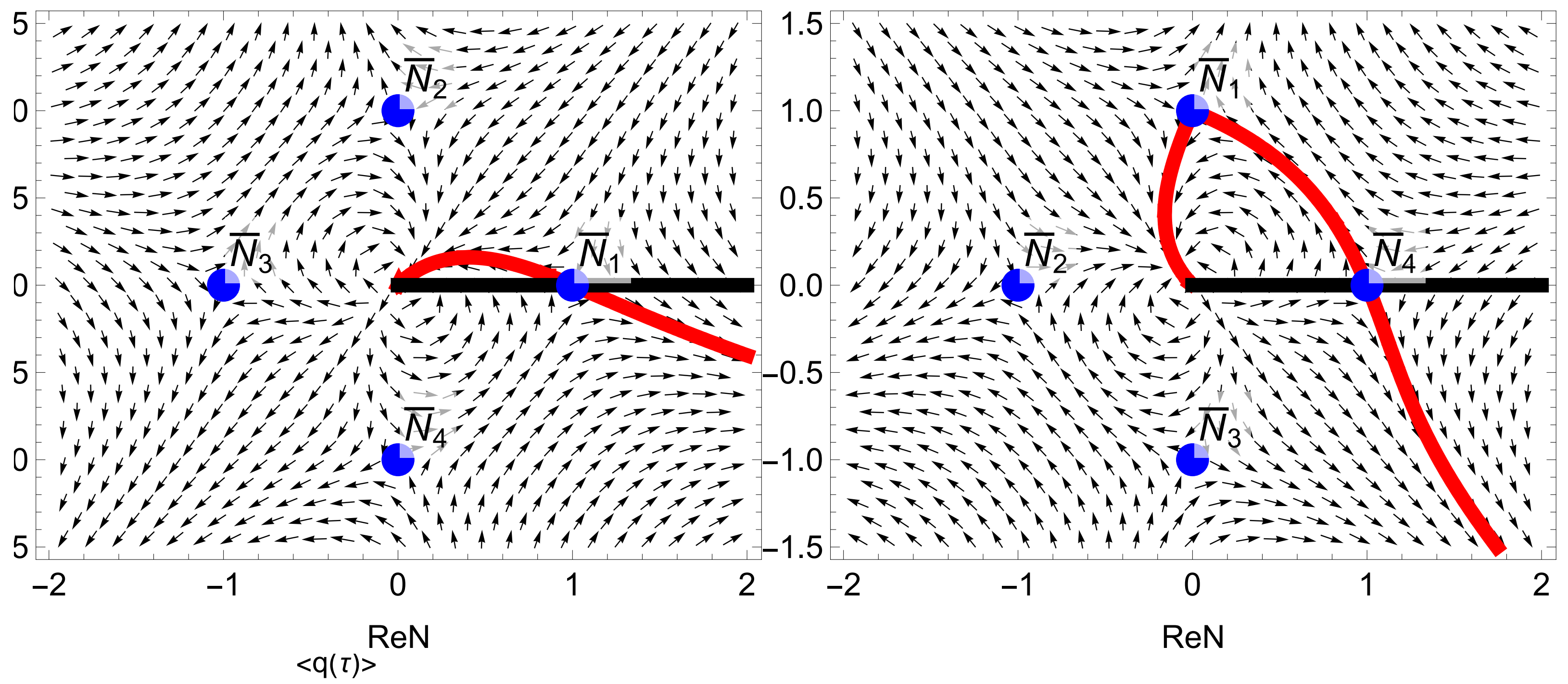
With fixed scale factor on both ends

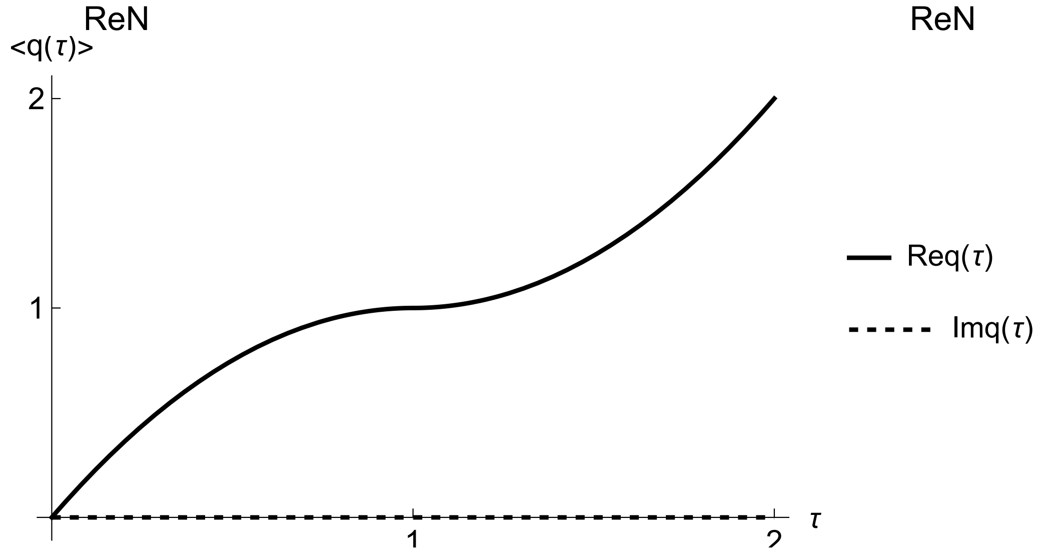
- Only saddle point with **instability** contributes
- Obtaining **complex** geometries

New proposal



- Specify the Wick rotation for the beginning of the universe by hand
- Keeping fixed scale factor on both ends





New models going beyond the two restrictions are defined
Detailed results and explanations at Y206

SOKENDAI KEK

Reflected Entropy of Conformal Fields in a Black Hole Background

Himanshu Chourasiya

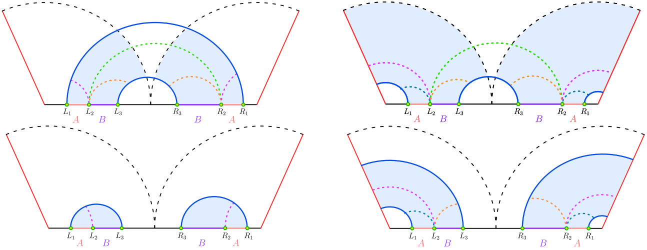
Indian Institute of Technology Kanpur
India

In collaboration with
Debarshi Basu, Vinayak Raj and Gautam Sengupta

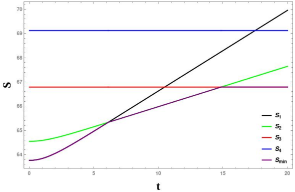
arXiv: 2311.17023

Overview (Y206 - Dec 11)

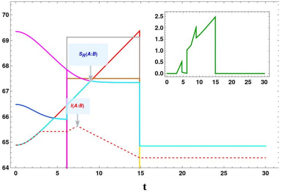
- We compute the reflected entropy (S_R) for two adjacent subsystems in $BCFT_2$ defined on a black hole background dual to AdS_3 black string geometry.
- The reflected entropy is computed after identifying the EE phases.



- Page curve of the EE and reflected entropy:



(a) *EE Page curve*



(b) S_R *Page curve*

HOLOGRAPHIC RG & EXACT RG

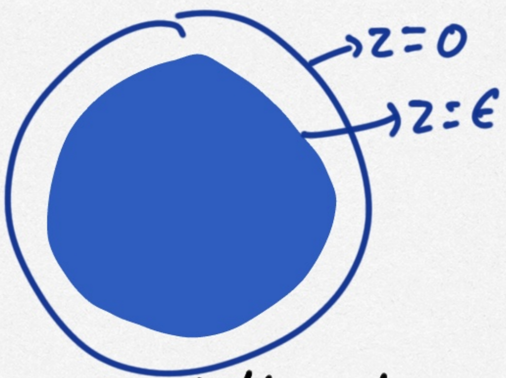
Pavan Dharanipragada

YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

THE INSTITUTE OF MATHEMATICAL SCIENCES

Holographic RG

Define the AdS boundary at a cutoff



Changing cutoff induces RG flow in the dual theory

"Holographic RG"

Exact RG

Path integral of field theory

$$Z = \int \mathcal{D}\phi \, e^{-S_B[\phi]}$$

↳ keep 0 to Λ modes

Integrate out Λ to ∞.

$$Z = \int_0^{\Lambda} \mathcal{D}\phi \, e^{-S_\Lambda[\phi]}$$

S_Λ → Wilson action

Polchinski equation

$$\Lambda \frac{\partial}{\partial \Lambda} e^{-S_{\Lambda,I}[\phi]} = \int \dot{\Delta} \frac{\delta^2 e^{-S_{\Lambda,I}[\phi]}}{\delta\phi\,\delta\phi}$$

$\dot{\Delta}$ → cutoff propagator

Mapping ERG to AdS

Start with 3D free O(N) model. Obtain 4D higher spin AdS in 3 steps

Step 1

Write ERG equation for operator O

Step 2

Write down evolution operator for this equation. It's a 4d path integral

Step 3

The 4d path integral offers a nonlocal action. Perform field redefinition

⟶ AdS_4 action

Transmission and Reflection through conformal dynamical Interface

Anirban Dinda

Indian Association for the Cultivation of Science, India

Kavli Asian Winter School 2023

Yukawa Institute for Theoretical Physics, Japan

Dec 6, 2023

Overview

- We have studied transmission and reflection coefficients through a dynamical conformal interface.

$$\mathcal{T}_L = \frac{c_{LR}}{c_L}\left(\frac{2}{1+e^{\frac{l}{\beta}}}\right), \ \mathcal{R}_L = \frac{c_L - c_{LR}}{c_L} \implies \mathcal{T}_L + \mathcal{R}_L = 1 - \frac{c_{LR}}{c_L}\left(\frac{e^{\frac{l}{\beta}}-1}{e^{\frac{l}{\beta}}+1}\right) \quad (1)$$

1. Unlike the static case, here everything depends on the profile of the states, most importantly where the states are being created in the presence of the interface.
2. The reflection and transmission coefficients are always less than one.
3. They will add up to one when we take the temperature very low ($\beta \to \infty$).
4. In the high temperature limit($\beta \to 0$), there is only reflection, no transmissions.
5. It means the moving mirror behaving as a semi-permeable membrane at high temperature

Thank You !

Boundary induced dynamical phase transition via inhomogeneous quenches

Dongsheng Ge (Osaka U.)

@ Y206

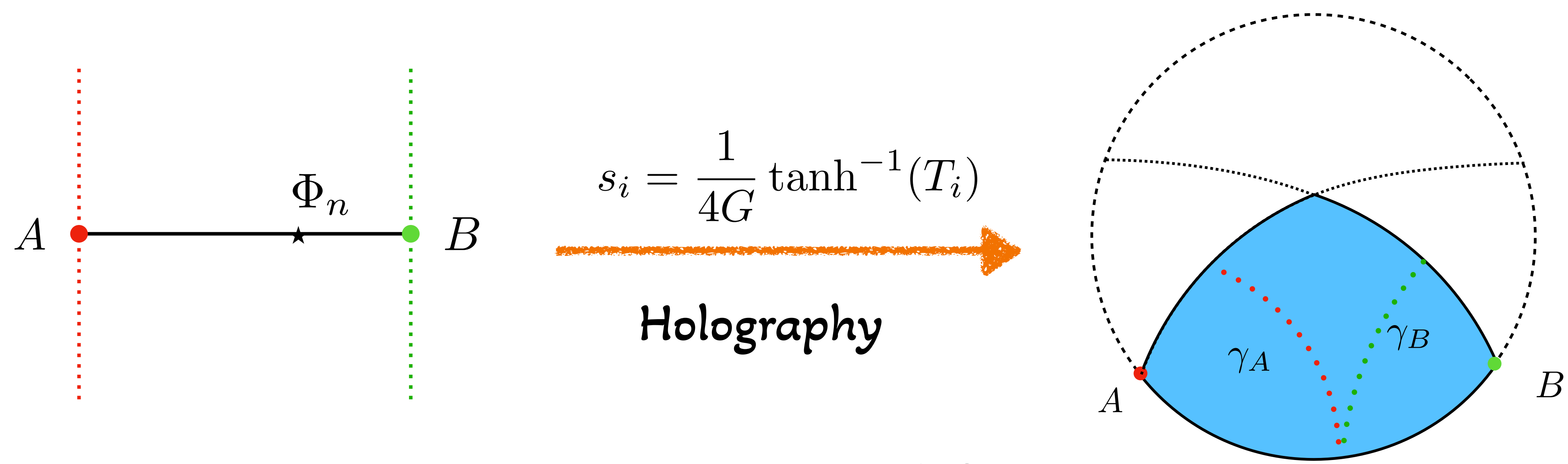
The question:

DOES the boundary effects influence the bulk dynamics ?

The answer:

YES !!! But HOW ?

Setup: 2D critical system with distinct boundary conditions



05.12.2023@ YITP

Bootstrapping the form factor with master integrals

Yuanhong Guo, Lei Wang, Qingjun Jin, Gang Yang, arXiv: 2106.01374, 2205.12969, 2209.06816
Institute of Theoretical Physics, CAS, Beijing, China
中国科学院理论物理研究所
Institute of Theoretical Physics, Chinese Academy of Sciences

Form factors of operators:

$$\mathcal{F}_{\mathcal{O}}(p_1, p_2, p_3, p_4; q) = \langle p_1, p_2, p_3, p_4 | \mathcal{O}(q) | \Omega \rangle$$

Bootstrap Method: *solving* physical quantities with linear equations

ansatz + *constraints* = *result*

Maximally transcendentality principle: deciphering the *similarity* between different theories via bootstrapping

similarity → *ansatz, constraints*; *result*

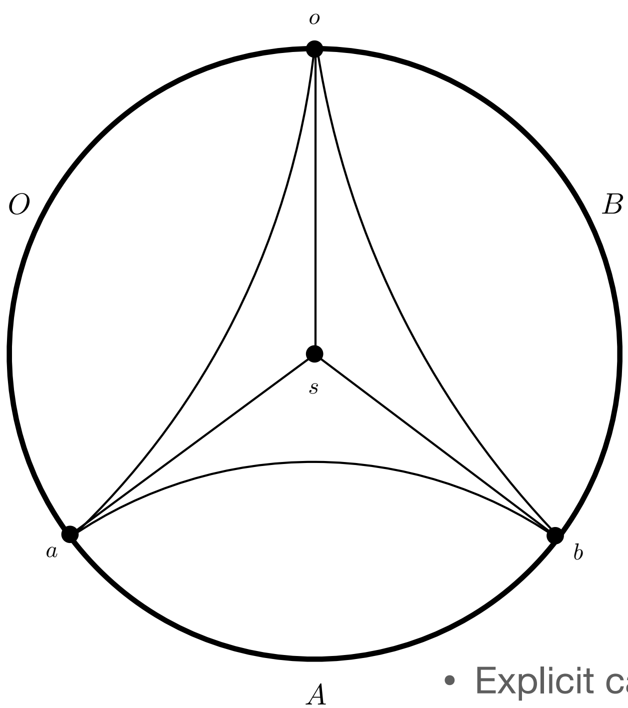
Aspects of Multi-entropy

Jonathan Harper (YITP) w/ T. Takayanagi and T. Tsuda (To appear)

- First proposed by [Gadde, Krishna, Sharma] and [Penington, Walter, Witteveen] ’22
- Generalization of entanglement entropy to three regions.
- Measure of multipartite entanglement.

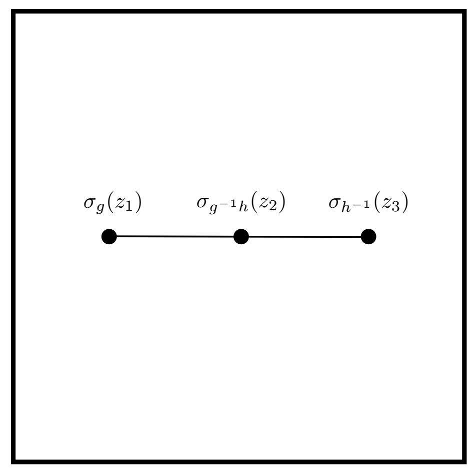
Bulk

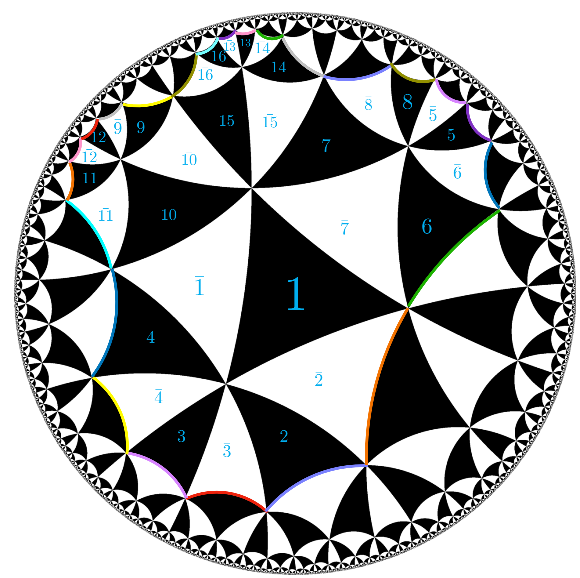
- Minimal surface dividing *entire* bulk in three regions.
- Geometrically related to RT surfaces.
- Multipartite contribution from angle at bulk intersection.



Boundary

- Three-point function of twist operators with $\mathbb{Z}_n^2$ replica symmetry.
- Multipartite contribution controlled by three-point coefficient.
  - Difficult to explicitly calculate.





Today:

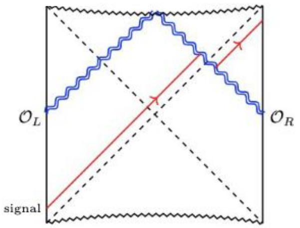
- Explicit calculation of low Renyi’s.
- Interesting puzzle for free fermion CFT.
- Generalizations to other finite group symmetry.

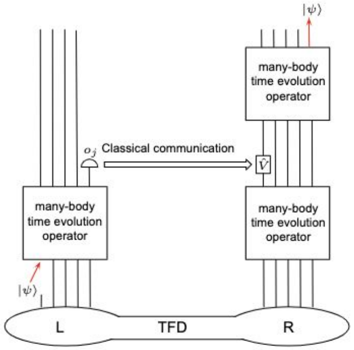
Teleportation through charged wormholes

Viktor Jahnke w/ Byoungjoon Ahn, Yichao Fu, Chang-Woo Ji, Keun-Young Kim. (To appear)

광주과학기술원
Gwangju Institute of Science and Technology

Gao-Jafferis-Wall traversable wormhole





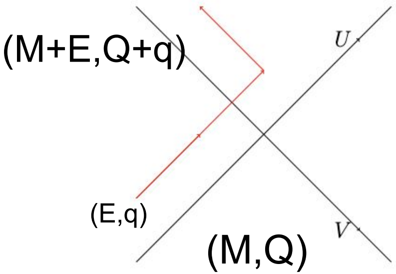
$$\delta S = h \int dt\, dx\, \mathcal{O}_L(t,x)\, \mathcal{O}_R(t,x)$$

$$\Downarrow$$

$$\int \langle T_{\mu\nu} \rangle_{\text{1-loop}}\, k^\mu k^\nu d\lambda < 0$$

$$\text{measure } \mathcal{O}_L \longrightarrow \text{obtain } o_j \longrightarrow \text{apply } \hat{V} = e^{i \int h o_j \mathcal{O}_R}$$

Charged wormholes & bouncing effects



- bouncing might prevent the teleportation of charged signals;
- we proposed a new protocol where a signal from the left enters the black hole, bounces, and then escapes the black hole's interior, returning to the left boundary;
- boundary description?

Holographic confining-deconfining gauge theories and entanglement measures with a magnetic field

Parul Jain, **Siddhi Swarupa Jena*** and Subhash Mahapatra

*National Institute of Technology Rourkela, Odisha, India

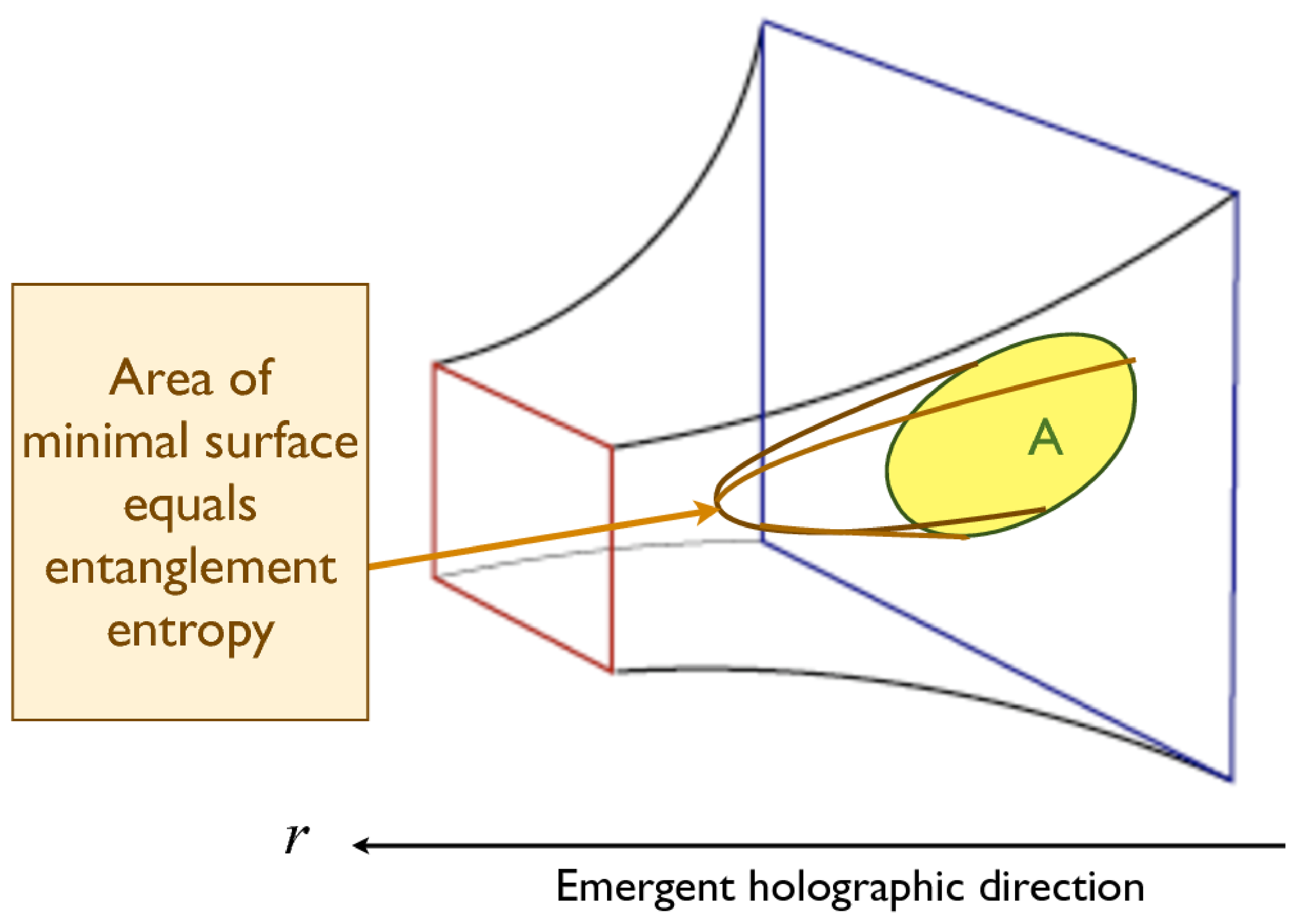
Based on our paper: **https://doi.org/10.1103/PhysRevD.107.086016**

Entanglement Measures

To probe the entanglement structure of confined/deconfined QCD phases, we discuss about various entanglement measures that have gravity duals.

Entanglement Entropy

A good measure of entanglement for pure states.



$$S(A) = \frac{\mathcal{A}(\Gamma_A^{\min})}{4G_{(d+1)}} , \qquad (1)$$

Mutual Information

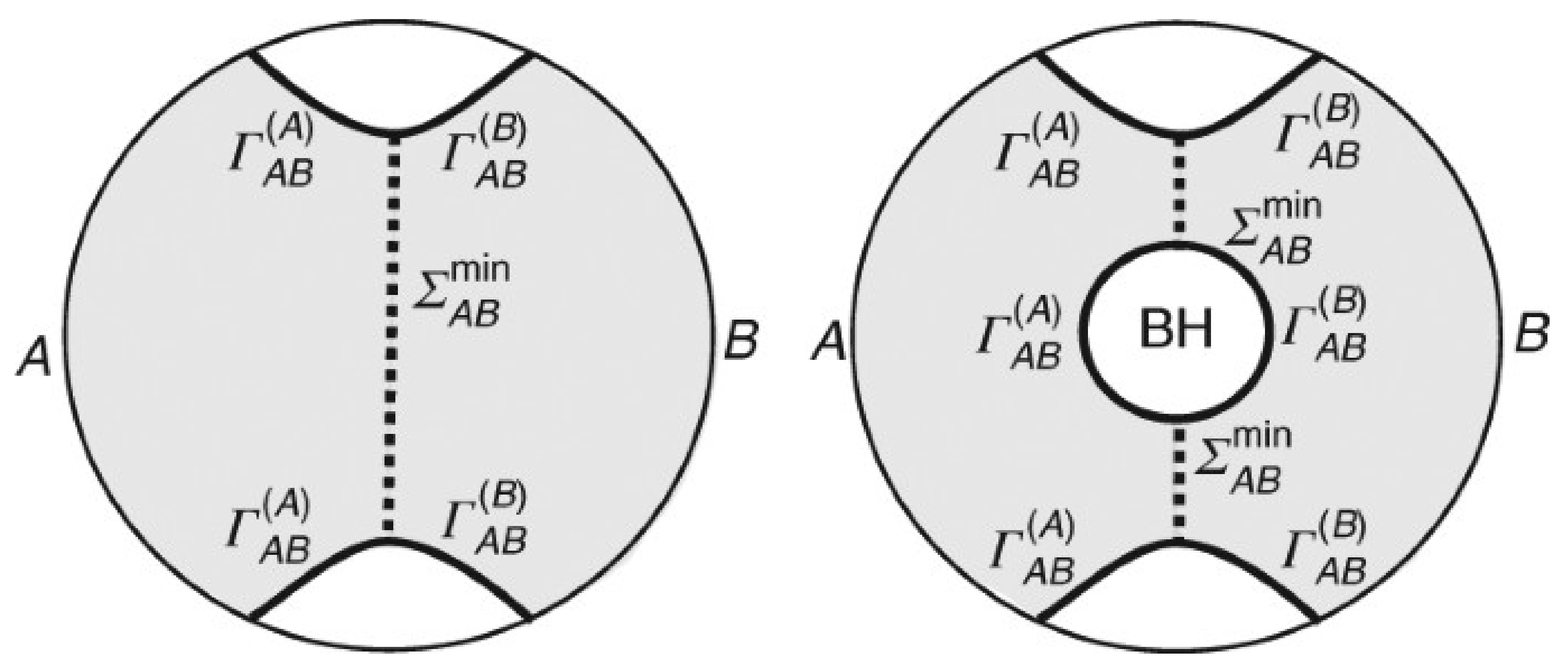
For two subsystems (A_1 and A_2), it reflects the amount of shared information between A_1 and A_2

$$I(A_1, A_2) = S(A_1) + S(A_2) - S(A_1 \cup A_2) , \qquad (2)$$

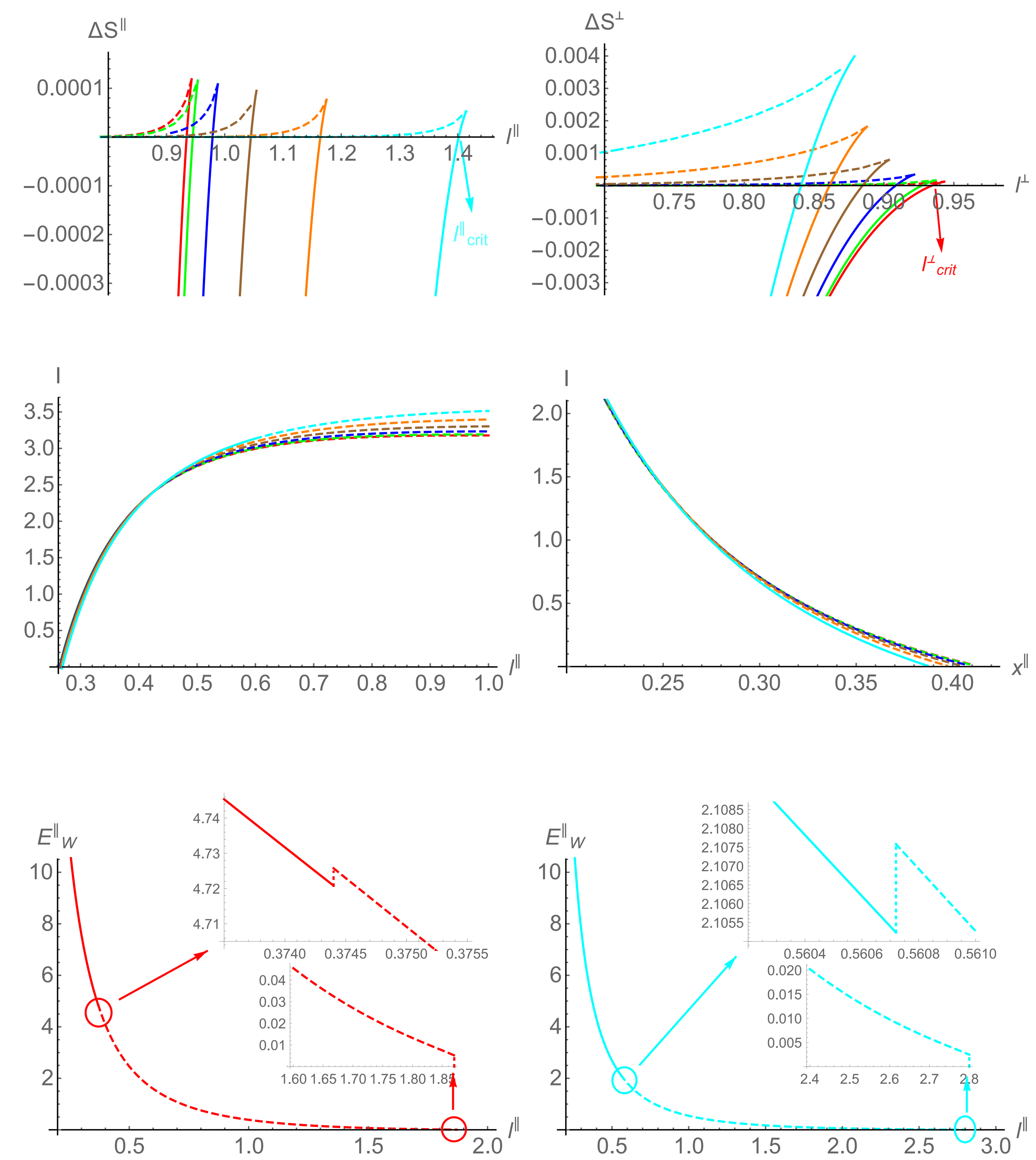
Entanglement Wedge Cross Section

The Entanglement Wedge Cross-section is given by the minimal area of the division of the entanglement wedge which connects subsystems A and B

$$E_W(\rho_{AB}) = \min_{\Gamma_{AB}^{(A)} \subset \Gamma_{AB}^{min}} \left[\frac{\mathcal{A}(\Sigma_{AB}^{min})}{4G_{(d+1)}} \right] . \qquad (3)$$

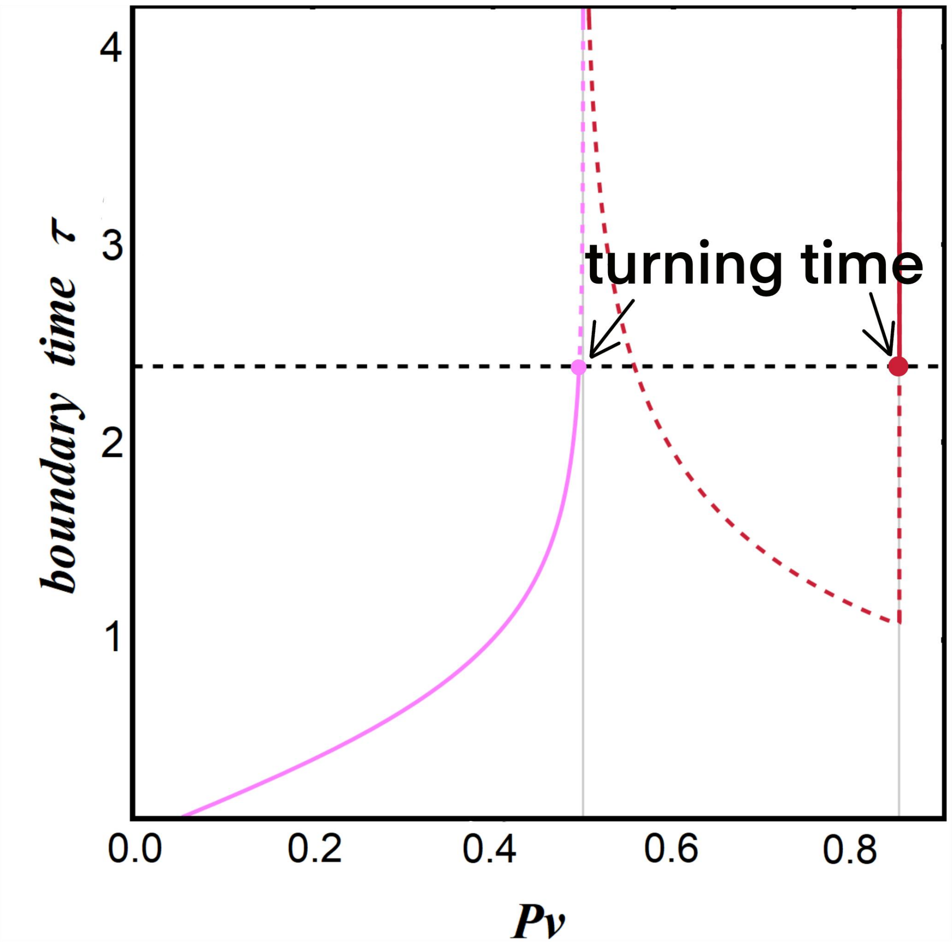


Results



For a deeper dive into the details, please visit my poster at Y206 on 11th December

Holographic Complexity with Different Gravitational Observables



Both the pink and red solid lines re-present larger generalized volumes at the corresponding boundary time.

Hello! I'm Hong-Yue Jiang from LanZhou university

Nice to meet you!

My recent work is some discussion of Complexity=Anything proposal.

In our reserch, we observe that the extremal hypersurfaces with the maximal generalized volume are not fixed.

The smaller one would "surpass" at a certain moment, which is named as the **turning time**.

Collaborator: Meng-Ting Wang, Yu-Xiao Liu

Phases of quantum field theories in thermal Anti-de Sitter Spaces

Astha Kakkar*
Department of Physics and Astrophysics, University of Delhi, Delhi - 110007, India
* asthakakkar8@gmail.com

Based on: JHEP07(2022)089, JHEP06(2023)009 and [arXiv:2311.06045 [hep-th]] with Swarnendu Sarkar

Motivation: Changes in IR behaviour of theories in AdS lead to deviations from flat space results and are captured by the Effective Potential. UV behavior however remains the same.

Introduction

- Effective action → Principal tool for studying phases of a QFT. Perturbative methods, to leading order, involve computation of one-loop determinants.

Partition Function on $\mathbb{H}^{d+1}/\mathbb{Z}$

- **Normal Modes** [F. Denef et al., 2010]
- **Hamiltonian Method** [G. W. Gibbons et al., 2006]
- **Heat Kernel** [S. Giombi et al., 2008; J. R. David et al., 2010]
- **Spectral form of propagator**

- Thermal AdS defined in terms of global coordinates by compactifying time circle leads to $\mathbb{H}^{d+1}/\mathbb{Z}$ identification in Poincaré coordinates.
  ⟶ We present a method for computing one-loop partition functions for scalars and fermions and then utilize these results to study phases of field theories in AdS$_{d+1}$ spaces.

Methodology and Basic Setup

- Effective potential

$$V_{eff}(\phi_{cl}) = -\frac{1}{\mathcal{V}_{d+1}}\left[\log Z_f^{(1)} + \log Z_b^{(1)}\right] + V(\phi_{cl}) = -\frac{1}{\mathcal{V}_{d+1}}\left[\mathrm{tr}\log[\not{D} + M_f(\phi_{cl})] - \frac{1}{2}\mathrm{tr}\log[-\Box_E + V''(\phi_{cl})]\right] + V(\phi_{cl}).$$

- log of trace is obtained by integrating the following:

$$\frac{1}{2\mathcal{V}_{d+1}}\mathrm{tr}\left[\frac{1}{-\Box_E + V''(\phi_{cl})}\right] \quad \text{and} \quad \frac{1}{\mathcal{V}_{d+1}}\mathrm{tr}\left[\frac{1}{\not{D} + M_f(\phi_{cl})}\right]$$

- We find the solution for eigenvalue equations corresponding to the respective differential operators.
- generalized eigenfunctions in thermal AdS obey respective periodicities under thermal identification

$$\Psi_{\vec{k},\lambda}(x) = \frac{1}{\mathcal{N}}\sum_{n=-\infty}^{\infty}\mathcal{R}(\gamma^n)\,\psi_{\vec{k},\lambda}(\gamma^n x)$$

Partition Functions: Results for scalars and transverse vectors

ZERO TEMPERATURE:

$$\frac{1}{L^2}\mathrm{tr}\left[\frac{1}{-\Box_E + V''(\phi_{cl})}\right] = \frac{\mathcal{V}_{d+1}}{L^{d+1}}\frac{\Gamma(d/2+\nu)\Gamma(1/2-d/2)}{\Gamma(1-d/2+\nu)\,(4\pi)^{(d+1)/2}}$$

FINITE TEMPERATURE:

$$\log Z = \sum_{n=1}^{\infty}\frac{1}{n}\frac{e^{-n\beta(d/2+\nu)}}{|1-e^{-n\beta}|^d}$$

$$\mathrm{tr}\left[\frac{1}{-\mathcal{O}^T + M_v^2 - d + 1}\right] = \frac{\mathcal{V}_{d+1}d}{(4\pi)^{(d+1)/2}}\frac{\left[\nu_v^2 - \left(\frac{d}{2}\right)^2\right]\Gamma\left(\frac{1}{2}-\frac{d}{2}\right)\Gamma\left(\frac{d-2}{2}\pm\nu_v\right)}{\Gamma\left(\nu_v-\frac{d}{2}\right)\Gamma\left(1-\nu_v+\frac{d}{2}\right)}$$

$$\log Z_{\text{gauge}} + \log Z_{\text{ghost}} = \sum_{n=1}^{\infty}\frac{1}{n}\frac{de^{-\Delta_v n\beta} - e^{-\Delta_s n\beta}}{(1-e^{-n\beta})^d}$$

Applications: Phases of Large N $O(N)$ model in AdS$_2$

- Effective potential to the leading order in $1/N$

$$\frac{V_{eff}}{N} = -\frac{(M^2-m^2)^2}{8\lambda} + \frac{1}{2}M^2(\phi_{cl}^i)^2 - \frac{1}{4\pi}\int_0^{M^2}dM^2\left[\psi^{(0)}\left(\nu+\frac{1}{2}\right)+\gamma\right] + \frac{1}{\beta}\sum_{n=1}^{\infty}\frac{1}{n}\frac{e^{-n\beta\left(\frac{1}{2}+\sqrt{\frac{1}{4}+M^2}\right)}}{|1-e^{-n\beta}|}$$

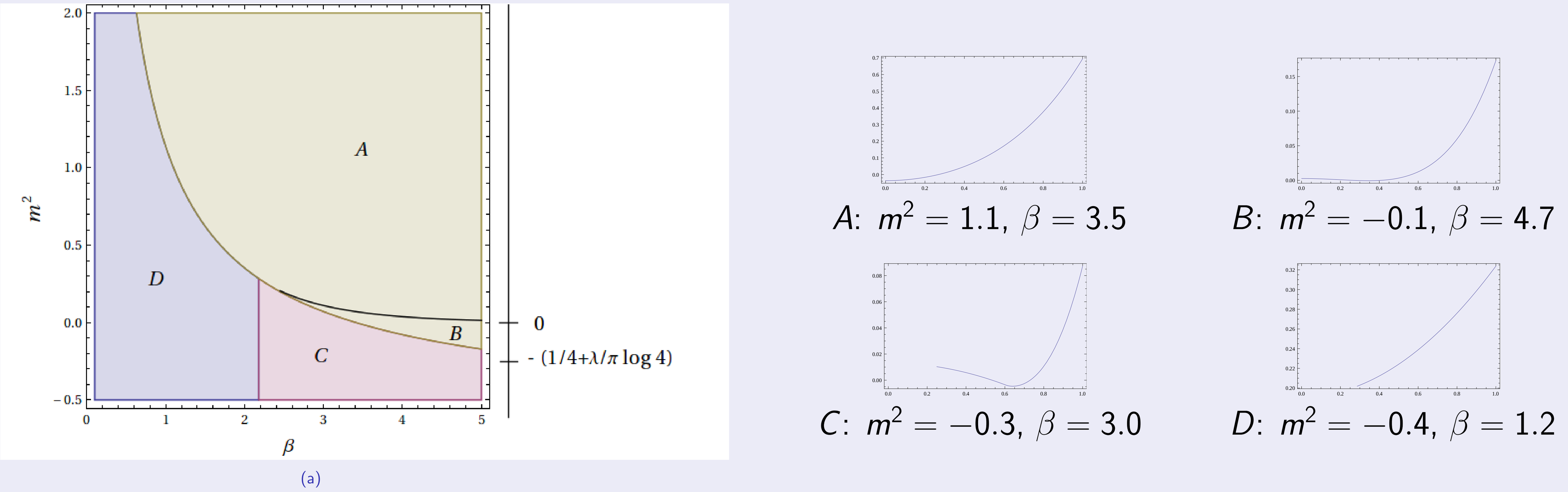


Figure: Phases in AdS_2 on the $\beta - m^2$ plane and representative potentials corresponding to different regions ($\lambda = 0.5$).

⟶ In finite temperature theory in AdS_2 there occurs a symmetry breaking phase, unlike flat space where Coleman-Mermin-Wagner theorem [N.D. Mermin and H. Wagner, 1966; S.R. Coleman, 1973] prohibits continuous symmetry breaking. This was also noted for AdS$_2$ in [T. Inami and H. Ooguri, 1985] and for large N $O(N)$ model in [Carmi et al. '19 ; T. Inami and H. Ooguri, 1985].

Further Directions of Work

- Further research involves other theories of fermion and vectors with Chern-Simons term in thermal AdS spaces.
- An interesting exercise would be to consider asymptotically AdS black hole geometry.
- Analyse correlation functions at finite temperatures to understand implications on dual boundary theory.
- It will be interesting to explore the connections between different methods for computation of partition functions.
- Another possible extension of our alternate method is to the case of higher spins.

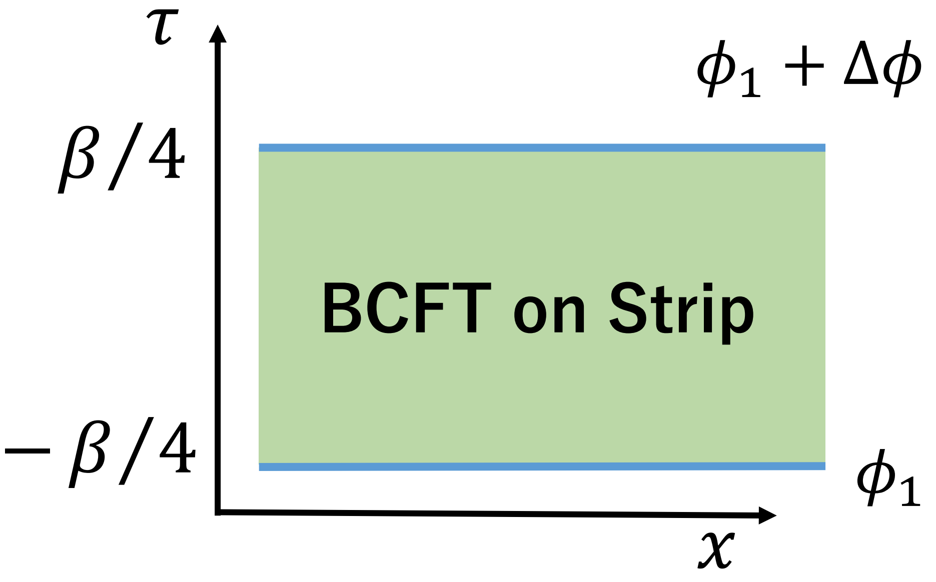
Acknowledgements: Astha Kakkar acknowledges the support of Department of Science and Technology (DST), Ministry of Science and Technology, Government of India, for the DST INSPIRE Fellowship with the INSPIRE Fellowship Registration Number: IF180721.

Analysis of Phase Transitions Caused by Brane-localized Field

Yukawa Institute for Theoretical Physics, Hiroki Kanda

Taishi Kawamoto, Yu-ki Suzuki, Tadashi Takayanagi, Kenya Tasuki, Zixia Wei
arXiv:2311:13201

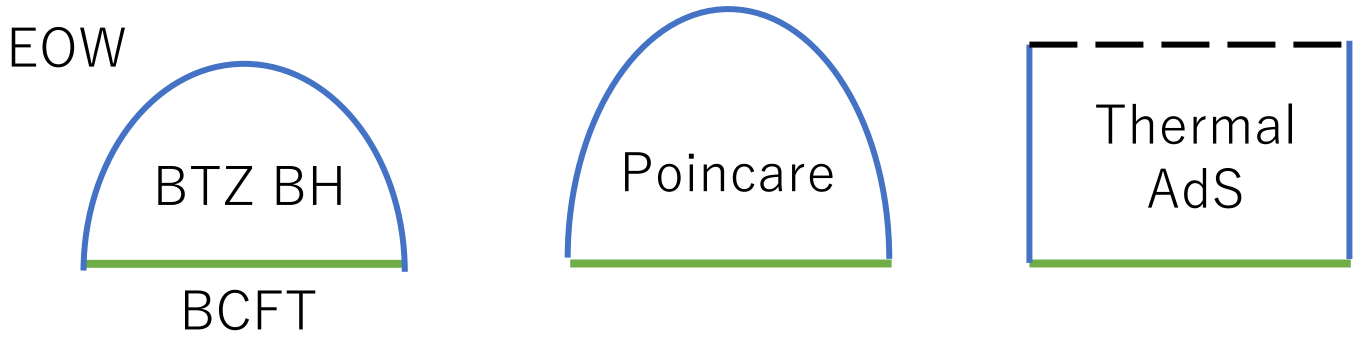
BCFT + Boundary Field ϕ
In Euclidean



AdS + Brane Field on EOW Brane

Gravity Dual has 3 Phases

(i) $\Delta\phi < \Delta\phi_*$ (ii) $\Delta\phi = \Delta\phi_*$ (iii) $\Delta\phi > \Delta\phi_*$



How these phases behave in Lorentzian?

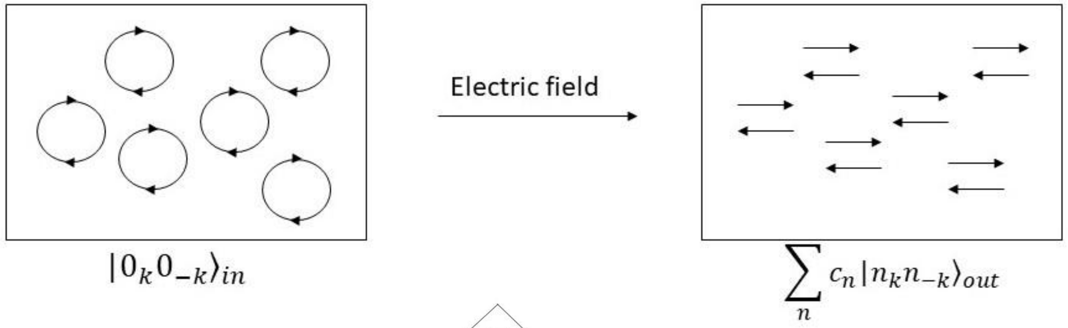
Background electromagnetic field and a uniformly accelerated observer

Shagun Kaushal, IIT Delhi, India

- Schwinger effect → a sufficiently high background electric field leads to pair production and this phenomenon is known as Schwinger effect[1].
- An interesting property of these particles is that they are entangled. The entanglement entropy for the vacuum of complex scalar field with background electric field in the Minkowski spacetime is studied in [2].
- It is also very interesting to introduce the magnetic field and see how it interplays with the correlations between particles and antiparticles.
- In [3,4], we computed the affect of magnetic field on the particles-antiparticles created by electric field in the Minkowski and de Sitter spacetime. We observed that magnetic field opposes affect of electric field.
- Unruh effect → A uniformly accelerated detector moving in flat spacetime perceives the Minkowski vacuum to be thermal vacuum [5].
- The Rindler spacetime → hyperbolic coordinate transformation between the Minkowski coordinates (τ, ρ, y, z) and (t, x, y, z) leads to the Rindler spacetime.

$$ds^2 = e^{2ax}(-dt^2 + dx^2) + dy^2 + dz^2$$

- We studied aspects of entanglement in the presence of background electric and magnetic fields from the perspective of a uniformly accelerated observer.



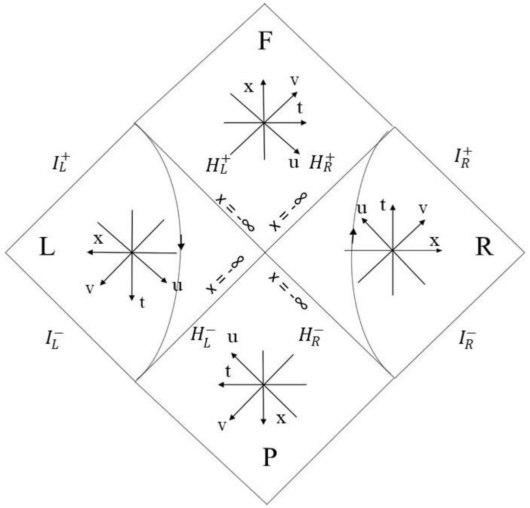


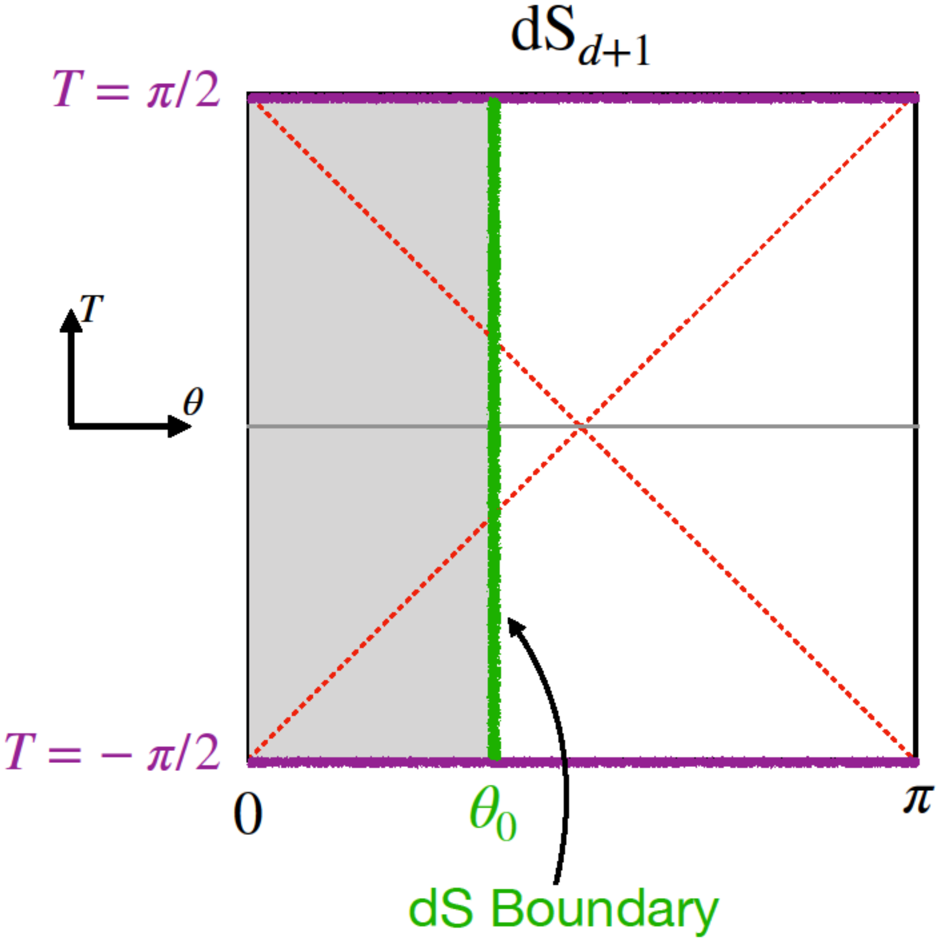
Fig. The four Rindler patches R, L, P , and F , with their coordinates.

[1] J. S. Schwinger, Phys. Rev. D **82**, 664 (1951).
[2]Z. Ebadi and B. Mirza, Annals Phys. **351**, 363(2014).
[3] S. Bhattacharya, S. Chakrabortty, H. Hoshino and S. K., Phys. Lett. B **811**, 135875 (2020).
[4] M. S. Ali, S. Bhattacharya, S. Chakrabortty and S. K., Phys. Rev. D **104**, no.12, 125012 (2021).
[5] W. G. Unruh, Phys. Rev. D. **14**, 870 (1976).

Half dS Holography

Taishi Kawamoto, YITP, Dec.11th Y206

Based on arXiv:2306.07575



(Q) Can we discuss dS Holography with usual time?

Half dS Holography

Cut dS_{d+1} QG = QFT on dS_d boundary

Properties of the boundary Theory

Naïve replica trick EE computation

→HEE Violates the Strong Sub Additivity

→The boundary theory is highly non-local

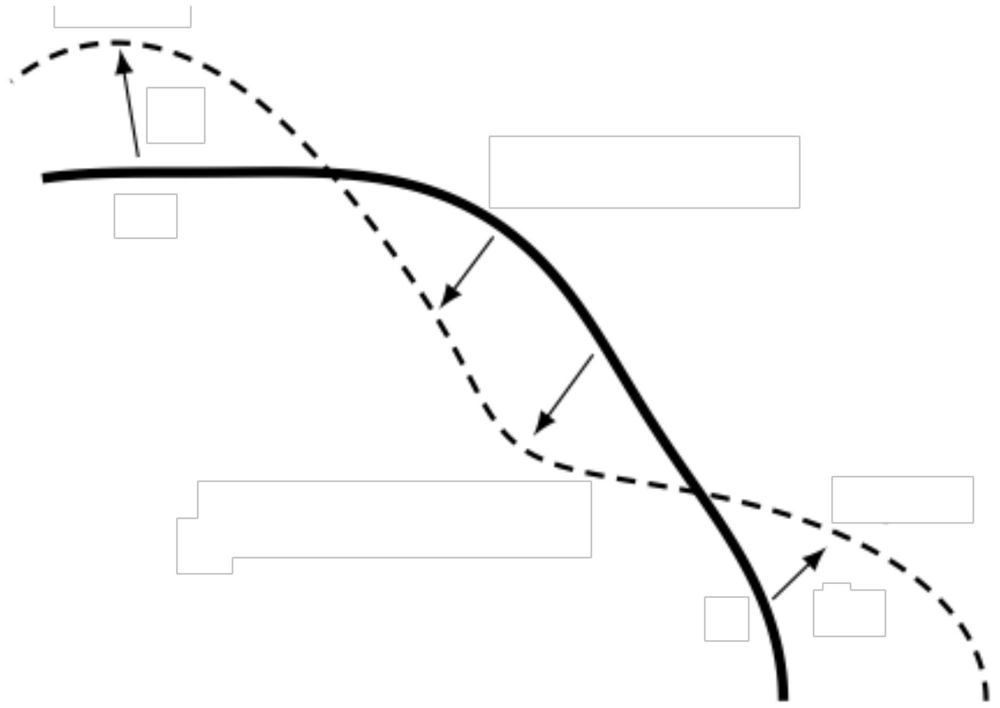
Posters at Y306

on Dec.11(Mon.) 18:00-

Gravitational edge mode in 2D super JT gravity

Kyungsun Lee (KIAS), Akhil Sivakumar (APCTP) and Junggi Yoon (APCTP)

Edge mode

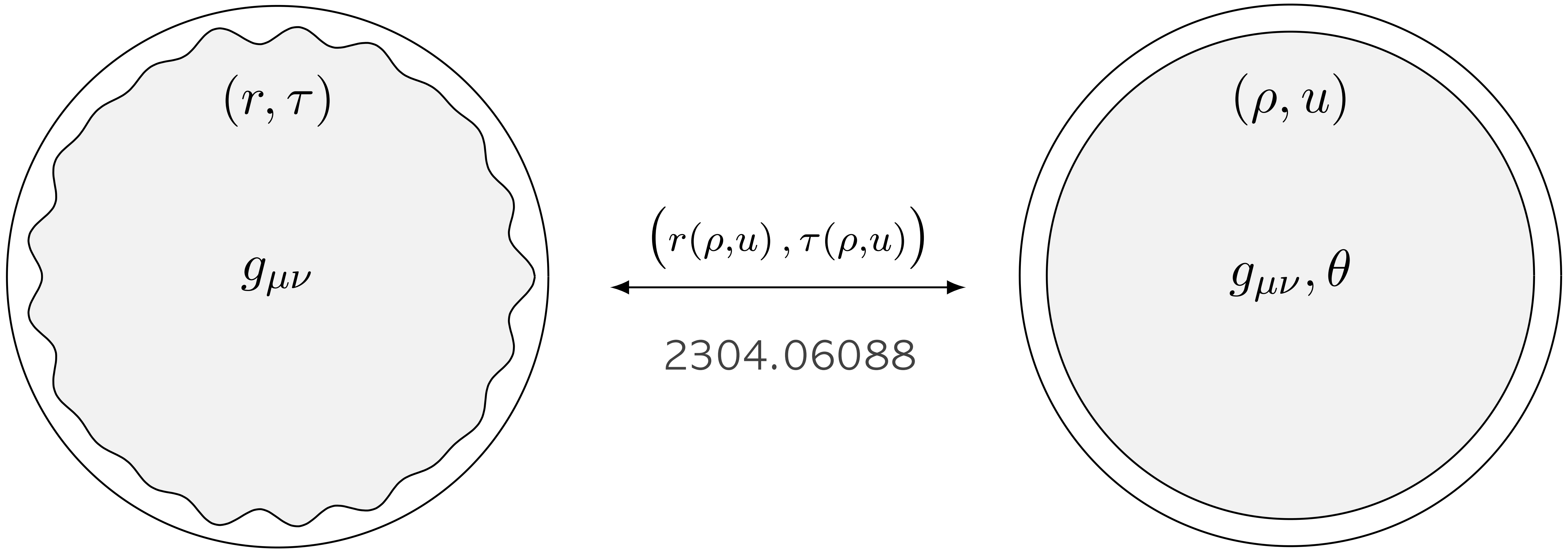


For gravitational system on disk, radial diffeomorphism is **not gauge symmetry anymore**

⇒ Realized as physical d.o.f

Conventional description of 2D Jackiw-Teitelboim (JT) gravity

Gravitational edge mode



Wiggling boundary

Boundary metric fluctuation

More story about edge mode in super JT gravity? ⇒ **Find Kyungsun Lee @Y306 on Dec. 11**

Revisit 3D Flat Holography: Causality Structure and Modular Flow

Yuefeng Liu , **Peking University**, Based on: 2309.05220

MOTIVATION:

1. AdS/CFT holography: Successful !

   Chaos, Island formula, Bulk reconstruction

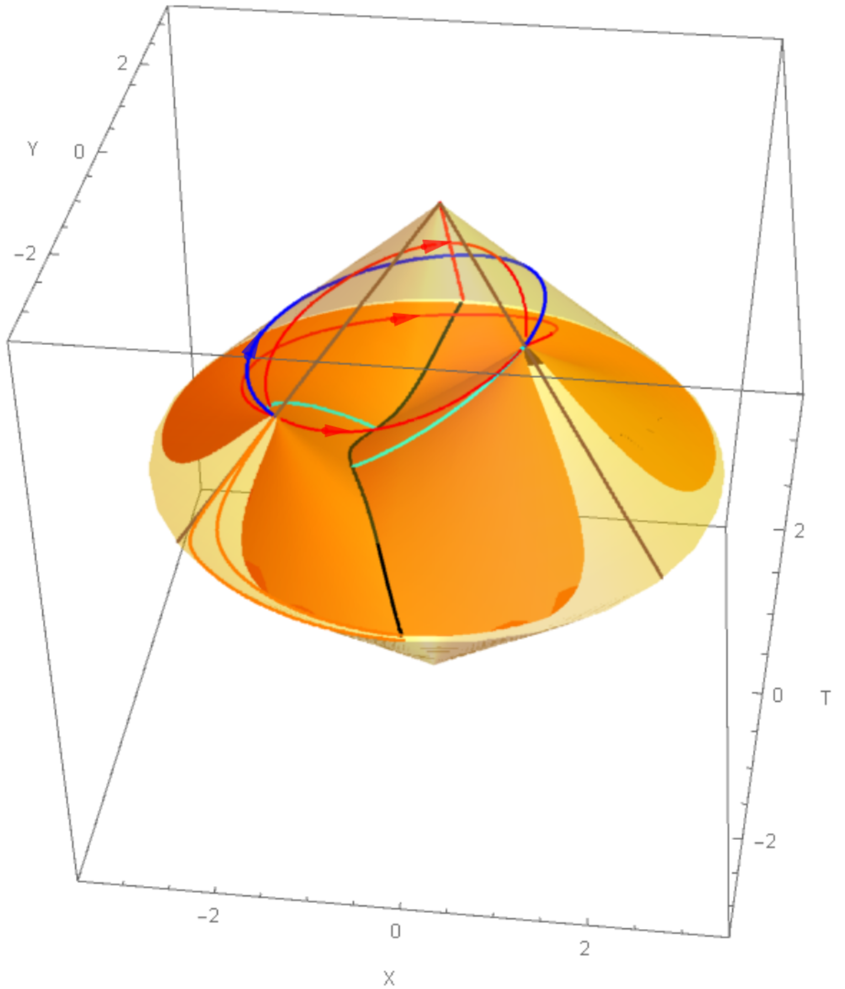
   RT formula, Entanglement Wedge

2. Flat Holography: Two systematic ways

   Carrollian holography ⟺ Carrollian CFT?

   Celestial holography ⟺ Symmetry ?

   Exploration: Bulk ⟸ Boundary



罗然, Ran Luo
Peking Univ.

Applications of Strict Higher Groups

Gauge Th. $\Longrightarrow$ Higher Gauge Th. + Matter

with
Ruizhi Liu
Yinan Wang

2312.xxxxx
(to appear)

Algebraic Info

Group G $\quad \mathrm{Rep}(G) \ni \rho : G \to GL(V)$

$\Downarrow$

$\alpha : \Pi_1 \to \mathrm{Aut}(\Pi_2)$
β : "twist" (Postnikov class)

2-Group $\mathcal{G} = (\Pi_1, \Pi_2, \alpha, \beta)$ Weak
$= (G, H, \triangleright, \partial)$ Strict

$\triangleright : G \to \mathrm{Aut}(H)$
$\partial : H \to G$

$$\mathrm{2Rep}(\mathcal{G}) \ni \rho : \begin{array}{ccc} H & \xrightarrow{\partial} & G \\ \downarrow \rho_H & & \downarrow \rho_G \\ A^\times & \xrightarrow[\mathrm{Ad}.]{} & \mathrm{Aut}(A) \end{array}$$

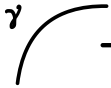
$$\left(\begin{array}{c} A : \text{ a chosen algebra.} \\ \mathcal{A}ut(A) = A^\times \underset{\mathrm{Ad}.}{\to} \mathrm{Aut}(A) \end{array} \right)$$

$\Downarrow$

3-groups $\left\{ \begin{array}{c} (\Pi_1, \Pi_2, \Pi_3, \rho, \beta, \gamma) \\ \Updownarrow \\ (G, H, L, \{\cdot,\cdot\}, \triangleright, \partial_1, \partial_2) \end{array} \right.$

Geometric Info

Holonomy

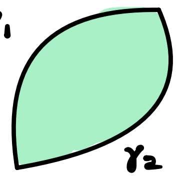


$\gamma \to W_A[\gamma] \in G$

$\xrightarrow{\text{gauge trans.}} g W_A g^{-1}$

$\Downarrow$

2-Holonomy



γ_1, γ_2, $\Sigma_{\gamma_1,\gamma_2} \to \mathcal{W}_{\mathcal{A}}[\Sigma_{\gamma_1,\gamma_2}]$

($\mathcal{A}$: Path-Space connection)

$\downarrow$

$a_\gamma \cdot g(W_A, \mathcal{W}_{\mathcal{A}}) g^{-1} \cdot a_\gamma^{-1}$

Matter Field

$\phi : M \to V$
$\phi \mapsto g \cdot \phi$

$\Downarrow$

Non-local matter
"$\Phi : P_1(M) \to A$"
Path Space.

$\Phi \mapsto a_\gamma \cdot g \cdot \Phi$

2-Gauge th. + matter

pure 0-form sym $\swarrow$ ordinary

pure 1-form sym $\searrow$ Mean String Field Th.

Black Hole Complementarity From Microstate Models: Encoding Quantum Information Inside Black Holes (Kibe, SM, Mukhopadhyay, Swain JHEP 10 (2023) 096)

Sukrut Mondkar (HRI)

Black Hole Complementarity Principle[1]: Information both inside and outside the horizon, but no observer can access both copies simultaneously.

(Assumptions: local semi-classical description of horizon + unitarity of evaporation)

We demonstrate how black hole complementarity can emerge via a microstate model that preserves unitarity and local semi-classical description of the horizon

Microstate model[2] based on fragmentation instability of near-extremal black holes[3]

Main Result: Information of the infalling quantum matter is encoded in both the late-time quantum trajectory of the quantum matter as well as the late-time (non-linear) ringdown of the black hole; the latter is a transitory copy, which is transferred to Hawking radiation

1: Susskind, Thorlacius, Uglum Phys Rev D (1993)
2: Kibe, Mukhopadhyay, Soloviev, Swain Phys Rev D (2020)
3: Maldacena, Michelson, Strominger JHEP (1999)

Please visit my Poster at Y306 on 11 Dec for more details

Integrability and non-integrability for marginal deformations of 4d $\mathcal{N}=2$ SCFTs

(Based on JHEP 10 (2023) 173)

Jitendra Pal, IIT Roorkee

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Introduction

- These new class of γ-deformed backgrounds are obtained following an $SL(3,R)$ transformation in eleven dimensional M-theory background while keeping γ as a deformation parameter.
- Upon dimensional reduction along one of the $U(1)$ isometric directions, one finds a ten dimensional type-IIA background of the form (Nucl. Phys. B **943**, 114617 (2019))

$$ds^2_{\text{IIA}} = \alpha'\mu^2\left[4f_1 ds^2_{AdS_5} + f_2\left(d\sigma^2+d\eta^2\right) + f_3 d\chi^2 + \frac{f_3\sin^2\chi}{1+\gamma^2 f_3 f_4 \sin^2\chi}d\xi^2 + \frac{f_4}{1+\gamma^2 f_3 f_4\sin^2\chi}\left(d\beta - \gamma f_5 \sin\chi d\chi\right)^2\right]$$

$$B_2 = \frac{\mu^2\alpha'}{1+\gamma^2 f_3 f_4 \sin^2\chi}\left(f_5 d\Omega_2(\chi,\xi) - \gamma f_3 f_4 \sin^2\chi d\xi\wedge d\beta\right), C_1 = \mu^4\sqrt{\alpha'}\left(f_6 d\beta + \gamma\left(f_7 - f_5 f_6\right)\sin\chi d\chi\right),$$

$$C_3 = \frac{\mu^6\alpha'^{\frac{3}{2}}}{1+\gamma^2 f_3 f_4\sin^2\chi} f_7 d\beta\wedge d\Omega_2(\chi,\xi)\,, e^{2\Phi} = \frac{f_8}{1+\gamma^2 f_3 f_4 \sin^2\chi}\,.$$

- In the limit $\gamma\to 0$, the above ten dimensional solution maps into the standard $\mathcal{N}=2$ supersymmetric Gaiotto-Maldacena background.
- In the expressions of f_i and Δ, the dot and the prime of the potential function $V(\sigma,\eta)$ can be explicitly written as

$$f_1 = \left(\frac{2\dot V - \ddot V}{V''}\right)^{\frac{1}{2}};\ f_2 = f_1\frac{2V''}{\dot V};\ f_3 = f_1\frac{2V''\dot V}{\Delta};\ f_4 = f_1\frac{4V''}{2\dot V - \ddot V}\sigma^2, f_5 = 2\left(\frac{\dot V\dot V'}{\Delta} - \eta\right);\ f_6 = \frac{2\dot V\dot V'}{2\dot V - \ddot V};\ f_7 = -\frac{4\dot V^2 V''}{\Delta};\ f_8 = \left[\frac{4\left(2\dot V - \ddot V\right)^3}{\mu^{12}V''\dot V^2\Delta^2}\right]^{\frac{1}{2}},$$

which satisfies Laplace's equation of the form

$$\ddot V + \sigma^2 V'' = 0\,.$$

Basic Setup and Results

- The dynamics of the string is characterised by the *Polyakov* action

$$S = -\frac{1}{2}\int d\tau d\tilde\sigma\left[\eta^{\alpha\beta}G_{\mu\nu} + \epsilon^{\alpha\beta}B_{\mu\nu}\right]\partial_\alpha X^\mu\partial_\beta X^\nu\,.$$

- To begin with, we consider that the string sits at the center ($r=0$) of the AdS$_5$ and wraps the $U(1)$ isometries of the γ-deformed background. We choose an ansatz of the following form

$$t = t(\tau)\,;\ \sigma=\sigma(\tau)\,;\ \eta=\eta(\tau)\,;\ \chi=\chi(\tau)\,, \xi=\xi(\tilde\sigma) = k\tilde\sigma\,;\ \beta=\beta(\tilde\sigma)=\lambda\tilde\sigma\,.$$

Example I : γ-deformed Abelian T-dual

- The potential function for the Abelian T-dual (ATD) (JHEP **05**, 107 (2016))

$$V_{\text{ATD}}(\sigma,\eta) = \ln\sigma - \frac{1}{2}\sigma^2 + \eta^2.$$

- The associated functions $f_i(\sigma,\eta)$ take the following form

$$f_1 = 1\,;\ f_2 = \frac{4}{1-\sigma^2}\,;\ f_3 = 1-\sigma^2\,;\ f_4 = 4\sigma^2\,, f_5 = -2\eta\,;\ f_6 = 0\,;\ f_7 = -2\left(1-\sigma^2\right)^2;\ f_8 = \frac{64}{1-\sigma^2}\,.$$

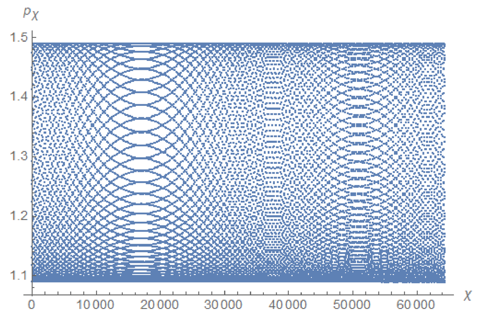

Figure 1: $E=3$, $\gamma=0.25$. Initial data: $\sigma=0.1$, $\chi=0.5$, $p_\sigma=0$, $p_\chi=1.40099$.

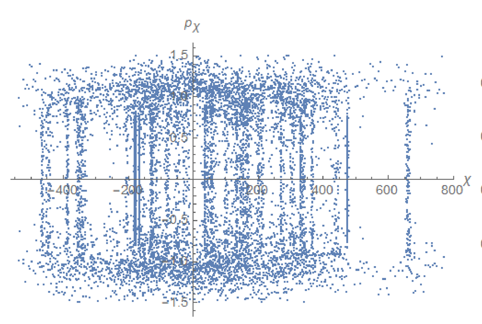

Figure 2: $E=3$, $\gamma=5$. Initial data: $\sigma=0.1$, $\chi=0.5$, $p_\sigma=0$, $p_\chi=1.41835$.

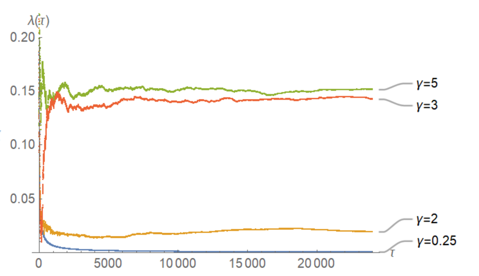

Figure 3: Numerical plots of Lyapunov exponent(s) for γ-deformed Abelian T-dual background.

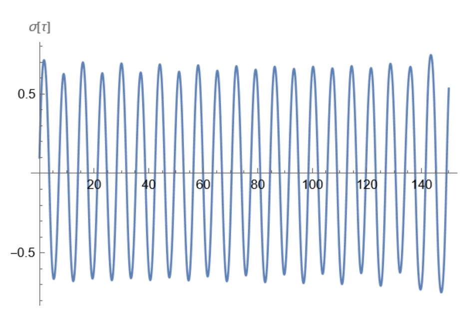

Figure 4: $\gamma=0.25$

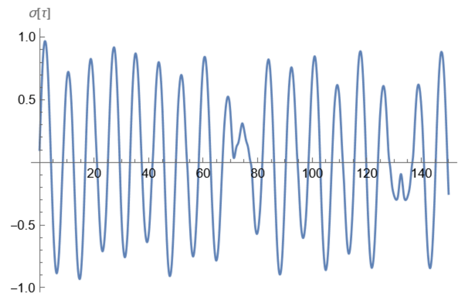

Figure 5: $\gamma=5$

Example II : γ-deformed Sfetsos-Thompson solution

- For Sfetsos-Thompson (ST) solution (also known as non-Abelian T-dual (NATD) solution) the corresponding potential function reads as (JHEP **05**, 107 (2016))

$$V_{\text{ST}}(\sigma,\eta) = \eta\left(\ln\sigma - \frac{1}{2}\sigma^2\right) + \frac{1}{3}\eta^3\,. \tag{1}$$

- The associated functions $f_i(\sigma,\eta)$ take the following form

$$f_1 = 1\,;\ f_2 = \frac{4}{1-\sigma^2}\,,\ f_3 = \frac{4\eta^2\left(1-\sigma^2\right)}{4\eta^2+\left(1-\sigma^2\right)^2}\,,\ f_4 = 4\sigma^2\,, f_5 = -\frac{8\eta^3}{4\eta^2+\left(1-\sigma^2\right)^2}\,,\ f_6 = \left(1-\sigma^2\right)^2,\ f_7 = -\frac{8\eta^3\left(1-\sigma^2\right)^2}{4\eta^2+\left(1-\sigma^2\right)^2}\,,\ f_8 = \frac{256}{\left(1-\sigma^2\right)^2\left(4\eta^2+\left(1-\sigma^2\right)^2\right)}$$

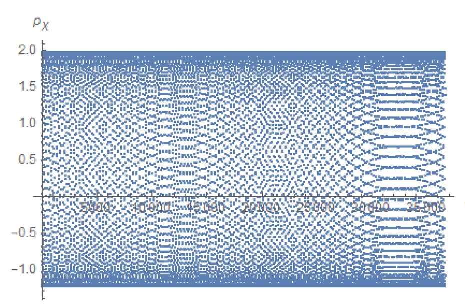

Figure 6: $E=2$, $\gamma=0.25$. Initial data: $\sigma=0.1$, $\chi=0.5$, $p_\sigma=0$, $p_\chi=0.0171369$.

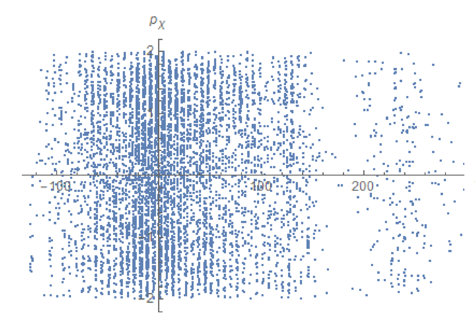

Figure 7: $E=2$, $\gamma=5$. Initial data: $\sigma=0.1$, $\chi=0.5$, $p_\sigma=0$, $p_\chi=0.374738$.

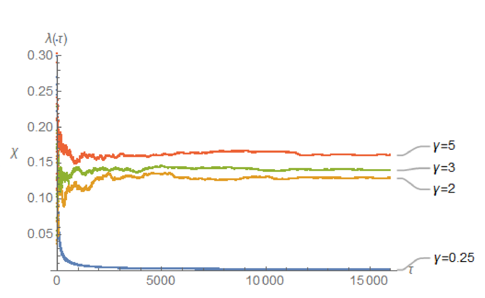

Figure 8: Numerical plots of Lyapunov exponent(s) for γ-deformed ST background.

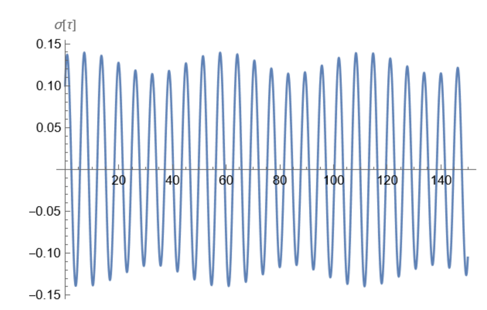

Figure 9: $\gamma=0.25$

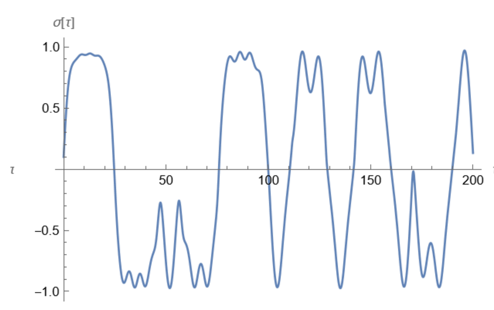

Figure 10: $\gamma=5$

Example III : Adding flavor branes

- The potential function corresponding to the *single kink* solution may be written as (JHEP **08** (2021) 030)

$$V(\sigma\sim 0,\eta) = \eta N_6\ln\sigma + \frac{\eta N_6\sigma^2}{4}\Lambda_k(\eta,P) - \frac{\eta N_6\sigma^2}{4}\frac{P+1}{P^2-\eta^2}\,,$$

where we define the above function as

$$\Lambda_k(\eta,P) = \left(P+1\right)\sum_{m=1}^{k}\left(\frac{1}{(2m+(2m-1)P)^2-\eta^2} - \frac{1}{(2m+(2m+1)P)^2-\eta^2}\right) + \frac{P}{(2k+1)^2(1+P)^2-\eta^2}\,.$$

- Next, in the case of *Uluru* space-time, the potential function may be expressed as (JHEP 08 (2021) 030)

$$V(\sigma\sim 0,\eta) = -\eta N_6\ln\sigma + \frac{\eta N_6\sigma^2}{4}\Lambda_u(\eta,K,P) + \frac{\eta N_6\sigma^2}{4(P^2-\eta^2)}\,,$$

where we define

$$\Lambda_u(\eta,K,P) = \sum_{n=1}^{u}(-1)^{n+1}\left(\frac{1}{(nK+(2n-1)P)^2-\eta^2} - \frac{1}{(nK+(2n+1)P)^2-\eta^2}\right)\,.$$

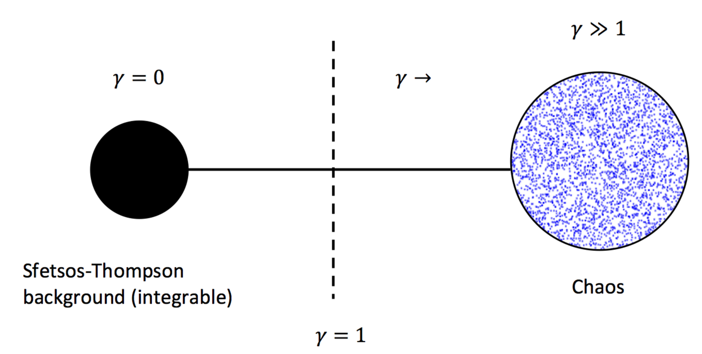

Figure 11: We show γ-deformation as an interpolation between Sfetsos-Thompson background and chaotic dynamics of strings.

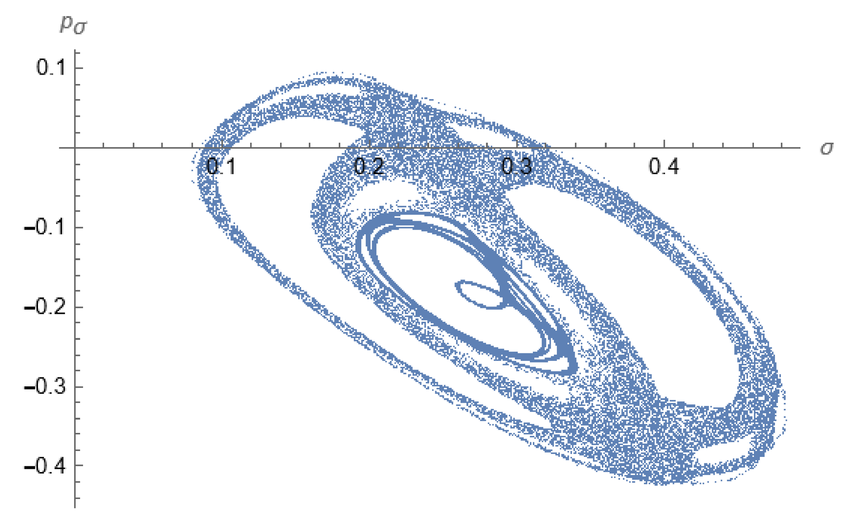

Figure 12: Plot of a Poincaré section for γ-deformed single kink profile. Here we fix the energy of the string $E=3$ and choose of the deformation parameter $\gamma=0.25$. Also, we set $\eta=7$, $p_\eta=0$, $P=6$ and $k=10$.

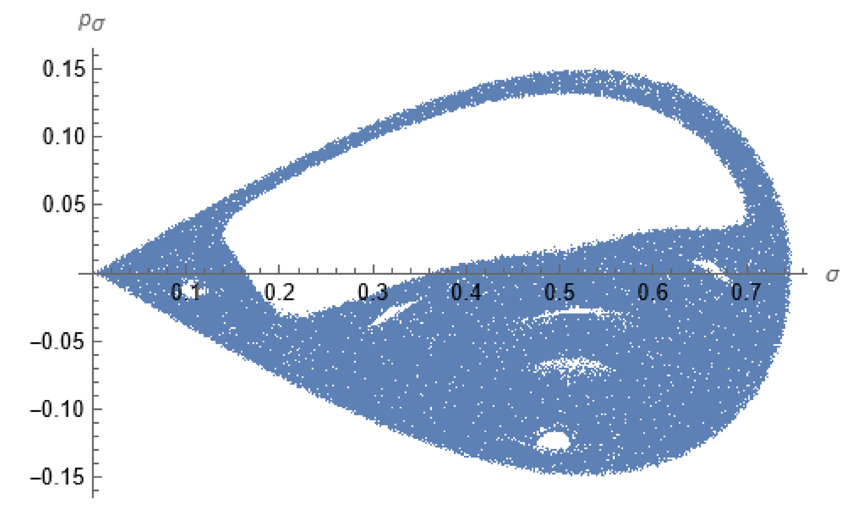

Figure 13: Plots of Poincaré sections for γ-deformed Uluru profile. Here we fix the energy of the string $E=3$ and choose of the deformation parameter $\gamma=0.25$. Also, we set $\eta=7$, $p_\eta=0$, $P=6$, $n=10$ and $K=10$.

Summary

- we explore chaotic dynamics for the γ-deformed abelian and non-Abelian T-dual of Gaiotto-Maldacena solutions.
- We examine the integrability of the semi-classical string trajectories in the presence of the γ-deformation as introduced in (Nucl. Phys. B **943**, 114617 (2019)).
- In our analysis, we use the standard Hamiltonian formulation and study the Poincaré sections and the Lyapunov exponents for different values of the deformation parameter (γ).
- We obtain distorted KAM tori and positive Lyapunov exponents for sufficiently large values of γ. On the other hand, we observe an integrable dynamics for sufficiently small values of $\gamma << 1$. This allows us to interpret the γ-deformation as an interpolation between an integrable and non-integrable dynamics sitting at two different extrema of the parameter space (see Fig.11.)
- A careful analysis reveals that the string hits $\sigma\sim 1$ singularity when the deformation parameter is large enough, $\gamma\gg 1$ (see Fig.5 and Fig.10). One the other hand, the string never reaches the above singularity for small values of the deformation ($\gamma << 1$) parameter (see Fig.4 and Fig.9). From the bulk perspective, we therefore argue that the chaotic motion of these semi-classical strings could be an artefact of $\sigma\sim 1$ singularity as seen by the "extended" string for large values of the deformation parameter ($\gamma >> 1$).

Holographic chaos and correlation in presence of backreaction

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Introduction and Motivation

- We consider a TFD state created by d-dimensional backreacted strongly coupled field theory at finite temperature. The backreaction is due to the uniform distribution of heavy static fundamental quarks. This state has a well defined holographic dual, eternal deformed AdS_{d+1} black hole.
- Holographic entanglement entropy (HEE) is $\mathcal{S} = \frac{\mathcal{A}_\gamma}{4G_N^{d+1}}$.
- **Out of time order correlator (OTOC)** can be extracted from chaos commutator $C(t,x)$ of two Hermitian operators $C(t,x) = < -[\hat{W}(t,x), \hat{V}(0)]^2 > \to OTOC = < \hat{W}(t,x)\hat{V}\hat{W}(t,x)\hat{V} >$.
- It is observed from a large class of spin-chains, higher dimensional SYK-models and CFTs that for chaotic systems, $C(t,x) \approx e^{\lambda_L(t-t_*-\frac{x}{v_B})}$.
- Using the holographic dual we study the thermo mutual information (TMI) and address the following: How backreacted system scramble the quantum information? What is the effect of backreaction on the butterfly velocity v_B and Lyapunov exponent λ_L?

Backreacted holographic geometry

- The solution of Einstein equation $R_{mn} - \frac{1}{2}G_{mn}R + \Lambda G_{mn} = 8\pi G_N T_{\mu\nu}$ with,

$$T^{\mu\nu} = -\sum_i \mathcal{T}_i \int \frac{d^2\zeta}{\sqrt{|g|}}\sqrt{-h}h^{\alpha\beta}\partial_\alpha X^\mu \partial_\beta X^\nu \delta_i^{d-1}(x - X_i)$$

gives the deformed AdS black hole solution,

$$ds^2 = \frac{R^2}{z^2}\left(-h(z)dt^2 + \frac{dz^2}{h(z)} + dx_i^2\right), \; h(z) = 1 - \frac{2mz^d}{R^{2d-2}} - \frac{2bz^{d-1}}{(d-1)R^{d-1}}$$

b is the deformation/ backreaction parameter due to strings.
- The Hawking temperature is

$$T = \frac{1}{4\pi z_H}\left(d - \frac{2bz_H^{d-1}}{(d-1)R^{d-1}}\right)$$

Shockwave analysis

- In Kruskal coordinate

$$ds^2 = 2A(U,V)dUdV + G_{ij}(U,V)dx^i dx^j, \quad i = j = 1,2,3$$

- Taking

$$U \to \hat{U} = U + \theta(V)\epsilon\alpha(x,t), V \to \hat{V} = V \text{ and } x^i \to \hat{x}^i = x^i$$
$$d\hat{s}^2 = 2\hat{A}(\hat{U},\hat{V})d\hat{U}d\hat{V} - \hat{A}(\hat{U},\hat{V})\epsilon\hat{\alpha}(t,x)\delta(\hat{V})d^2\hat{V} + G_{ij}(\hat{U},\hat{V})dx^i dx^j$$

- If $\partial_{\hat{U}}\hat{A}(\hat{U},\hat{V}) = \partial_{\hat{U}}G_{ij}(\hat{U},\hat{V}) = 0, \; T_{\hat{U}\hat{U}} = 0, \text{ at } \hat{V} = 0$.
- $d\hat{s}^2$ satisfies,

$$R_{mn} - \frac{1}{2}G_{mn}R + \Lambda G_{mn} = 8\pi G_N(T^m_{mn} + \epsilon T^{shock}_{mn}) \text{ where,}$$

- $T^{shock}_{mn} = E_0 e^{\frac{2\pi t}{\beta}}\delta(\hat{V})\delta(\hat{x}^i)d\hat{V}^2$ is the EM tensor of shock.
- For α the Einstein's equation gives,

$$(\partial_x^2 - M^2)\alpha(t,x) = \frac{8\pi E_0 G_{xx}(z_H)}{A(z_H)}\delta(x)e^{\frac{2\pi t}{\beta}}, \quad M^2 = \frac{3z_H G'_{xx}(z_H)}{2A(z_H)}$$

for large $|x|$,

$$\alpha(t,x) \approx \exp[\frac{2\pi}{\beta}(t - t_*) - Mx] \text{ where, } t_* = \text{scrambling time}$$

Chaos: Butterfly velocity and Lyapunov exponent

By comparing $\alpha(t,x)$ with $C(t,x) \approx e^{\lambda_L(t-t_*-\frac{x}{v_B})}$ we get,

$$\lambda_L = \frac{1}{2z_H}\left(d - \frac{2bz_H^{d-1}}{(d-1)R^{d-1}}\right), \quad v_B^2 = \frac{d}{2(d-1)} - \frac{b}{(d-1)^2}\left(\frac{z_H(T,b)}{R}\right)^{d-1}$$

For $R = 1, d = 4$ plot of butterfly velocity with respect to temperature T for various values of b.

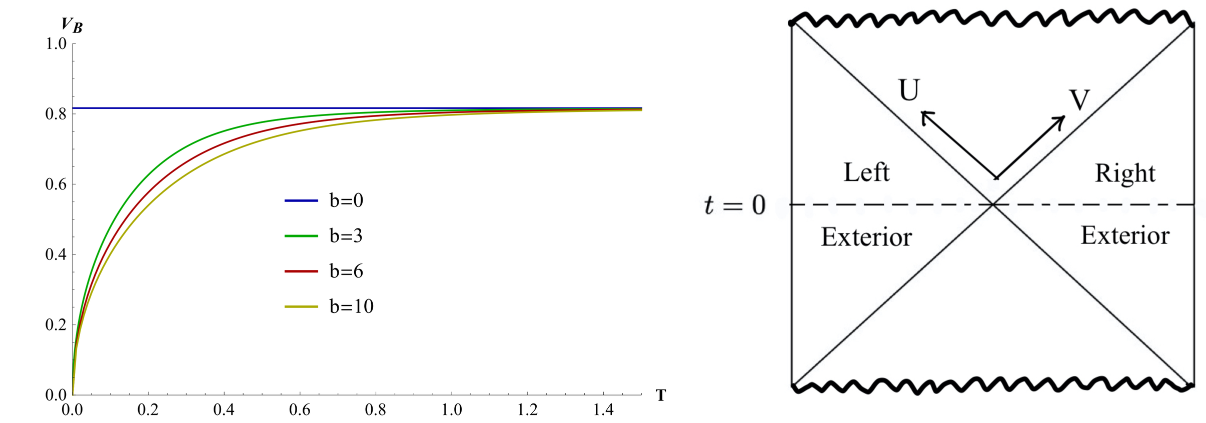

Figure 1. **Left:** Butterfly velocity for $R = 1$, $d = 4$, **Right:** Penrose diagram of eternal BH.

■ Figure-1 (left) $b = 0$ butterfly velocity is constant $v_B \approx 0.82$ at all temperatures T, while for $b \neq 0$ it starts increasing from zero and eventually saturates at $v_B \approx 0.82$. The effect of b can only be observed at intermediate temperature where if b increases v_B decreases.

Thermo mutual information (TMI)

- Thermo mutual information is defined as,

$$I(A,B) = \mathcal{S}(A) + \mathcal{S}(B) - \mathcal{S}(A \cup B)$$

between two subsystems A and B of a TFD state.
- Embedding for $\gamma_{A,B}$ and $\gamma_{A\cup B} = \gamma_1 \cup \gamma_2$ are,

$$\{t = 0, z, -l/2 \le x(z) \le l/2, -L/2 \le x^i \le L/2\}$$
$$\{0, z, x = \pm l/2, -L/2 \le x^i \le L/2\}, \quad i = 2, \cdots, d-1$$

- Finally the holographic thermo mutual information,

$$I(A,B) = \frac{L^{d-2}R_{\text{AdS}}^{d-1}}{G_N}[\int_0^{z_t}\frac{dz}{z^{d-1}\sqrt{h(z)}\sqrt{1-\left(\frac{z}{z_t}\right)^{2d-2}}} - \int_0^{z_H}\frac{dz}{z^{d-1}\sqrt{h(z)}}]$$

- z_t is turning point of γ at which $x'(z) \to 0$.

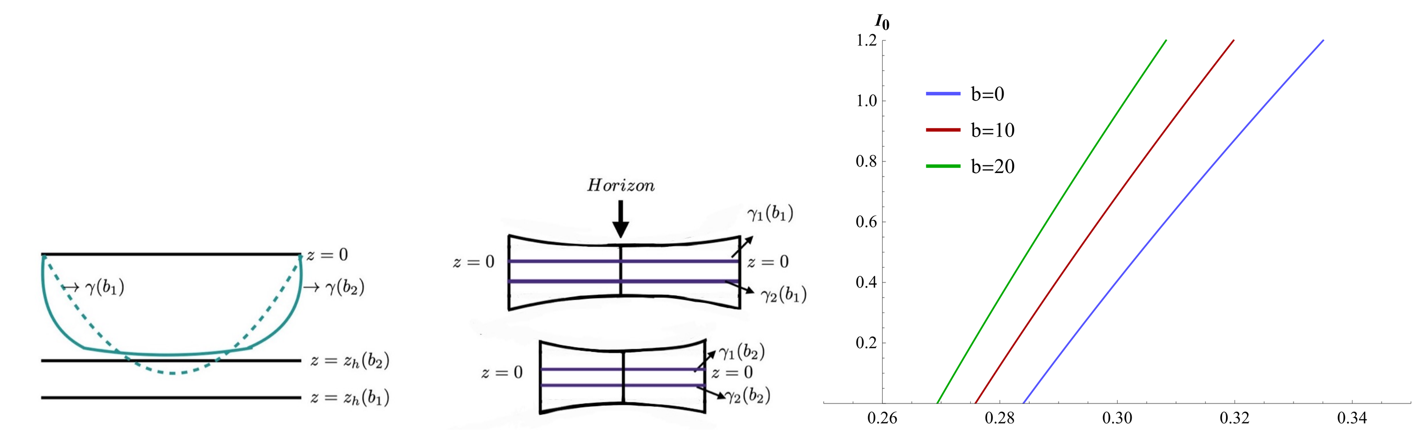

Figure 2. **Left:** Effect of b on RT and **Middle:** wormhole geometry **Right:** TMI vs width l

■ In fig.-2 (left) as b increases RT-surface get modified and it never touches the horizon even for large l. On the other hand the wormhole surface figure-2 (middle) stretches more for large b since horizon increases with b. Fig.-2 (right) Up to a critical width l_c TMI is zero and start increasing as $l \ge l_c$. The value of l_c depends on b. For fix T, the TMI increases with increase in b.

TMI in presence of shock

- Consider the shock $\alpha(t) \propto \exp\left(\frac{2\pi}{\beta}t\right)$
- TMI as, $I(\alpha) = I(0) - S^{reg}(A \cup B; \alpha)$, where $S^{reg}(A \cup B;\alpha)$ is the regularized entropy.

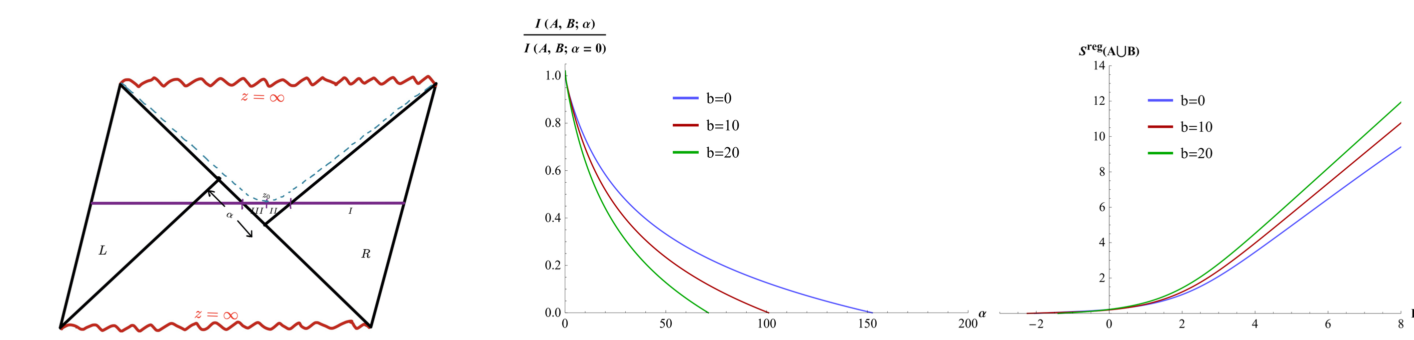

Figure 3. **Left:** Penrose diagram with shock, **Middle:** $I(\alpha)/I(0)$ vs α, **Right:** S^{reg} vs Logα

- For $S^{reg}(A\cup B;\alpha)$ the embedding is $\{t, z(t), x = \pm l/2, -L/2 \le x^j \le L/2\}$ for γ_1, γ_2. Finally we get,

$$S^{reg} = \frac{4L^{d-2}R_{\text{AdS}}^{d-1}}{4G}[\int_0^{z_H}\frac{dz}{z^{d-1}}(\frac{1}{\sqrt{h(z)+\mathcal{C}^2z^{2d-2}}} - \frac{1}{\sqrt{h(z)}}) + 2\int_{z_H}^{z_0}\frac{dz}{z^{d-1}}\frac{1}{\sqrt{h(z)+\mathcal{C}^2z^{2d-2}}}]$$

with conserved quantity $\mathcal{C} = -\left(\frac{R_{\text{AdS}}}{z_0}\right)^{d-1}\sqrt{-h(z_0)}$ and z_0 is the turning point of wormhole surface $\gamma_{1,2}$ (shown in fig-3(left)).
- The shockwave parameter

$$\alpha(z_0) = 2\exp(\eta_{\text{I}} + \eta_{\text{II}} + \eta_{\text{III}}) \text{ where,}$$
$$\eta_{\text{I}} = \frac{4\pi}{\beta}\int_{z_0}^{\tilde{z}}\frac{dz}{h(z)}, \quad \eta_{\text{II}} = \frac{2\pi}{\beta}\int_0^{z_H}\frac{dz}{h(z)}(1 - \frac{1}{\sqrt{1+\mathcal{C}^{-2}h(z)z^{2-2d}}}),$$
$$\eta_{\text{III}} = \frac{4\pi}{\beta}\int_{z_H}^{z_0}\frac{dz}{h(z)}(1 - \frac{1}{\sqrt{1+\mathcal{C}^{-2}h(z)z^{2-2d}}})$$

Summary

- We calculate the TMI in the dual bulk theory and observed that these correlation depends on the width l of the entangling region. For a critical width l_c TMI vanishes if $l \le l_c$.
- For $l \ge l_c$ at constant temperature the TMI increases with backreaction b. This behaviour indicates the enhancement of two sided correlation due to b.
- We conclude that the presence of backreaction makes the system more chaotic because of the contribution received by the butterfly velocity and Lyapunov exponent due to backreaction parameter b.
- As b increases the correlation in TFD state gets destroyed or scrambled more rapidly if one gives an early perturbation which grows with time.

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Quantum Corrction to Black Hole Entropy in EMD Models

Gurmeet Singh Punia [IISER Bhopal, INDIA] Based on [arXiv:2210.16230] JHEP 03 (2023) 028

- Bekenstein-Hawking formula describing black hole entropy classically at tree-level,

$$S_{\text{BH}} = \frac{\mathcal{A}_H}{4G_D} \qquad \text{Units: } \hbar = c = k_B = 1$$

$\mathcal{A}_H$: Area of the event horizon $\qquad G_D$: Newton's gravitational constant

Bekenstein (1974) & Hawking (1975)

- Logarithmic correction is the leading and universal quantum correction to Bekenstein-Hawking formula

$$S_{\text{BH}}(\mathcal{A}_H) = \frac{\mathcal{A}_H}{4G_D} + \mathcal{C} \ln\left(\frac{\mathcal{A}_H}{G_D}\right) + \cdots$$

- We computed logarithmic correction for AdS and flat black holes embedded in four-dimensional Einstein-Maxwell-Dilaton (EMD) models.

$$\mathcal{S}_{\text{EMD}} = \int \mathrm{d}^4x\sqrt{g}\left(\mathcal{R} - 2\Lambda - 2D_\mu\Phi D^\mu\Phi - e^{-2\kappa\Phi}F_{\mu\nu}F^{\mu\nu}\right)$$

Φ: Dilaton (a constant scalar) with coupling constants $\kappa = \frac{1}{\sqrt{3}}$, 1 and $\sqrt{3}$ in string theory

Gibbons, Stronger, Maeda, Garfinkle, Horowitz, Khuri, Orthin, $\cdots$

- EMD are the most ubiquitous building blocks of compactified IR string theory/supergravity in 4D.

- Contrary to the flat black holes, all AdS results are non-topological – providing a wider "infrared window into the microstates" of black holes.

For more details, Please visit my Poster.

Dec. 11
@Y306

Bulk reconstruction of AdS_{d+1} metrics and developing kinematic space

Kakeru Sugiura (Kyoto Univ.)

Based on [arXiv:2212.10065] w/ Daichi Takeda

Message

AdS_{d+1} metrics can be reconstructed explicitly!

We can use the CFT data to determine $g_{\mu\nu} = \Omega\, \tilde{g}_{\mu\nu}$:

- **Correlators** → causal structure $\tilde{g}_{\mu\nu}$
- **Causality & entanglement** → conformal factor Ω

Towards reconstruction of more general spacetimes…

kinematic space $:= \{\text{the minimal surfaces in bulk}\}$

Takanori Anegawa (Osaka U)

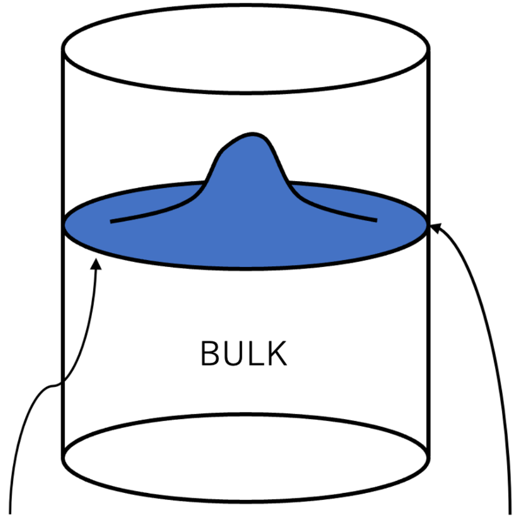
Shock waves and delay of hyperfast growth in de Sitter Complexity

Work with
Norihiro Iizuka, Sunil Kumar Sake, Nicolò Zenoni
JHEP 06 (2023) 213, *JHEP* 08 (2023) 115

Recently, JT de Sitter = DSSYK dual is focused on. [Susskind]

Important Quantity : **Complexity** ≈ Geometric volume in bulk

dS spacetime expanding ⇒ Hol Complexity shows "Hyperfast"



In this poster, we discuss

1. Dictionaries of Complexity in two-dim dS
2. The response of Complexity by perturbation.

CONCLUSION

1. In two-dim dS, CA is better than CV.
2. The growth of Complexity is delayed by small perturbation.

In my poster, there are further details!

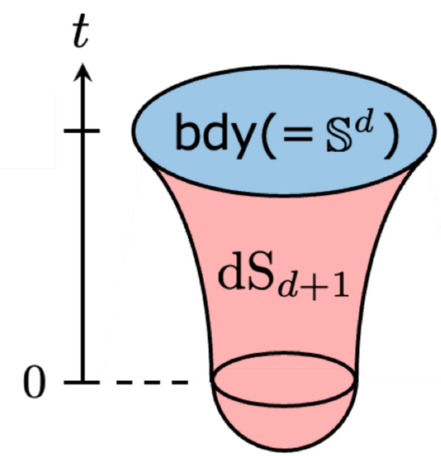
Complex saddles of three-dimensional de Sitter gravity via holography

Yusuke Taki (YITP)

Based on works with Heng-Yu Chen, Yasuaki Hikida, and Takahiro Uetoko

<u>Q.</u> **What are the allowable saddles** to the semi-classical wave functional of universe?

$$\Psi[g_{\mu\nu}^{(\mathrm{bdy})}] = \int \mathcal{D}g_{\mu\nu}\, e^{iS_{\mathrm{grav}}[g_{\mu\nu}]}$$



<u>Approach:</u> via **dS/CFT** with the CFT side being **Liouville theory** with $c = i \cdot \infty$

<u>A.</u> **Two complex saddles** contribute, as the result of the **Stokes phenomenon**.

On non-invertible symmetry with gravity

- In recent years, the concept of symmetry has been generalized and new types of symmetry have appeared, such as higher-form symmetry and non-invertible symmetry.
- I will talk about non-invertible symmetry of 4d QFT in curved spacetime.
- e.g.   massless QED
  QCD + QED
  Axion Yang-Mills

Kavli Asian Winter School / 2023-12-11 / Takahiro Tanaka(YITP)

Pseudo Entropy under Joining Local Quenches

Kotaro Shinmyo, Tadashi Takayanagi, **Kenya Tasuki** (YITP, KyotoU) [arXiv:2310.12542]

YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

Center for Gravitational Physics and Quantum Information
Yukawa Institute for Theoretical Physics, Kyoto University

entanglement entropy

$$S\left(\rho_A^{\psi}\right) := -\mathrm{Tr}\left[\rho_A^{\psi}\log\rho_A^{\psi}\right]$$

reduced **density** matrix

generalize ↓ ↑ $|\psi\rangle = |\varphi\rangle$

pseudo entropy

$$S\left(\mathcal{T}_A^{\psi|\varphi}\right) := -\mathrm{Tr}\left[\mathcal{T}_A^{\psi|\varphi}\log\mathcal{T}_A^{\psi|\varphi}\right]$$

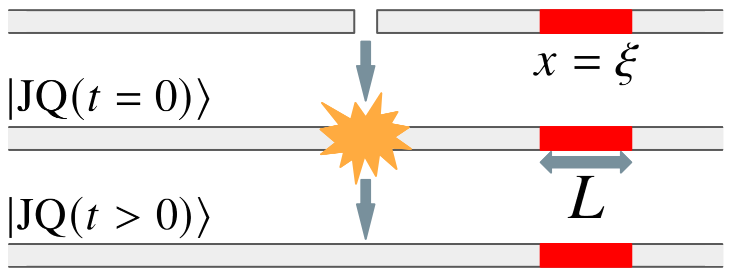
reduced **transition** matrix

$$\Delta S_A^{\psi|\varphi} := \mathrm{Re}\left[S\left(\mathcal{T}_A^{\psi|\varphi}\right)\right] - \frac{1}{2}\left(S(\rho_A^{\psi}) + S(\rho_A^{\varphi})\right)$$

→ ***positivity distinguishes different quantum phases***

Q. What properties does PE possess?

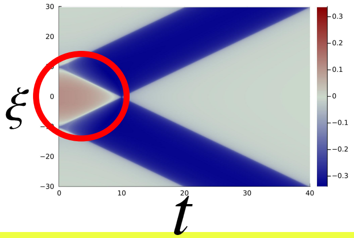
joining quench



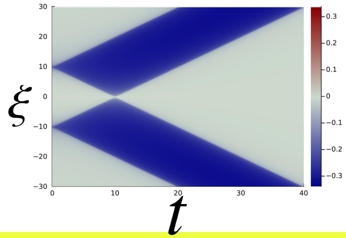
d=2 BCFTs

$|\psi\rangle = |\mathrm{JQ}\rangle$
$|\varphi\rangle = |\Omega\rangle$

holographic CFT



free Dirac fermion CFT



suggest multipartite entanglement in hol. CFT vac.

Symmetry from homotopy algebras

Jojiro Yoshinaka (Kyoto U.)
on-going work with Keisuke Konosu (U. of Tokyo)

Action in QFT S ⟺ Homotopy algebra $(T\mathcal{H}, \omega, M)$

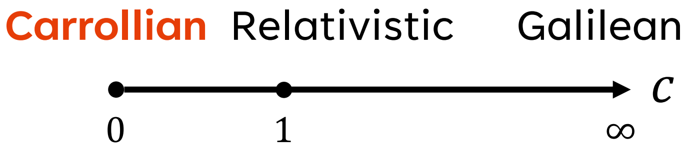
↑ derive some properties of QFT as algebraic identities

We investigated
how symmetry is described in terms of homotopy algebra
and showed
Ward-Takahashi identity can be derived from homotopy algebra

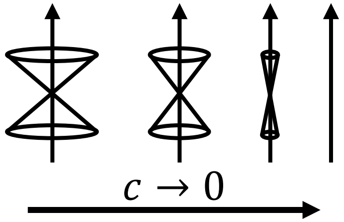
Carrollian Conformal Field Theories

Yu-fan Zheng Peking University 1801110091@pku.edu.cn

What is Carrollian



light-cone



Carrollian boost

$$t \to t + a^i x^i$$
$$x^i \to x^i$$

"Running without moving"

—— **Lewis Carroll**: Alice Through the Looking-Glass

Flat holography

Carrollian conformal symmetry $\cong$ (global) BMS symmetry

Carrollian CFT ⟵ duality ⟶ gravity in asymptotic flat space

Celestial holography

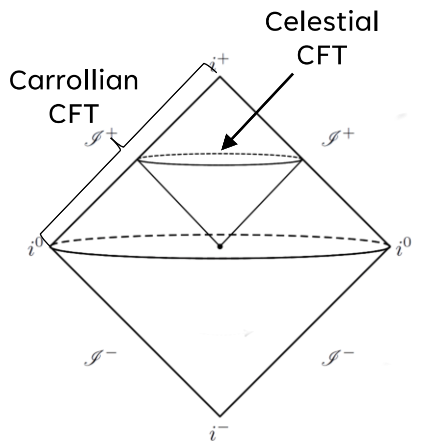
S-matrix element of **gravity** in **$4d$** asymptotic flat space

≀

source of **Carrollian CFT** on **$3d$** null infinity

≀

operator of **celestial CFT** on **$2d$** celestial sphere

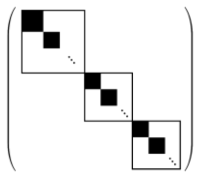


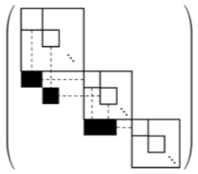
Our works [2112.10514] [2301.06011]

algebra $\{D, P^\mu, J^{ij}, B^i, K^\mu\}$

$$[D,P^\mu]=P^\mu,\quad [D,K^\mu]=-K^\mu,\quad [D,B^i]=[D,J^{ij}]=0,$$
$$[J^{ij},G^k]=\delta^{ik}G^j-\delta^{jk}G^i,\quad G\in\{P,K,B\}$$
$$[J^{ij},P^0]=[J^{ij},K^0]=0,$$
$$[J^{ij},J^{kl}]=\delta^{ik}J^{jl}-\delta^{il}J^{jk}+\delta^{jl}J^{ik}-\delta^{jk}J^{il},$$
$$[B^i,P^j]=\delta^{ij}P^0,\quad [B^i,K^j]=\delta^{ij}K^0,\quad [B^i,B^j]=[B^i,P^0]=[B^i,K^0]=0,$$
$$[K^0,P^0]=0,\quad [K^0,P^i]=-2B^i,\quad [K^i,P^0]=2B^i,\quad [K^i,P^j]=2\delta^{ij}D+2J^{ij}.$$

highest weight representation

$J =$ 

$B =$ 

correlation function

Level 3: $\langle \mathcal{O}_1^{m_1}\mathcal{O}_2^0\rangle = \dfrac{C\ t_{12}/|\vec{x}_{12}|\ I_{1,0}^{m_1}}{|\vec{x}_{12}|^{2\Delta}},$

Level 2: $\langle \mathcal{O}_1^0\mathcal{O}_2^0\rangle = \dfrac{C}{|\vec{x}_{12}|^{2\Delta}},\qquad \langle \mathcal{O}_1^{m_1}\mathcal{O}_2^{m_2}\rangle = \dfrac{C\ I_{1,1}^{m_1,m_2}}{|\vec{x}_{12}|^{2\Delta}},$

Level 1: $\langle \mathcal{O}_1^0\mathcal{O}_2^{m_2}\rangle = 0.$

$\mathcal{O}_1 \in\ (1) \to (0)\quad \mathcal{O}_2 \in\ (0) \to (1)\quad$ with $\Delta_1=\Delta_2=\Delta.$

Level 3: $\langle \mathcal{O}_1^{m_1}\mathcal{O}_2^{m_2}\rangle = C_1|t_{12}|^3\partial_{m_1}\partial_{m_2}\delta^{(3)}(x_{12}) + C_2|t_{12}|\delta^{(3)}(x_{12})\delta_{m_1,m_2},$

Level 2: $\langle \mathcal{O}_1^{m_1}\mathcal{O}_2^0\rangle = C_1|t_{12}|^2\partial_{m_1}\delta^{(3)}(x_{12}),$

Level 1: $\langle \mathcal{O}_1^0\mathcal{O}_2^0\rangle = C_1|t_{12}|\delta^{(3)}(x_{12}).$

$\mathcal{O}_1, \mathcal{O}_2 \in (1) \to (0)\quad$ with $\Delta_1=\Delta_2=\Delta.$

construction from $(d+1)$-dim Bargmann theory

$$S^e_{barg} = \int d^{d+1}x\, \xi^\mu\xi^\nu\partial_\mu\Phi\partial_\nu\Phi$$
$$\Rightarrow\ S^e_{carr} = \int d^dx\, \partial_t\phi\partial_t\phi$$

$$S^m_{barg} = -\frac{1}{2}\int d^{d+1}x\, G^{\mu\nu}\partial_\mu\Phi\partial_\nu\Phi$$
$$\Rightarrow\ S^m_{carr} = -\frac{1}{2}\int d^dx\, \pi\partial_t\phi + g^{ij}\partial_i\phi\partial_j\phi$$

Please see the poster for more information of our work!


Thank you !
Enjoy Welcome Party !