No Particle Production in AdS_2?

António Antunes, LPENS

Bootstrap 2026

Based on: W.I.P w/ Miguel P., Noé

see also 2502.06937 w/ Marco M., Nat

2109.13261 w/ Miguel C., João, Aaditya, Balt

No particle-production in AdS2?	*Antonio Antunes*
Oliver Thompson Lecture Theatre 101, Tait Building at City St George's, University of London	15:15 - 15:45
Coffee break	
	15:45 - 16:15
Where is tree-level heterotic string theory?	*Waltraut Knop*
Oliver Thompson Lecture Theatre 101, Tait Building at City St George's, University of London	16:15 - 16:45

Where is Integrability in AdS_2?

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How is Integrability in AdS_2?

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Is Integrability in AdS_2?

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Outline

- Motivation from Higher-d CFT
- C(F)T_1 / QFT in AdS_2
- Solutions to crossing with no "Particle-Production"
- Open Questions & Discussion

1.) Motivation

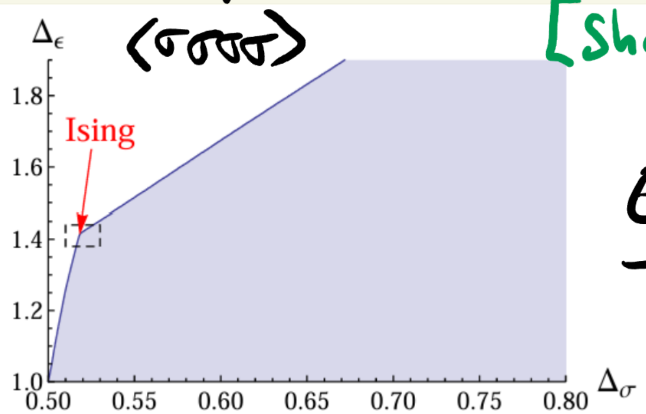
- A set of (local) CFT data $\{(\Delta_i, J), c_{ijk}\}$ is consistent if all 4-pt functions $\langle O_i O_j O_k O_l \rangle$ are crossing symmetric.

- In the Bootstrap, we consider crossing of one or a few 4-pt functions, and yet we often are very close to "solving" the CFT. Why?

(The unreasonable effectiveness of the Bootstrap)

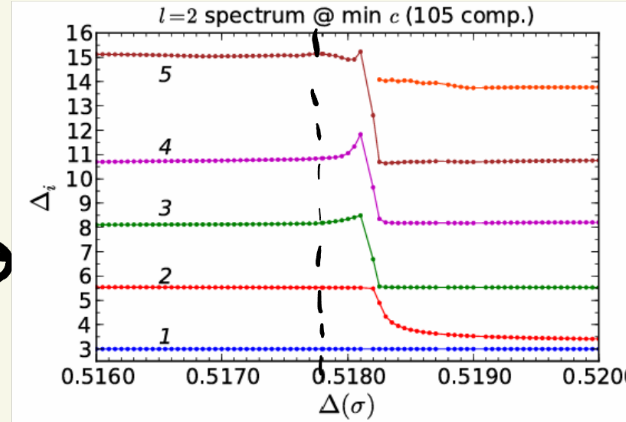
Example: Our Favorite child

$\langle\sigma\sigma\sigma\sigma\rangle$

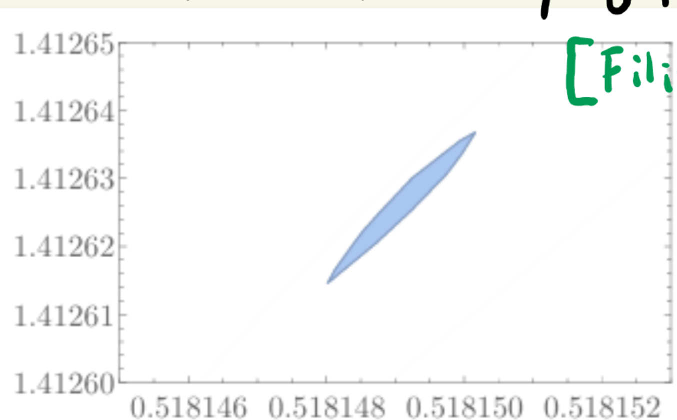


[Sheen eTal 12', 14']

Extremal
$\xrightarrow{\hspace{2cm}}$
Functional
c - min

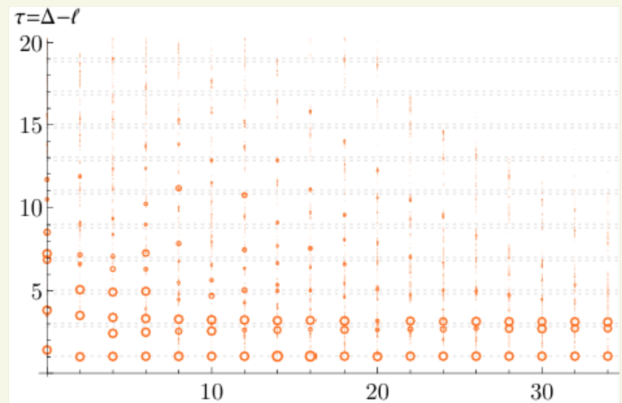


$\langle\sigma\sigma\sigma\sigma\rangle$, $\langle\sigma\sigma\epsilon\epsilon\rangle$, $\langle\epsilon\epsilon\epsilon\epsilon\rangle$, + gaps



[Filip eT al 16']

$\longrightarrow$



[David S-D 16']

Intuition: (No claim of Rigor here)

The Bootstrap (Extremal Functional) approximates a CFT by solving a Finite # of crossing Equations with as Few Operators / Regge Trajectories as Possible.

Single Corr.

$$\sigma \times \sigma \sim 1 + [\sigma\sigma]_{n,l} + \ldots$$

(Not Exactly)

Multi Corr.

$$\varepsilon \times \varepsilon \sim [\sigma\sigma]_{n,l} + [\varepsilon\varepsilon]_{n,l} + [TT]_{n,l} + \ldots$$

$$\sigma \times \varepsilon \sim [\sigma\varepsilon]^{\pm}_{n,l} + \ldots$$

$$\sigma \times \sigma \sim [\sigma\sigma]_{n,l} + [\varepsilon\varepsilon]_{n,l} + [TT]_{n,l} + \ldots$$

[See Zechuan's Talk]

Intuition (continued)

- This provides a systematic approximation scheme where correlators exhibit denser and denser spectra, as we increase # of ext. $\mathcal{O}$.

$\rightarrow$ Works well because our favorite correlators are $\approx$ sparse. (GFF + $\cdots$) (Maybe sparse = solvable?)

Goal today: Make this more precise in 1d,

+ find examples where expansion truncates.

"No particle-production / Integrability"

2.) C(F)T$_1$ / QFT in AdS$_2$

- In 1d, nospin (strong simplification), but also no $T_{\mu\nu}$ (non-local).

- Key Example: Bosonic GFF <=> Free AdS$_2$ scalar (GFB)

$$S_{GFF} = \int dx_1 dx_2 \, \frac{\phi(x_1)\phi(x_2)}{|x_{12}|^{2(1-\Delta_\phi)}} \Leftrightarrow S_{AdS} = \int_{AdS_2} dx\, dz \sqrt{g}\left(\frac{1}{2}(\nabla_\mu \Phi)^2 + \frac{1}{2} m^2 \Phi^2\right)$$

$$\boxed{\Delta_\phi(\Delta_\phi - d) = m^2 L^2} \qquad ds^2 = L^2 \frac{dx^2 + dz^2}{z^2} \qquad \boxed{\Phi(z,x) \sim z^{\Delta_\phi}\phi(x) + \dots}$$

Physics of GFB + deformations

$$\phi\times\phi \sim 1 + \underbrace{\sum_n \text{``}\phi\,\Box^n\phi\text{''}}_{\Delta_n = 2\Delta_\phi + 2n}$$

Deform?

Local AdS Interactions

GFF $+\lambda$  $+\lambda^2$  $+ \dots$

$\boxed{\text{Bootstrap}}$

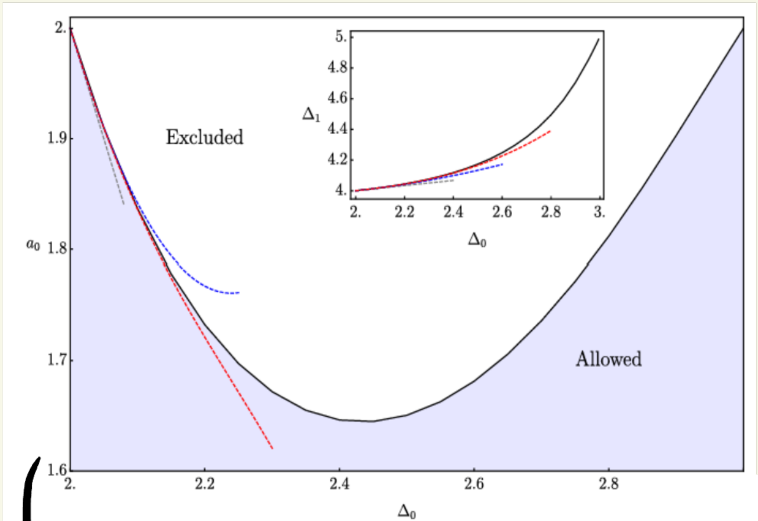
$\phi^2 \to \mathcal{O}_0$

1D Bootstrap Problem:

Let $\phi(\Delta_\phi)$ s.t. $\phi\times\phi \sim 1 + \mathcal{O}_0(\Delta_0) + \dots$

Maximize $C_{\phi\phi\mathcal{O}_0}(\Delta_0)$

Result: [Miguel P., Bernardo, '19] [Miguel, Noé, Kausik '24]



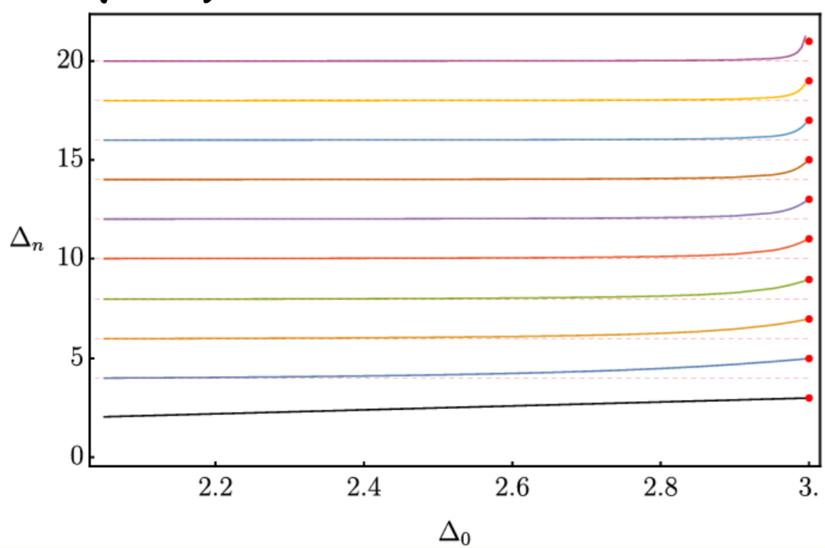
Smooth interpolation between GF Boson and GF Fermion.

$\phi \times \phi = 1 + \sum_n O_n$ $\quad \boxed{\Delta_n = 2\Delta_\phi + 2n + \gamma_n}$

$(\Delta_\phi = 1)$

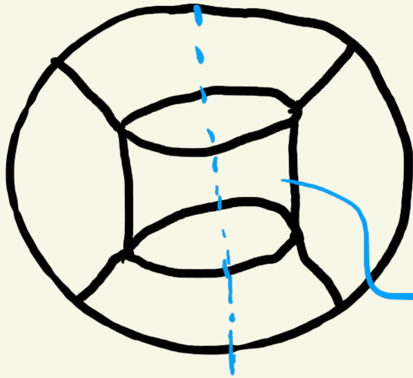
$\Delta_0 - 2\Delta_\phi \equiv g$ expansion agrees w/ $\lambda \Phi^4_{AdS}$!

- GFB/GFF assymptotics are general for 1d extremal solutions. [Nat's Talk]



Are we exactly Bootstrapping $\lambda \Phi^4_{AdS}$? NO!

$@\mathcal{O}(\lambda^4)$



$$\phi\times\phi \sim 1 + \phi^2_n + \lambda^2 \phi^4_n + \dots$$

"Particle Production"

- Single-correlator Bootstrap approximates Φ^4 by a single Tower in The $\phi\times\phi$ OPE.
- We can improve by considering

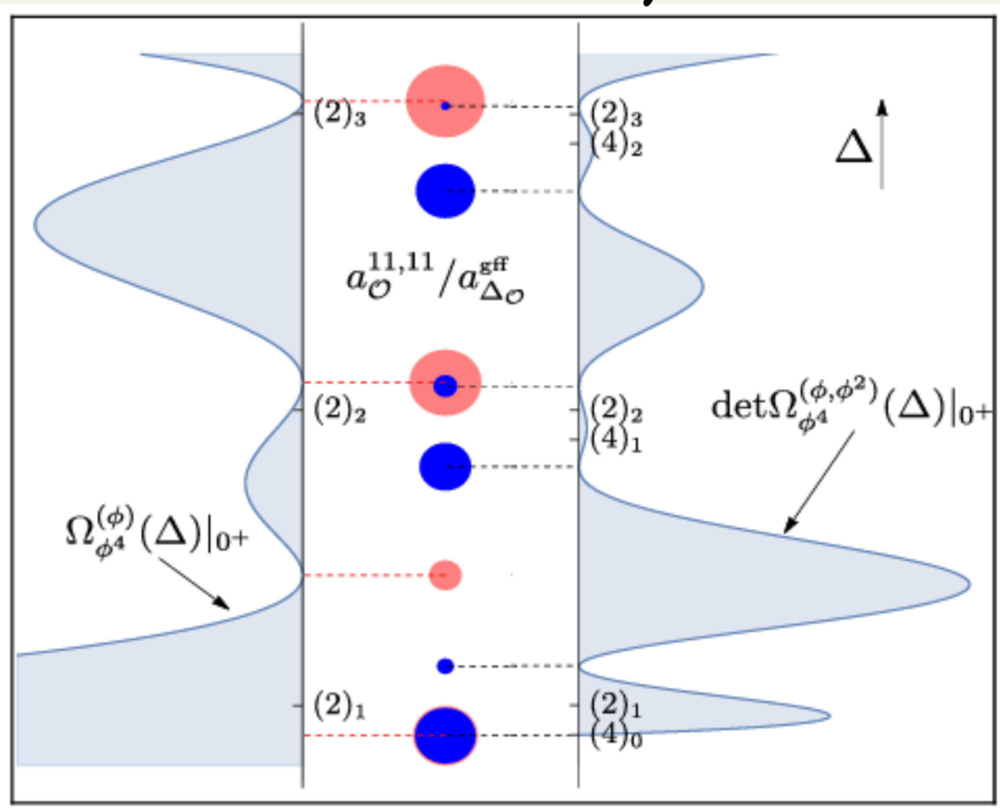
$$\phi^2\times\phi^2 \subset \phi^4$$

$$\langle\phi\phi\phi\phi\rangle, \quad \langle\phi\phi\phi^2\phi^2\rangle, \langle\phi^2\phi^2\phi^2\phi^2\rangle$$

$$\phi\times\phi \subset \phi^2 + \phi^4$$

Multi-Correlator Bootstrap [Miguel, Kausik, Apratim '23]

$\Delta_\phi > 1$



Single-Correlator

1-Tower

$\sim 2\Delta_\phi + 2n$

Multi-Correlator

2-Towers

$\sim \begin{cases} 2\Delta_\phi + 2n \\ 4\Delta_\phi + 2n \end{cases}$

Particle Production, as expected.

3) Dream / Obssession / illness:

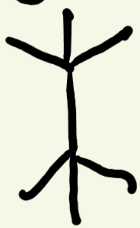
Are There CFTs where The single correlator extremal Functional is exact?

i.e. A single "Two-Particle" Tower in $\phi \times \phi$?

AKA No Particle Production?

[Virasoro BCFT]

After all, integrable $QFT_2(\mathbb{R}^2)$:

$S_{2\to 4} = \sum$  $+$  $= 0$

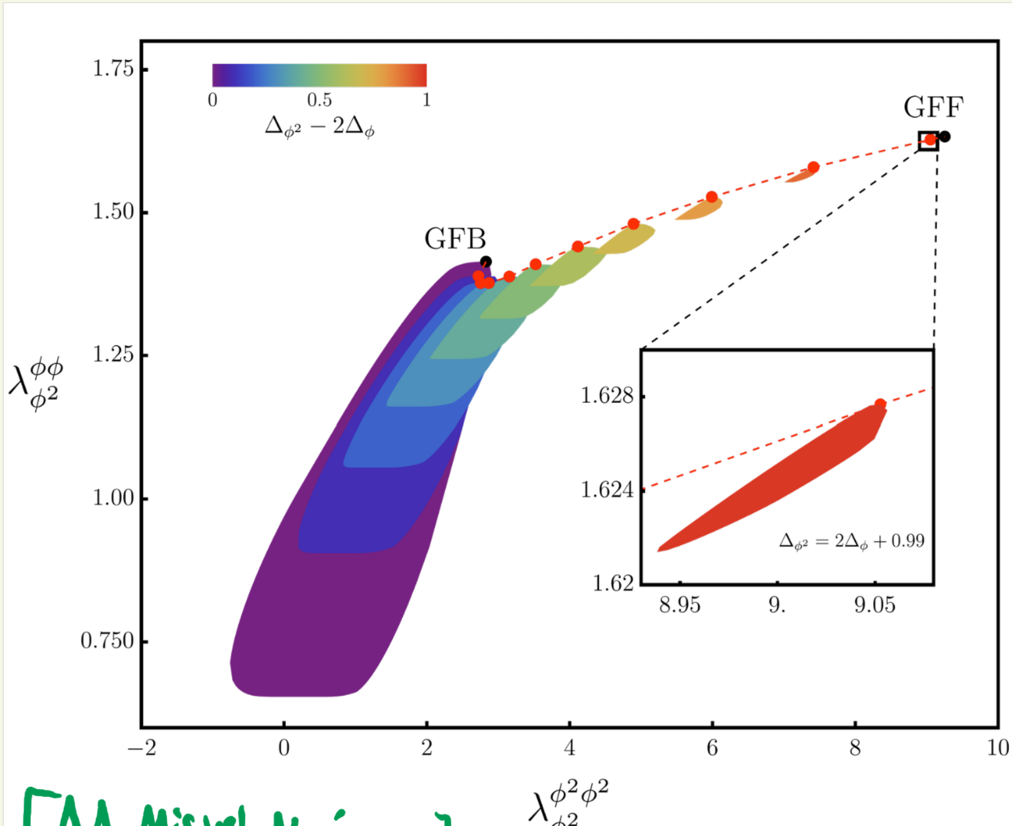
cf. Sinh-Gordon

$S_{2\to 2} \subset \sum$  $+$  $\propto |S_{2\to 4}|^2 = 0$

A direct generalization of the mechanism to AdS fails

But: (Multi-Correlator Analysis)

gaps: $\mathbb{Z}_2+$: $\sqrt{2}\Delta_\phi^2$, $\mathbb{Z}_2^-$: $\Delta_\phi+\Delta_\phi^2(+1)$

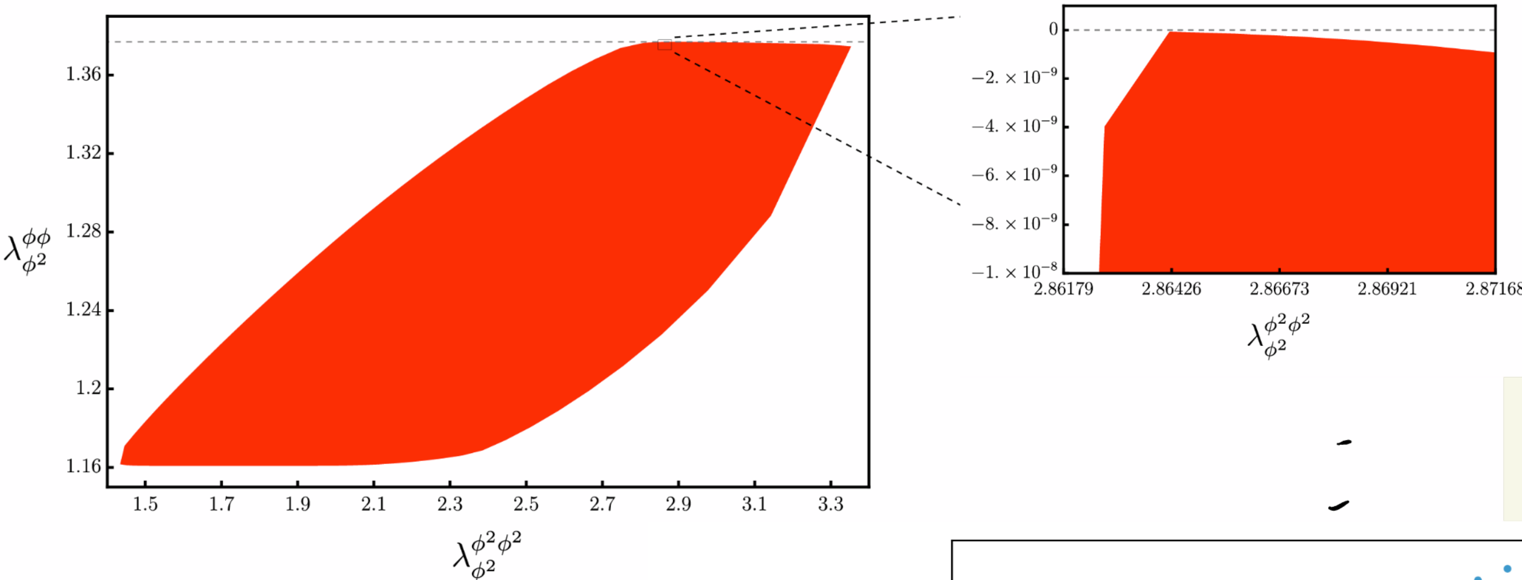


[AA, Miguel, Noé w.i.p]

- We might expect Max($\lambda_{\phi\phi\phi^2}$) to go down (new channel ϕ^4)
- But global Maximum seems to track single-correlator.

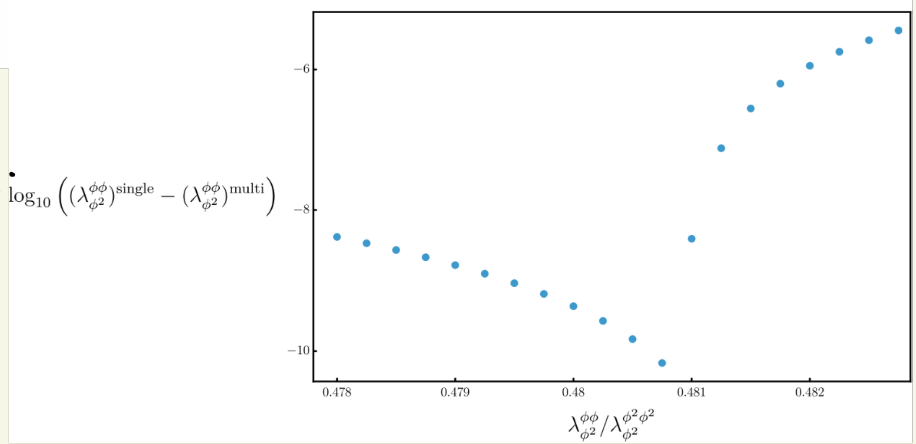
How well?

This well: $\left(\Delta_\phi = 4/3,\ \Delta_{\phi^2} = 2\times\frac{4}{3}+\frac{3}{10}\right)$

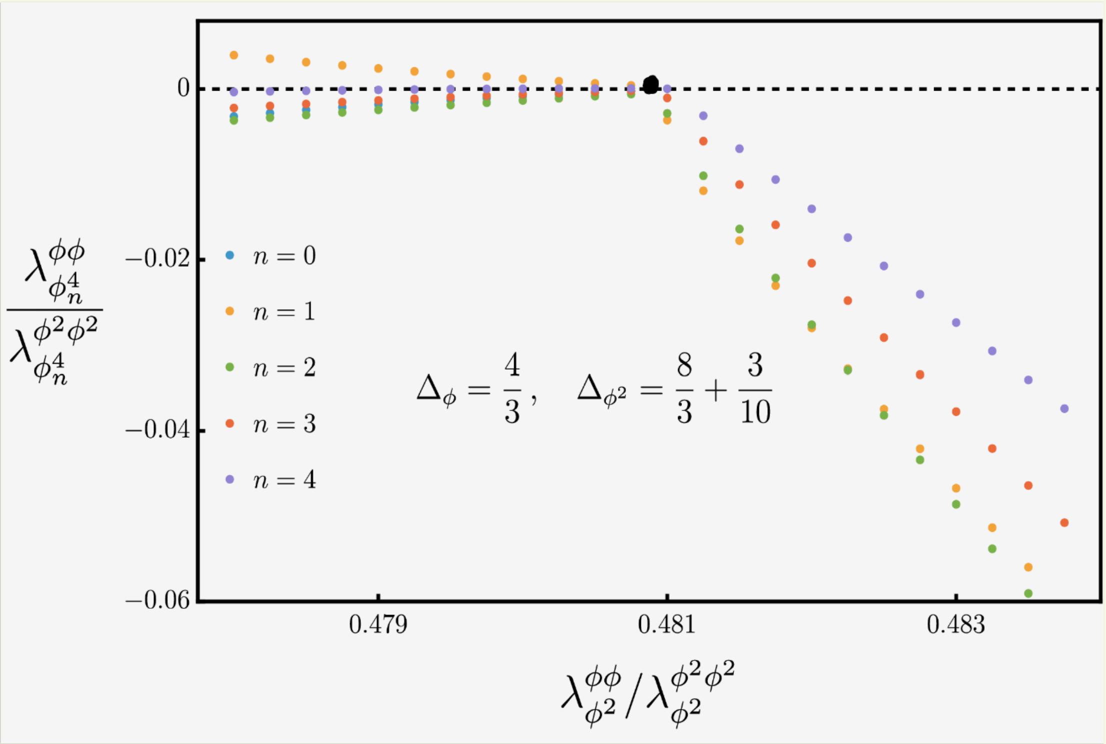


Seems generic for $\Delta_\phi > 1$.

(Not so for $\Delta_\phi < 1$!)



Furthermore, we can Track The OPE Coefficients



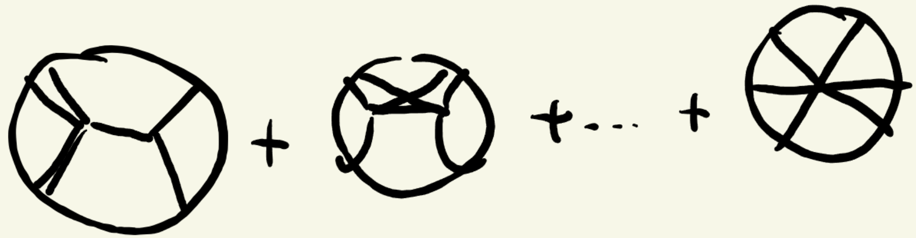
OPE Ratios Extracted From Eigenvectors of Matrix of Functionals

All "4-Particle" States seem To decouple Simultaneously at Tip!

4.) Open Questions / Discussion

- How?
- Why?
- What the hell is going on?

Direct AdS$_2$ Calculation

• One can compute 

(Say for $\Delta_\phi = 1/4$). No cancellation possible.

• In flat space: Integrability

$$\partial^\mu T_{\mu\nu\rho\sigma} = 0 \longleftrightarrow S_{2\to4} = 0$$

In AdS$_2$ HS currents $\Rightarrow$ Integer spacing $\gamma_n = $ cst.

(Incompatible w/ Bootstrap)

[AA, Marcoli. Nat '25]

Analytic Functional Analysis [Dalimil, Miguel --]

- Recall analytic functionals:

$$\alpha_n(\Delta_m) = \delta_{n,m} \qquad \partial_\Delta \alpha_n(\Delta_m) = 0$$

$$\beta_n(\Delta_m) = 0 \qquad \partial_\Delta \beta_n(\Delta_m) = \delta_{n,m}$$

- For the mixed correlator problem, $\alpha^{\phi\phi;\phi^2\phi^2}_{(\phi^4)_n}$ gives sum-rule

$$\lambda_{\phi\phi(\phi^4)_n}\lambda_{\phi^2\phi^2(\phi^4)_n} = \alpha^{\phi\phi;\phi^2\phi^2;t}_{(\phi^4)_n}(\Delta_\phi) + \sum_m (\gamma^{(1)}_m)^2 \lambda_m \alpha^{\phi\phi\phi^2\phi^2}_{(\phi^4)_n}(\phi^3_m)$$

$$\sum_m \left(\gamma^{(1)2}\lambda^{(0)} + \gamma^{(2)}\lambda^{(0)} + \lambda^{(1)}\gamma^{(1)}\right)\alpha^{\phi\phi;\phi^2\phi^2,s}_{(\phi^4)_n}(\phi^2_m) \stackrel{!}{=} 0 ?$$

Thanks For Your Attention!