AdS/BCFT from Bootstrap Construction of Gravity with particle & brane

Caltech

Yuya Kusuki

Based on [2206.03035] & [2210.03107], a collaboration with Wei

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- Introduction
  - Issues in AdS/BCFT
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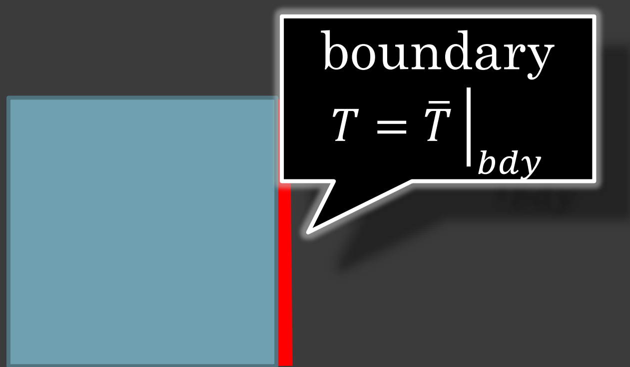
- Bootstrapping AdS/BCFT
- Construction of gravity with brane & particle
- Refined RT formula
- Discussion

BCFT [Cardy]



BCFT_2

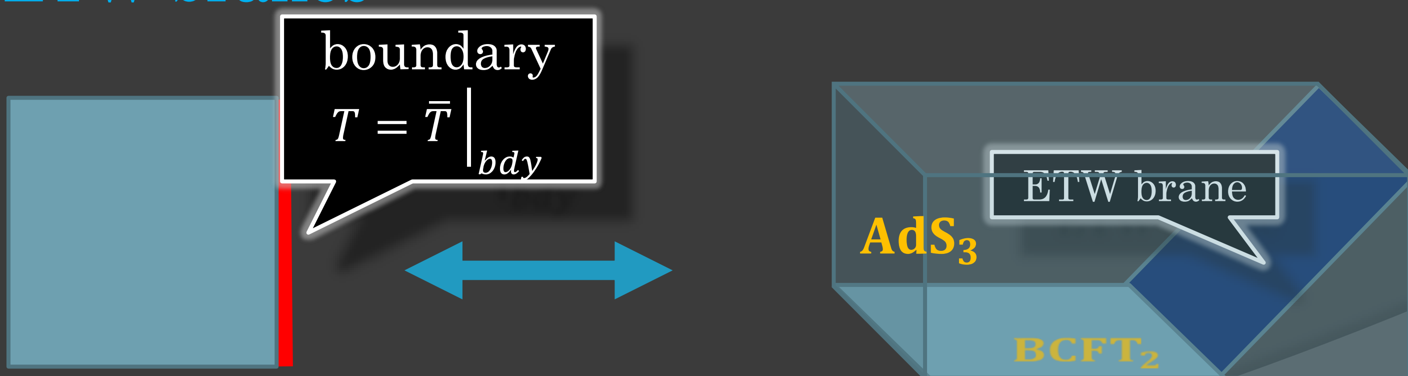
BCFT

AdS / BCFT

[Takayanagi]
[Fujita, Takayanagi, Tonni]

$$I_{grav} = -\frac{1}{16\pi G_N}\int_M d^3x\,\sqrt{g}(R-2\Lambda) + \sum_i m_i \int dl_i - \frac{1}{8\pi G_N}\int_Q d^2x\,\sqrt{h}(K-T)$$

Semiclassical gravity ($c = \frac{3}{2G_N} \gg 1$) with massive particles and ETW branes



$BCFT_2$

BCFT

AdS with ETW brane

$\partial(\text{ETW}) = \text{bdy. of CFT}$

AdS / BCFT

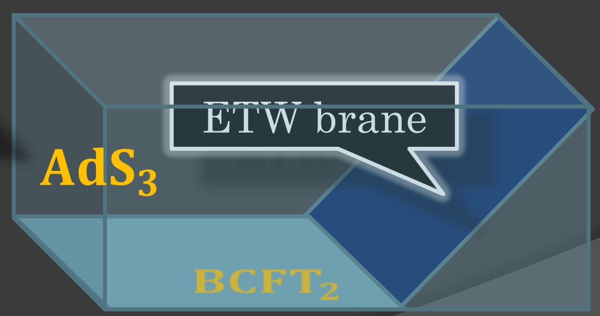
[Takayanagi]
[Fujita, Takayanagi, Tonni]

$$I_{grav} = -\frac{1}{16\pi G_N}\int_M d^3x\sqrt{g}(R-2\Lambda) + \sum_i m_i \int dl_i - \frac{1}{8\pi G_N}\int_Q d^2x\sqrt{h}(K-T)$$

Induced metric: $h_{\mu\nu} = g_{\mu\nu} - n_\mu n_\nu$,
Extrinsic curvature: $K_{\mu\nu} = h_\mu^{\ \rho} h_\nu^{\ \lambda} \nabla_\rho n_\lambda$

Neumann b.c. is imposed on the brane (Einstein eq. of brane).

$$K_{ab} - K h_{ab} = -T h_{ab}$$



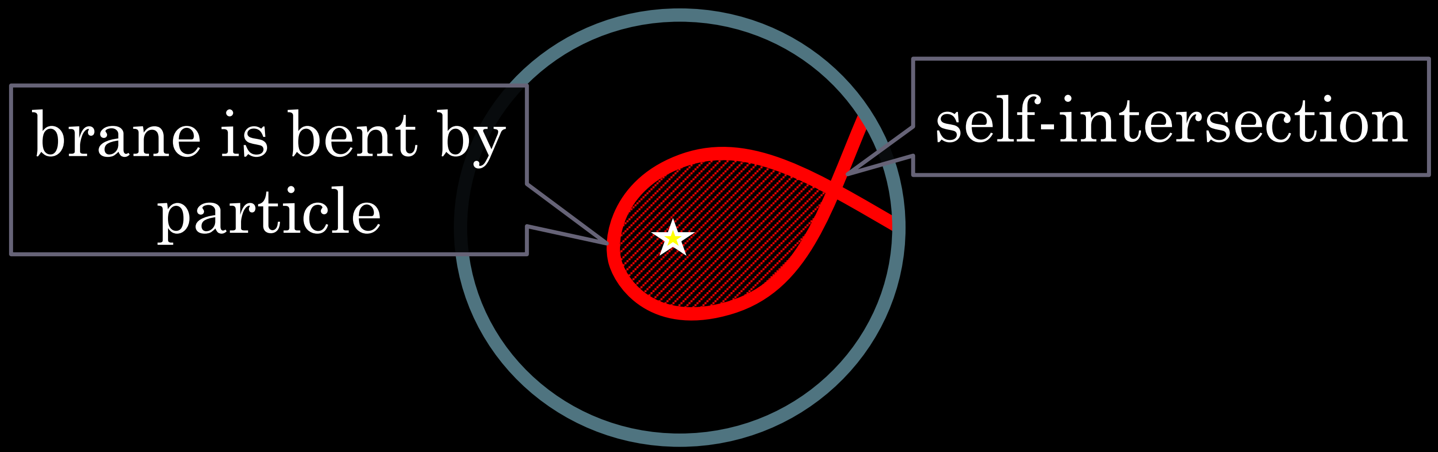
AdS with ETW brane
∂(ETW) = bdy. of CFT

AdS / BCFT

What is less understood?

gravity with brane & particle itself

- brane self-intersection (more explained later)

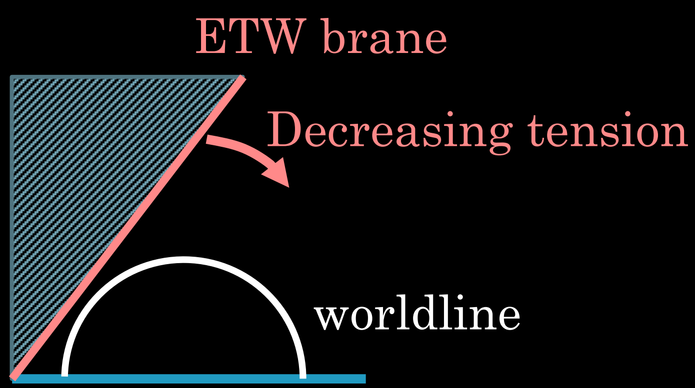


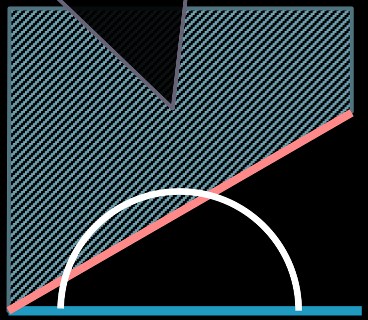
AdS / BCFT

What is less understood?

gravity with brane & particle itself

- brane self-intersection
- negative tension brane





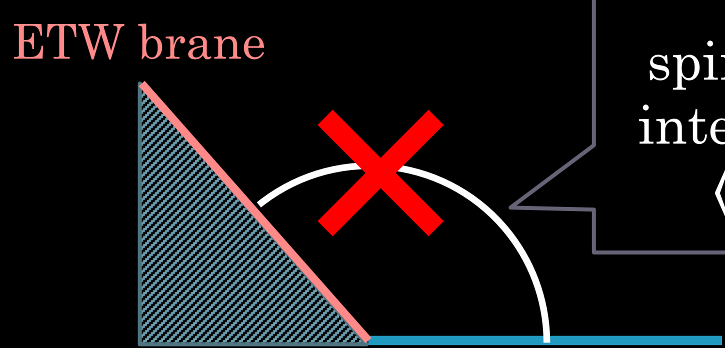
How to understand worldline behind ETW brane

AdS / BCFT

What is less understood?

gravity with brane & particle itself

- brane self-intersection
- negative tension brane
- how to deal with spinning particle



spinning particle cannot interact with brane since $\langle O \rangle_{disk} = 0$ if $h \neq \bar{h}$

AdS/BCFT

What is less understood?

gravity with brane & particle itself
- brane self-intersection
- negative tension brane
- how to deal with spinning particle

Why less understood?

We need details deep into the bulk,
unlike a common case where FG expansion works.
→ we need to solve Einstein eq. explicitly.
→ this is difficult & complicated.

AdS / BCFT

What is less understood?

gravity with brane & particle itself

how to address the issues on CFT side

- conformal bootstrap?

Not so explored in AdS/BCFT.
No (or limited) know-how to apply bootstrap to address the issues in AdS/BCFT

AdS / BCFT

What is less understood?

gravity with brane & particle itself

how to address the issues on CFT side

- conformal bootstrap?

If we succeed in translating the issues into a bootstrap problem, we can easily give a rigorous answer.

AdS/BCFT

What is less understood?

gravity with brane & particle itself

how to address the issues on CFT side

bottom-up AdS/BCFT

- Naïve RT-formula cannot reproduce

$$S_A^{(n)} = \frac{c}{12}\left(1+\frac{1}{n}\right) + \log g$$

AdS/BCFT

What is less understood?

gravity with brane & particle itself
- brane self-intersection
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AdS/BCFT

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bottom-up AdS/BCFT

- Naïve RT-formula cannot reproduce $S_A^{(n)}$
- gravity dual of boundary primary (explained later)

AdS/BCFT

What is less understood?

gravity with brane & particle itself

how to address the issues on CFT side

bottom-up AdS/BCFT

- Naïve RT-formula cannot reproduce $S_A^{(n)}$
- gravity dual of boundary primary (explained later)
- naïve and bottom-up construction

  → may need to be refined,
  when considering complicated setups,
  like gravity with branes + massive particles

Result

First part:

We address the issues with bootstrap.

The bootstrap tells us a robust answer on how to resolve the issues.

It implies the bootstrap is useful even in AdS/BCFT.

gravity with brane & particle itself

- brane self-intersection
- negative tension brane
- how to deal with spinning particle

how to address the issues on CFT side

- conformal bootstrap?

Result

Second part:

We develop a simple way to construct gravity with brane & particle.

The solution tells us how to resolve the issues from the gravity side.

Moreover, this is completely consistent with the bootstrap result.

We need details deep into the bulk,
unlike a common case where FG expansion works.
→ we need to solve Einstein eq. explicitly.
→ this is difficult & complicated.

We will overcome this point

Result

Third part: (skipped)

We give a refined RT formula, which completely reproduces $S_A^{(n)}$ in AdS/BCFT.

We also give the gravity dual of boundary primary.

bottom-up AdS/BCFT

- Naïve RT-formula cannot reproduce $S_A^{(n)}$
- gravity dual of boundary primary
- naïve and bottom-up construction

Result

Third part:

Everything is consistent.
It implies that the bottom-up AdS/BCFT nicely works without any refinements.

bottom-up AdS/BCFT

- Naïve RT-formula cannot reproduce $S_A^{(n)}$
- gravity dual of boundary primary
- naïve and bottom-up construction

Short Summary

- Bootstrapping AdS/BCFT to understand
  - brane self-intersection
  - negative tension brane
  - how to deal with spinning particle
- Constructing gravity with brane & particle
  - in a simple way, using cut & paste
  - our new construction gives results consistent with bootstrap.

  Note: There are many loopholes in gravity calculation. So, it is worth checking compared to robust results, i.e., results from bootstrap.
- Bonus
  - refined RT-formula
  - gravity dual of boundary primary

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  - Review of BCFT
- Bootstrapping AdS/BCFT
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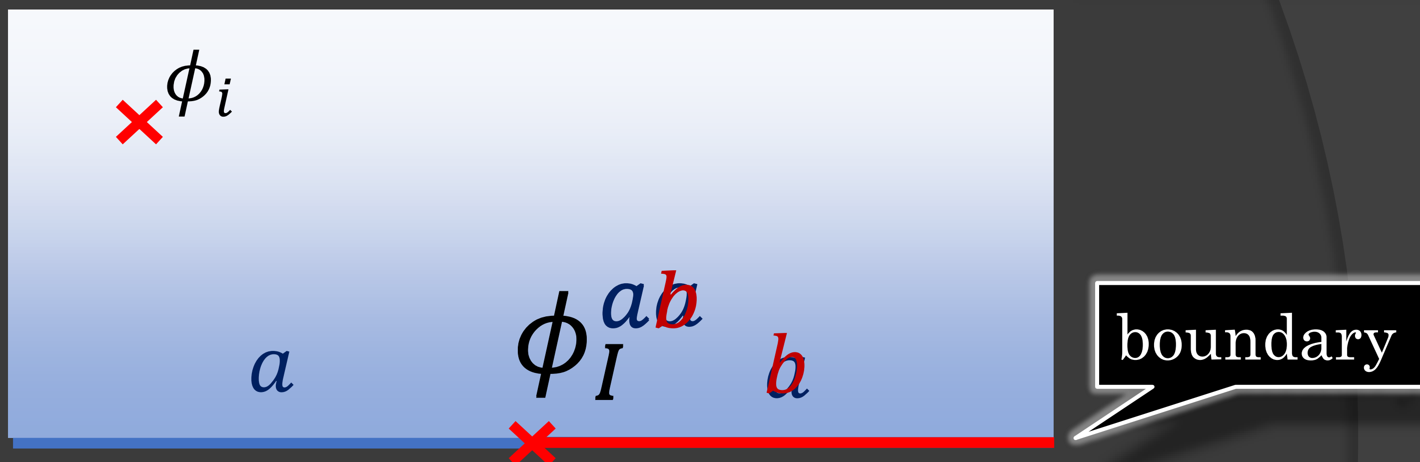
Review of BCFT

i: *bulk*
I: *boundary*

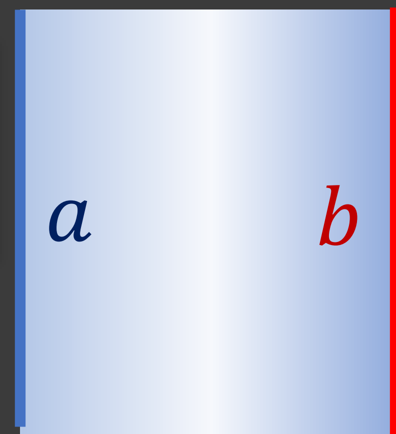


New ingredient (boundary primary)

Primary operator living on boundary,
which can change boundary condition.
Same transformation law under conformal mapping.

Review of BCFT

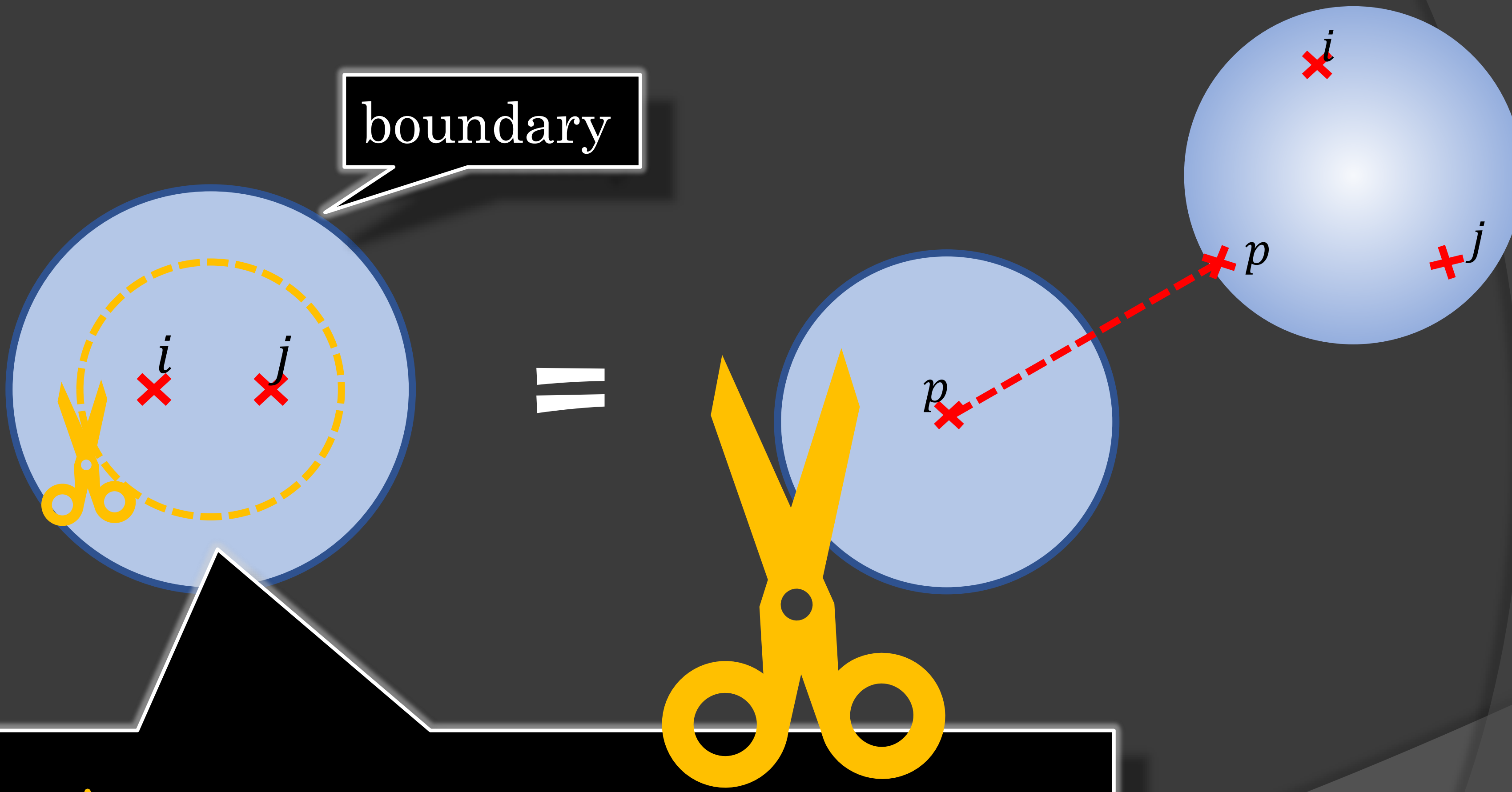
state – operator
like mapping



Conformal weight of ϕ_I^{ab}

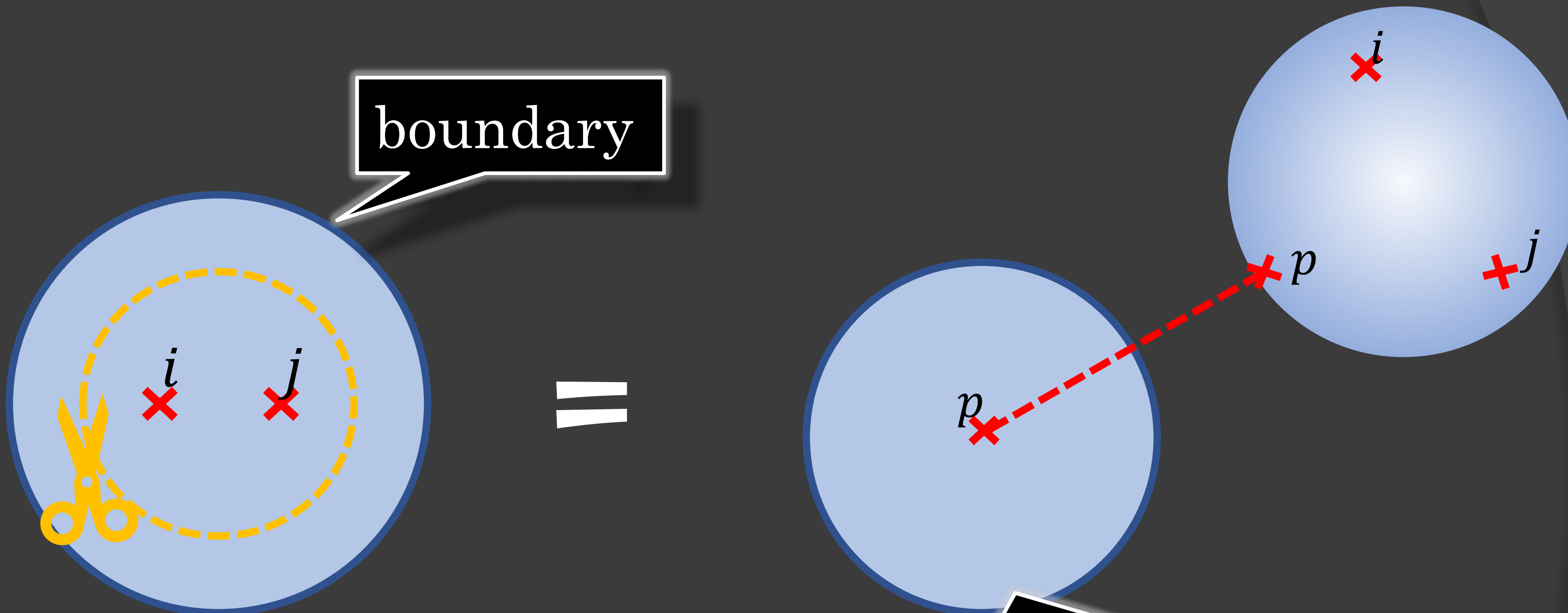
= Energy corresponding to the state on the strip

Review of BCFT [Lewellen]



Cutting:
Inserting (bulk operator) complete set

Review of BCFT [Lewellen]

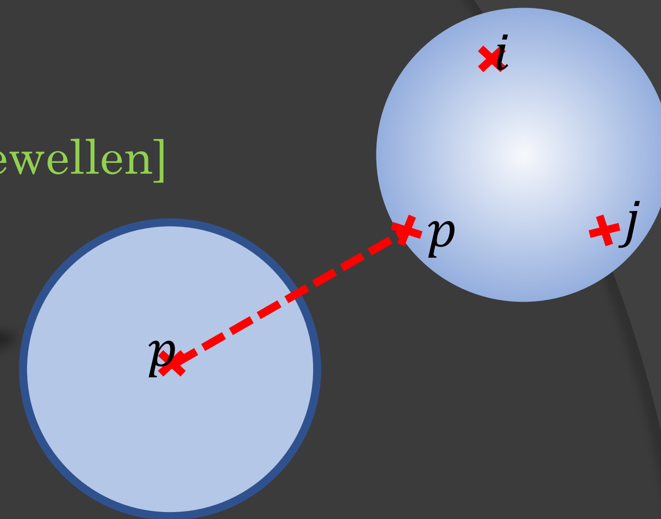


$$\sum_p C_{p0} C_{ijp} \mathcal{F}_{\bar{j}\bar{i}}^{ji}(p|z)$$

$\mathcal{F}_{\bar{j}\bar{i}}^{ji}$ is fixed by conformal sym. & mirror method

Review of BCFT [Lewellen]

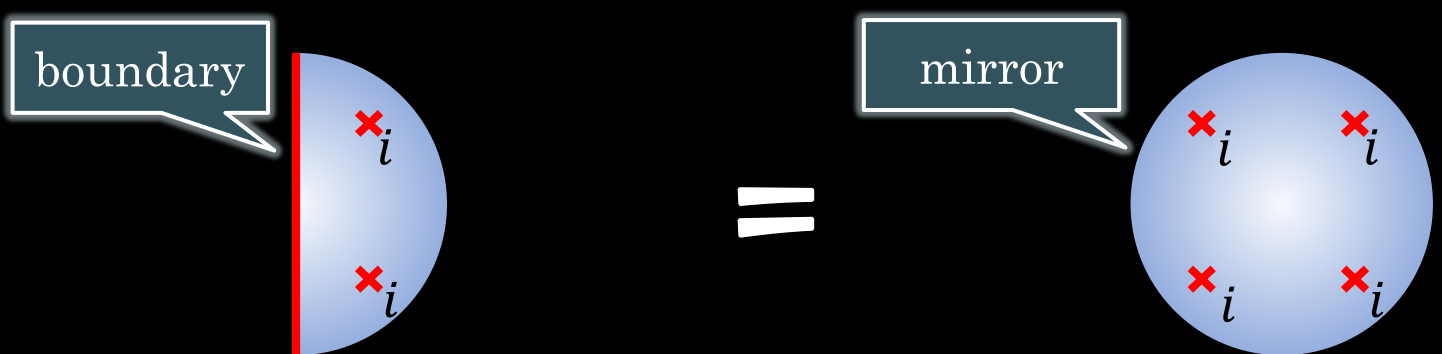
$$\sum_p C_{p0} C_{ijp} \mathcal{F}_{\bar{j}i}^{ji}(p|z)$$



Note:

$\mathcal{F}_{\bar{j}i}^{ji}(p|z)$ = Virasoro block.

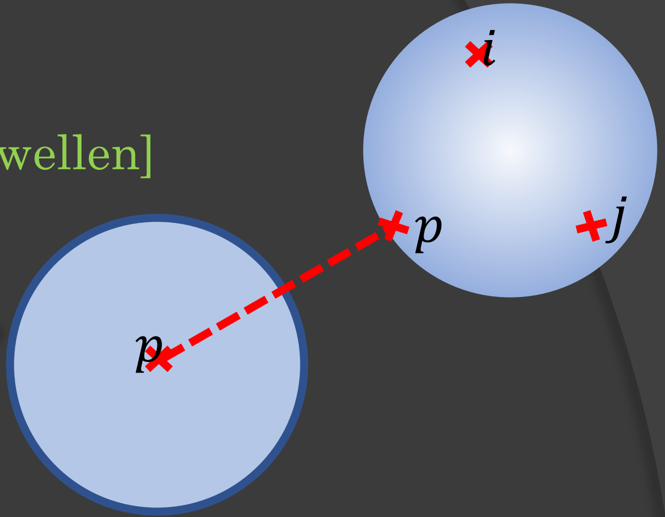
Because Ward id (with bdy) is equivalent to Ward id (without bdy) by mirror method



kinematic part = conformal block

Review of BCFT [Lewellen]

$$\sum_p C_{p0} C_{ijp} \mathcal{F}_{\bar{j}\bar{i}}^{ji}(p|z)$$



Note:

$\mathcal{F}_{\bar{j}\bar{i}}^{ji}(p|z)$ = Virasoro block.

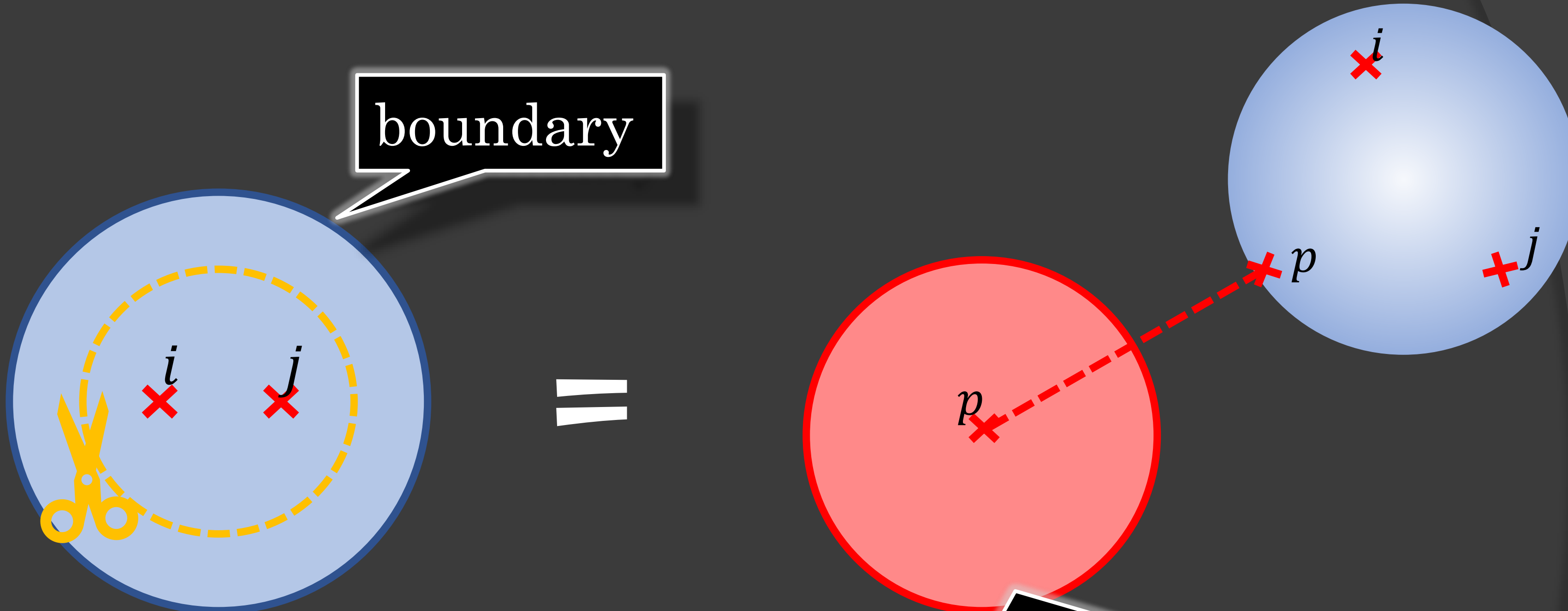
Because Ward id (with bdy) is equivalent to Ward id (without bdy) by mirror method

$$\sum_{p,\bar{p},N,\bar{N}} \langle\phi_i|\phi_j|L_{-N}\phi_p\rangle\langle\phi_{\bar{i}}|\phi_{\bar{j}}|L_{-\bar{N}}\phi_{\bar{p}}\rangle\langle L_{-N}L_{-\bar{N}}\phi_{p,\bar{p}}\rangle_{disk}$$

$$= \sum_{p,\bar{p},N,\bar{N}} \langle\phi_i|\phi_j|L_{-N}\phi_p\rangle\langle\phi_{\bar{i}}|\phi_{\bar{j}}|L_{-\bar{N}}\phi_{\bar{p}}\rangle\langle L_{-N}\phi_p\,|L_{-\bar{N}}\phi_{\bar{p}}\rangle$$

$$= \sum_{p,N} \langle\phi_i|\phi_j|L_{-N}\phi_p\rangle\langle\phi_{\bar{i}}|\phi_{\bar{j}}|L_{-N}\phi_p\rangle$$

Review of BCFT [Lewellen]



$$\sum_{p} C_{p0} C_{ijp} \mathcal{F}_{\bar{j}\bar{i}}^{ji}(p|z)$$

New ingredient: bulk-boundary OPE coef.

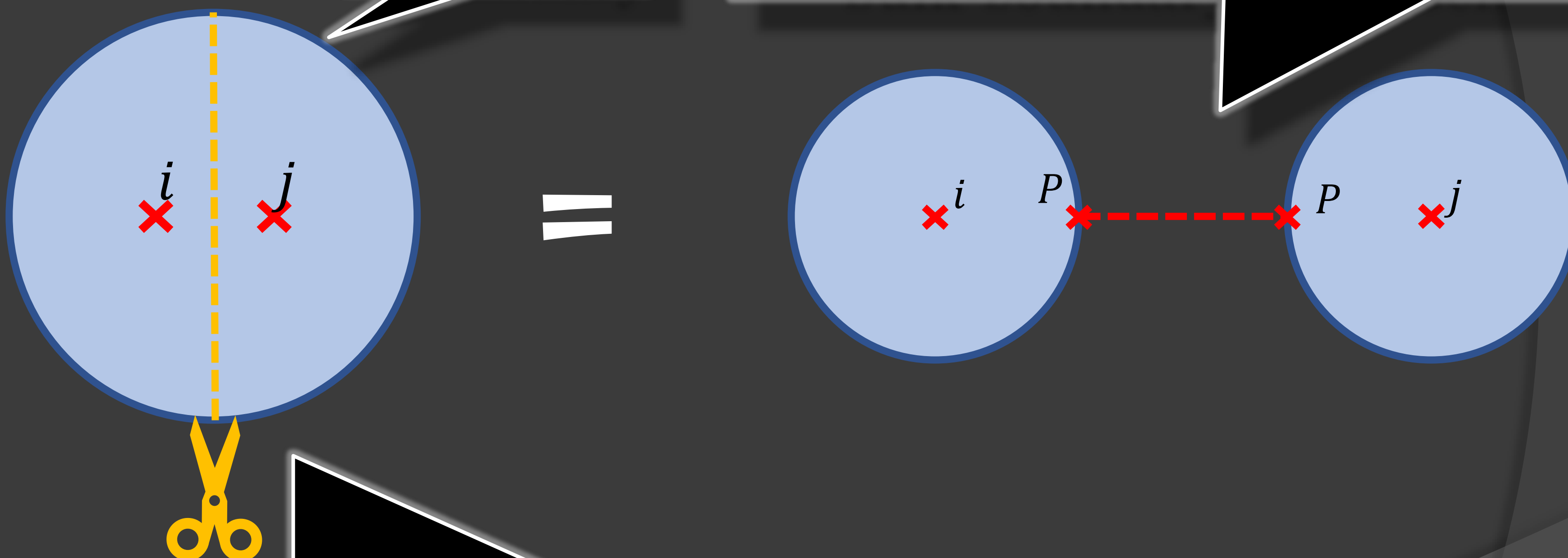
Review

or equivalently, using bulk-boundary OPE

$$\phi_i(z) \sim \sum_P C_{iP} (2\Im z)^{h_P - h_i - \bar{h}_i} \phi_P(\Re z) + \cdots$$

boundary

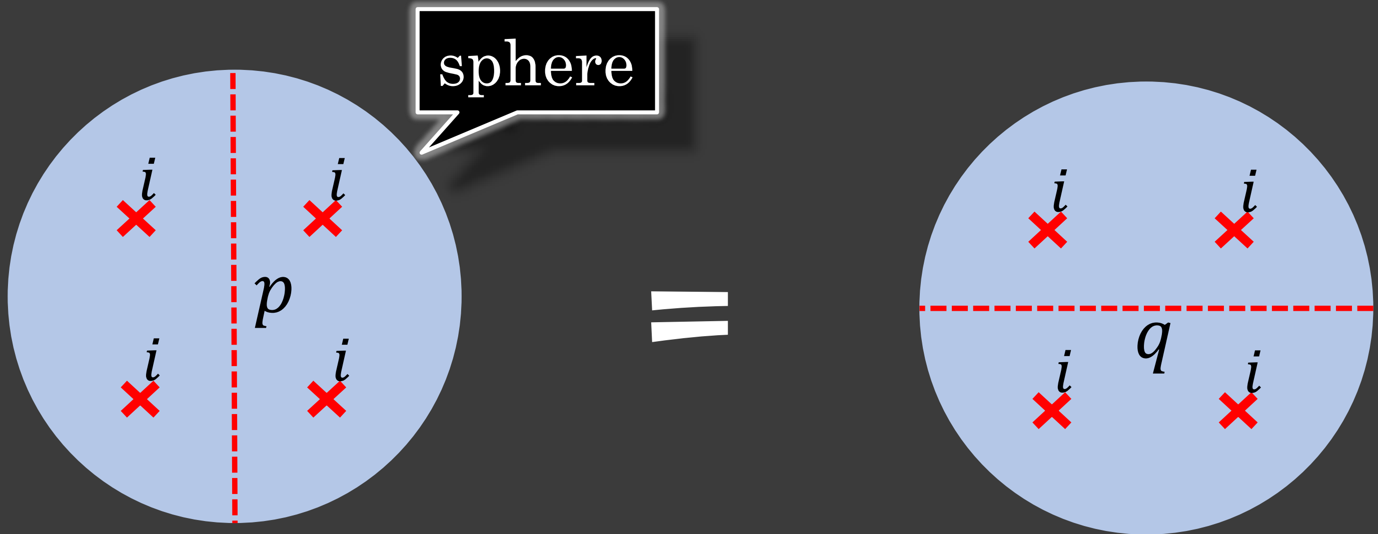
bulk-boundary OPE coef.



Cutting:

Inserting (boundary operator) complete set

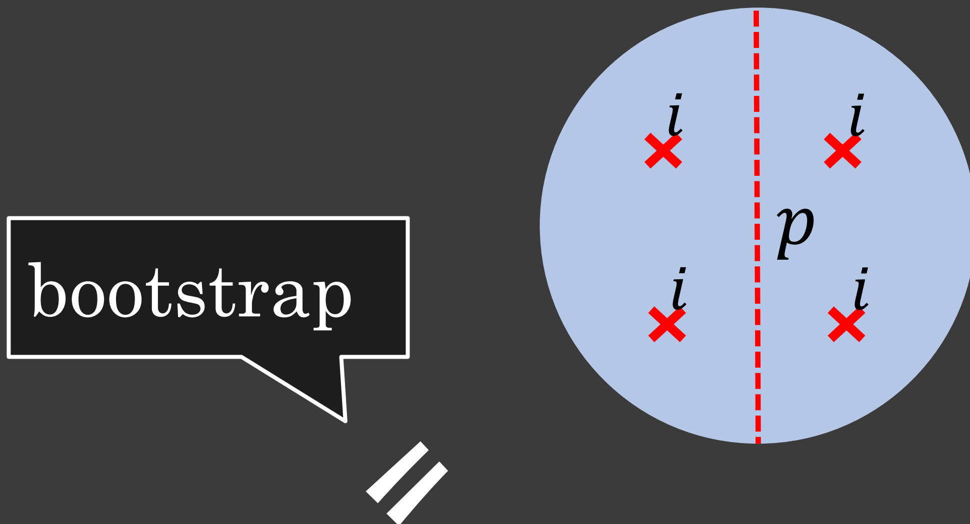
Bootstrap

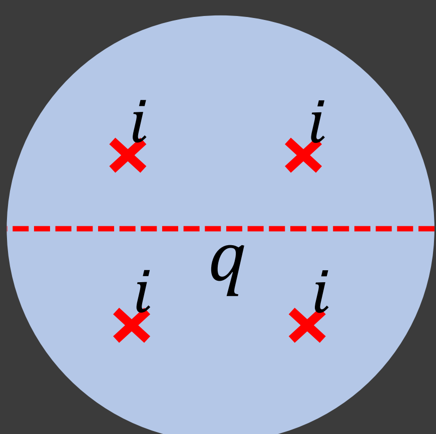


$$\sum_p C_{iip}^2 \left|\mathcal{F}_{ii}^{ii}(p|z)\right|^2 = \sum_q C_{iiq}^2 \left|\mathcal{F}_{ii}^{ii}(q|1-z)\right|^2$$

→ constraints on CFT data

Analytic Bootstrap

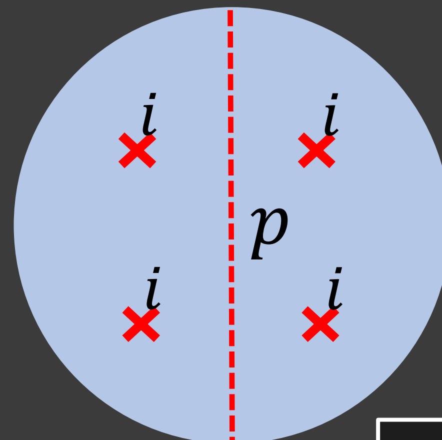




$$= \sum_q C_{iiq}^2 \left| \mathcal{F}_{ii}^{ii}(q|1-z) \right|^2$$

Analytic Bootstrap

bootstrap



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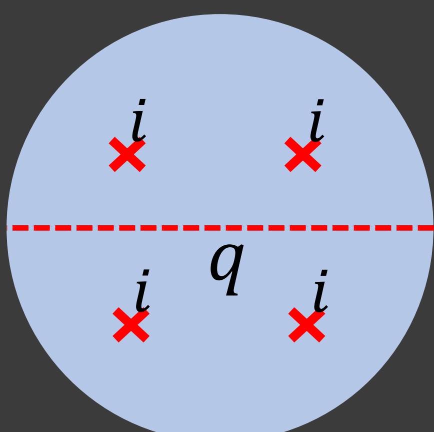
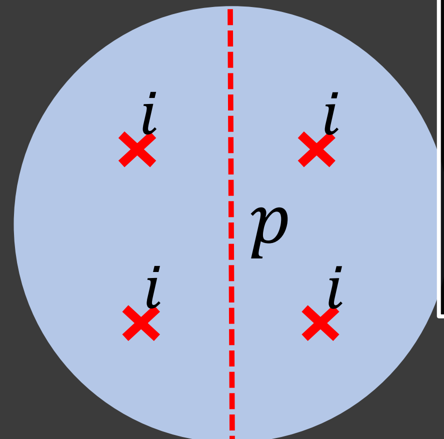


$\simeq \mathcal{F}^{ii}_{ii}(0|1-z)$

vacuum block
approximation by
$z, \bar{z} \to 0$ (Cardy formula)
$\bar{z} \to 0$ (large-spin)

Analytic Bootstrap

bootstrap



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Now it is expressed in terms of the same basis

$$\int \mathrm{d}\alpha_q \, C_{iiq}^2 \left|\mathcal{F}_{ii}^{ii}(q|z)\right|^2$$

It is possible to extract OPE coef. by the coefficient comparison.

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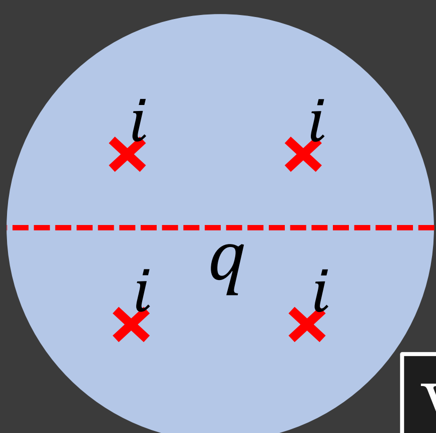


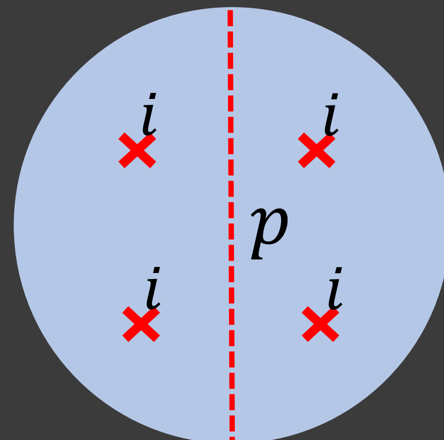
$$\simeq \mathcal{F}_{ii}^{ii}(0|1-z) = \int \mathrm{d}\alpha_q \, F_{0q}\begin{bmatrix} i & i \\ i & i \end{bmatrix} \mathcal{F}_{ii}^{ii}(q|z)$$

Vacuum block approximation

Fusion transformation

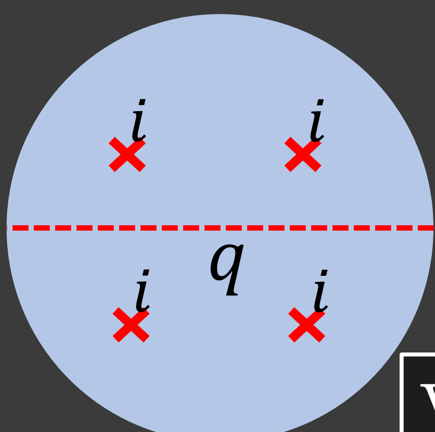
Analytic Bootstrap

[YK]
[Collier, Gobeil, Maxfield, Perlmutter]



bootstrap

$$C_{iip}^2 \simeq F_{0q}\begin{bmatrix} i & i \\ i & i \end{bmatrix}$$



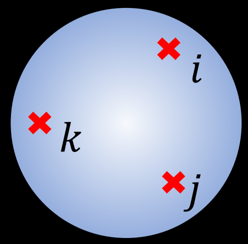
$$\simeq \mathcal{F}_{ii}^{ii}(0|1-z) = \int \mathrm{d}\alpha_q \, F_{0q}\begin{bmatrix} i & i \\ i & i \end{bmatrix} \mathcal{F}_{ii}^{ii}(q|z)$$

Vacuum block approximation

Fusion transformation

Analytic Bootstrap in BCFT

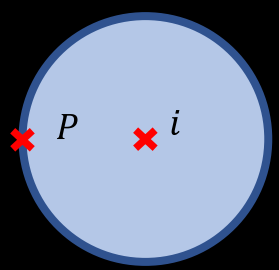
Universal formula in BCFT



[Collier, Maloney, Maxfield, Tsiares]

$\equiv C_{ijk}$

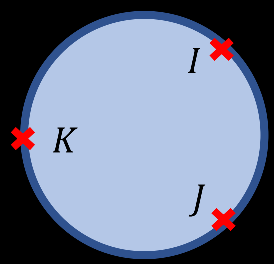
Bulk-bulk-bulk OPE coefficient



[YK], [Numasawa, Tsiares]

$\equiv C_{iP}$

Bulk-boundary OPE coefficient



[YK], [Numasawa, Tsiares]

$\equiv C_{IJK}$

Bdy-bdy-bdy OPE coefficient

[Cardy]

$\rho(h, h)$

Bulk primary spectrum

[YK], [Numasawa, Tsiares]

$\rho^{bdy}(h)$

Bdy primary spectrum

[Collier, Mazac, Wang]

g

Boundary entropy

Contents

- Introduction
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  - How to bootstrap AdS/BCFT?
  - Results from bootstrap
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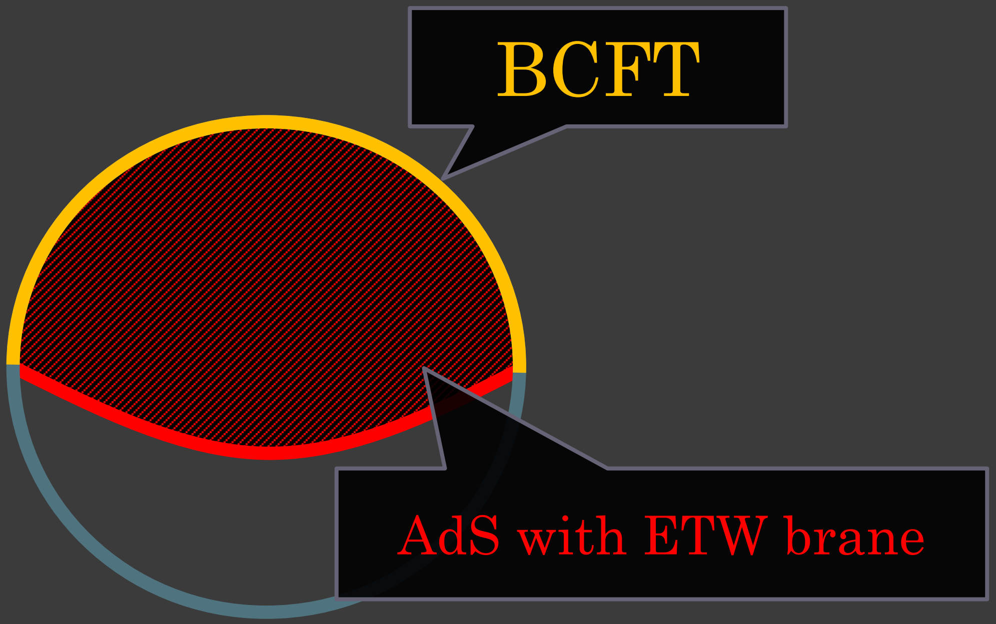
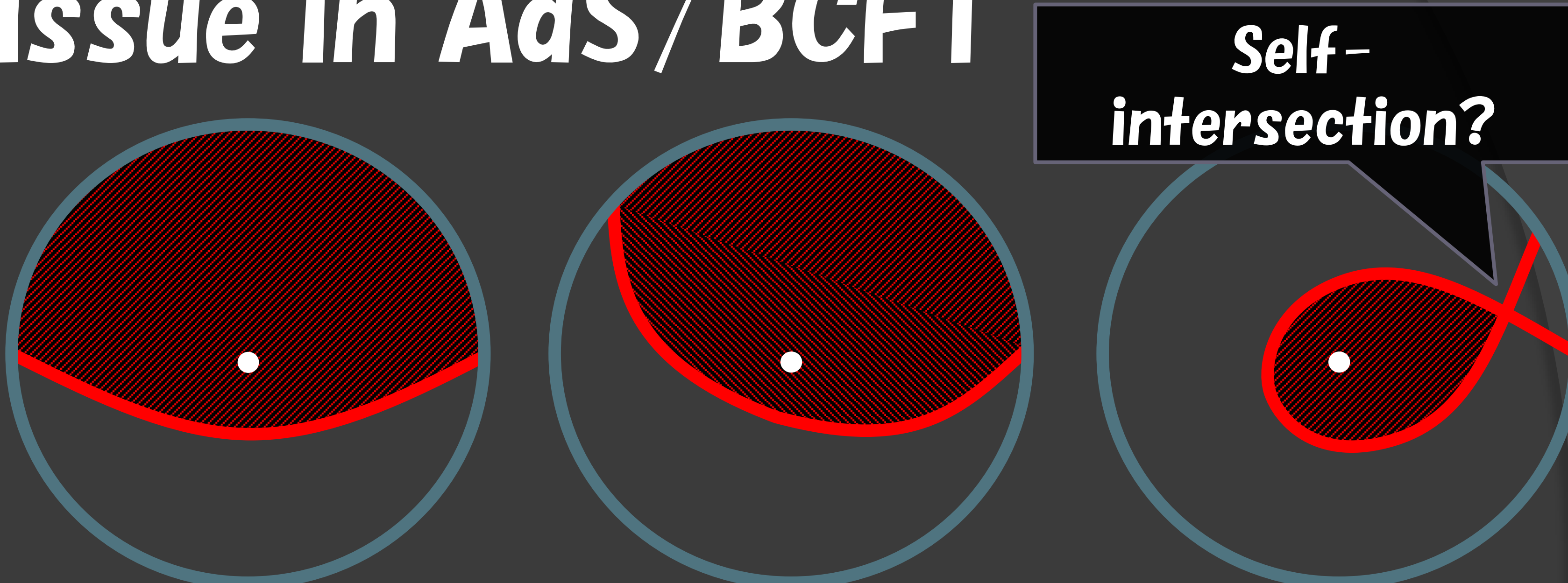
Issue in AdS/BCFT



Issue in AdS/BCFT



$h_i = 0$ $\quad$ $0 < h_i < \frac{c}{32}$ $\quad$ $\frac{c}{32} < h_i$

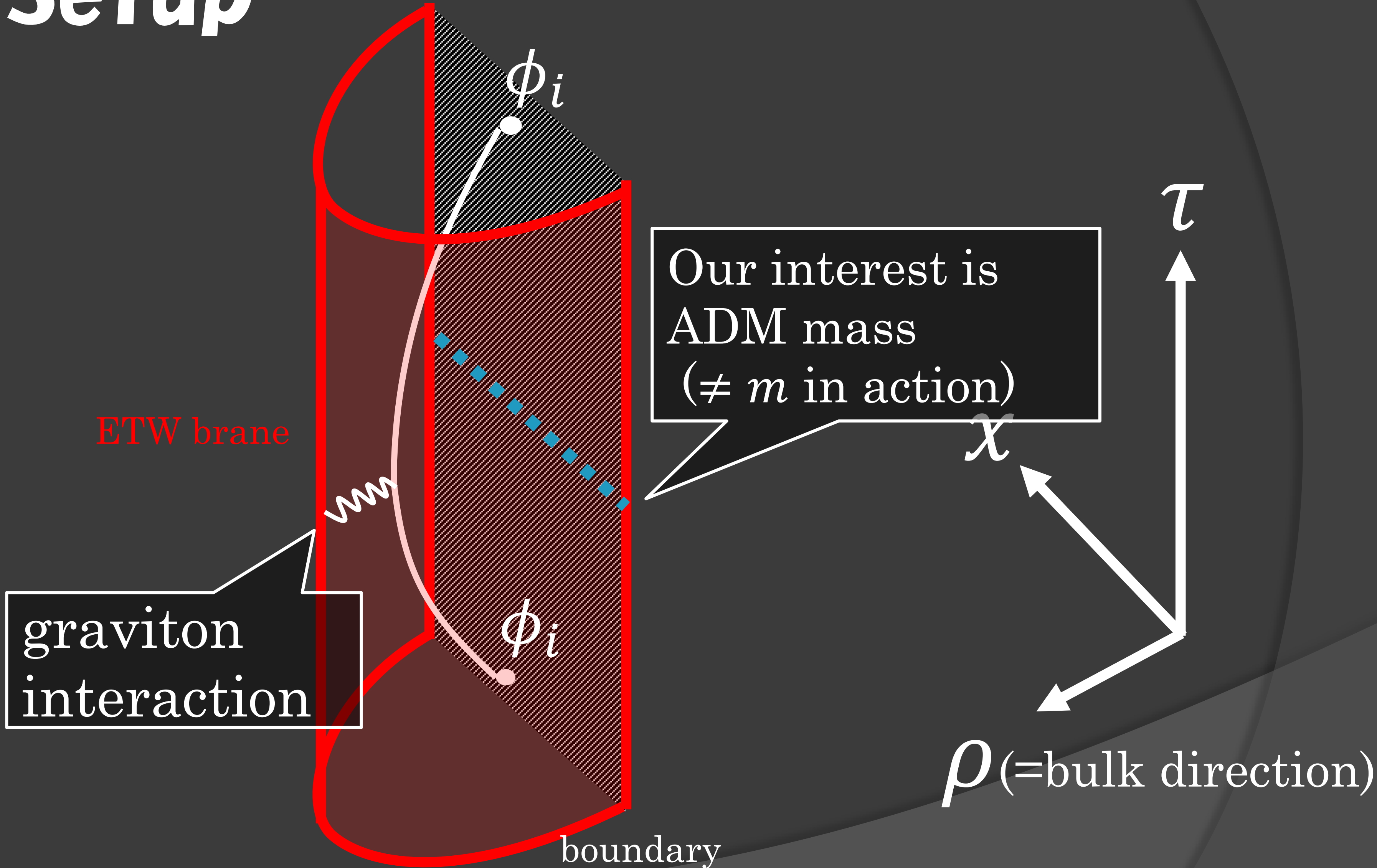
Massive particle produces deficit angle

$$\delta\theta = 2\pi\left(1 - \sqrt{1 - \frac{c}{24}h_i}\right)$$

Pointed out by
[Geng, Lust, Mishra, Wakeham]
[Kawamoto, Mori, Suzuki, Takayanagi]
[Bianchi, De Angelis, Meineri]

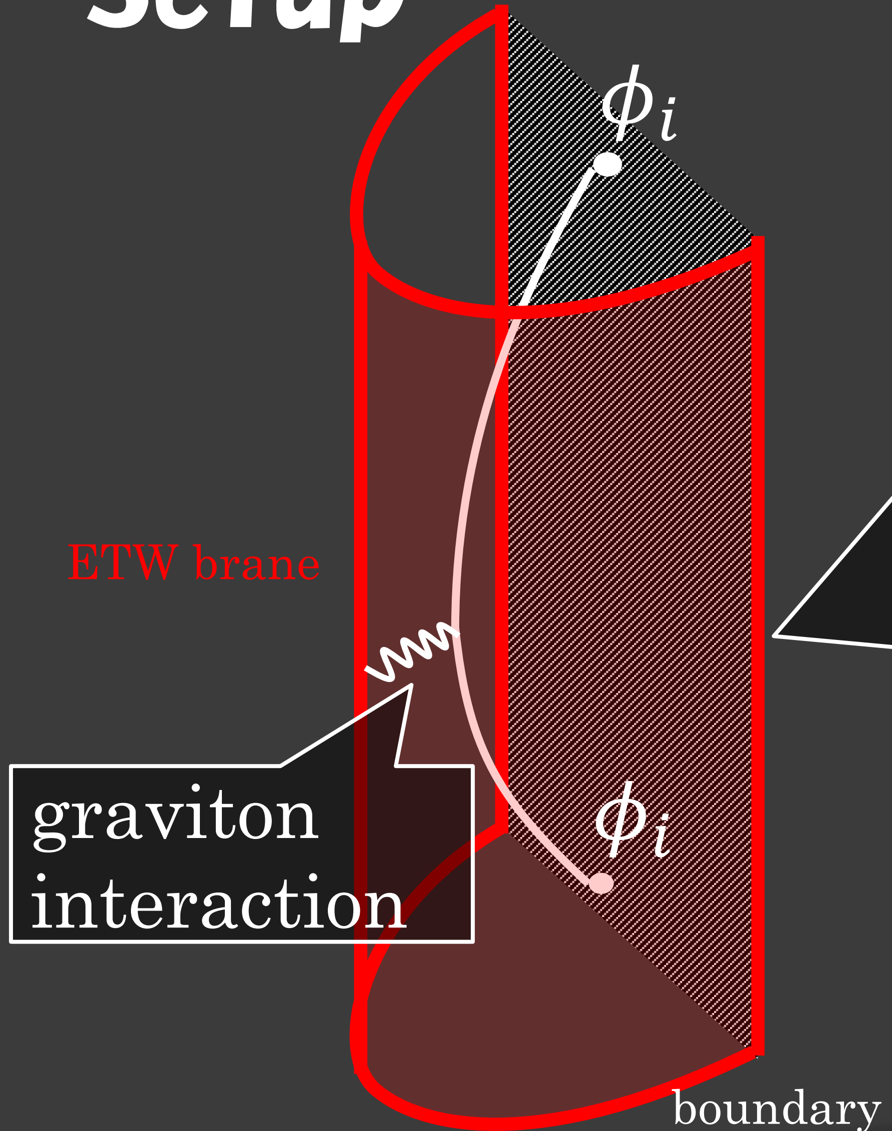
The first one proposed that $h_i \in \left[\frac{c}{32}, \frac{c}{24}\right)$ should be excluded in holographic CFT

Setup



ϕ_i
Our interest is
ADM mass
($\neq m$ in action)
τ
x
ETW brane
graviton
interaction
ϕ_i
ρ (=bulk direction)
boundary

Setup



Q. What is input to solve bootstrap?

A. No interaction between particle and brane, except for gravitons.

Bootstrap

Property of this solution to Einstein's equation:

No interaction between particle and brane, except for gravitons.
[Takayanagi], [Fujita, Takayanagi, Tonni], [Suzuki, Takayanagi]

CFT counterpart:

For states $\{p\}$ in OPE between ϕ_is, (in large c)

$$C^{a}_{p\mathbb{I}} = \delta_{p\mathbb{I}}$$

Note: This is possible at least in the case $p \neq \bar{p}$.

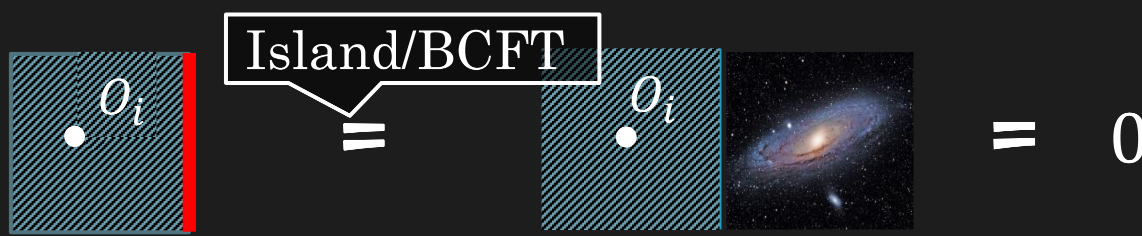
Comment

CFT counterpart:

For states $\{p\}$ in OPE between ϕ_is,

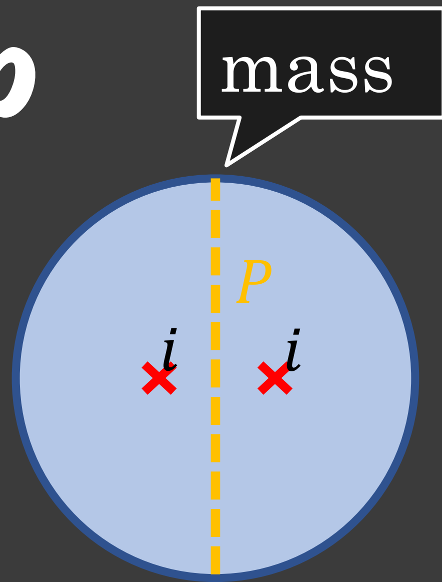
$$C^{a}_{p\mathbb{I}} = \delta_{p\mathbb{I}}$$

This assumption is related to the island model.



In this context, this may be interpreted as boundary averaging (see details in [YK])

Bootstrap



bootstrap

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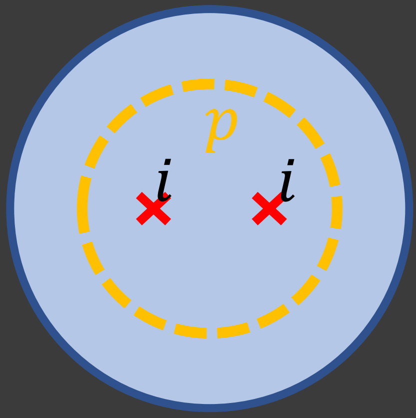
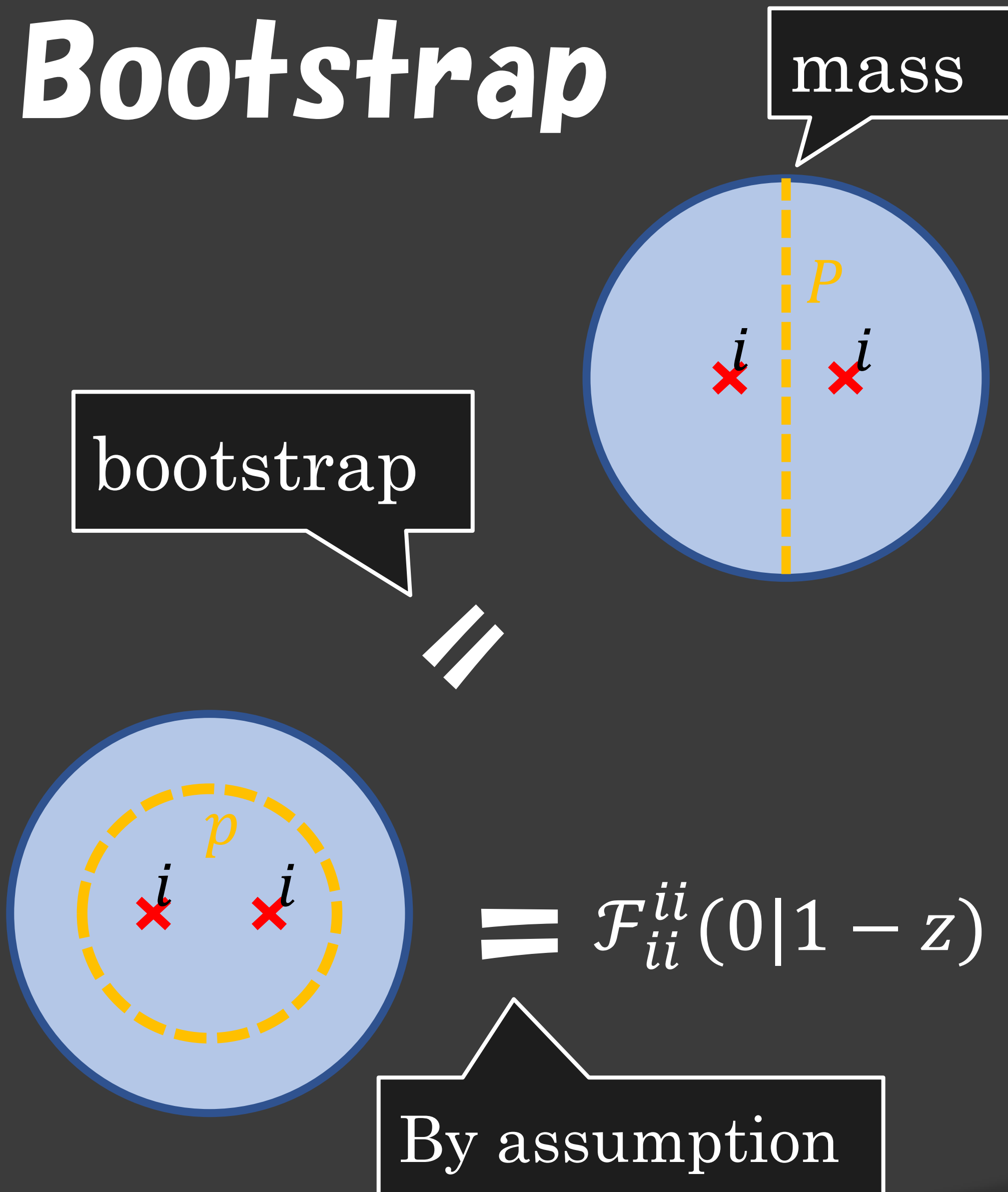


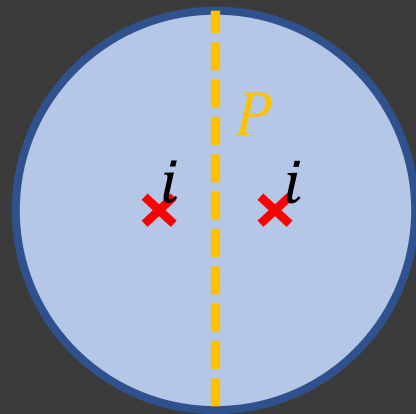
$$= \sum_p C_{p0} C_{iip} \mathcal{F}^{ii}_{ii}(p|1-z)$$

Bootstrap



Bootstrap

mass



bootstrap

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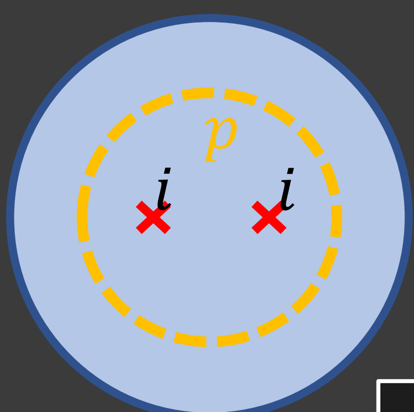


Liouville momentum

$c = 1 + 6Q^2,$
$h_i = \alpha_i(Q - \alpha_i)$

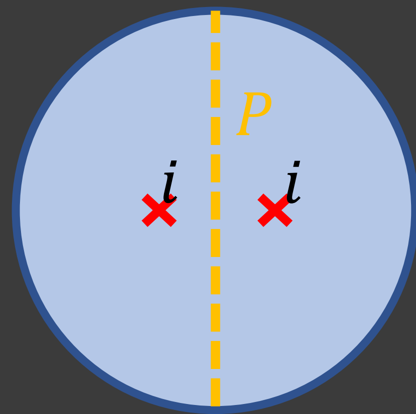
$$= \mathcal{F}^{ii}_{ii}(0|1-z) = \int \mathrm{d}\alpha_P \, F_{0P}\begin{bmatrix} i & i \\ i & i \end{bmatrix} \mathcal{F}^{ii}_{ii}(P|z)$$

By assumption

Fusion transformation

Bootstrap

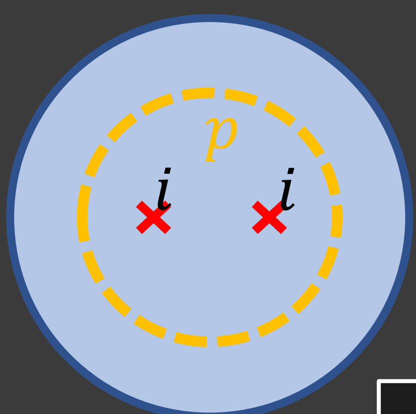
mass



ADM mass = lowest primary dimension

$$\alpha_P = 2\alpha_i$$

bootstrap



$$= \mathcal{F}^{ii}_{ii}(0|1-z) = \int \mathrm{d}\alpha_P \, F_{0P}\begin{bmatrix} i & i \\ i & i \end{bmatrix} \mathcal{F}^{ii}_{ii}(P|z)$$

By assumption

Fusion transformation

Implication [YK]

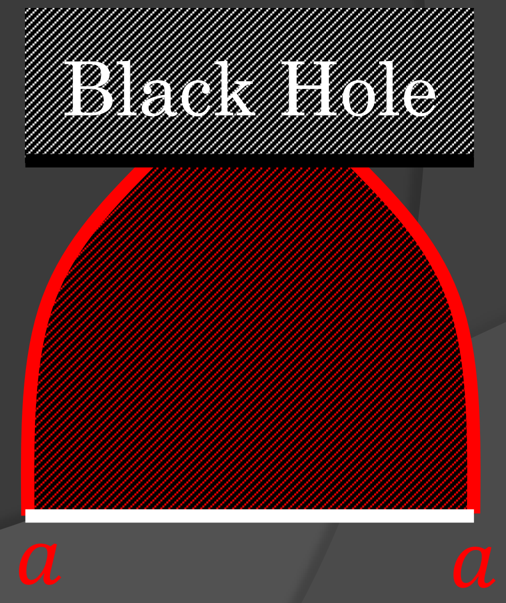
$c = 1 + 6Q^2,$
$h_i = \alpha_i(Q - \alpha_i)$

Relation between ADM mass & mass of particle

$$\alpha_P = 2\alpha_i$$

It implies that black hole forms when

$$h_i \geq \frac{c}{32} \quad \Leftrightarrow \quad h_P \geq \frac{c}{24}$$



This completely matches self-intersection bound

→ self-intersection can be avoided by blackhole formation

More results [YK, Wei]

The bootstrap also tells us the following theorems,

Relation between ADM mass & mass of spinning particle

$$\alpha_P = \alpha_i + \bar{\alpha}_i$$

Non-sensitivity to brane tension

The relation between ADM mass & particle mass is true even if brane tension is negative.

Contents

- Introduction
- Review
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- Construction of gravity with brane & particle
  - Cut & Paste construction
  - Gravity with brane & particle
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  - Gravity with negative tension brane
- Refined RT formula
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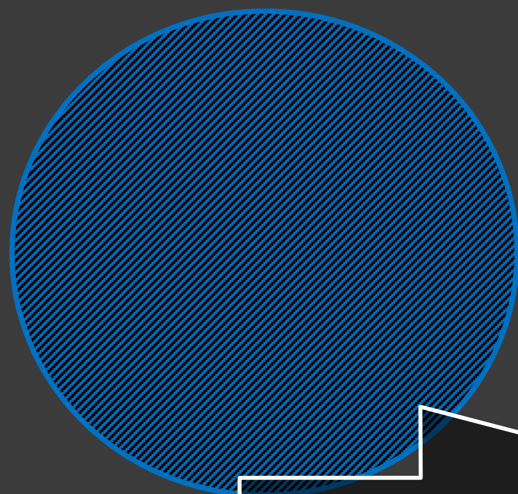
Cut & Paste construction

How can we construct a conical defect geometry?

→ very simple way by cut & paste



Time slice on

$$ds^2 = (1 + r^2)dt^2 + \frac{dr^2}{1 + r^2} + r^2 d\theta^2$$

Cut & Paste construction

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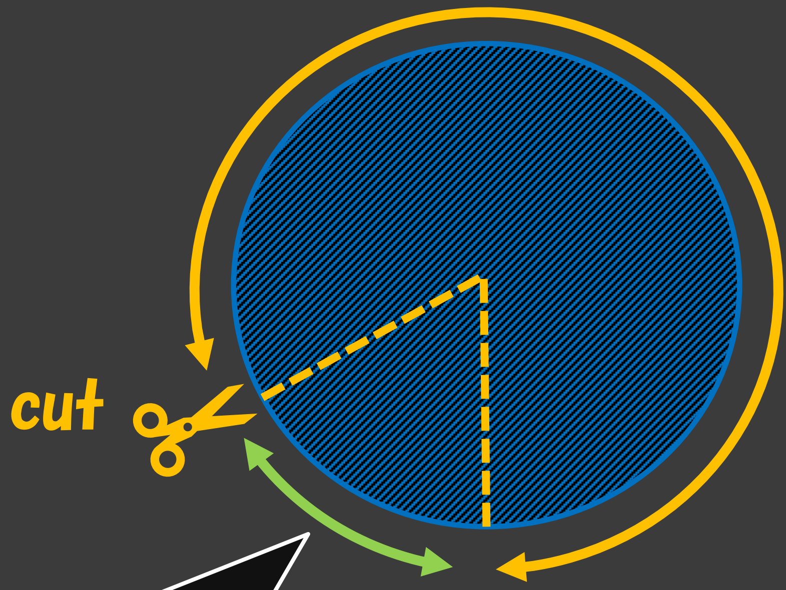
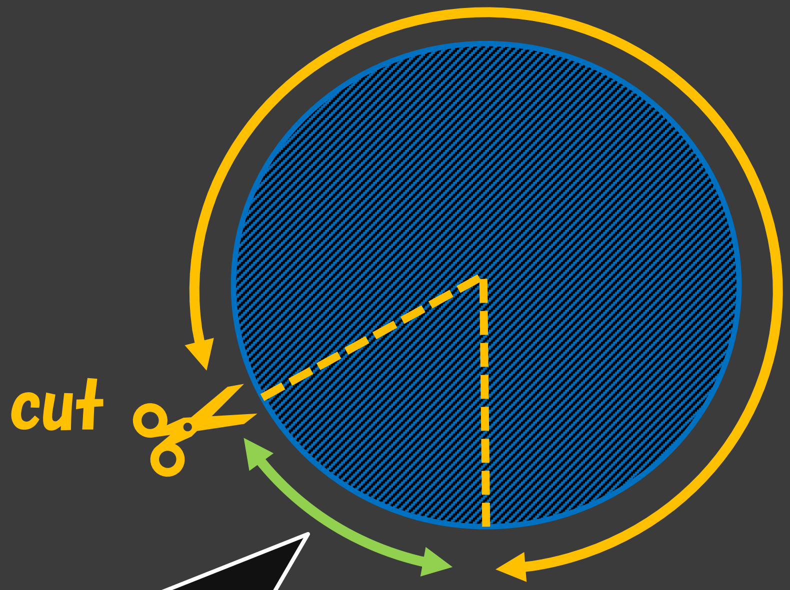


Circumference of asymptotic boundary
$2\pi\chi$

Deficit angle
$\delta\theta = 8\pi G_N m$

Cut & Paste construction

$$I_{grav} = -\frac{1}{16\pi G_N}\int_M d^3x\,\sqrt{g}(R-2\Lambda) + \sum_i m_i \int dl_i - \frac{1}{8\pi G_N}\int_Q d^2x\,\sqrt{h}(K-T)$$



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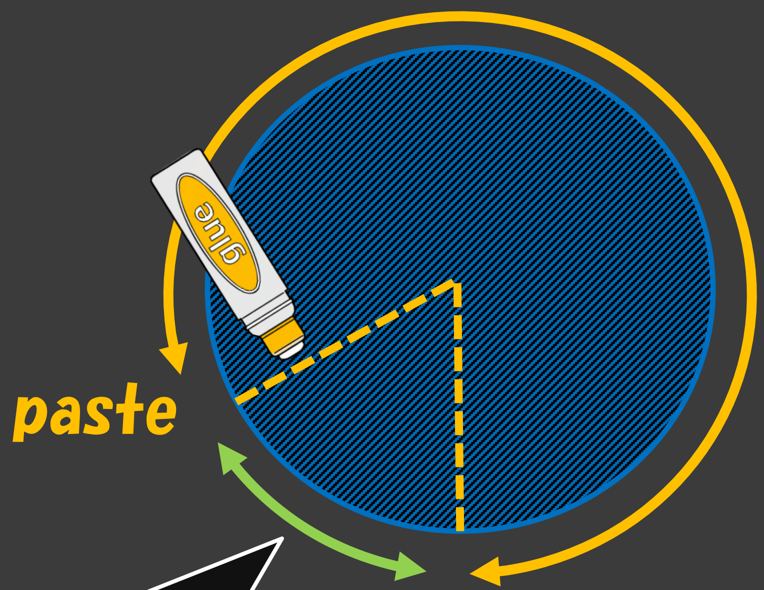

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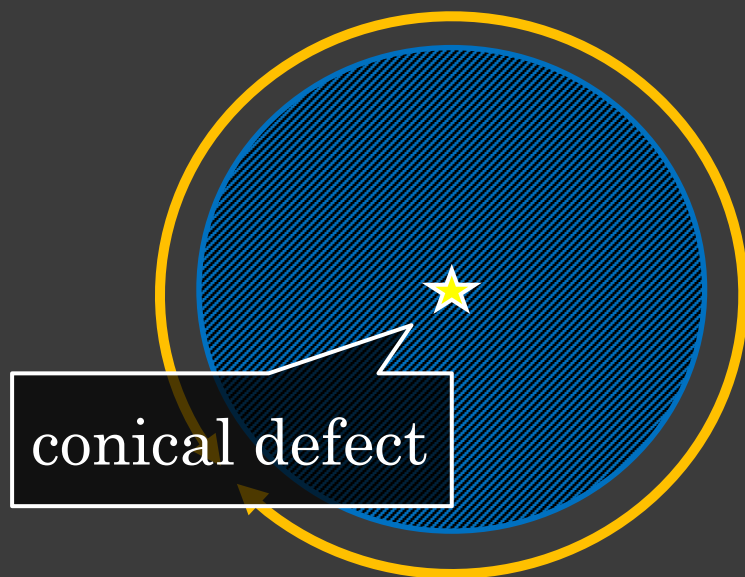


Circumference of asymptotic boundary
2π

Rescale to compare with conformal dimension

$$\theta \to \theta' = \frac{1}{\chi}\theta$$

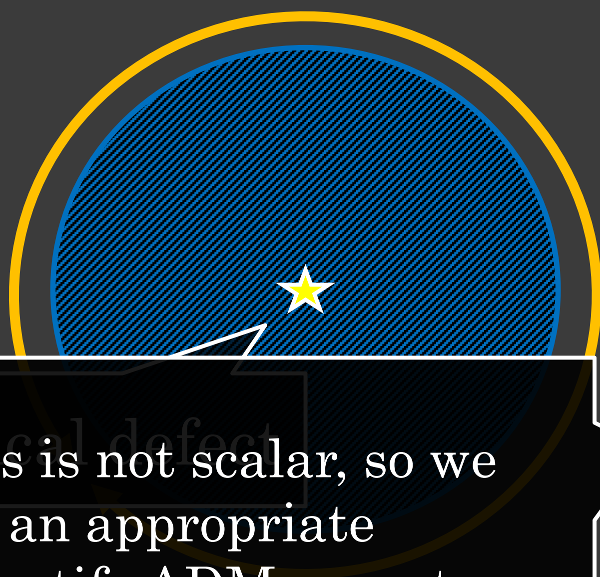
$$t \to t' = \frac{1}{\chi}t$$

Cut & Paste construction

How can we construct a conical defect geometry?

→ very simple way by cut & paste

Circumference of asymptotic boundary
2π



Note: ADM mass is not scalar, so we should consider an appropriate coordinate to identify ADM mass to conformal dimension

Rescale to compare with conformal dimension

$$\theta \to \theta' = \frac{1}{\chi}\theta$$

$$t \to t' = \frac{1}{\chi}t$$

Cut & Paste construction

How can we construct a conical defect geometry?
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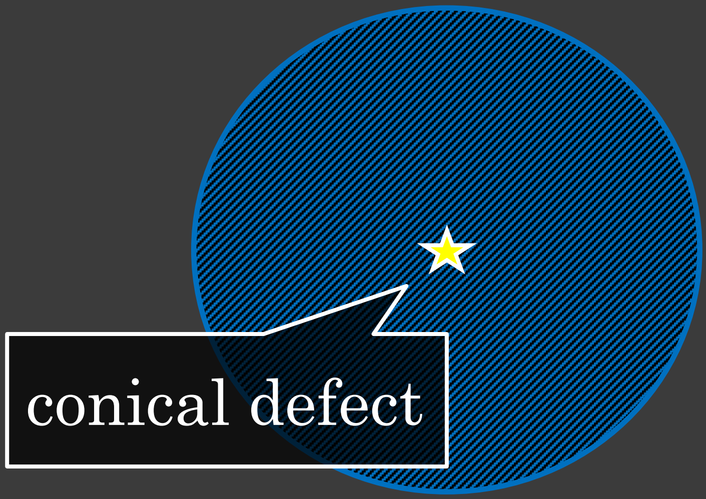


$$E_{ADM} = \int_0^{2\pi} d\theta \, T_{tt} = -\frac{\chi^2}{8G_N}$$

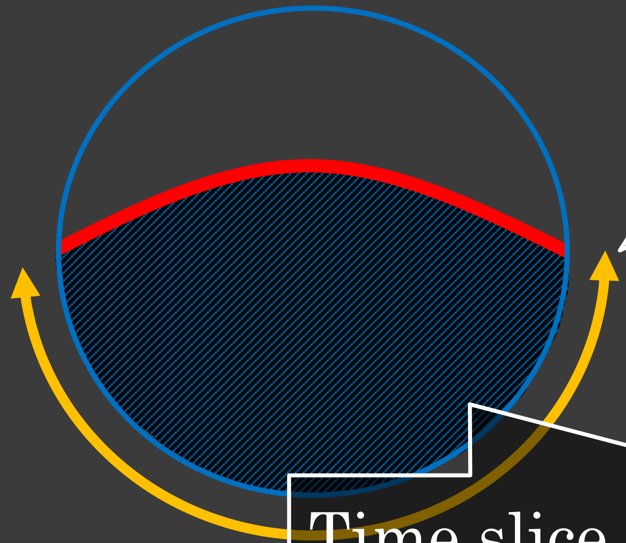
This leads to the well-known relation,

$$E_{ADM} + E_{Casimir} = 2h_i$$

Cut & Paste construction

How can we construct a conical defect geometry with a brane?

→ cut & paste in AdS/BCFT



Circumference of asymptotic boundary

π

Time slice on

$$ds^2 = (1 + r^2)dt^2 + \frac{dr^2}{1 + r^2} + r^2 d\theta^2$$

Cut & Paste construction

How can we construct a conical defect geometry with a brane?

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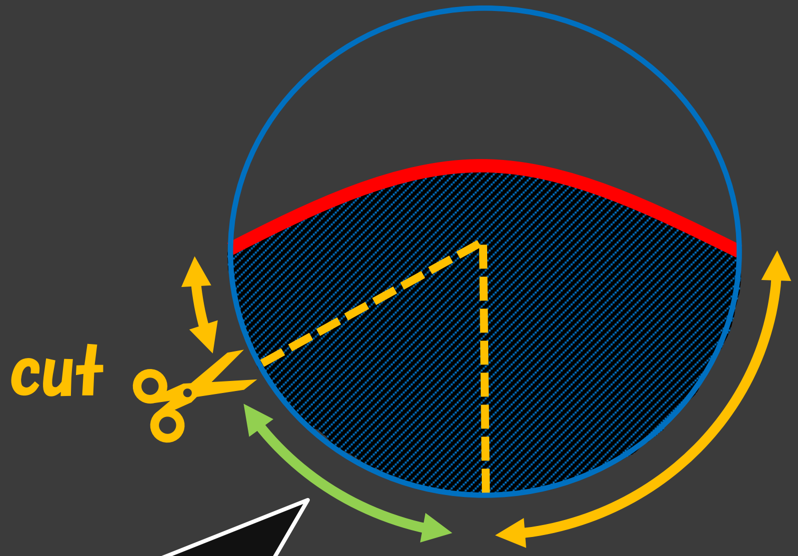


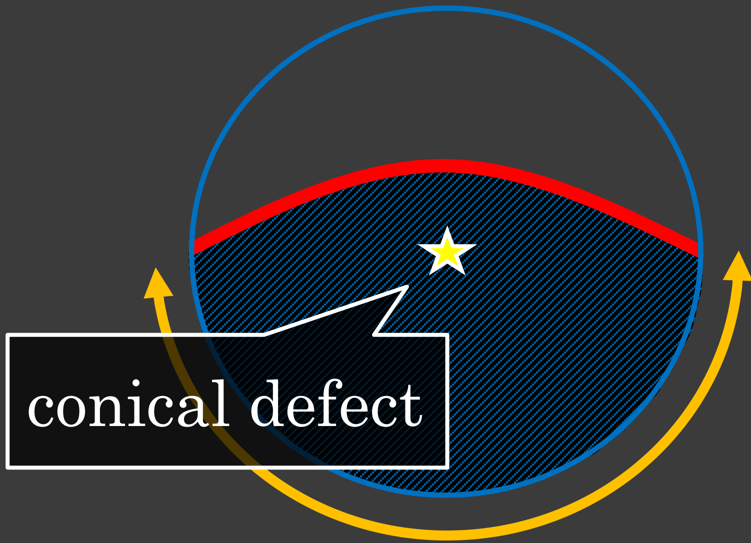
Circumference of asymptotic boundary
$\pi(2\chi - 1)$

Deficit angle
$\delta\theta = 8\pi G_N m$

Cut & Paste construction

How can we construct a conical defect geometry with a brane?

→ cut & paste in AdS/BCFT



Circumference of asymptotic boundary

$$\pi$$

Rescale to compare with conformal dimension

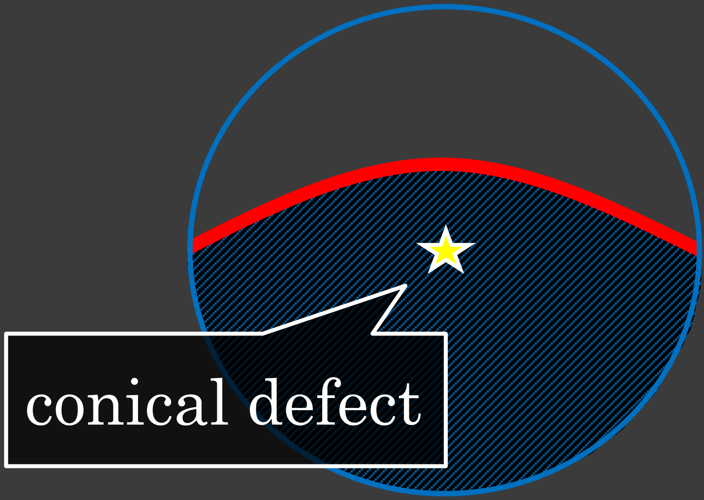
$$\theta \to \theta' = \frac{1}{2\chi - 1}\theta$$

$$t \to t' = \frac{1}{2\chi - 1}t$$

Cut & Paste construction

How can we construct a conical defect geometry with a brane?

→ cut & paste in AdS/BCFT



$$E_{ADM} = \int_0^{2\pi} d\theta \, T_{tt} = -\frac{(2\chi - 1)^2}{16G_N}$$

This leads to

$$E_{ADM} + E_{Casimir} = 2\alpha_i(Q - 2\alpha_i) \neq 2h_i$$

Particle is attracted close to brane by gravity force. This interaction changes the ADM mass.

Implication [YK]

$c = 1 + 6Q^2,$
$h_i = \alpha_i(Q - \alpha_i)$

Relation between ADM mass & mass of particle

$$\alpha_P = 2\alpha_i$$

It implies that black hole forms when

$$h_i \geq \frac{c}{32} \quad \Leftrightarrow \quad h_P \geq \frac{c}{24}$$

This completely matches self-intersection bound

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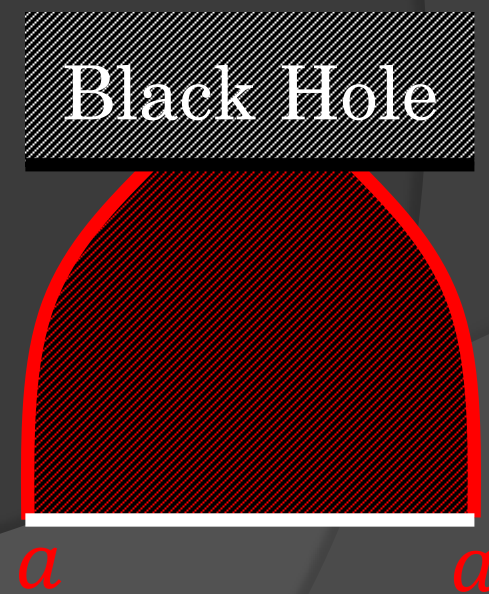
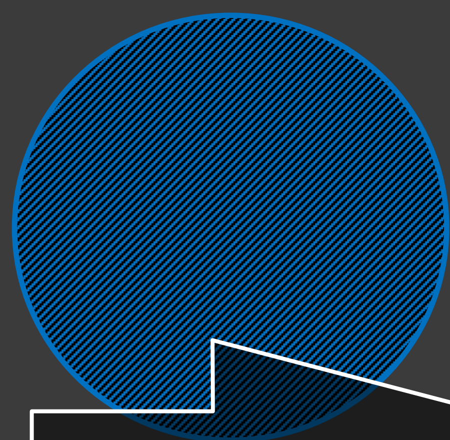


Cut & Paste construction

How can we construct a spinning defect geometry?

→ cut & twisted paste



Time slice on

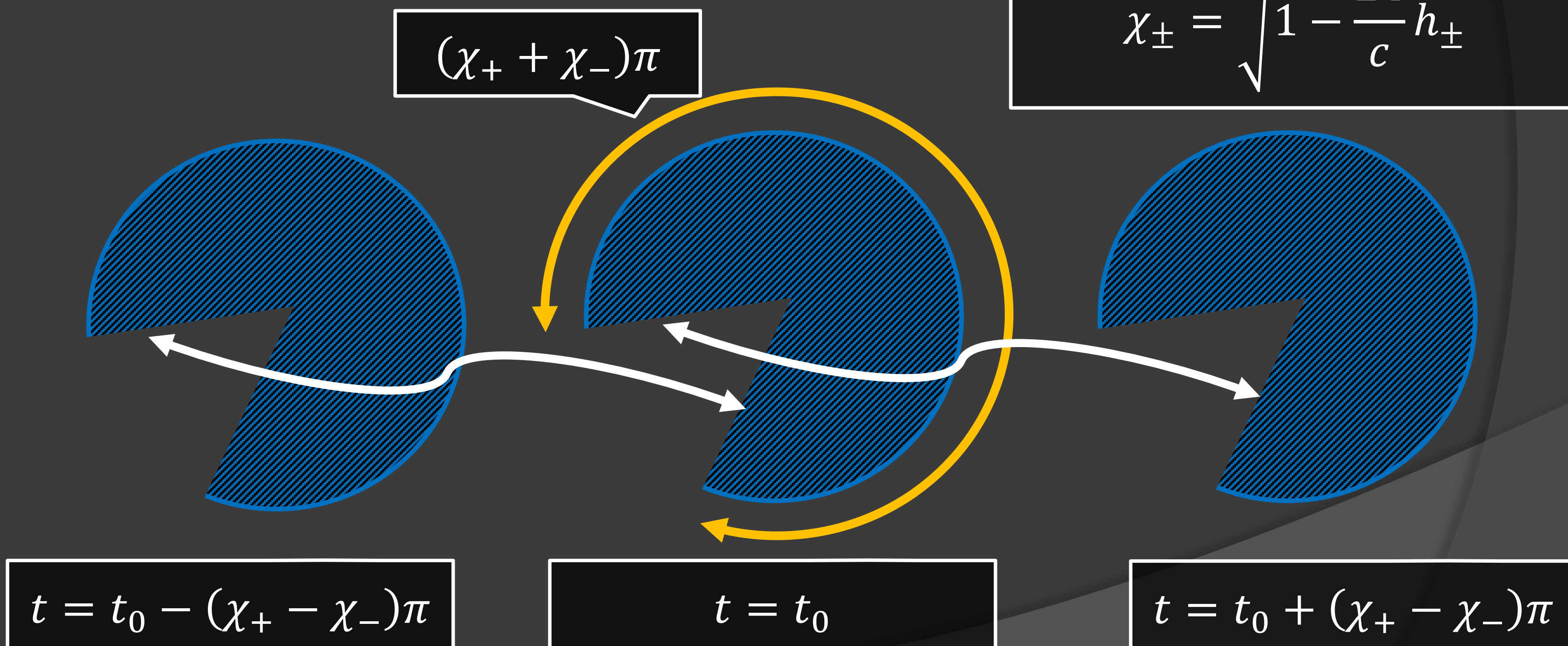
$$ds^2 = (1 + r^2)dt^2 + \frac{dr^2}{1 + r^2} + r^2 d\theta^2$$

Cut & Paste construction

How can we construct a spinning defect geometry?

→ cut & twisted paste

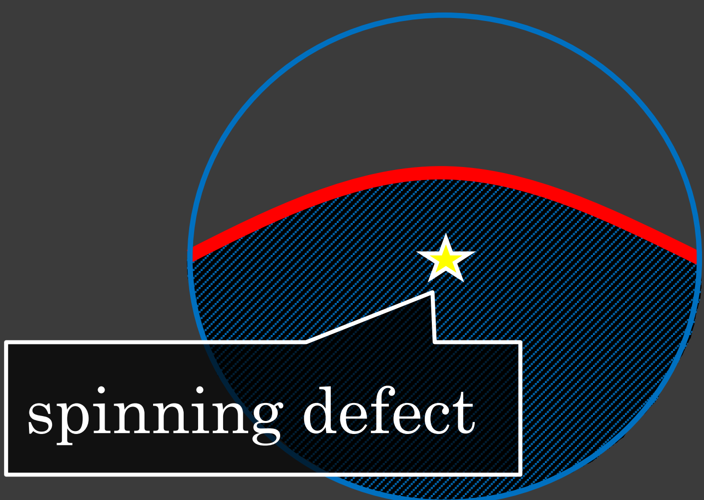
$$\chi_{\pm} = \sqrt{1 - \frac{24}{c} h_{\pm}}$$



Cut & Paste construction

How can we construct a spinning defect geometry?

$\rightarrow$ cut & twisted paste



By this construction, we obtain the self-intersection bound in the spinning defect geometry,

$$(\chi_+ + \chi_i)\pi < \pi$$

This matches the black hole threshold predicted from bootstrap.

More results [YK, Wei]

The bootstrap also tells us the following theorems,

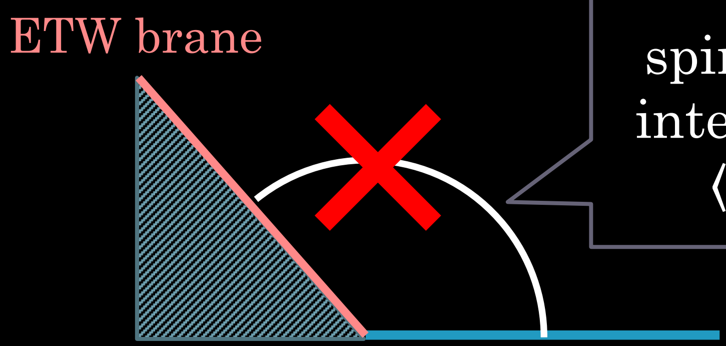
Relation between ADM mass & mass of spinning particle

$$\alpha_P = \alpha_i + \bar{\alpha}_i$$

Then, the black hole threshold is

$$\alpha_i + \bar{\alpha}_i = \frac{Q}{2}$$

One-point function



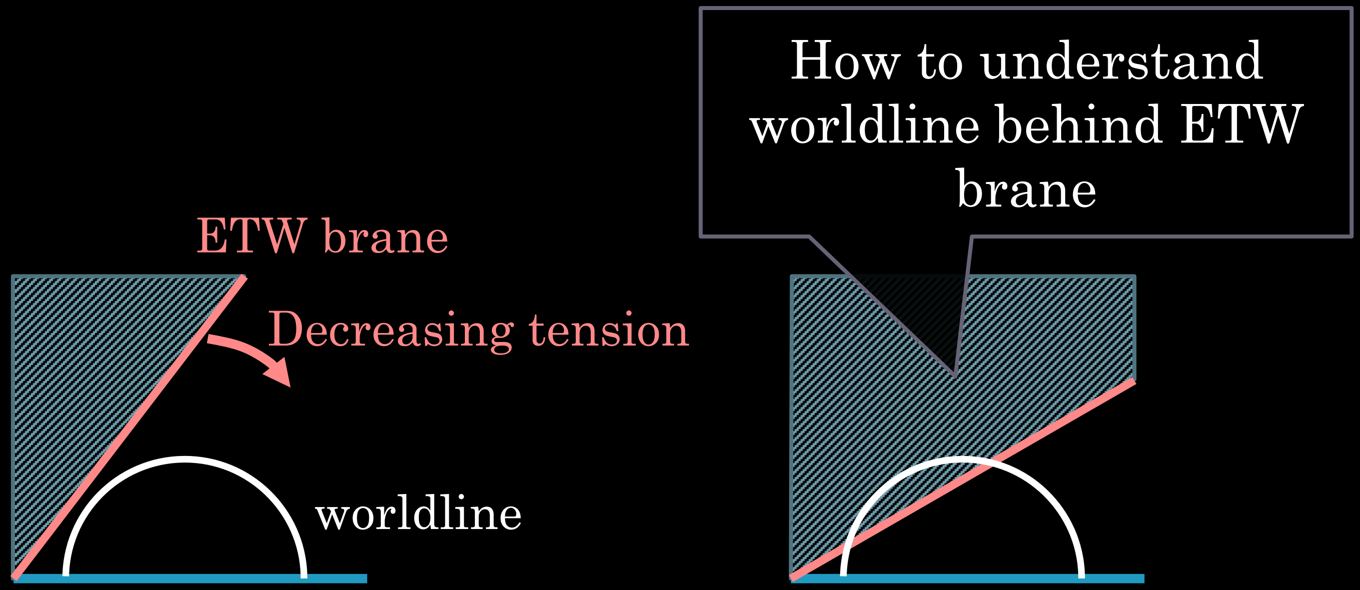
spinning particle cannot interact with brane since $\langle O \rangle_{disk} = 0$ if $h \neq \bar{h}$

Twisted identification leads to mismatch of brane.
Such a singular configuration is not a solution.
This explains

$$\langle O \rangle_{disk} = 0 \quad \text{if } h \neq \bar{h}$$

from the gravity side.

Negative tension brane



Transition?

[2203.10103] has proposed that the boundary primary spectrum should be changed if the tension is negative, and also proposed that this transition can be found by bootstrap.

More results [YK, Wei]

The bootstrap also tells us the following theorems,

Relation between ADM ... rticle

$\alpha_P = \; \ldots \; \alpha_i$

We should find the mechanism to explain this.

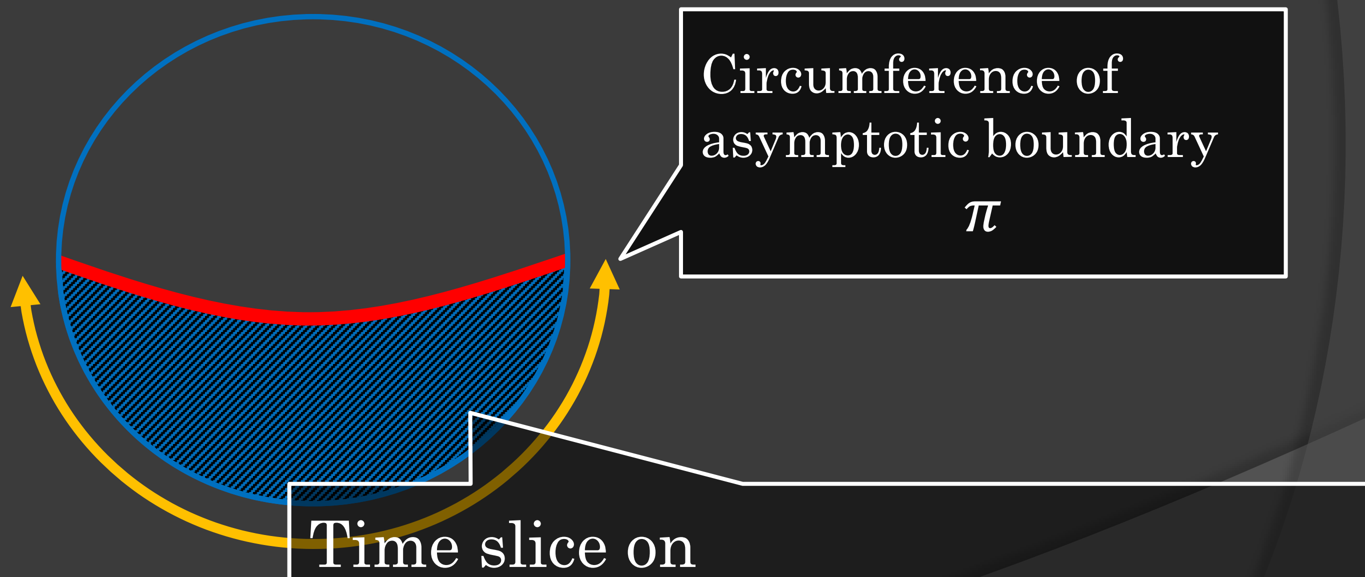
Non-sensitivity to brane tension

The relation between ADM mass & particle mass is true even if brane tension is negative.

Cut & Paste construction

How can we construct a conical defect geometry with a negative tension brane?

→ cut & paste in AdS/BCFT



$$ds^2 = (1+r^2)dt^2 + \frac{dr^2}{1+r^2} + r^2 d\theta^2$$

Cut & Paste construction

How can we construct a conical defect geometry with a negative tension brane?

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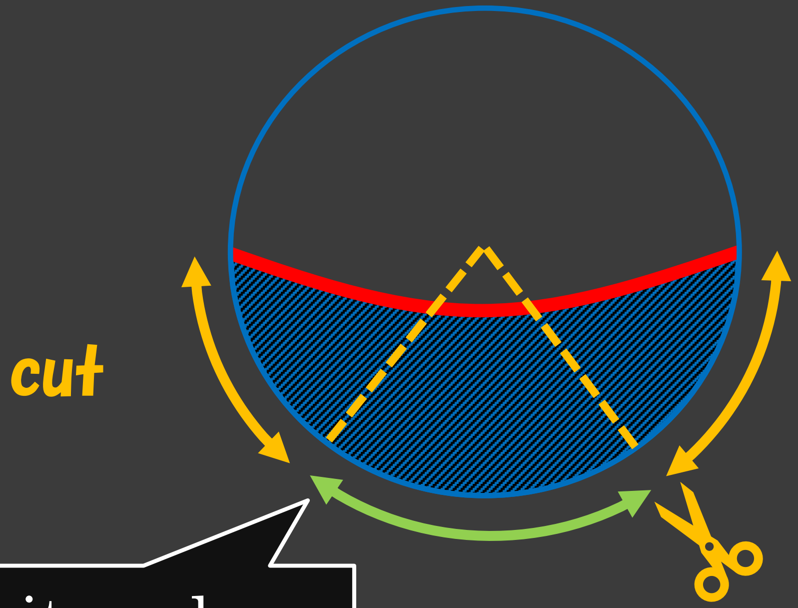

Circumference of asymptotic boundary
$\pi(2\chi - 1)$

Deficit angle
$\delta\theta = 8\pi G_N m$

Cut & Paste construction

How can we construct a conical defect geometry with a negative tension brane?

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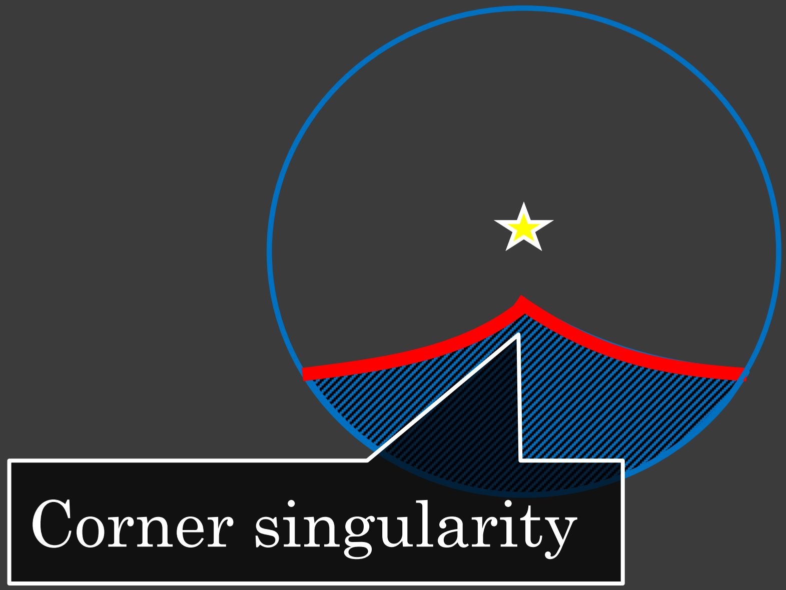
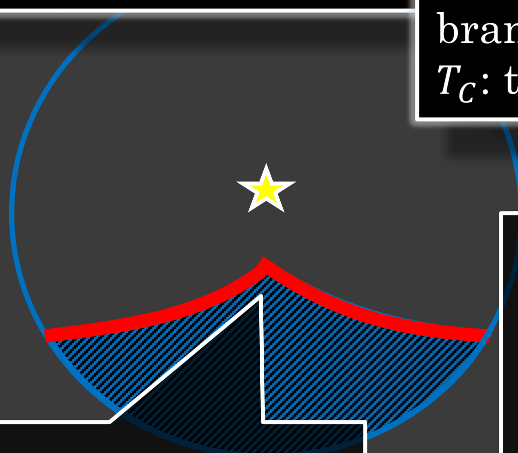


Cut & Paste construction

$$I_{grav} = -\frac{1}{16\pi G_N}\int_M d^3x\,\sqrt{g}(R-2\Lambda) + \sum_i m_i \int dl_i - \frac{1}{8\pi G_N}\int_Q d^2x\,\sqrt{h}(K-T) - \frac{1}{8\pi G_N}\int_C \sqrt{\eta}(\Theta - T_C)$$

$\eta_{\mu\nu}$: induced metric on C
Θ: internal angle between branes
T_C: tension of corner defect



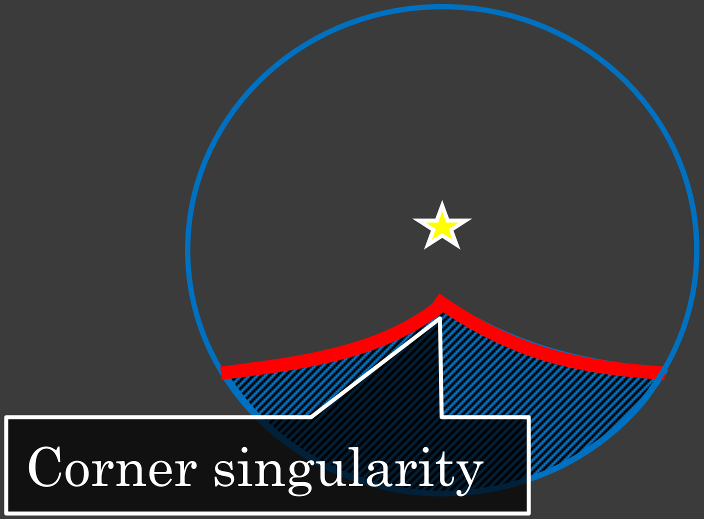
Note:
Generalized Hayward term has additional parameter T_C.

However, for the action to give solutions, T_C is dynamically determined by T and m_i

Cut & Paste construction

How can we construct a conical defect geometry with a negative tension brane?

→ cut & paste in AdS/BCFT



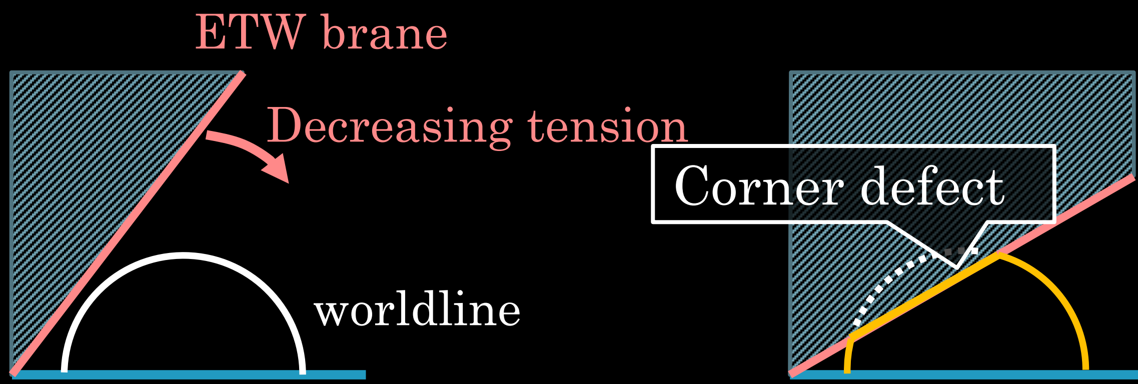
$$E_{ADM} = \int_0^{2\pi} d\theta \, T_{tt} = -\frac{(2\chi - 1)^2}{16G_N}$$

This leads to

$$E_{ADM} + E_{Casimir} = 2\alpha_i(Q - 2\alpha_i)$$

While the brane configuration looks sensitive to sign of tension, ADM mass is not sensitive to whether tension is positive or negative.

Negative tension brane



The singularity behind the ETW brane appears as a corner defect on the ETW brane.

This construction gives results consistent with conformal bootstrap.

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Refined RT formula

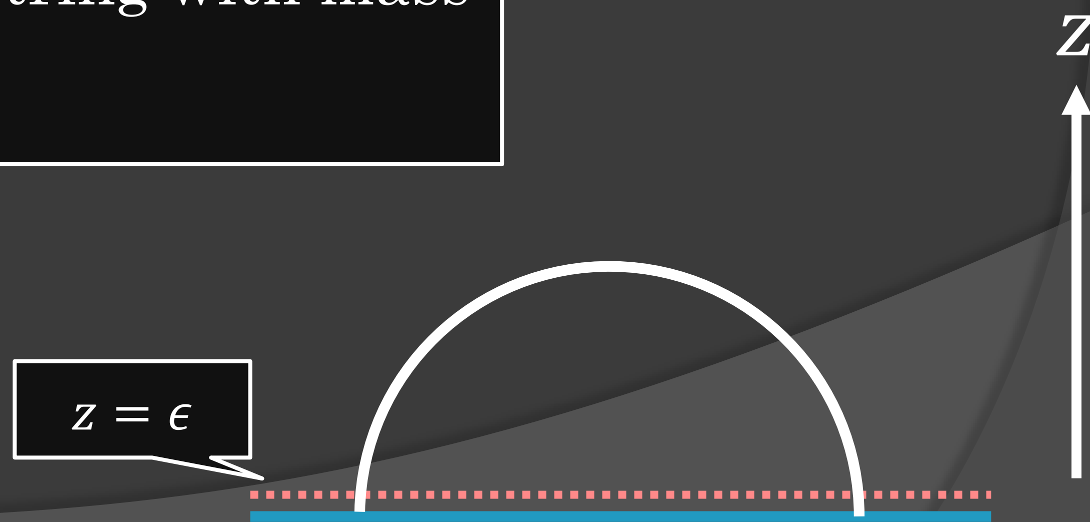
n-the modular Renyi entropy:

$$\tilde{S}_A^{(n)} = n^2 \frac{\partial}{\partial n} \frac{n-1}{n} S_A^{(n)}$$

Holographic dual:

$$\tilde{S}_A^{(n)} = \min_{\gamma_n} \frac{|\gamma_n|}{4G_N}$$

where γ_n is cosmic string with mass $m_n = \frac{1}{4G_N} \frac{n-1}{n}$

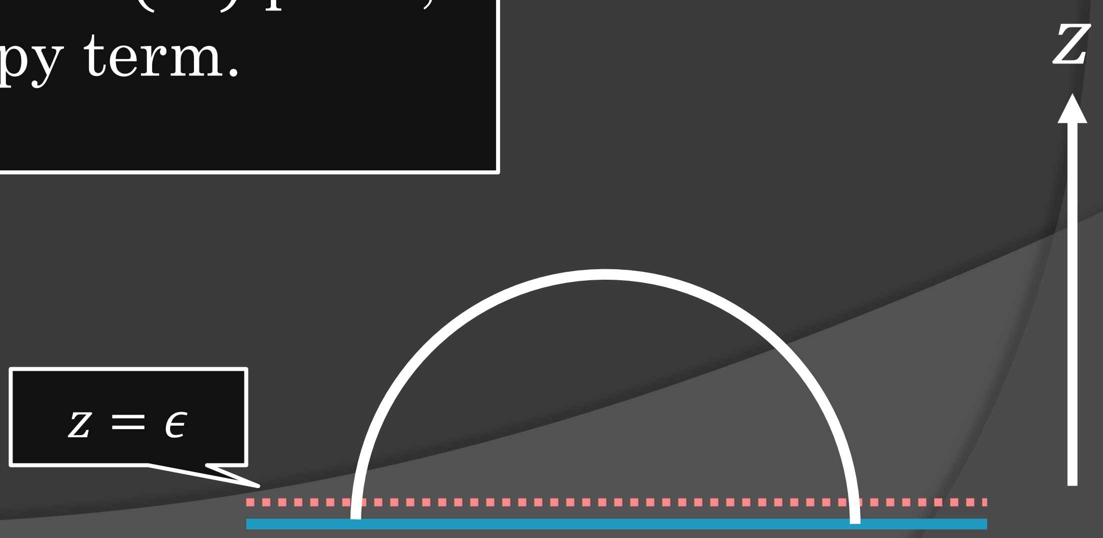


Refined RT formula

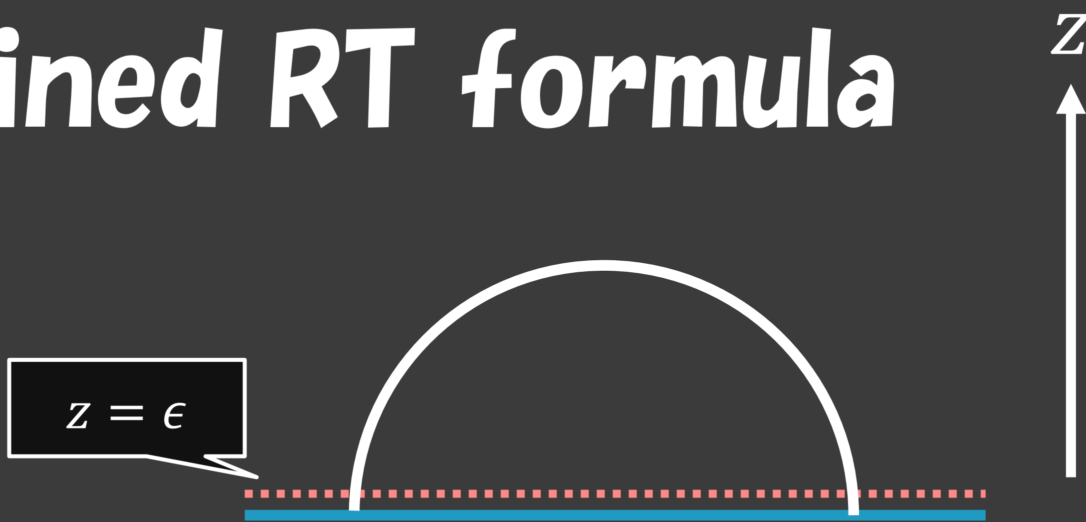
Holographic dual:

$$\tilde{S}_A^{(n)} = \min_{\gamma_n} \frac{|\gamma_n|}{4G_N}$$

Since the length of γ_n is UV-divergent, we need to specify cutoff, If we would like to see $O(\epsilon^0)$ parts, like boundary entropy term.



Refined RT formula



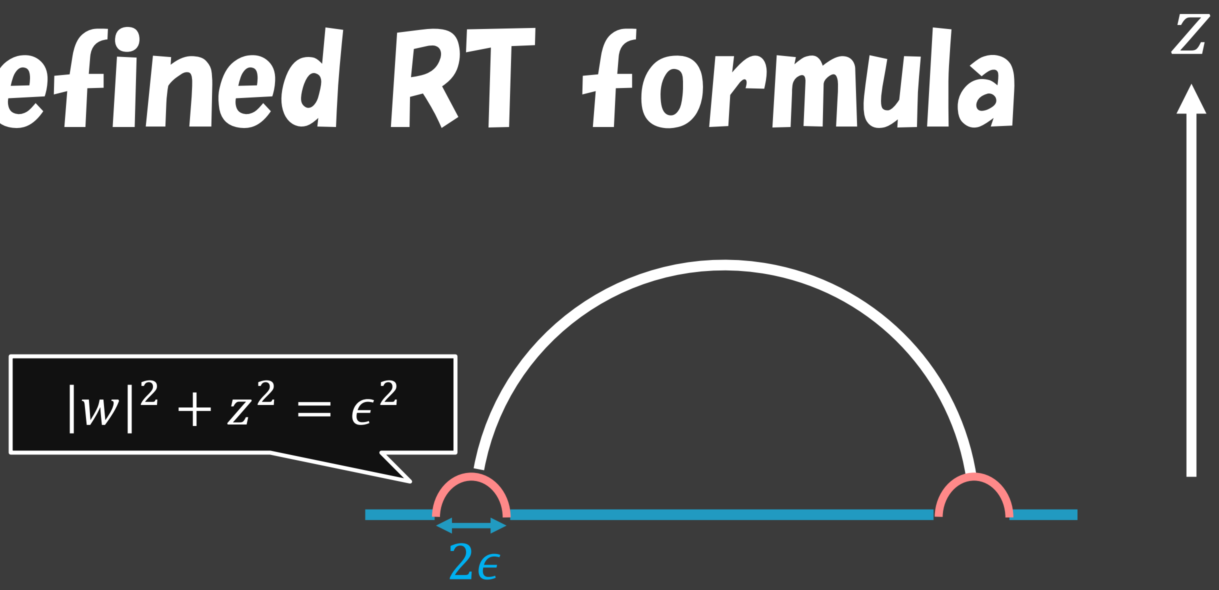
How about naïve cutoff surface?

NOT expected

$$\tilde{S}_A^{(n)} = \frac{1}{n} \log \frac{|A|}{\epsilon} + \log g + \log n$$

What is a reasonable cutoff surface?

Refined RT formula



What is a reasonable cutoff surface ?

→ ETW brane ending on entangling surface

This nicely reproduces

$$\tilde{S}_A^{(n)} = \frac{1}{n} \log \frac{|A|}{\epsilon} + \log g$$

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Discussion

- More bootstrapping AdS/BCFT ?

  We have six fundamental bootstrap equations in BCFT, but we only use one of them. We may be able to give more consistency conditions on branes from others.

- Spinning particle

  We present a way to induce spinning defects on gravity with branes. This can be applied to study more various setups including spinning particles

- Wormholes in AdS/BCFT [under consideration]
- Insights into braneworld holography
- Higher dimensional generalization