# On a holographic quantum quench with a finite size effect

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Based on work in progress with G.Mandal, R.Sinha

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# Introduction

There are several big problems which motivate us to think about time evolutions of black holes.

1. Information loss: apparent break down of unitarity in QFTs on BH backgrounds

2.CFT descriptions of the inside of black holes : introduction of time slices which penetrate the future horizons.

3. Black hole microstates and their dynamics.

Quantum quenches in CFT 2provide simple holographic playgrounds on these topics.

# Plan

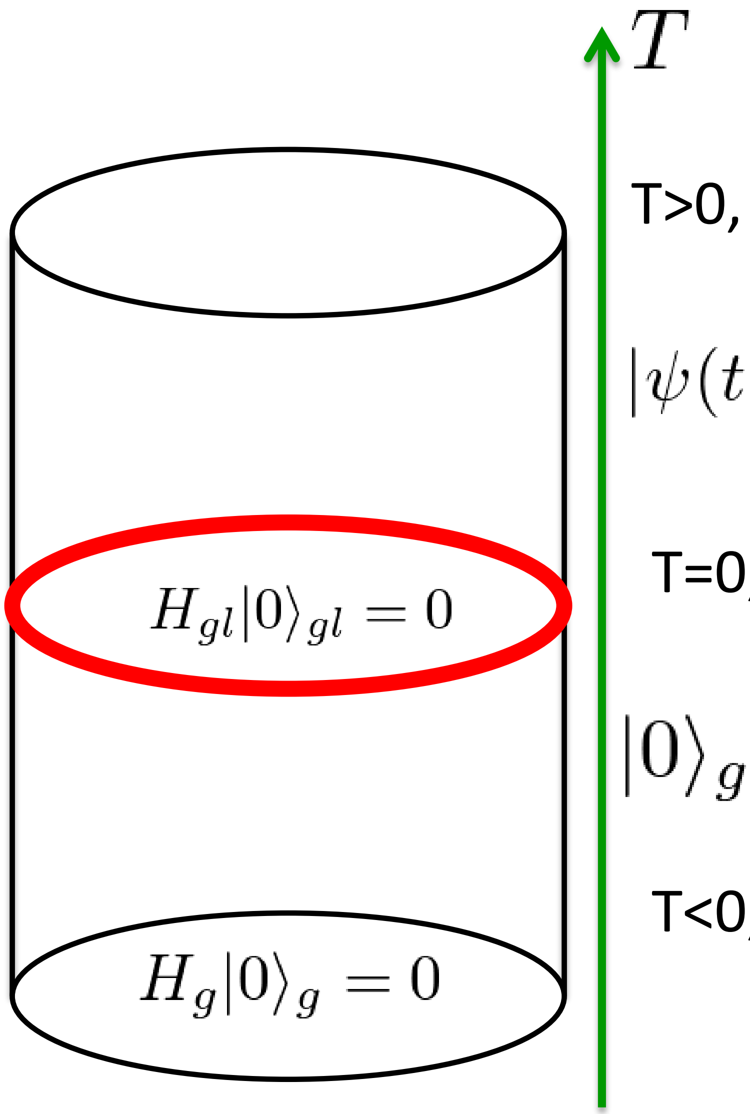
1.Quantum quenches in 2d CFTs

2.A holographic realization of 2d quenches

3.A holographic 2d quench with a finite size effect.

# Quantum Quenches

[Carabrese Cardy].....




T>0, Nontrivial time evolution. CFT dynamics

$$|\psi(t)\rangle = e^{iH_{gl}}|\psi_0\rangle$$

T=0, make the system gapless, Hg → Hgl

$$\mathcal{L} = (\partial\phi)^2$$

T<0, Prepare a gapped system

Ex: $\mathcal{L} = (\partial\phi)^2 + m_0^2\phi^2$

- **Assumption about** $|\psi_0\rangle$

We excite below the scale of the quench $\frac{1}{\epsilon}$ . Conformally invariant up to $\frac{1}{\epsilon}$

$$|\psi_0\rangle = e^{-\epsilon H_{gl}}|B\rangle$$ :Boundary state of the CFT (T>0)

Make it possible to study them by BCFT technique

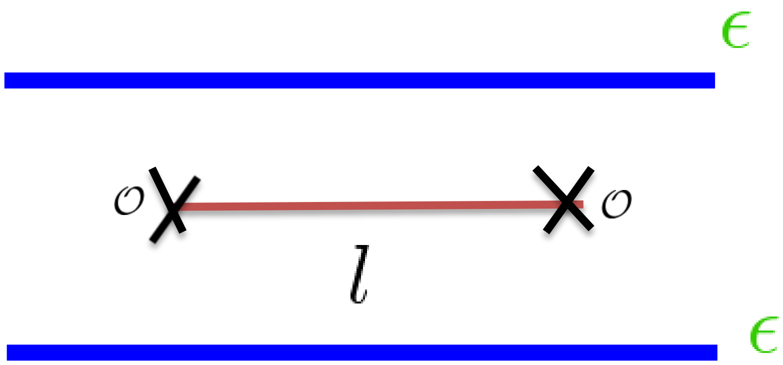
- **Observable in Quantum quench Process**

Desirable to be an universal quantity. Can be defined for any QFT

Entanglement Entropy

Evolution of trace of reduced density matrix $\mathrm{tr}\ \rho_A^n$ can be computed by a path integral on a strip with width $2\ \epsilon$ which can be mapped to upper half plane.

$$S_A \begin{cases} \frac{4\pi c}{3} T_{\mathrm{eff}}\, t & t \leq \frac{l}{2} \\ \frac{2\pi c}{3} T_{\mathrm{eff}}\, l & t > \frac{l}{2} \end{cases}$$




$$T_{\mathrm{eff}} = \frac{1}{4\epsilon}$$

Effective temperature
=width of the strip

Cf. Thermal entropy of CFT

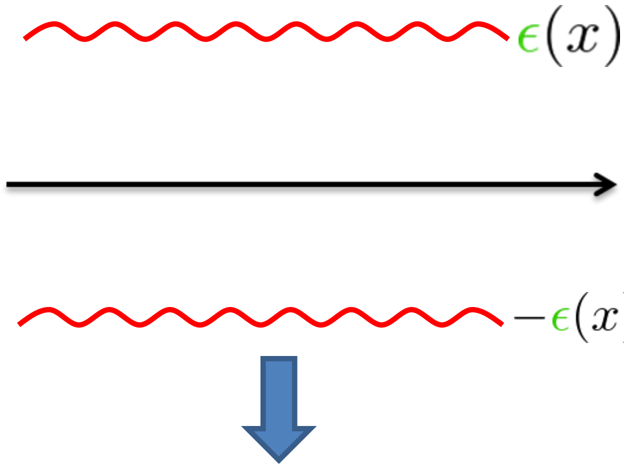
$$\frac{2\pi c}{3} T * \mathrm{Vol}$$

EE is thermalized in the Quench!!

## ▪Various generalizations

Make the width space dependent $\epsilon \longrightarrow \epsilon(x)$

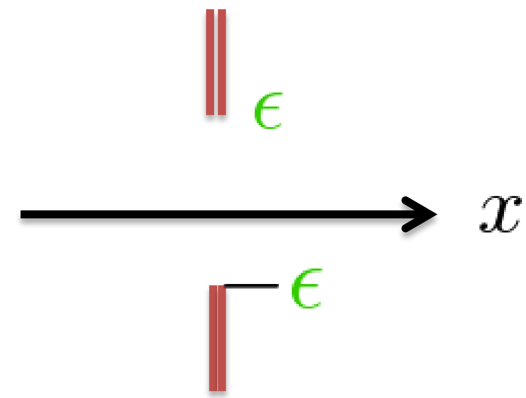
Energy scale of the quench depends on the location.




## ▪Local quench: excite only one point.

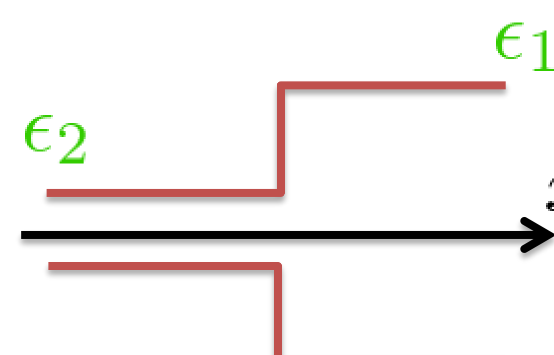
[Calabrese Cardy 07]

Path integral on a plane with slits



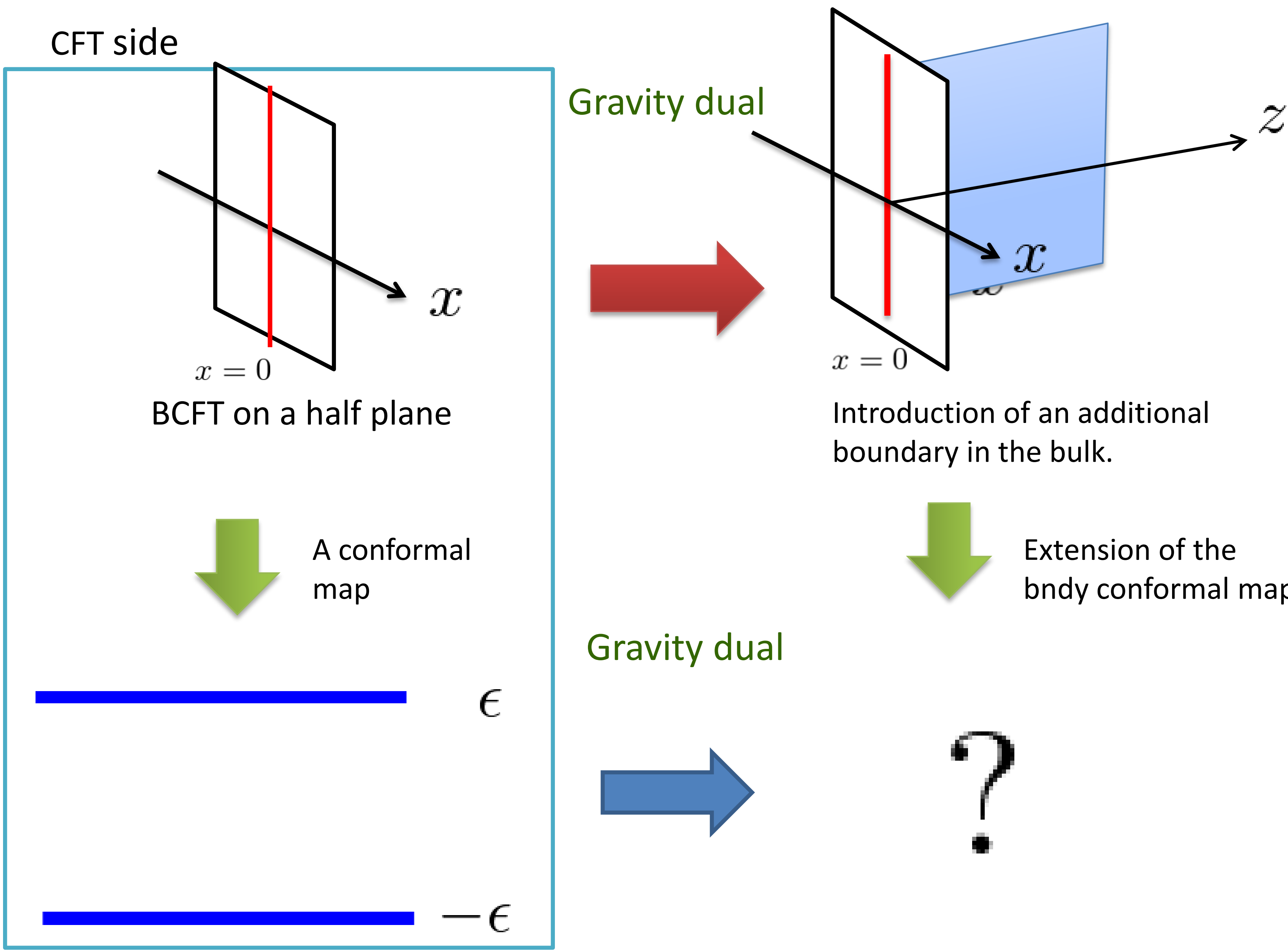

## ▪An inhomogeneous quench

Introduction of two different temperatures



# Holographic aspects of quantum quenches

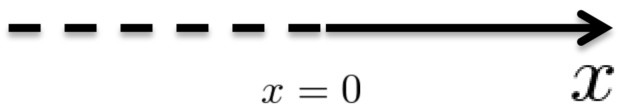
# Construciton of gravity duals

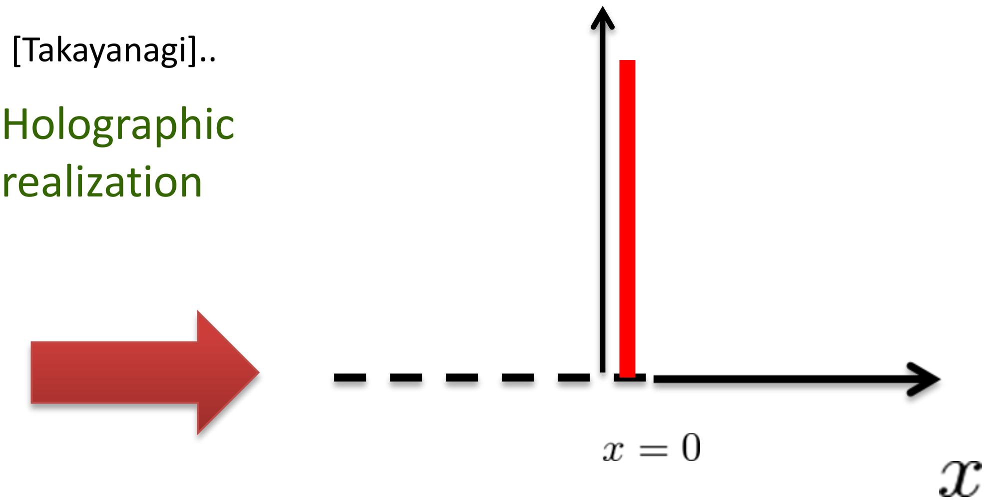


# Holographic realization of BCFT on HP : Space time boundary

[Karch, Randall], [Dewolfe Fredman Ooguri] [Takayanagi]..

Holographic
realization

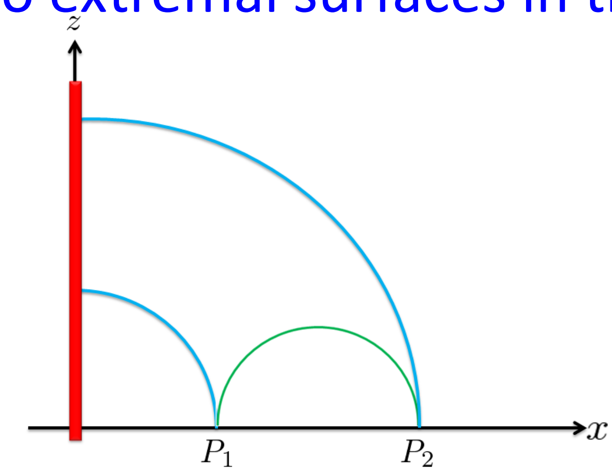



BCFT on HP

Introduction of spacetime boundary at x=0

# Two extremal surfaces in the holographic system




$$S_A = \frac{1}{4G_N} \min\{L_c, L_{dc}\}$$

# The Bulk extension of conformal maps [ Banados, Roberts]

If we impose the Fefferman Graham condition to the bulk metric, we obtain unique extension of the boundary conformal map $W^{\pm} = f_{\pm}(x^{\pm})$.

The resulting metric is

$$ds^2 = \frac{dz^2}{z^2} + \left( \frac{dx^+}{z} - \mathcal{L}^+(x^+)dx^- \right) \left( \frac{dx^-}{z} - \mathcal{L}^-(x^-)dx^+ \right)$$

$$\mathcal{L}^{\pm}(x^{\pm}) = -\frac{3f_{\pm}''^2 - 4f_{\pm}' f_{\pm}'''}{f_{\pm}'^2}$$ :Schwarzian derivative ~ stress tensor in CFT

# Global Quench and BTZ string

[Hartman, Maldacena] , [T.U]

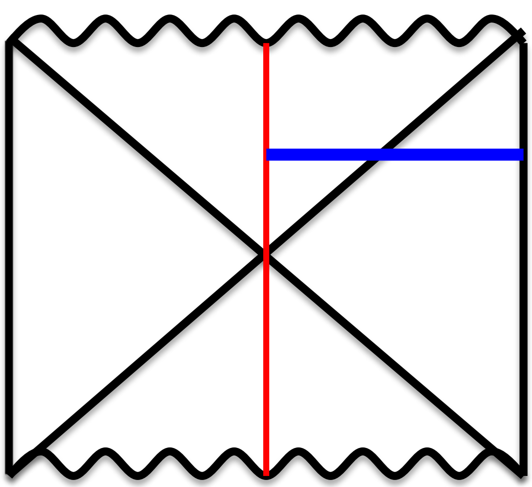
Length of connected/disconnected surface

$$L_c = \pi T_{\text{eff}} l$$

$$L_{dc} = 2\pi T_{\text{eff}} t$$

Disconnected surface probe

Inside of the event horizon



Evolution of entanglement entropy

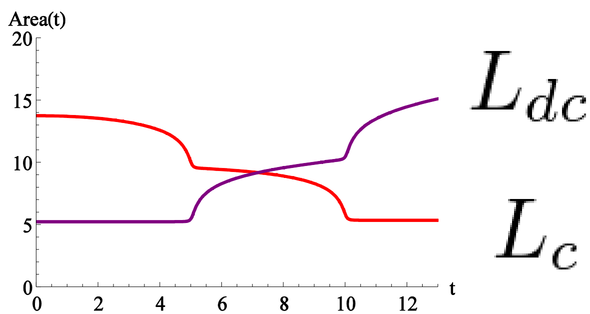
$$S_A = \frac{1}{4G_N} \min\{L_c, L_{dc}\}$$

$$= \begin{cases} \frac{4\pi c}{3} T_{\text{eff}} t & t \leq \frac{l}{2} \\ \frac{2\pi c}{3} T_{\text{eff}} l & t > \frac{l}{2} \end{cases}$$

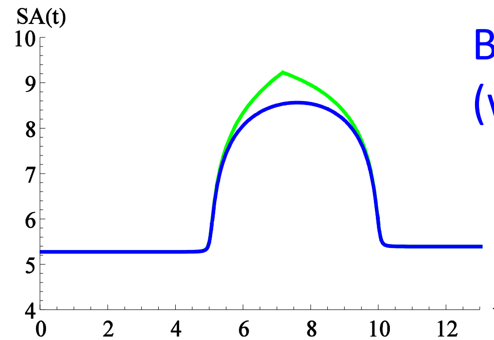
Reproduce CFT result !!

Local quench = Aichelburg  Sexl metric
(shock wave geometry )

Area of extremal surfaces



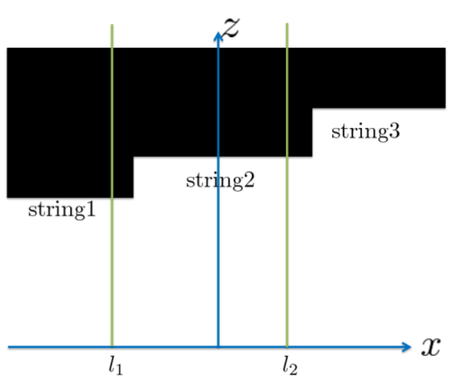

Comparison with CFT results




Blue: CFT result
(with an approximation)

Green: Gravity result

- An Inhomogeneous quench  : Nucleation  of two black strings into an another one.

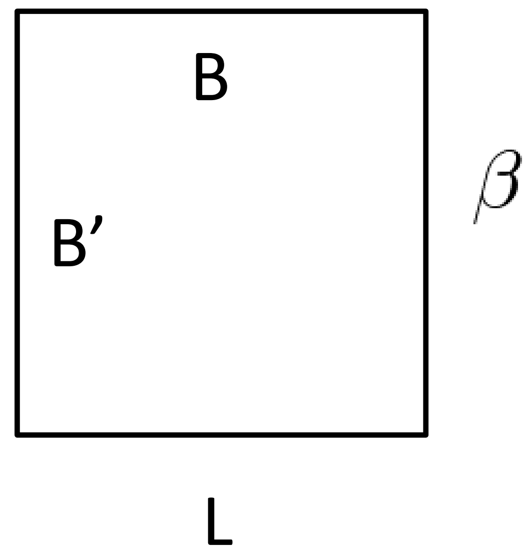



The evolution of entanglement entropy can be explained from the dynamics of these black strings  quantitatively.

# A quantum quench with a finite size effect

# Global quench in a finite size region by introducing spatial boundaries

Path integral on a rectangle
with boundary conditions B, B'
(below we choose B=B')

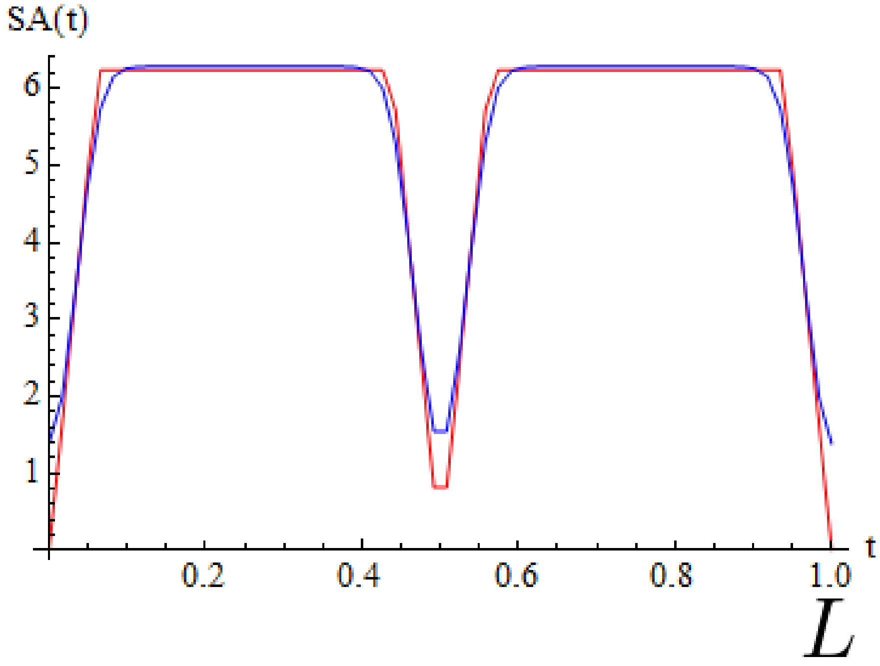



・Mapping to a half plane can be explicitly written in terms of elliptic functions.

・Doubling trick: By gluing two identical rectangles, this quench can be considered as a quench on a circle.

# Evolution of entanglement entropy

- Determination of EE requires detailed knowledge of 4 pt function of twisted operators.




Blue holographic result

Red Quasi particle picture result

- Recursion with period L. Similar behavior appears in quench of free fermion theory on S1.

[Takayanagi TU]

- This evolution of EE can be entangled quasi particle picture + their reflections by the boundary walls

# Some properties of the dual geometry.

The dual geometry quite looks like BTZ string locally. $\langle T_{\pm\pm}(x^{\pm})\rangle$ take nearly thermal values.

・When we impose the boundary condition B= B' , the CFT Partition function can be computed exactly [Kleban Vassiera].

$$Z = \frac{1}{\eta(q)^{\frac{c}{2}}}$$

・This indicates that only identity operator and its Virasoro descendants Are allowed to excite.

・This suggests the spectrum of the corresponding quantum gravity only contains AdS3 and (boundary) gravitational waves around it. → No Black holes

# Conclusion

・Quantum quenches in two dimension. Evolution of entanglement entropy.

・A holographic realization of 2d quantum quenches
= introduction of spacetime boundary+ bulk extension of conformal map

・A Holographic realization of a quantum qunech in finite region.
Recursion of entanglement entropy. Dual geometry is not a black hole.