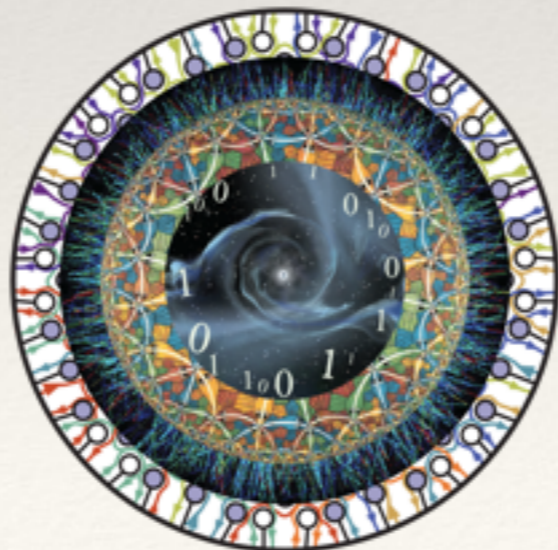
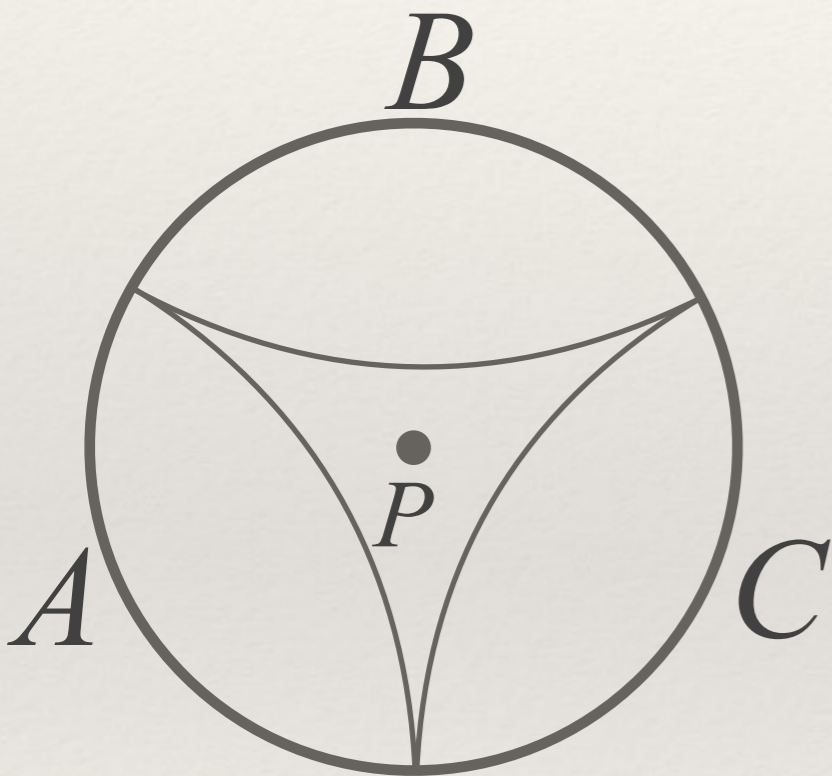


How to Excite your Spacetime by Swapping Entanglement

William Kelly (UC Davis, QMAP)



AdS/QEC



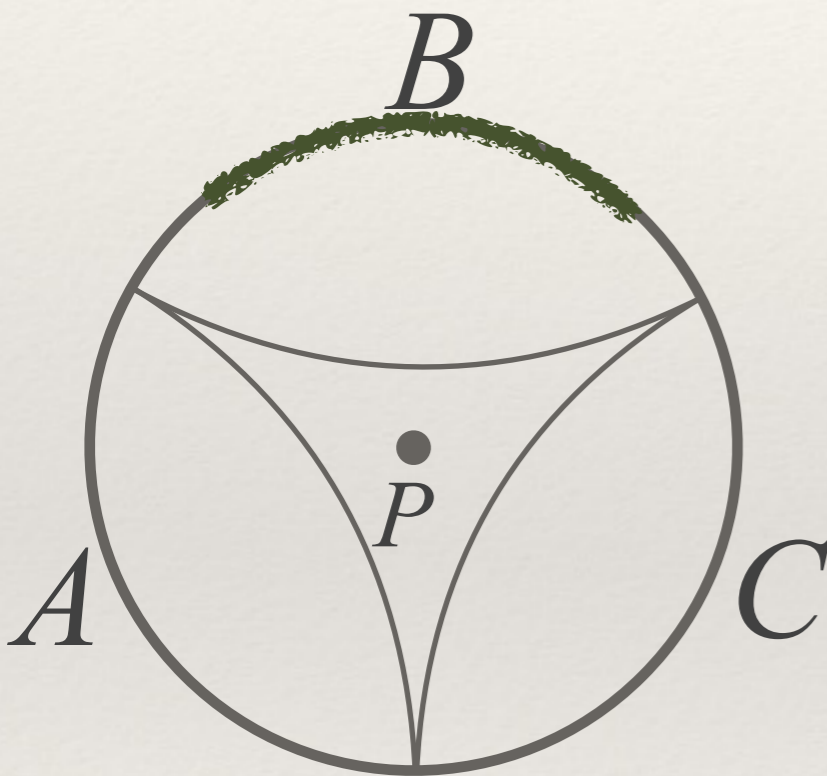
$$E = \int dx \langle T_{00}(x) \rangle_{\psi} \rightarrow 0$$

- Bulk effective theory reveals QEC structure of dual CFT
- Strict $N \rightarrow \infty$ limit has special properties (bulk operators are truly local)

$$\langle \chi | \phi_{AB} | \psi \rangle \approx \langle \chi | \phi_{BC} | \psi \rangle$$

$$|\chi\rangle, |\psi\rangle \in H_{\text{code}}$$

AdS/QEC at finite N



$$E = \int_B dx \langle T_{00}(x) \rangle_\psi \neq 0$$

$$\langle \chi | \phi_{AB} | \psi \rangle \approx \langle \chi | \phi_{BC} | \psi \rangle \approx \langle \chi | \phi_{AC} | \psi \rangle$$

$$|\chi\rangle, |\psi\rangle \in H_{\text{code}}$$

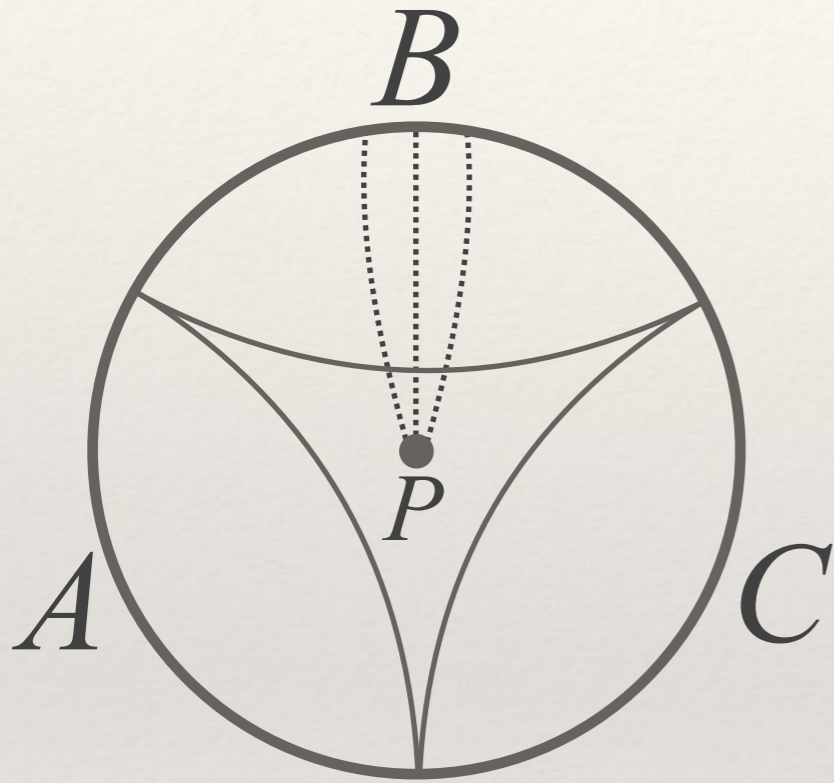


$$\langle \chi | \phi_{AB} | \psi \rangle \approx \langle \chi | \phi_{BC} | \psi \rangle$$

$$|\chi\rangle, |\psi\rangle \in H_{\text{code}}$$



The Bulk Story



$$\langle \chi | \phi_{AB} | \psi \rangle \approx \langle \chi | \phi_{BC} | \psi \rangle$$

$$|\chi\rangle, |\psi\rangle \in H_{\text{code}}$$

- Gravitational hair can be “combed” order by order into small region
- Multiple representations exist if “gravitational hair” lies in overlap of causal wedges
- Equivalence broken by non-perturbative effects

The Boundary Story

In any QFT we can construct “bulk operators” in a low energy subspace

$$(\phi_{AB})_{n,n}^{p,q} = (\phi_{BC})_{n,n}^{p,q}$$

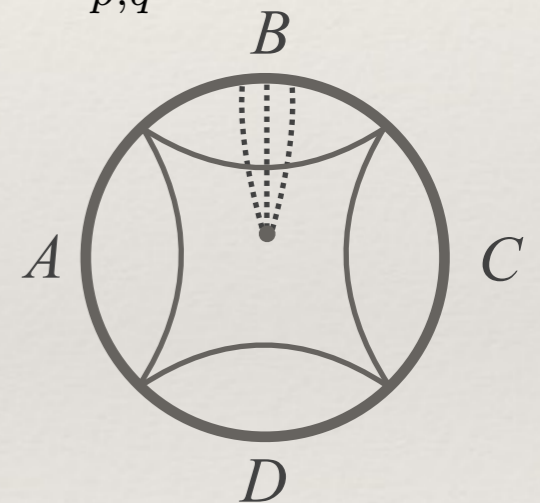
for $H_n < N^2$

$$\|(\phi_{AB} - \phi_{BC})|0\rangle\| \sim e^{-N^2}$$

$$|0\rangle = \sum_n e^{-H_n/2} |n_B, n_{\bar{B}}\rangle$$

$$\phi_{AB}|n_B, m_{\bar{B}}\rangle = \sum_{p,q} (\phi_{AB})_{n,m}^{p,q} |p_B, q_{\bar{B}}\rangle$$

$$\phi_{BC}|n_B, m_{\bar{B}}\rangle = \sum_{p,q} (\phi_{BC})_{n,m}^{p,q} |p_B, q_{\bar{B}}\rangle$$



But the Reeh-Schlieder Theorem implies this procedure ultimately breaks down

(corollary to)

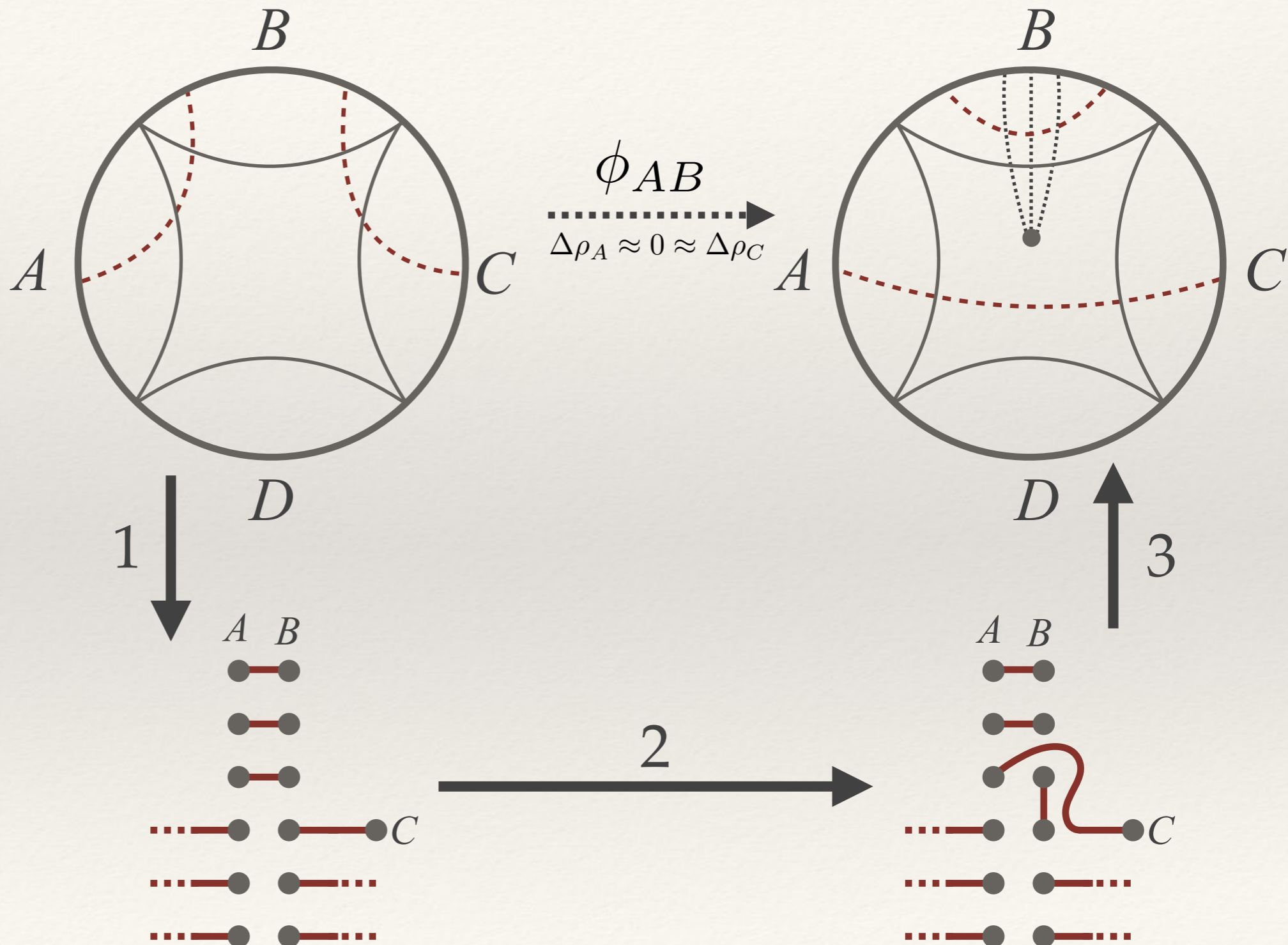
The Reeh-Schlieder Theorem

if $\overline{A \cup B \cup C} \neq \emptyset$

$$(\phi_{AB} - \phi_{BC})|0\rangle = 0 \Rightarrow \phi_{AB} = \phi_{BC}$$

Entanglement Swapping

1. Distill Bell pairs
2. Swap entanglement
3. Reverse the distillation



$$\Delta S_A = 0 = \Delta S_C$$

$$\Delta S_{ADC} = \Delta S_B < 0$$

Summary

- All QFT's admit basic features of QEC
- The “bulk” operators swap entanglement between boundary regions
- Understanding this process in detail may shed light on aspects of holography

