The amazing Super-Maze

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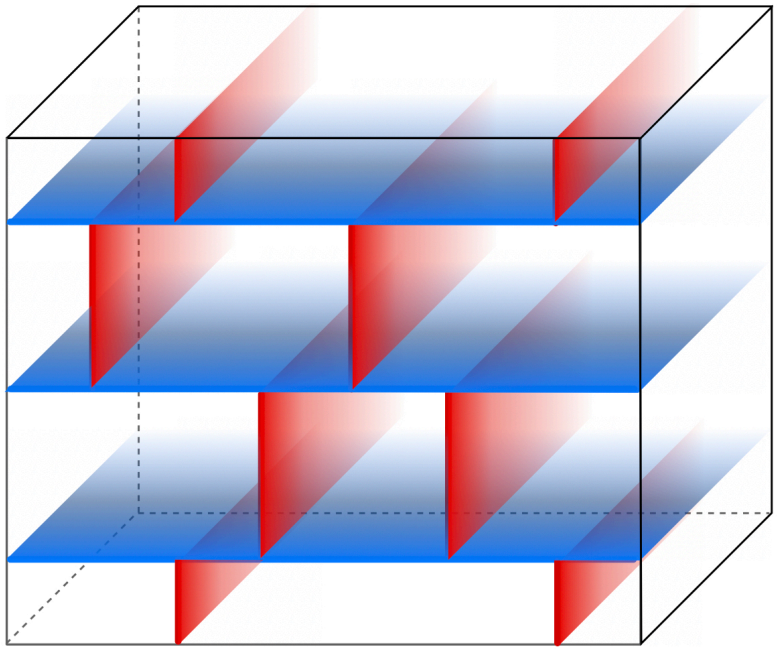

with Dimitrios Toulikas, Anthony Houppe, Yixuan Li, Nejc Ceplak, Shaun Hampton and Nick Warner

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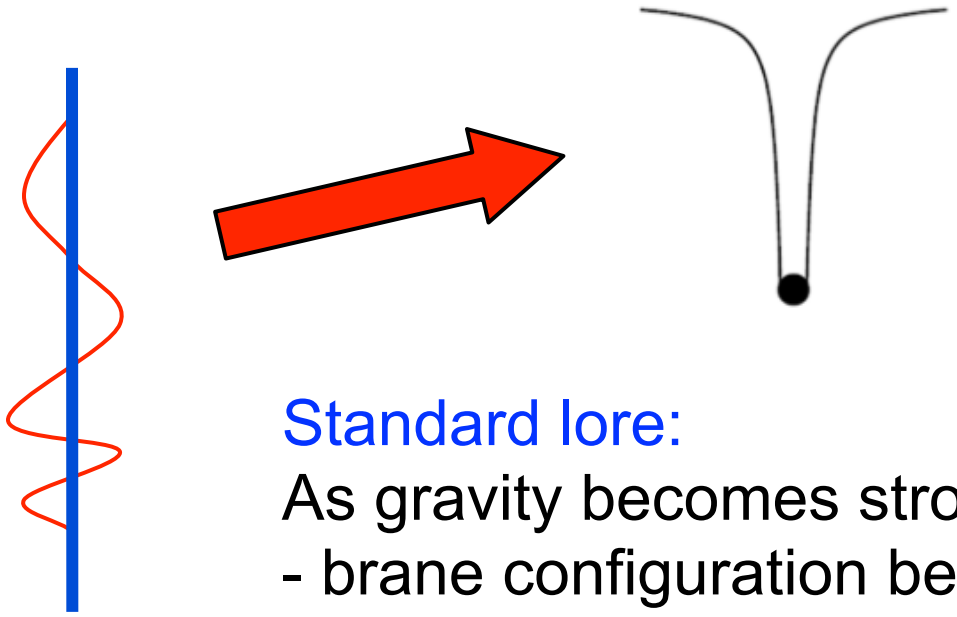
An amazing success of String Theory

Count Black Hole Microstates (branes + strings)

Correctly match B.H. entropy !!!

Zero Gravity

One Particular Microstate at Finite Gravity:



Standard lore:

As gravity becomes stronger,

- brane configuration becomes smaller
- horizon develops and engulfs it
- recover standard black hole

Susskind

Horowitz, Polchinski

Chen, Maldacena, Witten

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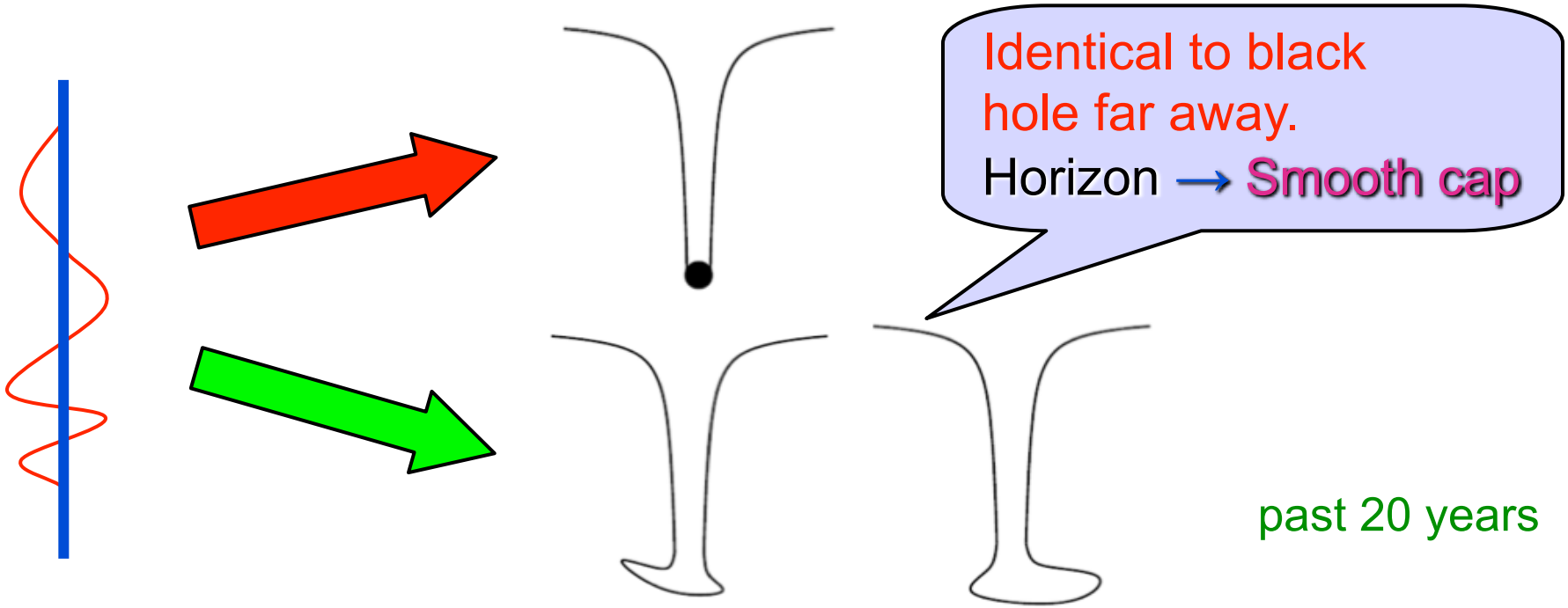


past 20 years

In an ideal world: Track **each and every** BH microstate from zero-gravity regime to fully-backreacted solution

20 years of microstate geometries

Nick's review talk

- Huge number of smooth horizonless solutions
  - Bubbling geometries, superstrata
  - Largest class of solutions to Einstein's equations ever
  - Many features of typical microstates (mass gap)
  - $S \sim (Q_1 Q_5)^{1/2} (Q_p)^{1/4} < S_{BH} \sim (Q_1 Q_5 Q_p)^{1/2}$ Mayerson, Shigemori *'20*
- Link with D1-D5 states that count BH entropy ?
  - Only known for a few (messy holographic procedure)
  - Hard to build fractional momentum carriers
    Bena, Martinec, Turton, Warner *'16*; Shigemori *'21, '22*
  - Painful reality: we have not succeeded to track typical D1-D5 Strominger-Vafa microstates to finite gravity

Do not pray to the saint who does not help you ! Romanian proverb

Instead of D1-D5 look at D2-D4 (or F1-NS5 in type IIA)

One F1 inside N_5 NS5 branes ➞ N_5 little strings.

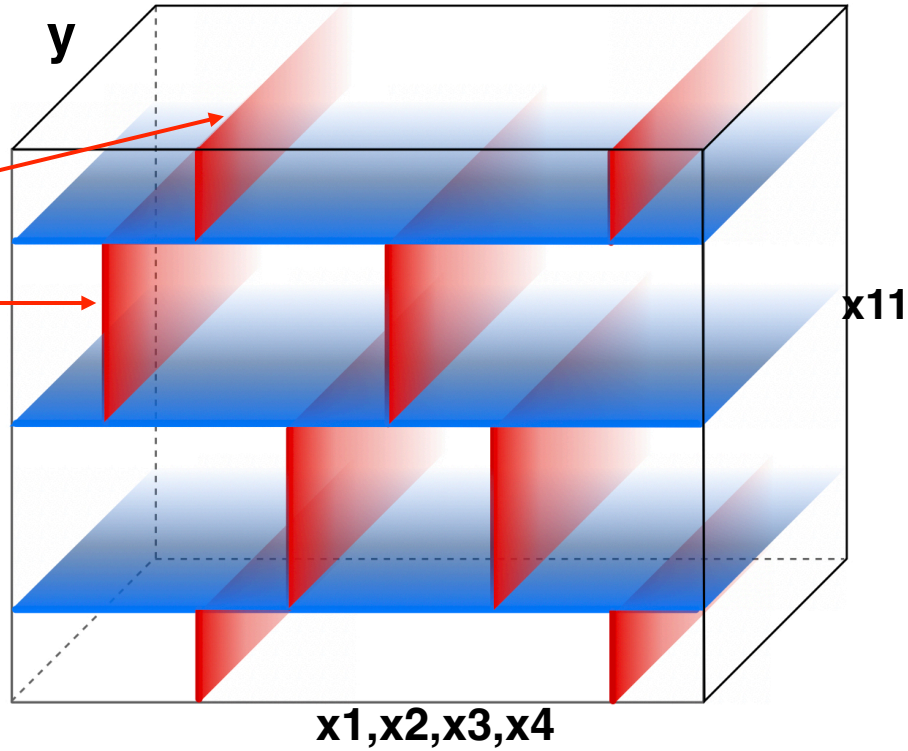
Dijkgraaf, Verlinde, Verlinde

- Visible as M2 brane strips in M-theory
- Total $N_1 N_5$ independent momentum carriers
- each has 4 oscillation directions (T^4) + 4 fermionic partners

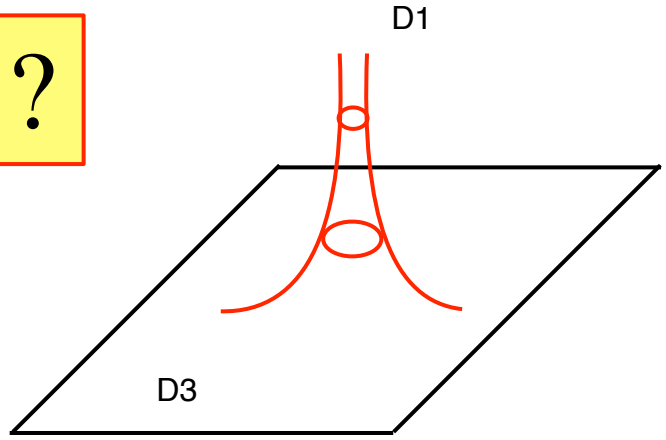
$$S = 2\pi\sqrt{\frac{4+2}{6}N_1 N_5 N_p}$$

M2 along y,11
M5 along y,1234
P along y

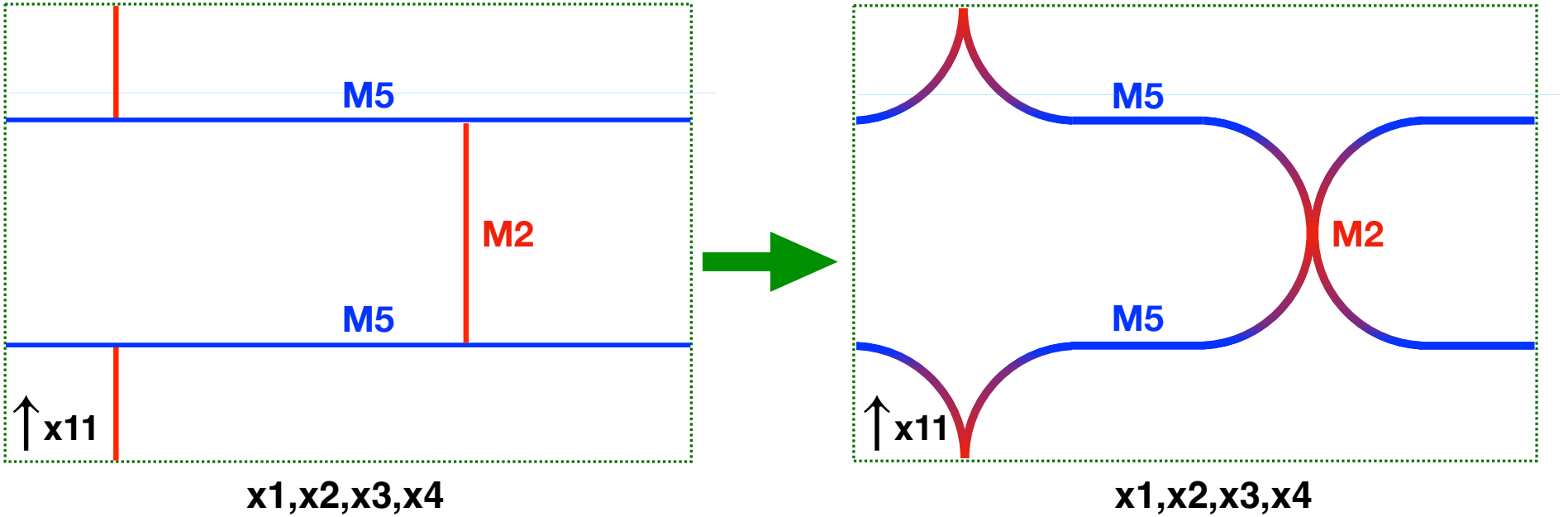
zero-coupling picture



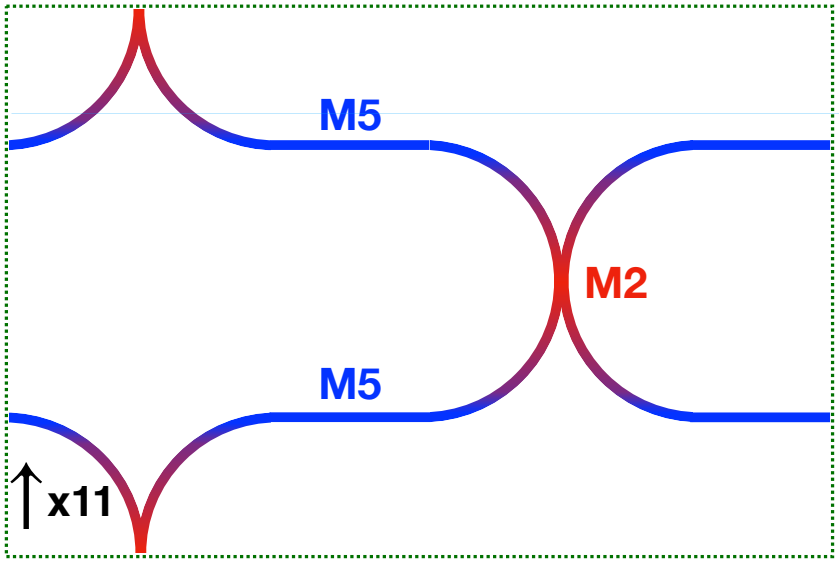
What about finite coupling ?

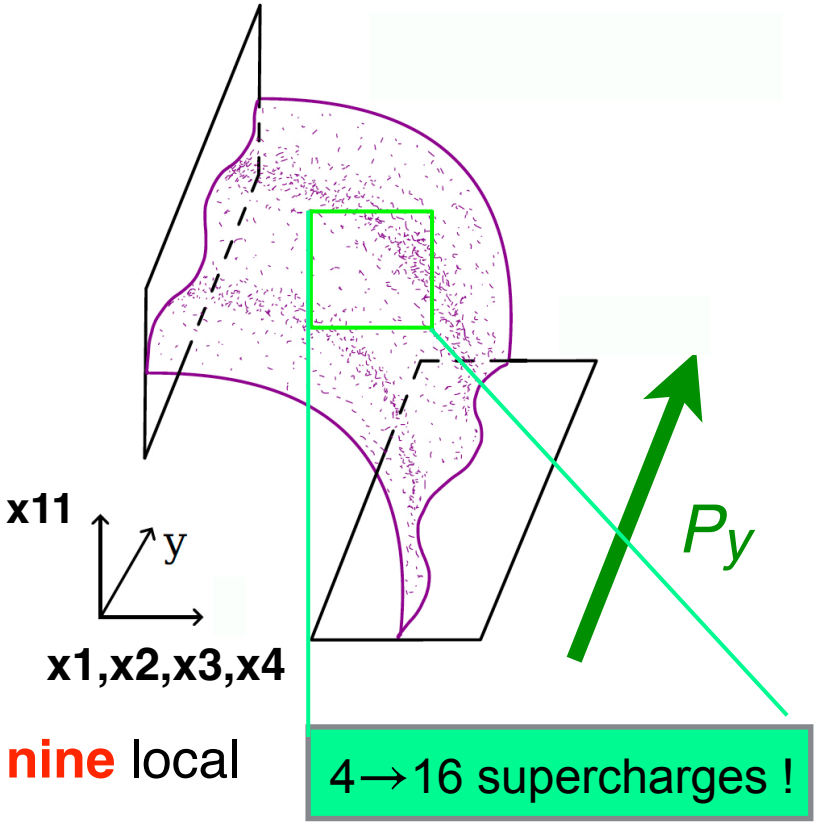


- Reminder:
  Callan-Maldacena spike formed by
  D1 pulling on an orthogonal D3
- M2 branes also pull on the M5 branes



Except that the spike is a *furrow* carrying momentum waves along y





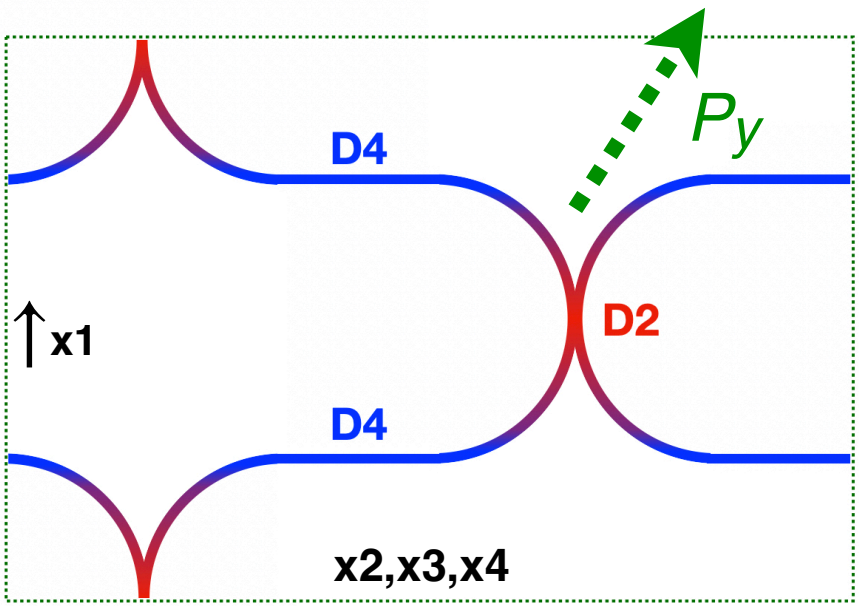
Zoom in on the furrow carrying momentum: **nine** local brane charges: $M2_{x11,y}$ $M5_{y,x1,x2,x3,x4}$ P_y

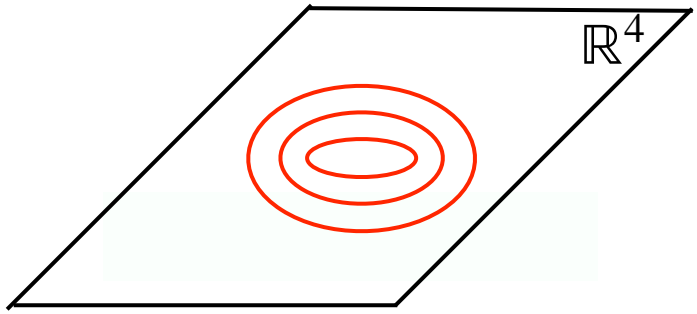
$M2_{x1,x11}$ $M5_{x11,y,x2,x3,x4}$ $M2_{x1,y}$ $M5_{x11,x1,x2,x3,x4}$ P_{x11} P_{x1}

Smoking gun of smooth horizonless solutions

Bena, de Boer, Shigemori, Warner 2011 (conjectured superstrata) → HABEMUS

How would these solutions look like ?





spherically symmetric in $\mathbb{R}^4$ (x5,x6,x7,x8)
same spacetime $SO(4)$ symmetry as BH

$SO(4)$ invariant solutions:

momentum carried by waves on fractionated strings (inside T^4) =

bosonic d.o.f. : $S_{bosonic} = 2\pi\sqrt{\frac{4}{6}N_1N_5N_p}$

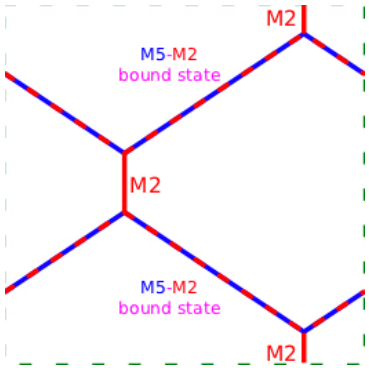
+ 2 *fermionic* d.o.f. preserving $SO(4)$ $\Rightarrow$ $S_{SO(4)\ \text{invariant}} = 2\pi\sqrt{\frac{5}{6}N_1N_5N_p}$

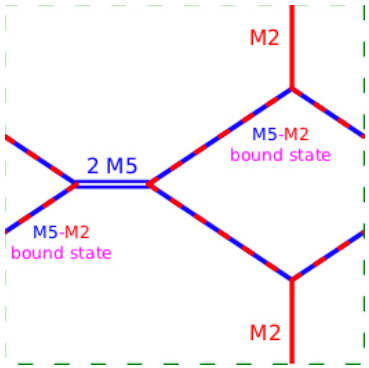
Remaining 2 *fermionic* d.o.f. break $SO(4)$ $\Rightarrow$ $S_{SO(4)\ \text{breaking}} = 2\pi\sqrt{\frac{1}{6}N_1N_5N_p}$

Confirms expectations from Bena, Shigemori, Warner 2014

How will the $SO(4)$-invariant solution look like ?

- 2-charge - Monge-Ampère *cohomog-3* at least Lunin 07
- 3-charge: at least *cohomog-4*
- smeared on $T^3 \Rightarrow$ string web:
- Horizonless $\Leftrightarrow$ *16-susy locally*





- Geometric transition $\Rightarrow$ Bubbles on internal dimensions
- Expectation: backreaction will make bubbles large *irrespective* of T^4 size at infinity
- Differs from BH only by T^4 KK modes:
- Asympt. $\mathbb{R}^{4,1} \times S^1 \times T^4$: *exponentially-decaying*
- Asympt. $AdS_3 \times S^3 \times T^4$: *high-dimension operators*
  - Dimension depends on T^4 moduli. SUSY ?
  - Visible at free-orbifold point ?
  - Can CFT distinguish different supermaze solutions ?

How will the generic solution look like ?

- Generic microstates will contain
  $SO(4)$ breaking modes + T^4 dependent modes
- 2-charge systems:
  - when $SO(4)$ breaking modes are present, smearing on T^4 does not lose information Kanitscheider, Taylor, Skenderis
  - If only T^4 dependent modes present, smearing erases information ⇒ singular, small horizon
- 3-charge story ?
  - superstrata with $SO(4)$-breaking (++) strands capture *some* smeared T^4 dependent modes: (00) strands

A. Could the presence of $SO(4)$-breaking modes in generic solution allow T^4 smearing without info loss ?

B. Would T^4-dependent information be lost upon smearing even when $SO(4)$-breaking modes exist ?

DVV microstates

$S = S_{BH}$

SUPERMAZE

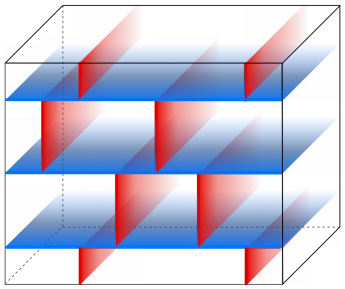
branes pull & merge

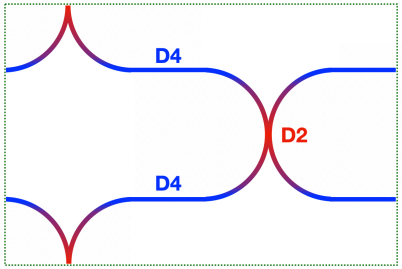
16 susy locally !

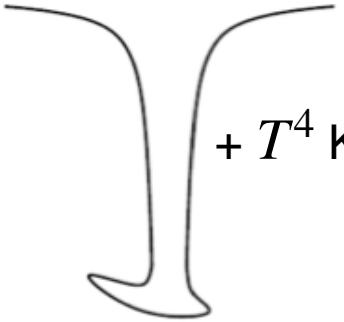
New Microstate Geometries

$S = S_{BH}$

Effective coupling (g_s)







- Build supergravity solution !
- Holographic dual to supermaze? T^4-dependent modes?
  $\langle \Psi_{\text{supermaze}} | \mathcal{O}_{T^4-\text{dependent}} | \Psi_{\text{supermaze}} \rangle \neq 0$
- Most generic beast: is 6D sugra enough? or one needs10D?
- Flat space: supermaze fields decay exponentially.
  Universal ?