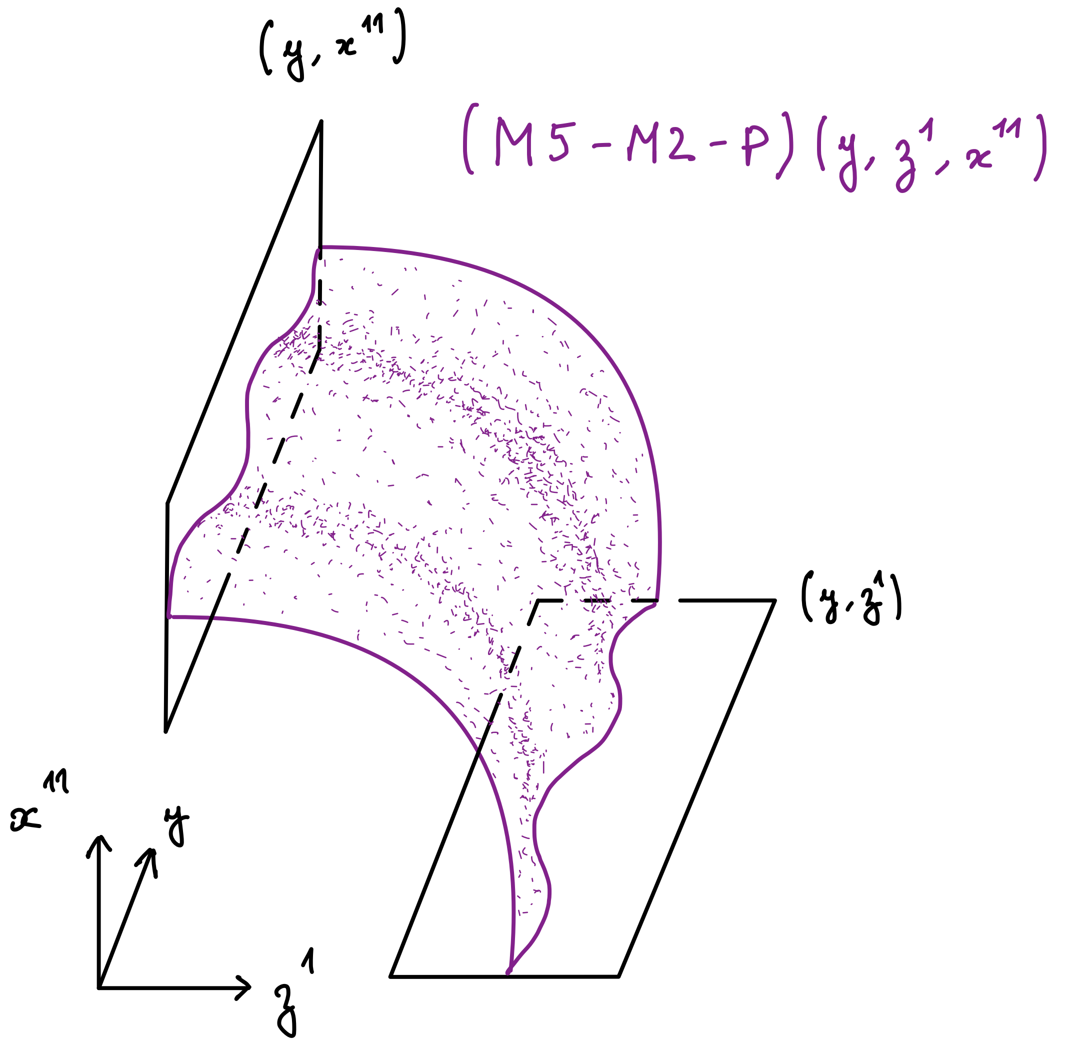
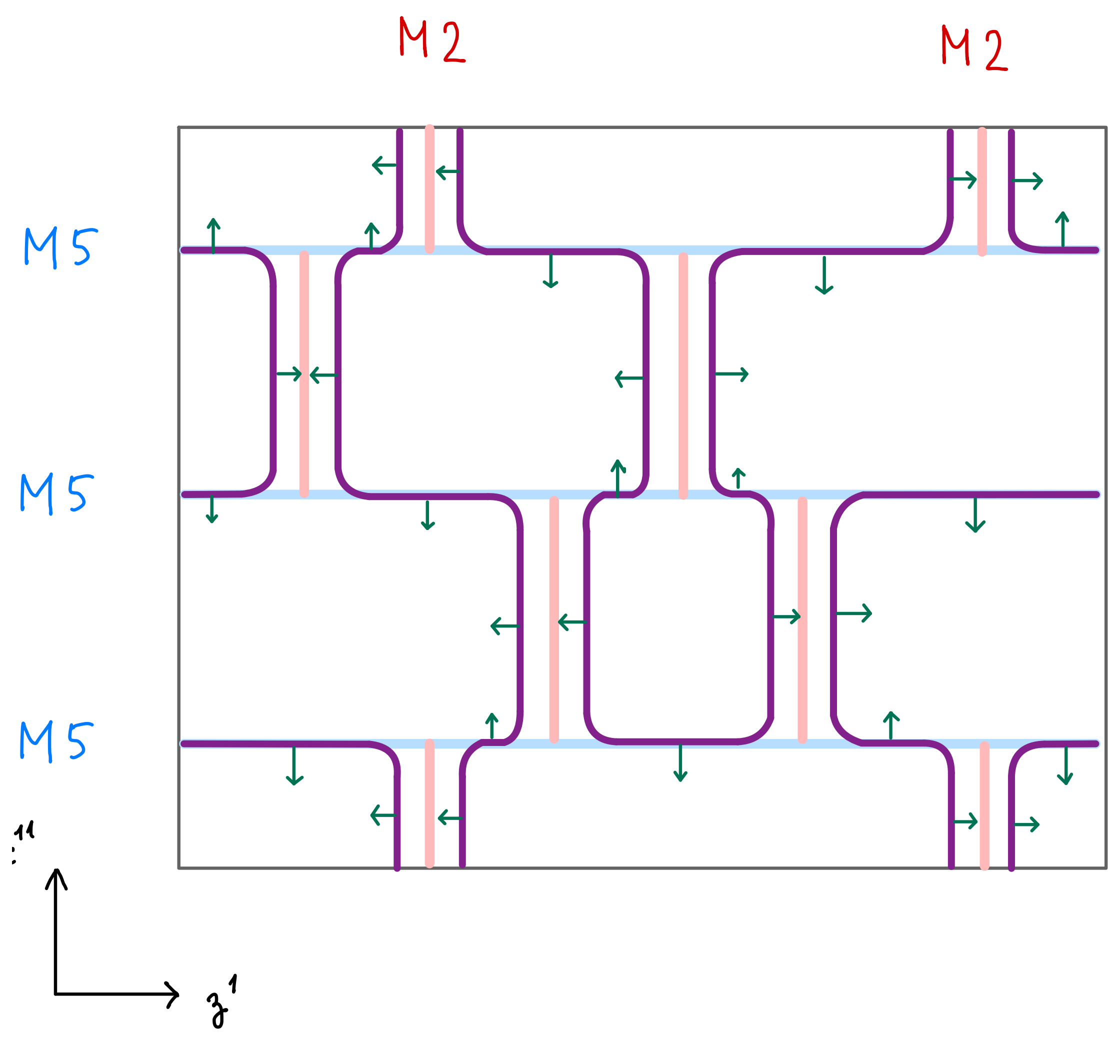
Shapes of M-theory black-hole microstates



Holography and the Swampland,
Corfu

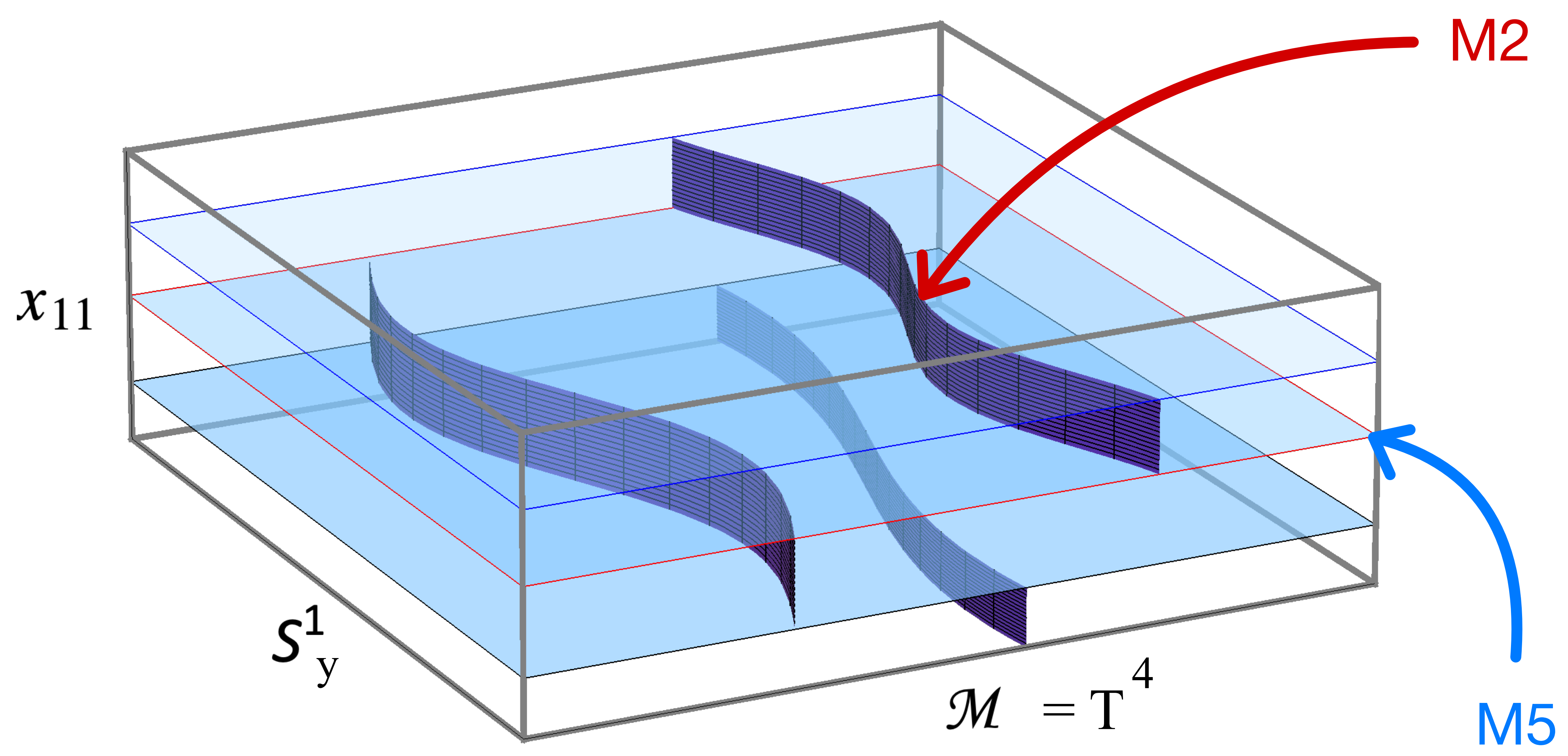
Yixuan Li
MPI Munich
& IPhT Saclay



Based on [22xx.xxxxx] with I. Bena, A. Houppe and D. Toulikas
and [2202.08844] with I. Bena, N. Ceplak, S. Hampton, D. Toulikas and N. Warner

September 8th, 2022

What this talk is about



« Dijkgraaf-Verlinde-Verlinde microstates »

- **M5-M2(-P) black hole:** The microstates that are made of **fractionated M2 branes** account for the entropy.
- We found: They can transition into microstates with 16 local supersymmetries.

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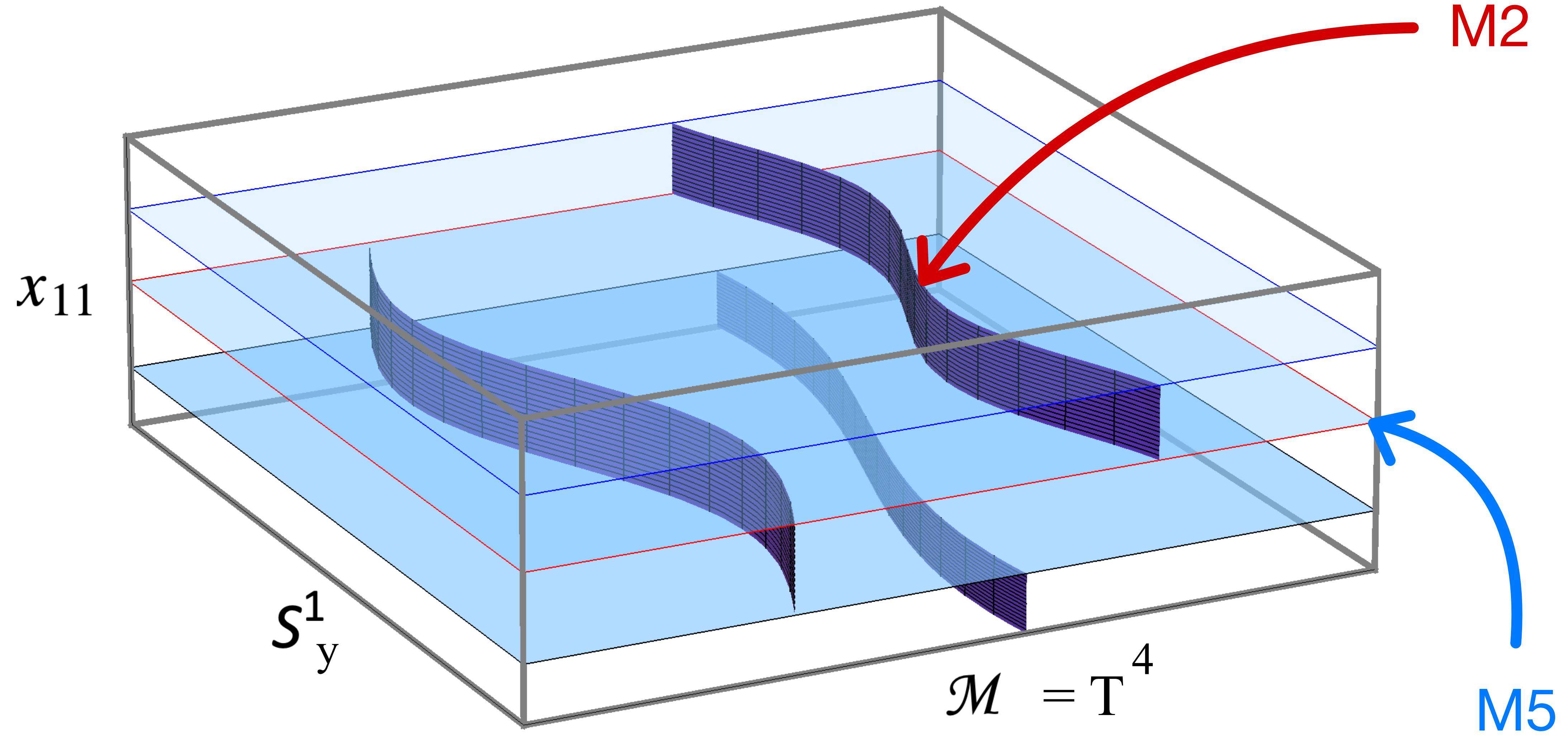

« Dijkgraaf-Verlinde-Verlinde microstates »

- **M5-M2(-P) black hole:** The microstates that are made of **fractionated M2 branes** account for the entropy.
- We found: They can transition into microstates with 16 local supersymmetries.

  Microstates with 16 local susys account for the black-hole entropy!
- We expect their backreaction to be horizonless microstates.

Outline

1. Local supersymmetries, bound states and black-hole microstates

2. The new M5-M2-P microstates with 16 local supersymmetries

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1. Local supersymmetries, bound states and black-hole microstates
2. The new M5-M2-P microstates with 16 local supersymmetries

1. a.

Supersymmetries and horizons

The 3-charge black hole and the supertube transition

- Type IIA/IIB: $\mathbb{R}^{4,1} \times S^1_y \times T^4$
- Take brane system with 3 charges:

  D5(y, T^4), D1(y), P(y)

  or NS5(y, T^4), F1(y), P(y)

  $\Rightarrow$ naively, 1/8-BPS everywhere

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⇒ controls form of harmonic functions in metric: $1/r^\sharp$

⇒ develops horizon in supergravity

$$ds^2 = -\frac{2}{\sqrt{H_1 H_5}}\left[dt^2 + dy^2 + (H_P - 1)^{-1}(dy - dt)^2\right] + \sqrt{H_1 H_5}\, ds^2_{\mathbb{R}^4} + (H_1 H_5)^{-1/2} ds^2_{T^4}$$

with

$$H_{1,5,P} = 1 + \frac{Q_{1,5,P}}{r^2}\,.$$

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Possible conclusion:

All of the microstates seem to develop the same horizon in supergravity.

Therefore nothing special happens at the scale of the horizon:
The microstates differ at Planck size away from singularity, where supergravity breaks down.

The 3-charge black hole and the supertube transition

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- Take brane system with 3 charges:

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  $\Rightarrow$ controls form of harmonic functions in metric: $1/r^\sharp$

  $\Rightarrow$ develops horizon in supergravity

- *Supertube transition*: ingredients combine together to form a *bound state* that is locally 1/2-BPS.

Local VS global supersymmetries

- The presence of fundamental objects halves the supersymmetries of ST vacua:

$$\Pi\,\epsilon \equiv \frac{1}{2}(1 + P)\,\epsilon = 0$$

- Generically, the number of constraints Π_i add up. But when the objects form a bound state:

$$\hat{\Pi}\,\epsilon \;\equiv\; \frac{1}{2}\left(1 + \alpha_1 P_1 + \ldots + \alpha_n P_n\right)\epsilon \;=\; 0$$

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- The α_i are not unique, can depend on *internal dimensions* x of bound state

$$\hat{\Pi}(x)\,\epsilon(x) = 0$$

→ *local supersymmetry*

- While for *global supersymmetry*:

$$\forall\, x\,, \quad \hat{\Pi}(x)\,\epsilon = 0.$$

Rewrite projector as:

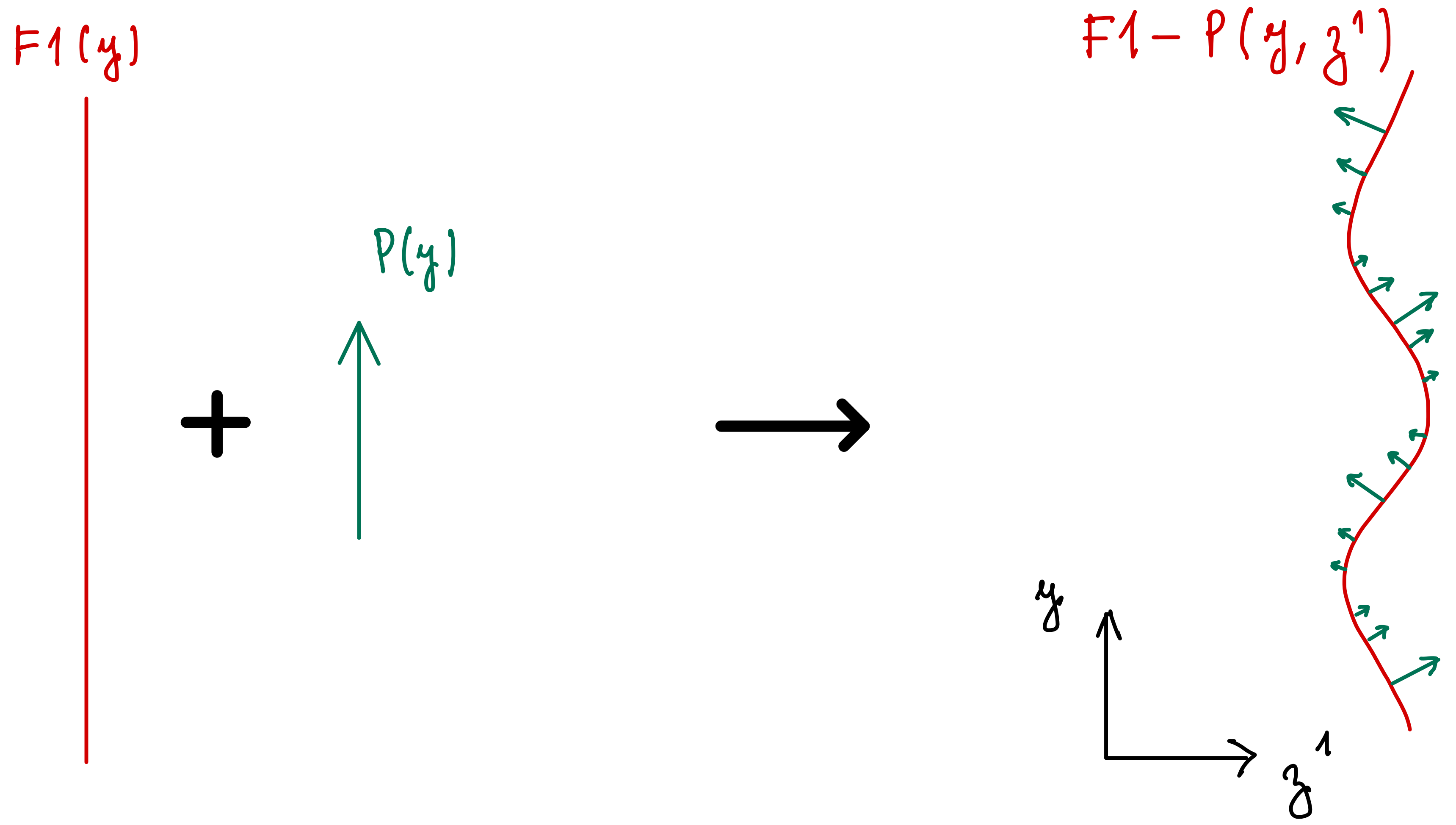
$$\hat{\Pi}(x) = F_1(x)\,\Pi_1 + \ldots + F_k(x)\,\Pi_k$$

and the global ϵ verifies

$$\Pi_1\,\epsilon = \ldots = \Pi_k\,\epsilon = 0$$

Supertube transition: example 1

- One can make a bound state out of F1(y) and P(y) by giving a profile to the F1:



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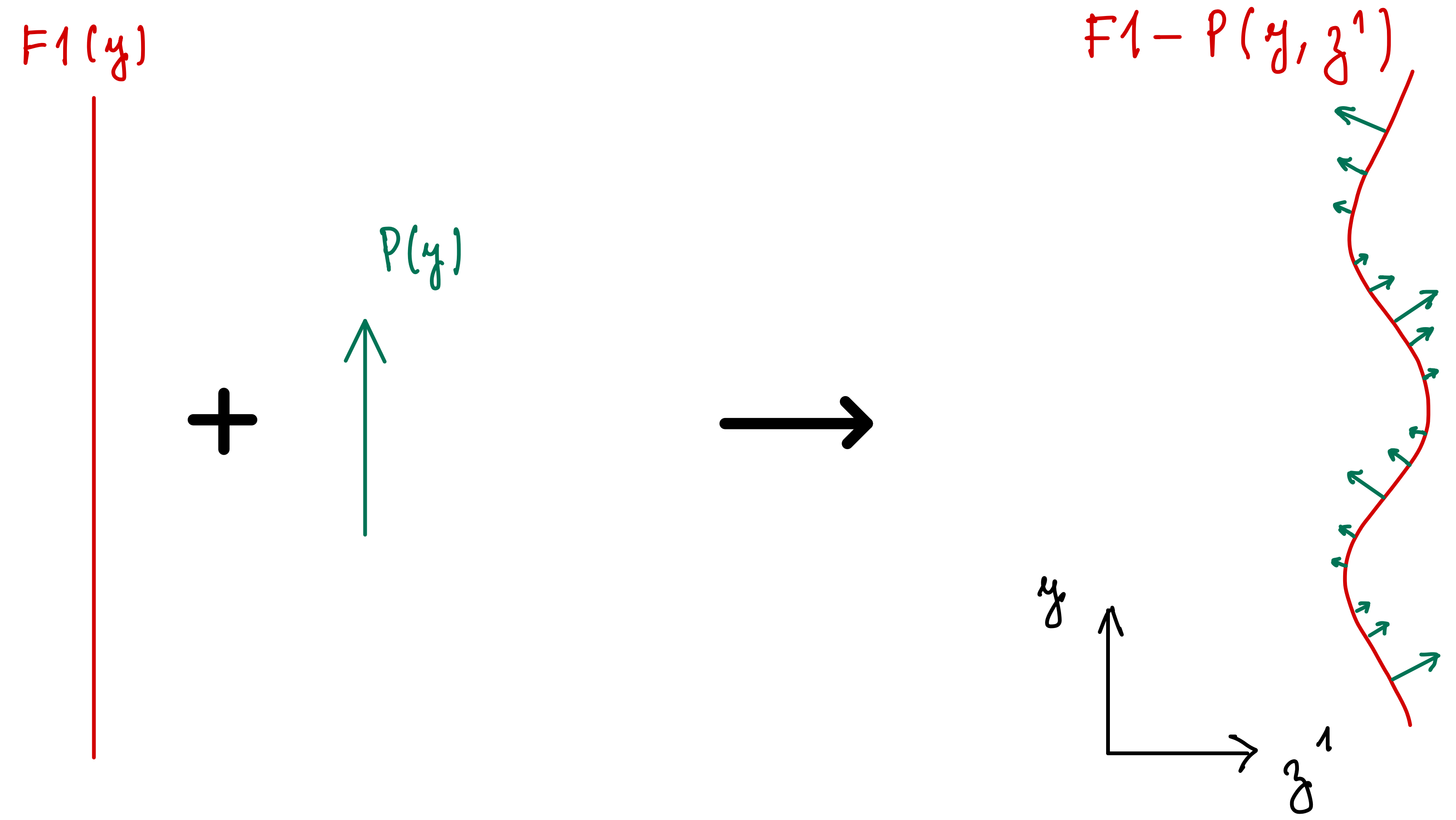

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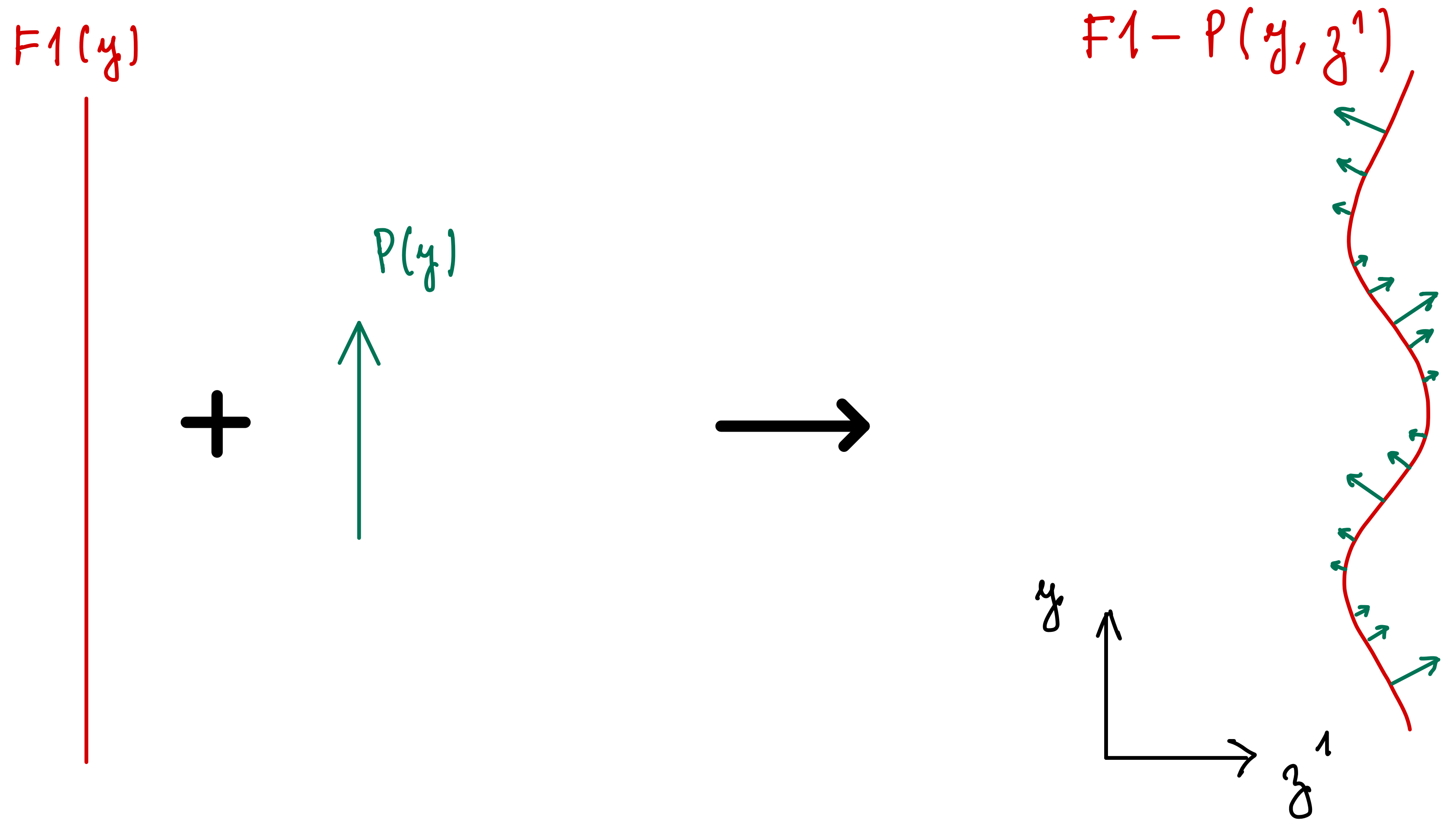

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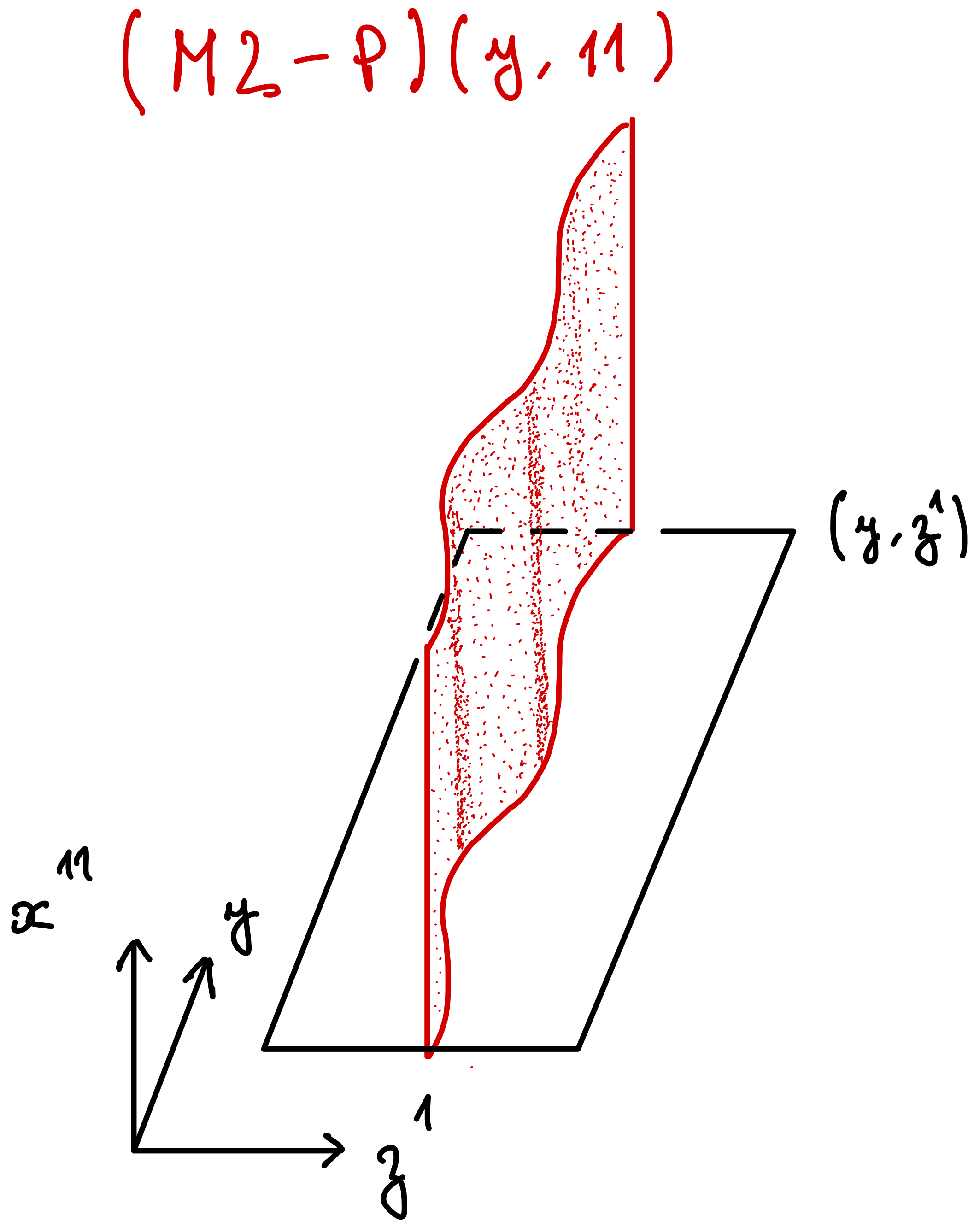
- From M-theory:

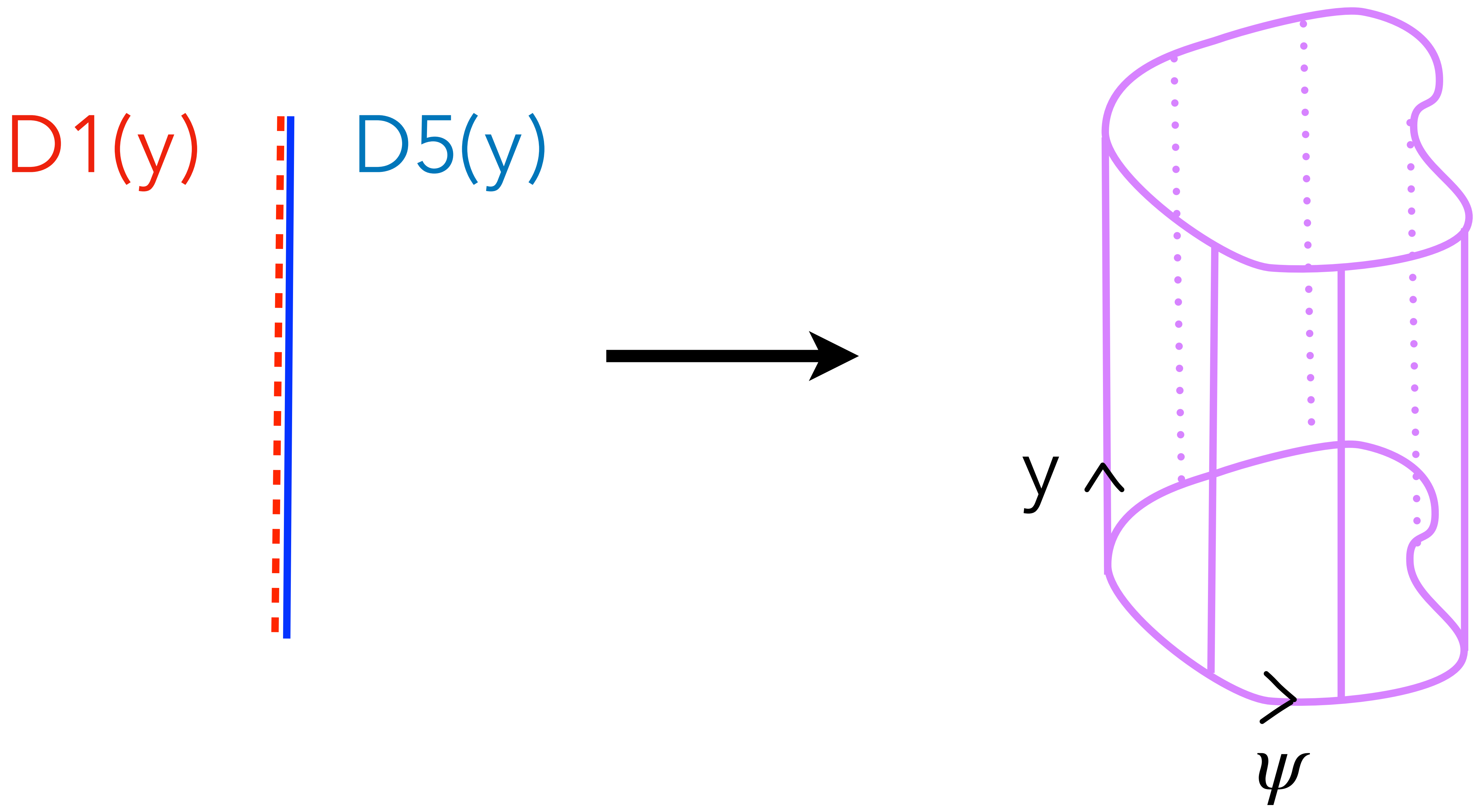


1. b.

Dealing with horizons: The old way

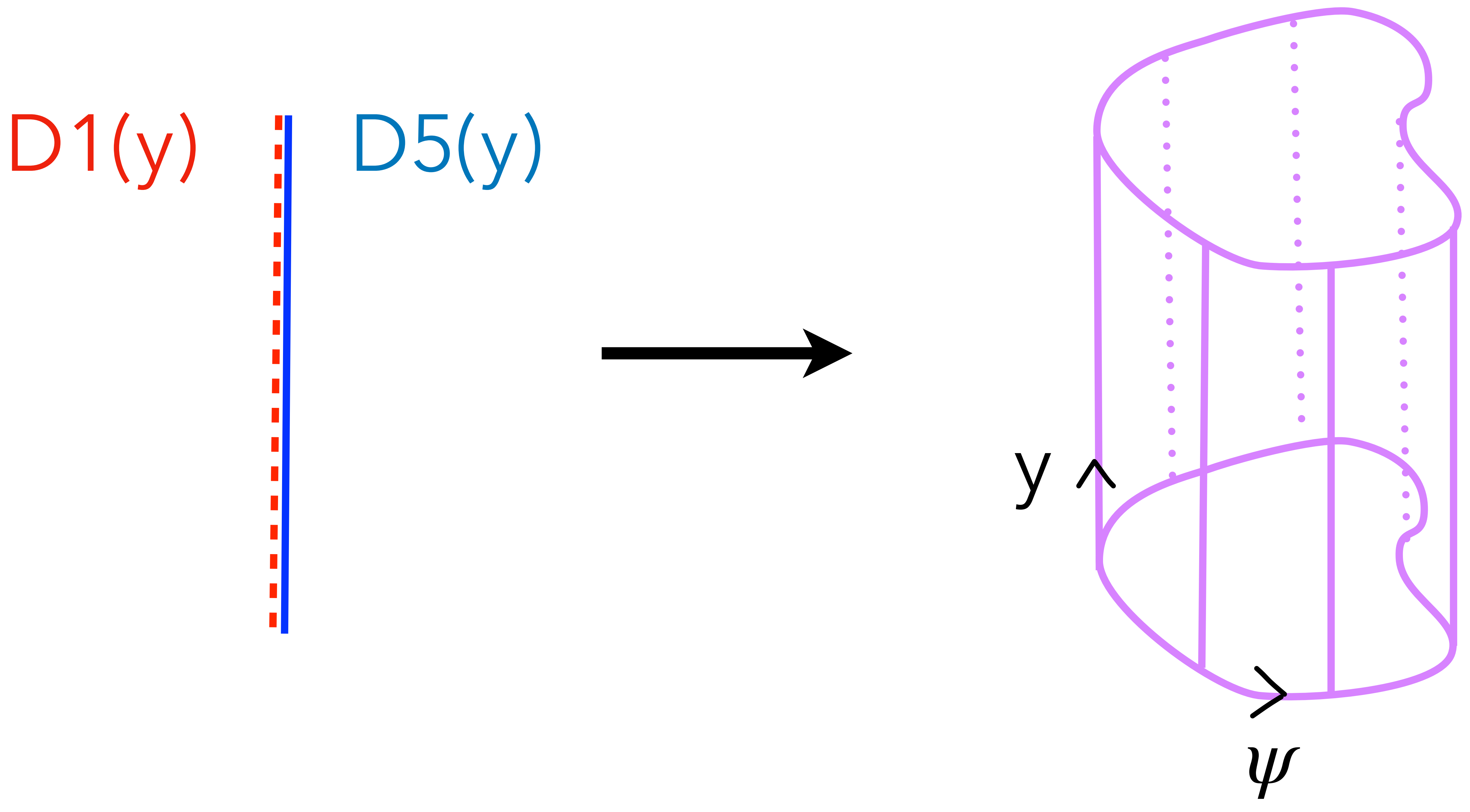
Supertube transition of D1-D5

- D1(y), D5(y1234) $\longrightarrow$ KKM(1234 ψ, y), P(ψ) dipoles
  - The D1-D5 brane system *gains* a dimension through the KKM



Supertube transition of D1-D5

- D1(y), D5(y1234) $\longrightarrow$ KKM(1234 ψ, y), P(ψ) dipoles
  - The D1-D5 brane system *gains* a dimension through the KKM
  - The (angular) momentum P(ψ) or J(ψ) stabilises the size of the supertube.



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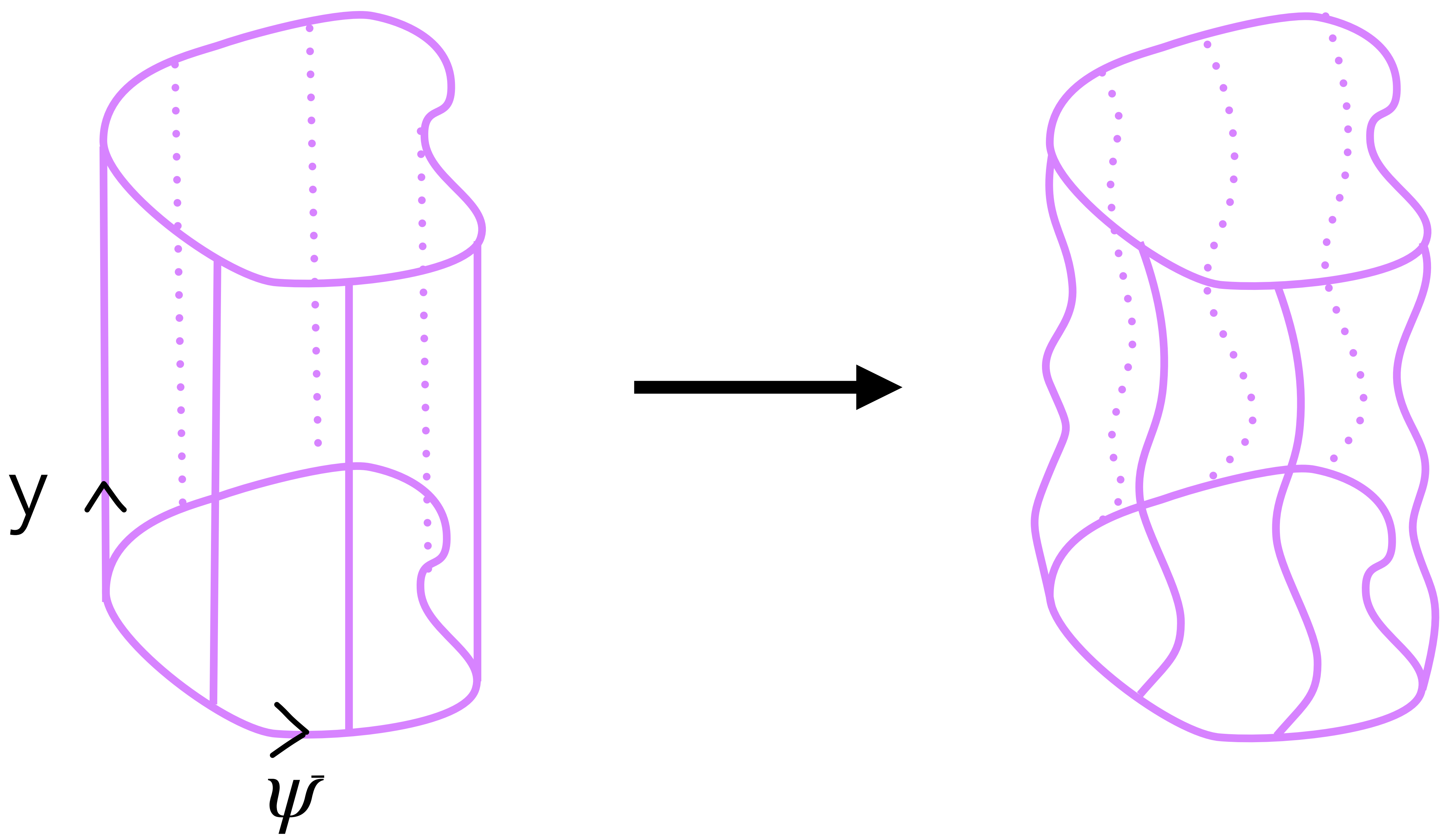
Supertube transition of D1-D5-P

- How to add momentum on D1-D5 supertube?

  → Add shape modes on the KKM in $\mathbb{R}^4$.



⇒ momentum Q_P along y.

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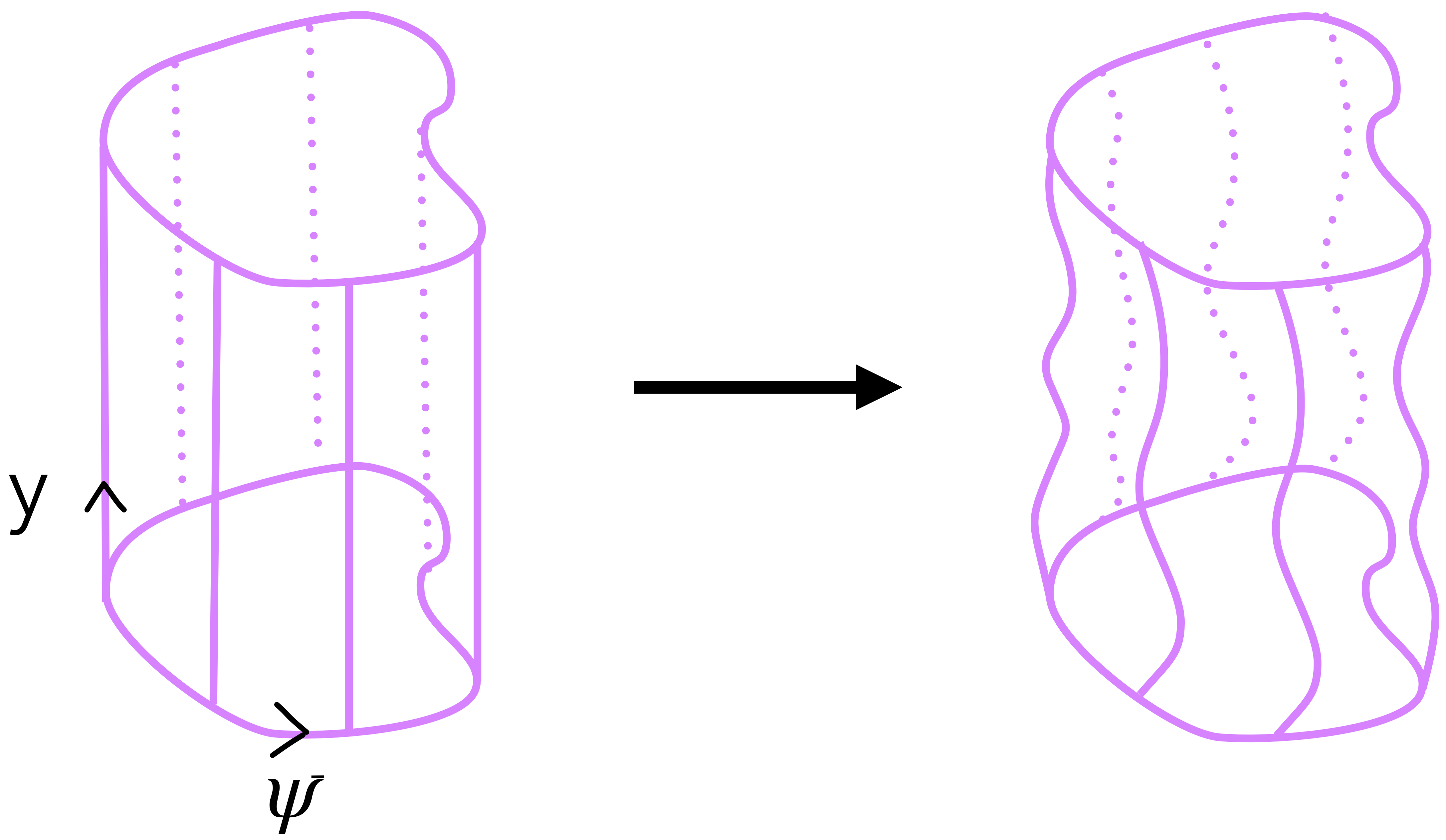

- The bound state is globally 1/8-BPS (like the black hole), but locally 1/2-BPS

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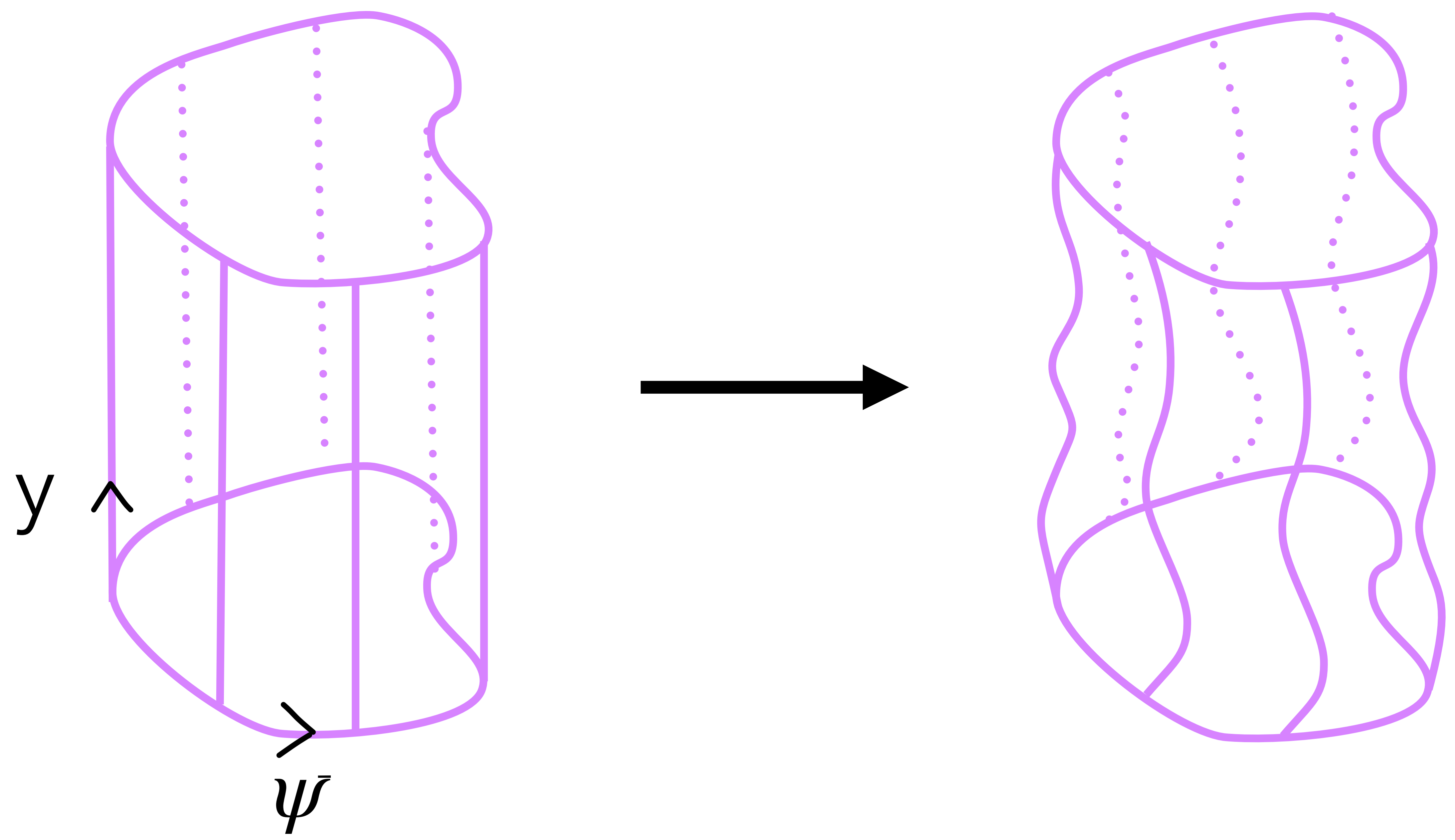

$\Rightarrow$ momentum Q_P along y.

- The bound state is globally 1/8-BPS (like the black hole), but locally 1/2-BPS
- Different *shape modes* give different microstates
- Their backreaction are the « ***superstrata*** »

[Bena, de Boer, Shigemori, Warner '11]

Superstrata and their limits

- *Superstrata* have been constructed in supergravity: horizonless

[Bena, Giusto, Martinec, Russo, Shigemori, Turton, Warner '16]

- Part of the

Fuzzball hypothesis:

*Individual black-hole microstates differ from themselves and from the BH solution at the **horizon scale**.*

Superstrata and their limits

- *Superstrata* have been constructed in supergravity: horizonless

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Fuzzball hypothesis:

*Individual black-hole microstates differ from themselves and from the BH solution at the **horizon** scale.*

Drawbacks:

1. $S \sim \sqrt{N_1 N_5 N_P^{1/4}} \ll \sqrt{N_1 N_5 N_P}$

   [Shigemori '19]

2. Have a non-vanishing angular momentum in $\mathbb{R}^4$

   $\Rightarrow$ are atypical

   $\uparrow$ are not ***exactly spherically symmetric***

   See also [Lin, Maldacena, Rozenberg, Shan '22]

Outline

1. Local supersymmetries, bound states and black-hole microstates

2. The new M5-M2-P microstates with 16 local supersymmetries

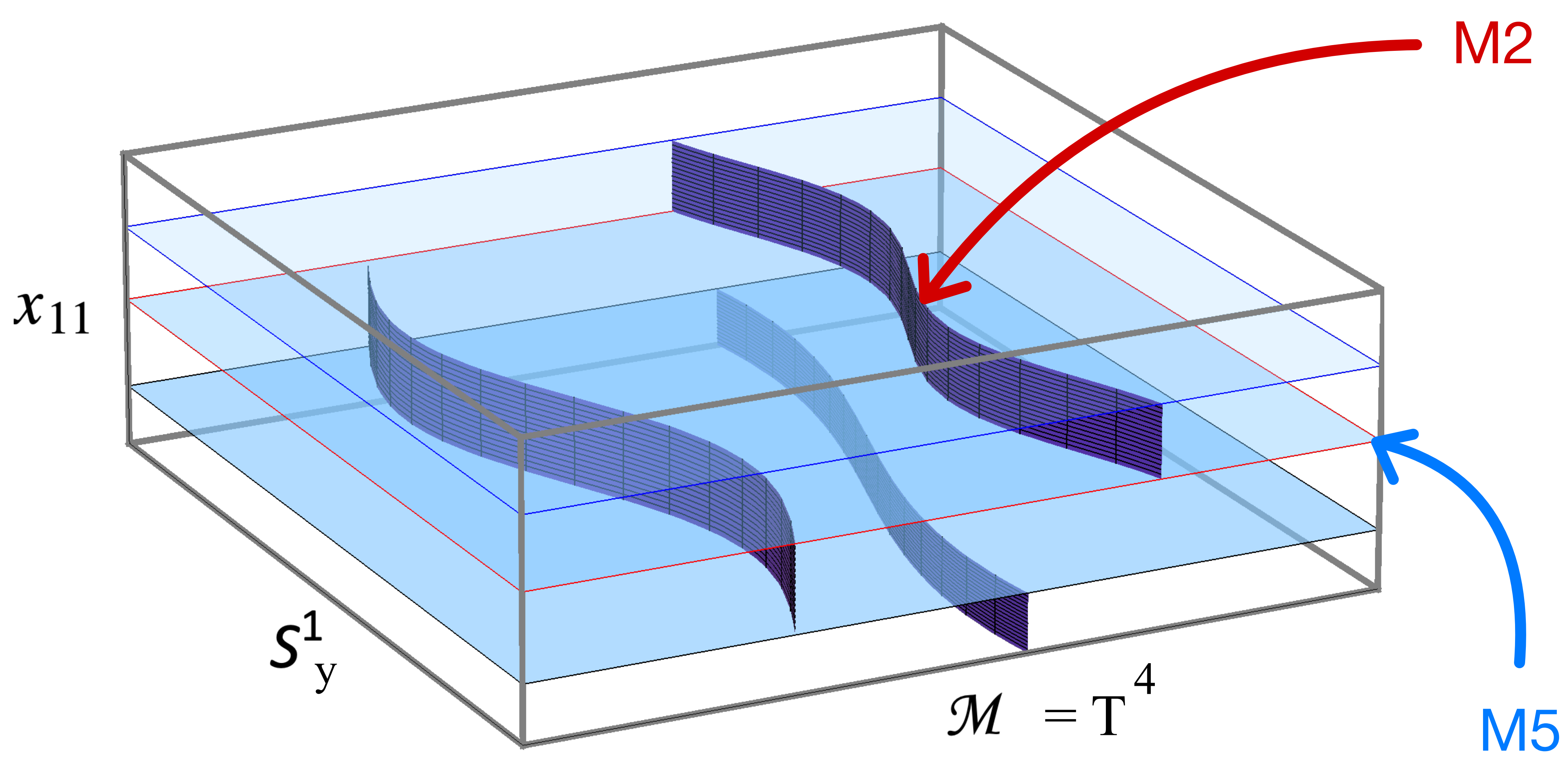
2. a.

Dealing with horizons: A new hope

Taking the problem from the other side

- For the NS5-F1-P black hole (IIA), we know where the entropy is coming from: little strings / fractionated (M2) branes

See e.g. [Martinec, Massai, Turton '19]



« Dijkgraaf-Verlinde-Verlinde microstates »

- The momentum is carried by the fractionated M2's through their motion in the T^4

  → *reproduce entropy*.

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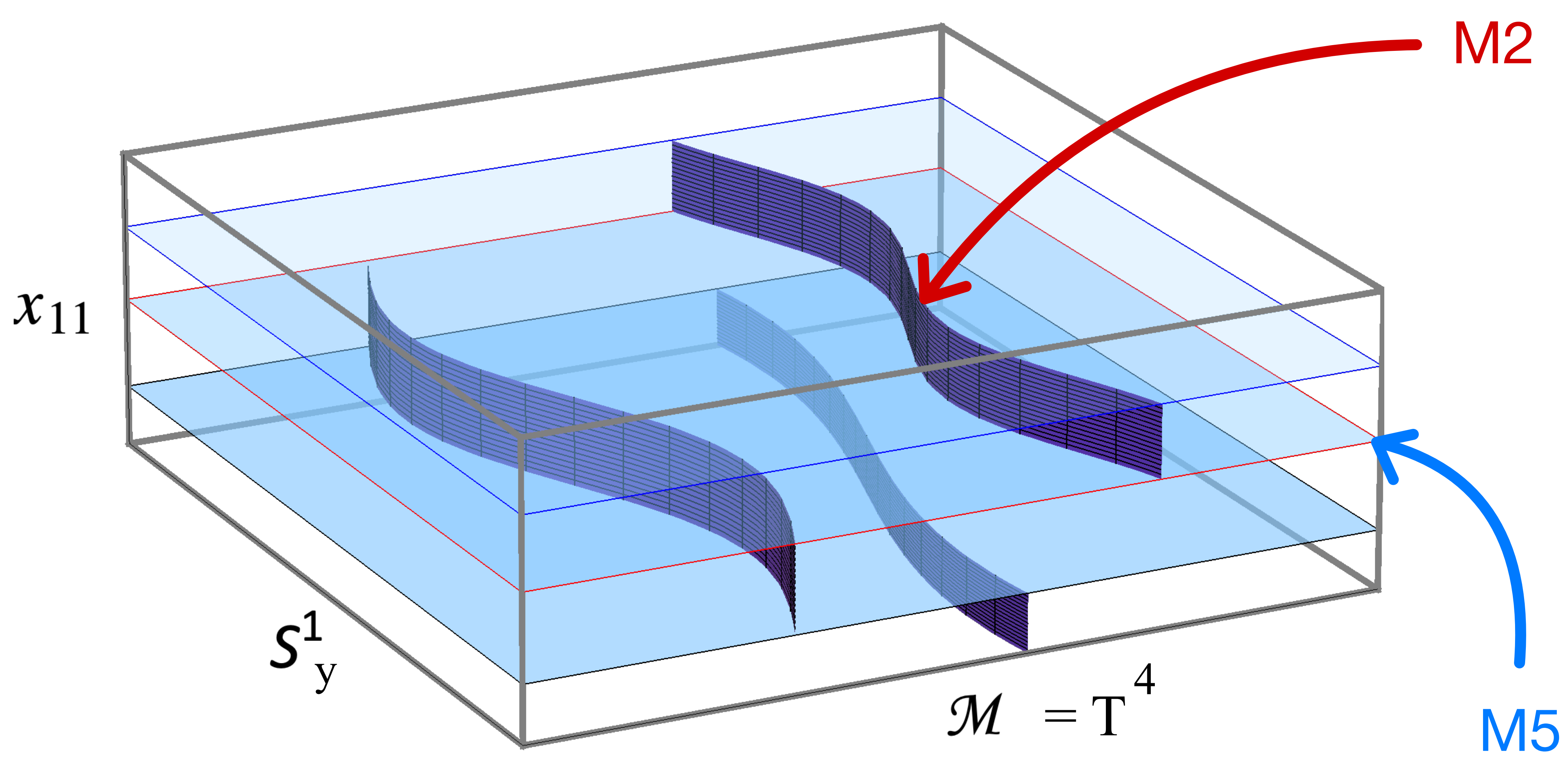

« Dijkgraaf-Verlinde-Verlinde microstates »

- The momentum is carried by the fractionated M2's through their motion in the T^4

  → *reproduce entropy.*

- The brane system is point-like in the non-compact spatial dimensions

  → *exact spherical symmetry.*

Our results

[Bena, Houppe, **YL**, Toulikas, to appear]

- We found the supertube transition of the Dijkgraaf-Verlinde-Verlinde (DVV) microstates.

Our results

[Bena, Houppe, **YL**, Toulikas, to appear]

- We found the supertube transition of the Dijkgraaf-Verlinde-Verlinde (DVV) microstates.
- We found the *supersymmetric projector*
  - preserving the supersymmetries of NS5(y, T^4), F1(y), P(y) (IIA)
  - corresponding to a locally 1/2-BPS (16 supersymmetries) object:

$$\Pi_{\mathrm{NS5-F1-P}} = \frac{1}{2}\Big[1 + a^2 P^{\mathrm{IIA}}_{\mathrm{NS5}(y1234)} + b^2 P_{\mathrm{F1}(y)} + c^2 P_{\mathrm{P}(y)} + ab\left(P_{\mathrm{D4}(y234)} - P_{\mathrm{D2}(y1)}\right) + bc\left(P_{\mathrm{P}(1)} - P_{\mathrm{F1}(1)}\right) + ca\left(P_{\mathrm{D4}(1234)} - P_{\mathrm{D0}}\right)\Big] .$$

First look at the projector

$$\Pi_{\mathrm{NS5-F1-P}} = \frac{1}{2}\Big[1 + a^2 P^{\mathrm{IIA}}_{\mathrm{NS5}(y1234)} + b^2 P_{\mathrm{F1}(y)} + c^2 P_{\mathrm{P}(y)}$$

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$$a^2 + b^2 + c^2 = 1$$

$$\begin{aligned} P_{\mathrm{P}} &= \Gamma^{01} \\ P^{\mathrm{IIA}}_{\mathrm{NS5}} &= \Gamma^{012345} \\ P^{\mathrm{IIA}}_{\mathrm{KKM}(12345;6)} &= \Gamma^{012345}\sigma_3 = \Gamma^{6789} \\ P_{\mathrm{D0}} &= \Gamma^{0} i\sigma_2 \\ P_{\mathrm{D2}} &= \Gamma^{012}\sigma_1 \\ P_{\mathrm{D4}} &= \Gamma^{01234} i\sigma_2 \\ P_{\mathrm{D6}} &= \Gamma^{0123456}\sigma_1 \end{aligned}$$

$$\begin{aligned} P_{\mathrm{F1}} &= \Gamma^{01}\sigma_3 \\ P^{\mathrm{IIB}}_{\mathrm{NS5}} &= \Gamma^{012345}\sigma_3 \\ P^{\mathrm{IIB}}_{\mathrm{KKM}(12345;6)} &= \Gamma^{012345} = \Gamma^{6789} \\ P_{\mathrm{D1}} &= \Gamma^{01}\sigma_1 \\ P_{\mathrm{D3}} &= \Gamma^{0123} i\sigma_2 \\ P_{\mathrm{D5}} &= \Gamma^{012345}\sigma_1 \end{aligned}$$

2. b.

Supertube transitions between 2 ingredients out of NS5, F1 and P

Glueing F1 and P

$$\Pi_{\mathrm{NS5-F1-P}} = \frac{1}{2}\Big[1 + a^2 P^{\mathrm{IIA}}_{\mathrm{NS5}(y1234)} + b^2 P_{\mathrm{F1}(y)} + c^2 P_{\mathrm{P}(y)} + ab\left(P_{\mathrm{D4}(y234)} - P_{\mathrm{D2}(y1)}\right) + bc\left(P_{\mathrm{P}(1)} - P_{\mathrm{F1}(1)}\right) + ca\left(P_{\mathrm{D4}(1234)} - P_{\mathrm{D0}}\right)\Big] .$$

- Put $a = 0$
- F1(y), P(y) $\longrightarrow$ F1(z), P(z) dipoles

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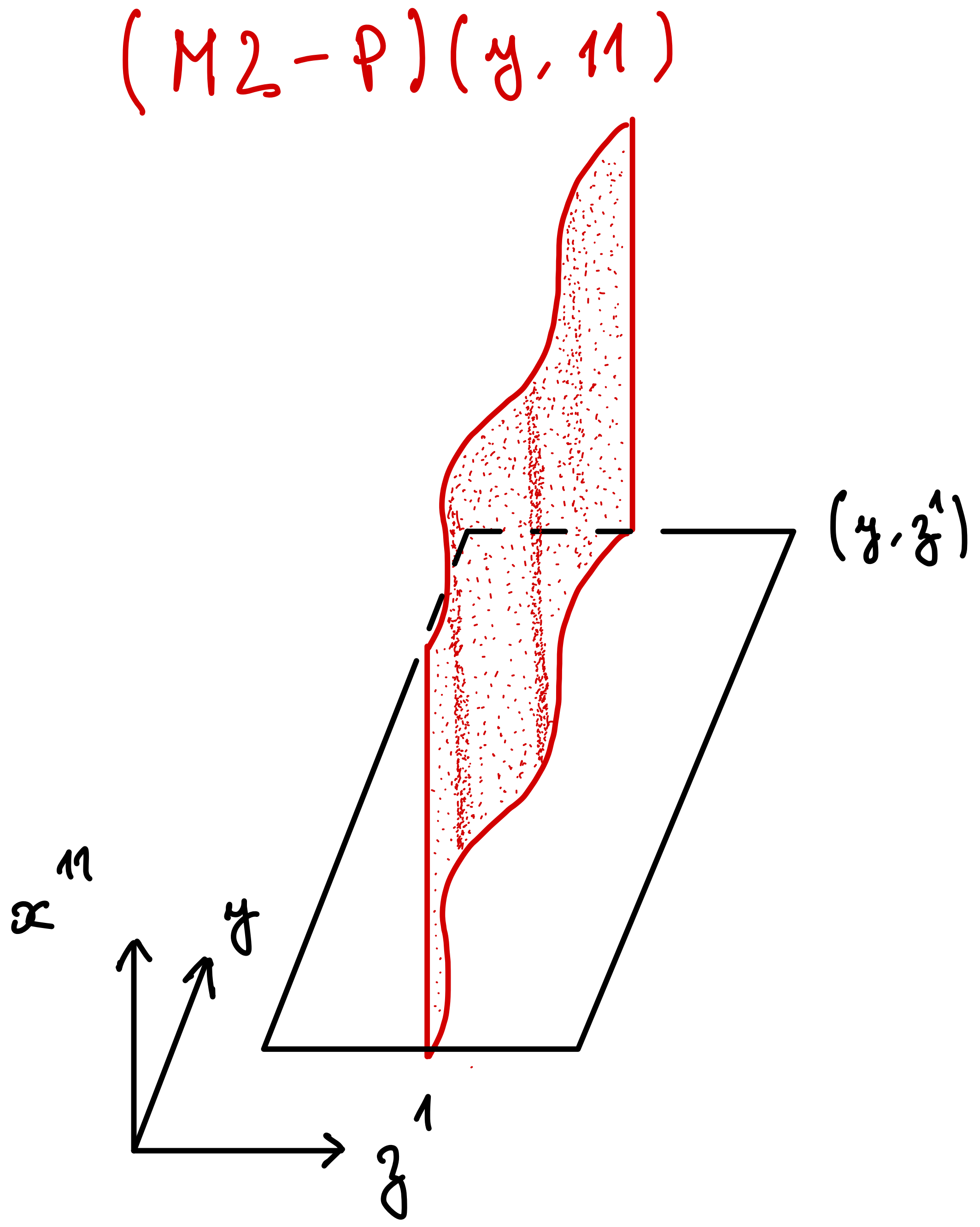
- Put $a = 0$
- F1(y), P(y) $\longrightarrow$ F1(z), P(z) dipoles
- Corresponds to a M2-brane carrying momentum along y by moving in T^4.
- $$b = \cos\alpha\,, \quad c = \sin\alpha$$
- Brane system is point-like in $\mathbb{R}^4$.



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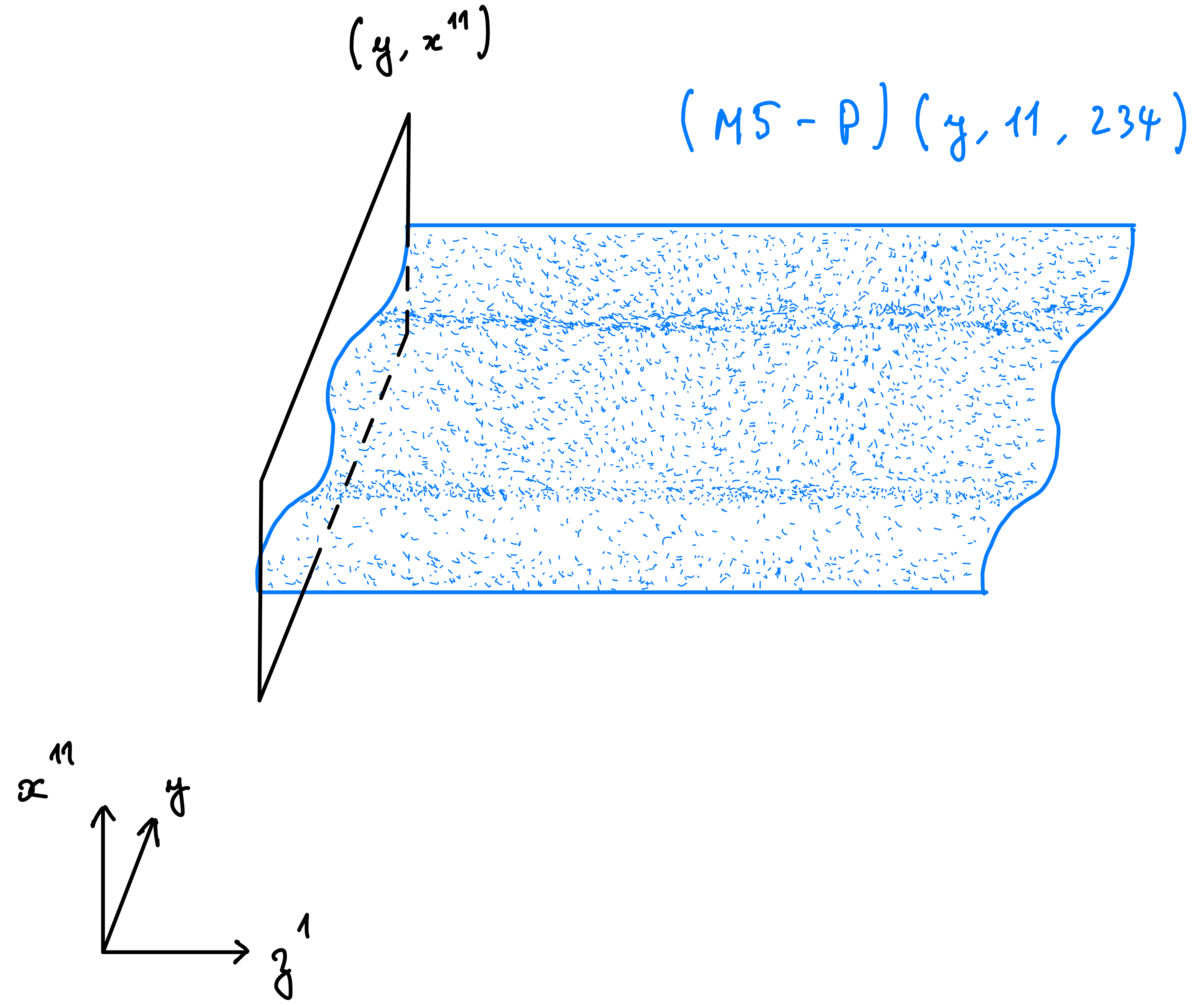

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- Put $c = 0$
- NS5(y, T^4), F1(y) $\longrightarrow$ local D4(y234), D2(y1)

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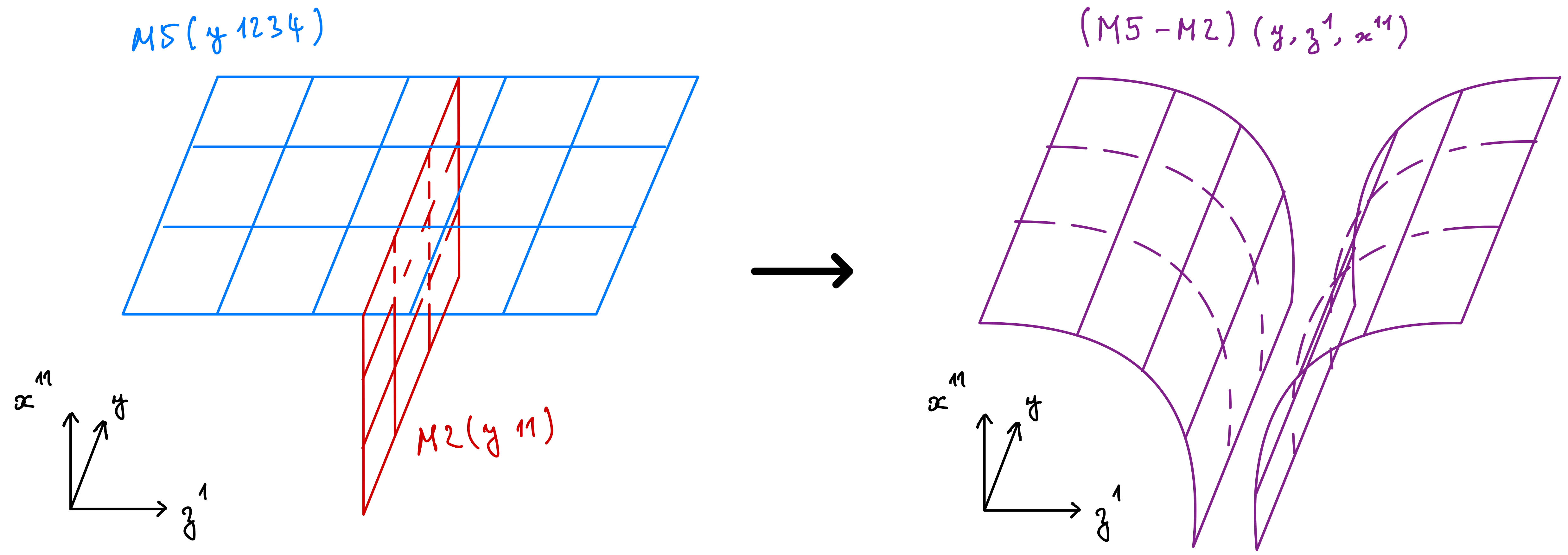
- Put $c = 0$
- NS5(y, T^4), F1(y) $\longrightarrow$ local D4(y234), D2(y1)
- Rough angles between M5's and M2's become *smooth*:

  → new brane system looks like a *furrow* along y.



↑ This M5-M2 furrow is dual to a D4-F1 Callan-Maldacena spike

Glueing NS5 and F1

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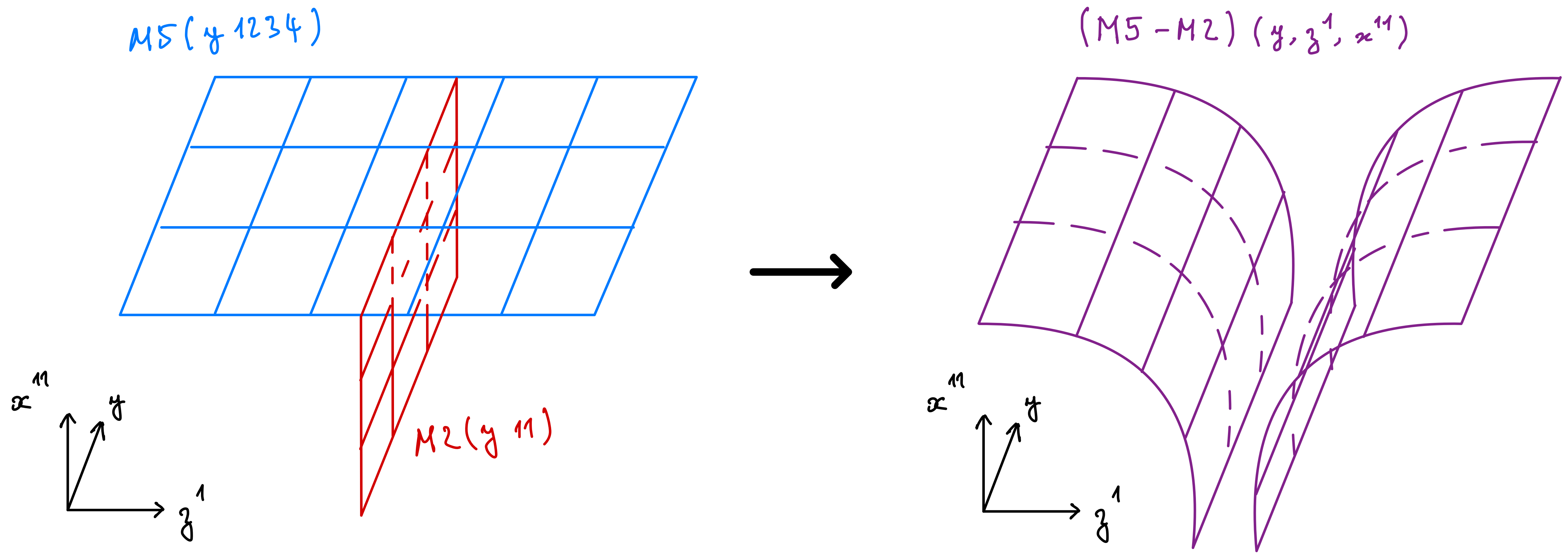
- The furrow interpolates between M5 and M2:

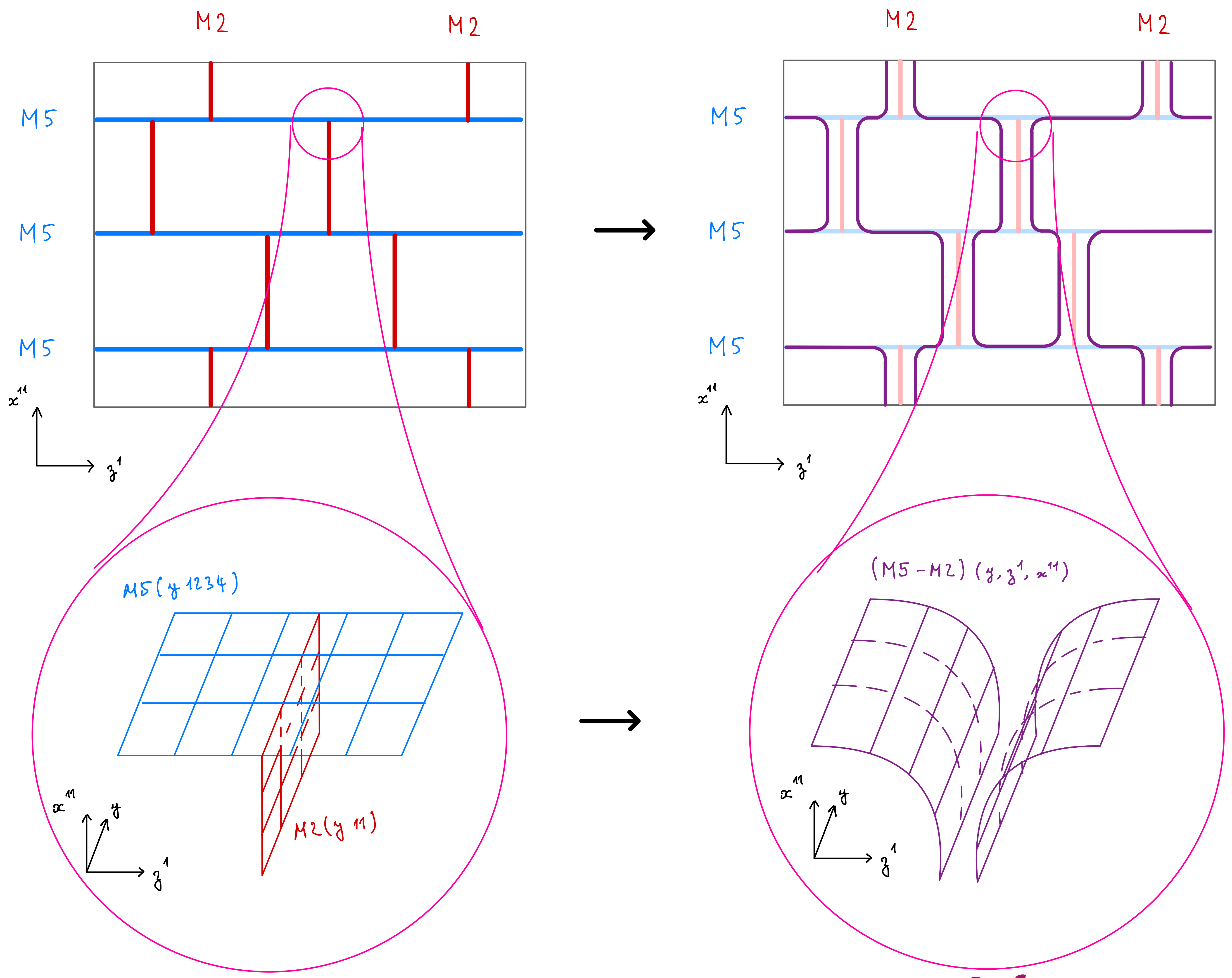
$$a = \cos\beta\,, \quad b = \sin\beta$$

$\Rightarrow$ The orientation of a local piece of the furrow determines the ratio between M5 and M2 charges.



Transition of a M5-M2 black-hole microstate

- Joining 2 furrows make a **tunnel** between two M5's
- Local transition ⇒ a M5-M2 black-hole microstate will transition into a « labyrinth » …



« M5-M2 furrow »

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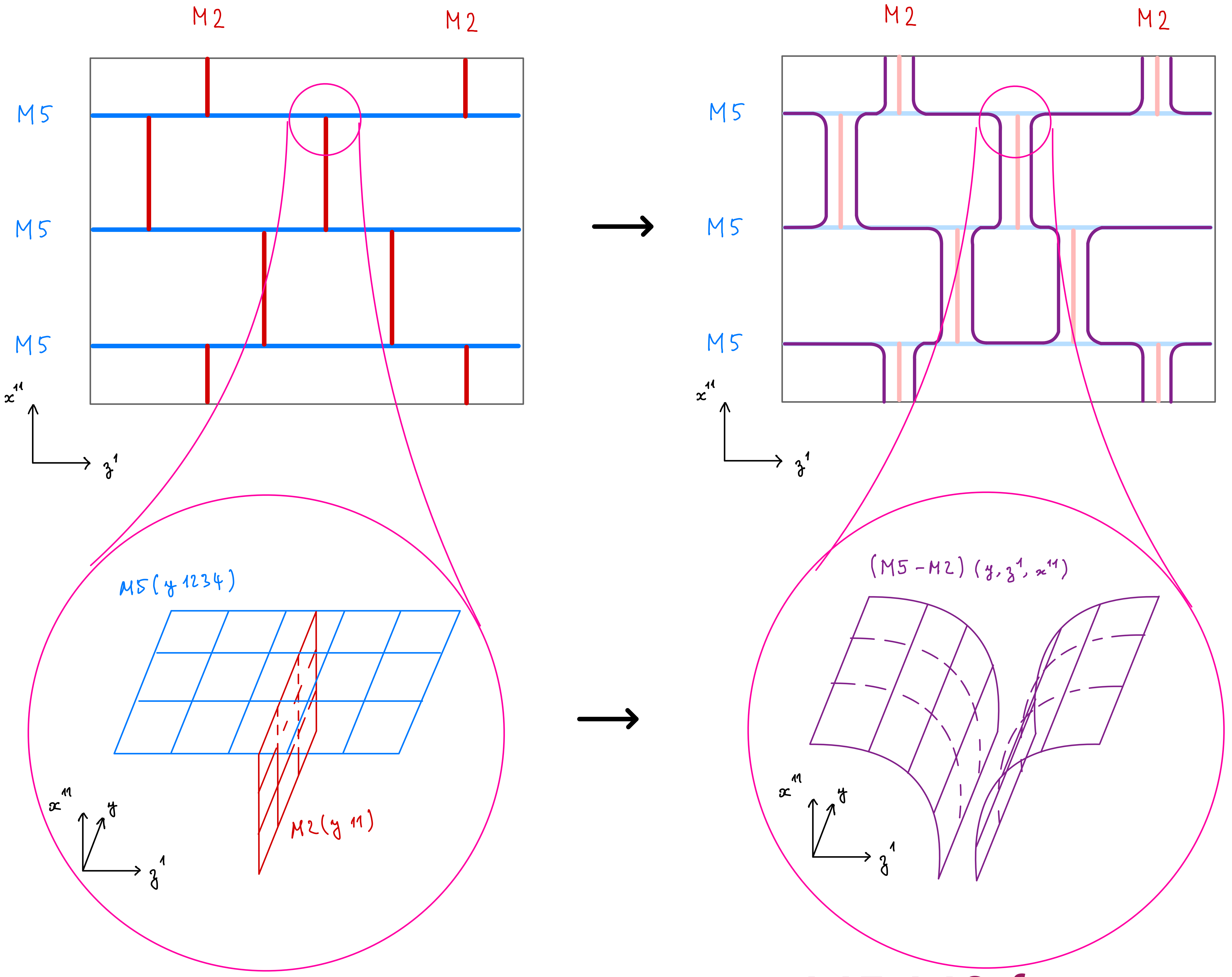
… which is actually multiple layers of multiple tunnels/columns



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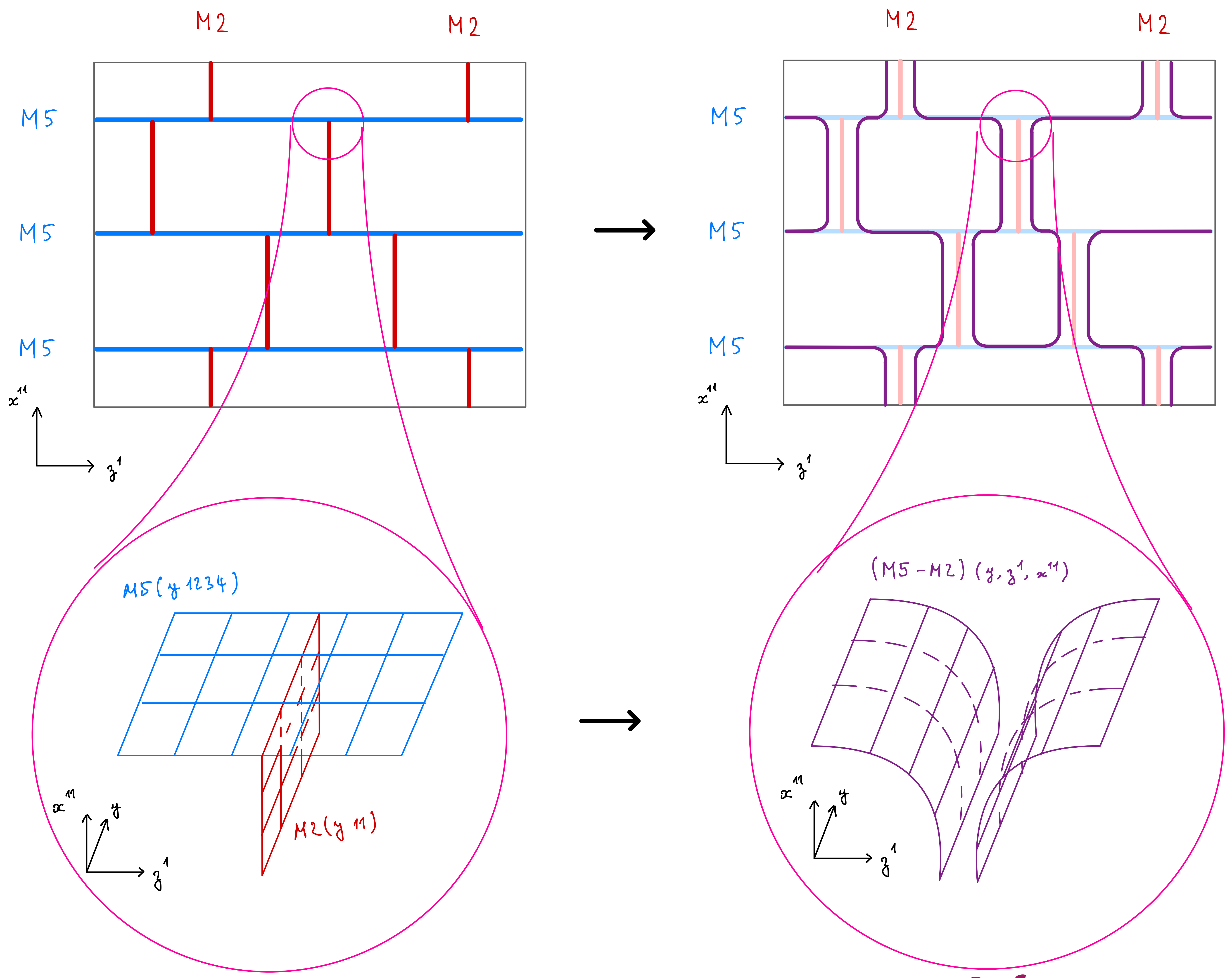
→ **« Multi-storey Greek temple »**



« M5-M2 furrow »

2. c.

Supertube transition of three-charge black-hole microstates

Glueing NS5, F1 and P

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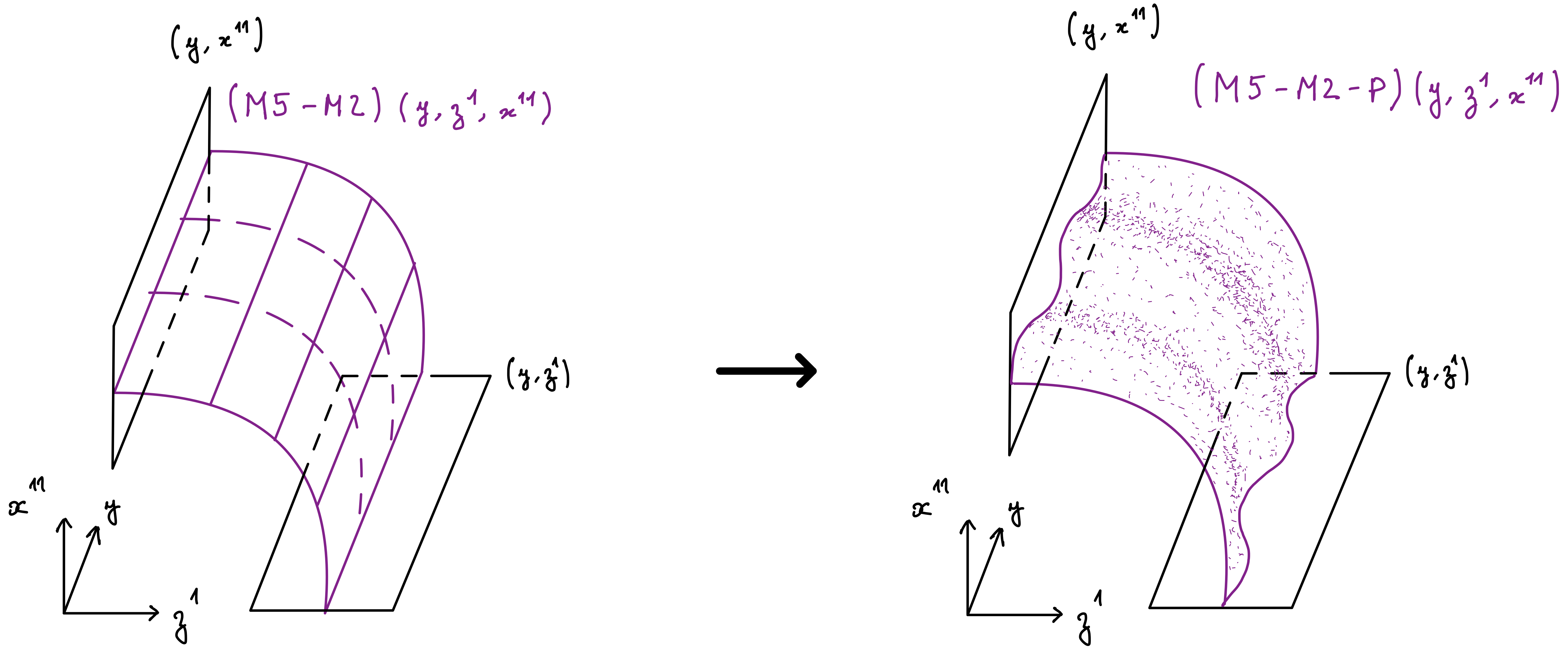
- The M5-M2 furrow carries momentum through *ripples* modulated orthogonally to its surface

$$a = \cos\alpha\cos\beta$$
$$b = \cos\alpha\sin\beta$$
$$c = \sin\alpha$$



Glueing NS5, F1 and P

- The M5-M2 furrow carries momentum through *ripples* modulated orthogonally to its surface

$$a = \cos\alpha\cos\beta$$
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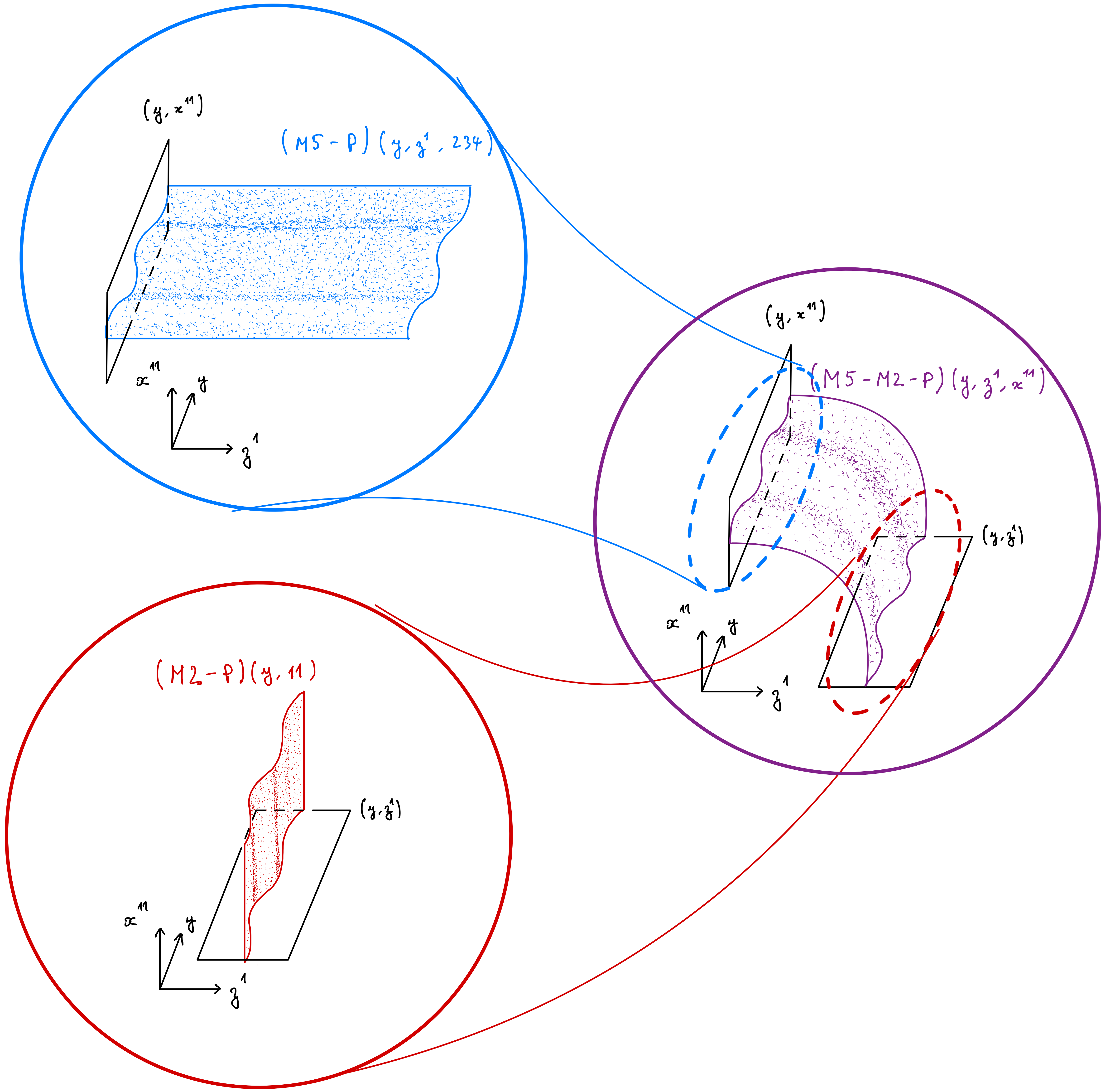
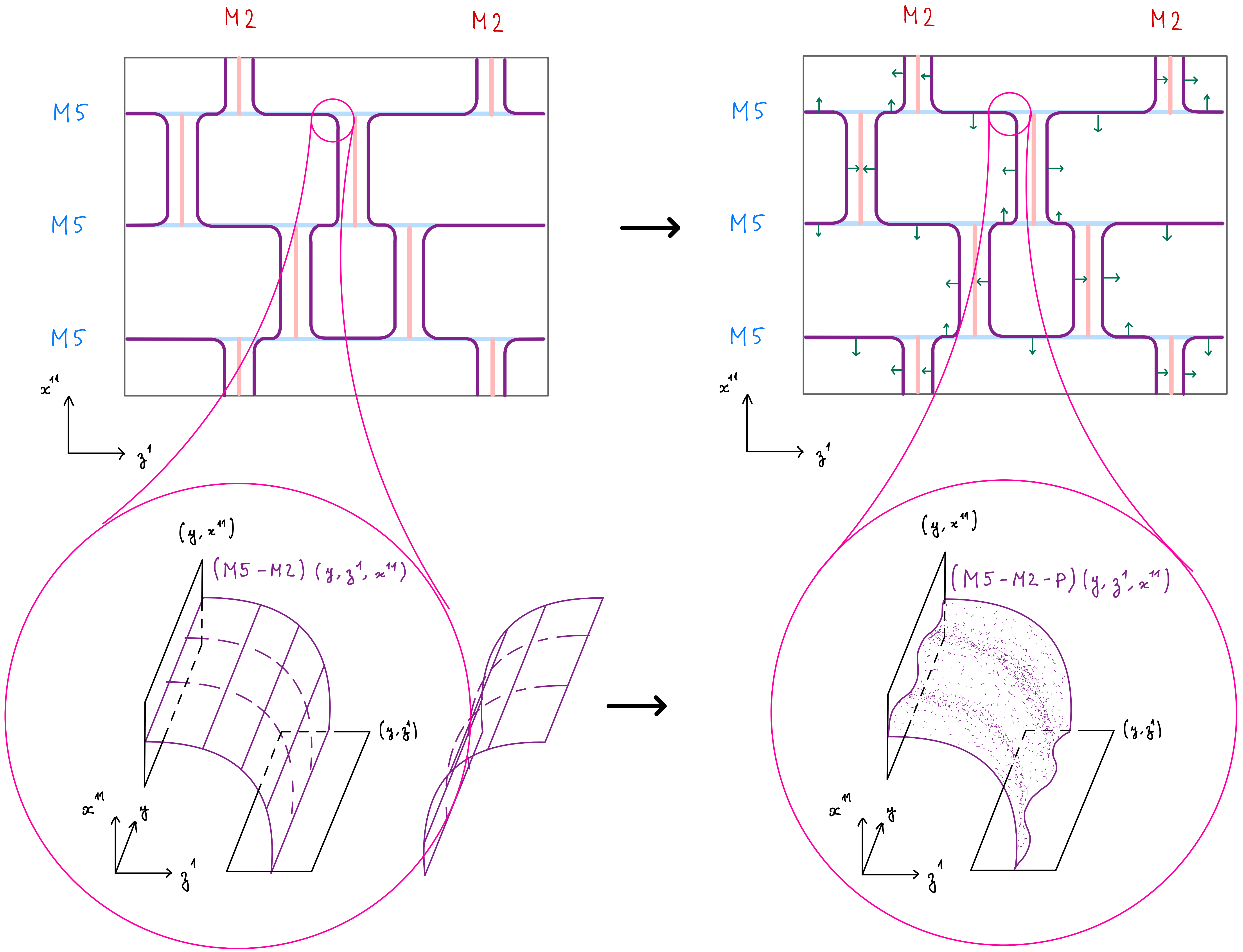
- β controls the bending angle of the furrow; α controls the angle of ripples orthogonal to the furrow.



Consequence on a M5-M2-P microstate

- The *ripples* of the furrow correspond to *shape modes* of the M5-M2 labyrinth
- The *shape modes* are the way 16-susy microstates carry momentum.



« M5-M2 furrow »

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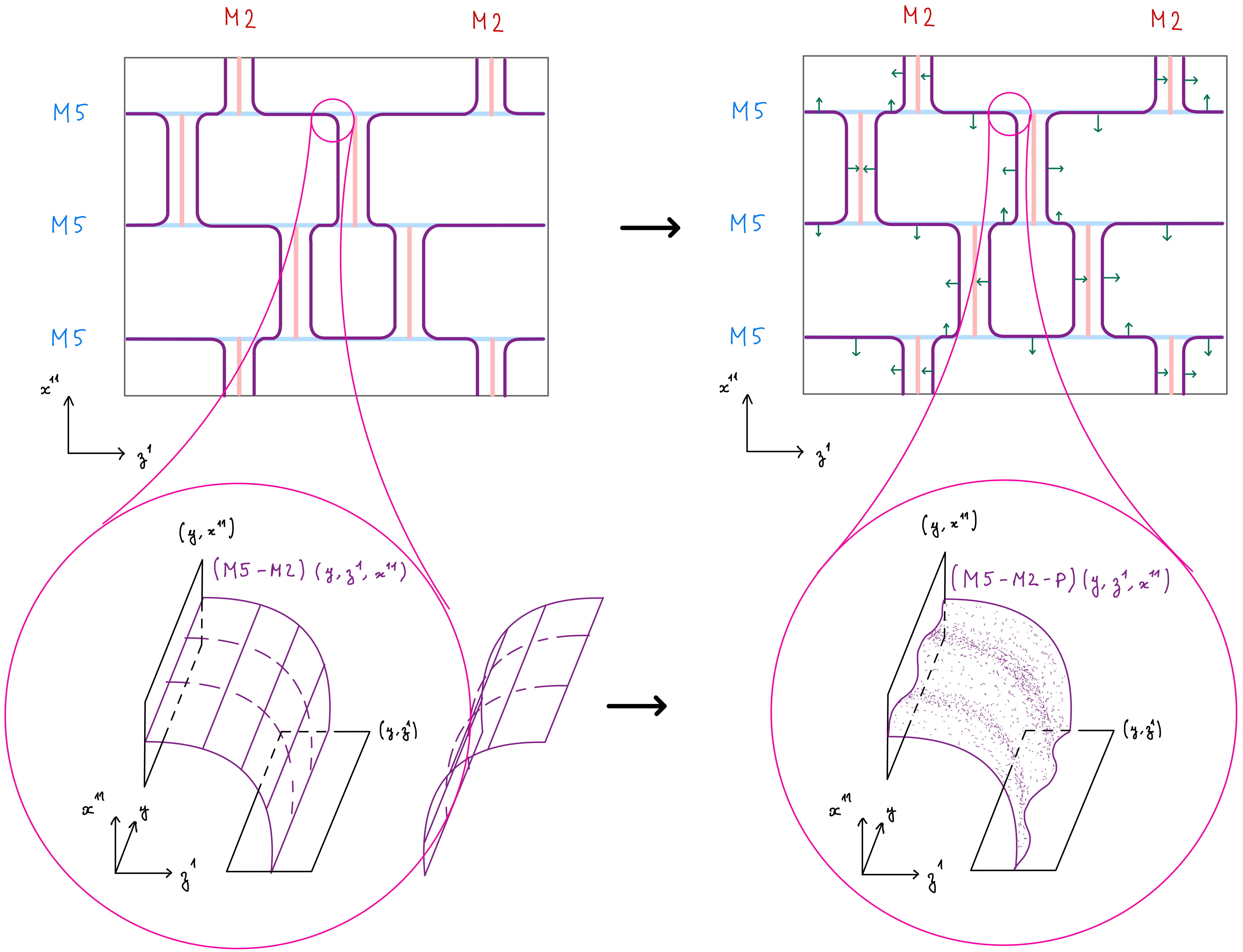
⇒ The microstates are ensured to have *exact spherical symmetry.*



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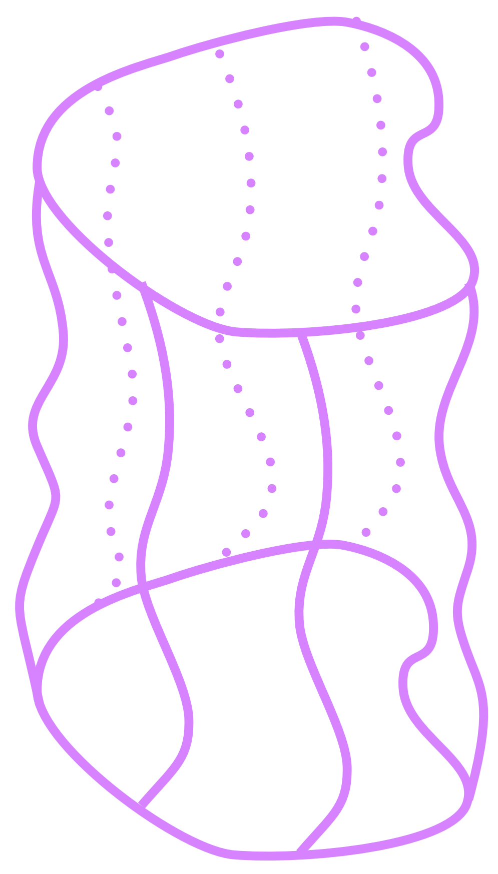

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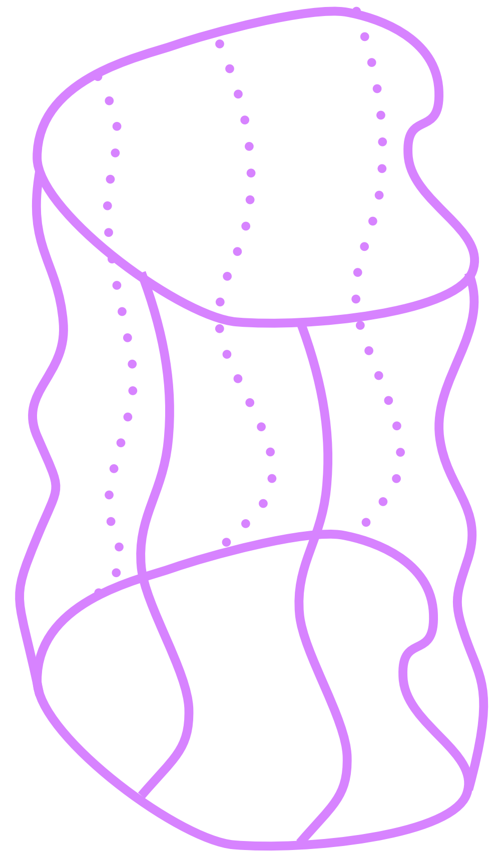

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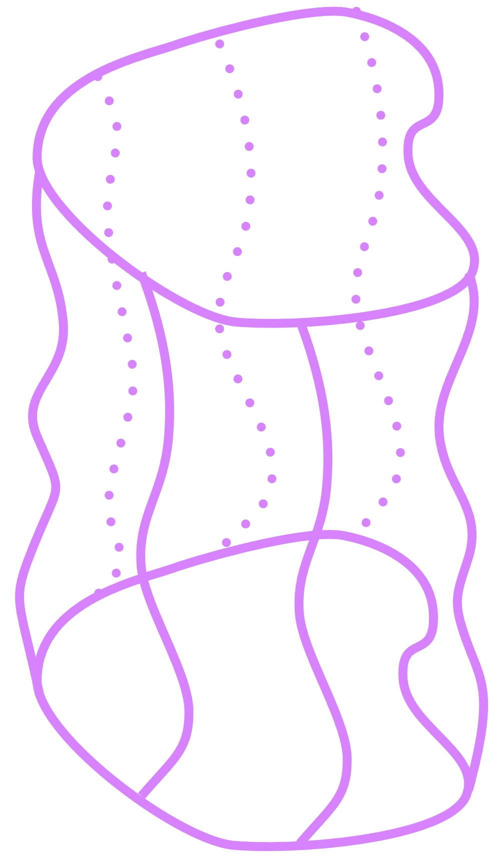
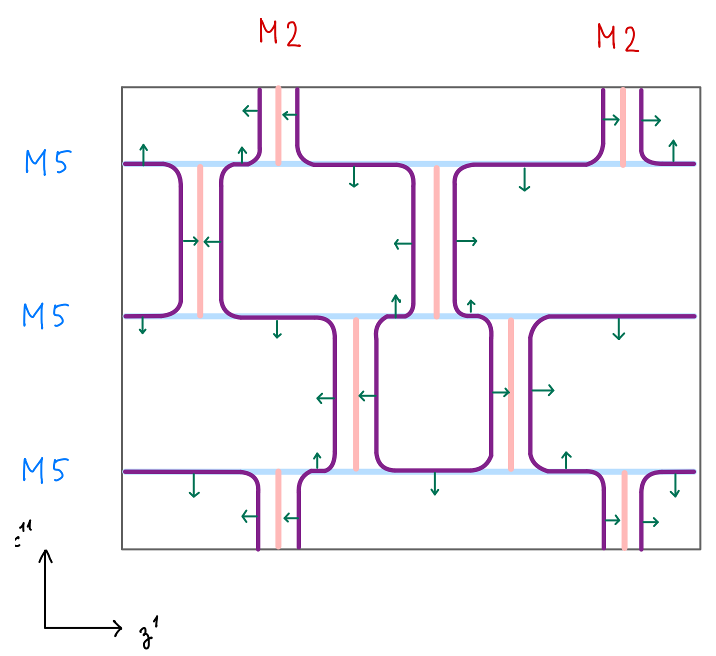


- New approach: microstates can carry momentum by having motion in the *internal dimensions* ⇒ exactly spherical symmetry

Conclusion



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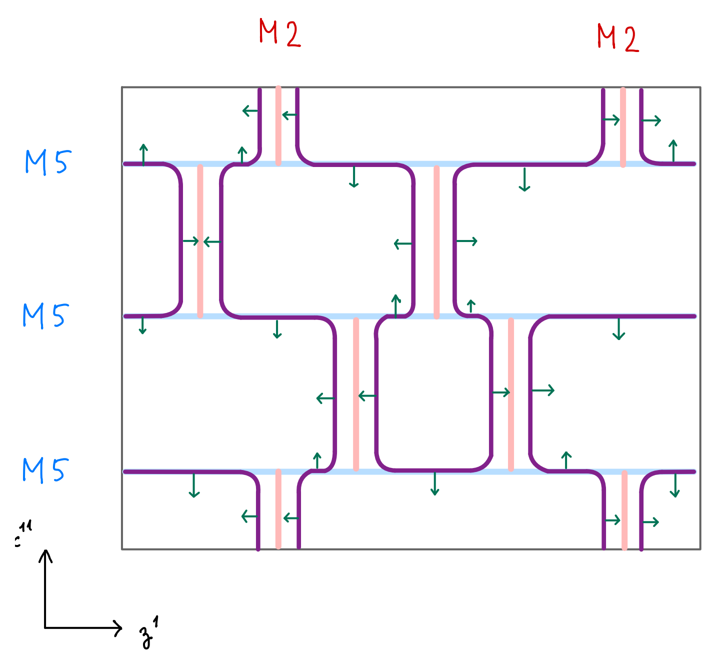

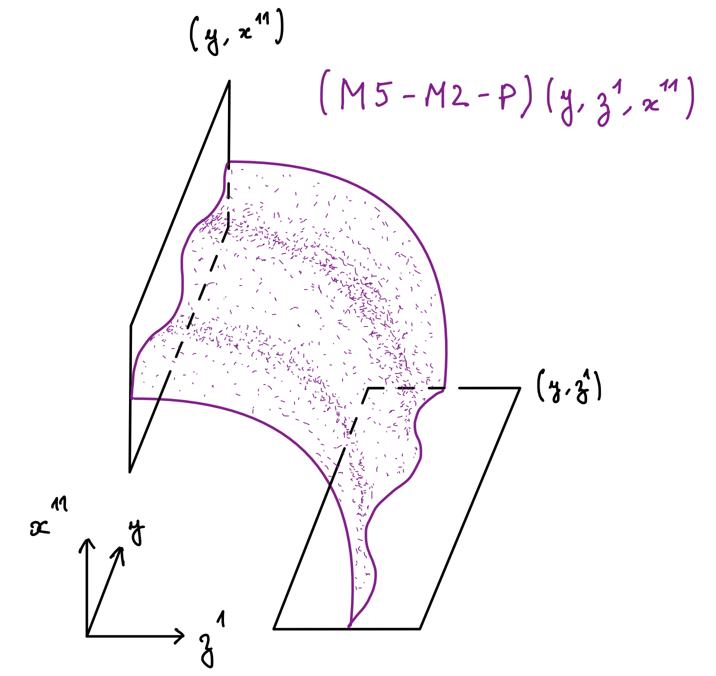

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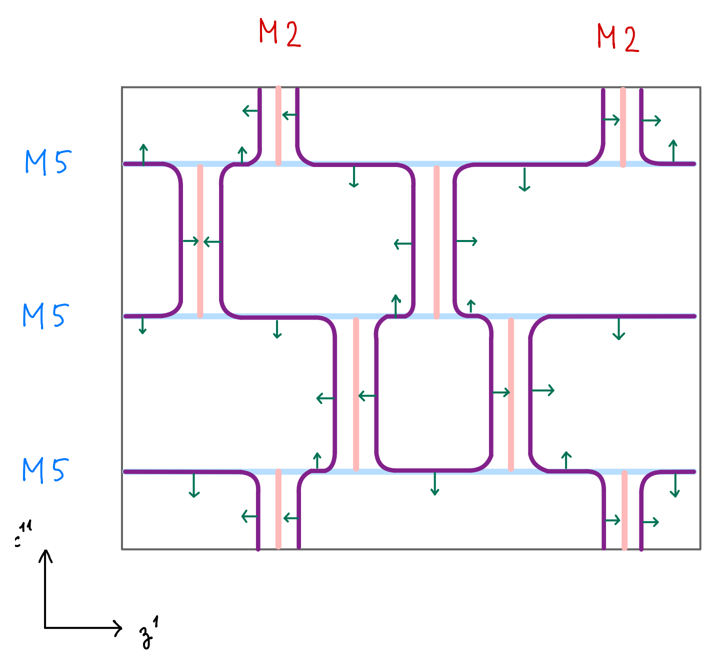

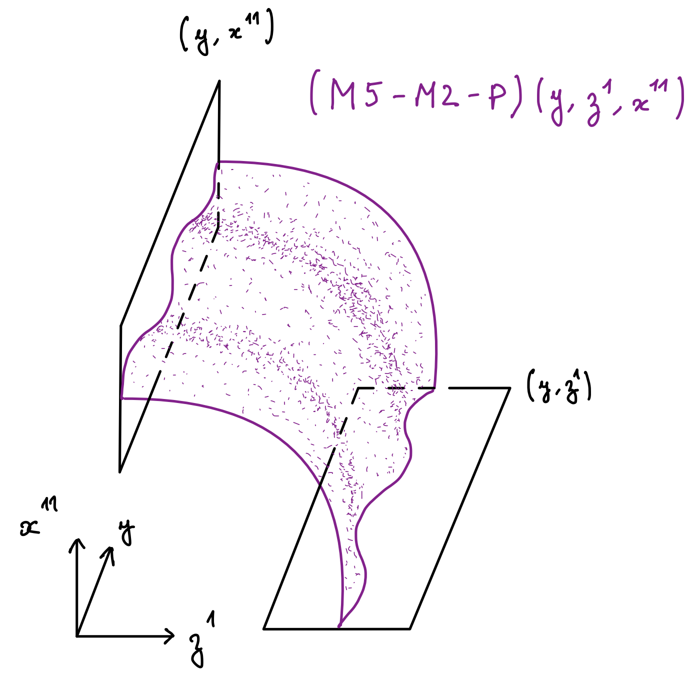

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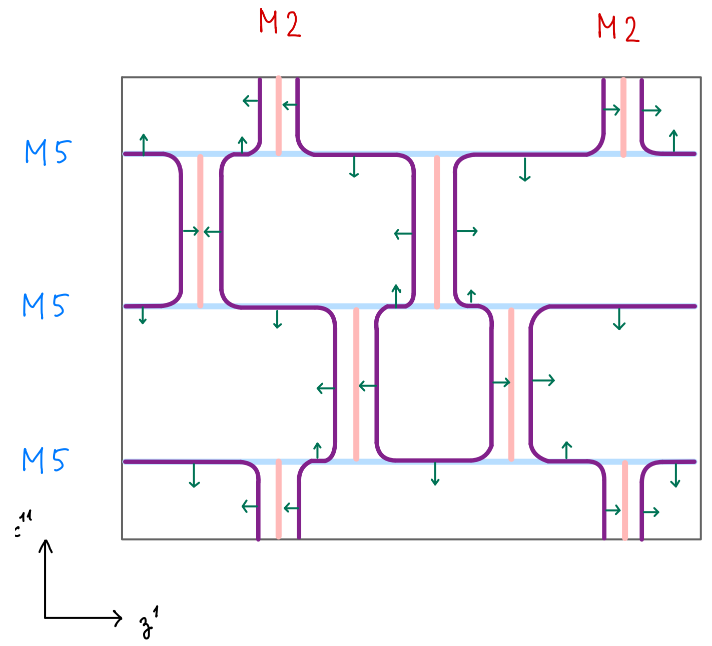
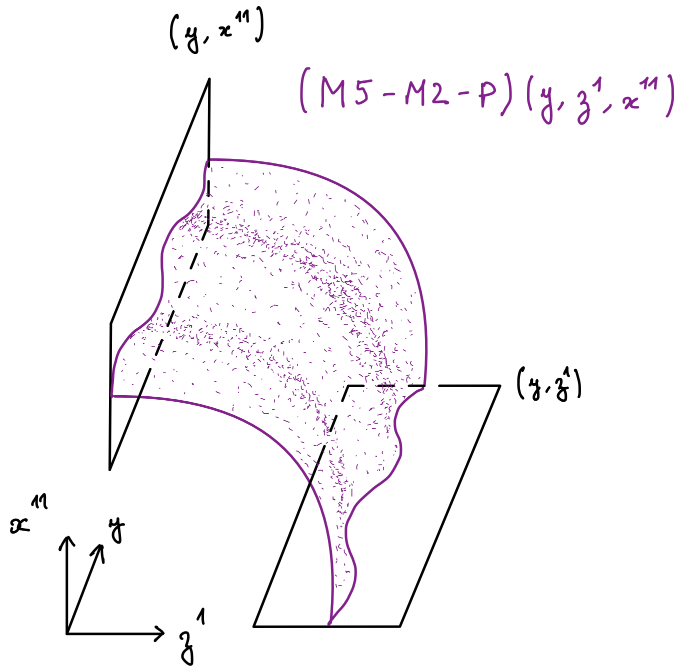
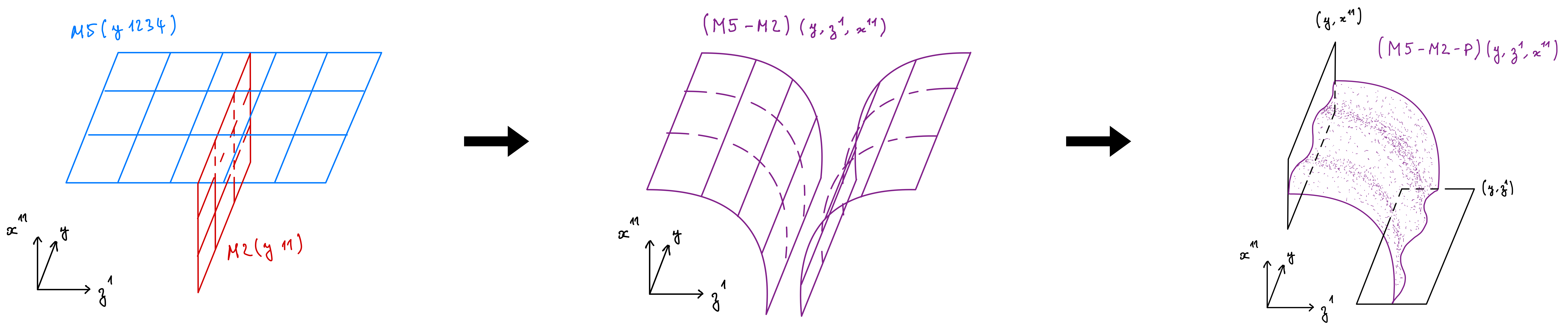
- We have already begun to build the fully-backreacted supergravity solution.







Thank you for your attention !!!!!