# Nonsupersymmetric Brane/Antibrane Configurations in Type IIA/M-theory

Masaki Shigemori (Caltech)

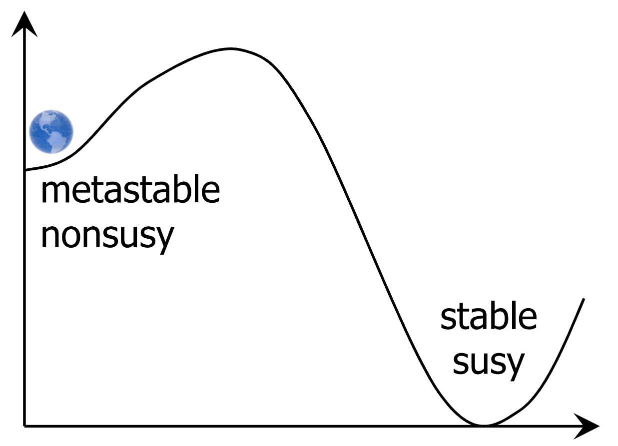
May 17, 2007 at KITP

# This talk is based on…

- arXiv:0705.0983
  Joe Marsano, Kyriakos Papadodimas
  & MS (84 pages!)
- Joe gave a preview at KITP in March.
  This is continuation/supplement

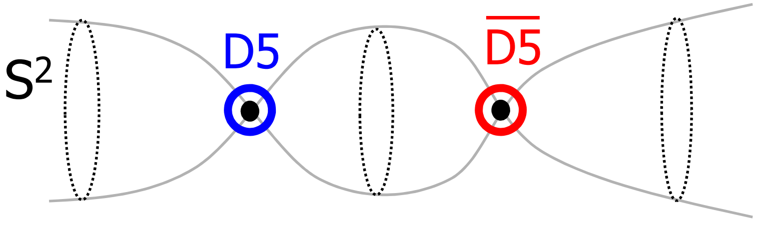
# Introduction

- Metastable nonsusy configs.
  in gauge theory / string theory
  - ISS
  - Landscape
  - Pheno./cosmo.



# Introduction

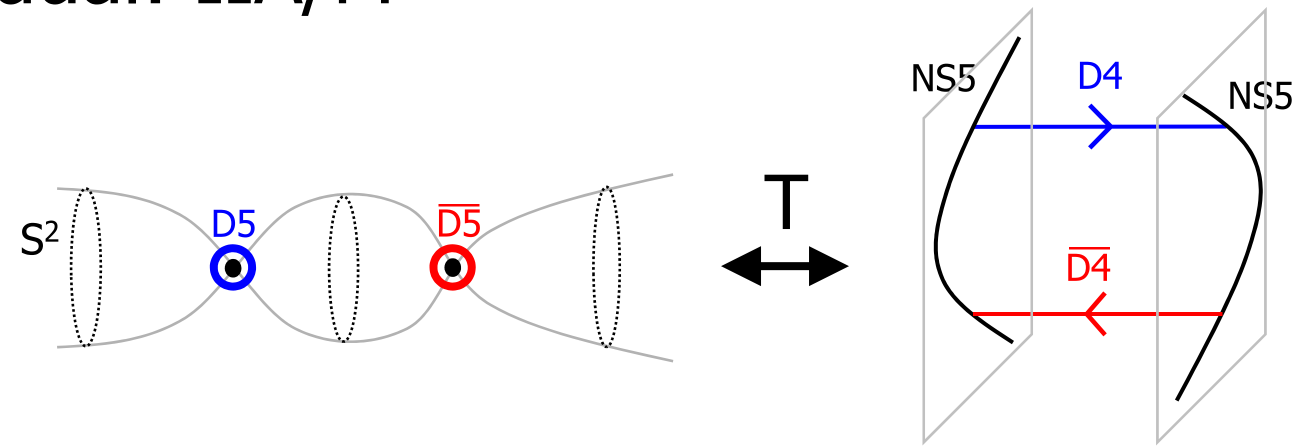
- Geometrically induced metastability
  - Aganagic-Beem-Seo-Vafa




  - Large N duality
  - Fluxes softly break N=2 → N=0
  - Calculational control

# Introduction

- T-dual: IIA/M



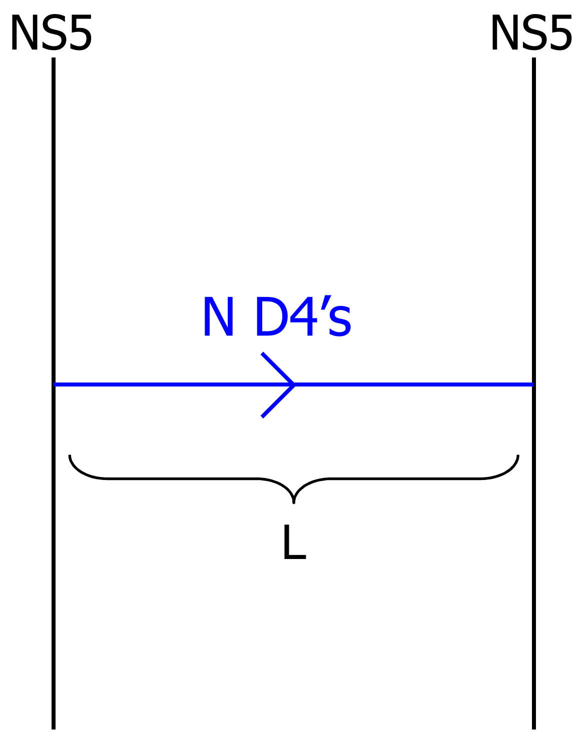

  - IIA side: M-theory lift
  - Unexplored param. regime in string/M-theory
  - "Softness" of breaking
  - Boundary conditions [Bena-Gorbatov-Hellerman-Seiberg-Shih]

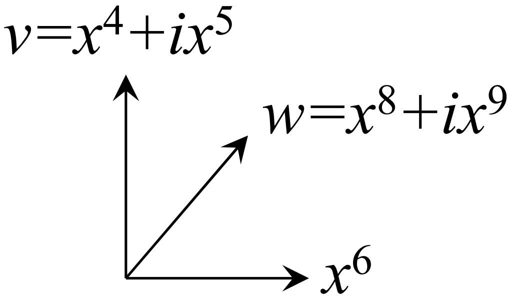
# Plan of this talk

- Introduction
- Susy case
- Nonsusy curves
- “Soft” limit
- Boundary conditions

# Review:
# Susy Case

# Type IIA brane construction (a.k.a. Hanany-Witten)

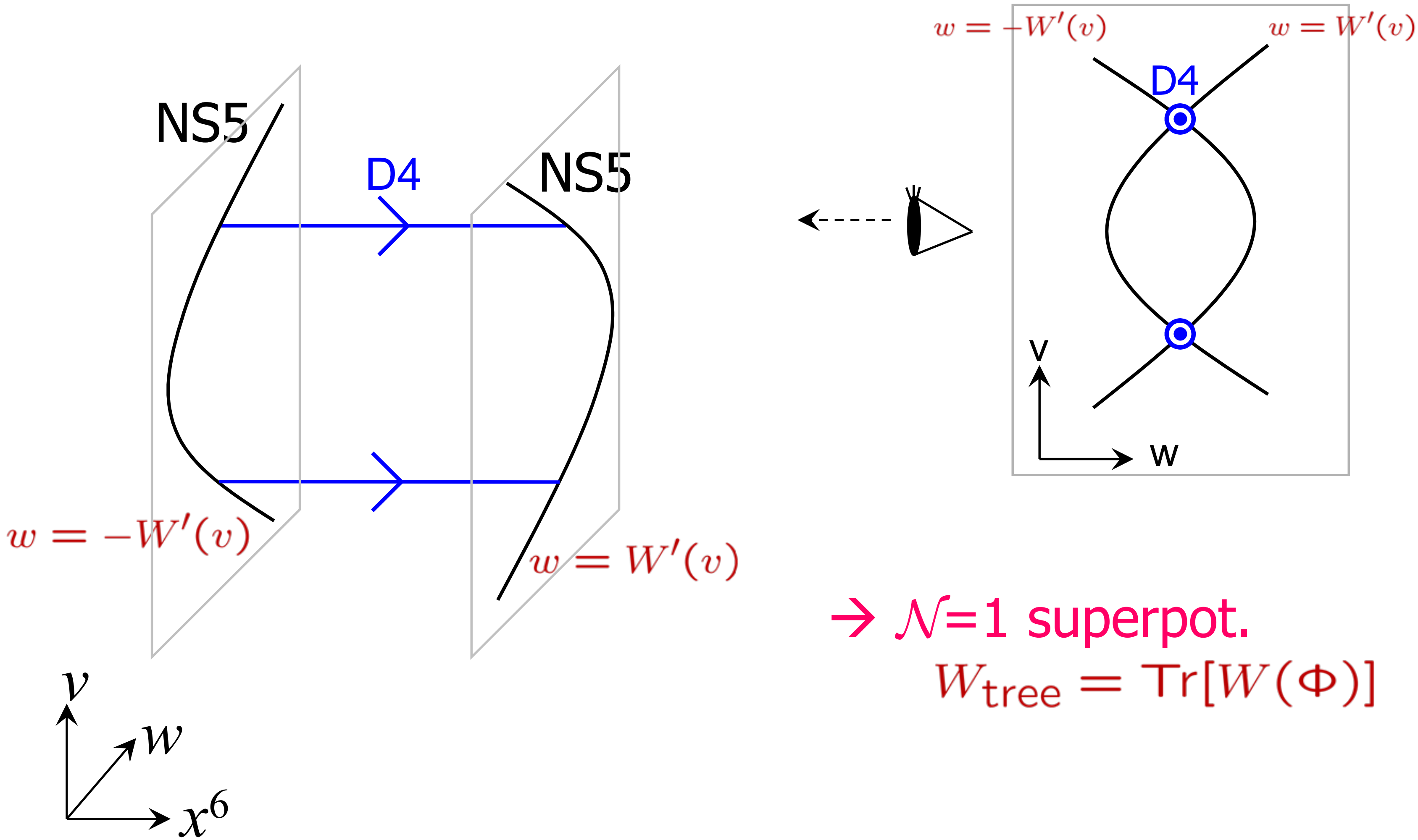



→ $\mathcal{N}$=2 U(N) gauge theory with adjoint $\Phi$

$$\frac{1}{g_{YM}^2} \sim \frac{L}{g_s\sqrt{\alpha'}}$$

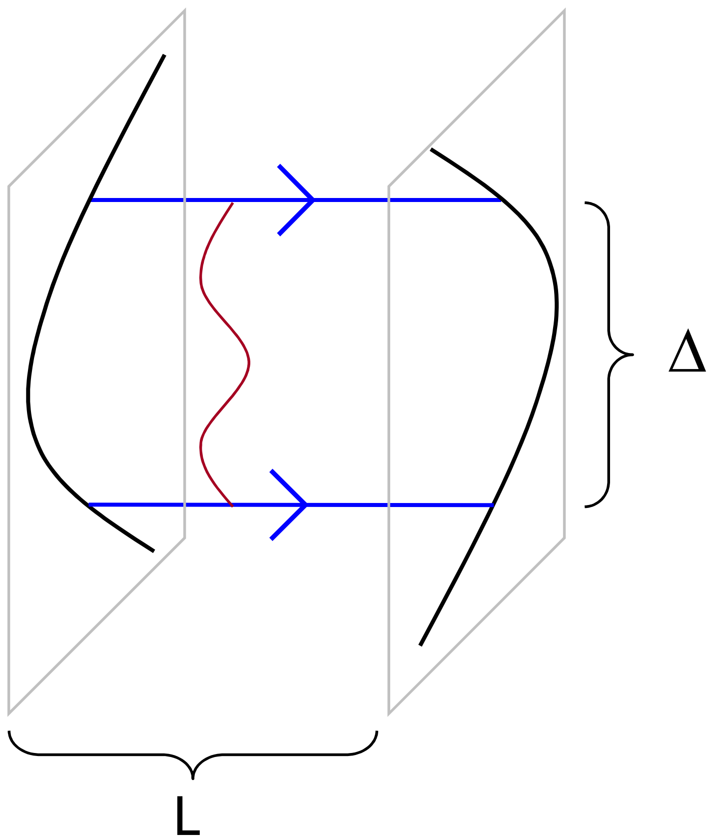
# Curving NS5




→ $\mathcal{N}$=1 superpot.

$$W_{\mathrm{tree}} = \mathrm{Tr}[W(\Phi)]$$

# Gauge theory limit




$$\alpha' \to 0$$

$$\frac{1}{g_{YM}^2} \sim \frac{L}{g_s\sqrt{\alpha'}} : \quad \text{fixed}$$

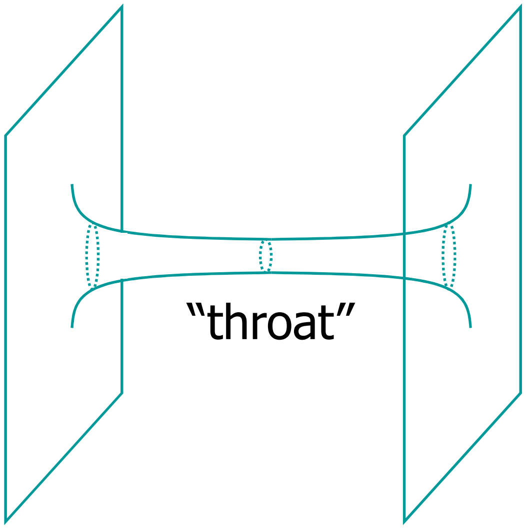
$$M_{\mathrm{F1}} \sim \frac{\Delta}{\alpha'} : \quad \text{fixed}$$

$$L \sim g_s\sqrt{\alpha'}$$

$$\Delta \sim \alpha'$$

System size is substringy

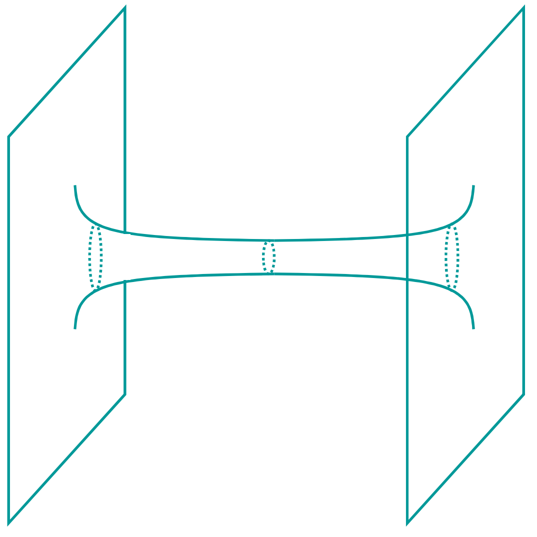
# Gauge dynamics: M-theory lift [Witten]




NS5/D4 → M5

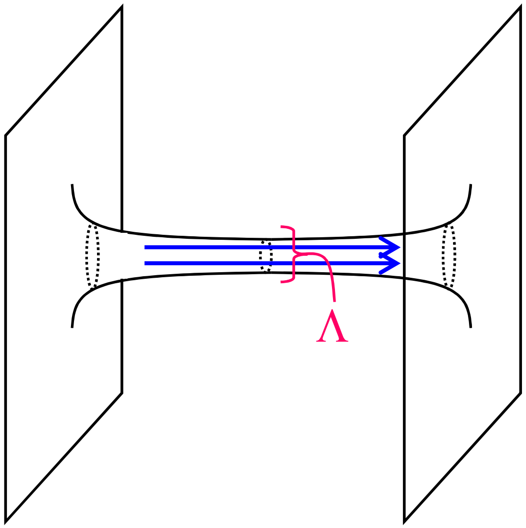
- NS5 & D4 both lift to M5
- Large $g_s$
  → NG action reliable
- M5 curve:
  - (Relatively) easily obtained by holomorphicity
  - SW curve itself!

# Strong coupling: M-theory lift



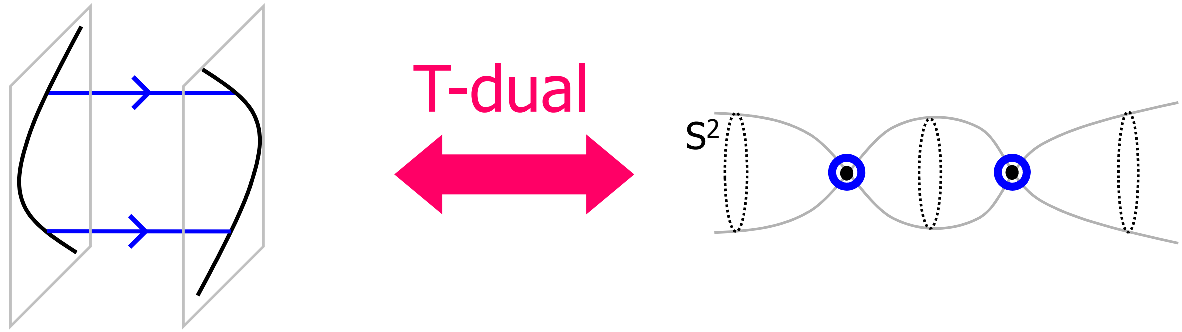
- Why does it work?
  — Power of susy
  - Scales irrelevant for holomorphic quantities
  - NG & gauge theory give same curve

# When is classical curve *really* reliable?




- As M5 curve ($g_s \gg 1$):
  - Curvature $\ll l_{11}$
  - Don't come within $l_{11}$ of self-intersecting
- As NS5 + flux ($g_s \ll 1$):
  - Curvature $\ll l_s$
  - Flux density $\ll 1/g_s$
- Never met in gauge theory limit

# T-duality

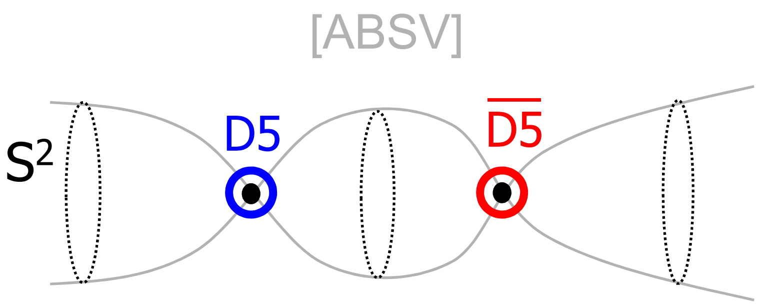


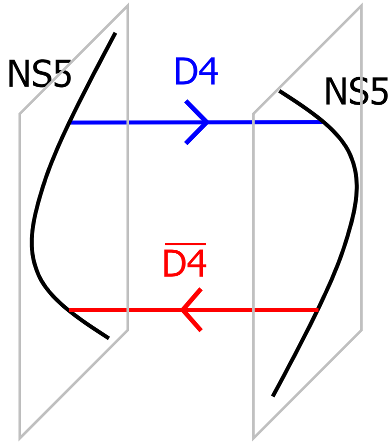

| IIA brane construction | IIB geom. engineering |
|---|---|
| NS5 in $\mathbf{R}^6$ | Noncpt. CY (ALE fibr.) |
| D4 | D5 |
| Tool: M-theory lift | Tool: large N duality |

- Why work? — power of susy
  - Scales irrelevant
  - Without susy, not expected to work, a priori

# Nonsusy Curves

# Nonsusy configurations




IIB

IIA

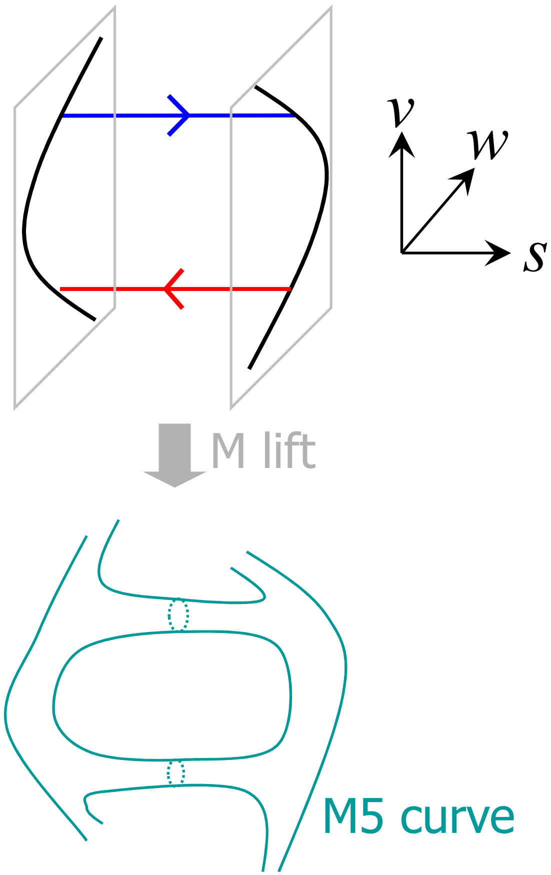
↓

↓

Large N dual

M-theory lift

# EOM's for nonsusy M5 curves




- Need to directly solve NG/Polyakov:

$$S_{NG} \sim \int \sqrt{g}$$

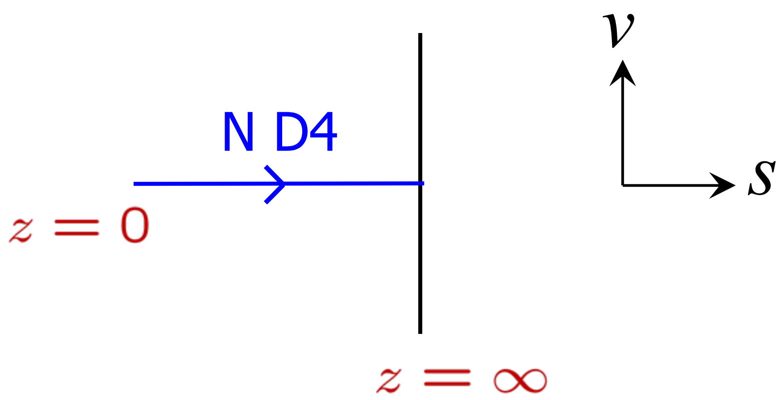
Harmonic:

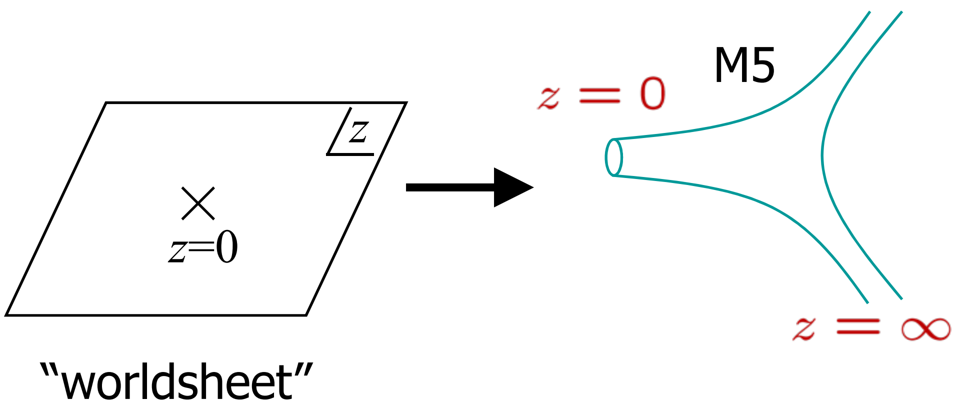
$$s = s_H(z) + \bar{s}_A(\bar{z})$$
$$v = v_H(z) + \bar{v}_A(\bar{z})$$
$$w = w_H(z) + \bar{w}_A(\bar{z})$$

Virasoro constraint:

$$\partial s_H \partial s_A + \partial v_H \partial v_A + \partial w_H \partial w_A = 0$$

# Practice 1: simple susy curve



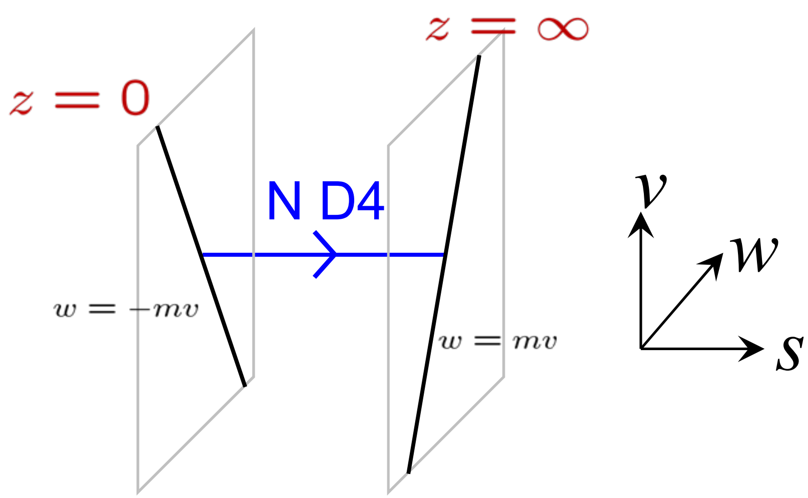

$$v = z$$

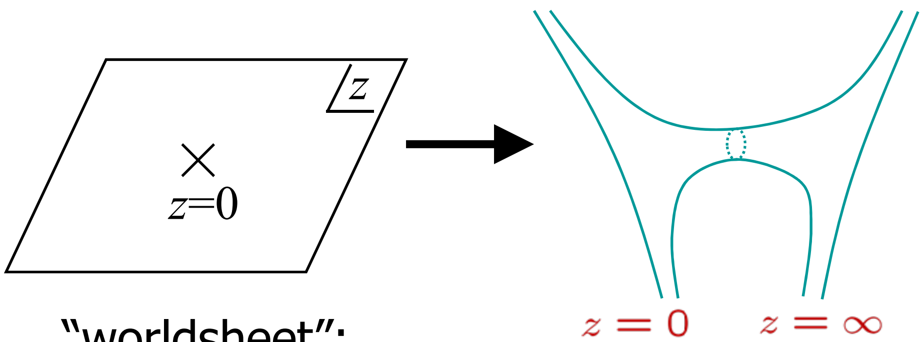
$$s = g_s N \log z$$

$$s \equiv x^6 + i x^{10}$$

log in $s$:
D4's "pull" NS5

# Practice 2: linearly curved NS5's



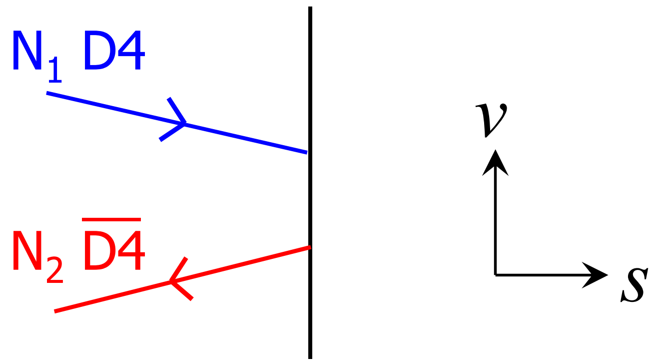

"worldsheet":
genus 0

$$v = z + \frac{a}{z}$$

$$w = m\left(z - \frac{a}{z}\right)$$

$$s = g_s N \log z$$

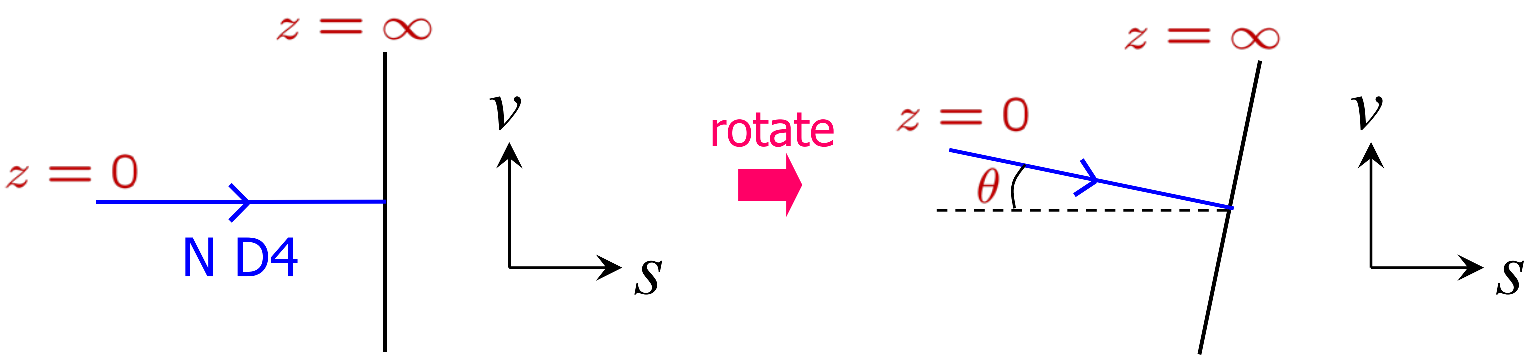
# Practice 3: simple nonsusy curve




- New features:
  - D4's and $\overline{\text{D4}}$'s attract
  - Need to "hold" back D4's
  - D4's "tilt" in $v$ direction

# Practice 3: simple nonsusy curve

- How to get tilted D4




$$v = z$$
$$s = g_s N \log z$$

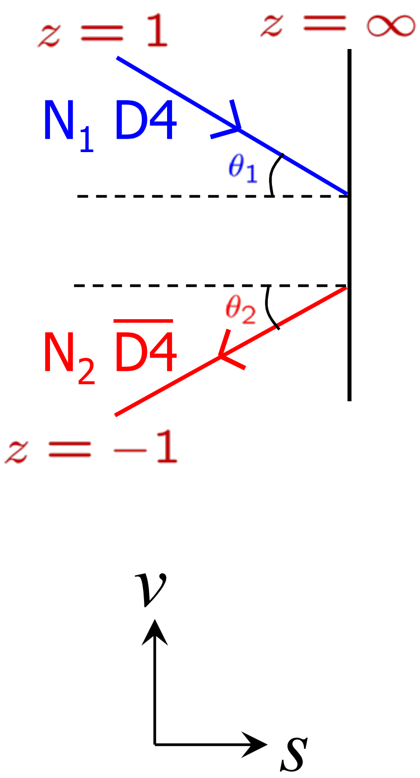
rotate

$$v = -g_s N \sin\theta \cdot \log|z| + \cos^2\frac{\theta}{2}\cdot z - \sin^2\frac{\theta}{2}\cdot\bar{z}$$
$$s = g_s N\left(\cos^2\frac{\theta}{2}\cdot\log z - \sin^2\frac{\theta}{2}\cdot\log\bar{z}\right) + \frac{1}{2}\sin\theta\cdot(z+\bar{z})$$

log appears in tilted direction

# Practice 3: simple nonsusy curve

- Now combine D4 and $\overline{\text{D4}}$ parts



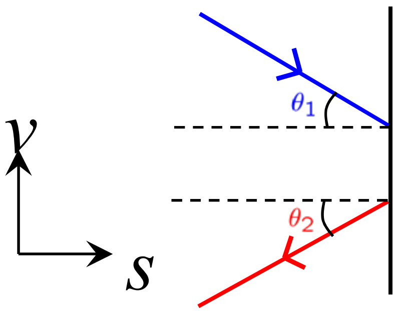

$$v = -g_s N_1 \sin\theta_1 \cdot \log|z-1| + g_s N_2 \sin\theta_2 \cdot \log|z+1| + \Delta v_H + \overline{\Delta v_A}$$

$$s = +g_s N_1 \left[\cos^2\frac{\theta_1}{2} \cdot \log(z-1) - \sin^2\frac{\theta_1}{2} \cdot \log(\bar{z}-1)\right] + g_s N_2 \left[\cos^2\frac{\theta_2}{2} \cdot \log(\bar{z}+1) - \sin^2\frac{\theta_2}{2} \cdot \log(z-1)\right] + \Delta s_H + \overline{\Delta s_A}$$

$\Delta v_{H,A},\ \Delta s_{H,A}$ : determined by Virasoro

# Practice 3: simple nonsusy curve

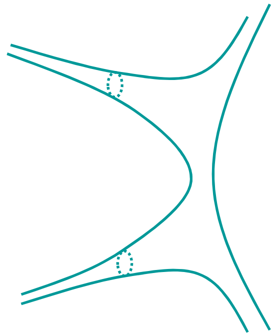
- Virasoro $\partial s_H \partial s_A + \partial v_H \partial v_A + \partial w_H \partial w_A = 0$




- Force balance

$$N_1 \sin\theta_1 = N_2 \sin\theta_2$$

- Full nonholo. curve obtained!

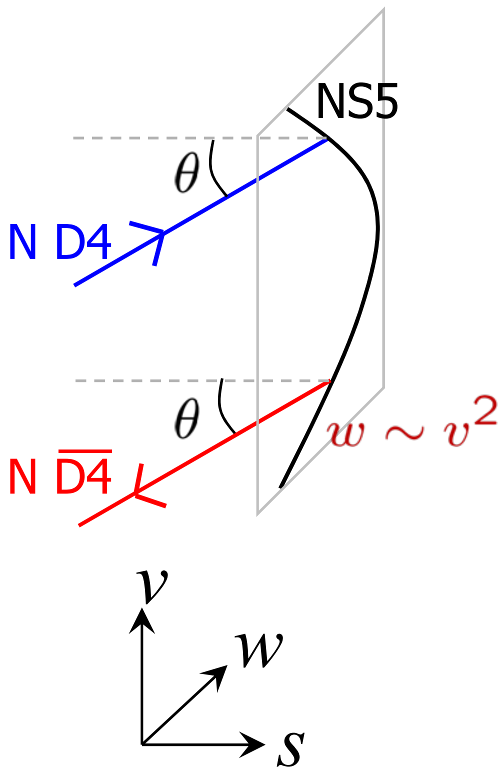


$$v = -g_s N_1 \sin\theta_1 \cdot \log|z-1| + g_s N_2 \sin\theta_2 \cdot \log|z+1| + az$$

$$s = +g_s N_1 \left[\cos^2\frac{\theta_1}{2} \cdot \log(z-1) - \sin^2\frac{\theta_1}{2} \cdot \log(\bar{z}-1)\right]$$
$$+g_s N_2 \left[\cos^2\frac{\theta_2}{2} \cdot \log(\bar{z}+1) - \sin^2\frac{\theta_2}{2} \cdot \log(z-1)\right]$$

$$a = \frac{2N_1 N_2 \cos^2\left(\frac{\theta_1+\theta_2}{2}\right)}{N_1 \sin\theta_1 + N_2 \sin\theta_2}$$

# Practice 4: quadratic curving (“half” of real thing)




- Same method works
- Full nonholo. curve:

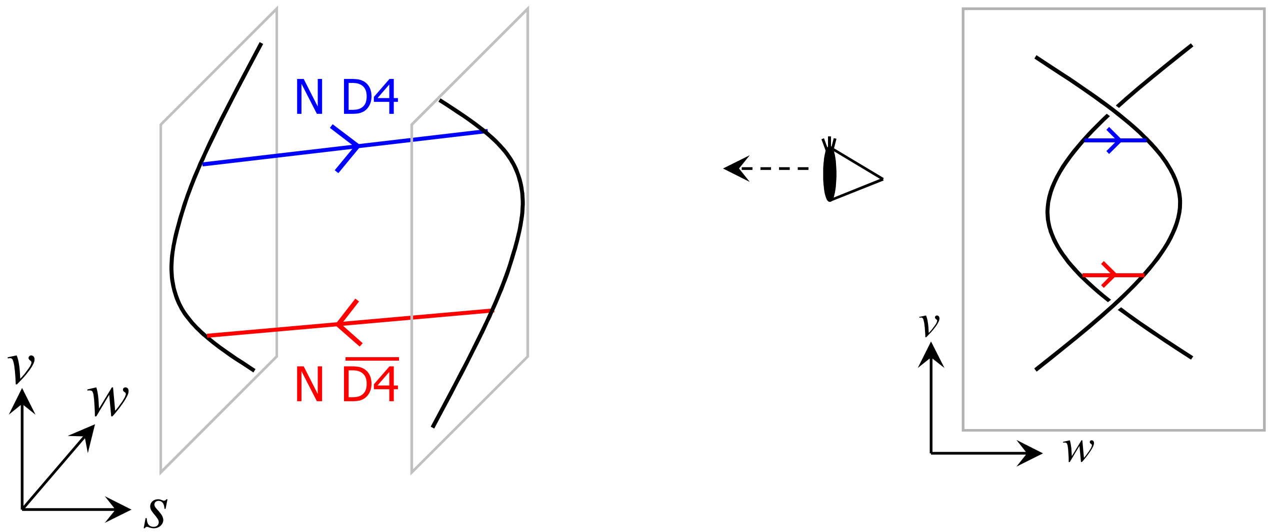
$$v = Xz + \frac{(g_s N)^2}{X}\bar{z}$$

$$w = g_s N \sin\theta \cdot \log|z-1| + g_s N \sin\theta \cdot \log|z+1| - \frac{g_s N}{2\sin\theta} z^2$$

$$s = +g_s N\left[\cos^2\frac{\theta}{2}\cdot\log(z-1) - \sin^2\frac{\theta}{2}\cdot\log(\bar{z}-1)\right]$$
$$+g_s N\left[\cos^2\frac{\theta}{2}\cdot\log(\bar{z}+1) - \sin^2\frac{\theta}{2}\cdot\log(z-1)\right]$$

- Log bending in *s*, *w*
- B.C. at ∞ not holomorphic
- Minimal distance b/t D4 & $\overline{\text{D4}}$

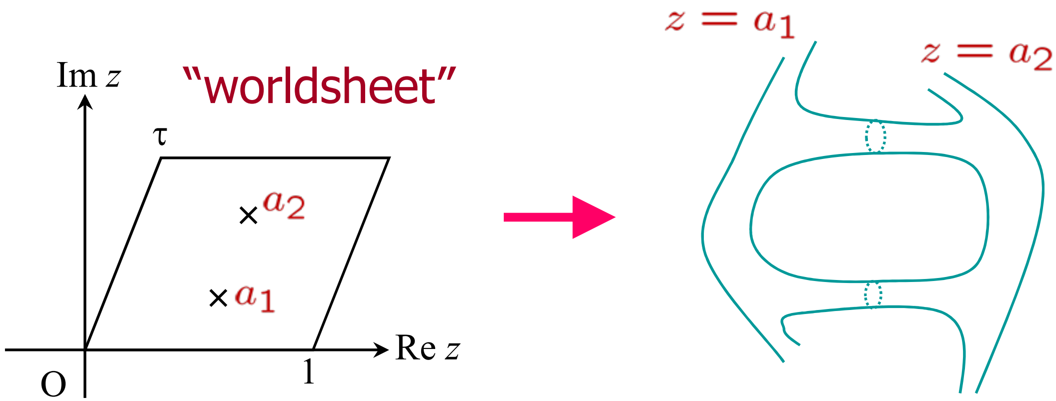
# The real problem




- “Worldsheet”: genus 1
- D4’s tilt in $w$ direction

→ $w$ have “logs”

# The exact curve



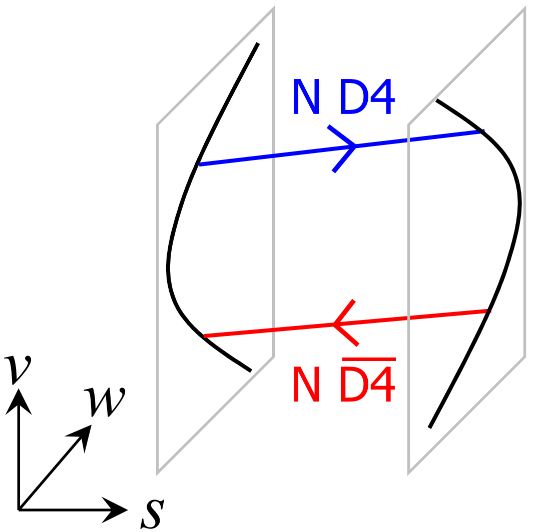

$$\begin{cases} v = X\left[F_1^{(1)} - F_2^{(1)}\right] + \frac{2\xi(g_s N)^2}{\overline{X}}\left[F_1^{(1)} - F_2^{(1)}\right] \\ w = g_s N r_0 \sin\theta\,[(F_2 - F_1 - i\pi)z + \mathrm{cc}] + \frac{g_s N \xi}{r_0 \sin\theta}(F_1^{(2)} - F_2^{(2)}) \\ s = g_s N r_0 \cos\theta\,[(F_1 - F_2 + i\pi z) + \mathrm{cc}] + i\pi g_s N(z + \overline{z}) \end{cases}$$

$$F_i(z) = \log\left[\theta\left(z - a_i - \frac{\tau+1}{2}\right)\right], \qquad F_i^{(n)}(z) = \left(\frac{\partial}{\partial z}\right)^n F_i(z)$$

$$r_0^2 \equiv \frac{3\pi^2\wp(\tau/2)}{3\wp(\tau/2)^2 - g_2}, \quad \xi \equiv \frac{\pi^2}{6\wp(\tau/2)^2 - 2g_2}$$

$$\mathrm{Re}(\tau) = 0, \quad \tau = 2(a_2 - a_1)$$

# The exact curve




- Same features as the “half” curve:
  - Log bending in $s, w$
  - B.C. at ∞ not holomorphic
  - Minimal distance between D4 & $\overline{\text{D4}}$
  - T-dual won’t even be a complex manifold
- Reliable as M5/NS5 curve

# The “Soft Limit”

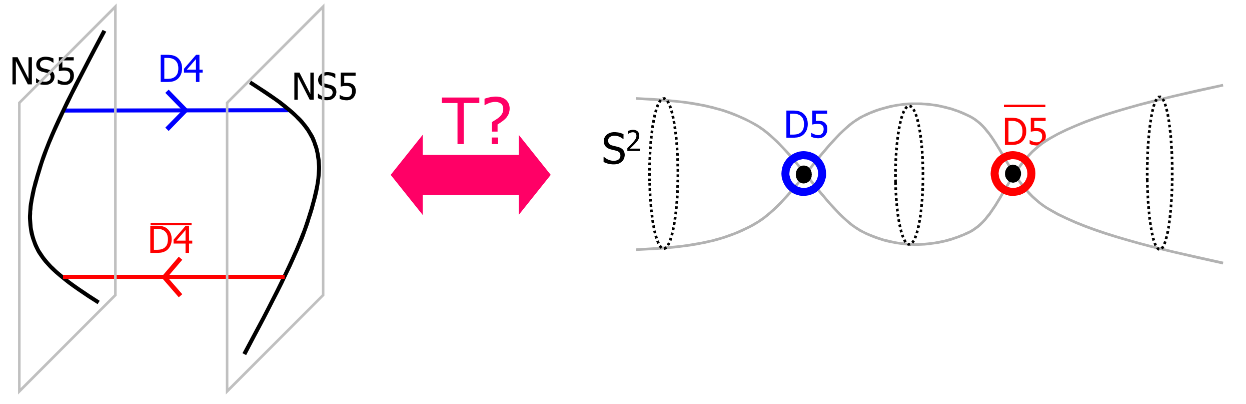
# What if $g_s N$ is small?

- Take $\dfrac{g_s N}{\Delta} \to 0$ in the exact curve:

$$v = X\left[F_1^{(1)} - F_2^{(1)}\right]$$
$$w = C\left[(F_2 - F_1 - i\pi)z + \mathrm{cc}\right]$$
$$s = g_s N r_0 \cos\theta\left[(F_1 - F_2 + i\pi z) + \mathrm{cc}\right] + i\pi g_s N(z + \bar{z})$$

  - Tilting vanishes
  - $v$, $w$ : holomorphic, $s$ : harmonic
  - Corresponds to exact min. of IIB potential : unexpected!

# "T-duality"

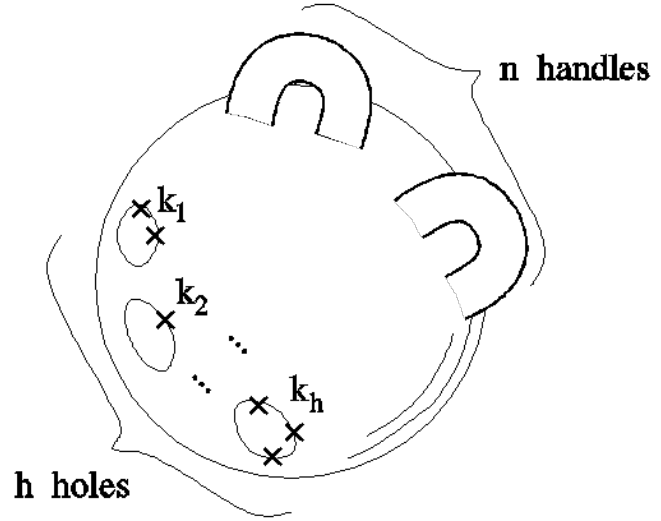



- Holds more generally
- Why work without susy?
  - There must be some protection
  - IIB [ABSV]: assuming soft breaking
  - $g_s N$ is controlling "softness"

# The "soft limit"

- Small $g_sN$ : consistent with reliability of curve
- Why is $g_sN$ controlling "softness"?
  - Tree level → soft
  - Higher genus can destroy this structure:

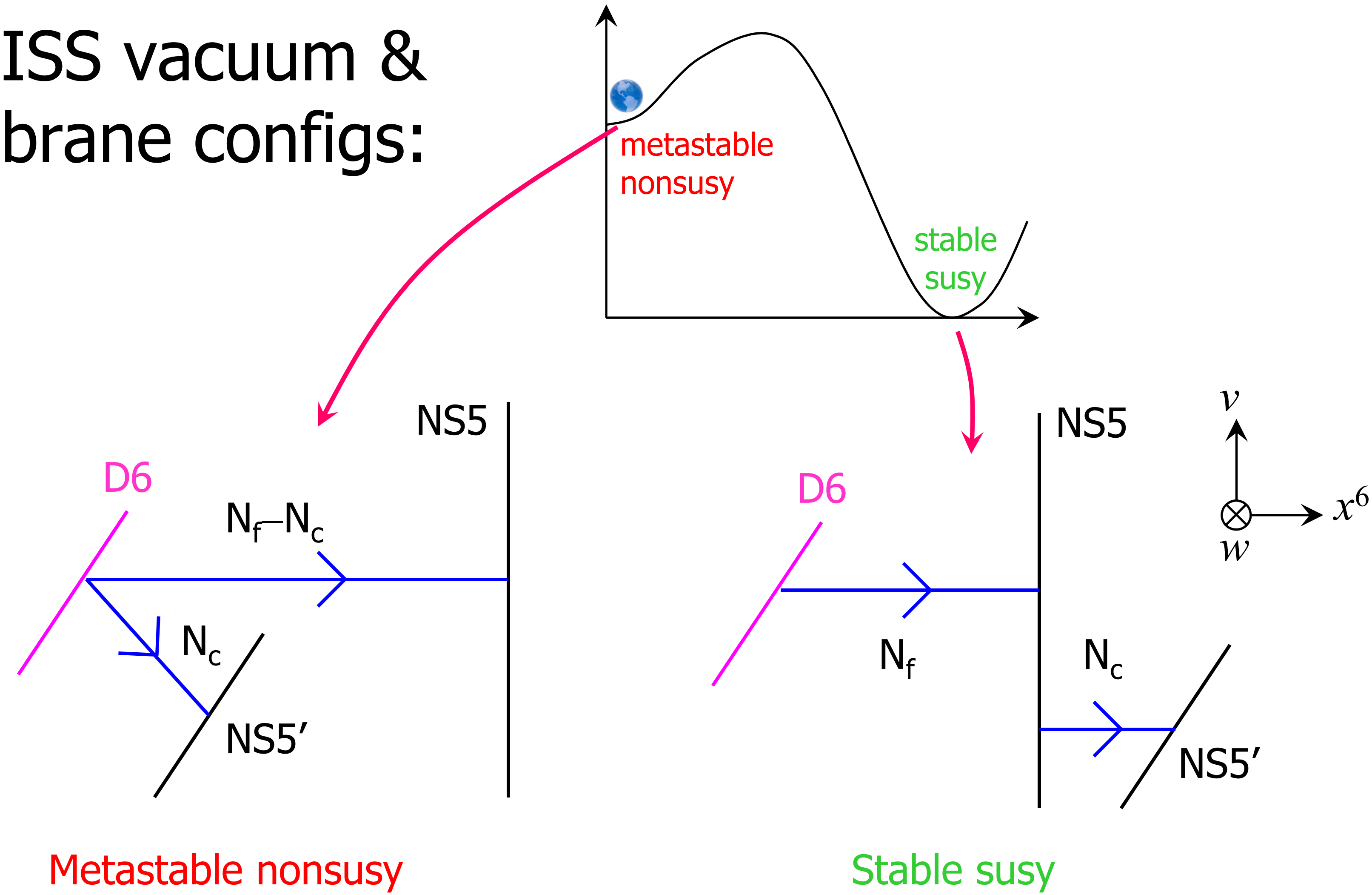
$$\sim g_s^{2n}(g_sN)^{h-1}$$



# Boundary Conditions

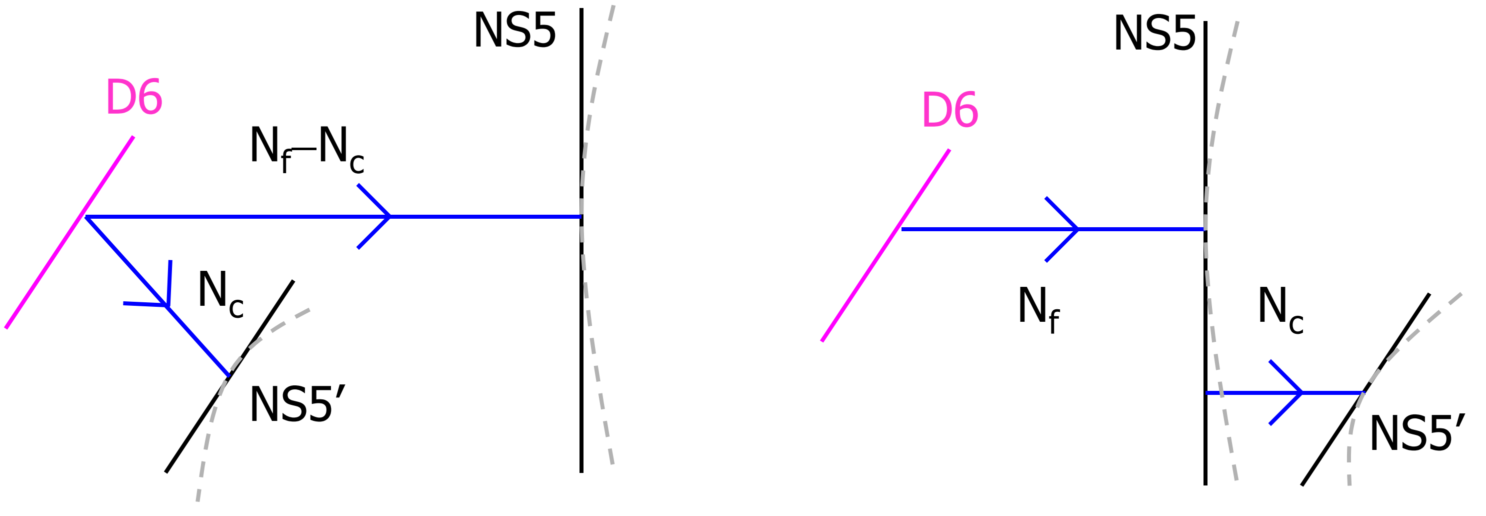
# The issue

- ISS vacuum & brane configs:



# The issue

- BGHSS:
  Boundary conds. different.
  - Two brane configs are in different theories
  - One can't decay into other

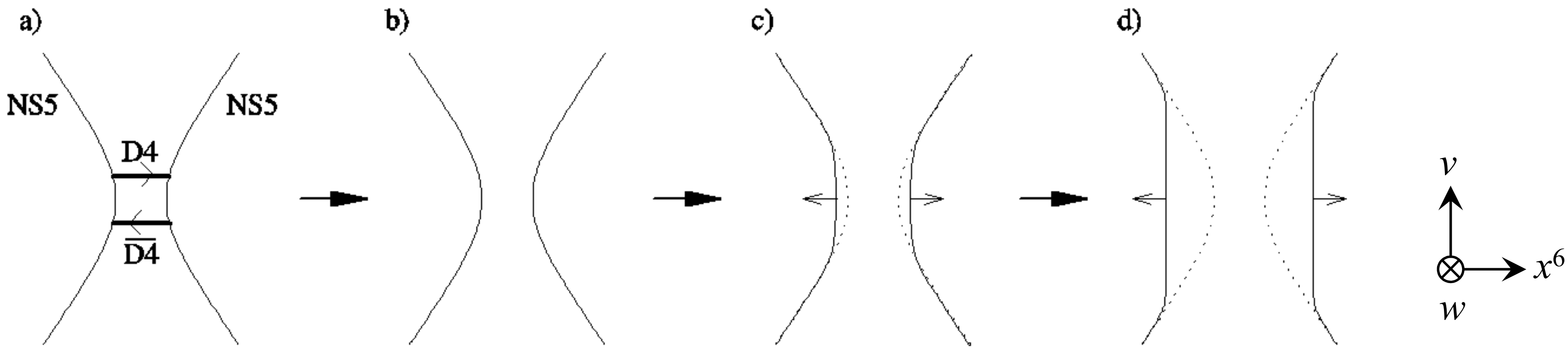



Metastable nonsusy

Stable susy

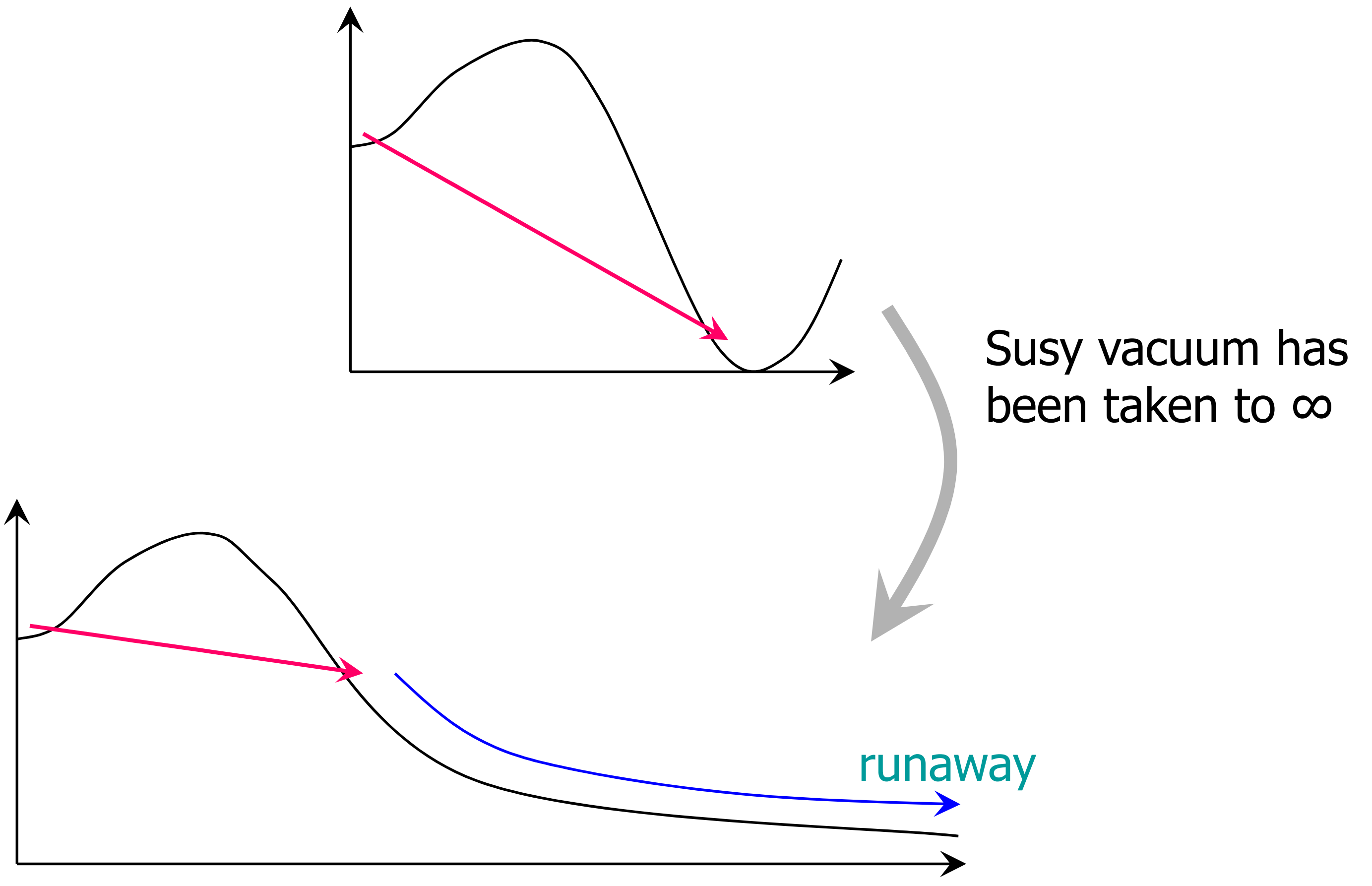
# Nonsusy configs decay

- Does not mean our nonsusy config is stable: It decays



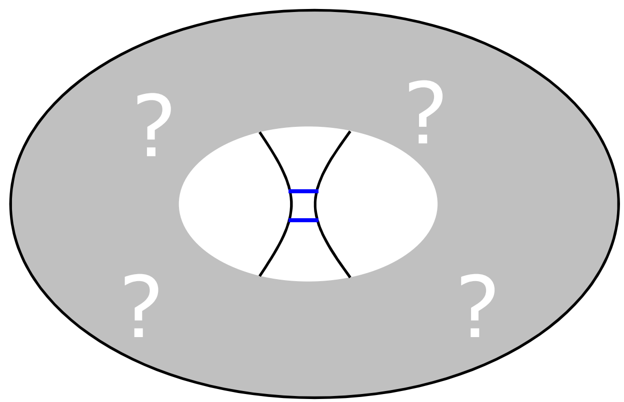

  - D4/$\overline{\text{D4}}$ pair annihilate by quantum tunneling (Cf. β-decay in EM field)
  - NS5's straighten
  - Takes ∞ time (runaway)

# Runaway instability



# Relevance of nonsusy brane configs

- Gauge theory is approximation of string ☺
- Embed in compact CY:
  BC arises from dynamics of "the rest"




- In the whole sys, runaway ends
- Local "building block" for model building

# Conclusions

- M5/NS5 curve:
  - Can explore nonsusy landscape of string/M-theory
  - Can be easily generalized (ADE, etc.)
- $g_s N$ controls “softness” of breaking
  - Can study string/M landscape in a controlled way
- Boundary conditions
- Building blocks for model building