GSO DEFECTS, IIA/IIB WALLS, AND A SURPRISINGLY STABLE R7-BRANE

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Lepton-Photon 2025

Madison, Wisconsin

Based on 2507.21210 with J.J. Heckman, J. McNamara, and J. Parra-Martinez

STRINGS WITHOUT SUSY

- A central goal in the string theory community is to understand non-supersymmetric backgrounds
- A question of exploration: What are the set of consistent non-susy vacua?
    - Non-susy 10D strings ($O(16) \times O(16)$ heterotic, $USp(32)$ Sugimoto, Type 0'B)
    - Non-susy compactifications of 10D superstrings to $d < 10$ (e.g. fluxes, "wrong" spin structure)

STRINGS WITHOUT SUSY

- A central goal in the string theory community is to understand non-supersymmetric backgrounds
- A question of computation: How do we calculate non-perturbative corrections when SUSY is (spontaneously) broken?
  - Are constructions of metastable de Sitter vacua (e.g. KKLT) well-controlled?

Strings 2024

The Future of String Theory: 100 Open Questions

(Collected by Ooguri + Strominger)

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86. How do we classify all of the possible branes in supersymmetric string theories?

Hint: In the past couple of years, some works motivated by the Swampland Cobordism Conjecture have provided evidence for new non-BPS branes in Type II and heterotic string theories.

Strings 2024

The Future of String Theory: 100 Open Questions

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Ethan Torres (current speaker)

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OLD NON-BPS BRANES IN STRING THEORY

- Non-BPS D-branes discovered in mid/late 1990s
  (Sen, Witten, Moore, + many others)
- Have explicit worldsheet CFT constructions
- Some stable and some unstable

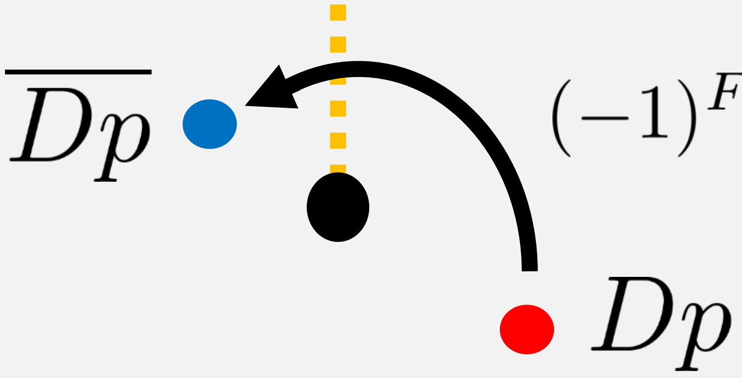
E.g.

Type I $D0$-brane

Type IIB $D(2p)$-branes

NEW NON-BPS BRANES IN STRING THEORY

- R7-branes [Dierigl, Heckman, Montero, ET ’22 +’23]



$(-1)^{F_L}$ monodromy

(also exist R7-branes with Ω monodromy in IIB)

- New branes in heterotic string theories

  [Kaidi, (Ohmori), Tachikawa, Yonekura ’23 +’24]

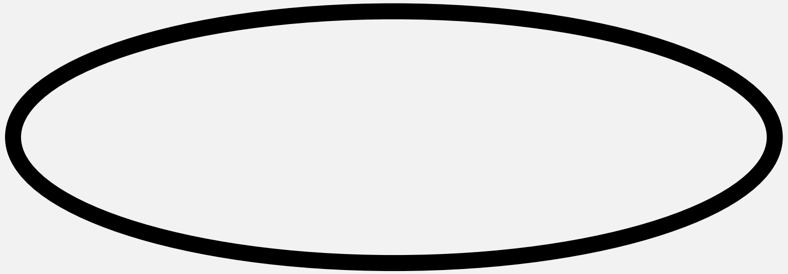
  - $(E_8 \times E_8) \rtimes \mathbb{Z}_2$ string theory (HE): 7-brane, 4-brane
  - $Spin(32)/\mathbb{Z}_2$ string (HO): 6-brane, 0-brane

    [Polchinski ’05]

COBORDISM CONJECTURE

- Much of this work was motivated by the Cobordism Conjecture [McNamara, Vafa '19]

$$\Omega_k^{\mathrm{QG}} = 0$$

 $(M_k,\ \text{flux data},\ \text{etc.})$

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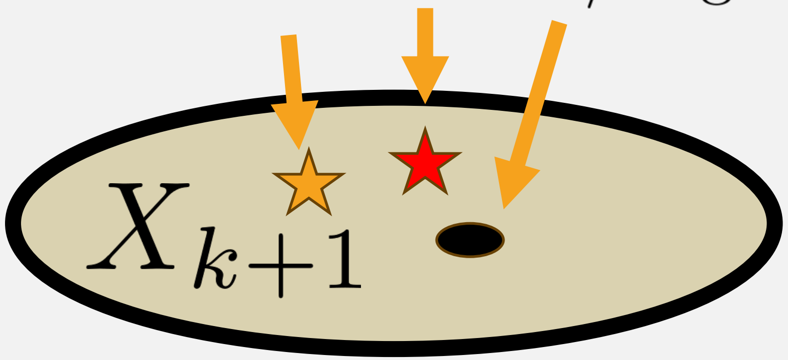
$$\Omega_k^{\mathrm{QG}} = 0$$

Some collection of branes/singularities/topology



$(M_k, \text{ flux data, etc.})$

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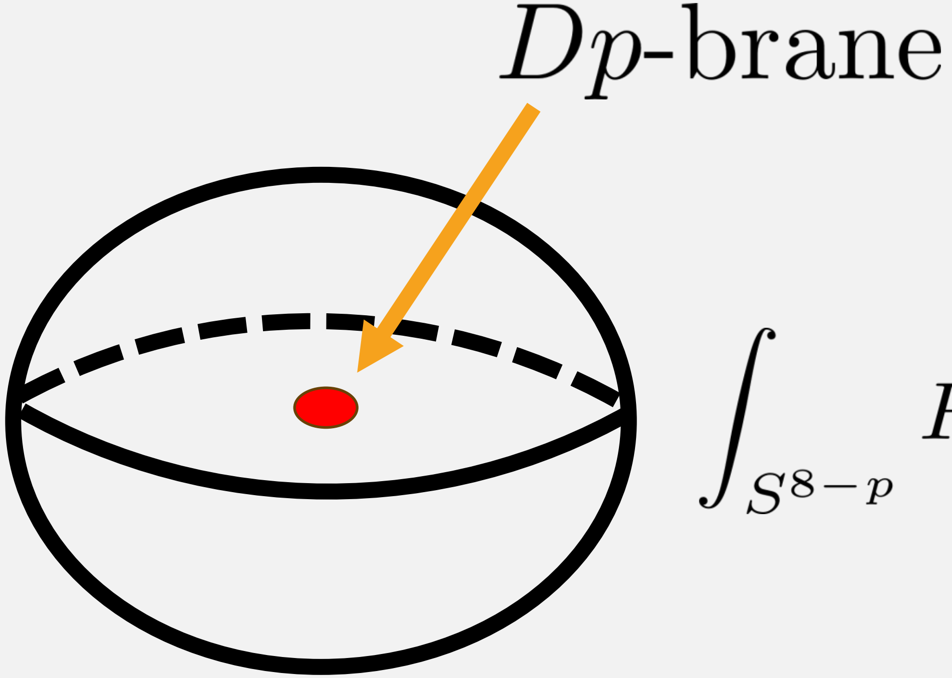
Example:



$$\int_{S^{8-p}} F_{8-p}^{\mathrm{RR}} = 1$$

COBORDISM CONJECTURE

- Much of this work was motivated by the Cobordism Conjecture [McNamara, Vafa '19]
- $k = 0$ case predicts domain walls of finite tension connecting all string theory vacua

(See also earlier discussion: [Distler, Freed, Moore '09])

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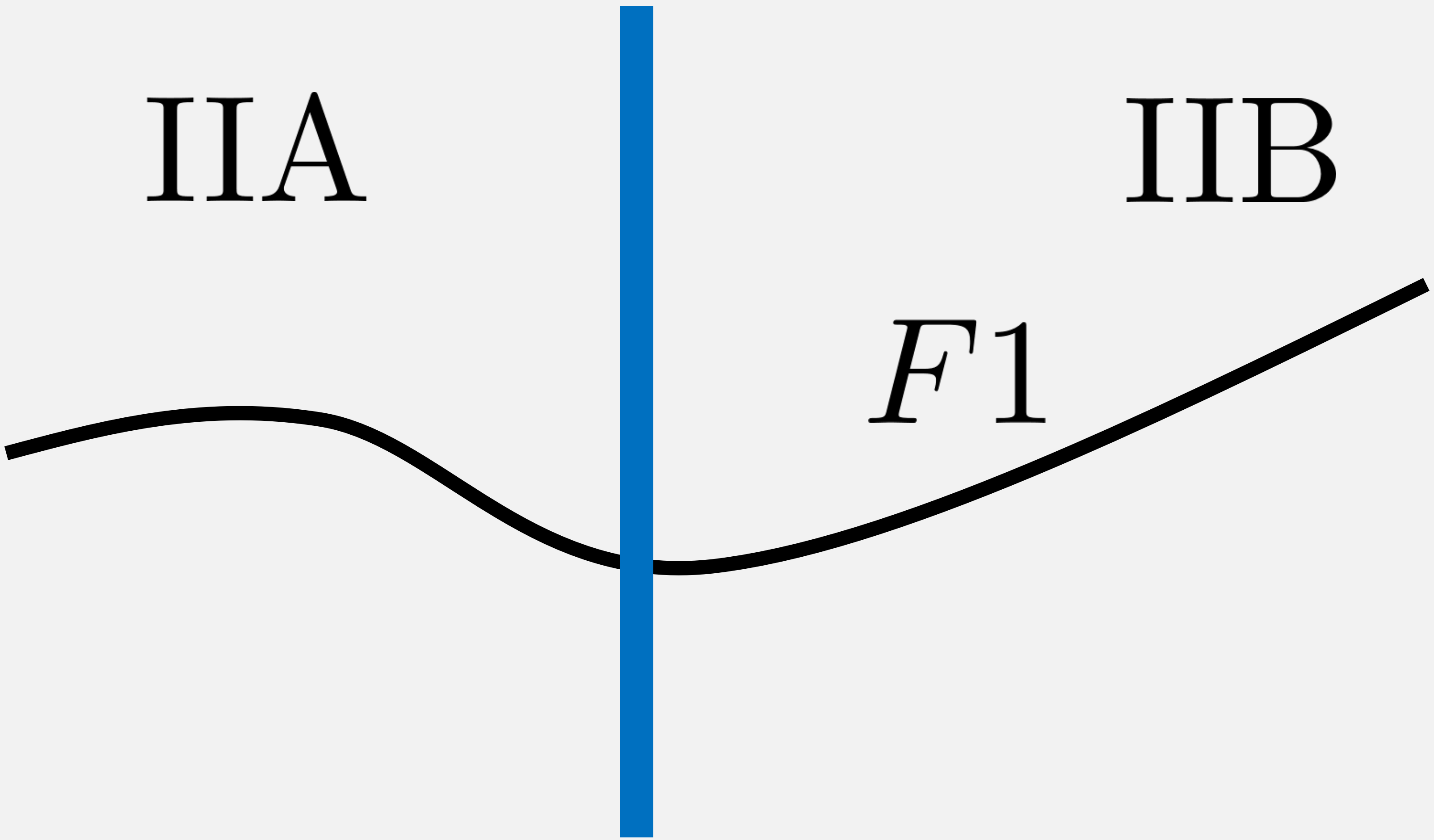
Today: IIA/IIB Walls as GSO defects

OUTLINE

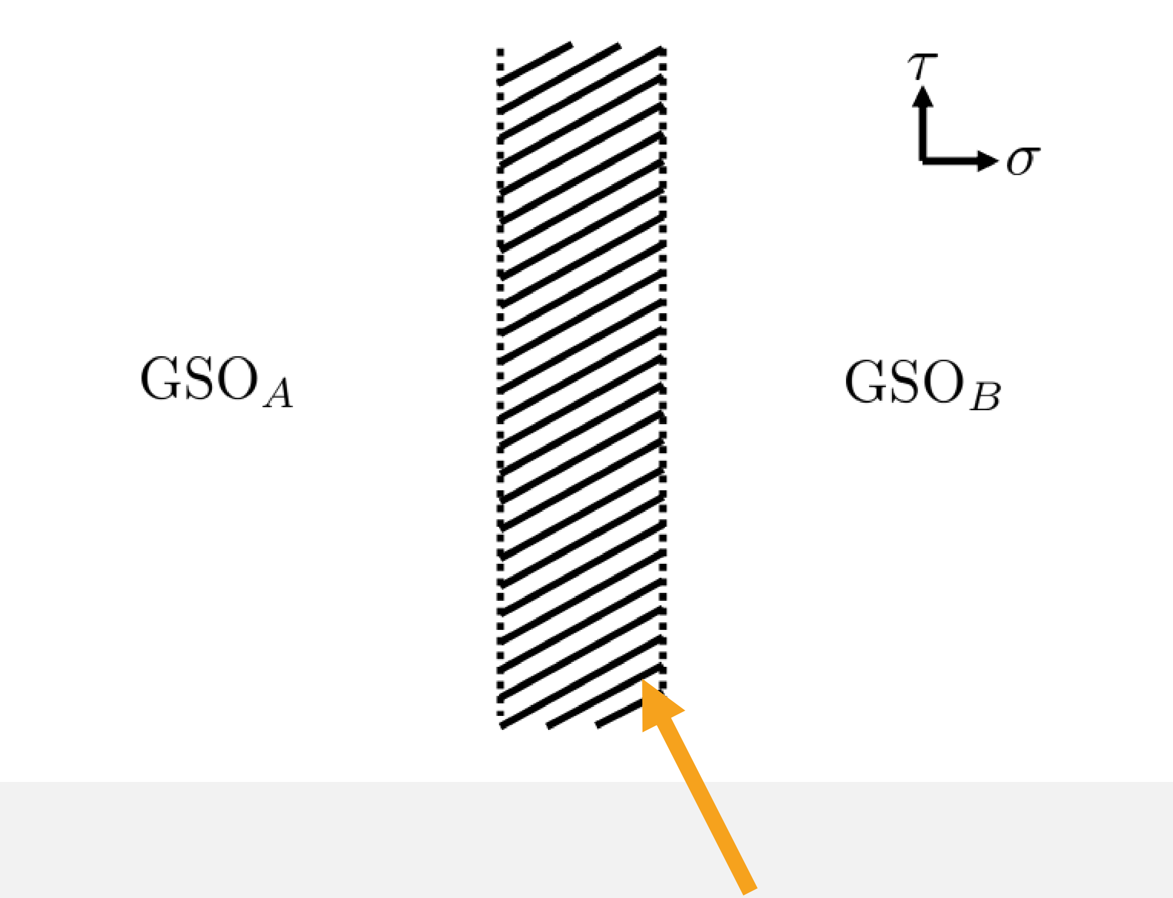
1. Worldsheet picture of IIA/IIB wall

2. Bulk Physics ($R7$-stability)

LONG STRING DEFECT



LONG STRING DEFECT



Can have some (yet) unknown localized 2D CFT deformation when $g_s > 0$

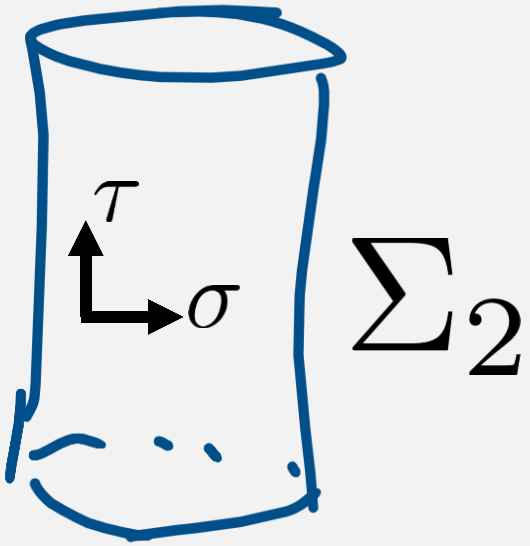
REVIEW OF TYPE II WORLDSHEET

Lightcone Gauge CFT content (RNS formalism)

Left-moving piece: $(X^{i=1,\ldots,8}, \psi^{i=1,\ldots,8})$

R sector: $\psi^i(\sigma + 2\pi) = +\psi^i(\sigma)$

NS sector: $\psi^i(\sigma + 2\pi) = -\psi^i(\sigma)$



(LCG: $X^+ = \ell_s^2 P^+ \tau$, where $X^+ = \frac{1}{\sqrt{2}}(X^0 + X^9)$)

REVIEW OF TYPE II WORLDSHEET

- NS sector has a tachyonic ground state due to negative Casimir energy
- Type IIA & IIB string obtained after GSO projection

  [Gliozzi, Scherk, Olive '77]
- Projects out NS tachyon + half of R-sector ground states

REVIEW OF TYPE II WORLDSHEET

In modern langauge:

$$\text{GSO proj.} = \text{gauging of } \mathbb{Z}_2 \text{ symmetry}$$
$$\text{generated by } (-1)^{\mathrm{f}_L}$$

$$\mathrm{f}_L = \text{ worldsheet fermion number}$$
$$(F_L = \textit{ spacetime} \text{ fermion number})$$

REVIEW OF TYPE II WORLDSHEET

In modern langauge:

$$\begin{aligned}\text{GSO proj.} &= \text{gauging of } \mathbb{Z}_2 \text{ symmetry} \\ &\quad\ \text{generated by } (-1)^{\mathrm{f}_L} \\ &= \text{sum over spin structures on } \Sigma_2\end{aligned}$$

[Seiberg, Witten '86]

(Interesting subtely: see [Boyle-Smith, Zhang'24] + our Appendix A)

REVIEW OF TYPE II WORLDSHEET

$$\text{Ex. } \Sigma_2 = T^2$$

$$Z = \tfrac{1}{2}\left(Z\Big(\underset{\mathrm{A}}{\boxed{\quad \mathrm{A}}}\Big) + Z\Big(\underset{\mathrm{A}}{\boxed{\quad \mathrm{P}}}\Big) + Z\Big(\underset{\mathrm{P}}{\boxed{\quad \mathrm{A}}}\Big) + Z\Big(\underset{\mathrm{P}}{\boxed{\quad \mathrm{P}}}\Big) \right)$$

ARF INVARIANT

- On T^2:

$$\{\text{AA, AP, PA}\} \longrightarrow \text{even spin structures}$$

$$\text{PP} \longrightarrow \text{odd spin structure}$$

- Are distinguished by # of zero modes (mod 2) of Dirac operator

$$\text{Arf}(\Sigma_2^{\text{even}}) = 0 \bmod 2$$

$$\text{Arf}(\Sigma_2^{\text{odd}}) = 1 \bmod 2$$

GSO THETA ANGLES

- Just as one can add theta angles in 4D Yang-Mills e.g. $\propto i\theta \int_{\Sigma_4} \epsilon^{\mu\nu\rho\lambda}\mathrm{Tr}F_{\mu\nu}F_{\rho\lambda}$, one can add a theta angle to this 2D $\mathbb{Z}_2$ gauge theory [Kaidi, Parra-Martinez, Tachikawa '19a, '19b]

4D	Analogy	2D
YM instanton on Σ_4		Odd spin structure on Σ_2
weight $= e^{2\pi i\theta N_{\text{inst.}}}$		weight $= e^{i\pi\theta_L \mathrm{Arf}(\Sigma_2)}$

GSO THETA ANGLES

$$\text{Ex. } \Sigma_2 = T^2$$

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$$\theta_L = 0 \bmod 2$$

GSO THETA ANGLES

$$\text{Ex. } \Sigma_2 = T^2$$

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$$\theta_L = 1 \bmod 2$$

GSO INTERFACES (CHIRAL VERSION)

$$\theta_L = 0 \bmod 2$$

$$\theta_L = 1 \bmod 2$$

Includes a universal 1D Maj. fermion due to anomaly inflow

(For same reason 1+1D Kitaev chain always has gapless boundary condtions)

GSO INTERFACES BETWEEN IIA AND IIB

- Left- and right-moving theta angles $(\theta_L,\ \theta_R)$

$$(\theta_L,\ \theta_R) = (1,0) \text{ or } (0,1) \longrightarrow \text{Type IIA}$$

$$(\theta_L,\ \theta_R) = (0,0) \text{ or } (1,1) \longrightarrow \text{Type IIB}$$

GSO INTERFACES BETWEEN IIA AND IIB

$$(\theta_L,\ \theta_R) = (1,0)$$

IIA

$$(\theta_L,\ \theta_R) = (0,0)$$

IIB

$$\mathcal{D}_{A/B}$$

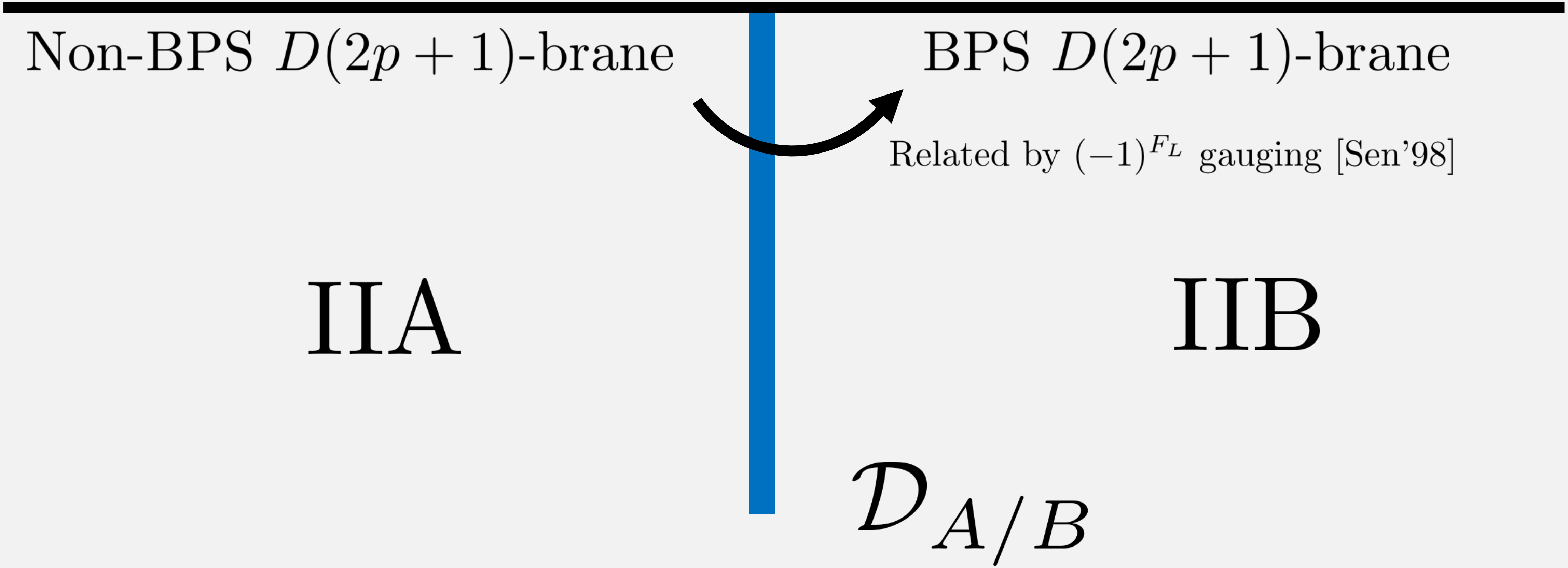
Equivalently, because IIB can be seen as an orbifold of IIA by gauging $(-1)^{F_L}$

(and vice-versa)

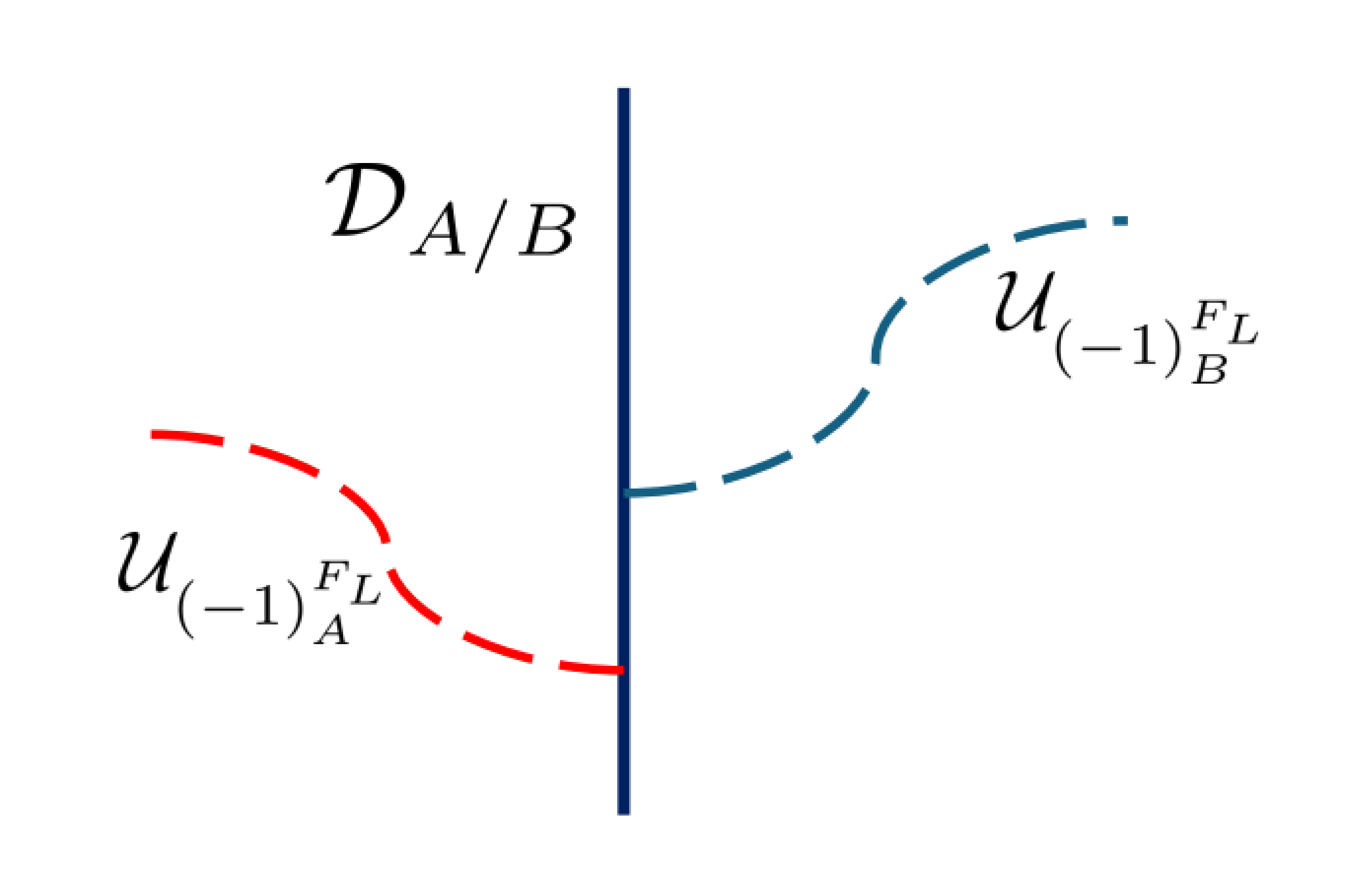
$$\mathcal{D}_{A/B} \simeq \text{ half-space gauging interface}$$

TWO IMPORTANT WORLDSHEET PROPERTIES THESE INTERFACES HAVE

PROPERTY I: GSO INTERFACES AND D-BRANES

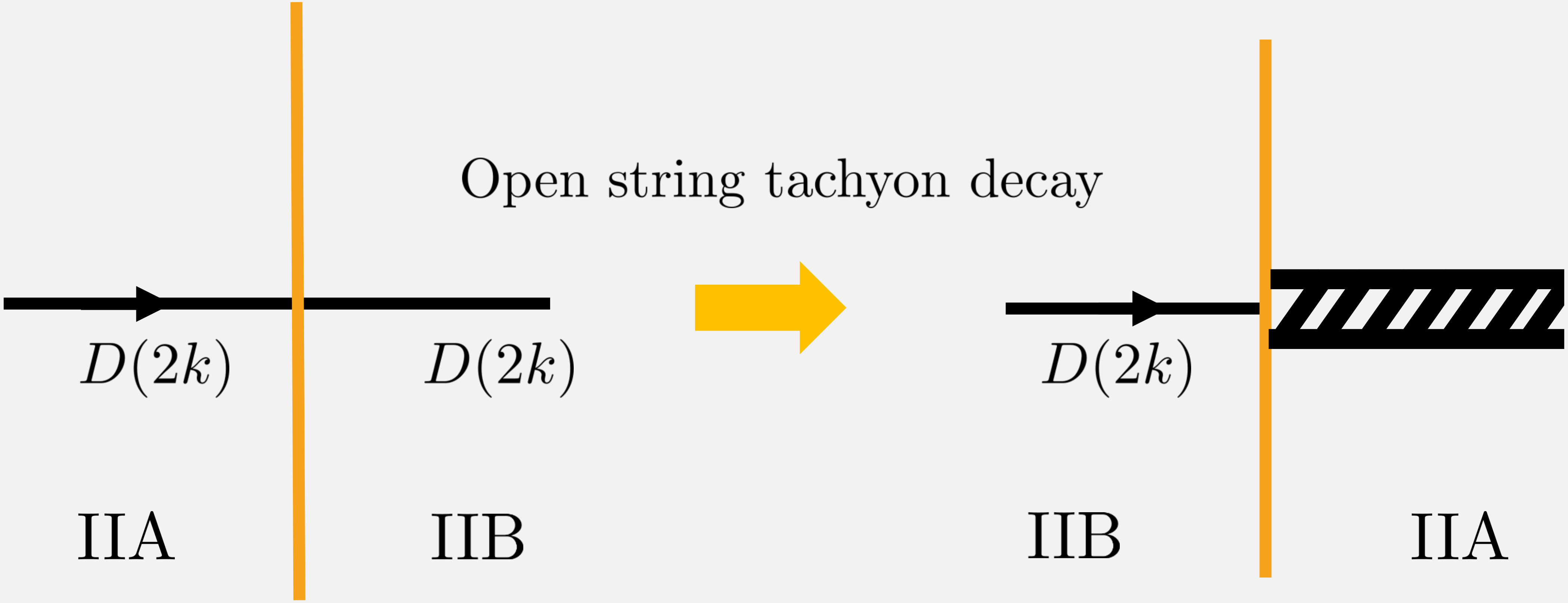


PROPERTY II: GSO INTERFACES AND SYMMETRY OPERATORS

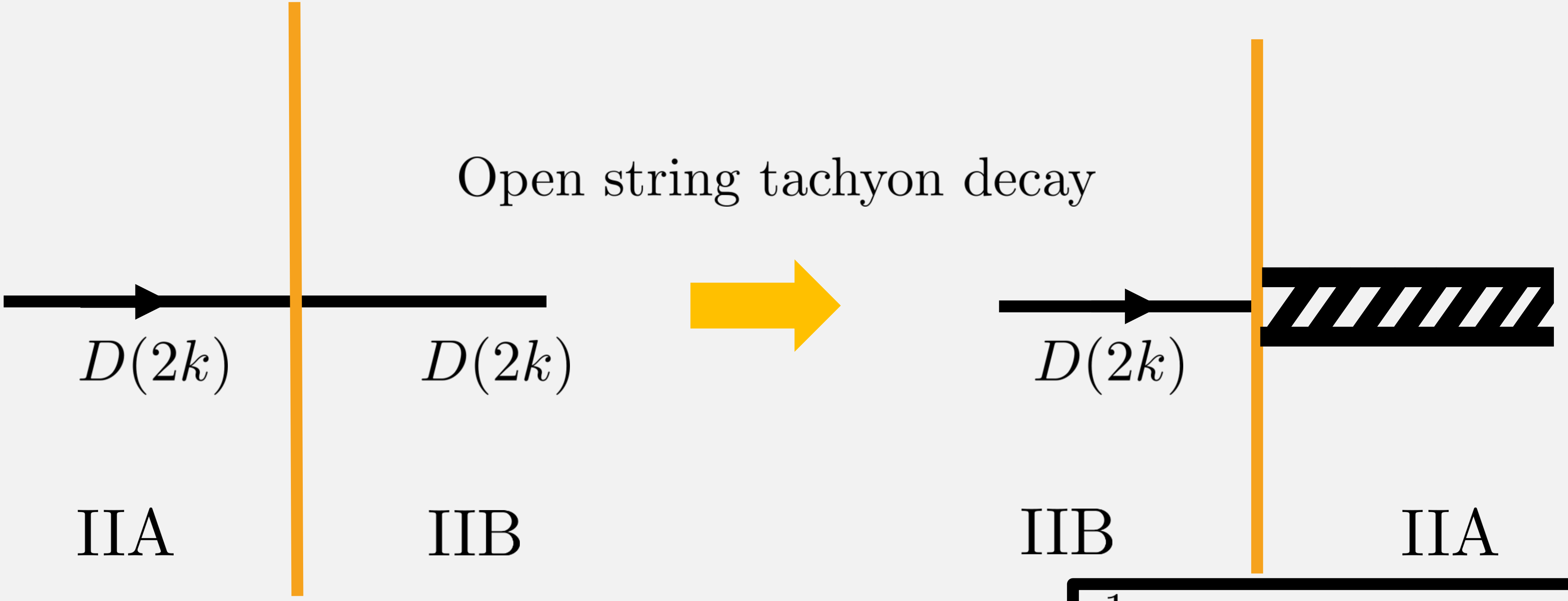


BULK PROPERTIES OF IIA/IIB WALL

D-BRANES GOING THROUGH WALL



D-BRANES GOING THROUGH WALL



We show this leads to interesting correspondence: $\boxed{\frac{1}{2}F^{\mathrm{RR}}_{2k+2} = C^{\mathrm{RR}}_{2k+2} \bmod 2\pi}$

R7 STABILITY

- One can use similar logic to the argument for stability of the new non-BPS heterotic branes

[Kaidi, Tachikawa, Yonekura '24]

- Namely, there is no candidate configuration of lower energy for the $R7$-brane to expand into

- $R7$ is $\mathbb{Z}_2$-charged and $(-1)^{F_L}$ is not a subgroup of a continuous group (contrast with ANO fluxtube)

R7 STABILITY

- One can go beyond this reasoning by considering how the $R7$-would resolve from the p.o.v. of a transverse string probe
- It would look like IIA/IIB on a cylinder!
- IIA/IIB wall being a finite tension will simply collapse

GSO WALL IN HO STRING THEORY

- Much of what we have said carries over to HO string theory

$$Spin(32)/\mathbb{Z}_2^s \qquad \mathcal{D}_{A/B} \qquad Spin(32)/\mathbb{Z}_2^c$$

- At $g_s >> 1$, this matches the *known* non-BPS $D8$-brane in Type I!

- $D7$-brane (analagous to the $R7$) is unstable since $\mathbb{Z}_2 \subset Spin(32)/\mathbb{Z}_2$

CONCLUSIONS

- Motivated by Cobordism Conjecture, we have proposed the existence of a IIA/IIB domain wall
- Appears as GSO interface on long string probe
- R7-branes in IIA and IIB string theory appear to be stable
- Closely related story for HO/Type I string

OUTLOOK

- Non-perturbative constructions of IIA/IIB wall and $R7$?
[w.i.p.]
- Interacting non-susy 8D CFT on $R7$?
- GSO domain wall between HO and HE string theories?
- Pheno applications from including $R7$ in compactifications?

THANK YOU!

GSO THETA ANGLES

- Up to choice of convention

$$\text{Integrating out Maj. fermion with } m = +\infty \implies \theta_L = 0 \bmod 2$$

$$\text{Integrating out Maj. fermion with } m = -\infty \implies \theta_L = 1 \bmod 2$$