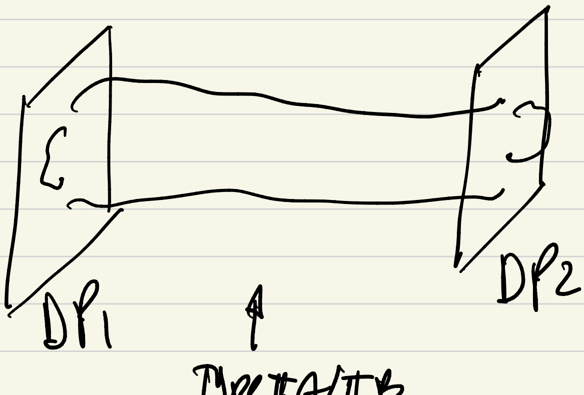
LECTURE VIII

open strings
&
D-branes

- given a D-brane system:
  - → what kind of open string?
  - → what kind of GSO projection?

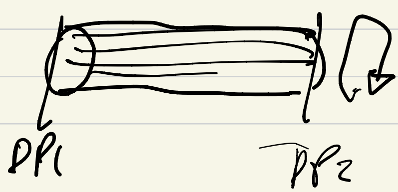


$$\Rightarrow \left(\begin{array}{c|c} H_{11} & H_{12} \\ \hline H_{21} & H_{22} \end{array}\right)$$

H_{ij} → GSO-PROJECTION

→ IIA/IIB
→ kind of D-branes

1-loop amplitude



① Parallel Dp-Dp system (BPS BRANE)

$$\Psi_{OPEN} = \left(\begin{array}{c|c} H_{11} & H_{12} \\ \hline H_{21} & H_{22} \end{array} \right)$$

bulk: $\frac{1}{2}$ SUSY PRESERVED

⇒ EXPECT OPEN STRINGS TO PRESERVE SUSY AS WELL

⇒ GSO is THE SAME FOR ALL 4 BLOCKS H_{ij}

$$GSO_{NS}^{(+)} \oplus \begin{cases} GSO_R^{(+)} \to \text{CHARGED D-BRANE} \\ GSO_R^{(-)} \to \text{ANTI D-BRANE} \end{cases}$$

A single Dp brane

NS: A_M in $D=10$ $\longrightarrow$ (A_μ, ϕ_i)

A_μ: GAUGE BOSON ON Dp brane

ϕ_i: TRANSVERSE SCALARS → TRANSVERSE POSITION OF THE D-BRANE

R: χ_α in $D=10$ $\longrightarrow$ $\chi_{a i}$ in $D=p+1$

(DIFFERENT CHIRALITY DEPENDING on BRANE/ANTIBRANE)

a: Spin of $SO(1,p)$

i: FLAVOUR

MULTIPLE D3 - BRANES

$M = (\mu, i)$ $\quad$ $\mu = 0, 1, 2, 3$ NEUMANN

$i = 4, \ldots, 10$ DIRICHLET

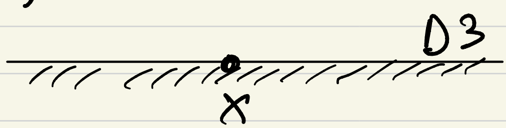
$$SO(1,9) \longrightarrow \underbrace{SO(1,3)}_{\text{LORENTZ}} \times \underbrace{SO(6)}_{\text{FLAVOUR}}$$

<u>NS SECTOR</u> $\quad GSO^{(+)}_{NS}$

$$A_\mu(p)\, c\psi^\mu e^{-\phi} e^{ip\cdot X}(x)$$

$$+$$

$$\Phi_i(p)\, c\psi^i e^{-\phi} e^{ip\cdot X}(x)$$



$$Q_B = 0 \Longrightarrow p^2 = 0 \quad p_\mu A^\mu(p) = 0$$

N^2 GAUGE BOSONS $+ \; 6 \times N^2$ TRANSVERSE SCALARS

$\Rightarrow U(N)$ Yang-Mills + scalars

N D-branes $\quad N \times N$ <u>CHAN PATON</u> MATRIX

R-sector $GSO_R^{(+)}$ N D3-branes

In 10D : $\chi^\alpha c S_\alpha e^{-\phi/2} e^{ip\cdot X}(x)$ $\alpha \in 16_c$ $SO(1,9)$

$$SO(1,9) \to SO(1,3) \times SO(6)$$

$$S_\alpha \sim e^{\pm\frac{1}{2}H_1} \cdots e^{\pm\frac{1}{2}H_5}$$

$$\alpha = \Big(\underbrace{\pm\tfrac{1}{2}, \pm\tfrac{1}{2}}_{\text{4 DIMENSIONAL SPINOR } SO(1,3)} \Big| \underbrace{\pm\tfrac{1}{2}, \pm\tfrac{1}{2}, \pm\tfrac{1}{2}}_{\text{FLAVOUR}}\Big)$$

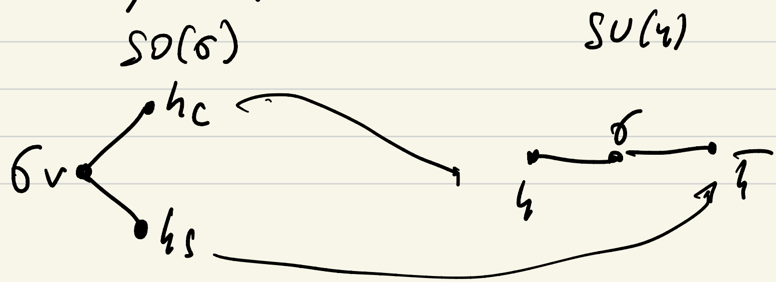
EVEN # OF "$-\frac{1}{2}$"

$SO(6) \simeq SU(4)$

$$\alpha = (a, I) \oplus (\dot{a}, \bar{I})$$

$I \to$ Weyl$^+$ of $SO(6)$ $\simeq$ 4 of $SU(4)$

$\bar{I} \to$ Weyl$^-$ of $SO(6)$ $\simeq$ $\bar{4}$ of $SU(4)$



$$\chi_\alpha \to \left(\chi^I_a , \chi^{\bar{I}}_{\dot{a}} \right)$$

4 left-handed + $\bar{4}$ right-handed

<u>GAUGINI</u>

NS + R

<u>$\mathcal{N}=4$ U(N)-SYM</u>

$$S = \frac{1}{g_s} \int d^4x \, \mathrm{Tr}\Big[F_{\mu\nu}F^{\mu\nu} + D_\mu \bar{\Phi}^i D^\mu \bar{\Phi}^i + \bar{\chi}^{\bar{I}} \not{D} \chi^I +$$

$$+ [\Phi_i, \Phi_j][\bar{\Phi}^i, \bar{\Phi}^j] + \bar{\chi}^I [\phi_i, \chi^{\bar{I}}] \gamma_i^{I\bar{I}}$$

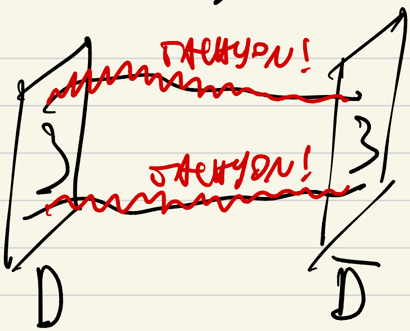
$$+ \alpha'\text{-corrections} \Big]$$

→ STRING'S AMPLITUDES REPRODUCE <u>ALL</u> THOSE INTERACTIONS + α' corrections

- $\beta(g) = 0$ $\qquad g_s = g^2_{YM}$

$$\begin{array}{c|l} A_\mu & s=1 \\ \chi_\alpha{}^I \;\; \bar{\chi}_{\dot{\alpha}}^{\bar{I}} & s=1/2 \\ \Phi_i & s=0 \end{array}$$

② D-$\bar{D}$ system



$$\to \left(\begin{array}{c|c} \phi_{DD} & \phi_{D\bar{D}} \\ \hline \phi_{\bar{D}D} & \phi_{\bar{D}\bar{D}} \end{array}\right)$$

<u>BULK</u>: SUSY IS BROKEN

$\to$ <u>NO SUSY FOR OPEN STRINGS</u>,

$$\phi_{DD} : GSO^{(+)}_{NS} \oplus GSO^{(+)}_{R}$$

$$\phi_{\bar{D}\bar{D}} : GSO^{(+)}_{NS} \oplus GSO^{(-)}_{R}$$

$$\left.\begin{array}{l} \phi_{D\bar{D}} : GSO^{(-)}_{NS} \oplus GSO^{(+)}_{R} \\ \phi_{\bar{D}D} : GSO^{(-)}_{NS} \oplus GSO^{(-)}_{R} \end{array}\right\} \to \text{STRETCHED STRINGS}$$

$D\bar{D}$

→ NO R-R charge

→ NO SUSY

→ TACHYON IN THE OPEN STRING SECTOR

⇒ $D\bar{D}$ system is UNSTABLE (TACHYON)

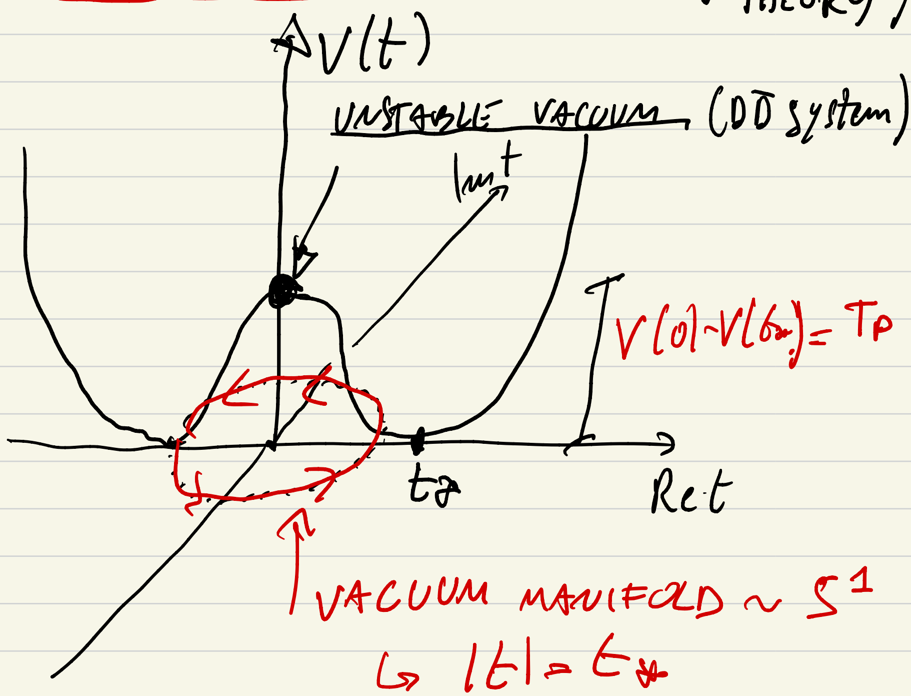
→ D-brane DECAY ⇒ TACHYON CONDENSATION

⇒ TACHYON EFFECTIVE POTENTIAL (STRING FIELD THEORY)

$$\begin{pmatrix} 0 & t \\ \bar{t} & 0 \end{pmatrix}$$

↑

TACHYON FIELD $\in \mathbb{C}$



• CONSTANT SOLUTION

$$t = t_{tr} \qquad V(0) - V(t_{tr}) = \tau_{D\bar{D}} \quad !!$$

→ 1st Sen's conjecture

⇒ $t = t_{tr}$ represents NO D-BRANES

→ 2nd Sen's conjecture

→ NO D-BRANES → NO OPEN STRINGS!

⇒ NO PERTURBATIVE ON-SHELL FLUCTUATIONS!

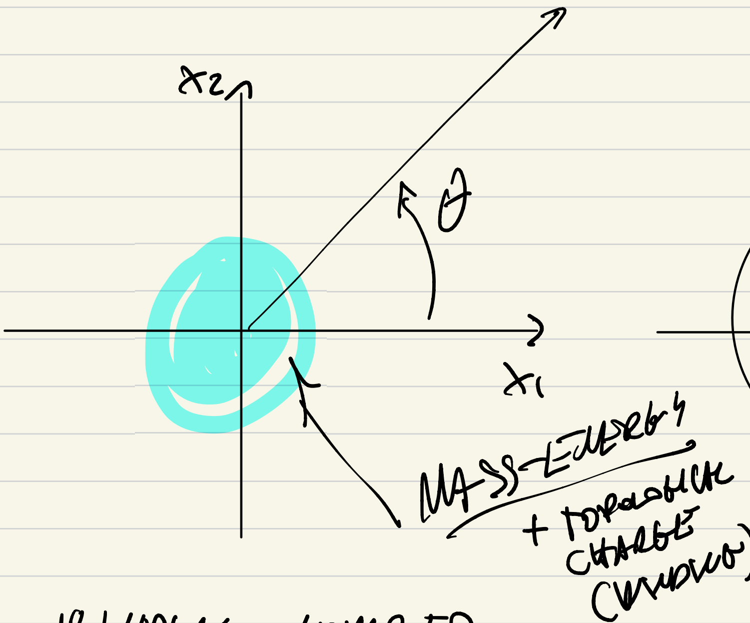
→ 3rd Sen's conjecture

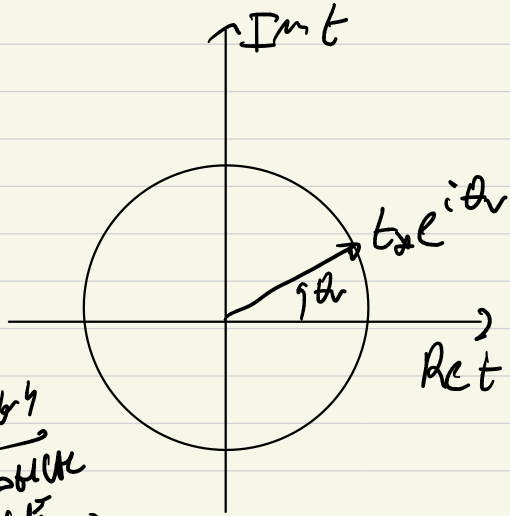
→ Non trivial solutions describing LOWER DIMENSIONAL D-BRANES!

→ VORTEX SOLUTIONS

$t(x^\mu) \qquad \mu = 0, \ldots, p$ | WORLD VOLUME

$$t(x_1, x_2) = t(|x| e^{i\theta}) \xrightarrow[|x| \to \infty]{} t_\infty e^{i\theta_v}$$





WINDING-NUMBER

map: $S_1^{(x_1,x_2)} \longrightarrow S_1^{(\text{TACHYON})}$

$t_m(x_1, x_2) \qquad m \in \mathbb{Z} \to$ VORTEX SOLUTIONS

m → $m > 0 \to m$ Dp-2 branes

m → $m < 0 \to m$ $\overline{\text{D}p\text{-}2}$ branes

→ OSFT on a set of EQUAL # OF

D9 - $\overline{D9}$ $\boxed{\text{Type IIB}}$

⇓ TACHYON CONDENSATION

ALL Type IIB branes are reproduced!

⊕ closed string vacuum

Type IIA (non-BPS D9)

⇓ TACHYON CONDENSATION

All type IIA BRANES

⇒ SEN'S CONJECTURES

- Superstring : 1) ✓ → ANALYTICALLY PROVEN
  2) ✓
  3) → still to prove!

- Bosonic : 1) ✓
  2) ✓ → ANALYTICALLY PROVEN
  3) ✓

→ NEW PICTURE OF D-BRANES

D-branes : CLASSICAL SOLUTIONS OF A MICROSCOPIC OPEN STRING FIELD THEORY

D-branes ≡ OPEN STRING SOLITONS.

$$T_p \sim \frac{1}{g_s} = \frac{1}{g^2_{open}}$$ ⇒ THE CLASSICAL DEPENDENCE