Title: String creation and effective field theory

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Abstract: We will discuss the missing pieces in the understanding of the effective field theory description of string creation, the T-dual of the Hanany-Witten effect, both in the open and closed string picture. We explain the origin of the \'bare\' Chern-Simons term, so far added in by hand. There however remain unsettled issues concerning the need to modify the DBI action and the interpretation of this term in M-theory.

Outline

- String creation a review
- Open string description
  - -Effective field theory
- Closed string description
  - -Arvis gauge and duality relations
- Summary and conclusions

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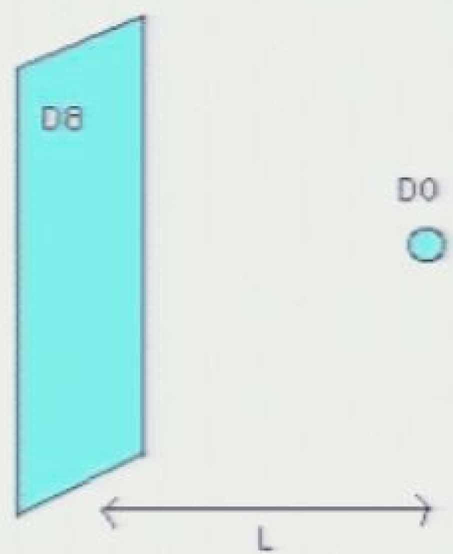
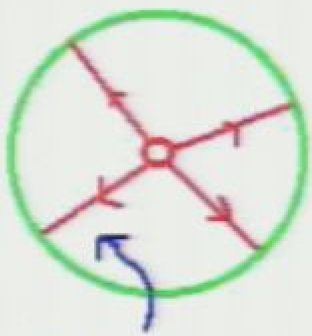
Supersymmetric configuration of branes

- $4n$ relatively transverse dimensions, n some integer
- Consider the $D0 - D8$ system

	x^0	x^1	x^2	x^3	x^4	x^5	x^6	x^7	x^8	x^9
$D8$	•	•	•	•	•	•	•	•	•	
$D0$	•									





- Consider wrapping the $D8$ brane on an S_8
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$$d\star(e^{(-2\phi)}dB_2) = 2\Lambda\star(dC_1 + \Lambda B_2),$$

where $\Lambda = \star dC_9$

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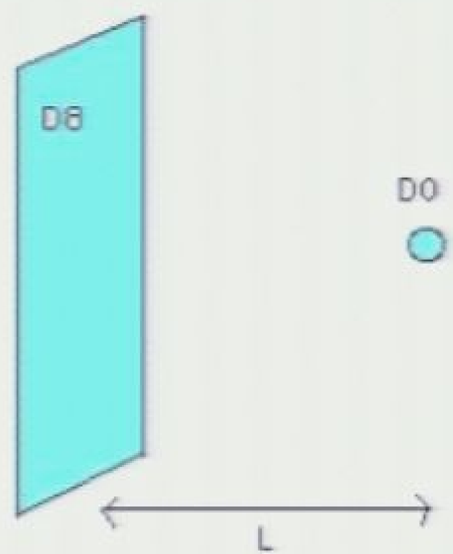

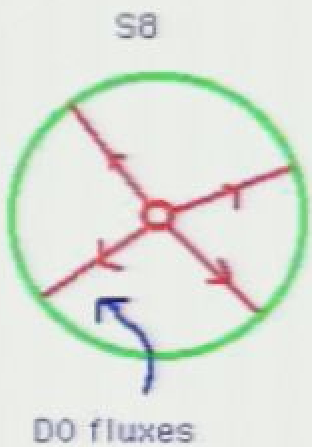

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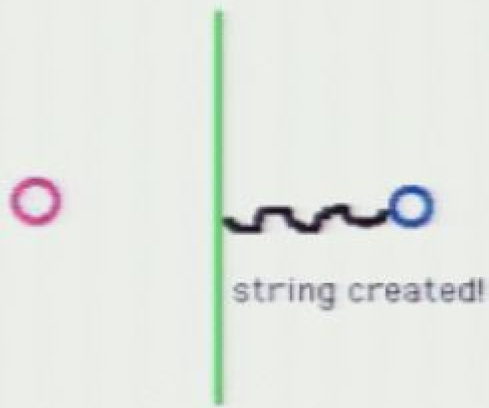
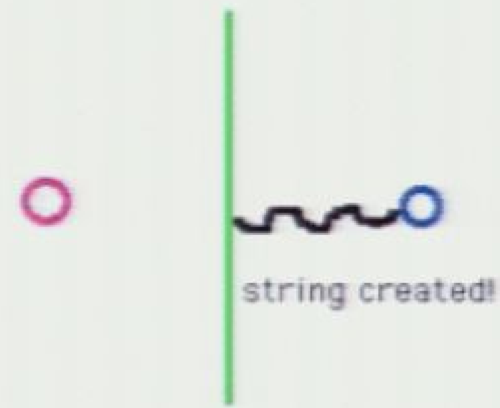


- Gauss's Law implies string creation to cancel induced NS flux
- Conclusion should hold even in the decompactification limit
- True for all other configurations related via T-duality

Open string description

- Ground state of stretched string is a fermion
- Low energy effective action -$(0,8)$ quantum mechanics



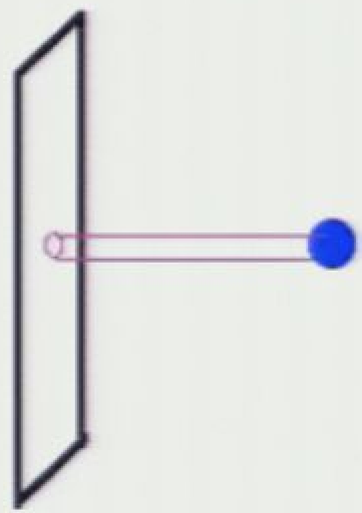
$$\mathcal{L}_\sigma = [-i\sigma^\dagger\dot{\sigma} - \sigma^\dagger(L + A_0)\sigma],$$

- $A_0 = A_0^{(8)} - A_0^{(0)}, L = X_9^{(8)} - X_9^{(0)}$

1-loop effective potential

$$V_{\text{eff}} = \frac{1}{2}|A + L|$$

- Born- Oppenheimer approximation -> vacuum energy
- Effective potential not consistent with-
  1. large gauge transfn.
  2. supersymmetry



Bare term and string creation

- bare term = $\frac{1}{2}(A_0 + L)$
- total potential cancels on one side of $D8$, but adds up on the other
- captures string creation! but where did it come from?

Open string calculation

- repeat 1-loop calculation carefully in open-string theory

$$\int_0^\infty \frac{dt}{2t}\sqrt{8\pi^2\alpha' t}\, e^{-L^2 t/(2\pi\alpha')}$$

$$\mathrm{tr}_R\Big(\frac{1+(-1)^{F_0+G_0}\Gamma_{\mathrm{R}}}{2}e^{-2\pi t(L_0-a_{\mathrm{R}})}\Big)$$

$$+\mathrm{tr}_{NS}\Big(\frac{1+(-1)^{F_0+G_0}\Gamma_{\mathrm{NS}}}{2}e^{-2\pi t(L_0-a_{\mathrm{NS}})}\Big)$$

$$= \quad \frac{1}{2}|L| \pm \frac{1}{2}|L|$$

Open string calculation

- $F_{(\mathrm{R,R})} = \mathrm{tr}_R((-1)^{F_0}\Gamma_{\mathrm{R}})|L|/2$ usually vanishes, but not in this case.
- two towers of super-ghost states

$$F_{\mathrm{R}}(x,q) = -\sum_{n=0}^{\infty}\left(x^{2n} <\downarrow|\downarrow> - <\uparrow|\uparrow> x^{2n+1}\right).$$

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& + \mathrm{tr}_{NS}\left(\frac{1+(-1)^{F_0+G_0}\Gamma_{\mathsf{NS}}}{2} e^{-2\pi t (L_0 - a_{\mathsf{NS}})}\right) \\
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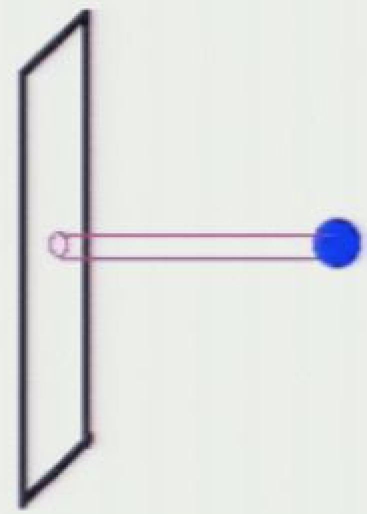
Local world-line SUSY

- put ghosts back in EFT i.e. couple EFT to local world-line SUSY
- ghosts action $\sim \beta G \gamma = \beta(\partial_\tau \pm i(L + A_0))\gamma$
- looks like gauged supergravity

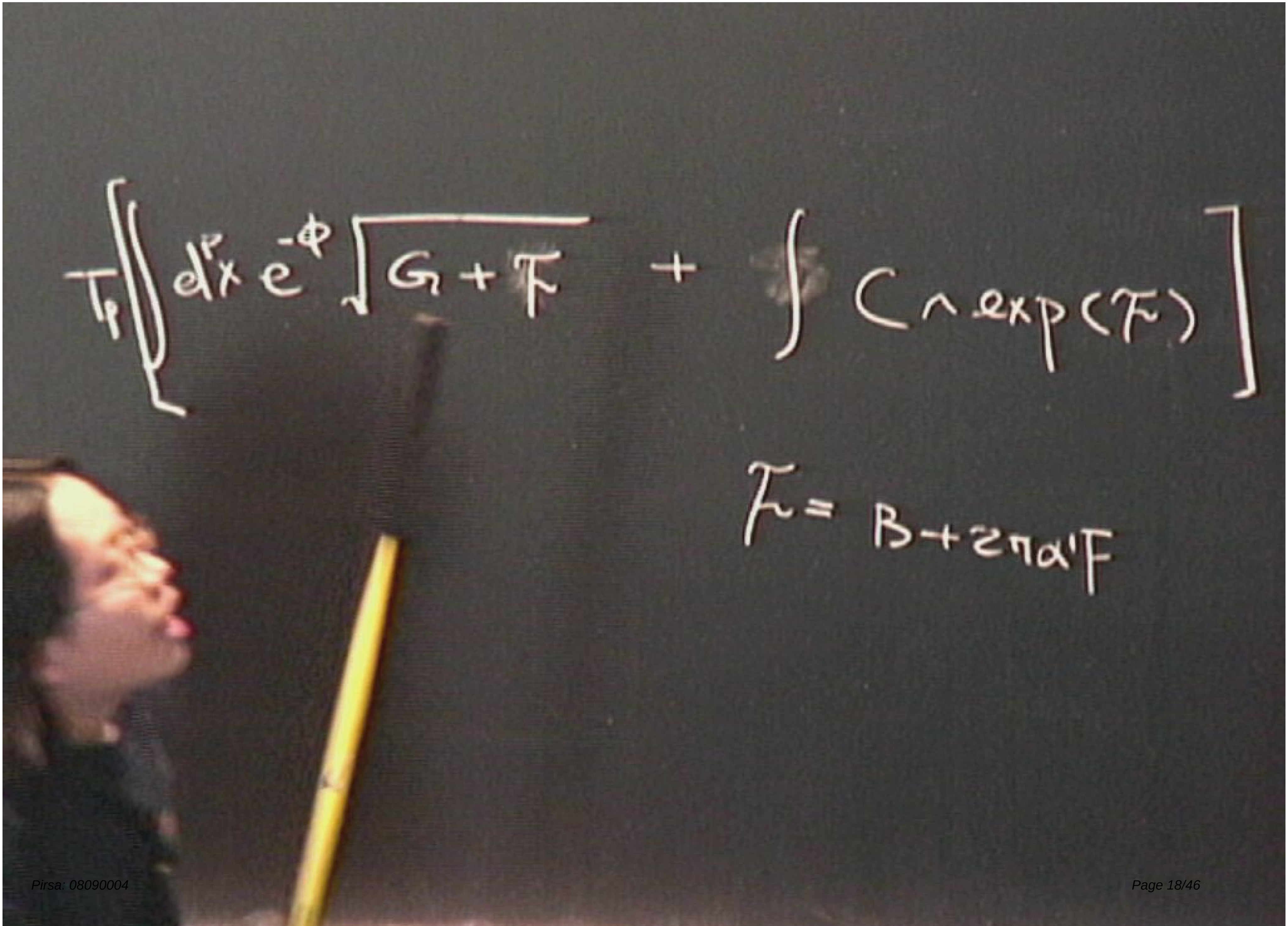
Closed string picture

- open string 1-loop = closed string tree level
- consider DBI action of Dp in $D(8-p)$ background

$$T_p \int d^{p+1}\sigma \exp(-2\phi)\sqrt{\det(G+}$$
$$+ \quad T_p \int C \wedge \exp(\mathcal{F})$$



- in general effective potential $V_{\text{eff}} = T_p \int d^{p+1}x H_q^{(r-4)/4}$
- for D0-D8 $V_{\text{eff}} = \frac{1}{4\pi\alpha'}\int d\tau L$


$-T_p\left[\int d^px\, e^{-\Phi}\sqrt{G+\mathcal{F}} + \int C\wedge \exp(\mathcal{F})\right]$
$\mathcal{F} = B + 2\pi\alpha' F$

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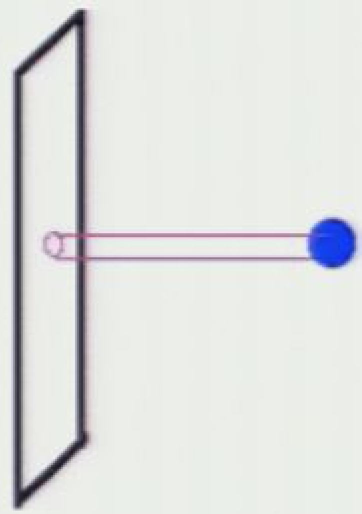

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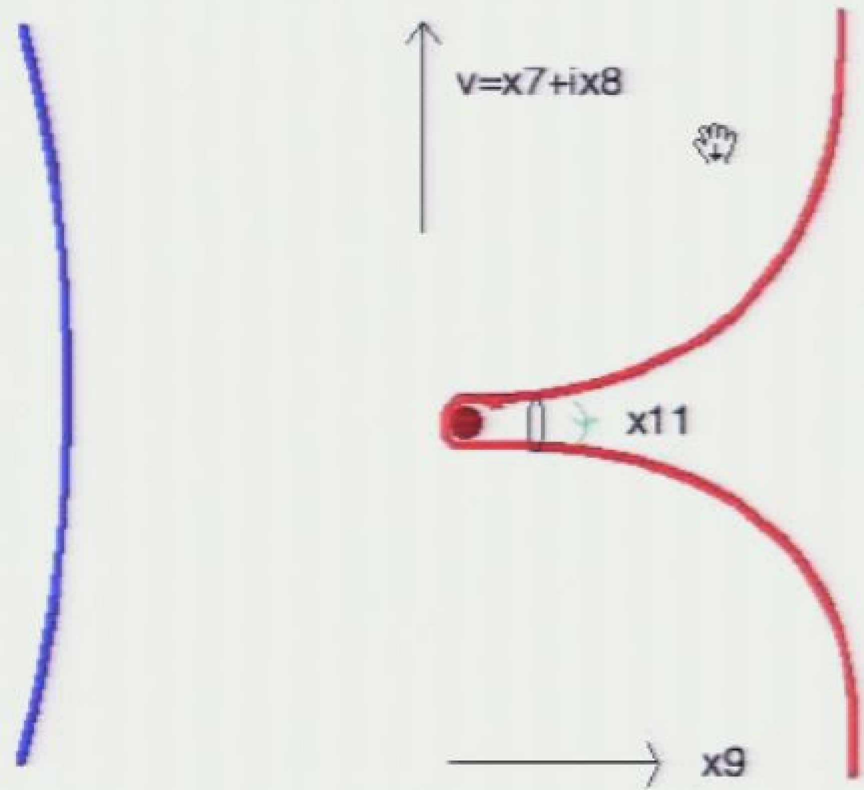
Brane solutions and lift to M-theory

- D2-D6 can be readily lifted to M-theory
- M2 solution in Taub-Nut space - a complex curve

$$y = \exp(-b), \qquad y = \exp(-b)v,$$

- $y = e^{-(x_9 + ix_{11})}(-x_9 + \sqrt{(x_9)^2 + |v|^2})^{\frac{1}{2}}$
- $v = x_7 + ix_8$ and R_{11} scaled to 1 .

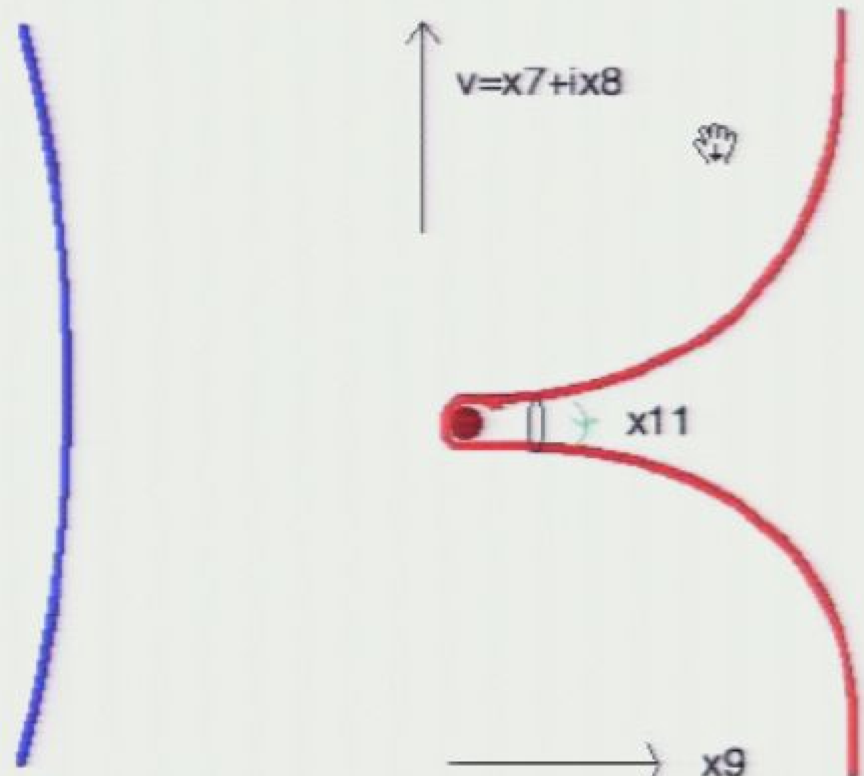


$$\frac{d|v|}{dx_9} = \frac{3e^{(x_9-b)}}{\sqrt{2x_9 + e^{2(x_9-b)}}}(x_9 + e^{(x_9-b)})$$

Net force on M2

- $$\begin{aligned} E &= T/2 \int dz d\bar{z} g_{\mu\nu} \partial X^{\mu} \bar{\partial} X^{\nu} \\ &= 2\pi T \{ \int dx_9 (1 + e^{2(x_9 - b)}) + \int |v| d|v| \} \end{aligned}$$

- $$F \equiv \frac{dE}{db}\bigg|_v = 2\pi T \frac{1}{2}$$



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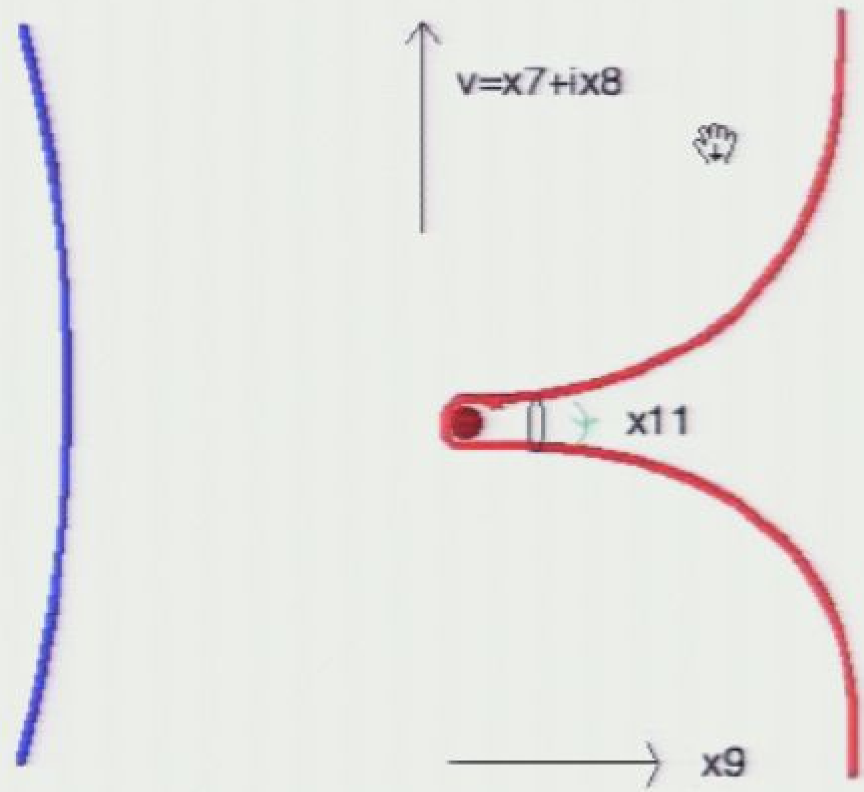

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Duality relations

- $$V_{\text{eff}} = < Dp|\Delta|Dq >,$$
- boundary states:

$$\partial_\tau X^l_{\tau=0}|B_X >= 0, \qquad \partial_\sigma X^t_{\tau=0}|B_X >= 0,$$
$$\psi^l - i\eta\tilde{\psi}^l|_{\tau=0}|B_\psi, \eta >= 0, \qquad \psi^t - i\eta\tilde{\psi}^t|_{\tau=0}|B_\psi, \eta >= 0,$$

- non-zero contribution from V_{NSNS} *and* V_{RR}
- V_{RR} corresponds to "bare term"
- stems from non-vanishing $< C_0|C_{012345678} >= -1$

Closed string extension of Arvis gauge

- get rid of ghosts in light-cone gauge
- Arvis gauge : pick different gauges for left and right movers

$$\partial_+ X^+ = \alpha' p_+, \qquad \partial_- X^- = \alpha' p_-.$$

Closed string extension of Arvis gauge

-

$$X^+ = x_0^+ + \alpha' p^+ \sigma_+ + \alpha' \hat{p}^+ \sigma_- + \sqrt{\frac{\alpha'}{2}} \sum_{n \neq 0} \tilde{\alpha}_n^+ \exp(in\sigma_-),$$

$$X^- = x_0^- + \alpha' \hat{p}^- \sigma_+ + \alpha' p^- \sigma_- + \sqrt{\frac{\alpha'}{2}} \sum_{n \neq 0} \alpha_n^- \exp(in\sigma_+).$$

- on-shell condition

$$p^\pm = \hat{p}^\pm.$$

Superstring generalisation - RNS

- NSNS sector $\psi_+^+ = \psi_-^- = 0$, where $\psi^\mu = (\psi_-^\mu \quad \psi_+^\mu)^\mathsf{T}$
- RR sector

$$\begin{aligned} \Gamma^+|\Psi_\mathsf{L}> &= 0, \\ \Gamma^-|\tilde{\Psi}_\mathsf{R}> &= 0, \end{aligned}$$

Superstring generalisation - GS

- $$\Pi^{\mu}_{\alpha} = \partial_{\alpha} X^{\mu} - i\bar{\theta}^{a}\Gamma^{\mu}\partial_{\alpha}\theta^{a}.$$

- $$\Pi^{+}_{+} = p^{+}, \qquad \Pi^{-}_{-} = p^{-},$$
  $$\Gamma^{-}\theta^{1} = 0, \qquad \Gamma^{+}\theta^{2} = 0.$$

- RR potentials given by (e.g. type IIA)

$$C_{+I_1 \ldots I_{2n}} = |\dot{m} > (\gamma^{I_1} \ldots \gamma^{I_{2n}})_{\dot{m}\dot{n}} |\dot{\tilde{n}} >,$$

-

$$\Gamma^{\mu} = \begin{pmatrix} 0 & \gamma^{\mu}_{m\dot{n}} \\ \gamma^{\mu}_{\dot{m}n} & 0 \end{pmatrix}$$

- naturally reproduces duality relationship in conformal gauge

Gauged fixed boundary state

- Our gauge choice automatically implies

$$\alpha_n^0 + \tilde{\alpha}_{-n}^0 |B, \eta >= \alpha_n^9 - \tilde{\alpha}_{-n}^9 |B, \eta >= 0.$$

-

$$|B_{I_1 \ldots I_p, 9} >= \exp(\sum_{q>0} (\frac{1}{q} T_{IJ} \alpha_{-q}^I \tilde{\alpha}_{-q}^J) - i M_{mn} S_{-q}^m S_{-q}^n) |B_0 >,$$

- $T_{IJ} = \{-\delta_p, \delta_{8-p}\}, M_{mn} = (\gamma_{i_1} \cdots \gamma_{i_p})_{mn}$
- $|B_{I_1 \ldots I_p, 9} >$ couples to $|C_{+I_1 \ldots I_p} >$

Effective potential from boundary states

- repeat calculation of $V =< Dp|\Delta|Dq >, \Delta = \int \frac{d^2z}{|z|^2} z^{L_0} \bar{z}^{\tilde{L_0}}$
-

$$L_0 = p^+(\hat{p}^- - p^-) = -p^+p^- + \frac{p^I p^I}{2} + N^\perp$$

-

$$\begin{aligned} V_{\text{eff}} &= W \int d^2z \int \frac{d^{d_{\perp Dp+Dq}}Q}{(2\pi)^{d_{\perp Dp+Dq}}} |z|^{\alpha' Q^2/2} \exp(iQ.L) \text{tr}(TT') \\ &= \frac{1}{2}|L|(1 \pm 1) \end{aligned}$$

- fermionic zero modes contribute $\mathrm{tr}(\gamma^1 ... \gamma^8) = \pm 8$
- contribution changes sign under parity - string creation

Still unsettled issues

- problem with propagator- off mass shell suggests non-vanishing coefficient of σ
- incorporate the new term in the DBI action?
- interpretation in M-theory

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Summary

- Gauss's law implies string creation
- effective theory description depends on existence of bare term
- open string - world-line supergravity
- closed string - duality relation
- unsettled issues - DBI action and M-theory

Thank you.