SD-Branes in String Theory

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Strings 2003

Kyoto

Collaborators

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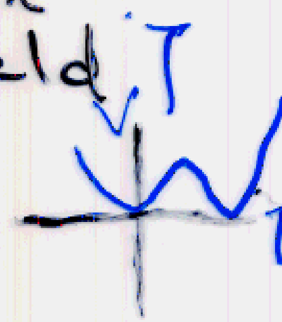
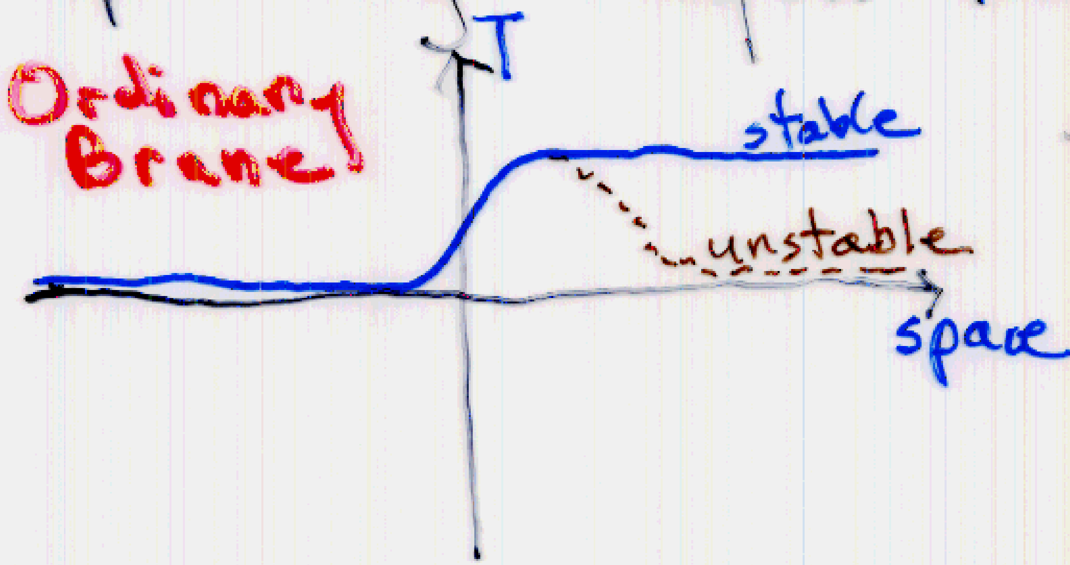
S(pacelike) brane

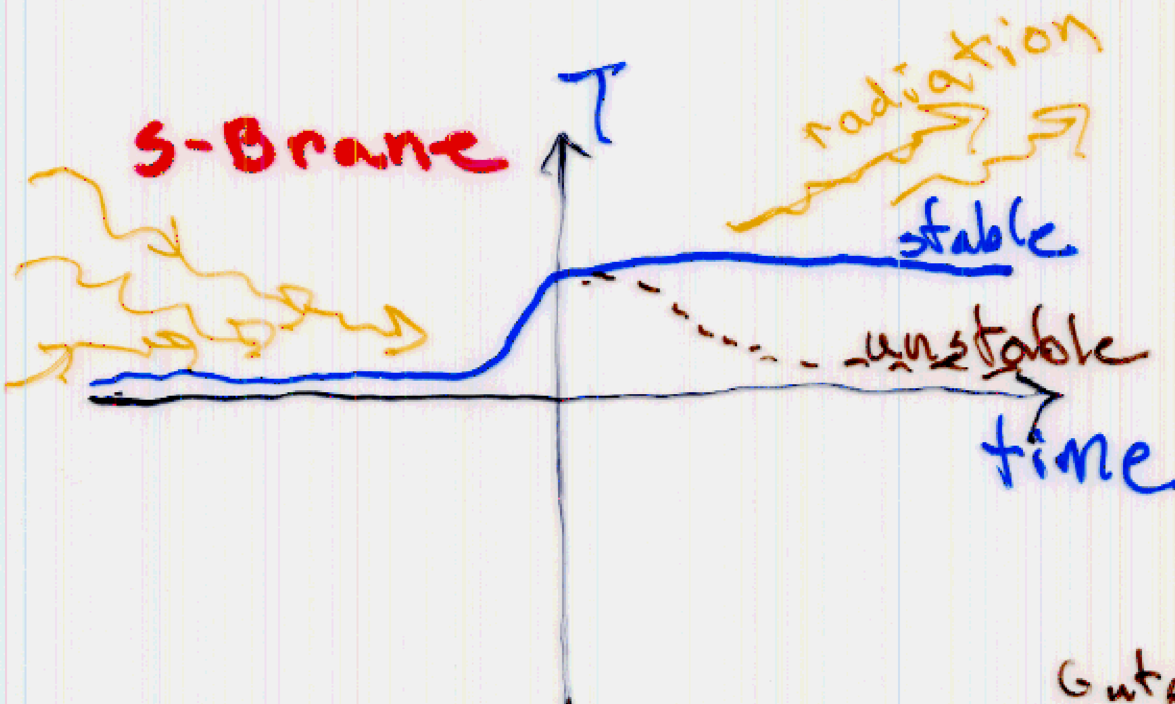
= Brane w/ transverse *time* direction

Can be viewed as a kink in open string tachyon field





Sen



Gutperle & AS

Requires energy.

It is hoped that the study of these and related backgrounds will yield insights into the deep conceptual issues surrounding time-dependent string theory. Over the last year we have begun to understand g_s string perturbation theory in this context. This talk will describe several interesting features that have emerged. Much remains to be understood.

Later talks will discuss $c=1$ analogs.

"Exact" BCFT Description

$$S = \int_{\text{world sheet}} \left(\partial \vec{X} \cdot \bar{\partial} \vec{X} - \partial X^0 \bar{\partial} X^0 \right) + S_{\text{boundary}}$$

$$S_{\text{boundary}} = \lambda \int d\tau \cosh X^0(\tau)$$ Full s-brane creation/de[cay]

Sen

$$= \lambda \int d\tau \, e^{X^0(\tau)}$$ Half s-brane, decay

Gutperle A[s]

Though related by analytic continuation to soluble Sine Gordon / Liouville BCFTs, these theories are mathematically quite subtle, corresponding to new physical phenomena

Chen Li Lin
Okuda Sugimoto
Lambert Liu
Maldacena
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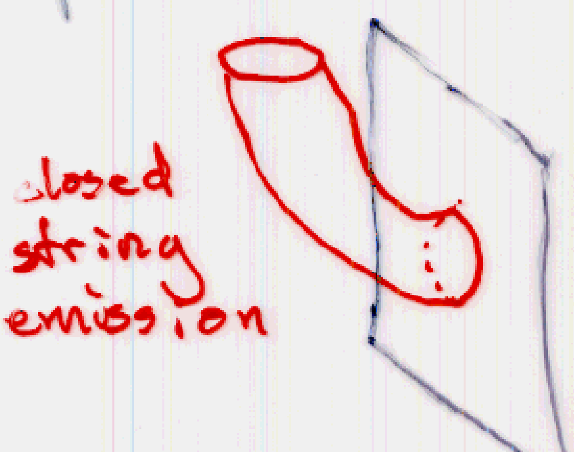
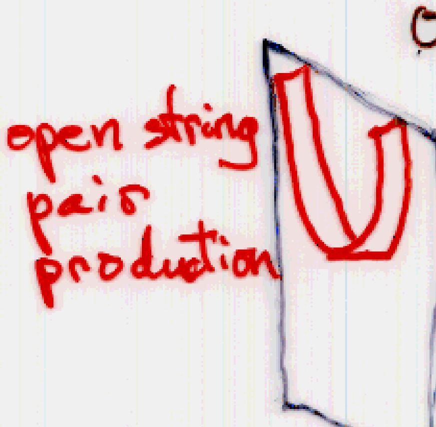
Larsen Constable
Naqvi Terashima
Sugawara





still incompletely understood.

$\boxed{\lambda = \pm\frac{1}{2} \text{ SD-Branes}}$

The full s-brane boundary interaction is part of an SU(2) current algebra

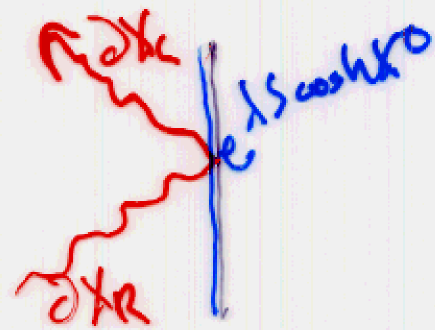
$$j_3 = \frac{1}{2}\partial X^0$$

$$j_1 = \cosh X^0$$

$$j_2 = i\sinh X^0$$

$j_i j_j \sim \epsilon_{ijk} j_k + \delta_{ij}$

w/ funny hermiticities. So $e^{\lambda\int \cosh X^0}$ generates an SU(2) rotation $2\pi\lambda$.



For $\lambda \to \pm\frac{1}{2}$

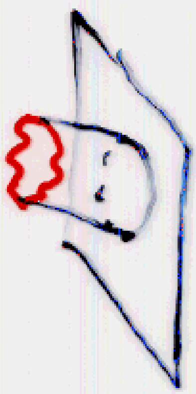
Neumann $\longrightarrow$ Dirichlet

s-brane $\longrightarrow$ SD-brane

Where is the sD-brane?

The sD-brane has a Dirichlet boundary condition on ~~the~~ the time coordinate, so it is an "event". To locate use:

time part



$$= |B\rangle = |\delta(\vec{x}_T)\rangle |\delta(\vec{p}_\perp)\rangle |B_0\rangle$$

$$|B_0\rangle = P e^{2\pi i \lambda} |N\rangle$$

$$= \left(\frac{1}{1+\sin\pi\lambda\, e^{x^0}} + \frac{1}{1+\sin\pi\lambda\, e^{-x^0}} - 1 \right) |0\rangle$$

sen

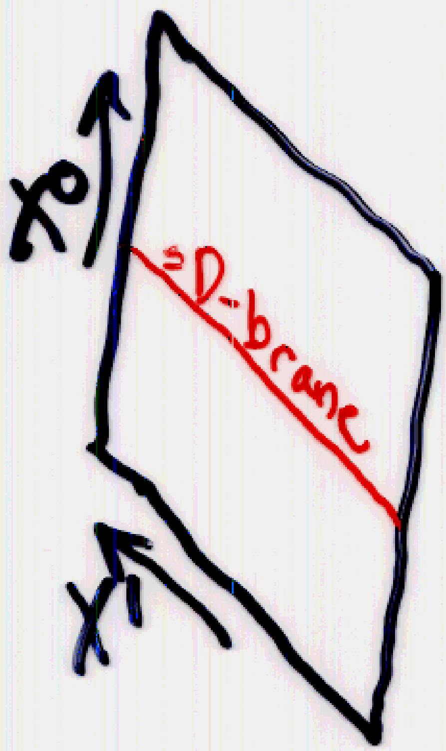
+ oscillators

$\lambda \to -\frac{1}{2}$

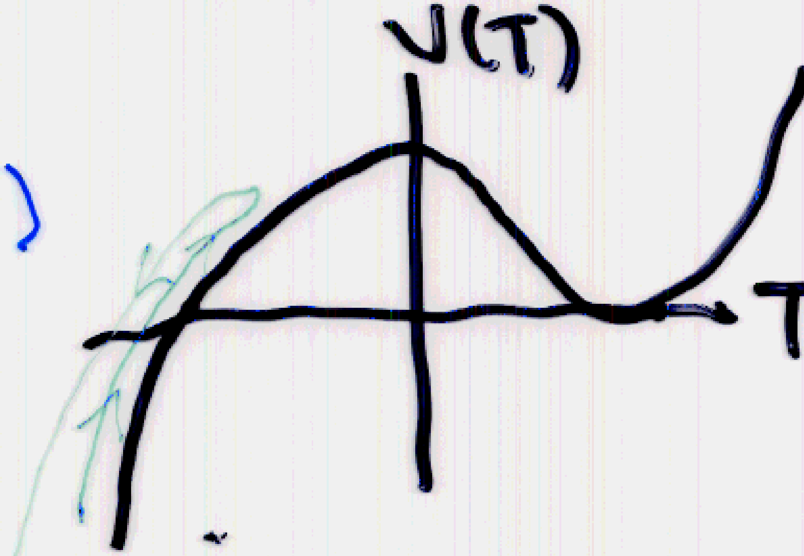
$$\to \sum_m |\delta(x^0 + 2\pi i m)\rangle$$

Okuda Sugimoto

This is a delta-function at $X^0 = 0$



Tachyon rolls up and back from $-\infty$:



$T^L_{\mu\nu} = \delta_{\mu\nu}\,\delta(X^0)\,\delta(\vec{X}^\perp)$

$T^T_{\mu\nu} = 0$

$\partial^\mu T_{\mu\nu} = 0$

$T_{00} = 0$!

Construction relies crucially on most unphysical aspects of bosonic string: no super analog.

$\boxed{\lambda \neq \frac{1}{2}}$

Has superstring analog.
Find

$$|B_0\rangle = \sum_{n\,odd} \delta(X^0 + i\pi i n)$$

$$= 0 \quad \forall \text{ real } X^0$$

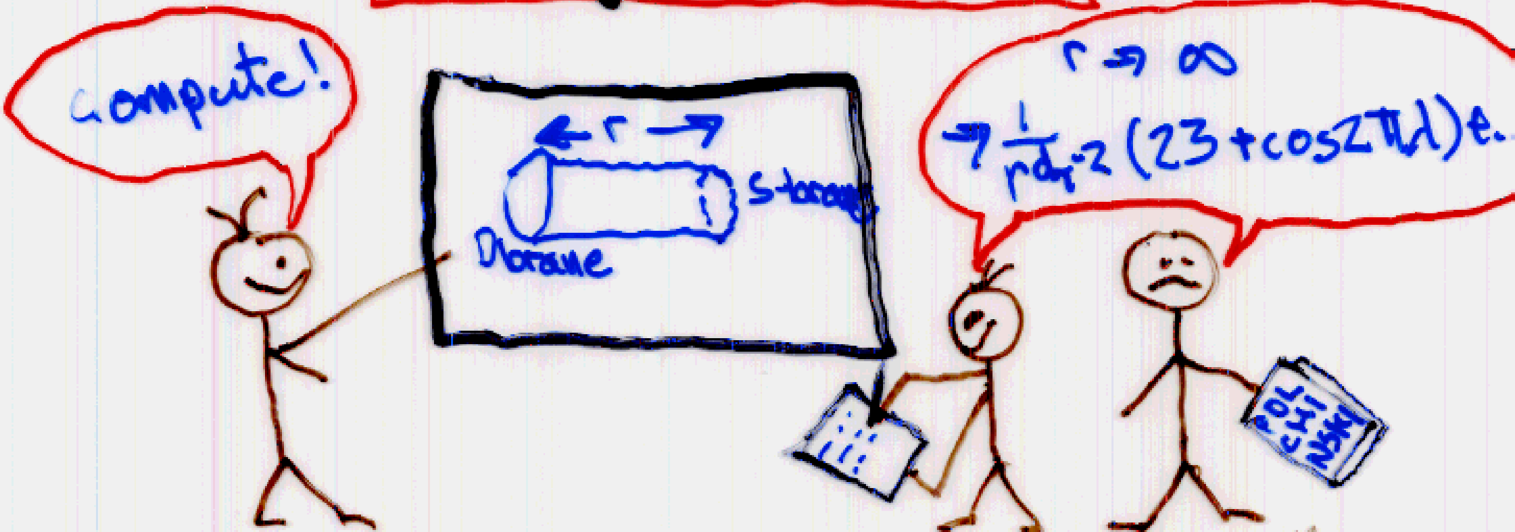
$$(\neq 0 \text{ for } \lambda < \tfrac{1}{2})$$

?

$\Rightarrow$ $\lambda = \frac{1}{2}$ is closed string vacuum. Sen

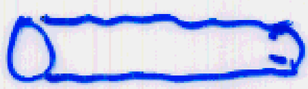
But this seems to conflict with recent experimental data....

Experiment



Maloney
Yin

As $\theta \to \lambda \to \frac{1}{2}$



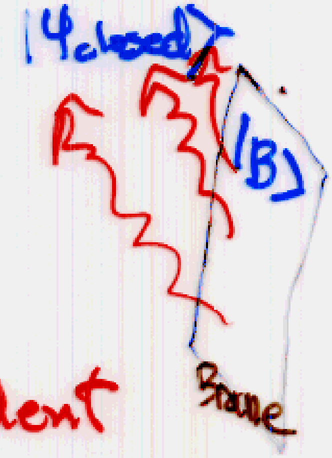
$$\frac{24}{r^{d_t-2}} \to \frac{23}{r^{d_t-2}}$$

Callan Klebanov
Ludwig Maldacena

So even at $\lambda = \frac{1}{2}$, a D-brane probe sees a disturbance in the force of order $\frac{1}{g}$. HOW IS THIS CONSISTENT WITH

$$|B_0\rangle \Big|_{\substack{\lambda=\frac{1}{2} \\ x^0 \in \mathbb{R}}} = 0 \;???$$

The single closed string state sourced by the s-brane is



$$|\psi_{closed}\rangle = \frac{1}{L_0 + \bar{L}_0}\,|B\rangle$$

Ambiguous   zero eigenvalues when time dependent

Consider

$$\Box\phi = \delta^4(\vec{x}, t - t_0)$$

solution

$$\phi(x) = \int d^4y\, \Delta_F(x-y)\,\delta^4(\vec{x}, t-t_0)$$

$$= \frac{1}{(t-t_0)^2 - r^2 + i\epsilon}$$

Now suppose $t_0 = i\Pi$ is imaginary

$$\phi(x) = \frac{1}{(t-i\Pi)^2 - r^2}$$

Obeys

$$\Box\phi = 0 \quad \text{for real } t.$$

String ws perturbation theory normally adopts this type of prescription and hence "sees" delta functions in $|B\rangle$ at imaginary t!

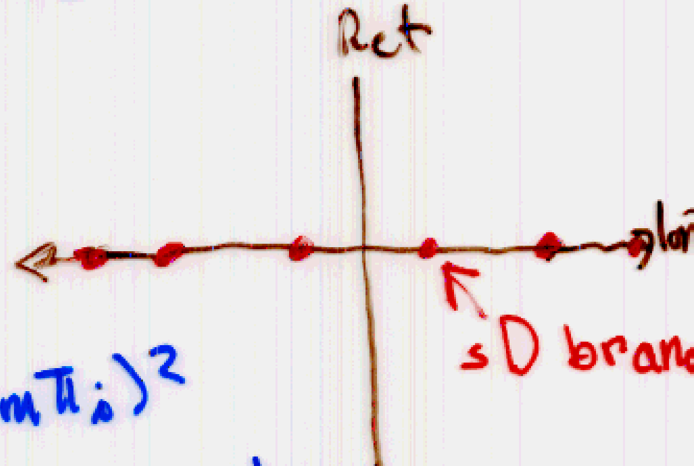
Dilaton

As an example, the dilaton component of

$$(L_0+\bar{L}_0)|\psi_{closed}\rangle = |B\rangle$$

is ($d_\perp = 3$)

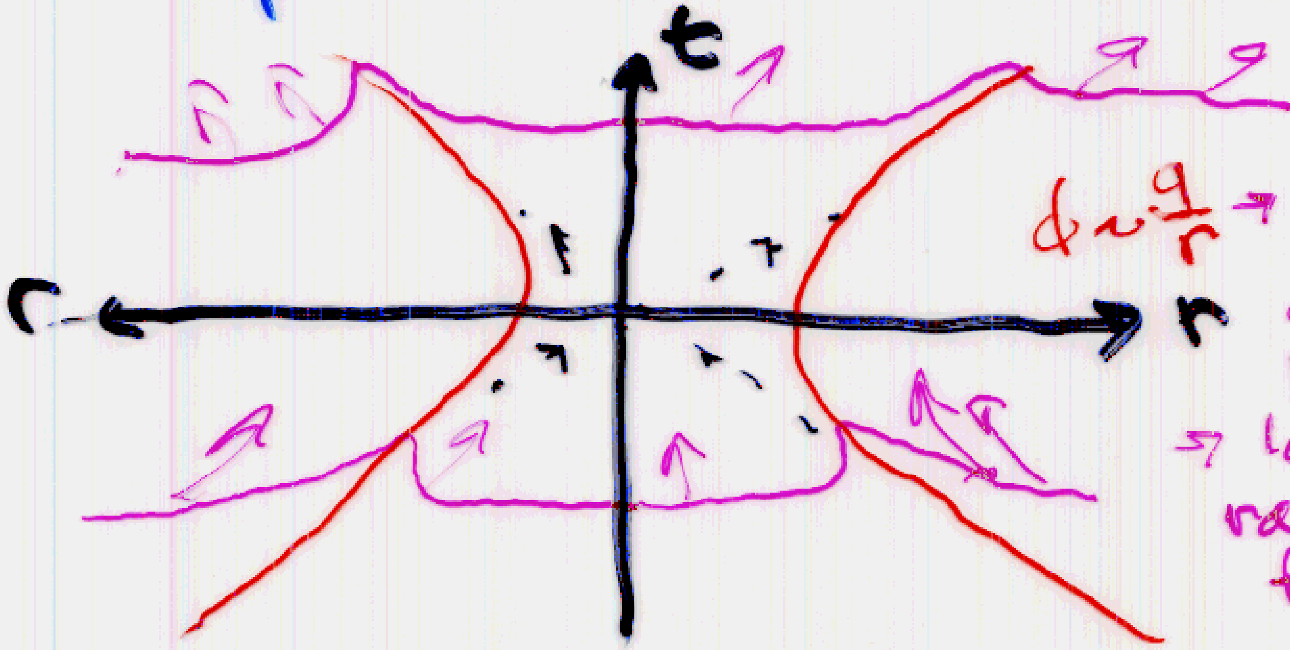
$$\Box\phi = g\sum_{m\ odd}\delta^4(\vec{x},\, t+m\pi i)$$



A solution is

$$\phi = \frac{g}{r}\sum_{m\ odd}\frac{1}{r^2-(t+m\pi i)^2}$$

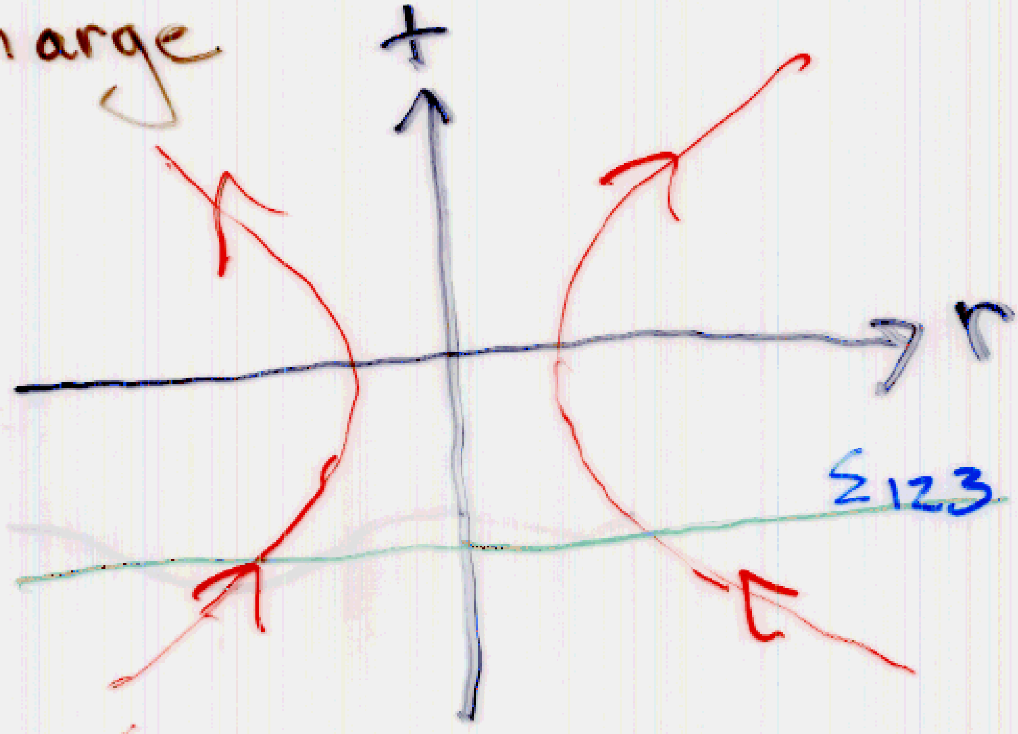
$$= \frac{g}{r}\left(\tanh\frac{r+t}{2}+\tanh\frac{r-t}{2}\right)$$



$\phi \sim \frac{g}{r}$ → looks like ordinary D-brane → long range force

s-Charge

In the superstring, a similar computation gives the RR field. One finds a nonvanishing s-charge

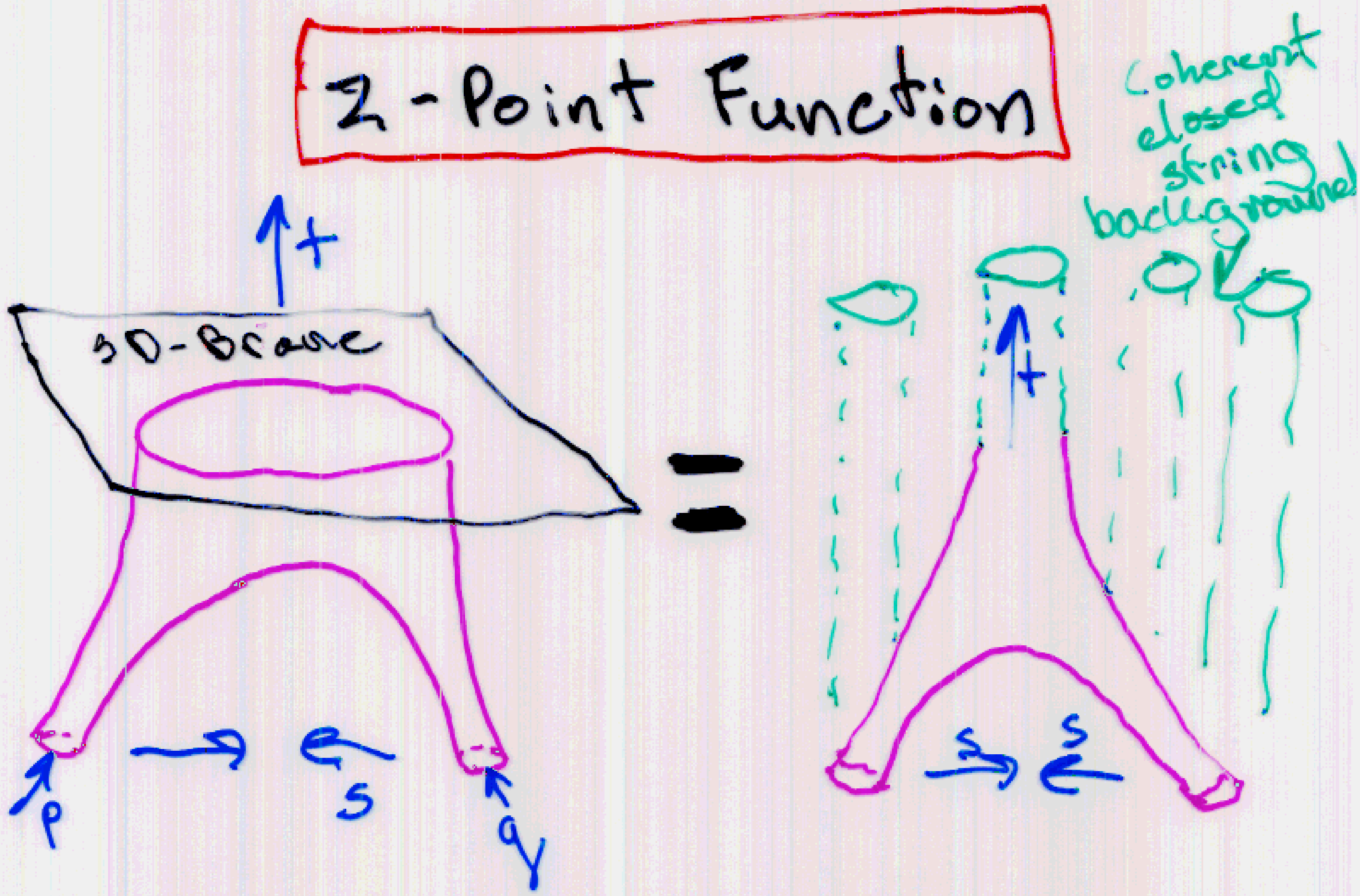


$$C_{456789} = \frac{1}{8\sqrt{2}\pi^2 r}\left[\frac{1}{\cosh\frac{r-t}{\sqrt{2}}} - \frac{1}{\cosh\frac{r+t}{\sqrt{2}}}\right]$$

$$Q_s = \int_{\Sigma_{123}} * dC = \frac{1}{2}$$

MHS

2-Point Function



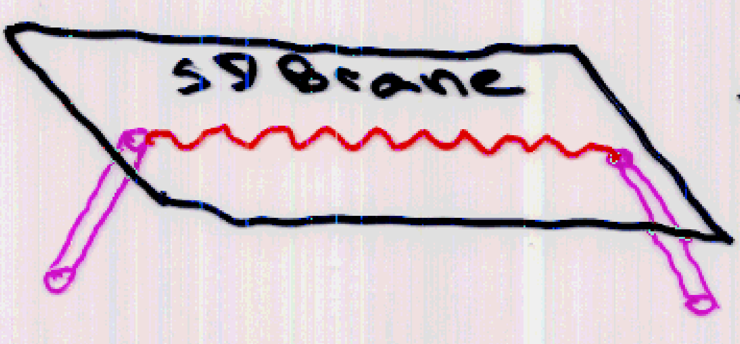
$s = p_{\parallel}^2 = q_{\parallel}^2 \qquad t = (p_\perp + q_\perp)^2 \approx -E^2$

$$\text{Amplitude} = \frac{1}{2\sinh\frac{\pi E}{2}} \sum_K \frac{(2-s)(3-s)\cdots(1+K-s)}{2K!} \times \delta\left(K-1-\frac{E^2}{4}\right)$$

closed string on-shell

No s poles,
but → constant s → 0

Gaiotto Itzhaki Rastelli



Can probe low energy SFT on sD-brane by low s scattering.

Summary

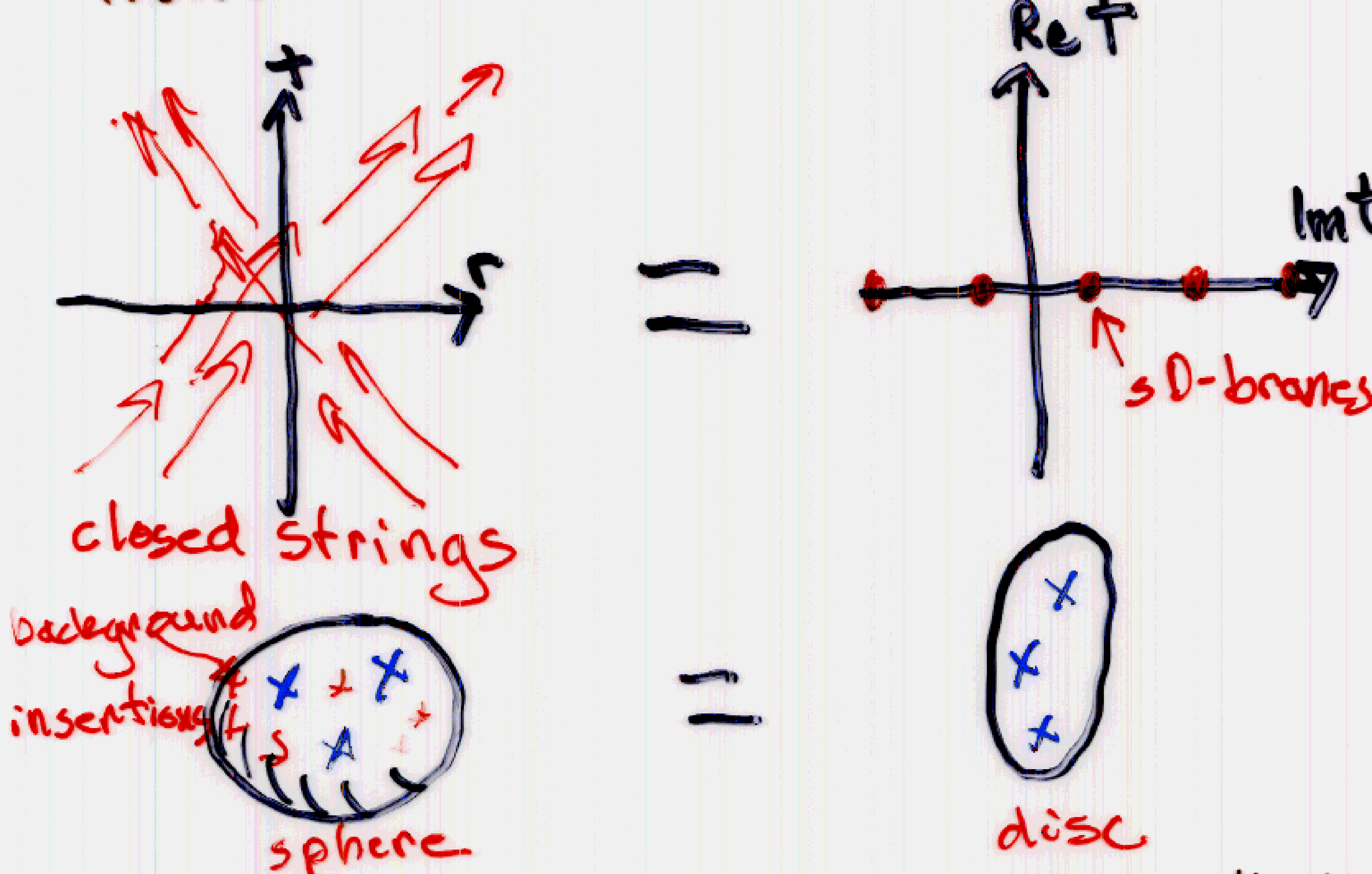
The closed string state

$$|\Psi_{closed}\rangle = \frac{1}{L_0+\bar{L}_0}|B\rangle$$

is not uniquely determined from $|B\rangle$ it depends on the propagator choice. Sen's $|\Psi_{closed}\rangle = 0$, is a consistent solution, but is not the one implicit in the usual string ws perturbation theory. Rather one finds an interesting "non-perturbative" (in the sense of D-branes) closed string field obeying $(L_0+\bar{L}_0)|\Psi_{closed}\rangle = 0$ with very special properties ....

Open/Closed Duality

It has a dual open string description:



Maloney Yin AS

This can be further generalized by moving location of sD-branes in complex t plane.

Gaiotto Itzhaki Rastelli

Large N Limit

How, if at all, is this related to AdS/CFT open/closed duality? Consider the case of an array of N sD-branes

Then

$$(L_0+\bar{L}_0)|\psi_{closed}\rangle = gN|B\rangle$$

has nontrivial for

$$g\to 0,\ N\to\infty\ ;\ gN \text{ fixed}$$

Defining both sides of this equation would give an example of timelike holography.

Before closing I'd like to mention the mysterious thermal properties of sD-branes. Notice

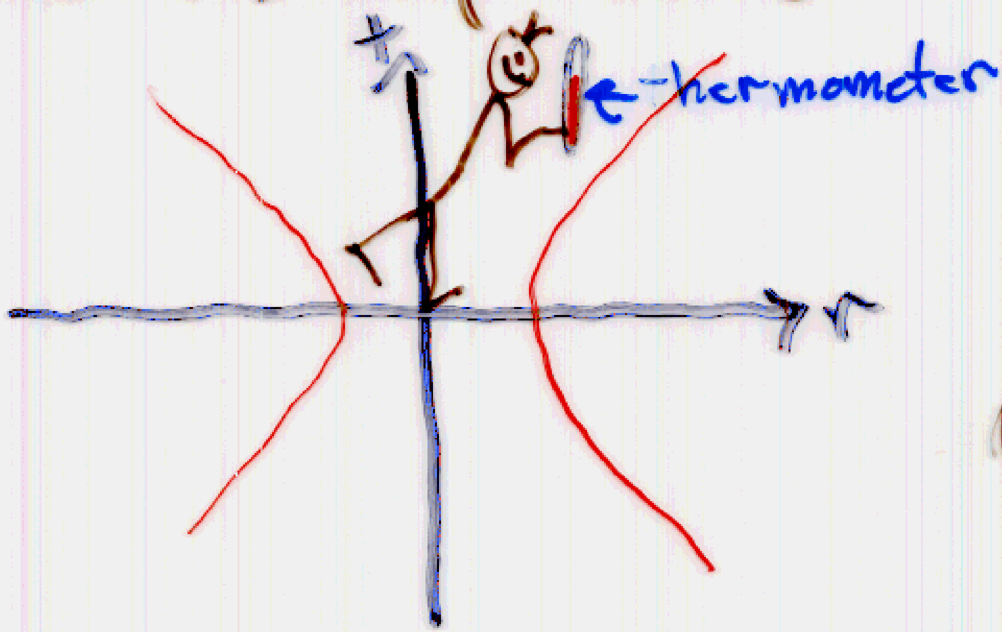
s-brane ws $\qquad S_{boundary} = \lambda \oint \cosh X^0$

spacetime fields $\qquad \phi = \frac{1}{?}(\tanh(r+X^0) + \tanh(r-X^0))$

black hole $\qquad ds^2 = -(1-\frac{2m}{r})(dX^0)^2 + \ldots\ldots$

de Sitter $\qquad ds^2 = -(1-\Lambda r^2)(dX^0)^2 + \ldots$

are all classical solutions periodic in imaginary time. S-brane observers measure this temperature



Maloney, Lin, AS

How does this fit with the rest of the puzzle?

Conclusions

Investigations into time-dependent tachyons in string theory have led to intriguing & surprising discoveries. We don't know what is around the next corner.