Brane decay in curved space-time

Dan Israël, IAP, Univ. Pierre et Marie Curie

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D. I., JHEP **0704** (2007)

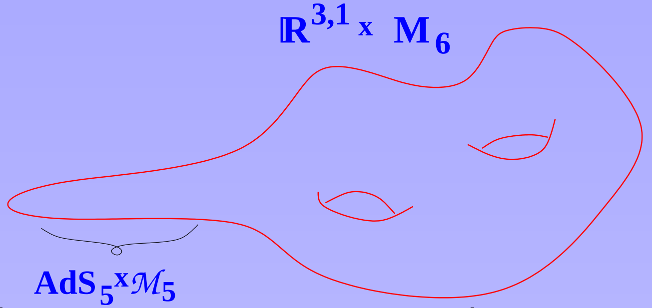
Outline of the Talk

1. Introduction & motivations from cosmology
2. Brane decay in flat space-time
3. Brane decay in AdS
4. Closed and open string emission
5. Open string tachyons in non-critical strings (geometric and universal)
6. Brane decay in non-critical strings
7. Conclusions

① *Brane inflation & open string tachyons*

✔ Natural setting of string cosmology: flux compactification of type II string theory, with stabilized moduli

➥ generically warped throats develop



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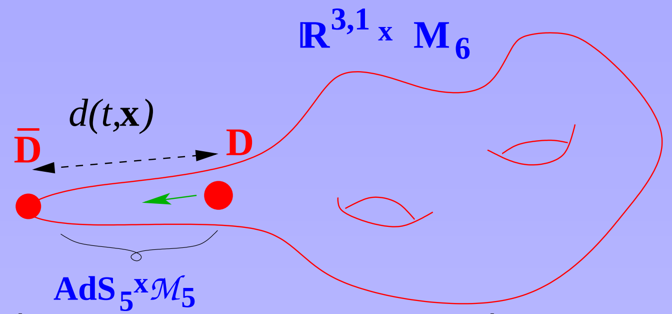

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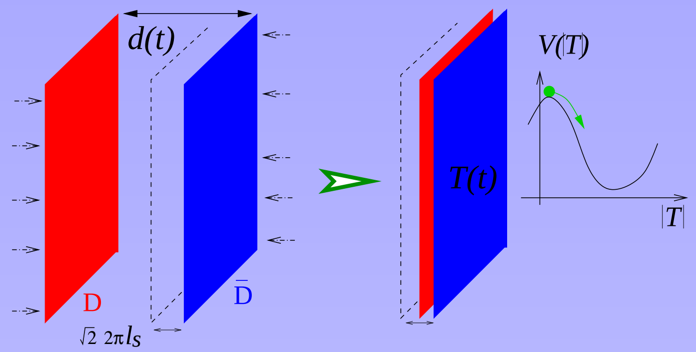
✔ D-brane/ anti D-brane pair in the throat: Coulombian attraction redshifted by AdS_5 metric ➥ slow-roll inflation *(inflaton $d(t,\mathbf{x})$)* *[Kachru, Kallosh, Linde, Maldacena, McAllister, Trivedi '03]*

Tachyon condensation & Brane Reheating

✔ End of inflation: D-$\bar{\text{D}}$ annihilation ➥ open string tachyon for $d^2 < 8\pi^2\ell_s^2$



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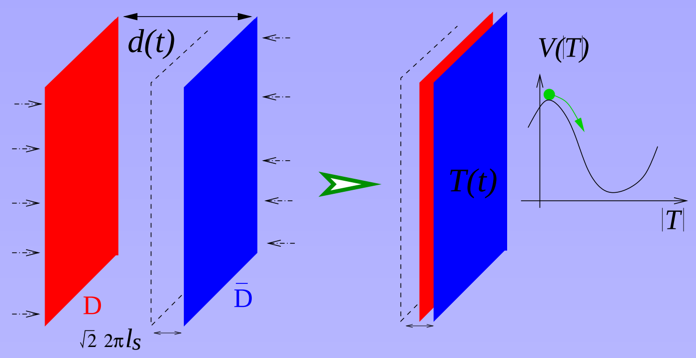

★String theory realization of hybrid inflation

✔ Tachyon condensation: involves all the massive string modes $(m > {}^1/\ell_s)$
➥ string corrections important

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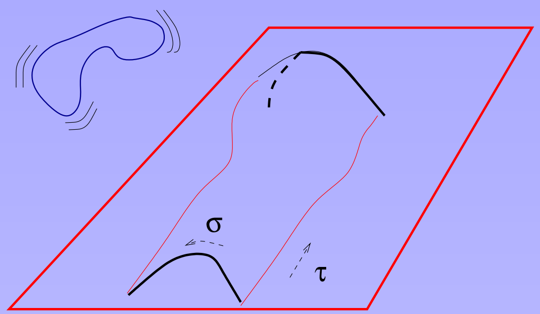
➥look for curved spacetimes (especially warped geometries) where the D-brane decay can be followed exactly (at the perturbative level)

② Brane Annihilation: Flat Space-Time

✔ Decay of an unstable D-brane: *equivalent to coincident D-$\bar{D}$ pair with no relative velocity (using $(-)^{F_L}$ orbifold)* ➥ solvable worldsheet string model *[Sen '02]*



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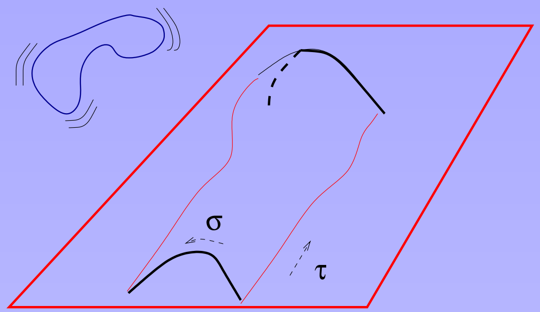

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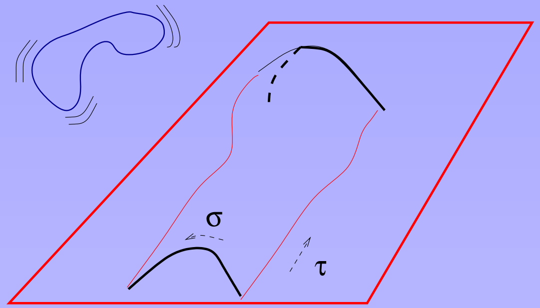

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★Closed strings production *(coherent state)*

Number of emitted strings *(tree-level)*: $\mathcal{N} = \int \frac{\mathrm{d}E}{2E}\, \rho(E)\, |\langle V_E \rangle_\lambda|^2$ *[Lambert, Liu, Maldacena '03]*

✔ Density of closed strings oscillators $\rho(N)$

➥ exponentially growing *(cf. Hagedorn transition at high temperature)*

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✔ One needs a UV cutoff at $E \sim m_{\mathrm{D0}}$

★fraction of total energy in strings of mass $m \sim$ cst. (up to m_{D0})

➥ most energy in strings $m \sim m_{\mathrm{D0}}$, non-relativistic ($p \propto {}^1\!/\ell_s\sqrt{g_s}$): tachyon dust

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5. Conjecture has been checked in 2D string theory

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★In particular, if all the brane energy is not radiated into massive closed strings, the whole picture may be challenged

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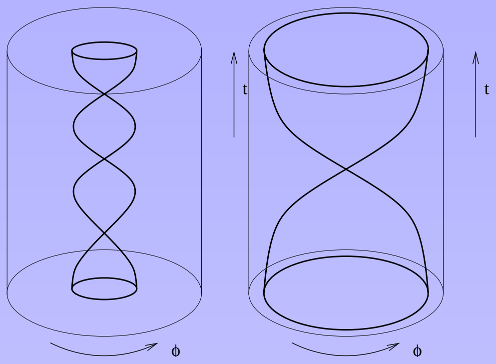

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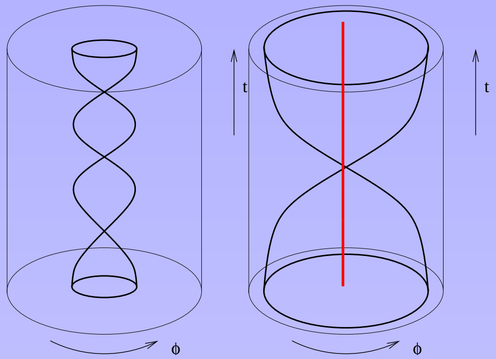

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✔ Unstable D0-brane of type IIB superstrings in AdS$_3 \times \mathcal{M}_7$: localized at the origin $\rho = 0$ (infrared) ➥ decay of the brane solvable *(equivalent to D-$\bar{\text{D}}$ annihilation)*

Closed Strings Emission by the brane decay

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$$\left|\langle V_{p_\rho,w,E}\rangle_\lambda\right| \propto \sqrt{\frac{\sinh 2\pi p_\rho \sinh \frac{2\pi p_\rho}{k}}{\cosh 2\pi\rho + \cos\pi(E-kw)}} \frac{1}{|\sinh \frac{\pi E}{\sqrt{2k}}|} \textit{ with } E = \frac{kw}{2} + \frac{2}{w}\left[\frac{p_\rho^2+\frac{1}{4}}{k} + N + \cdots\right]$$

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★Total number of emitted closed strings given by the imaginary part of the annulus one-loop amplitude, using *optical theorem + open/closed channel duality*

$$\mathcal{N} = \mathrm{Im}\left[\int \frac{\mathrm{d}s}{2s} \mathrm{Tr}_{\mathsf{open}} e^{-\pi s \mathcal{H}}\right]$$

✔ As in flat space, an important input is the asymptotic density of string states

★ $E \sim \frac{2N}{w}$ ➥ $\rho(E) \sim E^{\alpha} \exp\{2\pi\sqrt{(1-\frac{1}{2k})wE}\}$ ($while$ $|\langle V_E \rangle|^2 \sim \exp\{-\sqrt{\frac{2}{k}}\pi E\}$)

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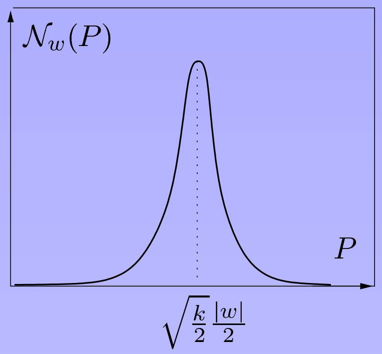

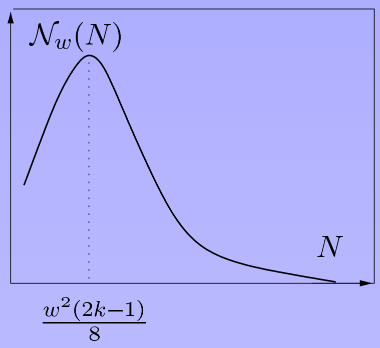

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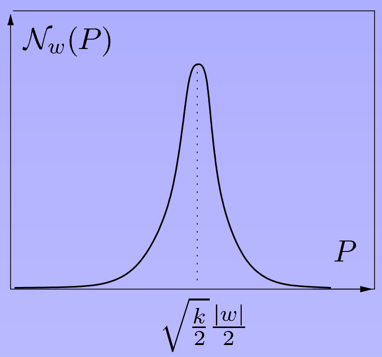

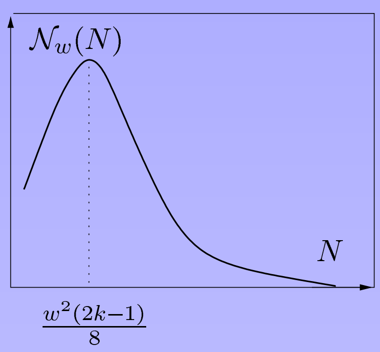

- Displacement of $\langle p_\rho \rangle$ due to non-perturbative corrections in ℓ_s^2 *(worldsheet instantons)*
  ➥ not seen in semi-classical limit

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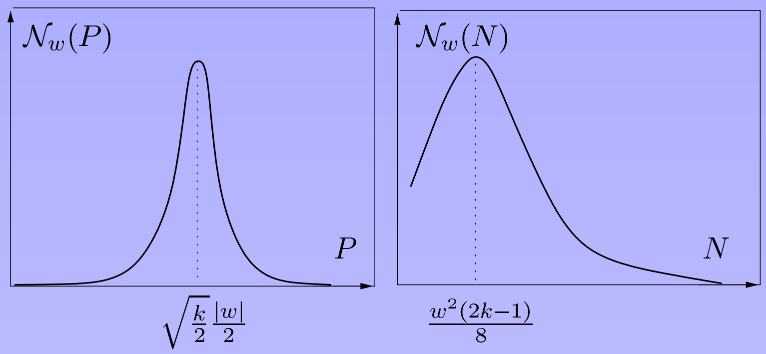

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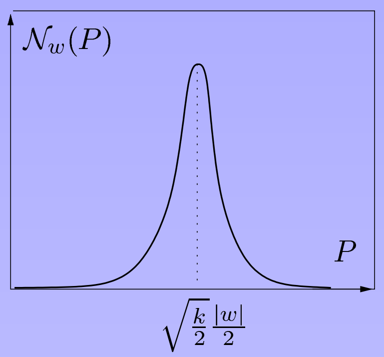

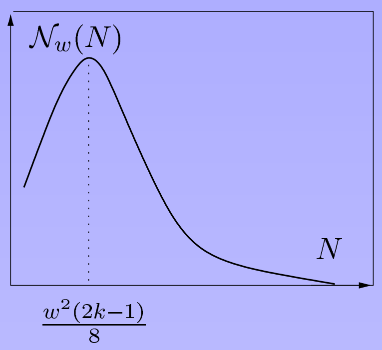

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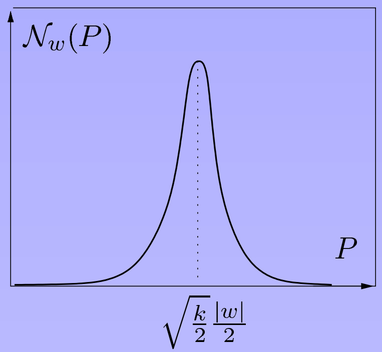

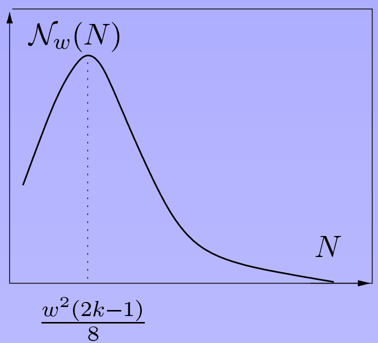

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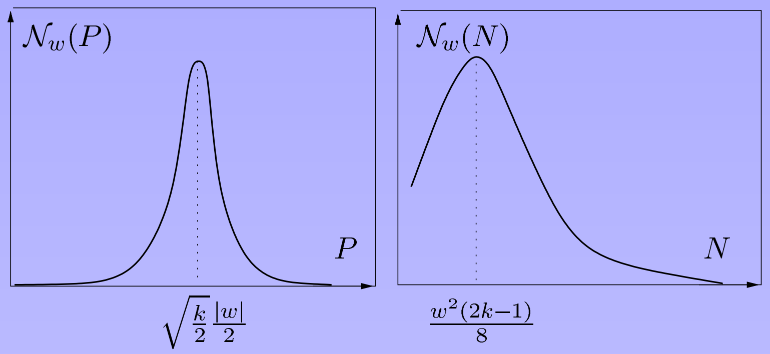

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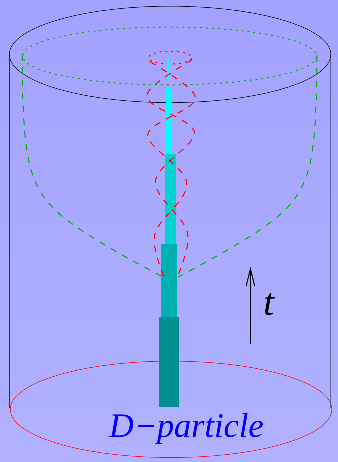
★ On the contrary, emission of *short strings* (localized strings) stays *finite*



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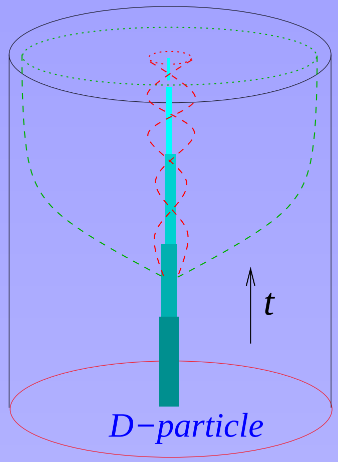

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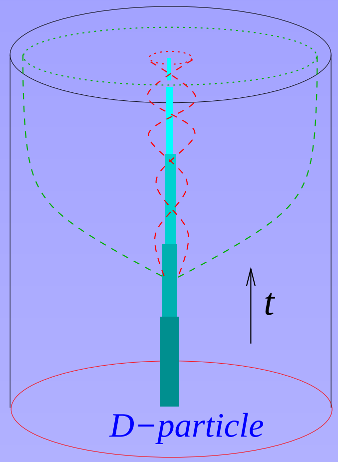

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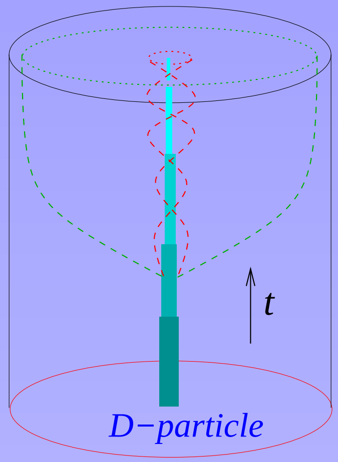

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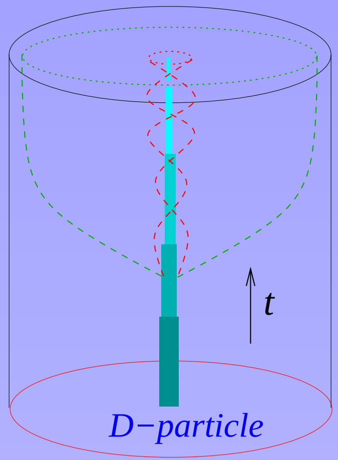

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★For AdS_5/CFT_4, corresponds to sphaleron decay *[Drukker,Gross,Itzhaki]*
★Difficult here since CFT is singular *(unstable to fragmentation ↔ long strings emission)*

Remarks on Open String Pair Production

✔ Open string point of view: time-dependent Hamiltonian ➥ pair production

Mini-superspace limit : $\left[\partial_t^2 + \lambda e^t + \mathbf{p}^2 + N - 1\right]\psi(t) = 0$ *[Gutperle, Strominger '03]*

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Rate of pair production $W = -\mathrm{Re} \ln \langle out | in \rangle \sim \int \mathrm{d}E \rho(E) e^{-2\pi E}$

➥ *power-law convergent* only (divergent for $D_{p>22}$ in bosonic strings)

✔ High energy behavior of open string pair production in AdS_3

★For open strings with angular momentum r, one gets (orbifold construction)

$$|R(E)| = \left| \frac{\sinh \pi (E + r/\sqrt{k}) \sinh \pi (E - r/\sqrt{k})}{\sinh^2 2\pi E} \right|$$

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★Density of states smaller ($\Delta_{\mathsf{min}} > 0$): $\rho(E) \sim \exp\{2\pi \sqrt{1 - {}^{1}/_{2k}}\, \ell_s E\}$

➥ open string production rate exponentially convergent for very massive open strings on the D0-brane in AdS_3

★One gets that open string perturbative string (field) theory remains a valid description *(despite the disappearance of the brane!)*

④ *Open string tachyons in non-Critical Strings*

✔ Non-critical superstrings: superstrings in spacetime dimension $d < 10$

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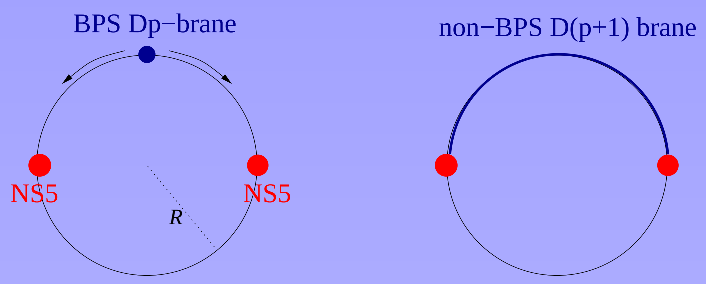
★ The universal tachyon appears on non-BPS D$(p+1)$-branes stretched between the NS5-branes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NS5
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R
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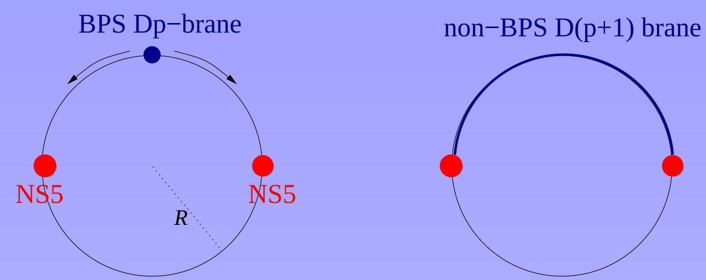

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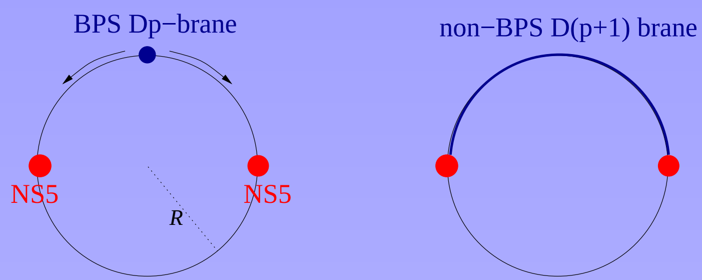

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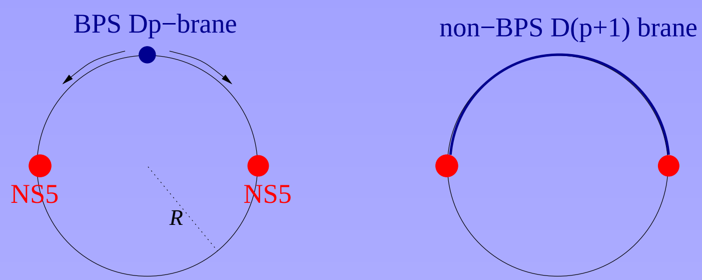

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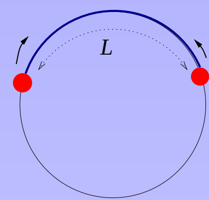

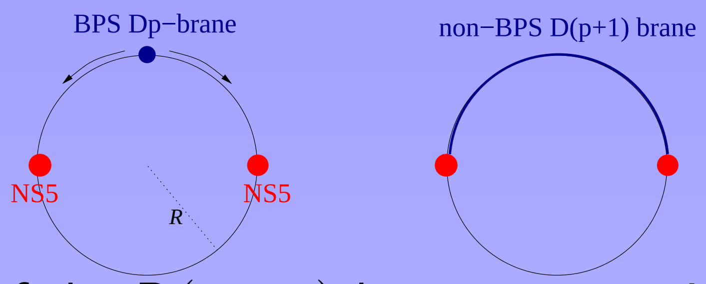

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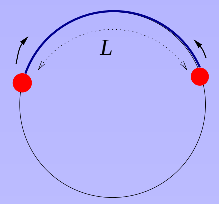

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★Gives near-horizon geometry of $k = 2$ close parallel fivebranes in non-compact transverse space ➥ six-dimensional non-critical string

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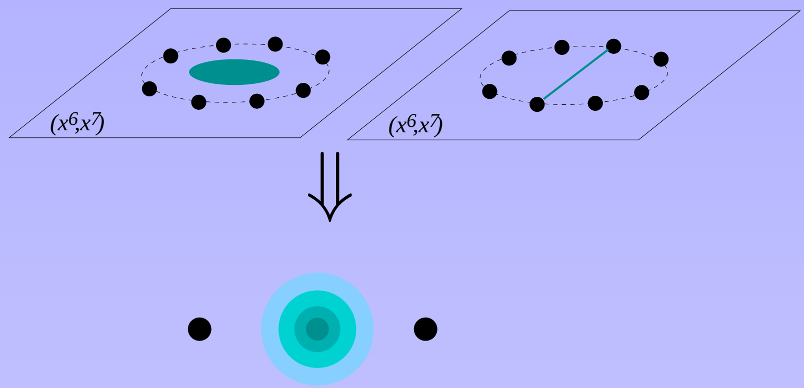
★One finds a transition at $k = 2$ where the Dp-brane with a geometric tachyon and the non-BPS suspended D$(p+1)$-brane boundary states become identical



★Proof of geometric/universal tachyon equivalence including all α' corrections.

Rolling tachyon in non-critical strings

✔ Mass gap in the closed string spectrum $\boxed{\ell_s\, m > \sqrt{8-d}/2}$ in the closed string sector (δ-normalizable states)

➥ lower density of states $\rho(E) \sim \exp\{2\pi\sqrt{1-\frac{8-d}{16}}E\}$ *(higher Hagedorn temp.)*

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• would raise a puzzle: what is the leftover of the brane mass? ($\ell_s m_{\rm D} \sim {}^1/g_s^{\rm local}$)

• would challenge Sen's conjecture ("universality" of DBI tachyonic action)

Decay of localized branes

✔ Brane localized in the strong coupling end in $\mathcal{N}=2$ Liouville *(cf.* ZZ *brane)*
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$$\mathcal{N} \sim \int \mathrm{d}E\ \mathrm{d}p_\phi\ \mathrm{d}\mathbf{p}\ \sum_N \rho(N)\ \left| \langle V_{p_\phi\, E\, \mathbf{p}\, s} \rangle_\lambda \right|^2\ \delta(E^2 - p_\phi^2 - 2N - \mathbf{p}^2 + d/8)$$

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➥ $\rho(N)$ smaller than in flat space, but $\int \mathrm{d}p_\phi$ gives UV divergent production of closed strings as in flat space (due to non-pert. α' corrections)

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★ Continuous spectrum (δ-norm) above a gap

➥ vertex operators: $V_p(x) = \exp\{-(\sqrt{1-d/8} + ip_\phi)\phi(x) + p_\mu X^\mu(x) + \cdots\}$

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➥ does not represent the decay of the open string tachyon but changes the boundary conditions at $\phi\to-\infty$ *(however leads to a* UV*-finite result)*

Conclusions

- D-brane decay ➥ involves all the tower of string modes
- Non-perturbative α' effects & asympt. density of states are crucial ingredients
- String theory clever enough to convert all brane mass into closed strings although the detailed outcome may be different
  ➥ Sen's conjecture seems universal !
- However, perturbative string theory leaves many issues open (backreaction)
- Future work: tachyon condensation and $\mathrm{D}/\bar{\mathrm{D}}$ scattering, relevant for cosmology