Brane Creation & Annihilation

Overview & Current Work

卢建新

Work done with
Chen, Roy & Wang

中国科技大学交叉学科理论研究中心
(& USTC-SIAS ?)

2004.10.27

一. Overview

二. Set up

三 Current work (to appear)

⇑ Done with Chen, Roy & Wang

一. Overview

String Theory $\Rightarrow$ Existence of Extended Objects

open string ⊕ T-duality $\longrightarrow$ Dp branes

NS 5-brane

F - String

As Solitons from the low-energy theory of superstring i.e., supergravity

Supergravities (low energy theories) contains more non-perturbative information than the worldsheet action of string

(Closed) String theories (plus possible open string)

low energy limit → {Various supergravities} ← also low-energy theories of non-perturbative string theories

⇓

Non-perturbative objects

and other non-perturbative information

D-branes can be described by open string theories with the open string ends obeying the Dirichelet boundary conditions in the directions perpendicular to the brane

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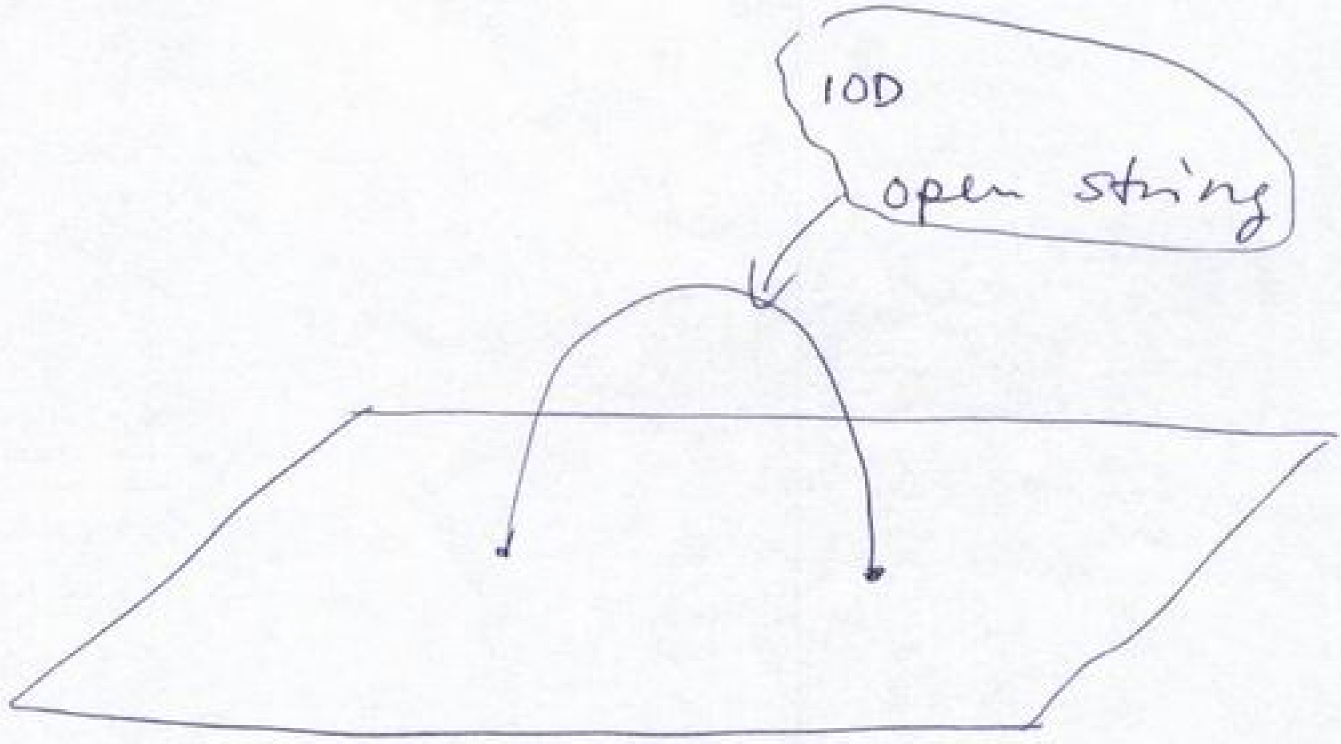

The low-energy limit of such open string which describes the dynamics of D-brane

$\Rightarrow$ DBI action

By the same token, we expect

DBI actions contains more, in particular the corresponding non-perturbative information, than the perturbative open string

DBI $\Longrightarrow$ Non-perturbative Objects

& other interesting non-perturbative information

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On the Dp-brane, low energy dynamics

$$\longleftrightarrow \text{DBI (SUSY)}$$

Field Content: SUSY Gauge Multiplet

$$\begin{cases} \Phi^I, \; F_{\mu\nu} & (\lambda \Phi^I = \cancel{2\pi}\,\lambda X^I) \\ & \lambda \cancel{=2\pi\alpha}\,' \\ \chi & \end{cases}$$

Consider BPS configuration,

DBI $\longrightarrow$ linearized DBI

$\Longleftrightarrow$ Super Yang-Mills

$\Leftarrow$ Dimension Reduction of 10D Super Yang-Mills

$$\delta \chi = \Gamma_{\mu\nu} F^{\mu\nu} \epsilon + \underset{\lambda}{\Gamma^{\mu I}} \partial_\mu \Phi^I \epsilon$$

(10D notations)

$$\begin{cases} D_\mu F^{\mu\nu} = 0 \\ \Box \Phi^I = 0 \end{cases}$$

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(C&M NPB 513 (98) 109
Gibbons NPB 514 (98) 663)

BPS F - String

$$X^9 = \frac{C_p}{r^{p-2}} , \qquad A_0 = \frac{C_p}{r^{p-2}}$$

$$F_{0r} = -\partial_r A_0 = -\partial_r X^9$$

$$\begin{aligned}
\delta\chi &= \Gamma^{0r} F_{0r}\,\epsilon + \Gamma^{r9}\,\partial_r X^I\,\epsilon \\
&= -\Gamma^9\,(\Gamma^0 + \Gamma^9)\,\partial_r X^9\,\epsilon \\
&= -\Gamma^9\,\partial_r X^9\,(\Gamma^0 + \Gamma^9)\,\epsilon = 0
\end{aligned}$$

$$(\Gamma^0 + \Gamma^9)\,\epsilon = 0 \quad \sim \quad (1 - \Gamma^0\Gamma^9)\,\epsilon = 0$$

preserving half
of SUSY

$$\boxed{\int_{S^{p-1}} {}^*F = g\,n\,(2\pi)^{p-1}}$$

$$\cancel{E(\delta) = \frac{1}{(2\pi)^p g}\int d^p r\, \frac{1}{2}\left(F_{0r}^2 + (\partial_r X^9)^2\right)}$$

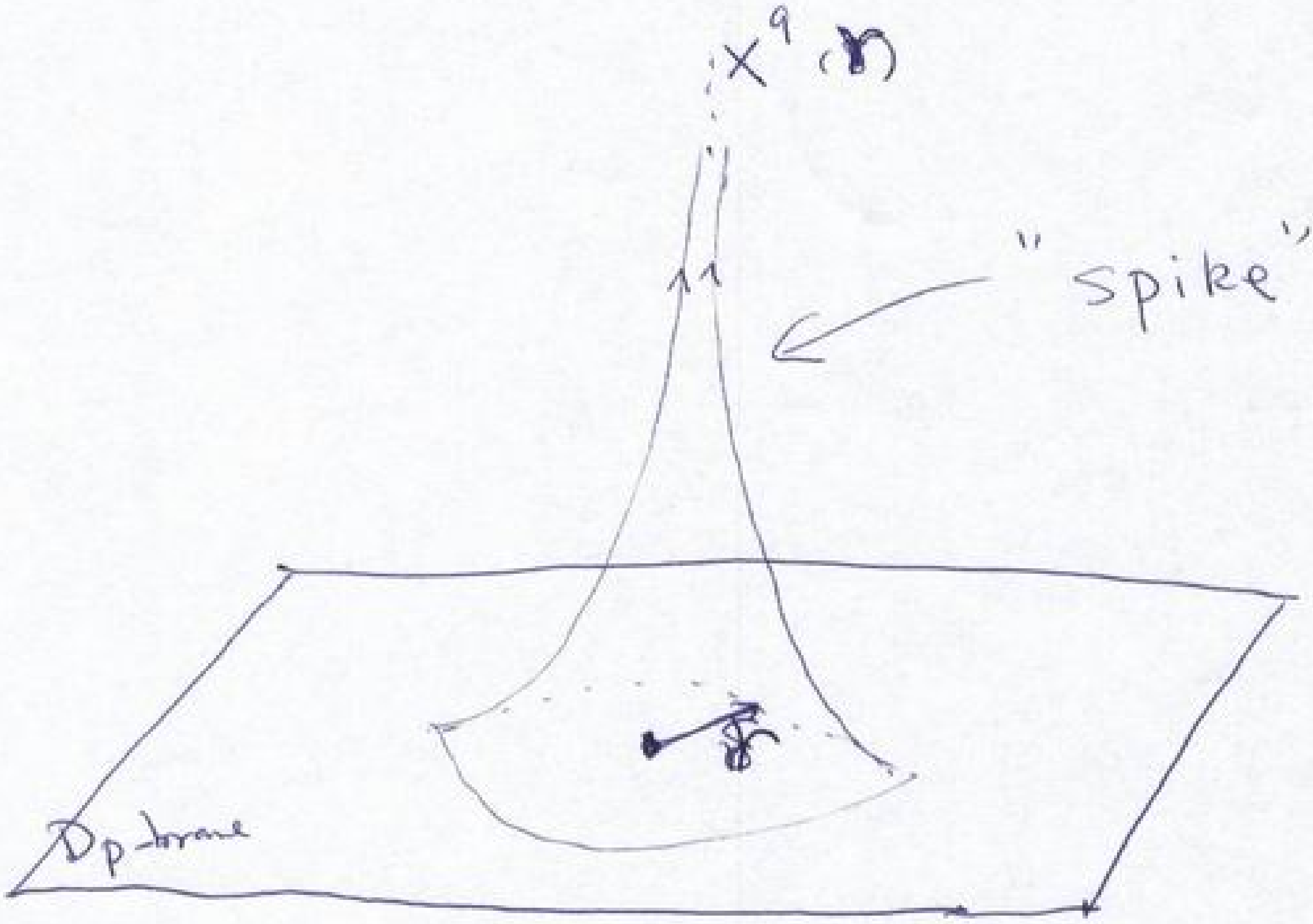
$$\cancel{= \frac{C_p\,\Omega_{p-1}\,(p-2)}{(2\pi)^p g}\, X^9(\delta)}$$

$$E(\delta) = \frac{1}{(2\pi)^p g}\int d^p r \, \frac{1}{2}\left[F_{0r}^2 + (\partial_r X^9)^2\right]$$

energy $(r \geq \delta)$

$$= \frac{1}{2\pi} X^9(\delta) = T_f \, X^9(\delta) \qquad (\alpha' = 1)$$

or $$\boxed{\frac{E(\delta)}{X^9(\delta)} = T_f} \qquad (\delta \to 0)$$



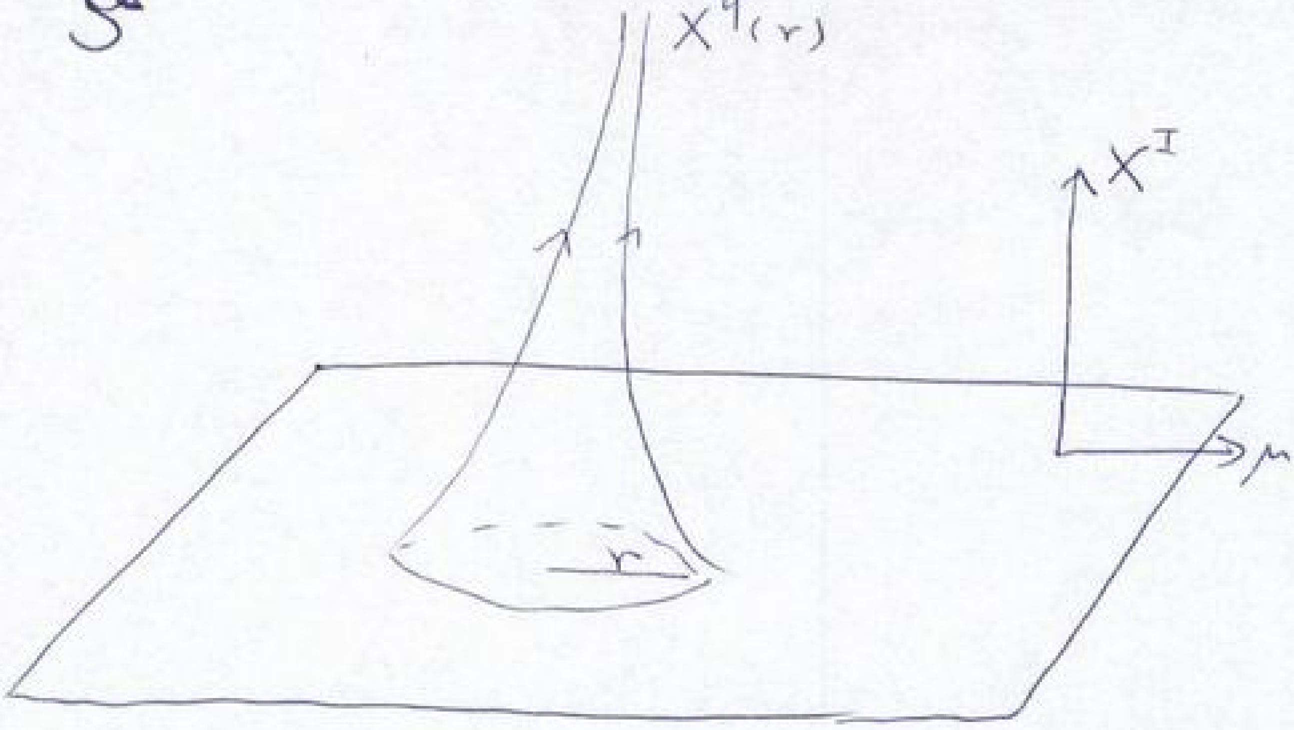
Note here

$$r^2 = x_1^2 + x_2^2 + \cdots + x_p^2$$

All the spatial directions on the brane are used but we do have one $X^9 \Rightarrow$ a string

BPS $D(p-2)$ brane

$$\int_{S^2} F \propto n \quad (\text{magnetic flux})$$



$$F_{\theta\varphi} = \frac{N\cancel{\Pi}m}{r}, \qquad X^9 = \frac{N\,C\,m}{r}$$

$$X^1, \dots X^p$$

$$r = (X^{p-2})^2 + (X^{p-1})^2 + X^{p^2}$$

We have $X^1, \dots X^{p-3}$ directions combined with $t \Rightarrow \underline{ISO(1, p-3)}$

$$R^{1,p-2} \oplus X^9$$

$\Rightarrow$ $(p-2)$ spatial directions

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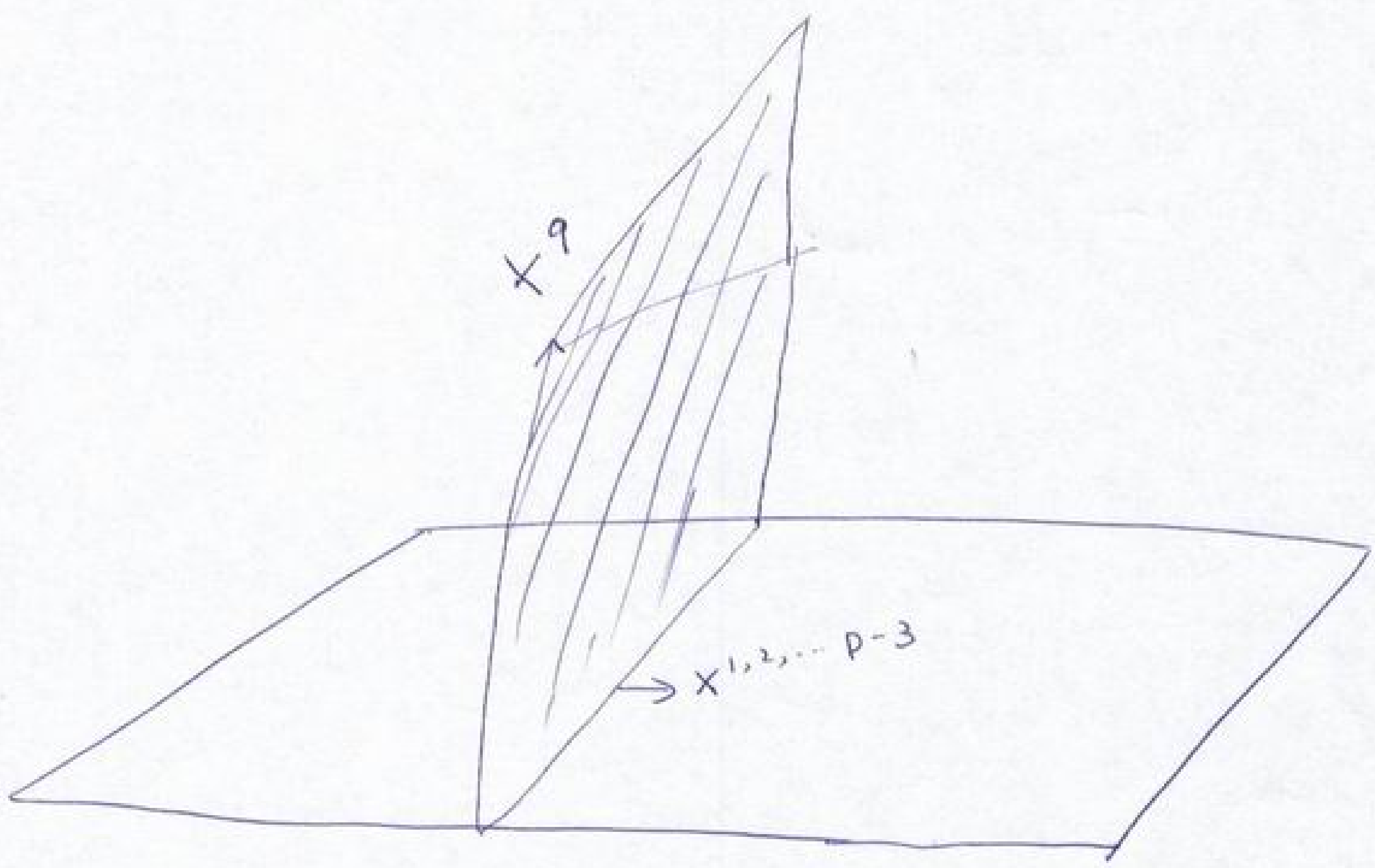
A magnetic charge on Dp

$\Rightarrow$ An object ending on Dp with ending with $(p-3)$ spatial directions

Since we have an additional X^9

$\Rightarrow$ Open $D(p-2)$ brane



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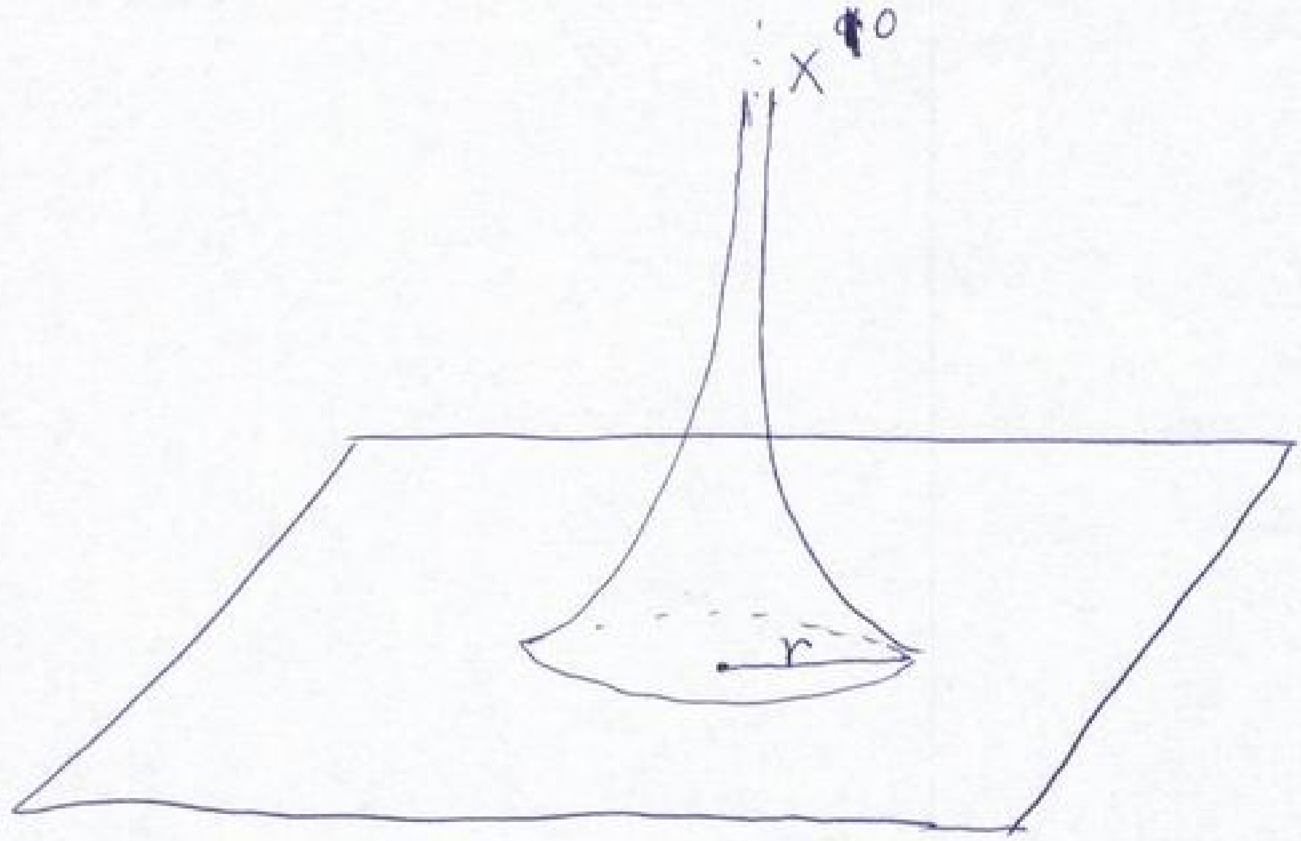
Similarly,

Howe, Lambert & West
NPB 515 (98) 203



$$r^2 = (x^3)^2 + (x^4)^2 + (x^5)^2 + (x^2)^2$$

$$\int_{S^3} H_3 = \int_{S^3} {}^*H_3 \propto n$$

$$M^5 = R^1 \times R^+ \times S^3$$

Another Picture of having other branes from a given one. (Emparan PLB 423 (98) 71 hep-th/9711106)

DBI action

$$S = - T_p \int d^{p+1}\sigma \sqrt{-\det\left[G_{\mu\nu} + (F_{\mu\nu} + B_{\mu\nu}) \times \lambda\right]}$$

$$+ \; T_p \int \sum_{i=0}^{10} \left(C_i \wedge e^{\lambda(F+B)} \right)_{p+1}$$

$B_{\mu\nu} \Rightarrow$ Electrix Flux B_{01} (or F_{01})

F - string $\Leftrightarrow$ a Dp - brane with
an Electrix ~~flux~~ along x^1
~~with~~ a topology $R^1 \times S^{p-1}$ with
S^{p-1} wrapping on trivial $(p-1)$ cycle
and vanishing size

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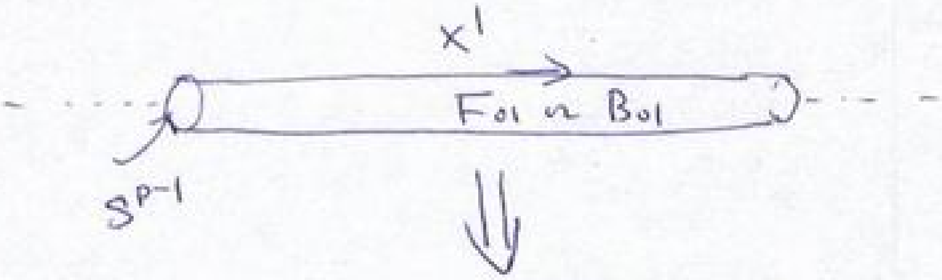
$$\int_{R^1 \times S^{p-1}} j^{012\cdots p} \, d^{p+1}\sigma = 0$$ (net zero charge for D_p)

S^{p-1} wrapping on a trivial and vanishing size $(p-1)$-cycle



$$\Downarrow$$

$$\boxed{\text{F-string}}$$

<u>$D(p-2k)$-brane</u> $\Longleftrightarrow$ D_p-brane with a topology $R^{p-2k} \times S^{2k}$ with S^{2k} wrapping on a vanishing size trivial $2k$-cycle

$$\int_{R^{p-2k} \times S^{2k}} j_R^{012\cdots p} \, d^p\sigma = 0$$

$(k \neq 0)$

but

$$T_p \int_{M^{p+1}} C_{p+1-2k} \wedge F^{2k}$$

$$= T_p \int_{M^{p+1-2k}} C_{p+1-2k} \wedge \boxed{\int_{S^{2k}} F \wedge \cdots \wedge F}$$

$$= T_{p-2k} \int_{M^{p+1-2k}} C_{p+1-2k}$$

$$= T_{p-2k} \int_{R^{p+1-2k}} C_{p+1-2k} \quad \sim \quad \boxed{\int_{R^{p+1-2k}} \partial^{0 1 \cdots (p-2k)} \neq 0}$$

{For example $k=1$, $F \Leftrightarrow$ magnetic charge

Aagain another picture

Obtaing lower dimensional p-branes including F-string from a higher dimensional one is Sen's from a so-called non-BPS D-brane ~ D-brane - Anti D-brane system.

$$D_p - \text{Anti } D_p \xrightarrow{(-)^{F_L}} \text{Non-BPS } D(p-1) \xrightarrow[\text{solution}]{\text{Kink}} \text{BPS } D(p-2)$$

~

$$D_p - \text{Anti } D_p \xrightarrow[\text{Solution}]{\text{Vortex}} \text{BPS } D(p-2)$$

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In summary,

low energy theory of D-brane (or its variance such as non-BPS or brane-anti brane) can give rise to F-string and other lower dimensional D-branes

In other words

Given a Dp-branes

$\Rightarrow$ F or $D_{p'}$ with $p' < p$

<u>Questions</u>?

Given a D_p

$\Rightarrow$ $D_{p'}$ with $p' > p$?

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The answer is Yes!

F - string in a R-R background $\longrightarrow$ Spherical D_p-branes can be spontaneously nucleated in a uniform field Background (the analog of Schwinger pair creation process).

Emparan PLB423 (98)71 hep-th/9711106

: hep-th/9810163

: hep-th/0204203

$D_{p'}$

$p' < p$

in a $\cancel{F}_{p+2}$ background flux

Nothing in a F_{p+2}

" "

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Example

F - string $\longrightarrow$ D2 brane

(cylinder or torus)

Consider a (cylinder or torus) D2 brane with an F-string flux

$$S_2 = -\frac{1}{4\pi^2 g}\int d^3\xi \left(\sqrt{-\det(g_{\alpha\beta} + 2\pi F_{\alpha\beta})} + \frac{1}{6}\epsilon^{\alpha\beta\gamma} A_{\mu\nu\rho}\,\partial_\alpha X^\mu \partial_\beta X^\nu \partial_\gamma X^\rho\right)$$

static gauge

$X^0 = t$, $2\pi F_{t z} = \mathcal{E}$

$X^1 = z$

$X^2 = R\cos\sigma$ rest X^M fixed.

$X^3 = R\sin\sigma$

$(0 \le \sigma \le 2\pi)$

R costant ,
$$\boxed{\begin{gathered} F_{0123} = -h = \text{const.} \\ A_{012} = \frac{h}{2}X^3,\ A_{013} = -\frac{h}{2}X^2 \end{gathered}}$$

$$\Rightarrow \quad E = \frac{1}{2\pi g}\int dz\left(\sqrt{(R^2+D^2)} - \frac{h}{2}R^2\right)$$

$$\boxed{\frac{1}{2\pi g}D = \frac{\delta S_2}{\delta \mathcal{E}}}\ ,\quad \boxed{D = ng}$$

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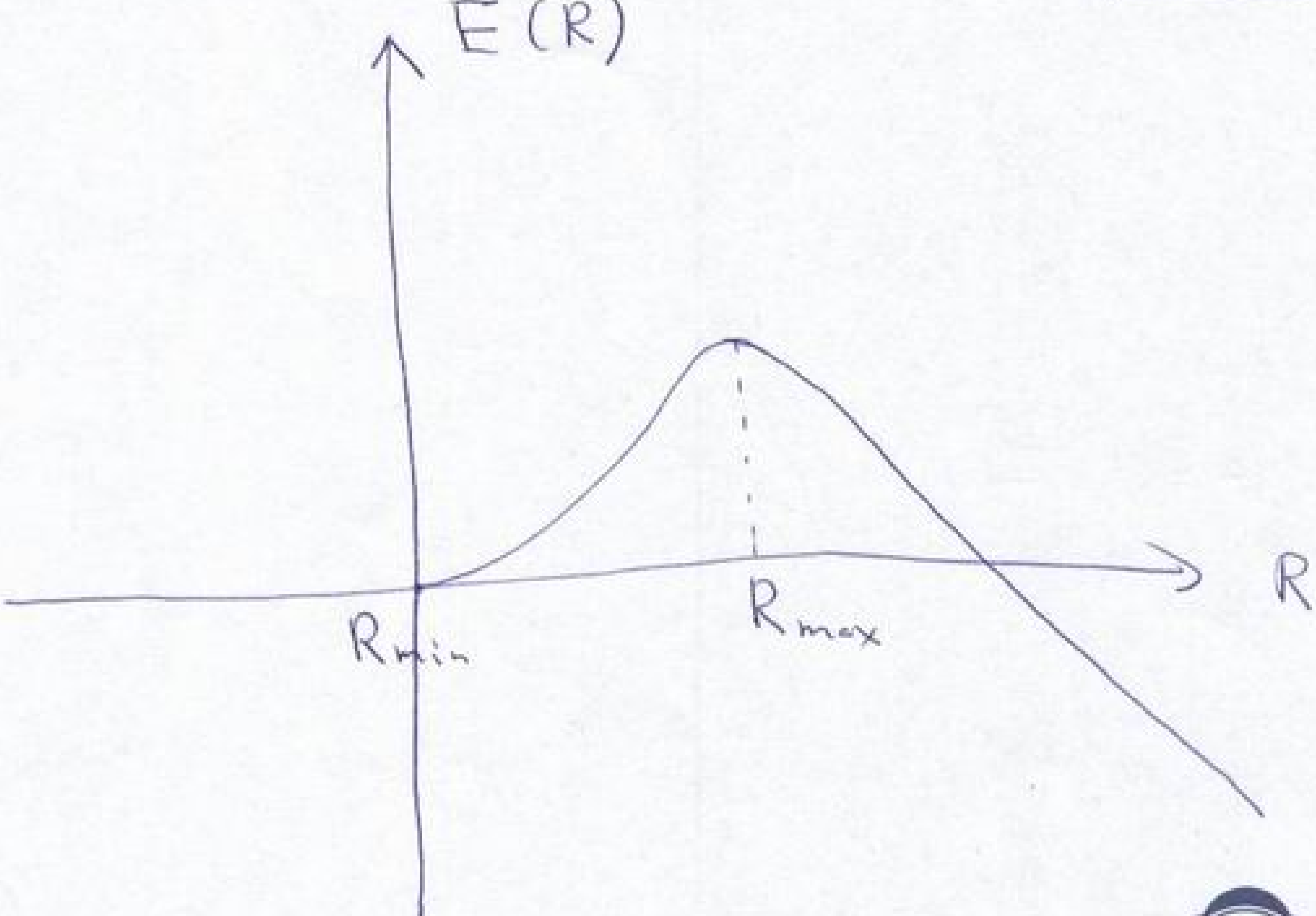
$$E = \frac{L}{2\pi g}\left[\sqrt{R^2 + n^2 g^2} - \frac{h}{2} R^2\right]$$

$$\frac{\delta E}{\delta R} = \frac{L}{2\pi g}\left[\frac{R}{\sqrt{R^2+n^2g^2}} - hR\right] = 0$$

$$\Rightarrow \quad R_{min} = 0 \qquad \text{or} \qquad h\sqrt{R^2+n^2g^2} = 1$$

$$\text{or} \quad R_{max} = \sqrt{\frac{1}{h^2} - n^2 g^2}$$

$$\text{if} \quad \boxed{hng < 1}$$



at $R = R_{min} = 0$

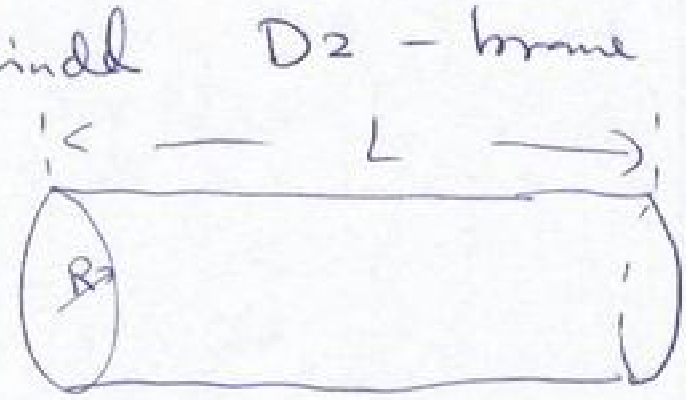
$$E = \frac{L}{2\pi g} \cdot n g = \frac{L}{2\pi} n$$

$$\frac{E}{L} = \frac{1}{2\pi} n = T_f n \leftarrow \text{ n F-strings}$$

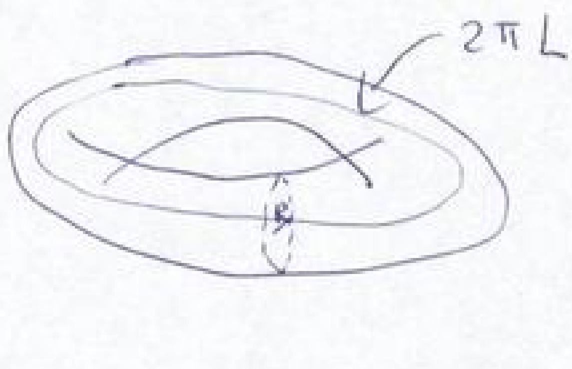
So $R = R_{min} = 0$ represents n F-strings

These n F-strings can tunnel by instanton tunnelling to have $R > 0 \Rightarrow$

a cylinder D2-brane if L is a line-integral



a torus if z is $2\pi L$ a circle



Another Example

D0 branes in a F_4 background $\xrightarrow[\text{effect}]{\text{Myers dielectric}}$ a spherical D2 brane

or

Nothing in this F_4 $\xrightarrow{\text{instanton tunnelling}}$ a spherical D2 brane

N D0 branes placed in a RR

$$F_{tr\theta\varphi} = -2fr^2\sin\theta \to C_{\theta\varphi} = \frac{2fr^3}{3}\sin\theta$$

Assume such a stable spherical D2 brane exist, then

$$N \text{ D0 branes} \Leftrightarrow F_{\theta\varphi} = \frac{N}{2}\sin\theta$$

DBI action in background

$$C_{t\theta\varphi} = \frac{2fr^3}{3}\sin\theta$$

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$$ds^2 = -dt^2 + dr^2 + r^2(d\theta^2 + \sin^2\theta \, d\varphi^2) + \sum_{i=4}^{9} dx_i^2$$

Static gauge

$$\sigma^0 = t$$
$$\sigma^1 = \theta$$
$$\sigma^2 = \varphi$$

$$S_2 = -T_2 \int d^3\sigma \left[\sqrt{-\det(\partial_\mu X^M \partial_\nu X^N g_{MN} + 2\pi\alpha' F_{\mu\nu})}\right] + T_p \int C_3$$

$$\Longrightarrow \quad E(r) = +T_2 \left[4\pi \sqrt{r^4 + \pi^2\alpha'^2 N^2} - 2f \times \frac{4\pi}{3} r^3 \right]$$

$$= 4\pi T_2 \left[\sqrt{r^4 + \pi^2 \alpha'^2 N^2} - \frac{2f}{3} r^3 \right]$$

$$\frac{\delta E(r)}{\delta r} = 0 \Rightarrow$$

$r = 0$, saddle point

$$r_{min} = \sqrt{\frac{1}{2f^2} - \sqrt{\frac{1}{4f^4} - \pi^2\alpha'^2 N^2}}$$

$$r_{max} = \sqrt{\frac{1}{4f^2} + \sqrt{\frac{1}{4f^4} - \pi^2\alpha'^2 N^2}}$$

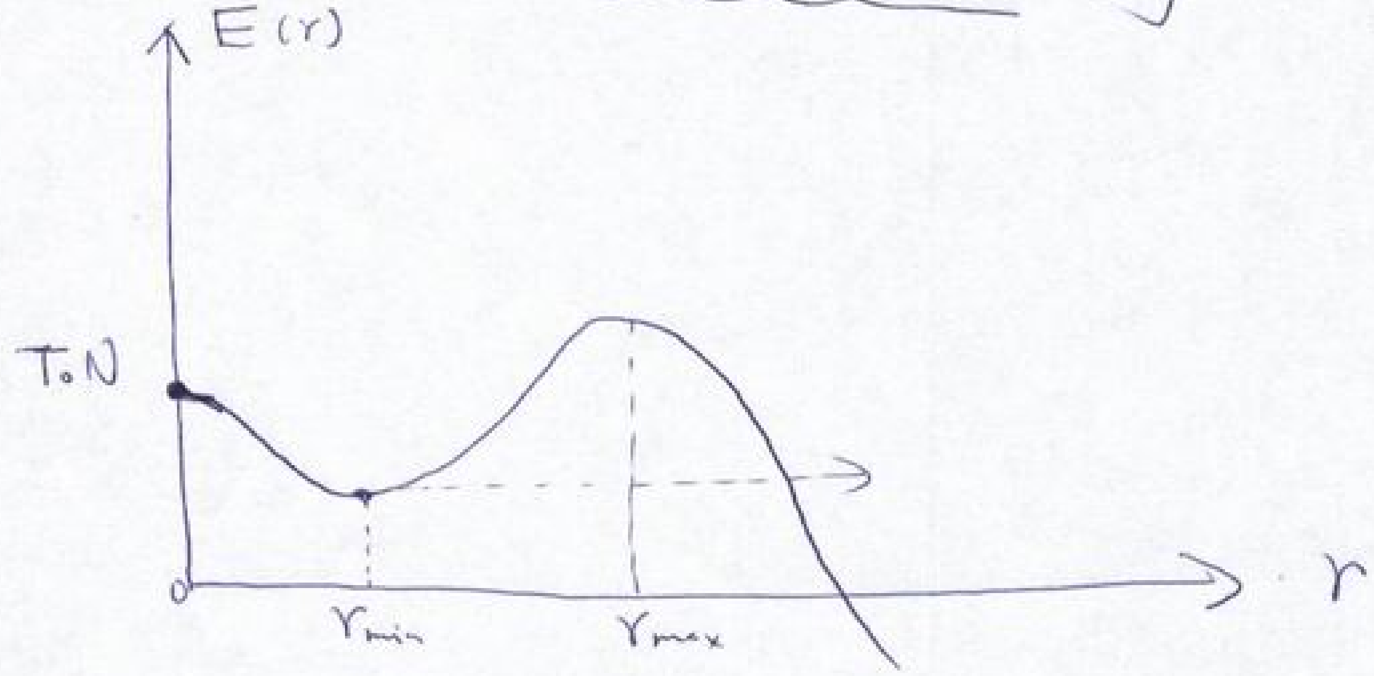
$$T_p = \frac{1}{g(2\pi)^p \alpha'^{\frac{p+1}{2}}}$$

$$E(r=0) = 4\pi T_2 \cdot \pi \alpha' N$$

$$= \frac{N}{g\sqrt{\alpha'}} = \underline{T_0 N}$$

$r = 0$ is a saddle point, corresponding to N D0 branes

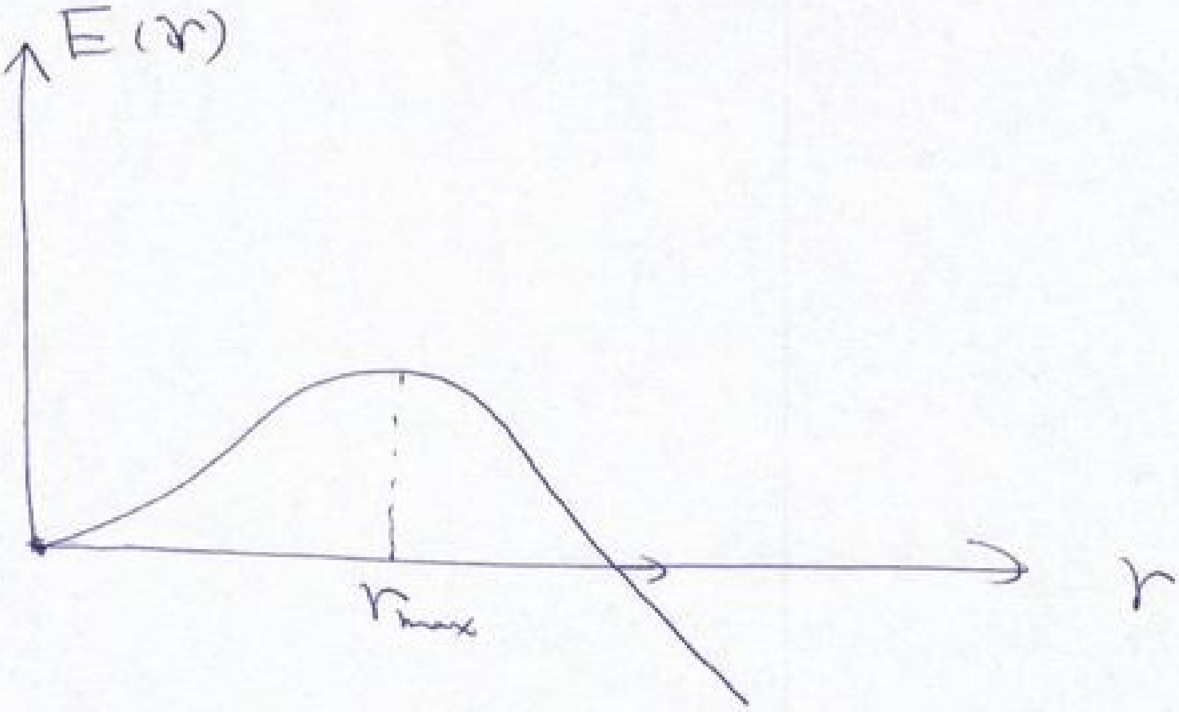
$$\cancel{E(r = r_{min}) = T_2 \left[4\pi \sqrt{} \right.}$$



Nothing

$N = 0$ (No $D0$ branes)

$r_{min} = 0, \quad r_{max} = \frac{1}{f}$



Nothing tunnels to a spherical $D2$ brane

In Summary,

To create a higher dimensional Dp brane from lower dimensional ones, EXIST TWO Processes.

Instanton Tunnelling → Schwinger Type Pair Creation

a Myers effects

Myers Effects

Myers JHEP9911 (99)022
hep-th/9910053

Abelian DBI $\longrightarrow$ Non-Abelian DBI

$$S_{BI} = -T_p \int d^{p+1}\sigma \; \mathrm{STr}\left[e^{-\phi} \sqrt{-\det\left(P\left[E_{ab} + E_{ai}(Q^{-1}-\delta)^{ij}E_{jb}\right] + \lambda F_{ab}\right)\det(Q^i{}_j)}\right]$$

$$S_{CS} = \mu_p \int \mathrm{STr}\left(P\left[e^{i\lambda i_\Phi i_\Phi}\left(\sum C^{(n)} e^{B}\right)\right] e^{\lambda F}\right)_{(p+1)}$$

$\lambda = 2\pi\alpha'$, $\quad E_{\mu\nu} = G_{\mu\nu} + B_{\mu\nu}$

$$Q^i{}_j \equiv \delta^i{}_j + i\lambda[\Phi^i, \Phi^j]E_{kj}$$

e.g.

$$i_\Phi i_\Phi C^{(p+3)} = \frac{1}{2}[\Phi^i, \Phi^j]\frac{1}{(p+1)!}C_{ji\, i_1 \cdots i_{p+1}}\, dx^{i_1}\wedge \cdots \wedge dx^{p+1}$$

interior product

Appearance of a higher dimensional D(p+2) brane e.g.

N D0 branes placed in a F_4 background

$\Rightarrow$ a static stable spherical D2 brane

1. Set up

Consider N $D(p-2)$ branes placed in a background

$$F_{(p-2+i)(p-2+j)(p-2+k)01\cdots(p-2)} = \begin{cases} 2f\,\epsilon_{ijk} & \text{for } i,j,k \in \{1,2,3\} \\ 0 & \text{Otherwise} \end{cases}$$

f carries dimensions of Length^{-1}

set

$B_{\mu\nu} = 0$, flat Minkowski

and take static gauge

$$\sigma^a = x^a \qquad a = 0, 1, \cdots (p-2)$$

$$\underbrace{\sqrt{\lambda}\, \Phi^I < 1}, \qquad \frac{I = p-1, \ldots 9}{a = 0, 1, \ldots p-2}$$

$$S_{DBI} = -T_{p-2} \int d^{p-1}\sigma \Big(N + \frac{\lambda^2}{2} \mathrm{Tr}\, D_a \Phi^I D^a \Phi^I + \frac{\lambda^2}{2} \mathrm{Tr}\, F_{ab} F^{ab} - \frac{\lambda^2}{4} \mathrm{Tr}\, [\Phi^I, \Phi^J]^2 \Big)$$

$$S_{CS} = -\frac{i \mu_{p-2} \lambda^2}{3} \int d^{p-1}\sigma \;\mathrm{Tr}\, \Phi^i \Phi^j \Phi^k F_{(p-2+i)(p-2+j)(p-2+k)\, 0 1 \cdots p-2}$$

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In the following, we try also to set $A_a = 0$

to do so, we need to be careful since

$$D_a F^{ab} \sim [\Phi^I, D^b \Phi^I]$$

Only

$$\Rightarrow [\Phi^I, D^b \Phi^I] = 0 \Leftrightarrow \boxed{[\Phi^I, \partial_a \Phi^I] = 0}$$

we can set $A_a = 0$ consistly.

$$S = S_{DBI} + S_{CS}$$

$$= -T_{p-2} \int d^{p-1}\sigma \left[N + \frac{\lambda^2}{2} \mathrm{Tr}\, \partial_a \Phi^I \partial^a \Phi^I - \frac{\lambda^2}{4} \mathrm{Tr} [\Phi^I, \Phi^J]^2 \right]$$

$$- \frac{i \mu_{p-2} \lambda^2}{3} \int d^{p-1}\sigma\, \mathrm{Tr}\, \Phi^i \Phi^j \Phi^k F_{(p-2+i)(p-2+j)(p-2+k)01\cdots(p-2)}$$

$$\mu_p = T_p = \frac{2\pi}{g_s (2\pi l_s)^{p+1}}, \quad \boxed{l_s^2 = \alpha'}$$

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The corresponding Hamiltonian density is

$$\mathcal{H} = N T_{p-2} + \frac{\lambda^2 T_{p-2}}{2} \left[\mathrm{Tr}(\dot{\Phi}^I)^2 + \mathrm{Tr}(\nabla \Phi^I)^2 \right]$$

$$- \frac{\lambda^2 T_{p-2}}{4} \mathrm{Tr}[\Phi^I, \Phi^J]^2$$

$$+ \frac{i T_{p-2} \lambda^2}{3} \mathrm{Tr}\, \Phi^i \Phi^j \Phi^k F_{(p-2+i)(p-2+j)(p-2+k)01\cdots(p-2)}$$

Potential density

$$\mathcal{V} = - \frac{\lambda^2 T_{p-2}}{4} \mathrm{Tr}[\Phi^I, \Phi^J]^2$$

$$+ \frac{i T_{p-2} \lambda^2}{3} \mathrm{Tr}\, \Phi^i \Phi^j \Phi^k F_{(p-2+i)(p-2+j)(p-2+k)01\cdots(p-2)}$$

EOM

$$\partial_a \partial^a \Phi^I - [[\Phi^I, \Phi^J], \Phi^J] - i \Phi^j \Phi^k F_{(p-2+I)(p-2+j)(p-2+k)01\cdots(p-2)} = 0$$

$\Rightarrow$

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$$\Rightarrow \begin{cases} \partial_a \partial^a \Phi^i - [[\Phi^i, \Phi^J], \Phi^J] \\ \qquad - 2 f i \Phi^j \Phi^k \epsilon_{ijk} = 0 & i, j, k \in \{1, 2, 3\} \\ \partial_a \partial^a \Phi^l - [[\Phi^l, \Phi^J], \Phi^J] = 0 & l = 4, \dots 11-p \\ & m, \end{cases}$$

In the following,

$$[\Phi^i, \Phi^l] = 0$$

the no mixing between i & l in the above, Φ^i & Φ^l are decoupled.

Static & spatial independant configuration

$$\partial_a \Phi^I = 0$$

$$\Rightarrow \quad [[\Phi^i, \Phi^j], \Phi^j] + 2 f i \Phi^j \Phi^k \epsilon_{ijk} = 0$$

$$[[\Phi^l, \Phi^m], \Phi^m] = 0$$

$$\Downarrow$$

$$[\Phi^l, \Phi^m] = 0$$

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① If there is a background, then a static stable configuration, i.e.,

N D(p-2) branes $\longrightarrow$ a spherical Dp brane can be created with $\underline{R^{p-2} \times S^2}$ topology

(Myers effect)

② If no background presence, the generated spherical Dp must be either time dependent or spatial dependent or both with a topology $R^{p-2} \times S^2$ with the radius of S^2 either time dependent or spatial dependent or both.