OSAKA 2000

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A. GIVEON

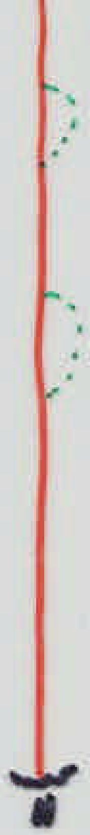
D. KUTASOV

E. R

G. SARKISSIAN

D BRANES IN THE BACKGROUND OF NS5 BRANES

D-p BRANE



POLCHINSKI

OPEN STRINGS ARE FREE TO ROAM

ON $p+1$ WORLD VOLUME

16 SUPERCHARGES, $U(N)$ SUSY YM

PERTURBATIVE ANALYSIS VALID.

IN THIS WORK WE DEAL WITH

MORE COMPLICATED SETTINGS

COMIC STRIPS VS. WORLD SHEET METHODS
B.D

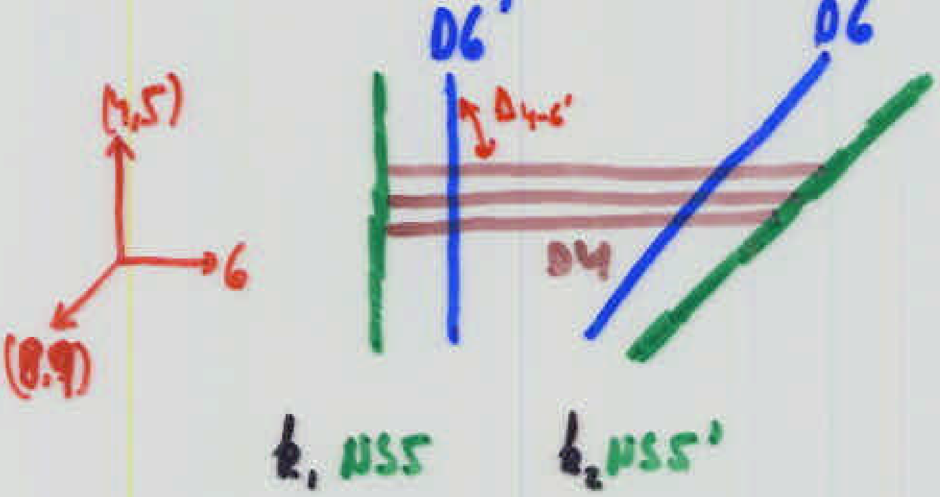
PHYSICALLY INTERESTING

HANANY – WITTEN

$N=1$

ELITZUR, GIVEON, KUTASOV

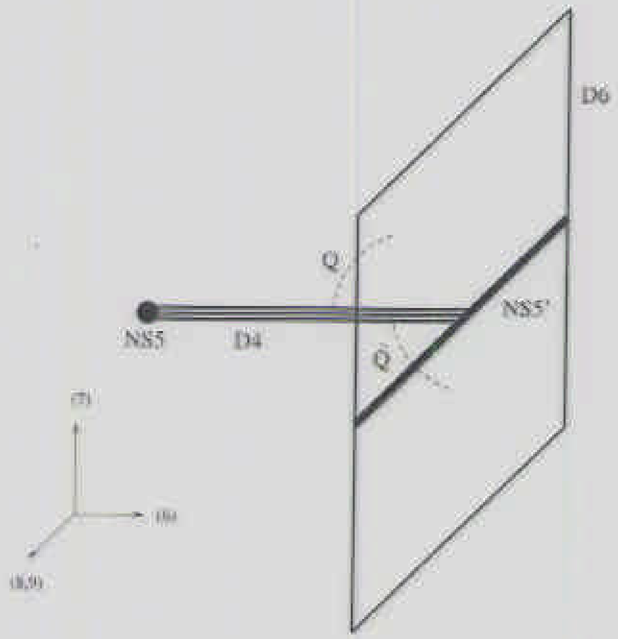
EGK + E.R., SCHWIMMER

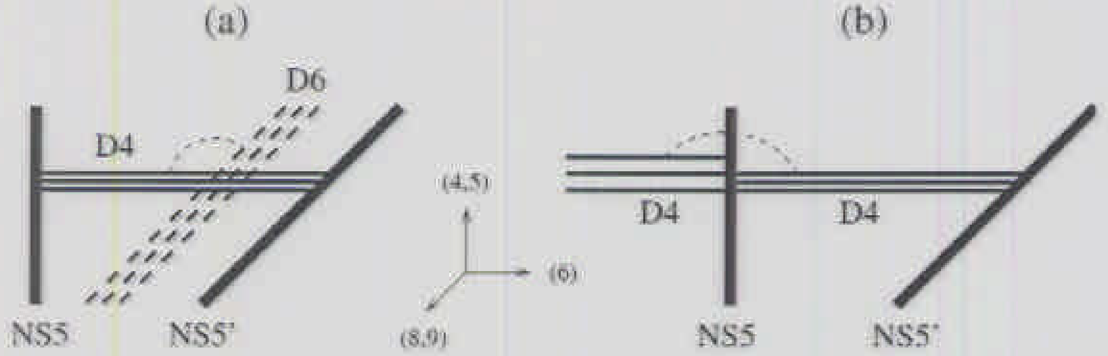


$\Delta_{4-6'}(x_4, x_5)$

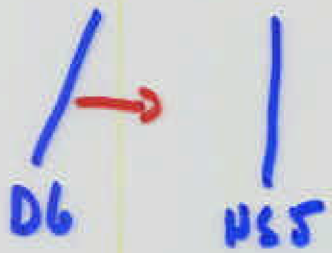
CHIRALITY

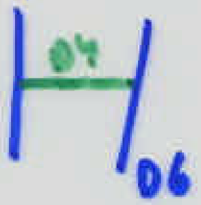
BRODIE – HANANY




(a)
(b)
D6
D4
NS5
NS5'
(4,5)
(6)
(8,9)
D4
D4
NS5
NS5'

HW TRANSITION



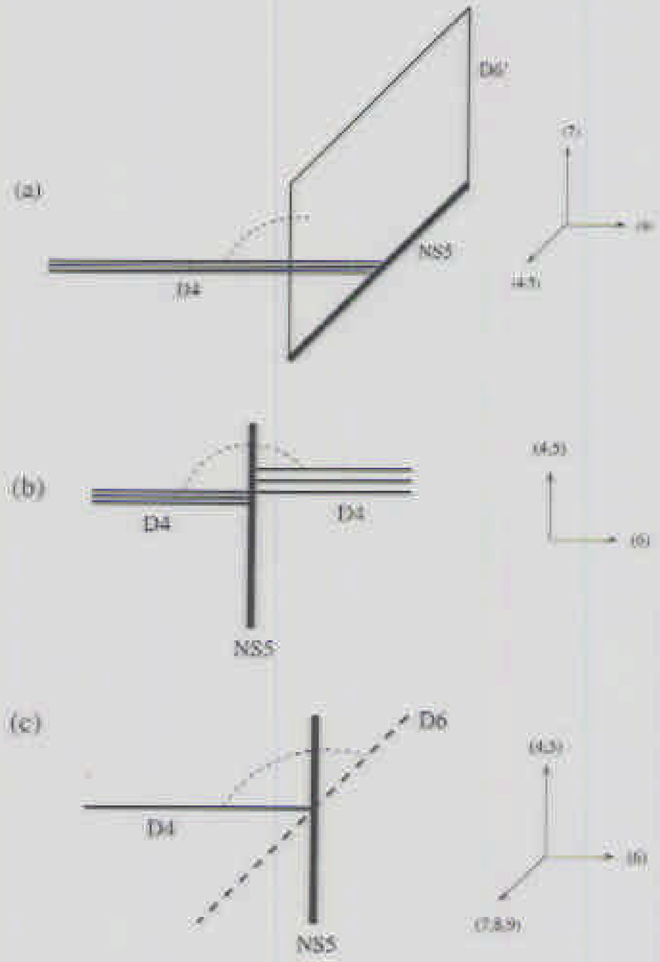


CONDENSATION

CHIRALITY

HIGGS

CONDENSE



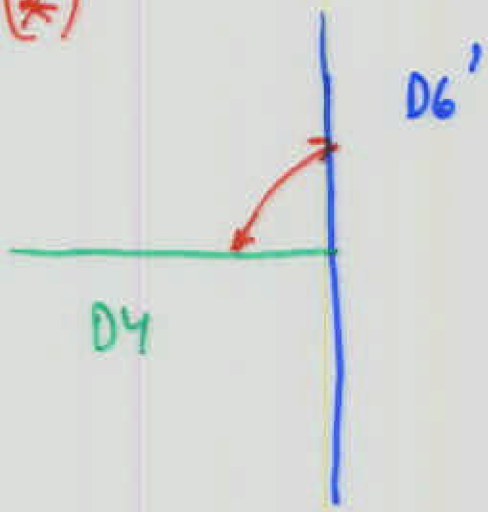
STATES "NEAR" THE NS5 BRANE

D4, D6 INTERSECT THERE.

SIMILAR METHODS TO CY WITH SMALL CYCLES

SINGULARITIES..

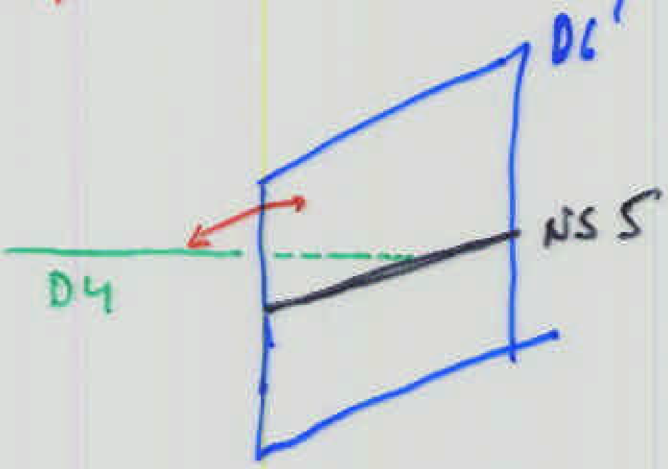
(*)



IN FLAT SPACE

(**)

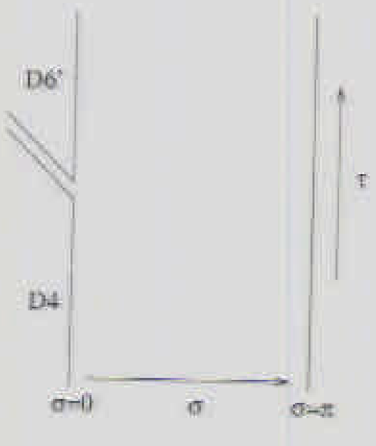
(***)



CALCULATE THE VERTEX OPERATOR FOR EMITTING A STRING CONNECTING THE D4 AND D6' BRANES. THAT IS:

$$\begin{array}{c|cccccccccc} & 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\ D6' & N & N & N & N & D & D & N & D & D & D \\ D4 & N & N & N & N & N & N & D & N & D & D \end{array}$$

$$V = V_{NN} \quad V_{ND} \quad V_{DD} \exp(-\varphi)$$


D6'
D4
σ=0
σ
σ=π
τ

POLCHINSKI, CHAUDHURI, JOHNSON
HASHIMOTO

$V = \quad V_{NN} \qquad V_{ND} \quad V_{DD} \quad \exp(-\varphi)$

$\exp(ik_\mu X^\mu)$

V_{ND} CHANGES BOUNDARY CONDITIONS

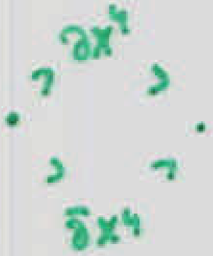
$\partial X^4 + \bar{\partial} X^4 \longrightarrow \partial X^4 - \bar{\partial} X^4$

X^4 A ND COORDINATE

THE RELATIVE SIGN OF ∂X^4 AND $\bar{\partial} X^4$

SHOULD CHANGE.

THAT MEANS :



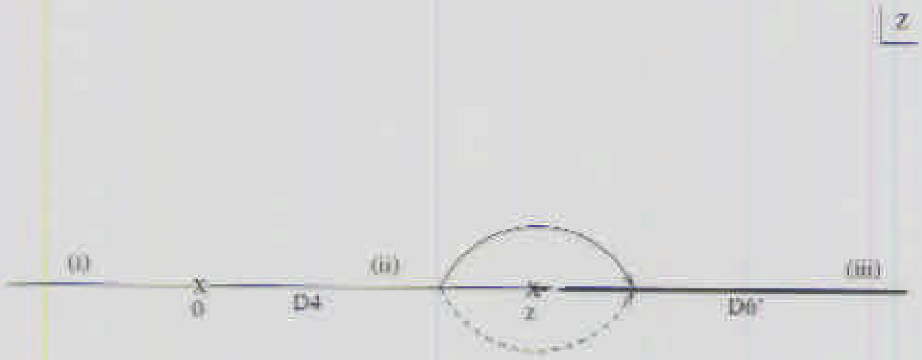
THE OPE:

$$V(z)\,\partial X^4(z')$$

SHOULD CONTAIN A BRANCH CUT

IN $z-z'$.

NAME: TWIST OPERATOR
GAME: ORBIFOLDS
WEIGHT: $1/16$ (THE LEAST)


z
(i)
(ii)
(iii)
0
D4
z
D6'

$$V_{ND} = \underbrace{\sigma_{4567}}_{\text{BOSONS}}\ \underbrace{S_{4567}}_{\text{FERMIONS}}$$

$$\frac{1}{16} \times 8 = \frac{1}{2}$$

SIMILAR WAY TO OBTAIN V_{DD}

THE D4 AT $(x^8=0, x^9=0)$

THE D6' AT (a, b)

ALL IN ALL

$$V = \exp(-\varphi)\,\sigma_{4567}\,S_{4567}\,\exp(ik_r x^r)\,\exp\Big(\frac{i}{\pi}\big(a(x_L^8 - x_R^8) + b(x_L^9 - x_R^9)\big)\Big)$$

$$1 = \frac{1}{2} + \frac{1}{4} + \frac{1}{4} - \frac{M^2}{2} + \frac{a^2+b^2}{2\pi^2}$$

BRST

$$\boxed{M^2 = \frac{a^2+b^2}{\pi^2}}$$

(SHORTEST DISTANCE)

$M^2 \leftrightarrow a=b=0$

FULL $N=2$ STRUCTURE

NS 5 BRANES AND THEIR NHL

CONSIDER k PARALLEL NS-5 BRANES

$$e^{2(\Phi-\Phi_0)} = 1 + \sum_{j=1}^{k} \frac{\ell_s^2}{|\vec{x}-\vec{x}_j|^2} \qquad \begin{array}{l} (g_s \to \infty) \\ \vec{x} \to \vec{x}_j \\ g_s \to 0 \quad |\vec{x}| \to \infty \end{array}$$

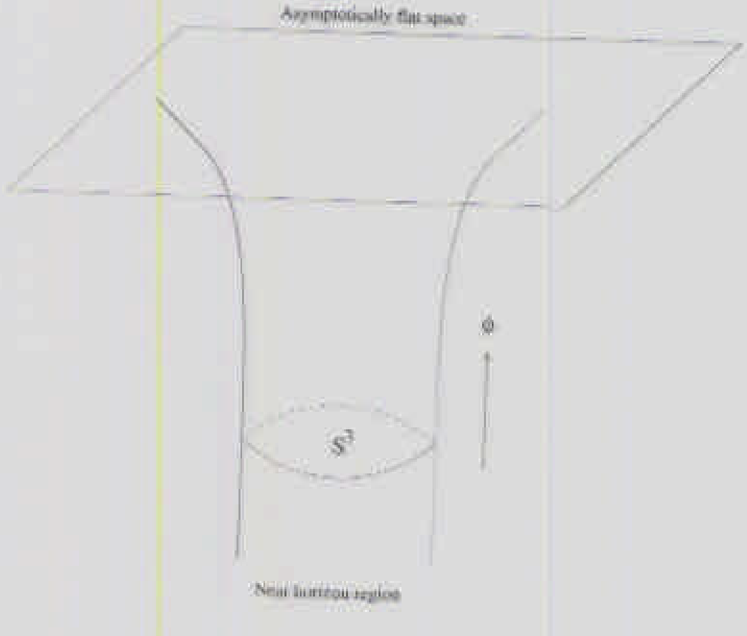
$$G_{IJ} = \exp\left(2(\phi-\phi_0)\right) \delta_{IJ} \qquad I, J = 6, 7, 8, 9$$

$$G_{\mu\nu} = \eta_{\mu\nu} \qquad \mu, \nu = 0, 1, \ldots, 5$$

$$H_{IJK} = -\varepsilon_{IJKL}\, \partial^L \Phi \qquad \vec{x}_i = (x^6, x^7, x^8, x^9)$$

INTERPOLATES BETWEEN FLAT SPACE $G_{IJ} = \delta_{IJ}$

AND NHL (NEAR HORIZON LIMIT)


Asymptotically flat space
ϕ
S^3
Near horizon region

NHL

$$\exp\left(2(\Phi-\Phi_0)\right) \to \frac{k\ell_s^2}{|\vec{x}|^2}$$ ALL BRANES AT $\vec{x}=0$

G_{IJ}, $G_{\mu\nu}$, H_{IJK} APPROPRIATE

CALLEN, HARVEY, STROMINGER

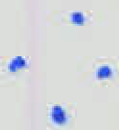
$$R^{5,1} \times R_\phi \times SU(2)_k$$

OOGURI, VAFA
GIVEON, KUTASOV
SFETSOS

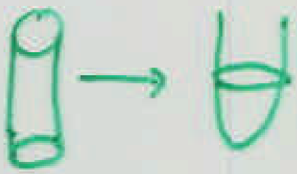
$$R^{5,1} \times \frac{SL(2,R)_k}{U(1)} \times \frac{SU(2)_k}{U(1)}$$

$k \geq 2$

GEOMETRY



NS5 SPLIT



CAPPED

CAN BE WEAKLY COUPLED

$$R^{5,1} \times \frac{SL(2,R)_k}{U(1)} \times \frac{SU(2)_k}{U(1)}$$

$V = \exp(-\varphi)\ \exp(ik^\mu x^\mu)$, V_{LST}, V WITH BRANES!

$$V_{LST} \simeq V_{j,m,\bar{m}}$$

POLES AT $|m| = j+n$

$|\bar{m}| = j+n$ $\quad n = 1,2,3\ldots$

$$-\frac{1}{2} < j < \frac{k-1}{2}$$

FOR $V_{\frac{SU(2)_k}{U(1)}}$ WITH BRANES.

FIRST $V_{SU(2)_k}$ WITH BRANES!

PRADISI, SAGNOTTI, STANEV
KLINCIK, SEVERA
KATO, OKADA
BIANCHI, STANEV
ALEKSEEV, SCHOMERUS
STANCIU
KAWEDZKI
BIRKS, FUCHS, SCHWEIGERT
GARCIA-COMPEAN, PLEBANSKI
BEHREND, PEARCE, PETKOVA, ZUBER
ALEKSEEV, RECKNAGEL, SCHOMERUS x2.
FELDER, FROHLICH, FUCHS, SCHWEIGERT
FIGUEROA-O'FARRILL, STANCIU
BACHAS, DOUGLAS, SCHWEIGERT

CLOSED STRINGS ON $S^3 - SU(2)_k$

WZ TERM $\int_{\partial\Sigma} d^2x \longrightarrow \int_{\Sigma} d^3x \longrightarrow k \in \mathbb{Z}$

OPEN STRINGS ON BRANES ON S^3

(*) THE SYMMETRY $g \to h_L(z)\, g\, h_R(\bar{z})$

IS SMALLER $g \to h g h'^{-1} \quad h' = f h$

ALLOWED g IN CONJUGACY CLASSES OF

$SU(2)$ (G)

$\exp(i\theta\sigma_3)$

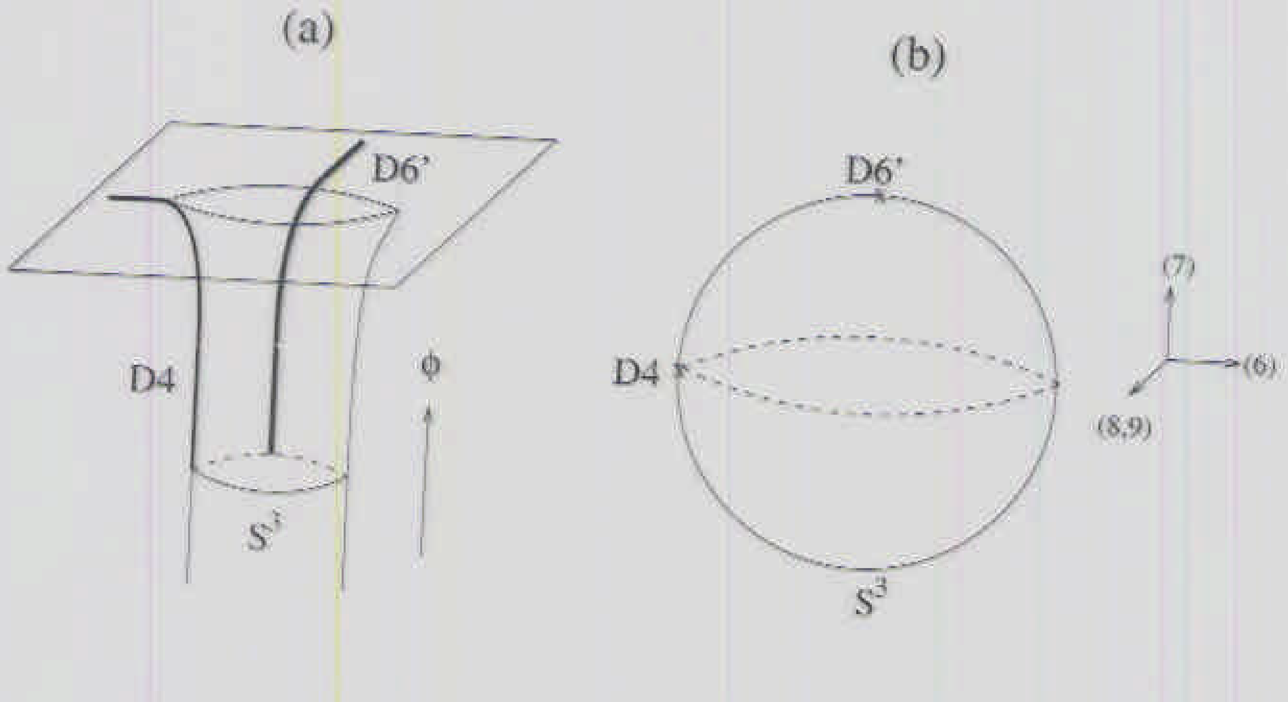
(**) $\int_{M \text{ (WITH BOUNDARIES)}} d^2x \qquad M \neq \partial\Sigma \quad \longrightarrow \int d^3x$

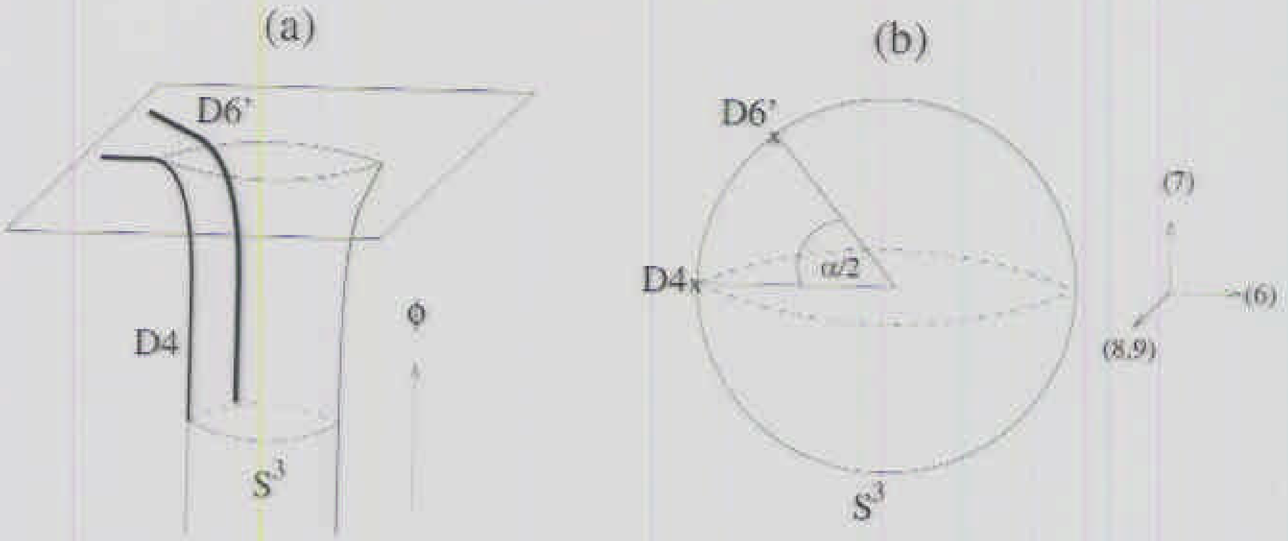
$\downarrow$

CONSTRAINTS

$$\boxed{\theta = 2\pi \frac{j}{k}} \qquad 0 \leq j < \frac{k}{2} \qquad j \in \begin{matrix}\mathbb{Z} \\ \mathbb{Z}+\frac{1}{2}\end{matrix}$$

$k+1$ ALLOWED VALUES (# PRIMARIES)


(a)
D6'
D4
ϕ
S^3
(b)
D6'
D4
S^3
(7)
(6)
(8,9)


(a)
D6'
D4
ϕ
S^3
(b)
D6'
D4
$\alpha/2$
(7)
(6)
(8,9)
S^3

A STRING CONNECTING D4 AND D6'

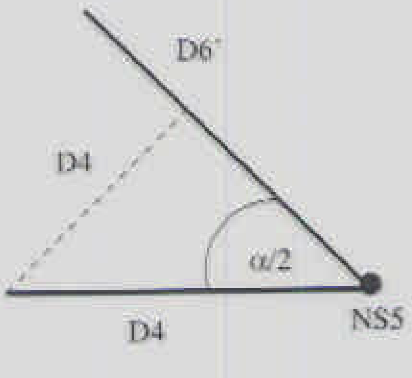
ON S^3.

$$J^3 = \bar{J}^3 \qquad J^{\pm} = \exp(\mp i\alpha)\, \bar{J}^{\pm}$$

$$\boxed{M^2(\alpha) = \frac{1}{2}\left(\frac{\alpha}{\pi} - 1\right)}$$

$M^2(\pi) = 0$!

$M^2(\alpha < \pi) < 0$?


D6'
D4
α/2
D4
NS5

(*) $4-6'_+$ Q (N_c, N_F)

$6'_+-4$ Q^+

$6'_- -4$ $\tilde{Q}$ $(\bar{N}_c, \bar{N}_F)$

$4-6'_-$ $\tilde{Q}^+$

(*) m QUANTIZED ?

A. NO WILSON LINES

B.

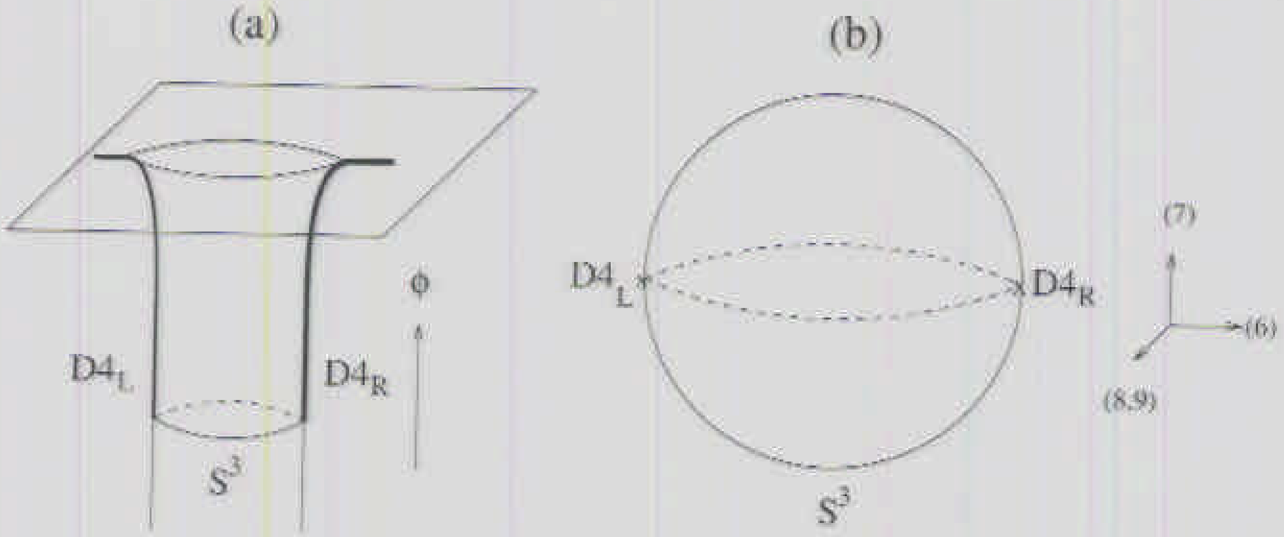
$\theta = n \frac{2\pi}{k}$

(*) AGREES WITH FI $\sim (Q^+ Q - \tilde{Q}^+ \tilde{Q} - r)^2$

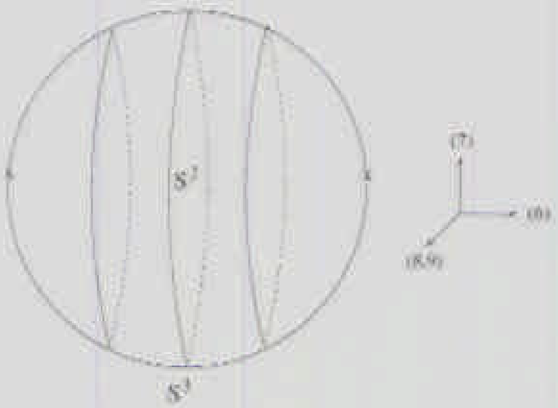
$r \propto \Delta x^7$

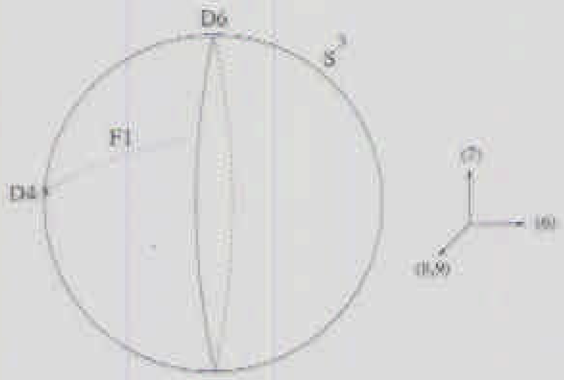
(*) MASSIVE STATES FORM HYPERMULTIPLETS

(*) $j = -\frac{1}{2}$ with mass gap $\sim \frac{1}{l_s}$



(a)
φ
D4$_L$
D4$_R$
S^3
(b)
D4$_L$
D4$_R$
S^3
(7)
(6)
(8,9)


S^2
S^1
(7)
(6)
(8,9)


D6
S^3
F1
D4

THE D6 WRAPS $S^2_n \in S^3$

IT IS TO THE LEFT OF n OUT OF k

NS5-BRANES. MOVING IT TO THE RIGHT

PAST n NS5 CREATES n D4-s

WHICH IN NHL SEEM LIKE n

POINTS ON S^3.

(n D0 $\longleftrightarrow$ D2 WRAPPED ON S^2 WITH RADIUS r_n)

THIS IS HW TRANSITION.

CONCLUSIONS

* CHIRAL STRUCTURE
* PARTICLE CONTENT
* TACHYONS

OBTAINED BY WS METHODS IN THE PRESENCE OF NS5 s

* CONFIDENCE IN METHODS USING HOLOGRAPHY NEEDED TO STUDY LST AND STRINGS IN THE PRESENCE OF SINGULAR STRUCTURES