

Chiral SUSY

Gauge Theories

via Branes

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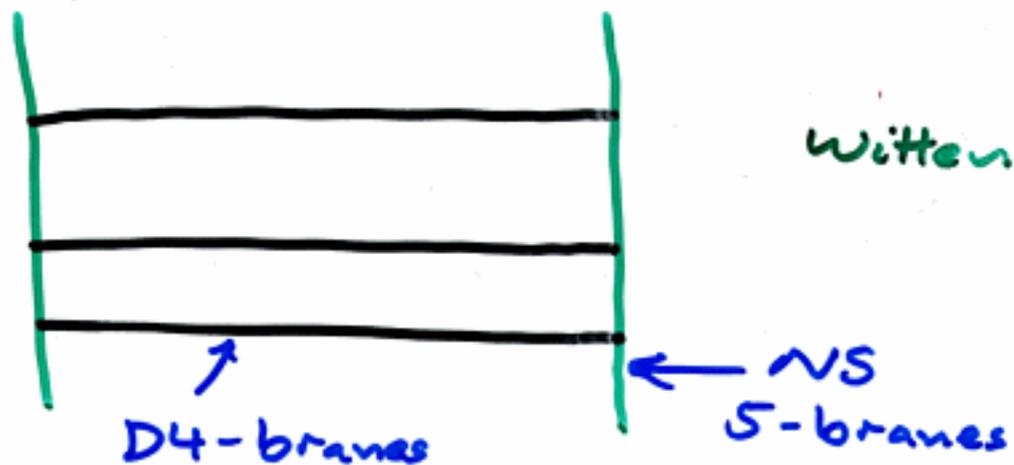
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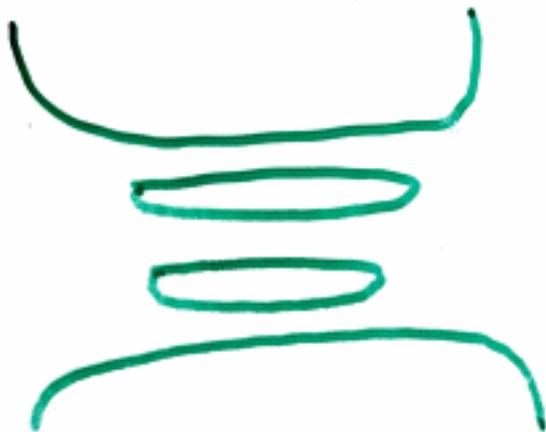
Motivation and Outline

- Can learn much nonperturbative information about gauge theories using their realization via D-branes



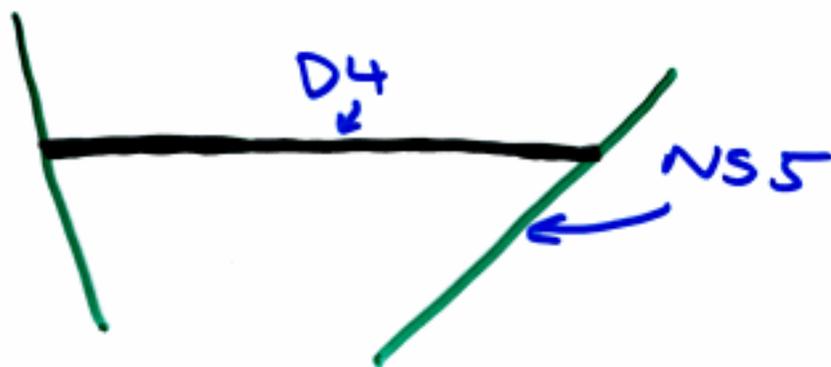
Gives 4d $SU(N)$ gauge theory
 $\mathcal{N}=2$ SUSY

- Lift to M -theory



Single M 5-brane on Riemann surface

- Riemann surface =
Seiberg-Witten curve of
 $\mathcal{N}=2$ gauge theory
- It has allowed construction
of new curves that describe
Coulomb branch of various
 $\mathcal{N}=2$ gauge theories with
various matter contents
- Can also break down to
 $\mathcal{N}=1$ SUSY by rotating
branes
Elitser, Giveon,
Kutasov; Barbon



• As described at last Strings conference :

- recover Seiberg duality by moving branes Elitzur, Giveon, Kutasov; ...
- construct curves describing the exact moduli space of $\mathcal{N}=1$ theories Witten; Hori, Ooguri, Oz; ...

• Outstanding problem : how do you get chiral matter via a brane construction ?

• One approach Lykken, Poppitz, Trivedi
put branes at orbifold singularities

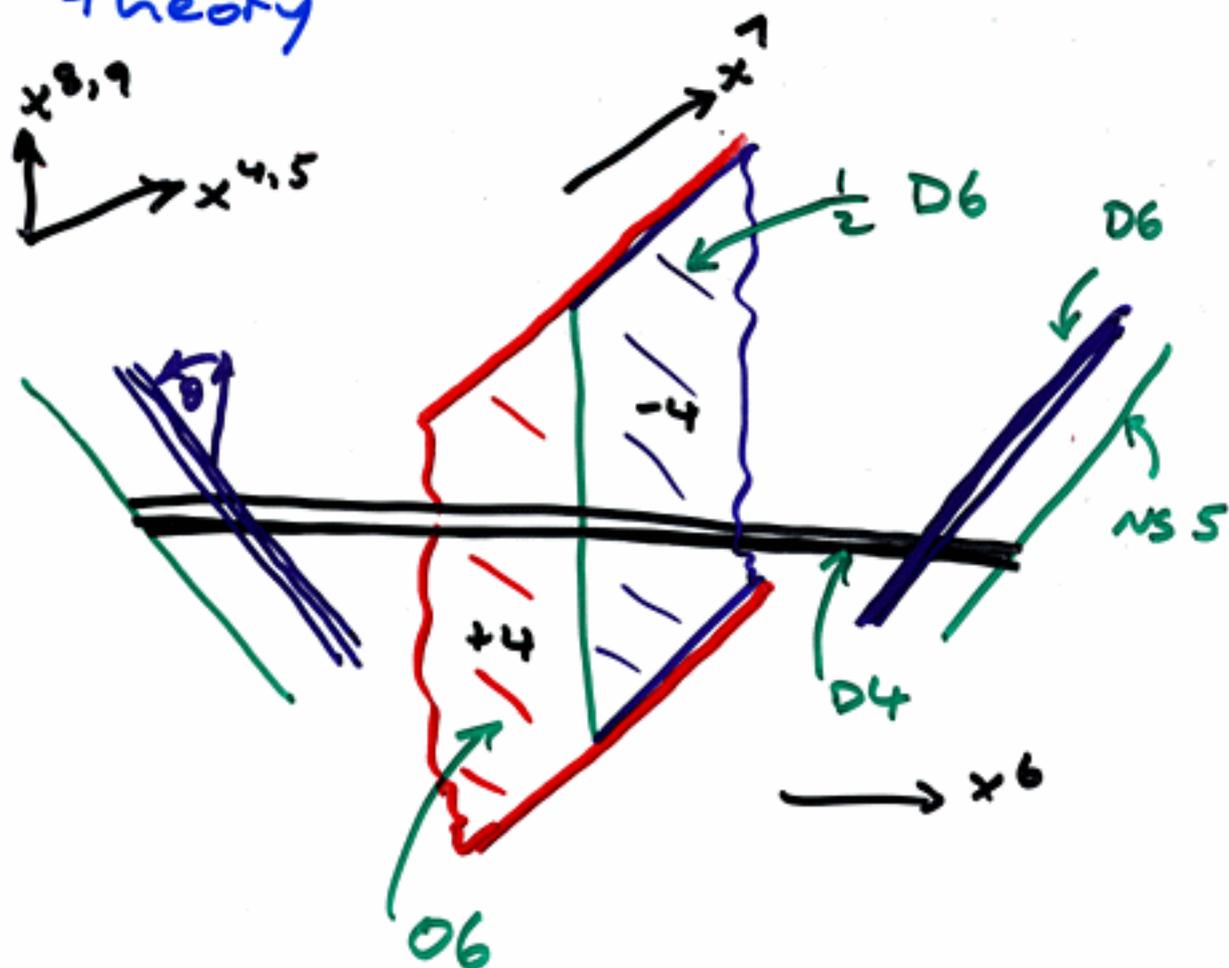
- Instead - introduce orientifold plane and D6-branes that end on an NS 5-brane \rightarrow chiral gauge theory with Seiberg dual (L^3 ; Elitzur, Giveon, Kutasov, Tsabar; Brunner, Hanany, Karch, Lust)

Deformation of a model considered in field theory
Intriligator, Leigh, Strassler

- Recently, L^3 constructed curve describing moduli space of this chiral theory (Park)

- Plus curves for many related non-chiral $\mathcal{N}=1$ and $\mathcal{N}=2$ gauge theories
- $\mathcal{N}=2$ $SU(N_c)$ with
 - (a) symmetric flavor and N_f fundamental flavors (arbitrary masses)
- Rotated $\mathcal{N}=1$ theories with massive tensor; massive fundamentals
- Application: understand Higgsing of $\mathcal{N}=1$ gauge theories geometrically by considering intersection of curve with blown-up D_N singularity

- Brane configuration for chiral theory



Orientifold plane

n D4 branes

m_f pairs D6 branes

8 $\frac{1}{2}$ D6 branes

- Orientifold sixplane carries ± 4 units of RR charge (c.f. D6 $\rightarrow +1$)
- +4 case \rightarrow symplectic gauge symmetry on D6 worldvolume
In M-theory, D_4 singularity
- -4 case \rightarrow orthogonal gauge symmetry on D6 worldvolume
In M-theory, D_0 "singularity"
 \sim Atiyah-Hitchin
- If orientifold crosses $\sim S$
S-brane - sign of projection changes
Evans, Johnson, Shapere

- Role of $8 \frac{1}{2} D6's \rightarrow$
cancel discontinuity in RR
charge. Corresponds to
anomaly cancellation in gauge
theory (c.f. Hanany, Zaffaroni)
 $\frac{1}{2} D6's \rightarrow$ chiral multiplets in
Fundamental

- Lift to M theory :
M5-brane at D_4 singularity

- Configuration \rightarrow

$SU(n)$ gauge theory with
 $n_f + 8$ fundamentals
 n_f antifundamentals

Symmetric } chiral multiplets
 antisymmetric }

\hookrightarrow non-anomalous chiral theory

- Deduce a superpotential of form

$$W = \frac{1}{\mu} \text{Tr} (X \tilde{X})^2 + \hat{Q} \tilde{X} \hat{Q}$$

X = antisymmetric

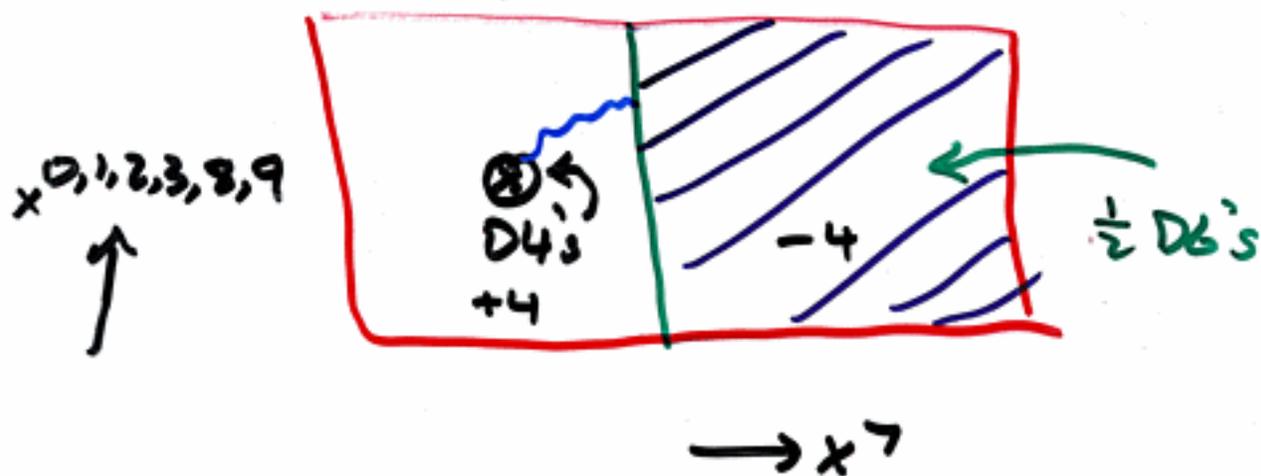
\tilde{X} = sym.

\hat{Q} = 8 fundamentals
From $\frac{1}{2}$ D6's

μ = mass of adjoint
chiral multiplet, integrated
out $\mu = \tan \theta$

See $\text{Tr}(X \tilde{X})^2$ by considering
how couplings change when
rotating from $\theta = 0$ configuration
Brodie & Hanany

- To see $\hat{Q} \tilde{X} \hat{Q}$ term
move middle 5-brane
in x^7 direction



\hat{Q} 's get a mass

Gauge group $\rightarrow SO(N_c)$

x^7 position \rightarrow FI parameter
that appears in D-term

$$\begin{aligned}
 \nu \delta_b^a &= \hat{Q}_a^i (\hat{Q}^{\dagger})_i^b + 2X_{ac} (X^{\dagger})^{cb} \\
 &\quad - 2(\tilde{X}^{\dagger})_{ac} \tilde{X}^{cb} + \dots
 \end{aligned}$$

\uparrow ϵx^7

- v has $-$ sign \Rightarrow
 \tilde{X} gets vev, gauge
 group breaks to $SO(N_c)$

\sim baryonic branch

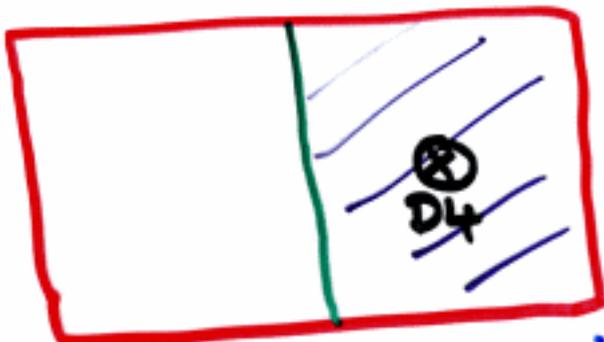
$$(\tilde{X})^{N_c} \neq 0$$

$\therefore \hat{Q} \tilde{X} \hat{Q}$ term needed

- v has $+$ sign \Rightarrow

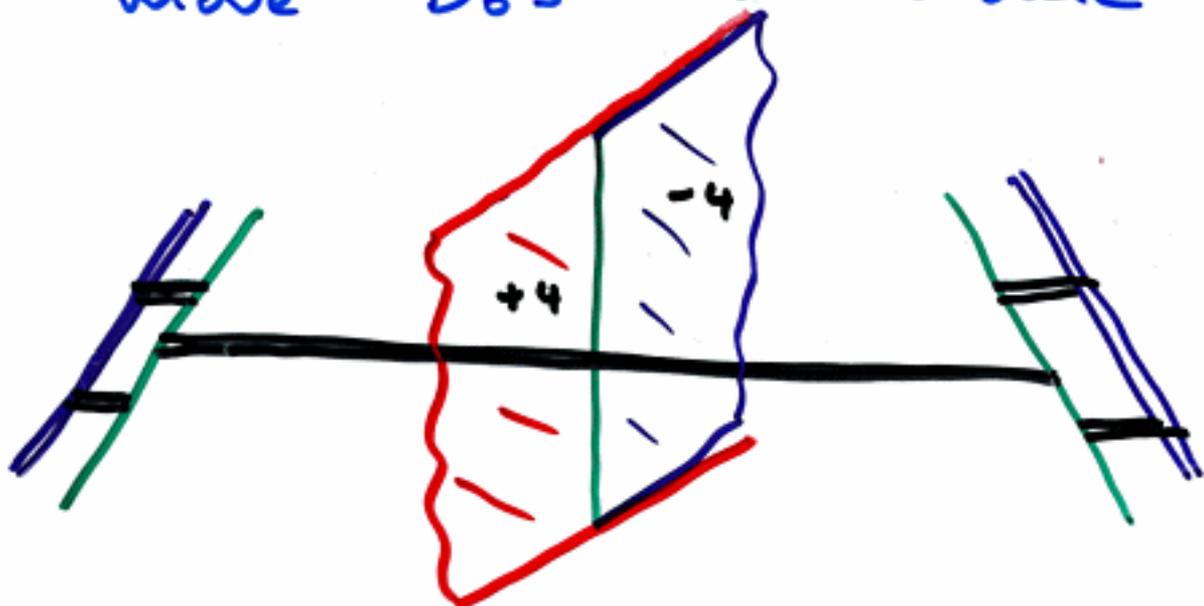
X gets vev, gauge
 group $\rightarrow Sp(N_c)$

\hat{Q} 's remain massless



Agrees with brane picture

- Can see transition to magnetic dual theory by moving branes to mirror image configuration + move D6's to outside

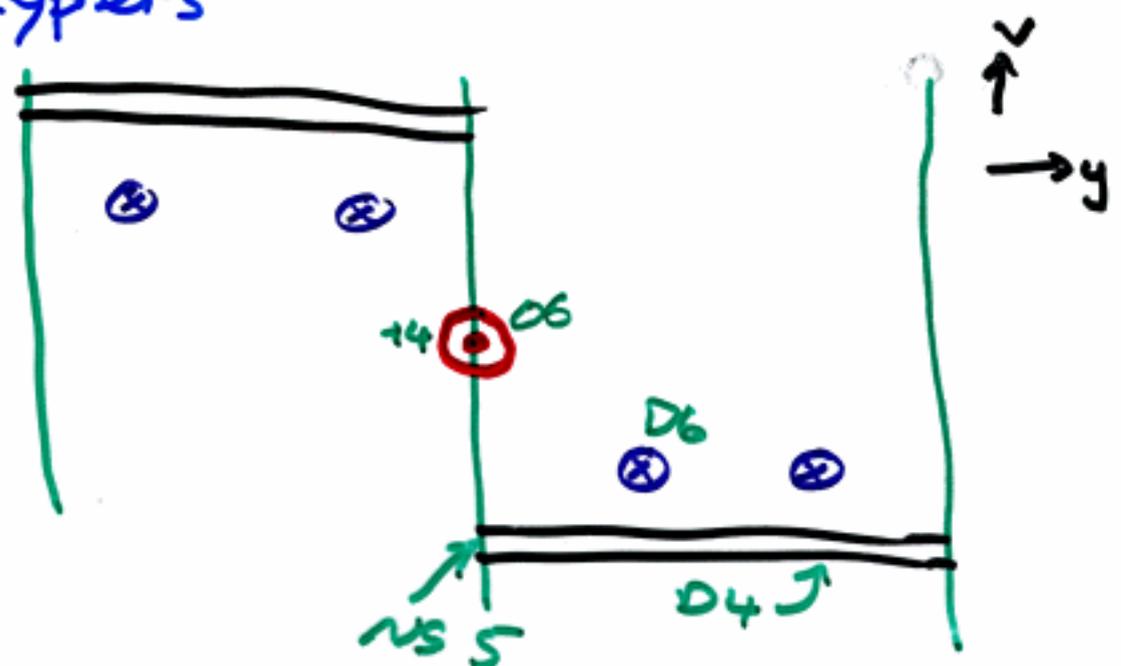


- Assume D4 created whenever NS 5 crosses non-parallel D6
Treat O6 + $\frac{1}{2}$ D6's as set of 4 D6's as far as D4 creation goes \rightarrow
 $SU(3m_f - N_c + 4)$ gauge theory
 $m_f + 8$ fundamentals, m_f antifund.
symmetric + antisymmetric

- Have checked 't Hooft anomaly matching conditions are satisfied + correspondence of some simple superpotential deformations + flat directions between electric \leftrightarrow magnetic theories.

Confirms brane prediction for magnetic dual.

- Can explicitly determine curve \rightarrow exact moduli space of chiral theory
- Take scenic route :
 construct new $N=2$ curves describing $SU(N)$ with 2-index tensor matter and fundamental hypers



\rightarrow Symmetric Flavor

- $$xy = (-1)^{N_f} \sqrt{4} \prod_{k=1}^{N_f} (v^2 - e_k^2)$$

$$y^3 + y^2 p(v) + y v^2 j(v) p(-v) + v^6 j^2(v) j(-v) = 0$$

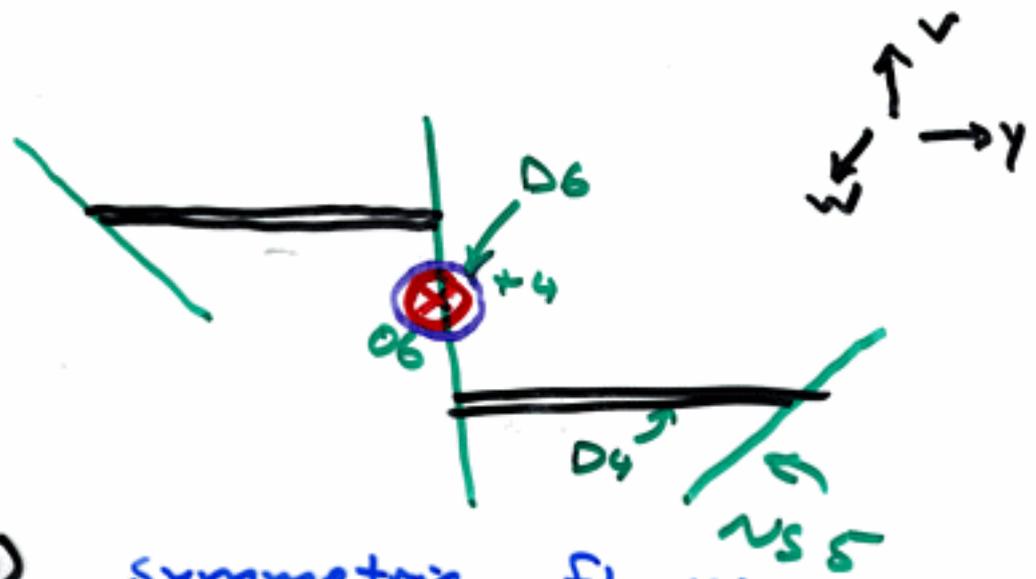
$$p(v) = v^{N_c} + \frac{1}{2} N_c m v^{N_c-1}$$

$$m_j(v) = \frac{1}{2} v^{N_c-2} + \dots = \prod_{k=1}^{N_c} (v - e_k)$$

= mass of symmetric

$$M_k = \frac{1}{2} - e_k = \text{mass of fundamental}$$

- Rotate to $N=1$ SUSY



$SU(N)$ symmetric flavor + fundamental flavors

- $$v = \frac{b}{\lambda-1} + \frac{b}{\lambda} + \frac{b}{\lambda+1}$$

$$w = \frac{b\mu}{\lambda-1} + 2b\mu - \frac{b\mu}{\lambda+1}$$

$$y = A \left(\frac{\lambda-1}{\lambda+1} \right)^{N_c - N_f - 2}$$

$\mu = \tan \theta$

b, A constants

$\tilde{b} \sim m$, symmetric mass

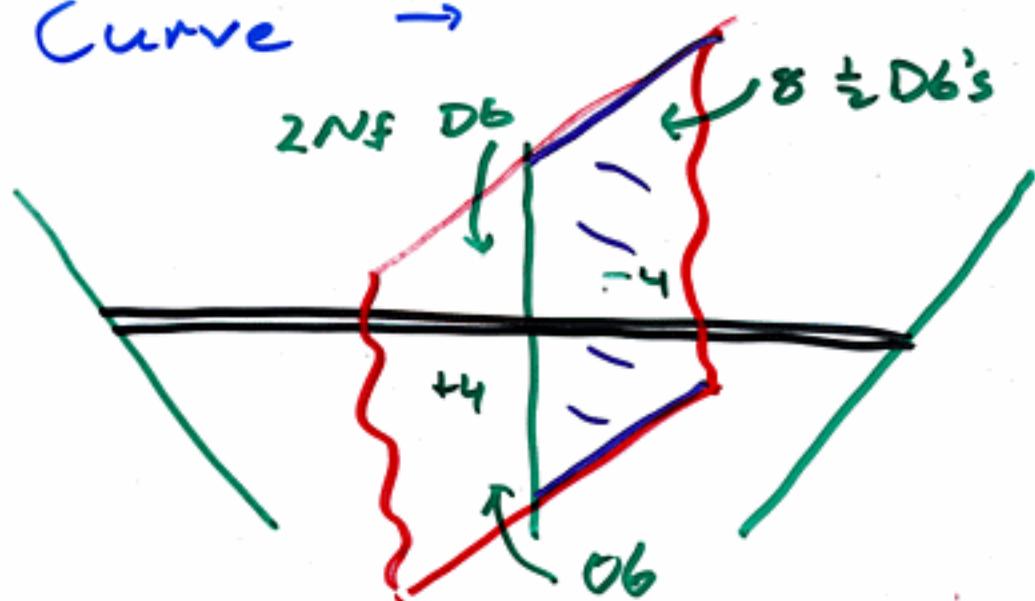
- When $\tilde{b} \rightarrow 0$ central fivebrane factorizes

→ Disconnected component $w=0$

Rotate so it is parallel with $06 \rightarrow$ chiral theory

Curve = same as above ($\tilde{b}=0$) plus $v=0$ component

Curve \rightarrow



Now have $2N_f$ D6 parallel
to O6 + $8 \frac{1}{2}$ D6 branes

Flavor symmetry

$$SO(2N_f + 8)_L \times Sp(2N_f)_R$$

Tree-level superpotential

$$W = Q X_{\text{sym}}^{\sim} Q + \tilde{Q}^2 X_{\text{sym}} \tilde{Q}^{\sim} + \frac{1}{\mu} (X_{\text{sym}}^{\sim} X_{\text{sym}})^2$$

\tilde{Q}^{\sim} = antifundamentals
 Q = fundamentals

Conclusions

- Nice example of a chiral gauge theory via branes.

Brane realization \rightarrow
read off Seiberg duality,
determines exact moduli
space using curve.

- Many new results for non-chiral $\mathcal{N}=1$ and $\mathcal{N}=2$ gauge theories as well.
- Small step closer to understanding phenomenologically interesting gauge theories using branes