Title: The holographic dual of the standard model on the throat

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Abstract:

Holographic dual of the Standard Model on the throat.

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Based on work in collaboration with M.P. García del Moral, F. Quevedo,
A. Uranga. hep-th/0312051 and
F. Saad, A. Uranga. hep-th/0503079

(Perimeter Institute, April 1, 2005)

Outline

- Quick introduction.

- Background material.

  ⋆ Model building with D-branes at singularities.

  ⋆ Review of the Klebanov-Strassler throat solution.

- Motivation and objective.

- First construction.

- Recent developments and improved model.

Flux compactifications

Focus on IIB in presence of $G_3 = F_3 - \phi H_3$ with $\phi = C_0 - i/g_s$.

Very appealing features:

- Induce superpotential and scalar potential for moduli fields.

$$W = \int_M G_3 \wedge \Omega \text{ (GVW-type)} \longrightarrow V_{sc} = e^{\mathcal{K}}\left(G^{i\bar{j}} D_i W \overline{D_j W} - 3|W|^2\right)$$

- Backreaction of the fluxes generates warped metrics $\rightarrow$ solution of hierarchy problem à la RS.

$$ds^2 = Z^{-1/2}(y)\, \eta_{\mu\nu}\, dx^\mu\, dx^\nu + Z^{1/2}(y) ds^2_{CY}$$

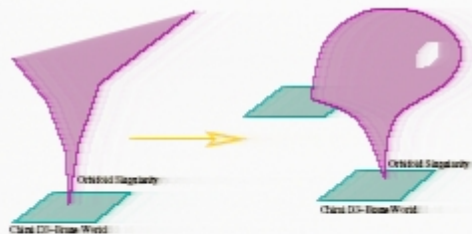- Can break SUSY in a controlled and computable manner (induce soft SUSY breaking terms).

D-branes at singularities I

- Center on D3 / $\overline{D3}$ on C^3/Z_N singularities.

M. R. Douglas and G. W. Moore, hep-th/9603167

- The bottom-up approach:

- Built up local configuration of D-branes leading to SM.
- Subsequently embed it into different global compactifications.

Aldazabal, L. E. Ibanez, F. Quevedo and A. M. Uranga, hep-th/0005067

- The worldvolume spectrum must be projected:

D3 on Flat C^3	D3 on C^3/Z_N
$\mathcal{N} = 4$ SYM	$\mathcal{N} = 1$ v. multiplet in $\prod_{i=0}^{N-1} U(n_i)$
$U(n)$ in $d = 4$	$\mathcal{N} = 1$ ch. multiplets in
	$\sum_{a=1}^{3} \sum_{i=0}^{N-1} \left(\mathbf{n}_i, \overline{\mathbf{n}}_{i+l_a} \right)$
	$\downarrow$
	Quiver diagrams

D-branes at singularities II

- C^3/Z_3 only one leading to 3 families:

$$(z_1, z_2, z_3) \longrightarrow (\alpha^{l_1} z_1, \alpha^{l_2} z_2, \alpha^{l_3} z_3) \ ; \ \alpha = e^{2\pi i/3} \ ; \ l_1 + l_2 + l_3 = 0$$

- $C^3/Z_3 \longrightarrow U(n_1) \otimes U(n_2) \otimes U(n_3)$

$$3 \times [(n_0, \overline{n_1}) \oplus (n_1, \overline{n_2}) \oplus (n_2, \overline{n_3})]$$

- Local geometry $\Longrightarrow$ Do not worry for untwisted tadpoles
- **BUT!** Twisted tadpole c.c. $\Longrightarrow n_1 = n_2 = n_3 \Longrightarrow U(n)^3$
- Can enrich the setup by adding D7-branes wrapping 4-cycles.

Fermions   Scalars

$\overline{D3}$ / D7 system (NON–SUSY)   D3 / D7 system (SUSY)
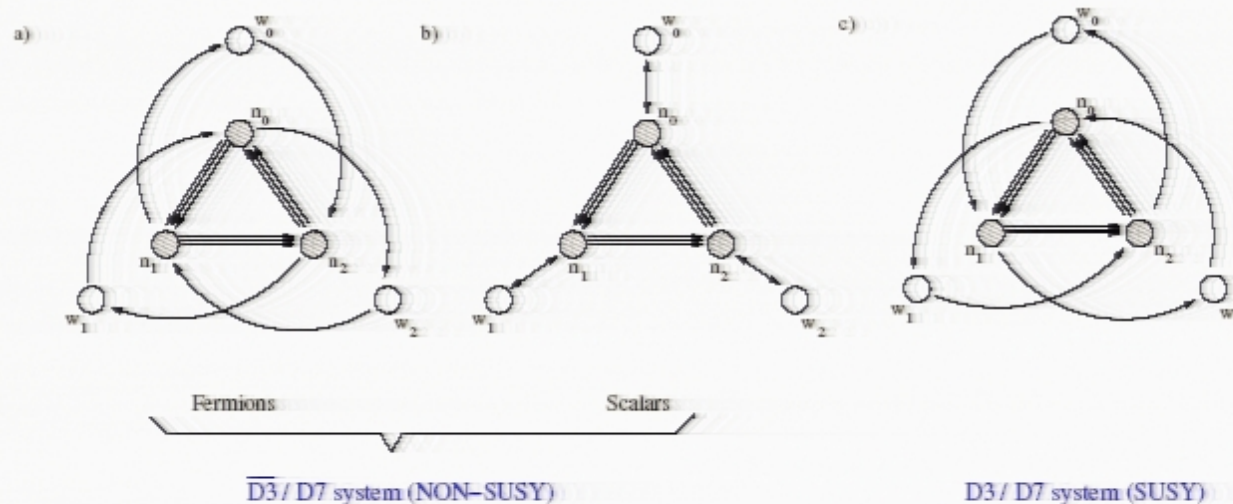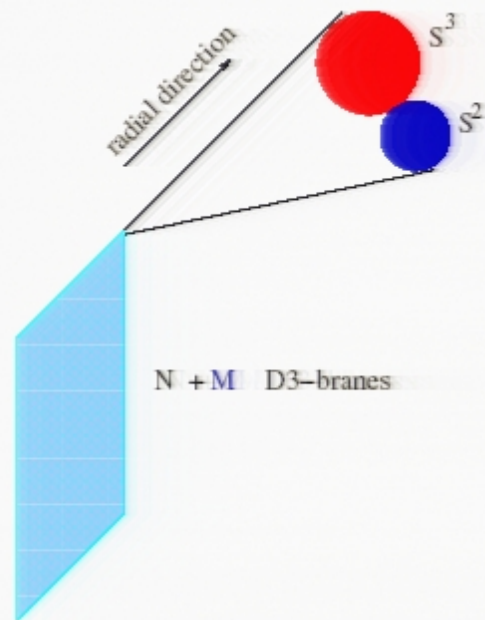
Klebanov-Strassler throat solution

A String Theory configuration that realizes both warping and moduli stabilization.

N regular + M fractional D3's on a conifold singularity

N +M D3–branes

$\mathcal{N}=1$, $d=4$ gauge theory:

$$SU(N) \otimes SU(N+M)$$

$A_{1,2}$ □ $\bar{\bar{\square}}$

$B_{1,2}$ $\bar{\bar{\square}}$ □

★ Fractional branes break conformal invariance.

★ The theory suffers cascade of Seiberg dualities and strong dynamics that deform moduli space.

I. R. Klebanov and M. J. Strassler, hep-th/0007191

Klebanov-Strassler throat solution II

Underlying geometry is a deformed (not singular) conifold:

$$xy - uv = \epsilon \quad \text{in } \mathbf{C}^4$$

- The metric has an exponential warp factor $Z(r)$
- The solution contains F_3 and H_3 fluxes: $\int_{S^3} F_3 = M$ and $\int_{dual} H_3 = -K$
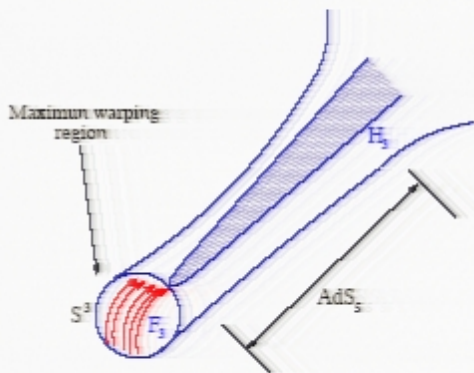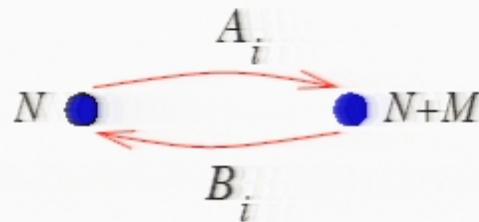

⋆ Highly warped throat $\sim$ AdS$_5$

⋆ But! finite S^3 caps it off at finite r.
Relative warp factor:

$$Z \sim e^{8\pi K/3Mg_S}$$

⋆ ϵ stabilized at $\epsilon = e^{-2\pi K/Mg_S}$
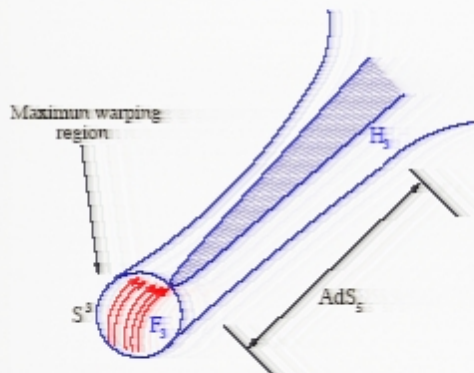
Klebanov-Strassler throat solution III

How to check that IR region $(r \to 0)$ of the geometry is deformed: study (the RG flow of) the dual gauge theory.

$$N \bullet \xrightarrow{A_i} \bullet N+M$$
$$\xleftarrow{B_i}$$

Moduli space:

$$\det \mathcal{M} = 0$$

$$\mathcal{M} = \begin{pmatrix} A_1 B_1 & A_1 B_2 \\ A_2 B_1 & A_2 B_2 \end{pmatrix}$$

Maximum warping region

S^3 F_3 H_3 AdS$_5$

Klebanov-Strassler throat solution III

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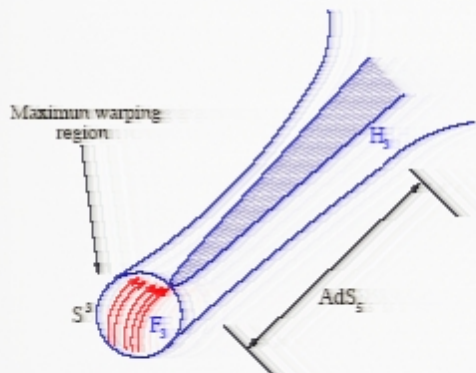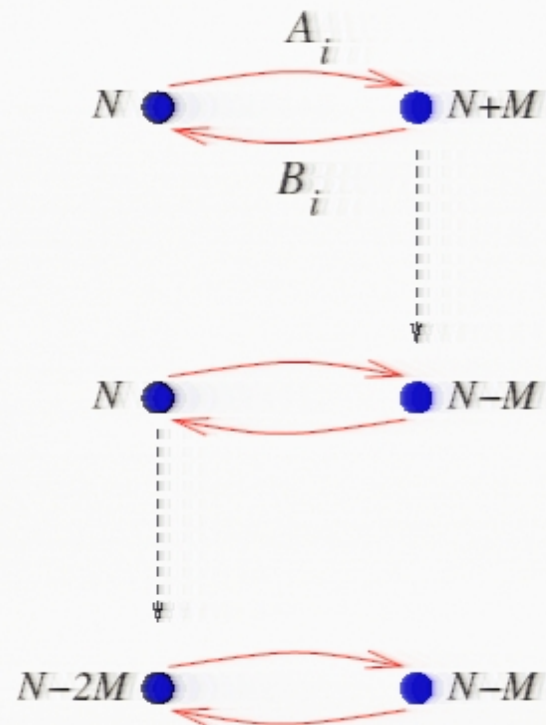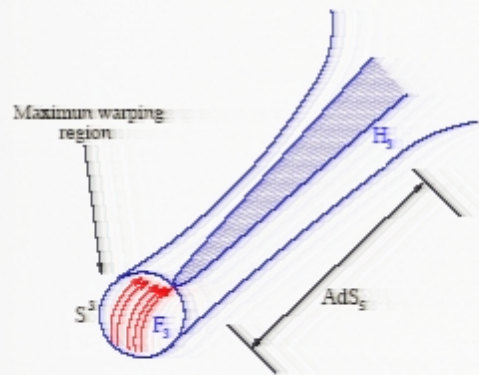
Klebanov-Strassler throat solution III

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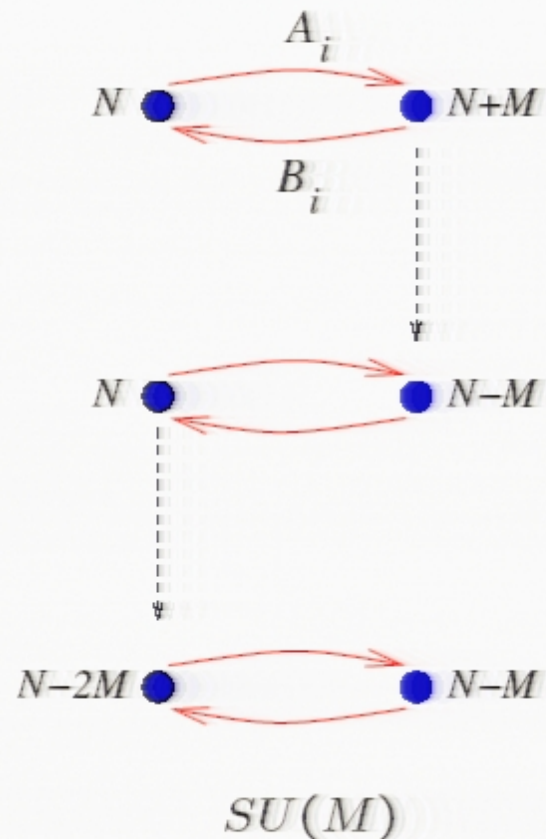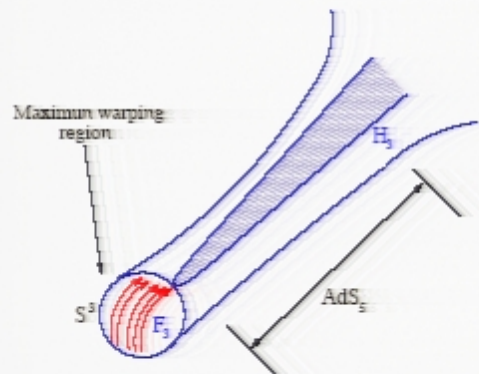
Moduli space:

$$\det \mathcal{M} = 0$$

$$\mathcal{M} = \begin{pmatrix} A_1 B_1 & A_1 B_2 \\ A_2 B_1 & A_2 B_2 \end{pmatrix}$$

Klebanov-Strassler throat solution III

How to check that IR region ($r \to 0$) of the geometry is deformed: study (the RG flow of) the dual gauge theory.

$$A_i$$

$N \bullet \quad \longrightarrow \quad \bullet \; N{+}M$

$$B_i$$

$N \bullet \quad \longrightarrow \quad \bullet \; N{-}M$

$N{-}2M \bullet \quad \longrightarrow \quad \bullet \; N{-}M$

$$SU(M)$$

Moduli space:

$$\det \mathcal{M} = 0$$

$$\mathcal{M} = \begin{pmatrix} A_1 B_1 & A_1 B_2 \\ A_2 B_1 & A_2 B_2 \end{pmatrix}$$

Klebanov-Strassler throat solution III

How to check that IR region $(r \to 0)$ of the geometry is deformed: study (the RG flow of) the dual gauge theory.

$N_c = N_f = 2M$

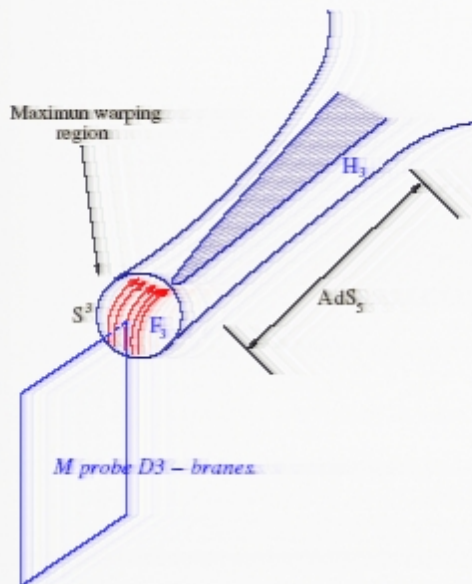Quantum deformation of moduli space:

$$\det \mathcal{M} = \Lambda^{4M}$$
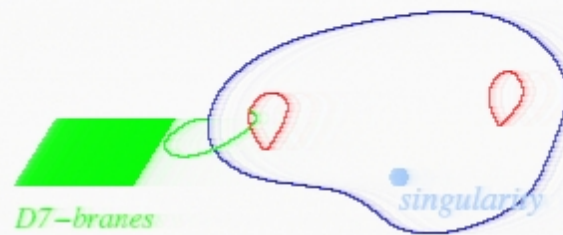$$x = A_1 B_1$$
$$u = A_1 B_2$$
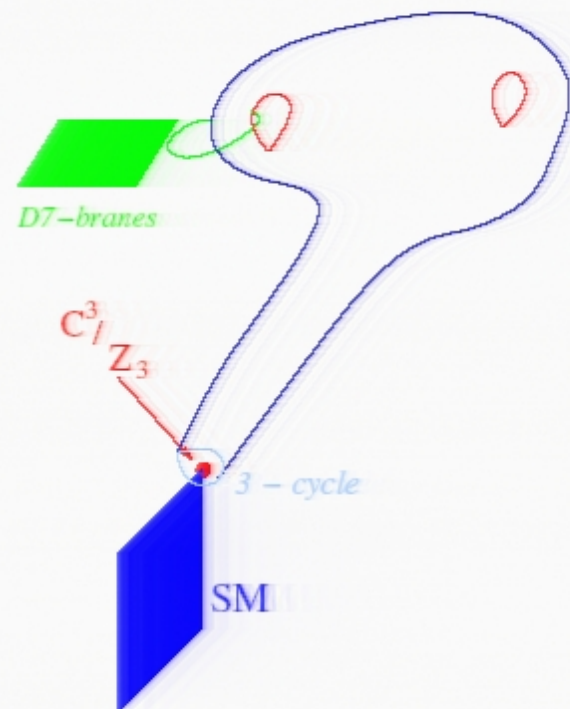$$v = A_2 B_1$$
$$y = A_2 B_2$$
$$xy - uv = \epsilon$$

Maximun warping region

H_3

S^3

F_3

AdS_5

M probe D3 − branes

What we search for

Combine {
Model building of D3's at singularities.
Klebanov-Strassler like setup: moduli fixing + hierarchy.
}

D7-branes

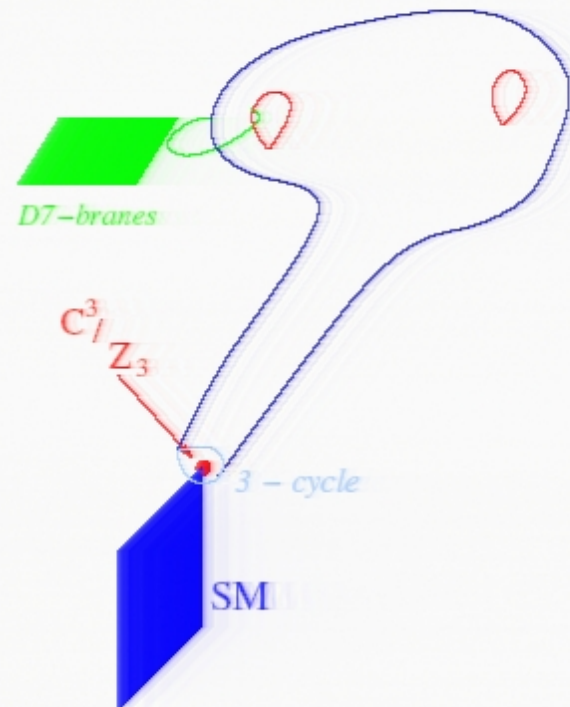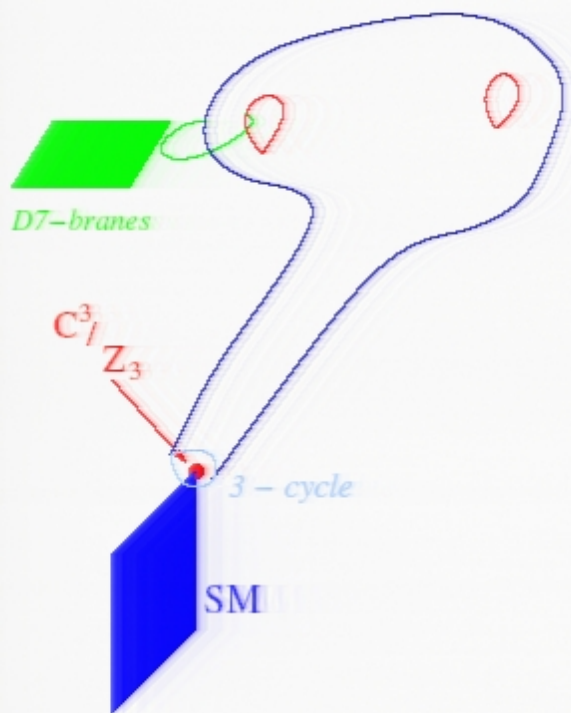singularity

What we search for

Combine
$\begin{cases} \text{Model building of D3's at singularities.} \\ \text{Klebanov-Strassler like setup: moduli fixing + hierarchy.} \end{cases}$

D7–branes

C^3/Z_3

3 − cycle

SM

What we search for

Combine
$\begin{cases} \text{Model building of D3's at singularities.} \\ \text{Klebanov-Strassler like setup: moduli fixing} + \text{hierarchy.} \end{cases}$

D7−branes

C^3/Z_3

3 − cycle

SM

What we search for

Combine
$\begin{cases}\end{cases}$ Model building of D3's at singularities.
Klebanov-Strassler like setup: moduli fixing + hierarchy.

- Most moduli stabilized
- SM degrees of freedom present in the setup
- At a point in transverse space where a "geometric" hierarchy is stabilized (à la RS)
- Potentially fix all moduli and lead to dS (à la KKLT)
- Implement Dp-$\overline{D}p$ inflation...

★ Obtain the holographic dual gauge theory (microscopic description of the geometry).
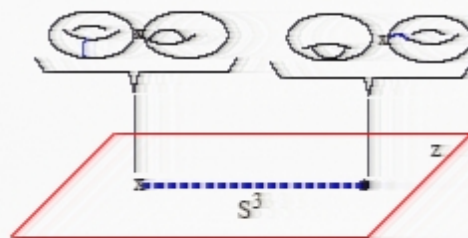
D7−branes

C^3/Z_3

3 − cycle

SM

How to engineer the geometry ?

- Deformed conifold: $xy - zw = \epsilon$. Has no Z_3 symmetry that leaves a C^3/Z_3 isolated singularity.
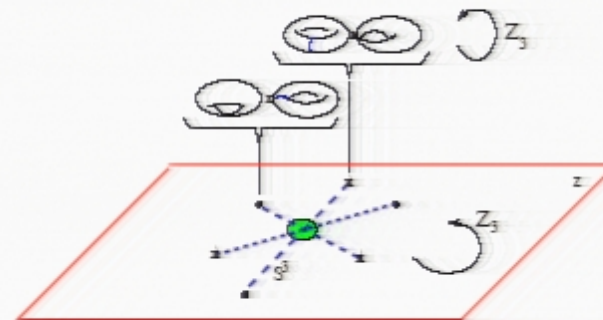- Need to device an adequate geometry:

Our 6d manifold is:
2d base (complex coordinate z)
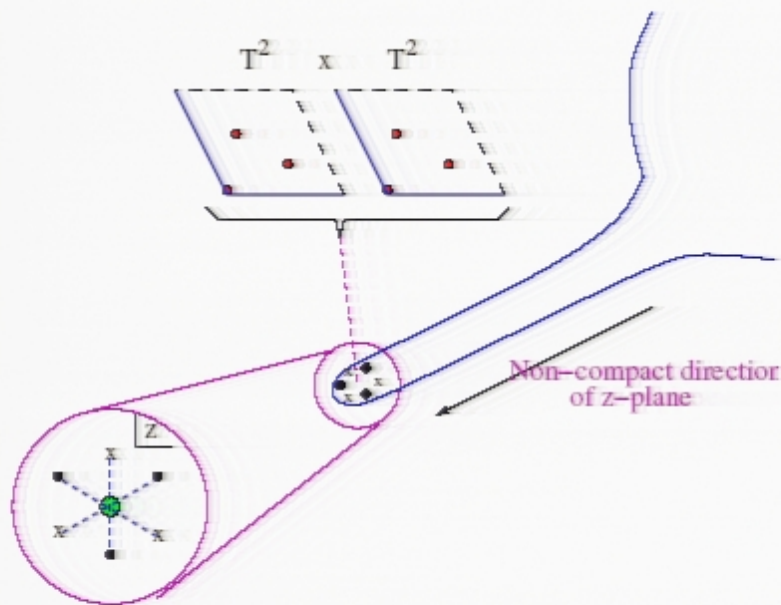4d fiber $T^2 \otimes T^2$ (double elliptic fibr.)

Conifold

$$y^2 = x^3 - 3(z/z_0)^2 x + 2(z/z_0)^3 - 4$$
$$y^2 = x'^3 - 3(z/z_0')^2 x' + 2(z/z_0')^3 - 4$$

$$Z_3 : (z, x, x') \longrightarrow e^{2\pi i/3}(z, x, x')$$

Final structure of the throat

We turn on $\begin{cases} \text{M units of } F_3 \text{ along the } S^3 \\ \text{K units of flux along the dual cycles.} \end{cases}$

$T^2 \quad x \quad T^2$

Non-compact direction
of z-plane

Several model building possibilities:

- n $\overline{D3}$'s at the bottom of the throat (and the required D7's and extra D3's to cancel tad-poles)
- n D3's

Problems $\begin{cases} \bullet \text{ SuGra side: very obscure geometry, no explicit metric.} \\ \bullet \text{ Holographic dual side: No idea of what the dual gauge theory is.} \end{cases}$

New approach

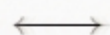Recently, deeper insight on warped throats and their holographic dual gauge theories.

Warped throats appear naturally on CY singu. that admit complex $\longleftrightarrow$ deformation (can be smoothed by a 3-cycle)

$\downarrow$

Turn on F_3, H_3

$\downarrow$

Highly warped throat with the 3- $\longleftrightarrow$ cycle structure at its bottom.

Holographic dual gauge theory? That in the worldvolume of N D3-branes placed at the singu.

$\downarrow$

Cascade of dualities until a final theory with strong dynamics.

$\downarrow$

Mesons get a vev. Deformation of moduli space.

Franco, He, Herzog, Walcher; hep-th/0402120
Ejaz, Herzog, Klebanov; hep-th/0412193
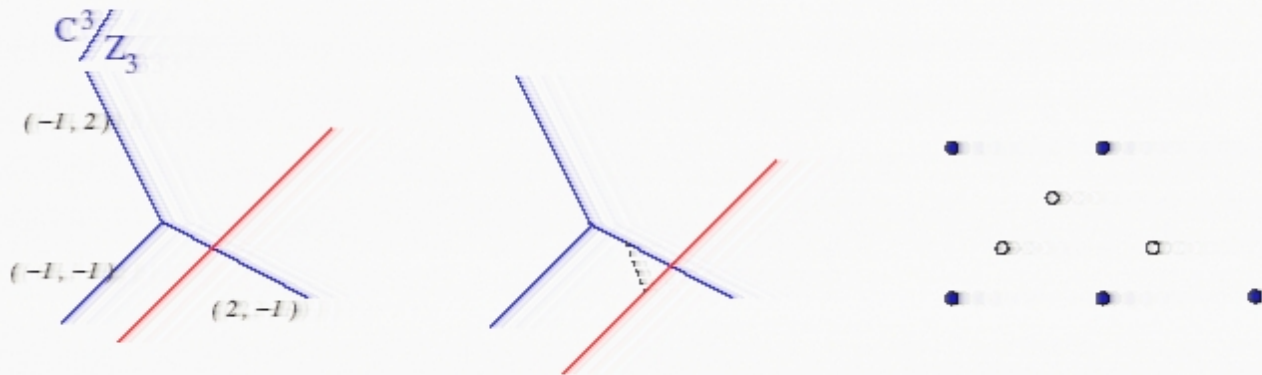Franco, Hanany, Uranga; hep-th/0502113

The nice singularity

Look for $\left\{ \begin{array}{l} \bullet \text{ Warped throat: a singularity that admits a complex def.} \\ \bullet \text{ After the deformation: a } C^3/Z_3 \text{ at its bottom.} \end{array} \right.$
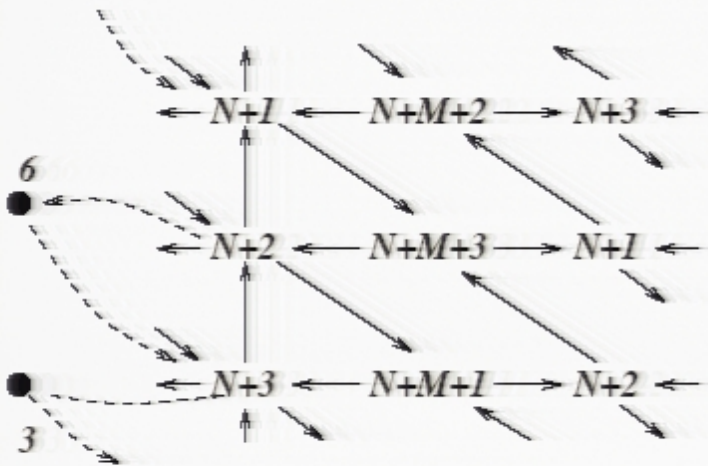
- Using techniques of toric geometry, very easily obtainable. One is:

  Suspended pinch point $(uv - zw^2 = 0)\ /Z_3$

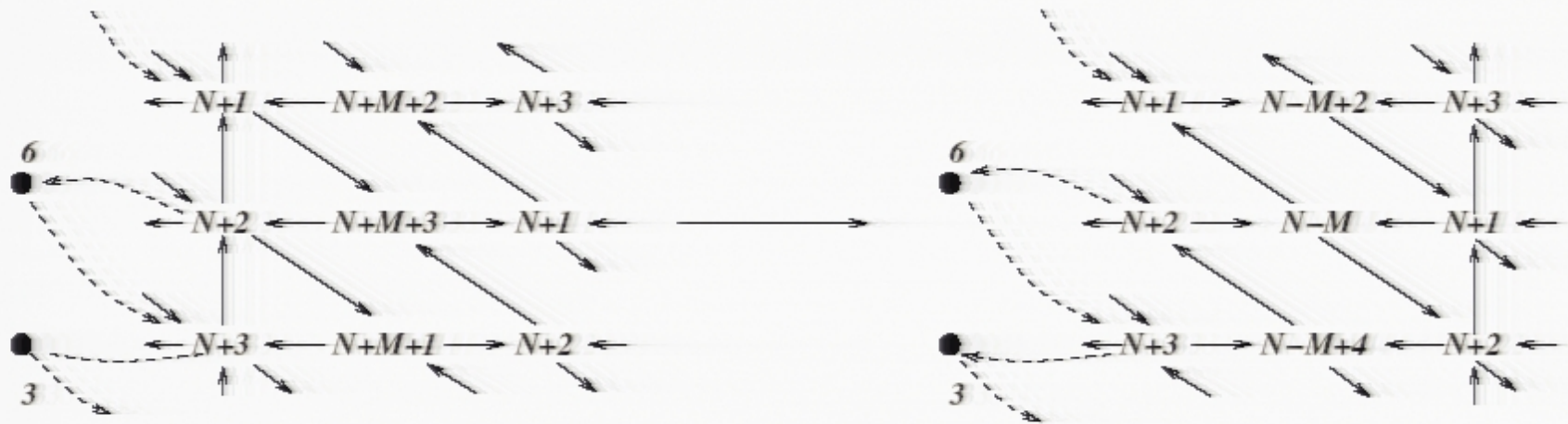- Interesting because one has the holographic dual description of it: the gauge theory in the worldvolume of N D3-branes at the SPP/Z_3 singularity.

Holographic dual gauge theory

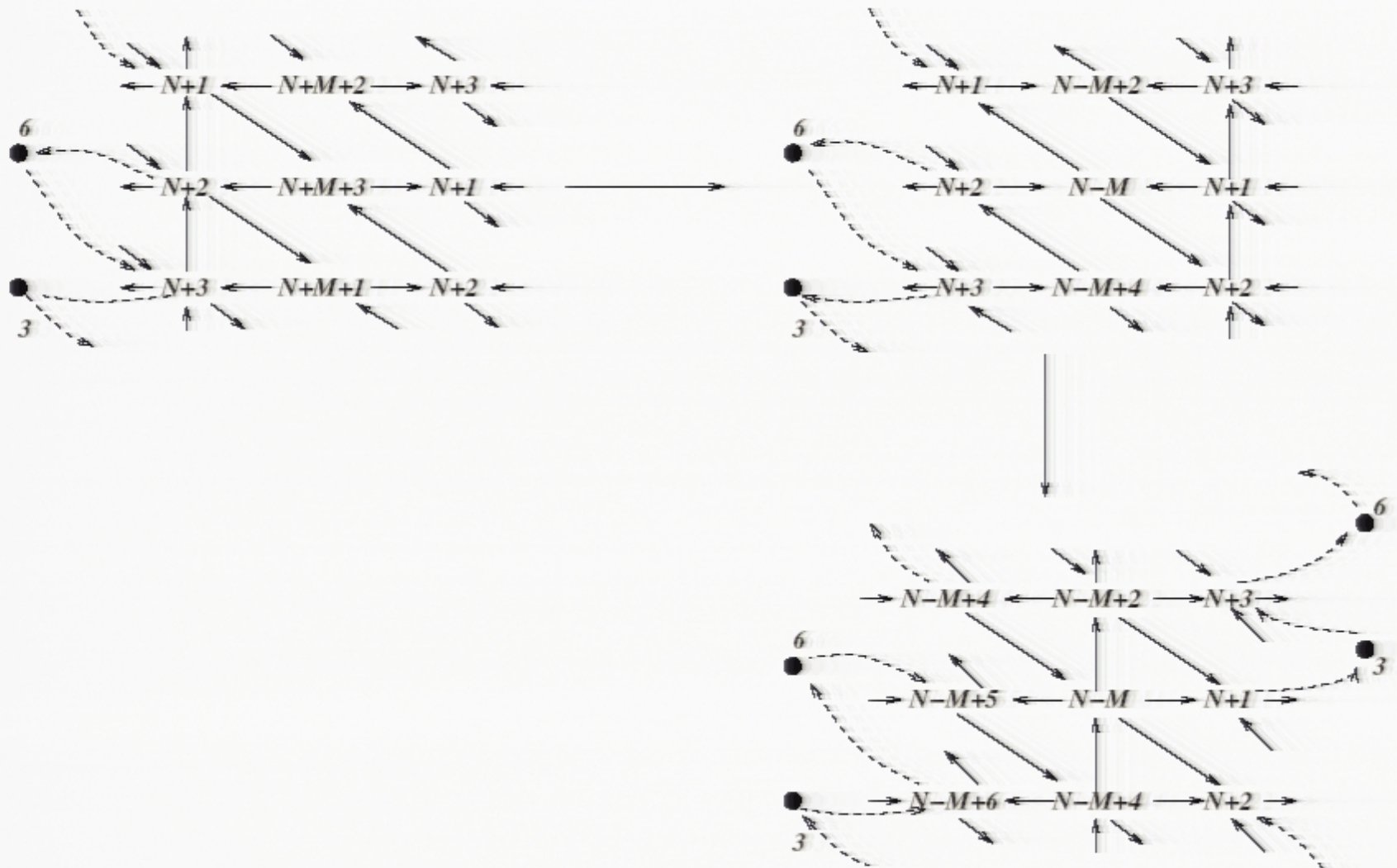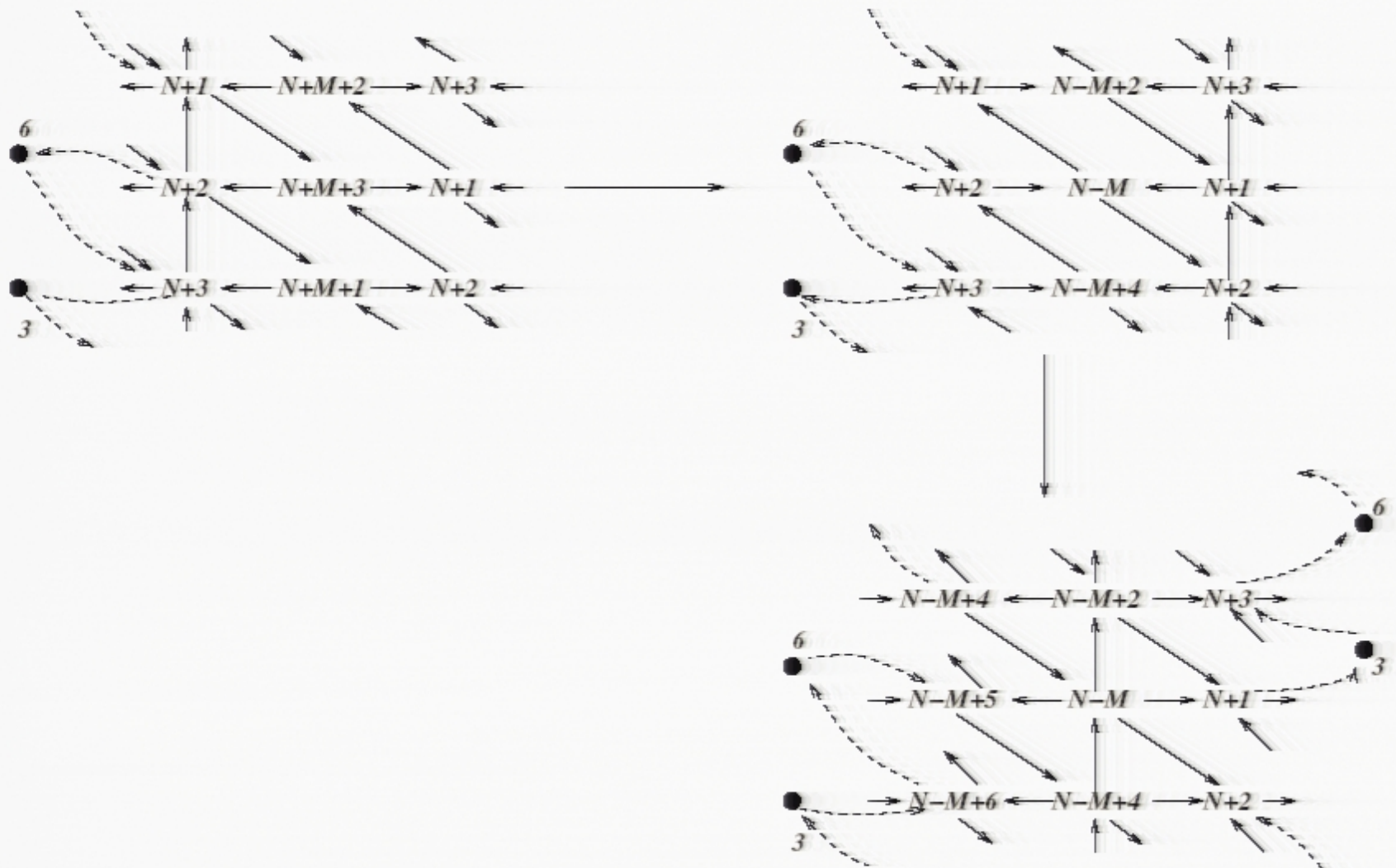# Holographic dual gauge theory

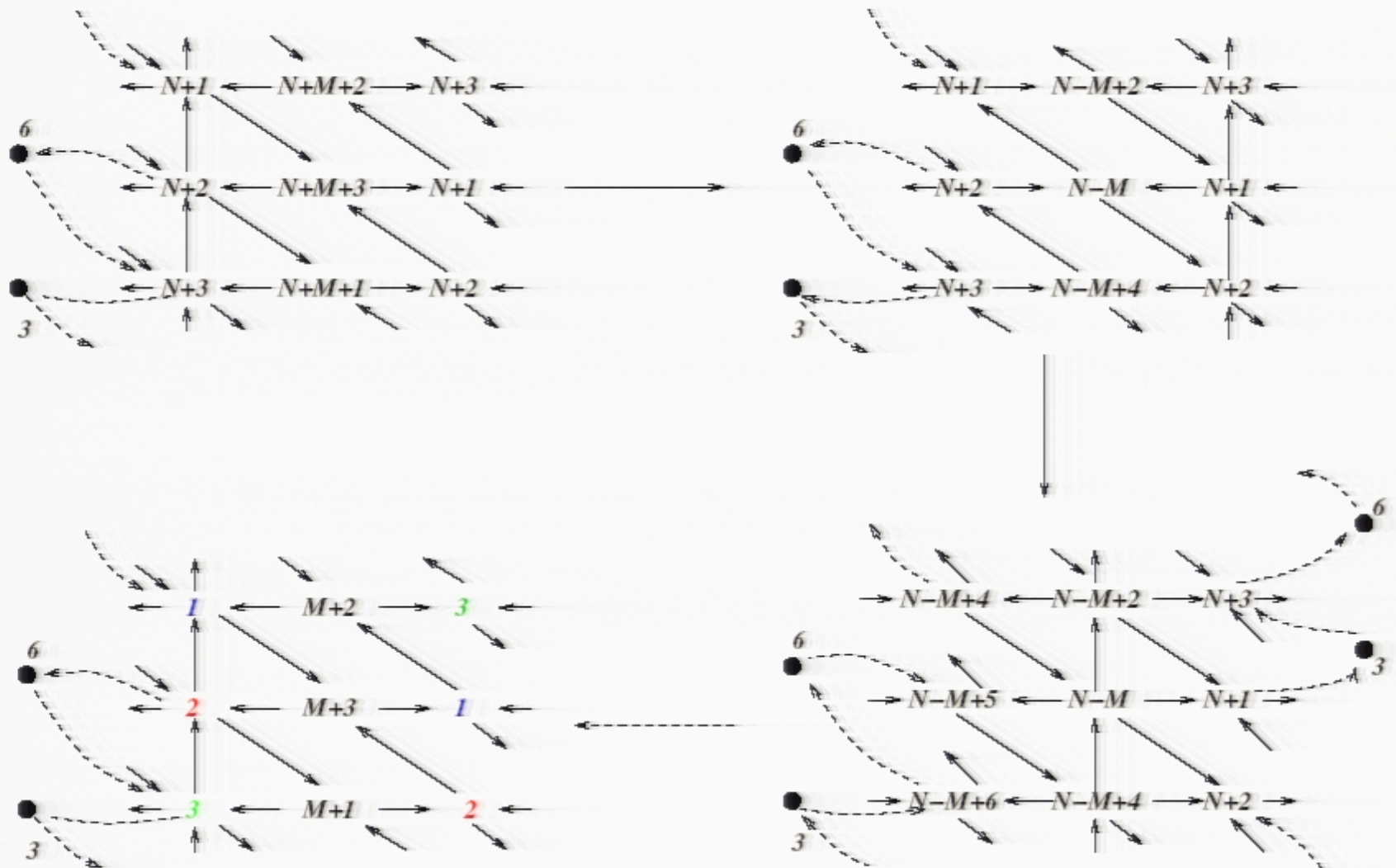# Holographic dual gauge theory

Holographic dual gauge theory

Holographic dual gauge theory

Holographic dual gauge theory

The left over light degrees of freedom correspond to:

★ Standard model gauge group $SU(3) \times SU(2)_L \times U(1)_Y$ with **3 generations**.

★ $U(1)_Y$ given by the linear combination:

$$Q_Y = -\left(\tfrac{1}{3}Q_3 + \tfrac{1}{2}Q_2 + Q_1\right)$$

★ Extra $U(1)'s$ become massive.

★ Extra gauge group $SU(6) \times SU(3)$ from **D7's** can be broken by vevs in the 77 sector.

Knowledge of the holographic dual gauge theory is remarkable:

$\left\{\begin{array}{l}\end{array}\right.$
- Provides a microscopic description of what happens at the IR end of the throat: you DO get C^3/Z_3
- Obtain a realization, in String Theory, of technicolor: all SM fields are composites of a larger gauge theory at higher energies

Multithroats

Singularities admitting several complex deformations $\Longrightarrow$ independent cycles $\Longrightarrow$ several warped regions with different warp factors.

Complex cone over dP$_3$

Franco, Hanany, Uranga; hep-th/0502113

Realistic multithroat

J.C., Fouad, Uranga; hep-th/0503079

- Have a holographic dual: several cascade-confining phases.
- A String Theory realization of RS with several positive tension branes.

Conclusions

⋆ Have presented a concrete example where the SM is placed at the end of a highly warped throat, and provided its holographic dual gauge theory, with the SM as the final product of a cascade of dualities (technicolor in String Theory).

⋆ Desirable to obtain a mechanism to break supersymmetry while keeping control of the throat geometry.

⋆ Adapt this idea to more flexible brane configurations (intersecting or magnetized D-branes).

⋆ Better understanding of the backreaction of D7-branes in models that contain them.