Supersymmetry breaking on generalized geometries

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Actually this is not even necessary, but rather

$$M_s \simeq 1 \text{ TeV} - 10^{19} \text{ GeV}$$

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Both scenarios are possible in string compactifications!

Outline

- Some comments on TeV string scale compactifications

  (The LHC string hunter's companion)

- Supersymmetry breaking on generalized geometries: DomainWallSusyBreaking (DWSB)

  (i) Type II compactifications

  (ii) Heterotic string compactifications

Work based on:

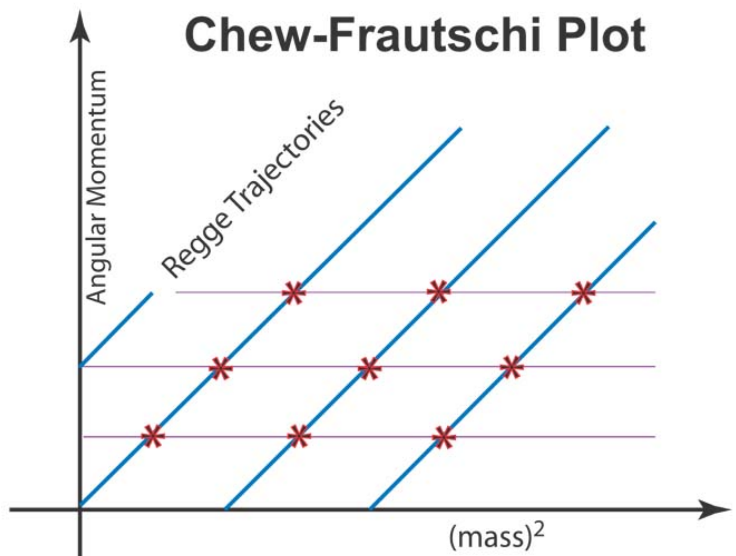
(D. Lüst, F. Marchesano, L. Martucci, D.Tsimpis, arXiv:0803.3149;
J. Held, D. Lüst, F. Marchesano, L. Martucci, arXiv:10mm.xxxx)

I) Low string scale compactifications

Suppose that the fundamental scale of gravity,
i.e. the string scale is around 1 TeV:

$$M_{\rm Grav.} = M_{\rm string} \simeq 1\,{\rm Tev}$$

$\Rightarrow$ Stringy Regge excitations at 1 TeV:



$$M_n^2 = M_{\rm string}^2 \left(\sum_{k=1}^{n} \alpha_{-k}^{\mu} \alpha_k^{\nu} - 1 \right) = (n-1)\, M_{\rm string}^2 \,, \quad (n = 1, \dots, \infty)$$

Then the following double string picture arises:

(i) Hadron spectrum at 1 GeV: String like objects (described by AdS/CFT)

(ii) Elementary (open) strings:

- Zero modes: quarks, gluons, etc
- Excited quarks, gluons etc at 1 TeV

g^* spin 0,1,2 & q^* spin 1/2, 3/2

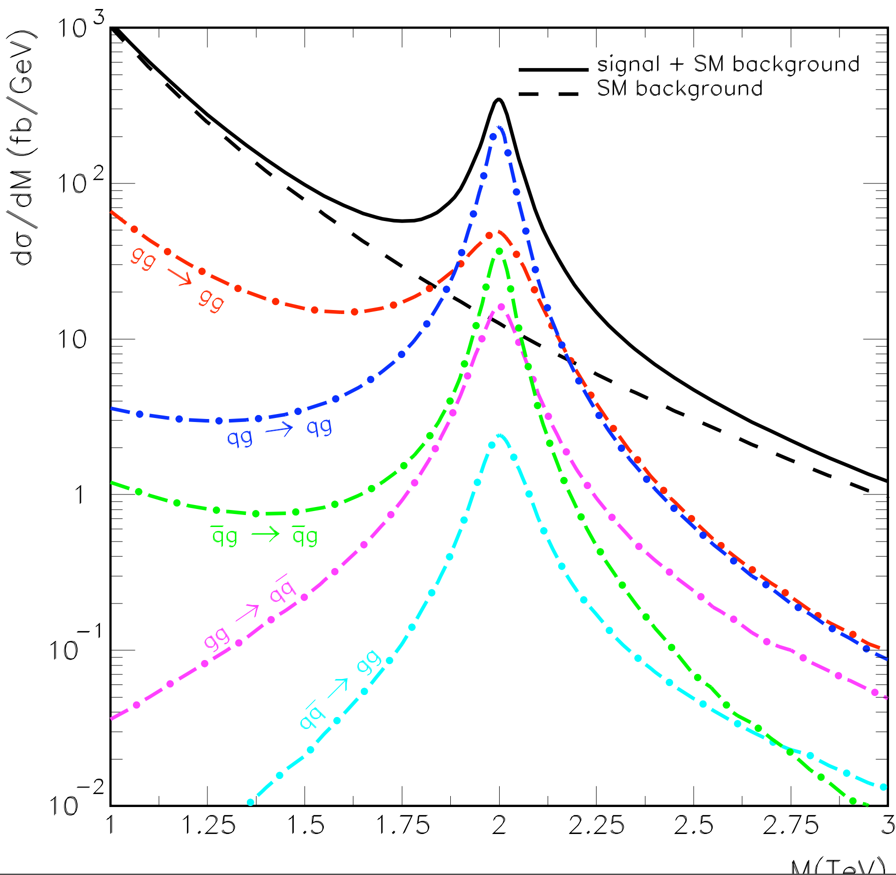
$\Rightarrow$ Two different kinds of Regge trajectories!

Model independent stringy corrections to quark & gluon scattering processes:

(D. Lüst, S. Stieberger, T. Taylor, arXiv:0807.3333;
L. Anchordoqui, H. Goldberg, D. Lüst, S. Nawata, S. Stieberger, T. Taylor, arXiv:0808.0497 [hep-ph]; arXiv:0904.3547 [hep-ph]
D. Härtl, D. Lüst, O. Schlotterer, S. Stieberger, T. Taylor, arXiv:0908.0409 [hep-th])

$$gg\ ,\ qq,\ ,\ qg\ \longrightarrow X \longrightarrow g, \gamma, Z, W, q, l$$

$\Rightarrow$ dramatic effects at the LHC:



How can one realize a low string scale?

(G. Dvali, arXiv:0706.2050; G. Dvali, D. Lüst, arXiv:0801.1287)

$\Rightarrow$ General framework: Large species models:

$$M_{\rm Planck}^2 = N\, M_{\rm Grav}^2 \qquad \text{(N: \# of species)}$$

E.g: $N = 10^{32} \quad \Longrightarrow \quad M_{\rm Grav} = 10^{-16} M_{\rm Planck} \simeq 1\ TeV$

This relation arise from natural bounds on black hole decays.

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Is there a stringy realization of the large N species scenario?

(i) Large volume compactifications

(Antoniadis, Arkani-Hamed, Dimopoulos, Dvali (1998))

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N is the effective number of Regge states that contribute to the black hole bound:

$$N = \frac{1}{g^2_{\mathrm{string}}} = 10^{32}$$

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N is the effective number of Regge states that contribute to the black hole bound:

$$N = \frac{1}{g_{\mathrm{string}}^2} = 10^{32}$$

(i) and (ii) are in agreement with the known relation

$$M_{\mathrm{Planck}}^2 = \frac{1}{g_{\mathrm{string}}^2} \mathrm{Vol}(M_6) M_{\mathrm{strings}}^2$$

2) Supersymmetry breaking on generalized geometries

Two ways for (spontaneous) supersymmetry breaking:

(i) Non perturbative SUSY breaking:

instantons, gaugino condensation

(S. Ferrara, L. Giradello, H.P. Nilles (1983);
M. Dine, R. Rohm, N. Seiberg, E. Witten (1985),....)

(ii) Classical SUSY breaking:

- Scherk/Schwarz boundary conditions

(J. Scherk, J. Schwarz (1979);
S. Ferrara, C. Kounnas, M. Porrati (1985), ...)

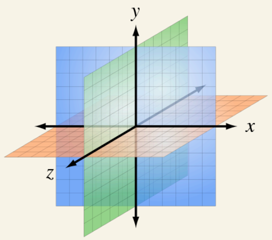
- Fluxes: F, H- fluxes & geometrical fluxes

(K. Becker, M. Becker (2001), ...)

- Consider 10D spaces of the form:

$$X_{10} = X_4 \times M$$

- Purely geometrical approach:



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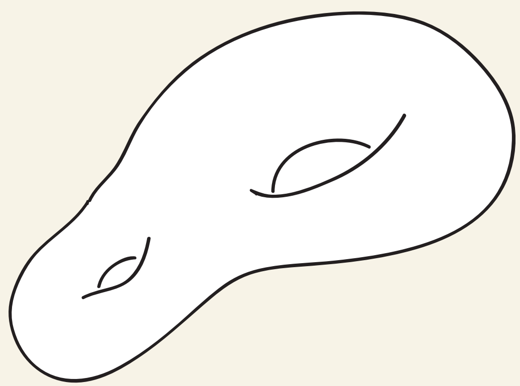


$X_4 = \mathbb{R}^{1,3}$

$M = \mathrm{CY}_3$

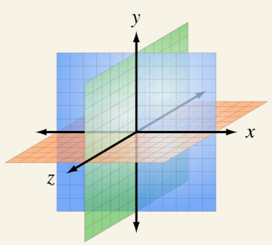
No superpotential

- many undetermined moduli
- no SUSY-breaking

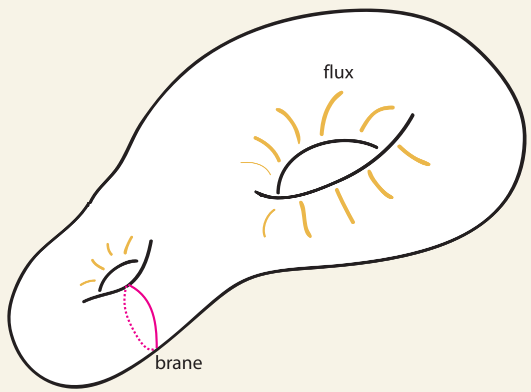
More recently: addition of fluxes and branes

(Reviews: M. Grana, hep-th/0509003;
R. Blumenhagen, S. Körs, D. Lüst, S. Stieberger, hep-th/0610327)

Back reaction to geometry:



$\times_w$



$X_4 = \mathbb{R}^{1,3}$
(or AdS_4)

$\boxed{M \neq \mathrm{CY}_3}$!

* moduli stabilization
* SUSY-breaking
* hierarchies from warping
* ...

Flux induced superpotentials, e.g.

$$W = \int_M \Omega \wedge (\text{fluxes})$$

2.1 Type II flux compactifications

- Metric ansatz: $\mathrm{d}s^2_{X_{10}} = e^{2A}\mathrm{d}s^2_{X_4} + \mathrm{d}s^2_{M_6}$
- Background fields: $\Phi, H;\ F_2, F_4\ \text{(IIA)};\ F_1, F_3, F_5\ \text{(IIB)}$
- SUSY conditions:

$$\delta\psi_M = \nabla_M \epsilon + \frac{1}{4}\not{H}_M \mathcal{P}\epsilon + \frac{1}{16}e^{\Phi}\sum_n \not{F}_n \Gamma_M \mathcal{P}_n \epsilon = 0$$

$$\delta\lambda = \not{\partial}\Phi\epsilon + \frac{1}{2}\not{H}\mathcal{P}\epsilon + \frac{1}{8}e^{\Phi}\sum_n (-1)^n(5-n)\not{F}_n \mathcal{P}_n \epsilon = 0$$

- Spinors: $\epsilon^{1,2}_{IIB(IIA)} \simeq \xi_{\pm}(x^{\mu}) \otimes \eta_{\pm(\mp)}(y^m)$

$\eta_{\pm}$ are spinors on M_6

We will break supersymmetry by violating one of these conditions in a controllable way.

Prototypical example: **type IIB on warped CY:**

(S. Giddings, S. Kachru, J. Polchinski (2001);
M. Grana, J. Polchinski (2002);)

$$\mathrm{d}s^2 = e^{2A(y)} g_4(x) + e^{-2A(y)} g_6^{\mathrm{CY}}(y)$$

with O3/O7
and D3/D7

- Background fields: $\mathcal{G}_3 \equiv F_3 + ie^{-\Phi} H, \; F_5, \; \tau \equiv C_0 + ie^{-\Phi}$

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$$\mathrm{d}(4A - \Phi) = e^{4A-\Phi} *_6 F_5'\,, \quad \bar{\partial}\tau = 0$$

(b) $\mathcal{G}_3 \wedge J = 0$

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SUSY conditions in terms of effective 4D superpotential:

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Scalar potential after supersymmetry breaking:

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No scale supersymmetry breaking!

E. Cremmer, S. Ferrara, C. Kounnas, D. Nanopoulos(1983);
J. Ellis, C. Kounnas, D. Nanopoulos (1984))

Gravitino mass:

$$m_{3/2} = e^{\mathcal{K}} |\mathcal{W}|^2 \sim |\mathcal{G}_{0,3}|^2$$

All soft masses on D3/D7-branes can be computed:

Gaugino masses: $m_{1/2} \sim f_\alpha D_\alpha \mathcal{W}$

(P. Camara, L. Ibanez, A. Uranga (2204;
M. Grana, T. Grimm, H. Jockers, J. Louis (2004);
D. Lüst, S. Reffert, S. Stieberger (2005))

D3-branes: $m_{1/2} = 0 \qquad (f = \tau)$

D7-branes: $m_{1/2} \sim D_{T_i} \mathcal{W} \qquad (f = T_i)$

Now we want to generalize this kind of supersymmetry breaking to non-SUSY type II vacua on non-CY spaces:

Step 1: Non-CY geometries with torsion

(Chiossi, Salomon (2002); S. Gurrieri, J. Louis, A. Micu, D. Walram (2002);
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real 2-form: $J_{mn} = i\eta_{\pm}^{\dagger}\gamma_{mn}\eta_{\pm}$

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$$dJ_2 = \frac{3}{2}\mathrm{Im}(\overline{W}_1 \Omega_3) + W_4 \wedge J_2 + W_3$$

$$d\Omega_3 = W_1 J_2 \wedge J_2 + W_2 \wedge J_2 + \overline{W}_5 \wedge \Omega_3$$

GKP (warped CY): $2W_5 = 3W_4 = -6\bar{d}A$

The SUSY conditions can be reformulated in terms of J_2 and Ω_3 by using calibration conditions of probe branes:

(J. Gutkowski, G. Papadopoulos, P. Townsend (1999); J. Gauntlett, N. Kim, D. Martelli, D. Waldram (2001); J. Gauntlett, D. Martelli, D. Waldram (2003); L. Martucci, P. Smyth (2005))

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(N. Hitchin (2002);
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These are characterized by SU(3) x SU(3) group structures.

Introduce pure spinors: $\Psi_1 = -\frac{8i}{|a|^2}\eta_1 \otimes \eta_2^\dagger\,, \quad \Psi_2 = -\frac{8i}{|a|^2}\eta_1 \otimes \eta_2^T$

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\mathcal{V} \; = \; & \frac{1}{2}\int_{M_6} \mathrm{dVol}_6 \, e^{4A}\left[\tilde{F} - e^{-4A}\mathrm{d}_H(e^{4A-\Phi}\mathrm{Re}\Psi_1)\right]^2 \\
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4D effective superpotential:

$$\mathcal{W} \;=\; \pi(-)^{|\mathcal{Z}|+1}\int_{M_6}\langle\mathcal{Z}, G\rangle$$

$$t \;:=\; e^{-\Phi}\Psi_1\,, \quad \mathcal{Z} \;:=\; e^{3A-\Phi}\Psi_2$$

4D effective Kahler potential:

$$e^{\mathcal{K}} \;=\; \frac{\pi i}{2}\int_{M_6}\langle t, \bar{t}\rangle^{2/3}\langle\mathcal{Z}, \bar{\mathcal{Z}}\rangle^{1/3}$$

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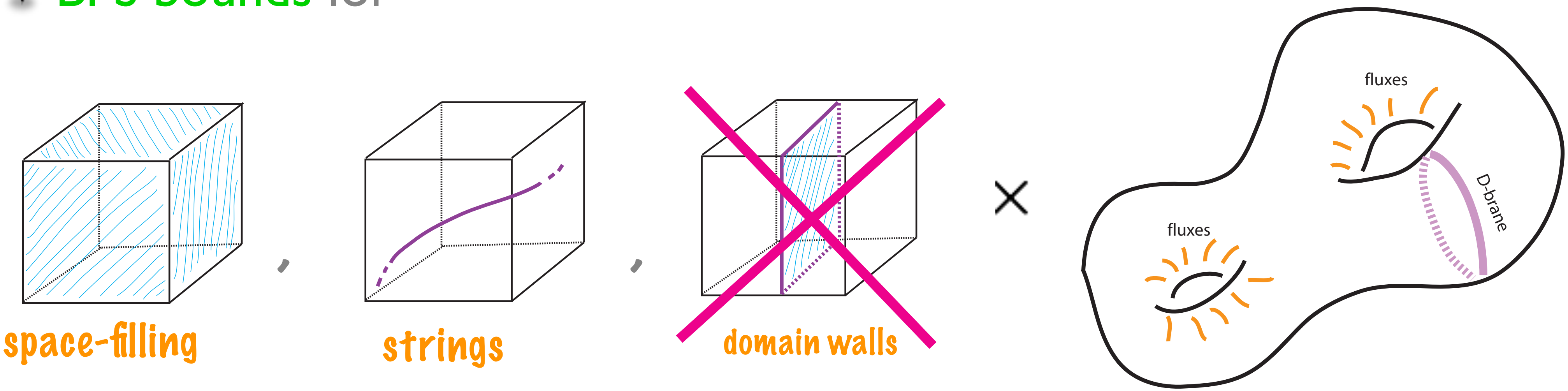

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Further examples: Type II B (Type I) with D5/D9-branes

Consider fibration: $$\Pi_2 \hookrightarrow M_6 \rightarrow \mathcal{B}_4$$

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Undetermined, SUSY breaking no-scale moduli: $\tau, T_1^{\mathcal{B}_4}, T_2^{\mathcal{B}_4}$

However $T_3^{\Pi_2}$ is now fixed!

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$$\mathrm{d}_H(e^{3A-\Phi-i\theta}e^{iJ}) = H + i\mathrm{d}J = 4ire^{3A-\Phi}\mathrm{Im}\Omega_{\mathcal{B}3}$$

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2.2. Heterotic flux compactifications

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Background: metric: $\mathrm{d}s^2_{X_{10}} = e^{2A}\mathrm{d}s^2_{X_4} + \mathrm{d}s^2_M$

internal fields: ϕ , H , F

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10D action: $$S = \frac{1}{2\kappa^2}\int \mathrm{d}^{10}x\sqrt{-g}\,e^{-2\phi}\left[\mathcal{R} + 4(\mathrm{d}\phi)^2 - \frac{1}{2}H^2 + \frac{\alpha'}{4}(\mathrm{tr}R_+^2 - \mathrm{tr}F^2)\right]$$

Bianchi identity: $$\mathrm{d}H = \frac{\alpha'}{4}(\mathrm{tr}R_+ \wedge R_+ - \mathrm{tr}F \wedge F)$$ (Bergshoeff, de Roo (1989))

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SUSY conditions: $$\epsilon = \zeta \otimes \eta + \text{ c.c.}$$

- external gravitino $\delta\psi_\mu = 0 \Rightarrow \mathrm{d}A = 0\ ,\ \Lambda_{4D} = 0$
- internal gravitino $\delta\psi_m = 0 \Rightarrow (\nabla_m - \frac{1}{4}\iota_m H)\eta = 0$
- dilatino $\delta\lambda = 0 \Rightarrow (\mathrm{d}\phi - \frac{1}{2}H)\eta = 0$
- gaugino $\delta\chi = 0 \Rightarrow F \cdot \eta = 0$

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J and Ω define again an SU(3)-structure.

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$$\text{(a)}\ \ \text{NS5GaugeBPS:} \quad e^{2\phi}\mathrm{d}(e^{-2\phi}J) = *H \rightarrow$$ space is not Kähler!

$$\mathcal{G} = H - i\mathrm{d}J = \mathcal{G}_{2,1} + \mathcal{G}_{0,3}$$

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J and Ω define again an SU(3)-structure.

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Effective scalar potential: $\mathcal{V} = \mathcal{V}_0 + \mathcal{V}_1$

$$\begin{aligned}
\mathcal{V}_0 = \quad & \tfrac{1}{4\kappa^2}\int \mathrm{vol}_{M_6}\; e^{4A-2\phi}\big[e^{-4A+2\phi}\mathrm{d}(e^{4A-2\phi}J) - *H\big]^2 \\
+ \quad & \tfrac{1}{4\kappa^2}\int \mathrm{vol}_{M_6}\; e^{4A-2\phi}\big\{\tfrac{1}{4}\big[e^{-2A+2\phi}\mathrm{d}\big(e^{2A-2\phi}J^2\big)\big]^2 + 4(\mathrm{d}A)^2\big\} \\
+ \quad & \tfrac{1}{4\kappa^2}\int \mathrm{vol}_{M_6}\; e^{-2A+2\phi}\Big[|\mathrm{d}(e^{3A-2\phi}\Omega)|^2 - |J\wedge \mathrm{d}(e^{3A-2\phi}\Omega)|^2\Big] \\
- \quad & \tfrac{1}{4\kappa^2}\int \mathrm{vol}_{M_6}\; e^{4A-2\phi}\Big\{2\mathrm{d}A + \tfrac{1}{4}e^{-2A+2\phi}(J\wedge J)\lrcorner\mathrm{d}(e^{2A-2\phi}J\wedge J) \\
& \qquad + \tfrac{1}{2}e^{-3A+2\phi}\mathrm{Re}[\bar{\Omega}\lrcorner\mathrm{d}(e^{3A-2\phi}\Omega)]\Big\}^2 \\
\mathcal{V}_1 = \quad & \tfrac{\alpha'}{8\kappa^2}\int e^{4A-2\phi}\big[\mathrm{tr}(F\wedge *F) + (F\wedge F)\wedge J\big] \\
& -\tfrac{\alpha'}{8\kappa^2}\int e^{4A-2\phi}\big[\mathrm{tr}(R_+\wedge *R_+) + \mathrm{tr}(R_+\wedge R_+)\wedge J\big] \\
& -\tfrac{\alpha'}{2\kappa^2}\int \mathrm{vol}_{M_6}\; e^{4A-2\phi}\Big[2\,e^{-2A}(\nabla^m\nabla^n e^A)(\nabla_m\nabla_n e^A) \\
& \qquad - (\iota_m H\cdot\iota_n H)\,\nabla^m A\nabla^n A - 6(\mathrm{d}A\cdot\mathrm{d}A)^2\Big]
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Effective 4D superpotential and Kahler potential:

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$$\mathcal{W} = \frac{i\, M_P^3}{8\sqrt{\pi}\, M_s^4} \int_{M_6} \Omega \wedge (H - i\mathrm{d}J) \equiv \frac{i\, M_P^3}{8\sqrt{\pi}\, M_s^4} \int_{M_6} \Omega \wedge \mathcal{G}$$

$$\mathcal{K} = -\log(\mathrm{Re} s) - \log\left(\frac{1}{3!} \int_{M_6} J \wedge J \wedge J \right) - \log\left(-\frac{i}{8} \int_{M_6} \Omega \wedge \bar{\Omega} \right)$$

Example: Heterotic dual of Type II B with D5/D9-branes

(See also: K. Becker, S. Sethi, arXiv:0903.3769;
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Undetermined, SUSY breaking no-scale moduli: $s\,,\, T_1^{\mathcal{B}_4}\,,\, T_2^{\mathcal{B}_4}$

However $T_3^{\Pi_2}$ is fixed!

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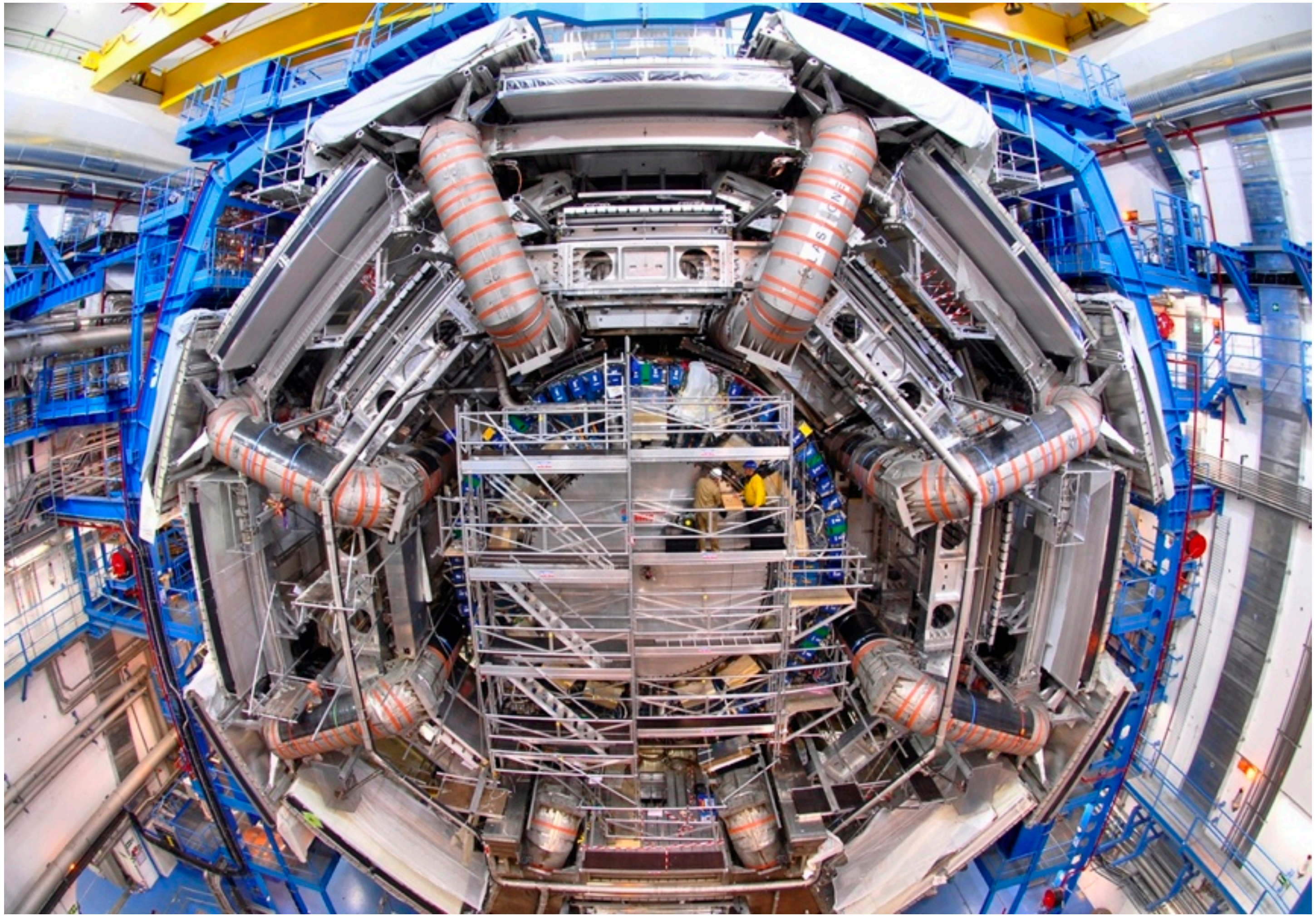
Soft terms on D-branes are calculable. ✓ $\Rightarrow$ LHC

If nature chooses strings with a string scale at a few TeV or strings with low energy supersymmetry, LHC should find them until 2012 .



Hopefully somebody can report on this during STRINGS 2012 in Munich: tentative dates: 23. - 28. July 2012