Aspects of string phenomenology and LHC

I. Antoniadis

CERN

Stringy Reflections on LHC
Clay Mathematics Institute, 13-16 October 2008

1. main questions and list of possibilities
2. phenomenology of low string scale
3. general issues of high string scale
4. framework of magnetized branes
   moduli stabilization, model building,
   SUSY breaking and D-term gauge mediation

- Are there low energy string predictions testable at LHC ?
- What can we hope from LHC on string phenomenology ?

STRINGS 2008
CERN | Geneva

Very different answers depending mainly on the value of the string scale M_s

- arbitrary parameter : Planck mass $M_P \longrightarrow$ TeV

- physical motivations $\Rrightarrow$ favored energy regions:

- High : $\begin{cases} M_P^* \simeq 10^{18} \text{ GeV} & \text{Heterotic scale} \\ M_{\rm GUT} \simeq 10^{16} \text{ GeV} & \text{Unification scale} \end{cases}$

- Intermediate : around 10^{11} GeV ($M_s^2/M_P \sim$ TeV)

  SUSY breaking, strong CP axion, see-saw scale

- Low : TeV (hierarchy problem)

Low string scale ⇒experimentally testable framework

- spectacular model independent predictions

perturbative type I string setup

- radical change of high energy physics at the TeV scale

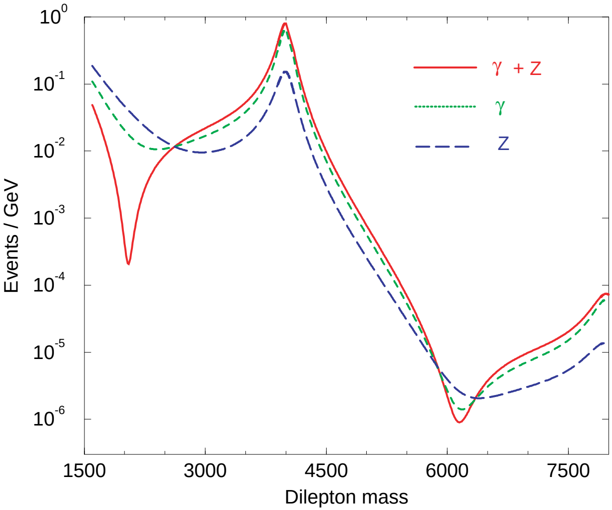
explicit model building is not necessary at this moment

but unification has to be probably dropped

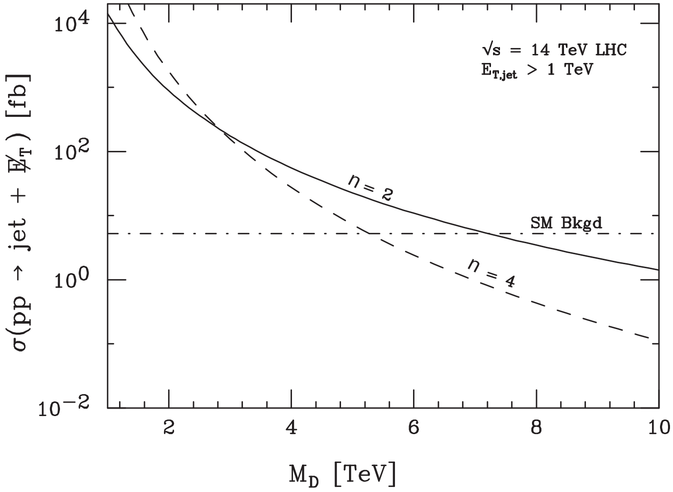
- particle accelerators
  - TeV extra dimensions ⇒ · KK resonances of SM gauge bosons [5]
    · Extra $U(1)$'s
  - Extra large submm dimensions ⇒
    missing energy from gravity radiation in the bulk [6]
  - string physics and possible strong gravity effects :
    · string Regge excitations [7]
    · production of micro-black holes ? [8]

$R^{-1} = 4$ TeV

I.A.-Benakli-Quiros '94, '99



Giudice-Rattazzi-Wells '98



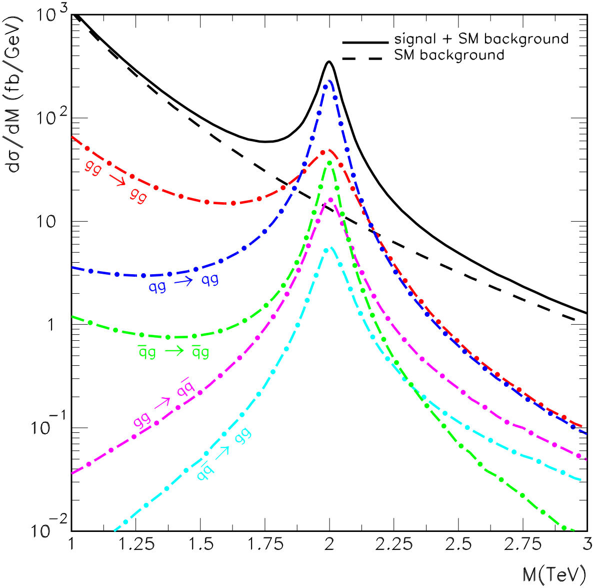
Angular distribution $\Rightarrow$ spin of the graviton

Universal deviation from Standard Model in jet distribution

$M_s = 2$ TeV

Width $=$ 15-150 GeV

Anchordoqui-Goldberg-Lüst-Nawata-Taylor-Stieberger '08



Energy threshold for black hole production :

$$E_{\rm BH} \simeq M_s/g_s^2 \quad \leftarrow \text{ string coupling}$$

Horowitz-Polchinski '96, Meade-Randall '07

weakly coupled theory $\Rightarrow$

strong gravity effects occur much above M_s, $M_P^* \simeq M_s/g_s^{2/(2+d_\perp)}$

higher-dim Planck scale   bulk dimensionality

$g_s \simeq \alpha_{\rm YM} \sim 0.1$; Regge excitations : $M_n^2 = M_s^2 n \Rightarrow$

gauge coupling

production of $\sim 10^4$ string states before reach $E_{\rm BH}$

- microgravity experiments

  - change of Newton's law at short distances

    detectable only in the case of two large extra dimensions

  - new short range forces

    light scalars and gauge fields if SUSY in the bulk

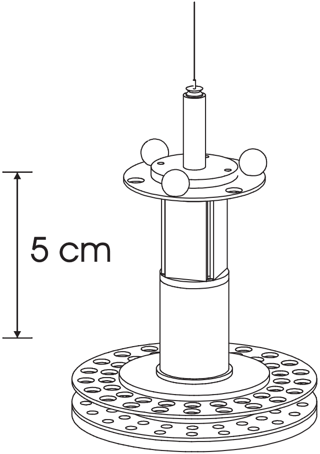
    such as radion and lepton number

    volume suppressed mass: $(\mathrm{TeV})^2/M_P \sim 10^{-4}$ eV $\rightarrow$ mm range

    can be experimentally tested for any number $d_\perp$ [11]

    of submm extra dimensions

Adelberger et al. '06

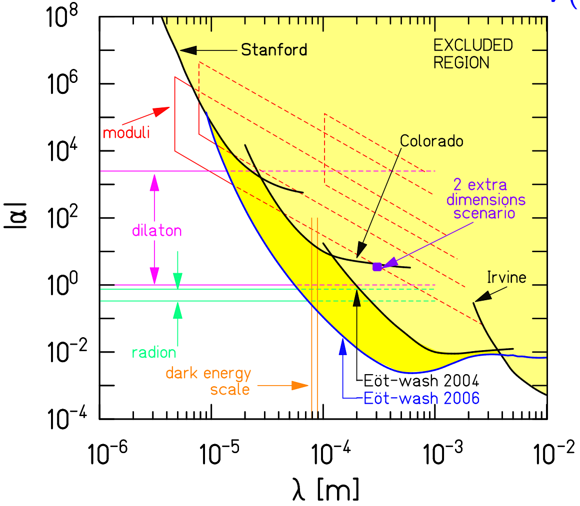


$R_\perp \lesssim 45\ \mu$m at 95% CL

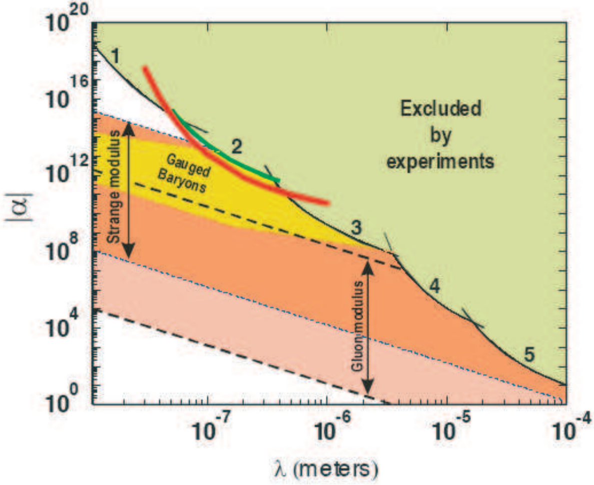
- dark-energy length scale $\approx 85\mu$m

Experimental limits on short distance forces

$$V(r) = -G\,\frac{m_1 m_2}{r}\left(1 + \alpha e^{-r/\lambda}\right)$$



Radion : $M_P^* \gtrsim 6$ TeV 95% CL Adelberger et al. '06 an order of magnitude improvement in the range 10-200 nm   Decca et al '07



5: Colorado   4: Stanford   3: Lamoureaux   1: Mohideen et al.

Extra $U(1)$'s: $SU(3) \times SU(2)_L \times U(1)_Y \times U(1)_X$

- SM fermions charged under $X \Rightarrow$ new resonances
- SM fermions neutral under X $\Rightarrow U(1)_X$ hidden

  unless new heavy fermions f with mixed quantum numbers

  Consider the case: fermion mass $M_f >> M_X$

  decoupling $\Rightarrow$ X-production suppressed by powers of E/M_f

  exception: if there are mixed anomalies

  $U(1)_X$ - SM - SM , $U(1)_X$ - $U(1)_X$ - $U(1)_Y$

1) fermions f vector-like with respect to SM but chiral w.r.t. $U(1)_X \Rightarrow$

Green-Scwarz anomaly cancellation: axion θ_X $\delta X = d\Lambda$ $\delta\theta_X = -M\Lambda$

$$-\frac{1}{4g_X^2}F_X^2 - \frac{1}{2}(d\theta_X + MX)^2 + \frac{\theta_X}{M}k_I F_I \wedge F_I \qquad M_X = g_X M$$

axion coupling + 1-loop anomaly $\Rightarrow 1/M_f^2$ suppression

2) avoid mass suppression: non-trivial anomaly cancellation

D'Hoker-Farhi terms: two sets of heavy fermions $f = \{\psi, \chi\}$

ψ : vector-like w.r.t. SM but chiral w.r.t. $U(1)_X$

χ : chiral w.r.t. SM but vector-like w.r.t. $U(1)_X$

$\Rightarrow$ dim-4 effective interaction : $D\theta_X \wedge D\theta_I \wedge F_I$

I.A-Boyarsky-Rucharsky '06, '07: $I \equiv \gamma, U(1)_X \equiv \mathrm{PQ}$, $M_X \sim$ subeV

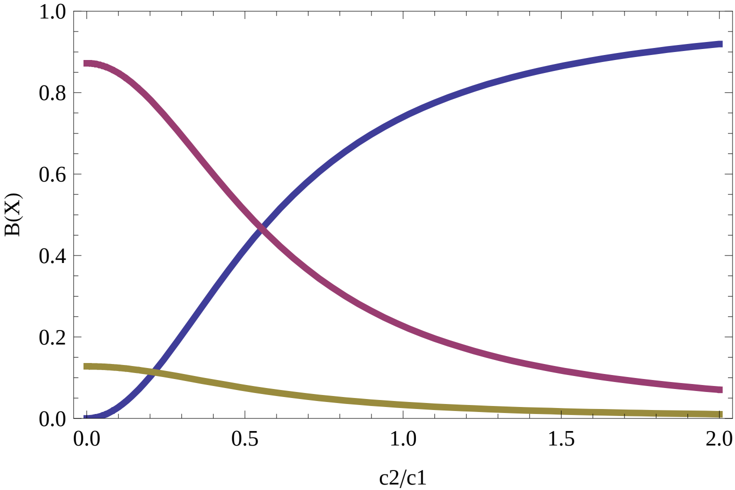
$$\theta_I \equiv \text{SM Higgs} \;\Rightarrow\; \mathcal{L}_{\text{eff}} = c_1 D\theta_X \frac{H^\dagger DH}{|H|^2} F_Y + c_2 D\theta_X \frac{HF_W DH^\dagger}{|H|^2}$$

$c_2 \to XW^+W^-$ $\quad$ $c_1 \to XZY$ $\quad$ $(XZ\gamma, XZZ)$ $\quad$ vertices

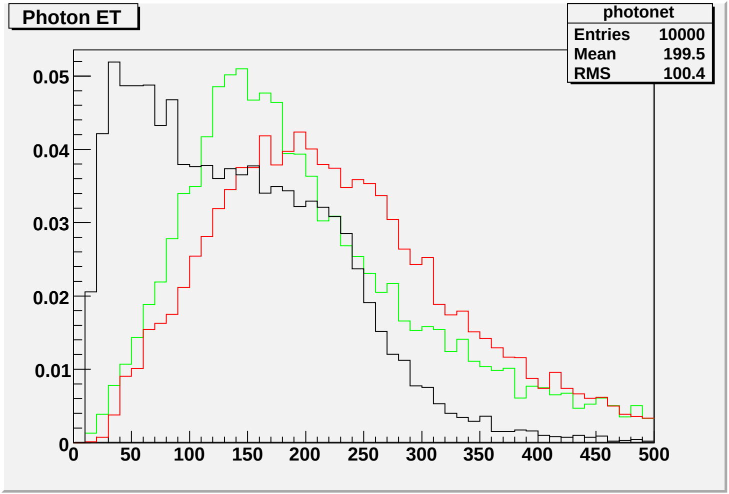
interesting LHC signatures : 3 vector boson final state (even $WZ\gamma$)

I.A-Boyarsky-Espahbodi-Rucharsky-Wells in preparation

Branching ratios: $X \to WW$, $X \to \gamma Z$, $X \to ZZ$



Comparison of X = vector versus X = scalar $M_X = 500$ GeV



$$pp \to WX \qquad X \to Z\gamma$$

Intermediate string scale :

not directly testable but interesting possibility with several implications

$\rightarrow$ 'large volume' compactifications   see Quevedo's talk

High string scale :

perturbative heterotic string : the most natural for SUSY and unification

prediction for GUT scale but off by almost 2 orders of magnitude

$M_s = g_H\, M_P \simeq 50\, M_{\rm GUT} \qquad g_H^2 \simeq \alpha_{\rm GUT} \simeq 1/25$

introduce large threshold corrections or strong coupling $\rightarrow$ $M_s \simeq M_{\rm GUT}$

but loose predictivity

High string scale: $M_s \sim M_{\mathrm{GUT}}$

Appropriate framework for SUSY + unification:

- intersecting branes in extra dimensions: IIA, IIB, F-theory
- Heterotic M-theory
- internal magnetic fields in type I

2 approaches: - Standard Model directly from strings

- 'orbifold' GUTs: matter in incomplete representations

Main problems: - gauge coupling unification is not automatic

different coupling for every brane stack

- extra states: vector like 'exotics' or worse

they also destroy unification in orbifold GUTs

Main steps of model building :

1. obtain MSSM spectrum and couplings
   - MSSM : part of total massless spectrum
   - 'fit' Yukawa couplings using moduli freedom (flat directions)

     that can be fixed by turning on fluxes (discrete parameters)
2. dynamical SUSY breaking in a 'hidden' sector

   $\Rightarrow$ gravity or gauge mediation to the MSSM sector

What can we learn from the LHC ?

If SUSY is found use experimental data on sparticle masses and couplings to constrain classes of models/compactifications

• different input for each step $\Rightarrow$ predictivity is highly reduced

Maximal predictive power if there is common framework for :

- moduli stabilization
- model building (spectrum and couplings)
- SUSY breaking (calculable soft terms)
- computable radiative corrections (crucial for comparing models)

Possible candidate of such a framework: **magnetized branes**

General framework

Type I string theory with magnetic fluxes on 2-cycles of the compactification manifold

- Dirac quantization: $H = \frac{m}{nA} \equiv \frac{p}{A}$

  H: constant magnetic field

  m: units of magnetic flux

  n: brane wrapping

  A: area of the 2-cycle

- Spin-dependent mass shifts for charged states

  $\Rightarrow$ SUSY breaking

- Exact open string description:

  $qH \to \theta = \arctan qH\alpha'$ weak field $\Rightarrow$ field theory

- T-dual representation: branes at angles

(m, n): wrapping numbers around the 2-cycle directions

Magnetic fluxes can be used to stabilize moduli

I.A.-Maillard '04, I.A.-Kumar-Maillard '05, '06

Bianchi-Trevigne '05

e.g. T^6: 36 moduli (geometric deformations)

internal metric: $6 \times 7/2 = 21 = 9 + 2 \times 6$

type IIB RR 2-form: $6 \times 5/2 = 15 = 9 + 2 \times 3$

$$\text{complexification} \Rightarrow \begin{cases} \text{Kähler class} & J \\ \text{complex structure} & \tau \end{cases}$$

9 complex moduli for each

magnetic flux: 6×6 antisymmetric matrix F

complexification $\Rightarrow$

$F_{(2,0)}$ on holomorphic 2-cycles: potential for τ

$F_{(1,1)}$ on mixed (1,1)-cycles: potential for J

T^6 parametrization/complexification

$x^i \equiv x^i + 1 \quad y_i \equiv y_i + 1 \quad i = 1, 2, 3$

$z^i = x^i + \tau^{ij} y_i$

τ: 3×3 complex structure matrix

$\delta g_{i\bar{j}}$: Kähler deformations

$\rightarrow J = \delta g_{i\bar{j}} i dz_i \wedge d\bar{z}_j$

W : covering map

of the brane world-volume over T^6

$N = 1$ SUSY conditions:

1. $F_{(2,0)} = 0 \quad \Rightarrow \tau$

   $\tau^{\mathsf{T}} p_{xx} \tau - (\tau^{\mathsf{T}} p_{xy} + p_{yx} \tau) + p_{yy} = 0$

2. $J \wedge J \wedge F_{(1,1)} = F_{(1,1)} \wedge F_{(1,1)} \wedge F_{(1,1)} \quad \Rightarrow J$

   vanishing of a Fayet-Iliopoulos term

   $\xi \sim F \wedge F \wedge F - J \wedge J \wedge F$

   e.g. $T^6 = \prod_{i=1}^{3} T_i^2 \leftarrow$ orthogonal 2-torus

   $\tau_i = i R_i^x / R_i^y \quad J_i = R_i^x R_i^y \quad H_i^a = F_i^a / J_i$

   $H_1 + H_2 + H_3 = H_1 H_2 H_3 \Leftrightarrow \theta_1 + \theta_2 + \theta_3 = 0$

3. $\det W(J \wedge J \wedge J - J \wedge F \wedge F) > 0$

   action positivity

Main ingredients for moduli stabilization

- "oblique" (non-commuting) magnetic fields

  $\Rightarrow$ fix off-diagonal components of the metric

  e.g. can be made diagonal

- Non linear DBI action $\Rightarrow$ fix overall volume

  not valid in six dimensions: $J \wedge F = 0$

- Kähler class RR moduli :

  absorbed by magnetized $U(1)$'s $\rightarrow$ massive

  kinetic mixing 10d : $dC_2 \wedge \star(A^a \wedge \langle F^a \rangle)$

  $\Rightarrow$ need at least 9 brane stacks

Stack $\sharp$	Fluxes	Fixed moduli	$5-$brane localization
$\sharp 1$ $N_1 = 1$	$(F^1_{x_1 y_2}, F^1_{x_2 y_1}) = (1,1)$	$\tau_{31} = \tau_{32} = 0$ $\tau_{11} = \tau_{22}$ $\mathrm{Re} J_{1\bar{2}} = 0$	$[x_3, y_3]$
$\sharp 2$ $N_2 = 1$	$(F^2_{x_1 y_3}, F^2_{x_3 y_1}) = (1,1)$	$\tau_{21} = \tau_{23} = 0$ $\tau_{11} = \tau_{33}$ $\mathrm{Re} J_{1\bar{3}} = 0$	$[x_2, y_2]$
$\sharp 3$ $N_3 = 1$	$(F^3_{x_1 x_2}, F^3_{y_1 y_2}) = (1,1)$	$\tau_{13} = 0\,,\ \tau_{11}\tau_{22} = -1$ $\mathrm{Im} J_{1\bar{2}} = 0$	$[x_3, y_3]$
$\sharp 4$ $N_4 = 1$	$(F^4_{x_2 x_3}, F^4_{y_2 y_3}) = (1,1)$	$\tau_{12} = 0$ $\mathrm{Im} J_{2\bar{3}} = 0$	$[x_1, y_1]$
$\sharp 5$ $N_5 = 1$	$(F^5_{x_1 x_3}, F^5_{y_1 y_3}) = (1,1)$	$\mathrm{Im} J_{1\bar{3}} = 0$	$[x_2, y_2]$
$\sharp 6$ $N_6 = 1$	$(F^6_{x_2 y_3}, F^6_{x_3 y_2}) = (1,1)$	$\mathrm{Re} J_{2\bar{3}} = 0$	$[x_1, y_1]$

Last column: 5-brane charge localization on the 2-cycles $[x_i, y_i]$

Fix areas of the 3 T^2's $\Rightarrow$ add 3 more stacks:

Stack $\sharp$	Multiplicity	Fluxes
$\sharp 7$	$N_7 = 1$	$(F^7_{x_1y_1}, F^7_{x_2y_2}, F^7_{x_3y_3}) = (-4, -4, 3)$
$\sharp 8$	$N_8 = 2$	$(F^8_{x_1y_1}, F^8_{x_2y_2}, F^8_{x_3y_3}) = (-3, 1, 1)$
$\sharp 9$	$N_9 = 3$	$(F^9_{x_1y_1}, F^9_{x_2y_2}, F^9_{x_3y_3}) = (-2, 3, 0)$

$$\Rightarrow \begin{pmatrix} F^7_1 & F^7_2 & F^7_3 \\ F^8_1 & F^8_2 & F^8_3 \\ F^9_1 & F^9_2 & F^9_3 \end{pmatrix} \begin{pmatrix} J_2 J_3 \\ J_1 J_3 \\ J_1 J_2 \end{pmatrix} = \begin{pmatrix} F^7_1 F^7_2 F^7_3 \\ F^8_1 F^8_2 F^8_3 \\ F^9_1 F^9_2 F^9_3 \end{pmatrix}$$

here: $i = 1, 2, 3 \equiv i\bar{i}$

$$\Rightarrow \tau_{ij} = i\delta_{ij} \qquad (J_{x_1y_1}, J_{x_2y_2}, J_{x_3y_3}) = 4\pi^2\alpha' \sqrt{\tfrac{3}{22}}(44, 66, 19)$$

- large volume:

- rescale all fluxes and all J_i $\Rightarrow$ three large T^2

  tadpole conditions remain invariant

Tadpole conditions

$Q_9 = \sum_a N_a \det W_a = 16$ $\leftarrow$ O9 charge

$Q_5 = \sum_a N_a \det W_a \epsilon^{\alpha\beta\gamma\delta\sigma\tau} p^a_{\gamma\delta} p^a_{\sigma\tau} = 0$

$\forall$ 2-cycle $\alpha, \beta = 1, \ldots, 6$

SUSY + tadpole conditions seem incompatible

- use 9 magnetized branes to fix all moduli

  impose SUSY conditions

- introduce an extra brane(s)

  to satisfy RR tadpole cancellation

  $\Rightarrow$ dilaton potential from the FI D-term

$\Rightarrow$ two possibilities:

• keep SUSY by turning on charged scalar VEVs

I.A.-Kumar-Maillard '06

D-term condition (2) is modified to:

$$qv^2(J\wedge J\wedge J - J\wedge F\wedge F) = -(F\wedge F\wedge F - F\wedge J\wedge J)$$

- EFT validity $\Rightarrow$ $v < 1$ in string units

- Infinite family of (large volume) solutions

  invariance: $\{F_a, J\} \rightarrow \{\Lambda F_a, \Lambda J\}$ for $\Lambda \in \mathbb{N}$

- fixing the dilaton?

  combine magnetic and 3-form fluxes

  3-brane charge $\Rightarrow$ $T^6/\mathbb{Z}_2$ with O3 planes

magnetized D7-branes

Tadpole cancellations + fix charged scalar VEVs

Stack $\sharp$	Multiplicity	Fluxes
$\sharp 7$	$N_7 = 1$	$(F^7_{x_1y_1}, F^7_{x_2y_2}, F^7_{x_3y_3}) = (-4, -4, 3)$
$\sharp 8$	$N_8 = 2$	$(F^8_{x_1y_1}, F^8_{x_2y_2}, F^8_{x_3y_3}) = (-3, 1, 1)$
$\sharp 9$	$N_9 = 3$	$(F^9_{x_1y_1}, F^9_{x_2y_2}, F^9_{x_3y_3}) = (-2, 3, 0)$
$\sharp 10$	$N_{10} = 2$	$(F^{10}_{x_1y_1}, F^{10}_{x_2y_2}, F^{10}_{x_3y_3}) = (5, 1, 2)$
$\sharp 11$	$N_{11} = 2$	$(F^{11}_{x_1y_1}, F^{11}_{x_2y_2}, F^{11}_{x_3y_3}) = (0, 4, 1)$

$$\Rightarrow \ \tau_{ij} = i\delta_{ij} \quad (J_{x_1y_1}, J_{x_2y_2}, J_{x_3y_3}) = 4\pi^2\alpha'\sqrt{\frac{3}{22}}(44, 66, 19)$$

$$v_{10}^2\alpha' \simeq \frac{0.71}{q} \simeq 0.35 \qquad v_{11}^2\alpha' \simeq \frac{0.31}{q} \simeq 0.15$$

v_{10}, v_{11}: antisymmetric reps $(q = 2) \Rightarrow$

$$SU(2)\times SU(3)\times U(2)^2 \rightarrow SU(2)\times SU(3)\times SU(2)^2$$

• break SUSY in a dS or AdS vacuum

I.A.-Derendinger-Maillard '08

General form of the localized dilaton potential:

$$V(\phi, d) = \frac{e^{-\phi}}{g^2}\left\{\left(\sqrt{1-d^2}-1\right)+\xi d+\delta T\right\}$$

DBI action   FI-term

d: D-auxiliary in $2\pi\alpha'$-units

δT: tension leftover RR tadpole cancellation

$$\Rightarrow\ \delta T = 1-\sqrt{1-\xi^2}$$

d elimination $\Rightarrow\ d = \frac{\xi}{\sqrt{1+\xi^2}}$

$$V_{\text{min}} = \delta\bar{T}e^{-\phi} \quad ; \quad \delta\bar{T} = \sqrt{1+\xi^2}-\sqrt{1-\xi^2}$$

Dilaton fixing:

1) by 3-form fluxes in a SUSY way

$\Rightarrow$ dS vacuum with positive energy

D-term uplifting possible from flat space

2) add a 'non-critical' (bulk) dilaton potential

$\Rightarrow$ AdS vacuum with tunable string coupling

$$V_{\text{non-crit}} = \delta c \, e^{-2\phi}$$

central charge deficit

minimization of $V = V_{\text{non-crit}} + V_{\text{min}} \Rightarrow \delta c < 0$

$$e^{\phi_0} = -\frac{2\delta c}{3\delta \bar{T}} \qquad V_0 = \frac{\delta c^3}{3\delta \bar{T}^2} \qquad R_0 = -\delta \bar{T} e^{3\phi_0}$$

curvature in Einstein frame

e.g. replace a free coordinate by a CFT minimal model

with central chage $1 + \delta c$

D-term SUSY breaking $\Rightarrow$

problem with Majorana gaugino masses

- lowest order: exact R-symmetry
- higher orders: suppressed by the string scale

I.A.-Taylor '04, I.A.-Narain-Taylor '05

However in toroidal models:

- gauge multiplets have extended SUSY

  $\Rightarrow$ Dirac gaugino masses without $\not{R}$

- non chiral intersections have $N = 2$ SUSY

  $\Rightarrow$ Higgs in $N = 2$ hypermultiplet

$\Rightarrow$ New gauge mediation mechanism

I.A.-Benakli-Delgado-Quiros '07

Spectrum multplicities

$(N_a, \bar{N}_b)$: $I_{ab} = \mathrm{det}W_a \mathrm{det}W_b \int_{T^6} \left(F^a_{(1,1)} - F^b_{(1,1)}\right)^3$

(N_a, N_b): $I_{ab^*} \leftarrow F^{b^*} = -F^b$

$T^6 = \prod_i T_i^2 \Rightarrow I_{ab} = \prod_i (m_i^a n_i^b - n_i^a m_i^b)$

$I_{aa^*} = \prod_i \left\{\frac{1}{2}(2m_i^a n_i^a \mp 2m_i^a) \pm 2m_i^a\right\}$

number of intersections along orientifold axis $(0, x)$

$$= \begin{cases} \text{Antisymmetric}: \frac{1}{2}\left(\prod_i 2m_i^a\right)\left(\prod_j n_j^a + 1\right) \\ \text{Symmetric}: \frac{1}{2}\left(\prod_i 2m_i^a\right)\left(\prod_j n_j^a - 1\right) \end{cases}$$

- non-chiral multiplicity: extract the vanishing factors
- $I_{ab^*} = 0 \rightarrow I_{ab}$ even $\Rightarrow$

  odd nb of generations: constant NS B-field

quantization $\rightarrow$ magnetic fluxes m half-intergers

SUSY $SU(5)$ with stabilized moduli

I.A.-Panda-Kumar '07

12 brane-stacks: $U_5,\ U_1,\ O_1, \ldots, O_8,\ A,\ B$

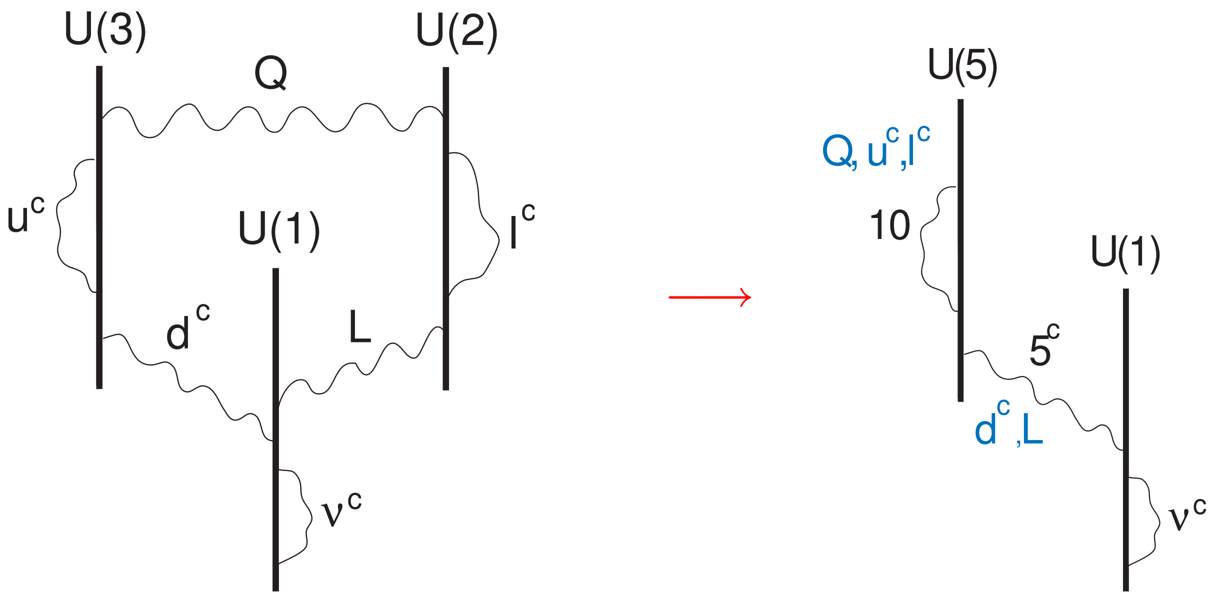
$$\underbrace{U(5) \times U(1)}_{U_5,\ U_1} \times \underbrace{U(1)^{10}}_{O_1,\ldots,O_8,\ A,\ B}$$

winding matrix $W = \mathbb{1}$, B-field $B_{x_i y_i} = \frac{1}{2}$

- $I_{U_5 U_5^*} = I_{U_5^* U_1} = 3 \Rightarrow$ 3 generations $(\mathbf{10} + \bar{\mathbf{5}})$
- $I_{U_5 U_1} = 0 \Rightarrow$ Higgs pairs $(\mathbf{5} + \bar{\mathbf{5}})$
- $I_{U_5 a} + I_{U_5 a^*} = 0,\ \forall a \neq U_5, U_1$

  $\Rightarrow$ no other $SU(5)$ chiral states
- $O_1, \ldots, O_8$: set of oblique fluxes for $B \neq 0$

  with diagonal induced 5-brane tadpoles



Q	$(\mathbf{3},\mathbf{2};1,1,0)_{1/6}$
u^c	$(\bar{\mathbf{3}},\mathbf{1};2,0,0)_{-2/3}$
d^c	$(\bar{\mathbf{3}},\mathbf{1};-1,0,\varepsilon_d)_{1/3}$
L	$(\mathbf{1},\mathbf{2};0,-1,\varepsilon_L)_{-1/2}$
l^c	$(\mathbf{1},\mathbf{1};0,2,0)_{1}$
ν^c	$(\mathbf{1},\mathbf{1};0,0,2\varepsilon_\nu)_{0}$

$$Y_A = -\frac{1}{3}Q_3 + \frac{1}{2}Q_2$$

$$\Rightarrow \qquad \sin^2\theta_W = \frac{1}{2+2\alpha_2/3\alpha_3}\bigg|_{\alpha_2=\alpha_3} = \frac{3}{8}$$

• SUSY conditions on $U_5, O_1, \ldots, O_8 \Rightarrow$

fix all geometric moduli to diagonal metric

$U(1)^9$ massive (absorb the RR Kähler moduli)

• Tadpole cancellation $\Rightarrow$ add branes A, B

• SUSY D-flatness on $U_1, A, B \Rightarrow$

charged scalar VEVs $\neq 0$ on their intersections:

- satisfy perturbativity constraint

- break $U(1)^3$

$\Rightarrow$ leftover gauge group: $SU(5)$

gauge non-singlet chiral spectrum:

three generations of quarks + leptons

Conclusions

Internal magnetic fields:

simple framework, exact string description,

$N = 1$ SUSY with chiral fermions

Moduli stabilization: ‘oblique’ magnetic fluxes

general: Kähler $\Rightarrow$ complem. to 3-form fluxes

toroidal: all geometric $+$ eventually the dilaton

Model building

natural implementation in intersecting branes

D-term SUSY breaking $\Rightarrow$

new mechanism of gauge mediation

Dirac gauginos, $N = 2$ Higgs potential