I. Antoniadis

CERN

String Phenomenology

Indian Strings Meeting

Puri, December 2006

OUTLINE

- Motivations
- Framework of low scale strings

  large extra dimensions, low scale gravity
- Exp predictions for particle accelerators

  strong gravity, TeV dimensions, string effects
- D-brane embedding of the Standard Model

  unification, proton stability, Right-neutrinos
- Electroweak symmetry breaking
- SUSY in the bulk and short range forces

  radion force, gauge bosons in the bulk
- SUSY breaking by internal magnetic fields

  or equivalently branes at angles
- Gaugino masses

  Split supersymmetry, Dirac masses

Hierarchy problem: why gravity is so weak compared to the other interactions?

Quantum theory: all particle masses $\nearrow M_P \sim 10^{19}$ GeV

- Supersymmetry: protection of hierarchy due to cancellations between fermions and bosons

$$\Rightarrow m_{\text{susy}} \sim \text{TeV}$$

- TeV strings: low UV cutoff

$$\Rightarrow M_s \sim \text{TeV}$$

- Split supersymmetry: unknown solution

  live with the hierarchy

$$\Rightarrow m_0 \text{ heavy, fermions light}$$

→ all of them testable at LHC

- Heterotic string:

Natural framework for susy and unification

However mismatch between string and GUT scales

$M_s = gM_P \simeq 50 M_{\mathrm{GUT}}$

- Framework of type I string theory

⇒ D-brane world

Natural separation of

global SUSY from gravity

↙ ↘

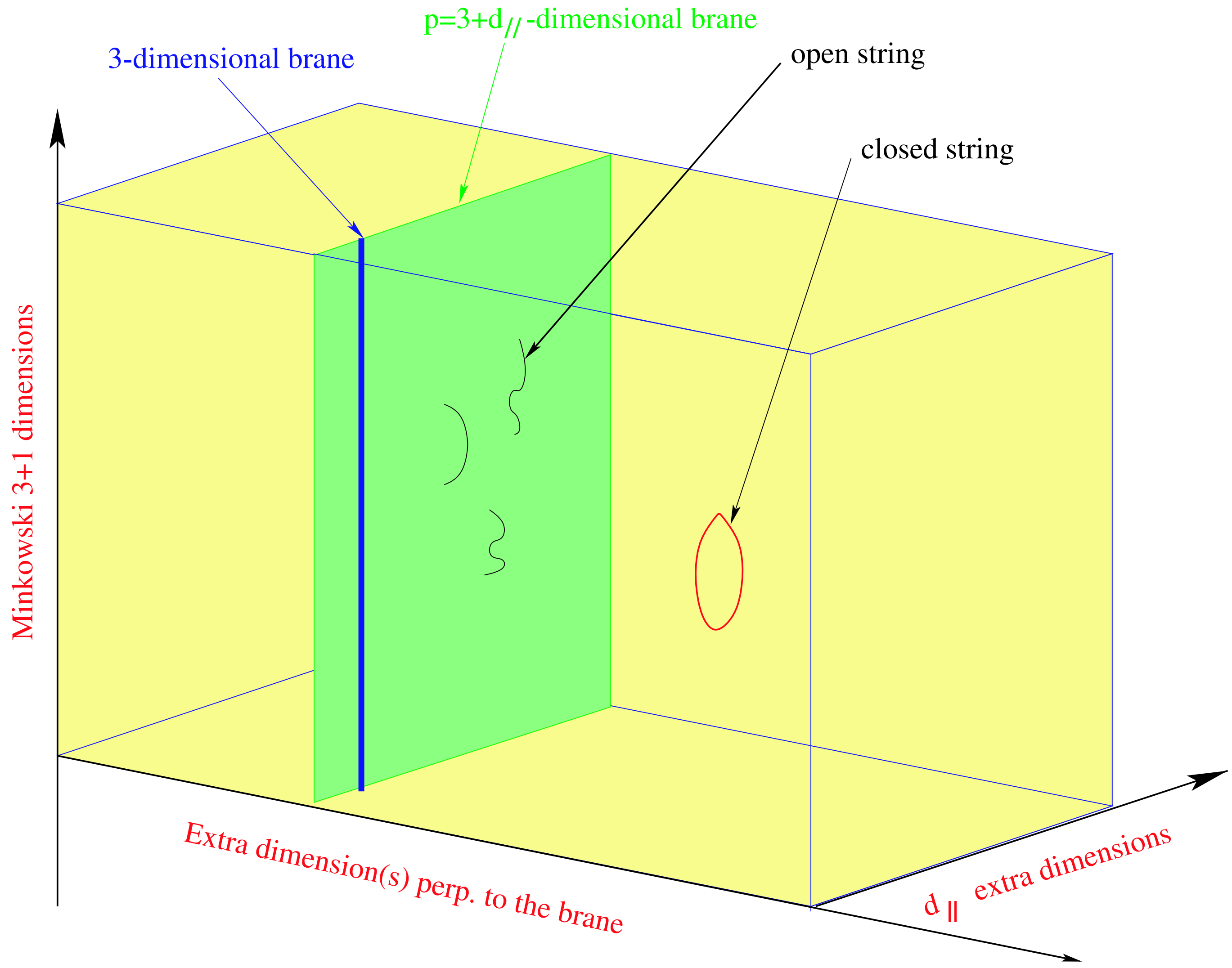
D-branes/open strings closed strings

⇒ 2 new scenaria besides ‘conventional’

low energy susy Standard Model

- low string scale
- split supersymmetry

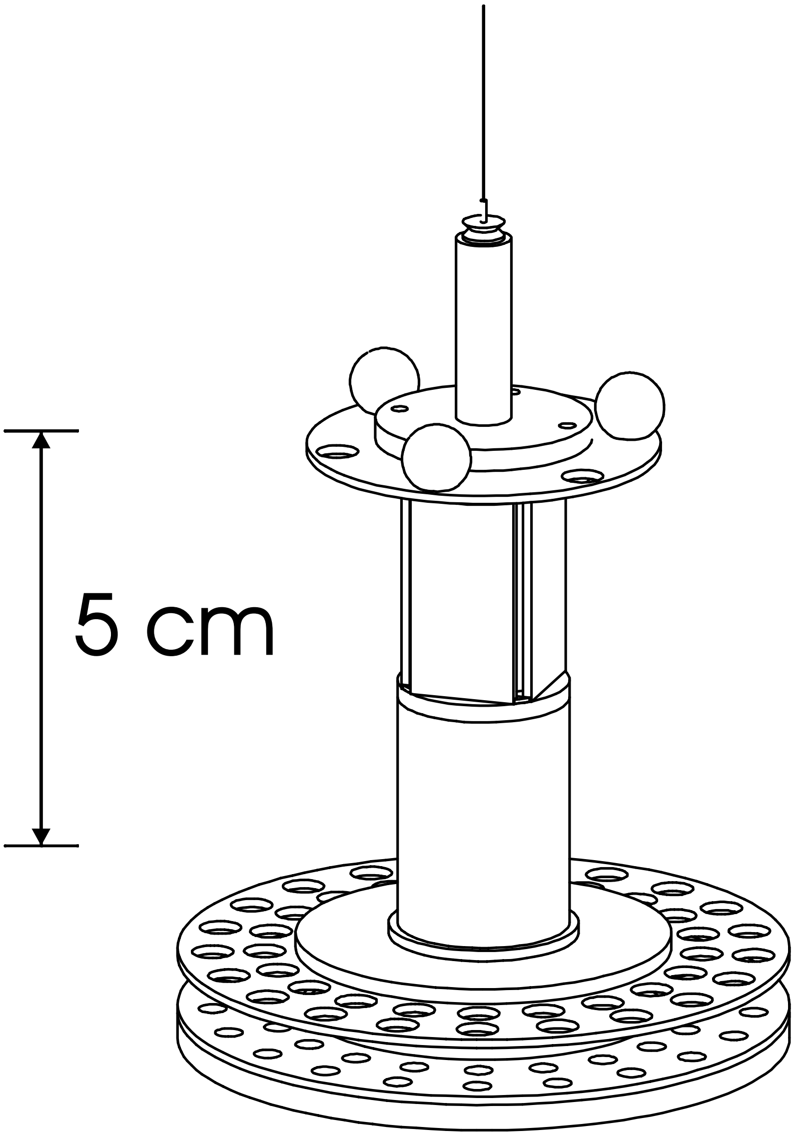
Braneworld



two types of compact extra dimensions:

- parallel ($d_{\parallel}$): can be as large as 10^{-16} cm (TeV^{-1})
- transverse ($\perp$): can be as large as 0.1 mm

Adelberger et al. ’06



$R_\perp \lesssim$ 45 μm at 95% CL

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

Dimensions of finite size: $p-3$ parallel

$n=9-p$ transverse

calculability $\Rightarrow R_{\|} \simeq l_{\text{string}}$; $R_{\perp}$ arbitrary

$$M_P^2 \simeq \frac{1}{\alpha^2} M_s^{2+n} R_{\perp}^n$$

Planck mass in $4+n$ dims: M_*^{2+n}

small $M_s/M_P \Rightarrow$ extra-large $R_{\perp}$

$M_s \sim 1$ TeV $\Rightarrow R_{\perp} \sim .1-10^{-13}$ mm $(n=2-6)$

I.A.-Arkani Hamed-Dimopoulos-Dvali '98

- weak string coupling: $g_s=\alpha$
- gravity strong at $M_* \sim M_s << M_P$

  10^{30} stronger than thought previously!

  deviations from Newton's law at distances $< R_{\perp}$

Hidden submillimeter dimensions

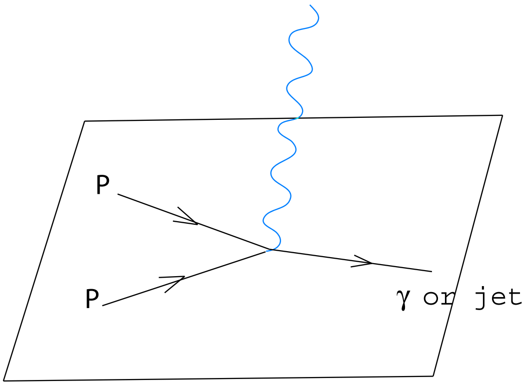
⇒ strong gravity at the TeV

Gravitational radiation in the bulk

3d: Kaluza Klein gravitons very light

⇒ high energy: huge number of particles produced

LHC: 10^{30} massive gravitons of intensity 10^{-30} each



Signal: missing energy

Angular distribution ⇒ spin of the graviton

Limits on $R_\perp$ in mm

Experiment	$R_\perp(n=2)$	$R_\perp(n=4)$	$R_\perp(n=6)$
Collider bounds			
LEP 2	4.8×10^{-1}	1.9×10^{-8}	6.8×10^{-11}
Tevatron	5.5×10^{-1}	1.4×10^{-8}	4.1×10^{-11}
LHC	4.5×10^{-3}	5.6×10^{-10}	2.7×10^{-12}
NLC	1.2×10^{-2}	1.2×10^{-9}	6.5×10^{-12}
Astrophysics/cosmology bounds			
SN1987A	3×10^{-4}	1×10^{-8}	6×10^{-10}
COMPTEL	5×10^{-5}	-	-

Large TeV dimensions

longitudinal dimensions: $R^{-1} \lesssim M_s \Rightarrow$

R^{-1} first scale of new physics I.A. '90

increasing the energy

- could happen for some of the internal dims
- explain coupling constant ratios g_2/g_3
- susy breaking
- fermion masses displace light generations

Massive tower of Kaluza Klein modes

for Standard Model particles

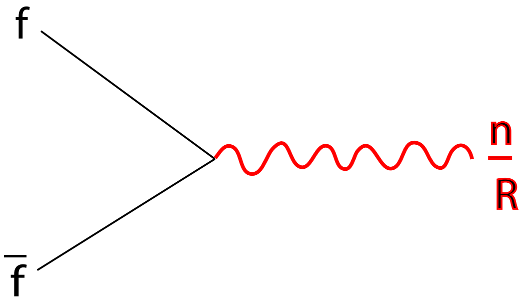
$$M_n^2 = M_0^2 + \frac{n^2}{R^2} \quad ; \quad n = \pm 1, \pm 2, \ldots$$

⇒ excited states of photon, $W^{\pm}$, Z, gluons

Localized fermions (on 3-brane intersections)

⇒ single production of KK modes

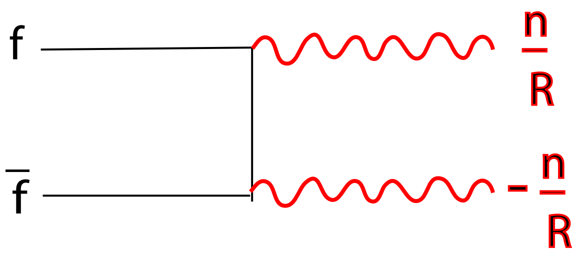
I.A.-Benakli '94



- strong bounds   indirect effects: $R^{-1} \gtrsim$ 3TeV
- new resonances   but at most $n = 1$

Otherwise KK momentum conservation

⇒ pair production of KK modes (universal dims)

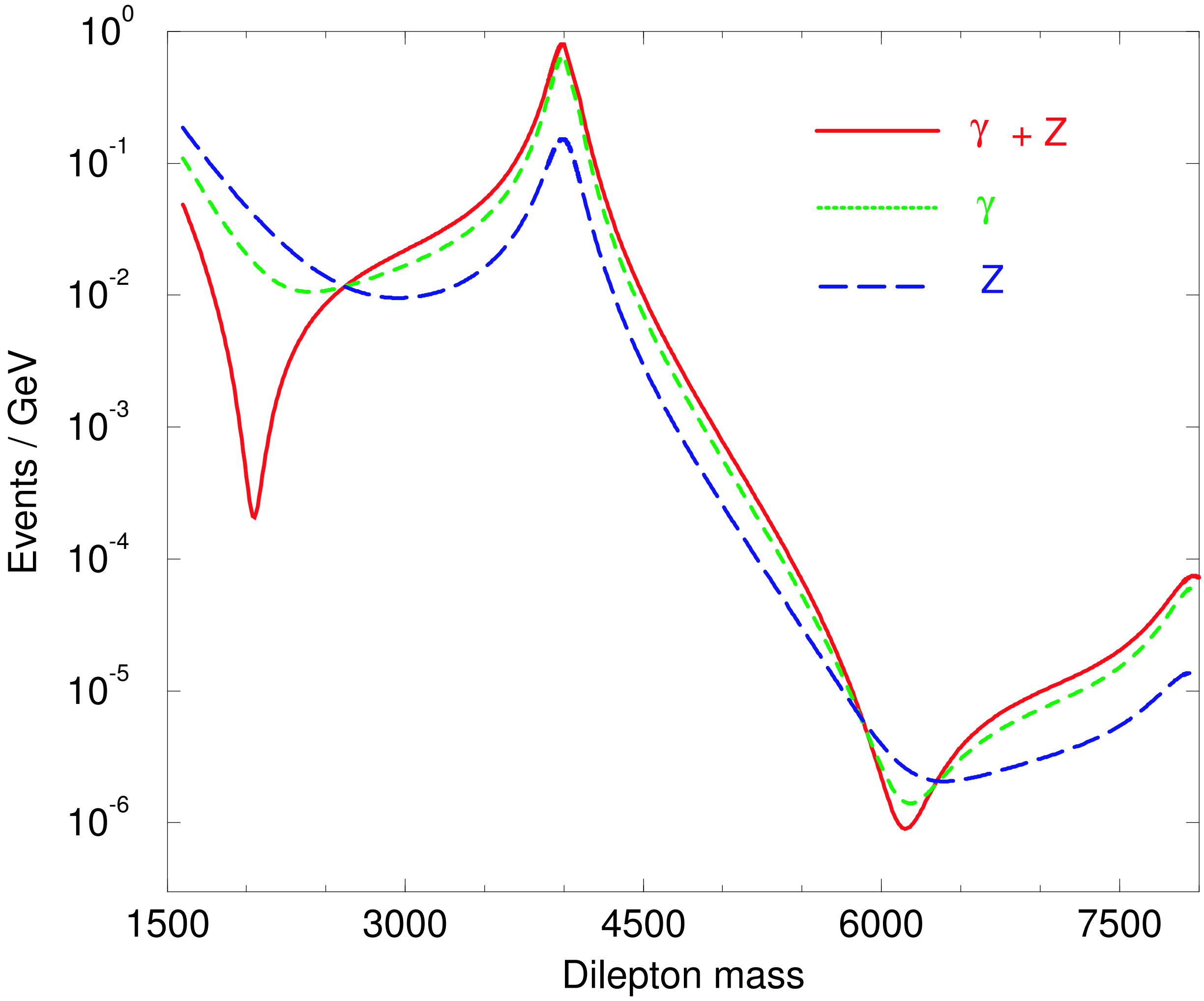


- weak bounds $R^{-1} \gtrsim$ 300-500 GeV
- no resonances
- lightest KK stable ⇒ dark matter candidate

Servant-Tait '02

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

$R^{-1} = 4$ TeV



- no observation in dijets

$$\Rightarrow R^{-1} \gtrsim 20 \text{ TeV} \; ; \; 95\% \text{ CL}$$

- more than one dimension ⇒ stronger limits

Massive string vibrations ⇒ indirect effects

virtual exchanges ⇒ effective interactions

e.g. four-fermion operators

Actual limits: Matter fermions on

- same set of branes ⇒ $M_s \gtrsim 500$ GeV

dim-8: $\frac{g^2}{M_s^4}(\bar{\psi}\partial\psi)^2$ Cullen-Perelstein-Peskin '00

- brane intersections ⇒ $M_s \gtrsim 2-3$ TeV

dim-6: $\frac{g^2}{M_s^2}(\bar{\psi}\psi)^2$ I.A.-Benakli-Laugier '00

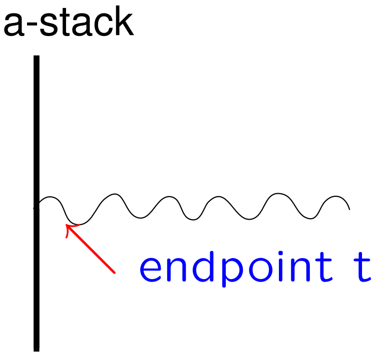
High energies ⇒

- direct production: string physics
- strong gravity: production of micro-black holes?

Giddings-Thomas, Dimopoulos-Landsberg '01

Generic spectrum

N coincident branes $\Rightarrow U(N)$

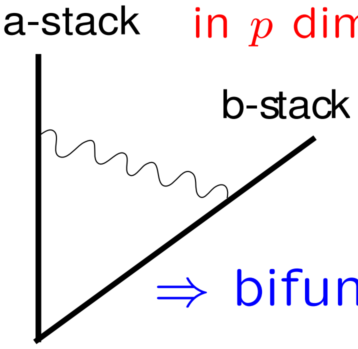


endpoint transformation: $\mathbf{N}_a$ or $\bar{\mathbf{N}}_a$

$U(1)_a$ charge: $+1$ or -1

$U(1)$: “baryon” number

- open strings from the same stack $\Rightarrow$
  adjoint gauge multiplets of $U(N_a)$
- stretched between two stacks



in p dims

in p' dims

$\Rightarrow$ bifundamentals of $U(N_a) \times U(N_b)$

in $p \cap p'$ dims

A D-brane embedding of the Standard Model

I.A.-Kiritsis-Tomaras '00

I.A.-Kiritsis-Rizos-Tomaras '02

- oriented strings ⇒

  need at least 4 brane-stacks

- existence of bulk with large dimensions ⇒

  minimal choice: $U(3)\times U(2)\times U(1)\times U(1)_{bulk}$

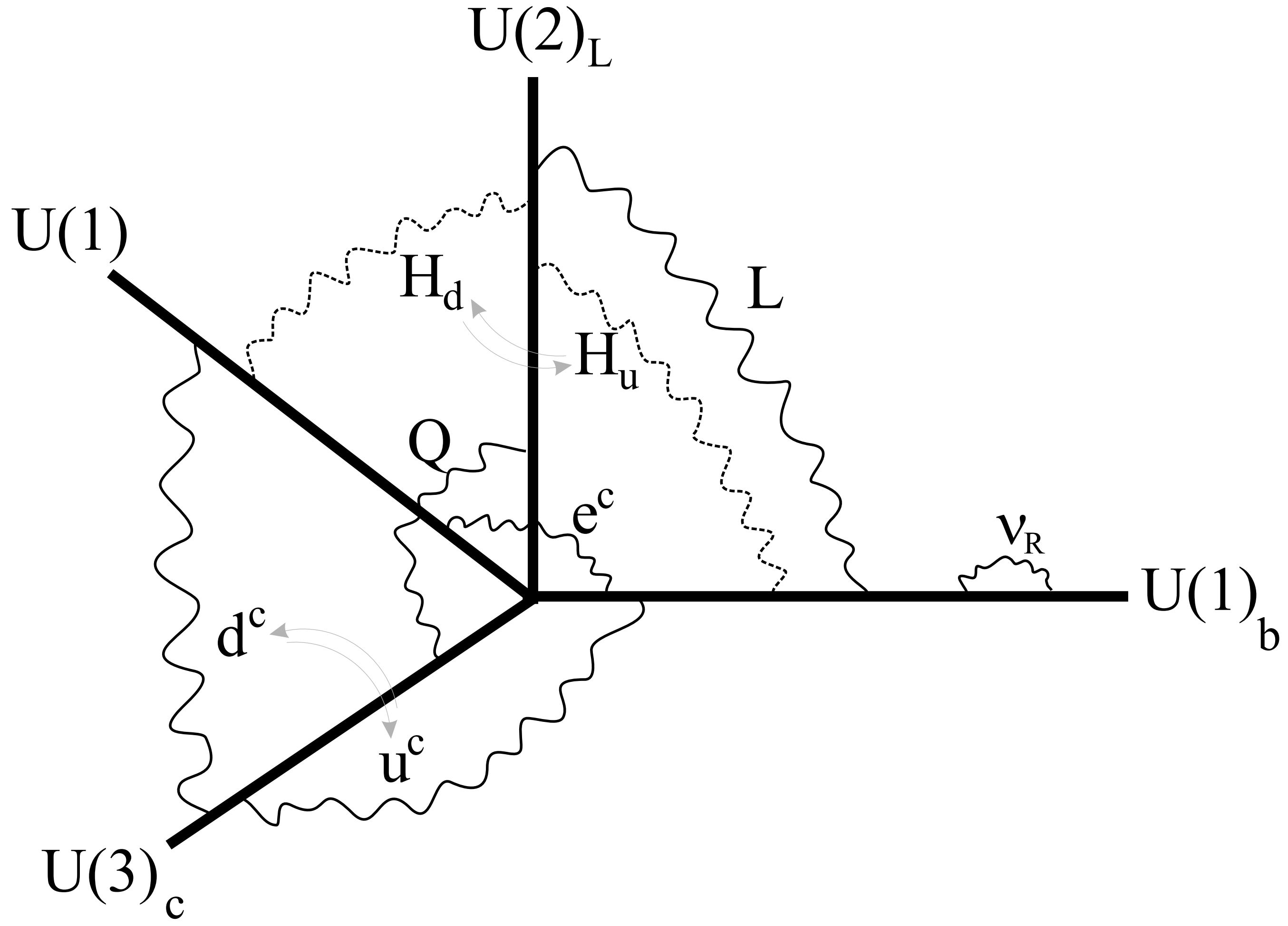
  ↗ ↖

  color branes (g_3) weak branes (g_2)

- also for non-oriented strings

  with Baryon and Lepton number symmetries

Standard Model on D-branes



- $g_2^2/g_3^2 = R/l_s \Rightarrow$ KK modes for $SU(2)_L$
- $U(1)^4 \Rightarrow$ hypercharge + B, L, PQ global
- $U(1)$ on top of $U(2)$ or $U(3) \Rightarrow$ prediction for $\sin^2\theta_W$
- ν_R in the bulk $\Rightarrow$ small neutrino masses

The remaining three $U(1)$'s : anomalous

Green-Schwarz anomaly cancellation $\Rightarrow$

- they become massive (absorb three axions)
- the global symmetries remain in perturbation

\- Baryon number $\Rightarrow$ proton stability

\- Lepton number $\Rightarrow$ protect small neutrino masses

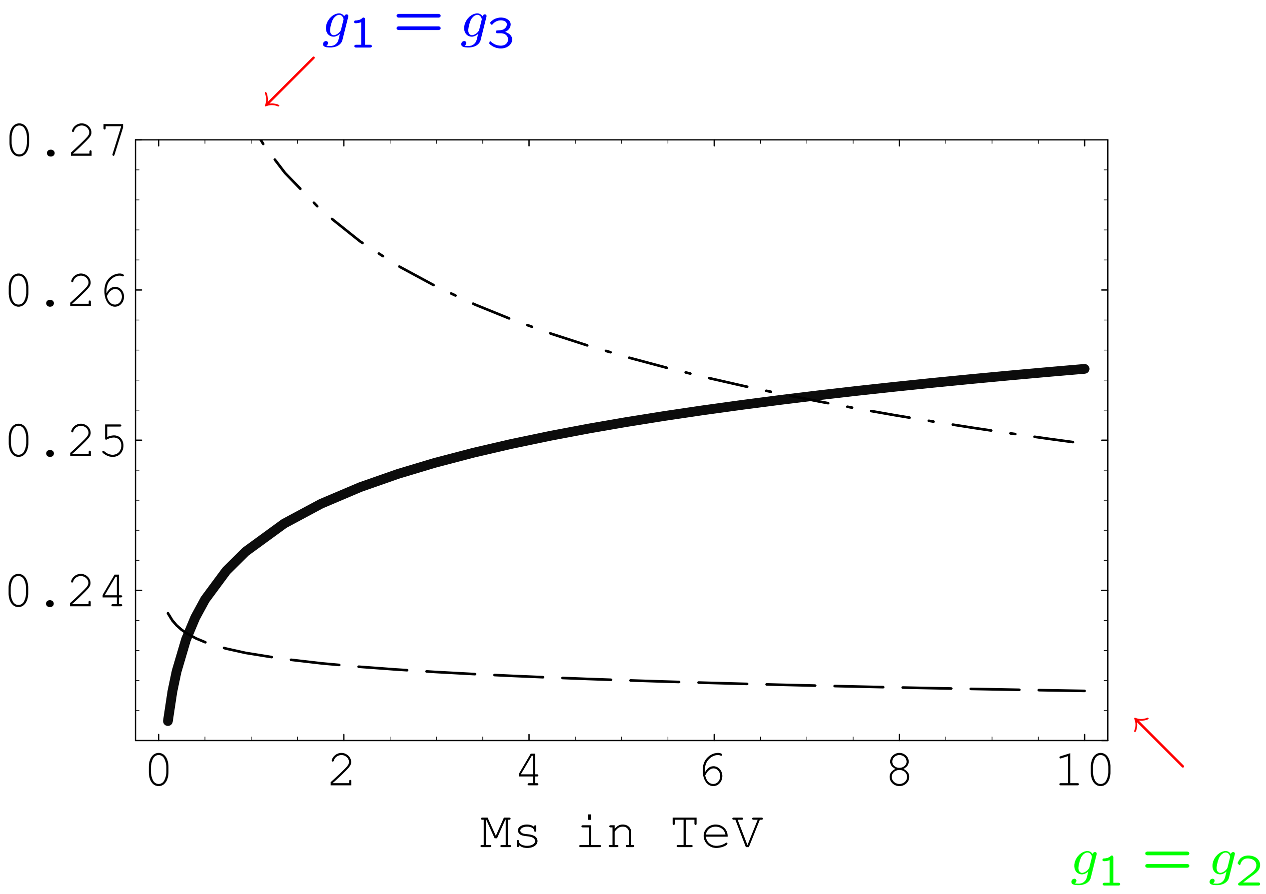
no Lepton number $\Rightarrow \frac{1}{M_s} LLHH$

$$\Rightarrow \text{Majorana mass: } \frac{\langle H\rangle^2}{\underset{\nearrow \sim \text{GeV}}{M_s}} LL$$

\- PQ-type symmetry $\Rightarrow$ electroweak axion

can be explicitly broken by moving slightly away from the orbifold point

$\sin^2\theta_W(M_s)$



$\Rightarrow$ correct prediction for $\sin^2\theta_W$

for $M_s \sim$ a few TeV

R-neutrinos: open strings in the bulk $H'L\nu_R$

Arkani Hamed-Dimopoulos-Dvali-March Russell '98

Dienes-Dudas-Gherghetta '98

- $\int d^{4+n}x\ \bar{\nu}\partial\!\!\!/\nu \qquad \nu = (\nu_R, \nu_R^c)\ \Rightarrow$

$$R_\perp^n \int d^4x \sum_m \left\{\bar{\nu}_{Rm}\partial\!\!\!/\nu_{Rm} + \bar{\nu}^c_{Rm}\partial\!\!\!/\nu^c_{Rm} + \frac{m}{R_\perp}\nu_{Rm}\nu^c_{Rm} + c.c.\right\}$$

- $S_{int} = g_s \int d^4x H(x)L(x)\nu_R(x, y = 0)$

$\langle H\rangle = v\ \Rightarrow$ mass-terms: $\frac{g_s v}{R_\perp^{n/2}}\sum_m \nu_L\nu_{Rm}$

$\frac{g_s v}{R_\perp^{n/2}} << \frac{1}{R_\perp}\ \Leftrightarrow\ g_s v << R_\perp^{n/2-1}$ in string units $\Rightarrow$

- $m \neq 0$: masses for KK ν_m unaffected

- $m = 0$: Dirac neutrino masses

$$m_\nu \simeq \frac{g_s v}{R_\perp^{n/2}} \simeq \frac{g_s}{g^2}v\frac{M_s}{M_p}$$

$\simeq 10^{-3} - 10^{-2}$ eV for $M_s \simeq 1 - 10$ TeV

In principle one $\nu_R \Rightarrow$

both solar and atmospheric oscillations

two frequencies: solar $\leftrightarrow m_\nu <<$

atmospheric $\leftrightarrow$ 1st KK excitation

however cannot be made realistic

e.g. KK modes $\rightarrow$ important sterile component

$\Rightarrow$ need to introduce three ν_R^i (at least 2)

explain oscillations in the traditional way

- only from zero modes ν_{R0}^i
- make KK modes heavy

Davoudiasl-Langacker-Perelstein '02

Origin of EW symmetry breaking?

little hierarchy: $m_W/M_s \lesssim \mathcal{O}(10^{-1})$

string tree-level: $m_W = 0$ or $\mathcal{O}(M_s)$

possible solution: radiative breaking

I.A.-Benakli-Quiros '00

$V = \mu^2 H^\dagger H + \lambda (H^\dagger H)^2$

$\mu^2 = 0$ at tree but becomes < 0 at one loop

non susy vacuum

simplest case: one Higgs from the same brane

$\Rightarrow$ tree-level V same as susy: $\lambda = \frac{1}{8}(g^2 + g'^2)$

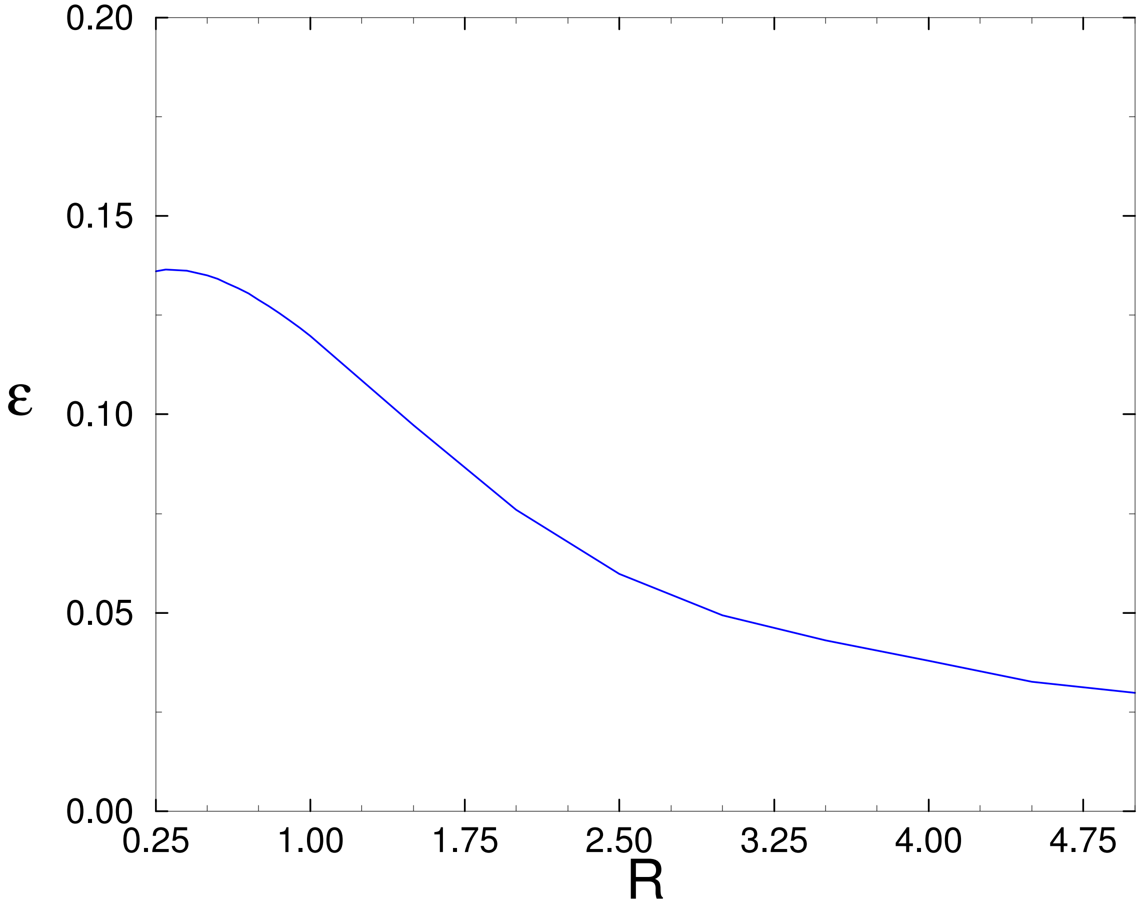
D-terms

$\mu^2 = -g^2 \varepsilon^2 M_s^2 \leftarrow$ effective UV cutoff

$\nwarrow$

loop-factor estimated by a toy model computation

$$\varepsilon^2(R) = \frac{R^3}{2\pi^2}\int_{\underset{\text{IR}\nearrow}{0}}^{\overset{\text{UV}\searrow}{\infty}} dl\, l^{3/2}\, \underset{\searrow 1}{\overset{\nearrow e^{-\pi l}}{\frac{\theta_2^4}{16 l^4 \eta^{12}}}} \left(il + \frac{1}{2}\right) \sum_n n^2 e^{-2\pi n^2 R^2 l}$$



$R \to \infty :\ \varepsilon(R) M_s \sim \varepsilon_\infty / R$ $\varepsilon_\infty \simeq 0.008$

$\nwarrow$ UV cutoff: $M_s \to 1/R$

$R \to 0 :\ \varepsilon(R) \simeq 0.14$ large transverse dim

- $M_H = M_Z$ at tree

  same as MSSM for tan $\beta, m_A \to \infty$

- $M_s = M_H/(\sqrt{2}g\varepsilon)$

Low-energy SM radiative corrections

top quark sector

$M_H \sim$ 120 GeV

$\Rightarrow$

$M_s \sim$ a few TeV

- global SUSY:

- No need to be there at least for hierarchy

- New ways of breaking

  using extra dimensions

  branes at angles/internal magnetic fields

- SUGRA: probably unbroken in the bulk $\Rightarrow$

  very weakly broken

- New forces at submm scales

  e.g. radion, graviphoton

- Non linear realization on branes

  SM + (light) goldstino

Energy density: Λ_{bulk}, Λ_{brane}

generic non-SUSY string model $\Rightarrow$

$\Lambda_{\text{bulk}} \sim M_s^{4+n} \Rightarrow \Lambda_{\text{brane}} \sim M_s^{4+n} R_\perp^n \sim M_s^2 M_P^2$

analog in softly broken SUSY: $m_{\text{SUSY}}^2 \Lambda_{UV}^2$

quadratic divergence to Λ

vanishing if bulk is (approximately) SUSY

$\Lambda_{\text{brane}} \sim M_s^4 \Rightarrow \Lambda_{\text{bulk}} \sim M_s^4 / R_\perp^n$

Prediction: possible new forces at submm scales

e.g. radion $\equiv \ln R_\perp$

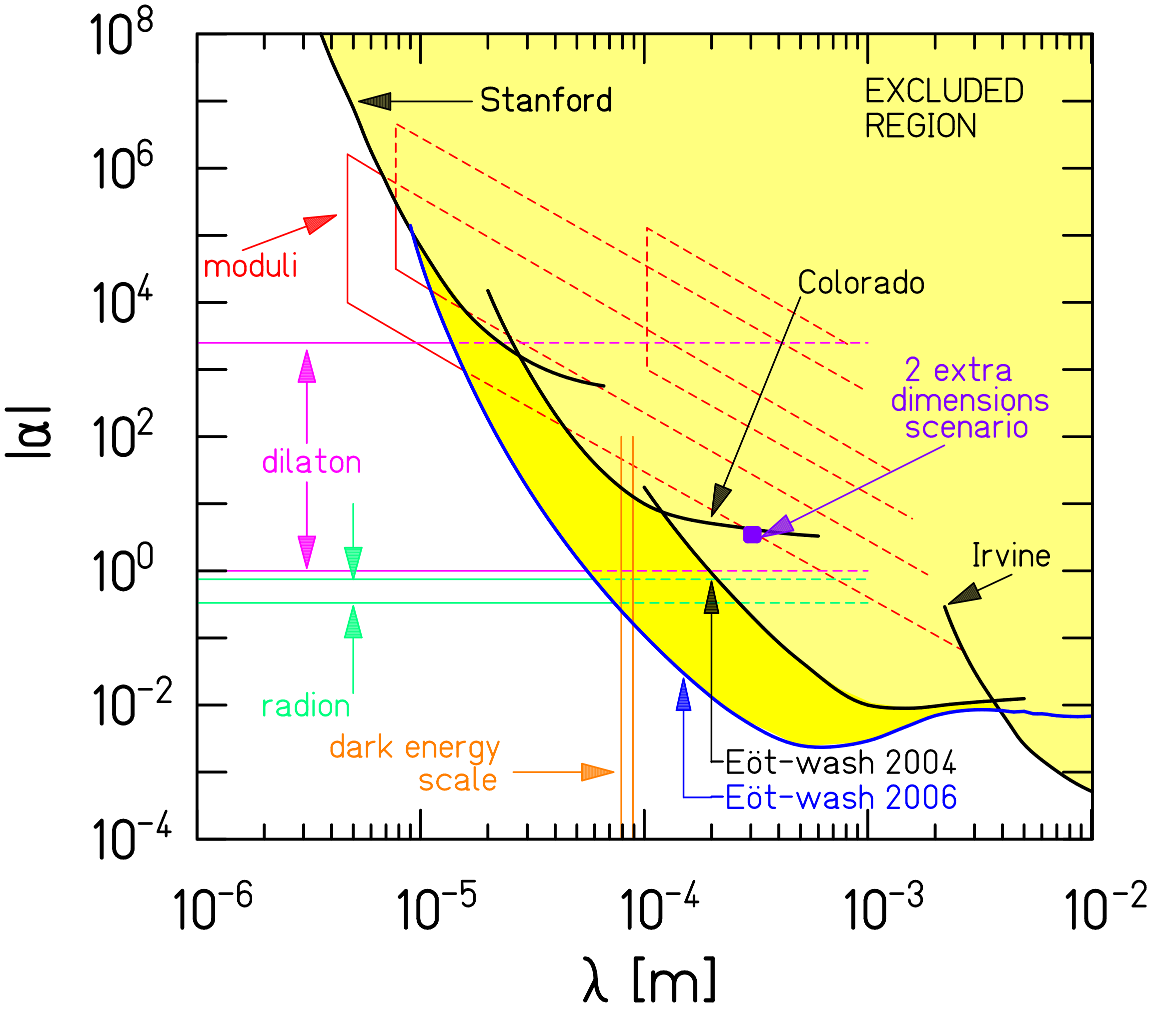
mass: $(\text{TeV})^2/M_P \sim 10^{-4}$ eV → mm range

coupling: $\frac{1}{m}\frac{\partial m}{\partial \ln R_\perp} = \sqrt{\frac{n}{n+2}} \times$ gravity

$\Rightarrow$ can be experimentally tested for all $n \geq 2$

I.A.-Benakli-Maillard-Laugier '02

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



Radion ⇒ $M_* \gtrsim$ 3 - 4.5 TeV 95% CL (n=2-6)

Adelberger et al. '04

Light $U(1)$ gauge bosons

I.A.-Kiritsis-Rizos '02

$U(1)$ anomalies ⇒ Green-Schwarz mechanism

$\delta A = d\Lambda \quad \Rightarrow \quad \delta a = -M\Lambda$

gauge field

axion

$$-\frac{1}{4g_A^2}F_A^2 - \frac{1}{2}(da+MA)^2 + \frac{a}{M}k_I^A \,\mathrm{Tr} F_I \wedge F_I$$

cancel the anomaly

⇒ $U(1)_A$ mass: $m_A = g_A M$

- a: Poincaré dual of a 2-form

  from RR closed string sector $da = *dB_2$

- $U(1)_A$ global symmetry remains

  (in perturbation)

ex. Baryon and Lepton number needed to prodect proton decay and neutrino masses

$$m_A = g_A\, M$$

small mass ⇒ small coupling

⇒ A in the bulk and a on the brane:

localized mass

$g_A \sim 1/\sqrt{V_\perp}$

$\Rightarrow m_A \gtrsim M_s^2/M_P \;\simeq\; 10^{-4}\,\mathrm{eV}$

↖

A propagates in part of the bulk

⇒ new submm forces

$g_A \sim 1/\sqrt{V_\perp} \gtrsim M_s/M_P \sim 10^{-16}$

$\Rightarrow\;\; \gtrsim\; 10^6 - 10^8 \times$ gravity

↖

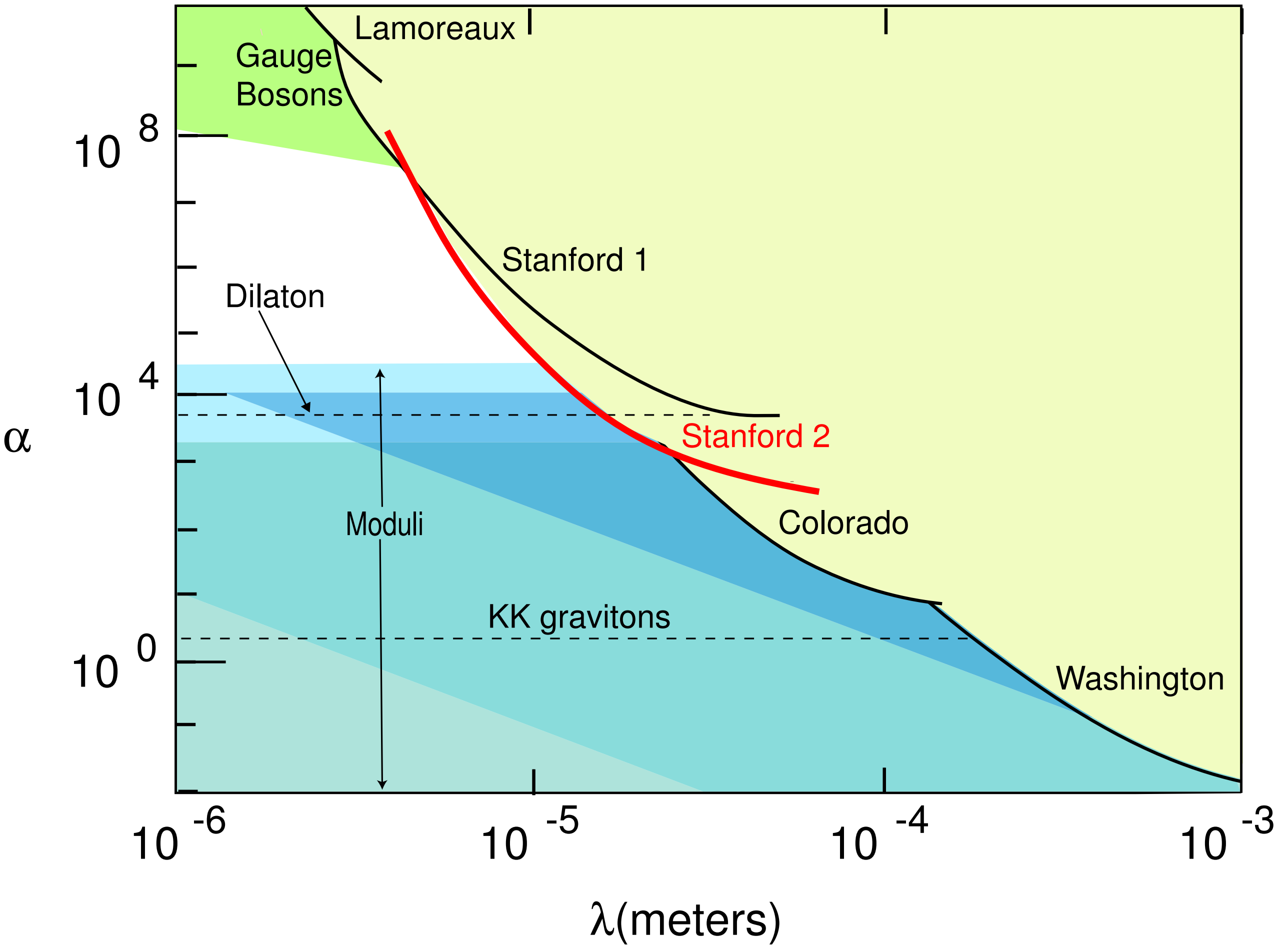
m_{proton}/M_s

supernova ⇒ dim of the bulk ≥ 4

an order of magnitude improvement

on bounds in the range 6-20 μm

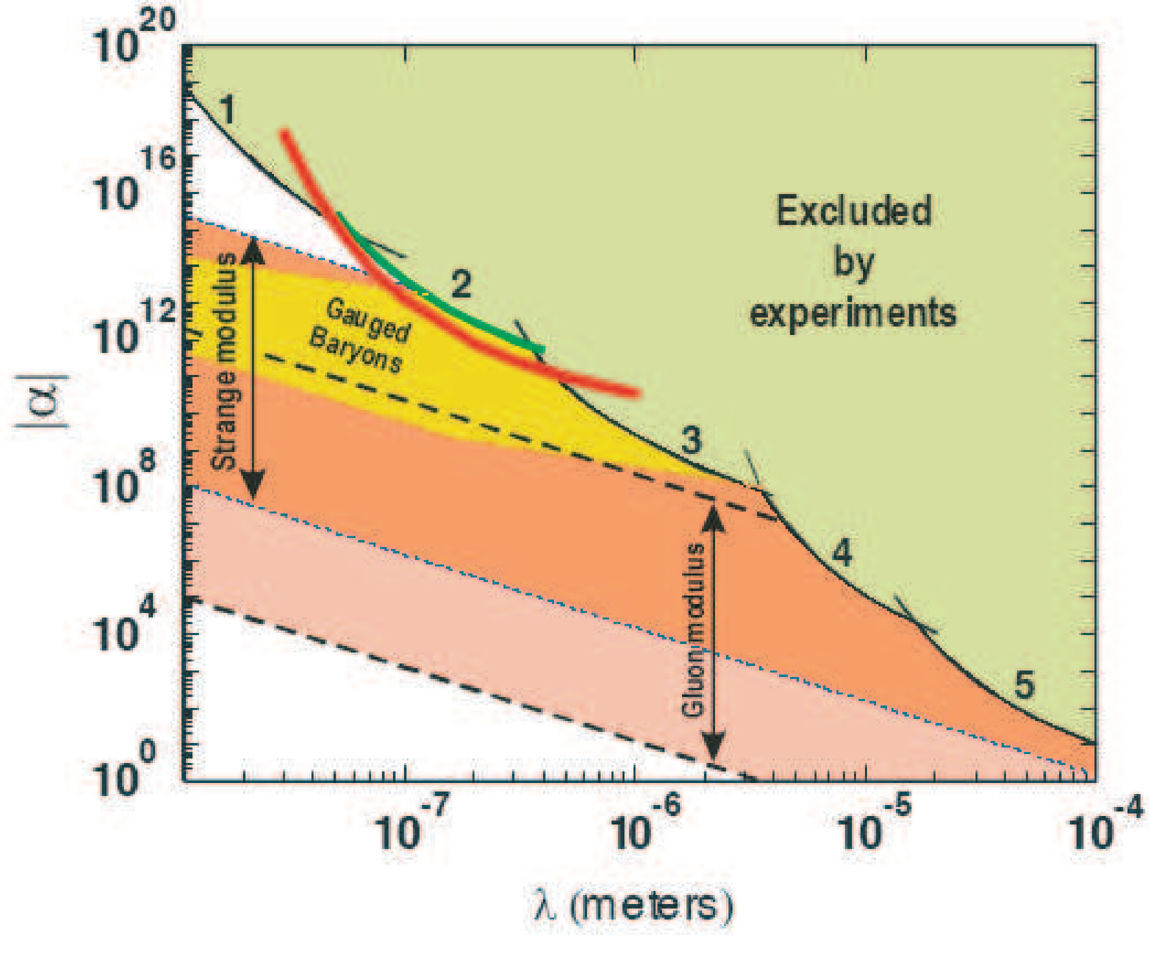
Smullin-Geraci-Weld-Chiaverini-Holmes-Kapitulnik ’05



an order of magnitude improvement

on bounds in the range 200 nm

Decca-López-Chan-Fischbach-Krause-Jamell ’05



5: Colorado

4: Stanford

3: Lamoureaux

1: Mohideen et al.

Internal magnetic fields

- Type I string theory compactified in 4d on 6d Calabi-Yau

$\Rightarrow$ $N = 2$ SUSY in the bulk, $N = 1$ on branes

- Magnetic fluxes on 2-cycles

$\Rightarrow$ SUSY breaking

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 all charged states

$[p_i, p_j] = iqH\epsilon_{ij}$ q: charge

$\Rightarrow$ Landau spectrum

T-dual representation: branes at angles

magnetized D9-brane wrapped on T^2

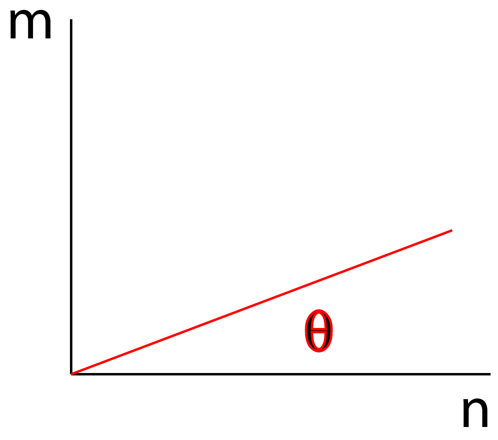
$$H = \frac{m}{n}\frac{1}{R_1 R_2}$$

T-duality: $R_2 \to \alpha'/R_2 \equiv \tilde{R}_2 \Rightarrow$ D8-brane

wrapped around a direction of angle θ in T^2

$$H = \frac{m}{n}\frac{\tilde{R}_2}{R_1} = \tan\theta$$

(m,n): wrapping numbers around $(\tilde{R}_2, R_1)$



Generic spectrum

Turn on H_I^a in several $U(1)_a$ directions

$\Rightarrow$ Gauge group: $\prod_a U(N_a) \leftarrow SU(N_a) \times U(1)_a$

- Neutral strings: adjoint representations

  $\Rightarrow$ massless gauge supermultiplets

- Charged strings $\Rightarrow$ massless chiral fermions

  but in general massive scalars

$\Rightarrow$ Generic spectrum of split SUSY:

- massless gauginos
- massive squarks and sleptons
- massless Higgs $\Leftrightarrow$ non chiral susy intersection

  two Higgs multiplets

Minimal Standard Model embedding

New possibilities using intersecting branes

- no large dimensions for low string scale
- no need for B or L conservation
- but need $\sin^2\theta_W = \frac{3}{8}$

General analysis using 3 brane stacks

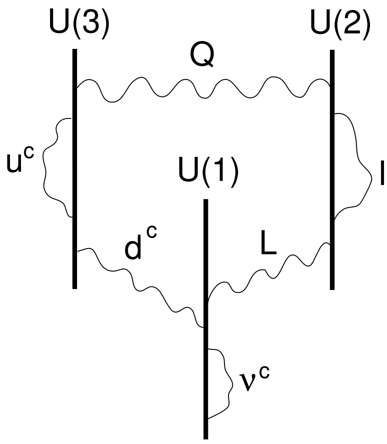
$\Rightarrow\ U(3) \times U(2) \times U(1)$

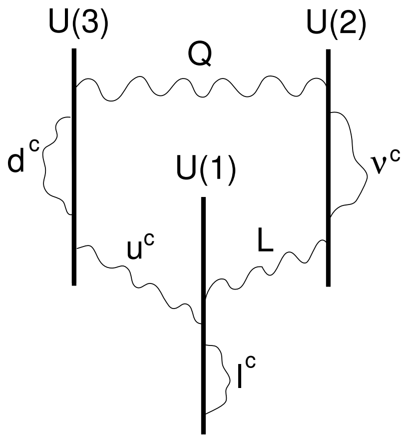
antiquarks u^c, d^c $(\bar{3}, 1)$:

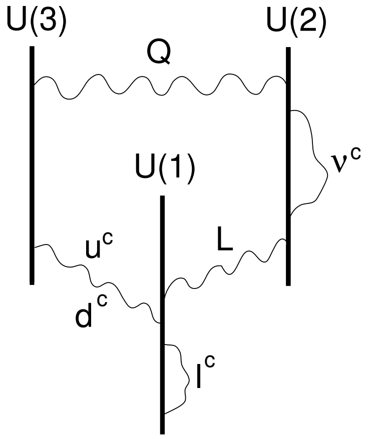
antisymmetric of $U(3)$ or

bifundamental $U(3) \leftrightarrow U(1)$

$\Rightarrow$ 3 models: antisymmetric is u^c, d^c or none







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

$$Y_A = -\frac{1}{3}Q_3 + \frac{1}{2}Q_2 \qquad\qquad Y_{B,C} = \frac{1}{6}Q_3 - \frac{1}{2}Q_1$$

Model A : $\sin^2\theta_W = \left.\frac{1}{2+2\alpha_2/3\alpha_3}\right|_{\alpha_2=\alpha_3} = \frac{3}{8}$

Model B, C : $\sin^2\theta_W = \left.\frac{1}{1+\alpha_2/2\alpha_1+\alpha_2/6\alpha_3}\right|_{\alpha_2=\alpha_3} = \frac{6}{7+3\alpha_2/\alpha_1}$

Gaugino masses: protected by R-symmetry

but broken in 4d SUGRA by the gravitino mass

Two possible ways for generating $m_{1/2}$:

(1) via gravity (brane susy) ⇒

generate $m_{1/2}$ from $m_{3/2}$

one gravitational loop: 1 handle + 1 boundary

$\Rightarrow m_{1/2} \sim g_s^2 \frac{m_{3/2}^3}{M_s^2}$ I.A.-Taylor '04

(2) keep gravity subdominant ⇒

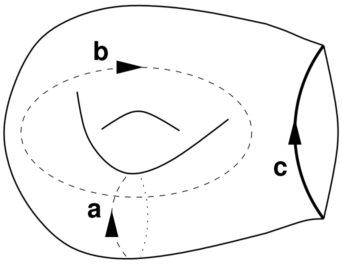
generate $m_{1/2}$ from brane α'-corrections

two gauge loops: 3 boundaries

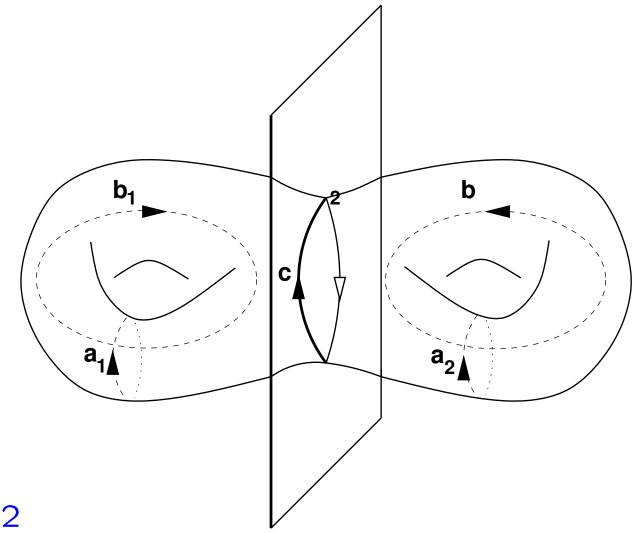
$\Rightarrow m_{1/2} \sim g_s^2 \frac{m_0^4}{M_s^3}$ I.A.-Narain-Taylor '05

Oriented case

(1) $g = 1$ $h = 1$ from mirror involution of $g = 2$



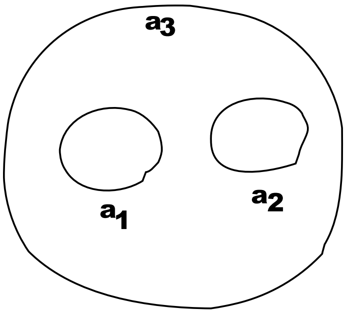
$\longleftarrow$



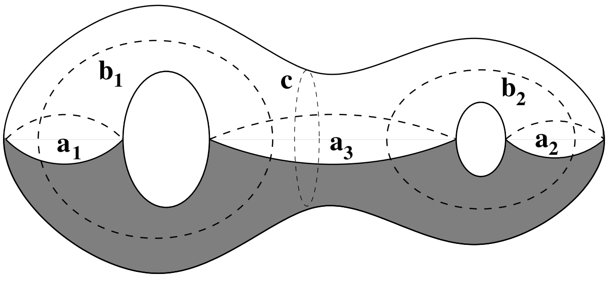
$a_1 \leftrightarrow a_2$

$b_1 \leftrightarrow -b_2$

(2) $g = 0$ $h = 3$ from mirror involution of $g = 2$



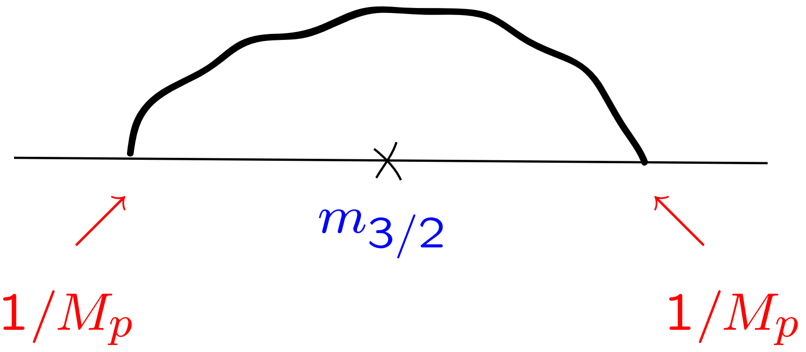
$\longleftarrow$



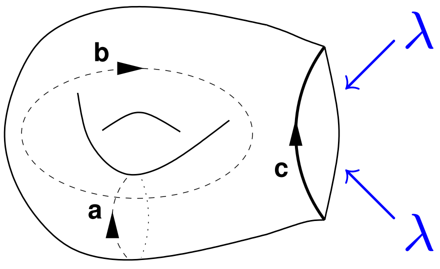
$a_i \leftrightarrow a_i$

$b_i \leftrightarrow -b_i$

$m_{1/2}:$



$$\sim \frac{m_{3/2}}{M_p^2} \times \begin{cases} \Lambda_{\rm UV}^2 & \text{if quadr. divergent} \\ m_{3/2}^2 & \text{if convergent} \end{cases}$$



$$\sim g_s^2 \, \frac{m_{3/2}^3}{M_s^2} \qquad g_s \sim g^2$$

but it vanishes for orbifolds

I.A.-Taylor '04

Sherk-Schwarz along an interval $\perp$ branes

$\Rightarrow m_{3/2} \sim 1/R$

gravity strength $\Rightarrow R^{-1} = \frac{2}{\alpha_G^2}\frac{M_s^3}{M_p^2} \sim 10^{13}$ GeV

for $M_s \sim M_{\mathrm{GUT}} \sim 10^{16}$ GeV

- $m_{1/2} \sim g_s^2 \frac{m_{3/2}^3}{M_s^2} \sim 1$ TeV

if every loop-factor $\sim 10^{-2}$

- $m_0 \gtrsim g_s \frac{m_{3/2}^2}{M_s} \sim 10^8$ GeV

scalar masses induced at one loop

$\Rightarrow$ split supersymmetry framework

heavy scalars, light fermions

Arkani Hamed-Dimopoulos, Giudice-Romanino '04

SUSY breaking by internal magnetic fields

or equivalently branes at angles

Effective QFT description: D-breaking

magnetic field $H \sim \langle \mathrm{D} \rangle$-term of $U(1)$

$\nearrow$

$\langle \mathrm{D} \rangle \sim m_0^2$ $U(N)$ brane stack

R-symmetry broken by string corrections

$\Rightarrow$ higher-dim effective operators:

I.A.-Narain-Taylor '05

$F_{(0,3)} \int d^2\theta \mathcal{W}^2 \mathrm{Tr} W^2$ $\langle \mathcal{W} \rangle = \theta \langle \mathrm{D} \rangle$

$\Rightarrow \; m_{1/2} \sim \epsilon^2 \frac{m_0^4}{M_s^3}$ ϵ^2: 2-loop factor

$\sim$ TeV for $m_0 \sim 10^{13} - 10^{14}$ GeV

- Higgsino mass

$$\int d^2\theta\mathcal{W}^2\underset{\nearrow\,\psi_1\psi_2}{\bar{D}^2}\bar{H}_1\bar{H}_2 \Rightarrow \mu \sim \epsilon\frac{m_0^4}{M_s^3} \lesssim m_{1/2}$$

- Simple toroidal models

gauge multiplets: $N=4$ (or $N=2$) SUSY

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

$$\int d^2\theta\mathcal{W}\mathrm{Tr}WA \;\Rightarrow\; m_D \sim \epsilon\frac{m_0^2}{M_s}$$ 1-loop factor

$N=2$ vector $=$ $N=1$ vector W $+$ chiral A

they can still be consistent with unification

in inermediate energy scales $\sim 10^7 - 10^{13}$ GeV

I.A.-Benakli-Delgado-Quirós-Tuckmantel '05

Evading the hierarchy $m_0 >> m_D$:

- SM on a SUSY brane
- gauge mediation with Dirac masses

I.A.-Benakli-Delgado-Quirós in preparation

$\not{S}\text{USY}$ brane with massive hypermultiplets

in its $(N = 2)$ intersection with SM brane

$(M, D) \longrightarrow$ SM $\quad \Rightarrow \quad M_s \to M$

$$D < M < M_s \quad \Rightarrow \quad m_D^a = \frac{\alpha_a}{4\pi}\frac{D}{M}$$

- adjoint SM scalars Σ_a: one loop masses

$$m_{\Sigma_a}^2 = \frac{\alpha_a}{4\pi}\frac{D^2}{M^2}$$

- squarks and sleptons Q: two loop masses

$$m_Q^2 = 2\sum_a C_a(Q)\left(\frac{\alpha_a}{4\pi}\right)^2\frac{D^2}{M^2}$$

Conclusions

TeV strings and large extra dimensions:

Physical reality or imagination?

Well motivated theoretical framework

with many testable experimental predictions

new resonances, missing energy

Stimulus for micro-gravity experiments

look for new forces at short distances

higher dim graviton, scalars, gauge fields

Gaugino masses from string loops:

High string scale ⇒ hierarchy $m_0 >> m_{1/2}$

1) Majorana masses

- gravity ‘mediation’ ⇒ $m_{1/2}^2 \sim m_0^3/M_s$
- gauge ‘mediation’ ⇒ $m_{1/2} \sim m_0^4/M_s^3$

2) Dirac masses ⇒ $m_D \sim m_0^2/M_s$

evading the hierarchy:

$M_s \to M_{\text{hyp}}$, $m_0^2 \to D$ in a SU$\!\!\!/$SY sector

$m_0^{\text{SM}} \sim m_D$ from 2-loops