The Intersection Numbers of the Standard Model

Luis E. Ibáñez

Instituto de Física Teórica (IFT)

Universidad Autónoma de Madrid

Strings-2002 Cambridge, July 2002

Traditional approach to SM embedding in String Theory

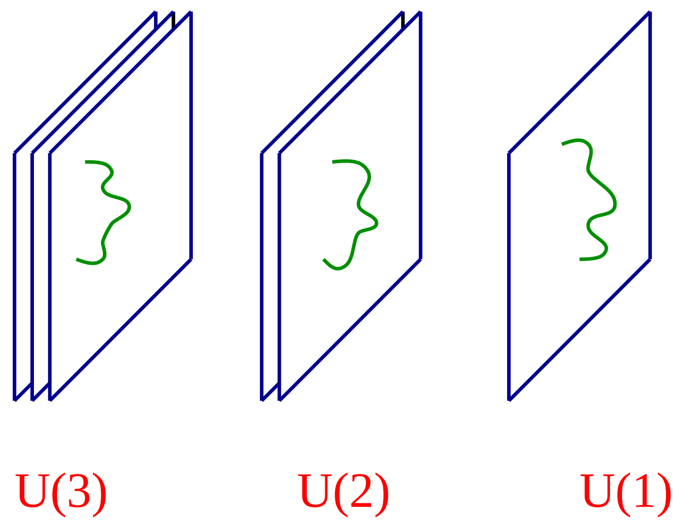
- Prototype: Heterotic $E_8 \times E_8$ compactified on a CY or Orbifold. Thus e.g., in CY's one has:

$$N_{gen} = \frac{1}{2}\chi$$

PRESENT STATUS :

- A number of 3-generation models have been constructed
- At present no model yielding JUST the SM or MSSM spectrum exists
- Typically extra fermions and U(1) bosons remain at low energies
- As a consequence the nice joining of gauge couplings in the MSSM has not yet been reproduced in a string context
- In all models studied proton stability appears as a consequence of arbitrarly chosen charged scalar flat directions.
- Models based on strongly coupled heterotic lead to analogous structure.

Bottom-Up Approach : D-branes as building blocks



Can we build a D-brane description of the Standard Model?

From such description of the SM one hopes:

- Unification of gravity and SM interactions
- Construct string realization of brane-world idea (perhaps)
- But also to find new avenues to understand misteries of the SM like:
  - Family triplication
  - The unreasonable stability of the proton
  - Fermion mass hierarchies
  - etc.

Chiral fermions

- A crucial requirement on the searched D-brane configuration is that it should lead to CHIRAL FERMIONS
- D-branes on a smooth space leads to non-chiral theories ($N = 4$ SUSY)

  Simplest ways to get chirality in explicit D-brane models (NOT unrelated):

  - D-branes at singularities (e.g., orbifold sing.)
  - Intersecting D-branes $\Rightarrow$

- Talk based on:

  L.I. , F. Marchesano and R. Rabadán, hep-th/0105155

  D. Cremades, L.I, F. Marchesano , hep-th/0201205; hep-th/0203160; hep-th/0205074

- Previous related work:

  R. Blumenhagen, L. Görlich, B. Kors, D. Lüst, hep-th/0007024

  G. Aldazabal, S. Franco, L.I., R. Rabadán, A. Uranga, hep-th/0011073 ; hep-ph/0011132

  R. Blumenhagen, B. Körs and D. Lüst , hep-th/0012156

- also:

  R. Blumenhagen, B. Körs, D. Lüst, T. Ott, hep-th/0107138

  M. Cvetic, G. Shiu, A. Uranga, hep-th0107166; hep-th/0107143

  D. Bailin, G. Kraniotis, A. Love, hep-th/0108131

  S. Förste, G. Honecker, R. Schreyer, hep-th/0008250

  G. Honecker, hep-th/0112174; hep-th/0201037

  C. Kokorelis, hep-th/0203187; hep-th/0205147

- brane intersections/fluxes :

  C. Bachas, hep-th/9503030

  M. Berkooz, M. Douglas, R. Leigh, hep-th/9606139

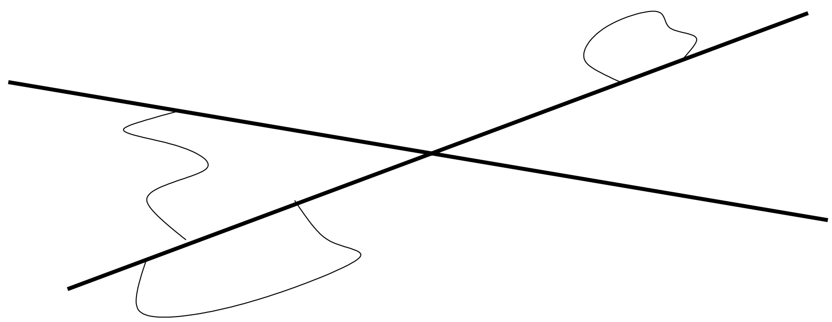
  C. Angelantonj, I. Antoniadis, E. Dudas, A. Sagnotti, hep-th/0007090

WHY INTERSECTING BRANES?

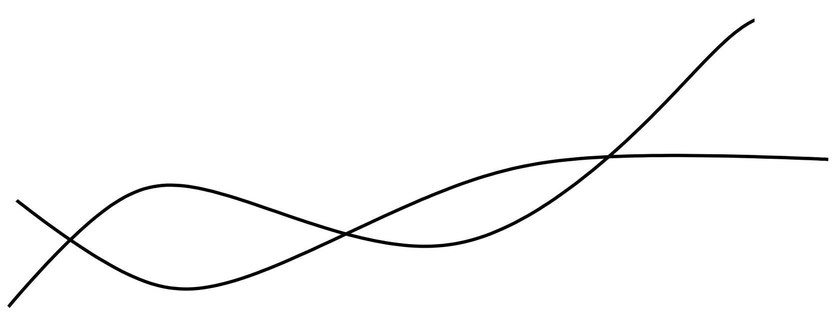
They have a number of properties present in the SM :

❶ Gauge group: Each stack of N branes carries a $U(N)$ gauge theory.

❷ Chirality: Two intersecting branes present chiral fermions at their intersection, transforming in bifundamental $(N, \bar{M})$ or (N, M).

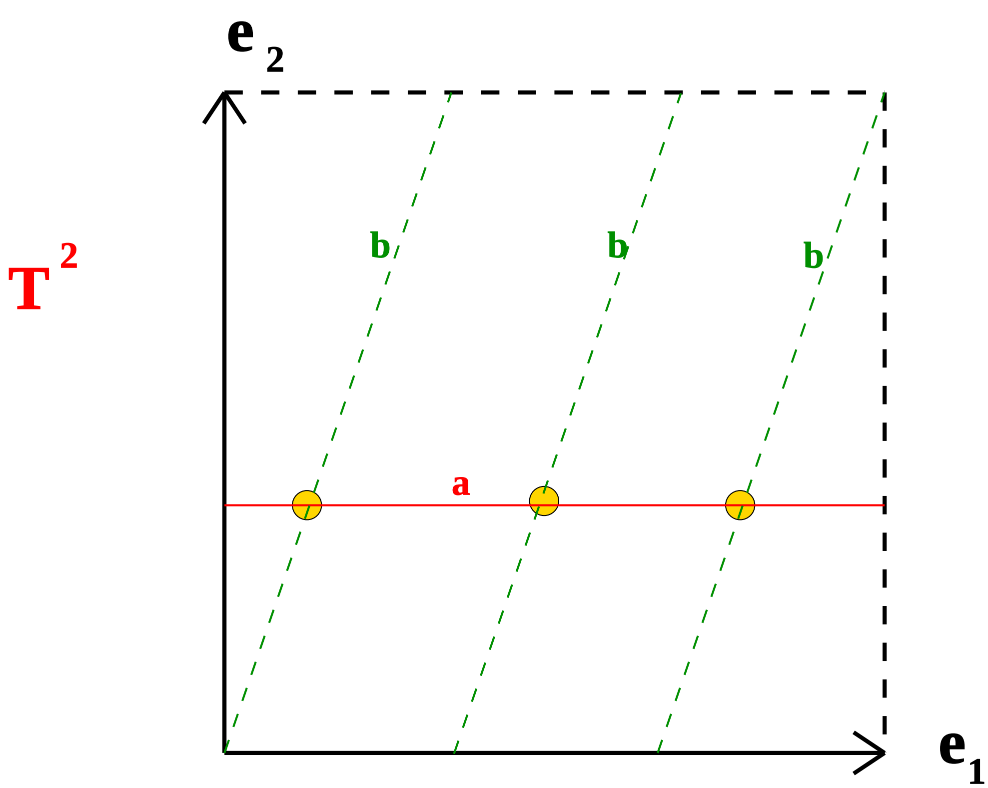


❸ Family replication: Branes at angles wrapping a compact manifold may intersect several times.



TRIPLICATION EXAMPLE

- Consider a pair of D4-branes
- 5-dimensional worldvolume = $M_4 \times C^1$, C^1 wrapping a cycle on a 2-torus



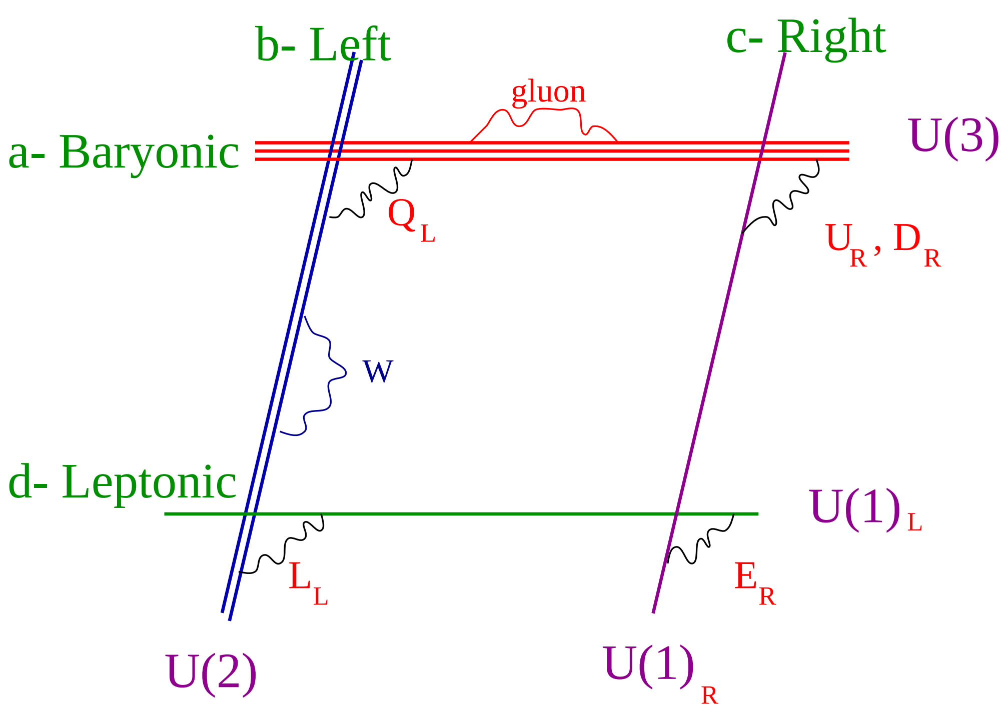
'a' and 'b' 4-branes intersect at three points

- wrapping numbers (n,m) = (1,0), (1,3)

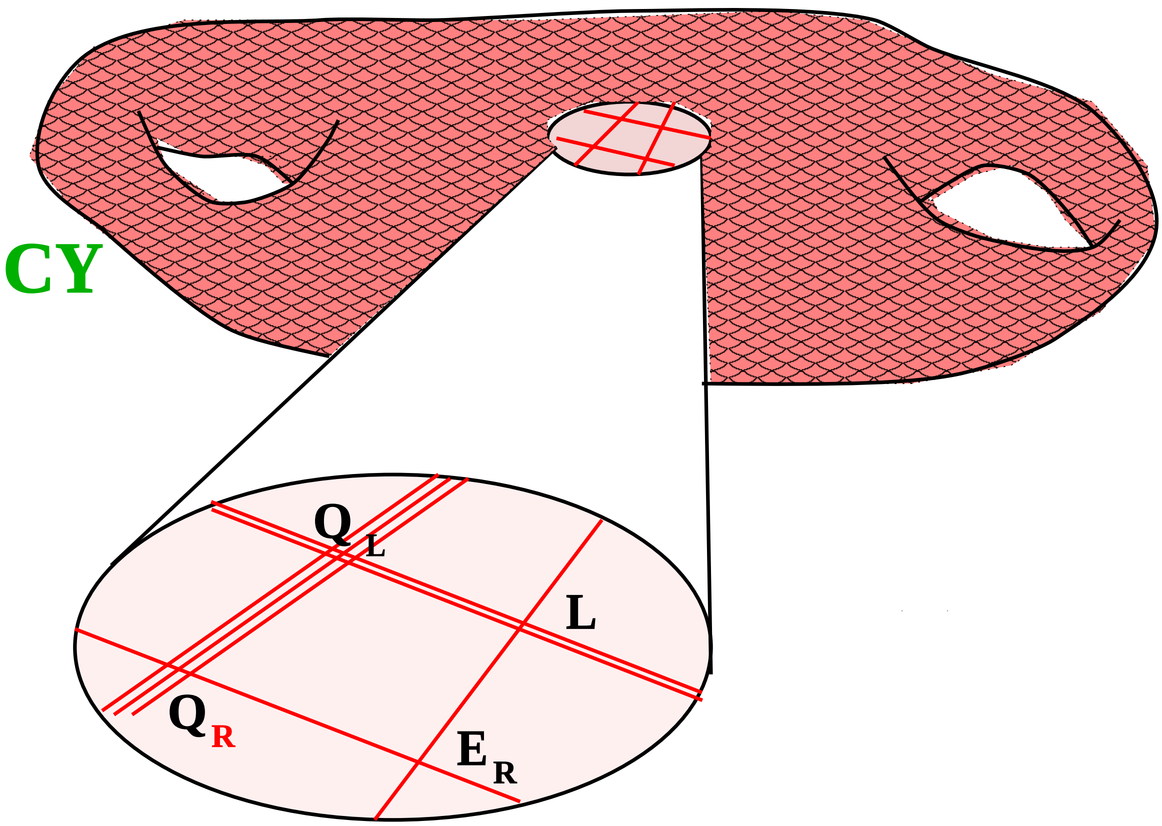
Minimal Structure of SM D-brane settings

Configuration of 4 stacks of branes:

stack a	$N_a = 3$	$SU(3) \times U(1)_a$	Baryonic brane
stack b	$N_b = 2$	$SU(2) \times U(1)_b$	Left brane
stack c	$N_c = 1$	$U(1)_c$	Right brane
stack d	$N_d = 1$	$U(1)_d$	Leptonic brane



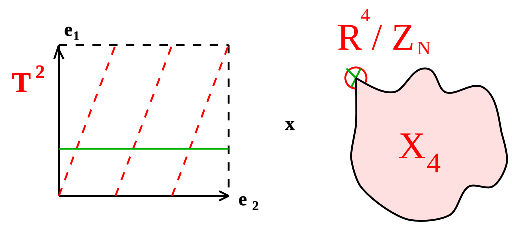
SM from Dp-branes wrapping cycles



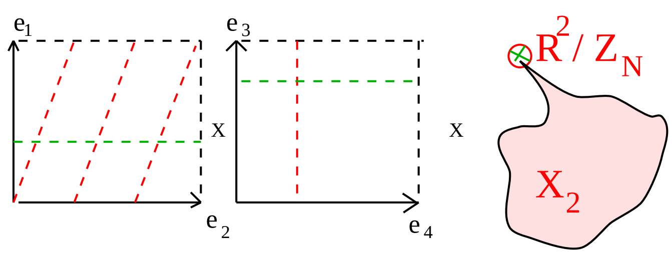
Varieties of Toroidal Intersecting Brane settings

Type II A, B String Theory

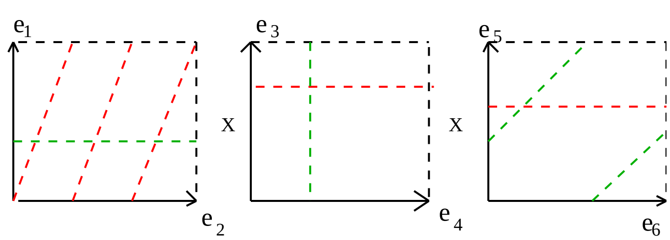
❶ D4-branes wrapping 1-cycles on $T^2 \times R^4/\mathbf{Z}_N$



❷ D5-branes wrapping 2-cycles on $T^4 \times R^2/\mathbf{Z}_N$



❸ D6-branes wrapping 3-cycles on T^6



Generations = # Colors ?

- Important constraint in ANY D-brane model with fermions in bifundamentals (comes from RR-tadpole cancellation):

  Number of N-plets = Number of $\bar{N}$-plets of $U(N)$

  This is true even for $U(2)$ or $U(1)$.

- Impose Number of 2-plets = Number of $\bar{2}$-plets of $U(2)$

  Left-handed SM fermions:

  3 Q_L = 3 $(3,2)$ $\longrightarrow$ 9 2-plets

  3 L = 3 $(1,\bar{2})$ $\longrightarrow$ 3 $\bar{2}$-plets

  $\rightarrow$ Minimal SM has 'U(2) anomalies'

  6 extra fermion $SU(2)$ doublets needed to cancel anomalies.

- Simple way to Cancel Anomalies :

  2 $(3,2)$ + 1 $(3,\bar{2})$ $\longrightarrow$ 3 net 2-plets

  3 $(1,\bar{2})$ $\longrightarrow$ 3 net $\bar{2}$-plets

  $\longrightarrow$ U(2) anomalies cancel !!

- this works only because # COLORS = # GENERATIONS

(N, M) and $(N, \bar{M})$ bifundamentals and orientifolds

We need (N, M) and $(N, \bar{M})$ bifundamentals to get the minimal fermion spectrum of the SM

- In string theory they appear in orientifold models:

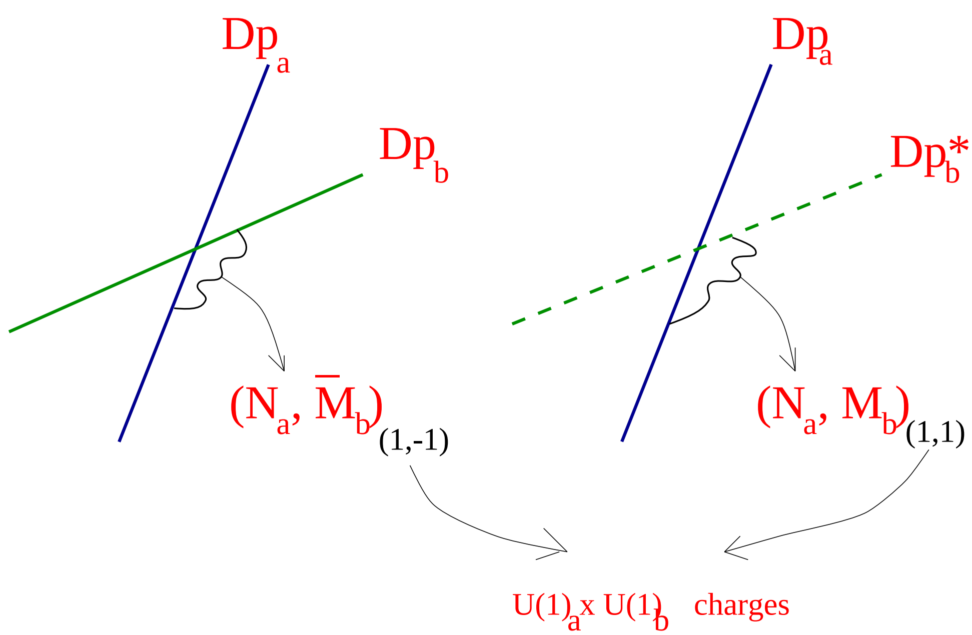
Orientifold = Type II / $\Omega\mathcal{R}$

Ω = worldsheet-parity ; $\mathcal{R}$ = some geometrical action (e.g., reflection)

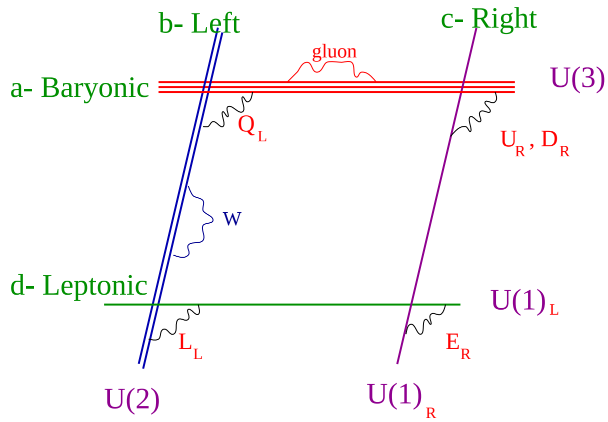
- Under $\Omega\mathcal{R}$:

Dp-brane $\longleftrightarrow$ Dp*-brane = 'mirror' = $(\Omega\mathcal{R})$Dp

Both brane and mirror need to be present in an orientifold configuration



Quantum numbers of SM in intersecting brane models



Assuming all fermions come from bifundamentals and imposing $\#N$-plets $=\#\bar{N}$-plets leads to the following model independent unique structure (up to redefinitions):

Intersection	Matter fields		Q_a	Q_b	Q_c	Q_d	Q_Y
(ab)	Q_L	$(3,2)$	1	-1	0	0	1/6
(ab*)	q_L	$2(3,2)$	1	1	0	0	1/6
(ac)	U_R	$3(\bar{3},1)$	-1	0	1	0	-2/3
(ac*)	D_R	$3(\bar{3},1)$	-1	0	-1	0	1/3
(bd*)	L	$3(1,2)$	0	-1	0	-1	-1/2
(cd)	N_R	$3(1,1)$	0	0	1	-1	0
(cd*)	E_R	$3(1,1)$	0	0	-1	-1	1

$$SU(3) \times SU(2) \times \ U(1)_a \times U(1)_b \times U(1)_c \times U(1)_d$$

Where hypercharge is defined as:

$$Q_Y \ = \ \frac{1}{6}Q_a \ - \ \frac{1}{2}Q_c \ - \ \frac{1}{2}Q_d \qquad (1)$$

(Orthogonal linear combinations will be massive, see below)

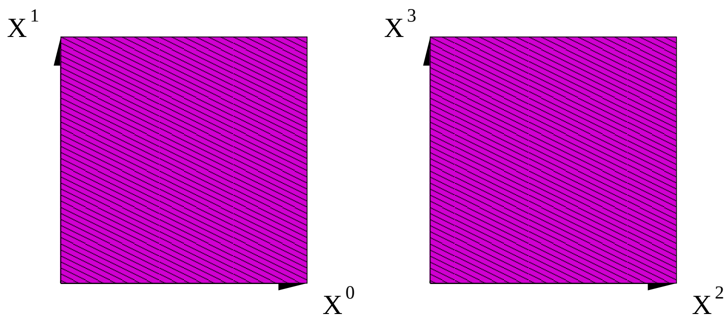
D6-BRANES WRAPPING AT ANGLES ON T^6

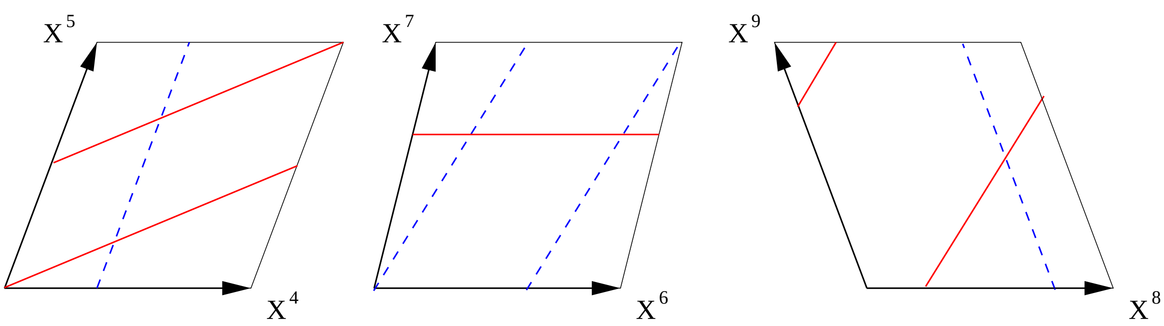
Setup: type IIA D6-branes filling M_4 and wrapping 3-cycles on T^6.

We further assume having a factorized torus and factorizable 3-cycles:

$$T^6 = T^2 \times T^2 \times T^2$$

3-cycle = 1-cycle $\times$ 1-cycle $\times$ 1-cycle





$$[\Pi_a] = (n_a^1, m_a^1) \times (n_a^2, m_a^2) \times (n_a^3, m_a^3)$$

Intersection number: $I_{ab} = I_{ab}^1 \times I_{ab}^2 \times I_{ab}^3$

$$I_{ab}^i = \left(n_a^i m_b^i - m_a^i n_b^i\right)$$

ORIENTIFOLD

Consider the theory

$$\frac{\text{Type IIA on } T^6}{\Omega\mathcal{R}} \overset{T-dual}{\longleftrightarrow} \text{Type I on } \tilde{T}^6 \qquad (2)$$

Ω : Worldsheet parity.

$\mathcal{R} = \mathcal{R}_{(5)}\mathcal{R}_{(7)}\mathcal{R}_{(9)}$

Consequences:

❶ only some tori lattices are allowed by $\Omega\mathcal{R}$ action: square ($b^{(i)} = 0$) or tilted ($b^{(i)} = \frac{1}{2}$).

❷ Mirror branes should be added

For each D6-brane a in our model, we must add its mirror image a^* under $\Omega\mathcal{R}$.

Deffine effective wrapping numbers as

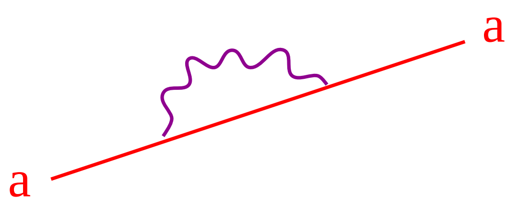
$$(n_a^i, m_a^i)_{\text{eff}} \equiv (n_a^i, m_a^i) + b^{(i)}(0, n_a^i),$$

Then $\Omega\mathcal{R}$ action reduces to

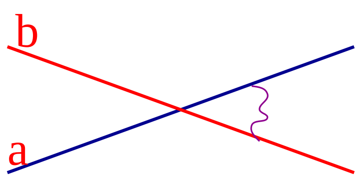
$$\begin{array}{ccc} \text{D6} - \text{brane}\, a & \mapsto & \text{D6} - \text{brane}\, a^* \\ (n_a^i, m_a^i) & & (n_a^i, -m_a^i) \end{array} \qquad (3)$$

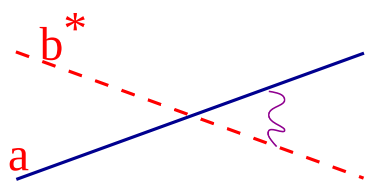
❸ Fermion spectrum

- $D6_a D6_a$ and $D6_a * D6_a *$ sectors : $U(N)$ $\mathcal{N} = 4$ SYM.



- $D6_a D6_b$ and $D6_a D6_b *$ sector: bifundamental fermion representations $I_{ab}(N_a, \overline{N_b}) + I_{ab*}(N_a, N_b)$





(asuming each brane does not intersect with its own mirror, which would lead to additional exotic symmetric/antisymmetric fermion fields)

RR Tadpole Cancellation Conditions

- Consistent compactifications must satisfy RR Tadpole conditions, which imply a vanishing total Charge under certain Ramond-Ramond antisymmetric fields. This automatically ensures non-abelian $SU(N_a)^3$ anomaly cancellation:

$$\sum_c N_c I_{ac} = 0.$$

Notice that, as advertised, in these systems $SU(N)^3$ anomaly cancellation reduces to

fundamentals = # antifundamentals

- If D6-branes have wrapping numbers $(n_a^1, m_a^1)(n_a^2, m_a^2)(n_a^3, m_a^3)$ the conditions read:

$$\begin{aligned} \sum_a N_a \, n_a^1 n_a^2 n_a^3 &= 16 \\ \sum_a N_a \, n_a^1 m_a^2 m_a^3 &= 0 \\ \sum_a N_a \, m_a^1 n_a^2 m_a^3 &= 0 \\ \sum_a N_a \, m_a^1 m_a^2 n_a^3 &= 0 \end{aligned} \tag{4}$$

SM INTERSECTION NUMBERS

$$I_{ab} = 1 \; ; I_{ab^*} = 2$$

$$I_{ac} = -3 \; ; I_{ac^*} = -3$$

$$I_{bd} = 0 \; ; I_{bd^*} = -3$$

$$I_{cd} = +3 \; ; I_{cd^*} = -3$$

$$a = U(3)_{baryon} \; ; b = U(2)_{left}$$

$$c = U(1)_{right} \; ; d = U(1)_{lepton}$$

Getting JUST the SM at intersecting D6-branes

Look for choices of wrapping numbers (n_a^i, m_a^i) yielding the fermion spectrum of the SM that we displayed before:

The general solution is:

N_i	(n_i^1, m_i^1)	(n_i^2, m_i^2)	(n_i^3, m_i^3)
$N_a = 3$	$(1/\beta^1, 0)$	$(n_a^2, \epsilon\beta^2)$	$(1/\rho, -\tilde{\epsilon}/2)$
$N_b = 2$	$(n_b^1, \epsilon\tilde{\epsilon}\beta^1)$	$(1/\beta^2, 0)$	$(1, -3\rho\tilde{\epsilon}/2)$
$N_c = 1$	$(n_c^1, 3\rho\epsilon\beta^1)$	$(1/\beta^2, 0)$	$(0, 1)$
$N_d = 1$	$(1/\beta^1, 0)$	$(n_d^2, \epsilon\beta^2/\rho)$	$(1, 3\rho\tilde{\epsilon}/2)$

Table 1: D6-brane wrapping numbers giving rise to a SM spectrum. The general solutions are parametrized by two phases $\epsilon, \tilde{\epsilon} = \pm 1$, the NS background on the first two tori $\beta^i = 1 - b^i = 1, 1/2$, four integers $n_a^2, n_b^1, n_c^1, n_d^2$ and a parameter $\rho = 1, 1/3$.

Tadpole conditions satisfied if:

$$\frac{3n_a^2}{\rho\beta^1} + \frac{2n_b^1}{\beta^2} + \frac{n_d^2}{\beta^1} = 16 \ . \qquad (5)$$

$U(1)$ symmetries

Intersection	Matter fields		Q_a	Q_b	Q_c	Q_d	Q_Y
(ab)	Q_L	$(3,2)$	1	-1	0	0	1/6
(ab*)	q_L	$2(3,2)$	1	1	0	0	1/6
(ac)	U_R	$3(\bar{3},1)$	-1	0	1	0	-2/3
(ac*)	D_R	$3(\bar{3},1)$	-1	0	-1	0	1/3
(bd*)	L	$3(1,2)$	0	-1	0	-1	-1/2
(cd)	N_R	$3(1,1)$	0	0	1	-1	0
(cd*)	E_R	$3(1,1)$	0	0	-1	-1	1

$$SU(3) \times SU(2) \times U(1)_a \times U(1)_b \times U(1)_c \times U(1)_d$$

❶ Q_a = 3 B ; Q_d = L ; Q_c = 2I_R

These known global symmetries of the SM are in fact gauge symmetries !!

❷ Two are anomaly-free :

$$\frac{Q_a}{3} - Q_d = B - L \qquad (6)$$
$$Q_c = 2I_R$$

with

$$Y = \frac{1}{2}(B-L) - I_R$$

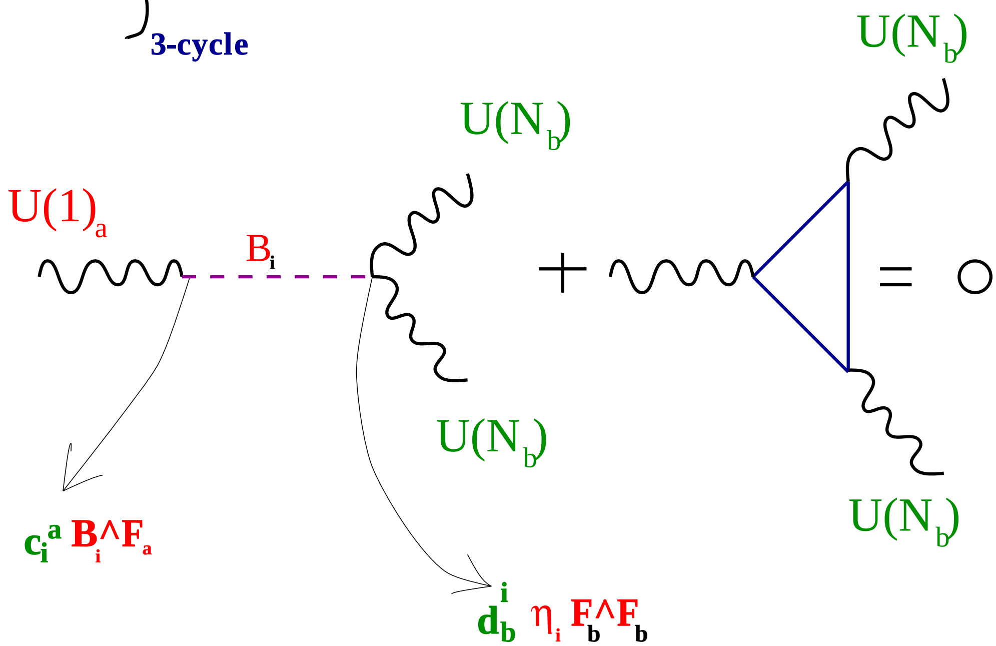
❸ Two have triangle anomalies:

$3Q_a + Q_d$; Q_b

Anomalies are cancelled by a Generalized Green-Schwarz mechanism

Green-Schwarz mechanism

$B_i^{\mu\nu} = \int_{3\text{-cycle}} C^5$ $\qquad$ C^5 = RR-form



$$\sum_i c_i^a d_b^i + A^a{}_b = 0 \qquad B_i^{\mu\nu} \xleftrightarrow{\text{duals}} \eta_i$$

- If a $U(1)$ is anomalous it is necessary massive, due to the $B \wedge F_a$ couplings:

$$\epsilon_{\mu\nu\rho\sigma} B^{\mu\nu}(\partial^\rho A^\sigma) = (\partial_\sigma \eta) A^\sigma \;=\; Higgs - like\;\; coupling$$

- but not the other way round.
- In above orientifold models, there are 4 $D = 4$ RR fields involved, thus at most 4 $U(1)$'s can gain mass.

- Even if the abelian gauge symmetry is lost, the $U(1)$'s remain as perturbative global symmetries (there are in general NO vevs for any charged scalar).
- There are no world-sheet instantons violating this symmetry. The RR-field couple to worldvolume of D2-branes $\longrightarrow$ space-time instantons.
- In our specific solutions, there are two model-independent anomalous $U(1)$'s, and only one $U(1)$ remains massless:

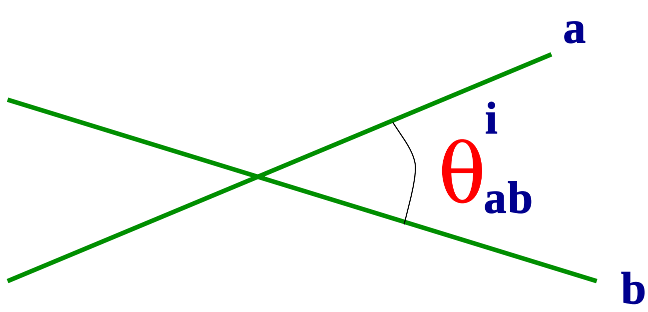
$$Q_0 \;=\; n_c^1(Q_a - 3Q_d) \;-\; \frac{3\tilde{\epsilon}\beta^2}{2\beta^1}(n_a^2 + 3\rho n_d^2)Q_c \qquad (7)$$

It coincides with standard hypercharge if:

$$n_c^1 \;=\; \frac{\tilde{\epsilon}\beta^2}{2\beta^1}(n_a^2 + 3\rho n_d^2). \qquad (8)$$

$\Rightarrow$ Just the SM group and 3 generations

Scalars at D6-brane intersections



i=1,2,3 tori

- There are three lightest scalars ("squarks/sleptons") at each intersection with masses in string units:

$$
\begin{aligned}
M_1^2 &= \tfrac{1}{2}(-|\vartheta^1| + |\vartheta^2| + |\vartheta^3|) \\
M_2^2 &= \tfrac{1}{2}(|\vartheta^1| - |\vartheta^2| + |\vartheta^3|) \\
M_3^2 &= \tfrac{1}{2}(|\vartheta^1| + |\vartheta^2| - |\vartheta^3|)
\end{aligned} \tag{9}
$$

- For wide ranges of parameters scalars are non-tachyonic
- For particular choices of radi and wrappings n_a^i, m_a^i there is a massless scalar, signaling the presence of $N = 1$ SUSY at THAT intersection
- A fully $N = 1$ SUSY toroidal brane configuration in which all intersections respect the same supersymmetry is not possible (due to RR-tadpole cancellation).
- But one can obtain configurations in which all intersections respect a DIFFERENT $N = 1$ SUSY $\Rightarrow$ Q- SUSY models.

A SM with different SUSY at each intersection

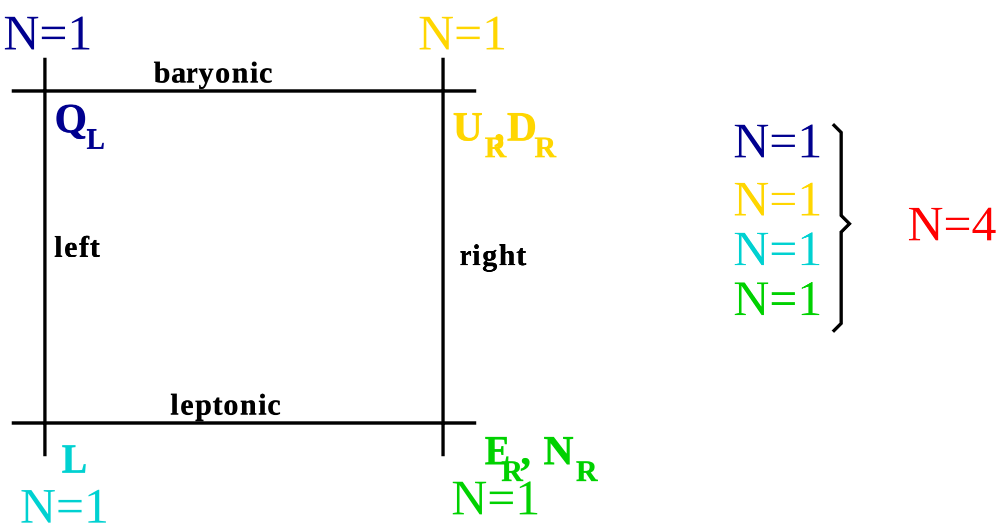
Consider the particular subset of models with wrapping numbers

N_i	(n_i^1, m_i^1)	(n_i^2, m_i^2)	(n_i^3, m_i^3)
$N_a = 3$	$(1, 0)$	(n_a^2, β^2)	$(3, -1/2)$
$N_b = 2$	$(n_b^1, 1)$	$(1/\beta^2, 0)$	$(1, -1/2)$
$N_c = 1$	$(0, 1)$	$(1/\beta^2, 0)$	$(0, 1)$
$N_d = 1$	$(1, 0)$	$(n_a^2, 3\beta^2)$	$(1, 1/2)$

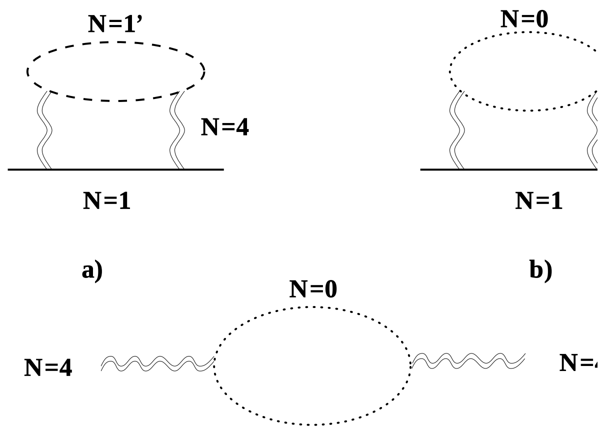
and verifying

$$U^1 = \frac{n_b^1}{2} U^3 \; ; \; U^2 = \frac{n_a^2}{6\beta^2} U^3 \;\; where \;\; U^i = R_2^i / R_1^i \; , \; i = 1, 2, 3$$

- One can check quarks and leptons have massless SUSY partners with respect to 4 different SUSY's:



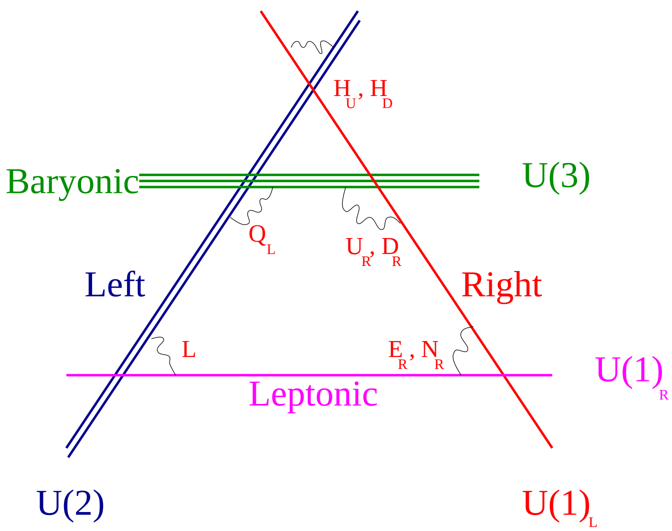
- Interesting class of theories in which quantum corrections to scalars appear only at two loops



- May help in stabalizing a modest hierarchy in between the weak scale and a low string scale $M_s \propto 10 - 100$ Tev

Getting the chiral spectrum of the MSSM

- It is also possible to get a D6-brane configuration with the chiral spectrum of the MSSM and quarks, leptons and Higgs multiplets respecting the same $N = 1$ SUSY



brane type	N_i	(n_i^1, m_i^1)	(n_i^2, m_i^2)	(n_i^3, m_i^3)
a_2	$N_a = 3$	$(1,0)$	$(3,1)$	$(3,-1/2)$
b_2	$N_b = 2$	$(1,1)$	$(1,0)$	$(1,-1/2)$
c_2	$N_c = 1$	$(0,1)$	$(0,-1)$	$(2,0)$
a_2'	$N_d = 1$	$(1,0)$	$(3,1)$	$(3,-1/2)$

Table 2: Wrapping numbers of a three generation SUSY-SM with $\mathcal{N}=1$ SUSY locally.

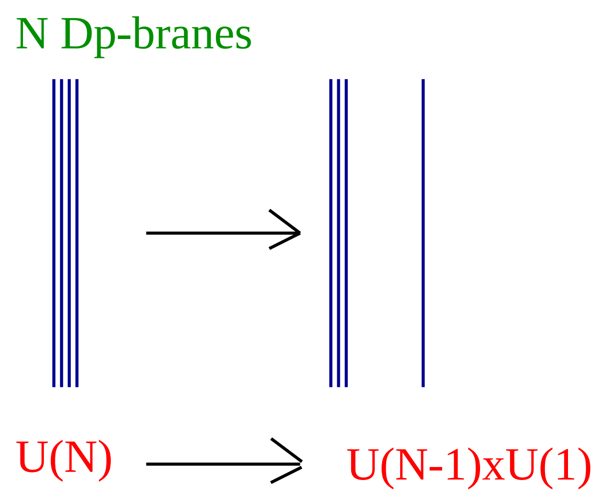
Intersection	Matter fields		Q_a	Q_b	Q_c	Q_d	Q_Y
ab	Q_L	$(3,2)$	1	-1	0	0	1/6
ab^*	q_L	$2(3,2)$	1	1	0	0	1/6
ac	U_R	$3(\bar{3},1)$	-1	0	1	0	-2/3
ac^*	D_R	$3(\bar{3},1)$	-1	0	-1	0	1/3
bd	L	$(1,2)$	0	-1	0	1	-1/2
bd^*	l	$2(1,2)$	0	1	0	1	-1/2
cd	N_R	$3(1,1)$	0	0	1	-1	0
cd^*	E_R	$3(1,1)$	0	0	-1	-1	1
bc	H	$(1,2)$	0	-1	1	0	-1/2
bc^*	H	$(1,2)$	0	-1	-1	0	1/2

Table 3: Chiral spectrum of the SUSY's SM obtained from the above wrapping numbers with $U^1 = U^2 = U^3/2$.

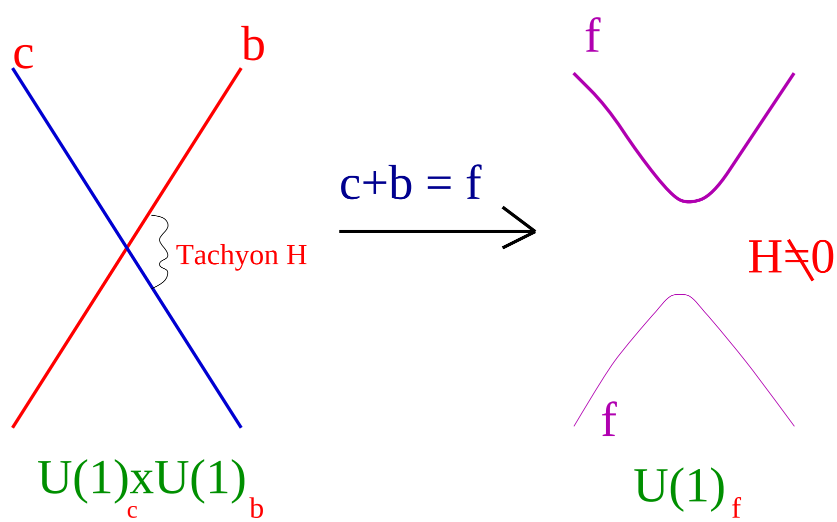
- The model is not fully $N=1$ SUSY because to cancel RR-tadpoles additional $N=0$ sectors (with no intersection with SM ones) have to be added.
- Due to these additional $N=0$ sectors the model looks somewhat like a gauge mediated SUSY-breaking model.
- There is an additional $U(1)_{B-L}$.

Higgs mechanism and brane recombination

❶ Brane separation = Adjoint Higgsing Does not lower the rank.



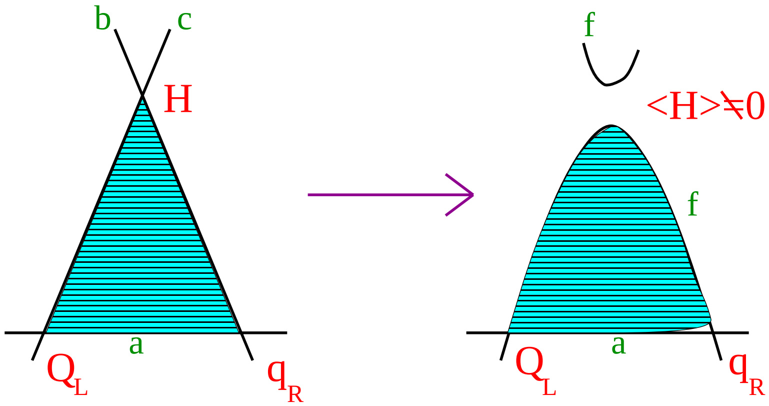
❷ Brane recombination lowers the rank



In SM the rank is lowered $\rightarrow$ brane recombination of the branes b and $c(c^*)$ at which intersection the Higgs scalars lie.

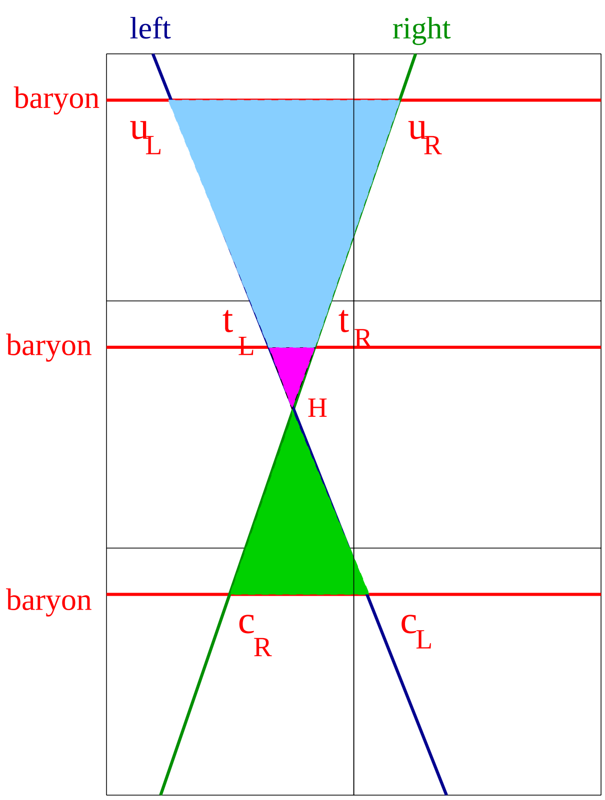
Hierarchical Yukawa couplings

- Yukawa couplings come from triangular worldsheets



$Y = \exp(-\text{Area})$ $\quad$ $m = \langle H \rangle \exp(-\text{Area})$

- Different distance to Higgs field gives rise to hierarchical Yukawas (Aldazabal, Franco, L.I., Rabadan, Uranga, hep-ph/0011132).



$m_t >> m_c >> m_u$

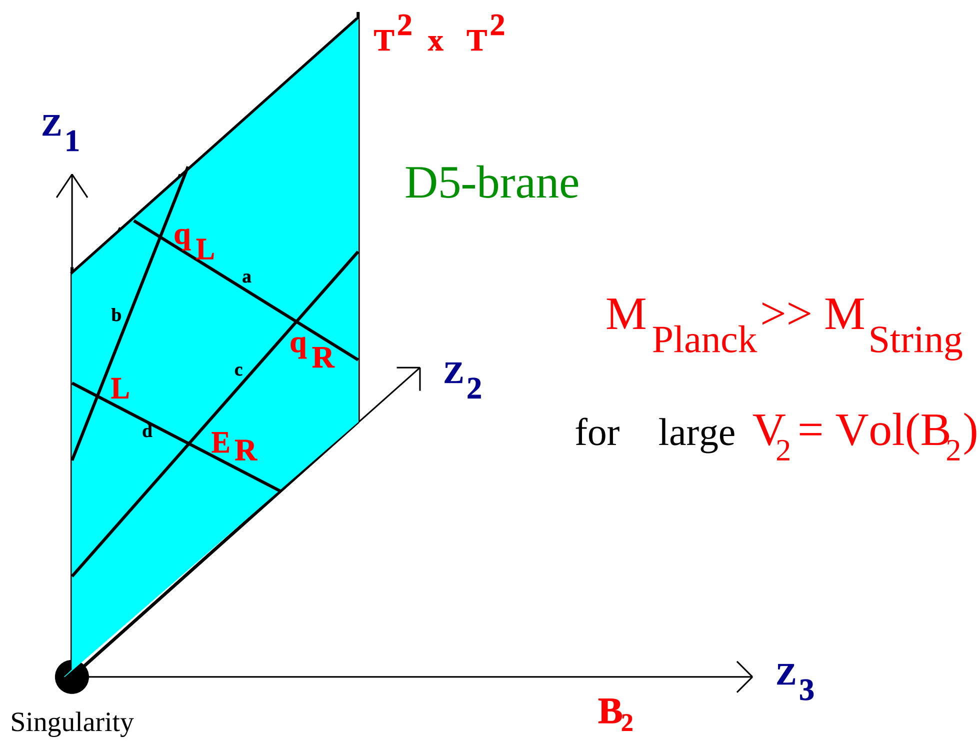
Getting $M_{Planck} >> M_{string}$

Non-SUSY models: To avoid hierarchy problem one should have $M_s \propto 1$ TeV (Arkani-Hamed,Dimopoulos, Dvali)

❶ D6-branes The A-D-D approach for $M_{Planck} >> M_{string}$ by making transverse volume large not possible: no tori direction transverse to all D6-branes simultaneously. CY? Warping?

❷ D5-branes Analogous intersecting models can be built yielding just the SM fermion spectrum. These are Type IIB compactified on e.g., $T^2 \times T^2 \times (T^2/Z_N)$ with D5-branes wrapping 2-cycles on $T^2 \times T^2$. In this case

$$M_{Planck} = M^2_{string} \frac{1}{\lambda} \sqrt{V_2}$$



Gauge coupling constants

$$SU(3) \times SU(2) \times \; U(1)_a \times U(1)_b \times U(1)_c \times U(1)_d$$

- Gauge couplings are not unified :

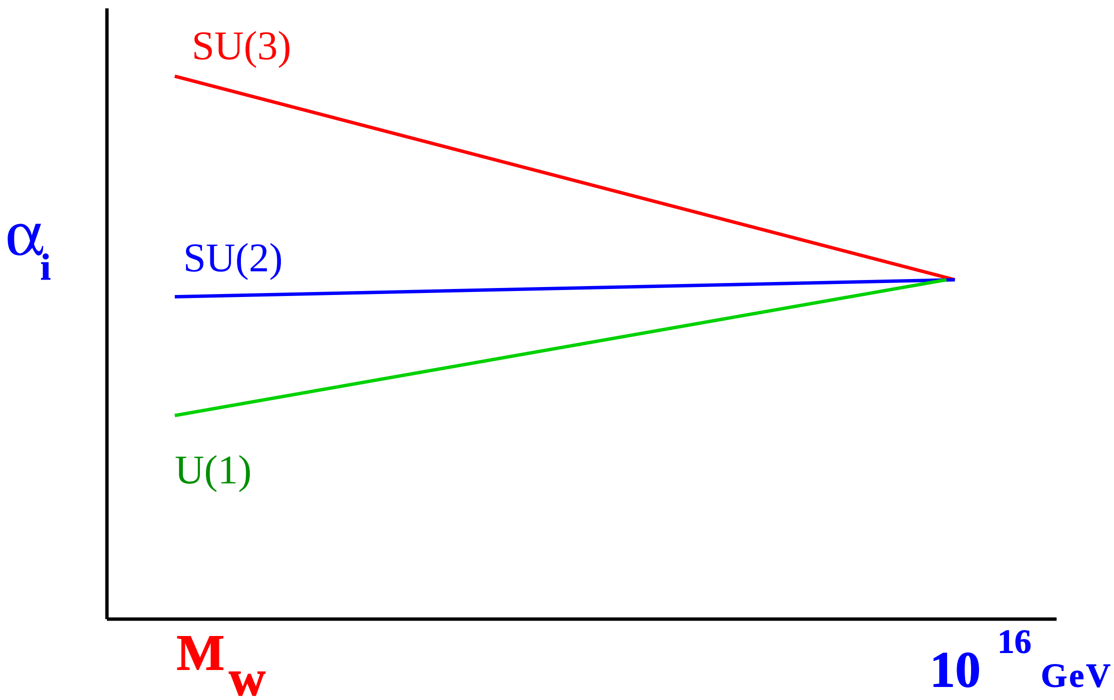
$$\frac{1}{g_i^2} = \frac{M_s^3}{(2\pi)^4 \lambda} \mathrm{Vol}(\Pi_i) \; ; \;\; i = a, b, c, d \tag{10}$$

$\mathrm{Vol}(\Pi_i)$ being the volume each D6-brane is wrapping.

- Thus, e.g., $SU(3)$ interactions are stronger than $SU(2)$ because 'baryonic' branes wrap less volume than 'left' branes
- There are 6 groups but only 4 couplings $\Rightarrow$ There are some relationships :

$$g_a^2 = \frac{g_{QCD}^2}{6} \; ; \; g_b^2 = \frac{g_L^2}{4} \; ; \; \frac{1}{g_Y^2} = \frac{1}{36 g_a^2} + \frac{1}{4 g_c^2} + \frac{1}{4 g_d^2} . \tag{11}$$

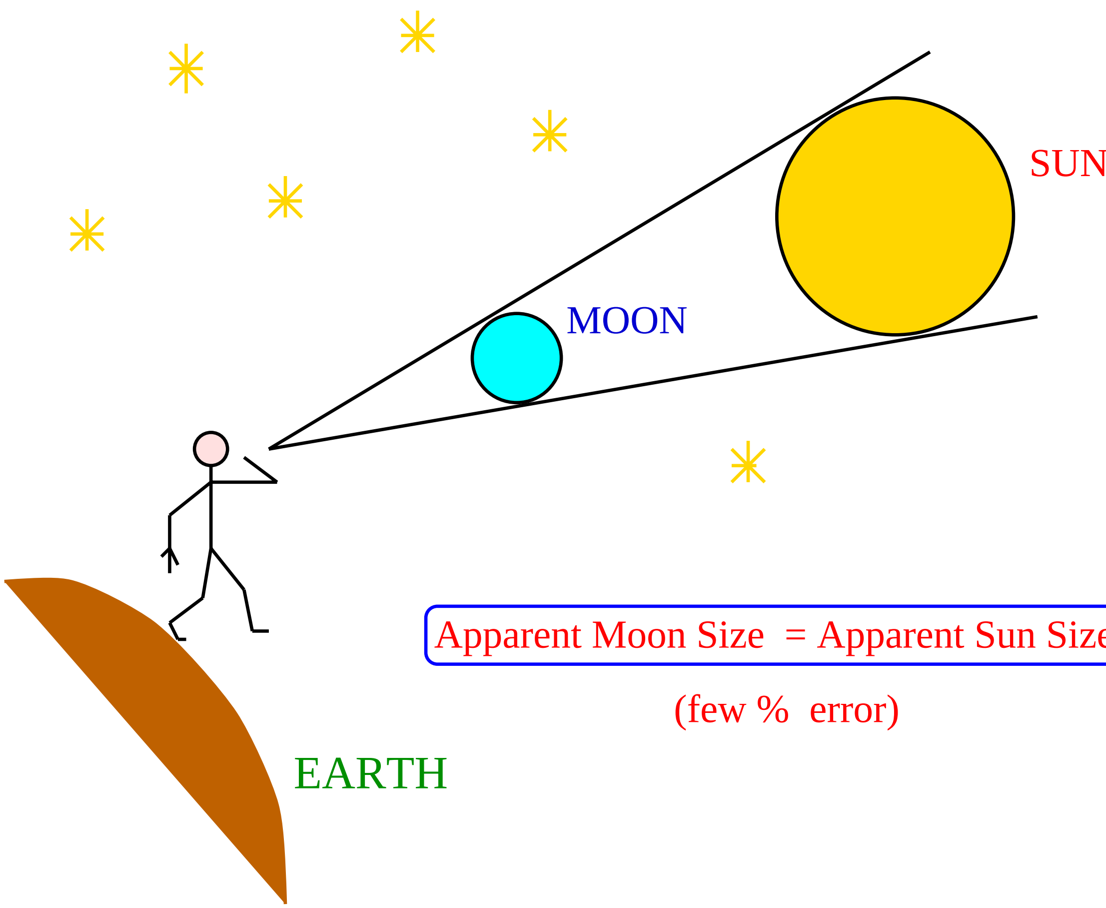
The MSSM gauge coupling unification



Minimal SUSY-SM: COUPLINGS UNIFY (within a few % error)

Do not forget that up to now nobody has constructed a string compactification in which the MSSM unification takes place!!

Is Nature cheating us?



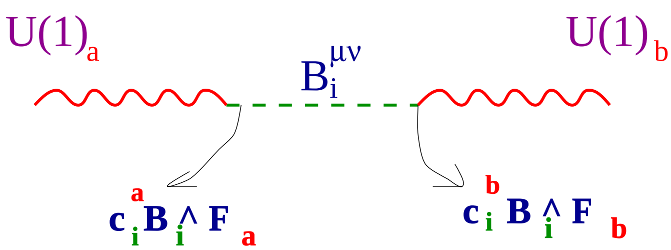
Apparent Moon Size = Apparent Sun Size

(few % error)

Whoever cheats once may cheat twice!!

TeV-Scale Z' Bosons from D-branes

- There
  is quite a generic structure of extra $U(1)$'s. They are NOT of E_6 type:
  $$(B-L)\ ;\ I_R\ ;\ (3B+L)\ ;\ Q_b$$
- If $M_s \propto 1 - 10$ TeV , could perhaps be tested at present/future accelerators
- Extra Z's get masses by combining with RR string fields $B_i^{\mu\nu}$



$$M^2_{ab} = \sum_i g_a g_b c_i^a c_i^b M^2_{string}$$

- Four Eigenvalues = $(0, M_2, M_3, M_4)$. In D5, D6-brane models one finds typically at least one of them $M_3 < \frac{1}{3} M_{string}$
- Three massive Z's mix with SM Z^0 . One can put constraints on M_i from the ρ-parameter. (D. Ghilencea, L.I., N. Irges, F.Quevedo, hep-ph/0205083.)

Baryon and lepton number violation

- Baryon number is a gauge symmetry. So the proton is automatically stable. (Baryogenesis should take place non-perturbatively).
- Lepton number is also a gauge symmetry. But may be spontaneously broken (e.g. $\tilde{\nu}_R$ vevs.). In the first case only Dirac masses. In the second case Majorana masses of order M_{string} possible.

CONCLUSIONS

❶ Intersecting D-brane constructions provide for an understanding from the string theory point of view of questions like

- chirality
- family triplication
- proton stability

❷ Certain phenomena of the SM have a geometrical interpretation:

- Hierarchical Yukawas come from the different areas of triangles connecting the Higgs with left and right fermions.
- Different sizes of gauge couplings come from different volumes wrapped by the different branes.
- The SM Higgs mechanism has a geometrical interpretation as brane recombination

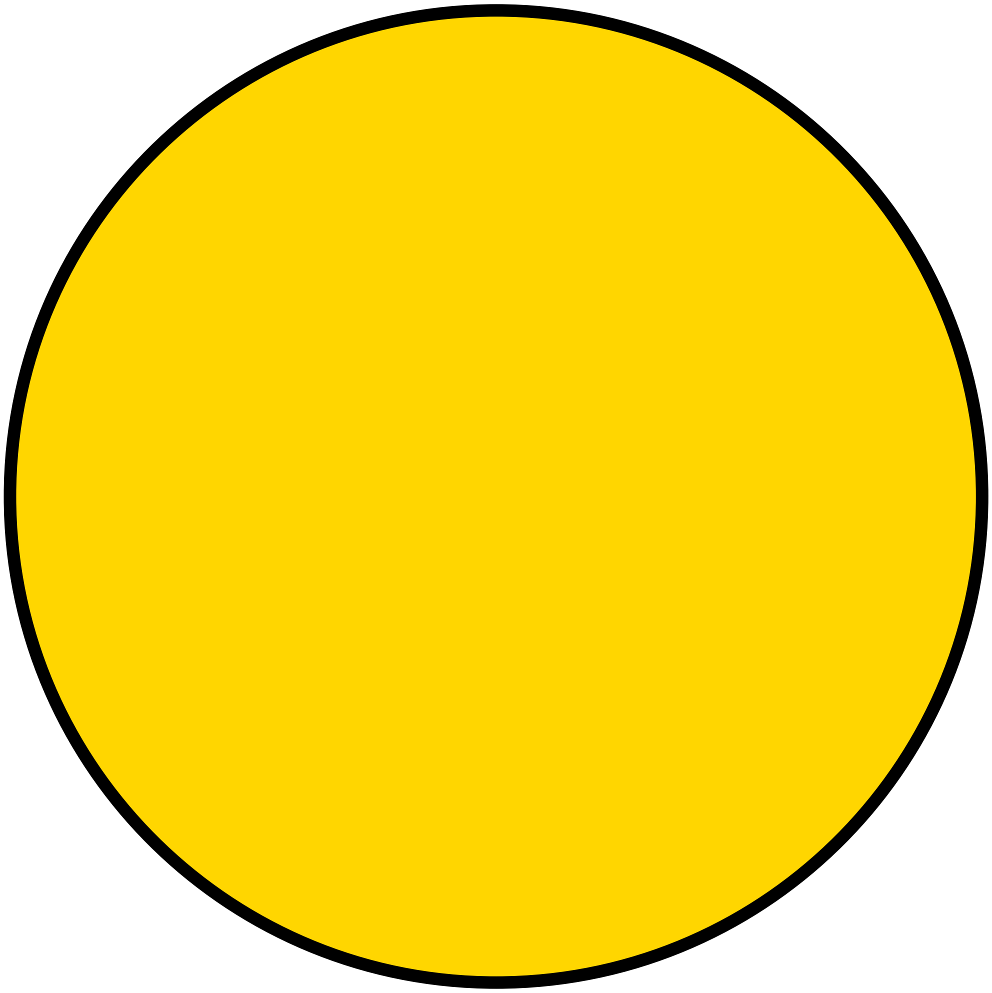
❸ We have constructed classes of Intersecting D6 and D5-brane models wrapping toroidal compactifications in (orientifolded) Type II strings.

- The minimal intersecting D-brane SM constructions are obtained from 4 stacks of branes: Baryonic, Leptonic, Left and Right.
- Some classes of $D6$ and $D5$ brane models provide the first explicit string constructions with just the fermions of the SM and gauge group $SU(3) \times SU(2) \times U(1)_Y$.

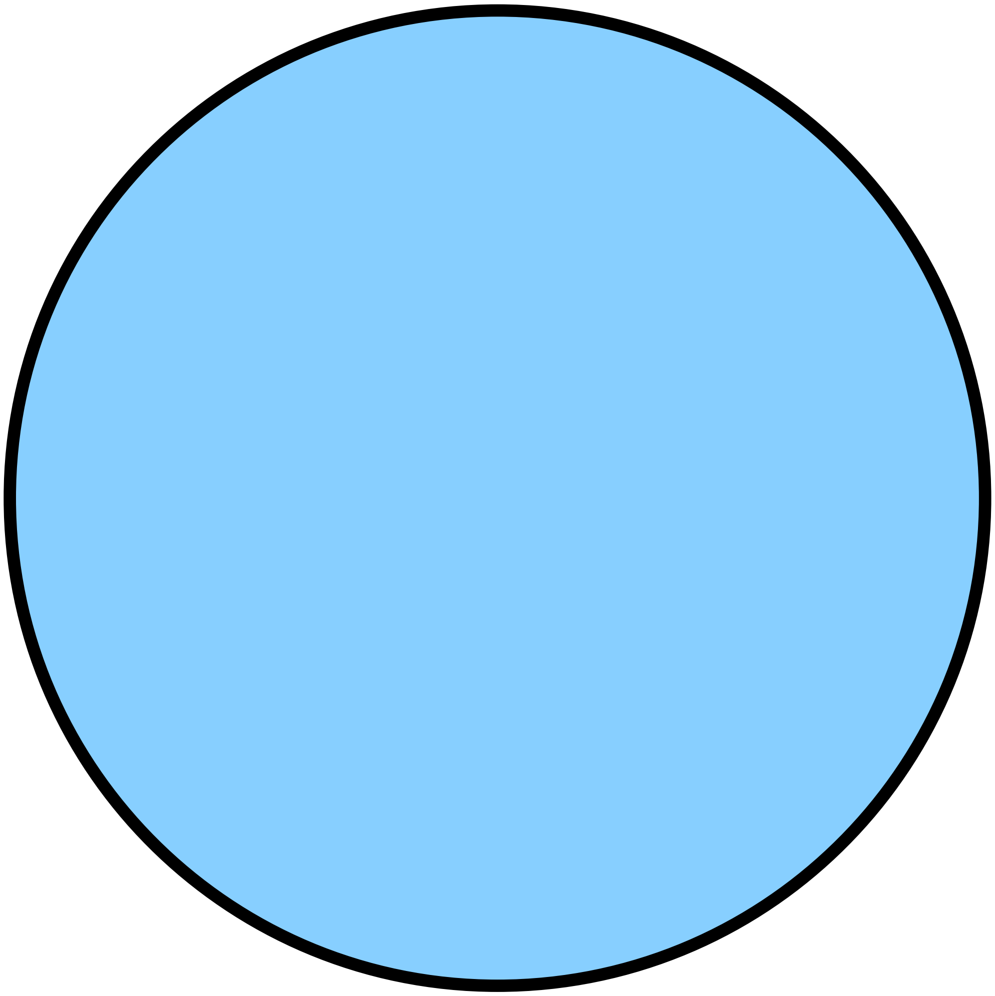
- The SM intersection numbers are topological in character and may appear in general D-brane configurations wrapping e.g., CY-compactifications.
- It is also possible to find D6-brane configurations with the chiral spectrum of the MSSM, although there is also a massive $N = 0$ sector in these toroidal examples.
- Note that these ideas are not necesarily tied up to a low string scale scenario.

some homework...

- New configurations of Dp-branes wrapping general cycles of e.g., CY_3 and same intersection structure. (R. Blumenhagen, V. Braun, B. Körs, D. Lüst, hep-th/0206038; Angel Uranga, to appear)
- Stability of configurations. The models discussed are non-SUSY and generically have NS-tadpoles. Look for stabilized vacua (e.g. with antisymmetric tensor fluxes).
- Build $N = 1$ models (see Cvetic,Shiu, Uranga hep-th/0107143).
- Phenomenology of $D6$ and $D5$ models :
  - Try to reproduce quark/lepton masses and mixings from hierarchical Yukawas.
  - Study of signatures of three 'canonical' extra Z's.
- ....



SUN



MOON