Particle Physics &String Theory: Type II/F-Theory Perspective

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Outline:

Focus on particle physics & D-branes:

I. Type II (w/ D-branes at small string coupling)

→ Standard Model & GUT's

Recent developments: Non-perturbative effects (D-instantons)

→ new hierarchy for couplings

II. F-theory (string theory w/ D-branes at finite coupling)

→ primarily (local) SU(5) GUT's — c.f. J. Heckman's talk

→ instantons — time permitting

III. Conclusions/outlook

I. Particle Physics implications (Type II):

Recent focus: landscape of realistic D-brane quivers w/ D-instantons

String Consistent MSSM Quivers w/ realistic fermion textures

M.C., J. Halverson, R. Richter; & P. Langacker '09-'10

Most MSSM Quivers-string inconsistent

What are the simplest extensions?

With no additional nodes:

landscape analysis all MSSM quivers & additional matter

(compatible with string constraints) → stringy inputs on exotic matter

M.C., J. Halverson & P. Langaceker, 1108.5187

With additional U(1)'s or U(N) node:

implications for SUSY breaking, dark matter, Z'

M.C., J. Halverson & H. Piragua, to appear

II. D-instantons – formal developments

No time

Recent focus on F-theory (finite string coupling)

→ multi pronged approach:

(a) string junctions

(b) anomaly inflow

(c) via dualities (F-theory/Heterotic; F-theory/M-theory)

Goals: Zero modes and superpotential structure (Pfaffians): →

Pfaffians via heterotic duality:

Geometric interpretation of zero loci (including E8 symmetric point)

M.C., I. Garcia-Etxebarria & J. Halverson, 1107.2388

Inclusion of fluxes & direct F-theory results

M.C., R. Donagi, J. Halverson & J. Marsano, to appear

Superpotential via N=2 D=3 M-theory

M.C., T. Grimm, J. Halverson & D. Klevers, to appear

Perturbative String Theories → (finite) theory of quantum gravity

Green&Schwarz'84

Phenomenologically promising

Recent (MSSM): Bouchard,M.C., Donagi'05

....Anderson,Gray,Lukas`09-'12

Lebedev,Nilles,Raby,Ramos,Ratz Vaudrevange,Wingerter'07-'10

Heterotic $E_8 x E_8$ string

Type IIA superstring
(closed)

Type IIB superstring
(closed)

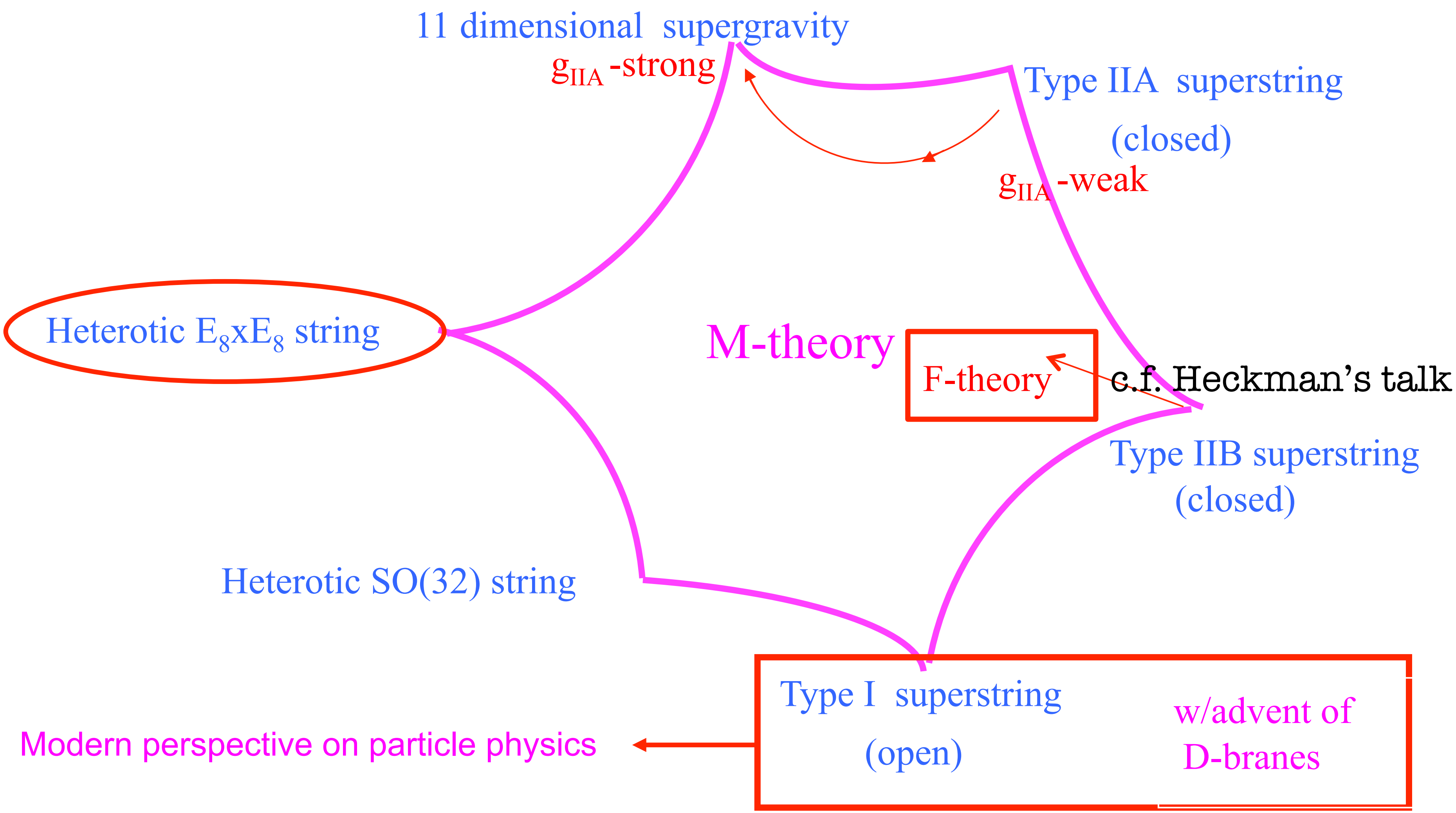
Heterotic SO(32) string

Type I superstring
(open)

Perturbative String Theories → (finite) theory of quantum gravity

Hull&Townsend'94
Witten'95

Non-perturbative Unification



Different String Theories related to each other by Weak-Strong Coupling DUALITY

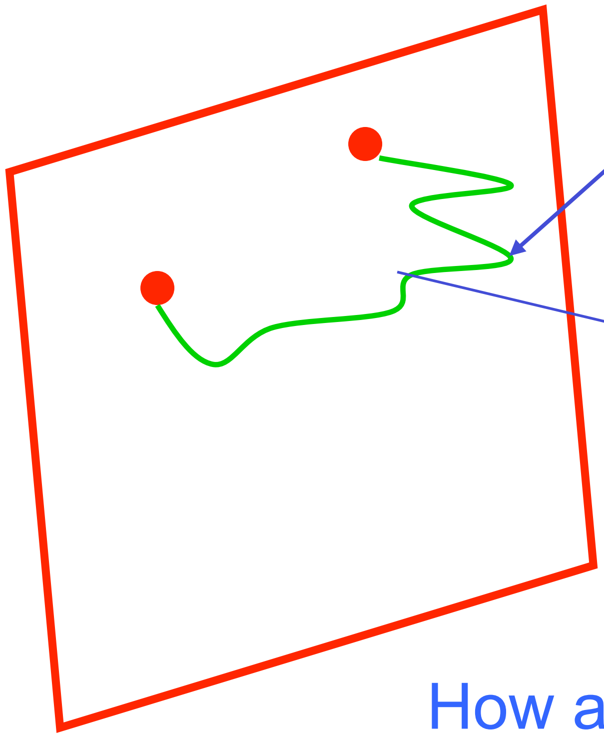
D-branes & Particle Physics →

Beautiful relation to particles & forces of nature - geometric

Open strings w/ charges at the ends

Ends ``attached " to boundary **Dp – branes** Polchinski'95

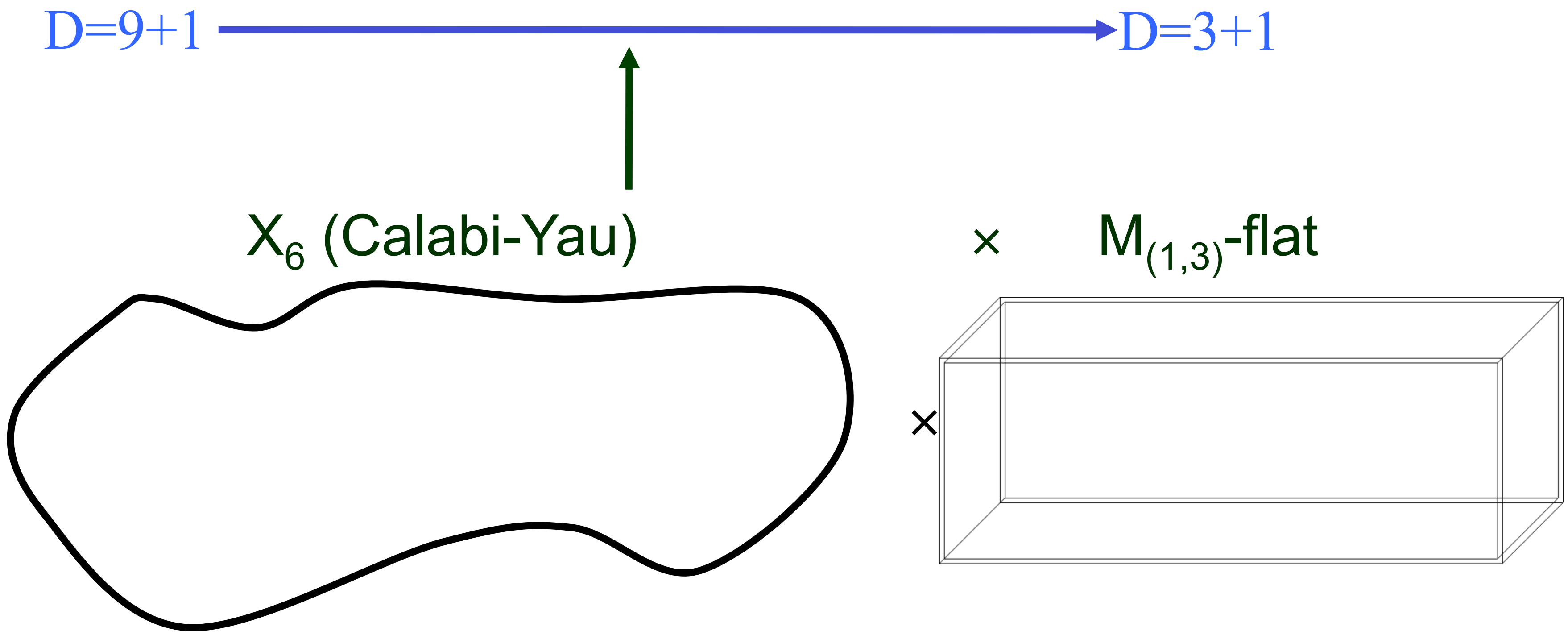
Extends in p+1 dim. world-volume



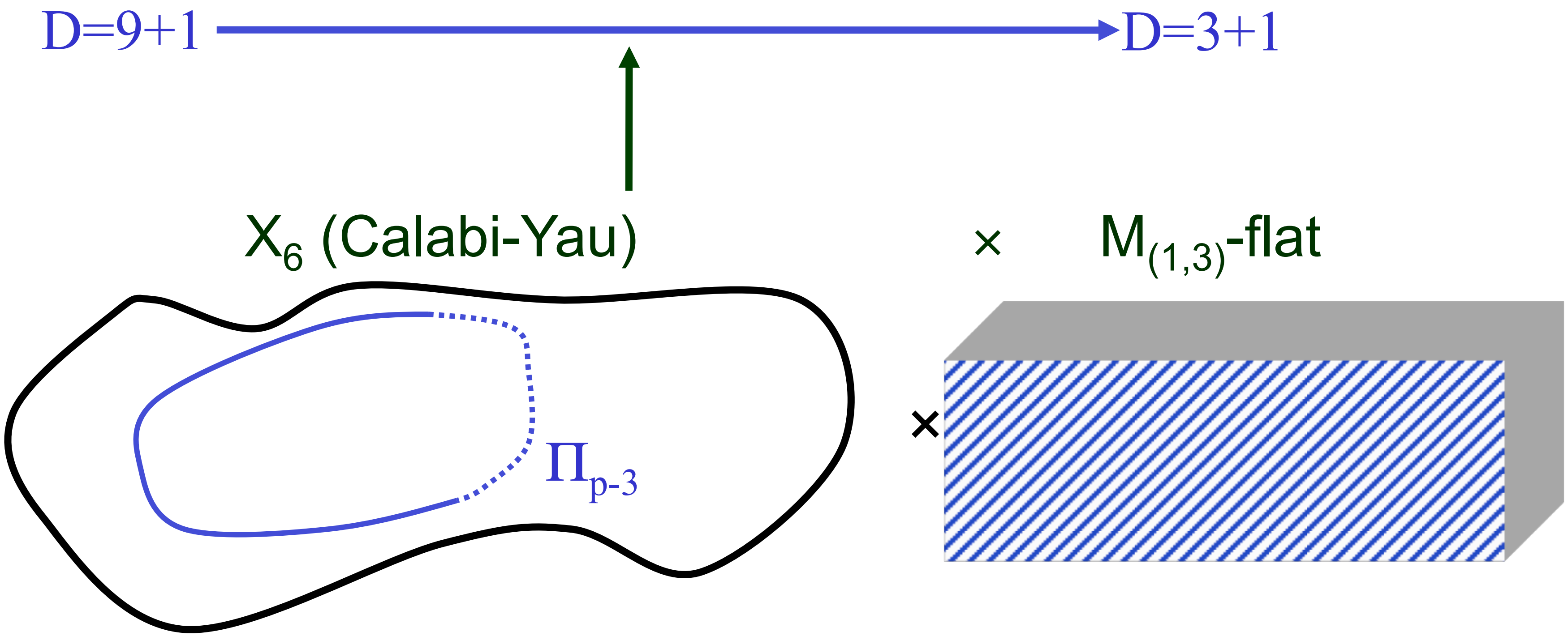
Quantum theory-string excitations result in MASSLESS spin -1 Gauge bosons →
Photon, gluon, W,Z-bosons live on the D-branes!

How about matter → compactification

Compactification



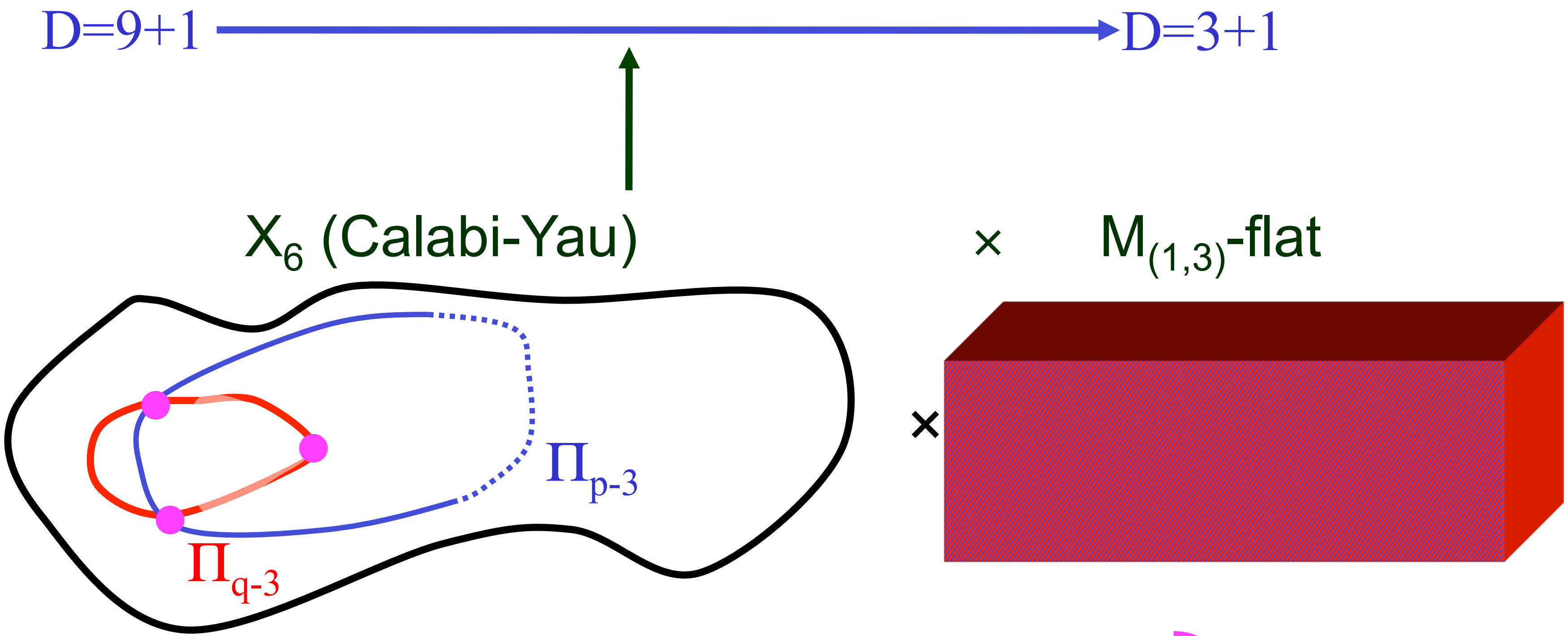
Compactification



D p-branes – extend in p+1 dimensions:

3+1-our world $M_{(3,1)}$;(p-3)-wrap Π_{p-3} cycles of X_6

Compactification



D p-branes – extend in p+1 dimensions:
3+1-our world $M_{(3,1)}$;(p-3)-wrap Π_{p-3} cycles of X_6

D q-branes – extend in q+1 dimensions:
3+1-our world $M_{(3,1)}$;(q-3)-wrap Π_{q-3} cycles of X_6

$\Pi_{q-3} \cap \Pi_{p-3}$
Two sets of D-branes typically Intersect at # of points

matter at each intersection → family replication   Geometric!

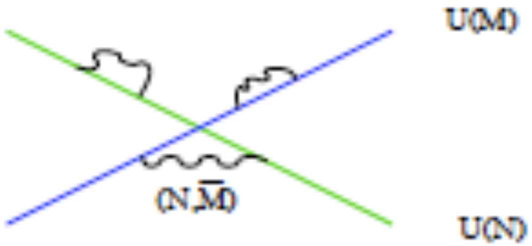
Type II w/ D-branes →

fertile ground for particle physics model building

[Pedagogical review: TASI'10 lectures, M.C., Halverson arXiv:1101.2907]

Type IIA w/intersecting D-branes → key features of SM & SU(5) GUT spectrum: non-Abelian gauge symmetry, chirality & family replication

Geometric



Representation	Multiplicity
$(\overline{a}, b)$	$\pi_a \circ \pi_b$
$(\overline{a}, \overline{b})$	$\pi_a \circ \pi_b'$
$\Box\!\Box_a$ (antisymmetric)	$\frac{1}{2}(\pi_a' \circ \pi_a + \pi_{O6} \circ \pi_a)$
$\Box\Box_a$ (symmetric)	$\frac{1}{2}(\pi_a' \circ \pi_a - \pi_{O6} \circ \pi_a)$

In addition global consistency : Gauss's law for D-brane charge on internal space.→ stringy

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Large classes (order of 100's) of globally consistent supersymmetric,SM-like & GUT constructions; also couplings

[M.C. ,Shiu, Uranga'01]...

[M.C. Papadimitriou '03],
[Cremades, Ibáñez, Marchesano'03]...

Recent developments:

New types of D-instantons: introduced to generate certain perturbatively absent couplings for charged sector matter

[Blumenhagen,M.C.,Weigand, hep-th/0609191]
[Ibañez,Uranga, hep-th/0609213]

- charged matter coupling corrections

. . .

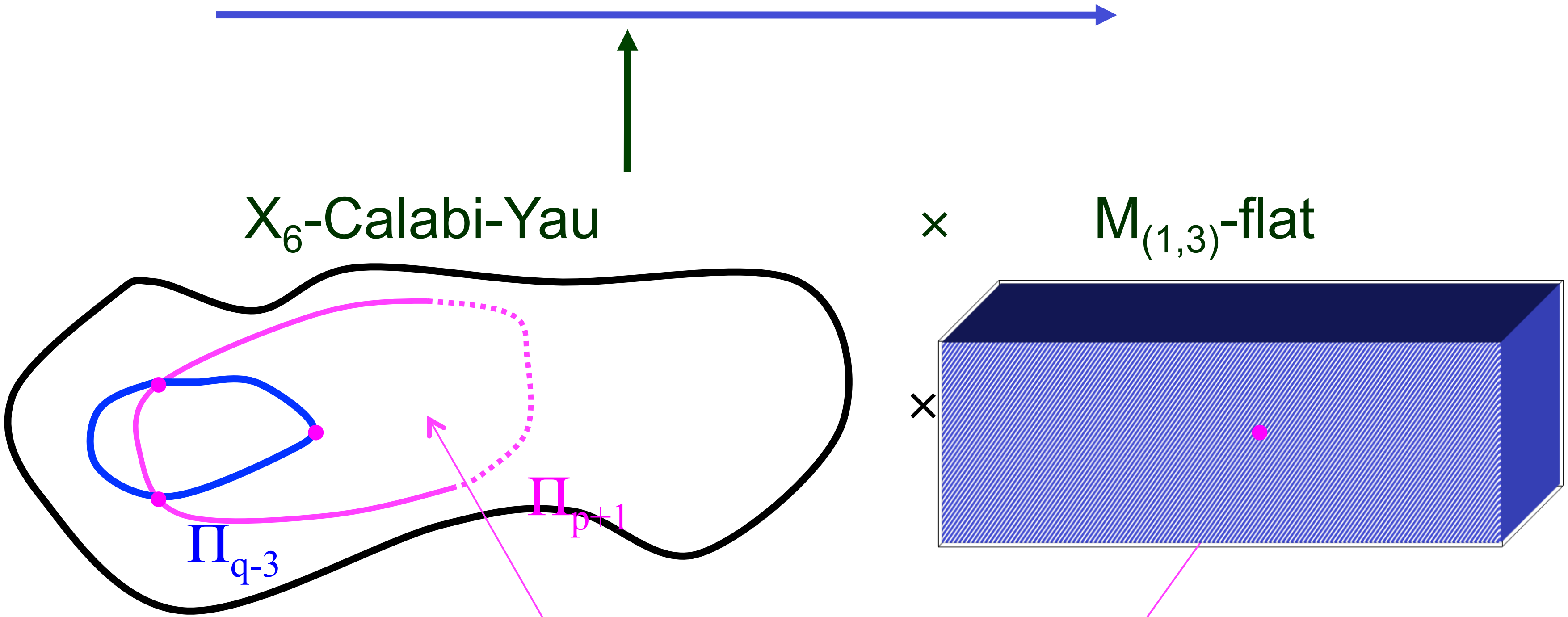
[Florea,Kachru,McGreevy,Saulina, 0610003]

- supersymmetry breaking

Review: [Blumenhagen, M.C., Kachru, Weigand, 0902.3251]

Encoded in non-perturbative violation of ``anomalous'' U(1)'s

D-Instanton - Euclidean D-brane background



Wraps cycle Π_{p+1} cycles of X_6 point-in 3+1 space-time

New geometric hierarchies for couplings:

$$\mathcal{R}e\left(e^{-S_{E2}}\right) = e^{-\frac{2\pi}{\ell_s^3\, g_s}\mathrm{Vol}_{E2}} = e^{-\frac{2\pi}{\alpha_{\mathrm{GUT}}}\frac{\mathrm{Vol}_{E2}}{\mathrm{Vol}_{D6}}}$$

stringy!

Instanton can intersect with physical D-brane (charged zero modes)

→ generate non-perturbative couplings of charged matter

Specific Examples:

i Majorana neutrino masses original papers,...

ii Nonpert. Dirac neutrino masses [M.C.,Langacker, 0803.2876]

iii 10 10 5 GUT couplings

[Blumenhagen,M.C.,Lüst,Richter,Weigand,0707.1871]

one-instanton effect $\longrightarrow g_s \rightarrow 1$ (M-theory on G_2)

iv Polonyi-type couplings $\longrightarrow$

[Aharony,Kachru,Silverstein 0708.0493] [MC,Weigand 0711.0209,0807.3953]
[Heckman,Marsano,Saulina,Schafer-Nameki,Vafa 0808.1286] ...

Examples of such instanton induced hierarchical couplings primarily for local Type IIA toroidal orbifolds SU(5) GUT's

↓

Challenge: global models → Type I/IIB/F-theory (algebr. geom.)

i. Type I GUT's on compact elliptically fibered Calabi-Yau
First global chiral (four-family) SU(5) GUT's w/ D-instanton generated Polonyi & Majorana neutrino masses
[M.C., T.Weigand,0711.0209,0807.3953]

ii. Global Type IIB GUT's : 1010 5_H non-perturbative coupling
(two family) SU(5) GUT on CY as hypersurface in toric variety
[Blumenhagen,Grimm,Jurke,Weigand, 0811.2938]

iii. Global F-theory lift [M.C., I. Garcia-Etxebarria, J. Halverson,003.5337]
[Develop a code to calculate zero modes/spectrum in Type IIB and F-theory on toric varieties; code w/ new efficient technique →
[Blumenhagen, Jurke, Rahn & Roschy, 1003.5217]]

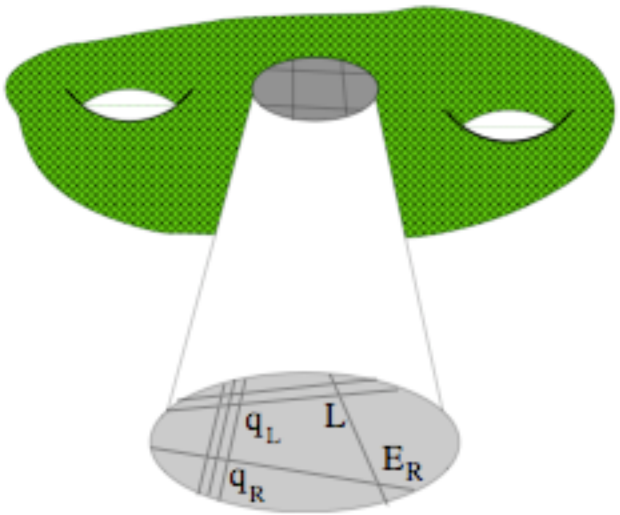
Most examples w/ O (1) instantons addressed SU(5) GUT's

How about directly Standard Model?

Adressed for local Madrid quiver [Ibanez,Richter, 0811.1583] →

Systematic Analysis of D-Instanton effects for MSSM's quivers

(compatible with global constraints)



Landscape analysis of MSSM w/ realistic fermion textures

[M.C., J. Halverson, R. Richter, 0905.3379; 0909.4292; 0910.2239]

Stringy Weinberg operator neutrino masses (examples of low string scale)

[M.C., J. Halverson, P. Langacker, R. Richter, 1001.3148]

Singlet-extended MSSM landscape

[M.C. J. Halverson, P. Langacker, 1006.3341]

Bottom-up approach initiated [Aldazabal,Ibanez,Quevedo,Uranga'00]..

Related recent works: Specific 3-stack [Leontaris, 0903.3691]

Madrid quiver [Anastasopoulos, Kiritsis, Lionetto, 0905.3044]

SU(5) GUT's [Kiritsis, Lennek, Schellekens, 0909.0271]...

MSSM at toric singularities: [Krippendorf, Dolan,Maharana,Quevedo,1002.1790, 1106.6039]

Approach: Bottom-up quivers

Spectrum and couplings geometric ➡
efficient classification of key physics
[compatible w/ global constraints →stringy, but without delving into specifics of globally defined string compactifications]

Quiver data: massless spectrum &
examination of couplings
[both perturbative & non-perturbative-instantons]

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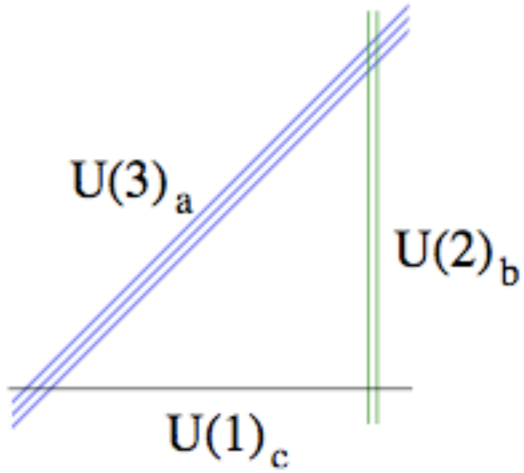
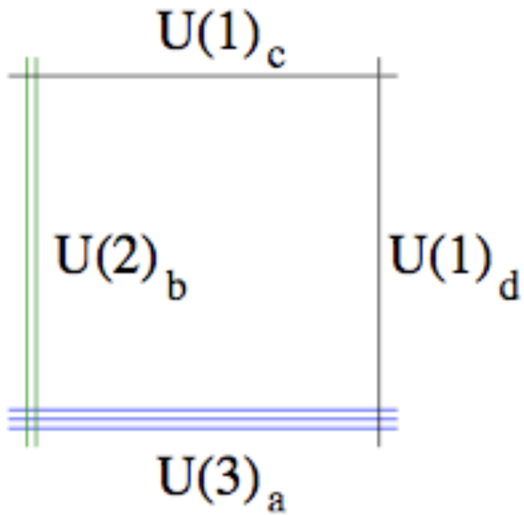
Probe ``quiver landscape''
to identify realistic quivers in the landscape of string vacua

Multi-stack MSSM quivers

Employ three-stack MSSM $U(3)_a \times U(2)_b \times U(1)_c$



& four-stack MSSM $U(3)_a \times U(2)_b \times U(1)_c \times U(1)_d$



five-stack….

Four-stack set of MSSM models w/ 3 N_R & potentially viable fermion textures

[M.C., J. Halverson, R. Richter, 0905.3379]

Solution #	q_L		d_R			u_R		L			E_R			N_R				H_u				H_d
	(a,b)	$(a,\bar{b})$	$(\bar{a},c)$	$(\bar{a},\bar{d})$	$\ulcorner_a$	$(\bar{a},\bar{c})$	$(\bar{a},d)$	$(b,\bar{c})$	(b,d)	$(\bar{b},d)$	$(c,\bar{d})$	$\bot\!\bot_c$	$\sqcup\!\sqcup_d$	$\urcorner_b$	$\sqcap_b$	(c,d)	$(\bar{c},\bar{d})$	(b,c)	$(\bar{b},c)$	$(b,\bar{d})$	$(\bar{b},\bar{d})$	$(\bar{b},\bar{c})$
1	3	0	3	0	0	0	3	0	0	3	0	0	3	2	0	0	1	0	0	0	1	1
2	3	0	2	0	1	0	3	0	0	3	0	0	3	2	0	0	1	0	0	0	1	1
3	3	0	1	0	2	0	3	0	0	3	0	0	3	2	0	0	1	0	0	0	1	1
4	3	0	0	0	3	0	3	0	0	3	0	0	3	2	0	0	1	0	0	0	1	1
5	3	0	0	0	3	0	3	0	0	3	0	0	3	3	0	0	0	1	0	0	0	1
6	3	0	3	0	0	2	1	0	0	3	0	2	1	2	0	1	0	0	0	0	1	1
7	3	0	3	0	0	3	0	0	0	3	2	1	0	2	0	0	1	0	1	0	0	1
8	3	0	3	0	0	3	0	0	0	3	0	2	1	2	0	0	1	0	1	0	0	1
9	3	0	3	0	0	3	0	0	0	3	1	2	0	2	0	1	0	0	1	0	0	1
10	2	1	3	0	0	1	2	0	0	3	0	0	3	0	0	0	3	1	0	0	0	1
11	2	1	3	0	0	1	2	0	0	3	3	0	0	0	0	3	0	1	0	0	0	1
12	2	1	3	0	0	3	0	0	0	3	3	0	0	0	0	0	3	1	0	0	0	1
13	2	1	3	0	0	3	0	0	1	2	3	0	0	0	0	0	3	0	1	0	0	1
14	1	2	3	0	0	3	0	0	3	0	3	0	0	0	0	0	3	1	0	0	0	1
15	0	3	0	3	0	0	3	3	0	0	0	1	2	0	3	0	0	0	0	1	0	1
16	0	3	0	0	3	0	3	0	3	0	0	0	3	0	3	0	0	1	0	0	0	1
17	0	3	0	0	3	0	3	1	2	0	1	0	2	0	3	0	0	0	0	1	0	1
18	0	3	0	0	3	0	3	3	0	0	2	0	1	0	3	0	0	0	0	1	0	1
19	0	3	0	0	3	0	3	3	0	0	0	1	2	0	3	0	0	0	0	1	0	1
20	0	3	0	0	3	1	2	1	2	0	2	0	1	0	3	0	0	1	0	0	0	1
21	0	3	0	0	3	1	2	1	2	0	0	1	2	0	3	0	0	1	0	0	0	1
22	0	3	0	0	3	1	2	3	0	0	3	0	0	0	3	0	0	1	0	0	0	1
23	0	3	0	0	3	1	2	3	0	0	1	1	1	0	3	0	0	1	0	0	0	1
24	0	3	0	0	3	2	1	0	3	0	3	0	0	0	3	0	0	1	0	0	0	1
25	0	3	0	0	3	2	1	0	3	0	1	1	1	0	3	0	0	1	0	0	0	1
26	0	3	0	0	3	2	1	2	1	0	2	1	0	0	3	0	0	1	0	0	0	1
27	0	3	0	0	3	2	1	2	1	0	0	2	1	0	3	0	0	1	0	0	0	1
28	0	3	0	3	0	3	0	3	0	0	0	3	0	0	3	0	0	1	0	0	0	1
29	0	3	0	2	1	3	0	3	0	0	0	3	0	0	3	0	0	1	0	0	0	1
30	0	3	0	1	2	3	0	3	0	0	0	3	0	0	3	0	0	1	0	0	0	1
31	0	3	0	0	3	3	0	1	2	0	1	2	0	0	3	0	0	1	0	0	0	1

Solutions for hypercharge $U(1)_Y = \frac{1}{6}U(1)_a + \frac{1}{2}U(1)_c - \frac{1}{2}U(1)_d$ - Madrid embedding

Concrete 5-stack model (benchmark)

(w/ three mass scales in top, bottom in charged lepton sector)

Sector	Matter Fields	Transformation	Multiplicity	Hypercharge
ab	q_L	$(a, \bar{b})$	1	$\frac{1}{6}$
ab'	q_L	(a, b)	2	$\frac{1}{6}$
ac'	u_R	$(\bar{a}, \bar{c})$	2	$-\frac{2}{3}$
ad'	u_R	$(\bar{a}, \bar{d})$	1	$-\frac{2}{3}$
aa'	d_R	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_a$	3	$\frac{1}{3}$
bc'	H_u	(b, c)	1	$\frac{1}{2}$
bd'	L	$(\bar{b}, \bar{d})$	3	$-\frac{1}{2}$
be'	H_d	$(\bar{b}, \bar{e})$	1	$\frac{1}{2}$
ce'	E_R	(c, e)	2	1
ce	N_R	$(\bar{c}, e)$	1	0
dd'	E_R	$\Box\Box_d$	1	1
de	N_R	$(\bar{d}, e)$	2	0

Allows for full (inter- & intra-) family mass hierarchy via ``factorization of Yukawa matrices'' due to vector-pairs of zero fermion modes-stringy (technical, no time)

Recent: String constraints & matter beyond the MSSM

[M.C., J. Halverson, P. Langacker,1108.5387]

I. Classify ALL possible MSSM quivers (three & four stacks) irrespective of global conditions → most quivers inconsistent

What is additional matter to be compatible w/ global constraints?

→ stringy inputs on exotic matter

3-stack analysis: global conditions ($T_{a,b,c}$=0) constraining, e.g., MSSM w/

$$U(1)_Y = \frac{1}{6}U(1)_a + \frac{1}{2}U(1)_c \quad T_a = 0 \quad T_b = \pm 2n \quad T_c = 0\, mod\, 3 \quad \text{with } n \in \{0, \ldots, 7\},$$

w/ preferred additions: quasi-chiral Higgs pairs, MSSM singlets
hypercharge-less SU(2) triplets,&
various quark anti-quark pairs, all w/ integer el. ch.;
one (massless) Z' quiver

4-stack analysis: richer structure
sizable number of quivers w/ Z', including leptophobic (tuned);
additional structures: possible $SH_{\underline{u}}H_{d,;}$ ν-masses;
exotics w/ fractional el. ch. …

Possible additions

Transformation		T_a	T_b	T_c	M_a	M_b	M_c
$\Box\Box_a$	$(6,1)_{\frac{1}{3}}$	7	0	0	$-\frac{1}{2}$	0	0
$\overline{\Box\Box}_a$	$(\overline{6},1)_{-\frac{1}{3}}$	−7	0	0	$\frac{1}{2}$	0	0
$\genfrac{}{}{0pt}{}{\Box}{\Box}_a$	$(\overline{3},1)_{\frac{1}{3}}$	−1	0	0	$-\frac{1}{2}$	0	0
$\overline{\genfrac{}{}{0pt}{}{\Box}{\Box}}_a$	$(3,1)_{-\frac{1}{3}}$	1	0	0	$\frac{1}{2}$	0	0
$\Box\Box_b$	$(1,3)_0$	0	6	0	0	0	0
$\overline{\Box\Box}_b$	$(1,3)_0$	0	−6	0	0	0	0
$\genfrac{}{}{0pt}{}{\Box}{\Box}_b$	$(1,1)_0$	0	−2	0	0	0	0
$\overline{\genfrac{}{}{0pt}{}{\Box}{\Box}}_b$	$(1,1)_0$	0	2	0	0	0	0
$(\overline{b},c)$	$(1,2)_{\frac{1}{2}}$	0	−1	2	0	$-\frac{1}{2}$	$-\frac{1}{3}$
$(b,\overline{c})$	$(1,2)_{-\frac{1}{2}}$	0	1	−2	0	$\frac{1}{2}$	$\frac{1}{3}$
(b,c)	$(1,2)_{\frac{1}{2}}$	0	1	2	0	$-\frac{1}{2}$	$-\frac{1}{3}$
$(\overline{b},\overline{c})$	$(1,2)_{-\frac{1}{2}}$	0	−1	−2	0	$\frac{1}{2}$	$\frac{1}{3}$
$\Box\Box_c$	$(1,1)_1$	0	0	5	0	0	$-\frac{4}{3}$
$\overline{\Box\Box}_c$	$(1,1)_{-1}$	0	0	−5	0	0	$\frac{4}{3}$
$(a,\overline{b})$	$(3,2)_{\frac{1}{6}}$	2	−3	0	0	$-\frac{1}{2}$	0
$(\overline{a},b)$	$(\overline{3},2)_{-\frac{1}{6}}$	−2	3	0	0	$\frac{1}{2}$	0
(a,b)	$(3,2)_{\frac{1}{6}}$	2	3	0	0	$-\frac{1}{2}$	0
$(\overline{a},\overline{b})$	$(\overline{3},2)_{-\frac{1}{6}}$	−2	−3	0	0	$\frac{1}{2}$	0
$(a,\overline{c})$	$(3,1)_{-\frac{1}{3}}$	1	0	−3	$\frac{1}{2}$	0	0
$(\overline{a},c)$	$(\overline{3},1)_{\frac{1}{3}}$	−1	0	3	$-\frac{1}{2}$	0	0
(a,c)	$(3,1)_{\frac{2}{3}}$	1	0	3	$-\frac{1}{2}$	0	−1
$(\overline{a},\overline{c})$	$(\overline{3},1)_{-\frac{2}{3}}$	−1	0	−3	$\frac{1}{2}$	0	1

• 105 3-node quivers (≤ 5 additions)

Multiplicity	Matter Additions				
4	$\Box\!\Box_b$, $(1,3)_0$	$\Box\!\Box_b$, $(1,3)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$(a,\overline{b})$, $(3,2)_{\frac{1}{6}}$	$(\overline{a},\overline{b})$, $(\overline{3},2)_{-\frac{1}{6}}$
4	$\Box\!\Box_b$, $(1,3)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$			
4	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$			
4	$\Box\!\Box_b$, $(1,3)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$
4	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$
4	$\Box\!\Box_b$, $(1,3)_0$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$	$(a,\overline{b})$, $(3,2)_{\frac{1}{6}}$	$(\overline{a},\overline{b})$, $(\overline{3},2)_{-\frac{1}{6}}$
4	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$			
4	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$		
4	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$	
4	$(a,\overline{b})$, $(3,2)_{\frac{1}{6}}$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_a$, $(\overline{3},1)_{\frac{1}{3}}$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	$(\overline{a},\overline{c})$, $(\overline{3},1)_{-\frac{2}{3}}$	$\Box\!\Box_c$, $(1,1)_1$
4	$\Box\!\Box_b$, $(1,3)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$
4	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$
4	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$		
4	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$	
4	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$
4	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$				
4	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$	
4	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$	
4	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$\overline{\Box\!\Box}_b$, $(1,3)_0$	$\overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}_b$, $(1,1)_0$	$(b,\overline{c})$, $(1,2)_{-\frac{1}{2}}$	(b,c), $(1,2)_{\frac{1}{2}}$
4	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}_b$, $(1,1)_0$	

Multiplicity	Matter Additions				
4	$\overline{\square\!\square}_b,\ (1,3)_0$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\overline{\boxminus}_b,\ (1,1)_0$	$\overline{\boxminus}_b,\ (1,1)_0$
4	$\overline{\square\!\square}_b,\ (1,3)_0$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\boxminus_b,\ (1,1)_0$		
1	$\boxminus_a,\ (\overline{3},1)_{\frac{1}{3}}$	$\square\!\square_b,\ (1,3)_0$	$\boxminus_b,\ (1,1)_0$	$(a,\overline{c}),\ (3,1)_{-\frac{1}{3}}$	
1	$\overline{\boxminus}_a,\ (3,1)_{-\frac{1}{3}}$	$\square\!\square_b,\ (1,3)_0$	$\boxminus_b,\ (1,1)_0$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$	
1	$\boxminus_a,\ (\overline{3},1)_{\frac{1}{3}}$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\boxminus_b,\ (1,1)_0$	$(a,\overline{c}),\ (3,1)_{-\frac{1}{3}}$	
1	$\overline{\boxminus}_a,\ (3,1)_{-\frac{1}{3}}$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\boxminus_b,\ (1,1)_0$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$	
1	$\boxminus_a,\ (\overline{3},1)_{\frac{1}{3}}$	$\overline{\boxminus}_b,\ (1,1)_0$	$\overline{\boxminus}_b,\ (1,1)_0$	$(a,\overline{c}),\ (3,1)_{-\frac{1}{3}}$	
1	$\overline{\boxminus}_a,\ (3,1)_{-\frac{1}{3}}$	$\overline{\boxminus}_b,\ (1,1)_0$	$\overline{\boxminus}_b,\ (1,1)_0$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$	
1	$\boxminus_a,\ (\overline{3},1)_{\frac{1}{3}}$	$\overline{\boxminus}_b,\ (1,1)_0$	$(b,\overline{c}),\ (1,2)_{-\frac{1}{2}}$	$(b,c),\ (1,2)_{\frac{1}{2}}$	$(a,\overline{c}),\ (3,1)_{-\frac{1}{3}}$
1	$\overline{\boxminus}_a,\ (3,1)_{-\frac{1}{3}}$	$\overline{\boxminus}_b,\ (1,1)_0$	$(b,\overline{c}),\ (1,2)_{-\frac{1}{2}}$	$(b,c),\ (1,2)_{\frac{1}{2}}$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$
1	$(a,\overline{b}),\ (3,2)_{\frac{1}{6}}$	$(b,\overline{c}),\ (1,2)_{-\frac{1}{2}}$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$	$(\overline{a},\overline{c}),\ (\overline{3},1)_{-\frac{2}{3}}$	$\square\!\square_c,\ (1,1)_1$
1	$\boxminus_a,\ (\overline{3},1)_{\frac{1}{3}}$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\overline{\boxminus}_b,\ (1,1)_0$	$\overline{\boxminus}_b,\ (1,1)_0$	$(a,\overline{c}),\ (3,1)_{-\frac{1}{3}}$
1	$\overline{\boxminus}_a,\ (3,1)_{-\frac{1}{3}}$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\overline{\boxminus}_b,\ (1,1)_0$	$\overline{\boxminus}_b,\ (1,1)_0$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$
1	$\boxminus_a,\ (\overline{3},1)_{\frac{1}{3}}$	$\boxminus_a,\ (\overline{3},1)_{\frac{1}{3}}$	$\boxminus_b,\ (1,1)_0$	$(a,\overline{c}),\ (3,1)_{-\frac{1}{3}}$	$(a,\overline{c}),\ (3,1)_{-\frac{1}{3}}$
1	$\overline{\boxminus}_a,\ (3,1)_{-\frac{1}{3}}$	$\overline{\boxminus}_a,\ (3,1)_{-\frac{1}{3}}$	$\boxminus_b,\ (1,1)_0$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$
1	$\boxminus_a,\ (\overline{3},1)_{\frac{1}{3}}$	$\boxminus_b,\ (1,1)_0$	$(a,\overline{c}),\ (3,1)_{-\frac{1}{3}}$		
1	$\overline{\boxminus}_a,\ (3,1)_{-\frac{1}{3}}$	$\boxminus_b,\ (1,1)_0$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$		
1	$\boxminus_a,\ (\overline{3},1)_{\frac{1}{3}}$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\boxminus_b,\ (1,1)_0$	$(a,\overline{c}),\ (3,1)_{-\frac{1}{3}}$
1	$\overline{\boxminus}_a,\ (3,1)_{-\frac{1}{3}}$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\overline{\square\!\square}_b,\ (1,3)_0$	$\boxminus_b,\ (1,1)_0$	$(\overline{a},c),\ (\overline{3},1)_{\frac{1}{3}}$

M.C., J. Halverson & H. Piragua, to appear

II. Implications for MSSM's with additional nodes

Up-to two additional U(1)'s or one U(N)

Systematic search (implement global consistency conditions)

i) SM singlets by far the most common fields

&(light anomalous) U(1)'-monochromatic gamma ray line dark matter scenario

à la Dudas, Mambrini, Pokorski, Romagnoni 1205.1520

w/ coupling to SM automatically forbidden by anomalous U(1)

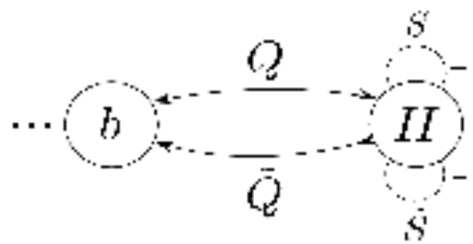
dacay to Z γ possible (via Z' - B_Y - B_Y ``Chern-Simons'' vertex).

ii) E.g., Stringy dynamical SUSY breaking scenario (à la Fayet)

Aharony,Kachru,Silverstein'07

Quasi –chiral matter → messenger masses instanton suppressed;
lifetime of metastable vacuum set by instanton superpotential

$$W \supset \lambda_{(0,0)} M_* S\tilde{S} + \lambda_{(-2,0)} M_* Q\tilde{Q} + \lambda_{(-2,0)} \frac{1}{M_*} S\tilde{S}Q\tilde{Q}$$



M.C., J. Halverson& P. Langacker, to appear

III. Axigluons w/ quiver embedding [$SU(3)_{CL}$ x$SU(3)_{CR}$]

(playground to explain Tevatron $t\bar{t}$ anomaly)

Accounting for the correct sign of the asymmetry requires a "mirror" generations, e.g.,

$$Q_{1,2} \sim (3,1,2)_{\frac{1}{6}} \qquad Q_3 \sim (1,3,2)_{\frac{1}{6}}$$

Quiver constraint: no tri-fundamental Higgs →
need effective Yukawas (e.g., A,C) & w/ mirror generations giving some perturbative Yukawas, (e.g., P_u)

$$Y_{QH_uu^c} = \begin{pmatrix} A & A & P_u \\ A & A & P_u \\ P_u & P_u & C \end{pmatrix}$$

$$A = \frac{M_Q}{\lambda_Q v_\phi} \qquad C = \frac{M_u}{\lambda_u v_{\bar{\phi}}}$$

$$\tilde{Q}H_u u_2^c,\ \lambda_Q \Phi \tilde{Q}\tilde{Q}^c,\ \text{and}\ M_Q \tilde{Q}^c Q_2$$

anomalous U(1)'s and instantons can help with scales of A, C
(still major difficulties with Yukawa couplings)

Foresee further progress:

a) DEVELOPMENT of TECHNIQUES! →generalize constructions to general Calabi Yau spaces (advanced algebraic geometry techniques); Fluxes in F-theory

b) Quantitatively improve realistic model constructions, including further progress on non-perturbative effects

Conclusions/Outlook

``Glimpses'' of particle physics from String Theory
Focus on D-branes → Type II (and F-theory)

a) Progress: development of techniques for constructions
sizable number of semi-realistic models

b) "The devil is in the details!"-typically not fully realistic
typically exotic matter → but viewed as a string prediction

c) Systematic searches within local D-quivers w/SSM
(compatible with string constraints)
→ probe for SM exotics; nature of hidden; SUSY breaking…

Hopefully, LHC & Astrophysics experiments → inputs
toward realistic particle physics from string theory

w/ efforts presented here playing a role