Stringy Instantons and Fermion Masses in Intersecting D-brane models

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On The Fermion Mass Problem

⋆The vast mass hierarchy among the three fermion generations:

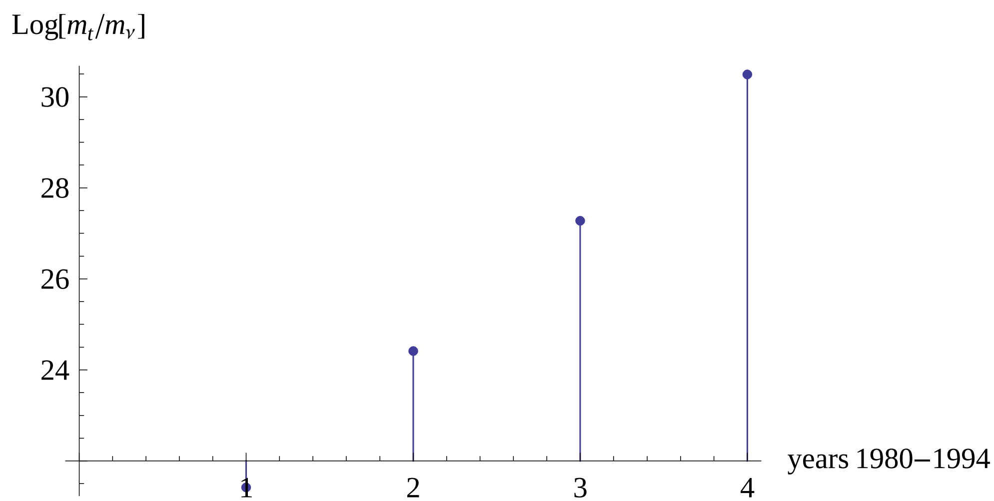
$$\frac{m_t}{m_u} \sim 10^5$$
$$\frac{m_t}{m_{\nu_e}} \sim \frac{M_{GUT}}{M_W} \tag{1}$$

has no satisfactory explanation in SM and SUSY-GUTs

The second ratio in (1) is the well known hierarchy problem

Early attempts: Additional 'family' symmetry. (*Froggatt & Nielsen, NPB147(1979)277 etc...*)

Strings: Predict additional $U(1)$ factors "incarnating" naturally the family symmetries.



$\mathrm{Log}[m_t/m_\nu]$
30
28
26
24
1
2
3
4
years 1980–1994

★ String Approach: The Main Features

▲ Restricted Superpotential couplings, due to selection rules and $U(1)$'s (*Normally only* 3^d *generation present at tree-level*)

$$\mathcal{W}_{tree} \supset \lambda_t Q_t t^c h_u + \lambda_b Q_t b^c h_d + \lambda_l L_\tau \tau^c h_d$$

▲ Gauge-Yukawa coupling relations, ($\lambda_t \sim g_{unif}$) fix $m_t \sim 180$ GeV.

▲ Anomalous $U(1)_A$ & $D/F-$ flatness fix various singlet vevs $\langle \Phi_i \rangle$

$$\frac{\partial \mathcal{W}}{\partial \Phi_j} = 0; \;\; \sum_j Q_j^k |\langle \Phi_j \rangle|^2 - \xi_{FI}^2 \delta_{A\,k} = 0, \quad (A = \text{Anomalous} U(1))$$

▲ Calculable NR-terms to all orders!

▲ Fermion mass entries expressed in terms of

$$\epsilon_{\mathbf{i}} = \frac{\langle \Phi_i \rangle}{\mathcal{M}} \; < \; 1$$

Stringy Inspired Classification: **Texture zeros:** (*see e.g. Ramond-Roberts-Ross, Nucl.Phys.B406:19-42,1993 ... etc*)

General Idea: Minimal structure, maximum information...

$$m_U = \begin{pmatrix} 0 & \epsilon^6 & 0 \\ \epsilon^6 & 0 & \epsilon^2 \\ 0 & \epsilon^2 & 1 \end{pmatrix} \qquad m_D = \begin{pmatrix} 0 & 2\epsilon^4 & 0 \\ 2\epsilon^4 & 2\epsilon^3 & 2\epsilon^3 \\ 0 & 2\epsilon^3 & 1 \end{pmatrix}$$

$$m_U = \begin{pmatrix} 0 & 0 & \sqrt{2}\epsilon^4 \\ 0 & \epsilon^4 & 0 \\ \sqrt{2}\epsilon^4 & 0 & 1 \end{pmatrix} \qquad m_D = \begin{pmatrix} 0 & 2\epsilon^4 & 0 \\ 2\epsilon^4 & 2\epsilon^3 & 4\epsilon^3 \\ 0 & 4\epsilon^3 & 1 \end{pmatrix}$$

$$m_U = \begin{pmatrix} 0 & \sqrt{2}\epsilon^6 & 0 \\ \sqrt{2}\epsilon^6 & \sqrt{3}\epsilon^4 & \epsilon^2 \\ 0 & \epsilon^2 & 1 \end{pmatrix} \qquad m_D = \begin{pmatrix} 0 & 2\epsilon^4 & 0 \\ 2\epsilon^4 & 2\epsilon^3 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$m_U = \begin{pmatrix} 0 & \sqrt{2}\epsilon^6 & 0 \\ \sqrt{2}\epsilon^6 & \epsilon^4 & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad m_D = \begin{pmatrix} 0 & 2\epsilon^4 & 0 \\ 2\epsilon^4 & 2\epsilon^3 & 4\epsilon^3 \\ 0 & 4\epsilon^3 & 1 \end{pmatrix}$$

$$m_U = \begin{pmatrix} 0 & 0 & \epsilon^4 \\ 0 & \sqrt{2}\epsilon^4 & \frac{\epsilon^2}{\sqrt{2}} \\ \epsilon^4 & \frac{\epsilon^2}{\sqrt{2}} & 1 \end{pmatrix} \qquad m_D = \begin{pmatrix} 0 & 2\epsilon^4 & 0 \\ 2\epsilon^4 & 2\epsilon^3 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

However....

Subtle is the real World!

▼ No zeros in realistic string constructions...

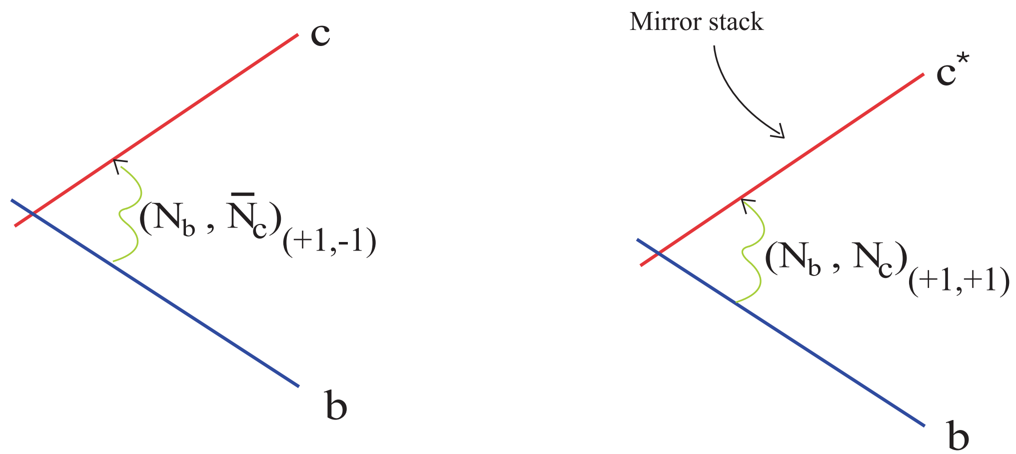
▼ Non-symmetric textures is usually the case!!!

♠Need of unified treatment of symmetric & non-symmetric mass matrices

Mass textures in a class of D-brane Standard-like Models

Preliminaries

Matter multiplets



A string stretched between:

i) D_b , D_c intersecting brane stacks giving rise to bifundamental $(N_b, \bar{N}_c)_{(+1,-1)}$, and

ii) D_b , D_{c^*} (mirror), incarnating the $(N_b, N_c)_{(+1,+1)}$

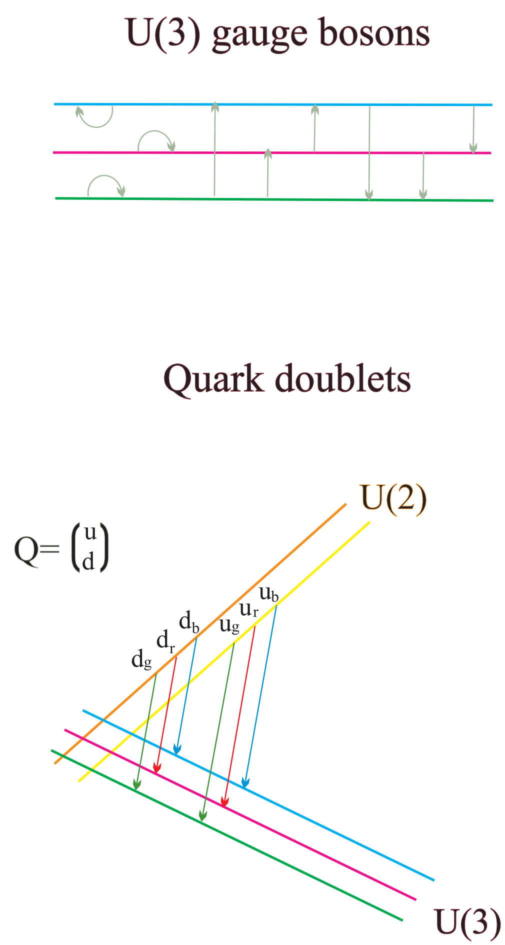


Figure 1: The 9 gauge bosons of $U(3)$ and the quark-doublets.

D-brane **SM** analogue with P extra $U(1)$ branes

$$G = U(3)_C \times U(2)_L \times U(1)^P \tag{2}$$

Antoniadis et al, Nucl. Phys. B 660 (2003) 81; Ibanez et al, JHEP 0111 (2001) 002; R. Blumenhagen et al, Nucl. Phys. B 616 (2001) 3...

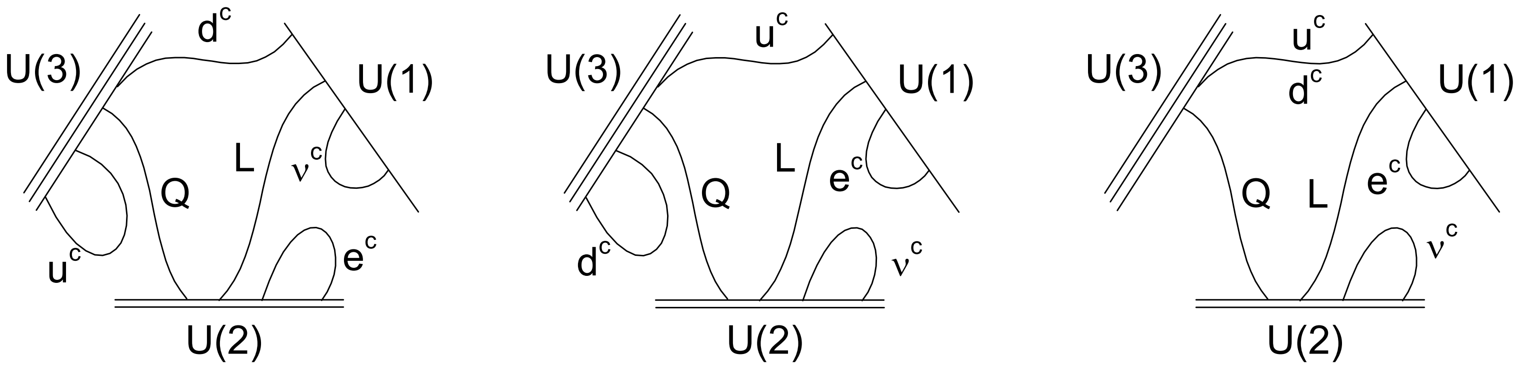
For $P = 0$, notice that

$$U(3)_C \times U(2)_L \to SU(3)_C \times SU(2)_L \times U(1)_C \times U(1)_L$$

Hypercharge $U(1)_Y \not\subseteq U(1)_C \times U(1)_L$,

$$\Rightarrow P \geq 1$$

Three **SM** variants for the simplest configuration $P = 1$:
(*Antoniadis and Dimopoulos, Nucl. Phys. B* **715** *(2005) 120*)



$\Longrightarrow$ **SM** embedding is not unique!

Most general hypercharge

$$Y \quad = \quad k_3 Q_3 + k_2 Q_2 + \sum_{i=1}^{P} k'_i Q'_i \tag{3}$$

and gauge coupling condition

$$\frac{1}{{g_Y}^2} = \frac{6{k_3}^2}{g_3^2} + \frac{4{k_2}^2}{g_2^2} + 2\sum_{i=1}^{P} \frac{{k'_i}^2}{{g'_i}^2} \tag{4}$$

The requirement to obtain the correct $U(1)_Y$ charges for the SM spectrum determines the coefficients $k_{2,3}, k'_i$.

• $k_{2,3}$ are due to the contributions of the abelian factors of $U(3)_C \to SU(3)_C \times U(1)_C$ and $U(2)_L \to SU(2)_L \times U(1)_L$

• k'_i are due to the abelian factors (the $U(1)$ branes).

• For $P = 1, 2, 3$ the results for $k_{2,3}, k'_i$ shown in table below:
(D.V. Gioutsos, **GKL** and A. Psallidas, Phys Rev D74:075007,2006

GKL, N. Vlachos and N. Tracas Phys Rev D76:115009,2007)

P		$\lvert k_3\rvert$	$\lvert k_2\rvert$	$\lvert k'_1\rvert$	$\lvert k'_2\rvert$	$\lvert k'_3\rvert$
1	a_1	$\frac{1}{3}$	$\frac{1}{2}$	0	–	–
	b_1	$\frac{1}{6}$	0	$\frac{1}{2}$	–	–
2	a_2	$\frac{1}{6}$	0	$\frac{1}{2}$	$\frac{1}{2}$	–
	b_2	$\frac{2}{3}$	$\frac{1}{2}$	1	0	–
	c_2	$\frac{1}{3}$	$\frac{1}{2}$	0	1	–
3	a_3	$\frac{1}{6}$	0	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	b_3	$\frac{1}{3}$	$\frac{1}{2}$	0	1	1
	c_3	$\frac{2}{3}$	$\frac{1}{2}$	1	0	0

Table 1: Simplest $U(3) \times U(2) \times U(1)^P$ hypercharge embeddings for $P = 1, 2, 3$

Analysis of various phenomenological issues of the above models shows that for models where the $U(1)$ branes are aligned to $SU(3)$ or $SU(2)$ branes:
(*Gioutsos, GKL, Rizos, EPJC* **45**, *241 (2006),hep-ph/0508120*)
•With respect to the predictions of the string scale, there are three classes of viable models: (P is the number of abelian branes)

1: There are $P = 1, 3$ models with string scale $M_S \sim 10^{16}$ GeV.
(*see also GKL arXiv:0903.3691 for intersecting branes*)

2: There are $P = 2$ models with $M_S \sim 10^{7-8}$ GeV;
In addition, the condition $m_b^0 = m_\tau^0$ at M_S is fulfilled.

3: There are $P = 3$ models with M_S as low as a few TeV.

Uniqueness could arise from the embedding in a higher gauge group

A closer look to a viable $P = 1$ case

GKL, arXiv:0903.3691

Conditions on wrappings:

$$(N_a, \bar{N}_b) \quad \rightarrow \quad I_{ab} = \prod_{i=1}^{3} (m_{ai} n_{bi} - m_{bi} n_{ai})$$

$$(N_a, N_b) \quad \rightarrow \quad I_{ab^*} = -\prod_{i=1}^{3} (m_{ai} n_{bi} + m_{bi} n_{ai})$$

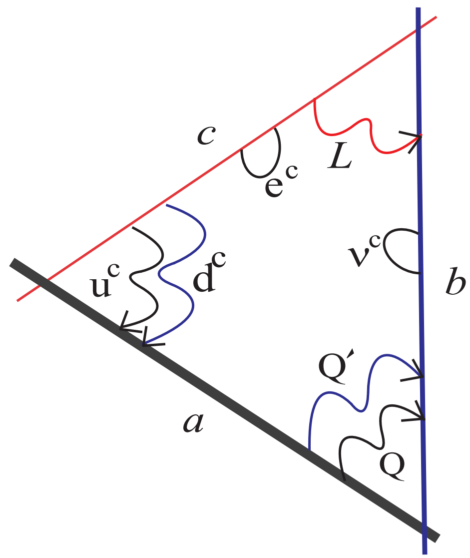
$$\mathrm{A} \quad \rightarrow \quad I^{A}_{aa^*} = 8 m_{a1} m_{a2} m_{a3}$$

$$\mathrm{A\&S} \quad \rightarrow \quad I'_{aa^*} = 4 m_{a1} m_{a2} m_{a3} \left(n_{a1} n_{a2} n_{a3} - 1 \right)$$

Anomaly cancelation conditions Imply $\# N_a = \# \bar{N}_a$, $\forall U(N_a)$

SPECTRUM

Inters.	$SU(3)\times SU(2)$	$\mathcal{Q}_a$	$\mathcal{Q}_b$	$\mathcal{Q}_c$	Y
ab	$1\times Q\,(3,\bar{2})$	1	-1	0	$\frac{1}{6}$
ab^*	$2\times Q'\,(3,2)$	1	1	0	$\frac{1}{6}$
ac	$3\times u^c\,(\bar{3},1)$	-1	0	1	$-\frac{2}{3}$
ac^*	$3\times d^c\,(\bar{3},1)$	-1	0	-1	$\frac{1}{3}$
bc	$3\times L\,(1,\bar{2})$	0	-1	1	$-\frac{1}{2}$
cc^*	$3\times e^c\,(1,1)$	0	0	-2	1
bb^*	$3\times \nu^c\,(1,1)$	0	-2	0	0
bc^*	$1\times H_d(1,2)$	0	1	1	$-\frac{1}{2}$
	$1\times H_u(1,\bar{2})$	0	-1	-1	$\frac{1}{2}$



Depiction of the $U(3) \times U(2) \times U(1)$ intersecting D-brane configuration. ($a \equiv U(3)$, $b \equiv U(2)$, $c \equiv U(1)$)

Blue string representing the quark doublet Q' is stretched between the $D6_a$ and $D6_{b^*}$.

One endpoint of the "d^c-string" is attached on the mirror $D6_{c^*}$.

Effective field theory model

String scale:

$$M_S \quad = \quad e^{\frac{\pi}{2}\left(\frac{\sin^2\theta_W}{\alpha}-\frac{1}{\alpha_3}\right)}\left(\frac{m_Z}{m_s}\right)^{\frac{13}{12}} m_Z \sim \mathcal{O}(10^{16})\mathrm{GeV} \qquad (5)$$

Yukawa couplings:

$$\begin{aligned} \mathcal{W} \quad \supset \quad & \lambda^u_{1j}\, Q'_1\, u^c_j\, H_u + \lambda^u_{2j}\, Q'_2\, u^c_j\, H_u \rightarrow \mathrm{up-quarks} \\ + \quad & \lambda^d_j\, Q_3\, d^c_j \rightarrow \mathrm{down-quarks} \\ + \quad & \lambda^l_{ij}\, L_i\, e^c_j H_d \rightarrow \mathrm{charged\ leptons} \end{aligned}$$

Resulting up and down quark Yukawa textures.

We have the following distinct possibilities

$$m_Q = \begin{pmatrix} 0 & 0 & 0 \\ \lambda^u_{21} & \lambda^u_{22} & \lambda^u_{23} \\ \lambda^u_{31} & \lambda^u_{32} & \lambda^u_{33} \end{pmatrix} \langle H_u \rangle, \qquad m_d = \begin{pmatrix} \lambda^d_{11} & \lambda^d_{12} & \lambda^d_{13} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \langle H_d \rangle$$

or

$$m_Q = \begin{pmatrix} \lambda^u_{11} & \lambda^u_{12} & \lambda^u_{13} \\ 0 & 0 & 0 \\ \lambda^u_{31} & \lambda^u_{32} & \lambda^u_{33} \end{pmatrix} \langle H_u \rangle, \qquad m_d = \begin{pmatrix} 0 & 0 & 0 \\ \lambda^d_{21} & \lambda^d_{22} & \lambda^d_{23} \\ 0 & 0 & 0 \end{pmatrix} \langle H_d \rangle$$

or

$$m_Q = \begin{pmatrix} \lambda^u_{11} & \lambda^u_{12} & \lambda^u_{13} \\ \lambda^u_{21} & \lambda^u_{22} & \lambda^u_{23} \\ 0 & 0 & 0 \end{pmatrix} \langle H_u \rangle \tag{6}$$

$$m_d = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \lambda^d_{31} & \lambda^d_{32} & \lambda^d_{33} \end{pmatrix} \langle H_d \rangle \tag{7}$$

$\Rightarrow$ at tree-level ... mass textures...not viable.

Possible solutions:

$*$ NR-terms (extending the spectrum)

$*$ Additional Higgs pair

$*$ Stringy Instanton Effects

$\ast$ NR-terms and/or Additional Higgs pair

Inters.	$SU(3)\times SU(2)$	$\mathcal{Q}_a$	$\mathcal{Q}_b$	$\mathcal{Q}_c$	Y
bb^*	${\nu'}^c\,(1,1)$	0	$+2$	0	0
bc	$H'_d(1,2)$	0	-1	1	$-\frac{1}{2}$
	$H'_u(1,\bar{2})$	0	1	-1	$\frac{1}{2}$

ν^c and H'_u, H'_d superpotential contributions

$$\mathcal{W}' \quad = \quad {\lambda'}^u_j\,Q\,u^c_j\,H'_u + {\lambda'}^d_j\,Q'_p\,d^c_j\,H'_d + {\lambda'}^{\nu}_{ij}\,\mathcal{L}_i\,{\nu'}^c_j H_u \qquad (8)$$

Instanton Effects

▷ YM Instantons: Classical Euclidean Solutions of F.T. Equations ($F_{\mu\nu} = \tilde{F}_{\mu\nu}$)

Physical Meaning: Tunneling event between degenerate classical vacua in the presence of fermion zero-modes.

▷ N=1 SUSY: Non-perturbative Superpotential couplings.

(a surrogate for the non-renormalizable terms.)

⋆ Intersecting D-brane models:

Non-perturbative string effects generate missing Yukawa Couplings

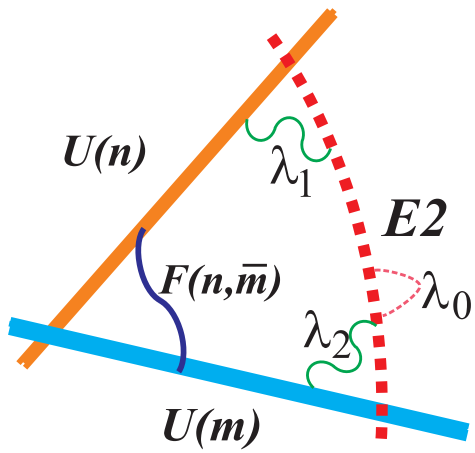
Blumenhagen et al, Nucl. Phys. B 771 (2007) 113,

Ibanez et al, JHEP 0703 (2007) 052,

M. Bianchi et al, JHEP 0707 (2007) 038

Depiction

of a Euclidean Brane intersecting $U(m), U(n)$ D-branes



$a)$ $E2 - E2$ (uncharged) instantons (broken SUSY).

$b)$ $D6 - E2$ (charged) instantons in the intersections.

The Stringy Mechanism:

Certain desired Yukawa couplings $\prod_j \Phi_j$ violate some $U(1)_a$ ($U(n)_a \rightarrow SU(n)_a \times U(1)_a$)

Under $U(1)_a$, the transformation property of the exponential instanton action is ($U(1)_a$ is broken by the instanton!)

$$e^{-S_{\mathcal{E}}} \quad \rightarrow \quad e^{-S_{\mathcal{E}}}\, e^{\imath\, \mathcal{Q}_a(\mathcal{E}2)\Lambda_a} \tag{9}$$

$\mathcal{Q}_a(\mathcal{E}2)$ depends on the $\mathcal{E}2$ intersections

$$\mathcal{Q}_a(\mathcal{E}2) \quad = \quad -\mathcal{N}_a\, \pi_{\mathcal{E}} \circ \pi_a \equiv -\mathcal{N}_a\, I_{\mathcal{E}a} \tag{10}$$

$U(1)_a$ charge violation of $\prod_j \Phi_j$ compensated by a S_{inst}-shift:

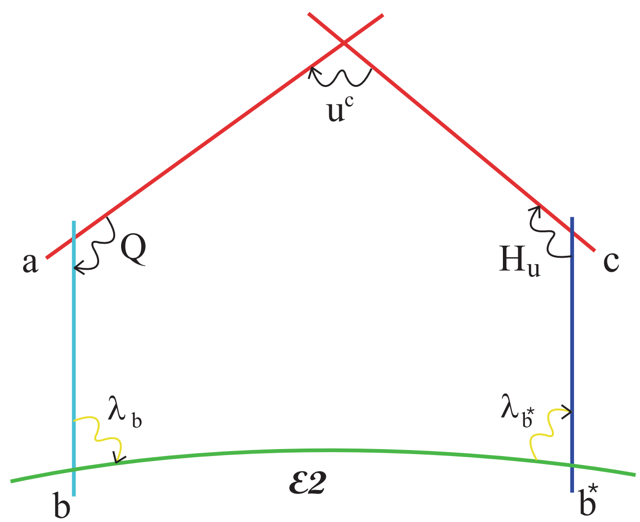
$$\mathcal{W}_{n.p.} \sim \prod_j \Phi_j\, e^{-S_{inst}}$$

Up Quark coupling $Qu^c_jH_u$ violates the $U(1)_b$ charge by two units

$$\mathcal{Q}_{b_Q} + \mathcal{Q}_{b_{u^c}} + \mathcal{Q}_{b_{H_u}} = -2$$

Choose $\#$ of $\bar{\lambda}^i_b, \lambda^i_b,\ i = 1, 2, 3$ so that $I_{\mathcal{E}b}$ satisfies

$$\mathcal{Q}_b(\mathcal{E}2) \quad = \quad -\mathcal{N}_b\, I_{\mathcal{E}b} \tag{11}$$



Integration over zero modes

$$\int \{d^4x\, d^2\theta\, d^2\lambda_b\}\, e^{-S_\mathcal{E}}\, y^u_j \epsilon_{mn}\epsilon_{r\ell} < \lambda^m_b Q^n u^c_j H^r_u \lambda^s_{b*} > e^{Z'}$$

(and similarly for down quarks) leads to the tree level superpotential couplings

$$\mathcal{W}_{n.p.} \quad = \quad \lambda^u_j Q\, u^c_j H_u + \lambda^d_{pj} Q'_p d^c_j H_d$$

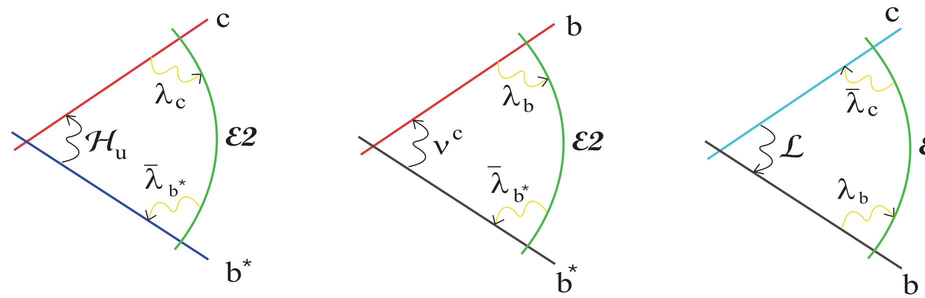
Final forms of quark matrices

$$m_Q = \begin{pmatrix} \lambda^u_{11} & \lambda^u_{12} & \lambda^u_{13} \\ \lambda^u_{21} & \lambda^u_{22} & \lambda^u_{23} \\ \lambda^u_{31} & \lambda^u_{32} & \lambda^u_{33} \end{pmatrix},\ m_d = \begin{pmatrix} \lambda^d_{11} & \lambda^d_{12} & \lambda^d_{13} \\ \lambda^d_{21} & \lambda^d_{22} & \lambda^d_{23} \\ \lambda^d_{31} & \lambda^d_{32} & \lambda^d_{33} \end{pmatrix}$$

$\lambda^{u,d}_{ji} \ll \lambda^{u,d}_{ji}$ (Instanton or NR contributions)
$\lambda^{u,d}_{ji} \sim \lambda^{u,d}_{ji}$ (Additional Higgs)

Neutrinos: Absent at tree level (minimal model)

Instanton induced masses through the following $D6 - E2$ intersections



Remarks:

1.) Exponential suppression: $m_\nu \propto e^{-S_{\mathcal{E}}} \frac{m_D^2}{M_S}$

2.) Factorizable couplings: $y_{ij} = e^{\imath\phi_{ij}} \lambda_i^\nu \lambda_j^\nu$

Results: Instantons induce a new hierarchical structure of mass matrices

Convenient parametrization

$$m_D = \begin{pmatrix} x_{11} & x_{12} & x_{13} \\ \zeta_{21} & \zeta_{22} & \zeta_{23} \\ \kappa_{31} & \kappa_{32} & \kappa_{33} \end{pmatrix}, |\vec{x}| \gg, |\vec{\kappa}|, \ |\vec{\zeta}|$$

Since m_D is non-symmetric, we form

$$m_D m_D^T = \begin{pmatrix} \vec{x}\cdot\vec{x} & \vec{x}\cdot\vec{\zeta} & \vec{x}\cdot\vec{\kappa} \\ \vec{x}\cdot\vec{\zeta} & \vec{\zeta}\cdot\vec{\zeta} & \vec{\zeta}\cdot\vec{\kappa} \\ \vec{x}\cdot\vec{\kappa} & \vec{\zeta}\cdot\vec{\kappa} & \vec{\kappa}\cdot\vec{\kappa} \end{pmatrix}$$

• A simple parametrization of m_D: $\vec{x}\cdot\vec{\zeta}=0 \rightarrow$

$$m_D m_D^T = \begin{pmatrix} 1 & -r\cos(\theta) & r\sin(\theta) \\ -r\cos(\theta) & s^2 & 0 \\ r\sin(\theta) & 0 & s^2 \end{pmatrix} m_0^2 \qquad (12)$$

with $r = \frac{\sqrt{(m_b^2-m_s^2)(m_s^2-m_d^2)}}{m_b^2+m_d^2-m_s^2}$, $s^2 = \frac{m_s^2}{m_b^2+m_d^2-m_s^2}$.

•Question: Is there a compatible up-quark texture?

We can check it using the

Cabbibo-Kobayashi-Maskawa (CKM) Matrix.

If $V_u^{L,R}$ and $V_d^{L,R}$ the diagonalizing matrices:

$$m_U^{diag.} = V_u^L m_U V_u^{R\dagger} \qquad (13)$$

$$m_D^{diag.} = V_d^L m_D V_d^{R\dagger} \qquad (14)$$

and V_d is known, we can use now the CKM matrix and the relation

$$V_u \quad = \quad V_{CKM} V_d \tag{15}$$

to construct the diagonalizing matrix of the up quarks. Then,

$$\mathcal{M}_U^2 \equiv m_U m_U^\dagger \quad = \quad V_U^\dagger \left(m_U^2\right)_{diag.} V_U \tag{16}$$

Wolfenstein parametrization of CKM:

$$V_{CKM} \quad = \quad \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - \imath\,\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-\imath\,\eta) & -A\lambda^2 & 1 \end{pmatrix} \tag{17}$$

with $\lambda \sim 0.2257$ and $A, \rho, \eta = \mathcal{O}(1)$, while putting $(\xi \sim s \sim r)$

Resulting up-quark mass texture:

see G.K.L., Stringy Instantons and Fermion Masses: (in Annual Meeting of HEP Society, Demokritos, Athens, 23/05/2009, Greece http://indico.cern.ch/conferenceDisplay.py?confId=55216

$$\begin{aligned} \epsilon &= A\sin(\theta)\lambda^2 + \xi\cos(\theta) \\ \epsilon' &= \xi\sin(\theta) - A\lambda^2\cos(\theta) \end{aligned}$$

$$m_U m_U^T \sim \begin{pmatrix} 1 & -\epsilon & \epsilon' \\ -\epsilon & \epsilon^2 & \epsilon\epsilon' \\ \epsilon' & \epsilon\epsilon' & {\epsilon'}^2 \end{pmatrix} m_t^2$$

$\Rightarrow m_U, m_D$ are Aligned

Neutrino sector

Since the couplings are factorizable,

$$y_{ij} = e^{\imath\phi_{ij}}\lambda_i^\nu\lambda_j^\nu \tag{18}$$

the Dirac neutrino mass matrix can be written

$$m_D^\nu = \begin{pmatrix} 1 & r\cos(\theta) & r\sin(\theta) \\ r\cos(\theta) & e^{\imath\phi_1}\, r^2\cos^2(\theta) & e^{\imath\phi_2}\,\frac{r^2}{2}\,\sin(2\theta) \\ r\sin(\theta) & e^{\imath\phi_3}\,\frac{r^2}{2}\,\sin(2\theta) & e^{\imath\phi_4} r^2\sin^2(\theta) \end{pmatrix} \tag{19}$$

Simple choice: $\chi_1 = 0$ and $\phi_i = \chi_{2,3} = \pi$, $r = 1 + \epsilon + O(\epsilon^2)$,

$$m_{\nu_1} \sim (-1-\epsilon)m_0,\; m_{\nu_2} \sim (1-\epsilon)m_0,\; m_{\nu_3} = 0$$

Inverse mass hierarchy!

A FEW COMMENTS

Simple D-brane configurations imply a variety of interesting SM-successors with desirable features. Among them:

i) Extra $U(1)$'s $\Rightarrow$ hierarchy, and proton stability

ii) $6d$ internal space $\Rightarrow$ Calculability

• **Quark mass ratios** determined in terms of the $6d$ compact space structure

• Factorizable neutrino mass texture, easy to handle

• Instanton corrections imply new mass textures not previously explored

• A new parametrization of mass textures and mixing is needed....
(*with N.D. Vlachos, to appear...*)