String Phenomenology 2005
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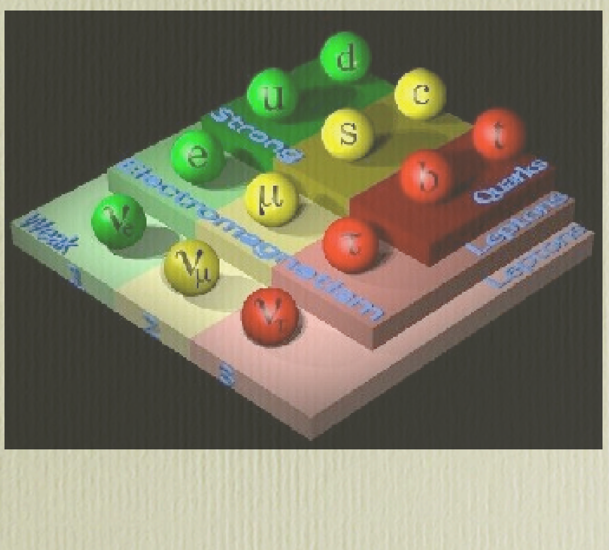
Scherk-Schwarz Deformations and Intersecting Branes

Carlo Angelantonj
(LMU-München & Torino Univ.)

Based on: C.A., M. Cardella, N. Irges, hep-th/0503179

The Standard Model of Particle Physics

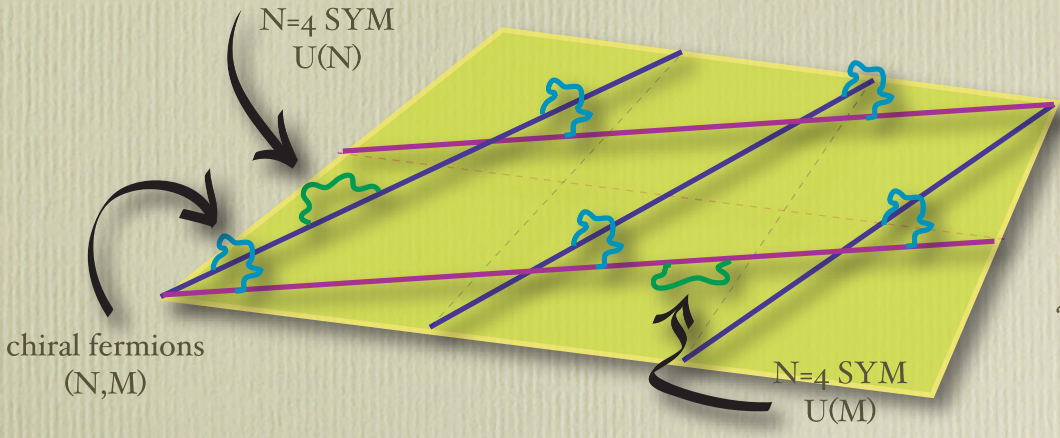


Can String Theory describe the Standard Model?

Intersecting D-branes

Berkooz
Douglas
Leigh

c.f. Cvetic's, Shiu's & Uranga's talks



wrapping #'s
$(\omega_\alpha, \kappa_\alpha)$

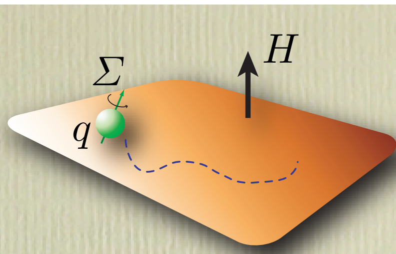
number of intersections = replicas of chiral spectrum

$$I_{ab} = \kappa_a\,\omega_b - \kappa_b\,\omega_a$$

Magnetised Backgrounds

analogue of Landau problem in quantum mechanics

Witten; Bachas; ...



$$\varDelta M \sim (2n+1)|qH| + 2\varSigma qH$$

Landau levels *Pauli couplings*

1. Supersymmetry broken due to different Pauli couplings
2. chirality index $\not{D} = \int F \neq 0$
3. multiple families $\mathbb{Z} \ni k = q\,H\,\mathrm{vol}(T^2)$

c.f. Antoniadis' & Bianchi's talks

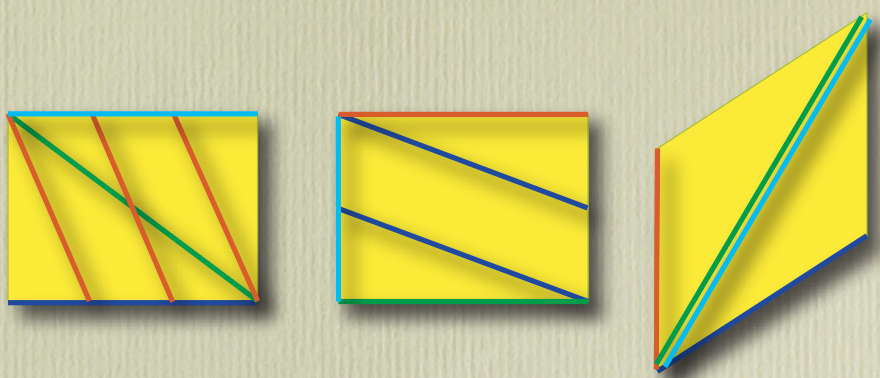
Several attempts to get the

(Minimal Supersymmetric) Standard Model Spectrum

from Intersecting Branes

Aldazabal, Antoniadis, Bachas, Bailin, Blumenhagen, Braun, Cremades, Cvetic, Förste, Franco, Görlich, Honecker, Ibáñez, Kiritsis, Kokorelis, Körs, Kraniotis, Li, Liu, Love, Lüst, Marchesano, Ott, Papadimitriou, Rabadan, Rizos, Schreyer, Shiu, Tomaras, Uranga, ...

A Standard-Model-like pattern



$U(3)$	$(1,0)$	$(2,-1)$	$(1,0)$
$U(2)$	$(1,-1)$	$(1,0)$	$(1,1)$
$U(1)$	$(1,-3)$	$(1,0)$	$(0,1)$
$U(1)$	$(1,0)$	$(0,1)$	$(1,1)$

Ibanez, Marchesano, Rabadan

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

$$Q_Y = \tfrac{1}{2}Q_a - \tfrac{1}{2}Q_c + \tfrac{1}{2}Q_d$$

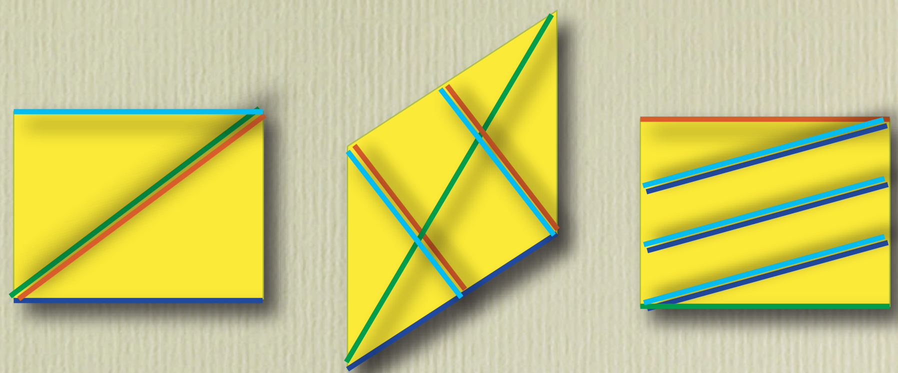
the chiral spectrum

quarks: $(3, 2_+, 1, 1)$ $\quad 2 \times (3, 2_-, 1, 1)$ $\quad 3 \times (\bar{3}, 1, 1_-, 1)$ $\quad 3 \times (\bar{3}, 1, 1_+, 1)$

leptons: $3 \times (1, 2_-, 1, 1_-)$ $\quad 3 \times (1, 1, 1_+, 1_-)$ $\quad 3 \times (1, 1, 1_-, 1_-)$

In addition non-chiral massless fermions

A Pati-Salam-like pattern



$U(3)$	$(1,0)$	$(1,0)$	$(3,1)$
$U(2)$	$(1,1)$	$(1,1)$	$(1,0)$
$U(2)$	$(1,1)$	$(1,-2)$	$(1,0)$
$U(1)$	$(1,0)$	$(1,-2)$	$(3,1)$

Blumenhagen, Körs and Lüst

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

the chiral spectrum

quarks:	$2 \times (3,2,1,1) + (3,\bar{2},1,1) + 2 \times (\bar{3},1,2,1) + (\bar{3},1,\bar{2},1)$
leptons:	$3 \times (1,\bar{2},1,1_+) + 3 \times (1,1,\bar{2},1_-)$

In addition non-chiral massless fermions

What is the source for non-chiral matter?

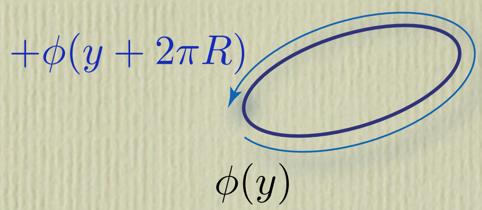
- Open strings ending on the same set of branes yield a full $\mathcal{N}$=4 Yang-Mills multiplet in the adjoint of $U(N)$
- Open strings stretched between branes which are parallel along (at least) one torus yield non-chiral fermions in bi-fundamentals

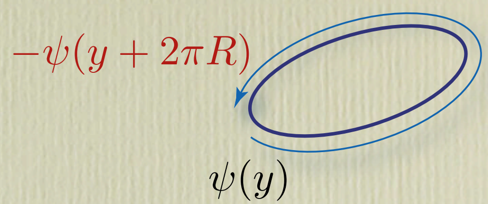
In either case the tower of Landau levels is replaced by momentum and winding zero-modes

Deforming zero-modes to generate (tree-level) masses for non-chiral fermions

that is to say ...

use the Scherk-Schwarz idea to deform the spectrum by affecting the Kaluza-Klein states





$$\phi(y) = \sum_n \phi_n \, e^{iny/R} \qquad\qquad \psi(y) = \sum_n \psi_n \, e^{i(n+\frac{1}{2})y/R}$$

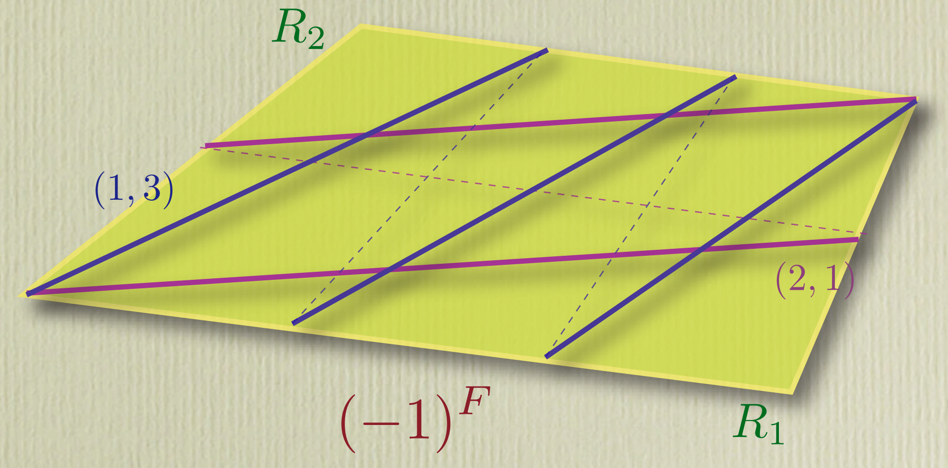
$$\Delta M \sim 1/R$$

Clearly, closed-string states are always affected!

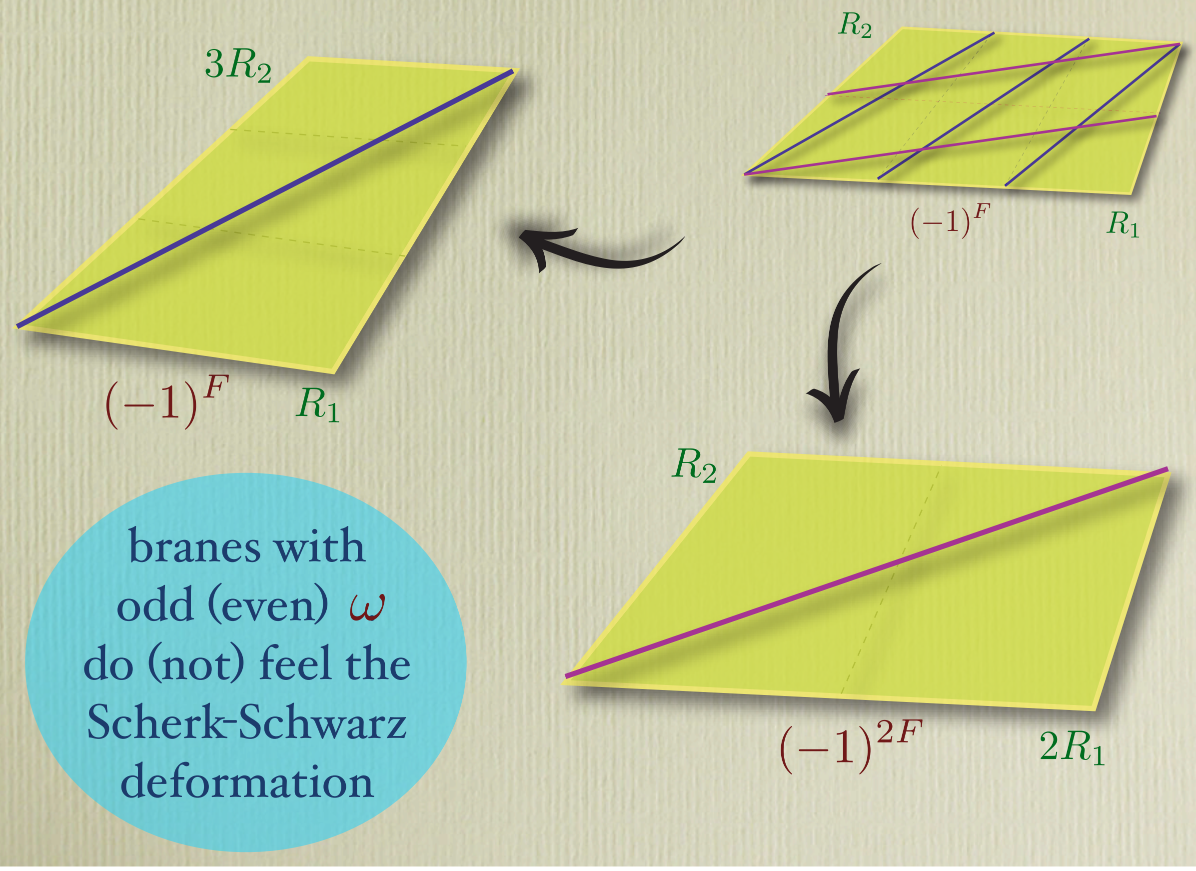
1. D-branes extend along y direction: susy breaking
2. D-brane are transverse to y direction: susy exact

Antoniadis, Dudas, Sagnotti

We are now facing a new situation whereby D-branes extend along directions which are neither parallel nor transverse to the Scherk-Schwarz deformation



Unwrap the branes on their multi-covering tori



in equations ...

for closed strings

$$\Phi_{p_1,p_2} \sim e^{2i\pi(p_1 y_1 + p_2 y_2)}$$

$$p_1 = \left(m_1 + \tfrac{1}{2}\Delta_{\rm F}\right)\frac{1}{R_1} \qquad p_2 = \frac{m_2}{R_1}$$

for rotated branes

$$\Phi_{p_1,p_2} \sim e^{2i\pi\bar{y}(p_1 \cos\varphi + p_2 \sin\varphi)}$$

The open-string mass-spectrum is then

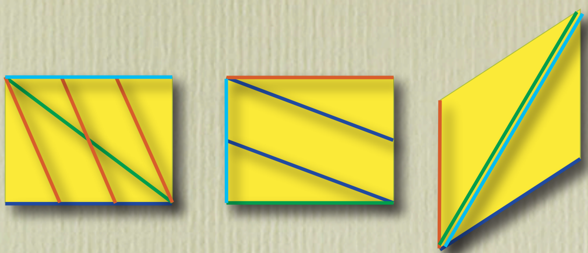
$$M^2 = \left(\frac{\cos\varphi}{\omega\, R_1}\right)^2 \left[\left(m_1 + \tfrac{1}{2}\Delta_{\rm F}\right)\omega + m_2\kappa\right]^2$$

Contributions to the vacuum energy

without deformation	with deformation
$N_\alpha \bar{N}_\alpha (V_8 - S_8)\left[{0 \atop 0}\right] P_m(L_\parallel) W_n(L_\perp)(PW)^2$	$N_\alpha \bar{N}_\alpha \left(V_8\left[{0 \atop 0}\right] P_m - S_8\left[{0 \atop 0}\right] P_{m+\frac{1}{2}}\right) W_n\,(PW)^2$
$N_\alpha \bar{N}_\beta (V_8 - S_8)\left[{\alpha\beta \atop 0}\right] \frac{I_{\alpha\beta}}{\Upsilon_1\left[{\alpha\beta \atop 0}\right]}$	$N_\alpha \bar{N}_\beta (V_8 - S_8)\left[{\alpha\beta \atop 0}\right] \frac{I_{\alpha\beta}}{\Upsilon_1\left[{\alpha\beta \atop 0}\right]}$
$N_\alpha \bar{N}_\beta (V_8 - S_8)\left[{\alpha\beta \atop 0}\right] P_m(L_\parallel) W_n(L_\perp) \frac{\hat{I}_{\alpha\beta}}{\hat{\Upsilon}_1\left[{\alpha\beta \atop 0}\right]}$	$N_\alpha \bar{N}_\beta \left(V_8\left[{\alpha\beta \atop 0}\right] P_m - S_8\left[{\alpha\beta \atop 0}\right] P_{m+\frac{1}{2}}\right) W_n \frac{\hat{I}_{\alpha\beta}}{\hat{\Upsilon}_1\left[{\alpha\beta \atop 0}\right]}$

In the transverse channel tadpoles for massless states are not affected

back to the Standard-Model-like configuration



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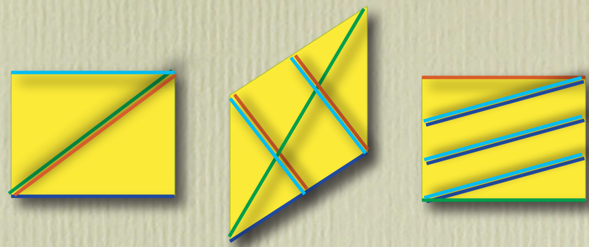
deforming along the three horizontal axis gives mass to all non-chiral fermions

back to the Pati-Salam-like configuration



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$U(1)$	$(1,0)$	$(1,-2)$	$(3,1)$

In this case it suffices to deform two of the three horizontal axis to give masses to all non-chiral states

- *Scherk-Schwarz along vertical axis affects branes with odd vertical wrapping number*
- *Scherk-Schwarz along diagonal affects branes with both horizontal and vertical w.n.'s odd*
- *Generalisation to orbifold compactification (several subtleties related to different projections at fixed points)*
- *"Partial supersymmetry breaking" ... work in progress*