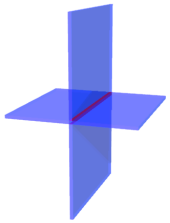
日本物理学会2009年秋季大会 甲南大学岡本キャンパス: (2009年9月12日) [12aSH-2]

Yet Another Alternative to Compactification

— Heterotic five-branes explain why Three Generations in Nature

arXiv: 0905.2185 [hep-th]



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A typical example: Calabi-Yau compactification in $E_8 \times E_8$ heterotic string theory

Standard Embedding: $\omega_m{}^{ab} \equiv A_m^{ab} \in SU(3) \quad \rightsquigarrow \quad E_8 \supset E_6 \times SU(3)$

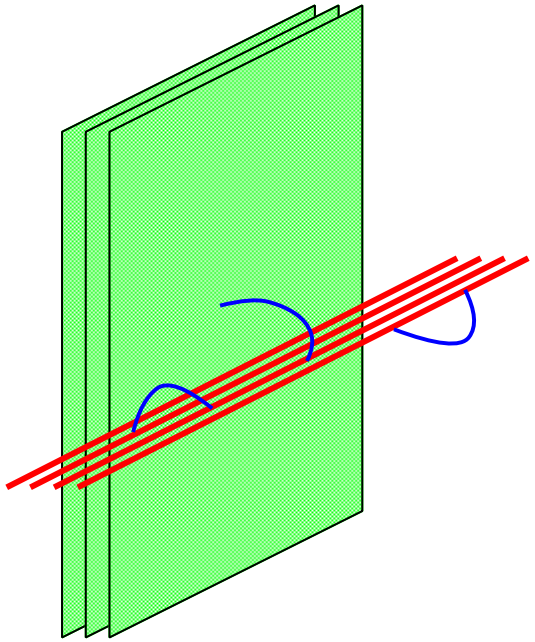
$$\#\text{ of generations } = \frac{1}{2}|\chi(\text{CY})| = \left|h^{1,1} - h^{2,1}\right|$$

$h^{1,1}$ = # of Kähler moduli = # of $(\overline{\mathbf{27}}, \overline{\mathbf{3}})$ repr. (size of CY)

$h^{2,1}$ = # of complex structure moduli = # of $(\mathbf{27}, \mathbf{3})$ repr. (shape of CY)

M.B. Green, J.H. Schwarz and E. Witten: *Chapter 16.2*

Another example: D-brane scenario in higher-dimensional theories



ex.)

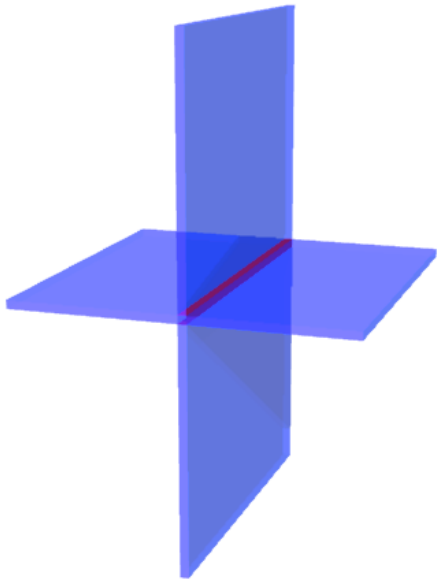
N_f D7-branes (green planes)

N_c D3-branes (red lines)

$SU(N_c)$ gauge theory with N_f flavors

Yet Another Alternative: Intersecting 5-branes in hetertotic string theory

– Our Model –



	0	1	2	3	4	5	6	7	8	9
5-brane	○	○	○	○	○	○				
5-brane'	○	○	○	○			○	○		
our world	○	○	○	○						

"Good Points"

Simple!

E_6 gauge symmetry appears

Naturally obtain 3 E_6-charged multiplets in four dimensions as Nambu-Goldstone modes

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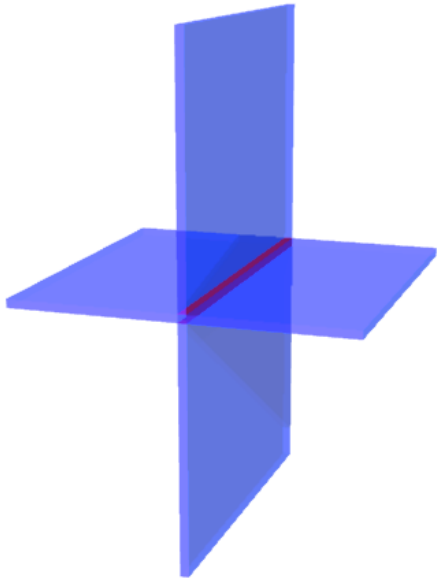


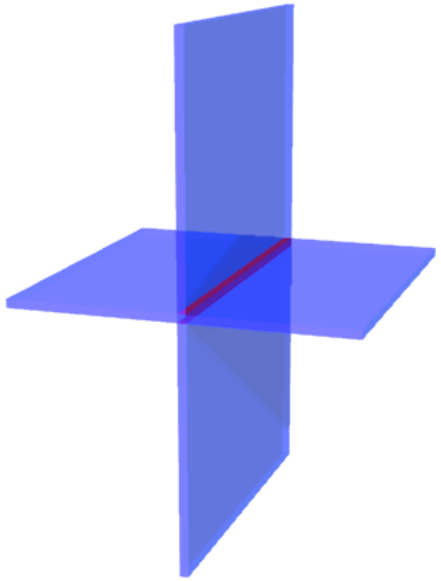
	0	1	2	3	4	5	6	7	8	9
5-brane	○	○	○	○	○	○				
5-brane'	○	○	○	○			○	○		
our world	○	○	○	○						

The string frame metric and the solution are given as

$$\mathrm{d}s^2 = \sum_{\mu,\nu=0}^{3} \eta_{\mu\nu}\,\mathrm{d}x^\mu \mathrm{d}x^\nu + h\sum_{m=4}^{7}(\mathrm{d}x^m)^2 + h^2\sum_{m=8}^{9}(\mathrm{d}x^m)^2$$

$$h = 1 + N|x^8|\,, \qquad h^2 = \mathrm{e}^{2\phi}\,, \qquad H_{459} = H_{679} = \frac{N}{2}|x^8|'$$

K. Ohta and T. Yokono, *JHEP 02 (2000) 023 + our new idea*



4 SUSY preserved (12 broken)

$\omega_{\pm m}{}^{ab} := \omega_m{}^{ab} \pm H_m{}^{ab}$

ω_{+m}: an $SU(3)$ holonomy connection in 6 directions

ω_{-m}: another $SU(3)$ holonomy connection in 6 directions

We can embed ω_{+m} into $A_m \quad \rightsquigarrow \quad SU(3)_{\text{spin}} \equiv SU(3)_{\text{gauge}} =: SU(3)_{\text{frozen}}$

$\downarrow$

E_8 gauge symmetry is broken to $E_6 \times SU(3)_{\text{frozen}}$

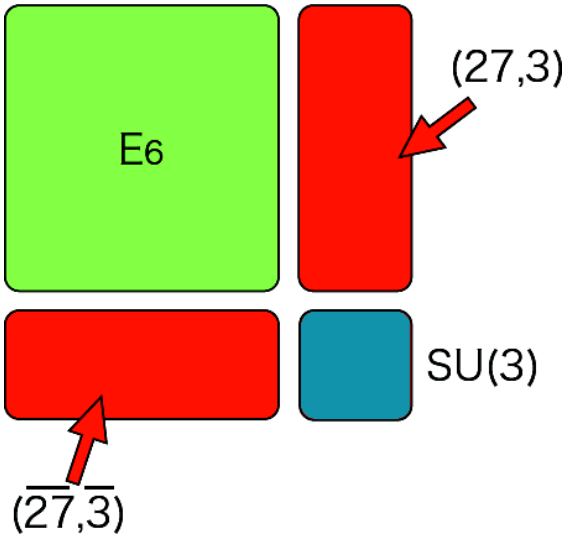
$\Downarrow$

4-dim'l $\mathcal{N} = 1$ E_6 on the intersecting spacetime

3 E_6-charged complex matter multiplets $= SU(3)$-Nambu-Goldstone modes

Counting E_6-charged chiral multiplets in 4-dim'l theory

$$E_8 \supset E_6 \times SU(3) \qquad \mathbf{248} = (\mathbf{78},\mathbf{1}) \oplus \underbrace{(\mathbf{1},\mathbf{8}) \oplus (\mathbf{27},\mathbf{3}) \oplus (\overline{\mathbf{27}},\overline{\mathbf{3}})}_{SU(3)\text{-Nambu-Goldstone}}$$



Focus only on $SU(3)$-Nambu-Goldstone

E_6 fundamental: $(27 \times 3) + (\overline{27} \times \overline{3})$

$(\mathbf{27},\mathbf{3})$ and $(\overline{\mathbf{27}},\overline{\mathbf{3}})$ are complex conjugate

$\{(27 \times 3) + (\overline{27} \times \overline{3})\}/2 = 27 \times 3$ $SU(3)$-Nambu-Goldstone complex chiral bosons

= 3 copies of complex chiral bosons of E_6 fundamental repr.

cf) C.W. Bernard, N.H. Christ, A.H. Guth and E.J. Weinberg, *Phys. Rev. D16 (1977) 2967*

The $SU(3)$-Nambu-Goldstone bosons and fermions are combined into

3 copies of complex chiral multiplets of E_6 fundamental repr.!

3 copies $=$ 3 generations!

Remark This intersecting five-brane configuration is T-dual to deformed conifold

(non-compact CY with $h^{2,1} = 1$, $h^{1,1} = 0$)

$\Downarrow$

# of generations is just one!? (from "ordinary" viewpoint)

Different counting of generations from CY compactification

- Dirac index is sensitive to # of set of $(\mathbf{27}, \mathbf{3})$,
  but insensitive to the way how these $\mathbf{27}$ are embedded into the original E_8 repr.

$\rightsquigarrow$ possibility of multiplication three by the Dirac index!

Then, the factor three differs from the counting in the CY compactification

deformed conifold (# is one) $\leftrightarrow$ intersecting five-brane (# is three)

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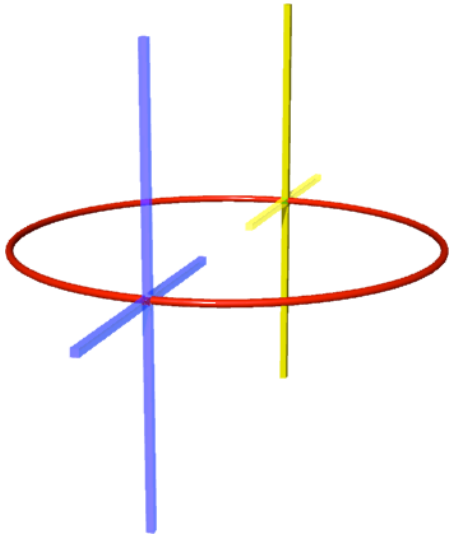
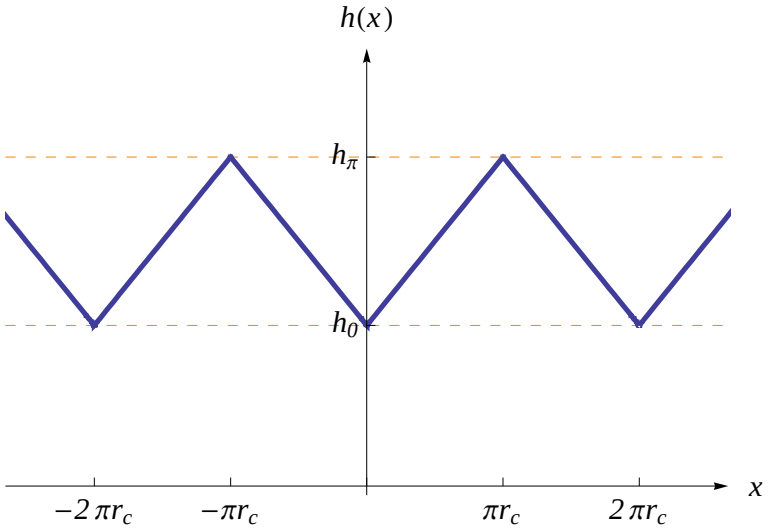
Yet Another Alternative to Compactification (cf. Randall-Sundrum 1 model)

Compactify all extra directions $(x^4, \ldots, x^9)$ to "six-torus" $(T^5 \times (S^1/\mathbb{Z}_2))$





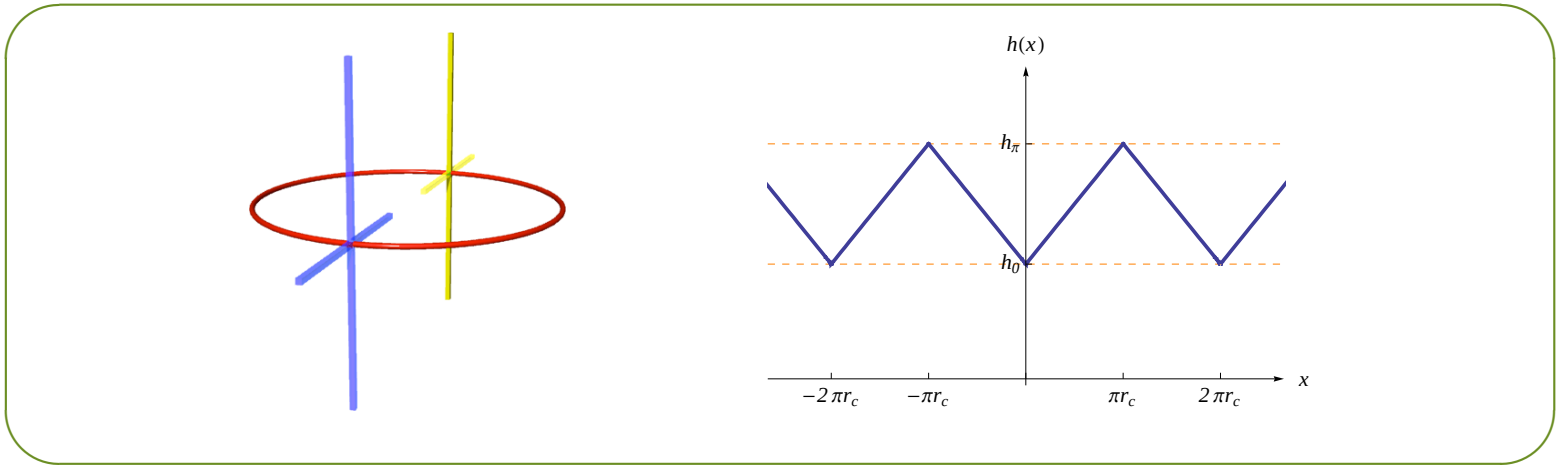
Notice:

In order to introduce objects which absorb/emit NS charges,

we have to put another intersecting 5-branes with negative tension in the x^8 direction

$\rightarrow$ Then, we modify the function h to

$$h(x^8) \;=\; h_0 + N|x^8 - 2\pi k r_c|\,, \qquad k \in \mathbb{Z}$$



- Cosmological constant vanishes

- Supersymmetry is broken completely!

  $\Rightarrow$ We obtain 4-dim'l non-SUSY model with E_6 gauge symmetry and 3 generations!

  (under the vanishing limit of h_0)

Summary

- Studied intersecting 5-branes in heterotic theory
- Obtained a simple model to yield 3 generations in four dimensions
- Applied it to considering a non-SUSY model via torus compactification