Towards flavor physics from the heterotic string

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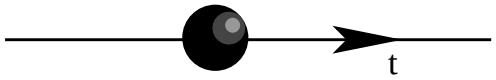
XIII Mexican Workshop on Particles and Fields

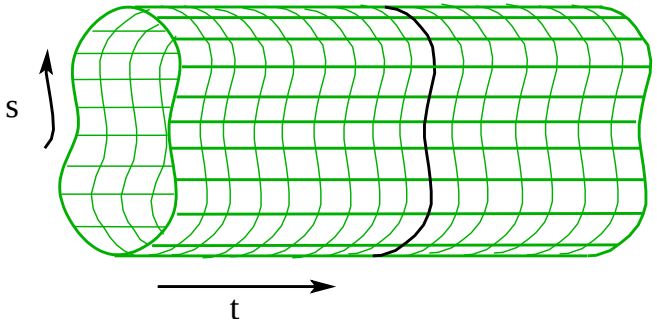
October 24, 2011

In colaboration with O. Lebedev and S. Raby: arXiv:1111.xxxx

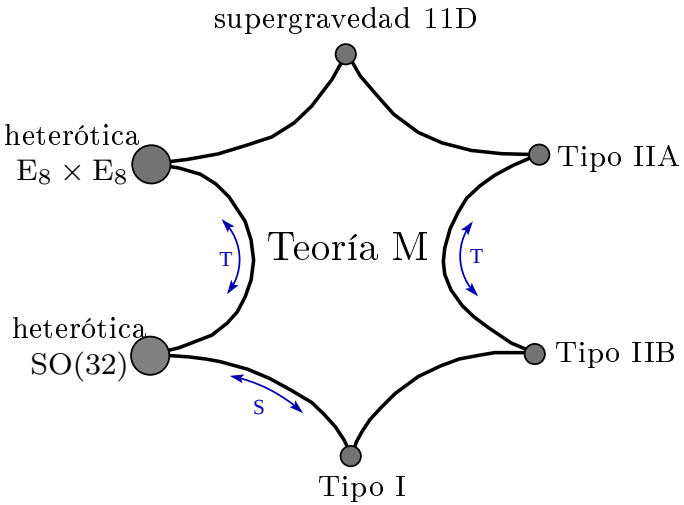
Strings

1970's: particles $\rightarrow$ strings





80-90's: 5 theories of superstrings (+branes)



quantum consistency

(no anomalies, "ghosts", tachyons):

$\rightarrow$

* graviton included ☺
* gauge bosons ☺
* supersymmetry ☺ ☹
* 10 dimensions ☹

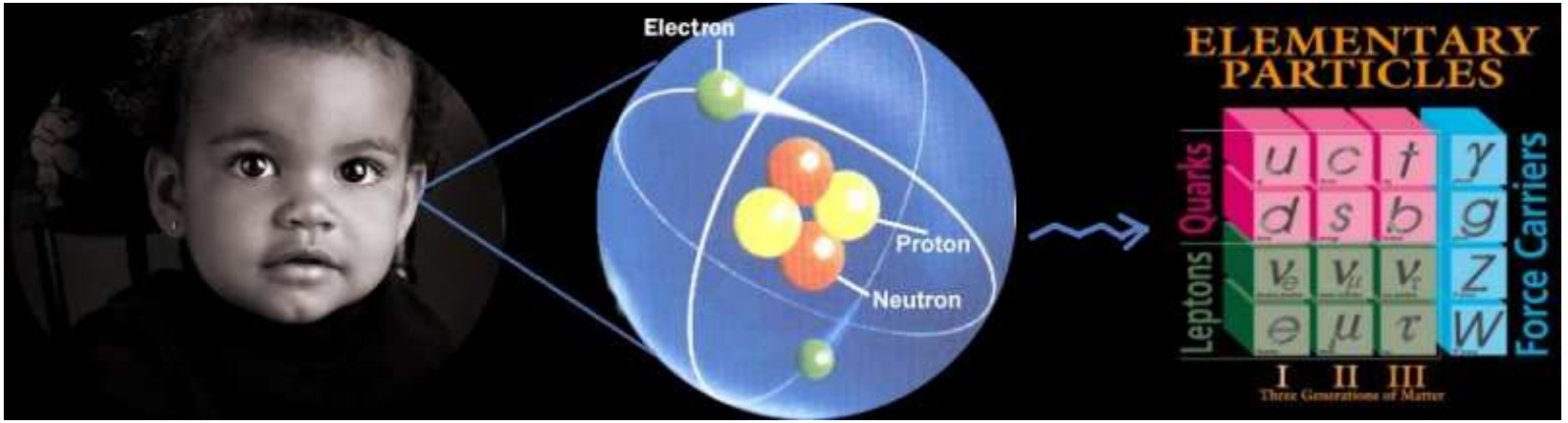
Heterotic String

- 10 D
- SUSY (rather SUGRA) $\mathcal{N}=1 \rightarrow$ chirality ✓
- gauge bosons

$$\mathrm{E}_8 \times \mathrm{E}_8 \supset \mathrm{E}_6, \mathrm{SO}(10), \mathrm{SU}(5), \mathrm{SU}(4) \times \mathrm{SU}(2)_L \times \mathrm{SU}(2)_R, \mathcal{G}_{SM} \checkmark$$

- dualities with
  heterotic $\mathrm{SO}(32)$, type IIB, F-theory,...
- only closed strings (no D-branas)
  $\rightarrow$ couplings are computable (not free parameters) !!

Where do we go to ?

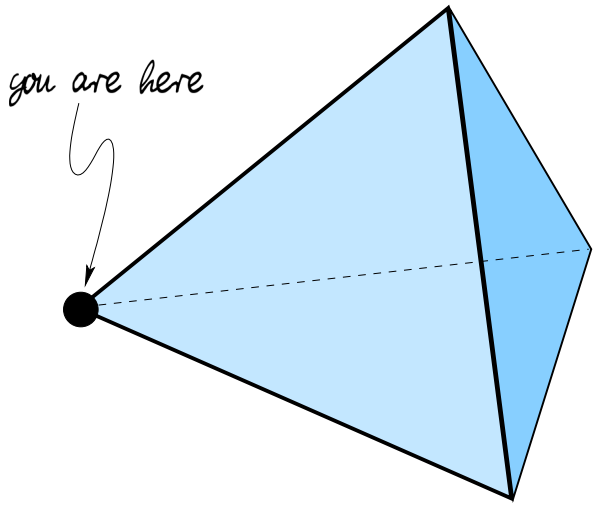


- SM = QCD $(\mathrm{SU}(3))$ + EW $(\mathrm{SU}(2)\times\mathrm{U}(1)_Y)$
- 3 generations of quarks and leptons + Higgs(es)
- (semi)realistic textures

$$V_{CKM} = \begin{pmatrix} 0.974 & 0.225 & 0.0039 \\ 0.23 & 1.02 & 0.04 \\ 0.008 & 0.038 & 0.88 \end{pmatrix}$$

- family symmetries ??

Orbifolds



Dixon, Harvey, Vafa, Witten (1985-86)

Ibáñez, Nilles, Quevedo (1987)

Casas, de la Macorra, Mondragón, Muñoz (1989-1990)

Katsuki, Kawamura, Kobayashi, Ohtsubo, Ono, Tanioka (1990)

Erler, Klemm (1993)

Förste, Nilles, Vaudrevange, Wingerter (2004)

Buchmüller, Hamaguchi, Lebedev, Ratz (2004-06)

Kobayashi, Nilles, Plöger, Raby, Ratz (2006)

Faraggi, Förste, Timirgaziu (2006)

Förste, Kobayashi, Ohki, Takahashi (2006)

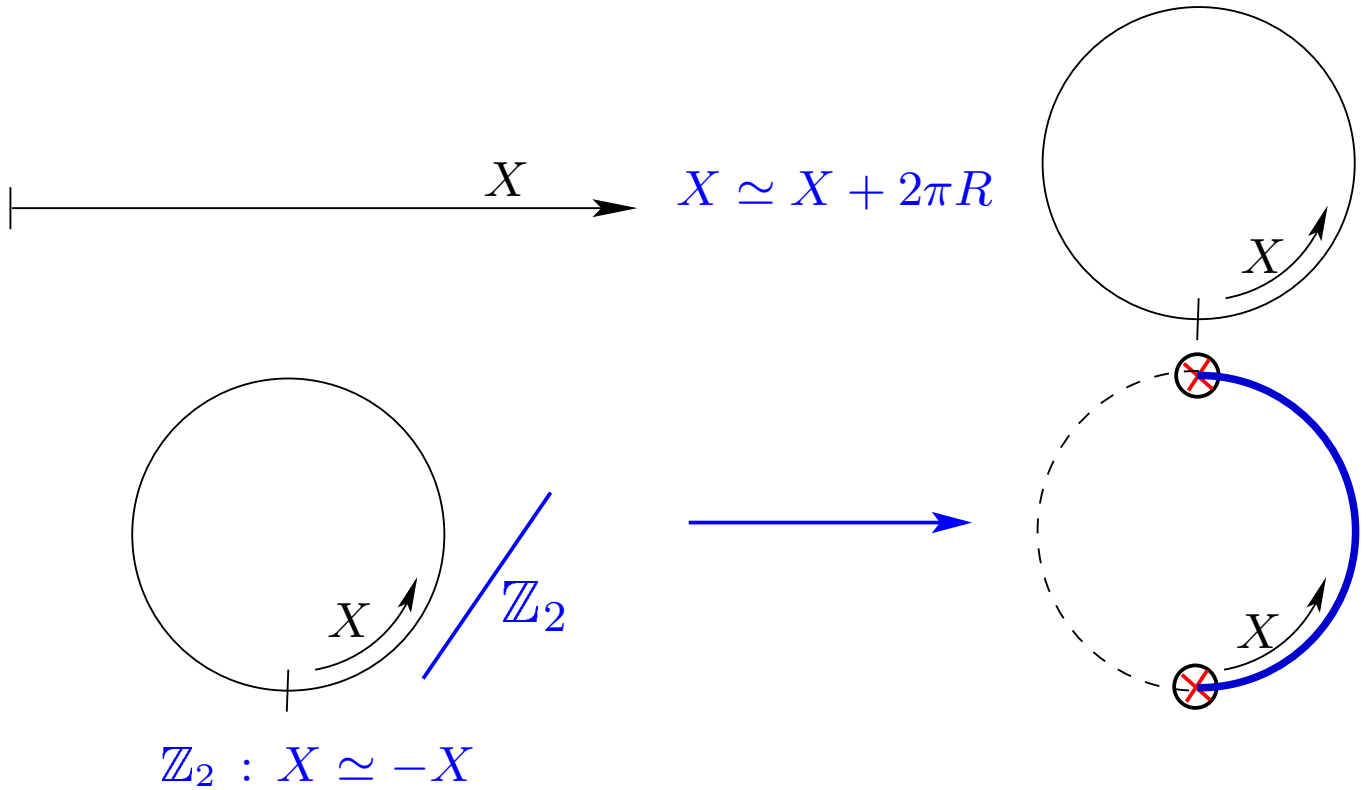
Kim, Kyae (2006-07)

Choi, Kim (2006-08)

...

Orbifold compactifications

1D $\mathbb{Z}_2$ orbifold in 5D

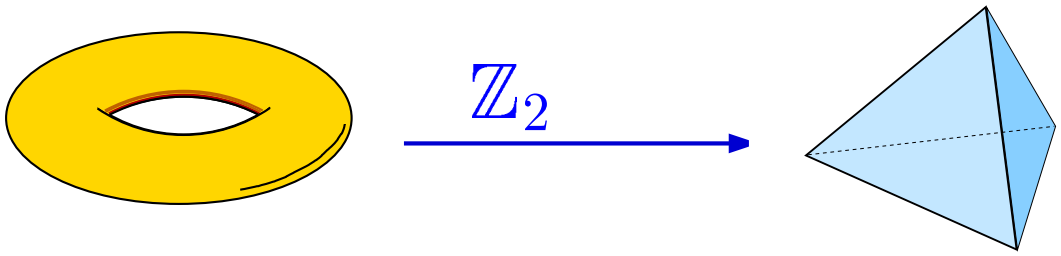


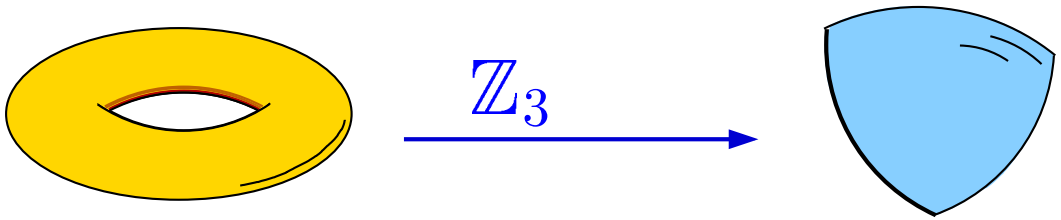
Very small singular space $R \ll 1mm \rightarrow$ inaccessible!!

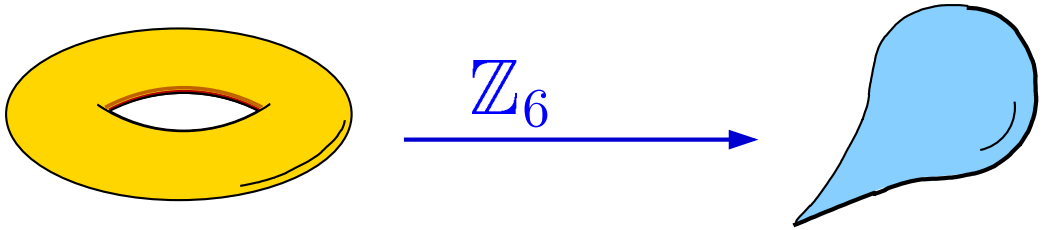
Kaluza, Klein (1920s)

Orbifold compactifications

2D $\mathbb{Z}_N$ orbifolds in 6D

T^2: 

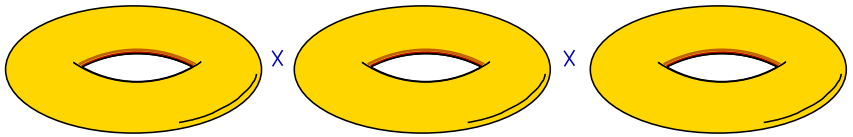
T^2: 

T^2: 

Orbifold compactifications

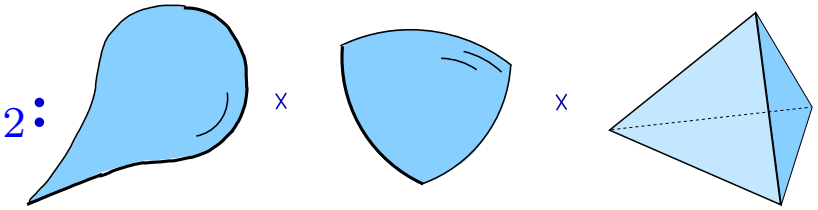
6D $\mathbb{Z}_6$–II orbifold in 10D

T^6:



$\mathbb{Z}_3 \times \mathbb{Z}_2$

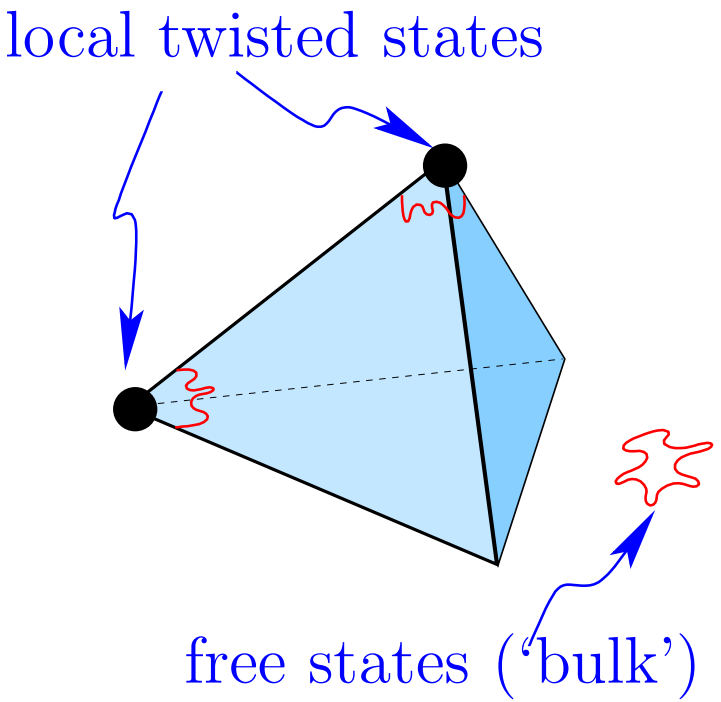
$T^6/\mathbb{Z}_3 \times \mathbb{Z}_2$:



$1 \times 3 \times 4 = 12$ equivalent fixed points

Degeneracy lifted by Wilson lines: $12 \to 6, 4, 3, 2, 1$

String on orbifolds



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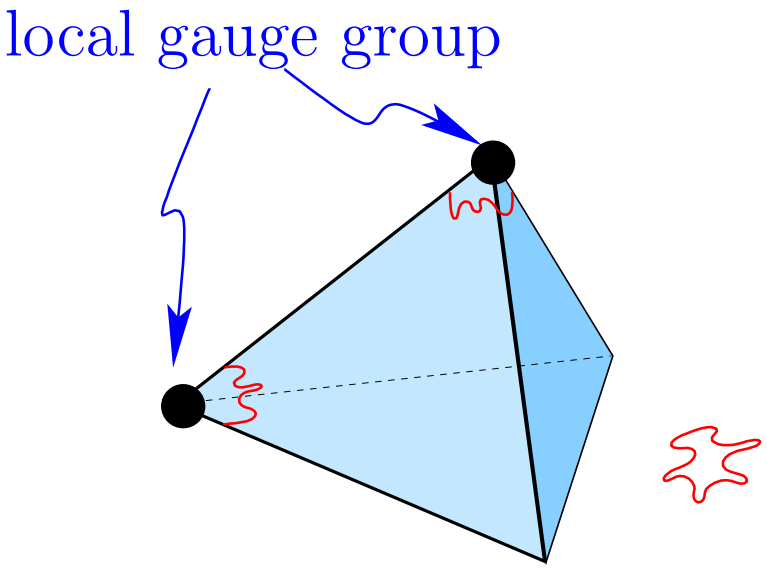
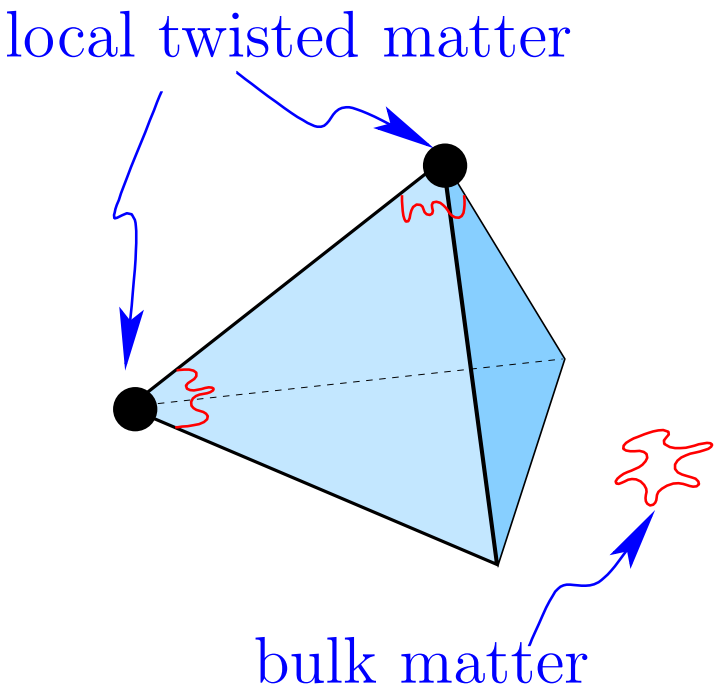


$$\mathcal{G}_{4D} = \cap \text{ local gauge groups}$$

String on orbifolds

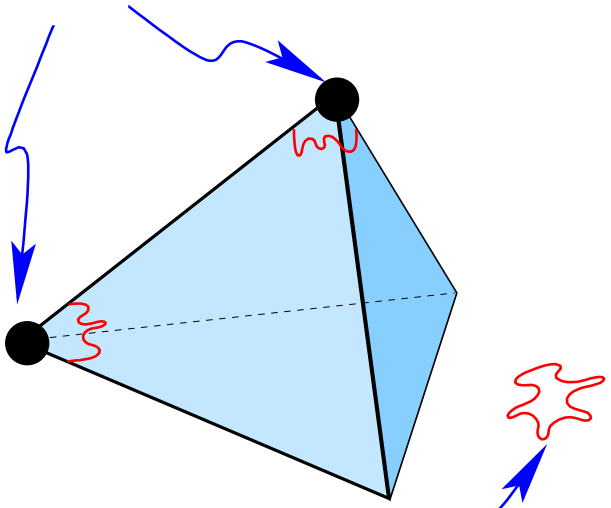


4D gauge bosons

4D gravity multiplet

String on orbifolds

2 generations



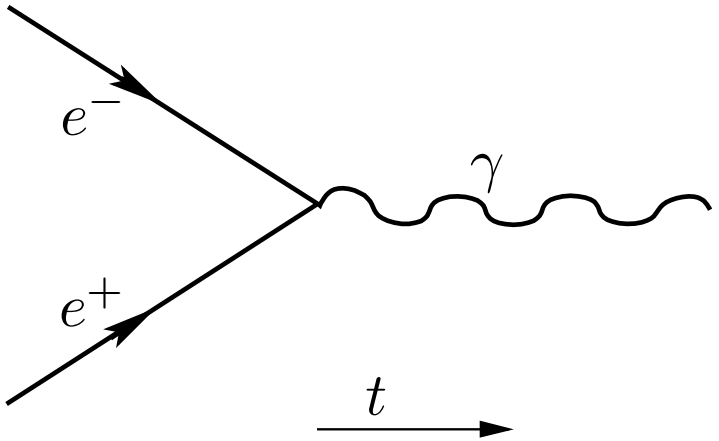
$$\mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \times \mathrm{U}(1)_{B-L} \times G_{hidden}$$

3rd generation + 2 Higgses

Lebedev,Nilles,SR-S,Ratz,Vaudrevange (2006-2008)

Couplings in orbifolds

In QFT



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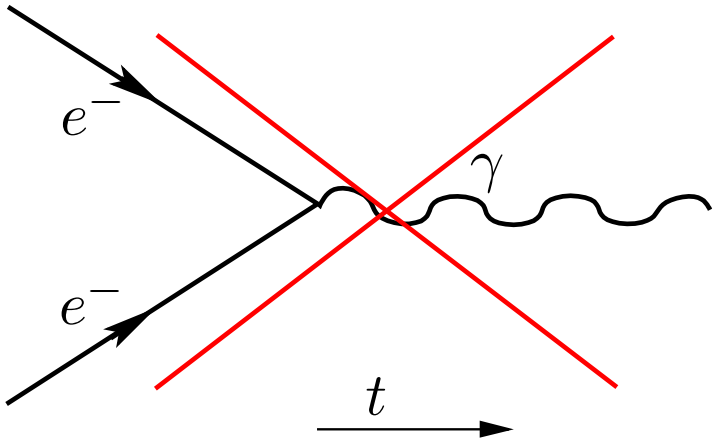
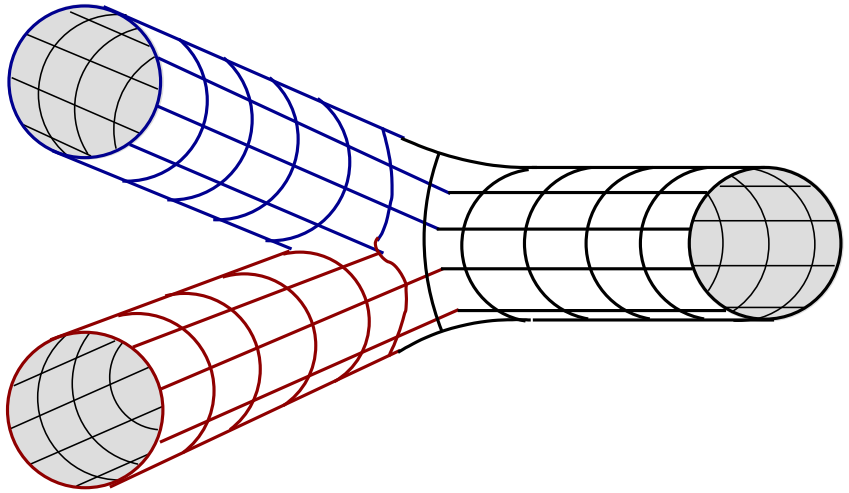


Couplings in orbifolds

In heterotic orbifolds (via instantons)



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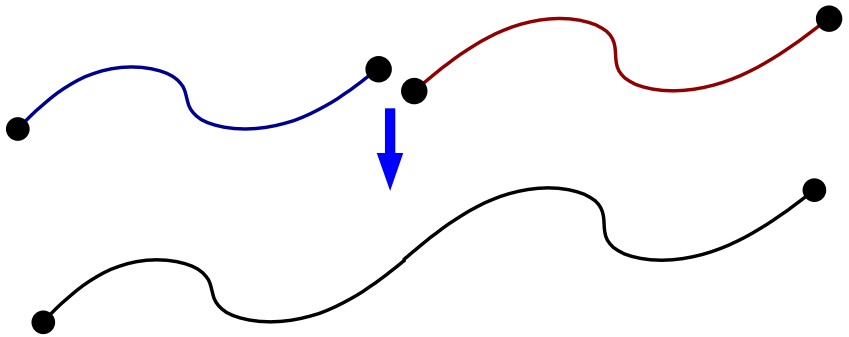

- Selection rules
  1. 'Space group' invariance: strings can combine
  2. Poincaré invariance
  3. Gauge invariance, instanton existence,...

Kobayashi, Raby, Zhang (2004); Kobayashi, Parameswaran, SR-S, Zavala (2011)

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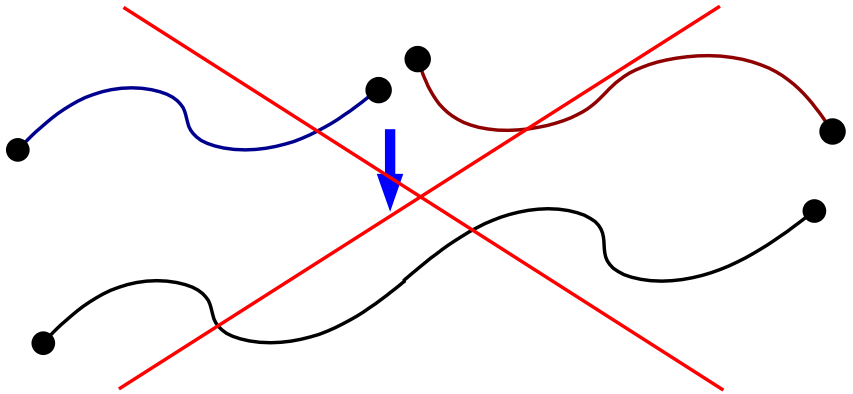

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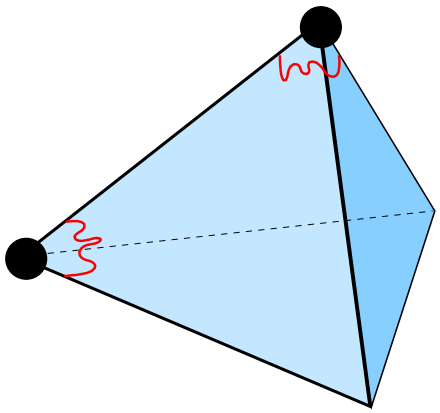
Family symmetries

- 'Space group' invariance $\longrightarrow$ $\mathbb{Z}_{n_1}$
- Poincaré invariance: $\mathrm{SO}(6)$ $\longrightarrow$ $\mathbb{Z}_{n_2}$
- Degeneracy of states $\longrightarrow$ non-abelian symmetries



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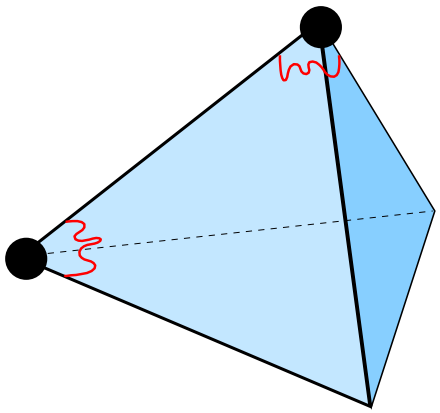

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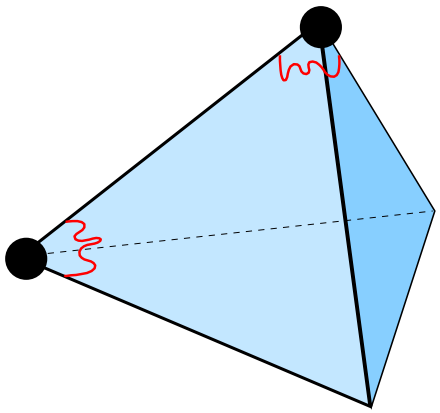

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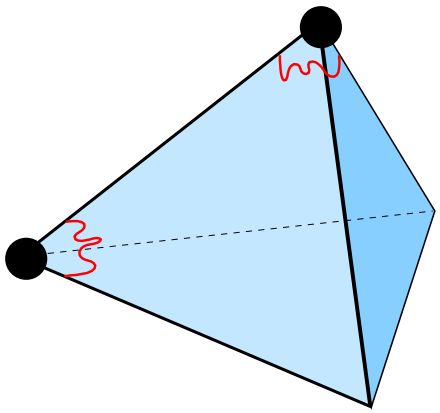

$\longrightarrow$ $S_2 \ltimes (\mathbb{Z}_2 \times \mathbb{Z}_2)$

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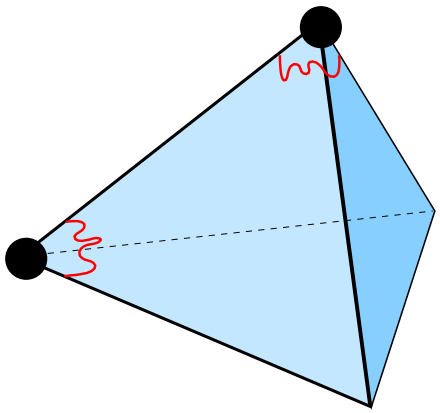

$\longrightarrow \quad S_2 \ltimes (\mathbb{Z}_2 \times \mathbb{Z}_2) = D_4$

D_4 family symmetry

Irreducible representations: $\mathbf{2}$, $\mathbf{1^{++}}$, $\mathbf{1^{+-}}$, $\mathbf{1^{-+}}$, $\mathbf{1^{--}}$

- $\mathbf{2}$: (1st gen., 2nd gen.), $(s_1, s_2), \ldots, (s_{49}, s_{50})$
- $\mathbf{1^{++}}$: 3rd gen., h_u, h_d, $s_{51}, \ldots, s_{70}$

Nontrivial doublet product $\Rightarrow$ mixing between first two generations

$$Y_u = \begin{pmatrix} y_u^{11}(s_i) & y_u^{12}(s_i) & 0 \\ y_u^{12}(s_i) & y_u^{11}(s_i) & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad Y_d = \begin{pmatrix} y_d^{11}(s_i) & y_d^{12}(s_i) & 0 \\ y_d^{12}(s_i) & y_d^{11}(s_i) & 0 \\ 0 & 0 & y_d^{33}(s_i) \end{pmatrix}$$

$y^{jk}_{u,d,e,\nu}(s_i)$ are computable (CFT techniques) ☺

s_i parameters, must be fixed dynamically!

D_4 symmetry breakdown

To fix s_i, compute W, K and impose $\mathcal{N} = 1$

$$\Rightarrow \quad F_{s_i} = 0 \quad \text{and} \quad D = 0$$

$$\Downarrow$$

some $s_i \sim \mathcal{O}(0.01) - \mathcal{O}(1)$

D_4 spontaneously broken ☺

$$Y_u = \begin{pmatrix} y_u^{11}(s_i) & y_u^{12}(s_i) & \epsilon \\ y_u^{21}(s_i) & y_u^{22}(s_i) & \epsilon' \\ \epsilon'' & \epsilon''' & 1 \end{pmatrix} \qquad Y_d = \begin{pmatrix} y_d^{11}(s_i) & y_d^{12}(s_i) & \varepsilon \\ y_d^{21}(s_i) & y_d^{22}(s_i) & \varepsilon' \\ \varepsilon'' & \varepsilon''' & y_d^{33}(s_i) \end{pmatrix}$$

Quark masses

- Quark sector of a particular model

$$Y_u \sim \begin{pmatrix} 0.0316 & 0.0316 & 0.0085 \\ 0.0316 & 0.031 & 0.00841 \\ 0.0183 & 0.0183 & 1.14437 \end{pmatrix},$$

$$Y_d \sim \begin{pmatrix} 0.00048 & 0.00066 & 6.2 \times 10^{-7} \\ 0.00066 & 0.00048 & 1.0 \times 10^{-7} \\ 0.00009 & 0.00004 & 0.036 \end{pmatrix},$$

$$|Y_u^{\text{diag}}| \sim \text{diag}(0.0003, 0.063, 1.14)\,,$$
$$|Y_d^{\text{diag}}| \sim \text{diag}(0.0002, 0.001, 0.036)\,.$$

semirealistic quark masses! ☺

Lebedev,Raby,SR-S (2011)

Mass mixing

- Matrix de CKM

$$V_{CKM}^{teo} = \begin{pmatrix} 0.99 & 0.05 & 0.0003 \\ 0.05 & 0.99 & 0.01 \\ 0.0008 & 0.01 & 0.98 \end{pmatrix}$$

but

Mass mixing

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$$V_{CKM}^{teo} = \begin{pmatrix} 0.99 & 0.05 & 0.0003 \\ 0.05 & 0.99 & 0.01 \\ 0.0008 & 0.01 & 0.98 \end{pmatrix}$$

but

$$V_{CKM}^{exp} = \begin{pmatrix} 0.974 & 0.225 & 0.0039 \\ 0.23 & 1.02 & 0.04 \\ 0.008 & 0.038 & 0.88 \end{pmatrix}$$

but close!

To conclude

- All ingredients to study textures in heterotic orbifolds ✓
- Models with the exact matter content of SM ✓
- Semirealistic quark/lepton masses ✓

To conclude

- All ingredients to study textures in heterotic orbifolds ✓
- Models with the exact matter content of SM ✓
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- *Close* but not quite there ☹
- *Possible* dangerous FCNC ☹ Raby,SR-S,Lebedev in progress...

2012 Estancias de Verano Teóricas

Φ-sica de altas energías

¿Te interesa la física teórica de altas energías y estudias el último año de licenciatura o el primero de maestría?

Compite para hacer una estancia de investigación de dos meses durante el verano del 2012 en el ICTP o en el JLab con todos los gastos cubiertos.

Bases e inscripción:
http://stringpheno.fisica.unam.mx/veranosteoricos/

Fecha límite de recepción de solicitudes:
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