BUCHMÜLLER

WB, MPI, 6-05

HYBRID UNIFICATION FROM STRINGS ON ORBIFOLDS*

- Motivation: Orbifold GUTs
- Symmetry breaking in a Z_6 model: geometry and zero modes
- Yukawa couplings etc.

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hep-ph/0412318, in preparation

some references :

- Dixon, Harvey, Vafa, Witten '86

  Ibáñez, Kim, Nilles, Quevedo '87

  ⋮

- Katsuki, Kawamura, Kobayashi, Ohtsubo, Ono, Tanioka '90

  ⋮

- Kobayashi, Raby, Zhang hep-ph/0403065, 0409098

  Förste, Nilles, Vandrevange, Wingerter, hep-ph/0406208

- Hebecker, Trapletti, hep-th/0411131

new ingredient : search for orbifold compactification of heterotic string with 'intermediate' GUT

(1) Motivation: Orbifold GUTs

effective SUSY field theory with GUT gauge group, $G = SU(5), SO(10), \ldots$, in $D = 5, 6, \ldots$, compactified on orbifold (Kawamura; Altarelli, Feruglio; Hall, Nomura; Hebecker, March-Russell; ...)

attractive features: simplicity of GUT symmetry breaking, related doublet-triplet splitting, absence of dim 5 operators for proton decay, characteristic flavour physics, ...

open questions: choice of gauge group, matter fields in bulk and at fixed points, UV completion

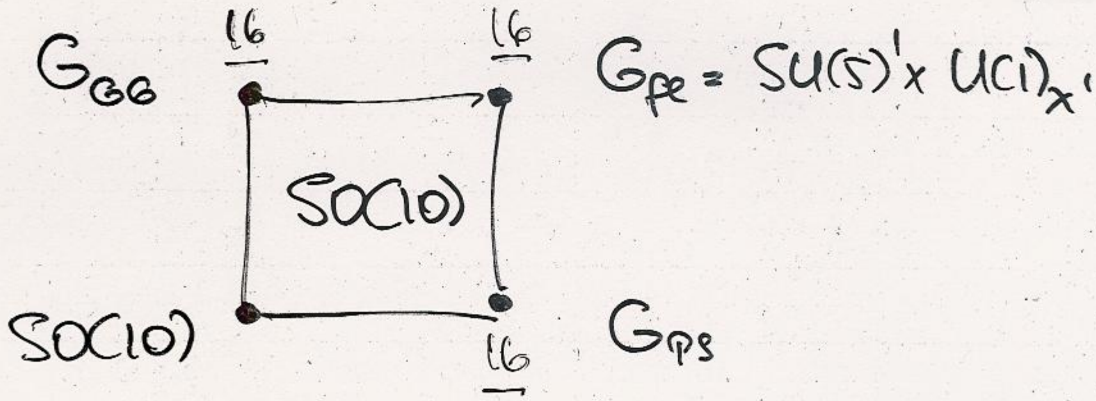
(i.e. limited predictivity)

$\longrightarrow$ strings on orbifolds

example (Asaka, WB, Covi)

SO(10) gauge theory in 6D, N=2 SUSY

space: $M_4 \otimes T^2/Z_2$



SM gauge group from intersection of Pati-Salam and Georgi-Glashow:

$$G_{PS} = SU(4) \times SU(2) \times SU(2), \quad G_{GG} = SU(5) \times U(1)_X$$

$$G_{PS} \cap G_{GG} = G_{SM'} = G_{SM} \times U(1)_X$$

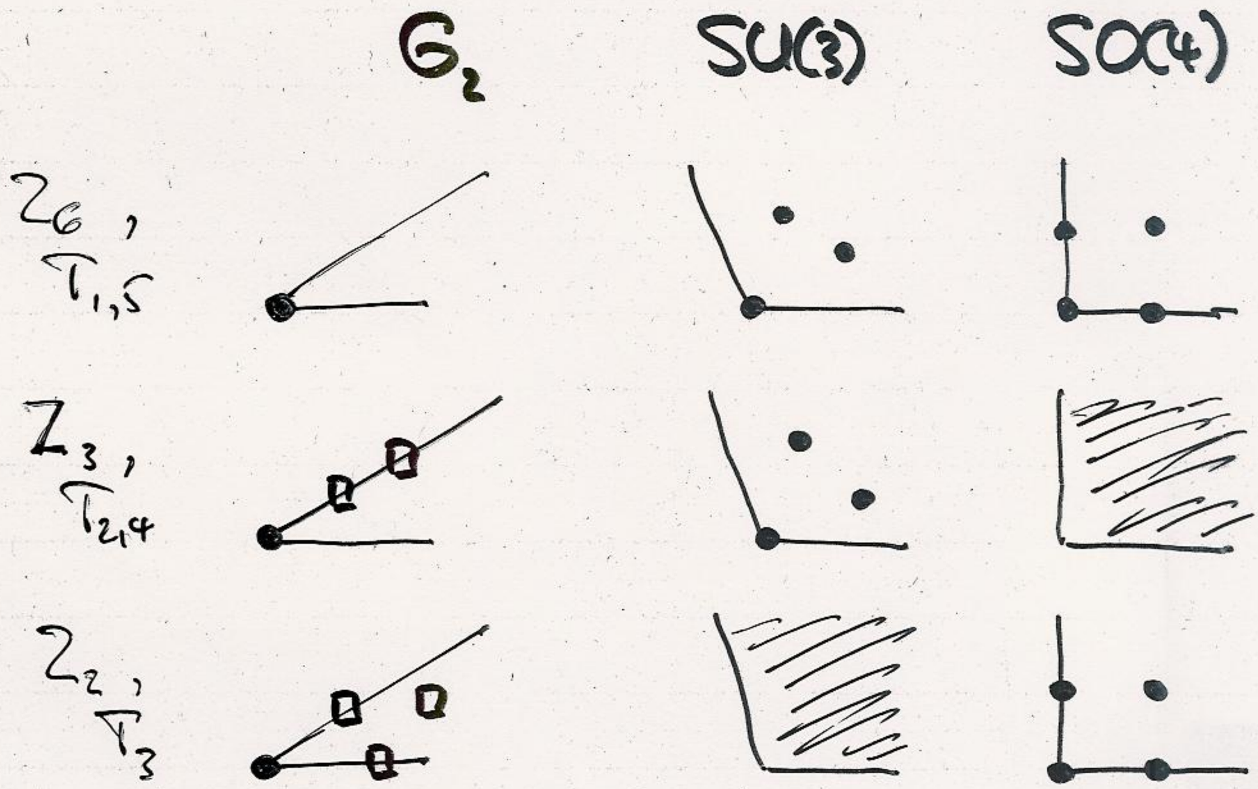
symmetry breaking is <u>local</u>, also part of the matter fields

results: realistic extension of SM, B-L breaking, seesaw mechanism, specific predictions for flavour physics

(2) Symmetry breaking in a Z_6 model: geometry and zero modes

search : compactification which has fixed points with $E_8 \supset G \supset SO(10)$, $(\underline{16}, \ldots)$ three generations, G_{SM} in $D=4$

$$O = T^6_{G_2 \times SU(3) \times SO(4)} / Z_6$$



characteristic feature : invariant planes w.r.t. subtwists ; additional fixed points in G_2 plane

the model :

$\mathcal{O}$: $v_6 = \frac{1}{6}(0;-1,-2,3)$

$T_{E_8\times E_8'}/Z_6$:

$$V_6 = \left(\tfrac{1}{2}\,\tfrac{1}{2}\,\tfrac{1}{3}\,0\,0\,0\,0\,0\right)\left(-\tfrac{1}{3}\,0^7\right)$$

$$W_2 = \left(-\tfrac{1}{2}\,\tfrac{1}{2}\,0\,\tfrac{1}{2}\,\tfrac{1}{2}\,0\,0\,0\right)\left(1\,0^7\right)\,,\quad W_2' = 0$$

$$W_3 = \left(\tfrac{1}{3}\,0\,0\,\tfrac{1}{3}\,\tfrac{1}{3}\,\tfrac{1}{3}\,\tfrac{1}{3}\,\tfrac{1}{3}\right)\left(0^8\right)$$

unbroken gauge group (up to U(1) factors):

$$G = SU(3)\times SU(2)\times [SO(14)]$$

hidden sector

massless spectrum :

$$2\times(16;1) + \Big((3,2;1)_{\frac{1}{6}} + (\bar{3},1;1)_{-\frac{2}{3}} + (\bar{3},1;1)_{\frac{1}{3}}$$

3 gen.

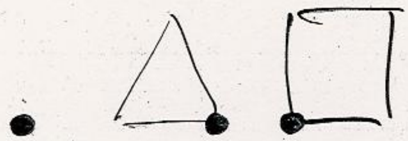
$$(1,2;1)_{-\frac{1}{2}} + (1,1;1)_{1} + (1,1;1)_{0}\Big)$$

2 sequ.

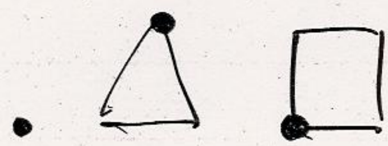
$$\left.\begin{aligned} &+ 16\big((\bar{3},1;1) + (3,1;1)\big) + 34\,(1,2;1) \\ &+ 7\,(1,1;14) + 86\,(1,1;1) \end{aligned}\right\}\ \text{vector-like}$$

Geometry of local symmetries (U_6)

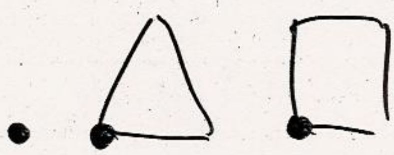
always: $SO(14)$ in hidden sector



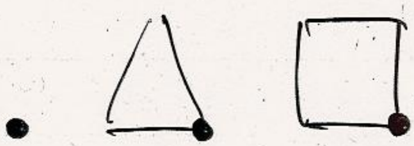
$SO(10) \times SO(4)' \supset SU(5)$



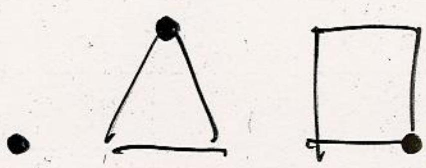
$SO(12)$ "



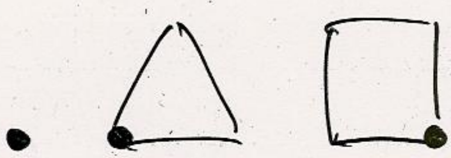
$SU(7)$ "



$SO(10)' \times SO(4) \supset SU(4)_{PS}$



$SU(7)'$ "



$SU(7)''$ "

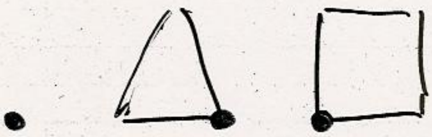
multiplicity: 2 ($n_2' = 0, 1$) ;

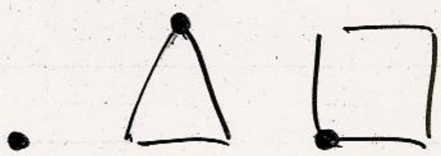
all groups different, intersection yields G_{SM}

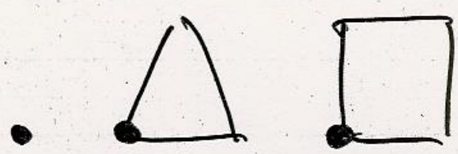
(hybrid) unification

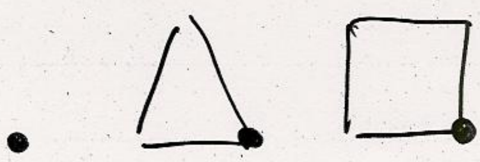
Localization of zero modes (T_1)

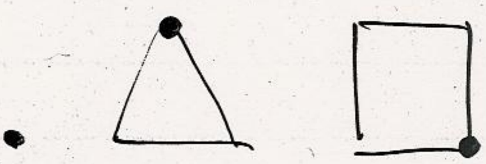
all singlets w.r.t. $SO(14)$

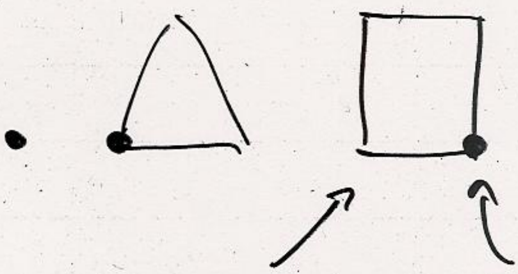
-  $\{(16,1,1)\} + 2\,(1,2,1) + (1,1,2)$

-  $12 + 5 \times 1$
  $\supset 5 + \bar{5}$ [$SU(5)$]

-  $7 + \bar{7} + 3 \times 1$
  $\supset 5 + \bar{5}$

-  $(1,2,1) + (1,1,2)$
  $\supset (1,2)_0$ [G_{SM}]

-  $7' + 1$
  $\supset (\bar{3},1)_{-\frac{1}{6}} + (1,2)_0$

-  $7'' + 1$
  $\supset (3,1)_{\frac{1}{6}} + (1,2)_0$

normal exotic

multiplicity : 2 ($n_2' = 0, 1$)

$\rightarrow \; 2 \times 16 + 6\,((3,1) + (\bar{3},1)) + 14\,(1,2)$ vector-lik

$T_{2,4}, T_3$: more complicated

untwisted sector:

U_1 : $(\bar{3},1;1)_{-\frac{2}{3}}$, $(1,1;1)_1$, $(1,1;1)_0$

U^c_3 E^c_3 N^c_0

U_2 : $(3,2;1)_{\frac{1}{6}}$, $(1,1;14)$

Q_3

U_3 : $(1,2;1)_{-\frac{1}{2}}$ $(1,2;1)_{\frac{1}{2}}$

H_d H_u

$(\ast, \ast; \ast)$ ← SO(14)

$SU(3)_c$ $SU(2)_L$

<u>puzzling</u> <u>feature</u> of SM: Higgs + gauge fields in split multiplets, matter in GUT reps.

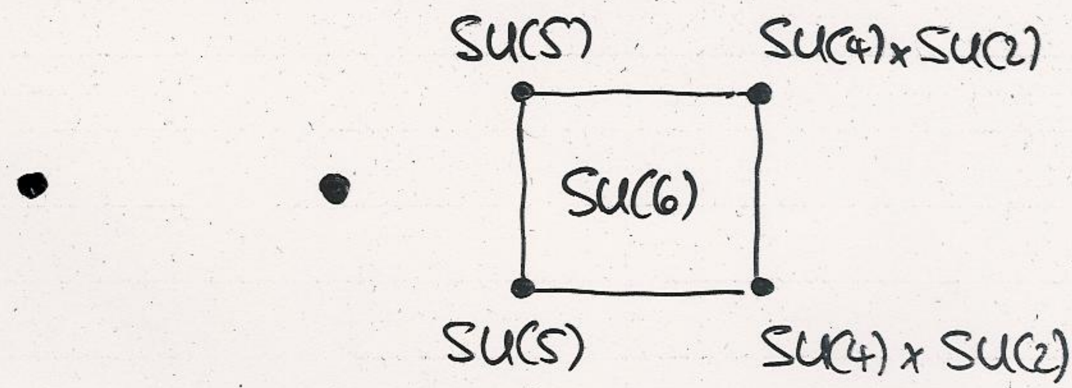
reason (mostly): localization at fixed points with enhanced (GUT) symmetry

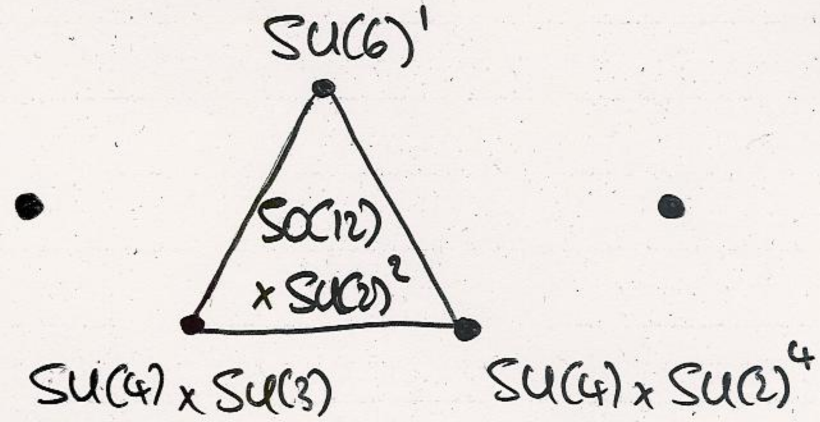
Intermediate GUTs

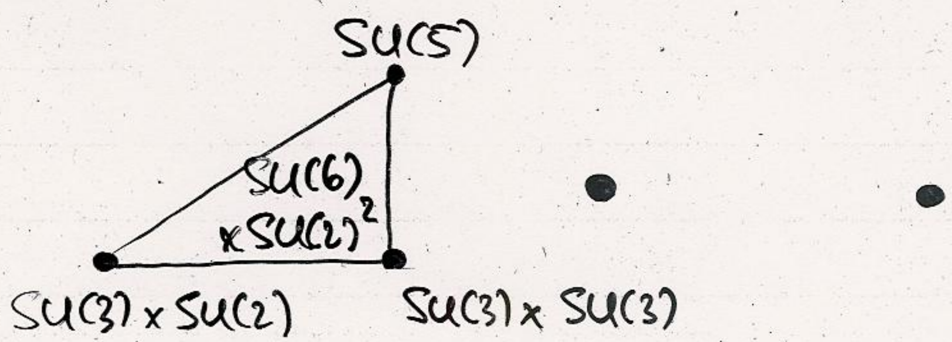
2 planes : $R_s \sim \frac{1}{M_{string}}$, 1 plane : $R_u \sim \frac{1}{M_{GUT}} \gg R_s$

→ 6D effective field theory (unification of couplings, dynamically possible ?)

3 possibilities :







same zero modes, but <u>different</u> <u>localization</u>

→ different Yukawa couplings

(3) Yukawa couplings etc.

Breaking of U(1) factors ? mass generation?
decoupling of vector-like zero modes ?
requires Yukawa couplings :

$$\langle V_{-\frac{1}{2}} V_{-\frac{1}{2}} V_{-1} V_0 \dots V_0 \rangle$$

→ <u>selection</u> <u>rules</u>; only one renormalizable
quark-lepton coupling :

$U_1 U_2 U_3$: $U_3^c Q_3 H_u$ top-quark

Flat directions of superpotential ? large
Majorana ν - masses from breaking of B-L ?
quark-lepton mass hierarchy from higher-
dimensional operators ? electroweak symmetry
breaking ?

......

supersymmetry breaking ?

... **geometrical understanding of quark-
lepton quantum numbers intriguing ...**