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Gauge symmetry breaking on orbifolds

XXXVIIth Rencontres de Moriond, 9-16 March 2002

Summary

1 New methods for symmetry breaking in space-time with extra spatial dimensions:
  - Scherk-Schwarz mechanism
  - Hosotani mechanism
  - Orbifold projection

2 Application to Grand Unified Theories: SUSY SU(5) on $S^1/Z_2 \times Z_2'$

3 Generalized Scherk-Schwarz mechanism on orbifolds

4 Application to SUSY SU(5) on S^1/Z_2

5 Comparison between the two methods

6 Localized Lagrangian terms from discontinuities

7 Conclusions

Symmetry breaking with extra dim

$4 + E \to 4$ DIMENSIONS

⇝ Ordinary dimensional reduction:
fields independent from y^α $\to$ no S.B.

⇝ Generalized dimensional reduction:
fields can depend on y^α $\to$ S.B.

★ E=1 on a circle S^1 of radius $R \sim 1/M_{GUT}$
$x_M = (x_\mu, y)$ $M = \mu, 5$ $\mu = 0, ..., 3$

$$\Phi(x,y) = \frac{1}{\sqrt{2\pi R}} \sum_{n=-\infty}^{\infty} \Phi_n(x)\ e^{i\frac{n}{R}y}$$

4 dim: $\Phi_n(x) \to m_n = \frac{n}{R}$ Kaluza-Klein tower

∗ Scherk-Schwarz mechanism Scherk,Schwarz (1979)

$\Phi(x, y + 2\pi R) = U\Phi(x,y)$ Φ not single valued
possible if U is a symmetry of the theory

· $\mathcal{L}^{5D} = \partial_M \Phi^\dagger \partial^M \Phi$ $\Phi \mapsto e^{i\alpha}\Phi$ symmetry

$$\Phi(x,y) = \frac{1}{\sqrt{2\pi R}} \sum_{n=-\infty}^{\infty} \Phi_n(x)\ e^{i\frac{n}{R}y} e^{i\frac{\alpha}{2\pi R}y}$$

4 dim: $\Phi_n(x) \to m_n = \frac{n}{R} + \frac{\alpha}{2\pi R}$

Symmetry breaking with extra dim

∗ Hosotani mechanism Hosotani (1983)

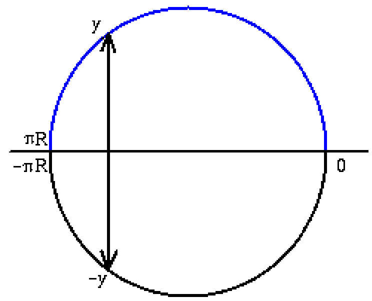
local symmetries → gauge symmetry

twisted fields → *gauge transformation* → periodic fields

$< A_5^a > \neq 0 \quad \Rightarrow \quad$ spontaneous symmetry breaking

⇝ Order parameter: WILSON LINE:

$$W = P \exp\left(ig \int_y^{y+2\pi R} A_5 dy \right) U$$



∗ Orbifold projection

discrete symmetry: $Z_2 : y \mapsto \text{-}y$

$\Phi(x,\text{-}y) = P\Phi(x,y) \quad P = \pm 1$

$$\Phi(x,y) = \begin{cases} \frac{1}{\sqrt{\pi R}} \sum_{n=0}^{\infty} \Phi_n^+(x)\ cos(\frac{n}{R}y) & P = +1 \\ \frac{1}{\sqrt{\pi R}} \sum_{n=1}^{\infty} \Phi_n^-(x)\ sin(\frac{n}{R}y) & P = -1 \end{cases}$$

⇝ zero modes only for even fields

· Φ N-plet of some gauge group

$P \neq \pm 1 \ \Rightarrow$ symmetry breaking

SUSY SU(5) on $S^1/Z_2 \times Z_2'$

Kawamura (2000)

$$M^4 \times S^1/Z_2 \times Z_2' \quad R \qquad \Leftrightarrow \qquad M^4 \times S^1/Z_2 \quad R' = \frac{R}{2}$$

$$Z_2 : y \mapsto \text{-}y \qquad\qquad Z_2 : y \mapsto \text{-}y$$

$$Z_2' : y' \mapsto \text{-}y' \;\; y' = y + \frac{\pi R}{2} \qquad\qquad T(2\pi R') : y \mapsto y + 2\pi R$$

$$Z_2' = Z_2 \times T(2\pi R')$$

Non trivial Z_2' $\Leftrightarrow$ non trivial U $\rightarrow$ S.S. mechanism

⋆ Fields content: $V = (A_M, \lambda^1, \lambda^2, \Sigma) \;\rightarrow \underline{24}$ of $SU(5)$
$H^1, H^2 \Leftrightarrow (H_5, \hat{H}_{\overline{5}}), (\hat{H}_5, H_{\overline{5}}) \rightarrow \underline{5}, \underline{\overline{5}}$

(Z_2,Z_2')	(Z_2,U)	fields	eigenfunctions
$(+,+)$	$(+,+)$	$A^a_\mu, \lambda^{2a}, H^D_u, H^D_d$	$cos\frac{2n}{R}y$
$(+,-)$	$(+,-)$	$A^{\hat{a}}_\mu, \lambda^{2\hat{a}}, H^T_u, H^T_d$	$cos\frac{2n+1}{R}y$
$(-,+)$	$(-,-)$	$A^{\hat{a}}_5, \Sigma^{\hat{a}}, \lambda^{1\hat{a}}, \hat{H}^T_u, \hat{H}^T_d$	$sin\frac{2n+1}{R}y$
$(-,-)$	$(-,+)$	$A^a_5, \Sigma^a, \lambda^{1a}, \hat{H}^D_u, \hat{H}^D_d$	$sin\frac{2n+2}{R}y$

- Z_2 breaks N=2 SUSY down to N=1 SUSY
- Z_2' breaks SU(5) down to SU(3)×SU(2)×U(1) (MSSM)
  - $\rightsquigarrow$ D-T splitting is solved

Generalized S.S. mechanism

Bagger, Biggio, Feruglio, Zwirner (to appear)

S^1 $\to$ boundary conditions: $T(2\pi R)$

S^1/Z_2 $\to$ fields can jump at the fixed point

$$\begin{cases} \Phi(2n\pi R + \xi) & = & U_0 \; \Phi(2n\pi R - \xi) \\ \Phi((2n+1)\pi R + \xi) & = & U_\pi \; \Phi((2n+1)\pi R - \xi) \\ \Phi(y + 2\pi R) & = & U_\beta \; \Phi(y) \end{cases}$$

and identical conditions for $\partial_y \Phi$

- Requirements:
  - $* \; -\partial_y^2$ self-adjoint
  - $*$ physical quantities periodic and continuous

    $\Rightarrow U \in G$ symmetry group of the theory
  - $*$ consistency conditions among $Z, \; U_\beta, \; U_0, \; U_\pi$:

    $U_\gamma Z U_\gamma = Z \quad \gamma = \beta, 0, \pi$

    $[U_0, U_\beta] = [U_\pi, U_\beta] = 0$

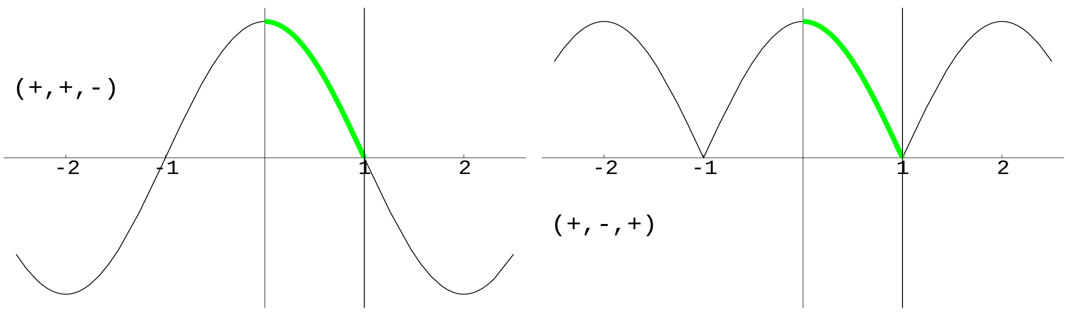
Generalized S.S. mechanism

One real scalar field

$G = Z_2 \Rightarrow Z = \pm 1 \quad (U_0,\ U_\pi,\ U_\beta) = (\pm 1, \pm 1, \pm 1)$

$$Z = 1 \quad \begin{array}{lll} (+1,+1,-1) & cos(my) & mR = n + \frac{1}{2} \\ (+1,-1,+1) & \epsilon(\frac{y}{2} + \frac{\pi R}{2}) cos(my) & mR = n + \frac{1}{2} \end{array}$$

$\rightsquigarrow$ The spectrum is the same!



Eigenfunctions: $\Phi(y) = \epsilon(\frac{y}{2} + \frac{\pi R}{2})\Phi^c(y)$

> We have a MAP between
> a smooth and twisted system
> and a discontinuous and periodic system

More scalar field

$\rightsquigarrow$ continuous parameters can appear

Examples: One complex scalar field

Gauge fields

SUSY SU(5) on S^1/Z_2

⋆ Fields content: $V = (A_M, \lambda^1, \lambda^2, \Sigma) \;\to \underline{24}$ of $SU(5)$
$H^1, H^2 \Leftrightarrow (H_5, \hat{H}_{\overline{5}}), (\hat{H}_5, H_{\overline{5}}) \to \underline{5}, \overline{\underline{5}}$

(Z_2, U_π)	fields	eigenfunctions
$(+,+)$	$A_\mu^a, \lambda^{2a}, H_u^D, H_d^D$	$cos(\frac{n}{R'}y)$
$(+,-)$	$A_\mu^{\hat{a}}, \lambda^{2\hat{a}}, H_u^T, H_d^T$	$\epsilon(\frac{y}{2}+\frac{\pi R}{2})cos(\frac{2n+1}{2R'}y)$
$(-,-)$	$A_5^{\hat{a}}, \Sigma^{\hat{a}}, \lambda^{1\hat{a}}, \hat{H}_u^T, \hat{H}_d^T$	$\epsilon(\frac{y}{2}+\frac{\pi R}{2})sin(\frac{2n+1}{2R'}y)$
$(-,+)$	$A_5^a, \Sigma^a, \lambda^{1a}, \hat{H}_u^D, \hat{H}_d^D$	$sin(\frac{n+1}{R'}y)$

$R' = \frac{R}{2} \Rightarrow$ Same spectrum as in the Kawamura model!!!

Eigenfuncions: 1 & 4: OK

2 & 3: field redefinition:

$$\Phi^c(y) = \epsilon(\frac{y}{2}+\frac{\pi R}{2})\Phi(y)$$

We obtained the same results of Kawamura

Our fields are periodic but discontinuous

This gives rise to localized lagrangian terms

Localized lagrangians terms

- Radiative corrections Georgi,Grant,Hailu (2000)
- Anomalies Scrucca,Serone,Silvestrini,Zwirner (2001)
  Barbieri,Contino,Creminelli,Rattazzi,Scrucca (2002)
- Yukawa interactions Barbieri,Hall,Nomura (2000)

We showed that in some cases

localized lagrangian terms can be reabsorbed through a field redefinition

⋆ From Kawamura's to our scheme

$$A^a_M(y) \to A^a_M(y) \qquad A^{\hat{a}}_M(y) \to \epsilon(\tfrac{y}{2} + \tfrac{\pi R}{2}) A^{\hat{a}}_M(y)$$

$a = 1, ..., 12 \quad \hat{a} = 13, ..., 24$

$\to$ We focus on $A^{\hat{a}}_\mu(y)$

The quadratic part of the lagrangian contains:

$$\epsilon^2 \partial_M A^{\hat{a}}_\mu \, \partial^M A^{\hat{a}}_\mu + 4\epsilon \, \delta(y - \pi R) \, A^{\hat{a}}_\mu \, \partial_y A^{\hat{a}}_\mu$$
$$+ 4[\delta(y - \pi R)]^2 \, A^{\hat{a}}_\mu A^{\hat{a}}_\mu$$

If we derive the equation of motion we'll obtain the jumps.

Conclusions

- ⋆ We have constructed a generalized Scherk-Schwarz mechanism on orbifold for a bosonic system in which fields are discontinuous at the orbifold fixed points.
- ⋆ We have built an $SU(5)$ GUT which breaks down to $SU(3) \times SU(2) \times U(1)$ in which some lagrangian terms for bulk fields are localized at the orbifold fixed points.
- ⋆ We have shown that a field redefinition relates this construction to the usual Scherk-Schwarz formalism where all fields are continuous and no localized terms for bulk fields appear.