MAGNETIC SUPERSYMMETRY BREAKING

Based on :

W. Buchmuller, M.Dierigl,E.D & J. Schweizer,

arXiv:1611.03798 [hep-th]

jan. 17, 2017

III Saha Theory Workshop

Kolkata

Outline

1) Higher-dimensional completions of the Standard Model
2) Magnetic compactifications
3) Effective field theory
4) Quantum corrections, Wilson lines as goldstone bosons
5) Conclusions

1) Higher-dimensional completions of the Standard Model

- Structure of Standard Model points towards Grand Unification (matter content, gauge group, unification of gauge couplings,neutrino masses)

- Strong theoretical arguments for supersymmetry at high scales (gravity,string theory)

- Extra dimensions unavoidable in string theory

Extra dims. do address:

- Unification of all forces (including at TeV energies)
- Holographic solutions to the hierarchy problem (RS)
- New ways to break SUSY: Scherk-Schwarz
- New models of inflation

- Sometimes higher-dim. symmetries protect quantum corrections in a way invisible from 4d.

Ex: Internal comp. of a gauge field protected by gauge symmetry

$$\delta m_0^2 \sim (\text{loop}) \times \frac{1}{R^2}$$

Orbifolds are a natural framework to compactify higher-dimensional theories:

- Fermion chirality
- Doublet-triplet splitting in orbifold GUT's
- Partial or total supersymmetry breaking

- Compactification scale $M_c = R^{-1}$ usually defines the GUT/unification scale.
- Scale of supersymmetry breaking M_{SUSY} usually much smaller.

2) Magnetic compactifications

Widely studied in string theory (« intersecting branes »), few papers in field theory.

Consider a 6-dim. theory : $x_0 x_1 x_2 x_3 x_5 x_6$

An internal magnetic field $F_{56} = B = f$

- break SUSY, due to the magnetic moment coupling

$$H = -\mu \mathbf{B} = -\frac{q}{m} \mathbf{S} \mathbf{B}$$

- Turns KK states k_1, k_2 into Landau levels n , mass

$$\delta M^2 = (2n+1)|qB| + 2qB\Sigma_{56}$$

where Σ_{45} is the internal helicity of particles.

- An internal magnetic field is quantized

$$f = \frac{N}{R^2} \sim M_{\rm GUT}^2 \quad , \qquad \text{N = integer flux}$$

- Each Landau level is N times degenerate.
- Precisely N chiral fermion zero modes.

- Starting with a SUSY 6d theory, it is usually said that the effect of the magnetic field is to add a D-term Fayet-Iliopoulos (FI) term in 4d

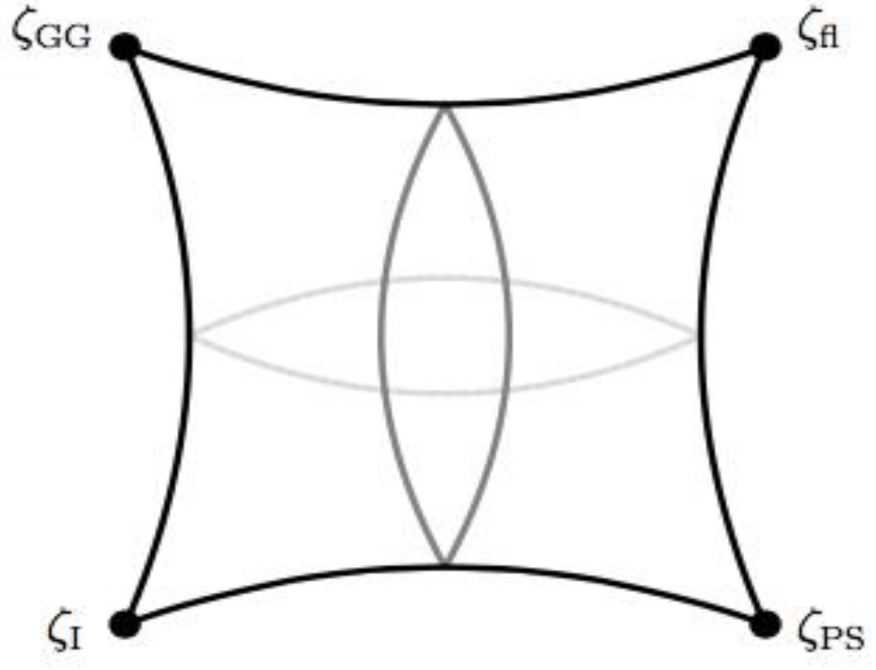
$$D = f \quad \rightarrow \quad V = \frac{1}{2} D^2 = \frac{1}{2} f^2 \sim M_{\rm GUT}^4$$

◆ Potential relevance to inflation

One example (Buchmuller, Dierigl,Ruehle,Schweizer, 2015,2016) :

- SO(10) GUT model in 6d, broken at orbifold fixed points, Standard Model in 4d

- Bulk fields $45, 16, 16^*, 10's$



$$SO(10) \to U(1)_A$$

In 4d there are N 16's from charged bulk 16-plet with N flux quanta :

$$16\ [SO(10)] \leftarrow \bar{5} + 10 + 1\ [SU(5)] \leftarrow q, l, u^c, e^c, d^c, \nu^c\ [G_{SM}]$$

- Higgs fields from uncharged bulk 10-plets form split multiplets.
- Magnetic flux break SUSY (Bachas;95); « soft » SUSY breaking only for quark-lepton families:

$$M^2 = m_{\tilde{q}}^2 = m_{\tilde{l}}^2 = \frac{4\pi N}{V_2} \sim (10^{15}\ \mathrm{GeV})^2$$

$$m_{3/2} \sim 10^{14}\ \mathrm{GeV}\,, \qquad m_{\tilde{q}}^2 = m_{\tilde{l}}^2 > m_{3/2} \sim m_{1/2} \gg m_{\tilde{h}}$$

However, not enough; there is no mass gap:
soft massed given by the FI term of the same order ($1/R^2$) as the masses of Landau levels

one needs an effective theory for the whole tower.

3) Effective field theory

- Consider an abelian 6d SUSY theory compactified on a torus.

N=2 SUSY in 4d before the magnetic flux;

4d Multiplets: vector (V, ϕ)

charged hyper $(Q, \tilde{Q})$

6d effective action in superfields: (Marcus,Sagnotti,Siegel ; Arkani-Hamed,Gregoire,Wacker)

$$S_6 = \int d^6x \Big\{ \frac{1}{4}\int d^2\theta\, W^\alpha W_\alpha + \text{h.c.} + \int d^4\theta \left(\partial V \bar{\partial} V + \phi\bar{\phi} + \sqrt{2} V \left(\bar{\partial}\phi + \partial\bar{\phi}\right)\right)$$

$$+ \int d^2\theta\, \tilde{Q}(\partial + \sqrt{2} g q \phi) Q + \text{h.c.} + \int d^4\theta \left(\overline{Q} e^{2gqV} Q + \overline{\tilde{Q}} e^{-2gqV} \tilde{Q} \right) \Big\}$$

$$\partial = \partial_5 - i\partial_6\,, \quad \phi|_{\theta=\bar{\theta}=0} = \frac{1}{\sqrt{2}}(A_6 + iA_5)$$

ϕ are internal components of gauge fields = Wilson lines

Mode expansions with flux:

$$\phi_0|_{\theta=\overline{\theta}=0} = \frac{f}{2\sqrt{2}}(x_5 - ix_6) + \varphi\,, \qquad \varphi = \frac{1}{\sqrt{2}}(a_6 + ia_5)$$

$$\mathcal{Q}(x_M) = \sum_{n,j} \mathcal{Q}_{n,j}(x_\mu)\psi_{n,j}(x_m) = \sum_{n,j} \mathcal{Q}_{n,j}(x_\mu)\frac{1}{\sqrt{n!}}\left(a^\dagger\right)^n \psi_{0,j}(x_m)\,,$$

$$\overline{\mathcal{Q}}(x_M) = \sum_{n,j} \overline{\mathcal{Q}}_{n,j}(x_\mu)\overline{\psi}_{n,j}(x_m) = \sum_{n,j} \overline{\mathcal{Q}}_{n,j}(x_\mu)\frac{1}{\sqrt{n!}}\left(a\right)^n \overline{\psi}_{0,j}(x_m)\,.$$

where (harmonic oscillator algebra)

$$a = \sqrt{\frac{1}{-2qgf}}(iD_5 - D_6)$$

$$a^\dagger = \sqrt{\frac{1}{-2qgf}}(iD_5 + D_6)$$

The final 4d effective action for Landau levels is

FI term

$$S_4^* = \int d^4x \left[\int d^4\theta \left(\overline{\varphi}\varphi + \sum_{n,j} (\overline{Q}_{n,j} e^{2gqV_0} Q_{n,j} + \overline{\tilde{Q}}_{n,j} e^{-2qgV_0} \tilde{Q}_{n,j}) + 2fV_0 \right) \right.$$
$$+ \int d^2\theta \left(\frac{1}{4} \mathcal{W}_0^\alpha \mathcal{W}_{\alpha,0} \right.$$
$$\left. \left. + \sum_{n,j} \left(-i\sqrt{-2qgf(n+1)} \tilde{Q}_{n+1,j} Q_{n,j} + \sqrt{2} qg \tilde{Q}_{n,j} \, \varphi \, Q_{n,j} \right) \right) + \text{h.c.} \right]$$

Mass terms

One also found the effective action for the non-abelian case

4) Quantum corrections, Wilson lines as goldstone bosons

Interested in Higgs = internal component of the gauge field. 6d gauge symmetry could protect its mass ?

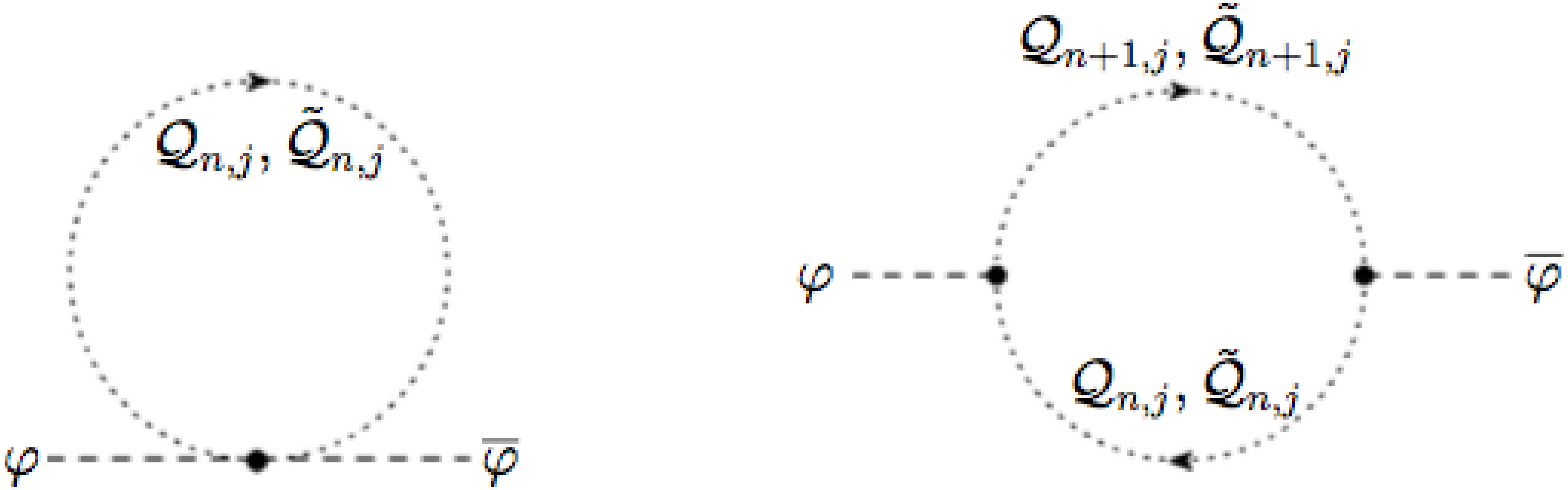


Figure 3: Bosonic contributions to the Wilson line mass with flux.

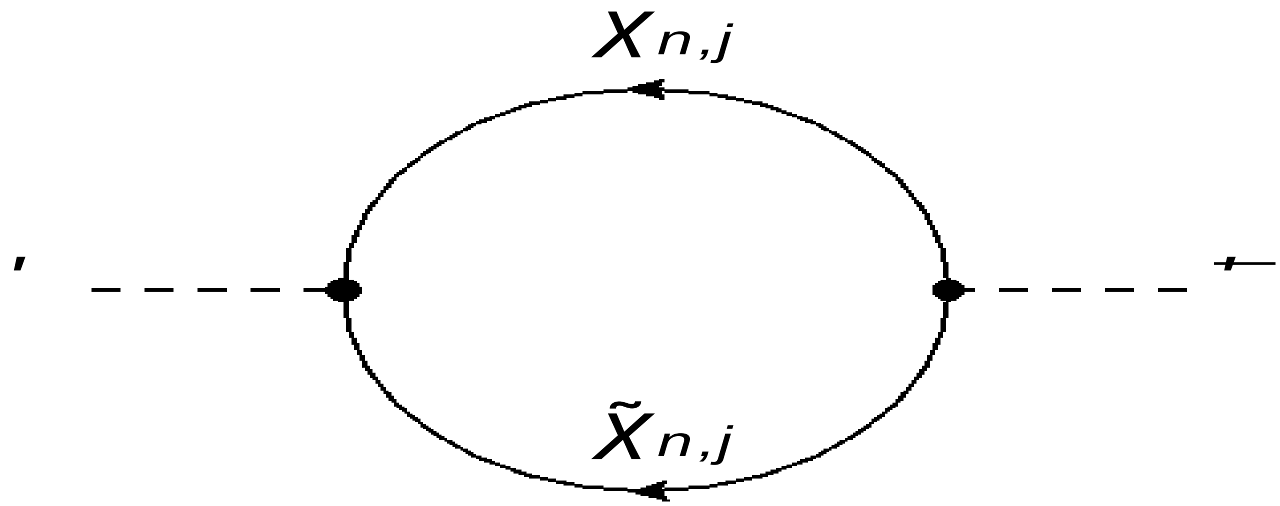
Each contribution is quadratically divergent: the sum of the whole tower is however exactly zero !

$$\delta m_b^2 = -4 q^2 g^2 |N| \sum_n \int \frac{d^4k}{(2\pi)^4} \left(\frac{n}{k^2 + \epsilon(n+\frac{1}{2})} - \frac{n+1}{k^2 + \epsilon(n+\frac{3}{2})} \right)$$

$$= -\frac{q^2 g^2}{4\pi^2} |N| \sum_n \int_0^\infty dt \, \frac{1}{t^2} \left[n e^{-\epsilon (n+\frac{1}{2})t} - (n+1) e^{-\epsilon (n+\frac{3}{2})t} \right]$$

$$= -\frac{q^2 g^2}{4\pi^2} |N| \int_0^\infty dt \, \frac{1}{t^2} \left(\frac{e^{\frac{1}{2}\epsilon t}}{(e^{\epsilon t}-1)^2} - \frac{e^{\frac{1}{2}\epsilon t}}{(e^{\epsilon t}-1)^2} \right) = 0$$

The same is true for the fermionic contribution



Is there's a symmetry reason ?

Action of charged matter fields invariant under translations

$$S_6 = \int d^6x \; (-D_M \bar{Q} D^M Q) \; , \qquad D_M Q = (\partial_M + iqg A_M) Q$$

$$\delta Q = \epsilon^m \partial_m Q \, , \qquad \delta A_n = \epsilon^m \partial_m A_n$$

Symmetries for constant Wilson line background

$$\delta Q = \epsilon^m \partial_m Q \, , \qquad \delta a_n = 0$$

Flux background breaks the symmetries spontaneously

$$D_m Q = \left(\partial_m + iqg \left(a_m + \frac{f}{2} \epsilon_{mn} x_n \right) \right) Q \, , \qquad \langle A_m \rangle = \frac{f}{2} \epsilon_{mn} x_n$$

Translational symmetries now non-linearly realized with Wilson lines as Goldstone bosons

$$\delta Q = \epsilon^m \partial_m Q \,, \quad \delta a_n = \epsilon^m \frac{f}{2} \epsilon_{nm}$$

Conclusions, Perspectives

- Strong theoretical arguments for SUSY at high scales: gravity, string theory
- Energy scale of grand unification $M_{GUT} \sim 10^{16}$GeV

Scale of SUSY breaking M_{SUSY} ?

- Magnetized compactifications : high-scale SUSY breaking

$$M_{SUSY} \sim M_{GUT} \sim R^{-1}$$

- Hope for a higher-dim. protection of scalar masses: Higgs mass, inflaton.
- Various applications possible: moduli stabilization, inflation, orbifold GUT's.

Thank you