SUPERWORLD WITHOUT *SUPERSYMMETRY*

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Phys.Lett. B754 (2016)]

Talk presented at PHENO 2016, University of Pittsburgh,
Pittsburgh, PA, May 9 - 11, 2016.

May 4, 2016

Overview

Introduction

What is Superworld?

- Superworld consists of particles which are superpartners of our SM particles, supplemented by a 2nd Higgs doublet.
- Our world $\Rightarrow$ SM particles plus a 2nd Higgs doublet
- Superworld$\Rightarrow$ contains the Superpartners of our world
- Thus the partcle spectrum is same as in MSSM
- But the two world (sectors) are NOT connected by supersymmetry

Introduction

Why consider such a model/scenario?

- May be supertners do exist, but supersymmetry is not realized in nature.
- SUSY breaking may be more general than the usual soft SUSY breaking we use.
- Conceivably a theory which breaks SUSY in a way which is strongly coupled to the standard sector may have similar features.
- inspite of intense effort over the past three decades, especially now at LHC, no SUSY signal has been observed. May be the restrictions imposed on the couplings by SUSY is too restrictive, and make the production cross sections low.

Introduction

Pros and cons of the model

Pros

- Retain many of the good features of SUSY
- Lightest superworld partcle is stable $\Rightarrow$ Good candidate for dark matter
- Can have gauge coupling unification
- Can have much larger cross sections for the production of these superworld particles $\Rightarrow$extend considerably their discovery reach at the LHC.

Cons

- Lose the solution to the Higgs mass hierarchy problem

Model and the formalism

- The gauge symmetry of our model is $SU(3)_C \times SU(2)_L \times U(1)_Y \times Z_2$
- Particle content: Same as in MSSM : separated into two worlds. SM particles$\Rightarrow$ our world, Superpartners $\Rightarrow$ Superworld.
- Two world separated by a unbroken discrete Z_2 discrete symmetry. Our world particles, $Z_2 = +1$, Superworld particles, $Z_2 = -1$.
- We also include a ν_R in our world, and a $\tilde{\nu_R}$ in superworld to generate a non-zero neutrino mass.

Model and the formalism

Particle of the model and their quantum numbers

	Our World($Z_2 = +1$)	Superworld ($Z_2 = -1$)
Matter	$\begin{pmatrix} u \\ d \end{pmatrix}_L \sim (3, 2, \frac{1}{6})$ $u_R \sim (3, 1, \frac{2}{3}), d_R \sim (3, 1, -\frac{1}{3})$ $\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \sim (1, 2, -\frac{1}{2})$ $e_R \sim (1, 1, -1), \nu_R \sim (1, 1, -1)$	$\begin{pmatrix} \tilde{u} \\ \tilde{d} \end{pmatrix}_L \sim (3, 2, \frac{1}{6})$ $\tilde{u_R} \sim (3, 1, \frac{2}{3}), \tilde{d_R} \sim (3, 1, -\frac{1}{3})$ $\begin{pmatrix} \tilde{\nu_e} \\ \tilde{e} \end{pmatrix}_L \sim (1, 2, -\frac{1}{2})$ $\tilde{e_R} \sim (1, 2, -1), \tilde{\nu_R} \sim (1, 2, -1)$
Gauge	$G_{a,a=1-8}, A_{i,i=1-3}, B$	$\tilde{g}_{a,a=1-8}, \tilde{A}_{i,i=1-3}, \tilde{B}$
Higgs	H_u, H_d	$\tilde{H}_u, \tilde{H}_d$

Table : Matter, gauge and higgs contents of our and the superworld.

Model and the formalism

The matter kinetic terms for the superworld is given by,

$$
\begin{aligned}
\mathcal{L}^{\text{kin}}_{\text{matter}} \supset \quad & + \quad (\mathcal{D}_\mu \bar{q}_{Li})^\dagger (\mathcal{D}^\mu q_{Li}) + \left(\mathcal{D}_\mu \tilde{d}_{Ri}\right)^\dagger \left(\mathcal{D}^\mu \tilde{d}_{Ri}\right) \\
& + \quad (\mathcal{D}_\mu \tilde{u}_{Ri})^\dagger (\mathcal{D}^\mu \tilde{u}_{Ri}) \\
& + \quad \left(\mathcal{D}_\mu \tilde{l}_{Li}\right)^\dagger \left(\mathcal{D}^\mu \tilde{l}_{Li}\right) + (\mathcal{D}_\mu \tilde{e}_{Ri})^\dagger (\mathcal{D}^\mu \tilde{e}_{Ri}) \\
& - \quad \tilde{m}^2_{q_L} \tilde{q}^\dagger_L \tilde{q}_L - \tilde{m}^2_{u_R} \tilde{u}^\dagger_R \tilde{u}_R - \tilde{m}^2_{d_R} \tilde{d}^\dagger_R \tilde{d}_R - \tilde{m}^2_{l_L} \tilde{l}^\dagger_L \tilde{l}_L - \tilde{m}^2_{e_R} \tilde{e}^\dagger_R \tilde{e}_R
\end{aligned}
$$

where $\mathcal{D}_\mu$ is the usual gauge covariant derivative and i = 1,2,3 represent three families.

Model and the formalism

Gauge Kinetic terms

$$\begin{aligned}\mathcal{L}^{\text{kin}}_{\text{gauge}} \supset & + \frac{1}{2} i \tilde{G}_a^T \left(\not{D} \tilde{G} \right)_a - \frac{1}{2} \mathrm{m}_{\tilde{G}} \tilde{G}_a^T C^{-1} \tilde{G}_a + \frac{1}{2} i \tilde{A}_i^T \left(\not{D} \tilde{A} \right)_i \\ & - \frac{1}{2} \mathrm{m}_{\tilde{A}} \tilde{A}_i^T C^{-1} \tilde{A}_i + \frac{1}{2} i \tilde{B}^T \left(\not{D} \tilde{B} \right) - \frac{1}{2} \mathrm{m}_{\tilde{B}} \tilde{B}^T C^{-1} \tilde{B} \\ & + i \bar{\tilde{H}}_u \not{D} \tilde{H}_u + i \bar{\tilde{H}}_d \not{D} \tilde{H}_d - \mu \tilde{H}_u{}^T i \sigma_2 \tilde{H}_d \qquad (1)\end{aligned}$$

Model and the formalism

Yukawa interactions in our model without involving the Higgs fields.

$$\mathcal{L}_{\text{O-S}}{}^{\text{yuk}} \supset \lambda_{\tilde{q}} \bar{q}_L \tilde{G} \tilde{q}_L + \lambda_{\tilde{u}} \bar{u}_R \tilde{G} \tilde{u}_R + \lambda_{\tilde{d}} \bar{d}_R \tilde{G} \tilde{d}_R + \text{h.c.} \qquad (2)$$

.

The Yukawa interaction involving the Higgs field, higgsinos and gauginos are

$$\begin{aligned} \mathcal{L}_{\text{H-H-G}}{}^{\text{yuk}} \supset\; & \lambda_{\tilde{A}\tilde{H}_u} \bar{\tilde{H}}_u \tilde{A} H_u + \lambda_{\tilde{A}\tilde{H}_d} \bar{\tilde{H}}_d \tilde{A} i\sigma_2 H_u^* + \lambda_{\tilde{B}\tilde{H}_u} \bar{\tilde{H}}_u \tilde{B} H_u \\ + \; & \lambda_{\tilde{B}\tilde{H}_d} \bar{\tilde{H}}_d \tilde{B} i\sigma_2 H_u^* \qquad (3) \end{aligned}$$

Model and formalism

Finally the Higgs potential in our model is

$$
\begin{aligned}
V = & - \left(\mu_u^2 H_u^\dagger H_u + \mu_d^2 H_d^\dagger H_d\right) + \lambda_1 \left(H_u^\dagger H_u\right)^2 \\
& + \lambda_2 \left(H_d^\dagger H_d\right)^2 + \lambda_3 \left(\left(H_u^T H_d\right)^2 + h.c\right) \\
& + \lambda_4 \left(\left(H_d^T H_u\right)^2 + h.c\right) + \lambda_5 \left(\left(H_u^T H_d\right)\left(H_d^T H_u\right) + h.c\right)
\end{aligned} \tag{4}
$$

Note that this is somewhat different than the usual two higgs doublet model with the same symmetry of $H_d \rightarrow -H_d$. This is because H_u has hypercharge Y=+1, whereas H_d has hypercharge Y=-1, so that the corresponding Higgsinos cancel the gauge anomalies in the superworld.

Phenomenology at the LHC

In this talk, I consider only

- Gluino pair production ($\tilde{G}\tilde{G}$)
- Gluino-Squark pair production ($\tilde{G}\tilde{q}$)
- Chargino pair productions ($\tilde{\chi}\tilde{\chi}$)
- In supersymmetry; all the couplings involved in these productions are gauge couplings.
- In our model, some the gauge couplings becomes arbitrary Yukawa couplings.

Phenomenology at the LHC

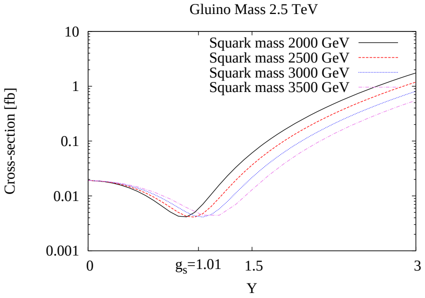

Figure : Gluino pair production cross-section as a function of gluino-squark-quark Yukawa coupling (Y) for four different values of squark mass. Gluino mass is assumed to be 2.5 TeV.. The cross-sections corresponding to this point represent gluino pair production cross-sections in supersymmetric scenarios.

Phenomenology at the LHC

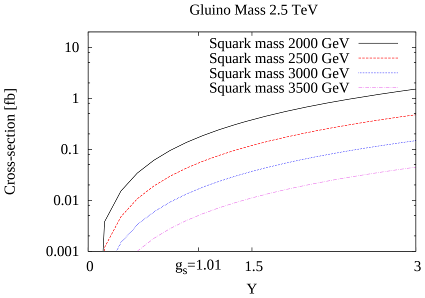

Figure : Same as Fig. 1 but for Squark-gluino pair production for a 2.5 TeV gluino and for four different values of squark mass.

Phenomenology at the LHC

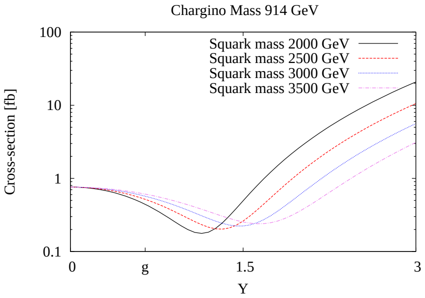

Figure : Chargino pair production cross-section for a 914 GeV chargino as a function of chargino-squark-quark Yukawa coupling (Y) for four different values of squark mass.

Conclusions

- Proposed a model where superpartner particles exist in the spectrum, but no supersymmetry.
- The model is renormalizable, and is more general than supersymmtry.
- Lose the solution to the Higgs mass hierarchy problem, but has a dark matter candidate, and gauge coupling unification.
- Some of the couplings, which were gauge couplings in supersymmtry, now become independent Yukawa coupilgs, and can be much larger.
- This gives rise to much bigger production cross sections compared to SUSY
- Thus reach at LHC for discovering the superparticles and hence new physics will be greatly enhanced.
- Possibilty of flavor-biased signal not present in supersymmetry