SUPERWORLD WITHOUT SUPERSYMMETRY

S. Nandi

Oklahoma State University &
Oklahoma Center for High Energy Physics

[Work done in collaboration with Shreyashi Chakdar and Kirtiman Ghosh
Phys.Lett. B754 (2016) ]

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

May 4, 2016
Overview

1. Introduction
   - What is superworld?
   - Motivation for Superworld

2. Model and the formalism
   - Superworld particle spectrum
   - Superworld Lagrangian

3. Phenomenology at the LHC
   - gluino pair production
   - gluino squark pair production
   - chargino pair production

4. Conclusions
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 particle spectrum is same as in MSSM
- But the two world (sectors) are NOT connected by supersymmetry
Why consider such a model/scenario?

- May be superpartners 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 particle is stable ⇒ Good candidate for dark matter
- Can have gauge coupling unification
- Can have much larger cross sections for the production of these superworld particles ⇒ 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 $\nu_R$ 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

| Matter | Our World ($\mathbb{Z}_2 = +1$) | Superworld ($\mathbb{Z}_2 = -1$) |
|--------|---------------------------------|----------------------------------|
|        | $\begin{pmatrix} u_d \end{pmatrix}_L \sim (3, 2, \frac{1}{6})$ | $\begin{pmatrix} \tilde{u} \tilde{d} \end{pmatrix}_L \sim (3, 2, \frac{1}{6})$ |
|        | $u_R \sim (3, 1, \frac{2}{3})$, $d_R \sim (3, 1, -\frac{1}{3})$ | $\tilde{u}_R \sim (3, 1, \frac{2}{3})$, $\tilde{d}_R \sim (3, 1, -\frac{1}{3})$ |
|        | $\begin{pmatrix} \nu_e \end{pmatrix}_L \sim (1, 2, -\frac{1}{2})$ | $\begin{pmatrix} \tilde{\nu}_e \end{pmatrix}_L \sim (1, 2, -\frac{1}{2})$ |
|        | $e_R \sim (1, 1, -1)$, $\nu_R \sim (1, 1, -1)$ | $\tilde{e}_R \sim (1, 2, -1)$, $\tilde{\nu}_R \sim (1, 2, -1)$ |
| 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.
The matter kinetic terms for the superworld is given by,

$$\mathcal{L}_{\text{kin matter}} \supset + \left( D_\mu \bar{q}_{Li} \right) \dagger \left( D^\mu q_{Li} \right) + \left( D_\mu \bar{d}_{Ri} \right) \dagger \left( D^\mu d_{Ri} \right)$$

$$+ \left( D_\mu \bar{u}_{Ri} \right) \dagger \left( D^\mu u_{Ri} \right)$$

$$+ \left( D_\mu \bar{l}_{Li} \right) \dagger \left( D^\mu l_{Li} \right) + \left( D_\mu \bar{e}_{Ri} \right) \dagger \left( D^\mu e_{Ri} \right)$$

$$- \tilde{m}_{qL} \bar{q}_L \bar{q}_L - \tilde{m}_{uR} \bar{u}_R \bar{u}_R - \tilde{m}_{dR} \bar{d}_R \bar{d}_R - \tilde{m}_{lL} \bar{l}_L \bar{l}_L - \tilde{m}_{eR} \bar{e}_R \bar{e}_R$$

where $D_\mu$ is the usual gauge covariant derivative and $i = 1, 2, 3$ represent three families.
Gauge Kinetic terms

\[ \mathcal{L}_{\text{gauge}}^{\text{kin}} \supset + \frac{1}{2} i \tilde{G}_a \left( \phi \tilde{G} \right)_a - \frac{1}{2} m_{\tilde{G}} \tilde{G}_a^T C^{-1} \tilde{G}_a + \frac{1}{2} i \tilde{A}_i \left( \phi \tilde{A} \right)_i \\
- \frac{1}{2} m_{\tilde{A}} \tilde{A}_i^T C^{-1} \tilde{A}_i + \frac{1}{2} i \tilde{B}^T \left( \phi \tilde{B} \right) - \frac{1}{2} m_{\tilde{B}} \tilde{B}^T C^{-1} \tilde{B} \\
+ i \tilde{H}_u \phi \tilde{H}_u + i \tilde{H}_d \phi \tilde{H}_d - \mu \tilde{H}_u^T i \sigma_2 \tilde{H}_d \] (1)
Model and the formalism

Yukawa interactions in our model without involving the Higgs fields.

\[ \mathcal{L}_{\text{O-S}^{\text{yuk}}} \supset \lambda \tilde{q}_L \tilde{G} \tilde{q}_L + \lambda \tilde{u}_R \tilde{G} \tilde{u}_R + \lambda \tilde{d}_R \tilde{G} \tilde{d}_R + \text{h.c.} \]  \hspace{1cm} (2)

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

\[ \mathcal{L}_{\text{H-H-G}^{\text{yuk}}} \supset \lambda \tilde{A} \tilde{H}_u \tilde{H}_u \tilde{A} + \lambda \tilde{A} \tilde{H}_d \tilde{H}_d \tilde{A} \sigma_2 \tilde{H}_u^* + \lambda \tilde{B} \tilde{H}_u \tilde{H}_u \tilde{B} H_u + \lambda \tilde{B} \tilde{H}_d \tilde{H}_d \tilde{B} i \sigma_2 \tilde{H}_u^* \]  \hspace{1cm} (3)
Finally the Higgs potential in our model is

\[ V = - \left( \mu_u^2 H_u^\dagger H_u + \mu_d^2 H_d^\dagger H_d \right) + \lambda_1 \left( H_u^\dagger H_u \right)^2 \\
+ \lambda_2 \left( H_d^\dagger H_d \right)^2 + \lambda_3 \left( \left( H_u^T H_d \right)^2 + h.c \right) \\
+ \lambda_4 \left( \left( H_d^T H_u \right)^2 + h.c \right) + \lambda_5 \left( \left( H_u^T H_d \right) \left( H_d^T H_u \right) + h.c \right) \]

(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.
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.
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.
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 supersymmetry.
- 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 supersymmetry, now become independent Yukawa couplings, 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.
- Possibility of flavor-biased signal not present in supersymmetry