Discrimination between NMSSM and MSSM at LHC

Shohei Sugiyama

Nagoya Univ.

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Collaborators: Junji Hisano (Nagoya Univ.)
Michihisa Takeuchi (Uni Heidelberg)
Masato Yamanaka (Maskawa Inst.)

Outline

Supersymmetry

Supersymmetry (SUSY) solves the hierarchy problem of the Standard Model.

Minimal Supersymmetric Standard Model (MSSM)

- successful gauge coupling unification
- Dark Matter candidate

MSSM has many dimensionful parameters. Most of them are soft SUSY breaking terms.

$$m_{\rm soft} \sim \mathcal{O}(100)\ \text{GeV}$$

μ problem

μ problem The only supersymmetric dimensionful coupling in MSSM is μ-term in superpotential.

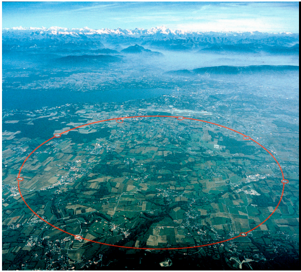
$$W \supset \mu H_u \cdot H_d$$

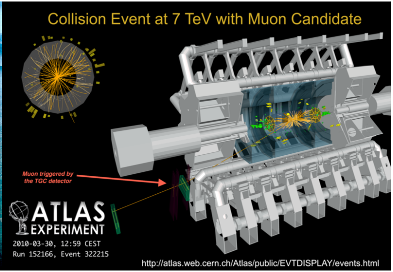
Electroweak symmetry breaking (EWSB) conditions constrain μ to be $\mathcal{O}(100)$ GeV.

One of the solutions for μ problem is the Next-to-Minimal Supersymmetric Standard Model (NMSSM) which have an additional singlet to MSSM.

LHC

If SUSY particles have masses with $\lesssim \mathcal{O}(1)$ TeV, they will be discovered at Large Hadron Collider (LHC).





Our question: Can LHC distinguish NMSSM from MSSM?

NMSSM

NMSSM = MSSM + one gauge singlet S

Superpotential:

$$W = \lambda S H_u \cdot H_d + \frac{\kappa}{3} S^3$$

Soft SUSY breaking terms:

$$-\mathcal{L}_{\rm soft} = m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + m_S^2 |S|^2 + (\lambda A_\lambda S H_u \cdot H_d + \frac{1}{3} \kappa A_\kappa S^3 + \text{h.c.})$$

Since all dimensionful parameters are SUSY breaking terms, vacuum expectation value (VEV) of S is expected to be $\mathcal{O}(100)$ GeV.

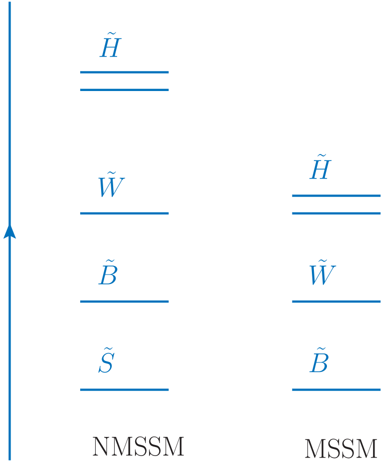
Properties of NMSSM

- 3 CP-even Higgs bosons, 2 CP-odd Higgs bosons and 5 neutralinos.
- Singlino mass is $2\kappa\langle S\rangle = \frac{2\kappa}{\lambda}\mu_{\text{eff}}$.
- In some parameter region one CP-odd Higgs boson become light as a pseudo-Nambu–Goldstone boson.
- Since λ induce Higgs four-point coupling, SM-like Higgs boson can have large mass; it is possible that $m_h > m_Z$ even at the tree level.

Neutralinos

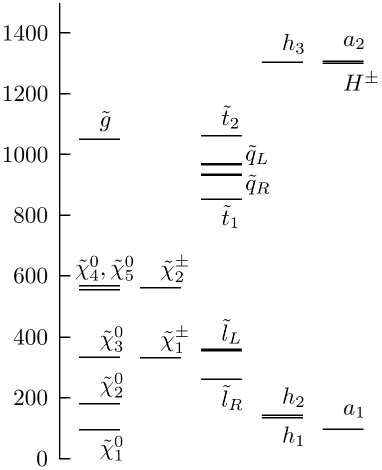
If singlino is the lightet SUSY particle (LSP), every SUSY event contains this particle.

Only light neutralinos will be observed.



Our sample point

- $\lambda = 0.7$
- $\kappa = 0.05$
- $\tan\beta = 2$
- h_1 (SM-like) 133 GeV
- $\tilde{\chi}_1^0$ (LSP) 93 GeV
- gaugino and sfermion masses are cMSSM-like.
- Production cross section of SUSY events is 1 pb.



Important decay chain

At our point, $\tilde{\chi}_2^0$ is allowed to decay into $\tilde{\chi}_1^0$ only via three-body decay.
$\Longrightarrow$ Difference cannot be observed.

Since more $\tilde{\chi}_3^0$ $(\tilde{W})$ is produced than MSSM, $\tilde{\chi}_3^0$ decay may discriminate two models.

$$\mathrm{BR}(\tilde{\chi}_3^0 \to h_1 \tilde{\chi}_1^0) = 49.7\%$$

$$\tilde{q} \to q\tilde{\chi}_3^0 \to q h_1 \tilde{\chi}_1^0 \to q b\bar{b}\tilde{\chi}_1^0$$

Simulation

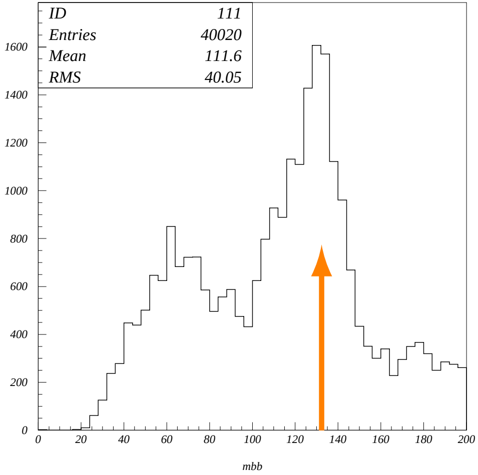
We used several public codes for simulation.

- NMHDECAY for computing mass spectrum.
- CalcHEP for event generation and computing decay table.
- Pythia for SUSY particle decay and hadronized processes.
- AcerDET for ditector simulation.

Conditions:

- $\int \mathcal{L} = 100\ \mathrm{fb}^{-1}$
- $\sqrt{s} = 14\ \mathrm{TeV}$

Invariant Mass of Two b-jets

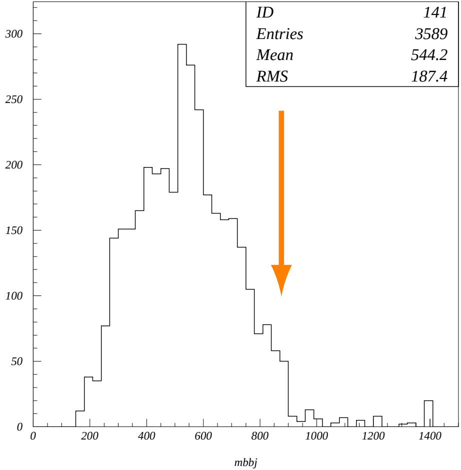


Cuts

- $E_T^{\text{miss}} > 200$ GeV.
- $E_T^{\text{miss}} > 0.2 M_{\text{eff}}$.
- $M_{\text{eff}} > 500$ GeV.
- Just 2 b-jets with $p_T > 50$ GeV and $\eta < 3$.

There is a peak of h_1 (133 GeV)

Endpoint



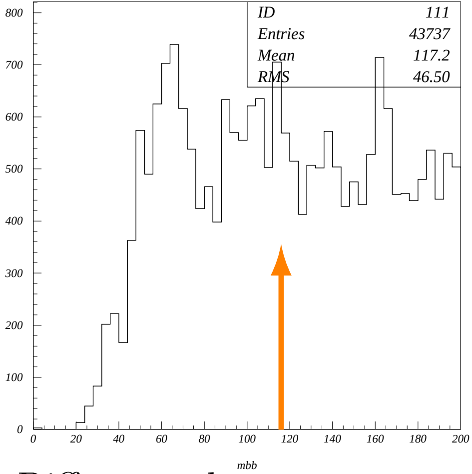
We imposed further cuts:

- At least 2 non-b jets (j_1, j_2) with $p_T > 100$ GeV and $\eta < 3$.
- $|M_{bb} - m_h| < 5$ GeV.

$\min\{M_{bbj_1}, M_{bbj_2}\}$ is plotted.

Expected endpoint (873 GeV) is seen and the existence of $\tilde{\chi}_3^0$ is confirmed.

Comparison with MSSM



We also simulated MSSM in which light neutralino masses are the same as our point of NMSSM. Imposing the same cuts as NMSSM there is no peak of h_1 (115 GeV).

Differrence between two models surely exists.

Summary

We have studied how signals of NMSSM can be discreminated from that of MSSM at LHC.

- In our sample point, decay of $\tilde{\chi}_2^0$ into $\tilde{\chi}_1^0$ is useless to discreminate the models.
- It is found that the difference in $\tilde{\chi}_3^0$ decay mode is possible to observe at LHC.

Further study is needed to reveal how the discremination is achieved in the cases of other set of the model parameters.