Status of low energy SUSY models confronted with the 125 GeV Higgs data

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On behalf of my collaborators J. M. Yang, et al

Based on our works arXiv: 1207.3698, 1206.3865, 1203.3694, 1202.5821, 1112.4391

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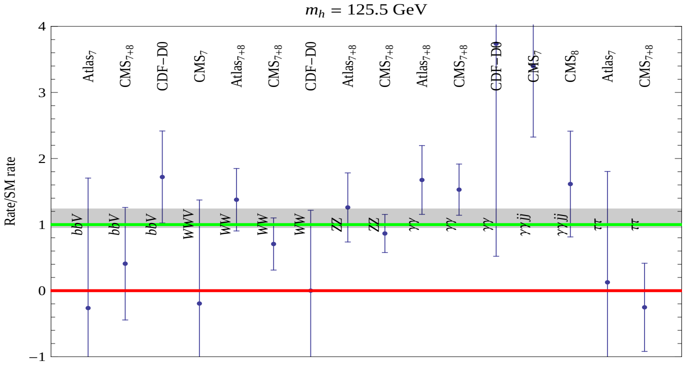
Conclusion:

- The MSSM can explain the LHC data quite well, but it suffers from severe fine tuning problem;
- The CMSSM is disfavored since it is hard to predict a 125 GeV Higgs boson, and at the same time cannot enhance the di-photon rate;
- The nearly Minimal Supersymmetric Standard Model (nMSSM) is excluded at 3σ level after considering available Higgs data;
- The most favored model is the Next to Minimal Supersymmetric Standard Model (NMSSM), whose predictions about the Higgs boson can naturally agree with the experimental data at 1σ level.

Catalogue

I. Experimental Progress in Higgs physics

- Announced discovery on July 4, 2012, by combining $5fb^{-1}$ 7-TeV data with $5fb^{-1}$ 8-TeV data.



I. Experimental Progress in Higgs physics

Properties:

- Mass: most precisely determined. Preferred region $125.5 \pm 0.54\mathrm{GeV}$.
- Couplings:
  - large uncertainty, may be greatly improved with the whole 2012 data.
  - Largest deviation from $\gamma\gamma$ rate (Especially $\gamma\gamma jj$ rate). Enhanced by a factor about 1.5.
  - Suppressed hgg coupling and enhanced $h\gamma\gamma$ coupling is currently favored.
- Spin:
  - Can not be determined in near future.
  - May be spin 0 and 2, can not be spin 1.
- CP: CP even state is favored, but there are discussions about CP-odd case.

Favored conclusions:

- The particle is at least partially responsible for EW breaking.
- The particle is at least partially responsible for mass generation.
- Agree with the SM predictions about the Higgs boson at 1σ level.

II. NMSSM: General overview

- NMSSM: singlet extension of the MSSM with Z_3 invariant superpotential.

  Superpotential: $W = W_{MSSM} + \lambda \varepsilon_{ij} \hat{H}_u^i \hat{H}_d^j \hat{S} + \frac{\kappa}{3} \hat{S}^3.$

  Soft breaking terms: $V_{\text{soft}} = V_{MSSM} + \tilde{m}_d^2 |H_d|^2 + \tilde{m}_u^2 |H_u|^2 + \tilde{m}_S^2 |S|^2$
  $+(\lambda A_\lambda \varepsilon_{ij} H_u^i H_d^j S + \frac{\kappa}{3} A_\kappa S^3 + h.c.).$

  W_{MSSM}: MSSM Superpotential without μ-term. $\hat{S}$: singlet superfield.

  V_{MSSM}: MSSM soft masses. $\varepsilon_{ij} \hat{H}_u^i \hat{H}_d^j \hat{S}$: doublet-singlet Higgs interaction.
- μ parameter is dynamically generated, $\mu = \lambda \langle s \rangle$.
- 3 CP-even Higgs bosons, 2 CP-odd Higgs bosons and 5 neutralinos.

  Rich Higgs physics and dark matter physics.

  May change squark decay signal.
- In the limit $\lambda, \kappa \to 0$, the singlet superfield decouples from the rest of ...

  If μ is fixed , phenomenology of NMSSM is same as that of MSSM.

  Only for large λ case can one expect large difference between the models.

II. NMSSM: SM-like Higgs boson mass

Define $H_{SM} = \sin\beta H_u + \varepsilon \cos\beta H_d^*$, $H_{NEW} = \cos\beta H_u - \varepsilon \sin\beta H_d^*$,

$$H_{SM} = \begin{pmatrix} G^+ \\ v + \frac{\phi_{\mathbf{sm}} + iG^0}{\sqrt{2}} \end{pmatrix}, \quad H_{NEW} = \begin{pmatrix} H^+ \\ \frac{\phi_{\mathbf{new}} + iP_1}{\sqrt{2}} \end{pmatrix}, \quad H_S = s + \frac{1}{\sqrt{2}} (\phi_{\mathbf{s}} + iP_2) .$$

Elements of CP-even Higgs mass matrix in the basis $(\phi_{\mathbf{new}}, \phi_{\mathbf{sm}}, \phi_{\mathbf{s}})$:

$$\begin{aligned}
\mathcal{M}^2_{11} &= M_A^2 + (m_Z^2 - \lambda^2 v^2) \sin^2 2\beta, \\
\mathcal{M}^2_{12} &= -\frac{1}{2}(m_Z^2 - \lambda^2 v^2) \sin 4\beta, \\
\mathcal{M}^2_{13} &= -(M_A^2 \sin 2\beta + \frac{2\kappa\mu^2}{\lambda})\frac{\lambda v}{\mu} \cos 2\beta, \\
\mathcal{M}^2_{22} &= m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta, \\
\mathcal{M}^2_{23} &= 2\lambda\mu v \left[1 - (\frac{M_A \sin 2\beta}{2\mu})^2 - \frac{\kappa}{2\lambda} \sin 2\beta\right], \\
\mathcal{M}^2_{33} &= \frac{1}{4}\lambda^2 v^2 (\frac{M_A \sin 2\beta}{\mu})^2 + \frac{\kappa\mu}{\lambda}(A_\kappa + \frac{4\kappa\mu}{\lambda}) - \frac{1}{2}\lambda\kappa v^2 \sin 2\beta.
\end{aligned}$$

II. NMSSM: SM-like Higgs boson mass

Large M_A Limit: $\mathcal{M}_{11}^2 \gg \mathcal{M}_{22}^2 \gg \mathcal{M}_{12}^2$ and $(\mathcal{M}_{11}^2 - \mathcal{M}_{33}^2) \gg \mathcal{M}_{13}^2$.
In this case, ϕ_{new} decouples from (ϕ_{sm}, ϕ_s) system.

$$\tilde{M}^2 = \begin{pmatrix} m_Z^2 \cos^2 2\beta + \lambda^2 \mathbf{v}^2 \sin^2 2\beta & 2\lambda\mu v \left[1 - (\frac{M_A \sin 2\beta}{2\mu})^2 - \frac{\kappa}{2\lambda} \sin 2\beta\right] \\ 2\lambda\mu v \left[1 - (\frac{M_A \sin 2\beta}{2\mu})^2 - \frac{\kappa}{2\lambda} \sin 2\beta\right] & \mathcal{M}_{33}^2 - \Delta^2 \end{pmatrix}$$

Two new features of the SM-like Higgs boson mass:

- Additional contribution $\lambda^2 v^2 \sin^2 2\beta$ at tree-level.
- Doublet-singlet mixing may push up or pull down the mass.

II. NMSSM: How to compare SUSY with data

- Select parameter points favored by low energy experiments and dark matter.
  - Scan randomly over the SUSY parameter space.
  - Calculate observables in low energy physics and dark matter physics.
  - Exclude points with the help of experimental data.
  - Optimize the scan region and repeat the scan.
- For each favored point, calculate χ^2 by available Higgs data.
- Investigate the properties of the SM-like Higgs boson for low χ^2 points.
- Perform similar study in the CMSSM, MSSM and nMSSM.

Scan region:

Assuming:

- $m_{\tilde{q}_{1,2}} = 2\text{TeV}$, $m_{\tilde{g}} = 1\text{TeV}$, $M_2 = 2M_1$.
- All soft parameters in the slepton sector have a common value $m_{\tilde{l}}$.

$$0.5 < \lambda \leq 0.7,\ 0 < \kappa \leq 0.7,\ 90\text{ GeV} \leq M_A \leq 1\text{ TeV},\ |A_\kappa| \leq 1\text{ TeV},$$
$$100\text{ GeV} \leq M_{Q_3}, M_{U_3}, M_{D_3} \leq 2\text{ TeV},\quad |A_t|, |A_b| \leq 5\text{ TeV},$$
$$1 \leq \tan\beta \leq 60,\quad 100\text{ GeV} \leq \mu, m_{\tilde{l}} \leq 1\text{ TeV},\quad 50\text{ GeV} \leq M_1 \leq 500\text{ GeV}.$$

II. NMSSM: Strategy to compare SUSY with data

Constraints:

- LEP constraints:
  - Electroweak precision observables such as ρ_l, $\sin^2\theta^l_{eff}$, M_W, R_b. Agree with experimental fit values at 95% CL;
  - Lower bound on sparticle masses;
  - Constraints on electroweak -ino sector: $Z \to \chi^0_1\chi^0$, $e^+e^- \to \chi^0_i\chi^0_j, \chi^+_1\chi^-_1$;
- B-physics constraints:
  - For $B \to X_s\gamma$, $B^0 - \bar{B}^0$ mixing, $D^0 - \bar{D}^0$ mixing, $K - \bar{K}^0$ mixing and $B^- \to \tau\nu_\tau$, agree with experimental measurements at 2σ level;
  - 95% CL upper bound: $B^0_{s,d} \to \mu^+\mu^-$, $B \to X_s\mu^+\mu^-$;
- Higgs physics constraints:
  - Stability of vacuum state;
  - SM-like Higgs mass satisfies $123\mathrm{GeV} \le m_h \le 127\mathrm{GeV}$;
  - Constraints from the Tevatron and LHC search for Non-standard Higgs boson;
- Dark matter physics constraints:
  - Dark matter relic density agrees with WMAP fit value at 2σ level;
  - 90% CL upper bound on spin independent rate of χ-nucleon scattering;
- Require SUSY to explain muon $g-2$ anomaly at 2σ level.

III. SUSY vs data: Di-photon rate

- Curves:
  central value (green) and 1σ region of the di-photon signal obtained by combing the ATLAS and CMS data with the method introduced in arXiv: 1203.4254 (by P. P. Giardino).
- 1σ best-fit mass:
  $125.5 \pm 0.54\mathrm{GeV}$.
  see arXiv: 1207.1374, by P. P. Giardino.
- Predictions of the MSSM and the NMSSM about the di-photon rate can agree with data at 1σ level.

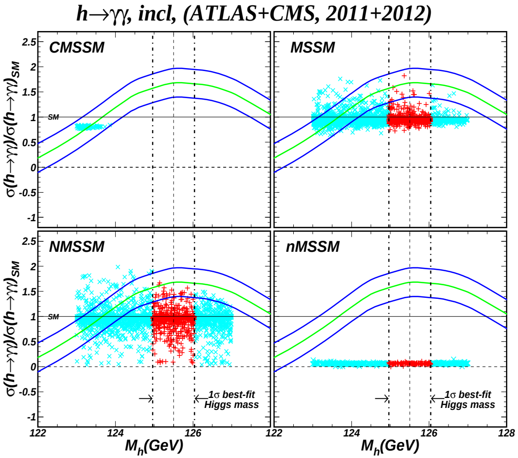


Fig.1: Surviving samples projected on the plane of the di-photon rate versus the SM-like Higgs mass. Only consider samples with $123\mathrm{GeV} \leq m_h \leq 127\mathrm{GeV}$.

III. SUSY vs data: Di-photon rate

- In CMSSM,
  - $m_h \leq 124\mathrm{GeV}$.
    Reason: Muon $g-2$ and $B_s \to \mu^+\mu^-$ forbid too large M_0, $M_{1/2}$ and A_0.
  - Di-photon rate is reduced.
    Reason: The $h\bar{b}b$ coupling is slighted enhanced.
- In nMSSM, di-photon rate is severely suppressed.
  Reason: Dark matter is light ($\leq 40\mathrm{GeV}$) and singlino-like, must annihilate via resonant CP-odd Higgs in early universe to get correct relic density.
  As a result, $h \to \chi_1^0\chi_1^0, A_1A_1$ will be dominant decay modes.

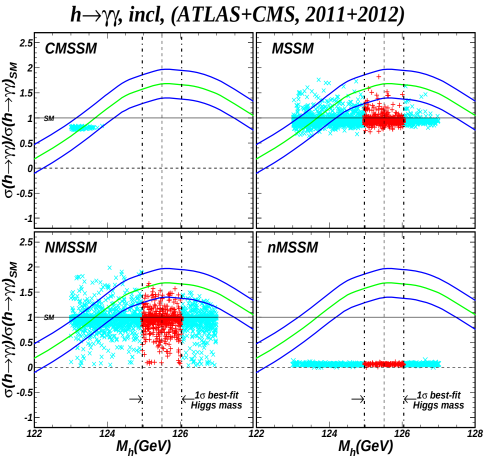


Fig.1: vertical axis: di-photon rate.

III. SUSY vs data: 4 lepton rate

- Curves:
  central value (green) and 1σ region of the 4 lepton signal obtained by combing the ATLAS and CMS data with the method introduced in arXiv: 1203.4254 (by P. P. Giardino).
- 1σ best-fit mass:
  $125.5 \pm 0.54\mathrm{GeV}$.
  see arXiv: 1207.1374, by P. P. Giardino.
- Except nMSSM, SUSY predictions about the 4 lepton signal can agree well with corresponding experimental data.

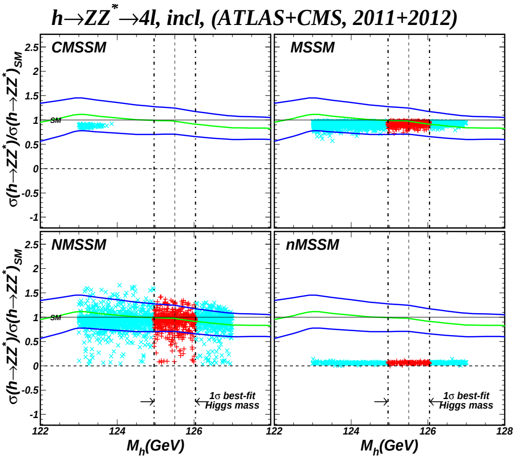


Fig.2: Same as Fig.1, but for 4 lepton rate.

III. SUSY vs data: Fine tuning extent Δ

- Fine tuning extent Δ:
  $\Delta = Max\{|\frac{\partial \ln m_Z}{\partial \ln p_i^{GUT}}|\}$.
- $+$: Samples with m_h in the range $125.5 \pm 0.54\mathrm{GeV}$, hereafter called Golden Sample.
- In CMSSM, $\Delta \geq 200$.
- In MSSM,
  - $\Delta \gtrsim 10$.
  - $\Delta \geq 100$ for samples with enhanced di-photon rate.
- In NMSSM with large λ,
  - Δ is usually less than 100.
  - Δ may be as low as 4 for samples with enhanced di-photon rate.

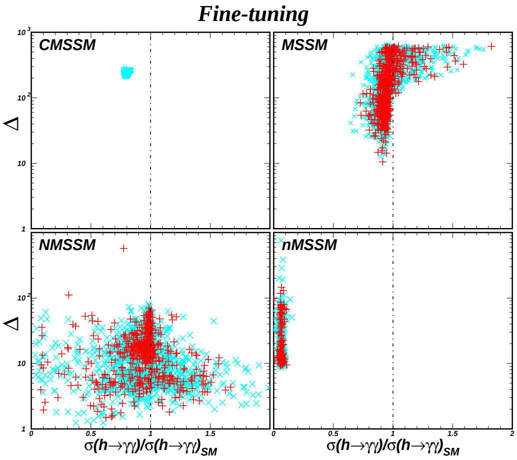


Fig.3 Same as Fig.1, but show Fine tuning extent for surviving samples as a function of the di-photon rate.

III. SUSY vs data: χ^2 for Golden Samples

- Golden Sample:
  $124.9\text{GeV} \le m_h \le 126.1\text{GeV}$.
- χ^2: Computed with 16 sets of latest experimental data for $m_h = 125, 125.5, 126\text{GeV}$.

  For calculation method, see 1203.4254 by P. P. Giardino.
- SM: $\chi^2/d.o.f = 16.5/16$.
- In MSSM: $\chi^2/d.o.f$ may be as low as $9.0/16$.
- In NMSSM with large λ,
  - $\chi^2/d.o.f$ may be as low as $11.0/16$.
  - $\chi^2 > 30$ for some samples.
- In nMSSM, $\chi^2 > 60$.
  Excluded by Higgs data.

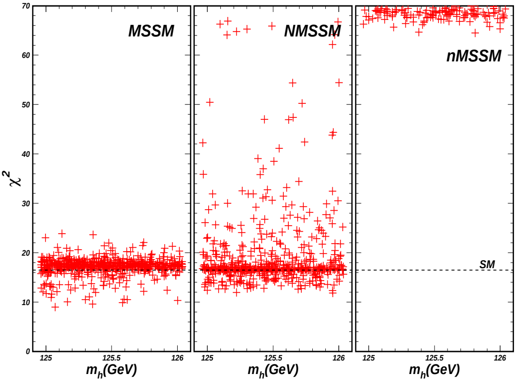


Fig.4 χ^2 for Golden samples in different models. 16 sets of latest experimental data were used.

III. SUSY vs data: Di-photon signal information

- Categorize Golden samples into:
  - $\chi^2 \leq 16.5$, better than SM.
  - $16.5 < \chi^2 \leq 26.3$, Agree with data at 2σ.
  - $\chi^2 > 26.3$, excluded at 2σ.
- Enhanced di-photon rate is strongly preferred by Higgs data, which is realized by enhanced $Br(h \to \gamma\gamma)$.
- In MSSM, the enhancement of the Br is mainly by the increase of $h\gamma\gamma$ coupling (through light $\tilde{\tau}$ loop). Samples with low χ^2, $\Delta > 100$.
- In NMSSM, the enhancement of the Br is by the suppression of $hb\bar{b}$ coupling (through the singlet component in h).

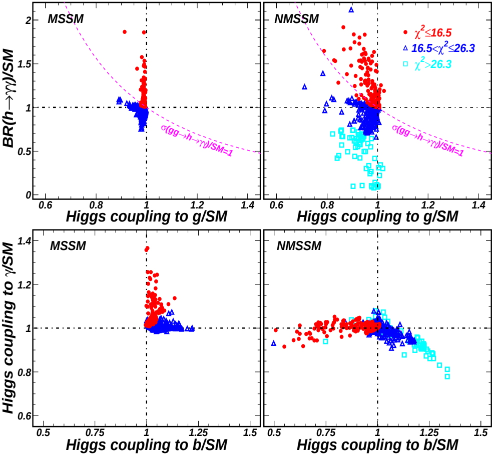


Fig.5 Detailed information about di-photon rate. Only Golden samples are considered.

III. SUSY vs data: Four lepton signal information

- Unlike the di-photon rate, an enhanced 4 lepton rate is not necessary to get a low χ^2.
- Although the hZZ coupling in the MSSM is same as that in the SM, the 4 lepton signal is never enhanced due to the reduction of $Br(h \to ZZ^*)$ (through the enhancement of $hb\bar{b}$ coupling).
- In the NMSSM, the 4 lepton signal may be enhanced by the increase of $Br(h \to ZZ^*)$ (through the suppression of $hb\bar{b}$ coupling).

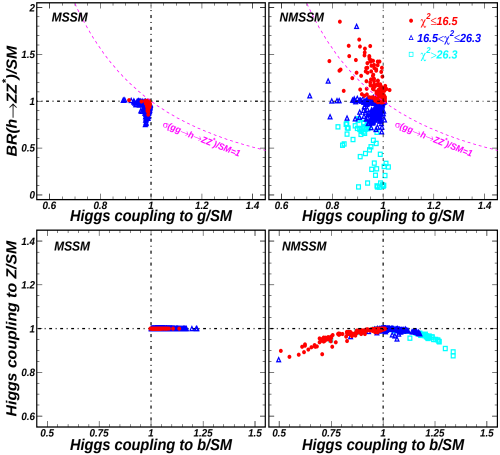


Fig.6: Same as Fig.4, but show the details about 4 lepton rate.

III. SUSY vs data: Coupling information

- In the MSSM,
  - Top quark Yukawa coupling is almost same as that in the SM.
  - Bottom quark Yukawa coupling is always enhanced.
- In the NMSSM with large λ,
  - Top quark Yukawa coupling is usually reduced.
  - Bottom quark Yukawa coupling may be either reduced or enhanced.

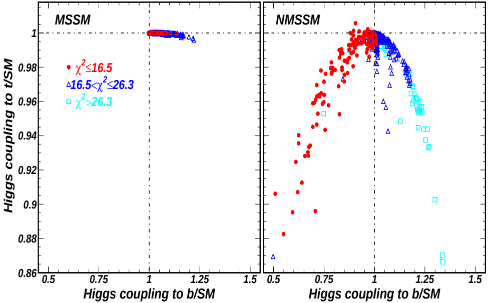


Fig.7: Same as Fig.4, but show the information about Top and Bottom quark Yukawa coupling.

III. SUSY vs data: Representative points information

	MSSM P1	MSSM P2	NMSSM P3	NMSSM P4
m_h(GeV)	125.1	125.4	125.9	125.2
χ^2	9.0	9.6	11.9	12.0
$\sigma(h \to \gamma\gamma)/SM$	1.59	1.82	1.45	1.35
$\sigma(h \to ZZ^*)/SM$	0.86	0.98	1.21	1.16
Δ(fine-tuning)	325.4	613.6	6.4	4.1
$\tan\beta$	59.9	37.1	4.7	4.0
$m_{\tilde{t}_1}$(GeV)	296.6	1470.3	405.6	262.5
$m_{\tilde{\tau}_1}$(GeV)	109.7	103.4	223.4	176.2
$m_{\tilde{\chi}_1^0}$(GeV)	57.8	49.7	79.1	78.1
$\Omega_{CDM}h^2$	0.112	0.104	0.104	0.109
$Br(B_s \to \mu^+\mu^-)/10^{-9}$	5.52	4.91	3.91	3.94
$\delta a_\mu/10^{-9}$	3.71	2.31	0.81	0.79
$\sigma(hV \to bbV)/SM$	1.01	1.00	0.62	0.73
$\sigma(hjj \to WW^*jj)/SM$	0.96	0.99	1.30	1.24
$\sigma(h \to WW^*)/SM$	0.86	0.98	1.21	1.16
$\sigma(hjj \to \gamma\gamma jj)/SM$	1.77	1.85	1.57	1.45
$\sigma(h \to \tau\tau)/SM$	0.86	0.99	0.55	0.64
$\sigma^{SI}/10^{-46}$ (cm^2)	0.32	0.04	14.3	17.0

III. SUSY vs data: Representative points information

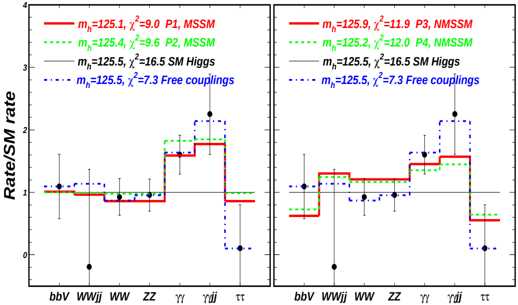


Fig.8: Predictions of two representative points for the MSSM and the NMSSM respectively.

- Free coupling scenario: $\chi^2 = 7.3$.
  Varying freely all Higgs couplings, including $h\gamma\gamma$ and hgg coupling.
- For four benchmark points, their predictions about various signal rates agree with data at 1σ.

III. SUSY vs data: Dark matter detection information

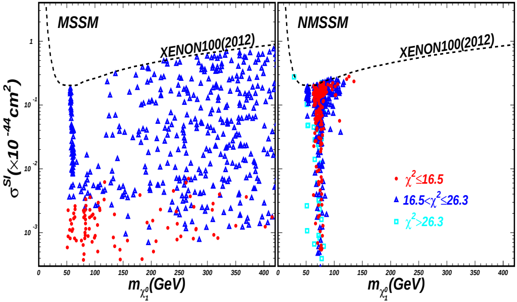


Fig.9: Spin-independent cross section of χ-nucleon scattering with $f_{Ts} = 0.020$.

- In MSSM, samples with $\chi^2 < 16.5$ predicts small cross section. Reason:
  - $\mu > 1\mathrm{TeV}$ so that the dark matter is highly bino-like.
  - Have considered constraints from $B_s \to \mu^+\mu^-$. For large $\tan\beta$, m_H very heavy.
- In NMSSM with large $\tan\beta$, dark matter mass is limited:

$$60\mathrm{GeV} \leq m_{\tilde{\chi}_1^0} \leq 140\mathrm{GeV}.$$

IV. Conclusion

- The MSSM can explain the LHC data quite well, but it suffers from severe fine tuning problem;
- The CMSSM is disfavored since it is hard to predict a 125 GeV Higgs boson, and at the same time cannot enhance the di-photon rate;
- The nearly Minimal Supersymmetric Standard Model (nMSSM) is excluded at 3σ level after considering available Higgs data;
- The most favored model is the Next to Minimal Supersymmetric Standard Model (NMSSM), whose predictions about the Higgs boson can naturally agree with the experimental data at 1σ level.

What are we doing? (Study Technique)

- Global Fit of SUSY models using latest experimental data;
- Simulation of sparticle production at the LHC;
- Implication of new data on SUSY models;
- Perform similar study for other new physics models.

Addendum: the nMSSM

1. General overview

Superpotential: $W = W_{MSSM} + \lambda \varepsilon_{ij} \hat{H}_u^i \hat{H}_d^j \hat{S} + \xi_F M_n^2 \hat{S}.$

Soft breaking terms:

$$V_{\text{soft}} = V_{MSSM} + \tilde{m}_d^2 |H_d|^2 + \tilde{m}_u^2 |H_u|^2 + \tilde{m}_S^2 |S|^2 + (\lambda A_\lambda \varepsilon_{ij} H_u^i H_d^j S + \text{h.c.}) + (\xi_S M_n^3 S + \text{h.c.}).$$

W_{MSSM}: MSSM superpotential without μ-term. $\hat{S}$: gauge singlet superfield.

V_{MSSM}: gaugino and sfermion soft masse. $\xi_F M_n^2 \hat{S}, \xi_S M_n^3 S$: Tadpole terms.

- 5 CP-even Higgs bosons, 2 CP-odd Higgs bosons and 5 neutralinos.
- In $N=1$ supergravity model with a Z_5 symmetry, the tadpole terms arise by supergravity effects at the six loop level.
  M_n is naturally at EW scale, not destabilize the gauge hierarchy!
  The tadpole terms can avoid the domain wall problem.
- The parameter μ is dynamically generated, $\mu = \lambda \langle s \rangle$.
- In the limit $\xi_S, \xi_F \to 0$, a Peccei-Quinn symmetry exists so that $m_{A_1} \to 0$.
- nMSSM is similar to NMSSM with no cubic self interaction of singlet field.
  Differences: the tree-level mass matrices and the minimization conditions.

Addendum: the nMSSM

2. Higgs sector:

λ, v_u, v_d, μ, $\tilde{m}_S$, A_λ and $m_A^2 = 2(\mu A_\lambda + \lambda \xi_F M_n^2)/\sin 2\beta$ as input parameters.

Basis $[\mathrm{Re}(H_u^0), \mathrm{Re}(H_d^0), \mathrm{Re}(S)]$, CP-even Higgs boson mass matrix:

$$\begin{pmatrix} m_A^2 \cos^2\beta + m_Z^2 \sin^2\beta & (2\lambda^2 v^2 - m_Z^2 - m_A^2)\sin\beta\cos\beta & \lambda v \cos\beta(2\mu\tan\beta - A_\lambda) \\ & m_A^2 \sin^2\beta + m_Z^2\cos^2\beta & \lambda v\cos\beta(2\mu - A_\lambda\tan\beta) \\ & & m_S^2 + \lambda^2 v^2 \end{pmatrix}$$

Basis $[\tilde{A} = \cos\beta\ \mathrm{Im}(H_u^0) + \sin\beta\ \mathrm{Im}(H_d^0), \mathrm{Im}(S)]$: $\mathcal{M_P}^2 = \begin{pmatrix} m_A^2 & \lambda A_\lambda v \\ & m_S^2 + \lambda^2 v^2 \end{pmatrix}$.

Two solutions to the Little Hierarchy Problem suffered by the MSSM:

- Consider $\tan\beta \to 1$ and $A_\lambda \to 2\mu$, $m_h^2 = (m_A^2 + m_Z^2)\cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta$.
- Choose the Peccei-Quinn symmetry limit. A_1 is light, $h \to A_1 A_1$ is the dominant decay. The LEP mass bound on h is not valid!

Addendum: the nMSSM

3. Neutralino sector: Define $\tilde{v}_{1,2} = \frac{1}{2}(v_2 \pm v_1)$.

Basis: $\psi^0 = \{-i\lambda', -i\lambda^3, \frac{1}{\sqrt{2}}(\psi_u^0 - \psi_d^0), \frac{1}{\sqrt{2}}(\psi_u^0 + \psi_d^0), \psi_s^0\}$

$$\mathcal{M}_{\tilde{\chi}} = \begin{pmatrix} M_1 & 0 & g'\tilde{v}_1 & g'\tilde{v}_2 & 0 \\ & M_2 & -g\tilde{v}_1 & -g\tilde{v}_2 & 0 \\ & & \mu & 0 & \sqrt{2}\lambda\tilde{v}_2 \\ & & & -\mu & -\sqrt{2}\lambda\tilde{v}_1 \\ & & & & 0 \end{pmatrix}.$$

$\tilde{\chi}_1^0$ is singlino-dominated with mass given by $m_{\tilde{\chi}_1^0} \simeq \frac{2\lambda^2\mu v^2}{(\mu^2+\lambda^2 v^2)(\tan\beta+\cot\beta)}$.

Three characters of $m_{\tilde{\chi}_1^0}$:

- The larger λ is, the heavier $\tilde{\chi}_1^0$ will be.
- The large $\tan\beta$ is, the lighter $\tilde{\chi}_1^0$ will be.
- The large μ is, the lighter $\tilde{\chi}_1^0$ will be.

Since a light, singlino-like neutralino is difficult to annihilate, dark matter relic density can impose constraints on λ, $\tan\beta$, μ and also $m_{\tilde{\chi}_1^0}$.

Addendum: the nMSSM

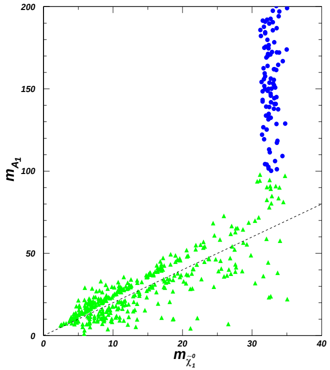


Fig.11: Scatter plot of the parameter space allowed by current experiments including constraints from a_μ with $m_{\tilde{\mu}} = 100 GeV$, projected in $m_{\tilde{\chi}_1^0} - m_{A_1}$ (in GeV) plane.

●: Characterized by $m_{A_1} \geq m_Z$.
In this case, $\tilde{\chi}_1^0$ mainly annihilates through exchanging a Z-boson.

△: Characterized by $m_{A_1} < m_Z$ and $m_{A_1} \simeq 2m_{\tilde{\chi}_1^0}$. Most samples.
In this case, $\tilde{\chi}_1^0$ mainly annihilates through exchanging a light A_1.

Addendum: the nMSSM

SM-like Higgs boson h

- Mass varies from 70 GeV to 145 GeV.
- Dominant decay may be any of the following:
  - $h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$;
  - $h \to \tilde{\chi}_1^0 \tilde{\chi}_2^0$;
  - $h \to A_1 A_1$;
  - $h \to h_1 h_1$.
- $Br(h \to b\bar{b})$ is always suppressed.
  For $m_h \sim 125\mathrm{GeV}$,
  $Br(h \to b\bar{b}) \lesssim 10\%$.

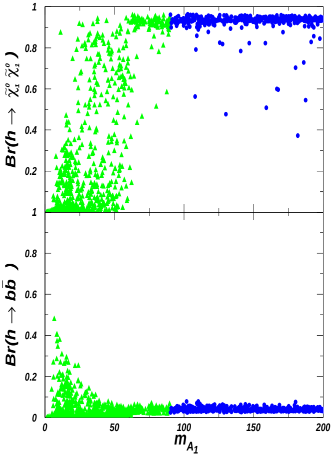
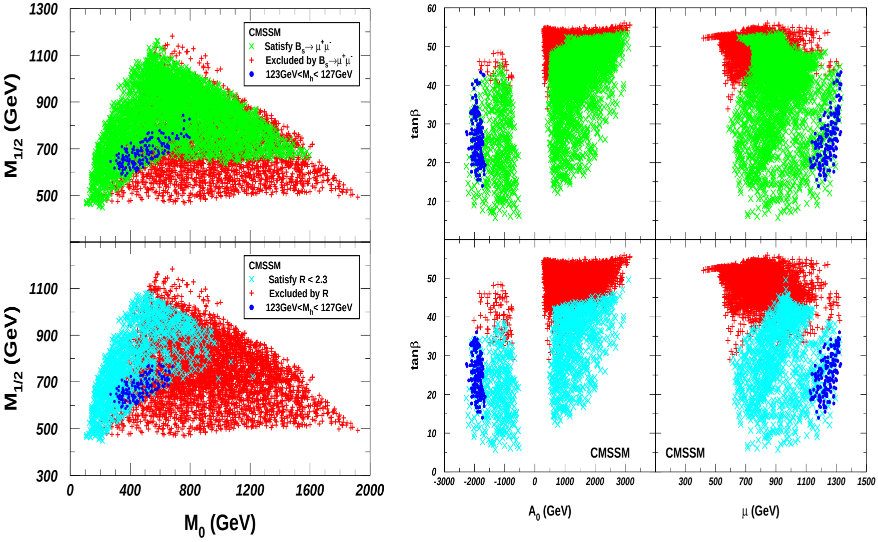
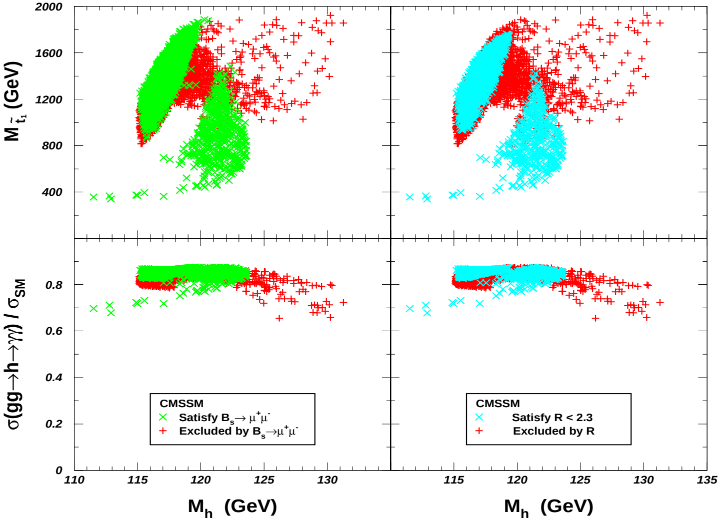


Fig.11: Decay rates of the SM-like Higgs boson as a function of the lightest CP-odd Higgs boson mass.

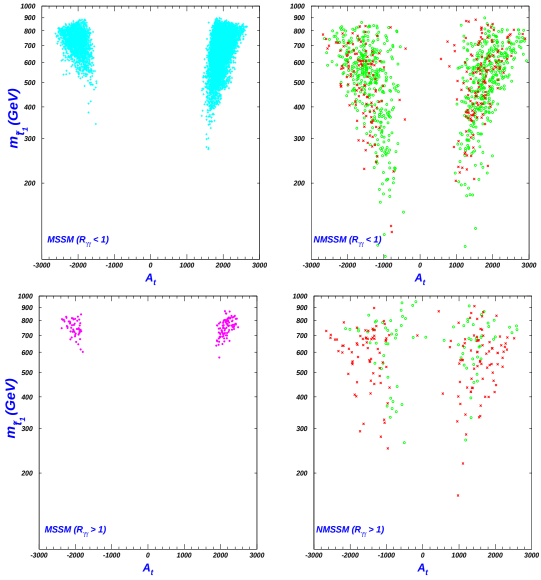
Addendum: the CMSSM



Addendum: the CMSSM



Addendum: Stop sector in MSSM and NMSSM



Addendum: Stop sector in MSSM and NMSSM

Relative light Stop can not be exclude by current LHC data.

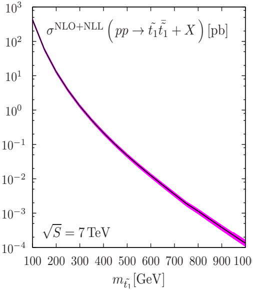
Consider Semi-leptonic Analysis:

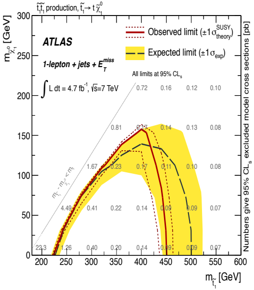
- $pp \to \tilde{t}_1 \tilde{t}_1^* \to (t\chi_1^0)(\bar{t}\chi_1^0) \to (b\ell^+\nu\tilde{\chi}_1^0)(\bar{b}jj\tilde{\chi}_1^0)$ or $(bjj\tilde{\chi}_1^0)(\bar{b}\ell^-\bar{\nu}\tilde{\chi}_1^0)$

  This channel can not impose any constraints after taking into account $\tilde{t}_1 \to t\chi_1^0$ decay branching ratio: $Br(\tilde{t}_1 \to t\chi_1^0) \lesssim 50\%$.

  For $\sigma(\tilde{t}_1\tilde{t}_1^*)$ at NLO, see W. Beenakker, 1006.4771.

  For ATLAS recent search result, see arXiv: 1208.2590.





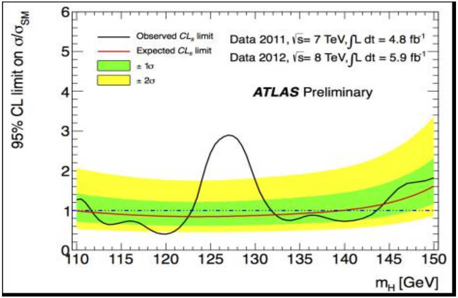
- $pp \to \tilde{t}_1 \tilde{t}_1^* \to (b\chi_1^+)(\bar{b}\chi_1^-) \to (b\ell^+\nu\tilde{\chi}_1^0)(\bar{b}jj\tilde{\chi}_1^0)$ or $(bjj\tilde{\chi}_1^0)(\bar{b}\ell^-\bar{\nu}\tilde{\chi}_1^0)$.

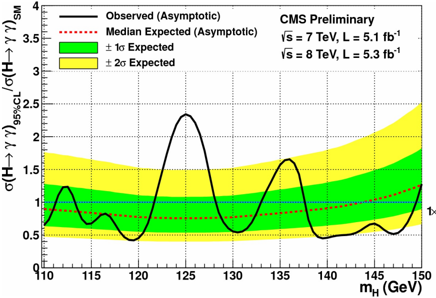
  The decay of χ_1^+ is rather complicated: $\chi_1^+ \to \chi_1^0 W, \tilde{\tau}^+\nu_\tau, \tilde{\nu}_\tau\tau^+$.

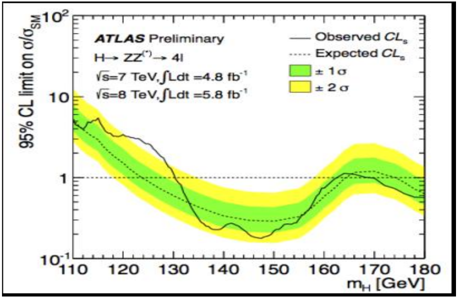
  $S/\sqrt{B} < 3$ when $m_{\tilde{\chi}_1^+} = 250\mathrm{GeV}$ for 5 fb^{-1} luminosity at 8TeV LHC.

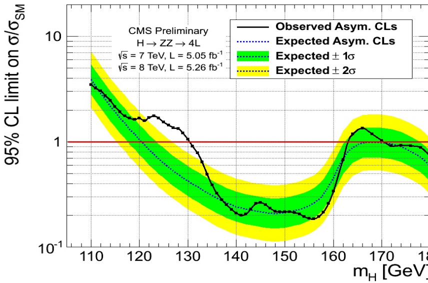
  See our work, arXiv: 1206.3865.

Addendum: Part of LHC data

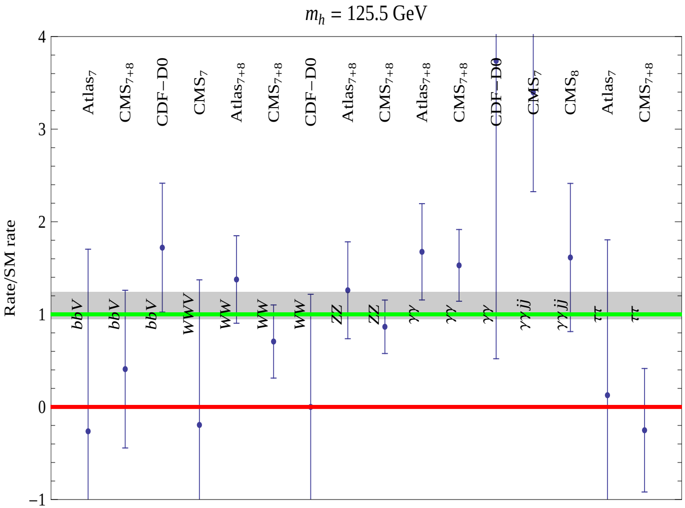




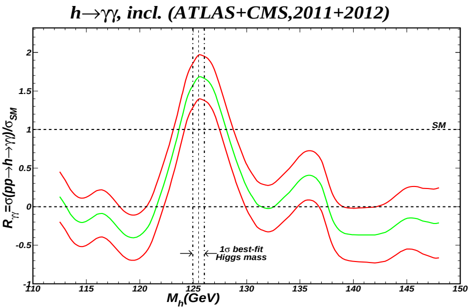




Addendum: Part of LHC data



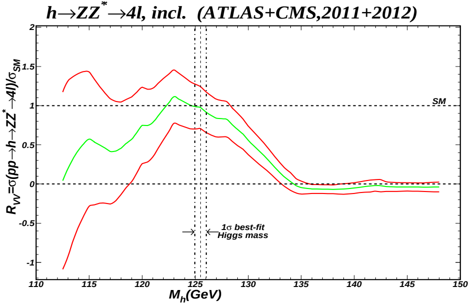
Addendum: Data Treatment (See 1203.4254)



Fiting

$$\bar{\mu}_i = R_{observed} - R_{expected}$$

$$\sigma_i = \frac{R_{expected}}{1.96}$$



Combining

$$\bar{\mu} = \frac{\bar{\mu}_a \sigma_c^2 + \bar{\mu}_c \sigma_a^2}{\sigma_a^2 + \sigma_c^2}$$

$$\sigma = \frac{\sigma_a \sigma_c}{\sqrt{\sigma_a^2 + \sigma_c^2}}$$