Implications of LHC Higgs and SUSY searches for MSSM

Nazila Mahmoudi
CERN TH & LPC Clermont-Ferrand (France)

In collaboration with A. Arbey, M. Battaglia & A. Djouadi
Search for SUSY is the main focus of BSM searches in both ATLAS and CMS!

Before the start of the LHC: high expectation for an early discovery of SUSY particles:

SUSY could be discovered even before the Higgs!

It appears not to be the case:
So far we have only limits which are pushing the masses to higher and higher values
Not enough to confirm/exclude SUSY

BUT:
- Supersymmetry is more than just the CMSSM!
- An alternative path to constrain SUSY efficiently is through the Higgs sector
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phenomenological MSSM (pMSSM)

A nice framework to go beyond CMSSM is the phenomenological MSSM:
The most general CP/R parity-conserving MSSM, assuming Minimal Flavour Violation at the TeV scale and suppressed FCNC’s at tree level, with 19 free parameters:
10 sfermion masses, 3 gaugino masses, 3 trilinear couplings, 3 Higgs/Higgsino

A. Djouadi et al., hep-ph/9901246

Flat scans over the pMSSM 19 parameters

| Parameter | Range (in GeV) |
|-----------|----------------|
| $\tan \beta$ | [1, 60] |
| $M_A$ | [50, 2000] |
| $M_1$ | [-2500, 2500] |
| $M_2$ | [-2500, 2500] |
| $M_3$ | [50, 2500] |
| $A_d = A_s = A_b$ | [-10000, 10000] |
| $A_u = A_c = A_t$ | [-10000, 10000] |
| $A_\mu = A_\tau$ | [-10000, 10000] |
| $\mu$ | [-3000, 3000] |
| $M_{\tilde{e}}_L = M_{\tilde{\mu}}_L$ | [50, 3000] |
| $M_{\tilde{e}}_R = M_{\tilde{\mu}}_R$ | [50, 3000] |
| $M_{\tilde{\tau}}_L$ | [50, 3000] |
| $M_{\tilde{\tau}}_R$ | [50, 3000] |
| $M_{\tilde{\nu}}_1 = M_{\tilde{\nu}}_2$ | [50, 3000] |
| $M_{\tilde{\nu}}_3$ | [50, 3000] |
| $M_{\tilde{u}}_R = M_{\tilde{c}}_R$ | [50, 3000] |
| $M_{\tilde{t}}_R$ | [50, 3000] |
| $M_{\tilde{d}}_R = M_{\tilde{s}}_R$ | [50, 3000] |
| $M_{\tilde{b}}_R$ | [50, 3000] |

- Spectrum generation (SoftSusy, Suspect)
- Low energy observables (SuperIso)
- Dark matter (SuperIso Relic, Micromegas)
- SUSY and Higgs mass limits (SuperIso, HiggsBounds)
- Higgs and SUSY decays (HDECAY, Higlu, FeynHiggs, SDECAY)
- Event generation and cross sections (PYTHIA, Prospino)
- Fast detector simulation (Delphes)

Imposing constraints from:
Flavour physics ($BR(B \rightarrow X_s \gamma)$, $BR(B_s \rightarrow \mu^+ \mu^−)$, $R(B \rightarrow \tau \nu)$, $BR(D_s \rightarrow \tau \nu)$, $BR(B \rightarrow D^0 \tau \nu)$, $R_{\mu23}(K \rightarrow \mu \nu$)), dark matter relic density, sparticle mass upper bounds and Higgs search limits.
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\( R_{\mu 23}(K \rightarrow \mu \nu) \), dark matter relic density, sparticle mass upper bounds and Higgs search limits.
Both ATLAS and CMS have confirmed the excess at $\sim 126$ GeV!

Combining ATLAS and CMS results: $M_h = 125.9 \pm 2.1$ GeV

We consider the interval $123 < M_h < 129$ GeV
Higgs searches

- In the SM, the Higgs mass is essentially a free parameter.
- In the MSSM, the lightest CP-even Higgs particle is bounded from above: \( M_h^{\text{max}} \approx M_Z |\cos 2\beta| + \text{radiative corrections} \lesssim 110 - 135 \text{ GeV} \)
- Imposing \( M_h \) places very strong constraints on the MSSM parameters through their contributions to the radiative corrections:
  \[
  M_h^{2M_A \gg M_Z^2 \cos^2 2\beta} + \frac{3m_t^4}{2\pi^2 v^2} \left[ \log \frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2} \left( 1 - \frac{X_t^2}{12M_S^2} \right) \right]
  \]
- Important parameters for MSSM Higgs mass:
  - \( \tan \beta \) and \( M_A \)
  - the SUSY breaking scale \( M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}} \)
  - the mixing parameter in the stop sector \( X_t = A_t - \mu \cot \beta \)
- \( M_h^{\text{max}} \) is obtained for:
  - a decoupling regime with a heavy pseudoscalar Higgs boson, \( M_A \sim O(\text{TeV}) \)
  - large \( \tan \beta \), i.e. \( \tan \beta \gtrsim 10 \)
  - heavy stops, i.e. large \( M_S \)
  - maximal mixing scenario, i.e. \( X_t = \sqrt{6}M_S \)
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Consequences of a 126 GeV Higgs on constrained MSSM scenarios

Maximal Higgs mass

Several constrained models are excluded or about to be!
Sensitivity to the top mass

Impact of $m_t$ on the Higgs mass:

$m_t = 170$, 173 and 176 GeV

The variations in the top mass is directly transmitted to the Higgs mass!

That can even resurrect mGMSB!
Consequences of a 126 GeV Higgs on pMSSM

Influence on squark spectra

With $M_h > 111$ GeV

With $123 < M_h < 127$ GeV

A. Arbey, M. Battaglia, F.M., Eur.Phys.J. C72 (2012) 1847
A. Arbey, M. Battaglia, F.M., Eur.Phys.J. C72 (2012) 1906
Consequences of a 126 GeV Higgs

Particular benchmark scenarios

In the maximal mixing scenario ($X_t \approx \sqrt{6} M_s$):

\[
\text{Cyan: CMS limit from } A^0 \to \tau\tau \text{ with 4.6/fb}
\]
\[
\text{Red: flavour constraints: } b \to s\gamma, B \to \tau\nu \text{ and } B_s \to \mu\mu
\]

Very strong constraint from the neutral Higgs searches!
Consequences of a 126 GeV Higgs

Particular benchmark scenarios

In the **typical mixing** scenario ($X_t \approx M_S$):

---

**Cyan**: CMS limit from $A^0 \rightarrow \tau\tau$ with 4.6/fb

**Red**: flavour constraints: $b \rightarrow s\gamma$, $B \rightarrow \tau\nu$ and $B_s \rightarrow \mu\mu$

Very strong constraint from the neutral Higgs searches!
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Particular benchmark scenarios

In the no mixing scenario ($X_t \approx 0$):

Cyan: CMS limit from $A^0 \rightarrow \tau\tau$ with 4.6/fb

Red: flavour constraints: $b \rightarrow s\gamma$, $B \rightarrow \tau\nu$ and $B_s \rightarrow \mu\mu$

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Favoured region: $\chi^2$ analysis and normalized distributions

Solid lines: accepted pMSSM points with $123 < M_h < 129$ GeV
Dashed lines: points favoured at 90% C.L. by $M_h$, $\text{BR}(h^0 \to \gamma \gamma)$, $\text{BR}(h^0 \to ZZ)$ and $\text{BR}(h^0 \to b\bar{b})$

$R_{\gamma\gamma} = 1.71 \pm 0.33$, $R_{ZZ} = 0.95 \pm 0.40$ (ATLAS+CMS), $R_{b\bar{b}} = 1.06 \pm 0.50$ (CMS+Tevatron)

$\rightarrow$ Heavy stops and light sbottoms favoured by the new results!
**Conclusion**

- Impressive impact of the Higgs searches on SUSY scenarios
- Complementary to the direct SUSY searches
- Several constrained MSSM scenarios are about to be ruled out by the Higgs discovery
- It is now mandatory to go beyond CMSSM
- There is still plenty of room in general MSSM

*Imagine what we can get by the end of the year with 3 times more data!*
### Backup

| Introduction | pMSSM | Higgs searches | Implications | Conclusion |
|--------------|-------|----------------|--------------|------------|
| o            | o     | o              | o            | o          |

Backup
Sensitivity to $M_A$ from $\text{BR}(B_s \rightarrow \mu^+\mu^-)$

Considering 2 scenarios:

- Current bound from LHCb+CMS + estimated th syst:
  \[
  \text{BR}(B_s \rightarrow \mu^+\mu^-) < 1.26 \times 10^{-8}
  \]

- SM like branching ratio with estimated 20% total uncertainty

A. Arbey, M. Battaglia, F.M., Eur.Phys.J. C72 (2012)

Light $M_A$ strongly constrained!
Dark matter direct detection

Considering 2 scenarios:

- Current Xenon 100 limit
- Projected 2012 90% C.L. upper limit

Again light $M_A$ strongly constrained!

A. Arbey, M. Battaglia, F.M., Eur.Phys.J. C72 (2012)
Higgs searches

Direct searches for $A \rightarrow \tau \tau$

Allowed region of $(M_A, \tan \beta)$ from full pMSSM scans for 1.1 and 15 fb$^{-1}$ compared to published CMS expected limit

Low $M_A$ region below 350 GeV can be explored and excluded if no signal except a narrow strip around $\tan \beta = 5$. 