HXSWG3 Meeting 2017: NMSSM

Conveners:

ATLAS: David Strom CMS: Abideh (Nadjieh) Jafari

Theory: Margarete Mühlleitner, Florian Staub and Ulrich Ellwanger

Outline:

Theory: Recent Developments

Phenomenology of the Higgs Sector

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Theory: Recent Developments

Improvements of NMSSM Higgs Mass Calculations:

- Comparison of various codes: F. Staub et al., Comput.Phys.Commun. 202 (2016) 113-130
- Improvements of FeynHiggs: P. Drechsel et al., Eur.Phys.J. C77 (2017) 1, 42
- EFT (effective SM) approach for heavy SUSY spectrum: P. Athron et al., JHEP 1701 (2017) 079 and
  F. Staub, W. Porod, Eur. Phys. J. C (2017) 77:338
- Analysis of On-Shell Calculations (NMSSMCALC/FeynHiggs),
  P. Drechsel et al., Eur.Phys.J. C77 (2017) no.6, 366
- NMSSM in SloopS, G. Belanger et al., Phys.Rev. D93 (2016) no.11, 115031
- "Goldstone Boson Catastrophe": Treatment of Cases with Infrared Divergencies, J. Braathen et al., arXiv:1706.05372

Ongoing work, it seems hard to improve the theoretical precision below $\Delta(M_{Higgs}) \sim 3$ GeV for all possible SUSY spectra, under discussion

Further Theoretical Aspects (recent $\geq$ 2016):

- Vacuum Stability: M. Krauss et al., Eur.Phys.J. C77 (2017) no.5, 331; J. Beuria et al., arXiv:1705.08208 and JHEP 1704 (2017) 024
- Naturalness in the NMSSM after LHC run I: J. Cao et al., JHEP 1608 (2016) 037
- $\Delta F = 2$ Flavour changing processes, J. Kumar et al., JHEP 1610 (2016) 134
- Alignment limit in the NMSSM Higgs sector, M. Carena et al., Phys.Rev. D93 (2016) no.3, 035013
- Complex NMSSM:
  - NMSSMCALC (M. Mühlleitner et al.), incl. test of EDMs
  - Combining SARAH/SPheno (F. Staub/W. Porod)
  - Comparison among codes (M. Goodsell, F. Staub, arXiv:1604.05335)
  - NMSSMTools (F. Domingo), incl. pheno-constraints from Higgs- K- and B-physics
  - FeynHiggs (F. Domingo et al., arXiv:1706.00437)

Phenomenology of the Higgs Sector

Field Content:
— H_{125}, mostly SM-like;
— H/A, mostly MSSM-like;
— H_S/A_S, mostly singlet-like, may be very light

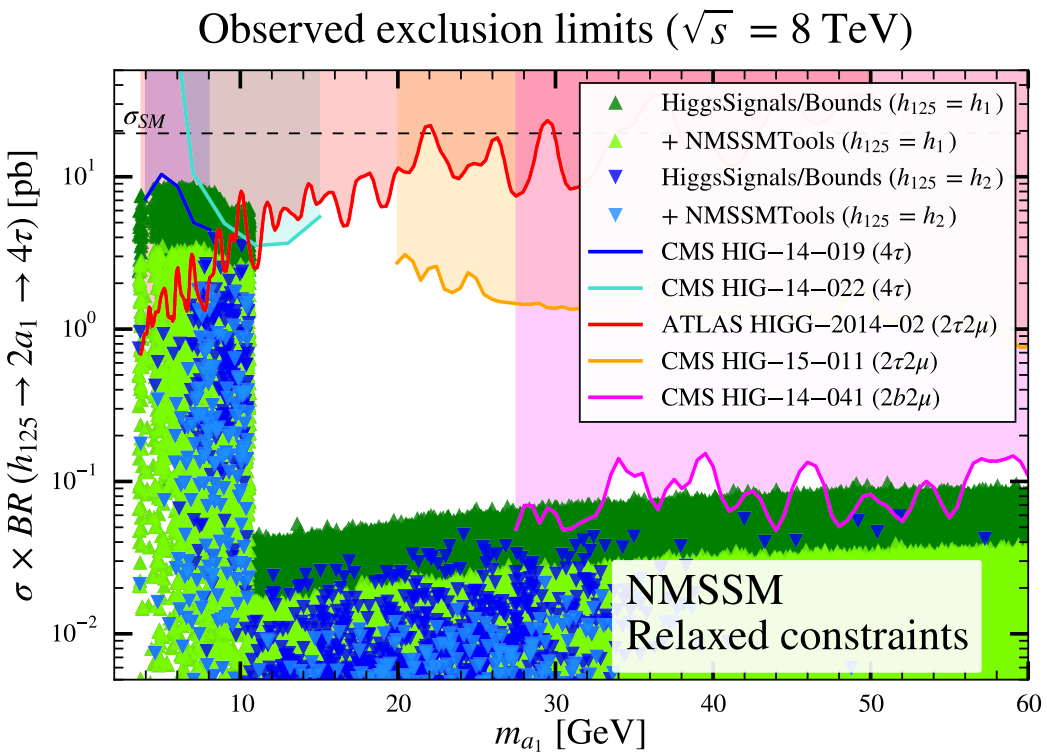
See the list of benchmark points for NMSSM specific Higgs (Higgs-to-Higgs) decays on the web page
`twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGNMSSM#Overview_...`

NMSSM specific phenomena:

- Exotic decays of H_{125}
- Direct production of light NMSSM specific Higgs states H_S/A_S
- Cascade decays into NMSSM specific Higgs states H_S/A_S

$H_{125} \to A_S A_S \to \ldots$:

Many possible final states, many recent and ongoing searches by ATLAS/CMS
Compilation by R. Aggleton et al., JHEP 1702 (2017) 035:



Light green/blue points: viable in the NMSSM after LEP/LHC constraints

Updated Summaries of Run I Searches for $H_{125} \to AA \to \ldots$:

ATLAS Collaboration, "Search for Higgs bosons decaying to aa in the $\mu\mu\tau\tau$ final state in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS experiment," Phys. Rev. D **92** (2015) no.5, 052002, arXiv:1505.01609

CMS Collaboration, "Search for light bosons in decays of the 125 GeV Higgs boson in proton-proton collisions at $\sqrt{s} = 8$ TeV," arXiv:1701.02032

The First Run II Results from Searches for $H_{125} \to AA \to \ldots$:

CMS-HIG-16-035, "A search for beyond Standard Model light bosons decaying into muon pairs", including searches for NMSSM-specific $H_{BSM} \to AA \to \ldots$

ATLAS-CONF-2017-042, "Search for Higgs boson decays to Beyond-the-Standard-Model light bosons in four-lepton events with the ATLAS detector at $\sqrt{s} = 13$ TeV"

$\to$ These searches for H_S/A_S have only scratched the NMSSM parameter space, but many more are ongoing!

Recent theoretical studies:

- Exploit $A_S \to \gamma\gamma$: M. Guchiat et al., Phys.Rev. D95 (2017) no.3, 035036 and arXiv:1705.06275
- Branching ratios of a very light A_S with $M_{A_S} \lesssim 1$ GeV: F. Domingo, JHEP 1703 (2017) 052
- Investigating light NMSSM pseudoscalar states with boosted ditau tagging: E. Conte et al., JHEP 1605 (2016) 100

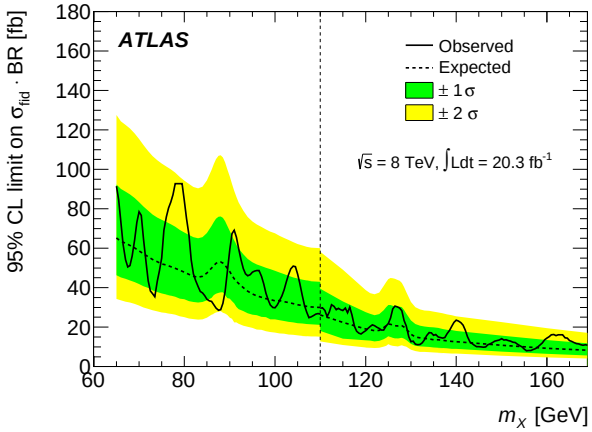
Direct Production of NMSSM specific Higgs Bosons:

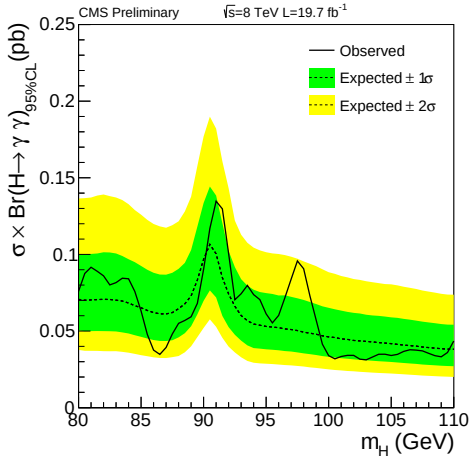
Recent theoretical Studies:

- Diphoton signal of H_S: J. Cao et al., Phys.Rev. D95 (2017) no.11, 116001
- Comparison of signal rates into ZZ, $\tau^+\tau^-$, $\gamma\gamma$, $t\bar{t}$: NMSSM, CxSM, N2HDM, C2HDM; M. Mühlleitner et al., arXiv:1703.07750
- Differential cross section for neutral Higgs-boson production, S. Liebler et al., arXiv:1608.02949
- bbA_S production: N.-E. Bomark et al., JHEP 1502 (2015) 044, prospects somewhat (too?) pessimistic

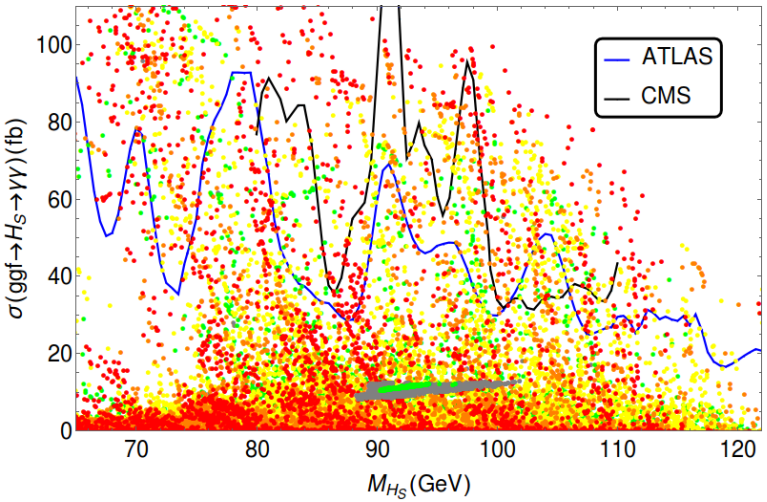
Searches at Run I:

ATLAS/CMS searches for $ggF \to H_S \to \gamma\gamma$ at 8 TeV:





Do the ATLAS/CMS searches touch possible values for $\sigma(ggF \to H_S \to \gamma\gamma)$ within the LEP/LHC-allowed NMSSM parameter space? (M. Rodríguez, U.E.):



YES, but far from exclusion...

NMSSM specific Higgs Bosons H_S/A_S via Cascade Decays (mostly from MSSM-like H/A)

Similar to searches for resonant H_{125} pair production or $H_{125} + X$ production, but with H_{125} replaced by H_S/A_S!

Recent theoretical studies:

- $H \to H_S +$ neutralinos (mono-Higgs): S. Baum et al., arXiv:1703.07800
- Review of Higgs Branching Ratios: C. Beskidt et al., Phys.Lett. B759 (2016) 141
- $H \to H_S + H_{125}$: R. Costa et al., JHEP 1606 (2016) 034: "Smoking gun"
  M. Rodríguez, U.E. to appear:
  $\to b\bar{b}b\bar{b}/b\bar{b}\tau^+\tau^-/b\bar{b}\gamma\gamma$ incl. background studies
- $H/A \to Z + A_S/H_S$: N.-E. Bomark et al., JHEP 1502 (2015) 044

CMS search for $H/A \to Z(\ell\ell) + A_{(S)}/H_{(S)}(b\bar{b})$:
Phys. Lett. B759, 369 (2016), could be interpreted in the NMSSM

Missing are more searches for Higgs pair or Higgs + X production with $M_{Higgs} \neq 125$ GeV

Dark Matter: Singlino-like LSP

— Easily compatible with constraints from direct detection experiments

— Good relic density via resonant s-channel annihilation via a light singlet-like pseudoscalar (or the SM Higgs/Z if M_{LSP} is close enough to $M_{Resonance}/2$)

— Impact on sparticle decay cascades! (See below)

Possible Consequences for the NMSSM Higgs Sector:

- A light singlet-like pseudoscalar is favoured (for a light singlet-like LSP)
- Sparticle decays can be important sources for SM- or NMSSM-Higgs pair production (+ jets + E_T^{miss})

NMSSM specific Higgs Bosons from Sparticle Decays

A singlino-like LSP can complicate sparticle decay cascades considerably:
No sparticle wants to decay into a singlino-like LSP unless it is the only possible decay mode

The last decay in a decay chain NLSP$\rightarrow$ LSP+X can lead to a very small energy of the LSP if
a) M_{LSP} is small (a few GeV),
b) $M_{NLSP} \sim M_X + M_{LSP}$
$\rightarrow$ most energy goes into X, little energy goes into the LSP $\rightarrow$ missing E_T^{miss}

$\rightarrow$ alleviation of lower limits on squark, gluino, stop... masses
X could be H_{125}, H_S or A_S which are pair produced

A corresponding CMS thesis is under way

Conclusions and Outlook

The precision of Higgs mass calculations in the NMSSM is at the level of the MSSM (± 3 GeV); a higher precision remains an issue!

The rich NMSSM Higgs sector is hardly explored/tested

Feasable:

- Exotic H_{125} decays into $(A_S + A_S)/(H_S + H_S) \to (b\bar{b}, \tau^+\tau^-, \mu^+\mu^-)^2$ for various $M_{b\bar{b},\tau^+\tau^-,\mu^+\mu^-}$ (done anyhow, no BMpoints needed)
- Search for direct H_S/A_S production in ggF (in ass. with $b\bar{b}$, $t\bar{t}$?)
- Higgs-to-Higgs cascade decays: Many possibilities!
  Largest production cross sections typically for MSSM-like states $H/A \to ...$
  Some BMpoints are available, more or BMplanes would be desirable
  Searches for Higgs pair or Higgs + X production with $M_{Higgs} \neq 125$ GeV would be desirable

Sparticle decay chains into singlino LSP $+X = H_{125},\ H_S,\ A_S$:

Possibly with "missing E_T^{miss}",
Hardly explored/tested, more BMpoints/planes would be welcome