NMSSM: Tools, Signatures and Benchmarks

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Possible features: enhanced tree-level Higgs mass ($\rightarrow$ Naturalness), Z_3 invariant version solves μ problem, new dark matter candidate (singlino), rich phenomenology, ...

Tools

Public tools for the NMSSM

We categorise the public tools to study the NMSSM in the YR4 as follows:

1. Codes to calculate the **mass spectrum** of the NMSSM:
   - `FlexibleSUSY & SARAH`: @HepForge
   - `NMSSMCALC`: www.itp.kit.edu/∼maggie/NMSSMCALC/
   - `NMSSMTools`: www.th.u-psud.fr/NMHDECAY/nmssmtools.html
   - `SPheno & SARAH`: @HepForge
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2. Code to check the **vacuum stability**:
   - `Vevacious`: @HepForge

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   - SPheno & SARAH: @HepForge
   - SoftSUSY: @HepForge
2. Code to check the **vacuum stability**:
   - Vevacious: @HepForge
3. Code to calculate the neutral Higgs **cross section**
   - SusHi: @HepForge
   - HiGlu

Spectrum generators

We give in the YR4 for each spectrum generator the most relevant information

- What models are supported?
- What is the method and accuracy of the Higgs mass calculation?
- What is about the calculation of decays?
- What other calculations are performed by the tool?

Overview of spectrum generators

	FlexibleSUSY	NMSSMCALC	NMSSMTools	SoftSUSY	SPheno
General					
Dependences	using SARAH	stand alone	stand alone	stand alone	using SARAH
Language	C++	Fortran77/90	Fortran77	C++	Fortran90
Supported Models beside general, scale invariant NMSSM					
Without Z_3	✓	✗	✓	✓	✓
GUT models	✓	✗	✓	✓	✓
Corrections to Higgs mass					
ren. scheme	$\overline{\text{DR}}$	OS, $\overline{\text{DR}}$	$\overline{\text{DR}}$	$\overline{\text{DR}}$	$\overline{\text{DR}}$
full 1-loop	✓	✓	✓	✓	✓
2-loop	$\alpha_s(\alpha_b+\alpha_t)$ +MSSM appr.	$\alpha_s\alpha_t$	$\alpha_s(\alpha_b+\alpha_t)$ +MSSM appr.	$\alpha_s(\alpha_b+\alpha_t)$ +MSSM appr.	$\alpha_i\alpha_j$ i,j=s,t,b,τ,λ,κ
CPV @(1,2)-loop	(✓,✗)	(✓,✓)	(✍,✗)	(✗,✗)	(✓,✍)
Calculation of other observables					
1-loop SUSY masses	✓	✗	✓	✓	✓
Decays	✍	✓	✓	via NHMDECAY	✓
Flavour observables	✗	✗	✓	✗	✓

✍: in preparation

Check for the vacuum stability

The **vacuum with correct EWSB is not necessarily the global minimum** of the scalar potential:

- Large stop mixing: charge and colour breaking minima with stop VEVs can appear
- Large A_κ, A_λ: deeper minima with other combinations of v_d,v_u,v_S more likely [Kobayashi et al. 1203.4328, and refs therein]

Check for the vacuum stability

The **vacuum with correct EWSB is not necessarily the global**

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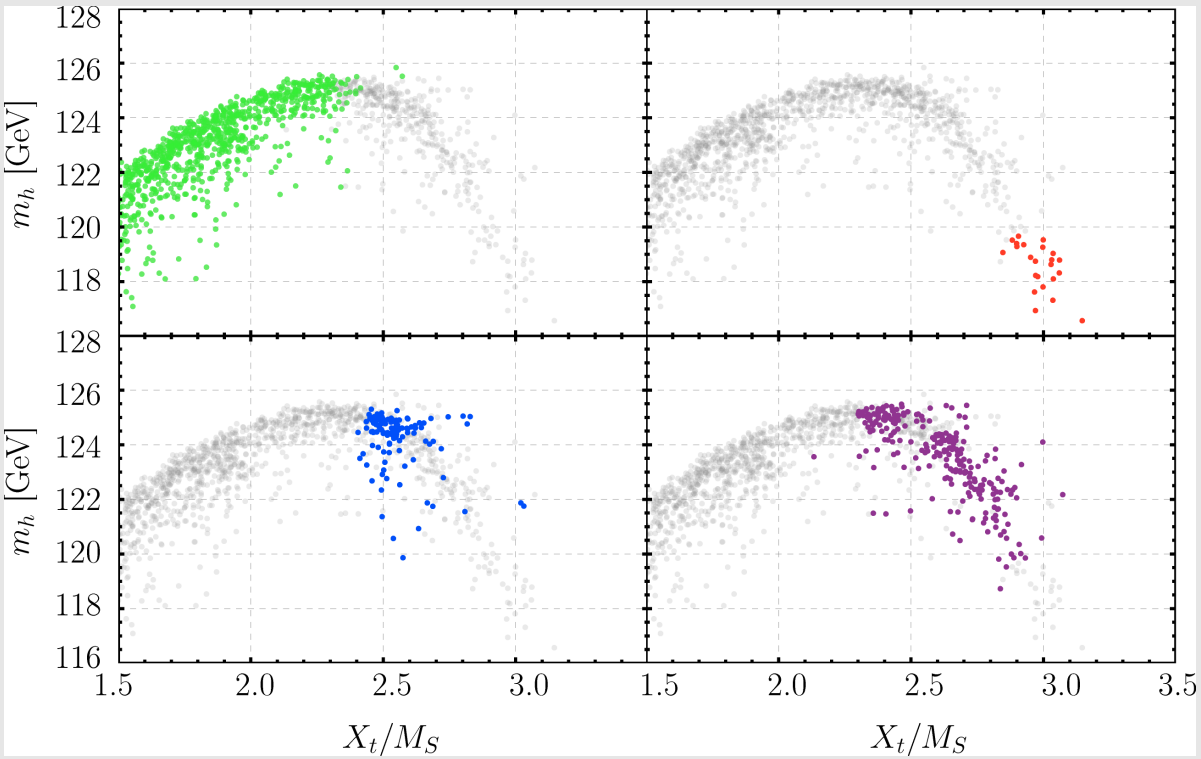
Charge and colour breaking minima

[Camargo-Molina et al.,1405.7376]



stable , metastable , unstable at $T = 0$, unstable at $T > 0$

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Information in YR4

- we briefly describe these issues
- we give some details about the tool `Vevacious` which can be used to check the vacuum stability and –if necessary– to calculate the life-time via `CosmoTransitions`.

Higgs cross section

- We summarise the main production channels
- We give details about the calculation of cross sections in the NMSSM
  - **Gluon fusion and bottom-quark annihilation** for the real NMSSM supported by SusHi v1.5.0
  - Private version of HiGlu for (s)quark induced contributions.
  - **Other production rates** can be estimated by reweighting the effective couplings to Z, W and t and using
- Discussion of higher order corrections, theoretical uncertainty and p_T distributions (via POWHEG-BOX, MoRe-SusHi, aMCSusHi) are similar to MSSM.
  $\rightarrow$ Many references to MSSM literature and MSSM section of YR4.

Signatures

NMSSM-specific signatures

We categorise NMSSM-specific signatures as follows:

1. Direct H_{125} production and decays
2. Direct light H_S/A_S production and decays
3. Direct H/A production and decays
4. Higgs bosons in squark/gluino/chargino/neutralino decays, singlino-like LSP
5. Displaced vertices

A few general comments for each category are given, and for most scenarios benchmark points are proposed.

NMSSM Signatures I

I	Direct H_{125} production and decays			
	Process	Signatures	Comments	BP
a	$H_{125} \to H_S + H_S$ or $H_{125} \to A_S + A_S$	Combinations of decays into $b\bar{b}$, $\tau^+\tau^-$, $\mu^+\mu^-$, $\gamma\gamma$	Notably A_S can be very light	✓
b	$H_{125} \to H_S + H_S \to 4A_S$	Combinations of decays into $b\bar{b}$, $\tau^+\tau^-$, $\mu^+\mu^-$,$\gamma\gamma$	A_S can be very light	✓
c	$H_{125} \to \tilde{\chi}_1^0 + \tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + H_S$	H_S decay products $+E_T^{miss}$		

- BR of H_{125} into singlets/singlino can be large

$\to$ Limits from non-standard decays of H_{125} can be more constraining than direct searches for H_S/A_S

NMSSM Signatures II

II	Direct light H_S/A_S production and decays			
	Process	Signatures	Comments	BP
a	H_S/A_S	$b\bar{b}$, $\tau^+\tau^-$, $\mu^+\mu^-$, $\gamma\gamma$		✓
b	$H_S \to A_S A_S$	Combinations of decays into $b\bar{b}$, $\tau^+\tau^-$, $\mu^+\mu^-$, $\gamma\gamma$	A_S can be very light	✓
c	$H_S \to H_{125} H_{125}$			✓
d	$A_S \to Z H_S$	$Z + b\bar{b}$		✓
e	$A_S \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$			✓

- Production cross section prop. to singlet-doublet mixing

$\to$ Can vary a lot

NMSSM Signatures III

III	Direct H/A production and decays			
	Process	Signatures	Comments	BP
a	$H \to H_S + H_S$ $H \to A_S + A_S$ $A \to H_S + A_S$	$b\bar{b} + b\bar{b}$, $b\bar{b} + \tau^+\tau^-$, $b\bar{b} + \gamma\gamma$, 4γ	A_S can be very light	✓ ✓
b	$H \to H_{125} + H_S$ $A \to H_{125} + A_S$	$b\bar{b} + b\bar{b}$, $b\bar{b} + \tau^+\tau^-$, $b\bar{b} + \gamma\gamma$, 4γ	A_S can be very light	✓ ✓
c	$H \to H_{125} + H_S$ $\to H_{125} + A_S + A_S$ $A \to A_S + H_S$ $\to A_S + A_S + A_S$	$b\bar{b} + b\bar{b} + b\bar{b}$, $b\bar{b} + b\bar{b} + \tau^+\tau^-$, $b\bar{b} + b\bar{b} + \gamma\gamma$, $b\bar{b} + \tau^+\tau^- + \gamma\gamma$, $b\bar{b} + 4\gamma$, $\tau^+\tau^- + 4\gamma$		✓ ✓
d	$H \to Z + A_S$ $A \to Z + H_S$	$l^+l^- + b\bar{b}$, $l^+l^- + \tau^+\tau^-$, $l^+l^- + \gamma\gamma$	l^+l^- from Z decays	✓ ✓
e	$A \to Z + H_S$ $\to Z + A_S + A_S$	$l^+l^- + b\bar{b} + b\bar{b}$	l^+l^- from Z decays	 ✓

- Production dominated by ggF because of typical small $\tan\beta$
- In competition with MSSM-like decays $H \to H_{125}H_{125}$, $H \to$ invisible, ...

NMSSM Signatures IV

IV	Higgs bosons in squark/gluino/chargino/neutralino decays, singlino-like LSP			
	Process	Signatures	Comments	BP
a	$\tilde{\chi}_i^0 \to \tilde{\chi}_1^0 + H_{125}$	Jets + $H_{125} + H_{125} + E_T^{miss}$ $H_{125} \to b\bar{b}$, $\tau^+\tau^-$ or $\gamma\gamma$		✓
b	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + H_{125}$	Jets + $H_{125} + H_{125}$ $H_{125} \to b\bar{b}$, $\tau^+\tau^-$ or $\gamma\gamma$	$\tilde{\chi}_1^0$ very light, little E_T^{miss}	✓
c	$\tilde{\chi}_i^0 \to \tilde{\chi}_1^0 + H_S$ $i > 1$	Jets + $H_S + H_S + E_T^{miss}$ $H_S \to b\bar{b}$, $\tau^+\tau^-$ or $\gamma\gamma$		✓
d	$\tilde{\chi}_i^0 \to \tilde{\chi}_1^0 + H_S$, $H_S \to A_S + A_S$	Jets + E_T^{miss} + $4t$ + up to $4A_S$		✓
e	$\tilde{\chi}_i^0 \to \tilde{\chi}_1^0 + A_S$	Trileptons + E_T^{miss}	A_S very light	✓

- NMSSM-specific feature is presence of singlino LSP

→ Sparticles usually decay in NLSP (bino)

→ For very light singlino and narrow phase space, E_T^{miss} can be tiny

NMSSM Signatures V

V	Displaced vertices		
	Process	Signatures	BP
a	Squark/gluino production	Jets + displaced vertices	✓
b	chargino/slepton production	Leptons + displaced vertices	✓

- Possible for Gravitino LSP as in the MSSM
- Alternatively, a very weakly coupled singlino LSP can have the same effect

Benchmarks

Benchmark points

- We summarise nine benchmark scenarios already published elsewhere
- All points are updated for YR4
  - . . . to use proposed SM parameters
  - . . . to use spectrum generator with highest available precision
- Main features as well as most important masses, cross sections and branching ratios are presented in YR4:
  $\rightarrow$ see the following 2 examples

BP1	
B. Allanach, M. Badziak, C. Hugonie and R. Ziegler from Phys.Rev. D92 (2015) 1, 015006, arXiv:1502.05836	
Main Features	GMSB combined with $\mathbb{Z}_3$-invariant NMSSM (gravitino $\tilde{G}$ LSP) $\tilde{\chi}_1^0$: singlino-like NLSP
BP1_1	
Spectrum	$M_{H_{125}} \approx 123$ GeV, $M_{A_S} \approx 26$ GeV, $M_{H_S} \approx 93$ GeV, $M_H \approx 891$ GeV, $M_A \approx 891$ GeV, $M_{\tilde{\chi}_1^0} \approx 102$ GeV, $M_{\tilde{\tau}_1} \approx 332$ GeV (NNLSP)
Production cross sections and branching fractions	
H_S	via ggF ≈ 15 pb, $BR(H_S \to b\bar{b}) \approx 84\%$, $BR(H_S \to \tau^+\tau^-) \approx 8\%$
A_S	via ggF ≈ 10 fb, $BR(A_S \to b\bar{b}) \approx 91\%$, $BR(A_S \to \tau^+\tau^-) \approx 8\%$
$\tilde{\chi}_1^0$	$BR(\tilde{\chi}_1^0 \to \tilde{G} + A_S) = 100\%$, displaced vertex (mostly inside the detector)
$\tilde{\tau}_1$	$BR(\tilde{\tau}_1 \to \tau + \tilde{\chi}_1^0) = 100\%$
Particular signatures	A_S appears at the end of every sparticle decay chain H_S potentially observable via direct production
BP1_2	
Spectrum	$M_{H_{125}} \approx 124$ GeV, $M_{A_S} \approx 32$ GeV, $M_{H_S} \approx 93$ GeV, $M_H \approx 1.4$ TeV, $M_A \approx 1.4$ TeV, $M_{\tilde{\chi}_1^0} \approx 103$ GeV, $M_{\tilde{\chi}_2^0} \approx 397$ GeV (NNLSP)
Production cross sections and branching fractions	
H_S	via ggF ≈ 15pb, $BR(H_S \to b\bar{b}) \approx 84\%$, $BR(H_S \to \tau^+\tau^-) \approx 8\%$
A_S	via ggF ≈ 0.1 fb, $BR(A_S \to b\bar{b}) \approx 91\%$, $BR(A_S \to \tau^+\tau^-) \approx 9\%$
$\tilde{\chi}_1^0$	$BR(\tilde{\chi}_1^0 \to \tilde{G} + A_S) = 100\%$, displaced vertex (mostly outside the detector)
$\tilde{\chi}_2^0$	$BR(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + H_S) \approx 22\%$, $BR(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + H_{125}) \approx 78\%$
Particular signatures	H_S or H_{125} appear at the end of every sparticle decay chain H_S potentially observable via direct production

BP2	
R. Aggleton, D. Barducci, N-E. Bomark, S. Moretti, A. Nikitenko, C. Shepherd-Themistocleous, L. Roszkowski from JHEP 1502 (2015) 044, arXiv:1409.8393, and arXiv:1503.04228	
BP2_1	
Main Features	A light pseudoscalar with $M_{A_S} \approx 9$ GeV
Spectrum	$M_{H_{125}} \approx 123.3$ GeV, $M_{A_S} \approx 8.6$ GeV, $M_{H_S} \approx 480$ GeV, $M_H \approx 2254$ GeV, $M_A \approx 2255$ GeV
Production cross sections and branching fractions	
$H_S \to A_S A_S$	ggF$(H_S) \approx 43.2$ pb (at 13 TeV), $BR(H_S \to A_S + A_S) \approx 9.7\%$ $BR(A_S \to \tau^+\tau^-) \approx 88.4\%$, $BR(A_S \to \mu^+\mu^-) \approx 0.34\%$ ggF$(H_S) \to A_S + A_S \to 4\tau \approx 3.27$ pb, ggF$(H_S) \to A_S + A_S \to 2\tau + 2\mu \approx 0.0254$ pb
Particular signatures	Considerable cross-section for very light pseudoscalar boson production with 4τ final signature state, with possibility for $2\tau + 2\mu$ final state, free from Upsilon contamination
BP2_2	
Main Features	GMSB, lightest scalar SM-like, light pseudoscalar just above $M_{H_{125}}/2$.
Spectrum	$M_{H_{125}} \approx 125.9$ GeV, $M_{H_S} \approx 201$ GeV, $M_{A_S} \approx 65$ GeV, $M_H \approx 448$ GeV, $M_A \approx 440$ GeV
Production cross sections and branching fractions	
$H_S \to A_S A_S$	ggF$(H_S) \approx 0.86$ pb (at 13 TeV), $BR(H_S \to A_S + A_S) \approx 91\%$ $BR(A_S \to b\bar{b}) \approx 91\%$, $BR(A_S \to \tau^+\tau^-) \approx 8.8\%$ ggF$(H_S) \to A_S + A_S \to 4b \approx 0.641$ pb ggF$(H_S) \to A_S + A_S \to 2b + 2\tau \approx 0.124$ pb ggF$(H_S) \to A_S + A_S \to 4\tau \approx 6$ fb
$H \to Z + A_S$	ggF$(H) \approx 1.254$ pb (at 13 TeV), $BR(H \to Z + A_S) \approx 3.8\%$ ggF$(H) \to Z + A_S \to l^+l^- + b\bar{b} \approx 2.88$ fb
Particular signatures	$H \to Z + A_S$ of particular interest, could potentially use fat b-jet techniques for $A_S \to b\bar{b}$

Future plans

Some ideas

- Identify signatures that allow us to distinguish the NMSSM from other NMSSM-like models, e.g. the SM extended by a complex singlet, the N2HDM
- To what extend can coupling measurements allow us to distinguish the NMSSM from other BSM Higgs sectors, in case not all NMSSM Higgs bosons are discovered?
- Higgs-to-Higgs decays: what do we learn in the presence/absence of signals?
- NMSSM Higgs bosons in sparticle decay cascades: what do we learn in the presence/absence of signals?
- ...

Thank you for your attention!

Backup

BP3	
C.T. Potter, from arXiv:1505.05554	
Main Features	Natural NMSSM with discovery potential at LHC13 via gluino $\tilde{g}$ pair production: light H_S, A_S, singlino-like $\tilde{\chi}_1^0$, higgsino-like $\tilde{\chi}_3^0$
Spectrum	$M_{H_{125}} \approx 123$ GeV, $M_{H_S} \approx 55.7$ GeV, $M_{A_S} \approx 10.0$ GeV, $M_H \approx 1063$ GeV, $M_A \approx 1061$ GeV $M_{\tilde{g}} \approx 621$ GeV, $M_{\tilde{t}_1} \approx 343$ GeV, $M_{\tilde{\chi}_3^0} \approx 115$ GeV
Production cross sections and branching fractions	
Gluino pair production	$pp \to \tilde{g}\tilde{g} \approx 5.8$ pb (at 14 TeV), $BR(\tilde{g} \to \tilde{t}_1 + t) \approx 94\%$ $BR(\tilde{t}_1 \to \tilde{\chi}_3^0 + t) \approx 15\%$, $BR(\tilde{\chi}_3^0 \to \tilde{\chi}_1^0 + H_S) \approx 80\%$ $BR(H_S \to A_S + A_S) \approx 72\%$ $BR(A_S \to \tau^+\tau^-) \approx 81\%$, $BR(A_S \to \mu^+\mu^-) \approx 0.3\%$
Particular signatures	4 tops and up to $4A_S$ as final states in gluino pair production (differs somewhat from the BMpoint in 1505.05554)

BP4	
D. Barducci, G. Belanger and C. Hugonie (to appear)	
Main Features	nMSSM ($\kappa = 0$, not $\mathbb{Z}_3$-invariant) very light singlino-like LSP
BP4_1	
Spectrum	$M_{H_{125}} \approx 122$ GeV, $M_{H_S} \approx 37$ GeV, $M_{A_S} \approx 7$ GeV, $M_H \approx 2.1$ TeV, $M_A \approx 2.1$ TeV, $M_{\tilde{\chi}_1^0} \approx 3$ GeV
Production cross sections and branching fractions	
A_S	ggF(A_S) ≈ 113 pb, $BR(A_S \to \tilde{\chi}_1^0\tilde{\chi}_1^0) \approx 73\%$, $BR(A_S \to \tau^+\tau^-) \approx 25\%$
H_S	ggF(H_S) ≈ 12 pb (at 13 TeV), $BR(H_S \to b\bar{b}) \approx 85\%$, $BR(H_S \to \tau^+\tau^-) \approx 7\%$, $BR(H_S \to \tilde{\chi}_1^0\tilde{\chi}_1^0) \approx 7\%$
H_{125}	$BR(H_{125} \to A_S A_S) \approx 8\%$
Particular signatures	Two additional light Higgs states A_S and H_S can be visible A_S potentially visible in H_{125} decays
BP4_2	
Spectrum	$M_{H_{125}} \approx 123$ GeV, $M_{H_S} \approx 44$ GeV, $M_H \approx 2.4$ TeV, $M_{A_S} \approx 7$ GeV, $M_A \approx 2.4$ TeV, $M_{\tilde{\chi}_1^0} \approx 3$ GeV
Production cross sections and branching fractions	
A_S	ggF(A_S) ≈ 112 pb, $BR(A_S \to \tilde{\chi}_1^0\tilde{\chi}_1^0) \approx 73\%$, $BR(A_S \to \tau^+\tau^-) \approx 25\%$
H_S	ggF(H_S) $\approx$1.6 pb (at 13 TeV), $BR(H_S \to b\bar{b}) \approx 65\%$, $BR(H_S \to \tau^+\tau^-) \approx 6\%$, $BR(H_S \to A_S A_S) \approx 27\%$
H_{125}	$BR(H_{125} \to H_S H_S) \approx 9\%$
Particular signatures	Two additional light Higgs states A_S and H_S can be visible H_S potentially visible in H_{125} decays

BP5	
U. Ellwanger and A. M. Teixeira JHEP 1410 (2014) 113, arXiv:1406.7221 and JHEP 1504 (2015) 172, arXiv:1412.6394	
BP5_1	
Main Features	Light singlino-LSP; all sparticle decay cascades end with $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + H_{125}$, the LSP carries little E_T^{miss}
Spectrum	$M_{H_{125}} \approx 125$ GeV, $M_{H_S} \approx 91.2$ GeV, $M_{\tilde{\chi}_1^0} \approx 3.2$ GeV, $M_{\tilde{\chi}_2^0} \approx 130$ GeV, $M_{\text{squarks}} \approx 1.5$ TeV, $M_{\tilde{g}} \approx 1.3$ TeV, $M_{\tilde{t}} \approx 2$ TeV
Production cross sections and branching fractions	
Squark + gluino production	Jets $+ H_{125} + H_{125} \to$ jets $+ 2b\bar{b}$: 63.1 fb Jets $+ H_{125} + H_{125} \to$ jets $+ b\bar{b} + \tau^+\tau^-$: 13.9 fb Jets $+ H_{125} + H_{125} \to$ jets $+ \gamma\gamma + X$: 0.8 fb
Particular signatures	Hard jets, little E_T^{miss}, invariant masses of $b\bar{b}$, $\tau^+\tau^-$, $\gamma\gamma$ peak at 125 GeV
BP5_2	
Main Features	Light singlino-LSP; all sparticle decay cascades end with $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + H_S$, the LSP carries little E_T^{miss}
Spectrum	$M_{H_{125}} \approx 125$ GeV, $M_{H_S} \approx 82.3$ GeV, $M_{\tilde{\chi}_1^0} \approx 5.3$ GeV, $M_{\tilde{\chi}_2^0} \approx 88.7$ GeV, $M_{\text{squarks}} \approx 1.1$ TeV, $M_{\tilde{g}} \approx 900$ GeV, $M_{\tilde{t}} \approx 2$ TeV
Production cross sections and branching fractions	
Squark + gluino production	Jets $+ H_S + H_S \to$ jets $+ 2b\bar{b}$: 1.341 pb Jets $+ H_S + H_S \to$ jets $+ b\bar{b} + \tau^+\tau^-$: 272 fb Jets $+ H_S + H_S \to$ jets $+ \gamma\gamma + X$: 3.7 fb
Particular signatures	Hard jets, little E_T^{miss}, invariant masses of $b\bar{b}$, $\tau^+\tau^-$, $\gamma\gamma$ peak at ≈ 82 GeV

BP6: Light Singlino LSP and Singlet-like Pseudoscalar, good Relic Density

BP6	
C. Han, D. Kim, S. Munir and M. Park, JHEP 1507 (2015) 002, arXiv:1504.05085	
Main Features	Good relic density, light singlino-like LSP, singlet-like pseudoscalar, can be probed at the 14 TeV LHC in the di-muon decay channel
Spectrum	$M_{H_{125}} \approx 123.8$ GeV, $M_{H_S} \approx 14.8$ GeV, $M_{A_S} \approx 3.0$ GeV, $M_H \approx 1504$ GeV, $M_A \approx 1504$ GeV, $M_{\tilde{\chi}_1^0} \approx 1.34$ GeV, $M_{\tilde{\chi}_2^0} \approx 131.7$ GeV, $M_{\tilde{\chi}_3^0} \approx 166.8$ GeV, $M_{\tilde{\chi}_1^\pm} \approx 147.2$ GeV
Production cross sections and branching fractions	
$\tilde{\chi}_{2,3}^0 + \tilde{\chi}_1^\pm$ production	$pp \to \tilde{\chi}_{2,3}^0 + \tilde{\chi}_1^\pm \to A_S + \tilde{\chi}_1^0 + W^\pm + \tilde{\chi}_1^0$ $\to \mu^+\mu^- + \tilde{\chi}_1^0 + l^\pm + \nu_l + \tilde{\chi}_1^0$: 3.16 fb After cuts: 0.126 fb, 38 events/300 fb^{-1}, S/B ≈ 8
Particular signatures	significance via A_S much larger than in standard trilepton channel

BP7	
S.F. King, M. Muhlleitner, R. Nevzorov and K. Walz N.P. B870 (2013) 323, arXiv:1211.5074; Phys.Rev. D90 (2014) 9, 095014, arXiv:1408.1120	
BP7_1	
Main Features	natural NMSSM: overall light Higgs spectrum testable at LHC13
Spectrum	$M_{H_{125}} \approx 124.4$ GeV, $M_{H_S} \approx 95.6$ GeV, $M_{A_S} \approx 108$ GeV, $M_H \approx 299$ GeV, $M_A \approx 298$ GeV
Production cross sections and branching fractions	
ggF(H_S):	3.34 pb, $H_S \to b\bar{b}$: 2.5 pb, $H_S \to \tau^+\tau^-$: 0.26 pb, $H_S \to \gamma\gamma$: 13 fb
ggF(H):	4.63 pb, $H \to W^+W^-$: 54.5 fb, $H \to ZZ$: 24.2 fb,
ggF(H) $\to ZA_S$	$\to Z + b\bar{b}$: 614 fb, $\to Z + \tau^+\tau^-$: 64.2 fb, $\to Z + \gamma\gamma$: 0.48 fb
ggF(H) $\to H_S H_S$	$\to 4b$: 310 fb, $\to b\bar{b} + \tau\tau$: 63.7 fb, $\to 4\tau$: 3.27 fb, $\to b\bar{b} + \gamma\gamma$: 3.21 fb
ggF(H) $\to H_{125} H_S$	$\to 4b$: 187 fb, $\to b\bar{b} + \tau\tau$: 39.4 fb, $\to 4\tau$: 2.08 fb, $\to b\bar{b} + \gamma\gamma$: 1.63 fb
ggF(H) $\to \tilde{\chi}\tilde{\chi}$	$\to \tilde{\chi}_1^0\tilde{\chi}_1^0$: 1662 fb, $\to \tilde{\chi}_1^0\tilde{\chi}_2^0$: 336 fb, $\to \tilde{\chi}_2^0\tilde{\chi}_2^0$: 575 fb, $\to \tilde{\chi}_1^+\tilde{\chi}_1^-$: 195 fb
ggF(A_S)	2.41 pb, $A_S \to b\bar{b}$: 2.1 pb, $H_S \to \tau^+\tau^-$: 0.22 pb, $H_S \to \gamma\gamma$: 1.63 fb
ggF(A)	11.18 pb, $A \to b\bar{b}$: 57.5 fb, $A \to \tau^+\tau^-$: 7.43 fb
ggF(A) $\to H_S A_S$	$\to 4b$: 878 fb, $\to b\bar{b} + \tau\tau$: 182 fb, $\to 4\tau$: 9.44 fb, $\to b\bar{b} + \gamma\gamma$: 5.23 fb
ggF(A) $\to H_{125} A_S$	$\to 4b$: 703 fb, $\to b\bar{b} + \tau\tau$: 149 fb, $\to 4\tau$: 7.93 fb, $\to b\bar{b} + \gamma\gamma$: 3.04 fb
ggF(A) $\to ZH_S$	$\to Z + b\bar{b}$: 392 fb, $\to Z + \tau^+\tau^-$: 40.3 fb, $\to Z + \gamma\gamma$: 2.03 fb
ggF(A) $\to \tilde{\chi}\tilde{\chi}$	$\to \tilde{\chi}_1^0\tilde{\chi}_1^0$: 3.7 pb, $\to \tilde{\chi}_1^0\tilde{\chi}_2^0$: 2.8 pb, $\to \tilde{\chi}_2^0\tilde{\chi}_2^0$: 1.0 pb, $\to \tilde{\chi}_1^+\tilde{\chi}_1^-$: 3.1 pb
Particular signatures	Large Higgs-to-Higgs, Higgs-to-gauge+Higgs decay rates

BP7_2	
Main Features	cascade Higgs-to-Higgs decays, spectacular signatures
Spectrum	$M_{H_{125}} \approx 126.6$ GeV, $M_{H_S} \approx 172$ GeV, $M_{A_S} \approx 85.9$ GeV, $M_H \approx 316.8$ GeV, $M_A \approx 306.7$ GeV
Production cross sections and branching fractions	
ggF(H_S)	90 fb, $\to b\bar{b}$: 6.15 fb, $\to \tau\tau$: 0.69 fb, $\to WW$: 61.5 fb, $\to ZZ$: 1.7 fb
ggF(H_S) $\to A_S A_S$	$\to 4b$: 13.3 fb, $\to b\bar{b}+\tau\tau$: 1.82 fb, $\to b\bar{b}+\gamma\gamma$: 4.1 fb, $\to 4\gamma$: 0.32 fb
ggF(H)	3 pb, $\to b\bar{b}$: 165 fb, $\to \tau\tau$: 21.4 fb, $\to WW$: 91.6 fb, $\to ZZ$: 41.1 fb
ggF(H) $\to \tilde{\chi}\tilde{\chi}$	$\to \tilde{\chi}_1^0\tilde{\chi}_1^0$: 391 fb, $\to \tilde{\chi}_1^+\tilde{\chi}_1^-$: 337 fb
ggF(H) $\to H_{125}H_S$ $\to H_{125}+A_S+A_S$	$\to b\bar{b}+4\gamma$: 2.41 fb, $\to 4b+2\gamma$: 29.7 fb, $\to \tau\tau+4\gamma$: 0.25 fb, $\to 4\tau+\gamma\gamma$: 0.21 fb, $\to 6\gamma$: 0.012 fb, $\to b\bar{b}+\tau\tau+\gamma\gamma$: 5.15 fb
ggF(H) $\to H_{125}H_{125}$	$\to 4b$: 203.7 fb, $\to b\bar{b}+\gamma\gamma$: 2.14 fb $\to \tau\tau+\gamma\gamma$: 0.23 fb
ggF(H) $\to A_S A_S$	$\to 4b$: 6.78 fb, $\to b\bar{b}+\gamma\gamma$: 2.10 fb $\to 4\gamma$: 0.16 fb
ggF(A_S)	7.71 fb, $\to b\bar{b}$: 6.25 fb, $\to \tau\tau$: 0.43 fb $\to \gamma\gamma$: 0.97 fb
ggF(A)	8.80 pb, $\to b\bar{b}$: 289.4 fb, $\to \tau\tau$: 39.9 fb
ggF(A) $\to \tilde{\chi}\tilde{\chi}$	$\to \tilde{\chi}_1^0\tilde{\chi}_1^0$: 3.46 pb, $\to \tilde{\chi}_1^+\tilde{\chi}_1^-$: 997 fb
ggF(A) $\to H_S A_S$ $\to A_S A_S A_S$	$\to 6\gamma$: 0.68 fb, $\to b\bar{b}+4\gamma$: 13.1 fb $\to 4b+\gamma\gamma$: 84.8fb $\to \tau\tau+4\gamma$: 0.90 fb, $\to b\bar{b}+\tau\tau+\gamma\gamma$: 11.6 fb, $\to 4\tau+\gamma\gamma$: 0.40 fb
ggF(A) $\to H_{125}A_S$	$\to 4b$: 210 fb, $\to b\bar{b}+\gamma\gamma$: 33.6 fb, $\to \tau\tau+\gamma\gamma$: 3.51 fb
ggF(A) $\to ZH_S$ $\to b\bar{b}+A_S+A_S$	$\to b\bar{b}+4\gamma$: 0.97 fb, $\to 4b+\gamma\gamma$: 12.5 fb, $\to b\bar{b}+\tau\tau+\gamma\gamma$: 0.85 fb
ggF(A) $\to ZH_S$ $\to ll/\tau\tau+A_S+A_S$	$\to ll/\tau\tau+4\gamma$: 0.21 fb, $\to ll/\tau\tau+b\bar{b}+\gamma\gamma$: 2.78 fb, $\to ll/\tau\tau+\tau\tau+\gamma\gamma$: 0.19 fb
Particular signatures	Cascade Higgs-to-Higgs decays lead to multi-photon and multi-fermion final states

BP8	
C. Beskidt, W. de Boer and D. Kazakov	
BP8_1	
Main Features	Light Higgs spectrum with heavier Higgs bosons just above $t\bar{t}$ threshold, so main decay into $t\bar{t}$ (absent in CMSSM)
Spectrum	$M_{H_{125}} \approx 125.5$ GeV, $M_{H_S} \approx 90.0$ GeV, $M_{A_S} \approx 300.0$ GeV, $M_H \approx 450.0$ GeV, $M_A \approx 446.3$ GeV
Production cross sections and branching fractions	
ggF(H_S)	1.11 pb, $\to b\bar{b}$: 1.00 pb, $\to \tau\tau$: 0.105 pb
ggF(H)	1.82 pb, $\to t\bar{t}$: 1.03 pb, $\to WW$: 2.13 fb $\to ZZ$: 1.01 fb
ggF(H) $\to H_{125} H_S$	407 fb
ggF(H) $\to A_S Z$	26.7 fb
ggF(H) $\to \tilde{\chi}\tilde{\chi}$	$\to \tilde{\chi}_1^0\tilde{\chi}_1^0$: 163 fb, $\to \tilde{\chi}_1^0\tilde{\chi}_2^0$: 18.6 fb, $\to \tilde{\chi}_1^0\tilde{\chi}_3^0$: 71.6 fb, $\to \tilde{\chi}_1^+\tilde{\chi}_1^-$: 29.2 fb
ggF(A_S)	144 fb, $\to b\bar{b}$: 18.5 fb, $\to \tau\tau$: 2.39 fb
ggF(A_S) $\to H_S Z$	120 fb
ggF(A)	3.96 pb, $\to t\bar{t}$: 2.63 pb, $\to b\bar{b}$: 20.1 fb, $\to \tau\tau$: 2.66 fb
ggF(A) $\to H_S Z$	448 fb
ggF(A) $\to \tilde{\chi}\tilde{\chi}$	$\to \tilde{\chi}_1^0\tilde{\chi}_1^0$: 520 fb, $\to \tilde{\chi}_1^+\tilde{\chi}_1^-$: 166 fb
Particular signatures	H, A produced simultaneously, decay mostly into $t\bar{t}$ $\to$ large fraction of $t\bar{t}$ final states, $\to$ search for broad bump around 450 GeV in tail of $t\bar{t}$ invariant mass spectrum, A_S decays largely into $Z + H_S$ $\to$ events with two Z bosons and H_S of 90 GeV with practically SM decay modes

BP8_2	
Main Features	Light Higgs spectrum, can be tested at LHC14, Higgs-to-Higgs decays
Spectrum	$M_{H_{125}} \approx 125.2$ GeV, $M_{H_S} \approx 90.0$ GeV, $M_{A_S} \approx 300$ GeV, $M_H \approx 349$ GeV, $M_A \approx 342$ GeV
Production cross sections and branching fractions	
ggF(H_S)	1.37 pb, $\to bb$: 1.24 pb, $\to \tau\tau$: 0.129 pb
ggF(H)	3.33 pb, $\to bb$: 102 fb, $\to \tau\tau$: 13.5 fb, $\to WW$: 30.6 fb, $\to ZZ$: 14.0 fb
ggF(H) $\to H_{125} H_S$	2.13 pb
ggF(H) $\to H_S H_S$	310 fb
ggF(H) $\to \tilde{\chi}\tilde{\chi}$	$\to \tilde{\chi}_1^0 \tilde{\chi}_1^0$: 286 fb, $\to \tilde{\chi}_1^+ \tilde{\chi}_1^-$: 15.7 fb
ggF(A_S)	185 fb
ggF(A_S) $\to H_S Z$	2 fb
ggF(A_S) $\to \tilde{\chi}\tilde{\chi}$	$\to \tilde{\chi}_1^0 \tilde{\chi}_1^0$: 183 fb
ggF(A)	12.4 pb, $\to bb$: 273 fb, $\to \tau\tau$: 34.5 fb,
ggF(A) $\to H_S Z$	4.84 pb
ggF(A) $\to \tilde{\chi}\tilde{\chi}$	$\to \tilde{\chi}_1^0 \tilde{\chi}_1^0$: 5.10 pb, $\to \tilde{\chi}_1^0 \tilde{\chi}_2^0$: 28.1 fb, $\to \tilde{\chi}_1^+ \tilde{\chi}_1^-$: 1.94 fb
Particular signatures	H, A produced simultaneously, H decays mostly (64%) into H_S, A decays (39%) into $H_S + Z$ remaining decay modes mostly into gauginos

BP9	
N. Christensen, T. Han, Z. Liu and S. Su	
JHEP 1308 (2013) 019, arXiv:1303.2113	
BP9_1	
Main Features	≈ 30 GeV singlino-like LSP (good DM candidate), two singlet-like Higgs states below 100 GeV decay mainly into $b\bar{b}$, H_{125} can decay into $H_S H_S$ with $\gtrsim 10\%$ BR
Spectrum	$M_{H_{125}} \approx 126$ GeV, $M_{H_S} \approx 19.1$ GeV, $M_{A_S} \approx 73.2$ GeV, $M_{\tilde{\chi}_1^0} \approx 36.7$ GeV, $M_H \approx 2340$ GeV, $M_A \approx 2340$ GeV
Production cross sections and branching fractions	
H_{125}	$BR(H_{125} \to H_S H_S) \approx 13\%$, $BR(H_{125} \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) \approx 1\%$
H_S	$BR(H_S \to b\bar{b}) \approx 89\%$, $BR(H_S \to \tau\tau) \approx 7.7\%$
A_S	$BR(A_S \to b\bar{b}) \approx 90\%$, $BR(A_S \to \tau\tau) \approx 9.4\%$
BP9_2	
Main Features	≈ 30 GeV bino-like LSP (good DM candidate), one singlet-like Higgs state below 100 GeV, decays mainly into bb. H_{125} can decay into $\tilde{\chi}_1^0 \tilde{\chi}_1^0$ with $\approx 10\%$ BR
Spectrum	$M_{H_{125}} \approx 125$ GeV, $M_{H_S} \approx 430$ GeV, $M_{A_S} \approx 65.7$ GeV, $M_{\tilde{\chi}_1^0} \approx 32.3$ GeV, $M_H \approx 2480$ GeV, $M_A \approx 2480$ GeV
Production cross sections and branching fractions	
H_{125}	$BR(H_{125} \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) \approx 10\%$
H_S	ggF$(H_S) \approx 0.23$ fb, $BR(H_S \to t\bar{t}) \approx 1.8\%$, $BR(H_S \to WW) \approx 5.7\%$, $BR(H_S \to ZZ) \approx 2.7\%$
$H_S \to A_S\ A_S$	$BR(H_S \to A_S\ A_S) \approx 85\%$
$H_S \to H_S\ H_S$	$BR(H_S \to H_S\ H_S) \approx 3.5\%$
A_S	$BR(A_S \to b\bar{b}) \approx 88\%$, $BR(A_S \to \tau\tau) \approx 9.0\%$, $BR(A_S \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) \approx 2.7\%$