Next-to-Minimal Supersymmetric Standard Model
- overview and (collider) phenomenology -

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[Ellwanger, Hugione, Teixeira, '10]
[Maniatis, '10]

NMSSM

All the usual SUSY motivation...
(hierarchy problem, gauge unification, beauty, SUGRA, superstring, ...)

Solves the μ-problem of the MSSM

Easily accommodates a 125 GeV Higgs boson

No need for stops to be very heavy

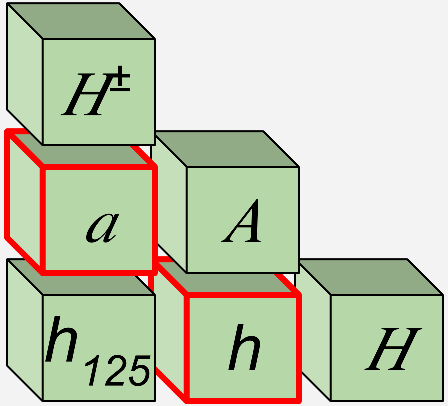
Rich Higgs-sector phenomenology

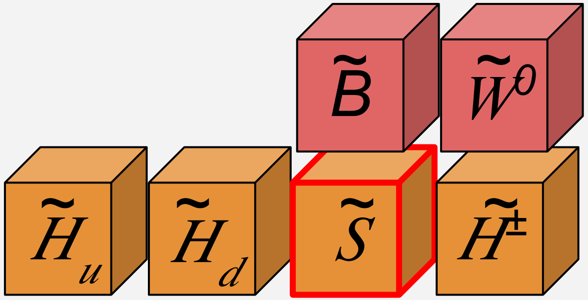
Dark Matter

Baryogenesis

The Next-to-Minimal Supersymmetric Standard Model

- MSSM + (SM gauge-)singlet chiral superfield $\hat{S}$





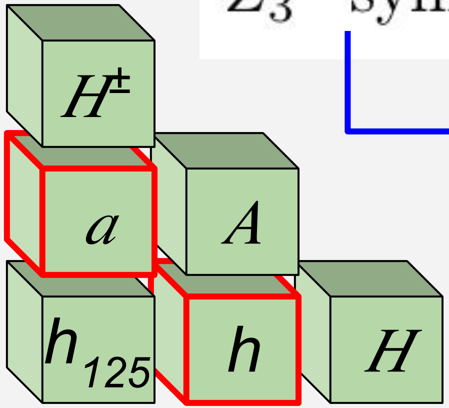
The Next-to-Minimal Supersymmetric Standard Model

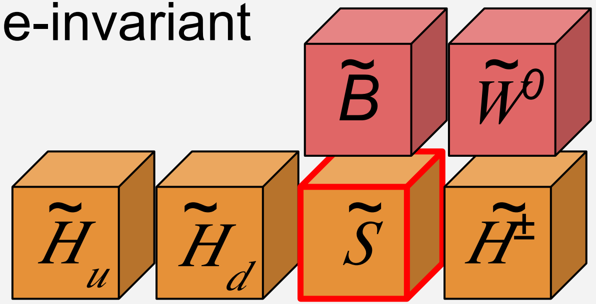
- MSSM + (SM gauge-)singlet chiral superfield $\hat{S}$

$$W = \lambda \widehat{S} \widehat{H}_u \cdot \widehat{H}_d + \frac{\kappa}{3} \widehat{S}^3 + W_{\rm Yuk}$$

$$Z_3\text{−symmetry} : \widehat{\Phi} \to e^{2\pi i/3} \widehat{\Phi}$$

→ Makes Superpotential scale-invariant





The “classic” NMSSM motivation: μ-problem

[Kim & Nilles, ‘84]

MSSM

- Minimization conditions:

$$m_Z^2 = \frac{2}{\cos 2\beta}\left(|\mu|^2 + m_{H_u}^2 - b\cot\beta\right) ,$$

$$m_Z^2 = -\frac{2}{\cos 2\beta}\left(|\mu|^2 + m_{H_d}^2 - b\tan\beta\right)$$

- But μ is not a soft parameter!

$$W = \mu \widehat{H}_u \cdot \widehat{H}_d + W_{\text{Yuk}}$$

The “classic” NMSSM motivation: μ-problem

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- But μ is not a soft parameter!

$$W = \mu \widehat{H}_u \cdot \widehat{H}_d + W_{\rm Yuk}$$

NMSSM

- No μ-term in superpotential

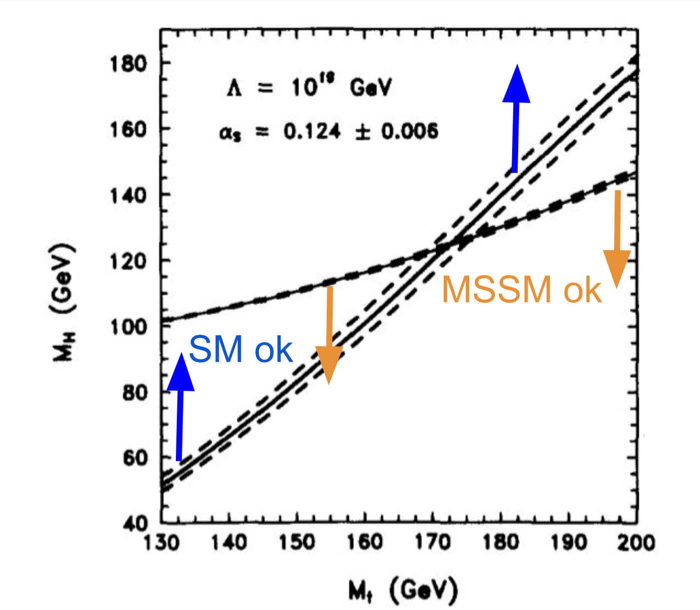
$$W = \lambda \widehat{S}\widehat{H}_u \cdot \widehat{H}_d + \frac{\kappa}{3}\widehat{S}^3 + W_{\rm Yuk}$$

- Effective μ-term:

$$\mu_{\rm eff} = \lambda \langle S \rangle$$

125 GeV Higgs boson…

Flash back to to the mid 90s, after the discovery of the top quark



[Casas, Espinosa, Quirós '95]

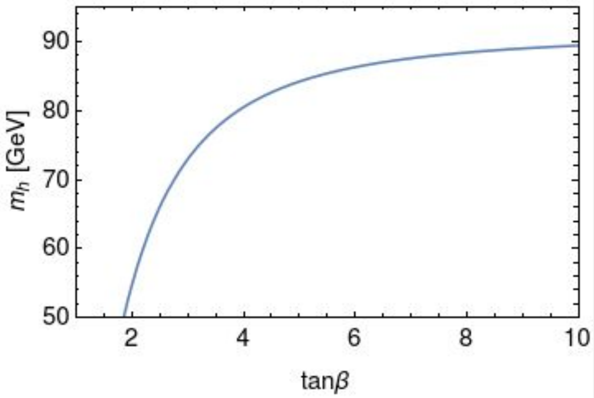
i) For $M_t = 173 \pm 4$ GeV, i.e. the crossing area of the SM and MSSM curves, the eventually measured Higgs mass will be compatible either with the pure SM or with the MSSM, but not with both at the same time (unless $M_H = 124$ with high accuracy). Accordingly, the experimental Higgs mass either will discard the MSSM or will be a clear signal of new physics beyond the SM compatible with the MSSM.

125 GeV Higgs boson in the (N)MSSM

MSSM

Tree-level mass of the SM-like state:

$$m_{h_{125}}^2 \simeq m_Z^2 \cos^2(2\beta)$$



$\Rightarrow$ need $\gg$ TeV stops!

[Draper+ 1112.3068]

125 GeV Higgs boson in the (N)MSSM

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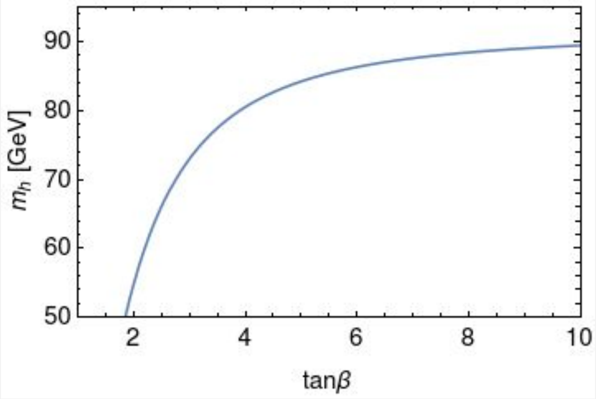
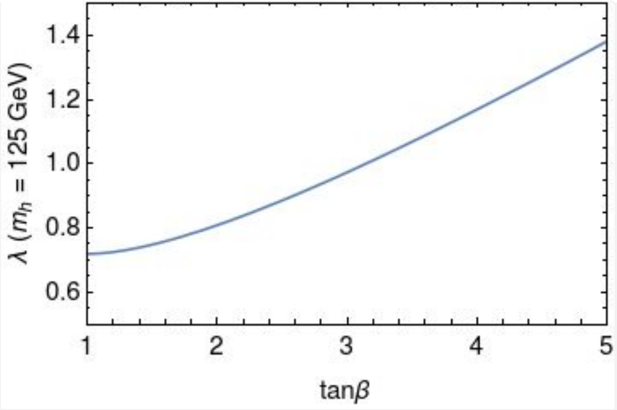


⇒ need ≫ TeV stops!

[Draper+ 1112.3068]

NMSSM

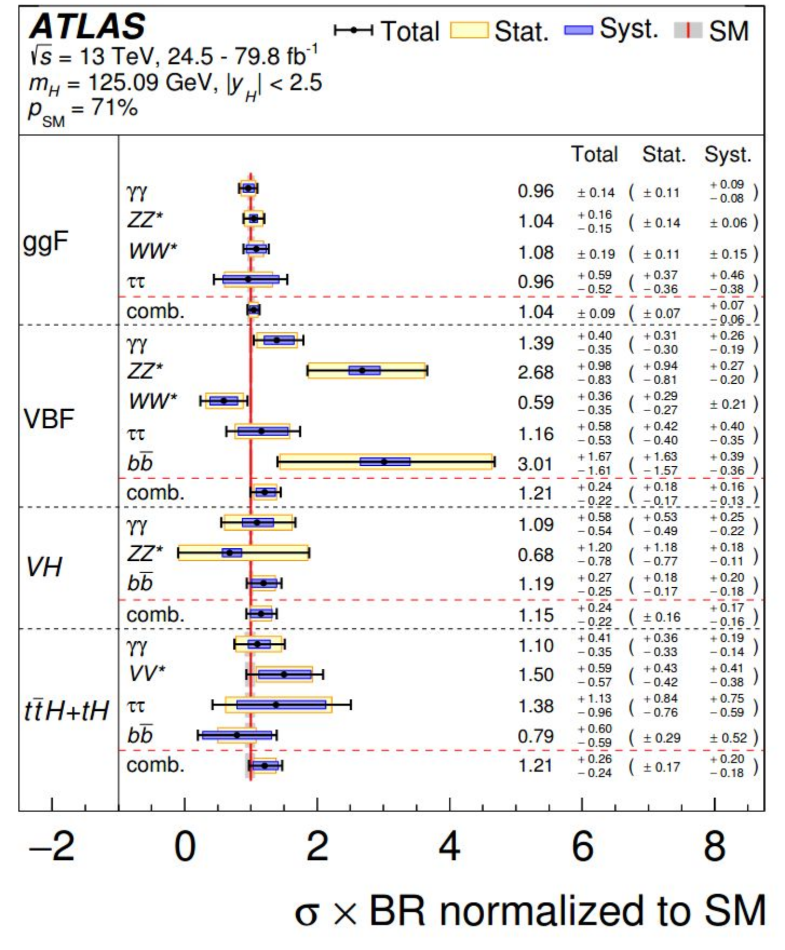
$$m_{h_{125}}^2 \simeq m_Z^2 \cos^2(2\beta) + \lambda^2 v^2 \sin^2(2\beta)$$



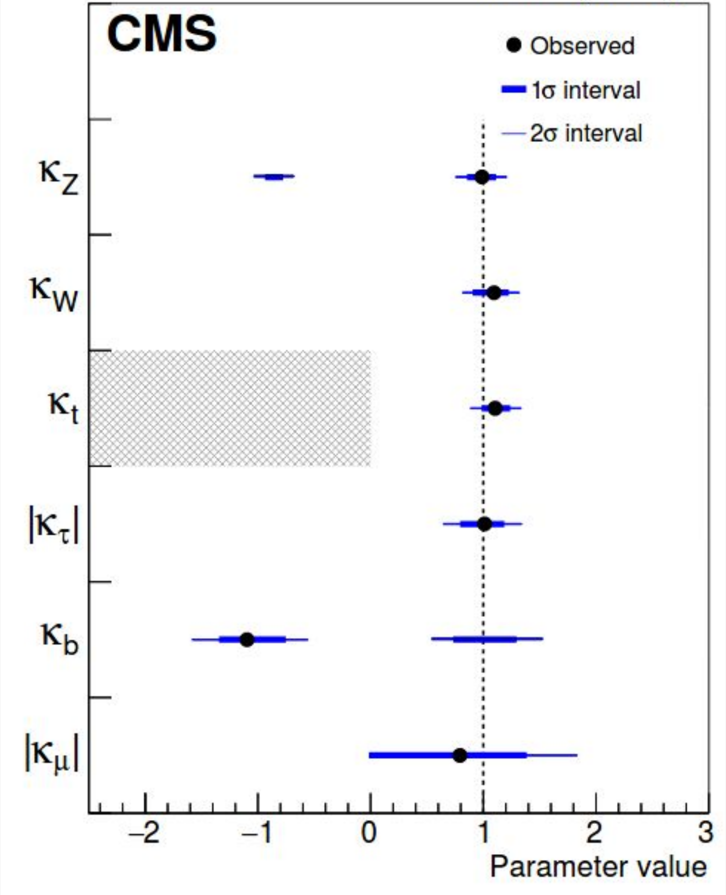
⇒ stops can be “light”

(in reach of the LHC ?)

[ATLAS 1909.02845]



[CMS 1809.10733]



Couplings become simple in the Higgs basis

$$H^{\rm SM}({\rm down,\ up\ ,VV}) = (g_{\rm SM},\ g_{\rm SM},\ g_{\rm SM})\ ,$$
$$H^{\rm NSM}({\rm down,\ up\ ,VV}) = (-g_{\rm SM}\tan\beta,\ g_{\rm SM}/\tan\beta,\ 0)\ ,$$
$$H^{\rm S}({\rm down,\ up\ ,VV}) = (0,\ 0,\ 0)\ ,$$

couples like the SM Higgs

tan β enhanced/suppressed fermion-couplings

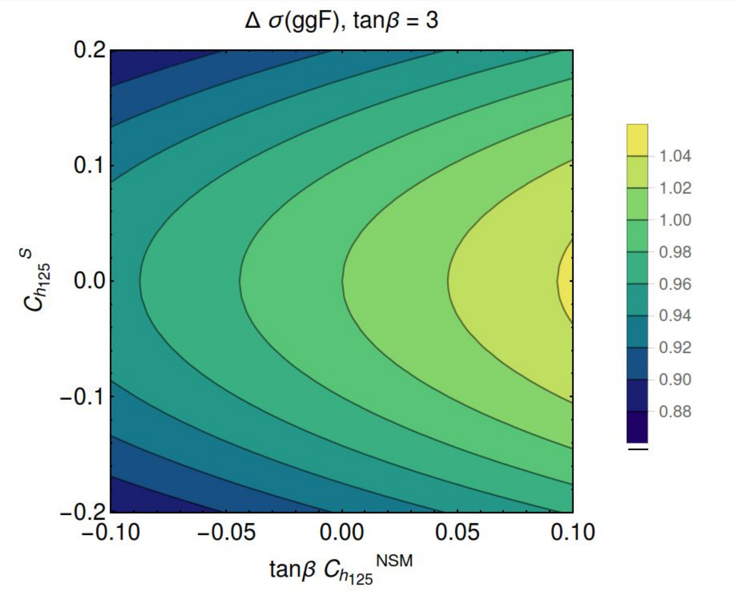
no direct couplings

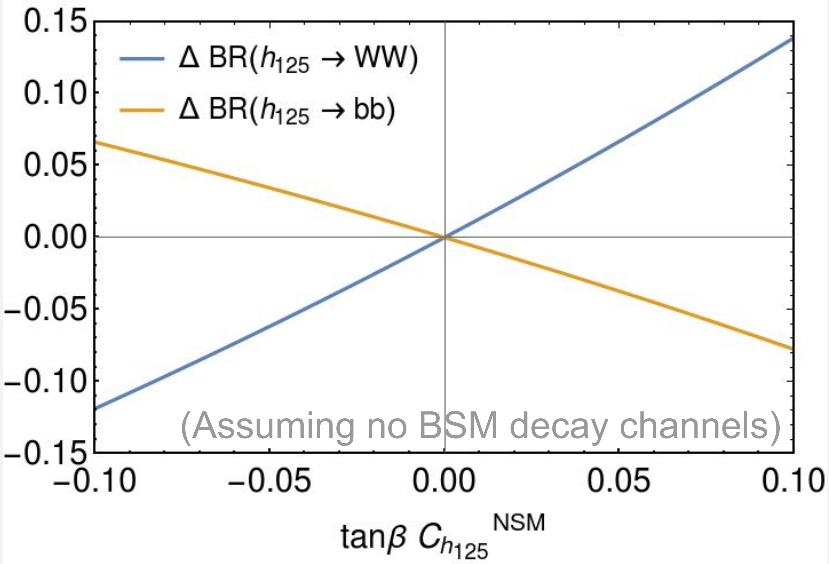
Only H^{SM} couples to WW and ZZ!

[Georgi & Nanopoulos ‘79]
[Donoghue & Li ‘79]
[Haber & Gunion ‘03]

Modifications to Higgs pheno

$$h_{125} = C_{h_{125}}^{\mathrm{SM}} H^{\mathrm{SM}} + C_{h_{125}}^{\mathrm{NSM}} H^{\mathrm{NSM}} + C_{h_{125}}^{\mathrm{S}} H^{\mathrm{S}}$$

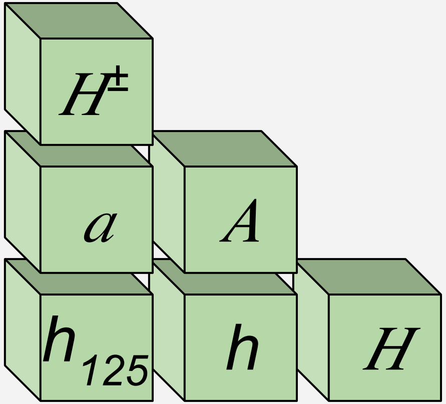




Alignment of h_{125} with H^{SM}

(I): Alignment by decoupling.

$m_h, m_H \gg m_{h125} \rightarrow$ new states not accessible at the LHC



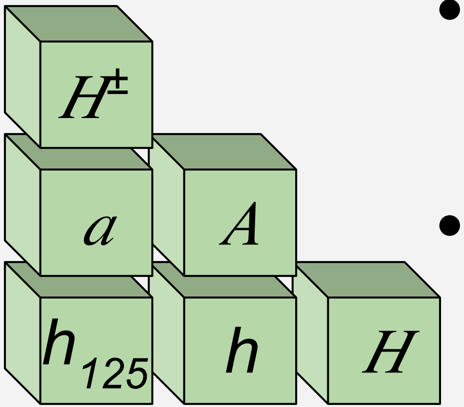
Alignment of h_{125} with H^{SM}

(I): Alignment by decoupling.

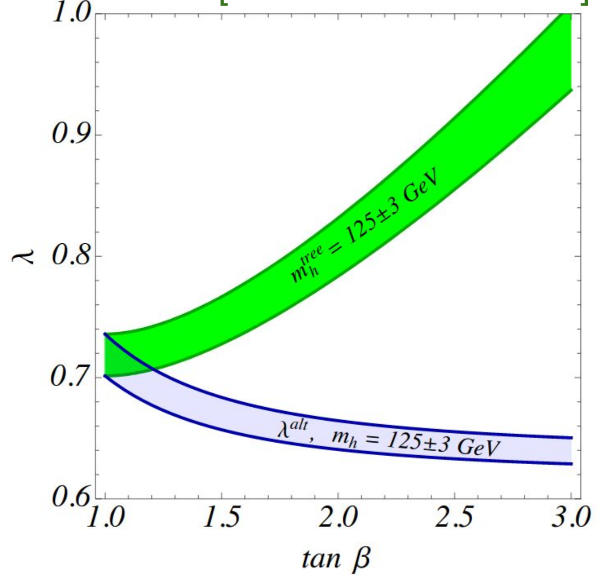
$m_h, m_H \gg m_{h125} \longrightarrow$ new states not accessible at the LHC

(II): Alignment-without-decoupling:

- $$\lambda^2 = \frac{m_{h125}^2 - m_Z^2 \cos(2\beta)}{2v^2 \sin^2\beta}$$
- $$M_A^2 = \frac{4\mu^2}{\sin^2(2\beta)}\left(1 - \frac{\kappa}{2\lambda}\sin 2\beta\right)$$

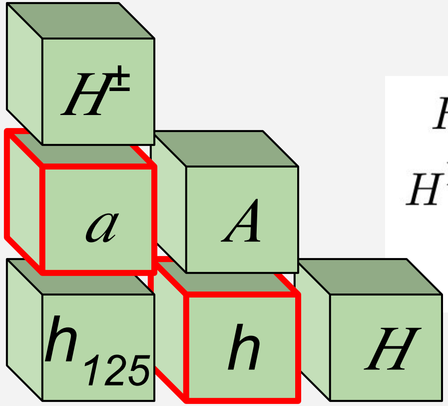


[Carena+ 1510.09137]



Collider phenomenology. What's new in the NMSSM?

- SM-like couplings and 125 GeV mass of observed Higgs lead to preference of small-to-moderate $\tan\beta \lesssim 5$, and sizable $\lambda \sim 0.65$
- Presence of new states opens up new decay channels
- Singlet component suppressed production cross section of Higgses



$$H^{\rm SM}({\rm down,\ up\,,VV}) = (g_{\rm SM},\ g_{\rm SM},\ g_{\rm SM})\ ,$$
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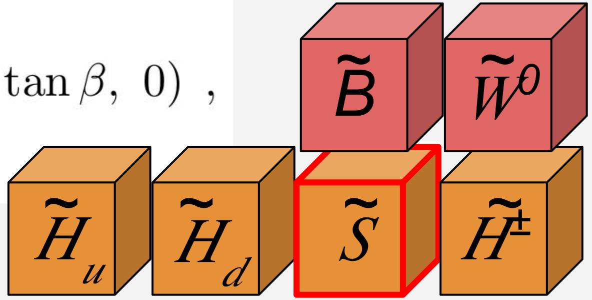
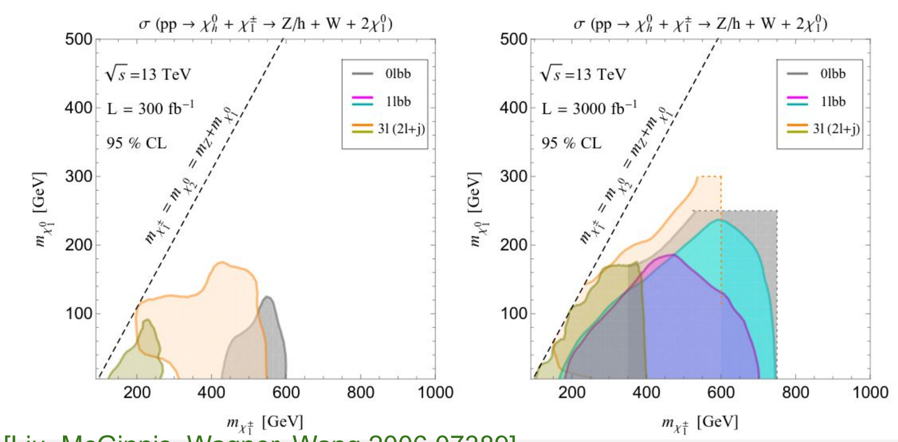


MSSM-like searches

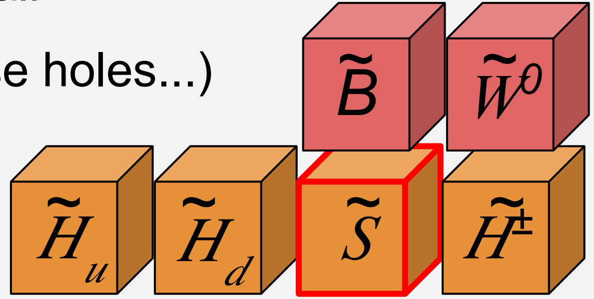
- Sfermion pheno very similar (but stops don’t have to be $\gg$ TeV!)

MSSM-like searches

- Sfermion pheno very similar (but stops don't have to be ≫ TeV!)
- Singlino enlarges neutralino sector
  - direct production cross sections still (too) small
  - HL-LHC will help (need lepton collider to close holes...)



[Liu, McGinnis, Wagner, Wang 2006.07389]



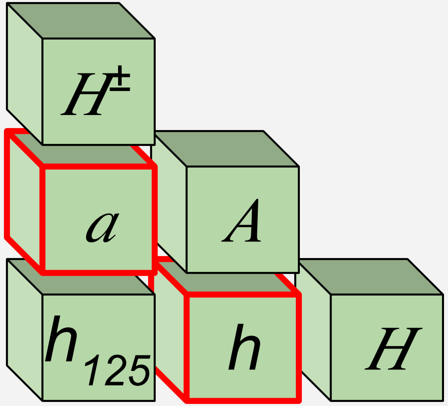
Note that this plot is for the MSSM with heavy Winos -- see e.g. [Ellwanger & Hugonie 1806.09478] for a NMSSM-specific analysis

MSSM-like BSM Higgs searches

- Charged Higgs very similar to MSSM
- Production cross sections of neutral Higgses suppressed by singlet component

$\longrightarrow$ go after doublet-like states

$$M_A^2 = \frac{4\mu^2}{\sin^2(2\beta)}\left(1 - \frac{\kappa}{2\lambda}\sin 2\beta\right)$$



MSSM-like BSM Higgs searches: $H/A \to ff$

- SM-like couplings and 125 GeV mass of observed Higgs lead to alignment & preference of small-to-moderate $\tan\beta \lesssim 5$

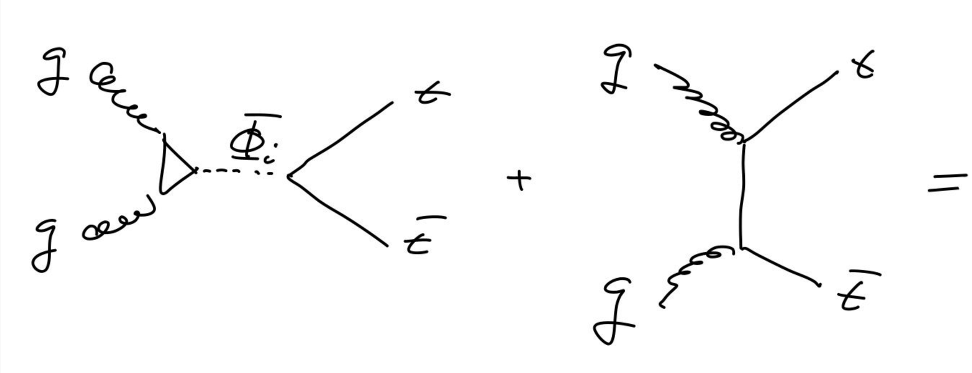
Only H^{SM} couples to WW and ZZ…
→ **VBF suppressed!**

$$H^{\rm SM}({\rm down,\, up\,, VV}) = (g_{\rm SM},\ g_{\rm SM},\ g_{\rm SM})\ ,$$
$$H^{\rm NSM}({\rm down,\, up\,, VV}) = (-g_{\rm SM}\tan\beta,\ g_{\rm SM}/\tan\beta,\ 0)\ ,$$
$$H^{\rm S}({\rm down,\, up\,, VV}) = (0,\ 0,\ 0)\ ,$$

small-to-moderate $\tan\beta \lesssim 5$

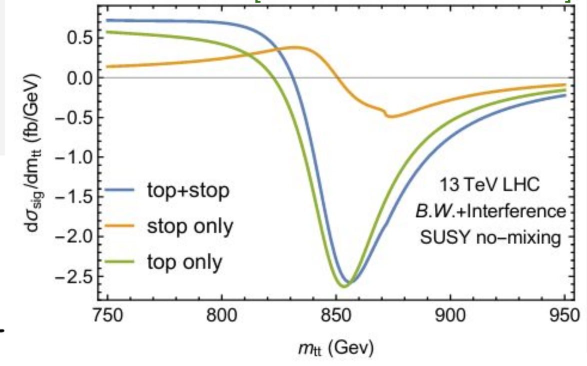
→ **no bb / $\tau\tau$ enhancement**
→ **no ggF suppression**

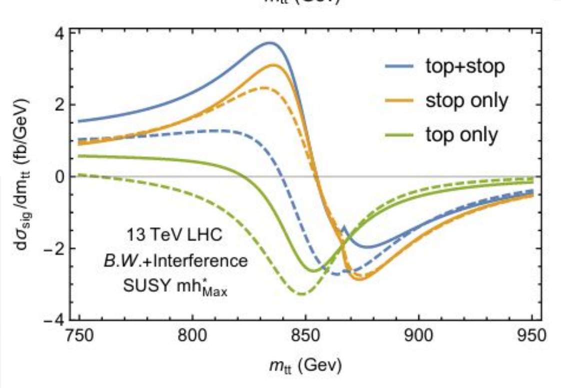
And what about $gg \to H/A \to tt$?



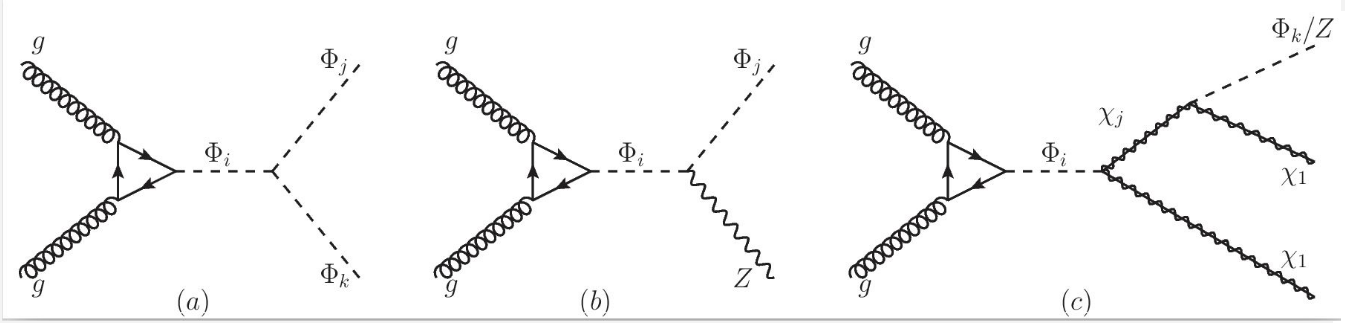
[Dicus, Stange & Willenbrock '94]

[Carena & Liu 1608.07282]

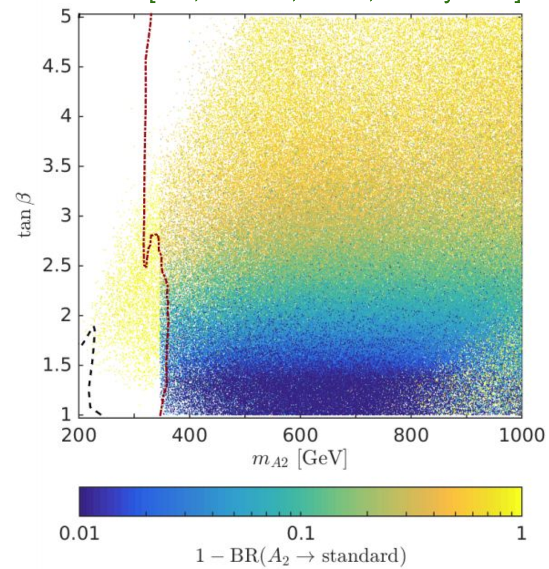




New (large!) decay modes of the Higgses



[**SB**, Freese, Shah, Shakya '17]



Couplings controlled by λ ~ 0.65, κ, and EW gauge couplings

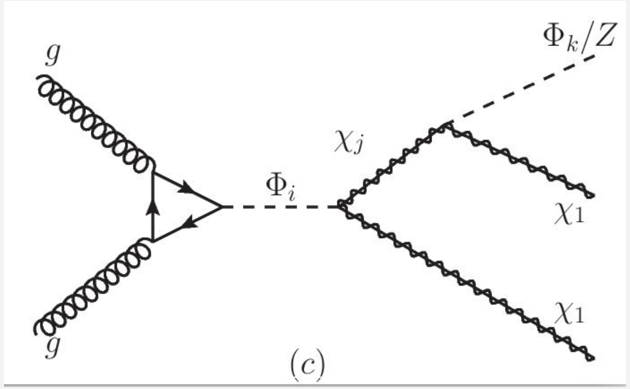
→ branching ratios tens of percent if kinematically open

[Kang, Li, Li, Liu & Shu '13; King, Muhlleitner, Nevzorov & Walz '14; Craig, D'Eramo, Draper, Thomas & Zhang, '15; Ellwanger & Rodriguez-Vazquez '15, '17; Carena, Haber, Low, Shah & Wagner '15; Costa, Muehlleitner, Sampaio & Santos '15; SB, Freese, Shah & Shakya '17; SB & Shah '18; Heng, Gong & Zhou '18; SB, Freese, Shah '19, Liu, McGinnis, Wagner & Wang '20, ...]

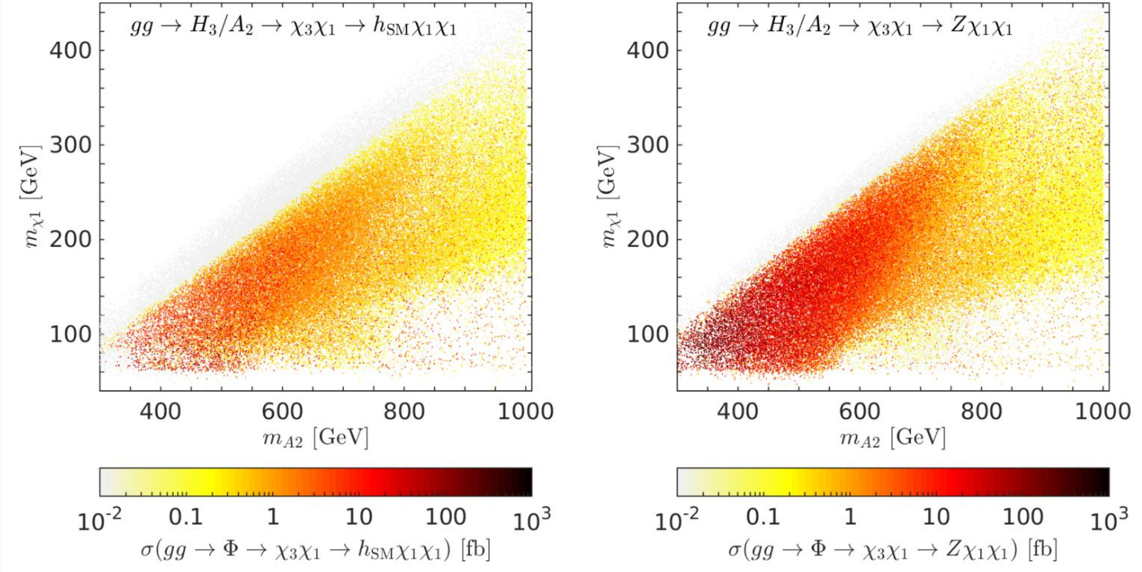
Higgs-decays into neutralinos

[Moortgat, Abdullin & Denegri, '01;
Denegri et al. '01;
Han, Liu & Natarajan '13;
Craig, D'Eramo, Draper, Thomas & Zhang, '15;
SB, Freese, Shah & Shakya '17;
Gori, Liu & Shakya, '18;
SB & Shah '18;
Liu, McGinnis, Wagner & Wang '20;
...]

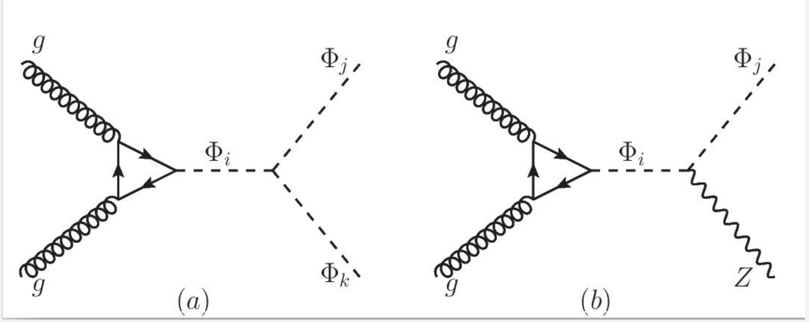
- Large branching ratios
  - Higgs-Higgsino-Singlino couplings $\propto \lambda \sim 0.65$
- But, difficult mono-X signatures



[SB, Freese, Shah, Shakya '17]



Higgs → di-boson decays



Many ATLAS & CMS searches in

- $H \to h_{125} h_{125}$
- $H \to ZZ$ / WW
- $A \to Z\, h_{125}$

ATLAS EXPERIMENT
JHEP 05 (2019) 124
DOI: 10.1007/JHEP05(2019)124
CERN-EP-2018-227
30th May 2019

Search for Higgs boson pair production in the $WW^{(*)}WW^{(*)}$ decay channel using ATLAS data recorded at $\sqrt{s}$ = 13 TeV

The ATLAS Collaboration

CMS
CMS-HIG-17-033
CERN-EP-2019-230
2020/06/03

Search for a heavy Higgs boson decaying to a pair of W bosons in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration*

CMS-HIG-18-023

Search for a heavy pseudoscalar Higgs boson decaying into a 125 GeV Higgs boson and a Z boson in final states with two tau and two light leptons at $\sqrt{s} = 13$ TeV

The CMS Collaboration*

Submitted to: JHEP
CERN-EP-2018-237
13th November 2018

Search for Higgs boson pair production in the $b\bar{b}WW^*$ decay mode at $\sqrt{s}$=13 TeV with the ATLAS detector

The ATLAS Collaboration

Higgs → di-boson decays

This is not NMSSM specific, but more general! [**SB**, Shah '18]

Many ATLAS & CMS searches in

- $H \to h_{125} h_{125}$
- $H \to ZZ$ / WW
- $A \to Z\, h_{125}$

Unfortunately, these couplings are suppressed by the SM-like couplings of h_{125} !

H^{SM} - H^{NSM} mixing!

$$(\mathrm{SM}-\mathrm{SM}-\mathrm{NSM}) \propto \mathcal{M}^2_{S,12}$$
$$(\mathrm{SM}-\mathrm{SM}-\mathrm{S}) \propto \mathcal{M}^2_{S,13}$$

H^{SM} - H^{S} mixing!

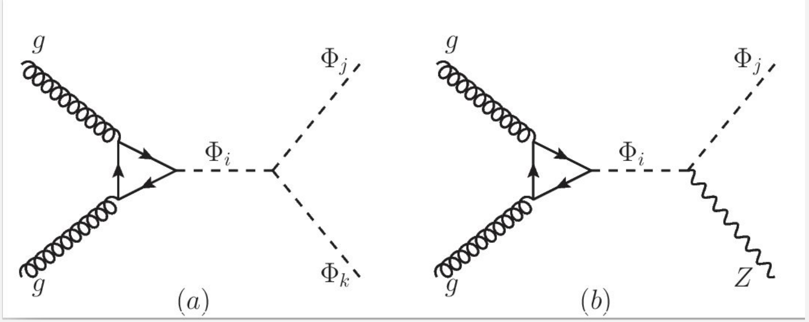
Only Z-A-H coupling!

$$\mathcal{L} \supset \frac{g_1}{2 s_W} Z^\mu A^{\mathrm{NSM}} \left(\overleftarrow{\partial}_\mu - \overrightarrow{\partial}_\mu \right) H^{\mathrm{NSM}}$$

Only H^{SM} couples to WW and ZZ!

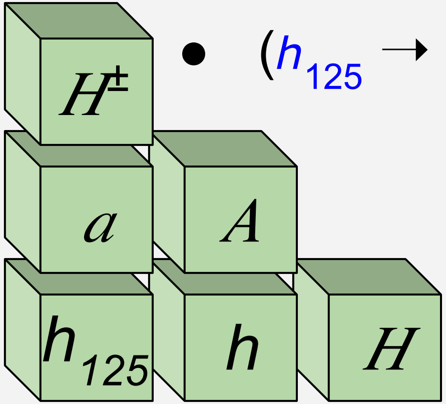
$$H^{\mathrm{SM}}(\mathrm{down},\, \mathrm{up}\,, \mathrm{VV}) = (g_{\mathrm{SM}},\ g_{\mathrm{SM}},\ g_{\mathrm{SM}})\ ,$$
$$H^{\mathrm{NSM}}(\mathrm{down},\, \mathrm{up}\,, \mathrm{VV}) = (-g_{\mathrm{SM}} \tan\beta,\ g_{\mathrm{SM}}/\tan\beta,\ 0)\ ,$$
$$H^{\mathrm{S}}(\mathrm{down},\, \mathrm{up}\,, \mathrm{VV}) = (0,\ 0,\ 0)\ ,$$

Higgs → di-boson decays

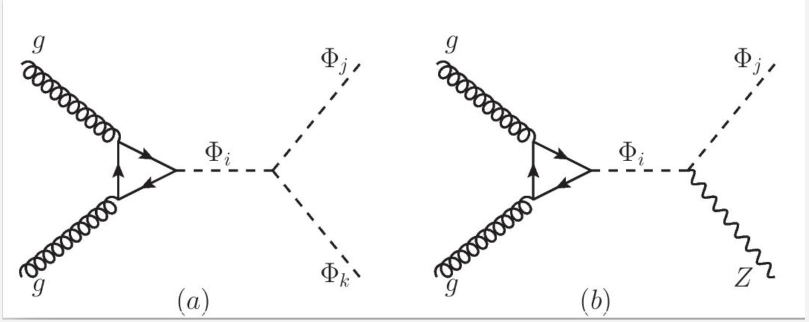


Unsuppressed decays:

- $(H \to h_{125} h)$, $(A \to h_{125} a)$
- $(H \to Z a)$, $(A \to Z h)$
- $(H \to hh)$, $(H \to aa)$, $(A \to ha)$
- $(h_{125} \to hh)$, $(h_{125} \to aa)$

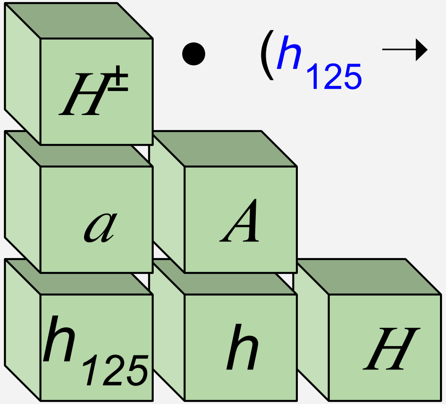


Higgs → di-boson decays



Unsuppressed decays:

- $(H \to h_{125} h)$, $(A \to h_{125} a)$
- $(H \to Za)$, $(A \to Zh)$
- $(H \to hh)$, $(H \to aa)$, $(A \to ha)$
- $(h_{125} \to hh)$, $(h_{125} \to aa)$

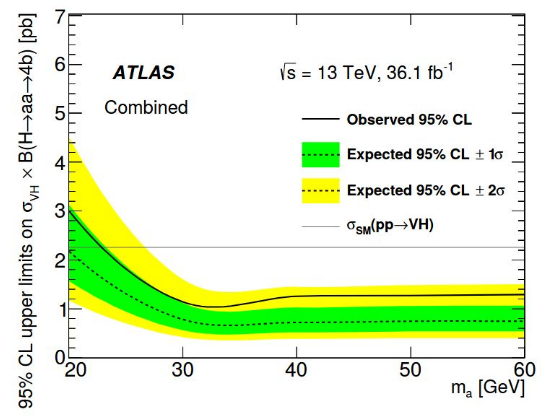


Final States

- Mono-Higgs / Mono-Z
- Higgs + resonance, Z + resonance
- Boosted resonance
- Two resonances with $m_1 = m_2$
- Two resonances with $m_1 \neq m_2$

Only very few searches done as yet...

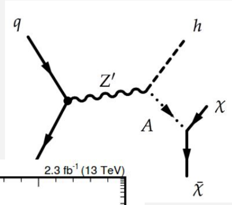
$(h_{125} \to hh)$, $(h_{125} \to aa)$

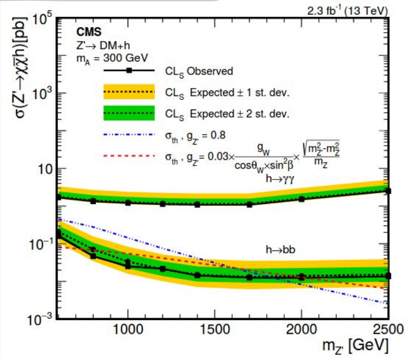


[ATLAS 1505.01609, 1806.07355, 1807.00539, 1812.03388; CMS 1701.02032, 1805.04865, 1805.10191, 1812.00380, 1812.06359, 1907.07235, ...]

mono-h_{125} / mono-Z

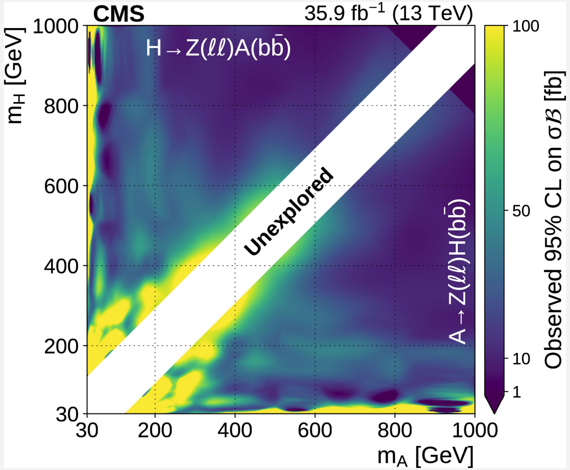
Rare example of resonant interpretation!





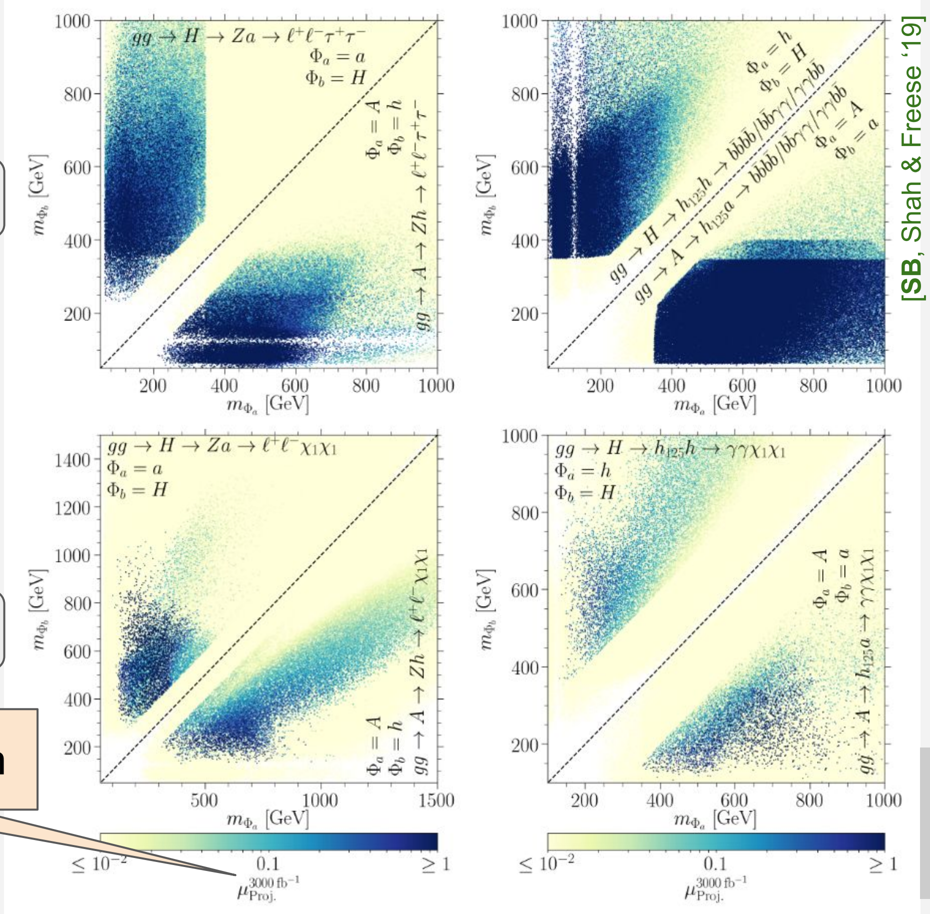
[ATLAS 1506.01081, 1510.06218, 1609.04572, 1706.03948, 1707.01302, 1708.09624; CMS 1703.05236, 1711.00431, 1806.04771, 1807.02826, 1811.06562, 1908.01713, 2008.04735...]

$(H \to Za)$, $(A \to Zh)$



[ATLAS 1804.01126; CMS 1911.03781]

… but lots of potential at LHC w/ 300/fb and HL-LHC!



Z + resonance

Higgs + resonance

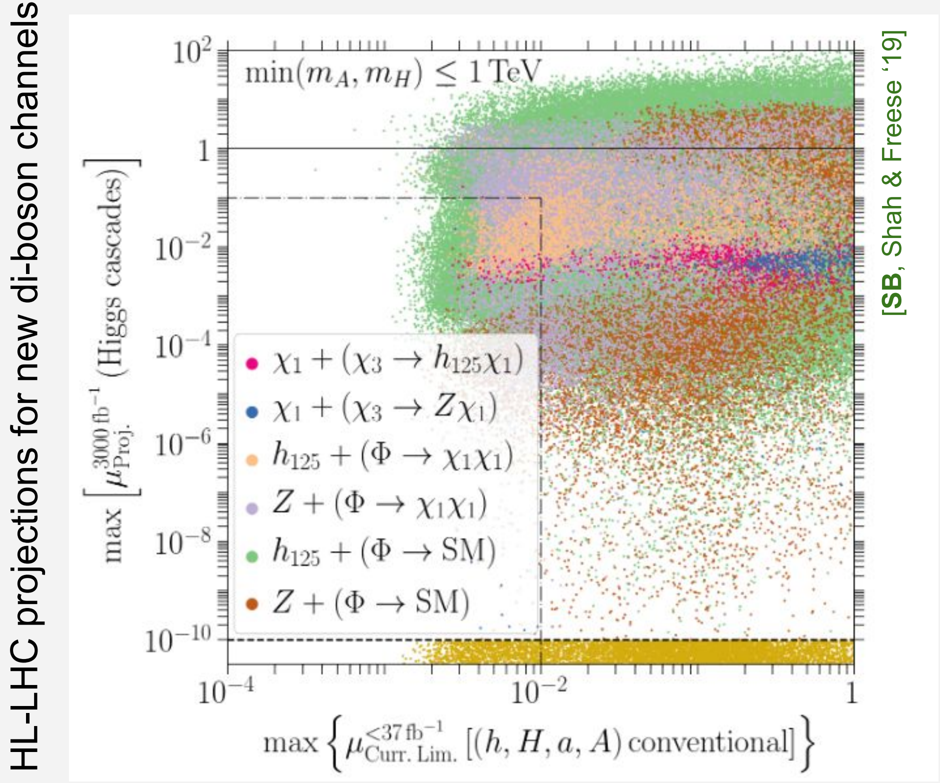
mono-Z

mono-Higgs

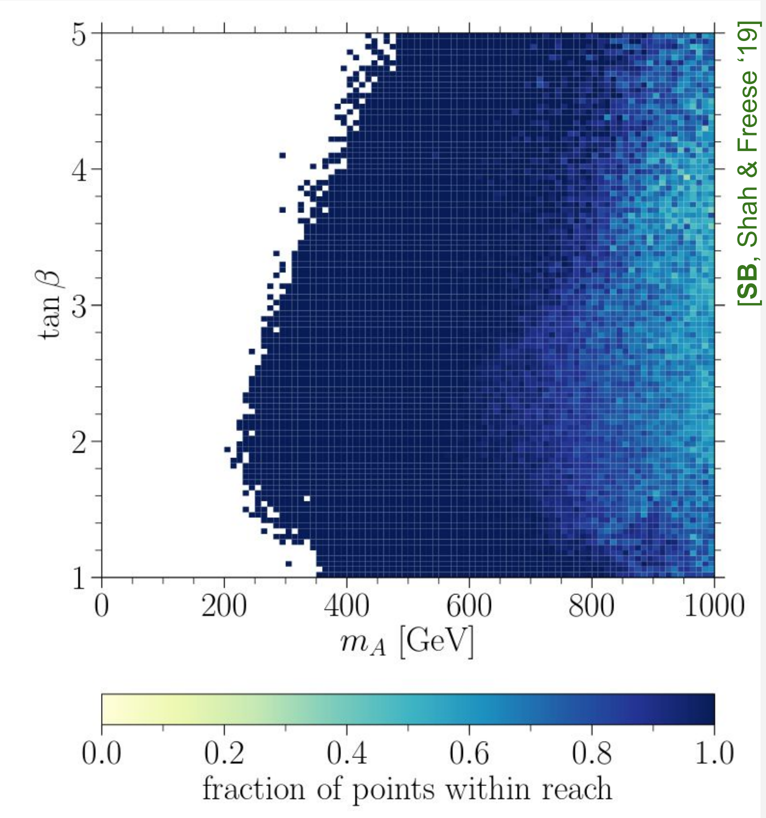
HL-LHC projection

Extrapolation of existing limits
+ projections in the literature
+ our projections for mono Z/Higgs

Combination of searches is crucial!



(~2019) bounds from $pp \to H/A \to$ SM SM searches



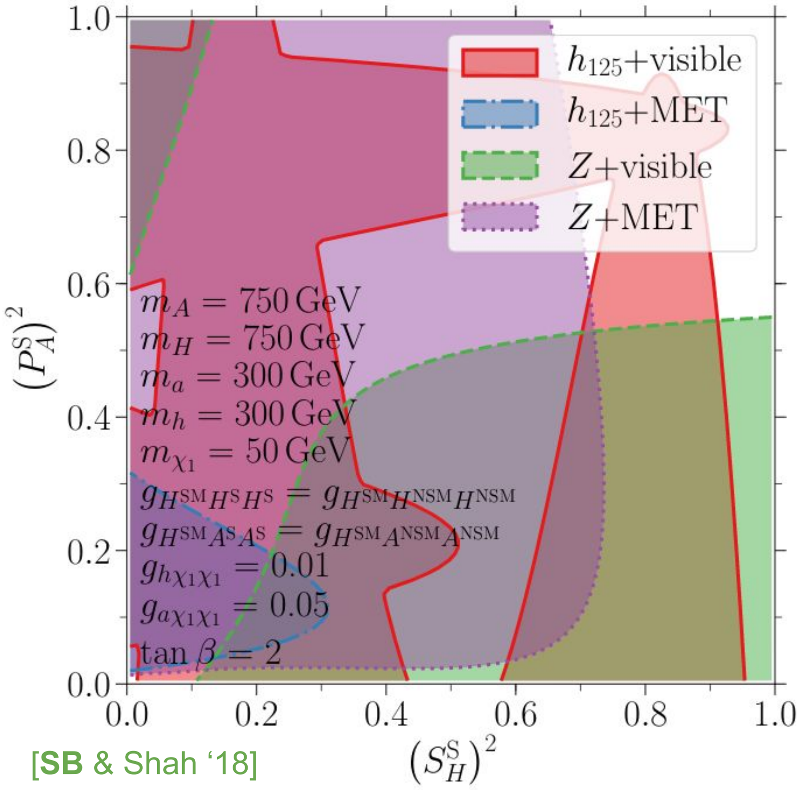
BTW, this happens in any 2HDM+singlet model

Alignment-suppressed channels

- $H \to h_{125} h_{125}$
- $H \to ZZ \,/\, WW$
- $A \to Z\, h_{125}$

Unsuppressed channels

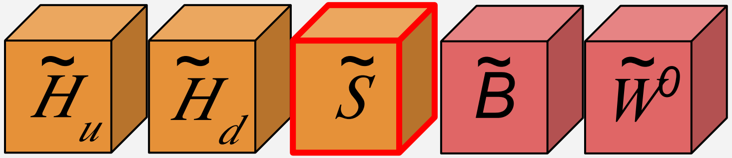
- $(H \to h_{125} h)$, $(A \to h_{125} a)$
- $(H \to Za)$, $(A \to Zh)$
- $(H \to hh)$, $(H \to aa)$, $(A \to ha)$
- $(h_{125} \to hh)$, $(h_{125} \to aa)$



[SB & Shah '18]

Extrapolation of existing limits + projections in the literature + our projections for mono Z/Higgs

And what about Dark Matter?



Singlino-Like LSP

- Right relic density easy to achieve (couples via λ & κ)
- But, direct detection must be suppressed
  - Blind-spot cancellations
  - Destructive interference

Bino-Like LSP

- Relic density too large
  - Resonant annihilation
  - Co-annihilation with the singlino
- Direct detection cross sections can be small

[Cheung, Papucci, Sanford, Shah & Zurek ‘14; Cao, Shang, Wu, Yang & Zhang ’15; Badziak, Olechowski & Szczerbiak ’15, ‘17; Ellwanger ’16; Cao, He, Shang, Su & Zhang ’16; Cao, He, Shang, Su, Wu & Zhang ’16; Beskidt, de Boer, Kazakov & Wayand ’17; **SB**, Carena, Shah and Wagner ’17; Ellwanger & Hugonie ’18; Abdallah, Chatterjee and Datta ‘19, ...]

NMSSM

All the usual SUSY motivation...
(hierarchy problem, gauge unification, beauty, SUGRA, superstring, ...)

No need for stops to be very heavy

Rich Higgs-sector phenomenology

Solves the μ-problem of the MSSM

Dark Matter

Easily accommodates a 125 GeV Higgs boson

Baryogenesis

Scalar potential

$$V^{H_u,H_d,S} = m_S^2 S^\dagger S + m_{H_u}^2 H_u^\dagger H_u + m_{H_d}^2 H_d^\dagger H_d + \left(\lambda A_\lambda S H_u \cdot H_d + \frac{\kappa}{3} A_\kappa S^3 + \text{h.c.}\right)$$
$$+ \frac{g_1^2 + g_2^2}{8}\left(H_u^\dagger H_u - H_d^\dagger H_d\right)^2 + \frac{g_2^2}{2}\left|H_d^\dagger H_u\right|^2 + \lambda^2 \left|H_u \cdot H_d\right|^2$$
$$+ \lambda^2 S^\dagger S \left(H_u^\dagger H_u + H_d^\dagger H_d\right) + \kappa^2 \left(S^\dagger S\right)^2 + \kappa\lambda \left(S^2 H_u^* \cdot H_d^* + \text{h.c.}\right) ,$$

$$H^{\rm SM} = \sqrt{2}{\rm Re}\left(\sin\beta H_u^0 + \cos\beta H_d^0\right) ,$$
$$H^{\rm NSM} = \sqrt{2}{\rm Re}\left(\cos\beta H_u^0 - \sin\beta H_d^0\right) ,$$
$$A^{\rm NSM} = \sqrt{2}{\rm Im}\left(\cos\beta H_u^0 + \sin\beta H_d^0\right) ,$$

$$S = \frac{1}{\sqrt{2}}\left(H^{\rm S} + i A^{\rm S}\right)$$

$$H^\pm = \cos\beta H_u^\pm + \sin\beta H_d^\pm$$

Scalar mass matrices

$$\mathcal{M}^2_{S,11} = m_Z^2 c_{2\beta}^2 + \lambda^2 v^2 s_{2\beta}^2 \,,$$
$$\mathcal{M}^2_{S,12} = -\left(m_Z^2 - \lambda^2 v^2\right) s_{2\beta} c_{2\beta} \,,$$
$$\mathcal{M}^2_{S,13} = 2\lambda v \mu \left(1 - \frac{M_A^2}{4\mu^2} s_{2\beta}^2 - \frac{\kappa}{2\lambda} s_{2\beta}\right),$$
$$\mathcal{M}^2_{S,22} = M_A^2 + \left(m_Z^2 - \lambda^2 v^2\right) s_{2\beta}^2 \,,$$
$$\mathcal{M}^2_{S,23} = -\lambda v \mu c_{2\beta} \left(\frac{M_A^2}{2\mu^2} s_{2\beta} + \frac{\kappa}{\lambda}\right),$$
$$\mathcal{M}^2_{S,33} = \frac{\lambda^2 v^2}{2} s_{2\beta} \left(\frac{M_A^2}{2\mu^2} s_{2\beta} - \frac{\kappa}{\lambda}\right) + \frac{\kappa\mu}{\lambda}\left(A_\kappa + \frac{4\kappa\mu}{\lambda}\right),$$

$$\mathcal{M}^2_{P,11} = M_A^2 \,,$$
$$\mathcal{M}^2_{P,12} = \lambda v \left(\frac{M_A^2}{2\mu} s_{2\beta} - \frac{3\kappa\mu}{\lambda}\right),$$
$$\mathcal{M}^2_{P,22} = \lambda^2 v^2 s_{2\beta} \left(\frac{M_A^2}{4\mu^2} s_{2\beta} + \frac{3\kappa}{2\lambda}\right) - \frac{3\kappa\mu}{\lambda} A_\kappa \,,$$

$$m_{H^\pm}^2 = M_A^2 + m_W^2 - \lambda^2 v^2$$

Approximate masses of the singlet-like states

$$m_h^2 \simeq \frac{\kappa\mu}{\lambda}\left(A_\kappa + \frac{4\kappa\mu}{\lambda}\right) + \lambda^2 v^2 s_{2\beta}^4 \frac{M_A^2}{4\mu^2} - \frac{\lambda\kappa v^2}{2} s_{2\beta}\left(1 + 2c_{2\beta}^2\right) - \kappa^2 v^2 \frac{\mu^2}{M_A^2} c_{2\beta}^2 \,,$$

$$m_a^2 \simeq 3\kappa v^2 \left[\frac{3}{2}\lambda s_{2\beta} - \left(\frac{1}{\lambda}\frac{\mu A_\kappa}{v^2} + 3\kappa\frac{\mu^2}{M_A^2}\right)\right] .$$

- Alignment limit
- first order in NSM - S mixing

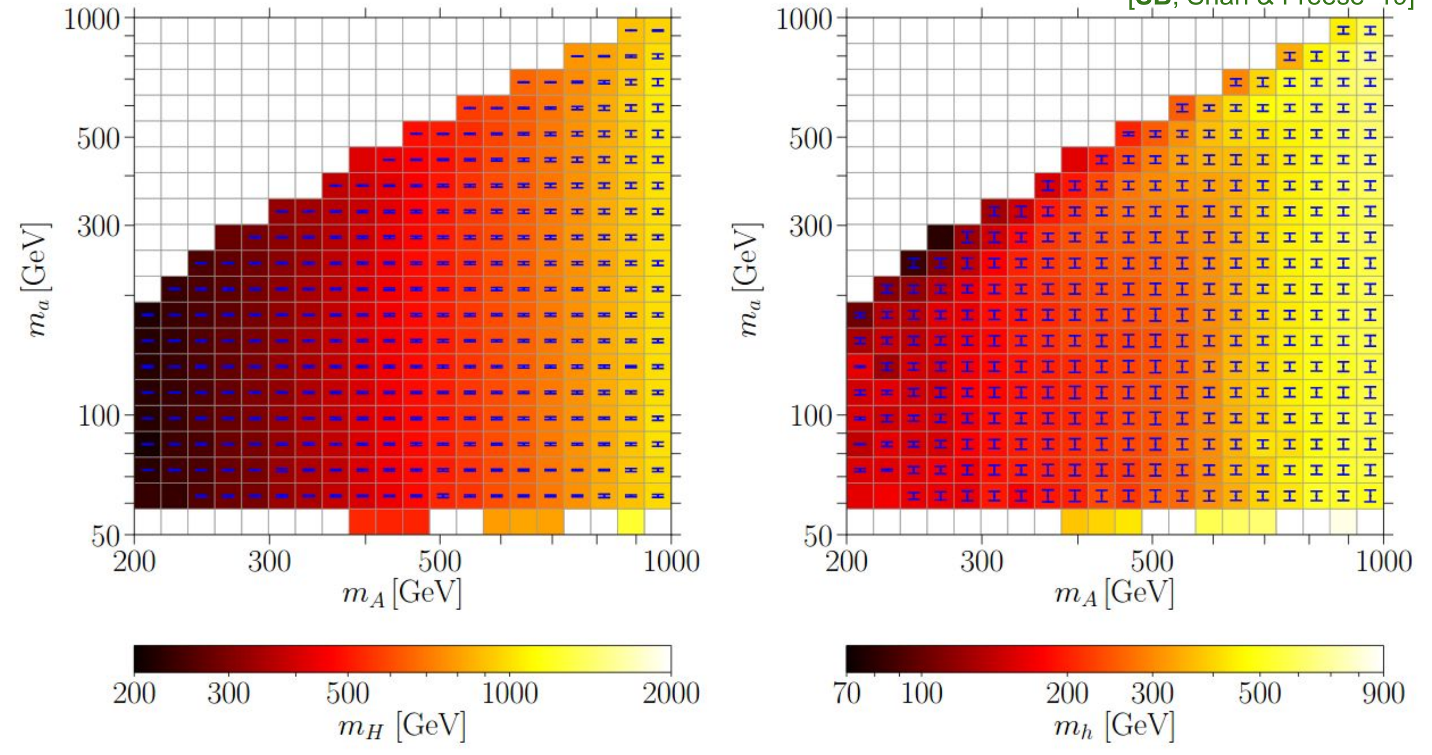
Neutralino mass matrix

$$M_{\chi^0} = \begin{pmatrix} M_1 & 0 & -m_Z s_W c_\beta & m_Z s_W s_\beta & 0 \\ & M_2 & m_Z c_W c_\beta & -m_Z c_W s_\beta & 0 \\ & & 0 & -\mu & -\lambda v s_\beta \\ & & & 0 & -\lambda v c_\beta \\ & & & & 2\kappa\mu/\lambda \end{pmatrix},$$

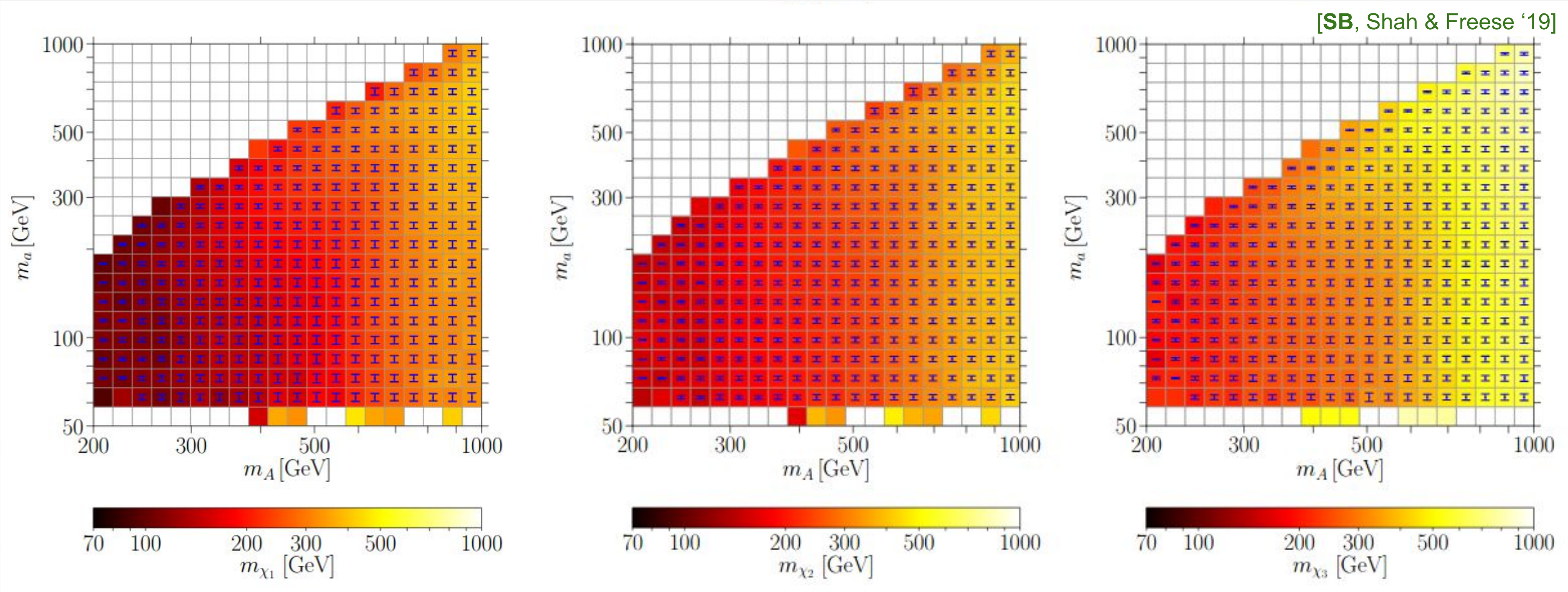
In basis $\{\widetilde{B}, \widetilde{W}^3, \widetilde{H}_d^0, \widetilde{H}_u^0, \widetilde{S}\}$

Mass correlations: Higgs bosons

[**SB**, Shah & Freese ‘19]

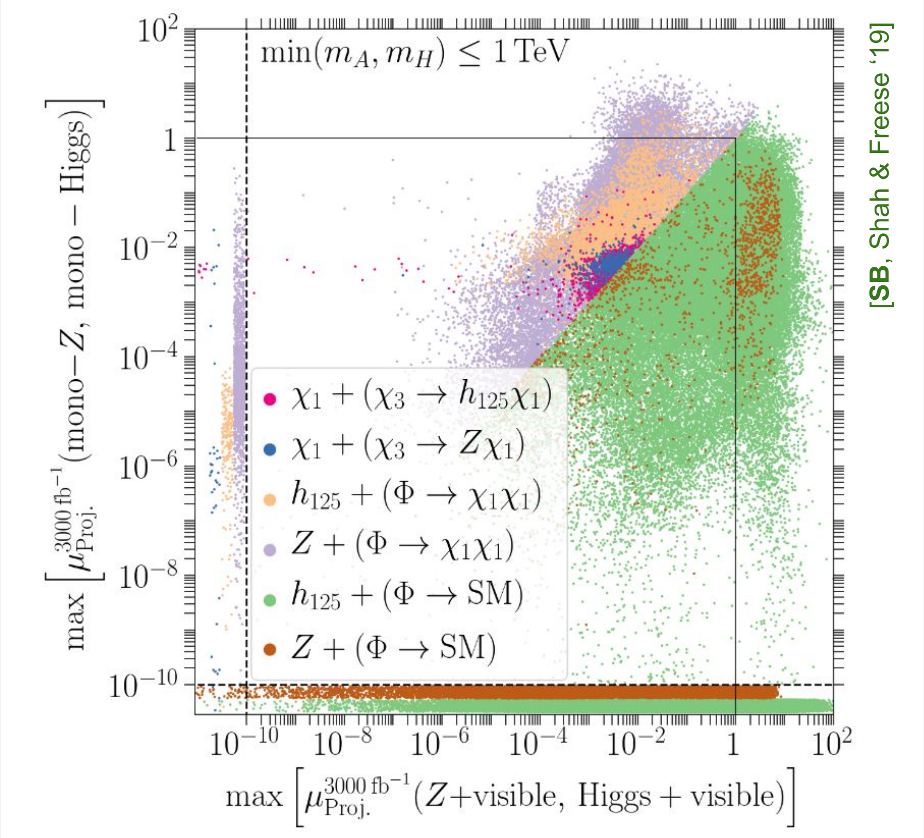


Mass correlations: neutralinos



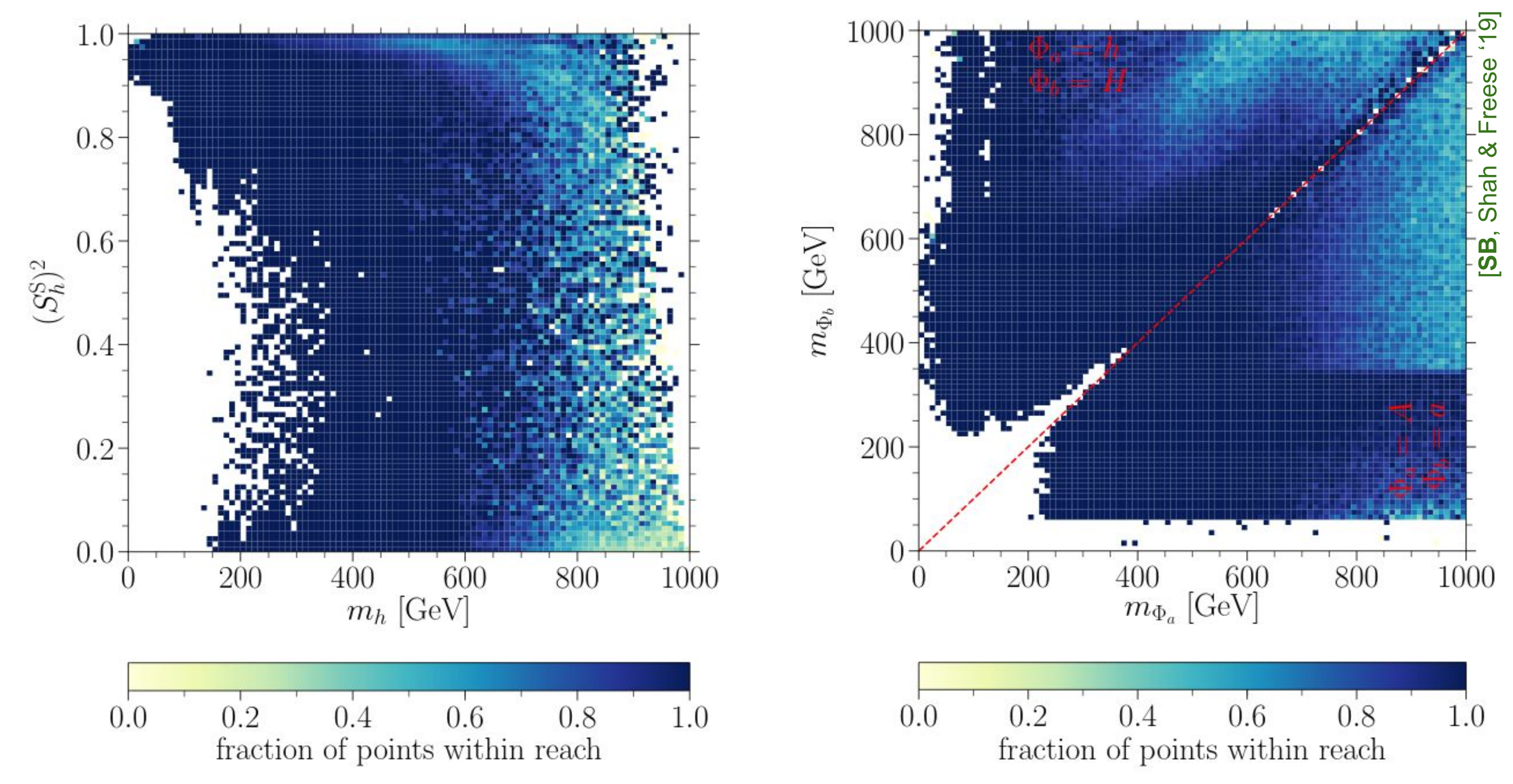
$M_1 = M_2 = 1$ TeV

Complementarity of mono-Z/Higgs and visible decays



[**SB**, Shah & Freese '19]

Combined reach projections



[**SB**, Shah & Freese '19]

Dark Matter--Higgs couplings

Singlino-like LSP

$$g_{\tilde{S}\tilde{S}H^{\rm SM}} = -\frac{\sqrt{2}v}{\mu}\lambda^2 \sin 2\beta + \frac{\sqrt{2}m_\chi v}{|\mu|^2}\lambda^2 \,,$$

$$g_{\tilde{S}\tilde{S}H^{\rm NSM}} = -\frac{\sqrt{2}v}{\mu}\lambda^2 \cos 2\beta \,,$$

$$g_{\tilde{S}\tilde{S}H^{S}} = i g_{\tilde{S}\tilde{S}A^{S}} = \frac{v^2}{\sqrt{2}\mu^2}\lambda^3 \sin 2\beta - \sqrt{2}\kappa\left(1 - \frac{v^2}{|\mu|^2}\lambda^2\right) \,,$$

$$g_{\tilde{S}\tilde{S}A^{\rm NSM}} = -i\frac{\sqrt{2}v}{\mu}\lambda^2 + i\frac{\sqrt{2}m_\chi v}{|\mu|^2}\lambda^2 \sin 2\beta \,,$$

$$g_{\tilde{S}\tilde{S}G^{0}} = -i\frac{\sqrt{2}m_\chi v}{|\mu|^2}\lambda^2 \cos 2\beta \,.$$

Bino-like LSP

$$g_{\tilde{B}\tilde{B}H^{\rm SM}} = \frac{v}{\sqrt{2}\mu}g_1^2 \sin 2\beta + \frac{m_\chi v}{\sqrt{2}|\mu|^2}g_1^2 \,,$$

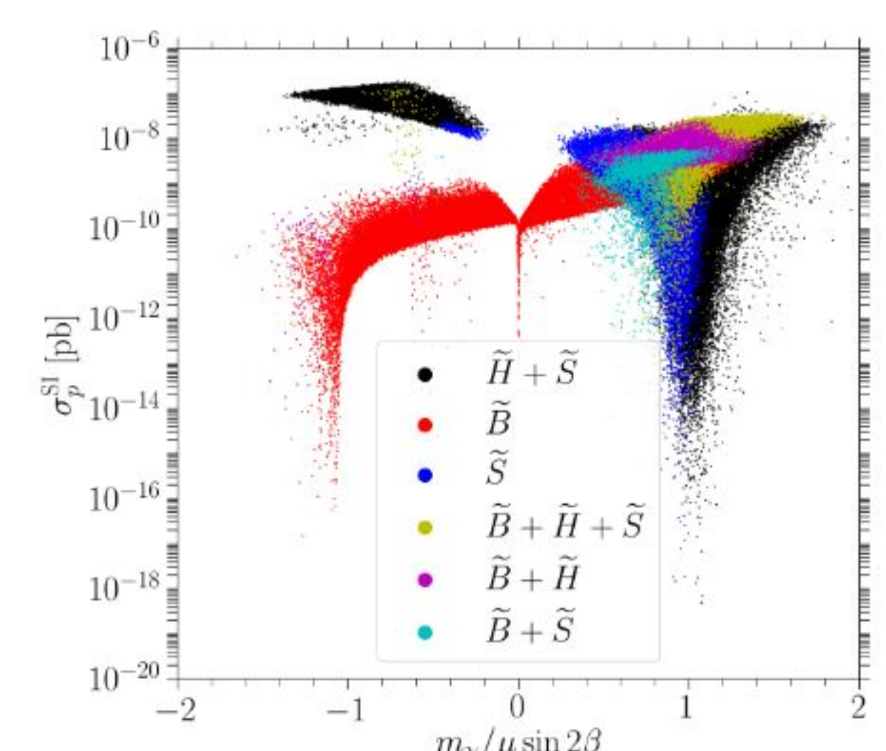
$$g_{\tilde{B}\tilde{B}H^{\rm NSM}} = \frac{v}{\sqrt{2}\mu}g_1^2 \cos 2\beta \,,$$

$$g_{\tilde{B}\tilde{B}H^{S}} = i g_{\tilde{B}\tilde{B}A^{S}} = -\frac{v^2}{2\sqrt{2}\mu^2}\lambda g_1^2 \sin 2\beta \,,$$

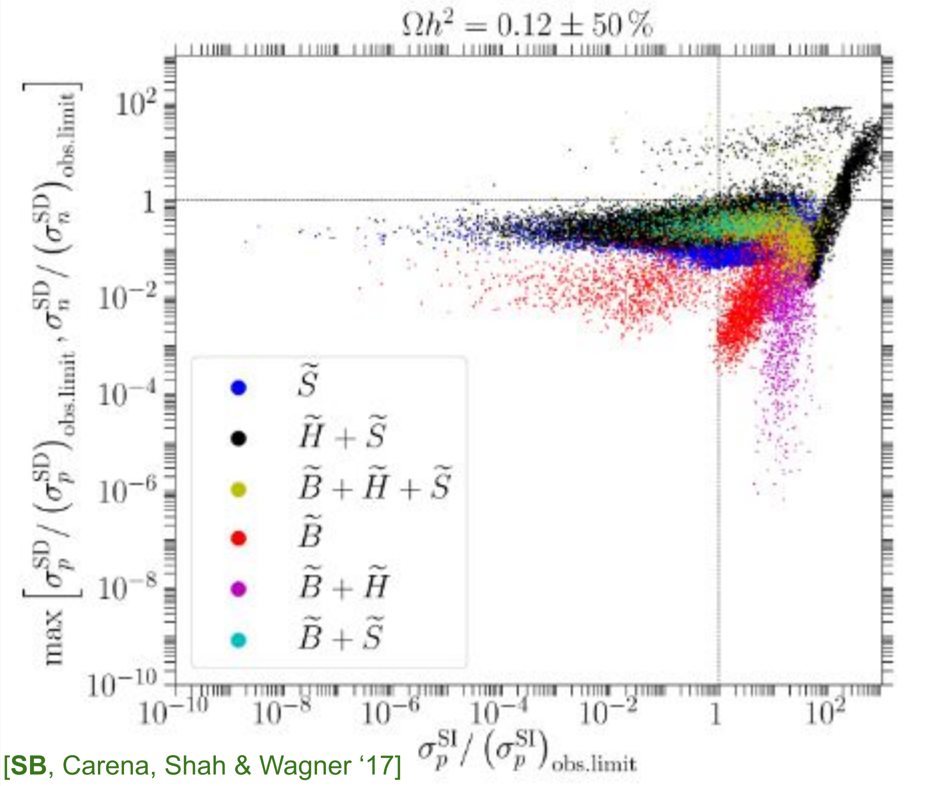
$$g_{\tilde{B}\tilde{B}A^{\rm NSM}} = -i\frac{v}{\sqrt{2}\mu}g_1^2 - i\frac{m_\chi v}{\sqrt{2}|\mu|^2}g_1^2 \sin 2\beta \,,$$

$$g_{\tilde{B}\tilde{B}G^{0}} = i\frac{m_\chi v}{\sqrt{2}|\mu|^2}g_1^2 \cos 2\beta \,,$$

Dark Matter: Blind-spots & detection prospects



[**SB**, Carena, Shah & Wagner '17]



[**SB**, Carena, Shah & Wagner '17]