

Constraining the MSSM Higgs sector in the low $\tan \beta$ region

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Constraints on the MSSM Higgs sector

Considered constraints:

- ▶ Properties of the Higgs boson discovered at the LHC,
 - mass (predictable in the MSSM),
 - couplings,
- ▶ searches for additional Higgs bosons.

→ Evaluate constraints in Higgs benchmark scenarios.

Additional constraints not considered here:

- ▶ Flavour constraints,
- ▶ vacuum stability,
- ▶ ...

Higgs benchmark scenarios – why do we need them?

- ▶ MSSM has large number of free parameters,
- ▶ interpretation of Higgs properties and searches for additional Higgs bosons would require large parameter scans.



Focus on benchmark scenarios with only two free parameters:

- ▶ Typically presented in M_A - $\tan \beta$ plane (or M_{H^\pm} - $\tan \beta$),
- ▶ other parameters chosen such that one neutral Higgs is SM-like,
- ▶ each scenario has a different phenomenology.

Six scenarios with sfermion mass scale $M_{\text{SUSY}} \sim 1.5 \text{ TeV}$

[Bagnaschi, HB, Fuchs, Hahn, Heinemeyer, Liebler, Patel, Slavich, Stefaniak, Wagner, Weiglein, 1808.07542]

Defined using:

- ▶ FeynHiggs \rightarrow Higgs masses and branching ratios,
- ▶ SusHi \rightarrow Higgs production cross-sections,
- ▶ HiggsBounds \rightarrow direct searches for extra Higgs bosons,
- ▶ HiggsSignals \rightarrow SM-like Higgs signal strengths.

Benchmark scenarios:

- ▶ M_h^{125} scenario \rightarrow all SUSY particles at the TeV scale,
- ▶ $M_h^{125}(\tilde{\tau})$ scenario \rightarrow light Stau, Bino and Winos,
- ▶ $M_h^{125}(\tilde{\chi})$ scenario \rightarrow light Bino, Winos and Higgsinos,
- ▶ $M_h^{125}(\text{alignment})$ scenario \rightarrow alignment without decoupling,
- ▶ M_H^{125} scenario \rightarrow heavy \mathcal{CP} -even Higgs is SM-like,
- ▶ $M_{h_1}^{125}(\text{CPV})$ scenario \rightarrow \mathcal{CP} -violation in the Higgs sector.

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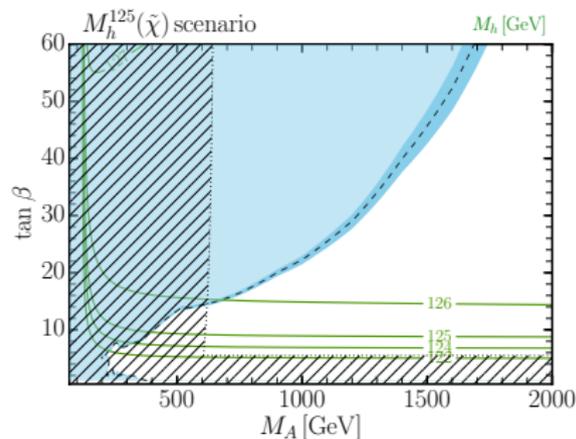
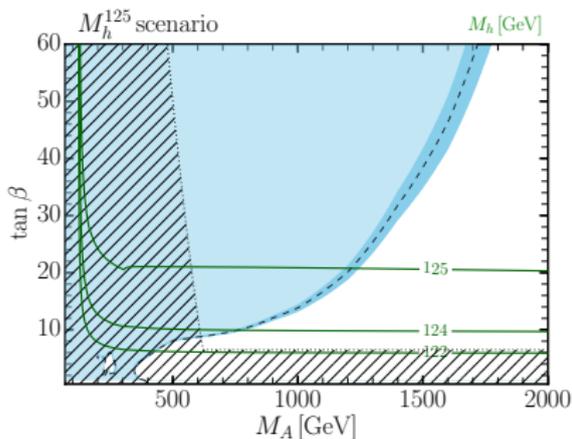
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M_h^{125} and $M_h^{125}(\tilde{\chi})$ scenarios

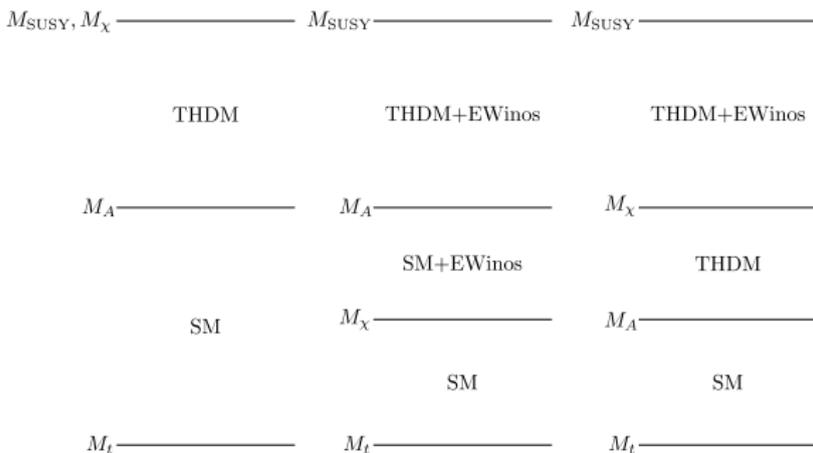
- ▶ Blue: Excluded by direct searches for heavy Higgs bosons,
- ▶ hashed: Excluded by SM-like Higgs signal strengths / mass.

Low $\tan \beta$ region?!

Region of $\tan \beta \lesssim 8$ excluded since mass $M_h < 125 \pm 3$ GeV.
 → Need to raise M_{SUSY} to push M_h upwards.



Large hierarchy between heavy Higgs scale and SUSY scale.
 Predictions should be evaluated in THDM-EFT framework!



THDM as EFT I

[HB&Hollik,1805.00867]

Procedure:

- ▶ Integrate out sfermions at scale M_{SUSY}
→ fixes values of THDM Higgs self-couplings,
- ▶ run down to heavy Higgs scale M_A ,
- ▶ integrate out heavy Higgses
→ fixes value of SM Higgs self-coupling,
- ▶ run down to electroweak scale
→ check compatibility with SM input parameters,

Result

THDM couplings at M_A , SM Higgs self-coupling at M_t .

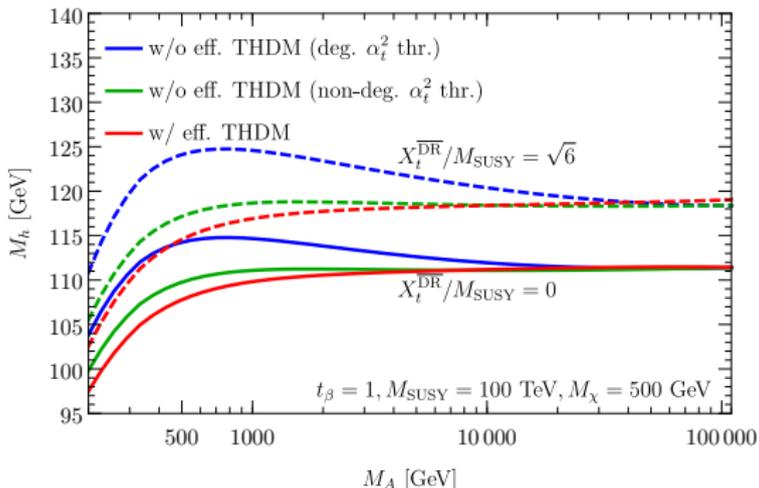
All large logarithms resummed

→ precise prediction for physical observables, $M_h^2 \simeq v^2 \lambda(M_t)$.

THDM as EFT II

[HB&Hollik,1805.00867]

- ▶ EFTs: SM(+EWinos,+Gluino), THDM(+EWinos,+Gluino),
- ▶ full LL+NLL and partial NNLL resummation,
- ▶ combined with existing 2L fixed-order calculation,
- ▶ incorporated into FeynHiggs.



Benchmark scenarios for the low $\tan \beta$ region

[HB,Liebler,Stefaniak,1901.05933]

Use this calculation to define low- $\tan \beta$ benchmark scenarios.

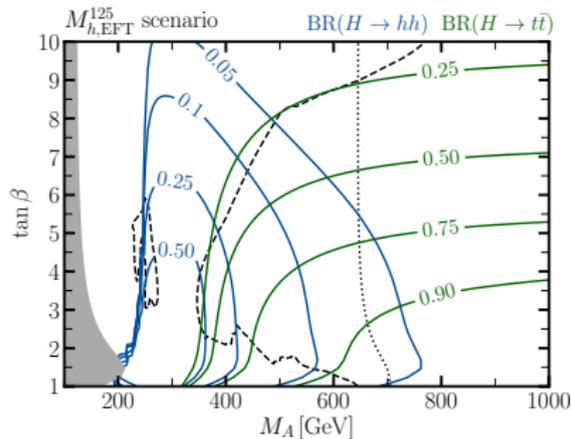
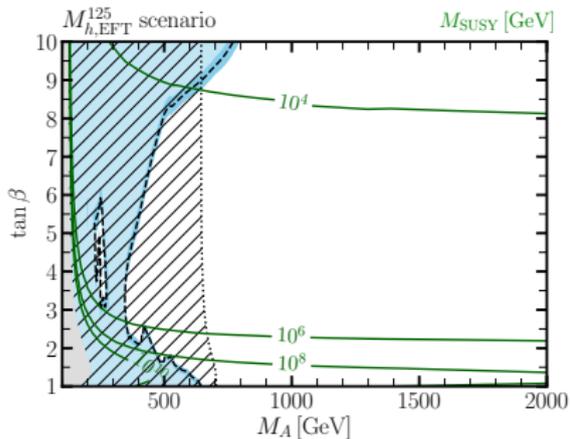
Concept

Take existing scenarios and raise M_{SUSY} at every point such that $M_h \sim 125$ GeV.

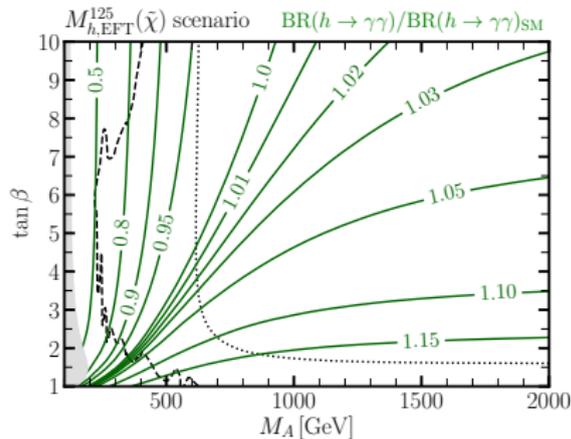
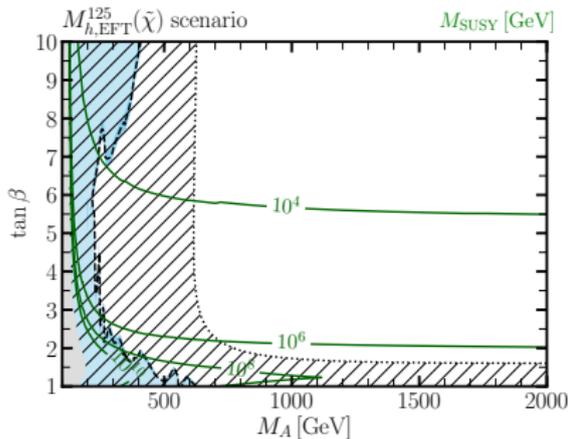
(upper limit: $M_{\text{SUSY}} \leq 10^{16}$ GeV)

⇒ Two low- $\tan \beta$ benchmark scenarios:

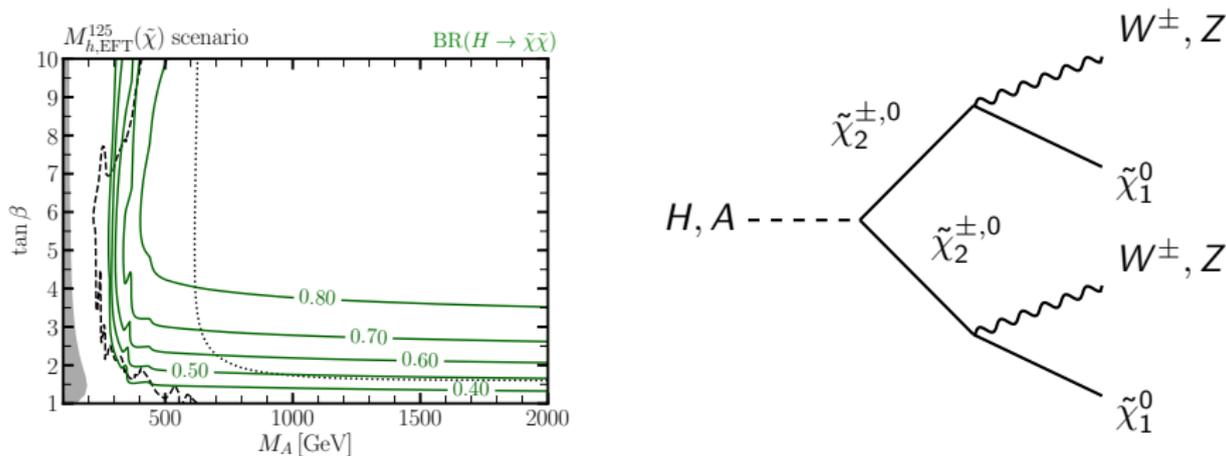
- ▶ $M_{h,\text{EFT}}^{125}$ scenario resembling M_h^{125} scenario,
- ▶ $M_{h,\text{EFT}}^{125}(\tilde{\chi})$ scenario resembling $M_h^{125}(\tilde{\chi})$ scenario.

$M_{h,EFT}^{125}$ scenario

- ▶ Gray: $M_h < 122$ GeV,
- ▶ blue: Excluded by direct searches for heavy Higgs bosons,
- ▶ hashed: Excluded by Higgs signal strengths.

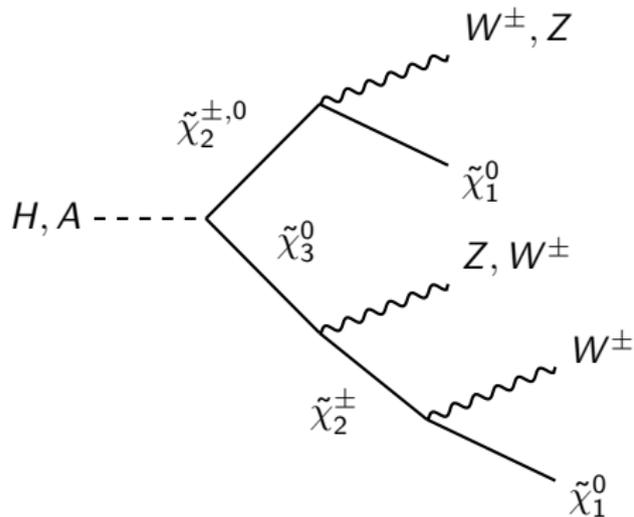
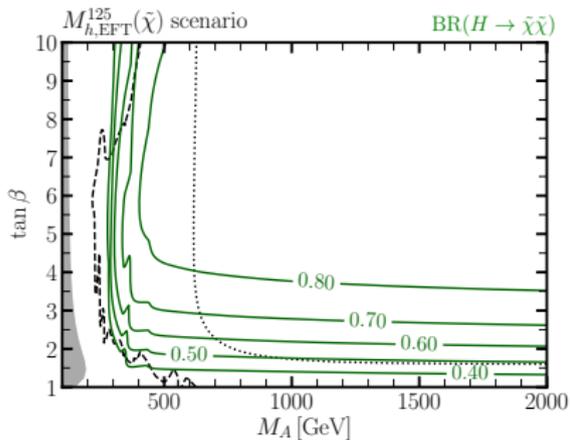
$M_{h,EFT}^{125}(\tilde{\chi})$ scenario

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$M_{h,\text{EFT}}^{125}(\tilde{\chi})$ scenario – $H, A, H^\pm \rightarrow \tilde{\chi}\tilde{\chi}$ 

- ▶ Interesting multilepton signatures,
- ▶ no experimental searches yet.

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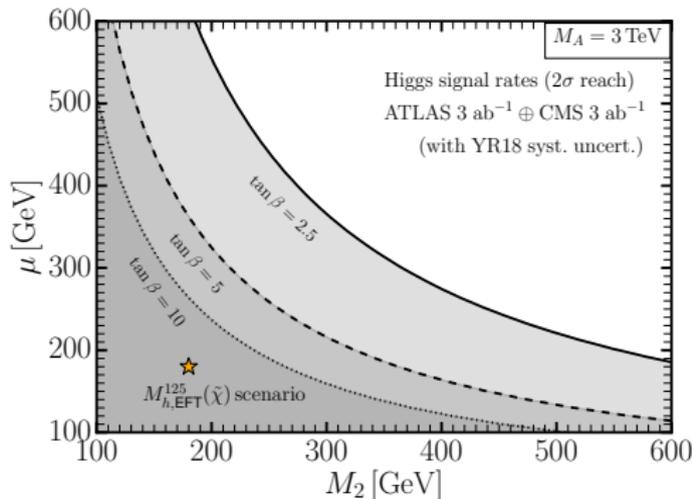
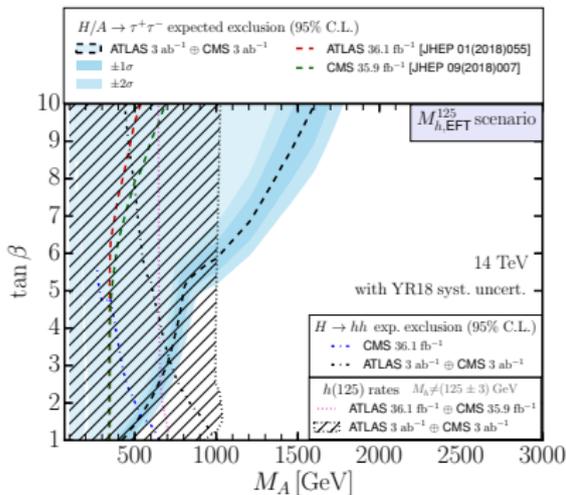


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HL-LHC projections

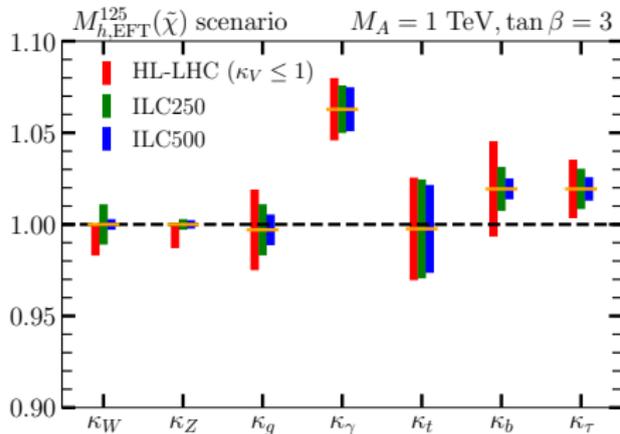
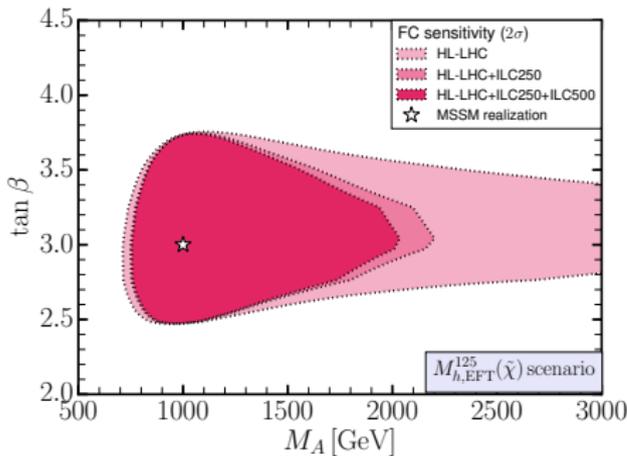
[HB,Bechtle,Heinemeyer,Liebler,Stefaniak,Weiglein,to appear]

► Assume discovered Higgs to have SM couplings.



What if $M_{h,\text{EFT}}^{125}(\tilde{\chi})$ scenario is realized?

- ▶ Assume discovered Higgs to have couplings as predicted for $M_A = 1$ TeV and $\tan \beta = 3$.



Conclusions

- ▶ Higgs benchmark scenarios help to interpret LHC results,
- ▶ to define scenarios valid in the low $\tan \beta$ region large M_{SUSY} needed,
- ▶ for accurate prediction of Higgs masses and decay widths THDM as EFT is crucial.

→ Two benchmark scenarios for the low $\tan \beta$ region.

HL-LHC and ILC constraints:

- ▶ $M_{h,\text{EFT}}^{125}$ scenario difficult to constrain,
- ▶ Strong constraints on $M_{h,\text{EFT}}^{125}(\tilde{\chi})$ scenario.

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Thanks for your attention!

hMSSM comparison

