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.

$\rightarrow$ Evaluate constraints in Higgs benchmark scenarios.

Additional constraints not considered here:

- flavour constraints,
- vacuum stability,
- EWPOs,
- ...

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.

$\Downarrow$

Focus on benchmark scenarios with only two free parameters:

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

Six scenarios with sfermion mass scale $M_{\text{SUSY}} \sim 1.5$ 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}(alignment) scenario $\rightarrow$ alignment without decoupling,
- M_H^{125} scenario $\rightarrow$ heavy $\mathcal{CP}$-even Higgs is SM-like,
- $M_{h_1}^{125}$(CPV) scenario $\rightarrow$ $\mathcal{CP}$-violation in the Higgs sector.

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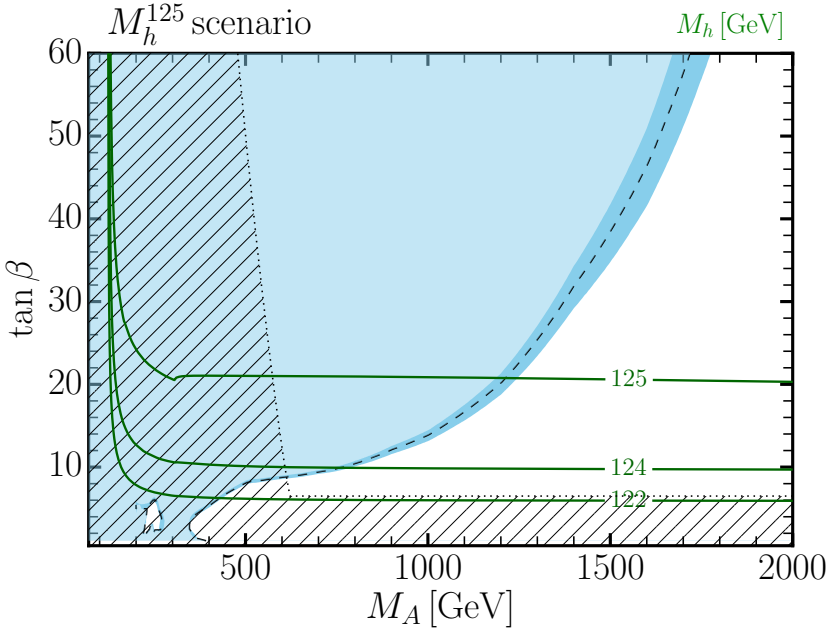
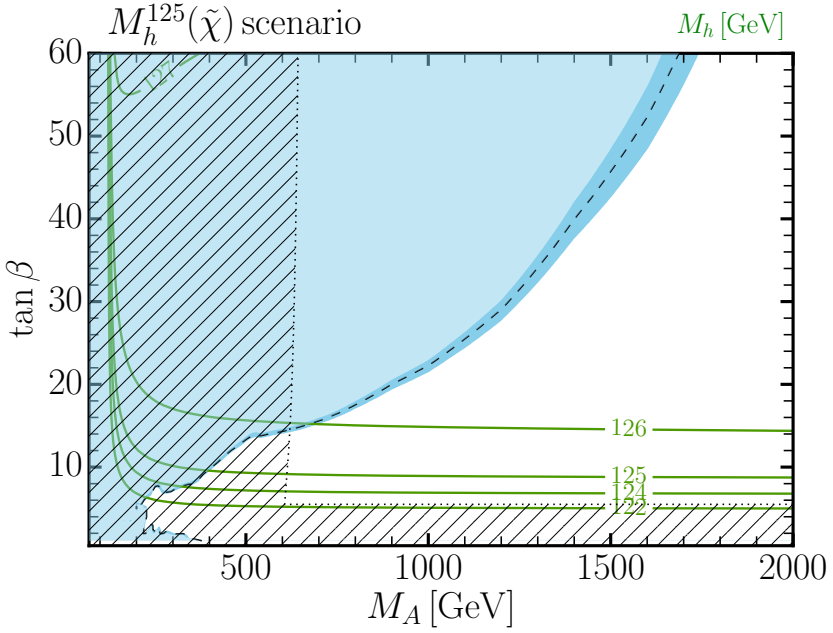
M_h^{125} and $M_h^{125}(\tilde{\chi})$ scenarios





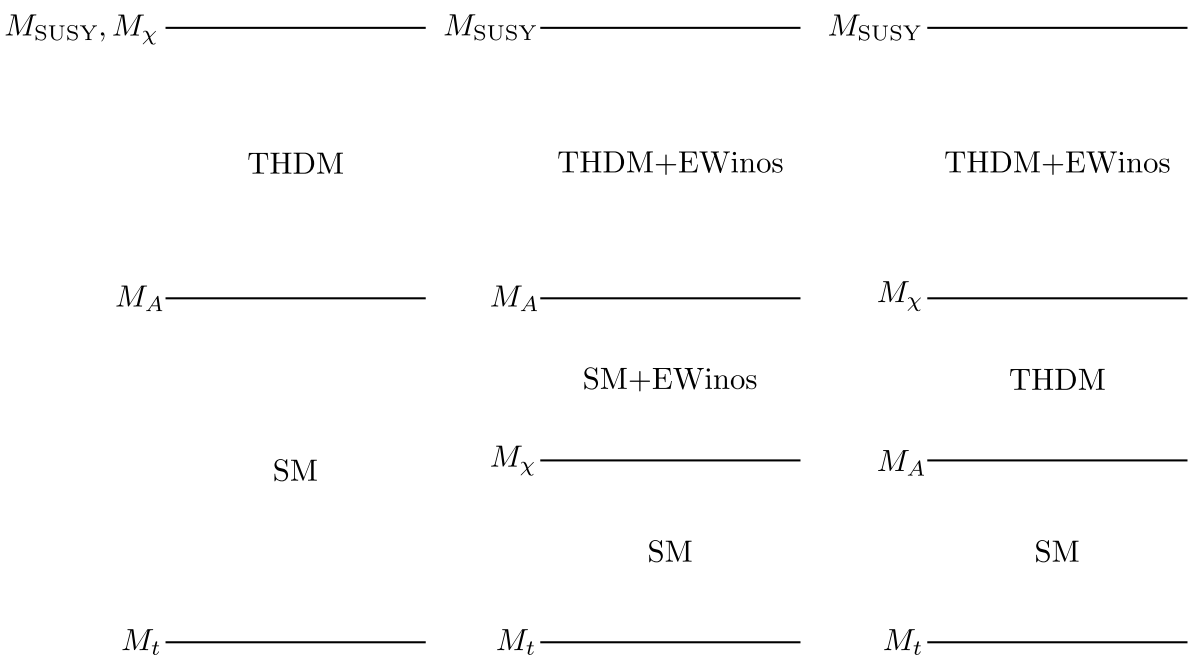
- Blue: Excluded by direct searches for heavy Higgs bosons,
- hashed: Excluded by SM-like Higgs signal strengths / mass.

Low tan β region?!

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

$\Downarrow$

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



[HB&Hollik,1805.00867]

Benchmark scenarios for the low tan β region

[HB,Liebler,Stefaniak,1901.05933]

Use THDM-EFT calculation to define low-tan β benchmark scenarios.

Concept

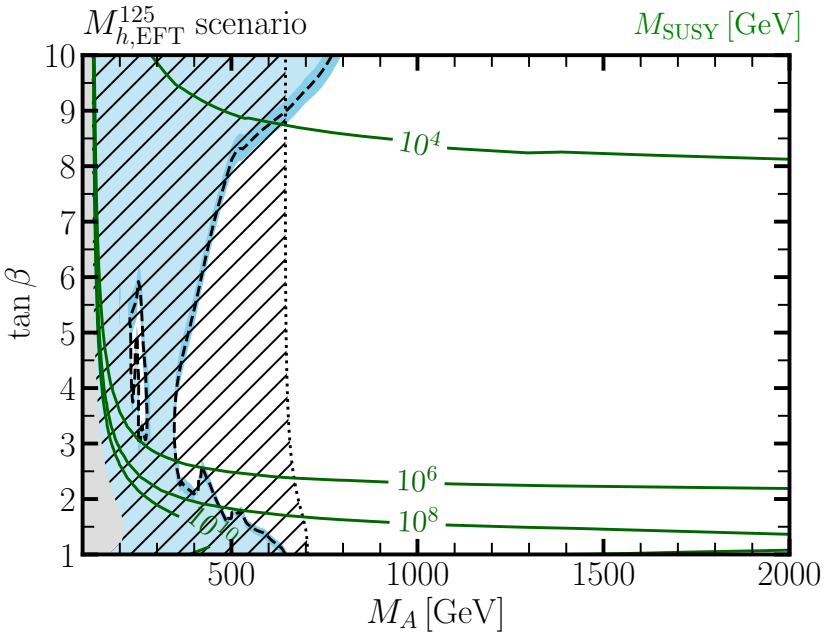
Take existing scenarios and raise M_{SUSY} at every point such that $M_h \sim 125$ GeV.

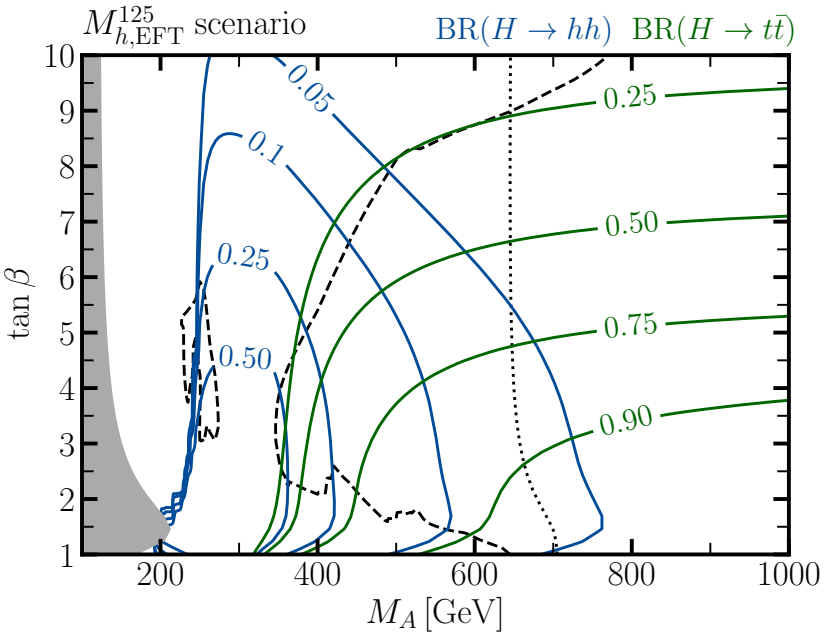
(upper limit: $M_{\text{SUSY}} \leq 10^{16}$ GeV)

Two low-tan β 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.

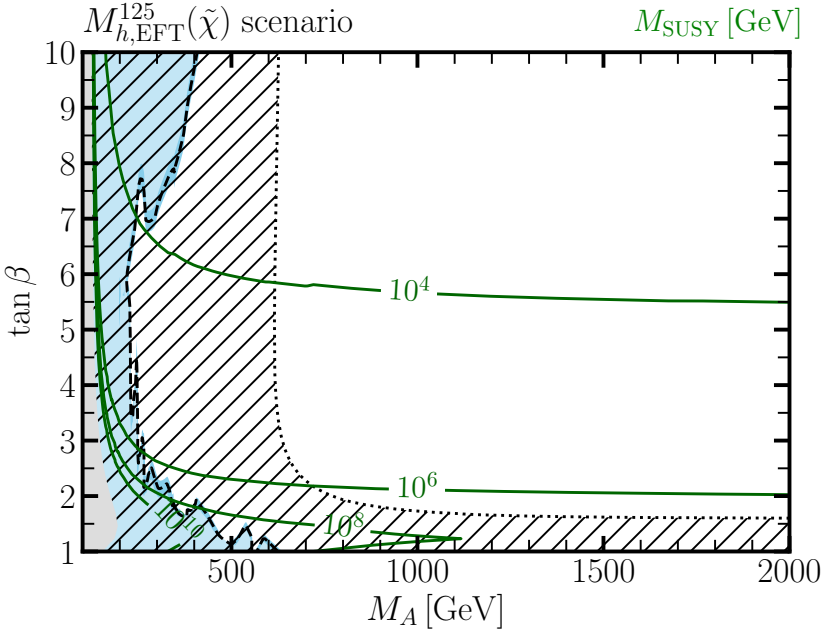
$M_{h,\mathrm{EFT}}^{125}$ scenario

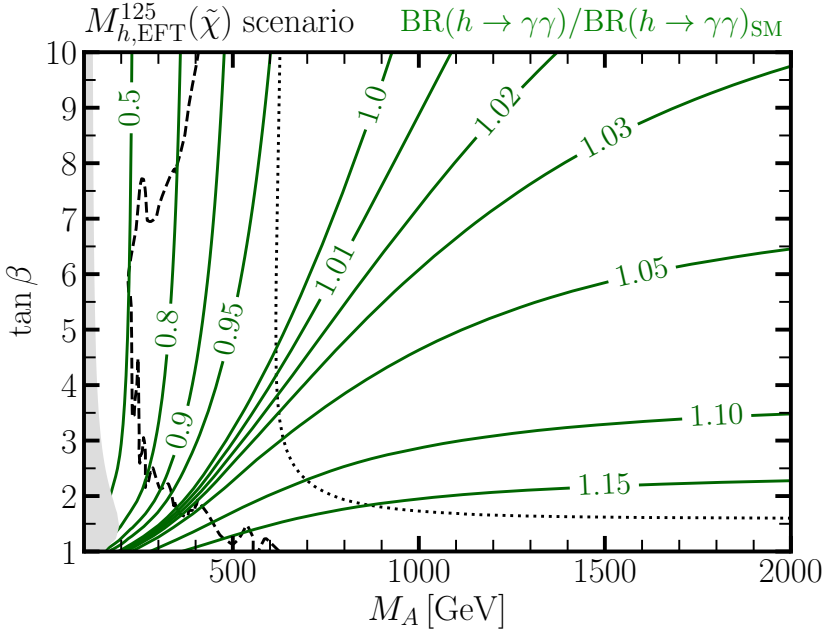




- Gray: $M_h < 122$ GeV,
- blue: Excluded by direct searches for heavy Higgs bosons,
- hashed: Excluded by Higgs signal strengths.

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



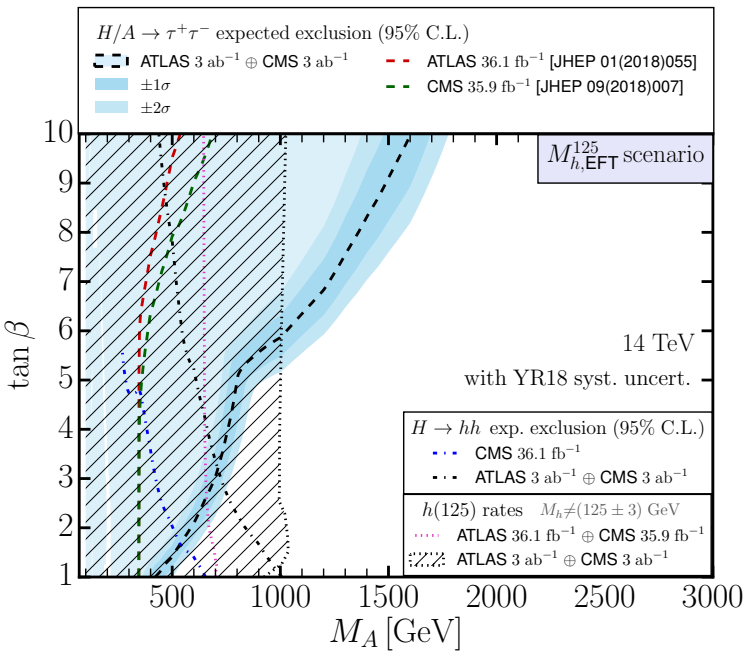


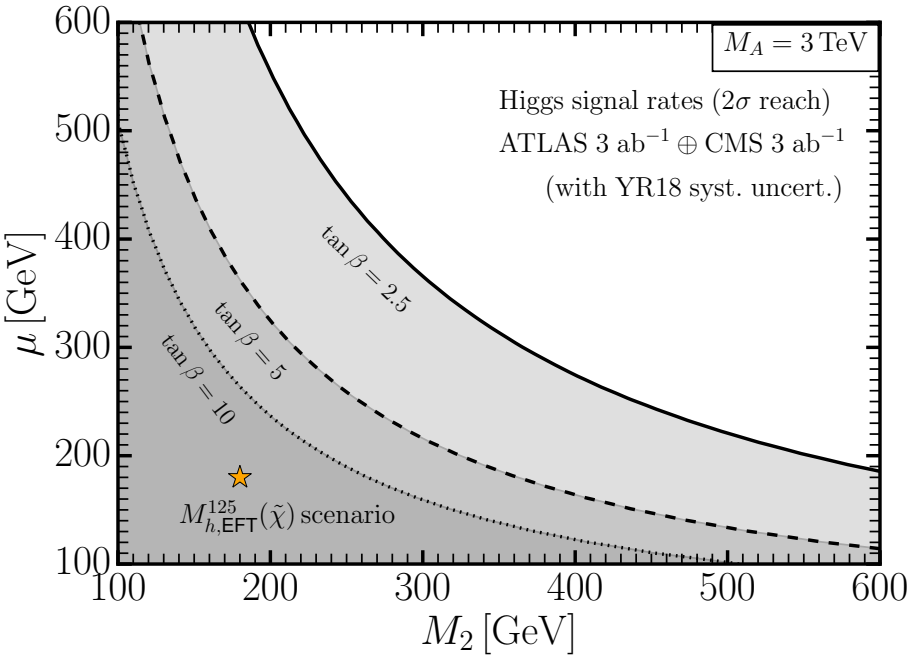
- Gray: $M_h < 122$ GeV,
- blue: Excluded by direct searches for heavy Higgs bosons,
- hashed: Excluded by Higgs signal strengths,
- interesting $H, A \to \tilde{\chi}\tilde{\chi} \to W^{\pm}, Z$ signatures.

HL-LHC projections

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

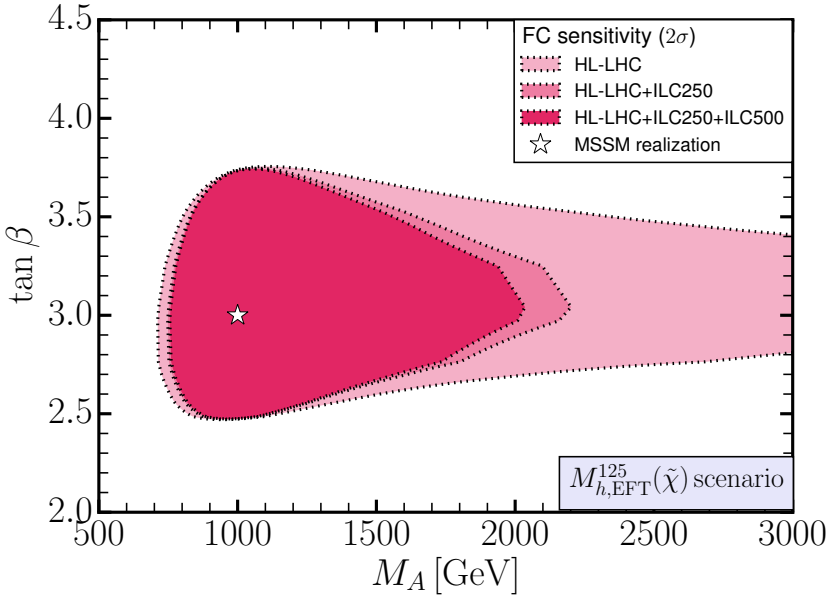
- Assume discovered Higgs to have SM couplings.

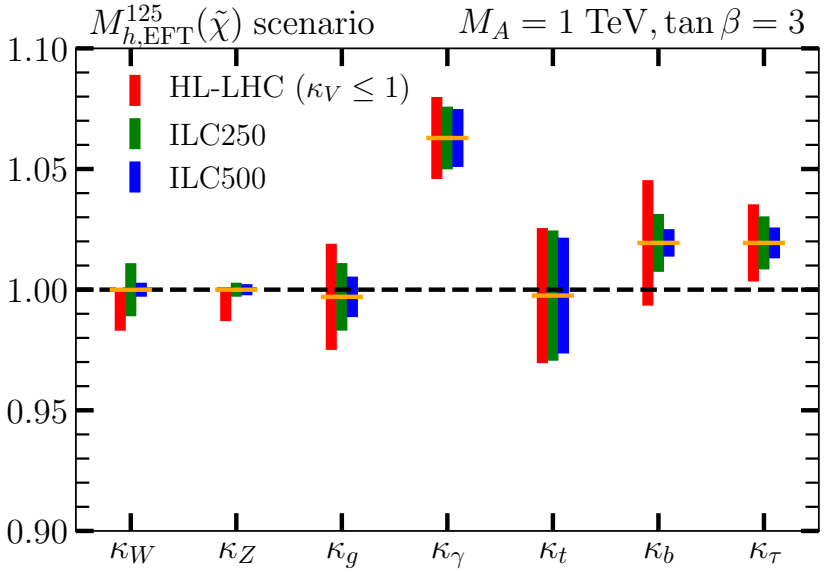




What if $M^{125}_{h,\mathrm{EFT}}(\tilde{\chi})$ scenario is realized?

- 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 β region large M_{SUSY} needed,
- for accurate prediction of Higgs masses and decay widths THDM as EFT is crucial.

$\rightarrow$ Two benchmark scenarios for the low tan β region.

HL-LHC and ILC constraints:

- $M_{h,\mathrm{EFT}}^{125}$ scenario difficult to constraint,
- strong constraints on $M_{h,\mathrm{EFT}}^{125}(\tilde{\chi})$ scenario.

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Thanks for your attention!

THDM as EFT I

[HB&Hollik,1805.00867]

Procedure:

- integrate out sfermions at scale M_{SUSY}
  $\rightarrow$ fixes values of THDM Higgs self-couplings,
- run down to heavy Higgs scale M_A,
- integrate out heavy Higgses $\rightarrow$ recover SM as EFT,
- run down to electroweak scale
  $\rightarrow$ check compatibility with SM input parameters.

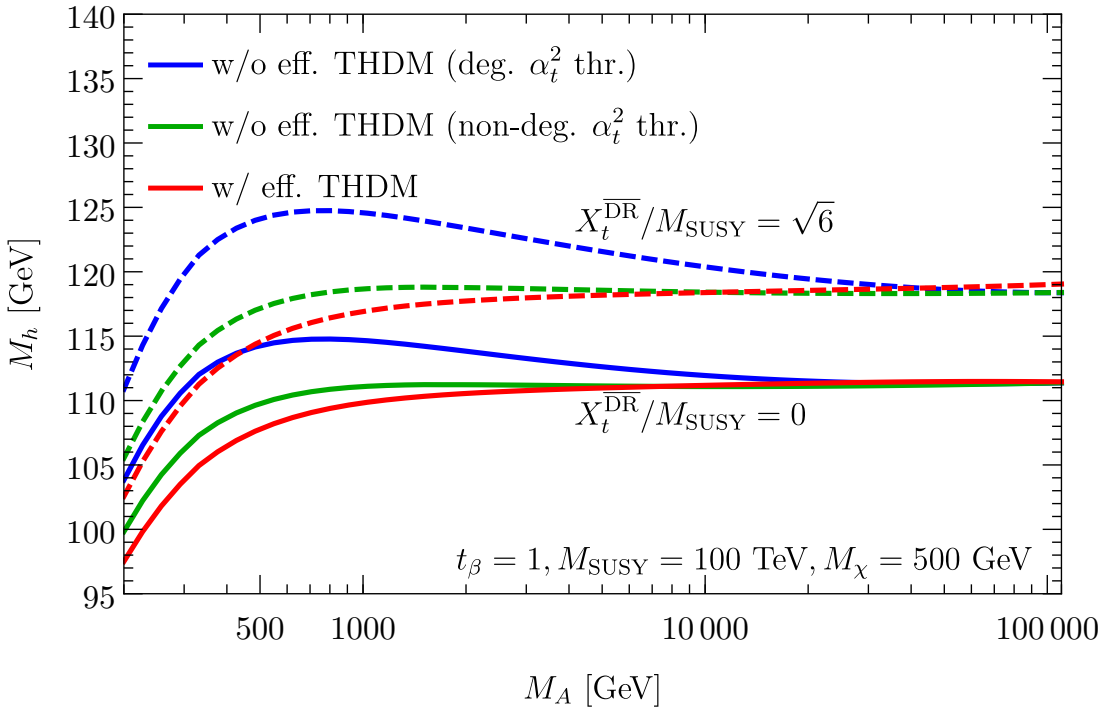
Result

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

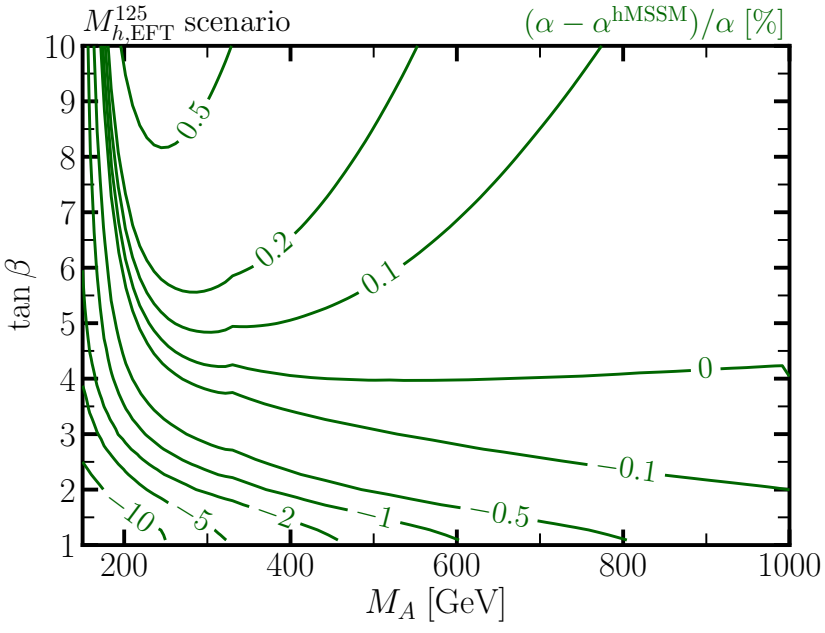
All large logarithms resummed
$\rightarrow$ presice prediction for physical observables.

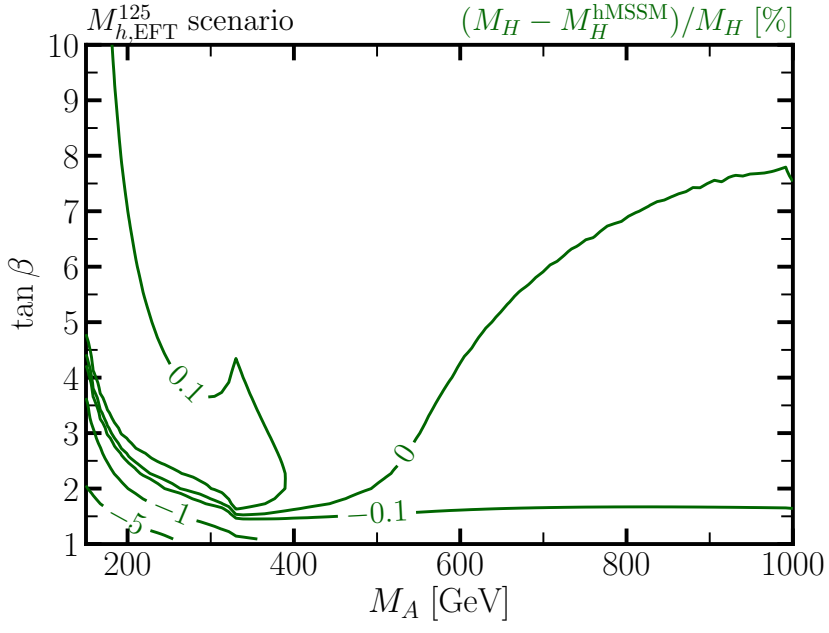
THDM as EFT II

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

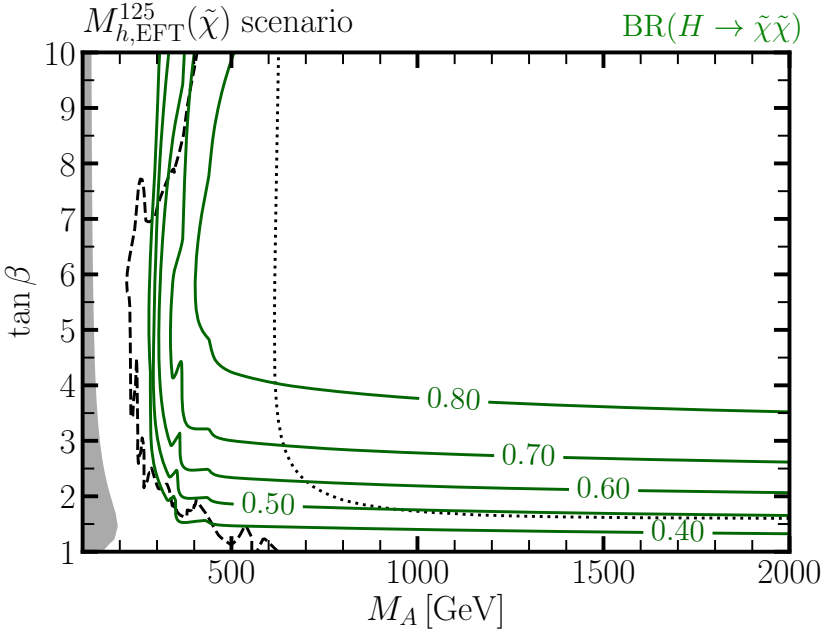


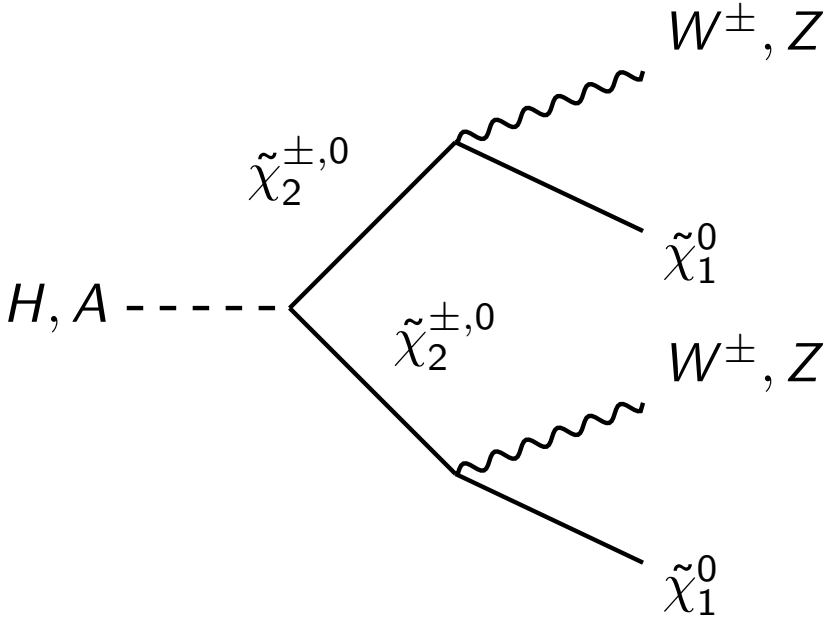
hMSSM comparison





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





- Interesting multilepton signatures,
- no experimental searches yet.