Benchmark Scenarios for MSSM Higgs Boson Searches at the LHC

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The MSSM Higgs sector

- SM Higgs sector enlarged by adding additional Higgs doublets
  $\rightarrow$ corresponds to type-II THDM at the tree-level
- Five physical Higgs bosons:
  $\mathcal{CP}$-even h and H, $\mathcal{CP}$-odd A, and charged $H^\pm$
- SUSY fixes Higgs potential parameters
  $\rightarrow$ only two non-SM parameters: M_A and $\tan\beta = v_2/v_1$
- But: through large loop corrections additional dependence on other MSSM parameters

Why do we need Higgs benchmark scenarios?

- Large number of free parameters
- Interpretation of measured Higgs properties and searches for additional Higgs bosons would require parameter scans $\rightarrow$ impractical

$\Downarrow$

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

Why do we need new Higgs benchmark scenarios?

Original benchmark scenarios presented in
[hep-ph/9912223,hep-ph/0202167,hep-ph/0009212,1302.7033,1512.00437]

Since then:

- Improved prediction of SM-like Higgs boson mass
  $\rightarrow$ lowered by several GeV
- Improved calculation of Higgs production cross-sections
- Updated SM input parameters
- More stringent limits on SUSY particles

New Higgs benchmark scenarios

Defined using

- `FeynHiggs` → Higgs masses and branching ratios
- `SusHi` → Higgs production cross-sections
- `HiggsBounds` → direct searches for heavy Higgs
- `HiggsSignals` → Higgs signal strengths

} Tim's talk

Six new scenarios:

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

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

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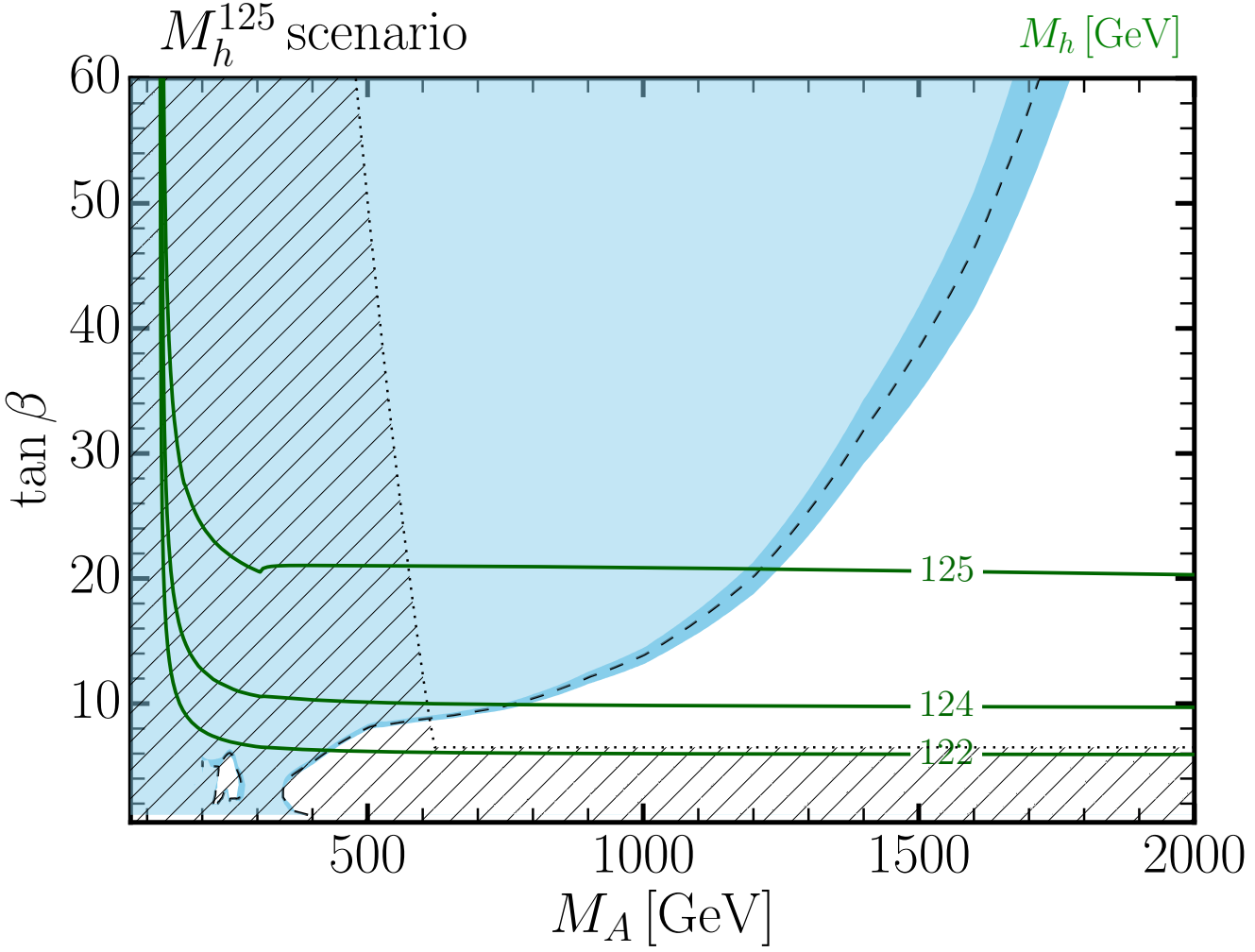
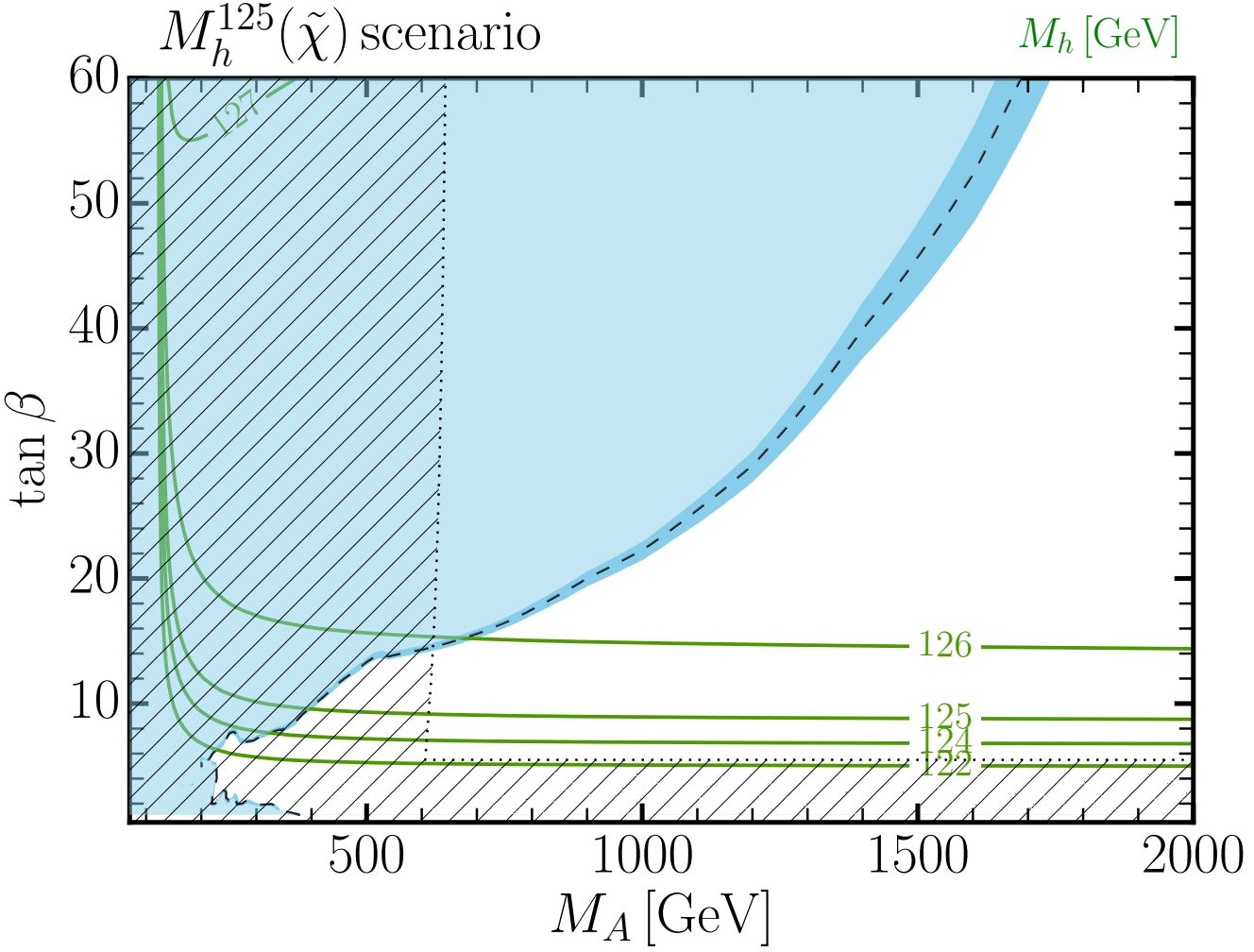
M_h^{125} scenario



- Blue: Excluded by direct searches for heavy Higgs bosons
- Hashed: Excluded by Higgs signal strengths / Higgs mass

$M_h^{125}(\tilde{\chi})$ scenario



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Low tan β region I

- Low tan β region excluded since M_h too small

$$M_h^2(\text{tree-level}) \simeq M_Z^2 \left(\frac{1 - \tan^2 \beta}{1 + \tan^2 \beta} \right)^2 \overset{\tan \beta = 1}{=} 0$$

- Need large loop corrections to reach $M_h \sim 125$ GeV
- Need to raise SUSY scale above the TeV scale

Old "low-tan β-high" scenario [LHCHXSWG-2015-002]

- M_{SUSY} of up to 100 TeV
- SM as EFT below M_{SUSY}

Low tan β region II

Large hierarchy between heavy Higgses and SUSY particles

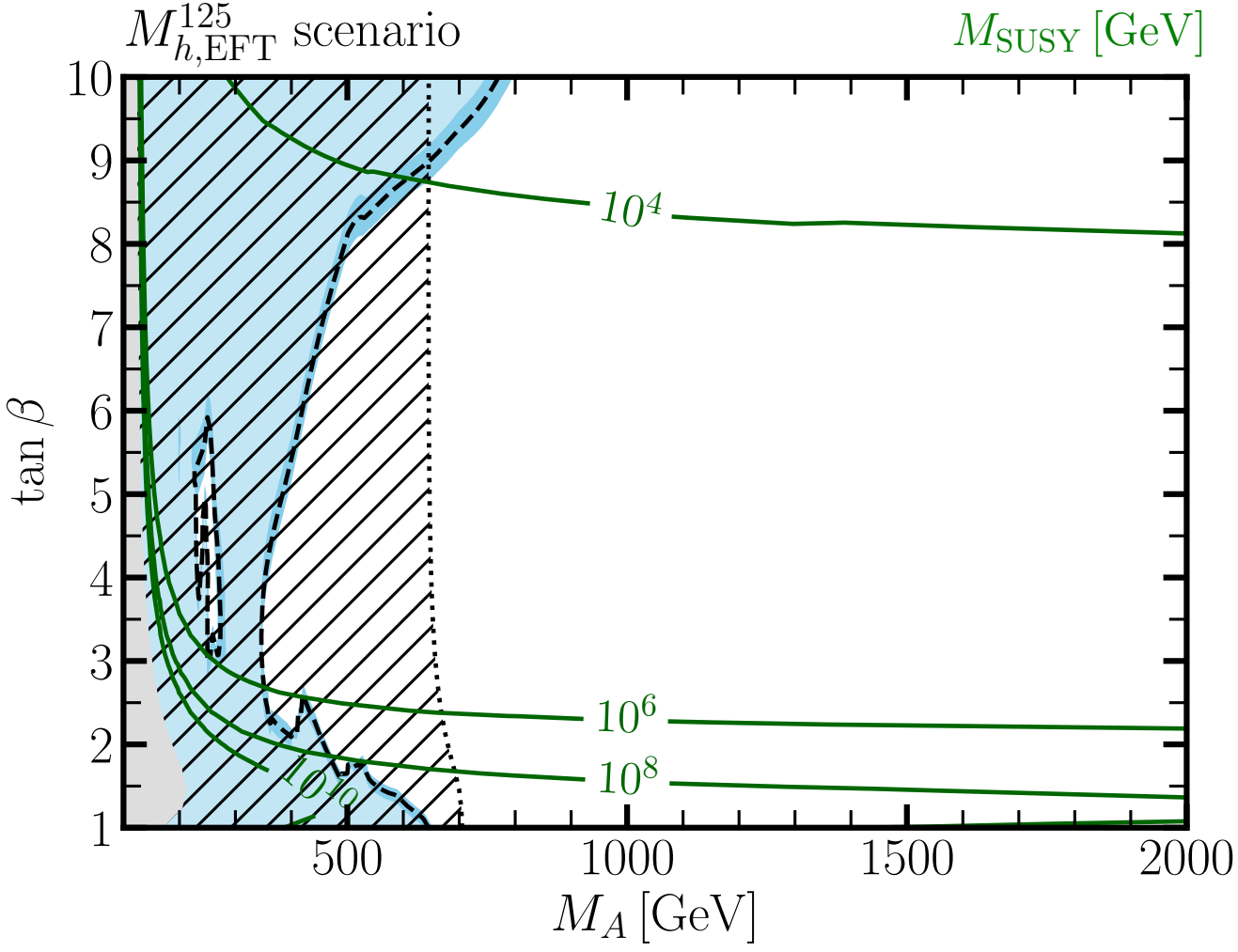
- SM as EFT is not a suitable
- Need THDM as EFT [1508.00576,1710.03760,1805.00867]
- Implemented into private version of `FeynHiggs`

$\rightarrow$ Adjust M_{SUSY} at every point such that $M_h \sim 125$ GeV (upper limit: 10^{16} GeV)

Two new low-tan β benchmark scenarios

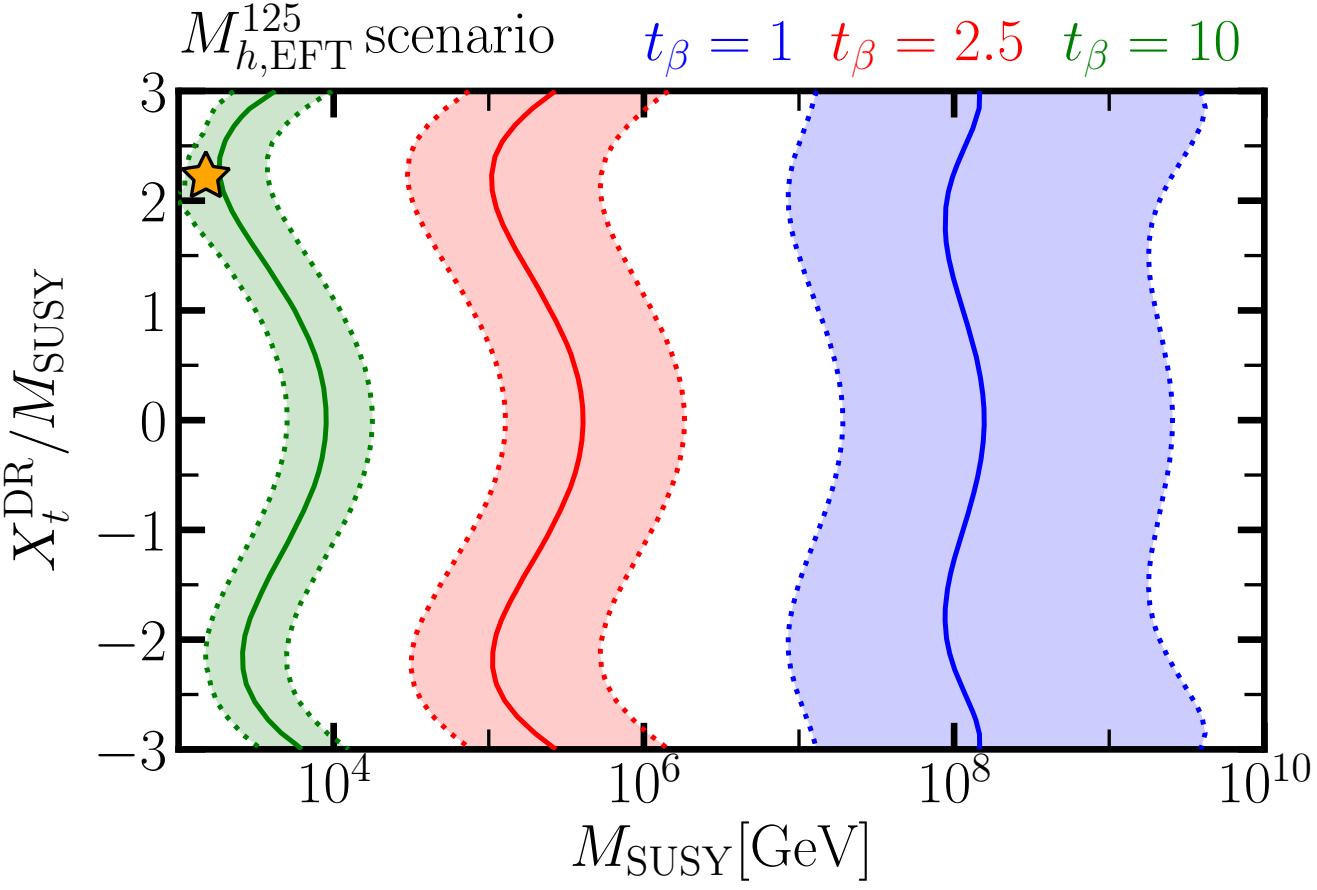
- $M_{h,\text{EFT}}^{125}$ scenario resembling M_h^{125} scenario
- $M_{h,\text{EFT}}^{125}(\tilde{\chi})$ scenario resembling $M_h^{125}(\tilde{\chi})$ scenario

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



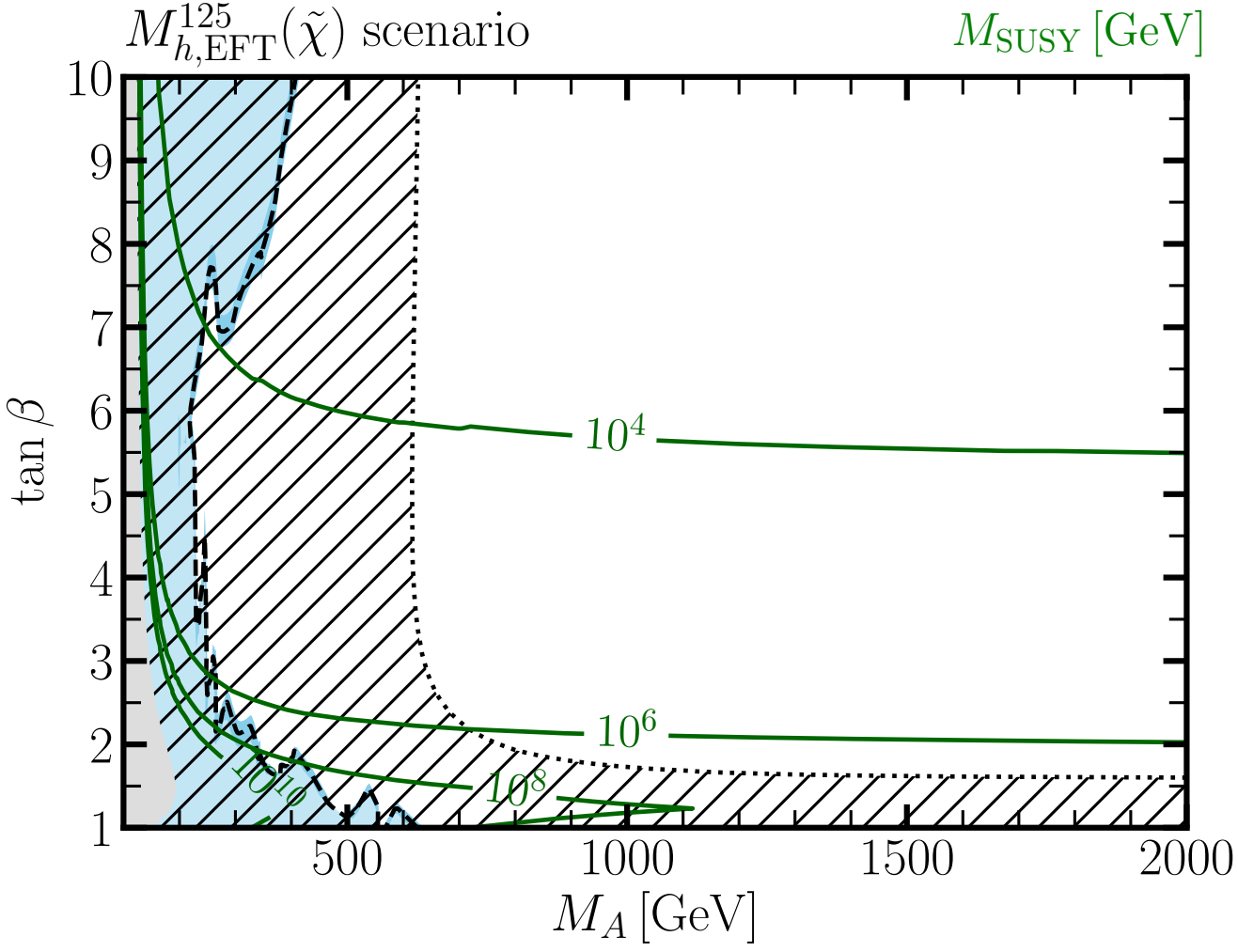
- Gray: $M_h < 122$ GeV

$M_{h,\mathrm{EFT}}^{125}$ — M_{SUSY} dependence for $M_A = 1$ TeV



- Bands: 125 ± 3 GeV
- Star: M_h^{125} scenario
- For actual scenario: $X_t^{\overline{\mathrm{DR}}} \simeq 0$

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



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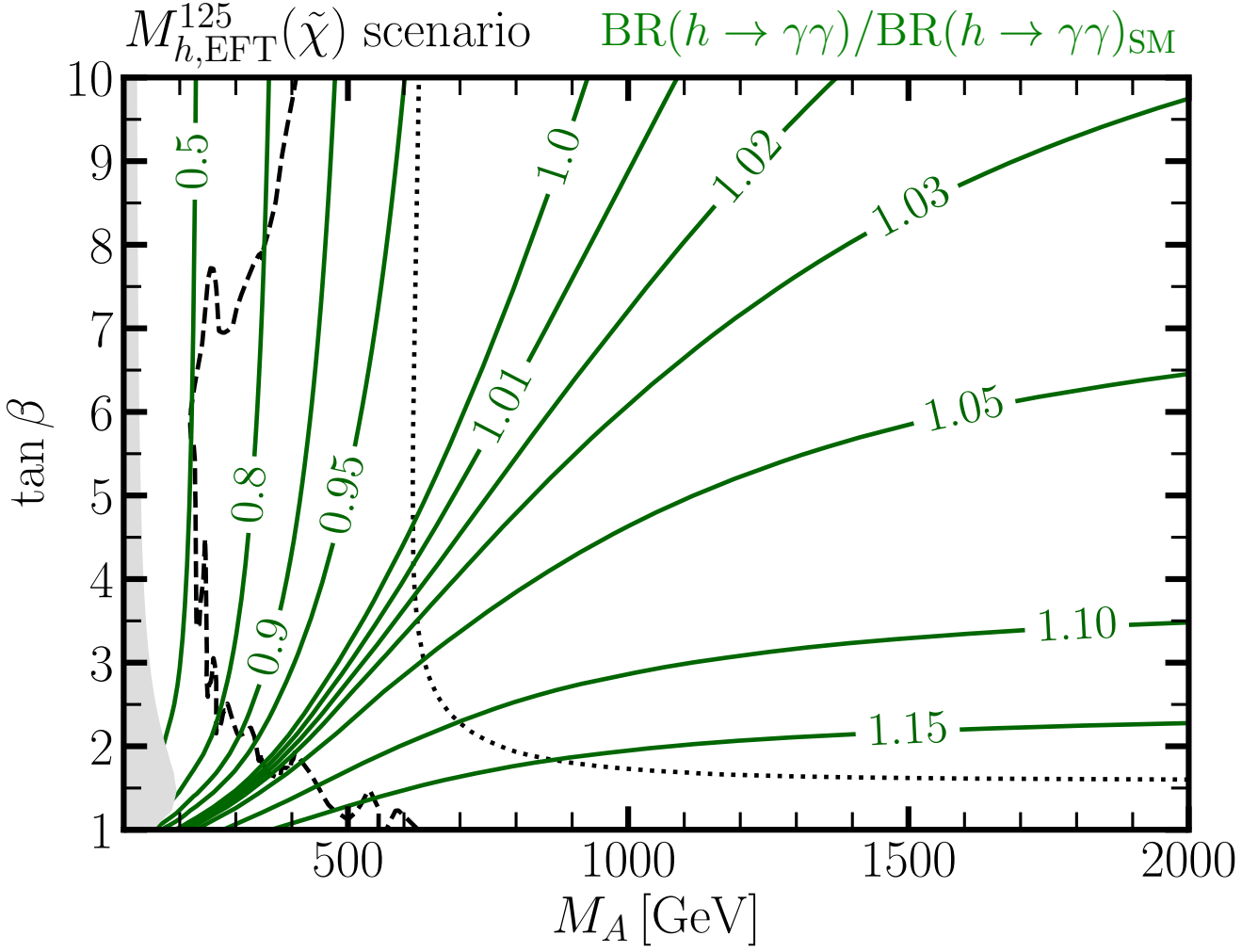
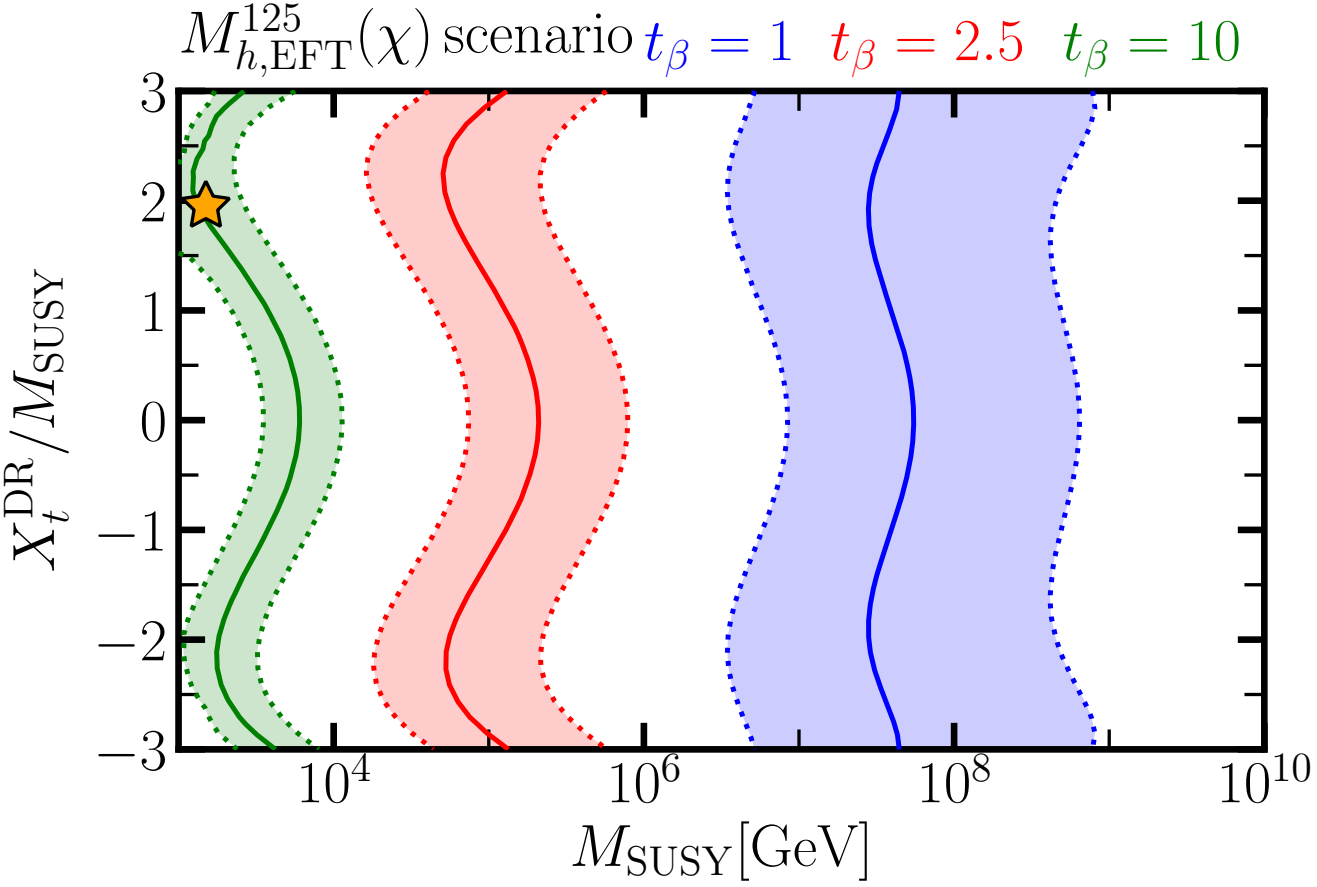
$M_{h,\mathrm{EFT}}^{125}(\tilde{\chi})$ — $h \to \gamma\gamma$ enhancement



→ Future precision measurement of $h \to \gamma\gamma$ might allow rule out large parts of the parameter space

$M_{h,\mathrm{EFT}}^{125}(\tilde{\chi})$ — M_{SUSY} dependence for $M_A = 1$ TeV



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- Benchmark scenarios ease interpretation of LHC Higgs results within the MSSM
- Existing scenarios outdated
- Proposed set of new scenarios based on state-of-the-art calculations
- Work in progress: Scenarios for low tan β

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Thanks for your attention!

M_h^{125} scenario - definition

$$M_{Q_3} = M_{U_3} = M_{D_3} = 1.5 \text{ TeV}, \quad M_{L_3} = M_{E_3} = 2 \text{ TeV},$$

$$\mu = 1 \text{ TeV}, \quad M_1 = 1 \text{ TeV}, \quad M_2 = 1 \text{ TeV}, \quad M_3 = 2.5 \text{ TeV},$$

$$X_t = 2.8 \text{ TeV}, \quad A_b = A_\tau = A_t \,.$$

$M_h^{125}(\tilde{\chi})$ scenario - definition

$$M_{Q_3} = M_{U_3} = M_{D_3} = 1.5 \text{ TeV}, \quad M_{L_3} = M_{E_3} = 2 \text{ TeV},$$

$$\mu = 180 \text{ GeV}, \quad M_1 = 160 \text{ GeV}, \quad M_2 = 180 \text{ GeV}, \quad M_3 = 2.5 \text{ TeV},$$

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

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