



We still believe in supersymmetry

You must be joking

Where are the SUSY Higgs Bosons?

Sven Heinemeyer, IFT/IFCA (CSIC, Madrid/Santander)

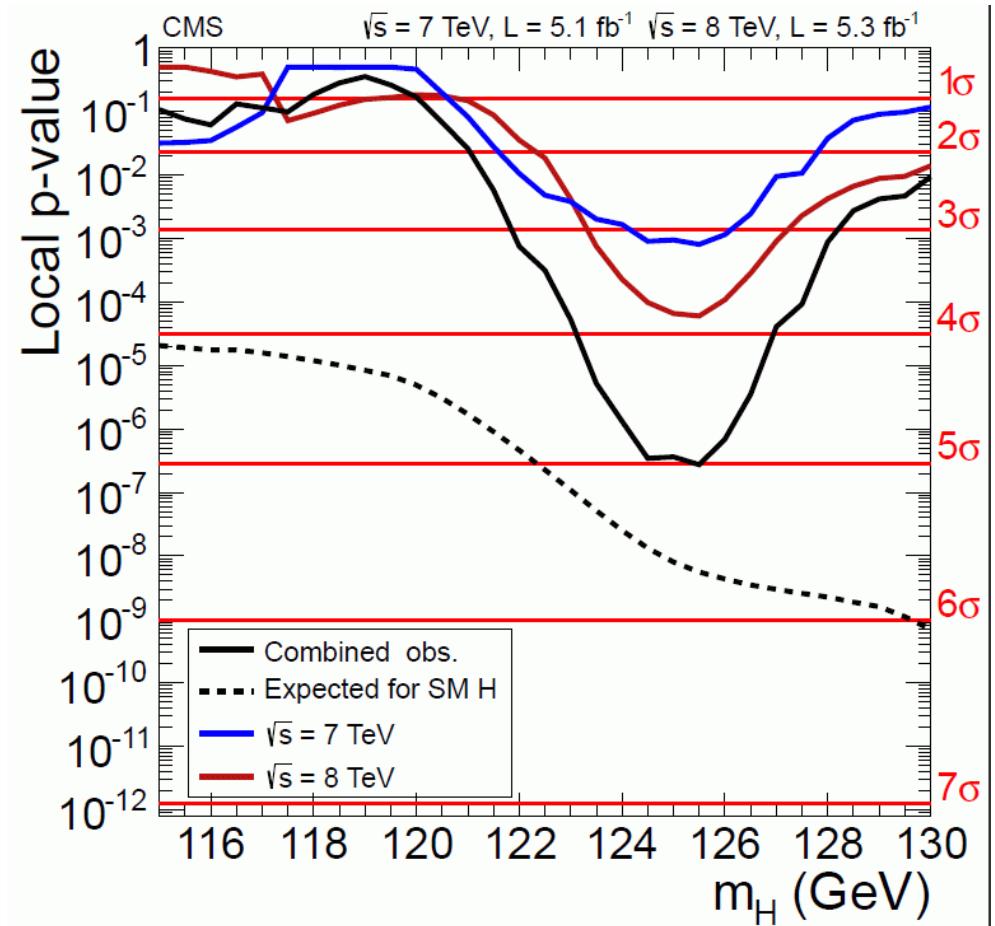
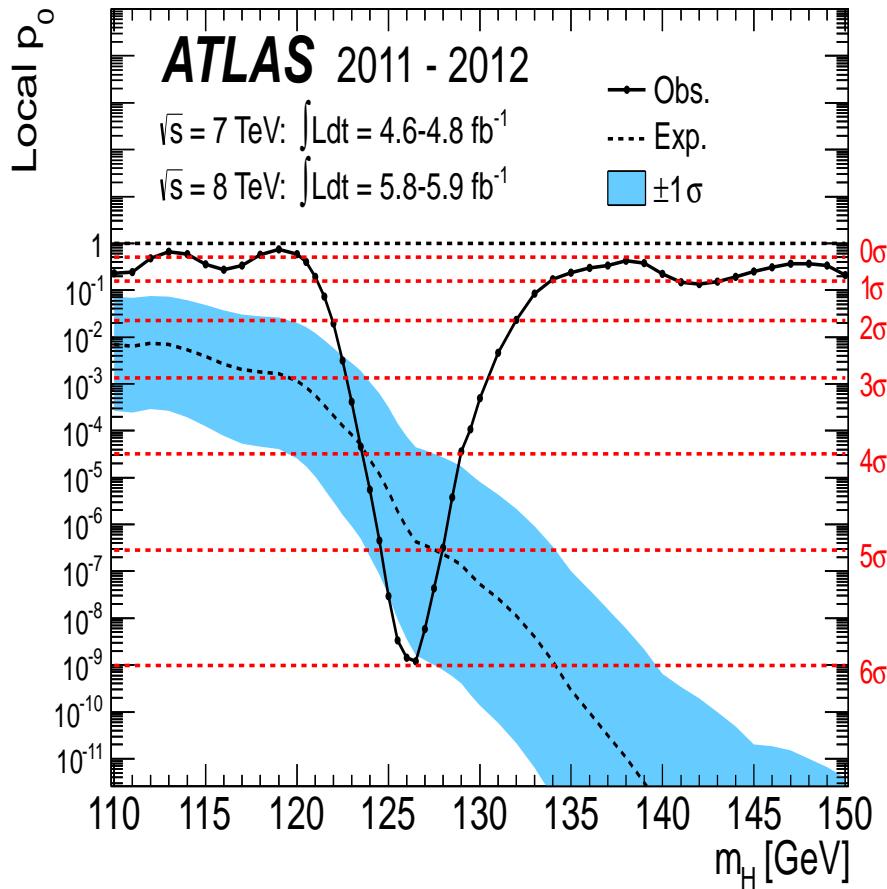
Tokyo, 12/2018

- Motivation & Models
- Experimental data & Alignment
- Here are the SUSY Higgs Bosons
- A Higgs Boson at 96 GeV?!
- Conclusions

1. Motivation & Models

Fact I:

We have a discovery!



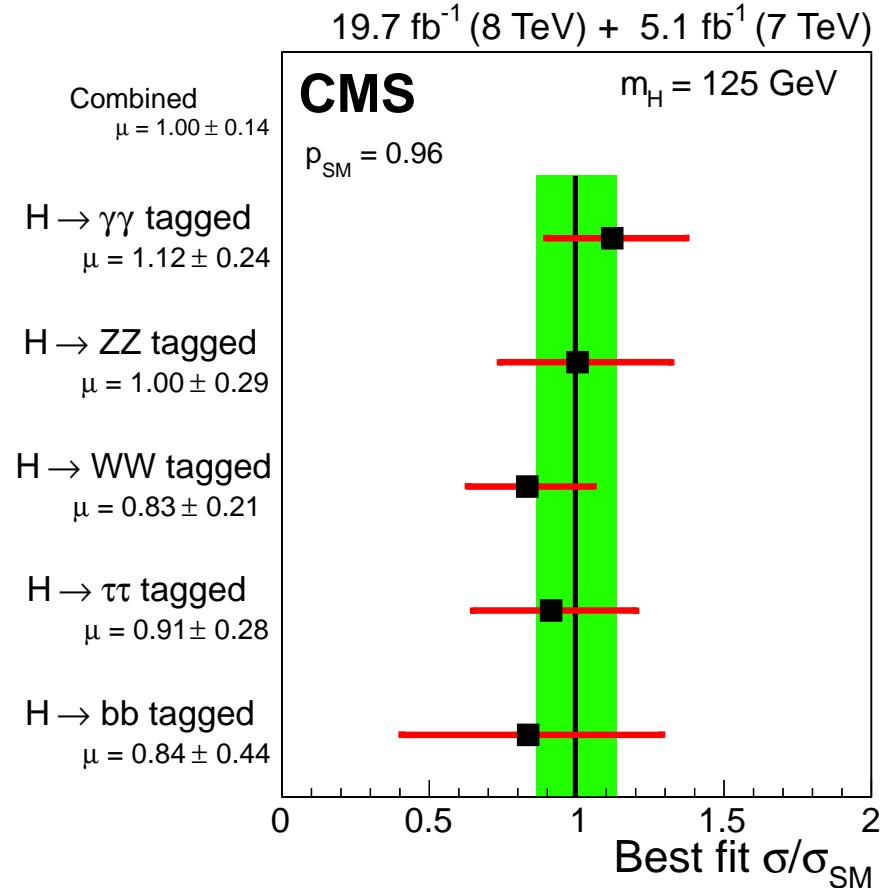
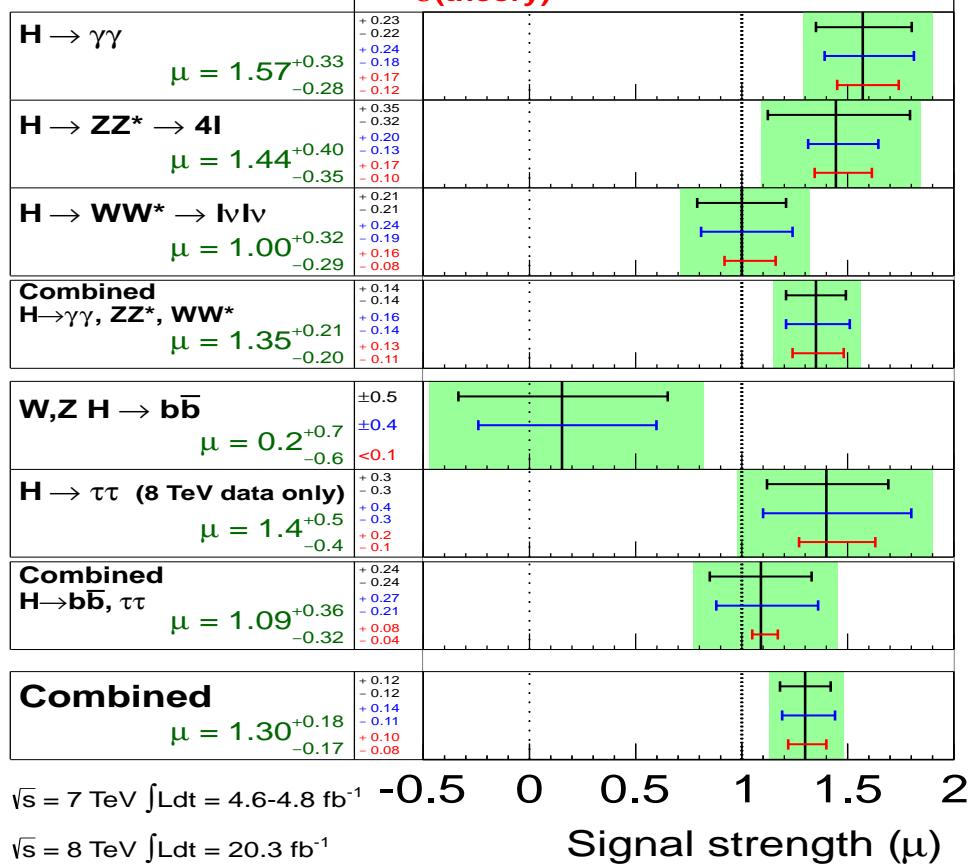
1. Motivation & Models

Fact I:

We have an SM-like discovery!

ATLAS Prelim.

$m_H = 125.5 \text{ GeV}$



Fact II:

The SM cannot be the ultimate theory!

Some facts:

1. gravity is not included
2. the hierarchy problem
3. Dark Matter is not included
4. neutrino masses are not included
5. anomalous magnetic moment of the muon shows a $\sim 4\sigma$ discrepancy

Fact I & II:

We have a discovery!

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Conclusion: It cannot be “the SM Higgs” !

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Q: Does the BSM physics have any (relevant) impact on the Higgs?

Q': Which model?

A1: check changed properties

A2: check for additional Higgs bosons

A2': check for additional Higgs bosons above and below 125 GeV

Models with extended Higgs sectors:

1. SM with additional Higgs singlet
 2. Two Higgs Doublet Model (THDM): type I, II, III, IV
 3. Minimal Supersymmetric Standard Model (MSSM)
 4. MSSM with one extra singlet (NMSSM)
 5. MSSM with more extra singlets
 6. SM/MSSM with Higgs triplets
 7.
- ⇒ BSM models without extended Higgs sectors still have changed Higgs properties (quantum corrections!)
- ⇒ SM + vector-like fermions, Higgs portal, Higgs-radion mixing,

Which model should we focus on?

Which model should we focus on? \Rightarrow experimental data as guidance!

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Some “recent” measurements:

- top quark mass
- Higgs boson mass
- Higgs boson “couplings”
- Dark Matter (properties)

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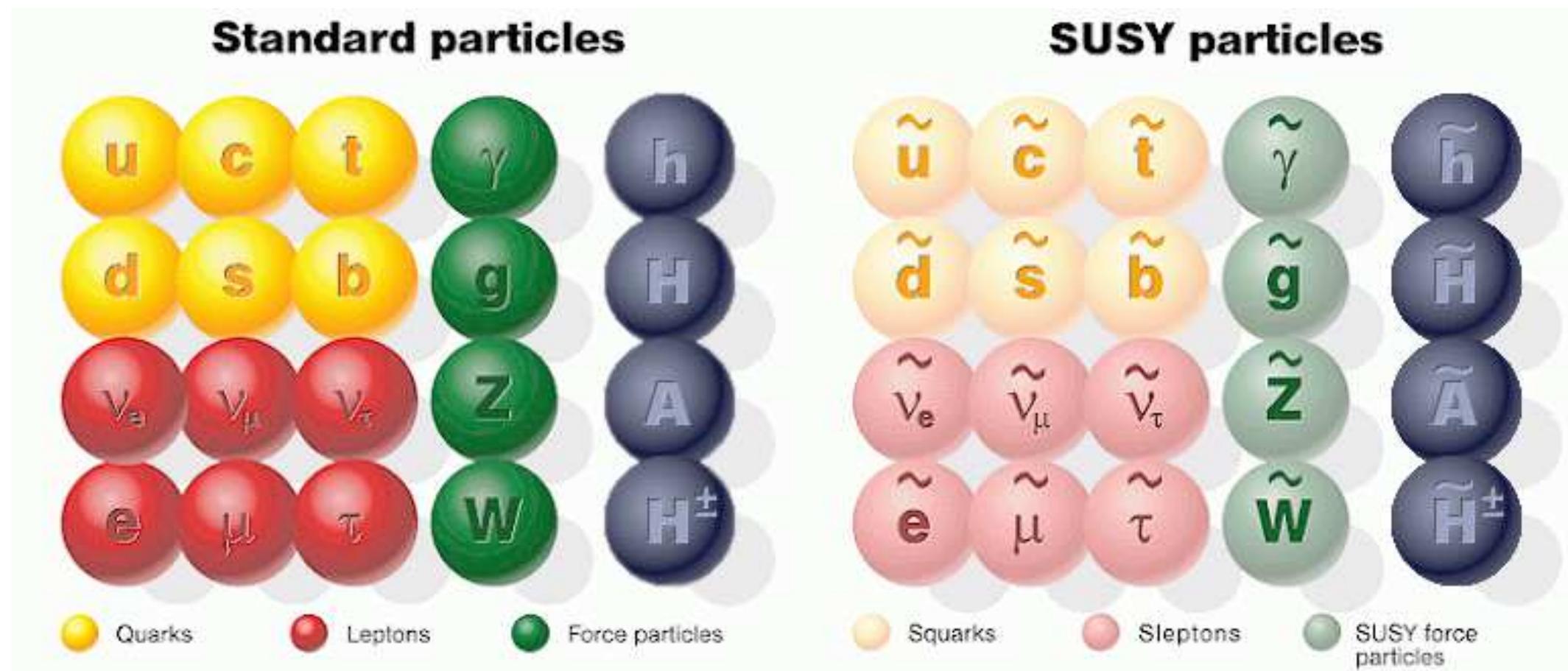
Simple SUSY models predicted correctly:

- top quark mass
- Higgs boson mass
- Higgs boson “couplings”
- Dark Matter (properties)

\Rightarrow good motivation to look at SUSY! :-)

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles



Problem in the MSSM: more than 100 free parameters

Nobody(?) believes that a model describing nature has so many free parameters!

A. Unconstrained models (MSSM):

agnostic about how SUSY breaking is achieved
no particular SUSY breaking mechanism assumed, parameterization of possible soft SUSY-breaking terms
most general case: 105 new parameters: masses, mixing angles, phases
(\Rightarrow many (close to) zero according to experimental data)
 \Rightarrow no model missed (within the MSSM)
 $\Rightarrow \mathcal{O}(100)$ parameters difficult to handle

B. Constrained models:

CMSSM, NUHM1, NUHM2, SU(5), mAMSB, sub-GUT, FUTs, . . . :
assumption on the scenario that achieves spontaneous SUSY breaking
 \Rightarrow prediction for soft SUSY-breaking terms
in terms of small set of parameters
 \Rightarrow easy to handle, but not all relevant phenomenology captured

C. Benchmark scenarios:

fix all-2 MSSM parameters in a smart way, explore benchmark planes
 \Rightarrow easy to handle, interesting phenomenology captured!

The MSSM Higgs sector:

Enlarged Higgs sector: Two Higgs doublets

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix}$$

$$\begin{aligned} V = & m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - m_{12}^2 (\epsilon_{ab} H_1^a H_2^b + \text{h.c.}) \\ & + \underbrace{\frac{g'^2 + g^2}{8}}_{\text{gauge couplings, in contrast to SM}} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \underbrace{\frac{g^2}{2}}_{\text{gauge couplings, in contrast to SM}} |H_1 \bar{H}_2|^2 \end{aligned}$$

physical states: h^0, H^0, A^0, H^\pm Goldstone bosons: G^0, G^\pm

Input parameters: (to be determined experimentally)

$$\tan \beta = \frac{v_2}{v_1}, \quad M_A^2 = -m_{12}^2(\tan \beta + \cot \beta)$$

The MSSM Higgs sector: with \mathcal{CP} violation

Enlarged Higgs sector: Two Higgs doublets

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix} e^{i\xi}$$

$$V = m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - \textcolor{magenta}{m_{12}^2} (\epsilon_{ab} H_1^a H_2^b + \text{h.c.})$$

$$+ \underbrace{\frac{g'^2 + g^2}{8}}_{\text{gauge couplings, in contrast to SM}} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \underbrace{\frac{g^2}{2}}_{\text{gauge couplings, in contrast to SM}} |H_1 \bar{H}_2|^2$$

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Input parameters: (to be determined experimentally)

$$\tan \beta = \frac{v_2}{v_1}, \quad M_{H^\pm}^2$$

2 \mathcal{CP} -violating phases: $\xi, \arg(m_{12}) \Rightarrow$ can be set/rotated to zero

The Higgs sector of the cMSSM at the loop-level:

Complex parameters enter via loop corrections:

- μ : Higgsino mass parameter
- $A_{t,b,\tau}$: trilinear couplings $\Rightarrow X_{t,b,\tau} = A_{t,b,\tau} - \mu^* \{\cot \beta, \tan \beta\}$ complex
- $M_{1,2}$: gaugino mass parameter (one phase can be eliminated)
- M_3 : gluino mass parameter

\Rightarrow can induce \mathcal{CP} -violating effects

Result:

$$(A, H, h) \rightarrow (h_3, h_2, h_1)$$

with

$$m_{h_3} > m_{h_2} > m_{h_1}$$

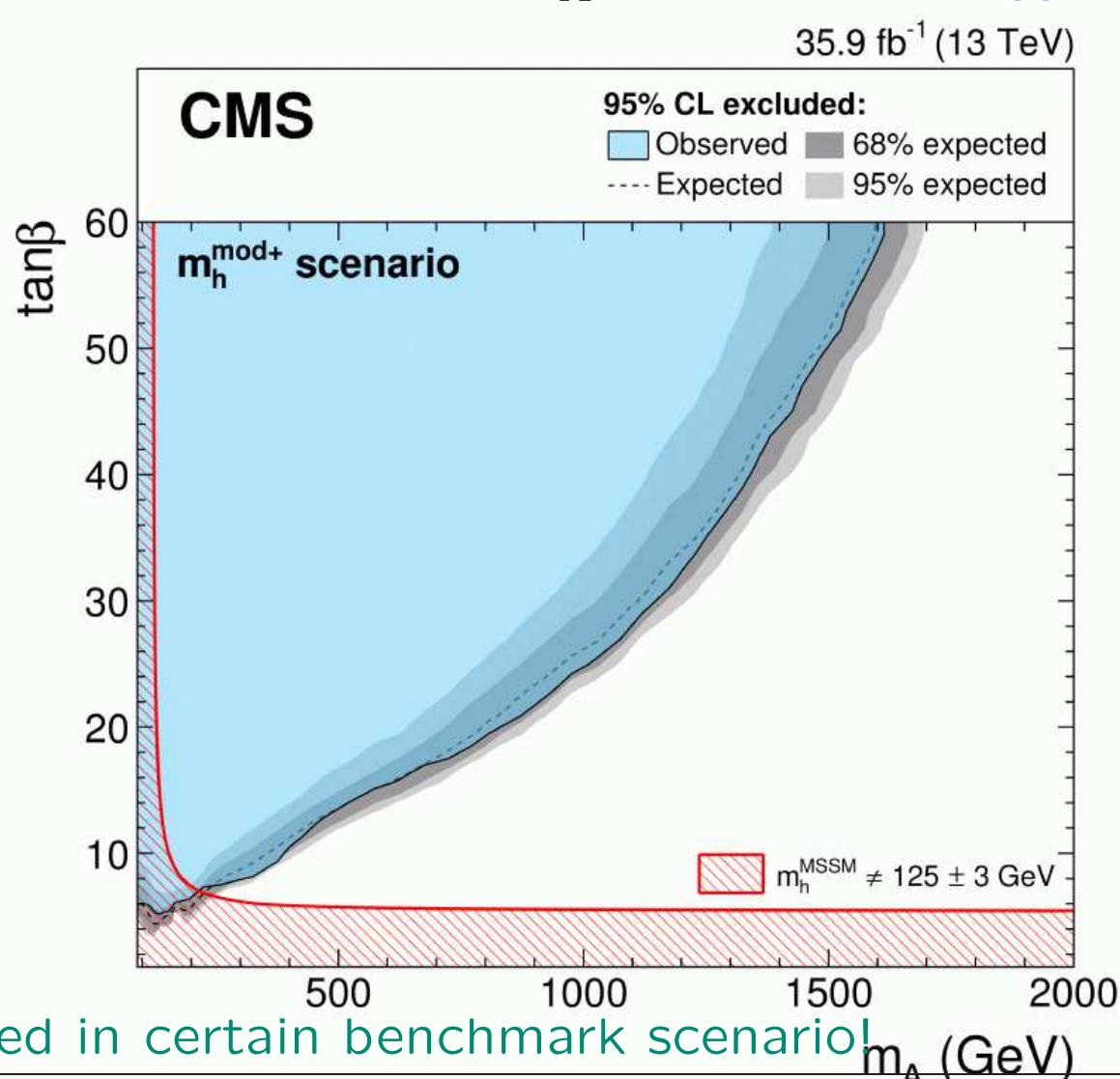
\Rightarrow strong changes in Higgs couplings to SM gauge bosons and fermions

2. Experimental Data and Alignment

Latest results for neutral heavy Higgs bosons:

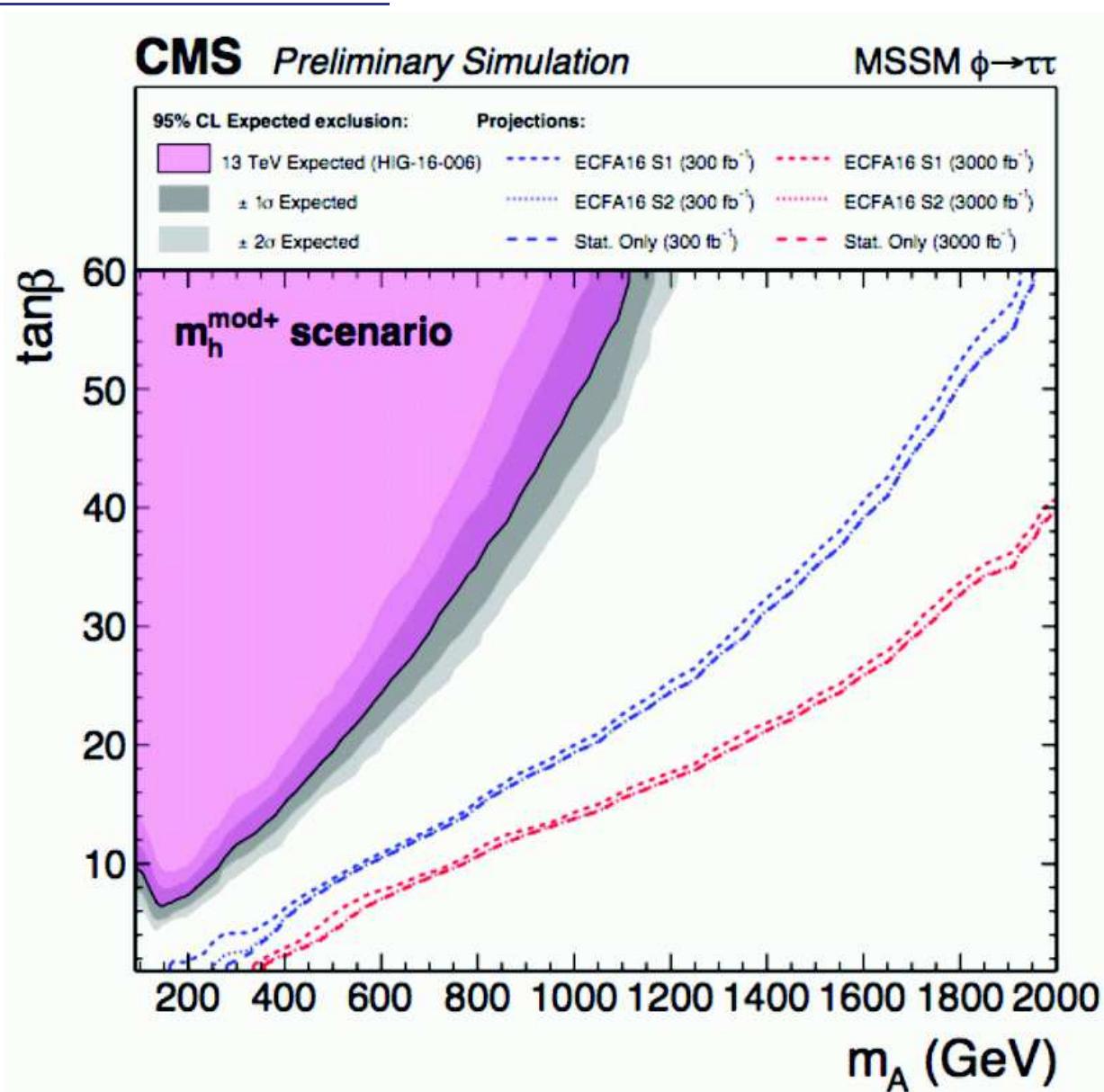
[CMS '18]

MSSM Higgs exclusion contours in M_A – $\tan\beta$ plane: $b\bar{b}, gg \rightarrow h, H, A \rightarrow \tau^+\tau^-$



⇒ limits obtained in certain benchmark scenario! m_A (GeV)

Future (HL-)LHC projections:

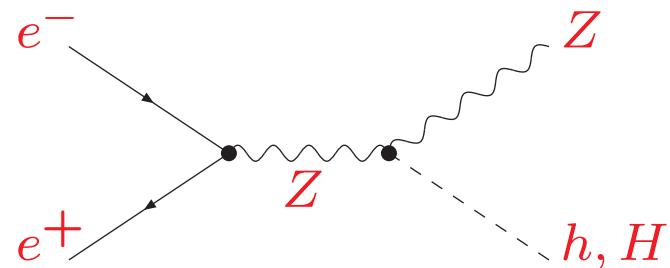


⇒ strong (HL-)LHC limits

Sum rule in the MSSM with h SM-like: $\sin(\beta - \alpha) \approx 1, \cos(\beta - \alpha) \approx 0$

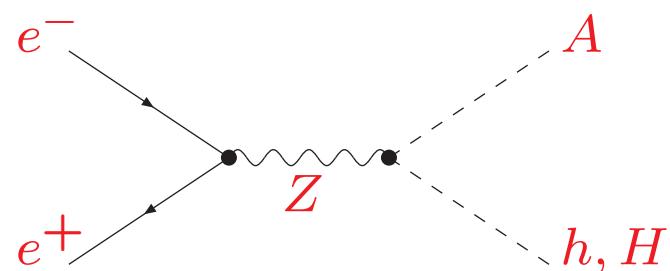
Search for neutral SUSY Higgs bosons:

$$\underline{e^+ e^- \rightarrow Z h, ZH}$$



$$\begin{aligned}\sigma_{hZ} &\approx \sin^2(\beta - \alpha_{\text{eff}}) \sigma_{hZ}^{\text{SM}} \\ \sigma_{HZ} &\approx \cos^2(\beta - \alpha_{\text{eff}}) \sigma_{hZ}^{\text{SM}}\end{aligned}$$

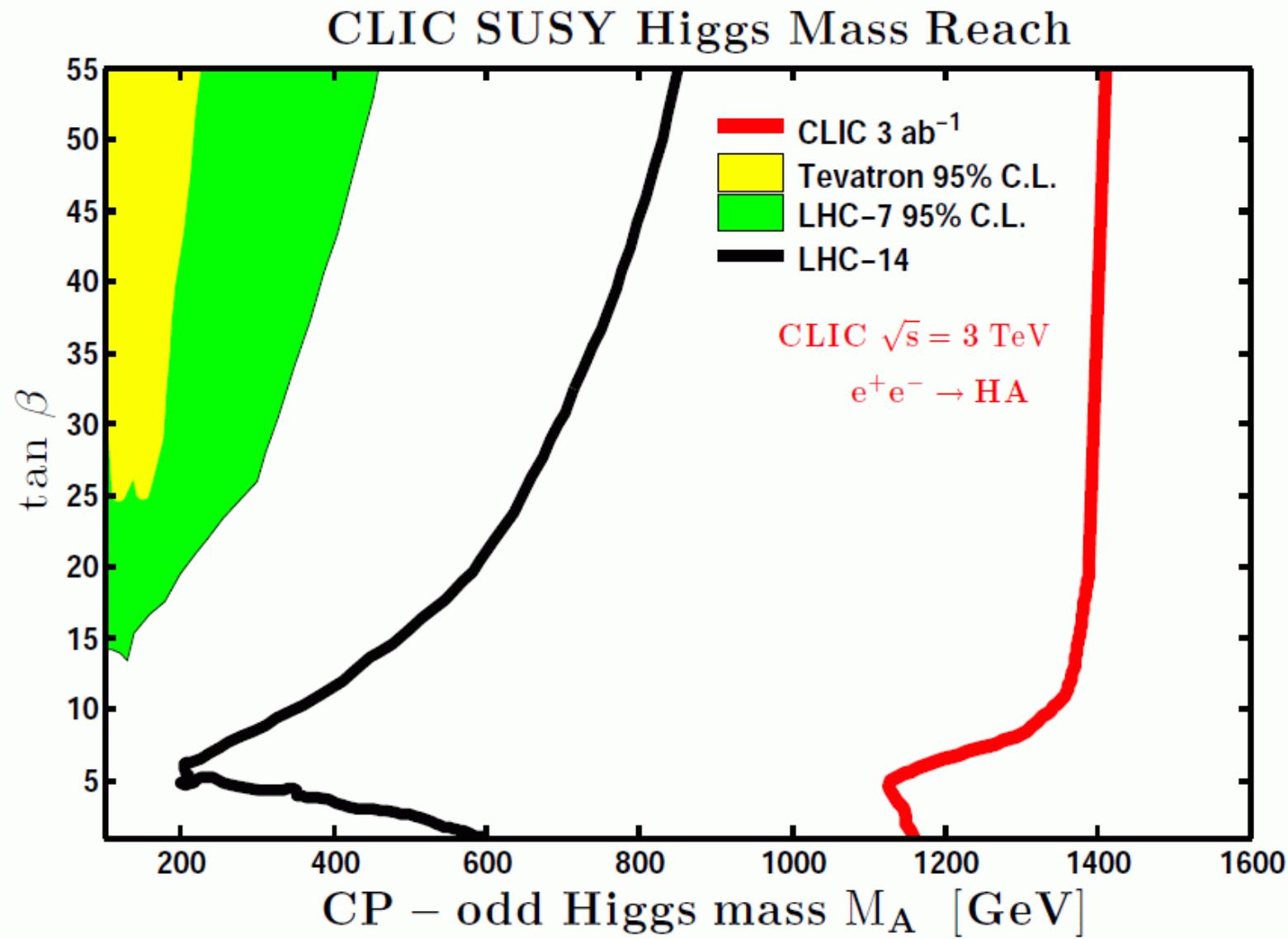
$$\underline{e^+ e^- \rightarrow Ah, AH}$$



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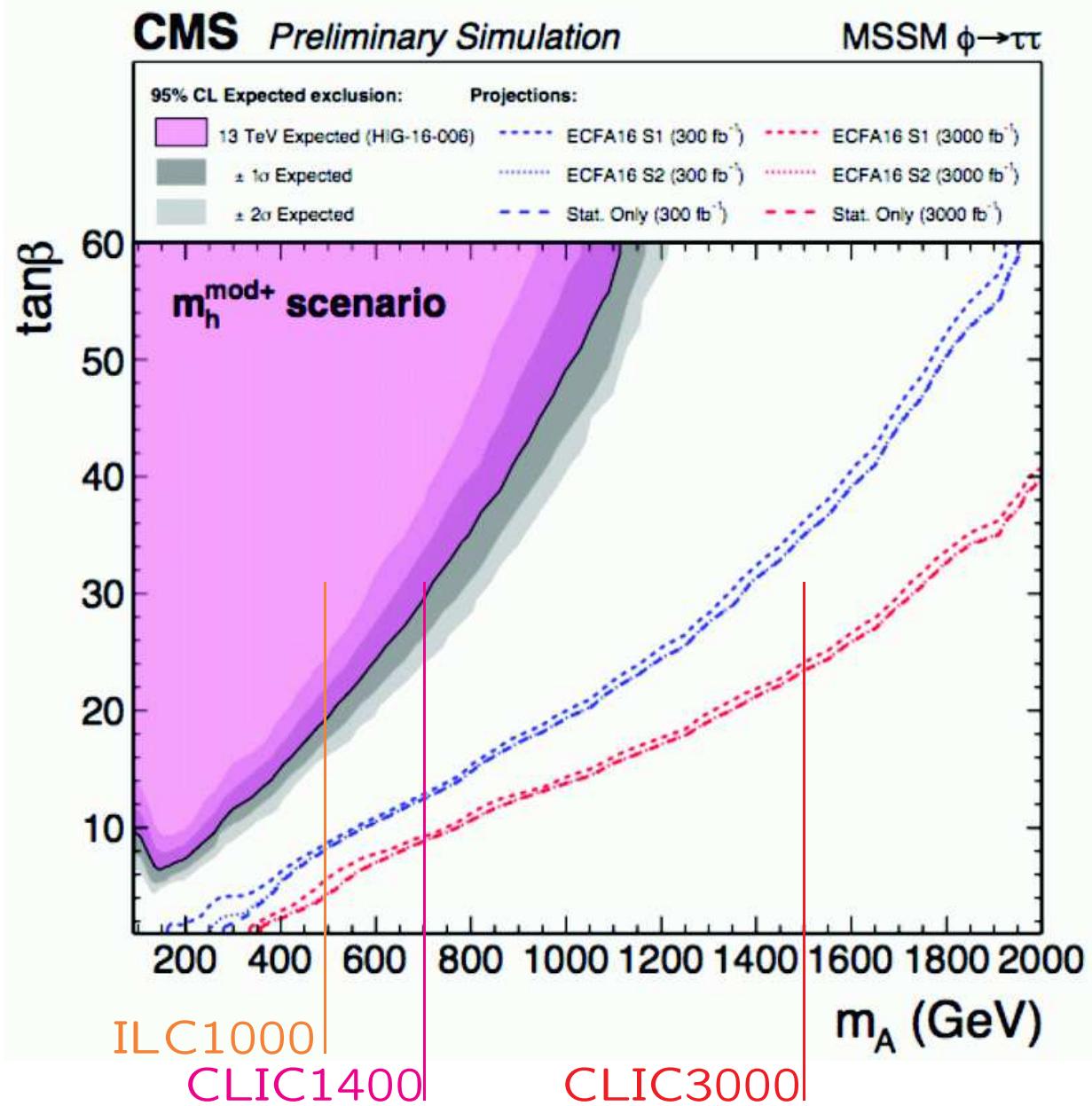
\Rightarrow only pair production of heavy Higgs bosons!

reach: $M_A \lesssim \sqrt{s}/2$



⇒ close to kinematic limit

"Simple" LC reach in the MSSM (neglecting $t\bar{t}$ final states)



⇒ unique opportunities!

We have a ~ 125 GeV SM-like Higgs boson

⇒ What are the options?

1. Decoupling limit:

$M_A \gg M_Z$ ⇒ the light Higgs becomes SM-like

2. Alignment without decoupling:

⇒ a \mathcal{CP} -even Higgs becomes SM-like due to an “accidental” cancellation

3. Heavy Higgs SM-like: (in the “alignment w/o decoupling” scen.)

⇒ is the case with the heavy \mathcal{CP} -even Higgs being SM-like (still) a viable solution?

Obtaining a light Higgs with SM-like couplings

[J. Gunion, H. Haber, [hep-ph/0207010](#)]

→ \mathcal{CP} conserving 2HDM in the Higgs basis ($\langle H_1 \rangle = v/\sqrt{2}$, $\langle H_2 \rangle = 0$)

$$\mathcal{V} = \dots + \frac{1}{2} Z_1 (H_1^\dagger H_1)^2 + \dots + \left[\frac{1}{2} Z_5 (H_1^\dagger H_2)^2 + Z_6 (H_1^\dagger H_1)(H_1^\dagger H_2) + \text{h.c.} \right] + \dots$$

⇒ \mathcal{CP} -even mass matrix:

$$\mathcal{M}^2 = \begin{pmatrix} Z_1 v^2 & Z_6 v^2 \\ Z_6 v^2 & M_A^2 + Z_5 v^2 \end{pmatrix}$$

with mixing angle $\cos(\beta - \alpha) \equiv c_{\beta-\alpha}$

Decoupling limit: $M_A^2 \gg Z_i v^2$

⇒ $m_h^2 \sim Z_1 v^2$, $|c_{\beta-\alpha} \ll 1|$, h is SM-like

Alignment limit: $Z_6 = 0$ and $Z_1 < Z_5 + M_A^2/v^2$

⇒ h is identical to the SM Higgs, $c_{\beta-\alpha} = 0$

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Alignment limit: see e.g.

[M. Carena, I. Low, N. Shah, C. Wagner '13][M. Carena, H. Haber, I. Low, N. Shah, C. Wagner '14]

In the **MSSM** $Z_6 = 0$ can be obtained through an “accidental” cancellation between tree-level and loop contribution, roughly at:

$$\tan \beta \sim \left[M_h^2 + M_Z^2 + \frac{3m_t^2\mu^2}{4\pi^2 v^2 M_S^2} \left(\frac{A_t^2}{2M_S^2} - 1 \right) \right] / \left[\frac{3m_t^2}{4\pi^2 v^2} \frac{\mu A_t}{M_S^2} \left(\frac{A_t^2}{6M_S^2} - 1 \right) \right]$$

Compare: $m_h^{\text{mod+}}$ and m_h^{alt} :

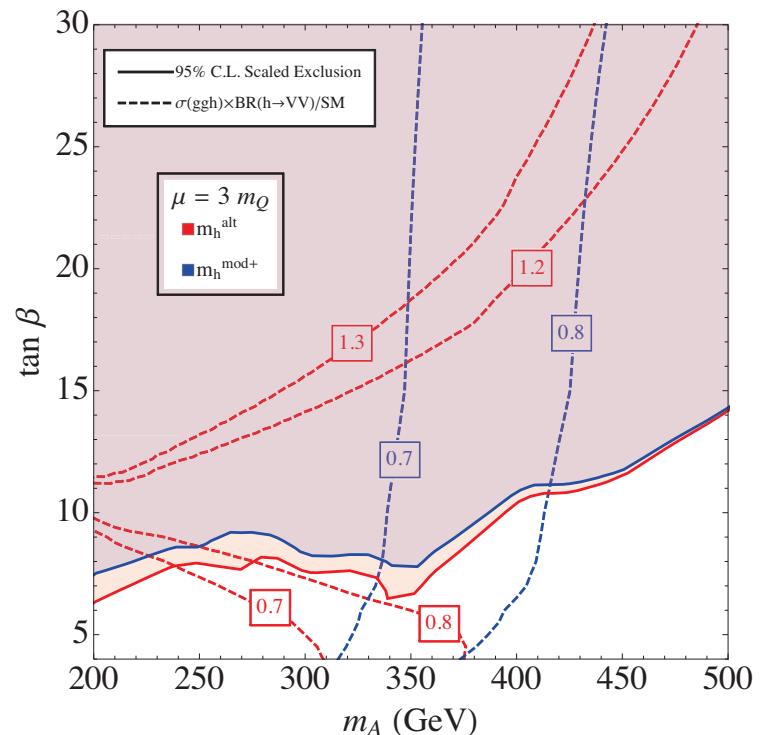
$$A_t/M_S = 2.45, \quad A_t = A_f,$$

$$M_S = m_{\tilde{f}} \geq 1 \text{ TeV}, \quad m_{\tilde{g}} = 1.5 \text{ TeV},$$

$$M_2 = 2M_1 = 200 \text{ GeV}, \quad \mu \text{ adjustable}$$

(low M_A and $\tan \beta$: tune $M_S \geq 1 \text{ TeV}$ to obtain $M_h \geq 122 \text{ GeV}$)

⇒ SM-like Higgs for all M_A



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m_h^{alt} : **HiggsSignals** [P. Bechtle et al. '15]

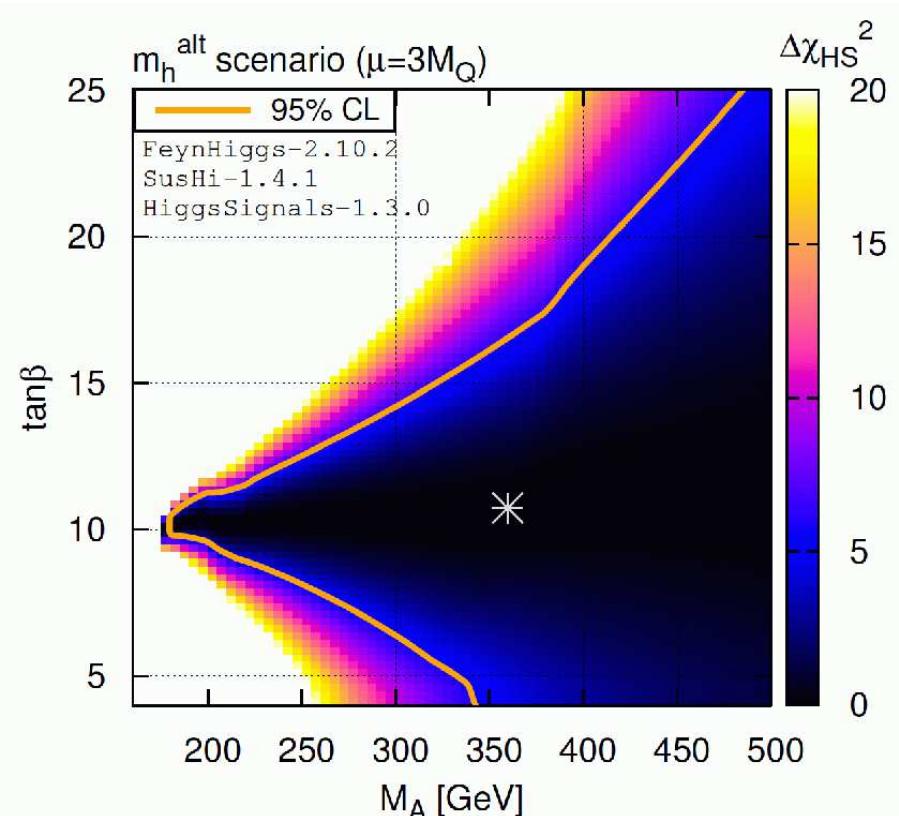
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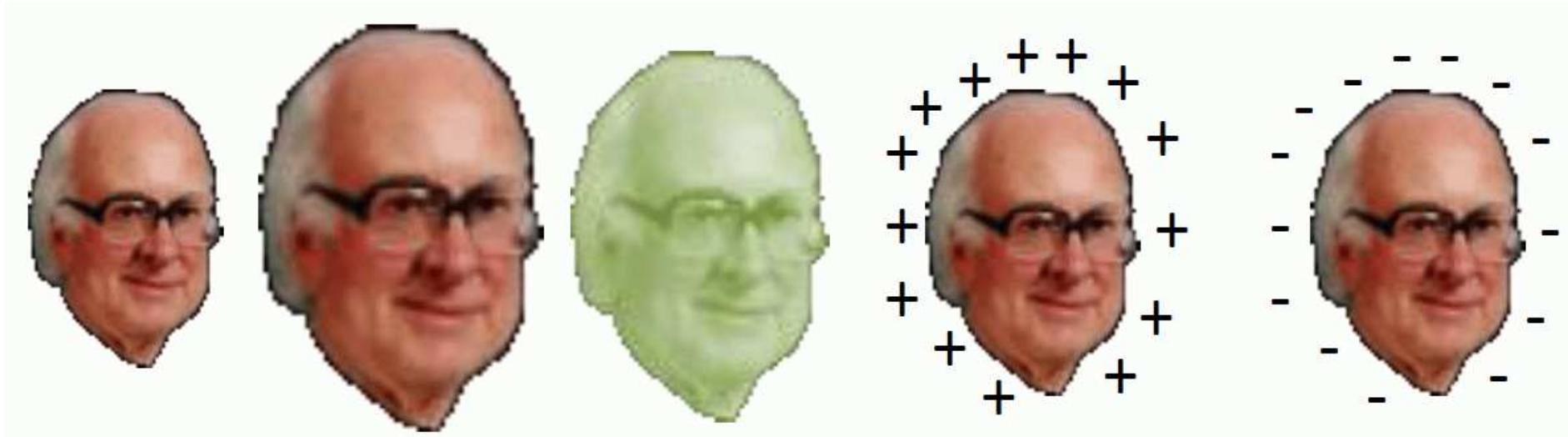
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⇒ **SM-like Higgs for all M_A**



3. Here are the SUSY Higgs bosons



Search for the MSSM Higgs bosons:

Smart choice of MSSM parameters?

→ investigate benchmark scenarios:

- Vary only M_A and $\tan\beta$
- Keep all other SUSY parameters fixed

[*H. Bahl, E. Fuchs, T. Hahn, S.H., S. Liebler, S. Patel, P. Slavich, T. Stefaniak, C. Wagner, G. Weiglein '18*]

1. M_h^{125} scenario: 2HDM-like model
2. $M_h^{125}(\tilde{\tau})$ scenario: light staus: $h \rightarrow \gamma\gamma$, $H/A \rightarrow \tilde{\tau}\tilde{\tau}$
3. $M_h^{125}(\tilde{\chi})$ scenario: light EW-inos: $H/A \rightarrow \tilde{\chi}_i^0 \tilde{\chi}_j^0, \tilde{\chi}_k^\pm \tilde{\chi}_l^\mp$
4. M_h^{125} (alignment) scenario: h SM-like for very low M_A
5. M_H^{125} scenario: $M_H \sim 125$ GeV, all Higgses light
6. $M_{h_1}^{125}$ (CPV) scenario: complex phases, h_2-h_3 interference

Data to be taken into account:

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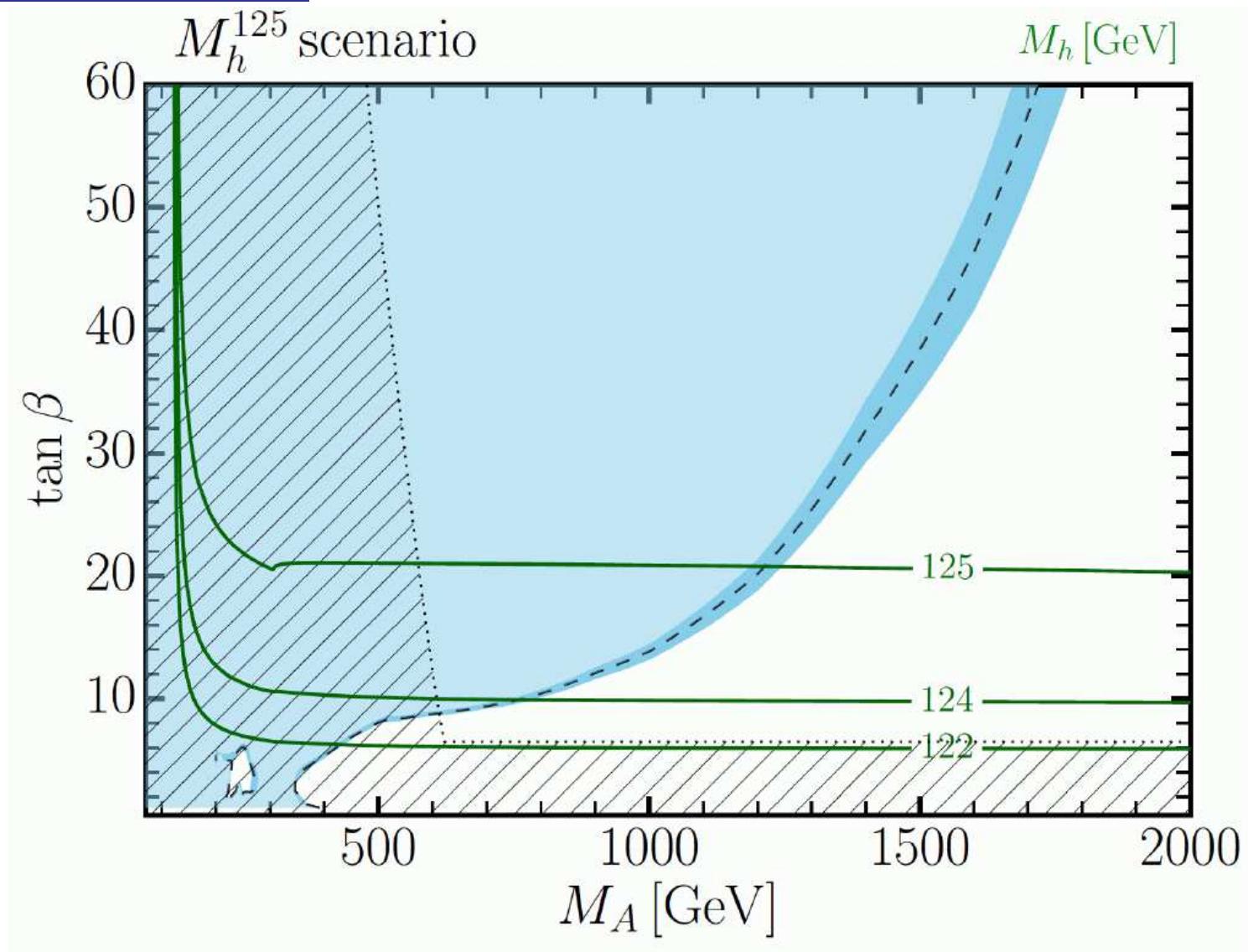
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Data not necessarily to be taken into account:

- electroweak precision data
- flavor data
- astrophysical data (DM properties)

New benchmark: M_h^{125}

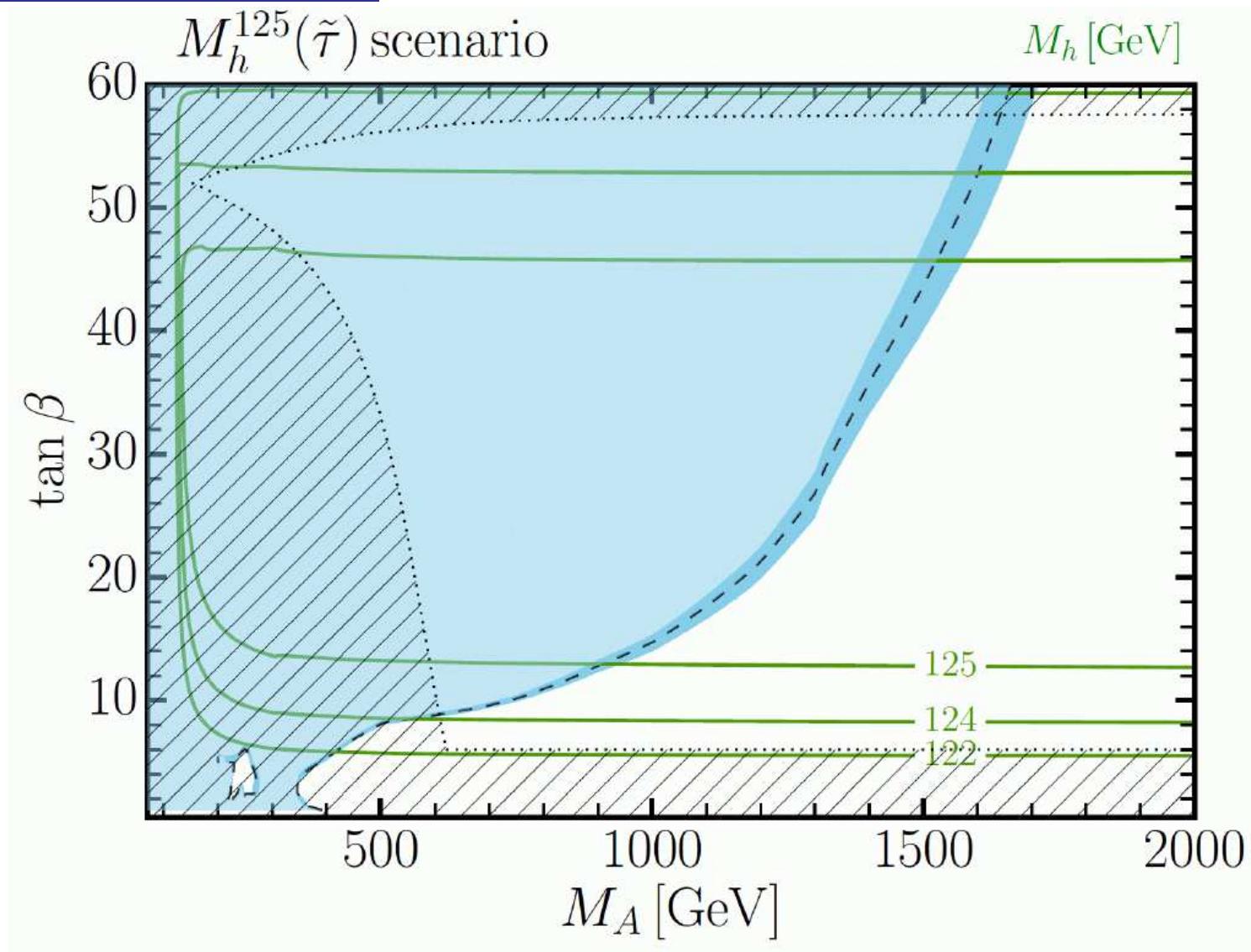
[H. Bahl et al., '18]



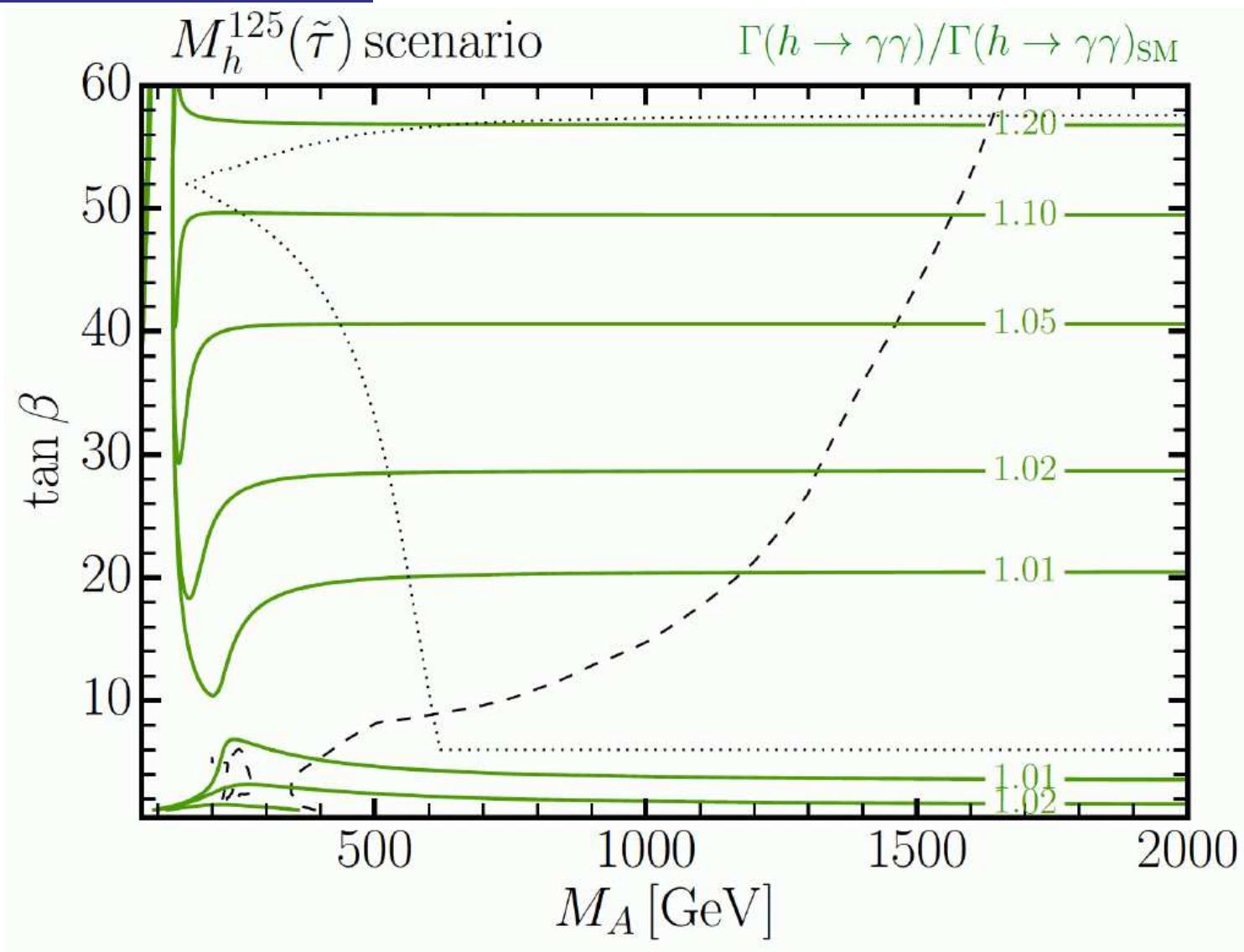
→ new vanilla benchmark model

New benchmark: $M_h^{125}(\tilde{\tau})$

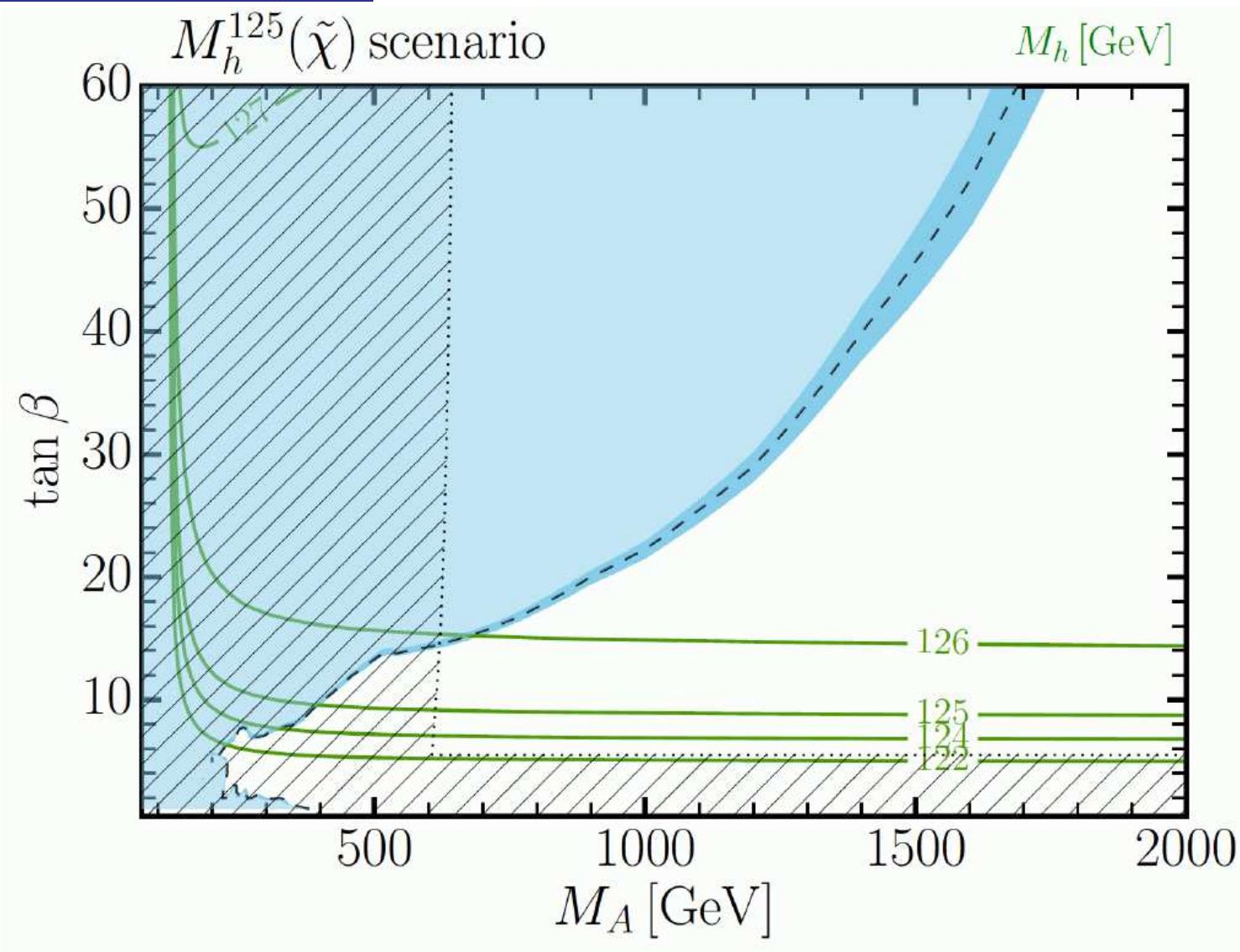
[H. Bahl et al., '18]



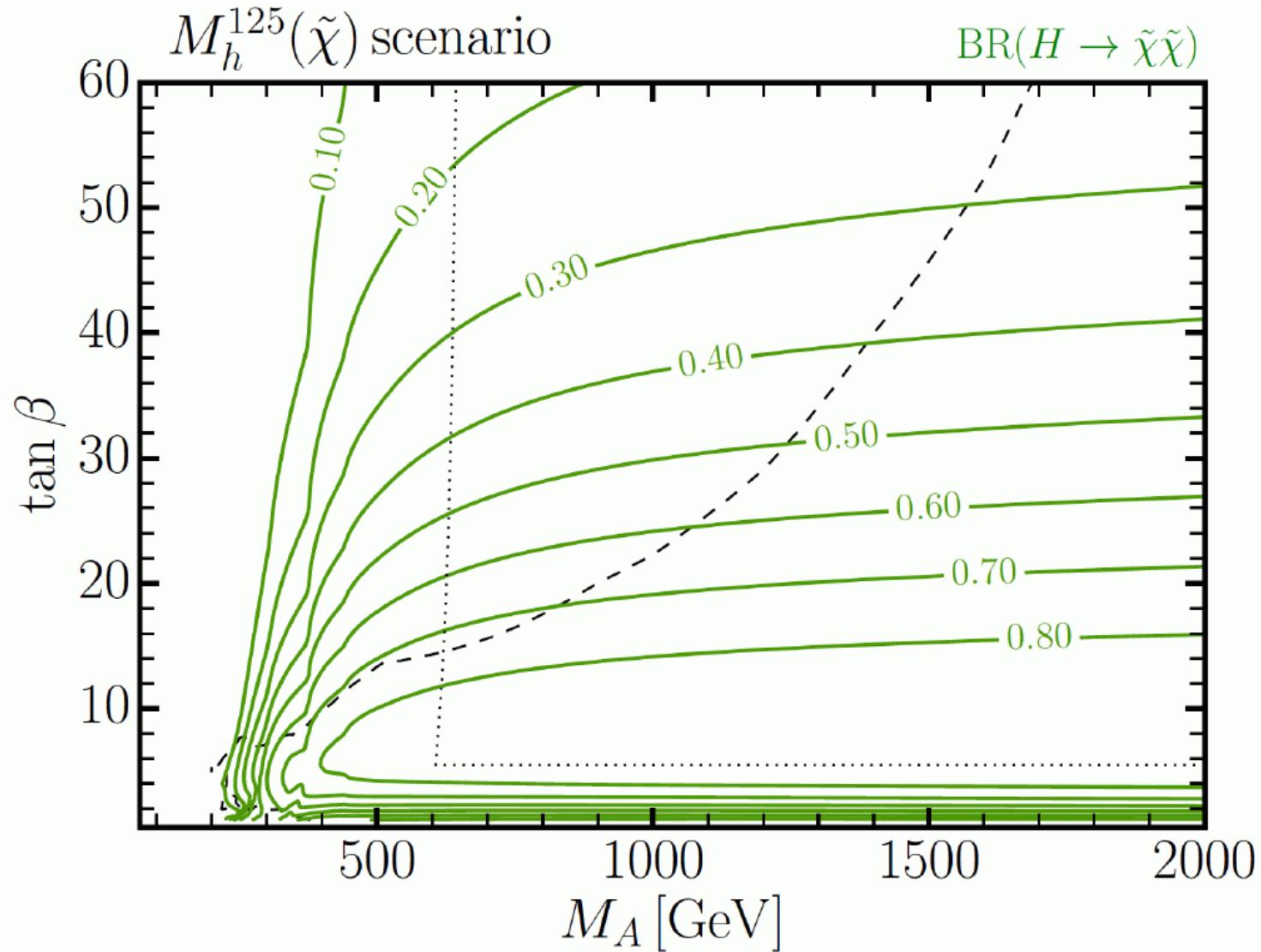
→ slightly reduced heavy Higgs coverage



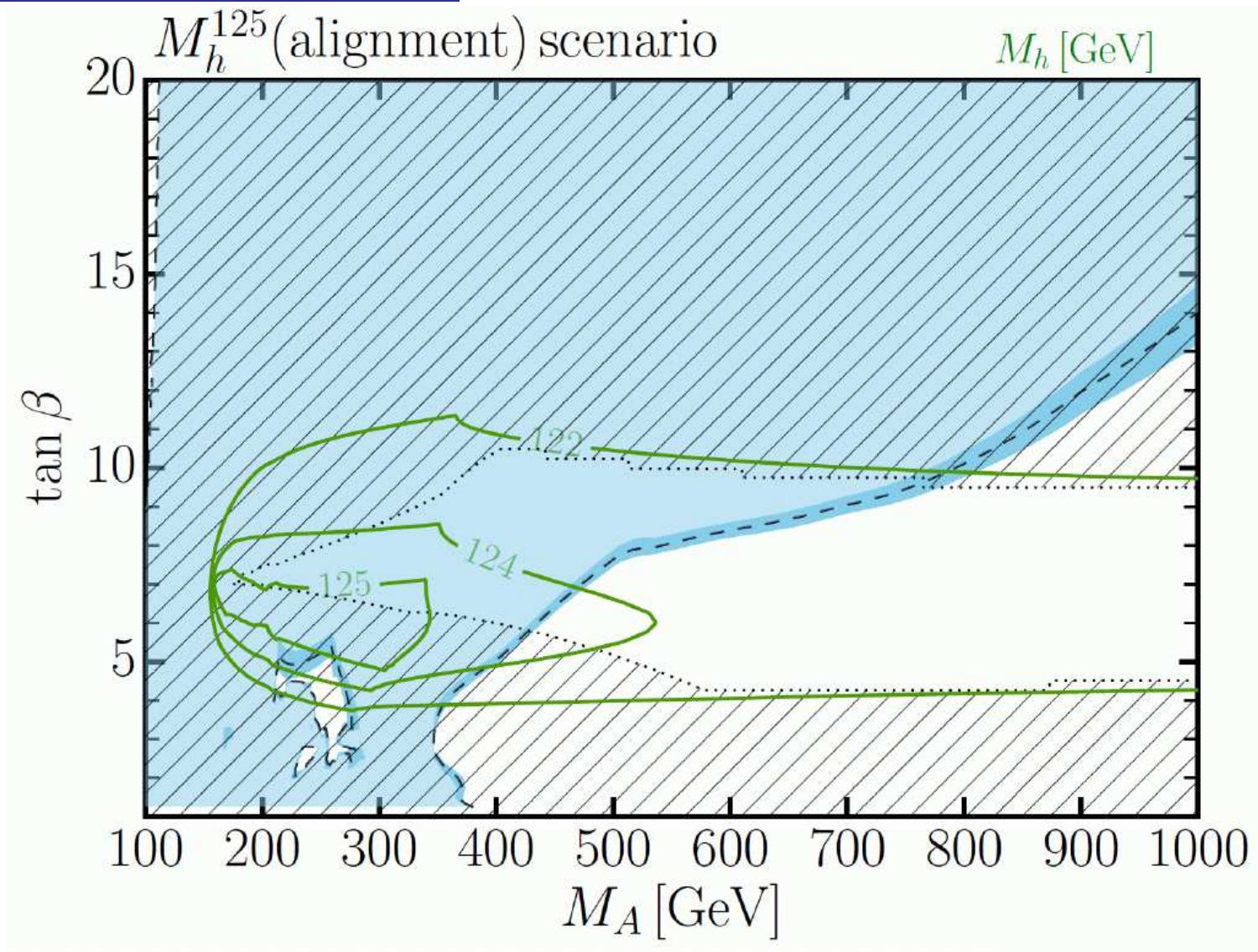
→ strong impact on $\Gamma(h \rightarrow \gamma\gamma)$



→ strongly reduced heavy Higgs coverage



→ Huge BR of heavy Higgses to EW-inos

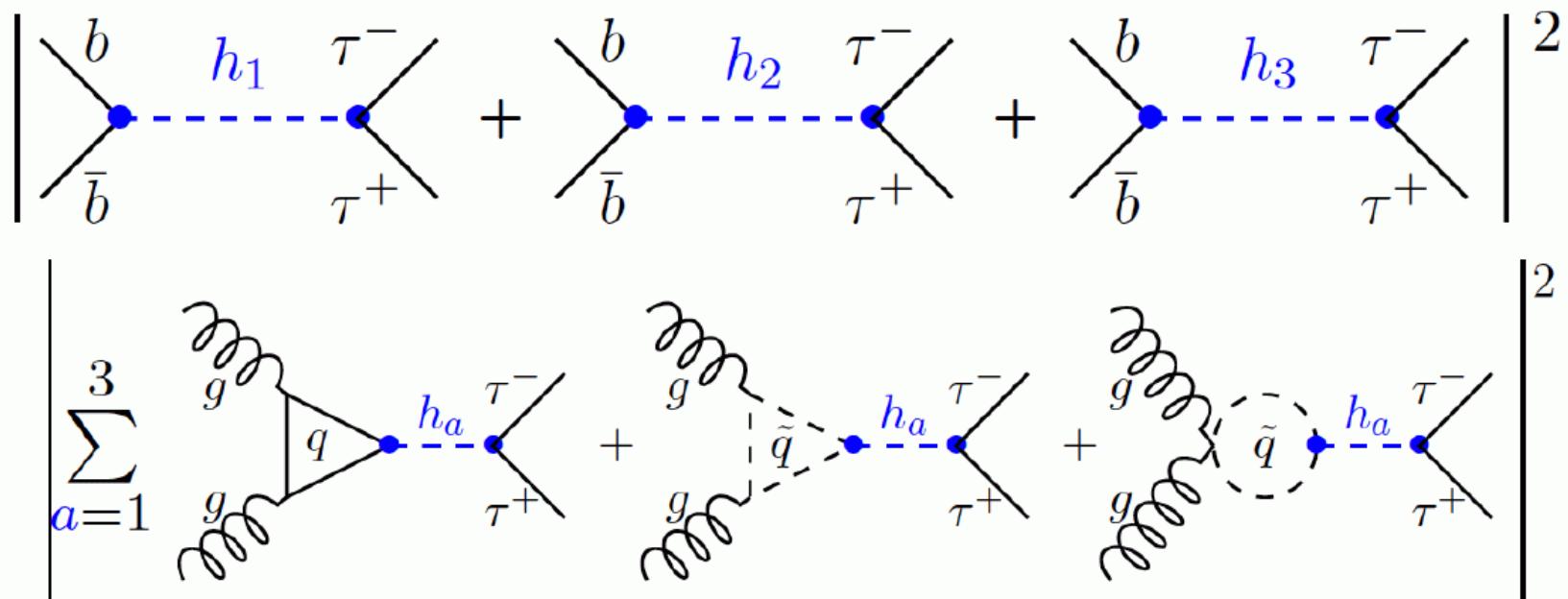


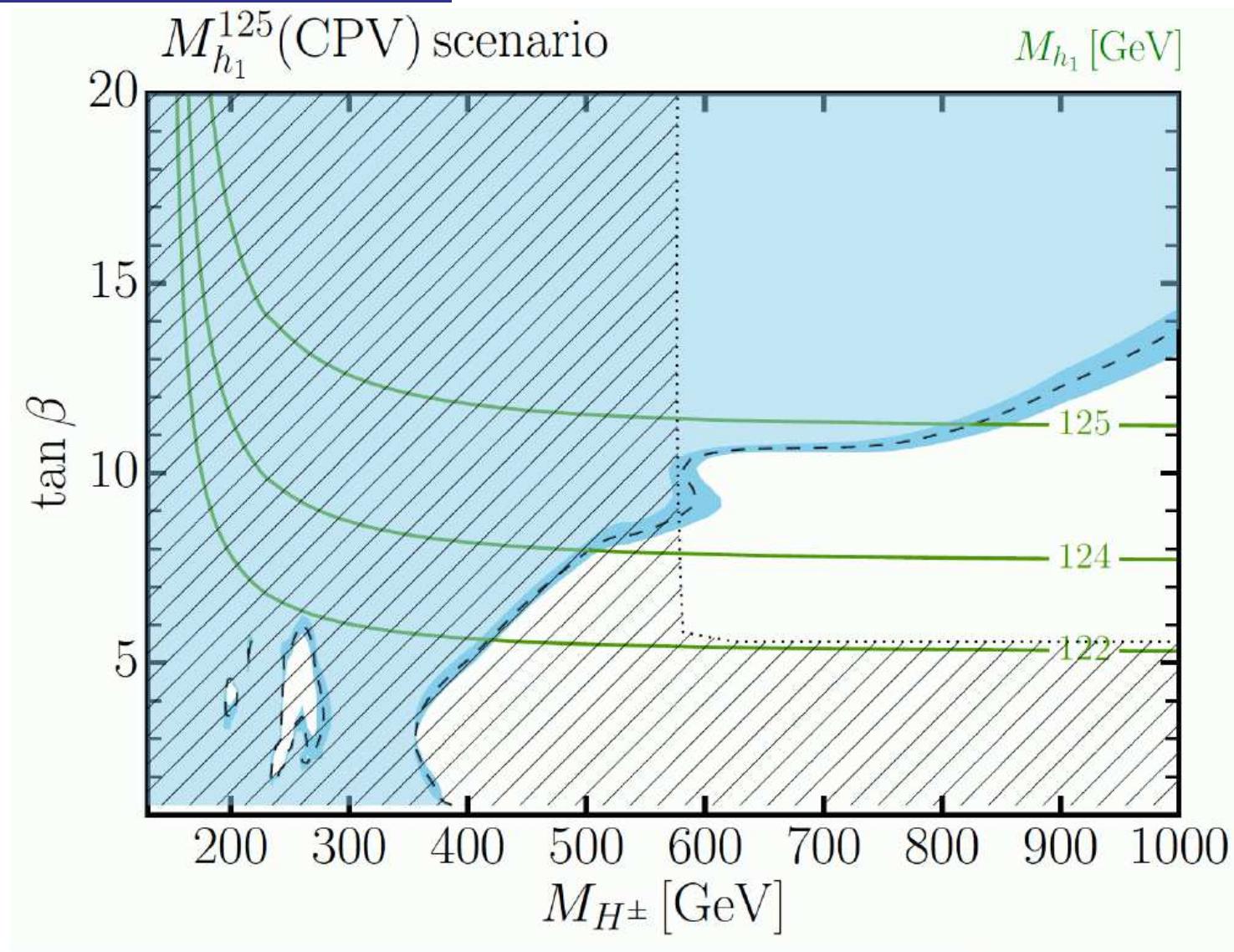
$\rightarrow h$ SM-like for very low M_A

LHC Higgs searches for complex parameters:

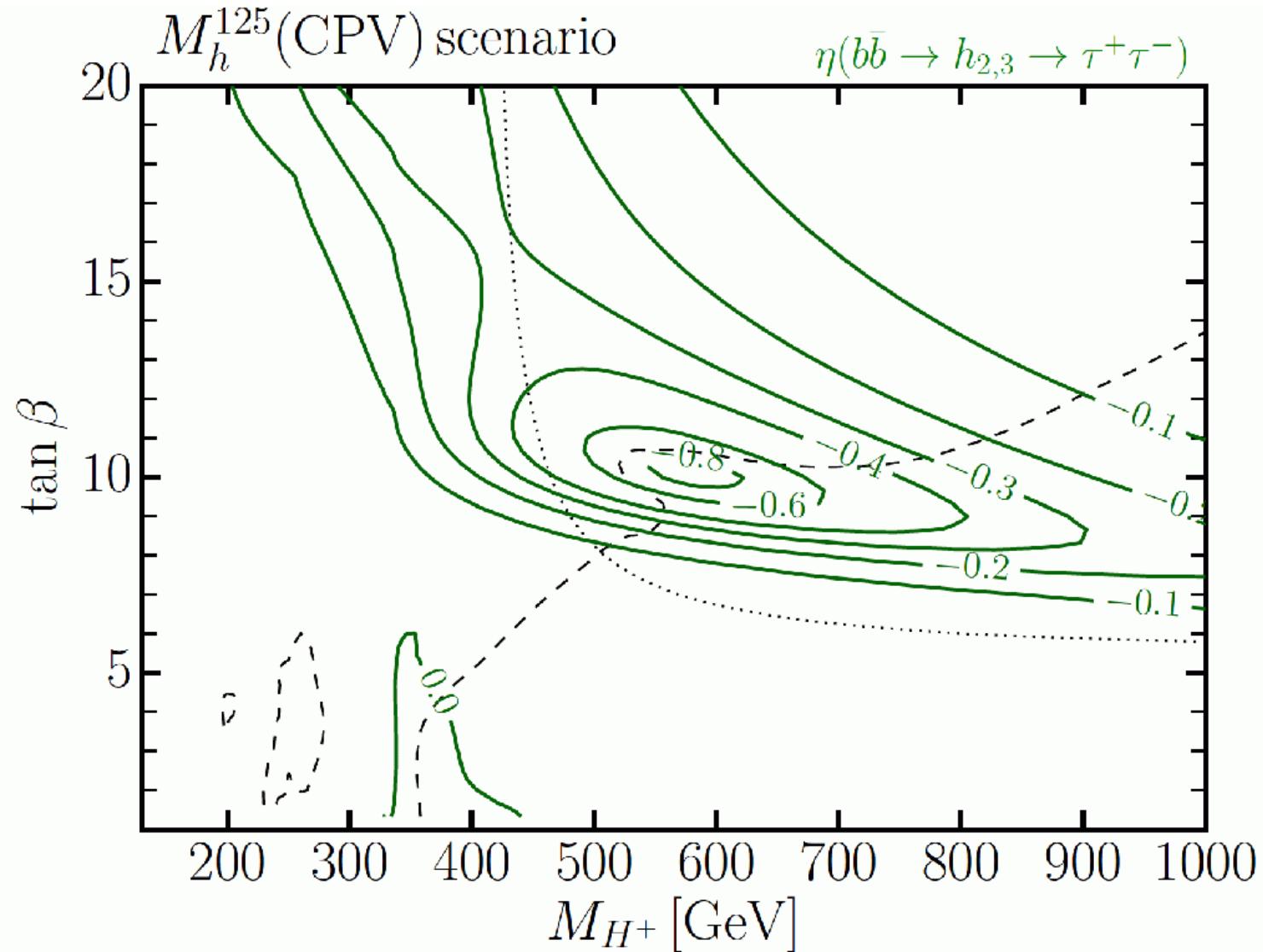
$h_1 \sim H_{125}$, $M_{h_2} \approx M_{h_3}$, CPV: large h_2 - h_3 mixing possible:

Higgs bosons as intermediate states in $\{b\bar{b}, gg\} \rightarrow h_a \rightarrow \tau\tau$

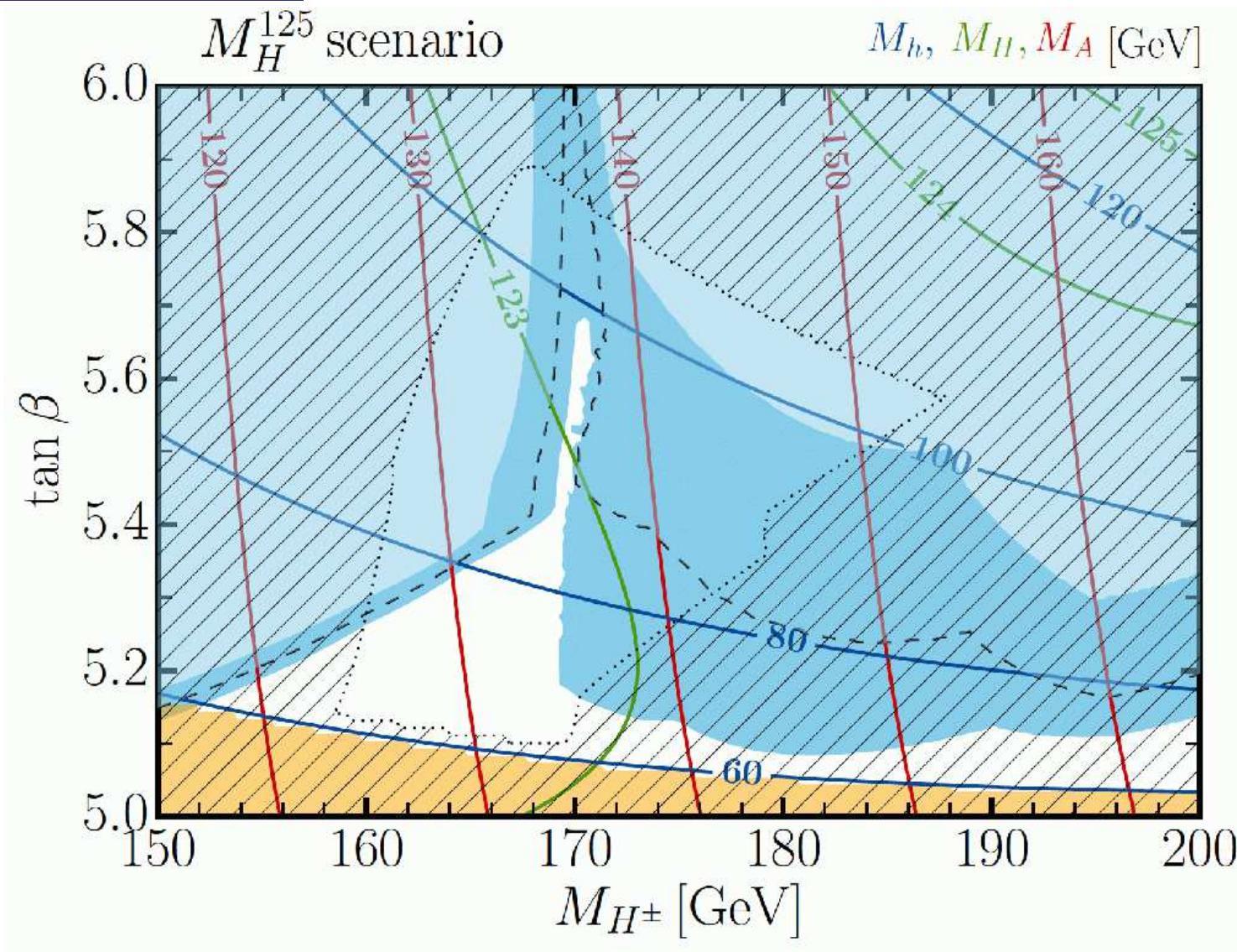




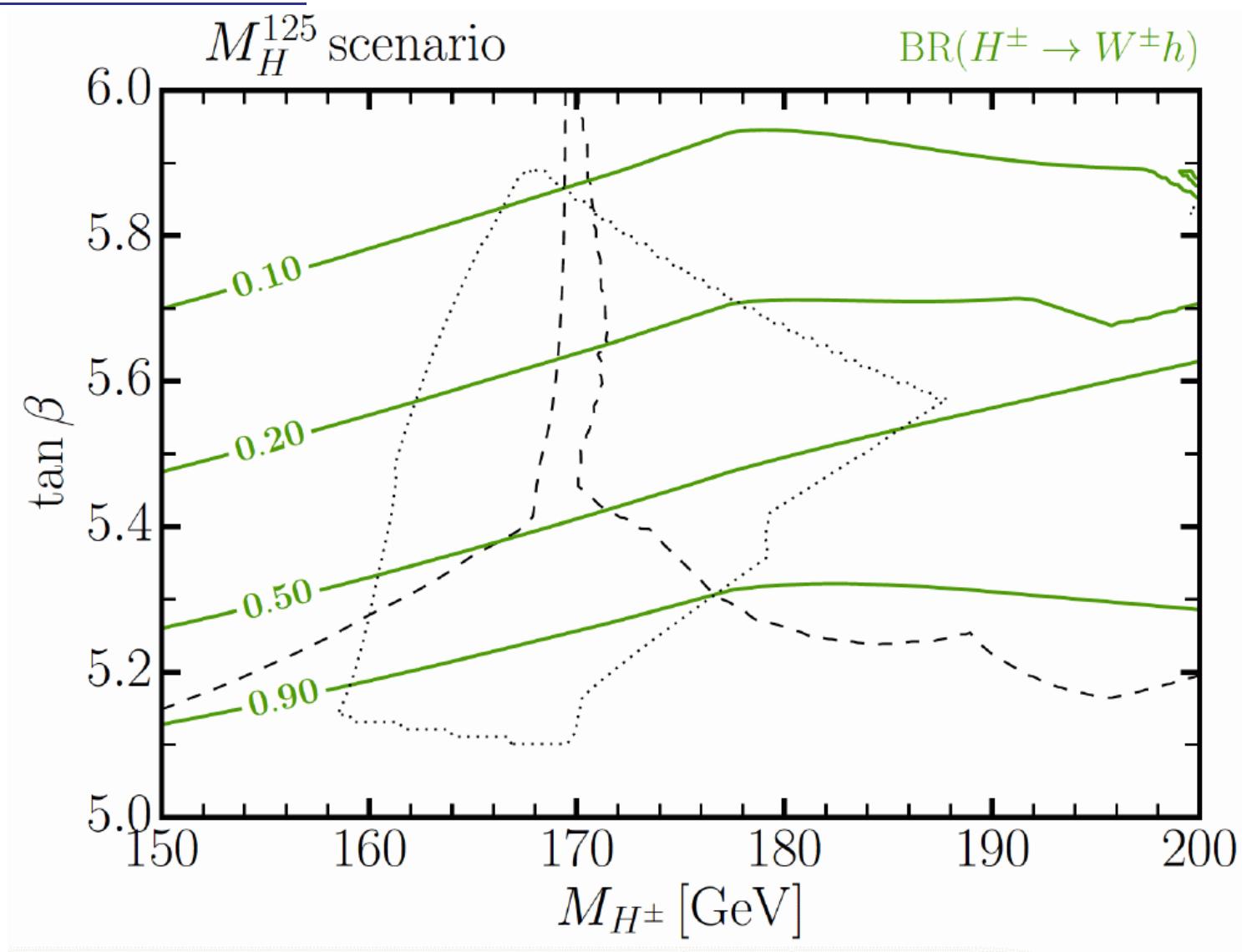
⇒ reduced coverage due to h_2 - h_3 interference



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⇒ exotic solution still viable!



→ large $\text{BR}(H^\pm \rightarrow W^\pm h)$

Interesting case: light singlet

Singlet does not couple to SM particles!

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“Non-interacting particles are hard to detect.”



[F. Klinkhamer]

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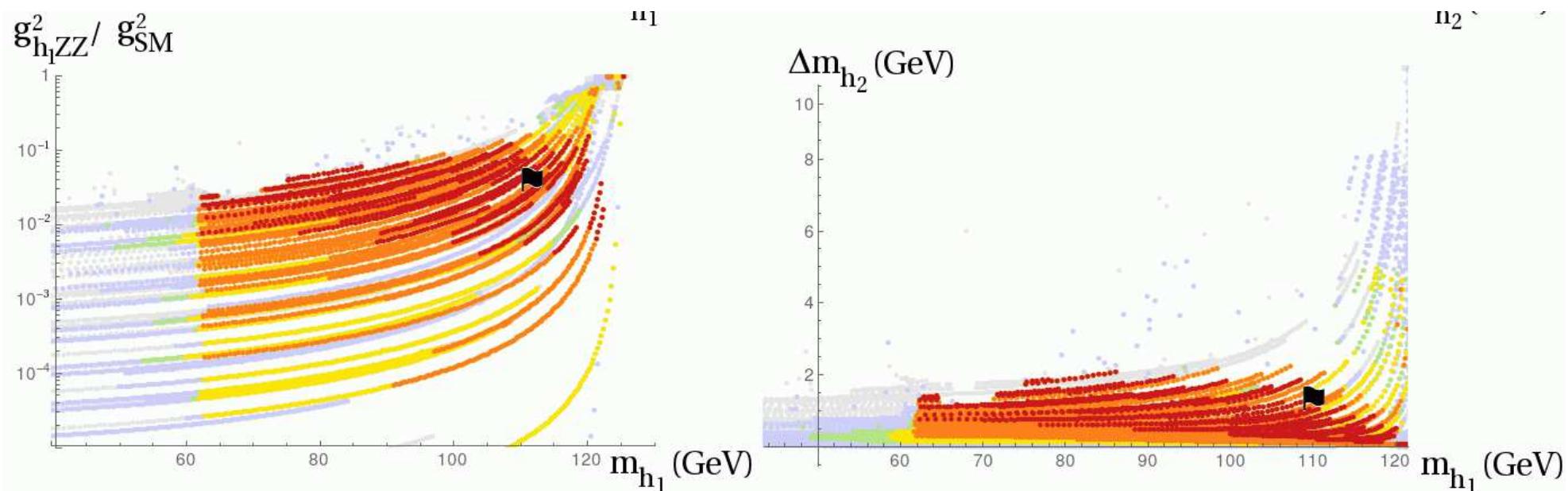
“Easily” possible in the NMSSM:

Light, singlet-like Higgs below 125 GeV

Which collider can find them?

Parameters:

$\tan \beta = 8$, $M_A = 1 \text{ TeV}$, $A_\kappa = -2...0 \text{ TeV}$, $\mu = 120...2000 \text{ GeV}$,
 $2M_1 = M_2 = 500 \text{ GeV}$, $M_3 = 1.5 \text{ TeV}$, $m_{\tilde{Q}_3} = 1 \text{ TeV}$, $m_{\tilde{Q}_{1,2}} = 1.5 \text{ TeV}$,
 $A_t = -2 \text{ TeV}$, $A_{b,\tau} = -1.5 \text{ TeV}$



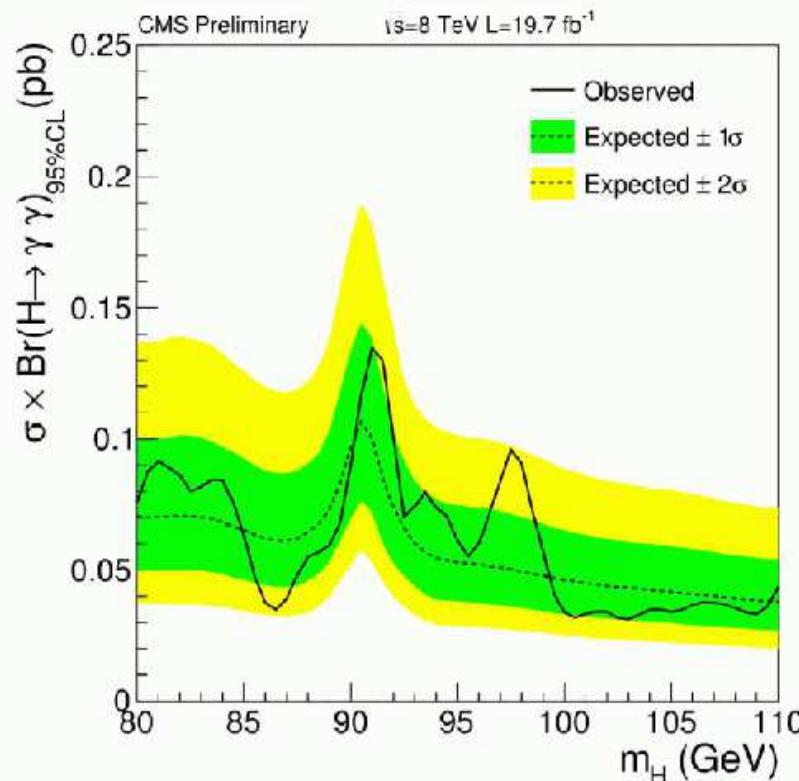
- ⇒ light Higgs below 125 GeV
- ⇒ strongly reduced couplings to gauge bosons!
- ⇒ possibly within ILC reach!

4. A Higgs Boson at 96 GeV?!

- What was seen in Run I?
- What was seen in Run II?
- What was seen at LEP?
- Should we get excited?
- Which model fits?
- Next project?!

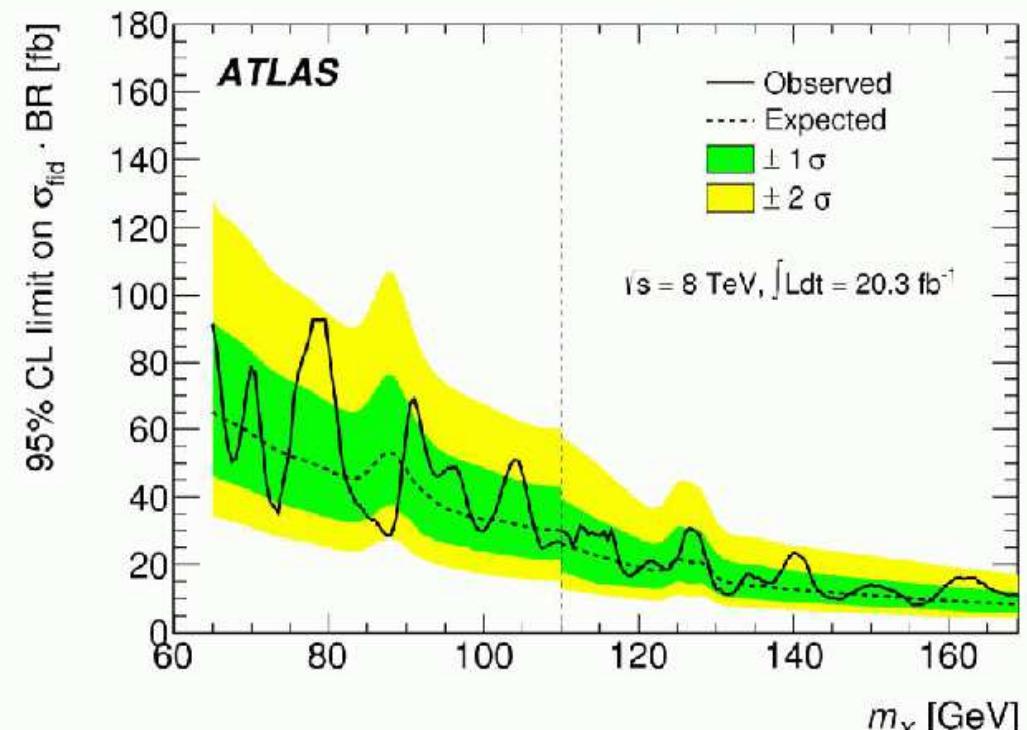


CMS PAS HIG-14-037



$h \rightarrow \gamma\gamma$ (65-110GeV) Run 1

PRL 113 171801 (2014)



- $\sim 2\sigma$ excursion @ $\sim 97.5 \text{ GeV}$

- $\sim 2\sigma$ excursion @ $\sim 80 \text{ GeV}$

18

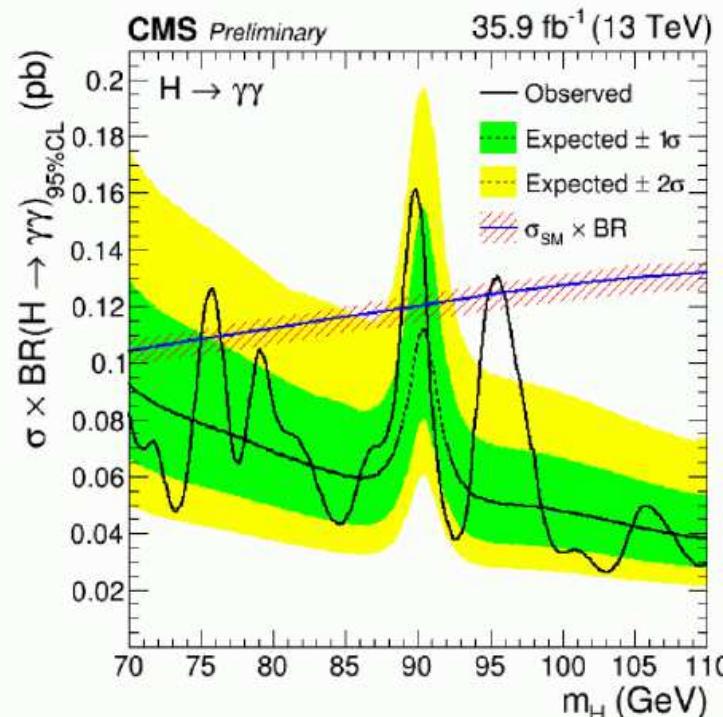
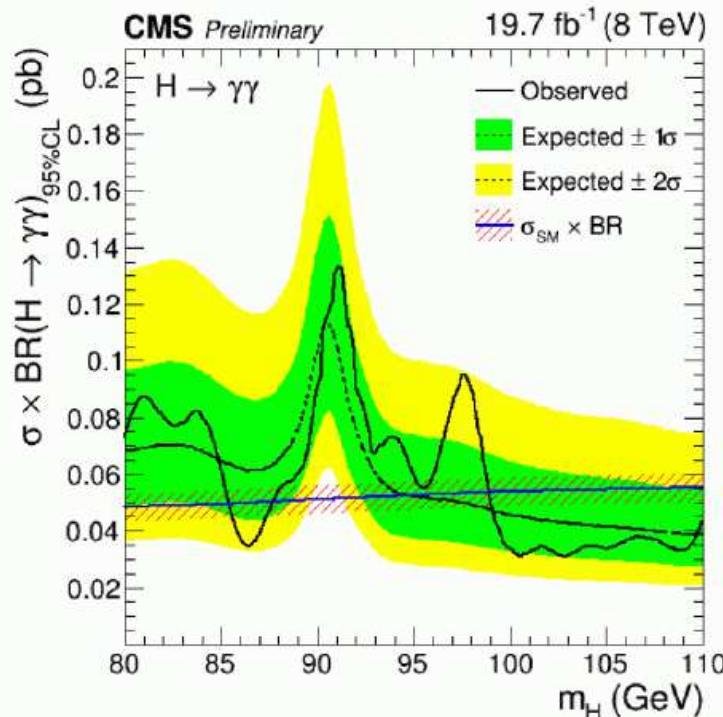
S. Gascon-Shotkin HDays17, Santander, ES Sept. 22 2017



$h \rightarrow \gamma\gamma$ (70-110 GeV) Runs 1+2

New!

CMS PAS HIG-17-013



8 TeV:
minimum(maximum)
limit on $\sigma \times \text{Br}$:
 $31(133) \text{ fb}$ at
 $m=102.8(91.1) \text{ GeV}$

13 TeV:
minimum(maximum)
limit on $\sigma \times \text{Br}$:
 $26(161) \text{ fb}$ at
 $m=103.0(89.9) \text{ GeV}$

- 8 TeV limits on $\sigma \times \text{Br}$ redone with 0.1 GeV step. Production processes assumed in SM proportions. No significant excess with respect to expected limits observed.

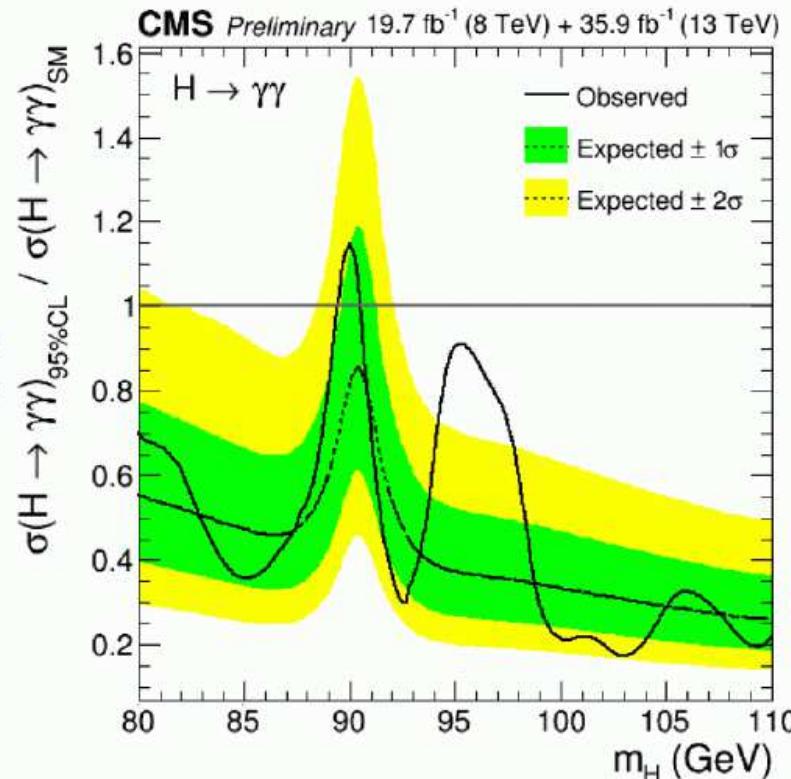
26

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$h \rightarrow \gamma\gamma$ (70-110 GeV) Runs 1+2

All experimental + theoretical systematic uncertainties assumed uncorrelated except for those on signal acceptance due to scale variations + those on production cross sections (assumed 100% correlated).



- Combined 8 TeV+13 TeV $\sigma \times BR$ limit normalized to SM expectation (production processes assumed in SM proportions). No significant excess with respect to expected limits observed.



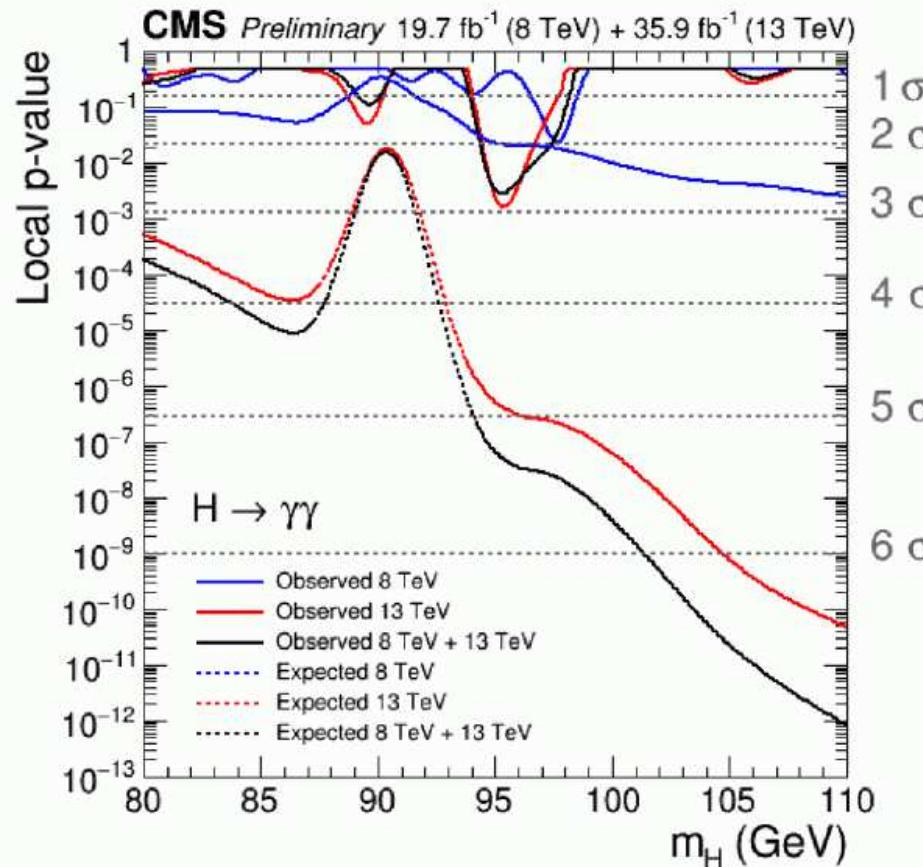
8 TeV+13 TeV:
minimum(maximum) limit
on $(\sigma \times Br) / (\sigma \times Br)_{SM}$:
0.17(1.15) at
 $m=103.0(90.0)$ GeV

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$h \rightarrow \gamma\gamma$ (70-110 GeV) Runs 1+ 2



- Expected and observed local p-values for **8 TeV**, **13 TeV** and their combination

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8 TeV: Excess with $\sim 2.0 \sigma$ local significance at $m=97.6$ GeV

13 TeV: Excess with $\sim 2.9 \sigma$ local (1.47σ global) significance at $m=95.3$ GeV

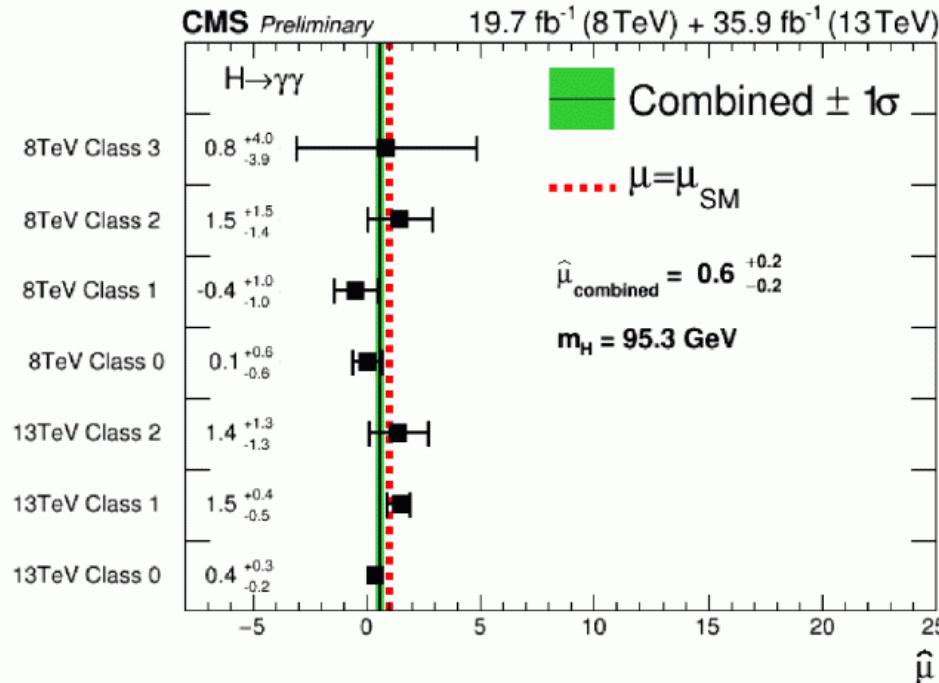
8TeV+13 TeV: Excess with $\sim 2.8 \sigma$ local (1.3σ global) significance at $m=95.3$ GeV

More data are required to ascertain the origin of this excess

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$h \rightarrow \gamma\gamma$ (70-110 GeV) Runs 1+2



CMS PAS HIG-17-013

Excess here mostly driven by class 1 (&2) at 13 TeV

χ^2 probability for the seven individual values to be compatible with a single signal hypothesis: 41%

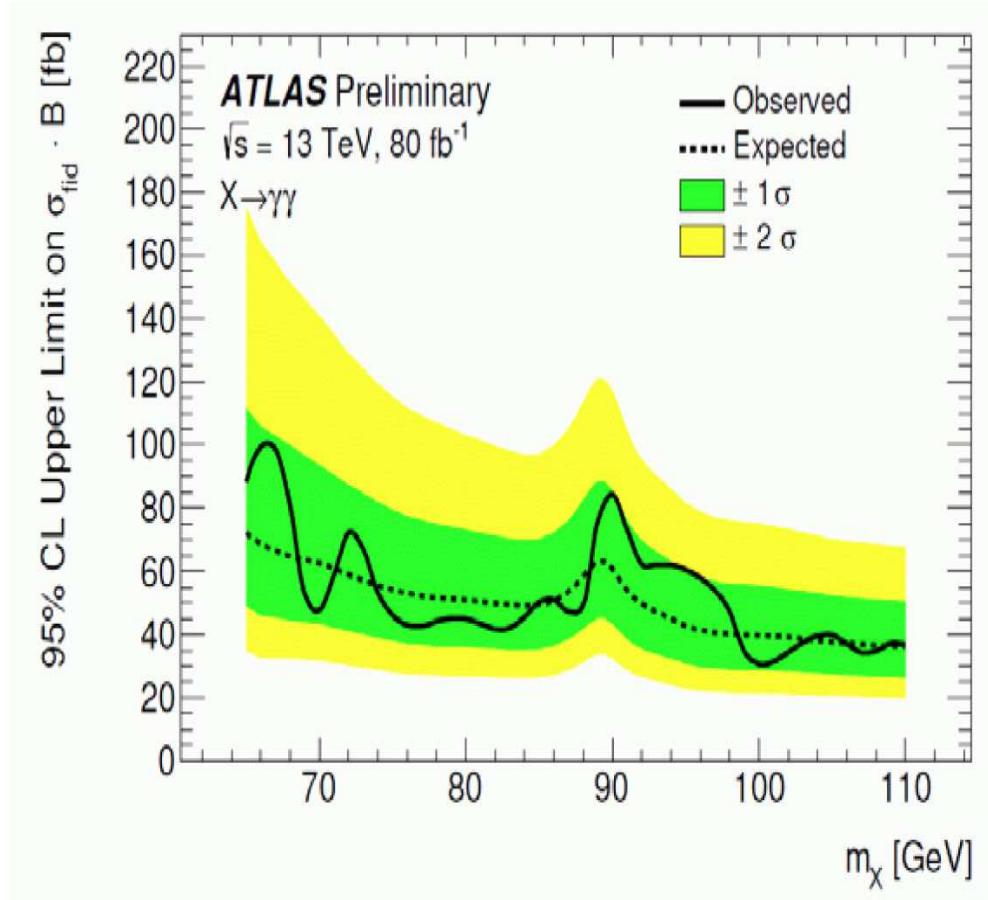
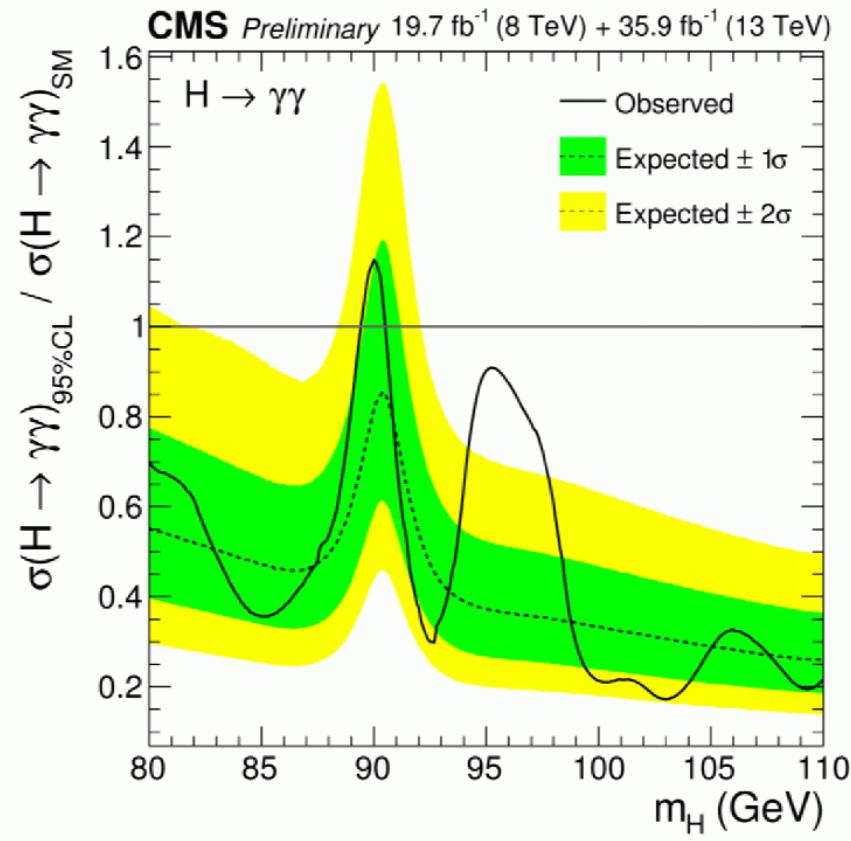
- ‘Signal’ strengths for the 7 event classes and overall, in the 8 TeV+13TeV combination, fixing $m_H=95.3$ GeV
- More data are required to ascertain the origin of this excess

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$$\mu_{CMS}(96 \text{ GeV}) = [\sigma(pp \rightarrow h_1) \times BR(h_1 \rightarrow \gamma\gamma)]_{exp/SM} = 0.6 \pm 0.2$$

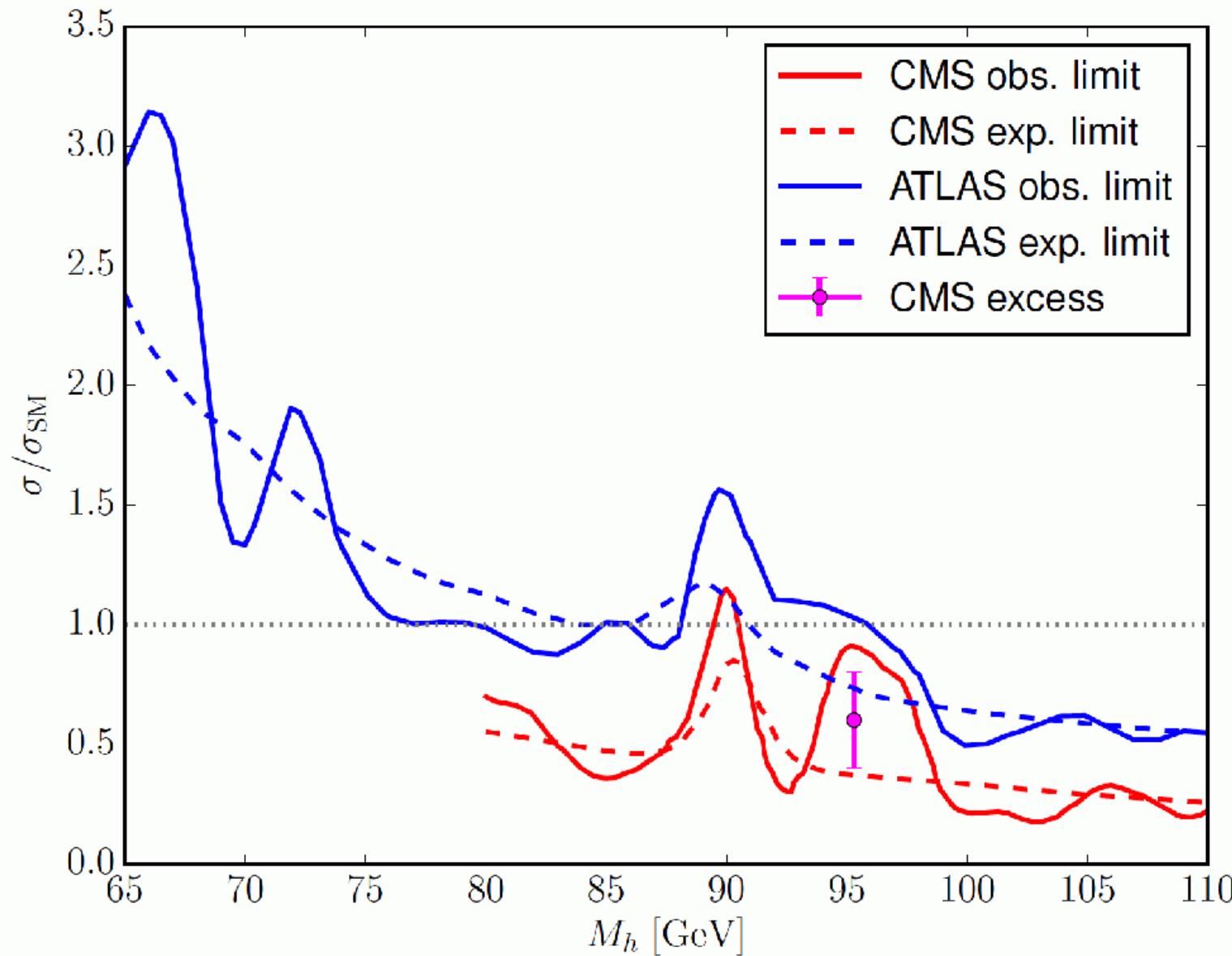
What about ATLAS?



Note: ATLAS gives fiducial cross section! Conversion factor: $1/0.45$

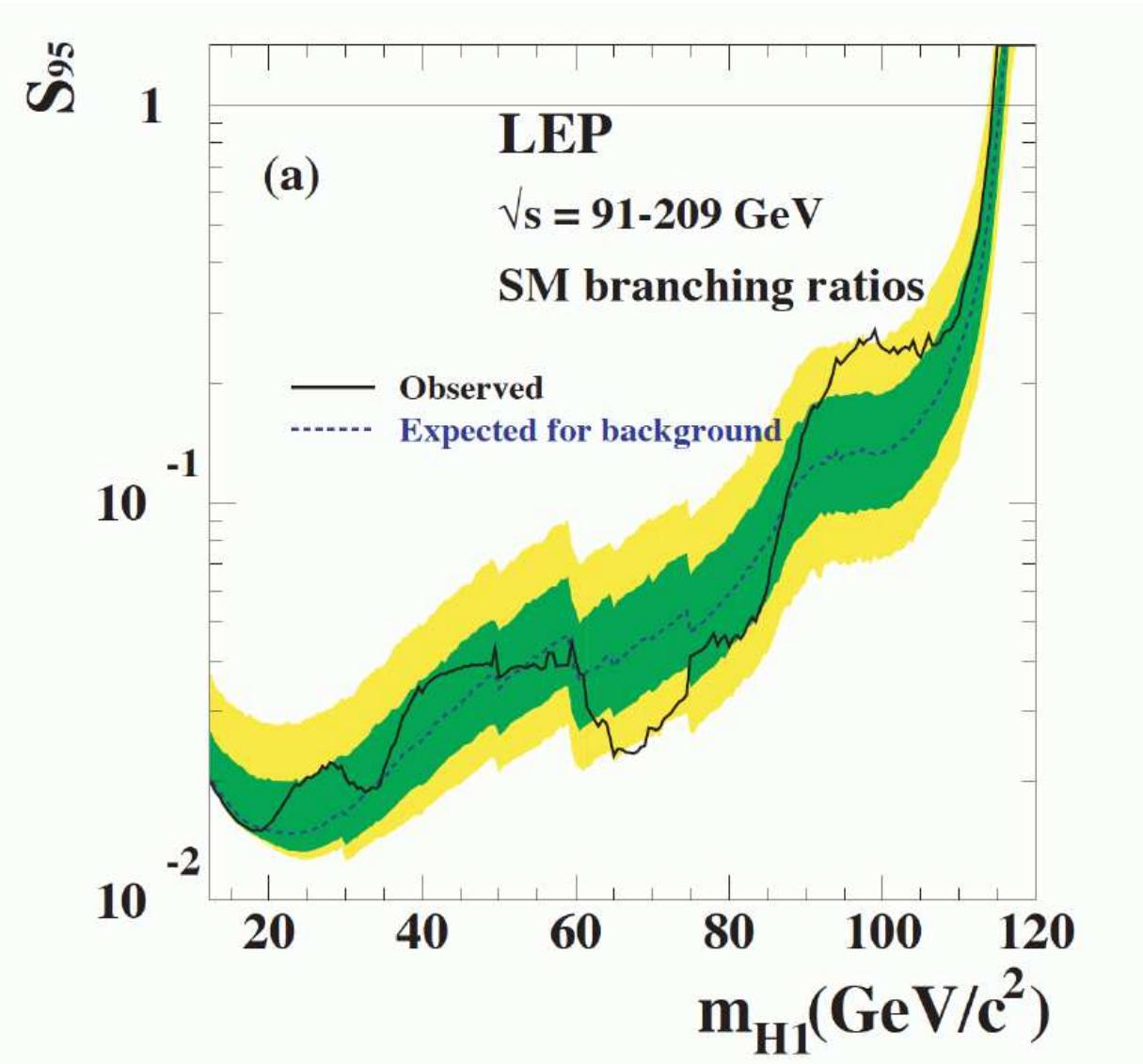
→ ATLAS and CMS exclusion limit **identical!** (120 fb)

Q: why does ATLAS has same sensitivity with twice amount of data?



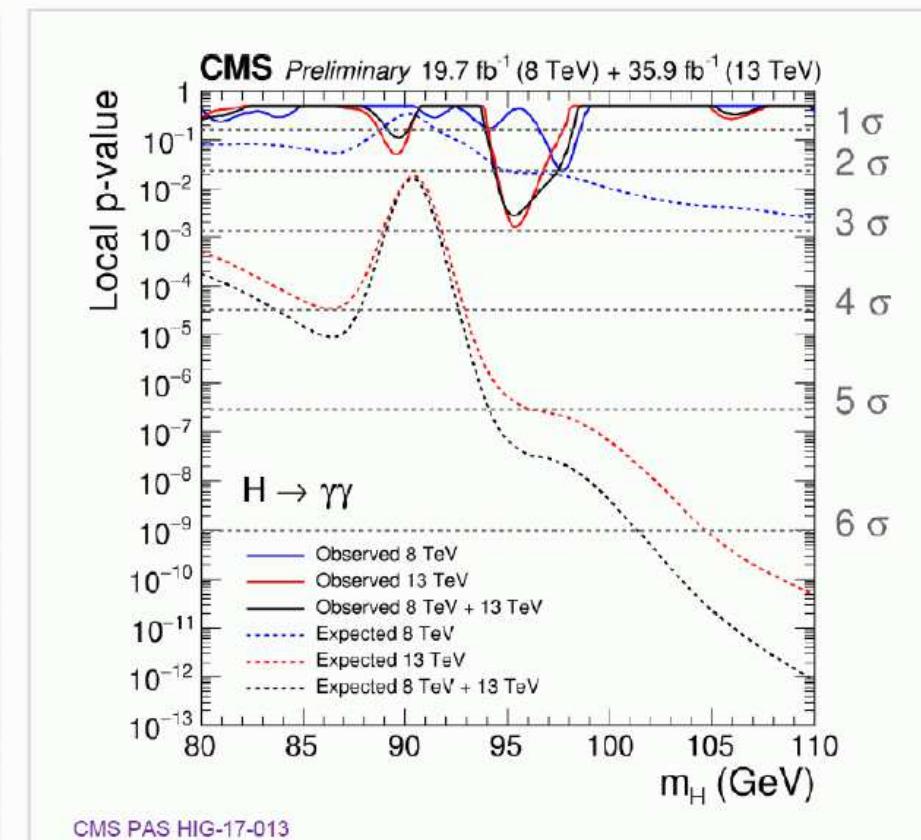
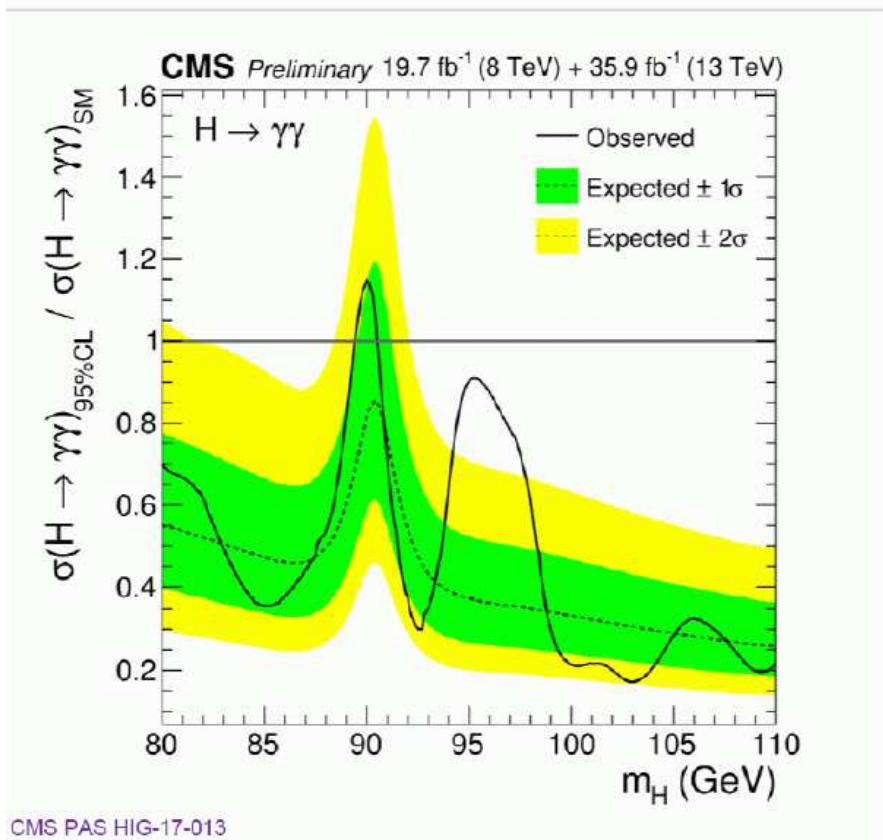
⇒ everything well compatible with the excess!

What was seen at LEP?



$$\mu_{\text{LEP}}(98 \text{ GeV}) = [\sigma(e^+e^- \rightarrow Z h_1) \times \text{BR}(h_1 \rightarrow b\bar{b})]_{\text{exp/SM}} = 0.117 \pm 0.057$$

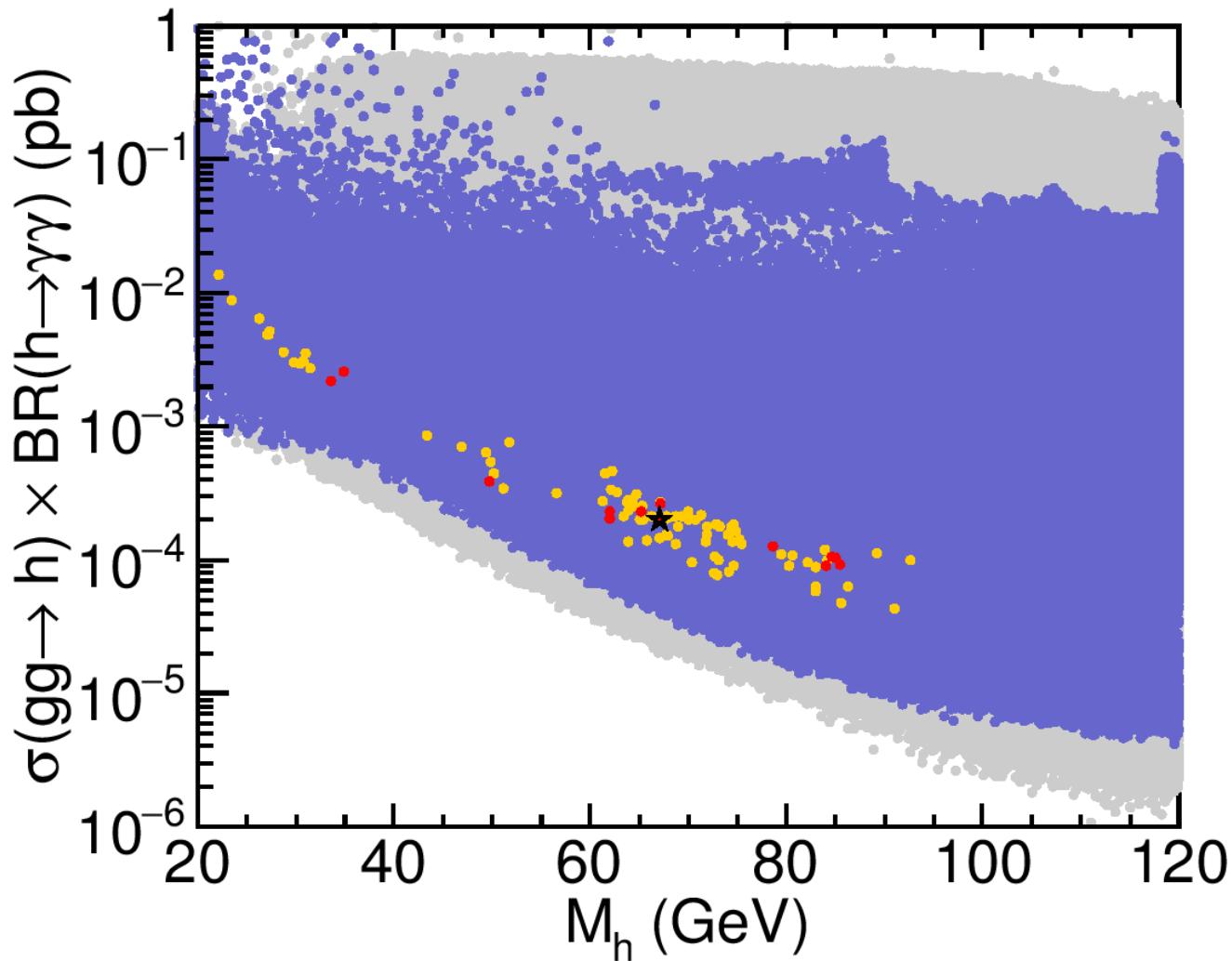
- **Combined 8 TeV + 13 TeV** $\sigma \times \text{BR}$ limit normalized to SM expectation:
 - Production processes assumed in SM proportions
 - **No significant excess** with respect to background expectations
- Expected and observed local p-values for **8 TeV**, **13 TeV** and their **combination**



Q: When do you dare to something “significant” ?

What about the MSSM?

[*P. Bechtle, H. Haber, S.H., O. Stål, T. Stefaniak, G. Weiglein, L. Zeune '16*]



⇒ too small rates!

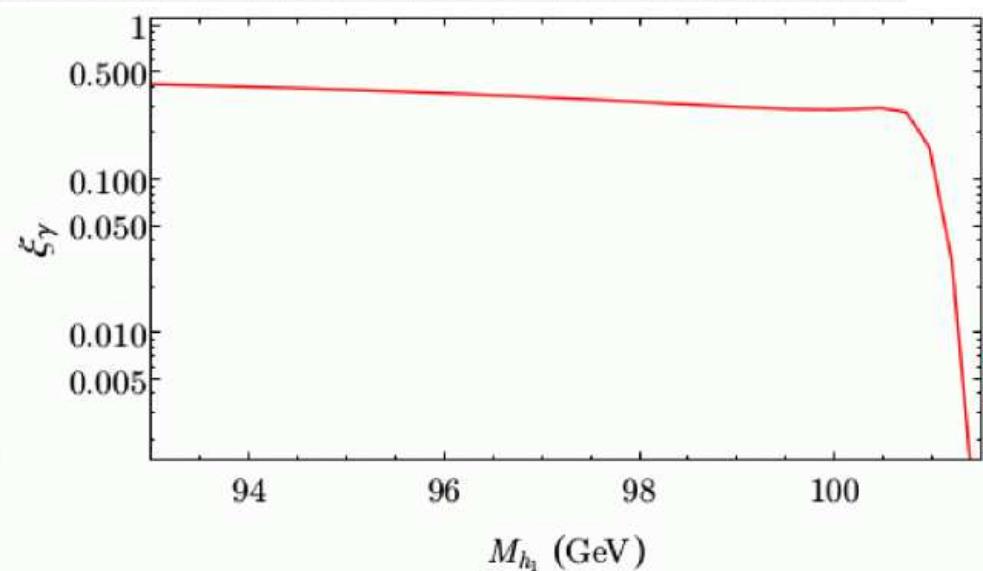
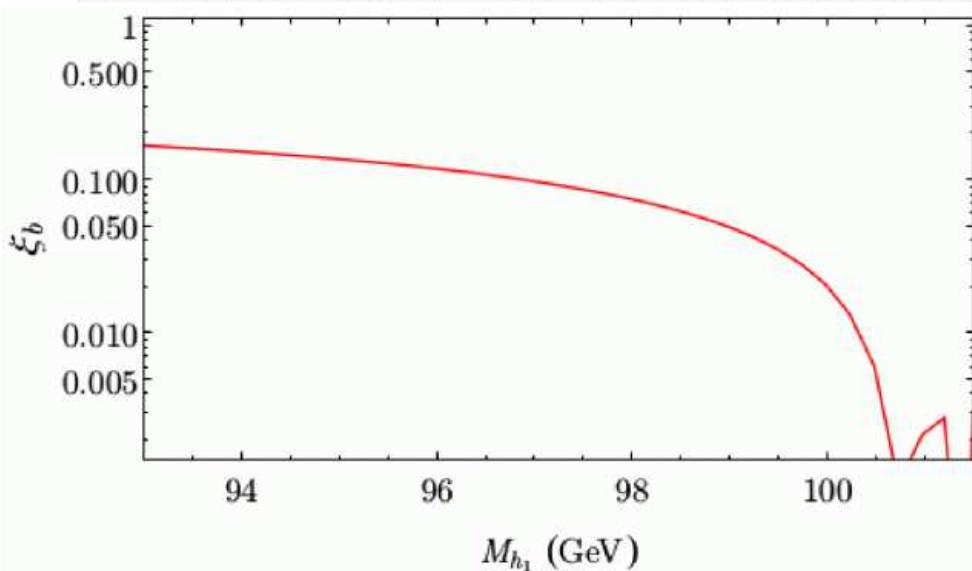
What about the NMSSM?

[F. Domingo, S.H., S. Passeehr, G. Weiglein '18]

Parameters:

$\lambda = 0.6$, $\kappa = 0.035$, $\tan \beta = 2$, $\mu_{\text{eff}} = (397 + 15x) \text{ GeV}$, $M_{H^\pm} = 1 \text{ TeV}$,
 $A_\kappa = -325 \text{ GeV}$, $M_{\text{SUSY}} = 1 \text{ TeV}$, $A_t = A_b = 0$

$$\xi_b \equiv \frac{\Gamma[h_1 \rightarrow ZZ] \cdot \text{BR}[h_1 \rightarrow b\bar{b}]}{\Gamma[H_{\text{SM}}(M_{h_1}) \rightarrow ZZ] \cdot \text{BR}[H_{\text{SM}}(M_{h_1}) \rightarrow b\bar{b}]} \sim \frac{\sigma[e^+e^- \rightarrow Z(h_1 \rightarrow b\bar{b})]}{\sigma[e^+e^- \rightarrow Z(H_{\text{SM}}(M_{h_1}) \rightarrow b\bar{b})]}$$
$$\xi_\gamma \equiv \frac{\Gamma[h_1 \rightarrow gg] \cdot \text{BR}[h_1 \rightarrow \gamma\gamma]}{\Gamma[H_{\text{SM}}(M_{h_1}) \rightarrow gg] \cdot \text{BR}[H_{\text{SM}}(M_{h_1}) \rightarrow \gamma\gamma]} \sim \frac{\sigma[gg \rightarrow h_1 \rightarrow \gamma\gamma]}{\sigma[gg \rightarrow H_{\text{SM}}(M_{h_1}) \rightarrow \gamma\gamma]}.$$



⇒ both “excesses” can be fitted simultaneously!

What about the $\mu\nu$ SSM?

$\mu\nu$ SSM: [D. Lopez-Fogliani, C. Muñoz '06]

$\mu\nu$ SSM: NMSSM + well motivated RPV (in simple terms)
⇒ EW scale seesaw to reproduce the neutrino data

What about the $\mu\nu$ SUSY?

$\mu\nu$ SUSY: [D. Lopez-Fogliani, C. Muñoz '06]

$\mu\nu$ SUSY: NMSSM + well motivated RPV (in simple terms)
⇒ EW scale seesaw to reproduce the neutrino data

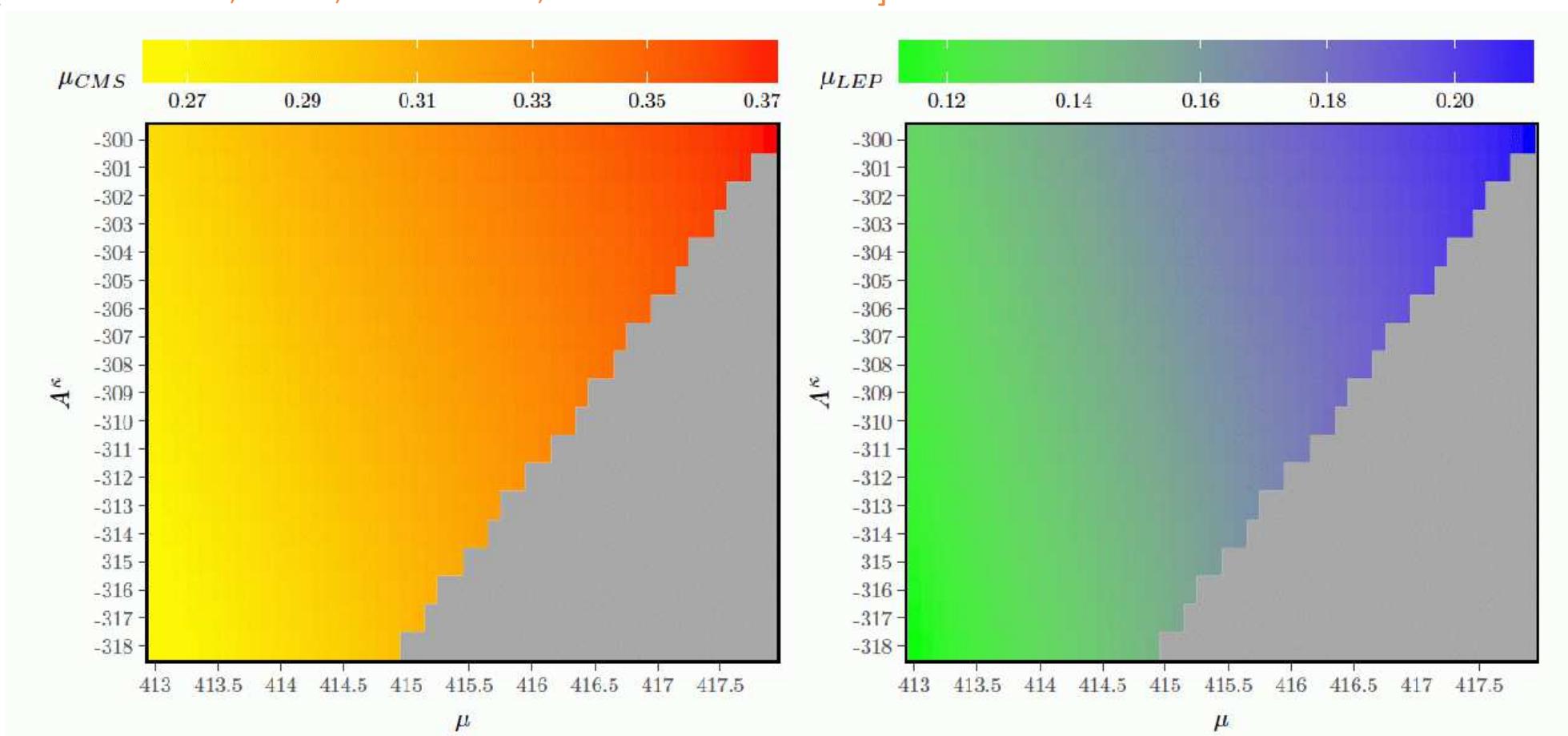
Can the $\mu\nu$ SUSY explain the two “excesses” ?

[T. Biekötter, S.H., C. Muñoz, arXiv:1712.07475]

| v_{iL} | Y_i^ν | A_i^ν | $\tan \beta$ | μ | λ | A^λ | κ | A^κ | M_1 |
|--------------------------|-----------|------------------------|------------------------|------------------------|-----------|-----------------|----------------|--------------|---------------|
| $\sqrt{2} \cdot 10^{-5}$ | 10^{-7} | -1000 | 2 | [413; 418] | 0.6 | 956.035 | 0.035 | [-300; -318] | 100 |
| M_2 | M_3 | $m_{\tilde{Q}_{iL}}^2$ | $m_{\tilde{u}_{iR}}^2$ | $m_{\tilde{d}_{iR}}^2$ | A_1^u | $A_{2,3}^{u,d}$ | $(m_e^2)_{ii}$ | A_{33}^e | $A_{11,22}^e$ |
| 200 | 1500 | 800^2 | 800^2 | 800^2 | 0 | 0 | 800^2 | 0 | 0 |

Can the $\mu\nu$ SSM explain the two “excesses”?

[T. Biekötter, S.H., C. Muñoz, arXiv:1712.07475]

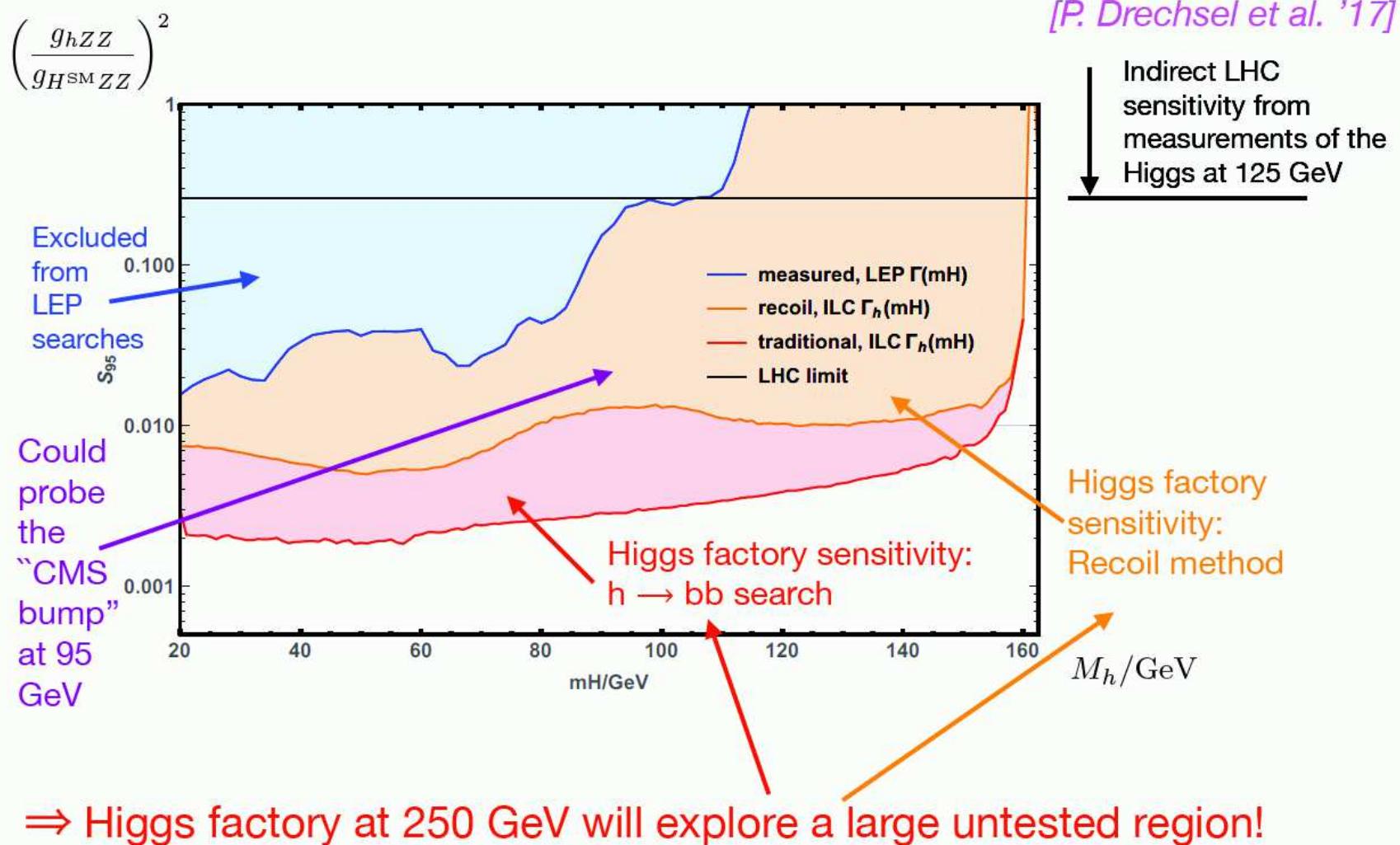


⇒ YES, WE CAN! :-)
(at the $1 - 1.5\sigma$ level)

Next project?

Next project? ILC reach for light Higgs bosons:

Example for discovery potential for new light states:
Sensitivity at 250 GeV with 500 fb⁻¹ to a new light Higgs



[Taken from G. Weiglein '18]

5. Conclusinos

- SUSY is (still) the best-motivated BSM scenario
 - unconstrained MSSM: 105 new parametes
 - constrained: CMSSM, NUHM, SU(5), mAMSB, sub-GUT, FUT, ...
 - benchmark models: parameter planes
- ILC/CLIC have unique opportunities to discover MSSM Higgs bosons
- Benchmark scenarios/searches: Data taken into account: Higgs/SUSY
Data not necessarily taken into account: EW/Flavor/DM
- New benchmark proposal:
 - M_h^{125} scenario: 2HDM-like model
 - $M_h^{125}(\tilde{\tau})$ scenario: light staus: $h \rightarrow \gamma\gamma$, $H/A \rightarrow \tilde{\tau}\tilde{\tau}$
 - $M_h^{125}(\tilde{\chi})$ scenario: light EW-inos: $H/A \rightarrow \tilde{\chi}_i^0 \tilde{\chi}_j^0, \tilde{\chi}_k^\pm \tilde{\chi}_l^\mp$
 - M_h^{125} (alignment) scenario: h SM-like for very low M_A
 - M_H^{125} scenario: $M_H \sim 125$ GeV, all Higgses light
 - $M_{h_1}^{125}$ (CPV) scenario: complex phases, h_2-h_3 interference
- A light Higgs at 96 GeV? ⇒ perfect case for the ILC250
new CMS/ATLAS result (and old LEP result) possibly interesting!
 - NMSSM can explain CMS(/ATLAS) and LEP “excesses”
 - $\mu\nu$ SSM can explain CMS(/ATLAS) and LEP “excesses”

Higgs Days at Santander 2019

Theory meets Experiment

16.-20. September



Horizon 2020
European Union funding
for Research & Innovation



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Further Questions?