“Tell me that you have found no sign of New Physics again, I dare you. I double dare you. Tell me one more goddamn **time!**”

Higgs Physics

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

Dubna, 07/2018

1. Before the Higgs discovery

2. The Higgs sector of the SM

3. The Higgs sector of the (N)MSSM

4. Higgs boson(s) at the LHC

Higgs Physics

Higgs Boson(s) at the LHC

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

Dubna, 07/2018

1. The LHC

2. The SM Higgs boson at the LHC

3. MSSM Higgs boson searches at the LHC

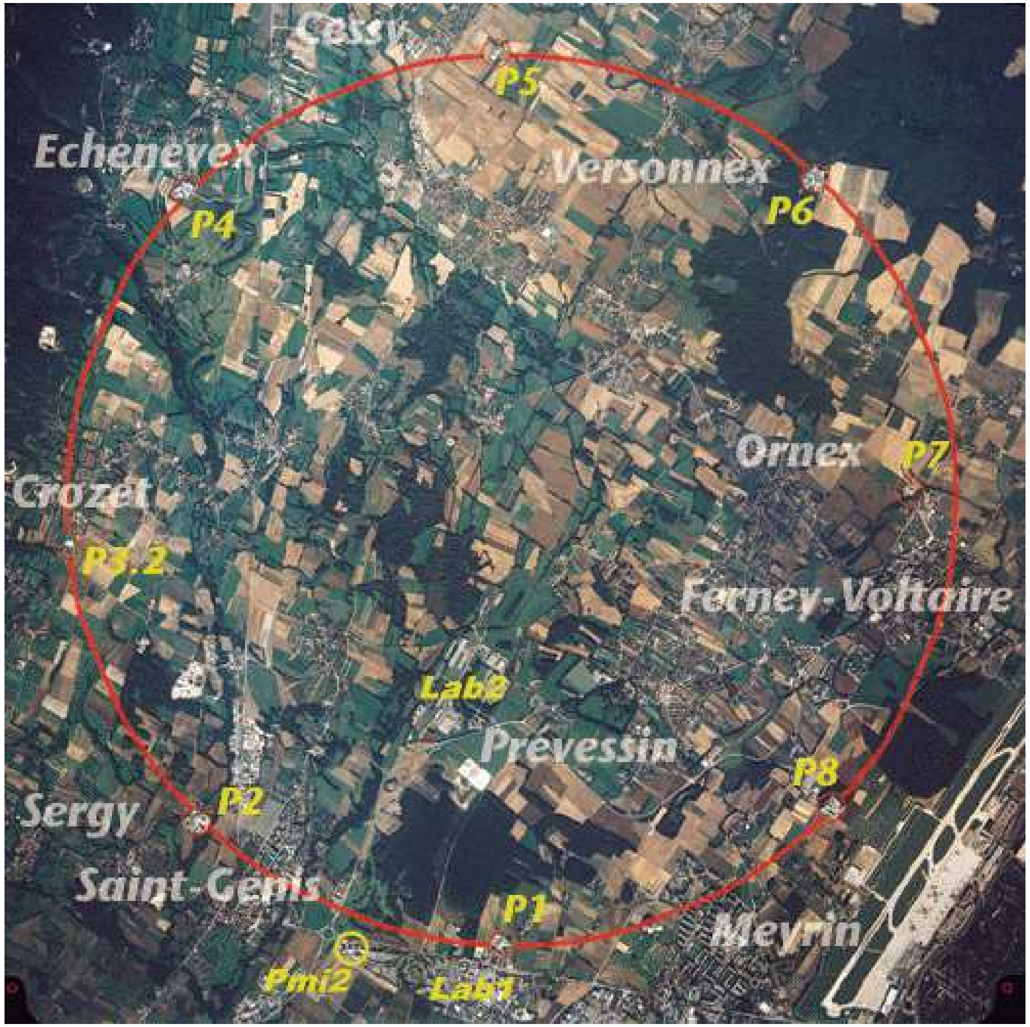
4. $\phi_{96} \to \gamma\gamma$

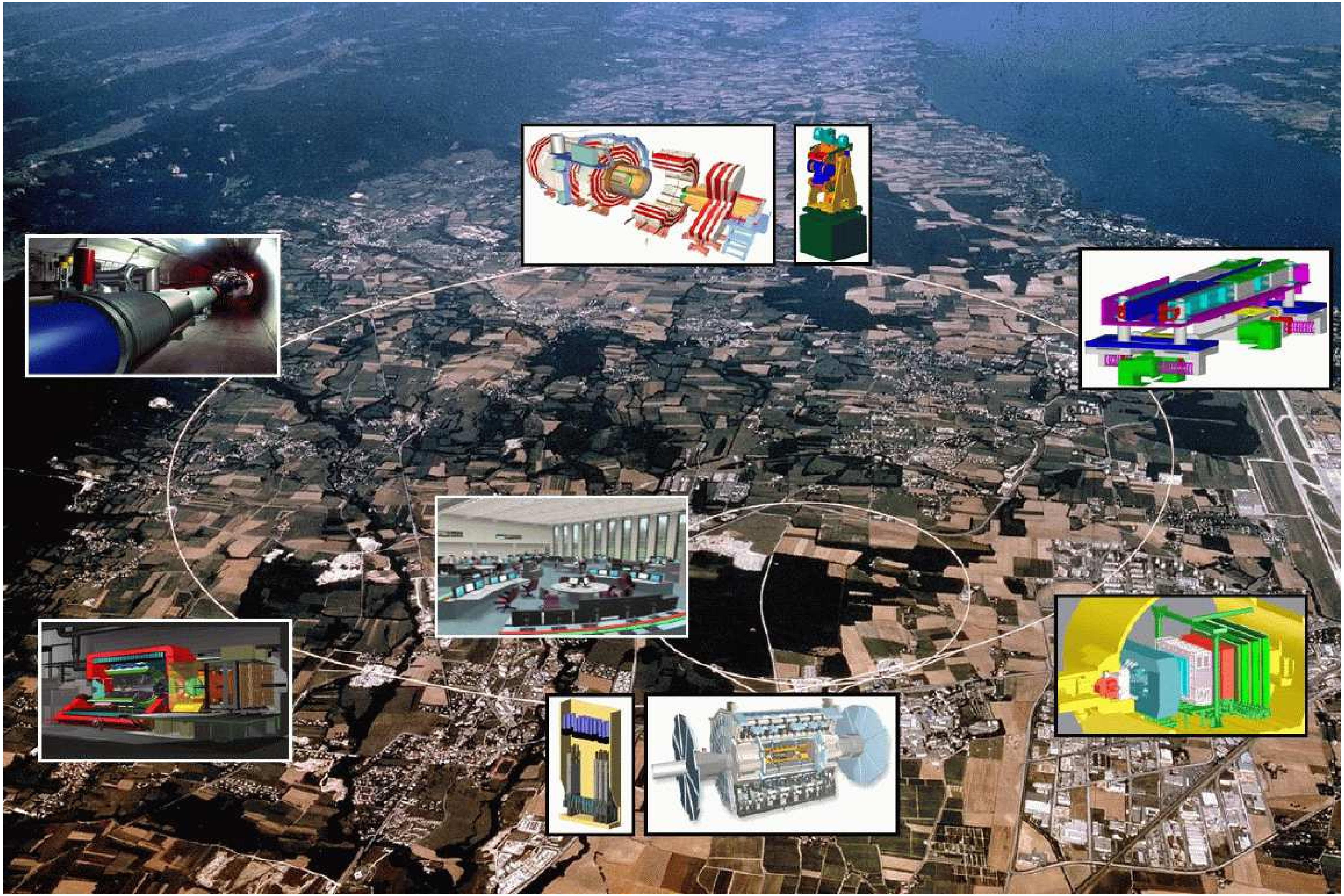
1. The LHC

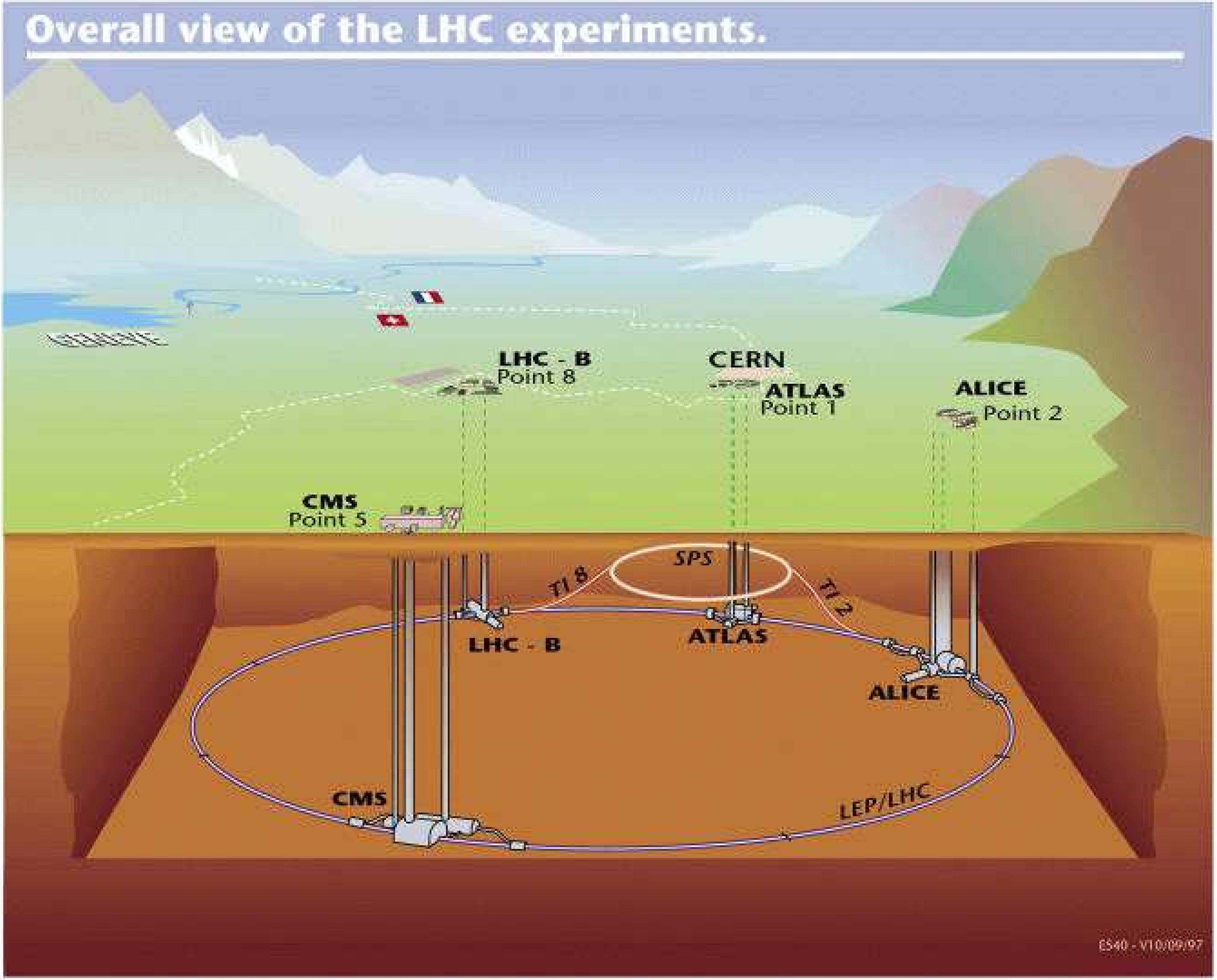
LHC:

$p\,p$ collisions at $\sqrt{s} \lesssim 14$ TeV

– 27 km circumference
– two general purpose detectors: ATLAS and CMS
– one B physics detector: LHCb
– one heavy ion detector: Alice






Overall view of the LHC experiments.
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
ES40 - V10/09/97

The (un)official (optimistic?) LHC time line:

03/2010: first collisions at record breaking energy

2010: $\lesssim 0.05\,\text{fb}^{-1}$ (at $\sqrt{s} = 7$ TeV)

2011: $\sim 5\,\text{fb}^{-1}$ (at $\sqrt{s} = 7$ TeV) $\Rightarrow$ first physics results!

2012: $\sim 20\,\text{fb}^{-1}$ (at $\sqrt{s} = 8$ TeV) $\Rightarrow$ **Higgs discovery!**

2013 – 2014 shutdown, further splice checks, repairs, . . .

2015 – 2018: $40\,\text{fb}^{-1}$ per year $\Rightarrow$ physics results at $\sqrt{s} \lesssim 14$ TeV

2019 – 2020: shutdown, preparation for "high luminosity"

2021 – 2023: $100\,\text{fb}^{-1}$ per year $\Rightarrow$ physics results with "high" luminosity

2024 – 2026: upgrade to HL-LHC?

$2026 + X$ ($X > 0$): HL-LHC?

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YOU live in an exciting time!!!

LHC Results: Executive Summary

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$\boxed{\text{No evidence for BSM physics - yet!}}$

LHC Results: Executive Summary

$\boxed{\text{Standard Model has been rediscovered!}}$

$\boxed{\text{No evidence for BSM physics - yet!}}$

$\boxed{\text{But a groundbreaking discovery in the Higgs searches!}}$

Physics at the LHC: basics

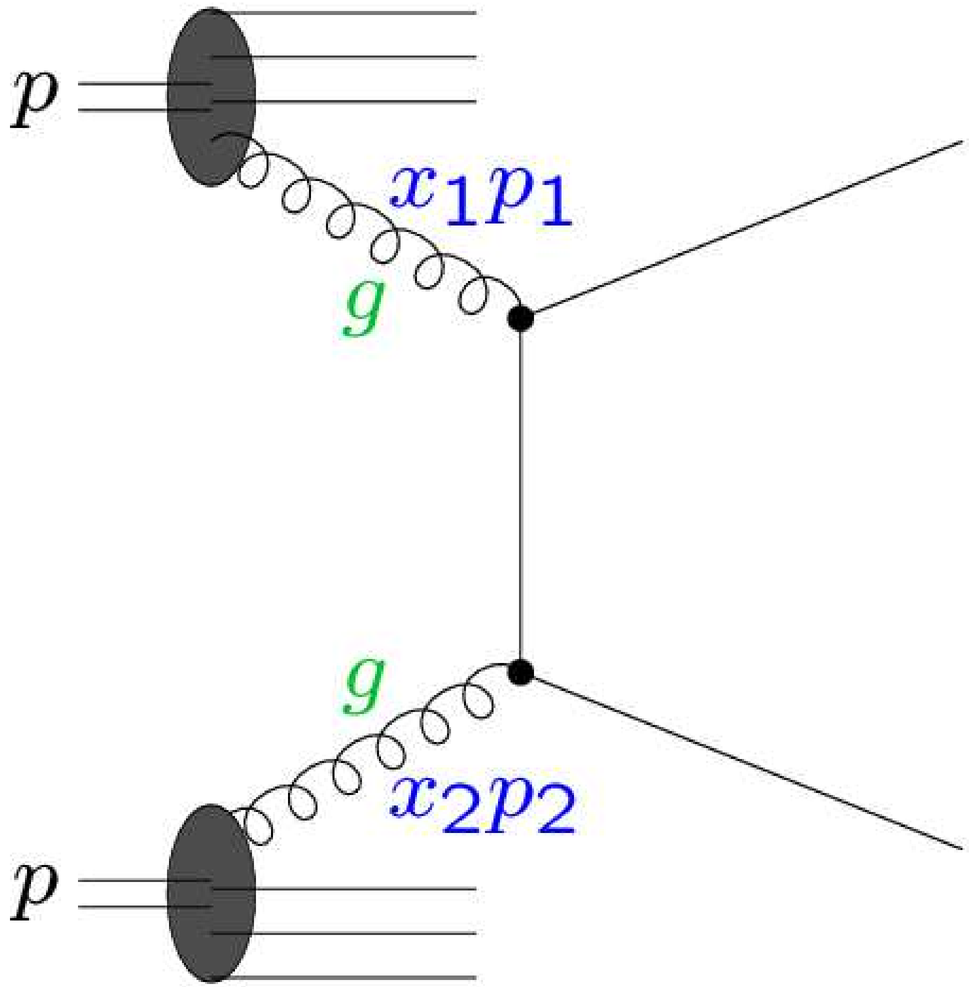
$p\,p$ scattering at $\sqrt{s} = 14$ TeV

Scattering process of proton constituents (q, $\bar{q}$, g) with energy up to several TeV, strongly interacting

$\Rightarrow$ huge QCD backgrounds, low signal–to–background ratios

interaction rate of 10^9 events$/s$

$\Rightarrow$ can trigger on only 1 event in 10^7

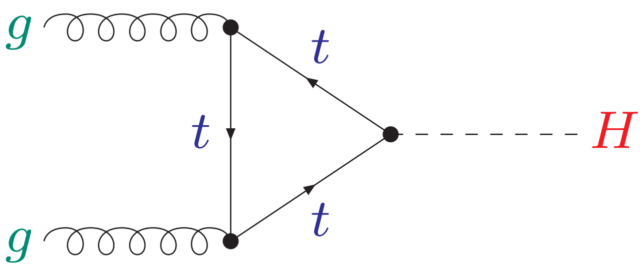


2. The SM Higgs boson at the LHC

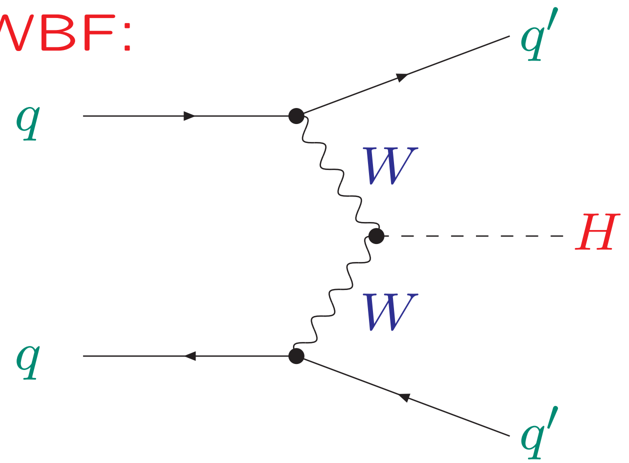
(SM) Higgs search at the LHC: (the minimum to remember)

Important SM production channel at the LHC:

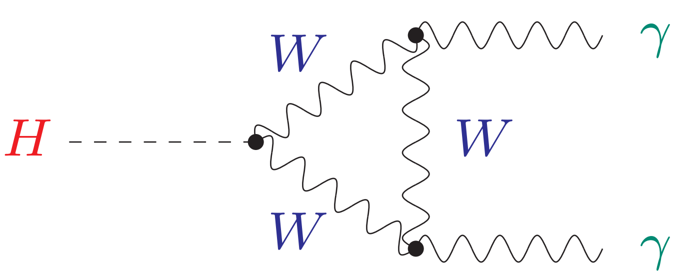
Gluon-Fusion:

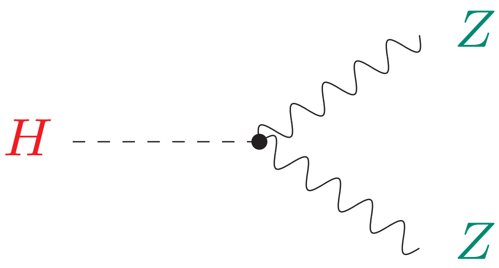


WBF:



Important decays for Higgs discovery/mass measurement:

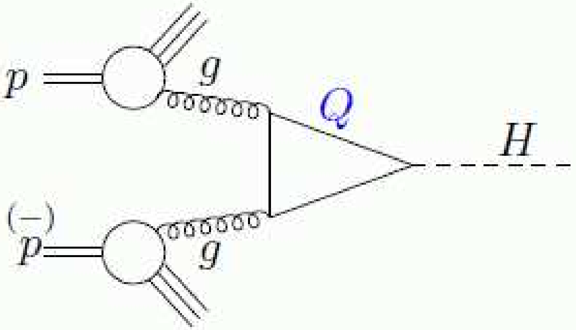




(SM) Higgs search at the LHC: Higgs production:

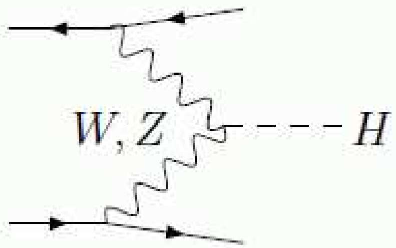
- **Gluon Gluon Fusion**

$pp \to gg \to H$



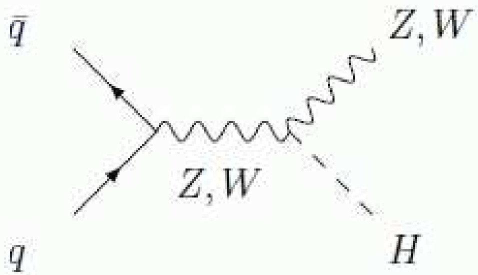
- **W/Z Fusion**

$pp \to qq \to qq + WW/ZZ \to qq + H$



- **Higgs-strahlung**

$pp \to W^*/Z^* \to W/Z + H$



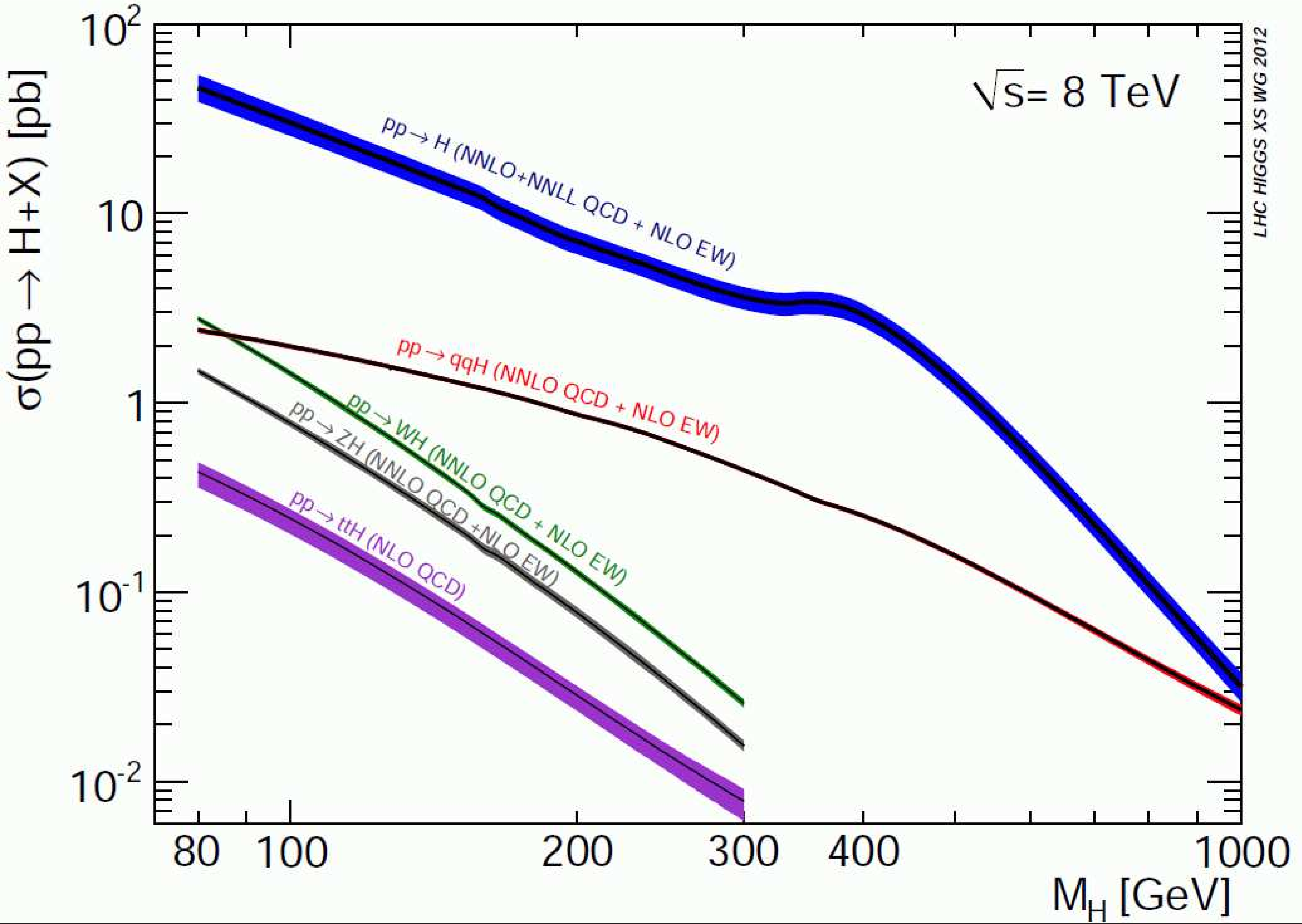
- **Associated production with $t\bar{t}$**

$pp \to t\bar{t} + H$

[*taken from M. Mühlleitner*]

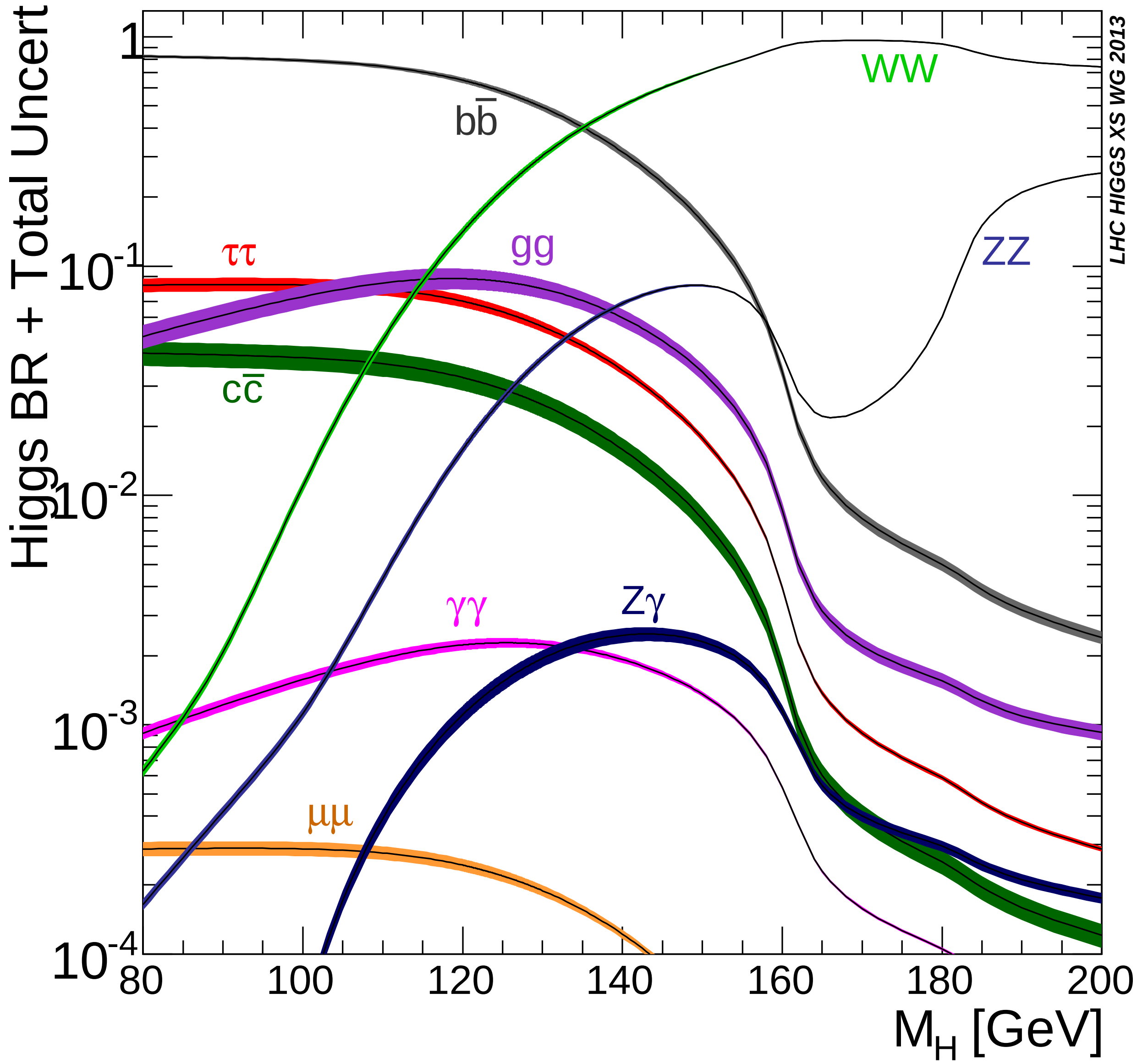
Latest theory predictions for the SM Higgs: LHC production XS

[*LHC Higgs XS WG '12*]



Latest theory predictions for the SM Higgs: branching ratios

[*LHC Higgs XS WG '13*]



Various possible "observables":

$\to$ normally given as a function of M_H

- Local p_0 value:

  probability that the observed signal/number of events is caused by "background only" (i.e. the SM without a Higgs)

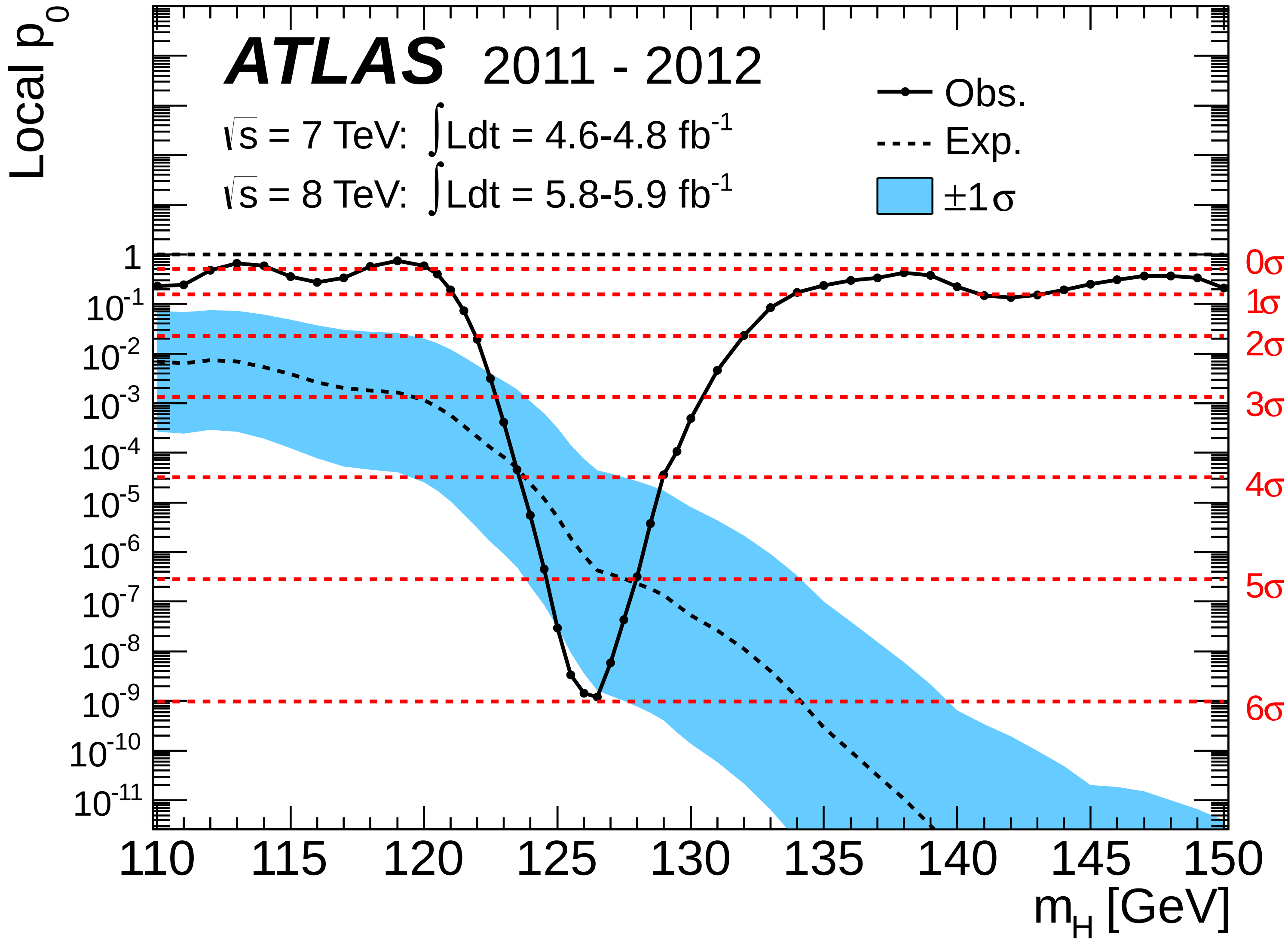
- $\sigma_{\text{excl.}}/\sigma_{\text{SM}}$:

  excluded cross section divided by SM cross section:
  if for a certain M_H a cross section smaller than the SM cross section excluded, this M_H value is excluded, as it would have led to more events than observed.

- signal strength μ:

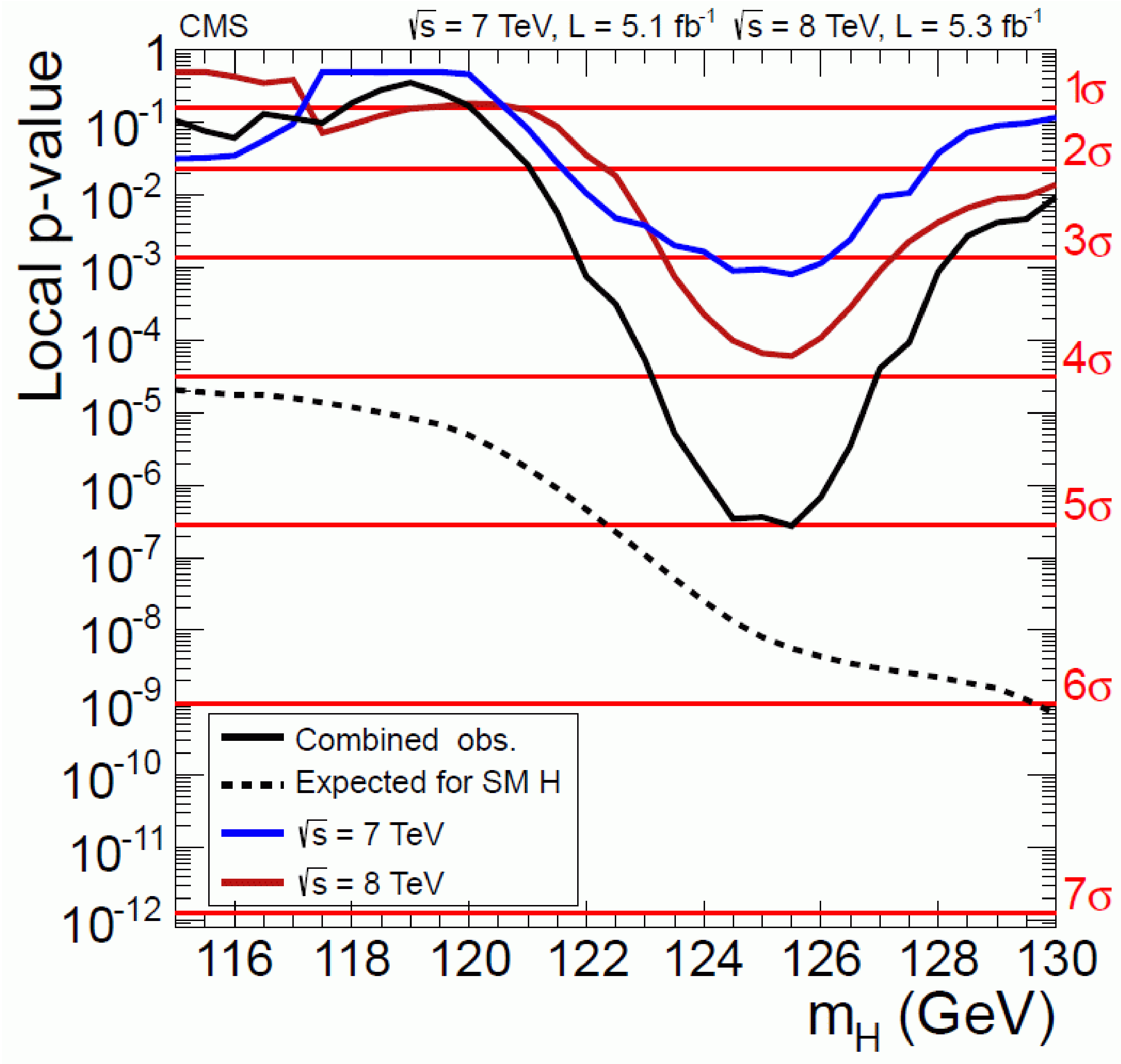
$$\mu := \frac{\sigma(pp \to H) \times \text{BR}(H \to dd')_{\text{observed}}}{\sigma(pp \to H) \times \text{BR}(H \to dd')_{\text{SM}}}$$

  should be "around 1" to find agreement with SM



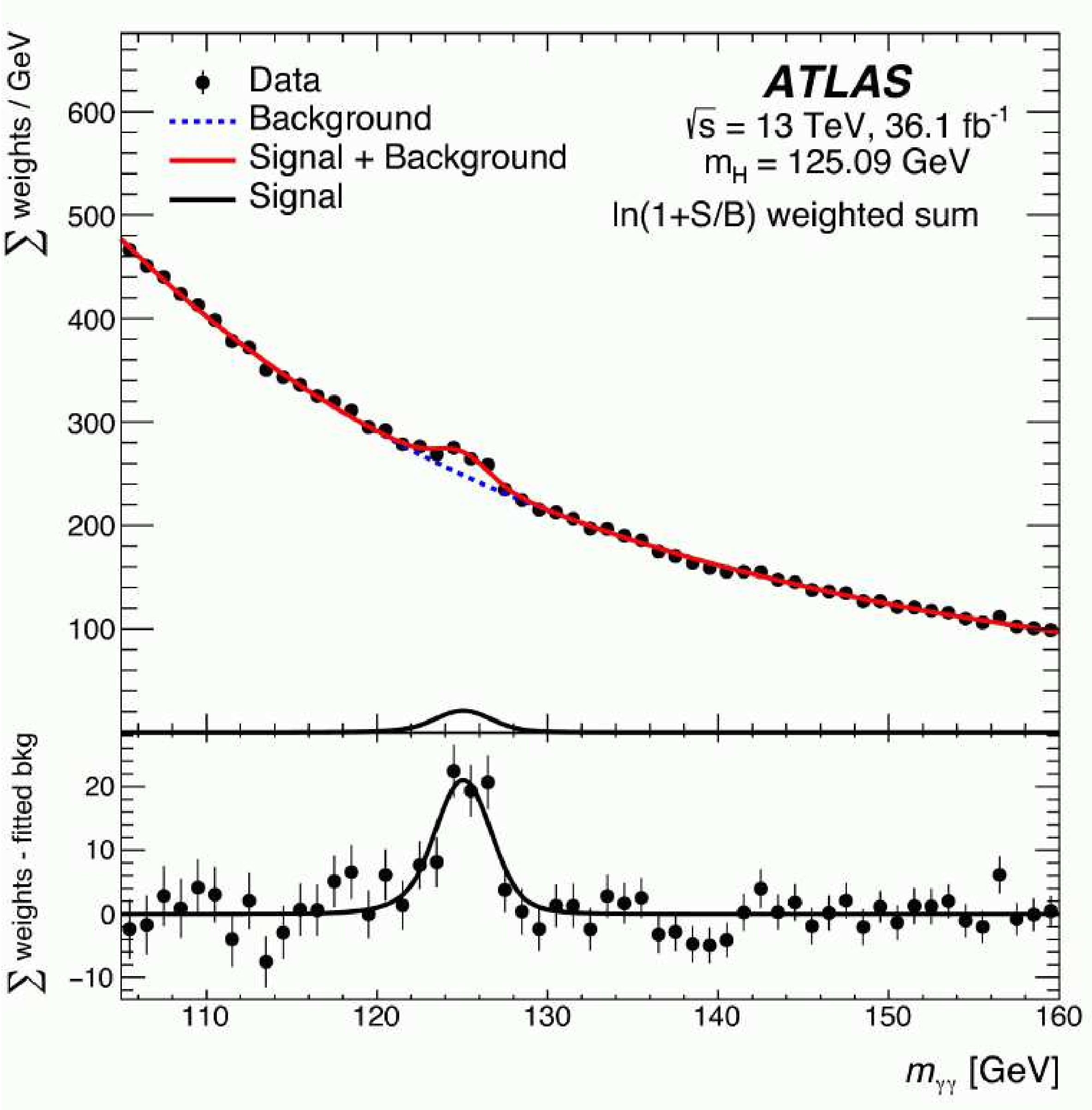
⇒ clear excesses for around $M_H \simeq 126.0$ GeV

04/07 CMS results in search for a SM Higgs: p_0 combined: [*CMS '12*]



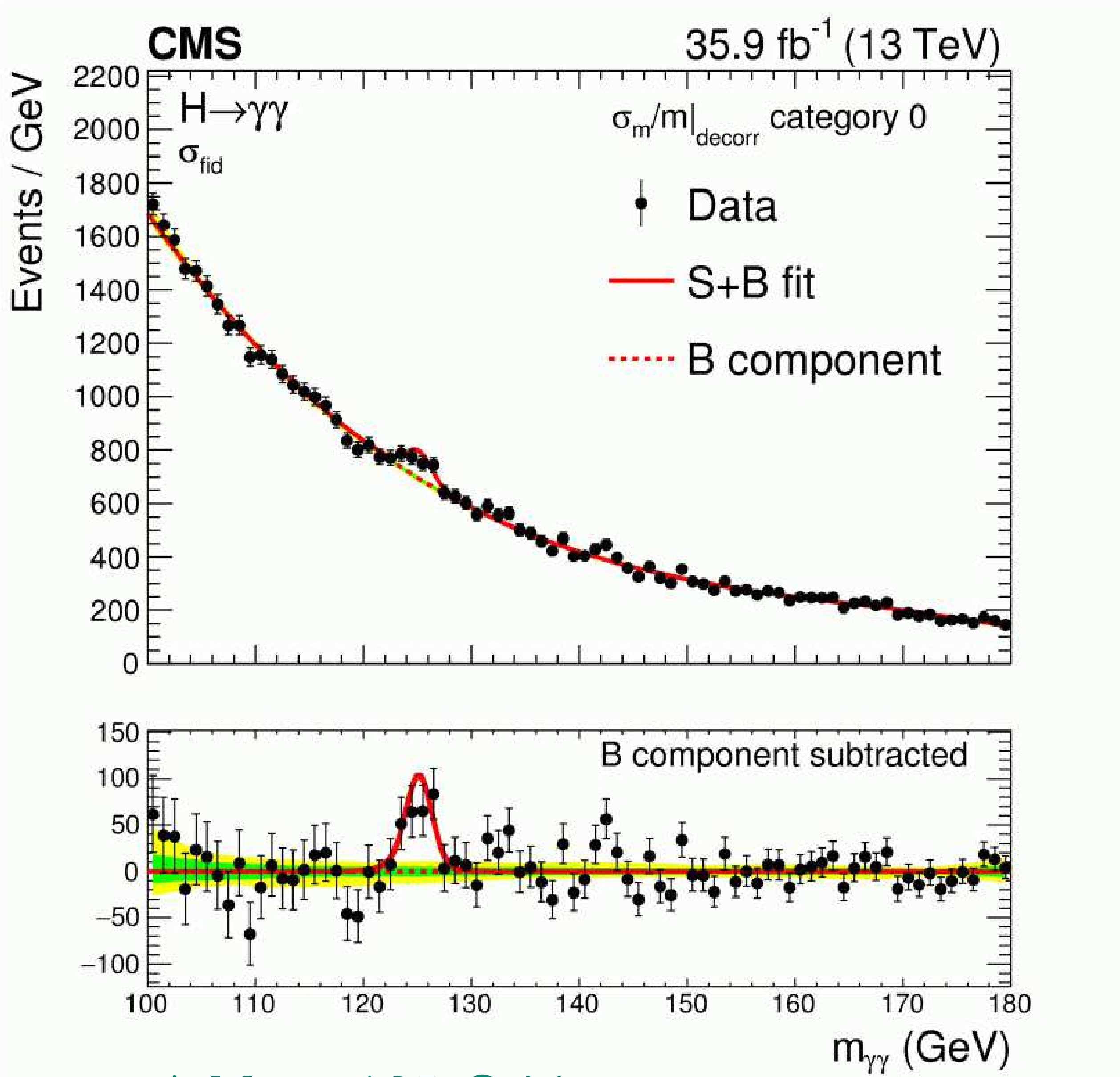
$\Rightarrow$ clear excesses for around $M_H \simeq 125.3$ GeV

ATLAS results in search for a SM Higgs in $\gamma\gamma$: [*ATLAS '18*]



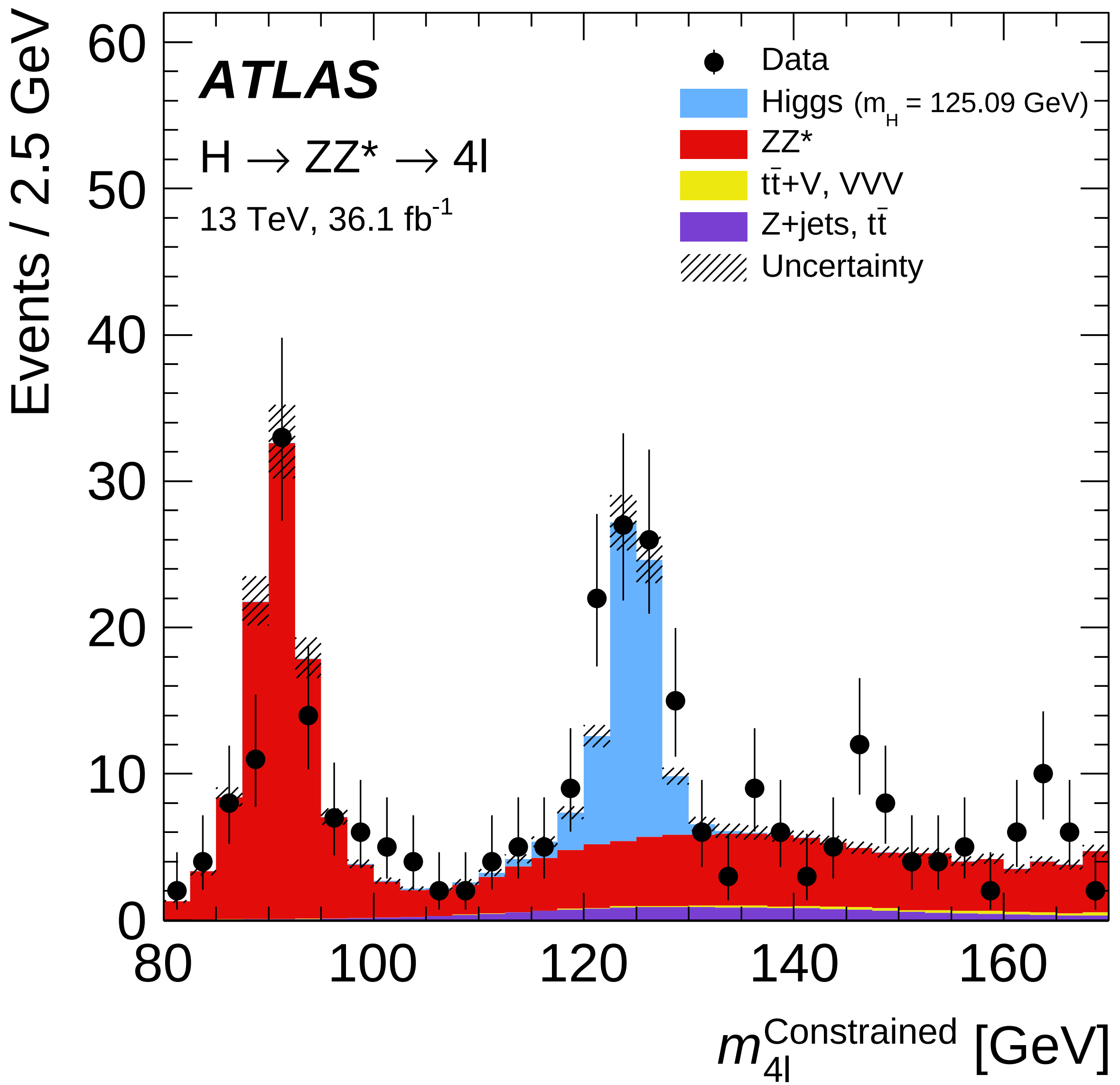
$\Rightarrow$ clear signal around $M_H \simeq 125.1$ GeV

CMS results in search for a SM Higgs in $\gamma\gamma$: [CMS '18]



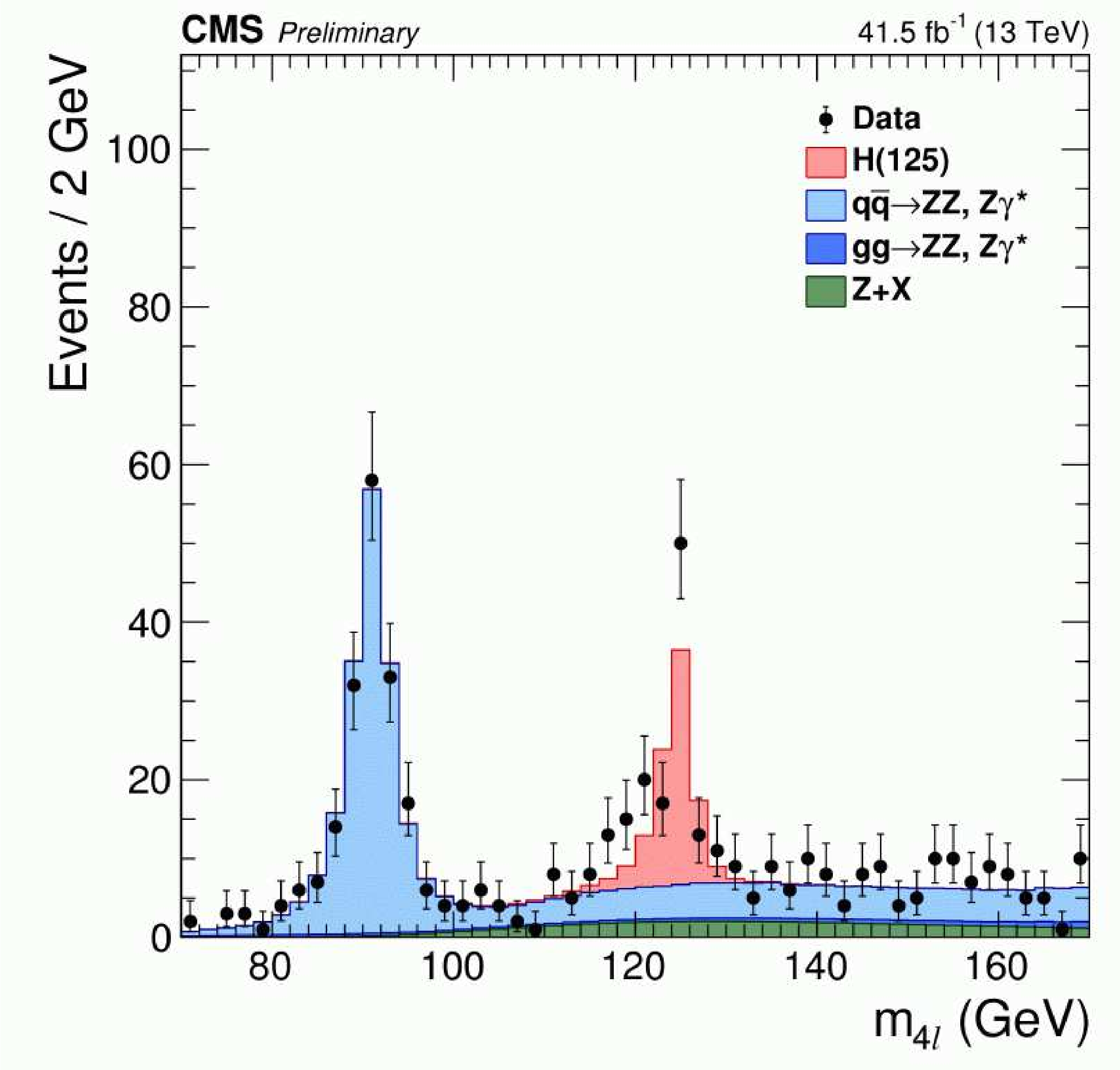
$\Rightarrow$ clear signal around $M_H \simeq 125$ GeV

ATLAS results in search for a SM Higgs in ZZ^*: [*ATLAS '18*]



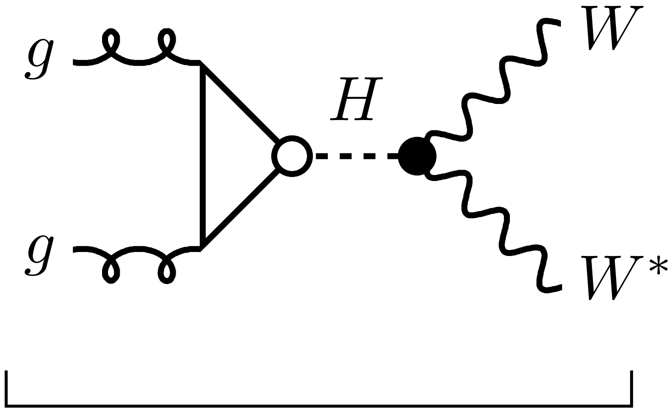
$\Rightarrow$ clear excesses for around $M_H \simeq 125$ GeV

CMS results in search for a SM Higgs in ZZ^*, 08/16: [*CMS '18*]

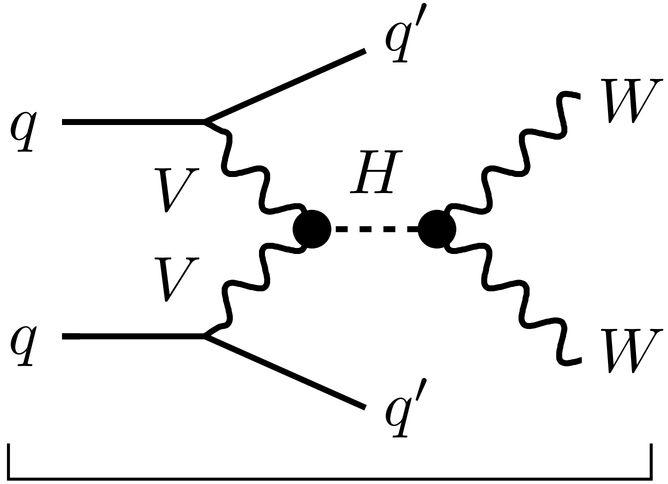


$\Rightarrow$ clear excesses for around $M_H \simeq 125$ GeV

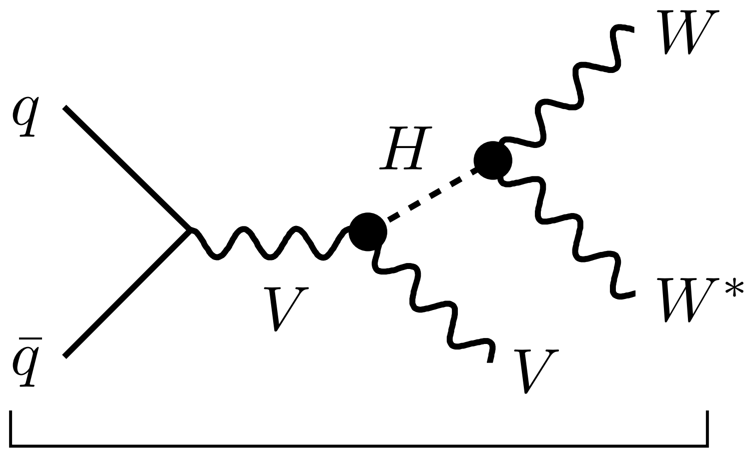
Other channels: $H \to WW^*$



ggF production



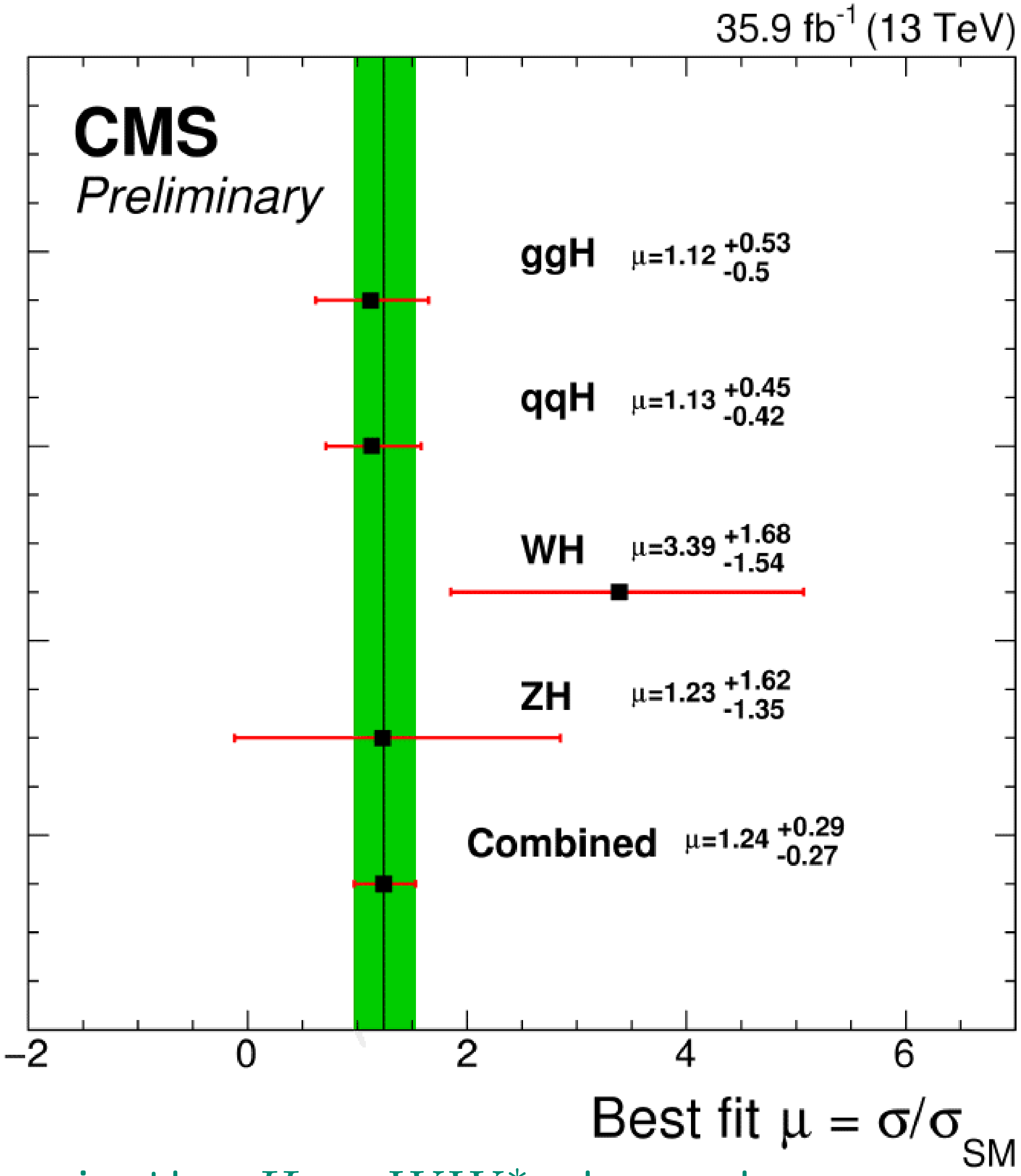
VBF production



VH production

Other channels: $H \to WW^*$

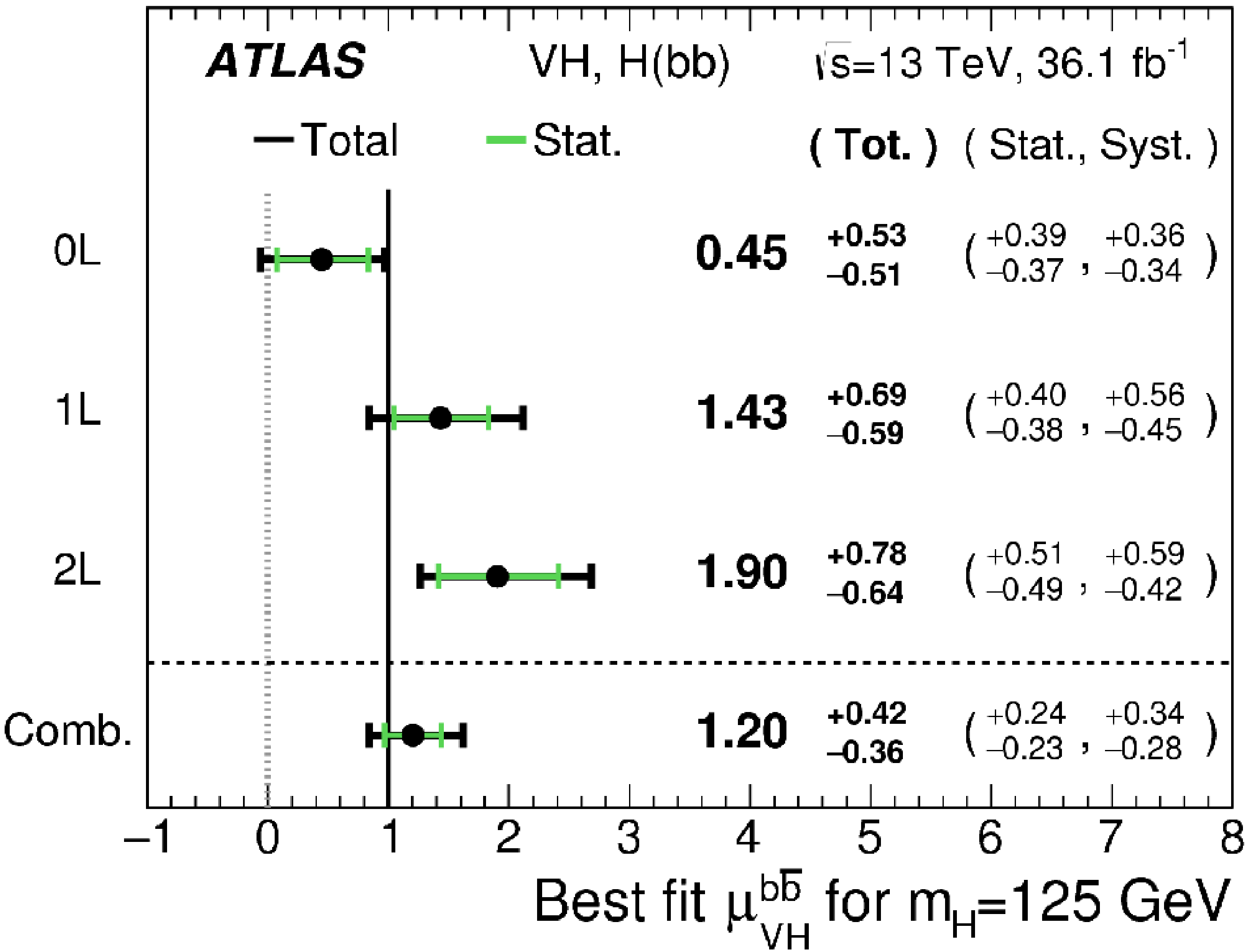
[CMS '18]



$\Rightarrow$ strong confirmation in the $H \to WW^*$ channel

Other channels: $H \to b\bar{b}$

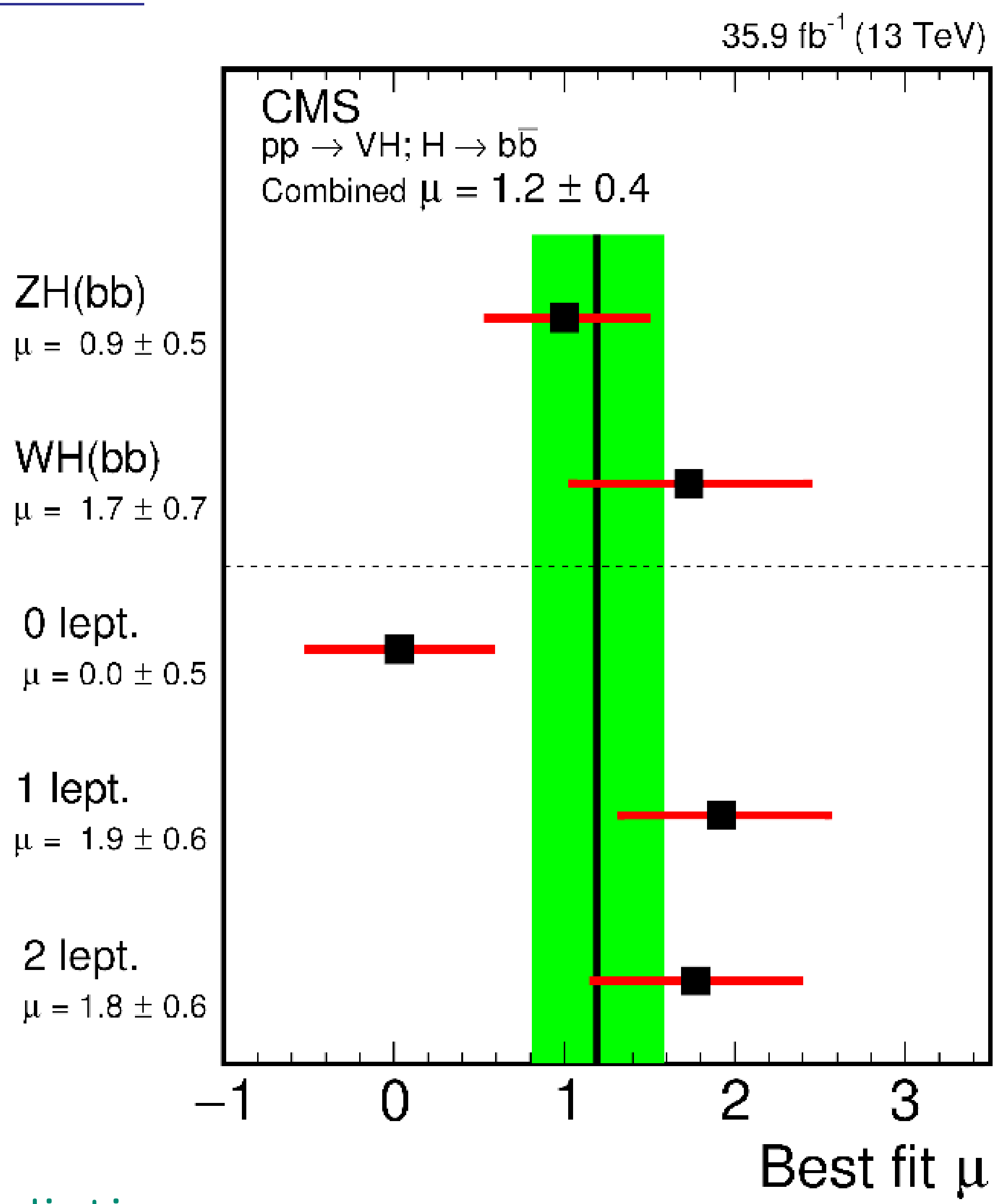
[ATLAS '18]



$\Rightarrow$ close to SM predictions

Other channels: $H \to b\bar{b}$

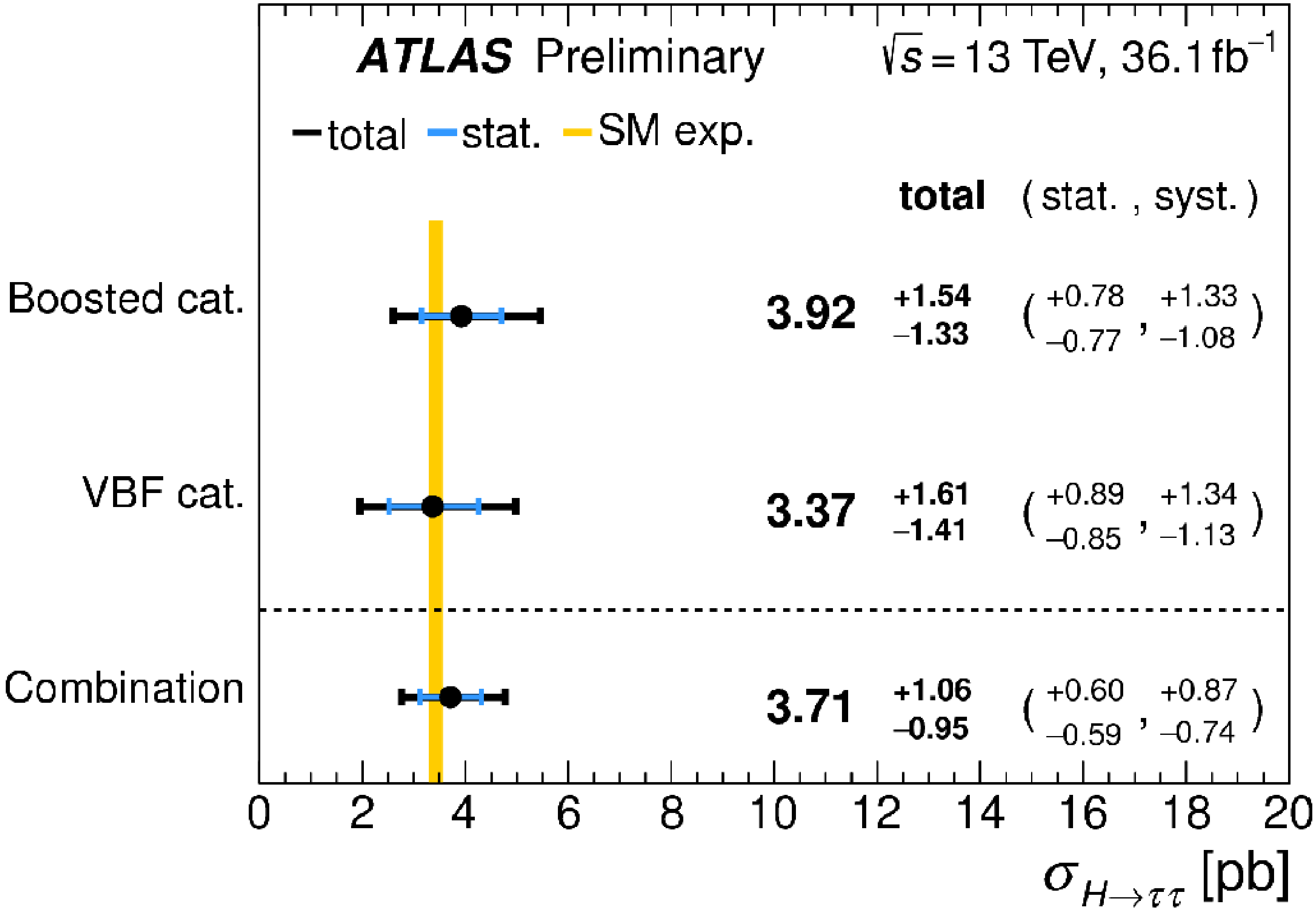
[*CMS '18*]



⇒ close to SM predictions

Other channels: $H \to \tau^+\tau^-$

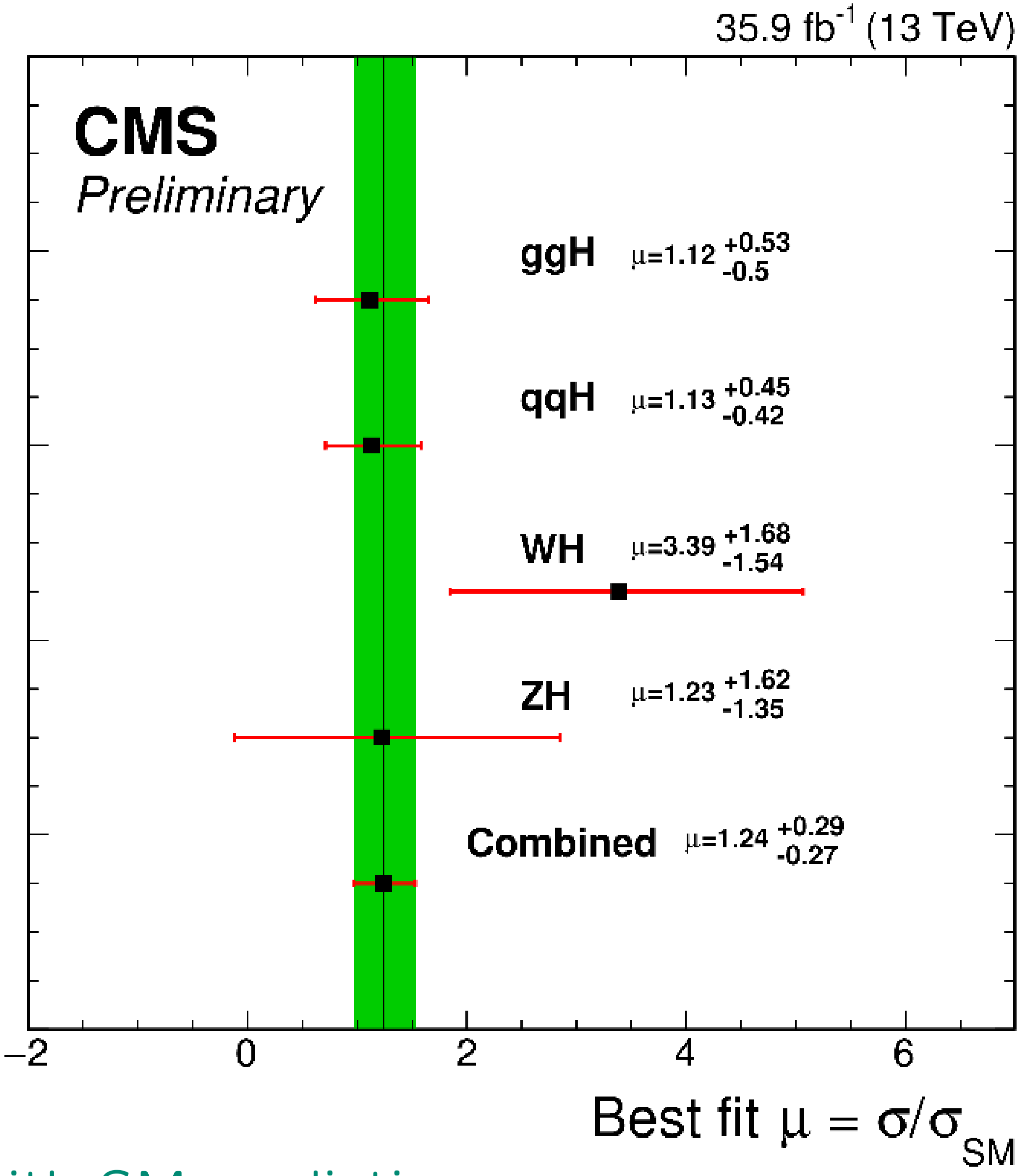
[ATLAS '18]



$\Rightarrow$ well compatible with SM prediction

Other channels: $H \to \tau^+\tau^-$

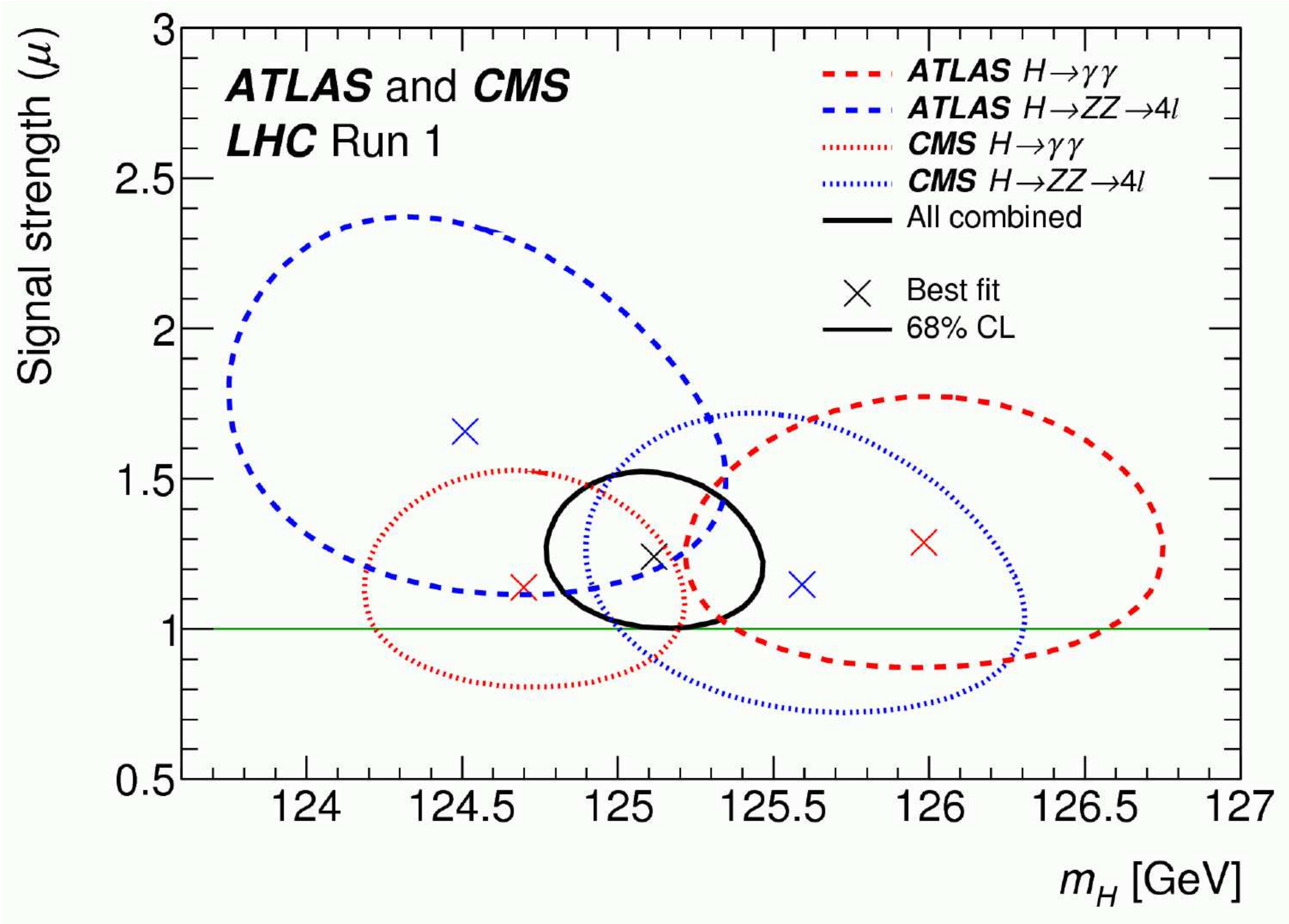
[*CMS '18*]



$\Rightarrow$ well compatible with SM prediction

Mass measurement, combination of $\gamma\gamma$ and ZZ^*:

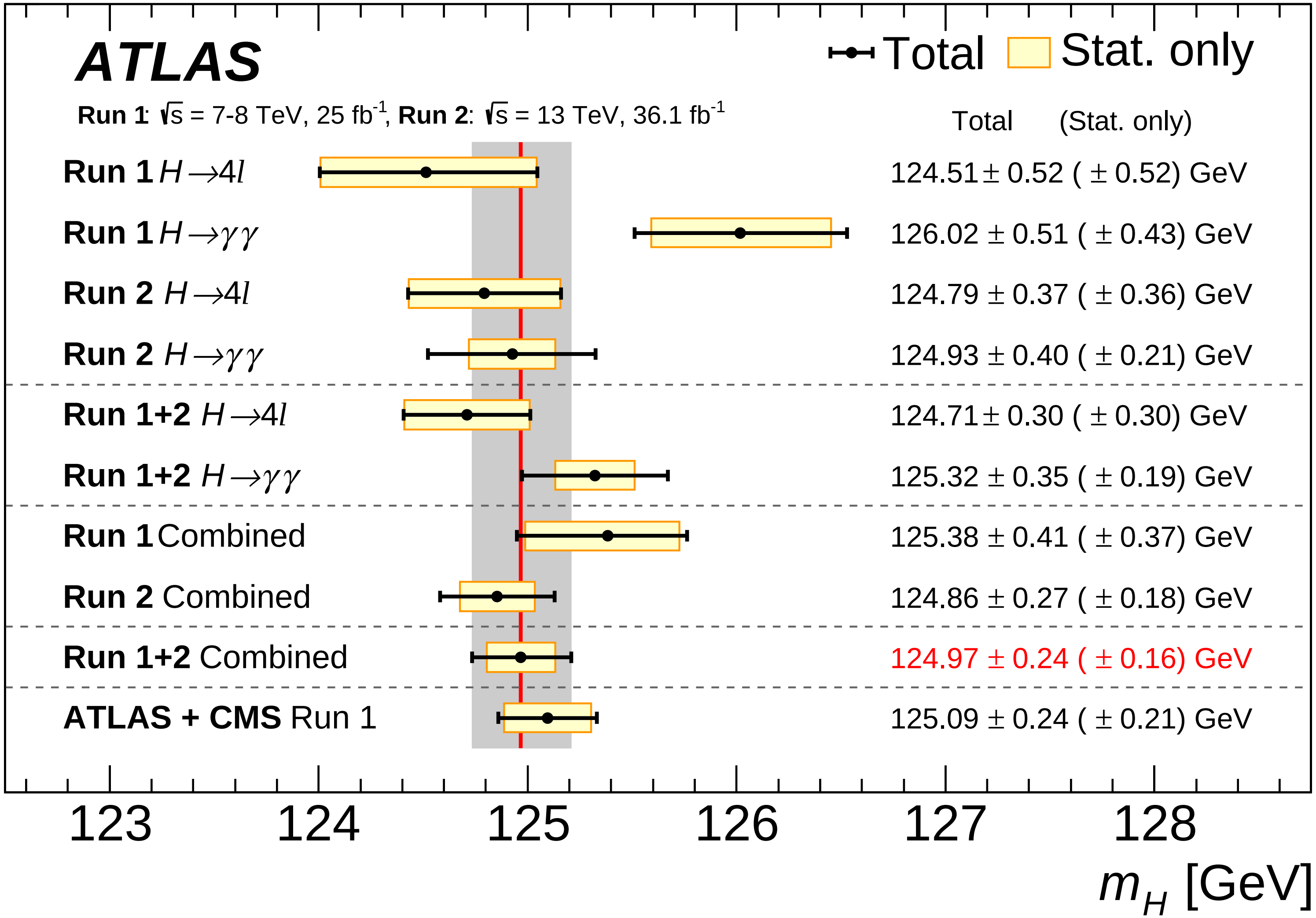
[ATLAS, CMS '15]



$\Rightarrow$ permille level "first" combination

Latest mass measurement in $\gamma\gamma$ and ZZ^*:

[*ATLAS, CMS '18*]



$\Rightarrow$ newer measurements confirm first combination

Comparison to SM prediction:

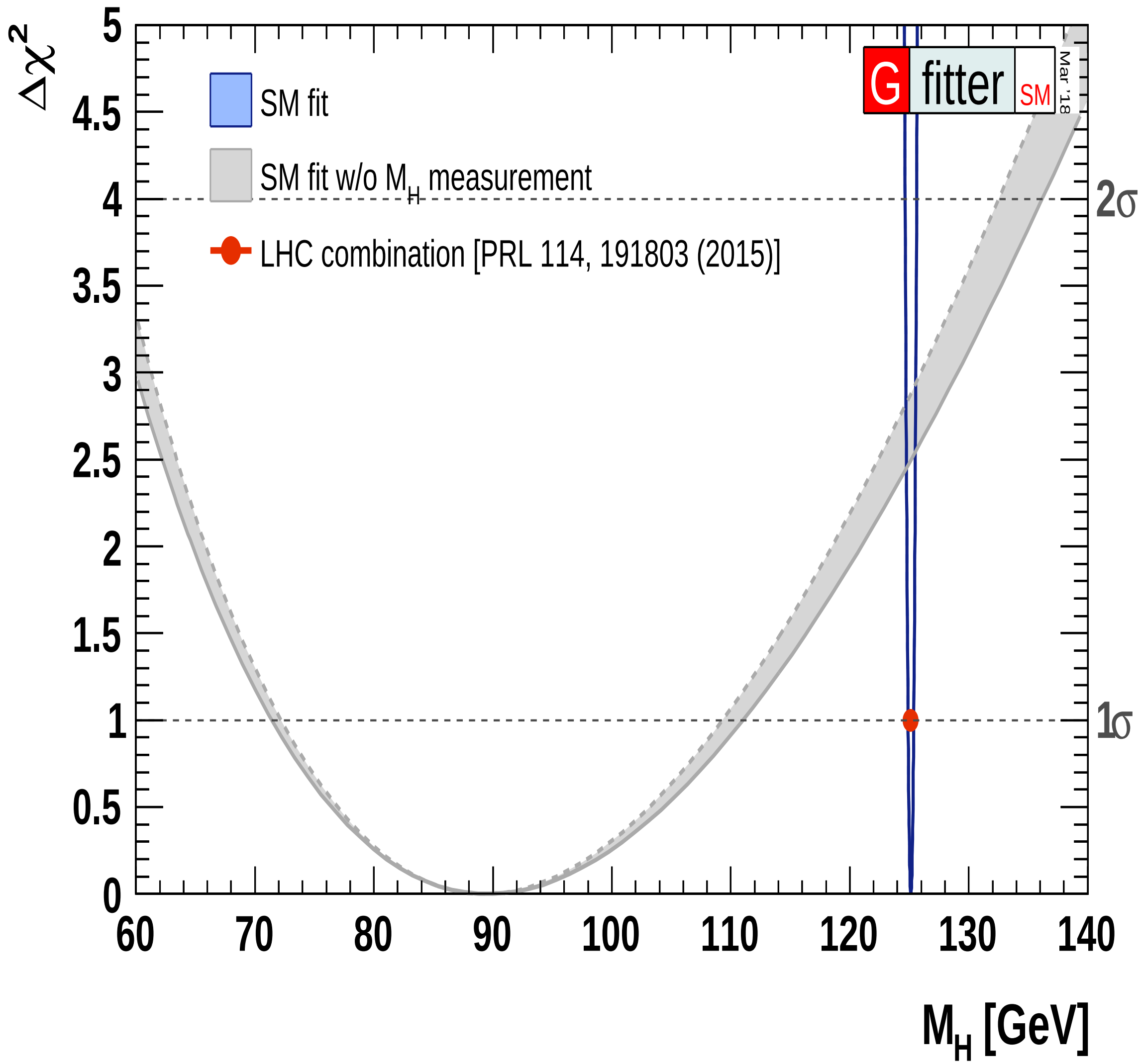
[GFitter '18]

$\Rightarrow\ M_H = 90^{+21}_{-18}$ GeV

"agreement" at $1.8\,\sigma$

Assumption for the fit:
SM incl. Higgs boson

$\Rightarrow$ no confirmation of
Higgs mechanism



$\Rightarrow$ Observed Higgs well compatible with SM prediction (at $1.8\,\sigma$)

LHC Higgs Cross Section Working Group: Low Mass (LM) subgroup:

Assumptions (for Run I data):

1. Signal corresponds to only one state, no overlapping signal etc.
2. Zero-width approximation
3. Only modification of coupling strength (absolute values of couplings) but not of tensore structure wrt. to SM

Recommendations (for Run I data):

1. Use state-of-the-art predictions in the SM and rescale the predictions with "leading order inspired" scale factors κ_i
   ($\kappa_i = 1$ corresponds to the SM case)
2. Most general case: $\kappa_W, \kappa_Z, \kappa_t, \kappa_b, \kappa_\tau, \ldots \oplus$ extra loop contributions to $\sigma(gg \to H)$, $\Gamma(H \to gg)$, $\Gamma(H \to \gamma\gamma)$, $\Gamma_{H,\text{tot}}$
3. benchmarks:
   - one parameter: overall signal strength $\kappa^2 \equiv \mu$
   - two parameters: $\kappa_V := \kappa_W = \kappa_Z$, $\kappa_F := \kappa_t = \kappa_b = \kappa_\tau = \ldots$
   - ...

Recommendations continued:

Total width $\Gamma_{H,\text{tot}}$ cannot be measured without further theory assumptions. (This is not a recommendation, but a fact!)

For each benchmark (except overall coupling strength) two versions are proposed:
with and without taking into account the possibility of additional contributions to the total width

1) additional contributions to $\Gamma_{H,\text{tot}}$ are allowed:

$\Rightarrow$ Determination of ratios of scaling factors, e.g. $\kappa_i\,\kappa_j/\kappa_H$

2) additional contributions to $\Gamma_{H,\text{tot}}$ are allowed:

but assume that all additional decays are "invisible" with MET

$\Rightarrow$ Determination of κ_i

3) additional contributions to $\Gamma_{H,\text{tot}}$ are allowed:

but assume that $\kappa_{W,Z} \le 1$ (fulfilled for Higgs-singlets, -doublets)

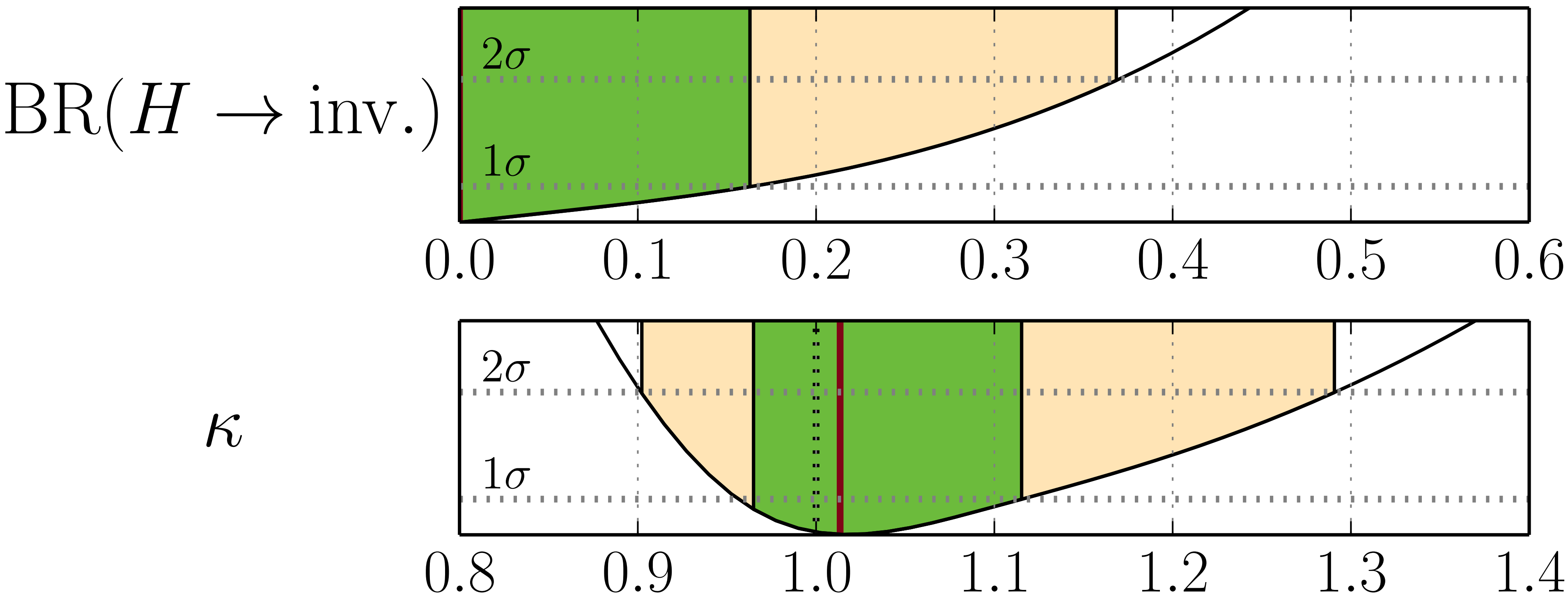
$\Rightarrow$ Determination of κ_i

4) no additional contributions to $\Gamma_{H,\text{tot}}$ are allowed: $\Rightarrow$ Determination of κ_i

Coupling scale factor results (I):

[*P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein - full Run I*]

Simplest model: κ, BR($H \to$ inv.)



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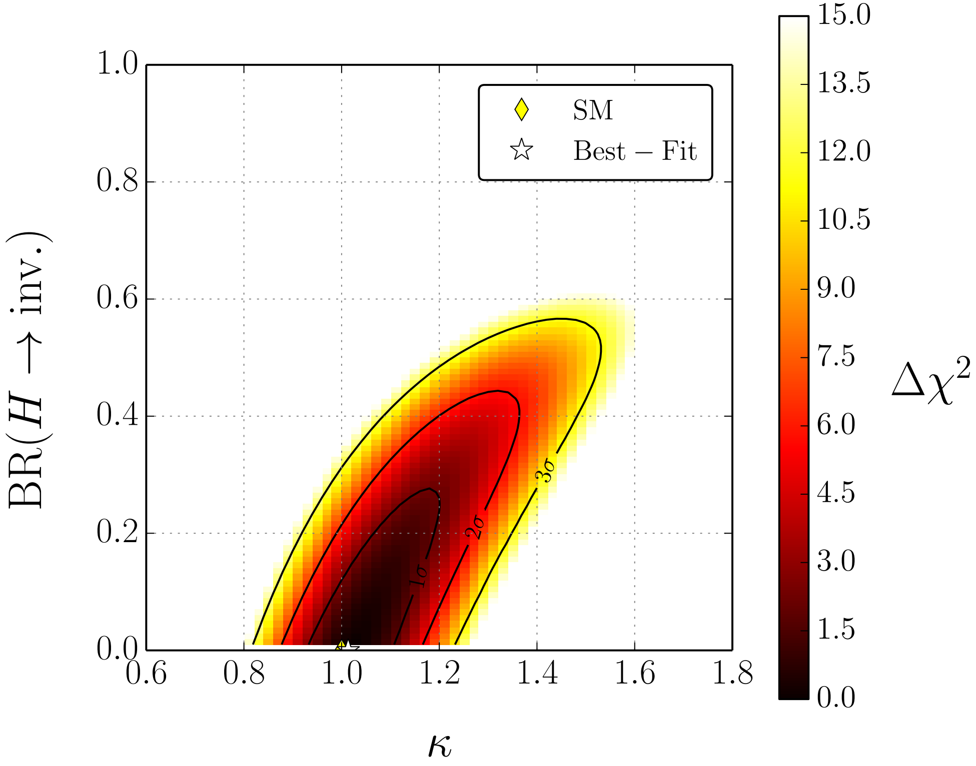
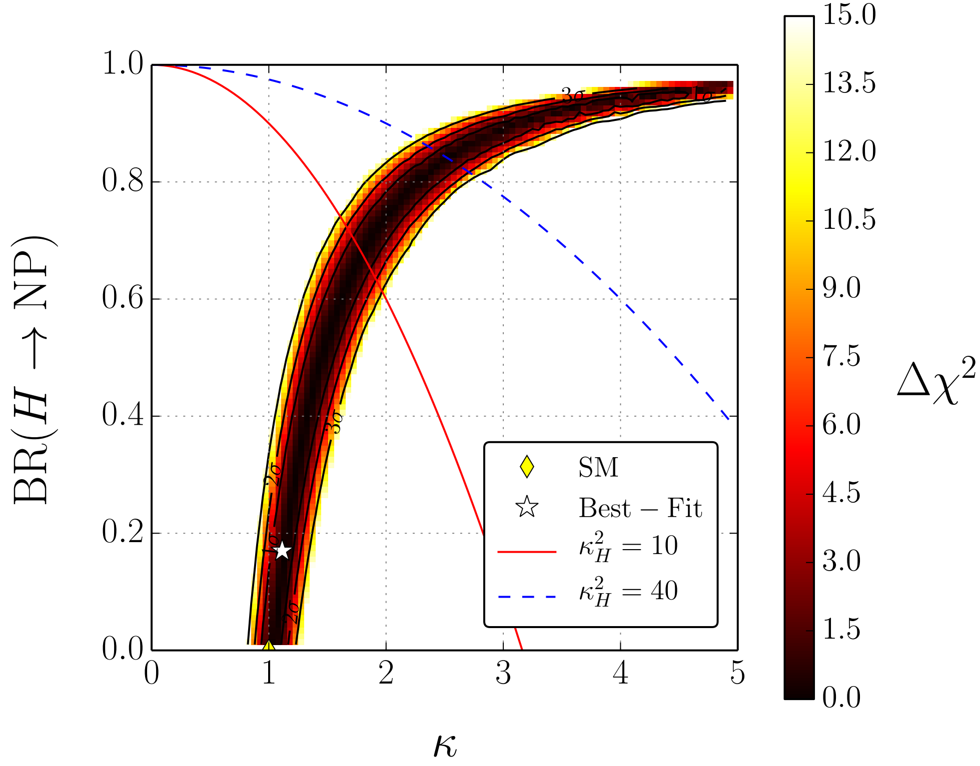
Simplest model: κ, BR($H \to$ inv.)

BR($H \to$ NP) = BR($H \to$ inv.)



no assumptions

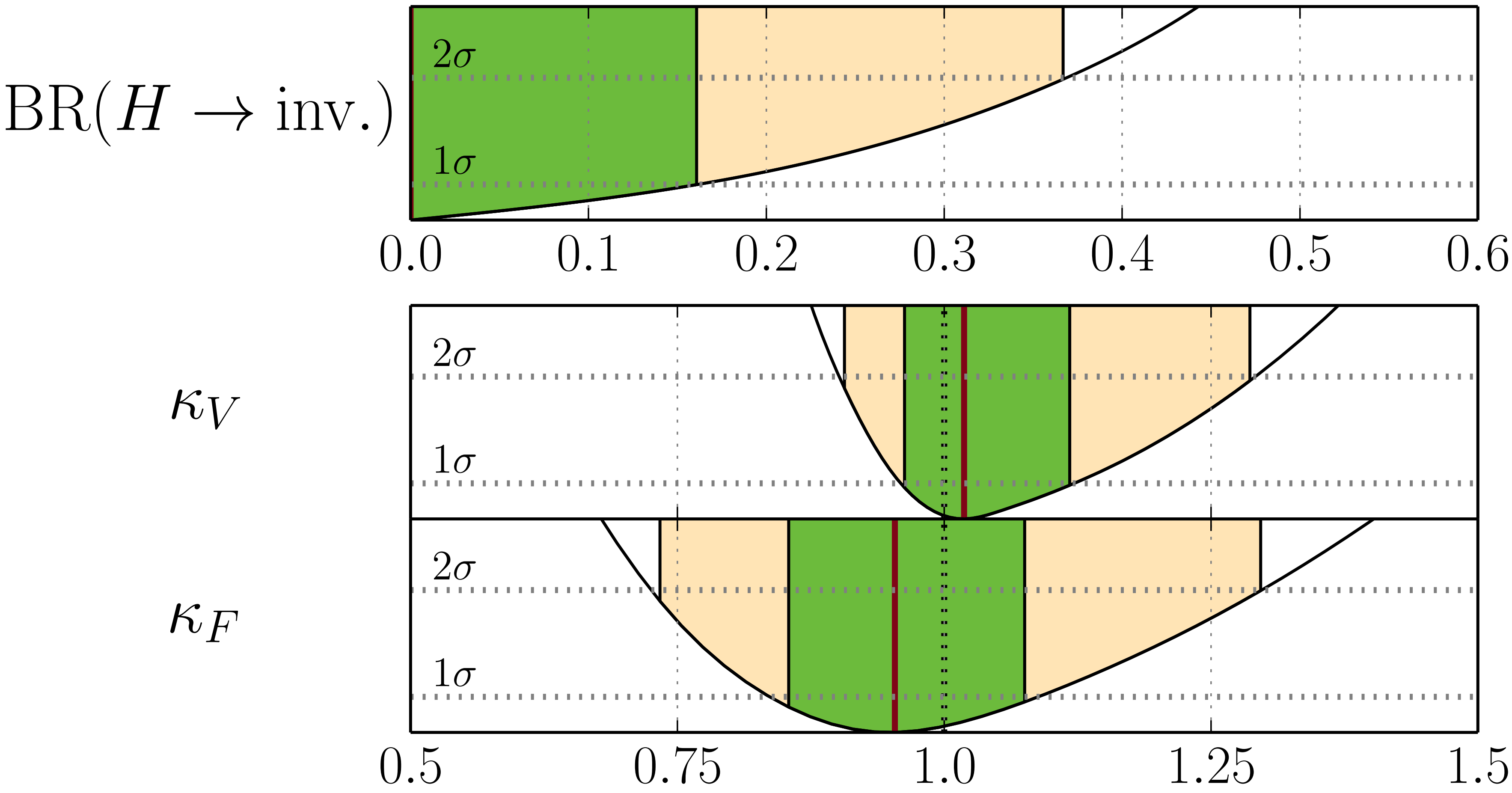


$\Rightarrow$ no theory assumptions on $\Gamma_{H,\text{tot}}$: no limits on κ

Coupling scale factor results (II):

[*P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein - full Run I*]

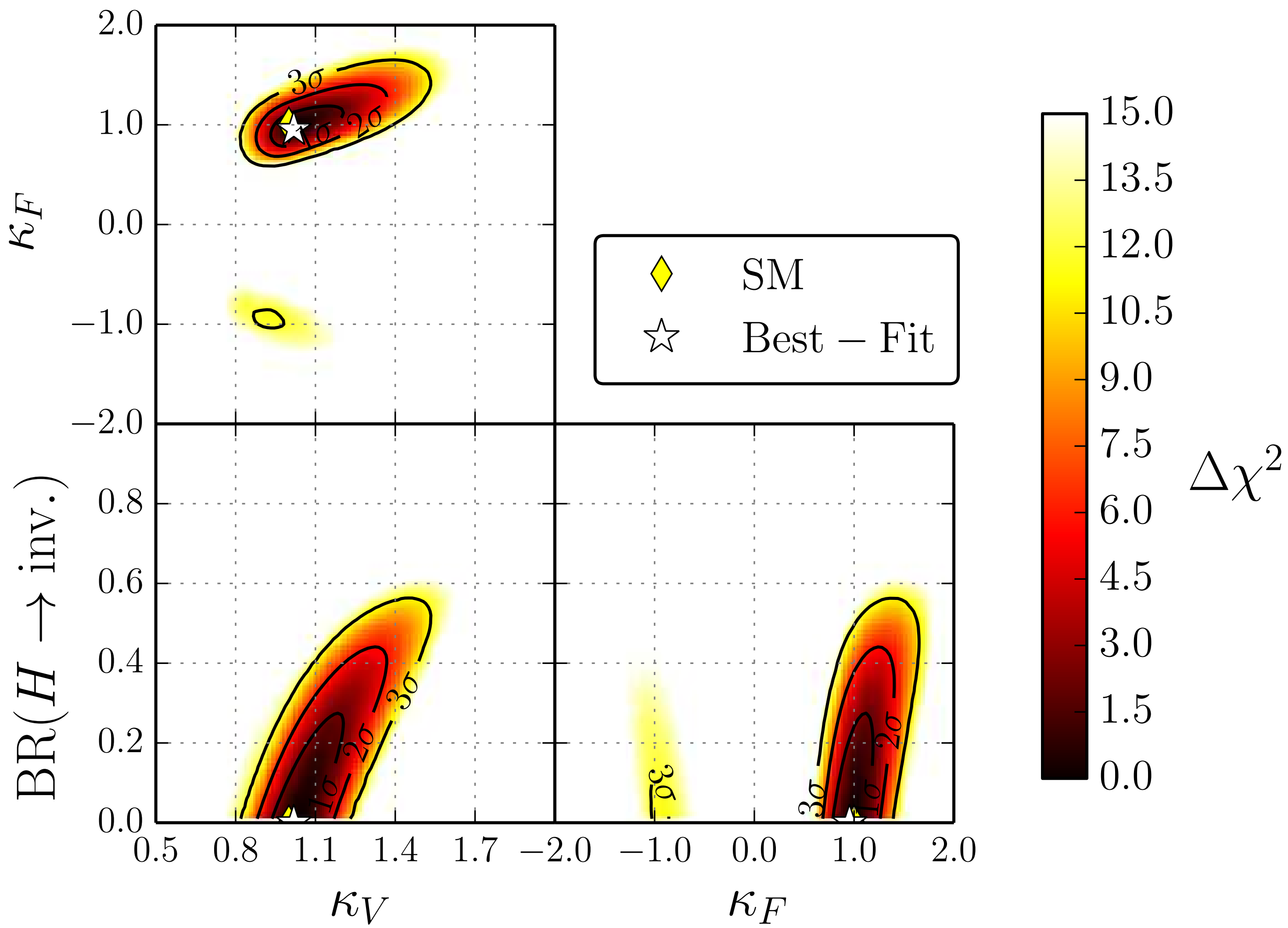
Another simple model: $\kappa_V, \kappa_F, \mathrm{BR}(H \to \mathrm{inv.})$



Coupling scale factor results (II):

[*P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein - full Run I*]

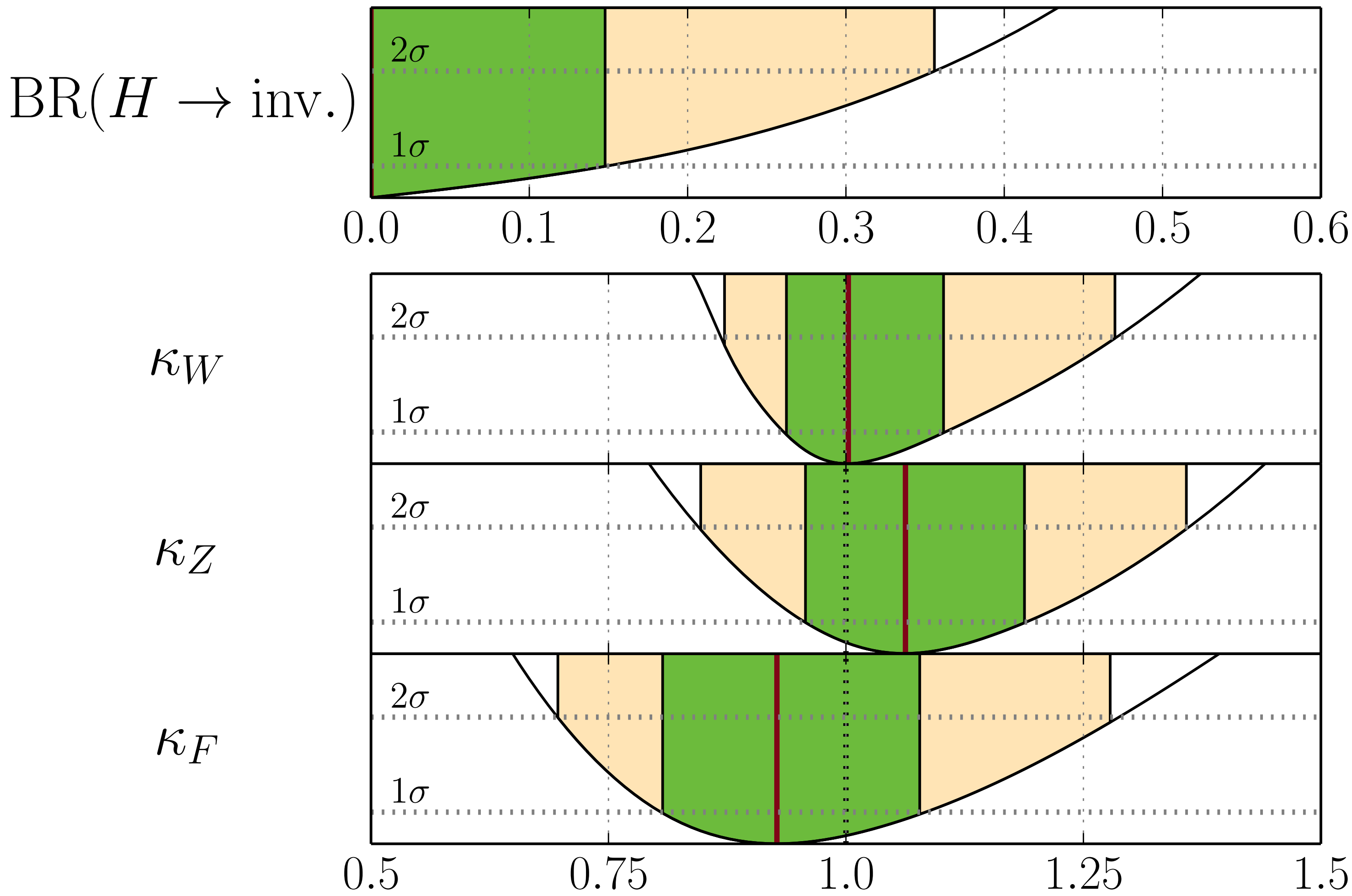
Another simple model: κ_V, κ_F, BR($H \to$ inv.)



Coupling scale factor results (III):

[P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein - full Run I]

Probing the custodial symmetry: $\kappa_W, \kappa_Z, \kappa_F, \mathrm{BR}(H \to \mathrm{inv.})$



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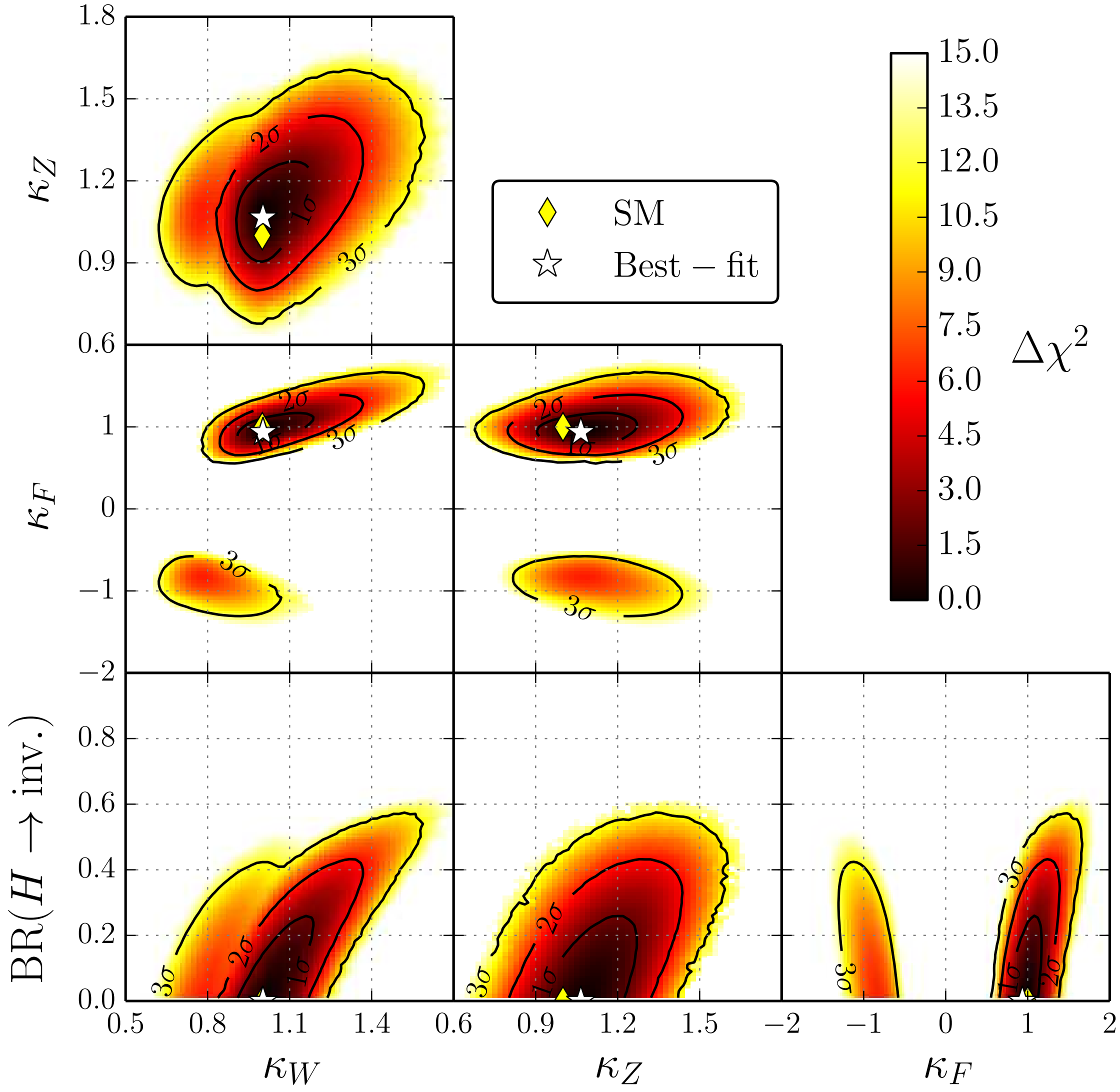
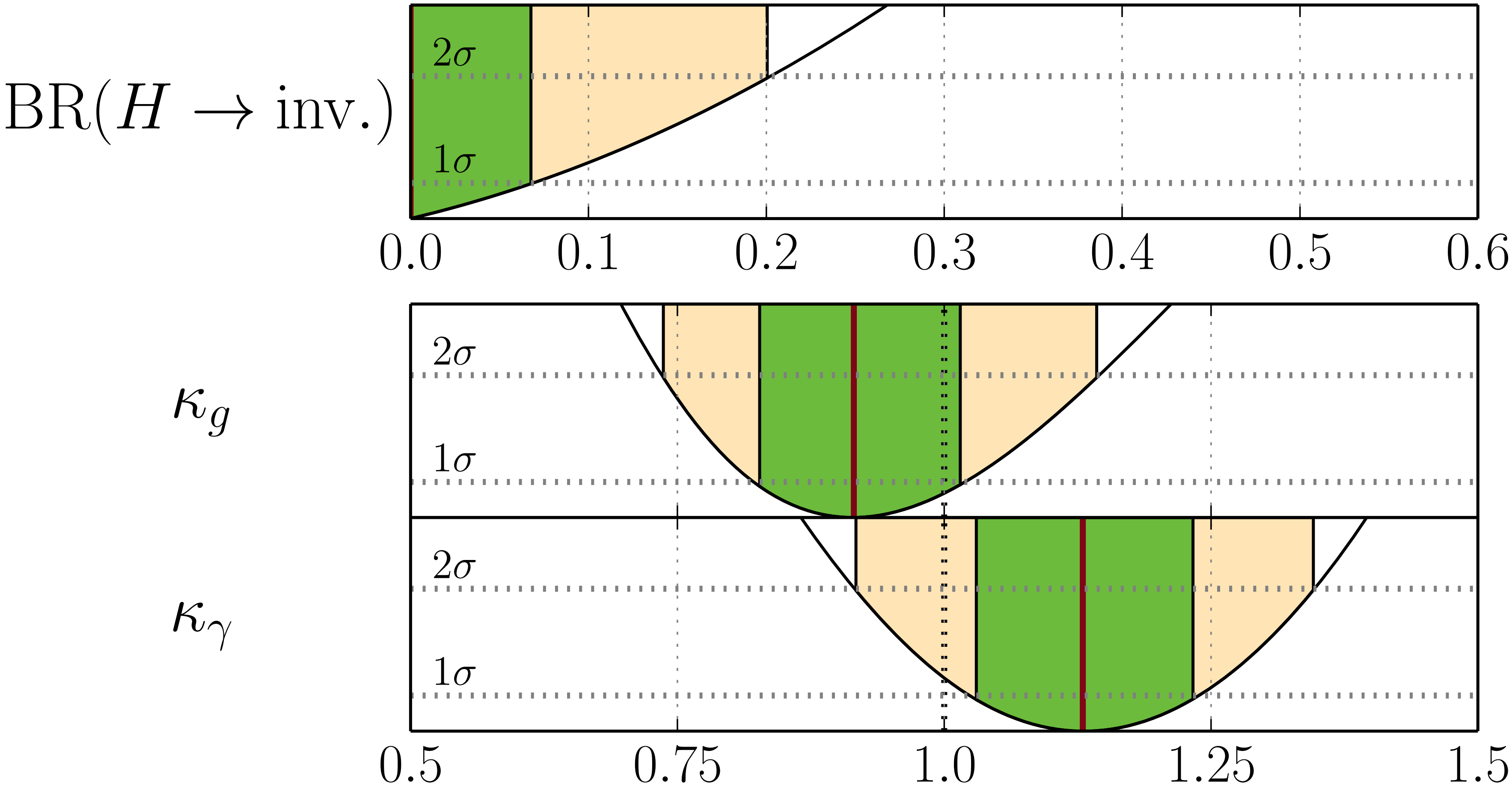


Coupling scale factor results (IV):

[*P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein - full Run I*]

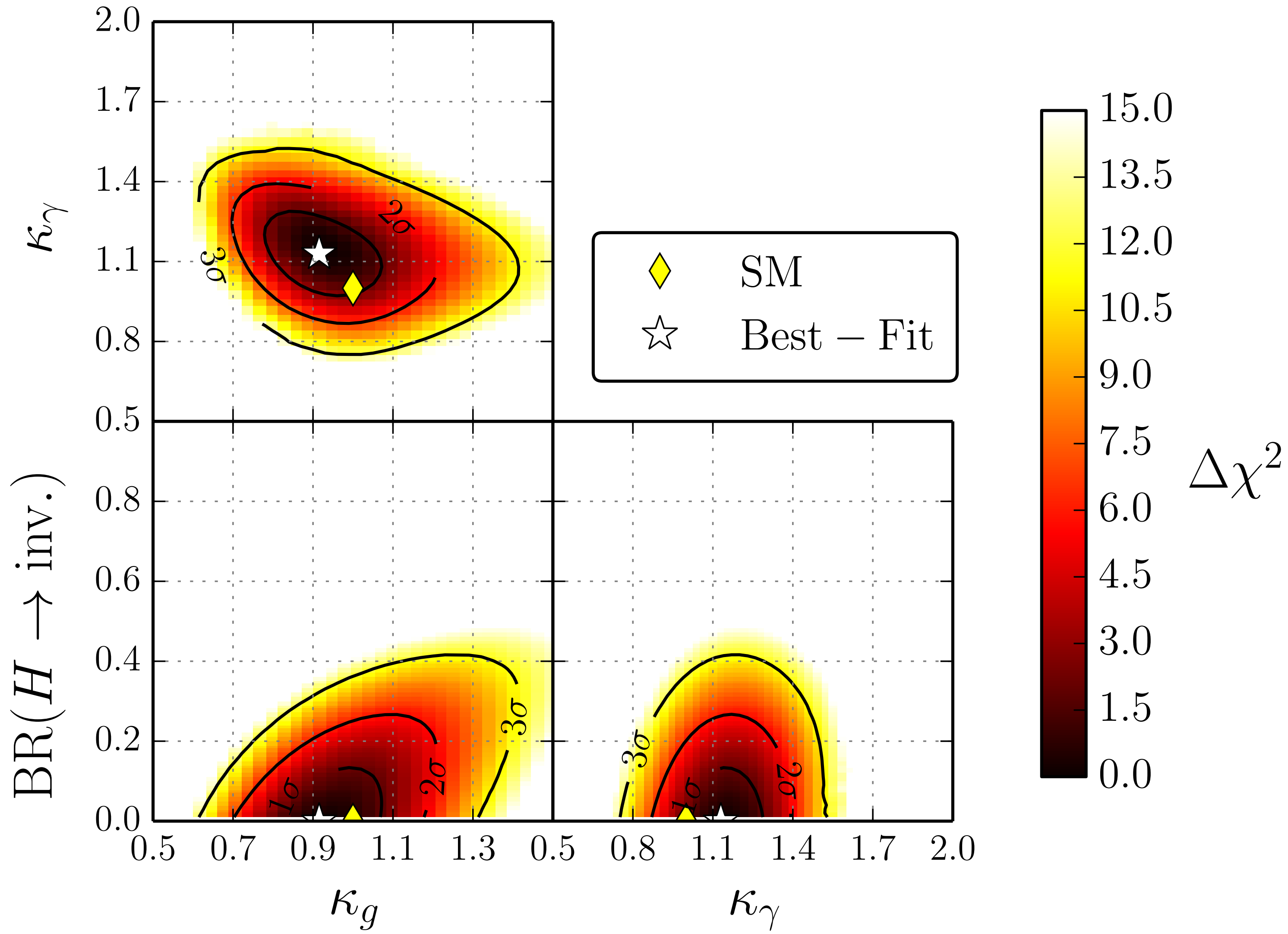
New physics in loop-induced couplings: κ_g, κ_γ, BR($H \to$ inv.)



Coupling scale factor results (IV):

[P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein - full Run I]

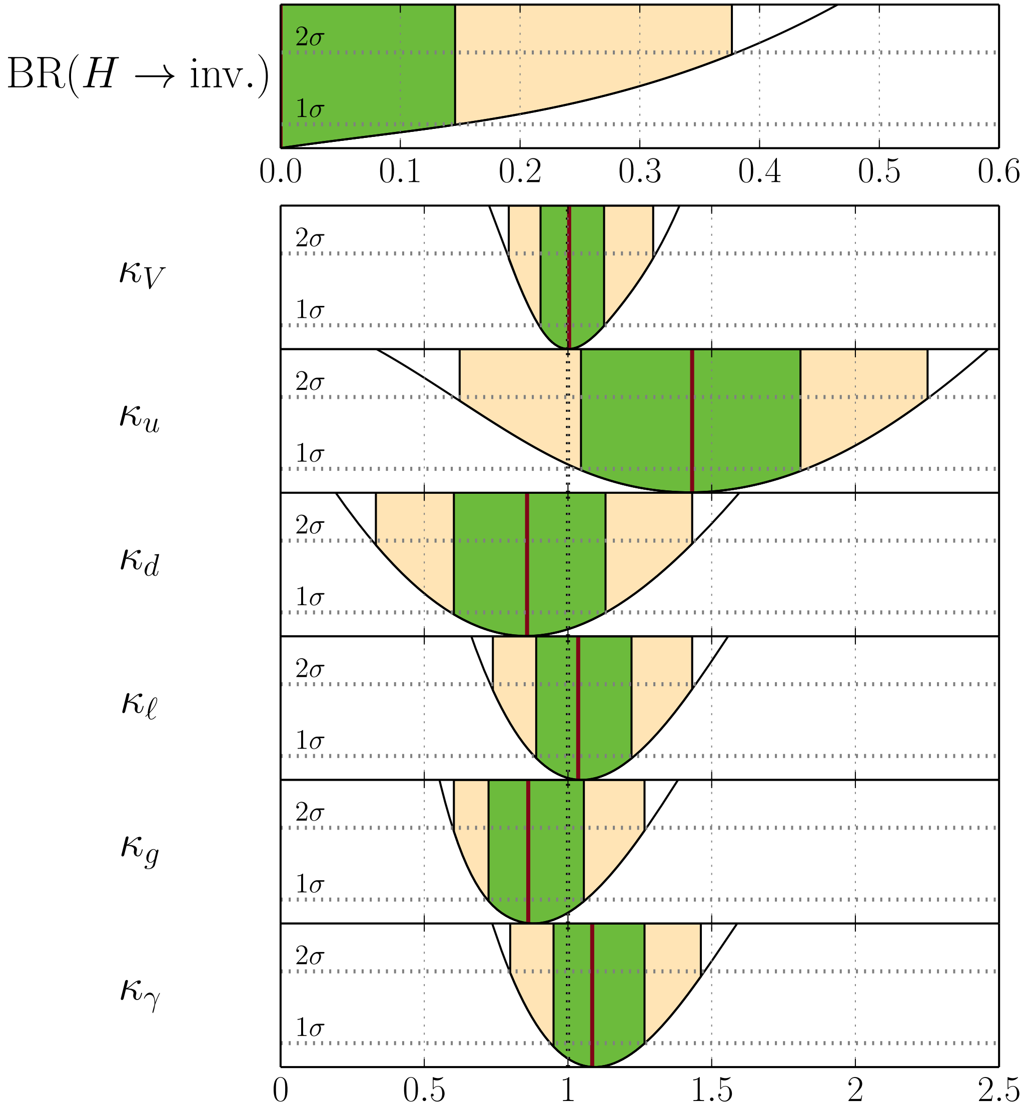
New physics in loop-induced couplings: $\kappa_g, \kappa_\gamma, \mathrm{BR}(H \to \mathrm{inv.})$



Coupling scale factor results (V):

[*P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein - full Run I*]

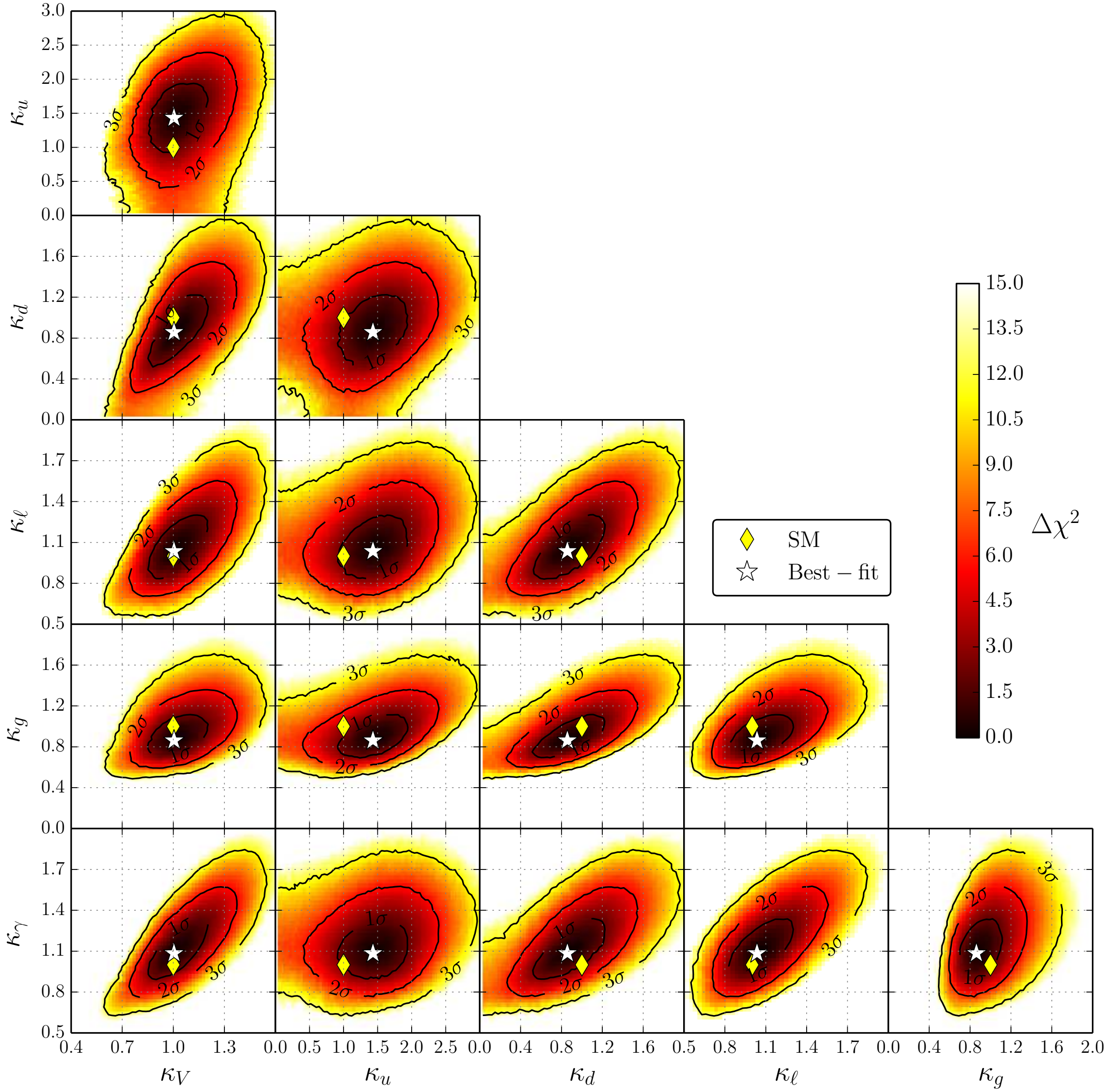
Very general model: $\kappa_V, \kappa_u, \kappa_d, \kappa_l, \kappa_g, \kappa_\gamma$, BR($H \to$ inv.)



Coupling scale factor results (V):

[P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein - full Run I]

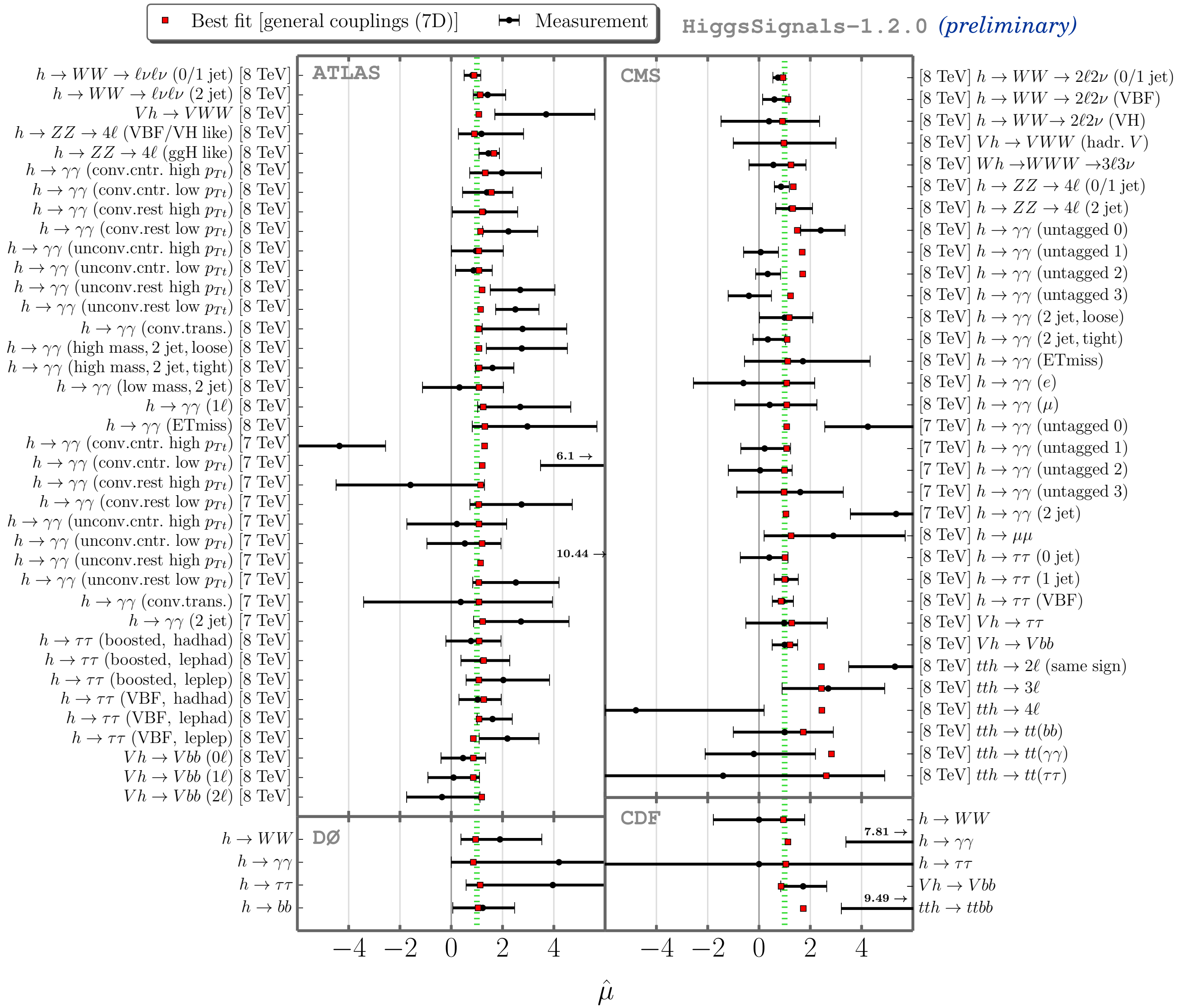
Very general model: $\kappa_V, \kappa_u, \kappa_d, \kappa_l, \kappa_g, \kappa_\gamma$, BR($H \to$ inv.)



Coupling scale factor results (V):

[P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein - full Run I]

Very general model: $\kappa_V, \kappa_u, \kappa_d, \kappa_l, \kappa_g, \kappa_\gamma$, BR($H \to$ inv.)



Measurement of the Higgs boson spin

$\Rightarrow$ first results from the LHC:

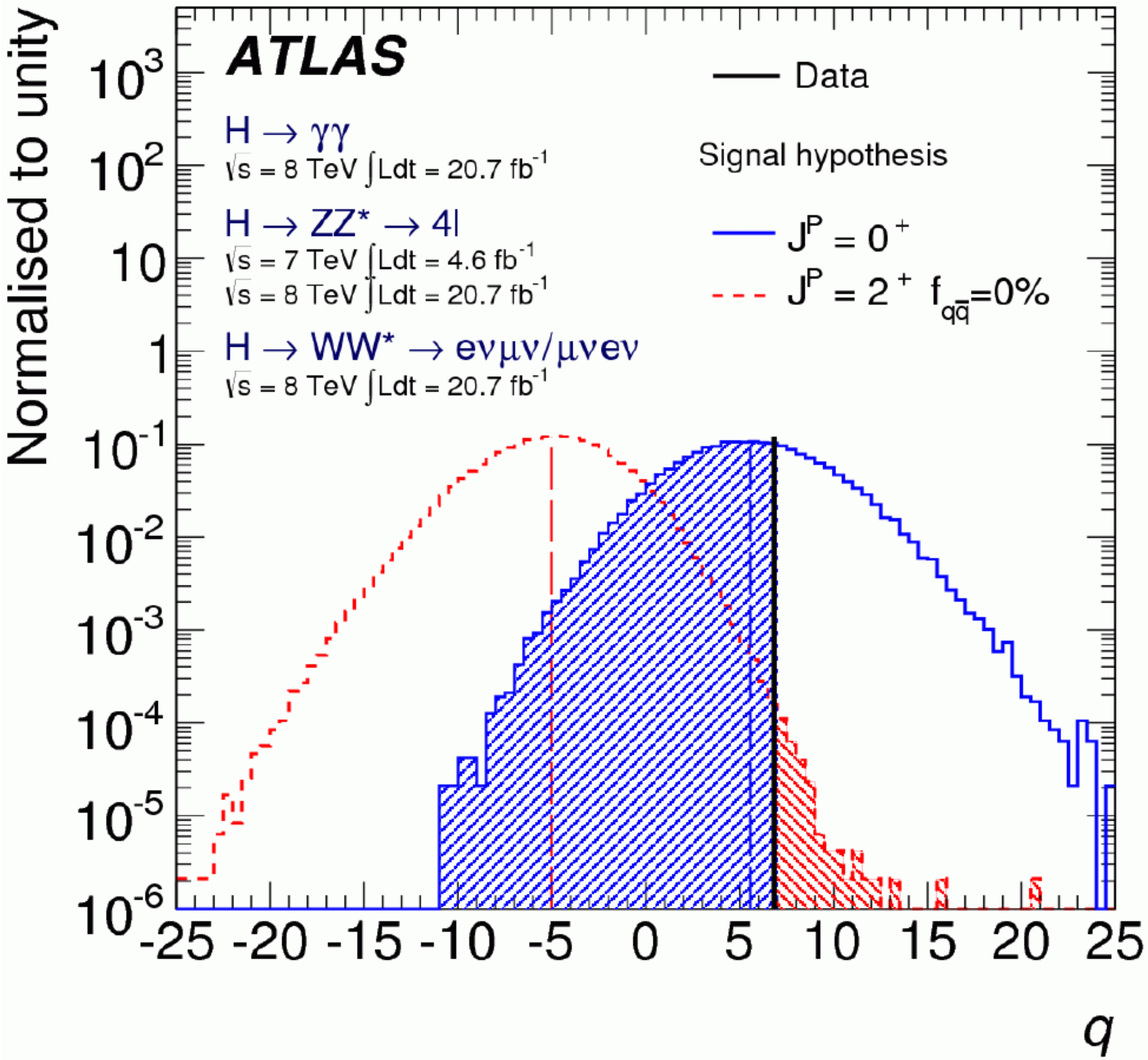
Investigating the decay

$H \to \gamma\gamma, ZZ^*, WW^*$

comparing predictions . . .

$q = \log\left(\mathcal{L}(O^+)/\mathcal{L}(2^+)\right)$

$\Rightarrow$ Spin 0 clearly preferred



Measurement of the Higgs boson spin

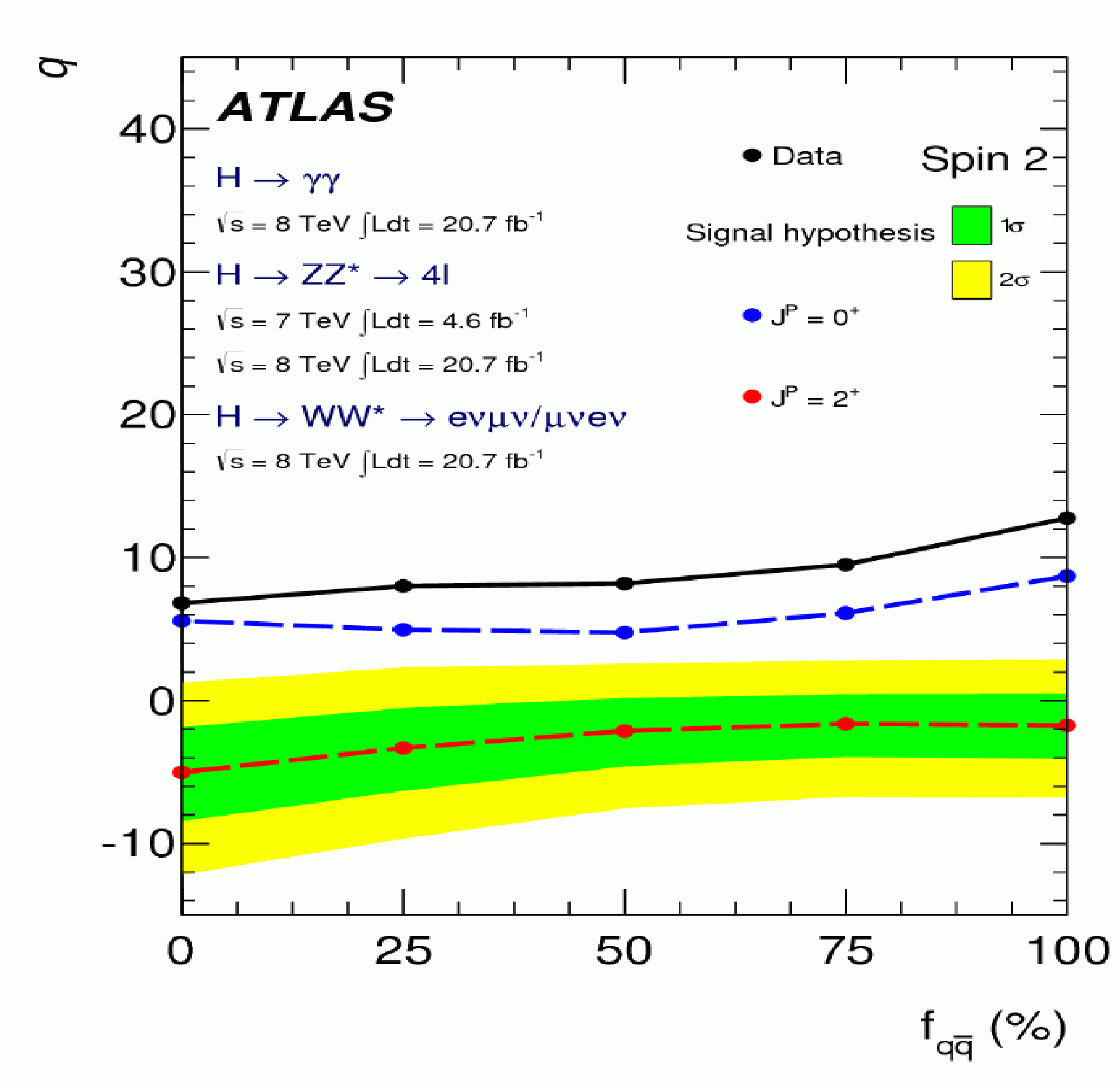
⇒ first results from the LHC:

Investigating the decay
$H \to \gamma\gamma, ZZ^*, WW^*$

comparing predictions . . .

$q = \log\left(\mathcal{L}(O^+)/\mathcal{L}(2^+)\right)$

⇒ Spin 0 clearly preferred



Has the Higgs particle been discovered?

Has the Higgs particle been discovered? YES!

3. MSSM Higgs boson searches at the LHC

We have a $\sim 125\ \mathrm{GeV}$ SM-like Higgs boson

$\Rightarrow$ What are the options?

1. Decoupling limit:
   $M_A \gg M_Z \Rightarrow$ the light Higgs becomes SM-like

2. Alignment without decoupling:
   $\Rightarrow$ 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.)
   $\Rightarrow$ 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*]

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

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

$\Rightarrow$ $\mathcal{CP}$-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: $M_A^2 \gg Z_i v^2$
$\Rightarrow m_h^2 \sim Z_1 v^2$, $|c_{\beta-\alpha} \ll 1|$, h is SM-like

Alignment limit: $Z_6 = 0$ and $Z_1 < Z_5 + M_A^2/v^2$
$\Rightarrow$ h is identical to the SM Higgs, $c_{\beta-\alpha} = 0$
$Z_6 = 0$ and $Z_1 > Z_5 + M_A^2/v^2$
$\Rightarrow$ H is identical to the SM Higgs, $c_{\beta-\alpha} = 1$

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

Example: $m_h^{\rm alt}$ scenario:

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

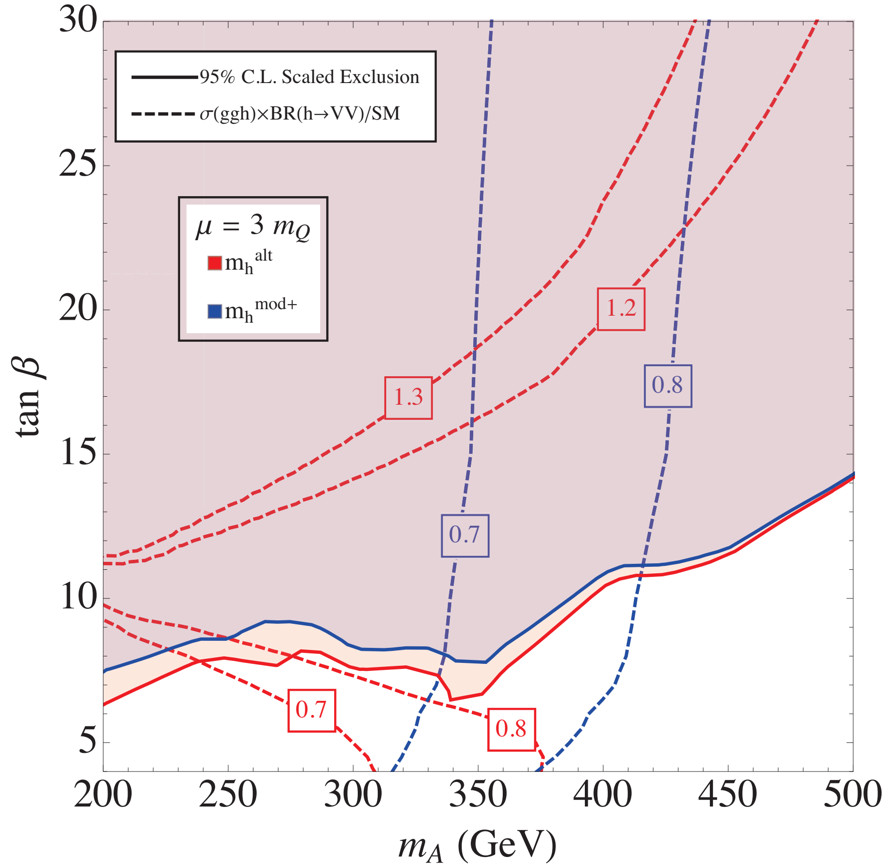
$M_S = m_{\tilde f} \geq 1$ TeV, $m_{\tilde g} = 1.5$ TeV,

$M_2 = 2\,M_1 = 200$ GeV, μ adjustable

$\Rightarrow$ SM-like Higgs for all M_A

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

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



Alignment limit: see e.g.

[P. Bechtle, S.H., O. Stål, T. Stefaniak, G. Weiglein '15]

In the MSSM $Z_6 = 0$ can be obtained through an "accidental" cancellation between tree-level and loop contribution

Example: $m_h^{\rm mod+}$ scenario:

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

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

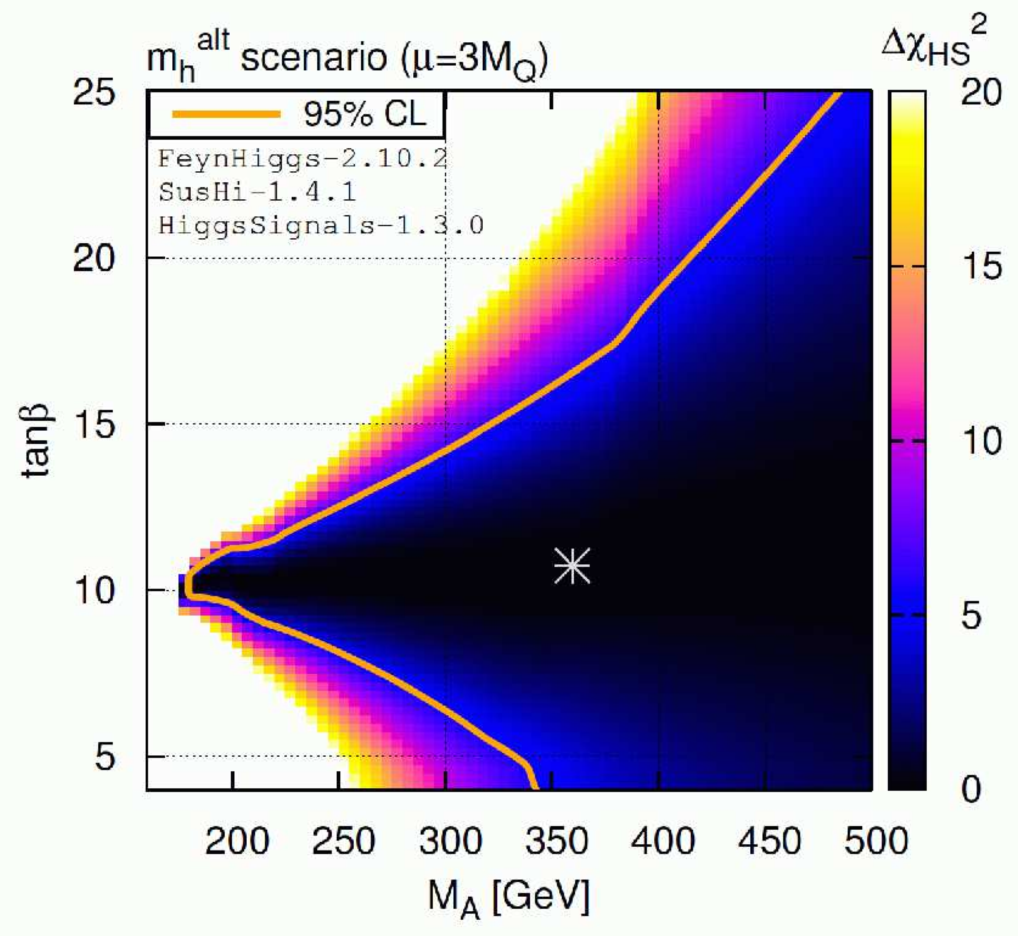
$M_2 = 2\,M_1 = 200$ GeV, μ adjustable

$\Rightarrow$ SM-like Higgs for all M_A

$\tan\beta \sim$

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

$m_h^{\rm alt}$ scenario with HiggsSignals :



Overview about MSSM Higgs boson searches at the LHC:

1. Light MSSM Higgs boson in the decoupling limit:
   $\to$ SM Higgs searches apply
   $\Rightarrow$ compatible with the discovery at $\sim$ 125 GeV?!

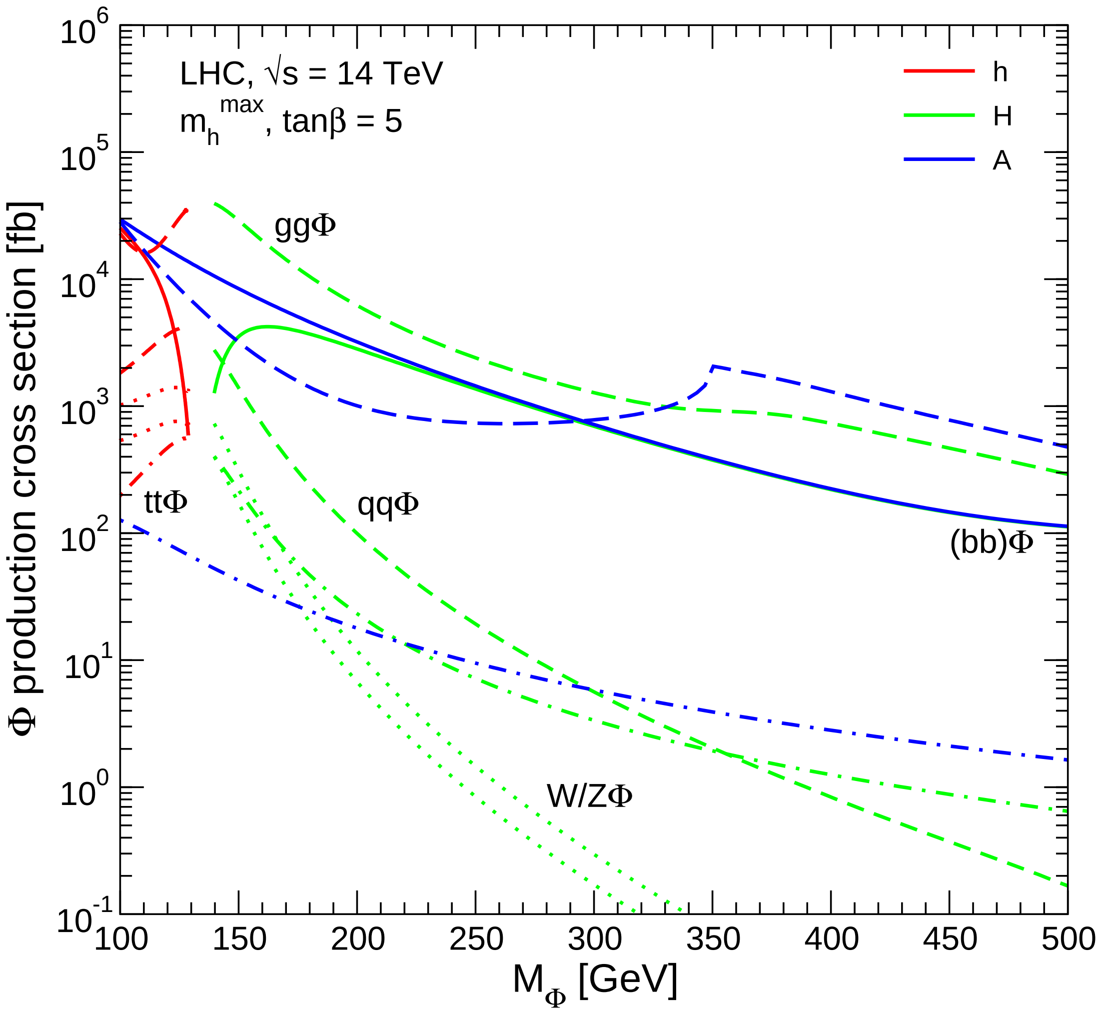
2. Light MSSM Higgs boson "before" the decoupling limit:
   $\to$ dedicated analyses necessary
   $\to$ challenged by Higgs rate measurements!?
   $\Rightarrow$ compatible with the discovery at $\sim$ 125 GeV?!

3. Hevay MSSM Higgs boson:
   $\to$ dedicated search
   $\to$ keep in mind the discovery at $\sim$ 125 GeV
   $\Rightarrow$ model independent results on $\sigma \times$ BR
   $\Rightarrow$ specific MSSM results for H/A

4. Higgs below 125 GeV: $\Rightarrow$ see "$\phi_{96} \to \gamma\gamma$"!

Situation is a bit more complicated for SUSY Higgses $(\phi = h, H, A)$

[*Tev4LHC Higgs working group report '06*]



gluon fusion: $gg \to \phi$

weak boson fusion (WBF): $q\bar{q} \to q'\bar{q}'\phi$

top quark associated production: $gg, q\bar{q} \to t\bar{t}\phi$

weak boson associated production: $q\bar{q}' \to W\phi, Z\phi$

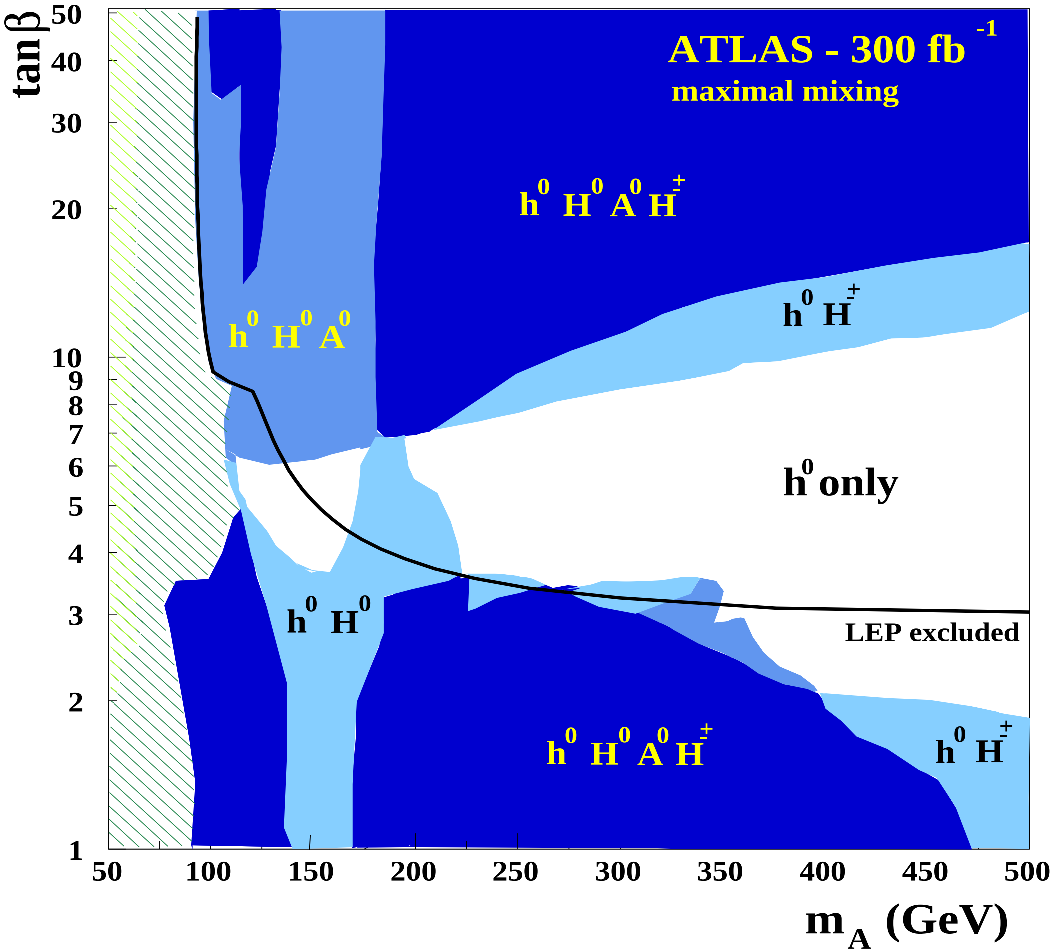
NEW: $b\bar{b}\phi$

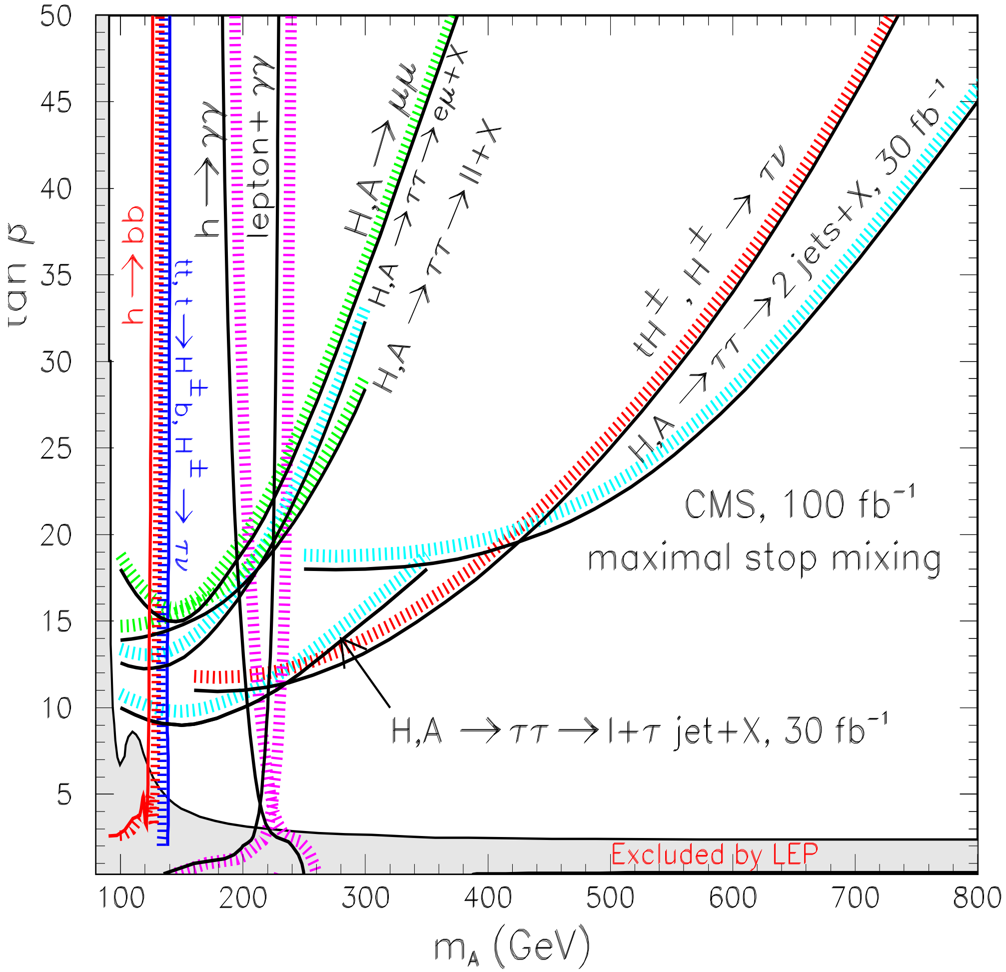
Search for the lightest MSSM Higgs at the LHC:

$\Rightarrow$ full parameter accessible   But there might be problems . . .

Dedicated search for the heavy MSSM Higgs bosons

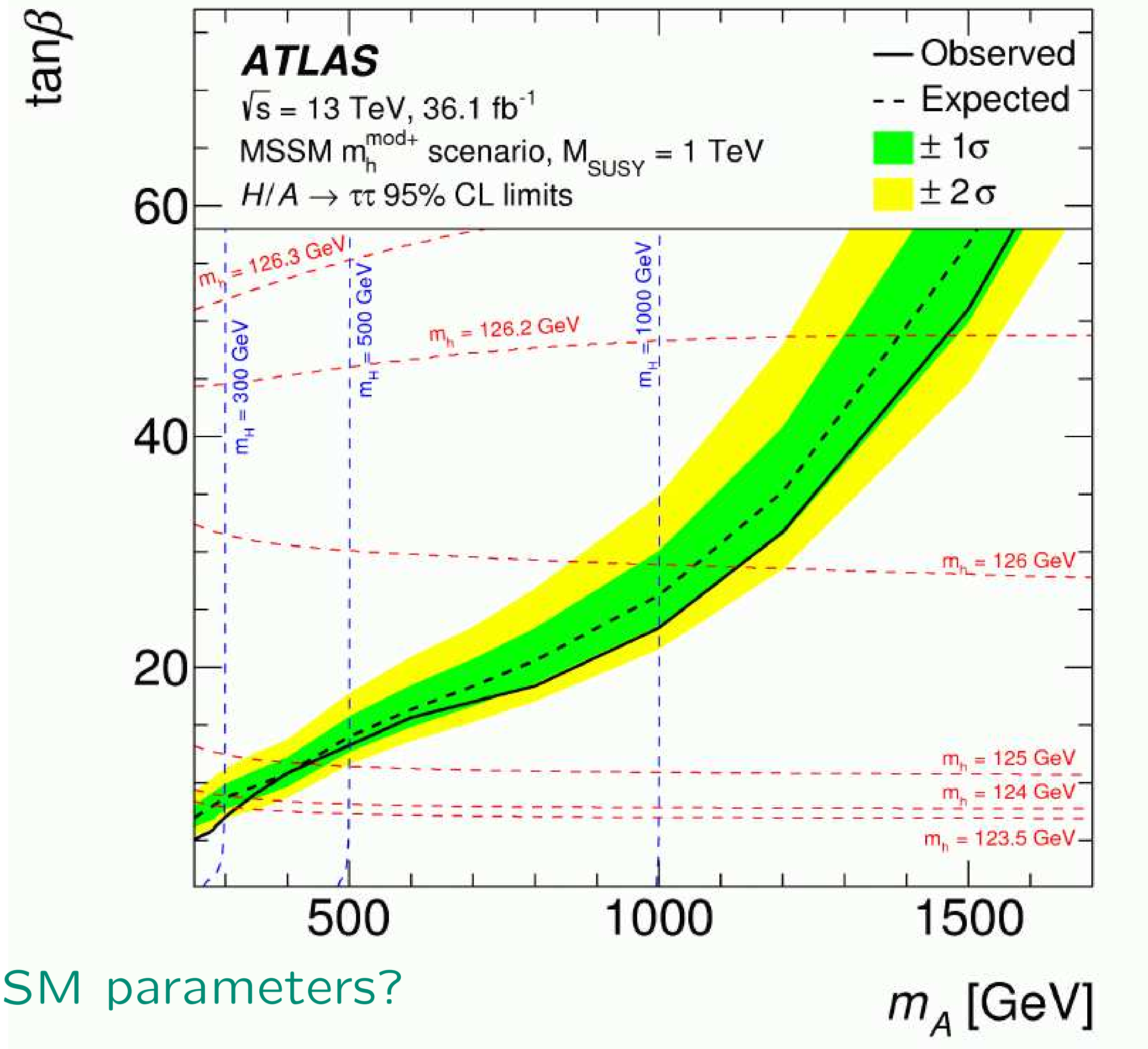
MSSM Higgs discovery contours in M_A–$\tan\beta$ plane
($m_h^{\rm max}$ benchmark scenario): [*ATLAS '99*] [*CMS '03*]





areas where only h is observable $\Rightarrow$ "LHC wedge"

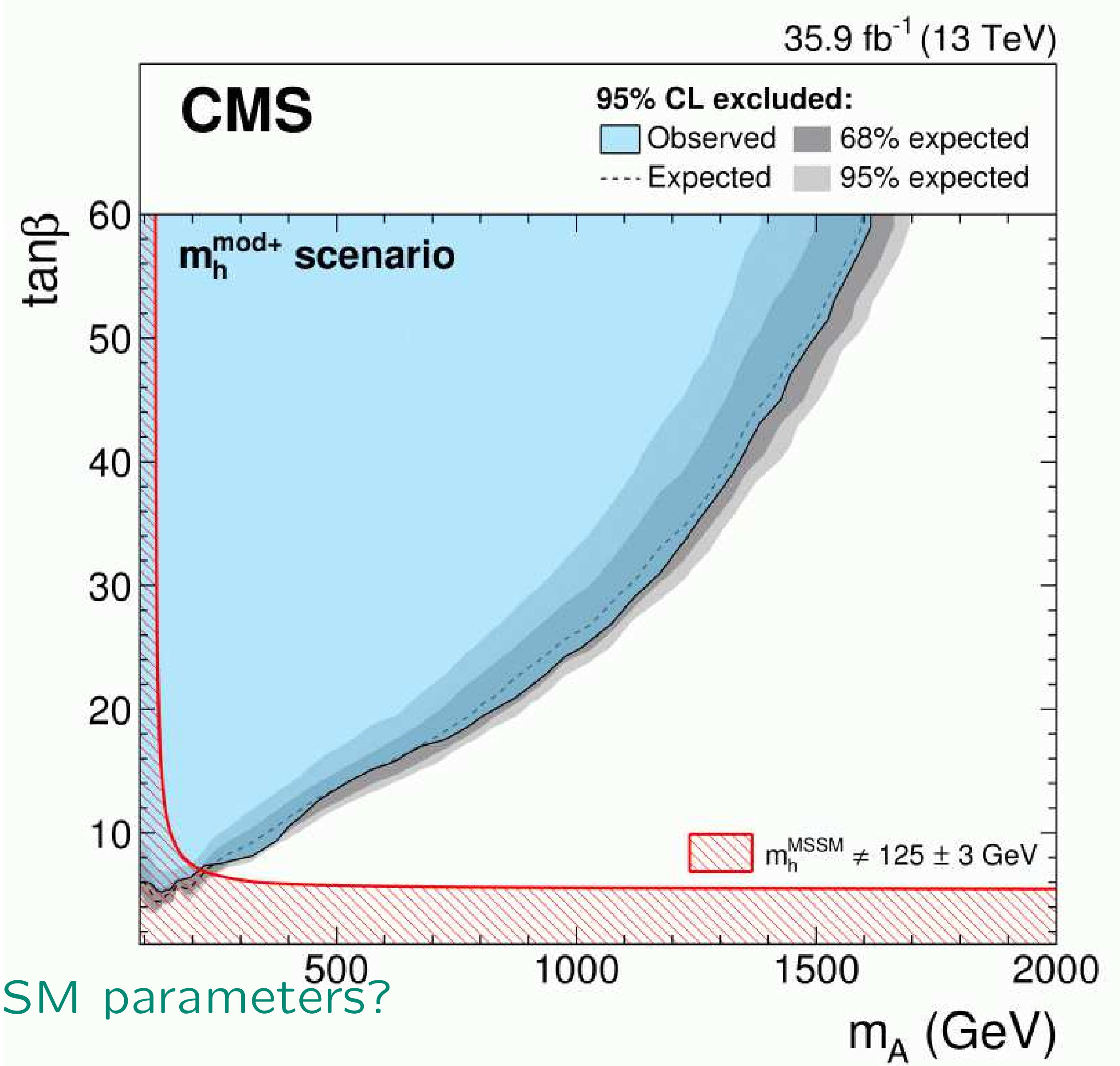
MSSM Higgs exclusion contours in M_A–$\tan\beta$ plane: $b\bar{b}, gg \to h, H, A \to \tau^+\tau^-$



Choice of MSSM parameters?

Latest results for neutral heavy Higgs bosons: [CMS '18]

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



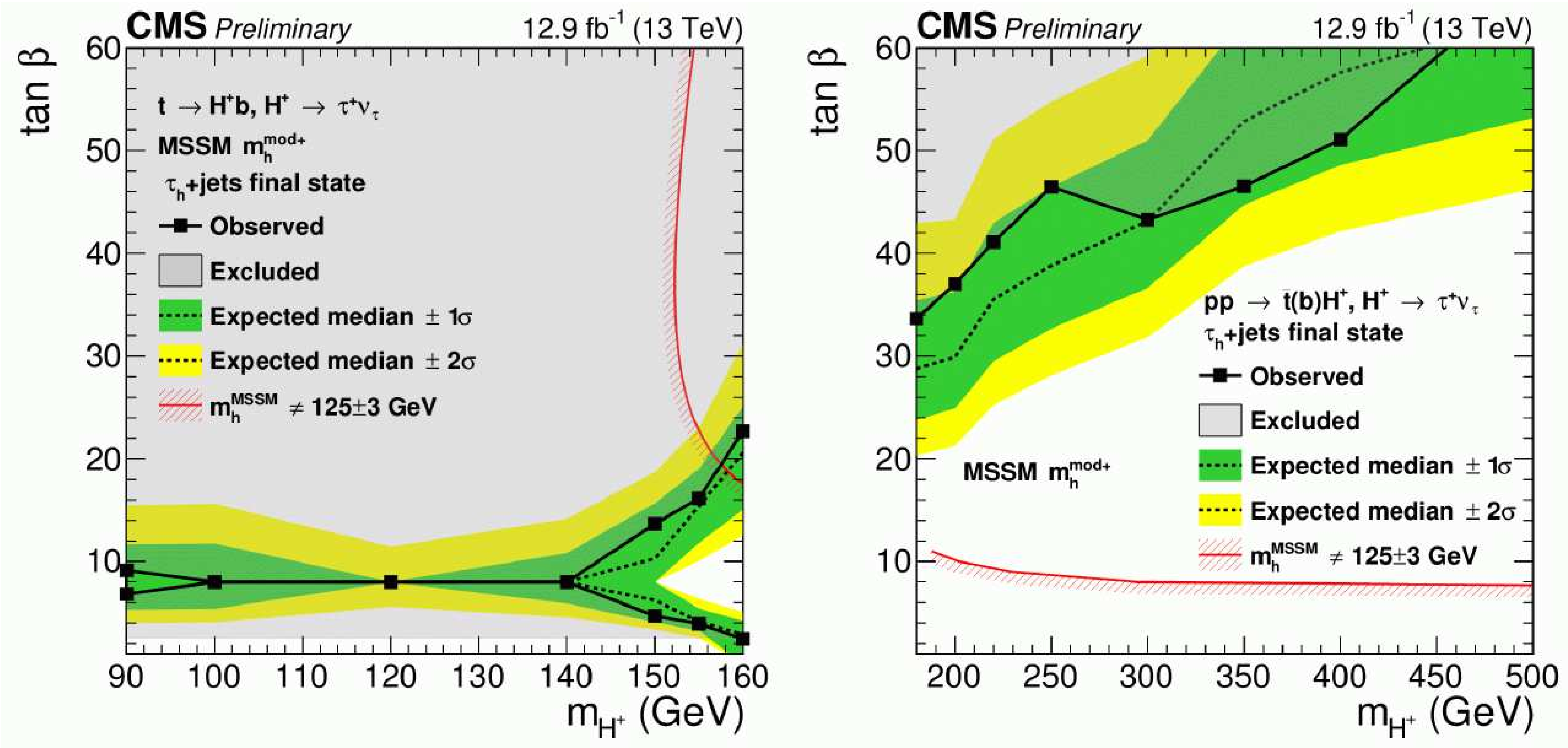
Choice of MSSM parameters?

Nearly latest results for charged Higgs bosons:

[CMS '17]

MSSM Higgs exclusion contours in M_A–$\tan\beta$ plane: $pp \to H^\pm \to \tau\nu_\tau$

$M_{H^\pm} < m_t$ $\qquad\qquad$ $M_{H^\pm} > m_t$

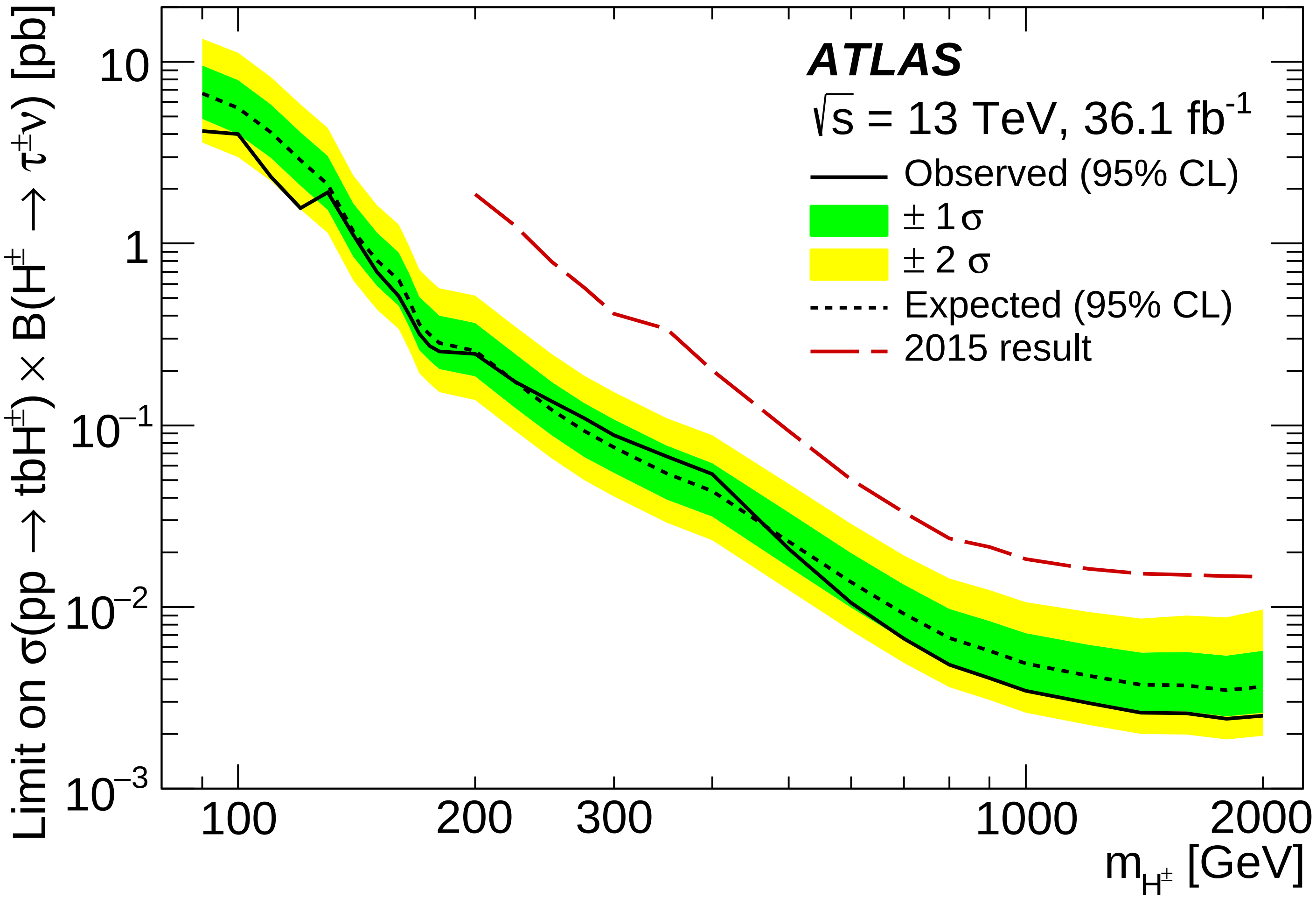


Choice of MSSM parameters?

Latest results for charged Higgs bosons: [ATLAS '18]

2HDM type II results: $pp \to H^{\pm} \to \tau\nu_\tau$

$M_{H^\pm} < m_t$ $M_{H^\pm} > m_t$



⇒ gap finally closed!

Search for the MSSM Higgs bosons:

Choice of MSSM parameters?

$\to$ investigate benchmark scenarios:

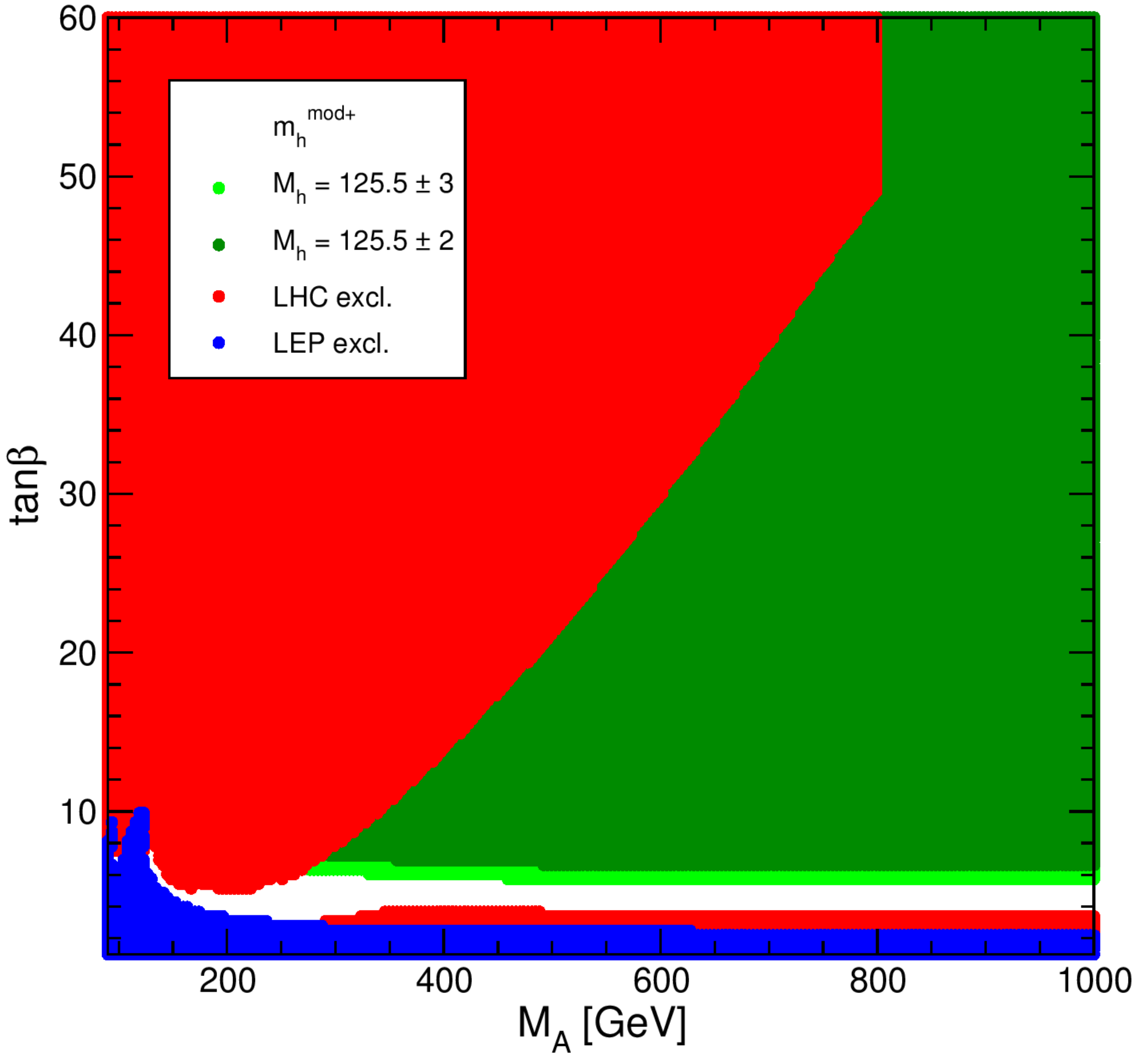
$\boxed{\begin{array}{l} \to \text{Vary only } M_A \text{ and } \tan\beta \\ \to \text{Keep all other SUSY parameters fixed} \end{array}}$

[*M. Carena, S.H., O. Stål, C. Wagner, G. Weiglein '13*]

1. m_h^{max} scenario: conservative limits on M_A, $M_{H^\pm}$, $\tan\beta$
2. m_h^{mod} scenario: in good agreement with $M_h \approx 125$ GeV
3. light stop scenario: sizable effects on $\sigma(gg \to h)$
4. light stau scenario: sizable effects on $\Gamma(h \to \gamma\gamma)$
5. τ-phobic scenario: suppression of $\Gamma(h \to \tau^+\tau^-)$, $\Gamma(h \to b\bar{b})$
6. low-M_H scenario: in good agreement with $M_H \approx 125$ GeV

$\Rightarrow$ 2018 update nearly ready . . . [*H. Bahl, S.H., P. Slavich et al. '18*]

$m_h^{\text{mod}+}$ scenario:



$$m_t = 173.2 \text{ GeV},$$
$$M_{\text{SUSY}} = 1000 \text{ GeV},$$
$$\mu = 200 \text{ GeV},$$
$$M_2 = 200 \text{ GeV},$$
$$X_t^{\text{OS}} = 1.5\, M_{\text{SUSY}}$$
$$A_b = A_\tau = A_t,$$
$$m_{\tilde{g}} = 1500 \text{ GeV},$$
$$m_{\tilde{l}_3} = 1000 \text{ GeV} \;.$$

$\Rightarrow$ $M_h \approx 125$ GeV nearly "everywhere"

$\Rightarrow$ to be updated (improved M_h calculation)!!

4. $\phi_{96} \to \gamma\gamma$

- What was seen in Run I?

- What was seen in Run II?

- What was seen at LEP?

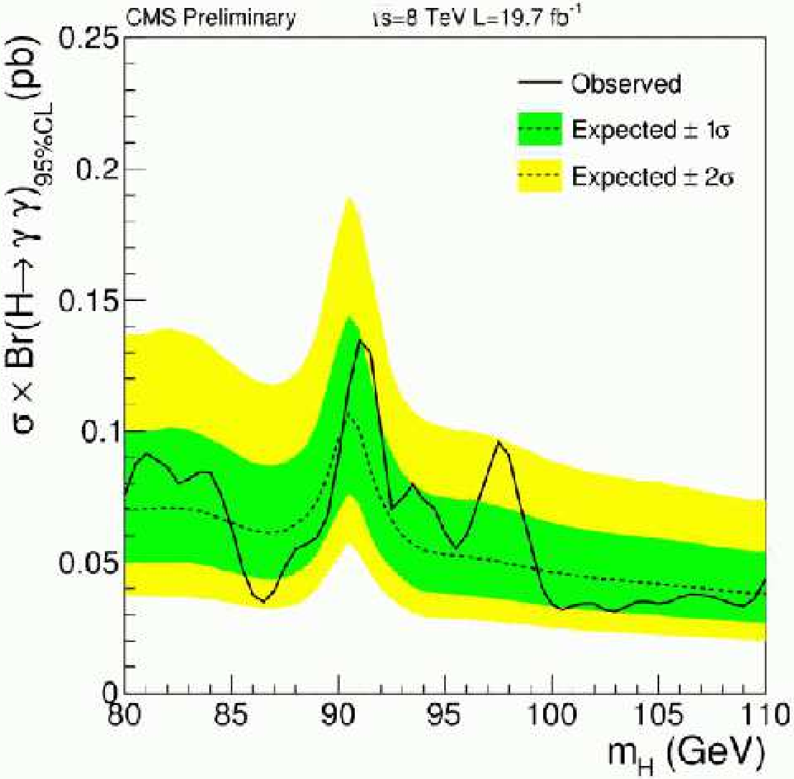
- Should we get excited?

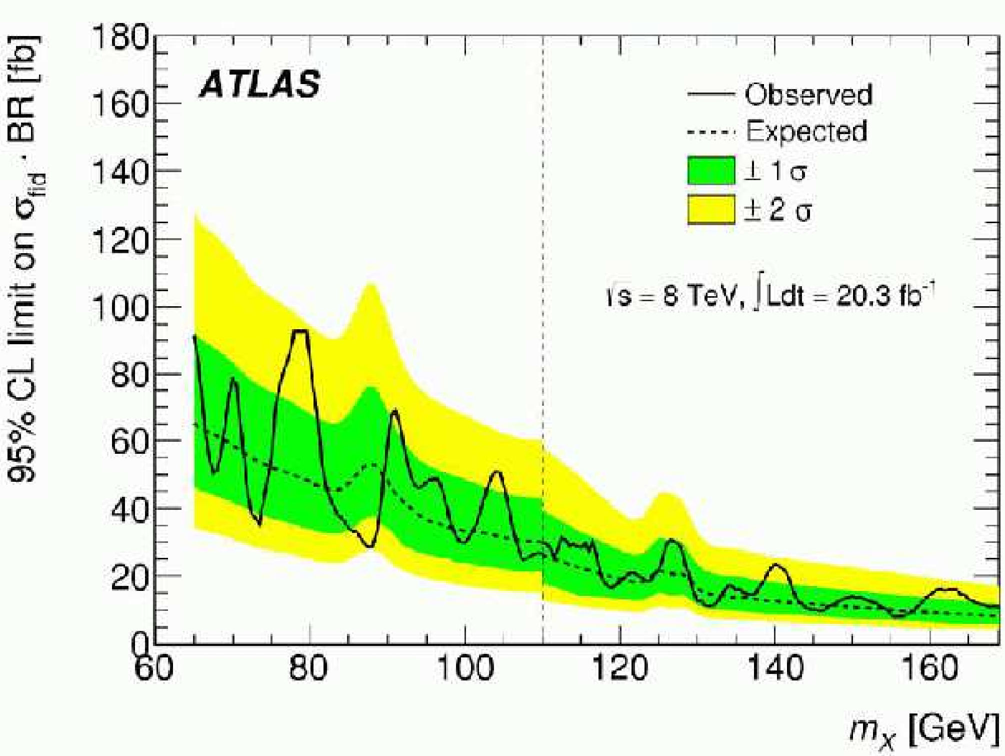
- What about the NMSSM?

h-->γγ (65-110GeV) Run 1

CMS PAS HIG-14-037

PRL 113 171801 (2014)





- ~2σ excursion @~97.5 GeV
- ~2σ excursion @~80 GeV

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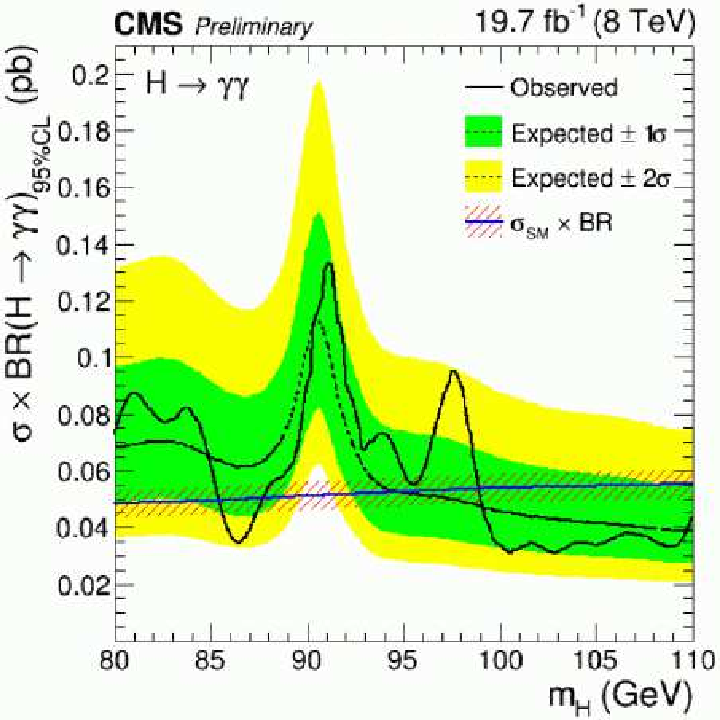
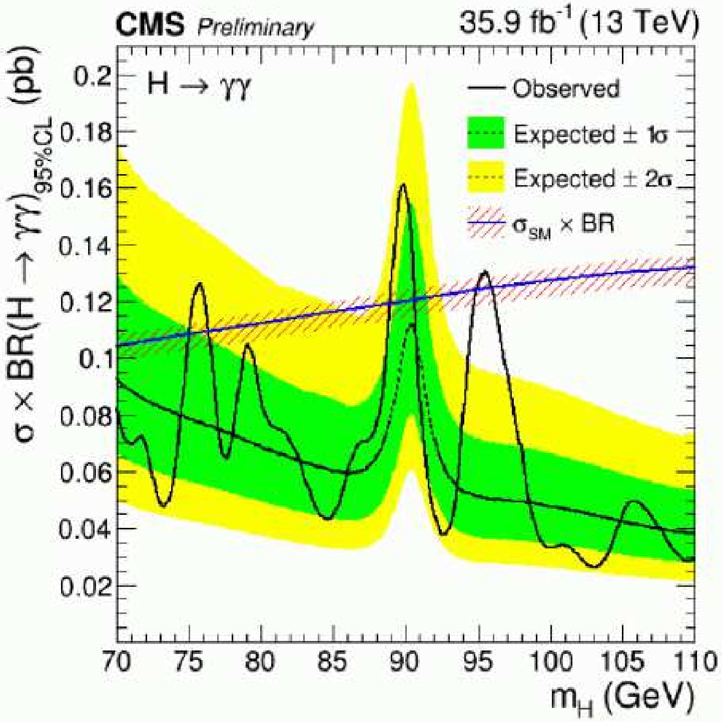
S. Gascon-Shotkin HDays17, Santander, ES Sept. 22 2017

h-->γγ (70-110 GeV) Runs 1+2

New!





CMS PAS HIG-17-013

8 TeV:
minimum(maximum) limit on σ X Br : 31(133) fb at m=102.8(91.1)GeV

13 TeV:
minimum(maximum) limit on σ X Br : 26(161) fb at m=103.0(89.9)GeV

- 8 TeV limits on σ X Br redone with 0.1 GeV step. Production processes assumed in SM proportions. No significant excess with respect to expected limits observed.

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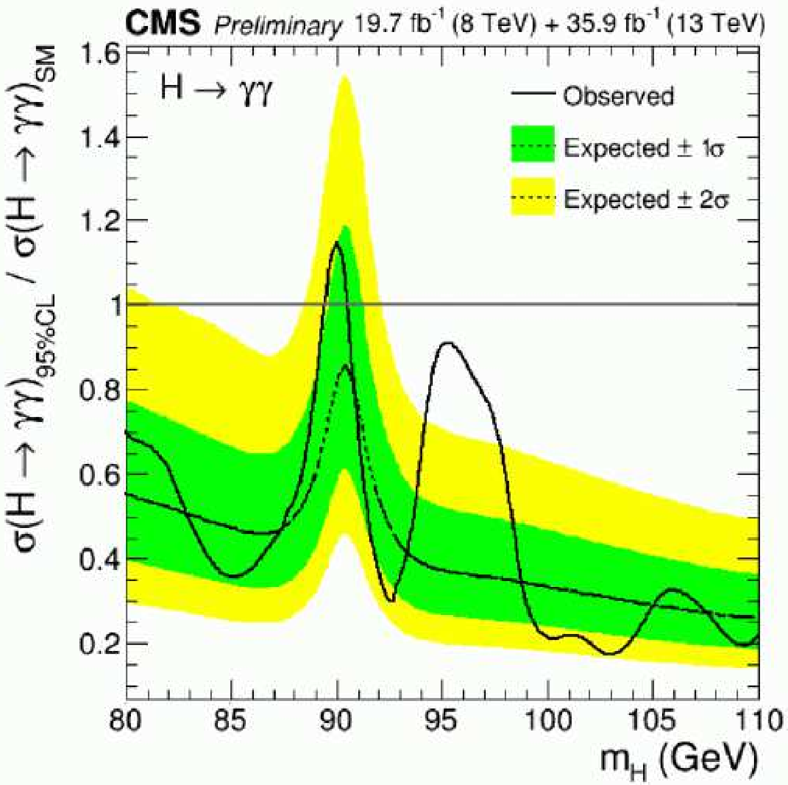
S. Gascon-Shotkin HDays17, Santander, ES Sept. 22 2017

h-->γγ (70-110 GeV) Runs 1+ 2

New!

CMS PAS HIG-17-013

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).



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

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

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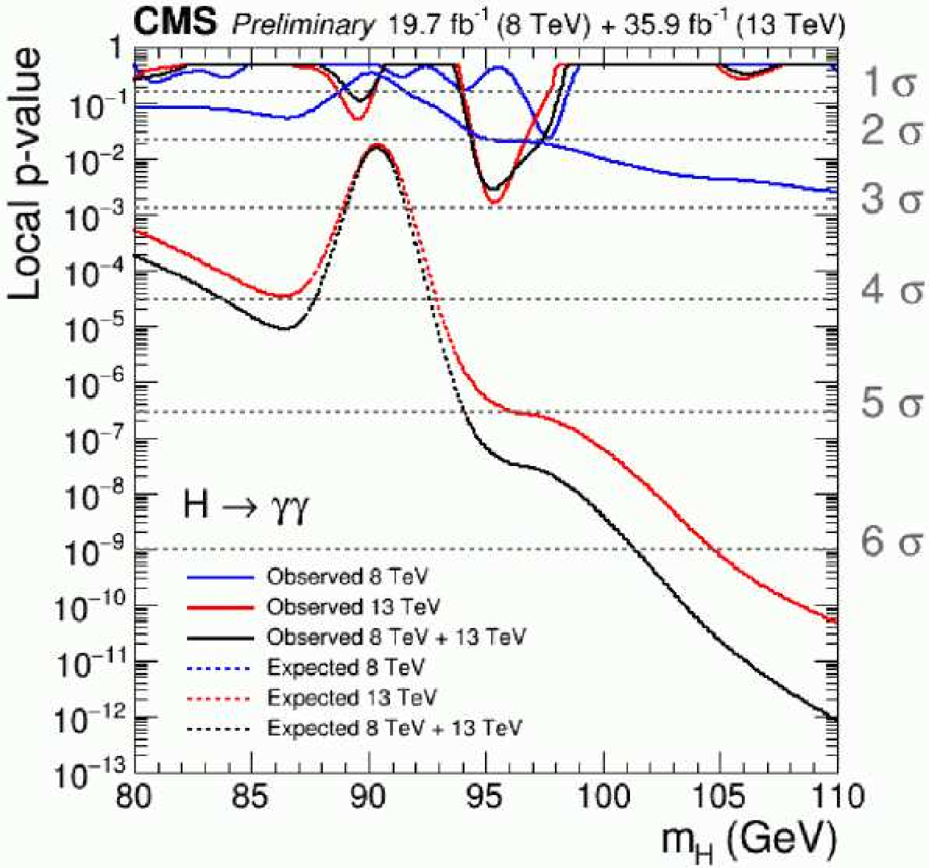
S. Gascon-Shotkin HDays17, Santander, ES Sept. 22 2017

h-->γγ (70-110 GeV) Runs 1+ 2

New!

CMS PAS HIG-17-013



8 TeV: Excess with ~2.0 σ local significance at m=97.6 GeV

13 TeV: Excess with ~2.9 σ local (1.47 σ global) significance at m=95.3 GeV

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

More data are required to ascertain the origin of this excess

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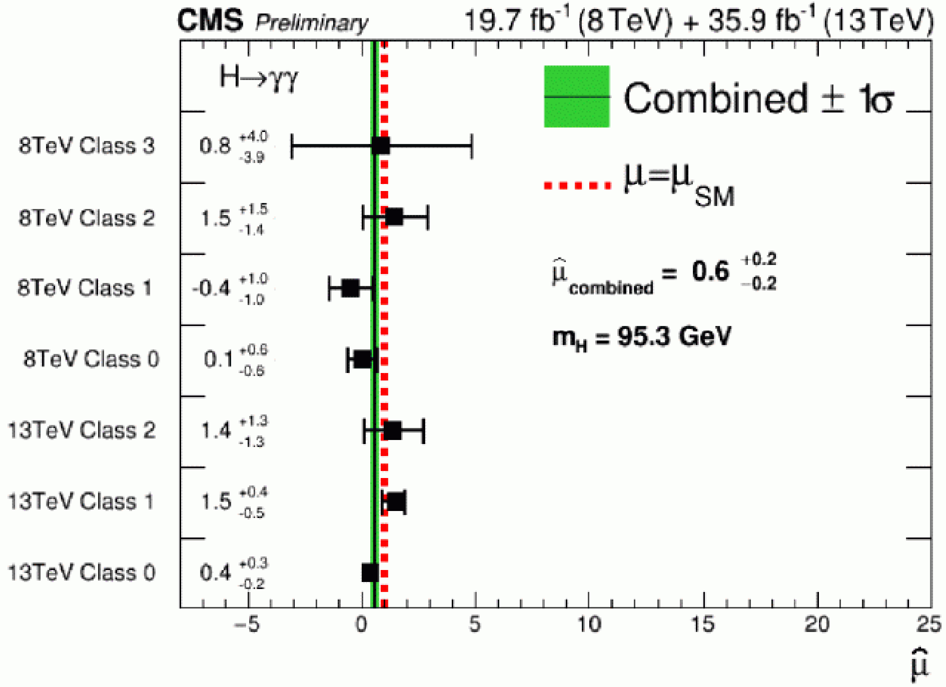
- Expected and observed local p-values for 8 TeV, 13 TeV and their combination

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

h-->γγ (70-110 GeV) Runs 1+2

New!

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%

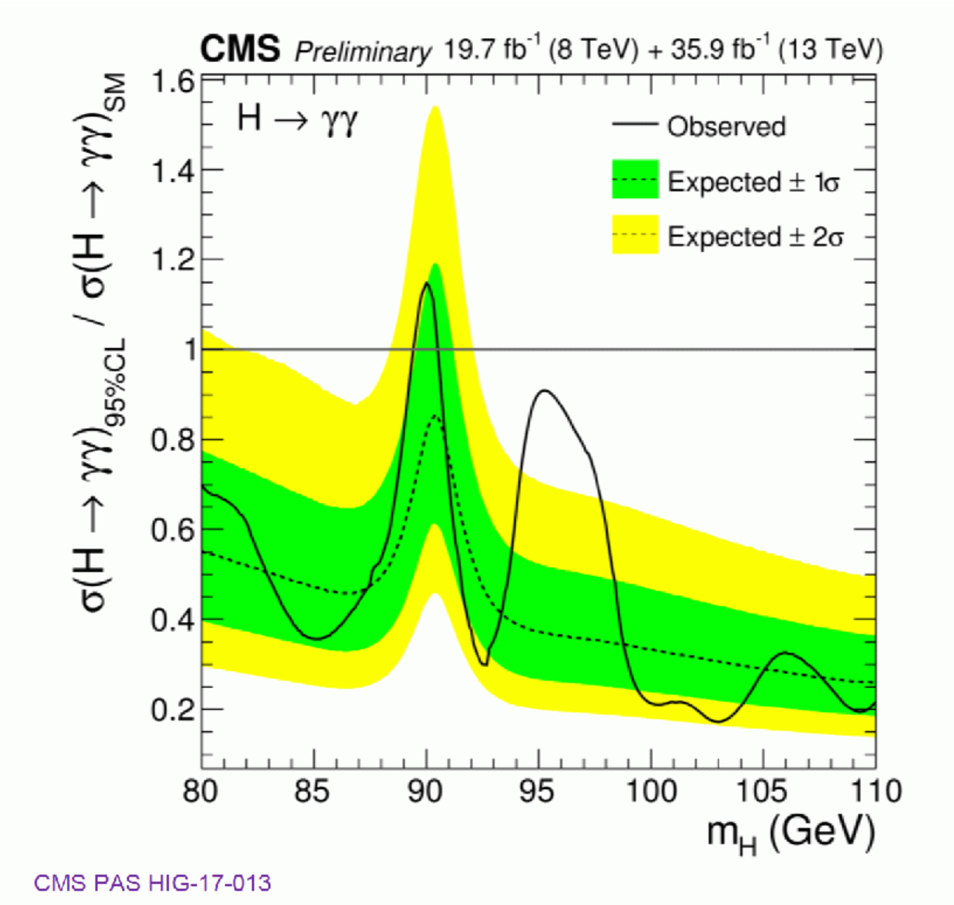
- 'Signal' strengths for the 7 event classes and overall, in the 8 TeV+13TeV combination, fixing m_H=95.3 GeV
- More data are required to ascertain the origin of this excess

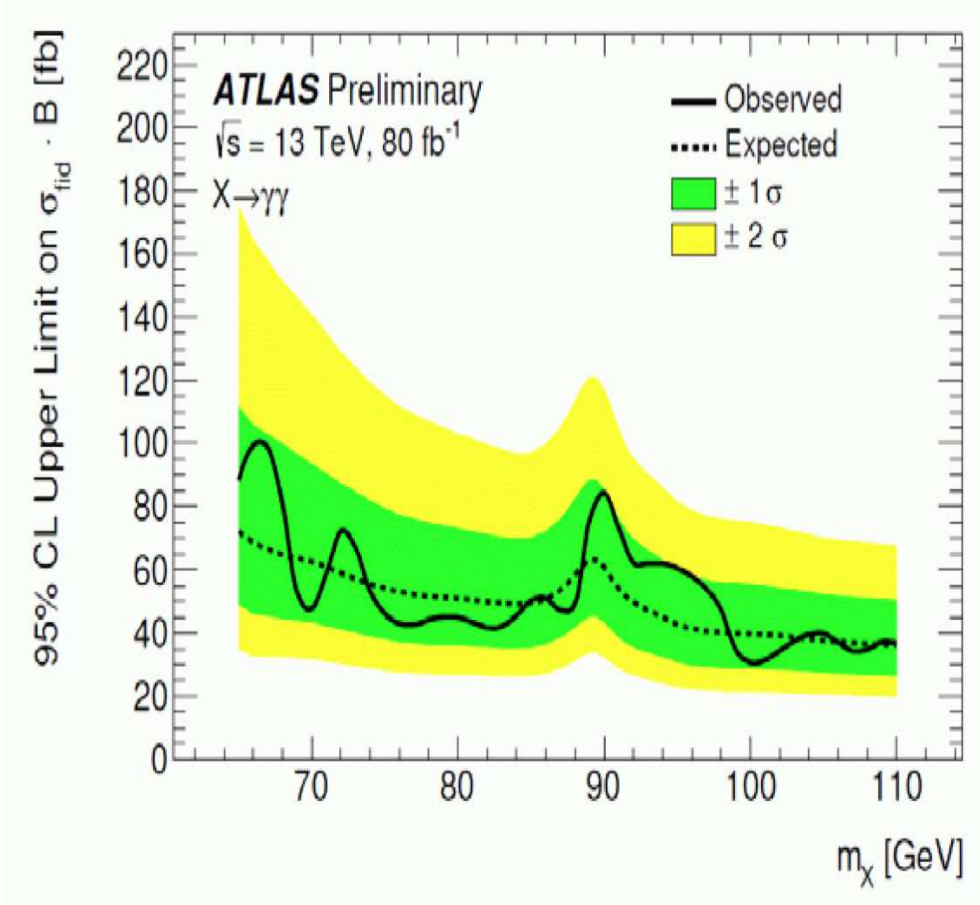
55

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

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

What about ATLAS?



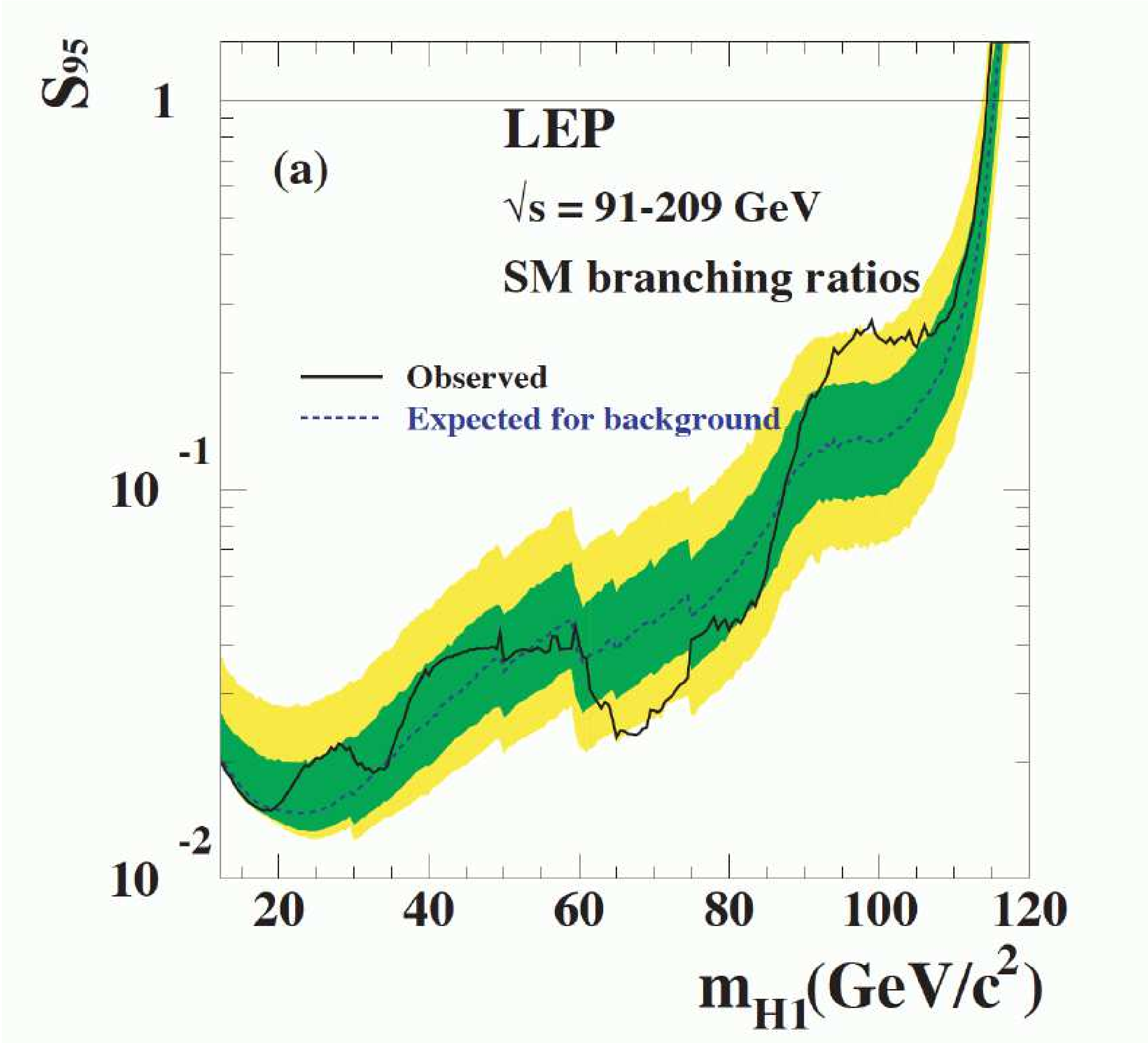


Note: ATLAS gives fiducial cross section! Conversion factor: 1/0.45

$\Rightarrow$ ATLAS and CMS exclusion limit **identical!** (120 fb)

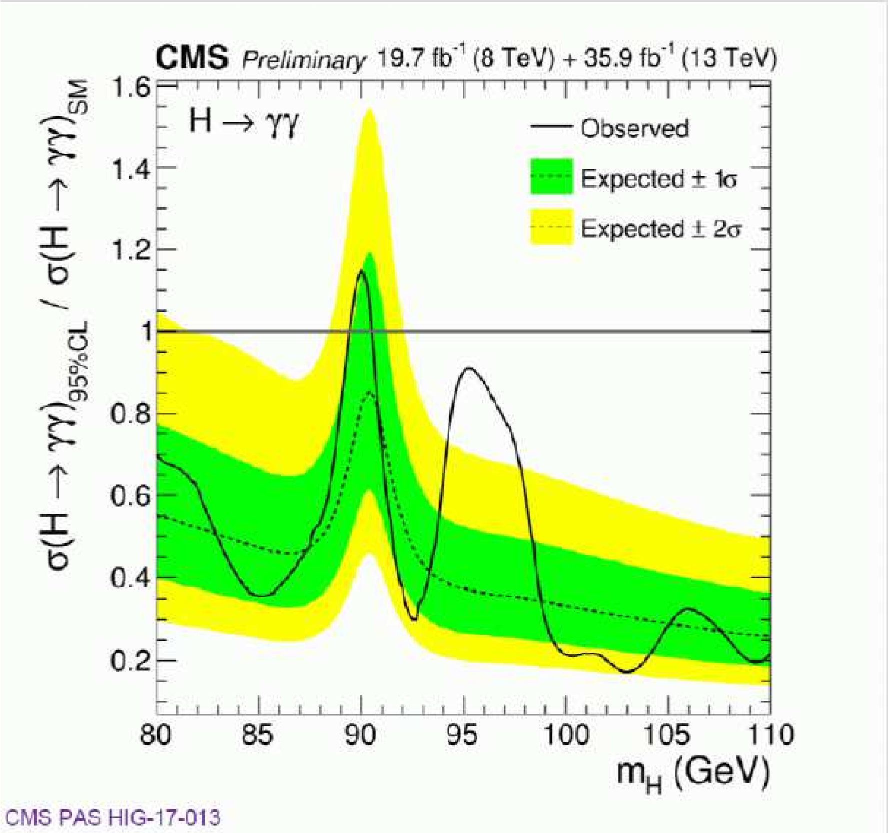
Q: why does ATLAS has same sensitivity with twice amount of data?

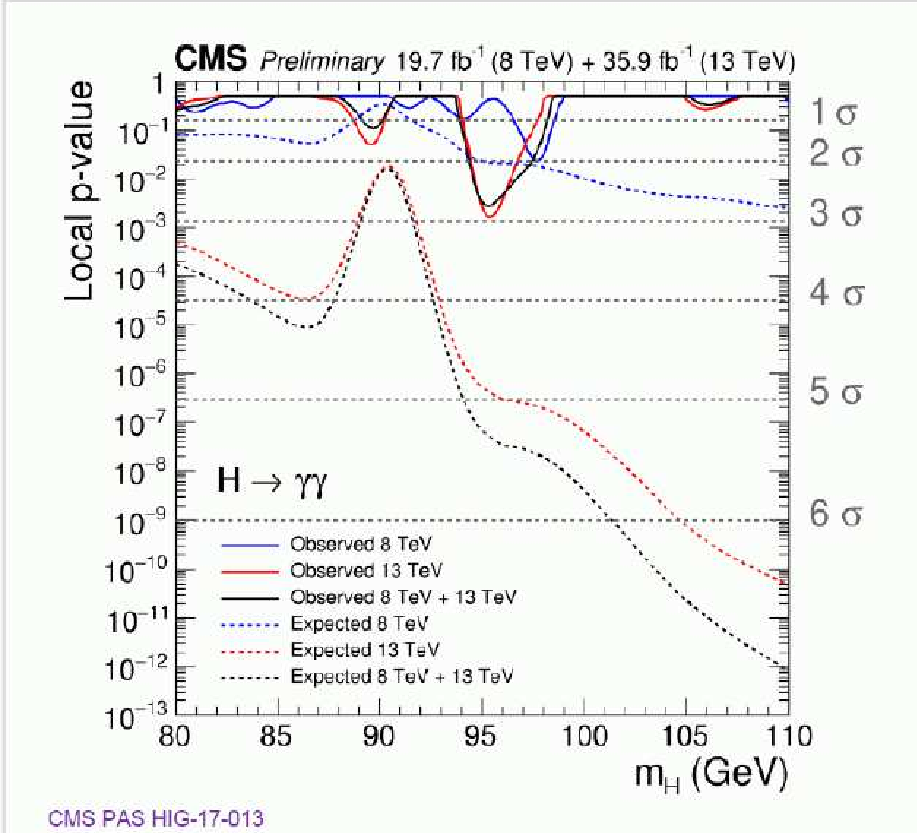
What was seen at LEP?



$$\mu_{\text{LEP}}(98\ \text{GeV}) = \left[\sigma(e^+e^- \to Zh_1) \times \text{BR}(h_1 \to b\bar{b})\right]_{\text{exp/SM}} = 0.117 \pm 0.057$$

- **Combined 8 TeV + 13 TeV** σ×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"?

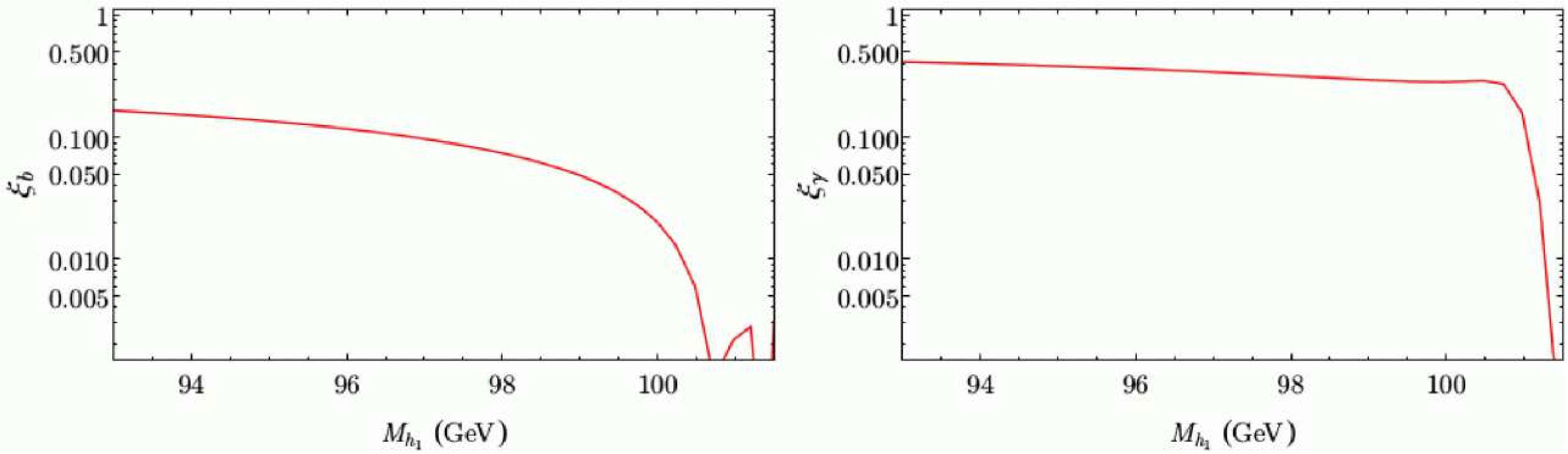
What about the NMSSM? [F. Domingo, S.H., S. Passehr, G. Weiglein '18]

Parameters:

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

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

$$\xi_\gamma \equiv \frac{\Gamma[h_1 \to gg] \cdot \text{BR}[h_1 \to \gamma\gamma]}{\Gamma[H_{\text{SM}}(M_{h_1}) \to gg] \cdot \text{BR}[H_{\text{SM}}(M_{h_1}) \to \gamma\gamma]} \sim \frac{\sigma[gg \to h_1 \to \gamma\gamma]}{\sigma[gg \to H_{\text{SM}}(M_{h_1}) \to \gamma\gamma]} \,.$$



$\Rightarrow$ both "excesses" can be fitted simultaneously!


Further Questions?