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(Nearly) Degenerate Higgs Bosons

Theory motivations and questions

HEFTI Higgs Signal Workshop, UC Davis, 22-26 April 2013

Motivation

- Our original motivation to be interested in the possibility of (quasi)degenerate Higgs bosons was the enhanced $\gamma\gamma$ signal rate:

- In a variety of multi-Higgs models, a $\gamma\gamma$ enhancement is associated with the observed state at ~125 GeV mixing with a nearby (unobserved) 2nd Higgs-like state.

- With a little tuning, this 2nd state can easily be made degenerate with the observed one.

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Examples:

★ h1 and h2 in the NMSSM Ellwanger, 1112.3548
Gunion, Jiang, SK, 1207.1545

★ Higgs and radion in RS models
Grzadkowski, Gunion, Toharia, 1202.5017

★ h/H/A in 2HDM Ferreira, Haber, Sanots, Silva, 1211.3131
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- With a little tuning, this 2nd state can easily be made degenerate with the observed one.

- Even without $\gamma\gamma$ enhancement the question

  "is there more than one Higgs hiding in the 125 GeV signal ?"

  is an intriguing one.

Next-to-minimal SUSY

- MSSM with the addition of a singlet superfield

$$W_{\rm MSSM} = \mu H_u H_d + \ldots \;\rightarrow\; W_{\rm NMSSM} = \lambda S H_u H_d + \frac{1}{3}\kappa S^3 + \ldots$$

- Neutral Higgs sector: 3 CP-even states (h_1, h_2, h_3); 2 CP-odd states (a_1, a_2)

$$h_1 = S_{1,d} H_d + S_{1,u} H_u + S_{1,s} S,$$
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$$h_3 = S_{3,d} H_d + S_{3,u} H_u + S_{3,s} S.$$

$$\frac{g_{h_i bb}}{g_{H_{SM} bb}} = \frac{S_{i,d}}{\cos\beta}, \qquad \frac{g_{h_i VV}}{g_{H_{SM} VV}} = \cos\beta S_{i,d} + \sin\beta S_{i,u}$$

- Extra tree-level contribution to Higgs mass ~ $\lambda^2 v^2 \sin 2\beta$

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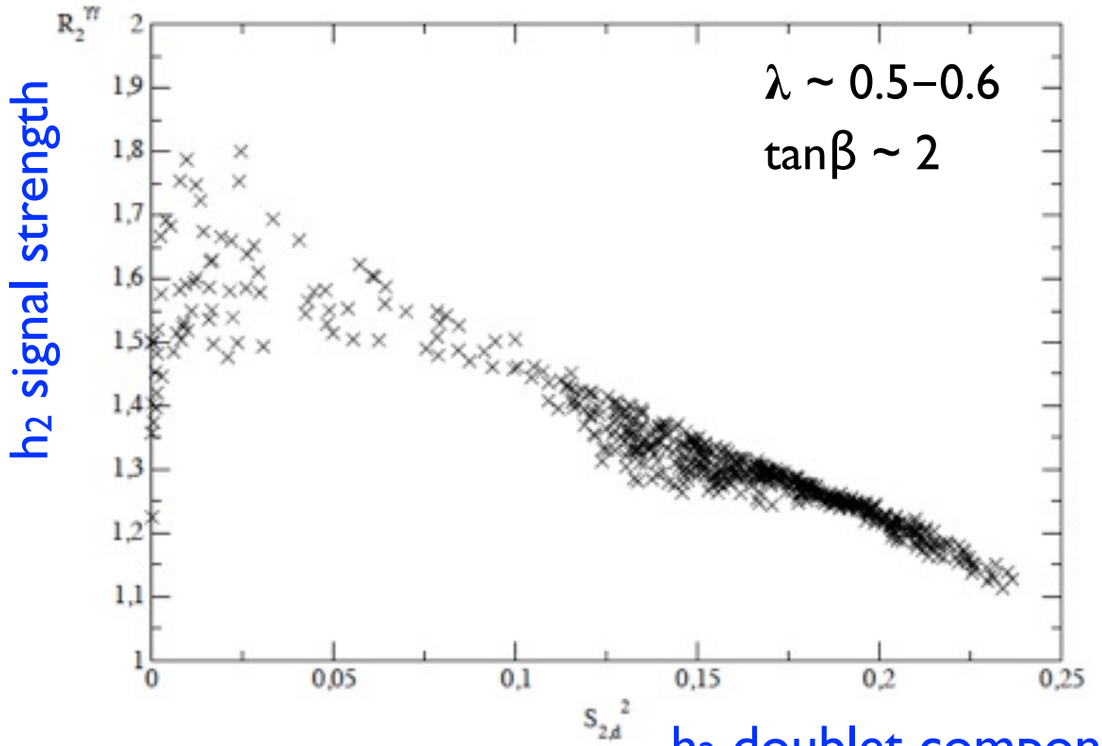
Ulrich's talk just afterwards

Enhancement of $\gamma\gamma$ rate

- In 2010, Ulrich Ellwanger pointed out that for large λ (and small tanβ), doublet-singlet mixing can reduce the hbb coupling, thus enhancing $h \to \gamma\gamma$.

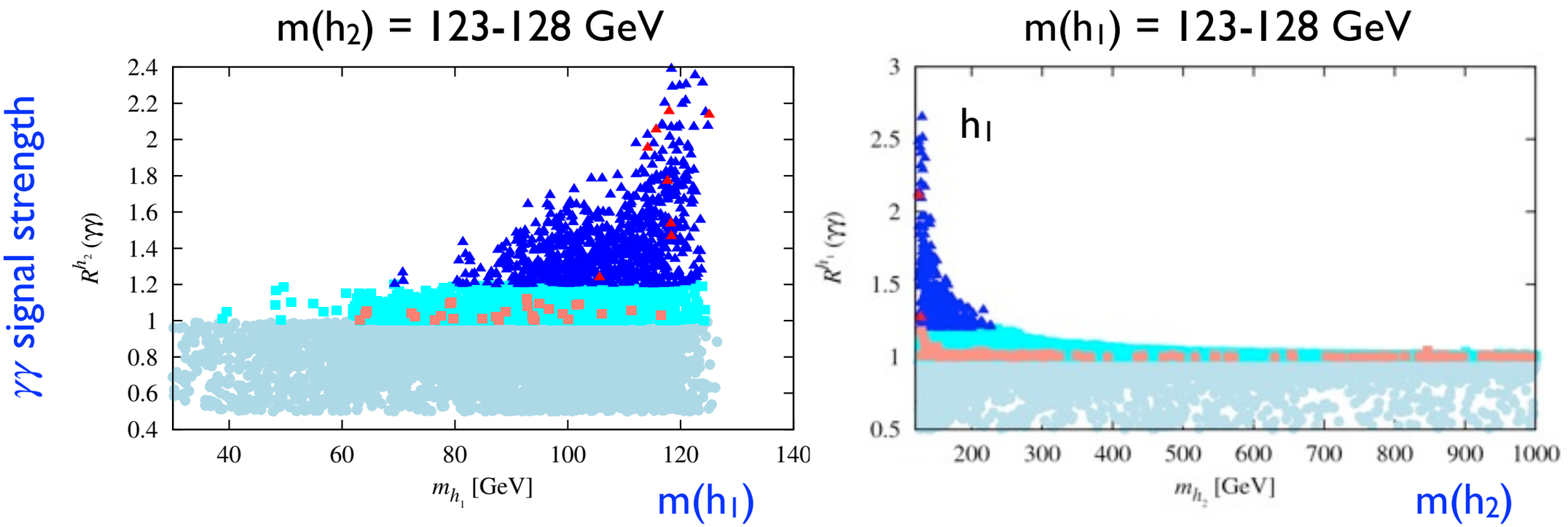


Ellwanger, arXiv:1112.3548

- This works for both CP-even scalars, h_1 and h_2

h_1 or h_2 at 125 GeV?

Scan over "semi-constrained NMSSM" with universal m_0, $m_{1/2}$, A_0 at the GUT scale plus λ, κ, A_λ, A_κ, μ_{eff} and tanβ at EW scale.

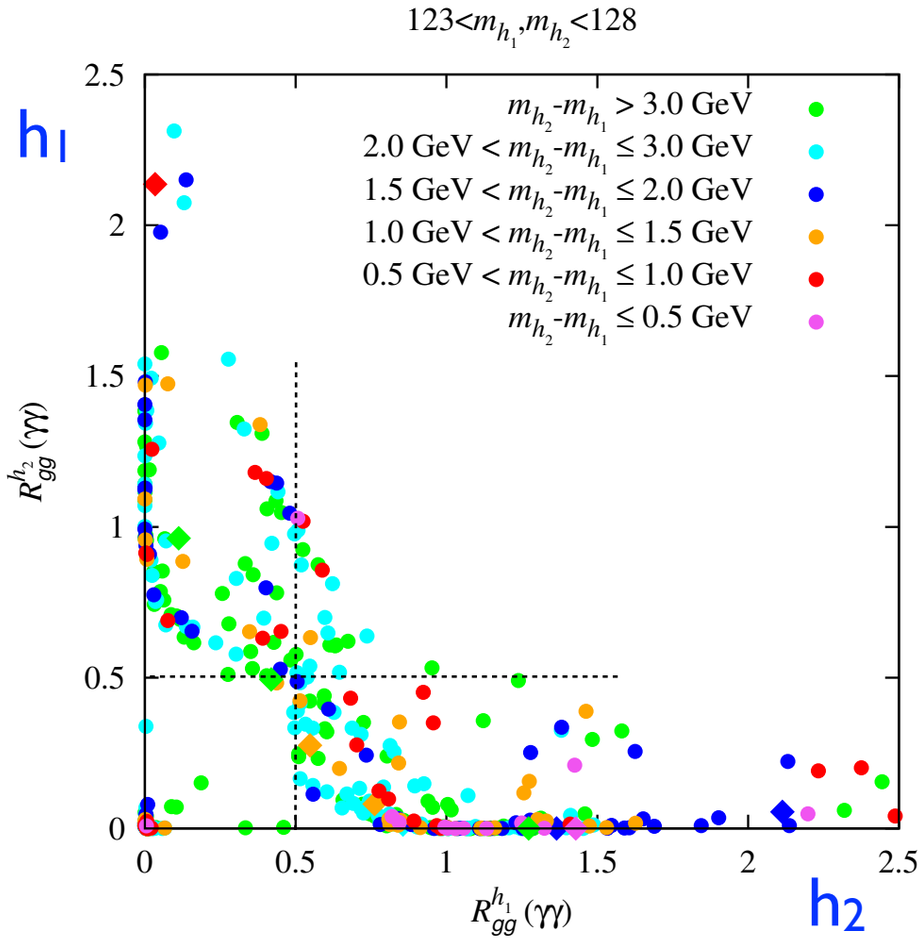


limits imposed: mass limits, B-physics constraints, $\Omega h^2 < 0.135$

Two NMSSM Higgses near 125 GeV?

J.F. Gunion, Y. Jiang, SK, arXiv:1207.1545

- On the previous slide, we had either h_1 or h_2 at 125 GeV, but the "other" Higgs need not be very far away.
- It is possible the h_1 and h_2 are so close in mass that they both fall into the 123-128 GeV mass window.
- In this case they may either both contribute to the signal at 125 GeV, or one Higgs contributes dominantly while the other one is hidden.
- Effective Higgs mass and signal rate:

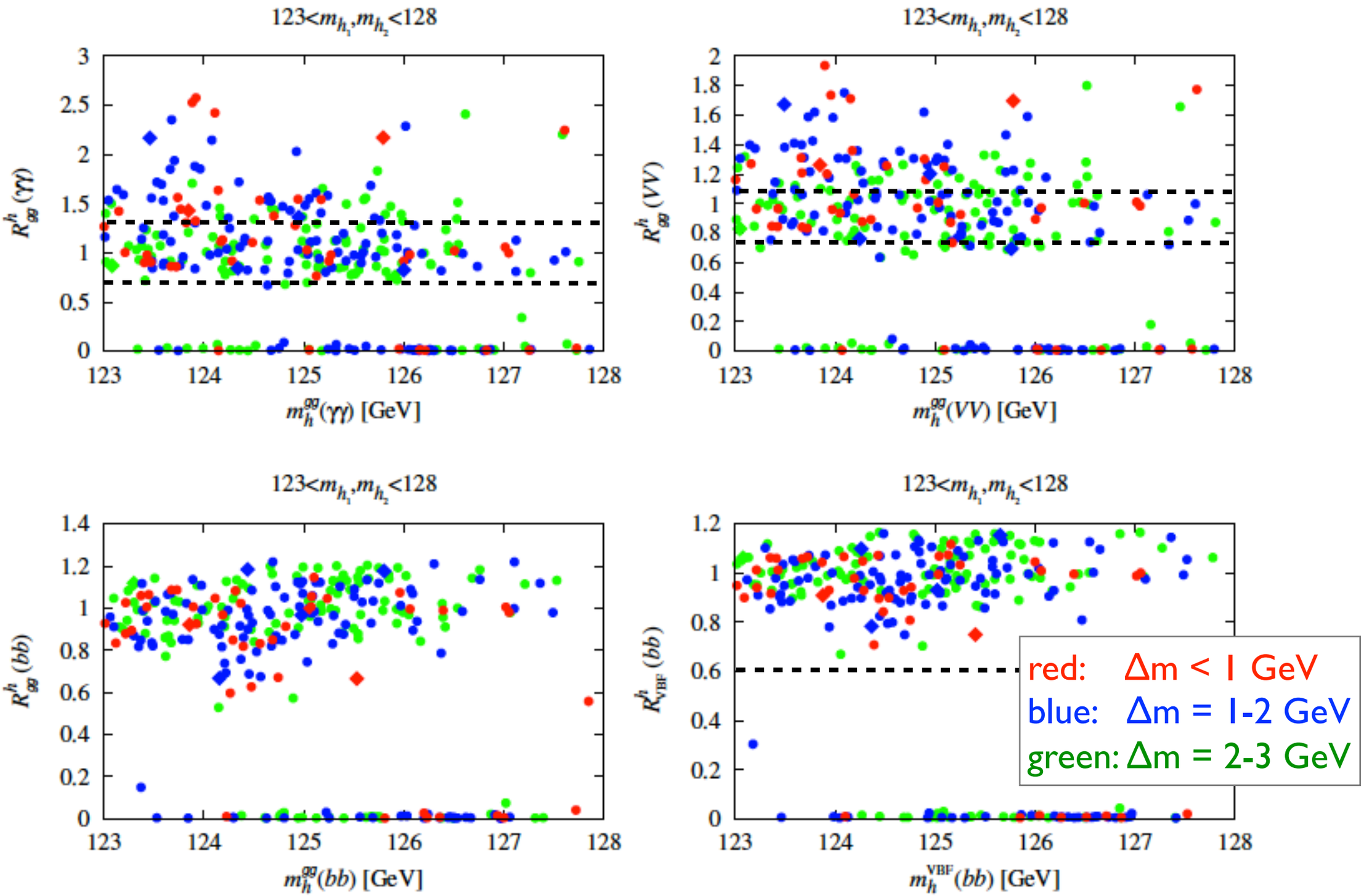


$$m_h^Y(X) \equiv \frac{R_Y^{h_1}(X) m_{h_1} + R_Y^{h_2}(X) m_{h_2}}{R_Y^{h_1}(X) + R_Y^{h_2}(X)}$$

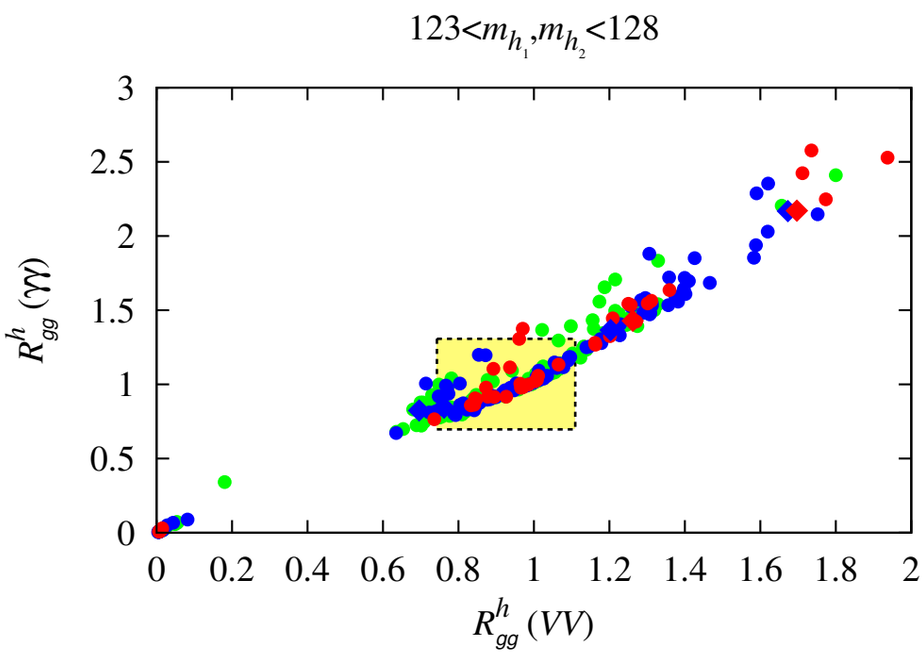
$$R_Y^h(X) = R_Y^{h_1}(X) + R_Y^{h_2}(X)$$

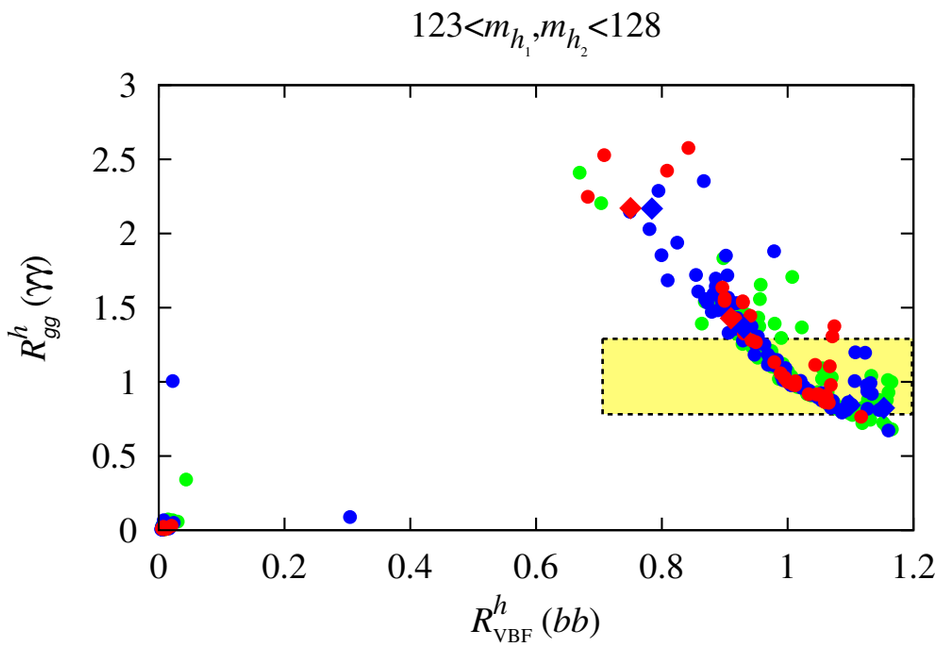
$$R_{gg}^{h_i}(X) = \frac{\Gamma(gg \to h_i)\ BR(h_i \to X)}{\Gamma(gg \to H_{\rm SM})\ BR(H_{\rm SM} \to X)}$$

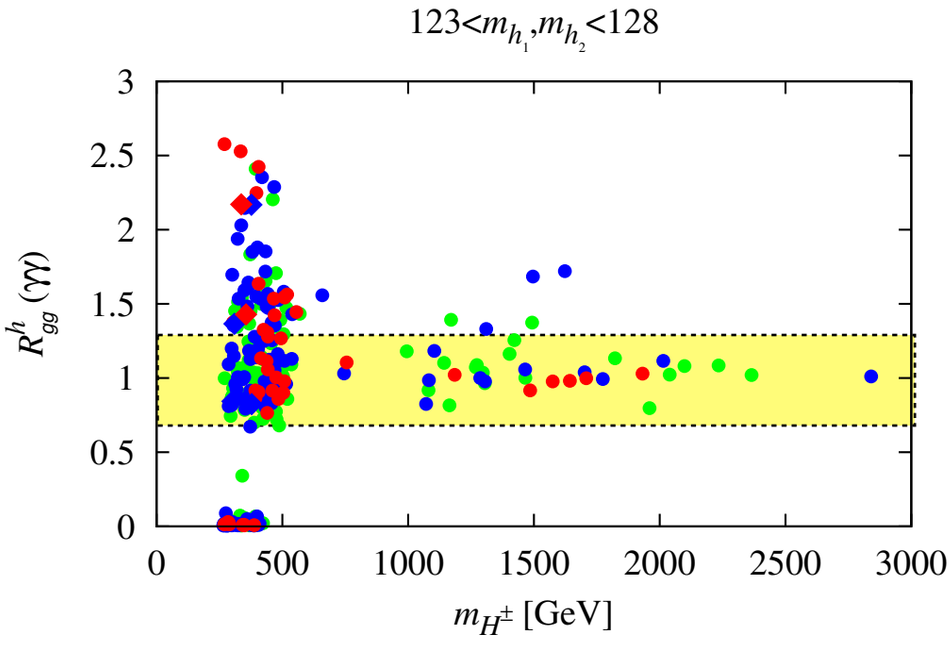
Two NMSSM Higgses near 125 GeV?



Two NMSSM Higgses near 125 GeV?







red: $\Delta m < 1$ GeV
blue: $\Delta m = 1$-2 GeV
green: $\Delta m = 2$-3 GeV

Preferred signal strength regions:
see Beranger's talk yesterday

Diagnosing degenerate Higgs bosons

J.F. Gunion, Y. Jiang, SK, arXiv:1208.1817

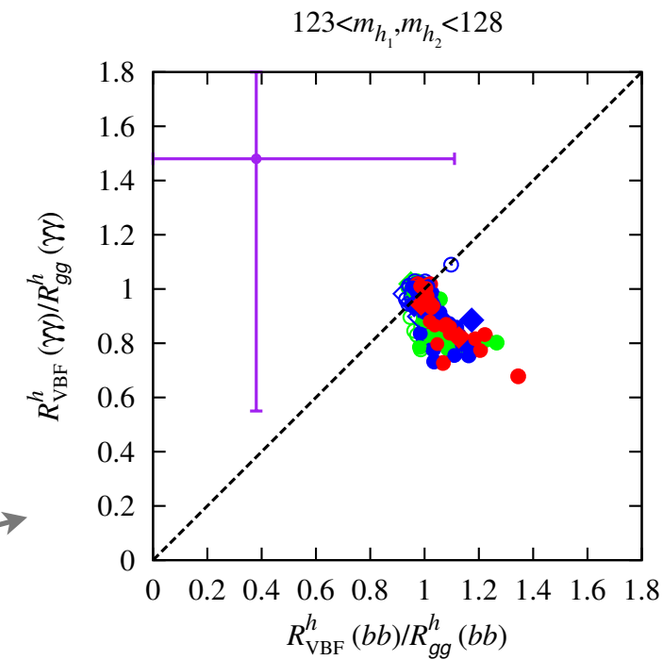
- A way to reveal the presence of degenerate Higgs bosons is through double ratios of signal strengths.

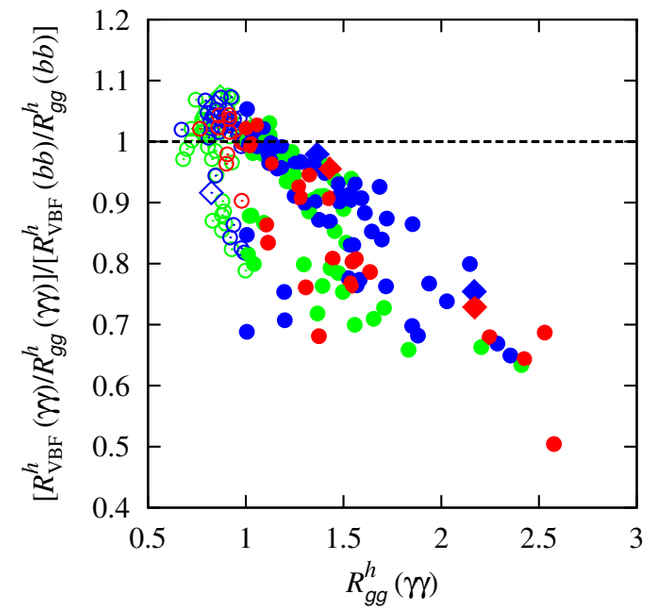
- Not all signal strengths are independent from each other. In models with doublets +singlets, we can form 3 independent double ratios:

$$\text{I):}\quad \frac{R^h_{VBF}(\gamma\gamma)/R^h_{gg}(\gamma\gamma)}{R^h_{VBF}(bb)/R^h_{gg}(bb)},$$

$$\text{II):}\quad \frac{R^h_{VBF}(\gamma\gamma)/R^h_{gg}(\gamma\gamma)}{R^h_{VBF}(WW)/R^h_{gg}(WW)},$$

$$\text{III):}\quad \frac{R^h_{VBF}(WW)/R^h_{gg}(WW)}{R^h_{VBF}(bb)/R^h_{gg}(bb)},$$





- If there is only one Higgs, each of these double ratios = 1.

Diagnosing degenerate Higgs bosons

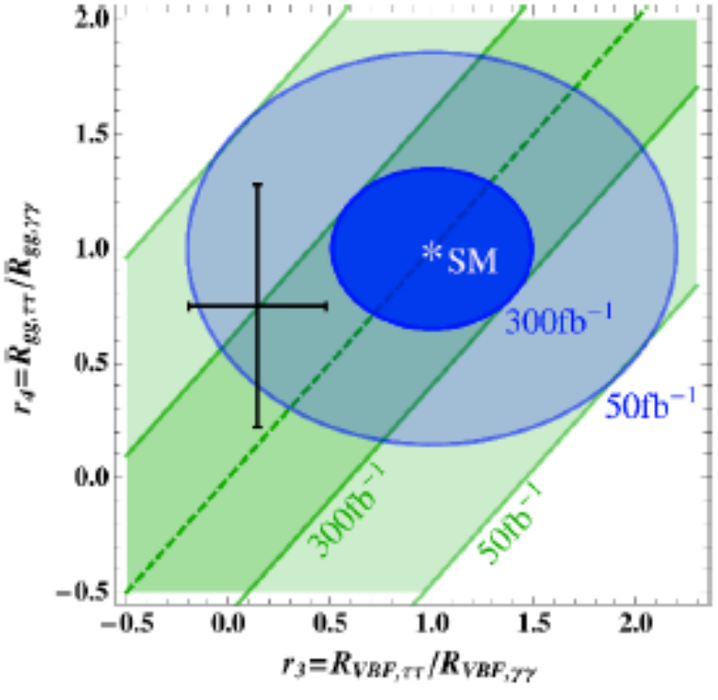
- More generally, one can form a "signal matrix" based on different initial and final states:

$$R = \frac{R_a}{R_b} = \frac{R(X \to h \to Y)_a}{R(X \to h \to Y)_b}$$

- Then rank(R) gives a lower limit on the number of resonances required to explain the data

- When R is a block matrix, det(*R*)=0 implies one resonance, while det(*R*)≠0 implies at least two contributing states

➡ using 2x2 sub-matrices this gives our "double ratios" from the previous slide



Grossman, Surujon, Zupan, arXiv:1301.0328

Questions, concerns

- How should we best combine the signals (signal strengths) of two nearby, or maybe not so nearby, states?

- So far: effective mass definition for two almost degenerate states

$$m_h^Y(X) \equiv \frac{R_Y^{h_1}(X) m_{h_1} + R_Y^{h_2}(X) m_{h_2}}{R_Y^{h_1}(X) + R_Y^{h_2}(X)}$$

and just adding up the signal strengths

$$R_Y^h(X) = R_Y^{h_1}(X) + R_Y^{h_2}(X) \ .$$

- But this depends on the channel-by-channel resolutions!

- Moreover, for scans, we need to describe the transition from two separate peaks (to one of which exclusion limits apply) to a combined signal

➔ need a reliable, general prescription

SO …

although there is currently no evidence for more than one Higgs in the data

it may be ...

a matter of perspective?

a matter of perspective?

a matter of perspective?

a matter of perspective?

a matter of perspective?

(it's all the same mountain on the same climb)

search

~~climb~~ with an open mind


maybe a whole new landscape opens up