Modified Higgs Couplings and New Physics

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Based on the following works :

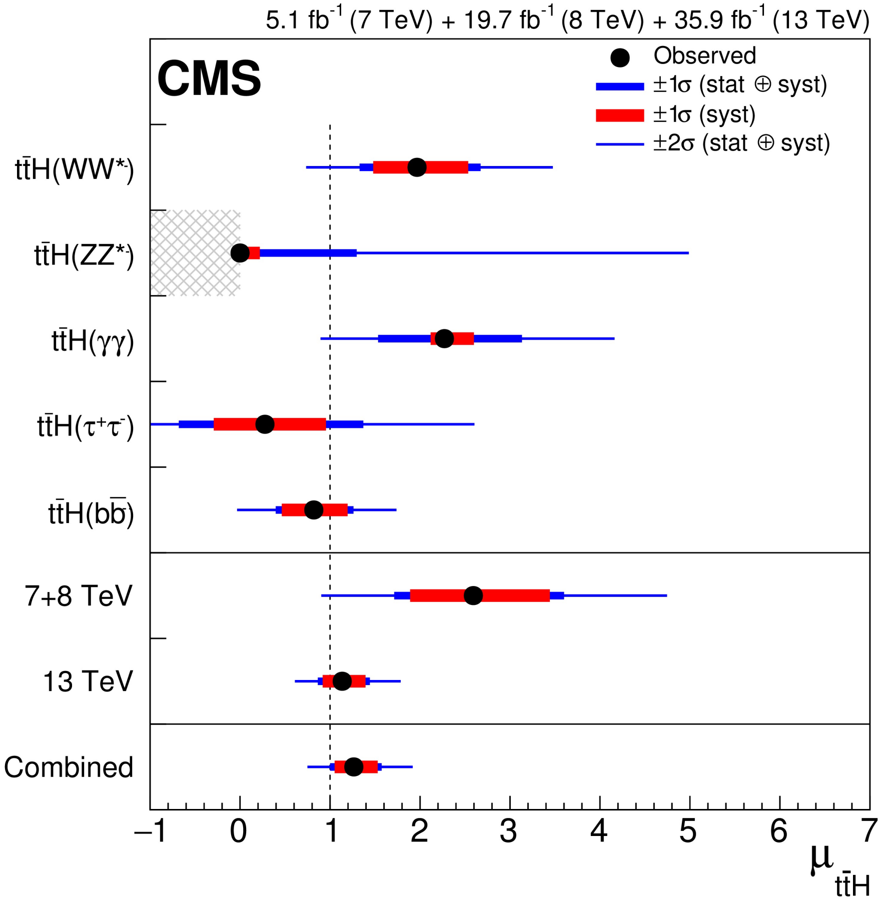
- M. Carena, I. Low, N. Shah, C.W., arXiv:1310.2248, JHEP 1404 (2014)
- M. Carena, H. Haber, I. Low, N. Shah, C.W., arXiv:1410.4969, PRD91 (2015); arXiv:1510.09137, PRD93 (2016)
- M. Badziak, C.W. , arXiv:1602.06198, JHEP 1605 (2016); arXiv: 1611.02353, JHEP 1702 (2017)
- D. Liu, I. Low, C.Wagner, arXiv:1703.07791, PRD96 (2017)
- A. Joglekar, M. Li, P. Huang, C.W., arXiv:1711.05743, to appear in PRD.
- N. Coyle, B. Li, C.W., arXiv:1802.09122

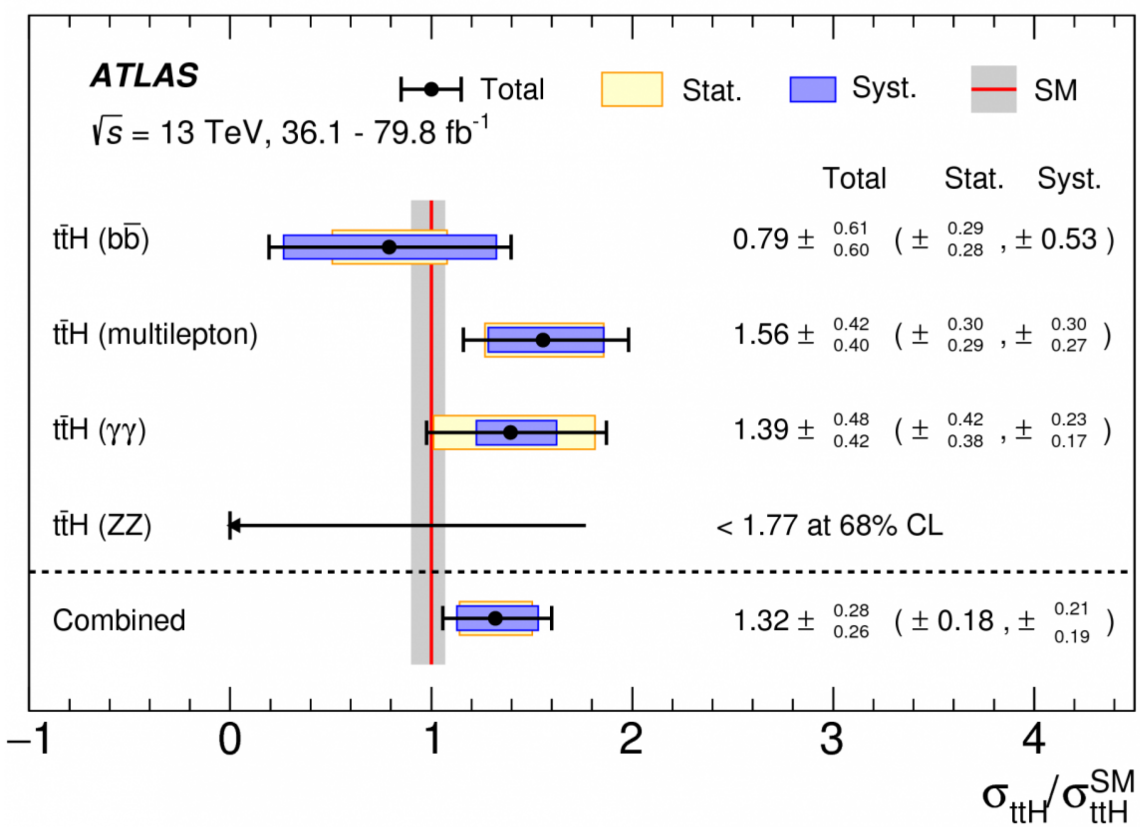
Modified Couplings ?

- Today, we know that the observed Higgs Boson couples to top and bottom quarks.
- The values of the couplings are within a few tens of percents of the SM values (at least in modulus).
- In the presence of new Higgs states at the weak scale, something I consider likely, the couplings will not coincide with the SM ones.
- I will discuss the impact of such modifications and how they appear in some New Physics Models.

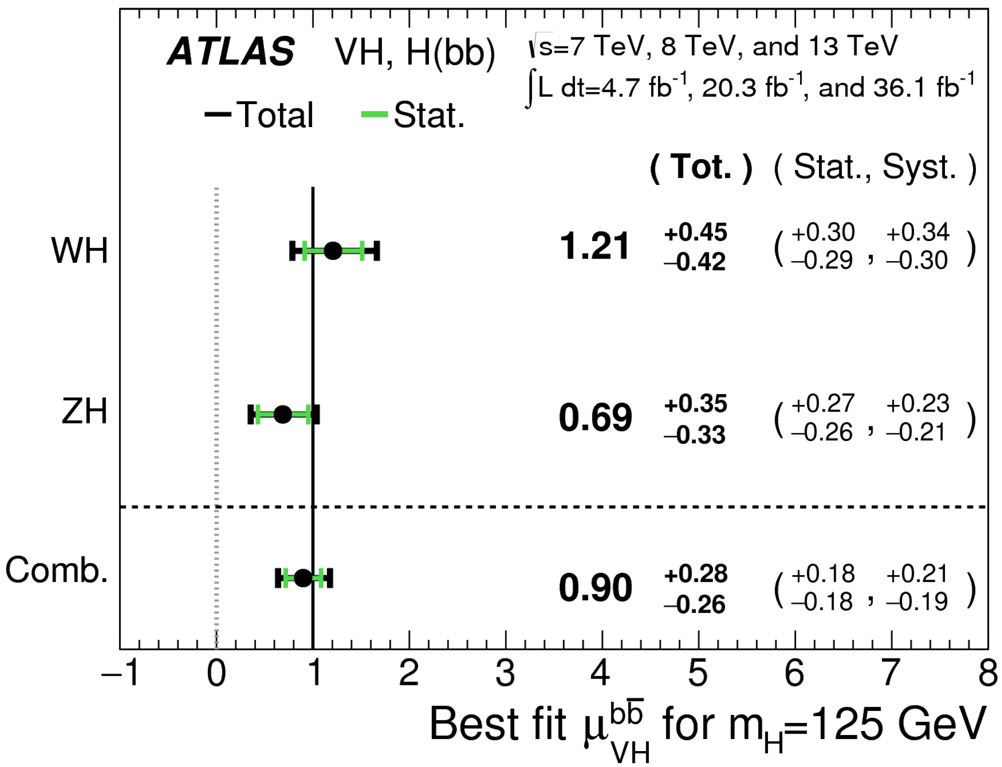
New tth results

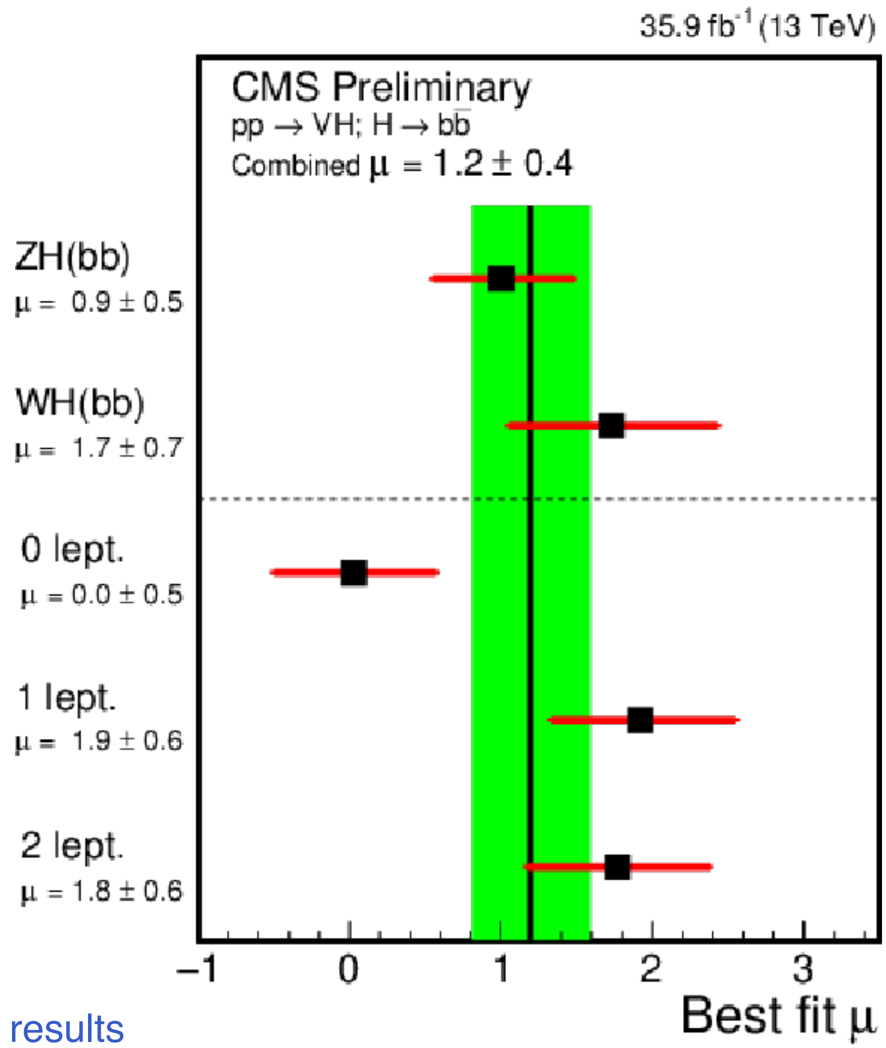
Values overall consistent with the SM, but a few interesting small discrepancies are present at both experiments.





There is today evidence of a Higgs decaying to bottom quarks





Consistency with SM results

Errors are still large an admit deviations of a few tens of percent from the SM results

Impact of Modified Couplings

- In general, assuming modified couplings, and no new light particle the Higgs can decay into, the new decay branching ratios are given by

$$BR(h \to XX) = \frac{\kappa_X^2 \; BR(h \to XX)^{\rm SM}}{\sum_i \kappa_i^2 \; BR(h \to ii)^{\rm SM}}$$

- For small variations of (only) the bottom coupling, and $X \neq b$

$$BR(h \to b\bar{b}) \simeq BR(h \to b\bar{b})^{\rm SM}(1 + 0.4(\kappa_b^2 - 1))$$

$$BR(h \to XX) \simeq BR(h \to XX)^{\rm SM}(1 - 0.6(\kappa_b^2 - 1))$$

$$\frac{BR(h \to b\bar{b})}{BR(h \to XX)} = \frac{BR(h \to b\bar{b})^{\rm SM}}{BR(h \to XX)^{\rm SM}}(1 + (\kappa_b^2 - 1))$$

- So, due to the its large contribution to the Higgs decay width, a modification of a bottom coupling leads to a large modification of all other decay branching ratios (larger than the one into bottoms !)

- Observe that the coefficients are just given by the SM bottom decay branching ratio and its departure from one.

Modified couplings in 2HDMs

Modifying the top and bottom couplings in two Higgs Doublet Models

- Measurement of the top and bottom couplings still subject to large errors.
- The enhancement on the top coupling is somewhat weaker in the 13 TeV data. Modifications of a few tens of percent possible.
- Modifying the top-quark coupling is simple for small values of tanβ, but the bottom coupling is modified as well in an opposite direction

$$h = -\sin\alpha H_d^0 + \cos\alpha H_u^0$$
$$H = \quad \cos\alpha H_d^0 + \sin\alpha H_u^0$$

$$\kappa_t = \sin(\beta-\alpha) + \cot\beta\cos(\beta-\alpha)$$
$$\kappa_b = \sin(\beta-\alpha) - \tan\beta\cos(\beta-\alpha)$$
$$\kappa_V = \sin(\beta-\alpha) \simeq 1$$

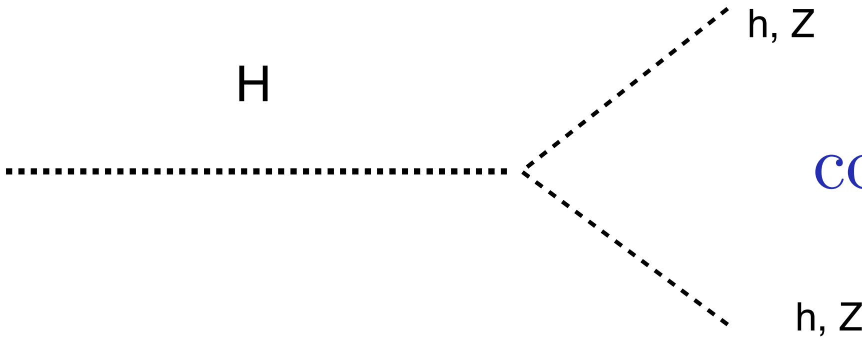
$$\tan\beta = \frac{v_u}{v_d}$$

Alignment Condition : $\cos(\beta-\alpha) = 0$

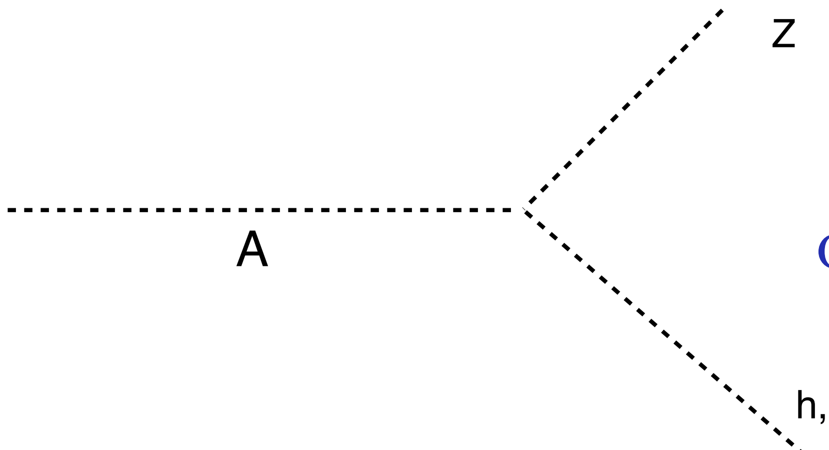
SM-like Higgs tree level couplings equal to SM couplings

H and A Decay to Boson Pairs

Suppressed at Alignment



$$\cos(\beta - \alpha)$$



$$\cos(\beta - \alpha)$$

Carena, Low, Shah, C.W.'13

Deviations from Alignment

$$c_{\beta-\alpha} = t_\beta^{-1}\eta\ , \qquad s_{\beta-\alpha} = \sqrt{1 - t_\beta^{-2}\eta^2}$$

$$\begin{aligned} h &= -\sin\alpha H_d^0 + \cos\alpha H_u^0 \\ H &= \quad \cos\alpha H_d^0 + \sin\alpha H_u^0 \end{aligned}$$

The couplings of down fermions are not only the ones that dominate the Higgs width but also tend to be the ones which differ at most from the SM ones

$$g_{hVV} \approx \left(1 - \frac{1}{2} t_\beta^{-2}\eta^2\right) g_V\ , \qquad g_{HVV} \approx t_\beta^{-1}\eta\ g_V\ ,$$

$$g_{hdd} \approx (1-\eta)\, g_f\ , \qquad g_{Hdd} \approx t_\beta(1 + t_\beta^{-2}\eta) g_f$$

$$g_{huu} \approx (1 + t_\beta^{-2}\eta)\, g_f\ , \qquad g_{Huu} \approx -t_\beta^{-1}(1-\eta) g_f$$

For small departures from alignment, the parameter η can be determined as a function of the quartic couplings and the Higgs masses

$$\eta = s_\beta^2\left(1 - \frac{\mathcal{A}}{\mathcal{B}}\right) = s_\beta^2 \frac{\mathcal{B}-\mathcal{A}}{\mathcal{B}}, \qquad \mathcal{B} - \mathcal{A} = \frac{1}{s_\beta}\left(-m_h^2 + \tilde{\lambda}_3 v^2 s_\beta^2 + \lambda_7 v^2 s_\beta^2 t_\beta + 3\lambda_6 v^2 s_\beta c_\beta + \lambda_1 v^2 c_\beta^2\right)$$

$$\tilde{\lambda}_3 = \lambda_3 + \lambda_4 + \lambda_5$$

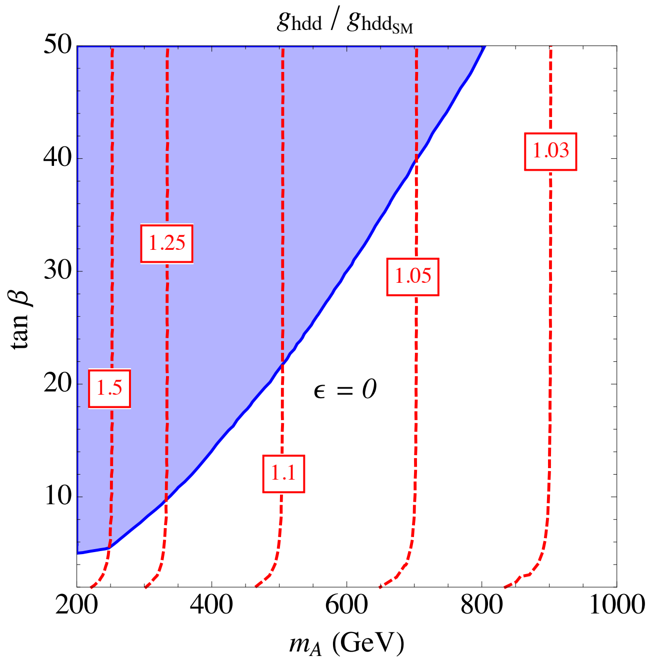
$$\mathcal{B} = \frac{\mathcal{M}_{11}^2 - m_h^2}{s_\beta} = \left(m_A^2 + \lambda_5 v^2\right) s_\beta + \lambda_1 v^2 \frac{c_\beta}{t_\beta} + 2\lambda_6 v^2 c_\beta - \frac{m_h^2}{s_\beta}$$

Down Couplings in the MSSM for low values of μ

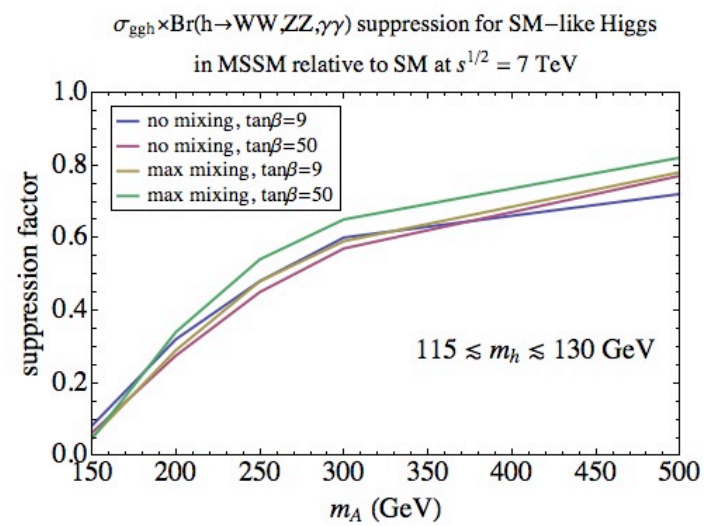
- In this regime, $\lambda_{6,7} \simeq 0$, and

$$\lambda_1 \simeq -\tilde{\lambda}_3 = \frac{g_1^2 + g_2^2}{4} = \frac{M_Z^2}{v^2} \simeq 0.125 \qquad \lambda^{\rm SM} \simeq 0.26 \qquad \lambda_7 \propto \frac{A_t \mu}{M_S^2}\left(1 - \frac{A_t^2}{6M_S^2}\right)$$

$$\lambda_2 \simeq \frac{M_Z^2}{v^2} + \frac{3}{8\pi^2} h_t^4 \left[\log\left(\frac{M_{\rm SUSY}^2}{m_t^2}\right) + \frac{A_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{A_t^2}{12 M_{\rm SUSY}^2}\right)\right]$$



Carena, Low, Shah, C.W.' 13



All vector boson branching ratios suppressed by enhancement of the bottom decay width

$$t_\beta\, c_{\beta-\alpha} \simeq \frac{-1}{m_H^2 - m_h^2}\left[m_h^2 + m_Z^2 + \frac{3 m_t^4}{4\pi^2 v^2 M_S^2}\left\{A_t \mu t_\beta \left(1 - \frac{A_t^2}{6M_S^2}\right) - \mu^2 \left(1 - \frac{A_t^2}{2M_S^2}\right)\right\}\right]$$

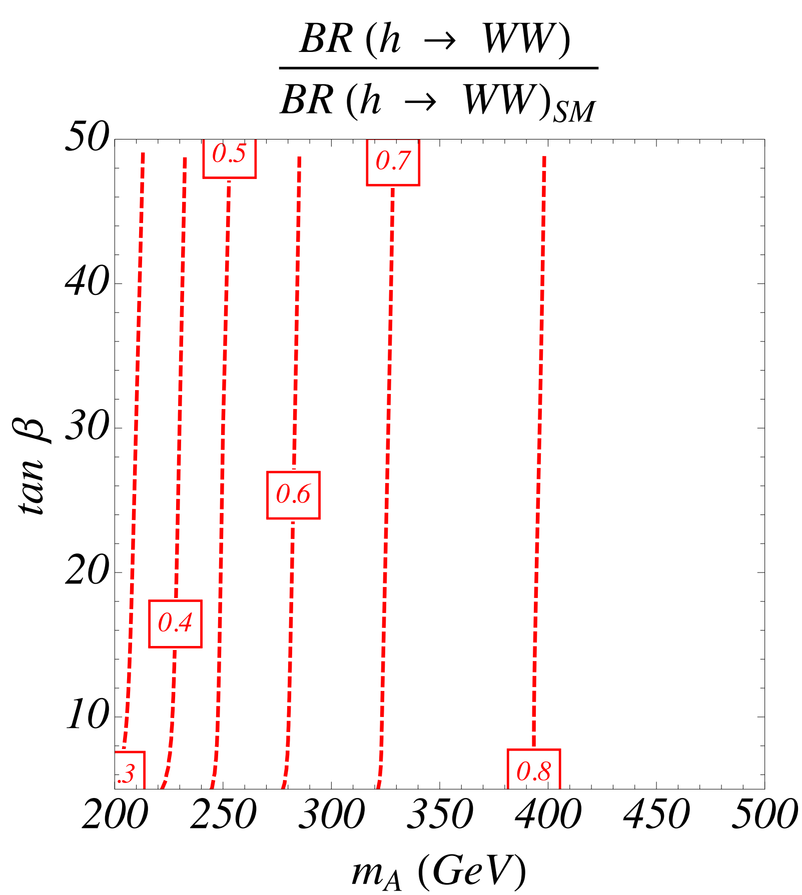
Carena, Haber, Low, Shah, C.W.' 14

M. Carena, I. Low, N. Shah, C.W.' 13

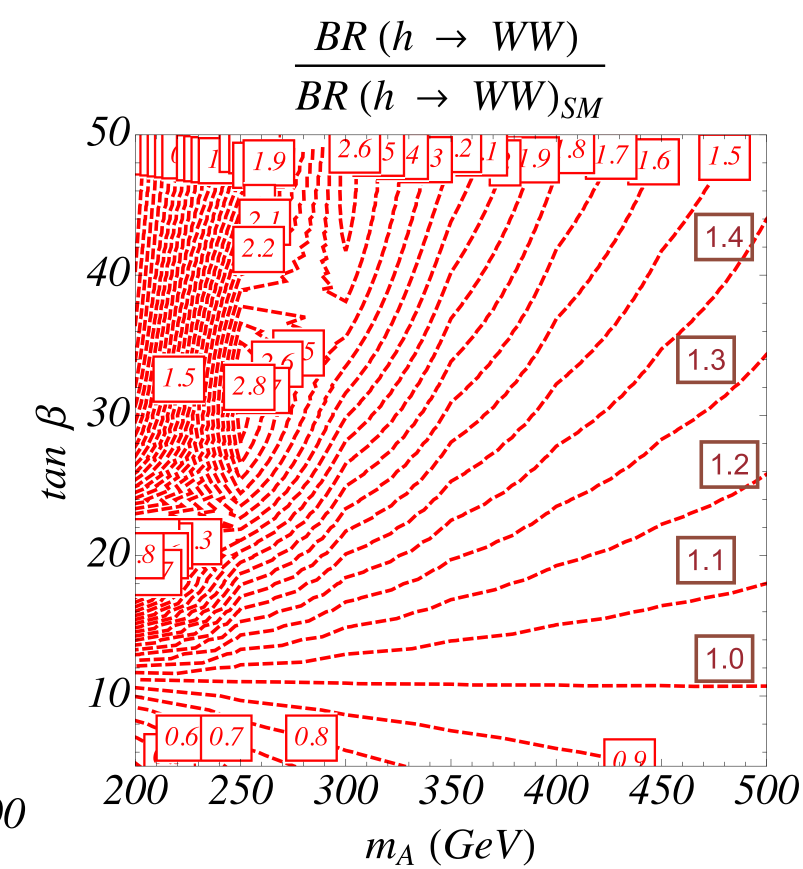
Higgs Decay into Gauge Bosons

Mostly determined by the change of width

Small μ



$\mu/M_{\rm SUSY} = 2, \quad A_t/M_{\rm SUSY} \simeq 3$



CP-odd Higgs masses of order 200 GeV and tanβ = 10 OK in the alignment case

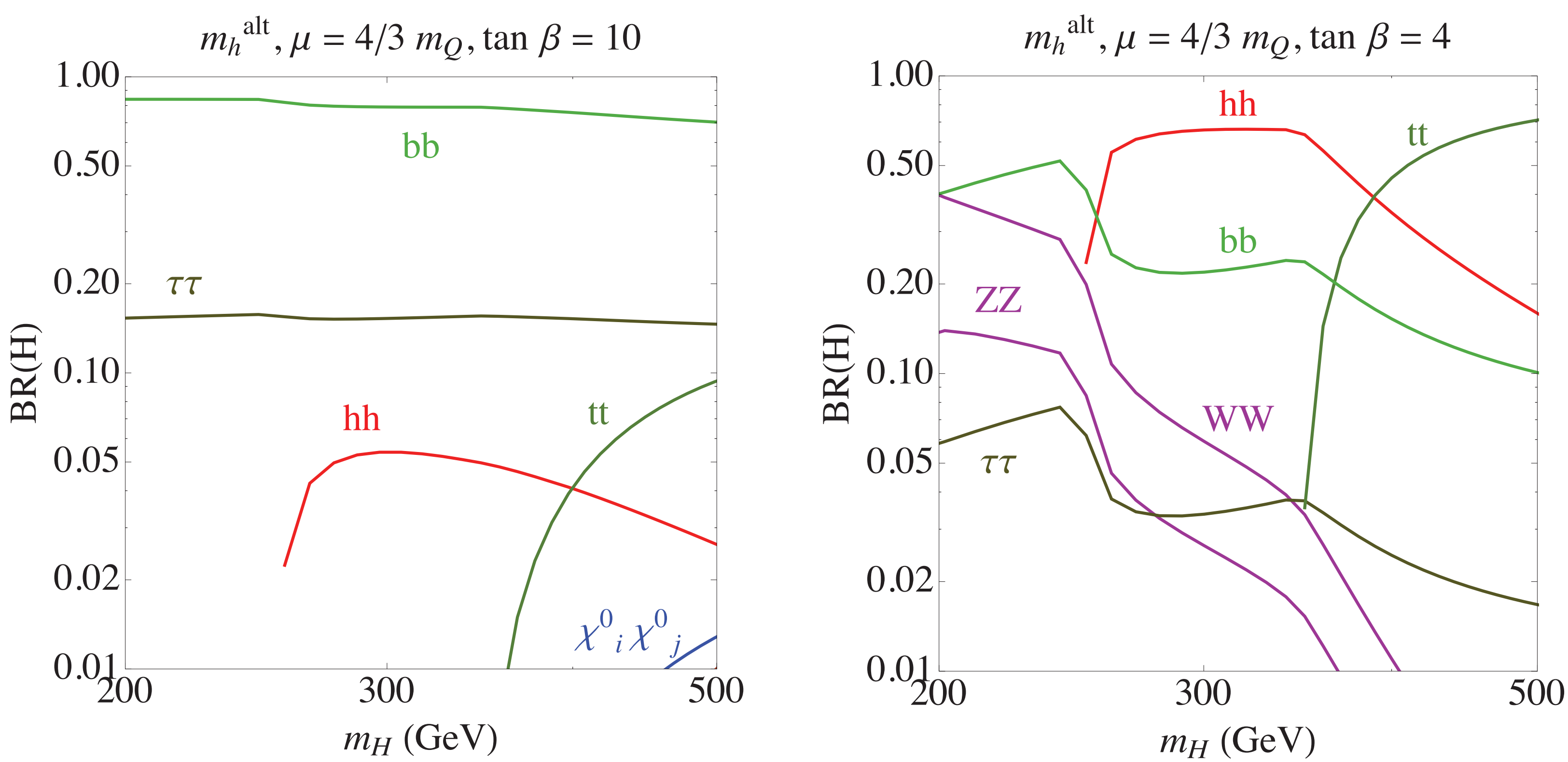
Heavy Supersymmetric Particles

Heavy Higgs Bosons : A variety of decay Branching Ratios

Carena, Haber, Low, Shah, C.W.'14

$m_h^{\rm alt}$: Large μ. Alignment at values of $\tan\beta \simeq 12$

Depending on the values of μ and tanβ different search strategies must be applied.



At large tanβ, bottom and tau decay modes dominant.

As tanβ decreases decays into SM-like Higgs and wek bosons become relevant

Carena, Haber, Low, Shah, C.W.'15

Naturalness and Alignment in the NMSSM

see also Kang, Li, Li,Liu, Shu'13, Agashe,Cui,Franceschini'13

- It is well known that in the NMSSM there are new contributions to the lightest CP-even Higgs mass,

$$W = \lambda S H_u H_d + \frac{\kappa}{3} S^3$$

$$m_h^2 \simeq \lambda^2 \frac{v^2}{2} \sin^2 2\beta + M_Z^2 \cos^2 2\beta + \Delta_{\tilde{t}}$$

- It is perhaps less known that it leads to sizable corrections to the mixing between the MSSM like CP-even states. In the Higgs basis, (correction to λ_4)

$$M_S^2(1,2) \simeq \frac{1}{\tan\beta}\left(m_h^2 - M_Z^2 \cos 2\beta - \lambda^2 v^2 \sin^2\beta + \delta_{\tilde{t}}\right)$$

$$\delta\tilde{\lambda}_3 = \lambda^2 \qquad\qquad \cos(\beta-\alpha) \simeq -M_S^2(1,2)/(m_H^2 - m_h^2)$$

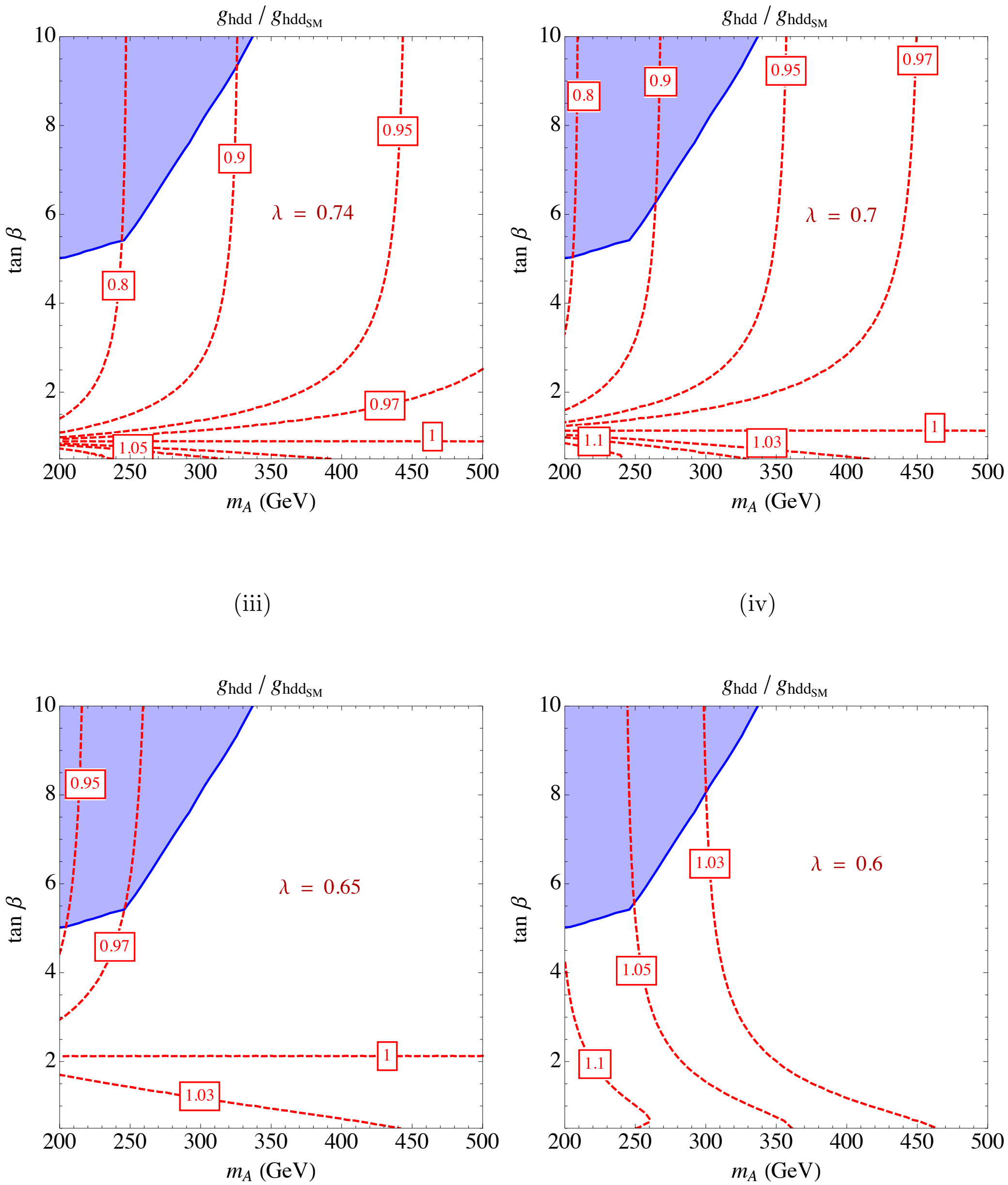
- The last term is the one appearing in the MSSM, that are small for moderate mixing and small values of $\tan\beta$

- The values of λ end up in a very narrow range, between 0.65 and 0.7 for all values of tan(beta), that are the values that lead to naturalness with perturbativity up to the GUT scale

$$\lambda^2 = \frac{m_h^2 - M_Z^2 \cos 2\beta}{v^2 \sin^2\beta}$$

Alignment in the NMSSM (heavy or Aligned singlets)

Carena, Low, Shah, C.W.'13



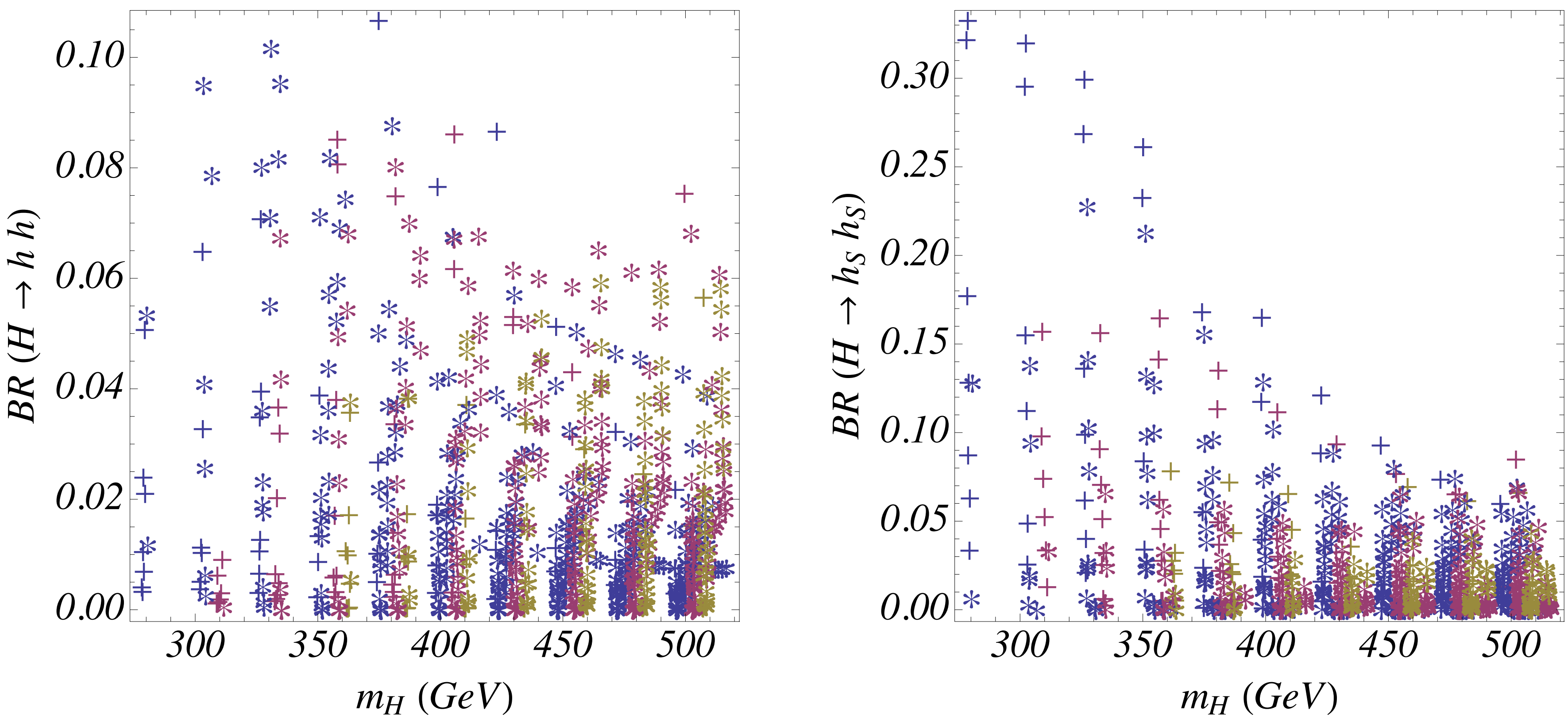
It is clear from these plots that the NMSSM does an amazing job in aligning the MSSM-like CP-even sector, provided λ is about 0.65

Decays into pairs of SM-like Higgs bosons suppressed by alignment

Carena, Haber, Low, Shah, C.W.'15

Crosses : H1 singlet like
Asterix : H2 singlet like

Blue : $\tan\beta = 2$
Red : $\tan\beta = 2.5$
Yellow: $\tan\beta = 3$



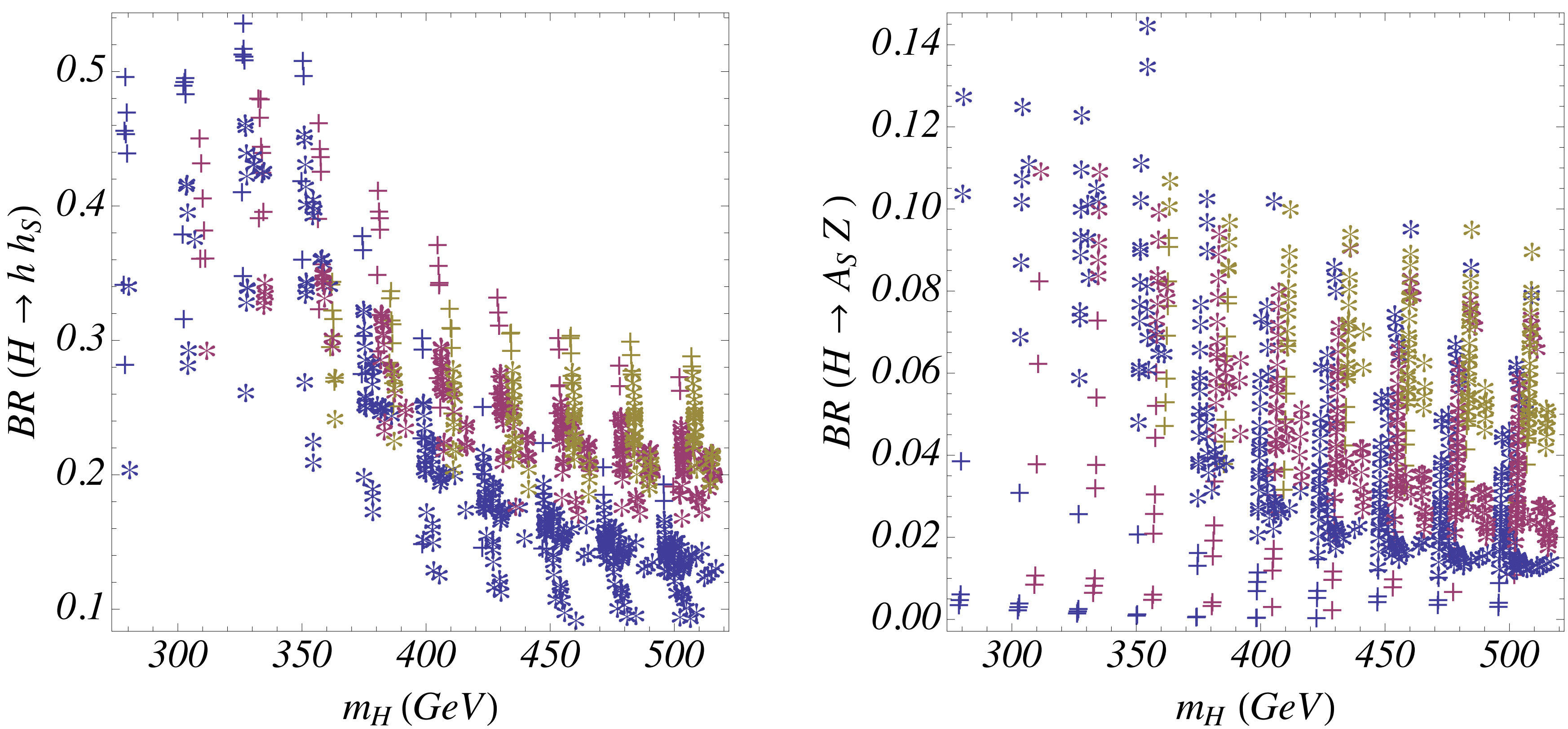
Significant decays of heavier Higgs Bosons into lighter ones and Z's

Relevant for searches for Higgs bosons

Crosses : H1 singlet like
Asterix : H2 singlet like

Blue : $\tan\beta = 2$
Red : $\tan\beta = 2.5$
Yellow: $\tan\beta = 3$

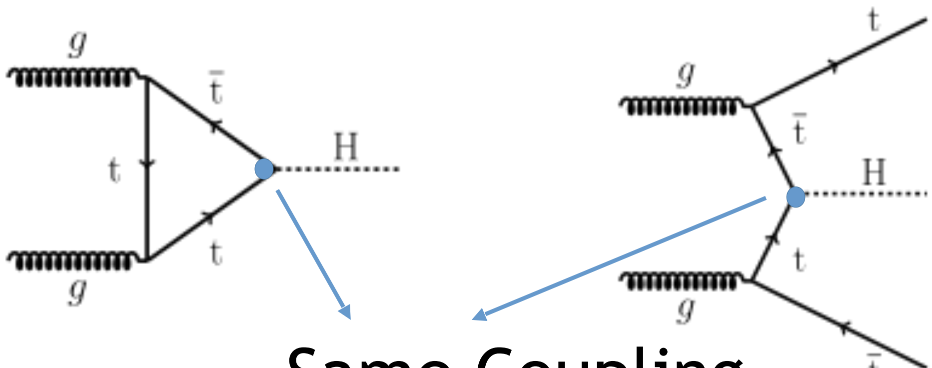
Carena, Haber, Low, Shah, C.W.'15



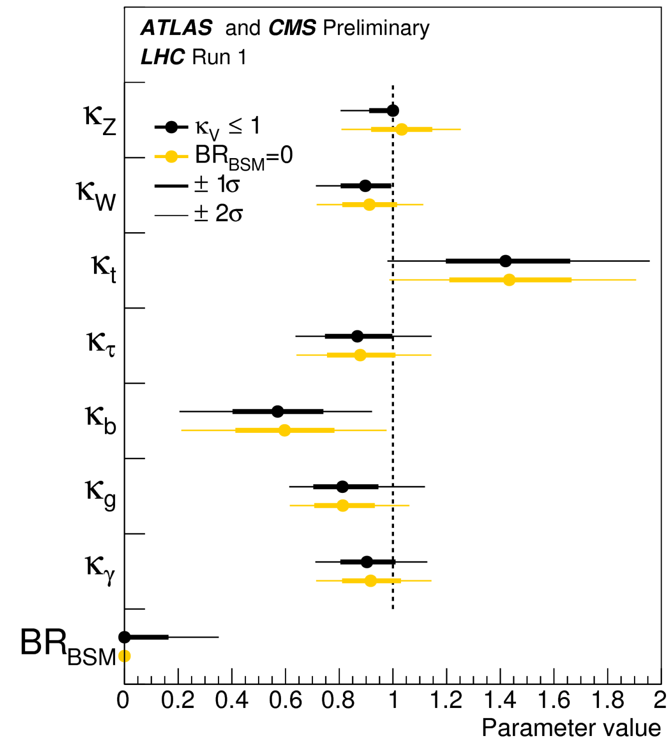
More on Top Quark and Bottom Quark Couplings Modifications

What is the problem in 2HDM ?

Suppression of the gluon fusion rate ?



Same Coupling



Would expect top rate to be suppressed as well ! No evidence of that in data, although errors are too large to tell.

M. Badziak and C.W. ‘1602.06198, 1611.03253

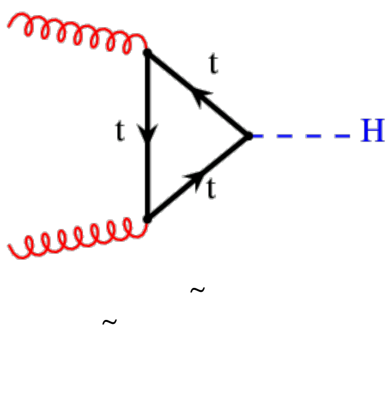
The Gluon Fusion Rate

- Suppression of the bottom coupling would demand some suppression of the gluon-Higgs coupling.

- Problem is even more severe when the top coupling is enhanced, since we have to compensate for this potential source of ggh enhancement

$$\kappa_t = \sin(\beta - \alpha) + \cot\beta \cos(\beta - \alpha)$$
$$\kappa_b = \sin(\beta - \alpha) - \tan\beta \cos(\beta - \alpha)$$
$$\kappa_V = \sin(\beta - \alpha) \simeq 1$$

- However, the gluon fusion cross section could also be modified in the presence of extra color particles. For instance, for scalar tops,



$$\frac{\kappa_g}{\kappa_g^{\rm SM}} \simeq \kappa_t \left[1 + \frac{m_t^2}{4}\left(\frac{1}{m_{\tilde{t}_1}^2} + \frac{1}{m_{\tilde{t}_2}^2} - \frac{X_t^2}{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}\right)\right]$$

Badziak, C.W. , to appear

NMSSM Scenarios with light singlets

	P1	P2	P3	P4
λ	0.5	0.53	0.5	0.55
$\tan\beta$	1.6	1.6	2	2
m_{Q_3}	800	800	800	800
m_{U_3}	320	310	280	270
A_t	-1500	-1400	-1500	-1400
μ	600	800	600	800
μ'	330	500	330	310
M_A	300	300	300	400
M_P	246	382	347	382
A_λ	905	1125	1055	1610
m_s	98	98	79	85
m_h	124.5	125.8	124.7	125.1
m_H	317	390	393	465
$m_{H^\pm}$	236	200	225	325
m_a	101	136	130	89
m_A	329	412	395	496
$m_{\tilde{\chi}_1^0}$	243	245	243	245
$m_{\tilde{t}_1}$	282	282	276	275
$m_{\tilde{t}_2}$	954	960	952	954

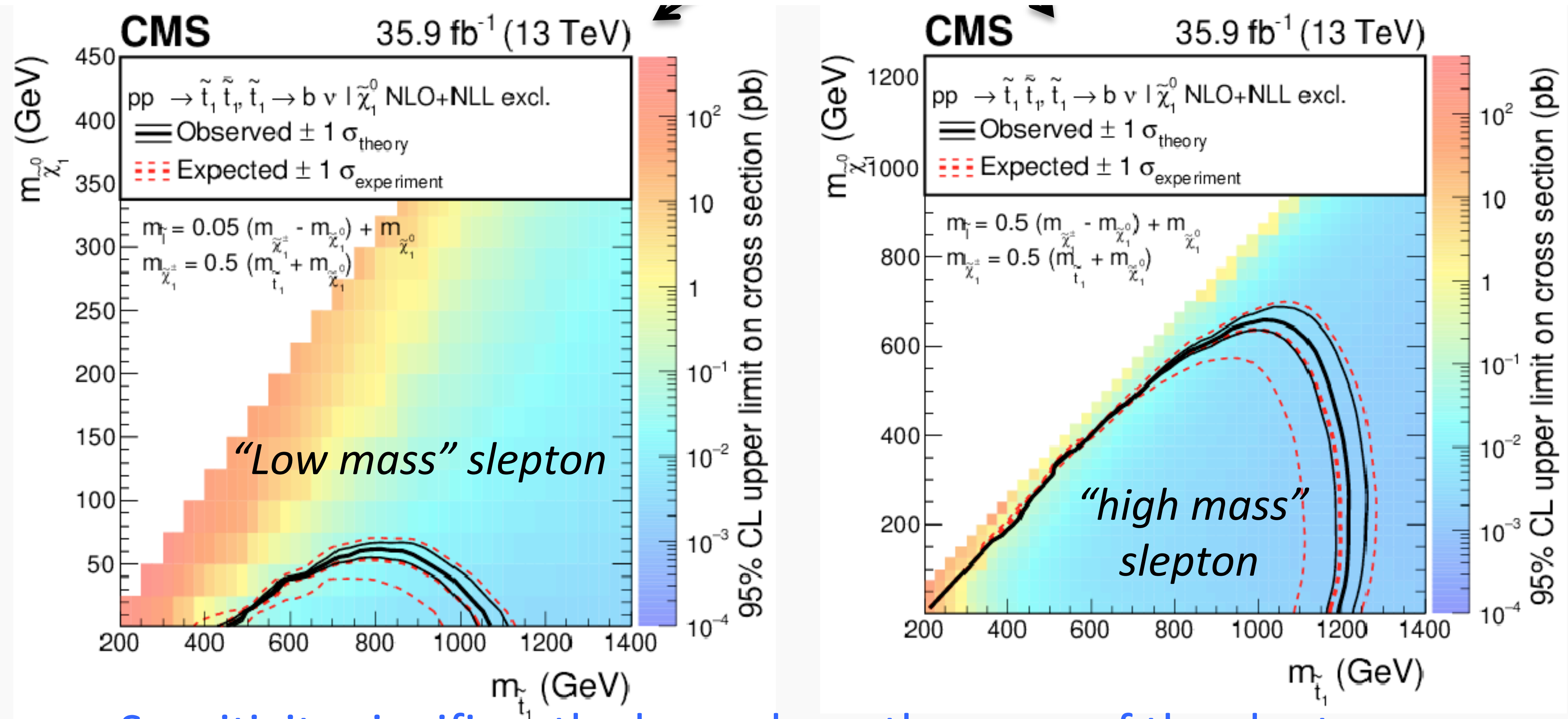
	P1	P2	P3	P4
$R_{VV}^{\rm tth}$	1.60	1.61	1.62	1.61
$R_{\gamma\gamma}^{\rm tth}$	1.82	1.82	1.81	1.79
$R_{VV}^{\rm gg}$	1.02	1.01	1.04	1.04
$R_{\gamma\gamma}^{\rm gg}$	1.16	1.15	1.16	1.16
$R_{VV}^{\rm VBF/VH}$	1.32	1.34	1.43	1.42
$R_{\gamma\gamma}^{\rm VBF/VH}$	1.51	1.53	1.60	1.57
$R_{\tau\tau}^{\rm VBF/VH}$	0.73	0.78	0.78	0.77
$\xi_{b\bar{b}}^{\rm LEP}$	0.10	0.04	0.04	0.04
$\bar{g}_s$	0.31	0.20	0.18	0.20
$\mathrm{BR}(H\to t\bar{t})$	0	0.024	0.036	0.071
$\mathrm{BR}(H\to ss)$	0.37	0.04	0.002	0.15
$\mathrm{BR}(H\to aa)$	0.23	0.63	0.42	0.24
$\mathrm{BR}(H\to aZ)$	0.23	0.11	0.26	0.39
$\mathrm{BR}(H\to hs)$	0.15	0.03	0.019	0.017
$\mathrm{BR}(H\to H^\pm W^\mp)$	0	0.15	0.25	0.13
$\mathrm{BR}(A\to t\bar{t})$	0	0.13	0.12	0.12
$\mathrm{BR}(A\to as)$	0.64	0.26	0.26	0.31
$\mathrm{BR}(A\to Zs)$	0.22	0.24	0.32	0.34
$\mathrm{BR}(A\to ah)$	0.10	0.036	0.021	0.002
$\mathrm{BR}(A\to H^\pm W^\mp)$	0.02	0.33	0.27	0.22
$\mathrm{BR}(H^+\to t\bar{b})$	0.52	0.63	0.36	0.24
$\mathrm{BR}(H^+\to W^+a)$	0.26	0	0.08	0.40
$\mathrm{BR}(H^+\to W^+s)$	0.22	0.37	0.56	0.35

Large decay Branching ratio of MSSM Higgs into singlet states

Consistent with the LEP2 Excess (not a necessary ingredient)

Limits on Stops may be diluted by light EW states

Eric Chabert, Talk at PASCOS 2018

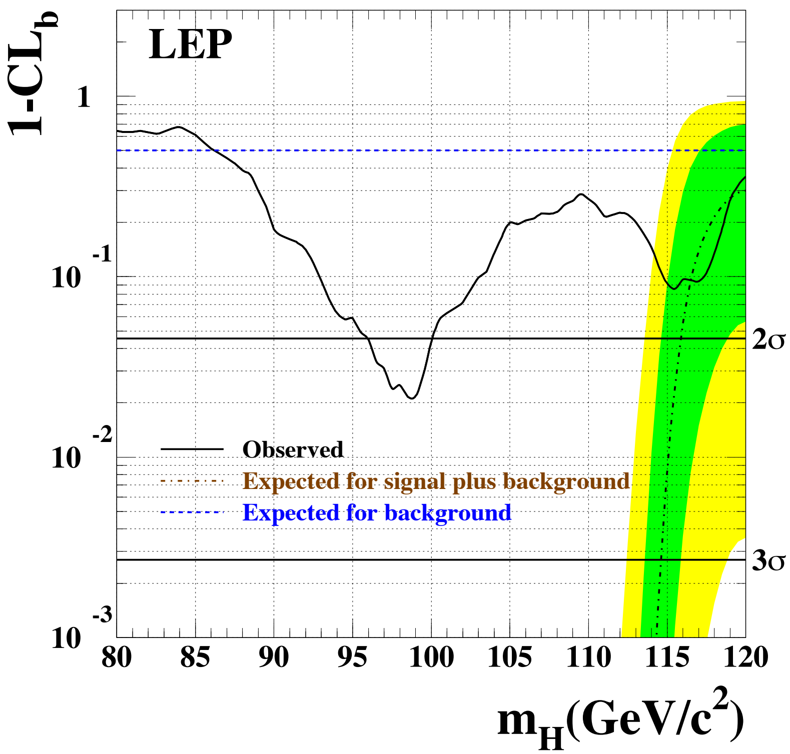


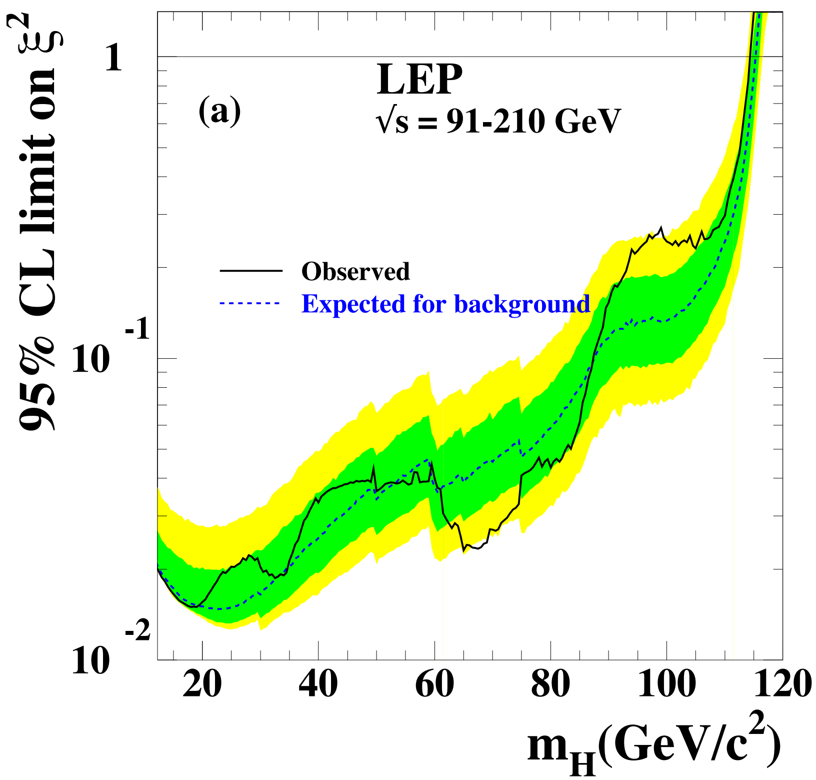
Sensitivity significantly depends on the mass of the slepton

LEP2 Excess

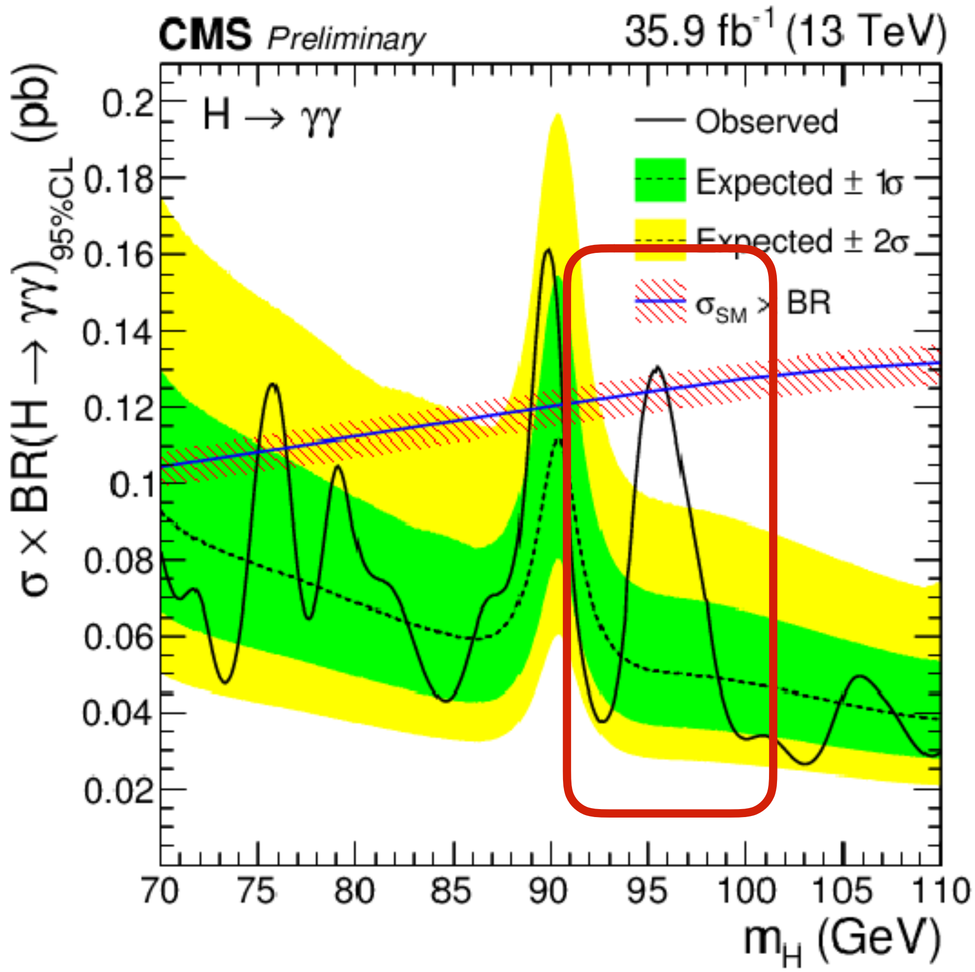
LHWG-2003-011

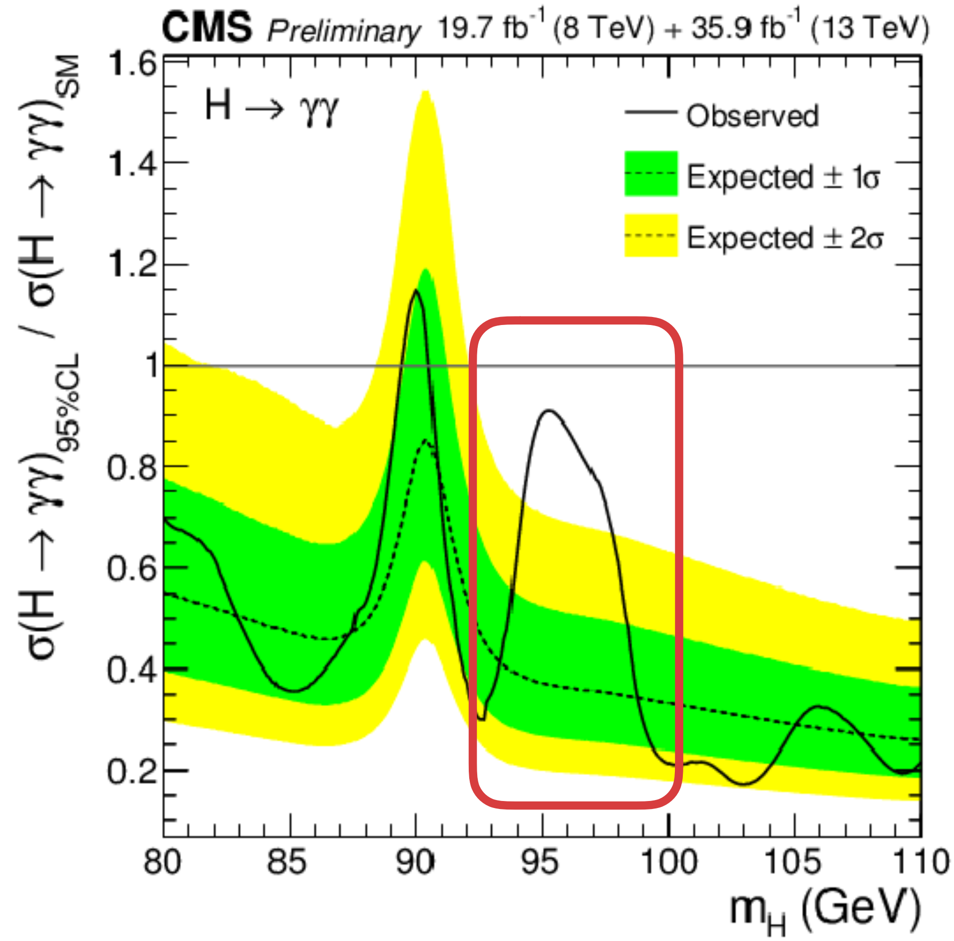
$$\xi^2 = g^2_{ZZh}/g^2_{ZZh_{SM}} \times \frac{\mathrm{BR}(s \to b\bar{b})}{\mathrm{BR}(h^{\mathrm{SM}} \to b\bar{b})}$$





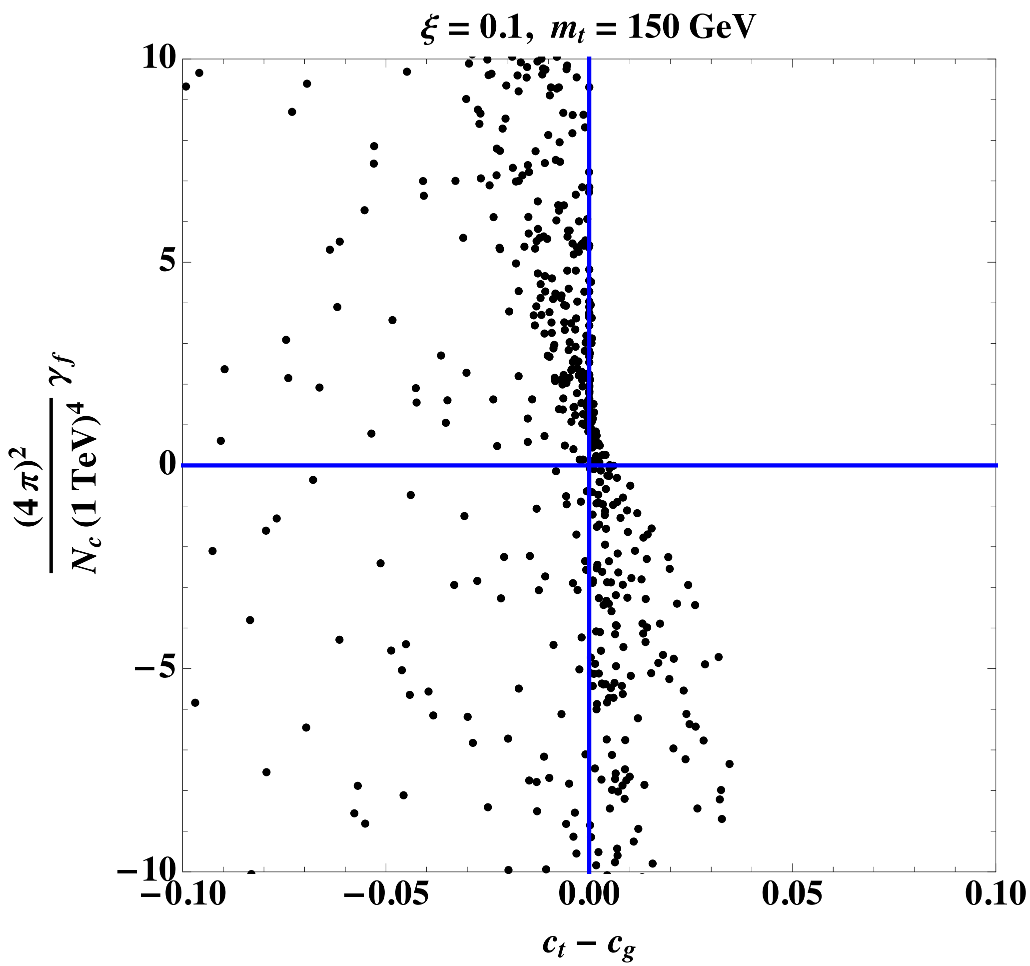
Related to CMS Excess？





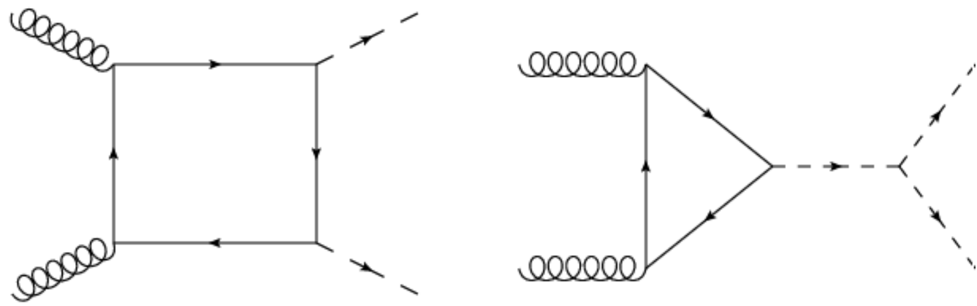
Minimal Composite Models

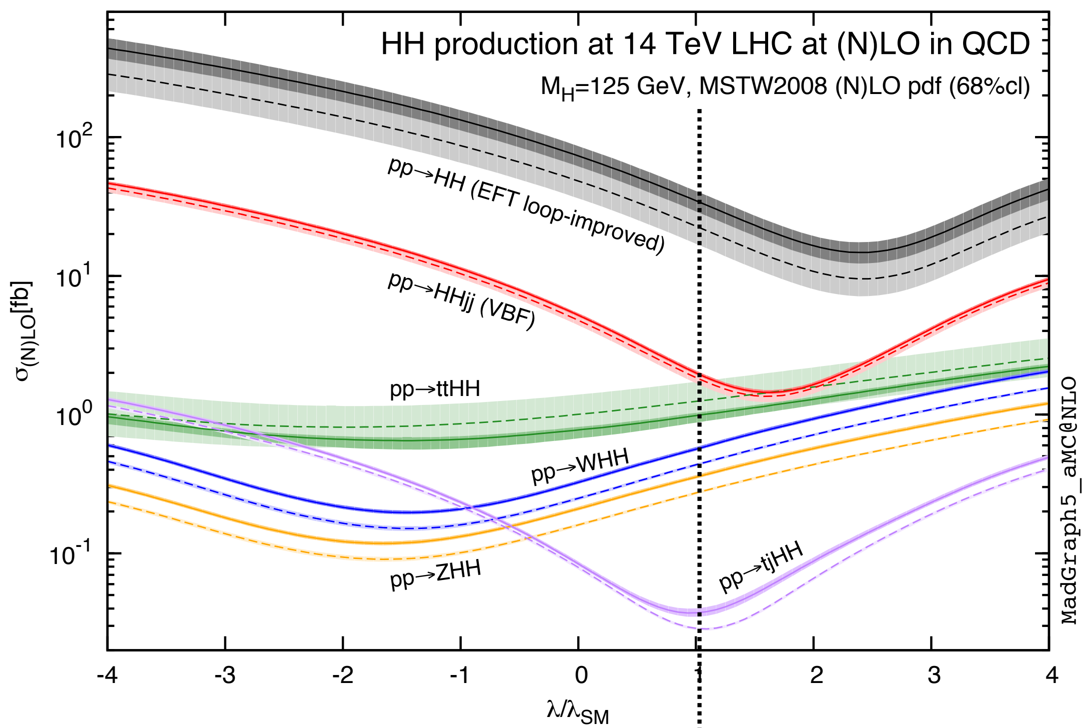
D. Liu, I. Low, C.W.'17



Difficult to enhance the top coupling without enhancing at the same time the gluon coupling

Connection with Di-Higgs Production





Frederix et al'14

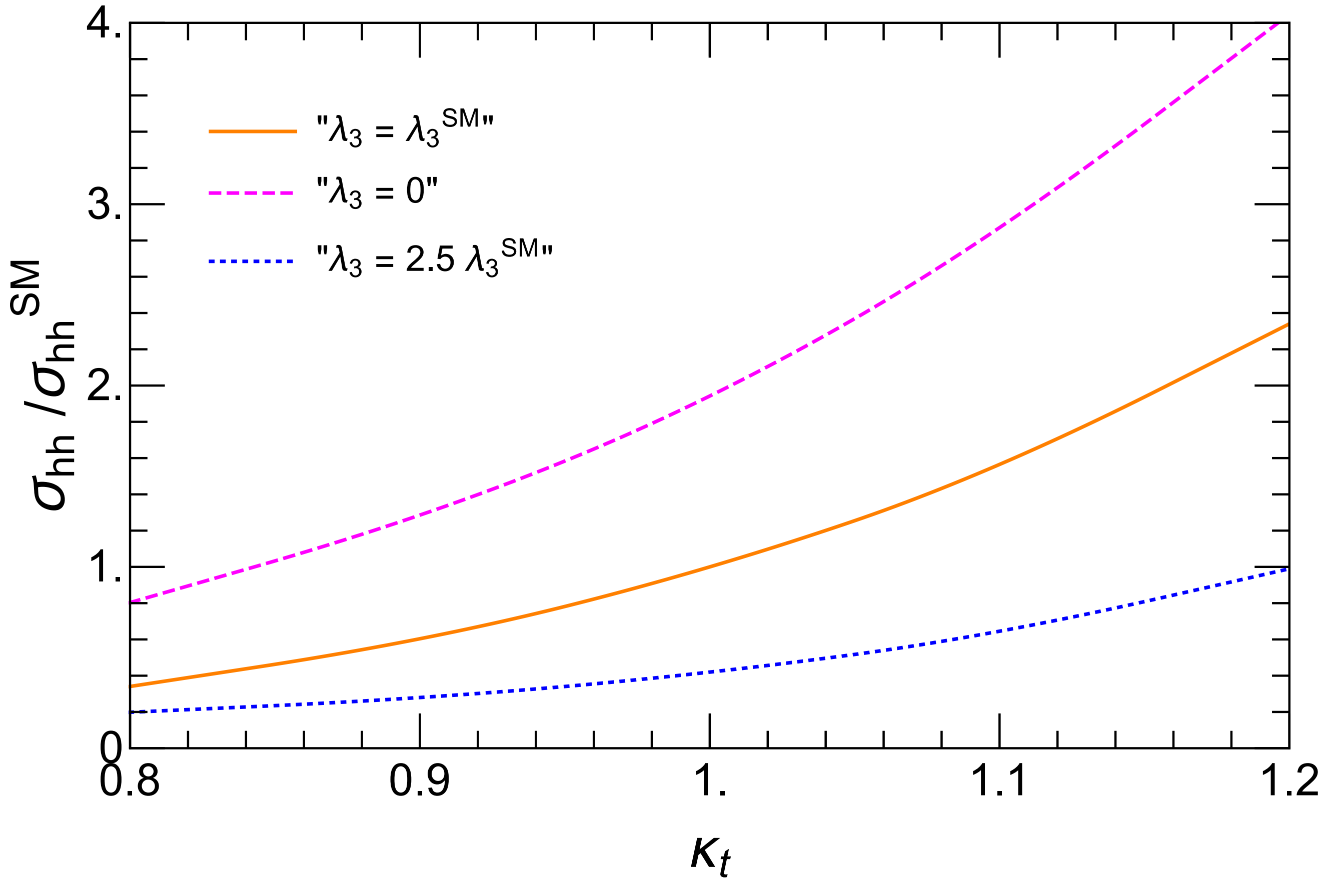
Very few events in the SM case after cuts are implemented.

Light Stops or small modifications of the top quark coupling (or both) can strongly enhance the di-Higgs production rate.

Joglekar, Huang, Li, C.W.'17

Variation of the Di-Higgs Cross Section with the Top Quark and Self Higgs Couplings

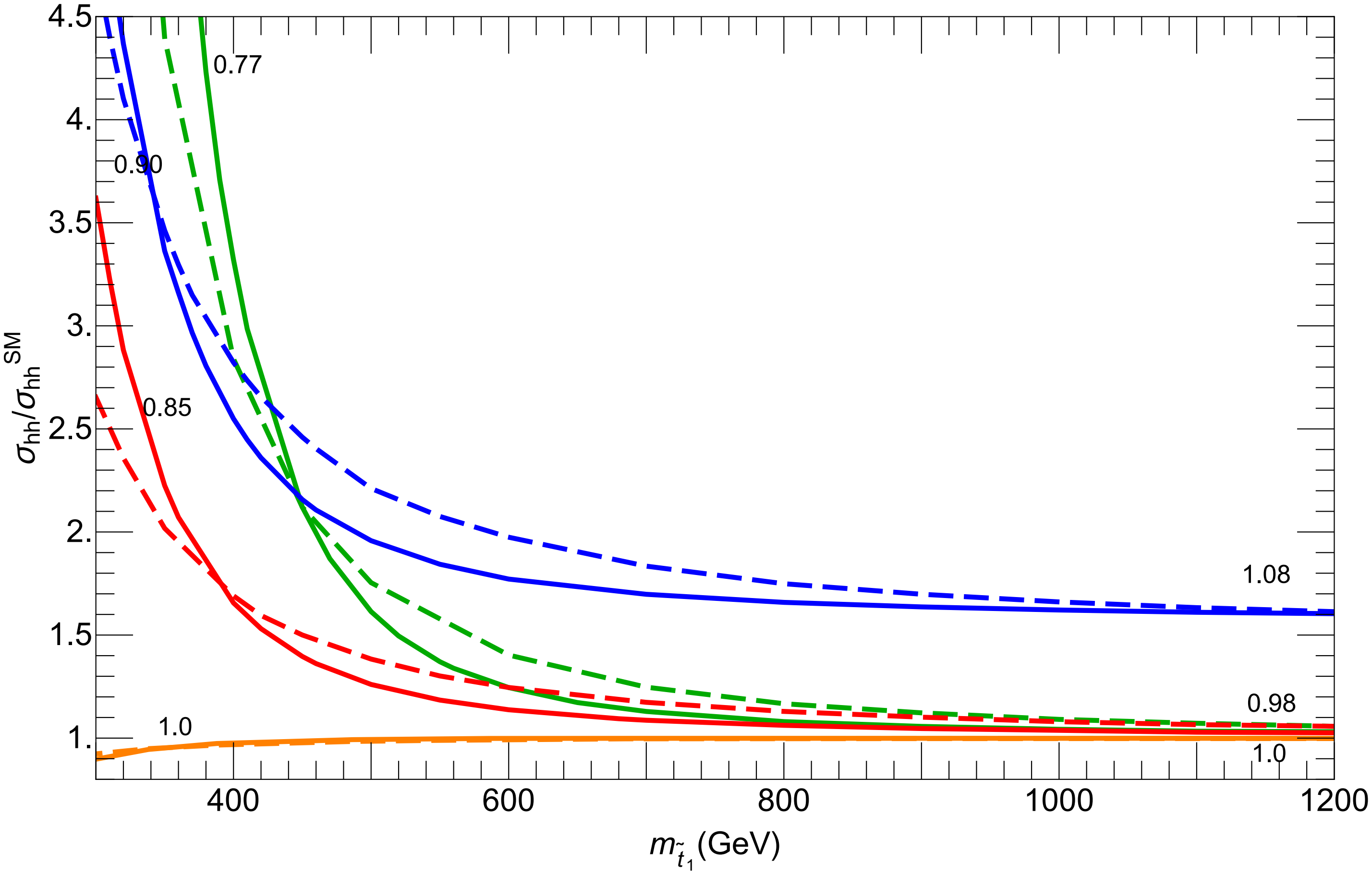
Huang, Joglekar, Li, C.W.'17



Strong dependence on the value of kt and λ3
Even small variations of kt can lead to 50 percent variations of the di-Higgs cross section

Stop Effects on Di-Higgs Production Cross Section

Huang, Joglekar, Li, C.W.'17



Orange : Stop corrections to kappa_g decoupled

Red : X_t fixed at color breaking vacuum boundary value, for light mA

Green : X_t fixed at color breaking boundary value, for mA = 1.5 TeV

Blue : Same as Red, but considering \kappa_t = 1.1

$$
\begin{aligned}
V \;=\; & m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - m_{12}^2(\Phi_1^\dagger\Phi_2 + \text{h.c.}) + \frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 \\
& +\lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) \\
& + \left\{\frac{1}{2}\lambda_5(\Phi_1^\dagger\Phi_2)^2 + [\lambda_6(\Phi_1^\dagger\Phi_1) + \lambda_7(\Phi_2^\dagger\Phi_2)]\Phi_1^\dagger\Phi_2 + \text{h.c.}\right\} \;,
\end{aligned}
$$

Inverting the sign of the bottom coupling

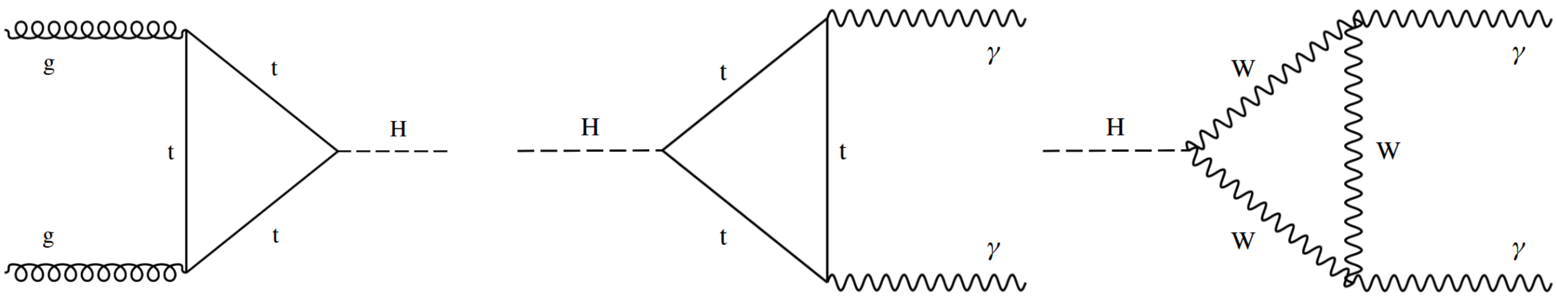
$$t_\beta \; c_{\beta-\alpha} \approx 2.$$

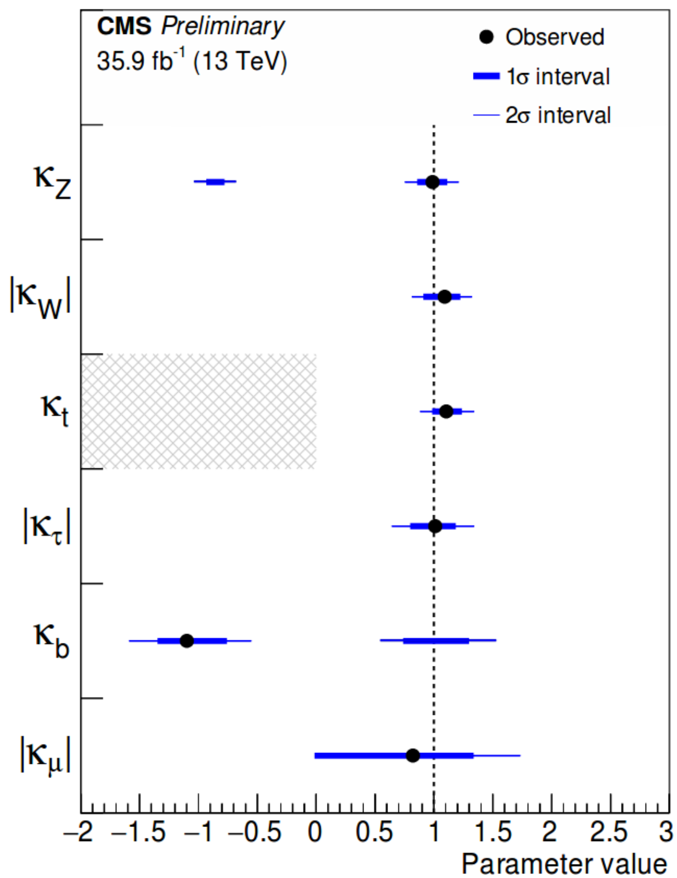
$$[(\lambda_3 + \lambda_4 + \lambda_5) - \lambda_2 + \lambda_7 t_\beta]v^2 \simeq 2(m_H^2 - m_h^2).$$

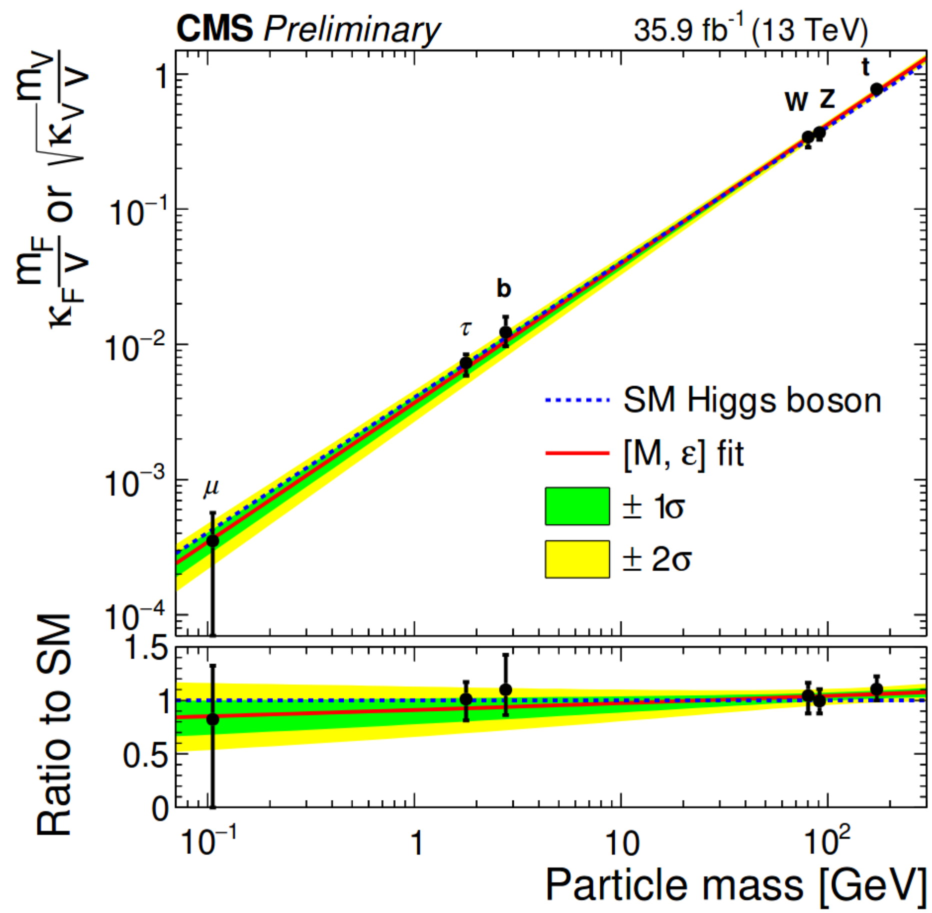
N. Coyle, B. Li, C.W.' arXiv:1802.09122

Couplings: Resolved Loops

CMS-PAS-HIG-17-031







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What about inverting the sign of the third generation couplings ?

- Easy to invert the bottom coupling in type II Higgs doublet models
- In the NMSSM, in particular, this implies to go to larger values of lambda, since this is the parameter that allows to control this coupling.

$$t_\beta \, c_{\beta-\alpha} \approx \frac{-1}{m_H^2 - m_h^2}\left[\left(m_h^2 + m_Z^2 - \lambda^2 v^2\right) + \frac{3 m_t^4 A_t \mu t_\beta}{4\pi^2 v^2 M_S^2}\left(1 - \frac{A_t^2}{6 M_S^2}\right)\right]$$

- This causes problems with the spectrum, since some scalars tend to become tachyonic in the relevant region of parameters. We cured this problem by adding a tadpole term

$$\Delta V = \ \xi_S \ S + h.c. \qquad\qquad \delta\lambda_2 \simeq \frac{\lambda^4}{16\pi^2}\ln\left(\frac{m_S^2}{\mu^2}\right) \simeq \frac{\lambda^4}{16\pi^2}\ln\left(\left|\frac{\lambda \xi_S}{\mu^3}\right|\right)$$

- Since the Higgs-gauge boson coupling with respect to the SM is $\sin(\beta-\alpha)$, one needs sizable values of $\tan\beta$, and moderate values of m_H, but still allowed by searches for non-standard Higgs bosons. Values of $\tan\beta \simeq 7 - 10$ are the most appropriate ones.

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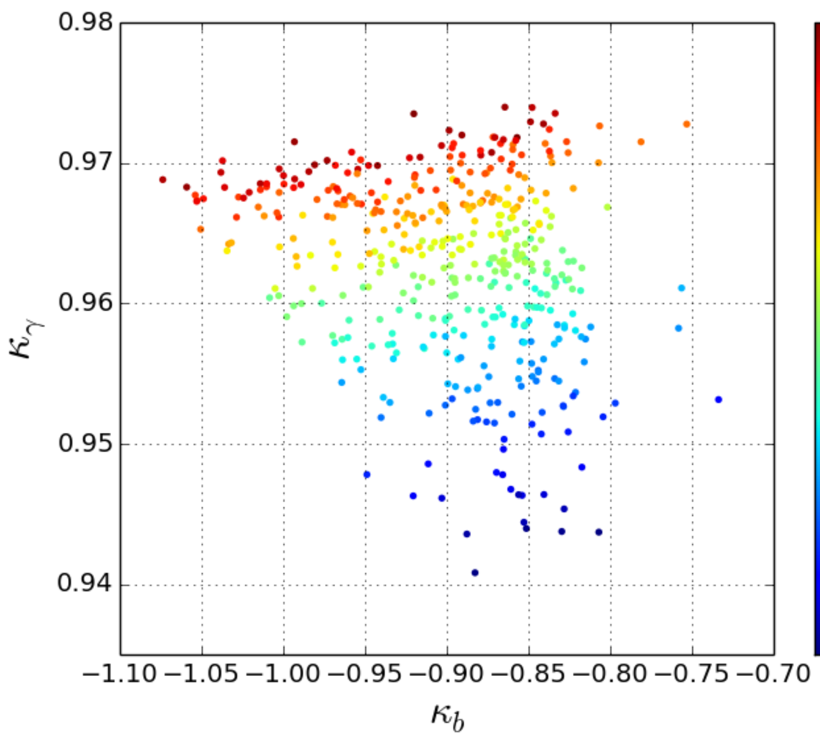
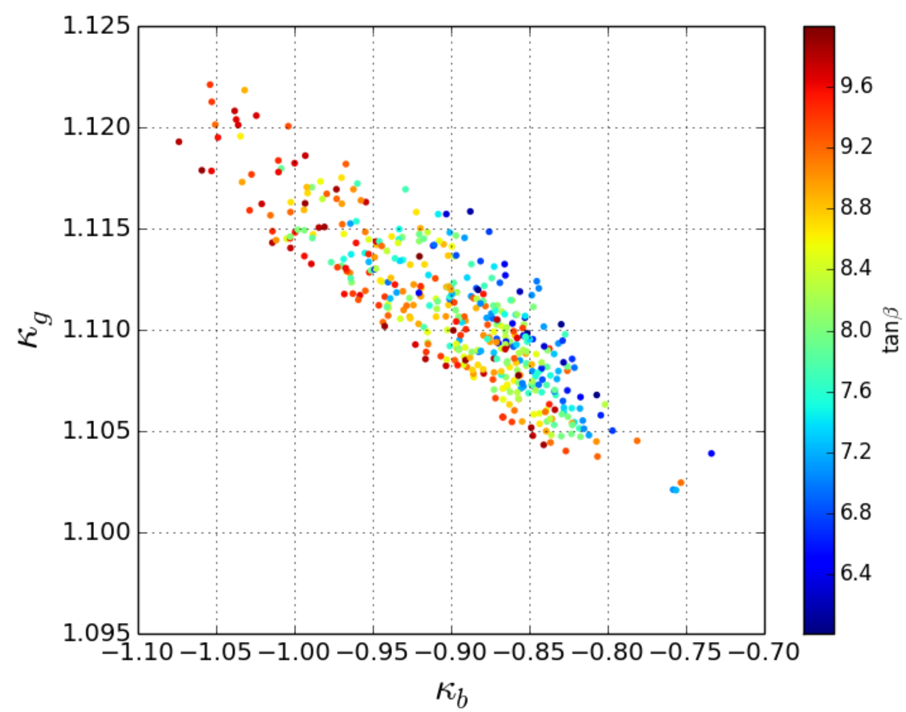
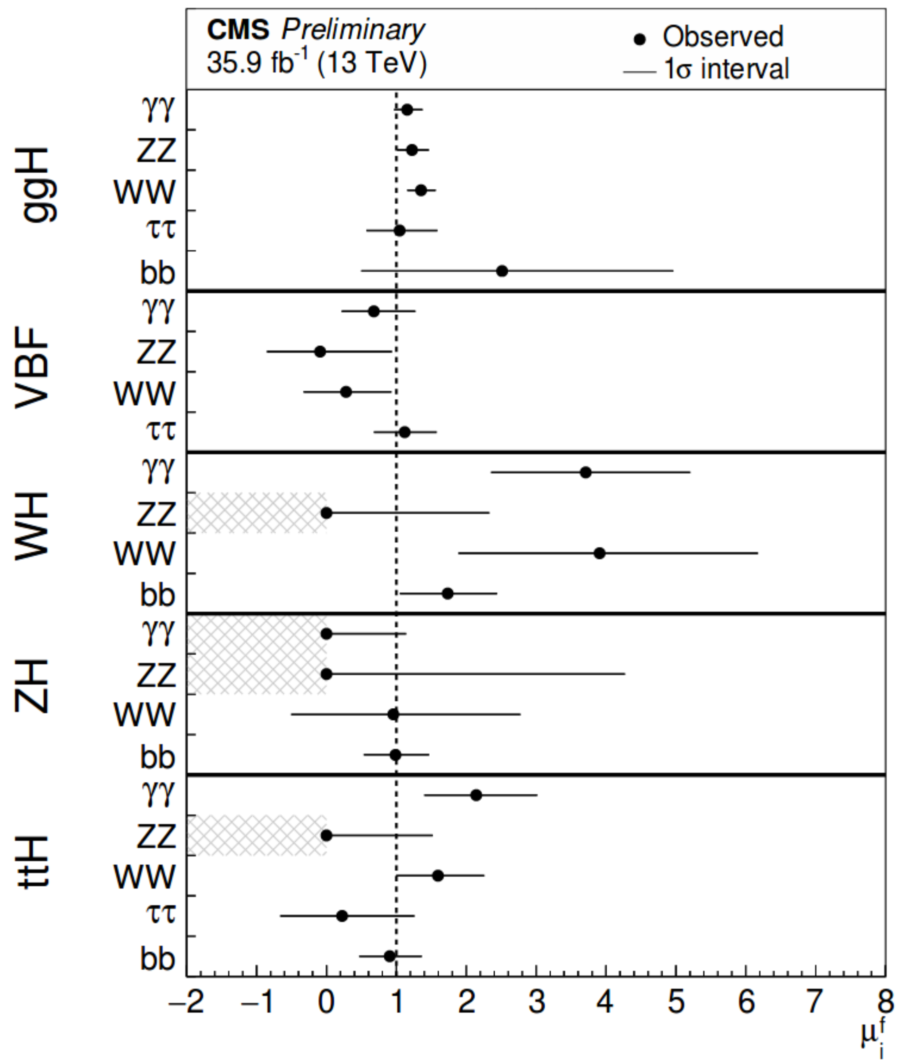
Effects on gluon Fusion

- Changing the sign of the bottom coupling changes the gluon fusion rate by about 12 percent !
- Assuming that no other effect is present, the LHC collaborations announce a precision of about 5 percent for the gluon coupling by the end of the LHC run. So, under this assumption this effect may be tested.





CMS Combination



D. Sperka's talk, Moriond EW

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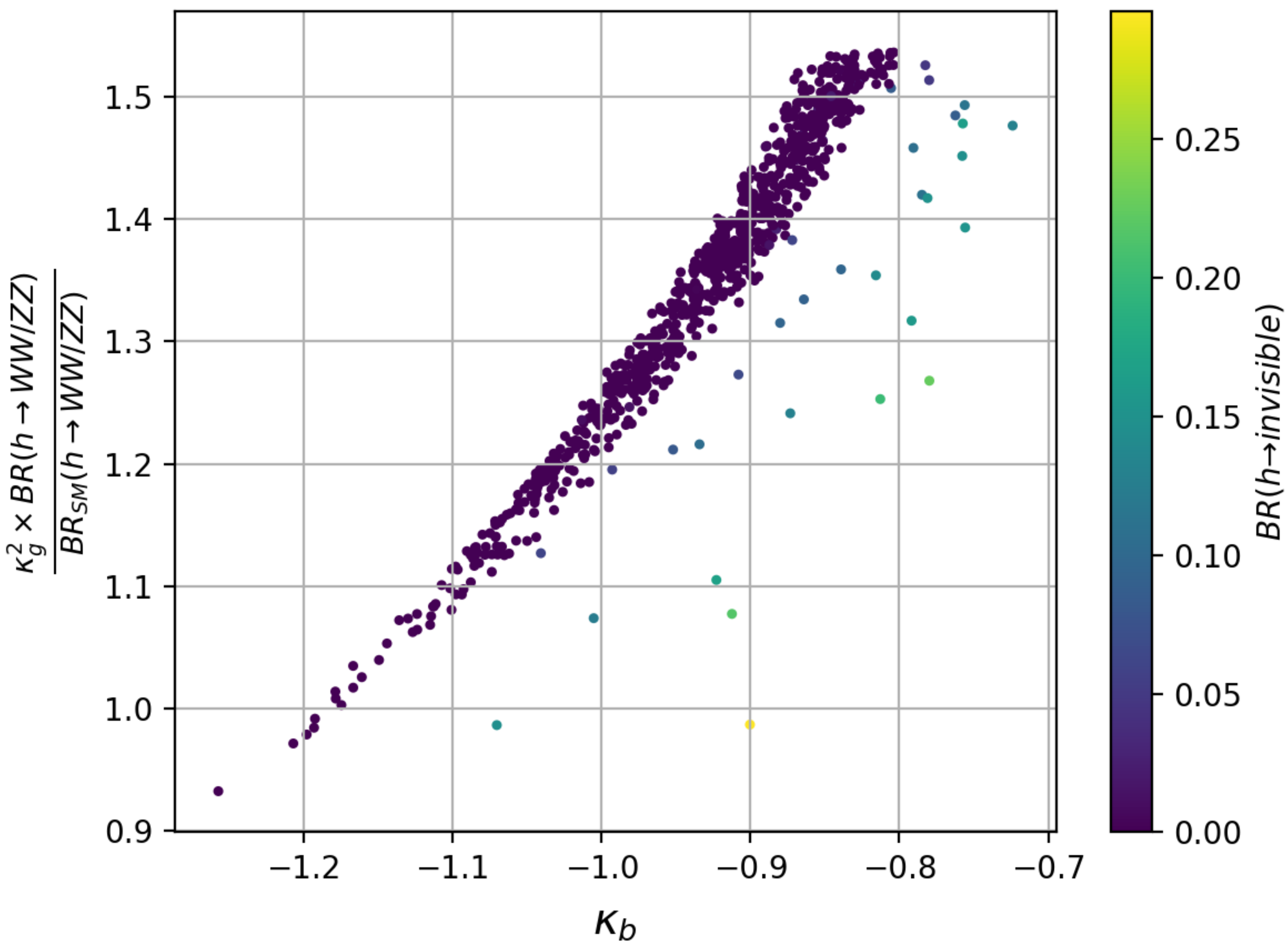
Dibosons from Gluon Fusion

Signal Mostly Enhanced, due to Gluon Fusion Coupling Enhancement.
Values of order the SM values are possible, depending on the exact value of the bottom coupling.



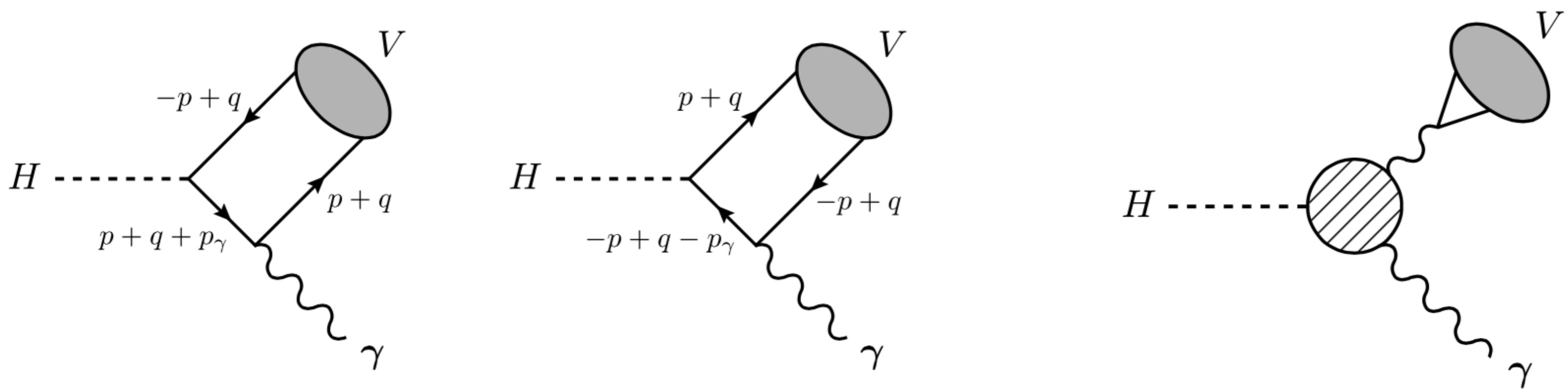
Additional tests of this idea ?

Radiative Higgs Decays

Bodwin et al'14, Neubert et al'15

$$\Gamma[H \to \Upsilon(1S) + \gamma] = |(3.33 \pm 0.03) - (3.49 \pm 0.15)\kappa_b|^2 \times 10^{-10}\ \mathrm{GeV}$$

$$\Gamma[H \to \Upsilon(2S) + \gamma] = |(2.18 \pm 0.03) - (2.48 \pm 0.11)\kappa_b|^2 \times 10^{-10}\ \mathrm{GeV}$$



Accidental cancellation present in the SM would lead to a large enhancement in the case of a change in sign of the bottom coupling to Higgs bosons.

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LHC Sensitivity

Branching ratios are small and therefore the number of events become only sizable at high luminosities. The approximate number of events are

For $\kappa_b = -1$

$$BR(H \to \Upsilon(1S) + \gamma) \simeq 1.1 \times 10^{-6}$$

$$BR(H \to \Upsilon(2S) + \gamma) \simeq 0.5 \times 10^{-6}$$

$$BR(H \to \Upsilon(3S) + \gamma) \simeq 0.4 \times 10^{-6}$$

κ_b	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
	Run 2 (130 fb^{-1})		
1	0.00442 ± 0.06214	0.0155 ± 0.0483	0.0178 ± 0.0414
-1	8.02 ± 0.32	3.75 ± 0.15	2.73 ± 0.11
	Run 3 (300 fb^{-1})		
1	0.0102 ± 0.1434	0.358 ± 0.1115	0.0408 ± 0.0956
-1	18.5 ± 0.7	8.65 ± 0.36	6.31 ± 0.26

Therefore, at most a few hundred of events available in these channels.

Run I bound on the Branching ratios of order of a few 10^{-3}. Improvement in search sensitivity will be required to reach the required sensitivity at the HL-LHC.

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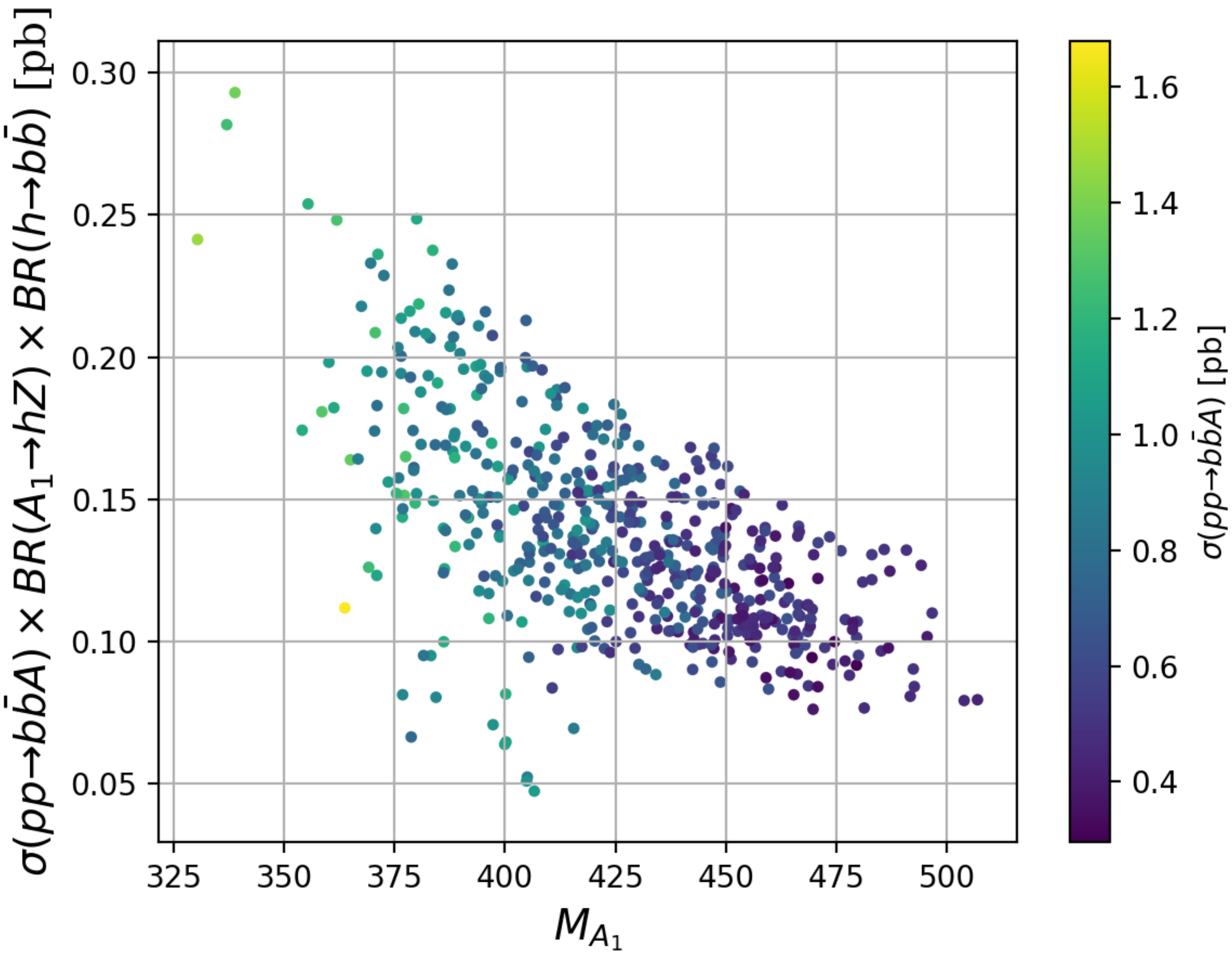
More general Parameters : Superpotential Tadpole

One may reduce the mass gap with the charged Higgs, and due to the large misalignment, decays into Higgs and gauge bosons open up.

$$\delta W = \xi_F S$$



$$\cos(\beta-\alpha) \simeq 2/\tan\beta$$

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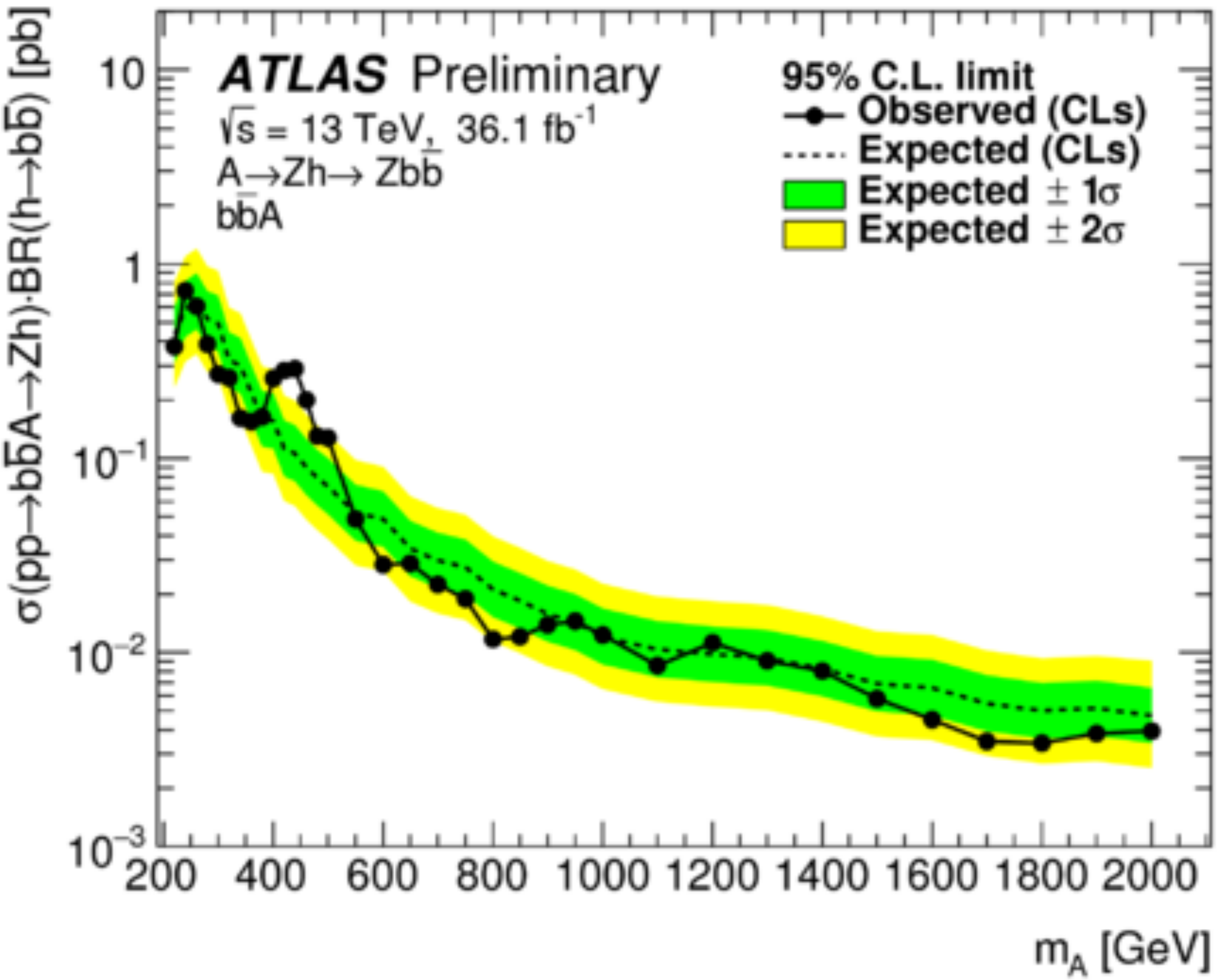
Consistent with ATLAS Excess

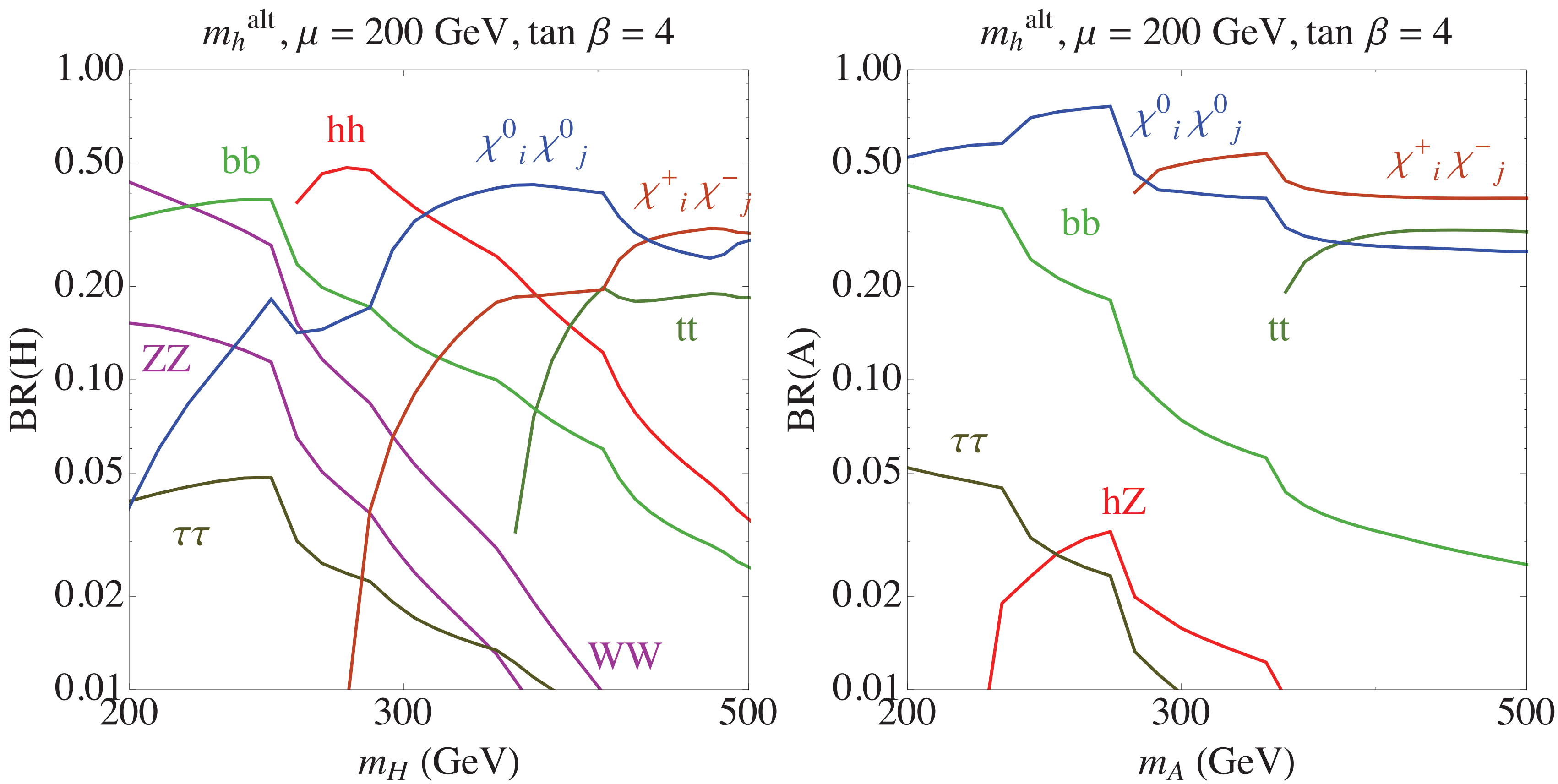


Conclusions

- Current Higgs measurements are in agreement with the values predicted in the SM.
- Determination of bottom and top couplings still lacks precision, with a few tens of percent errors. Therefore, relevant modifications of these couplings may be present.
- Bottom coupling governs the width and therefore its departure from SM values leads to a relevant modification of all decay widths.
- An interesting, even if unlikely, possibility is that the sign of this coupling is inverted.
- In this talk, after discussing the alignment condition, we have also explored scenarios in which relevant modifications of the bottom coupling may be present, in well motivated low energy supersymmetry extensions of the SM
- Relevant implications for Higgs phenomenology, that go beyond the modifications of the decay widths, and may allow to test these scenarios.

Light Charginos and Neutralinos can significantly modify M the CP-odd Higgs Decay Branching Ratios

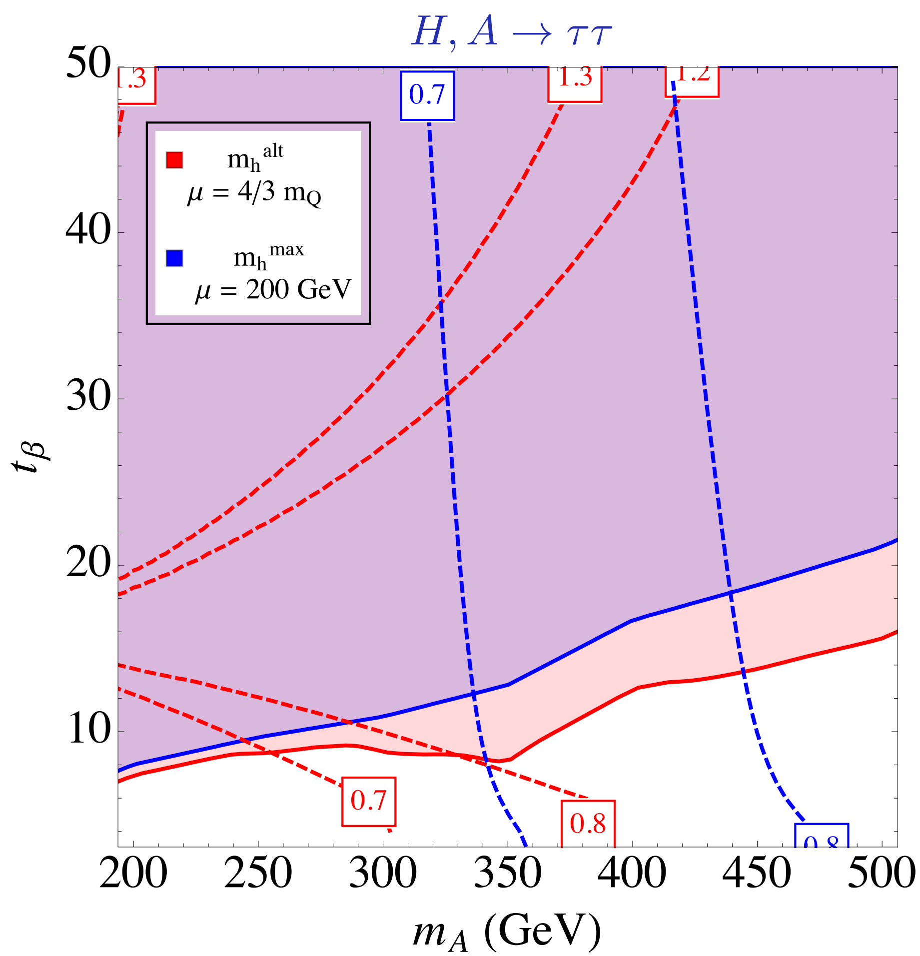
Carena, Haber, Low, Shah, C.W.'14



At small values of μ ($M_2 \simeq 200$ GeV here), chargino and neutralino decays prominent. Possibility constrained by direct searches.

Complementarity between precision measurements and search for new Higgs going to τ pairs

Carena, Haber, Low, Shah, C.W.'14



— $\sum_{\phi_i=A,H}\sigma(bb\phi_i+gg\phi_i)\times BR(\phi_i\to\tau\tau)$ (8 TeV)

--- $\sigma(bbh+ggh)\times BR(h\to VV)/SM$

Limits coming from measurements of h couplings become weaker for larger values of μ

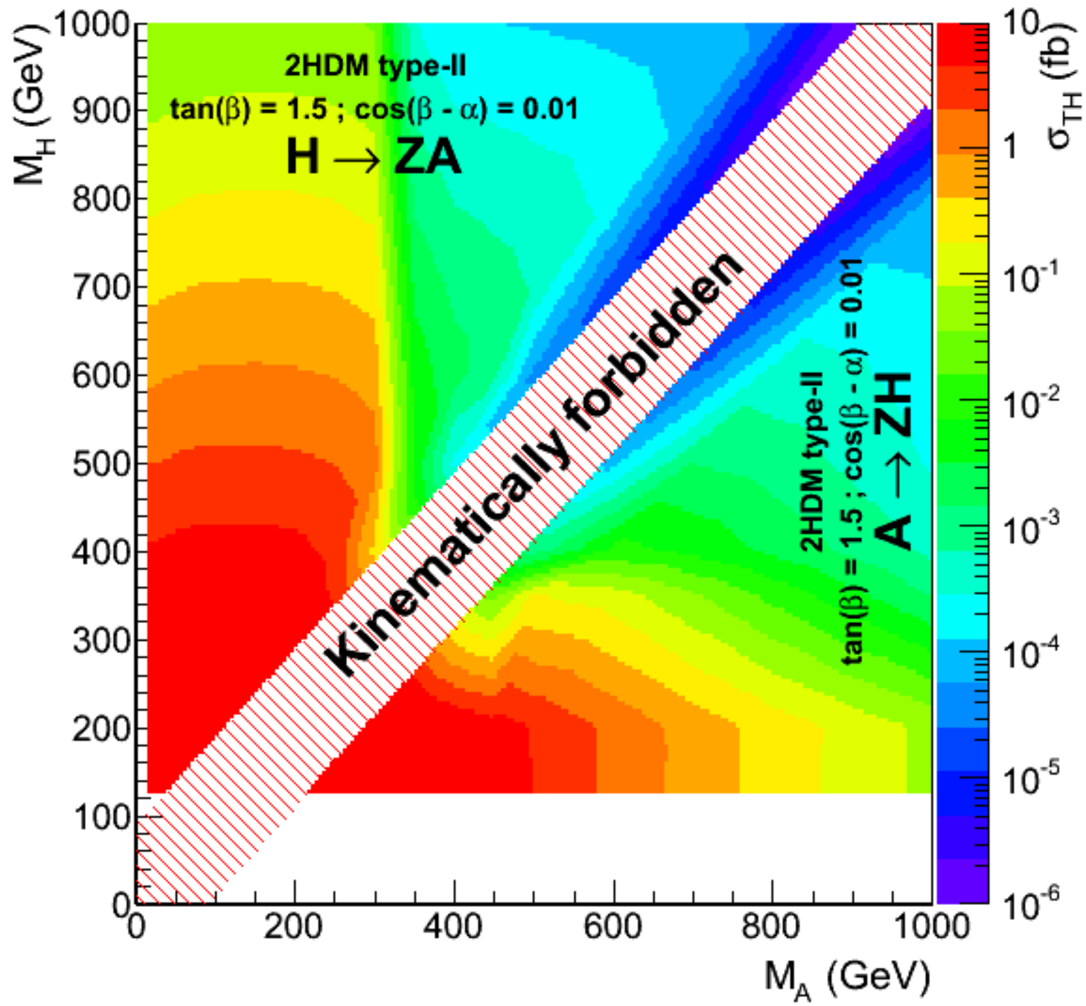
Limits coming from direct searches of $H, A \to \tau\tau$ become stronger for larger values of μ

Bounds on m_A are therefore dependent on the scenario and at present become weaker for larger μ

With a modest improvement of direct search limit one would be able to close the wedge, below top pair decay threshold

Search for (psudo-)scalars decaying into lighter ones

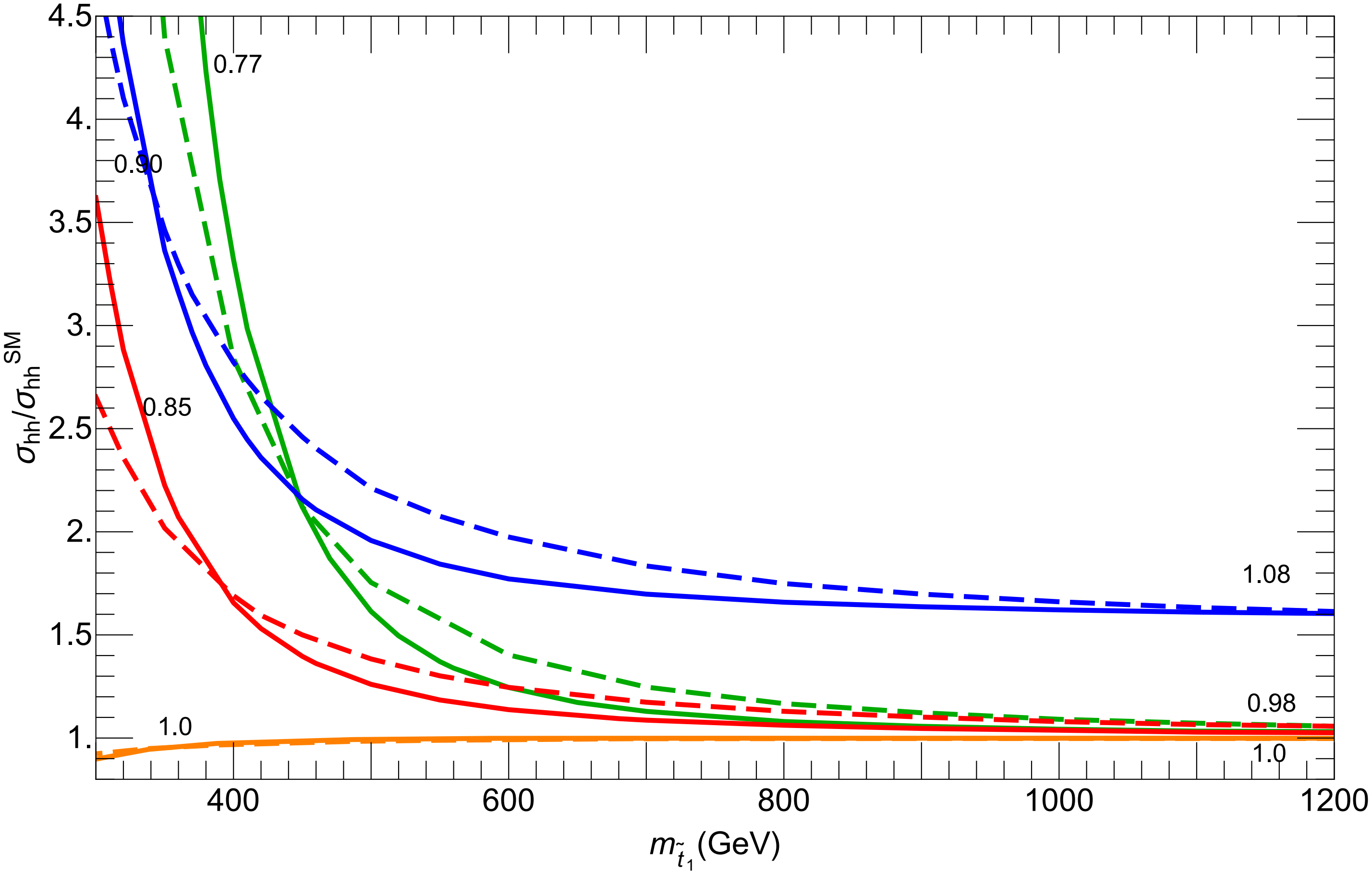
CMS-PAS-HIG-15-001



It is relevant to perform similar analyses replacing the Z by a SM Higgs !

Stop Effects on Di-Higgs Production Cross Section

Huang, Joglekar, Li, C.W.'17



Orange : Stop corrections to kappa_g decoupled
Red : X_t fixed at color breaking vacuum boundary value, for light mA
Green : X_t fixed at color breaking boundary value, for mA = 1.5 TeV
Blue : Same as Red, but considering \kappa_t = 1.1

Values of the dimensionless couplings

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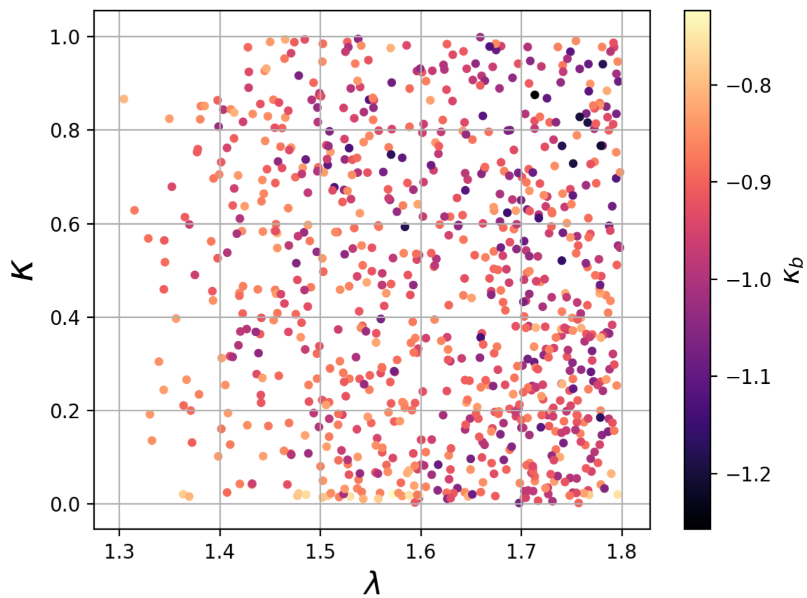

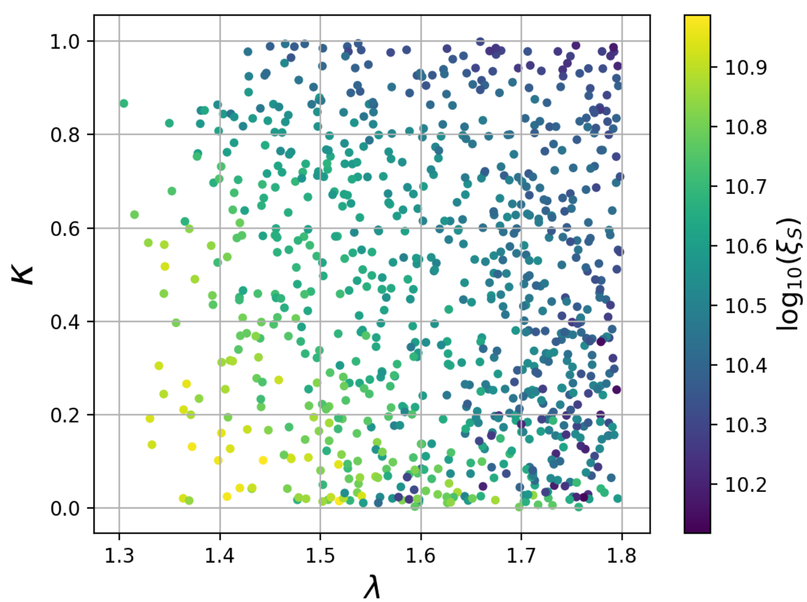

Necessary values to invert the bottom coupling

$\delta W = \xi_F S$

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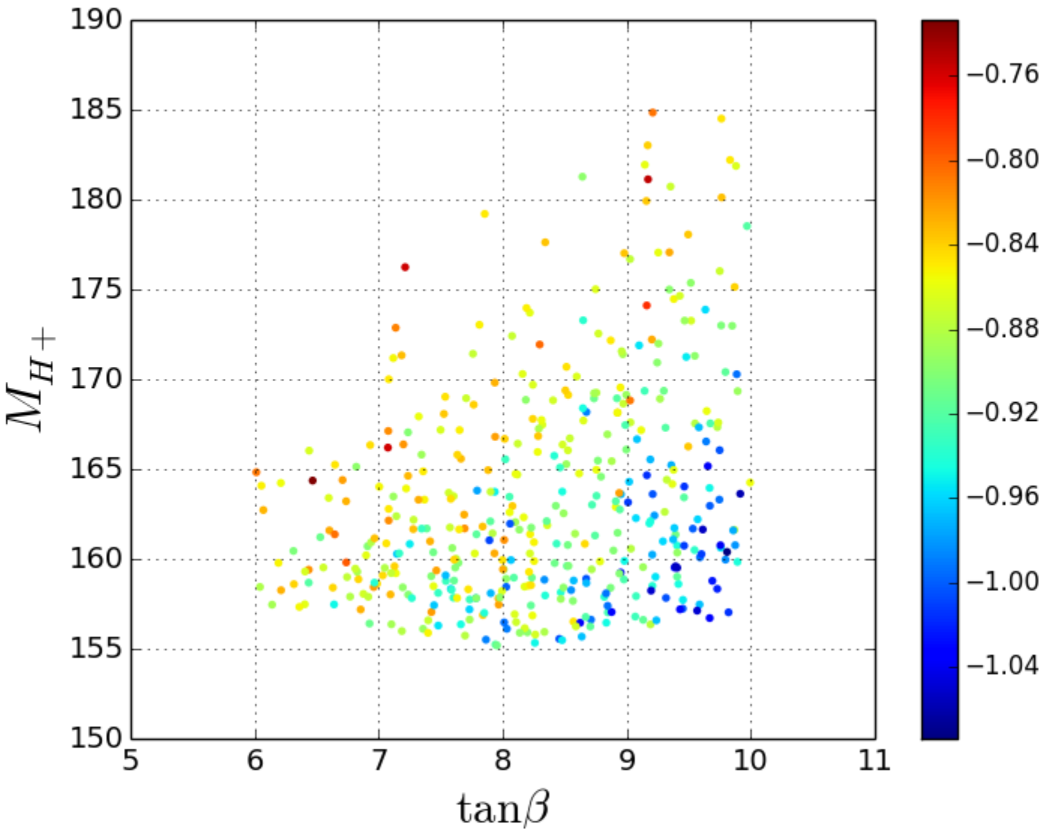
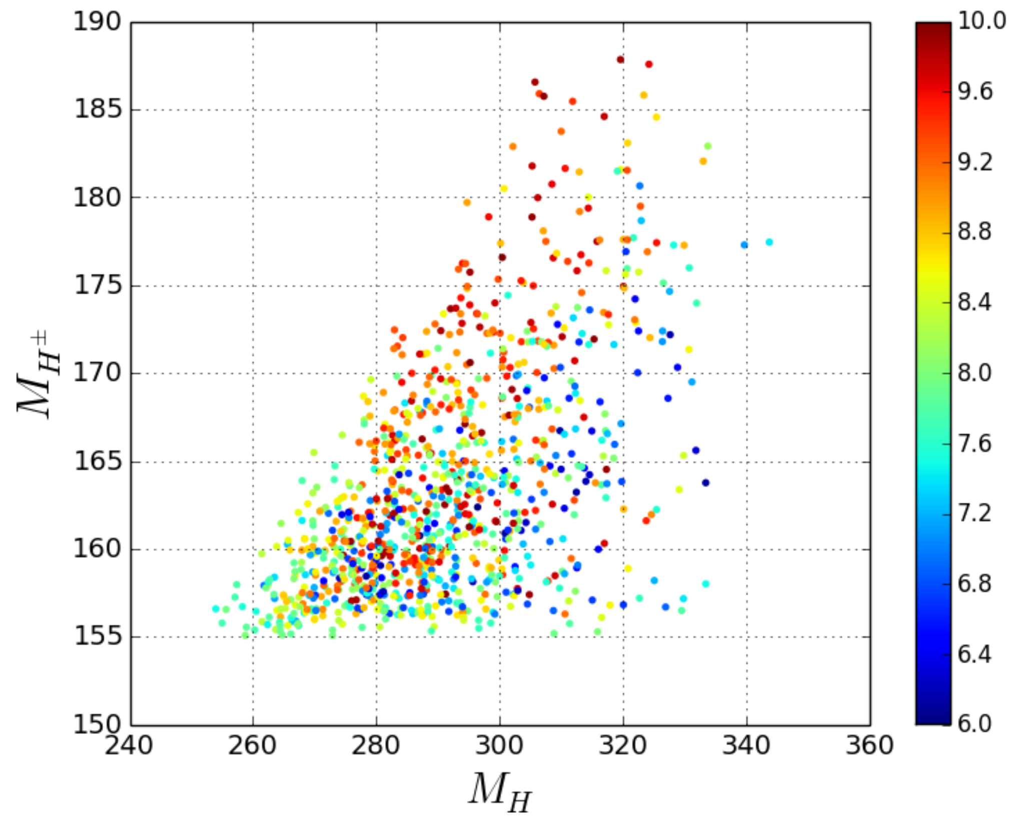
Low charged Higgs masses

Part of the reason for large value of λ is the relation between the CP-odd and charged Higgs masses in these theories, namely

$$m_{H+}^2 \simeq m_A^2 - \lambda^2 v^2 \qquad v = 174\ GeV$$

Constraints on Charged Higgs Mass coming from $t \to bH^+$ considered





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Novelty : Decay into charged Higgs Bosons

Large values of λ imply that the charged Higgs mass becomes significantly lower than the neutral MSSM-like Higgs masses.