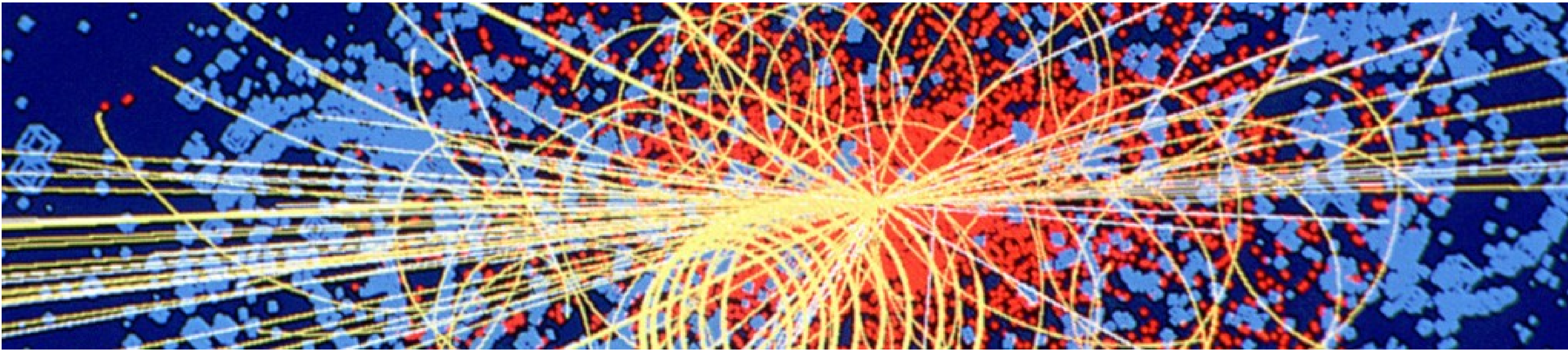
MSSM Interpretations of the LHC Discovery:

Light or Heavy Higgs?

based on [1211.1955]
with P. Bechtle, S.Heinemeyer, O.Stål, T. Stefaniak, G.Weiglein



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Helmholtz Alliance Workshop, Hamburg

December 4, 2012

Higgs discovery

- Higgs-like particle with mass ~ 126 GeV discovered
- Observation compatible with SM Higgs

However:

- Results show slight deviation from SM Higgs
- Many new physics explanations possible
- Observed Higgs can also be interpreted in the MSSM

  → Light CP-even Higgs: h

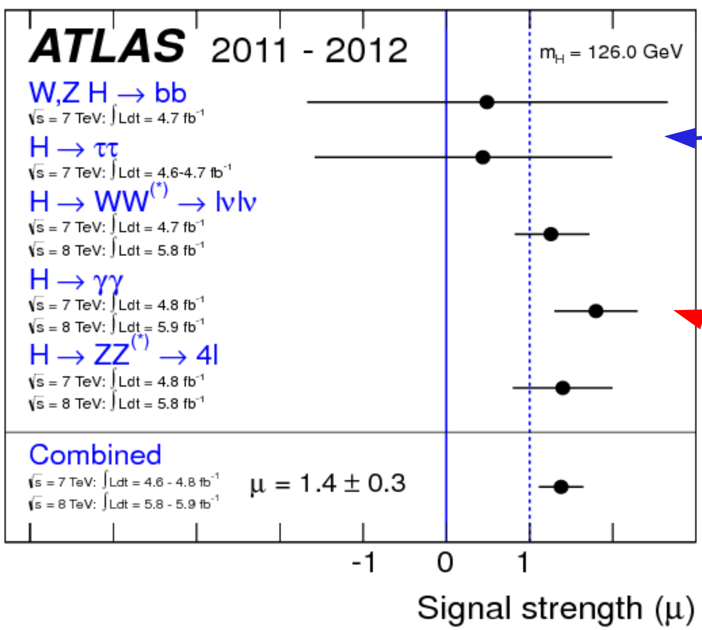
  → Heavy CP-even Higgs: H
- How well does the MSSM describe the signal seen by the experiments?

Higgs decay rates

- In each decay channel ATLAS and CMS give best fit signal strength

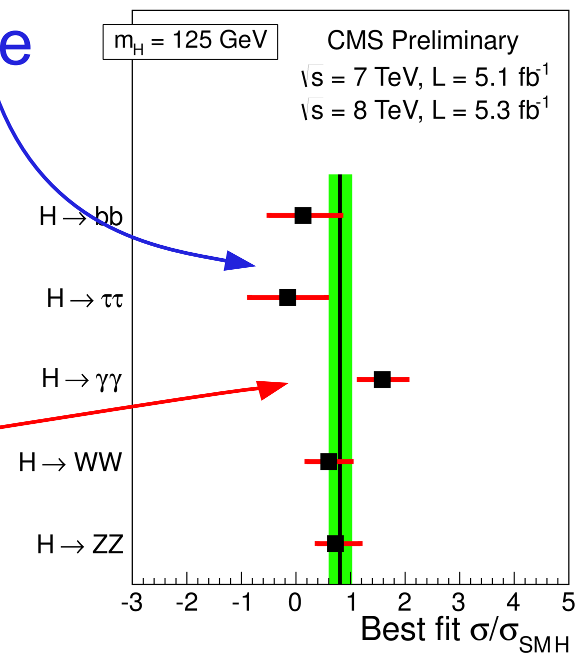
$$\mu = (\sigma \times BR)/(\sigma \times BR)_{SM}$$

Results from July '12



ττ and bb rate supressed

Enhanced γγ rate



- New updated Higgs results have been shown at HCP

  → Not included in our analysis yet → See comments later!

Higgs sector of the MSSM

- Two Higgs doublets

$$H_1 = \begin{pmatrix} v_1 + \frac{1}{\sqrt{2}}(\phi_1 - \mathrm{i}\chi_1) \\ -\phi_1^- \end{pmatrix}, \quad H_2 = \begin{pmatrix} \phi_2^+ \\ v_2 + \frac{1}{\sqrt{2}}(\phi_2 + \mathrm{i}\chi_2) \end{pmatrix}$$

- 5 physical Higgs bosons: 2 CP-even, 1 CP-odd, 2 charged

$$\begin{pmatrix} H \\ h \end{pmatrix} = U_\alpha \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}, \quad \begin{pmatrix} G \\ A \end{pmatrix} = U_\beta \begin{pmatrix} \chi_1 \\ \chi_2 \end{pmatrix}, \quad \begin{pmatrix} G^\pm \\ H^\pm \end{pmatrix} = U_\beta \begin{pmatrix} \phi_1^\pm \\ \phi_2^\pm \end{pmatrix}$$

- Tree level: $M_h \leq M_Z$
- Large radiative corrections: $M_h \lesssim 135\ \mathrm{GeV}$
- $\alpha \to \alpha_{\mathrm{eff}}$ approximation beyond LO

In the MSSM the Higgs signal at 126 GeV can be the light (h) or the heavy (H) $\mathcal{CP}$- even Higgs

How well can the MSSM describe the Higgs signal?

- Scanning over 7 pMSSM parameters (~10 million points)
- Standard χ^2 method:

$$\chi^2 = \sum_{i=1}^{n_{\mathrm{LHC}}+n_{\mathrm{Tev}}} \frac{(\mu_i - \hat{\mu}_i)^2}{\sigma_i^2} + \frac{(M_{h,H} - \hat{M}_H)^2}{\sigma_{\hat{M}_H}^2} + \sum_{i=1}^{n_{\mathrm{LEO}}} \frac{(O_i - \hat{O})^2}{\sigma_i^2}$$

LHC and Tevatron data for the Higgs signal strength
SM: $\mu_i = 1 \; \forall i$

Higgs mass
$\hat{M}_H = 125.7$ GeV
$\sigma_{\hat{M}_H} = 3$ GeV

Low energy observables (LEO):
$b \to s\gamma, B_s \to \mu\mu,$
$B \to \tau\nu, (g_\mu - 2), M_W$

- MSSM Higgs decay rates calculated with channel efficiencies as weights (when available)

$$\mu_{xx} = \frac{\sum_k w_k \; \sigma_k \times BR(h \to xx)}{\sum_k w_k \; \sigma_k^{SM} \times BR(h \to xx)^{SM}}$$

Results of the fit

Case	LHC only			LHC+Tevatron			LHC+LEO			LHC+Tevatron+LEO		
	χ^2/ν	χ^2_ν	p	χ^2/ν	χ^2_ν	p	χ^2/ν	χ^2_ν	p	χ^2/ν	χ^2_ν	p
SM	27.6/34	0.81	0.77	31.0/37	0.84	0.74	41.6/39	1.07	0.36	45.3/42	1.08	0.34
h	23.3/28	0.83	0.72	26.8/31	0.86	0.68	26.7/33	0.81	0.77	30.4/36	0.84	0.73
H	26.0/28	0.93	0.57	33.1/31	1.07	0.37	35.5/33	1.08	0.35	42.4/36	1.18	0.21

Naive calculation if dof: $\nu = n_{\rm obs} - n_{\rm para}$

- Only collider data:
  SM and both MSSM interpretations similar
- Including also low energy observables (LEO):
  SM and heavy Higgs case become slightly worse

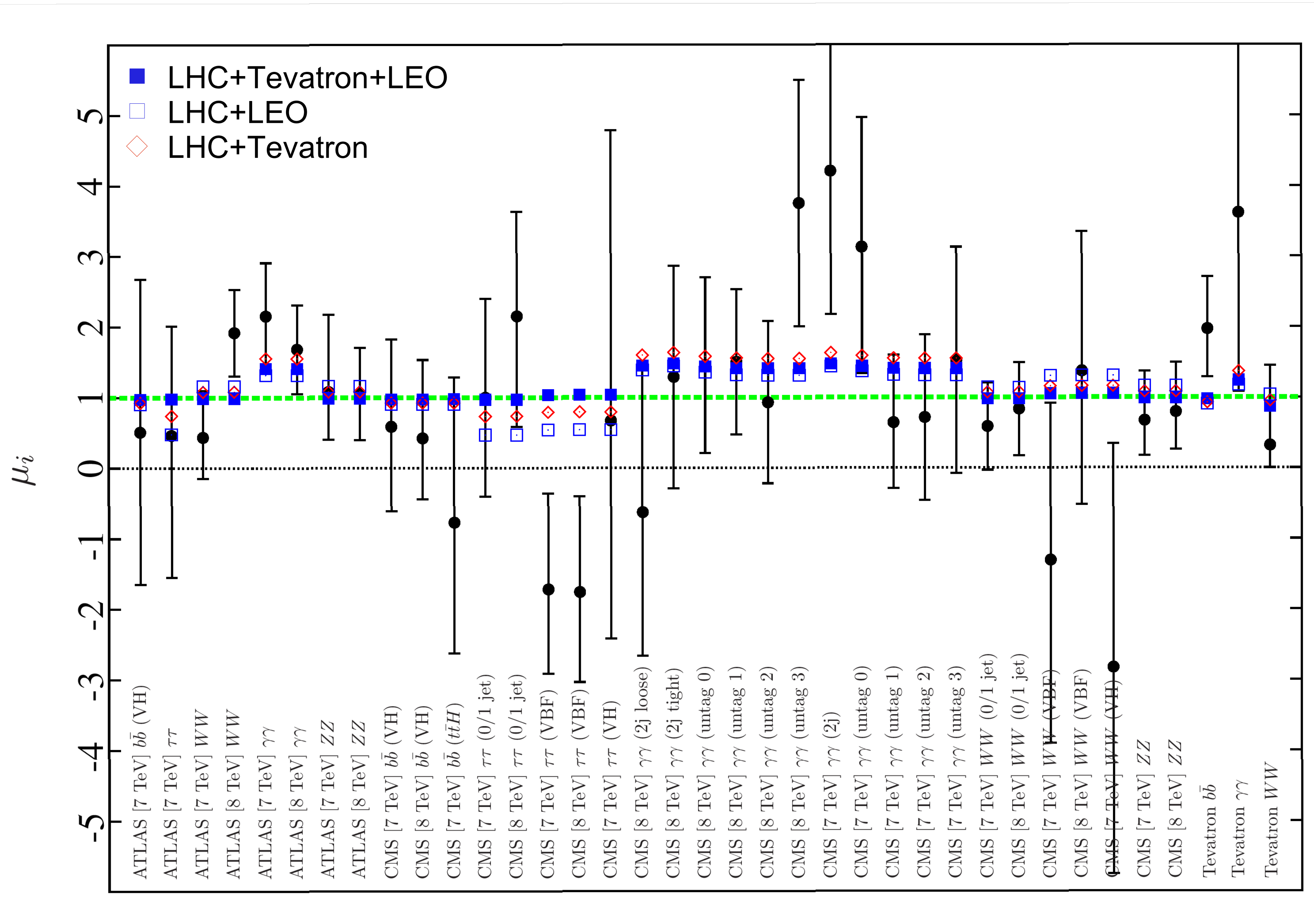
  → SM because $(g_\mu - 2)$ differs by more than 3σ

  → H case because light charged Higgs give (too) large contributions to B physics observables
- Overall good MSSM fits (for both cases)
- No clear preference for either MSSM or SM

Light Higgs case

$$M_h \approx 126 \text{ GeV}$$

Best fit points

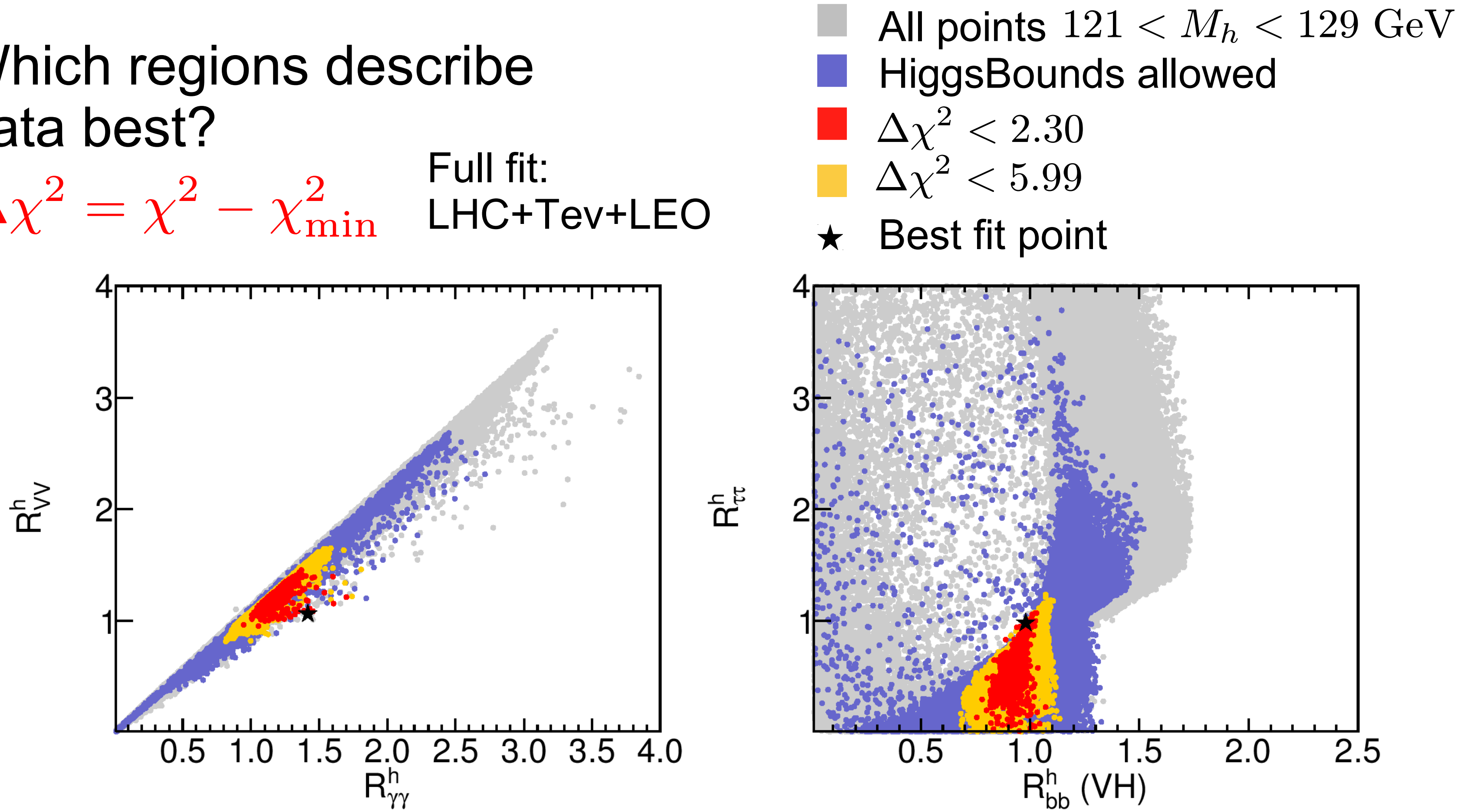


Favored region – Higgs decay rates

- Which regions describe data best?

$\Delta\chi^2 = \chi^2 - \chi^2_{\min}$

Full fit:
LHC+Tev+LEO

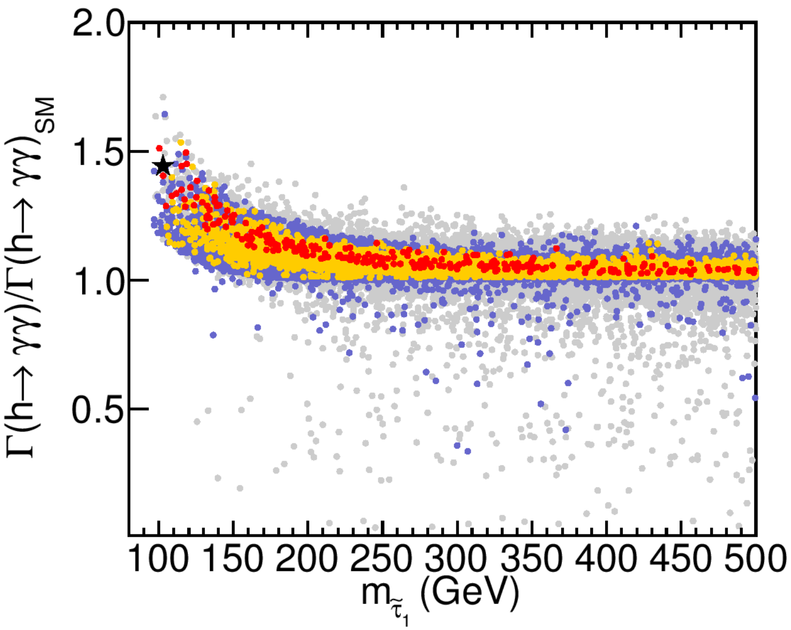


- $R_{xx}\ (\approx \mu_{xx})$: $\sum_i \sigma_i^{(8\ \mathrm{TeV})} \times \mathrm{BR}(h \to xx)/\mathrm{SM}$
- Favored region:
  Enhanced $\gamma\gamma$ rate, bb and $\tau\tau$ rate SM-like/ slightly suppressed

Enhancing the $\gamma\gamma$ rate in the MSSM

Two mechanisms to enhance the $h \to \gamma\gamma$ rate in the MSSM

1. Light staus



- SUSY contributions to the partial width

  → Enhancement up to 50% of $\Gamma\left(h \to \gamma\gamma\right)$

- Main contribution from light staus

Carena, Gori, Shah, Wagner, [1112.3336], [1205.5842]

- Implies staus with mass close to PDG bound (> 81.2 GeV)
- Small effect on other decay rates

Enhancing the $\gamma\gamma$ rate in the MSSM

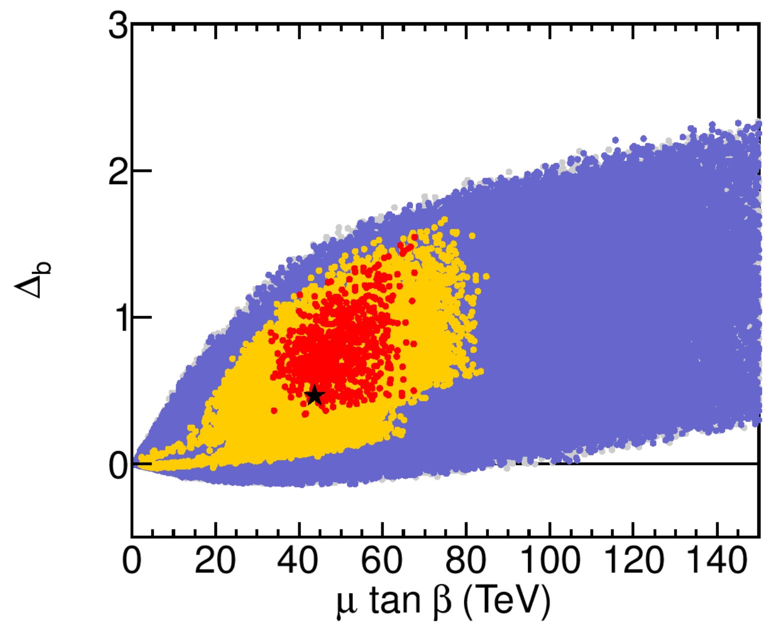
2. Suppression of the total width

- Suppression of dominant decay mode h $\rightarrow$ bb
- Reduced hbb coupling in the MSSM

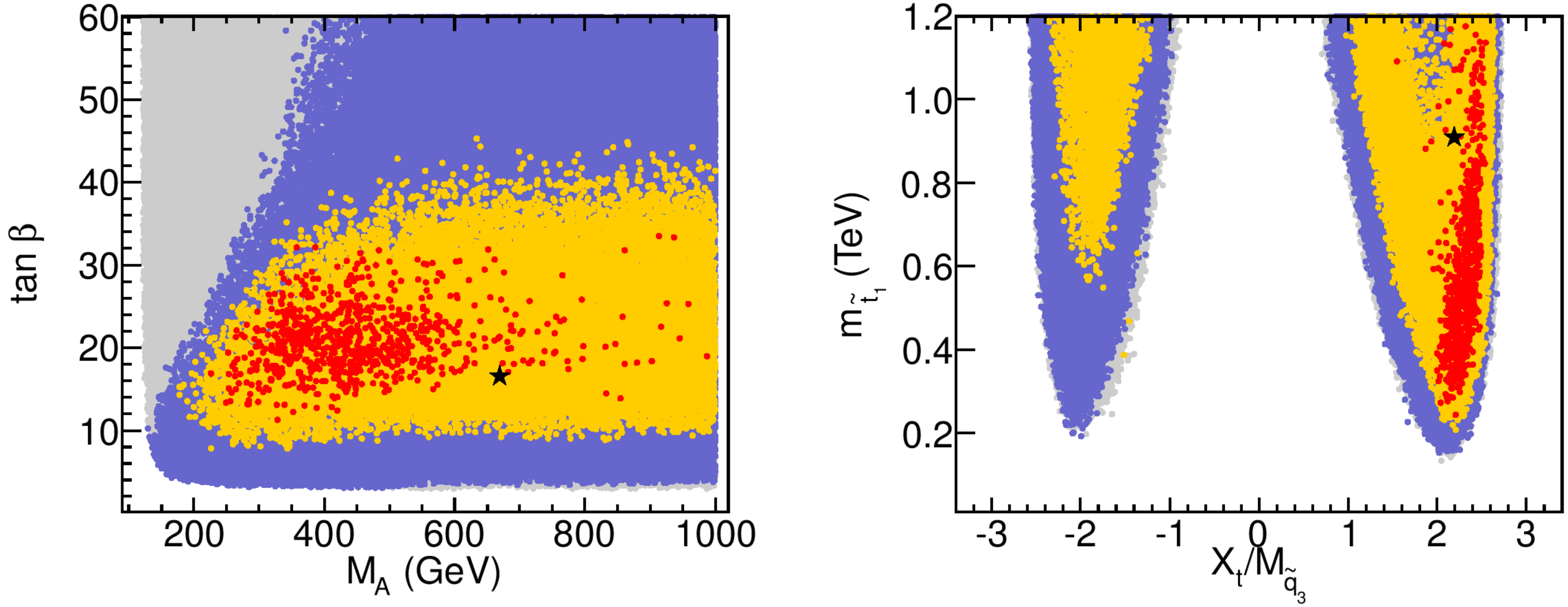
$$\frac{g_{hb\bar{b}}}{g_{H_{\rm SM}b\bar{b}}} = \frac{1}{1+\Delta_b}\left(-\frac{\sin\alpha_{\rm eff}}{\cos\beta} + \Delta_b \frac{\cos\alpha_{\rm eff}}{\sin\beta}\right).$$

Loop-induced SUSY correction

- Favored region has intermediate-large Δ_b corrections
- Largest bb suppression for
  - Large X_t
  - Large μ (1-3 TeV)



Favored region

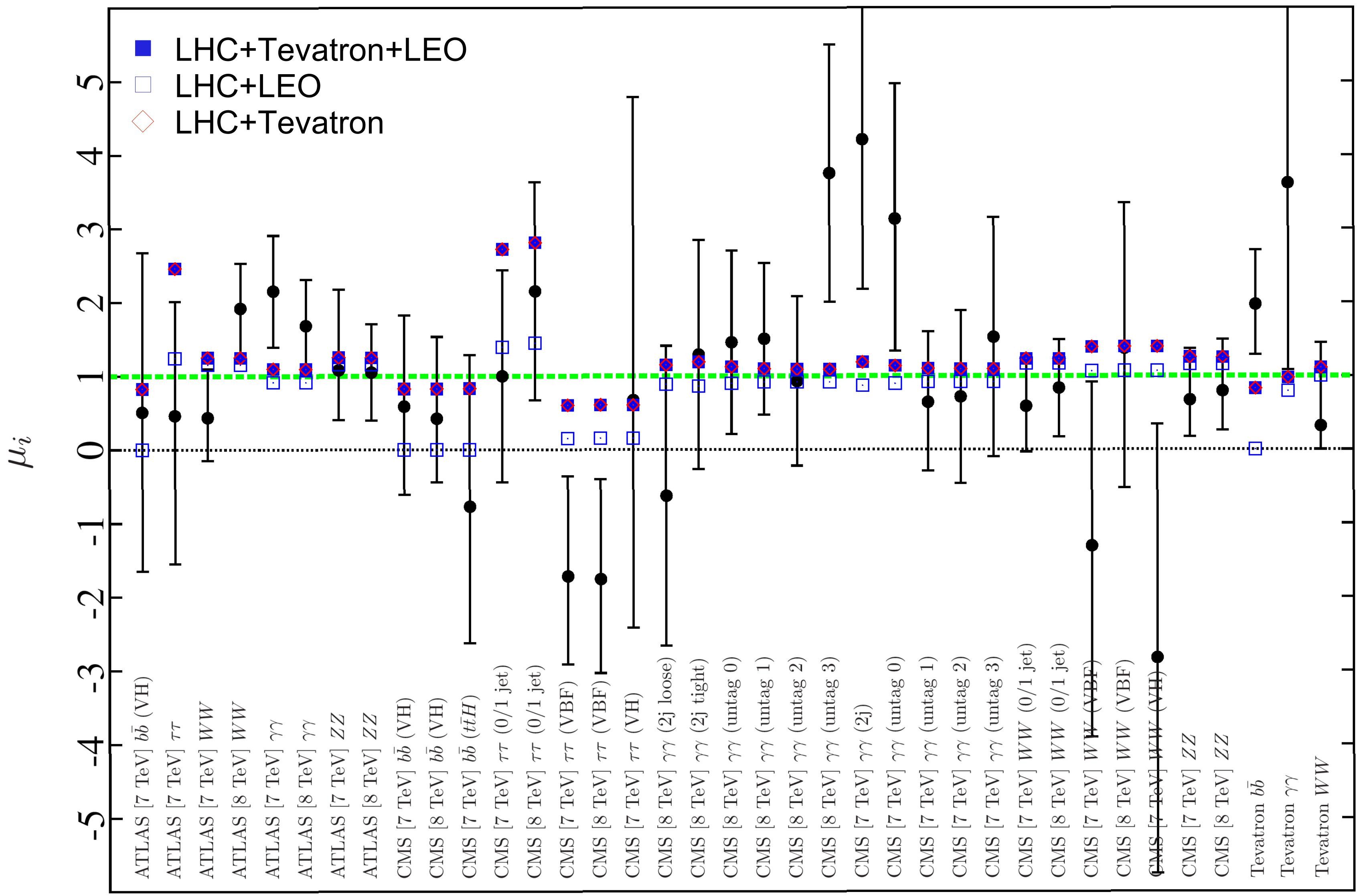


- Regions of high $\gtrsim 40$ and low $\lesssim 8$ tan β disfavoured by the fit
- To get $M_h \simeq 126$ GeV:
  - Large mixing in stop sector required, $|X_t/M_{\tilde{q}_3}| > 1$
  - Stop masses down to 150 GeV possible
- Most favoured region has $m_{\tilde{t}_1} > 200$ GeV and positive X_t

Heavy Higgs case

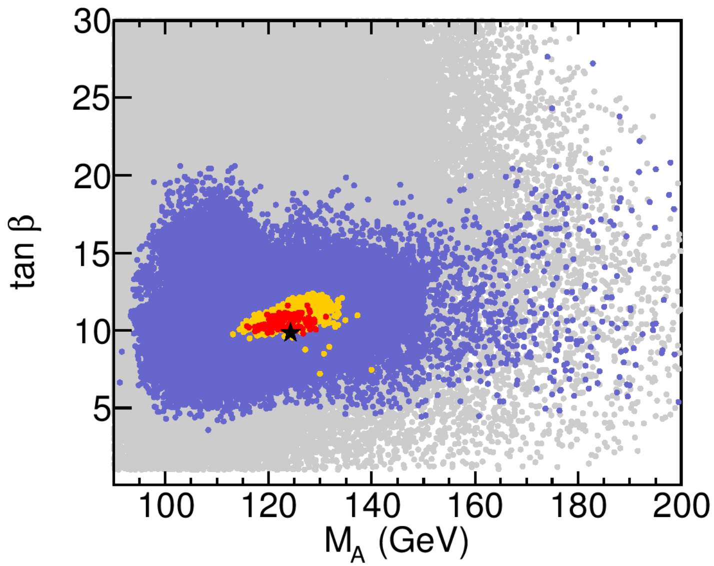
$$M_H \approx 126 \text{ GeV}$$

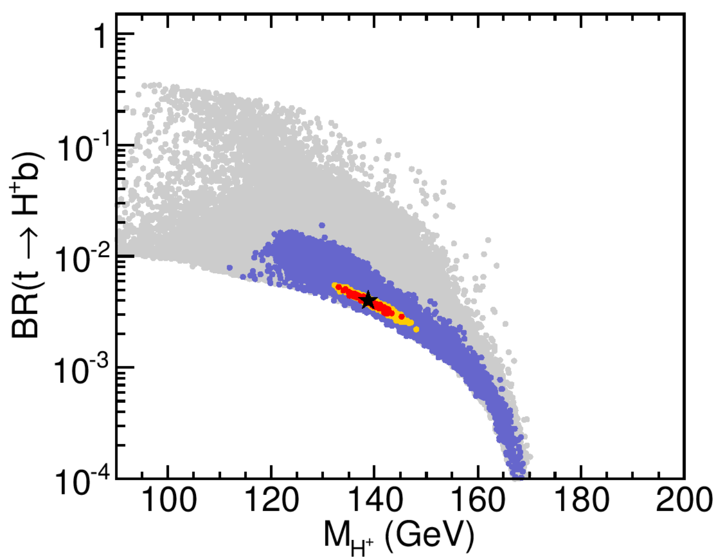
Best fit points



Heavy Higgs case

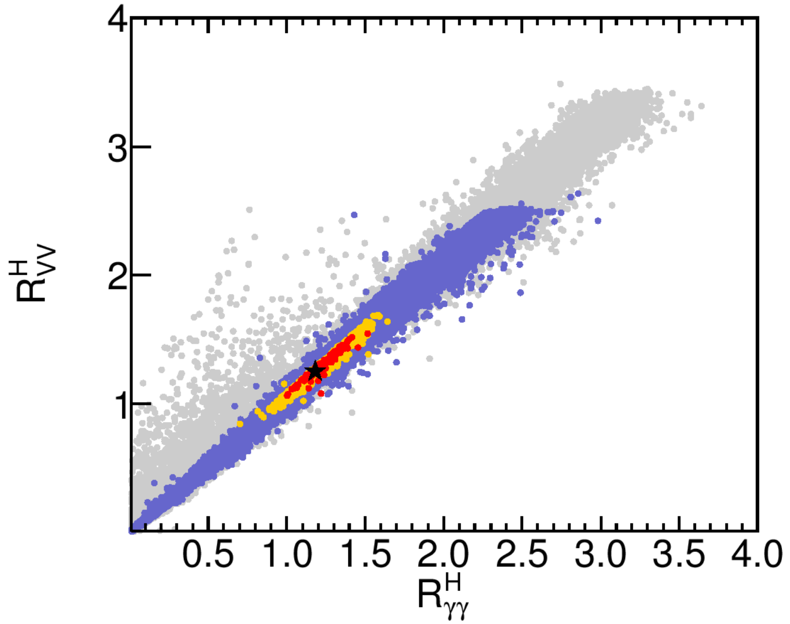
- Allowed region in parameter space limited
  - Low $M_A \rightarrow$ Other Higgs states should be accessible soon

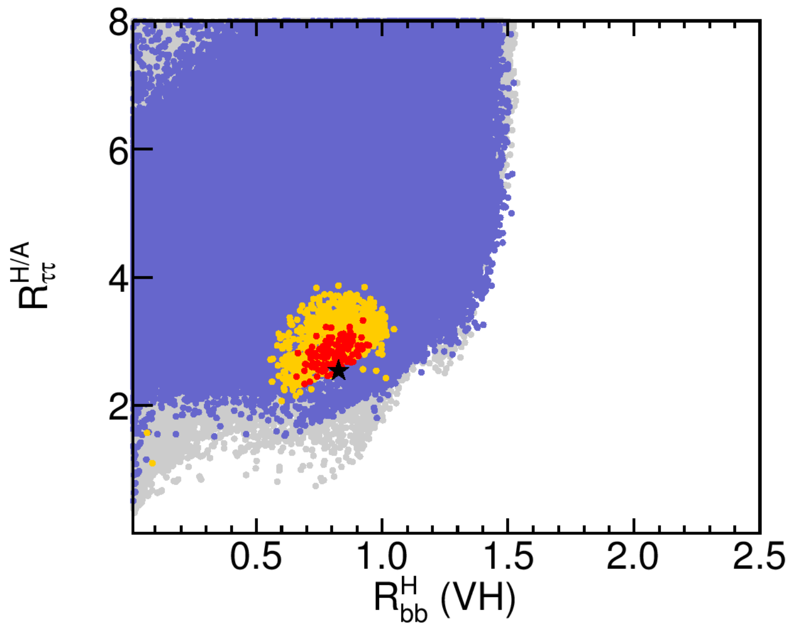




- Additional light CP-even Higgs
- Reduced couplings to vector bosons
  $\rightarrow$ can be below LEP limit for SM Higgs

Favored region – Higgs decay rates





- Favored regions for Higgs decay rates similar to h case:

  Enhanced $\gamma\gamma$ rate, slightly suppressed bb rate

- Notable difference: $\tau\tau$ rate
  - H and A close in mass

    → Contributions added in channels with bad mass resolution

    → Favored region has high $\tau\tau$ rate

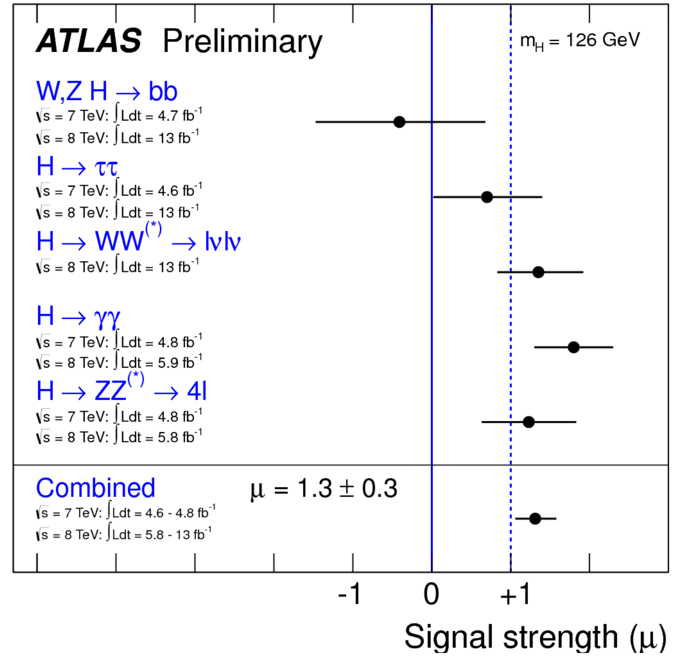
Higgs update at HCP

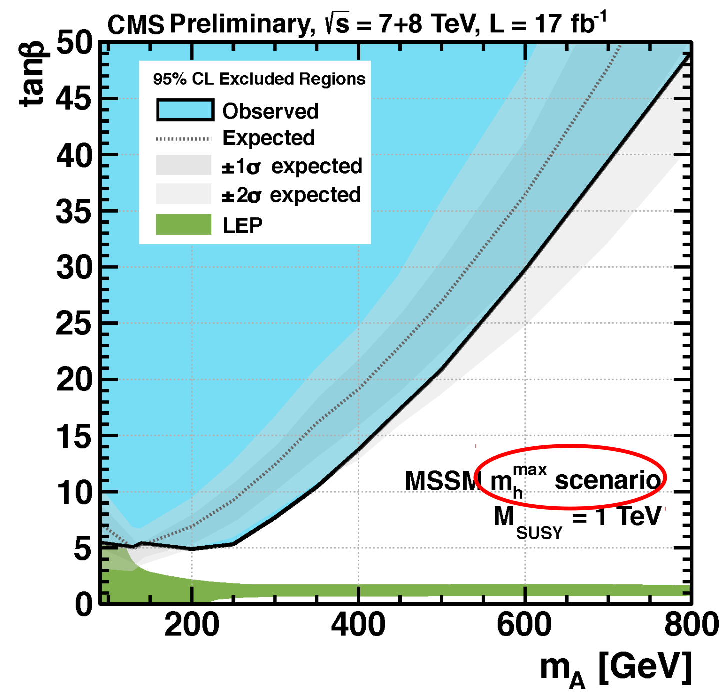
- Both ATLAS and CMS see an excess in the $\tau\tau$ channel
  - Signal strength ~ 0.7
- $\gamma\gamma$ channel not updated

Possible effects for our fit:

- Best fit point in h-case in good agreement with new data
- We find low impact of $\tau\tau$ data
  - → No big change expected from new data
- Favoured region in heavy Higgs case (probably) effected by new results
  - → Model independent cross section limits from CMS needed

Results from HCP





Conclusions

- LHC experiments provide measurements of the decay of the new state
- Fitting the MSSM to experimental rates
  - Including also Tevatron data and low energy observables
- Viable MSSM interpretations:

  Light CP - even Higgs h:
  - Excellent fit for the light Higgs case

  Heavy CP - even Higgs H:
  - Acceptable fit for heavy Higgs case (somewhat worse after including flavour data)
- Fit prefers enhancement of $h \to \gamma\gamma$ and a (small) suppression $h \to bb$
- Plan to update the fit $\to$ Experimental input needed!

Back-up slides

Parameter ranges for MSSM fit

Random scan of 7 "pMSSM" parameters (~10 M points)
(+m_t varied in 2σ interval)

	Min	Max
M_A	90	1000
$\tan\beta$	1	60
M_{Q_3}	200	1500
A_t	$-3\,M_{Q_3}$	$3\,M_{Q_3}$
μ	200	3000
M_{L_3}	200	1500
M_2	200	500

$M_{Q_{1,2}} = M_{U_{1,2}} = M_{D_{1,2}} = 1\,\mathrm{TeV}$

$M_{D_3} = M_{U_3} = M_{Q_3}$

$M_{L_{1,2}} = M_{E_{1,2}} = 300\,\mathrm{GeV}$

$M_{E_3} = M_{L_3}$

$A_b = A_\tau = A_t$

$M_3 = 1\,\mathrm{TeV}$

M_1 fixed by GUT relation

Values used for BPO and (g-2)

Observable	Experimental value	SM value
$\mathrm{BR}(B \to X_s\gamma)$	$(3.43 \pm 0.21 \pm 0.07) \times 10^{-4}$	$(3.08 \pm 0.22) \times 10^{-4}$
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	$< 4.2 \times 10^{-9}$	$(3.55 \pm 0.38) \times 10^{-9}$
$\mathrm{BR}(B_u \to \tau\nu_\tau)$	$(1.66 \pm 0.33) \times 10^{-4}$	$(1.01 \pm 0.29) \times 10^{-4}$
δa_μ	$(30.2 \pm 9.0) \times 10^{-10}$	–
M_W	$(80.385 \pm 0.015)\ \mathrm{GeV}$	$(80.363 \pm 0.004)\ \mathrm{GeV}$

MSSM best fit values for LEO

Channel		Light Higgs case μ_h	χ^2_h	Pull	Heavy Higgs case μ_H	χ^2_H	Pull
LEO	$\mathrm{BR}(B \to X_s\gamma) \times 10^4$	3.41	0.00	-0.03	4.38	2.12	1.46
LEO	$\mathrm{BR}(B_s \to \mu^+\mu^-) \times 10^9$	2.79	0.00	0.00	2.24	0.00	0.00
LEO	$\mathrm{BR}(B_u \to \tau\nu_\tau) \times 10^4$	0.98	2.37	-1.54	0.80	3.78	-1.94
LEO	$\delta a_\mu \times 10^9$	2.58	0.24	-0.49	1.34	3.48	-1.87
LEO	M_W [GeV]	80.379	0.04	-0.19	80.383	0.00	-0.05

- Best fit points give small values for $\mathrm{BR}(B_s^0 \to \mu^+\mu^-)$
- Rather large χ^2 contribution from $\mathrm{BR}(B_u \to \tau\nu_\tau)$
  - Including new Belle result would reduce χ^2 contribution
- In the heavy Higgs case large χ^2 contribution from $(g-2)$
  - Could be improved by treating also slepton parameters as free fit parameters

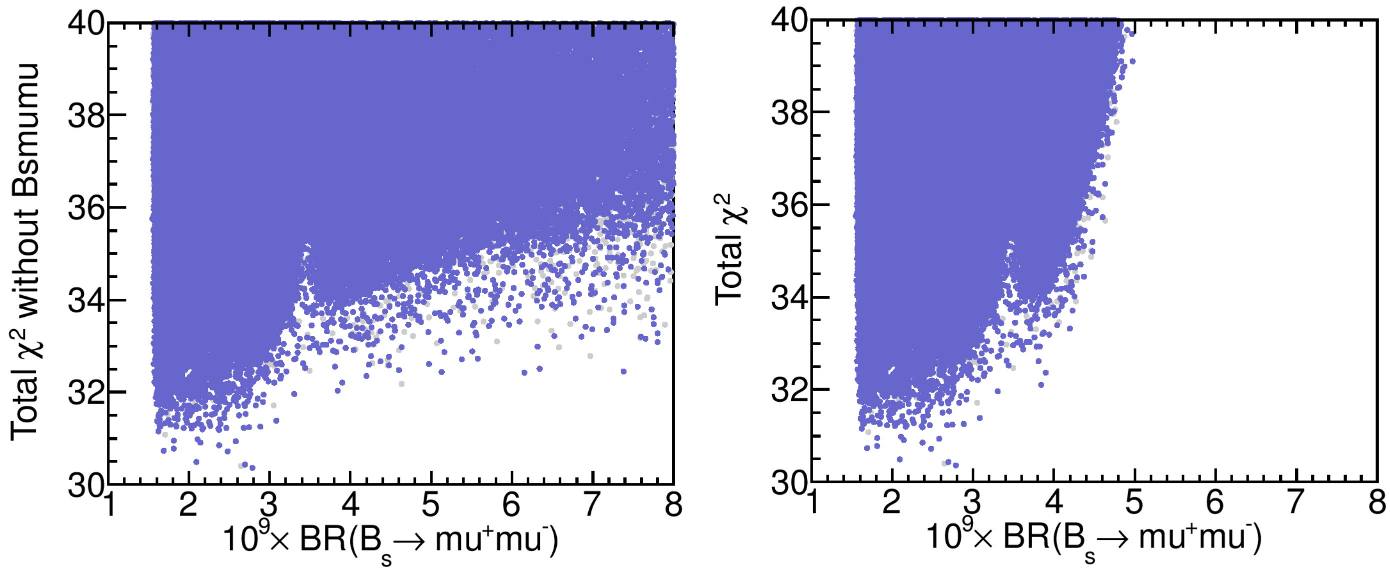
$B_s \rightarrow \mu^+\mu^-$

- Branching ratio measurement from LHCb presented at HCP

$$\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

SM prediction:
$3.55 \pm 0.38 \times 10^{-9}$

- MSSM fit predicts low values of $\mathrm{BR}(B_s^0 \to \mu^+\mu^-)$
  - Already without including $\mathrm{BR}(B_s^0 \to \mu^+\mu^-)$ measurement/limit in χ^2 calculation

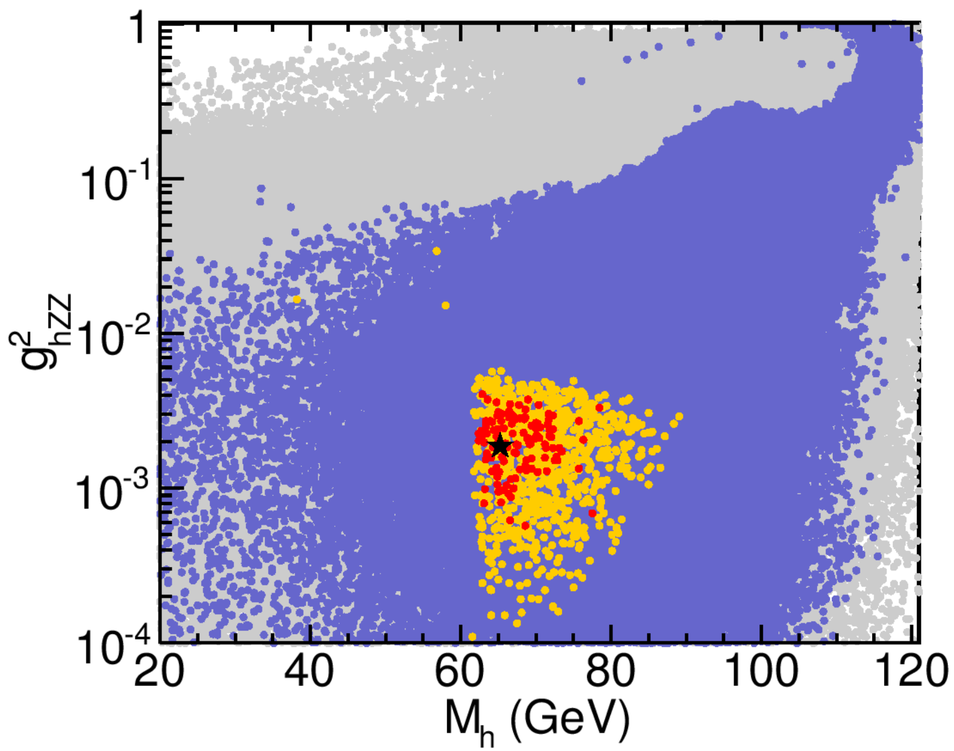


- Points predicting $b \to s\gamma$ in the right range and an enhanced $\gamma\gamma$ rate, automatically feature a suppressed $\mathrm{BR}(B_s^0 \to \mu^+\mu^-)$

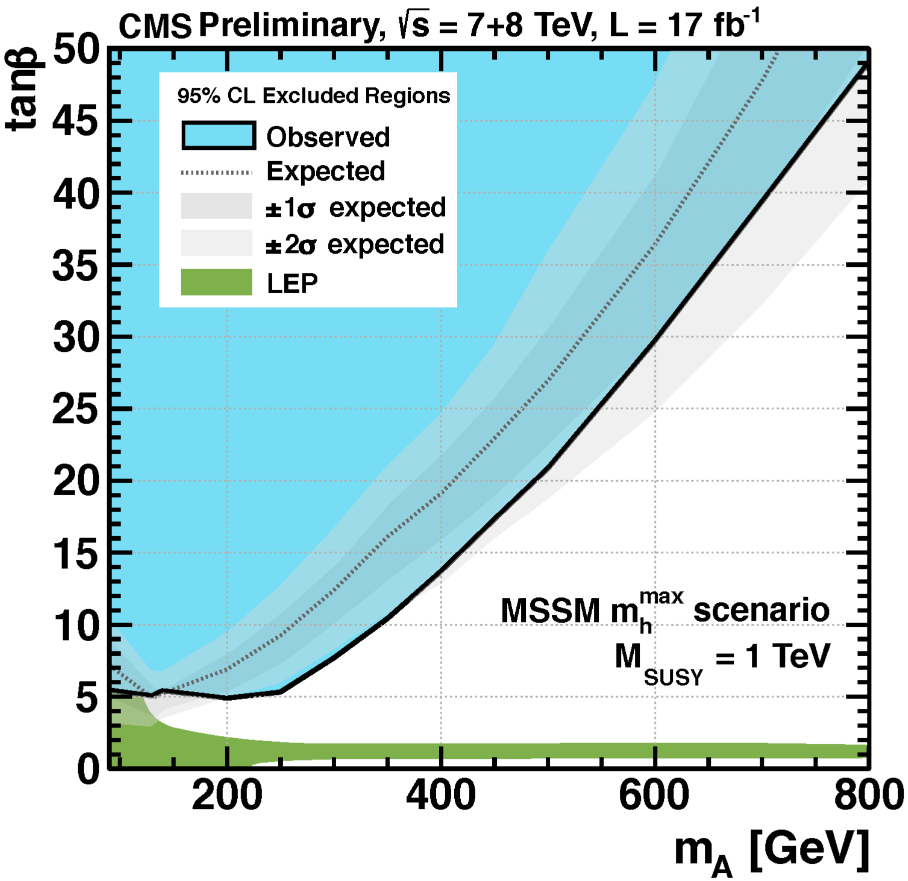
Haisch, Mahmoudi, 'arXiv:1210.7806

Heavy Higgs case

- Additional light CP-even Higgs with reduced couplings to vector bosons
  → Not excluded by LEP searches



New limits from MSSM Higgs boson searches



- New results given only in the $m_h^{\max}$ - scenario
- No model-independent cross section limits
- Favoured region in heavy Higgs case (probably) effected by new results
- Effects need to be investigated

  → Experimental input missing...