Implications of the LHC Higgs Discovery for SUSY models

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Higgs Hunting 2013, Orsay

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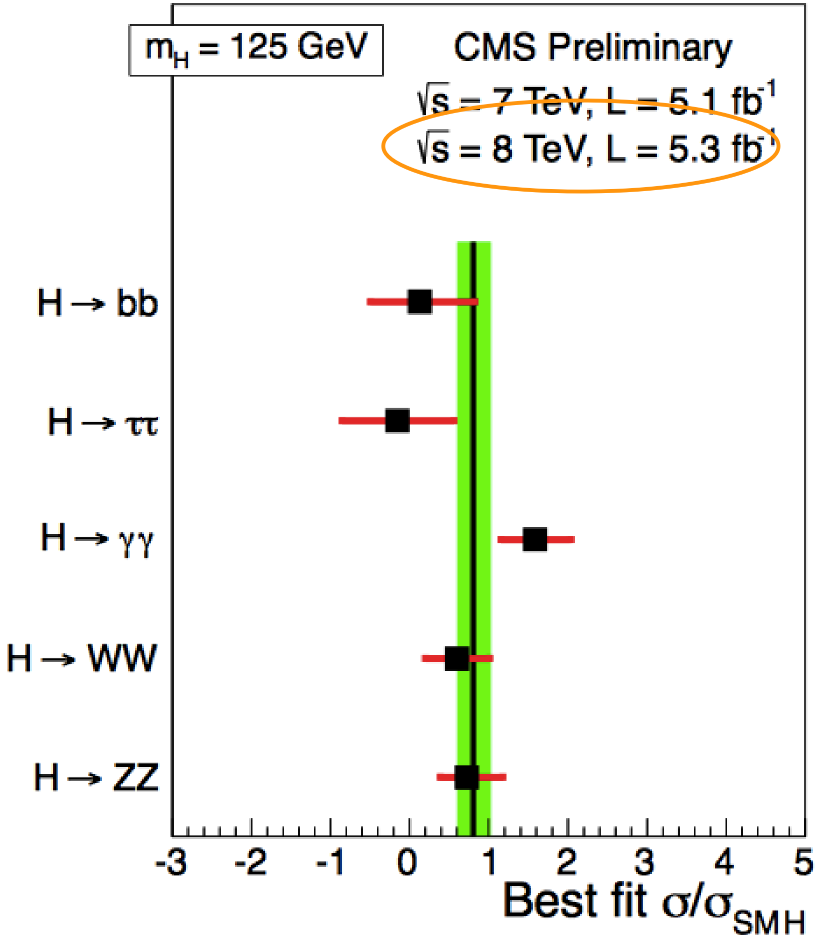
Together with P. Bechtle, S.Heinemeyer, O.Stål, T. Stefaniak, G.Weiglein,
based on [1211.1955]

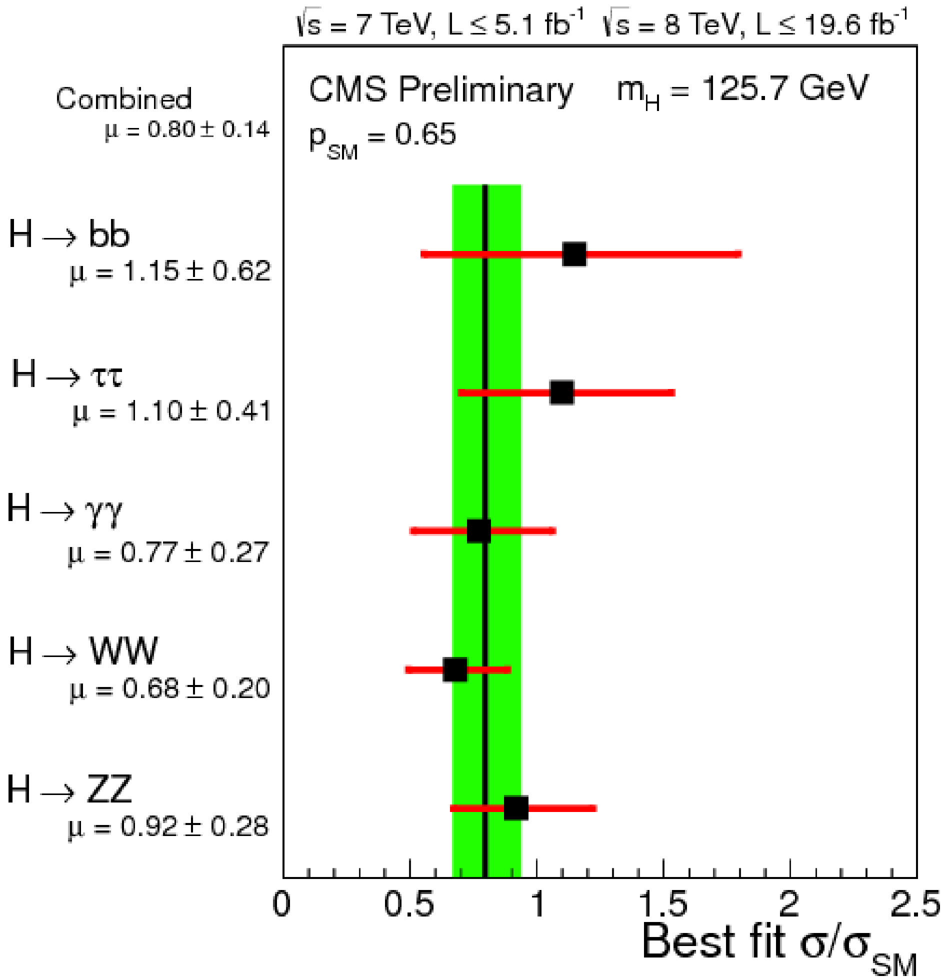
Motivation

- In each decay channel experiments give best fit signal strength $\mu = (\sigma \times BR)/(\sigma \times BR)_{SM}$
- Slight deviation from the SM
- Tendency in 2011/12 analysis:
  - Suppressed bb, $\tau\tau$
  - Enhanced $\gamma\gamma$



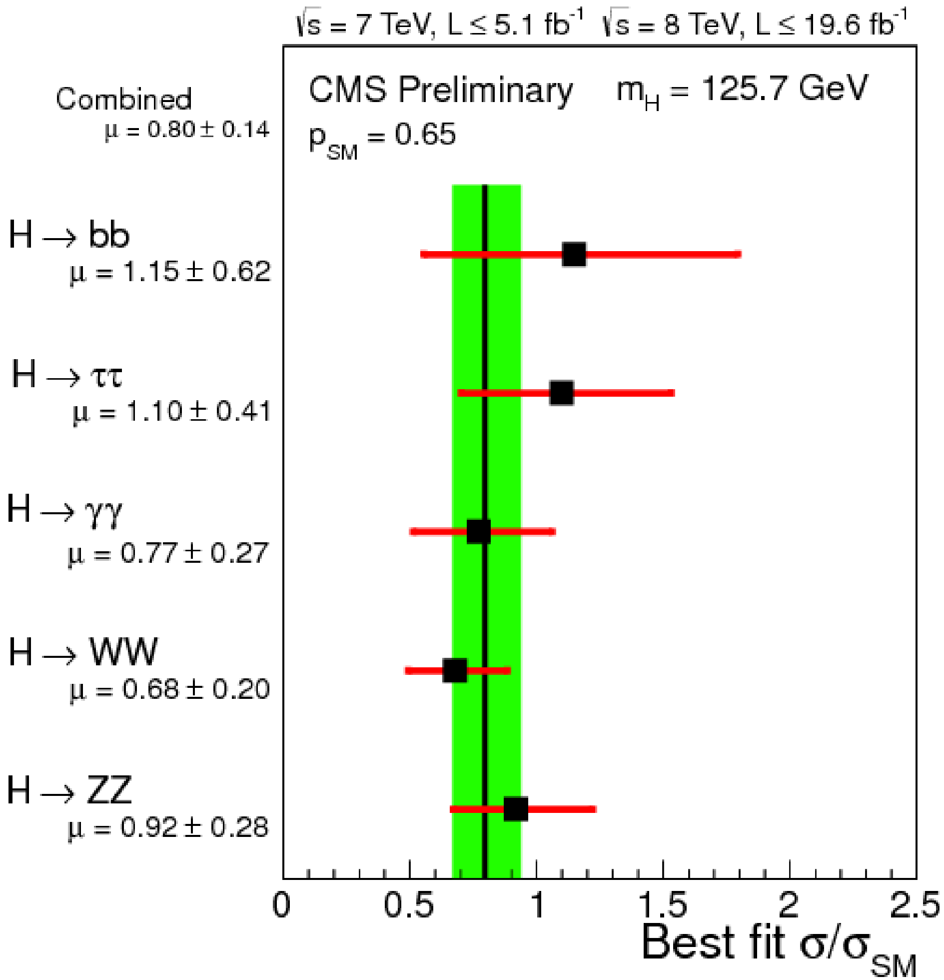
Motivation

- In each decay channel experiments give best fit signal strength $\mu = (\sigma \times BR)/(\sigma \times BR)_{SM}$
- This tendency (more or less) vanished



Motivation

- In each decay channel experiments give best fit signal strength $\mu = (\sigma \times BR)/(\sigma \times BR)_{SM}$
- Observation compatible with SM Higgs
- Many new physics explanations possible
- Signal strength measurements can be use to restrict models
- How well does the MSSM describe the signal seen by the experiments?



Parameter scan

- Random scan over 7 (8) pMSSM parameters
  + top mass varied in 2σ
- ~ 10 million points (in update so far only ~ 2 million)

	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

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1.2 TeV

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4000

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Stop sector parameter MU3 scanned independently

M1 fixed by gut relation

How well can the MSSM describe the Higgs signal?

- For every point a χ^2 value is calculated
- Standard χ^2 method:

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

- Signal strength and Higgs mass χ^2 calculated using `HiggsSignals`*
- MSSM Higgs decay rates calculated with channel efficiencies as weights (when available)

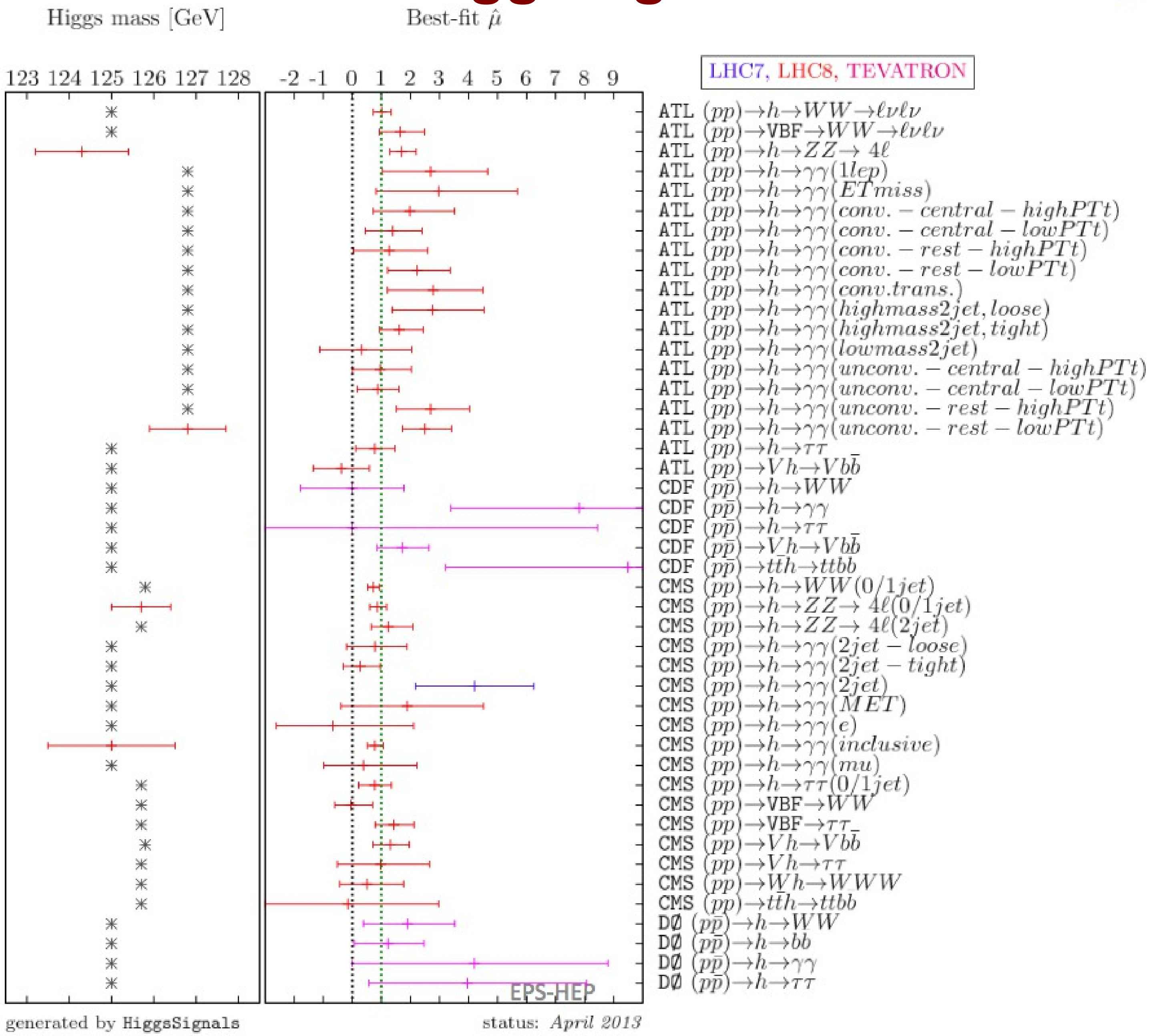
$$\mu_{xx} = \frac{\sum_k w_k \, \sigma_k \times BR(h \to xx)}{\sum_k w_k \, \sigma_k^{SM} \times BR(h \to xx)^{SM}}$$

- Low energy observables (LEO) taken into account:

$$b \to s\gamma, B_s \to \mu\mu,$$
$$B \to \tau\nu, (g_\mu - 2), M_W$$

* Bechtle, Heinemeyer, Stål, Stefaniak, Weiglein: arXiv:1305.1933

Observables included in HiggsSignals

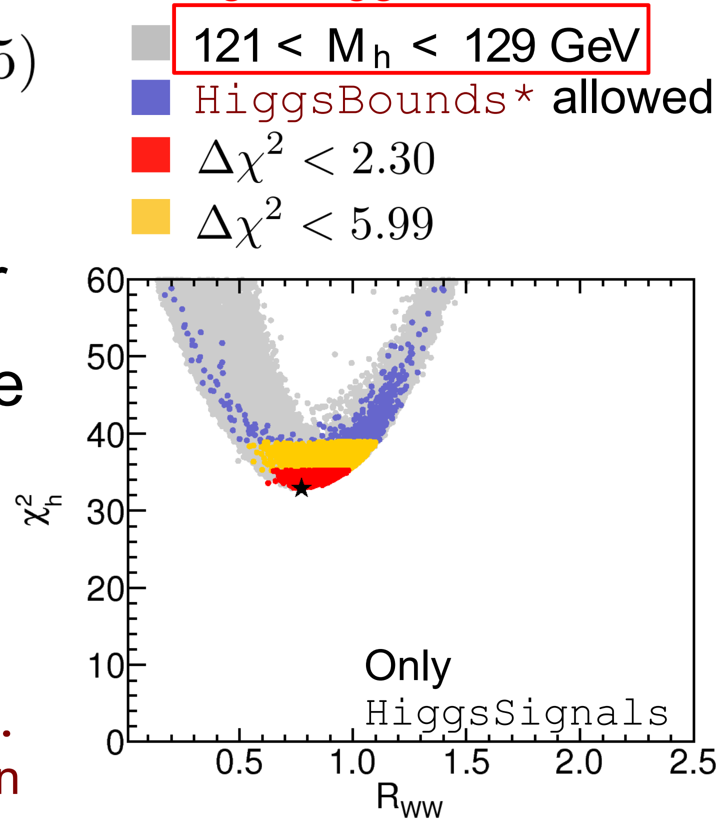


Results of the fit

Naive calculation of degrees of freedom: $\nu = n_{\rm obs} - n_{\rm para}$

- Minimal χ^2 result:
  - Higgs signal strength and Higgs mass:
    $\chi^2/\nu = 33.9/43$ (SM: $\chi^2/\nu = 38.94/50$)
  - including LEO:
    $\chi^2/\nu = 38.6/48$ (SM: $\chi^2/\nu = 53.27/55$)
- SM and MSSM interpretations similar
- Including LEO, SM gets slightly worse
  - $(g_\mu - 2)$ differs by more than 3 σ
- Overall good MSSM fit

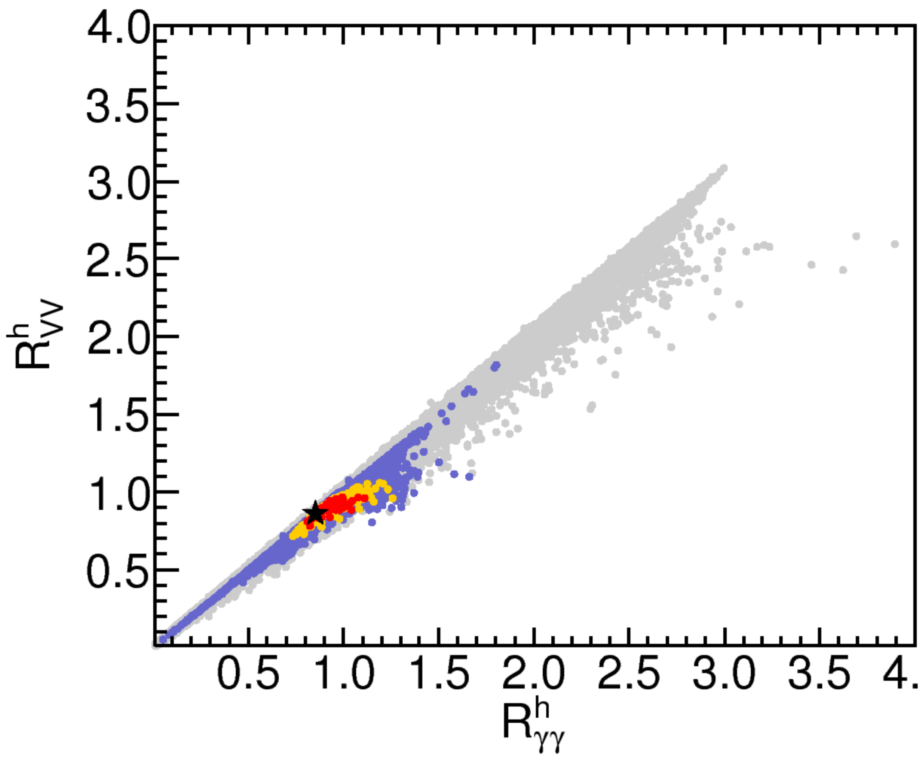
'Light Higgs scenario'

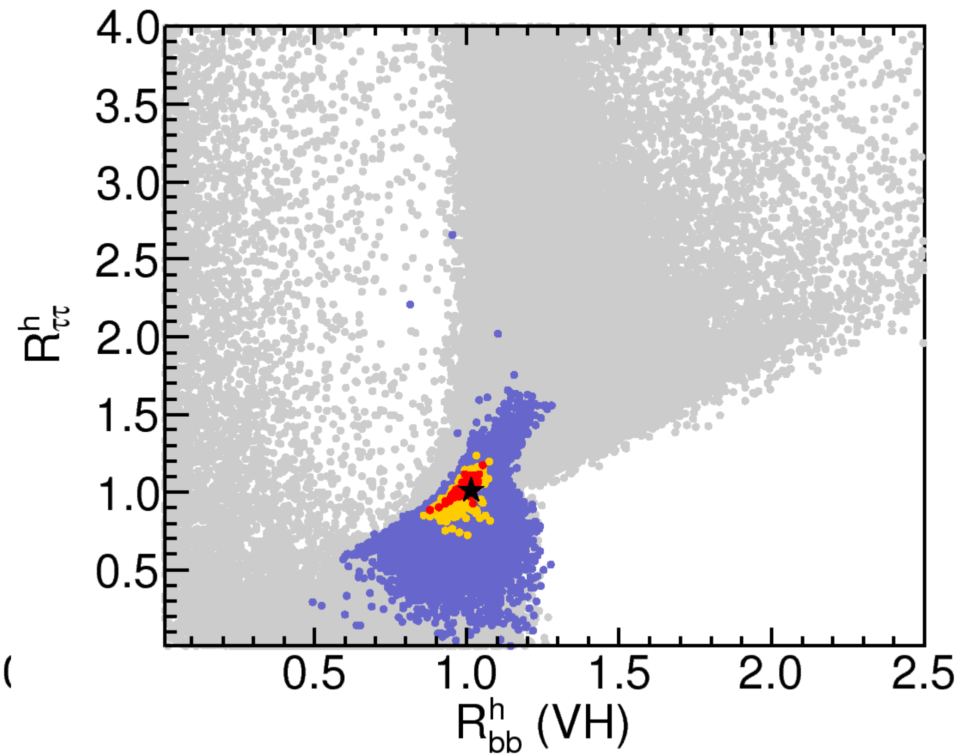


* HiggsBounds 4.0.0.
Bechtle, Heinemeyer, Stål, Stefaniak, Weiglein

Higgs decay rates

Plots here and in the following always refer to the complete fit, including LEO



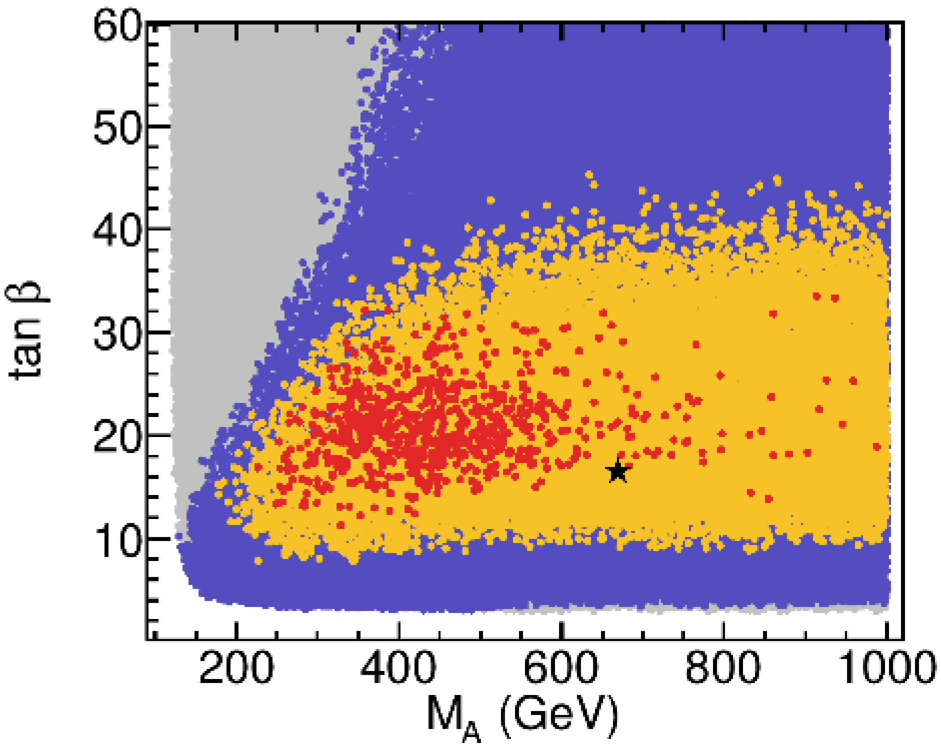


- $R_{xx}\ (\approx \mu_{xx}) : \sum_i \sigma_i^{(8\ \mathrm{TeV})} \times \mathrm{BR}(h \to xx)/\mathrm{SM}$
- Decay rates close to SM value preferred

$121 < M_h < 129$ GeV
HiggsBounds* allowed
$\Delta\chi^2 < 2.30$
$\Delta\chi^2 < 5.99$

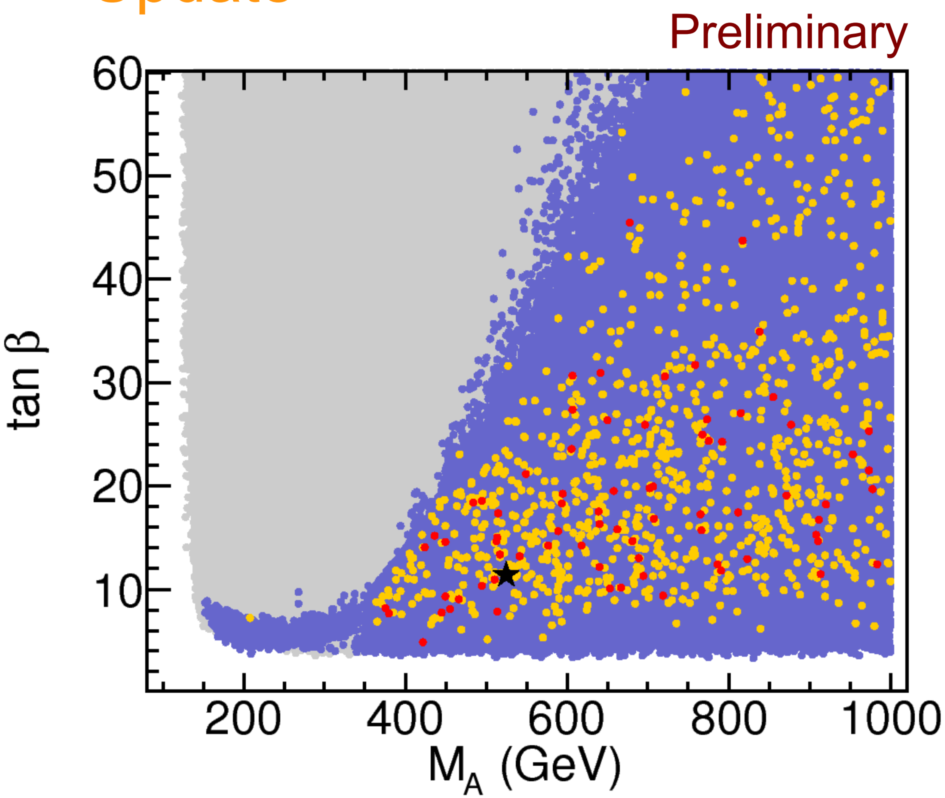
Favored region

- Which MSSM region describes data best?
- With autumn 2012 data



Favored region

- Which MSSM region describes data best?
- Update



- Larger HiggsBounds excluded region
- Still slight preference for intermediate $\tan\beta$ values
- Preferred region opens up

Statistics still much lower

Favored region

- Which MSSM region describes data best?
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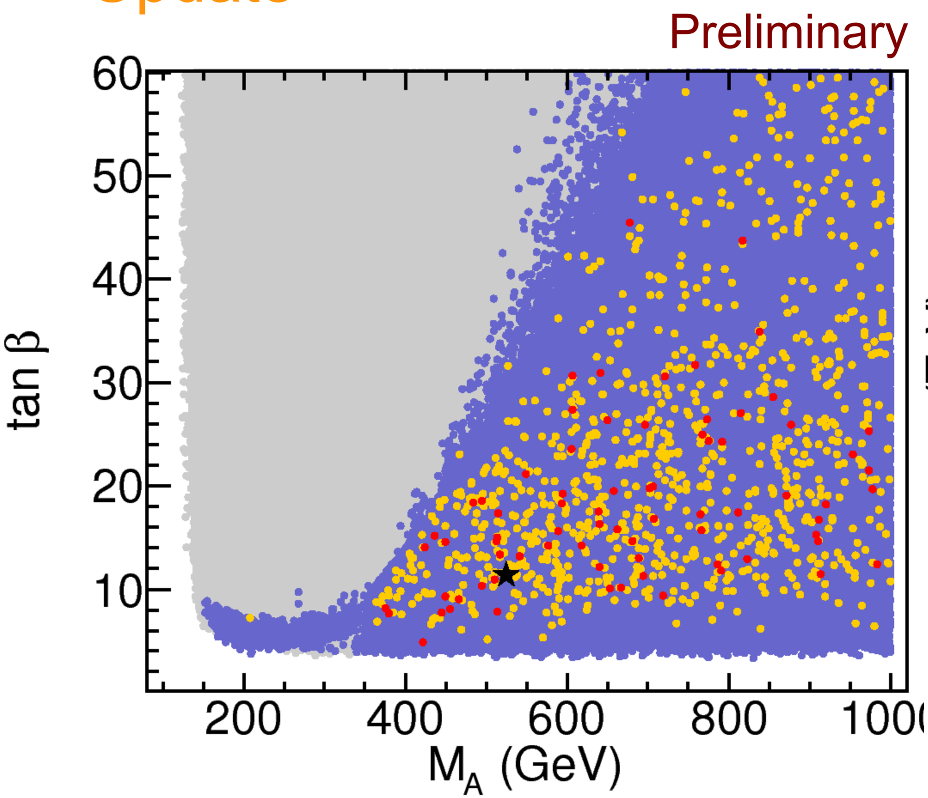

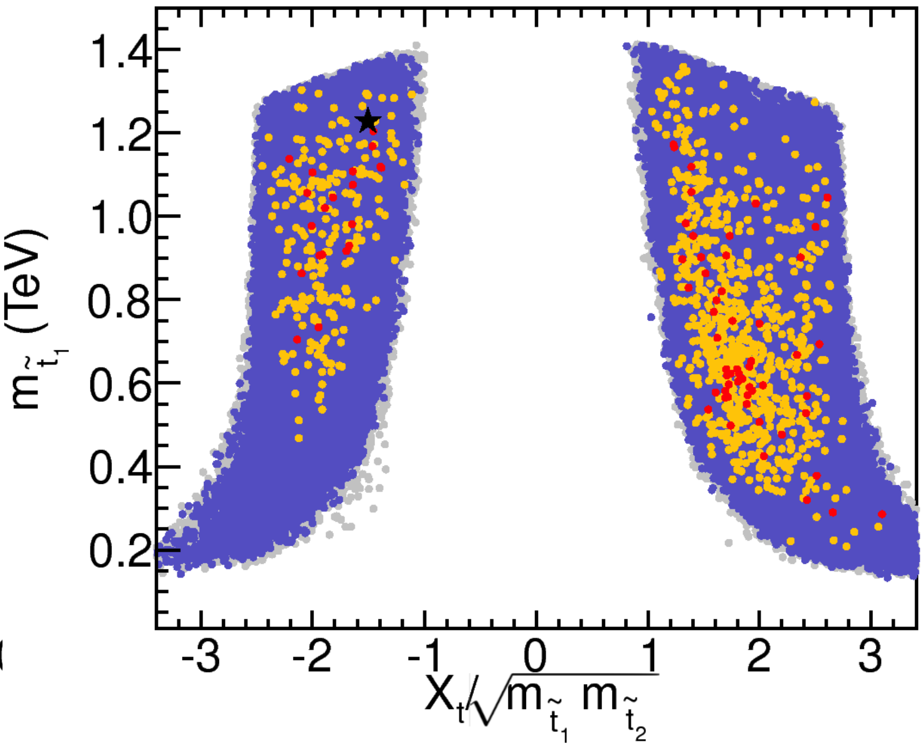

Conclusions

- LHC experiments provide measurements of the Higgs decay rates
- Signal rates got closer to 1(SM)

  → MSSM decoupling region
- Fitting the MSSM to experimental rates
  - Using `HiggsSignals`
  - Including low energy observables
- Discovered Higgs can be interpreted as the light CP even Higgs

  → Good fit for the light Higgs case
- To investigate favored regions in parameter space higher statistics in needed

Backup

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

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

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$M_{E_3} = M_{L_3}$

$A_b = A_\tau = A_t$

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

M_1 fixed by GUT relation

MU3 scanned independently

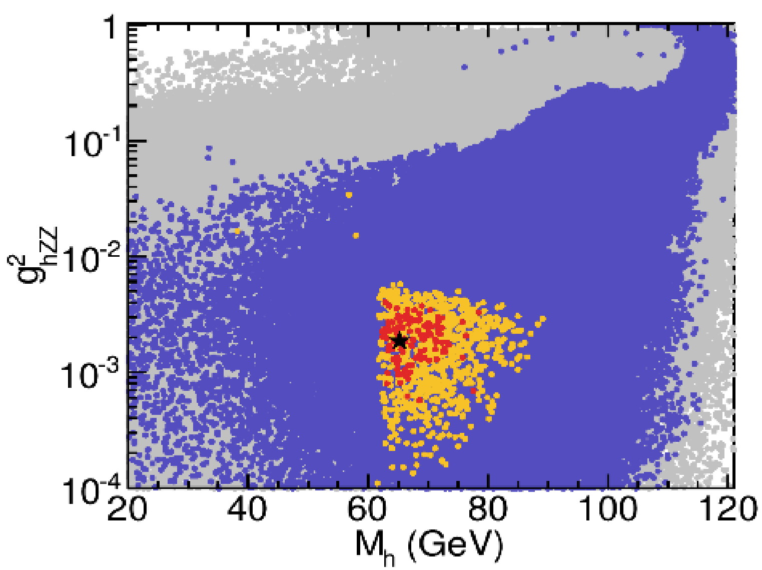
New Belle result not included

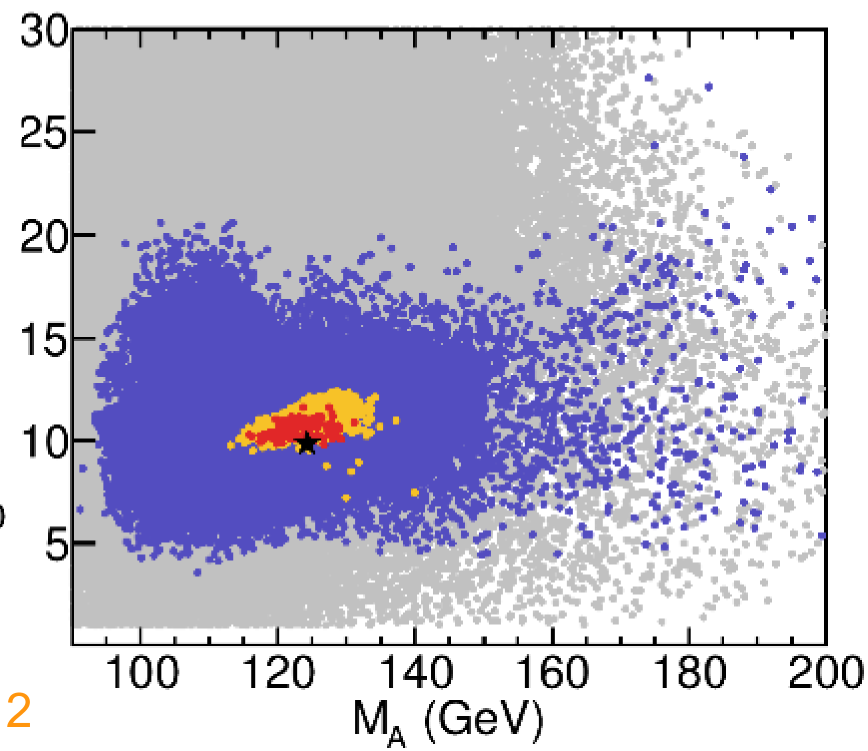
Values used for BPO and (g-2)

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

Heavy Higgs scenario

- Possible only in very small corner of parameter space
- All MSSM Higgs would be light → Should be accessible soon
- Lightest CP-even Higgs reduced couplings to vector bosons
- Very constraint by LHC searches





Not updated!
Higgs results from autumn '12

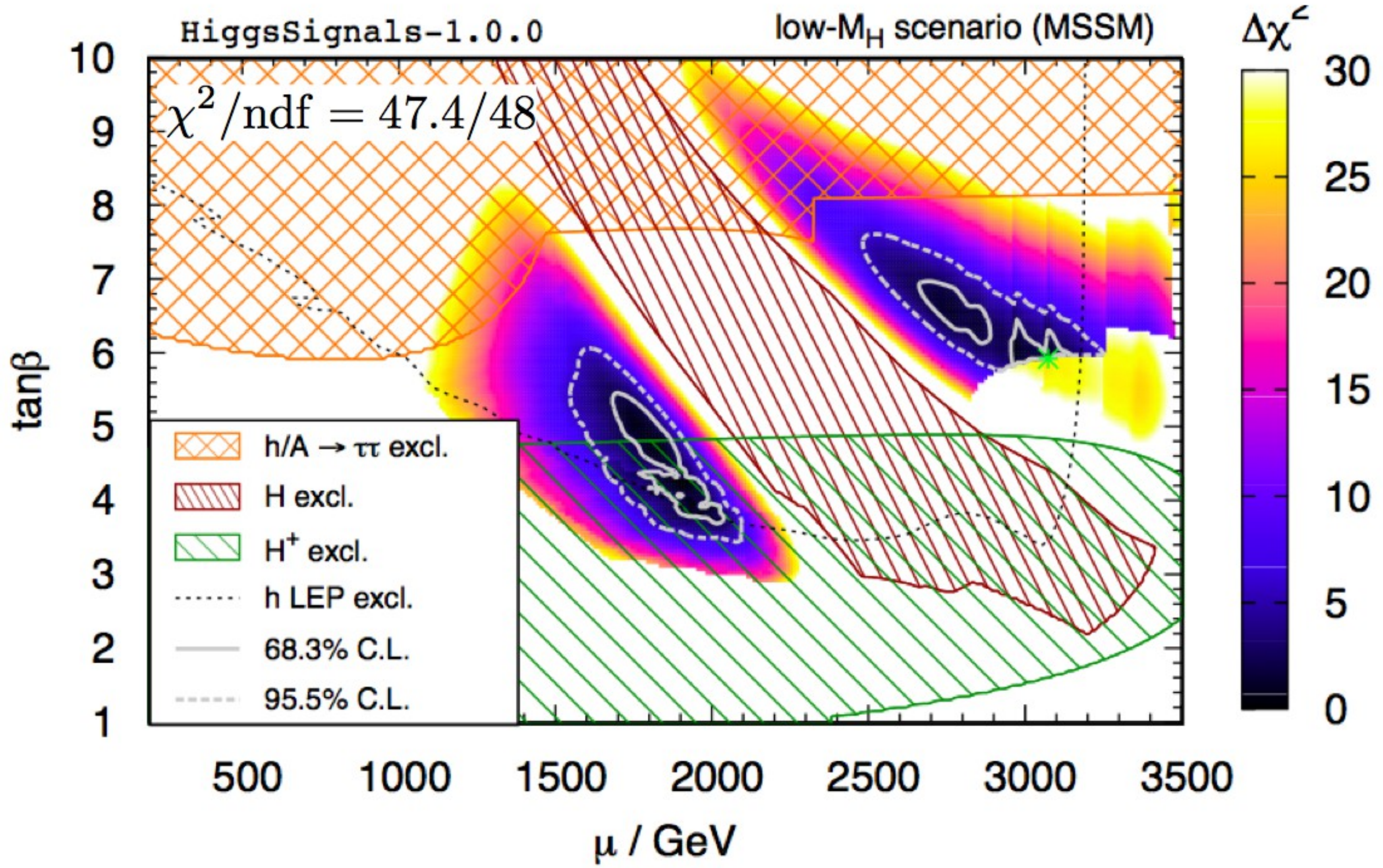
Heavy Higgs scenario

- Possible only in very small corner of parameter space
- All MSSM Higgs would be light → Should be accessible soon
- Lightest CP-even Higgs reduced couplings to vector bosons
- Very constraint by LHC searches
- Result of previous fit (using LHC Higgs results from 11/2012)

  - Higgs signal strength: $\chi^2/\nu = 33.1/31$ (SM: $\chi^2/\nu = 31.0/37$)
  - Including LEO: $\chi^2/\nu = 42.4/36$ (SM: $\chi^2/\nu = 45.3/42$)
    Large contribution of light Higgs bosons to b-physics observables

Low-M_H MSSM benchmark scenario

Low energy observables not included!



Bechtle, Heinemeyer, Stål, Stefaniak, Weiglein

Results of the fit (Nov 12)

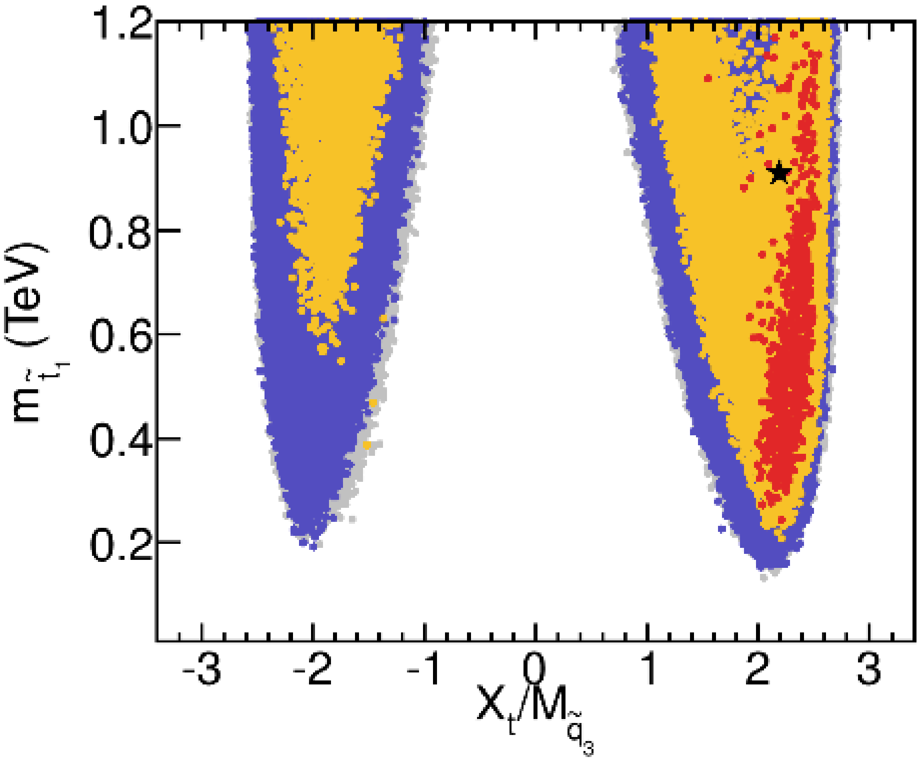
	LHC only			LHC+Tevatron			LHC+LEO			LHC+Tevatron+LEO		
Case	χ^2/ν	χ^2_ν	p	χ^2/ν	χ^2_ν	p	χ^2/ν	χ^2_ν	p	χ^2/ν	χ^2_ν	p
SM	27.6/34	0.81	0.77	31.0/37	0.84	0.74	41.6/39	1.07	0.36	45.3/42	1.08	0.34
h	23.3/28	0.83	0.72	26.8/31	0.86	0.68	26.7/33	0.81	0.77	30.4/36	0.84	0.73
H	26.0/28	0.93	0.57	33.1/31	1.07	0.37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

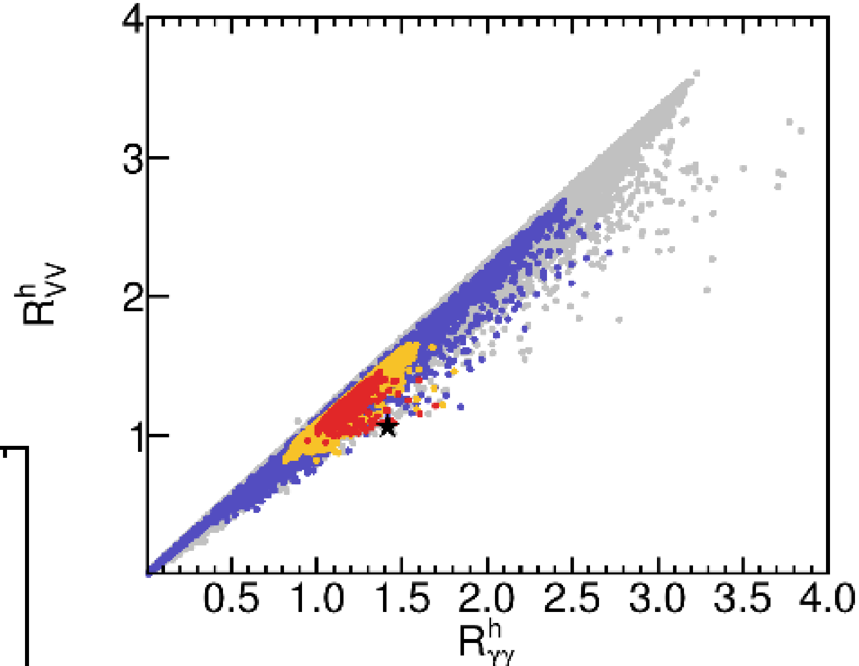
Naive calculation if dof: $\nu = n_{\mathrm{obs}} - n_{\mathrm{para}}$

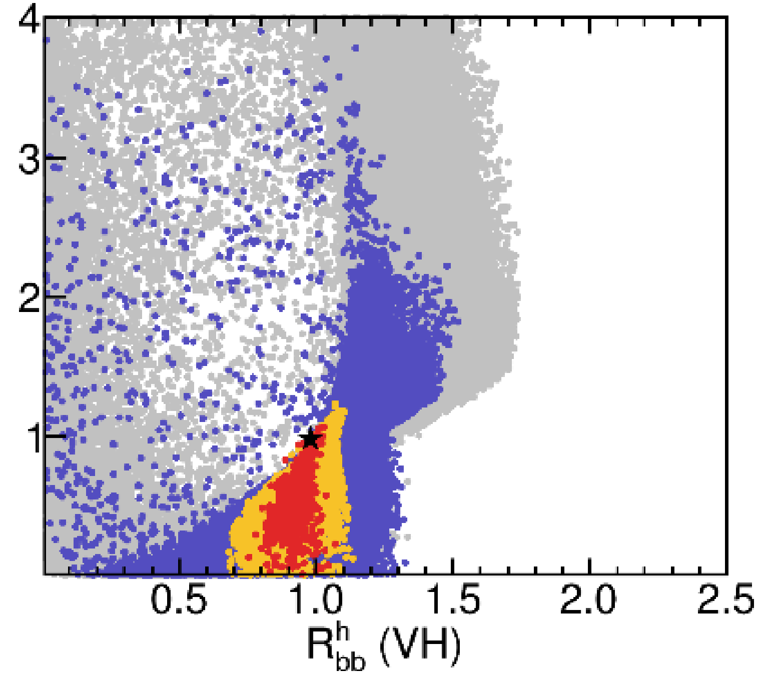
- Only collider data:
  SM and both MSSM interpretations similar
- Including also low energy observables (LEO):
  SM and heavy Higgs case become slightly worse
  - → SM because $(g_\mu - 2)$ differs by more than 3σ
  - → H case because light charged Higgs give (too) large contributions to B physics observables
- Overall good MSSM fits (for both cases)
- No clear preference for either MSSM or SM

Favored regions in h-case

- Plots using Higgs data from autumn 2012







MSSM best fit values for LEO

		Light Higgs case			Heavy Higgs case		
Channel		μ_h	χ_h^2	Pull	μ_H	χ_H^2	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
- 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

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:
- In the MSSM the Higgs signal at 126 GeV can be:
  - Light CP-even Higgs: h
  - Heavy CP-even Higgs: H

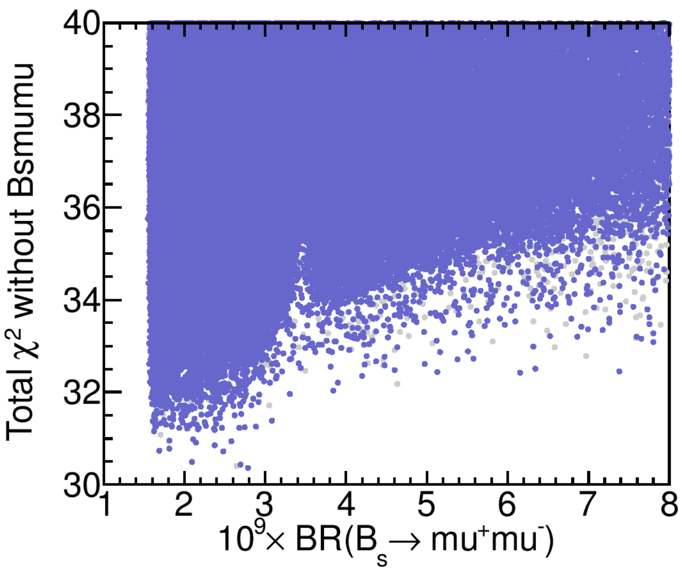
$B_s \to \mu^+\mu^-$

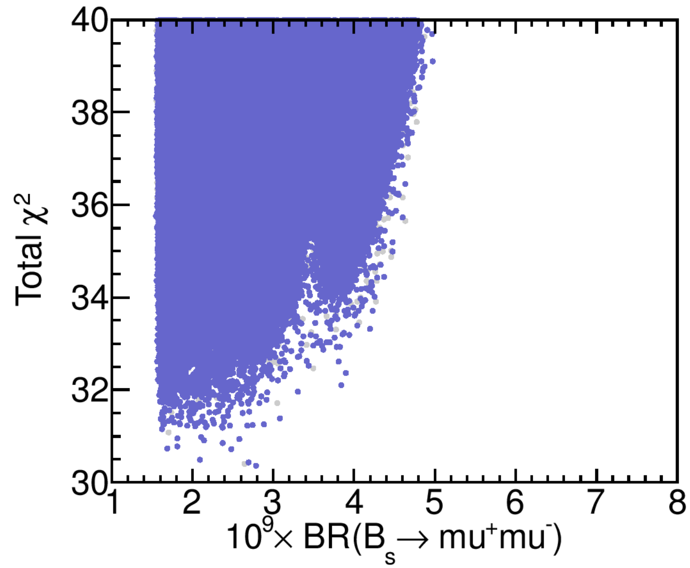
- Branching ratio measurement from LHCb presented at HCP

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

SM prediction:
3:55 § 0:38 £ 10ⁱ 9

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

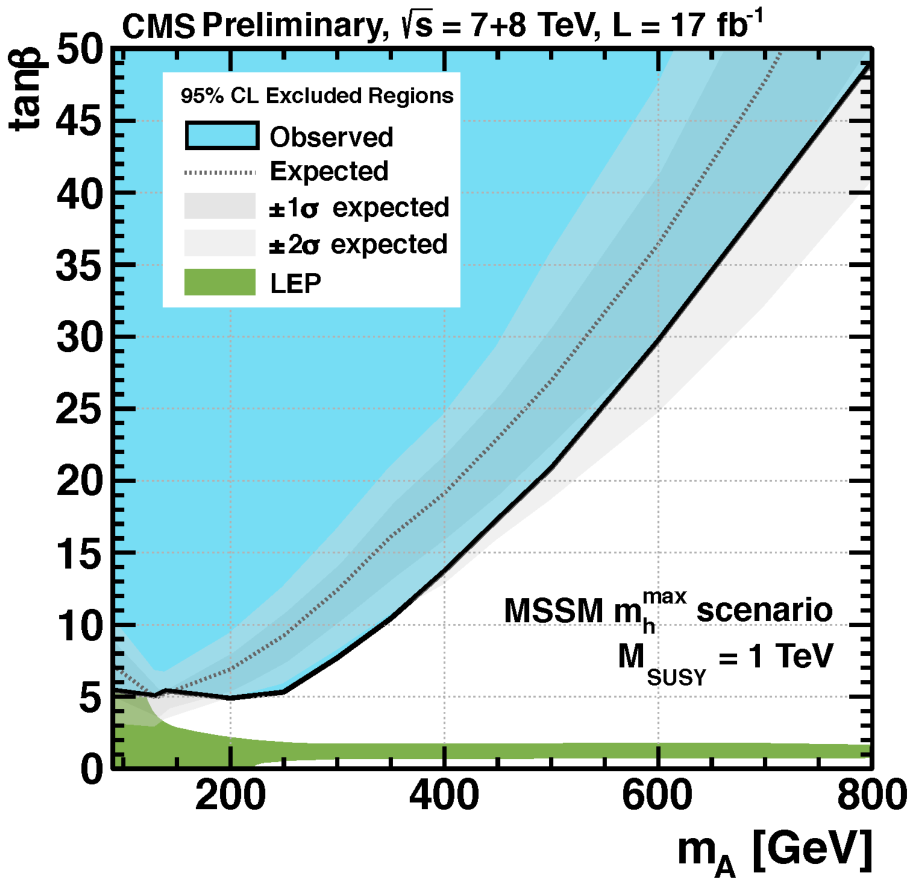




- Points predicting $b \to s\gamma$ in the right range and an enhanced $\gamma\gamma$ rate, automatically feature a suppressed

Haisch, Mahmoudi, 'arXiv:1210.7806

New limits from MSSM Higgs boson searches



- New results given only in the m_h^{max} - scenario
- No model-independent cross section limits