A 126 GeV Higgs boson with enhanced $\gamma\gamma$ rate in Supersymmetry

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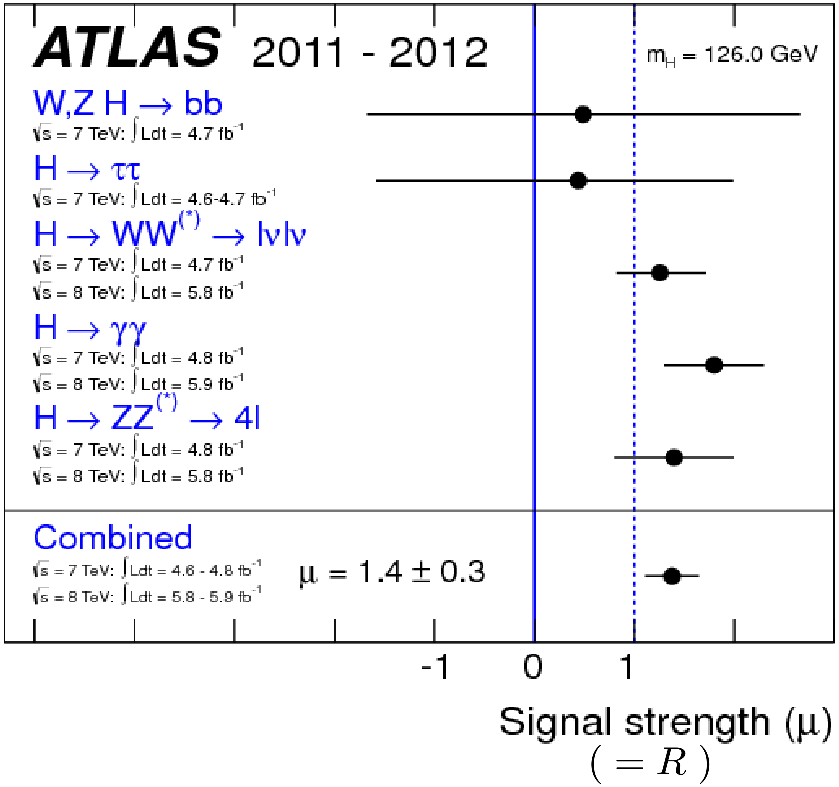
Theory Workshop 2012,
DESY, Hamburg

September 27, 2012

Based on [1207.1096]
with R.Benbrik, S.Heinemeyer, M.Gomez, O.Stål, G.Weiglein
and on work in progress
with P. Bechtle, S.Heinemeyer, O.Stål, T. Stefaniak, G.Weiglein

Decay rates

Higgs-like particles with mass of 126 GeV observed



- ATLAS and CMS give best fit signal strength

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

- Consistent with the SM

However:

- Enhanced $\gamma\gamma$ signal
- Nothing seen in $\tau\tau$ and $b b$ mode
  - What about Tevatron?
- Many new physics alternatives possible

Higgs sector in 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: $M_h \lesssim 135 \text{ GeV}$
- $\alpha \to \alpha_{\text{eff}}$ approximation beyond LO

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

How well does the MSSM describe the Higgs signal?

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

$$\chi^2 = \sum_{i=1}^{N_{\rm obs}} \frac{(R_i - \hat{R}_i)^2}{\sigma_i^2} + \frac{(M_h - M_h^{\rm ref})^2}{\Delta M_h^2}$$

$$M_h^{\rm ref} = 125.7 \text{ GeV}$$
$$\Delta M_h = 1 \text{ GeV}$$
$$\text{SM: } R_i = 1$$

$$N_{\rm obs} = N_{\rm ATLAS} + N_{\rm CMS} (+N_{\rm others})$$

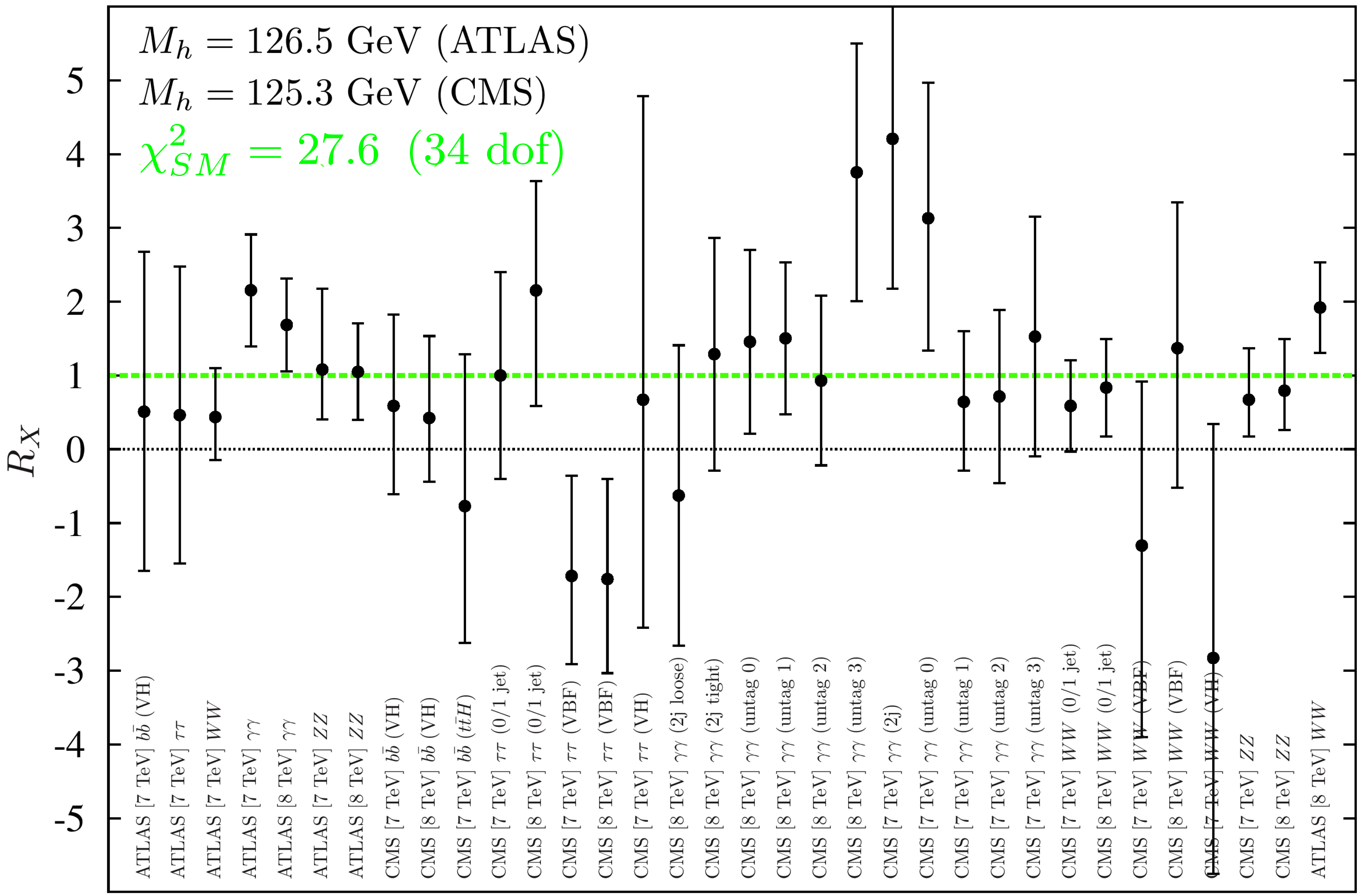
Tevatron data not included yet!

- χ^2 calculated with/without B-physics observables and $(g-2)_\mu$
- MSSM Higgs decay rates calculated with channel efficiencies as weights

Weights available only for $\gamma\gamma$
Naive prediction for other channels

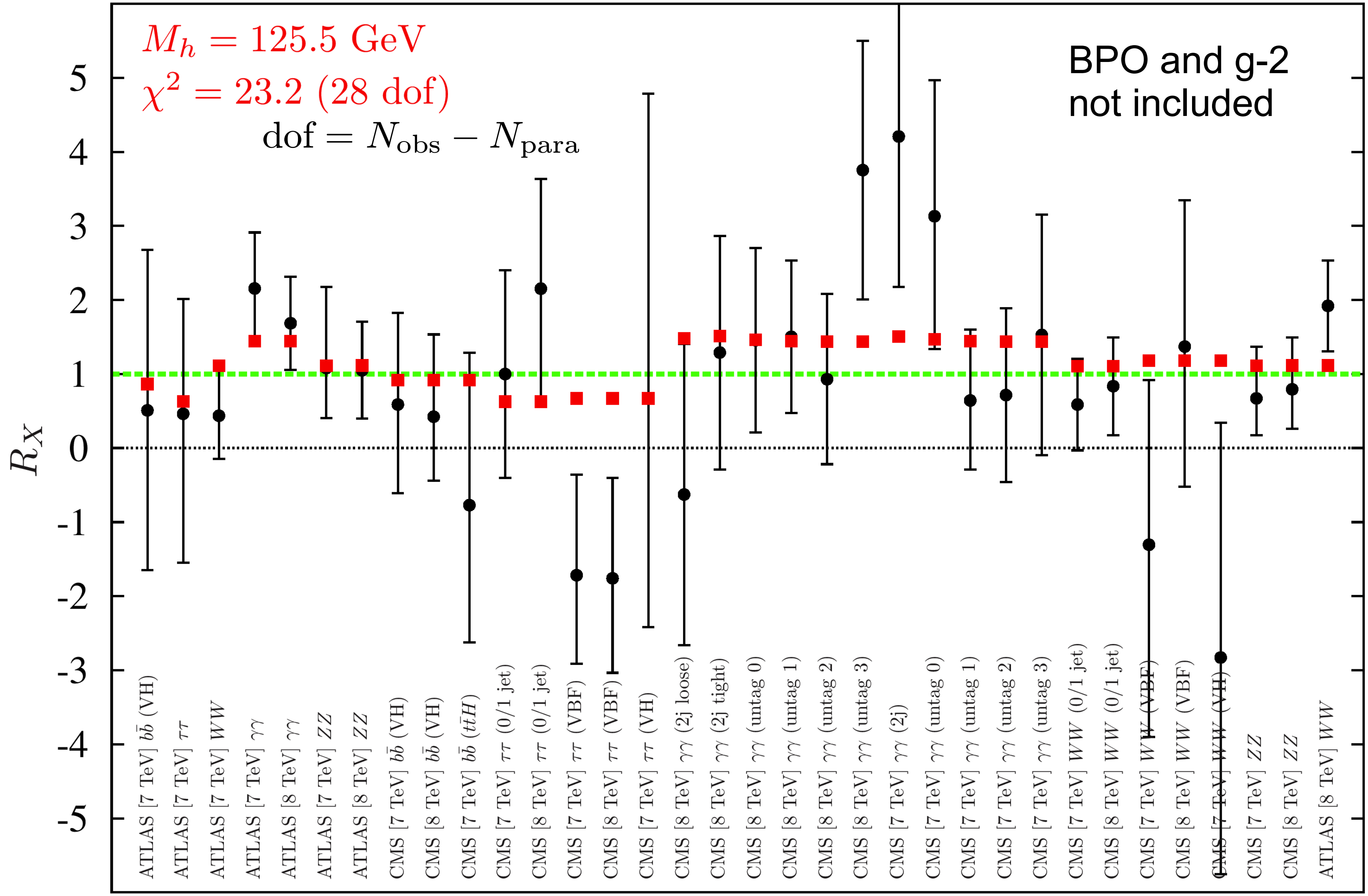
$$R_{xx} = \frac{\sum_k w_k \sigma_k \times BR(h \to xx)}{\sum_k w_k \, \sigma_k^{SM} \times BR(h \to xx)^{SM}}$$

LHC data



$M_h = 126.5$ GeV (ATLAS)
$M_h = 125.3$ GeV (CMS)
$\chi^2_{SM} = 27.6$ (34 dof)
R_X
5
4
3
2
1
0
-1
-2
-3
-4
-5
ATLAS [7 TeV] $b\bar{b}$ (VH)
ATLAS [7 TeV] $\tau\tau$
ATLAS [7 TeV] WW
ATLAS [7 TeV] $\gamma\gamma$
ATLAS [8 TeV] $\gamma\gamma$
ATLAS [7 TeV] ZZ
ATLAS [8 TeV] ZZ
CMS [7 TeV] $b\bar{b}$ (VH)
CMS [8 TeV] $b\bar{b}$ (VH)
CMS [7 TeV] $b\bar{b}$ ($t\bar{t}H$)
CMS [7 TeV] $\tau\tau$ (0/1 jet)
CMS [8 TeV] $\tau\tau$ (0/1 jet)
CMS [7 TeV] $\tau\tau$ (VBF)
CMS [8 TeV] $\tau\tau$ (VBF)
CMS [7 TeV] $\tau\tau$ (VH)
CMS [8 TeV] $\gamma\gamma$ (2j loose)
CMS [8 TeV] $\gamma\gamma$ (2j tight)
CMS [8 TeV] $\gamma\gamma$ (untag 0)
CMS [8 TeV] $\gamma\gamma$ (untag 1)
CMS [8 TeV] $\gamma\gamma$ (untag 2)
CMS [8 TeV] $\gamma\gamma$ (untag 3)
CMS [7 TeV] $\gamma\gamma$ (2j)
CMS [7 TeV] $\gamma\gamma$ (untag 0)
CMS [7 TeV] $\gamma\gamma$ (untag 1)
CMS [7 TeV] $\gamma\gamma$ (untag 2)
CMS [7 TeV] $\gamma\gamma$ (untag 3)
CMS [7 TeV] WW (0/1 jet)
CMS [8 TeV] WW (0/1 jet)
CMS [7 TeV] WW (VBF)
CMS [8 TeV] WW (VBF)
CMS [7 TeV] WW (VH)
CMS [7 TeV] ZZ
CMS [8 TeV] ZZ
ATLAS [8 TeV] WW

Light Higgs case – Best fit for LHC rates

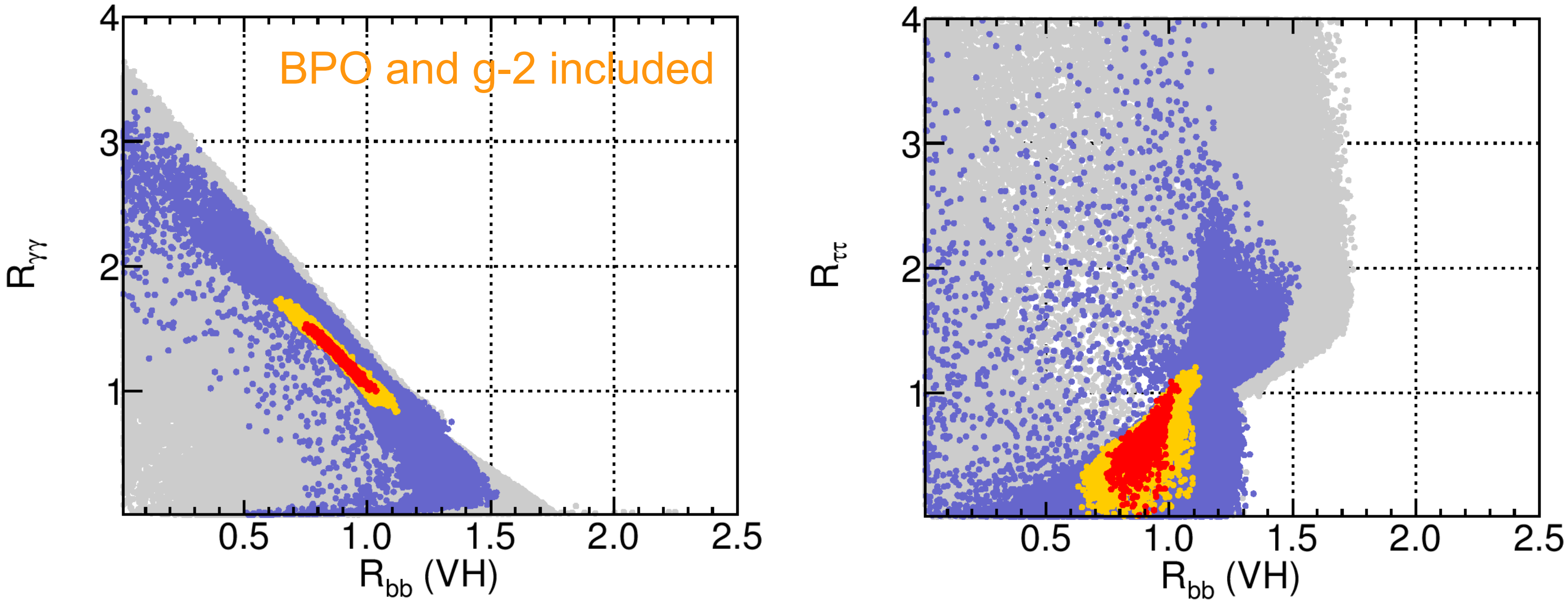


Modified decay rates

- Which regions describe data best?

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

- All points $121 < M_h < 129$ GeV
- HiggsBounds allowed
- $\Delta\chi^2 < 2.30$
- $\Delta\chi^2 < 5.99$

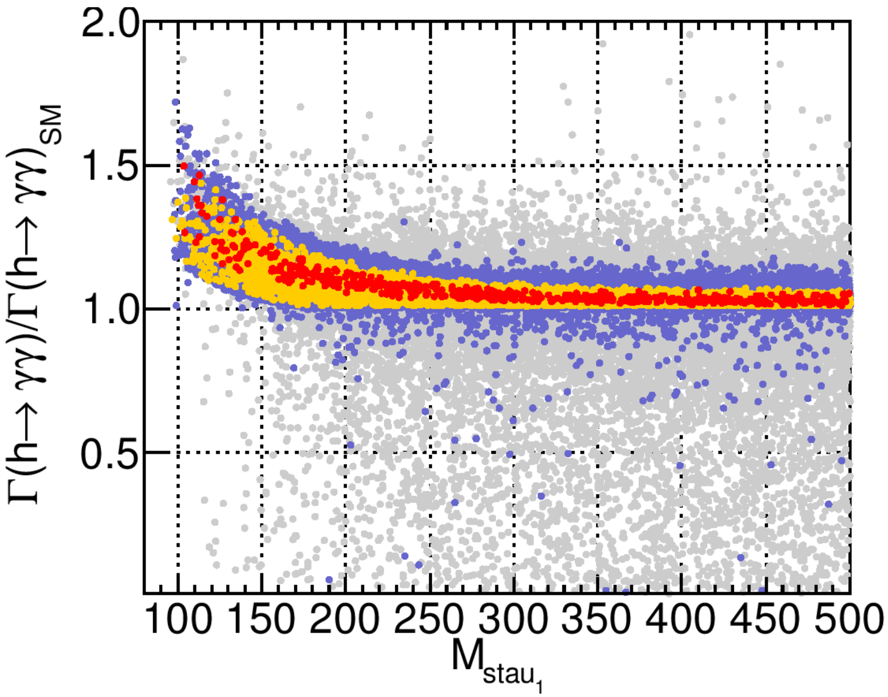


- Favored region in the MSSM: Enhanced $\gamma\gamma$ rate, suppressed bb and $\tau\tau$ rates
- Favored region might change when Tevatron data included

Enhancing the γγ 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 $\Gamma(h \to \gamma\gamma)$

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

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

Enhancing the γγ rate in the MSSM

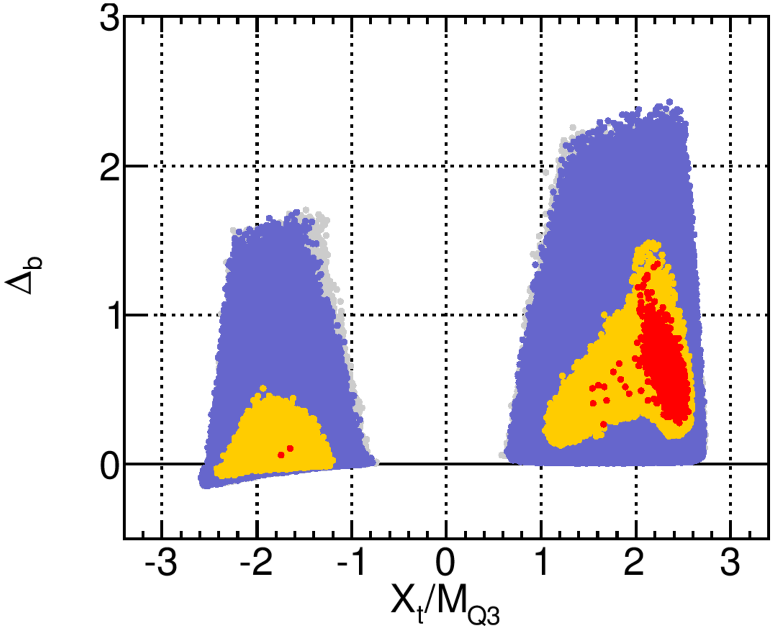
2. Suppression of the total width

- Suppression of dominant decay mode h → bb
- Reduced hbb coupling in the MSSM

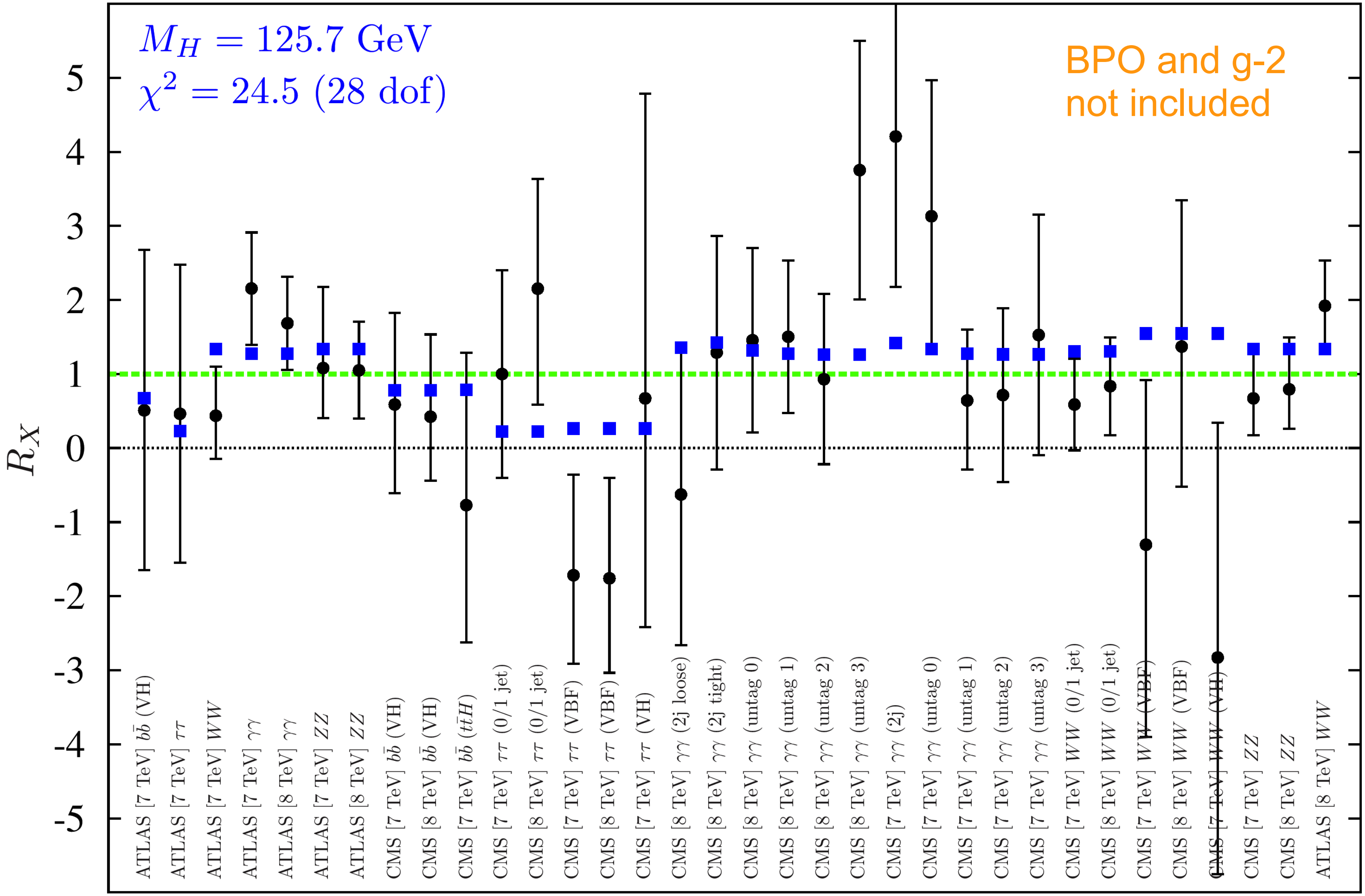
$$\frac{g_{hb\bar{b}}}{g_{H_{\rm SM}b\bar{b}}} = \frac{1}{1+\Delta_b}\left(-\frac{\sin\alpha_{\rm eff}}{\cos\beta} + \Delta_b\frac{\cos\alpha_{\rm eff}}{\sin\beta}\right).$$

Loop-induced SUSY correction

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



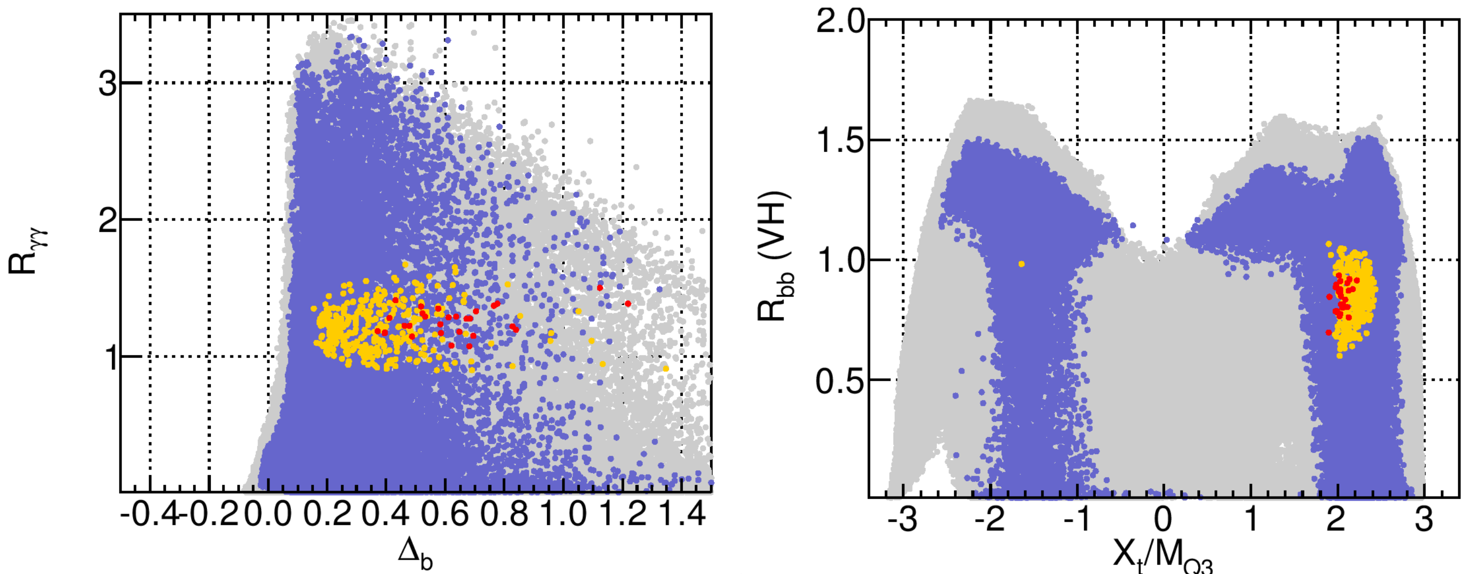
Heavy Higgs case – Best fit for LHC rates



Heavy Higgs case

- Allowed region in parameter space limited
  - Relatively low M_A

    $\rightarrow$ Other MSSM 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
- Best fit decay rates similar to the light Higgs case



Higgs sector in the NMSSM

- Motivation for NMSSM:
  Solved 'μ-problem' of the MSSM

$$W_{(2)} = \mu \hat{H}_2 \hat{H}_1 \to \lambda \hat{S} \hat{H}_2 \hat{H}_1$$

$\to$ $\mu_{\text{eff}} = \lambda v_s$ naturally of the EW scale

- Additional Higgs singlet

$$S = v_s + \frac{1}{\sqrt{2}} \left(\phi_s + \mathrm{i}\chi_s \right).$$

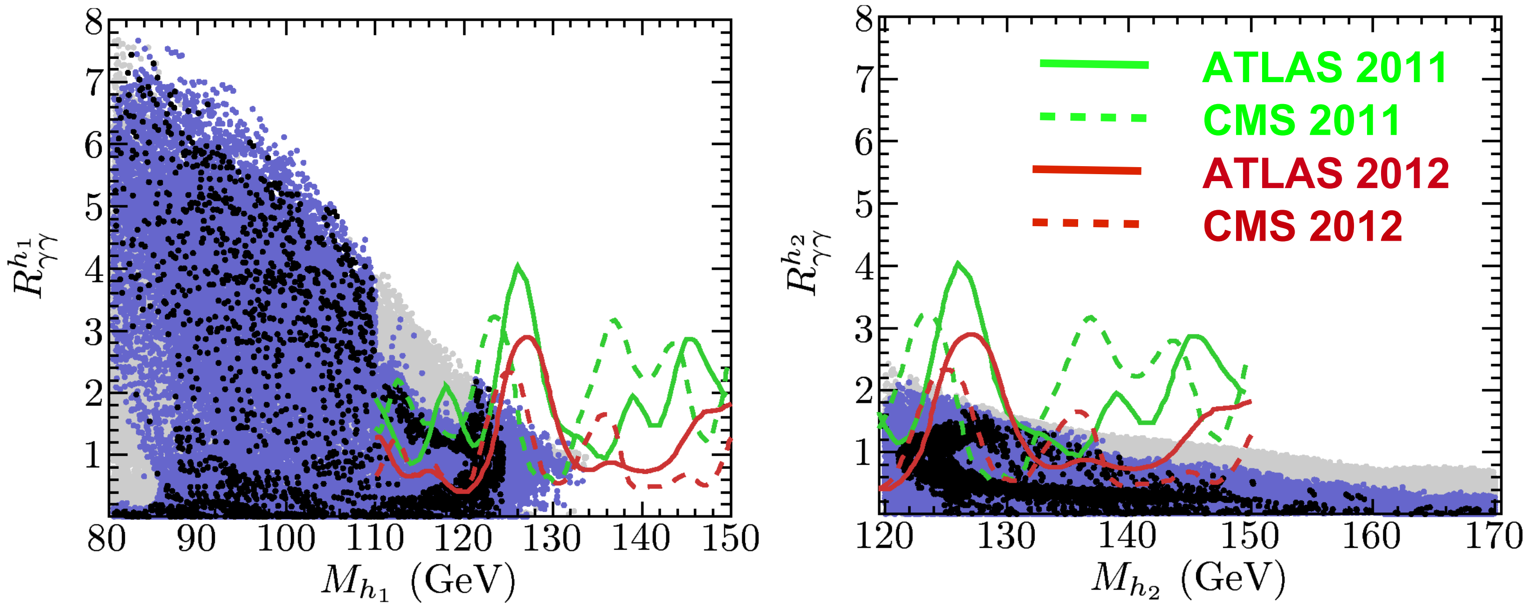
- Extended Higgs sector $\to$ 7 physical Higgs bosons

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = U^H \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_s \end{pmatrix}, \quad \begin{pmatrix} a_1 \\ a_2 \\ G \end{pmatrix} = U^A \begin{pmatrix} \chi_1 \\ \chi_2 \\ \chi_s \end{pmatrix}, \quad \begin{pmatrix} H^\pm \\ G^\pm \end{pmatrix} = U^C \begin{pmatrix} \phi_1^\pm \\ \phi_2^\pm \end{pmatrix}$$

In the NMSSM the Higgs signal at 126 GeV can be the lightest (h_1) or the second lightest (h_2) CP-even Higgs

NMSSM Higgs with enhanced γγ rate

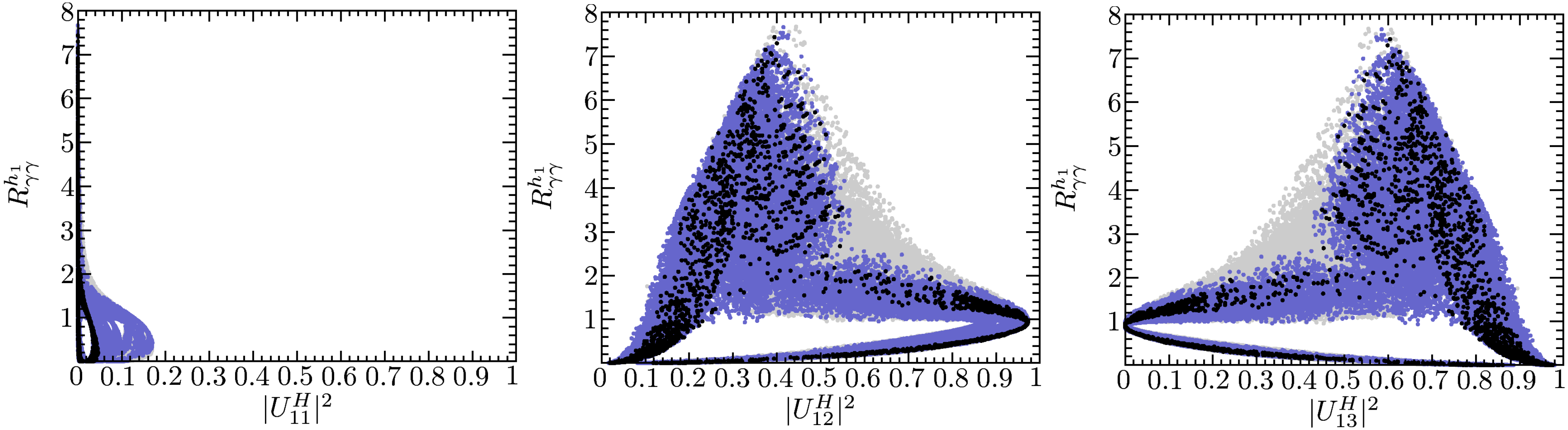
- Scan over the NMSSM parameter space
- $R_{\gamma\gamma}$ calculated with **`FeynArts/FormCalc`**
  (Effective coupling approximation of gluon fusion)



Gray: All points
Blue: Direct Higgs searches (2011) ok
Black points: Direct Higgs searches (2011) +flavour +(g - 2) ok

- In the NMSSM for both h_1 and h_2 interpretations:
  Enhancement of di-photon rate possible

Mechanism to enhance the γγ rate in the NMSSM



H_1 component of h_1 — H_2 component of h_1 — S component of h_1

- Reduced h_1bb coupling in the NMSSM $\propto U^H_{11}$
- $R_{\gamma\gamma}$ enhanced by a strong suppression of $h \to bb$ via doublet – singlet mixing
- Requires large sizable singlet component
  $\rightarrow$ Genuine feature of the NMSSM

U. Ellwanger,[1012.1201], [1112.3548]

Conclusions

- Signal in the two photon channel higher than SM prediction

MSSM

- Fitting the MSSM to experimental rates
- Both h and H at 126 GeV interpretations viable
- Fit prefers enhanced $h \to \gamma\gamma$, suppressed $h \to bb$ rate

NMSSM

- Higgs at 126 GeV can be interpreted as h_1 or h_2
- Additional mechanism to enhance di-photon rate

  $\to$ Suppression of $h \to bb$ via doublet-singlet mixing

Thank you!

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	Experiment	SM prediction	Total unc. used
$\mathrm{BR}(B\to X_s\gamma)_{E_0>1.6\,\mathrm{GeV}}$	$(3.55\pm0.24\pm0.09)\times10^{-4}$	$(3.08\pm0.24)\times10^{-4}$	0.7×10^{-4}
$\mathrm{BR}(B_s\to\mu^+\mu^-)$	$<4.5\times10^{-9}$ (95% CL)	$3.5\pm0.4\times10^{-9}$	0.5×10^{-9}
$\mathrm{BR}(B\to\tau^+\nu_\tau)$	$(1.64\pm0.34)\times10^{-4}$	$(1.01\pm0.29)\times10^{-4}$	0.45×10^{-4}
δa_μ	$(30.2\pm8.8)\times10^{-10}$	0	9×10^{-10}

Parameter ranges for NMSSM scan

Parameter	Minimum	Maximum	
$A_t = A_b = A_\tau$	$-2\,400$	$2\,400$	GeV
μ_{eff}	150	250	GeV
$M_{H^\pm}$	500	$1\,000$	GeV
$\tan\beta$	2.6	6	
λ	0.5	0.7	
K	0.3	0.5	
A_κ	-100	-5	GeV

Fixed parameters:

$$M_{\text{SUSY}} = 1000 \text{ GeV}$$
$$M_L = M_E = 250 \text{ GeV}$$
$$M_2 = 400 \text{ GeV}$$
$$M_1 \approx M_2/2$$
$$m_{\tilde{g}} = 1200 \text{ GeV}$$

Calculation of Rγγ in the NMSSM

- Production cross section approximated by gluon fusion
- Approximation $\sigma(gg \to h)$ by $\Gamma(h \to gg)$
  - Couplings the same, difference in kinematics neglected
- Total width:

$$\Gamma_{\text{tot}} = \frac{1}{m_h} \text{Im}\left[\Sigma(m_h^2)\right] + \Gamma(h \to WW^*) + \Gamma(h \to \gamma\gamma) + \Gamma(h \to gg)$$

Summary of fits

	Only LHC data				LHC + BPO + $(g\text{-}2)_\mu$			
Case	min χ^2	dof	χ^2/dof	p	min χ^2_{tot}	dof	$\chi^2_{\text{tot}}/\text{dof}$	p
SM	27.6	34	0.811	0.77	42.3	38	1.11	0.29
MSSM-h	23.2	28	0.828	0.72	28.3	32	0.886	0.65
MSSM-H	24.5	28	0.874	0.65	31.0	32	0.969	0.52

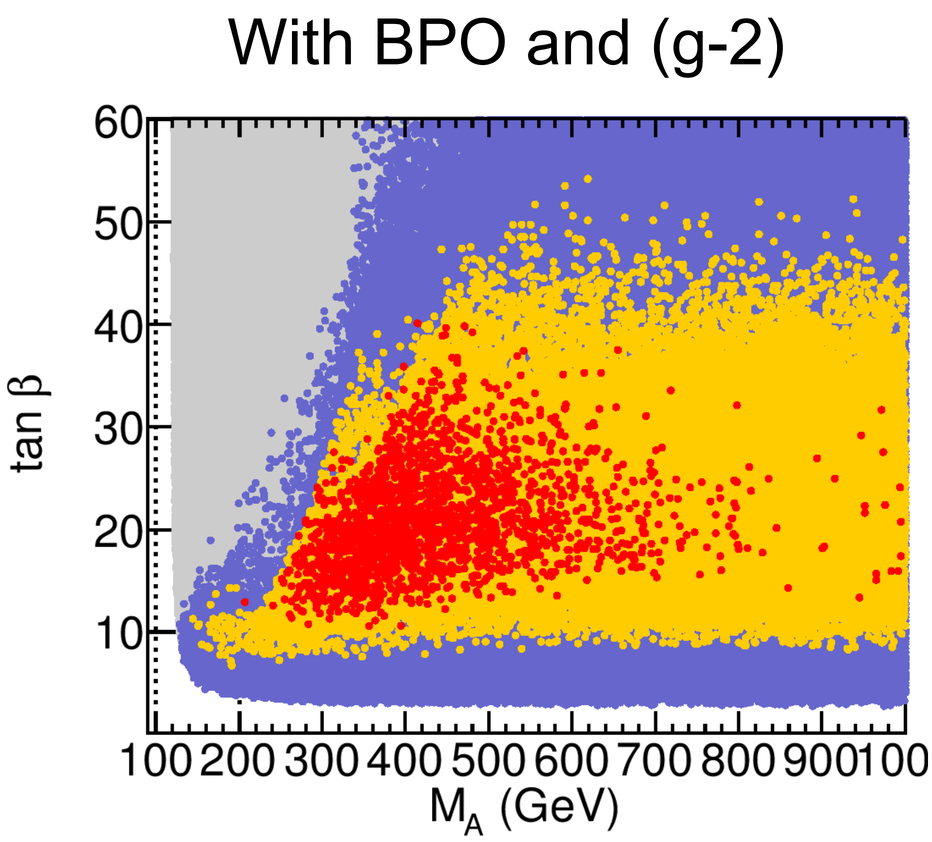
$$\text{dof} = N_{\text{obs}} - N_{\text{para}}$$

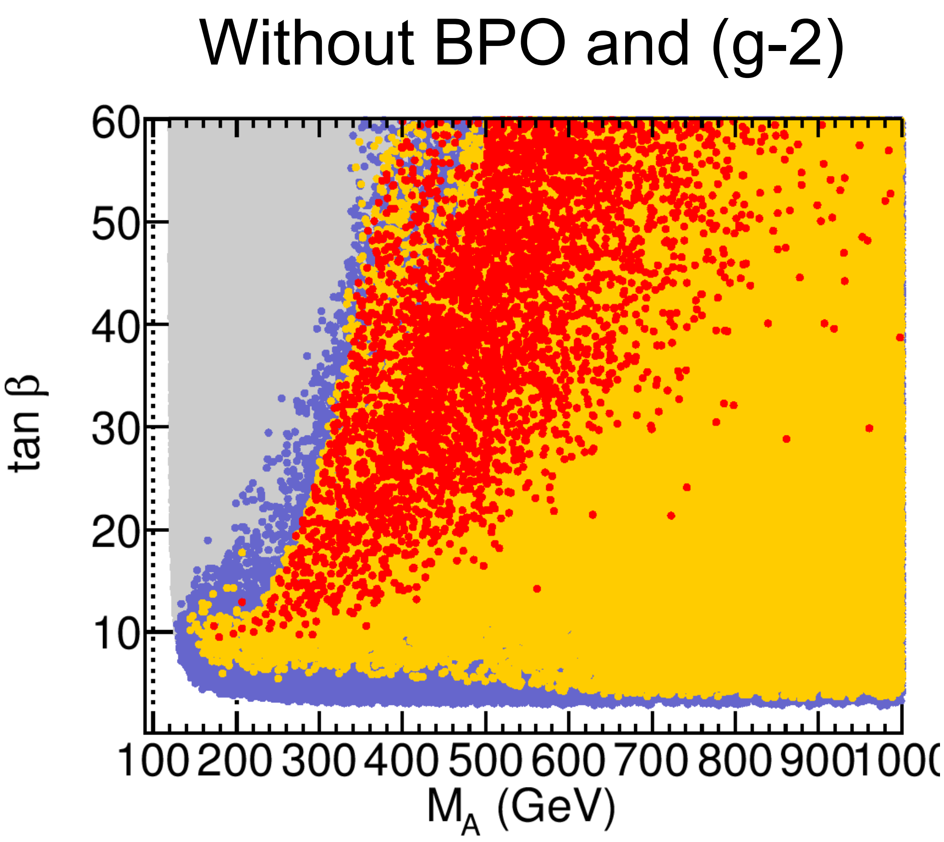
SM fit worse if (g-2) included
(3σ deviation)

- Fits in good shape for SM and MSSM (both interpretations)
- No model preferred over the others

MSSM light Higgs case

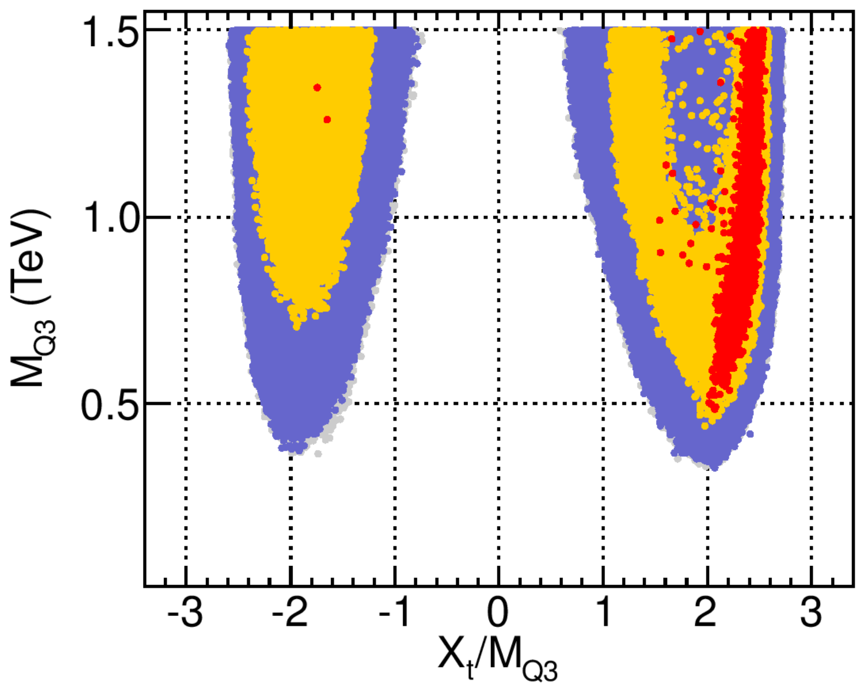
Favored region in the MA – tanβ plane:

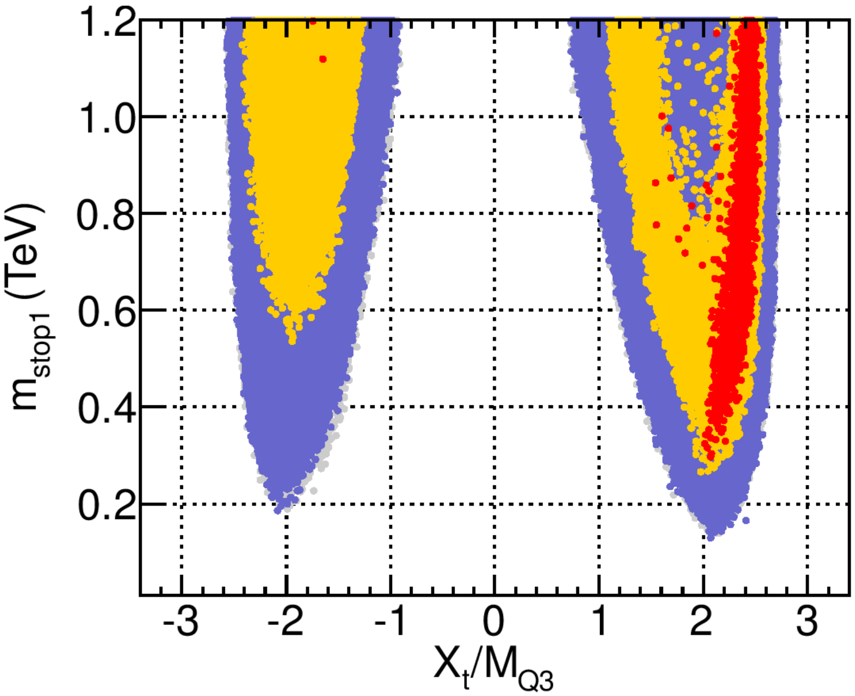




MSSM light Higgs case

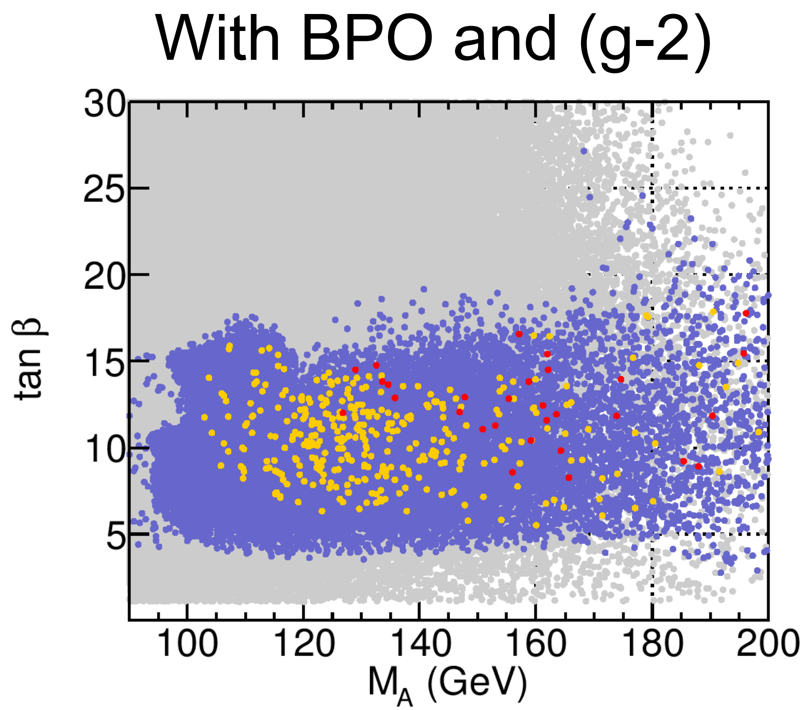
Favored stop mixing, stop masses

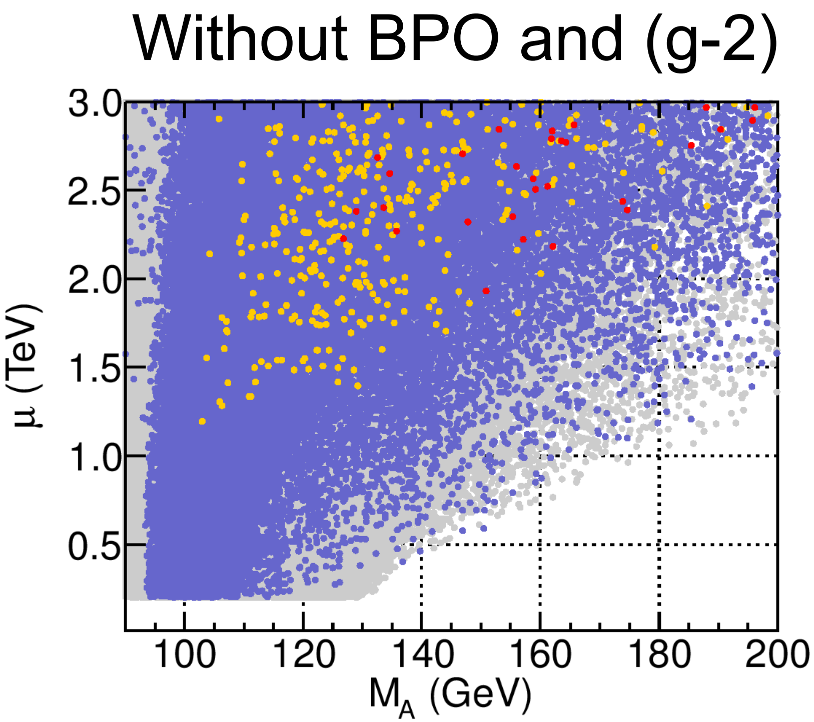




MSSM heavy Higgs case

Favored region in the MA – tanβ plane:



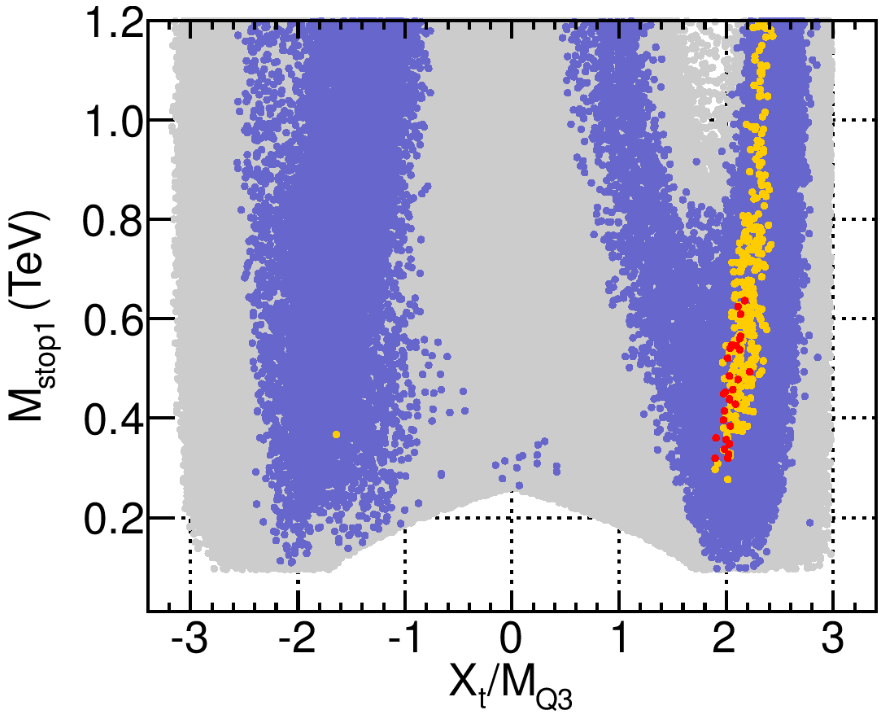


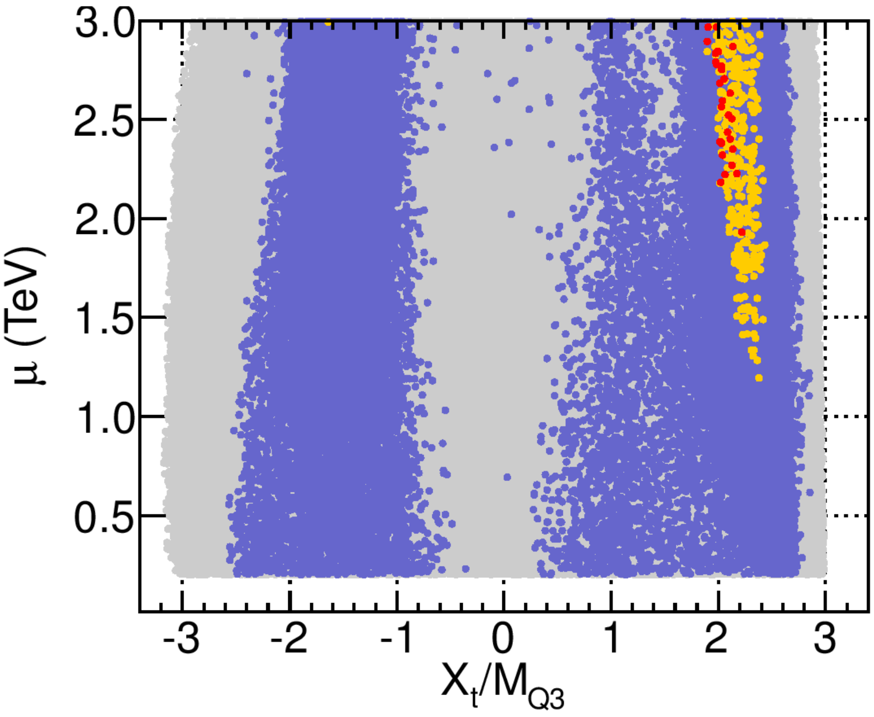
Allowed range for MA unexpectedly large (for large μ)

Higgs mass prediction stable?

MSSM heavy Higgs case

Favored stop mixing, stop masses





Example points

Parameter	$M_h \sim 126$ GeV	$M_H \sim 126$ GeV
M_A (GeV)	277.0	107.3
$\tan\beta$	17.49	15.88
M_{Q_3} (GeV)	567.46	738.79
A_t (GeV)	1344.	1733.
μ (GeV)	2400.	1411.
M_{L_3} (GeV)	1239.	953.6
M_2 (GeV)	459.5	245.9
Calculated		
M_h (GeV)	125.8	86.4
M_H (GeV)	235.7	125.4
M_A (GeV)	277.0	107.3
$M_{H^\pm}$ (GeV)	280.0	130.5