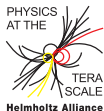


# Constrained SUSY after the Higgs Discovery: A Global View with Fittino



Tim Stefaniak<sup>1</sup>

in collaboration with



P. Bechtle, K. Desch, H. Dreiner, M. Hamer, M. Krämer, B. O'Leary,  
W. Porod, X. Prudent, B. Sarrazin, M. Uhlenbrock, P. Wienemann

<sup>1</sup>Physics Institute and Bethe Center for Theoretical Physics, Bonn University



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Bonn-Cologne Graduate School  
of Physics and Astronomy



# Global fits of supersymmetry

The SUSY parameter space is **strongly constrained** by

- indirect effects on SM observables:

$\text{BR}(b \rightarrow s\gamma)$ ,  $\text{BR}(B_s \rightarrow \mu\mu)$ ,  $\text{BR}(b \rightarrow \tau\nu)$ ,  $\Delta m_{B_s}$ ,  $(g-2)_\mu$ ,  $m_W$ ,  $\sin^2 \theta_{\text{eff}}$

- astrophysical observations:

$\Omega_{\text{DM}}$ , direct and indirect DM detection limits

- direct sparticle and Higgs boson search limits from colliders:

in particular LHC limits from jets +  $E_T^{\text{miss}}$  searches

- the LHC Higgs signal

**Global SUSY fits** are addressing the following questions:

- What is the **most probable SUSY model parameter space** including all available and relevant observables/constraints?
- To what extent are the **observations / constraints in mutual agreement?**

[see e.g. Mastercode (arXiv:1207.7315), BayesFITS (arXiv:1206.0264), Fittino (arXiv:1204.4199)]

# The Fittino SUSY fits

- Consider constrained SUSY models, *here*: **CMSSM**
- For the evaluation of the model predictions we use
  - ▶ the SUSY spectrum generators **SPheno** and **SoftSUSY**;
  - ▶ **FeynHiggs** for Higgs masses and couplings,  $(g - 2)_\mu$ ;
  - ▶ **SuperISO** for  $B$ -physics observables;
  - ▶ **MicrOMEGAs** for dark matter relic density;
  - ▶ **AstroFit** and **DarkSUSY** for direct and indirect detection limits;
  - ▶ **HiggsBounds** and **HiggsSignals** for the Higgs limits and signal.
- Calculate and minimize

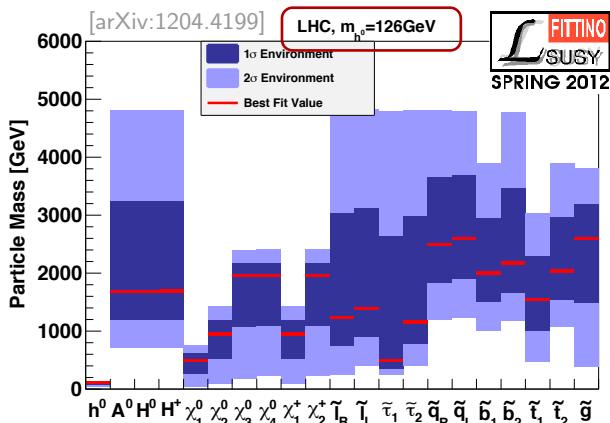
$$\chi^2 = (\vec{O}_{\text{obs}} - \vec{O}_{\text{pred}}(\vec{P}))^T \text{COV}^{-1} (\vec{O}_{\text{obs}} - \vec{O}_{\text{pred}}(\vec{P}))$$

for each point  $\vec{P}$  in the SUSY parameter space.

- Perform sampling with an **auto-adaptive Markov Chain Monte Carlo**.

# The Fittino CMSSM fit as of spring 2012 predicted

- particles and  $H, A, H^\pm$  most likely beyond current LHC reach:



# The Fittino CMSSM fit as of spring 2012 predicted

- sparticles and  $H$ ,  $A$ ,  $H^\pm$  most likely beyond current LHC reach. ✓
- branching ratios of the light Higgs  $h$  similar as in SM. ✓
- branching ratio  $B_s \rightarrow \mu\mu$  close to the SM prediction. ✓
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*In summary the picture in the CMSSM is:*

- The CMSSM looks like the **SM with dark matter**.
- **Grim prospects for LHC phenomenology**  
(both for sparticle and heavy/charged Higgs searches).

⇒ Can we test the CMSSM through the properties of  $h$ ?

# What is new in the Fittino CMSSM fit for summer 2013?

- updated observables:

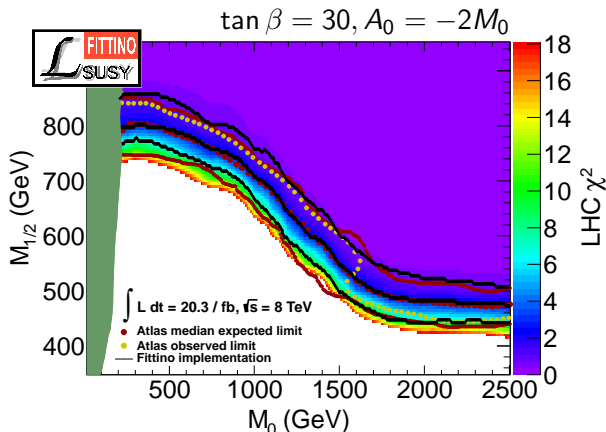
$\text{BR}(b \rightarrow s\gamma)$	$(3.43 \pm 0.21 \pm 0.07 \pm 0.23) \cdot 10^{-4}$	
$\text{BR}(B_s \rightarrow \mu\mu)$	$(\mathbf{3.20} \pm \mathbf{1.50} \pm \mathbf{0.76}) \cdot 10^{-9}$	LHCb '12
$\text{BR}(B \rightarrow \tau\nu)$	$(\mathbf{0.72} \pm \mathbf{0.27} \pm \mathbf{0.11} \pm \mathbf{0.07}) \cdot 10^{-4}$	Belle '12
$\Delta m_{B_s}$	$(17.719 \pm 0.043 \pm 4.200) \text{ ps}^{-1}$	
$(a_\mu - a_\mu^{\text{SM}})$	$(28.7 \pm 8.0 \pm 2.0) \cdot 10^{-10}$	
$m_W$	$(80.385 \pm 0.015 \pm 0.010) \text{ GeV}$	
$\sin^2 \theta_{\text{eff}}$	$0.23113 \pm 0.00021$	
$\Omega_{\text{CDM}} h^2$	$\mathbf{0.1187} \pm \mathbf{0.0017} \pm \mathbf{0.0119}$	Planck '13
$m_{\text{top}}$	$(173.18 \pm 0.94) \text{ GeV}$	

# What is new in the Fittino CMSSM fit for summer 2013?

- LHC implementation refined and updated to  $20.3 \text{ fb}^{-1}$

[Herwig++, Delphes, Prospino]

[ATLAS-CONF-2013-047]





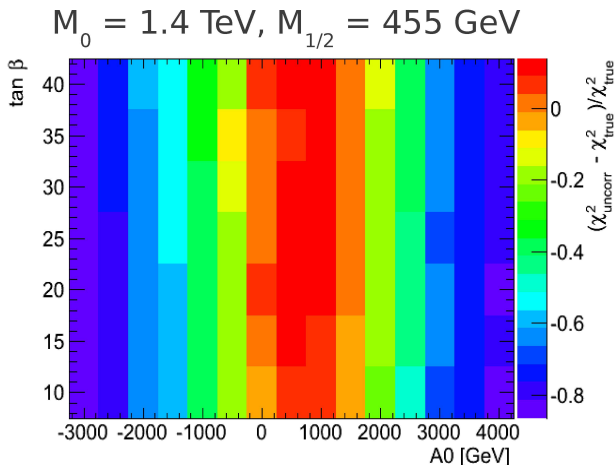
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⇒ Additional acceptance grid in  $A_0 - \tan \beta$  needed due to  $\tilde{t}_1 \tilde{t}_1$  contribution.

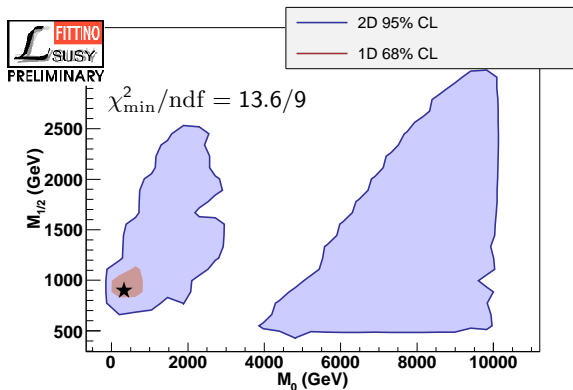


# What is new in the Fittino CMSSM fit for summer 2013?

- Include Higgs mass and rate measurements via HiggsSignals.  
[Bechtle, Heinemeyer, Stål, TS, Weiglein, 1305.1933] (→ see O. Stål's talk today)  
<http://higgsbounds.hepforge.org>
  - ▶ Combine latest results from ATLAS, CMS and Tevatron.
    - 4 mass measurements (ATLAS & CMS,  $H \rightarrow ZZ^{(*)}, \gamma\gamma$ ),
    - 47 signal strength measurements.
  - ▶ Treat theory uncertainties for cross sections, branching ratios and the Higgs mass as fully correlated Gaussian errors.
  - ▶ Assume a theoretical Higgs mass uncertainty of 3 GeV.

# Preferred parameter space

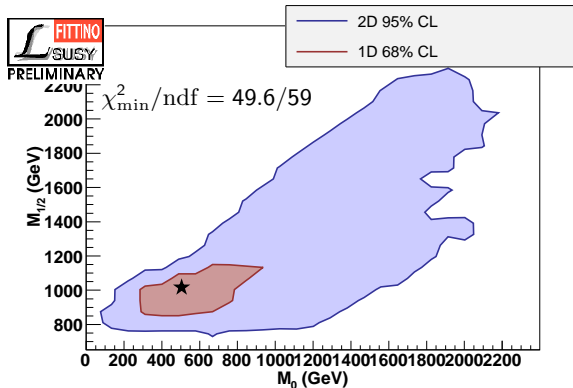
... with  $m_H = (125.5 \pm 2 \pm 3)$  GeV but **without signal strength**:



- focus-point region allowed at  $2\sigma$  level.
- tension: (LHC limit and  $m_H$ ) vs. ( $a_\mu$  and  $\text{BR}(b \rightarrow s\gamma)$ ).

# Preferred parameter space

...with mass and signal strengths measurements via HiggsSignals:

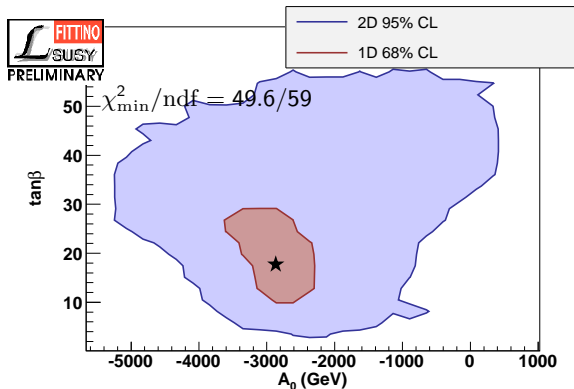


→ focus-point region disfavored.

→ overall fit quality improves.

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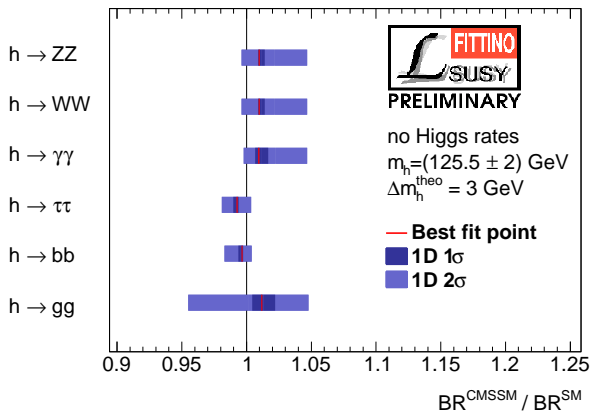


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# Preferred Higgs boson branching ratios

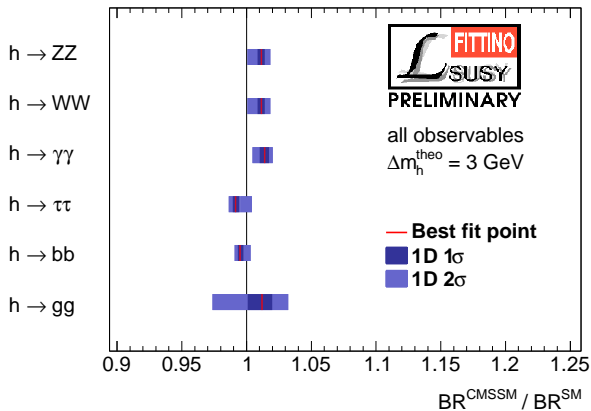
... with  $m_H = (125.5 \pm 2 \pm 3)$  GeV but **without signal strength**:



$\Rightarrow$  SM-like Higgs, small deviations allowed from  $BR_{SM} \lesssim 5\%$ .

# Preferred Higgs boson branching ratios

...with mass and signal strengths measurements via HiggsSignals:



$\Rightarrow$  SM-like Higgs, small deviations allowed from  $BR_{SM} \lesssim 2 - 3\%$ .

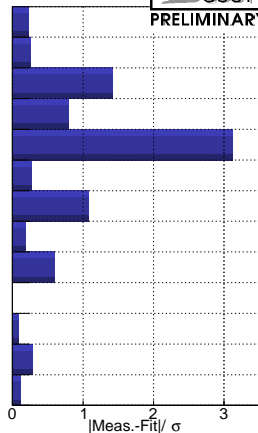
# Agreement of observations with model predictions

$M_0=504\text{GeV}$ ,  $M_{1/2}=1016\text{GeV}$ ,  $A_0=-2870\text{GeV}$ ,  $m_t=174\text{GeV}$ ,  $\tan\beta=18$



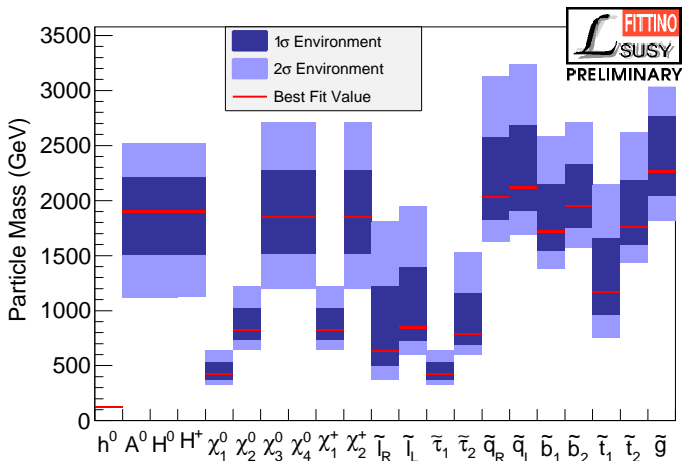
PRELIMINARY

$\text{BR}(B_s \rightarrow \mu^+ \mu^-) / 10^{-9}$	$3.20 \pm 1.50 \pm 0.76$	3.59
$\text{BR}(b \rightarrow \tau \nu) / 10^{-4}$	$0.72 \pm 0.27 \pm 0.11 \pm 0.07$	0.80
$\text{BR}(b \rightarrow s \gamma) / 10^{-4}$	$3.43 \pm 0.21 \pm 0.07 \pm 0.23$	2.97
$\Delta m_s / \text{ps}^{-1}$	$17.719 \pm 0.043 \pm 4.200$	21.058
$(a_\mu - a_\mu^{\text{SM}}) / 10^{-10}$	$28.7 \pm 8.0 \pm 2.0$	2.9
$m_W / \text{GeV}$	$80.385 \pm 0.015 \pm 0.010$	80.390
$\sin^2 \theta_{\text{eff}}^l$	$0.23113 \pm 0.00021$	0.23136
$\Omega_{\text{CDM}} h^2$	$0.1187 \pm 0.0017 \pm 0.0119$	0.1165
$m_t$	$173.18 \pm 0.94$	173.74
$\sigma^{\text{SI}} / \text{pb}$		1.3e-11
LHC		
$m_h / \text{GeV}$		125.2
$\mu_h$		





# Preferred Higgs and sparticle mass spectrum



# Summary and Outlook

## We have fitted the CMSSM including

- updated low energy observables,
- refined and updated LHC limits from full hadronic SUSY search,
- Higgs mass and rate measurements (via [HiggsSignals](#)).

⇒ We find that the CMSSM is not dead, but pretty dull.

- Fit quality improved with inclusion of (SM-like) Higgs rates.
- Resolving the possible small deviations in Higgs rates will be tough:  
⇒ need precise Higgs measurements and theory predictions!

## Outlook:

- Calculate  $\mathcal{P}$ -values with fits to pseudo-measurements (“Toys”).
- Future fits should address [more general models](#), in particular with [different connection between colored and uncolored sparticles](#).
- Then, other LHC sparticle searches become relevant (→ simplified models).

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Thanks for you attention!

# Backup slides

# HiggsSignals: Implemented observables

