CMSSM and NUHM Analysis by BayesFITS

Leszek Roszkowski*

National Centre for Nuclear Research (NCBJ)
Warsaw, Poland

BayesFITS group: A. Fowlie (UoS), M. Kazana, K. Kowalska, K. Nawrocki, L. Roszkowski, E. Sessolo, Y.-L. S. Tsai, ….

*On leave of absence from
University of Sheffield

Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund

Outline

- Statistical approach
- Bayesian posterior
- LHC SUSY limits: derive likelihood maps for alphaT (1.1/fb) and razor (4.4/fb)
- Impact of possible m_h~125 GeV
- CMSSM – results
- NUHM – results
- Summary

Based on:
- **Fowlie, Kalinowski, Kazana, Roszkowski, Tsai (arXiv:1111.6098 -> PRD)**
- **Roszkowski, Sessolo, Tsai (arXiv:1202.1503)**
- **in preparation**

Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund

Statistical approach

Best way to go with so much data (sometimes mutually exclusive)

Central object: Likelihood function

For positive measurements:

Take a single observable $\xi(m)$ that has been measured (e.g., M_W)

- c – central value, σ – standard exptal error
- define

$$\chi^2 = \frac{[\xi(m)-c]^2}{\sigma^2}$$

- assuming Gaussian distribution ($d \to (c, \sigma)$):

$$\mathcal{L} = p(\sigma, c|\xi(m)) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{\chi^2}{2}\right]$$

- when include theoretical error estimate τ (assumed Gaussian):

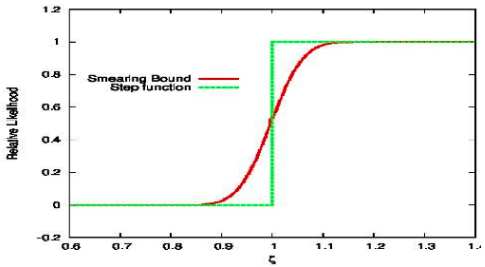
$$\sigma \to s = \sqrt{\sigma^2 + \tau^2}$$

TH error "smears out" the EXPTAL range

- for several uncorrelated observables (assumed Gaussian):

$$\mathcal{L} = \exp\left[-\sum_i \frac{\chi_i^2}{2}\right]$$

For limits:



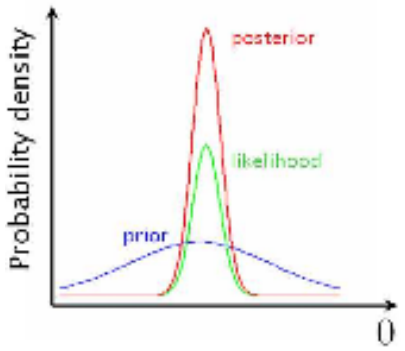
- Smear out bounds.
- Can add theory error.

Bayesian statistics

Bayes theorem: $$\text{Posterior} = \frac{\text{Prior} \times \text{Likelihood}}{\text{Evidence}}$$

- **Prior**: what we know about hypothesis BEFORE seeing the data.
- **Likelihood**: the probability of obtaining data if hypothesis is true.
- **Posterior**: the probability about hypothesis AFTER seeing the data.
- **Evidence**: normalization constant, crucial for model comparison.

If hypothesis is a function of parameters, then posterior becomes posterior probability function (pdf).



Reproducing alpha_T (1.1/fb) limit

Poisson distribution to characterize counting experiments. (arXiv:1111.6098)

$$\mathcal{L} = \prod_i \frac{e^{-(s_i+b_i)}\,(s_i+b_i)^{o_i}}{o_i!}$$

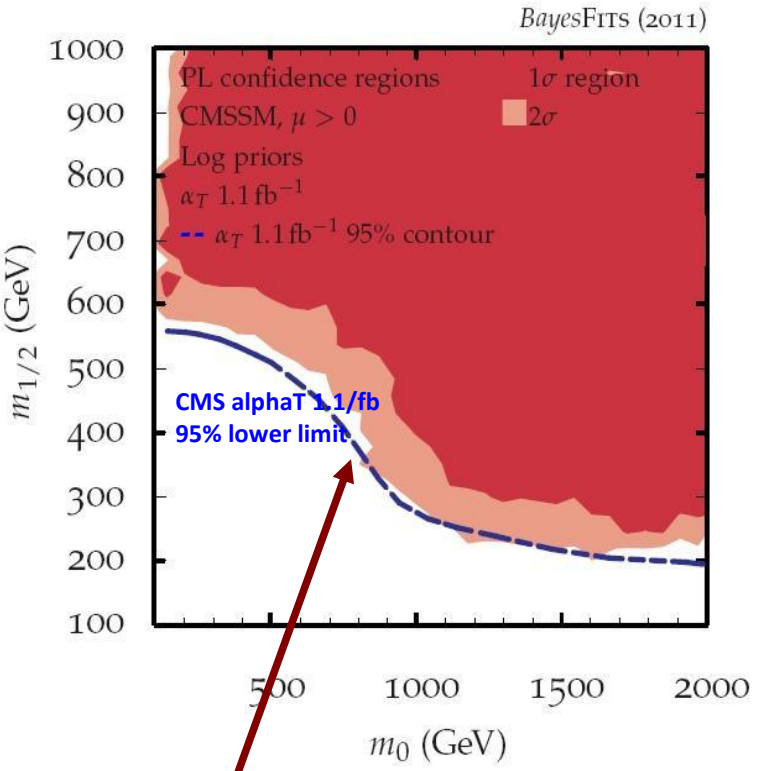
o_i : observed events in LHC.

b_i : expected SM background events.

s_i : $s_i = \epsilon_i \times \sigma \times \int L.$

ϵ_i : $N_i(\alpha_T > 0.55)/N_{\text{total}}$

$i = 1, 2, 3..., 8.$



- **SUSY events: generate MC simulations (50 GeV x 50 GeV grid, 5k events/point -> Pythia (LO) -> PGS4)**
- **Apply the same kinematical cuts as CMS.**
- **Obtain approximate efficiency and likelihood maps (combine 8 bins, rescale by ~2).**

VERY GOOD AGREEMENT WITH CMS 95% LIMIT!

CMSSM: global scan

- Perform random scan over 4 CMSSM +4 SM parameters **simultaneously**

- Use Nested Sampling algorithm to evaluate posterior

(arXiv:1111.6098)

- Very wide ranges:

$$100\,\mathrm{GeV} \leq m_0 \leq 4\,\mathrm{TeV}$$

$$100\,\mathrm{GeV} \leq m_{1/2} \leq 2\,\mathrm{TeV}$$

$$-2\,\mathrm{TeV} \leq A_0 \leq 2\,\mathrm{TeV}$$

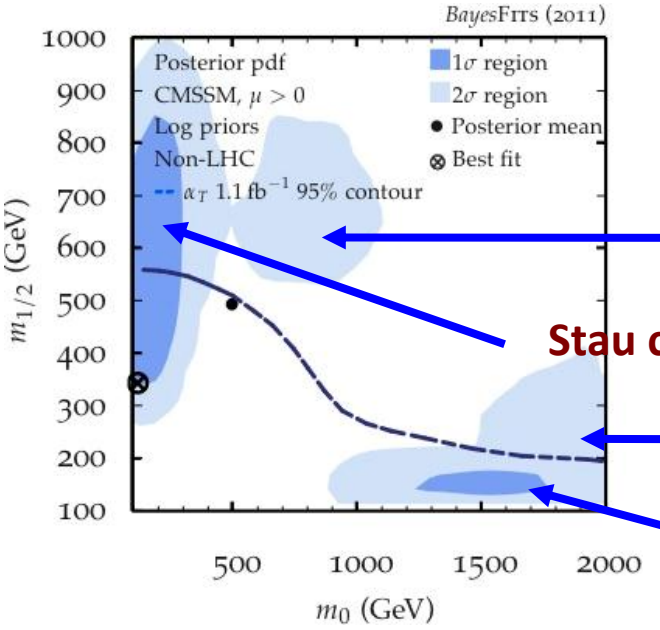
$$3 \leq \tan\beta \leq 62$$

Measurement	Mean	Exp. Error	The. Error	Likelihood Distribution
CMS α_T 1.1/fb analysis				
α_T	See text	See text	0	Poisson
XENON100				
$\sigma_p^{\mathrm{SI}}(m_\chi)$	$< f(m_\chi)$ – see text	0	1000%	Upper limit – Error Function
Non-LHC				
$\Omega_\chi h^2$	0.1120	0.0056	10%	Gaussian
$\sin^2\theta_{\mathrm{eff}}$	0.23116	0.00013	0.00015	Gaussian
M_W	80.399	0.023	0.015	Gaussian
$\delta(g-2)_\mu^{\mathrm{SUSY}}\times 10^{10}$	30.5	8.6	1.0	Gaussian
$\mathcal{BR}(\bar{B}\to X_s\gamma)\times 10^4$	3.60	0.23	0.21	Gaussian
$\mathcal{BR}(B_u\to\tau\nu)\times 10^4$	1.66	0.66	0.38	Gaussian
ΔM_{B_s}	17.77	0.12	2.40	Gaussian
$\mathcal{BR}(B_s\to\mu^+\mu^-)$	$< 1.5\times 10^{-8}$	0	14%	Upper limit – Error Function
Nuisance				
$1/\alpha_{\mathrm{em}}(M_Z)^{MS}$	127.916	0.015	0	Gaussian
m_t^{pole}	172.9	1.1	0	Gaussian
$m_b(m_b)^{\overline{MS}}$	4.19	0.12	0	Gaussian
$\alpha_s(M_Z)^{\overline{MS}}$	0.1184	0.0006	0	Gaussian
LEP and Tevatron – 95% Limits				

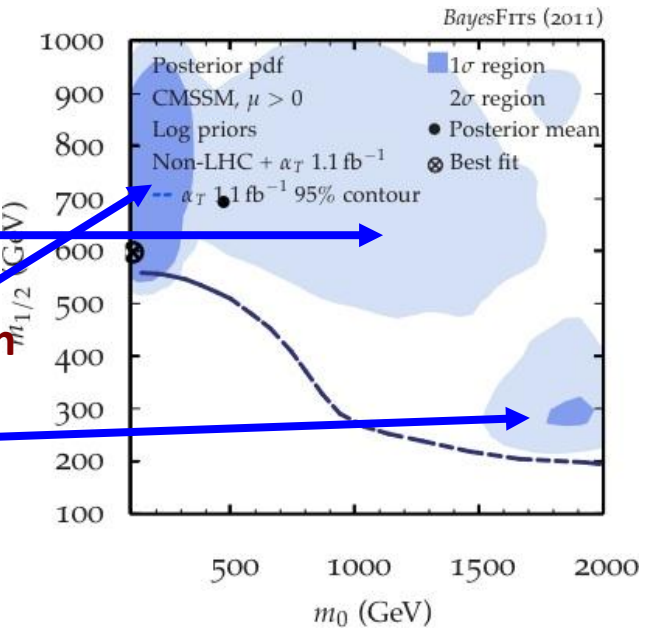
Impact of CMS alpha_T limit on CMSSM

(arXiv:1111.6098)

Before LHC (1/fb)



After LHC (1/fb)



A-funnel

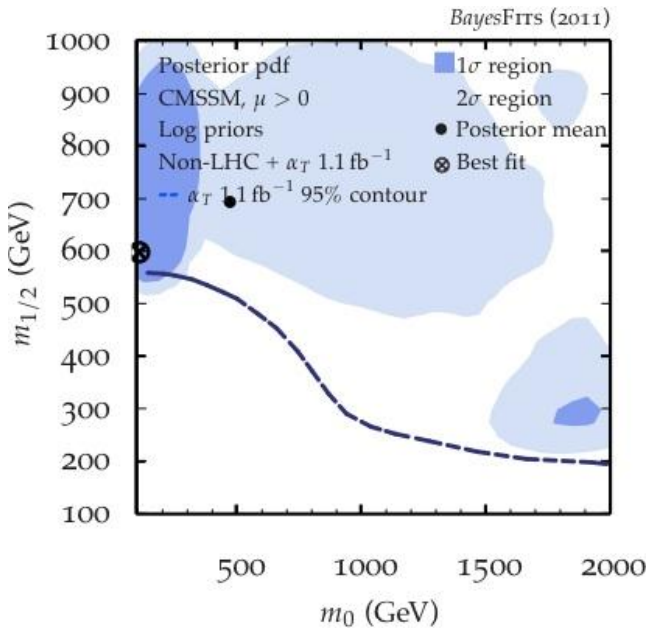
Stau coannihilation

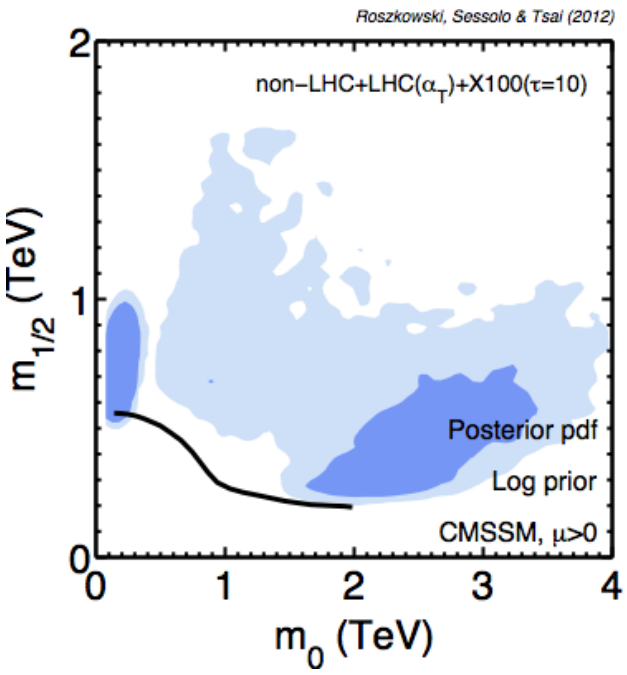
FP/HB

h-funnel

- **Favored (high posterior) regions (stau coan., A-funnel) are pushed up.**
- **Light Higgs funnel region is excluded.**
- **Focus point/horizontal branch region gets enhanced and pushed out.**
- **Best-fit point pushed up but remains in the stau coannihilation region, tanb(BF)~11 (but location of BF is very sensitive to input from bsgamma).**

CMSSM: extend mass range



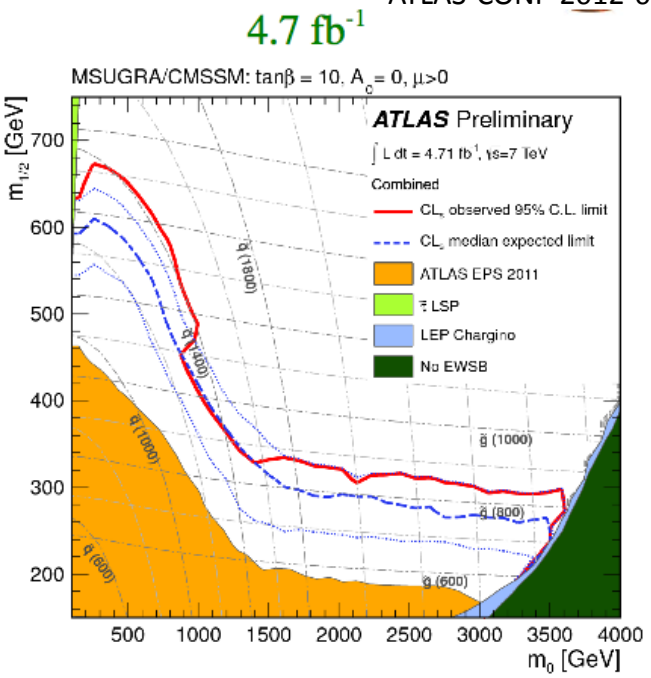


- **Increased importance of the FP/HB region.**
- **Somewhat decreased importance of A-funnel region.**

Current hadronic limits

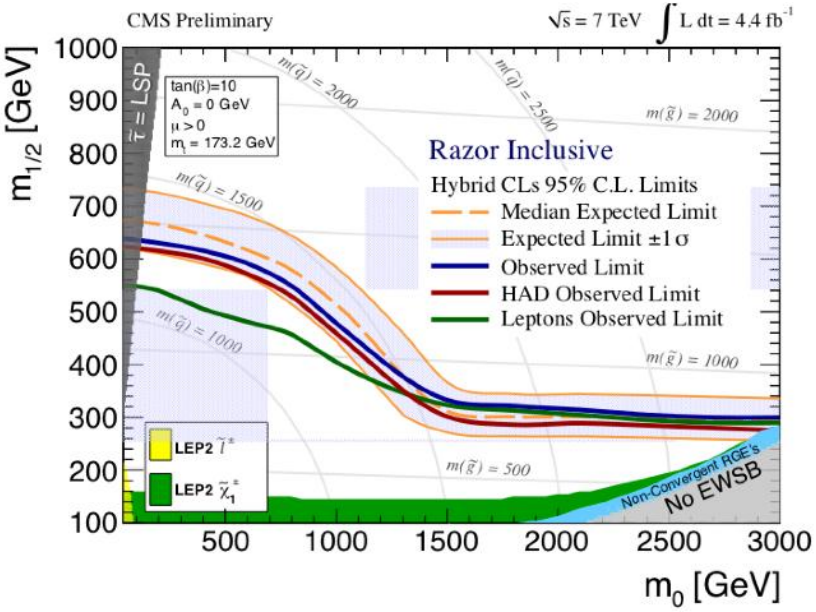
- ATLAS

ATLAS-CONF-2012-037



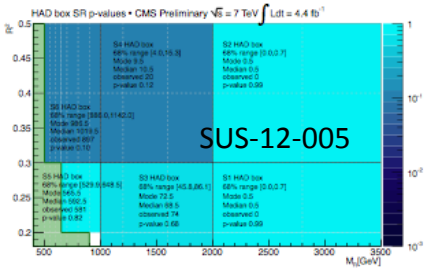
- CMS

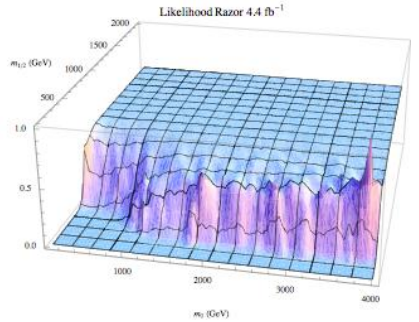
SUS-12-005



Reproducing Razor (4.4/fb) limit

Follow CMS analysis

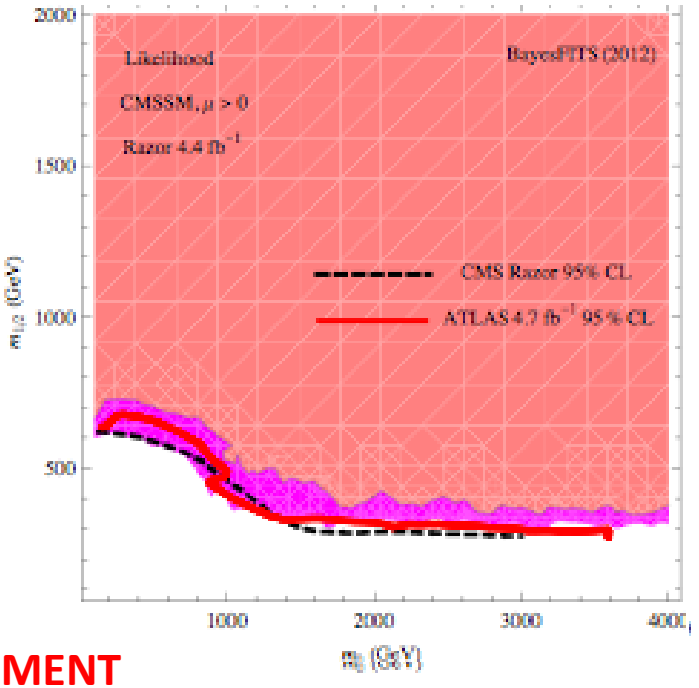




For each SUSY point:

- simulated mass spectrum
- 10k events with reconstructed variables
- Consider 6 bins in R^2 and M_R
- Efficiency after final cuts
- Compute likelihood function
- Need to rescale by ~7 (for 6 bins)

(Previously we could ``reproduce'' 1.1/fb razor limit with scale factor of ~2)

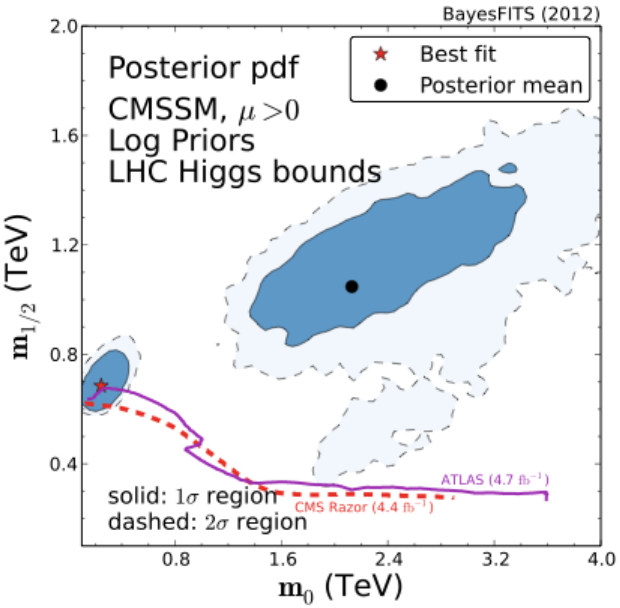


VERY GOOD AGREEMENT

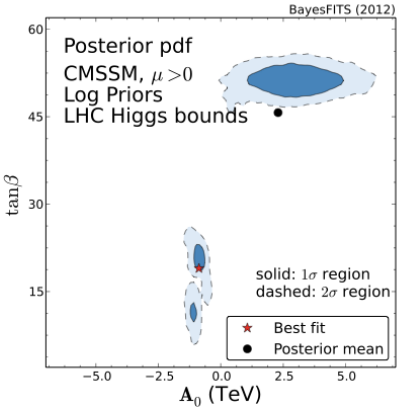
Impact of Razor(4.4/fb) limit on CMSSM

Extend range: $-7\,\mathrm{TeV} \leq A_0 \leq 7\,\mathrm{TeV}$

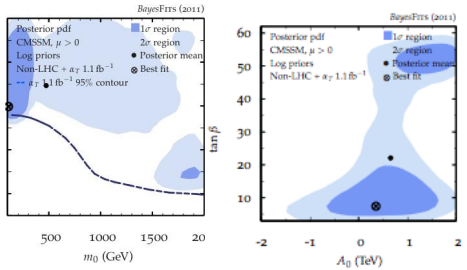
Measurement	Mean or Range	Exp. Error	Th. Error	Likelihood Distribution
CMS Razor 4.4/fb analysis	See text	See text	0	Poisson
SM-like Higgs mass m_h	117.5 – 118.5 and 122.5-129	0	2	Lower/Upper limit – Error Fn
	114.4 – 127.5	0	2	Lower/Upper limit – Error Fn
	> 114.4	0	2	Lower limit – Error Fn
ζ_h^2	$< f(m_h)$	0	0	Upper limit – Step Fn
$\Omega_\chi h^2$	0.1120	0.0056	10%	Gaussian
$\sin\theta_{\rm eff}$	0.23116	0.00013	0.00015	Gaussian
m_W	80.399	0.023	0.015	Gaussian
$\Delta(g-2)_\mu^{\rm SUSY}\times10^{10}$	30.5	8.6	1.0	Gaussian
$\mathrm{BR}(\overline{B}\to X_s\gamma)\times10^4$	3.60	0.23	0.21	Gaussian
$\mathrm{BR}(B_u\to\tau\nu)\times10^4$	1.66	0.66	0.38	Gaussian
ΔM_{B_s}	17.77	0.12	2.40	Gaussian
$\mathrm{BR}(\overline{B}_s\to\mu^+\mu^-)$	$< 4.5\times10^{-9}$	0	14%	Upper limit – Error Fn



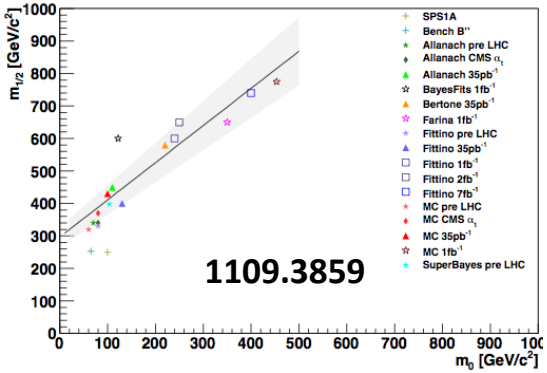
plus LHC higgs bounds and $\mathrm{BR}(\overline{B}_s \to \mu^+\mu^-) < 4.5\times10^{-9}$



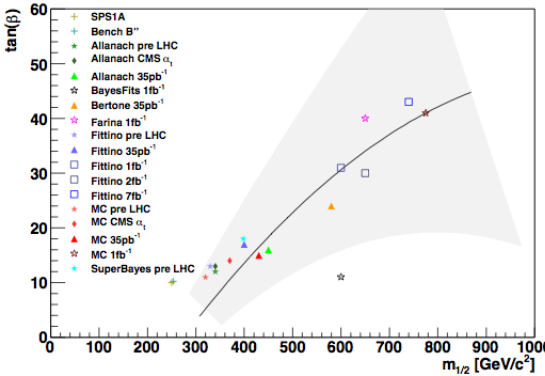
Compare:
impact of alphaT (1/fb)
(arXiv:1111.6098)



- **FP/HB is now much larger**
- **A-funnel region suppressed**
- **Stau coann. region: still best fit**
- **tanbeta(BF point)~21**



1109.3859



Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund

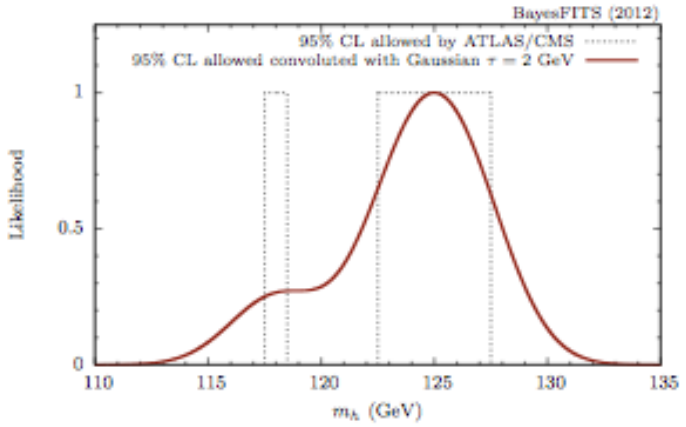
…and IF mh~125 GeV?

- Currently allowed (95%)

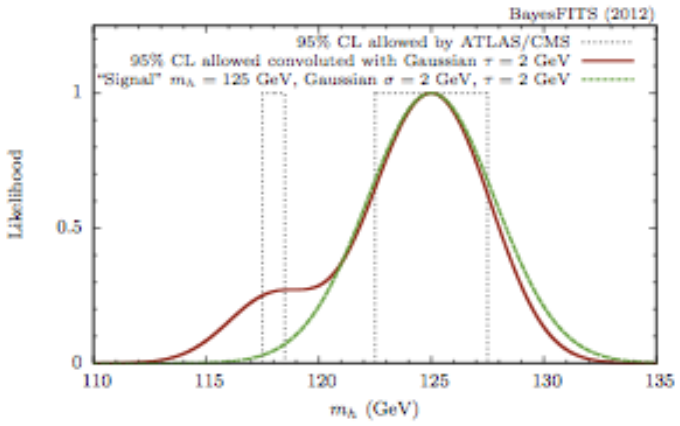
ATLAS: 117.5-118.5 GeV and 122.5-129 GeV

CMS: 114.4 – 127.5 GeV

- Add tau=2GeV th error (via Gaussian)
- Construct likelihood



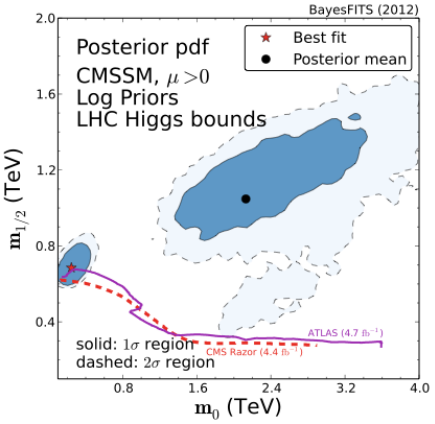
- Assume mh~125 GeV confirmed
- Add tau=2GeV (th) and sigma=2GeV (expt)



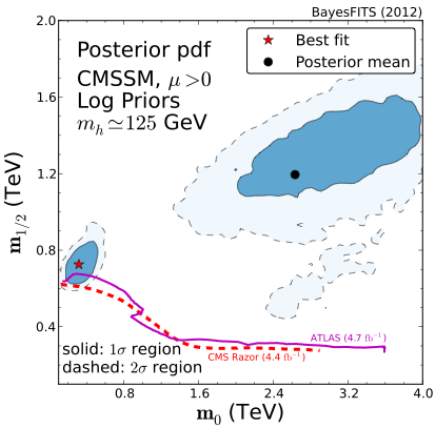
The Like-function only differs in the lower mass window where it is rather small anyway.

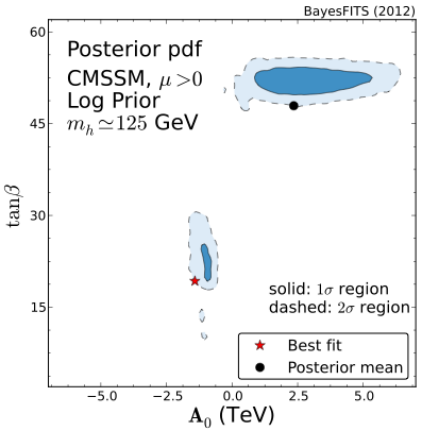
CMSSM w/o and w/ mh~125 GeV

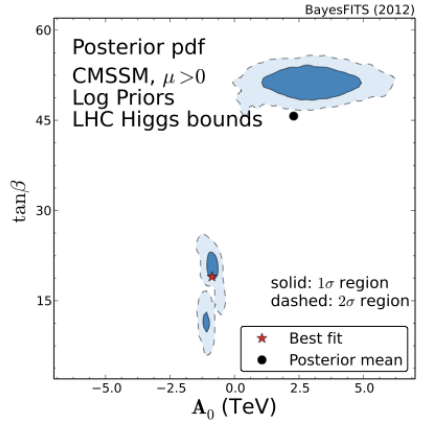
- **LHC mh limits only**



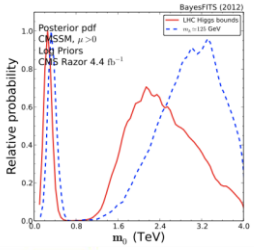
- **mh~125 GeV**

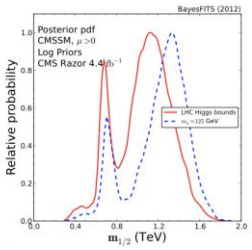


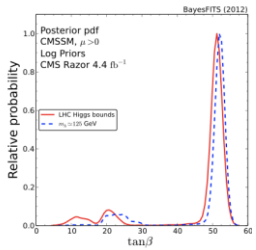


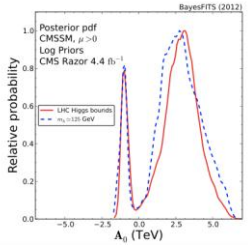


- **Fairly similar probability maps!**
- **m_0 pushed up if mh~125 GeV**
- **Location of best-fit point also similar.**



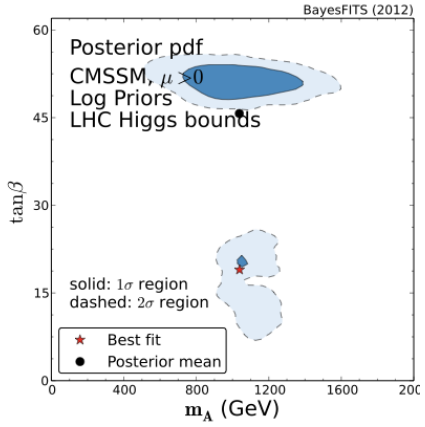


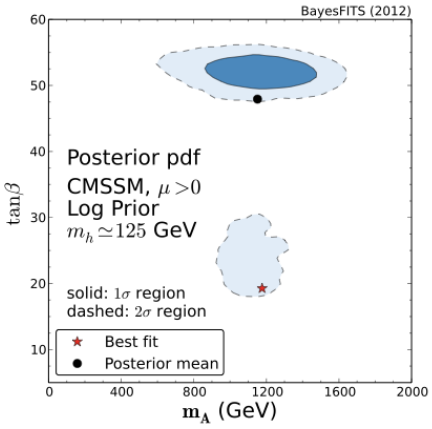


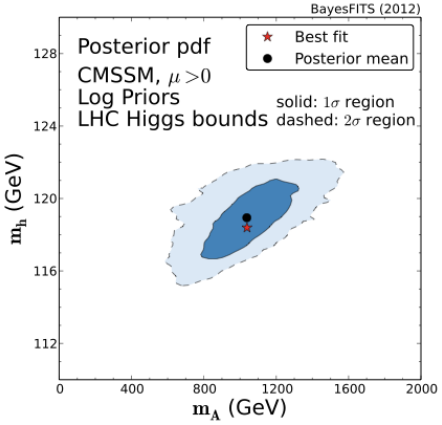


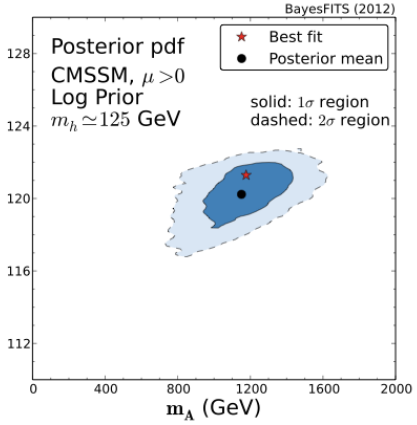
Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund

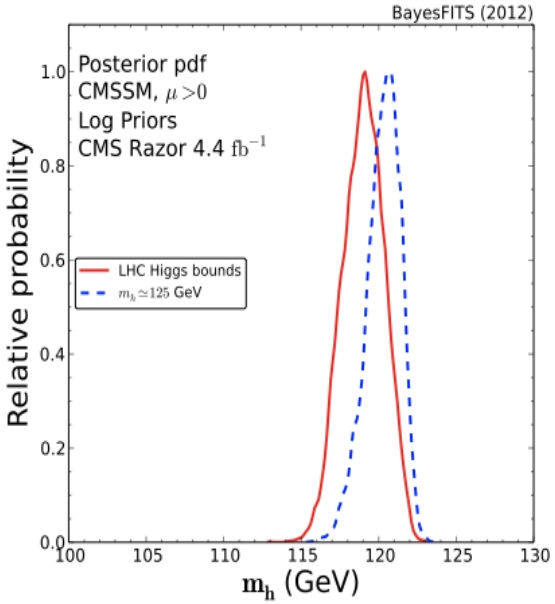
CMSSM w/o and w/ mh~125 GeV











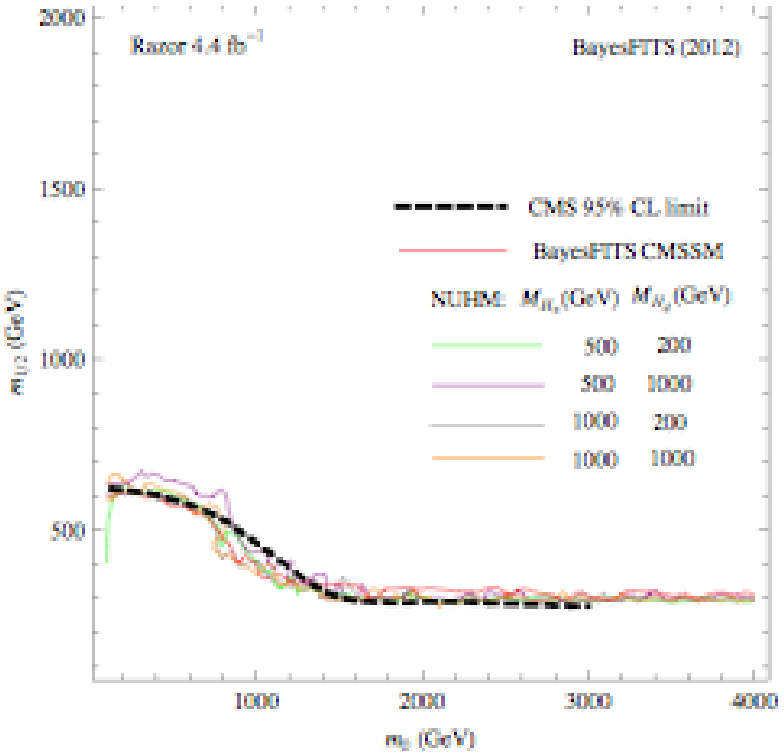
CMSSM: short of producing m_h=125 GeV, but fine with both limits and `signal' within realistic uncertainties!

INNOVATIVE ECONOMY NATIONAL COHESION STRATEGY
FNP Foundation for Polish Science
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND
Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund

Non-Universal Higgs Model (NUHM)

$$m_{H_u}^2, m_{H_d}^2 \neq m_0^2$$

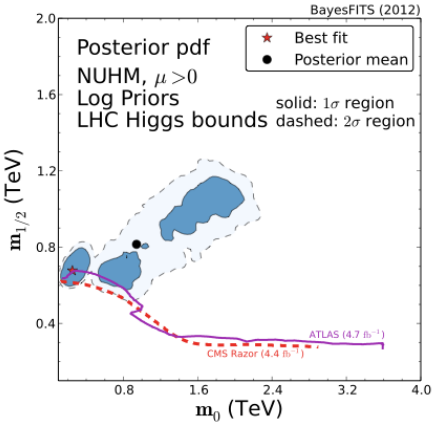
- **Our efficiency map derived for the razor (4.4/fb) limit in CMSSM works also for NUHM**



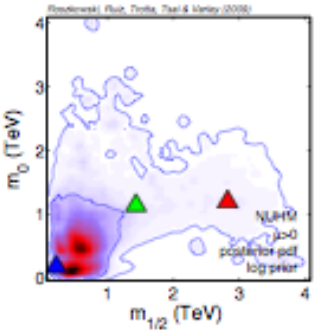
Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund

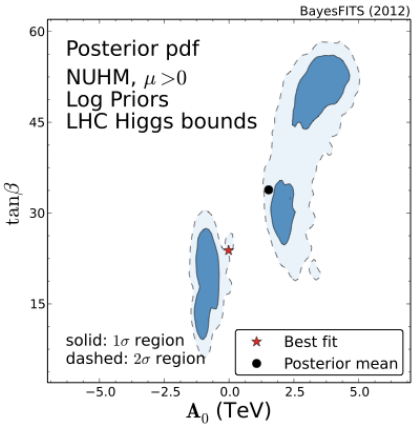
NUHM w/o and w/ mh~125 GeV

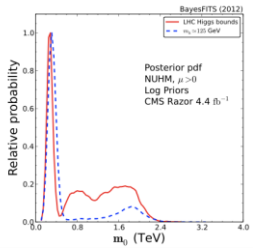
- **LHC mh limits only**



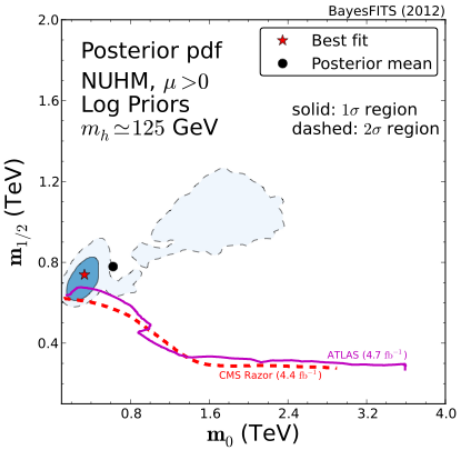
compare 2009:

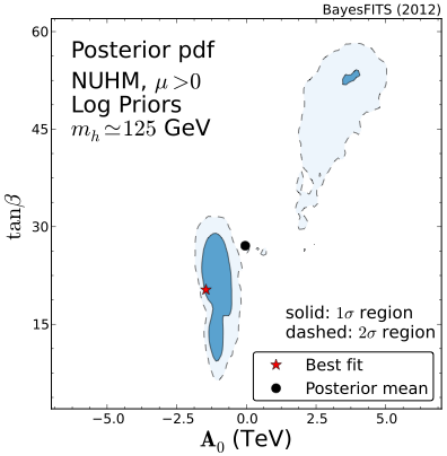


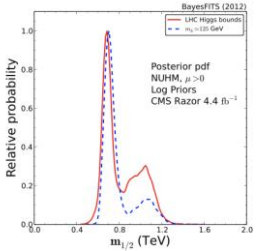


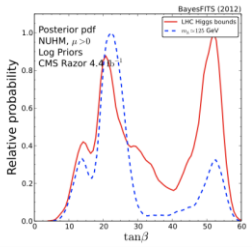


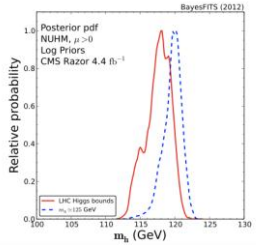
- **mh~125 GeV**









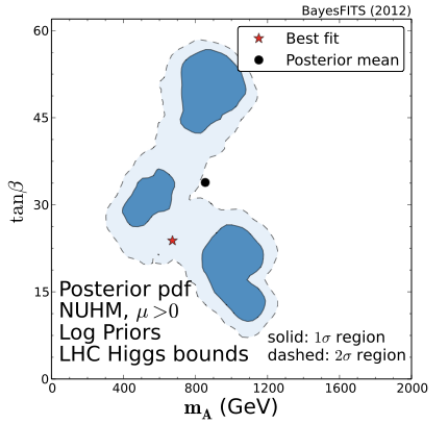


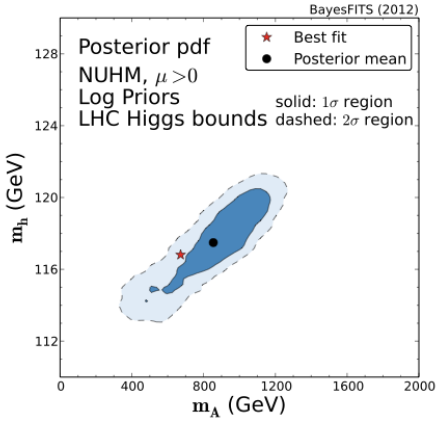
m_h~125GeV actually prefers lower MSUSY and tanb!

Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund

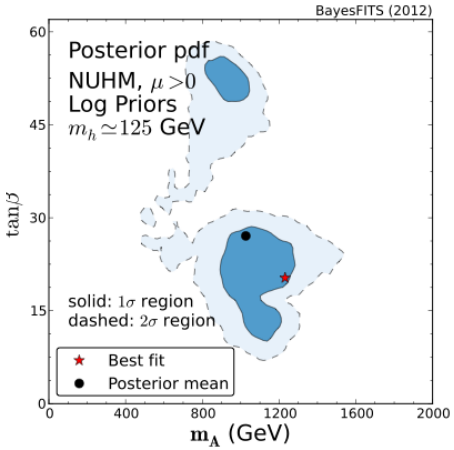
NUHM w/o and w/ mh~125 GeV

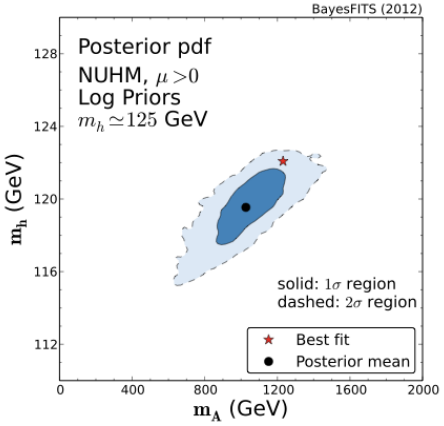
- **LHC mh limits only**





- **mh~125 GeV**

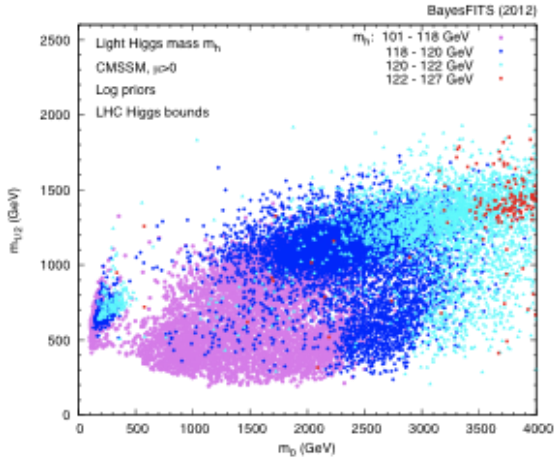


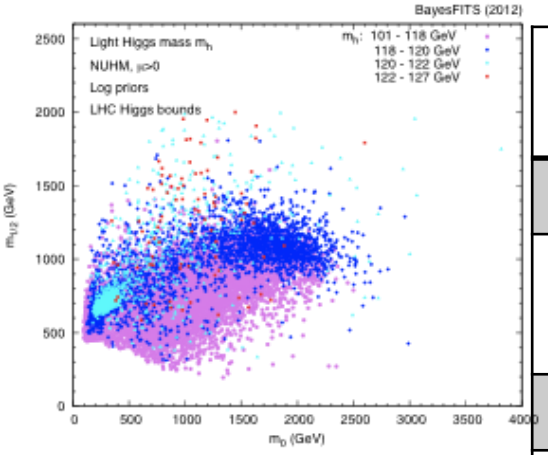


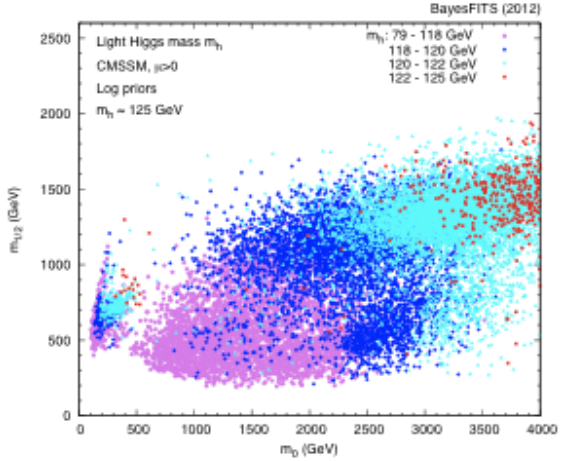
Fairly similar pattern with and without m_h~125GeV

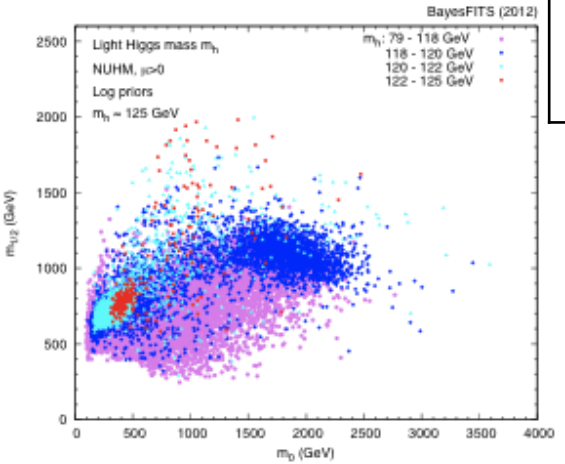
Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund

Light Higgs in CMSSM and NUHM









	max m_h	Chi2 at max m_h	Chi2_min
CMSSM	124.04	125	14.57
CMSSM+ m_h~125	123.44	26.3	15.83
NUHM	126.28	101	12.98
NUHM + m_h~125	124.64	118	15.28

Can find m_h~125 GeV but poor fit to constraints!

Summary

- **Global Bayesian fits: a powerful tool to analyze SUSY models**
- **CMS razor SUSY limit included via our approximate likelihood maps (applicable to any MSSM-based R-parity conserving model)**
- **CMSSM is alive and reasonably well (both w/o and with mh~125 GeV, if uncertainties are taken into account)**
- **NUHM: equally (if not more) so**
- **NUHM: high probability regions very different from CMSSM, lighter spartners preferred**

…just getting heavier, with a poorer fit

Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund

INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY
FNP Foundation for Polish Science
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND
Grants for innovation. Project operated within the Foundation for Polish Science "WELCOME" co-financed by the European Regional Development Fund