The CMSSM and the NUHM in Light of new LHC Limits

Enrico Maria Sessolo

National Centre for Nuclear Research (NCBJ)
Warsaw, Poland

BayesFITS group: A. Fowlie (UoS), A. Kalinowski (UoW), M. Kazana, K. Kowalska, S. Munir, K. Nawrocki, L. Roszkowski*, E. Sessolo, S. Trojanowski, Y.-L. S. Tsai.

*On leave of absence from University of Sheffield

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Outline

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

Based on work in preparation.
Out Soon.

Statistical approach

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

For positive measurements:

Central object: Likelihood function

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 ($d \rightarrow (c,\sigma)$):

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

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

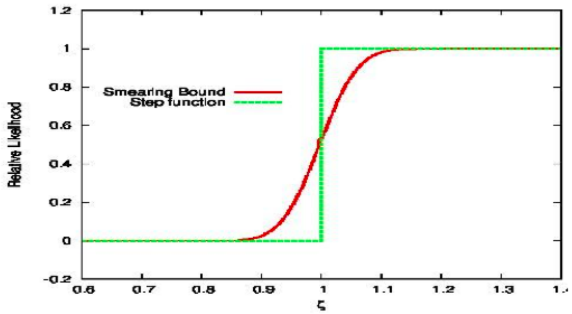
$$\sigma \rightarrow s = \sqrt{\sigma^2 + \tau^2}$$

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).

Marginalize to get credible regions: $$p(\psi_{i=1,..,r}|d) = \int p(m|d) d^{n-r} m$$

CMSSM: global scan

- Perform random scan over 4 CMSSM +4 SM parameters **<u>simultaneously</u>**
- Use Nested Sampling algorithm to evaluate posterior

Parameter	Description	Prior Range	Prior Distribution
CMSSM and NUHM			
m_0	Universal scalar mass	100, 4000	Log
$m_{1/2}$	Universal gaugino mass	100, 2000	Log
A_0	Universal trilinear coupling	-7000, 7000	Linear
$\tan\beta$	Ratio of Higgs vevs	3, 62	Linear
$\mathrm{sgn}\,\mu$	Sign of Higgs parameter	+1	Fixed
additionally in NUHM			
m_{H_u}	GUT-scale soft mass of H_u	100, 4000	Log
m_{H_d}	GUT-scale soft mass of H_d	100, 4000	Log
Nuisance			
M_t	Top quark pole mass	163.7, 178.1	Gaussian
$m_b(m_b)^{\overline{MS}}_{\mathrm{SM}}$	Bottom quark mass	3.92, 4.48	Gaussian
$\alpha_s(M_Z)^{\overline{MS}}$	Strong coupling	0.1096, 0.1256	Gaussian
$1/\alpha_{\mathrm{em}}(M_Z)^{\overline{MS}}$	Reciprocal of electromagnetic coupling	127.846, 127.99	Gaussian

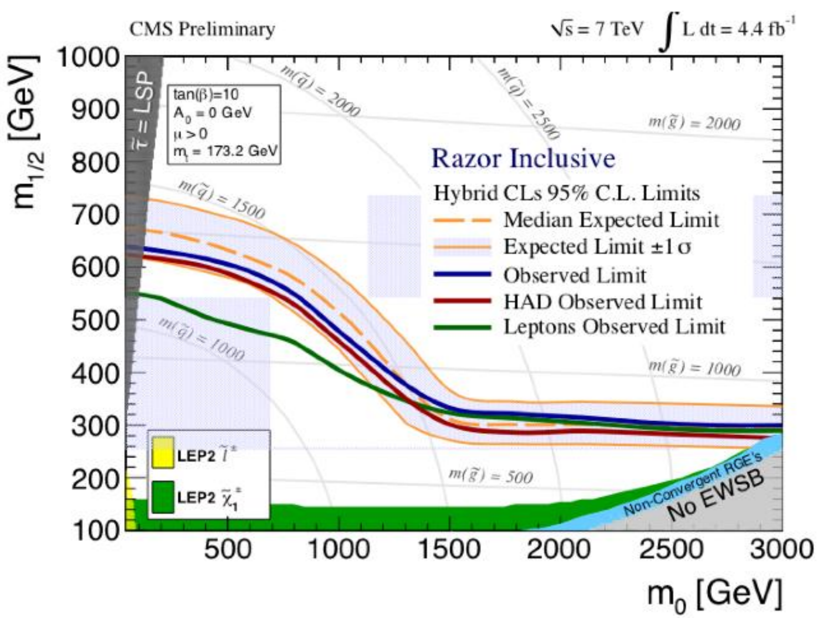
Very wide ranges!

For the NUHM
Two more free parameters:

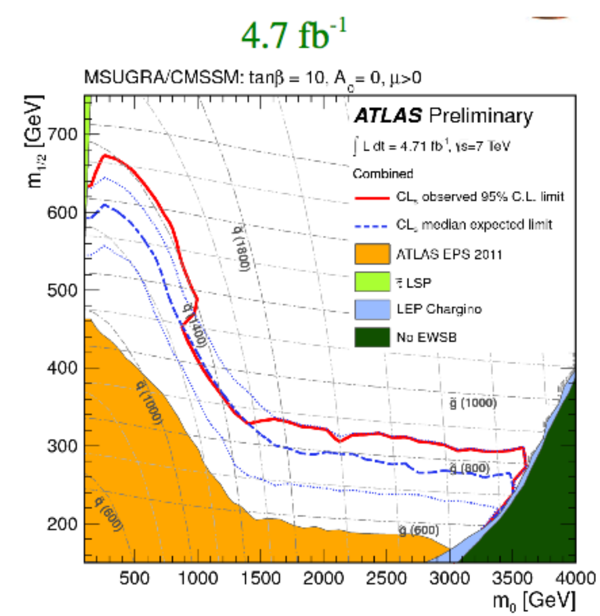
$$m^2_{H_u}, m^2_{H_d} \neq m^2_0$$

Measurement	Mean or Range	Exp. Error	Th. Error	Likelihood Distribution	Ref.
CMS razor 4.4/fb analysis	See text	See text	0	Poisson	[2]
SM-like Higgs mass m_h	117.5 – 118.5 and 122.5-129	0	2	Lower/Upper limit – Error Fn	[9]
	114.4 – 127.5	0	2	Lower/Upper limit – Error Fn	[8]
	> 114.4	0	2	Lower limit – Error Fn	[34]
ζ_h^2	$< f\left(m_h\right)$	0	0	Upper limit – Step Fn	[34]
$\Omega_\chi h^2$	0.1120	0.0056	10%	Gaussian	[35]
$\sin\theta_{\rm eff}$	0.23116	0.00013	0.00015	Gaussian	[36]
m_W	80.399	0.023	0.015	Gaussian	[36]
$\delta\left(g-2\right)_\mu^{\rm SUSY}\times 10^{10}$	30.5	8.6	1.0	Gaussian	[36, 37]
$\mathrm{BR}\left(\overline{\mathrm{B}}\to \mathrm{X_s}\gamma\right)\times 10^4$	3.60	0.23	0.21	Gaussian	[36]
$\mathrm{BR}\left(\mathrm{B_u}\to\tau\nu\right)\times 10^4$	1.66	0.66	0.38	Gaussian	[38]
ΔM_{B_s}	17.77	0.12	2.40	Gaussian	[36]
$\mathrm{BR}\left(\mathrm{B_s}\to\mu^+\mu^-\right)$	$< 4.5\times 10^{-9}$	0	14%	Upper limit – Error Fn	[19]

- **CMS** SUS-12-005



- **ATLAS** ATLAS-CONF-2012-037

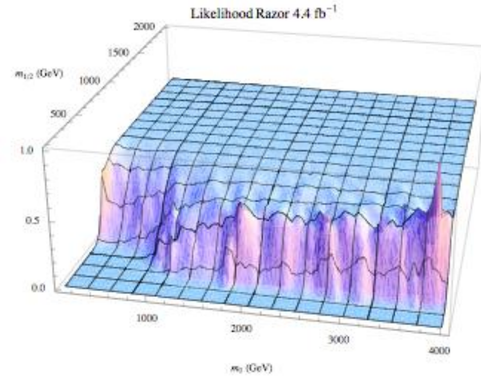


Reproducing Razor (4.4/fb) limit

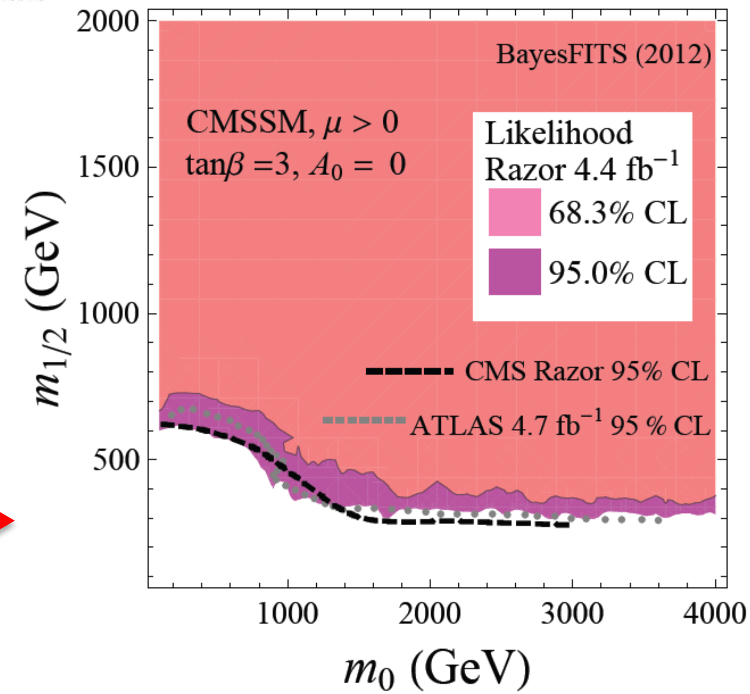
Follow CMS analysis

For each SUSY point simulate signal:

- Construct mass spectrum
- Generate 5k events + reconstruct objects
- Consider 38 bins in R^2 and M_R
- Efficiency after final cuts
- Compute likelihood function
- Need to rescale by ~2 (w/PGS4)



VERY GOOD AGREEMENT →



NOW ABLE TO DO IT IN MANY MODELS!

(pMSSM, NMSSM…)

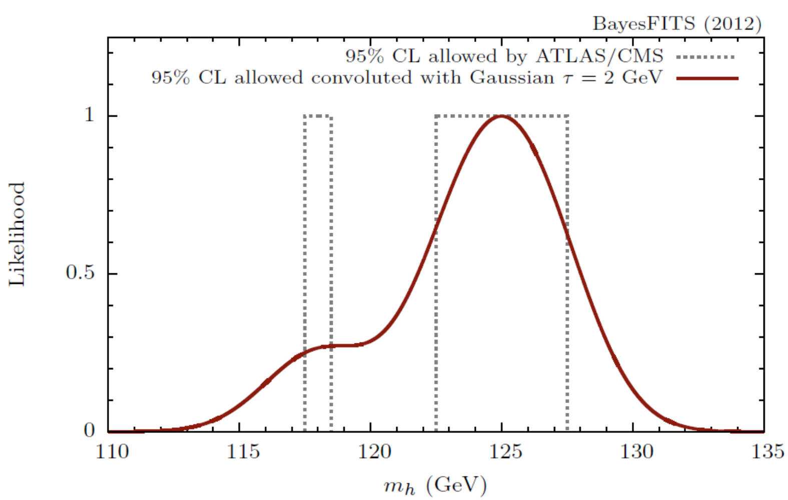
Implementing the Higgs Constraints

- Currently allowed (95%)

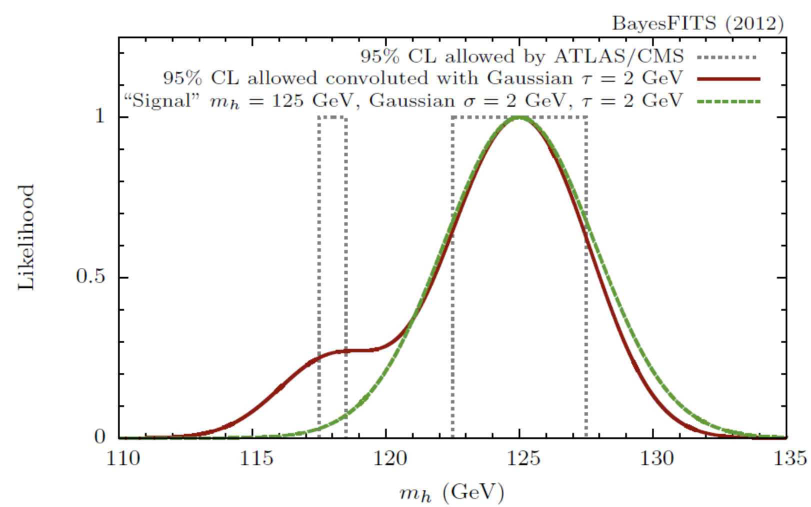
ATLAS: 117.5-118.5 GeV and 122.5-129 GeV

CMS: 114.4 – 127.5 GeV

- Add tau=2GeV th error
- Construct likelihood

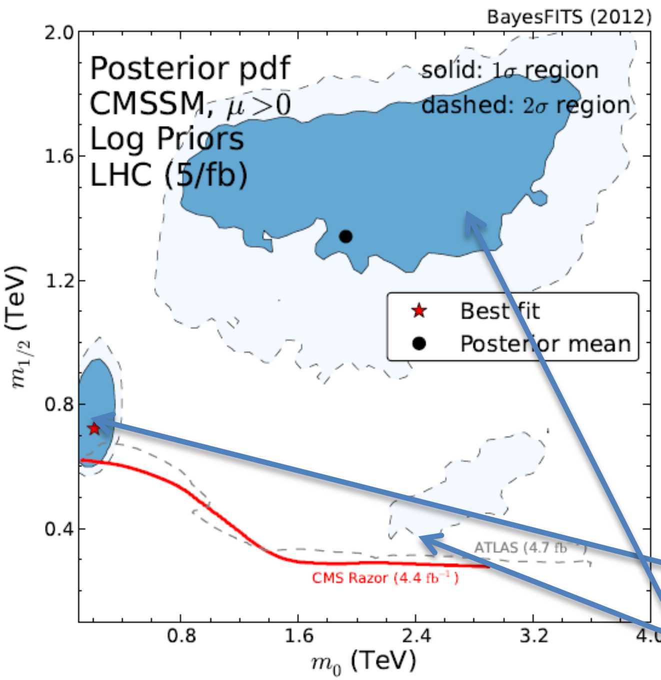


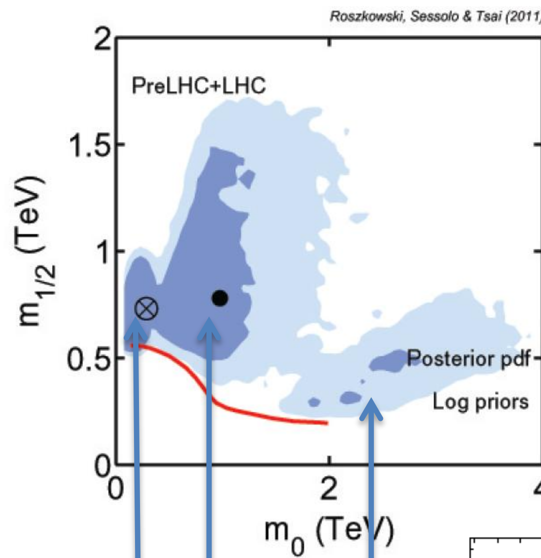
- Assume mh~125 GeV confirmed
- Add tau=2GeV (th) and sigma=2GeV (expt)



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

Impact of LHC razor and Higgs bounds on the the CMSSM





Previously (=preLHC+LHC)

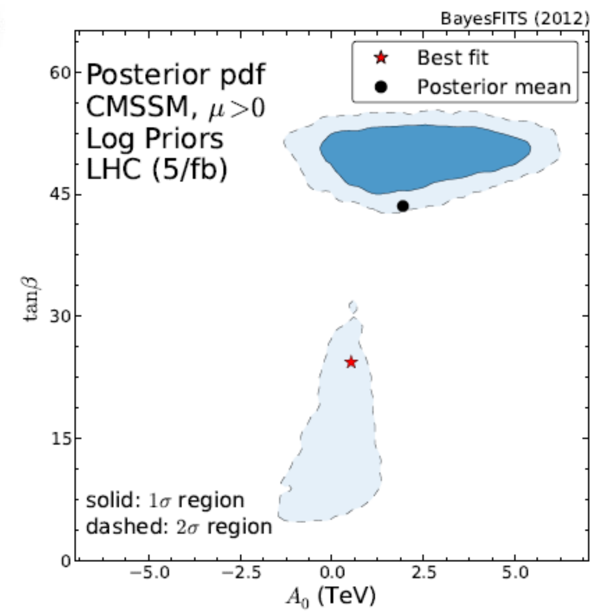
- **HIGGS: mh > 114.4 GeV**
- **LHC: αT at 1.1/fb**
- **Bs → μ+μ- old**

←←←

Stau-coannih.

Focus Point

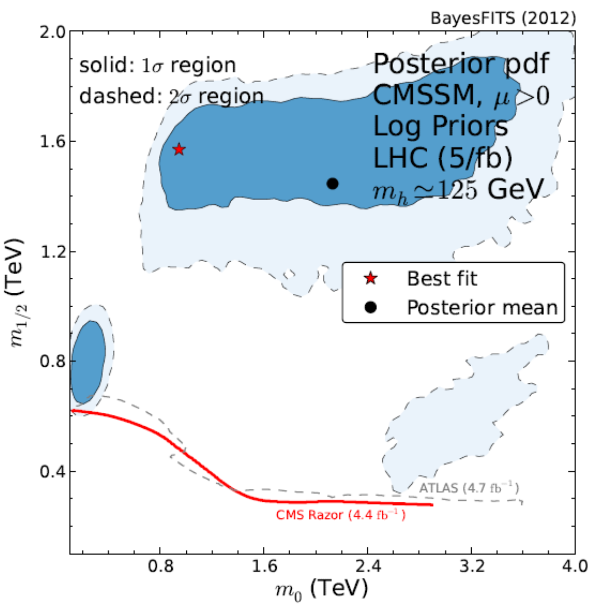
***A*-funnel**

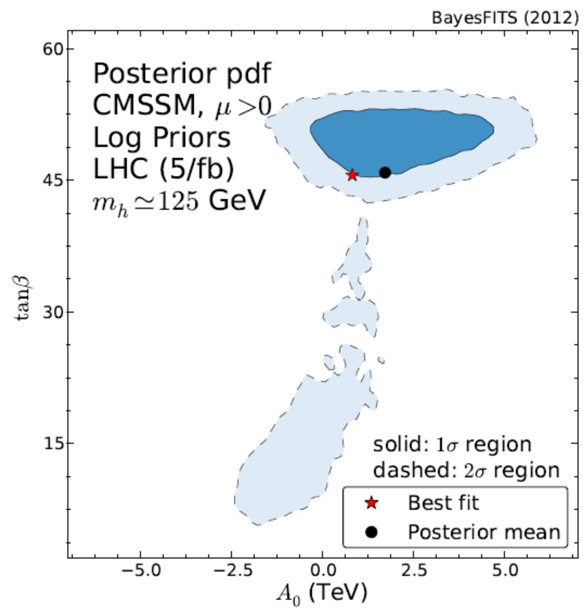


- ***A*-funnel region now enhanced**
- **FP region suppressed**
- **Stau coann. region: still best fit**
- **Importance of modeling Likelih.**

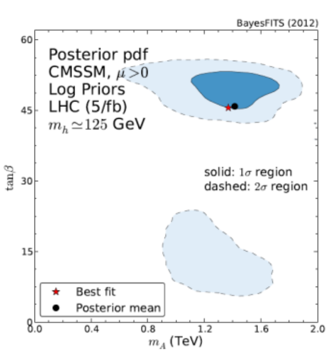
CMSSM w/o and w/ mh~125 GeV

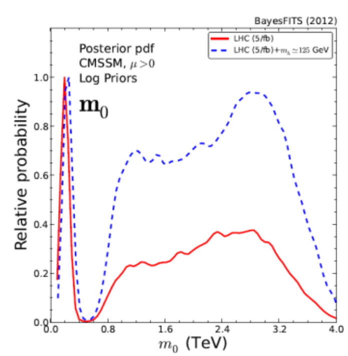
- **mh~125 GeV**

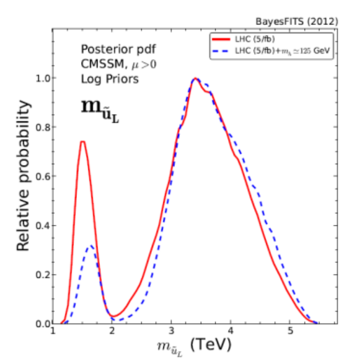


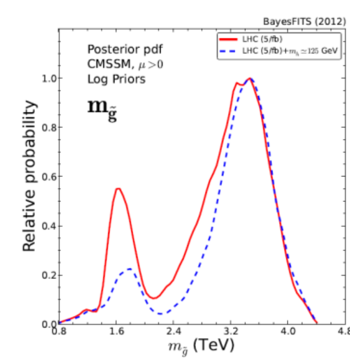


- **Apparently similar to bounds**
- **Probability moves to higher scales**
- **Best fit point pushed up**
- **Lower bounds on masses → razor**

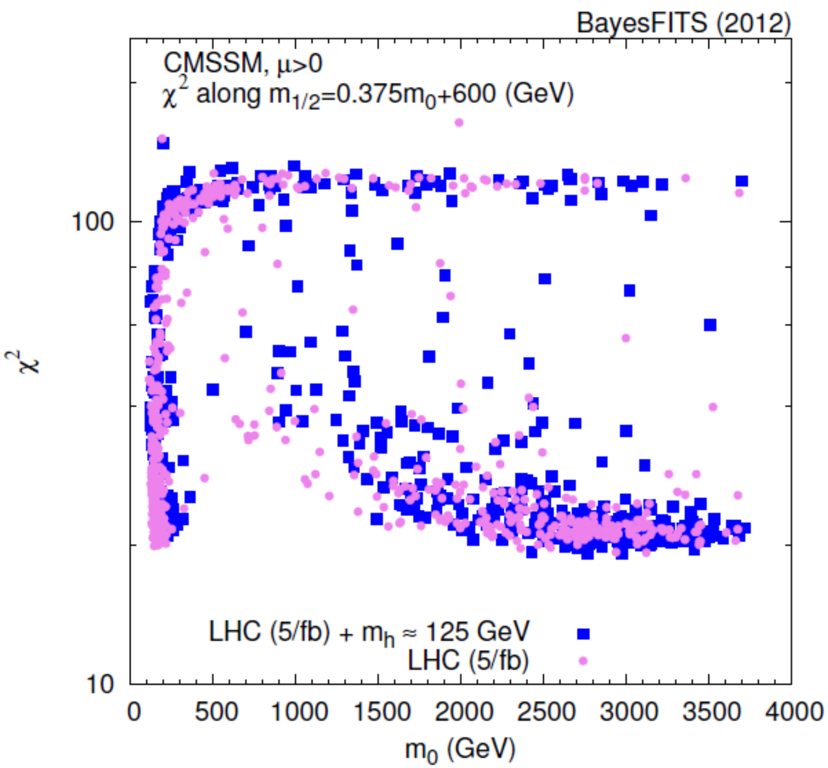


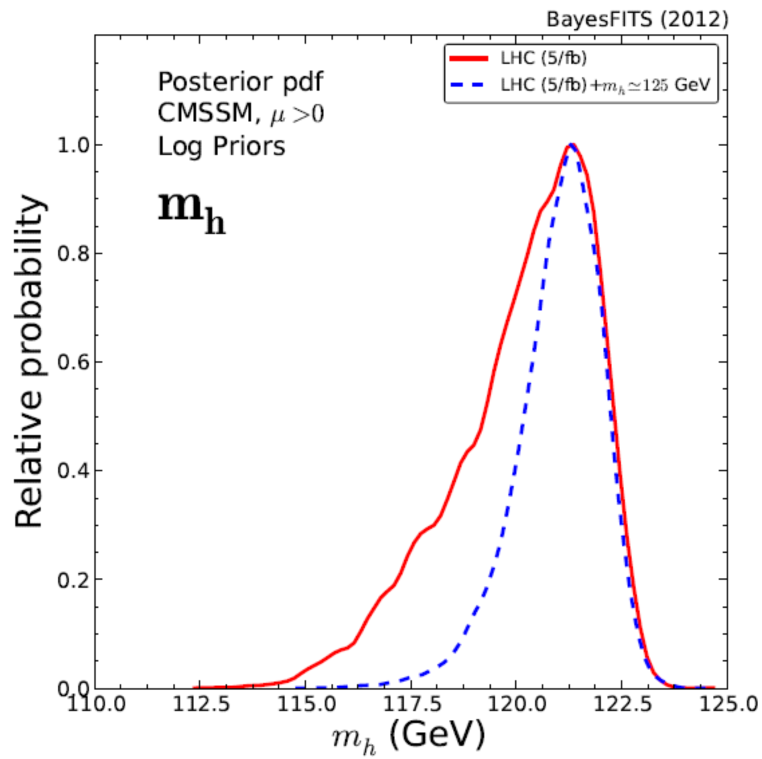






CMSSM w/o and w/ mh~125 GeV

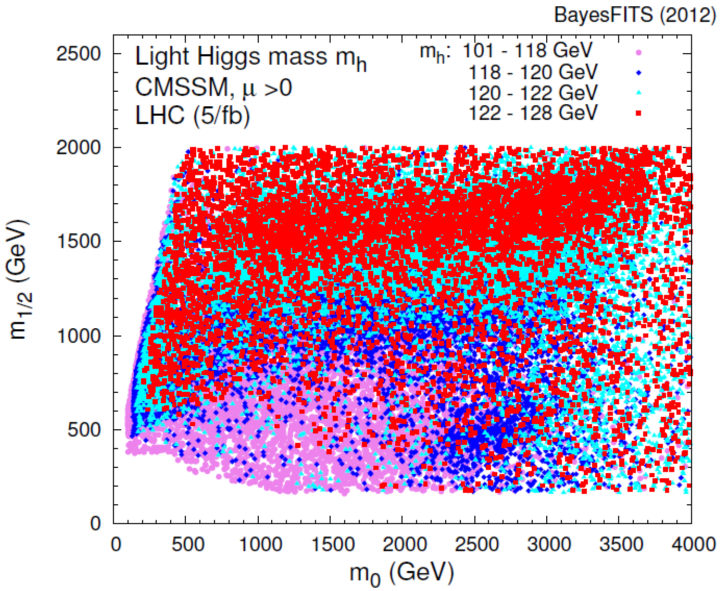


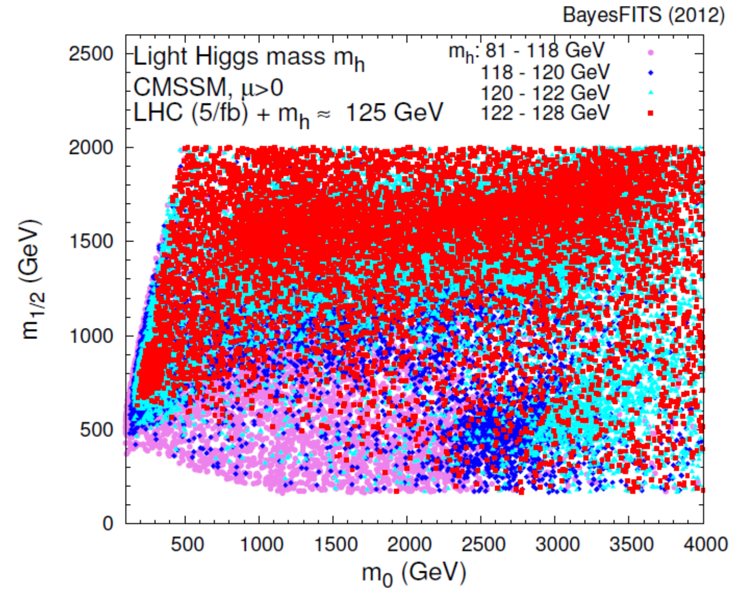


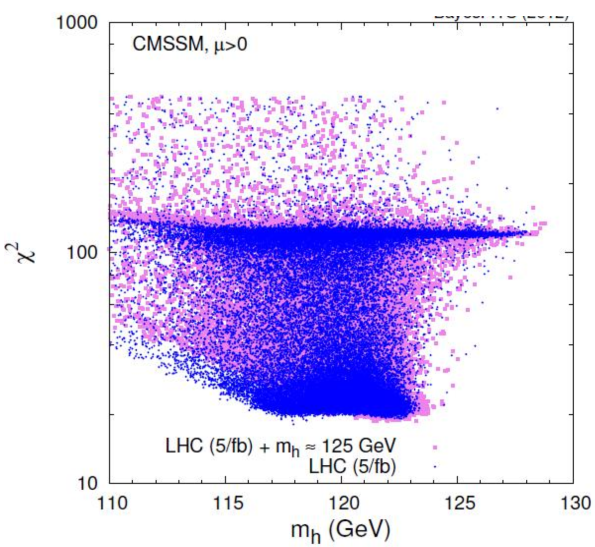
CMSSM: Fit poor + wide plateau in total chisquare!

CMSSM: can produce m_h=125 GeV, but generally poor likelihood!

Light Higgs in the CMSSM







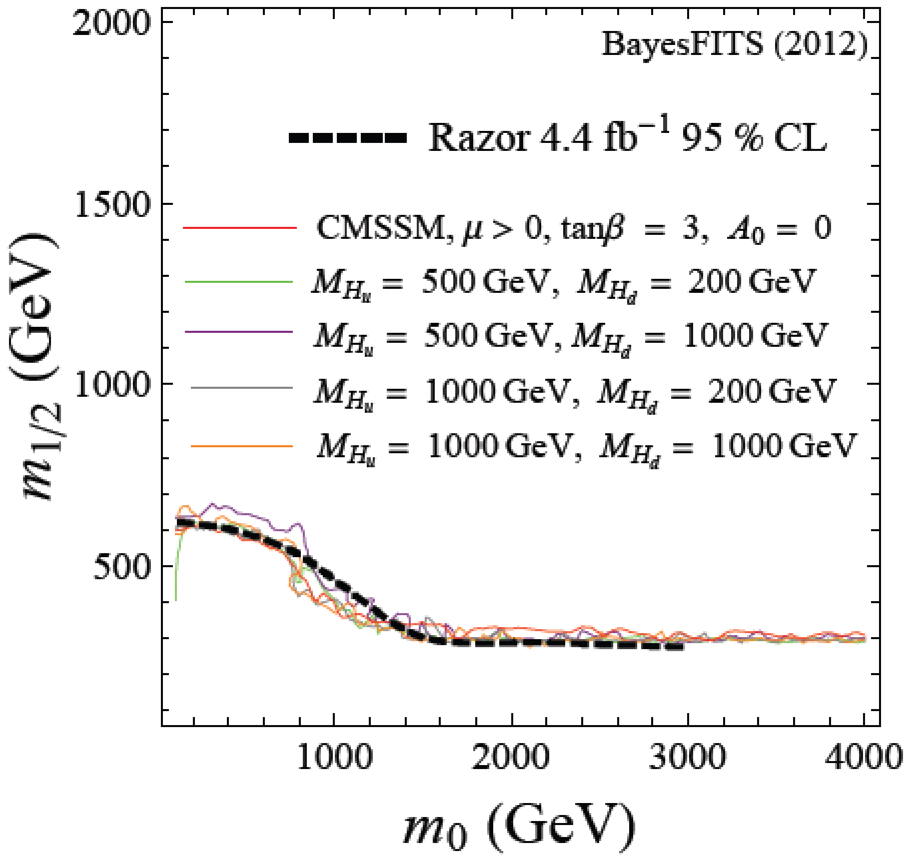
Can find m_h~125 GeV but poor fit to constraints!

χ^2	$\Omega_\chi h^2$	m_h	$\overline{B} \to X_s\gamma$	$B_s \to \mu^+\mu^-$	$\sin\theta_{\rm eff}$	m_W	$\delta\,(g-2)_\mu^{\rm SUSY}$	razor	Total
m_h bounds	7.62×10^{-14}	2.66	1.86	0.09	1.83	0.69	6.08	3.89	18.09
m_h (125 GeV)	0.1	0.38	1.52	0.7	1.07	0.13	10.6	3.37	18.65

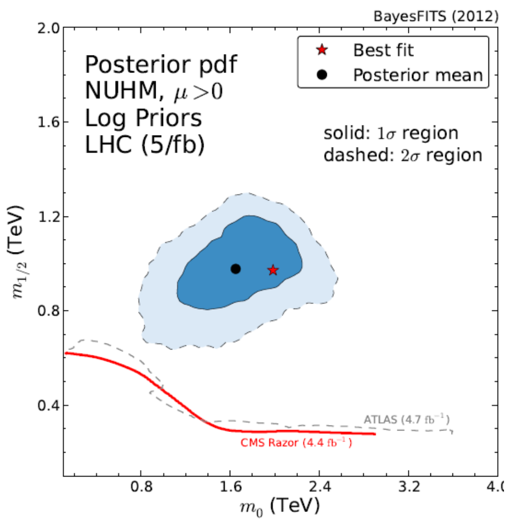
Non-Universal Higgs Model (NUHM)

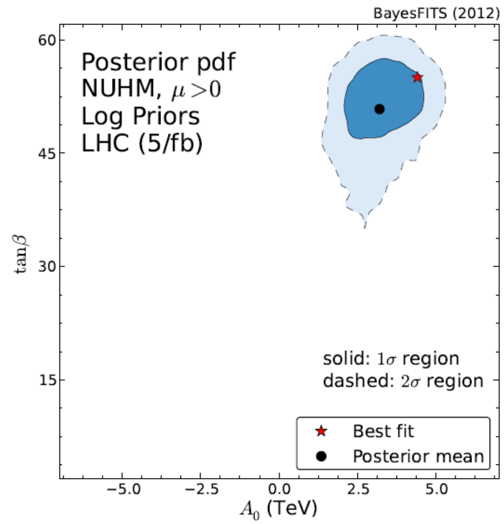
$$m_{H_u}^2, m_{H_d}^2 \neq m_0^2$$

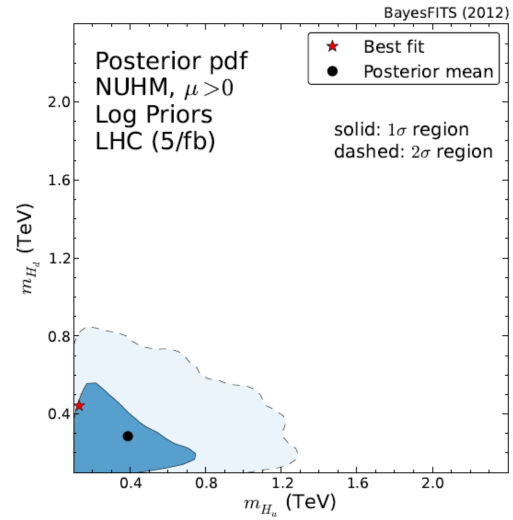
- Our efficiency map derived for the razor (4.4/fb) limit in CMSSM works also for NUHM
- Only slight difference when $m_{H_u} << m_{H_d}$ (Not large fraction of points)
- We can use the CMSSM likelihood map for NUHM

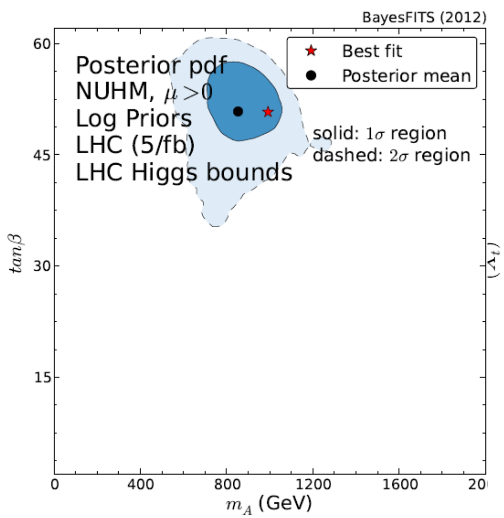


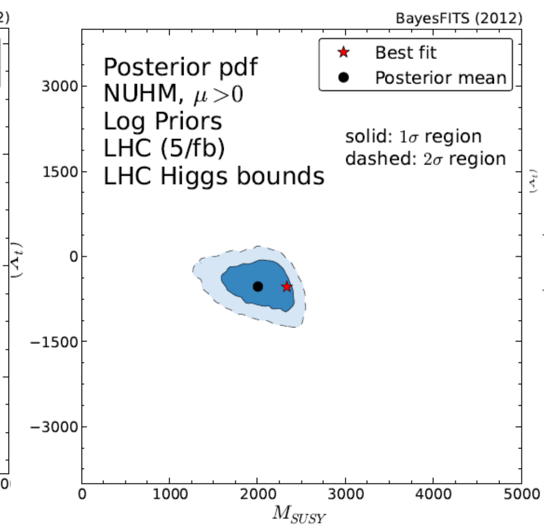
NUHM with new Higgs Bounds

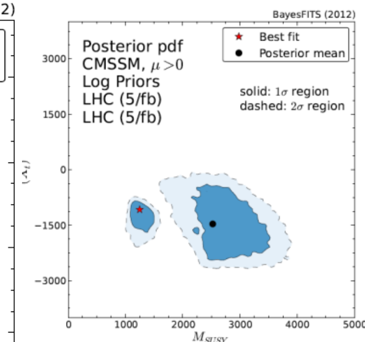












Best Fit Better

No proper scan of parameter space

Work in progress!

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 not doing well (Plateau, poor fit)**
- **NUHM: Slightly better fit**

… But problems with live-in points, need more time.