Two ultimate tests of constrained supersymmetry

Kamila Kowalska

National Centre for Nuclear Research (NCBJ)
Warsaw, Poland

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KK, L.Roszkowski, E.Sessolo

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Outline

1. Bayesian statistics

2. CMSSM - results of the global scan

3. CMSSM - experimental tests

4. Conclusions

Bayesian approach

A theoretical model is described by *N* free parameters:

$$m = (m_1, m_2, \ldots m_N)$$

The model gives a set of physical predictions $\xi(m)$:

$$\xi = (\xi_1, \xi_2, \ldots \xi_K)$$

The values of $\xi(m)$ are measured experimentally *d:*

$$d = (d_1, d_2, \ldots d_K)$$

The question is:

How can we quantify probability of obtaining parameters *m*, by looking at the data *d*, accounting for all theoretical and experimental uncertainties?

Bayesian approach

The probability is a **measure of the degree of belief** about a set of parameters *m*, given the outcome *d*.

Bayes theorem:

$$p(m|d) = \frac{p(d|\xi(m))\pi(m)}{p(d)}$$

Posterior *pdf*: the probability about hypothesis ***m*** AFTER seeing the data ***d***.

Likelihood: the probability of obtaining data ***d*,** given an expected value of observable ***ξ(m)***.

Prior *pdf*: what we know about hypothesis ***m*** BEFORE seeing the data ***d***.

Evidence: normalization constant (crucial for model comparison) – probability of obtaining the particular set of data d given the theoretical model and irrespective of actual values of *m*

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Marginalized *pdf* → **credible posterior regions** for specific parameters:

$$p(\psi_{i=1,..,r}|d) = \int p(m|d)d^{n-r}m$$

CMSSM global scan

Constrained Minimal Supersymmetric Standard Model (CMSSM)

→ soft SUSY parameters unified at the GUT-scale

Random <u>simultaneous</u> scan over 4 CMSSM + 4 SM parameters

CMSSM parameter	Prior Range	Prior Distribution
m_0	0.1, 20 (TeV)	Log
$m_{1/2}$	0.1, 10 (TeV)	Log
A_0	-20, 20 (TeV)	Linear
$\tan\beta$	3, 62	Linear
$\text{sgn}\,\mu$	$+1$ or -1	Fixed
Nuisance	Central value $\pm$ std. dev.	Prior Distribution
M_t	173.5 ± 1.0 (GeV)	Gaussian
$m_b(m_b)^{\overline{MS}}_{\text{SM}}$	4.18 ± 0.03 (GeV)	Gaussian
$\alpha_s(M_Z)^{\overline{MS}}$	0.1184 ± 0.0007	Gaussian
$1/\alpha_{\text{em}}(M_Z)^{\overline{MS}}$	127.916 ± 0.015	Gaussian

Experimental constraints

Measurement	Mean or Range	Error: (Exp., Th.)	Distribution
m_h by CMS	$125.8\,\mathrm{GeV}$	$0.6\,\mathrm{GeV}, 3\,\mathrm{GeV}$	Gaussian
$\Omega_\chi h^2$	0.1120	0.0056, 10%	Gaussian
$\delta\,(g-2)_\mu^{\mathrm{SUSY}} \times 10^{10}$	28.7	8.0, 1.0	Gaussian
$\mathrm{BR}\left(\overline{B} \to X_s \gamma\right) \times 10^4$	3.43	0.22, 0.21	Gaussian
$\mathrm{BR}\,(B_u \to \tau\nu) \times 10^4$	1.66	0.33, 0.38	Gaussian
ΔM_{B_s}	$17.719\,\mathrm{ps}^{-1}$	$0.043\,\mathrm{ps}^{-1},\ 2.400\,\mathrm{ps}^{-1}$	Gaussian
$\sin^2\theta_{\mathrm{eff}}$	0.23116	0.00012, 0.00015	Gaussian
M_W	80.385	0.015, 0.015	Gaussian
$\mathrm{BR}\left(B_s \to \mu^+\mu^-\right)_{\mathrm{current}} \times 10^9$	3.2	$+1.5-1.2$, 10% (0.32)	Gaussian
Combination of:			
CMS razor 4.4/fb , $\sqrt{s} = 7\,\mathrm{TeV}$	Likelihood map		Poisson
CMS α_T 11.7/fb , $\sqrt{s} = 8\,\mathrm{TeV}$	Likelihood map		Poisson

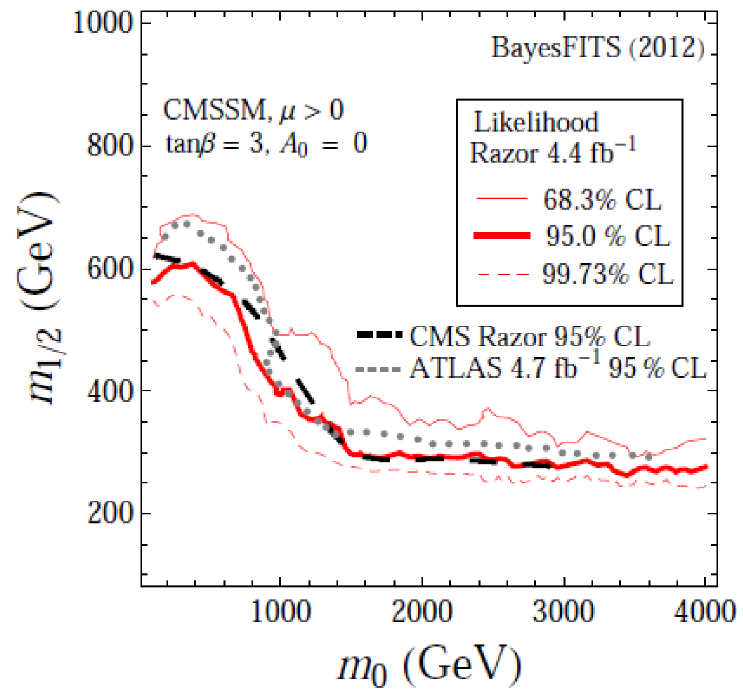
Positive measurements: Gaussian distribution

$$\mathcal{L}(m) = \frac{1}{\sqrt{2\pi s}} e^{-\frac{(\xi(m)-d)^2}{2s^2}}$$

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

LHC limits on SUSY

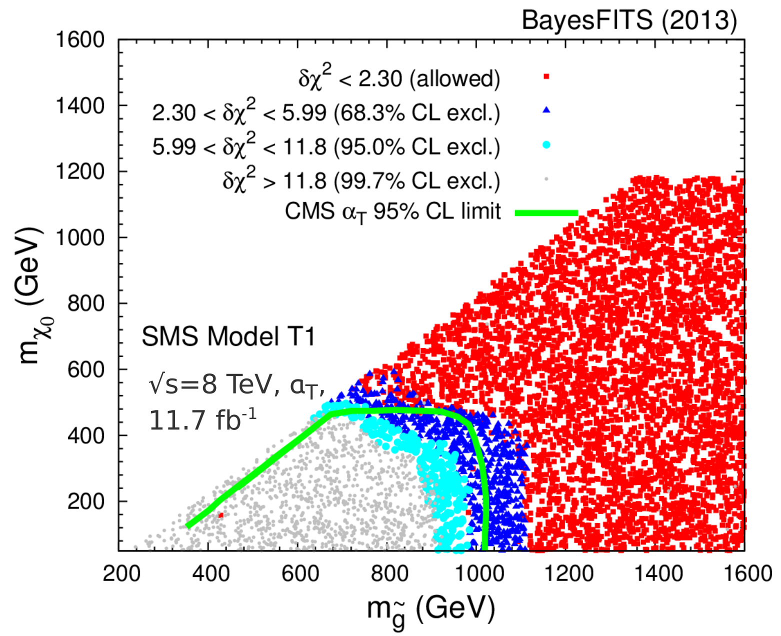
more details → *talk by E.Sessolo, 21.05.13*



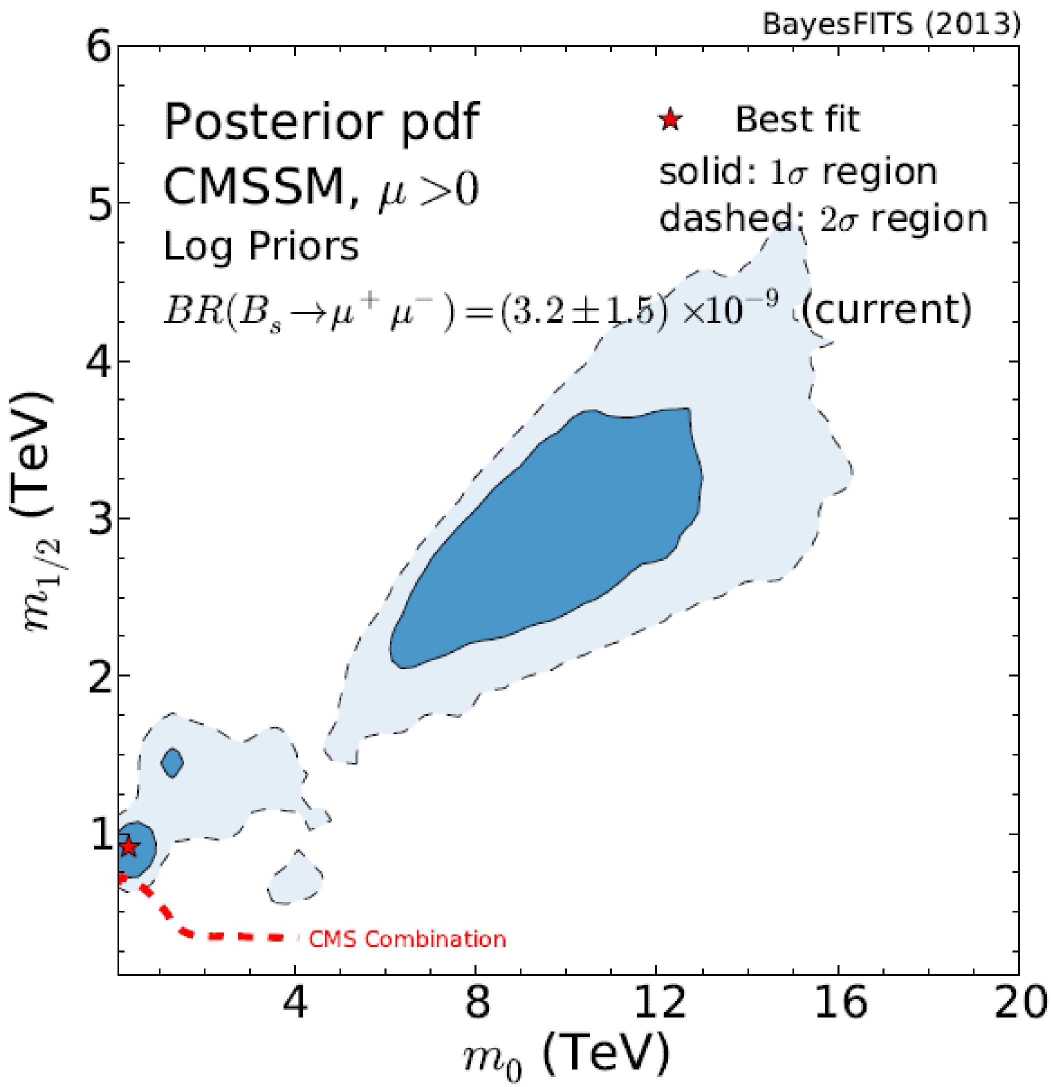
SUSY Likelihood:

$$\mathcal{L}(s) = \int p(o|s;b') \exp\left[-\frac{(b-b')^2}{2\delta b^2}\right] db'$$

- full simulation of event generation + detector response (PYTHIA6, PGS4)
- closely follows the experimental analysis
- validated against the official limits



Total impact of 8 TeV LHC



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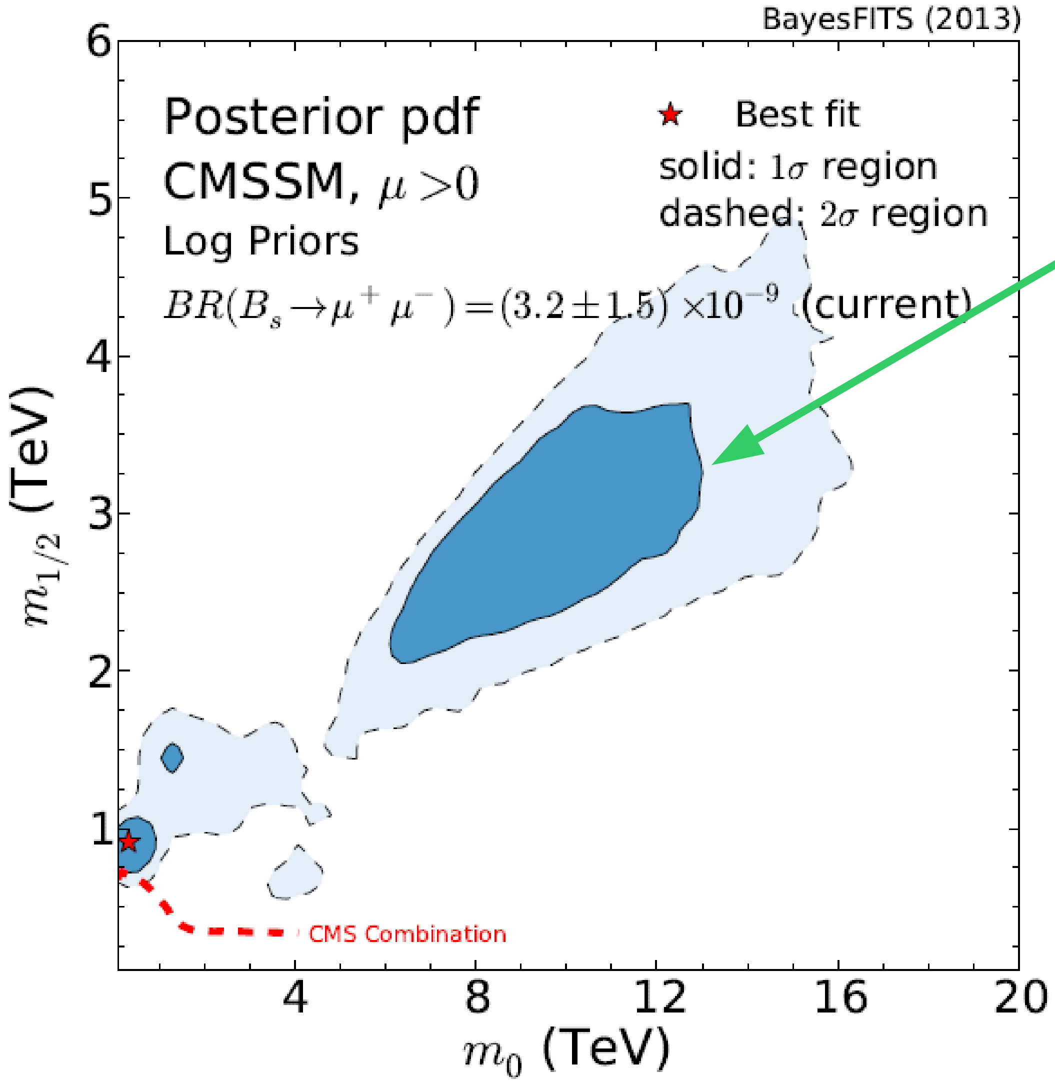

High-mass region favored by m_h~126 GeV

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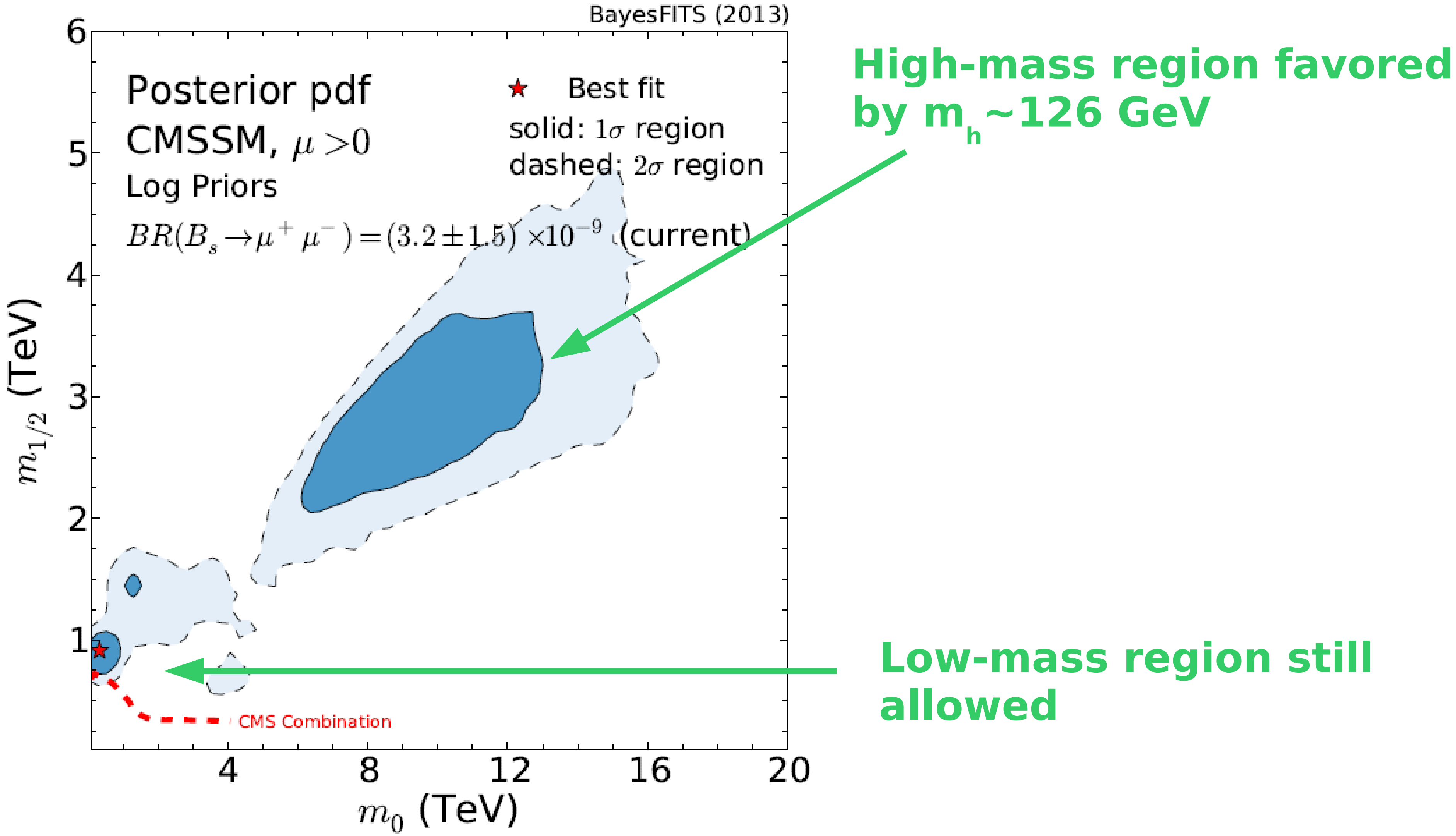

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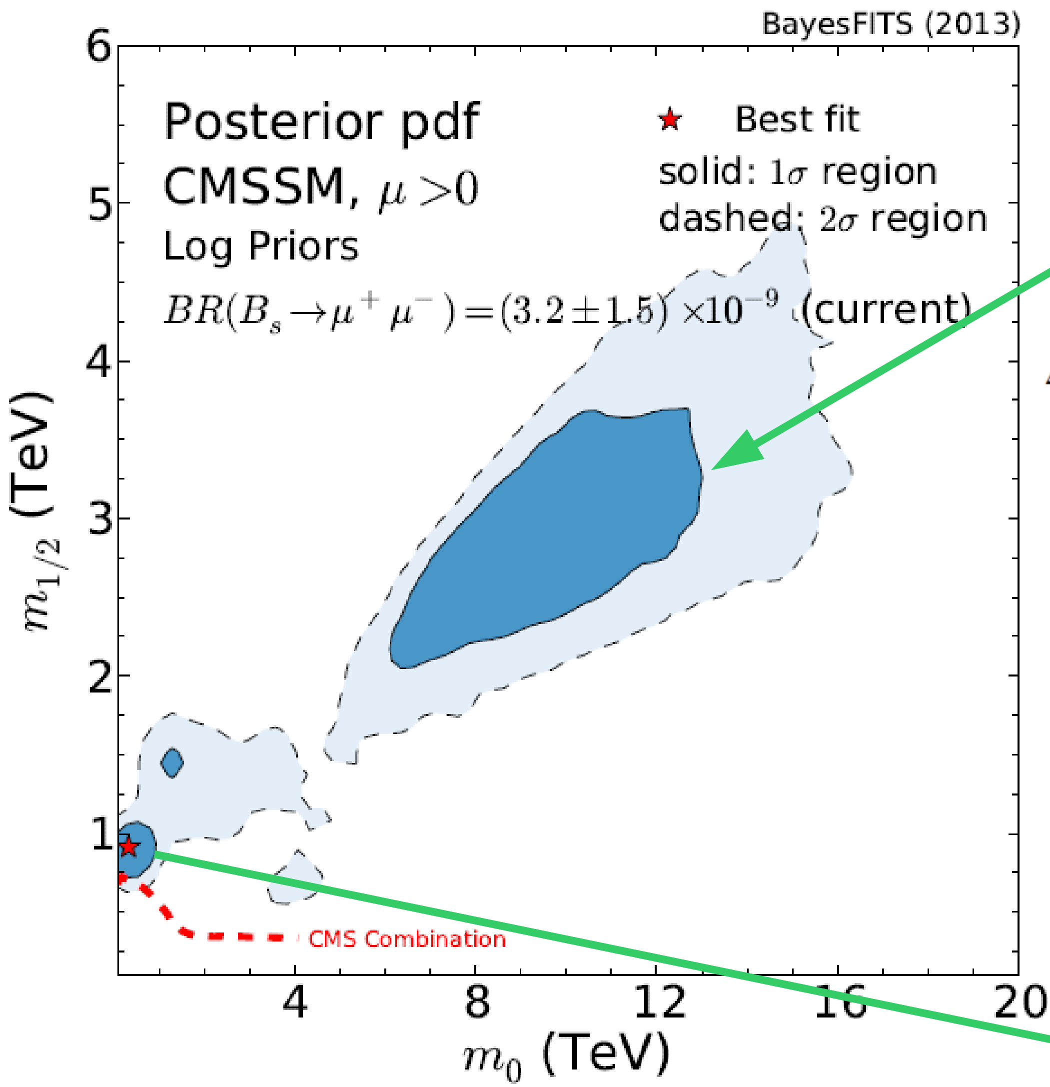
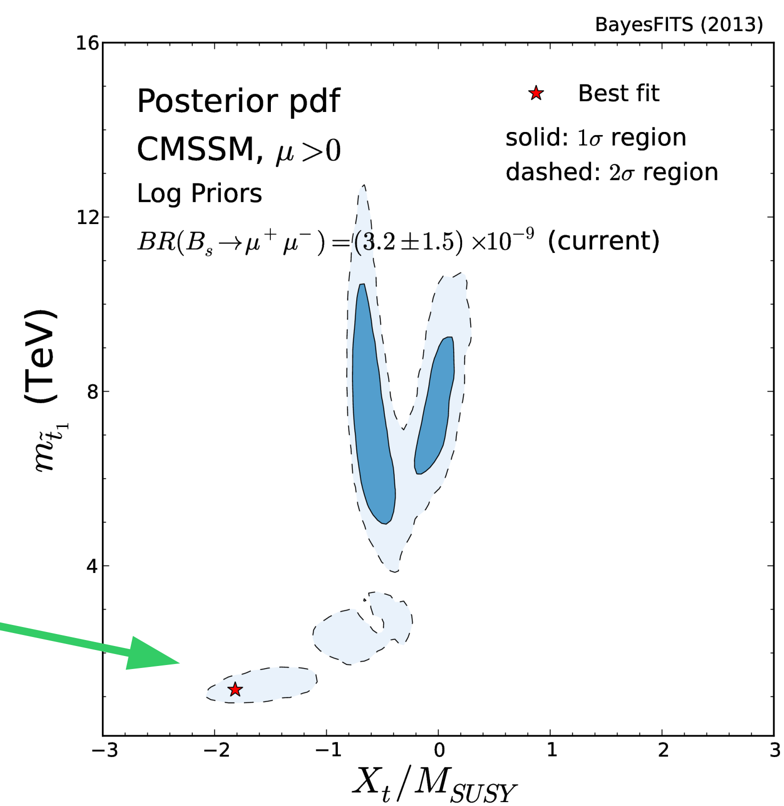


High-mass region favored by m_h~126 GeV

1-loop:

$$\Delta m_h^2 = \frac{3m_t^4}{4\pi^2 v^2}\left[\ln\left(\frac{M_{\rm SUSY}^2}{m_t^2}\right) + \frac{X_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{X_t^2}{12M_{\rm SUSY}^2}\right)\right.$$

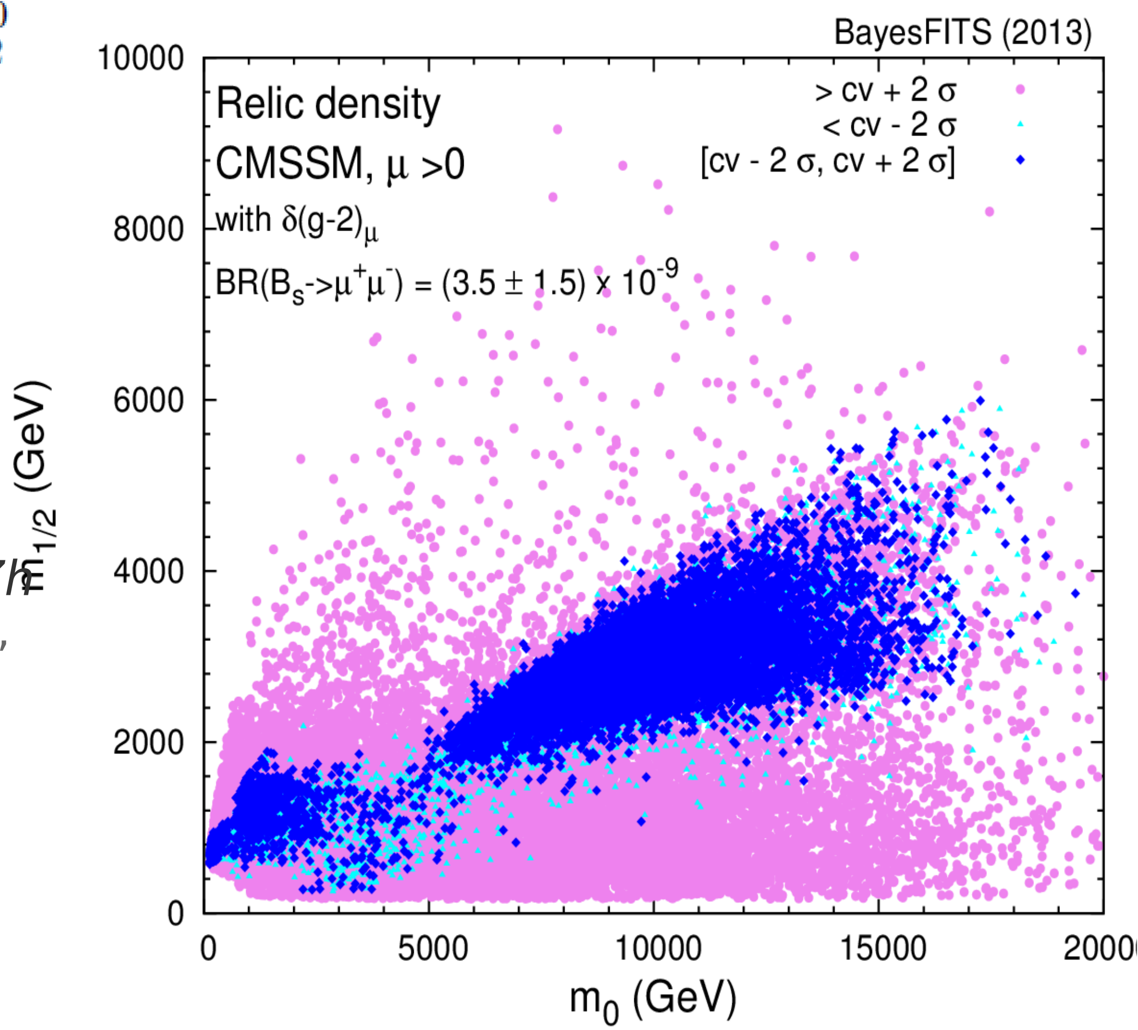


LSP relic density

$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

Mechanisms of reducing $\Omega_\chi h^2$:

- neutralino-stau co-annihilation
- *A*-resonance annihilation
- enhanced annihilation into *ZZ, WW, Zh* (mixed bino-higgsino in Focus Point region, pure higgsino in 1TeV higgsino region)
- chargino coannihilation (1TH region)



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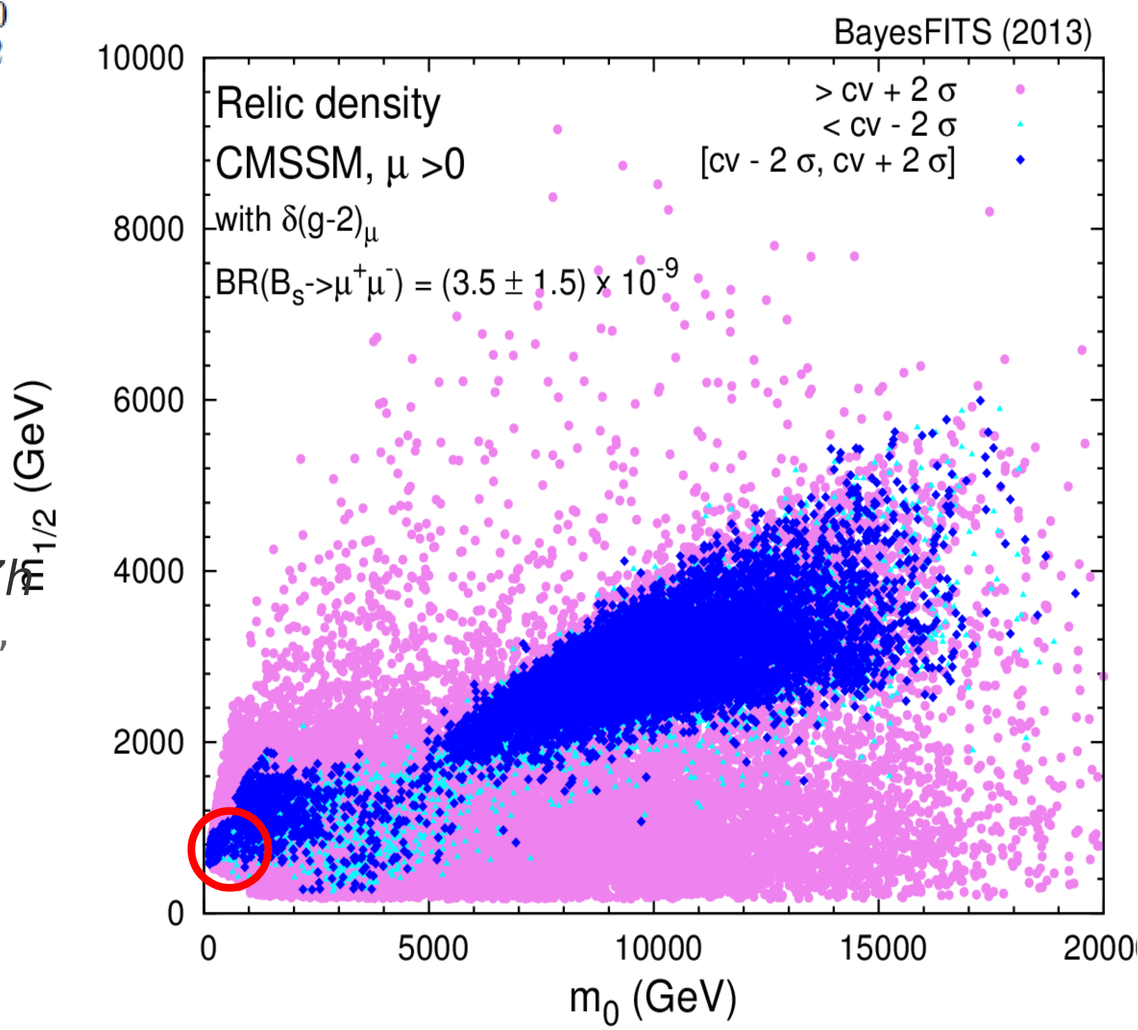

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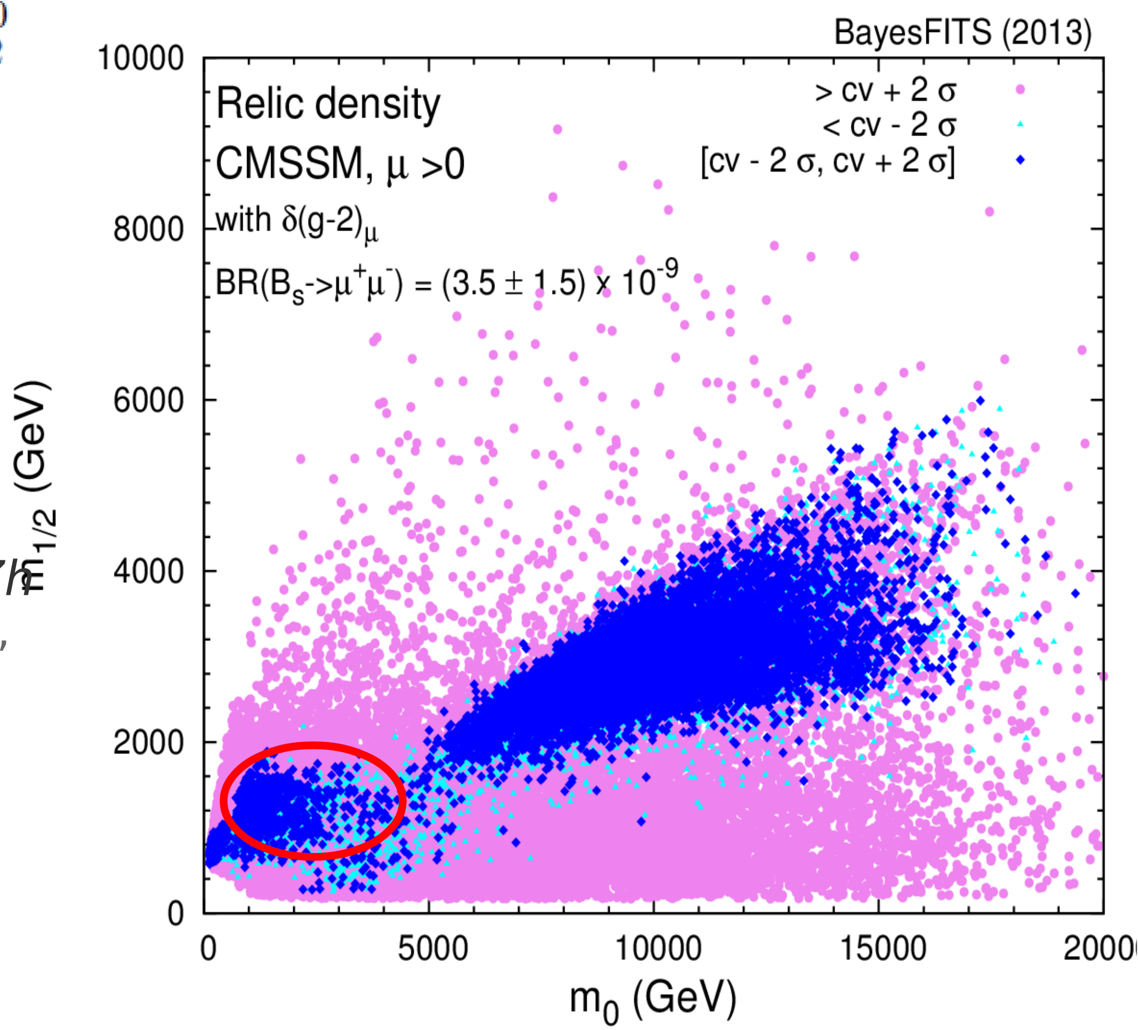

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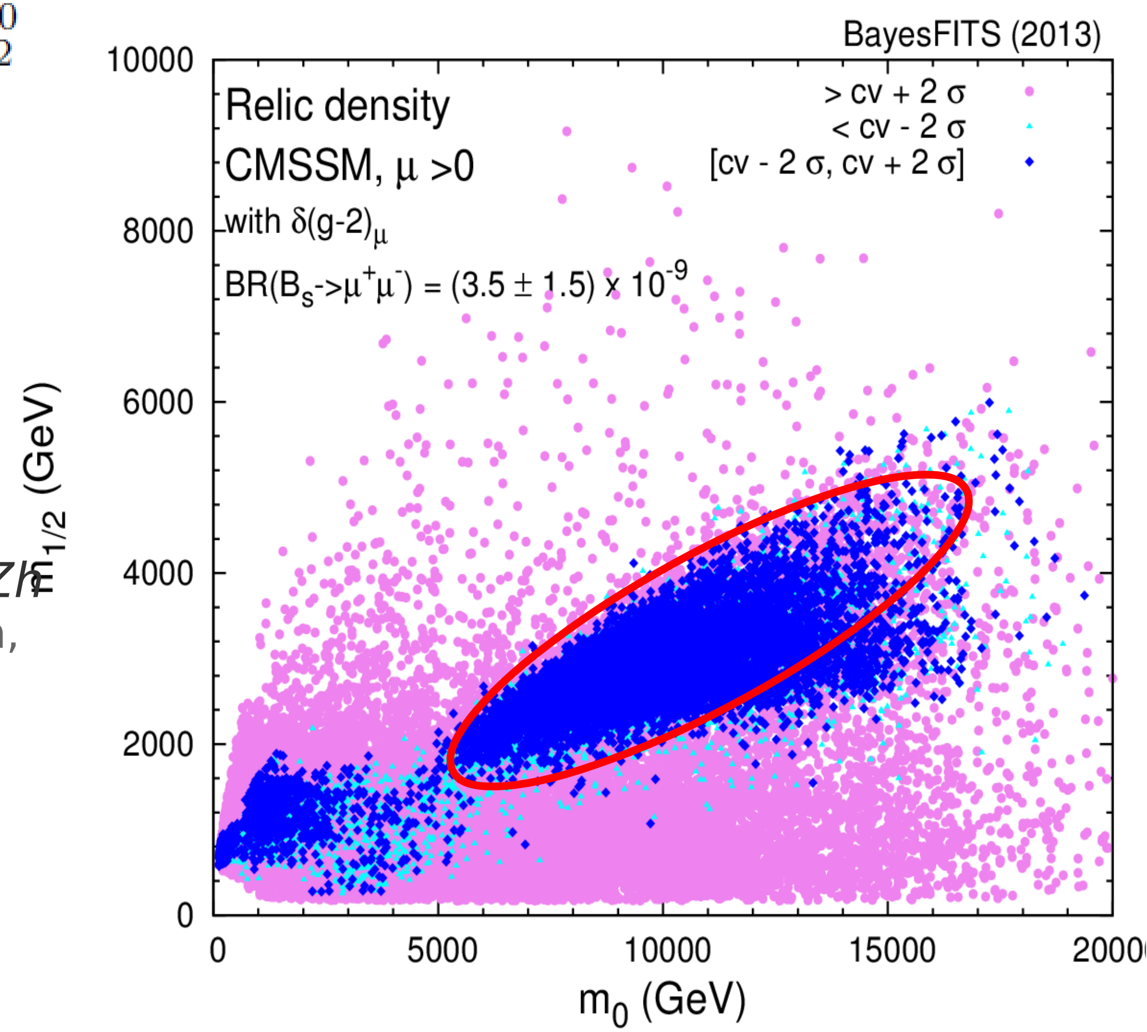
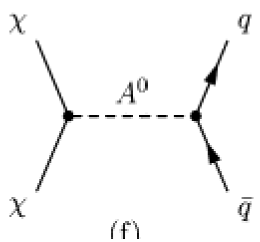


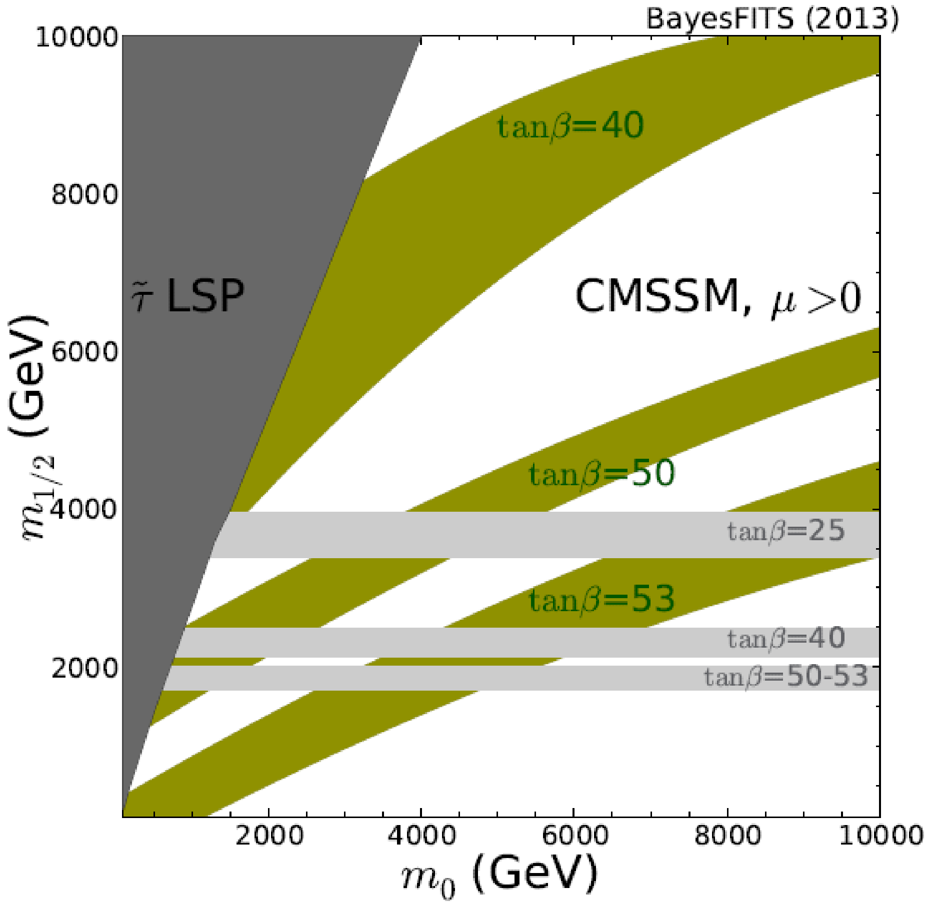
Relic density in the AF region

Resonance condition: $\mathbf{m_A \approx 2m_\chi}$

Relic density: $$\sigma v \approx \frac{\text{const}}{m_\chi^2} \frac{\tan^2\beta}{(4 - m_A^2/m_\chi^2)^2 + (\Gamma_A m_A/m_\chi^2)^2} \left(1 + \frac{v^2}{4}\right)$$

AF region





***tanβ* very limited:**

48-55 (μ>0)

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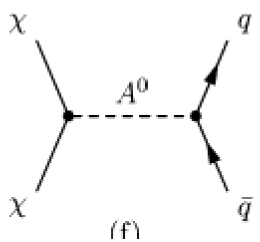
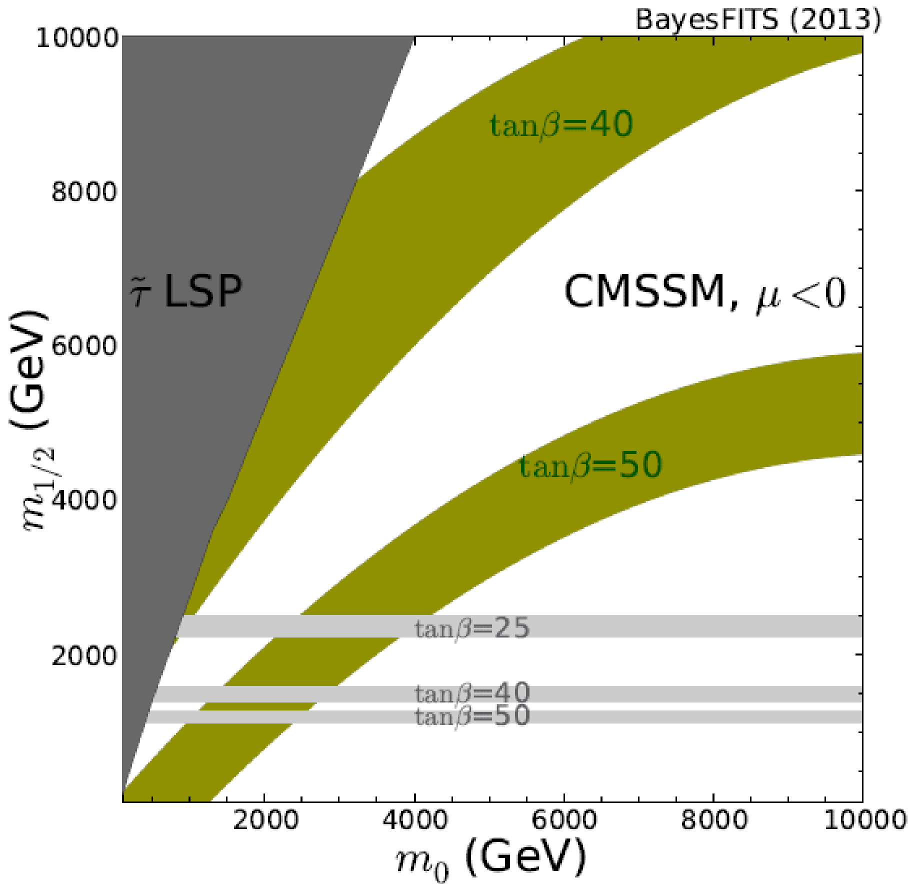
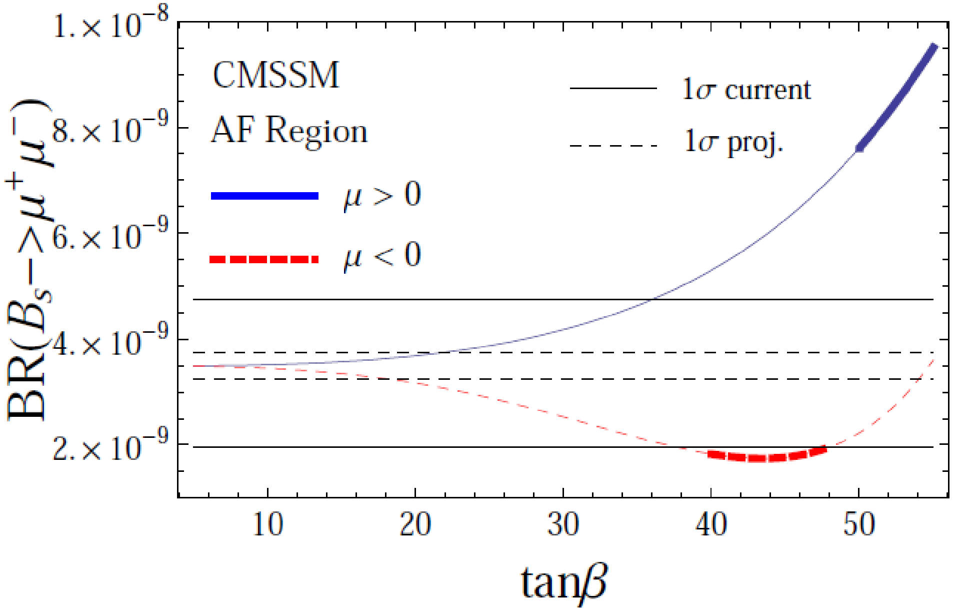




***tanβ* very limited:**

38-50 (μ<0)

BR($B_s \to \mu^+\mu^-$) in the AF



dominant chargino-squark contribution

$$C_{S,P} = \mp \frac{m_\mu}{4\sin^2\theta_W M_W^2}\frac{\tan^3\beta}{m_A^2}\mathcal{F}_{\rm LO}$$

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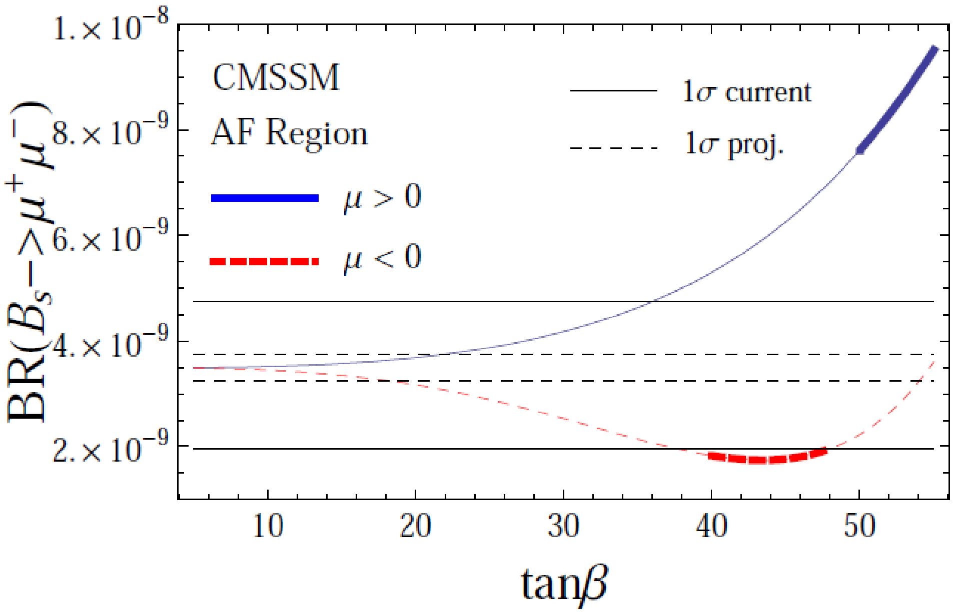

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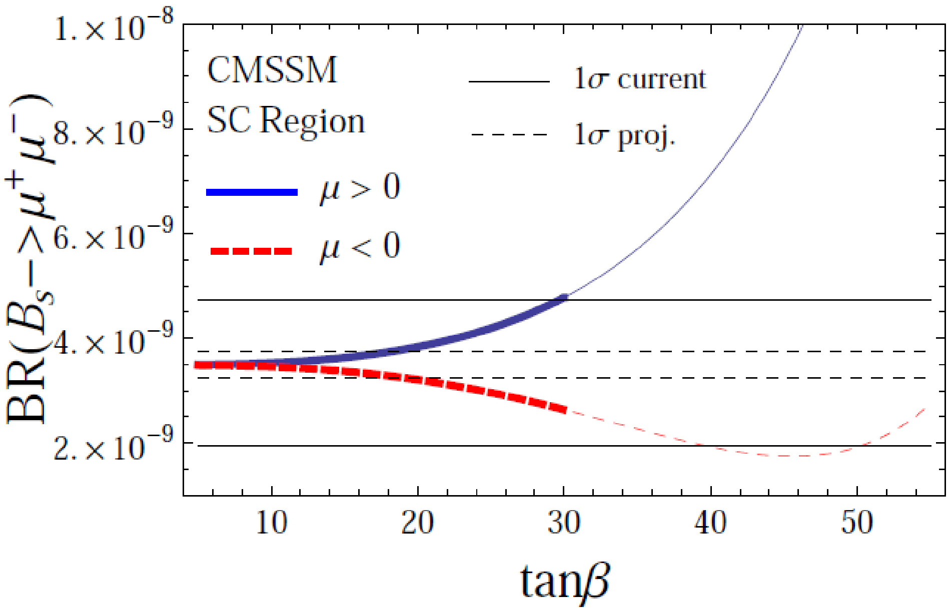
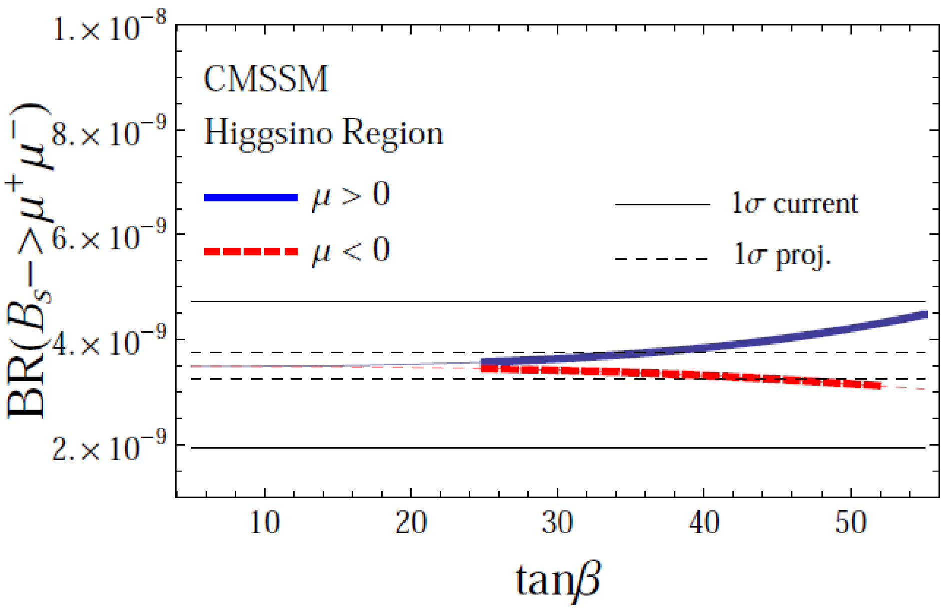




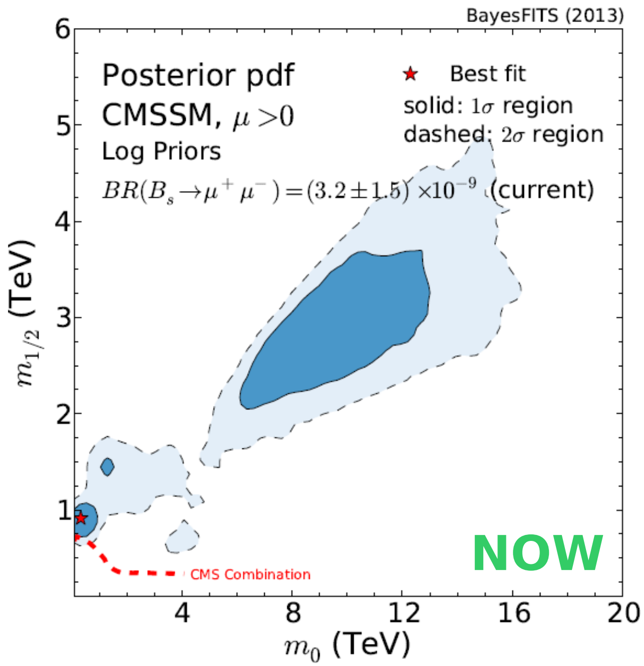
BR($B_s \to \mu^+\mu^-$) - ultimate precision

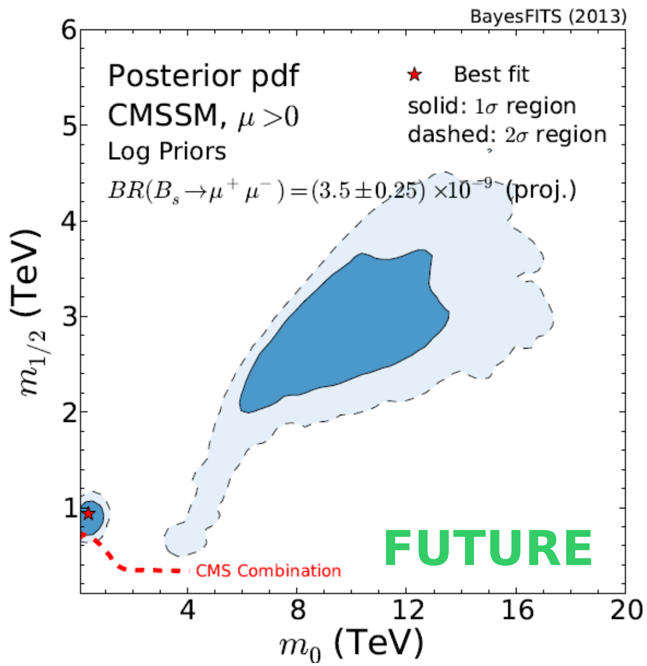
Experimental error (~300 fb^{-1}) → 5%

Theoretical error reduced to 5%

Central value ~ SM

BR(Bs → μ+μ-)=3.5 ± 0.25 x 10^{-9}

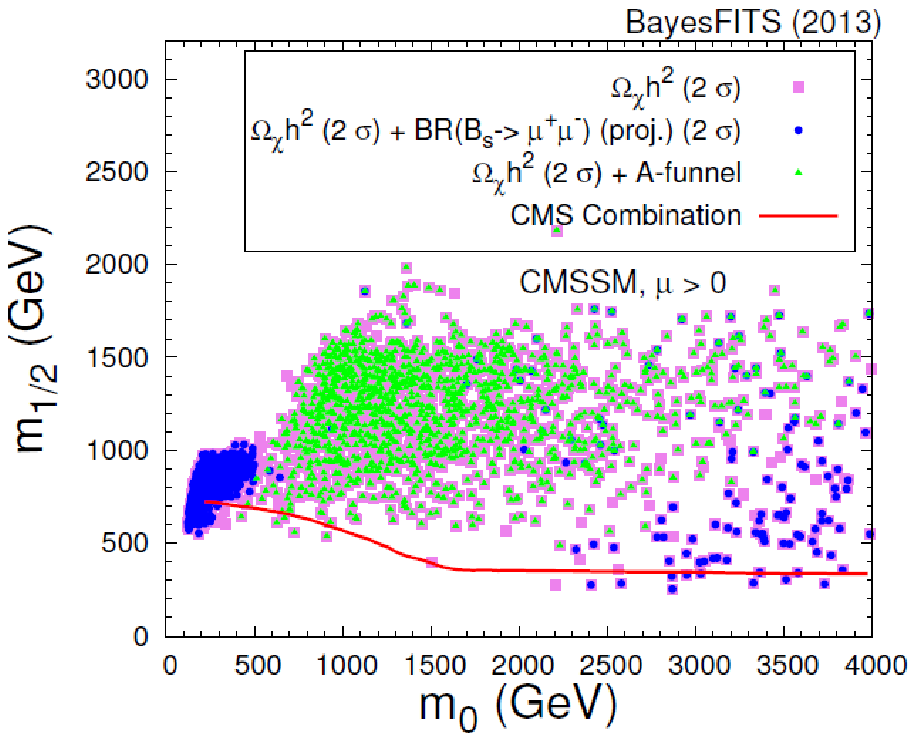


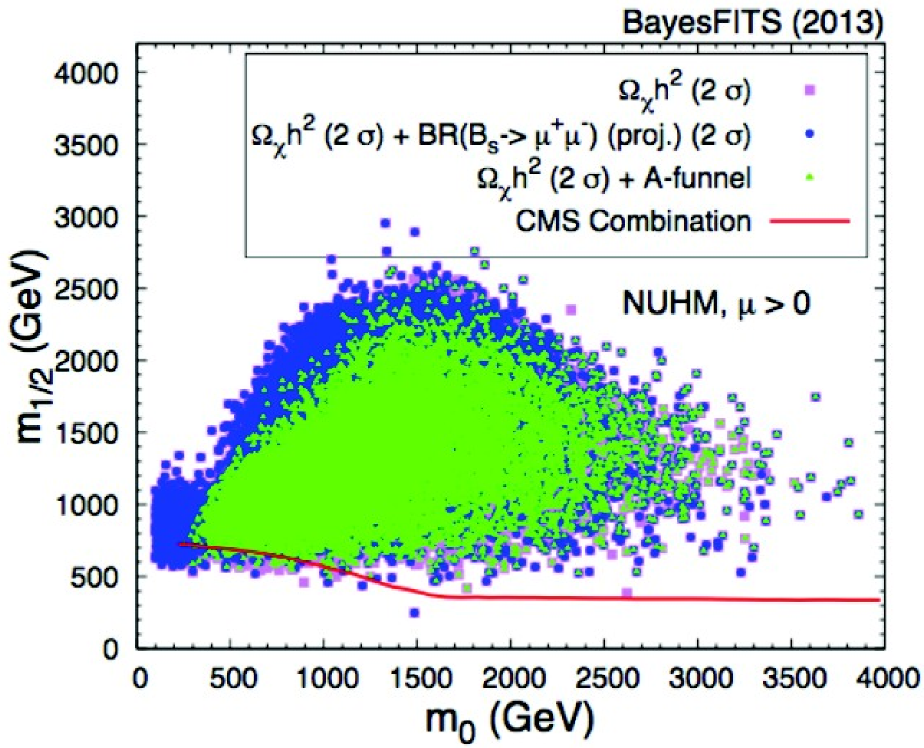


AF region is gone!

$B_s \to \mu^+\mu^-$: CMSSM vs NUHM

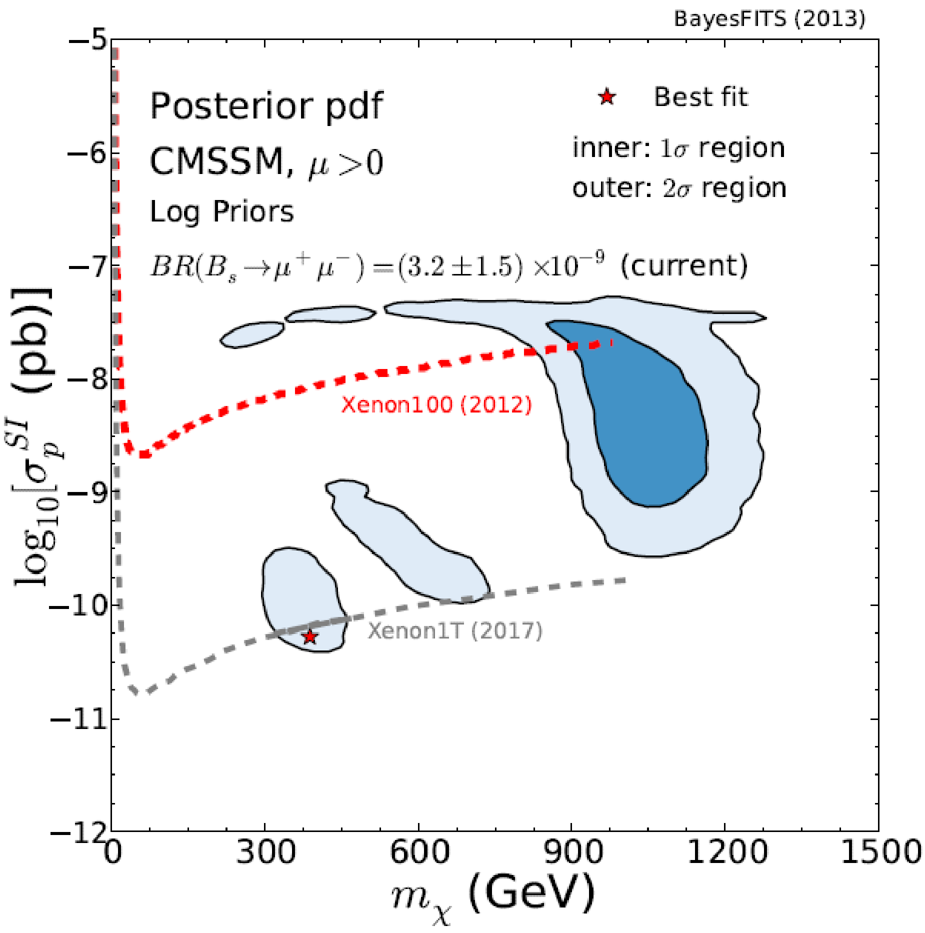
NUHM: m_0, $m_{1/2}$, A_0, $\tan\beta$, sgn(μ), m_{H_u}, m_{H_d}





$B_s \to \mu^+\mu^-$ not constraining

PROSPECTS FOR XENON1T



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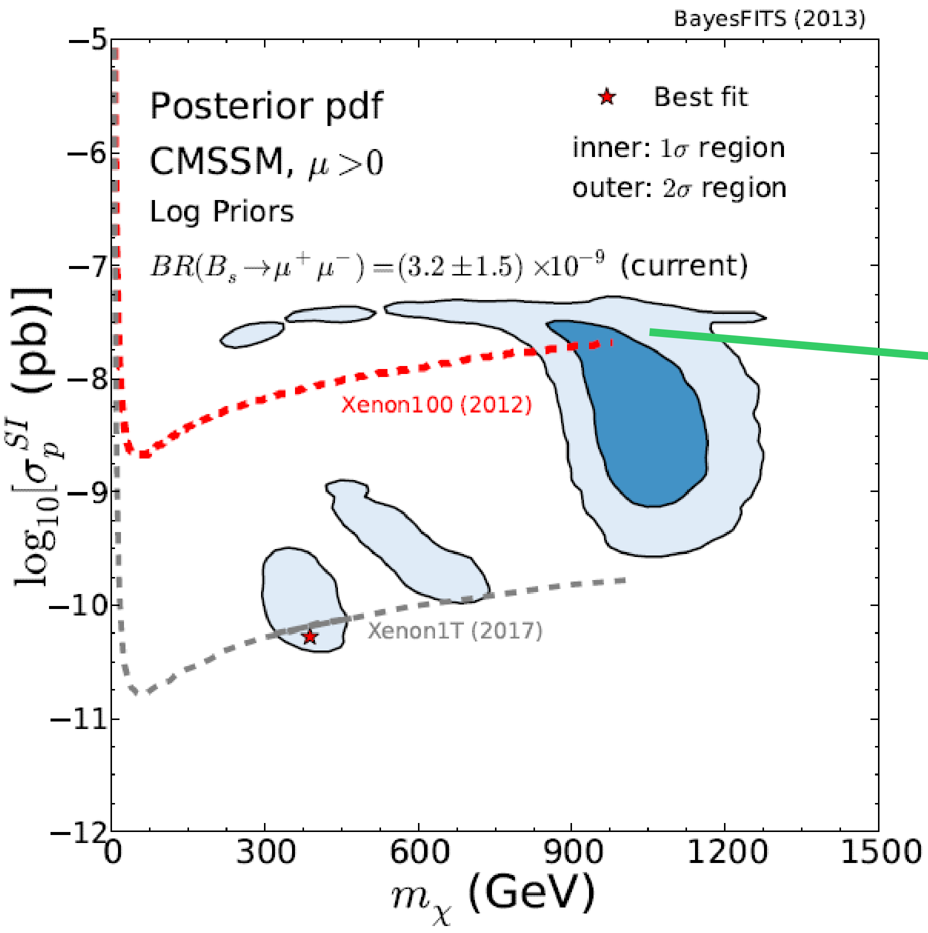
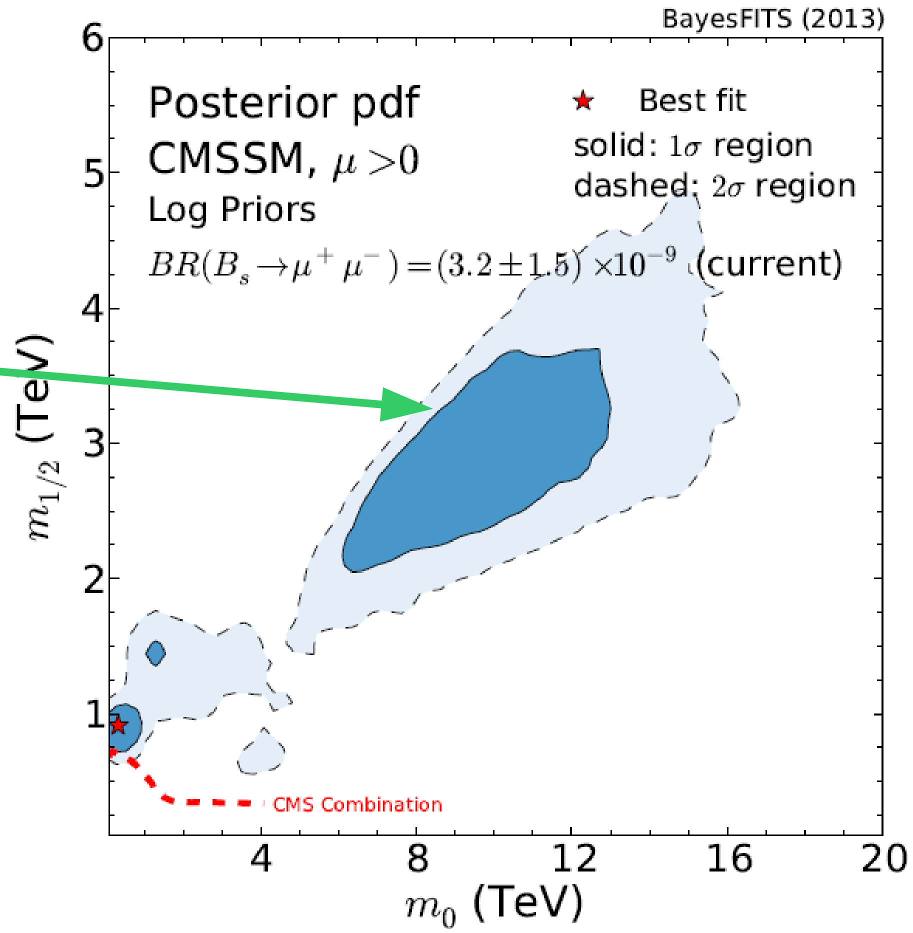
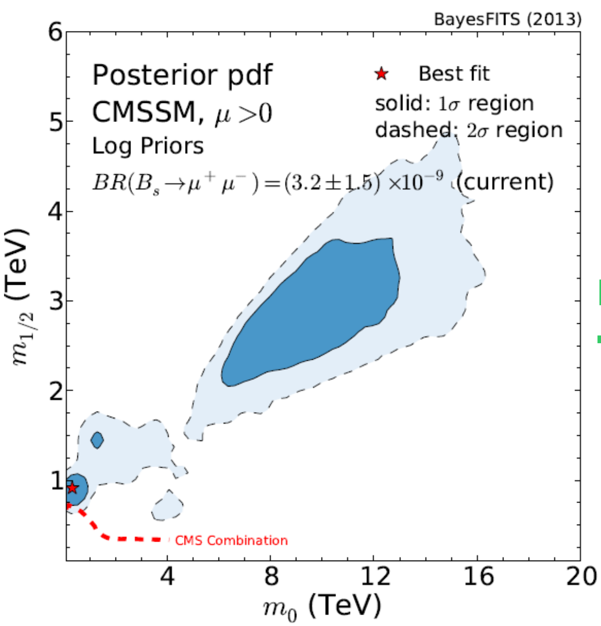
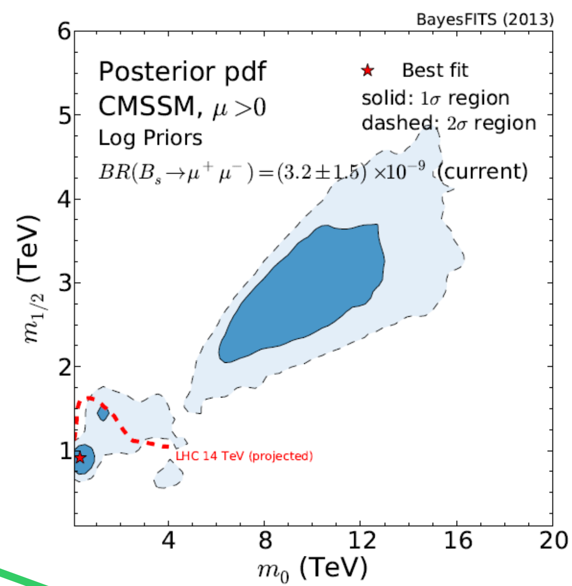




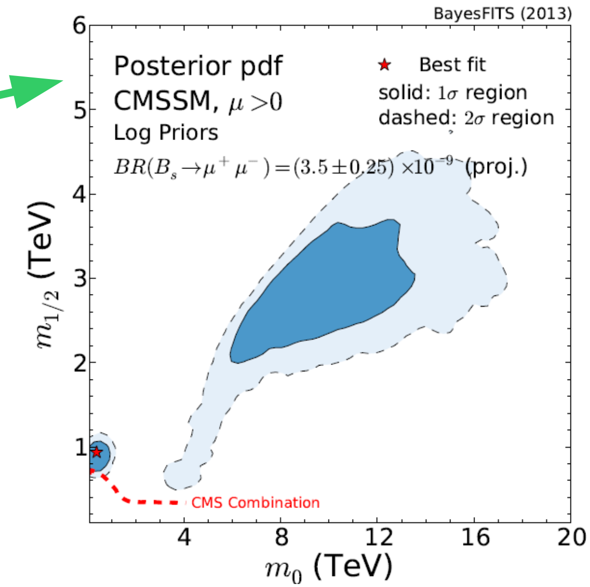
CMSSM – ultimate fate



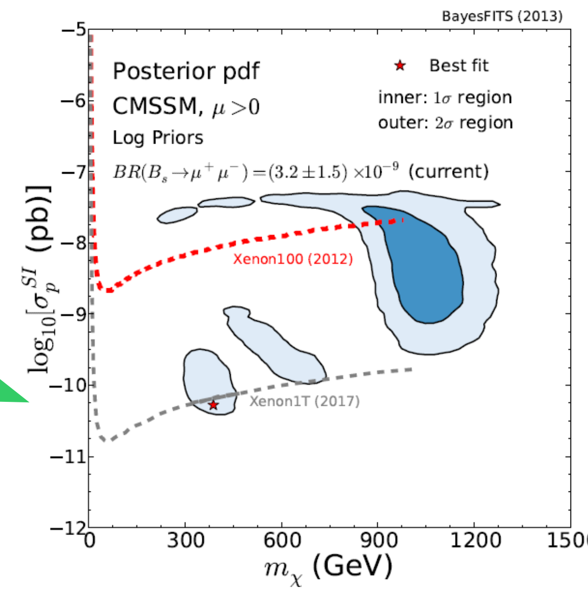
LHC 14 TeV



$BR(B_s \to \mu^+ \mu^-)$



XENON1T



CMSSM TOTALLY TESTABLE!

Conclusions

- There is a tension between the BR($B_s \to \mu^+\mu^-$) and relic density in the A-resonance region.
- The whole parameter space of CMSSM could be tested by the LHC 14 TeV and XENON-1T.
- It is important to use complementary experimental tests.

BACKUP

How to compare theory with experiment

Goal: to determine the allowed parameter space of the model under study given the data; to quantify the 'goodness' of the results

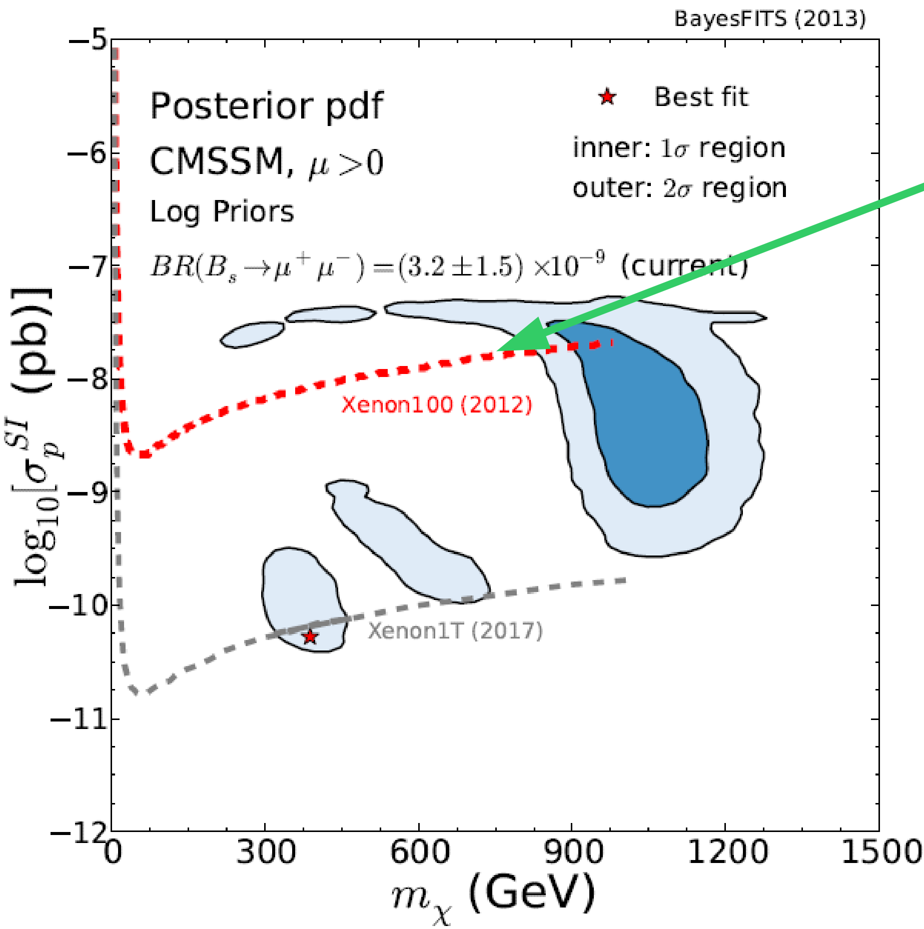
HOWEVER...

- A lot of data
- Different statistical meaning: measurement ± errors, 95% CL limits, 90% CL limits, theoretical errors, ...
- Sometimes hardly consistent (recent $R_{\gamma\gamma}$ from CMS and ATLAS)
- Sometimes favoring different parts of parameter space, eg. Higgs mass vs $(g-2)_\mu$

HOW TO TREAT IT CORRECTLY?

PROSPECTS FOR XENON1T

p9MSSM → *talk by E.Sessolo, 21.05.13*



Theoretical uncertainties:

- astrophysical
- nuclear physics (large)

$\Sigma_{\pi N} \sim \langle N|u\bar{u}+d\bar{d}|N\rangle$

↓

σ_p^{SI}

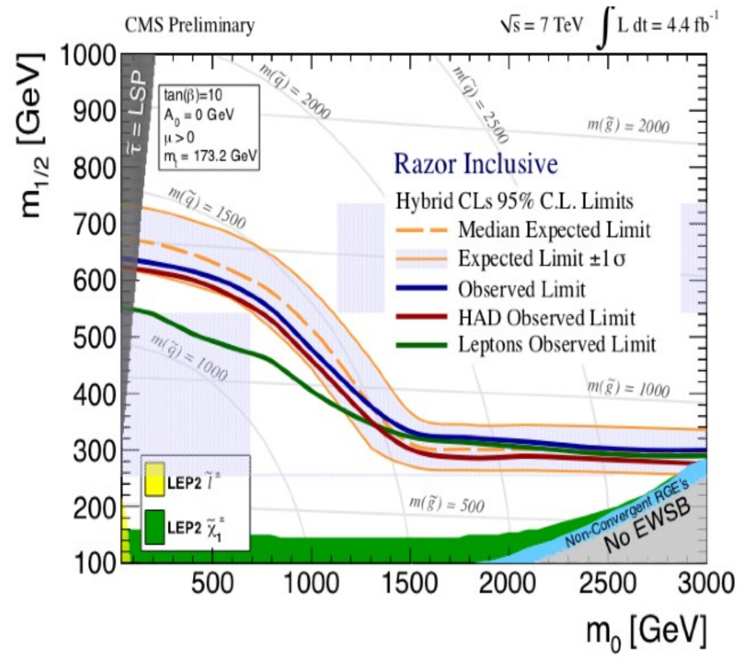
Different determinations of $\Sigma_{\pi N}$:
→ XENON100 constrains more/less

LHC limits on SUSY

p9MSSM → talk by E.Sessolo, 21.05.13

Official CMS/ATLAS results:

- only selected models: CMSSM, simplified models



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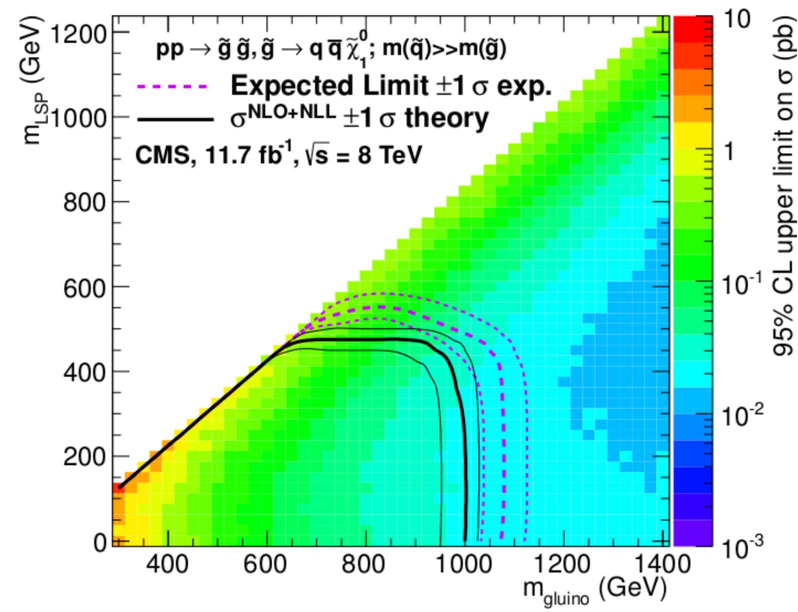
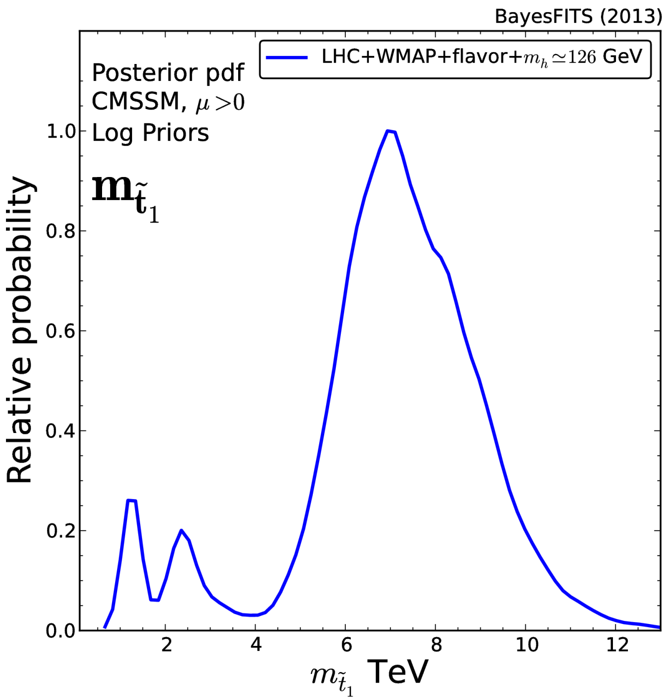
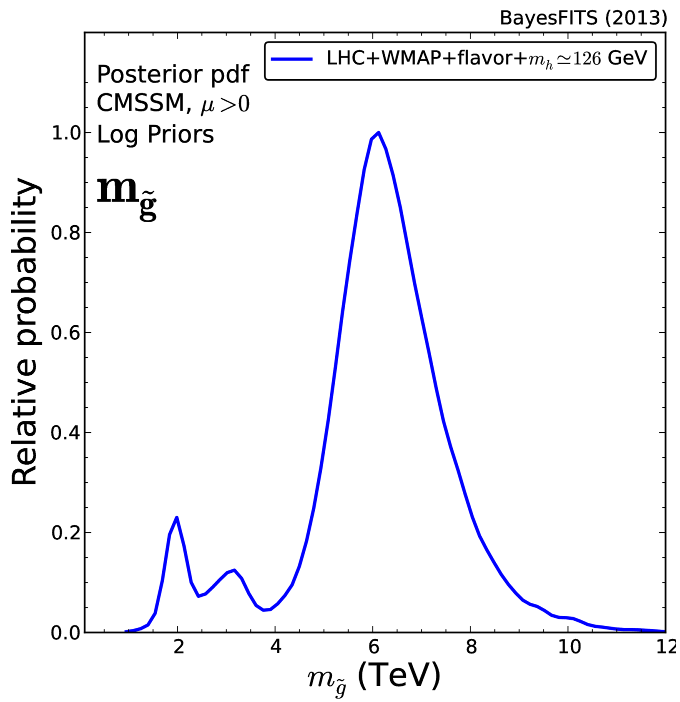
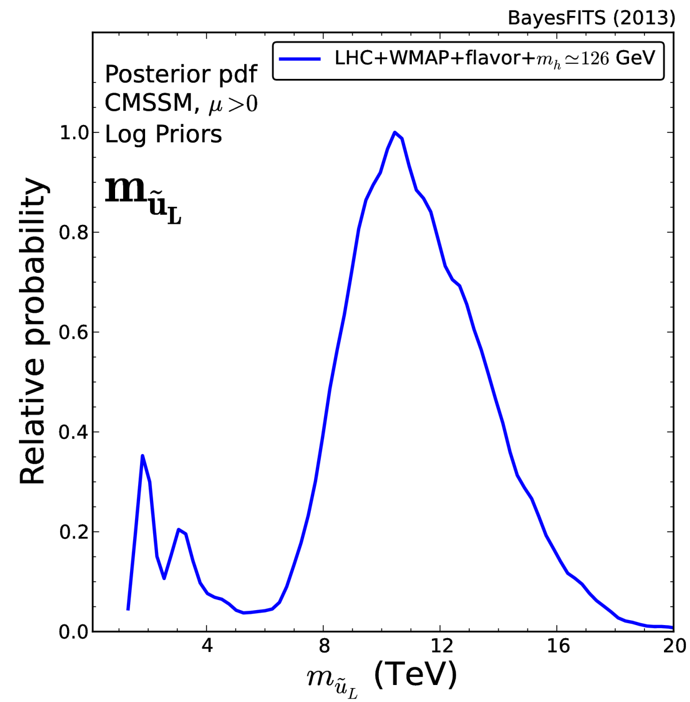


SUSY masses

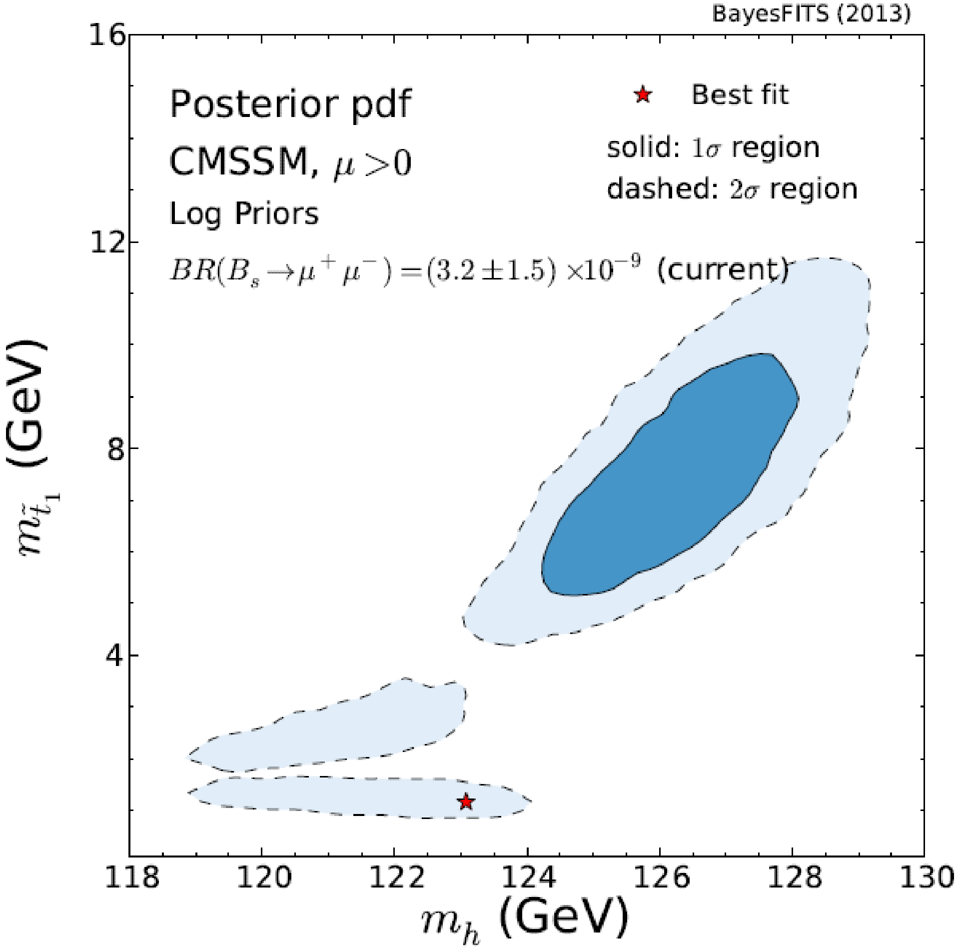






Light SUSY (~1 TeV) still allowed in CMSSM

Higgs mass at 126 GeV



1-loop:

$$\Delta m_h^2 = \frac{3 m_t^4}{4\pi^2 v^2}\left[\ln\left(\frac{M_{\rm SUSY}^2}{m_t^2}\right) + \frac{X_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{X_t^2}{12 M_{\rm SUSY}^2}\right)\right]$$

$$M_{\rm SUSY} \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

Higgs ~ 126 GeV requires:

$$X_t = A_t - \mu \cot\beta$$

- large M_{SUSY}
- large stop mixing