Implications of Higgs boson discovery and other data for SUSY - A theorist's perspective

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Outline

- ✧ Introduction: SUSY primer
- ✧ How to compare theory with data
- ✧ Implications of mh~126 GeV for favored SUSY mass scale
- ✧ Probe CMSSM with DM searches
- ✧ Implications of BR(B_s to mu mu)
- ✧ Beyond the CMSSM
- ✧ Comments on g-2
- ✧ Summary

Based on:

- Two ultimate tests of constrained SUSY, 1302.5956
- The Constrained NMSSM with a 125 GeV Higgs boson -- A global analysis, 1211.1693
- Constrained MSSM favoring new territories: The impact of new LHC limits and a 125 GeV Higgs boson, 1206.0264

…with updates

BayesFITS group: A. Fowlie (UoS), M. Kazana, K. Kowalska, S. Munir, E. Sessolo, S. Tsai, S. Trojanowski, LR, plus external collaborators (M. Misiak, K. Turzyński, K. Jedamzik)

Many open questions in particle physics

- **Origin of particle masses?**
- **Origin of EWSB?**
- **Origin and structure of flavor and CP X?**
- **New physics beyond the Standard Model?**
- **Dark matter in the Universe?**
- **Why is the Universe made up of matter and not antimatter?**
- **Unification of fundamental forces?**
- **Role of gravity?**
- **History of the early Universe?**
- **…**

LHC: chance to shed light on some of them

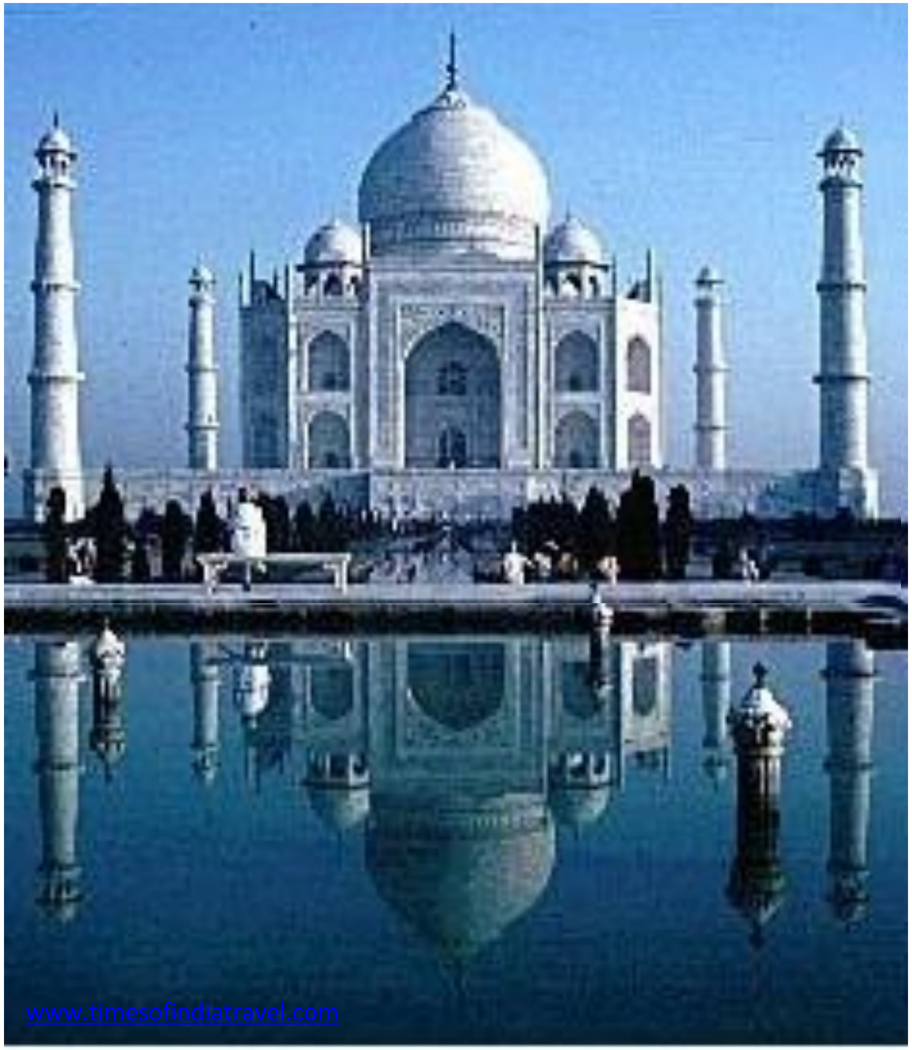
Many BSM ideas waiting to be tested…

- Supersymmetry of several sorts

…by far most attractive

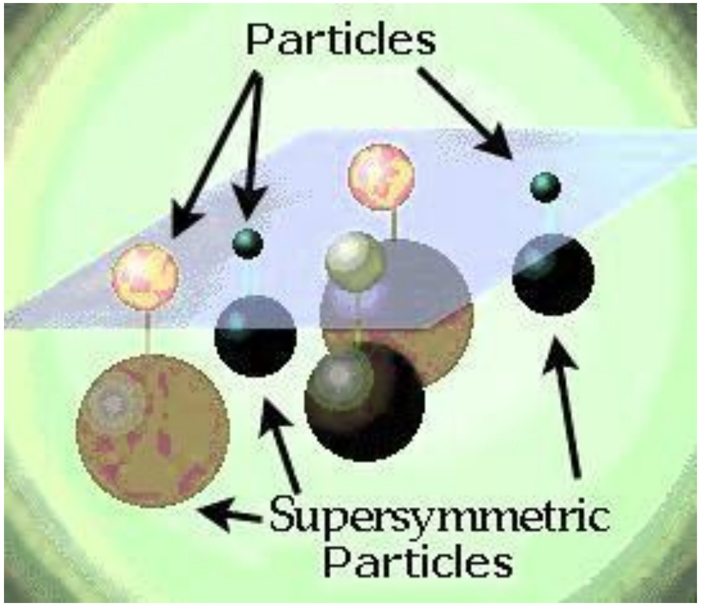
- Large/warped extra dimensions
- Low-scale gravity, microscopic black holes
- Little Higgs framework
- Extra gauge bosons
- Extra fermions
- Extra interactions
- …

Supersymmetry

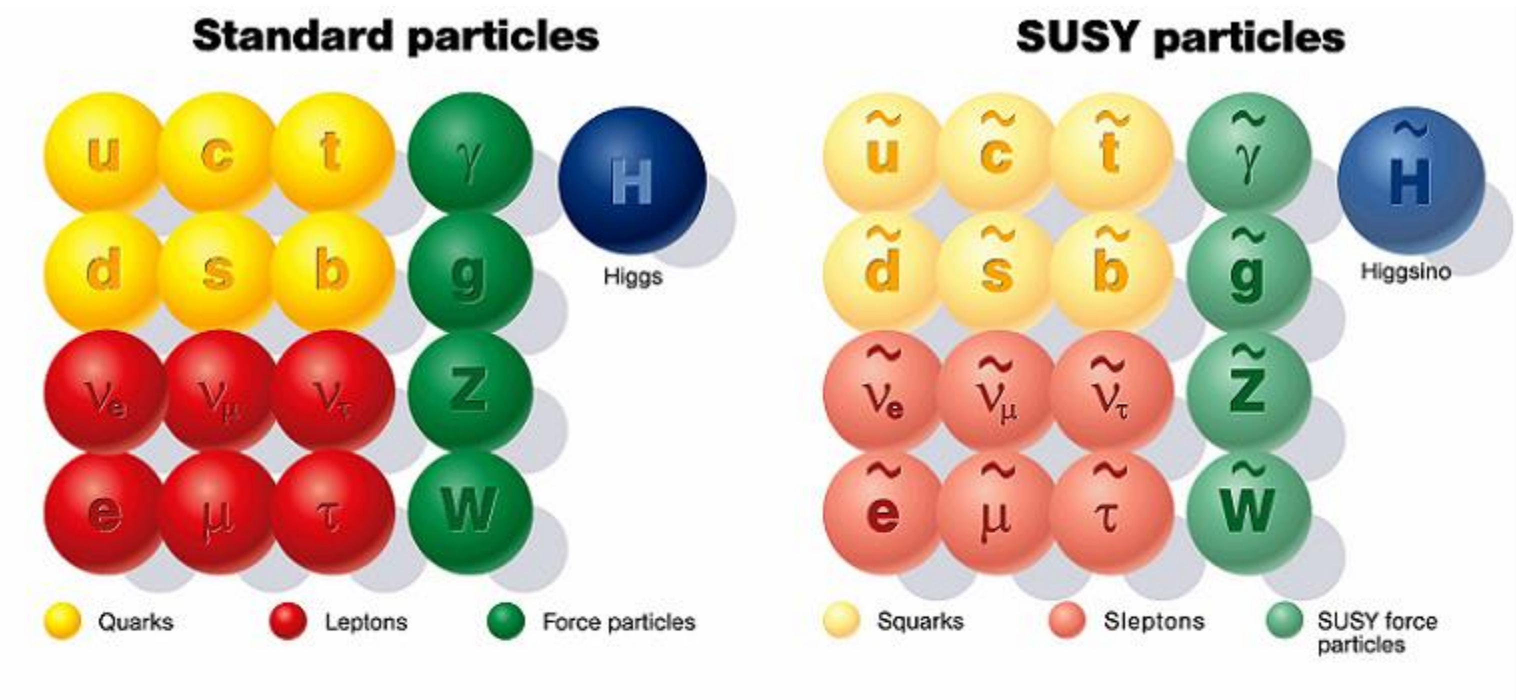


Symmetry among particles

bosons <-> fermions



Supersymmetry



SUSY: superpartners of known SM particles; mass expected at ~1 TeV

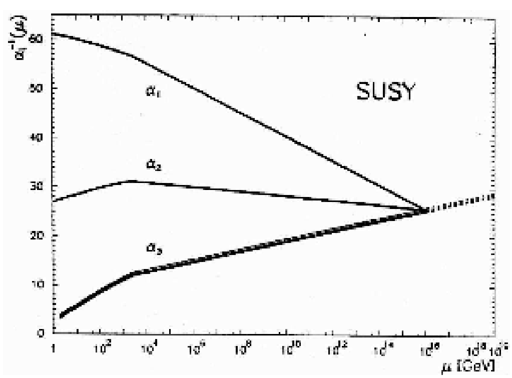
"neutralino" χ: lightest mass state of neutral gauginos and higgsinos

stable WIMP: excellent DM candidate

Supersymmetry

particle physics

- grand unification,
- supergravity, superstrings,
- hierarchy/naturalness/fine-tuning,
- fermion masses and mixings,
- neutrino masses and mixings,
- CP/flavor violation,
- . . .



astroparticle physics

- WIMP dark matter,
- E–WIMPs: gravitinos and axinos
- other relics

particle cosmology

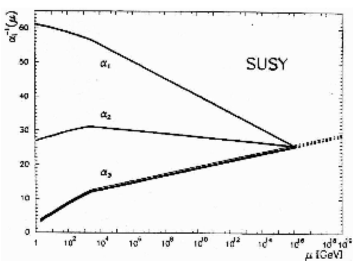
- cosmic inflation,
- baryogenesis/leptogenesis,
- relic production and decay after BB,
- effect on and constrains from BBN,
- effect on and constrains from CMB,
- . . .

SUSY has dominated theoretical efforts beyond the SM for the last two-three decades. . .

SUSY: Constrained or Not?

- **Constrained:**

Low-energy SUSY models with grand-unification relations among gauge couplings and (soft) SUSY mass parameters



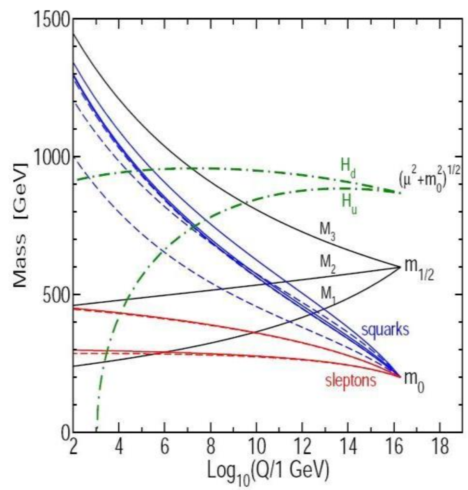


figure from hep-ph/9709356

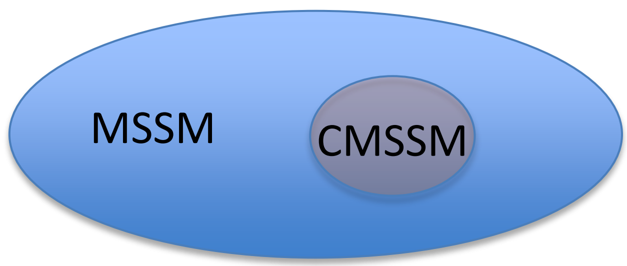
Virtues:
- Well-motivated
- Predictive (few parameters)
- Realistic

Many models:
- CMSSM (Constrained MSSM): 4+1 parameters
- NUHM (Non-Universal Higgs Model): 6+1
- CNMSSM (Constrained Next-to-MSSM) 5+1
- CNMSSM-NUHM: 7+1
- etc

- **Phenomenological:**

Supersymmetrized SM…

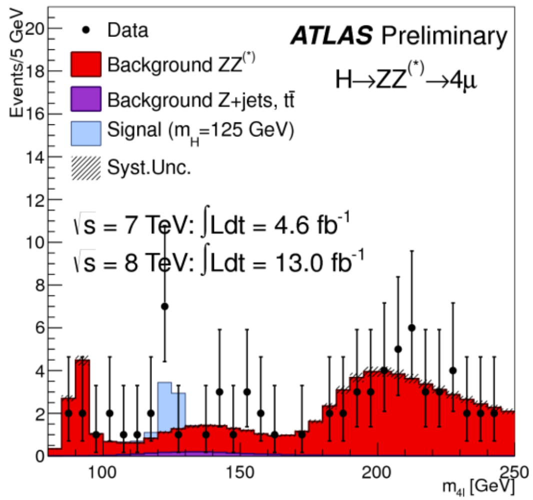
Features:
- Many free parameters
- Broader than constrained SUSY

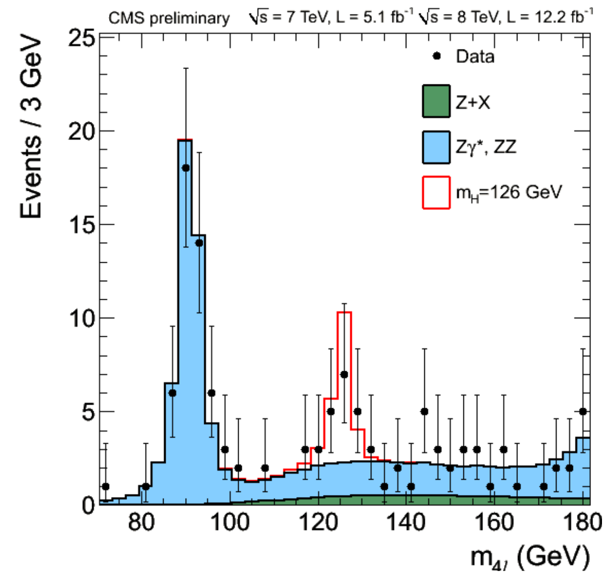


Many models:
- general MSSM – over 120 params
- MSSM + simplifying assumptions
- pMSSM: MSSM with 19 params
- p9MSSM, p12MSSM, pnMSSM, …

Main news from the LHC so far…

- **Higgs(-like) particle at ~126 GeV**





- **No (convincing) deviations from the SM**

$$\mathrm{BR}(\overline{B}_s \to \mu^+\mu^-) = \left(3.2^{+1.5}_{-1.2}\right) \times 10^{-9}$$

- **Stringent lower limits on superparner masses**

SUSY masses close to 1 TeV scale…

…and from the media…

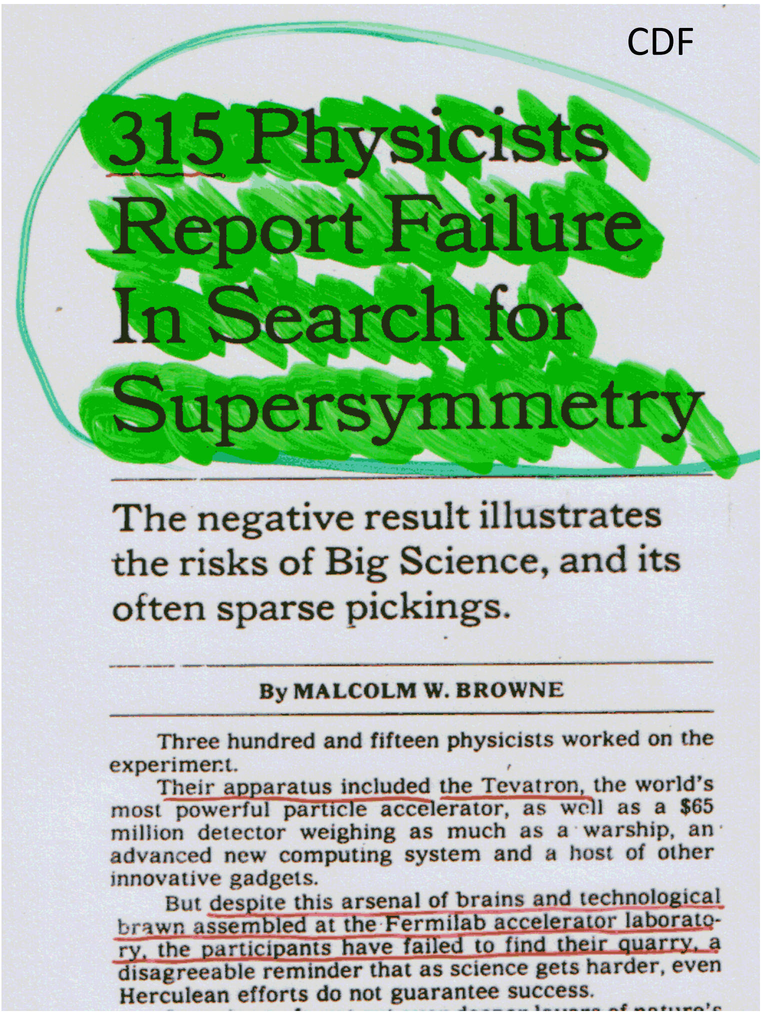
Is Supersymmetry Dead?

The grand scheme, a stepping-stone to string theory, is still high on physicists' wish lists. But if no solid evidence surfaces soon, it could begin to have a serious PR problem

SCIENTIFIC AMERICAN™

April 2012

Nothing new…


CDF

315 Physicists Report Failure In Search for Supersymmetry

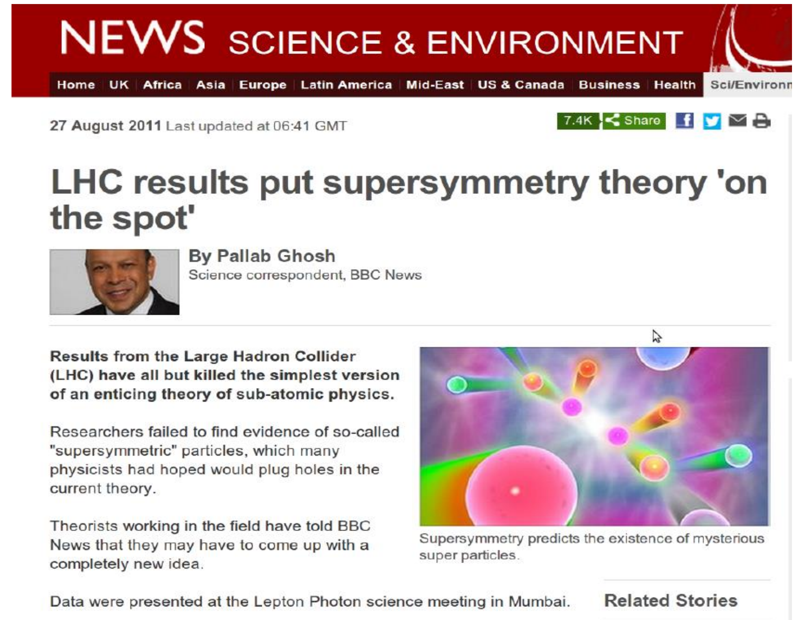
The negative result illustrates the risks of Big Science, and its often sparse pickings.

By MALCOLM W. BROWNE

Three hundred and fifteen physicists worked on the experiment.

Their apparatus included the Tevatron, the world's most powerful particle accelerator, as well as a $65 million detector weighing as much as a warship, an advanced new computing system and a host of other innovative gadgets.

But despite this arsenal of brains and technological brawn assembled at the Fermilab accelerator laboratory, the participants have failed to find their quarry, a disagreeable reminder that as science gets harder, even Herculean efforts do not guarantee success.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27 August 2011 Last updated at 06:41 GMT

7.4K Share

LHC results put supersymmetry theory 'on the spot'

By Pallab Ghosh
Science correspondent, BBC News

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.

Researchers failed to find evidence of so-called "supersymmetric" particles, which many physicists had hoped would plug holes in the current theory.

Theorists working in the field have told BBC News that they may have to come up with a completely new idea.

Data were presented at the Lepton Photon science meeting in Mumbai.

Supersymmetry predicts the existence of mysterious super particles.

Related Stories

Increasing energy, luminosity and the number of physicist failing to find SUSY have increased by factor of 10...

Constrained SUSY – still alive?

The constrained MSSM (CMSSM) paradigm is "hardly tenable"

At Open Symposium of the European Strategy Preparatory Group, Krakow, Poland, 10-12 Sept. 2012

Really?

Higgs discovery: ways to go

- SM confirmed – end of the story (and collider physics?)
- Higgs is fundamental - > SUSY
- Higgs is composite -> effective theory

In this talk: explore implications of Higgs properties for SUSY

Do not worry about theoretical and/or aesthetic arguments (fine-tuning, naturalness, etc).

See what the data says!

126 GeV Higgs boson and SUSY

- **Is the discovered Higgs boson consistent with SUSY? Which SUSY model(s)?**
- **What does the mass of ~126 GeV tell us about superpartner masses?**
- **Is a SM-like Higgs boson a natural prediction of SUSY, or rather an oddity?**
- **Is the found Higgs consistent with all other relevant observational constraints on SUSY?**
- **…**

SUSY - most important constraints:

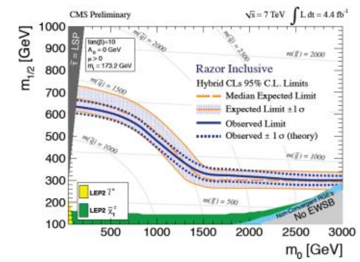
- **Higgs mass**

  CMS: $m_h \sim$ 125.8 GeV (in ZZ); m_h = 124.9. GeV (in γγ)

  ATLAS: m_h = 124.3 GeV (in ZZ); m_h = 126.8 GeV (in γγ)

- **Direct search limits**

  Lower limit…



- **Dark matter density**

  Positive measurement, **inconsistent with SM**

- **B_s -> mu mu**

$$\mathrm{BR}(\overline{B}_s \to \mu^+\mu^-) = \left(3.2^{+1.5}_{-1.2}\right) \times 10^{-9}$$

  LHCb (Nov 2012)

- **Other flavor (b to s gamma, etc)**
- **EW observables (M_W,…)**
- **(g-2)_muon**

How to compare theory with experiment

- Rigid step-function application of limits/allowed ranges (e.g. DM relic abundance, etc) **Mahmoudi et al, Hewett et al, …**
- **F**requentist (chi^2-based) **MasterCode, Fittino, …**
- **B**ayesian **BayesFITS, Allanach, SuperBayes, Balazs,…**

Frequentist: "probability is the number of times the event occurs over the total number of trials, in the limit of an infinite series of equiprobable repetitions"

Bayesian: "probability is a measure of the degree of belief about a proposition"

Both F and B are based on the likelihood function.

The Likelihood function

Central object: Likelihood function

- **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):

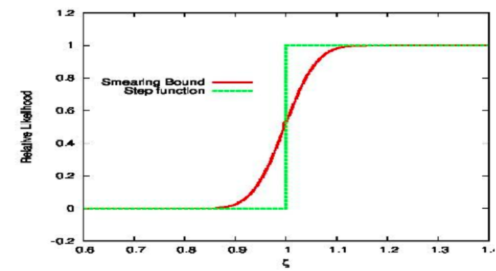
$$\sigma \to s = \sqrt{\sigma^2+\tau^2}$$

TH error "smears out" the EXPTAL range

- for several uncorrelated observables (assumed Gaussian):

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

- **Limits:**



- Smear out bounds.
- Add theory error.

- **LHC direct limits:**
  - Need careful treatment. Typically use Poisson.

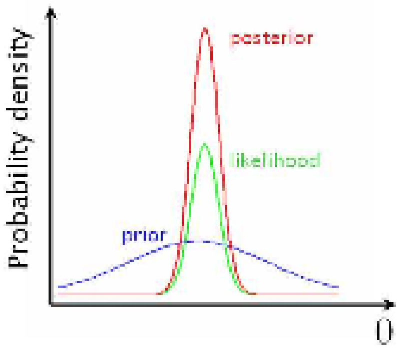
Bayesian statistics

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).

Posterior → credible regions at chosen CL



Minimum chi2 approach: find best-fit and draw confidence regions about it

Bayesian Approach

<u>Prior</u> (info on model *prior* to seeing the data)

<u>Likelihood</u> (same as frequentist)

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

<u>Posterior PDF</u> (the main Bayesian quantity)

<u>Evidence</u> (model likelihood)

<u>Marginalization:</u> $p(\psi_{i=1,..,r}|d) = \int p(m|d)d^{n-r}m$

Posterior → credible regions at chosen CL

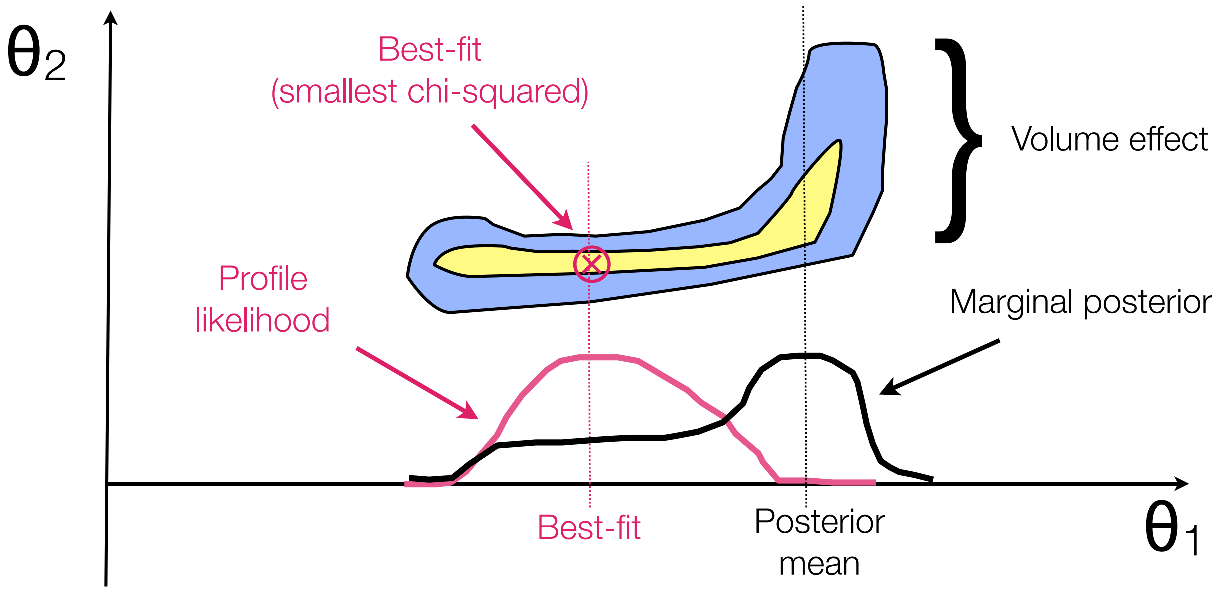
Bayesian ≠ Frequentist

Marginal posterior:

$$P(\theta_1|D) = \int L(\theta_1, \theta_2) p(\theta_1, \theta_2) d\theta_2$$

Profile likelihood:

$$L(\theta_1) = max_{\theta_2} L(\theta_1, \theta_2)$$



(2D plot depicts likelihood contours - prior assumed flat over wide range)

Trotta

Bayesian ≠ Frequentist

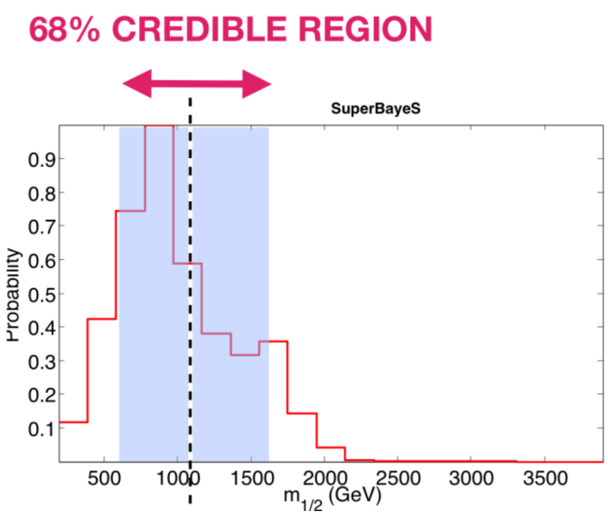
- **Bayesian**

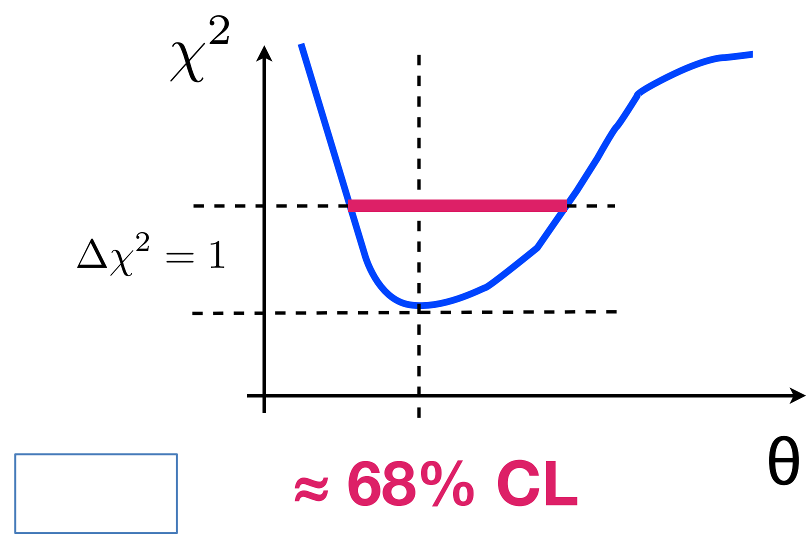
Best fit plays no special role.

Central object: posterior probability

- **Frequentist**

Determine best-fit parameters:
find minimum of -2Log(Likelihood)=chi^2





Determine posterior credible regions: e.g. symmetric interval around the mean containing 68% of samples

Determine approximate confidence intervals: Local Δ(chi-squared) method

Trotta

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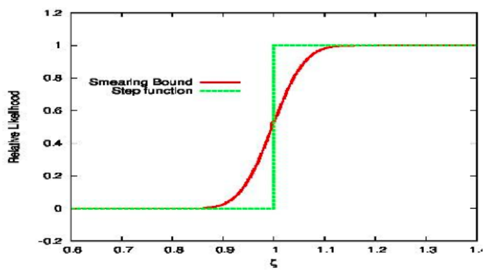
- **Limits:**



- Smear out bounds.
- Add theory error.

- **LHC direct limits:**
  - Need careful treatment. Typically use Poisson.

Constrained Minimal Supersymmetric Standard Model (CMSSM)

G. L. Kane, C. F. Kolda, L. Roszkowski and J. D. Wells, Phys. Rev. D 49 (1994) 6173

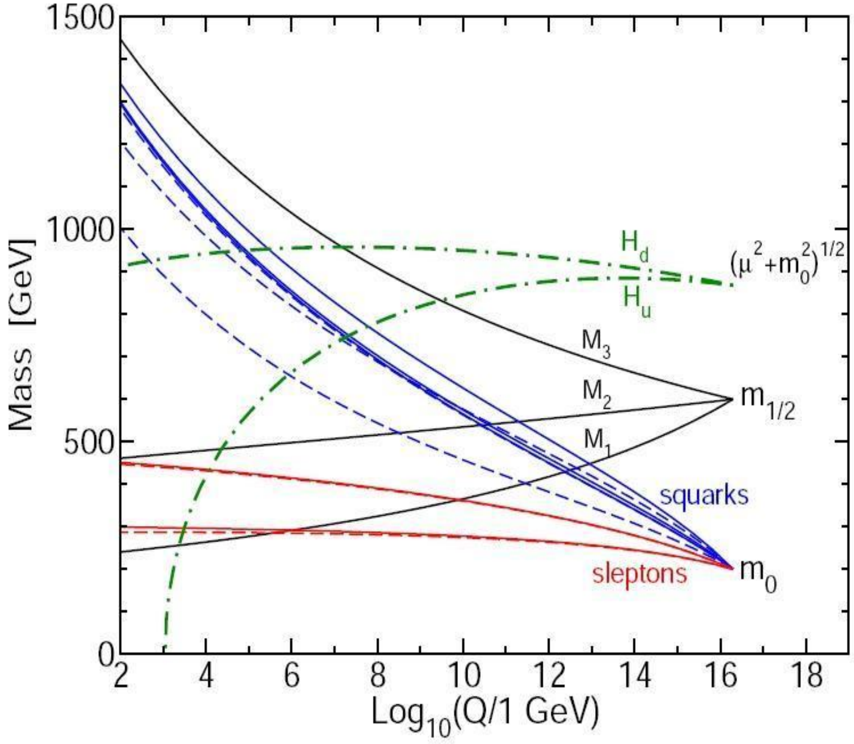


figure from hep-ph/9709356

At $M_{\rm GUT} \simeq 2\times 10^{16}\,{\rm GeV}$:

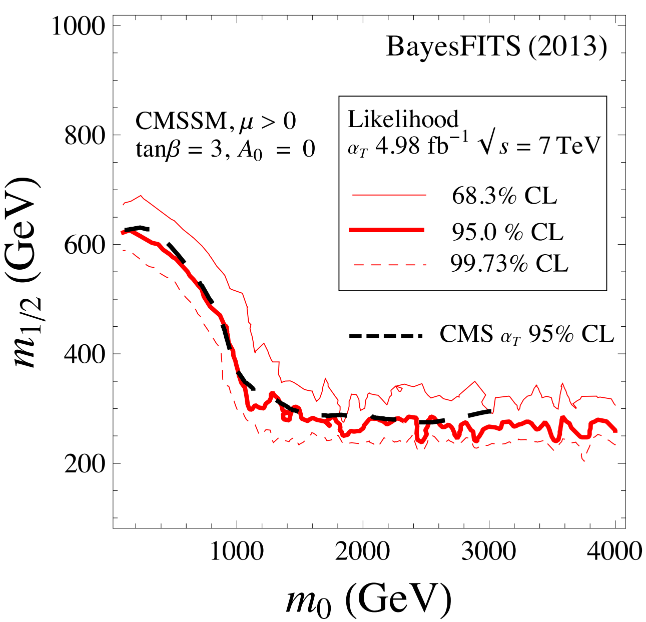
- gauginos $M_1 = M_2 = m_{\tilde g} = m_{1/2}$
- scalars $m^2_{\tilde q_i} = m^2_{\tilde l_i} = m^2_{H_b} = m^2_{H_t} = m_0^2$
- 3–linear soft terms $A_b = A_t = A_0$
- radiative EWSB $\mu^2 = \frac{m^2_{H_b} - m^2_{H_t}\tan^2\beta}{\tan^2\beta - 1} - \frac{m_Z^2}{2}$
- five independent parameters:

  $m_{1/2},\ m_0,\ A_0,\ \tan\beta,\ {\rm sgn}(\mu)$
- well developed machinery to compute masses and couplings

Reproducing CMS limits on SUSY

We approximate CMS limits by deriving likelihood maps

First, validate our method:

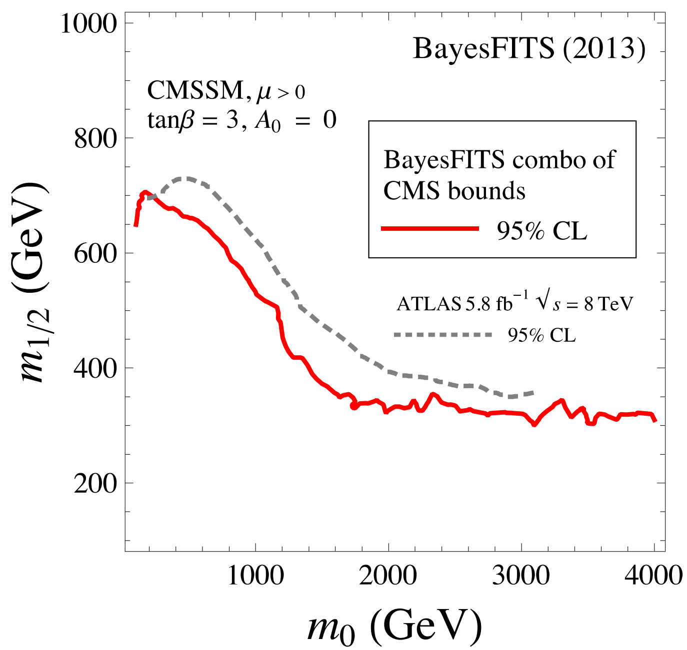


Excellent agreement

Next, derive combined CMS limit based on datasets:

α_T 11.7/fb, $\sqrt{s} = 8$ TeV

Razor 4.4/fb, $\sqrt{s} = 7$ TeV



Applies to both signs of mu
And to similar models: NUHM, CNMSSM,…

Below will use combined CMS limit via likelihood function

Specialty of BayesFITS

CMSSM: numerical scans

- **Perform random scan over 4 CMSSM +4 SM (nuisance) parameters <u>simultaneously</u>**

- Very wide ranges:

$$100\,\mathrm{GeV} \leq m_0 \leq 20\,\mathrm{TeV}$$
$$100\,\mathrm{GeV} \leq m_{1/2} \leq 10\,\mathrm{TeV}$$
$$-20\,\mathrm{TeV} \leq A_0 \leq 20\,\mathrm{TeV}$$
$$3 \leq \tan\beta \leq 62$$

- Use Nested Sampling algorithm to evaluate posterior
- Use 4 000 live points

Nuisance	Description	Central value $\pm$ std. dev.	Prior Distribution
M_t	Top quark pole mass	$173.5 \pm 1.0\,\mathrm{GeV}$	Gaussian
$m_b(m_b)^{\overline{MS}}_{\mathrm{SM}}$	Bottom quark mass	$4.18 \pm 0.03\,\mathrm{GeV}$	Gaussian
$\alpha_s(M_Z)^{\overline{MS}}$	Strong coupling	0.1184 ± 0.0007	Gaussian
$1/\alpha_{\mathrm{em}}(M_Z)^{\overline{MS}}$	Inverse of em coupling	127.916 ± 0.015	Gaussian

Use Bayesian approach (posterior)

Hide and seek with SUSY

The experimental measurements that we apply to constrain the CMSSM's parameters. Masses are in GeV.

Measurement	Mean or Range	Error: (Exp., Th.)	Distribution
Combination of:			
CMS razor 4.4/fb , $\sqrt{s} = 7\,\text{TeV}$	See text	See text	Poisson
CMS α_T 11.7/fb , $\sqrt{s} = 8\,\text{TeV}$	See text	See text	Poisson
m_h by CMS	$125.8\,\text{GeV}$	$0.6\,\text{GeV}, 3\,\text{GeV}$	Gaussian
$\Omega_\chi h^2$	0.1120	0.0056, 10%	Gaussian
$\delta\,(g-2)_\mu^{\text{SUSY}} \times 10^{10}$	28.7	8.0, 1.0	Gaussian
$\text{BR}\left(\overline{B} \to X_s\gamma\right) \times 10^4$	3.43	0.22, 0.21	Gaussian
$\text{BR}\,(B_u \to \tau\nu) \times 10^4$	1.66	0.33, 0.38	Gaussian
ΔM_{B_s}	$17.719\,\text{ps}^{-1}$	$0.043\,\text{ps}^{-1}$, $2.400\,\text{ps}^{-1}$	Gaussian
$\sin^2\theta_{\text{eff}}$	0.23116	0.00012, 0.00015	Gaussian
M_W	80.385	0.015, 0.015	Gaussian
$\text{BR}\left(B_s \to \mu^+\mu^-\right)_{\text{current}} \times 10^9$	3.2	+1.5 − 1.2, 10% (0.32)	Gaussian
$\text{BR}\left(B_s \to \mu^+\mu^-\right)_{\text{proj}} \times 10^9$	3.5 (3.2*)	0.18 (0.16*), 5% [0.18 (0.16*)]	Gaussian

SM value: $\simeq 3.5 \times 10^{-9}$

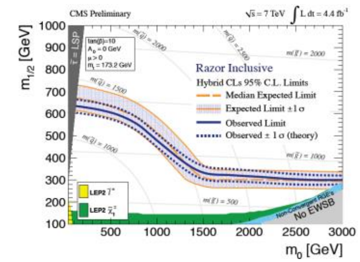
10 dof

SUSY - most important constraints:

- **Higgs mass**

CMS: m_h ~ 125.8 GeV (in ZZ); m_h = 124.9. GeV (in γγ)

ATLAS: m_h = 124.3 GeV (in ZZ); m_h = 126.8 GeV (in γγ)



- **Direct search limits**

Lower limit…

- **Dark matter density**

Positive measurement, **inconsistent with SM**

- **B_s -> mu mu**

$$\mathrm{BR}(\overline{B}_s \to \mu^+\mu^-) = \left(3.2^{+1.5}_{-1.2}\right) \times 10^{-9}$$

LHCb (Nov 2012)

- **Other flavor (b to s gamma, etc)**
- **EW observables (M_W,…)**
- **(g-2)_muon**

~126 Gev Higgs in SUSY

- **In SUSY m_h is a calculated quantity.**
- **1-loop corr: positive, up to ~45 GeV**

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

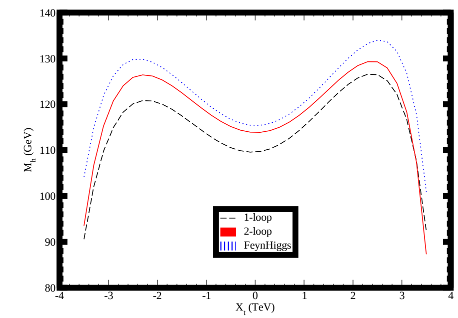
- **2-loop corr: negative, ~3 GeV**

  two most complete calculations differ by a 2-5 GeV

  (DR-bar (Slavich,…) used in SoftSusy, Spheno, Suspect, and on-shell (Hollik,…) in FeynHiggs

Substantial theory error!

Djouadi, arXiv:hep-ph/0503173



$$M_{\rm SUSY} \equiv \sqrt{m_{\tilde t_1} m_{\tilde t_2}}$$

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

Two ways to obtain m_h~126 GeV:

1. **increase M_SUSY -> heavy superparners!**

or

2. **take large |X_t|~|A_t|-> stop_1 at ~1TeV**

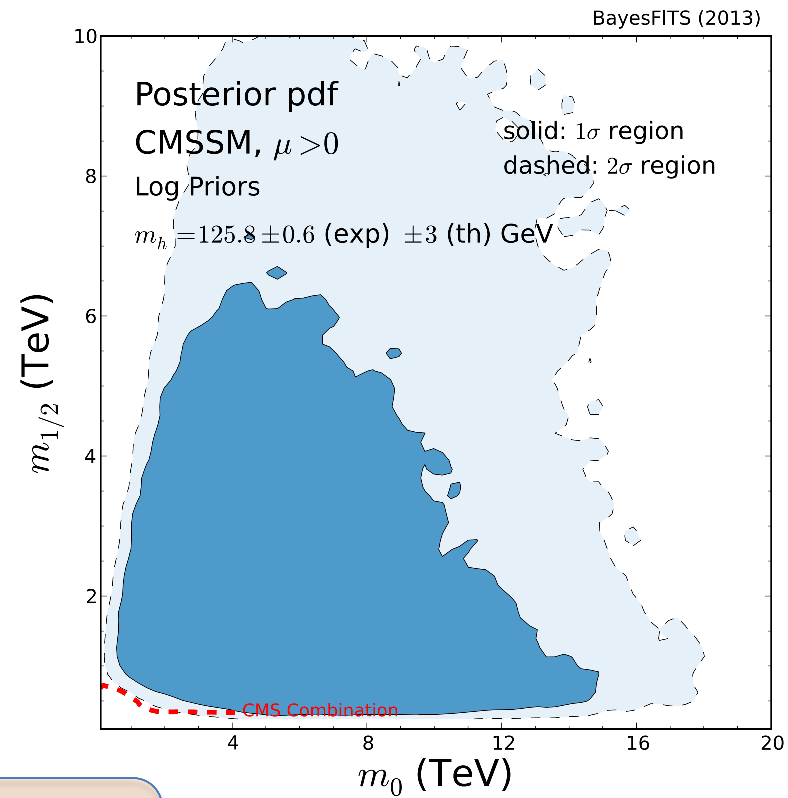
Applies to SUSY generally, not just constrained models.

~126 GeV Higgs in the CMSSM

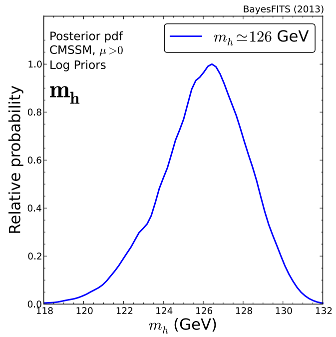
- **Include <u>only</u> m_h~126 GeV and lower limits from direct SUSY searches**

$$\mathcal{L} \sim e^{\frac{(m_h - 125.8\,\mathrm{GeV})^2}{\sigma^2+\tau^2}}$$

$$\sigma = 0.6\ \mathrm{GeV}, \tau = 2\ \mathrm{GeV}$$



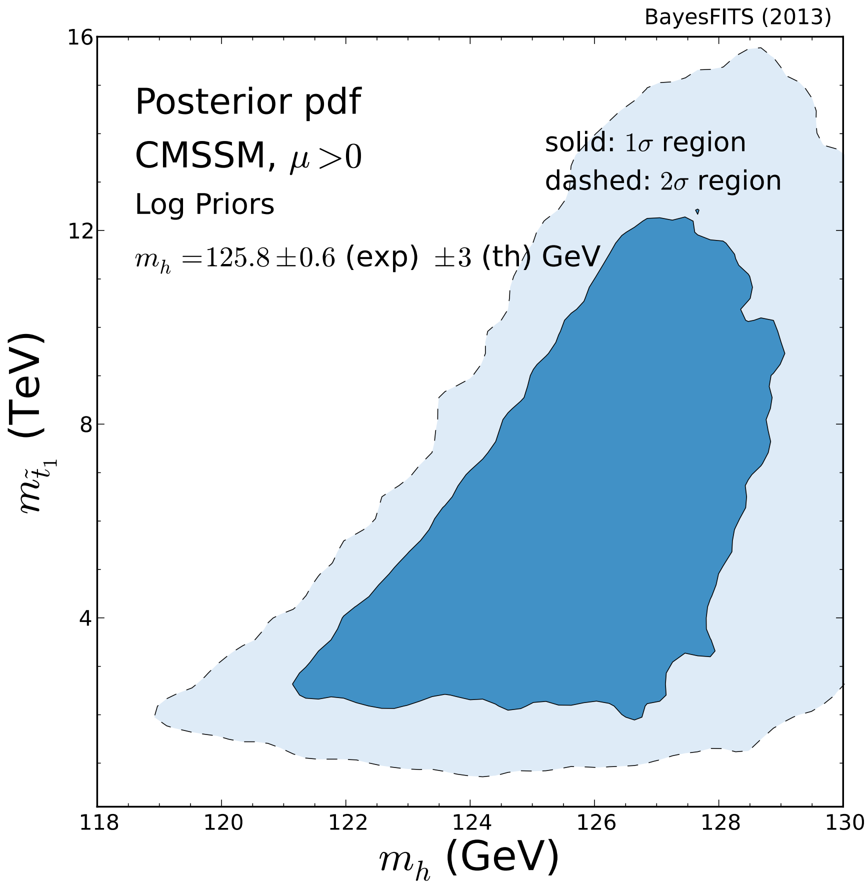
~126 GeV Higgs mass implies multi-TeV SUSY masses

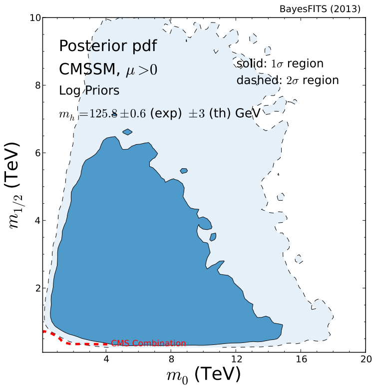


NO tension with LHC direct lower limits

~126 GeV Higgs in the CMSSM

Include <u>only</u> m_h~126 GeV and lower limits from direct SUSY searches





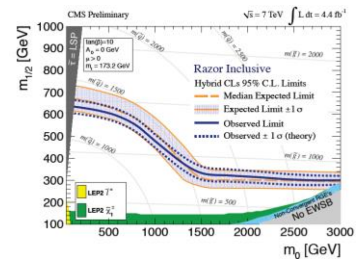
~126 GeV Higgs mass implies multi-TeV SUSY masses

SUSY - most important constraints:

- **Higgs mass**

  CMS: $m_h \sim 125.8$ GeV (in ZZ); $m_h = 124.9.$ GeV (in $\gamma\gamma$)

  ATLAS: $m_h = 124.3$ GeV (in ZZ); $m_h = 126.8$ GeV (in $\gamma\gamma$)



- **Direct search limits**

  Lower limit...

- **Dark matter density**

  Positive measurement, **inconsistent with SM**

- **B_s -> mu mu**

  $$\mathrm{BR}(\overline{B}_s \to \mu^+\mu^-) = \left(3.2^{+1.5}_{-1.2}\right) \times 10^{-9}$$

  LHCb (Nov 2012)

- **Other flavor (b to s gamma, etc)**

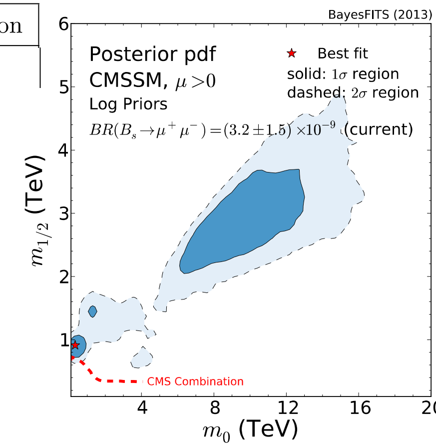
- **EW observables (M_W,...)**

- **(g-2)_muon**

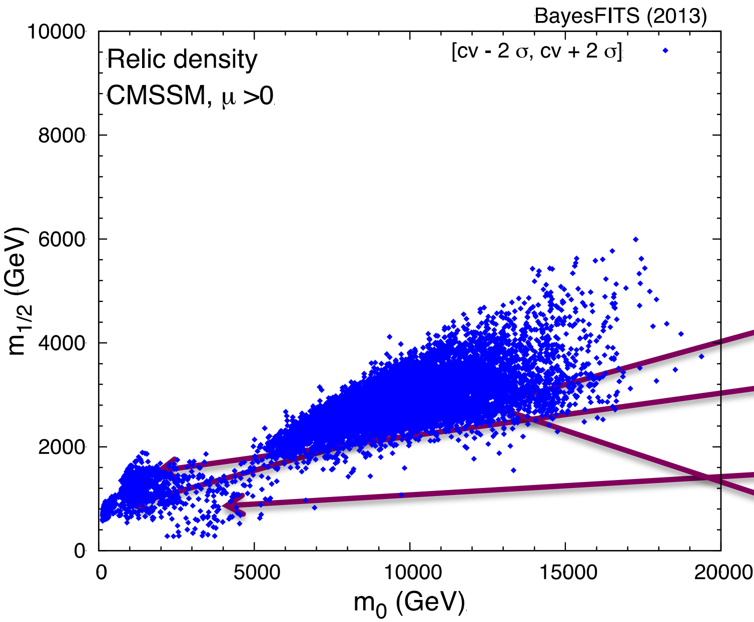
Dark matter density

- **Unified SUSY: neutralino relic density is typically 1-2 orders of magnitude too large**

Measurement	Mean or Range	Error: (Exp., Th.)	Distribution
$\Omega_\chi h^2$	0.1120	0.0056, 10%	Gaussian



- **Remaining mechanisms of reducing it to correct range:**



- ✧**neutralino-stau coannhilation**
- ✧**pseudoscalar Higgs A resonance** $\Omega h^2 \propto m_A^4 / \tan^2\beta$
- ✧**focus point/hyperbolic branch region**
- ✧**(~1 TeV higgsino LSP at larger MSUSY)**
- ✧**Plus (very rare) LSP-stop coannihilation**

Scan with all other relevant constraints imposed

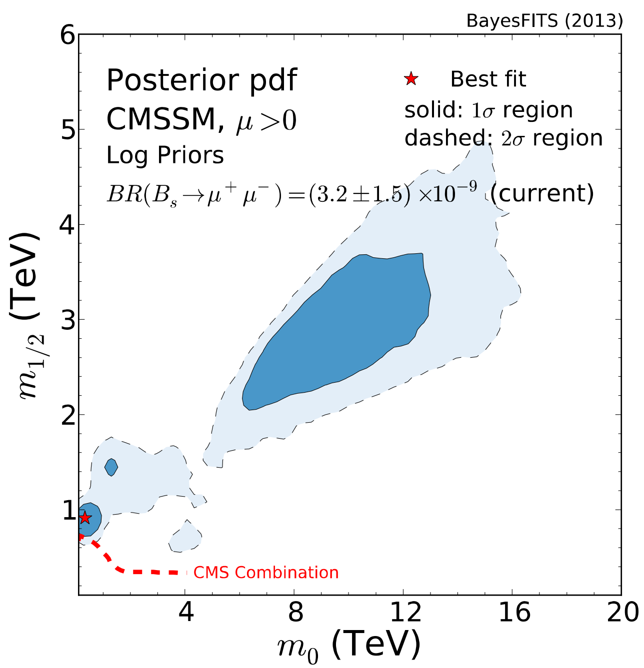
CMSSM: these are the only DM-favored regions

Light Higgs in the CMSSM

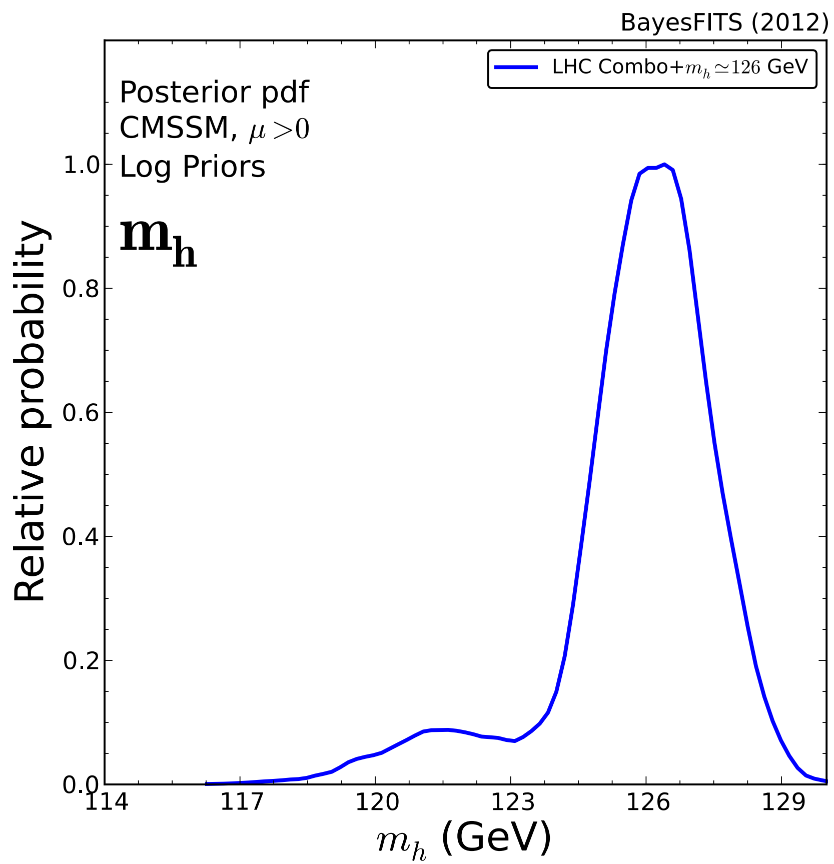
Likelihood function

$$\mathcal{L} \sim e^{\frac{(m_h - 125.8\,\mathrm{GeV})^2}{\sigma^2+\tau^2}}$$

$$\sigma = 0.6\ \mathrm{GeV}, \tau = 2\ \mathrm{GeV}$$

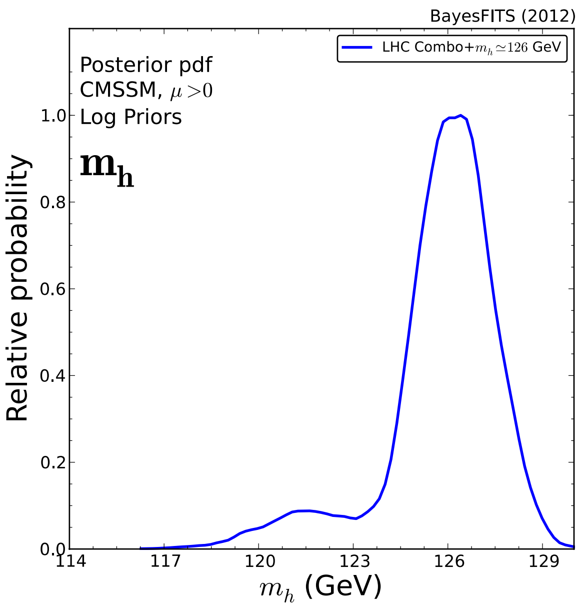


...with all relevant constraints imposed

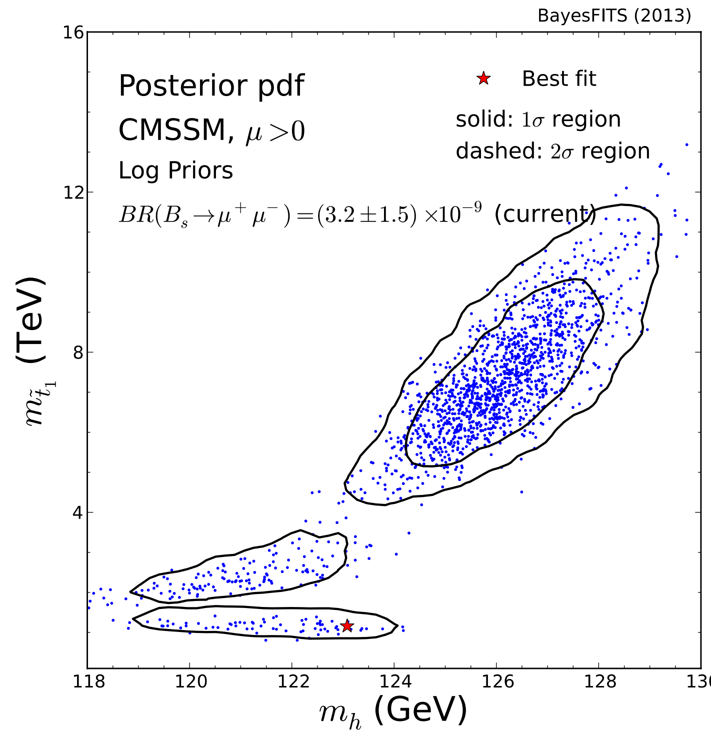


~126 GeV Higgs at/near lowest chi2 (S.C./AF) and at X_SUSY>> 1TeV

Higgs vs stop mass



Stop_1 mass at or above 1 TeV



Best fit to ~126 GeV Higgs
-> M_SUSY~ or >> 1 TeV

$$\text{best-fit point } \chi^2_{\text{min}}/\text{dof} = 18.26/10$$

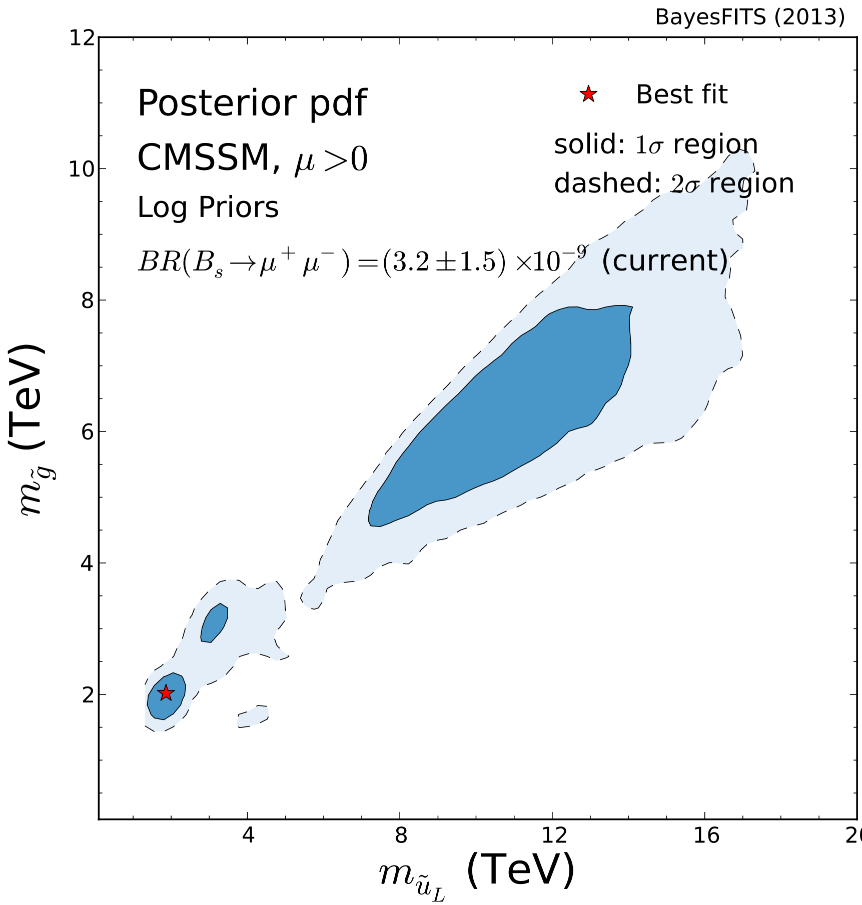
$$[\chi^2_{\text{min}}/\text{dof} \simeq 4/9 \text{ when drop } (g-2)_\mu]$$

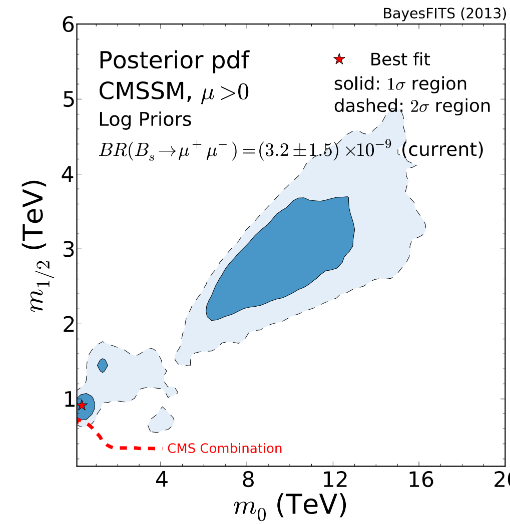
Dark matter relic density: selects some regions

L. Roszkowski, 22/3/2013

Can mulit-TeV ranges of parameters be experimentally tested?

LHC?

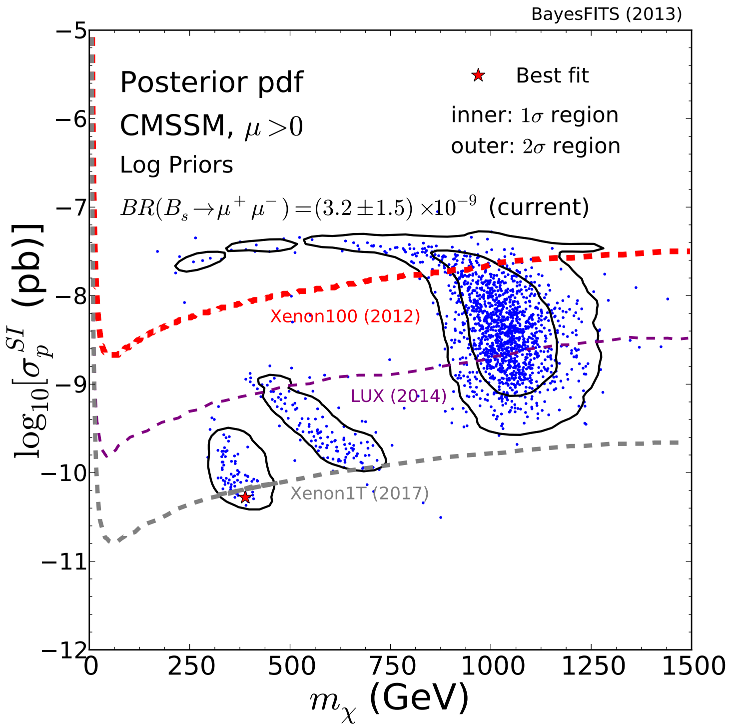




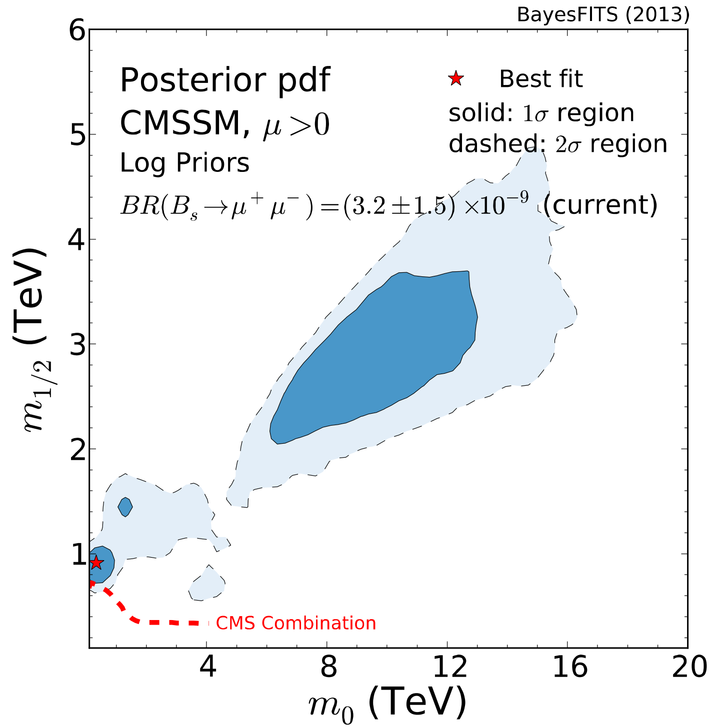
LHC reach:
Gluino: ~2.7 GeV
Squarks: ~3 TeV

…not guaranteed

CMSSM and 1-tonne DM detectors



$\mu > 0$



1-tonne DM detectors to cover most of CMSSM predictions

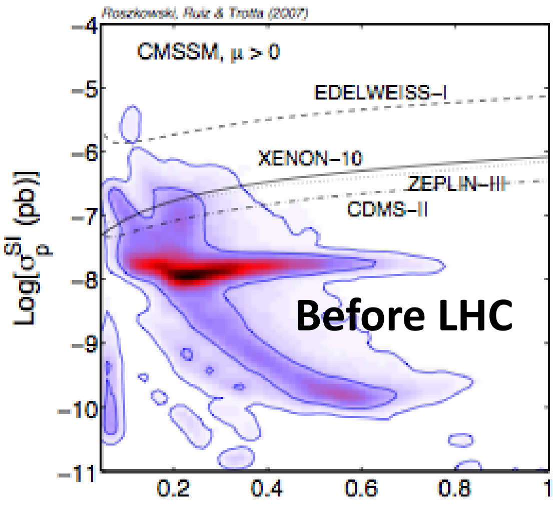
…over ALL multi-TeV ranges of mass parameters

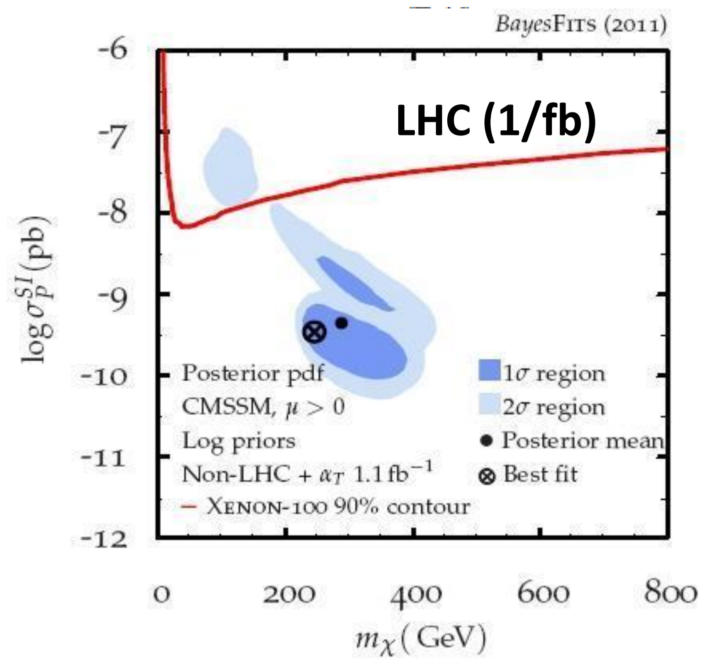
(Except for some cases at mu<0)

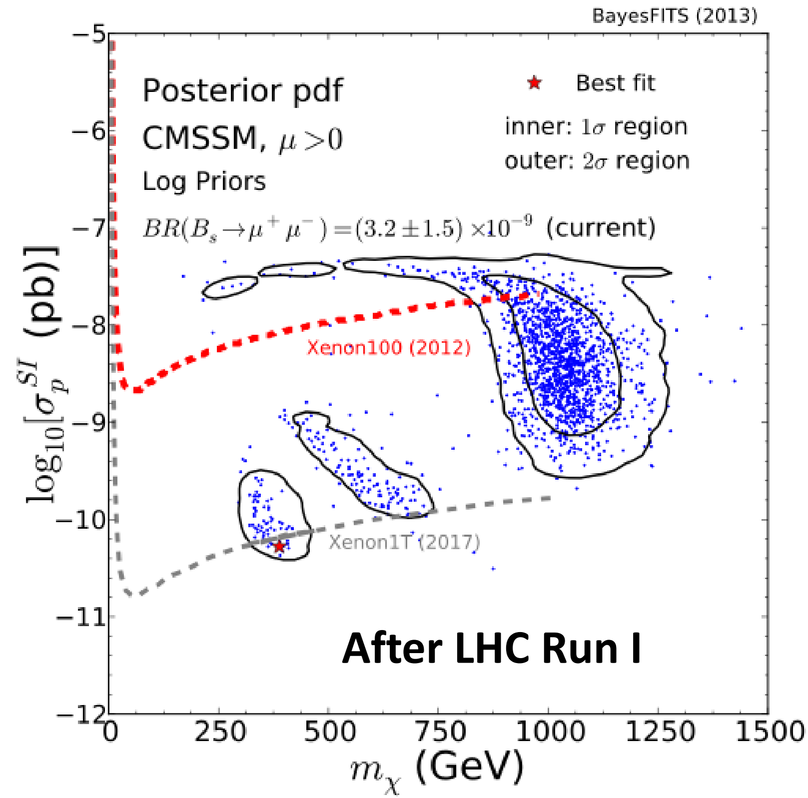
Generic prediction of multi-TeV SUSY: ~1TeV LSP (higgsino)

LUX (2014) to improve sensitivity by ~1 decade

LHC: Impact on DM Searches







XENON(2011) limit not applied

- **extended ranges of SUSY parameters**
- **no other SUSY regions exist**

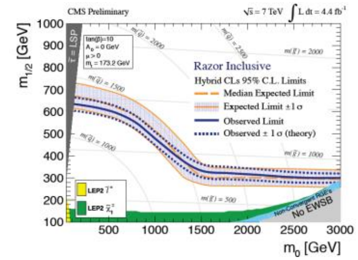
SUSY - most important constraints:

- **Higgs mass**

CMS: $m_h \sim 125.8$ GeV (in ZZ); $m_h = 124.9.$ GeV (in $\gamma\gamma$)

ATLAS: $m_h = 124.3$ GeV (in ZZ); $m_h = 126.8$ GeV (in $\gamma\gamma$)

- **Direct search limits**



Lower limit...

- **Dark matter density**

Positive measurement, **inconsistent with SM**

- **B_s -> mu mu**

$$\mathrm{BR}(\overline{B}_s \to \mu^+\mu^-) = \left(3.2^{+1.5}_{-1.2}\right) \times 10^{-9}$$

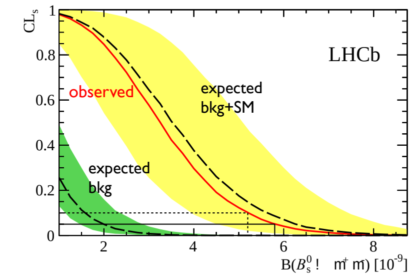
LHCb (Nov 2012)

- **Other flavor (b to s gamma, etc)**
- **EW observables (M_W,...)**
- **(g-2)_muon**

BR(Bs->mu mu)

$$\mathrm{BR}(\overline{B}_s \to \mu^+\mu^-) = \left(3.2^{+1.5}_{-1.2}\right) \times 10^{-9}$$

M. Palutan (LHCb), 13 Nov 2012



$1.1 \times 10^{-9} < B(B^0_s \to \mu^+\mu^-) < 6.4 \times 10^{-9}$ at 95% CL

Note this gives weaker upper bound than before.

LHC combination (June 2012): $B(B^0_s \to \mu^+\mu^-) < 4.2 \times 10^{-9}$ at 95% CL

LHCb-CONF-2012-017
CMS-PAS-BPH-12-009
ATLAS-CONF-2012-061

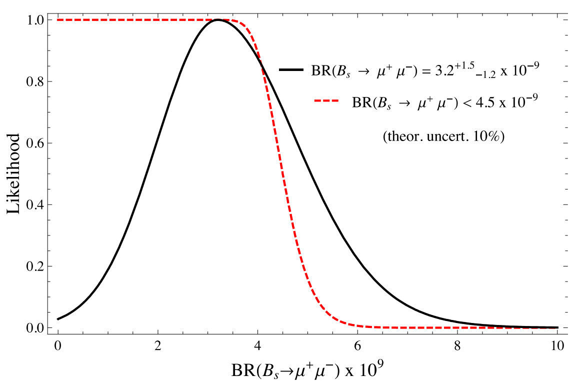
$$\mathcal{B}(B^0_s \to \mu^+\mu^-)^{\langle t \rangle} = \frac{1}{1-y_s} \cdot \mathcal{B}(B^0_s \to \mu^+\mu^-)^{t=0}$$
$$= (3.54 \pm 0.30) \cdot 10^{-9}$$

SM value

De Bruyn et al., PRL 109, 041801 (2012)
uses LHCb-CONF-2012-002

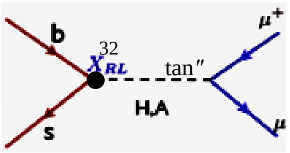
We approximate the signal with a Gaussian

Note the Gaussian Like allows larger BR than 4.2 bound before.

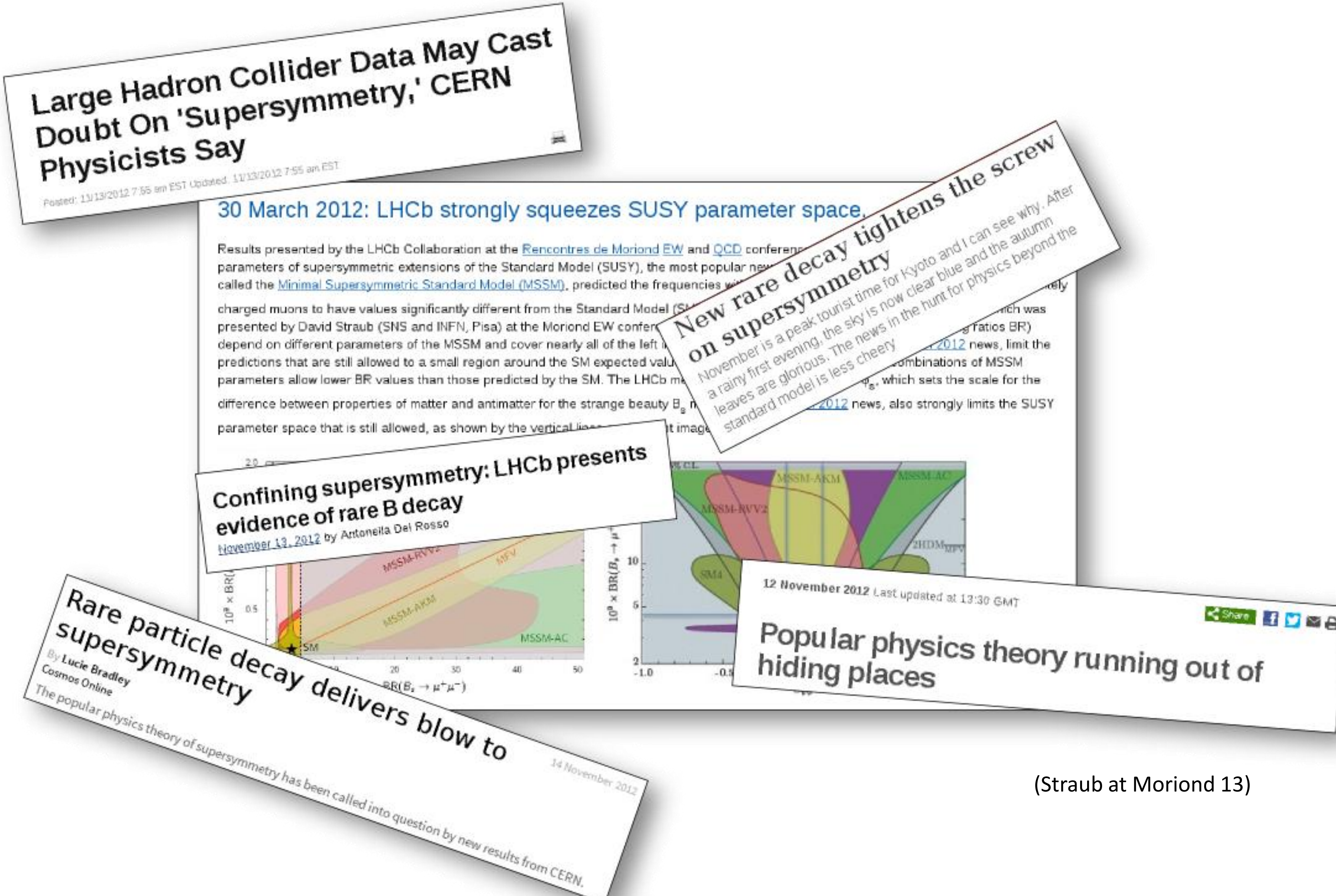


$-$ sensitive probe of new physics

$$\mathrm{BR}(\overline{B}_s \to \mu^+\mu^-) \propto \tan^6\beta / m_A^4$$



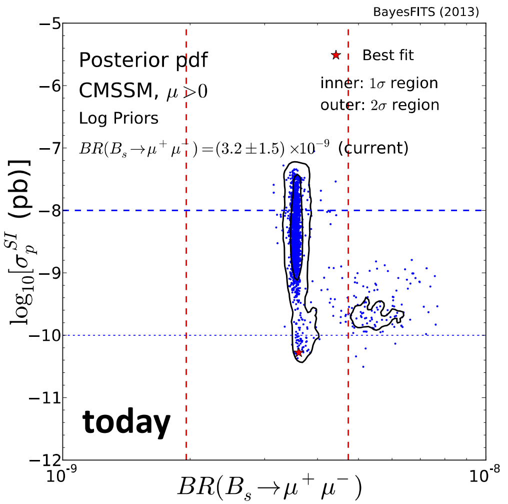
LHCb result agrees with SM value => limits on SUSY

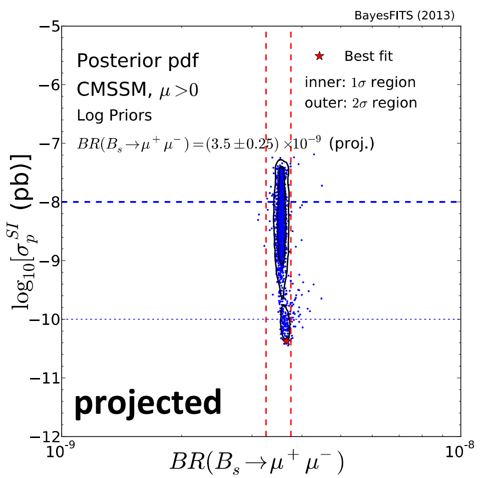


(Straub at Moriond 13)

Effect of precise $BR(\overline{B}_s \to \mu^+\mu^-)$

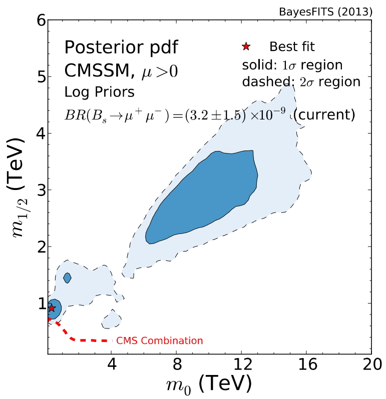
mu>0

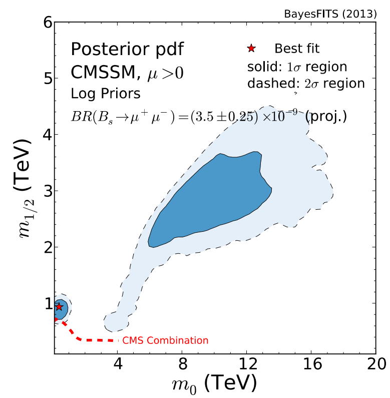




If $BR(\overline{B}_s \to \mu^+\mu^-) \simeq$ SM value with 5-10% precision (both TH and EXPT)

$\Rightarrow$ A funnel region gone





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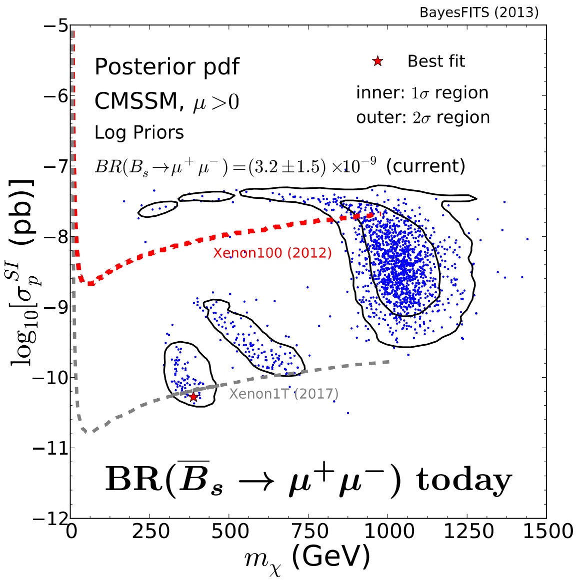
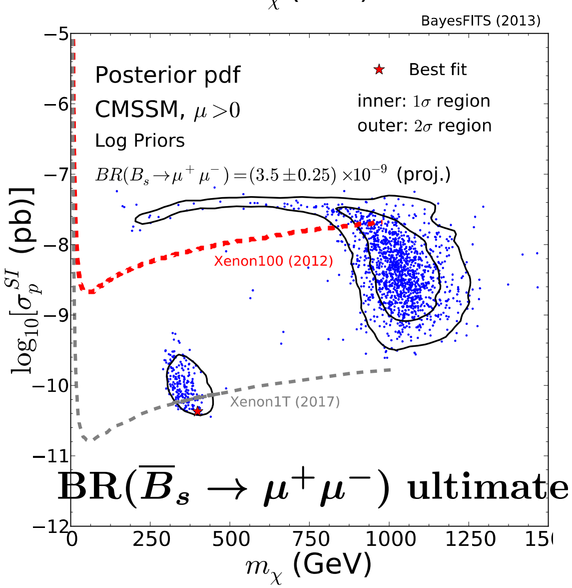




If $\mathrm{BR}(\overline{B}_s \to \mu^+\mu^-) \simeq$ SM value with 5-10% precision $\Rightarrow$ A funnel region gone

Ways to rule out the CMSSM:

- **No DM signal in 1-tonne detectors**
- **DM signal at ~500 to 750 GeV**

SC: for $\mu < 0$ σ_p^{SI} lower (cancellations)

NUHM, CNMSSM: similar ranges of sigma_p but DM-favored regions overlap

- **Even the simplest unified SUSY model (CMSSM) is consistent with all data (Higgs mass, DM relic density, direct limits, flavor-violating processes, …)**

…except for g-2, R(gamma gamma)

- **M_SUSY >~ (or even >>) 1 TeV favored by ~126 GeV Higgs**
- **In less unified models somewhat lower SUSY masses are allowed (but not by much)**

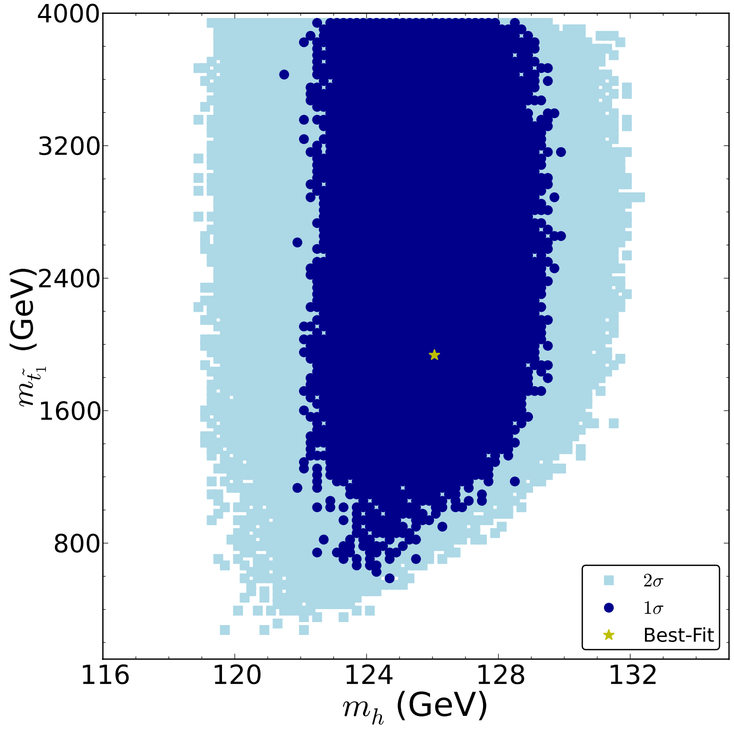
…except for very fine tuned corners

~126 GeV Higgs in general MSSM

- **More free parameters, more freedom**

…here 9 parameters

BayesFITS (in prep)



~126 GeV Higgs still implies heavy superpartners

…except for very fine tuned corners which allow much lighter staus, stops, charginos

SUSY - most important constraints:

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ATLAS: $m_h = 124.3$ GeV (in ZZ); $m_h = 126.8$ GeV (in γγ)

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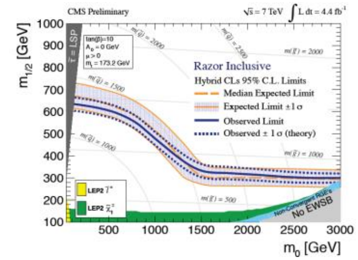

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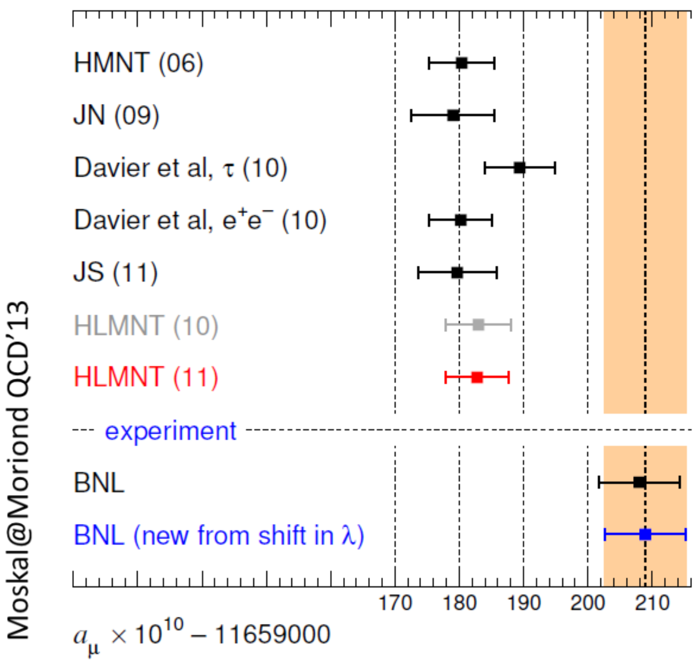
LHCb (Nov 2012)

- **Other flavor (b to s gamma, etc)**
- **EW observables (M_W,…)**
- **(g-2)_muon**

(g-2)_muon



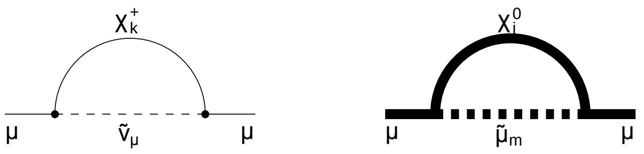
The anomalous magnetic moment of the muon

>3 sigma deviation

Now more believable with recent results on hadr. contribution from Kloe and Kloe-2

New physics?

SUSY:



This is the only result pointing towards low superparner masses!

Need sneutrino/chargino and/or smuon/neutralino in ~ few hundred GeV range

Unified SUSY: sleptons are unified with squarks and are too heavy

General MSSM: if (g-2)_muon anomaly is true: expect light sleptons/chargino/neutralino

But what about fine-tuning/naturalness?!

- I prefer to follow what the data implies, rather than theoretical prejudice

- Naturalness: fundamental Higgs -> SUSY
- 126 GeV -> M_SUSY ~1TeV or >> 1TeV

- Fine-tuning is needed at any scale above the EW scale!

1 TeV is not a magic number

- If SUSY is discovered, the FT issue will have to be understood
- If SUSY is not discovered, the issue will become irrelevant

- There are ideas around of how to live comfortably with high fine-tuning

To take home:

- CMSSM: consistent with all experimental constraints.

  except (g-2)_muon, R(gamma gamma)

  (Other simple constrained SUSY models: similar story.)

- Higgs of 126 GeV --> typically M_SUSY at multi-TeV scale.

  Plus a window of light stop_1 (~1TeV) – best fit region (stau coann.)

- 1-tonne DM detectors to probe most CMSSM parameters.

  Far beyond direct LHC reach.

  Other simple constrained SUSY models: similar story.

- 1TeV (higgsino) LSP DM – generic prediction of constrained SUSY models (and also MSSM) – look for it!

- precise determination of BR(B_s to mu mu) can be very helpful in CMSSM (but not beyond)

- Lighter superpartners allowed in general MSSM