SUSY global fits: implications for dark matter

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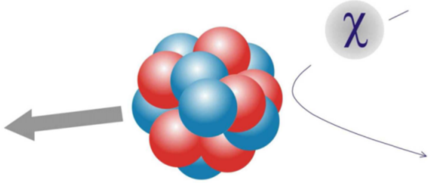
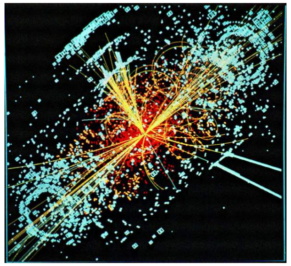
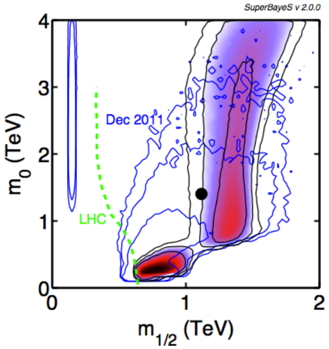






Identifying and Characterizing Dark Matter via Multiple Probes
KITP – 15/05/2013

Overview

- Introduction and statistical methods
- Models and experimental constraints
- Global fits of the cMSSM including data from the LHC and the Xenon100 direct detection experiment
- Comparison with global fits of the NUHM
- Conclusions and Outlook

The search for dark matter

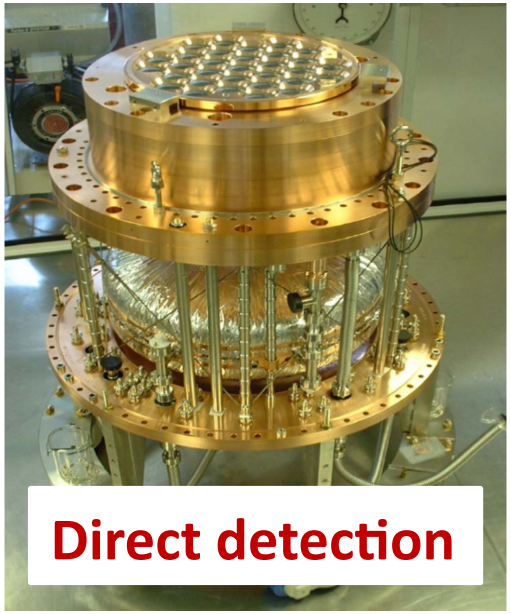
Colliders

BSM Physics

SUSY

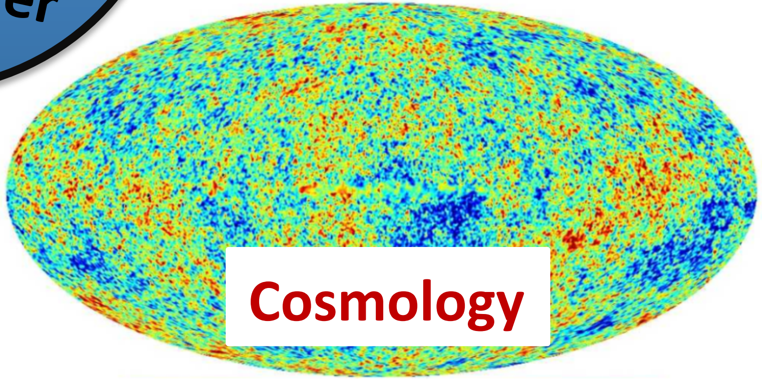
WIMPs

Dark Matter



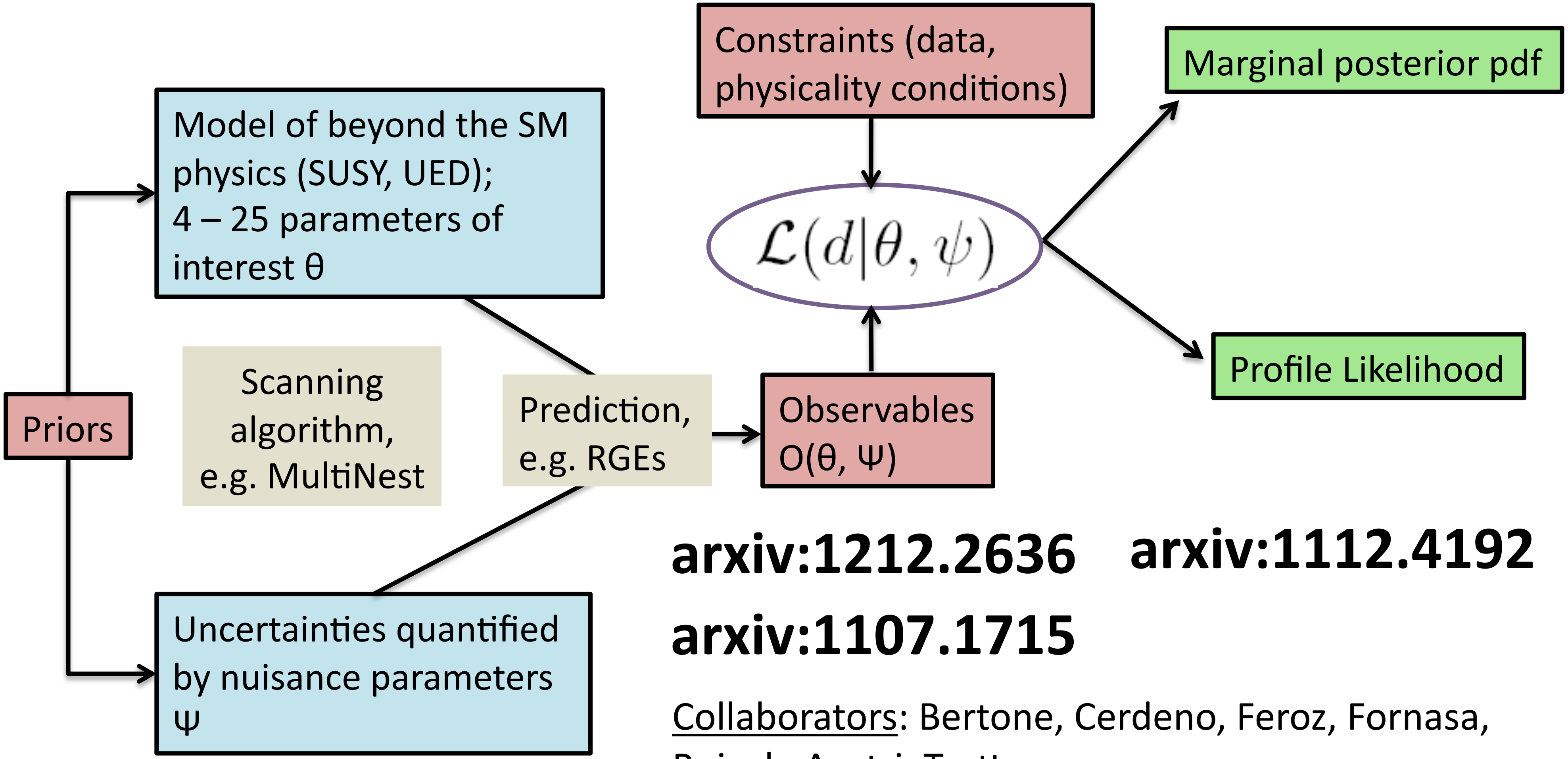
Direct detection

Indirect detection



Cosmology

Global Fits



Priors

Model of beyond the SM physics (SUSY, UED); 4 – 25 parameters of interest θ

Uncertainties quantified by nuisance parameters Ψ

Scanning algorithm, e.g. MultiNest

Prediction, e.g. RGEs

Observables O(θ, Ψ)

Constraints (data, physicality conditions)

$\mathcal{L}(d|\theta, \psi)$

Marginal posterior pdf

Profile Likelihood

arxiv:1212.2636 **arxiv:1112.4192**

arxiv:1107.1715

<u>Collaborators</u>: Bertone, Cerdeno, Feroz, Fornasa, Ruiz de Austri, Trotta

Statistical inference

Given some parameters of interest θ and a data set *d* we can obtain the posterior distribution p(θ|d) from **Bayes' theorem**:

$$p(\vec{\theta}|d) = \frac{\mathcal{L}(d|\vec{\theta})p(\vec{\theta})}{p(d)}$$

By marginalising over the unwanted parameters we can obtain **the 1D marginal posterior pdf** for any parameter θ_i:

$$p(\theta_i|d) = \int \mathrm{d}\theta_1 ... \mathrm{d}\theta_{i-1} \mathrm{d}\theta_{i+1} ... \mathrm{d}\theta_n \; p(\vec{\theta}|d)$$

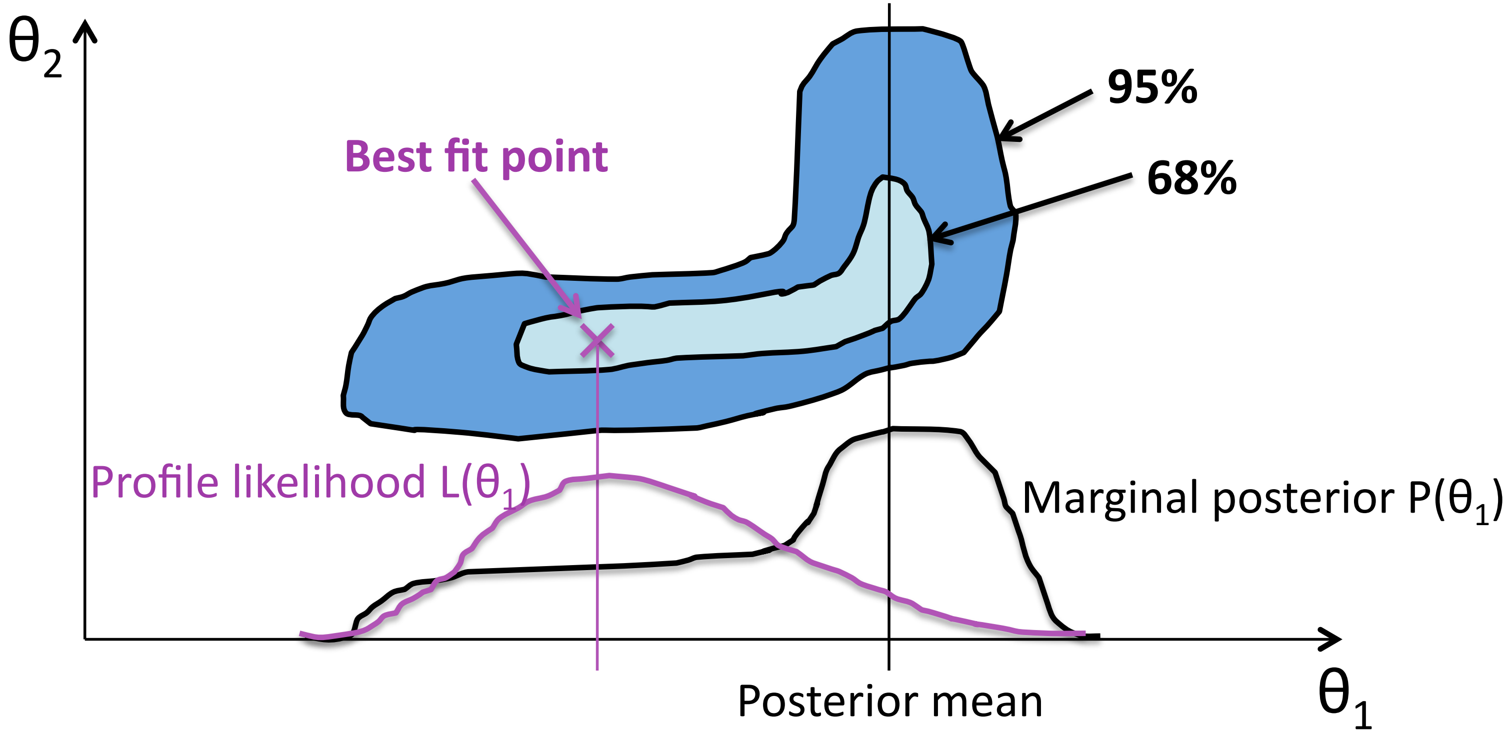
By maximising over the unwanted parameters we can obtain **the 1D profile likelihood** for any parameter θ_i:

$$\mathcal{L}_{PL}(\theta_i) = \max_{\theta_1, ... \theta_{i-1}, \theta_{i+1}, ... \theta_n} \mathcal{L}(\vec{\theta})$$

Marginalization vs. profiling

$$\boxed{p(\theta_i|d) = \int \mathrm{d}\theta_1 ... \mathrm{d}\theta_{i-1} \mathrm{d}\theta_{i+1} ... \mathrm{d}\theta_n \; p(\vec{\theta}|d)}$$

$$\boxed{\mathcal{L}_{PL}(\theta_i) = \max_{\theta_1,...\theta_{i-1},\theta_{i+1},...\theta_n} \mathcal{L}(\vec{\theta})}$$



SUSY: the cMSSM and the NUHM

- Minimal field content SUSY: Minimal Supersymmetric Standard Model (MSSM). SUSY phenomenology is usually studied in simplified MSSM scenarios, e.g.:

cMSSM: constrained Minimal Supersymmetric Standard Model

- Boundary conditions imposed on the MSSM at the Grand Unification scale:
  - Unified scalar masses m_0
  - Unified gaugino masses $m_{1/2}$
  - Unified trilinear couplings A_0

Only 4 free parameters

m_0 $m_{1/2}$ A_0 $\tan(\beta)$ $[\mathrm{sgn}(\mu)]$

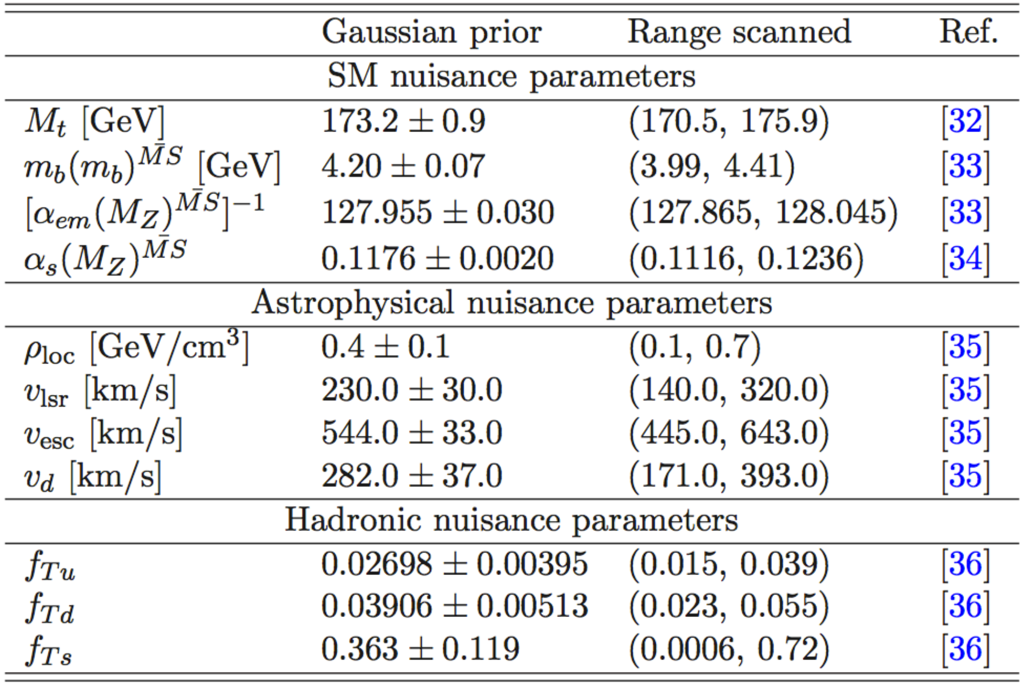
$+ m_{Hu} + m_{Hd}$

NUHM: Non-universal Higgs model

Only 6 free parameters

cMSSM, NUHM: popular (toy) models to explore SUSY phenomenology

Nuisance parameters



	Gaussian prior	Range scanned	Ref.
	SM nuisance parameters		
M_t [GeV]	173.2 ± 0.9	(170.5, 175.9)	[32]
$m_b(m_b)^{\bar{MS}}$ [GeV]	4.20 ± 0.07	(3.99, 4.41)	[33]
$[\alpha_{em}(M_Z)^{\bar{MS}}]^{-1}$	127.955 ± 0.030	(127.865, 128.045)	[33]
$\alpha_s(M_Z)^{\bar{MS}}$	0.1176 ± 0.0020	(0.1116, 0.1236)	[34]
	Astrophysical nuisance parameters		
$\rho_{\rm loc}$ [GeV/cm^3]	0.4 ± 0.1	(0.1, 0.7)	[35]
$v_{\rm lsr}$ [km/s]	230.0 ± 30.0	(140.0, 320.0)	[35]
$v_{\rm esc}$ [km/s]	544.0 ± 33.0	(445.0, 643.0)	[35]
v_d [km/s]	282.0 ± 37.0	(171.0, 393.0)	[35]
	Hadronic nuisance parameters		
f_{Tu}	0.02698 ± 0.00395	(0.015, 0.039)	[36]
f_{Td}	0.03906 ± 0.00513	(0.023, 0.055)	[36]
f_{Ts}	0.363 ± 0.119	(0.0006, 0.72)	[36]

4 (6) model parameters
+ 11 nuisance parameters

Hadronic uncertainties:

The cross-section depends on the effective coupling to the proton, which depends on the contribution of light quarks to the proton composition:

$$\sigma^{SI} \equiv \sigma^{SI}_{\chi-p} \propto f_p^2$$

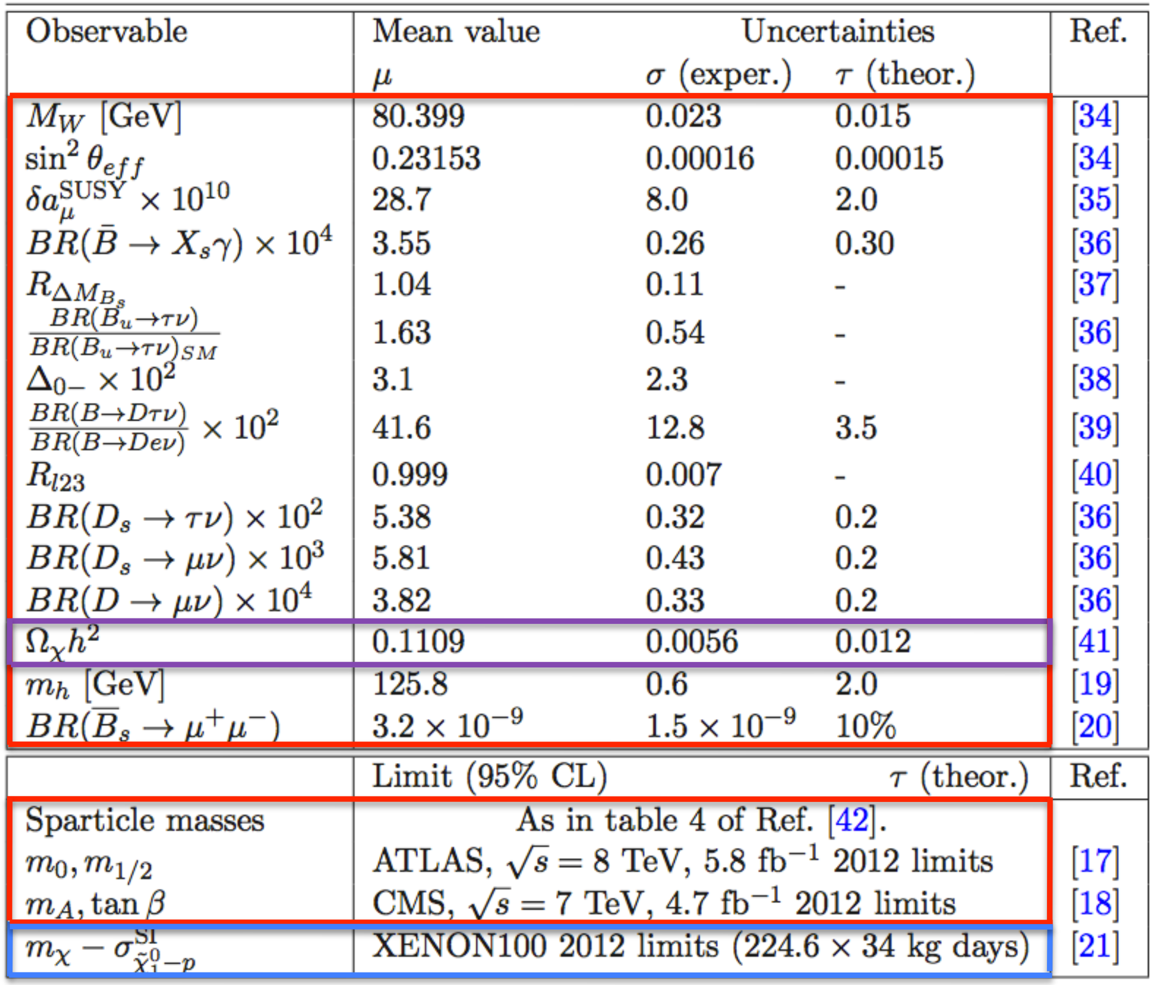
$$f_p \leftarrow \boxed{f_{T_q}} = m_p < p | m_q \bar{q} q | p >$$

Astrophysical uncertainties:

$$\frac{\mathrm{d}R}{\mathrm{d}E} = \frac{\sigma^{SI} \boxed{\rho_0}}{2 m_\chi \mu^2} F^2 \int_{v > v_{min}} \mathrm{d}^3 v \frac{\boxed{f(\mathbf{v}, t)}}{v}$$

ρ_0 = 0.39 ±0.03 GeV cm^{-3}, Ullio&Catena (2009)
ρ_0 = 0.43 ±0.21 GeV cm^{-3}, Salucci et al. (2010)
ρ_0 = 0.47 ±0.03 ±0.077 GeV cm^{-3}, Pato et al. (2010)

Constraints included in global fits



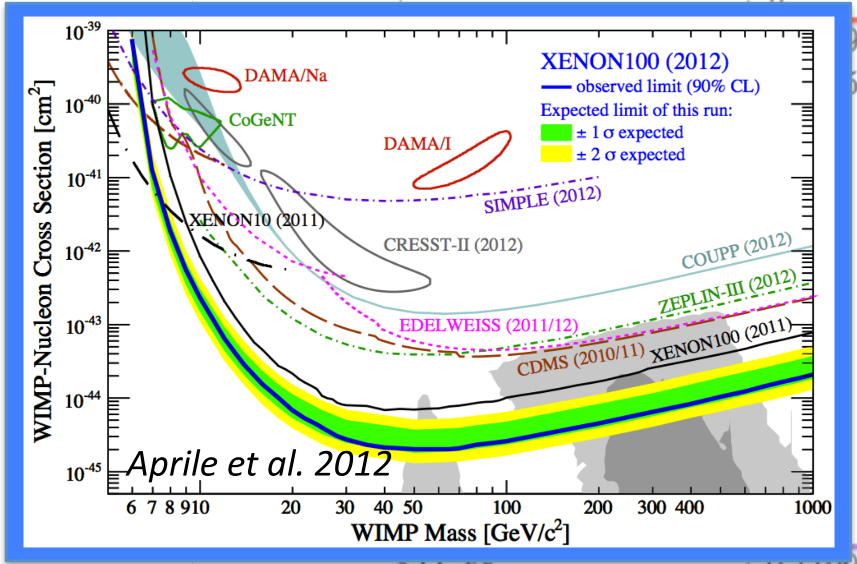
Observable	Mean value	Uncertainties		Ref.
	μ	σ (exper.)	τ (theor.)	
M_W [GeV]	80.399	0.023	0.015	[34]
$\sin^2\theta_{eff}$	0.23153	0.00016	0.00015	[34]
$\delta a_\mu^{SUSY} \times 10^{10}$	28.7	8.0	2.0	[35]
$BR(\bar{B} \to X_s\gamma) \times 10^4$	3.55	0.26	0.30	[36]
$R_{\Delta M_{B_s}}$	1.04	0.11	-	[37]
$\frac{BR(B_u \to \tau\nu)}{BR(B_u \to \tau\nu)_{SM}}$	1.63	0.54	-	[36]
$\Delta_{0-} \times 10^2$	3.1	2.3	-	[38]
$\frac{BR(B \to D\tau\nu)}{BR(B \to De\nu)} \times 10^2$	41.6	12.8	3.5	[39]
R_{l23}	0.999	0.007	-	[40]
$BR(D_s \to \tau\nu) \times 10^2$	5.38	0.32	0.2	[36]
$BR(D_s \to \mu\nu) \times 10^3$	5.81	0.43	0.2	[36]
$BR(D \to \mu\nu) \times 10^4$	3.82	0.33	0.2	[36]
$\Omega_\chi h^2$	0.1109	0.0056	0.012	[41]
m_h [GeV]	125.8	0.6	2.0	[19]
$BR(\overline{B}_s \to \mu^+\mu^-)$	3.2×10^{-9}	1.5×10^{-9}	10%	[20]

	Limit (95% CL)	τ (theor.)	Ref.
Sparticle masses	As in table 4 of Ref. [42].		
$m_0, m_{1/2}$	ATLAS, $\sqrt{s} = 8$ TeV, 5.8 fb^{-1} 2012 limits		[17]
$m_A, \tan\beta$	CMS, $\sqrt{s} = 7$ TeV, 4.7 fb^{-1} 2012 limits		[18]
$m_\chi - \sigma^{SI}_{\tilde{\chi}^0_1 - p}$	XENON100 2012 limits (224.6×34 kg days)		[21]

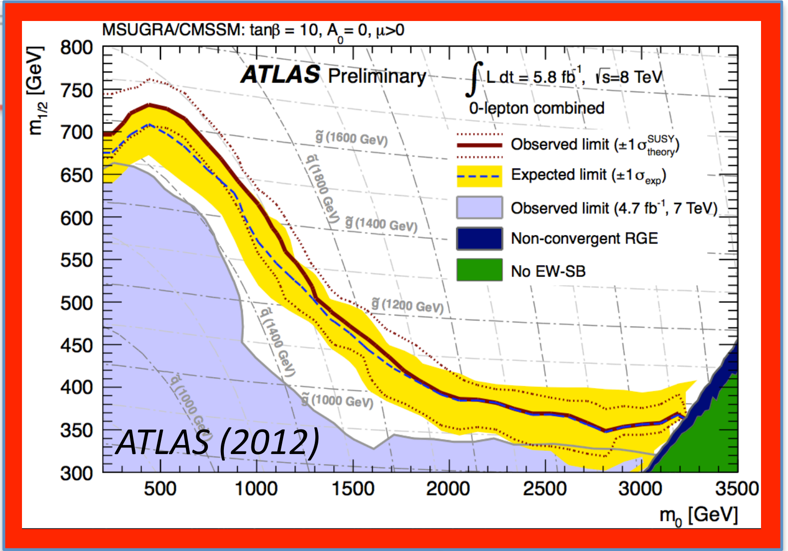
Summary of the experimental constraints that enter in the likelihood function

Constraints included in global fits

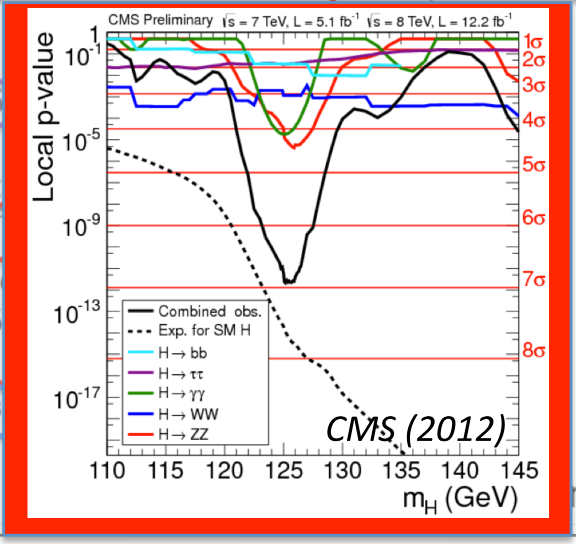
Observable	Mean value	
	μ	
	9	
	53	
		0.43
		0.33
$\Omega_\chi h^2$	0.1109	0.005
m_h [GeV]	125.8	0.6
$BR(\overline{B}_s \to \mu^+\mu^-)$	3.2×10^{-9}	$1.5 \times$
	Limit (95% CL)	
Sparticle masses	As in table 4	
$m_0, m_{1/2}$	ATLAS, $\sqrt{s} = 8$ TeV, 5	
$m_A, \tan\beta$	CMS, $\sqrt{s} = 7$ TeV, 4.7	
$m_\chi - \sigma^{SI}_{\tilde{\chi}^0_1-p}$	XENON100 2012 limits	



Aprile et al. 2012



ATLAS (2012)



CMS (2012)

Summary of the experimental constraints that … n

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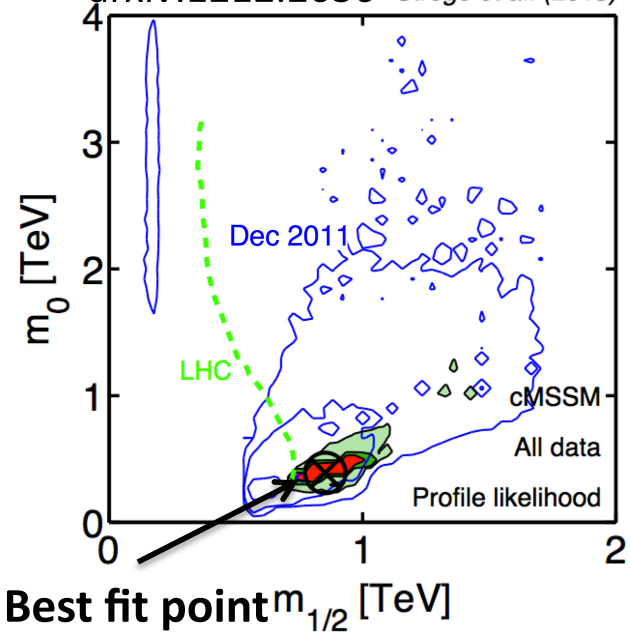
cMSSM results

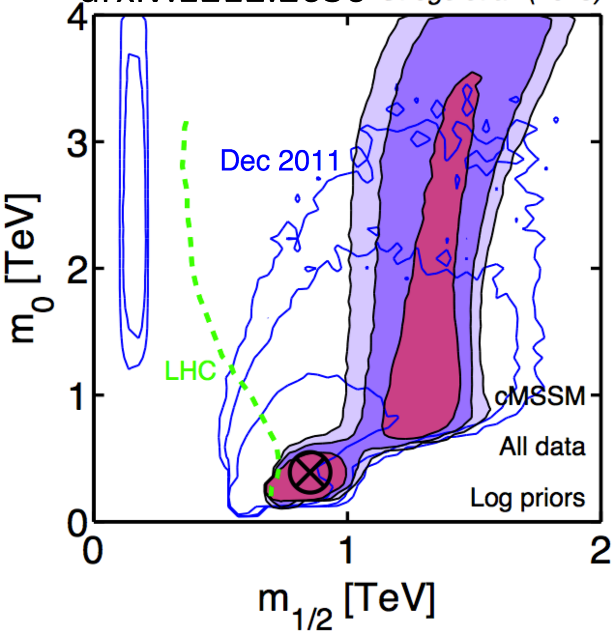
Profile likelihood

arxiv:1212.2636



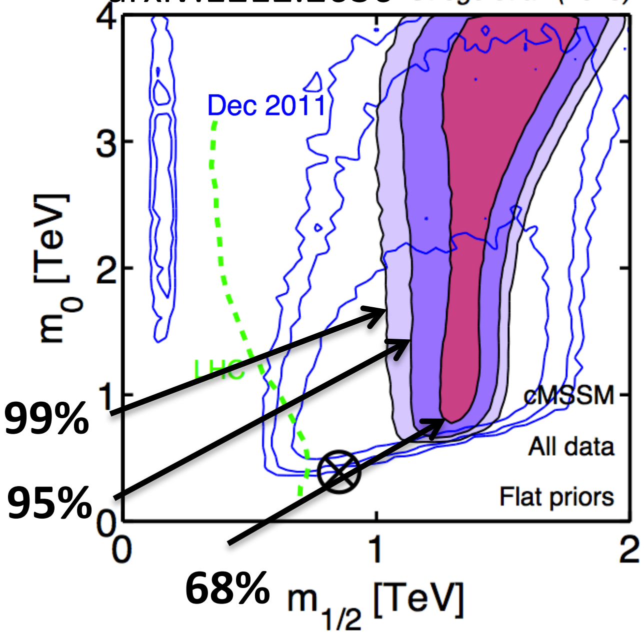
Bayesian posterior Log priors

arxiv:1212.2636



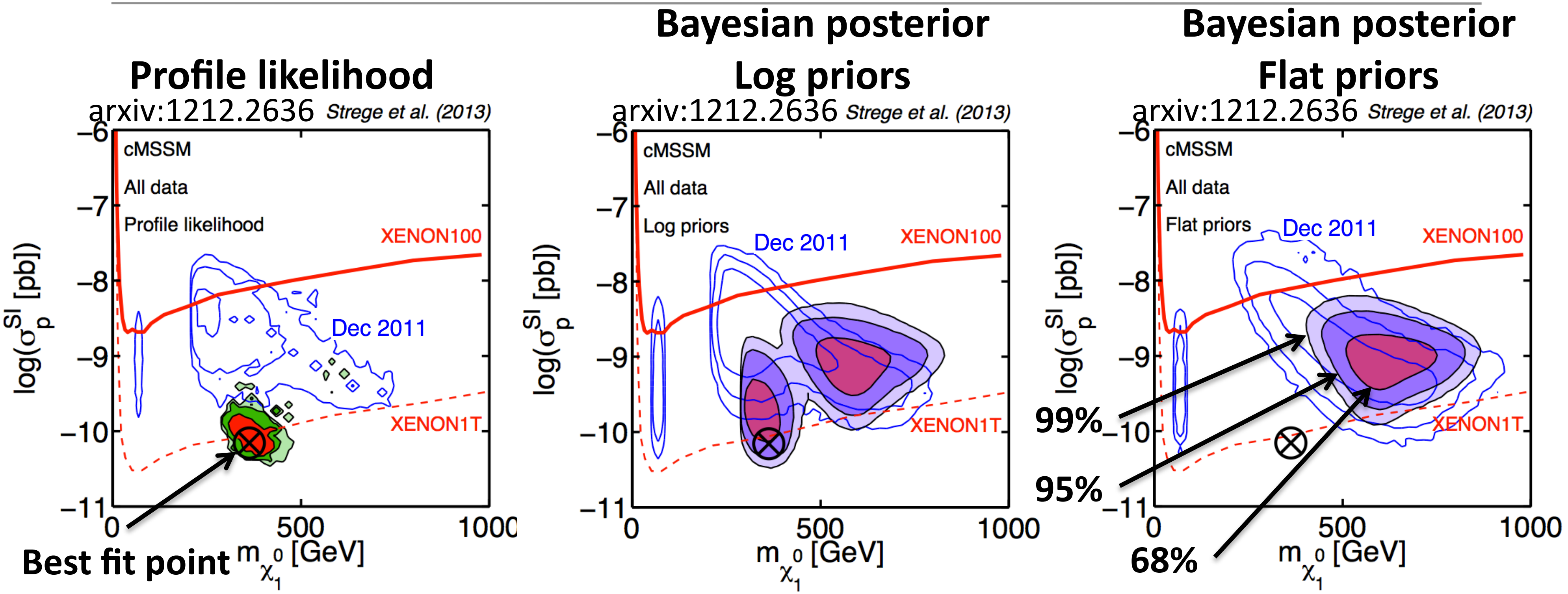
Bayesian posterior Flat priors

arxiv:1212.2636



The LHC exclusion limit further constrains the cMSSM parameter space. The Higgs mass constraint has a significant impact, ruling out regions that were previously favoured at 68% level. Posterior contours are pushed towards large values of $m_{1/2}$. In contrast, the PL strongly favours the SC region at small masses.

cMSSM: direct detection



Profile likelihood

Bayesian posterior Log priors

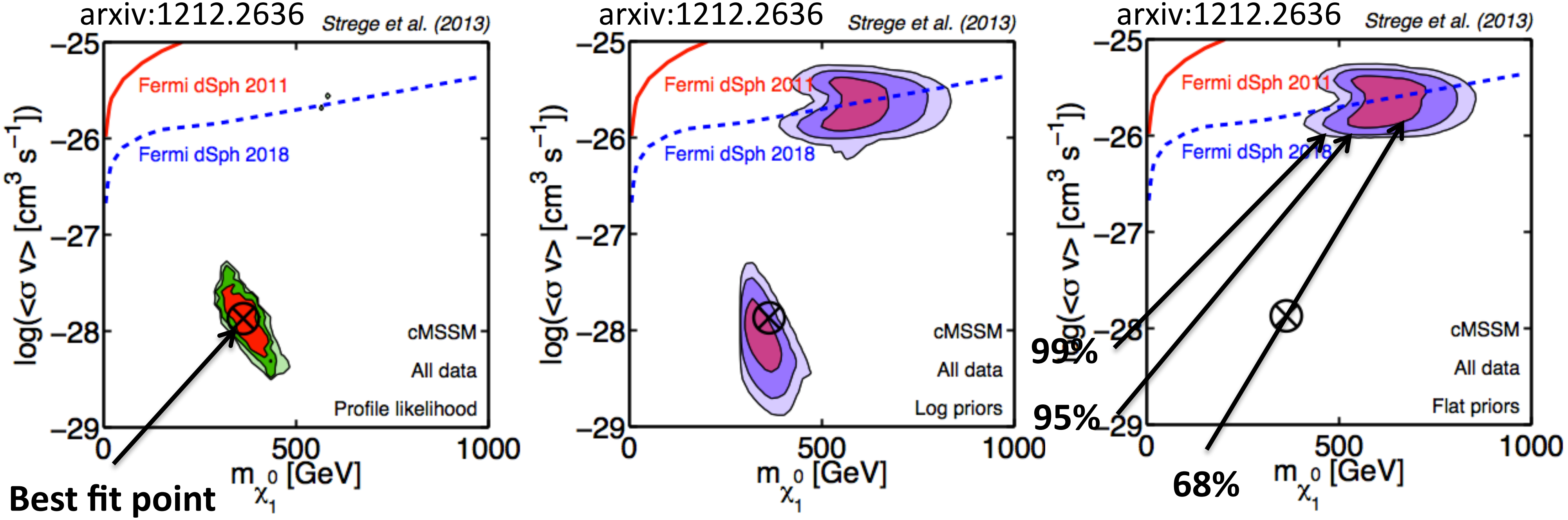
Bayesian posterior Flat priors

arxiv:1212.2636 *Strege et al. (2013)*

The LHC Higgs constraint shifts contours towards higher WIMP masses and lower cross-sections, rendering direct detection of dark matter more difficult. This is especially true from the PL statistical perspective. The Xenon100 2012 limit has almost no impact. Prospects for detection by future direct detection experiments are mixed.

cMSSM: indirect detection

Profile likelihood | **Bayesian posterior Log priors** | **Bayesian posterior Flat priors**



Best fit point

99%

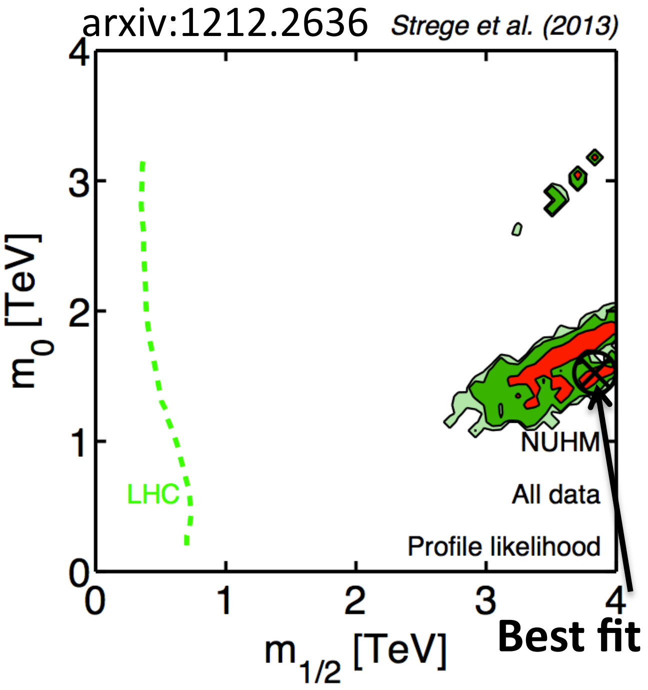
95%

68%

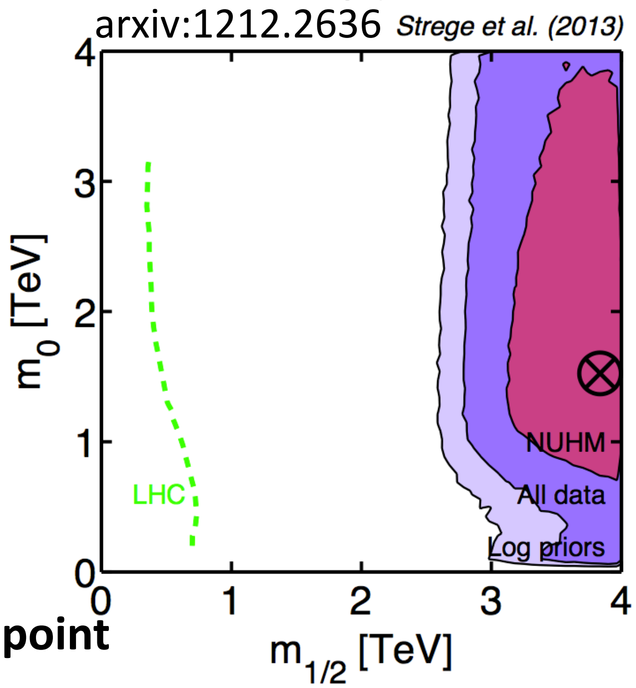
The favored regions of the cMSSM parameter space are below the current 95% limit from Fermi LAT dSph dark matter searches. Future limits from 10 years of data will probe a large fraction of the parameter space currently favoured by the posterior pdf. The PL, which strongly favours the SC region, will remain out of reach.

NUHM results

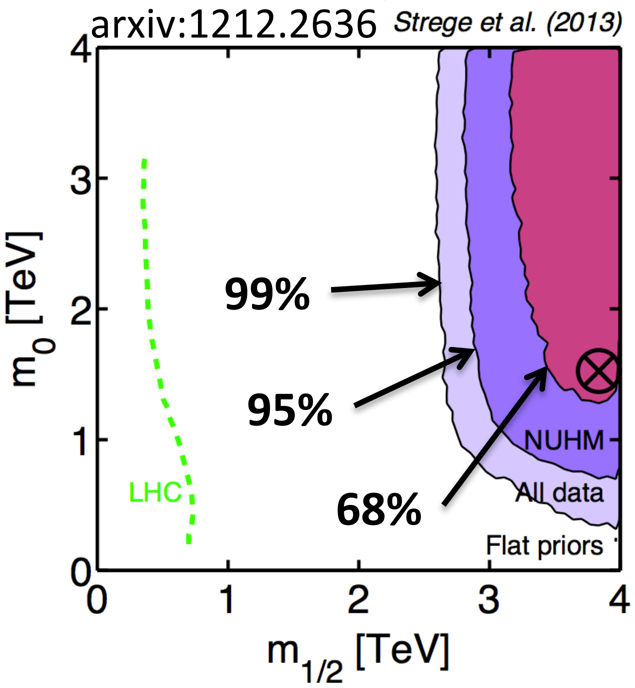
Profile likelihood



Bayesian posterior
Log priors



Bayesian posterior
Flat priors



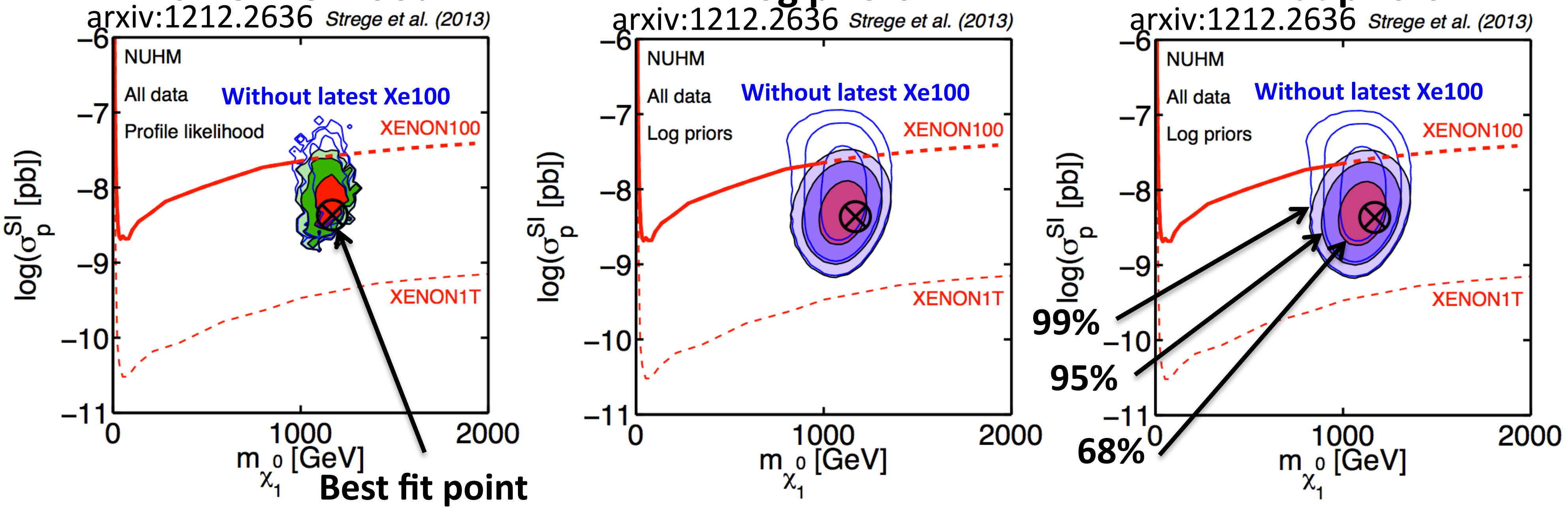
The LHC exclusion limit has essentially no impact on the NUHM parameter space. The posterior distributions favour regions at large m$_{1/2}$, in which the Higgs mass measurement can be reproduced. The region favoured by the PL is qualitatively similar, but much more localised.

NUHM: direct detection

Profile likelihood

Bayesian posterior Log priors

Bayesian posterior Flat priors



Present-day constraints favour large dark matter masses $m_\chi \approx 1$ TeV and relatively large cross-sections. The latest Xenon100 results rule out part of this otherwise unconstrained region, that is inaccessible at the LHC. Future direct detection experiments will probe the entire currently favoured NUHM parameter space.

Conclusions and Outlook

- Recent experimental constraints, most importantly the LHC measurement of the Higgs boson mass, have a strong impact on simple SUSY parameter spaces.

- Observational consequences vary strongly with the model studied (and the choice of prior / statistical perspective):
    - The cMSSM favours low sparticle masses and relatively small DM scattering cross-sections with an LSP mass of a few hundred GeV
    - The NUHM favours heavy sparticles and ~1 TeV dark matter with a large scattering cross-section.

- This results in very different detection prospects:
    - The entire favoured NUHM parameter space will be probed by future direct detection experiments. Detection prospects by Fermi and the LHC are negative.
    - Direct detection prospects for the cMSSM are mixed, but currently favoured regions will be accessible to both Fermi and the LHC.

- Constrained models of minimal SUSY are put under strong pressure by recent experimental results, but SUSY as a theory is still very viable. Global fits analyses are moving on to higher-dimensional models of richer phenomenology. Stay tuned!