Constrained SUSY after the Higgs discovery

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The status of the CMSSM

healthy?

pretty dull?

almost dead?

buried?

Outline

Methods

- Introduction
- Construction of χ^2
- Statistics

Results

- Previous results
- Preliminary updates

Summary

Fittino

C++ program for SUSY model testing and SUSY parameter analysis

- Currently supported SUSY models CMSSM, GMSB, AMSB, MSSM24, NMSSM, NUHM1, NUHM2
- Uses all kind of available experimental measurements
- Uses public theory codes to calculate predictions
- This year 10th anniversary!
- Previous publications:
  arXiv:0412012[hep-ph], arXiv:0511006[hep-ph], arXiv:0907.2589[hep-ph] arXiv:0909.1820[hep-ph], arXiv:1105.5398[hep-ph], arXiv:1102.4693[hep-ph], arXiv:1204.4199[hep-ph]

The CMSSM

Constrained MSSM reduces 124 parameters of MSSM to 4.5:

M_0	common scalar mass parameter
$M_{1/2}$	common gaugino mass parameter
A_0	common trilinear coupling
$\tan\beta$	ratio of Higgs VEVs
$\operatorname{sgn}\mu$	sign of Higgsino mass parameter

We fix $\operatorname{sgn}\mu = +1$ to get a positive SUSY contribution to $g - 2$.

We use m_t as additional free fit parameter.

CMSSM fit

CMSSM is experimentally constrained by

- indirect constrains from LEO
- direct searches for sparticles and Higgs bosons
- astrophysical observations

To evaluate the corresponding model predictions we use:

- SPheno for spectrum calculation
- FeynHiggs for Higgs properties & $g-2$
- SuperIso for B-Physics observables
- MicrOMEGAs for dark matter relic density
- DarkSUSY via Astrofit for direct detection cross sections

χ^2 contributions

At each parameter point $\vec{P}$ calculate:

$$\chi^2 = \left(\vec{O}_{\text{meas}} - \vec{O}_{\text{pred}}(\vec{P})\right)^T cov^{-1} \left(\vec{O}_{\text{meas}} - \vec{O}_{\text{pred}}(\vec{P})\right) + \chi^2_{\text{limits}}$$

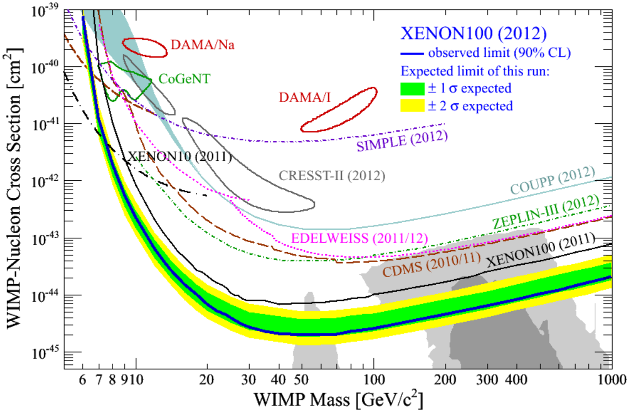
- Simplest implementation of a limit: hard cut
- Next to simplest implementation of a limit:

$$\chi^2_{\text{UL/LL}} = \begin{cases} \left(\frac{O_{\text{UL/UL}} - O_{\text{pred}}(\vec{P})}{\sigma_{\text{pred}}}\right)^2 & \text{if } \left(O_{\text{UL/LL}} - O_{\text{pred}}(\vec{P})\right) \lessgtr 0 \\ 0 & \text{otherwise} \end{cases}$$

Currently used for LEP limit $m_{\chi^\pm} \geq 103.5$ GeV.

χ^2 contribution from limit on WIMP-nucleon cross section

Experiments present result as 1D upper limit for given WIMP mass:



χ^2 contribution from limit on WIMP-nucleon cross section

- Slightly different limit implementation:

$$\chi^2_{\mathrm{DD}}\left(O_{\mathrm{pred}}, \sigma_{\mathrm{pred}}\right) = \frac{\left(0 - O_{\mathrm{pred}}\right)^2}{\sigma^2_{\mathrm{meas}} + \sigma^2_{\mathrm{pred}}}$$

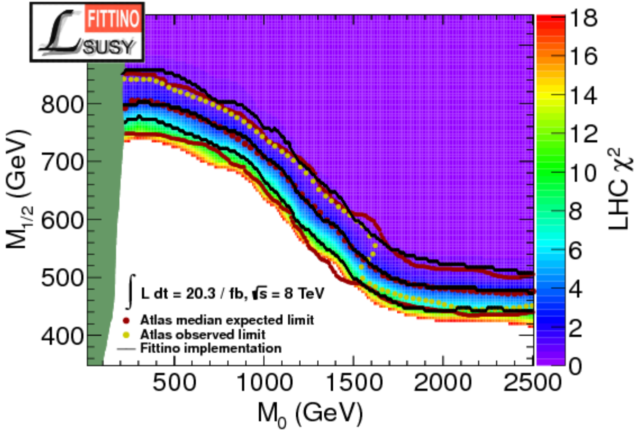
- σ_{meas} chosen such that

$$\chi^2_{\mathrm{DD}}\left(O^{0.9}_{UL}, 0\right) = Q^2_{0.9} = 1.64$$

- σ_{pred} dominated by the uncertainty on form factor of nucleon
- See AstroFit, `arXiv:1202.1385`

χ^2 contribution from ATLAS SUSY searches

Experiments present results as 2D 95% lower limit on M_0 - $M_{1/2}$:



MET + jets + 0 lepton channel ATLAS-CONF-2013-047

χ^2 contribution from ATLAS SUSY searches

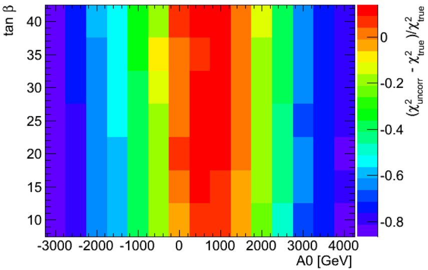
- Take background prediction from ATLAS
- Take signal prediction from Spheno, Herwig++, Prospino, Delphes
- Construct likelihood

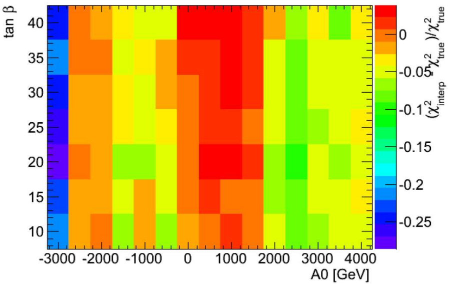
$$\begin{aligned}&\mathcal{L}(\mathrm{data}|s,\theta_s,\theta_b)\\=&\mathrm{Poisson}(\mathrm{data}|s\theta_s+b\theta_b)\mathrm{Gauss}(1|\theta_s,\sigma_s)\mathrm{Gauss}(1|\theta_b,\sigma_b)\end{aligned}$$

- Calculate

$$\chi^2_{\mathrm{LHC}}(s)=-2\ln\frac{\max_{\theta_s,\theta_b}\mathcal{L}(\mathrm{data}|s,\theta_s,\theta_b)}{\max_{s',\theta_s,\theta_b}\mathcal{L}(\mathrm{data}|s',\theta_s,\theta_b)}$$

χ^2 contribution from ATLAS SUSY searches

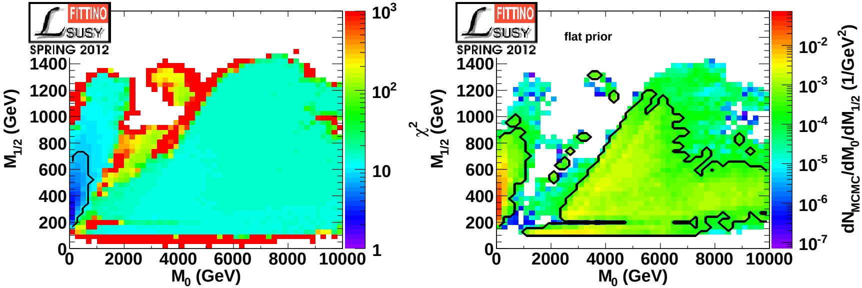




- Depending on value of A_0 and $\tan\beta$ stop-production increases
- Along exclusion line we produced grids of correction factors in A_0-$\tan\beta$

Statistics

- We use markov chains of total length $O(10^9)$ to sample parameter space
- These can be used for frequentist and bayesian interpretation

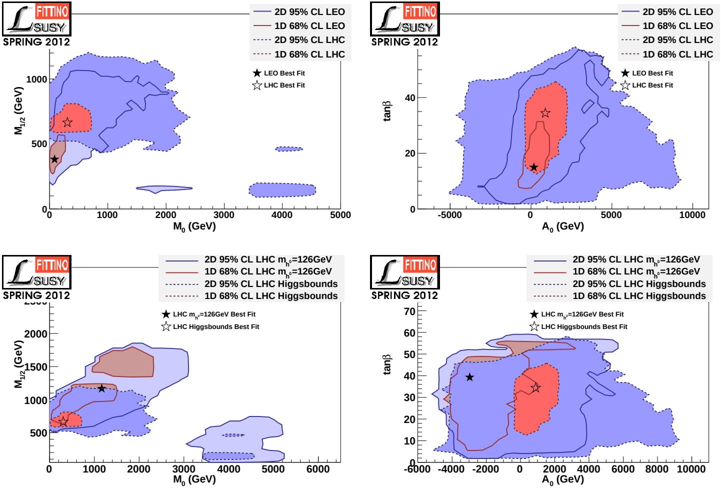


In the following use frequentist interpretation

- Get rid of dependence on prior
- Allows use of variable (auto-adaptive) width of proposal density
- Allows to make use of rejected parameter points

Reminder: The CMSSM getting into trouble

arXiv:1204.4199



	χ^2/ndf
LEO	10.3/8
LHC	13.1/9
Higgs	18.4/9

Updated measurements

LEO

$\mathcal{B}(B_s \to \mu^+\mu^-)$	$(3.20 \pm 1.50 \pm 0.76) \times 10^{-9}$	LHCb '12
$\mathcal{B}(B^\pm \to \tau^\pm\nu)$	$(0.72 \pm 0.27 \pm 0.11 \pm 0.07) \times 10^{-4}$	Belle '12
$\mathcal{B}(b \to s\gamma)$	$(3.43 \pm 0.21 \pm 0.07 \pm 0.23) \times 10^{-4}$	
Δm_s	$(17.719 \pm 0.043 \pm 4.200)\,\mathrm{ps}^{-1}$	
$a_\mu - a_\mu^{\mathrm{SM}}$	$(28.7 \pm 8.0 \pm 2.0) \times 10^{-10}$	
m_W	$80.385 \pm 0.015 \pm 0.010$	
m_t	$(173.18 \pm 0.94)\,\mathrm{GeV}$	
$\sin^2\theta_{\mathrm{eff}}$	0.23113 ± 0.00021	

Updated measurements

Direct searches for sparticles and Higgs Bosons

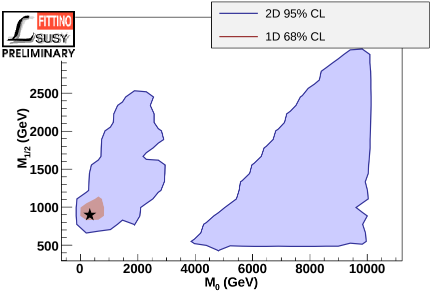
- Higgs limits via HiggsBounds
- Higgs signals via HiggsSignals
- LEP chargino mass limit
- ATLAS MET + jets + 0 lepton search (20fb^{-1})

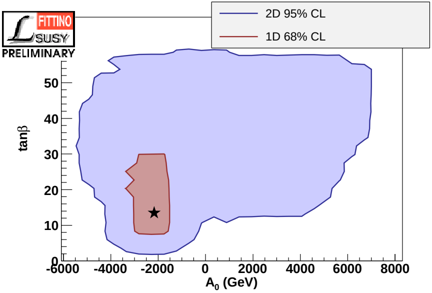
Astrophysical observables

- We require χ_1^0 to be the LSP
- Dark matter relic density:
  $\Omega_{\rm CDM} h^2 = 0.1187 \pm 0.0017 \pm 0.0119$ (Planck '13)
- Direct detection limit from 225 live days of Xenon100 ('12)

Preferred parameter space

... with $m_h = (125.5 \pm 2 \pm 3)$ GeV but without Higgs rates



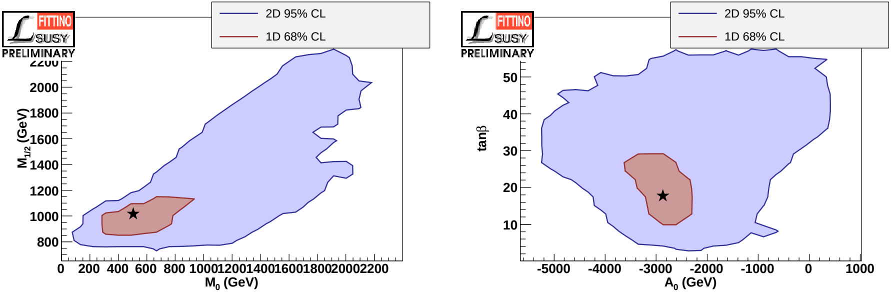


$\chi^2/\mathrm{ndf} = 13.6/9$

- Fit quality improves due to new measurement of $B \to \tau\nu$
- FP / Higgs funnel region allowed at 2σ

Preferred parameter space

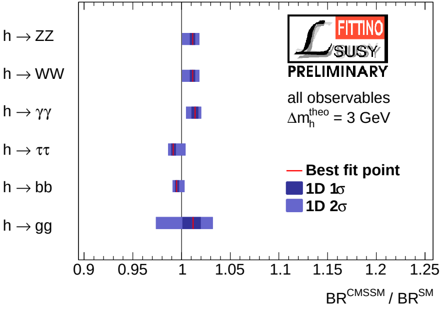
...with mass und Higgs rates measurements via HiggsSignals

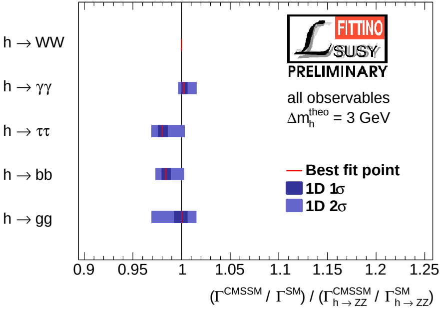


$\chi^2/\mathrm{ndf} = 49.6/59$

- Fit quality improves: SM like Higgs well described by CMSSM
- FP / Higgs funnel region disfavored at 2σ

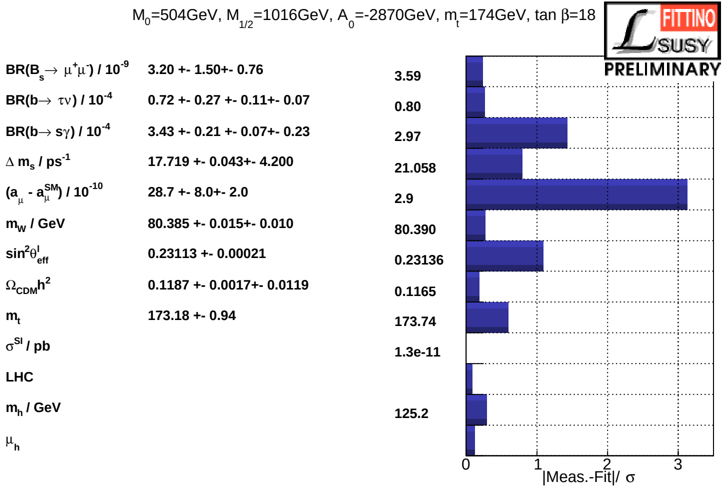
Predicted Higgs properties





- SM-like Higgs boson, not much room left

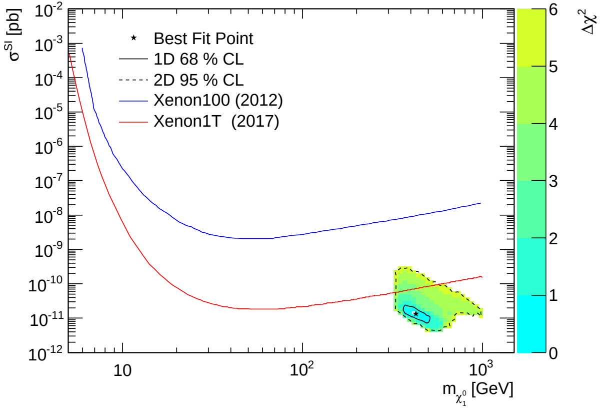
Agreement of observations with model predictions



SM like region of parameter space

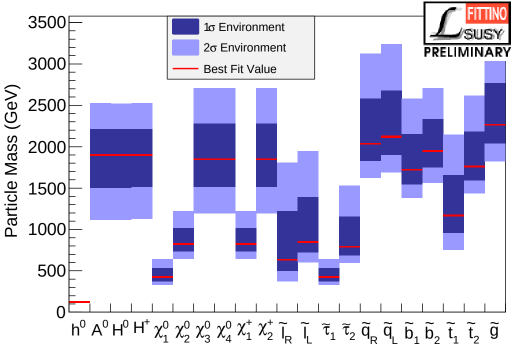
$\Rightarrow$ SUSY is loosing its advantage in prediction of $g-2$

Predicted direct detection cross section



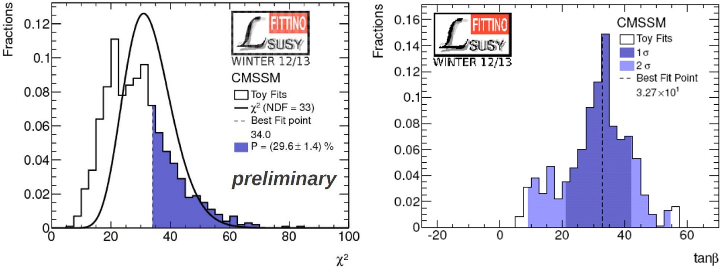
- Xenon 100 currently not sensitive
- Xenon1T will start to probe 2σ region

Predicted mass spectrum



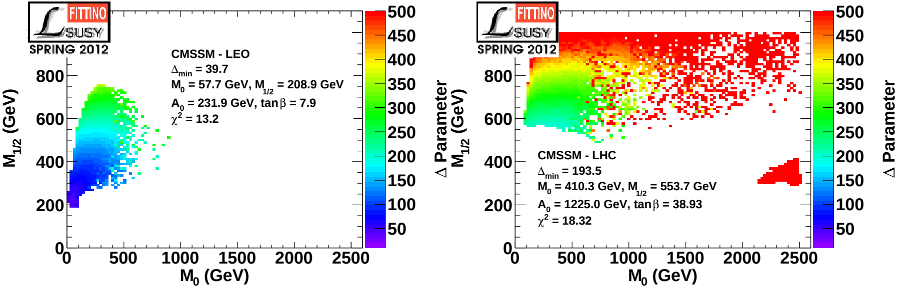
- Lower bound of 1 TeV on heavy Higgs bosons
- Relative light $\tilde{\tau}_1$ because of coannihilation region
- Relative light $\tilde{t}_1$ because of large stop mixing
- $\tilde{q}$ and $\tilde{g}$ masses at best fit point about 2 TeV

First glimpse of real frequentist $\mathcal{P}$-Values



- χ^2/ndf not best measure for goodness-of-fit because our χ^2 is not χ^2-distributed
- What we really want are $\mathcal{P}$-Values from toys (computationally expensive)
- As a benefit we get "Toy-Parameter-Distributions" - but no real frequentist confidence intervals (computationally too expensive)

Finetuning

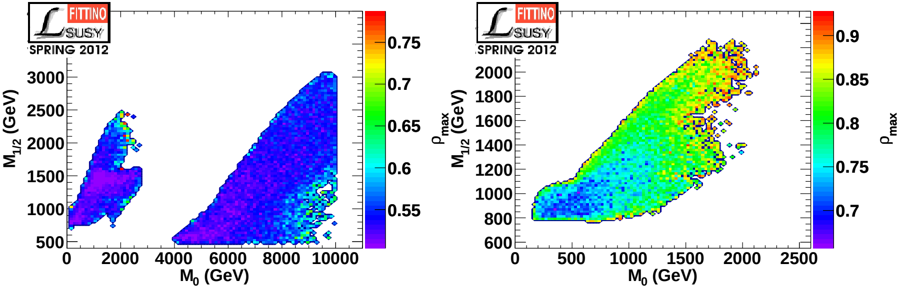


- Measure of amount of finetuning:

$$c(a_i) = \left| \frac{a_i}{m_Z^2} \frac{\partial m_Z^2(a_i)}{\partial a_i} \right|, \qquad \Delta = \max_i(c(a_i))$$

- Calculated using SoftSUSY
- Finetuning increases when including LHC exclusions

Correlations



- Measure of correlations of parameters:

$$\varrho_{ij} = \left\langle \frac{(P_i - \langle P_i \rangle) \cdot (P_j - \langle P_j \rangle)}{\sigma_{P_i} \sigma_{P_j}} \right\rangle, \quad \varrho_{\max} = \max_{ij} \left(|\varrho_{ij}| \right)$$

- This measures amount of tuning necessary if all observables are taken into account
- Increases when using HiggsSignals

Summary

- The CMSSM might seem less attrative nowadays . . .
- . . . but it describes all data well.
- However it becomes difficult to distinguish it from the SM.
- CMSSM $\approx$ SM with dark matter.
- If you want to kill *The lady* you'll have to kill the *The tramp* first.