Bayesian Implications of Current LHC Limits for the Constrained MSSM

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Young Theorists' Forum

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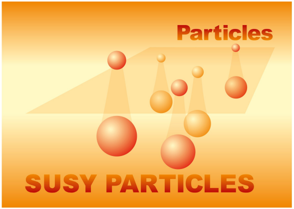
Supersymmetry



Cartoon of supersymmetry, from SUSY DESY

Supersymmetry

- A symmetry between fermions and bosons
- Postulates the existence of a "mirror image" of the Standard Model
- The superparticles have not been seen, so must be massive
- and supersymmetry must be spontaneously broken!
- Protects the mass of the Higgs boson, and solves the "fine-tuning" problem

The CMSSM

The Constrained Minimal Supersymmetric Standard Model

- Supersymmetry is very economical
- But a phenomenological parameterisation of supersymmetry *breaking* introduces ≈100 free parameters
- That's too many to work with!
- We use the CMSSM, which has only four free parameters
- Soft-breaking scalar masses, gaugino masses and trilinears are degenerate the the GUT scale
- CMSSM: m_0, $m_{1/2}$, A_0 and $\tan\beta$

Comparing theory with experiments

- The CMSSM has four free parameters
- Does it agrees with all experiments, including the CMS α_T search?
- We use *SuperBayeS* computer program, to scan the CMSSM's parameter space and find regions that agree with experiments

SuperBayeS includes the nested sampling Monte Carlo algorithm

We use Bayesian statistics

Frequentist *versus* Bayesian

- We use Bayesian statistics; we consider probability of theory given data
- A frequentist statistician, however, would consider probability of data given theory
- Frequentist *versus* Bayesian is a long-running argument…
- Posterior $\propto$ Likelihood $\times$ Prior

$$p(m_0, m_{1/2}, A_0, \tan\beta | d) \propto \mathcal{L}(m_0, \ldots) \times \pi(m_0, \ldots)$$

- We must construct likelihood functions for the constraints on supersymmetry

The Non-LHC likelihoods

Non-LHC experiments

The significant Non-LHC constraints on the CMSSM are:

- WMAP7 constraint on the relic density of the neutralino, $\Omega_\chi h^2$
- LEP and Tevatron limits on sparticle masses and $m_h > 114.4\,\text{GeV}$
- Loop contributions to Δa_μ, $b \to s\gamma$ and $B_s \to \mu^+\mu^-$

The likelihoods for these constraints are Gaussians (central value) or half-Gaussians (upper or lower limit)

$$\mathcal{L} = e^{-\frac{(\mu-x)^2}{2\sigma^2}}$$

The total likelihood is a product of the individual likelihoods

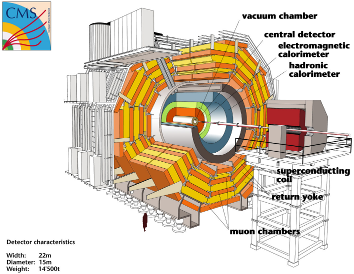
Constraints on the CMSSM

Experimental data

Measurement	Mean	Exp. Error	The. Error	Likelihood Distribution
CMS α_T 1.1/fb analysis				
α_T	See text	See text	0	Poisson
XENON100				
$\sigma_p^{SI}(m_\chi)$	$< f(m_\chi)$ — see text	0	1000%	Upper limit — Error Function
Non-LHC				
$\Omega_\chi h^2$	0.1120	0.0056	10%	Gaussian
$\sin^2\theta_{\text{eff}}$	0.231160	0.00013	15.0×10^{-5}	Gaussian
M_W	80.399	0.023	0.015	Gaussian
$\delta(g-2)_\mu^{SUSY} \times 10^{10}$	30.5	8.6	1	Gaussian
$\mathcal{BR}(\bar{B} \to X_s\gamma) \times 10^4$	3.6	0.23	0.21	Gaussian
$\mathcal{BR}(B_u \to \tau\nu) \times 10^4$	1.66	0.66	0.38	Gaussian
ΔM_{B_s}	17.77	0.12	2.4	Gaussian
$\mathcal{BR}(B_s \to \mu^+\mu^-)$	$< 1.5 \times 10^{-8}$	0	14%	Upper limit — Error Function
Nuisance				
$1/\alpha_{\text{em}}(M_Z)^{\overline{MS}}$	127.916	0.015	0	Gaussian
m_t^{POLE}	172.9	1.1	0	Gaussian
$m_b(m_b)^{\overline{MS}}$	4.19	0.12	0	Gaussian
$\alpha_s(M_Z)^{\overline{MS}}$	0.1184	0.0006	0	Gaussian
LEP — 95% Limits				
m_h	> 114.4	0	3	Lower limit — Error Function
ζ_h^2	$< f(m_h)$	0	0	Upper limit — Step Function
m_χ	> 50	0	5%	Lower limit — Error Function

The CMS α_T LHC likelihood

The CMS detector



Exploded view of the CMS detector, from *cdsweb.cern.ch*

Compact Muon Solenoid

- Observe the results of the collisions with a detector
- CMS is a "general purpose" detector
- Sensitive to all particles and decay signatures
- Discriminate between "interesting" and background events with off-line cuts

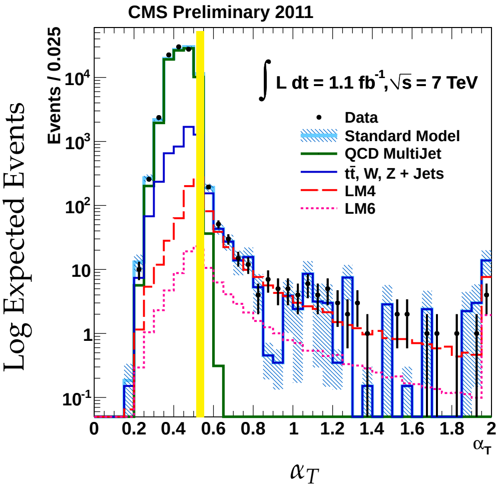
The CMS α_T search for supersymmetry

- CMS looked for supersymmetry in its 2011 data, by looking for "jets" and missing transverse energy
- Discriminator against background was its $\alpha_T > 0.55$ cut
- No significant excess over the Standard Model background

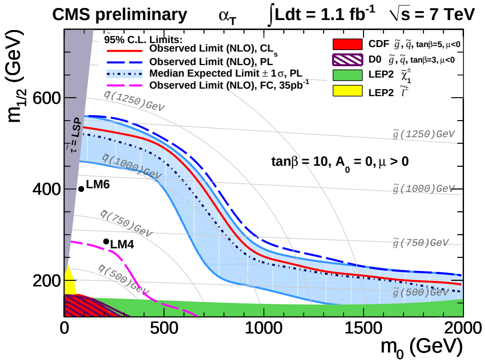
The CMS α_T search for supersymmetry

From CMS Public Web

- — = Expected SM QCD background
- — = Expected SUSY signal
- ■ = Excluded by $\alpha_T > 0.55$ — mostly QCD background
- ⸸ = The observed data — close to total expected SM background



Exclusion in CMSSM from the CMS α_T



Exclusion, from CMS Public Web

- Supersymmetry particles were not seen
- So low-mass region of the CMSSM below the blue dotted line (– – –) is excluded at 95%

Simulating α_T likelihood

- Wanted to know the likelihood at each point on the (m_0, $m_{1/2}$) plane, not just the 95% exclusion contour
- Likelihood of observing o events, given that we expected s supersymmetry events and b Standard Model background events is given by a Poisson

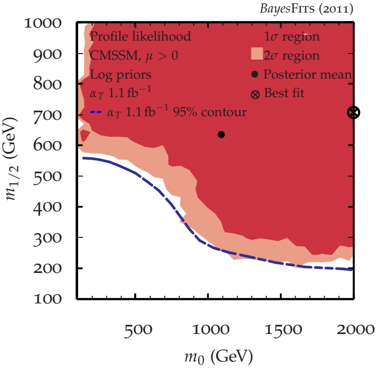
$$\mathcal{L} = \frac{e^{-s+b}\,(s+b)^o}{o!}$$

- We follow CMS treatment — bin events into eight H_T bins
- Simulated the selection efficiency and calculated the cross section to LO with PYTHIA

$$s = \epsilon \times \sigma \times L$$

Validating our α_T likelihood

- We calculated our likelihood map on the $(m_0, m_{1/2})$ plane, and our 95% contour with the PL method with $\Delta\chi^2 = 5.99$
- Excellent agreement between our 95% contour (■) and the official CMS 95% contour (– – –)
- Fixed $\tan\beta = 10$ and $A_0 = 0$ — but checked that likelihood was independent first



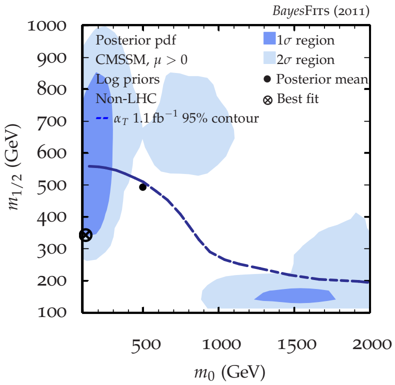
My result, from forthcoming publication

Results — Global fit of CMSSM

Results — CMSSM global fit pre-LHC

- Posterior probability map on the CMSSM's $(m_0, m_{1/2})$ plane
- Consider Non-LHC experiments only
- Stau co-annihilation region and focus point region
- 95% region = ▇, 68% region = ▇

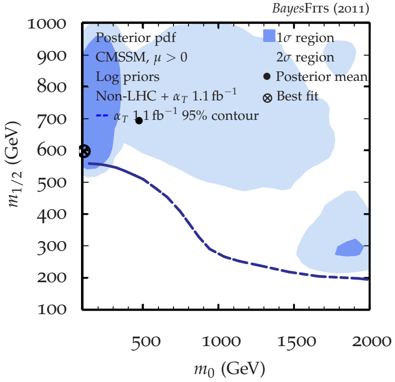
From arXiv:1111.6098v1 [hep-ph]



Results — CMSSM global fit post-LHC

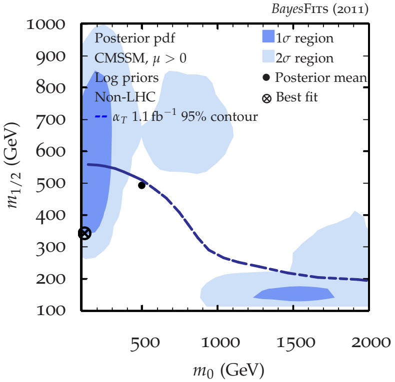
- Posterior probability map on the CMSSM's $(m_0, m_{1/2})$ plane
- Consider all experiments, including the latest LHC results
- Stau co-annihlation region severed
- 95% region = ■, 68% region = ■

From arXiv:1111.6098v1 [hep-ph]

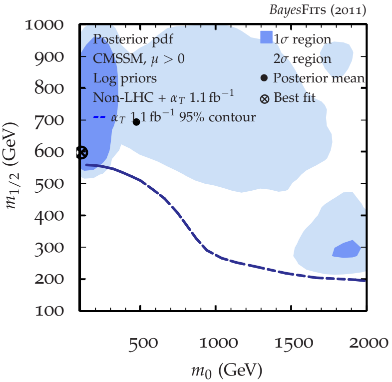


Comparing pre- and post-LHC

Pre-LHC



Post-LHC



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