Observation of constrained MSSM and Maximum Entropy Principle

Surabhi Gupta, Sudhir Kumar Gupta
surabhigupta426@gmail.com, sudhir.ph@amu.ac.in
Aligarh Muslim University, Aligarh, 202002, UP, India

Abstract

The discovery of a 125 GeV Higgs-boson at the Large Hadron Collider poses a significant challenge for the minimal supersymmetric standard model (MSSM). We present our phenomenological research on various Higgs allied processes in the light of the pre-existing data from several other experiments including the data on electroweak precision observables, B-physics and the data from dark matter searches to investigate finely tuned CMSSM using Bayesian inference technique which is also compared with other advanced statistical techniques to restrict the SUSY parameter space.

Information theory

The information theory provides a quantitative measure of uncertainty in finding the state of the certain system by means of an analog of Boltzmann entropy which is known as the Gibbs-Shannon entropy or information entropy. [1]
The entropy of the system would then be

$$S = -k_B \langle \ln p \rangle = -k_B \sum_{i \in \{micro\}} p_i \ln p_i. \quad (1)$$

where, the i^{th} microstate having probability p_i with k_B being the Boltzmann's constant.

Formalism

The above idea is directly applicable to study new physics models by assuming $\mathcal{N}$–number of independent Higgs-boson forming an ensemble wherein each of them is allowed to decay through its various decay modes permissible by the underlying new physics theory with probabilities $p_d(m_h)$ given by the branching ratio $Br_d(m_h)$ in its d^{th} decay mode, n_d to be the number of allowed decay modes of the Higgs-boson. The probability that this ensemble reaches to a final state through its various decay modes is given by the following multinomial distribution

$$\mathcal{P}_{\{m_d\}}(m_h) = \frac{\mathcal{N}!}{m_1!...m_d!} \prod_{d=1}^{n_d} (p_d(m_h))^{m_d}, \quad (2)$$

with $\sum_{d=1}^{n_d} Br_d = 1$ and $\sum_{d=1}^{n_d} m_d = \mathcal{N}$; m_d represents the number of Higgs-bosons decaying through d^{th} detection mode. The total information entropy associated with the $\mathcal{N}$–Higgs-bosons in their final state could therefore be written as

$$S(m_h) = -\sum_{\{m_d\}}^{\mathcal{N}} \mathcal{P}_{\{m_d\}}(m_h) \ln \mathcal{P}_{\{m_d\}}(m_h). \quad (3)$$

The masses of Higgs of the MSSM at the tree-level [2],

$$m_{A^0}^2 = 2|\mu|^2 + m_{H_u}^2 + m_{H_d}^2, \quad (4)$$

$$m_{h,H}^2 = \frac{1}{2}(m_{A^0}^2 + m_Z^2 \mp \sqrt{(m_{A^0}^2 - m_Z^2)^2 + 4 m_Z^2 m_{A^0}^2 sin^2(2\beta)}), \quad (5)$$

$$m_{H^\pm}^2 = m_{A^0}^2 + M_W^2, \quad (6)$$

Thus, the leading contribution to the lighter CP-even Higgs is a term of order,

$$\triangle m_h^2 = \frac{3g^2 m_t^4}{8\pi^2 m_W^2}[ln(\frac{M_S^2}{m_t^2}) + \frac{X_t^2}{M_S^2}(1 - \frac{X_t^2}{12 M_S^2})]. \quad (7)$$

Results

An asymptotic expansion of the expression (3) would result in the following form of entropy of the Higgs-bosons,

$$S(m_h) \simeq \frac{1}{2} \ln \left((2\pi \mathcal{N} e)^{n_d - 1} \prod_{d=1}^{n_d} p_d(m_h) \right) + \frac{1}{12\mathcal{N}} \left(3n_d - 2 - \sum_{d=1}^{n_d} (p_d(m_h))^{-1} \right) + \mathcal{O}(\mathcal{N}^{-2}). \quad (8)$$

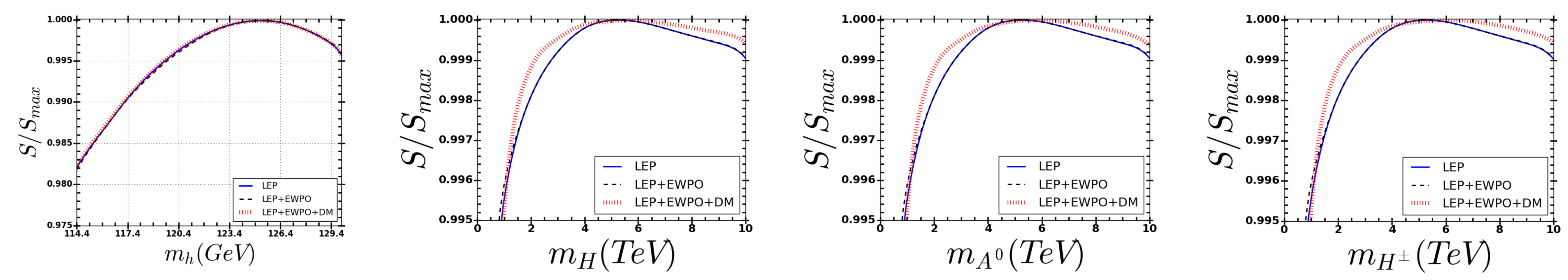

Fig1: *Marginalized entropy vs (a) lighter CP-even neutral Higgs-boson h, (b) heavier CP-even neutral Higgs-boson H, (c) CP-odd neutral Higgs-boson A^0 and (d) charged Higgs-boson $H^\pm$. By taking into account (a) only LEP bound (blue solid line), (b) LEP and electroweak precision observables (EWPO) bounds (black dashed line) and (c) LEP, EWPO and dark matter relic density (DM) bounds (red dotted line).*

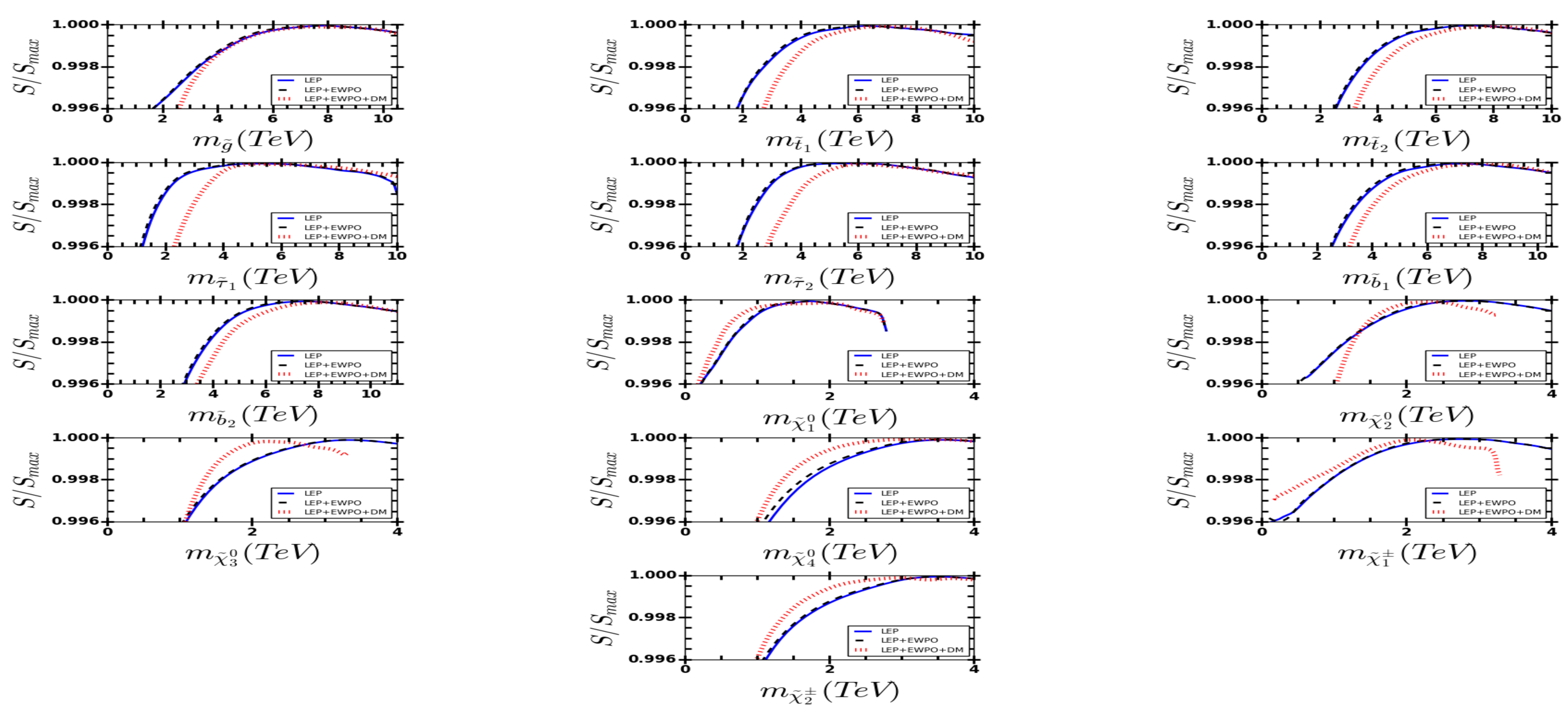

Fig2: *Marginalized entropy vs masses of the sparticle*

Scanned parameters

We have scanned free parameters of CMSSM along with the SM parameter i.e. top quark mass, m_t, in our analysis within following limits

1. $m_0 \in [0.1, 10]$ TeV,
2. $m_{1/2} \in [0.1, 6]$ TeV,
3. $tan\beta \in [2, 60]$,
4. $A_0 \in [-10, 10]$ TeV,
5. $sign(\mu) = +1$,
6. $m_t \in [171, 176]$ GeV.

Experiments	Observables	Experimental Values
LEP	m_h	> 114.4 GeV
	$m_{\tilde{\chi}^0_{1,2,3,4}}$	$> M_Z/2$
	$m_{\tilde{\chi}^\pm_{1,2}}$	> 103.4 GeV
EWPO	$\triangle\rho$	0.0008 ± 0.0017
	$BR(b \to s\gamma)$	$(3.55 \pm 0.24) \times 10^{-4}$
	$\triangle a_\mu$	$(2.68 \pm 0.43) \times 10^{-9}$
DM	$\Omega_\chi h^2$	0.1186 ± 0.002

Table1: *Experimental observables used as constraints in our analysis. [2, 3]*

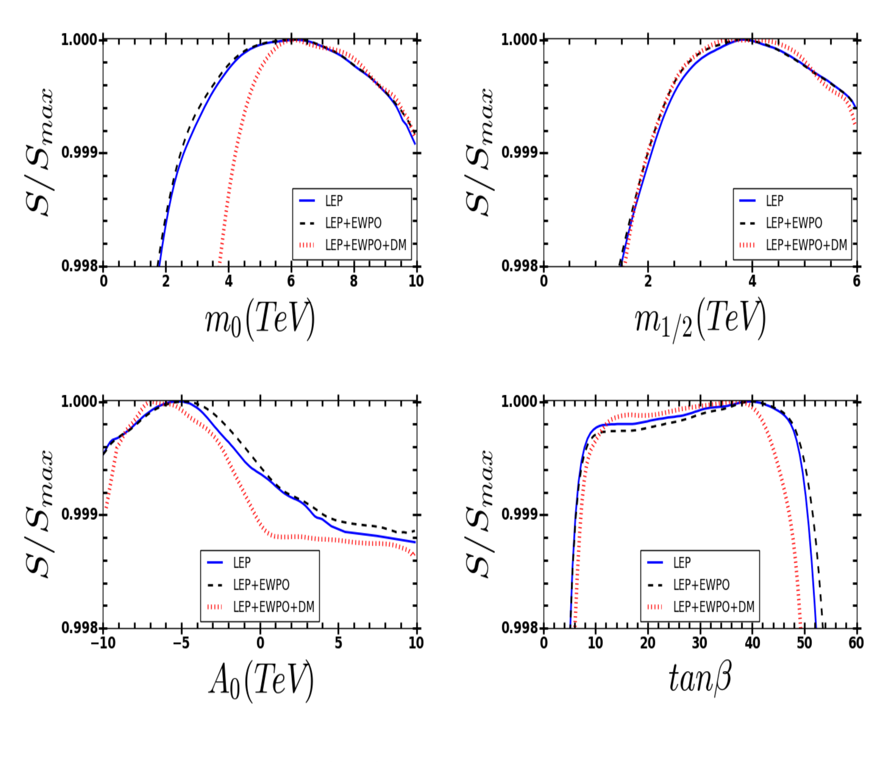

Fig3: *Marginalized entropy vs CMSSM parameters.*

Conclusions

Parameters	Constraints		
	LEP	LEP+EWPO	LEP+EWPO+DM
m_0	6.16	6.00	5.99
$m_{1/2}$	3.80	3.74	3.58
A_0	-5.40	-4.93	-6.92
$tan\beta$	39.37	39.56	36.83
m_h	125.16	125.16	125.24
m_H	5.21	5.22	5.61
m_{A^0}	5.20	5.19	5.71
$m_{H^\pm}$	5.27	5.28	6.19
$m_{\tilde{\chi}^0_1}$	1.73	1.71	1.92
$m_{\tilde{\chi}^0_2}$	2.84	2.79	3.20
$m_{\tilde{\chi}^0_3}$	3.31	3.35	2.23
$m_{\tilde{\chi}^0_4}$	3.55	3.50	3.11
$m_{\tilde{\chi}^\pm_1}$	2.71	2.71	2.10
$m_{\tilde{\chi}^\pm_2}$	3.45	3.45	2.96
$m_{\tilde{g}}$	7.78	7.73	7.44
$m_{\tilde{q}_L}$	8.17	7.99	8.97
$m_{\tilde{q}_R}$	7.81	7.76	8.71
$m_{\tilde{b}_1}$	7.09	7.088	7.94
$m_{\tilde{b}_2}$	7.49	7.486	8.33
$m_{\tilde{t}_1}$	6.24	6.24	6.75
$m_{\tilde{t}_2}$	7.15	7.12	7.96
$m_{\tilde{l}_L}$	5.73	5.73	6.60
$m_{\tilde{l}_R}$	6.06	5.76	6.18
$m_{\tilde{\tau}_1}$	5.31	5.12	5.26
$m_{\tilde{\tau}_2}$	5.45	5.35	6.09

Table2: *The sparticle mass spectrum for the marginalized maximum entropy for different constraints. All parameters except $tan\beta$ with mass dimension, m_h is in GeV and rest sparticles are in TeV.*

We have studied the allowed parameter space by imposing different constraints from direct sparticle and Higgs-boson search limits, indirect constraints and from astrophysical observable. Even with the constrained space, the lightest Higgs mass of the MSSM model is in a good agreement with the LHC observations. The masses of rest of the Higgs of this model have also been evaluated through this approach. We found that Higgs's entropy describe the MSSM parameters and evaluate the sfermions and gauginos masses of the order of the TeV scale.

References

[1] C.E. Shannon, *A mathematical theory of communication*, Bell Syst. Tech. J. **27**, 379–423 (1948).
[2] M. Tanabashi *et al.* (Particle Data Group), *Review of Particle Physics*, Phys. Rev. D **98**, 030001 (2018).
[3] C. Balazs, A. Buckley, D. Carter, B. Farmer and M. White, *Should we still believe in constrained supersymmetry?*. Eur. Phys. J. C **73**, 2563 (2013), arXiv:1205.1568 [hep-ph].