36^{th} International Conference on High Enegery Physics -2012

A 125 GeV Higgs in PQ violating Minimal Supergravity model

Sudhir K Gupta in collaboration with **Csaba Balázs**

COEPP, Monash University, Melbourne, Australia

The model

Peccei-Quinn (PQ) symmetry is a global $U(1)$ symmetry which was originally proposed to solve the "Strong CP problem" of QCD by replacing the CP violating parameter with a (pseudo-scalar) axion field.

Solution to the strong CP problems requies that the PQ-symmetry must be broken at an scale $\Lambda_{PQ} > 10^9$ GeV or so.

axino mass $m_a \simeq \frac{6.2\times10^{-3}}{\Lambda_{PQ}}$ GeV.

PQ extension of Minimal Supersymmetric Standard Model (MSSM) will result in an axion, an axino (the fermionic superpartner) and the s-axion (scalar superpartner).

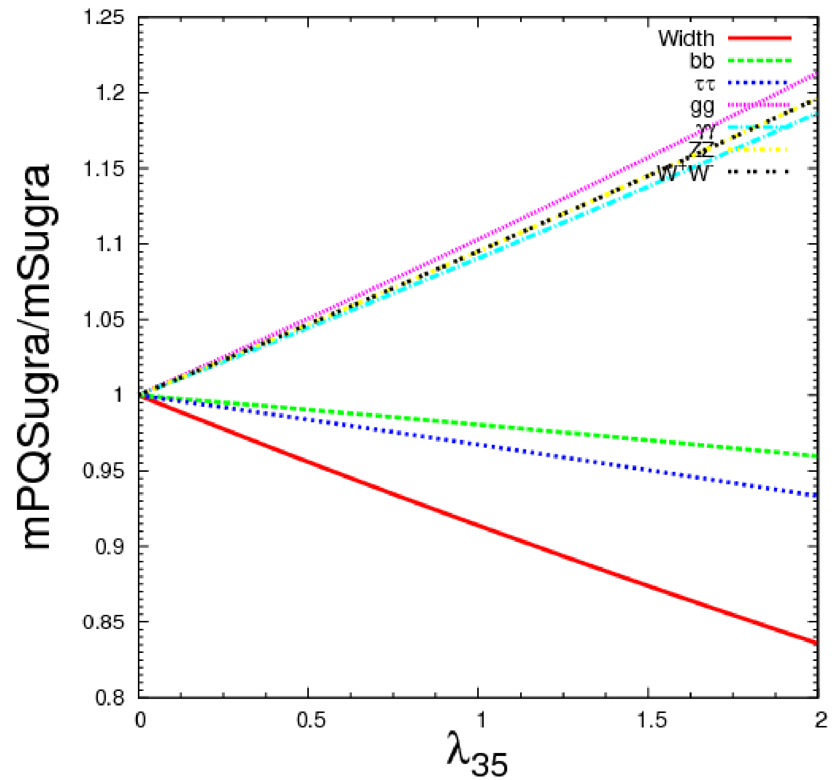
$m_{axino} \simeq \frac{\Lambda_{PQ}^2}{M_{Planck}}$, $m_{s-axion} \simeq \Lambda_{PQ}$.

Cosmology puts an upper bound on the $\Lambda_{PQ} \lesssim 5 \times 10^{11}$ GeV.

Consequences

- Cosmological(DM related): It is possible to have axino dark matter for a wide range of PQMSSM paramter space provided R-parity is conserved.
  Three Dark Matter (DM) scenarios are possible:
  Scenario 1: ($\tilde{\chi}_1^0$ is LSP) $m_{Axino} > m_{\tilde{\chi}_1^0} \rightarrow \tilde{\chi}_1^0$ as a DM candiate.
  Scenario 2: (Axino is LSP) $m_{Axino} < m_{\tilde{\chi}_1^0} \rightarrow$ Axino as a DM candidate.
  Scenario 3: (Axino and $\tilde{\chi}_1^0$ are co-LSPs) $m_{Axino} \simeq m_{\tilde{\chi}_1^0} \rightarrow$ both Axino and $\tilde{\chi}_1^0$ are viable DM candidates.

- Collider (Higgs Searches): A slight PQ violation can also modify Higgs potential significantly which may result in observable deviations into the LHC Higgs production and its decay rates into various modes.



Ratio of Total decay width and various Branching ratios of the SM-like Higgs boson in the PQ-violating mSUGRA to the conserved mSUGRA case for $m_0 = 1000$, $m_{1/2} = 500$, $A_0 = 0$ (all in GeV units), $\tan\beta = 30$, $sgn(\mu) = +$.

- Theoretical (on NMSSM): The so called "Tadpole problem" and "domain wall problem" can be solved in the "next-to-minial" extensions of SSM. (arXiv:1205.2486 [hep-ph])

A Bayesian analysis of the Model

To test how good/bad these PQ-mSugra scenarios can be in the light of current LHC Higgs searches, we performed a Bayesian analysis of these and compared our results with the mSugra model.

Input Parameters

- $m_0 \in [10, 2000]$ GeV
- $m_{1/2} \in [10, 2000]$ GeV
- $A_0 \in [-3000, 4000]$ GeV
- $\tan\beta \in [0, 62]$
- $\lambda_{35} \in [0, 2]$
- $\Lambda_{PQ} \in \left[10^6, 5 \times 10^{11}\right]$ GeV.

Experimental and Theoretical Constraints

1. EWPOs

- $\delta\rho = 0.0008 \pm 0.0017$
- $a_\mu^{SUSY} = (3.353 \pm 8.24) \times 10^{-9}$
- $BR(b \to s\gamma) = (3.55 \pm 0.26 \pm 5\%) \times 10^{-4}$

1. LEP2/Tevatron bounds

- $m_{\tilde{\chi}_1^0} > 45.6$ GeV
- $m_{\tilde{\chi}_1^\pm} > 103.5$ GeV
- $m_{\tilde{l}} > 99$ GeV
- $m_{\tilde{l}} - m_{\tilde{\chi}_1^0} > 10$ GeV
- $m_h > 114.4$ GeV

3. Late 2011 LHC Higgs Searches @7 TeV

- $m_h = 126 \pm 1.5(exp.) \pm 2(th.)$
- $R_{gg\gamma\gamma} = \left(\frac{\sigma^{SUSY}}{\sigma^{SM}}\right)_{gg \to h \to \gamma\gamma} = 2 \pm 0.8$
- $R_{gg2l2\nu} = \left(\frac{\sigma^{SUSY}}{\sigma^{SM}}\right)_{gg \to h \to WW^* \to l^+ \nu_l l^- \bar{\nu}_l} = 0.16 \pm 0.6$
- $R_{gg4l} = \left(\frac{\sigma^{SUSY}}{\sigma^{SM}}\right)_{gg \to h \to ZZ^* \to l^+ l^- l'^+ l'^-} = 1.2 \pm 1$

A brief introduction to The Bayesian Statistics

In bayseian statistics, we deal with the posterior probabilities and evidences which essentially measure the degree of change of theoretical belief on the availability of experimental data.

In order to calculate evidence of a given model, we follow the following procedure:

1. We first calculate χ_i for each of the experimentally measured observables obervable $\mathcal{O}_i$ as follows,

$$\chi_i = \frac{\left(\mathcal{O}_i^{th.} - \mathcal{O}_i^{exp.}\right)}{\sigma_i} \;\; ; \quad \sigma_i = \sqrt{\left(\sigma_i^{th.}\right)^2 + \left(\sigma_i^{exp.}\right)^2}$$

2. The likelihood function can then be defined as,

$$\mathcal{L}_i = \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\chi_i^2/2}$$

3. The posterior probablity can then be,

$$\mathcal{L} = \prod_i \mathcal{L}_i$$

$$P(x_j) = \frac{\displaystyle\int_{\{x \neq x_j\}} \mathcal{P}(\{x\}) \mathcal{L} \prod_{x \neq x_j} dx}{\int_{\{x\}} \mathcal{P}(\{x\}) \mathcal{L} \prod_x dx}$$

where $\mathcal{P}(\{x\})$ is the prior function and $P(x_j)$ is the posterior probability distribution for the variable x_j; i runs over the observables.

In our case, $\{x\} = \big(m_0, m_{1/2}, A_0, \tan\beta, \lambda_{35}, \Lambda_{PQ}\big)$.

We present our result for the flat prior and the natural $(1/(m_0 m_{1/2})$ prior. Note: The later is preferred by the fine tunning of the Higgs mass.

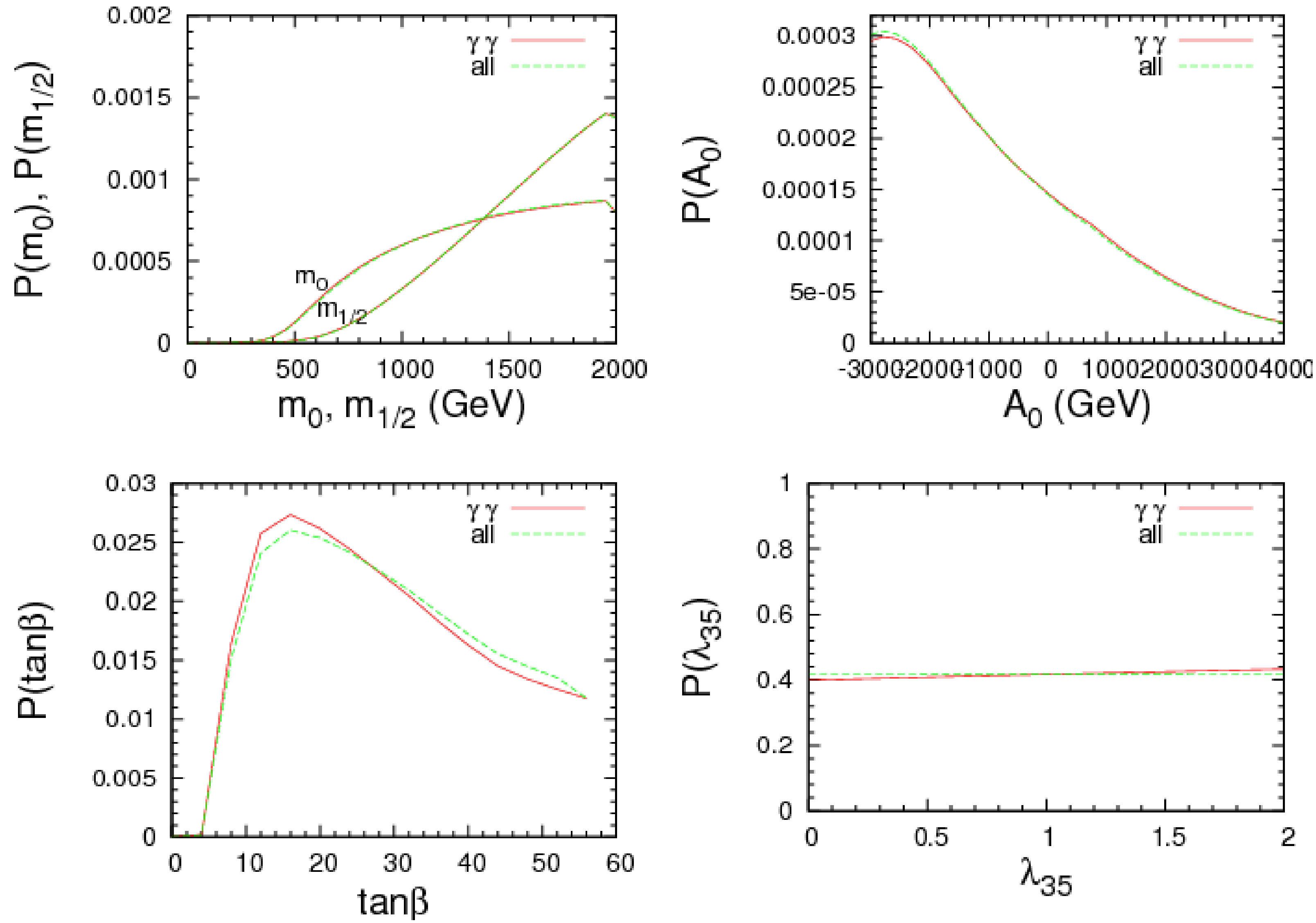


Figure 1: Posterior probability distributions using the flat prior.

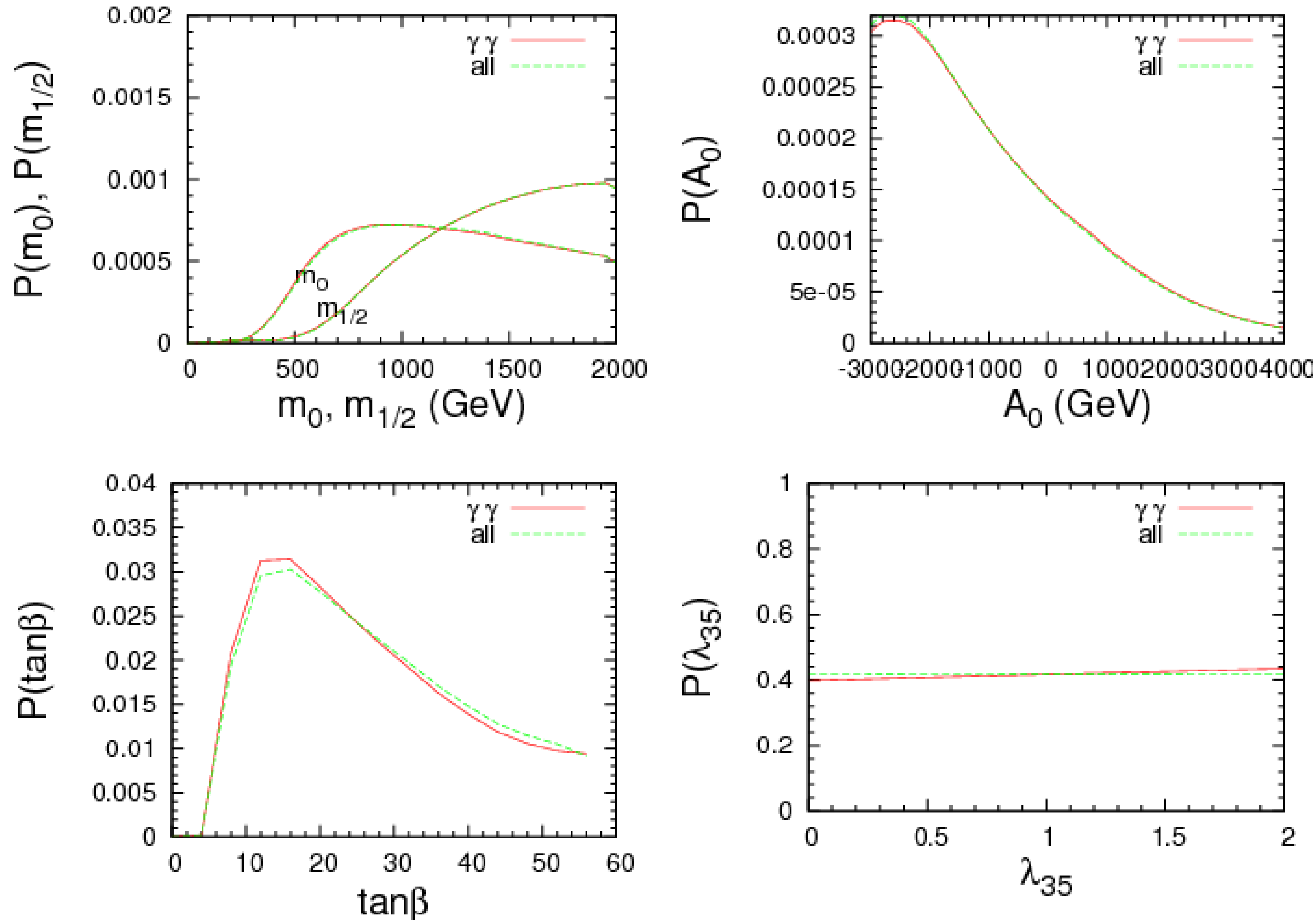


Figure 2: Posterior probability distributions using the natural prior.

Evidence estimates

We define Bayes factor as, $Q = \log_{10}\left(\frac{\mathcal{E}_{mPQSugra}}{\mathcal{E}_{mSugra}}\right)$

Observables	$Q = \log_{10}\left(\frac{\mathcal{E}_{mPQSugra}}{\mathcal{E}_{mSugra}}\right)$		
	Scenario 1	*Scenario 2*	*Scenario 3*
Higgs Searches at the LHC	0.05	0.05	0.57
+ EWPO & LEP data	0.02	0.02	0.55
+ WMAP data	0.001	–	3.86

Bayes factors for various mPQSugra scenarios for $m_0 \in [10, 2000]$, $m_{1/2} \in [10, 2000]$, $A_0 \in [-3000, 4000]$ (all in GeV units), $\tan\beta \in [0, 62]$, $\lambda_{35} \in [0, 2]$, $\lambda_{PQ} \in \left[10^9, 5 \times 10^{11}\right]$ (in GeV).

Jefferey's scale

Barely Worth Mentioning: $Q < 0.5$,

Substentially Better: $0.5 < Q < 1$, **Strong:** $1 < Q < 1.5$,

Very Strong: $1.5 < Q < 2$, **Decisive:** $Q > 2$.

Summary

It is possible to lift-up $h \to \gamma\gamma$ branching ratio substantially in the PQ extended minimal supergravity model.

Our Bayesian analysis suggests that the scenario with axino LSP is strongly preferred over the neutralino LSP, and, axino + neutralino co-LSP scenarios.

An event based LHC study with different Higgs detection modes can put further light onto the model.