LHC-7 supersymmetry search interpretation within the pMSSM

Shehu S. AbdusSalam *
The Abdus Salam International Centre for Theoretical Physics, Strada Costiera 11, Trieste 34014, Italy

Abstract
The ATLAS collaboration published supersymmetry limits based on up to about 4.7 fb−1 data collected over the year 2011 from LHC runs at 7 TeV. These were mainly interpreted within restricted, particular or simplified models for supersymmetry breaking schemes or scenarios. The pMSSM is an alternative and more generic supersymmetry framework which captures broader phenomenological features. Searching for more generic conclusions from the supersymmetry limits interpretation, we update a Bayesian global fit of the pMSSM to pre-LHC data using the LHC-7 limits. The posterior distributions show the most up to date features, revealing allowed versus excluded regions in sparticle mass planes within the MSSM.

1. Introduction
The discovery of Higgs boson-like state around 126.5 GeV [1] or 125 GeV [2] at the large hadron collider (LHC) is an excellent accomplishment. However this only marks the beginning of exciting moments for particle physics endeavour in establishing the mechanism of electroweak symmetry breaking and for shedding light on new physics beyond the Standard Model (BSM.) During the year 2011 run of the LHC machine both ATLAS and CMS detectors have recorded up to about 5 fb−1 of data. The collaborations have conducted many analyses on the data, searching for, amongst other new physics models, supersymmetry (SUSY) by looking for final states containing jets and large missing transverse energy (MET) that could indicate the production of squarks and gluinos in the collider [3, 4]. There is no sign for SUSY observed as of the time of writing this article according to public results. As such findings of the experiments were presented in the form of model-independent non-SM cross section limits and interpretations showing exclusion regions within specific models of SUSY such as the constrained version of the R-parity conserving minimal supersymmetric standard model (MSSM) called CMSSM/mSUGRA, particular SUSY breaking schemes (for a review see e.g. [5]) or simplified models [6] of SUSY scenarios.

1.1 Aim of the article
In this article we will assess the impact of the LHC-7 SUSY results on the R-parity conserving phenomenological MSSM (pMSSM). In particular we are going to use the ATLAS SUSY limits reported in Refs. [7–17] to discriminate between allowed and excluded regions in the pMSSM sparticle mass planes. To date several research groups have looked into analysing the impact of LHC-7 data on various SUSY models. For a non exhaustive instances see Refs. [18–34]. Out of these, the interpretation, within the pMSSM, for the CMS collaboration’s SUSY limits based on 1 fb−1 data presented in [22] has a particular relevance. Our analyses updates the impact of LHC results on the pMSSM, here by using SUSY limits from the ATLAS collaboration with up to about 4.7 fb−1 data. Following the approach in Ref. [22], the data $d$ from the various experiments used for our analysis is decomposed into two independent parts,

\[ d = d_{\text{pre-LHC}} \oplus d_{LHC} \]  

where $d_{\text{pre-LHC}}$ represents the indirect pre-LHC collider and cold dark matter relic density constraints summarised in Table 1 and $d_{LHC}$, the LHC-7 SUSY limits shown in Table 2. The pMSSM posterior

*email: shehu@ictp.it
distributions from the Bayesian global fit \([36]\) to pre-LHC data is now used as the prior, \(\pi(\theta)\), for updating the pMSSM posterior sample with the LHC SUSY limits. Using Bayes theorem, weighing the prior with the likelihood over the LHC data \(L(d_{\text{LHC}}|\theta)\) gives an updated, post-LHC, posterior distribution

\[
p(\theta|d_{\text{LHC}}) \sim L(d_{\text{LHC}}|\theta) \pi(\theta)
\]

valid up to a normalisation factor. Analysing this will reveal information about the impact of the LHC-7 data on the pMSSM parameter space.

This article is structured as follows. In remaining part of this Section we give a brief recapitulation of the Bayesian global fit of the pMSSM to the pre-LHC data allowing us to set the context for explaining our analysis. In Section 2, we present the methodology employed in simulating SUSY event at the LHC and the computation of the pMSSM predictions for the cross section within acceptance, the main observable to compare with the upper limits from ATLAS. The impact of the experimental limits on the pMSSM is presented in Section 3. The last Section is preserved for discussing our conclusions and outlook.

1.2 The pre-LHC pMSSM fit review

The Bayesian global fit of the pMSSM to pre-LHC data were performed in \([35, 36]\). The posterior samples reveal SUSY spectra with various characteristics satisfying different phenomenological scenarios \([37–39]\) which are mainly difficult to capture within the classic constrained benchmark models. For the pMSSM fit, the parametrisation is completely decoupled from the details of the physics responsible for SUSY breaking. Requiring compatibility with observations about CP violation and flavour changing neutral current processes, only real soft SUSY breaking terms are considered, with all off-diagonal elements in the sfermion mass terms and trilinear couplings set to zero, and the first-and second-generation soft terms equalised; leading to a set of 20 parameters:

\[
\theta = \{M_{1,2,3}; m_{3\text{rd gen}}^{\text{lepton}}; m_{1/2}^{\text{1st/2nd gen}}; A_{t,b,\tau,\mu=\pm}; m_{H_u,d}^2; \tan \beta\},
\]

where \(M_1, M_2\) and \(M_3\) are the gaugino mass parameters; and \(m_\tilde{f}\) are the sfermion mass parameters. \(A_{t,b,\tau,\mu=\pm}\) represent the trilinear scalar couplings while the Higgs-sector parameters are specified by the two Higgs doublet masses \(m_{H_u}^2, m_{H_d}^2\), the ratio of the vacuum expectation values \(\tan \beta = \langle H_2 \rangle / \langle H_1 \rangle\) and the sign of the Higgs doublets mixing parameter, \(s\text{ign}(\mu)\). The pre-LHC data, \(d_{\text{pre-LHC}} = \delta = \{\mu_i, \sigma_i\} \text{ where } i = 1, 2, \ldots\), represents the experimental central values and errors for the electroweak physics observables, B-physics observables and the cold dark matter relic density, summarised in Table 1:

\[
\begin{align*}
Q & = \{m_W, \sin^2 \theta_{\text{eff}}^\text{exp}, \Gamma_Z, \delta a_\mu, R_0^b, A_{f_{\text{lepton}}}^0, A_i^l = A^e, R_0^b, A_{f_{\text{lepton}}}^b; A_i^c, B_R(B \rightarrow X_s \gamma), B_R(B_s \rightarrow \mu^+ \mu^-), \Delta_{0-}, R_{BR(B_u \rightarrow \tau\nu)}, R_{\Delta M_{B_s}}; \\
& \Omega_{\text{CDM}} h^2\}\end{align*}
\]

The pre-LHC posterior distribution from the Bayesian global fit which is now considered as a prior distribution for the update with the LHC data is given by

\[
\pi(\theta) = \pi'(\theta) \prod_{i=1} \left(2\pi \sigma_i^2\right)^{-1/2} \exp \left[-(O_i - \mu_i)^2 / 2\sigma_i^2\right]
\]

where \(\pi'(\theta)\) is the prior probability density for the Bayesian global fits to \(d_{\text{pre-LHC}}\) which can be flat over the individual parameters \(\theta_i\) (for flat prior fits) or flat over the logarithm of the parameters, \(\log \theta\) (for log prior fits). Here we do not aim at checking the constraining strength of the LHC data over the pMSSM parameters. Thus no prior dependence analysis is discussed and we work with only the log prior posterior-samples of the pre-LHC global fits. In the next Section we describe the data, i.e. the extra-SM cross sections within acceptance, the simulation of SUSY events at the LHC, and the ATLAS-like analyses of the events. These are used in constructing the likelihood, \(L(d_{\text{LHC}}|\theta)\) required in addition to the prior, \(\pi(\theta)\), for completing the required variables in the target eq. (2).
2. Analysis

Our analyses are centred around computing the likelihood for $d_{LHC}$, given the pMSSM parameters, $\theta_i$. In this Section we describe the ATLAS data and the simulation of SUSY events. The latter allows for computing the extra- SM, here SUSY, cross sections within acceptances, $\sigma^{acc}$, over various cuts on the collider final state characteristics. The degree of agreement or deviation between the pMSSM predictions for $\sigma^{acc}$ and the experimental values is used to quantify the plausibility of obtaining the data from the model parameters, $L(d_{LHC}|\theta)$.

2.1 The data, $d_{LHC}$

The LHC data we use are the 95% C.L. upper limits on the non-SM cross section within acceptance. For each of the ATLAS analyses [7-17], there are various signal regions defined by specific set of cuts and events selection criteria. The results are based on various, namely 35 $\text{pb}^{-1}$ up to 4.7 $\text{fb}^{-1}$, data set recorded by the ATLAS detector at 7 TeV centre of mass energy run of the LHC in the year 2011. The analyses were designed to capture different possible manifestations of SUSY after the proton-proton collisions at the LHC.

SUSY production at the collider would be dominated by large direct production of squark and gluino pairs ($\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, or $\tilde{q}\tilde{q}$) that would decay ($\tilde{g} \rightarrow q\tilde{\chi}_i^0$ and $\tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_i^0$) to the weakly interacting neutralino lightest supersymmetric particle (LSP), $\tilde{\chi}_1^0$, which escapes the detector unseen in the form of missing transverse energy, MET. The different groups of search channels, which we briefly describe here, are all MET-based. The first is the search for squarks and gluinos that lead to final states containing high-$p_T$ jets, MET and no leptons (electrons or muons) as in Refs. [7][11][14]. The strategy for this group of searches is optimised for maximal discovery reach in the $m_{\tilde{g}}$-$m_{\tilde{q}}$ plane. This group of search channels could be specialised to the case of having heavy flavour jets. Doing this would capture the scenario where the sbottoms ($\tilde{b}_1$) and stops ($\tilde{t}_1$) are lighter than other squarks such that direct or gluino-mediated production ($\tilde{g} \rightarrow \tilde{b}\tilde{b}$ or $\tilde{g} \rightarrow \tilde{t}\tilde{t}$) is the dominant SUSY production mode in the collider as considered in Refs. [10][16].

Requiring final states containing one (or more) electron or muon in addition to jets and MET would capture scenarios where gluinos cascade decay products include a charginos, $\tilde{\chi}_i^\pm$, which subsequently decays into final states containing high-$p_T$ leptons as considered in Refs. [9][15]. Further, in scenarios, such as Natural SUSY [41], where first and second generation sfermion masses are larger than few TeVs, the direct production of weak gauginos may be the dominant SUSY processes. When both gauginos decay leptonically, a distinctive signature with no jets, three leptons and significant MET, as considered in Ref. [17], can be observed.

| Observable | Constraint | Observable | Constraint |
|------------|------------|------------|------------|
| $m_W$ [GeV] | 80.399 ± 0.027 | $A^l = A^e$ | 1.0153 ± 0.0021 |
| $\Gamma_Z$ [GeV] | 2.4952 ± 0.0025 | $A^b$ | 0.923 ± 0.020 |
| $\sin^2 \theta_{eff}$ | 0.2324 ± 0.0012 | $A^c$ | 0.670 ± 0.027 |
| $\delta a_\mu$ | (30.2 ± 9.0) × 10$^{10}$ | $Br(B \rightarrow X_s\gamma)$ | (3.55 ± 0.42) × 10$^4$ |
| $R_{\ell}^b$ | 20.767 ± 0.025 | $Br(B_s \rightarrow \mu^+\mu^-)$ | < 5.8 × 10$^{-8}$ (see caption.) |
| $R_{\ell}^b$ | 0.21629 ± 0.00066 | $R_{\Delta M_{Bs}}$ | 0.85 ± 0.11 |
| $R_{\ell}^c$ | 0.1721 ± 0.0030 | $R_{Br(B_s \rightarrow \tau\nu)}$ | 1.26 ± 0.41 |
| $A^H_{FB}$ | 0.0992 ± 0.0016 | $\Delta_{0-}$ | 0.0375 ± 0.0289 |
| $A^c_{FB}$ | 0.0707 ± 0.035 | $\Omega_{CDM} h^2$ | 0.11 ± 0.02 |

Table 1: Summary for the central values and errors for the electroweak physics observables, B-physics observables and cold dark matter relic density constraints. The posterior distribution from the pre-LHC fit for $Br(B_s \rightarrow \mu^+\mu^-)$ is centred around 2.8 × 10$^{-9}$ so most of the points are in agreement with the more recent bound 4.5 × 10$^{-9}$ [40].
In all, we considered 55 SUSY signal regions. For each region the number of events that pass the selected criteria and also the expected Standard Model (background) events were reported. In addition the upper bound on the cross sections for non-SM interactions were also given. These allow for comparisons with any BSM predictions to determine whether the new physics model is allowed or ruled out at the 95% confidence level. This is the approach we have chosen. The LHC data, $d_{LHC}$, for our analysis is represented by the set summarised in Table 2. The limits are used to constrain the pMSSM $\sigma^{acc}$ predictions from the simulation of SUSY production at the LHC.

### Table 2: The ATLAS 95% C.L. upper limits on the extra-SM cross sections within acceptance for the various signal regions described in the text. The limits on each search channel row are ordered; with the first representing the first corresponding name of the signal region described in the corresponding experimental paper. The unit for each cross section is the inverse of the corresponding luminosity.

| Channels + MET | Signal regions, $\sigma_{BSM}$ upper limits | Luminosity |
|----------------|-------------------------------------------|-------------|
| **jets + 0-lep** | 1.3 0.35 1.1 0.11 - - - - - | $35 \text{ pb}^{-1}$ [7] |
| **jets + 0-lep** | 22 25 429 27 17 - - - - - | $1.04 \text{ fb}^{-1}$ [11] |
| $\geq 6$ jets | 194 8.4 12.2 4.5 - - - - - | $1.34 \text{ fb}^{-1}$ [12] |
| 0jet + 2-lep | 0.22 0.09 0.21 0.07 0.07 - - - - - | $35 \text{ pb}^{-1}$ [8] |
| jets + 1-lep | 41 53 - - - - - - - - - | $165 \text{ pb}^{-1}$ [9] |
| b-jet + 0-lep | 288 61 78 17 - - - - - - - | $830 \text{ pb}^{-1}$ [10] |
| $\geq(2-6)$jets + 0-lep | 0.62 5.3 6.2 0.65 3.5 3.7 12 2.2 2.6 2.5 18 | $4.7 \text{ fb}^{-1}$ [13] |
| $\geq(6-9)$jets + 0-lep | 14 4.2 1.2 9.8 3.2 0.81 - - - - - | $4.7 \text{ fb}^{-1}$ [14] |
| $\geq(2-4)$b-jets + 1-lep | 1.3 1.5 3.7 - - - - - - - - | $4.7 \text{ fb}^{-1}$ [15] |
| $\geq(1-2)$b-jets + 0-lep | 283 65 15.4 61 14.4 4.3 22.2 8.5 - - - | $2.05 \text{ fb}^{-1}$ [16] |
| 3-lep | 3.5 1.5 - - - - - - - - - | $2.06 \text{ fb}^{-1}$ [17] |

1. No detector simulation is attempted as that would make no significant effect on our findings or conclusions.
2. About half of the posterior samples we consider have a negative gluino mass, allowed by the SLHA accord, that crashes the NLO calculator we have access to. As such the NLO correction is dropped out.
to analye each and every SUSY event generated by the Monte Carlo collider simulator, without the need for detector simulations, and the publicly available Rivet analyses for the ATLAS SUSY searches in Refs. [7–17]. The Rivet analyses are plugged-in to Herwig++ for computing the acceptances, $A_i = N_{\text{cuts}}/N_{\text{total}}$, after applying the various cuts on the kinematic variables of the collider final states. Here $N_{\text{cuts}}$ is the number of events that pass the experimental cuts and $N_{\text{total}} = 1000$ is the total number of generated SUSY events. Rivet acts per-event wise on the events produced by Herwig++. The jet identification is done using fastjet [46]. The cross section within acceptance is computed as

$$\sigma_{i}^{\text{acc}} = \epsilon A_i \sigma_{i}^{\text{SUSY,LO}}$$

where we consider the efficiency, $\epsilon = 1$ (since no detector simulation); $i = 1, 2, \ldots, 55$ runs over the 55 different signal regions, and $\sigma_{i}^{\text{SUSY,LO}}$ is the total LO SUSY production cross section.

### 2.3 The likelihood, $L(d_{\text{LHC}}|\theta)$

The likelihood is a simple step function that equals to unity if the ATLAS limits are satisfied else zero if excluded. SUSY points with predicted cross sections smaller (greater) than the ATLAS non-SM limits are then allowed (excluded) at 95% confidence level according to

$$L(d_{\text{LHC}}|\theta) = \prod_{i=1}^{55} \ell_i; \quad \ell_i = \begin{cases} 0 & \text{if } \sigma_{i}^{\text{acc}} > \sigma_{i}^{\text{acc,max}} \\ 1 & \text{if } \sigma_{i}^{\text{acc}} \leq \sigma_{i}^{\text{acc,max}} \end{cases}.$$  

### 3. The SUSY limits’ impact on the pMSSM

The relative number of the pMSSM points that survive the SUSY limits and in various combinations with the Higgs-sector data (in the di-photon channels as applied in Ref. [47] and other ATLAS, CMS, LEP and Tevatron Higgs-sector constraints implemented in the HEP packages HiggsBounds [48] and FeynHiggs [49]) are summarised in Table 3. The posterior probability distribution for the sparticle masses derived from the post-LHC distribution eq.(2) are shown in Fig.1. As can be seen from the mentioned plots, the ATLAS SUSY limits are most sensitive in constraining the gluino mass whose central value is now shifted from around 2 TeV to 3 TeV followed by the squark masses. The effect of the SUSY limits on the gluino mass seems to be very different from what happen for the case of constrained models such as CMSSM/mSUGRA (addressing this is outside the purpose of this article). The limits are relatively less sensitive in constraining sleptons, electroweak gauginos and the lighter

---

Table 3: Summary of the relative number of surviving posterior points, from the pre-LHC Bayesian global fits of the pMSSM, and after imposing the Higgs discovery data and SUSY limits.

| No. | Constraint | Log prior survive |
|----|------------|-------------------|
| 1. | $m_h = 122 - 128$ GeV | 36.08% |
| 2. | $m_h = 125 - 126.5$ GeV | 9.17% |
| 3. | SUSY $\sigma^{\text{acc}}$ limits | 57.47% |
| 4. | $m_h(1)$ and SUSY $\sigma^{\text{acc}}$ limits | 14.53% |
| 5. | $1.67$-\(\sigma\) $R_{ZZ;\gamma\gamma}$ | 13.30% |
| 6. | $m_h(1)$ & $1.67$-\(\sigma\) $R_{ZZ;\gamma\gamma}$ | 4.67% |
| 7. | $1.67$-\(\sigma\) $R_{ZZ;\gamma\gamma}$ & SUSY $\sigma^{\text{acc}}$ limits | 6.11% |
| 8. | $m_h$, $1.67$-\(\sigma\) $R_{ZZ;\gamma\gamma}$ & SUSY $\sigma^{\text{acc}}$ limits | 2.19% |

---

$^3$Performing the analysis with fast detector simulation will not have a significant effect on our results or conclusions. For instance, a \(\pm 2\) GeV accuracy gain in the MET or jet $p_T$ will have little or no affect on our results.

$^4$The SUSY search channels that involves final states with high number of jet multiplicities severely constrains the gluino mass to higher values relative to the pre-LHC mass distribution.
sbottom or stop quarks. The resultant effect of applying the limits coming from the 55 different ATLAS’ SUSY signal regions shown in Table 3 on the pMSSM can be summarised in plots showing allowed versus ruled out regions in sparticle mass planes. For gluino-stop and gluino-sbottom mass planes the plots are shown in Fig. 2 Region where $\max\left(\frac{\sigma^{acc}}{\sigma^{SM}}\right) > 1.0$ are excluded at 95% confidence level by the combined ATLAS limits. The plots shows that unlike the gluino mass which is now constrained to be heavy $\sim 3 \, TeV$, the third generation squarks can be much lighter.

4. Conclusions and outlook

We have computed the effect of SUSY searches results from ATLAS collaboration with up to 4.7 fb$^{-1}$ of 7 TeV LHC data sets taken during the year 2011. This is done by simulating SUSY events at the LHC with Herwig++ [42] and the experimental analyses of the data with Rivet [45]. The particle-level per-event Rivet analysis is used for calculating the pMSSM predictions for the cross section within acceptances of the analyses cuts and events selection criteria. Comparing with the experimental 95% C.L. upper limits (shown in Table 2) rule out about 40% of the initial pMSSM sample from a pre-LHC global fit to data. The SUSY limits are most sensitive in constraining the gluino mass whose distribution is now centred around 3 TeV (shifted from 2 TeV). There is also a shift, but less significant compared to gluino mass case, in preference for heavier 1st/2nd generation and stop masses as can be seen in the posterior distributions in Fig. 1. The excluded versus allowed regions by the ATLAS’ extra-SM cross section upper limits on the gluino-stop and gluino-sbottom mass planes are shown in Fig. 2.

Combining the SUSY and Higgs boson discovery data as described in Ref. [47] further constrain the pre-LHC posterior samples as summarised in Table 3 with only a single point (out of the initially about 40000 pre-LHC posterior sample points) surviving all of the following requirements:

$$\begin{align*}
\text{SUSY} & \quad \sigma^{acc} \text{ upper limits,} \\
\mu_X &= \frac{\sigma(gg \rightarrow h) Br(h \rightarrow X)}{\sigma(gg \rightarrow h)_{SM} Br(h \rightarrow X)_{SM}} \\
R_{ZZ;\gamma\gamma} &\equiv \frac{\mu_{ZZ}}{\mu_{\gamma\gamma}} = 0.56 \pm 0.25.
\end{align*}$$

Here $\mu_X$ is the ratio of the pMSSM to the SM SUSY cross section for the Higgs decay into a particular final state $X = \gamma\gamma$ or $ZZ$. The spectrum is characterised with a quasi-degenerate sbottom and LSP and heavy gluino and 1st/2nd generation squarks. It is of the difficult-to-see at the LHC type discussed in Refs. [38,50]. It is worth mentioning that the data from the Higgs sector (4.67% model points survived) is far more constraining compared to the SUSY limits (57.47% model points survived). There is however some complementarity between the two set of constrained since applying the SUSY limits on the Higgs-data surviving models points brings down the surviving number to 2.19%.

Our results go beyond the 1 fb$^{-1}$ analysis done in Ref. [22] from various perspectives. First, our pre-LHC prior construction takes into account the constraint on the neutralino LSP relic density. We use the more stringent ATLAS SUSY limits from up to 4.7 fb$^{-1}$ of data which include channels that better constrain gluino production with subsequent decay chains with several jets in the final states.

The results and conclusion obtained from our analyses are conservative. This is because: the SUSY signal simulations were done at leading order (LO) in perturbative QCD as opposed to the next-to-leading order (NLO) results reported by ATLAS. Since the NLO cross sections are generally greater compared to the LO values, the exclusions here are more conservative, we will be allowing points that otherwise will be ruled out is as the case for the SPS4 bench mark point in Tab. 4 where the the LO and NLO cross sections within acceptance for snow mass points and slopes benchmark points can be

---

5 About half of the volume of the pMSSM sample we employ have a negative gluino mass. This feature is the standard format allowed by the SLHA conventions. However such negative gluino SUSY points are not possible for the NLO cross section calculator that we have access to.
Fig. 1: The plots compare the log prior pMSSM sparticle masses’ marginalised 1-dimensional pre-LHC posterior distributions (dashed-red curves) and the surviving parameter regions after imposing only the SUSY limit (black curves) and both $m_h = 122.0 - 128.0$ GeV and SUSY limits together (blue curves). All the masses are in TeV units. The vertical axes represent the relative probability weights of the model points.
Fig. 2: The plots show 95% confidence level exclusion contours for gluino-stop and gluino-sbottom mass planes derived from the combined set of ATLAS limits. The colour scales are proportional to the expected number of signal events normalised to the combined exclusion limit. The contour $max(\frac{\sigma_{acc}}{\sigma_{cutoff}}) = 1.0$ determines the exclusion boundaries within the sparticle masses plane. Region with colour code greater than unity are excluded at 95% confidence level.

compared. There is an approximate agreement, within the expected $\sim 50\%$ accuracies, with the corresponding values obtained by previous computations (with NLO corrections) [27].

For the analysis here only the posterior samples from a pre-LHC global fit to data with a logarithmic prior distribution over the 20 pMSSM parameters were considered. No analysis is done with the flat prior sample because it know that the pre-LHC fits were prior-dependent. However, it will be interesting [52] to estimate the strength of the LHC data by checking whether it allows for prior independent results which is necessarily needed for making conclusions regarding the predictive power of the pMSSM. This seems possible given the apparent interplay between Higgs boson decay rate in the di-photon decay channels which would require light sparticles and the absence of SUSY signal to date at the LHC.

Acknowledgments
Thanks to D. Choudhury, F. Quevedo, and D. Grellscheid for helpful comments and discussions; and to the IPPP for hospitality during the early stage of this project.

References
[1] G. Aad et al. [ATLAS Collaboration], “Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC,” Phys. Lett. B 716 (2012) 1.

[2] S. Chatrchyan et al. [CMS Collaboration], “Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC,” Phys. Lett. B 716 (2012) 30.

[3] ATLAS Supersymmetry Searches, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

[4] CMS Supersymmetry Searches, https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Assuming that R-parity conserving MSSM is responsible for the physics behind the observed deviation from the SM model expectation in the di-photon channel.
| Benchmark point | $\sigma$/pb | status |
|-----------------|-------------|--------|
|                 | A           | B      | C      | D      | ATLAS 35pb$^{-1}$ |
| ATLAS limits    | 1.3         | 0.35   | 1.1    | 0.11   |
| sps1a           | 1.347       | 0.640  | 1.172  | 0.299  | A,B,C,D           |
|                 | 2.031       | 0.933  | 1.731  | 0.418  | A,B,C,D           |
| sps1b           | 0.077       | 0.057  | 0.062  | 0.041  | allowed           |
|                 | 0.120       | 0.089  | 0.098  | 0.067  | allowed           |
| sps2            | 0.499       | 0.280  | 0.425  | 0.169  | D                 |
|                 | 0.674       | 0.388  | 0.584  | 0.243  | B,D               |
| sps3            | 0.079       | 0.059  | 0.061  | 0.043  | allowed           |
|                 | 0.123       | 0.093  | 0.097  | 0.067  | allowed           |
| sps4            | 0.218       | 0.132  | 0.195  | 0.084  | allowed           |
|                 | 0.334       | 0.199  | 0.309  | 0.144  | D                 |
| sps5            | 0.468       | 0.259  | 0.417  | 0.125  | D                 |
|                 | 0.606       | 0.328  | 0.541  | 0.190  | D                 |
| sps6            | 0.523       | 0.289  | 0.411  | 0.149  | D                 |
|                 | 0.721       | 0.416  | 0.584  | 0.226  | B,D               |
| sps7            | 0.007       | 0.005  | 0.008  | 0.005  | allowed           |
|                 | 0.022       | 0.016  | 0.023  | 0.015  | allowed           |
| sps8            | 0.011       | 0.005  | 0.015  | 0.003  | allowed           |
|                 | 0.021       | 0.011  | 0.022  | 0.009  | allowed           |
| sps9            | 0.015       | 0.003  | 0.004  | 0.001  | allowed           |
|                 | 0.019       | 0.004  | 0.006  | 0.002  | allowed           |

Table 4: The status of SUSY snow mass points and slopes benchmarks [51] predicted with our LO calculations (top values) compared to the NLO done in [27] (bottom values). The conservative nature of the LO results manifests for the SPS4 case which is rather ruled out by the NLO calculations. Note the agreements for the SPS9 cross sections which are all computed at LO.

[5] P. Nath, “Twenty years of SUGRA,” [hep-ph/0307123].

[6] D. Alves et al. [LHC New Physics Working Group Collaboration], J. Phys. G 39 (2012) 105005 [arXiv:1105.2838 [hep-ph]].

[7] G. Aad et al. [Atlas Collaboration], Phys. Lett. B 701 (2011) 186.

[8] G. Aad et al. [ATLAS Collaboration], Eur. Phys. J. C 71 (2011) 1682.

[9] The ATLAS Collaboration, and one lepton at sqrt(s) = 7 TeV,” ATLAS-CONF-2011-090, Jun 2011.

[10] The ATLAS Collaboration, ATLAS-CONF-2011-098, Jul 2011.

[11] G. Aad et al. [ATLAS Collaboration], Phys. Lett. B 710 (2012) 67.

[12] G. Aad et al. [Atlas Collaboration], JHEP 1111 (2011) 099.

[13] The ATLAS Collaboration, ATLAS-2012-CONF-2012-033, Mar 2012.

[14] The ATLAS Collaboration, ATLAS-2012-CONF-2012-037, Mar 2012.

[15] The ATLAS Collaboration, ATLAS-2012-CONF-2012-041, Mar 2012.

[16] G. Aad et al. [ATLAS Collaboration], [arXiv:1203.6193 [hep-ex]].

[17] G. Aad et al. [ATLAS Collaboration], [arXiv:1204.5638 [hep-ex]].

[18] C. Balazs, A. Buckley, D. Carter, B. Farmer and M. White, “Should we still believe in constrained supersymmetry?,” [arXiv:1205.1568 [hep-ph]].
[19] B. C. Allanach, T. J. Khoo and K. Sakurai, “Interpreting a 1 fb−1 ATLAS Search in the Minimal Anomaly Mediated Supersymmetry Breaking Model,” arXiv:1110.1119 [hep-ph].

[20] O. Buchmueller et al., “Supersymmetry in Light of 1/fb of LHC Data,” arXiv:1110.3568 [hep-ph].

[21] P. Bechtle, T. Bringmann, K. Desch, H. Dreiner, M. Hamer, C. Hensel, M. Kramer and N. Nguyen et al., “Constrained Supersymmetry after two years of LHC data: a global view with Fittino,” JHEP 1206 (2012) 098.

[22] S. Sekmen, S. Kraml, J. Lykken, F. Moortgat, S. Padhi, L. Pape, M. Pierini and H. B. Prosper et al., “Interpreting LHC SUSY searches in the phenomenological MSSM,” JHEP 1202 (2012) 075.

[23] M. W. Cahill-Rowley, J. L. Hewett, S. Hoeche, A. Ismail and T. G. Rizzo, “The New Look pMSSM with Neutralino and Gravitino LSPs,” arXiv:1206.4321 [hep-ph].

[24] M. Carena, J. Lykken, S. Sekmen, N. R. Shah and C. E. M. Wagner, “The pMSSM Interpretation of LHC Results Using Renormalization Group Invariants,” arXiv:1205.5903 [hep-ph].

[25] A. Arbey, M. Battaglia and F. Mahmoudi, “Implications of LHC Searches on SUSY Particle Spectra: The pMSSM Parameter Space with Neutralino Dark Matter,” Eur. Phys. J. C 72 (2012) 1847.

[26] M. E. Cabrera, J. A. Casas, V. A. Mitsou, R. Ruiz de Austri and J. Terron, “Histogram comparison as a powerful tool for the search of new physics at LHC. Application to CMSSM,” JHEP 1204 (2012) 133.

[27] M. J. Dolan, D. Grellscheid, J. Jaeckel, V. V. Khoze and P. Richardson, “New Constraints on Gauge Mediation and Beyond from LHC SUSY Searches at 7 TeV,” JHEP 1106 (2011) 095.

[28] D. Grellscheid, J. Jaeckel, V. V. Khoze, P. Richardson and C. Wymant, “Direct SUSY Searches at the LHC in the light of LEP Higgs Bounds,” JHEP 1203 (2012) 078.

[29] A. Fowlie, A. Kalinowski, M. Kazana, L. Roszkowski and Y. L. S. Tsai, “Bayesian Implications of Current LHC and XENON100 Search Limits for the Constrained MSSM,” Phys. Rev. D 85 (2012) 075012.

[30] C. Strege, G. Bertone, D. G. Cerdeno, M. Fornasa, R. R. de Austri and R. Trotta, “Updated global fits of the cMSSM including the latest LHC SUSY and Higgs searches and XENON100 data,” JCAP 1203 (2012) 030.

[31] R. Essig, E. Izaguirre, J. Kaplan and J. G. Wacker, “Heavy Flavor Simplified Models at the LHC,” arXiv:1110.6443 [hep-ph].

[32] Y. Kats, P. Meade, M. Reece and D. Shih, “The Status of GMSB After 1/fb at the LHC,” arXiv:1110.6444 [hep-ph].

[33] C. Brust, A. Katz, S. Lawrence and R. Sundrum, “SUSY, the Third Generation and the LHC,” arXiv:1110.6670 [hep-ph].

[34] M. Papucci, J. T. Ruderman and A. Weiler, “Natural SUSY Endures,” arXiv:1110.6926 [hep-ph].

[35] S. S. AbdusSalam, “The Full 24-Parameter MSSM Exploration,” AIP Conf. Proc. 1078 (2009) 297-299.

[36] S. S. AbdusSalam, B. C. Allanach, F. Quevedo, F. Feroz, M. Hobson, “Fitting the Phenomenological MSSM,” Phys. Rev. D81 (2010) 095012.
[37] S. S. AbdusSalam and F. Quevedo, “Cold Dark Matter Hypotheses in the MSSM,” Phys. Lett. B 700 (2011) 343.

[38] S. S. AbdusSalam, “Can the LHC rule out the MSSM?,” Phys. Lett. B 705 (2011) 331.

[39] S. S. AbdusSalam, B. C. Allanach, H. K. Dreiner, J. Ellis, et al., “Benchmark Models, Planes, Lines and Points for Future SUSY Searches at the LHC,” Eur. Phys. J. C 71 (2011) 1835.

[40] R. Aaij et al. [LHCb Collaboration], Phys. Rev. Lett. 108 (2012) 231801 [arXiv:1203.4493 [hep-ex]].

[41] K. L. Chan, U. Chattopadhyay and P. Nath, Phys. Rev. D 58 (1998) 096004 [hep-ph/9710473].

[42] M. Bahr, S. Gieseke, M. A. Gigg, D. Grellscheid, K. Hamilton, O. Latunde-Dada, S. Platzer and P. Richardson et al., “Herwig++ Physics and Manual,” Eur. Phys. J. C 58 (2008) 639.

[43] S. Gieseke et. al., ”Herwig++ 2.5 Release Note,” arXiv:1102.1672.

[44] B. C. Allanach, ”SOFTSUSY: a program for calculating supersymmetric,” Comput. Phys. Commun. 143 (2002) 305–331.

[45] A. Buckley, J. Butterworth, L. Lonnblad, H. Hoeth, J. Monk, H. Schulz, J. E. von Seggern and F. Siegert et al., ”Rivet user manual,” arXiv:1003.0694 [hep-ph].

[46] M. Cacciari, G. P. Salam and G. Soyez, Eur. Phys. J. C 72 (2012) 1896 [arXiv:1111.6097 [hep-ph]].

[47] S. S. AbdusSalam and D. Choudhury, [arXiv:1110.3331] [hep-ph].

[48] P. Bechtle, O. Brein, S. Heinemeyer, G. Weiglein and K. E. Williams, “HiggsBounds: Confronting Arbitrary Higgs Sectors with Exclusion Bounds from LEP and the Tevatron,” Comput. Phys. Commun. 181 (2010) 138.

[49] G. Degrassi, S. Heinemeyer, W. Hollik, P. Slavich and G. Weiglein, “Towards high precision predictions for the MSSM Higgs sector,” Eur. Phys. J. C 28 (2003) 133.

[50] T. J. LeCompte and S. P. Martin, “Large Hadron Collider reach for supersymmetric models with compressed mass spectra,” Phys. Rev. D 84 (2011) 015004 [arXiv:1105.4304 [hep-ph]].

[51] B. C. Allanach, M. Battaglia, G. A. Blair, M. S. Carena, A. De Roeck, A. Dedes, A. Djouadi and D. Gerdes et al., “The Snowmass points and slopes: Benchmarks for SUSY searches,” Eur. Phys. J. C 25 (2002) 113.

[52] S. S. AbdusSalam et. al., project under consideration.