PARTICLE PHYSICS | RESEARCH ARTICLE

Interplay of LHC and dark matter searches in the MSSM

Alexandre Arbey and Farvah Mahmoudi

Abstract: The Minimal Supersymmetric extension of the Standard Model (MSSM) provides suitable candidates for cold dark matter. We discuss here the constraints from dark matter direct detection and cosmological dark matter density, as well as LHC data from Higgs, SUSY and monojet searches, and flavour physics data, in the context of the phenomenological MSSM (pMSSM) with neutralino dark matter. We show that the complementarity of the different sectors is essential to probe the pMSSM parameter space.

Subjects: Cosmology; Particle & High Energy Physics; Theoretical Physics

Keywords: dark matter; LHC; supersymmetry; Higgs

1. Introduction

The Minimal Supersymmetric extension of the Standard Model (MSSM) is one of the most studied new physics models. When $R$-parity is conserved, supersymmetric particles can only be produced in pairs off Standard Model (SM) particles, and the lightest supersymmetric particle (LSP) is stable. If the LSP is neutral and weakly interacting, it can constitute a suitable dark matter candidate. This is the case of the lightest neutralino, which interacts weakly enough to make an ideal dark matter candidate. Studies in the MSSM however suffer from the large number of parameters—more than a hundred—which makes a systematic analysis impossible. On the other hand, constrained MSSM scenarios, such as the constrained MSSM, have only a handful of parameters, but cover only a small region of the MSSM parameter space. The phenomenological MSSM (pMSSM) (Djouadi, XXXX) offers a convenient compromise: it is the most general version of the MSSM with CP and $R$-parity conservations respecting minimal flavour violation, which has 19 independent parameters. In this work, we will concentrate on the pMSSM with neutralino dark matter. We study its 19 parameter space by performing flat scans on all the parameters, as described in Arbey, Battaglia, and Mahmoudi (2012a, 2012b), for masses up to 3.5 TeV. Other analyses in the pMSSM can be found for example in AbdusSalam, Allanach, Quevedo, et al. (2015).

ABOUT THE AUTHORS

Alexandre Arbey and Farvah Mahmoudi are associate professors at University of Lyon and members of the CERN Theory Division. A Arbey is a cosmologist and astroparticle physicist, working on the Dark Matter problem, as well as dark energy and Big-Bang nucleosynthesis. F Mahmoudi is a particle physicist, specialist of Higgs, Flavour and Dark Matter physics. Their work consists in combining the constraints from all their sectors of expertise to constrain New Physics models. The project reported in this effort is performed in the context of Supersymmetry, but it can extend to other categories of particle physics scenarios beyond the Standard Model.

PUBLIC INTEREST STATEMENT

Cosmological and astrophysical observations reveal that dark matter constitutes the major part of matter in the Universe. Yet, the current Standard Model of particle physics does not provide any particle candidate to explain its nature. The supersymmetric extension of the Standard Model suggests that dark matter could be made of neutralinos, which is a neutral and weakly interacting particle not been discovered yet. In this paper, the authors investigate the current constraints on supersymmetric dark matter, by considering simultaneously the results from cosmological observations, dark matter particle detection experiments, as well as LHC searches for new particles.
Feroz and Hobson (2010), Conley, Gainer, Hewett, Le, and Rizzo (XXXX), Sekmen et al. (2012), Cahill-Rowley, Hewett, Hoeche, Ismail, and Rizzo (2012), CMS Collaboration (XXXXa, XXXXb), Kowalska, Roszkowski, Sessolo, and Trojanowski (2014), Cahill-Rowley et al. (2015). In the following, we first consider LHC constraints from supersymmetry (SUSY) and monojet searches. In Section 3, we study the consequences of the Higgs boson discovery. In Section 4, we account for constraints from flavour physics. The results of dark matter searches are discussed in Section 5. Finally, we consider all the constraints simultaneously to assess their complementarity, before concluding in Section 6.

2. SUSY and monojet searches at the LHC

We first consider the constraints from SUSY and monojet searches at the LHC in the context of the pMSSM. Since supersymmetric particles are pair produced and the LSP is stable, supersymmetric search channels at the LHC feature elusive neutralinos in the final state. Hence, the experimental signatures consist in final states with missing transverse energy (MET). In this analysis, we consider the jets+MET channels, relevant for the search for first and second generation squarks and gluinos (ATLAS Collaboration, XXXXa), as well as b-tagged jets+MET channels for sbottom and stop searches (ATLAS Collaboration, XXXXb), and chargino/neutralino searches in two leptons+MET (ATLAS Collaboration, XXXXc) and three leptons+MET (ATLAS Collaboration, XXXXd) channels. We generate the events with PYTHIA 8.1 (Sjostrand, Mrenna, & Skands, 2008), with the CTEQ6L1 parton distribution functions (Pumplin et al., 2002). Detector simulation is performed with DELPHES 3.0 (Ovyn, Rouby, & Lemaitre, XXXX).

Contrary to the previous analyses in the pMSSM, here, we systematically use the monojet search results, which are particularly important in the case of compressed spectra. To study the consequences of the monojet searches on the pMSSM parameter space, we have designed a specific method to reinterpret the monojet search data in the context of the MSSM, as described in Arbey, Battaglia and Mahmoudi (2014). Monojet channels consist of one hard jet+MET in the final state. The results are usually presented in effective or simplified models (ATLAS Collaboration, XXXXe; CMS Collaboration, XXXXc), in which the final state is interpreted as generated by two dark matter particles and one jet, as shown in the left panel of Figure 1. However, within a specific model like the MSSM, there are other means to generate a monojet final state at the LHC. In particular, since the LHC is a hadronic machine, the production of squarks and gluinos which have larger cross sections is more likely. Moreover, in compressed MSSM scenarios, the squarks, gluinos and neutralinos can have similar masses, so that the squark or gluino would mostly decay to soft jet(s) + one neutralino. Due to the cuts applied in the monojet searches, the soft jet(s) will not be observed, and the final state with two squarks/gluinos + one hard jet will be the same as the typical monojet signature. Such a topology is presented in the right panel of Figure 1. For this reason, to assess the implications of the monojet searches in the MSSM, it is important to consider the processes \( pp \rightarrow (N)LSP + (N)LSP + j \), where \( j \) is a hard jet and (N)LSP stands for the (next-to-)LSPs. We compute the matrix elements corresponding to the full diagrams with MadGraph 5 (Alwall et al., 2014) and generate events using the CTEQ6L1 parton distribution functions. The parton showering is performed with PYTHIA 6 (Sjostrand, Mrenna, & Skands, 2006), and detector simulation with DELPHES 3.0. We consider the ATLAS and CMS monojet results (ATLAS Collaboration, XXXXe; CMS Collaboration, XXXXc) to obtain the exclusion of the pMSSM points by the monojet searches.

Figure 1. Schematic representation of monojet channels in the effective or simplified models (left panel) and additional diagrams in the MSSM with neutralino dark matter (right panel).
In Figure 2, we show the difference of exclusion potential between the case where only neutralino LSPs are considered in the monojet final states (left panel), and the case with in addition squarks and gluinos decaying to soft jets and neutralinos (right panel), for the LHC 14 TeV run with 300 fb$^{-1}$. As can be seen from the figure, considering the squark and gluino final states would lead to a large increase in the monojet production cross section, enhancing substantially the monojet sensitivity.

The current exclusion limits by the SUSY and monojet searches are presented in Figure 3 as functions of the lightest squark and gluino masses. As expected the direct SUSY searches strongly probe the small squark and gluino masses, and the monojet searches nicely complement them up to an
exclusion of close to 100% of the points for masses below 400 GeV. In Figure 4, the excluded points are presented in two-dimensional plots, in the lightest squark/gluino vs. neutralino mass plane and in the lightest squark/gluino mass splitting with the neutralino vs. neutralino mass plane. We see that the SUSY searches can probe squark/gluino masses up to 1.5 TeV when the neutralino is light, whereas the monojet searches improve the constraints on the neutralino mass by ∼ 100 GeV for small mass splittings. This shows the important complementarity between the SUSY and monojet searches, in particular when investigating compressed scenarios with small mass splittings.

3. Higgs searches
The discovery of a Higgs boson at 125 GeV (Aad et al., 2012; Chatrchyan et al., 2012) has strong implications for the MSSM, as it can be considered to be the lightest MSSM Higgs boson $h$. In the MSSM, the lightest Higgs mass and couplings are mainly determined by the parameters $M_A$ (CP-odd Higgs mass), $M_{\tilde{t}}$ (geometric average of the stop masses), $X_t = A_t - \mu \cot \beta$ (stop mixing parameter) and $\tan \beta$. To obtain a Higgs mass of 125 GeV, it is necessary to have a large $M_A$ or a large $X_t$ (Arbey, Battaglia, Djouadi, Mahmoudi, & Quevillon, 2012). In our scans, we impose a Higgs mass of $125 \pm 3$ GeV to account for the experimental and theoretical uncertainties, and consider the measured signal strengths in the $\gamma\gamma$, $ZZ$, $W^+W^-$, $bb$ and $\tau^+\tau^-$ channels, and impose the limits from heavier Higgs $H/A \rightarrow \tau^+\tau^-$ searches, as described in Arbey, Battaglia, Djouadi, and Mahmoudi (2012a, 2012b). The results are presented in Figure 5 in the $(M_A, \tan \beta)$ and $(M_{\tilde{t}}, X_t)$ parameter planes. It is clear that large values of $M_A$ ($\gtrsim 350$ GeV) and $X_t$ are favoured by the current measurements.

The searches for heavier Higgs states can impose further constraints on the MSSM parameter space. In Figure 6, the constraints obtained from the searches at 8 TeV for $H \rightarrow \tau^+\tau^-$, $H \rightarrow ZZ$ and $H \rightarrow bb$ are shown in the left panel. $H \rightarrow \tau^+\tau^-$ gives the strongest constraints, particularly important at large $\tan \beta$. The $H \rightarrow ZZ$ channel on the other hand provides constraints in the small $\tan \beta$ region, which are complementary to the constraints from the light Higgs signal strength measurements. In the right panel, extrapolations for the 14 TeV run are provided for the same channels, as well as for $H \rightarrow t\bar{t}$. 

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Figure 5. pMSSM points in agreement with the Higgs measurements projected on the $(M_A, \tan \beta)$ (left panel) and $(M_{\tilde{t}}, X_t)$ (right panel) parameter planes.

Notes: The black points are in agreement with the Higgs mass and $H/A \rightarrow \tau^+\tau^-$ constraints. The dark and light green points are compatible at 68% and 95% C.L. with the additional $h$ signal strength measurements, respectively (Arbey et al., 2012b).

Figure 6. Fraction of excluded points (blue scale) by the heavy Higgs searches for the 8 TeV run (left panel) and extrapolations for the 14 TeV run (right panel).

Notes: The lines delimit the excluded regions from different heavy Higgs search channels (Arbey, Battaglia, & Mahmoudi, 2013).
As can be seen, $H \rightarrow \tau^+ \tau^-$ searches will probe a much larger parameter space, while $H \rightarrow t\bar{t}$ will provide complementary information at small $\tan\beta$.

4. Flavour physics constraints

$B$ physics observables provide also additional constraints on the pMSSM parameter region. In particular, the branching ratio of $B_s \rightarrow \mu^+ \mu^-$ is of interest since it can receive large contributions from scalar and pseudoscalar operators in the MSSM. Using SuperIso (Mahmoudi, 2008, 2009), we have computed and studied the constraints from this observable on the pMSSM. In Figure 7, we present the constraints from $\text{BR}(B_s \rightarrow \mu^+ \mu^-)$ in the $(M_A, \tan\beta)$ and $(M_A, M_{\tilde{t}_1})$ parameters planes. As can be seen, the branching fraction of $B_s \rightarrow \mu^+ \mu^-$ is particularly constraining at large $\tan\beta$ and disfavours small $M_A$ and $M_{\tilde{t}_1}$. In this respect, it is complementary to the Higgs searches, and in particular the $H/A \rightarrow \tau^+ \tau^-$ channel is sensitive to the same parts of the parameter space as $\text{BR}(B_s \rightarrow \mu^+ \mu^-)$. Other important constraints from flavour physics are provided by $\text{BR}(B \rightarrow X_s \gamma)$, $\text{BR}(B \rightarrow X_s \ell\bar{\ell})$, $\text{BR}(B \rightarrow \tau\nu)$ and $\text{BR}(B \rightarrow K^\ast \ell\bar{\ell})$, which can also set limits on the pMSSM parameters (Mahmoudi, Neshatpour, & Virto, 2014).

5. Dark matter searches

Dark matter can be considered as currently the only (indirect) evidence for new physics. Cold dark matter is likely to be made of weakly interacting massive particles (WIMPs), so elusive that none has been detected yet. Cold dark matter constitutes about 23% of the total energy density of the Universe. In a scenario like the pMSSM with neutralino dark matter, the density of dark matter particles, the so-called relic density, can be computed. This relic density can then be compared to the observed cosmological density of dark matter to set constraints on the MSSM parameters, namely:

$$0.076 < \Omega_\chi h^2 < 0.163.$$  \hspace{1cm} (1)

However, the calculation of the relic density is based on assumptions on the cosmological past of the Universe, in particular before Big-Bang nucleosynthesis where the Universe cannot be observed. Small deviations from these assumptions can lead to large differences (in general increases) in the relic density (Arbey & Mahmoudi, 2008, 2010a; Gelmini, Gondolo, Soldatenko, & Yaguna, 2006; Kamionkowski & Turner, 1990). In addition, dark matter may be made of several components, and the neutralino can therefore constitute only part of it. For these reasons, we prefer to apply a loose relic density constraint:

$$10^{-4} < \Omega_\chi h^2 < 0.163.$$  \hspace{1cm} (2)

We compute the relic density with SuperIso Relic (Arbey & Mahmoudi, 2010b). In Figure 8, we show the relic density as a function of the neutralino mass, for the different types of neutralinos. While a bino leads in general to a too large relic density because of its suppressed couplings to the Higgs and Z bosons, a higgsino of about 1.5 TeV and a wino of about 2.7 TeV can lead naturally to a relic density compatible with the measured dark matter density. For binos, it is mandatory to have either resonant
annihilation channels or coannihilation channels to get a small enough relic density. Therefore, the relic density constraints have strong consequences on the selection of the neutralino natures.

Other important constraints come from the dark matter direct detection experiments such as XENON 100 (Aprile et al., 2012) and LUX (Akerib et al., 2014). These experiments are sensitive to the scattering of WIMPs with nuclei, and can set limits on the WIMP mass as well as their spin-independent scattering cross sections with protons in absence of detection. We compute the neutralino scattering cross section with micrOMEGAs (Belanger, Boudjema, Pukhov, & Semenov, 2009). In Figure 9, we present the neutralino spin-independent scattering cross section with protons as a function of the neutralino mass, for the different neutralino types. The higgsinos have larger scattering cross sections, and are therefore currently more probed by the XENON and LUX experiments. Winos have smaller cross sections, and will mostly be probed by the LZ experiment. Finally, binos interact only very weakly and are more likely to escape detection by the direct detection experiments.

In Figure 10, the exclusion by the LUX experiment is shown in the $(M_A, \tan \beta)$ parameter plane. It is clear that dark matter direct detection restricts mostly large $\tan \beta$ and small $M_A$ values. One can notice that direct detection is complementary to the heavy Higgs and flavour physics searches since the same part of the parameter space is probed. Since in addition to $M_A$ and $\tan \beta$ other MSSM...
parameters are also relevant for these searches, such redundancies are important to probe deeply the pMSSM parameter space.

6. Summary and conclusions
Direct SUSY and monojet searches, Higgs and flavour physics data, as well as dark matter constraints provide complementary information on the pMSSM parameters. To highlight the interplay between
the different observables, in this section we pre-impose at the same time the constraints from Higgs physics, flavour physics and relic density.

In Figure 11, we show the fraction of excluded pMSSM points in the neutralino scattering cross section with matter vs. neutralino mass parameter plane, considering simultaneously constraints from SUSY direct searches and monojet searches. The limits from LUX are also displayed in the same plane. We first see that the LHC searches are complementary to dark matter direct detection, and probe different parts of the parameter space. In particular, LHC searches are sensitive to the strong sector of the MSSM, while direct dark matter detection is more sensitive to the neutralino sector. We also see that the LHC probes regions well below the LUX limits, and that monojet searches nicely increase the LHC discovery potential in the regions where the neutralino scattering cross section with matter is very small.

In Figure 12, the fraction of excluded points is shown as a function of the neutralino mass, and of the mass splitting between the lightest squark or gluino and the lightest neutralino. It shows that the SUSY and monojet searches probe more strongly scenarios with light neutralinos, excluding up to 65% of the points for light neutralinos, and that the dark matter direct detection limits can increase this exclusion up to 75%, presenting a nice complementarity between the two sectors. Additionally, the LHC searches are very powerful for mass splittings up to 700 GeV where more than 50% of the points are excluded, while direct detection is less dependent on the mass splittings.

To conclude, we have demonstrated the synergy between the different observables of separate sectors, namely the LHC, flavour and dark matter sectors. During the next LHC run, this interplay will become even more important, either in the case no new phenomenon is found to ensure that no region of the parameter space remains uncovered, or in the case new phenomena or particles are discovered to allow for a determination of the underlying scenario and parameters.

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Notes
1. This article is associated with the From Higgs to Dark Matter 2014 meeting in Geilo, Norway.
2. It should be noted that several independent dark matter experiments had claimed for possible detection of WIMPs of the order of 10 GeV (Bernabei et al., 2010, Aalseth et al., 2011, Angloher et al., 2012, Ahmed et al., 2011). While the pMSSM can provide scenarios compatible with such data (Arbey, Battaglia, & Mahmoudi, 2012, 2013), they are actually disfavoured by the latest LUX results.

References
Aad, G., et al. (ATLAS Collaboration). (2012). Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC. Physics Letters B, 716, 1 (arXiv:1207.7214 [hep-ex]).
Aadseth, C. E., Barbeau, P. S., Colaresi, J., Collar, J. I., Diaz Leon, J., Fast, J. E., ... Yocum, K. M. (2011). Search for an annual modulation in a P-type point contact germanium Dark Matter detector. Physical Review Letters, 107, 141301 (arXiv:1106.0650 [astro-ph.CO]).
AbdusSalam, S. S., Allanach, B. C., Quevedo, F., Feroz, F., & Hobson, M. (2010). Fitting the phenomenological MSSM. Physical Review D, 81, 095012 (arXiv:0904.2548 [hep-ph]).
Ahmed, Z., et al. (CDMS-II Collaboration). (2011). Results from a low-energy analysis of the CDMS II germanium data. Physical Review Letters, 106, 131302 (arXiv:1011.2482 [astro-ph.CO]).
Akerib, D. S., et al. (LUX Collaboration). (2014). First results from the LUX dark matter experiment at the Sanford Underground Research Facility. Physical Review Letters, 112, 091303 (arXiv:1310.8214 [astro-ph.CO]).
Alwall, J., Frederix, R., Frixione, S., Hirschi, V., Maltos, F., Mattelaer, O., ... Zaro, M. (2014). The automated computation of tree-level and next-to-leading order
differential cross sections, and their matching to parton shower simulations. *Journal of High Energy Physics*, 1407, 079 (arXiv:1405.0301 [hep-ph]).

Angloher, G., Bauer, M., Boykina, I., Bento, A., Buco, C., CERNIN et al., (2014). *Results from 730 kg days of the CREST-II Dark Matter search*. European Physical Journal C, 72, 1971 (arXiv:1109.0702 [astro-ph.CO]).

Aprile, E. et al. (XENON100 Collaboration). (2012). Dark Matter results from 225 live days of XENON100 data. *Physical Review Letters*, 109, 181301 (arXiv:0908.3588 [astro-ph.CO]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F. (2012a). The Higgs sector of the phenomenological MSSM in the light of the Higgs boson discovery. *Journal of High Energy Physics*, 1209, 107 (arXiv:1207.1348 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).

Arbey, A., Battaglia, M., Djouadi, A., Mahmoudi, F., & Quevillon, J. (2012). Implications of a 125 GeV Higgs for supersymmetric models. *Physics Letters B*, 708, 162 (arXiv:1112.3028 [hep-ph]).
Sjostrand, T., Mrenna, S., & Skands, P. Z. (2006). PYTHIA 6.4 physics and manual. *Journal of High Energy Physics*, 0605, 026 (hep-ph/0603175).

Sjostrand, T., Mrenna, S., & Skands, P. Z. (2008). A brief introduction to PYTHIA 8.1. *Computer Physics Communications*, 178, 852 (arXiv:0710.3820 [hep-ph]).