AAPG2019	Com-SENSUAL-DARMA		PRC
Coordinated by :	Steve MUANZA	48 months	Requested Funding : 495k€
scientific evaluation committee			

Complementarities between Searches for Natural SUSY with ATLAS at LHC and for Dark Matter

I. Pre-proposal's context, positioning and objective(s)

One of the biggest puzzle in modern physics is the evidence from astrophysics and cosmology of non-baryonic Dark Matter (DM) not made of Standard Model (SM) particles. These particles are thought to interact with standard matter so they can be produced at colliders, or cause nuclear recoils, or annihilate into SM particles. These 3 crossed types of interaction offer complementary signatures to search for DM. Hereafter we consider DM made of weakly interacting massive particles (WIMP) from natural supersymmetric (SUSY) extensions of the SM. Given the mass of the Higgs boson discovered at the LHC [1]: M_H=125 GeV, natural SUSY [2] implies light higgsinos which in turn make the charginos ($C_{1,2}$) and the neutralinos ($N_{1,2,3,4}$) not too heavy (the 3 lightest ones should be below 350 GeV or so). During the target period of the project, typically 2020-2023, collider experiments will reach unprecedented sensitivity to possible signals of natural SUSY owing to an increase in the center-of-mass energy of pp collisions from 13 to 14 TeV and to the doubling of the present integrated luminosity [3]. Concomitantly an unprecedented sensitivity will be reached in DM detection experiments. For example, for direct detection Xenon-nT [4b] (the successor of the current most sensitive experiment Xenon-1T [4a]) could closely approach the so-called "neutrino-floor" [5]. If SUSY WIMPs exist, this could lead to a discovery or to very significant exclusion of the SUSY models parameter space. Hence a negative outcome could narrow down the remaining scenarios and lead to re-optimization or renewal of search strategies. In case of a positive outcome, obviously a whole new field of characterization of the underlying physics model would open for which correlations between the different experimental signatures and constraints would be critical.

Different SUSY scenarios will be considered and for each of them the complementarities between searches at LHC and (in)direct WIMP detection will be addressed:

1. *MSSM with a bino-like N_1 as Lightest SUSY Particle (LSP) and an admixture of wino/higgsino as Next-to-Lightest SUSY Particle (NLSP). Co-annihilation from light right-handed stau so as to ensure a proper N_1 relic density [6a] without significant reduction the main N_2 decays of interest: $N_2 \to h/Z(\to b\bar{b})+N_1$.*
2. *Search for heavy DM (M_{WIMP} > 1 TeV) with Sommerfeld enhancement in the MSSM with wino/higgsino N_1 LSP [6b]*
3. *Next-to-minimal DM, with $N_2 \to Z^*+N_1$ [6c]*
4. *NMSSM with a singlino-like N_1 as LSP and an admixture of bino/wino/higgsino NLSP, see for example [7]. Here an acceptable N_1 relic density can be achieved through co-annihilation with higgsinos, or annihilation via the light pseudo-scalar, or through Z/H funnel.*
5. *Effective field theories capturing some features of the above scenarios will also be designed and used to interpret the experimental results and evaluate their complementarities*

The project is sub-divided into 5 work packages (WP):

1. "Search for $C_1+N_2 \to W(\to l\nu)+h/Z(\to b\bar{b})+$mET with ATLAS at LHC Run 3"

The CPPM ATLAS group has a solid experience with this analysis. Indeed 3 PhD students, working under the supervision of S. Muanza, have participated (or will participate) in this analysis. The first one, M. Ughetto, participated in the start-up of this ATLAS analysis [8a] with 20 fb^{-1} of the 2012 dataset at $\sqrt{s}$=8 TeV at the end of LHC Run1. A second PhD student, R. El Kosseifi, took over to analyze

36 fb^{-1} of the 2015-2016 datasets at √s=13 TeV at the beginning of LHC Run2 [8b]. A third student, N.K. Vu, will continue this effort by analyzing the 150 fb^{-1} of the 2017-2018 datasets at √s=13 TeV so as to complete this Run2 search. Each of these PhD students also have/will work(ed) on the ATLAS pixel detector and on the closely related b-tagging algorithms which are crucial for this search. M. Ughetto and R. El Kosseifi also worked on Suspect, a SUSY spectrum calculator, initially developed by theorists in Montpellier (v1,2) [9a], including G. Moultaka and J-L Kneur, both participants in this project. M. Ughetto was a co-developper of the C++ version of Suspect v3 [9b] and his thesis director was J-L Kneur. R. El Kosseifi, J.-L. Kneur and G. Moultaka have performed a bottom-up inversion where the Higgs boson mass is used as an input instead of the top trilinear coupling A_t. R. El Kosseifi did her PhD co-tutored by S. Muanza and J-L Kneur. Our work plan is that M. Vu will contribute to the standard C_1+N_2 → $W(\rightarrow lnu)+h(\rightarrow b\bar{b})$+mET, starting in november 2018. He will especially focus on the signal regions optimization, through b-tagging operating points and improvement on the $M_{b\bar{b}}$ resolution and the signal systematic uncertainties. He will extend the search to C_1+N_2 → $W(\rightarrow lnu)+Z(\rightarrow b\bar{b})$+mET.

We request an ANR post-doctoral fellow (PD) to prepare a new strategy for this search at Run3. This would be a realistic implementation of a technique based upon the stransverse mass assisted by on-shell mass relations [10]. S. Muanza is currently working on such an implementation which is not based upon "rigid" analytical relations as in [10], but which accounts for finite resolutions in the objects kinematic measurements and the widths of the on-shell particles at play. In view of the Run3, the aim of the PD will be to apply the new method to the full Run2 analysis to estimate the increase of sensitivity with respect to the standard analysis. Besides, just to illustrate our work plan on the scenario 4, proposed by C. Hugonie: S. Muanza and the PD will provide limits on excluded cross-sections like in [11], check the effect of mass differences between C_1 and N_2, extend the analysis to simultaneously opened $N_2\rightarrow h/Z(\rightarrow b\bar{b})+N_1$ decay modes, and test its sensitivity to lighter Higgs bosons.

2. "Bottom-up inversions in SUSY Spectrum calculations"

In the current SUSY spectrum calculators, the mass spectrum and the couplings of the SUSY particles are calculated using soft-SUSY breaking parameters at the GUT scale. Since these parameters are not physical observables, it's desirable to trade-off some of them for physical masses. We plan to implement the first M_h-A_t inversion as a new option into Suspect. Then the charginos and neutralinos masses will be subject to further inversions. Even though these sparticles have not yet been discovered, this would enable to use their exclusion limits in SUSY parameters scans. Any such inversions available at the time of SUSY scans in this project will be exploited.

3. "Xenon-nT and the impact of theoretical and astrophysical uncertainties on its sensitivity"

The sensitivity of a direct detection experiment depends on WIMP-nucleus cross-sections and on astrophysical assumptions. Ongoing studies conducted by L. Lellouch, J. Lavalle and E. Nezri are improving QCD uncertainties affecting these cross-sections as well as testing and improving the various assumptions behind the reconstruction of the hypothesized velocity distribution of WIMPs in our galaxy [12]. These studies are well advanced and their results will be used to make improved signal predictions for the future Xenon-nT experiment. They will also be used to make more accurate interpretations of the future measurements of, or exclusion limits on, SUSY or other WIMP DM by that and other experiments. For this task, a PD is requested. S/he will work in collaboration with S. Diglio and J. Masbou and will contribute to preparations in view of Xenon-nT and to the analysis of its data.

4. "Low Energy Nuclear Recoils Detection with Directionality"

The reconstruction of the nuclear recoil track direction, enabling to correlate elastic scatterings in the detector with the relative motion of our Solar system with respect to the galactic halo [13], would constitute an unambiguous proof of WIMP detection [14], since it would be disctintive from neutron-nucleon and even neutrino-nucleon scatterings. D. Santos, F. Naraghi, J.-F. Muraz have developed a dedicated facility COMIMAC [15] to measure ionization-quenching factors and possibly 3D nuclear recoil tracks. Together with C. Tao and J. Busto, they will use COMIMAC to measure low energy neutron-nucleus cross-sections which are not well reproduced by simulations, showing the latter

should be revisited and the tools evaluating the background improved. This should improve the sensitivity to low mass WIMPs of MIMAC and other direct detection experiments. Besides, the MIMAC sensitivity to the SUSY scenarios listed above will be studied. To this end we request a PhD student co-tutored by C. Tao and D. Santos.

5. "Indirect detection of WIMPs with the KM3NeT experiment"

We plan to study KM3NeT sensitivity to a signal of WIMPs annihilation from the center of the earth, sun or galactic halo and to analyze the data of the first lines of ARCA and ORCA. We also plan to pursue the estimate of hadronic uncertainties on the WIMP capture rate and of astrophysical uncertainties on the WIMPs annihilation rates based upon cosmological DM+baryons simulations. The predictions of the neutrinos from these WIMPs annihilations through spin-dependent cross-sections [16] will be assessed. For this we request a PhD student co-tutored by V. Bertin and E. Nezri.

II. Partnership

The scientific coordinator is Steve Muanza, an experimental particle physicist who has a CRCN position with CNRS-IN2P3, based at CPPM Marseille. He has both a PhD and an Habilitation theses on Higgs bosons, SUSY particles searches at colliders. He will be involved in the coordination of the project, in searches for SUSY with the ATLAS detector at the LHC Run3, and in bottom-up inversions of parameters in Suspect. He has been a member of the L3 collaboration where he was co-responsible for a search for invisible decays of the Higgs boson. He has been the initiator, a co-founder and the head of the D0 group at IPN Lyon. Within the D0 collaboration he had responsabilities in the calorimeter offline calibration, the jet energy scale and had been convener of the simulation group. He is involved in the ATLAS SUSY and Physics Modelling working groups. He has been convener of the Tools working group of the SUSY and Terascale GDR. He has tutored six PhD theses, sat on PhD and HDR theses jurys and has been elected to several scientific committees (IPNL, CPPM, OCEVU Labex).

The consortium gathers experimentalists and theorists. The experimentalists work either on collider searches for charginos-neutralinos, or on (in)direct DM searches at detection experiments. The link between these activities is ensured by a close interplay with theorists so as to recast and interpret the outcomes of existing experimental searches and also to suggest dedicated new analyses, A. Bharucha will be especially involved in this task. The consortium members are listed in the following table:

Name	Home Institution	Contributions
Steve Muanza, CRCN, HDR	CPPM Marseille	Coordination. WP: 1, 2
Ngoc Khanh Vu, PhD Student	CPPM Marseille	WP : 1
Vincent Bertin, CRCN	CPPM Marseille	WP : 5
Emmanuel Nezri, CRCN	LAM Marseille	WP : 3,4,5
Laurent Lellouch, DR1	CPT Marseille	WP : 3,4,5
Aoife Bharucha, CRCN	CPT Marseille	WP : 1,3,5
Gilbert Moultaka, CRCN	L2C Montpellier	WP : 1, 2
Jean-Loïc Kneur, DR2	L2C Montpellier	WP : 2
Julien Lavalle, CRCN, HDR	LUPM Montpellier	WP : 3,4,5
Cyril Hugonie, MdC CN	LUPM Montpellier	WP : 1
Sara Diglio, CDD (CRCN à partir 01/11/2018)	Subatech Nantes	WP : 3
Julien Masbou, MdC CN	Subatech Nantes	WP : 3
Charling Tao, DR2	CPPM Marseille	WP : 4
José Busto, PU1	CPPM Marseille	WP : 4

Most of these participants, were/are members of the OCEVU Labex and of the Terascale IRN and have experience in working together. To recap, in terms of personnel, we request: 2 post-doctoral fellows, one based at CPPM Marseille, the other at Subatech Nantes; and 2 PhD, one based at LAM Marseille and the other at LSPC Grenoble.

III. References related to the project

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[15] J.F. Muraz, J. Médard, D. Santos et al., Nuclear Instruments and Methods 832 (2016), 214-218

[16] N. Fornengo et al., arXiv:1710.02155v1 [hep-ph]