Institut national de physique nucléaire et de physique des particules

COLLABORATION AGREEMENT

IN2P3 - COPIN

I. Identification of the laboratories	
Partner	COPIN
IN2P3 laboratories	**IPHC**
Partner laboratories	Lublin (UMCS)

II. Identification of the collaboration	
Title of the collaboration	Broken symmetries, nuclear structure and collective motion
Number of the collaboration	08-131
IN2P3 spokesperson	J. BARTEL
COPIN spokesperson	A. POMORSKI
Scientific Domain	Nuclear Physics

Status of the collaboration	
Status	The renewal of the collaboration is requested for the period January 1st - December 31st, 2023

III. Status report for the period January 1st to December 31st, 2022	
III.1 IN2P3 scientists in COPIN	
Total time approved for 2022	45
Total time used for 2022	30
List of scientists	1. C.SCHMITT (7 days) 2. H.MOLIQUE (7 days) 3. J.BARTEL (16 days)
III.2 COPIN scientists in France	
Total time approved for 2022	45
Total time used for 2022	45
List of scientists	1. A.DOBROWOLSKI (12 days) 2. J.M.BLANCO (12 days) 3. K. POMORSKI (8 days) 4. B. NERLO-POMORSKA (8 days) 5. A.ZDEB (5 days)

III.3 Scientific results of the above-mentioned collaboration

Description

Even though the restrictions due to the Covid-19 virus have been slightly less coercive in 2022 as compared to the two previous years, our collaboration "Broken symmetries, nuclear structure and collective motion" in the framework of our COPIN (08-131) project has nevertheless strongly suffered, mainly due to the fact that respective visits to the partner laboratory were difficult to plan in advance, except for the last few months, before the infection rates are now again skyrocketing. In spite of these difficulties we have tried to keep our scientific activity and collaboration alife, and have made some progress as will be explained below.

Our research activity has, in the past year, again been concentrated on the the theoretical description of the structure of heavy and super-heavy nuclei [C1] with the possible decay of these nuclei through the fission process, or their de-excitation through alpha or cluster decay. For our purpose, one of the fundamental results of such calculations are the deformation-energy landscapes of the nuclear isotopes in the studied region of the nuclear chart, with the localization and characterization of minima, saddle points, valleys and ridges, which would be a measure of the appearance of different symmetric and asymmetric fission channels in a multidimensional deformation space. In this respect, i.e. what the description of nuclear shapes in a multidimensional deformation space is concerned, function of the elongation (quadrupole), left-right asymmetry (octupole), neck formation (hexadecapole) and non-axiality of the nuclear system is concerned, we believe to be particularly well equipped with our Fourier shape paramerization [P1-P4] which has proven to give an excellent description of the large variety of nuclear deformations as they appear throughout the periodic table, including shapes encountered in the fission process, comprising the possible formation of a more or less pronounced neck region. It has been particularly rewarding to realize that our Fourier shape paramerization is, indeed, able to account for such subtile details as the coexistance of rather compact asymmetric, but also more elongated symmetic (so called superlong) fission channels [P3], as they are encountered in a region of the periodic table between Californium und Fermium (see Ref. [P5]). Another aspect that demonstrates the performance of our shape parametrization consists in the reproduction of mono-modal fission as it occurs e.g. in ^{180}Hg (asymmetric) or ^{218}Th (symmetric fission), as well as in multi-modal fission like in ^{226}Th (one symmetric, one asymmetric valley) or in ^{246}Pu (two asymmetric fission valleys) [P2]. An essential detail concerning our Fourier shape paramerization consists in the fact that it is not only able to describe a huge variety of nuclear shapes, but that it is also very rapidly converging [P2-P4].

Using the above mentioned, very rapidly converging analytical Fourier-type shape parametrization and the macroscopic-microscopic model with the Lublin-Strasbourg-Drop [P7] and another simple but quite effective liquid-drop type mass formula [P8] together with the Yukawa-folded single-particle potential, the Strutinsky shell-correction method, and the BCS approximation for including pairing correlations, potential-energy surfaces and other properties of even-even super-heavy nuclei have been analysed in our recent publication [C1].The evaluated nuclear binding energies, fission-barrier heights, and Q-alpha energies show a relatively good agreement with the experimental data. A simple one-dimensional WKB model à la Swiatecki is used to estimate spontaneous fission lifetimes, while alpha-decay probabilities are evaluated within a Gamow-type model. The obtained predictions of our models are in a large majority of cases very close to the experimental data.

Publications cited in the above status report or in the proposed research program below:

[P1] K. Pomorski, B. Nerlo-Pomorska, J. Bartel, C. Schmitt, Acta Phys. Pol. Proc. Supp. **B11** (2018) 137.

[P2] C. Schmitt, K. Pomorski, B. Nerlo-Pomorska, J. Bartel, Phys. Rev. **C95** (2017) 034612.

[P3] K. Pomorski, B. Nerlo-Pomorska, J. Bartel, C. Schmitt, Phys. Rev. **C97** (2018) 034319.

[P4] K. Pomorski, B. Nerlo-Pomorska, A. Dobrowolski, J. Bartel, C. Petrache, Eur. Phys. J. **A56** (2020) 107.

[P5] E.K. Hulet, et al., Phys. Rev. Lett. **56** (1986) 313.

[P6] J. Bartel, B. Nerlo-Pomorska, K. Pomorski, A. Dobrowolski, Comp. Phys. Comm. **241** (2019) 139.

[P7] K. Pomorski, J. Dudek, Phys. Rev. C67 (2003) 044316.

[P8] L.G. Moretto, P.T. Lake, L. Phair, J.B. Elliott, Phys. Rev. **C86** (2012) 021303(R).

Publications realized in 2022 by our collaboration:

[C1] K. Pomorski, A. Dobrowolski, B. Nerlo-Pomorska, M. Warda, J. Bartel, Z.G. Xiao, Y.J. Chen, L.L. Liu, J.L. Tian, X. Diao, Eur. Phys. J. **A58** (2022) 77.

IV. Renewal of the collaboration for 2023

IV.1 Proposed scientific program

Description

In a continuation of our efforts to present an always more performant description of heavy and super-heavy nuclei and their decay through the fission process, we have achieved already a very reasonable evaluation of spontaneous-fission half-lives for even-even actinide and super-heavy elements, as exposed in our progress report above. This motivates us to try now to obtain a similar evaluation for nuclei having an **odd** number of protons and/or neutrons. These calculations will again be performed using the potential energy surfaces obtained using the microscopic-macroscopic model with the Lublin-Strasbourg Drop and the Yukawa-folded single-particle potential.

We also plan to discuss the dynamical coupling of quadrupole-octupole collective excitations with rotation in actinide and super-heavy nuclei by solving the eigenvalue problem of a corresponding collective Hamiltonian. These calculations are projected for a few selected even-even nuclei where such a coupling is expected to play an essential role.

Another essential item in our quest to obtain a description of fission dynamics, as realistic as ever possible, consists in the evaluation of microscopic transport parameters. A numerical program which allows to determine such transport parameters, like moments of inertia, mass and friction tensors has already been published in Ref. [P6] for the case of the fission process at higher energies. Such *macroscopic* transport parameters do, of course, not contain shell and pairing effects as they will turn out to be important when evaluating low-energy phenomena, like spontanteous-fission probablilites, or energies of the lowest collective levels. To be able to ajust to these lower energies, we are going to evaluate these transport coefficients by using the cranking model, as well as the GCM + GOA approach.

Finally, and this is one of our major objectives, we are going to evaluate mass, charge and total kinetic energies (TKE) of fission fragments and the TKE and multiplicities of light particles, primarily neutrons emitted in the course of the fission process. These quantities will be assessed by solving a 3D Langevin equation coupled to Master equations for the evaluation of the light-particle emission. Using our Fourier shape paramerization [P1-P4] and the microscopic-macroscopic model based on the LSD mass formula and the Yukawa-folded potential, these calculations will be performed at low and medium excitation energies of the fissioning nuclear system.

For a more effective realization of the above ambitious research project, the present French and Polish project leaders and their teams have decided, that the time has come to replace the present spokespersons by some younger collegues.

IV.2 Estimated duration for IN2P3 scientists in COPIN

Total time requested for 2023	45
List of scientists	1. H. MOLIQUE (new spokesperson) (15 days) 2. C. SCHMITT (10 days) 3. J.BARTEL (10 days) 4. M.DUFOUR-FOURNIER (10 days)

IV.3 Estimated duration for COPIN scientists in France	
Total time requested for 2023	45
List of scientists	1. A.DOBROWOLSKI (new spokesperson) (8 days) 2. A.ZDEB (8 days) 3. M. WARDA (7 days) 4. K.POMORSKI (8 days) 5. B.NERLO-POMORSKA (8 days) 6. J.BLANCO (6 days)

Comment Validation	
Unity Director	Sandrine COURTIN (IPHC) - 2022-10-14 12:25:24