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	IFJ PAN Cracow Poland

II. Identification of the collaboration	
Title of the collaboration	Exotic nuclear structure mechanisms and symmetries â€" their identifications through theory and experiment
Number of the collaboration	23-157
IN2P3 spokesperson	Jerzy DUDEK
COPIN spokesperson	Irene DEDES
Scientific Domain	Nuclear Physics

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

IV. New collaboration for 2023

IV.1 Proposed scientific program

Description

Introductory remarks

The presently submitted proposition of the collaboration project is motivated by the results of the preparative preceding collaboration between our groups, in particular the COPIN project 05-119. The mentioned research was multi-fold and provides a natural basis for the present new proposition.

A part of our activity was based on the large scale nuclear energy calculations in multidimensional deformation spaces. Calculations were performed using realistic phenomenological nuclear mean field theory with the Hamiltonian optimised using modern methods of the inverse problem theory and Monte Carlo simulations. The latter allow detection of the parametric correlations within the Hamiltonian and removing them from the final optimal parametrisation.

As it is well known today from applied mathematics, these steps are necessary to stabilise the modelling predictions and eliminate divergencies of predictions when approaching zones far away from the parameter fit areas — in our case: Exotic and super-heavy nuclei. The full approach has been tested on the experimental equilibrium deformations with excellent correspondence between theory and experiment, the results of comparison have been published.

This allowed us to collect significant data base of theory results giving precise indications, important for the experimental investigations, about shape coexistence, shape evolution, shape isomers and provided a firm starting point for the next steps aiming at various quantum mechanisms which might strongly vary from one nucleus to another — and thus require a case-by-case approach.

We would like to proceed within the following research sub-fields.

1) Giant Dipole Resonances (GDR) and related phenomena

Having established our theory data base which provides all the necessary starting point information about the ground-state shape properties and shape coexistence we gain our direct access to the following issues for which all the necessary computer programs have been implemented and tested:

— Giant Dipole Resonances and their evolution with spin and temperature — therefore with shapes;

— Jacobi and Poincare shape transitions — identification via GDR spectra;

— GDR configurations based on extreme-deformation configurations: super-deformed, hyper-deformed.

— GDR configurations based on isomeric states.

Our Cracow-Strasbourg collaboration has published over a dozen of common articles on the earlier results and the new project would facilitate next steps based on the newly developed, increasingly realistic theory methods and computer programs.

We foresee systematic theory modelling of the GDR properties in selected nuclei in which the existing experimental information will be helpful in appropriate verifications.

2) Isomers in axially symmetric nuclei

One of the preceding subjects of interest concerns GDR built on isomeric states. To perform this type of analysis satisfactorily it is of great advantage to have at our disposal the cross-check information about the isomers of interest — and this in more than just a single nucleus. Consequently, we envisage selective studies of various classes of isomers in axially symmetric nuclei and underlying mechanisms together with their evolution with the Z and N numbers. These are:

— The so-called K-isomers and, similarly

— The so-called yrast-trap isomers, in particular at high spins;

— Particle-hole excited configurations and related isomerism.

In this part of the project we will address the nuclei selected for the preceding part of the project (and possibly neighbouring nuclei for possible cross-checks). Let us mention that this approach is encouraged by the recently established collaborations with the colleagues working on the high resolution mass spectrometry with complementary access to the isomer information.

3) Since our collaboration has established a number of unique results concerning the geometrical symmetries of nuclei, we wish of course to pursuit this path of research — with the nuclear shape analysis involving first of all exotic symmetries. (By exotic symmetries we understand geometrical symmetries, which are NOT due to prolate/oblate shape coexistence, neither to the long studied pear-shape symmetry states). Examples of the latter

ones: Tetrahedral symmetry or the so-called C_2v symmetry both recently discovered by our collaborating teams.

This subject seems particularly important in view of what we refer to as new nuclear spectroscopy challenges (or: new spectroscopy for short) — identification of molecular symmetries in sub-atomic systems. It is our recent publication in

PHYSICAL REVIEW C 105, 034348 (2022) in which we establish systematic and practicable experimental identification methods. Combining the hand-in-hand theory and experimental techniques we should be able to progress quickly in those new frontier domains of nuclear structure combining geometrical symmetries in molecular and nuclear systems — thus systems governed by totally different interactions. These considerations provide an extra motivations for the foreseen projects.

Recently — in parallel with the theory developments related to the application of the point groups and identification of exotic symmetries — we have completed and tested the specific computer algorithm adapted to automatic analysis of the experimental information stored in the NNDC data base from the point of view of symmetry identification. We plan applying it in comparison with our theory predictions on symmetries such as C_2v, D_3h and D_2d.

4) The shape analysis of nuclei, as seen from the literature, has been performed so far typically addressing static properties of nuclear equilibrium deformations visible form the potential energy surfaces. Our collaboration has established a new technique based on the generalised formulation of the nuclear adiabaticity rules [PHYSICAL REVIEW C 99, 041303(R) (2019)] together with the collective model of Bohr by calculating microscopically the fundamental ingredient of the Bohr theory — the deformation-dependent inertia tensor. This will allow us to operate with the most probable (so-called dynamical equilibrium) deformations — rather that very approximate static equilibrium points — and better approach the experimental challenges.

We will perform the microscopic calculations of the inertia tensor for the nuclei in which the richest information about the low-lying collective excitations of both parities exist and solve the Bohr Hamiltonian, thus obtaining systematic tests of the dynamical equilibrium deformations.

IV.2 Estimated duration for IN2P3 scientists in COPIN

Total time requested for 2023	28
List of scientists	1. J.Dudek (7 days) 2. D.Curien (7 days) 3. O.Dorvaux (7 days) 4. C.Schmitt (7 days)

IV.3 Estimated duration for COPIN scientists in France

Total time requested for 2023	28
List of scientists	1. I.Dedes (14 days) 2. A.Maj (7 days) 3. P.Bednarczyk (7 days)

Comment Validation	
Unity Director	Sandrine COURTIN (IPHC) - 2022-10-13 19:59:45