Project closing report for postdoctoral project
PD124717 - Collective and single-particle motions in nuclei

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In my post-doctoral project the main goal was to experimentally study the most current problems of nuclear physics related to collective and single-particle motions in nuclei.

The two cornerstones of my work were the participation in the data analysis from experiments carried out with the contribution of the nuclear spectroscopy group of ATOMKI, and the development and use of the DIAMANT detector array.

In my nuclear chirality studies I planned to identify a new type of multiple chiral band structure based on the same two-quasiparticle configuration; to identify new examples of multiple chiral bands with different configurations; and to confirm the chiral behavior of several chiral candidate doublets in Rh nuclei. I also intended to search for signs of wobbling motion in the nuclei of this region.

In the period of my postdoctoral project with our group, we focused our research activities to study medium- and high-spin band structure of nuclei in the mass region A~100, namely ^{102}Rh,^{103}Rh, ^{104}Rh and ^{105}Pd in order to search for new multiple chiral doublet bands and bands corresponding to the transverse wobbling motion.

Data analysis for ^{102}Rh was reaching its final phase during 2020. After the thorough analysis, the level scheme of this nucleus was extended significantly. Currently the comparison of the experimental Routhians and aligned angular momenta with theoretical predictions is in progress. After completion, a draft will be prepared for publication. The submission of the paper is expected in the following year.

In ^{103}Rh several new band structures have been identified and their properties were compared with constrained covariant density functional theory and particle rotor model calculations. Based on this comparison, three chiral band pairs were identified in ^{103}Rh, of which two belong to the same configuration. These results give a better understanding of the robustness of nuclear chirality against the excitation of a certain configuration.

During the data analysis several new positive- and negative-parity bands in ^{104}Rh were identified which form chiral band pairs according to their experimental properties and to the preliminary calculations, thus the existence of multiple chiral doublet bands in this nucleus is possible.

Experimental properties of one of the observed negative-parity bands in ^{105}Pd are characteristic of transverse wobbling motion. The transverse wobbling scenario is confirmed by the results of the calculations. Thus, this is the first wobbling case observed in the A~100 mass region and in a nucleus with odd neutron number.

These observations provide experimental evidence for the predicted triaxial shape in this mass region, and new data which enable a better understanding of the studied phenomena [1,2,3,4].

On the basis of the results obtained for ^{105}Pd, our group submitted an experimental proposal for the planned EXOGAM2 - NEDA - DIAMANT campaign at GANIL to search for wobbling motion in ^{107}Pd. The clover detectors of this setup would provide an excellent and unique possibility to study the angular correlation and linear polarization properties of the transitions of this nucleus, which are necessary for the identification of the wobbling phenomena. We presented this proposal at the PAC meeting of GANIL, in November 2018.

I also attended to the AGATA@LNL workshop in Legnaro in March 2019, to present a Letter of Intent, focusing on the search for chiral structures based on a new type, 1-particle 2-hole configurations in ^{105}Pd. High efficiency in detecting coincidences is ultimately needed for these kind of measurements. AGATA has an excellent spectral response which provides the necessary spectrum quality even for high-fold coincidences.

Additionally to the study of the chirality in mass region A~100, I also participated in the research of triaxially deformed nuclei with A~130 mass number. In one of these studies we identified a new band in ^{130}Ba built on the 8^- isomer state. In addition, we successfully observed a cascade of excited states in this nucleus, connected to a special motion where the the rotational axis is being tilted into the intermediate long-short plane. Such cascade is called as a t-band, and was discovered in this nucleus for the first time in the A~130 region [5,6,7]. Another experimental result was the identification of multiple chirality in ^{135}Nd, ^{136}Nd and ^{137}Nd extending the limits of the region of MχD phenomenon in the A~130 mass region, and encouraging further investigations of possible candidates for multiple chiral bands [8,9,10,11,12,13,14].

As a part of my work plan, I was planning to propose experiments for lifetime measurements in Rh nuclei, also to prepare proposals for chirality studies in the A~130 region. Unfortunately due to the COVID-19 pandemic all institutes with the suitable infrastructure postponed or cancelled their call for proposals/LoIs. These proposals and letter of intents will be submitted after the end of this postdoctoral project.

The other main goal of my postdoctoral project was to develop and operate the DIAMANT charged-particle detector system and take part in performing experiments at AGATA gamma-detector array. This detector system has been developed with the major contribution of ATOMKI and was operated by our group in the last decade. The latest results on one of the interesting physics cases obtained using this detector system, effects arising from isospin-symmetry-breaking interactions by measuring energy differences between analogue states in the ^{23}Mg and ^{23}Na mirror nuclei, studied with the EXOGAM – NeutronWall – DIAMANT setup was published in July 2018 [15].

Being the responsible person of DIAMANT, the main task in the first year of my project was the preparation and participation in the AGATA campaign of 2018. In the first few months of this project, under my coordination and with my significant contribution, the development of the firmware for the digital signal processing electronics, as well as the necessary hardware developments of the DIAMANT detector array came to a final phase.

The first in-beam tests were carried out in GANIL, in October and November of 2017. During the first tests we successfully coupled the new DSP and the data acquisition systems of DIAMANT, NEDA, and EXOGAM, however a proper particle identification couldn't be realized. The root of the problem was later identified as a bad setting in the register values.

To proof the basic functionality of the firmware in experimental circumstances, a short in-beam test was done in Atomki in December 2017. The test resulted in success, the particle discrimination was feasible with the new firmware. The commissioning for the 2018 AGATA campaign has begun in January 2018, with the transportation of the detectors and the necessary electronics. A source commissioning was done in March, which revealed a minor problem with the trigger validation. This problem was resolved by a modification in the firmware. The in-beam commissioning took place in April 2018.

For the 2018 campaign 5 experiments were scheduled between April and August 2018. The experiments showed a broad variety of physics cases, such as the determination of mirror energy differences, the studies of shape-coexistence in the A~50-70 mass region, as well as to reveal quadrupole and octupole correlations in N = Z nuclei around ^{100}Sn. All of these measurements were based on the combination of at least three detector systems: AGATA, NEDA and DIAMANT; the last experiment also used a plunger device. DIAMANT provided a unique possibility for charged particle discrimination regarding the setup described above. I spent approximately three months during 11 trips in GANIL in the first year of this project, actively participating in the preparation, the commissioning of the experimental setup, and running the experiments of this campaign. The main part of my contribution was the mechanical preparation and installation of the detectors, also setting up the electronics and the related software. Moreover, during the experiments I was continuously monitoring the operation of the system. I also actively participated in the on-line analysis by setting the 2D particle gates in the collected spectra, in order to achieve the most precise light charged particle – thus reaction channel – selection, which had crucial importance for a quality data set.

The results showed that the performance of the new DIAMANT setup was beyond expectations e.g. in terms of particle discrimination capabilities at higher reaction rates. A meeting took place in 2019 October in Firenze, Italy, where the possible more permanent detector setup including DIAMANT were also discussed. The data analysis of the 2018 campaign is still ongoing (the quantity of the collected data is in the range of tens of terabytes), the first drafts are in preparation for publication.

During the 2nd year of my grant I also had the possibility to represent Hungary as a deputy in the AGATA collaboration, at the Steering Committee meeting in October 2018 in London.

After the 2018 campaign, AGATA was coupled to MUGAST, and then the zero degree separator VAMOS++, to explore new physics cases which need different setup, and no experiment was carried out involving DIAMANT. However I also participated in two experiments carried out with the AGATA-VAMOS++ setup. After the thorough analysis of the data from one of these experiments, clarification and extension of the level scheme of ^{81}Ga were made. The results show the presence of strong proton-neutron correlations associated with the promotion of neutrons across the magic N = 50 shell gap, only few nucleons away from ^{78}Ni [16]. In the other experiment, the lifetimes of the low-lying excited states 2+ and 4+ have been directly measured in the neutron-deficient ^{106,108}Sn isotopes [17].

In the second fiscal year of the project, the possible use of DIAMANT for e+e- detection emerged. To examine the possibilities, I organized a test experiment in Atomki in

October 2018 which was carried out in the framework of an international collaboration. As the infrastructure had some limitations (e.g. no dedicated reaction chamber was available for DIAMANT at that time), I proposed a new, more permanent setup for DIAMANT at one of the available beam lines of the Cyclotron of Atomki. In early 2019 the extension of the GANIL reaction chamber and a compatible target loader were designed. The parts were shipped in August 2019, and the commissioning of the DIAMANT@ATOMKI setup begun in October 2019. A new rack for the electronics has been bought and installed in late 2019. A modified chamber based on the one used for the AGATA campaign was assembled, and a supporting structure was manufactured and installed at the beamline 3 at the cyclotron of ATOMKI. With this new setup, a vacuum/source test has been carried out successfully by the end of the year. During the tests, the idea of the use of DIAMANT in fragmentation reactions came to mind. In order to study the feasibility, beam time was requested for the spring of 2020 for two in-beam tests, and for an experiment to characterize the DIAMANT detector array for the measurement of E0 transitions with large pair conversion decay.

Unfortunately, due to the global pandemic, travel bans and home office came into force, so changes had to be made to the original work plan. To carry on with the development during the lockdown, the plans for a new FlexiBoard (the flexible main printed circuit serving also as a self-supporting structure) were revised and modified with the possibility of a vertical target loading mechanism when using a full geometry. Orders were placed during July 2020, and the parts arrived in August 2020. Even though the assembly and final test of the renewed detector will happen only after the closing date of this postdoctoral project, the development can be said to be very successful.

As the study of N=Z nuclei is one of the main topics of my project, I contributed to the publications on the structural studies in the semi-magic ^{94}Ru and ^{88}Ru nuclei lying close to the N=Z line. The experiments were performed using the AGATA detector array coupled to the DIAMANT detector. In ^{94}Ru lifetimes for 5 excited states have been determined for the first time using DSAM technique [18]. In ^{88}Ru the presence of isoscalar neutron-proton pairing in the low-lying structure has been shown for the first time [19].

During the project, I was participating in the supervision of a BSc student from our group, who was working on the analysis of the ^{105}Pd nucleus. A dissemination paper on the transverse wobbling scenario in this nucleus was published [4]. I also contributed to the computer training of another BSc student preparing his thesis in nuclear spectroscopy. In order to get them further involved in the research work of the current project, they joined me in one of the experiments of the AGATA campaign of 2018. They both spent nearly a week in institute GANIL (Caen, France), and got familiar with the acquisition system of the AGATA – NEDA – DIAMANT setup, as well as got introduced of how to run an experiment.

As a part of this postdoctoral project I participated in the investigation of the evolution of shapes and search for possible shape-coexistence in neutron-rich nuclei ^{87}Br and ^{89}Br. The results obtained for ^{87}Br has been submitted to Physical Review C [20], the final steps of the data analysis and the theoretical interpretation of the experimental results for ^{89}Br are ongoing.

In addition to the tasks summarized in my work plan I also contributed to several publications: on studying excited states via beta-decay heavier nuclei with A~160 [21]; on studying the low-lying structures of the midshell isotopes $^{73\text{-}75}$Ni [22]; and extending the southern shore of the Island of Inversion to ^{28}F [23]. The experiments for these cases were carried out in RIBF facility of RIKEN. Furthermore, in 2019 I participated in an experiment at Jyvaskyla, aiming to study the collectivity and shape phenomena in extremely neutron deficient nuclei of the mass region A~120. In this region, according to theoretical models, large ground-state deformations and configuration dependent triaxial shapes are expected, which so far remained untested by experiment.

Debrecen, 30/09/2020

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