様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

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研究課題名（和文）A high-resolution gamma-ray tracking detector for in-beam spectroscopy of unstable nuclei

研究課題名（英文）A high-resolution gamma-ray tracking detector for in-beam spectroscopy of unstable nuclei

研究代表者
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研究成果の概要（和文）：2020年度の実験キャンペーンの結果、非常にエキゾチックな原子核の構造に関する新しい実験データが得られました。詳細には、(i) N=50での侵入粒子-空孔構成とその結果生じる集団性、(ii) 110Zrの周りの形状と殻、(iii) r過程に向かう中性子過剰原子核、(iv) 反転島と形状遷移を調べます。合計8つの実験でこれらの側面を調べ、遷移エネルギー、準位寿命、分光因子を抽出し、抽出された行列要素を通じて原子核の単一粒子および集団特性に関する新しい洞察を提供します。

研究成果の学術的意義や社会的意義
私たちは、分光法と寿命を測定することで、エキゾチック核に関する知識を大幅に拡大しました。私たちの結果は、核構造モデルの開発に影響を与え、陽子と中性子の相互作用、核の基本的な単一粒子構造からの集団現象の出現、および宇宙における元素合成の影響予測に関する理解を深めます。

研究成果の概要（英文）：As a result of our experimental campaign in FY2020, we have obtained new experimental data on the structure of very exotic nuclei. In detail we will examine (i) intruder particle-hole configurations at N=50 and the resultant collectivity, (ii) shapes and shells around 110Zr, (iii) neutron-rich nuclei toward the r-process, (iv) islands of inversion and shape transitions. A total of 8 experiments looks at these aspects and we will extract transition energies, level lifetimes, and spectroscopic factors giving new insights to the single-particle and collective properties of nuclei trough the extracted matrix elements.

研究分野：nuclear physics

キーワード：gamma-ray spectroscopy　nuclear structure　exotic nuclei

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様　式　Ｃ－１９、Ｆ－１９－１（共通）

１．研究開始当初の背景

In the nuclear shell model magic numbers correspond to large gaps between adjacent nuclear orbitals with fully occupied levels below the Fermi surface. Many experimental and theoretical investigations in the last

decades have shown that these magic numbers are not universally valid over the whole nuclear chart, but rather change as function of proton number Z or neutron number N. A large part of the experimental evidence for shell evolution comes from the spectroscopy of excited states in exotic nuclei. The excitation energy of the lowest excited state in a nucleus provides (indirect) information on its nature as in a closed shell configuration, with a large gap to the next level, it costs more energy to promote nucleons across that gap. More unambiguous information comes from direct reaction experiments. Here the initial and final state of the reaction are linked by a matrix element, and thus a measurement of the reaction cross section provides access to the overlap of two nuclear states. Single-particle properties in exotic nuclei, i.e. the locations and occupations of orbitals, are investigated through transfer reactions. The study of very exotic nuclei with low production rates was particularly driven forward by nucleon knockout reactions in combination with γ-ray spectroscopy. Another observable are electromagnetic transition probabilities which connect states within one nucleus. These give access to collective properties of nuclei. In a simplified interpretation, the magnitude of the transition probability can be expressed as the number of nucleons participating in the excitation. Transition probabilities can be determined experimentally by either measuring the excitation cross section (Coulomb excitation) or the decay properties, lifetimes, branching ratios, and multipolarities.
The overarching goal of the project is to overcome the present limitations for in-beam γ-ray spectroscopy at the RIBF and measurements of collective properties in very neutron-rich nuclei.

２．研究の目的

The purpose of the project is to construct a high resolution γ-ray detector array and to conduct an experimental campaign at the RIBF. This detector will overcome the present limitations and will be realized within an international collaboration. The anticipated performance for experiments is world leading, achieving the highest efficiency for an array of its kind. Together with the ability to perform experiments at the limits of existence of the nuclear chart, the results that can be obtained from the proposed project are unprecedented. Experiments will focus on the shell and shape evolution of exotic nuclei. They will greatly enhance our understanding of shell evolution along isotopic and isotonic lines. Direct experimental evidence for the newly proposed shell evolution within a nucleus can be obtained for the first time. Lastly the sensitivity to lifetimes and transitional matrix elements will allow for systematic studies of octupole deformation, and thus contribute to the search of physics beyond the standard model. The realization of this project will open a new era for studying the structure of exotic nuclei.

In total we performed 8 experiments:
Neutron intruder states and collectivity beyond N = 50
RIBF196, F. Flavigny, M. Gorska, Zs. Podolyak et al.

Quadrupole and octupole collectivity of 84,86Ge and 86,88,90Se
RIBF190, F. Browne, V. Werner et al.

Spectroscopy and lifetime measurements in neutron-rich Zr and Mo
RIBF187, W. Korten, K. Wimmer et al.

Single-particle states in the N = 82 nucleus 129Ag
RIBF189, Zs. Podolyak, M. Gorska et al.

Characterization of a transition above 4 MeV in 136 Te
RIBF193, A. Jungclaus, P. Doornenbal et al.

Evolution of collectivity in Ti isotopes towards N = 40
RIBF142R1, T. Koiwai, K. Wimmer et al.

Proton Removal and Lifetimes in the Ca Isotopes
RIBF170R1, H. Crawford, M. Petri, S. Paschalis et al.

Gamma-ray spectroscopy in the vicinity of double-magic 78Ni
RIBF181, R. Taniuchi, D. Suzuki, S. Franchoo et al.

３．研究の方法

The HiCARI array was constructed as planned. Eight MINIBALL cluster detectors, each containing three six-fold segmented Ge crystals will be provided by the MINIBALL collaboration from Europe. Clover-type detectors from IBS Korea and IMP China were also installed to improve the efficiency of the array. A triple of 36-fold segmented Ge detectors belonging to Lawrence Berkeley National Laboratory in the USA and one quad of also 36-fold segmented detectors from RCNP Osaka complement the array.
The data acquisition system was built and tested.
A detailed simulation software was developed and benchmarked with source data.
The resolving power is significantly higher such that also weak, and close-lying transitions
could be identified with confidence. A second application of high resolution in-
beam γ-ray spectroscopy is the measurement of lifetimes. If an excited state in a nucleus has a finite lifetime, its decay will happen after the target. A decay further downstream will thus lead to larger angles for the Doppler-correction, and therefore a tail in the γ-ray energy spectrum. This technique has been widely exploited during the campaign.

４．研究成果

We have significantly expanded the knowledge about exotic nuclei by measuring spectroscopy and lifetimes. Our results have impact on the development of nuclear structure models, improve our understanding of the interaction of protons and neutrons, the emergence of collective phenomena from the underlying single-particle structure of nuclei as well as impact predictions of element synthesis in the universe.

５．主な発表論文等

〔雑誌論文〕　計0件

〔学会発表〕　計18件（うち招待講演　13件／うち国際学会　0件）

１．発表者名 Kathrin Wimmer
２．発表標題 In-beam gamma-ray spectroscopy with HiCARI
３．学会等名 Zakopane Conference on Nuclear Physics（招待講演）
４．発表年 2022年

１．発表者名 Kathrin Wimmer
２．発表標題 In-beam gamma-ray spectroscopy with swift radioactive beams
３．学会等名 NUSTAR seminar 2022（招待講演）
４．発表年 2022年

１．発表者名 Kathrin Wimmer
２．発表標題 From magicity to deformation: neutron-rich nuclei between N = 32 and 40
３．学会等名 SFB Workshop 2022（招待講演）
４．発表年 2022年

１．発表者名 Kathrin Wimmer
２．発表標題 In-beam gamma-ray spectroscopy with HiCARI and LISA
３．学会等名 Annual Swedish Nuclear Physicist’s meeting and SFAIR Meeting 2022（招待講演）
４．発表年 2022年

1．発表者名
K. Wimmer

2．発表標題
In-beam gamma-ray spectroscopy at RIKEN

3．学会等名
African Nuclear Physics Conference 2021（招待講演）

4．発表年
2021年

1．発表者名
K. Wimmer

2．発表標題
High-resolution in-beam γ-ray spectroscopy and lifetime measurements with HiCARI

3．学会等名
Theme Meeting on Nuclear Lifetimes, Transitions and Moments (NLTM2022)（招待講演）

4．発表年
2022年

1．発表者名
K. Wimmer

2．発表標題
High-resolution In-beam Gamma-ray Spectroscopy: Recent Progress and Future Avenues

3．学会等名
Center for Exotic Nuclear Studies IBS（招待講演）

4．発表年
2021年

1．発表者名
K. Wimmer

2．発表標題
Nuclear Structure with Swift Radioactive Ion Beams

3．学会等名
Physikalisches Kolloquium, TU Darmstadt（招待講演）

4．発表年
2021年

１．発表者名 P. Doornenbal
２．発表標題 HICARI@RIKEN
３．学会等名 NUSTAR annual meeting（招待講演）
４．発表年 2021年

１．発表者名 K. Wimmer
２．発表標題 Towards high-resolution in-beam gamma-ray spectroscopy at the RIBF
３．学会等名 Nuclear Structure and Dynamics NSD2019, May 13 - 17 2019, Venice, Italy（招待講演）
４．発表年 2019年

１．発表者名 K. Wimmer
２．発表標題 In-beam gamma-ray spectroscopy at the RIBF: latest results and future plans
３．学会等名 Nuclear Spectroscopy Instrumentation Network (NuSpIn), June 24 - 28 2019, Orsay, France（招待講演）
４．発表年 2019年

１．発表者名 K. Wimmer
２．発表標題 Structure at the extremes: In-beam gamma-ray spectroscopy at the RIBF
３．学会等名 27th International Nuclear Physics Conference (INPC 2019), July 29 - August 2 2019, Glasgow, UK（招待講演）
４．発表年 2019年

１．発表者名
K. Wimmer

２．発表標題
High resolution in-beam spectroscopy at the RIBF

３．学会等名
Vth Topical Workshop on Modern Aspects in Nuclear Structure The Many Facets of Nuclear Structure, February 3 - 9 2020, Bormio, Italy（招待講演）

４．発表年
2020年

１．発表者名
K. Wimmer

２．発表標題
Simulations for the High Resolution array

３．学会等名
High resolution in-beam gamma-ray spectroscopy at the RIBF Workshop, April 10 - 12 2019, Darmstadt, Germany

４．発表年
2019年

１．発表者名
K. Wimmer

２．発表標題
Single-particle and collective structure of neutron-rich N = 40 nuclei

３．学会等名
High resolution in-beam gamma-ray spectroscopy at the RIBF Workshop, April 10 - 12 2019, Darmstadt, Germany

４．発表年
2019年

１．発表者名
K. Wimmer

２．発表標題
Status of HiCARI

３．学会等名
8th SUNFLOWER Workshop / HiCARI Workshop (JSPS A3Foresight), August 26 - 28 2019, Osaka, Japan

４．発表年
2019年

１．発表者名 K. Wimmer
２．発表標題 Proton and Neutron Knockout from 64Cr
３．学会等名 8th SUNFLOWER Workshop / HiCARI Workshop (JSPS A3Foresight), August 26 - 28 2019, Osaka, Japan
４．発表年 2019年

１．発表者名 K. Wimmer
２．発表標題 High resolution spectroscopy and lifetime measurements in neutron-rich Zr and Mo isotopes
３．学会等名 8th SUNFLOWER Workshop / HiCARI Workshop (JSPS A3Foresight), August 26 - 28 2019, Osaka, Japan
４．発表年 2019年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

HiCARI: High-resolution Cluster Array at RIBF
https://www.nishina.riken.jp/collaboration/SUNFLOWER/devices/hrarray/index.php

６．研究組織

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６．研究組織（つづき）

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７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関