IL NUOVO CIMENTO **45 C** (2022) 125
DOI 10.1393/ncc/i2022-22125-5

Communications: SIF Congress 2021

Decay studies in the A∼225 Po-Fr region from the DESPEC campaign at GSI in 2021

M. Polettini(1)(*), J. Pellumaj(2)(3), G. Benzoni(1), J. J. Valiente-Dobón(3), G. Zhang(4), D. Mengoni(4), R. M. Perez Vidal(3), D. Genna(1), A. Bracco(1), G. Aggez(5), U. Ahmed(6), Ö. Aktas(7), M. Al Aqueel(8), B. Alayed(9)(10), H. M. Albers(11), A. Algora(12), S. Alhomaidhi(11)(6), C. Appleton(13), T. Arici(5), M. Armstrong(14), K. Arnswald(14), M. Balogh(3), A. Banerjee(11), J. Benito García(15), A. Blazhev(14), S. Bottoni(1), P. Boutachkov(11), A. Bruce(16), C. Bruno(13), F. Camera(1), B. Cederwall(7), M. M. R. Chishti(17), M. L. Cortés(6), D. M. Cox(18), F. C. L. Crespi(1), B. Das(7), T. Davinson(13), G. De Angelis(3), T. Dickel(11), M. Doncel(19), R. Donthi(20), A. Ertoprak(3), R. Escudeiro(4), A. Esmaylzadeh(14), L. M. Fraile(15), L. Gaffney(9), E. R. Gamba(1), J. Gerl(11), M. Górska(11), A. Gottardo(3), J. Ha(4), E. Haettner(11), O. Hall(13), H. Heggen(11), Y. Hrabar(18), N. Hubbard(11)(6), S. Jazrawi(17)(21), P. R. John(6), J. Jolie(14), C. Jones(16), D. Joss(9), D. Judson(9), D. Kahl(22), V. Karayonchev(14), E. Kazantseva(11), R. Kern(6), L. Knafla(14), I. Kojouharov(11), A. Korgul(23), W. Korten(24), P. Koseoglou(6), G. Kosir(25), D. Kostyleva(11), T. Kurtukian-Nieto(26), N. Kurz(11), N. Kuzminchuk(11), M. Labiche(27), S. Lenzi(4), S. Leoni(1), M. Llanos Expósito(15), R. Lozeva(28), T. J. Mertzimekis(29), M. Mikolajczuk(23), B. Million(1), A. K. Mistry(11)(6), A. Morales(12), I. Mukha(11), J. R. Murias(15), D. Napoli(4), B. S. Nara Singh(30), D. O'Donnell(30), S. E. A. Orrigo(12), R. Page(9), S. Pelonis(29), J. Petrovic(7), N. Pietralla(6), S. Pietri(11), S. Pigliapoco(4), Zs. Podolyak(17), C. Porzio(1), B. Quintana Arnes(31), F. Recchia(4), P. H. Regan(17)(21), J.-M. Régis(14), P. Reiter(14), K. Rezynkina(4), P. Roy(32)(11), M. Rudigier(6), P. Ruotsalainen(33), E. Sahin(11)(6), L. G. Sarmiento(18), M.-M. Satrazani(9), H. Schaffner(11), C. Scheidenberger(11), L. Sexton(13), A. Sharma(34), J. Smallcombe(9), P.-A. Söderström(22), A. Sood(7), P. Vasileiou(29), J. Vesic(25), J. Vilhena(35), L. Waring(9), H. Weick(11), V. Werner(6), J. Wiederhold(6), O. Wieland(1), K. Wimmer(11), H. J. Wollersheim(11), P. Woods(13), A. Yaneva(14), I. Zanon(2)(3), J. Zhao(11), R. Zidarova(6), S. Ziliani(1), G. Zimba(33) and A. Zyriliou(29)

(1) *Dipartimento di Fisica, Università degli Studi di Milano and INFN Milano - Milan, Italy*
(2) *Dipartimento di Fisica e Scienze della Terra, Università di Ferrara - Ferrara, Italy*
(3) *INFN, Laboratori Nazionali di Legnaro - Legnaro, Italy*
(4) *Dipartimento di Fisica e Astronomia, Università di Padova and INFN Padova - Padua, Italy*

(*) On behalf of the HISPEC-DESPEC Collaboration.

([5]) *Istanbul University, Graduate School of Sciences, Department of Physics - Istanbul, Turkey*
([6]) *Institut für Kernphysik, Technische Universität Darmstadt - Darmstadt, Germany*
([7]) *KTH Royal Institute of Technology - Stockholm, Sweden*
([8]) *Imam Mohammad Ibn Saud Islamic University - Riyadh, Saudi Arabia*
([9]) *Department of Physics, Oliver Lodge Laboratory, University of Liverpool - Liverpool, UK*
([10]) *Ar Rass College of Sciences and Arts, Qassim University - Quassim, Saudi Arabia*
([11]) *GSI Helmholtzzentrum für Schwerionenforschung GmbH - Darmstadt, Germany*
([12]) *Instituto de Fisica Corpuscular, CSIC-Universidad de Valencia - Valencia, Spain*
([13]) *University of Edinburgh, School of Physics and Astronomy - Edinburgh, UK*
([14]) *Institut für Kernphysik der Universität zu Köln - Köln, Germany*
([15]) *Grupo de Física Nuclear and IPARCOS, Universidad Complutense de Madrid - Madrid, Spain*
([16]) *School of Computing Engineering and Mathematics, University of Brighton Brighton, UK*
([17]) *Department of Physics, University of Surrey - Guildford, UK*
([18]) *Department of Physics, Lund University - Lund, Sweden*
([19]) *Department of Physics, University of Stockholm - Stockholm, Sweden*
([20]) *Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research Mumbai, India*
([21]) *National Physical Laboratory - Teddington, UK*
([22]) *ELI-NP Center for Extreme Light Infrastructure, Nuclear Physics - Magurele, Romania*
([23]) *Department of Physics, University of Warsaw - Warsaw, Poland*
([24]) *Irfu, CEA, Université Paris-Saclay - Paris-Saclay, France*
([25]) *Jozef Stefan Institute - Ljubljana, Slovenia*
([26]) *CENBG, Université de Bordeaux, CNRS/IN2P3 - Bordeaux, France*
([27]) *STFC, Daresbury Laboratory - Daresbury, UK*
([28]) *Université Paris-Saclay, IJCLab, CNRS/IN2P3 - Paris-Saclay, France*
([29]) *National and Kapodistrian University of Athens - Athens, Greece*
([30]) *School of Computing, Engineering and Physical Sciences, University of West Scotland Glasgow, UK*
([31]) *Laboratorio de Radiaciones Ionizantes, Universidad de Salamanca - Salamanca, Spain*
([32]) *Variable Energy Cyclotron Centre - 1/AF Bidhan Nagar, Kolkata, India*
([33]) *University of Jyväskylä - Jyväskylä, Finland*
([34]) *Department of Physics, Indian Institute of Technology Ropar - Ropar, India*
([35]) *LPMCN, Université de Lyon - Lyon, France*

received 1 February 2022

Summary. — The HISPEC-DESPEC collaboration aims at investigating the structure of exotic nuclei formed in fragmentation reactions with decay spectroscopy measurements, as part of the FAIR Phase-0 campaign at GSI. This paper reports on first results of an experiment performed in spring 2021, with a focus on β-decay studies in the Po-Fr nuclei in the $220 < A < 230$ island of octupole deformation exploiting the DESPEC setup. Ion-beta correlations and fast-timing techniques are being employed, giving an insight into this difficult-to-reach region.

1. – Introduction

Octupole correlations are the result of the long range octupole-octupole interaction between nucleons occupying pairs of orbitals which differ by 3 units in both orbital and total-angular momentum. This results in asymmetric shapes, also known as pear-like shapes [1]. These exotically-deformed nuclei can be found in selected areas of the nuclear chart, in particular in the mass regions $A \simeq 146$ (Xe-Sm region) and $A \simeq 222$ (Rn-Th region), called islands of octupole deformation [2]. To find direct experimental evidence of these elusive shapes proves to be very challenging, and it is worth exploring several spectroscopic properties in a wide range of nuclei. The first signature is the excitation energy spectrum itself, characterised by alternating, almost degenerate, negative- and positive-parity states. Octupole deformation also results in large E3 and E1 strengths due to the separation of the centre of mass and the centre of charge in the nucleus [3]. Atoms whose nucleus displays static octupole deformation can be an ideal laboratory for measurements of electric dipole moments [4]. The Rn-Th isomers with $A \simeq 222$ are expected to show the largest octupole deformations, as highlighted both by recent experimental measurements [5, 6] and by theoretical calculations [7, 8]. Our experiment was focused on two main aims: finding evidence of octupole deformation in the nuclei of interest populated via β decay and providing new β-decay data to test r-process nucleosynthesis models.

2. – Experimental setup

The experiment described here was performed at the GSI-FAIR facility in Darmstadt, Germany, in April 2021, within the experimental program of DESPEC Phase-0. The campaign focused on investigating the inner structure of exotic nuclei formed in high-energy projectile-fragmentation reactions. The nuclei of interest were produced in fragmentation reactions of a primary beam of ^{238}U on a ^{9}Be target. The primary beam had an intensity of $\sim 10^9$ /s and a spill length of 4 s. The fragments composing the secondary beam were selected using the FRagment Separator (FRS) [9] with the $B\rho - \Delta E - B\rho$ method and identified using the $TOF - B\rho - \Delta E$ method [10], collecting information on the ions' time of flight, position in the focal planes, and atomic number Z. The ions of interest were then transported towards the DEcay SPECtroscopy (DESPEC) station [11], where they were implanted into the AIDA (Advanced Implantation Detector Array) stack of three double-sided silicon-strip detectors (DSSDs) [12]. This active stopper is sandwiched between two plastic detectors made of tiles of BC-400 scintillator material, read out by 16 series of SiPM coupled to each side. The plastic detector is used for timing measurements of the β particle emitted in the decay. The decay station also comprises a hybrid array of HPGe and $LaBr_3$(Ce) detectors to measure the γ rays emitted in the de-excitation of the daughter nuclei. The FATIMA (FAst TIMing Array) consists of 36 $LaBr_3$(Ce) detectors with a full-energy peak efficiency of 2.9% at $\sim$1 MeV [13, 14]. An array of four 7-fold EUROBALL HPGe clusters [15] in forward position is used for precision γ-ray energy measurements, with an efficiency of 2% at $\sim$1 MeV. Independent data acquisitions of the subsystems were synchronised with a time sorter using a distributed clock.

3. – Study of the implantation profile in AIDA

The initial stages of the data analysis were focused on the identification of the ions of interest and the study of their implantation profile. The Particle IDentification (PID) plot, reported in fig. 1, shows the ions of interest in terms of their reconstructed Z and A/Q ratio: ^{228,229,230}Fr, ^{226,227,228,229}Rn, ^{224,225}At, together with several other ion

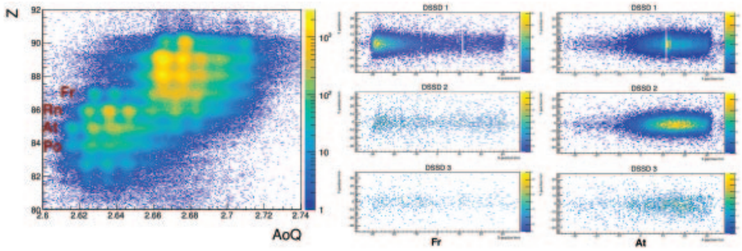

Fig. 1. – Left: particle identification plot obtained for our dataset. Middle (right): implantation profile of francium (astatine) isotopes in the three AIDA detectors.

species that can be investigated with this measurement. A study of the implantation profile in AIDA was performed by evaluating the depth reached by the nucleus within AIDA layers, as shown in the middle and right panels of fig. 1 for Fr and At isotopes, respectively. Ions with different atomic number Z have a different implantation profile, which will be of help in the study of ion$-\beta$ correlations. Ad-hoc correlation algorithms are being developed in order to perform ion-β and ion- $\beta - \gamma - \gamma$ correlations. This analysis will be used to study the inner structure of the daughter nuclei by identifying new decay transitions and evaluate the presence of octupole deformation.

4. – Conclusions

This paper reports on the study of the implantation profile in an experiment performed at GSI in April 2021 within the DESPEC-Phase 0 campaign framework. The study presented here is focused on the investigation of the presence of octupole deformation in Po-Fr nuclei in the $A{\sim}225$ island of octupole deformation.

* * *

The authors acknowledge the GSI accelerator team and the FRS group. Support by INFN, the BMBF and the UK Science and Technology Facilities Council is acknowledged.

REFERENCES

[1] Butler P. A., *Phys. G: Nucl. Part. Phys.*, **43** (2016) 073002.
[2] Carpenter M. P., *J. Phys.: Conf. Ser*, **312** (2011) 092006.
[3] Butler P. A., *Proc. R. Soc. A*, **476** (2020) 0202.
[4] Chupp T. E., *Rev. Mod. Phys.*, **91** (2019) 015001.
[5] Gaffney L. P. *et al.*, *Nature*, **497** (2013) 199.
[6] Chishti M. M. R. *et al.*, *Nat. Phys.*, **16** (2020) 853.
[7] Robledo L. M. and Butler P. A., *Phys. Rev. C*, **88** (2013) 051302(R).
[8] Xia S. Y. *et al.*, *Phys. Rev. C*, **96** (2017) 054303.
[9] Geissel H. *et al.*, *Nucl. Instrum. Methods Phys. Res. B*, **70** (1992) 286.
[10] Münzenberg G., *Nucl. Instrum. Methods Phys. Res. B*, **70** (1992) 265.
[11] Mistry A. K. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **1033** (2022) 166662.
[12] AIDA, Technical report (2008).
[13] FATIMA, Technical report (2015).
[14] Rudigier M. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **969** (2020) 163967.
[15] Beck F., *Prog. Part. Nucl. Phys.*, **28** (1992) 443.