Single-particle states in *fp-shell* nuclei through ^{50}Ca$(d,p)^{51}$Ca transfer reaction

C. Ferrera,[*1] K. Wimmer,[*2,*3] D. Suzuki,[*3] N. Imai,[*4] M. Armstrong,[*5] T. Chillery,[*4] Y. Cho,[*6] M. Dozono,[*3,*7] F. Endo,[*8,*3] S. Escrig,[*1] N. Fukuda,[*3] T. Haginouchi,[*3,*8] S. Hanai,[*4] S. Hayakawa,[*4] Y. Hijikata,[*3,*7] J. W. Hwang,[*6] S. Ishio,[*3,*8] A. Jungclaus,[*1] A. Kasagi,[*9,*10] K. Kawata,[*4] N. Kitamura,[*4] R. Kojima,[*4] J. Li,[*4] S. Masuoka,[*4] S. Michimasa,[*4] B. Moon,[*6] K. Okawa,[*4] S. Ota,[*4,*11] T. Saito,[*4] H. Sakurai,[*3] Y. Shimizu,[*3] S. Shimoura,[*3,*4] Y. Son,[*6] T. Sumikama,[*3] H. Suzuki,[*3] H. Takeda,[*3] Y. Togano,[*3] J. Vesic,[*12] K. Yako,[*4] R. Yokoyama,[*4] K. Yoshida,[*3] and M. Yoshimoto[*3]

Neutron-rich Ca isotopes towards neutron number $N = 34$ are pivotal for exploring the evolution of the fp-shell orbitals. Beyond the $N = 28$ shell gap in ^{48}Ca, new magic numbers at $N = 32$ and 34 were established through spectroscopy of low-lying states and mass measurements. Most recently, the spatial extension of the $1f_{7/2}$ and $2p_{3/2}$ neutron orbitals was determined via a one-neutron knockout reaction from ^{52}Ca.[1)] However, the single-particle $2p_{1/2}$ and $1f_{5/2}$ orbitals defining the shell gaps at $N = 32, 34$ remain to be established experimentally. The one-neutron transfer reaction is an experimental method well-suited to study low-spin single-particle orbitals. The cross section of this reaction gives access to the spectroscopic factors, while the angular distribution of the reaction products allows for deduction of the angular momentum transfer.

In December 2022, the SHARAQ12 experiment was performed at RIKEN, aiming to study the single-particle structure of ^{51}Ca via the (d,p) transfer reaction using an energy-degraded secondary ^{50}Ca beam. The beam was produced at BigRIPS from a primary ^{70}Zn beam at an energy of 345 MeV/nucleon fragmented on a Be target. For the energy degrading procedure, the ^{50}Ca beam was conducted to the OEDO[2)] beamline, where a combination of an angle-tunable wedge-shaped degrader and an additional aluminum flat-plate degrader placed at FE9 successfully reduced the beam energy to approximately 15 MeV/nucleon, which improves the momentum matching of the reaction compared to the typical beam energies at RIBF. Particle identification based on the ToF-$B\rho$ method showed excellent isotope separation, is shown in Fig. 1, where the ^{50}Ca beam can be clearly identified. Therefore, the use of the Radio-Frequency Deflector (RFD) of OEDO was not required. The secondary target of CD$_2$ (260 μg/cm^2) was placed at the SHARAQ spectrometer reaction chamber with the purpose of inducing one-neutron transfer reactions. The recoiling protons were measured with the detector setup TINA2,[3)] consisting of a box of four TTT double-sided silicon strip detectors backed by CsI crystals and a backward annular YY1-type silicon strip detector array with CsI crystals behind. The array was placed at laboratory backward direction covering $\theta_{lab} = 95$–165 deg (solid angle 35% of 4π) which is the angular range most sensitive to the angular momentum transfer of the reaction. The excitation energy of states populated will be determined from the measured missing mass of the reaction. Heavy ^{51}Ca ejectiles were measured by the QQD spectrometer equipped with a set of Strip-Readout PPAC detectors and an ionization chamber, so background coming from fusion reactions can be suppressed via charge identification. The analysis of excitation energies and angular distributions is ongoing.

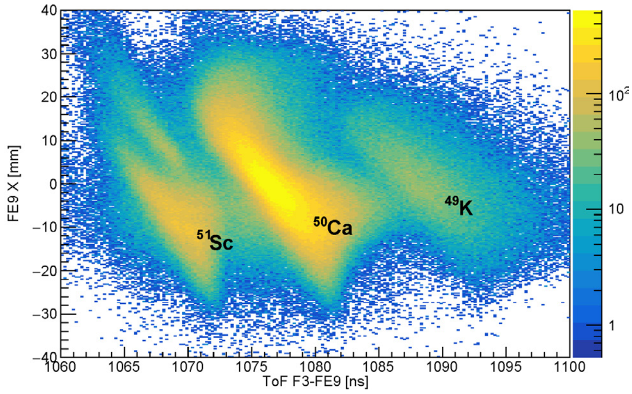

Fig. 1. Particle identification in OEDO with horizontal position at FE9 and corrected time-of-flight between F3 and FE9.

*1 Instituto de Estructura de la Materia, CSIC
*2 GSI Helmholtzzentrum für Schwerionenforschung GmbH
*3 RIKEN Nishina Center
*4 Center for Nuclear Study, University of Tokyo
*5 Institute of Nuclear Physics, University of Cologne
*6 CENS Institute for Basic Science
*7 Department of Physics, Kyoto University
*8 Department of Physics, Tohoku University
*9 Department of Physics, Gifu University
*10 RIKEN Cluster for Pioneering Research
*11 Research Center for Nuclear Physics, Osaka University
*12 Department of Low and Medium Energy Physics, Jožef Stefan Institute

References

1) M. Enciu *et al.*, Phys. Rev. Lett. **129**, 262501 (2022).
2) S. Michimasa *et al.*, Prog. Theor. Exp. Phys. **2019**, 043D01 (2019).
3) P. Schrock *et al.*, RIKEN Accel. Prog. Rep. **51**, 20 (2018).