Robustness of the $N = 34$ shell closure: First spectroscopy of ^{52}Ar

H. N. Liu,[*1,*2] Y. L. Sun,[*1] A. Obertelli,[*3,*1,*4] P. Doornenbal,[*4] H. Baba,[*4] F. Browne,[*4] D. Calvet,[*1] F. Château,[*1] S. Chen,[*5,*6,*4] N. Chiga,[*4] A. Corsi,[*1] M. L. Cortés,[*4] A. Delbart,[*1] J-M. Gheller,[*1] A. Giganon,[*1] A. Gillibert,[*1] C. Hilaire,[*1] T. Isobe,[*4] T. Kobayashi,[*7] Y. Kubota,[*4,*8] V. Lapoux,[*1] T. Motobayashi,[*4] I. Murray,[*9,*4] H. Otsu,[*4] V. Panin,[*4] N. Paul,[*1] W. Rodriguez,[*10,*4] H. Sakurai,[*4,*12] M. Sasano,[*4] D. Steppenbeck,[*4] L. Stuhl,[*8] Y. Togano,[*11,*4] T. Uesaka,[*4] K. Wimmer,[*12,*4] K. Yoneda,[*4] N. Achouri,[*13] O. Aktas,[*2] T. Aumann,[*3] L. X. Chung,[*14] F. Flavigny,[*9] S. Franchoo,[*9] I. Gašparić,[*15,*4] R. -B. Gerst,[*17] J. Gibelin,[*13] K. I. Hahn,[*18] D. Kim,[*18,*4] T. Koiwai,[*12] Y. Kondo,[*19] P. Koseoglou,[*3,*16] J. Lee,[*6] C. Lehr,[*3] B. D. Linh,[*14] T. Lokotko,[*6] M. Maccormick,[*9] K. Moschner,[*17] T. Nakamura,[*19] S. Y. Park,[*18,*4] D. Rossi,[*3] E. Sahin,[*20] D. Sohler,[*21] P-A. Söderström,[*3] S. Takeuchi,[*19] H. Toernqvist,[*16] V. Vaquero,[*22] V. Wagner,[*3,*4] S. Wang,[*23] V. Werner,[*3] X. Xu,[*6] H. Yamada,[*19] D. Yan,[*23] Z. Yang,[*4] M. Yasuda,[*19] and L. Zanetti[*3]

It is now well known that magic numbers are not universal across the nuclear landscape and that new shell closures may emerge in exotic nuclei. For example, a new subshell closure at $N = 34$ has been predicted for neutron-rich nuclei.[1)] On the experimental side, the systematics of the $E(2_1^+)$ of Ti isotopes show no evidence for the existence of the $N = 34$ shell gap.[2)] Recently, the $E(2_1^+)$ of ^{54}Ca was measured to be ∼0.5 MeV smaller than that of ^{52}Ca.[3)] This drop was attributed to the larger ground state correlation energy of ^{52}Ca, and the results were interpreted as confirming the $N = 34$ magic number in Ca isotopes. For ^{52}Ar, no spectroscopic information has been measured; however, its $E(2_1^+)$ was predicted to be the highest among Ar isotopes with N > 20.[4)] The spectroscopy of ^{52}Ar thus offers a unique chance to explore the robustness of the $N = 34$ subshell closure and pin down the mechanism of its emergence.

The measurement of ^{52}Ar was performed at the RIBF as part of the third campaign of the SEASTAR program. The fast radioactive beam containing ^{53}K, amongst other products, was produced by fragmentation of a ∼220 pnA ^{70}Zn primary beam at 345 MeV/nucleon on a 10-mm thick Be target. The constituents were identified using the BigRIPS fragment separator with the ΔE-TOF-$B\rho$ method. The incident beam, magnetically centered on ^{53}K, was impinged on a 150-mm thick MINOS[5)] liquid hydrogen target to induce proton-removal reactions. The recoil protons were detected by the MINOS TPC tracker[5)] to reconstruct the reaction vertex. The MINOS efficiency was measured to be 90(5)%. The kinematic energy and intensity of the ^{53}K beam in front of the target were ∼240 MeV/nucleon and 1.0 pps, respectively. The reaction residues passed through the SAMURAI[6)] magnet with a central magnetic field of 2.7 T, and were identified by a 24-element plastic hodoscope and two forward drift chambers. Figure 1 shows the particle identification of the reaction residues. The de-excitation γ rays from the reaction residues were measured by the upgraded DALI2+ array,[7)] which consists of 226 NaI(Tl) crystals. The preliminary Doppler-corrected γ-ray spectrum of ^{52}Ar was obtained, and a clear ($2_1^+ \rightarrow 0_1^+$) candidate peak was found. Evidence for other transitions in ^{52}Ar requires further analysis.

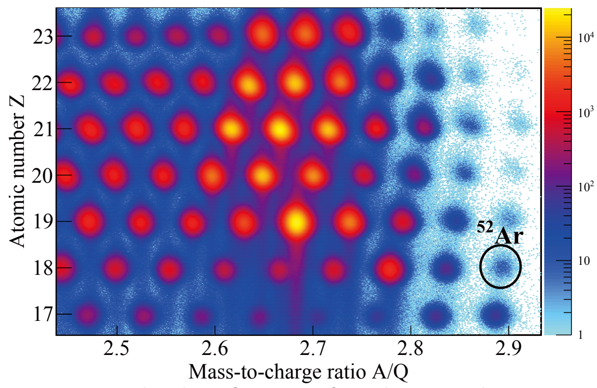

Fig. 1. Particle identification after the secondary target.

*1 IRFU, CEA, Université Paris-Saclay
*2 Department of Physics, KTH
*3 Institut für Kernphysik, TU Darmstadt
*4 RIKEN Nishina Center
*5 Department of Physics, Peking University
*6 Department of Physics, The University of Hong Kong
*7 Department of Physics, Tohoku University
*8 CNS, The University of Tokyo
*9 IPN Orsay, CNRS, Univ. Paris-Sud, Univ. Paris-Saclay
*10 Universidad Nacional de Colombia, Sede Bogotá, Facultad de Ciencias, Departamento de Física
*11 Department of Physics, Rikkyo University
*12 Department of Physics, The University of Tokyo
*13 LPC, Caen
*14 INST Hanoi
*15 Ruđer Bošković Institute, Zagreb
*16 GSI Helmoltzzentrum Darmstadt
*17 Institut für Kernphysik, Universität zu Köln
*18 Department of Physics, Ewha Womans University
*19 Department of Physics, Tokyo Institute of Technology
*20 Department of Physics, University of Oslo
*21 MTA Atomki
*22 Instituto de Estructura de la Materia, CSIC
*23 Institute of Modern Physics, Chinese Academy of Sciences

References
1) T. Otsuka *et al.*, Phys. Rev. Lett. **87**, 082502 (2001).
2) S. N. Liddick *et al.*, Phys. Rev. Lett. **92**, 072502 (2004).
3) D. Steppenbeck *et al.*, Nature (London) **502**, 207 (2013).
4) D. Steppenbeck *et al.*, Phys. Rev. Lett. **114**, 252501 (2015).
5) A. Obertelli *et al.*, Eur. Phys. J. A **50**, 8 (2014).
6) T. Kobayashi *et al.*, Nucl. Instrum. Methods B **317**, 294 (2013).
7) I. Murray *et al.*, in this report.