Isomeric states in neutron-rich nuclei near $N = 40$

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(Received 3 October 2020; revised 3 November 2020; accepted 24 June 2021; published 6 July 2021)

Neutron-rich nuclei in the vicinity of the $N = 40$ island of inversion are characterized by shell evolution and exhibit deformed ground states. In several nuclei isomeric states have been observed and attributed to excitations to the intruder neutron $1g_{9/2}$ orbital. In the present paper we searched for isomeric states in nuclei around $N = 40$, $Z = 22$ produced by projectile fragmentation at the Radioactive Isotope Beam Factory. Delayed γ rays were detected by the Euroball RIKEN Cluster Array germanium detector array. High statistics data allowed for an updated decay scheme of ^{60}V. The lifetime of an isomeric state in ^{64}V was measured for the first time in the present experiment. A previously unobserved isomeric state was discovered in ^{58}Sc. The measured lifetime suggests a parity changing transition, originating from an odd number of neutrons in the $1g_{9/2}$ orbital. The nature of the isomeric state in ^{58}Sc is, thus, different from isomers in the less exotic V and Sc nuclei.

DOI: 10.1103/PhysRevC.104.014304

I. INTRODUCTION

In the region of neutron-rich nuclei around $N = 40$ the occurrence of isomeric states is a consequence of the structure evolution in this region. The valence space consists of the negative-parity proton and neutron fp orbitals and for the neutrons the positive-parity $\nu 1g_{9/2}$ orbital. Above $N = 50$, the s and d orbitals also contribute. In ^{67}Ni, at $N = 39$, a $9/2^+$ isomer at 1007 keV [1] originates from the promotion of a particle above the $N = 40$ harmonic-oscillator shell closure occupying the $\nu 1g_{9/2}$ orbital [2]. Systematic investigations of isomeric states at and beyond $N = 40$ [3] found many more cases arising from one- or two-particle configurations in the $\nu 1g_{9/2}$ orbital. Below Ni, the neutron-rich Fe and Cr isotopes show enhanced collectivity and deformation [4]. In addition to spin-gap isomers, also shape isomers are, thus, expected. Surveys over broad regions of nuclei found several

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isomers [5,6], but the interpretation remains a challenge since theoretical shell-model calculations need to involve a large number of shells in order to describe the structure of nuclei around ^{68}Ni. Particularly, many isomers are found in odd-odd systems where the coupling of protons and neutrons leads to multiplets of states. This can result in states with a large difference in angular momentum and/or small difference in excitation energy, hindering the decay rate. Experimentally, in many cases not even the spins of the ground states are known, making the interpretation challenging.

Here, we present a new study on isomeric states in the vicinity of $N = 40$ and $Z = 22$. We clarify the decay scheme of $^{60\mathrm{m}}$V, which was previously suggested as a cascade of two states [5], provide a first lifetime measurement of a known isomeric state in ^{64}V, and report on the discovery of a new isomeric state in ^{58}Sc. Data from the same experiment for the Ti isotopes has already been published elsewhere [7]. The proposed level schemes are compared to results from large-scale Shell-model calculations performed with the ANTOINE code [8] using the LNPS interaction [9].

II. EXPERIMENT

The experiment was performed at the Radioactive Isotope Beam Factory (RIBF), operated by RIKEN Nishina Center and CNS, University of Tokyo. Neutron-rich exotic nuclei were produced by fragmentation of a ^{238}U beam incident on a Be primary target (thickness 4 mm) at a beam energy of 345 AMeV. This way, nuclei in the vicinity and beyond $N = 40$ could be produced efficiently. These were separated and analyzed in the BigRIPS fragment separator [10] and transported to the experimental station at the F11 focus of the ZeroDegree spectrometer. The particle identification was achieved by measurements of the magnetic rigidity $B\rho$, the time of flight, and the energy loss. Two separate settings focused on ^{64}V and ^{60}Ti, and the corresponding particle identification plots are shown in Fig. 1 of Ref. [7]. The nuclei were implanted in the Advanced Implantation Detector Array (AIDA) [11] surrounded by the the high-purity Ge EUroball RIKEN Cluster Array (EURICA) [12]. EURICA consists of 84 high-purity Ge crystals arranged in 12 clusters of seven detectors sharing one cryostat. The full energy peak efficiency of the array amounted to about 10% at 1332 keV. Three data-acquisition systems recorded independently the data of BigRIPS, AIDA, and EURICA. For the analysis presented here, the data were correlated offline by means of a common synchronized time stamp.

III. RESULTS

The results for the even-odd Ti nuclei have already been presented in Ref. [7]. Here, we present a revised level scheme for ^{60}V, extract the lifetime of a previously observed isomer in ^{64}V, and report on the discovery of a new isomer in ^{58}Sc.

A. Internal decay of ^{60}V

The isomeric decay of ^{60}V was first measured at GANIL, two transitions at 103.2 and 98.9 keV were observed [5,13]. The measured half-lives of 13(3) and 320(90) ns (corresponding to lifetimes $\tau = 19(4)$ and 462(130) ns, respectively) suggested a sequential decay from a state at 202.1 keV through a state at 103.2 keV. The longer-lived isomer was suggested to feed the 13(3)-ns isomer, whose lifetime was extracted from a subtraction of the two decay-time distributions [13]. The proposed multipolarities of $E2$ for the 99-keV transition and mixed $M1$ and $E2$ transitions for the 103-keV transition suggested spins and parities of (2^+) and (4^+) for the two states. In a previous experiment performed at the RIBF, a half-life of 229^{+25}_{-23} ns ($\tau = 330^{+36}_{-33}$ ns) was extracted from the sum of the decay time distributions of the 99.7- and 104-keV transitions [6]. The γ-ray energy spectrum measured in the present paper in delayed coincidence with identified ^{60}V ions is shown in Fig. 1(a). In order to exclude the prompt γ flash originating from atomic processes, such as bremsstrahlung of the ions slowing down in the silicon detectors of AIDA as well as from secondary particles, a time gate excluding events within 300 ns of the implantation was applied. Two transitions at 99.1(1) and 103.2(1) keV were observed in delayed coincidence with ^{60}V identified in BigRIPS. Statistics was sufficient to construct γ-γ coincidence matrices. The gated spectra, shown in Figs. 1(b) and 1(c) for the 99- and 103-keV

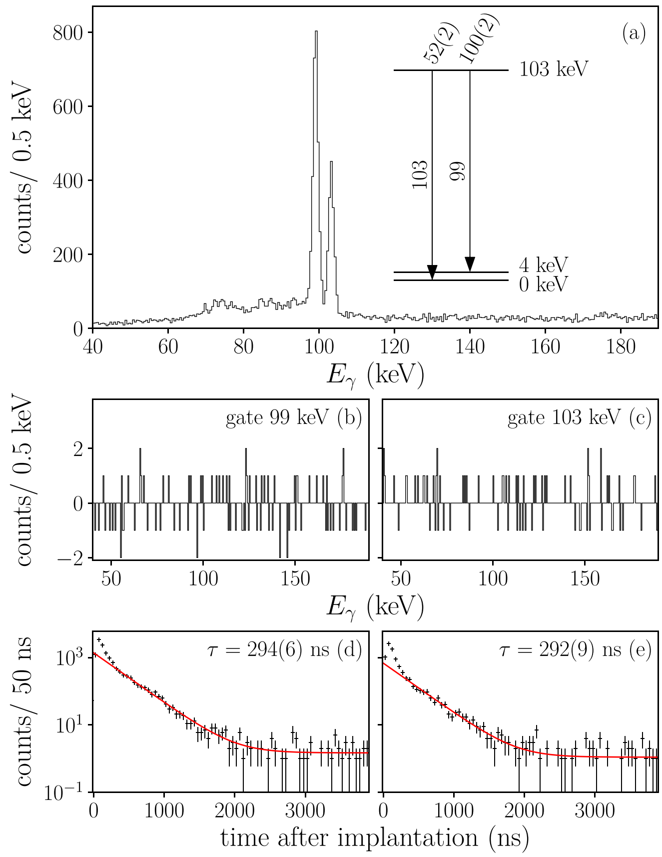

FIG. 1. Decay of the isomeric state in ^{60}V. Panel (a) shows the γ-ray energy spectrum in delayed coincidence with the implantation of ^{60}V. Panels (b) and (c) show the coincidence spectrum gated on each of the transitions, and panels (d) and (e) show the decay time curves together with a fit. The spectra in panels (a)–(c) exclude the prompt γ flash which dominates the spectra for $t < 300$ ns. The fits in panels (d) and (e) also exclude early times.

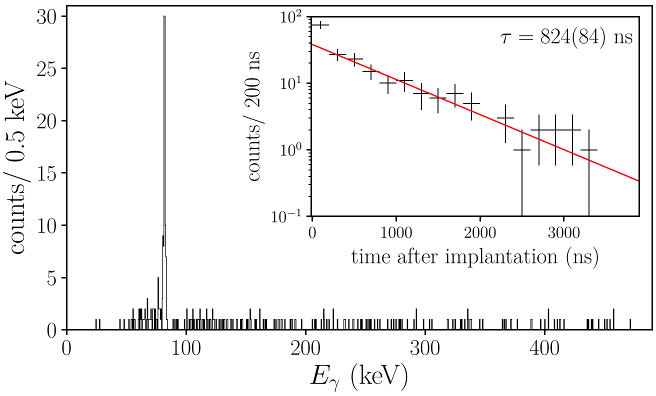

FIG. 2. Decay of the isomeric state in ^{64}V. The inset shows the decay time distribution with a fit using an exponential function.

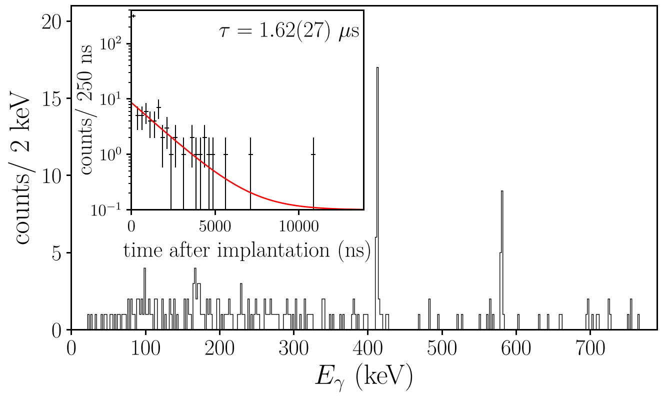

FIG. 3. Decay of the isomeric state in ^{58}Sc. Two transitions are clearly observed in the spectrum, and the indication for another one at 167 keV matches their difference. The inset shows the decay time distribution gated on both the 413- and the 580-keV transitions.

transitions, respectively, indicate that the two transitions proceed in parallel and not in coincidence as previously suggested [5,13]. Based on the number of counts in the singles spectrum shown in Fig. 1(a) and the efficiency of the EURICA array, we would expect several hundred counts in the coincidence spectra when including all events from 300 ns to 5 ms after the implantation of ^{60}V. Furthermore, the decay curves were analyzed, and the resulting lifetimes $\tau = 294(6)$ and 292(9) ns for the two transitions were identical within their uncertainties. The intensity ratio of the two transitions also suggests a parallel decay as the relative intensity of the 99-keV transition is higher than the one of the 103-keV line which is at variance with the cascade decay proposed in Refs. [5,13]. The suggested level scheme is shown in Fig. 1(a), a new state at an excitation energy of 4 keV is suggested from the present data. Such a state is likely to be isomeric and will decay by β decay. Indeed, a β-decaying isomer was suggested, based on the two different β-decay lifetimes obtained from different experiments [14]. Weisskopf estimates indicate that both transitions are of $E2$ character with $B(E2) = 140(5)$ and 60(3) e^2fm^4, respectively, for the decays to the first excited and to the ground states.

B. Isomeric decay of ^{64}V

A γ ray originating from the isomeric decay of ^{64}V had been previously observed at the National Superconducting Cyclotron Laboratory. The transition energy was determined to be 81.0(7) keV, but for the half-life only an upper limit of 1 μs could be obtained [15]. The present measurement of γ rays in delayed coincidence with ^{64}V is shown in Fig. 2. The energy of the γ ray was measured to be 82.0(3) keV, and the lifetime 824(84) ns is in agreement with the previously determined upper limit. The decay lifetime is consistent with a $E2$ transition with a reduced transition probability of 147(17) e^2fm^4.

C. New isomer in ^{58}Sc

A new isomeric state in ^{58}Sc was discovered in the present experiment. The γ-ray energy spectrum is shown in Fig. 3. Two transitions at 412.5(3) and 580.0(5) keV were observed for the first time. The decay curves gated on these transitions yield lifetimes of 1.71(35) and 1.12(30) μs for the 413- and 580-keV transitions, respectively. These are consistent within their uncertainties, suggesting that the two transitions originate from the same level or are emitted in a cascade. The sum of the two time distributions which is shown in Fig. 3 results in a lifetime of 1.62(27) μs. The expected coincidence rate is about two events if the 413- and 580-keV transitions are in coincidence, one such event has been observed. The intensity ratio of the two transitions, however, is not in agreement with the relative efficiency, suggesting a parallel decay. In addition, an excess of counts at low energies suggest a peak at 167(1) keV. This energy matches the differences between the 413- and the 580-keV transitions, and, thus, a branch from a level at 580 keV to a state at 167 keV could be suggested. However, due to limited statistics, the level scheme of ^{58}Sc cannot be constructed without ambiguities. The two scenarios will be discussed in Sec. IV.

IV. DISCUSSION

Table I summarizes the observed isomeric transitions and the extracted lifetimes τ. For each transition, the reduced transition probabilities $B(\pi\lambda)$ have been calculated and compared to Weisskopf estimates. For the decay of the isomeric states in ^{60}V and ^{64}V these are compatible with $E2$ transitions, whereas $M1$ admixtures cannot be excluded. The level schemes based on the present analysis are shown in Fig. 4.

Shell-model calculations performed with the ANTOINE code [8] using the LNPS interaction [9] predict a high level density for ^{60}V with ten states below an excitation energy of 500 keV. The population of the 644-keV $J^\pi = 2^+$ state in ^{60}Cr in the β decay of ^{60}V in several experiments with different ratios of the two β-decaying isomers [14,17,18] suggests that they are both of low spin. The near degeneracy of the ground and first excited states is not reproduced by the calculations, and no isomeric states are predicted at low excitation energy. It should be noted that the calculated excitation energies for these odd-odd nuclei depend strongly on the two-body matrix elements of the effective interaction. Small changes, which

TABLE I. Isomers observed in the present paper. The transition energies, mean lifetimes, and γ-ray intensities were obtained in this paper. The transition multipolarities are inferred based on comparison to Weisskopf estimates. The energies and lifetimes are also compared to previous experiments. In the case of ^{58}Sc, the level scheme could not be constructed, and two scenarios are proposed, (a) an isomeric state at 580 keV decaying by two branches, and (b) two isomeric states. For details, see the text.

	This paper							Previous work		
Nucleus	E_γ (keV)	τ (ns)	I_γ	$\pi\lambda$	α [16]	$B(\pi\lambda)$	(W.u)	E_γ (keV)	τ (ns)	Reference
^{60}V	99.1(1)	294(6)	100(2)	$E2$	0.392(6)	140(5) e^2fm^4	10.0(4)	98.9	19(4)	[5]
								99.7		[6]
	103.2(1)	292(9)	52(2)	$E2$	0.335(5)	140(5) e^2fm^4	4.3(2)	103.2	462(130)	[5]
								104.0	330^{+36}_{-33}	[6]
^{64}V	82.0(3)	824(84)		$E2$	0.820(17)	147(17) e^2fm^4	9.7(11)	81.0(7)		[15]
^{58}Sc	412.5(3)	1620(270)	100(24)	$M2$	$1.80(3) \times 10^{-3}$	$2.2^{+0.8}_{-0.6}$ μ^2fm^2	$0.090^{+0.033}_{-0.024}$			
(a)	580.0(5)	1620(270)	71(26)	$M2$	$6.96(10) \times 10^{-4}$	$0.28^{+0.12}_{-0.09}$ μ^2fm^2	$0.011^{+0.005}_{-0.004}$			
	167(1)									
^{58}Sc	412.5(3)	1710(350)	100	$M2$	$1.80(3) \times 10^{-3}$	$3.6^{+0.9}_{-0.6}$ μ^2fm^2	$0.144^{+0.036}_{-0.024}$			
(b)	580.0(5)	1120(300)	100	$M2$	$6.96(10) \times 10^{-4}$	$1.0^{+0.4}_{-0.2}$ μ^2fm^2	$0.040^{+0.016}_{-0.008}$			

have negligible effect for the even-even nuclei, can lead to changes in the excitation energies in the odd-odd systems by few hundred keV. Therefore, a detailed comparison between the calculated and the experimental level schemes is not possible. The identification of other excited states and their decay branches to the three known states will constrain spin and parity assignments in the future.

The population of the ground and the first excited 2^+ states in the decay of ^{64}V to ^{64}Cr [15] suggests a low spin $J \leqslant 2$ for the ground state of ^{64}V. The shell-model calculations predict a 2^+ ground state, which is in agreement with the experiment. The predicted first excited states in ^{64}V have $J^\pi = 3^+$ and 1^+. The calculated $E2$ and $M1$ transition probabilities, however, are not consistent with an isomeric state. At present, no other excited states are known in ^{64}V preventing us from making more detailed comparisons with the shell-model calculations.

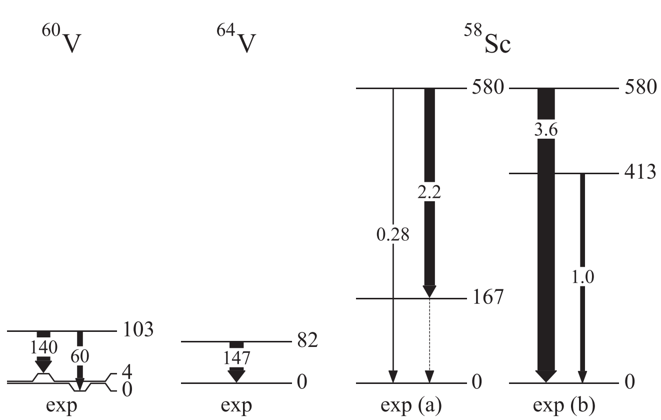

FIG. 4. Level schemes of the three nuclei discussed in the present paper. States are labeled with their excitation energies in keV. The arrows indicate the observed transitions with their respective reduced transition probabilities in units of e^2fm^4 for the $E2$ decays in ^{60,64}V and μ^2fm^2 for the case of ^{58}Sc with $M2$ transitions inferred from the lifetime measurements.

For ^{58}Sc, the data did not allow to construct the level scheme unambiguously. Two scenarios are discussed in the following. Scenario (a) assumes an isomeric state at 580 keV which decays by two branches. The 580-keV transition proceeds directly to the ground state, whereas the 413-keV line feeds a state at 167 keV. Although the lifetimes of the two transitions are compatible within their error bars, the intensity observed for the 167-keV transition is less than for the 413-keV line after correction for efficiency. This would suggest that the 167-keV state is also long lived with a lifetime longer than the possible correlation window of the present experiment, or with a significant β-decay branch. The study of the ^{58}Sc β decay did not allow to discern two β-decaying states, however, the statistics were limited [19]. Using the lifetime of 1.62(27) μs and the branching ratio determined from the γ-ray yield, the reduced transition probabilities suggest $M2$ transitions, albeit $E3$ transitions cannot be excluded. In this scenario, the transition from the isomer would involve, thus, a parity change. The second scenario assumes the population of two isomeric states at 580 and 413 keV. Also in this case, the measured lifetimes favor $M2$ decays, whereas again $E3$ cannot be fully excluded. Recently, isomeric states have also been reported in another experiment focused on measuring the mass of nuclei in the $N = 40$ island of inversion [20]. In that study, the transitions at 413 and 580 keV have been observed, albeit with a larger relative intensity for the 580-keV γ ray. This would favor scenario (b) with two different isomers. Statistics of that experiment were, however, limited and prevent firm conclusions. Two other transitions at 181 and 247 keV were also claimed, which are not observed in the present paper. The large background of the work of Ref. [20] also prevented the extraction of consistent lifetimes.

The shell-model calculations predict a positive-parity multiplet below $\approx$200 keV with negative-parity states above 400 keV. Again, the calculated high level density and the lack of experimental information on ^{58}Sc prevent us from drawing conclusions about the level scheme and favor one scenario over the other. The calculations indicate that the low-lying states are dominated by a neutron in the fp orbits, whereas in the excited negative-parity states have one neutron excited to the $1g_{9/2}$ orbital. This situation in ^{58}Sc is significantly different from the isotones ^{60}V and ^{62}Mn [5] where decays proceed via $E2$ (and $M1$) transitions. In ^{62}Mn, a 4^+ β-decaying isomer at 346 keV has been proposed [21,22]. Also in the less neutron-rich Sc isotopes experimental results on isomeric and β decays suggest positive parity for the γ- and β-decaying isomers of ^{54,56}Sc as well [23]. The parity changing transitions observed in the present paper suggest a different nature of the isomeric states in ^{58}Sc. Couplings across the $N = 40$ harmonic-oscillator shell gap play a significant role at low excitation energy in ^{58}Sc at $N = 37$. This is similar to the even-odd Ti isotopes where the transition into the $N = 40$ island of inversion starts in ^{59}Ti at $N = 37$ [7].

V. SUMMARY

To summarize new data on isomeric states in the vicinity of the $N = 40$ island of inversion have been obtained. The decay scheme of the isomeric state in ^{60}V to the ground state and a very low-lying state at only 4 keV have been established using γ-γ coincidence analysis. The decay of the isomeric state in ^{64}V has $E2$ multipolarity, based on the newly measured lifetime. Delayed γ-ray transitions in ^{58}Sc show that, at least, one isomeric state exists in this nucleus. However, due to limited statistics the level scheme could not be clarified. Spin and parity assignments are not possible based on the present experimental results, and a comparison to shell-model calculations is challenging due to the high predicted level densities. Based on the lifetime, however, the decay is compatible with parity changing $M2$ transitions, suggesting a different nature of the ^{58}Sc isomer(s) compared to the V cases and the less exotic Sc isotopes.

ACKNOWLEDGMENTS

This experiment was carried out at the RIBF operated by RIKEN Nishina Center, RIKEN, and CNS, University of Tokyo. We would like to thank the RIKEN accelerator and BigRIPS teams for providing the high intensity beams. This work has been supported by JSPS KAKENHI (Grants No. 25247045 and No. 19H00679), by the German BMBF (Grants No. 05P15RDFN1 and No. 05P19RDFN1), by the German DFG (Project No. 279384907-SFB 1245), by the STFC (U.K.), by the Korean National Research Foundation (Grants No. NRF-21A20131111123 and No. NRF-2015H1A2A1030275), by NKFIH (Grant No. NN128072), and by the UNKP-20-5-DE-2 New National Excellence Program of the Ministry of Human Capacities of Hungary. K.W. acknowledges support from the Spanish Ministerio de Economía y Competitividad Grant No. RYC-2017-22007. G.K. acknowledges support from the Janos Bolyai Research Fellowship of the Hungarian Academy of Sciences.

[1] T. Pawlat *et al.*, Nucl. Phys A. **574**, 623 (1994).
[2] J. Diriken *et al.*, Phys. Lett. B **736**, 533 (2014).
[3] R. Grzywacz *et al.*, Phys. Rev. Lett. **81**, 766 (1998).
[4] H. L. Crawford *et al.*, Phys. Rev. Lett. **110**, 242701 (2013).
[5] J. M. Daugas *et al.*, Phys. Rev. C **81**, 034304 (2010).
[6] D. Kameda *et al.*, Phys. Rev. C **86**, 054319 (2012).
[7] K. Wimmer *et al.*, Phys. Lett. B **792**, 16 (2019).
[8] E. Caurier, G. Martínez-Pinedo, F. Nowacki, A. Poves, and A. P. Zuker, Rev. Mod. Phys. **77**, 427 (2005).
[9] S. M. Lenzi *et al.*, Phys. Rev. C **82**, 054301 (2010).
[10] T. Kubo, Prog. Theor. Exp. Phys. **2012**, 03C003 (2012).
[11] C. Griffin *et al.*, *Proceedings, 13th International Symposium on Nuclei in the Cosmos (NIC XIII), Debrecen, Hungary, 2014*, edited by Z. Elekes and Z. Fülöp (Sissa, Trieste, Italy, 2015), Vol. 204, p. 97.
[12] P.-A. Söderström *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. B **317**, 649 (2013).
[13] J. M. Daugas, Ph.D. thesis, Université de Caen, 1999.
[14] O. Sorlin *et al.*, Eur. Phys. J. A **16**, 55 (2003).
[15] S. Suchyta *et al.*, Phys. Rev. C **89**, 067303 (2014).
[16] T. Kibédi *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **589**, 202 (2008).
[17] F. Ameil *et al.*, Eur. Phys. J. A **1**, 275 (1998).
[18] O. Sorlin *et al.*, Nucl. Phys. A **660**, 3 (1999).
[19] L. Gaudefroy *et al.*, Eur. Phys. J. A **23**, 41 (2005).
[20] S. Michimasa *et al.*, Phys. Rev. Lett. **125**, 122501 (2020).
[21] H. Heylen *et al.*, Phys. Rev. C **92**, 044311 (2015).
[22] L. P. Gaffney *et al.*, Eur. Phys. J. A **51**, 136 (2015).
[23] H. L. Crawford *et al.*, Phys. Rev. C **82**, 014311 (2010).