Shape coexistence is an ubiquitous phenomenon in the neutron-rich nuclei belonging to (or sitting at the shores of) the $N = 20$ Island of Inversion (IoI). Exact isospin symmetry predicts the same behaviour for their mirrors and the existence of a proton-rich IoI around $Z = 20$, centred in the (surely unbound) nucleus $^{32}$Ca. In this article we show that in $^{36}$Ca and $^{36}$S, Coulomb effects break dramatically the mirror symmetry in the excitation energies, due to the different structures of the intruder and normal states. The Mirror Energy Difference (MED) of their $2^+$ states is known to be very large at $-246$ keV. We reproduce this value and predict the first excited state in $^{36}$Ca to be a $0^+$ at 2.7 MeV, 250 keV below the first $2^+$. In its mirror $^{36}$S the $0^+$ lies at 55 keV above the $2^+$ measured at 3.291 MeV. Our calculations predict a huge MED of $-720$ keV, that we dub “Colossal” Mirror Energy Difference (CMED). A possible reaction mechanism to access the $0^+_2$ in $^{36}$Ca will be discussed. In addition, we theoretically address the MED’s of the $A = 34$ $T = 3$ and $A = 32$ $T = 4$ mirrors.

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The study of the effects of the Isospin Symmetry Breaking (ISB) terms of the nucleon-nucleon interaction on nuclear properties, particularly the Coulomb repulsion among the protons, has a long-standing history, starting with the Nolen and Schiffer anomaly [1], which involves the mass difference of a pair of mirror nuclei, and following up with their effects in spectroscopic properties like the Mirror Energy Differences (MED) and the Triplet Energy Differences (TED) extracted from the comparison of the excitation spectra of the members of an isobaric multiplet [2,3]. These studies have shown that the MED’s reflect nicely some structural properties of the states in question, such as deformation, alignment, occupancies of particular orbits, etc. On another register, the study of neutron-rich nuclei near the neutron magic shell closures has lead to the discovery of the so called Islands of Inversion (IoI’s), groups of nuclei which, unexpectedly, have their ground states dominated by intruder configurations, most often of deformed nature. The relevant IoI for our present purpose is at $N = 20$, centred about $^{33}$Na [4–13]. At or around these IoI’s it is very frequent to find states of different shapes coexisting in the same nucleus. Therefore, if isospin symmetry holds (and we know it does to a very large extent) each IoI at the neutron-rich side should have a mirror IoI at the proton-rich side. However, only for relatively light nuclei can one hope to reach or even to approach such proton IoI’s. For the $Z = 20$ isotopes, $^{32}$Ca most likely is experimentally out of reach, perhaps we can reach $^{34}$Ca, and there is already some information about $^{36}$Ca in refs. [14,15].

The structure and location of coexisting intruder $0^+$ states at $N = 20$ evolves as we move away from $N-Z$. Indeed, the first excited state in $^{40}$Ca at 3.353 MeV is the head of a deformed band of 4p-4h nature. The relevant experimental information about the $A = 38$ $T = 1$ mirrors is gathered in Table I. The second $0^+$ and $2^+$ states are again of intruder nature; neutron 2p-2h in $^{38}$Ar and proton 2p-2h in $^{38}$Ca. And this is clearly manifested in their MED’s which are very large, because the two protons promoted to the pf shell suffer less Coulomb repulsion than when occupying the sd shell, that is why the excitation energies of the intruders are reduced in $^{38}$Ca. With this anchor we can proceed further into the proton-rich side $A = 36$ looking for an enhanced ISB effect associated with shape coexistence.

### Table I. Experimental excitation energies (in MeV) and MED’s (in keV) for the mirror nuclei $A = 38$ $T = 1$.

| $J^+$ | $^{36}$Ca (exp) | $^{38}$Ar (exp) | MED (exp) | MED(th) |
|------|----------------|----------------|----------|--------|
| $0^+_1$ | 0.0 | 0.0 | | |
| $2^+_1$ | 2.213 | 2.168 | +45 | -25 |
| $0^+_2$ | 3.084 | 3.378 | -294 | -340 |
| $2^+_2$ | 3.684 | 3.936 | -252 | -340 |

$^{36}$S is stable and extensively studied experimentally. We list the states of interest in Table III the normal $0^+$ and $2^+$ states and the intruder $0^+$. For $^{36}$Ca the only spectroscopic information available is the excitation energy of the first $2^+$ state [16] from refs. [14,15]. Note the very large experimental MED for the spherical $2^+$ state of $-246(3)$ keV, at variance with the situation in the $A = 38$ mirrors, where the MED is $+45$ keV. Indeed this large shift in the $A = 36$ mirrors cannot have the same origin as the ones found in the intruder states of $A = 38$.

We proceed now with the theoretical description of the $A = 36$ $T = 2$ mirrors in the framework of the Shell
Model with Configuration Interaction \[17\]. We adopt the valence space and the effective interaction (sdpfu-mix) which has been successfully applied in the simultaneous description of the \( N = 20 \) and \( N = 28 \) IoI’s in ref. \[18\]. We add to the nuclear interaction the two-body matrix elements of the Coulomb potential computed in an oscillator basis with the appropriate oscillator parameter \( \hbar \omega = 45 \text{ A}^{-1/3} \cdot 25 \text{ A}^{-2/3} \). The proton \( sd \)-shell single-particle energies (SPE) could be derived from the experimental spectra of \( ^{37}\text{P} \) and that of the proton \( pf \)-shell orbits from the spectrum of \( ^{41}\text{Sc} \). The value of the Coulomb shift of the \( 1s_{1/2} \) proton single particle energy relative to the corresponding neutron single particle energy would then be 375 keV and that of the \( 1p_{3/2} \) and \( 1p_{1/2} \) proton orbits 200 keV. However, it is seen experimentally that the MED’s in the mirrors \( ^{39}\text{Ca} - ^{39}\text{K} \) and \( ^{37}\text{Ca} - ^{37}\text{Cl} \) are much smaller, 56 keV and 120 keV respectively. Drawing from the findings of ref. \[19\] which concludes that the \( 1s_{1/2} \) orbit has a very large radius when empty at the mean field level, independent of any energy threshold effect, becoming smaller as it is filled. We take an interpolated value of 300 keV for the shift in \( A = 36 \). However, these SPE’s have unwanted effects in some MED’s directly related to the \( Z = 14 \) gap. Hence, following the analysis of ref \[14\], we have resorted to a minimal modification of the proton SPE’s. Our ansatz is the following: the \( Z = 14 \) proton gap remains unchanged whereas the \( Z = 16 \) gap is reduced by 300 keV. This choice of the proton SPE’s results in a MED for the \( ^{29}\text{S} - ^{29}\text{Al} \) mirror pair of \(-46 \text{ keV} \), in reasonable agreement with the experimental value \(-176(20) \text{ keV} \) from ref. \[20\]. The experimental \( Z = 20 \) and \( N = 20 \) shell gaps at \( ^{40}\text{Ca} \) are essentially equal, they differ by just 29 keV, our calculations reproduce nicely this difference, a theoretical value of 27 keV is obtained. The MED’s of the \( A = 38 \) mirror pair are also well reproduced, as can be seen in Table \[1\]. Since the choice of proton SPE’s is irrelevant for this case and the neutron and proton gaps are equal, the large MED’s of the intruder states have their origin only on the two-body Coulomb repulsion.

The results for the mirror pair \( ^{36}\text{Ca} - ^{36}\text{S} \) are shown in Table \[II\]. The calculation reproduces the large MED of the \( 2^+ \), with the same mechanism discussed in Ref. \[14\]. The origin of this large MED is easily grasped if we compare the spectra of \( ^{36}\text{S} \) and \( ^{36}\text{Ca} \), shown in Fig. \[1\] with the spectrum obtained in the calculation without the Coulomb interaction. Whereas the excitation energy of the \( 2^+ \) in \( ^{36}\text{Ca} \) barely moves with respect to the no-Coulomb reference, in \( ^{36}\text{S} \) it goes up by 280 keV. The reason lies in the fact that the proton \( 1s_{1/2} \) orbit is more tightly bound than the neutron \( 1s_{1/2} \), relative to the corresponding \( 0d_{3/2} \)-orbits. As the configuration of the \( 2^+ \) is \( 1s_{1/2} \) \( 0d_{3/2} \) the result follows trivially. But what happens for the intruder \( 0^+ \) state? Let’s compare again the two mirrors with the no-Coulomb case: in \( ^{36}\text{S} \) the \( 0^+_2 \) excitation energy increases by the same amount as in the \( 2^+ \) case. And this may seem unexpected because one might naively think that its proton configuration is close to \( 1s_{1/2} \). Which is not the case indeed, because due to the deformed nature of the intruder band, the \( sd \) shell occupancies approach the pseudo-SU3 limit, being rather close to \( 1s_{1/2} \) \( 0d_{3/2} \). Moving to \( ^{36}\text{Ca} \), the proton configuration becomes \( (sd)^{16}(pf)^2 \) which, as discussed for the \( A = 38 \) pair, has less Coulomb repulsion than the \( (sd)^{12} \) configuration of the \( 0^+ \) ground state. These two shifts of quite different origin add constructively to produce a Colossal Mirror Energy Difference (CMED) of \(-720 \text{ keV} \), without advocating energy threshold effects. This is our main prediction. As a consequence, the intruder \( 0^+ \) becomes the first excited state of \( ^{36}\text{Ca} \), decaying by an \( E0 \) transition to the ground state. We do not expect energy threshold effects due to the proximity of the excitation energy of the \( 0^+ \) intruder to the \( 2p \) separation energy, because of the Coulomb barrier which makes the (less bound) \( 2^+ \) a very narrow state (the one- and two-proton separation energies, \( S(p) \) and \( S(2p) \) are about \( 2.6 \text{ MeV} \) in \( ^{36}\text{Ca} \)). Our prediction agrees nicely with what can be naively expected from the known experimental MED nearby. Indeed, the experimental MED of the excited

| J \( \Lambda \= 36 \) T\( = 2 \) \( ^{36}\text{Ca} \) (exp) (th) \( ^{36}\text{S} \) (exp) th MED (th) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( 0^+_1 \)      | 0.0             | 0.0             | 0.0             | 0.0             |
| \( 2^+_1 \)      | 2.97            | 3.045           | 2.95            | 3.291           | 3.25            | 3.42            | 3.0              |
| \( 0^+_2 \)      | 2.97            | 2.70            | 3.346           | 3.42            | 3.720           |

FIG. 1. (Colour online) Low-lying excited states in the mirror pair \( ^{36}\text{Ca} - ^{36}\text{S} \). The known experimental information is shown together with shell-model calculations using the sdpfu-mix interaction. At the center of the figure, the results without the Coulomb interaction are shown. The main configurations for \( ^{36}\text{S} \) are: \( 0^+_1 \), \( d_{5/2}^1 s_{1/2}^2 \) (protons) and \( (sd)^{12} \) (neutrons); \( 2^+ \) \( d_{5/2}^1 s_{1/2}^1 d_{3/2}^1 \) (protons) and \( (sd)^{12} \) (neutrons). Instead, for the intruder second \( 0^+ \) the main configuration is: \( d_{5/2}^2 s_{1/2}^1 d_{3/2}^1 \) (protons) \( d_{5/2}^2 s_{1/2}^1 d_{3/2}^2(pf)^2 \) (neutrons). For \( ^{36}\text{Ca} \) it suffices to exchange the role of protons and neutrons.
0+ state of the A=38 mirrors gives a hint of the extra contribution to the MED in the case of intruder states, whereas the experimental MED of the 2+ state in the 36Ca - 36S mirror pair, does the same for the contribution to the MED of a configuration 1s1/2 0d3/2. Knowing from theory that this is indeed the neutron(proton) configuration in the intruder 0+ of 36Ca(36S), one can conclude that both contributions add constructively to produce a MED of about -600 keV. In this discussion we have not adopted any theoretical ansatz for the one body and two body Coulomb effects, we have just made an educated guess drawing from the available experimental data.

There are a few other known cases of MED’s of similar size. However, all of them are dominated by energy threshold effects, i.e. they involve an excited state with an important 1s proton wave function which is well above the proton separation energy of the proton rich mirror. For instance, the 19Na - 19O pair has an MED of -750 keV, due to the fact that both the 5/2+ ground state and the 1/2+ excited state are proton unbound. The latter has a width of 110 keV, therefore the very large spatial extension of the 1s1/2 proton wave function should be the sole reason for the huge value of the MED. Similar arguments apply to the 14O - 14C (MED= -669 keV) 21 and 12O - 12Be (MED= -630 keV) 22 mirror pairs.

The calculated B(E2; 2+ → 0+) for 36Ca is very small, 4.7 e²fm⁴ (the Dufour-Zuker 23 effective charges e_e = 1.31e and e_v = 0.46e have been used). In fact this value is the smallest of all the Calcium isotopes together with that of 50Ca, 7.5±0.2 e²fm⁴. 24 The 2+ decay to the intruder 0+ is suppressed by a factor 2×10⁴ with respect to the decay to the ground state due to the phase space factor. For completeness, our prediction for the B(E2; 2+ → 0+⁰) in 36S is 19.5 e²fm⁴, which is in good agreement with the experimental value, 17.7±1.7 e²fm⁴. 25 The calculated ρ²(E0) for the decay of the 0+_2 state to the ground state in 36Ca is 40×10⁻³, which corresponds to a lifetime of τ(E0) = 8.3 ns. An effective isoscalar E0 charge of 1.0 e has been assumed. This effective E0 charge has been deduced from the known experimental value in 36S, where the 0+_2 has been observed to decay directly via an E0 transition to the 0+ ground state and its half-life has been measured to be 8.8 ± 0.2 ns 26, no γ transition has been observed from the 0+_2 state to the 2+ state. Therefore, using eq. 1 of Ref. 27, we can compute an upper limit for the ρ²(E0), considering an experimental sensitivity limit of 1% for the 0+_2 to 2+ decay branch

\[ \rho²(E0) = \frac{I(E0)}{I(E2)} × \frac{1}{2} \times \frac{1}{2} = 9 \times 10⁻³ \]

The electronic Ω(E0) = 8.7 × 10⁹ s⁻¹ factor has been calculated with Brice 28.

As discussed previously, the T = 2 mirrors 36Ca and 36S are known experimentally very unequally. While the 36Ca isotope is the heaviest acknowledged Tz = -2 nucleus, just two neutrons away from the proton drip line, the 36S is stable. The excitation energy of the 2+ state, for the N = 20 36Ca isotope, was measured both at GSI 14 and GANIL 15 by using a knock-out reaction from a secondary 37Ca beam. In these two experiments a unique γ was observed at an energy of 3015 (16) keV at GSI and 3036 (11) keV at GANIL. The momentum distribution measurement of the 36Ca at GANIL with the SPEG spectrometer, indicates a ℓ = 0, ℓ = 2 character of the excited 2+ state, that agrees well with our calculations, where the 2+ state has a dominant sd configuration. This is all the information that currently exists for the Tz = -2 36Ca, in contrast, the experimental information available for the stable 36S is copious. Over the last decades many reactions have been used to study the semi-magic nature of this (N = 20) isotope.

The intruder 0+_2 state in the mirror 36S, that has mainly a neutron (sd)¹⁰⁺(pf)² nature, was selectively populated via a two-neutron transfer reaction 34S(t,p)³⁶S 20, 34S(t,pγ)³⁶S 21, as well as via a less selective reactions such as inelastic scattering with protons and α particles. 36S(p,p')³⁶S and 36S(α,α')³⁶S 30. Considering the proton nature, (sd)¹⁰⁺(pf)² predicted by our calculations, of the intruder 0+_2 state in 36Ca, one could experimentally access this state by using a two-proton transfer reaction with a radioactive 34Ar beam, such as 34Ar(²H,α)³⁶Ca. The 0+_2 would decay directly to the 0+, with a 2.63 MeV E0 transition with an expected lifetime of 8.3 ns. The internal pair formation, according to Brice 28 calculations is more than 50 times larger than the internal conversion. For the T=4, Tz = +4, 32Mg which represents the pivotal nucleus in the N = 20 36Ca, the second 0+_2 state was also populated via a two-neutron transfer reaction since it presents a neutron nature 31. While, the second 0+_2 state in the T=3, Tz = +3, 34Si was directly observed via β decay of a 1+ isomer in 34Si 32, so in this case no transfer reaction was needed to measure the properties of the intruder state. For the 36Ca isotope, one cannot populate the intruder state via β decay since its progenitor 36Sc is unbound.

| \(J^\pi\) | A=34 T=3 | ³⁴Ca | ³⁴Si | MED |
|-------|-----------|------|------|-----|
| 0⁰⁺  | 0.0       | 0.0  | 0.0  |     |
| 0²⁺  | 2.57      | 2.33 | 2.75 | -120|
| 2⁰⁺  | 3.45      | 3.20 | 3.62 | -120|
| 2²⁺  | 4.46      | 4.43 | 4.49 | -60 |

As a purely academic exercise, because of their almost certain unbound nature, we examine now what happens when we go to the A = 34 T = 3 and A = 32 T = 4 mirrors, where the intruder configurations become more significant. The theoretical results for the A = 34 T = 3 mirrors ³⁴Ca and ³⁴Si are displayed in Table III. The
ground state and the $2^+_1$ are dominated by the "normal" $sd$ configurations $0d_{5/2}^0$ and $0d_{3/2}^51s_{1/2}^1$ respectively. This results in the small MED of the $2^+_1$. The intruders $0^+_2$ and $2^+_1$ decreases by 400 keV in $^{34}$Ca with respect to the no-Coulomb result, as they did in $^{36}$Ca. However, at difference with what happened in $^{38}$S, this does not add constructively with a large pure sd-shell effect in $^{34}$Si and the resulting MED’s are very large but not huge.

Table IV. Theoretical excitation energies (in MeV) and MED's (in keV). In the column labeled "A = 32 T = 4" we list the results of a calculation without the Coulomb interaction. In the right side box, we give the amplitudes of the np-nh configurations (in percentage) for the calculation without the Coulomb contribution.

| J  | A=32 T=4 | $^{32}$Ca | $^{32}$Mg | MED | 0p-0h | 2p-2h | 4p-4h |
|----|----------|----------|----------|-----|-------|-------|-------|
| $0^+_1$ | 0.0 | 0.0 | 0.0 | 9 | 54 | 35 |
| $2^+_1$ | 0.85 | 0.77 | 0.85 | -80 | 2 | 46 | 50 |
| $0^+_2$ | 1.20 | 1.18 | 1.20 | -20 | 33 | 12 | 54 |
| $0^+_4$ | 1.91 | 2.09 | 1.91 | 180 | 48 | 37 | 15 |

Even farther beyond the proton-drip line would eventually sit $^{32}$Ca, the mirror of the prominent member of the $N = 20$ foil $^{32}$Mg. In Table IV we give the (rather exotic) structure of the low-lying states according to the no-Coulomb calculation. The only state dominated by the normal (closed $N = 20$ or closed $Z = 20$) configurations is the $0^+_1$. Due to the presence of 4p-4h configurations in addition to the 2p-2h ones, the two lowest states have quite small MED’s. Only the $0^+_3$ has a large MED due to its mainly spherical nature. In fact, when we include the Coulomb interaction in the calculation, the percentage of the 0p-0h configuration in the $0^+_3$ of $^{32}$Ca increases to 70%. For this state only, the Coulomb degeneracy induces important differences in the structure of the wave functions of the two mirrors, due to the quasi degeneracy of the different np-nh configurations before their mixing by the nuclear interaction. The evolution of the MED’s as a function of the isospin of the mirror pair for the proton rich calcium isotopes. Open and full symbols indicate experimental data and theoretical predictions, respectively. For the T=1 mirror pair the experimental errors are within the symbols.

$A = 34 T = 3$ and $A = 32 T = 4$. A two-proton transfer reaction, such as $^{34}$Ar($^3$He,n)$^{36}$Ca, will give access to the $0^+_1$ intruder state that is predicted to have a proton $(sd)^{16}(pf)^2$ configuration.

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[1] J. A. Nolen and J. P. Schiffer, Annual Review of Nuclear and Particle Science 19, 471 (1969).
[2] A. P. Zuker, S. M. Lenzi, G. Martínez-Pinedo, and A. Poves, Physical Review Letters 89, 142502 (2002).
[3] M. A. Bentley and S. M. Lenzi, Progress in Particle and Nuclear Physics 59, 497 (2007).
[4] C. Thibault, R. Klapisch, C. Rigaud, A. M. Poskanzer, R. Prieels, L. Lessard, and W. Reisdorf, Physical Review C (Nuclear Physics) 12, 644 (1975).
[5] G. Huber, F. Touchard, S. Büttgenbach, C. Thibault, R. Klapisch, H. T. Duong, S. Liberman, J. Pinard, J. L. Vialle, P. Juncar, and P. Jacquiniot, Physical Review C 18, 2342 (1978).
[6] C. Détraz, D. Guillemaud, G. Huber, R. Klapisch, M. Langevin, F. Naulin, C. Thibault, L. C. Carraz, and F. Touchard, Physical Review C (Nuclear Physics) 19, 164 (1979).
[7] D. Guillemaud-Mueller, C. Détraz, M. Langevin, F. Naulin, M. de Saint Simon, C. Thibault, F. Touchard, and M. Epherre, Nuclear Physics A 426, 37 (1984).
[8] P. Baumann, A. Huck, G. Klotz, A. Knipper, G. Walter, G. Marguier, H. L. Rav, C. Richard-Serre, A. Poves, and J. Retamosa, Physics Letters B 228, 458 (1989).
[9] X. Campi, H. Flocard, A. K. Kerman, and S. Koonin, Nuclear Physics 251, 193 (1975).
[10] A. Poves and J. Retamosa, Physics Letters B 184, 311 (1987).
[11] E. K. Warburton, J. A. Becker, and B. A. Brown, Physical Review C (Nuclear Physics) 41, 1147 (1990).
[12] K. Heyde and J. L. Wood, Journal of Physics G: Nuclear and Particle Physics 17, 135 (1991).
[13] N. Fukunishi, T. Otsuka, and T. Sebe, Physics Letters B 296, 279 (1992).
[14] P. Doornenbal, P. Reiter, H. Grawe, T. Otsuka, A. Al-Khatib, A. Banu, T. Beck, F. Becker, P. Bednarz, G. Benzoni, A. Bracco, A. Bürger, L. Caceres, F. Camera, S. Chmel, F. C. L. Crespi, H. Geissel, J. Gerl, M. Gőrska, J. Grebosz, H. Hübel, M. Kavatsyuk, O. Kavatsuky, M. Kmiecik, I. Kojouharov, N. Kurz, R. Lozeva, A. Maj, S. Mandal, W. Meczynski, B. Million, R. Lozeva, A. Maj, S. Mandal, W. Meczynski, B. Million, A. Góren, S. Grévy, H. Hübel, F. Ibrahim, W. Korten, A. Drouart, C. Engelhardt, S. Franchoo, Z. Fülop, A. Görge, S. Grévy, H. Hübel, F. Ibrahim, W. Korten, J. Mrazek, A. Navin, F. Rotaru, P. Roussel-Chomaz, M. G. Saint-Laurent, G. Sletten, D. Sollier, O. Sorlin, M. Stanoiu, I. Stefan, C. Theisen, C. Timis, D. Verney, and S. Williams, Physical Review C 86, 705 (2012).
[15] An experiment of relativistic Coulomb excitation at RIKEN, only published in conference proceedings [?], claims that B(E2; 0⁺ → 2⁺) = 71±12 e²fm⁴ in 36Ca, a value five times larger than the USD prediction [?].
[16] E. Caurier, G. Martinez-Pinedo, F. Nowacki, A. Poves, and A. P. Zuker, Reviews of Modern Physics 77, 427 (2005).
[17] E. Caurier, F. Nowacki, and A. Poves, Physical Review C 90, 014302 (2014).
[18] J. Bonnard, S. M. Lenzi, and A. P. Zuker, Physical Review Letters 116, 396 (2016).
[19] R. R. Reynolds, P. D. Cottle, A. Gade, D. Bazin, C. M. Campbell, J. M. Cook, T. Glasmacher, P. G. Hansen, T. Hoagland, K. W. Kemper, W. F. Mueller, B. T. Roeder, J. R. Terry, and J. A. Tostevin, Physical Review C 81, 1057 (2010).
[20] F. Ajzenberg-Selove, Nuclear Physics 523, 1 (1991).
[21] D. Suzuki, H. Iwasaki, D. Beaumel, M. Assié, H. Baba, Y. Blumenfeld, F. De Oliveira Santos, N. de Séréville, A. Drouart, S. Franchoo, J. Gibelin, A. Gillibert, S. Giron, S. Grévy, J. Guilhot, M. Hackstein, F. Hamache, N. Keeley, V. Lapoux, F. Maréchal, A. Matta, S. Michimasa, L. Naips, F. Naqvi, H. Okamura, H. Otsu, J. Pancin, D. Y. Pang, L. Perrot, C. M. Petraceh, E. Pollacco, A. Ramus, W. Rother, P. Roussel-Chomaz, H. Sakurai, J. A. Scarpaci, O. Sorlin, P. C. Srivastava, I. Stefan, C. Stodel, Y. Tanimura, and S. Terashima, Physical Review C 93, 603 (2016).
[22] M. Dufour and A. Zuker, Physical Review C 54, 1641 (1996).
[23] J. Valiente-Dobón, D. Mengoni, A. Gadea, E. Farnea, S. Lenzi, S. Lunardi, A. Dewald, T. Pissulla, S. Szilner, R. Broda, F. Recchia, A. Algara, L. Angus, D. Bazzacco, G. Benzoni, P. Bizzeti, A. Bizzeti-Sona, P. Boutachkov, L. Corradi, F. Crespi, G. D. Angelelli, E. Fioretto, A. Görge, M. Gorska, A. Gottardo, E. Grodner, B. Guiot, A. Howard, W. Królas, S. Leoni, P. Mason, R. Menegazzo, D. Montanari, G. Montagnoli, D. Napoli, A. Obertelli, T. Pawlow, G. Pollaro, B. Rubio, E. Sähin, F. Scarlassara, R. Silvestri, A. Stefanini, J. Smith, D. Steppebeck, C. Ur, P. Wady, J. Wrezinski, E. Maglione, and I. Hamamoto, Physical Review Letters 102, 242502 (2009).
[24] B. Pritychenko, M. Birch, and B. Singh, Nuclear Physics A 962, 73 (2017).
[25] J. W. Olness, W. R. Harris, A. Gallmann, F. Jundt, D. E. Albuerger, and D. H. Wilkinson, Physical Review C 3, 2323 (1971).
[26] W. Schwerdtfeger, P. G. Thirolf, K. Wimmer, D. Habs, H. Mach, T. R. Rodríguez, V. Bildstein, J. L. Egidio, L. M. Fraile, C. Henshaw, H. Rutherford, K. Heyde, H. Hülbel, U. Köster, K. Kröll, R. Krücken, R. Lutter, T. Morgan, and P. Ring, Physical Review Letters 103, 63 (2009).
[27] T. Kibedi, T. W. Burrows, M. B. Trzhaskovskaya, P. M. Davidson, and C. W. Nestor Jr., Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 589, 202 (2008).
[28] E. A. Samworth and J. W. Olness, Physical Review C 5, 1238 (1972).
[29] A. Hogenbirk, H. P. Blok, M. G. E. Brand, A. G. M. Van Hees, J. F. A. Van Hienen, and F. A. Jansen, Nuclear Physics 516, 205 (1990).
[30] K. Wimmer, T. Kröll, R. Krücken, V. Bildstein, R. Gernhauser, B. Bastin, N. Bree, J. Diriken, P. Van Duppen, M. Huyse, N. Patronis, P. Vermaelen, D. Voulot, J. Van De Walle, F. Wenander, L. M. Fraile, R. Chapman, B. Hadinia, R. Orlandi, J. F. Smith, R. Lutter, P. G. Thirolf, M. Labiche, A. Blazhev, M. Kalkihler, P. Reiter, M. Seidlitz, N. Warr, A. O. Macchiavelli, H. B. Jeppesen, E. Fiori, G. Georgiev, G. Schrieder, S. Das Gupta, G. Lo Bianco, S. Nardelli, J. Butterworth, J. Johansen, and K. Riisager, Physical Review Letters 105, 252501 (2010).
[31] F. Rotaru, F. Negoiţă, S. Grévy, J. Mrazek, S. Lukyanov, F. Nowacki, A. Poves, O. Sorlin, C. Borcea, R. Borcea, A. Buta, L. Caceres, S. Calinescu, R. Chevrier, Z. Dombrádi, J. M. Daugas, D. Lebhertz, Y. Penionzhkevich, C. Petrone, D. Sollier, M. Stanoiu, and J.-C. Thomas, Physical Review Letters 109, 092503 (2012).