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Pauli-principle driven correlations in four-neutron nuclear decays

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In the last decade there was a great progress in the studies of three-body decays (e.g. two-proton radioactivity) [1]. In contrast to "conventional" two-body decays, three-body decays encrypt a lot of additional information in the momentum (energy and angular) correlations of the decay products. Theoretical studies indicate that both effects of the initial nuclear structure and the decay mechanism may show up in the core+n+n and core+p+p fragment correlation patterns in various ways [2–13].

With the development of experimental techniques, more and more "complicated" nuclear systems become available for studies. One of such complicated cases are isotonic neighbors of the $4n$-halo systems located beyond the neutron dripline, which are expected to have narrow resonance ground state decaying via $4n$-emission. The examples of such systems, which are now actively studied by experiment, are ^{7}H and ^{28}O. The $4n$-emission phenomenon is known to be widespread beyond the neutron dripline, and other possible candidates for such a decay mode, e.g., ^{18}Be can be mentioned. Their ground states are expected to be unbound with $E_T \lesssim 2$ MeV (E_T is energy above the $4n$ decay threshold), and the decay mechanism can be assumed as "true" $4n$ emission: there are no sequential neutron emissions, which mean that all neutrons are emitted simultaneously.

In the $4n$-emission (core+$4n$ decay) the five-body correlations encrypt enormously more information compared to the three-body decay. In five-body case the complete correlation pattern is described by 8-dimensional space compared to the 2-dimensional space in the three-body decay. The core+$4n$ system permutation symmetries should decrease the effective dimension of the correlation space, but there should be still a lot. The question can be asked here "How we should look for physically meaningful signals in this wealth of information?"

The concept of "Pauli focusing" was proposed in [14] and further discussed, e.g., in [15, 16] for the bound state structure of three-body core+n+n systems. It was demonstrated that due to the Pauli exclusion principle, the population of orbital configurations $[l_{j_1} \otimes l_{j_2}]_J$ for the valence nucleons may induce strong spatial correlations depending on the specific values of j_1, j_2, and J. Various forms of such correlations were actively discussed as an integral part of the two-nucleon halo phenomenon.

Pauli focusing for 5-body systems was discussed in [17, 18] by example of ^{8}He nucleus described by the α+$4n$ model. The complicated spatial correlation patterns were predicted. However, Pauli focusing has never been discussed for decays of the systems located above the five-body core+$4n$ breakup threshold.

The theoretical model we develop in this work for dynamics of 5-body decay is generalization of the *improved direct 2p-decay* model [19] to the $4n$ emission case. In direct decay models it is assumed that emitted particles are propagating to asymptotics in fixed quantum states, while the total decay energy is shared among single-particle configurations described by R-matrix-type amplitudes. In the three-body case the direct decay model is powerful and reliable phenomenological tool broadly used in the application to $2n$ and $2p$ decays for lifetime estimates [12, 20–22] studies of two-nucleon correlations [1, 19] and transitional dynamics [19, 23, 24].

As a result, in this work we have for the first time theoretically studied the correlations in emission of four nucleons in the nuclear 5-body decay. We have demonstrated that for true five-body decays of core+$4n$ systems the *Pauli focusing* – the cumulative effects of anti-

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symmetrization and population of definite orbital configurations – may lead to distinctive correlation patterns. These patterns are not very expressed in the one-dimensional energy and angular distributions. Here they can also be masked by other dynamical effects. However, we have found a way to reliably extract the information on internal structure from correlations. In addition to the one-dimensional distributions, the *correlated two-dimensional energy* $\{\varepsilon_{ik}, \varepsilon_{nm}\}$ and *angular* $\{\theta_{ik}, \theta_{nm}\}$ ($i \neq k$, $n \neq m$) *distributions* may be constructed. For core+4n decays in total five topologically nonequivalent two-dimensional distributions exist. The reconstruction of all these distributions requires a complete kinematical characterization of the core+4n decay, which is within the reach of the modern experiment. We propose to study the *full set of the two-dimensional correlated energy or/and angular distributions* for derivation of the information concerning the quantum-mechanical 4n-decay configuration. We predict that taken together these distributions form a unique "fingerprint" of the decaying quantum state.

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1. M. Pfützner, M. Karny, L. V. Grigorenko, and K. Riisager, Rev. Mod. Phys. **84**, 567 (2012).
2. L. V. Grigorenko and M. V. Zhukov, Phys. Rev. C **68**, 054005 (2003).
3. I. Mukha, E. Roeckl, L. Batist, A. Blazhev, J. Döring, H. Grawe, L. Grigorenko, M. Huyse, Z. Janas, R. Kirchner, M. L. Commara, C. Mazzocchi, S. L. Tabor, and P. V. Duppen, Nature **439**, 298 (2006).
4. L. V. Grigorenko and M. V. Zhukov, Phys. Rev. C **76**, 014008 (2007).
5. L. V. Grigorenko and M. V. Zhukov, Phys. Rev. C **76**, 014009 (2007).
6. I. Mukha, L. Grigorenko, K. Sümmerer et al. (Collaboration), Phys. Rev. C **77**, 061303 (2008).
7. L. V. Grigorenko, T. D. Wiser, K. Miernik et al. (Collaboration), Phys. Lett. B **677**, 30 (2009).
8. L. V. Grigorenko, T. D. Wiser, K. Mercurio, R. J. Charity, R. Shane, L. G. Sobotka, J. M. Elson, A. H. Wuosmaa, A. Banu, M. McCleskey, L. Trache, R. E. Tribble, and M. V. Zhukov, Phys. Rev. C **80**, 034602 (2009).
9. I. A. Egorova, R. J. Charity, L. V. Grigorenko et al. (Collaboration), Phys. Rev. Lett. **109**, 202502 (2012).
10. L. V. Grigorenko, I. G. Mukha, and M. V. Zhukov, Phys. Rev. Lett. **111**, 042501 (2013).
11. K. W. Brown, R. J. Charity, L. G. Sobotka et al. (Collaboration), Phys. Rev. Lett. **113**, 232501 (2014).
12. K. W. Brown, R. J. Charity, L. G. Sobotka et al. (Collaboration), Phys. Rev. C **92**, 034329 (2015).
13. L. V. Grigorenko, J. S. Vaagen, and M. V. Zhukov, Phys. Rev. C **97**, 034605 (2018).
14. B. V. Danilin, M. Zhukov, A. Korsheninnikov, V. Efros, and L. Chulkov, Sov. J. Nucl. Phys. **48**, 766 (1988).
15. M. V. Zhukov, B. Danilin, D. Fedorov, J. Bang, I. Thompson, and J. S. Vaagen, Phys. Rep. **231**, 151 (1993).
16. P. Mei and P. V. Isacker, Annals of Physics. **327**, 1162 (2012).
17. M. V. Zhukov, A. A. Korsheninnikov, and M. H. Smedberg, Phys. Rev. C **50**, R1 (1994).
18. P. Mei and P. V. Isacker, Ann. Physics **327**, 1182 (2012).
19. T. A. Golubkova, X.-D. Xu, L. Grigorenko, I. Mukha, C. Scheidenberger, and M. Zhukov, Phys. Lett. B **762**, 263 (2016).
20. B. A. Brown and F. C. Barker, Phys. Rev. C **67**, 041304 (2003).
21. F. C. Barker, Phys. Rev. C **68**, 054602 (2003).
22. E. Olsen, M. Pfützner, N. Birge, M. Brown, W. Nazarewicz, and A. Perhac, Phys. Rev. Lett **110**, 222501 (2013).
23. I. Mukha, L. V. Grigorenko, X. Xu, L. Acosta et al. (Collaboration), Phys. Rev. Lett. **115**, 202501 (2015).
24. X.-D. Xu, I. Mukha, L. V. Grigorenko et al. (Collaboration), Phys. Rev. C **97**, 034305 (2018).