Neutron-neutron correlations in light exotic nuclei [1]

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Abstract. For light exotic nuclei modeled as two neutrons *n* and a core *A*, we report results for the two-neutron correlation functions and also for the mean-square radii, considering a universal scaling function. The results of our calculations for the neutron-neutron correlation functions are qualitatively consistent with recent data obtained for ^{11}Li and ^{14}Be nuclei. The root-mean-square distance in the halo of such nuclei are also consistent with data, which means that the neutrons of the halo have a large probability to be found outside the interaction range. Therefore the low-energy properties of these halo neutrons are, to a large extend, model independent as long as few physical input scales are fixed. The model is restricted to $s-$wave subsystems, with small energies for the bound or virtual states. For the radii we are also shown results for the ^{6}He and ^{20}C. All the interaction effects, as higher partial wave in the interaction and/or Pauli blocking effect are, to some extend, included in our model, as long as the three-body binding energy is supplied.

Considering a renormalized three-body model with a pairwise pointlike interaction, we report results obtained for the two-neutron correlation functions and also for the mean-square radii of light exotic nuclei modeled as two neutrons and a core ($n-n-A$). The results are derived from a universal scaling function that depends on the mass ratio of the neutron and the core, as well as on the nature of the subsystems, bound or virtual. The model consider a minimal number of physical inputs, which are directly related to observables: the two-neutron separation energy $S(2n) = -E3$, the neutron-neutron and neutron-core $s-$wave scattering lengths (or the corresponding virtual or bound energies).

The results of our calculations are compared with recent data for the neutron-neutron root-mean-square distances, in case of the halo nuclei ^{6}He, ^{11}Li and ^{14}Be nuclei. We also made an estimate prediction for ^{20}C system. For the neutron-neutron correlation function we compare our results for ^{11}Li and ^{14}Be with available experimental data. The neutrons of the halo have a large probability to be found outside the interaction range. Therefore the low-energy properties of these halo neutrons are, to a large extend, model independent as long as few physical input scales are fixed. The model provides a good insight into the three-body structure of halo nuclei, even considering some of its limitations. It is restricted to $s-$wave subsystems, with small energies for the bound or virtual states. We note that, all the interaction effects, such as higher partial wave in the

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TABLE 1. Results of the neutron-neutron root mean-square radii in halo nuclei. Table from Ref. [1]. The virtual states are indicated by (v). The *nn* virtual state energy was taken as -143 keV.

Core	E_3 (MeV)	E_{nA} (MeV)	$\sqrt{\langle r_{nn}^2\rangle}$ (fm)	$\sqrt{\langle r_{nn}^2\rangle_{exp}}$ (fm)
^{4}He	0.973	0	5.1	5.9±1.2
		0.3(v)	4.6	
		4.0(v)	3.6	
^{9}Li	0.29	0	9.7	6.6±1.5
		0.05(v)	8.5	
		0.8(v)	6.7	
^{12}Be	1.337	0	4.6	5.4±1.0
		0.2(v)	4.2	
^{18}C	3.50	0.16	3.0	-
		0.53	4.4	-

interaction and/or Pauli blocking effect are, to some extend, included in the model, as long as the three-body binding energy is supplied.

In order to analyze weakly-bound three-body systems, it is useful a classification scheme as given in [1]. The most natural case is where all the two-body subsystems are bound. We call it *all-bound* three-body system. In a quite different configuration of three-body system, the case where all the two-body subsystems are unbound, we have the well-known Borromean system. In intermediate situations we can distinguish two other configurations: the *Tango* case [2], where only one pair of the subsystems is bound; and the *Samba* [1] case, where only one pair is unbound. Within these configurations, by solving the corresponding Faddeev equations, with renormalized zero-range two-body interactions, we obtain some general properties related to the particle distributions in the halo [1,3]. Our results, for the radii and for the two-neutron correlation functions, can be summarized in Table 1 and in Figs. 1(a) and 1(b).

In Table 1, we present our results for the radii of the three-body halo nuclei ^{6}He, ^{11}Li, ^{14}Be and ^{20}C. A few energies for the (bound/virtual) subsystems are considered according to references given in [1]. When available, the experimental results for the radii are shown in the last column.

In Figs. 1(a) and 1(b) we present results for the neutron-neutron correlation functions, $C_{nn}(\vec{p}_{nn})$, in case of the halo-nuclei ^{11}Li and ^{14}Be, respectively. The neutron-neutron correlation function, for the $n-n-A$ three-body system, is given by

$$C_{nn}(\vec{p}_{nn}) = \frac{\int d^3q_{nn}|\Psi_{Ann}(\vec{q}_{nn},\vec{p}_{nn})|^2}{\int d^3q_{nn}\int d^3q_{nA}|\Psi_{Ann}(\vec{q}_{nA},\vec{p}_{nA})|^2\int d^3q_{n'A}|\Psi_{Ann}(\vec{p}_{n'A},\vec{q}_{n'A})|^2}, \quad (1)$$

where Ψ is the corresponding wave function in the Jacobi relative momentum coordinates. With $\gamma = n$ or A, $\vec{p}_{n\gamma}$ is the relative momentum between the particles $n\gamma$, and $\vec{q}_{n\gamma}$ the relative momentum between the expectator particle and the center-of-mass of the pair $n\gamma$.

In conclusion, we observe that our model, with renormalized zero-range two-body interaction, when applied to three-body system with $s-$wave subsystems and with small

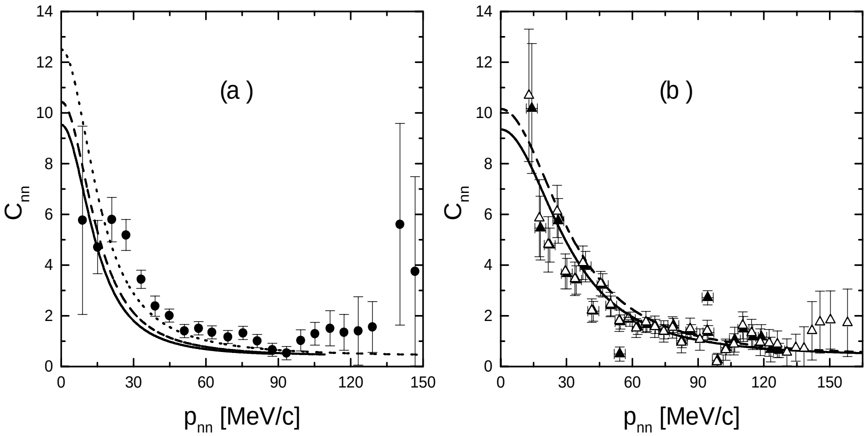

FIGURE 1. Correlation functions for ^{11}Li (a) and for ^{14}Be (b) as functions of the relative momentum, p_{nn}, of halo neutrons. Experimental data in (a) are from [4]; and, in (b), from [4] (open triangles) and [5] (solid triangles). The three-body energies was set as 0.29 MeV, for ^{11}Li; and, 1.337 MeV, for ^{14}Be. In (a), the solid, dashed and dotted lines are, respectively, the results for E_{nA}=0, 0.05 and 0.8 MeV. In (b), the solid and dashed lines are, respectively, the results for E_{nA}=0 and 0.2 MeV.

bound or virtual two-body energies, give results consistent with available experimental results. With respect to the size of weakly-bound three-body system $n-n-A$, when we consider all configurations (Borromean, tango, samba and all-bound) with the same three-body energy, we verify the following interesting relation for the two-particle mean-square distances:

$$\left\langle r^2\right\rangle\Big|_{Borromean} < \left\langle r^2\right\rangle\Big|_{Tango} < \left\langle r^2\right\rangle\Big|_{Samba} < \left\langle r^2\right\rangle\Big|_{All-bound} .$$

Our results for the correlation functions and also for the radii are qualitatively consistent with recent data for the ^{11}Li and ^{14}Be nuclei, which means that the neutrons of the halo have a large probability to be found outside the interaction range. The model provides a good insight into the three-body structure of halo nuclei, even considering some of its limitations: it is restricted to $s-$wave subsystems, with small energies for the bound or virtual states. However, considering that in our model the three-body binding energy is supplied, interaction effects as higher partial waves and/or Pauli blocking effect are, to some extend, included.

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