A method for determination of the s-orbital component of 12Be ground state (Postprint)

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Abstract

The ambiguity in the structure of 12Be, particularly regarding the configuration of its ground state, has attracted considerable attention recently. We note that the nuclear reaction cross section σR in the low-energy region is sensitive to the surface structure of 12Be, which is strongly influenced by the ground-state configuration, especially by the occupancy probability of the s-orbital component. By utilizing existing interaction cross-section data for 12Be on C at 790 MeV/nucleon and the Glauber model, the upper limit of the s-orbital occupation probability in the 12Be ground state is roughly determined to be approximately 56% through Single Particle Model calculations. This demonstrates that the method holds considerable promise for determining the s-orbital component of 12Be with appropriate nuclear-matter density distribution calculations for different orbitals of the 12Be ground state. Therefore, we propose determining the s-orbital component of 12Be by measuring the σR of 12Be on C and Al at several tens of MeV/nucleon. In this paper, the feasibility and detailed experimental scheme for the σR measurement are carefully investigated. The precision of the s-orbital occupation probability for the 12Be ground state is expected to reach 9% using the proposed σR data with 2% precision.

Full Text

Preamble

A Method for Determination of the s-Orbital Component of 12Be Ground State

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The ambiguity of the structure of 12Be, particularly regarding the configuration of its ground state, has attracted considerable attention recently. We note that the nuclear reaction cross section σR in the low-energy region is sensitive to the surface structure of 12Be, which is greatly impacted by the ground-state configuration, especially by the occupancy probability of the s-orbital component. By using existing interaction cross-section data of 12Be on C at 790 MeV/nucleon and the Glauber model, the upper limit of the s-orbital occupation probability of the 12Be ground state is roughly determined to be about 56% through Single Particle Model calculations. This demonstrates that the method is very promising for determining the s-orbital component of 12Be with proper nuclear-matter density distribution calculations for different orbitals of the 12Be ground state. Hence, we propose to determine the s-orbital component of 12Be by measuring the σR of 12Be on C and Al at several tens of MeV/nucleon. In this paper, the feasibility and detailed experimental scheme of the σR measurement are carefully studied. The precision of the s-orbital occupation probability of the 12Be ground state is expected to achieve 9% by using the proposed 2% σR data.

Keywords: 12Be, Density distribution, MOL[FM], Ground state configuration
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Introduction

During the past decades, studies on exotic nuclei have been stimulated considerably by the enormous development of radioactive ion beam (RIB) techniques. Many peculiarities of exotic nuclei have been revealed, such as halo/skin-like structures [1], cluster structures [2], and the breakdown of shell closure [3, 4]. Studies on these peculiarities have greatly improved our understanding of exotic nuclei, such as the beryllium isotopes. Theoretical research on properties of Be isotopes is based on the three-body model [5, 6] and the density-dependent relativistic mean-field model [7, 8]. The neutron halo of 14Be has been well explained using these models [5–8]. Located between the halo nuclei 11Be and 14Be, 12Be is an interesting combination of these peculiarities and plays a key role in the beryllium chain. In the shell model, 12Be is supposed to be a "magic nucleus" with a simple structure. However, recent experiments [4, 9, 10] provided direct evidence for the breakdown of the N = 8 shell closure in 12Be and the presence of (s, d) intruder states. In principle, this intruder-state configuration can cause a halo-like structure, yet neither the wide momentum distribution [11] nor the relatively large two-neutron separation energy (S2n = 3.67 MeV [12]) indicates a signature for a halo.

There exists controversy between recent theoretical and experimental results regarding the halo-like structure of 12Be. The giant deformation in the ground state of 12Be [13] is also predicted by Antisymmetrized Molecular Dynamics (AMD), and the ground-state structure of 12Be remains ambiguous. Additionally, explorations of the level structure, parity, spin, and deformation of the excited states of 12Be with molecular cluster models have drawn considerable attention [14–18]. The ground-state structure properties of 12Be are indispensable in these studies because they provide fundamental information for investigations of the excited states. Therefore, it is of significant importance to study the ground-state structure of 12Be.

As an essential property of the ground-state structure, the nuclear-matter density distribution of 12Be not only provides basic structural information such as the nuclear-matter radius but also helps determine whether the 12Be ground state has a halo structure. Recently, particle-particle random-phase approximation (pp-RPA) [19] and microscopic no-core shell-model (NCSM) calculations [18] have shown that the ground-state wave functions of 12Be are dominated by the p-shell configuration, which is in conflict with previous calculations [20–24] and knockout measurements [4, 9]. The nuclear-matter density distribution may be used to determine the configuration mixing between the 1p1/2, 1d5/2, and 2s1/2 orbitals, thereby helping to resolve the inconsistencies between current data and various theoretical models. Therefore, we were motivated to determine the nuclear-matter density distribution of the 12Be ground state.

In the following text, the experimental method of the σR measurement is introduced in Sec. II, the feasibility analysis and optimization of the reaction cross-section (σR) measurement are elaborated in Sec. III, the method to determine the s-orbital component of 12Be ground state through σR is illustrated in Sec. IV, and a summary is given in Sec. V.

II. General Scheme

Typically, the nuclear-matter density distribution is investigated by measuring σR (or the total interaction cross sections σI). This involves theoretical models, and several methods have been developed to study the total reaction cross section, such as the multi-step scattering theory of Glauber [25], the transport model method of Ma et al. [26, 27], and the semi-empirical formulas of Kox et al. [28] and Shen et al. [29]. A series of investigations on 12Be were carried out in past decades. By measuring σI on Be, C, and Al at 790 MeV/nucleon, Tanihata et al. successfully determined the effective root-mean-square (RMS) radius of 12Be through a Glauber model in 1988 [30]. Liatard et al. measured the σR of radioactive Be isotopes on Cu at around 25 to 65 MeV/nucleon and deduced the radii using a simple microscopic model [31]. Later, Warner et al. measured the σR of 12Be on Pb and Si at about 30 to 60 MeV/nucleon and obtained the radius of 12Be [32]. However, these studies have several drawbacks. First, their energy regions did not cover both low and high energy regions. Data in the low-energy region constrain the outer structure, while data in the high-energy region provide more information on the core part; hence, data from both low and high energy regions are needed to obtain an accurate nuclear-matter density distribution. Second, generally, their targets were too heavy, making σR insensitive to the surface structure of 12Be. Third, their models were too simple to interpret the data, especially at low energies. The results did not provide detailed nuclear-matter density distributions of 12Be, particularly for the surface area.

To obtain detailed outer structure of nuclei, two improvements were made recently for extracting accurate nuclear-matter density distributions. First, a method of proton elastic scattering at intermediate energies was developed. Ilieva et al. applied this proton-scattering method to 12Be in 2012 [33] and determined the nuclear-matter density distribution of the 12Be ground state. However, the result has considerable uncertainty because of various parametrizations, so the method is not yet well established for studying the surface structure of especially unstable nuclei. Second, the applicability of the Glauber model in the whole energy region was studied, and a Modified Optical Limit Glauber model (MOL[FM]) was developed by incorporating the Fermi motion of nucleons in the finite-range MOL [34]. The MOL[FM] has reduced the discrepancy between calculated and measured data to just 1%–2% for the whole energy region. By measuring σR on Be, C, and Al targets at intermediate energies, the nuclear-matter density distributions of 22C [35] and 17Ne [36] were determined accurately with MOL[FM]. Through this method, we obtained the nuclear-matter density distribution of 8Li precisely [37], and a relevant paper about our further study is in preparation. Therefore, MOL[FM] provides a powerful tool for interpreting σI or σR data, and measuring σI or σR to determine the nuclear-matter density distribution with MOL[FM] remains a good method at present.

Thus, we were motivated to precisely measure σR of 12Be in the low-energy region and extract the nuclear-matter density distribution of the 12Be ground state using MOL[FM].

Regarding the measurement of σR, the transmission method is typically used. Typical experimental procedures are given in Ref. [38]. The σR is obtained by Eq. (1),

$$\sigma_R(E) = -\frac{\ln R}{t},$$

where E is the energy point; t is the target thickness expressed by the target particle numbers per unit area; and $R = N_{\text{out}}/N_{\text{in}}$ is the ratio of outgoing projectile particles number to incident projectile particles. Since the energy of the projectile particles decreases as they pass through the target, we determine the energy point of σR by the mean energy E_{mean}, which is given by

$$E_{\text{mean}} = \frac{\int_0^t E(x)dx}{t},$$

where t is the target thickness, and $E(x)$ is the residual energy of the incident beam traveling along the path by distance x. $E(x)$ can be calculated by the improved Bethe-Bloch formula [39].

The main relative error of σR can be written as

$$\left(\frac{\Delta\sigma_R}{\sigma_R}\right)^2 = \left(\frac{\Delta t}{t}\right)^2 + \left(\frac{1}{\ln R}\right)^2 \left[\left(\frac{\Delta R}{R}\right)^2_{\text{sys}} + \left(\frac{\Delta R}{R}\right)^2_{\text{stat}}\right],$$

where $\Delta t/t$ stands for the uncertainty of the target thickness, the subscripts "sys" and "stat" denote the systematic and statistical error of R, respectively, and the statistical error of R is given by

$$\left(\frac{\Delta R}{R}\right)_{\text{stat}} = \sqrt{\frac{1-R}{RN_{\text{in}}}},$$

because it follows the binomial distribution.

In practice, $R_{\text{in}}/R_{\text{out}}$ is taken as R in order to remove events that interact outside the target, where R_{in} and R_{out} are the ratios of $N_{\text{out}}/N_{\text{in}}$ corresponding to the target-in and target-out measurements, respectively. Accordingly, the relative error of σR becomes

$$\left(\frac{\Delta\sigma_R}{\sigma_R}\right)^2 = \left(\frac{\Delta t}{t}\right)^2 + \left(\frac{1}{\ln R}\right)^2 \left(\frac{\Delta R}{R}\right)^2_{\text{sys}} + \frac{1}{N_{\text{tar-in}}}\frac{1-R_{\text{in}}}{(\ln R_{\text{in}})^2} + \frac{1}{N_{\text{tar-out}}}\frac{1-R_{\text{out}}}{(\ln R_{\text{out}})^2}.$$

Besides the contribution of statistical error, the systematic uncertainty of σR mainly comes from the correction of the number of inelastic-scattering events merged into the non-reaction events. By using the method in Ref. [40] and Monte Carlo simulation, the systematic error of σR can be limited within 1%-2% [34]. So 1%-2% total uncertainty can be achieved if sufficient reaction events are recorded. In fact, this was achieved recently in most experiments of this kind.

Based on available nuclear-matter density distributions of 12Be from experiments and theories (Fig. 1), we calculated the σR (Fig. 2) at different energies by MOL[FM]. The momentum width and the finite-range parameter β were taken from Ref. [34]. From Fig. 2, one sees that below $ $50 MeV/nucleon, σR data with uncertainty around 2% is sufficient to distinguish several previous results and determine whether 12Be has a clear halo-like structure. However, the specific requirements on experimental conditions for achieving 2% precision in σR are still unknown, and investigation is needed for further discussion of the method' s feasibility.

III. Feasibility Study and Optimization of σR Measurement

To ensure that the experiment is practical, we have studied the feasibility and optimized the experimental method. The experimental feasibility mainly relies on the detecting system, reaction targets, and 12Be beam. In the energy region below 50 MeV/nucleon, the $\Delta E - E$ method is often used for particle identification. The required energy deposition of 12Be in the ΔE detector is about 10 MeV/nucleon, while the required energy in the E detector shall be above 10 MeV/nucleon, just for ensuring validity of the particle identification. Therefore, the energy of 12Be right before the ΔE detector is supposed to be over 20 MeV/nucleon. Usually, Si detectors and scintillator detectors are used as the ΔE and E detectors, respectively. Their thicknesses depend on the specific energy of 12Be right before the ΔE detector. As for particle identification before the reaction target, the $B\rho - \Delta E$-TOF technique is often used. A typical layout of the detecting system is shown in Fig. 3 [Figure 3: see original paper].

Besides the detection system, the target material and thickness t and incident energy of the 12Be beam E_{in} shall be determined before the experiment. Regarding the target material, 12C is a good candidate because its nuclear-matter density distribution is well determined and its mass number is comparable with 12Be, making its σR more sensitive to the 12Be surface structure. Another target, 27Al, is also needed for reducing the target-dependence of the result.

For t and E_{in}, there are direct impact factors, such as the transmission rate R, 12Be outgoing energy E_{out} after the reaction target, and energy point E_{mean}, with certain restrictions for each of these factors, making it difficult to consider t and E_{in} separately. We studied the relations between these parameters through calculations, which include: (1) E_{out} for certain E_{in} and t, where E_{out} was calculated by LISE++ [43]; (2) E_{mean} could be determined through $(E_{\text{in}} + E_{\text{out}})/2$ approximately; (3) $\sigma_R(E_{\text{mean}})$ was calculated using MOL[FM] based on the nuclear-matter density distribution of the expectation in Fig. 1; (4) R is calculated by Eq. (1) with certain t and corresponding $\sigma_R(E_{\text{mean}})$.

Then, the trends of R varying with E_{in} under different t and E_{out} were obtained. Fig. 4 [Figure 4: see original paper] shows the calculation results for 12Be+C. Each dashed line corresponds to the same t, and each dash-dot line corresponds to the same E_{out}. Subsequently, we took into account the restrictions of R, E_{out}, and E_{mean} to determine proper t and E_{in}. As mentioned before, E_{mean} should be less than 50 MeV/nucleon to ensure the physical goal, and E_{out} (i.e., the energy of 12Be right before the ΔE detector) should be above 20 MeV/nucleon to ensure the availability of the $\Delta E - E$ method. R is restricted by systematic error if the statistical error is small enough. It is of certain difficulty to achieve

0.1% systematic error for a directly measured quantity like R. To ensure a <2.5% precision of σR, the factor $1/\ln R$ before the systematic error of R in Eq. (5) shall be less than 25. Accordingly, R should be less than 0.96. Therefore, proper ranges of t and E_{in} are indicated as the hatched area in Fig. 4.

In the energy region of 30-50 MeV/nucleon, we intend to obtain three data points by using the subtraction method. As shown by Conditions (1) and (2) in Fig. 5 [Figure 5: see original paper], at incident beam energies of E_1 and E_2, with target thicknesses of t_1 and t_2, reaction cross sections σ_1 and σ_2 are measured by the transmission method, respectively, and by adjusting E_1 and E_2, both outgoing beam energies E_{out} can be made the same. Then, the reaction rate in the target in Condition (2) shall be equal to that of the corresponding thickness of t_2 in the target in Condition (1). By subtracting the two data, one obtains another σR as,

$$\sigma_R = \frac{t_1\sigma_1 - t_2\sigma_2}{t_1 - t_2} = -\frac{\ln R_{\text{in-1}} - \ln R_{\text{in-2}}}{t_1 - t_2},$$

where $R_{\text{in-1}}$ and $R_{\text{in-2}}$ denote the transmission rates of the target-in experiment in Conditions (1) and (2), respectively. The transmission rates of the target-out experiments do not appear in Eq. (6) because the reaction rate outside the target is canceled between the two measurements. The error of this deduced σR was determined in Ref. [40]. Through this method, three data points can be obtained with only two measurements, greatly improving the efficiency of the experiment. The key point is that the outgoing energies E_{out} in the two measurements should be the same, and the interval between the two adjacent incident beam energies E_{in} should be over 15 MeV/nucleon to ensure the energy points are evenly distributed between 30-50 MeV/nucleon.

Thus, we have determined the range of E_{in}, the C and Al target thicknesses, and the detecting system. Next, we must determine the number of events needed according to the requirement of the statistical error and estimate the requisite beam intensity.

According to Eq. (3), the statistical error should be less than 0.5% so that it will not be a main error source, which gives

$$\sqrt{\frac{1-R}{RN_{\text{in}}}} < 0.5\%.$$

Since R is at most 0.96, N_{in} of 10^6 is already sufficient. Therefore, it will take only 10^3 seconds of beam time under typical conditions of $10^3\ \text{s}^{-1}$ beam intensity, which is very practical.

TABLE 1 . Experimental scheme

Target	E_{in} (MeV/n)	E_{out} (MeV/n)	Thickness (g/cm^2)	R	N_{in}
C	35	20	0.086	0.86	2.9×10^5
C	50	20	0.180	0.90	4.0×10^5
Al	50	20	0.094	0.94	6.7×10^5
Al	70	20	0.140	0.96	1.0×10^6

To summarize, for the experiment, a 12Be beam of about 10^3 s^{-1} intensity at 20–70 MeV/nucleon is needed to provide the projectile particles, and the outgoing energy of 12Be after the reaction targets in the two measurements should be the same. In addition, Si and scintillator detectors are needed for particle identification. Finally, we select two energy points, find the corresponding target thickness, evaluate R, and determine the corresponding requirement for N_{in}. The detailed experimental scheme is given in Table 1.

We find that the Radioactive Ion Beam Line in Lanzhou (RIBLL) [44] is a suitable candidate for providing the 12Be beam. The schematic diagram of the layout of RIBLL is shown in Fig. 6 [Figure 6: see original paper]. The primary beam $^{18}O^{8+}$ is accelerated by the Heavy Ion Research Facility of Lanzhou (HIRFL) and introduced to RIBLL. It bombards the production target of Be at T0 and generates the secondary beam of 12Be. An Al degrader at C1 is used for energy-loss analysis of the secondary beam separation. Another Al degrader at T1 is used for energy degradation. Two slits at C1 and C2 are used for momentum acceptance control. Two plastic scintillation counters at focal points T1 and T2 can provide the TOF information. A Si solid-state detector (SSD) at T2 can be used to provide the ΔE signals for particle identification before the reaction target. The energy E_{in} of the incident beam right before the reaction target is determined by the $B\rho$ value of the fourth dipole magnet D4.

Based on this configuration, the 12Be beam condition is simulated by LISE++ using a typical 100 enA primary beam of $^{18}O^{8+}$ at 80 MeV/nucleon. Major parameters of the simulation result are given in Table 2 . It is worth mentioning that similar experiments have been performed on RIBLL since 2000 [45–49]. From their results, we infer that typically the error of σR is up to about 5%, including 3%–4% systematic error. Therefore, we need further consideration based on the real performance of RIBLL to reduce the error, especially the systematic error.

For the detecting system, typically Si detectors of 1500 µm thickness are competent for the ΔE measurement, and CsI(Tl) scintillator detectors of 30 mm thickness are adequate for the E measurement. It should be noted that the Si detector is made of single crystal, hence the concern of channeling effect for the particles being detected. By tilting the Si detector against the beam axis at a certain angle, the fraction of channeling events can be reduced to <1% [40]. The tilting angle can be determined by studying the angle dependence of the channeling events in advance.

Based on the above feasibility study, the σR measurement is reasonable and valid, and the requisite conditions can be satisfied. Through the measurement, the nuclear-matter density distribution of the 12Be ground state can be determined and then used to extract the component of the 12Be ground state. In Sec. IV, we elaborate on how to determine the s-orbital component through σR.

IV. Extraction of the s-Orbital Component of 12Be Ground State

As shown by the fermionic molecular dynamics (FMD) calculations (see the inset (b) in Fig. 10 of Ref. [33]), different configuration mixings of the two valence neutrons in 12Be lead to different nuclear-matter density distributions of 12Be, and the difference is clearly indicated in the surface structure of 12Be. Inspired by this result, we propose a method to extract the ground-state component of 12Be.

In this method, we treat 12Be as a system of a 10Be core plus two valence neutrons, as usual. The 10Be core determines the nuclear-matter density distribution of the core part of 12Be, while the two valence neutrons determine the outer part density distribution. According to the intruder configuration of 12Be [4], the two valence neutrons are populated in 1p1/2, 1d5/2, and 2s1/2 states at certain occupation probabilities. Therefore, we can construct the outer structure of 12Be according to a certain configuration as long as a model can provide a preferable density distribution of the two valence neutrons corresponding to different states. By using an appropriate function to describe the core structure of 12Be, we can construct a nuclear-matter density distribution of the ground state of 12Be. By adjusting the proportion of the components, we can find a nuclear-matter density distribution that is consistent with the experimental result. The corresponding proportion can then provide configuration information about the 12Be ground state.

We have attempted to extract the ground-state component of 12Be to verify the feasibility of the method. As mentioned above, a precondition of the method is to obtain the valence neutron density distributions corresponding to the 1p1/2, 1d5/2, and 2s1/2 states. Usually, single-particle model (SPM), three-body model, cluster model, shell model, etc., are used to calculate the density distribution of the valence neutron. In this article, the SPM [35] is used. In this SPM, the Woods-Saxon potential, the Coulomb barrier, and the centrifugal barrier are taken into account. The nuclear part of the potential is assumed to be written as

$$V(r) = [-V_0 + V_1(\mathbf{l}\cdot\mathbf{s})]\left[1+\exp\left(\frac{r-R_c}{a}\right)\right]^{-1},$$

where V_0 is the depth of the Woods-Saxon potential, $V_1 = 17$ MeV is the $\mathbf{l}\cdot\mathbf{s}$ strength taken from Ref. [50], $r_{\mathbf{l}\cdot\mathbf{s}} = 1.1$ fm is the radius of the spin-orbit potential, $R_c = r_{0A}^{1/3}$ ($r_0 = 1.2$ fm) is the radius of the Woods-Saxon potential, and $a = 0.6$ fm is the diffuseness parameter. V_0 is adjusted to reproduce the separation energy of the valence neutron. Here we treat the two valence neutrons as equal and set the separation energy of a single valence neutron to be half of the two-neutron separation energy of 12Be. The corresponding nuclear-matter density distributions of the two valence neutrons are shown in Fig. 7 [Figure 7: see original paper]. We can see that the 2s1/2 state has larger density at the surface. Although different models will not give exactly the same density distributions of the two valence neutrons, we infer that our result is less model-dependent based on the fact that the s-intruder valence neutron configuration is the chief cause of the halo-like structure in light nuclei, as in the cases of 11Li and 11Be.

Then we consider a configuration mixing of 1p1/2, 1d5/2, and 2s1/2 for the two valence neutrons as follows:

$$\rho_{2n} = \alpha\rho[(1p_{1/2})^2] + \beta\rho[(1d_{5/2})^2] + (1-\alpha-\beta)\rho[(2s_{1/2})^2],$$

where α and β denote the occupation probabilities of the $(1p_{1/2})^2$ and $(1d_{5/2})^2$ configurations, respectively. The integrals of the single-configuration density and mixed density are all normalized to two nucleons. Combining the 10Be core distribution of Gaussian-Gaussian (GG) parametrization given in Ref. [33], we calculated the corresponding σR and obtained a range of σR accordingly, as indicated in Fig. 8 [Figure 8: see original paper]. We can see clearly that σR is sensitive to the s-orbital occupancy, and it is difficult to derive the p- and d-orbital occupancies from the σR data. This is because the 2s1/2 component contributes much more to the surface structure of 12Be than the other components. By using the σI of 12Be on C in Ref. [30], we extract the upper limit of the s-orbital occupation probability to be about 56%. The upper limits are indicated by the vertical line in Fig. 8(c).

The result indicates that the s-orbital is not a dominant component in the 12Be ground state. This is supposed to be the reason why the halo-like structure in 12Be is not evident, because the s-orbital component is the major contribution to the halo-like structure. Compared with the calculations given in Refs. [4, 20–22, 24], our result is relatively small (Table 3). Although our result is consistent with the β-decay result given in Ref. [42], large uncertainty exists in both results. Therefore, higher-precision extraction is needed.

By comparing the increasing trend of σR in insets (c) and (f) of Fig. 8, one sees that in the low-energy region, σR is even more sensitive to the s-orbital occupancy. This implies that the extraction uncertainty can be reduced if σR in the low-energy region is used. Therefore, we calculate σR based on an s-orbital occupation of 28% (half the value of the upper limit) and a p-orbital occupation probability of 25%, as the percentage of the 1p1/2 component was determined as $25 \pm 5\%$ [10]. The result is shown in Fig. 8(f), in which the hatched area indicates a 2% error band. Thereby we can extract that the uncertainty of the s-orbital occupation probability is about 23%. Taking into account that six data points will be available from the experiment introduced in the previous section, the precision of the extracted s-orbital occupation probability is expected to be around 9%. This makes the experimental measurement of σR in the low-energy region more desirable.

Since the percentage of the 1p1/2 component has been determined by Gamow-Teller transition strengths [10], if either the 1d5/2 or 2s1/2 component is extracted precisely, the ground-state configuration of 12Be shall be reliably determined. Our method provides a promising approach to extract the 2s1/2 component of the 12Be ground state and to determine the ground-state configuration of 12Be. Through the proposed σR measurements, we expect to extract the s-orbital occupation probability with 9% uncertainty.

TABLE 3 . Two-neutron occupancy (%) for 12Be (g.s.) as 10Be + 2n.

Method	$(1p)^2$	$(1d)^2$	$(2s)^2$
Calc. [20]	0	0	100
Calc. [21]	0	0	100
Calc. [22]	0	0	100
Calc. [23]	0	0	100
Calc. [24]	0	0	100
(^{3}He,^{6} He) [4]	0	0	100
β decay [42]	0	0	100
β decay [53]	0	0	100
β decay [54]	0	0	100
nucleon transfer reaction [55]	0	0	100
extracted from spectroscopic factors [9]	0	0	100
extracted from Gamow-Teller Transition Strengths [10]	25 ± 5	0	75 ± 5
extracted from σI [30]	-	-	56 (upper limit)
present work	-	-	56 (upper limit)

V. Summary

In summary, the ground-state structure of 12Be is of great significance. The ambiguity of the configuration of the 12Be ground state has attracted our attention. We propose to determine the s-orbital component of the 12Be ground state by measuring the σR of 12Be on C and Al at several tens of MeV/nucleon. By using existing interaction cross-section data of 12Be on C at 790 MeV/nucleon, we roughly determine the upper limit of the s-orbital occupation probability of the 12Be ground state to be 56% with SPM calculations. The precision of the s-orbital occupation probability is expected to be 9% by using the proposed 2% σR data. The feasibility of the σR measurement is carefully studied, and concrete procedures of the experiment are given.

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