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Studies on the exotic structure of ^{23}Al*

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Abstract The longitudinal momentum distribution ($P_{//}$) of fragments after one-proton removal from ^{23}Al and reaction cross sections ($\sigma_{\rm R}$) for ^{23,24}Al on carbon target at 74A MeV have been measured simultaneously. An enhancement in $\sigma_{\rm R}$ is observed for ^{23}Al compared with ^{24}Al. The full width at half maximum of the $P_{//}$ distribution for ^{22}Mg fragments has been determined to be 232±28 MeV/c. Analysis of $P_{//}$ using the Few-Body Glauber Model indicates a dominant d-wave configuration for the valence proton in the ground state of ^{23}Al. The exotic structure in ^{23}Al is discussed.

Key words proton-rich nuclei, reaction cross section, longitudinal momentum distribution

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1 Introduction

Since the observation of an remarkably large interaction cross section ($\sigma_{\rm I}$) for ^{11}Li[1], it has been shown that there is exotic structure like neutron halo or skin in light neutron-rich nuclei. Measurements of $\sigma_{\rm R}$, $P_{//}$ of one or two nucleons removal reaction, quadrupole moment and Coulomb dissociation have been demonstrated to be very effective methods to identify and investigate the structure of halo nuclei. The neutron skin or halo nuclei ^{6,8}He, ^{11}Li, ^{11}Be, ^{19}C etc.[1—3], have been identified by these experimental methods. Due to Coulomb barriers, the identification of a proton halo is more difficult compared to a neutron halo. Discrepancies have been found for proton halo in ^{8}B[1, 4—6].

Proton-rich nucleus ^{23}Al has a very small separation energy ($S_p = 0.125$ MeV)[7] and is a candidate of proton halo. An enhanced $\sigma_{\rm R}$ for ^{23}Al has been observed previously[8]. A long tail in the proton density distribution has been extracted for ^{23}Al which indicates an exotic structure. While the spin and parity (J^{π}) for ^{23}Al has been deduced to be $5/2^+$ recently[9]. This result favors the d-wave configuration for the

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valence proton in ^{23}Al. In this paper we will report the simultaneously measurement of σ_R and $P_{//}$ for study on the exotic structure of ^{23}Al.

2 Experiment

The experiment was performed at RIPS in RIKEN. Secondary beams were generated by fragmentation reaction of 135 AMeV ^{28}Si beam on a ^{9}Be target. At the first dispersive focus, a Al wedge-shape degrader was installed and a Parallel Plate Avalanche Counter (PPAC) was placed. An ion chamber was used to measure the energy loss (ΔE) at the second focus. A plastic was placed before a C reaction target to measure the time-of-flight (TOF) from the PPAC at F1. The particle identification before the reaction target was done by means of $B\rho$-ΔE-TOF method. After the reaction target, a quadrupole triplet was used to transport and focus the beam onto F3. Another plastic gave a stop signal of the TOF from F2 to F3. Another ion chamber was used to measure ΔE. The total energy (E) was measured by a NaI(Tl) detector. The particles were identified by TOF-ΔE-E method.

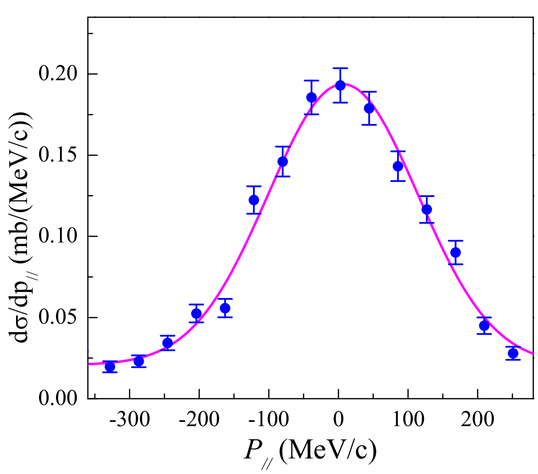

Fig. 1. $P_{//}$ distribution of fragment ^{22}Mg after one-proton removal from ^{23}Al. The closed circles with error bars are the present data, the solid curve is a Gaussian fit to the data.

For one-proton removal reactions of ^{23}Al, $P_{//}$ of the fragments is determined from the TOF after the target. The obtained $P_{//}$ of the ^{22}Mg fragments from ^{23}Al breakup at 74 AMeV is shown in Fig. 1. A Gaussian function was used to fit the results. The full width at half maximum (FWHM) was determined to be 232±28 MeV/c after unfolding the Gaussian-shaped system resolution. The FWHM is consistent with the Goldhaber model's prediction within the error bar[10].

Reaction cross section is determined using the transmission method, by events of projectile before and after the reaction target from target-in and target-out measurements. The σ_R of ^{23,24}Al at 74 AMeV were obtained to be 1609±79 mb and 1527±112 mb, respectively. The errors include the statistical and systematic uncertainties. We observed an enhanced σ_R for ^{23}Al in our data again as in the previous experiment[8].

3 Discussion

To interpret the measured σ_R and $P_{//}$ data, we performed a Few-Body Glauber Model (FBGM) analysis[11]. In this model, a core plus proton structure is assumed for the projectile. For the core, HO-type functions were used for the density distributions. The wavefunction of the valence neutron was calculated by solving the eigenvalue problem in a Woods-Saxon potential. The separation energy of the last proton is reproduced by adjusting the potential depth.

The spin and parity for the ground state of ^{23}Al is shown to be $5/2^+$. Assuming the ^{22}Mg+p structure, three different configurations are possible for $J^\pi = 5/2^+$ of ^{23}Al: $0^+ \otimes 1d_{5/2}$, $2^+ \otimes 1d_{5/2}$ and $2^+ \otimes 2s_{1/2}$[9].

The $P_{//}$ for the valence proton in the s or d-wave are calculated by use of the FBGM. The width parameters in the HO density distribution of ^{22}Mg were adjusted to reproduce the σ_I data at around 1 AGeV[12]. The extracted effective root-mean-square matter radii ($R_{\rm rms}$) for ^{22}Mg is 2.89±0.09 fm. To see the one-proton separation energy (S_p) dependence, the $P_{//}$ is calculated assuming an arbitrary S_p in calculation of the wavefunction for the valence proton in ^{23}Al and shown in Fig. 2. If we adopt a larger radii of $R_{\rm rms} = 3.6$ fm for ^{22}Mg to see the core size effect on $P_{//}$, we obtained solid and open squares of FWHM in Fig. 2. S_p for ^{22}Mg in the ground and excited ($J^\pi = 2^+$, $E_x = 1.25$ MeV) states are taken as 0.125 MeV and 1.375 MeV ($E_x + 0.125$ MeV). Those two values are marked by two arrows in Fig. 2. In this figure, we can see that the width for the s and d-wave are obviously separated. The width for the

s-wave is much lower than the data, while that of the d-wave is close to the experimental FWHM. With the increase of S_p, the width of $P_{//}$ increases slowly. That means $P_{//}$ will become wider for ^{22}Mg in the excited state. The effect of the core size on $P_{//}$ is negligible for the s-wave but not for the d-wave configuration. The larger sized core will give a wider $P_{//}$ distribution. From comparison of the FBGM calculation with the data in Fig. 2, it clearly indicates that the valence proton in ^{23}Al is dominantly in the d-wave configuration. This is consistent with the shell model calculations and also the Coulomb dissociation measurement[9, 13].

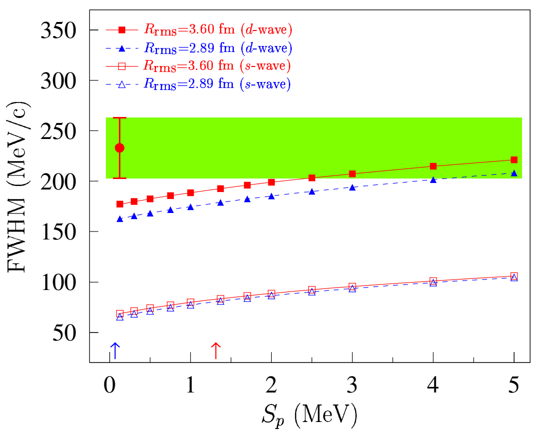

Fig. 2. The dependence of FWHM for $P_{//}$ after one-proton removal of ^{23}Al on the separation energy of the valence proton. The solid circles with error bars is the present data, the shaded area refers to its error. The solid and open squares are the FBGM calculations for the d and s-wave of the valence proton with the core $R_{\rm rms} = 3.6$ fm. The solid and open triangles are for the core $R_{\rm rms} = 2.89$ fm. The lines are just for guiding the eyes. The two arrows refer to the separation energy of 0.125 MeV and 1.37 MeV.

For the calculation of $\sigma_{\rm R}$ using the FBGM, $R_{\rm rms} = 2.89\pm0.09$ fm is used for ^{22}Mg and the valence proton is assumed to be in d-wave as discussed above. But the calculated $\sigma_{\rm R}$ for ^{23}Al is much lower than the obtained $\sigma_{\rm R}$ data. Similar puzzle is also encountered for some neutron-rich nuclei ^{19}C and ^{23}O. One way is to enlarge the core size to reproduce the $\sigma_{\rm R}$ data[14]. Here we changed the core size of ^{22}Mg. The dependence of $\sigma_{\rm R}$ on $R_{\rm rms}$ of the core is shown in Fig. 3. In the FBGM calculations, The range parameter (β) is calculated by the formula which is determined by fitting the σ_R of ^{12}C + ^{12}C from low to high energies[15]. β is 0 and 0.35 fm for 1 AGeV and 74 AMeV, respectively. The $\sigma_{\rm R}$ of ^{23}Al is very sensitive to the size of ^{22}Mg core. To reproduce the measured $\sigma_{\rm R}$ of ^{23}Al, the calculated results indicates an enlarged ^{22}Mg core with $R_{\rm rms} = 3.37 \pm 0.18$ fm. It is 17±7% larger than the size of the bare ^{22}Mg nucleus.

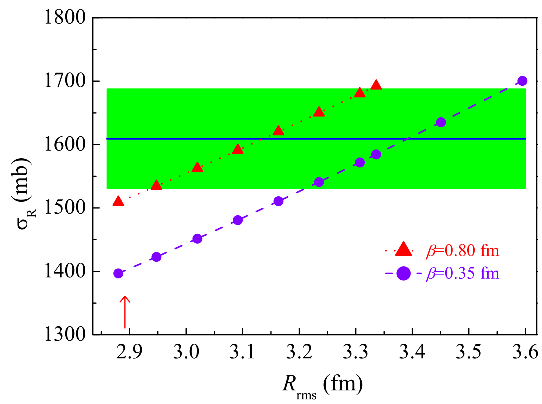

Fig. 3. The dependence of $\sigma_{\rm R}$ at 74 AMeV on the core size ($R_{\rm rms}$). The horizontal line is the experimental $\sigma_{\rm R}$ value, the shadowed area is the error of $\sigma_{\rm R}$. The solid circles and triangles denote the FBGM calculations with the range parameter $\beta = 0.35$ fm and $\beta = 0.80$ fm, respectively. The size of ^{22}Mg obtained by fitting the $\sigma_{\rm I}$ data at around 1 AGeV is marked by an arrow.

But there may be another possibility due to the Glauber model's underestimation of $\sigma_{\rm R}$ at intermediate energies[16]. The $\sigma_{\rm R}$ of ^{24}Al is calculated with the size of ^{23}Mg core determined by fitting $\sigma_{\rm I}$ at around 1 AGeV[12]. But the calculated $\sigma_{\rm R}$ for ^{24}Al is only 1430 mb and it is 10% lower than the data. Since scope of the discrepancies in the Glauber model is large, underestimation may still exist for $\beta = 0.35$ fm at 74 AMeV. To correct the possible underestimation, we adjusted β to fit the $\sigma_{\rm R}$ of ^{24}Al from the present measurement. $\beta = 0.8$ fm is obtained when the $\sigma_{\rm R}$ of ^{24}Al is reproduced. Using this range parameter, the $\sigma_{\rm R}$ of ^{23}Al is calculated and shown in Fig. 3. The calculated results indicates the core size of $R_{\rm rms} = 3.13 \pm 0.18$ fm (8±7% larger than the size of ^{22}Mg deduced by the $\sigma_{\rm I}$ data). The obtained size of ^{22}Mg is different for the two range parameters, but both calculations suggest an enlarged core inside ^{23}Al.

4 Conclusion

In summary, the $P_{//}$ for ^{23}Al and $\sigma_{\rm R}$ for ^{23,24}Al were measured. An enhancement was observed for

σ_R of ^{23}Al. The $P_{//}$ was found to be wide. We determined the valence proton to be a dominant d-wave in the ground state of ^{23}Al. An enlarged core was revealed in order to explain both the σ_R and $P_{//}$ data.

References

1 Tanihata I et al. Phys. Rev. Lett., 1985, **55**: 2676; Tanihata I et al. Phys. Lett. B, 1992, **287**: 307

2 Fukuda M et al. Phys. Lett. B, 1991, **268**: 339

3 Bazin D et al. Phys. Rev. Lett., 1995, **74**: 3569; Nakamura T et al. Phys. Rev. Lett., 1999, **83**: 1112; Ozawa A et al. Nucl. Phys. A, 2001, **691**: 599

4 Minamisono T et al. Phys. Rev. Lett., 1992, **69**: 2058; Schwab W et al. Z. Phys. A, 1995, **350**: 283

5 Warner R E et al. Phys. Rev. C, 1995, **52**: R1166; Negoita F, Borcea C, Carstoiu F. Phys. Rev. C, 1996, **54**: 1787; Fukuda M et al. Nucl. Phys. A, 1999, **656**: 209

6 Obuti M M et al. Nucl. Phys. A, 1996, **609**: 74

7 Audi G, Wapstra A H. Nucl. Phys. A, 1993, **565**: 66

8 CAI X Z et al. Phys. Rev. C, 2002, **65**: 024610

9 Ozawa A et al. Phys. Rev. C, 2006, **74**: 021301R

10 Goldhaber A S. Phys. Lett. B, 1974, **53**: 306

11 Ogawa Y et al. Nucl. Phys. A, 1992, **543**: 722; Abu-Ibrahim B et al. Comput. Phys. Comm., 2003, **151**: 369

12 Suzuki T et al. Nucl. Phys. A, 1998, **630**: 661

13 Gomi T et al. Nucl. Phys. A, 2005, **758**: 761c

14 Kanungo R et al. Nucl. Phys. A, 2000, **677**: 171; Kanungo R et al. Phys. Rev. Lett., 2002, **88**: 142502

15 ZHENG T et al. Nucl. Phys. A, 2002, **709**: 103

16 Ozawa A et al. Nucl. Phys. A, 1996, **608**: 63