## The structure of $^{23}$Al studied with breakup at intermediate energies

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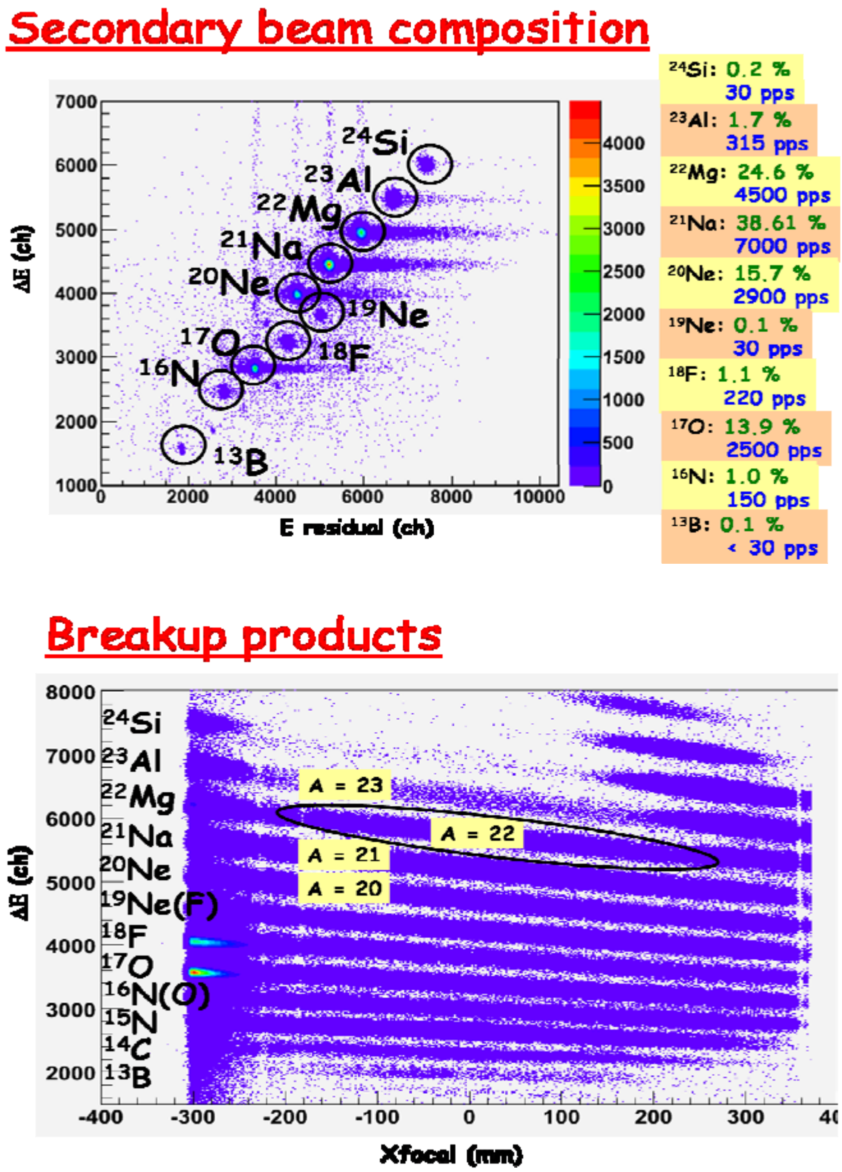
We report on the use of one proton-removal reactions of loosely bound nuclei at intermediate energies as an indirect method in nuclear astrophysics, with particular reference to the results of an experiment carried out at GANIL that investigated a cocktail beam around $^{23}$Al at 50 MeV/nucleon. Momentum distributions of the core fragments, inclusive and in coincidence with γ rays detected at the target position with 8 Germanium clovers of the powerful gamma spectrometer EXOGAM [1], were measured. The parallel and transverse momentum distributions of the core measured in one-nucleon removal (breakup) reactions are the spectroscopic tools available to determine the single particle structure of the loosely bound, exotic nuclei, due to their sensitivity to the angular momentum of the orbital involved. By measuring the core momentum distributions, from the shape one can determine the quantum numbers of the s.p. orbital, and from the integrated total and partial cross sections one is able to extract the corresponding asymptotic normalization coefficients (ANCs) of the wave function's components [2]. One can extract also the spectroscopic factors, but the values are parameter dependent. Our experiment was aimed to determine with an independent method the structure of the ground state of $^{23}$Al by measuring the inclusive one-proton breakup cross section at intermediate energies, as well the configuration mixing from coincidences with gamma rays from the $^{22}$Mg core left excited after the proton removal. The proton breakup reactions can provide information needed to determine astrophysical reaction rates for radiative proton captures (p,γ) that are outside the reach of other direct or indirect methods, or can give complementary information to the one obtained from transfer reactions (the ANC method [3]) which requires radioactive beams of much better purity and intensity.  This new method was successfully applied in the past to the study of $^{8}$B [2] and $^{9}$C [4] breakup and the ANCs determined were used to determine the astrophysical S-factors for the proton radiative capture reactions $^{7}$Be(p,γ)$^{8}$B and $^{8}$B(p,γ)$^{9}$C, respectively.

The method has also the advantage that can be used for beams of low quality, such as cocktail beams, and intensities as low as a few pps. In the experiment E491 at GANIL, a primary $^{32}S$ beam at 95 MeV/u impinged on a C target and SISSI was used to separate 14 secondary beams at 1.95 Tm rigidity.




(a) (b)

FIG. 1. (a) Composition of the secondary cocktail beam: 14 ion species were produced, their production rates is also illustrated in the figure. (b) Separation of the breakup products by their mass and position in the focal plane of the SPEG energy loss spectrometer at GANIL. The "gate" corresponding to mass A = 22 shows the distribution of the $^{22}Mg$ fragments resulted from $^{23}Al$ breakup.

They impinged on another C target at the entrance of the spectrometer SPEG that was tuned to measure the momentum of the cores after one-proton removal. EXOGAM was positioned around the target. Only preliminary results on the proton breakup of $^{23}Al$ are presented in the following. Fig. 1 (a) shows the composition of the secondary cocktail beam that was used in the experiment along with the production rates for some of the 14 ion species. Fig. 1 (b) shows the selection of the breakup fragments by their mass and position in the focal plane of the SPEG energy loss spectrometer at GANIL. Fig. 2 (a) shows the gamma lines detected by EXOGAM in coincidence with the fragments resulting from the breakup of $^{23}$Al.

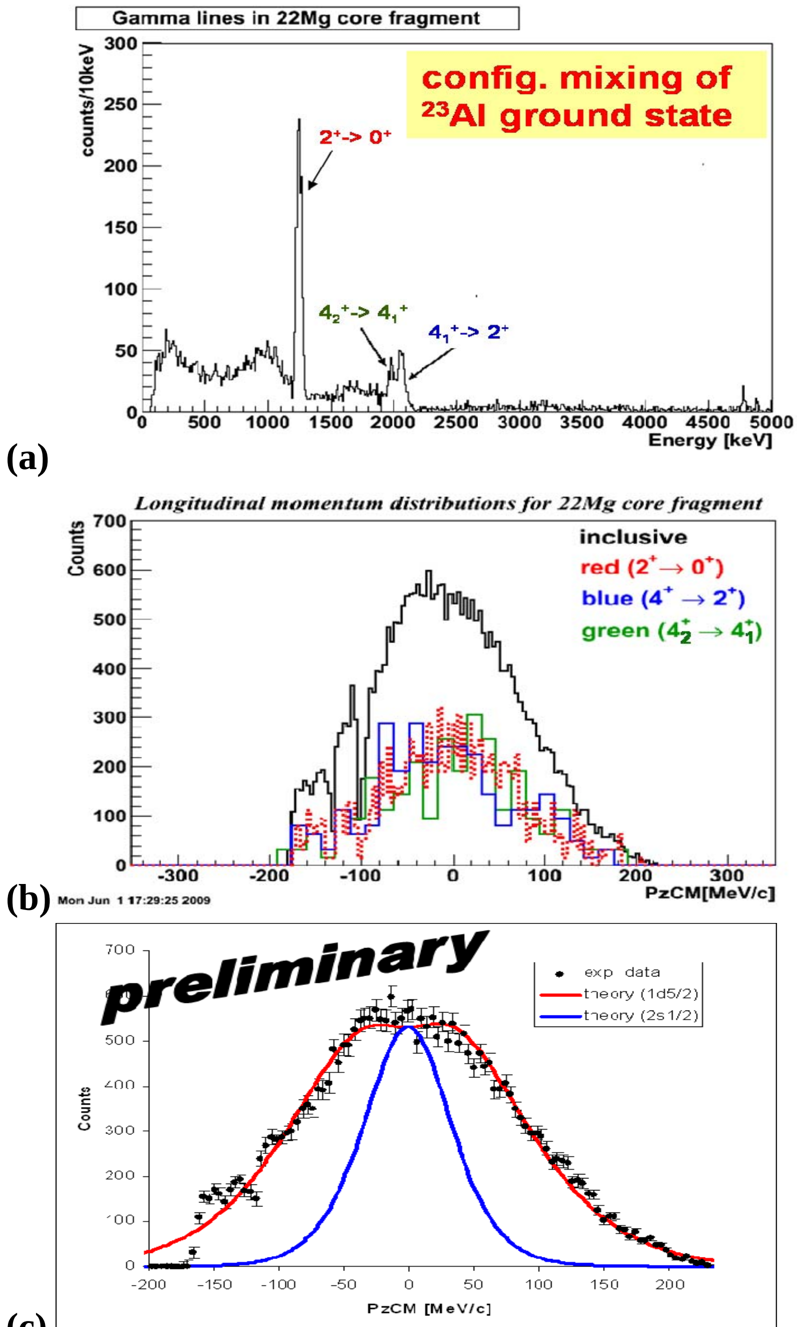



FIG. 2. (a) Measured gamma lines (Doppler corrected) depopulationg excited states in $^{22}$Mg breakup fragments: 1246.98 keV, 1984.8 keV, and 2061.09 keV giving us information about the configuration mixing characterizing the ground state of $^{23}$Al. (b) Corresponding longitudinal momentum distributions in the rest frame along with the inclusive longitudinal momentum distributions. Their widths are about 200 MeV/c (FWHM) and are reproduced by theoretical calculations for d5/2 wave states. Note that the drops around -100 and -140 MeV/c are of instrumental nature, reflecting some non-functioning pads in the SPEG focal plane detectors. (c) Direct comparison between experimental inclusive longitudinal momentum distribution and the theoretical calculations: in red colour with d5/2 wave states and in blue colour with s1/2 wave states. (See text for details)

An add-back procedure was implemented and used here to increase the gamma-ray detection efficiency, and the spectrum is corrected for Doppler shift. The lines observed correspond to transitions in $^{22}$Mg, attesting that the $^{22}$Mg core is left in various excited states after the removal of the least bound proton. That provides us with information about the configuration mixing that characterizes the ground state of $^{23}$Al. We observe clearly three gamma lines: 1246.98 keV ($2_1^+ \rightarrow 0_{gs}^+$), 2061.09 keV ($4_1^+ \rightarrow 2_1^+$), and 1984.8 keV ($(3^+,4^+,5^+) \rightarrow 4_1^+$), attesting for a large and complex configuration mixing. Fig. 2 (b) shows the corresponding longitudinal momentum distributions in the rest frame of the projectile and the inclusive longitudinal momentum distribution. The widths of these momentum distributions are approximately 200 MeV/c (FWHM) and are reproduced by theoretical calculations carried out with an extended version [5] of the Glauber model incorporating second-order noneikonal corrections. Double folding semi-microscopic potentials proton-target and core-target were calculated using the JLM effective nucleon-nucleon interaction. The potentials were used to evaluate the scattering matrix elements needed to describe the nuclear breakup process. The measured momentum distributions for the $^{22}$Mg core agree in shape (about 200 MeV/c width) with those calculated for the $1d_{5/2}$ orbital, not with those for $2s_{1/2}$ (about 60 MeV/c width), as illustrated in Fig. 2 (c). This confirms the ground state spin and parity for $^{23}$Al to be $J^{\pi} = 5/2^+$, not $1/2^+$, a distinction very important for the rate of the astrophysical reaction, and in agreement with the results from beta decay [6]. A detailed discussion of these results will be given elsewhere [7].

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