


Development of a PID algorithm for the CALIFA detector to study multinucleon knockout reactions in exotic nuclei

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ABSTRACT

Previous studies have shown a reduction in cross sections relative to theoretical predictions for single-nucleon knockout reactions, with varying conclusions about the dependence of this reduction on the N/Z ratio of the projectile. The (p,pX) knockout reactions studied with the R³B setup offer a unique opportunity for kinematically complete measurements using inverse kinematics. This work focuses on the development of an algorithm for performing particle identification using the CALIFA detector, of vital importance for the study of knocked-out clusters such as deuterium.

1. Introduction

Single nucleon knockout cross sections are often reduced relative to theoretical predictions, with varying dependence on the neutron-proton asymmetry (N/Z) of the projectile. While some studies report a significant correlation between the reduction factor and N/Z of the projectile [1,2], others suggest a weaker dependence [3,4]. The mechanisms behind this quenching remain unclear, necessitating further investigation into whether it stems from nucleon correlations or other factors.

This experiment measures both single-particle and multiple-knockout reactions to clarify the factors contributing to the observed quenching. Key contributors include short-range correlations (SRC) -pairs of nucleons have large relative momentum compared to their center of mass one [5]-, final state interactions, cluster emission, model inadequacies, and underestimation of the excitation energy of the remaining core [6], each affecting the observed reduction in cross sections.

2. The R³B experimental setup

Complete kinematical measurements of all the reaction products can be performed with the versatile R³B setup (Fig. 1 in [7]). Exotic light isotopes (B, C, N, O) produced with the Fragment Separator (FRS) impinge onto a liquid hydrogen target. The incoming

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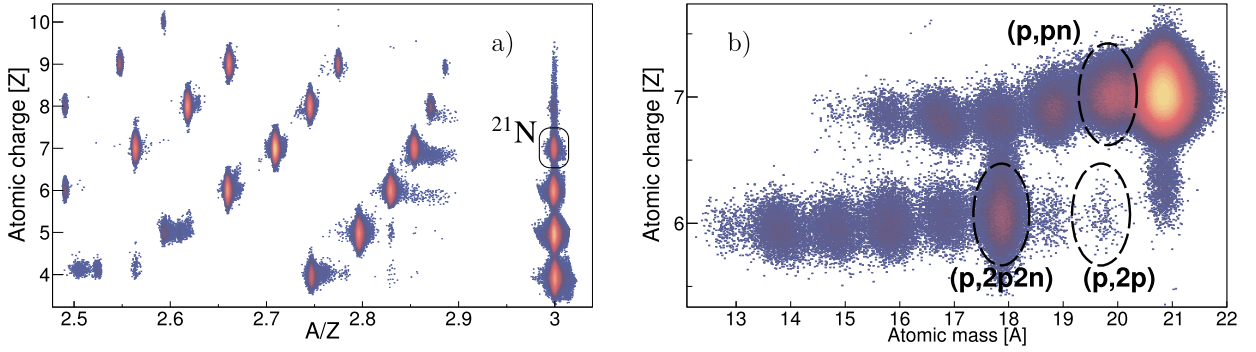


Fig. 1. (a) Identification of the incoming isotopes arriving at the experimental setup. (b) Outgoing fragments when selecting ^{21}N as the incoming isotope.

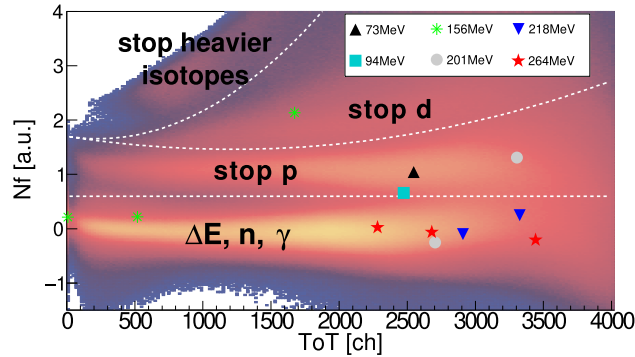


Fig. 2. Fast component of the signal vs ToT. The white dashed lines define the regions assigned for each type of particle. Points are crystals of 6 clusters, shown as example. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

ions are identified in terms of charge (Z) and mass (A) by using a MUSIC detector and the time-of-flight between the FRS and a plastic scintillator at the beginning of the R^3B setup, as shown in the Fig. 1(a). The outgoing fragment's charge is measured in the ToFD, a set of plastic scintillators. The mass is calculated from the $B\rho$ using the positions in the SciFibers. An example of the identification of the fragments is shown in Fig. 1(b) when selecting ^{21}N as incoming. Of special interest for this work is the CALIFA detector, a highly segmented (1504 crystals) calorimeter that surrounds the target. The expected energy resolution is 6% for 1 MeV γ -rays and around 1% for light charged particles (LCP) up to 320 MeV [8].

3. Results

The current focus is developing a particle identification algorithm using the signal shape in the crystals of CALIFA. This is performed using the Time-over-Threshold (ToT) and the fast component of the signal (N_f) in the CsI(Tl), which is calculated as the integral of the signal during its rise after some shaping, as explained in detail in Ref. [9]. A linearization is applied to the variables, achieving a matrix identification as the one shown in Fig. 2. The different regions for the particle identification are delimited with dashed white lines. When a particle reaches the CALIFA detector, its deposited energy is usually spread into several crystals. To reconstruct the initial energy, a clusterization algorithm that adds the energies measured in neighboring crystals is applied when a high-energy signal is detected. After that, to perform the particle identification it is needed to check the signals in all the crystals of a cluster. Suppose the particle that created the cluster is stopped in the calorimeter. In that case, only one of the crystals will have a stopped-particle-like signal (in the proton, deuteron or heavier isotope region, depending on the particle). The others will be punchthrough-like (ΔE), being in the same region as neutrons (n) and γ 's.

Moreover, inelastic reactions that produced particles inside a crystal can be identified in some cases with this method. In Fig. 2, in addition to the identification matrix, six clusters (total energy in legend) are displayed for the $^{21}\text{N}(p,2p)^{20}\text{C}$ channel reaction. Each marker type represents one of the six clusters, being the different points the crystal with $\text{ToT} > 0$ inside that cluster. The gray circle, black triangle and cyan square clusters are compatible with a stopped proton, because even though the gray one had a crystal with a punchthrough-like signal, the three of them have one crystal with a stopped proton. On the contrary, the blue triangle and the red star clusters could be punchthrough protons, since all their crystal lay in the punchthrough region. There is a third case, the green asterisk cluster, which has a crystal with a signal compatible with a deuteron. Since a $(p,2p)$ channel reaction is selected, this deuteron is most likely created in an inelastic reaction inside the calorimeter.

Table 1 summarizes the probabilities of the different outcomes when selecting a $(p,2p)$ reaction. The addition of the numbers in blue is the probability of identifying an inelastic reaction, because they correspond to outcomes that are neither a stopped proton nor

Table 1

Probabilities (%) of experimentally finding $No.$ crystals inside a certain region for a cluster when selecting a $(p,2p)$ reaction. Some other inelastic channels such as $stop\ p + stop\ d$ are not included in the Table, but their probabilities are considered for the total estimation of inelastic reactions. The defined regions are displayed in Fig. 2, from bottom to top: ΔE , n and γ ; stopped p ; stopped d ; stopped heavier isotopes.

$No.$	ΔE	Stop p	Stop d
1	18.2	42.7	14
2	15.4	3.5	1.0
3	4.9	1.4	0.3
4	2.4	0.0	0.0
total	40.9	47.6	15.4

a punchthrough one: they are events when more than one stopped proton was identified, or a deuteron was stopped. Our probability estimation of inelastic reactions (21%) is in good agreement with calculations and previous observations [10].

4. Conclusions

The development and application of the particle identification algorithm using the signal shape in the CALIFA calorimeter has proven effective in distinguishing various cluster types, of utter importance for the study of (p,pX) knockout reactions. The ability to differentiate between stopped and punchthrough particles, as well as inelastic reactions, demonstrates the potential of this method and lays the groundwork for its further refinement and application in other experiments. In particular, the next step would be applying the algorithm with a gate in the fragment Z-1 A-2, to try to distinguish (p,pd) events vs. (p,ppn) ones. Linking the outcome of this algorithm with other observables in a systematic way is now planned, so valuable information about the knockout cross section quenching is obtained.

CRedit authorship contribution statement

M. Feijoo-Fontán: Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **A. Barrière:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **N. Mozumdar:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **H. Álvarez-Pol:** Writing – review & editing, Validation, Conceptualization. **J.L. Rodríguez-Sánchez:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **O. Sorlin:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **J. Benlliure:** Writing – review & editing, Methodology, Investigation, Conceptualization. **D. Cortina-Gil:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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