β decay of ^{22,23}Si studied at MARS with the optical time projection chamber

A.A. Ciemny,[1] C. Mazzocchi,[1] W. Dominik,[1] A. Fijałkowska,[2] J. Hooker,[3] K. Hunt,[3]
H. Jayatissa,[3] Z. Janas,[1] Ł. Janiak,[1] G. Kamiński,[4] Y. Koshchiy,[3] M. Pfützner,[1] M. Pomorski,[1]
B. Roeder,[3] G. Rogachev,[3] A. Saastamoinen,[3] S. Sharma,[1] and N. Sokołowska[1]
[1]*Faculty of Physics, University of Warsaw, Warsaw, Poland*
[2] *Rutgers University, New Brunswick, New Jersey*
[3]*Cyclotron Institute, Texas A&M University, College Station, Texas*
[4] *JINR Dubna, Russia*

Nuclei at or very close to the proton drip-line are characterized by large Q-value windows for delayed charged particle emission, with one, two and even three protons emitted promptly after β decay (βp, β2p, β3p). The investigation of such nuclei using charged-particle spectroscopy illuminates the structure of highly-unbound states in these exotic nuclei.

An experiment was conducted in Spring 2017 at the focal plane of the MARS spectrometer at the Cyclotron Institute of Texas A&M University, in order to search for unobserved decay channels of ^{22,23}Si. βp and β2p emission has been reported for these two isotopes, mostly proceeding via the isobaric analogue state (IAS) in the daughter nucleus [1, 2]. The β3p decay channel, as well as the delayed alpha-proton and the new ^{3}He channels, are open and so-far unobserved, as well as decay through other states than IAS. These nuclei were investigated using silicon-detector based arrays, which are sensitive only to the higher-energy portion of the proton spectrum. Therefore, the previously measured branching ratios for (multi-) proton emission in this region very often need to be (re)measured and corrected.

A ^{28}Si beam at 45 AMeV with a 150 µm-thick Ni target, was used to produce the ^{22,23}Si ions. The nuclei of interest were separated from the unwanted reaction products by using the MARS separator, optimized for transmission of ^{23}Si first and later of ^{22}Si, and implanted into the Optical Time Projection Chamber (OTPC) [3], which was installed at the MARS focal plane. The experimental set-up is described in detail in the 2016/17 Progress Report [4]. In brief, the OTPC is a time-projection chamber in which photons are emitted during the charge amplification. These are recorded by a sensitive CCD camera and two photomultiplier tubes (PMT). The former provides the projection of the tracks generated by charged particles on the plane of the anode (horizontal), while the latter provides the projection of the signal along the electric field lines (vertical). The PMTs were read out by fast oscilloscopes, providing the time distribution of the light emitted in the chamber.

A total of 6000 ions of ^{23}Si ($T_{1/2}$ = 42 ms) and less than 100 of ^{22}Si ($T_{1/2}$ = 29 ms) were implanted into the active volume of the OTPC detector. In both cases the observation window for detecting the decay was set to ~160 ms. After implantation of the ion the beam was stopped while waiting for the decay to happen and the data acquisition to record the event. For the analysis, only identified ^{22}Si and ^{23}Si ions implanted into the active volume were considered.

βp and β2p emission was observed as well as candidate events for β3p emission. The branching ratio for βp emission was measured to be 82.2(12) %, while the one for β2p emission about two times larger than reported in the literature. This discrepancy can be explained by the fact that the literature values (71% and 3.6% [5], respectively) stem from measurements based on a silicon-detector set-up, which has a higher threshold for observing the protons unambiguously because of the β background. The

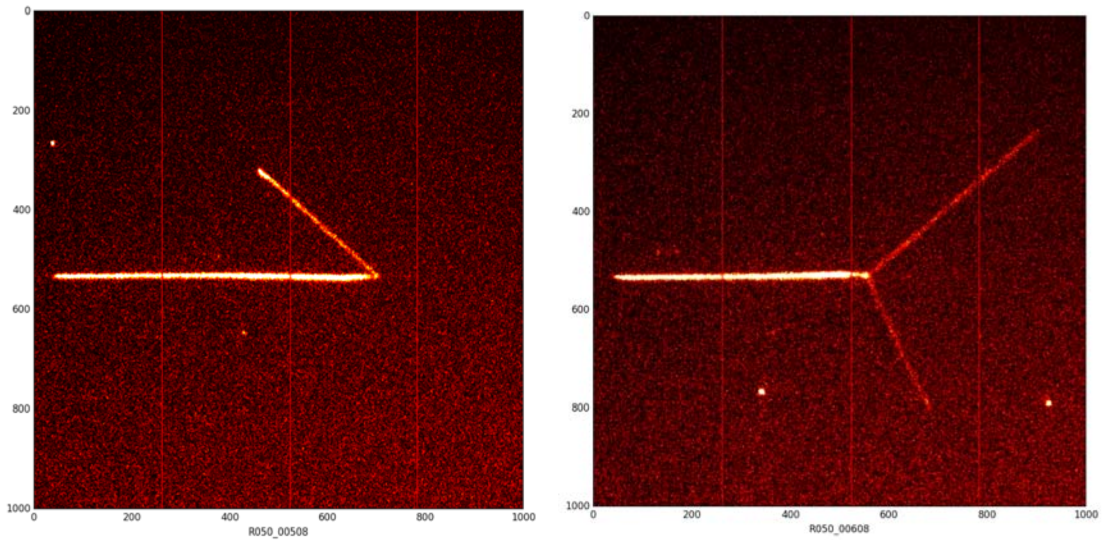

FIG. 1. On the left: CCD image of βp emission event from ^{23}Si. The track of the implanted ion is seen from left to right at the end of which the delayed proton is seen. The proton was stopped into the active volume of the detector (the Bragg peak is visible at the end of the proton trajectory). On the right: CCD image of β2p emission event from ^{23}Si. The two delayed protons are seen starting from the end of the ion trajectory. Both escape the active volume of the detector.

analysis is ongoing in order to reconstruct the energy spectrum for those protons that did not escape the active volume of the detector. In Fig. 1 two sample events of βp and β2p emission respectively are shown. The candidate events for β3p events are being analyzed.

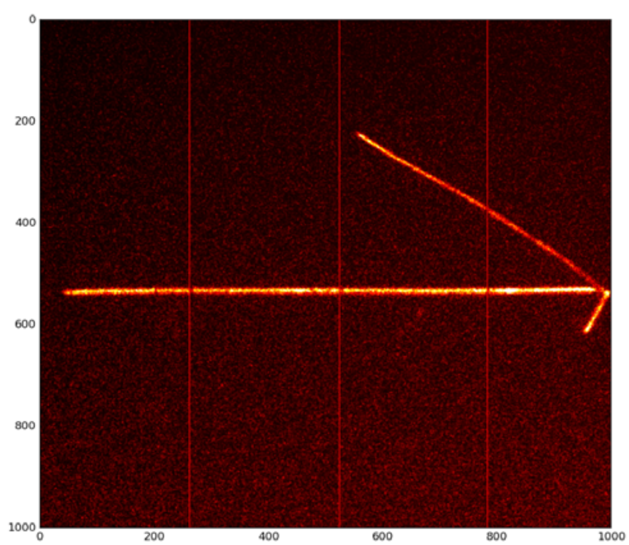

FIG. 2. Example of β2p emission decay event from ^{22}Si. In the CCD image the track of the ion (from left to right) and of the two protons can be seen.

The analysis of the decay of ^{22}Si is ongoing. Preliminarily, both the βp and β2p decay branches were seen. In Fig. 2 an example of β2p event is shown.

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