Nuclear Instruments and Methods in Physics Research A 607 (2009) 576–580

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

The Silicon Cube detector

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ARTICLE INFO

Article history:
Received 30 March 2009
Received in revised form
19 May 2009
Accepted 3 June 2009
Available online 16 June 2009

Keywords:
Nuclear Physics
β decay
Charged particles
Angular correlations
Silicon detectors

ABSTRACT

A new experimental device, the Silicon Cube detector, consisting of six double-sided silicon strip detectors placed in a compact geometry was developed at CENBG. Having a very good angular coverage and high granularity, it allows simultaneous measurements of energy and angular distributions of charged particles emitted from unbound nuclear states. In addition, large-volume Germanium detectors can be placed close to the collection point of the radioactive species to be studied. The setup is ideally suited for isotope separation on-line (ISOL)-type experiments to study multi-particle emitters and was tested during an experiment at the low-energy beam line of SPIRAL at GANIL.

1. Introduction

The advances made in accelerator physics in the last quarter of the 20th century allowed for the production of nuclei close to or on the drip lines, especially on the proton-rich side of the valley of β stability. One of the particularities of these very unstable nuclei is that the isobaric mass differences are bigger than for nuclei closer to stability. At the same time, the particle or cluster separation energies diminish, increasing thus the number of channels open after β decay. The exclusive detection of particles from these channels allows a full characterization of the decay of a nuclear state. To do this, one needs to identify the emitted particles and to measure their energies and emission angles. Several constraints have to be imposed on the detection system designed for such cases: (i) wide energy range with a good energy resolution; (ii) large angular coverage for particle detection in order to maximize the probability of detection of these exotic decays; (iii) high granularity for the individual detection of simultaneously emitted particles and for angular correlation measurements; (iv) possibility of discrimination between β rays and other charged particles emitted in the decay.

Setups similar to the one presented here, although not with the same angular coverage and granularity, have been used in the past at ISOL (isotope separation on-line) facilities like ISOLDE [1], the Accelerator Laboratory of the University of Jyväskylä [2] or LBNL Berkeley [3]. Descriptions of these setups can be found in Refs. [4–6].

2. Physics motivation

Beta-delayed multi-particle emission becomes increasingly important when approaching the drip lines. In particular, much attention has been paid lately on the proton-rich side to β-delayed two-proton (β2*p*) emission, since one expects to obtain direct information about the two-proton correlation inside the nucleus. The first and, up to now, the only high-statistics study of a β2*p* emitter was carried out at ISOLDE/CERN [5,7] on ^{31}Ar. There are other known β2*p* emitters [8] for which an angular correlation measurement was never performed (^{22}Al, ^{23}Si, ^{26}P, ^{27}S, ^{35}Ca, ^{39}Ti, ^{43}Cr and ^{50}Ni), or for which little information is available (^{22}Al, ^{26}P) [9].

Obviously, measurements for other types of prompt or delayed multi-particle emission processes can be performed with the proposed device. Studies of β3*p* emitters [10] might be interesting and decays of astrophysical interest [11] can be performed with the present setup.

3. The Silicon Cube

In the following sections we will describe the geometrical parameters, the electronics and the performances of the new setup.

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doi:10.1016/j.nima.2009.06.016

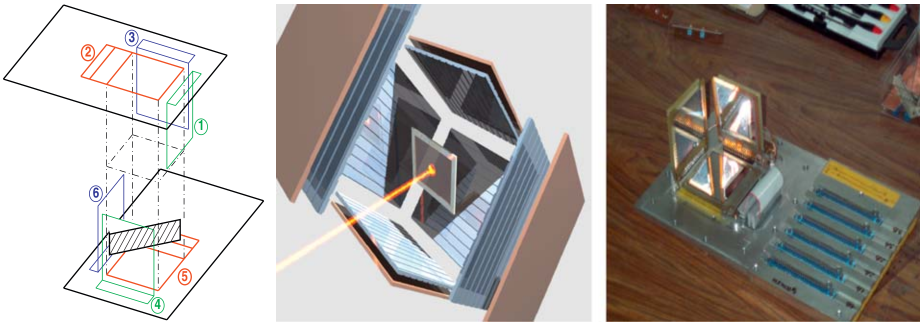

Fig. 1. Left-hand side: schematic view of the positioning of the detectors in the cube. The numbering reflects the DSSSD numbers used throughout this paper. The beam arrives between the detectors marked by 3 and 6 and is implanted in the middle of the cube, either on a fixed support or on a removable tape (represented in the center). The large rectangles represent the aluminum plate on which three DSSSDs are mounted and which contain the printed circuits for the readout. Center: artistic three-dimensional view of the setup showing the catcher foil in the center and the six DSSSDs backed by the PIPS detectors. Right-hand side: one half of the cube mounted on a plate supporting three DSSSDs and three PIPS detectors together with a printed circuit to connect the DSSSDs with the preamplifier cards outside the vacuum chamber.

3.1. *Geometrical design and detector description*

The Silicon Cube design combines the advantages of a compact structure with a high geometrical efficiency and a high transparency for γ radiation. As the name suggests, the detectors are placed in a cube-like geometry. In order to assure an important granularity the device is assembled with six $50 \times 50\,\text{mm}^2$ double-sided silicon strip detectors (DSSSDs). The present version of the device uses DSSSDs with 16 strips on each side and a pitch of 3 mm. Thus the entire device contains a total of 1536 ($3 \times 3\,\text{mm}^2$) pixels having only 192 electronics readout channels. The strip detector thickness used depends on the energy of the charged particles to be measured. When thick detectors (more than, e.g., 300 μm are needed to stop protons with energies up to 6 MeV) are required, one should also consider the pile-up with β electrons that can affect the energy resolution. In order to discriminate between β electrons and other charged particles, each DSSSD is backed by a $50 \times 50\,\text{mm}^2$ Passivated Implanted Planar Silicon (PIPS) detector that can be used as a veto for β electrons or to measure the total energy for particles that are not stopped in the strip detectors. The PIPS detectors should be sufficiently thick in order to maximize the probability of detecting the electrons. The detector system is placed in a compact vacuum chamber that allows to place up to four Germanium detectors close (for the present version of the device the minimum distance is 50 mm) to the center of the cube where the radioactive nuclei are implanted.

On the left-hand side of Fig. 1, a schematic drawing of the positioning of the detectors in the cube is shown and on the right-hand side one can see half of the cube mounted on the plate which carries three DSSSDs and the PIPS detectors as well as a printed circuit board which connects the DSSSDs with the preamplifier (PA) cards outside the vacuum chamber. The beam arrives between the detectors marked by 3 and 6 and is implanted in the middle of the cube, either on a fixed support that is represented in the center of the left drawing in Fig. 1 or on a tape that can be periodically moved in order to remove the deposited activity. The center of Fig. 1 shows an artist's view of the setup.

3.2. *Electronics*

Because of the important number of channels to be read (six DSSSDs and six PIPS detectors) one needs specific front-end electronics. An important issue is that the signal-to-noise ratio should be kept as good as possible. To do so, the preamplifiers for the silicon detectors should be placed as close as possible to the detectors. As one can see in Fig. 1, three detectors are grouped on a printed circuit plate that holds also the PAs. The PAs are grouped by packages of 16 channels and six such packs are connected to one printed circuit plate. Thus, each printed circuit board holds the electronics for three DSSSDs. The output of each PA can be connected, e.g., to a 16 channels CAEN N568B Spectroscopic Amplifier [12]. The acquisition system should support the readout of about 200 channels. Fig. 2 shows the Silicon Cube mounted at the end of the SPIRAL identification station [13].

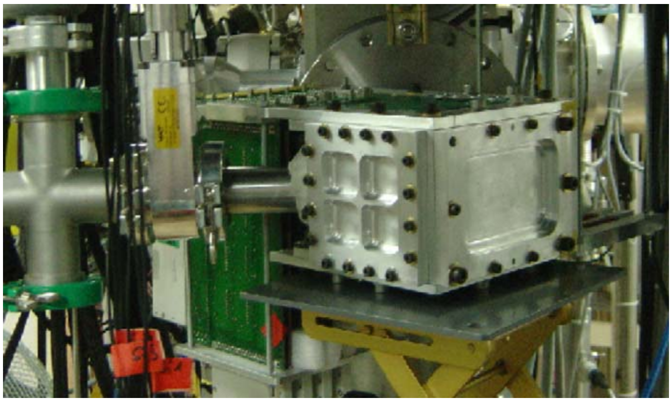

Fig. 2. The photo shows the setup as mounted at the identification station of SPIRAL at GANIL. From the left arrives a vacuum tube, which allows via a valve to insert and remove the catcher in the center of the Silicon Cube. Behind this pipe, one can see in green six PA cards connected to the upper printed circuit plate holding three DSSSDs and three PIPS detectors. The low-energy beam arrives from behind. On the extreme right, on the bottom of the chamber, one can identify the second printed circuit plate without the PA cards mounted. Germanium detectors (removed for the photo) were mounted against the two front sides and from the bottom. A fourth detector can be mounted on the top. The other two sides are occupied by the PA cards. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.3. *Angular distribution*

As mentioned above, the Silicon Cube was designed to measure angular correlations between charged particles emitted from decaying nuclear states. In order to do so, we have privileged granularity and angular coverage. In this compact geometry, the silicon detectors cover a solid angle of 54.2% of 4π. Table 1 gives the distances between the source point, where the radioactive nucleus is implanted, and the different DSSSDs of the cube. The distances from the source point are different for the different