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Musett: A segmented Si array for Recoil-Decay-Tagging studies at VAMOS

Ch. Theisen [a,*], F. Jeanneau [a], B. Sulignano [a], F. Druillole [a], J. Ljungvall [b], B. Paul [a], E. Virique [a], P. Baron [a], H. Bervas [a], E. Clément [c], E. Delagnes [a], A. Dijon [c,1], E. Dossat [a], A. Drouart [a], F. Farget [c], Ch. Flouzat [a], G. De France [c], A. Görgen [a,2], Ch. Houarner [c], B. Jacquot [c], W. Korten [a], G. Lebertre [c], B. Lecornu [c], L. Legeard [c], A. Lermitage [d], S. Lhenoret [a], C. Marry [c], C. Maugeais [c], L. Menager [c], O. Meunier [a], A. Navin [c], F. Nizery [a], A. Obertelli [a], E. Rauly [d], B. Raine [c], M. Rejmund [c], J. Ropert [c], F. Saillant [c], H. Savajols [c], Ch. Schmitt [c], M. Tripon [c], E. Wanlin [d], G. Wittwer [c]

[a] CEA, Centre de Saclay, IRFU, F-91191 Gif-sur-Yvette, France
[b] CSNSM, F-91405 Orsay Campus, France
[c] GANIL, Boulevard Henri Becquerel, BP 55027 – F-14076 CAEN Cedex 05, France
[d] IPNO, 15 rue Georges Clémenceau, F-91406 Orsay, France

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A B S T R A C T

A new segmented silicon-array called MUSETT has been built for the study of heavy elements using the Recoil-Decay-Tagging technique. MUSETT is located at the focal plane of the VAMOS spectrometer at GANIL and is used in conjunction with a γ-ray array at the target position. This paper describes the device, which consists of four $10 \times 10\ cm^2$ Si detectors and its associated front-end electronics based on highly integrated ASICs electronics. The triggerless readout electronics, the data acquisition and the analysis tools developed for its characterization are presented. This device was commissioned at GANIL with the EXOGAM γ-ray spectrometer using the fusion–evaporation reaction $^{197}Au(^{22}Ne,5n)^{214}Ac$. Additionally, the performance of the VAMOS Wien filter used during the in-beam commissioning is also reported.

1. Introduction

The study of the heaviest elements having extreme mass and charge is a major topic in nuclear physics. These elements are artificially produced using fusion–evaporation reactions and suffer from low production cross-sections, which decrease dramatically with atomic number. While decay studies have been performed for decades, prompt γ-ray or conversion-electron spectroscopy of transfermium elements (atomic number larger than 100) is more difficult and the associated challenges have been overcome since 1998, with the pioneering study of ^{254}No at the Argonne National Laboratory (USA) and at the University of Jyväskylä, Finland (see Ref. [1] for a recent review).

These studies require highly efficient and selective devices to detect and unambiguously identify the rare isotopes produced in an overwhelming background of unwanted reactions. The optical elements of a zero degree separator or spectrometer provide the basic selection needed. Since the rejection of projectiles and parasitic reactions is never ideal, the focal plane (FP) detection setup provides the additional identification of the transmitted reaction products. Prompt spectroscopy experiments are possible thanks to the Recoil-Tagging (RT) and Recoil-Decay-Tagging (RDT) techniques [2]. In the former case, the prompt transitions emitted around the target are filtered when a recoil having the expected characteristics (for instance energy, Time-of-Flight (ToF), energy loss, etc.) is identified at the FP of the spectrometer/separator. The RDT technique provides an additional and in most cases univocal identification, exploiting the decay characteristics of implanted nuclei. This technique uses time and position correlations between the implanted nuclei and its subsequent decays (e.g. α-decay).

At GANIL, the VAMOS (VAriable MOde Spectrometer) high acceptance ray-tracing spectrometer was initially designed for the study of exotic nuclei produced with SPIRAL1 radioactive

* Corresponding author.
E-mail address: christophe.theisen@cea.fr (Ch. Theisen).
[1] Present address: CEA Bruyères-le-Châtel, DIF/DPTA/SPN, F-91297 Arpajon, France.
[2] Present address: Department of Physics, University of Oslo, Oslo, Norway.

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beams, for a wide range of reactions such as transfer or deep-inelastic [3–5]. A zero degree operation for fusion–evaporation reaction studies was not a primary focus of VAMOS. However, a separation between the fusion–evaporation residues and the direct beam can be obtained either with its Wien Filter (WF), or in a gas-filled mode [6].

VAMOS can be coupled to the prompt γ-ray spectrometer EXOGAM [7,8]. EXOGAM is made of germanium clover detectors assembled in a close geometry around the target. The 12-clover configuration compatible with VAMOS provides a large efficiency of ∼11% at 1.33 MeV, and is ideal for detecting medium-spin cascades emitted by heavy nuclei. In the near future the coupling with the γ-tracking array AGATA [9] will provide a further increase in efficiency and sensitivity. The coupling of EXOGAM and AGATA scheduled in 2014–2016 is expected to reach a photopeak efficiency of ∼15% at 1.33 MeV along with an improved Doppler correction. The VAMOS zero degree mode combined with EXOGAM/AGATA will be suited and efficient for spectroscopic studies using fusion–evaporation reactions. A series of in-beam tests have been consequently conducted to characterize VAMOS for RT and RDT studies.

A first test of VAMOS as a zero degree separator was performed using the reaction ^{208}Pb(^{18}O, $3-4n$) $^{222-223}$Th. The α decay of ^{223,223}Th and their daughters could be measured. The known level scheme of the ^{222}Th octupole band could be built using γ–γ coincidences.

A second characterization of VAMOS and its WF was performed, using the idea[3] to direct the beam "straight through" thus allowing a better control of the beam (see details in Section 4.2). During this test the transmission for the fusion–evaporation reaction ^{197}Au(^{22}Ne, $5n$)^{214}Ac was measured.

In parallel, the VAMOS gas-filled mode was successfully tested [6]. Unprecedented transmissions have been deduced for the ^{40}Ca+^{152}Sm reaction (80% for α *xn* and above 95% for *xn yp* channels).

Finally, the FP array MUSETT (*MUr de Silicium pour l'Etude des Transfermiens par Tagging* - Silicon wall for the study of transfermium by tagging) segmented Si wall built for RDT studies at VAMOS was commissioned. The segmented Si wall and its new electronics and data acquisition system were tested at VAMOS (using the WF mode) coupled to EXOGAM using mainly the ^{197}Au (^{22}Ne, $5n$)^{214}Ac reaction.

This article describes the technical aspects of the MUSETT Si wall and the results of the in-beam commissioning. It is organized as follows: MUSETT is described in the next section. The test-bench and characterization are then detailed in Section 3. Section 4 is devoted to the in-beam commissioning, including the performance of the VAMOS WF. Finally, a summary and perspectives are given in Section 5. Supplementary material related to this article can be found online.

2. The MUSETT Si array

2.1. Specifications and constraints

MUSETT is originally designed for the VAMOS FP and has therefore to be adapted as much as possible to its ion optics, which is dispersive in the horizontal plane. Since the fusion–evaporation residues produced in the most asymmetric reactions carry low kinetic energy (typically 0.05 MeV/A or less), the implantation depth is shallow (a few μm). The dead layer at the entrance of the detector should therefore be minimized. As mentioned earlier, using the RDT technique requires energy, time and position measurement of the recoil and its subsequent decay. This is usually achieved using Double-sided Silicon Strip Detectors (DSSDs).

The large number of electronics channels required (for about 1000 strips) rules-out the choice of Font-End Electronics (FEE) preamplifiers using discrete components not only because of the volume constraints, but also due to the large number of corresponding feedthroughs. ASICs with multiplexed output are the only viable solution.

The energy resolution is a critical requirement and is necessary to resolve α-decay fine structures (i.e. better than 1%). On the other hand, the time resolution is not a critical issue in the present application. In the case of RDT experiments, the electronic dead-time is not only constrained by the average detection rate (typically a maximum of a few kHz) but a more severe constraint is related to the minimum lifetime of the nuclear states of interest. We would like to measure the times between the implantation and subsequent decay in the same detector element as low as few tens of μs. In the case of RDT experiments, events separated by long periods of time, up to minutes or more need to be correlated in time. This can be achieved using a universal clock.

It should be pointed out that the above-mentioned specifications overlap to a large extend with that of the MUST II array [10] designed mainly for direct reaction studies at GANIL. MUSETT capitalized extensively on the MUST II developments.

2.2. Technical description

We present below the silicon detectors and their FEE. The infrastructure needed and the integration performed to operate the detector modules is then described.

2.2.1. Si detectors

The MUSETT silicon array is made of four modules of $\sim 10 \times 10$ cm^2 each, to obtain a total detection area of $\sim 40 \times 10$ cm^2, which covers the recoil implantation profile in both VAMOS WF and gas-filled modes. The detectors are to a large extent based on the MUST II detectors with substantial improvements to cope with the implantation and detection of very heavy nuclei and their subsequent decay.

Each n-type, DC coupled DSSD is 300 μm thick and has 128 strips on each side (*X-Y* readout) : see Fig. 1. The crystal orientation is ⟨100⟩. *X* (*Y*) strips correspond to the front junction (back ohmic) side of the detector. Particles enter the detector from the junction side. The junction p+ implantation is made of a shallow Boron implantation of less than 0.25 μm (typically 0.1 μm). The front side segmentation is made with an aluminium contact grid 3000 Å thick whose total area is of 2.73% coverage only. There is no other metallic or oxide layer on the front side in order to reduce the energy loss for the incoming heavy nuclei. On the back ohmic side, the contacts consist of Al strips. The strip width on both sides is 700 μm with a pitch of 760 μm. The strip separation (interstrip) is therefore 60 μm. The thickness of the SiO_2 layer between the p+ front strips is 1 μm. The isolation between the n+ back strips is made with p-stop structures. The strip length is 97.220 mm for each side. The Si detector is mounted on a 2.4 mm epoxy (FR4) printed circuit board. The guard rings are kept floating. The Si detectors were provided by Micron Semiconductors, UK [13] and are known as "TTT3 design" in the catalogue.

The high voltage (negative) is applied on the front junction face of the Si detectors, which is therefore AC coupled to the FEE through polarization circuits. The depletion voltage of all detectors is less than −60 V for which the leakage current does not exceed 1 μA at room temperature for a new detector. Fig. 2 shows examples of capacitance as a function of the bias voltage (courtesy of Micron Semiconductors). A typical value is ∼4 nF above the

[3] Suggested by M.R.