Validation and Characterization of the GALTRACE Silicon Detector Array Demonstrator

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***Abstract*—The preliminary results of the GALTRACE (GALILEO TRacking Array for Charged Ejectiles) demonstrator are reported. GALTRACE is an array of Silicon PAD detectors for particle spectroscopy and discrimination to be employed in low-energy nuclear physics experiments with stable and radioactive beams at the Legnaro National Laboratories (LNL, Italy). The readout is perfomed with multi-channel, VLSI preamplifiers realized in AMS 350 nm technology, directly wire-bonded on the PCB. These preamplifiers have a resolution of 125 electrons rms and a risetime of 10 ns with a 4 pF capacitance referred to the input. The preamplifiers have a spectroscopic dynamic energy range of 40 MeV. This value is boosted by more than one order of magnitude by an innovative fast-reset device that allows for 40-700 MeV spectroscopy with a resolution of less than 0.3% FWHM. After preamplifier test-bench characterization, a full validation of a TRACE demonstrator including detector, front-end electronics, single-ended to differential converters and digitalization system has been performed. The resolution of the 60 active channels, evaluated at the 5486 keV ^{241}Am alpha peak, is 35±5 keV**

I. Introduction

The study of nuclei far from the stability valley is one of the main topics in the present panorama of nuclear physics research. Such exotic species have a short lifetime (generally of the order of tens of seconds or less) and require dedicated cutting-edge facilities for their production. SPES [1] at Legnaro is an upcoming ISOL (Isotope Separation On-Line) source of radioactive nuclei that will be commissioned in the next years at the Legnaro National Laboratories (LNL, INFN). A 35-70 MeV proton beam will collide on a UC_X target. The exotic species, after diffusion and effusion processes will be extracted from the hot target and re-accelerated in the ALPI linear accelerator up to 10AMeV.

These beams have typically lower intensity than stable beams and thus the interesting reaction channels may have low absolute rate. These relatively rare events are immersed in a overwhelming background of unwanted events: in such conditions the detection systems must have the highest possible efficiency. At the same time the angular information (both for particles and γ rays) is useful to perform Doppler correction and is obtained thanks to the detectors segmentation.

The continuously-increasing detector segmentation leads to the increment of the total acquisition channels: modern DSSSDs (Double-Sided Silicon Strip Detectors) easily have more than 256 strips per side. The FEE (front-end electronics) of such detectors is generally placed inside the reaction chamber in order to obtain better spectroscopic resolution, at the price of operating the preamplifiers in vacuum.

At the same time the current signals from the detector gives information about the spatial distribution of the free charge carriers produced from the interaction with the incoming particles. Pulse-Shape Analysis (PSA) algorithms are used to discriminate the particles in mass and charge, identifying interesting reaction channels and discarding the others [2], [3].

The technological challenge of designing an analog front-end for modern segmented particle detectors involves the following key-aspects:

1) the minimization of the power consumption due to the vacuum operation
2) the rise-time reduction down to 10 ns or less to allow PSA
3) the packaging of hundreds or thousands of channels in relatively small volumes.

ASIC (Application Specific Integrated Circuit) solutions are mandatory to fulfill the aforementioned requirements. In this work preliminary results from the commissioning of the GALTRACE detector array are presented. This is a silicon pad detector array for particle spectroscopy/discrimination to be used as ancillary for large γ-ray spectrometers (like AGATA or GALILEO) at LNL.

II. Description of the demonstrator under test

The demonstrator under test was made of three silicon telescope (ΔE-E) detectors, an array of 12 preamplifier boards (for a total of 24 chips and 204 acquisition channels), a group of 9 SeDiff modules and the corresponding digitizers.

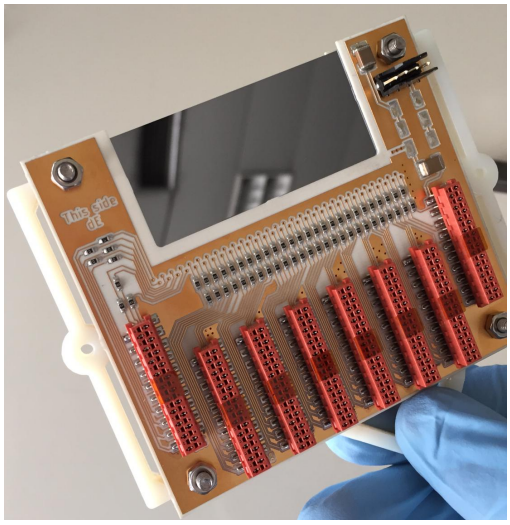

Fig. 1. Photo of a thin ΔE layer silicon detector mounted on its PCB board.

A. The Detector

The GALTRACE detectors (see fig. 1) are mounted in telescopic configuration and have different thicknesses according to their placement: $200\,\mu\mathrm{m}$ for the ΔE layer and 1 to $1.5\,\mathrm{mm}$ for the E layer. Each ΔE detector is segmented into 60, 4x4 mm^2 pads in order to achieve a good angular resolution with the detector placed at roughly 5 cm from the scattering point. Although the detector of the E layer has the same segmentation of the one in the ΔE layer, in order to reduce the total channel count the 60 pads are grouped 15-by-15 and acquired with just 4 preamplifiers.

The detector PCB, realized on a Rogers 4003c substrate, incorporates the load resistances and the power supply filtering. A clever implementation allows for different usages with a single physical board. Populating the board on one side connects the detector as ΔE (all 60 anodic channels available separately) while populating it on the other side connects the detector as E (pads interconnected in 4 groups).

B. The ASIC preamplifiers

The detector readout is performed with dedicated ASIC charge-sensitive preamplifiers (CSP, see fig. 2) designed by the INFN of Milan electronics group [4], [5], [6], [7]. These CSPs are realized in AMS $350\,\mathrm{nm}$ BiCMOS technology [8]. The chip is constituted by eight channels for anodic signals (those coming from the front segmented side of the detector) and one channel for cathodic ones (those generated by the common back detector electrode), separately powered. A very simple $\mathrm{I}^2\mathrm{C}$ receiver is used to adjust gain, bandwidth and other key parameters of the device.

The low-power design ensured a static power consumption under $12\,\mathrm{mW}$ per channel and the low-noise design allows for an equivalent input noise charge in the order or 125 electrons rms with $4\,\mathrm{pF}$ of detector capacitance.

The spectroscopy energy range, according to the selected sensitivity, goes from $8\,\mathrm{MeV}$ to $40\,\mathrm{MeV}$. Above this threshold the preamplifier goes into saturation. An auxiliary controlled-reset device is able to recover the CSP from saturation at the rate of $10\,\frac{\mathrm{MeV}}{\mu\mathrm{s}}$, reducing the duration of the typical dead-time from milliseconds to microseconds. Nonetheless, this technique enables also for high-resolution spectroscopy even when the CSP is in deep saturation condition. Thanks to a Time-Over-Threshold measurement of the reset time, it is possible to retrieve the energy information up to $700\,\mathrm{MeV}$ with a FWHM (full-width at half-maximum) resolution of 0.3% or better.

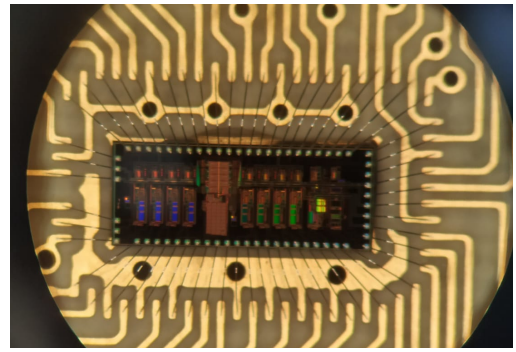

Fig. 2. Microscope photograph of the ASIC preamplifier wire-bonded to the dedicated PCB.

C. SeDiff and Digitizers

The preamplifier signals run out from the scattering chamber in single-ended mode. A short connection to the single-ended-to-differential (SeDiff) modules allows for long connections to the digitizers rack. The SeDiff modules are built around the AD8139 integrated operational amplifier and convert the single-ended signals in differential ones. These boards have been designed at the INFN LNL and are compliant with the preamplifier standards in terms of dynamic range, bandwidth and noise. The waveforms are sampled with 14-bit precision at $100\,\mathrm{MHz}$ with the same digitizers of the GALILEO spectrometer [9].

III. Experimental Performance

The array (see fig. 3) was commissioned with an in-beam test in July 2019. The experiment involved a ^{13}C beam impinging on a ^{7}Li (LiF) target. The calibration of the detectors was made with a mixed nuclide (^{241}Am, ^{244}Cm) alpha source. The detectors were operated at 35-60 V (ΔE) and 150-200 V (E) and showed an average dark current respectively of $1.3\,\mu\mathrm{A}$ and $4.4\,\mu\mathrm{A}$ throughout the 3-day experiment. The average resolution obtained on the ΔE layer was $45\pm9\,\mathrm{keV}$ (slightly worse than the $35\,\mathrm{keV}\pm5\,\mathrm{keV}$ obtained in the test chamber). The best case is $25.4\,\mathrm{keV}$ measured on the Americium $5486\,\mathrm{keV}$ peak. The channel resolution homogeneity was thus quite high: in fig. 4 the sum of the ^{241}Am, ^{244}Cm spectra from 30 adjacent channels is pictured. As expected there is possibility of charge-sharing between adjacent pads: this phenomenon can be clearly seen in fig. 5. This aspect must be taken into account for the final analysis. In fig. 6 the signals and corresponding spectrum from a central pad during calibration are pictured.

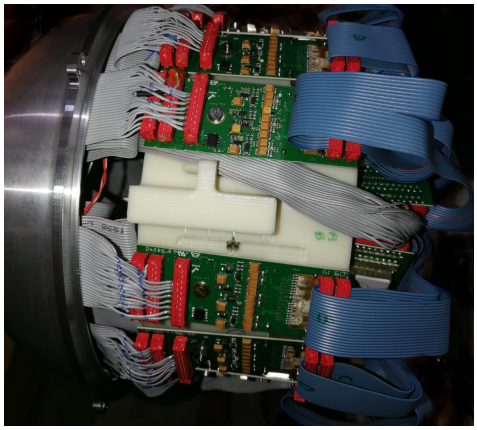

Fig. 3. GALTRACE Array being inserted inside the reaction chamber. The preamplifier boards are visible, while the detectors are hidden inside the 3D-printed frame.

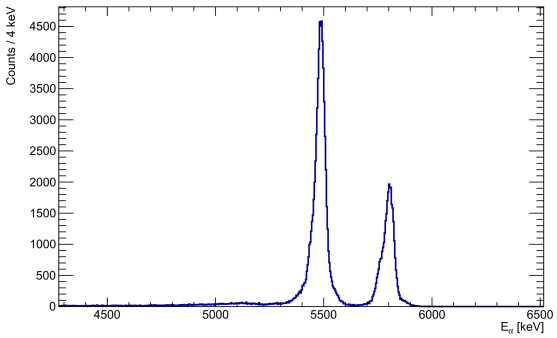

Fig. 4. Sum of ^{241}Am, ^{244}Cm alpha source spectra from 30 adjacent pads during the calibration phase.

The risetime for α particles is in the order of $180\,\mathrm{ns}$ for the thin detectors: this demonstrates that the preamplifier risetime of $10\,\mathrm{ns}$ is fast enough to appreciate the different pulse shapes coming from the detectors.

IV. Final Notes

The results of this commissioning are still very preliminary, but the available data is quite promising. Great part of the data analysis will be focused on the pulse-shape analysis: the actual charged-particle discrimination capabilities of the device will be pointed out in future works.

As expected, being the experimental situation slightly less ideal than the one of the previous lab tests with alpha source and vacuum chamber, the actual resolution is 30% worse. The cause of this can be found in long connection cable, grounding problems and distant detector and FEE power supplies.

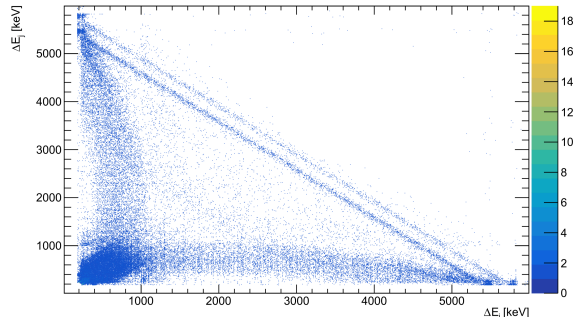

Fig. 5. 2D matrix of the energies measured on two neighboring pads. As expected there are charge-sharing phenomena due to the possibility that the charge carriers produced by an inter-pad event are shared among adjacent pads.

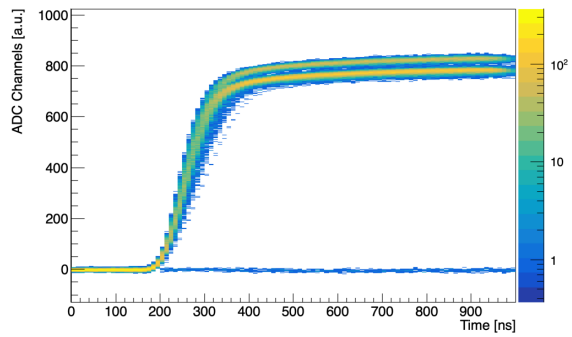

Fig. 6. Signals produced by a central pad during the calibration phase in the bottom figure. The two α-lines are clearly visible.

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