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First in-beam test of the GALTRACE innovative silicon detector array

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Summary. — In this work, the characterization and the preliminary results of the GALTRACE silicon detector array are reported. The paper describes the setup used in the 2019 experimental campaign and shows some preliminary results together with some technical details.

1. – Introduction

Collective clusterization phenomena are a hot topic of contemporary nuclear physics. In light neutron-rich nuclei (from Be to Ne –a good example is ^{19}O) single-particle states and cluster-like structures coexist. While shell-model calculations can describe single-particle states, cluster models are required to describe more collective phenomena. Both approaches, however, fail to account for the great impact that the continuum has on both the structure and the decay of the states above the particle-decay threshold. The newly developed shell models embedded in the continuum can address this issue, considering the nucleus as an open quantum system. The couplings to the decay channels induces a mixing of the shell-model eigenstates that leads to the appearance of cluster states near the corresponding particle-decay thresholds. Electromagnetic (EM) decay information from unbound states is a key element to probe the structure of this type of excited states, but the low branching ratios (from 10^{-5} to 10^{-3}) make them hard to access.

A new generation of highly segmented silicon detectors is being designed and built all across the world [1-3] to overcome the limitations of pre-existing setups. The goal of these ancillary devices is multiple and includes the possibility to perform a selection on specific reaction channels thanks to the discrimination capability of the detected particles. At the INFN Laboratori Nazionali di Legnaro (Padua, Italy) the commissioning of the GALTRACE silicon detector array has been carried out in 2019 within a first experimental campaign. The topics discussed in this work include the description of the front-end electronics of the GALTRACE array and the description of the experimental setup used in the 2019 GALTRACE/GALILEO campaign.

2. – Technical description of the GALTRACE array

The GALTRACE array, developed by the Universities and INFN departments of Milan and Padua together with Laboratori Nazionali di Legnaro, is an array made of four telescopic E-ΔE silicon detectors designed to work coupled to the GALILEO high-purity germanium γ spectrometer. The first silicon layer is 200 μm thick, while the second can be 1 or 1.5 mm thick. Each detector is segmented into 60, $4 \times 4\,\mathrm{mm}^2$ square pads. The first layer is read pad by pad, while the pads of the E layer are read in groups of 15.

The front-end electronics was developed by University and INFN of Milan. It is based on low-power, low-noise integrated Charge-Sensitive Preamplifiers (CSP) [4, 5] realized in AMS C35 technology [6]. The preamplifiers are characterized by an equivalent input noise of 130 electrons rms that can ensure an equivalent resolution of roughly 1 keV in silicon. This contribution is practically negligible compared with the intrinsic resolution of GALTRACE detectors that, in turn, determines the total spectroscopic performance of the system (see fig. 1(a)). These preamplifiers are equipped with the fast-reset technology [7, 8] that boosts the spectroscopic dynamic range of the preamplifier more than one order of magnitude above its natural saturation limit and ensures dead times in the order of some microseconds in the case of saturation. If the natural CSP dynamic range is 40 MeV, in the fast-reset mode it is possible to perform spectroscopy up to 700–800 MeV with a resolution around 0.2% FWHM.

The preamplifier ensures a rise time (10%–90%) of 9 ns with 4 pF of detector capacitance. This parameter is mandatory to be able to perform pulse-shape analysis on the sampled signals. This allows to discriminate also the particles that do not punch through the first silicon layer [9].

3. – The 2019 experimental campaign

In 2019, the GALTRACE array was used in a setup with the goal of investigating the EM transitions from near-threshold states in light nuclei produced in heavy-ion fusion-evaporation reactions. At Laboratori Nazionali di Legnaro the PIAVE-ALPI accelerator was used to produce a ^{13}C beam with a total kinetic energy of 23 MeV. The target was made of a ^{7}LiF deposition (150 μg/cm^2) on a ^{12}C substrate (30 μg/cm^2).

A total of 14 Compton-suppressed high-purity germanium detectors from the GALILEO array have been used as γ spectrometer and placed at backward angles.

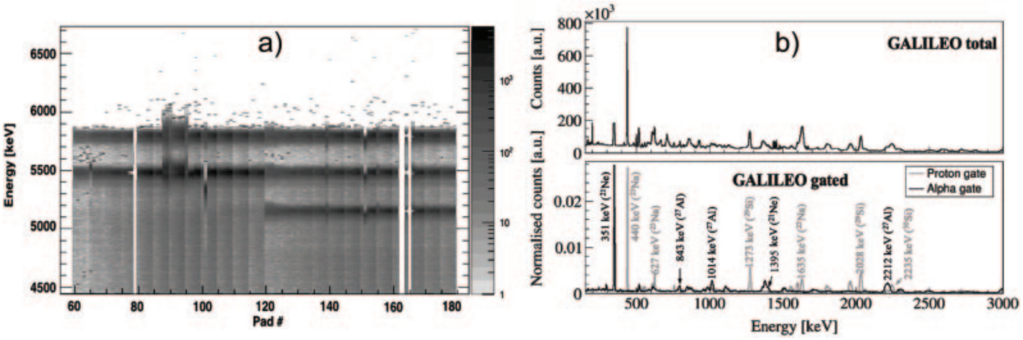

Fig. 1. – (a) Spectra from two ΔE detectors of the array obtained with two calibration sources: ^{241}Am-^{244}Cm for the first detector (from pad 61 to 120) and ^{241}Am-^{244}Cm-^{239}Pu for the second detector (from pad 121 to pad 180). The spectrum of each pad occupies a column of the plot. The Y-axis represents the energy. The color scale represents the spectrum population. From this plot it is possible to appreciate the good resolution homogeneity across the different channels. The average FWHM resolution, measured on the ^{241}Am 5486 keV peak is roughly worse than 30 keV. (b) GALILEO γ spectra with (top) and without (bottom) coincidences with particle detection in GALTRACE.

Three GALTRACE telescope detectors have been placed inside the scattering chamber at different angles, both forward and backward with respect to the beam direction. All the signals have been acquired with the 100 MHz, 14-bit DIGIOPT-12 GALILEO digitizers.

The signals from GALTRACE have been processed with digital pulse shape analysis algorithms. The chosen figure of merit was the maximum current produced by the detector during the particle interaction. In practice, this is proportional to the maximum derivative of the signal, calculated after proper oversampling. Plotting a matrix of this figure of merit against the deposited energy it is possible to recognize some clusters of events, each one representing a different particle impinging on the detectors. Thanks to PACE4 Monte Carlo calculation it is possible to evaluate the open reaction channels with their respective cross sections and evaporated particles [10]. This information is used to select, among all the γ events in GALILEO, only those in coincidence with a specific particle detected in GALTRACE. In this way, the sensitivity to those gammas emitted by reaction channels with a very low cross section is greatly enhanced. A good example is reported in fig. 1(b), where a γ spectrum from the GALILEO array (top) and the two obtained with a proton or α-particle gate (bottom) are reported.

Gamma radiation emitted by an excited nucleus is Doppler shifted due to the nucleus velocity in the laboratory system. According to kinematic equations, we can correct the energy of the detected γ events knowing the nuclei velocity, which can be reconstructed from the energy and mass of the beam and of the ejected particles. If the energy information about the ejected particles is not present, the only way to perform the Doppler correction is to evaluate the average β-factor. This correction is far from being accurate since the direction of the recoiling nucleus is neglected. This can be overcome by detecting all the evaporated particles and reconstructing on an event-by-event basis the velocity vector of the residual nucleus. Thanks to the energy and angular resolution of GALTRACE, the Doppler correction on γ spectra can give much better results (see fig. 2).

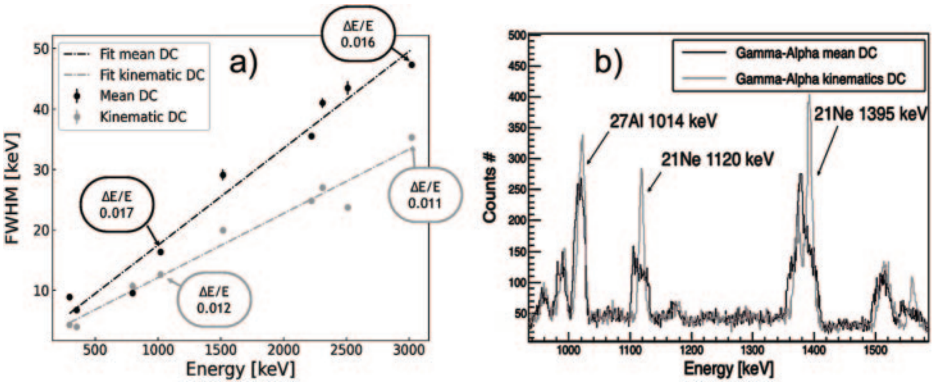

Fig. 2. – (a) Energy resolution (FWHM) plotted against the energy in a range between 0 and 3 MeV of the γ peaks after Doppler correction with β-factor calculated from the γ event or with the information from GALTRACE. (b) Two γ spectra obtained with the aforementioned methods.

4. – Conclusion and perspectives

The 2019 experimental campaign demonstrated the spectroscopic performance of the GALTRACE silicon detector array and its particle-discrimination capabilities using pulse-shape analysis algorithms on the digitized signals. The energy information on ejected particles has been used to perform Doppler correction on the γ spectra measured by the GALILEO HPGe detector array.

In 2021 the European γ Tracking Array AGATA will be installed at Laboratori Nazionali di Legnaro and the experimental campaign will start in early 2022. The GALTRACE array will be adapted to be mounted in the new scattering chamber and the number of detectors may be increased from 4 to 5 to achieve a better solid angle coverage. Experiments with both stable and radioactive beams are planned in the future.

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