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GALTRACE: A highly segmented silicon detector array for charged particle spectroscopy and discrimination

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Summary. — GALTRACE is an array of segmented silicon detectors specifically built to work as an ancillary of the GALILEO γ-ray spectrometer at Legnaro National Laboratory of INFN. GALTRACE consists of four telescopic ΔE-E detectors which allow discriminating light charged particles also via pulse-shape analysis techniques. The good angular and energy resolutions, together with particle discrimination capabilities, make GALTRACE suitable for experiments where coincidences with specific emitted particles allow for the selection of reaction channels with very low cross section. The first in-beam experiment is reported here, aiming at identifying a narrow resonance, near-proton-threshold state in ^{11}B, currently under discussion.

1. – Introduction

Light nuclei, such as carbon, oxygen, nitrogen, . . ., represent a fertile ground to search for new experimental evidence which can be exploited to benchmark modern theoretical approaches. In particular, such systems are an ideal laboratory to attempt a unified description of the atomic nucleus as on open quantum system, where bound and unbound excitations are described on equal footing. While traditional Shell-Model approaches fail in describing weakly bound nuclei, recent theory models, like the Shell Models Embedded in the Continuum (SMEC) [1] provide, for example, first predictions for the structure and decay properties of near-threshold resonance states. New challenging measurements are therefore needed, which can greatly benefit from the synergic interaction of high-resolution γ spectroscopy with high-performance particle spectroscopy and discrimination.

The technological answer to such demand is the development of new-generation detector arrays. High-Purity Germanium (HPGe) detectors constitute the gold standard in γ spectroscopy due to their unpaired energy resolution. At the Legnaro National Laboratories (LNL) the resident HPGe array is GALILEO [2], comprising a total of 50 detectors: 20 single Compton-suppressed crystals and 10 triple clusters with Compton shields. The need for a particle detector characterized by high granularity, high resolution, high angular coverage and good particle-discrimination capability led to the development of GALTRACE [3], an array of segmented silicon detectors in ΔE-E telescopic configuration. Designed to fit inside the GALILEO reaction chamber, this array features a total of 256 acquisition channels, distributed among four pairs of crystals. In order to cope with such a high-density application, a compact, integrated front-end electronics has been developed. This is based on a custom ASIC pre-amplifier realized in 350 nm AMS CMOS technology. This pre-amplifier [4] ensures high energy resolution (up to 1.2 keV measured on a dedicated test-bench [5]), low-power consumption ($\leq$15 mW/channel) and wide bandwidth (between 15 and 45 MHz, adjustable with digital slow-control [6]). These pre-amplifiers are designed to fully exploit the potential of the technology, minimizing the $1/f$ noise at the input and optimizing the input capacitance. The only discrete component required by these pre-amplifiers is the 1 GΩ feedback resistor. This choice is aimed at minimizing the parallel noise [7] and avoiding non-white noise components [8] produced by integrated feedback devices.

The pre-amplifiers are equipped with an evolution of the fast-reset [9] circuit technology. The reset current generator draws charge directly from the input node of the first pre-amp stage, extending the dynamic range of the pre-amplifier above its natural saturation limit imposed by the power supply voltage. In case of saturation, this technique also reduces the dead time roughly by a factor 1000 (from milliseconds to microseconds). The channels that perform the readout of the detectors' non-segmented back electrodes implement an innovative Time-To-Amplitude (TAC) circuit [10] that rejects the base-line stray contribution [11, 12] from reset duration measurements.

The first ΔE layer, segmented in 60 pads, is 200 μm thick and the second layer, divided in 4 pads, is 1 or 1.5 mm thick. The 4-by-4 mm^2 detector segmentation ensures an angular resolution around 4° in ϕ, the azimuthal angle with respect to the vertical axis, and between 3 and 4° in θ, the polar angle with respect to the beam direction.

2. – Physics case

A perfect physics case to evaluate the performance of the GALTRACE silicon detector array, to be used as an ancillary of the GALILEO gamma spectrometer, is represented by the decay of the unbound ^{11}B nucleus. In recent experiments performed at ISOLDE and TRIUMF [13, 14], a very rare β^--delayed proton emission was measured from ^{11}Be: ^{11}Be was found to decay to ^{11}B, that can in turn decay into ^{10}Be after the emission of the newly created proton. Although the energy window available for this decay is only 280 keV, the process was observed with a branch (upper limit) of 10^{-6}, namely two orders of magnitude higher than predicted by theory. These results are compatible with the existence in ^{11}B of a resonant state, just above the proton-separation energy, unobserved thus far. An alternative approach to prove the existence of such resonance is the measurement of its possible gamma decay, which is predicted by the SMEC model with a branch of $\sim 3 \cdot 10^{-3}$ [15], namely within the experimental sensitivity of the GALILEO+GALTRACE array.

3. – Experimental setup and performance

A week-long experiment was performed at LNL in February 2021, employing the fusion reaction ^{6}Li + ^{6}Li to populate ^{11}B after one-proton emission from the ^{12}C compound nucleus. The experimental setup consists of the GALILEO array, coupled with three GALTRACE detectors placed inside the GALILEO reaction chamber. A 11 μm-thick aluminum absorber was put in front of each telescope to protect it from the scattered ^{6}Li ions. The counting rate for each telescope detector was between 4 and 6 kHz. The signals were acquired with the same 100 MHz, 14-bit digitizers of the GALILEO array. The energy was calculated with on-line Moving-Window Deconvolution (MWD) algorithms performed on dedicated FPGAs, obtaining an average resolution of 60 keV on the front pixels. The pulse-shape was analyzed partially on-line and partially off-line by applying digital algorithms.

The GALTRACE array was used to select the protons emitted from the compound nucleus ^{12}C, feeding excited states in ^{11}B, in coincidence with gamma rays detected by the GALILEO spectrometer. This particle-gamma coincidence greatly enhanced the overall sensitivity of the apparatus for the desired reactions, significantly suppressing the huge background from uncorrelated gamma events. In panel (a) of fig. 1 the PSA matrix is shown for those particles that are stopped in the first telescope layer [16]. The chosen figure of merit is the maximum signal derivative ($I_{\max}$). Event clusters for protons,

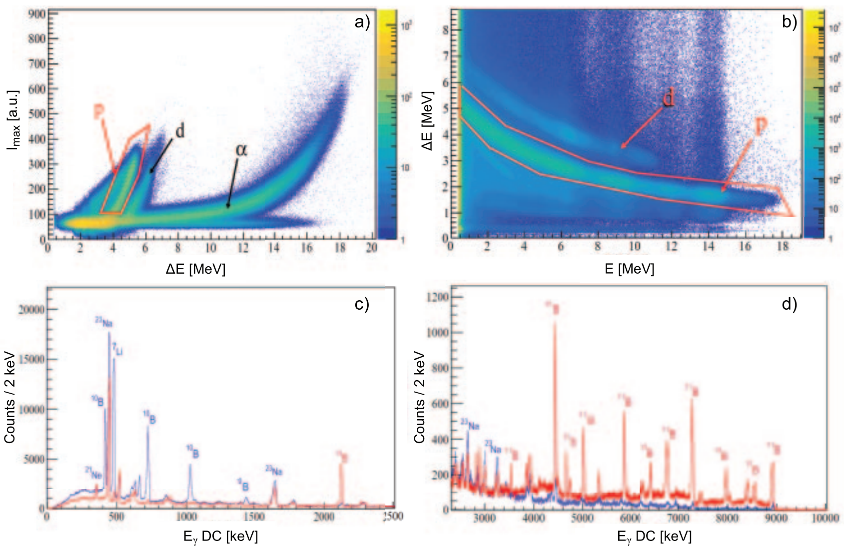

Fig. 1. – (a), (b): particle-identification matrices obtained respectively with the PSA algorithm and ΔE-E technique. (c), (d): projections of γ-γ matrices in coincidence with protons.

deuterons and α particles are clearly visible and partially separable. Panel (b) shown instead the ΔE-E matrix built on the collection of particles that cross the first layer and are stopped in the second one.

The combination of the information obtainable with these two techniques allows for efficient identification of the particles detected by the GALTRACE array. The selection of the gamma events in coincidence with the desired particle ensures a great background rejection and isolation of peaks otherwise absolutely not visible. In panels (c) and (d) of fig. 1 gamma spectra in coincidence with protons stopped in the ΔE layer (blue line) and stopped in the E layer (red line) are shown. Most of the visible peaks are identified with the corresponding excited nucleus. The spectrum is divided in two halves: under 2.5 MeV (panel (c)) and above 2.5 MeV (panel (d)).

4. – Conclusion and perspectives

The experiment discussed in this contribution represents the first in-beam validation of the GALTRACE array's functionality. Future developments will be focused on the coupling of GALTRACE with the AGATA array. Further improvements may include the possibility to sample the pre-amplifier signals directly inside the reaction chamber with analog memories [17]. The data analysis is ongoing and will contribute to shed light on the existence of the near-threshold resonance in ^{11}B which is currently under debate.

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