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Author: K. Zelgay, Z. Majka, R. Płaneta, Z. Sosin, A. Wieloch, M. Adamczyk, Seweryn Kowalski i in.

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DEDICATED ΔE–E DETECTOR SYSTEM FOR SEARCHING LONG-LIVED HEAVIEST NUCLEI DEPOSITED IN SCINTILLATORS*

K. Zelga†, Z. Majka, R. Płaneta, Z. Sosin‡, A. Wieloch
M. Adamczyk, K. Łojek

M. Smoluchowski Institute of Physics, Jagiellonian University
Łojasiewicza 11, 30-348 Kraków, Poland

M. Barbui, S. Wuenschel, K. Hagel, X. Cao, J. Natowitz
R. Wada, G. Giuliani

Cyclotron Institute, Texas A&M University, College Station, Texas 77843, USA

E.-J. Kim

Division of Science Education, Chonbuk National University, Jeonju 54896, Korea

H. Zheng

School of Physics and Information Technology, Shaanxi Normal University
Xi'an 710119, China

S. Kowalski

Institute of Physics, University of Silesia
75 Pułku Piechoty 1, 41-500 Chorzów, Poland

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We present a dedicated experimental setup which is currently used to search for long-lived super-heavy elements (SHE) implanted in catcher scintillators which were irradiated by reaction products of ^{197}Au (7.5 A MeV) projectile and ^{232}Th target collisions during our experiment performed at the Cyclotrone Institute, Texas A&M University in 2015. The built-in novel measuring apparatus consists of ΔE–E detector pairs which are able to register α or spontaneous fission (SF) decays of heavy-reaction products deposited in the catcher scintillators. Their unique feature is that the examined catcher scintillators are at the same time ΔE part of each of ΔE–E

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† Corresponding author: `kamila.zelga@gmail.com`

‡ Deceased.

detector pair while E part is a silicon detector. Our apparatus is dedicated to search for SHEs which have a lifetime of a year till tens of years. Results of commissioning tests of our setup are presented.

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1. Introduction

The search for the island of stability of SHEs is one of the most challenging problems in nuclear physics. All already discovered SHE isotopes, mainly in complete fusion reactions, are characterized by lifetimes of only a few minutes or shorter [1–3]. However, many attempts to search for stable (lifetime of billions of years) SHEs in Nature have not yet yielded positive results [4]. Along the lifetime axis of heaviest elements, there is a time region of the order of years that is accessible for experimentalists, but so far only briefly explored [5].

In recent years, scientists from the Jagiellonian University and Texas A&M University (TAMU) tested the multi-nucleon transfer reaction as a way to create SHEs [6, 7]. One of the studied reactions was ^{179}Au (7.5 A MeV) projectile on ^{232}Th target of 12 mg/cm^2 thickness and 3×10^{15} of Au beam ions were delivered to the target. Measurements were done at the Cyclotron Institute of TAMU in 2015. The detector, based on the BC-418 plastic scintillators, prepared for the experiment, was built in such a way that segmented 63 plastic scintillators played the role of an active catcher (AC), into which the reaction products and SHEs were implanted. The aim of this experiment was to search for short-lived SHEs with life times from nanoseconds to microseconds.

In our current project, we constructed a dedicated detection apparatus, which is a simple multi-element system to search for long-lived SHEs (LLSHEs) with lifetimes of years to tens of years, deposited in the scintillators of the AC during our measurement in year 2015 [6].

The article is organized as follows: in Sec. 2, we describe the idea and the construction of the apparatus then in Sec. 3, we present some results of measurements and, finally, a short discussion is given in Sec. 4.

2. Experimental setup

The idea of the apparatus is based on the registration of α/SF decays of LLSHEs, possibly implanted in the AC scintillators. To search for such decays, ΔE–E detectors were constructed. A scheme of one such a pair is presented in Fig. 1, where ΔE is the AC scintillator and E is lithium drifted silicon detector (Si). The AC detection element (ΔE) is attached to a light guide placed inside a cavity to accumulate light on a photomultiplier tube

(R9880U-110). Front of the scintillator is covered by thin aluminium foil of thickness below 1 μm. The E part is connected to the charge pre-amplifier which is placed very close to the detector. Both detectors are placed in the air facing each other with a small gap between them (less then 1 mm).

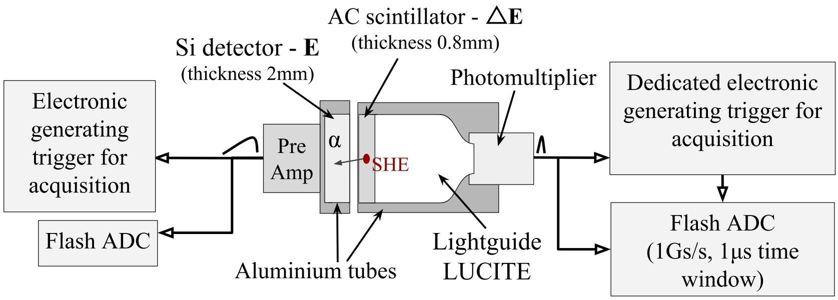

Fig. 1. Scheme of ΔE–E detector. See the text for details.

Based on the ΔE–E pair, a simple multi-pairs system was built. The whole setup consists two walls of detectors. A wall of 8 Si detectors provides information about energy of the registered α/SF particle, while the second wall includes 8 AC scintillators, which deliver ΔE signal. Both walls are placed on movable rails, to adjust the ΔE–E mutual positions.

The background signals from the ΔE–E detectors create a serious problem in the search for very rare events which are decays of SHEs. The background is composed of natural radiation from the environment from various radioactive decay chains (thorium, uranium–radium, *etc.*) and cosmic radiation. Natural radiation contains α, β, γ particles of which only α particles can mimic the signal of the genetic chain from the decay of SHE. Fortunately, the energy of α emitted at the beginning of a genetic chain in the decay of SHE, reaches the value of 10 MeV and higher [8], while the highest energy of α particles coming from natural radiation is 8.99 MeV (decay of ^{217}Ra).

Estimated depths of implanted SHEs in AC scintillators are a few microns [7]. Some of the α particles from the decay of SHEs will be emitted in the direction of the E detector, leaving only a small part of energy in the AC scintillator (ΔE) and in the small gap of the air between ΔE–E, while the greater part of their energy will be registered by the Si detector. At the same time, the scintillator is an anti-coincidence shield against cosmic radiation, because its actual thickness is 0.8 mm, while energy deposited by such radiation in Si detector is not higher than a few MeV. In the case of SF from SHE decays, the energy registered in both detectors should be high. Estimated effective geometrical efficiency of the ΔE–E pair for interesting events is not higher then 20% of a 4π solid angle.

Signals from any of the ΔE or E detector pair are split and sent into analog and digital logic branches of the electronics (see Fig. 1). To produce triggers from signals of ΔE detectors, dedicated electronics were used (see Fig. 3 (a) in [6]), while in the case of Si detectors, standard fan-in fan-out modules (Caen v925) with discrimination capability were applied. The signals themselves were recorded as a wave forms using the Caen FADC V1742 digitizer modules. These modules were set to a sampling rate of 1 Gs/s in the case of E and ΔE detectors with a 1024 points buffer. Inspection of the recorded signal waveforms saved on HD drive allows us to distinguish in further analysis the real physical signal from an artificial disturbance of electronics. All detectors were calibrated in the vacuum with sources of ^{241}Am (which emits α) and ^{252}Cf (which emits α as well as SF fragments). Energy resolution deduced from the calibration procedure was 1% in the case of E detectors and around 30% in the case of ΔE detectors.

In the next section, we present measurement results to discuss the performance of our detection system.

3. Presentation of results

The most convenient way to search for interesting events (candidates for SHE decays) is an anlysis of two-dimensional maps of ΔE–E energies. In the left panel of Fig. 2, we present a typical map for the AC scintillator — Si coincidence signals, received after 25 days of continuous measurement. A rectangular area on the map is showing an expected localization of interesting events. The heights of this rectangle is estimated from the observation that the SHEs should be implanted in the AC scintillator at depths of several microns [7], hence it is assumed to be around 2 MeV (80 mV). The base of the rectangle is chosen to be in the range of α energies expected for decays of heaviest SHEs, *i.e.* 10–18 MeV [8]. In this area, one can see three interesting events and each one of those events was directly inspected to check its physical origin. In the right panel of this figure, we present an example of signal of the event marked by dashed circle. We see a relatively slow well-defined pulse from Si detector which confirms the detection of a charged particle. Its energy is 16 MeV. The pulse from the AC scintillator is very fast, with a duration of 10 ns and energy around 1 MeV. The spike of the 10 mV amplitude seen on the right of the pulse is commonly present in the acquisition and it is generated by the power supply which drives the VME crate of ACQ system. As one can see, the fast pulse from the AC scintillator is in place where a slower pulse from the Si detector starts. Both pulses are properly located with respect to the arrival of the ACQ trigger (a vertical arrow on the figure) which confirms that presented pulses from ΔE and E detectors were produced by the same particle.

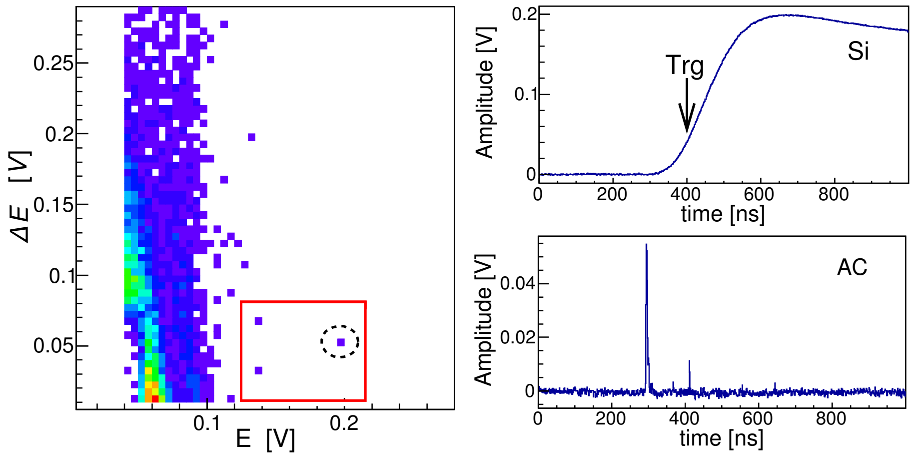

Fig. 2. Left: ΔE–E coincidence signals map. Right: Signals from Si and AC detectors for the event marked inside dashed circle on the left panel.

The recorded pulses can be further analysed by using digital signal processing (DSP) tools. This is especially straightforward for signals from the Si detector where DSP methods frequently enable particle identification. For this, it is useful to get characteristics of the Si charge pulse such as its rise time and its amplitude. More information can be extracted by converting the charge pulse into the current pulse and calculating its second (m_2) and third (m_3) moment [9]. In Fig. 3, we present two examples of a DSP applied to the data collected from calibration measurements with the ^{252}Cf source. On the left-hand side, a 2-dimensional map for the charge (original) pulse amplitudes *versus* m_2 of the current pulses is shown. The right fig-

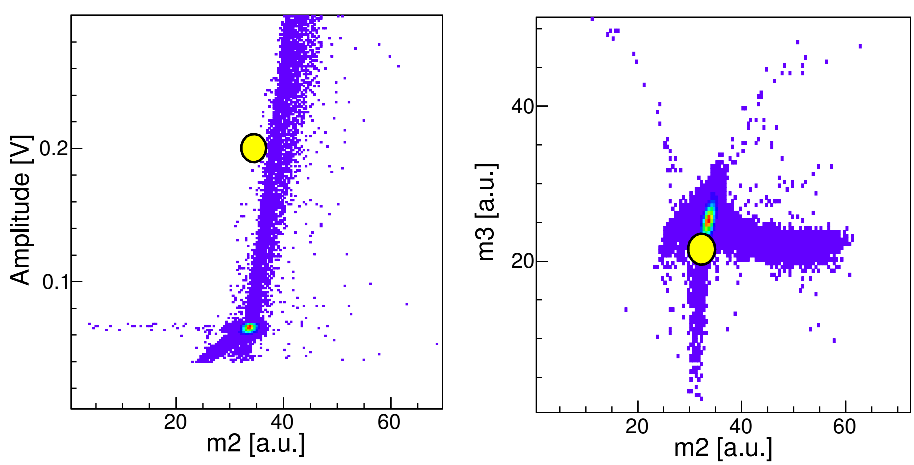

Fig. 3. (Colour on-line) Left: map of charge pulse amplitude *versus* m_2 of current pulse. Right: map of m_3 *versus* m_2 of current pulse. Measurement for Cf source.

ure presents the third moment of current pulse *versus* m_2. The maximum (yellow and light blue area in the on-line version) seen on both maps corresponds to 6.1 MeV α particles emitted by the californium source, while the dark tail (blue colour in the on-line version) spanning upwards on the left panel and to the right on the second panel represent the SF events of our source. This type of map can be used to show patterns validating interesting events, *e.g.* event presented in the previous figure, which is indicated here as a solid circle (yellow colour in the on-line version).

In the case of AC scintillators, DSP tools are not so obvious. This is due to the very fast pulse registered from the scintillators and this needs a new DSP approach to extract more detailed information about particles that produced a pulse.

4. Summary and conclusions

In our paper, we have presented a dedicated detection apparatus constructed to search for LLSHEs created in heavy-ion collisions and deposited in scintillator material. Presented results show that our detectors are capable of recording interesting events using coincidence techniques on an ΔE–E map. Presently, we are collecting more data that will be carefully analysed using digital signal processing to distinguish more precisely α particles from the SF fragments.

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REFERENCES

[1] Y.T. Oganessian *et al.*, *Phys. Rev. C* **74**, 044602 (2006).
[2] S. Hofmann *et al.*, *Eur. Phys. J. A* **14**, 147 (2002).
[3] K. Morita *et al.*, *J. Phys. Soc. Jpn.* **73**, 2593 (2004).
[4] G. Korschinek, W. Kutschera, *Nucl. Phys. A* **944**, 190 (2015).
[5] H. Gäggeler *et al.*, *Phys. Rev. Lett.* **45**, 1824 (1980).
[6] Z. Majka *et al.*, *Acta Phys. Pol. B* **49**, 1801 (2018).
[7] S. Wuenschel *et al.*, *Phys. Rev. C* **97**, 064602 (2018).
[8] M. Bender, P.H. Heenen, *J. Phys.: Conf. Ser.* **420**, 012002 (2013).
[9] S. Barlini *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **600**, 644 (2009).