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ΔE - E Detector System For Searching Long Lived Heaviest Nuclei In Activated Scintillators

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We present a dedicated experimental setup that has been built in Institute of Physics of the Jagiellonian University and is currently used to search long lived super heavy elements (LLSHE) that could be produced in the reaction between heavy ions and then deposited in the active catcher (AC) scintillation material. The collisions between heavy nuclei ^{197}Au (7.5 A.MeV) and ^{232}Th have been performed during our experiment at the Cyclotron Institute, Texas A&M in 2015. An innovative apparatus, which consists of ΔE-E detectors, enables the registration and identification of spontaneous decays (α or fission - SF) of heavy products, which were deposited in the scintillation material of the AC. Unique feature of the apparatus is that the AC scintillators are at the same time ΔE part of each of ΔE-E detector. The other part, E part, is a silicon detector. This construction largely eliminates background events in the region where alpha particles emitted by decaying reaction products are expected. Our measurements should be sensitive to search for super heavy elements (SHE) which could be deposited in irradiated scintillators and which have lifetimes of a year till over a dozen of years. Some results of the continuous measurement that already lasts 1.5 year will be shown.

KEYWORDS: superheavy elements, multinucleon transfer, plastic scintillators, Si detectors, digital signal processing.

1. Introduction

Despite the discovery of many SHEs isotopes, which are predominantly short lived [1–3], the actinides stability island is still out of the reach of experimental nuclear physics. Also, attempts to search for SHEs in Nature have so far failed [4]. Nevertheless, results obtained from complete fusion reactions, encourage for further experimental efforts to reach the island. It was observed that the experimentally measured lifetimes of isotopes of elements Z=114 and their neighbours is increasing when approaching predicted neutron magic number N=184. In this paper, we concentrate on exploring a region of a lifetime of SHEs of the order of years which we will call LLSHEs [5].

In previous years, scientists from Jagiellonian University and Texas A&M University tested the multinucleon transfer in the reaction ^{179}Au (7.5 A.MeV) on ^{232}Th target as a way to create SHEs [6–9]. In this experiment the created SHEs candidates with different lifetimes were deposited in the AC detector which was the BC-418 plastic scintillators. Few years after the experiment those irradiated BC-418 are used to search for LLSHEs using dedicated detection apparatus constructed in the Institute of Physics of the Jagiellonian University.

2. Some remarks on LLSHE lifetimes

It is interesting to know what range of lifetimes of LLSHEs can be measured by our apparatus. The answer is illustrated by Fig.1 where we present probability of α/SF decays for five cases of lifetimes. Vertical axis gives probability of an α/SF decay of the LLSHE versus its lifetime, τ, assuming the measurement started t_{init} years after implantation and lasted 2 months in each case. Setting threshold for decay probability - horizontal line on the figure - to be equal to 0.01, one can estimate range of lifetimes for which the measurement is sensitive. This is shown in upper right panel, as a bar graphs for several cases of t_{init}. Our measurement corresponds to the solid line from the figure (see also third bar) and one can see that it is the most sensitive, for lifetimes of LLSHEs that are in the range 0.8 to 18 years, with maximum sensitivity for 2.2 years.

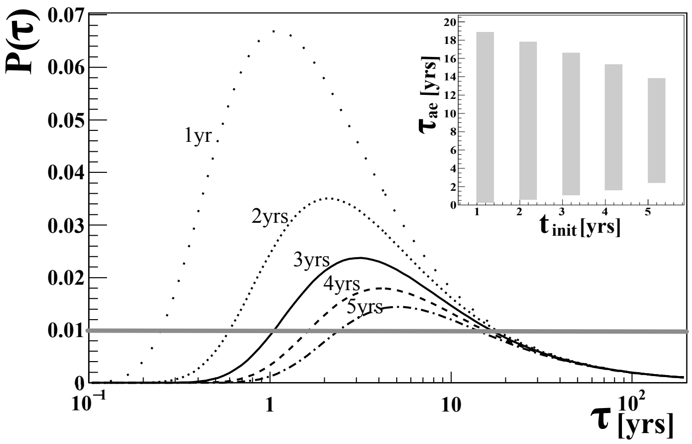

Fig. 1. Main panel: probability of α/SF decay as a function of an element lifetime for 1 (rarely dotted line), 2 (dotted line), 3 (solid line), 4 (dashed line) and 5 (dotted-dashed line) years, t_{init}, after the irradiation. Upper right panel: experimentally accessible range of element lifetimes vs t_{init}.

3. Brief description of detection setup

The idea of the measurement is based on the registration of α/SF decays of LLSHEs, implanted in the AC scintillators. To identify such decays, pairs of ΔE-E detectors were constructed, where ΔE is the AC scintillator and E is lithium drifted silicon detector (Si). Both detectors are placed in the air facing each other with a small gap between them (less then 1 mm). Our present setup consists 8 ΔE-E pairs. Si detectors provide information about energy of the registered α/SF particle, while AC scintillators deliver ΔE signal (for details see [10]).

It is expected that SHEs are implanted few microns in AC scintillators [9]. All α/SF particles after the decay are emitted isotropically. To isolate interesting cases (α/SF decays) we are limited to quite narrow angle (around 30°) of α/SF emission when α is escaping out of the AC scintillator in the Si detector direction. In such a case α is 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 main part of its energy will be deposited in the Si detector. In the case of SF from SHE decays, the energy registered in both detectors should be high. A single ΔE-E pair has geometrical efficiency not higher then 20% of a 4π solid angle.

Signals from any of the ΔE or E detector pairs were recorded as a waveforms using FADC digitizer module and saved on HD drive for further analysis. Calibration done in the vacuum with sources of ^{241}Am (which emits α) and ^{252}Cf (which emits α as well as SF fragments) showed that the energy resolutions are 1% in case of Si detectors and around 30% in the case of AC scintillator detectors. For more detailed specification of the electronics/acquisition arrangement see ref [10].

It should be mentioned that the ΔE-E detectors work in an environment where natural radiation is present. The radiation is composed of radioactive decay chains of thorium, uranium, radium, etc. which produces a background in our measurements. This may create some problems in the search for very rare events of investigated SHEs decays. Natural radiation contains α, β, γ particles of which only α particles can mimic the signal of SHE decays. Fortunately, the energy of α emitted at the beginning of a SHE chain decays reaches the value of 10 MeV and higher [11], while the highest energy of α particles coming from natural radiation is 8.99 MeV (decay of ^{217}Ra). Another source of background is cosmic rays. In this case the energy deposited by such radiation in Si detector is not higher than a few MeV.

4. Presentation and discussion of results

Procedure to identify interesting events, candidates for LLSHE decays, is based on an analysis of two-dimensional maps of ΔE-E energies. On such a map one can define a rectangular area that is showing an expected localization of interesting events. The heights of 2 MeV, ΔE energy, of this rectangle is estimated from the observation that the SHEs should be implanted in the AC scintillator at depths of several microns [9]. The base, E energy, from 10 to 18 MeV, of the rectangle is chosen to be in the range of α energies expected for decays of heaviest SHEs [11]. Due to the lack of the place in this article, example of the map together with shapes of pulses of an interesting event from Si detector and AC scintillator can be found in [10]. In selecting interesting events, located in the rectangular area, we demanded that a pulse from charge pre amplifier of Si detector represents detection of charged particle i.e. it has well defined heaviside-like shape with a rise time of around 200 ns while coincidence pulse from the AC scintillator should be very fast, with a duration of several nanoseconds, asymmetric in shape with a tail extended to several dozen of ns. Besides, both pulses ΔE and E should be properly located with respect to the arrival of the acquisition trigger. Interesting events

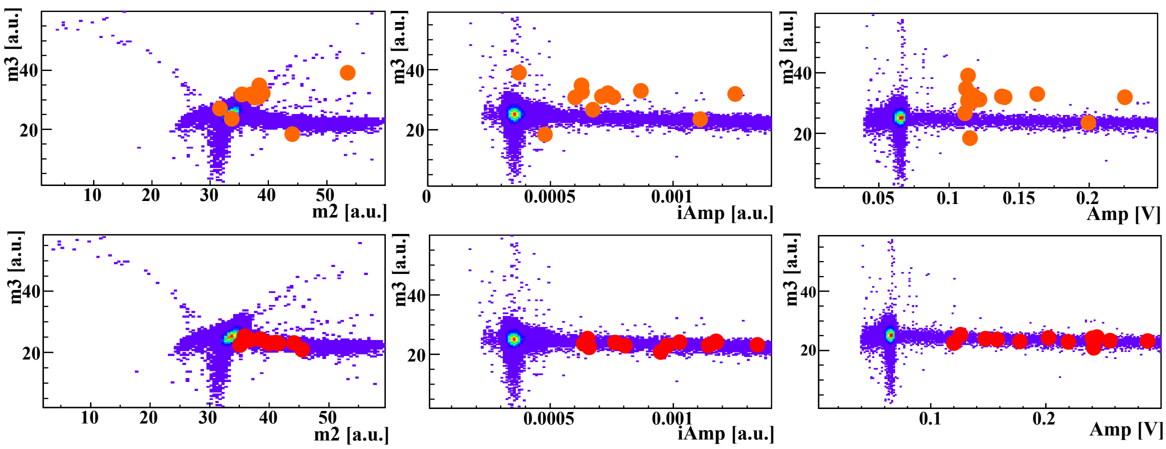

Fig. 2. Left column: third moment, m_3, versus second moment, m_2, of current pulse. Central column: m_3 versus amplitude, iAmp, of current pulse. Right column: m_3 versus amplitude, Amp, of charge pulse. In the upper raw 12 interesting events are presented, while in the lower raw 12 randomly chosen events for ^{252}Cf spontaneous fission are shown. Both type of events are marked as full circles (red color in electronic version).

represented by recorded pulses can be further analysed by using digital signal processing (DSP) tools. In the first approach the DSP was used for signals from the Si detector for which it frequently enable particle identification. For this, we got several characteristics (observables) of the Si pulse such as amplitude of charge pulse (original one), the amplitude of the current (derivative of the original one) and also the second (m_2) and third (m_3) moments of the current pulse [12]. In Fig. 2 we present three examples for one pair of ΔE-E detectors (consecutive columns) of a DSP applied to the data collected from calibration measurements with the ^{252}Cf source. All the 2-dimensional maps presented in the figure were sorted using different combinations of observables mentioned above. The maximum (red, yellow and light blue area in electronic version) seen on the maps corresponds to 6.1 MeV α particles emitted by the californium, while the dark tail (blue colour in electronic version) spanning to the right on all panels represents the SF events of the source.

This type of maps is used to show patterns validating interesting events, selected from a previously defined rectangle of ΔE-E map. Full circles in the upper row in the figure (orange color in electronic version) represents 12 events which were selected after 70 days of continuous measurement. In the lower row of the figure, we present same amount of randomly chosen events extracted from the population of californium source decays, in the same rectangular area on the map ΔE-E as discussed before. Location of those randomly chosen events is quite different than in case of our LLSHE candidates, what justify our assumption to consider this events as a interesting ones.

It is interesting to look on the energy in Si detector (amplitude of the charge pulse - Amp) for the interesting events which can be extracted from figure ”m3 vs Amp”. Seven of those events grouped below 130 mV correspond to the energy 8.8 -9.8 MeV, a next five spread on the right of 130 mV covers the energy 10.9 - 18.4 MeV. If one takes into account energy loss in the AC scintillator, aluminium foil and thin layer of air (1 mm) total energy of all this events should be increase about 1-2 MeV. The events from the range of 10.9 -18.4 MeV require more detailed analysis. Production cross section estimated from target density (12 mg/cm^2), dose of beam ions (3×10^{15}) impinging the target, radius of a scintillator (10 mm) and geometrical efficiency is 1 nb/sr per one event.

In the case of AC scintillators which produce very fast pulses of detected particles the DSP tools need new approach to extract more detailed information about particles that produced a pulse.

5. Summary and perspectives

We have presented a detection apparatus constructed to search for LLSHEs created in heavy-ion collisions, presumably by multinucleon transfer reactions, and deposited in AC scintillator material. Results show that the coincidence technique on an ΔE-E map and the DSP tools are capable of selecting interesting events detected and recorded by our apparatus. More data which we have collected has to be analysed applying presented digital signal processing technique to distinguish more precisely α particles from the SF fragments. Currently we are modifying our detector system to eliminate this part of background which is connected with cosmics radiation by adding high efficiency anti-coincidence shield, with thick BC-400 scintillators of large area.

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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**, (2004) 2593.
[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] Z. Majka *et al.*, *Acta Phys. Pol. B* **45**, 279 (2014).
[8] A. Wieloch *et al.*, *EPJ web of Conf.* **117**, 01003 (2016).
[9] S. Wuenschel *et al.*, *Phys. Rev. C* **97**, 064602 (2018).
[10] K. Zelga *et al.*, *Acta Phys. Pol. B* **50** 579 (2019).
[11] M. Bender, P.H. Heenen, *J. Phys.: Conf. Ser.* **420**, 012002 (2013).
[12] S. Barlini *et al.*, *Nucl. Instrum. Methods Phys. A* **600**, 644 (2009).