Searching for long-lived superheavy elements produced during multinucleon transfer

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Searching for superheavy elements (SHE) with the use of the multinucleon transfer (MNT) has been a subject of study at the Cyclotron Institute at Texas A&M University since 2002. It was a collaborative work of two institutes, TAMU and Jagiellonian University in Poland. Since the beginning, the detection setup has changed several times [1,2]. In the final form, it was using an active catcher (AC) detector. The first version of AC was built out of 63 modules based on the plastic scintillator BC-418 attached via LUCITE light guide to the photomultiplier Hamamatsu R9880U-110 [3,4]. The second version was built out of 40 modules based on YAP detectors connected to the photomultipliers Hamamatsu R1355 with the LUCITE light guide [5].

The last experiment dedicated to searching for superheavy elements conducted with AC based on YAP was studying MNT on ^{197}Au + ^{232}Th (7.5AMeV) reaction. Its results showed that it is possible to produce SHEs with this method [5]. The experiment was focusing on searching short-lived SHEs, with a lifetime on the level of several ns to 1 us. The obtained results, however, open possibilities to study if in irradiated by MNT reaction products YAP material were implanted any long-lived SHEs (with a lifetime on the level of several years).

The main motivation for studying the area of long-lived SHEs (LLSHE) is a desire of reaching an island of stability (Fig. 1) predicted and determined by scientists as N=184 or N = 196 and Z =114 [6,7,8]. Conducting this type of experiment is justified for two reasons. The first reason is the property of MNT which was used for irradiating YAP detectors during previous SHE-related tests (from 2018 to 2021). Lighter nuclei (Z<103) produced during MNT are neutron-rich nuclei, which is a property of stable/long-

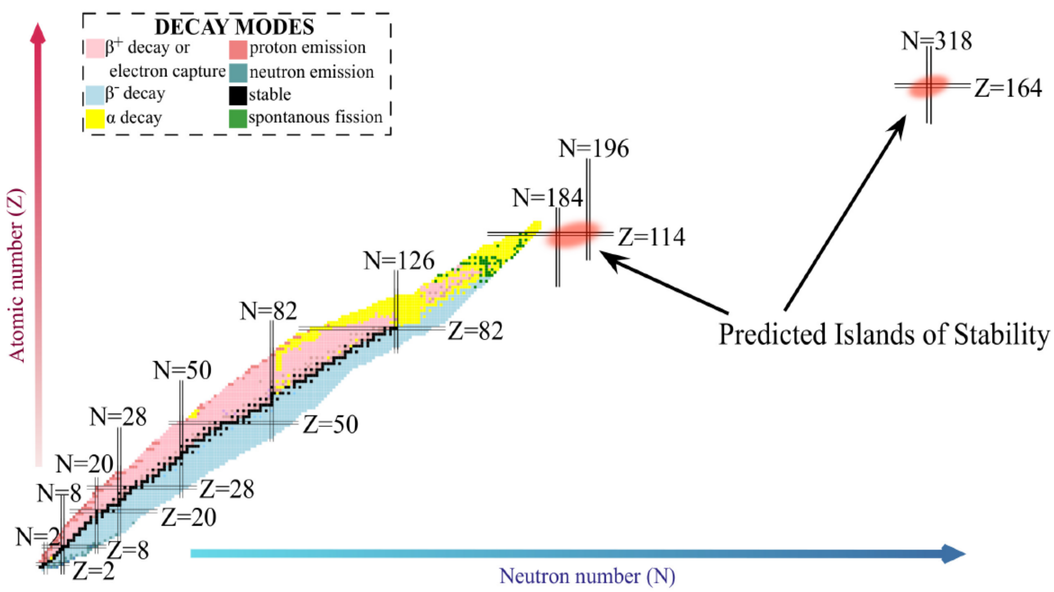

Fig. 1. Nuclide chart for already known elements with marked predicted islands of stability [9].

lived elements. Presently all of the already discovered nuclei are neutron-poor elements, which caused short lifetimes terminated with alpha decay or spontaneous fission. Results obtained by S. Heinz show the advantages of using MNT for producing long-lived SHE elements [10].

The second argument in favor of examining irradiated YAPs in terms of observing the decay of long-lived SHEs is the result of research carried out on scintillators used in AC before its upgrade [11,12]. These results showed that during experiments in 2016 in the BC-418 scintillator were implanted several long-lived nuclei with the energy of alpha decay above 10 MeV, which corresponds to the energy expected for the alpha decay of SHEs. During that experiment full identification of the implemented nuclei wasn't possible because of the poor energy resolution of the used scintillators. YAPs better energy resolution will return better information about implanted elements.

To test if LLSHE can be found in the irradiated YAPs, a new ΔE-E detector setup was prepared, Fig. 2. The prepared detector setup is built out of 8 pairs of Si detectors faced with YAP detectors. Seven out of eight YAP were irradiated during previous experiments (with reactions like ^{197}Au + ^{232}Th, ^{238}U +^{232}Th, ^{197}Au + ^{197}Au) while one remains clean, never used in the experiment before. The goal of that one detector pair is to be a control group to see how background radiation (including high energetic cosmic radiation) affects a counting rate in the energy area considered the interesting one in this experiment. The whole setup is placed in the vacuum chamber and connected with SIS 3316 ADC. Triggering of the acquisition is made by each of the detectors separately. The acquisition time window allows recording 2 us of the signal’s waveform per event.

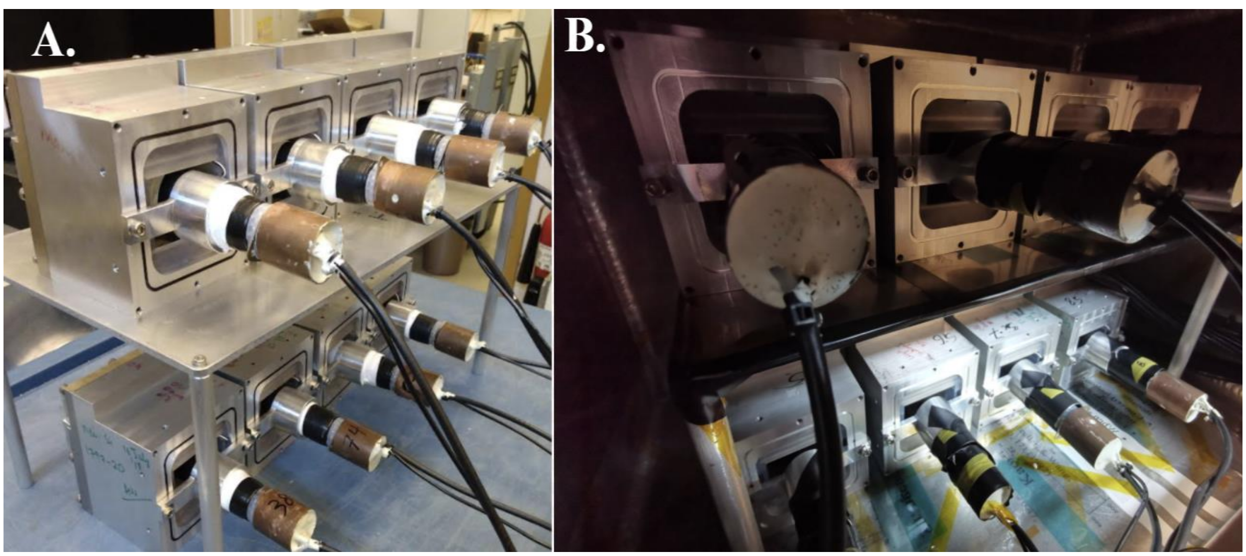

Fig. 2. Photo of the 8 pairs of detectors outside (A) and inside (B) the vacuum chamber.

There are two types of events that will be considered interesting during this experiment. First, case when implanted SHE decay with alpha particle emission outside the YAP detector in direction of the Si detector. Because implantation of the SHE should be rather shallow (several micrometers) the energy deposited (ΔE) in the YAP detector should be lower than 2 MeV, while the remaining energy (E) deposited in Si should be high. Recording such a coincidental event with total energy above 9 MeV/10 MeV will be considered a candidate for SHE decay. The second possibility is to record the alpha decay chain only in the YAP detector. At this point, interesting events will be those with at least two pulses registered in the one time window. Oslo in that case the energy of at least one signal should be higher than 9 MeV/10 MeV. Such energy of the sought alpha decay was selected as a lower limit due to the dependence between the energy of the emitted alpha particle and the atomic number of the decaying element. Namely, with the increasing atomic number Z of the decaying element, the energy of the emitted alpha particle also increases, as shown in Fig. 3.

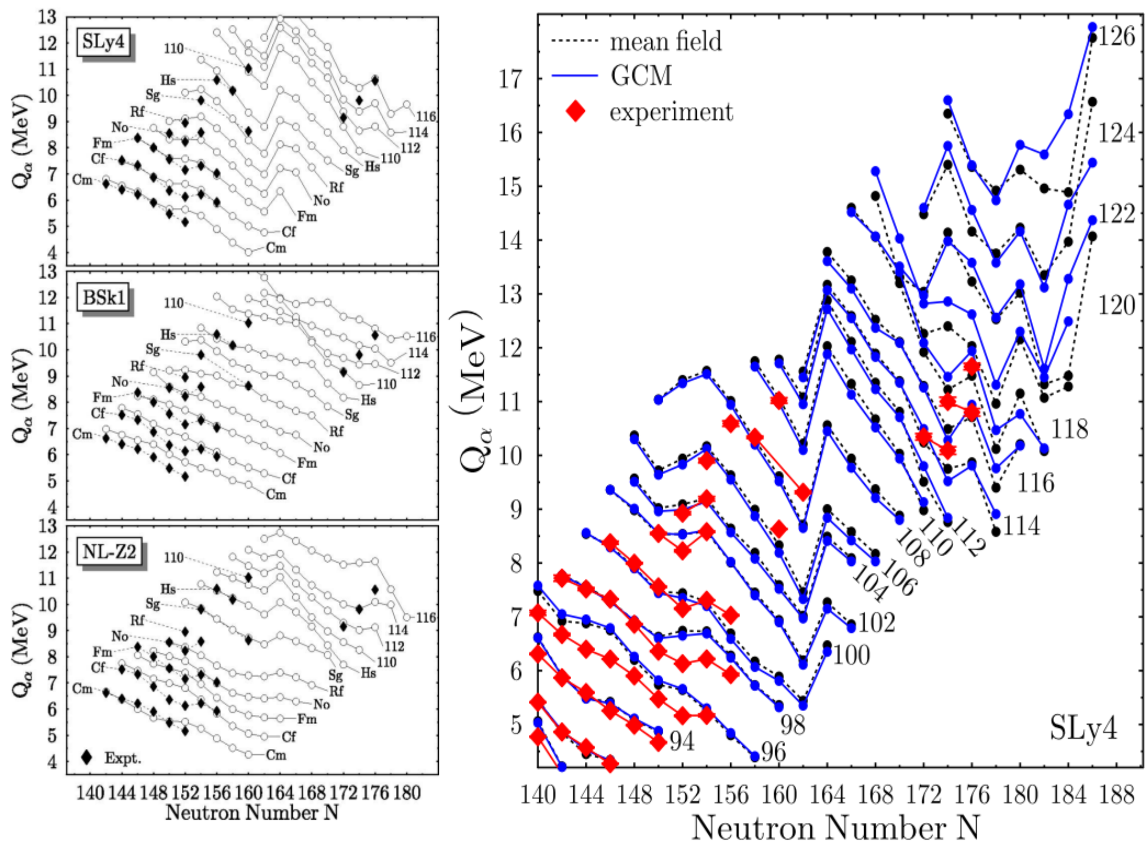

Fig. 3. Qα values for α particles emitted from even-even nuclei as a function of neutron number for increasing atomic number of heavy and superheavy nuclei [13][14].

To conduct this experiment special detector holders were prepared to allow mounting YAP detectors on the Si modules (how it is shown in Fig. 2). The process of calibration of all 16 modules was also made (8 Si and 8 YAPs detectors). For calibration purposes, a set of measurements with ^{241}Am, ^{252}Cf, and ^{228}Th sources were conducted. Due to the configuration of the ΔE - E detection setup and the size of the used vacuum chamber, it was necessary to make those measurements in two steps. Separately for the wall of Si detectors and the wall of YAP detectors. Its configuration is presented in Fig. 4 and Fig. 5.

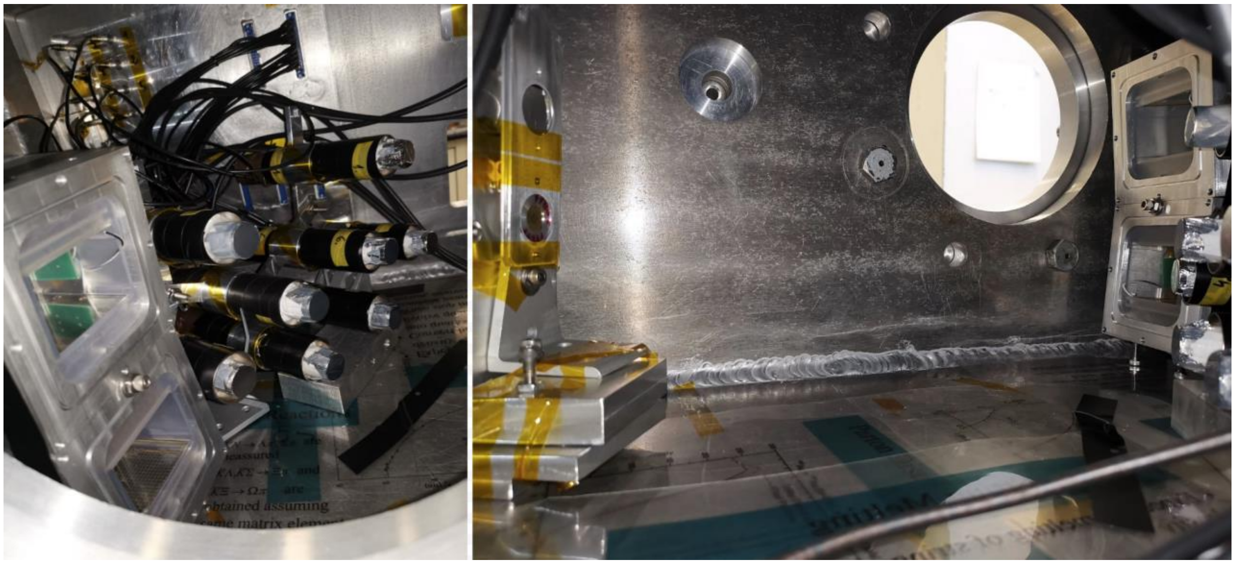

Fig. 4. Example setup of detection modules in the vacuum chamber during the calibration runs. The photo on the left figure presents the position of YAP modules and one pair of Si detectors. The photo on the right side presents the location of the source in front of the detector wall.

Fig. 5. Setup of detection modules in the vacuum chamber during the calibration runs. The photo on the left figure presents the position of Si modules in the vacuum chamber. The photo on the right side presents the location of the source in front of the detector wall.

Amplitude spectrums obtained from those runs are presented in Figs. 6 and 7. Used Si detectors have very good energy resolution which will provide reliable information about the deposited energy of the alpha particle emitted from the YAP detector. YAPs energy resolution is not satisfactory enough, but the results of its calibration will be supported by pulse shape analysis used before in the MNT experiments with AC for SHE identification. That should be enough to show if we can produce superheavy elements with long-lived times using MNT.

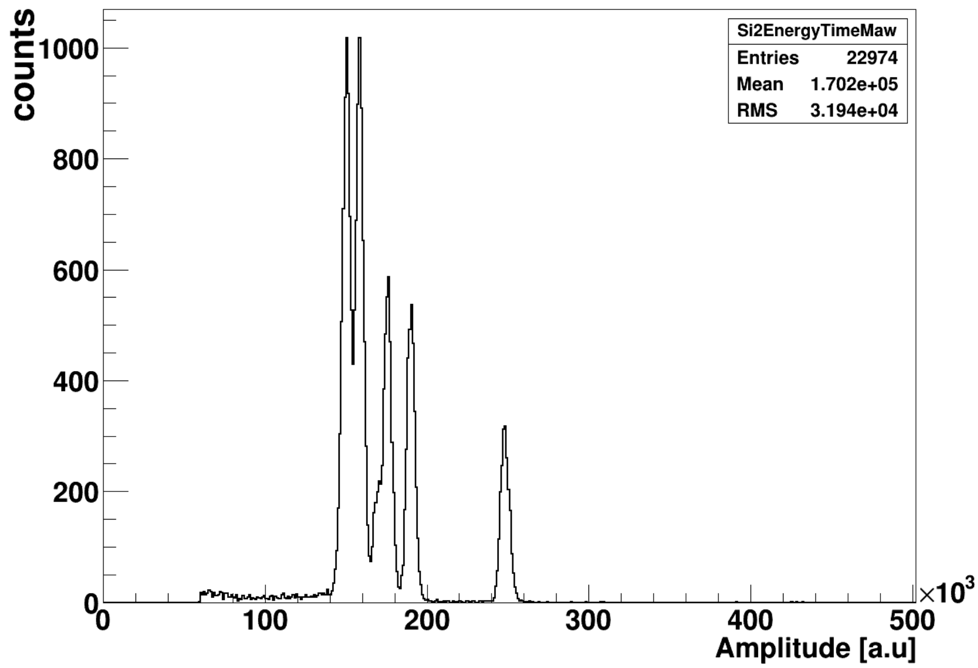

Fig. 6. Typical amplitude spectrum for Si detector, for run with ^{228}Th source.

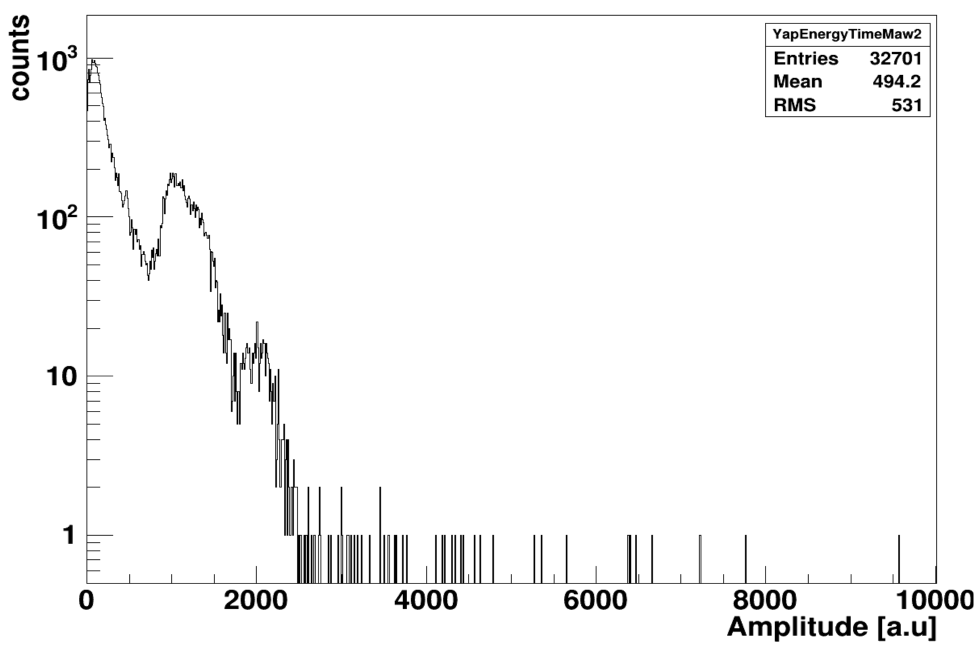

Fig. 7. Typical amplitude spectrum for YAP detector, for run with ^{228}Th source.

At the moment main measurements are started. They will last 2-3 months of offline counting. After this time and after careful analysis of already collected data, the decision of continuing measurements with the same or a new set of irradiated YAPs should be taken. If after this experiment in collected data any superheavy element will be found, then the next step may be preparing a dedicated detection setup which right after irradiation by MNT reaction products will be placed inside the vacuum chamber. Such a detector would be monitored constantly for several months or longer to enlarge the range of observable times of life.

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