A search for super heavy elements using a catcher foil

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The search for super heavy elements (SHE) located on the predicted island of stability has a long history. The search usually involves at attempt at the direct detection of heavy elements that may have been produced. We made an attempt to collect SHE from the reactions of ^{197}Au + ^{232}Th using a magnet spectrometer and detect them at the focal point [1]. This experiment yielded a number of candidates but the results were not conclusive.

Super heavy elements are expected to be alpha-particle emitters. A calculation indicating alpha particle energies [2] expected for various heavy elements is shown in Fig. 1. We observe that with increasing charge that the alpha-particle Q-value increases. This suggests that it might be possible to search indirectly for super heavy elements and significantly improve the efficiency of the measurement.

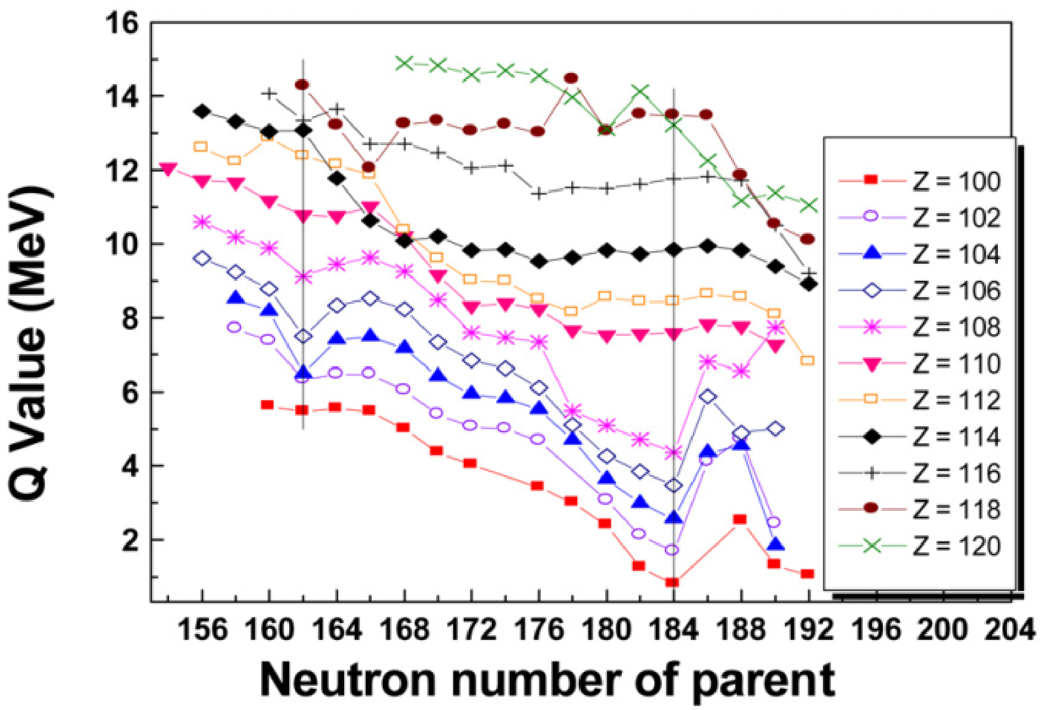

FIG. 1. Alpha Q-values for a range of heavy elements; from [2]

We have therefore embarked on a study to attempt to detect the alpha particles emitted from a super heavy element. The experimental setup is shown in Fig. 2. We note that the beam is incident on a ^{232}Th target. Immediately downstream of the target is a shield constructed of Borated Polyethylene with a conical hole that allows the products to travel to the catcher foil further downstream. Behind the blocker is a series of 7 strip silicon detectors that view only products that would be emitted from downstream, but not directly from the target. There were also two sets of thin silicon detectors placed in front of the strip detectors for the purpose of confirming particle identification for measured products.

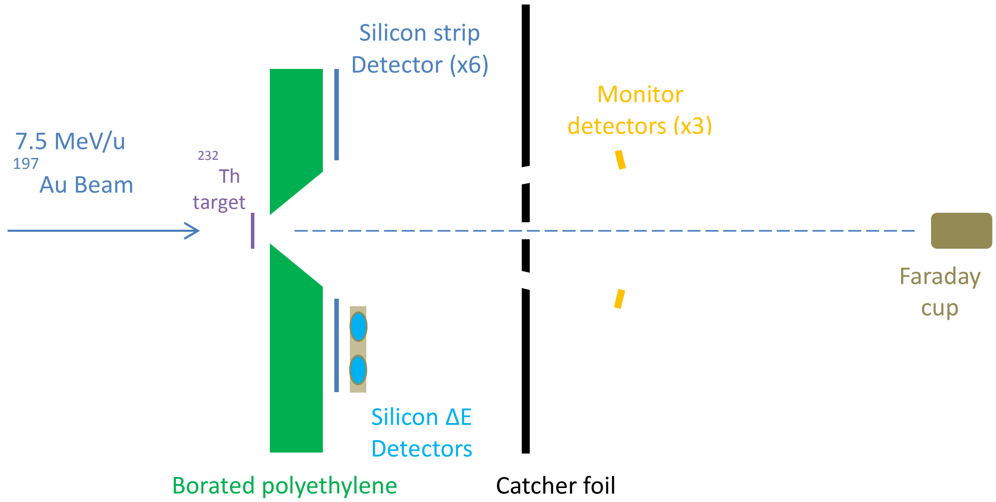

FIG. 2. Experimental Setup

The left two panels in Fig. 3 show the energy spectra and time distributions of particles detected in the silicon detectors when the beam was on. The relative time that the beam is on versus when it is off is indicated in the figure. We observe signals in the silicon detectors above 20 MeV with peaks around 6 MeV. When the beam was on, the time distributions show an increase with time. The high energy tail of the energy distributions are significantly suppressed when the beam is turned off as shown in the third column of Fig. 3. The peak of the distributions remains around 6 MeV and there are only a few signals

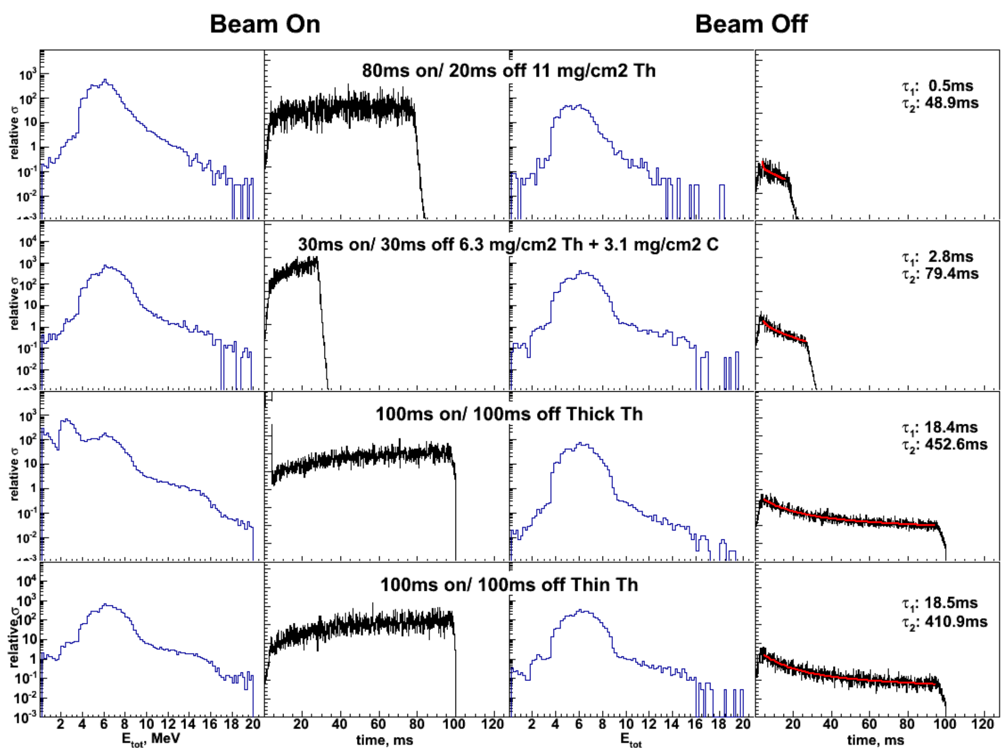

FIG. 3. Left two Columns: Energy distributions in the silicon detectors when beam was on (1st column) and time distribution of events from start of beam when beam was on. Right two columns: same for when beam was off. Time distributions in this column are measured from time beam was turned off.

above 15 MeV. The time distributions show a decay during the duration of no beam. In order to obtain an estimate of the lifetime of any heavy element decaying in the catcher foil, we performed a two component fit of the decay. A short as well as a long component is suggested. For the cases where the beam was off for 100ns, the short component is about 18ms and the decay of the long component is around 425ms.

We show the time distributions that are gated on the energy for the selected configuration of beam on/off of 100ms/100ms. These are shown in Fig. 4 along with the corresponding energy spectra shown at the top of the figure. The left side shows the time distributions when the beam was on and the right side shows the same when the beam was off. The two component fit shown on the right hand side hints at a decreasing lifetime for the higher energy window with the slow component decreasing from about 20ms at lower energies to about 3ms at the highest window and the long component decreasing from about 500ms at low energies to about 275ms at the higher energy window.

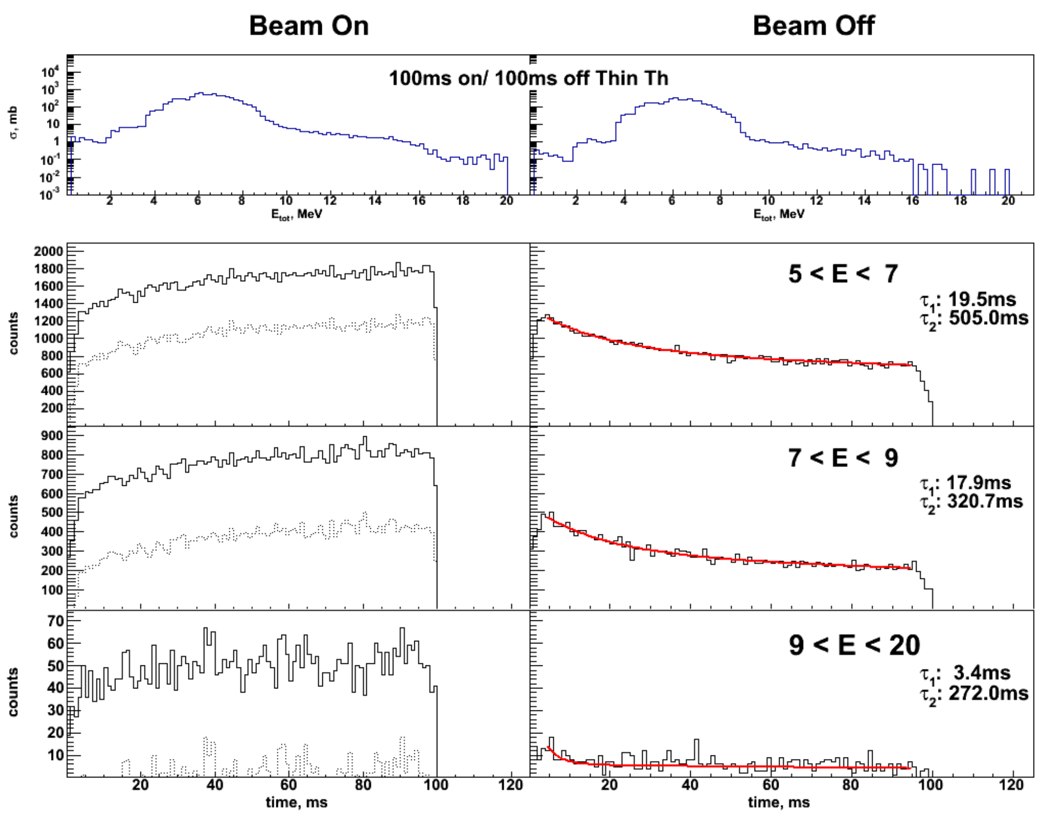

FIG. 4. Time distributions gated on energy for beam on (left) and beam off. The energy spectra that are gated are shown at the top.

The spectra obtained when a target was inserted, but the catcher foil was absent shows that the majority of events that are obtained when beam is off indeed result from decay from the catcher foil. This is demonstrated in Fig. 5. The top part of Fig. 5 shows the spectra obtained when a tantalum target thick enough to stop the beam was inserted. When the beam was on (left panels), events were observed that probably result from neutron reactions with the silicon producing protons or alpha particles. When the beam was off, there were very few events and the events observed are less than 9 MeV.

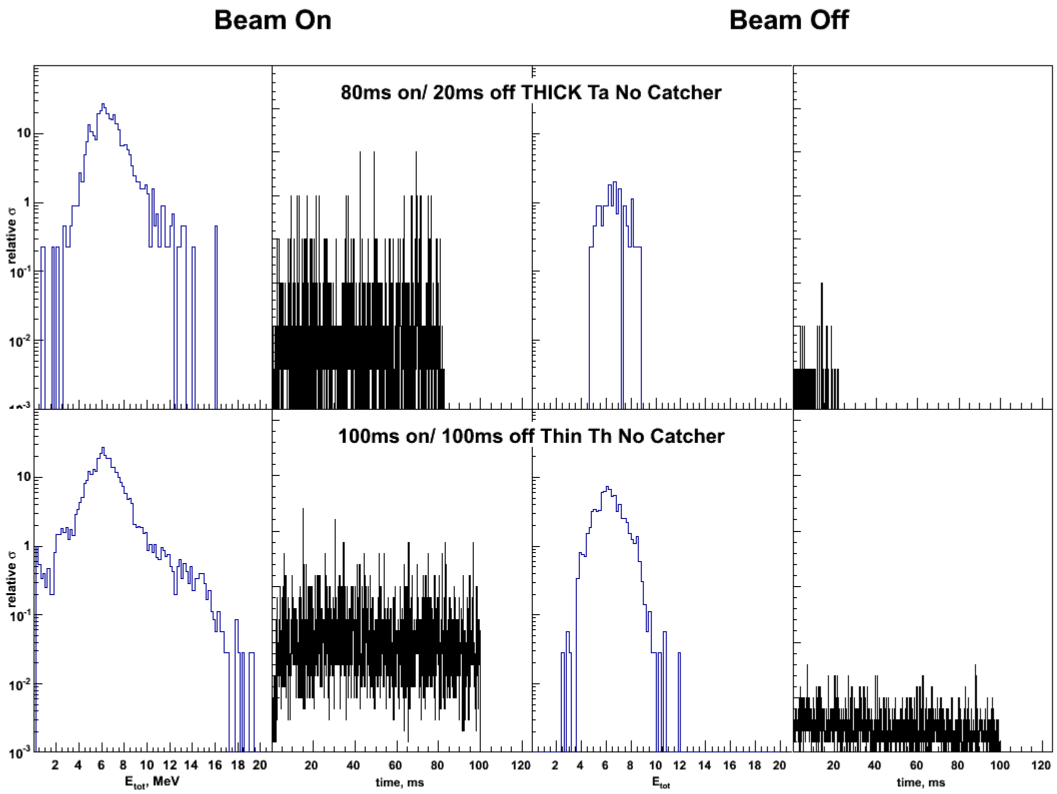

FIG. 5. Similar to Figs. 3 and 4, but for the cases where there was no catcher foil present. Top: beam on/off 80/20 ms with a Ta target thick enough to stop the beam. Bottom: beam on/off 100/100ms which a thin Th target that was used in the experiment.

The lower panel of Fig. 5 shows the measured quantities when the target is inserted, but no catcher foil present. In this case the beam was off for 100ms and the spectra extend to somewhat higher energies, but still remain below 12 MeV.

To determine whether the energy signals in the silicon detectors shown in figures 3-5 truly result from alpha particles, some 50um ΔE detectors were inserted in front of two of the silicon strip detectors. The ΔE-E maps that result from these measurements are shown in Fig. 6 where the left column, again, shows the maps with beam on and the right column shows the maps with beam off. The red curves show the alpha particle limits expected from range energy calculations. The lower limit results when the particle passes straight through the detector and the upper limit shows the range energy curve when the particle passes at the larges angle allowed by the geometry. The blue curves show the same quantity for protons. Any events falling inside the limits of the red curves are identified as alpha particles.

We observe two events that fall in the limits where alpha particles are expected when beam is off. We note a cluster of events just below the lower limit. It is not clear whether these could be alpha particles and the detector is thinner than advertised or perhaps not fully depleted or if they are not alpha particles. Further investigation is necessary.

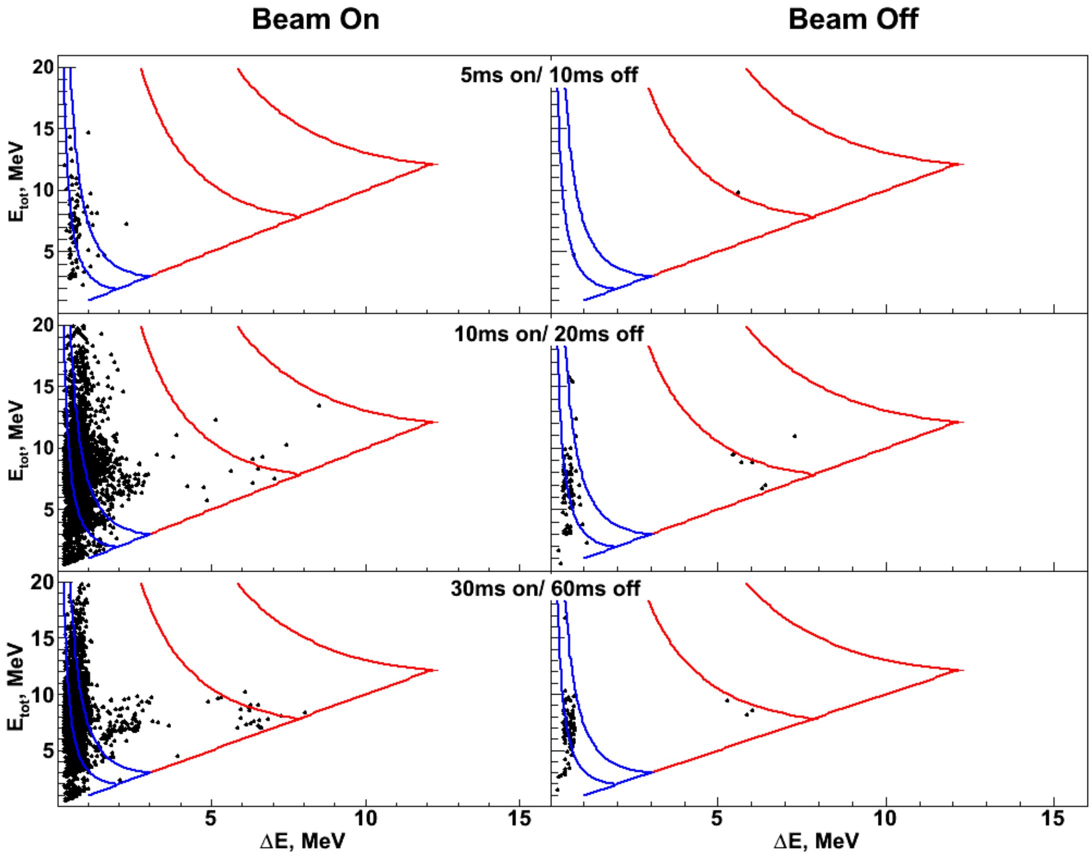

FIG. 6. ΔE-E maps for beam on (left) and beam off (right) for different beam on/off configurations.

To again ensure that the particles shown in Fig. 6 result from nuclei decaying in the catcher foil, we again inserted the beam stopping thick tantalum target and generated the ΔE-E maps. The catcher foil was inserted during this test. The result of this test is shown in the top row of Fig. 7. We observe a much smaller production of signals in the ΔE-E maps. There is, however, one event that is identified as an alpha particle. The bottom row of Fig. 7 shows a background where the data was acquired with no beam. In this case, beam on and beam off are the same. No alpha particles are observed in this background run.

In conclusion, we have observed decay of fragments from the catcher foil. This has been proven by background runs that show an absence of signals when the catcher foil is removed. The plethora of signals when beam is on as opposed to when beam is off indicate to us that neutrons interacting with silicon in the detector are a challenge. This means that pulsing the beam to observe the fragments decaying while beam is off is imperative. We have also observed alpha particles identified in ΔE-E maps.

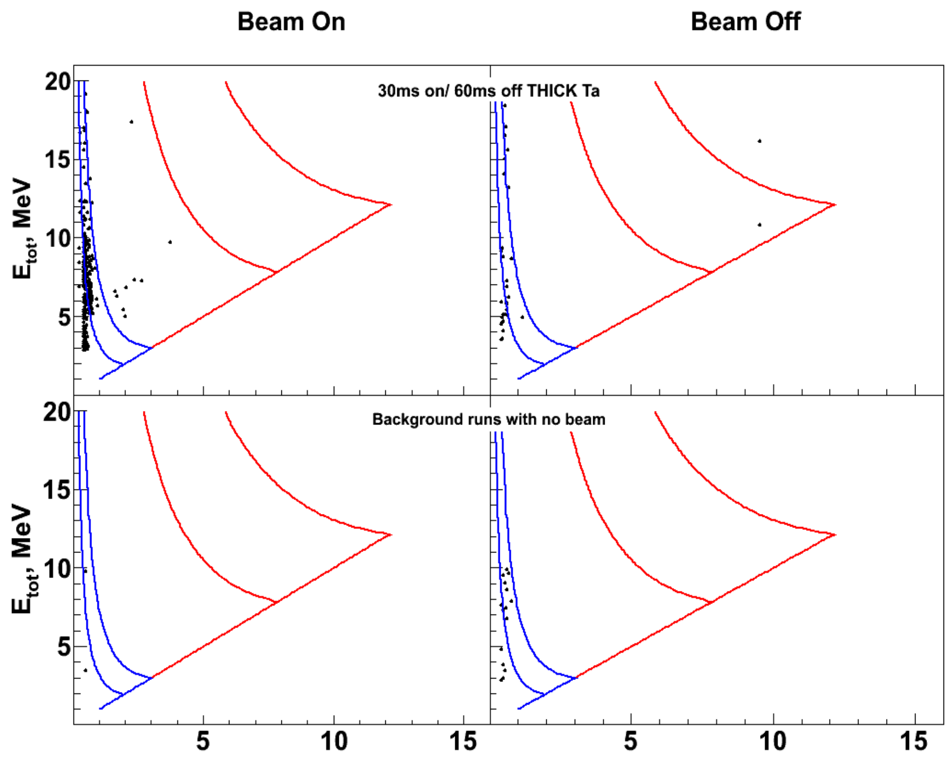

FIG. 7. ΔE-E maps for a run where the beam stopping thick Ta target is inserted (top) and for runs without beam (bottom). The catcher foil was inserted.

A number of improvements can be made in the search for super heavy elements. A larger efficiency of the ΔE-E maps is imperative as we note in the difference of signals between figures 3-5 versus what is observed in the ΔE-E maps. In order to reduce the contribution from neutron induced signals, a thinner ΔE detector needs to be implemented. We plan to accomplish this by using thinner strip detectors that will be placed in front of the thicker E detectors. In addition, we are designing a set of gas ionization chambers (ICs) which will be used either with the E detectors alone or along with the thinner ΔE detectors. Along with the ICs, we plan to implement a position sensitive parallel plate avalanche counter (PPAC). Together with the thin silicon strip detectors, the particles can be tracked to determine their origin.

Finally, we are investigating the possibility of an active catcher. This would allow us to identify where the heavy nucleus was implanted and together with the tracking capability of the position sensitive PPAC + silicon strip detectors we could confirm that the particles originate from the same position in the catcher foil where the heavy nucleus was implanted.

[1] J.B. Natowitz *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2008-2009), p. II-1.
[2] K.P. Santhosh *et al.*, Nucl. Phys. **A825**, 159 (2009).