Determination of masses of the super heavy elements in the experiments on synthesis of Cn and Fl using the reactions $^{48}$Ca + $^{242}$Pu and $^{48}$Ca + $^{244}$Pu


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# Contents

## Abstract

Understanding the structure of atoms can leap chemistry and other branches of science in various ways. Through the study of super heavy elements (SHEs), new elements can be discovered and the understanding of known elements can be deepened. This study aims to test different methods of forming element 112. That allows us to explore its various nuclear and chemical properties and learn about islands of stability in elements. MASHA is used to create and study those SHEs through the collision of ion beams with appropriate actinides. Element 112 is obtained directly, once, then through the $\alpha$-decay of element 114. The results of testing confirm the existence of islands of stability and allow for the creation of a sample of element 112 with sufficient lifetime. They also assess the relativistic effects of electron velocities on the properties of the material.


## 1 Introduction

The study of SHEs has significant implication on the understanding of atomic structure. Most notably, studying the trends in properties in the periodic table and learning about islands of stability. Almost all of the heaviest elements to have been discovered act similar to those in their groups in the periodic table. Although that result is reasonable, it is noteworthy that it holds even with relativistic effects. This area of research struggles, however, from the resources required. One atom of SHE can take weeks to form, all while consuming a significant amount of energy. Additionally, most SHEs have short lifespans before decaying due to instability. However, an increase in stability as some elements get heavier indicates the existence of islands of stability. [1]

One of the most notable SHEs is element 112, where it seems to break the trend with its homologue mercury. Classically, it is predicted to act as a noble metal. When relativistic effects are taken into account, though, it is predicted to act as a noble gas.Alternate methods of producing the element are used, which shows more consistent and reliable results with higher stability. Element 112 is either produced directly or through the alpha decay of element 114. [2]

## 2 Setup

Mass Analyzer of Super Heavy Atoms (MASHA) was first developed at JINR to study the $\alpha$-decay and spontaneous fission of the nuclei of synthesized superheavy elements. The primary components of the device are Target box, Ion source, Graphite stopper,

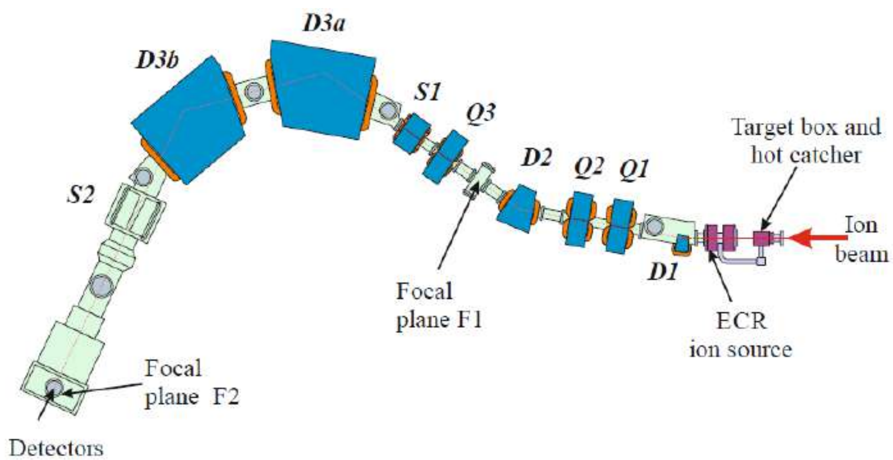


Figure 1: MASHA setup diagram [3]

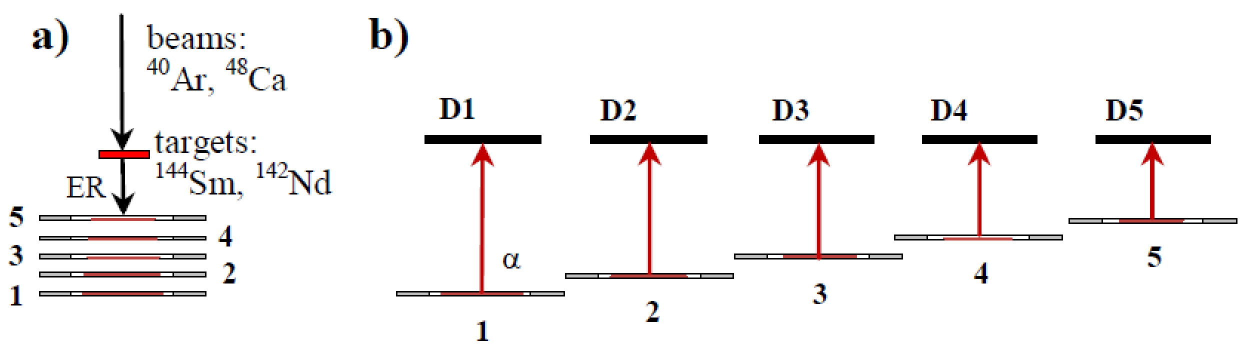


Figure 2: Target array [5]

and Focal planes as seen in Figure 1. [4]

## 2.1 Target box

Previously the targets were created as an array of parallel foils placed one behind the other, as shown in Figure 2.a. The array would then expand placing each foil opposite a corresponding silicon detector, as shown in Figure 2.b. Currently, however, rotating targets are used to optimise the efficiency and heat distribution as shown in Figure 3. The heat redistribution is done by changing the targets to be powered directly by current through thermally expanded graphite. [5, 4]

Figure 3: Rotating target [4]

## 2.2 Ion source and Mass-separator

The ion source generates a beam that is separated by magneto-optical mass-to-charge ratio analyzer. The walls of the source are plated with Titanium Nitride - which is close to ceramic - to increase the chemical inertia of the walls, and consequently the life time of atoms. Mercury, however, has strong adhesion to steel, making the atoms bounce around before getting ionized. Helium is, therefore, injected inside the tube at low pressure as a buffer gas to gather stable plasma from the beam. The ion beam is then passed onto the ECR to be accelerated. [4]

## 2.3 Graphite stopper

The stability of the total separation efficiency deteriorated during experiments when high intensity beams were used. As such, a layer of graphene foil was added ahead of the main heater. This isolates low-energy products inside it, while also taking on some of the heat through radiation. [4]

## 2.4 Beam diagnostics and Focal planes

The focal plane of the mass-separator is composed of a silicon strip detector and TIMEPIX. The signals are amplified to obtain 3 outputs: alpha, fragment, and digital channels. Alpha and fragment signals are basically the source signal at different amplifications. The strip detector is calibrated using 228Th emanation. Gas catchers are used for the generation of radioactive beams, and are useful for mass-spectrometery.

The energy of the beam is measured through two independent methods; one of them uses two pick-up detectors, and the other uses MCP and a silicon detector

TIMEPIX has 65536 channels which allows it to detect single particles and radiations in a wide dynamic range. [4]

# 3 Methods

## 3.1 Theory

According to the periodic table, element 112 lies in group 12, placing it with metals as zinc, cadmium, and mercury - which are considered to be its homologues. In turn, it is predicted to have an electronic ground state configuration of a closed-shell. That implies that it should act as a nobel metal in reactions. Relativistic calculations, though, indicate a contraction of its s and $p_{1/2}$ orbitals which would increase its stability making it function more like a noble gas (as Radon) rather than a noble metal. Some other calculations showed that it should behave as a semiconductor solid metal with clear chemical bonds. [1]

The element is identified in the experiment using their measured life time and the energy of the $\alpha$-particles emitted during the decay process. The life time of the element is calculated as the difference between the start of measurement with the detection of the element and the time when the $\alpha$-particle is detected. [5]

## 3.2 Procedure

SHEs are synthesized at large accelerators through the collision of heavy ion beams with a matching target element. The accelerator used in MASHA setup is the U400M. $^{48}$Ca is fused with an actinide target through a nuclear reaction, then the product is collected in He+Ar gas so that the volatile elements would get transported to a chormotographic column through a Teflon capillary. Along the column there are 32 pairs of silicon detecors, all covered in thin gold layers. A temperature gradient is created by keeping each pair of detectors at a different temperature at a range from $+35°$C to $-185°$C. This is known as Thermochromatography, which is used to identify the deposition temperature of volatile elements along the column. [2]

Two experiments were performed. In the first one, element 112 was obtained from the fusion of $^{48}$Ca + $^{238}$U. Here, the element did not decay, but the experiment had low sensitivity with a cross-section of 1.3 pb, which was insufficient to properly confirm the results. In the second experiment, element 112 was obtained from the $\alpha$-decay of element 114 before it arrived at the silicon detectors. Element 114 itself was obtained from the fusion of $^{48}Ca$ + $^{242}Pu$ as that reaction has a cross-section of nearly 4 pb. [2]

# 4 Analysis

The setup gathered data related to super heavy Hg isotopes as analogues to element 112 to study its different properties and their trends, and stability. The data analysis can be seen on the plots on Figures **??**, **??**, **??**, and their respective heat-maps on Figures 7.

# 5 Discussion

Through the analysis, it is shown how element 112 is one of the long-sought islands of stability. This was the first instance that this has been found by chemists. Although the chemical analysis was done on few atoms, their behaviour could be statistically generalized to larger masses of the element. It was also found that some atoms of element 114 acted more volatile than element 112, which was an unexpected observation. That was potentially attributed to strong relativistic effects. [2]

# 6 Conclusion

After being theorized for some time, the existence of islands of stability was proven experimentally. The properties of the elements were measured experimentally when multiple theories started to arise. This opens to door for the exploration of new atomic structures, such as elements where the 5g electron shell gets filled, which is estimated to begin at element 125. Future experiments could try to overcome the issue of low production rate by developing new accelerators and collision targets. [2]

# 7 Acknowledgement

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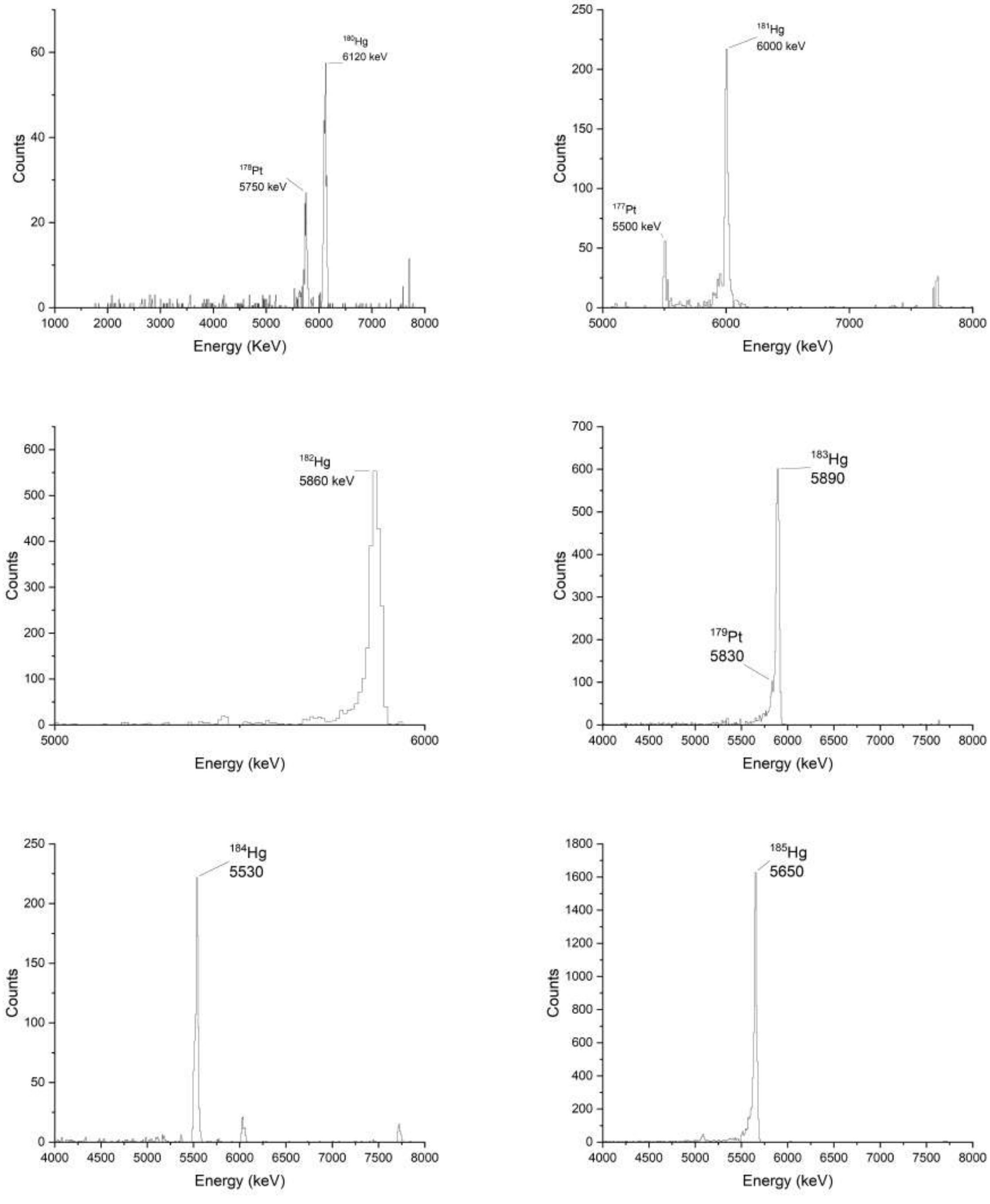


Figure 4: 40Ar+148Sm Reaction

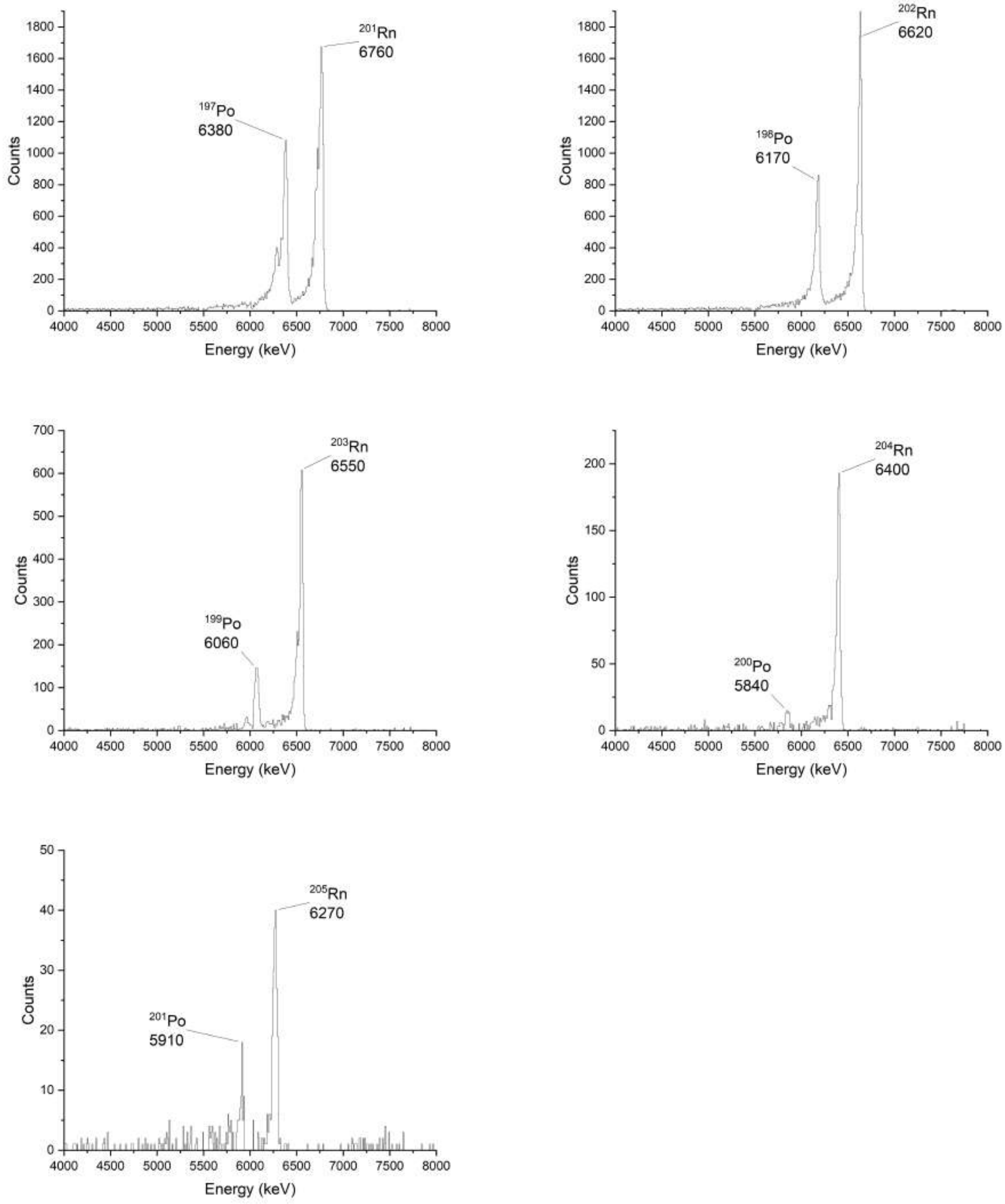


Figure 5: 40Ar+166Er Reaction

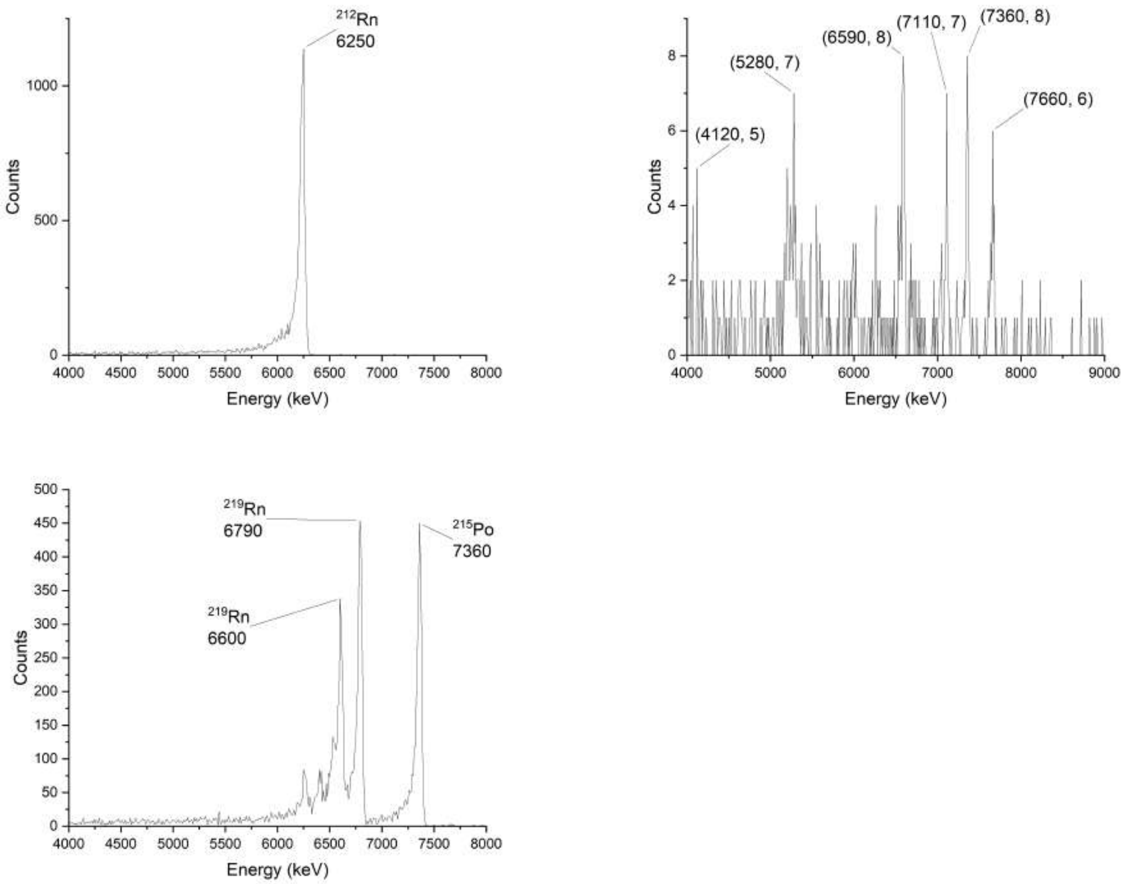


Figure 6: 48Ca+242Pu Reaction

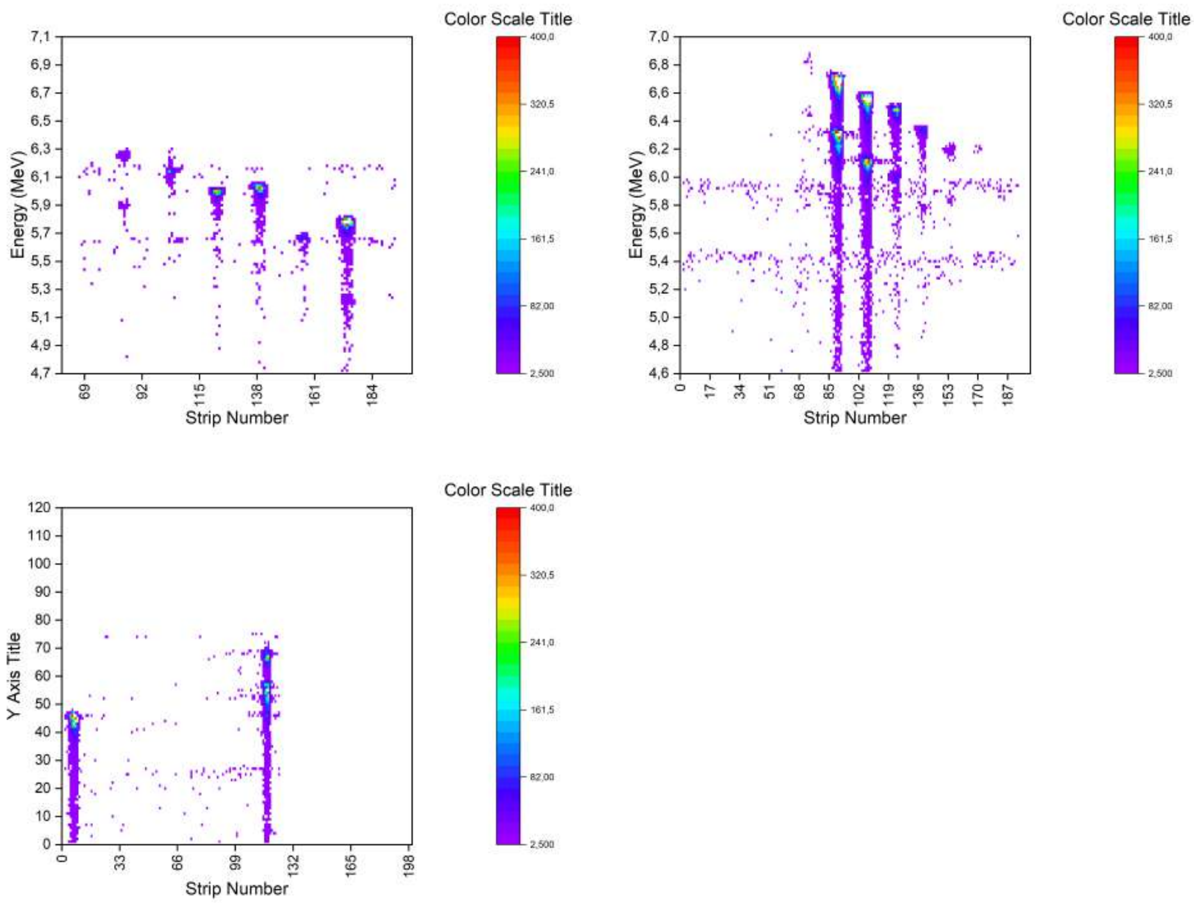


Figure 7: Heatmaps

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