Multi-detector registration system for the study of multi-body decays of heavy nuclei

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Abstract. The new ternary decay of low and middle excited nuclei referred to as Collinear Cluster Tri-partition (CCT) has been observed in the framework of the "missing mass" method. In this method only two of the three ternary fragments are detected, the third one is missing. In order to detect all the three fragments, a multi-detector registration system is needed. This paper presents two multi-detector registration systems, namely; Correlation Mosaics Energy-Time Array (COMETA) and Light Ion Spectrometer (LIS) setup. The COMETA setup detects fission fragments using silicon detectors. There are two challenges that come with detecting fission fragments using silicon detectors namely Pulse-height defect (PHD) and "Plasma Delay". A special procedure that takes into account the influence of the PHD has already being designed. The LIS setup is designed to solve the challenge of "plasma delay" in detecting fission fragments using silicon detectors.

1. Introduction

The new ternary decay of low and middle excited nuclei called Collinear Cluster Tri-partition (CCT) was observed in our previous experiments [1], [2] and [3]. The CCT was observed under the framework of the "missing mass" method, meaning only two out of the three fission fragments were actually detected and the third one was missing. The total mass of the fission fragments being less than the mass of the mother system served as an indication of a multi-body decay. The direct detection of all the decay products will provide the most convincing experimental approach. However direct detection of all the decay partners presents its own set of complications as one needs to use a mosaic detection system.

Two multi-detector systems have been designed to study the multi-body decays of heavy nuclei. The two detector systems are the Correlation Mosaics Energy-Time Array (COMETA) and Light Ion Spectrometer (LIS) setup. The COMETA setup detects fission fragments using silicon detectors (PIN diodes). It is known that detecting fission fragments using silicon detectors comes with a challenge of taking into account a so called pulse-height defect (PHD) when detecting energy and "plasma delay" when detecting time-of-flight. A special procedure that takes into account the PHD effect for the

COMETA setup has been designed. The LIS setup is designed to take into account the influence of the "plasma delay" when measuring the time-of-flight for fission fragments using silicon detectors.

2. COMETA Setup

The COMETA setup is a double arm time-of-flight spectrometer that includes a Micro-Channel Plate (MCP) based "start" detector, two mosaics of eight PIN diodes each and a "neutron belt". The schematic view of the COMETA setup is shown in figure 1 and the overall view of the COMETA setup is shown in figure 2.

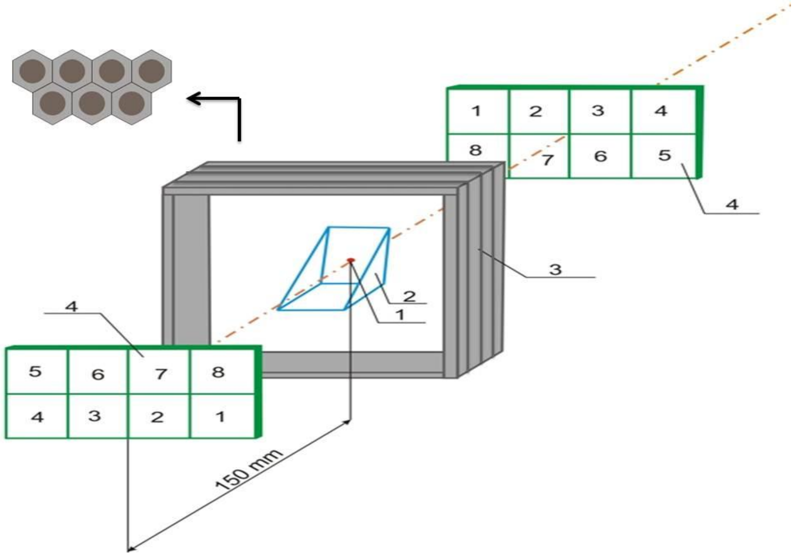

Figure 1. Schematic view of the COMETA Setup where 1 - Cf source, 2 - Micro-channel based start detector, 3 - Belt of neutron counters, and 4 - Mosaics of PIN diodes detectors.

The MCP based "start" detector is designed in such a way that the ^{252}Cf source is installed inside the detector. The size of one PIN diode in each mosaic is $2cm \times 2cm$ and provides both the energy and time signals. The "neutron belt" which comprises of 28 ^{3}He filled neutron counters is located in the plane that is perpendicular to the symmetry axis of the setup. The distance between the MCP based "start" detector and the mosaics in each arm is *15cm*.

2.1. "Neutron belt" of the COMETA setup

COMETA setup consist of 28 ^{3}He filled neutron counters that are positioned as a belt around the start detector as shown in figure 1 above and also figure 2 below. The neutron counters detect neutrons in coincidence with fission events. This means that when a fission event is being registered by the mosaics or PIN diodes, it triggers the neutron counters to open a gate for the detection of neutrons. The aim of installing neutron counters that operate in this manner is to be able to introduce a gate for fission events such that events that are coincident with detection of three or more neutrons are collected. This ensures that only ternary events are considered.

Each neutron counter consists of a modulator, a high-voltage input and a preamplifier. The counters operate under a gas pressure of 7bar (with an additional of 1% CO_2). Each counter has a length of 50cm and a diameter of *3.2cm*. The counters are housed in moderators which are made up of polyethylene material. The spacing between the parallel planes of the modulator is *5cm*. The neutrons that enter the detector are slowed down for about *1-4μs* before they reach the polyethylene. Then after a few microseconds neutrons diffuse into the moderator where they are either absorbed by the ^{3}He-counter and a polyethylene or they escape the detector.

Figure 2. Overall view of the COMETA setup and the “Neutron Belt”.

The detection of neutrons inside the counter occurs due to the absorption of thermal neutrons according to the following reaction

$$^{3}He + n \rightarrow {}^{3}H + p + 764 keV \tag{1}$$

This equation tells us that one neutron can only be registered once, meaning that there is absolutely no “cross-talks” where one neutron can be detected more than once by the detectors. The helium counters do not give information about the energy of the neutrons, but that is not a concern as the objective of the setup is to measure the number of neutrons not their energies.

2.2. Pulse-Height Defect correction

As it has been mentioned above that detecting the energy of fission fragment using silicon detectors comes with a negative effect of a so called pulse-height defect (PHD). PHD which is defined as the difference between the energy of a heavy ion and that of an alpha particle yielding the same pulse height. The situation is exacerbated by the known fact that the pulse height for a heavy ion is higher than that of a light ion of the same energy. Studies of PHD showed that its value consists of three components and each of them has a complicated dependence of the mass M and energy E of the registered fragment. A special procedure that takes into account the PHD value in the calibration process of the COMETA setup has been designed and its algorithm is shown in figure 3 below.

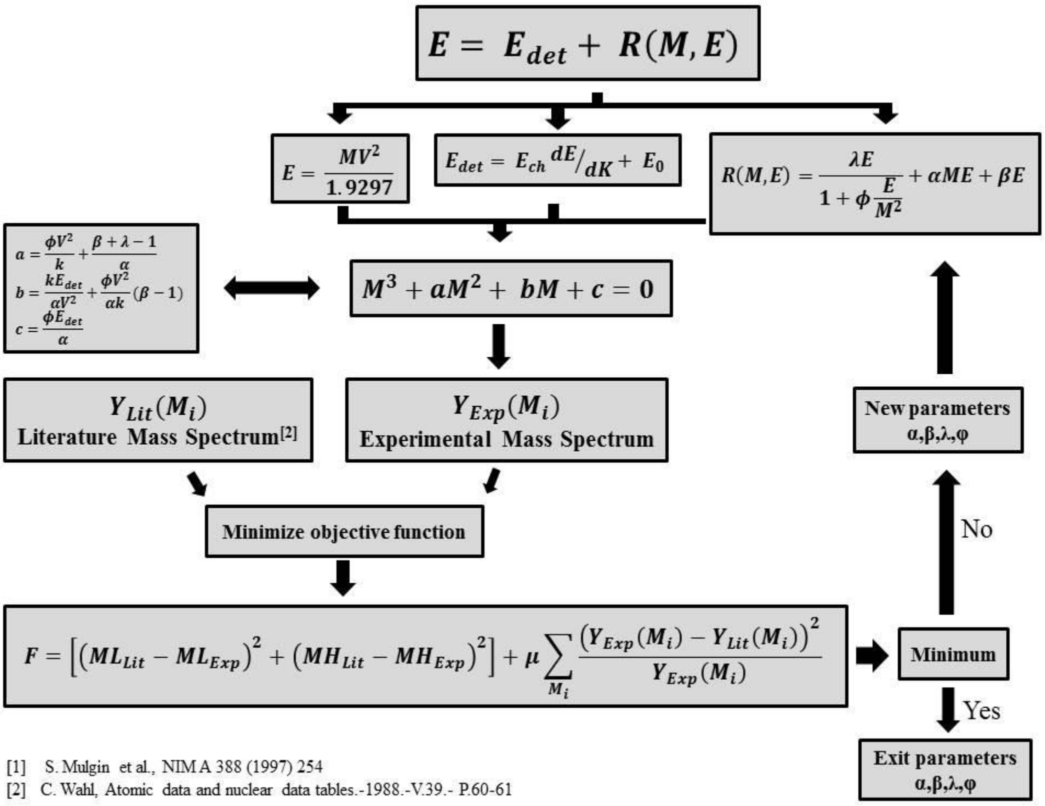

Figure 3. Algorithm that takes into account the PHD value in the calibration process of the COMETA setup.

3. LIS Setup

The LIS setup consists of three Micro-Channel Plate (MCP) timing detectors arranged as shown in figure 4. The first MCP (referred to as “start” MCP) is used to deliver a “start” signal and the other two MCPs (referred to as “stop” MCP1 from arm 1 and “stop” MCP2 from arm 2) are used to deliver a “stop” signal from both arms.

The energy signal is measured from the two PIN diodes. PIN1 is used in the first arm and PIN2 is used in the second arm. The distance between the “start” MCP and both stop MCPs is *84mm* and the distance between each “stop” MCP and a PIN diode in the corresponding arm is *48mm* that makes the distance between the start MCP and each PIN to be *132mm* as shown in figure 2. The size of each PIN is *18mm* × *18mm*. Note that each arm consists of only one PIN diode detector.

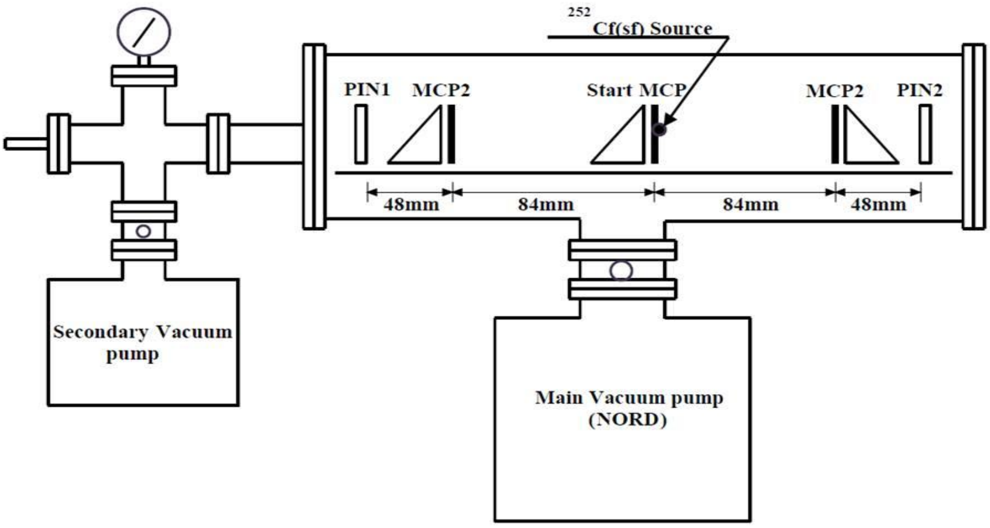

Figure 4. Schematic view of the LIS setup.

4. Conclusion

We have presented two double arm spectrometer set ups that can be used independently to study the decay of heavy nuclei. The COMETA setup has been successfully used to detect all the decaying fragments of CCT directly [3]. The challenge of the plasma delay was partially solved by estimating it roughly in the detection of the decaying fragments. The LIS spectrometer on the other hand is designed to take into account the influence of plasma delay in the experimental data. This is accomplished by making use of MCP detectors in measuring the time of flight of the fragments instead of using pin diodes as shown in figure 4 above. MCP detectors do not suffer from the “plasma delay” effect as in the silicon detectors. It is worth noting that the silicon detectors installed in the LIS setup can still be used to measure the time-of-flight which will enable us to investigate the “plasma delay” in more details.

References

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