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Tests of ionization chambers for future photofission experiments*

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Abstract. A recent set-up of a multi-cathode Frisch-grid ionization chamber and experimental results of a proof-of-principle experiment are presented. Preliminary data on the obtained polar angular and mass distributions as well as total kinetic energy of fission fragments produced in neutron-induced fission of ^{232}Th and ^{238}U are discussed that show that the chamber has been operated successfully. For the additional measurement of the azimuthal angular distribution, a design of segmented anodes has been tested. Preliminary data do not allow a sufficient reconstruction of the azimuthal angle.

1 Introduction

Photofission in the barrier region suffers from relatively low cross sections [1]. Hence, besides using intense bremsstrahlung at the **S**uperconducting-**DA**rmstadt **LIN**ear **AC**celerator (S-DALINAC) [2] or monochromatic γ-ray beams at the future ELI-NP facility [3], significant amounts of target material need to be placed in the beam to reach sufficient luminosity. Target thickness, however, influences the extracted experimental results and limits the resolution of the fission-fragment properties [4, 5]. To avoid this negative effect and yet gain a better experimental luminosity, multiple fission targets may be installed in a multi-cathode chamber inside the beam. This raises the luminosity by a factor identical to the installed targets. Another benefit of studying several targets simultaneously is to measure the properties of the fission fragments detected in each detector segment parallel, thereby, e.g., allowing to calibrate relative energies between the chamber parts.

Photofission experiments on ^{234,238}U and ^{232}Th in the excitation energy region close to the fission barrier have been carried out using bremsstrahlung at the injector of the S-DALINAC [6], and the fission fragment properties have been studied with a twin Frisch-grid ionization chamber using a thin target on a backing transparent for both fission fragments located at the common cathode [7]. The determination of fission fragment masses was based on the well established double-kinetic-energy (2E) technique, and the fragment polar emission angle was extracted from the drift time of the ionization electrons [8]. This quite simple experimental set-up and the excellent results acquired motivated using the design as a blueprint for a multi-cathode Frisch-grid ionization chamber. The detailed structure

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will be discussed in Section 2.1. For the measurement of the azimuthal angular distribution, the usual anode plates in the twin Frisch-grid ionization chamber have been replaced by segmented anodes. This new design and its operation principle is also presented.

2 Set-up and measurements

2.1 Multi-cathode Frisch-grid ionization chamber

The multi-cathode Frisch-grid ionization chamber is designed and set up to study 3 fission targets simultaneously. Electrode distances and electric potentials are calculated for the usage of P-10 gas (90% Argon, 10% Methane) as operating gas at atmospheric pressure. The ratio E_{g-a}/E_{c-g} for the electric fields between grid - anode and cathode - grid is set to a fixed value of 3.07. In Figure 1 the interior of the multi-cathode ionization chamber is shown. The electrodes are held by two PVC plates that facilitate easy installation and removal comparable to a CD rack. Anodes and Frisch-grids have been installed symmetrically around the cathodes whose centres accommodate the transparent fission targets (Uranium and Thorium compounds on gold-coated polyimide backing). Anodes 2 and 3 share signals from fission in cathodes 1 and 2 and 2 and 3, respectively. By using shared anodes between two neighbouring chamber parts a more compact set-up has been realized.

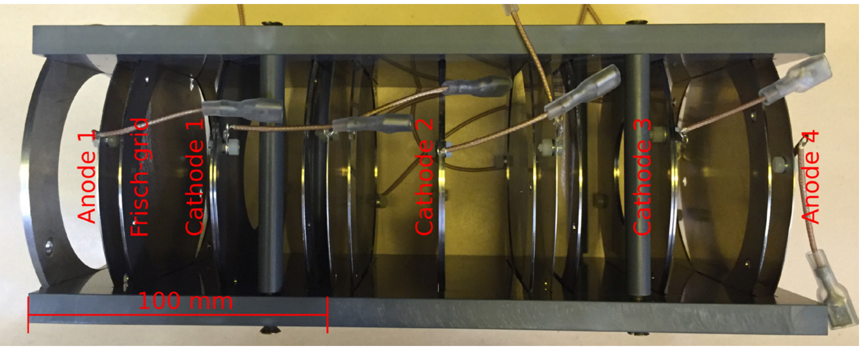


Figure 1. The interior of the multi-cathode ionization chamber: Anodes, cathodes and Frisch-grids are sandwiched by two PVC plates. The fission targets will be placed at the cathodes. Shared anodes between two neighbouring chamber parts will detect signals from both sides, hence a more compact chamber design is achieved.

Proof-of-principle experiments were carried out with fast neutrons from a ^{241}AmBe source. The total neutron emission rate was 2.5×10^6 n/s, and the kinetic energies of the neutrons amounted to 2 - 10 MeV [9]. At cathode 1 a ^{232}Th target and at cathodes 2 and 3 ^{238}U targets were placed, the target properties can be derived from Ref. [10]. The neutron source was placed near anode 4. The following results are obtained from fission-fragment signals originating from cathode 3.
The angular distribution is determined by applying the electron drift-time method, which uses the time that the free electrons need to drift from the location of their creation, e.g. by a fission fragment in the counting gas, to the grid, before inducing a signal at the anode [8]. The polar angular distribution of fission products created in ^{238}U(n,f) is shown in Figure 2. For both the heavy and light fission fragments, with low and high kinetic energies, respectively, a superposition of isotropic angular distributions is found. Despite the wide neutron energy range, the obtained results are in good agreement with expectations.

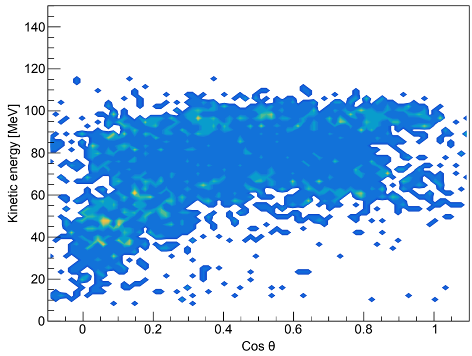
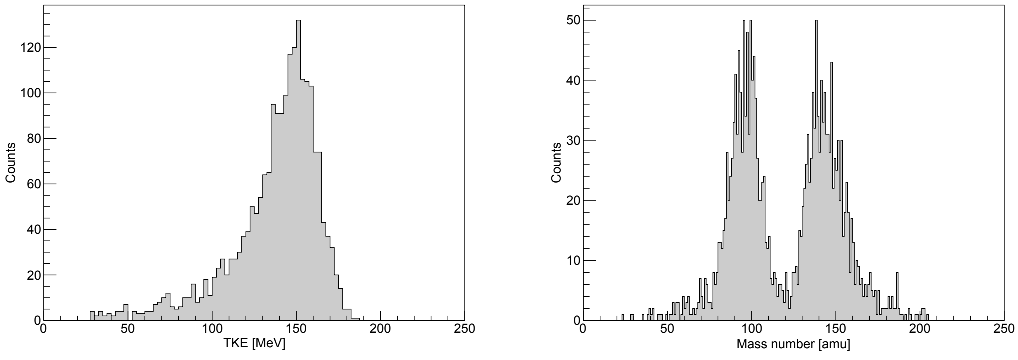


Figure 2. Polar angular distribution of fission fragments created in ^{238}U(n,f) detected in the chamber part around cathode 3. A superposition of isotropic angular distributions for both the heavy and light fission fragments is visible.

Besides the polar angular distribution, the total kinetic energy (TKE) and the mass distribution of the emitted fission fragments in ^{238}U(n,f) could also be studied. Theses quantities are determined by means of the double kinetic energy technique, based on conservation of mass and linear momentum. In Figure 3a the TKE distribution is shown. The extracted peak value of (151.75 ± 4.70) MeV is about 15 MeV smaller than expected [11, 12] because the energy loss in both the target backing (30 μg/cm^2 PI-backing with a 50 μg/cm^2 Au-coating) and in the target material itself (130 μg/cm^2 ^{238}U) has not yet been corrected. In Figure 3b a preliminary mass distribution is presented. Two Gaussian fits deliver peak values of A_L = (100 ± 2) amu and A_H = (139 ± 2) amu for the light and heavy fission fragments,



(a) total kinetic energy (b) mass distribution

Figure 3. Total kinetic energy and mass distribution of ^{238}U(n,f). The extracted peak value for the TKE of (151.75 ± 4.70) MeV has not yet been corrected for energy loss in the target. In the mass distribution, peak values of A_L = (100 ± 2) amu and A_H = (139 ± 2) amu for both the light and heavy fission fragment, respectively, were observed.

respectively. These values are in good agreement with data taken by other groups [13]. The missing corrections influence in particular the heavy fission fragment, which loses more energy, resulting in a slightly broadened peak. We estimate the mass resolution after corrections to be comparable to the established single twin-Frisch-grid ion chambers, where the corrections depend on the target thickness [5].

2.2 Test of segmented anodes

For the determination of the azimuthal angular distribution of the fission fragments, a new design of segmented anodes has been tested. The knowledge of azimuthal angles are of interest if the target orientation is not perpendicular to the incident beam (for count-rate maximization) or if an incident linear polarization will result on an azimuthal asymmetry in the fission fragment distribution. The principle concept behind the tested design is the spatial variation of the anode-segment areas: The detected pulse heights at each anode segment are proportional to the collected amount of charged particles produced by stopped fission fragments in the counting gas. Hence, by segmenting the anode and evaluating the detected pulse heights at each segment separately, one can derive information about the azimuthal angular distribution of the fission products. The tested design is shown in Figure 4a. The area of wedges (W), displayed in red, varies along the x-axis. The area of stripes (S), displayed in green, varies along the y-axis. The zig-zag pattern (Z) in blue is used to collect the rest of the signals. Coordinates according to

$$
\begin{aligned}
x &= P_W/(P_S + P_W + P_Z) \\
y &= P_S/(P_S + P_W + P_Z)
\end{aligned}
$$

can be implemented, where P_S, P_W and P_Z are the detected pulse heights at each segment, denoted by the subscripts. By using two segmented anodes, one rotated by 90° (Figure 4b), and by evaluating signals of both electrodes in coincidence, the azimuthal angular distribution of the fission fragments should be extractable.

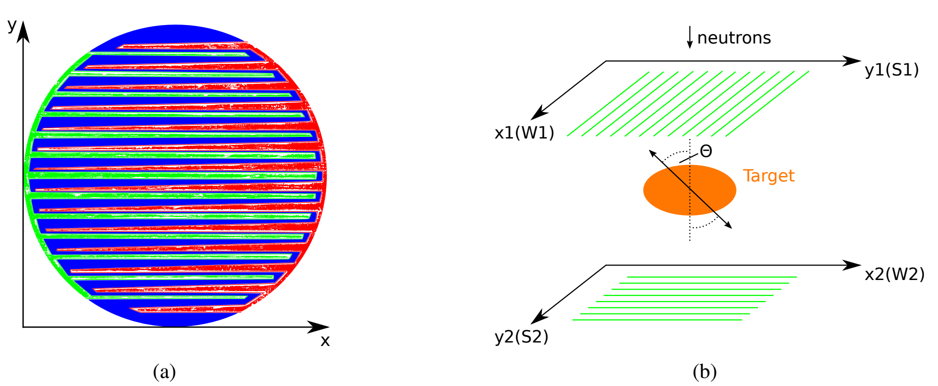


Figure 4. Schematic design of the tested segmented anode (a) and the implemented coordinate system (b). The area of wedges (red) varies along the x-axis and the area of stripes (green) along the y-axis. Using two segmented anodes in coincidence (rotated by 90°) should allow the azimuthal angular distribution of the fission fragments to be extracted.

For a proof-of-principle experiment the reaction ^{238}U(n,f) was studied by replacing the usual anode plates in the twin Frisch-grid ionization chamber by Budtz-Jørgensen et al. [7] with segmented ones. Polar angular and mass distribution as well as the total kinetic energy of the fission fragments could be obtained. Nevertheless, the desired measurement of the azimuthal angular distribution was not successful, calculations and data analysis were inconclusive. Obviously, the data analysis needs additional input, such as the reconstruction of the location of the fissioning nucleus on the target, or the electronic signals of the different events need to be analyzed more thoroughly.

3 Conclusion and outlook

The performance of the multi-cathode Frisch-grid ionization chamber on the basis of the results around the proof-of-principle experiments ^{238}U(n,f) and ^{232}Th(n,f) was successfully demonstrated, fission events in all 3 chamber parts could be studied simultaneously. Polar angular and mass distributions, as well as total kinetic energies of the fission fragments were detected. Preliminary results compare well to established data, a correction due to target thickness has not yet been implemented. In addition, a test experiment is planned where the functionality of the multi-cathode ionization chamber will be validated once more by studying photofission of ^{238}U and ^{232}Th at the S-DALINAC.
Results from a test measurement of ^{238}U(n,f) using a segmented anode design turned out to be inconclusive and did not allow the azimuthal emission angle to be extracted. A more promising set-up has recently been realized at JRC Geel, where a position-sensitive ionization chamber based on resistive charge-division readout and an additional grid has been used [14].

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