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A position-sensitive twin ionization chamber for fission fragment and prompt neutron correlation experiments

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ABSTRACT

A twin position-sensitive Frisch grid ionization chamber, intended as a fission fragment detector in experiments to study prompt fission neutron correlations with fission fragment properties, is presented. Fission fragment mass and energies are determined by means of the double kinetic energy technique, based on conservation of mass and linear momentum. The position sensitivity is achieved by replacing each anode plate in the standard twin ionization chamber by a wire plane and a strip anode, both readout by means of resistive charge division. This provides information about the fission axis orientation, which is necessary to reconstruct the neutron emission process in the fully accelerated fragment rest-frame. The energy resolution compared to the standard twin ionization chamber is found not to be affected by the modification. The angular resolution of the detector relative to an arbitrarily oriented axis is better than 7° FWHM. Results on prompt fission neutron angular distributions in ^{235}U(n,f) obtained with the detector in combination with an array of neutron scintillation detectors is presented as a proof of principle.

1. Introduction

An experimental program at the Joint Research Centre—Institute for Reference Materials and Measurements (JRC–IRMM) aims at studying the correlation between neutrons and fission fragments from resonance neutron induced fission. The experiments employ an array (SCINTIA) of scintillators as neutron detectors. For reconstruction of the kinematics of a fission event and the subsequent neutron emission it is mandatory to know the relative orientation of the neutron and fragment momentum directions. In a pioneering experiment on prompt fission neutrons (PFNs) and fission fragment correlations in ^{252}Cf(sf), Budtz-Jørgensen and Knitter exploited the combination of a twin Frisch grid ionization chamber (FGIC) and a liquid scintillator placed along its axis [1]. As a preparatory step to the aforementioned experimental program this experiment was repeated recently using modern digital technique and refined data analysis [2]. The FGIC has a large solid angle, which not only facilitates the fragment neutron coincident rate, but also introduces a less biased selection of coincident events. The FGIC allows determination of the fission fragment emission angle relative to the chamber axis. By placing the neutron detector along the chamber axis this angle coincides with the angle relative to the momentum direction of the detected neutrons. Hence, the projection of the neutron momentum on the fragments direction of travel is known, and the relevant kinematics in the fission fragment rest frame can be reconstructed. Employing an array of neutron detectors, each detector forms an axis of symmetry around which the fission fragment direction of travel needs to be known. Hence the traditional ionization chamber is no longer sufficient to reconstruct the kinematics in the fragment rest frame. Therefore we have replaced the ionization chambers anode plates by a position-sensitive readout structure, which allows determination of all three space components of the fission fragments' direction of travel.

2. Description of the detector

As already mentioned the position-sensitive structure replaces the anode plates in a standard twin FGIC. The ionization chamber itself has been described in detail in earlier publications [3]. For operation as a fission fragment detector the ionization chamber is assembled in a back to back configuration with a common cathode as shown schematically in Fig. 1, where the relevant distances are also given. The Frisch grid is a 0.035 mm diameter wire mesh with a period of 0.5 mm. The chamber is operated with P-10 gas (90% Ar +10% CH_4) at a pressure of 108.5 kPa under constant flow of ~80 ml/min.

The fission target is a thin deposit on a backing transparent to

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0168-9002/

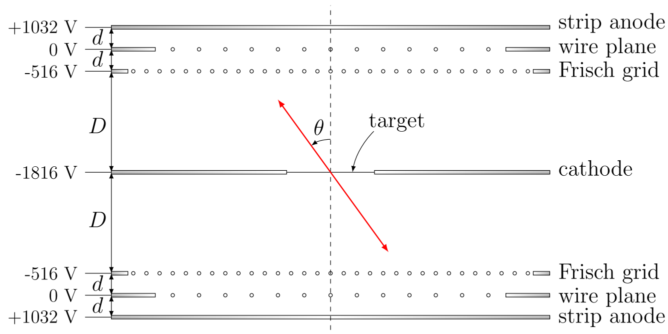

Fig. 1. Schematic view of the ionization chamber assembly. The distances between the electrodes are $D=31$ mm and $d=4$ mm. The red arrows represent the ionization tracks left by the fission fragments in the counting gas. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

fission fragments. It is placed in the central hole of the common cathode so that each fragment from a binary fission event can be detected simultaneously in the two chamber sides. For the purpose of investigating the response to fission fragments a ^{252}Cf sample on a thin (0.25 µm) nickel foil was used, the deposit was a circular spot with a diameter of 5 mm. All data presented in Section 5 originate from this configuration of the ionization chamber, with the ^{252}Cf sample. The detector has also been applied in an experiment studying prompt neutron emission correlations with fission fragments in resonance neutron induced fission of ^{235}U. The data presented in Section 6 originate from this experiment. The electrode configuration in the ^{235}U(n,f) experiment was the same as in the measurements of ^{252}Cf(sf) above. The sample was in this case a circular 7 cm diameter spot of 67.2 µ gU/cm^2 UF_4 evaporated onto a 27 µg/cm^2 polyimide + 50 µg/cm^2 gold backing.

For the purpose of finding correct setup of voltages and for testing the position sensing structure with respect to energy resolution a mixed nuclide (^{239}Pu, ^{241}Am, ^{244}Cm) alpha-particle calibration source was mounted on the cathode. In this configuration the cathode to Frisch grid distance D was 5 cm, and the chamber was operated at a pressure 120 kPa, in order to fully stop the alpha particles before passing the Frisch grid.

The electric field strength between the cathode and the Frisch grids is chosen according to physical requirements on stable electron drift velocity and minimum recombination of electrons and ions in the gas. Taking these requirements into account the reduced field strength between cathode and Frisch grid when operating the chamber for fission fragments is chosen to be 4 V/cm/kPa. The electric fields between Frisch grid, wire plane and anode should be of increasing strength in order to minimize collection of electrons on Frisch grid and wire plane. Field strength ratios sufficient to achieve this were found by following the procedure outlined in Ref. [4]. A Frisch grid to wire plane field strength 3 times that between cathode and Frisch Grid is sufficient, while between wire plane and anode a field strength twice that between Frisch grid and wire plane is sufficient.

2.1. Description of the position sensing electrodes

The position sensing structure consists of two parts, a plane of parallel wires and a strip anode. The wire plane is placed 4 mm above the Frisch grid and the strip anode is placed 4 mm further above the wire plane, with the strips oriented perpendicular to the wires. A drawing of the wire plane is shown in Fig. 2. Tungsten wires of 0.025 mm radius are soldered 2 mm apart to the support structure. The support structure is a circular printed circuit board (PCB) of 17.76 cm diameter with a 10 cm × 10 cm quadratic hole exposing the wires. Groves in the PCB were machined to form

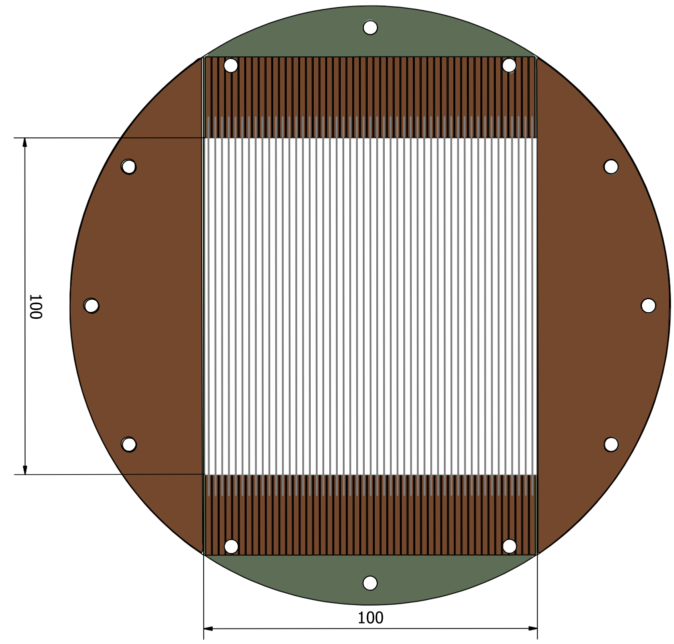

Fig. 2. Drawing of the position sensing wire plane. Tungsten wires of 0.025 mm radius soldered 2 mm apart from each other cover the central 100 mm × 100 mm quadratic cut out. A chain of resistors (not shown) connect the wires from left to right. The scale is given in millimeters.

electrically insulated soldering pads. The soldering pads are connected via 100 Ω surface-mount resistors, forming a resistive charge-divider with 51 resistors in total. The near and far-end of the charge divider is connected to charge sensitive pre-amplifiers.[1] The choice of resistances of the charge divider components needs to balance two effects [5]. The resistances should be small in order to reduce the importance of phase shifts caused by the resistors and the capacitance of the electrodes. On the other hand, the preamplifier decoupling capacitance acts as a barrier at low frequency and the charge cannot be transmitted out of the resistor chain. Instead the charge redistributes over the near and far-end amplifiers with an RC time-constant given by the combination of the resistor chain and the pre-amplifiers decoupling capacitor. This time constant must be large, compared to the charge collection time. The maximum charge collection time is the drift time for electrons from the cathode to the anode, which amounts to ~600 ns. The pre-amplifiers decoupling capacitance is 1 nF, together with the resistor chain this yields a time constant [5]

$$\tau = \frac{nR}{2} C_d = 2.55\ \mu\text{s}, \tag{1}$$

where n is the number of resistors, R their individual resistance and C_d the decoupling capacitance. The strip anode consists of the same components as the wire plane except the wires themselves and the 10 cm × 10 cm quadratic hole.

3. Principle of operation

As a charged particle is stopped in the gas it leaves a trace of electrons and positive ions that drift in the electric field. The drift velocity of the positive ions is small, and they can be considered as stationary during the time it takes to collect the faster drifting electrons. The Frisch grid shields the position sensing electrodes from charge induction caused by charge carriers in the ionization

[1] The pre-amplifier model is IKDA CSTA2HV.