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Secondary electron flight times and tracks in the carbon foil time pick-up detector

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ABSTRACT

Carbon foil time pick-up detectors used in the time-of-flight measurements of MeV energy ions have been studied in connection to time-of-flight-energy spectrometer used for heavy ion elastic recoil detection analysis. In experimental coincident TOF-E data characteristic halos are observed around light element isobars, and the origin of these halos were studied. The experimental data indicated that these halos originate from single electron events occurring before the electron multiplication in the microchannel plate. By means of electron trajectory simulations, this halo effect is explained to originate from single electron, emitted from the carbon foil, hitting the non-active area of the microchannel plate. This electron creates a secondary electron from the surface and which ends up to the microchannel plate pore, is multiplied and create now a detectable signal. Other general timing gate parameters such as wire-to-wire spacing of the grids, acceleration potential of the 1st grid and the mirror grid potential gradient were also studied in order to improve the detector performance.

1. Introduction

Modern time-of-flight elastic recoil detection (ToF-ERD) spectrometers often use two carbon foil time pick-up detectors [1–3], similar to the design by Busch et al. [4]. This type of timing detector has typically five basic components (see Fig. 1): (1) The carbon foil that emits the electrons due to ion passage, (2) the toblerone-part which accelerates the electrons from the carbon foil and is accompanied by transparent grid, or mesh structures providing field free central region, (3) electrostatic mirror to bend the path of the electrons by 90 degrees back to the field free toblerone-part, (4) microchannel plate (MCP) for electron multiplication and (5) the anode to collect the electrons. In addition to these, the decision of using the timing gate in forward or backward direction related to the incident ion needs to be made.

All of these individual detector components affect the timing performance through their material properties, structural geometry or by applied voltages. Energetic ion impact into the carbon foil will induce emission of zero to multiple secondary electrons, that can have wide energy and angular distributions [5,6]. The number of emitted electrons can be increased by other materials deposited on top of the carbon foil. These materials, such as LiF [2] or Al_2O_3 grown by atomic layer deposition (ALD) [7] can enhance the electron emission and therefore increase the detection efficiency for light ions. The emitted electrons having both the high energy and large emission angle perpendicular to the foil, can distort the timing signal already before the first accelerating grid causing non-isochronous electron transportation to the MCP. The grid spacing grid uniformity/smoothness and voltages applied to the mirror grid and toblerone-part also affect the electron trajectories before the MCP. The voltage, pore size and pore length of the MCP, and the distance between the individual MCP plates and their potential difference in chevron composition affect the rise time and width of the electron pulse [8]. Finally the anode design can have a big effect to the timing properties of the carbon foil time pick-up detectors in the time-of-flight measurements. In addition to these individual timing gate components, the decision of using the timing gate in forward direction related to the incident beam i.e. the foil faces the beam first or in the backward geometry where mirror faces towards the incident beam, needs to be made as well.

In this paper we focus on the timing pulse properties of the single carbon foil time pick-up detector. Main emphasis is given to the individual parts before the MCP and how the different grid designs can affect the electron flight time properties from the carbon foil to the MCP. An explanation to the halo effect typically seen also in other studies [9,10] around the hydrogen events in the ToF-E histograms is proposed. The MCP and anode part are left for less attention as ready MCP solutions with fast rise times (down to 300 ps in standard products [8,11]) and matched anodes can be

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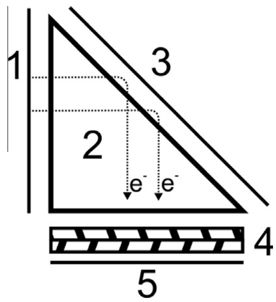

Fig. 1. Basic components of the carbon foil time pick-up detector. This type of timing gate has five components: (1) carbon foil, (2) field free toblerone-part, (3) mirror grid, (4) MCP for electron multiplication and (5) anode to collect the electrons.

acquired commercially by several suppliers. For the case of timing gate orientation, one can for example win few centimeters in the ToF length if the first timing detector is facing forward and the second in backward electron emission direction. The forward direction can also produce more electrons due to the ion impact but their energy and especially their angular distribution is not that favorable than in the backward direction, according to the data in [6]. The angle and energy distributions of electrons and their effect to the timing properties are discussed in more detail in the following.

2. Experimental and simulation parameters

ToF-ERDA spectrometer with two carbon foil time pick-up detectors is located at the +15° beam line of the 1.7 MV Pelletron accelerator of the Accelerator Laboratory, University of Jyväskylä. ToF-ERDA method is best suited for light elements on heavy substrates, but the hydrogen recoils are often the most difficult ones to detect. One reason for this is the small stopping force of the detector carbon foils for hydrogen. Due to this, only a very small number of electrons is emitted from the carbon foil by the passing hydrogen ion. The single electron events are studied as a cause for the halos observed in the hydrogen isobars. The halos were experimentally studied with 2 MeV $^{1}H^{+}$ beam scattered from a thick target. The model system in the simulations was the second timing gate.

2.1. Timing gates of the ToF-ERDA spectrometer

The first (T1) and second (T2) timing gates are not identical in our system. The main differences are the physical sizes and the voltages of the different individual components.

The measures and voltages of the TOF telescope are shown in Fig. 2. The T2 has a solid angle of 0.29 msr, roughly half of the T1, although it is physically considerably larger. The total solid angle of the ToF-E telescope is governed by the T2 carbon foil holder (see also Fig. 3b) as the silicon energy detector, placed right after the T2, has larger surface area of 450 mm^2. The same MCP's (>40 mm active area, 12 μm pore size, d/L = 1:40) are used in both of the timing gates. The anodes in both timing gates are modified from the original MCP stack-structure and are currently made from a printed circuit board. Anode to MCP electrode distance is 4.5 and 3.0 mm for the T1 and T2, respectively. Supplier for the MCP's was Tectra [11].

The used voltages are different for T1 and T2. In the T1 the anode is at +2750 V, MCP lower (closer to anode) and upper electrodes are at +2660 V and +1000 V respectively, and the carbon foil can be grounded or slightly negatively biased. The T1 mirror grid needs to be negatively biased as it otherwise would accelerate free electrons towards the grid and the MCP; typically −500 V is used in our measurements. The signal is taken from the T1 anode over a 1 nF capacitor. For T2–2800 V is applied on both mirror and foil, −1800 V on MCP upper electrode and on toblerone-part and anode is at ground potential.

High transparency grids in our timing gates compose of thin (diameters 25 and 20 μm) Au plated tungsten wires [12] that are point welded to their support frames (see Fig. 3a). The wire-to-wire spacing is 1.0 mm which was adopted from the timing gates developed earlier in our lab for nuclear physics experiments [13,14]. Distances from the foil to the first accelerating grid are 3.0 and 5.0 mm for T1 and T2, respectively. The distances of the mirror grids from the toblerone grids are the same than those of the foils. By using this type of point welded grid structure we have achieved better than 86% optical transmission through two timing gates (6 wire grids in total) together with the highly parallel and well aligned grid structure.

2.2. Electron flight time and -path simulation at the timing gate

A 2D model of the T2 timing gate was brought to the Simion program [15]. Simion is a software package primarily used for calculating electric fields and the charged particle trajectories in those fields [15].

Physically larger T2 was selected for the simulations as electron flight times, and possible time spreads were expected to be larger in it. Possible results were expected to scale down for the smaller T1. The model of the T2 timing gate had 20,000 × 20,000 pixels so that one pixel corresponded to about 3.5 μm. Thus 25 μm wires in the real system had diameter of 7 pixels in the simulations.

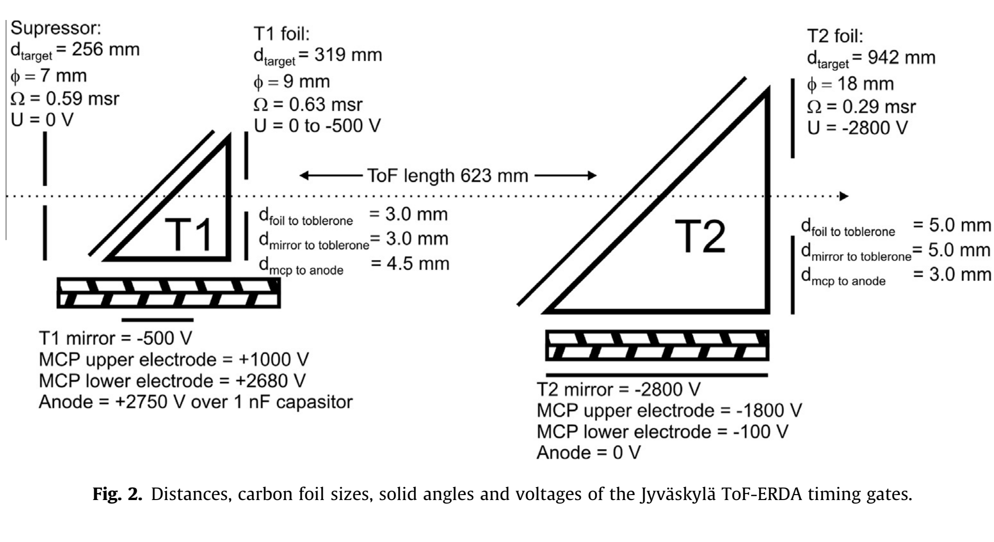

Fig. 2. Distances, carbon foil sizes, solid angles and voltages of the Jyväskylä ToF-ERDA timing gates.