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Time-of-flight detector applied to mass measurements in Rare-RI Ring

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ABSTRACT

A large time-of-flight (TOF) detector has been developed for the Rare-RI Ring. This detector consists of a Multi Channel Plate (MCP) and a carbon foil. Secondary electrons from the carbon foil are transported to the MCP by crossed electric and magnetic fields. In order to cover the beam size of the ring, a large and thin carbon foil (100 mm × 50 mm^2 and 60 μg/cm^2) is used as a sensitive material. The time resolution of $\sigma \approx 130$ ps, the detection efficiency about 56% and a position dependence of the TOF about 1 ns are obtained. A calculated position dependence of TOF adopting experimental (inhomogeneous) electric field and a homogeneous magnetic field is in agreement with the experimental one. These results suggest that the homogeneity of electric field is important to improve the time resolution in the large size detector.

1. Introduction

A Rare-RI Ring project [1–3] to measure masses of short-lived rare RI with a precision of 10^{-6} is in progress at RIKEN. The mass is determined by measuring a time-of-flight (TOF) of rare RI between the entrance and the exit of the ring. A principle of the mass measurement is described elsewhere [1–3]. For determination of nuclear masses with the precision of 10^{-6}, dedicated TOF detectors have being developed. Three TOF detectors are planned to be installed; two among three are placed at the entrance (start detector) and exit (stop detector) of the ring and one inside the ring (beam monitor). The required specifications for the start detector and the beam monitor are: (i) Good time resolution less than 100 ps because the flight time in the ring is about 0.7 ms. (ii) Small energy loss and energy straggling to keep the energy of nuclei within the energy acceptance and the energy distribution less than 10^{-5}, (iii) Unchanging of the charge state by passing through a detector to avoid reduction of the transmission efficiency, and (iv) A large sensitive area to match the beam size of 100 mm × 50 mm. The required specification for the stop detector is only a good time resolution.

As a start detector, a thin plastic scintillator coupled with a photomultiplier tube (PMT) is adopted for light nuclei. Measurements of the time resolution for the thin plastic scintillators were conducted using Xe beam at $E = 200A$ MeV [5]. These results show that a few tens of picoseconds of the time resolution were obtained using 10-, 50-, 100-, and 500-μm-thick plastic scintillator. While a new TOF detector consisting of thin carbon foil and Multi Channel Plate (MCP) is prepared as a start detector for heavier nuclide about $A \geqslant 50$ and as a beam monitor in the ring. The basic concept of the TOF detector is same as those developed at ESR/GSI [6] and CSRe/IMP [7], an enlargement of the sensitive area is needed to cover a large beam profile in the Rare-RI Ring. Thus, we have been developing a large TOF detector using a large and thin carbon foil (100 mm × 50 mm and 60 μg/cm^2) [8] and a large MCP (95 mm × 42 mm).

Here we assume an interested nucleus is $^{78}Ni^{28+}$ ($E = 200A$ MeV) and the detector material is carbon. In view of the energy loss (ΔE) and straggling (δE), a thickness t of the carbon foil is allowed up to $t = 6$ mg/cm^2 for the start detector and $t = 50$ μg/cm^2 for the beam monitor. The values of energy loss and straggling are calculated as $\Delta E \approx 19$ MeV and $\delta E \approx 9.3 \times 10^{-3}$ MeV/u, $\Delta E \approx 0.160$ MeV and $\delta E \approx 8.5 \times 10^{-4}$ MeV/u for $t = 6$ mg/cm^2 and $t = 50$ μg/cm^2, respectively. In this case, ^{78}Ni will circulate approximately 1000 turns. A charge state after passing though the 6-mg/cm^2-thick carbon foil is calculated by CHARGE code [4] to be same as approximately 99.8% that of before passing through.

2. TOF detector

A principle of the TOF detector is that a beam generates secondary electrons in passing through a thin carbon foil. These electrons

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are transported to the MCP by crossed electric and magnetic fields. The secondary electrons are accelerated to several keV by the electric field to reduce the initial energy spread and angular spread of the emitted electrons on time resolution. A schematic view of the TOF detector is shown in Fig. 1. The accelerating electric field is produced by nine potential plates, the carbon foil and the MCP, and the magnetic field is produced by iron yoke and coils as shown in Fig. 1. To achieve an isochronous condition, electric (E) and magnetic (B) fields, and a horizontal displacement of the secondary electrons (D) are satisfied a relation [9], $D = (2\pi m/q)(E/B^2)$, where m and q denote a mass and a charge of electron, respectively. The horizontal displacement is chosen as $D = 140$ mm, and the electric and the magnetic fields are determined so as to a flight time spectrum is narrow.

3. Experiment

Experiments to investigate property of the TOF detector were performed by using α particle emitted from ^{241}Am source and by using heavy ion beams. As shown in Fig. 2(a), a small MCP was set to detect the α particle at opposite of the ^{241}Am. A time spectrum was obtained between the small MCP and the large MCP. The position of the ^{241}Am and the small MCP were moved in order to obtain the position dependences of the time resolution and the TOF. Other experiments were carried out by using the secondary beam line, SB2 course [10] in the heavy-ion synchrotron facility, Heavy Ion Medical Accelerator in Chiba (HIMAC) at National Institute of Radiological Sciences. Heavy ion beams such as ^{84}Kr ($E = 200A$ MeV), ^{60,64}Ni ($E \approx 300A$ MeV) were delivered to the final focus of the SB2 course with a typical intensity of 2×10^3 particles per pulse. An experimental setup is shown in Fig. 2(b). In order to investigate the time resolution, a TOF between a trigger detector and the TOF detector was measured. As the trigger detector which was located after a vacuum window of 100-μm-thick aluminum of the SB2, a 1-mm-thick plastic scintillator of which both ends were connected on PMTs was used. The TOF detector was placed about 1 m downstream of the trigger detector. Two parallel plate avalanche counters (PPAC) were used to measure the position distribution of the beam and to estimate the beam profile at the carbon foil by a ray-trace technique.

4. Result

In order to obtain the suitable electric field, an electric field dependence of the time resolution was measured using heavy ion beams as shown in Fig. 3. In these measurements, the magnetic field was set in order to satisfy the isochronous condition for each electric field. The value of the time resolution decreases with increasing electric field and stays a constant about $\sigma \approx 140$ ps at E=60 V/mm and over. In the following measurement, the electric and magnetic fields were set at $E = 60$ V/mm and $B \approx 40$ G, respectively. An inhomogeneity of E along an electron trajectory (see Figs. 1 and 2(a)) was calculated as 40% by using SIMION [11]. Shown in Fig. 4 by the solid line is an electric potential calculated along the dashed line (x = 0 mm, z = 26.5 mm) in Fig. 2(a). The result suggests that an opening of the ground electrode and an electric potential of MCP distort the electric field to the opposite directions. A measured inhomogeneity of B was about 4% as shown in Fig. 5. A typical flight time spectrum obtained using ^{64}Ni beam is shown in Fig. 6. The time resolution was determined by fitting the flight time spectrum with a Gaussian function. The fitting range was selected so as to $\chi^2 \sim 1$. The obtained width of the peak in-

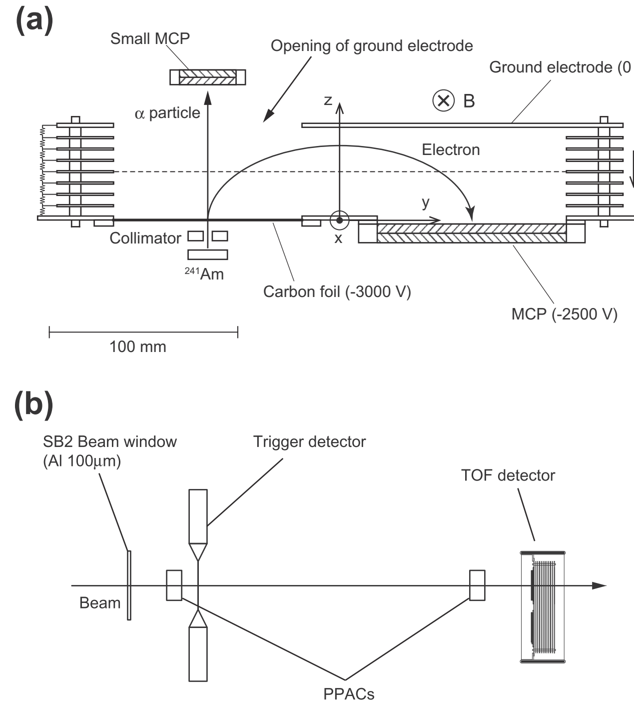

Fig. 2. (a) An experimental setup using ^{241}Am source with the electric potentials indicated. The dashed line indicates the calculation axis of the electric potential. (b) A schematic view of setup using heavy ion beams.

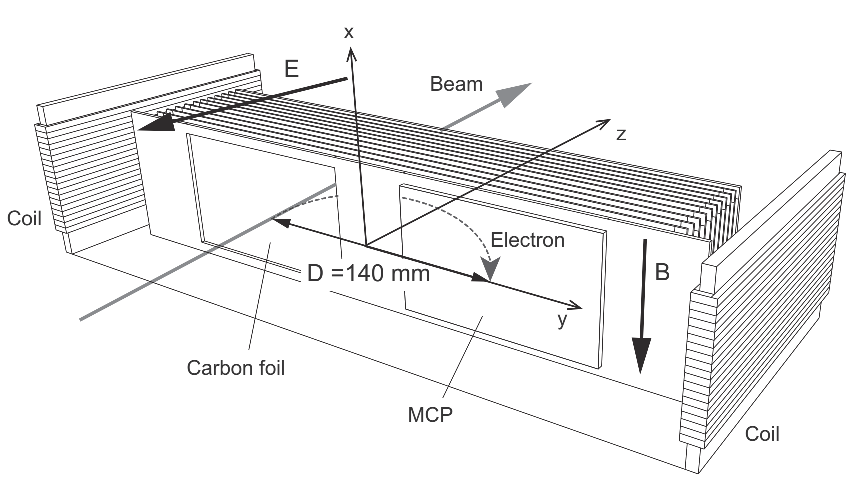

Fig. 1. Schematic view of the detector. A top yoke is not drawn to help the understanding.