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A transmission time-of-flight system for particle identification at a recoil mass separator at low energies

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ABSTRACT

A new time-of-flight (TOF) system has been installed at the recoil mass separator DRAGON at the radioactive beam facility TRIUMF-ISAC in Vancouver, Canada. The addition of a velocity measurement to the existing energy measurement provides an effective separation of heavy ion reaction particles from remaining beam particles reaching the end detector, especially at low beam energies of interest to nuclear astrophysics research. The TOF detector system is based on two electrostatic mirrors equipped with thin carbon foils as a secondary electron emitter, and micro-channel plates for a fast timing signal. The system has been commissioned with stable ^{23}Na, ^{24}Mg and ^{27}Al beams in the energy range from 200 to 800 A keV.

1. Introduction

Recoil mass separators have been designed to investigate nuclear reactions with small cross-sections by detecting the heavy ion reaction particle of a nuclear reaction (here called 'recoil'). As an example, the recoil mass separator DRAGON at the radioactive beam facility TRIUMF-ISAC in Vancouver, Canada, was built to measure radiative capture reactions for nuclear astrophysics [1]. The astrophysically relevant energy range depends on various parameters like the temperatures proposed in a stellar scenario and the energy levels in the compound nucleus. In general, the interesting energy range is low (typically at center-of-mass energies of $E_{cm} = 50$–1000 keV). As an example, the ^{25}Mg(p, γ)^{26}Al reaction, which is the main production reaction for the astrophysically important nuclide ^{26}Al, has resonances at $E_{cm} = 92, 189, 304, 374$ and 418 keV [2]. The 92 keV resonance is the most important one in static hydrogen burning of Wolf–Rayet stars [3].

From the experimental side, measuring low energy resonances is very challenging as nuclear reaction probability in charged particle reactions drops rapidly below the Coulomb barrier. In addition, the separation power of the electromagnetic separator and the energy detector resolution decrease towards lower energies [4]. This makes direct measurements of the relevant reactions very difficult or even impossible. In those cases, extrapolations towards lower energies from measurements at higher energies or indirect measurements are required.

Sophisticated detectors have been developed to identify the particles reaching the end of the electromagnetic separator. Energy detectors like silicon diodes or ionization chambers (IC) are commonly used. If the IC is based on a multi-anode design, isobaric components of the incoming particles can be identified [5]. However, these detectors usually measure the energy of the particles by stopping them in the active volume, which does not allow a subsequent measurement. Energy-loss straggling and statistics of charge carrier collection limit the resolution of these detectors at low energies. In proton capture reactions at DRAGON, the recoils of interest have generally slightly lower energy than the beam particles leaking through the separator (here called 'leaky beam') which tends to have the full incoming beam energy [6]. Even with a good resolution, recoils are often buried under the low-energy tail of the leaky beam peak in the energy spectrum when the recoil yield is low and the leaky beam rate high. In many cases, additional information like a coincidence condition with a gamma ray detected at the reaction target location is required for a clear identification.

Velocity detectors have been developed in other accelerator-based experiments (see e.g. [7]). These detectors are transmission detectors which interact only minimally with the particles, generating timing signals at a certain position in the path of the

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particles. This has the advantage of enabling an additional measurement (usually a partial or total energy measurement). The resolution of the timing detectors is to the first order independent of the ion energy; thus, at lower energies the flight time of the particles is longer, resulting in a better separation between different particles.

Here we describe the setup of the DRAGON local time-of-flight (TOF) system. We refer to 'local' meaning the recoil detectors located after the separator, as opposed to TOF through the entire separator where the start signal comes from deexcitation gamma rays from the reaction detected in the BGO array. The performance during the commissioning runs with stable ^{23}Na, ^{24}Mg and ^{27}Al beams is described in the second part of the paper.

2. Setup

The DRAGON local TOF system is based on time measurement between two timing detectors, following by a multi-anode IC or a double-sided silicon strip detector (DSSSD) for an energy measurement (Fig. 1). Each timing detector consists of a thin carbon foil through which the particles pass generating secondary electrons on either side of the foil; an electrostatic mirror which accelerates and deflects the electrons perpendicular to the beam axis; and a micro-channel plate (MCP) which generates a fast timing signal. The first timing detector (MCP0) is located about 10 cm upstream of a set of slits which are located at the achromatic focus at the end of the separator; the second one (MCP1) is further downstream in front of the energy detector with a flight path between the two foils of 59 ± 0.5 cm. To maximize the flight path, MCP0 detects electrons from the downstream side of the foil whereas MCP1 is mounted backwards detecting the electrons from the upstream side. Motor-driven actuators allow removal of both detectors without breaking the vacuum during beam tuning into a Faraday cup located right after the slits and in experiments without local TOF measurements. The vacuum in the box is usually in the low 10^{-7} Torr range, but can rise by one order of magnitude when the gas-filled IC is operated at higher pressures.

MCP0 has already been used in some previous experiments to improve the time resolution of the slow IC [8]. Due to its location close to the focus, it is the smaller of the two MCPs and is based on a Quantar 3394A MCP/REA sensor (diameter of MCP 40 mm). Carbon foil diameters between 15 and 40 mm can be used. Three wire planes are in the path of the beam; a fourth one is in front of the MCP detector. The wire planes are made of 20 μm gold-plated tungsten wires with a line spacing of 1 mm. The voltages are optimized for good timing resolution and high efficiency of the MCP detector. MCP0 is equipped with a resistive encoded anode (REA) which gives position information on the particles.

MCP1 is about twice the size of MCP0 in order to collect all recoils with a large divergence emitted in certain experiments (usually reactions with low mass, low energy and high *Q*-value). The foil has a diameter of 70 mm, the MCP detector has 75 mm (Burle APD 3075 MA). The wire plane configuration is similar to MCP0. The performance of both MCP detectors is similar, except for a slightly higher dark count rate of the larger MCP.

The production of large, flat carbon foils is challenging. We use diamond-like carbon (DLC) foils produced by Advanced Applied Physics Solutions (AAPS) Inc. located at TRIUMF. Very homogeneous and pinhole-free DLC foils with a thickness of 4–5 μg/cm^2 have been produced by laser ablation of carbon and were floated onto Ni-plated support meshes with high transmission (98% and 95%). The thickness is a compromise between number of electrons produced per particle and minimal energy-loss and angular straggling.

The detector electronics consists of a fast timing discriminator (Ortec 9327 1-GHz Amplifier and Timing Discriminator) which uses a signal picked off from the high voltage feed in case of MCP0 and the anode signal in case of MCP1. The fast timing signals are fed into a time-to-amplitude converter (TAC, Ortec 567) starting with the signal from MCP1 and stopping with the delayed signal from MCP0. The delay depends on the velocity of the ions and is in the range of 30–100 ns. Separate timing signals from the fast timing discriminator are used to generate trigger signals for both MCPs and a 100 ns coincidence signal indicating a valid local TOF trigger signal (MCP-TOF). The MCP coincidence trigger is delayed

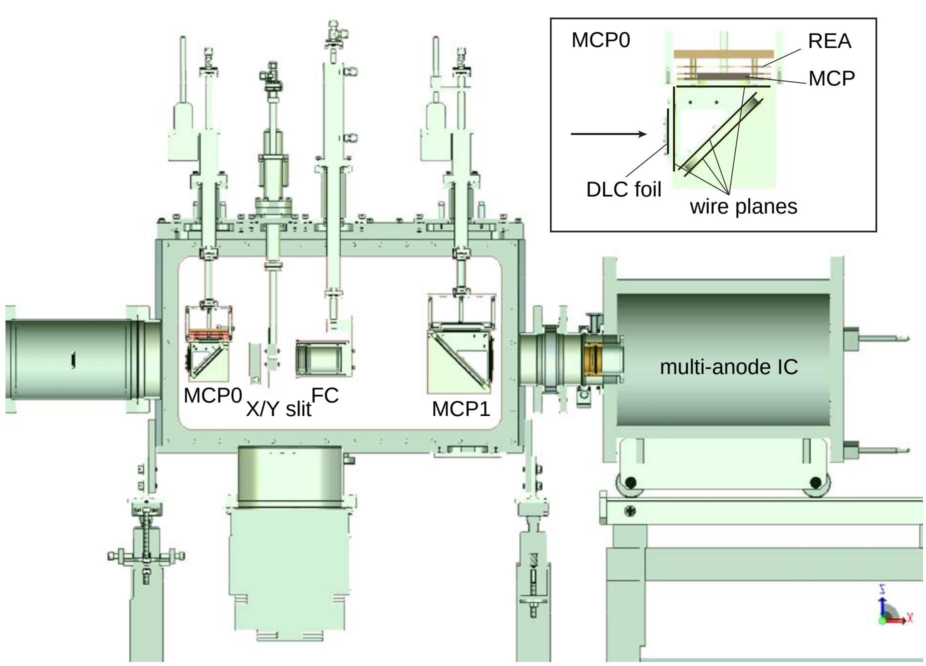

Fig. 1. Schematic setup of the DRAGON end detector comprises two MCP based timing detectors and a multi-anode IC as an energy detector (which can be easily exchanged with a DSSSD). The inset shows the details of MCP0.