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An ellipsoidal time detector with PMT readout

LI Jiaxing[1,*] LIU Pingping[1] WANG Jiansong[2] XIAO Guoqing[2] GUO Zhongyan[2] HU Zhengguo[2] MAO Ruishi[2] SUN Zhiyu[2] XU Hushan[2] ZHAN Wenlong[2]

[1] *School of Physical Science and Technology, Southwest University, Chongqing 400715, China*

[2] *Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*

Abstract In this paper we present a timing detector which has low detection threshold and is radiation-resistant. The photons induced by radioactive beam ions passing through a thin plastic-scintillator foil BC422, emit from the foil center corresponding to one focal point of an aluminum ellipsoidal mirror and are reflected to another focus point at which the cathode of a photomultiplier tube locates. A time resolution of about 115 ps can be achieved for ^{12}N of 58.5 MeV/u and 130 ps for ^{17}B of 43.7 MeV/u. The counting rate up to 10^8 packets per second (pps) is allowed.

Key words Time of flight, Ellipsoidal mirror focusing, RIBLL (Radioactive Ion Beam Line in Lanzhou)

1 Introduction

Timing properties of plastic scintillator foils have been systematically investigated[1,2]. The most frequent and important use of the foil is to extract timing signal, especially for time of flight (TOF) system due to its advantages of fast response, small energy loss of the transmitting particles, insensitive to the radiation damage and γ-rays background, high efficiency, size-free, low cost, etc.

With the development of light collection technique and photomultiplier, time resolution of thin plastic scintillator detector has been improved. Galindo-Uribarri *et al*[2] developed a high quality ellipsoidal mirror detector with a pair of ellipsoidal reflector half-shells, and a central piece that is of help in supporting, centering and completing the mirror surface of the ellipsoid. With the mirrors of a rhodium-coated nickel substrate, the Galindo-Uribarri group has achieved an intrinsic time resolution of 177 ps for a heavy ion beam depositing 14.1 MeV in the BC418 scintillator with XP2030 PMT readout.

In this paper we report a concave ellipsoidal mirror detector with a reflector of one ellipsoidal shell made of aluminum. This detector is easy to fabricate with reduced cost. An intrinsic time resolution of about 115 ps is deduced for elastically scattered ^{12}N ions passing through 50 μm BC422 foil with R2083 PMT readout. It serves as time detectors for Radioactive Ion Beam Line in Lanzhou (RIBLL)[3].

2 Detector and techniques

The detector system consists of an ellipsoidally shaped reflector, a thin scintillator placed at one focal point of the ellipsoid and the center of photocathode at the other (Fig.1). The configuration has the following advantages: all optical path lengths from one focus to the other *via* a single reflection are equal and the collected light pulse resembles the original pulse from the scintillation process, and, the light is concentrated into a small area of the photocathode and this leads to a narrower pulse-height distribution of the PMT signals. The ellipsoidal mirror in this work is a well-polished Al ellipsoidal reflector, with high enough reflectivity to obtain good time resolution. The mirror has two access holes for the incident ion beams to pass through. A self-supporting BC422 foil (50 μm) glued with a holed conventional transparent film is positioned in such a way that the beam hits the

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* Corresponding author. *E-mail address:* lijx@swu.edu.cn

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scintillator at focal point of the ellipsoid. The third hole on the vertex opposite to the focal point allows the photocathode of R2083 phototube to sit at the second focal point. The mirror can be moved relative to the front surface of the PMT to make the second focal point coincide with the photocathode.

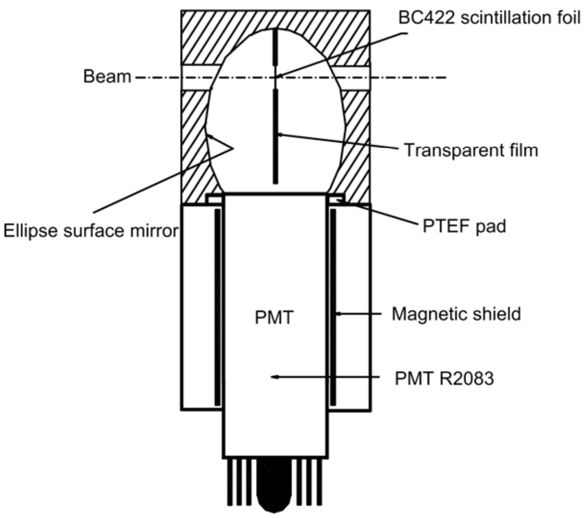

Fig.1 Schematic diagram of the ellipsoidal mirror detector.

Emitting 425-nm fluorescence with a decay time of 2.1 ns and a 64% light extraction of anthracene, the BC422 scintillator is of high luminous efficiency and fast time response. And with response wavelength of 300-650 nm, anode pulse rise time of 0.7 ns[4] and gain of 2.5×10^6, the PMT R2083 well matches the BC422. The R2083 PMT is placed in a cylindrical metal cover wrapped with a layer of μ-metal for magnetic shielding. The voltage divider of the PMT, which is biased at –3500 V, is designed to have proper gain, a wide dynamic range and a good time resolution.

3 Results and discussion

The experiment used 80 MeV/u ^{20}Ne at RIBLL of the Heavy Ion Research Facility in Lanzhou (HIRFL) (Fig.2)[5]. The Be production target (3 mm thick) was mounted in the target box (T0). Products of the reaction were separated and selected at the doubly achromatic magnetic spectrometer, by means of magnetic rigidity ($B\rho$) and two energy degraders of aluminum foil mounted on curved frames at the dispersive plane of C1 and C2. TOF of the fragments was measured by two ellipsoidal time detector at the first (T1) and second (T2) achromatic focal planes with a flight path of 16.690 m.

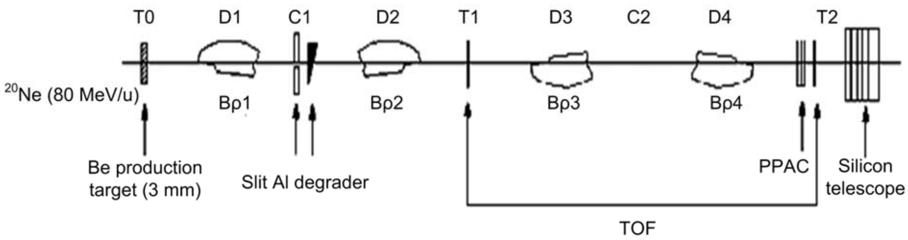

Fig.2 Experimental setup at RIBLL.

The BC422 scintillator serves as both the start and the stop timing detector of the spectrometer. The ellipsoidal profile is given by $x^2/a^2 + y^2/b^2 + z^2/c^2=1$, where the semiaxes are $a=b=65.0$ mm, $c=75.8$ mm.

Behind the second ellipsoidal time detector is a telescope, which consists of five transmission Si(Au) detectors to detect the energy loss (ΔE_i). Particle ejected from the target can be identified clearly (Fig.3.).

Fig.3 shows the scatter plot of ΔE_1-TOF of products from ^{9}Be induced by 80 MeV/u ^{20}Ne ions and selected only by setting the $B\rho$ value for 58.5 MeV/u ^{12}N ions. Fig.4 shows the corresponding TOF spectrum of the ^{12}N ions, and FWHM of the ^{12}N peak is 2.255 channels. The time-to-digital convertor was calibrated at 50 ps per channel, hence a time resolution of about 115 ps.

By setting the $B\rho$ value for ^{17}N ions, the detector worked properly under bombardment of the ^{20}Ne beam of 10^8 packets per second (pps) without pile-up signals. With coincidence of silicon detectors, the efficiency was 100% for the beam intensity of 10^4.

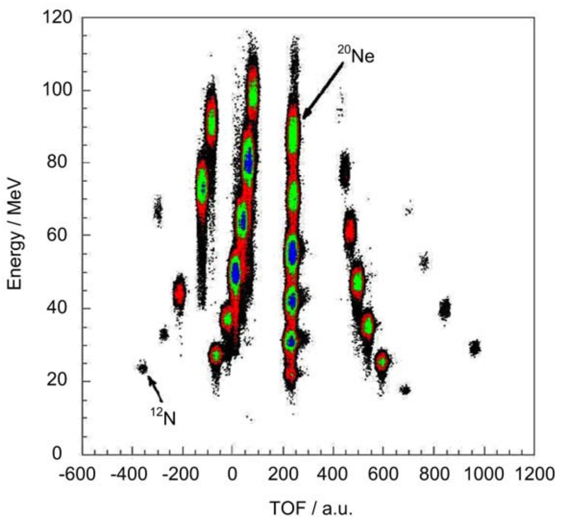

Fig.3 Scatter plot of ΔE_1-TOF of products from ^{9}Be induced by 80MeV/u ^{20}Ne ions and selected by setting the Bρ value for 58.5MeV/u ^{12}N ions.

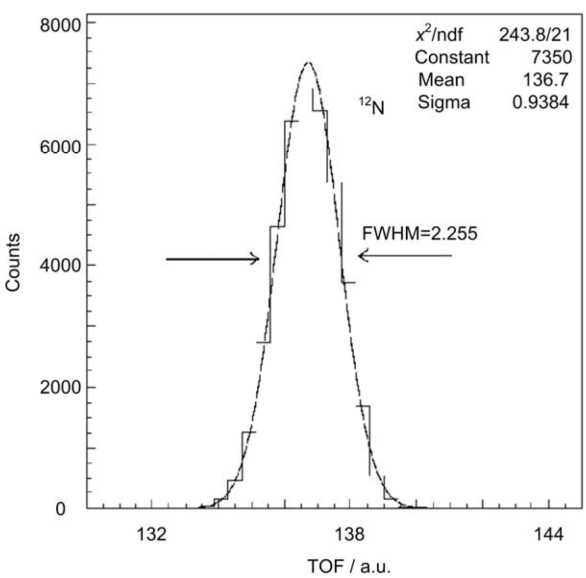

Fig.4 TOF spectrum of ^{12}N corresponding to Fig.3.

To examine capability of this detector for nuclei far from the β-stability line, an experiment was performed with the same setup as the one described above and the primary beam was ^{22}Ne at 69.3 MeV/u. The $B\rho$ value was setting for ^{17}B. The degrader was not used during the experiment in order to get enough counts of ^{17}B[6]. Fig.5 shows the scatter plot of ΔE_1-TOF of products selected only by setting the $B\rho$ value for 43.7 MeV/u ^{17}B ions. The products were clearly separated. The same analysis was performed for TOF spectrum of ^{17}B ions, a time resolution of about 130 ps could be reached.

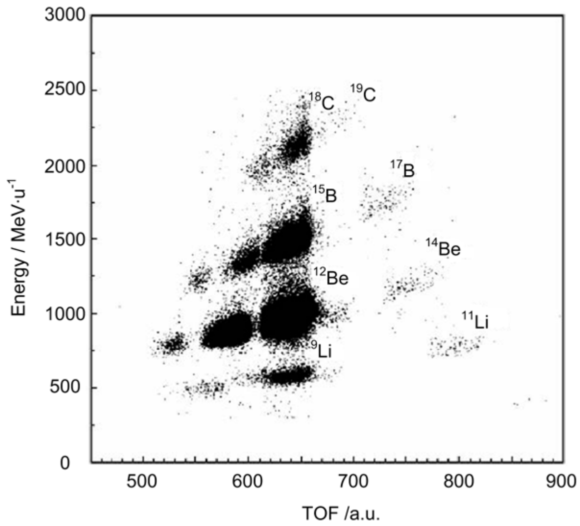

Fig.5 Scatter plot of ΔE_1-TOF of products from ^{9}Be induced by 69.3 MeV/u ^{22}Ne ions and selected by setting the $B\rho$ value for 43.7 MeV/u ^{17}B ions.

In conclusion, the ellipsoidal mirror detector with PMT readout is useful for studies on heavy ion reactions in intermediate energy region. Intrinsic time resolution of the TOF system can be 115 ps for ^{12}N ions and 130 ps for ^{17}B ions passing through a 50-μm BC422 foil. Lighter or heavier ions can be measured by using scintillator foils of different thicknesses.

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