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Measurement of Proton Beam Energy and Flux by Using a LYSO Crystal

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We investigated the beam profiles of the 45-MeV proton beam from the MC-50 cyclotron at Korea Institute of Radiological and Medical Science. We used a 45-MeV proton beam of 0.2-nA beam current to measure the beam energy and flux. The 45-MeV proton beam passed through a 0.2-cm thick aluminum window capping the beam pipe and then was collimated to a 1-mm-diameter beam spot by using a 1-mm aluminum collimator. We examined the dependence of the energy profile of the proton beam on the transverse distance from the beam center by using the LYSO crystal scintillator. Also, the flux of the proton beam was measured with the LYSO crystal scintillator. Accurate information on the energy profile of the beam is important not only for understanding the characteristic of the beam but also for understanding the light output response of a scintillation crystal. From our investigation, the energy profiles of the beam at the near point from the center and some distance points from the center were found to be very different. Thus, it is very important to test the energy profile of the beam at the point where the detector will be located before one performs the beam test for a detector, such as a silicon sensor.

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I. INTRODUCTION

It is generally assumed that a particle beam generated by a proton accelerator has a monochromatic energy spectrum. Thus, when we perform an experiment on detector performance using an energetic particle beam, usually we use a collimator and set the detectors at a point apart from the beam center and a long distance from the end of the beam pipe to protect the device from the radiation damage if the detector is not radiation hard. However, the energy profile of the protons may depend on the transverse distance.

The 50-MeV proton-beam test facility at the MC-50 cyclotron of KIRAMS (Korea Institute of Radiological and Medical Science) was established by the PEEP (Proton beam Engineering Frontier Project) of Korea Atomic Energy Research Institute (KAERI) [1]. This facility can be used for studies using very low proton beam fluxes, $10^4 \sim 10^{10}$ protons/cm^2 s [1,2]. The energy of the proton beam from the MC-50 cyclotron at KIRAMS is also regarded as monochromatic.

The crystal scintillator is one of the most widely used particle detection devices for nuclear and high-energy physics experiments. It is also used for medical applications, security examination, nondestructive testing, and geological exploration. Some properties of the LYSO, the GSO, and the BGO crystals are shown in Table 1 [1, 3]. From this, we see that the LYSO and the GSO crystals have advantages for proton-energy monitoring due to their high light output, fast decay time, and radiation-hard characteristics [1,4,5].

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Table 1. Properties of LYSO, GSO and BGO crystal scintillators.

Crystal	LYSO	GSO	BGO
Number of photoelectron for 662-keV gamma ray	4910 ± 250	1930 ± 100	880 ± 40
Energy Resolution (%) at 662 keV (FWHM)	8.9 ± 0.4	8.9 ± 0.4	11.7 ± 0.5
Decay time (ns)	48.5 ± 1.7	65.2 ± 2.3 605.8 ± 21.2	300
Radiation hardness (Gray)	$> 10^6$	$> 10^6$	10^{2-3}

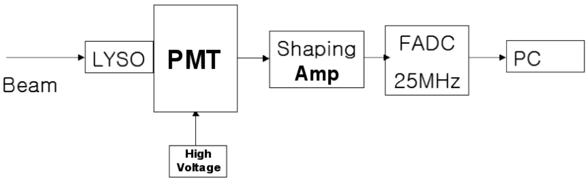

Fig. 1. Schematic diagram of the experimental setup for the proton-beam energy measurement.

The flux profile of the proton beam in the longitudinal direction with a 3-mm collimator was measured with the GSO crystal [6]. In this work, we investigated the dependence of the energy and the flux profiles of the proton beam on the distance along the line transverse to the incident direction. We used a LYSO crystal scintillator to investigate the dependence of the energy and the flux of the beam on the transverse distance from the beam center.

II. EXPERIMENTS

The beam line of the MC-50 cyclotron is composed of a collimator, a Faraday cup, a vacuum tube for beam drift, bellows for easy alignment, a beam profile monitor (BPM), an exit window for an external beam, a phosphor screen, a scattering foil, energy degrader, a target stage, an irradiation uniformity measurement system, a dose measurement system, an energy measurement system, *etc.* [6,7]. We used a 45-MeV proton beam with a 0.2 nA beam current for this study. The 45-MeV incoming proton beam passes through a 0.2-cm-thick aluminum window capping the beam pipe. Then it is collimated to a 1-mm-diameter beam spot by using a 1-mm-diameter aluminum collimator. Finally the incoming 45-MeV proton beam to the detector loses energy down to 37.5 MeV after passing through the equipment [1].

A LYSO ($7 \times 5 \times 30$ mm^3) crystal was prepared for this work. It was wrapped in Teflon, followed by black tape. The 30 mm longitudinal dimension of the LYSO crystal was enough to stop 38-MeV proton inside the crystal. The energy resolution of the crystal with the 38-MeV protons beam was measured before by Kim *et al.* [1].

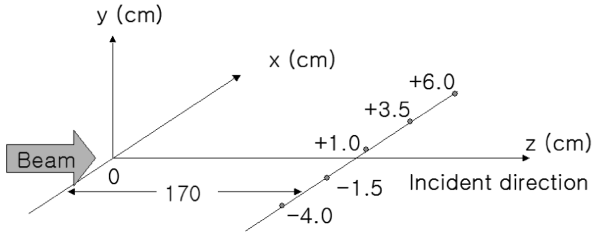

Fig. 2. Location of the LYSO crystal to measure the proton-beam energy.

1. Energy Measurement

For the measurement of the energy, a metal package E5780 PMT of 8 mm in diameter (Hammamatsu Co.) was attached to the long side of the crystal. A high voltage of –800 V was applied to the PMT. A 25-MHz USB2-based flash analog-to-digital converter (FADC) board was used to digitize the analog signal [8]. The analog signal from the PMT attached to the crystal scintillator went into the analog input of the FADC board via an ORTEC 576 shaping amplifier. The FADC output was recorded into a personal computer, and the data were analyzed by using a C++ data analysis program. A schematic diagram of the experimental setup for the proton-beam energy measurement is shown in Figure 1.

To investigate the proton beam energy profile, we varied the position of the LYSO scintillation crystal along a line parallel to the x-axis. The z-position of the LYSO crystal was fixed at 170 cm from the 1-mm aluminum collimator, the y-position was fixed at the beam center, 0 cm and the x-positions are +1.0 cm, +3.5 cm and +6.0 cm to the left of the beam center and –1.5 cm and –4.0 cm to the right of the incidence direction. Figure 2 shows the locations of the LYSO crystal.

2. Flux Measurement

For the flux measurement, the analog signal from PMT (E5780) attached to the LYSO crystal was connected into the analog input of the preamplifier (PreAmp). The amplified signal was fed into the discriminator (Disc) for the

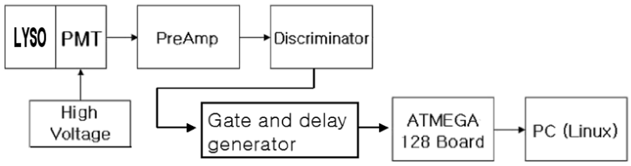

Fig. 3. Schematic diagram of the experimental setup for the flux measurement.

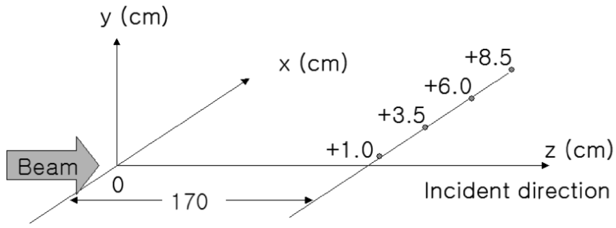

Fig. 4. Location of the LYSO crystal for the proton-beam flux measurement.

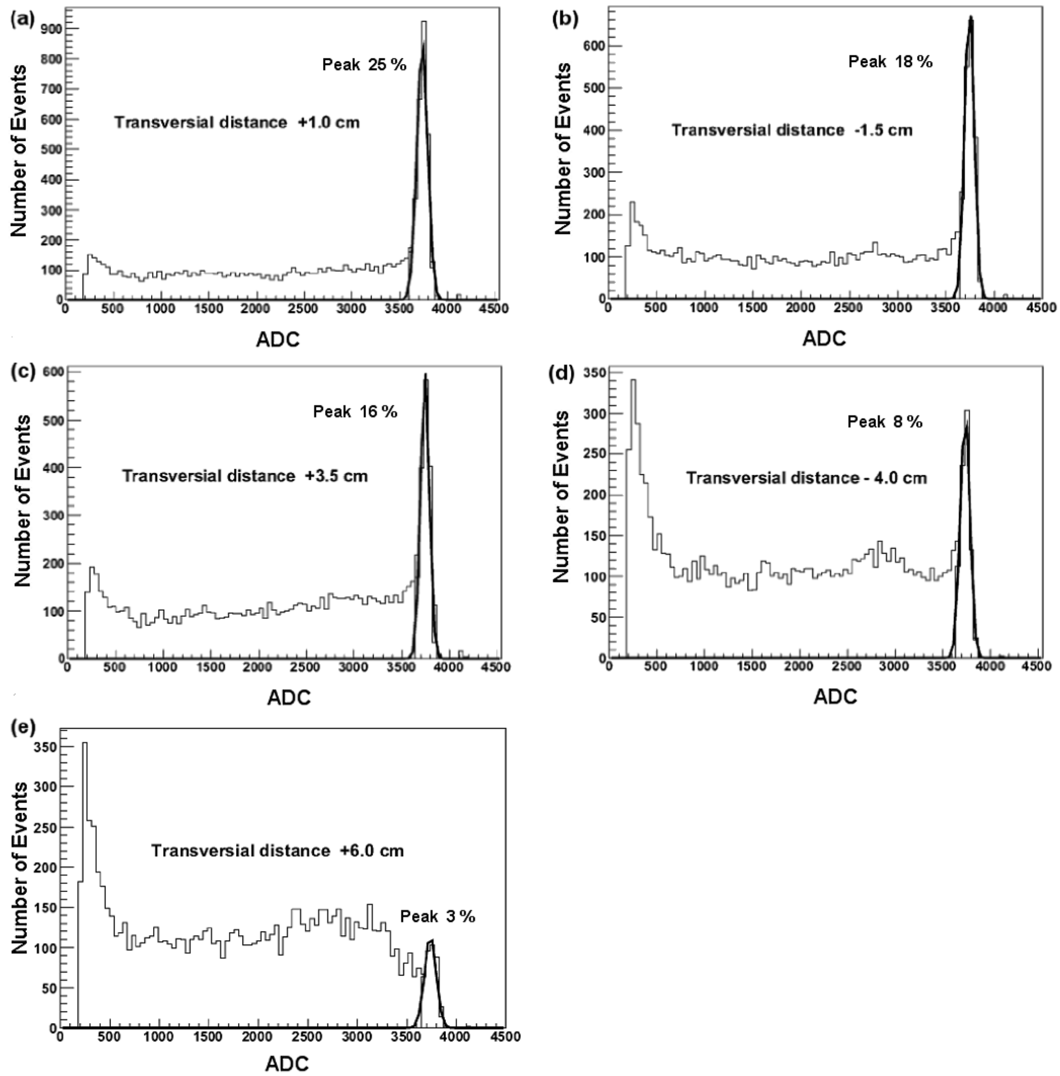

Fig. 5. Dependence of the energy profile of the proton beam on the distance along the line transverse to the incident direction. (a), (b), (c), (d) and (e) are the energy spectra of the proton beam at the points (1.0, 0.0, 170.0), (–1.5, 0.0, 170.0), (+3.5, 0.0, 170.0), (–4.0, 0.0, 170.0) and (+6.0, 0.0, 170.0) cm, respectively.

proton signal tagging. The output signal of the Disc was sent into the gate-and-delay generator to make it into a transistor-transistor logic (TTL) signal. The TTL signal was fed into an ATMEGA 128 embedded board and then, at a personal computer. The data were analyzed with a C++ data analysis program based on the ROOT package. A schematic diagram of the experimental setup for the proton-beam flux measurement is shown in Figure 3.

The position of the LYSO scintillation crystal was varied along a line parallel to the x-axis. The x-position was varied and had values of +1.0 cm, +3.5 cm, +6.0 cm and

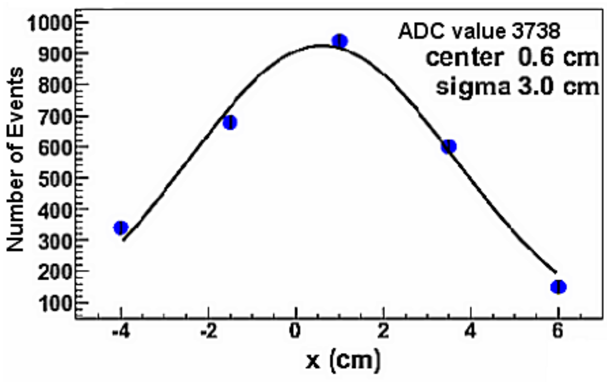

Fig. 6. The monochromatic proton beam energy intensity distribution.

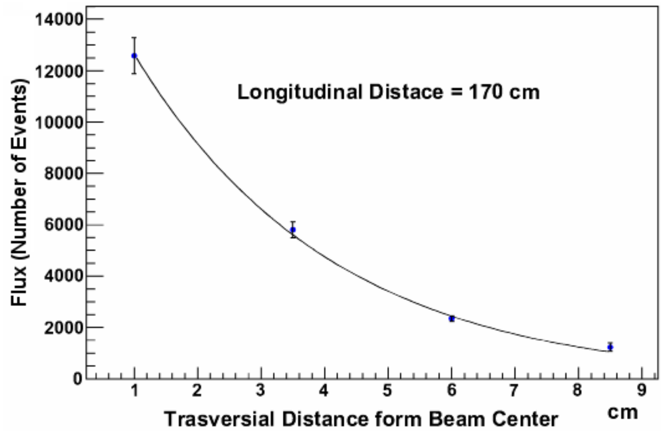

Fig. 7. The proton beam flux distribution.

+8.5 cm to the left of the beam incidence direction. The y- and the z-position of the LYSO crystal were fixed to be the same position to measure the energy of the proton beam. Figure 4 shows the location of the LYSO crystal for the measurement of the proton beam's flux.

III. RESULTS AND DISCUSSION

We measured the energy profile of the proton beam by using a LYSO scintillation crystal along a straight line transverse to a incident direction from the center. The results are shown in Figure 5. This figure was obtained from a data analysis by the program based on the ROOT package. As shown in Figure 5, there is a sharp peak at an ADC value of 3738 ± 55 due to the monochromatic proton energy, where the ADC value is proportional to the proton energy. The spread of the proton energy below the peaks as shown in Figure 5, is due to the proton scattering at the collimator. Figure 5(a)-(e) show sharp peaks at the same energies, and the peaks have a Gaussian form. The ratio of the peak to the total events is also shown in Figure 5. The ratio is reduced from 25 % to 3 % as transversal distance is increased. This reduction of the ratio with the transversal distance shows a deterioration of the monochromatic characteristics of the proton beam. Figure 6 shows the monochromatic energy intensity distribution. Figure 6 shows that the proton beam's intensity is distributed around the beam center in a Gaussian form. Figure 5(e) and Figure 6 show that the beam become much less monochromatic at a point away from the beam center. This can be interpreted as follows: The beam intensity of the protons directly coming from the collimator become weak, and the protons scattered by the collimator have various energies and are dominant at points far from the beam center.

We have to very careful when we prepare a experiment requiring a definite energy, for example, the energy calibration of a detector, such as silicon sensor or scintillator. Usually, we set the detectors at a point apart from the beam center to protect the device from radiation damage, but from above result, we can conclude that the detector must be set as near as possible to the beam center.

We measured the beam flux by using the counting method described in Ref. [9]. The result is shown in Figure 7. In Figure 7, the flux distribution is fitted by using an exponential form. The result shows that the proton flux decreased rapidly for a detector located off center, as expected.

IV. CONCLUSION

We investigated the beam profiles of the 45-MeV proton beam from the MC-50 cyclotron at Korea Institute of Radiological and Medical Science. We used a 45-MeV proton beam with a 0.2-nA beam current to measure the beam energy and flux with a LYSO crystal. We examined the dependence of the energy profile of the proton beam on the transverse distance from the beam center by using a crystal scintillator. Also, the flux profiles of the proton beam were measured with a crystal scintillator.

From our investigation, we see that taking the accurate information on the energy profile of the beam is important for understanding the characteristic of the beam. Also, we found that the energy profiles of the beam at points near from the center and at some distant points from the center are very different, so it is very important to test the energy profile of the beam at the point where the detector will be located before one performs the beam test.

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