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DEVELOPMENT OF POSITION-SENSITIVE PROTON RECOIL TELESCOPE (PSPRT)

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Abstract - We have developed a position-sensitive proton recoil telescope (PSPRT) which employs a position-sensitive photomultiplier (PS-PMT) and a scintillator for both a radiator and a proton-detector. This system is expected to achieve high energy resolution under a large solid angle, because it enables to obtain the information not only on the proton energy but also the recoil angle from the position data for both detectors. The response of the PSPRT for 14.1 MeV mono-energetic neutrons was measured, and the PSPRT proved to be operating as expected.

INTRODUCTION

Fast neutron spectra measurement is important in the area of radiation safety. As a fast neutron spectrometer, a proton recoil counter telescope (PRT) detector [1] is widely used. The PRT can deduce the neutron energy (*En*) by using a recoil proton energy (*Ep*) and a recoil angle(θ);

$$Ep = En \cos^2\theta, \quad (1)$$
$$\Delta Ep = En \sin^2\theta. \quad (2)$$

The equation (2) expresses the uncertainty of the proton energy for the angular spread $\Delta\theta$, and it indicates that the uncertainty at forward angles is smaller than in backward angles. In the PRT, θ is determined by the geometry in the experimental setup, and only *Ep* is measured. In conventional design, the detection efficiency must be lower to achieve good energy resolution, because a thin radiator and a small angular spread of recoil protons are required.

In order to achieve high resolution as well as high efficiency concurrently, we have developed a position-sensitive proton recoil telescope (PSPRT) which employs a position-sensitive photomultiplier (PS-PMT) and a scintillator for both a radiator and a proton-detector. This system enables to obtain the information not only on *Ep* but also θ from the position data for both detectors. Therefore the PSPRT can be used under a large solid angle, without deterioration in the energy resolution.

For example, if protons within 5 degree recoil angle are collected with radiator-detector distance of 5 cm, in the case of a conventional PRT, the sizes of the radiator and the detector should be smaller than 4.4 mm in diameter. On the other hand, in the PSPRT, both detectors are allowed to be as large as 50 mm in diameter corresponding to an effective area of PS-PMT (Hamamatsu R2486) for the same energy resolution as the former case. Therefore, roughly speaking, the efficiency of the PSPRT is more than one hundred times as high as the conventional one with the same energy resolution.

Further, a thick radiator can be used in the PSPRT, because the information of energy loss in the radiator can be obtained from the light output from the radiator scintillator. The PSPRT, therefore, is expected to achieve both of good energy resolution and high detection efficiency concurrently with a compact and solid composition. We expect that the PSPRT contributes to the measurements of neutron spectrum behind shields in accelerator facilities and the spectrum of cosmic neutrons, and fusion neutrons for the plasma diagnostics.

STRUCTURE OF THE SPECTROMETER

As shown in Fig.1, the PSPRT consists of two position sensitive detectors (PS-DET), a radiator-detector (PS-DET1) and a proton-detector (PS-DET2), placed facing each other.

The PS-DET1 consists of an NE102A plastic scintillator and a PS-PMT (Hamamatsu R2486), and the PS-DET2 is essentially the same as PS-DET1. The R2486 photomultiplier is of cross-anode type with an effective area of 50 mm in diameter. A neutron enters from backward of the PS-DET1 and ejects a proton, which is stopped in the PS-DET2. Signals are taken in coincidence between two PS-PMTs in order to decrease background events. En is determined by using eq.(1). Ep is obtained from the pulse heights from PS-DET1 and PS-DET2, and θ is deduced by the position-information in x-y coordinates of both detectors.

PS-PMT outputs four signals, x1, x2, y1 and y2. A scintillating point (x,y) is provided by the method of charge-division;

$$x = x2 / (x1 + x2) , \tag{3}$$

$$y = y2 / (y1 + y2) . \tag{4}$$

The pulse height is obtained by $(x1+x2+y1+y2)$. The position resolution of PS-PMT itself is better than 1 mm (FWHM ~0.3 mm) from the result of position calibration using a LED. However, the sensitivity of PS-PMT is not uniform enough, and the maximum difference is about 40 % even in the center part. To obtain pulse height information, therefore, the correction for the non-uniformity is necessary.

MEASUREMENT OF RESPONSE FOR 14.1 MEV NEUTRONS

1. Experimental Setup

The response of the PSPRT was measured at the Tohoku University 4.5 MV Dynamitron facility for 14.1 MeV mono-energetic neutrons produced by the T(d,n)α reaction. The experimental setup is shown in Fig.1. The neutrons at emergent angle of 90° were used to reduce the energy spread of neutrons less than 100 keV. The distance between the neutron source and radiator was taken longer than 100 cm to reduce divergence of the neutron incident angle to the radiator. In this experiment, NE102A plastic scintillators, 1 mm and 3 mm-thick, were employed for the PS-DET1 and PS-DET2, respectively. The distance between the scintillators was 5 cm. To prevent a crosstalk of lights between scintillators, a 0.03 mm-thick black polypropylene foil was placed on the surface of PS-DET2.

Four anode signals from each PS-PMT, eight signals in total were collected using CAMAC electronics. At first, the anode signal was divided into two signals in a linear fan-out, one is input into a charge-sensitive ADC and

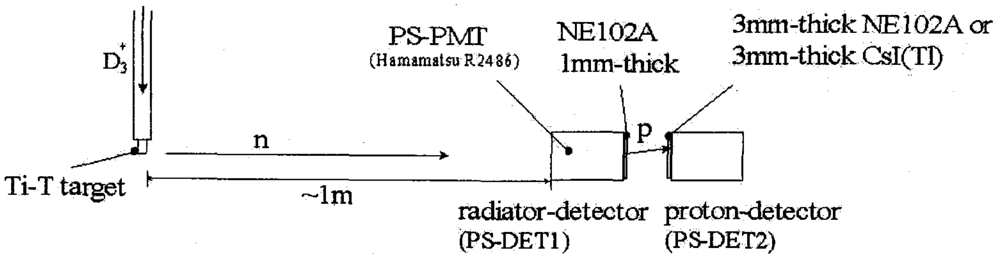

Fig. 1. Structure of the PSPRT and the experimental setup

collected as a pulse height signal, and the other one is used for logic signal to take coincidence and make a gate-signal.

2. Data Reduction

The position information was deduced by using eq.(2),(3). Since the PS-PMT is cylindrical and difficult to align against rotation in the experimental setup, a position calibration was performed by scanning x and y axes with a LED to determine a relation between the signal height and the position. Therefore, position data was adjusted to make consistent the position data of both detectors.

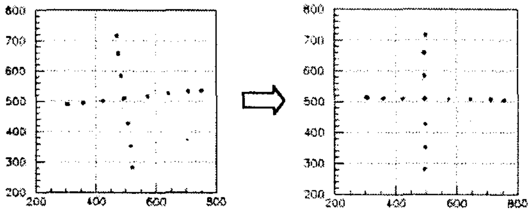

Fig. 2. Result of position calibration to obtain the relation between position data from PS-PMT and real one

The validity of position calibration of both detectors was confirmed experimentally by shadowing protons with a cadmium plate placed vertically and horizontally between detectors as shown in Fig.3(a). Cadmium was selected as a non-proton emitting element due to high Z. As an example, the result for the horizontal scale is shown in Fig.3(b). Neutrons are cut in the upper half and it confirmed the consistency of axis-calibration for both detectors.

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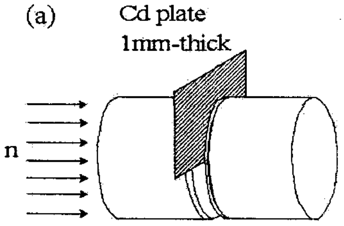

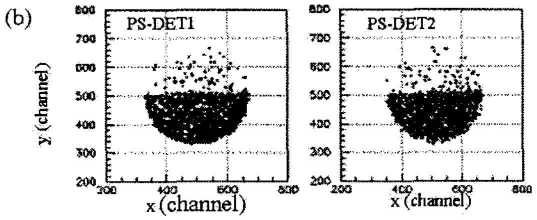

Fig. 3. Experimental confirmation of coordinate axes between PS-DET1 and PS-DET2 (a) experimental setup (b) results of position data

The scattering angle was obtained by the following equation,

$$\cos\theta = \frac{\vec{A}\cdot\vec{B}}{|A||B|} \tag{5}$$

where $\vec{A}$ and $\vec{B}$ are the vectors describing the position of PS-DET1 and PS-DET2, respectively.

The proton energy was determined by taking a sum of pulse heights PH1 and PH2 from the PS-DET1 and PS-DET2, respectively. The gain of pulse height was adjusted to satisfy the following equation,

$$\mathrm{PH1}(\theta) + \mathrm{PH2}(\theta) = \mathrm{Ep}(\theta) = (\mathrm{constant}). \tag{6}$$

Finally, neutron energy was deduced by using eq.(1).

RESULTS AND DISCUSSION

In this measurement, the effective area of PS-PMT was limited within 20 mm in diameter due to problems in light-collection for events in outer regions of one PS-PMT.

Figure 4 shows a scatter plot for pulse height of PS-DET1 vs. PS-DET2. The gains were adjusted to satisfy the eq.(6). The high energy events around the solid line in Fig.4 correspond to forward scattering. The range of 14 MeV protons in the NE102A plastic scintillator is ~ 2.19 mm, then the recoil proton can stop in the PS-DET2. In the PS-DET1, proton goes out from the radiator of 1mm-thick, and a portion of the energy was lost there.

Figure 5 shows a scatter plot for the proton energy Ep vs. the recoil angle θ. In this figure, two groups are observed. The group in the higher energy region is due to proton events, and this should be on a curve of eq.(1). The other group, which locates in the lower energy region and corresponds to a large number of events around 0 channel in fig.4, is caused by gamma ray. This identification was done by the following facts; (a) when a lead plate inserted between PS-DET1 and PS-DET2, proton events disappeared, but no change for the low energy group, (b) when the neutron beam was stopped, both groups diminished.

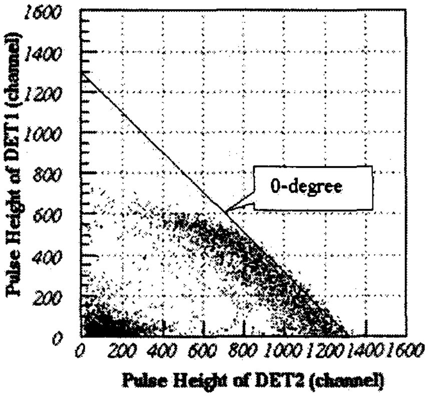

Fig. 4. Scatter plot for pulse height of PS-DET1 vs. PS-DET2

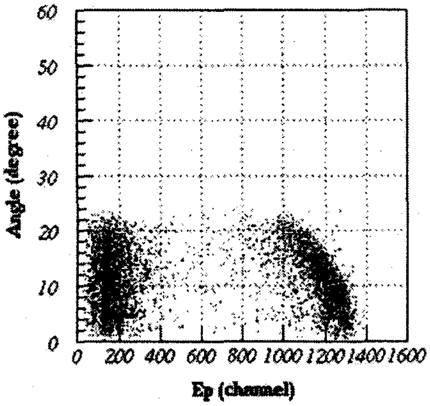

Fig. 5. Scatter plot for *Ep* vs. recoil angle

Figure 6 shows the comparison of the neutron spectra for events with $\theta < 10$ deg. and all events corresponding to the result of the conventional PRT.

The energy resolution of PS-PMT was ~7.7 % by a Gaussian fitting, and this is much better than the conventional PRT in the same geometry. The present resolution is expected to be improved significantly by performing the correction for non-uniformity of the sensitivity in the PS-PMT and proton energy-loss through the air and the polypropylene foil. Now the sensitivity measurement for the device is in progress for the former correction.

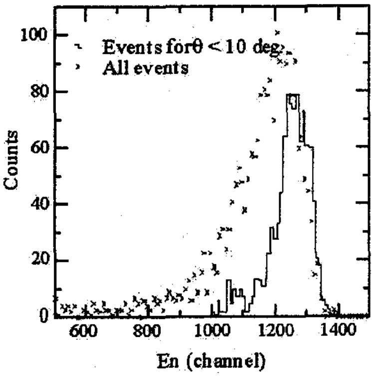

Fig. 6. Neutron spectra

CONCLUSIONS

Position sensitive proton recoil telescope (PSPRT) has been developed. The PSPRT consists of two detectors using position-sensitive photomultipliers (PS-PMT) and scintillators, and achieves much higher detection efficiency than a conventional proton recoil telescope without losing energy resolution so much, because information can be obtained on (1) scattering-angles, (2) proton energy and (3) energy-loss in the radiator scintillator.

The response of the PSPRT was measured for 14.1 MeV neutrons, and the validity of position calibration was confirmed. The energy resolution, however, was not good enough, 7~8 %. Correction for (a) non-uniformity of sensitivity in the PS-PMT and (b) a proton energy-loss through the air and the thin polypropylene foil will improve the resolution markedly. Furthermore, improvement of energy resolution can be expected by employing scintillators producing higher light output than

NE102A for the proton detector.

The PSPRT is expected to detect the high energy neutron (10~100 MeV) by improving the design of scintillators.

REFERENCES

[1] Glenn F. Knoll, Radiation Detection and Measurement, John Wiley & Sons, Inc.(1979)