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In order to determine density distributions of unstable nuclei, we have developed a recoil proton detection system to measure **E**lastic **S**cattering of **P**rotons with **RI** beams (ESPRI)[1). Using this system, a missing mass distribution of the H(*X*,*p*) reactions is constructed and the angular distribution of elastically recoiled protons is measured. With a 300 MeV/*u* RI beam, it covers a horizontal angular range of 68 deg. to 80 deg. in the laboratory frame, which corresponds to an energy range of 20 MeV to 120 MeV.

We selected a NaI(Tl) scintillating counter as a calorimeter of recoil protons to conform with the above noted situation and achieve an energy resolution of around 200 keV (rms) at 100 MeV, which corresponds the missing mass resolution of around 300 keV (rms). And fourteen single-crystals were manufactured and housed in shield boxes. The volume of the crystal is 18 inches wide, 2 inches thick and 2inches high. The entrance window is aluminum with 100 micrometers thickness. Two photomultiplier tubes (PMT, Hamamatsu R1307) are mounted on the both sides of the 2inchs square, respectively. We have evaluated whether all the rods satisfy the required resolution.

At first, the performance was studied with a 12 MeV proton beam at Tandem Van de Graff Accelerator Laboratory at Kyoto University[2)]. When the geometric mean value of read-out charge of two PMTs was used as relative proton energy, the energy resolution was about 0.6% (rms) at every irradiated point but the mean relatively fluctuated around 5% among these points. Therefore scintillating photons turned out not to be attenuated as an exponential function of a length from scintillating position to PMT. It can’t become negligible with recoil energy going up to 100 MeV.

Next, the energy resolution and fluctuation at higher energy was studied using the C4 beam line at CYRIC in December 2005[2,3]. Four rods were irradiated with a 77.6 MeV proton faint beam. The beam intensity was around 200 Hz. For each rod, the energy resolution was about 0.2% (rms) but the fluctuation of the mean was around 6% and its functional shape was different from the others. So each of outputs from PMTs turned out to need to be corrected individually, especially at higher energy.

Therefore a further study of the fluctuation for all the rods was performed at CYRIC in February 2007. The beam energy and arrangement of the setup was the same as before. In this experiment, following topics were mainly studied.

1) Time dependence : The fluctuation was checked against the previous measurement. In both measurements, following circuits were used. Anode outputs from PMTs were converted into voltage pulses with preamplifiers. These were further amplified with spectroscopic amplifiers. (Ortec 671), then fed to peak hold ADCs (Hoshin C008). Figure 1 shows the fluctuation as a function of the irradiated position. The latest data were not consistent with the previous. That is to say, the inclination of fluctuation changes with the passage of time. Because the energy resolution was almost unchanged, we can use these rods on condition that correction functions of fluctuation get every experiment.

2) Range dependence : The dependence of fluctuation on proton range was examined. Beam energy was varied from 20.0 to 77.6 MeV, which corresponds to the range of 2 mm to 23 mm in NaI crystal, using a degrader installed in the beam line. During this measurement, Ortec 671 and Hoshin C008 were exchanged for Caen N568B and V785, respectively. Figure 2 shows the dependence of fluctuation on beam energy. Each fluctuation was consistent with the others. Therefore we can take into no consideration the proton range to get correction functions of fluctuation.

In summary, we confirmed that the manufactured rod could satisfy the required resolution throughout its active area and the required energy range to correct the fluctuation for the long side of the rod every experiment. With our detection system including these rods, we are measuring proton elastic scattering of ^{9}C and ^{20}O at NIRS-HIMAC.

References

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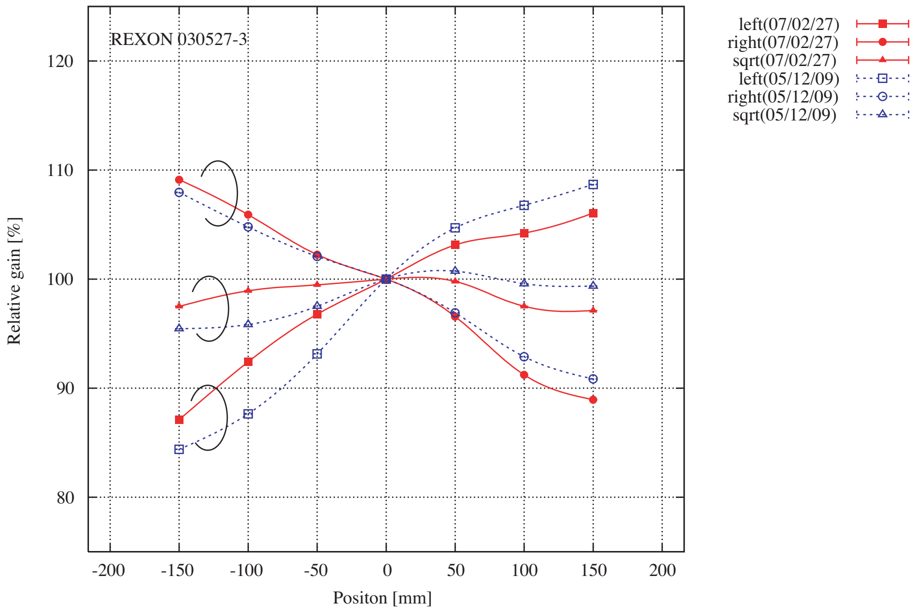

Figure1. Relative gain fluctuation. Closed and open markers are the latest and previous data, respectively. Squares and circles are relative read-out charge of one side of two PMTs, respectively. Triangles are relative values of the geometric mean of squares and circles. All the cubic spline curves are to guide the eye.

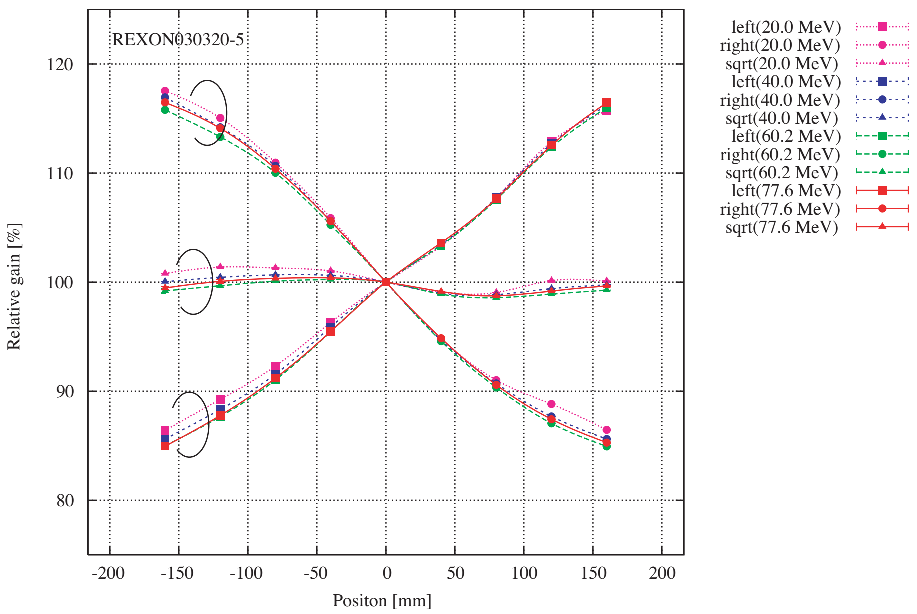

Figure 2. Dependence of relative gain fluctuation on proton energy. Red, green, blue and purple markers are data at 20.0, 40.0, 60.2, 77.6 MeV, respectively. And each maker at each energy and curves are the same as Fig. 1.