HUA Master's Thesis Award abstract

Construction of a BGO Calorimeter System for the Σp scattering experiment

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Introduction

We plan to perform a Σp scattering experiment (J-PARC E40) for the study of the ΣN interaction. In this experiment, we are going to determine the differential cross sections of the $\Sigma^+ p$, $\Sigma^- p$ elastic scatterings and the $\Sigma^- p \to \Lambda n$ inelastic scattering with high statistics.

In the E40 experiment, π beams are irradiated to a liquid hydrogen target. $\Sigma^\pm$ are generated by the $(\pi^\pm, K^+)$ reactions, and some Σ particles are scattered with a proton in the target. A momentum vector of the incident $\Sigma^\pm$ is measured by two spectrometers, that is, the K1.8 beamline spectrometer and the KURAMA spectrometer. In order to identify the Σp scattering events, the relation between the scattering angle and the kinetic energy of the scattered proton is requested to be consistent with the Σp scattering kinematics. For this identification, we are newly developing detector system, which is composed by a cylindrical fiber tracker (CFT) and BGO calorimeters. By surrounding the target with this detector system, the scattering angle and the kinetic energy of the scattered proton are measured with CFT and the BGO calorimeters, respectively. The BGO calorimeter is a large BGO scintillation counter ($30 \times 25 \times 400$ mm^3), read by PMT. Here, the resolution of the BGO calorimeters is required to be better than 3% (σ) for 80 MeV proton.

In the E40 experiment, BGO calorimeters are placed under a high counting rate (40k - 400 kHz). The purpose of this research is to develop a readout system of the BGO calorimeters which satisfies required resolution in the E40 condition. Then we will construct an actual BGO calorimeter system.

Readout system of BGO calorimeter

Under the high counting rate, the signal from BGO must be piled up with a high probability due to its long decay time of 300 ns. In order to decompose the pile-up signal, we decided to employ a readout system with a Flash ADC. In this system, waveforms are recorded with Flash ADC and are analyzed to separate pile-up signals offline. A signal from the PMT is shaped by a integral circuit and are recorded by CAEN V1724 Flash ADC to keep a reasonable resolution with rather long sampling time of 30 ns. In this readout system, the waveform can be reconstructed sufficient accuracy from 70 sampling points.

Evaluation of the readout system

In order to check the performance under the high rate condition, we performed a test experiment using a 77.8 MeV proton beam at a cyclotron facility in Tohoku University (CYIRC). The proton beam was injected to the BGO calorimeter by changing the beam rate from 1 kHz to 700 kHz. The stability of PMT was also studied by changing the applied voltage. As a result, the resolution was obtained to be 1.3% (σ) at 450 kHz beam rate by operating PMT with 600 V (rated voltage: 900 V). The efficiency of the offline waveform analysis was also obtained to be 99% at 40 kHz. From these results, BGO calorimeter system has achieved the required energy resolution under the high counting rate.

Furthermore, it is necessary to establish an energy calibration method as a calorimeter. In the experiment at CYRIC, we obtained the information about the four different beam energies by degrading the beam energy with the Cu degraders. From the relation between the BGO signals and proton beam energy, an energy calibration formula was obtained. Using this formula, we could reproduce the pp scattering data with an accuracy of 0.4 MeV in the energy range of more than 10 MeV.

Actual calorimeter system

We assembled a frame structure for the BGO calorimeters and installed 22 BGO calorimeters to the frame. We have constructed the actual BGO calorimeter system. In order to operate in the E40 experiment, the actual system was checked its various performances, such as energy resolution and so on. The resolution was obtained to be 15% (σ) at 662 keV γ ray from a ^{137}Cs source. Assuming that the energy resolution is proportional to $1/\sqrt{E}$, the resolution at 80 MeV is expected to be 1.4%. This resolution satisfies the requirement.

On the other hand, we also construct and tested the data acquisition (DAQ) system of the BGO calorimeters. From the E40 experiment, DAQ is required to operate sufficiently at 5 kHz trigger rate.

By devising the data transfer of V1724, actual calorimeter system has efficiency of 98% at 5 kHz trigger rate. Therefore, it is expected that DAQ can be performed with sufficient efficiency.

From these works, the BGO calorimeter system becomes ready for the E40 experiment.