Test of a scintillating fiber target for the hypernuclear spectroscopy

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A missing-mass spectroscopy of Ξ hypernucleus by using the ^{12}C(K^-, K^+) reaction is planned to perform at J-PARC K1.8 beam line [1, 2]. In this experiment, a bound state(s) of Ξ hypernucleus, $^{12}_{\Xi}$Be, is expected to be observed as a peak(s) for the first time. The peak position and width provide the information of the real part and imaginary part of Ξ-nucleus potential, respectively. As a recent theoretical calculation predicts complex peak structures due to nuclear core excitations [3], mass resolution is required to be better than 2 MeV (FWHM) in order to deduce the ΞN interaction.

The production cross section of $^{12}_{\Xi}$Be is estimated to be only about 60nb/sr. Although the beam power of J-PARC accelerator has been gradually improving, we need to use more than several g/cm^2-thick target to obtain enough yield of $^{12}_{\Xi}$Be in a reasonable run time at the current beam intensity. In this case, the mass resolution would be more than a few MeV because of the energy loss straggling in the thick target, and the peak structure and widths cannot be measured precisely.

To achieve both high resolution and statistics, we have been developing an active fiber target, which is comprised of a bundle of about a thousand of scintillating fibers. While carbon nuclei in fibers are used as the production target of hypernuclei, scintillation light yields generated by passage of kaons are measured by MPPCs attached on every fiber. The light yield is assumed to correlate with the energy loss in the target, and enable us to correct momentum of kaons event by event. Thus, the deterioration of mass resolution due to straggling is expected to be avoided even with a substantial thickness of a target.

In order to prove the principle of the active fiber target, a test experiment was carried out by using proton beams at RCNP WS course. In this experiment, 20 cm-long scintillating fibers with different sizes (3 mm and 1 mm) and shapes of cross section (round and square) were exposed to proton beams at 65 MeV and 295 MeV. The energy loss and light yield in the fiber were measured with the high-resolution spectrometer Grand Raiden (GR) and the target system, respectively. Comparing these information, the energy loss resolution of a single fiber was studied. A prototype with 15 fibers in 5 layers was also used to study possible effects of δ ray, cross-talk, and so on. These information will be important inputs for Monte Carlo simulation to estimate the performance of the active fiber target as a bundle.

Figure 1 shows a typical result of round-shape 3 mm fiber at the beam energy of 65 MeV. The horizontal axis represents energy loss of proton beam measured with the GR spectrometer (ΔE_{GR}), and the vertical one indicates the number of photons detected with the target (N_{ph}). It is found that there is a clear correlation between ΔE_{GR} and N_{ph}, and that it is not linear. Effects of fiber structure and linearity of MPPC are considered as a reason. A fiber consists of scintillating core and cladding with a thickness of 3% of diameter. While a beam losses its energy in the whole fiber, measured light yield corresponds to the energy loss only in the core. Assuming an average of energy losses is proportional to path length, the correlation depends on the path lengths for the all and core part of the fiber which are geometrically determined by a beam incident position. In addition, N_{ph} should be underestimated by more than 10% at 400 photons because of non-linear nature of MPPC.

The N_{ph} distribution at ΔE_{GR} of 2.5 MeV is shown in Fig. 2. It roughly depends on Poisson statistics, while the existence of cladding slightly effects on it. The peak positions of fitting curves at all energies give a function to estimate the energy loss in a fiber from the N_{ph} (ΔE_{Fiber}). Figure 3 presents the correlation between the ΔE_{GR} and ΔE_{Fiber}. The energy loss resolution of the single fiber target is evaluated as a width of the ΔE_{Fiber} distribution. The energy dependence of the resolution is shown in Fig. 4. The result of round-shape 3 mm fiber is better than that of square one in all the energy range. As a typical energy loss of the kaons at 1.8 GeV/c is assumed to be about 0.6 MeV for a single fiber with the thickness of 3 mm, the result indicates a resolution of about 10% will be achieved in the hypernuclear experiment. In this case, about 8.4 g/cm^2-thick target is expected to be tolerable to achieve the mass resolution of 2 MeV.

In summary, we clearly observed correlation between the energy loss in the fiber and the number of photons, N_{ph} , from the fiber. The energy loss resolution was better than about 10%, as the result of the test experiment with a single fiber target. In addition to the above, by using the prototype target, the position resolution and detection efficiency for a single layer were estimated to be 0.15 mm and 93.8%, respectively. The detail of the experiment and analysis is described in [4]. We would like to understand the energy dependence of the energy resolution of a single fiber, and estimate how it affects in multiple layers. A realistic simulation taking accounts of these results is needed to design an actual active fiber target and develop analysis procedures on energy correction.

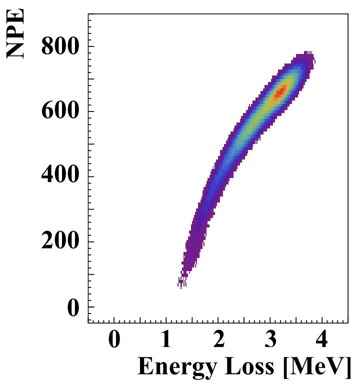

Figure 1: The correlation between ΔE_{GR} and N_{ph} for 3 mm ϕ fiber with 65 MeV beam.

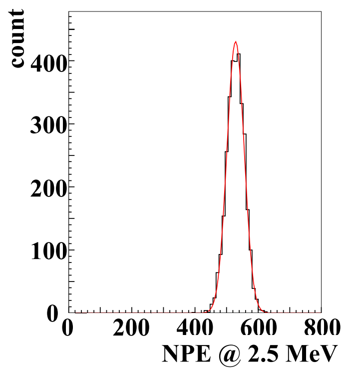

Figure 2: The N_{ph} distribution at ΔE_{GR} of 2.5 MeV. The red fitting curve is Gauss function.

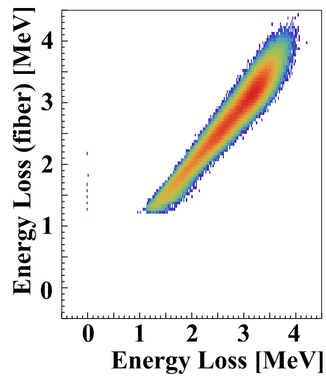

Figure 3: The correlation between ΔE_{GR} and ΔE_{Fiber} for 3 mm ϕ fiber with 65 MeV beam.

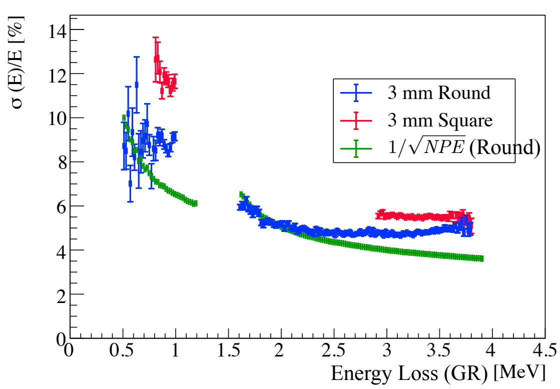

Figure 4: The energy loss resolution of a single fiber target. The left part is results at 295 MeV and the right part at 65 MeV. The red and blue plots are data of 3 mm round and square fiber, respectively. The green plots indicate inverses of the square root of peak N_{ph} in the data of round shape fiber.

References

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