Study of the effect of radiation damage on the quantum efficiency of a CsI photocathode

K. Kanno[*1,*2] for the J-PARC E16 Collaboration

We measured the effect of radiation damage on the quantum efficiency of a CsI photocathode. This study is of great importance for the performance of the J-PARC E16[1)] hadron blind detector (HBD), which uses a CsI photocathode to detect Cherenkov photons produced by an incident electron in the CF_4 radiator. In the E16 experiment, the HBD is required to identify electrons with high efficiency in the high-rate neutron environment (<10 MeV, 3 kHz/cm^2). The radiation damage of a CsI photocathode caused by these neutrons will degrade the sensitivity of the photocathode to Cherenkov photons. This degradation of a photocathode decreases the electron detection efficiency of the HBD.

We performed a test experiment at the RIKEN AVF cyclotron to estimate the effect of the radiation damage on a CsI photocathode caused by a high-rate neutron environment. The radiation damage was evaluated by comparing the quantum efficiency before and after the experiment. In the experimental area, low-energy neutrons were produced by stopping an α-particle beam at 12.5 MeV/u from the cyclotron at a beam dump. A CsI photocathode contained in a prototype HBD was irradiated with these low-energy neutrons. It should be noted that the CsI photocathode was not directly irradiated with the α-particle beam. The photocathode was not exposed to air at all, because the water contaminant caused the CsI photocathode to change its composition and degraded the quantum efficiency.[2)] The prototype was operated under CF_4 gas flow, and the water contaminant was monitored and maintained below 15 ppm, which ensured that the photocathode did not deteriorate at all owing to the water contaminant. The CsI photocathode was evaporated by Hamamatsu Photonics K.K. and the thickness was 300 nm. The neutron rate evaluated with a ^{3}He gas-filled neutron monitor in the area and a GEANT4 simulation was approximately 17 kHz/cm^2 (<10 MeV) at the position the prototype was located, which was higher than that of the E16 experiment by a factor of approximately six. The photocathode was irradiated for 35 h in total, and this duration corresponded to approximately nine days in the E16 experiment in terms of the total amount of neutrons.

The result is shown in Fig. 1. The top panel represents the quantum efficiency of the CsI photocathode before and after the irradiation. The bottom panel represents the systematic errors in the relative value of quantum efficiency. This systematic error arises from the calibration error of our quantum efficiency measurement system. Thus, the enhancement of the quantum efficiency after the irradiation over the wavelength of 120–200 nm is significant. Although we detected no changes in the CsI photocathode by visual inspection, this enhancement might be caused by the change in the surface structure of the photocathode by high-rate neutrons. The surface structure of a photocathode affects the photoelectron escape probability from the photocathode.[3)] Even though further studies are required to understand this enhancement, this result ensures that the quantum efficiency does not decrease for at least nine days in the E16 experiment.

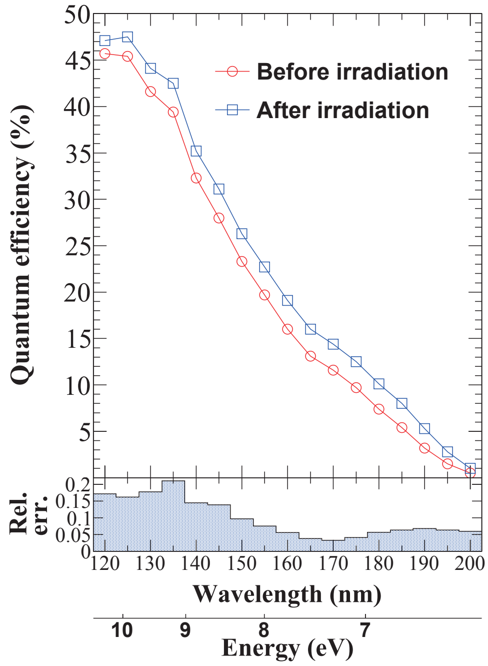

Fig. 1. Quantum efficiency of the photocathode (top panel) and its systematic error (bottom panel) as a function of wavelength and energy.

References
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*1 RIKEN Nishina Center
*2 Department of Physics, Graduate School of Science, The University of Tokyo