Proton irradiation experiment of the Cherenkov detector onboard lunar explorers Lunar-RICheS

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The construction of the Lunar Gateway will start in 2025 as part of the Artemis program, an international manned lunar exploration. Outside the magnetosphere, galactic cosmic rays and solar energetic particles fall on astronauts directly and cause health hazards. Effects on health depend on the energy of particles. GeV protons, which easily penetrate the spacecraft enclosure, are especially harmful. Spectroscopy of GeV particles is important to estimate the total exposure. Compact spectrometers for GeV particles have not been developed. Therefore, we developed the compact Ring-Imaging Cherenkov Spectrometer, Lunar-RICheS, to measure the energy spectrum of high energy (> 0.2 GeV) charged particles and clarify the response of RICheS in this paper.

RICheS measures the number of Cherenkov photons and ring size. The number of photons N is

$$\frac{d^2N}{d\lambda dx} = \frac{2\pi z^2 \alpha}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right) \quad (1)$$

and the angle of emission θ_C is $\cos\theta_C = 1/(\beta n(\lambda))$. The critical angle θ_C exists when $\beta n(\lambda) > 1$. α is the fine structure constant, $\beta = v/c$ is particle velocity, z is particle charge in electron unit, n is reflection index of a radiator, x is particle path length, and λ is wave length of Cherenkov photon.

As the energy increases, the number of photons and ring size increase. Charged particles also produce secondary particles in the radiator, which become backgrounds for our detector. We can eliminate the background by discarding the events that have an inappropriate relation between the number of photons and ring size. We use radiation-resistant glass S-BSL7 (OHARA) with refractive index $n_d = 1.516$ as the radiator. We employ multi-anode photomultiplier (MAPMT) H12700A-03 (Hamamatsu). The pixel size of MAPMT is 6×6 mm^2 and the number of pixels is 64 (8×8). Fig. 1. shows the overview. Theoretically, $\sim 10^2$ photons are detected at GeV proton incidence after quantum efficiency of the MAPMT is considered.

We performed a protons irradiation experiment at J-PARC 3NBT in March 2023. Protons accelerated to 3 GeV were scattered at an aluminum window (0.3 mm-t) and irradiated to the detector. We placed RICheS at 14 m away from the aluminum window in a scattering angle of 13°. The input energy spectrum is quasi-mono-energetic.[1)]

An image of Cherenkov photons emitted by a proton is shown in Fig. 2(a). We fit an ellipse to the pixel image data to derive the ring diameter. The number of photons and ring size increase in correlation, as

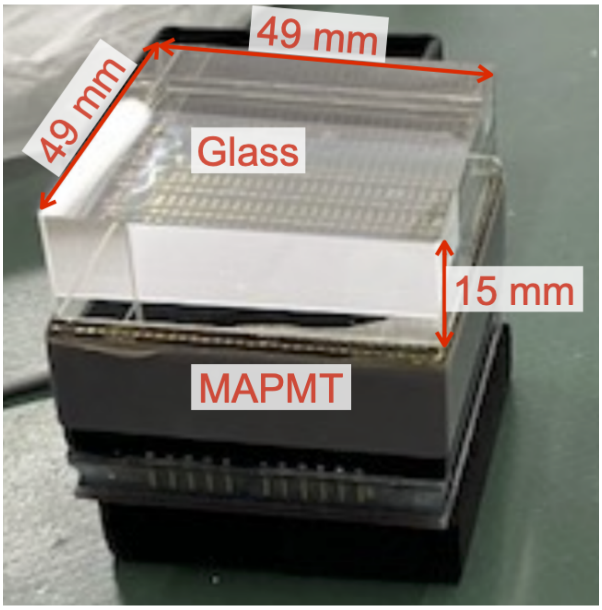

Fig. 1. Detector overview. An aluminum cover for light shading will be attached later.

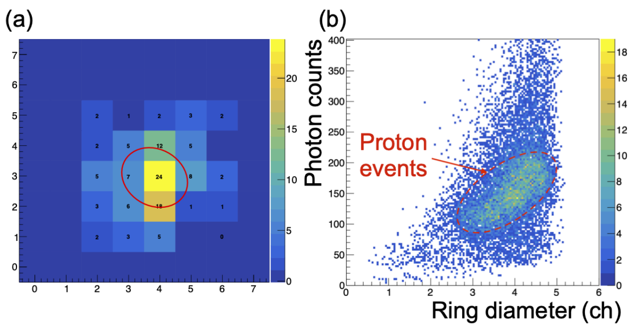

Fig. 2. (a) Cherenkov photon image by $\sim$3 GeV proton. (b) 2D histogram of the number of Cherenkov photons and ring diameter.

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shown in Fig. 2(b). The result is consistent with the theoretical Cherenkov emission trend. The number of photons per event was 100–200. Additionally, some events deviate from the main distribution supposedly caused by secondary particles. These backgrounds can be eliminated by extracting events by elliptical features. We plan to repeat a similar calibration with high-resolution TOF counters which can specify the energy of incident protons.

Reference

1) S. Meigo *et al.*, Proc. 19th Annual Meeting of Part. Accel. Soc. Jpn., THOB01, (2022), pp. 132–136.