# Geant4 simulation of Lunar-RICheS for human lunar exploration

R. Nakamura,[*1] T. Tamagawa,[*1,*2,*3] N. Ota,[*3,*2] K. Uchiyama,[*3,*2] T. Takeda,[*3,*1] T. Kohmura,[*4] Y. Uchida,[*4] J. Sato,[*4] Y. Watanabe,[*4] M. Fujii,[*5] and A. Nagamatsu[*6]

Construction of the lunar orbiting space station, Gateway, will begin soon for long-term manned exploration of the Moon and beyond. We are developing the Ring Imaging Cherenkov Spectrometer onboard the Gateway (Lunar-RICheS) that measures proton energies up to 2 GeV for radiation protection of astronauts.[1)] The compact Cherenkov counter (CCC) of the Lunar-RICheS comprise a Cherenkov radiator ($MgF_2$, $n = 1.39$) and a 64-pixel multi-anode photomultiplier tube (MAPMT) Hamamatsu H12700A-03. In this paper, we describe the initial results of a Geant4-based CCC simulator.

The simulation setup is shown in Fig. 1(a). Cherenkov photons are detected with $6 \times 6$ mm$^2$ pixels of MAPMT. The quantum efficiency as a function of wavelength is also considered in the simulation (typically 32.8% at 300 nm). A typical Cherenkov image is shown in Fig. 1(b) with an elliptical fit result for determining the ring radius.

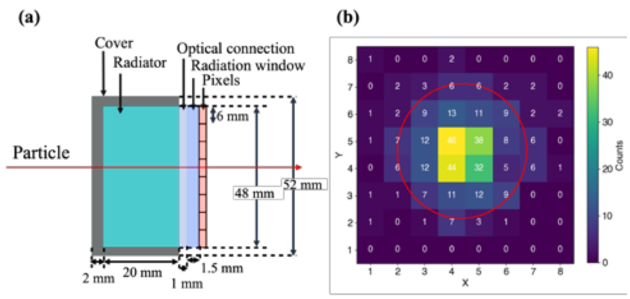


Fig. 1. (a) Geant4 simulation setup. (b) A typical ring image of MAPMT with an elliptical fit result (red circle).

The primary background of the CCC is the secondary particles generated by nuclear spallation and high energy electrons knocked out by the primary proton ($\delta$-ray). We can reduce the background by extracting only the events with appropriate Cherenkov photon counts estimated from the ring diameter. Figure 2(a) shows a 2D histogram of Cherenkov photon counts and fitted radii. The two lines in the figure show the cut boundaries set at $\pm 1\sigma$ around the peak. The events below the red line are mainly from spallation reactions, while the events above the black line mostly contain $\delta$-rays; these events are recognized as the background.

The proton energy is derived from Cherekov photon counts $N$ using $N(\beta) = \mathrm{a}\,(1 - (\mathrm{b}\beta)^{-2})$, where a and b are constants and $\beta$ is the velocity normalized by the speed of light. We fitted the function to the photon counts for 0.4–3 GeV protons produced with Geant4 and a calibration curve shown in Fig. 2(b).

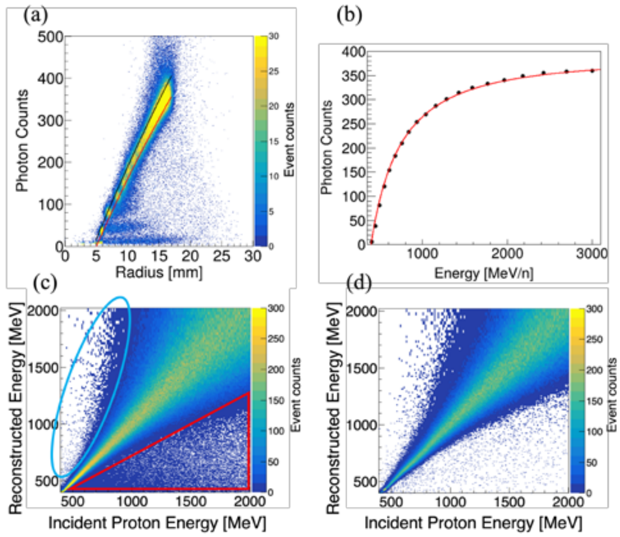


Fig. 2. (a) A typical event cut on photon counts-ring radius plane. (b) The calibration curve. (c), (d) The 2D histograms of reconstructed energy by $N(\beta)$ and incident proton energy (c) without and (d) with background cut. See text for details.

Figures 2(c) and 2(d) show the 2D histograms of the reconstructed energies derived from $N(\beta)$ and incident proton energies, without and with background cut, respectively. While the events are broadly spread in Fig. 2(c) due to backgrounds, the events are aligned on a diagonal line in Fig. 2(d). The events surrounded by the blue circle in Fig. 2(c) are mainly the $\delta$-ray backgrounds in which extra Cherenkov photons are generated. The events surrounded by the red triangle are the spallation backgrounds in which the Cherenkov photons are reduced. The fraction of spallation events ($\delta$-ray events) was reduced from 7% (18%) to 3% (10%) by the event cut at the incident proton energy of 2 GeV.

We presented the initial results of the Geant4-based CCC simulator here. In future work, the simulator results will be compared with experimental data to improve the reproducibility of the detector response.

Reference

1) N. Ota *et al.*, RIKEN Accel. Prog. Rep. **57**, 79 (2024).

*1 RIKEN Cluster for Pioneering Research
*2 RIKEN Nishina Center
*3 Department of Physics, Tokyo University of Science
*4 Department of Physics and Astronomy, Tokyo University of Science
*5 Space Environment Utilization Center, JAXA
*6 Space Exploration Innovation Hub, JAXA

DOI:10.34448/RIKEN.APR.58-250