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Development of the GDM system for imaging the internal structure of the Usu Cryptodome

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We developed a multilayer, scintillator based, segmented muon hodoscope whose number of layers can increase systematically by combining newly developed muon read out modules. The precise selection of muon trajectories from other cosmic ray background components are one of the most important processes for cosmic ray muon radiography. As the size of the target becomes larger, the muon path length in the target becomes longer, and thus the flux of the penetrating muon substantially decreases and the effect of the background (BG) noise becomes significant. The most probable source to create a BG track is the simultaneously arriving, vertical electromagnetic (EM) shower. When the EM shower hits only one point on each position sensitive detector (PSD), a hodoscope that consists of two PSD layers creates a fake muon track. This is because each shower particle is a charged particle and it is difficult for us to separate it from a muon. Another possible source degrading the quality of the measurement comes from the uncertainty in the muon spectrum model. Radiography using the propagation of muons utilizes a muon energy spectrum and a specific muon propagation model through matter. Conventionally, after passing through the target the integrated muon flux is compared with the muon flux directly from the sky to calculate the muon transmission. In this work, we attempted to reduce the vertical EM shower originated background events and to screen the low energy muons with energies below 10 GeV, by constructing a multi-layered, rotational muon hodoscope named GDM (gradient of density measurement). The maximum detectable thickness (MDT) of the GDM was designed to be 4 km.w.e. The trajectory of the cosmic-ray muons was measured by four or more PSD layers while the low energy muons were screened in the process of GDM analysis. We measured the internal structure of the 1910 cryptodome of Usu volcano located in Hokkaido, Japan during 290 hours with +/-2% precision in the density measurement. The obtained image is different from its conventional picture.