PROCEEDINGS OF SCIENCE

Comparison cosmic ray irradiation simulation and particle beam test on UFFO Burst Alert & Trigger telescope(UBAT) detectors

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Ultra-Fast Flash Observatory pathfinder(UFFO-p) was launched onboard Lomonosov on 28th of April, 2016, and now is under various types of calibration for detection of Gamma Ray Bursts (GRBs). Since last September UFFO-p has taken X-ray data in space with UFFO Burst Alert & Trigger telescope (UBAT), those X-rays are mostly diffused backgrounds however, the rate turns out to be higher than expected by a factor of three. We assumed cosmic rays can contribute by making the count rate higher. We did such a simulation to investigate the effect of cosmic rays. In December 2016, we irradiated fragmented high energy heavy ions at CERN on the UBAT detector. We will report the result of comparison between simulation and beam test.

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1. Intruduction

Ultra-Fast Flash Observatory (UFFO) is a project to collect early photons of Gamma Ray Butsts (GRBs). As a pioneer of this project, UFFO-pathfinder (UFFO-p) is launched on-board *Lomonosov* on Apr. 28, 2016, and now is under various types of calibration for detection of GRBs. To observe GRB events, two different telescopes were included [1]: first one is the UFFO Burst Alert & Trigger telescope (UBAT), an X-ray telescope that has wide Field of View (FOV) to localize GRBs. With it's coded aperture and codes written in Field Programmable Gate Array (FPGA), UBAT can localize GRBs within 10 arc-sec resolution [2, 3]. After localizing a GRB, UBAT sends GRB's direction to another telescope, the Slewing Mirror Telescope (SMT); an optical/UV telescope made of a slewing mirror and an Intensified Charge-Coupled Device (ICCD) camera [4]. As SMT got direction of the GRB, SMT rotate slewing mirror to record images by ICCD camera [1].

Detector of UBAT consist of 6×6 modules made of Cerrium-doped Yttrium Orthosilicate (Y_2SiO_5:Ce, YSO) crystal scintillator and MAPMT. Each module has 8×8 pixel array, and each pixel has a size of 2.88×2.88 mm^2. Therefore whole detectors of UBAT has 48×48 pixels [2].

From the calibration runs, two issues came out in UBAT part; one is 3 times higher count than expected, another one is big clusters hardly considered to me made from a photon. Even if we decrease exposure time of UBAT to 1 *ms*, still UBAT reports big clusters. Comic rays are the candidates that could make these effects as they themselves or the secondary particles produced by them pass through the crystals. We carried out the charged particle irradiation test on UBAT detectors at the European Organization for Nuclear Research (CERN). We also simulated the response of the UBAT detector to charged particles using GEometry ANd Tracking 4 (Geant4). We compare the results of the test and simulation to verify that charged particles (i.e., comic rays) can make such clusters in the UBAT detector.

2. Materials and Methods

2.1 CERN beam test experimental setup

At beam radiation area of CERN, UBAT detectors are set with other scintillation detectors and counter system as shown in Fig. 1. As incident particle beam is made of bunch of ions, direct irradiation on UBAT detector is not proper to check the procedure to make a cluster from a single particle. Therefore incident particles, which have $A/Z \approx 2.0$ and momentum ~ 62.3 GeV/c per nucleon, hit the lead blocks that have a thickness of 20 *cm*, and generate fragmented particles like protons, electrons, gammas and other ions with $Z \geq 2$. For this experiments, just 2 modules made of YSO and MAPMT are fixed on aluminium structure and are placed in a black box covered with black clothes to block any visible light from outside. And the box is placed 30 *cm* behind of the lead blocks and shifted 30 *cm* to one side from the beam axis to reduce the flux of incident fragmented particles

Expected number of particle to hit lead blocks within 6 *ms*, exposure time of a frame of UBAT, is $\approx 90/frame$. As proton and electrons hardly make secondary particles [5], only ions with $Z \geq 2$ are considered, and expected number of that ions is less than 1 with 6 ms exposure time.

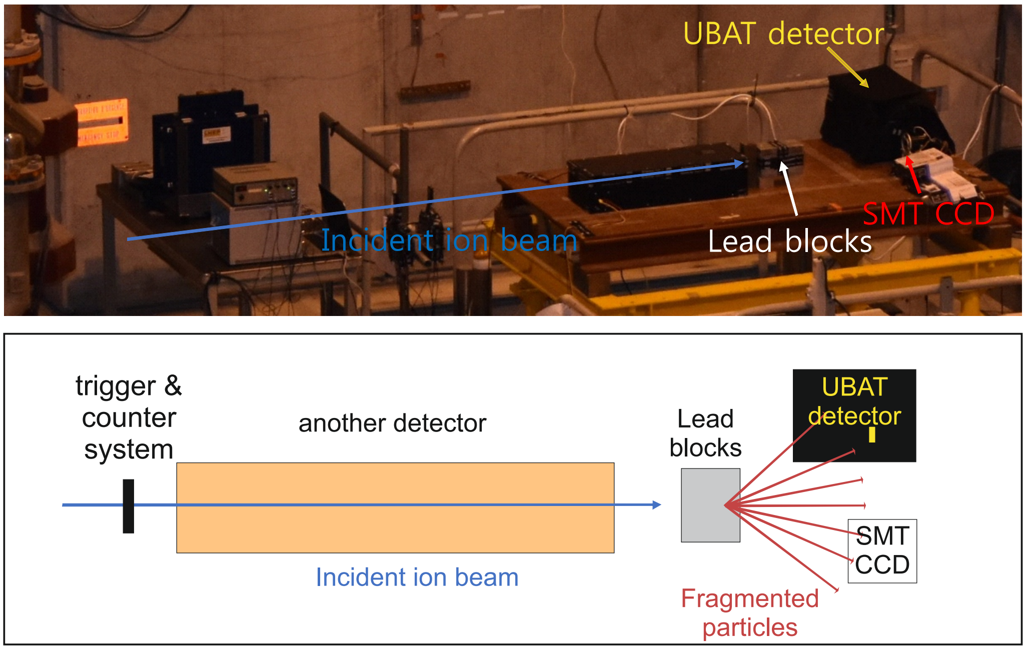

Figure 1: Top: Picture of experimental set-up at CERN. Shown are, from the left to right, the counter detector system for triggering and counting heavy ions, another detector for the measurement of the heavy ion charges, the lead target, and the UBAT detector. Bottom: Sketch of experimental set-up as bird's-eye view.

2.2 Geant4 simulation

To simplify simulation set-up, 8×8 YSO crystal pixels were set and various ions were irradiated on YSO crystal (Fig. 2). Instead of emulate all procedure including process to making fragmented particles from high energy incident ion beam and the lead blocks, only incident ions on UBAT detectors were considered to simplify simulation. When charged particle penetrate a YSO crystal pixel, energy depositions of incident particles and secondary particles are scored and converted to hit-map.

3. Results

3.1 CERN beam test results

As incident ion beam flux is not constant during beam is on, only 113 frames of collected 700 frames have some hit patterns. UBAT collected images with 6 *ms* exposure time when beam is turned on, and only 113 frames of collected 700 frames in total have some hit patterns. Almost all hit pattern was cluster-like as shown in Fig. 3, and single-hit-like pattern is rare. And when clusters are made, the patterns on detectors are hardly thought that they were made from propagating secondary particles via crystal as shown right one of Fig. 2.

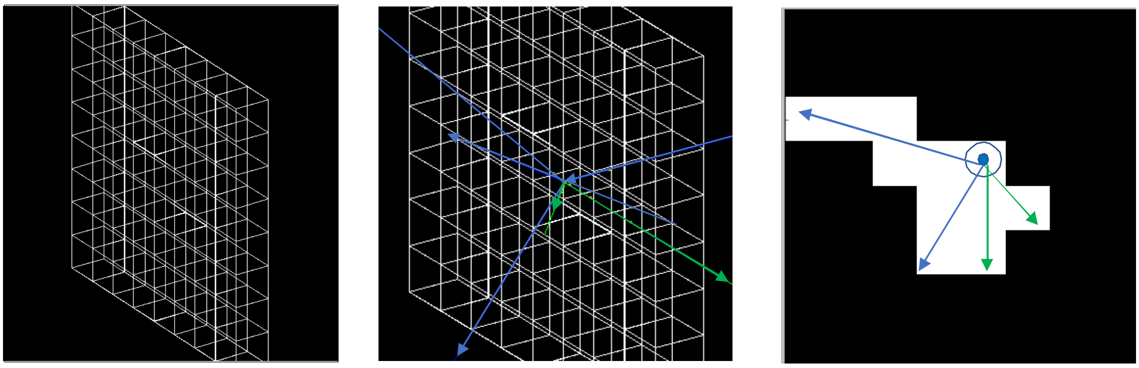

Figure 2: Left: Detector construction of simulation via Geant 4. Center: Expected procedure to make secondary particles. Right: Example of hit map of clusters from secondary particles. YSO pixels make signal along the trajectory of secondary particles.

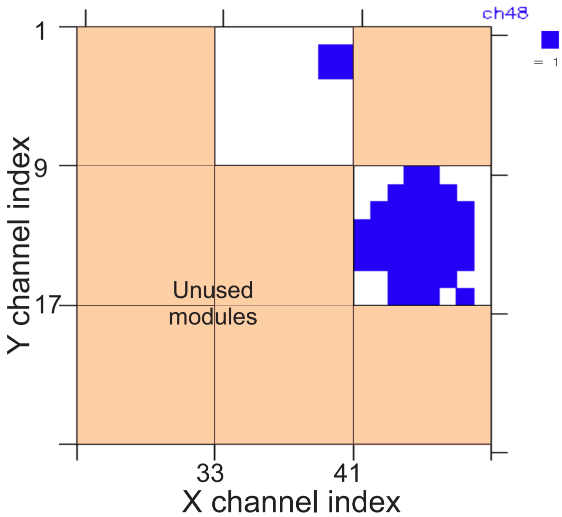

Figure 3: Example image of cluster. Only 6 YSO and MAPMT modules were displayed that is near by used ones, and unused modules were represented orange.

3.2 Geant4 simulation results

Several clusters were verified from Geant4 simulation, but probability to make secondary particles is too low to contribute generate big clusters. Various ions were incident on UBAT detectors with energy from 1 *MeV* to 10 *GeV*, but at any particles with such energy level can't make secondary particles dominantly in this simulation. Fig. 4 shows how rare to make cluster via generating secondary particles is. Only the case of incident alpha particles with 60 *GeV* kinetic energy is show, but the particles with atomic number from 2 to 26 and kinetic energy 100 *MeV*, 1 *GeV*, 10 *GeV* and 6 *GeV* made similar results. And when clusters were made, hit pattern has a tail-shape make along the trace of secondary particles.

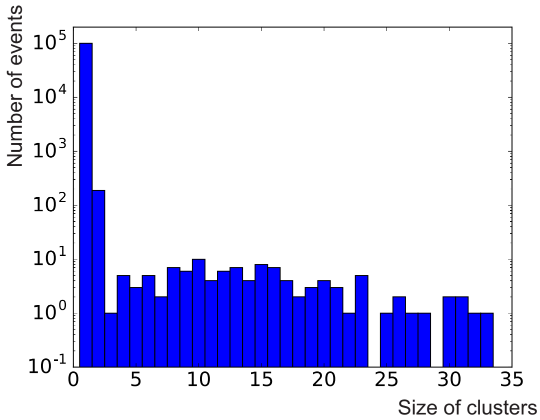

Figure 4: Hitoram of size of clusters by incident alpha particles. 100,000 events were collected totally, and incident particles have energy of 60 GeV. Probability to make cluster larger than 9 is about 0.08 %, and 99.7 % of events were just single hit.

4. Discussion

Two results from experiment and simulation are not agree with each other. Pattern of clusters from experiment don't seem to be made from secondary particles' track, and the result from the simulation shows clusters from the track of secondary particles are hardly occur in YSO crystal by incident charged particles. Therefore we can make conclusion that secondary particles can't make big effect to make clusters on UBAT detector. Gammas sometimes make clusters smaller than 3×3 by cross-talk effects, but because of experimental signal yield is $0.72 photoelectron/keV$ and probability to occur cross-talk is 8% for diagonal and 29% for alongside [6], gamma can't make big cluster within UBAT's sensitive energy range from 5 keV to 200 keV.

To solve this disagreement, energy deposition of incident charged particles is considered. Energy depositions of that particles can be calculated from Bethe-Bloch formula [7],

$$-\frac{dE}{dx} = 2\pi N_a r_e^2 m_e c^2 \rho \frac{Z}{A} \frac{z^2}{\beta^2} \left[ln \left(\frac{2 m_e \gamma^2 v^2 W_{max}}{I^2} \right) - 2\beta^2 \right] \tag{4.1}$$

From Eq. 4.1, expected energy deposition of incident helium ion that has 60 GeV kinetic energy in YSO crystal is 42.25 MeV when we assume $Z = 39$ and $A = 78$. Z is supposed from effective atomic number of YSO, from specification of the crystal and A is assumed just 2 times of atomic number. For particles with kinetic energy of $\sim$ GeV kinetic energy, energy deposition is tens of MeV. Light yield, from the specification from the YSO crystal manufacturer, is $9,200 \sim 10,000$ photons per MeV, expected number of scintillation photon per charged particle with $\sim$ GeV is $\sim 10^5$. These extremely high number of photon may easily make clusters via cross-talk without secondary particles.

5. Summary

From several calibration runs of UFFO-p, UBAT detector, the X-ray telescope of UFFO-p, reports higher count rate than expected and there are large clusters even though short exposure time of 1*ms*. Cosmic rays were believed to make that effect, especially secondary particles generated from incident particles and the material of YSO crystal, and we designed charged particle irradiation test on CERN and a simulation. Experimental data reported clusters, but the patterns from results disagreed with expected procedure. And from simulation, secondary particles hardly generated from $\sim$ *GeV* energy range. But as energy deposition of incident particles are much larger than photons in range of 5 *keV* to 200 *keV*, UBAT detector's cross-talk effect between YSO crystal and MAPMT may make bit cluster. This effect will be carefully considered with UBAT detector's geometric structure and optical characteristic, and be investigated by further study.

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