PROCEEDINGS OF SCIENCE

Radiation detectors fabricated by secondary students

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Accel Kitchen LLC offers online support to over 150 high school and junior high school students in their personal radiation research. Many of these students have fabricated original detectors, such as a depth of interaction (DOI) detector comprising multiple scintillator layers for particle identification and positional sensitivity measurement, a Cherenkov detector made from an acrylic block and Silicon photomultiplier, and a time-of-flight detector capable of sub-nanosecond resolution using a Red Pitaya ADC board. Thus, students not only conduct their measurements with given detectors but also assemble and modify them for their own research purposes.

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1. Background

Accel Kitchen [1] provides various handy particle detectors for high school and junior high school students mostly in Japan. It also builds a research network consisting of students, mentors and researchers with text and voice chat system, Discord. Mentors continuously support student's online and there are over 150 students conducting their own research [2, 3]. Individual students conduct their research as personal activities and usually schools are not concerned about their research. Some of the students have designed and fabricated detectors and analyzed data on their own over a period of one year or longer [4, 5]. Examples of detector fabrication are introduced here.

2. Example of detector developments by students

2.1 Segmented detector

Recently, various handy particle detectors have been widely spread by using a SiPM (Silicon Photomultipliers), such as a Cosmic Watch [6], which consists of SiPM, plastic scintillator and microcomputer. Even though these detectors are cheap and easy to use for students, it is hard to obtain the particle's trajectory.

The segmented detector has developed by high school stundents at Sendai Daisan High School. It consists of multiple plastic scintillators stacked on top of each other and sandwiched by SiPMs (Fig. 1A) in purpose of obtaining a type of particle, particle ' s energy and position of particles passing through. This technique is known as Depth of interaction (DOI) and is mainly applied as a method of upgrading PET detectors [7]. When radiation enters the scintillator, it emits light corresponding to the energy deposit at the position where it passes through the scintillator. Since this emission is attenuated and reflected depending on the number of scintillator plates that pass through to the top and bottom two SiPMs, positions of particles passing through are reconstructed from the ratio of the output voltages of two SiPMs (Fig. 1B).

Figure 1C shows a typical correlation between the outputs of two SiPMs when the scintillators are aligned vertically on the ground. The outputs of the two SiPMs are almost equal for cosmic-ray muons that come mostly from the zenith and pass through all scintillators, while environmental radiation such as beta rays is divided into several distributions depending on the position of the radiation. Thus, it also enables us to identify the type of particles.

2.2 Cherenkov detector

A Cherenkov detector based on the Cosmic Watch was fabricated by high school students at Toshimaoka Girls' High School: an acrylic block without UV-cut treatment is optically glued to the SiPM. They measured cosmic-ray with this detector placed perpendicular to the ground and a plastic scintillator detector is placed on top of it as a trigger (Fig. 2A,B). Fig. 2C. The decrease in the detection rate with increasing the zenith angle which is consistent to the zenith angle distribution of cosmic-ray muons. Figure. 2 (D) shows the detection rate with the length of the acrylic is 10 cm, 20 cm, to 30 cm.

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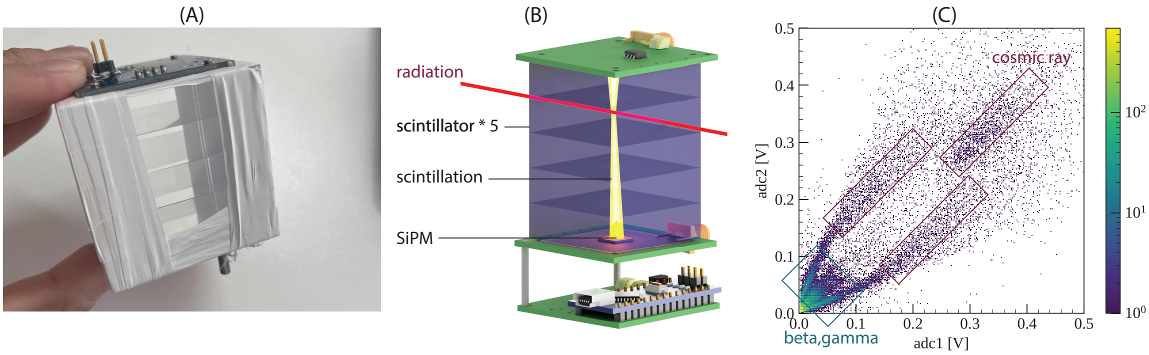

Figure 1: (A) Photograph of a segment detector, consisting of five plastic scintillators (50 mm * 50 mm * 10 mm) sandwiched between two SiPMs (MICROFC-60035,SensL). (B) Each layer of scintillator emits scintillation light when radiation passes through it. Since the scintillation light reaches the SiPM through attenuation and reflection between scintillators, it is possible to estimate the position where the radiation passed, and the radiation type from the output voltage at the two SiPMs. (C) Correlation between the output voltages of two SiPMs when the detectors are placed perpendicular to the ground. Cosmic rays from the zenith often pass through all layers of scintillators and are distributed in the same area of SiPM output (red box). On the other hand, beta and gamma rays from environment have relatively small scintillation light and the output voltage of SiPM varies depending on the position of their passage, so they are divided into multiple distributions.

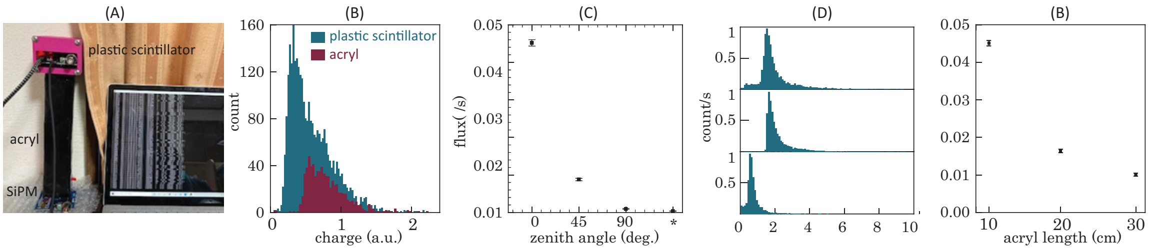

Figure 2: (A) Cherenkov detector developed by a high school student at Toshimaoka Girls' High School. A scintillator detector is placed above the Cherenkov detector as a trigger. (B) Output charge of Cherenkov detector and scintillator detector for trigger measured using Red Pitaya. Since the output signal of the SiPM derived from Cherenkov light is smaller than the scintillation light of the plastic scintillator, the charge is measured after amplification. (C) Comparison of the detection rate of cosmic rays by zenith angle. For *, the trigger detector was not placed on top of the Cherenkov detector but was moved farther away from it as a control measurement. It can be seen that the detection rate decreases as the zenith angle increases that is consistent to the zenith angle distribution of cosmic-ray muons. (D) Comparison of the arrival frequency of cosmic rays when the length of the acrylic is changed from 10 cm, 20 cm, to 30 cm. The acrylic surface is polished manually by high school students and covered with aluminum foil. It can be inferred that the amount of emission decreases with increasing length due to the low reflectivity of the acrylic.

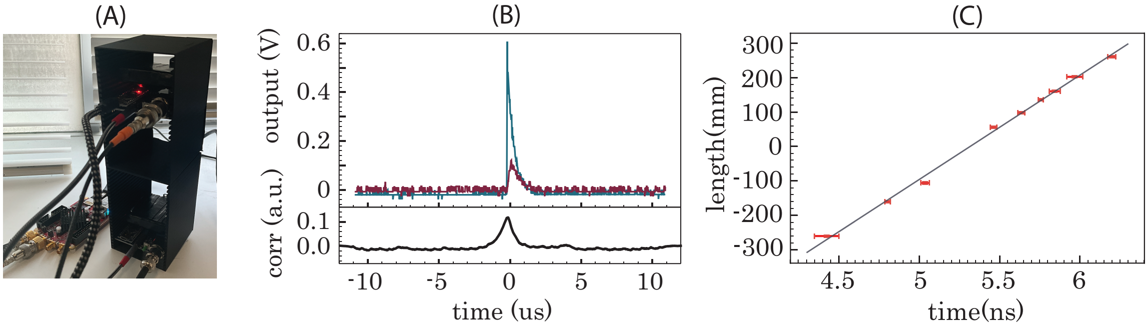

Figure 3: : (A) Time of Flight measurement setup; output signals from two scintillation detectors based on Cosmic Watch are input to Red Pitaya. Detectors are mounted on the plastic case made by 3D printer which enable 30 cm distance between 2 detectors. (B) Typical waveforms from each detectors and cross-correlation of them.The peak appears at a position corresponding to the time difference between the two peaks of each waveforms. (C) Relationship between length between the two detectors and time of flight of detected cosmic-ray. Estimated speed of cosmic-rays from the linear fitting is $3.03 \pm 0.06 \times 10^5$ km/s

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2.3 Time-of-Flight detector

High school students of Toshimaoka Girls ' School have been working on an experimental system to measure time of flight using a high-speed FPGA board Red Pitaya (STEMlab 125-10) [8] and scintillator detectors based on Cosmic Watch (Fig. 3A). Even the Red Pitaya ' s sampling rate is 125 MHz, the cross-correlation analysis allows time-of-flight measurements with sub-nanosecond resolution [9] (Fig. 3B) which is enough to measure speed of cosmic-rays with only 30 cm distance between 2 detectors. Figure 3C shows a relationship between length between the two detectors and time-of-flight of detected cosmic-ray with 5 days measurement. Estimated speed of cosmic-rays from the linear fitting is $3.03 \pm 0.06 \times 10^5$ km/s. Thus this analysis technique allows sub-percent precision with 5 days.

3. Conclusion

To support the cosmic-ray research works by junior and senior high school students, Accel Kitchen has distributed detectors and organized an online support network. The main features of this program are that students do not simply treat the detector as a black box, but assemble and improve it by themselves as their own purpose and now various original detectors have been created by students. The results of their research are reported at report meetings held twice a year in our network and summarized annual reports once a year, and are also presented at various conferences in Japan. We expect that more unique research activities will be conducted based on these results, and that these examples of detector fabrication and measurement students will emerge more.

4. Acknowledgment

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