Development and Evaluation of a Two-Dimensional Detector

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1. Why we want to go to CERN

We want to go to CERN to use the two-dimensional position sensitive detector we developed for future use in muography. This two-dimensional detector is an innovative detector that could be constructed for under 100,000 yen (660 US Dollars), and if put into practical use, this detector could help lower the experimental costs. We have already tested the detector's one-dimensional functionality using cosmic rays and electron beams in KEK (The High Energy Accelerator Research Organization). However, to reach our final goal, we need to test this detector using muon beams. There are no beamlines in Japan where students can conduct experiments using muons. Thus, an opportunity to carry out an experiment at CERN is invaluable.

Also, all members of our group have experienced presentations at academic conferences and are participating in a Japanese cosmic ray outreach group for over 150 high school students. If we were able to experiment in CERN, we would like to spread our experience to high school students all over Japan.

2. What is a two-dimensional detector?

The detector we created can determine where a particle hits using CsI scintillators placed in a 5×5 array (Fig. 1, 2). The detector works in the following steps. First, when a particle hits any of the scintillators placed in the 5×5 array, the scintillator emits light. Next, the light reaches the four surrounding SiPM (Silicon Photomultiplier) boards (Fig. 3) after attenuation caused by air gaps when passing through the adjacent scintillators. Finally, the light intensity ratio of each sensor to the total light intensity of the facing sensor pair is calculated for both the vertical and horizontal axes. By using these ratios, we could reconstruct the distribution of particle hits.

Fig. 1 Phots of developing the detector. A: Soldering the circuit board, B: Applying light-absorbing paint to the case for light shielding, C: Performance evaluation using a radiation source.

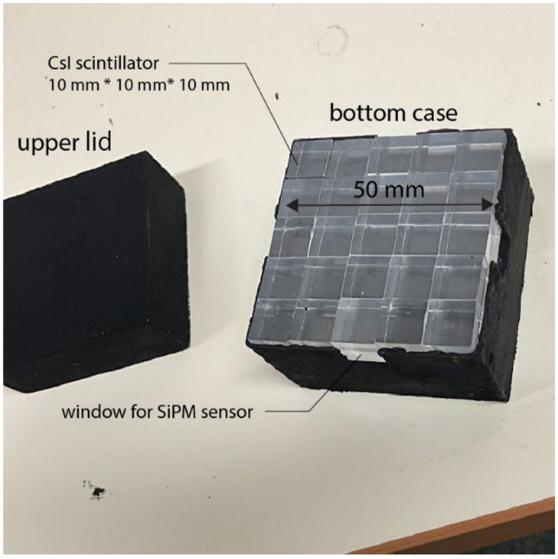

Fig. 2 A 5×5 array of CSI scintillators used in our detector. Each scintillator measures 1cm×1cm in size.

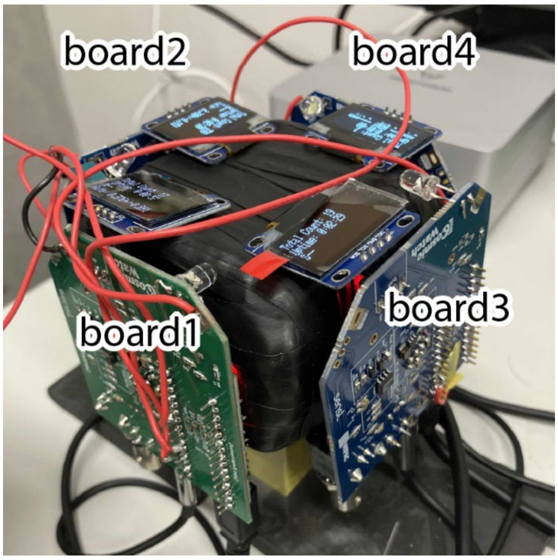

Fig. 3 Overall picture of the detector; it is surrounded by four SiPM boards.

3. Testing detector using cosmic rays

We began by testing our detector using cosmic rays for almost 24 hours and measuring background noise. For this analysis, events with extremely high or low energy were rejected. We created two-dimensional histograms for each facing SiPM board pair (board 1 vs. 4 and board 2 vs. 3) as depicted in Fig. 4. Five distinct lines, corresponding to five scintillators aligned along each axis, could be observed.

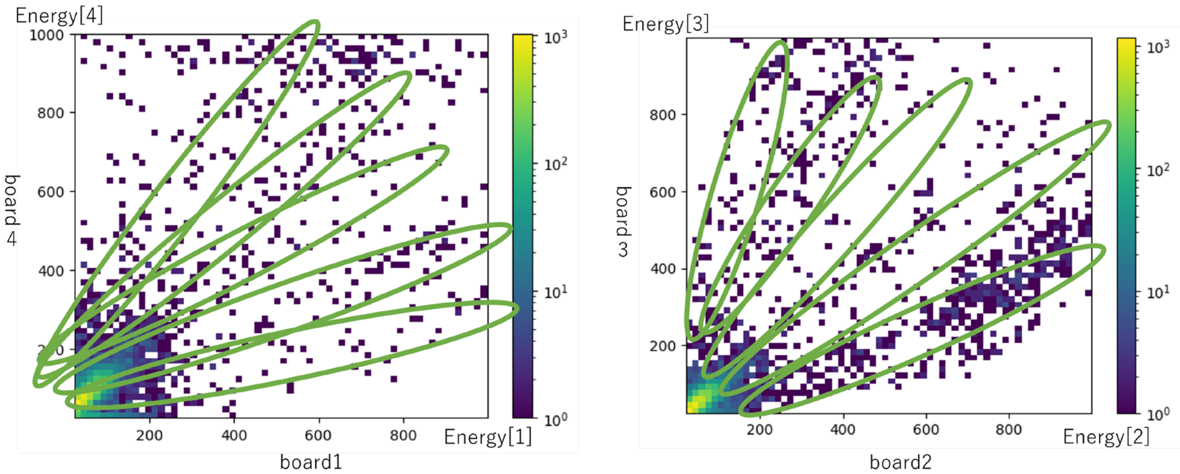

Fig. 4 Two-dimensional histograms for SiPM board 1 vs. 4, board 2 vs. 3, Five separate lines could be seen. Each line represents data for one row of scintillators and indicates the difference caused by attenuation. The result that correlation was found only in these pairs agrees with the fact that SiPM boards 1 and 4, 2 and 3 are facing each other.

Next, we calculated the relative locations of x and y using the following equations.

$$x = \frac{E_2}{E_2 + E_3}$$

$$y = \frac{E_1}{E_1 + E_4}$$

where E_1, E_2, E_3, and E_4 represent the outputs of boards 1, 2, 3, and 4, respectively. Subsequently, the cosmic ray hit distribution was reconstructed, as shown in Fig. 5.

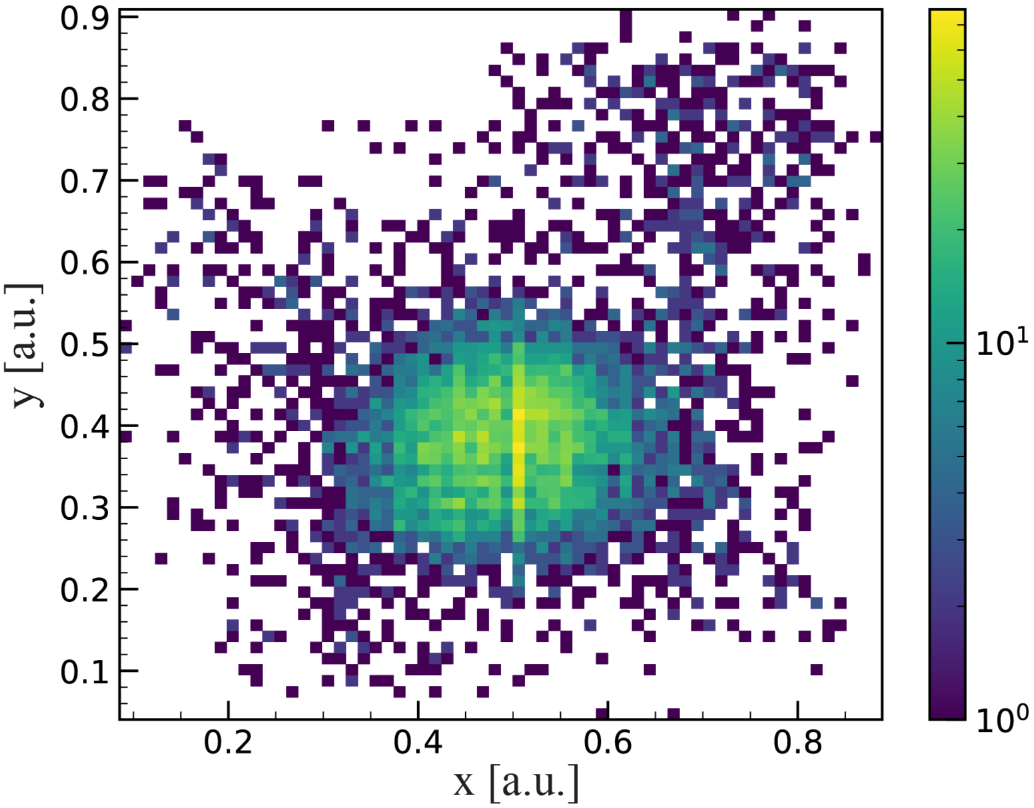

Fig. 5 The reconstructed cosmic ray hit distribution, The horizontal axis is x, and the vertical axis is y.

There are more events measured around the center, where stronger light was expected to be seen because of the placement of SiPM, but cosmic rays are detected throughout the entire detector. From this result, we determined that our detector could be used for imaging. Consequently, we proceeded to conduct an experiment at the beamline in KEK for further investigation.

4. Testing detector using electron beams at KEK

Thanks to the cooperation of the outreach group we belong to, we earned an opportunity to conduct the experiment at KEK PF AR Test Beam Line (KEK-ARTBL), where the detector's one-dimensional functionality was tested.

Setup for the beamline experiment

The experiment was conducted using the setting shown in Fig. 6.

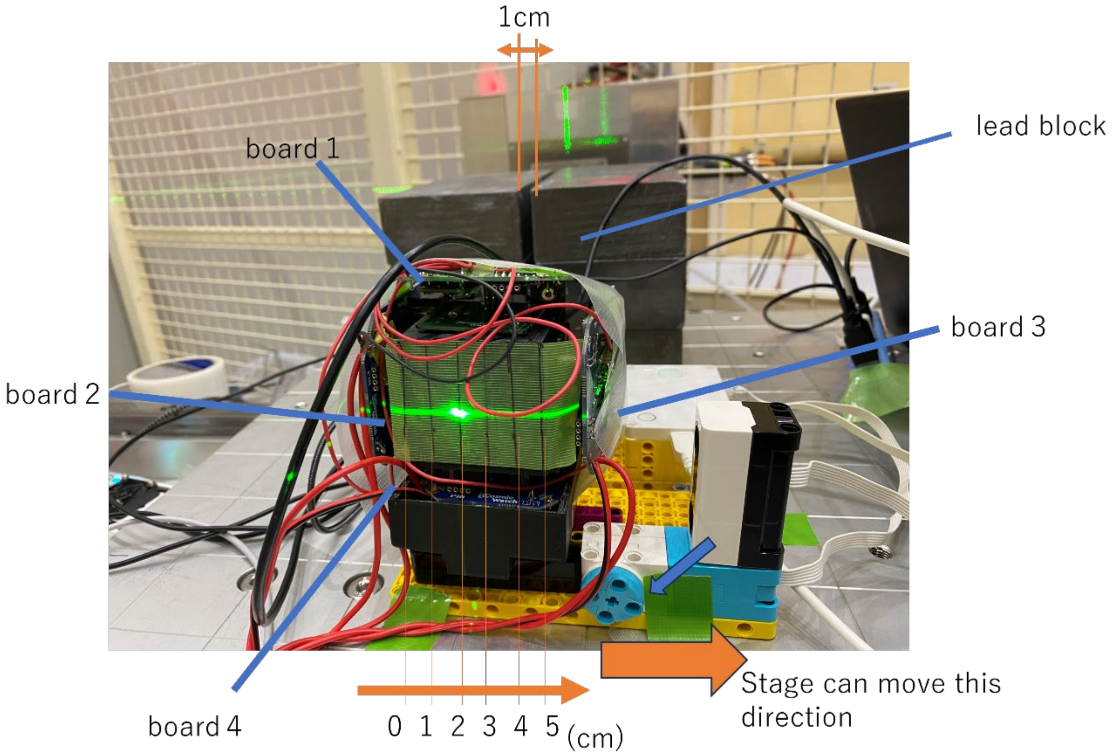

Fig. 6 Setup for the beamline experiment. The irradiation positions ranged from 0 cm (reference point) to 5 cm, at six different locations.

Experimental Method

In the experiment at KEK, a 2 GeV electron beam with a frequency of 1500 Hz was collimated to a width of 1 cm with lead blocks so that it hit the detector in a vertical line. The detector was installed on a motorized stage that could move horizontally through a remote control. Measurements were performed at six positions at 1 cm intervals, each taking 5 minutes.

Analysis Procedure

As in the previous section, two-dimensional histograms were created as shown in Fig. 7. Along the x-axis, more events were measured at the points where the beam was irradiated, while for the y-axis, the data were almost the same as the background measurement.

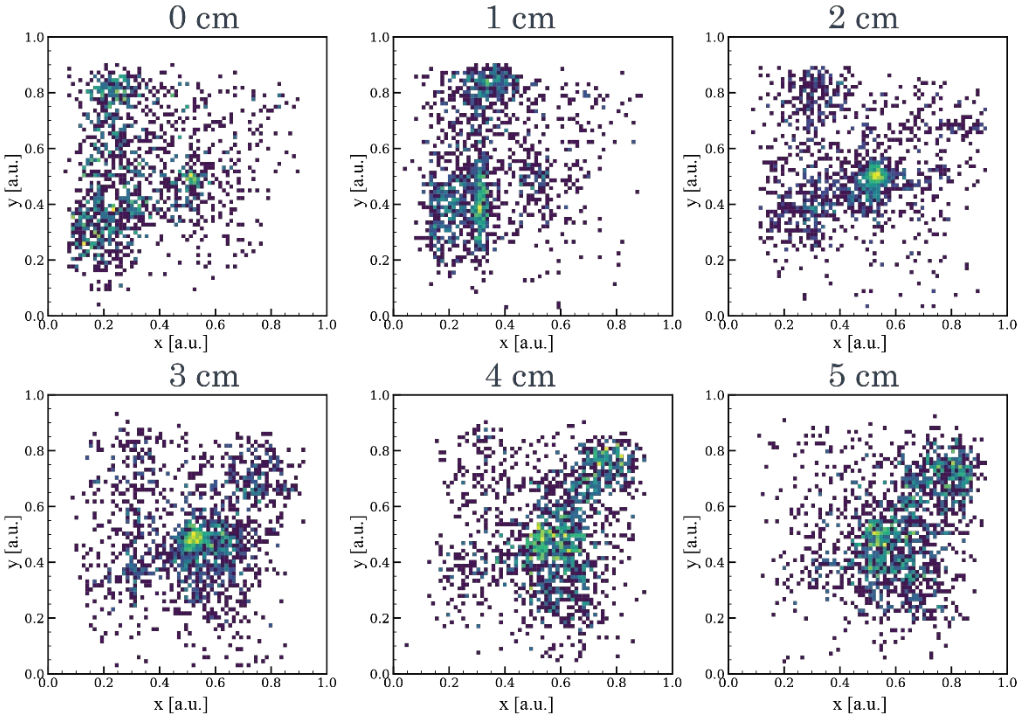

Fig. 7 x-y two-dimensional histogram.

These results show that our detector exhibits one-dimensional functionality. Consequently, we hypothesized that by conducting an experiment that changes the irradiation point along both horizontal and vertical axes, it may be possible to measure the position of particle hits in two dimensions.

5. Proposals for experiments at CERN

Experiment Flow

As a starting point, we intend to measure the beam trajectory to establish a reference detector position (Phase 1 and Phase 2) for our primary experiment (Phase 3)

<u>Phase1: Tentative determination of beam trajectory (2 hours)</u>

1. As depicted in Setup 1 (Fig. 8), place two Delay Wire Chambers (DWCs).
   -To make the conditions the same
2. Use a muon beam with an energy of 2 GeV and a frequency of 1000 Hz.
   - The reason to use a 2 GeV beam is that the previous measurements at KEK were conducted at this energy without encountering any issues. The 1000 Hz

beam frequency is chosen based on the maximum number of events per minute that this detector can effectively handle.

Phase2: Measurement of the beam trajectory (5 hours)

3. As illustrated in Setup 2 (Fig. 8), place black cloth to block out light.
   -The black cloth will be used in subsequent experiments, so it is placed at this phase to maintain consistent conditions. Stage for detector movement is installed inside the black cloth. It can be remotely controlled to adjust the detector's position.
4. Emit a beam.
5. Record the detailed beam position.
   -This information will serve as a reference to place the detector in the next experiment.

Phase3: Test the two-dimensional position sensitive detector (7 hours)

6. Direct the beam to the center of the 25 scintillators under the same conditions as the previous experiment and conduct measurements for all 25 positions.
7. Repeat the measurements in the reverse order for all 25 positions.
   -This step is to consider the potential effect of cloth radioactivation on the measurements.

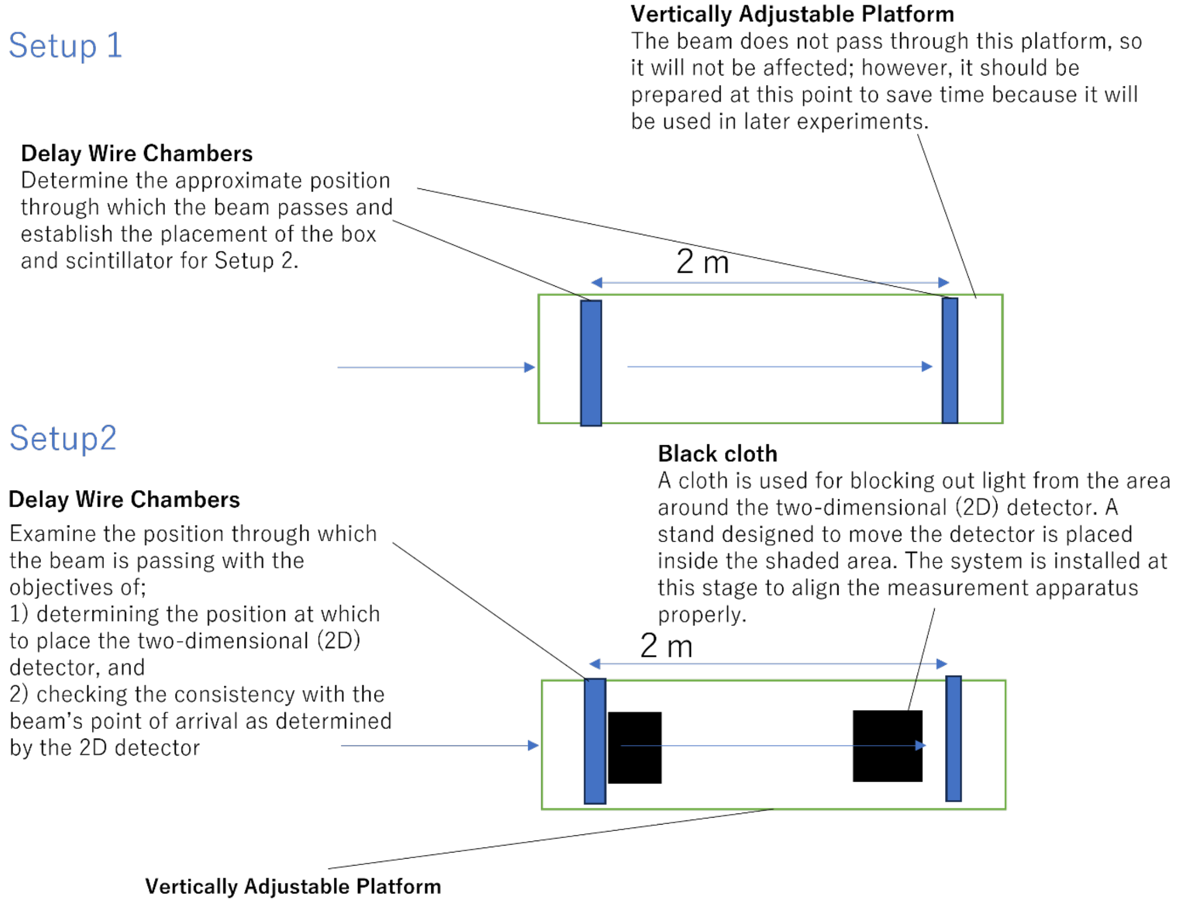

Fig. 8 Setup 1 and Setup 2: The configurations planned for the experiments at CERN.

Proposed Schedule

Table 1 outlines a proposed schedule for the experimental opportunities available over several days. It can be optimized from a minimum of one day, depending on the experimental opportunities provided, and adjusted as necessary.

Table 1 Experimental schedule plan

day	1	2	3	4	5
Phase1	X				
Phase2		X			
Phase3			X	X	
backup					X

Experimental Equipment

1. Equipment to bring.
   -A stage to control the detector's movement
   -A two-dimensional position sensitive detector and its cable to operate it
2. Equipment to borrow.
   -Two Delay Wire Chambers (DWCs)
   -A table with a length of more than 2.5 m that can be moved both up and down freely

6. Outreach activities

For us high school students, the opportunity to conduct experiments at CERN and DESY is precious. Thus, we will disseminate our BL4S experience in many ways. We are all participating in Accel Kitchen LLC, Japan's largest particle physics outreach community, which supports more than 150 high school students from Japan and abroad. This community offers multiple platforms and events that facilitate both offline and online interactions among students. Through reporting our experiments in BL4S, we can inspire more students in our community to be interested in BL4S (Fig. 9).

Furthermore, Accel Kitchen LLC actively communicates our research activities to external students and researchers through conferences, social media, and outreach events (Fig. 10, 11). This allows us to share our BL4S experience, encouraging a wider range of students to be interested in accelerator facilities. We believe these contributions will lead to the growth and development of the high school student scientific community.

Fig. 9 In March 2024, this research plan was introduced during a workshop aimed at Japanese junior high and high school students

Fig. 10 In October 2023, we showcased and introduced the detectors we have developed at our booth exhibition at the Science Fair held in Tokyo.

7. Acknowledgement

The work is supported by the KEK PF AR Test Beam Line (KEK-ARTBL), with special thanks to Dr. Yoichi Ikegami and Dr. Isamu Nakamura. We would like to thank all the people involved in Accel Kitchen, LLC who performed the experimental operations at KEK-ARTBL on our behalf.

Fig. 11 The members are actively engaged in particle physics awareness activities through social media, one of us achieving over 1 million impressions on X.