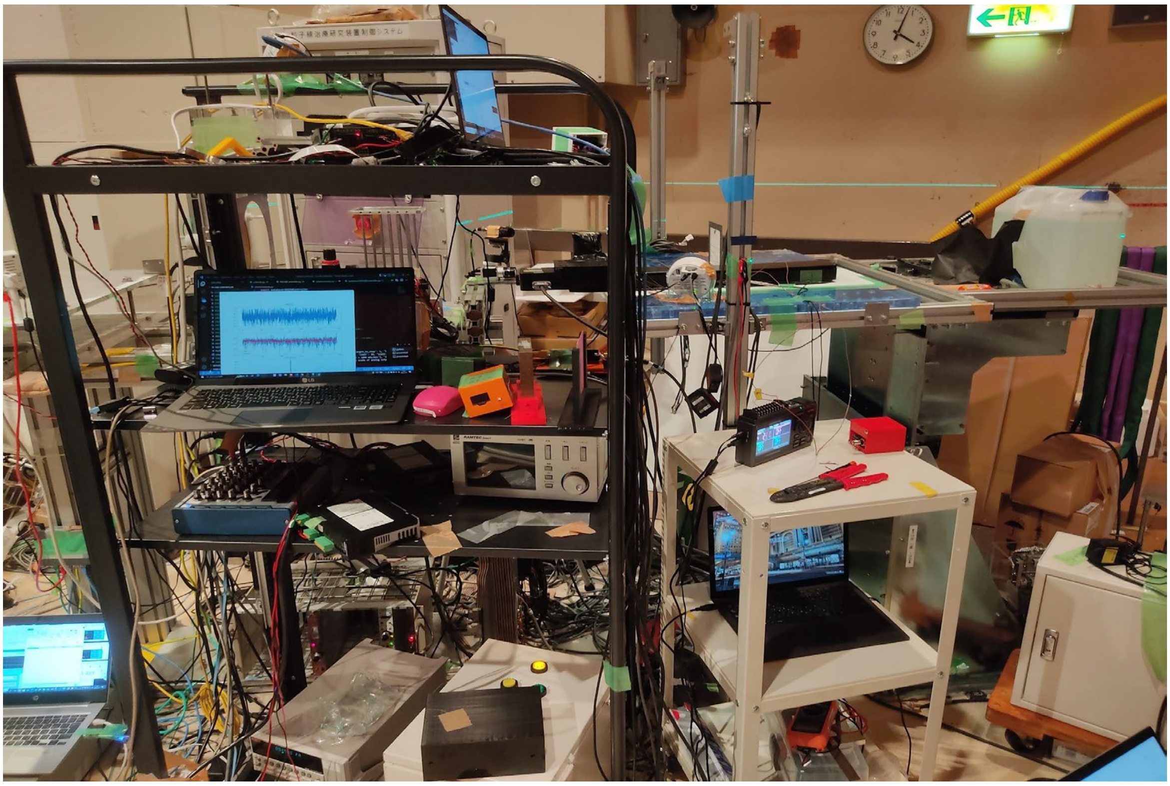
Measurement of dose distribution in a body for future muon therapy

Member:
Akie Inoue[a], Aki Miyazawa[b], Chiori Matsushita[c],Kaho Kubota[d], Manami Sawai[e], Niki Nagata[c], Mihiro Nukiwa[f]

Schools:
[a]Hiratsuka Secondary school, [b]St. Margaret´s School, [c]Joshigakuin Senior High school, [d]Toshimagaoka Joshigakuen Senior High school, [e]Kawawa Senior High School, [f]Kawagoe Girls' High school

Team name: Sakura Particles



1. Introduction

We have developed an online monitoring detector capable of measuring the dose distribution in a patient's body during proton therapy. This detector was created by modifying the Cosmic Watch, a simple cosmic ray detector [1]. Scattered protons from the body can be measured by scanning the detector near the body during proton irradiation. This scanning data can contribute to reconstructing the dose distribution inside the body, especially position of the Bragg peak [2] . We performed the detector test at the Cyclotron Radioisotope Center in Tohoku University with an 80 MeV proton beam, and the result of the scanning is consistent with the simulation by Phits[3] (Fig. 1) .

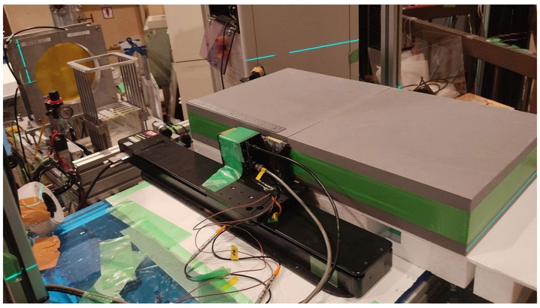


Figure 1. The experimental setup of the detector performance test at Cyclotron Radioisotope Center. The detector mounted on a linear manipulator scans the radiation from the phantom box.

Our motivation for this proposal is to try to apply this technique to the high-energy muon beam provided at CERN. Since muons produce decay positrons and gamma rays from annihilation of decay positrons, scanning distribution could consist of not only scattered muons, but also positrons and gamma-rays.

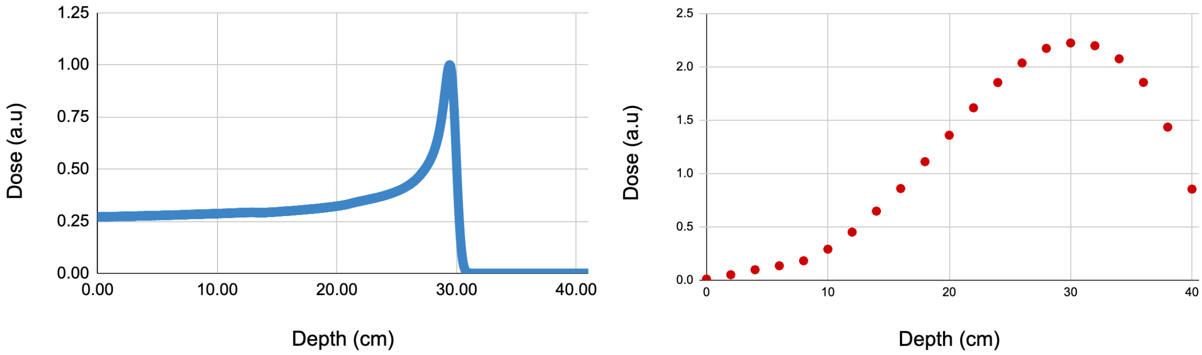


Figure 2. The left figure shows the dose distribution inside the phantom with an 80MeV proton beam simulated by Phits. The right figure shows the scanning distribution measured by the detector. The coordinates in the right figure are about 7 cm behind those in the left figure due to the alignment issue [4].

2. Why we want to go CERN

Each of us belongs to a different school in Japan and engaged in their own radiation research [4,5,6,7]. Thus, we have enough skills to prepare and perform beam experiments such as detector development, data analysis and simulation works.

Even one of the research projects is performed by the proton beam in Japan as previous research of this proposal, there are no cases to perform muon-beam experiments by secondary students in Japan yet. We are sure that we propose an interesting enough experiment idea to perform at CERN now and want to be the first Japanese students to conduct a muon beam experiment.

3. Plan of the experiment

The purpose of this experiment is to verify whether the dose distribution in a water tank can be reconstructed by irradiating a muon beam into the tank and scanning a detector at its side.

Beam conditions

- **Energy**: 0.2 GeV
- **Beam profile**: 1-3 cm in diameter by using a collimator.
- **Flux**: ~ 10^4 /s and monitor flux fluctuation by the plastic scintillator

Setup

The water tank is located on the beam axis as a phantom (Fig. 3). The linear actuator is placed at the side of the tank and the monitoring detector is mounted on this actuator. The output from the detector and the position of the detector from the position encoder is measured by Red Pitaya. This DAQ system was developed in the previous experiment and confirmed the rate of data-taking up to about 10^5 /s. It enables recording every energy deposit by each particle in this condition. These setups are delivered from Japan.

Measurement Sequence

The scanning sequence is two round-trip scans of 10 minutes each way made at a distance of 100 cm to check the consistency (Fig. 4). This sequence will be performed with different conditions of beam such as position and diameter. Background scans will be performed before and after the experiment with no beam irradiation so that the effect of activation on the experimental area can be checked.

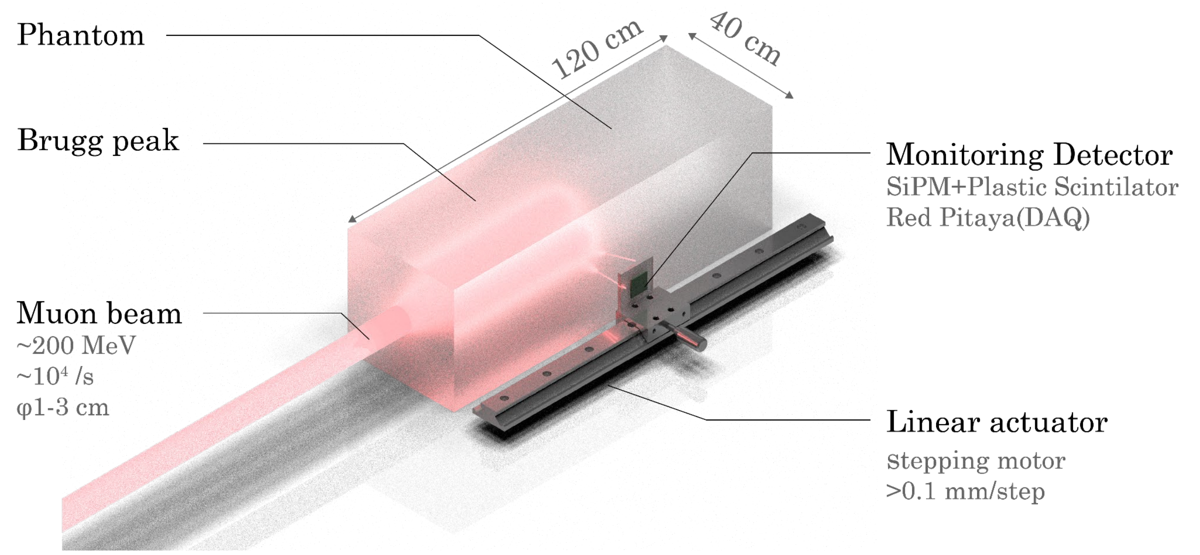


Figure 3. The schematic setup of this experiment. Muon beams irradiate to the phantom (water tank) and measure the radiation on the side of this phantom.

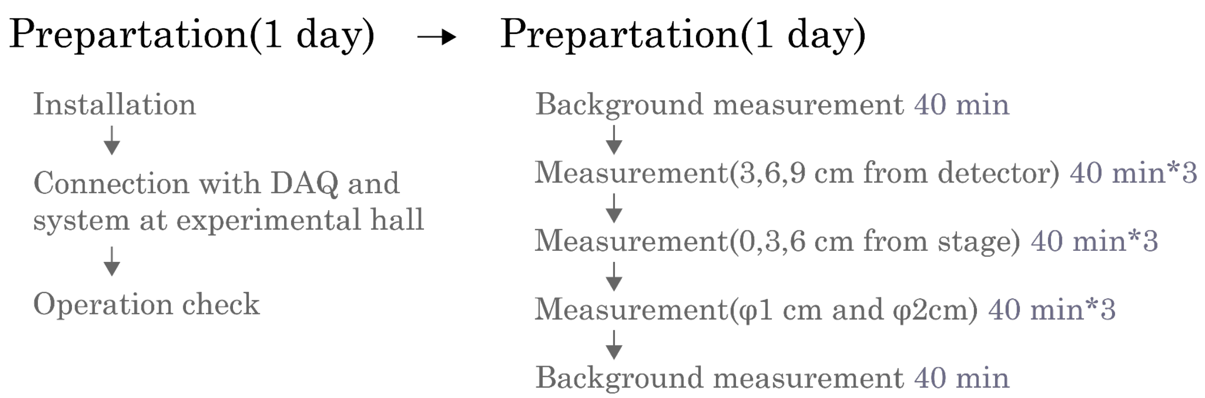


Figure 4. The sequence of this experiment. The scanning sequence is two round-trip scans of 10 minutes each way made at a distance of 100 cm.

3.2 Simulation

Simulation works were performed by Phits for checking the feasibility (Fig. 4).

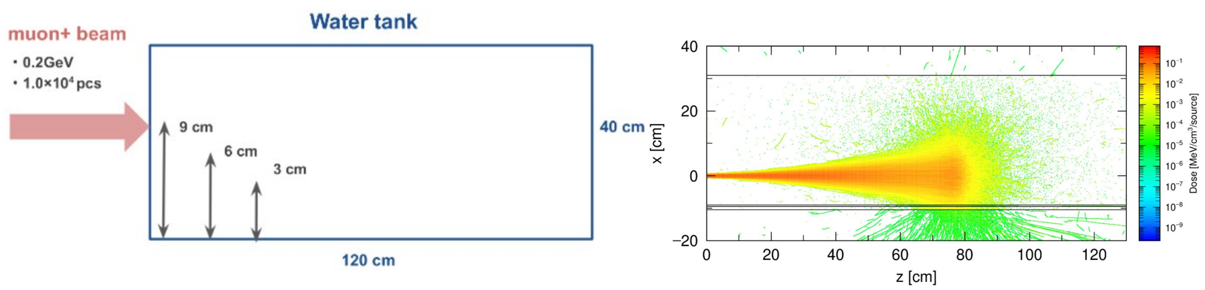


Figure 5. The left figure shows the top view of the geometry of the simulation. The right figure shows the two-dimensional dose distribution.

Figure 6 shows the dose distribution on the beam axis, where a small Bragg peak by the ionization effect can be observed at a depth of about 80 cm. According to the simulated scanning result (Fig. 7,8), the scattered muon component dominates, and the peak is a few centimeters shallower than the Bragg peak, which is consistent with the results of a previous proton experiment. On the other hand, gamma rays originating from decaying positions and their annihilation have a peak at a depth corresponding to the Bragg peak. Thus, it is expected that the measurement results corresponding to such characteristic dose distributions can be obtained by measuring the energy deposit distribution for each particle through particle identification based on the differences in the energy deposit of each particle.

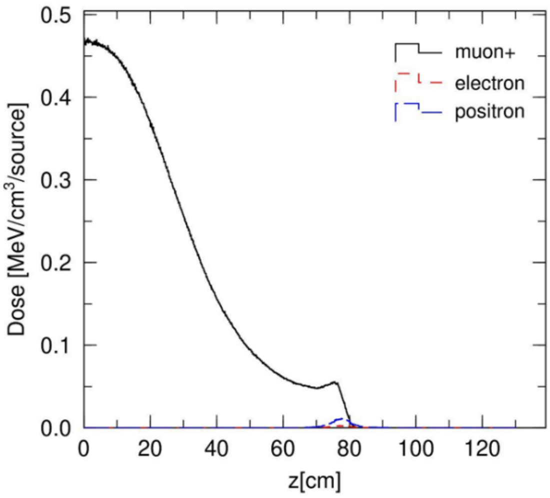


Figure 6 . The dose distribution at the beam axis.

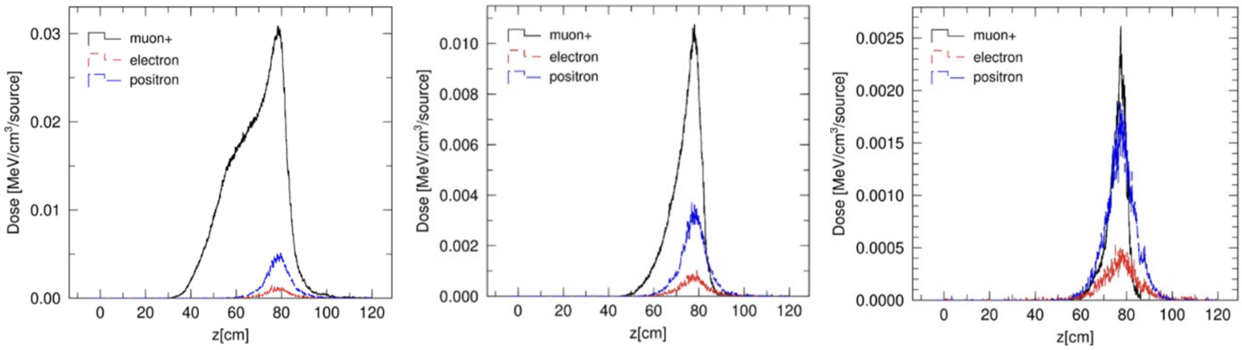


Figure 7. The simulated energy deposit measured by the detector with the distance between the beam axis and the side of the phantom is 3, 6, and 9 cm.

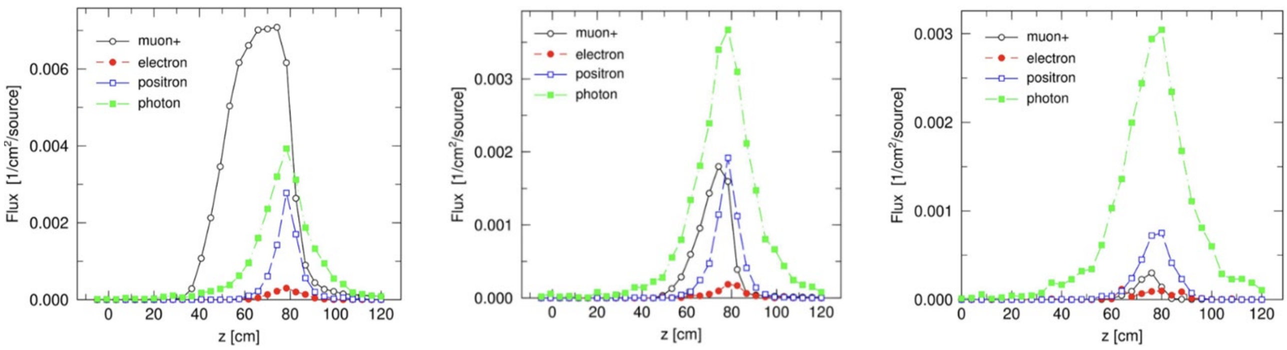


Figure 8. The simulated flux distribution measured by the detector with the distance between the beam axis and the side of the phantom is 3, 6, and 9 cm.

6. What we want to take away

Students who engage in particle-physics research are increasing rapidly due to the spreading of the cosmic-ray detector in Japan. However, most of them can only perform their experiments with cosmic-rays or environmental radiation because it is difficult for students to use accelerators. Therefore, through our experience at CERN, we hope to convey the importance of accelerator experiments by students with handy detectors. It will contribute to spreading opportunities of experiments for junior or senior high school students using Japanese accelerator facilities.

7. Outreach Activity

Many secondary students in Japan are interested in particle physics, but due to language barriers, they often miss out on cutting-edge particle-physics research works, especially those conducted at CERN, and precious opportunities such as Beamline for Schools. Therefore, we will use Twitter, Instagram, and YouTube to continuously report about preparations and activities of Beamline for schools mainly for secondary school students who love particle and accelerator physics.

In addition, after the experiment, we will make presentations at conferences such as the Japan Physics Society Jr. Session and submit papers to disseminate the experience of our experiment more widely.

Our research activity is supported by Accel Kitchen which has the largest particle-physics outreach community in Japan. More than 150 secondary students conduct their research in this community. By reporting our activities in this community and supporting junior and senior high school students who are interested in Beamline for schools in 2024, we will enlighten more Beamline for schools' participation from Japan in the future.

8. Acknowledgements

I would like to thank Accel Kitchen and Associate Professor Kazuo Tanaka (Waseda University).

9. References

[1] S.N. Axani *et al.*, *JINST* 13 P03019 (2018)

[2] S.Sato et al *et al.*, *JSAP Spring Meeting*, 15p-D311-12 (2023)

[3] T. Sato et al *et al.*, *J. Nucl. Sci. Technol.* 50:9, 913-923 (2023)

[4] K. Kubota *et al.*, *Junior Session in the 65th Annual Meeting of JPS* (2022)

[5] M. Nukiwa, *Junior Session in the 66th Annual Meeting of JPS* (2023)

[6] M. Sawai *et al.*, *Junior Session in the 66th Annual Meeting of JPS* (2023)

[7] C. Matsushita *et al.*, *Junior Session in the 66th Annual Meeting of JPS* (2023)