Feasibility test of cavity exploration using a prototype muography detector

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1. Introduction

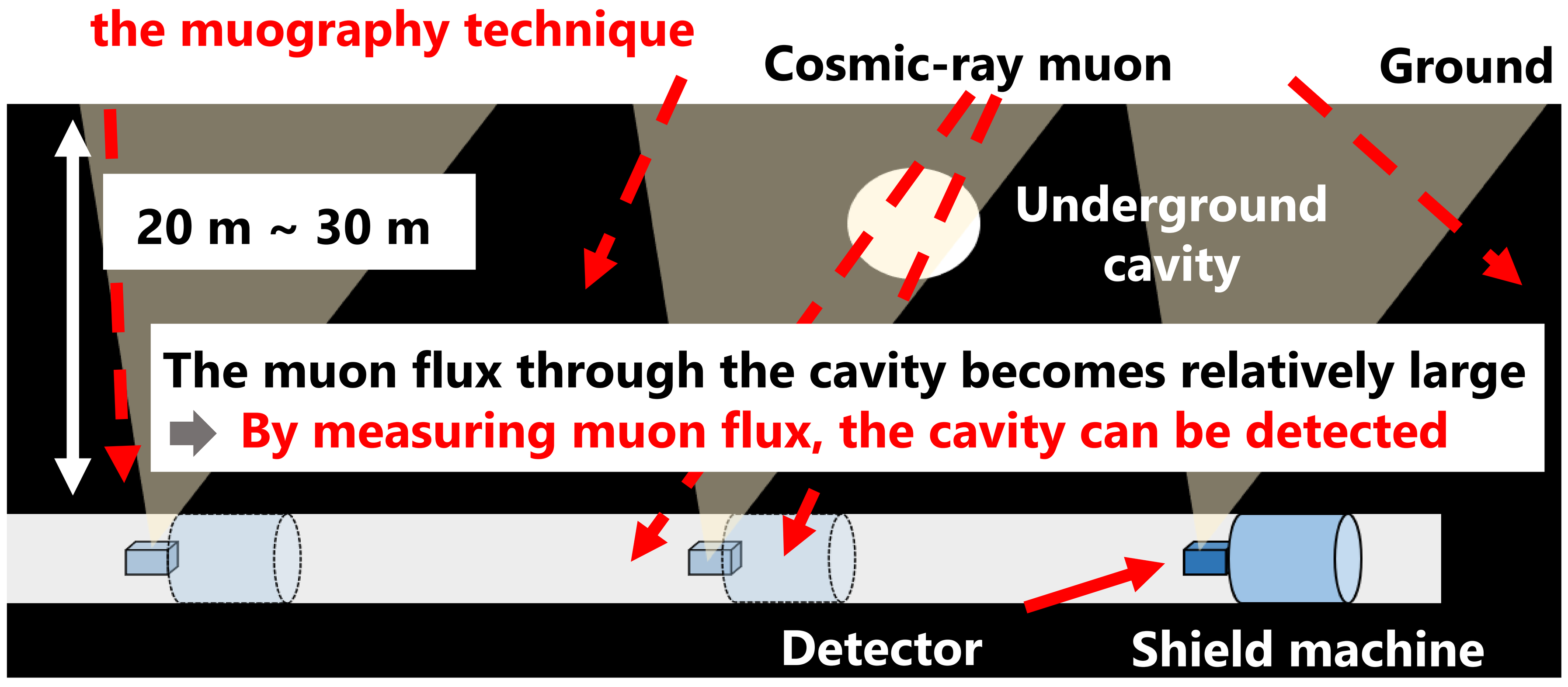
Cave-ins have occurred in recent years, due to **underground cavities** created during tunnel excavation using **shield tunnel excavation**

A cave-in caused by **shield tunneling method** in Tokyo in 2020 [1]

[1] JFE engineering Co., Ltd. HP https://www.enexco.co.jp/pressroom/kanto/2020/1018/00008605.html

➡ It is **difficult to detect cavities** deeper than 10 m underground using **conventional exploration methods (ex. ground-penetrating radar)**

➡ **We are developing an exploration method using the muography technique**



2. Our goal and scope of this study

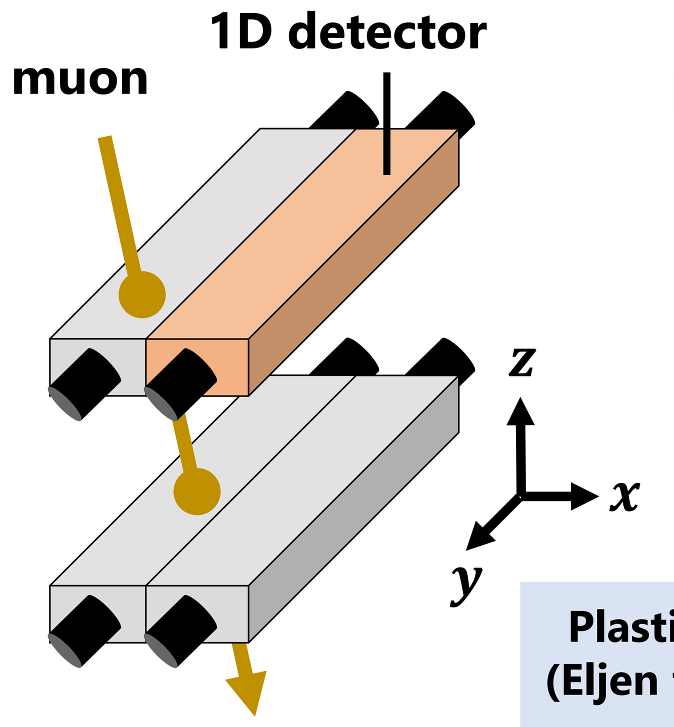
Goal

To **develop a disaster prevention system** for cave-ins

Scope of this study

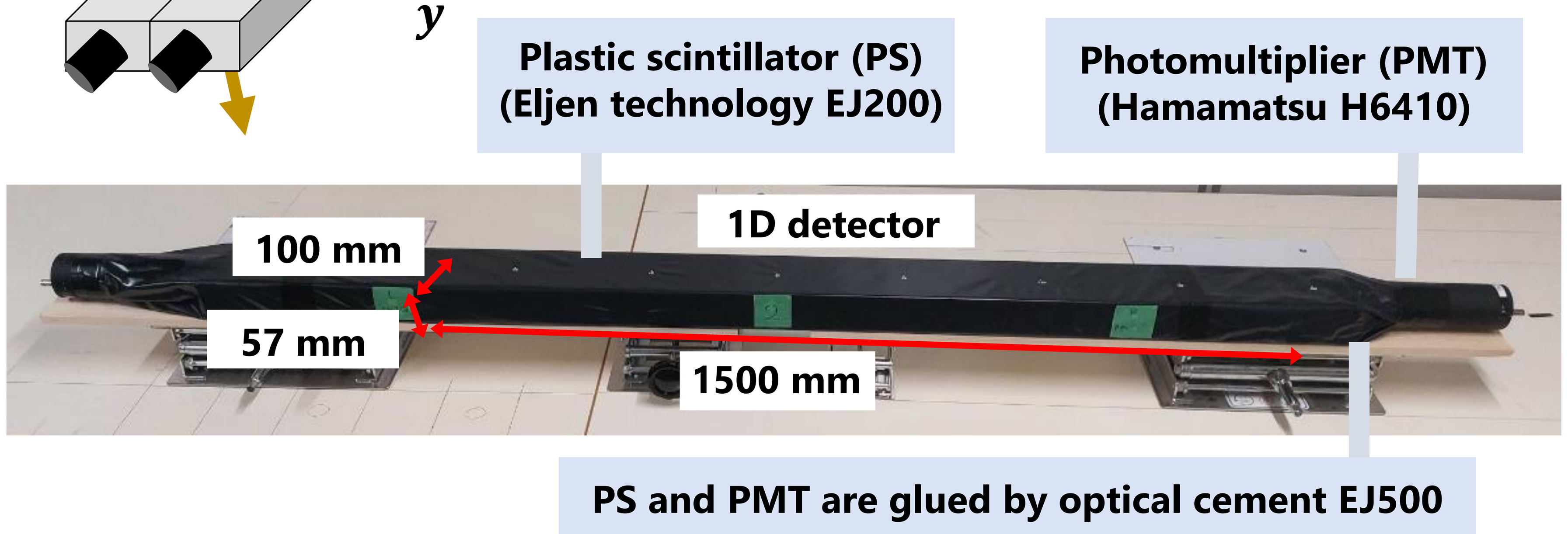
To detect a cavity using **prototype detector**

3. Prototype detector



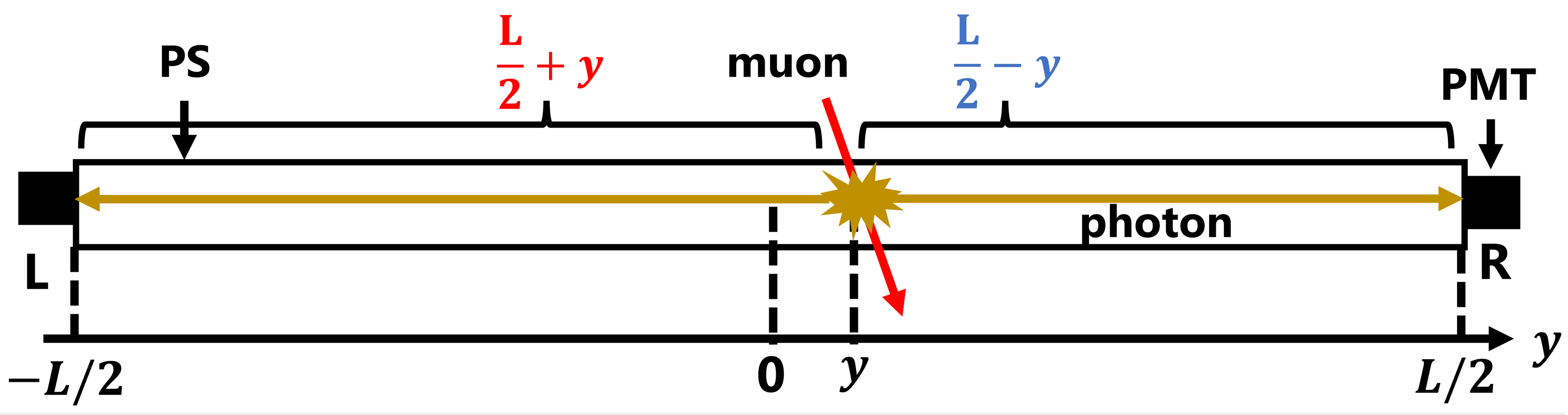
Detector principle

- **The position of the muon is** measured through **each 1D detector**
- **Muon's track** are reconstructed from the coordinates of **two points**



4. Principle of position measurement

The muon passing position is determined from the time difference between the left and right PMT signals (Δt)

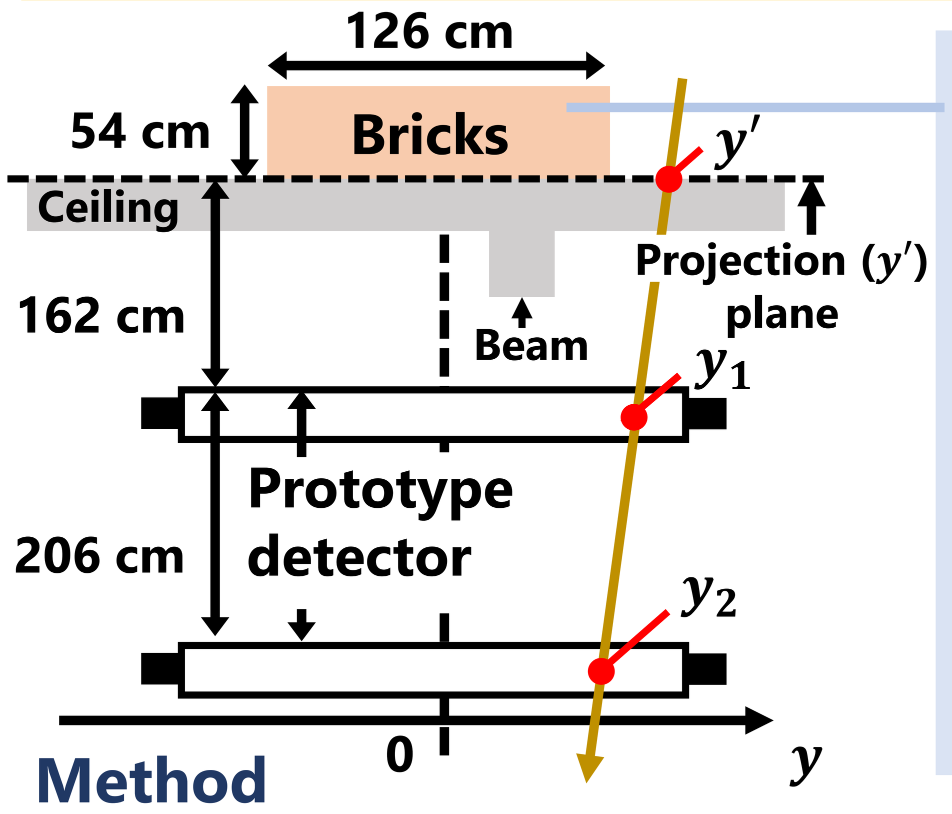


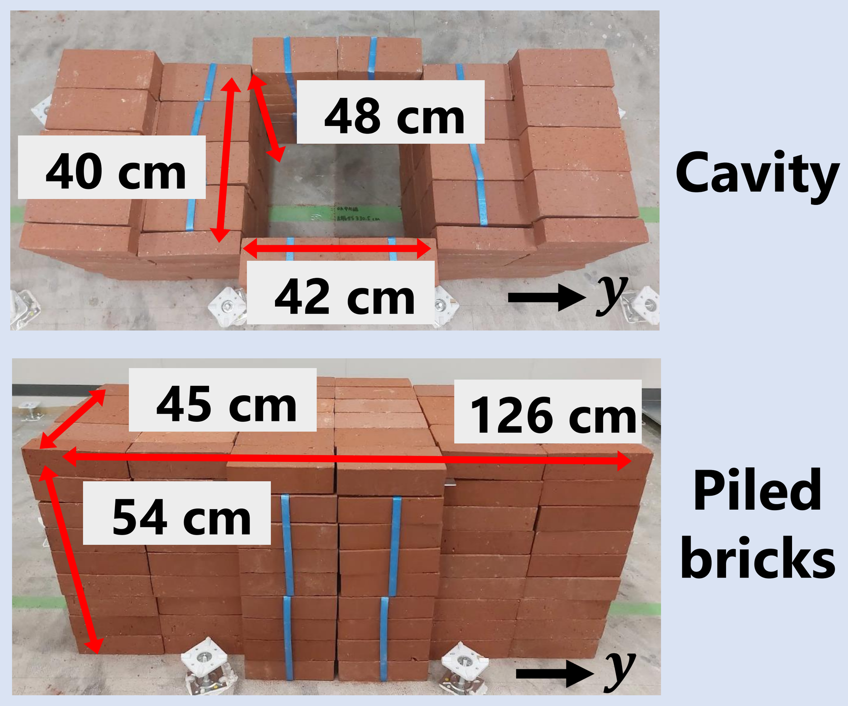
$$\Delta t = t_L - t_R \quad \leftrightarrow \quad \Delta t = \frac{L/2 + y}{v} - \frac{L/2 - y}{v} \quad \leftrightarrow \quad \Delta t = 2y/v \quad \leftrightarrow \quad y = \frac{v}{2}\Delta t$$

[t_R, t_L : the time that photons reach PMT,
L : the length of PS
y : the position of the muon passing through the 1D detector
v : light velocity in PS]

5. Feasibility test

Demonstrating cavity detection with a prototype detector





Method

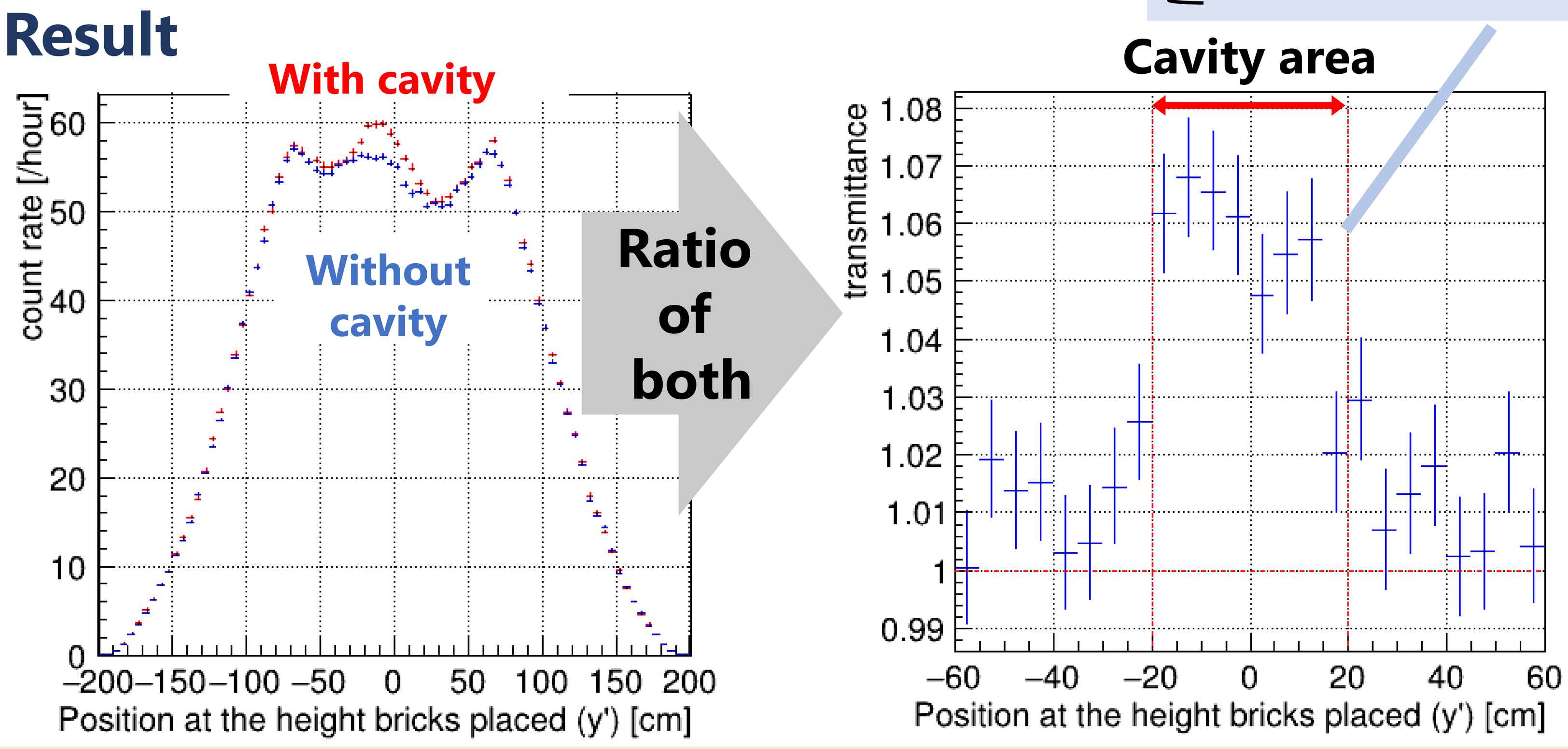
- A cavity was created by **piling clay bricks (2.0 g/cm³)** above the detector
- Muon tracks were reconstructed by using two position information (y_1, y_2)
- **y-coordinate of the muon track at the brick height ($=y'$)** was extrapolated using y_1 **and** y_2

Transmittance is defined as

$$\frac{n_{\text{with cavity}}(y', y' + \Delta y')}{n_{\text{without cavity}}(y', y' + \Delta y')}$$

[$n(y', y' + \Delta y')$ is the number of muons passed [y', $y' + \Delta y'$)]

Result



Transmittance is significantly **larger than unity** around -20 cm $\leq y' \leq 20$ cm **(cavity area)**
➡ **consistent with the cavity's position and size**

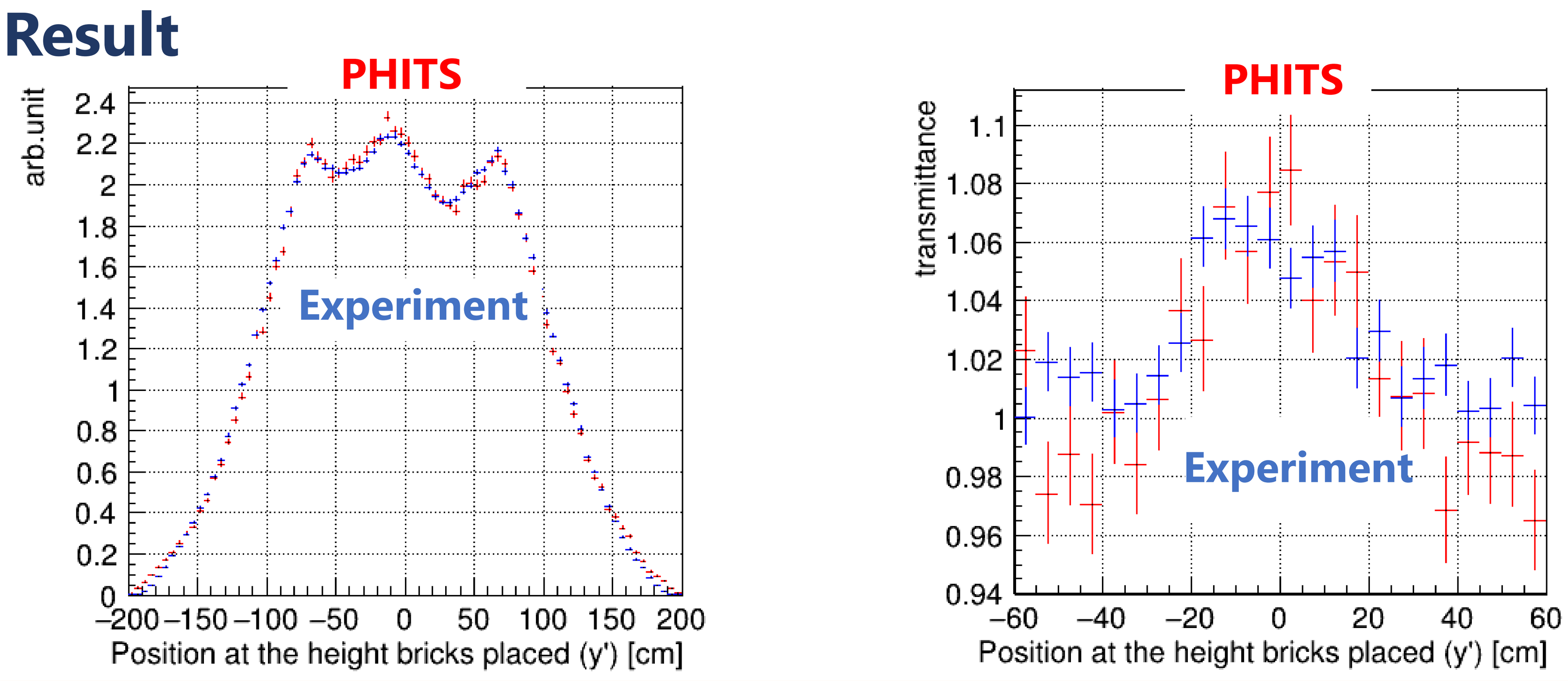
6. Comparison with PHITS

The experimental result was compared with PHITS calculations [2]

Method

- PHITS simulation was performed **incorporating a realistic building structure**
- The incident muons were generated using **PARMA model [3]**

Result



The experimental results were well reproduced

[2] T.Sato, Y. Iwamoto, S. Hashimoto et al., Niita, Recent improvements of the Particle and Heavy Ion Transport code System – PHITS version 3.33, J. Nucl. Sci. Technol. DOI:10.1080/00223131.2023.2275736
[3] T. Sato, Analytical Model for Estimating Terrestrial Cosmic Ray Fluxes Nearly Anytime and Anywhere in the World: Extension of PARMA/EXPACS, PLOS ONE 10(12).

7. Summary and outlook

Summary

The **feasibility of muography for the cavity detection was confirmed** by using **our fabricated prototype detector**

Outlook

Estimation of 3D location and size of cavities by measuring muon flux at multiple locations