MUOGRAPHERS 17 General Assembly

October 2, 2017 / Ambassade de France au Japon

Muography at Kyushu University

~ Investigation of Infrastructure Degradation~

Department of Advanced Energy Engineering Science

Kyushu University

Tadahiro Kin

KYUSHU UNIVERSITY

Contents

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Background

History of cosmic-ray muon and Muography

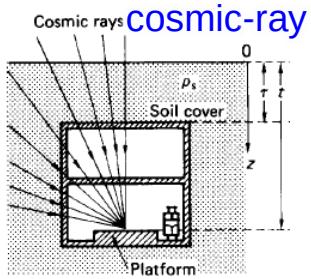
Cosmic ray discovered (Hess)

1912

Overburden thickness of tunnel by cosmic-ray flux attenuation (George)

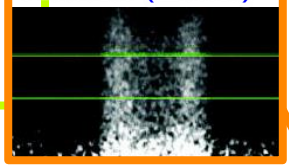
1955

Subway station depths and cosmic-ray intensity (Minato)

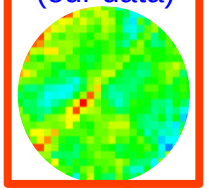


1987

Critical Assembly Reactor (Morris)

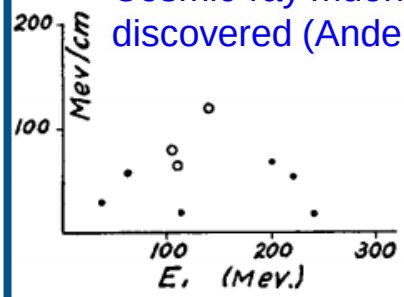


University Building (our data)



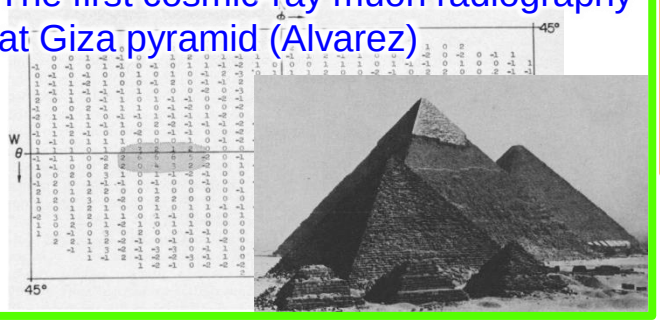
1937

Cosmic-ray muon discovered (Anderson)



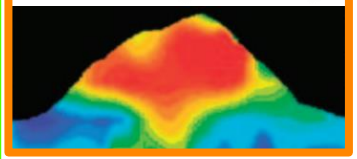
1970

The first cosmic-ray muon radiography at Giza pyramid (Alvarez)

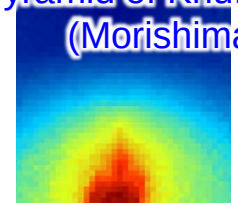


2008

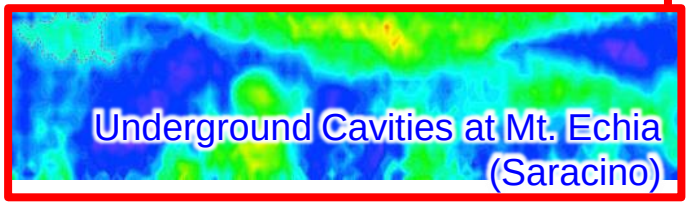
Mt. Usu (Tanaka)



Pyramid of Khufu (Morishima)

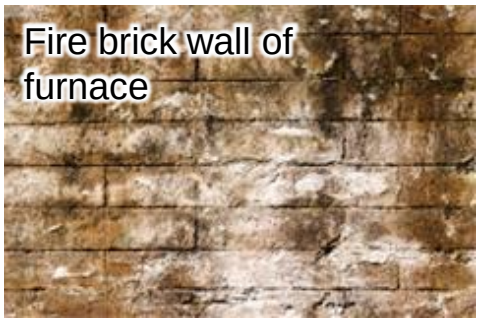


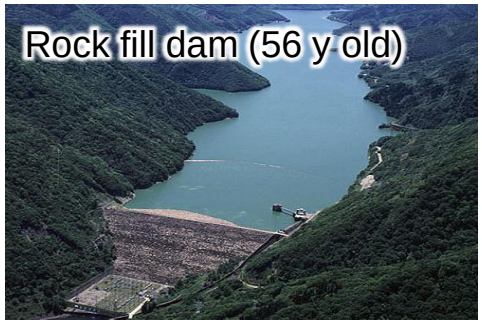
Underground Cavities at Mt. Echia (Saracino)



Background

Infrastructure Degradation





Target Object	Degradation size	Existing Survey Method
Road & Bridge	**0.1~10cm** in ~200cm	Ground Penetrating Radar **Visual check**
Fire brick	**5~20cm** in 30~35cm	**Visual check** Heat leakage monitoring
Rock fill dam	**1~10m** in 20~300m	**Visual check** Underground water gauge

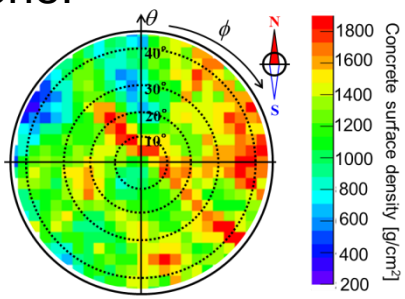
Muography has potential to explore the degradation

Muography at Kyushu University

Background: Aims of our study

Development of Muography Detector for Infrastructure Degradation Investigation

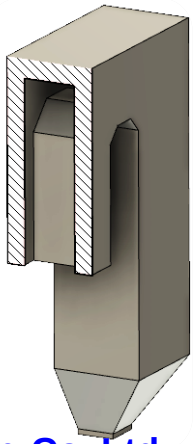
Demonstration of a building muography have successfully done.



To be submitted to TNS by K. Chaiwangkhot

Feasibility study on fire brick wall muography

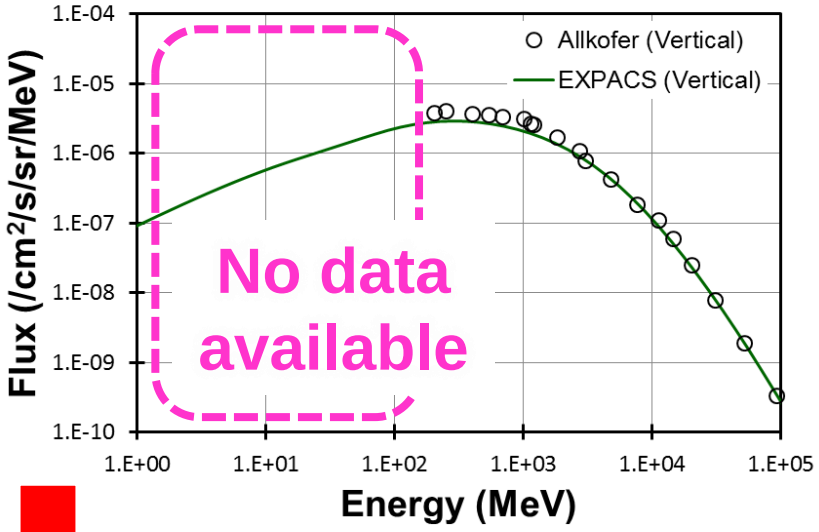
- Imaging of fire bricks installed in gas duct of a furnace
- Their thickness estimation to inspect its degradation



Collaboration study with **JFE Engineering Co. Ltd.**

Measurement of Terrestrial Muon Energy Spectrum

Lower energy muons have possibility to investigate **small sized structures**.



We have been conducting measurements of muon energy spectrum from **10** to **350** MeV.

(Not by muography detector)

Contents

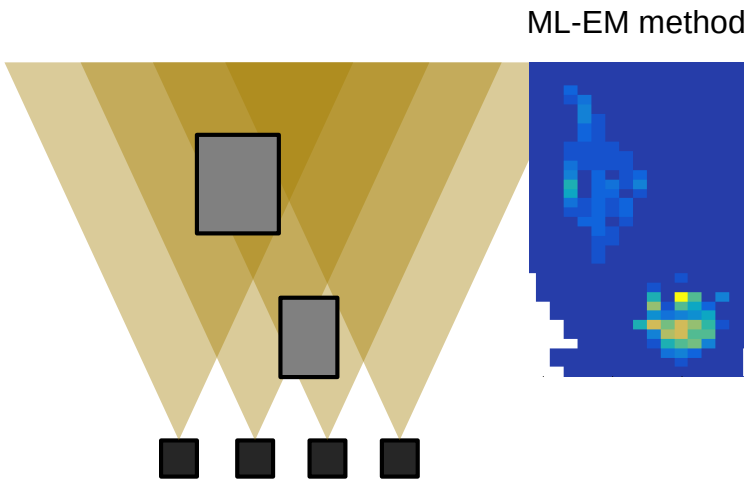
Prototype Muography Detector

Requisites for the Muography Detector

◆Portability

→ Easy detection position arrangement

→ Multi-point measurements for 3D tomography

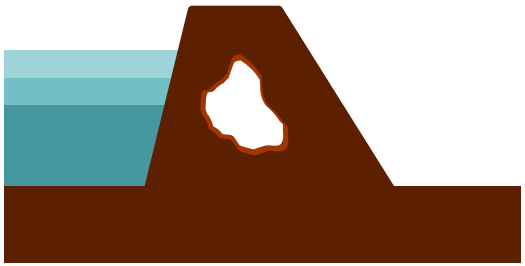


◆Stability / Maintenance-free

→ a few weeks ~ a few months

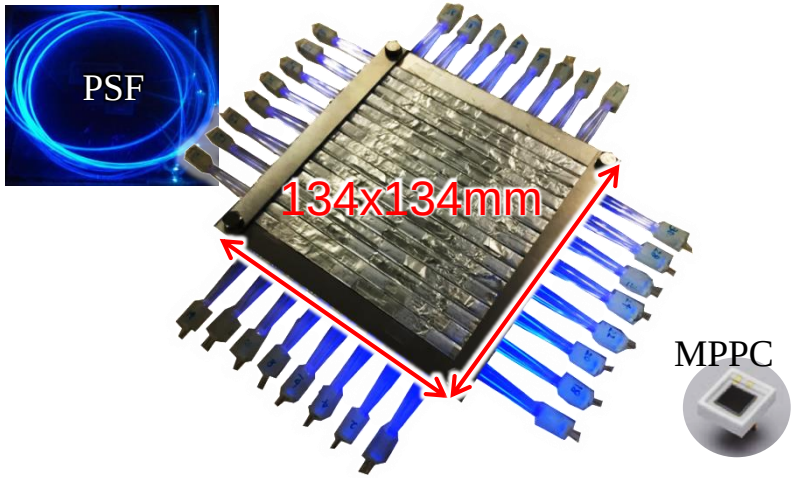
◆Online Data Acquisition

→ e. g. water level deviation for dam, levee

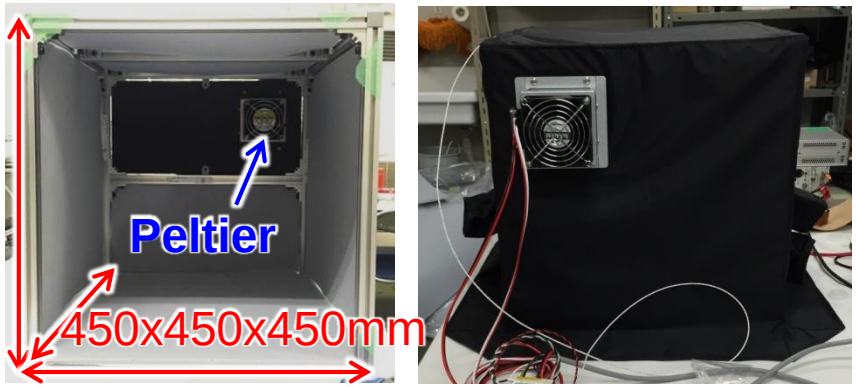


Prototype Muography Detector

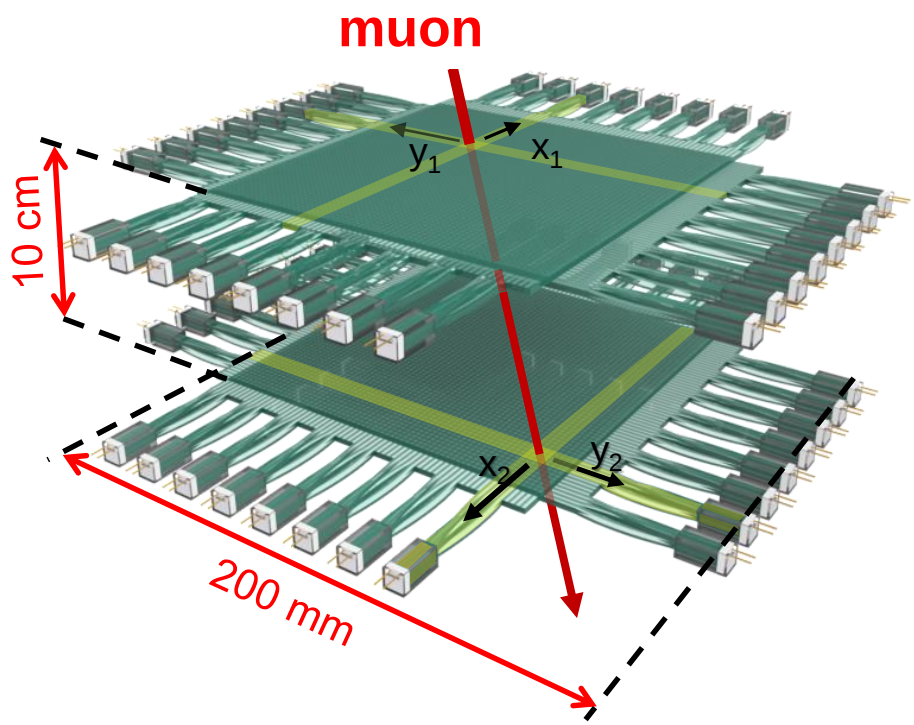
Mu-PSD (Muon position sensitive detector)



Light shielding and Heat insulating Box with Peltier heating-cooling unit



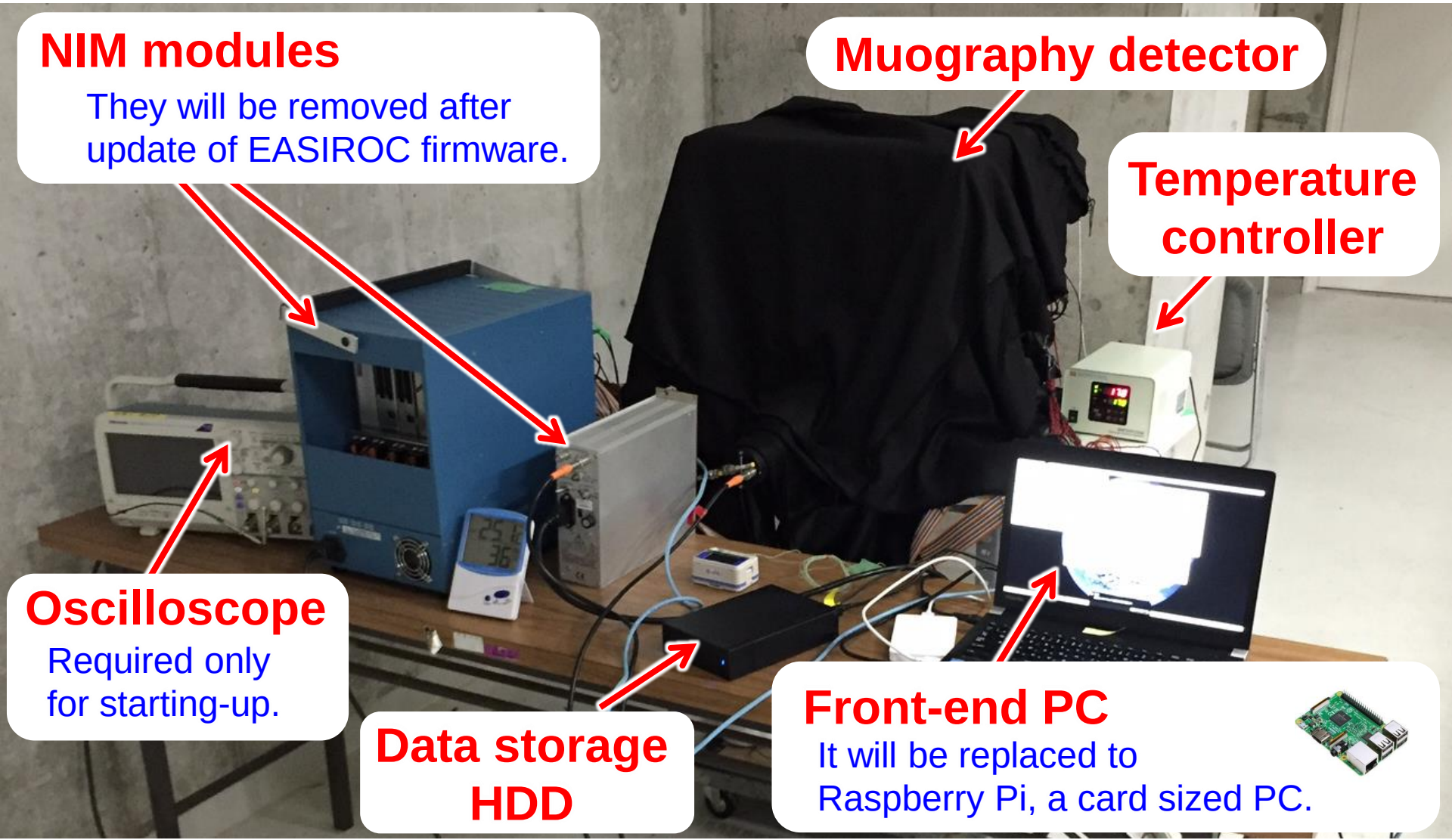
Prototype Muography Detector



- Attenuation type
- Portable
- ~8msr resolution
- Long term stability
- ~200 Watts

Prototype Muography Detector

All we need for a measurement are …



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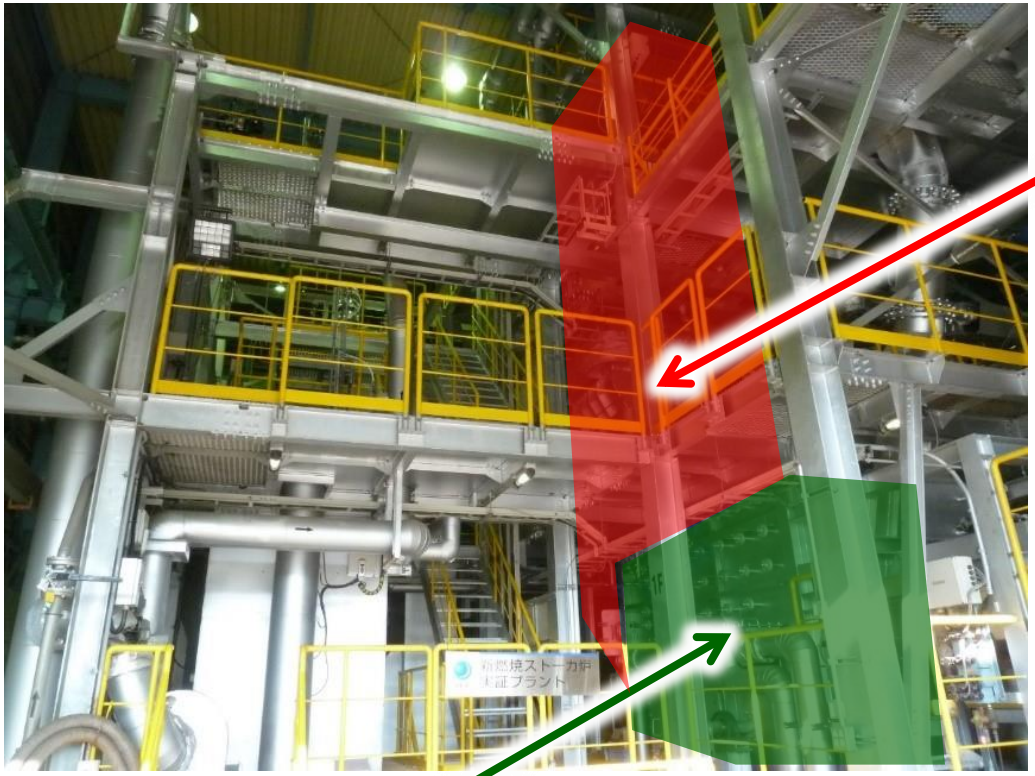
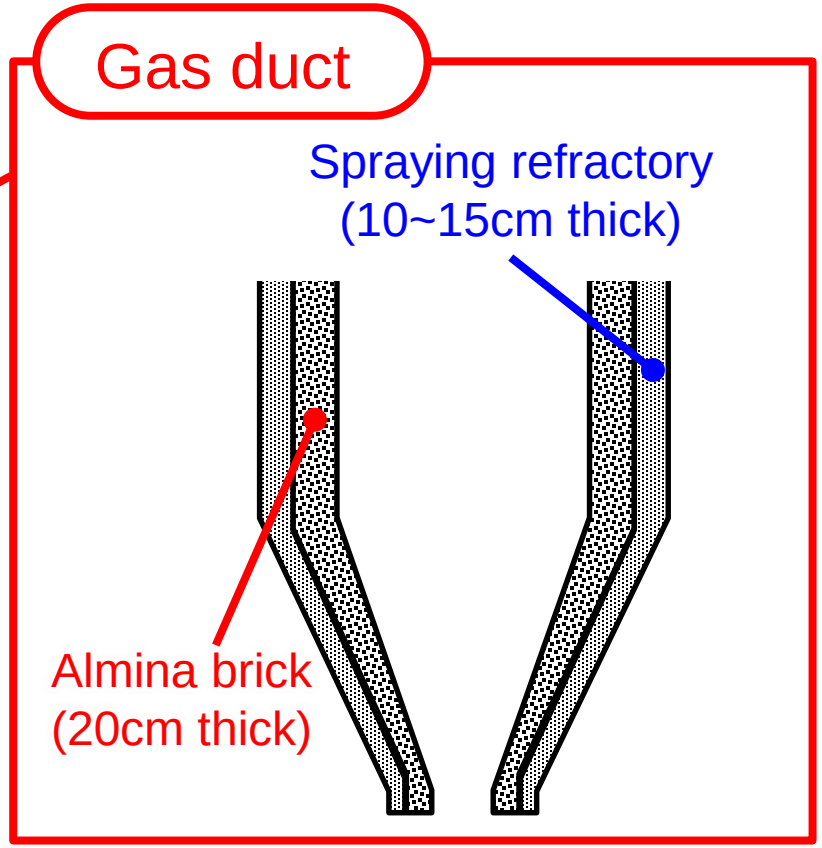
Experiment: Muography

Infrastructure Muography Test of Fire Brick Wall of Duct of Demonstration Plant of Stoker Furnace



Gas duct



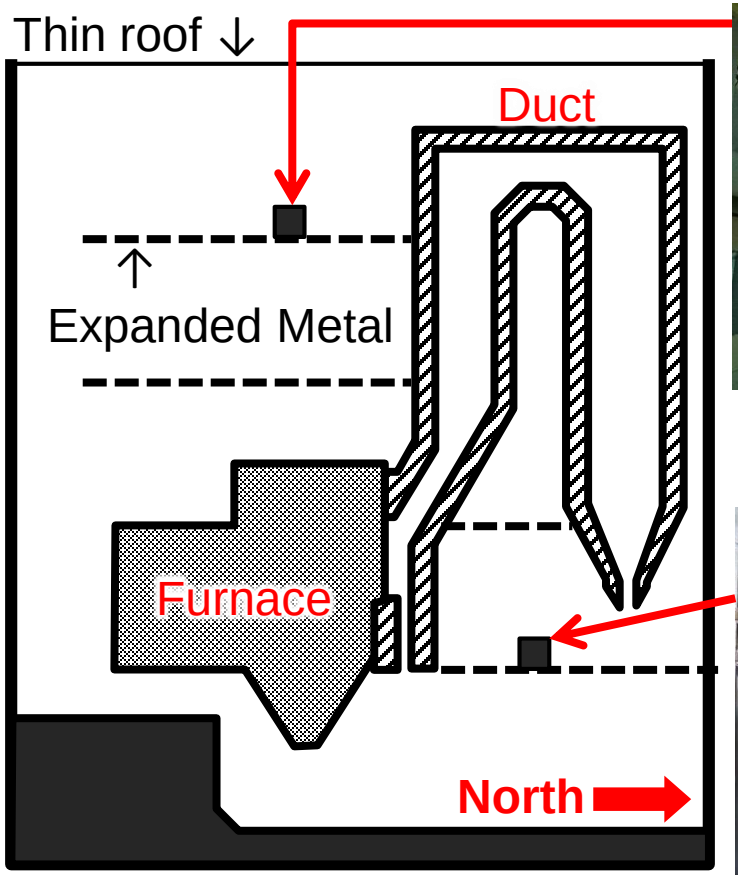
Furnace

Collaboration study with JFE engineering Co. Ltd.

Experiment: Muography

Open-air & Duct Imaging Measurement

Fire brick wall of duct of stoker furnace of JFE Eng. Co. Ltd.



Cross section view

Measurement Time:
2 weeks

Detector Temperature:
17 degrees

Location:
Nearby the following measurement

Measurement Time:
3 weeks

Detector Temperature:
17 degrees

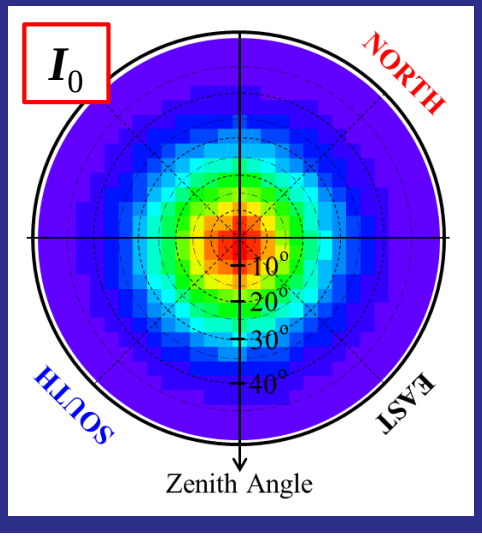
Location:
Just beside the duct

by K. Chaiwongkhot, R. Sasaki, Y. Nagata, T. Komori

Contents

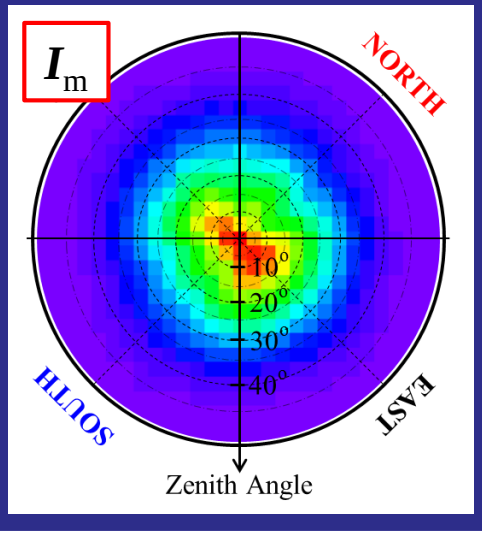
Results and Discussion: Muography

Open-air Measurement

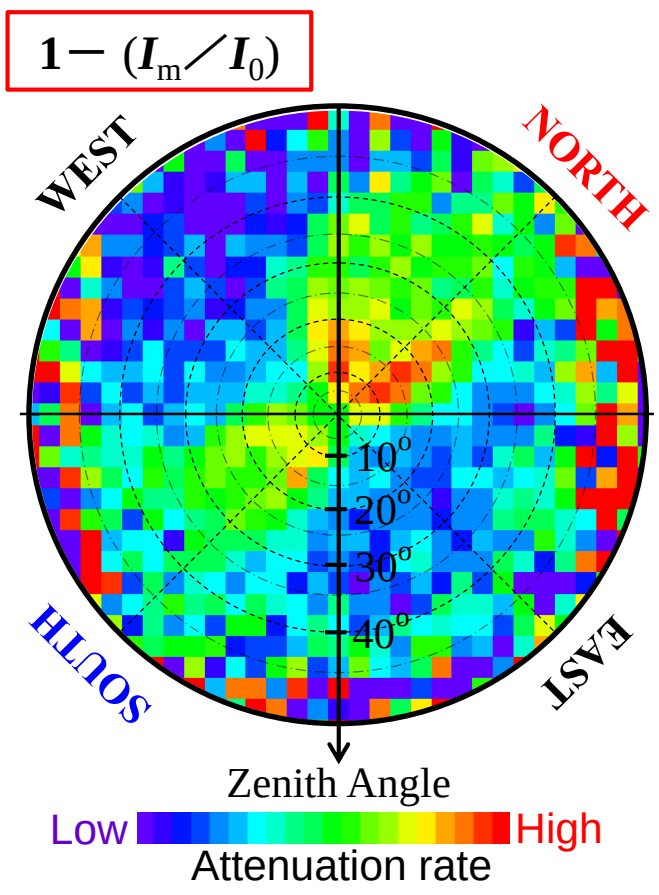


Muon Intensity Low High

Gas Duct Measurement



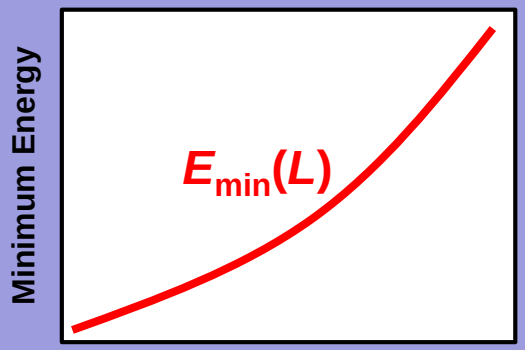
Attenuation rate map



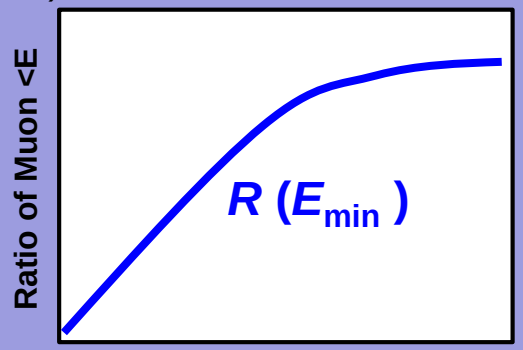
Results and Discussion: Muography

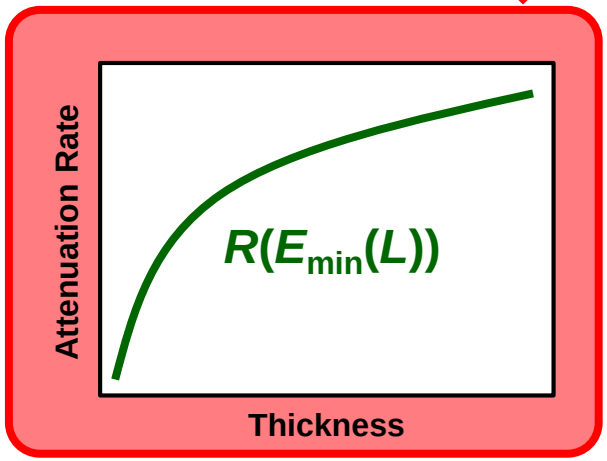
Conversion Function: Attenuation Rate → Fire Brick Thickness

Function of minimum muon energy (E_{min}) required to penetrate target material having thickness L was obtained by PHITS code



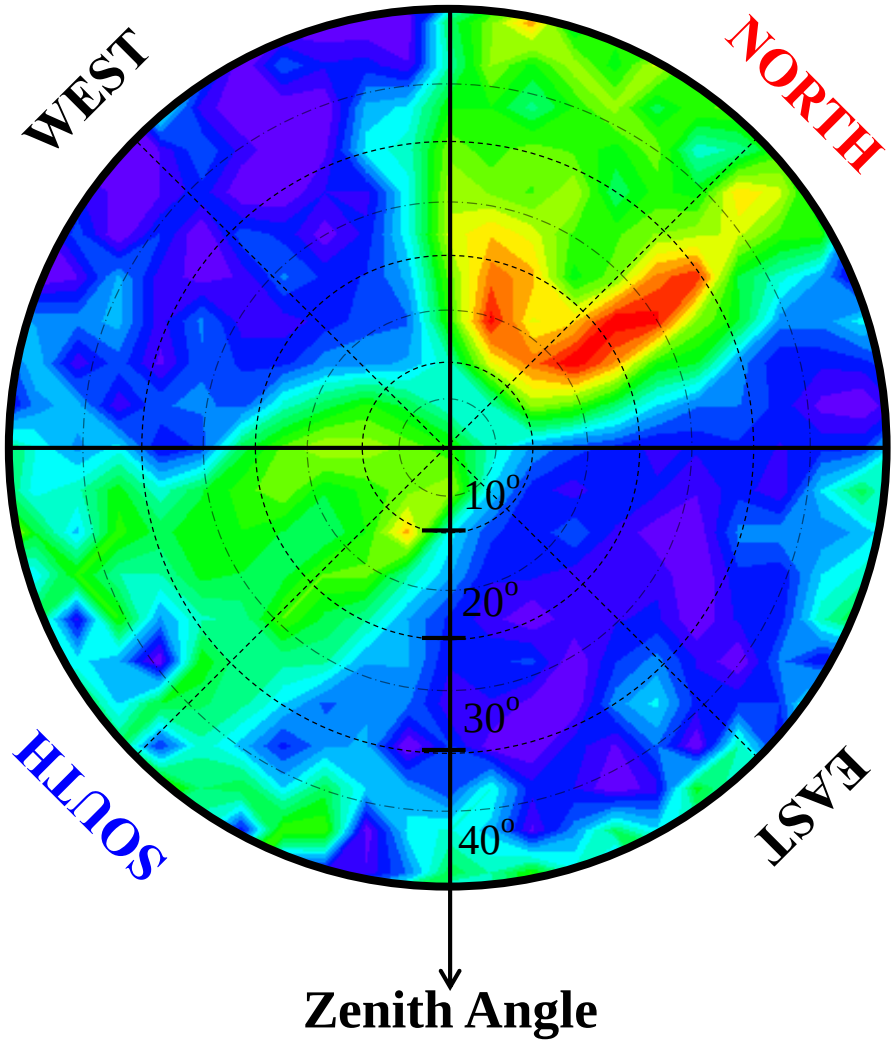
Ratio R of muon having higher energy than E_{min} to total was calculated by EXPACS (PARMA model).

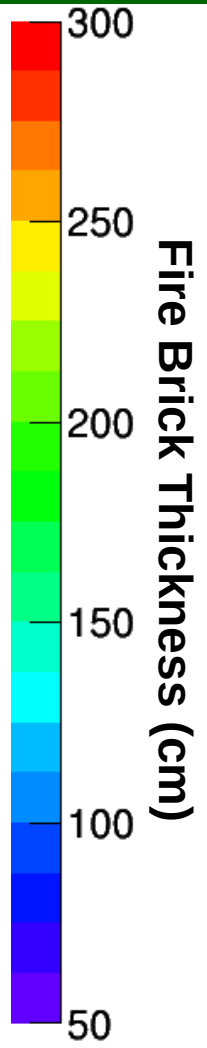




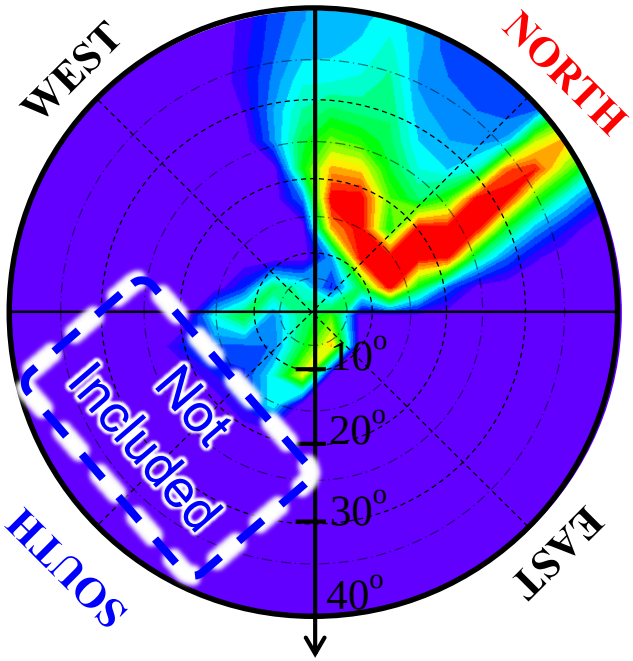
Inversion Function of "$R(E_{min}(L))$" is **the conversion function**

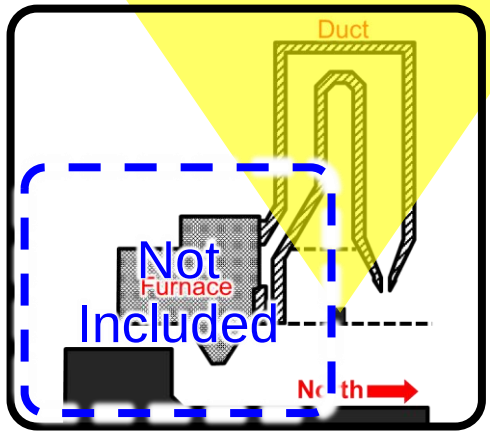
Results and Discussion: Muography





Ideal Thickness by drawing

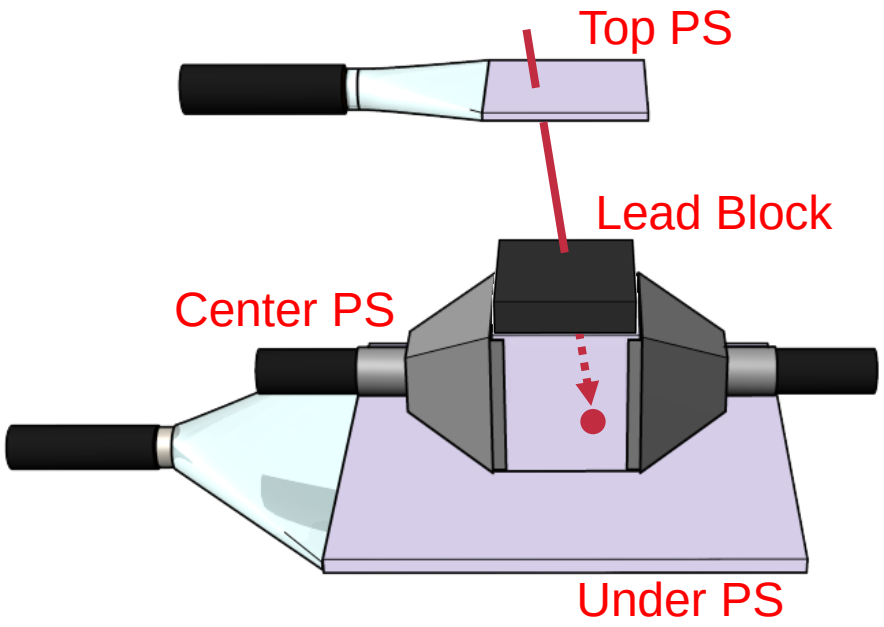




Our detector has enough performance for fire brick muography

Contents

Detector: Low Energy Muon Spectrum



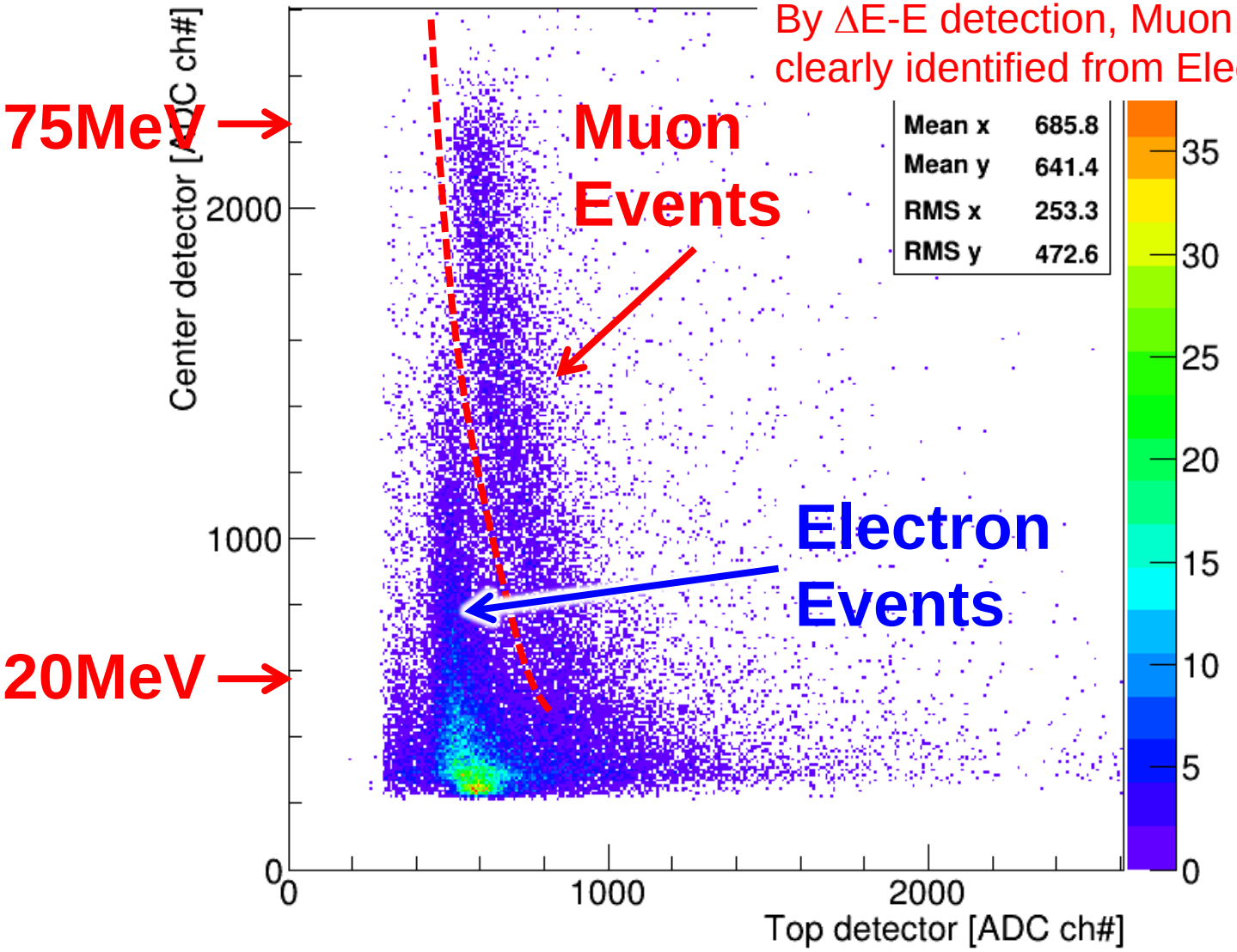
Detector ID	Size (cm)
Top PS	$20x20x1^{t}$
Center PS	$19x19x20^{t}$
Under PS	$60x60x2^{t}$

- **Center PS:** Main detector of energy spectrum measurement
- **Top + Center PS:** ΔE-E detection to suppress cosmic-ray electrons
- **Under PS:** Reject penetrating high energy muon events
- **Lead between Top and Center PSs**: Energy degrader

by H. Sato

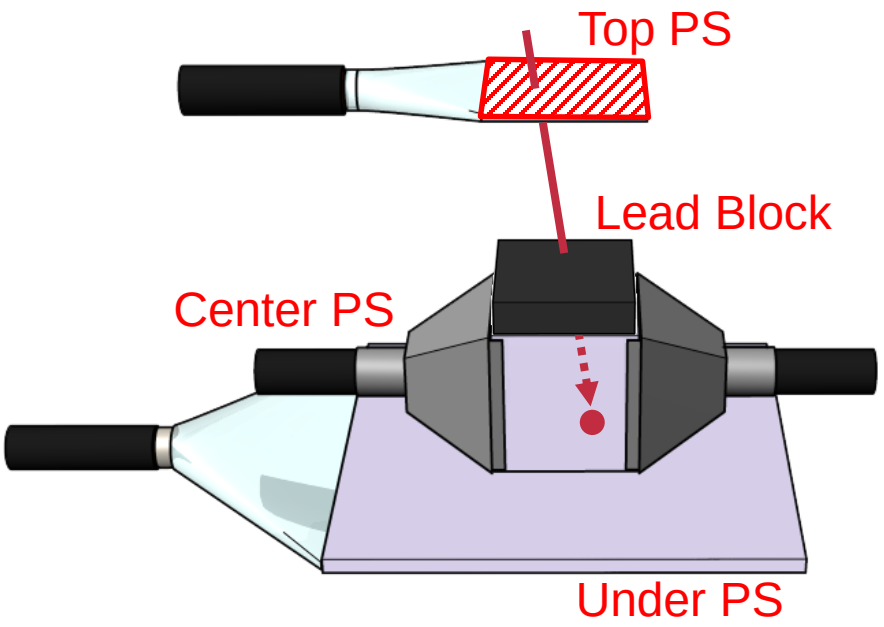
Results: Low Energy Muon Spectrum

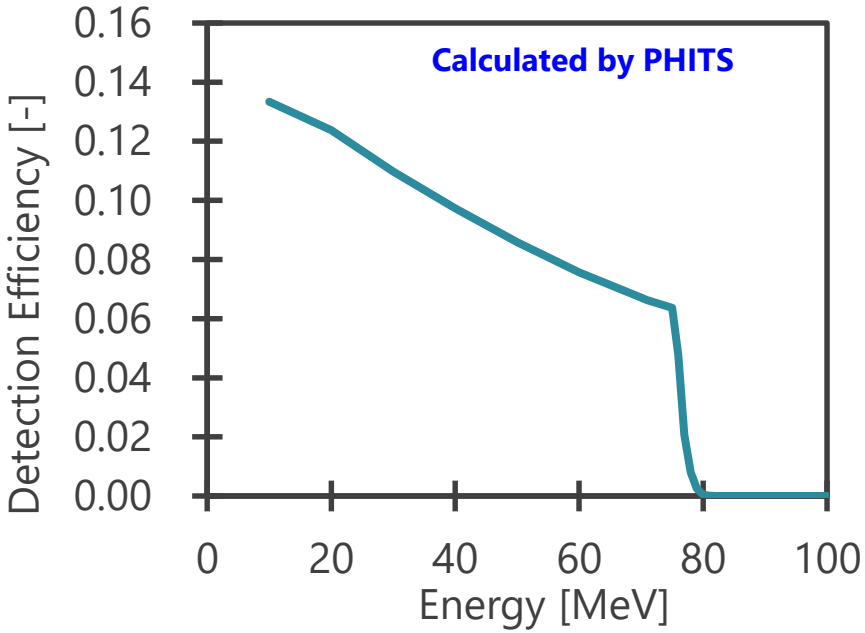
By ΔE-E detection, Muon events are clearly identified from Electron events



Count rate function respect to muon energy is obtained

Results: Low Energy Muon Spectrum





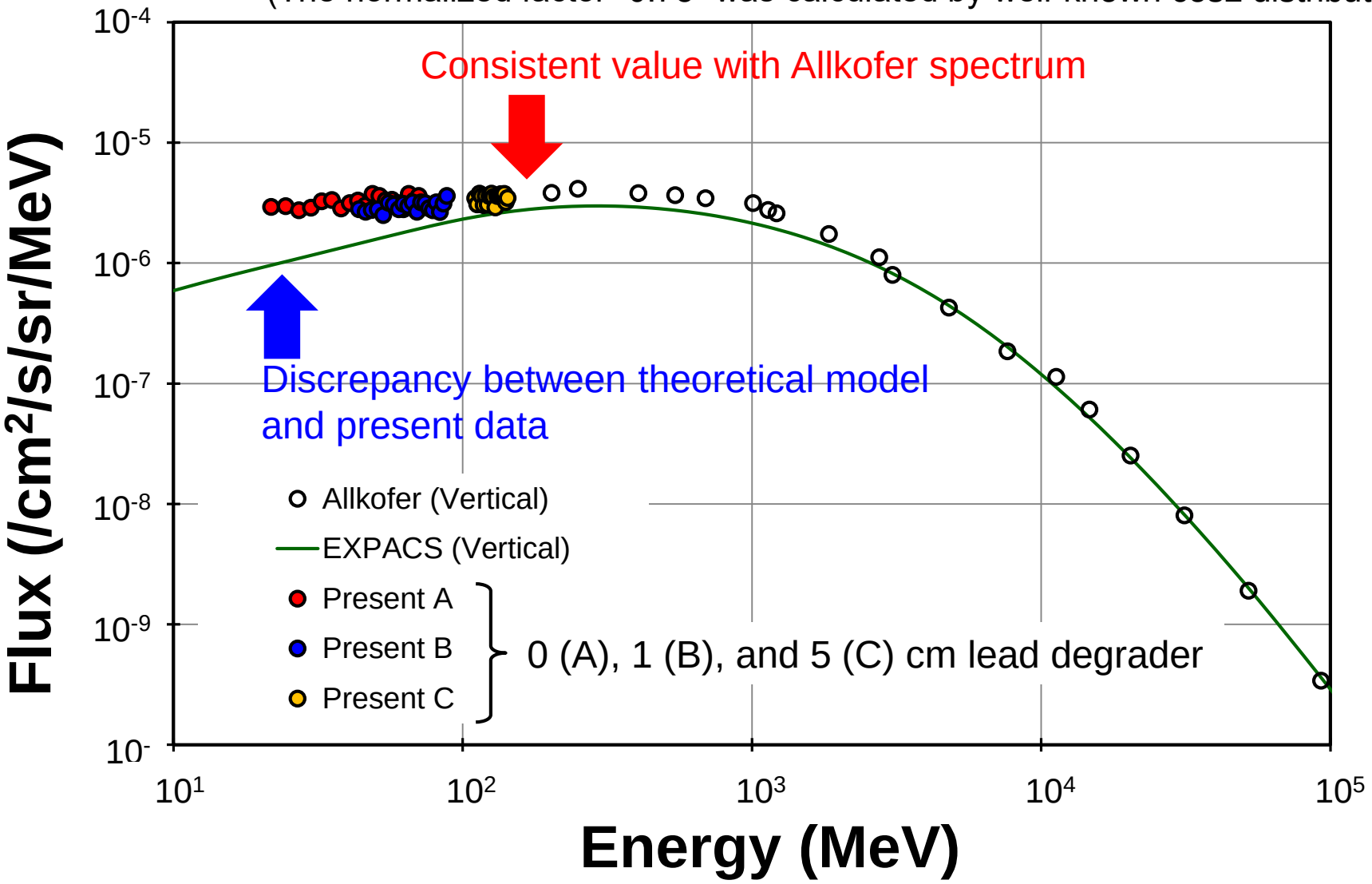
Cosmic-ray muon spectrum

from 20 to 140 MeV
at Top PS position
in 40 degrees of zenith angle

was obtained

Results: Low Energy Muon Spectrum

*Present values are divided by 0.78 for the comparison with vertical fluxes.
(The normalized factor “0.78” was calculated by well-known cos2 distribution.)

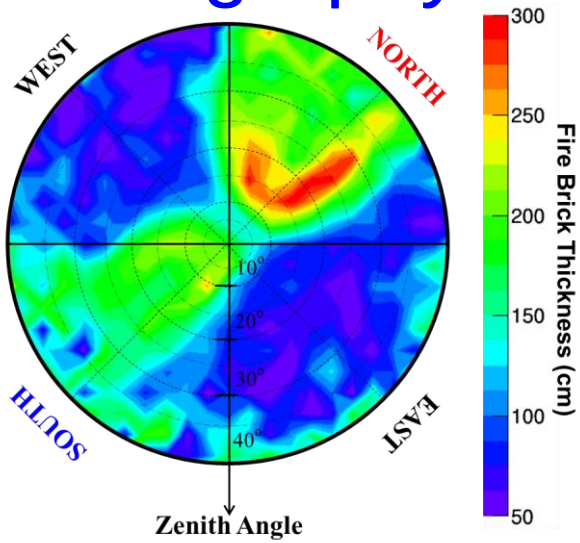


Contents

Summary and Future plans

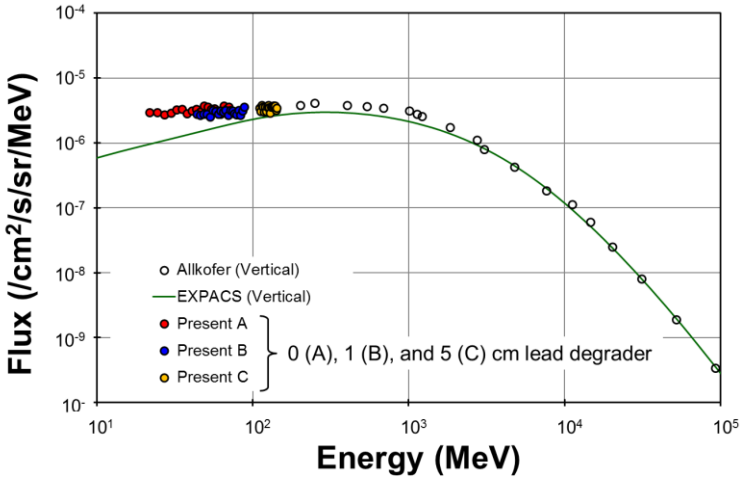
◆Demonstration of Infrastructure Muography

- Collaboration study with **JFE Eng. Co. Ltd.**
- The muography result of the gas duct of the furnace was **in reasonably good agreement with the fire brick wall thickness obtained by drawing**.
- **Muography is a feasible technique** for the investigation of fire brick degradation.



◆Measurement of Low Energy Muon Spectrum

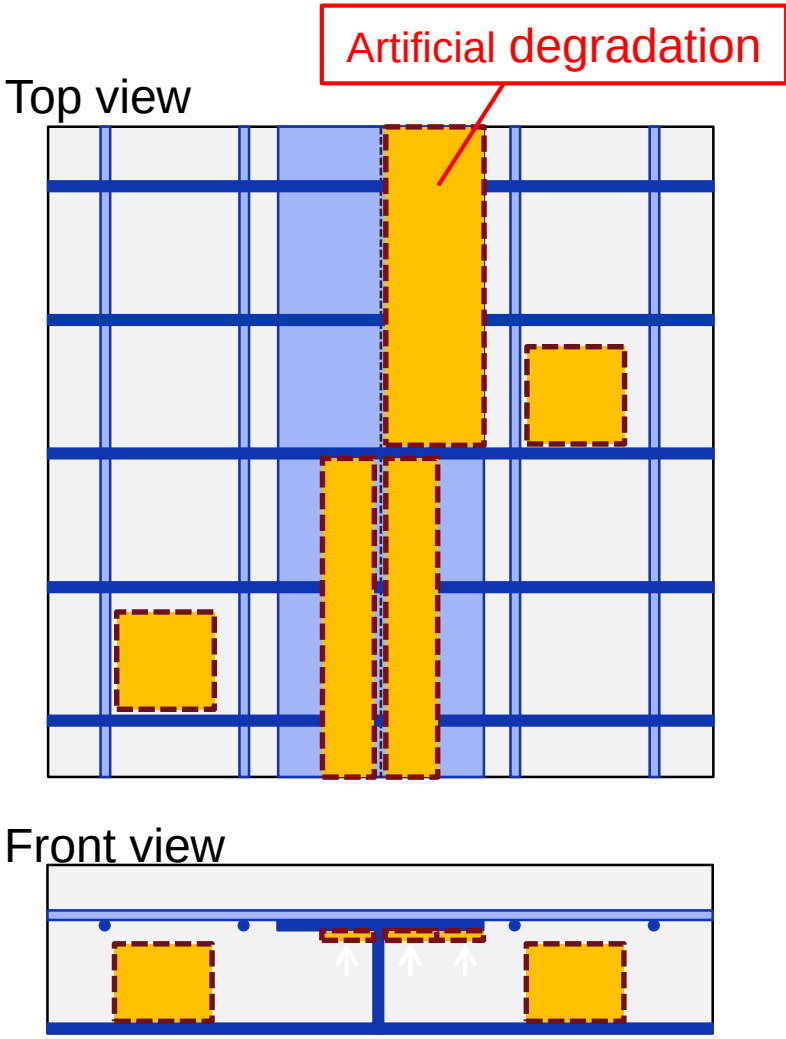
- The **cosmic-ray muon energy spectrum in low energy region** has measured.
- **Inconsistency** with theoretical model **in lower energy region**.



Summary and Future plans

◆Investigation of Degradation of Bridge

- Collaboration study with **JFE Eng. Co. Ltd.**
- Construction of test samples of bridge which include **artificial degradation** such as cavities or concrete gravel
- Development of **screening** method
- Probing the **limit size** of investigation
- **Simulation approach** by PHITS



◆Muon Energy Spectrum

- Obtain **higher energy region** to know the consistency with Allkofer spectrum
- Measurement of **zenith angular differential flux** with other detector setup
- Improve the **muon event identification process**

Contents

One More Thing…

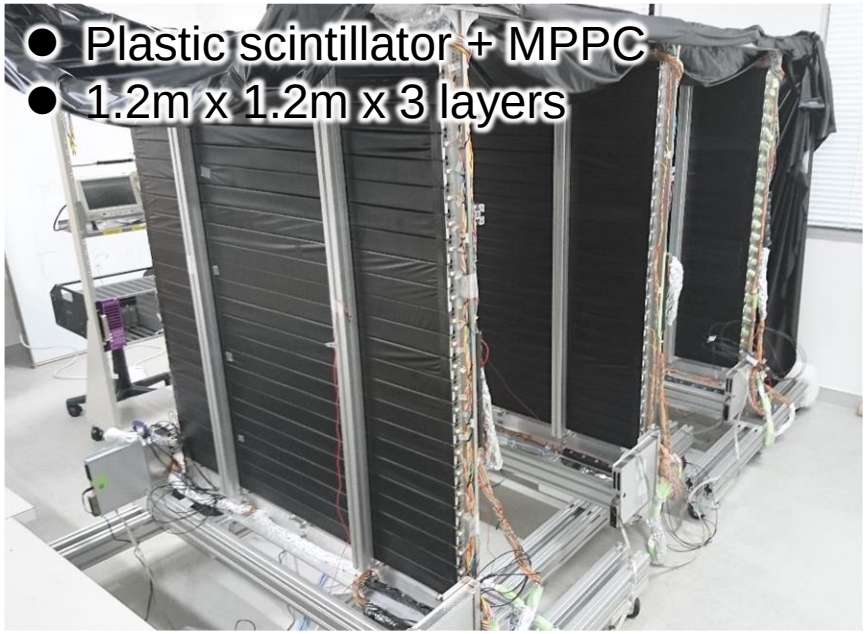
Another Muography at Kyushu University

"Volcano Monitoring with Scintillators with SiPM Readout"

by Faculty of Science and Institute of Seismology and Volcanology

Prof. Kawagoe and Prof. Shimizu organize the project has started **this year**

1st candidate of the monitoring



Detector Fabrication and 1st Engineering test has finished.

Monitoring of Mt. Unzen will be soon started.