MuoGraphers 2017

SAKURAJIMA Muography Project

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Lendület program

Outline

I. Motivation

II. MWPC-based Muographic Observation System

III. Sakurajima measurement campaign

IV. Future perspectives

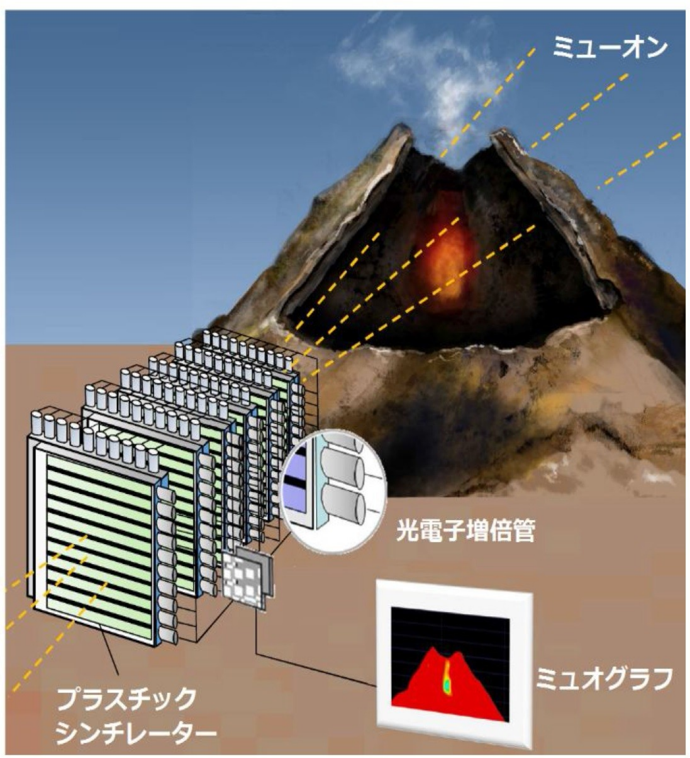
I. Motivation

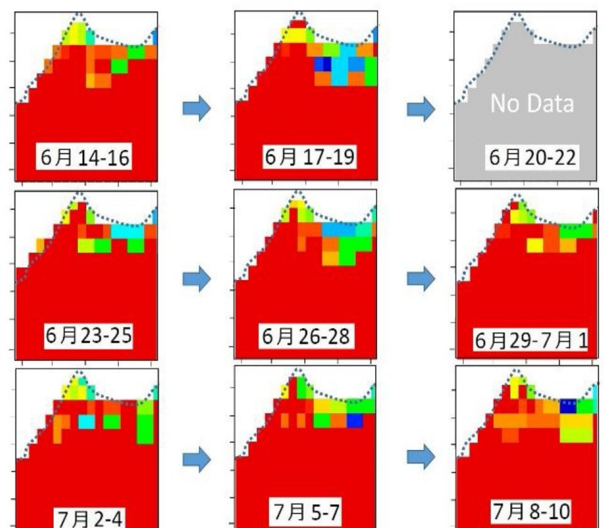
- **Muography allows good precision (< 50 m × 50 m) imaging of the interior of active volcanoes from safety distance (> 1 km)**
- **Scintillators and gaseous detectors are applicable for time-sequential muography**

H. Tanaka et al: Nat. Commun. 5:3381 doi: 10.1038/ncomms4381 (2014)

- **Low energy muons (E < few GeV) , high energy (E >> few GeV) electrons and hadrons produce background on the flux of muons**

R. Nishiyama et al.: Geophys. J. Int. 206 1039-1050 (2016)
L. Oláh and D. Varga: Astroparticle Physics 93 17-27 (2017)

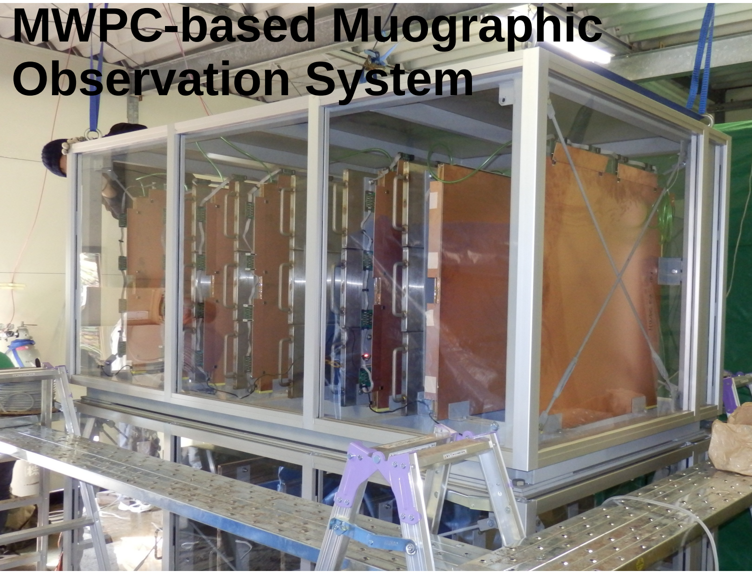




2013年　薩摩硫黄島の噴火の推移

6月	4	6	7	16	17	30
噴煙の高さ	−	300	600	400	100	200
火映	−	−	−	X	−	X

I. Motivation



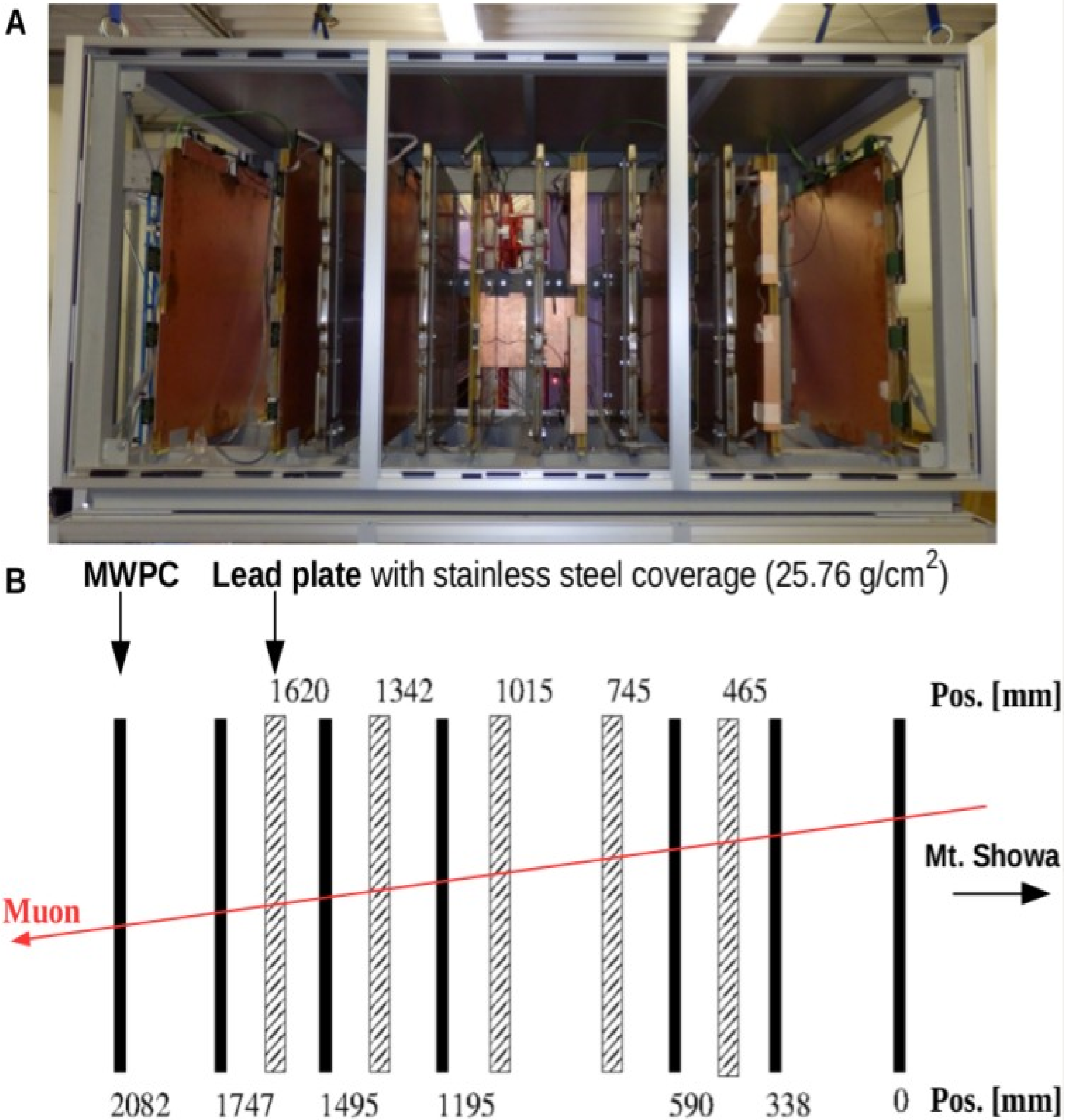
- **Motivation of Sakurajima Muography Project (Earthquake Research Institute and Wigner RCP of the HAS):**

- **High-definition imaging of the interior of Sakurajima volcano**
  → makes visible the thin (< 50 m) magma conduits as well

- **Performing of low-noise muography:**
  → extends the range of imaging up to the thickness of few kilometers

- **Development of large-size (~ 10 m^2) MWPC-based Muographic Observation System**
  → optimized time sequential (few hours) muography of Sakurajima volcano

II. MWPC-based Muographic Observation System



mMOS is a joint development of Wigner RCP and Earthquake Research Institute

High-definition, low-noise and real-time muography can be performed by mMOS:

- **Detector layers:** seven MWPCs (surface of 0.6 m^2, length of 2 m): Positional resolution of MWPCs: **4 mm** → angular resolution of mMOS: **2.7 mrad**
- **Shielding layers:** five 2-cm-thick lead plates placed in 2-mm-thick stainless steel casettes
- Raspberry Pi controlled **Data Acquisition System is accessible in real-time via Virtual Private Network**

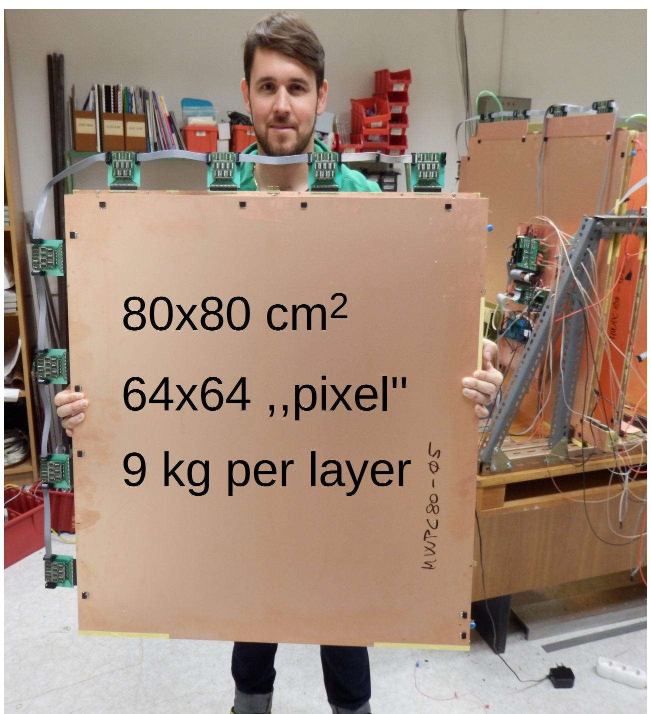
H. Tanaka, T. Kusagaya, H. Shinohara: Nat. Commun. 5:3381 doi: 10.1038/ncomms4381 (2014)
D. Varga, G. Hamar, G. Nyitrai, L. Oláh: Advances in High Energy Physics **2016** (2016) 1962317
G. Hamar, T. Kusagaya, L. Oláh, H.. Tanaka, D. Varga: **Muographic Observation System, PTZATA153, PATPEND 2016**

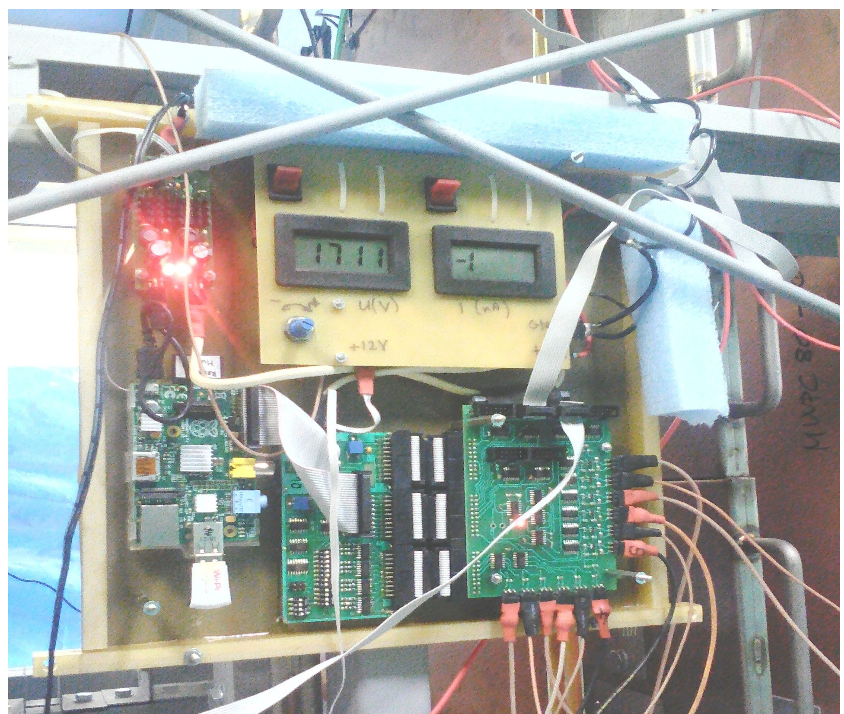
See details in Dezső Varga's talk in Section Technical developments for Muography

II. MWPC-based Muographic Observation System

- Low material budget MWPC with simplified design and **exceptional operating stability**
- **2D positional information** is provided by the field shaping wires and pick-up wires (100 μm copper, on ground potencial) inside a 2-cm-thick gap filled with Ar-CO_2 gasmixture
- Anode wires (25 μm gold-plated tungsten, + 1700 V) are connected and provide trigger signal
- **Portable (< 5 kg), integrated, low-power (< 5 Watt) DAQ system operated by Raspberry Pi allows remote control and online data analysis (parallel data readout, dead time ~ 100 μs)**

D. Varga, G. Hamar, G. Nyitrai, L. Oláh: Advances in High Energy Physics **2016** (2016) 1962317





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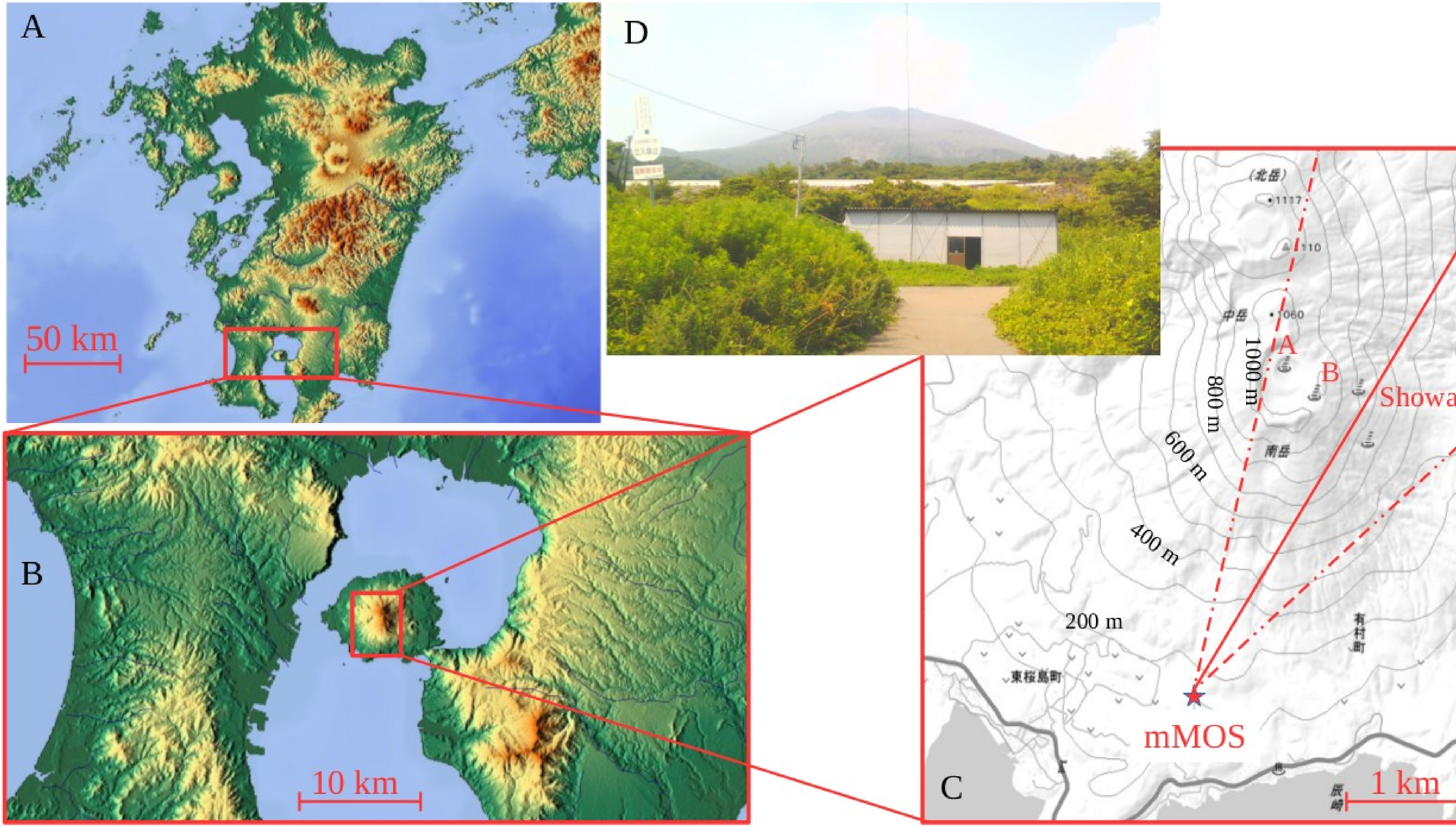
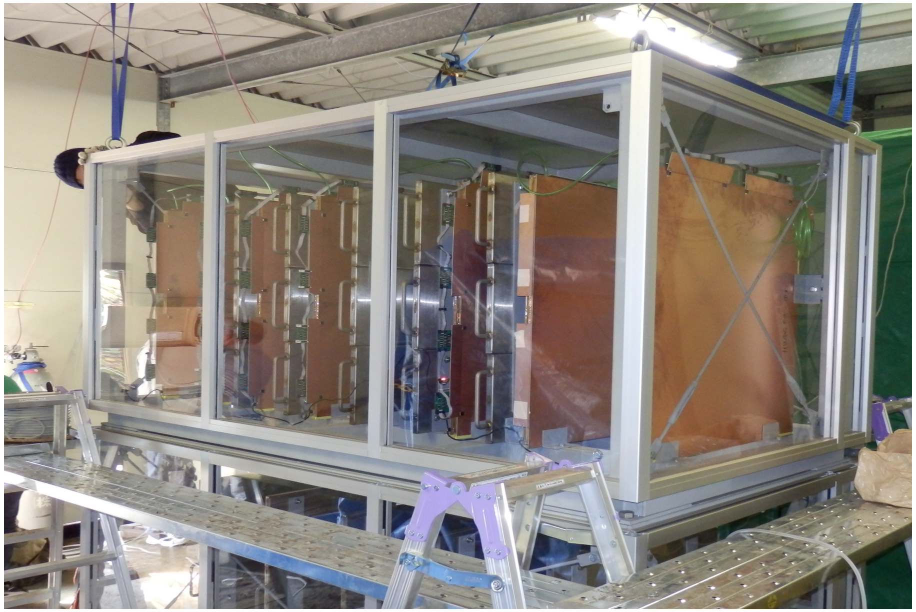
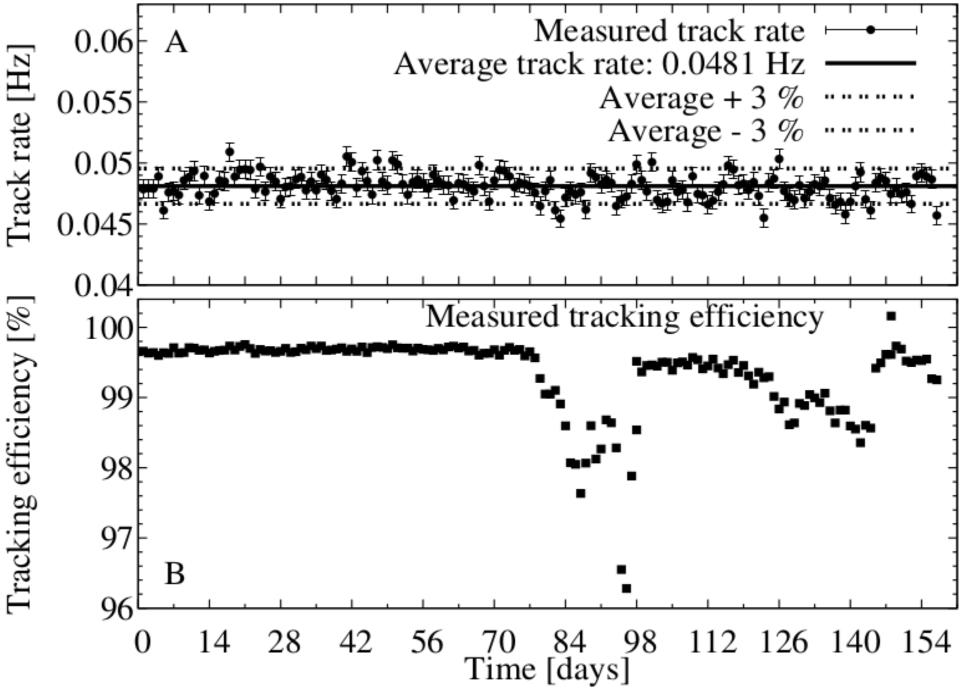
III. Sakurajima measurement campaign



mMOS maintenance and long-term performance

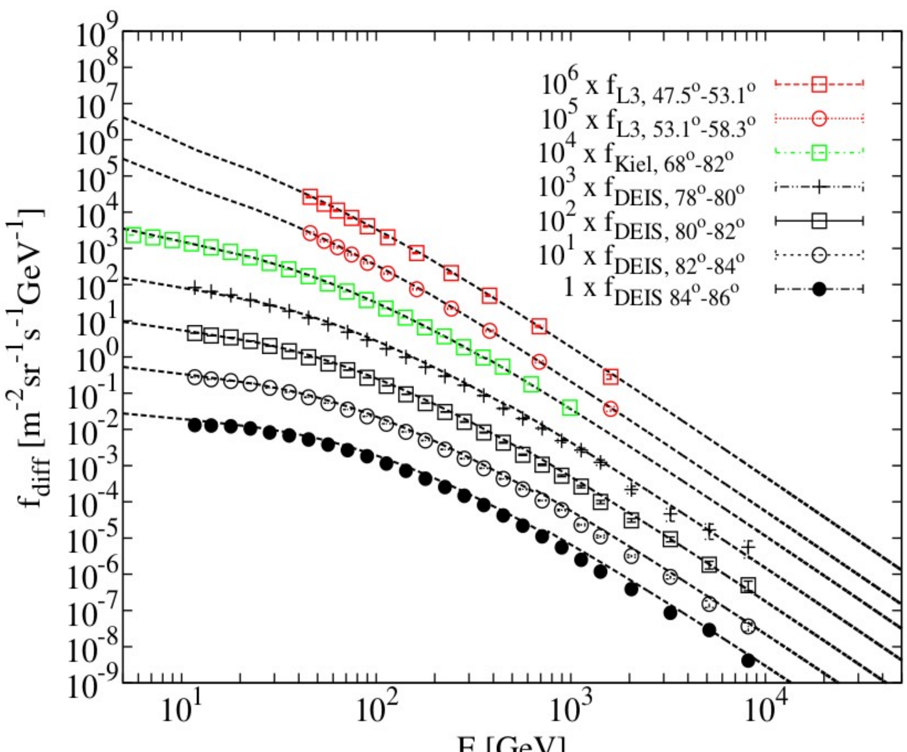
- Ar-CO_2 (80-20) gasmixture → **gas consumption is ~ 0.5-2 Liters/hour**
- Detector power is provided by local electricity network → **power consuption is < 10 Watt**
- **Detector maintenance performed in every two months**
- **The mMOS operated reliably more than six months:**
  - resonable trigger rate of 7-9 Hz and stable track rate of around 0.05 Hz
  - tracking efficiency was found above 98 %

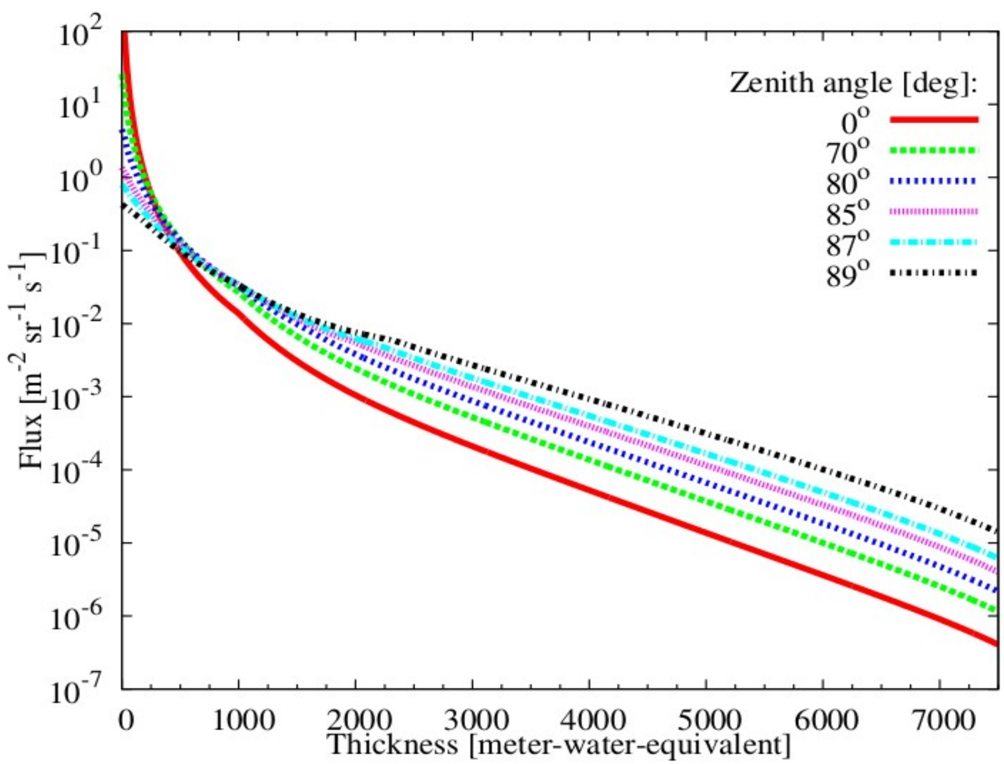




Data analysis and analytical methods

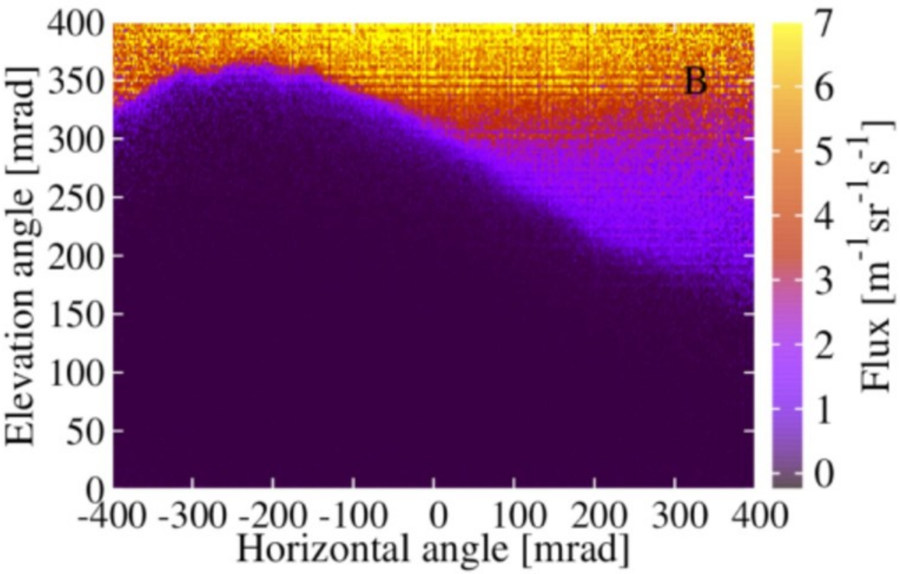
- **Measured flux was determined by event-by-event offline data analysis:**
  - Cluster findind on MWPCs, combinatorial tracking algorithm
  - Selection of well fitting (χ^2/ndf <2) tracks above the noise level (A >120 ADC, 1 ADC = 1800 e^-) and flux calculation with correction on detector acceptance, solid angle and time of data taking
- **Calculation of expected flux:**
  - Path-lenth distribution was dermined from elevation map of GSI, minimum energy (E_{min}) of penetrating muons were calculated using CSDA Groom et al.: Atomic Data and Nuclear Data Tables 76 183-356 (2002)
  - Spectra of muons were parametrized by Modified Gaisser model and were integrated from E_{min} A. Tang et al.: Phys. Rev. D 74 (2006) 053007
- **Density equals with the modeled one with which the residual of expected and measured fluxes is minimal**

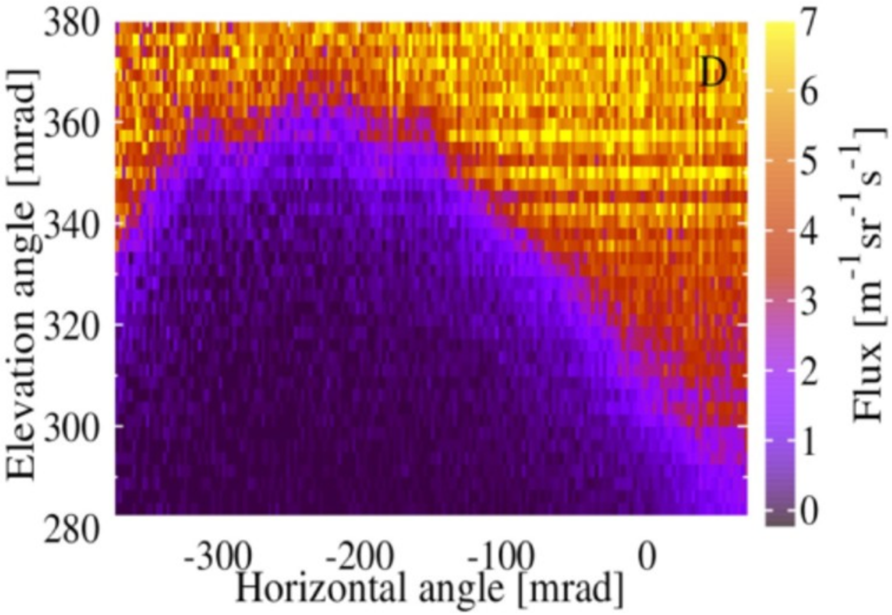




High-definition muography with mMOS

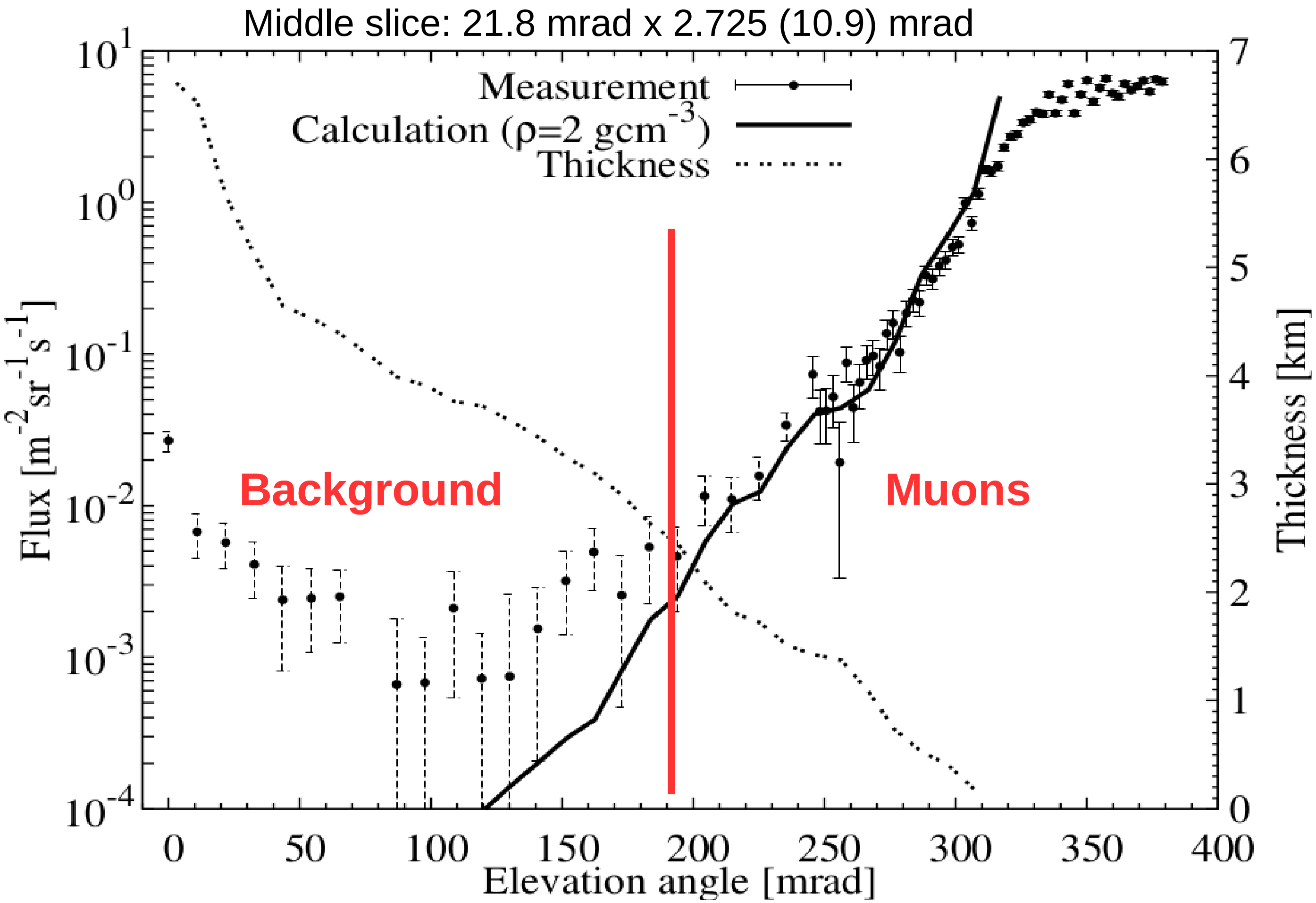
- **Measured muon flux with the precision of 2.7 × 2.7 mrad^2 (7.5 × 7.5 m^2 resolution image from the distance of 2.8 km) well reproduces the ridge of the Sakurajima**





Low-noise muography with mMOS

- **Low energy (< 1 GeV) background particles were suppressed in mMOS and the measured flux was found in good agreement with the expected flux up the thickness of 5000 meter-water-equivalent**



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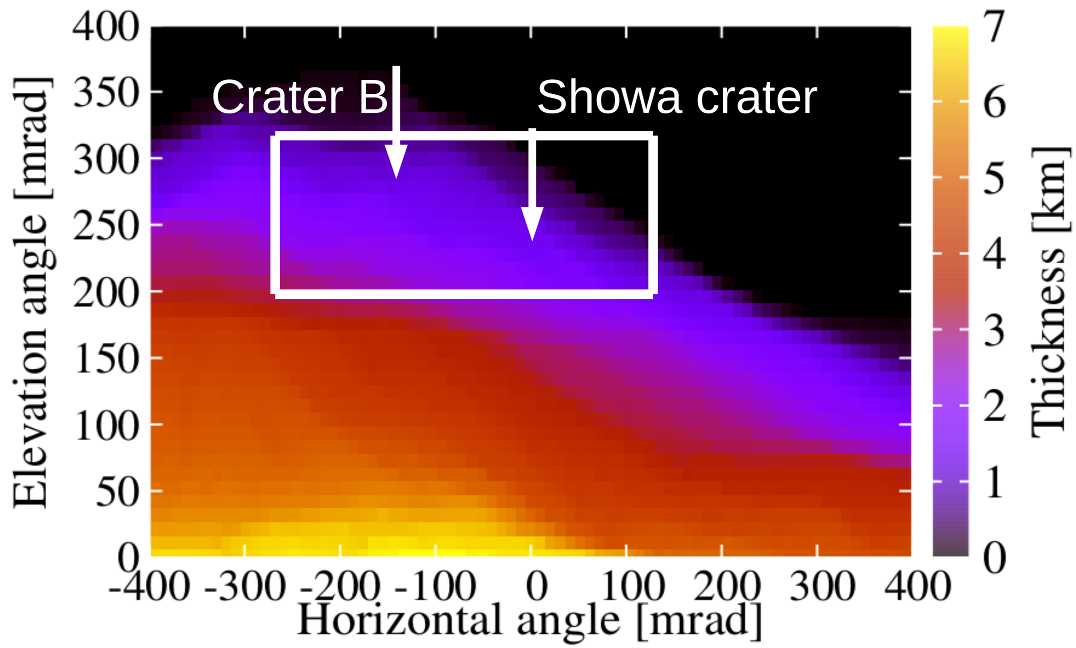
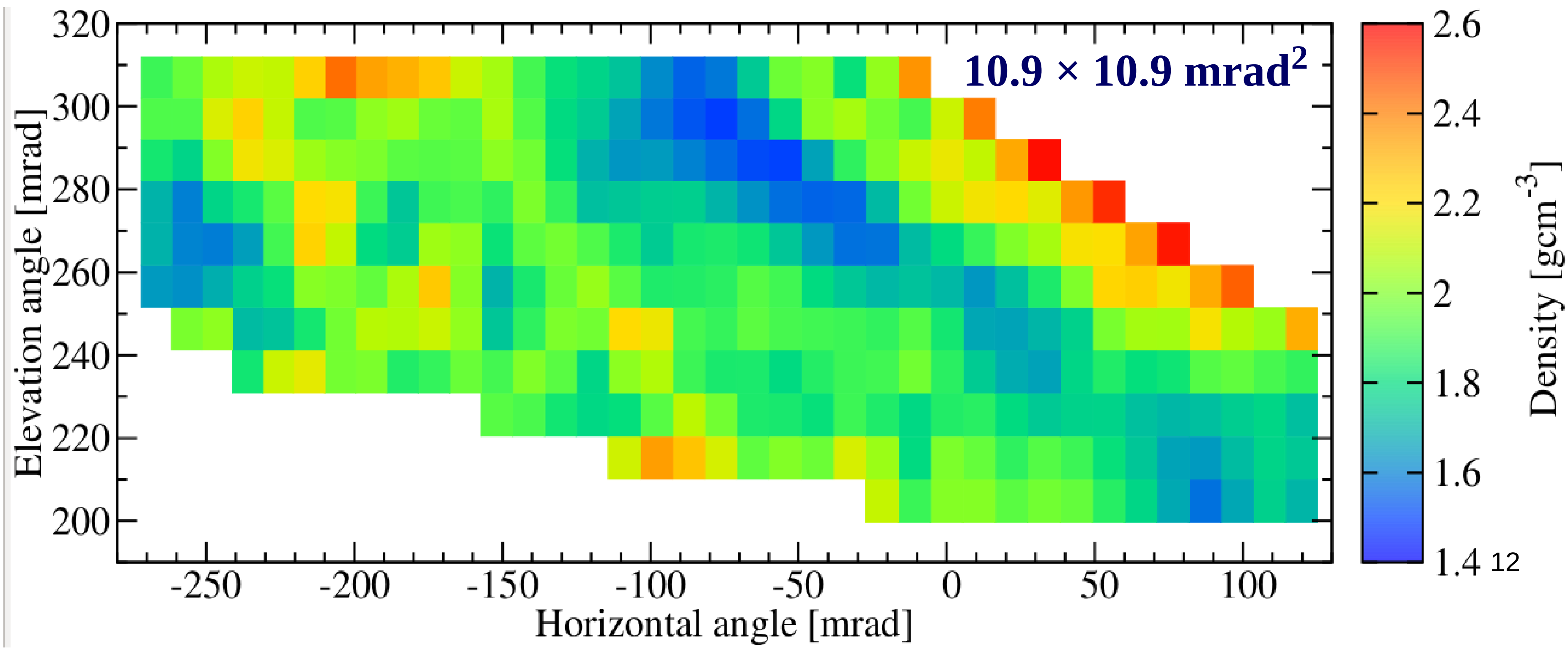
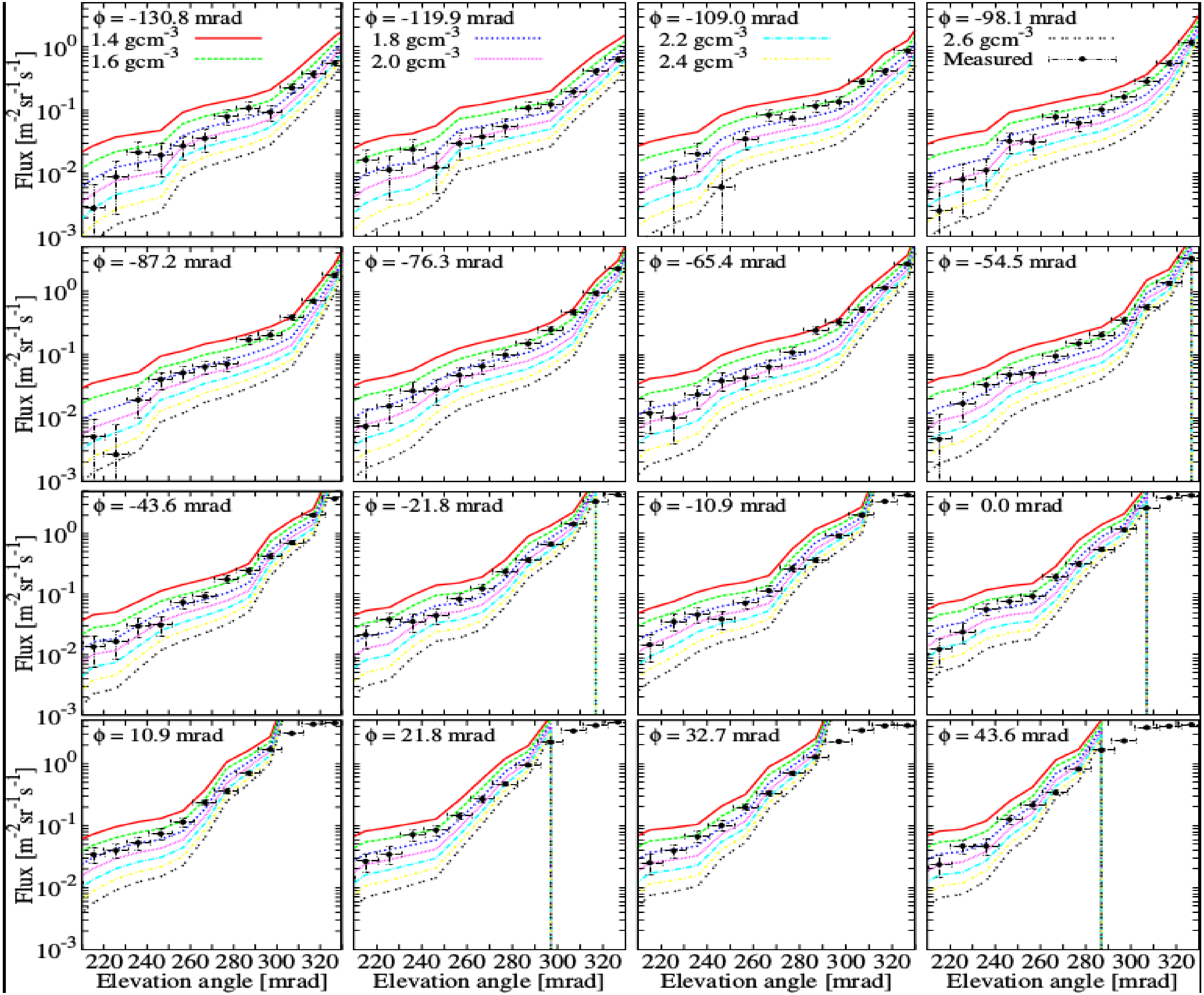
Density map between the craters B and Showa



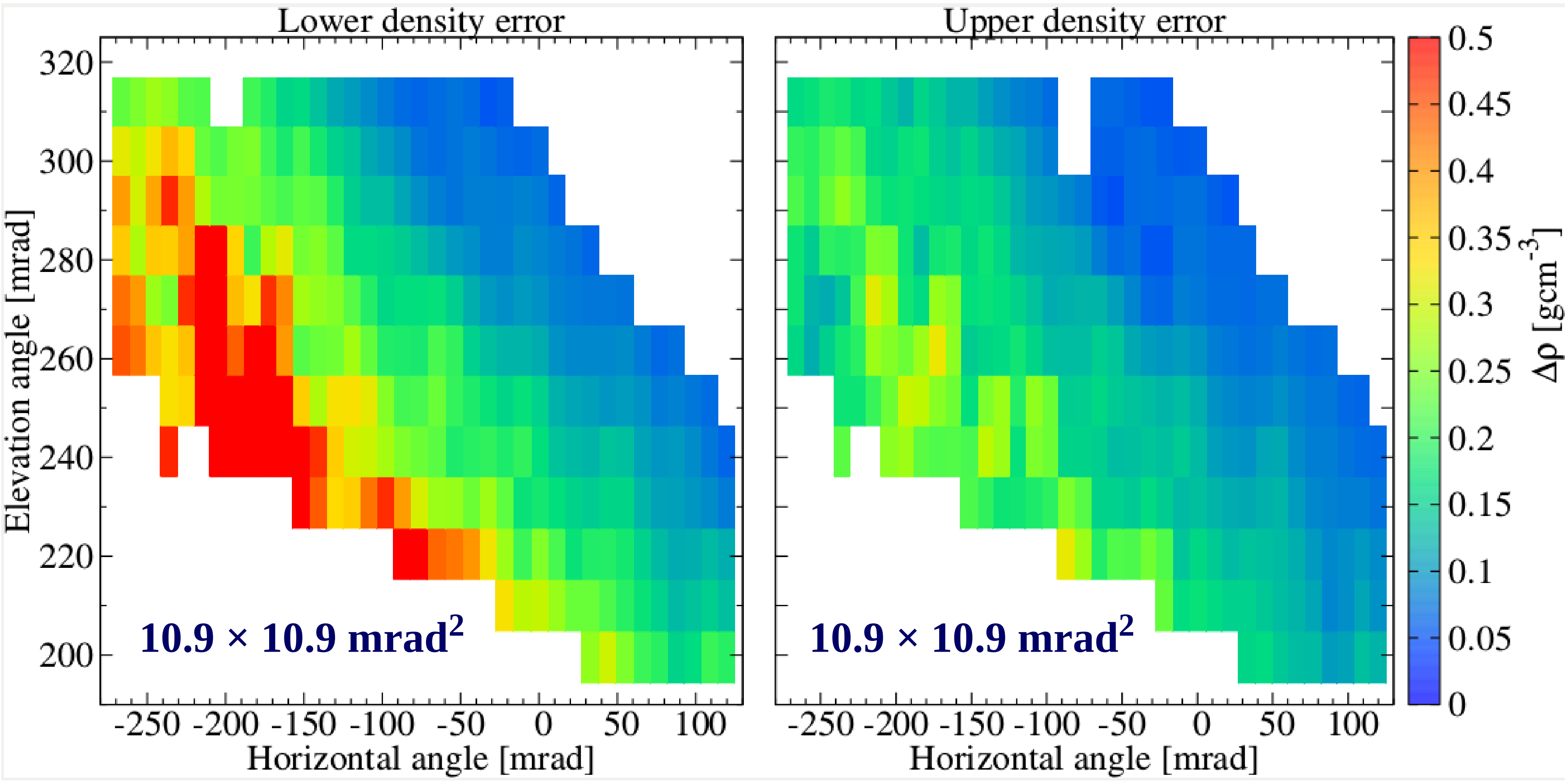


Comparison of vertical flux slices

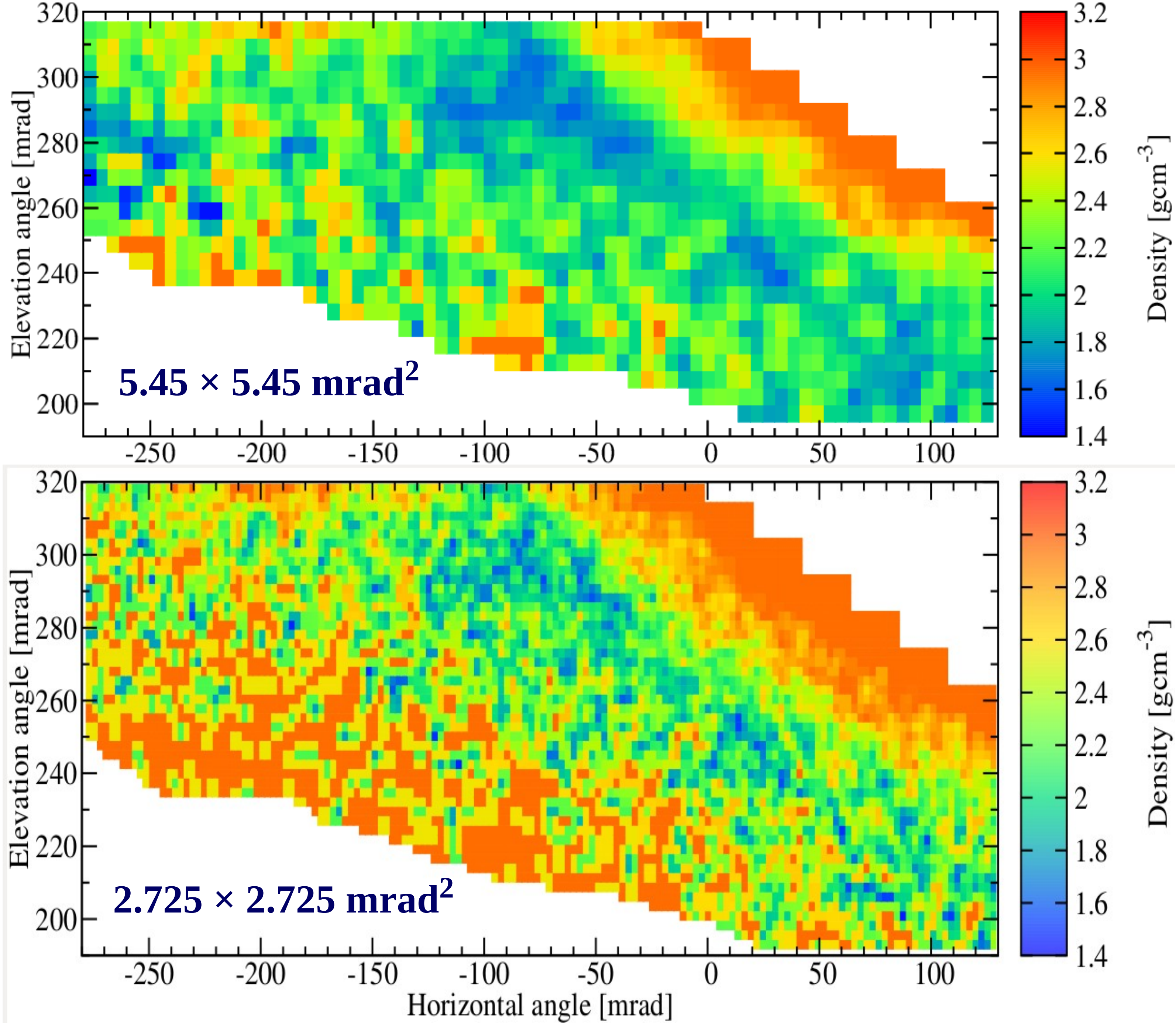


The uncertainty of the density map

- **The observed density error, Δρ is 0.1-0.2 g/cm3 (~ 5-10 %) in 10.9 × 10.9 mrad² angular bins between the crater B and Showa**

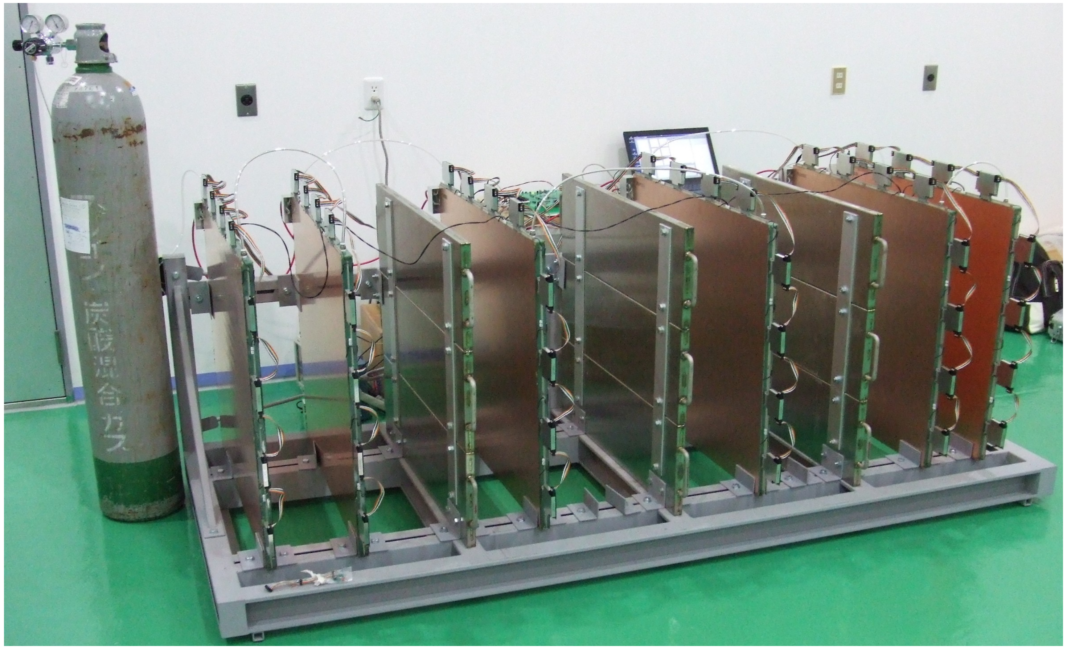


High-definition density maps



IV. Future perspectives

- **Development of MWPCs is ongoing in ERI, University of Tokyo:**
  - First MWPCs are constructed in the beginning of FY 2017
  - Mass production will be expected to start during FY 2018
  - Real-time (few hours) imaging $\rightarrow$ 10 m^2 mMOS (FY 2020)
- **Development of software framework is ongoing for real-time data QA and time-sequential imaging (FY 2018)**



Summary

- Muography is a promising technique for the investigation of volcanoes
- **MWPC-based Muographic Observation System:**
  - Based on lightweight, low power and high-precisional MWPCs (position resolution of 4 mm, angular resolution of 2.7 mrad)
  - Raspberry Pi controlled DAQ allows remote control and data management
- **Sakurajima measurement campaign:**
  - High operational stability of mMOS was demonstrated during 156 days
  - High-definition (2.7×2.7 mrad^2 from 2.8 km $\rightarrow$ 7.5×7.5 m^2) muography
  - Low background noise up to the thickness of ~ 5000 meter-water-equivalent
- **Future developments:**
  - Large-size mMOS (~ 10 m^2) for time-sequential (few hours) imaging

Thank You for your attention!

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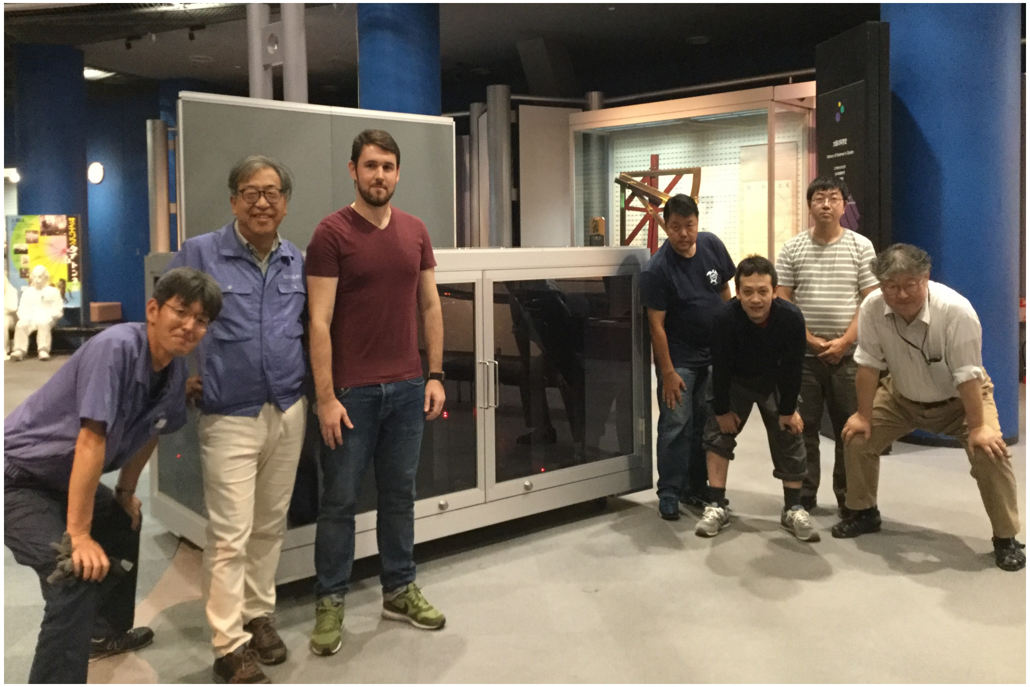

Back-up slides