BUDAPEST, JUNE, 2026

Status and Upgrades of the MuGrid-v2 Detector

Muographers 26

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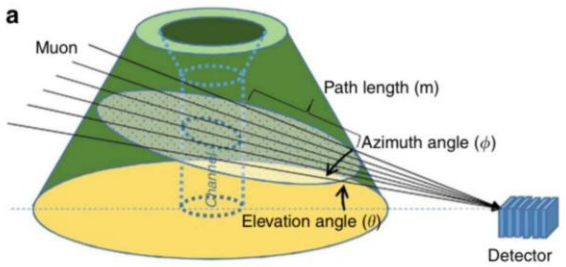
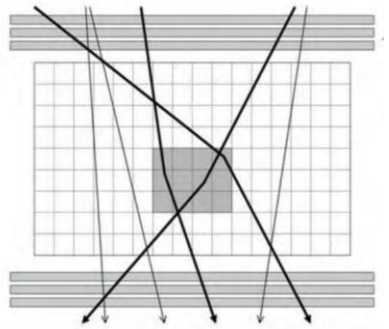
Cosmic-ray Muon & transmission muography

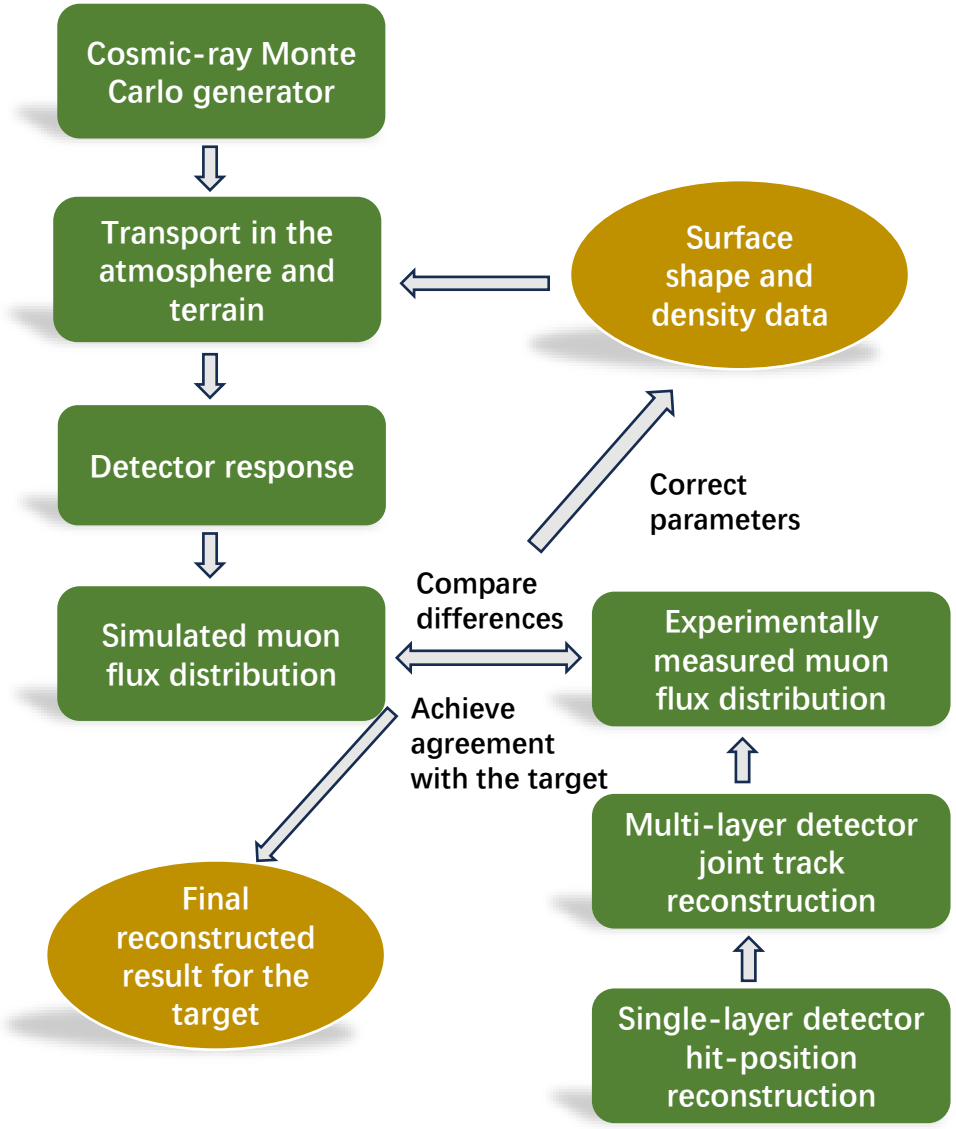
- Cosmic-ray muons are secondary particles produced by interactions between primary cosmic rays and the air.
- Internal structure imaging enabled by muon energy loss during material penetration.
- Muography can generally be divided into:
  - Scattering imaging: Sensitive to high-Z anomalies
  - Transmission imaging: Suitable for large-volume object inspection



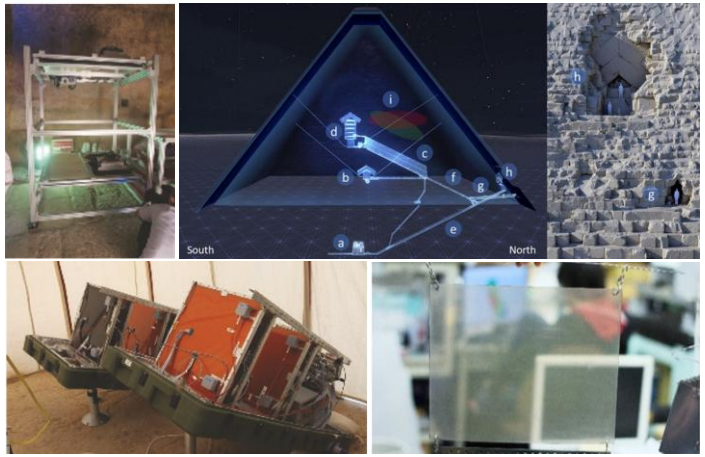
transmissing muography



Scattering muography

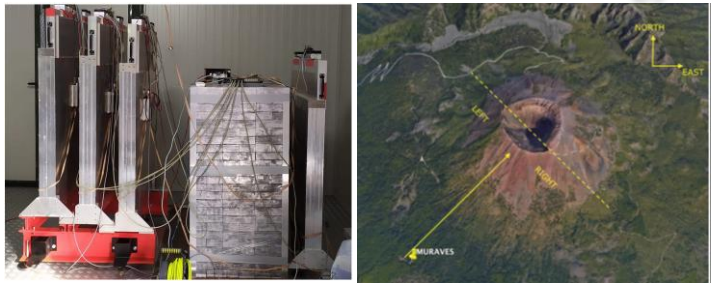


Multidisciplinary Applications of muography



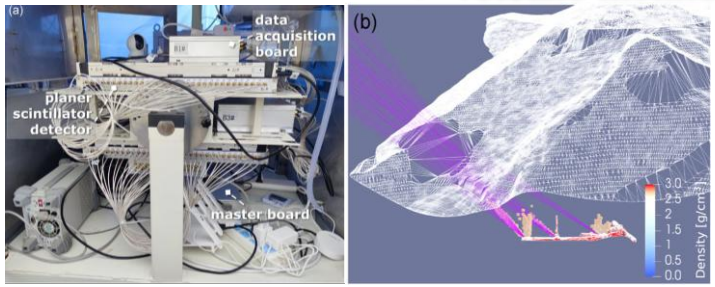
Kunihiro Morishima. et al
Nature 552, 386–390 (2017)

➢ Archaeology



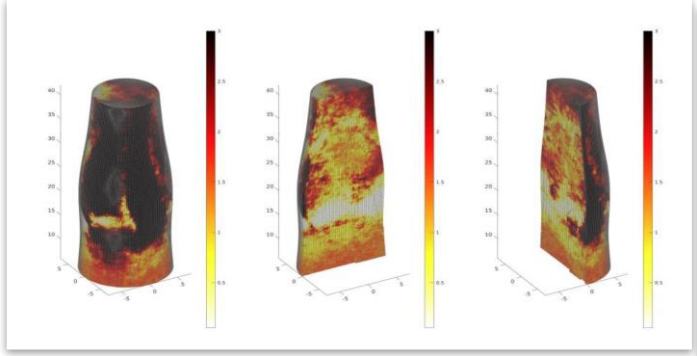
M. Derrico, F. Ambrosino et al
arxiv:2202.12000

➢ Volcano monitoring



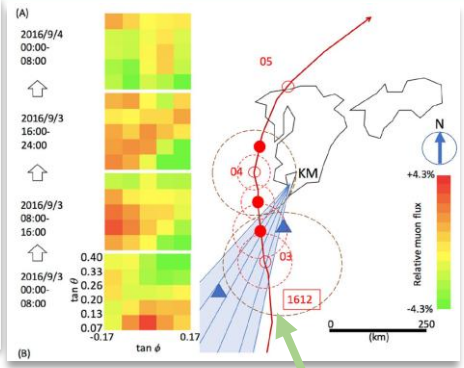
Guorui Liu et al
Geophysical Journal International , Vol. 237, 588-603

➢ Geological exploration

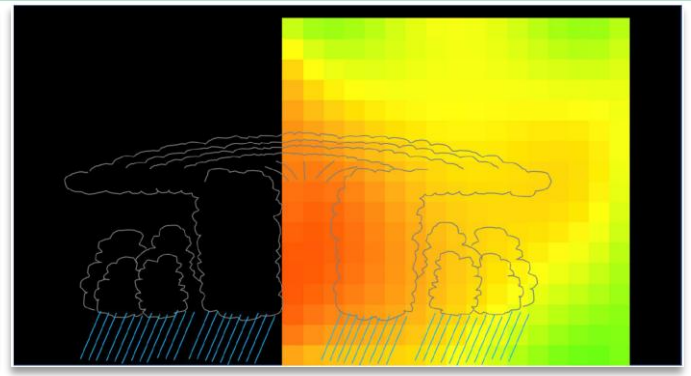


➢ Blast furnace inspection

Cohu et.al
JINST 18 (2023) 07, P07004



➢ Typhoon warning

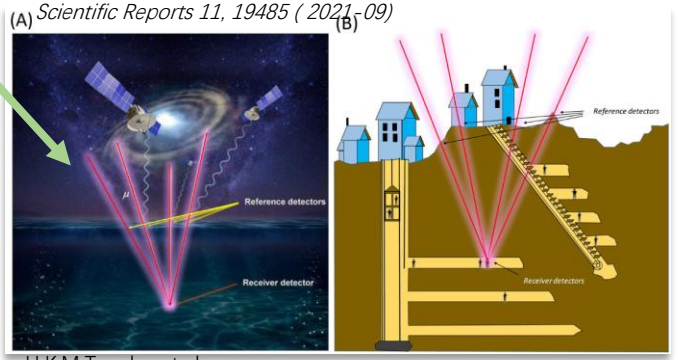


H.K.M Tanaka, et al
Scientific Reports 12, 16710 (2022)

➢ Sea-level monitoring

H.K.M Tanaka, et al
Scientific Reports 11, 19485 (2021-09)

➢ Underwater navigation



H.K.M Tanaka, et al
Scientific Reports 13, 15272 (2023)

Muography has shown rapidly growing potential across multiple disciplines!

Gas detectors
- High spatial resolution & Large-area coverage
- typically need continuous gas supply

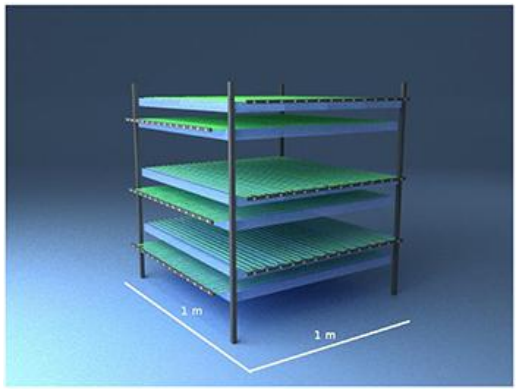
Nuclear emulsion detectors
- Ultra-high spatial resolution
- melting under high-temperature

Scintillator detectors
- mm-level spatial resolution
- Robust and environmentally adaptable

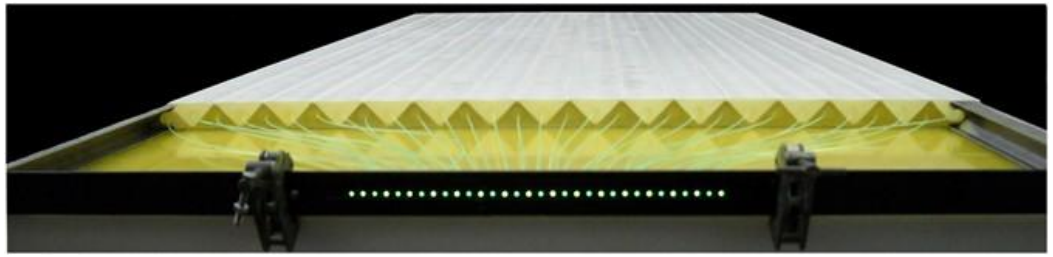
MuGrid-v2 design

Conventional plastic-scintillator detector configurations

semicircular *G. Saracino et al Sci Rep 7, 1181 (2017)*



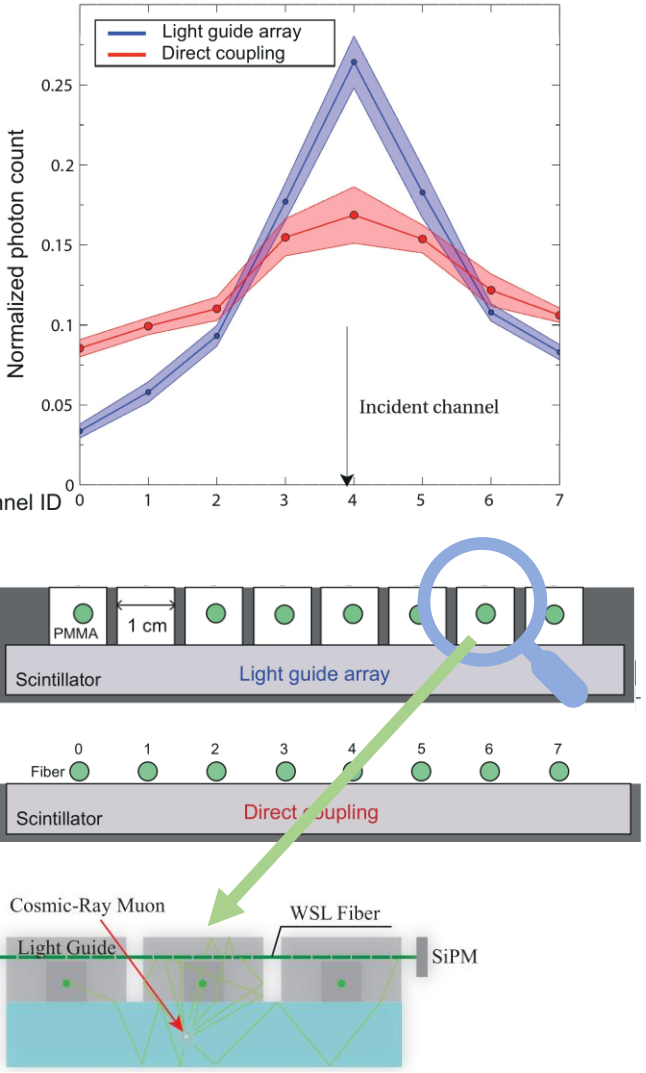
Rectangular *M. Niculescu-Oglinzanu et al J. Appl. Phys. 136, 174501 (2024)*



Triangular *A. Anastasio et al NIMA 732 (2013) 423–426*

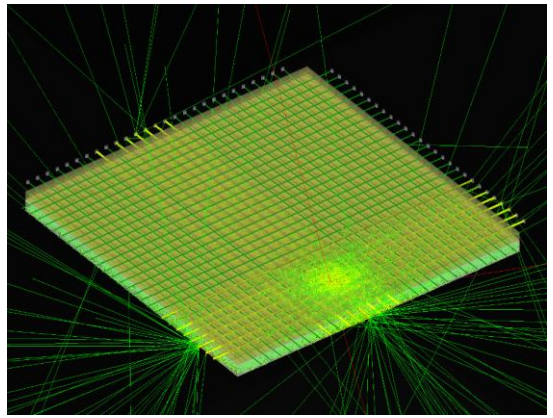
These are all excellent detector solutions, but scalability and production cost remain important challenges.

- Use Light-guide arrays to optically segment the scintillator without physical cutting.
- Scintillation photons are collected by WLS fibers and read out by edge-mounted SiPMs
- Two-dimensional light-intensity distributions can be obtained from the X and Y fiber arrays.
- Muon hit positions can be reconstructed by centroid methods or Gaussian fitting.
- Easily achieve X and Y readout on a single scintillator block.



Hang Yang, Yao Yu, et al NIMA 1042 (2022) 167402

MuGrid-v2 Simulation comparison

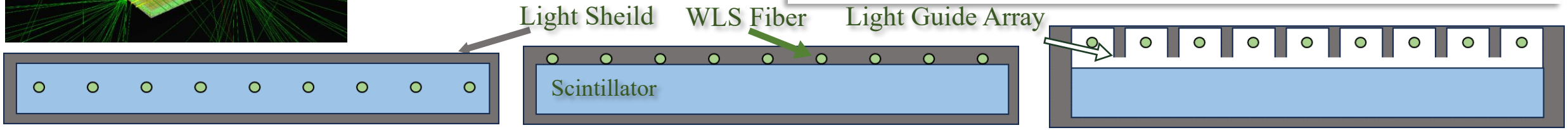


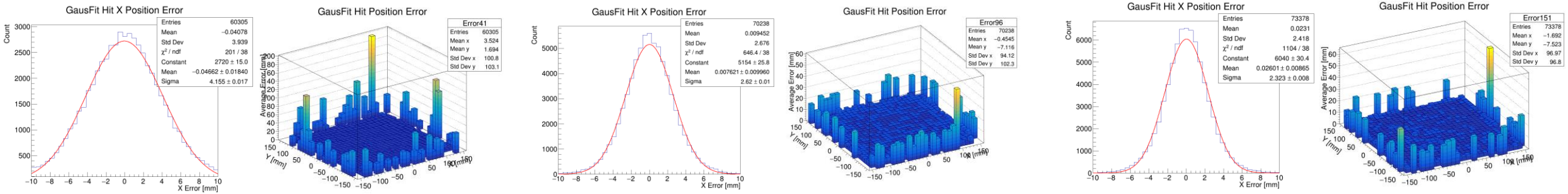
Geant4 visualization

- Geant4 simulations were conducted on the three coupling modes of WSL fibers:

  surface coupling, internal coupling, light guide array.
- The scintillator size is 30cm*30cm, with 27 channels per direction（11mm gap）.

High cross talk　　Low efficiency

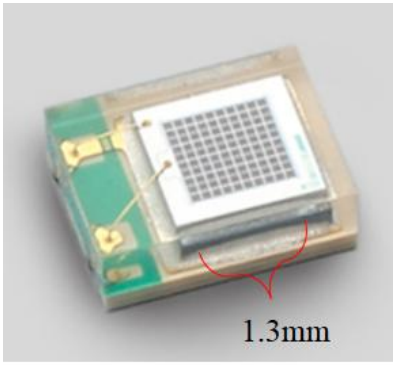




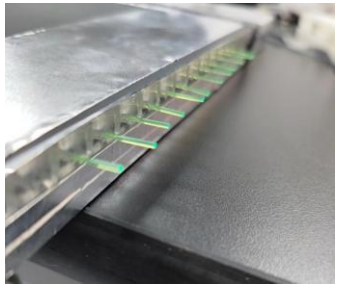
Coupling method / Reconstruction methods	Internal	Surface	Light guide
Resolution of centroid/mm	15.46±0.82	3.576±0.012	2.706±0.009
Resolution of fitting/mm	4.155±0.017	2.62±0.015	2.323±0.008

MuGrid-v2 Electronics

- SiPM



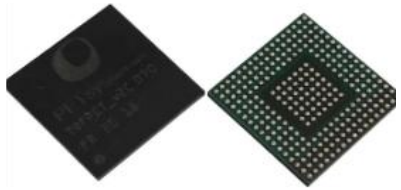
  - S13360 series
    - Size: 1.3mm× 1.3mm
    - Gain: 1.7×10^6
    - V_{BR} : 53±5 V



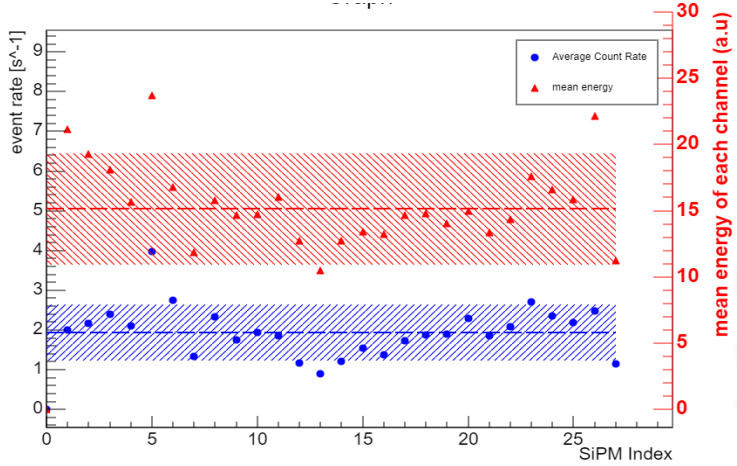
- WLS fiber
  - Kuraray Y-11
    - Emission Peak: 476 nm
    - Attention Length: 3.5 m
    - good spectral matching

Use cosmic-ray muons to test the uniformity of channel responses and repair abnormal channels.

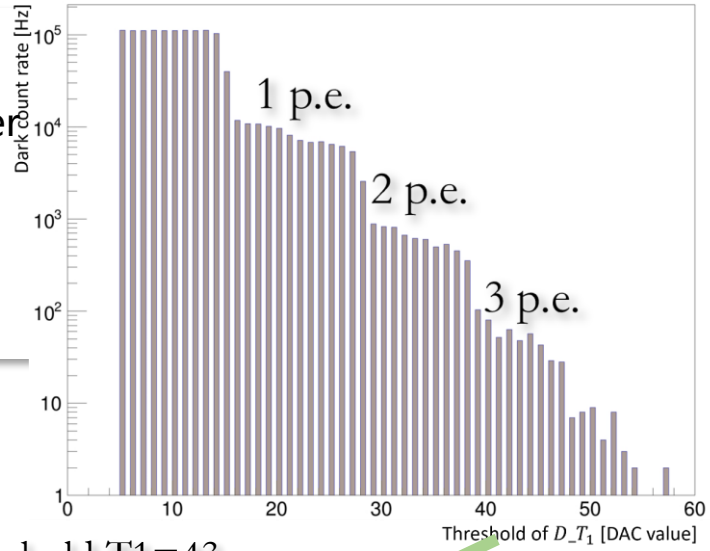
- ASIC



TOFPET2 ASIC features
- 64 independent channels
- TDC time binning: 30 ps.
- Max channel hit rate: 600 kHz
- Dynamic range: 1500 pC.

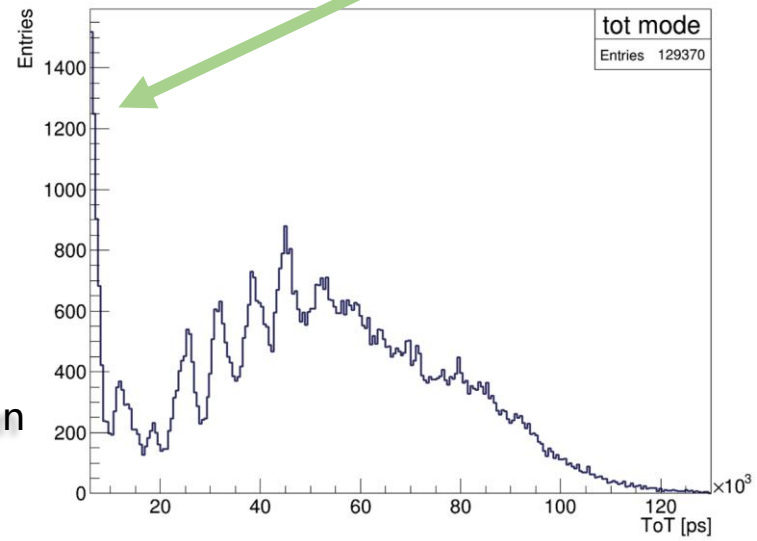


Count dark count rate to calibrate the number of photoelectrons corresponding to the threshold

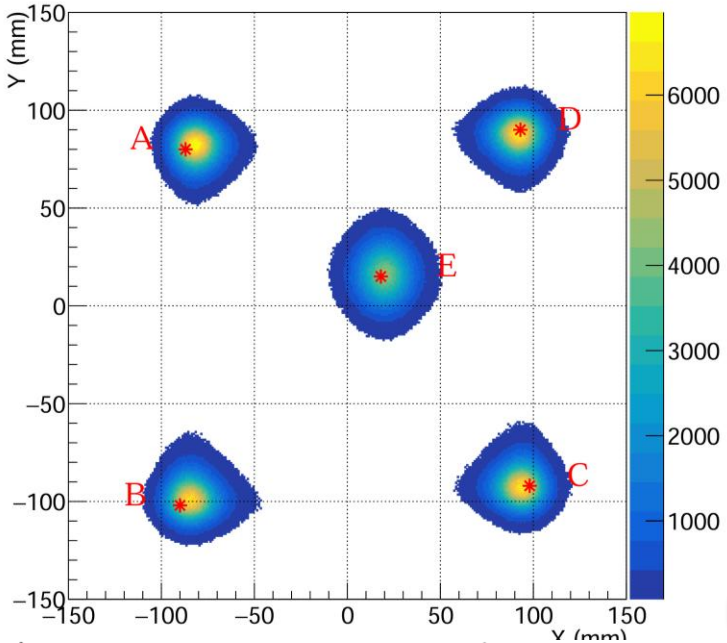


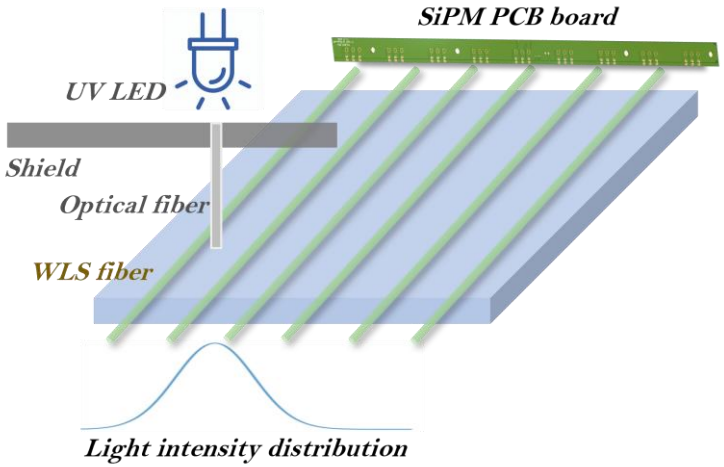
Threshold T1=43

Multi p.e. spectrum in TOT mode

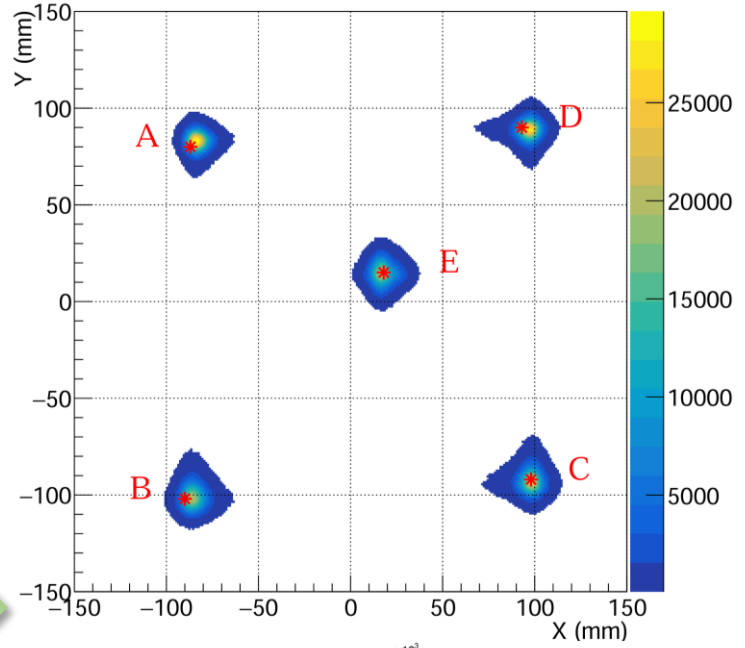


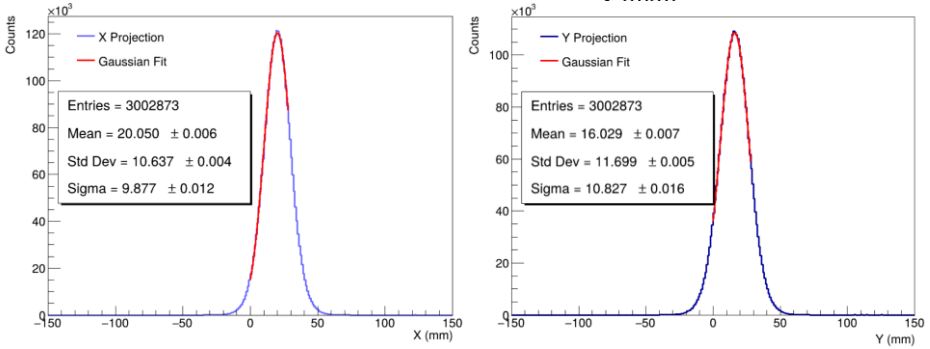
MuGrid-v2 Reconstruction algorithm



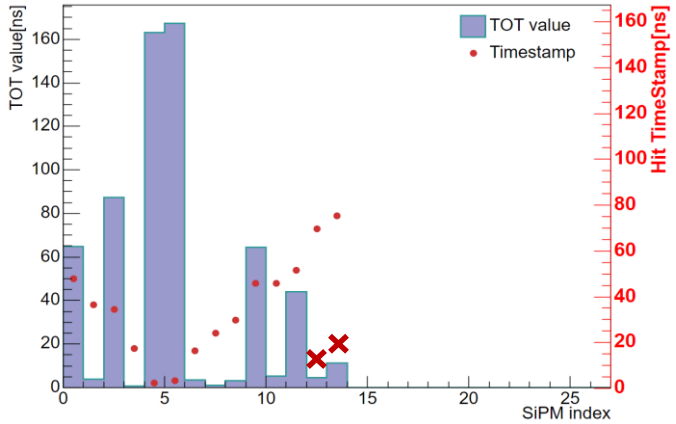


Calibrate the spatial resolution with LED in 5 points on the scintillator

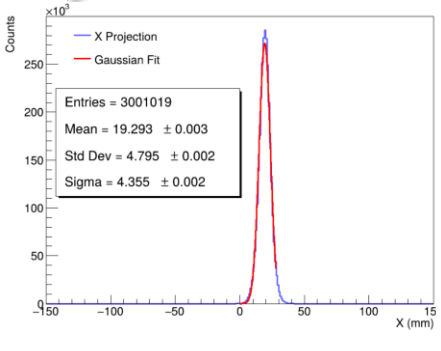


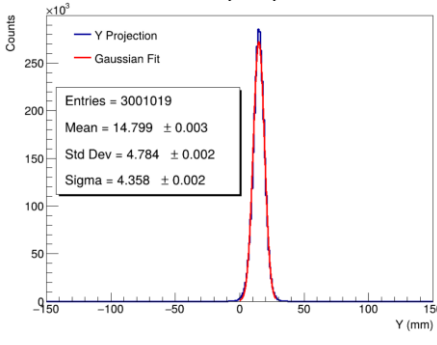


$$\hat{X} = \Sigma E_i X_i / \Sigma E_i$$



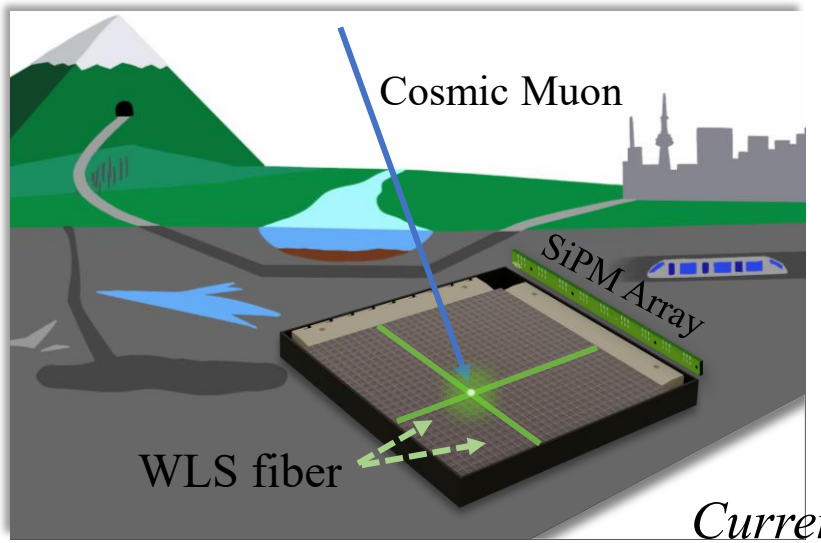
For trigger channels farther from the hit point, the timestamp will be further late





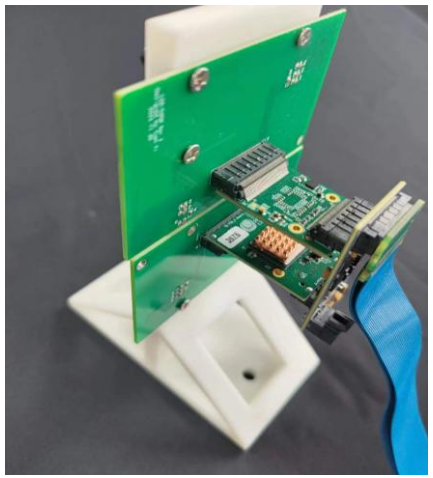
$$\hat{X} = \Sigma \frac{E_i X_i}{\sqrt{1+(t_i/\sigma_t)^2}} / \Sigma \frac{E_i}{\sqrt{1+(t_i/\sigma_t)^2}}$$

MuGrid-v2 workflow



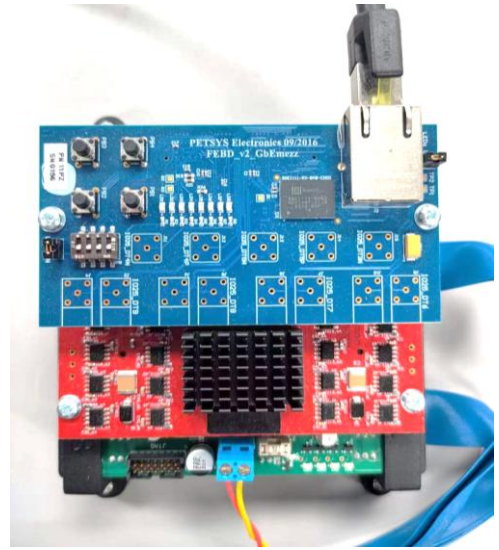
MuGrid detector

Current signal



FEB module&
TOFPET2 ASIC

Digital signal

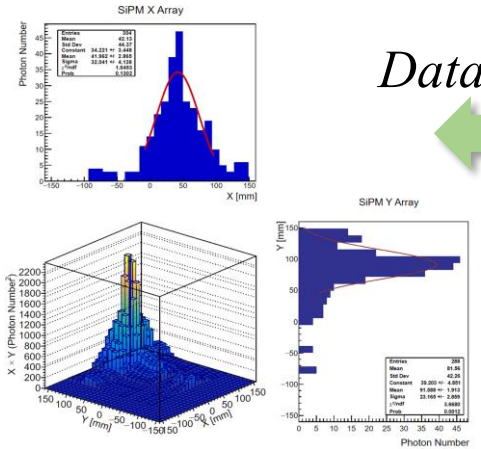


Mother board

Gigabit Ethernet

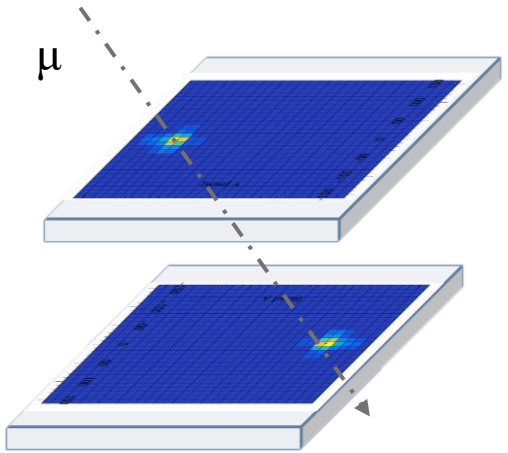
Upper computer

Data acquisition



Hit position reconstruction

Analysis

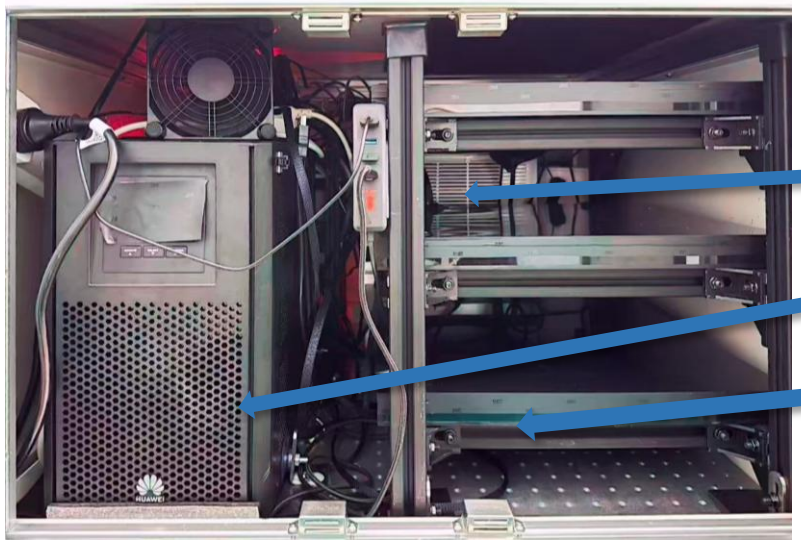


Track reconstruction

MuGrid-v2 open-sky measurement

Three-layer Detector integrated into a protective box, equipped with a UPS for power security, an air conditioner for temperature control and a WIFI module for remote control.

- Dimensions: 1.4m×0.8m×0.55m
- Total Weight: ~50kg
- Power Consumption: ~120W(mainly driven by the AC unit)



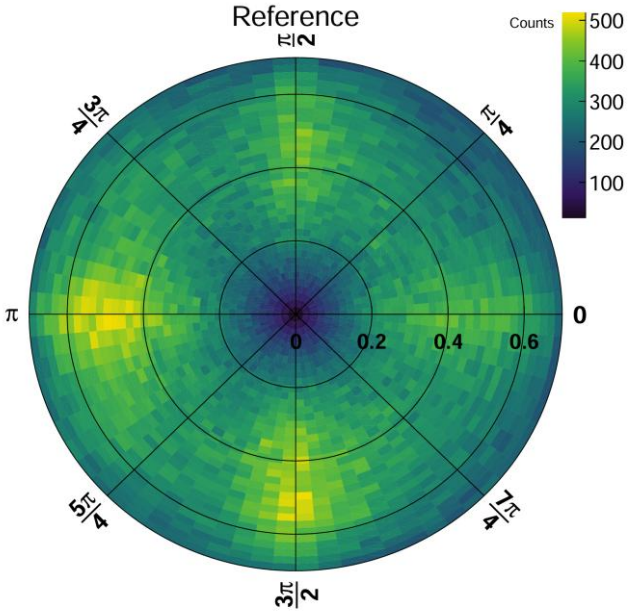
Monitoring camera

Air conditioning

UPS Power

MuGridv2 detector

90hours of open-sky muon flux were collected. Because the detector is square, there is some flux enhancement in the four directions.

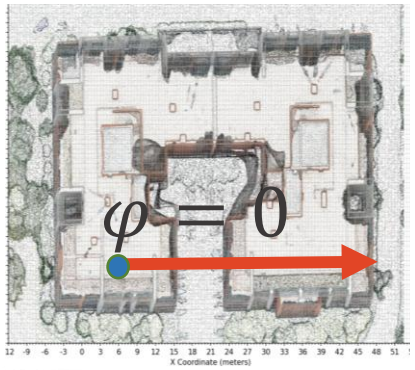


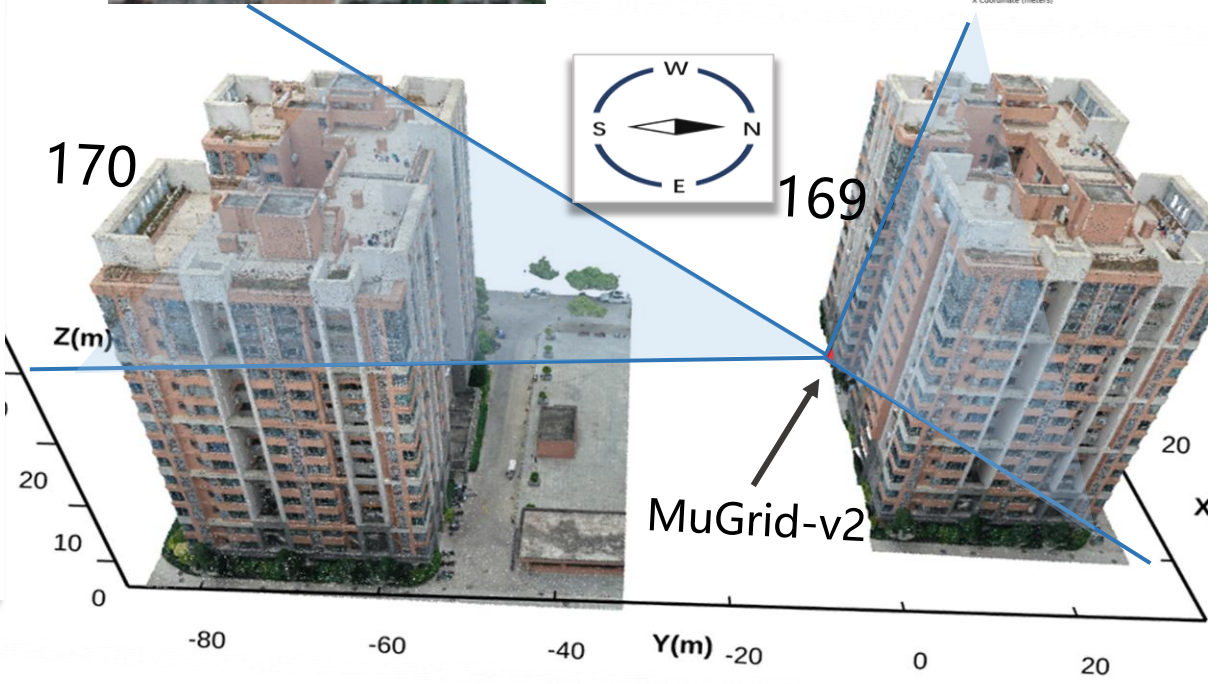
Case study： Dormitory building shadow

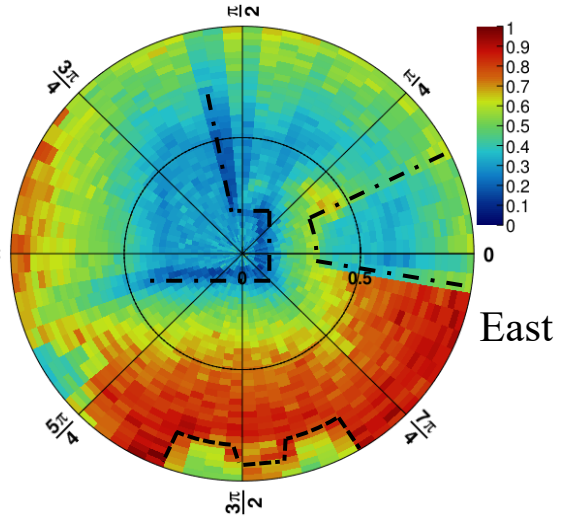
- Drone scanning was used to obtain 3D models of the two dormitories
- The detector is placed in a room on the south side of the first floor of Building 169.
- Significant muon flux reduction observed on the north side due to shielding by Building 169
- Flux suppression at low elevation angles on the south side caused by Building 170

front view ← of 170

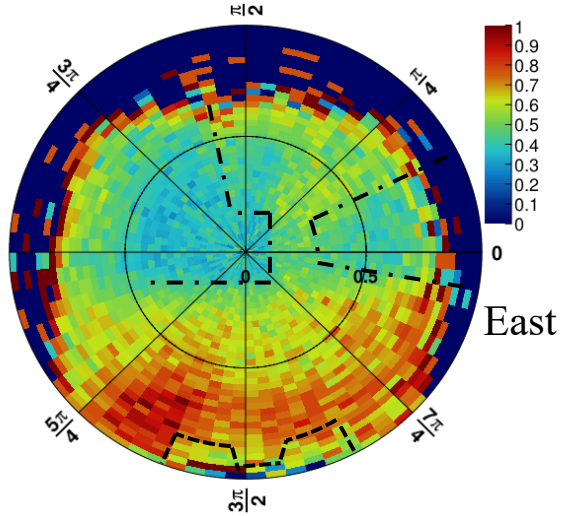
vertical → view of 169







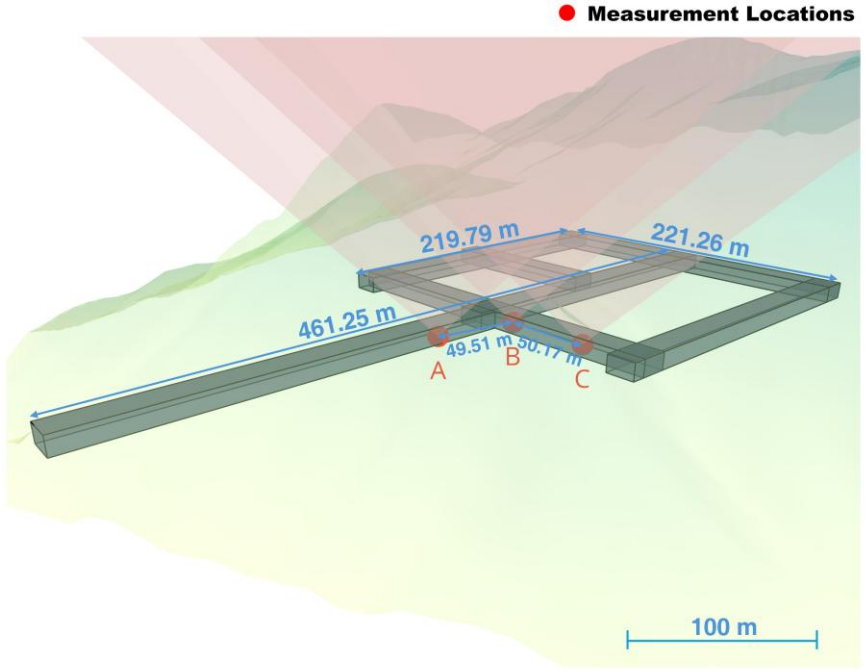
Simulation result

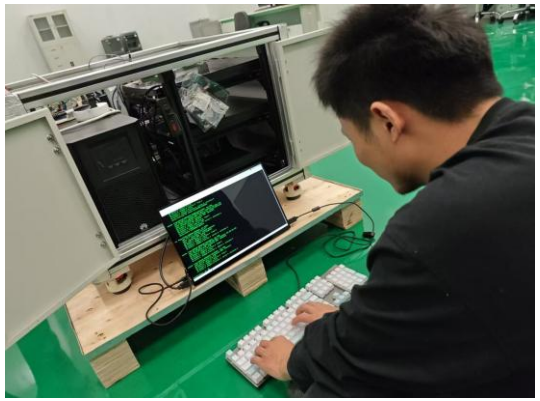


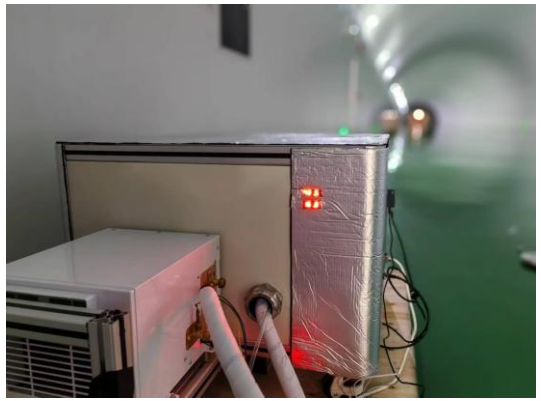
experiment result

Case study： Tianqin tunnel terrain inversion

- We try to perform 3D reconstruction of the mountain's orientation within the detector's field of view.
- 3D topographic model of Tianqin tunnel constructed using LiDAR measured terrain data .
- Detector deployed in three laboratories (A, B, and C) for 7, 14, and 15 days, collecting 10,727, 24,405, and 17,909 valid muon events, respectively



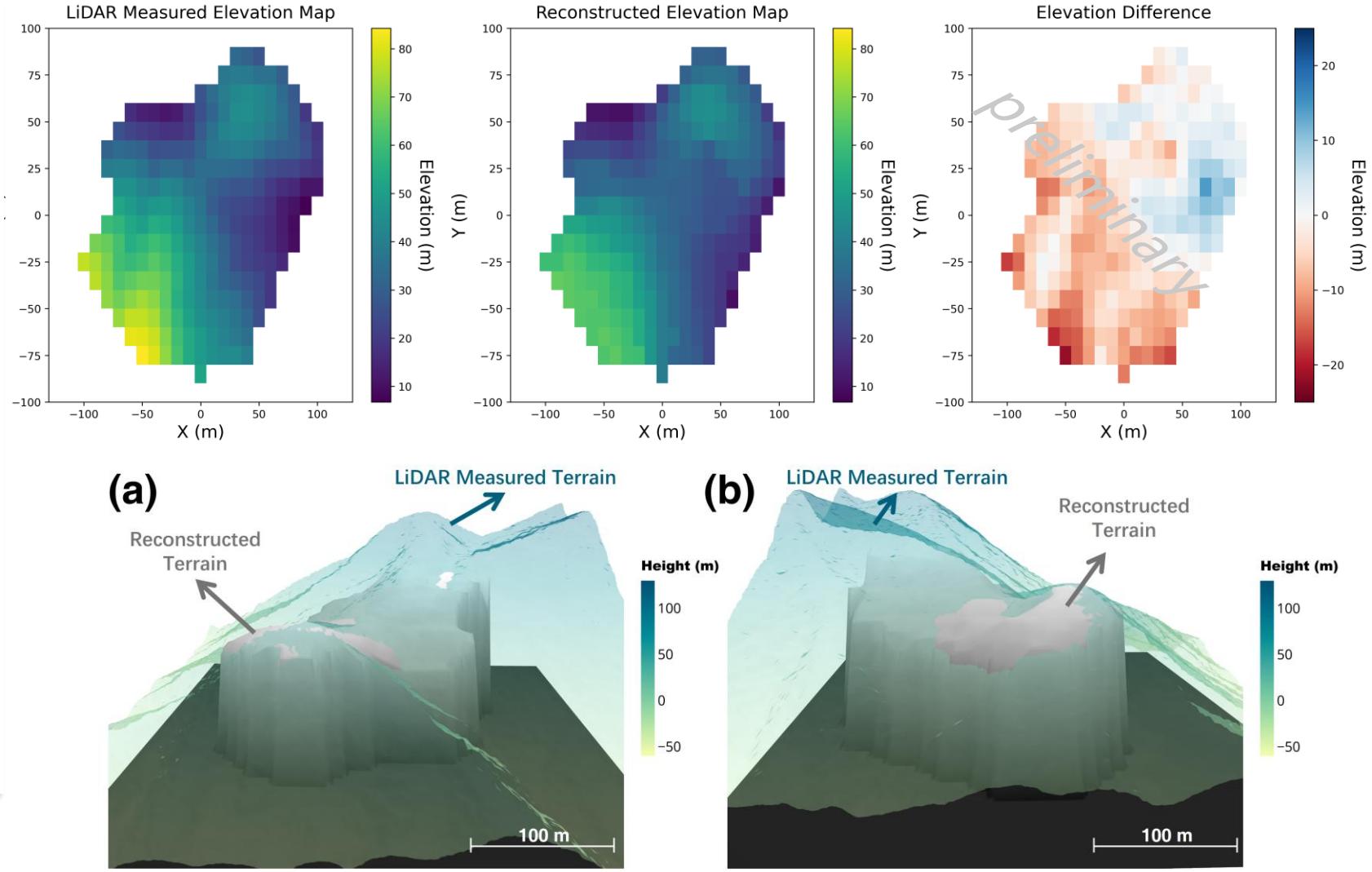





Debugging and measuring location coordinates inside the tunnel

Case study： Tianqin tunnel terrain inversion

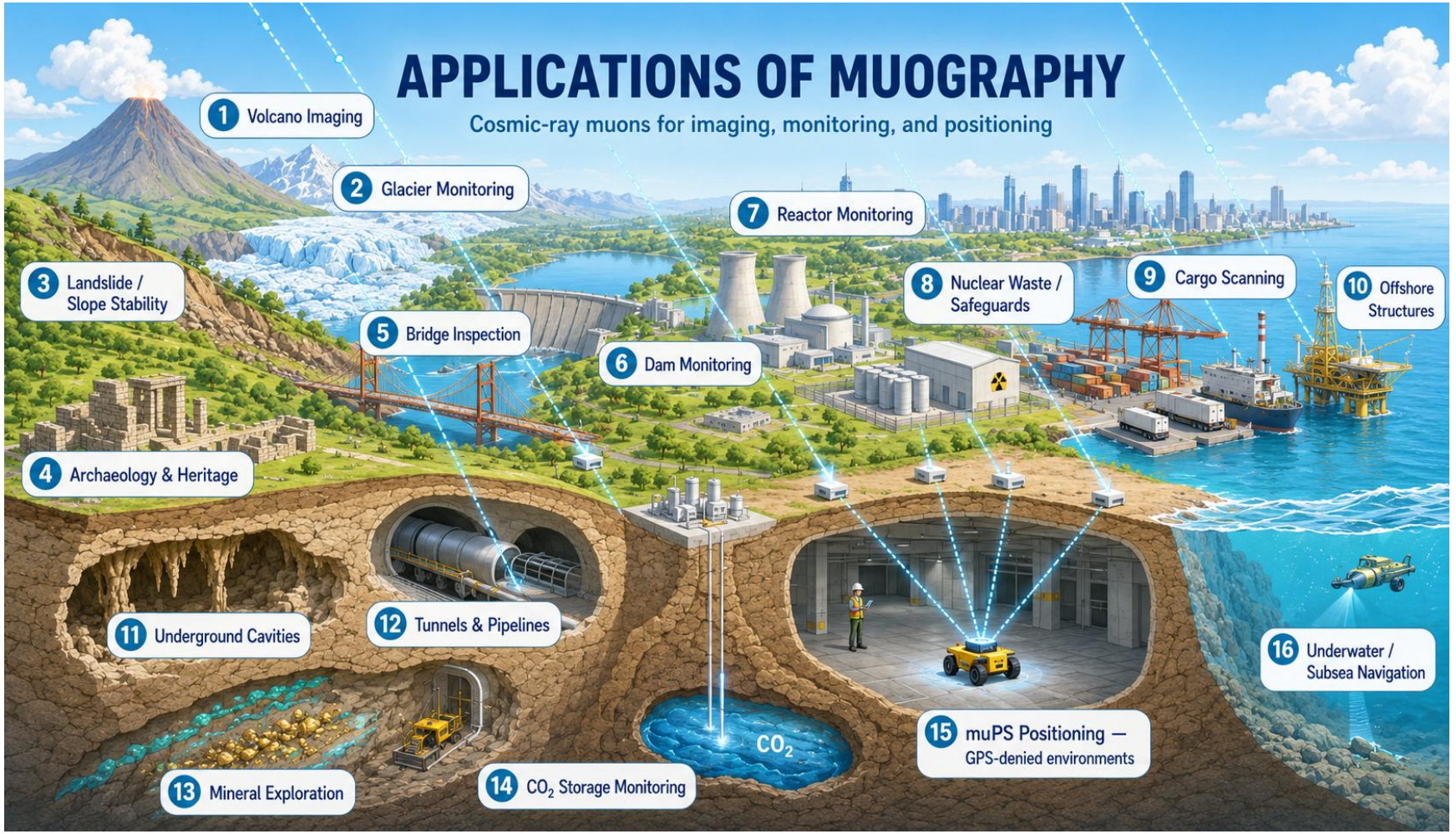
- Colored shell represents the real terrain data. Black-and-white columns represent the reconstructed results
- the reconstructed terrain successfully reproduced the main topographical features overall.
- Mean absolute error: approximately 7m.
- Slight systematic underestimation, possibly introduced by the air cavity of the tunnel.



Terrain inversion results

Summary & outlook

- Proposed a method based on light-guide arrays for low-cost, high-resolution scintillator detectors.
- Built a MuGrid-v2 prototype with a spatial resolution of 4.6 mm
- Performed two outdoor imaging experiments with good agreement to known targets.
- 60cm × 60cm prototype is under development with upgraded materials and better spatial resolution is expected.



Broad horizons, boundless possibilities

Thanks