The ScIDEP Project at the Egyptian Pyramid of Khafre

Shereen Aly, with Michael Tytgat as backup …

on behalf of the ScIDEP Collaboration

Outline:

- Introduction
- Construction of the Detector System
- Experimental work
- Simulation Work
- Summary and outlook

Introduction:

- Muography is potentially useful for discovering voids inside the Great Pyramids

- The first **“muography”** application to investigate Khafre’s pyramid was in 1970 by the Physics Nobel Prize winner L.W. Alvarez, looking for hidden chambers inside it using 4m^2 spark chambers, but nothing was found

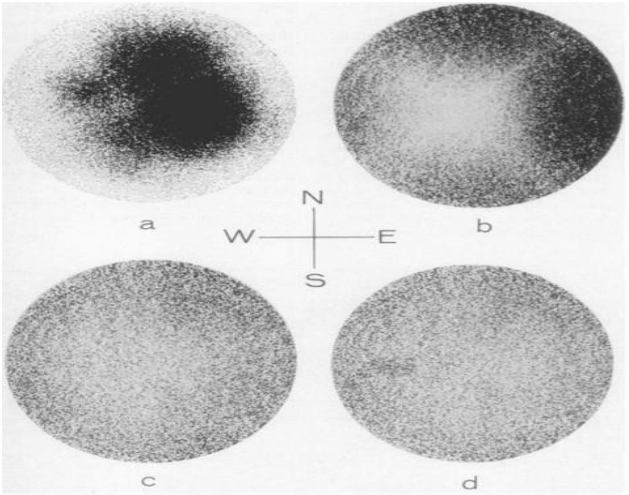


Fig. 13. Scatter plots showing the three stages in the combined analytic and visual analysis of the data and a plot with a simulated chamber. (a) Simulated “x-ray photograph” of uncorrected data. (b) Data corrected for the geometrical acceptance of the apparatus. (c) Data corrected for pyramid structure as well as geometrical acceptance. (d) Same as (c) but with simulated chamber, as in Fig. 12.

[L.W. Alvarez *et al*., “*Search for hidden chambers in the pyramids using cosmic rays*”, Science 167 (1970) 832]

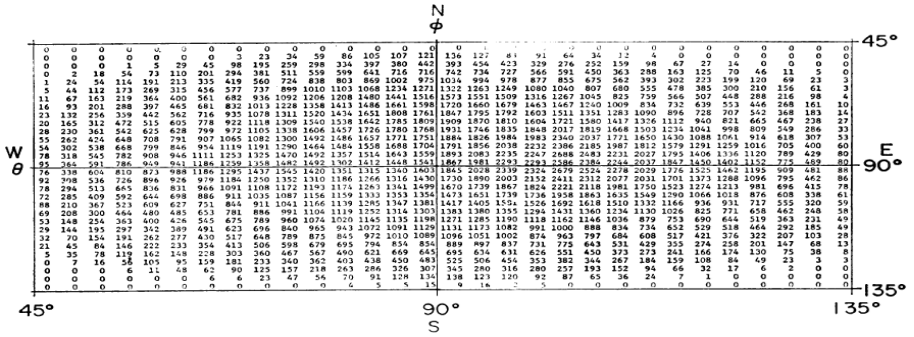
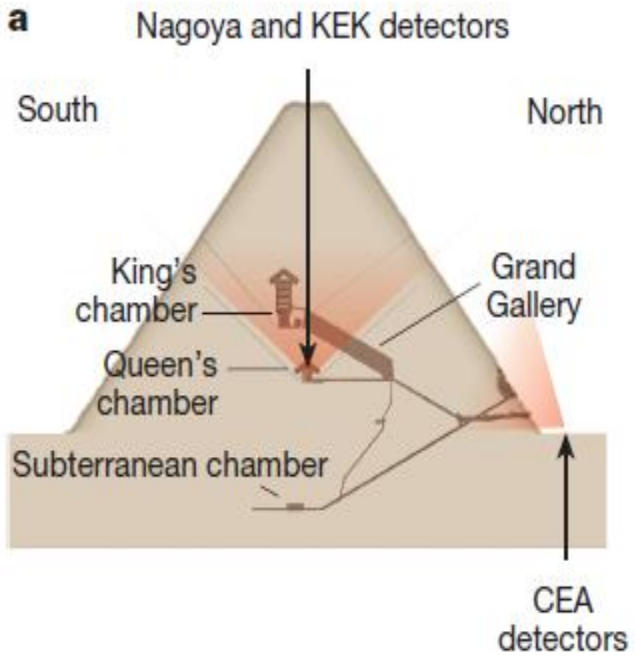


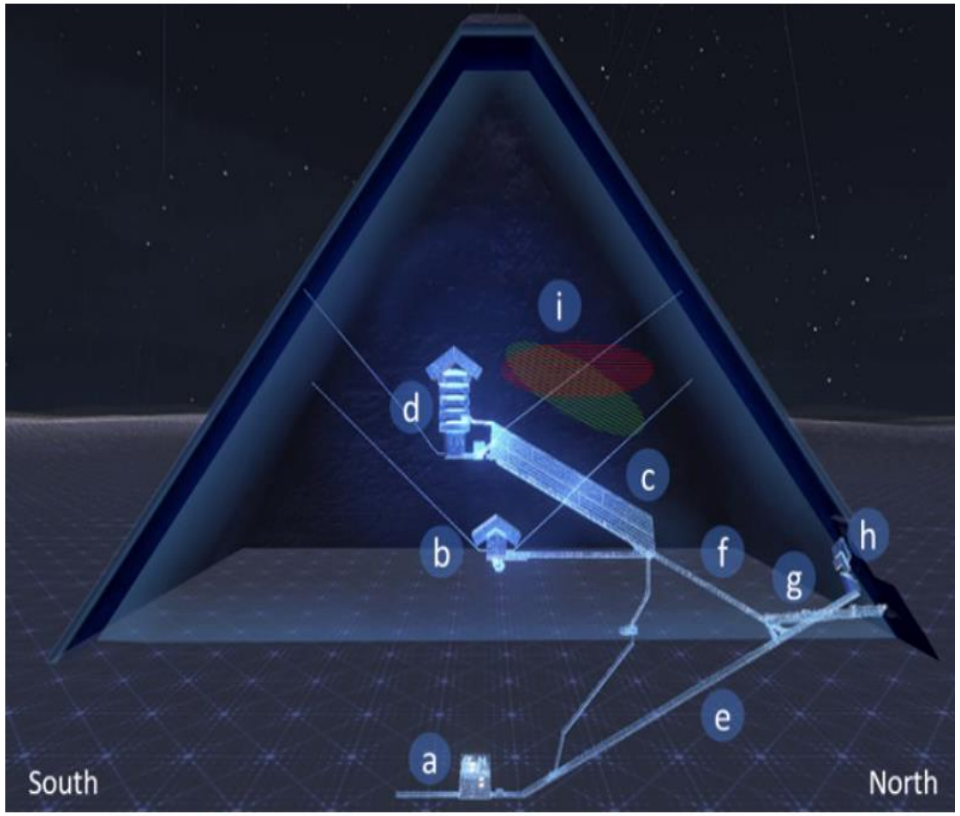
Fig. 8. An array containing the numbers of events (uncorrected) observed during several months of operation in each 3- by 3-degree bin.

Introduction:

- The Muography technique is also used for the discovery of new voids inside Khufu Pyramid by the ScanPyramids project.
- Three different muon detectors were used for the pyramid scan, which are nuclear emulsions, scintillators, micromegas.
- In 2017, a big new void above the Grand Gallery in the Great Pyramid of Khufu was discovered.
- In 2023, ScanPyramids provides detailed data on North Face Corridor behind North Face Shevron



[K. Morishima et al., "Discovery of a big void in Khufu's Pyramid by observation of cosmicray muons", Nature 552 (2017) 386]



Scientists probed a void that lay just behind the north face of the Great Pyramid (illustrated). The void is located behind a chevron-shaped structure visible from the exterior (h). Possible locations of another void, discovered in 2017, are marked in red and green. Known chambers, such as the Queen's Chamber (b), Grand Gallery (c) and King's Chamber (d), are indicated.

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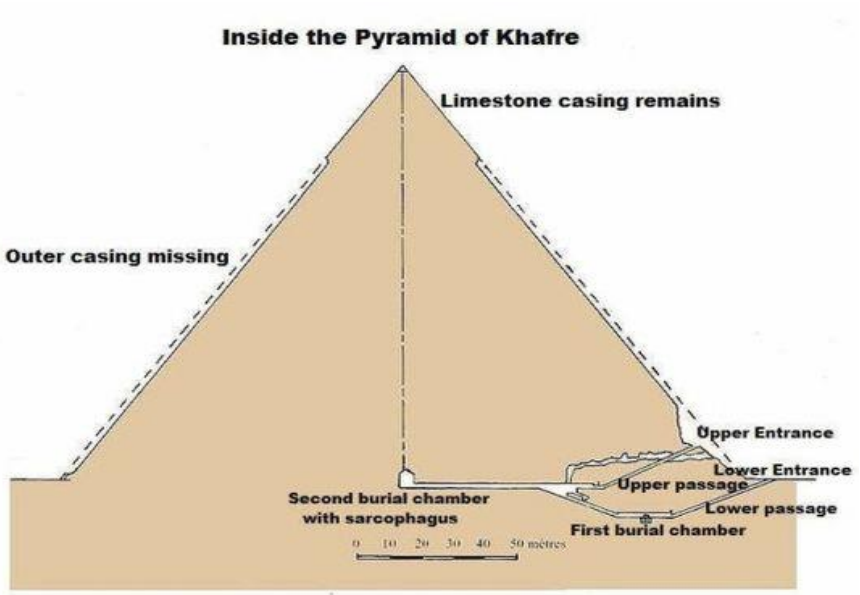
Introduction:

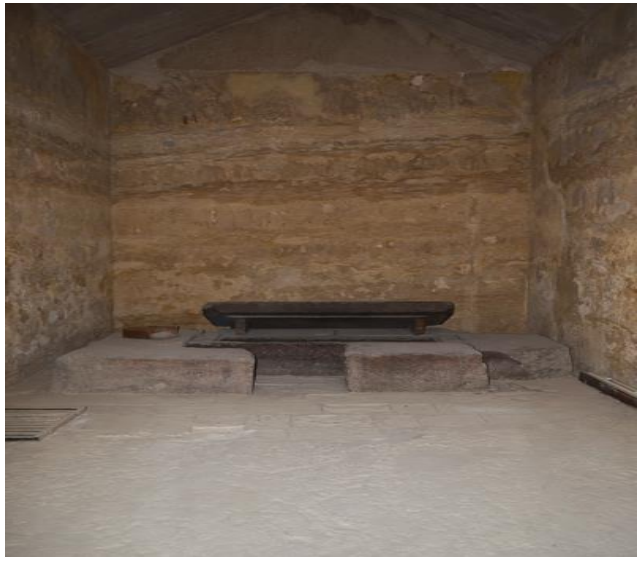
- The ScIDEP (Scintillator Imaging Detector for the Egyptian Pyramids) Collaboration is constructing a new scintillator-based muon telescope to investigate the internal structure of the Pyramid of Khafre at the Giza Plateau in Egypt.
- This pyramid is only slightly smaller than the Great Pyramid, however its known internal structure seems much simpler compared to the latter and hence raises the question if there are any hidden rooms or structures that have yet to be discovered.
- The current project aims to install a new muon telescope inside the king's burial chamber which is located at the very bottom of the pyramid, slightly off-center from the central axis.

Introduction:

- **<u>Layout of Khafre's Pyramid</u>**:

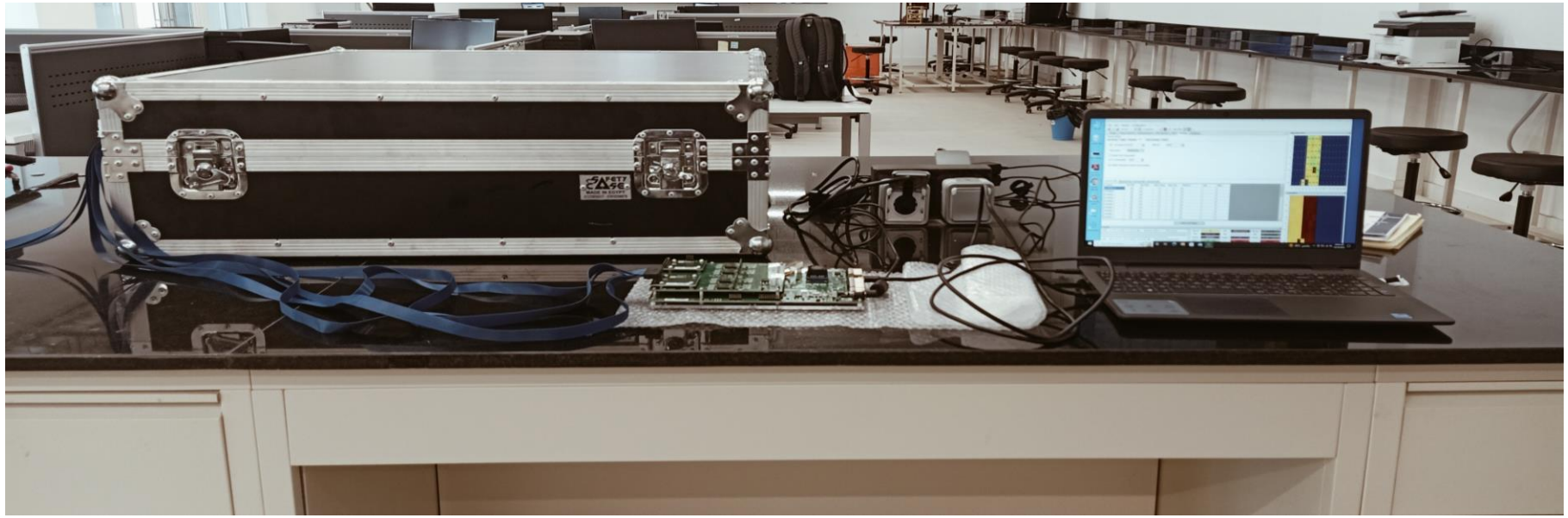
- Original height :143.5 m (471ft)
- Height:136.4 m (448 ft)
- Base's length: 215.25 m (706 ft)
- Volume: 2,211,096 m³
- Slope: 53°10'





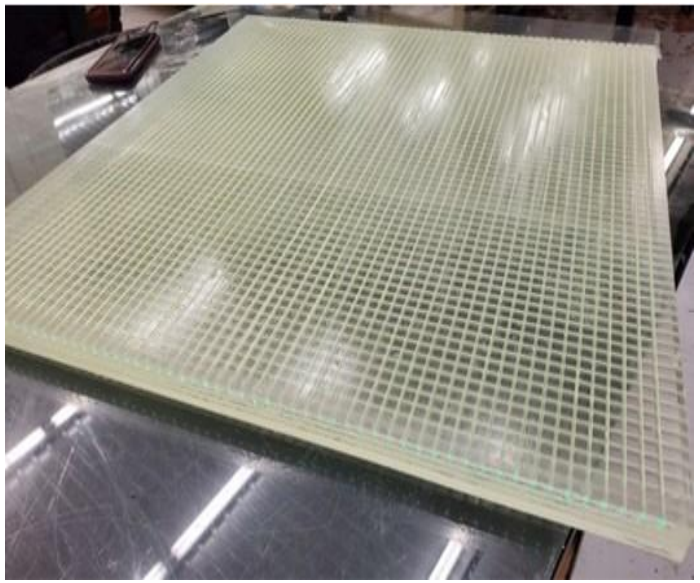
Room and burial chamber of king Khafre

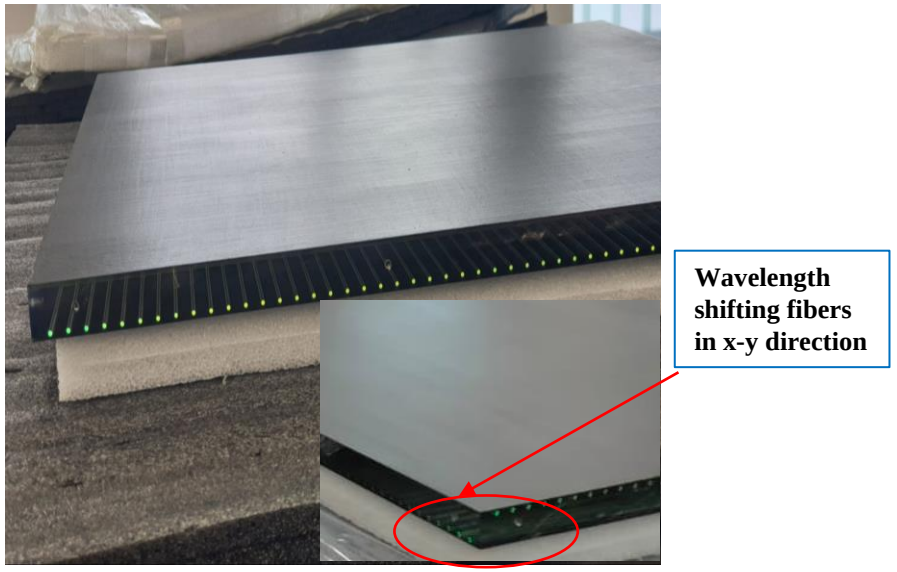
Construction of the detector system



Construction of the Detector system:

- The Detector system consists of EJ-200 (Eljen Technology) polyvinyl toluene (PVT) scintillator planes of 61 x 61 x 2 cm^3 active area.
- BCF-92 (Saint-Gobain) 2 mm diameter wavelength shifting fibers, embedded in both faces of each scintillator plane in 3 mm deep grooves spaced at 1 cm in orthogonal X-Y directions, i.e. 60 fibers per direction per plane.

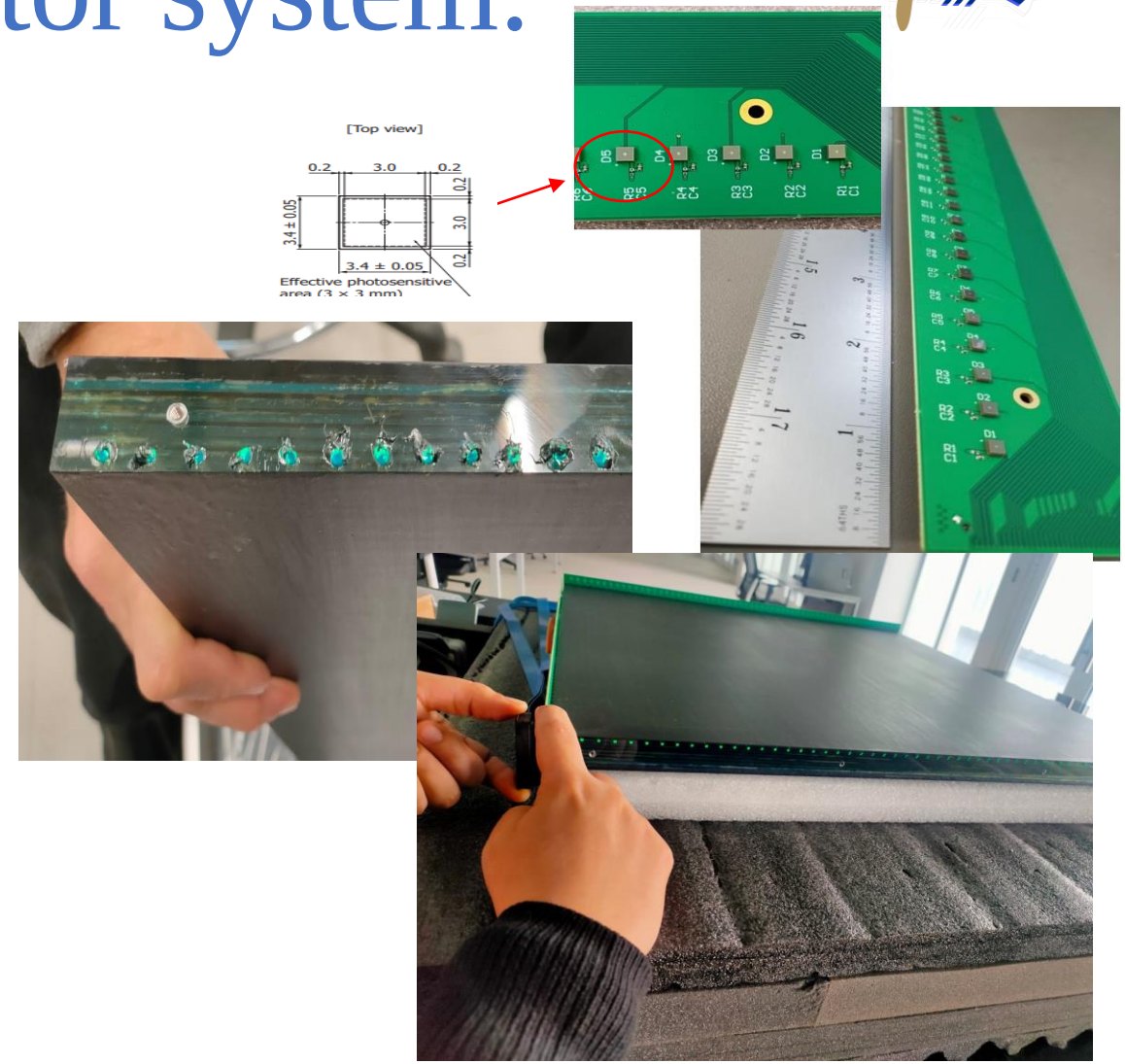




Construction of the Detector system:

- Each end of the fiber is connected to a S14160 (Hamamatsu) Multi-Pixel Photon Counter (MPPC) for the light readout .

- The MPPCs are mounted to a custom made PCB (Nalu Scientific), and connected to the scintillator using an optical grease.

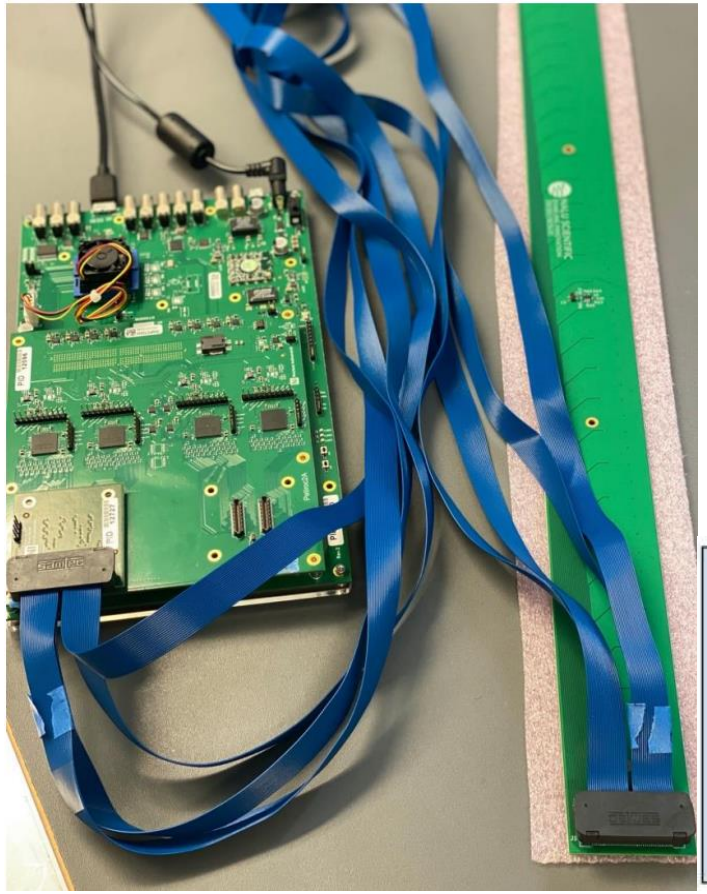


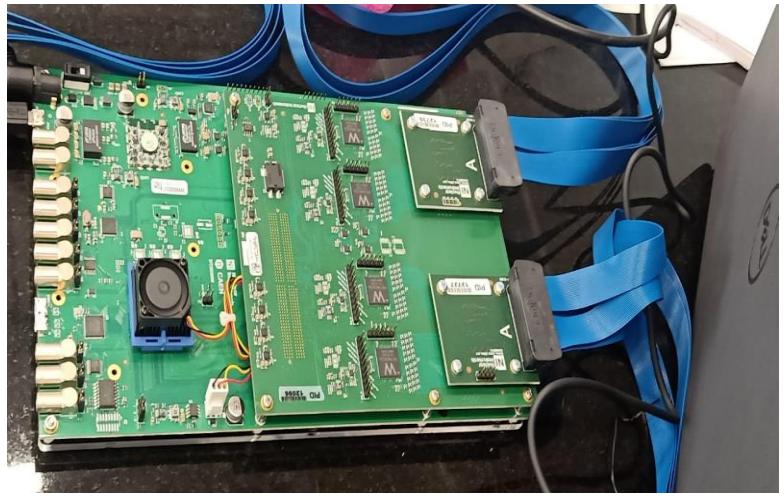
Construction of the Detector system

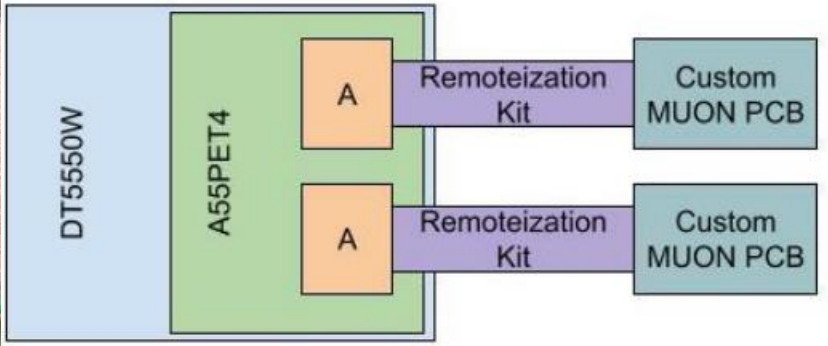
The Muon board readout signal is received in DAQ system that uses CAEN DT5550W motherboards with two A55PET4 piggybacks mounted to it.

Each of the piggybacks attached to a motherboard consists of 128 channels, distributed over 4 PETIROC2A ASICS, i.e.
ASIC0: (0-31)A
ASIC1: (0-31)B
ASIC2: (0-31)C
ASIC3: (0-31)D
enough to read one detector XY plane

DT550W has on-board power supply for SiPM bias (20-85V)





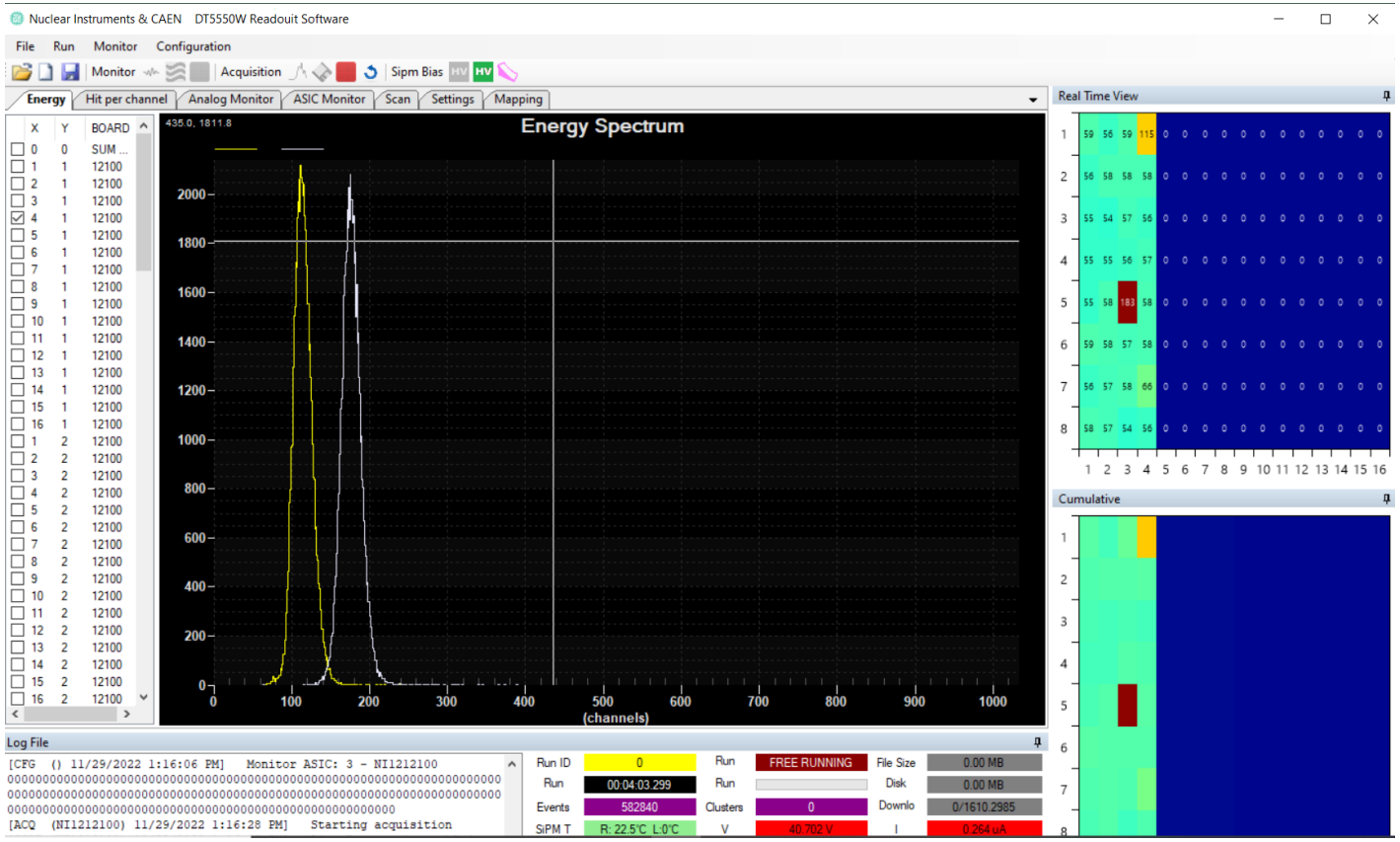


Experimental Work

SCI-5550W readout software:

The DAQ software is used to set the HV bias of the SIPMs.The output can be seen as a real time plot during the run where the charge value of each channel corresponding to each SIPM on the muon board is shown . The parameters of the run can be controlled (e.g. time thresholds, delay, trigger type, etc..).

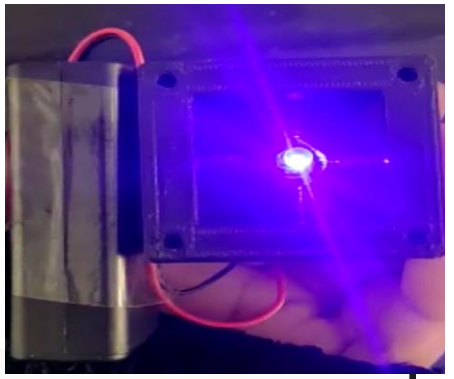
Many parameters like the Energy spectrum, ASIC number and hits per channel, the dark current and SIPMs temperature are monitored.

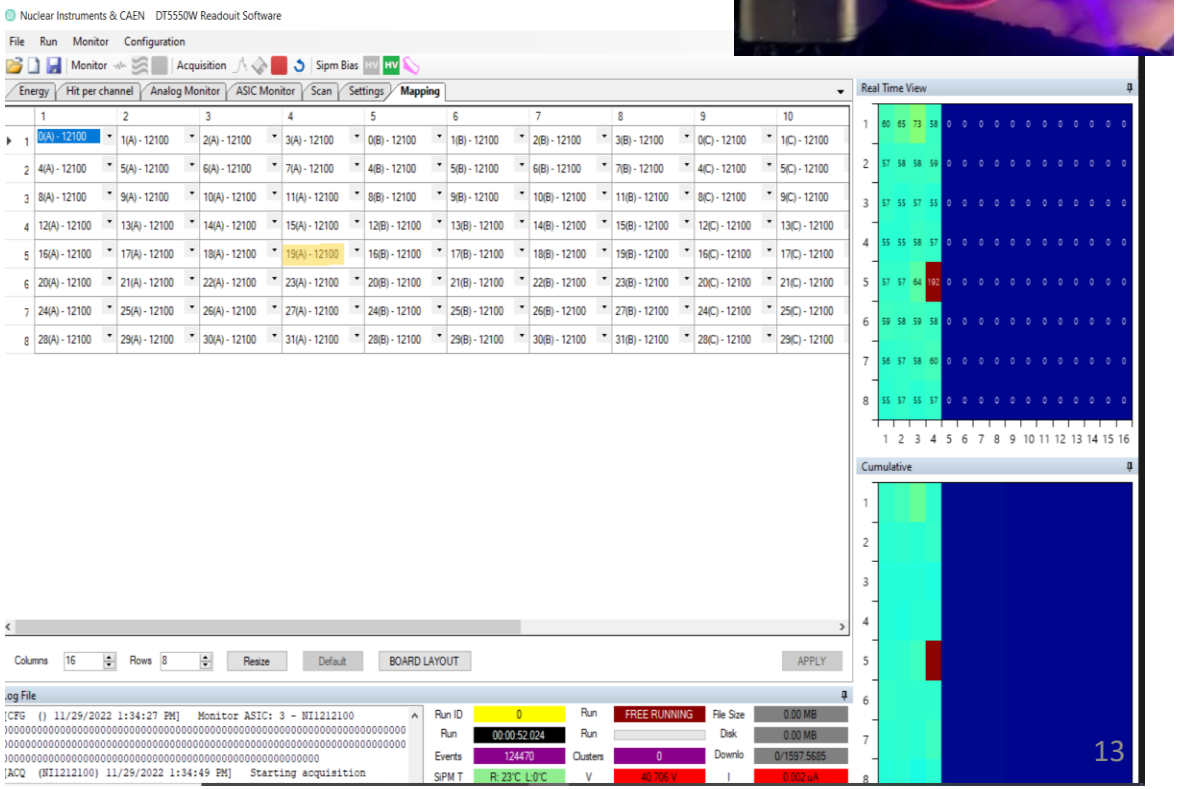


Detector Commissioning

1. Muon board Mapping:

- Each Channel on the DT5550W system should be corresponding to each MPPC on the muon board. All the SiPMs are tested individually using RGB led, each SiPM is exposed to it, while the rest of them are completely covered. The corresponding channel is shown on the real time view plot that shows the charge value of the channel.
- E.g. The figure shows the highest charge value of the channel 19(A) that is exposed to the RGB led, and it corresponds to SiPM no.12

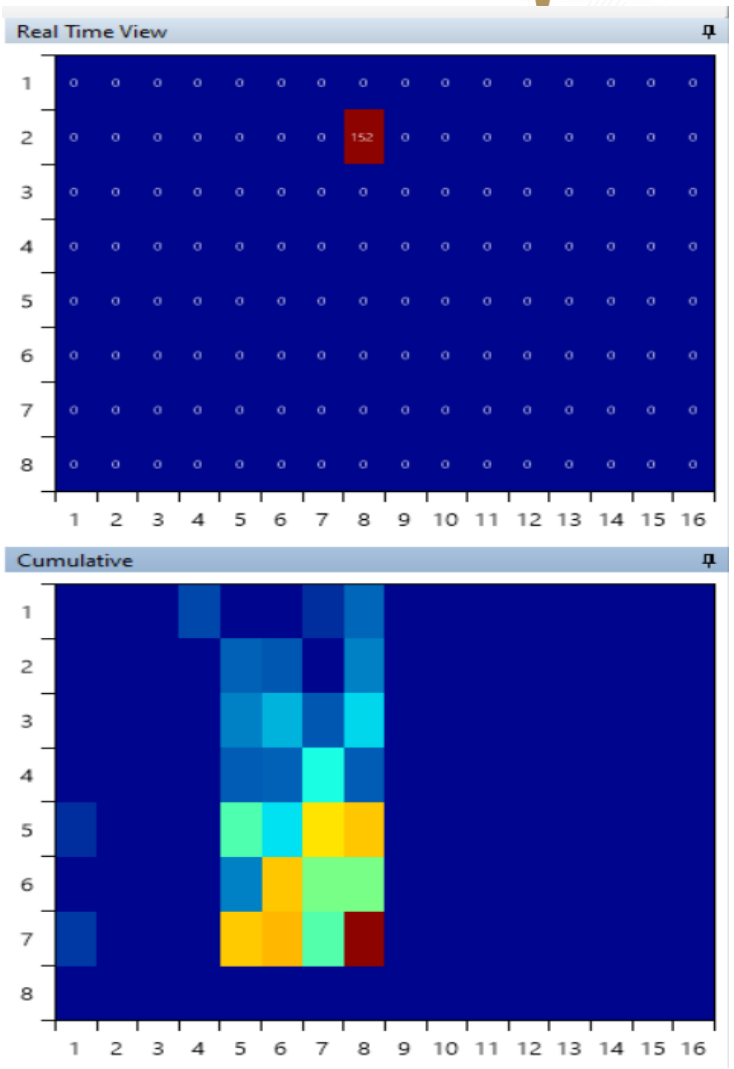




Detector Commissioning:

2. <u>Scintillator localization test:</u>

- a ^{60}Co gamma source of 1 microCurie is used for the localization test of the scintillator fibers, the source is effective up to 6cm from the SiPMs
- The figure on the right bottom shows the accumulation of the charge values into 4 channels, i.e. SiPMs where the radiation source is located, the bias voltage of the SiPMs is 41V, internal trigger delay is 8ns and input pulse time threshold is 800ns



Detector Commissioning:

Ongoing tests:

- Performance with cosmic ray muons.
- Setting best delay.
- Adjustment of time threshold.

Longer future:

- First outdoor test of the full system inside in the tunnels of E-JUST, Egypt
- In the end, moving the system to the Khafre pyramid.

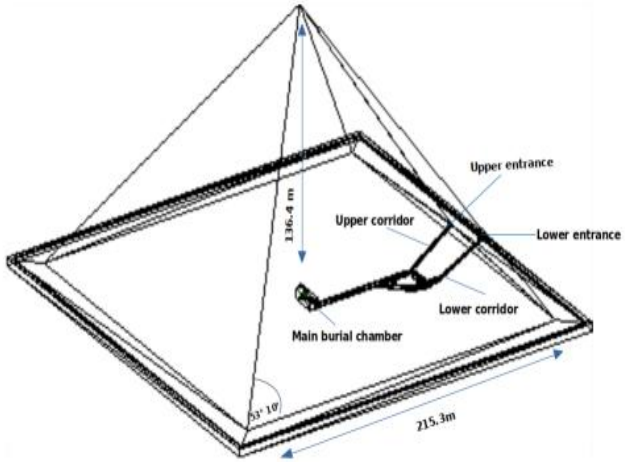
Simulation Work

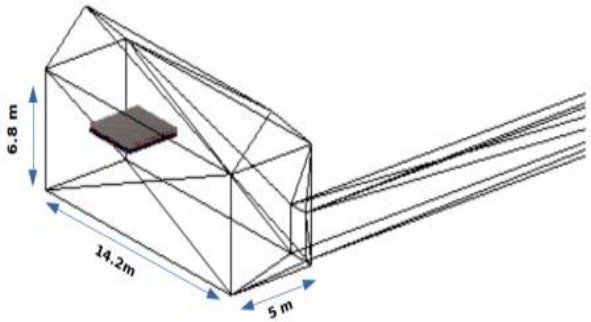
Simulations:

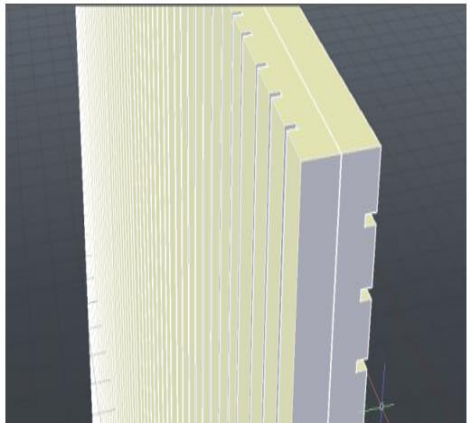
- Simulations for the muon radiography measurements of the Khafre pyramid have been carried out with both Geant4 and MCNP .

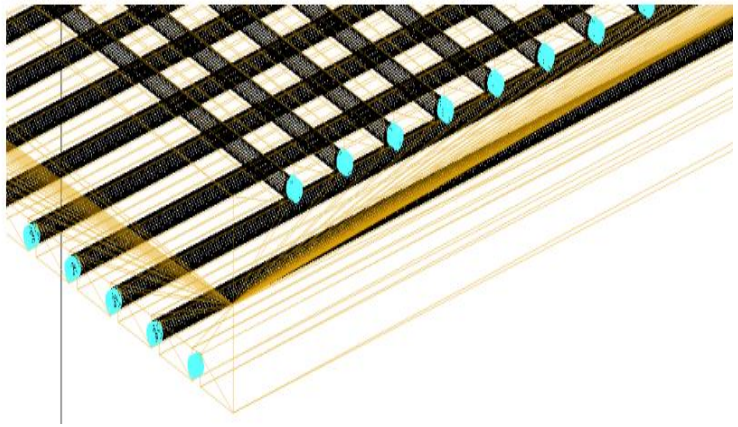
GEANT4:

- Full simulation of our study is on going .
- CRY cosmic muon generator.
- A CAD model of the Khafre Pyramid and the detector design are imported into GEANT4.
- Geant4 detector model and muon transport through pyramid and detector with full modeling of scintillator planes, fibers, MPPC geometry and optical properties to use Optical Photon processes



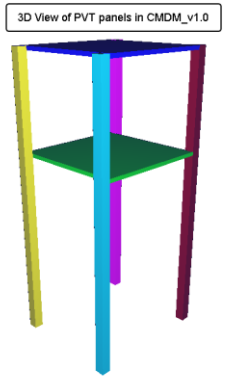


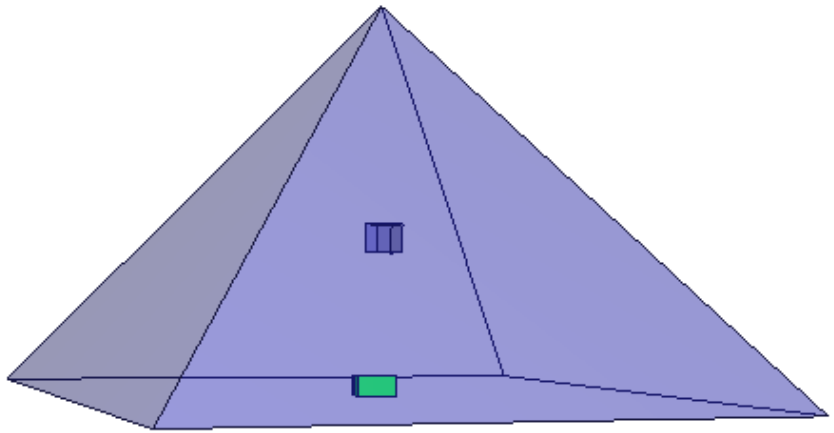




Simulations:

- **MCNP:** The Monte Carlo n-particle (MCNP) version 6 simulation package was used in several iterations to build a model of the Khafre pyramid with the detector at its center at ground level. The detector was modeled as two PVT plates separated by 50 cm supported by four legs.

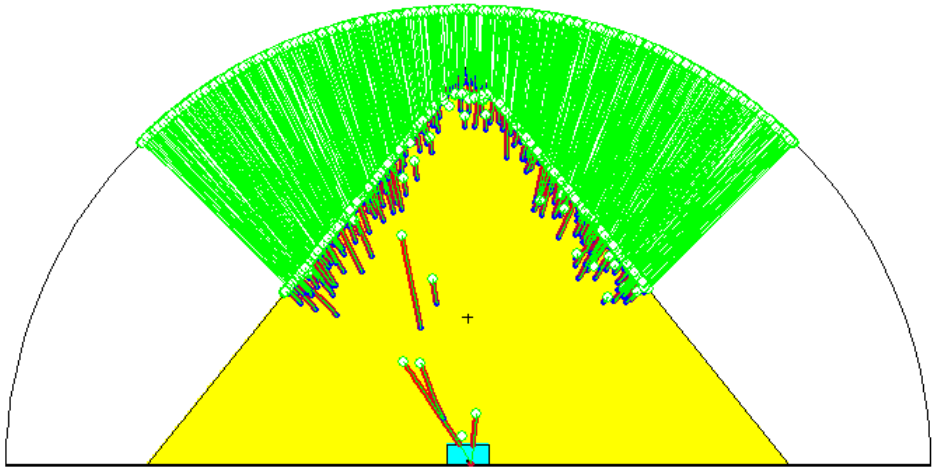




Simulations:

MCNP:

- Muons with energies above 50 GeV were modeled as a hemispherical dome of radius 155 m that emitted muons inward with a bias (forcing particles in a certain direction) of 2000 so that all muons were directed toward the detector region.
- The source was limited to the angular region of 45 degrees from the vertical since muons at larger angles could not pass through both of the PVT detector planes.
- For simplicity, the angular distribution was taken as uniform rather than a $\cos^2$ distribution.



Summary and outlook:

- The ScIDEP Collaboration aims to install a new muon telescope inside the burial chamber of the Pyramid of Khafre.
- Base version of the telescope consists of two scintillator plates with embedded fibers in X-Y orientation, readout by SiPMs.
- Data-acquisition based on CAEN Weeroc digitizer system.
- Construction of detector components and electronics has been completed; final detector assembly and commissioning ongoing in Egypt.
- Full simulation package for the setup under development using CRY, Geant4 and CAD model of pyramid

➢ Aim for first test measurements in the lab with full telescope in 2023

ScIDEP Collaboration:

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R.T. Kouzes et al, "Novel Muon Tomography Detector for the Pyramids", Journal of Advanced Instrumentation in Science (2022) 240 DOI: https://doi.org/10.31526/jais.2022.240 S. Aly et al., "Simulation Studies of a Novel Muography Detector for the Great Pyramids", Journal of Advanced Instrumentation in Science (2022) 306 DOI: https://doi.org/10.31526/jais.2022.306

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Thank you!