Micromegas Based Muon Telescopes for The ScanPyramids Mission

- Performance & First Results -

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8th SYMPOSIUM ON LARGE TPCs FOR LOW-ENERGY RARE EVENT DETECTION

Outline

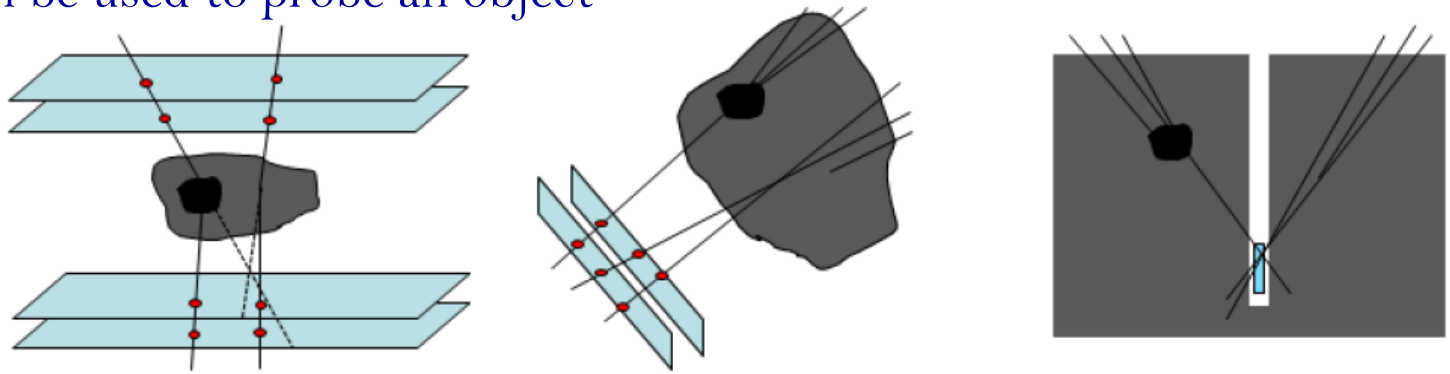
- Muon tomography
- Genetic Multiplexed Resistive Bulk Micromegas
- Demonstrator for a Water Tower (WatTo) imagery
- WatTo to ScanPyramids
- Installation at the Khufu Pyramid
- Results
- Conclusions

Muon Tomography

- Muons from cosmic rays interacts with matter and can be either **deviated** by Coulomb scattering or **absorbed**
- Deviation and absorption depend on
  - material length
  - density

Material	Thickness	θ (deg)	$P_{absorption}$
Air	100 m	0.094	0.78%
Lead	1 cm	0.28	0.49%
Lead	10 cm	1.01	2.9%
Water	1 m	0.35	4.2%
Limestone	1 m	0.74	9.5%
Limestone	100 m		99%
Limestone	1 km		99.999%

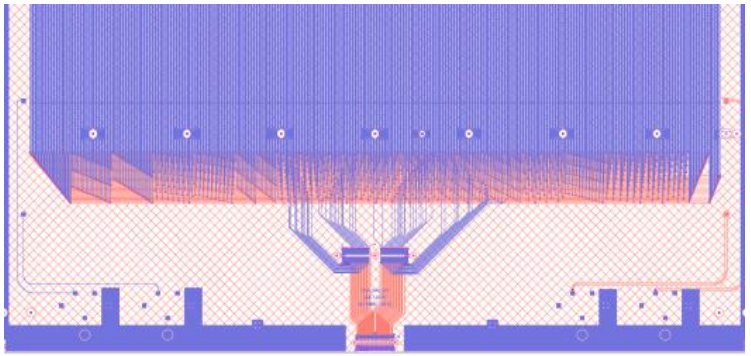
- can be used to probe an object

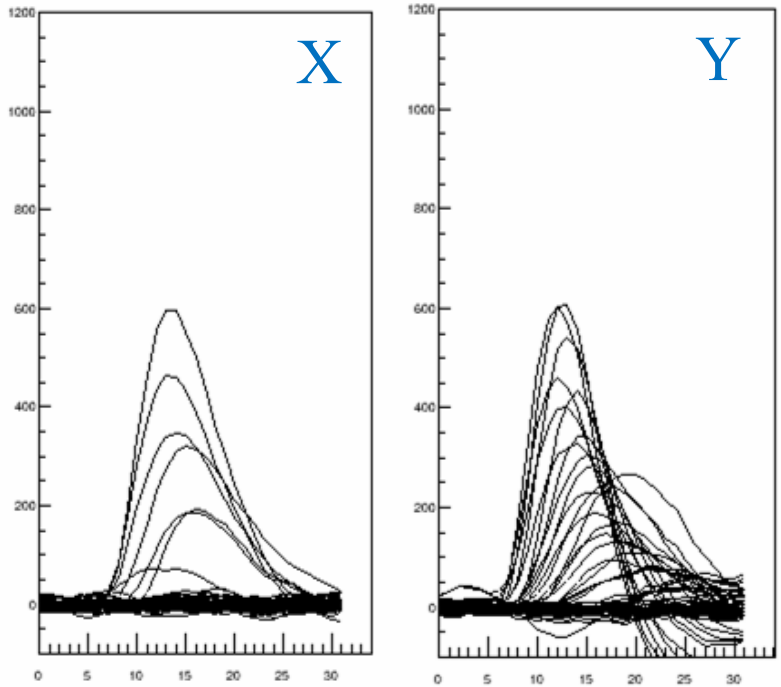


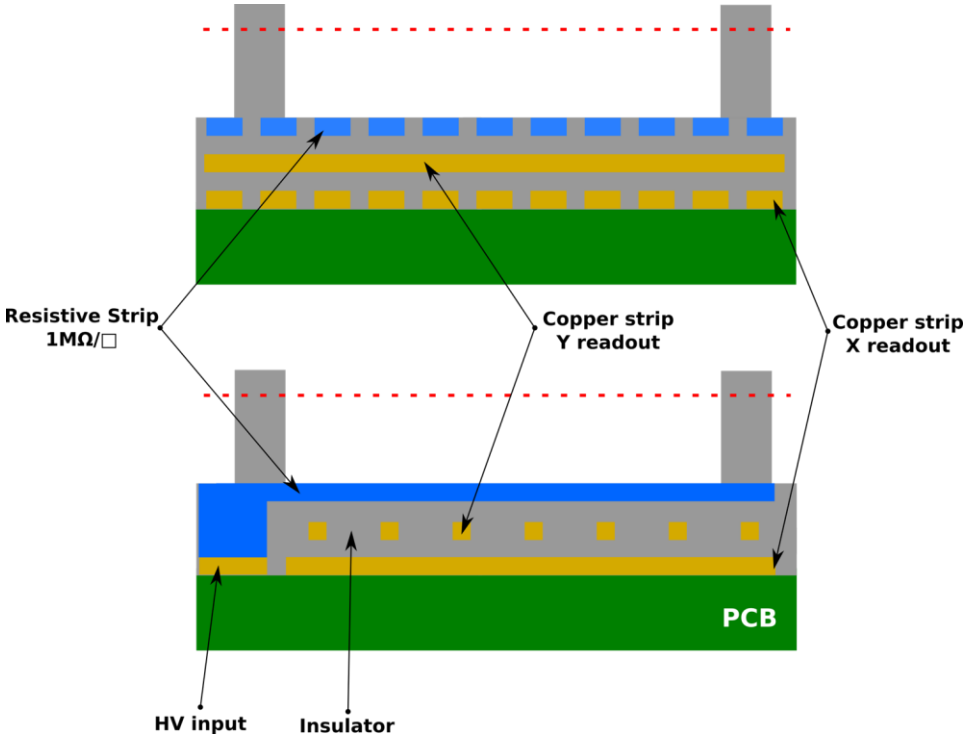
  - Many applications in the world: homeland security, volcanology, archeology, mining, …
  - In France: Diaphane, TomuVol, Geo-Azur
  - Why another one? *Micromegas offer spatial resolution 10-20 times better*

Genetic Multiplexed Resistive Bulk Micromegas

- Bulk Micromegas technology (1996, 2005)
- Genetic multiplexing readout (2012)
- Resistive strips X & Y (2010, 2012)
  - capacitive induction
  - spread signal over several strips

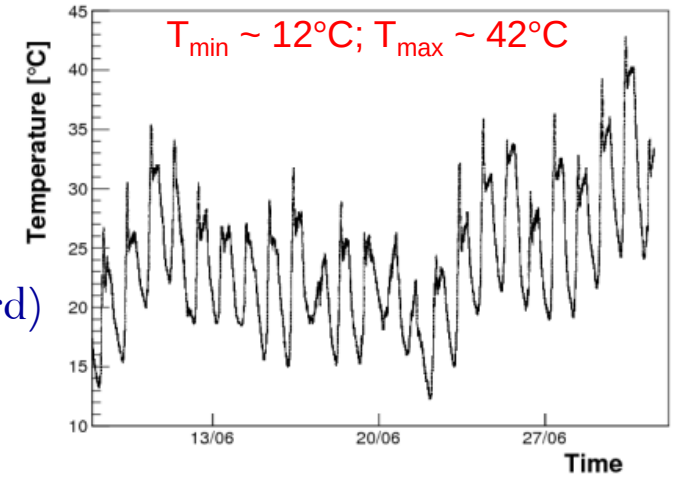


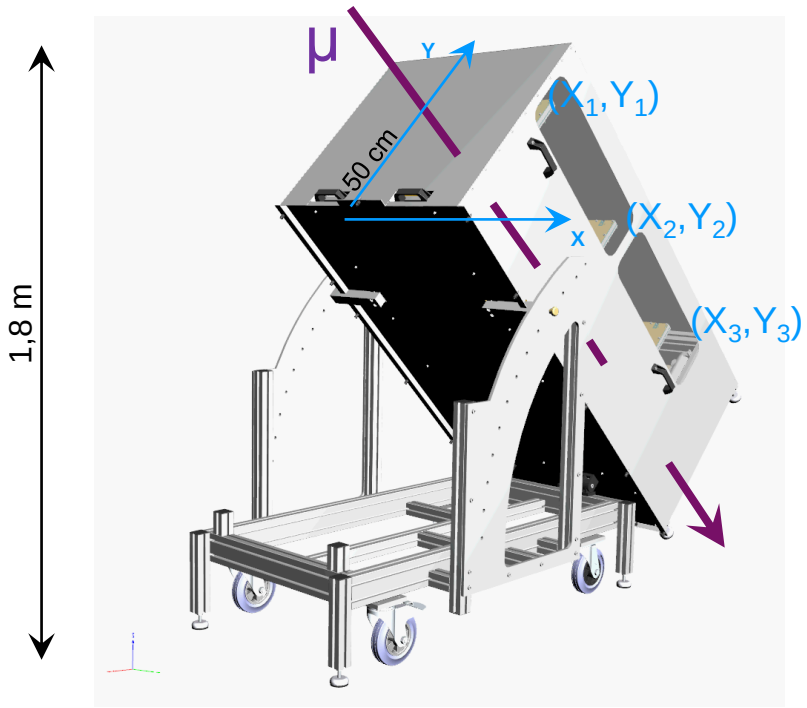




WatTo (Water Tower): Micromegas Muon Telescope

- 1st muon telescope with multiplexed Micromegas
  - 1st use of Micromegas outside: gain stability f(T,P)
  - Self trigger mode of Particle Physics electronics
  - Compact electronic system (nano-PC, specific HV card)
  - 30 W power consumption

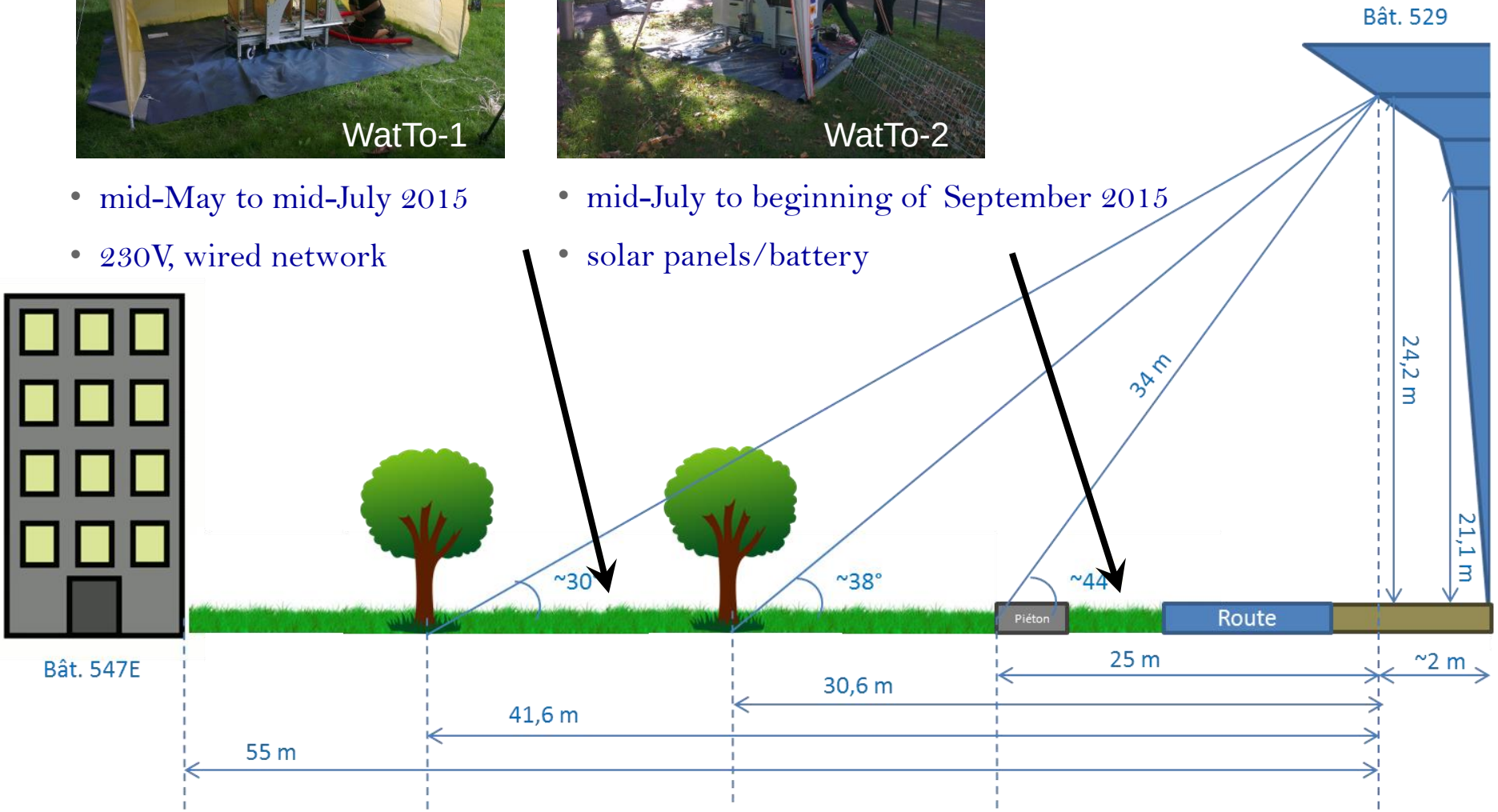




WatTo Configurations

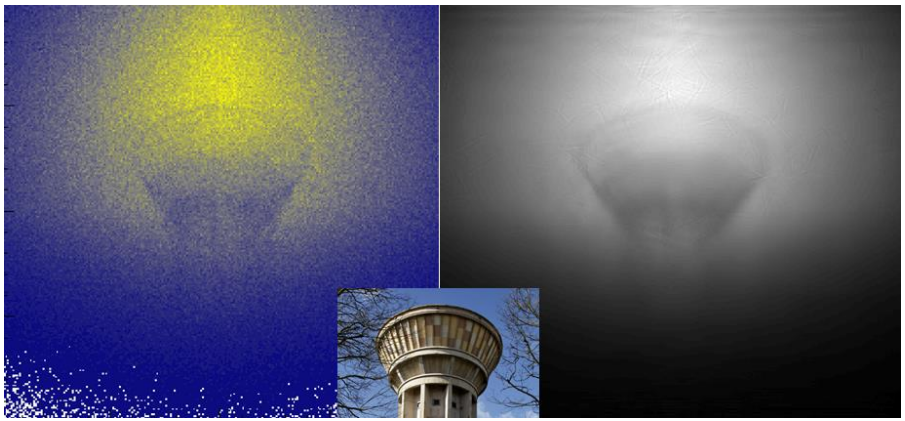
- mid-May to mid-July 2015
- 230V, wired network

- mid-July to beginning of September 2015
- solar panels/battery



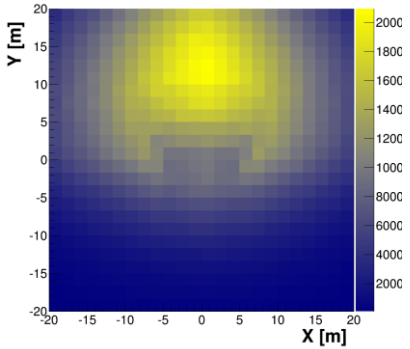
WatTo Results

- WatTo-1: 4 weeks of data

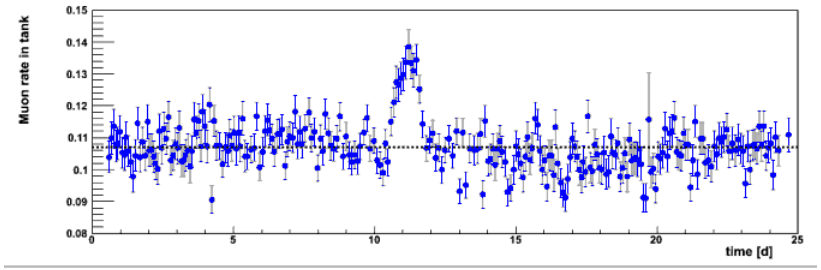


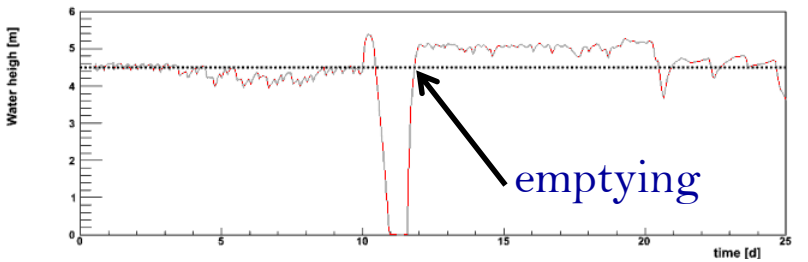
4 weeks of data

Scintillators resolution @ same compactness

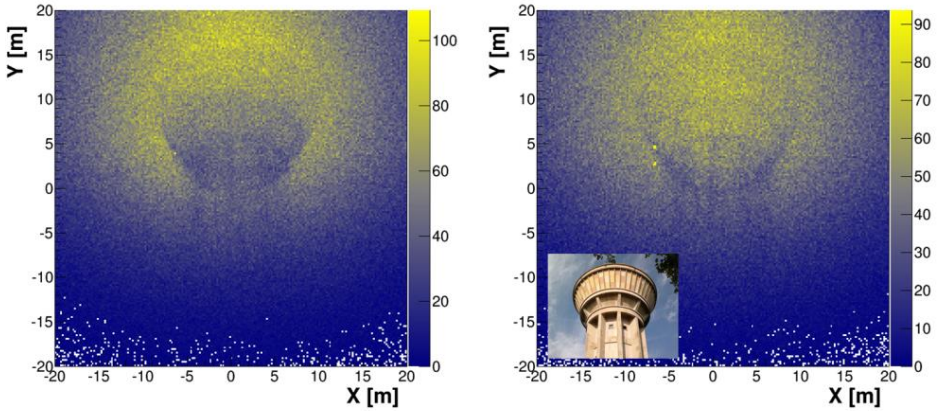


- WatTo-2 (solar boards + dynamics)





4 days of data each

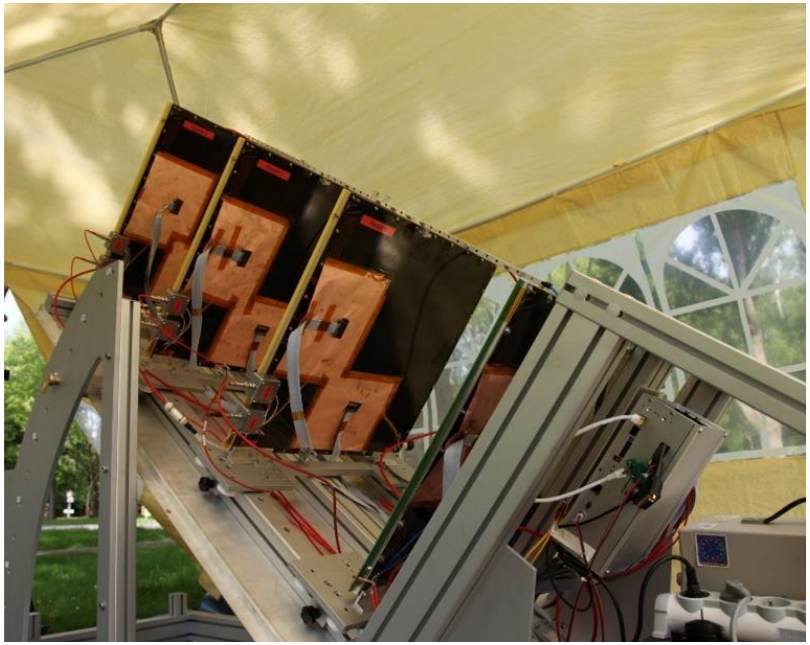


Bouteille *et al.*, NIMA 834 (2016) 222–228

⇒ ***Validation of the most precise muon telescope in the world***

WatTo → ScanPyramids

- Telescopes: 1 → 3
- Mechanical structure → case
- Detectors: prototype (Cern) → final version (built by PCB's company Elvia)
- Construction time: 9 monts → 3 months
- Weight: ~ 200 kg → ~ 130 kg
- Detector power supply: no temperature feedback → f(T)
- Data: raw → raw + pre-processed



SCAN PYRAMIDS

HIP.INSTITUTE HERITAGE INNOVATION PRESERVATION

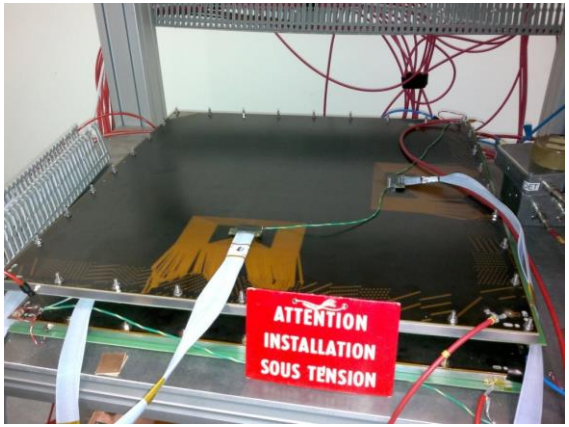
ARAB REPUBLIC OF EGYPT MINISTRY OF ANTIQUITIES

FACULTY OF ENGINEERING CAIRO UNIVERSITY

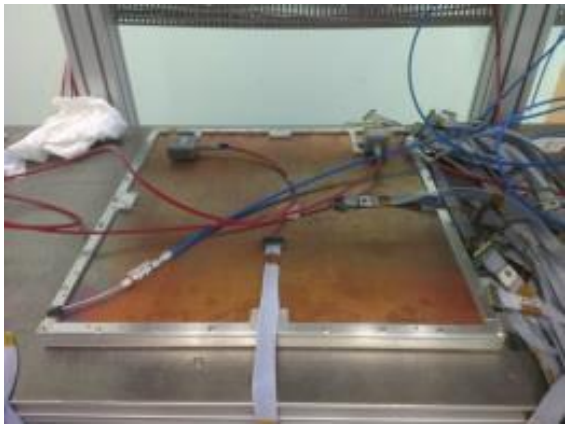
www.scanpyramids.org

Detection Plane Evolution

Prototype (2014)



Version 2 (2015)

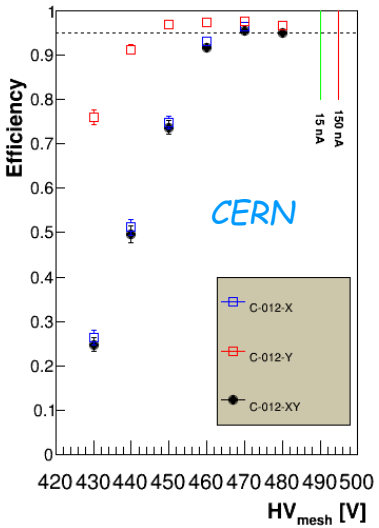


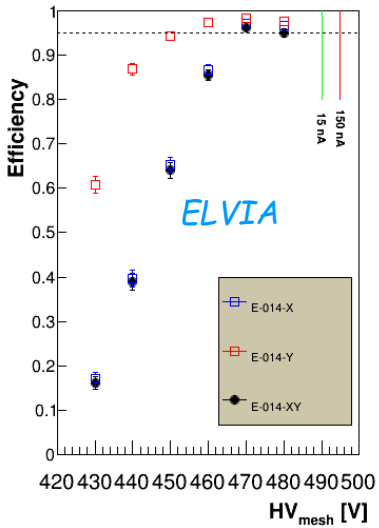
- Better shielding
- 13 strips added
- Decreased dead space
- Mechanics improved

Bouteille *et al.*, NIMA 834 (2016) 187–191

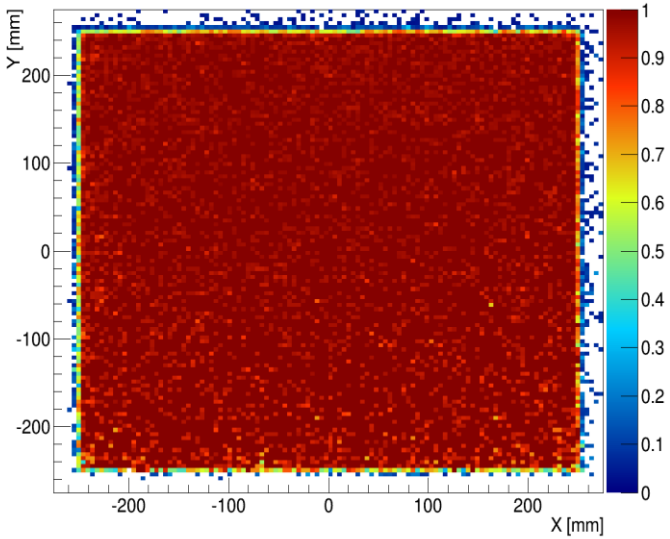
- Detector performance

Efficiency vs. HV





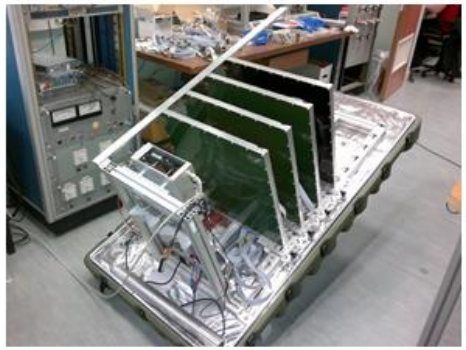
2D Efficiency



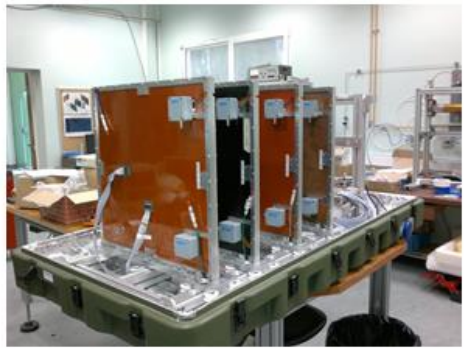
Installation at Khufu Pyramid

- 3 telescopes installed in front of the Khufu (Cheops) Pyramid end of May 2016

Alhazen (n°1)

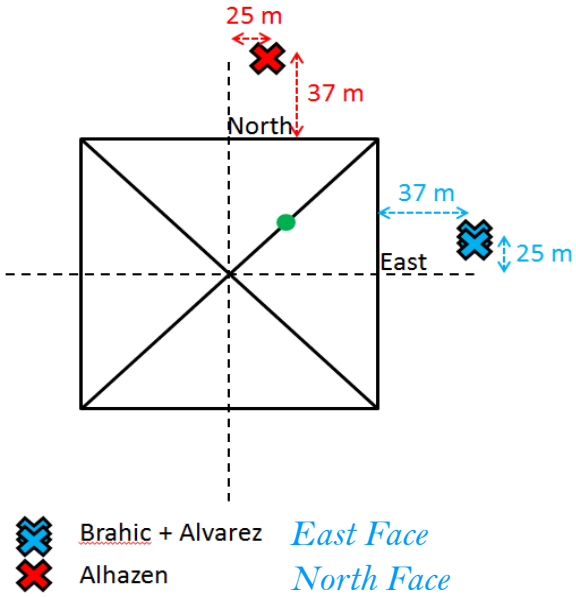


Alvarez (n°2)

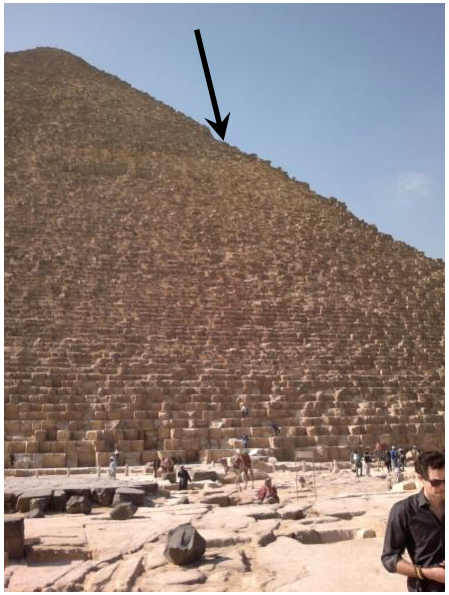


Brahic (n°3)

- **First campaign:** performance validation looking to a known cavity



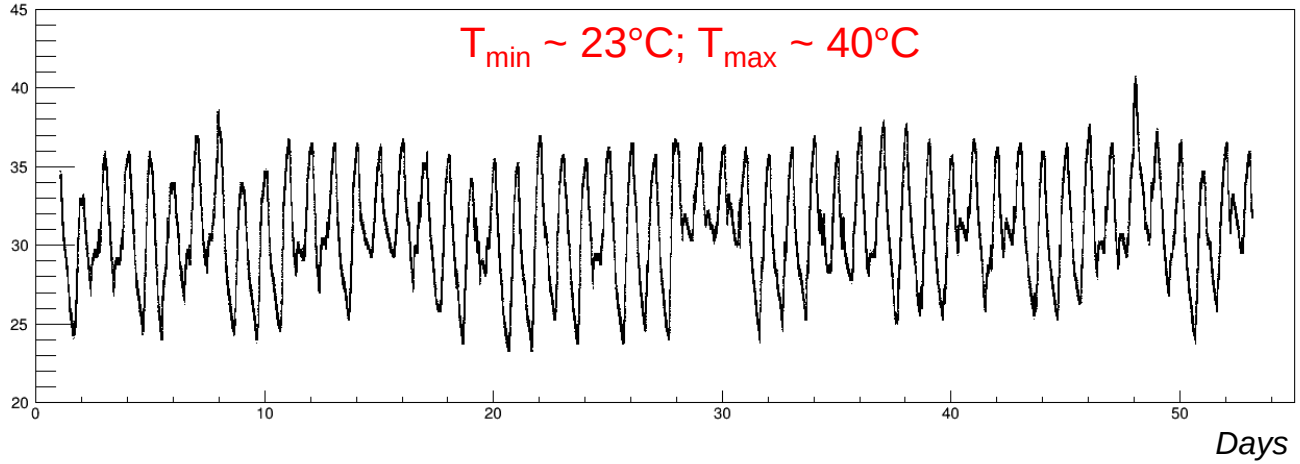
Challenge:
Detect a 3 m cavity in 20 m of rocks at a distance of 150 m!



Installation at Khufu Pyramid

Data Taking

- Each telescope operate during 2 to 3 months (gas autonomy)
  - *Temperature variation*



- Stable data taking, thanks to local team (3G, gaz, maintenance)
- Excellent spatial resolution → ≤ 1 m accuracy at a distance of 150 m
- Number of recorded events:
  - *Alhazen (Nord): 30.8 millions of triggers (4.5 Hz)*
  - *Brahic (Est): 24.6 millions (4.2 Hz)*
  - *Alvarez (Est): 18.7 millions (3.3 Hz)*

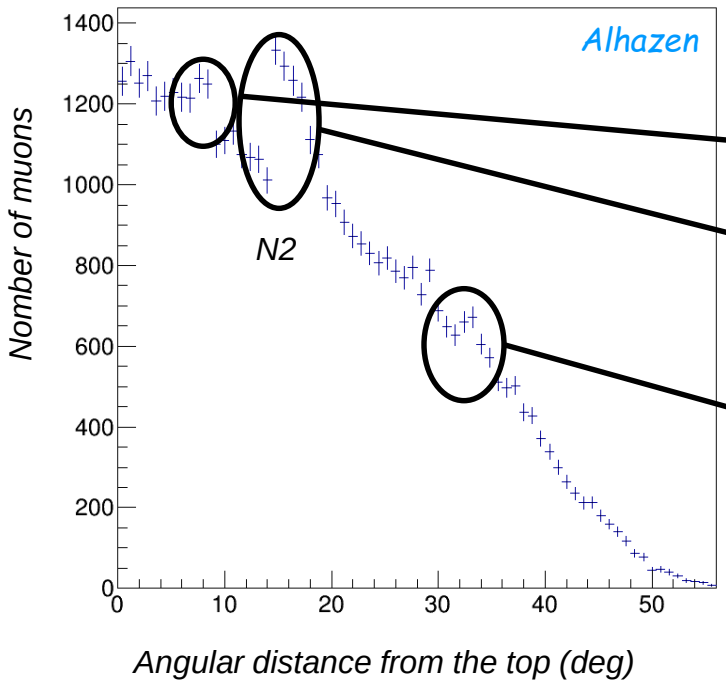
~70% are can be reconstructed

- Issue with *Alvarez* (July 1st, alignment change)

→ *Investigation in process*

Data Analysis

- First slices show notches along the edge

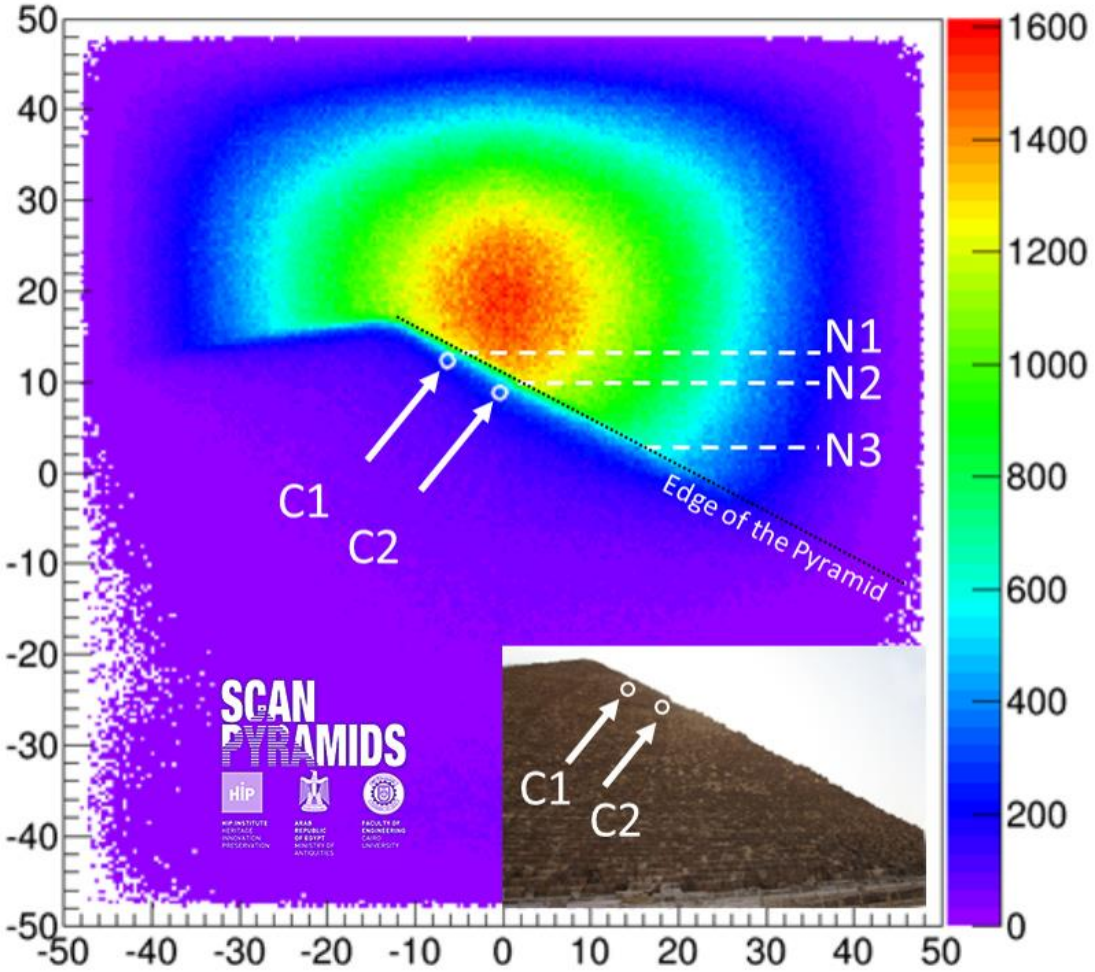


1st validation: N1 is not visible from ground (and not known from the team!)

- *Brahic* & *Alvarez* see the same pattern with 3 notches

Results

- Press released: October 15th, 2016



- ***Performance validation N1 et C2***
- ***Discovery of C1***

→ ***Question for archaeologist: what was the use of these cavities?***

Probably use for the pyramid building

Conclusions and Perspectives

- The first ScanPyramids campaign was a success
- Discovery of a new cavity (C1)
- The 3 telescopes are still in Cairo waiting for redeployment
- Next steps:
  - look at other edges
  - scan other Pyramid edges (Khafre, etc.)
  - data analysis is in continuing (add reconstructed events)
- Contact in progress with several private companies (RATP, etc.) for societal applications, but first need simulations or in situ demonstration

Thank You!