DE LA RECHERCHE À L'INDUSTRIE

cea

SCAN PYRAMIDS

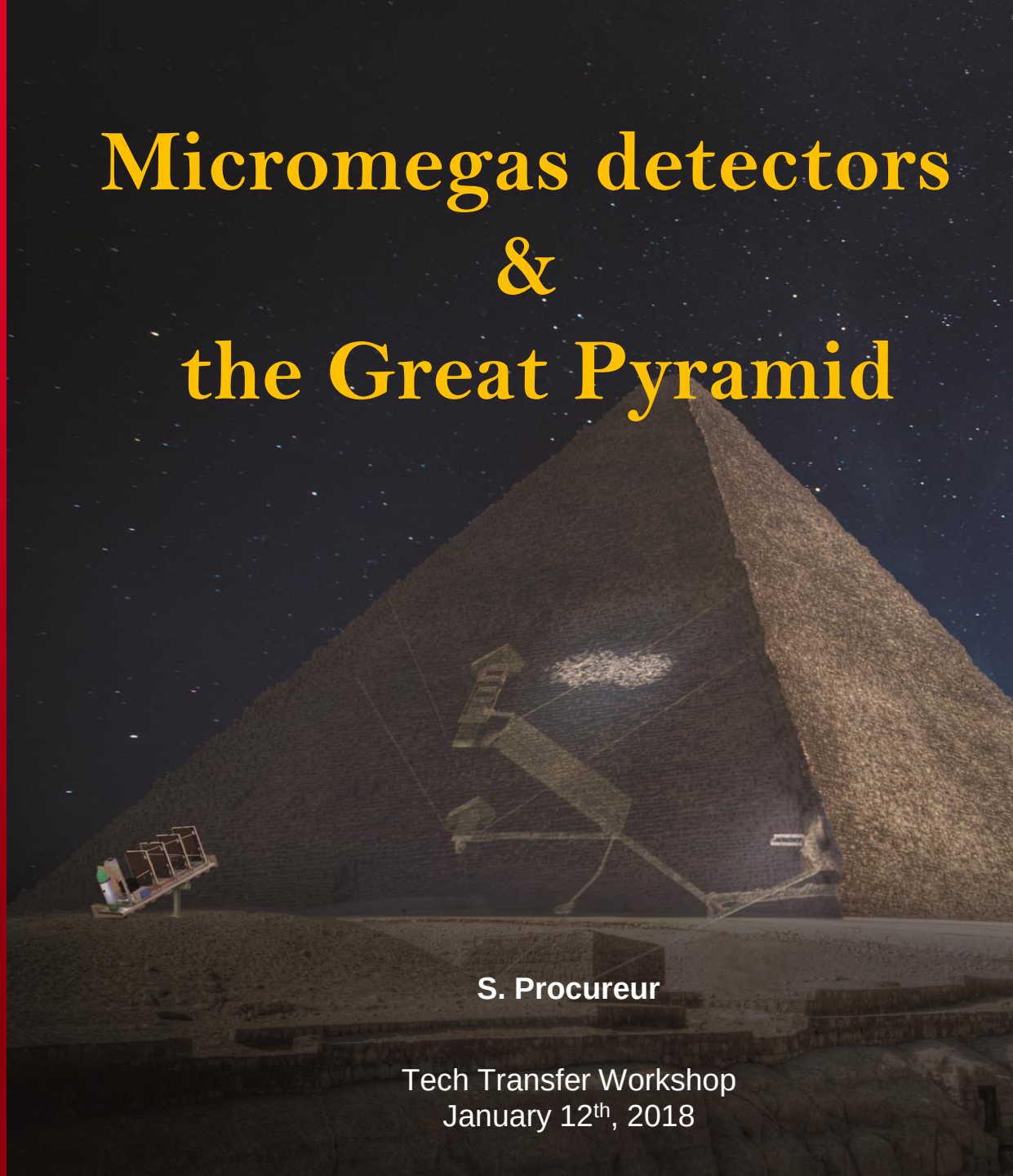
HIP INSTITUTE HERITAGE INNOVATION PRESERVATION

ARAB REPUBLIC OF EGYPT MINISTRY OF ANTIQUITIES

FACULTY OF ENGINEERING CAIRO UNIVERSITY

Irfu

Micromegas detectors & the Great Pyramid



S. Procureur

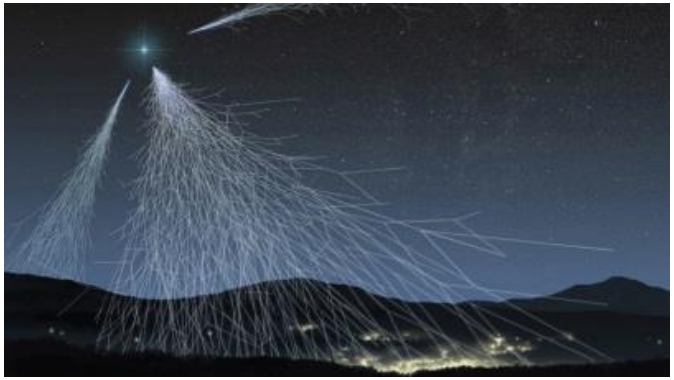
Tech Transfer Workshop
January 12th, 2018

CONTENT

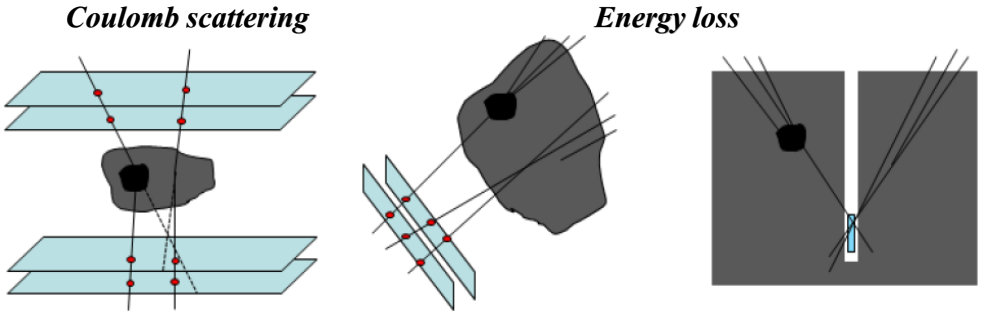
- Introduction
- Micromegas and CLAS12
- First muon instruments @ Saclay
- ScanPyramids: preparation and discoveries

MUON TOMOGRAPHY

- Cosmic muons produced by cascade of reactions induced by cosmic rays in the upper atmosphere
  - Flux: ~150/m²/s ~ $\cos^2\theta$ (maximum in zenith direction)
  - Mean energy: 4 GeV
  - Life-time: 2 μs
  - Natural, free and harmless radiation
  - Straight propagation (in average)



- Electromagnetic interactions with matter



Deviation (3D) *Absorption/Transmission (2D)*

Material	Thickness	θ (°)	$P_{absorption}$
Air	100 m	0.094	0.78%
Lead	10 cm	1.01	2.9%
Water	1 m	0.35	4.2%
Ground	100 m		99%

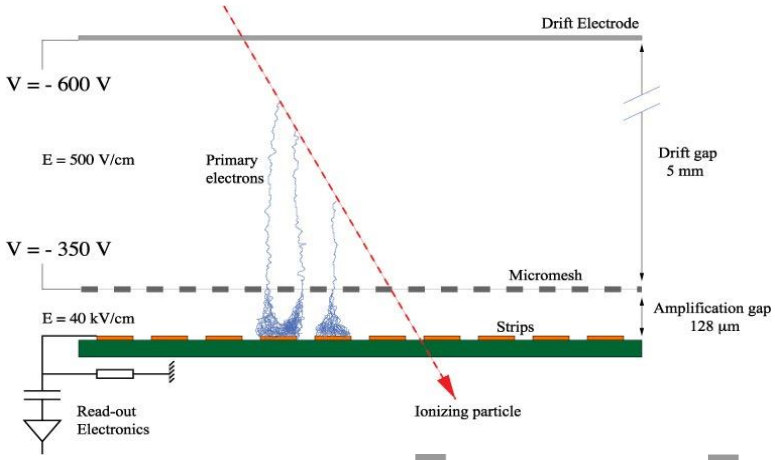
- Many potential applications

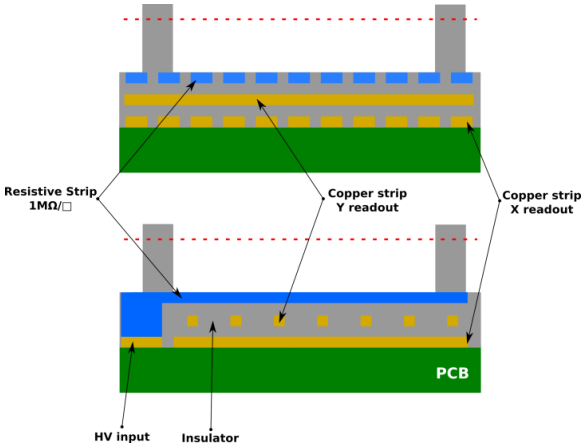
MICROMEGAS DETECTOR

- Gaseous detector invented at CEA-Saclay (1996)

- Excellent performance for detection in nuclear and particle physics
  - spatial resolution < 100 µm
  - time resolution < 10 ns
  - high rate capability

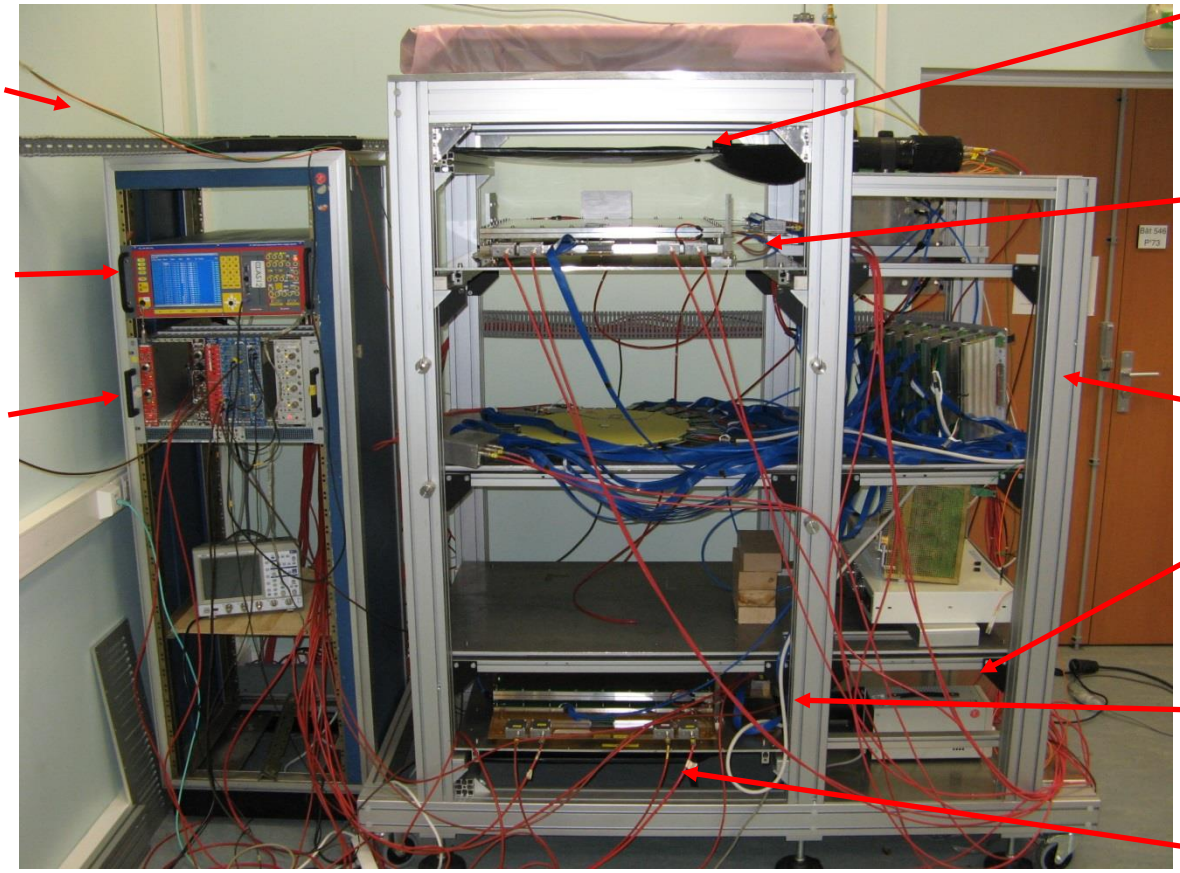
  - *Micromegas bulk* technology (2005) :
    - robust, high area possible
    - easily made in company (printed circuit board)
  - resistive strips for spark suppression and 2D readout





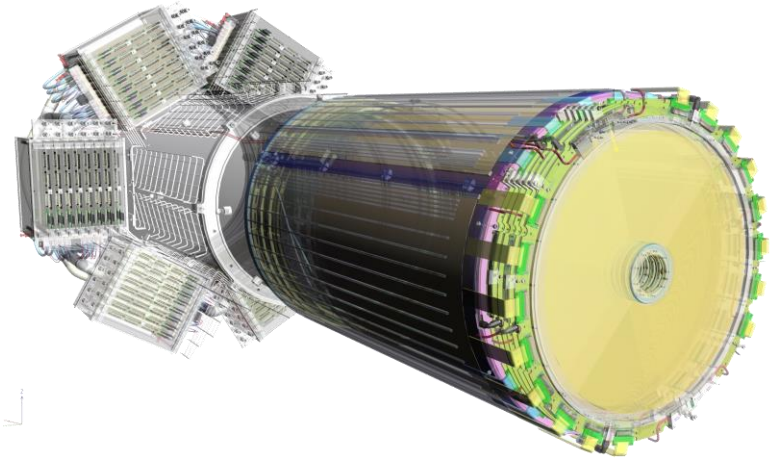
COSMIC BENCH FOR CLAS12 DETECTORS

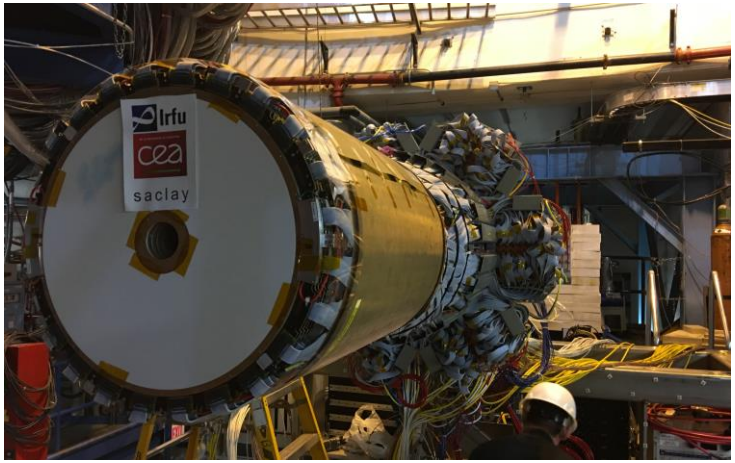
- Cosmic test bench used to characterize detectors for physics expts.

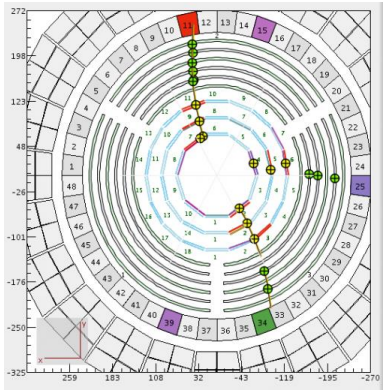


CLAS12 MICROMEGAS DETECTORS

- 4 m² of Micromegas detectors installed in 2017 (last month) in 5T magnet
  - *Forward* detectors:
    - 6×430 mm diameter dimension
    - high rate (30 MHz) supported by resistive strips divided in 2 zones inner/outer
  - cylindrical *Barrel* detectors
    - 3×6 layers in 10 cm space for low momentum particles (light detectors)





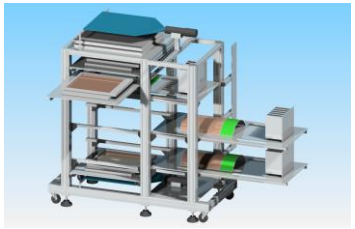


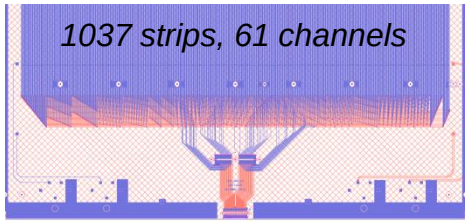
CLAS12 Micromegas Vertex Tracker

Jefferson Lab
Thomas Jefferson National Accelerator Facility

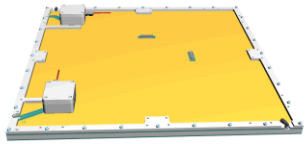
ORIGIN OF MUOGRAPHY @ SACLAY

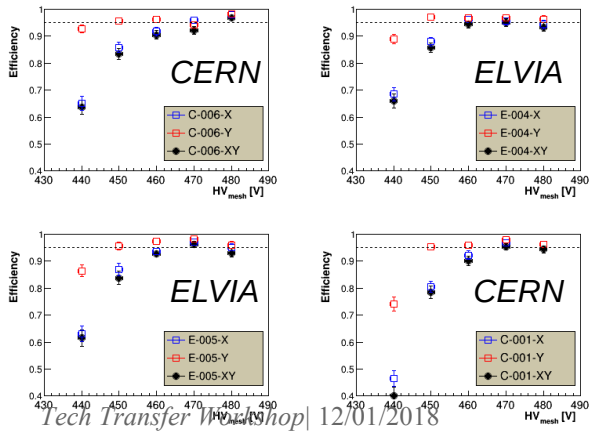
- Dvt of 50x50 cm² MM with genetic multiplexing (2012)
  - *Reduction of electronics (price, consumption) by factor of ~15*
  - *Use of resistive strips to increase S/N and efficiency*





- First final prototypes available in 2015 (made @ CERN)
  - *N~2600 e-, S/N~60-100)*
  - *1.5 cm drift gap*
  - *~97% efficiency in 2D*
  - *Ar-Iso-CF_4 (95-2-3) mixture (non flamable)*
  - *~300 micron resolution*

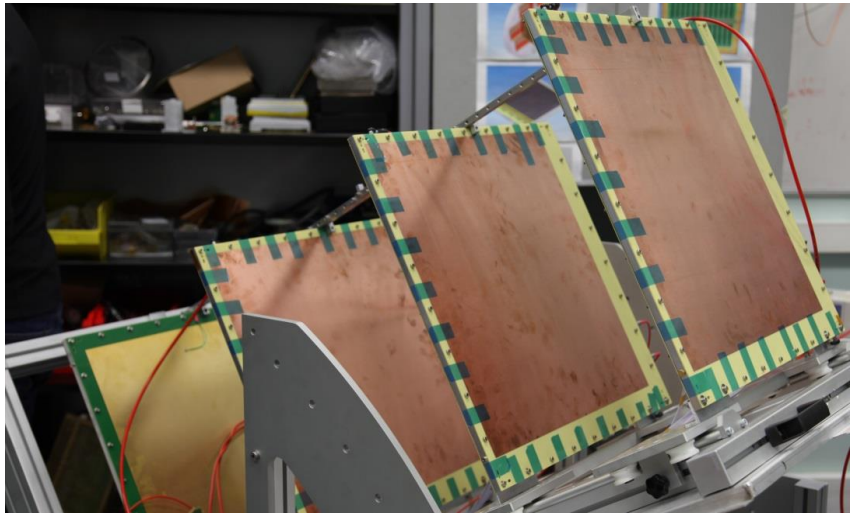


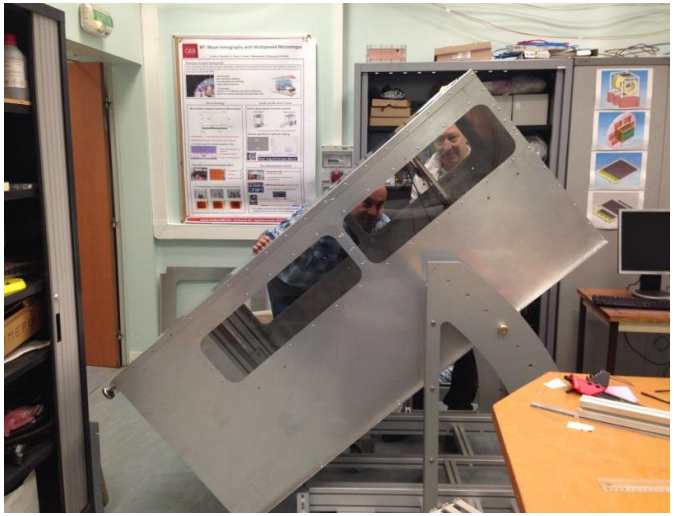


- Know-how transfer with PCB company in France

⇒ **2014: proposition of a Micromegas-based muon telescope (WatTo)**

WATTO: INTEGRATION



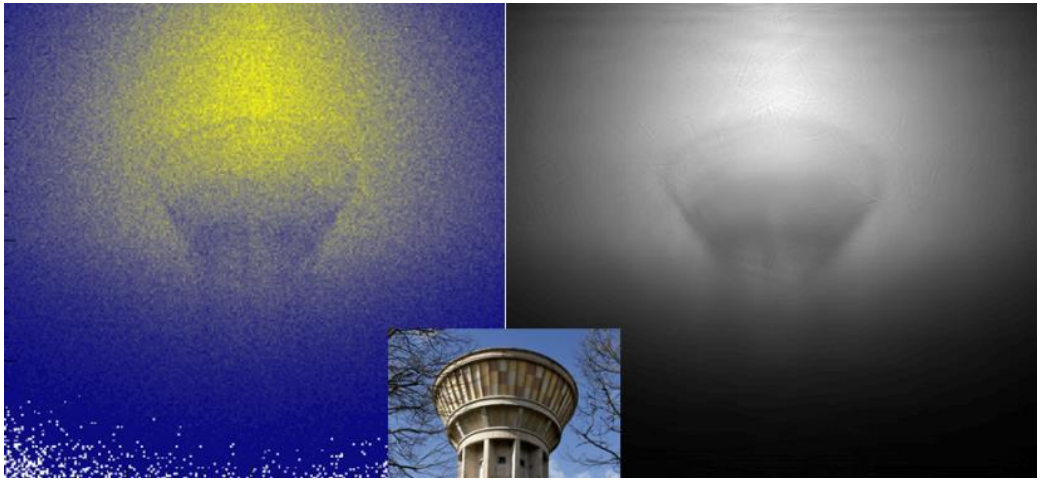


HV+ nano PC + Dream electronics board in a box

WATTO: RESULTS (1/2)

- Static Muography:

Integration time: 4 weeks (position 1)



How to read a muography:

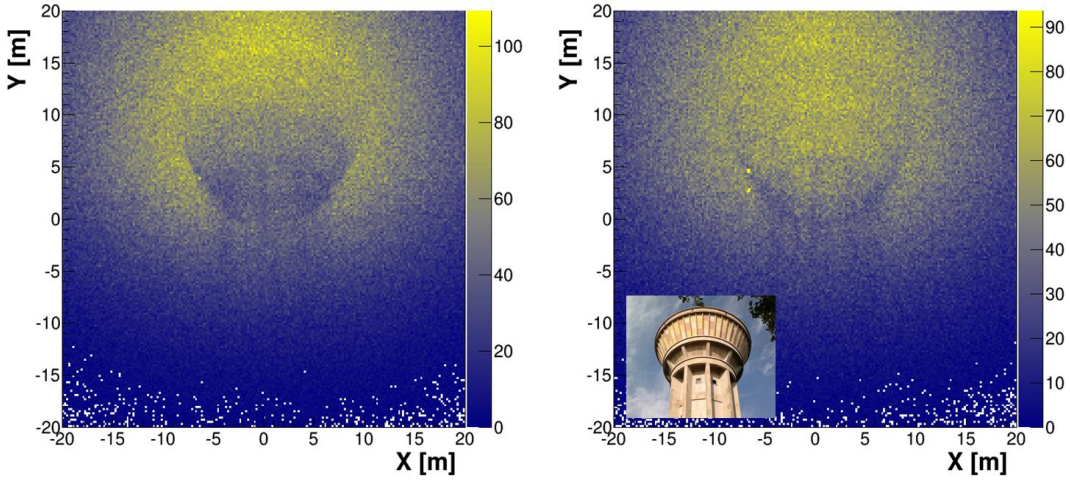
- *Each pixel is a number (or a flux) of reconstructed muons in the corresponding direction*
- *Light (yellow) colour → more muons → less absorption → less matter*
- *Dark (blue) colour → less muons → more absorption → more matter*

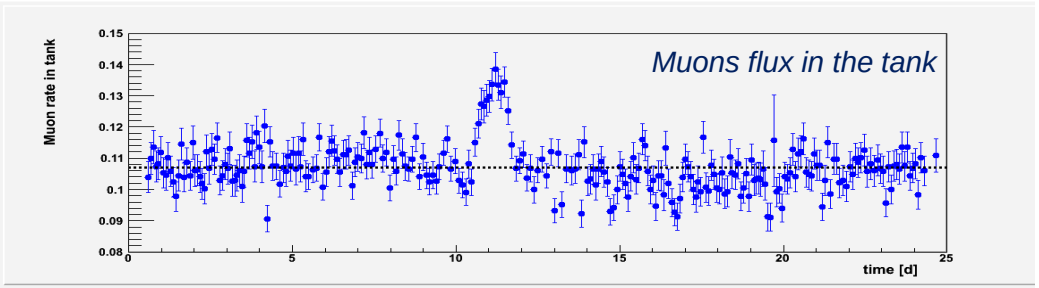
→ First muography of a recognizable building

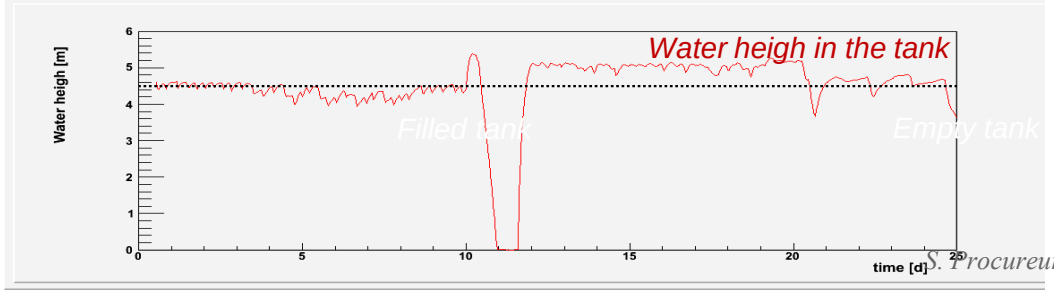
WATTO: RESULTS (2/2)

- Dynamic Muography:

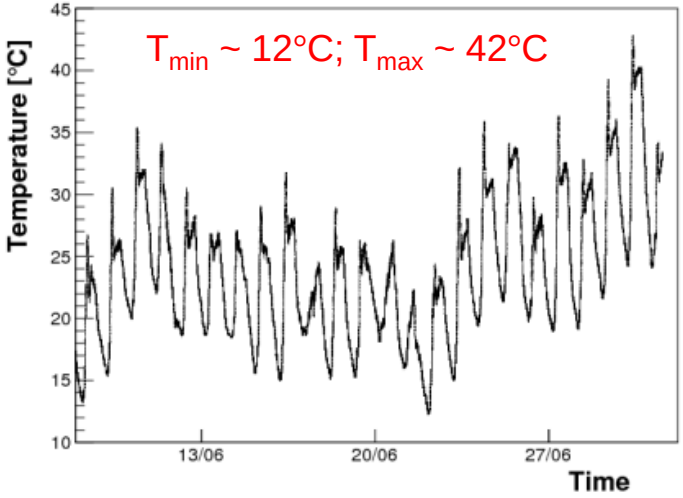
Integration time: 4 days each (position 2)







- *Environmental conditions (noise, T&P effects, etc.)*



- *30 W on solar panel*

WATTO → SCANPYRAMIDS

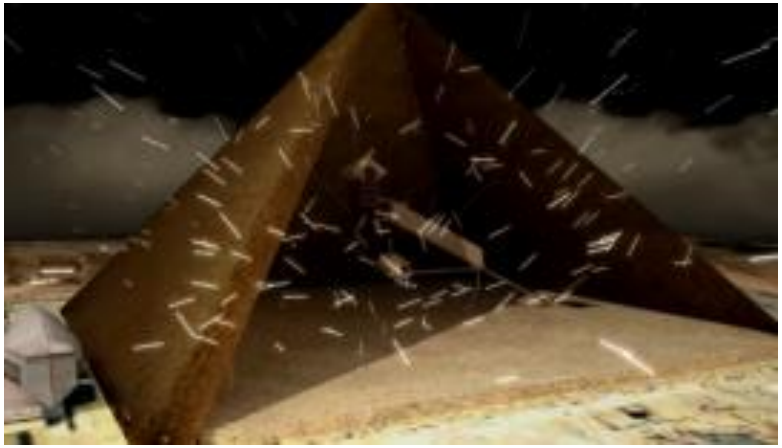
- September 2015: end of WatTo experiment …
- … announcement of ScanPyramids on October 25th

→ *Email to Mehdi Tayoubi on October 26th*

→ *1st meeting mid-December in Paris*

→ *Official announcement CEA participation April 2016*

→ *1st telescope installation in Egypt May 2016*



Mehdi Tayoubi
President & co-founder

Innovation Strategist

Hany Helal
Vice-president & co-founder

Professor, Faculty of Engineering, Cairo University
Former Minister of Higher Education & Scientific Research

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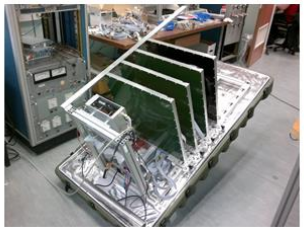
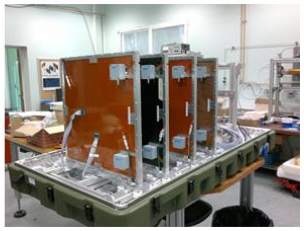
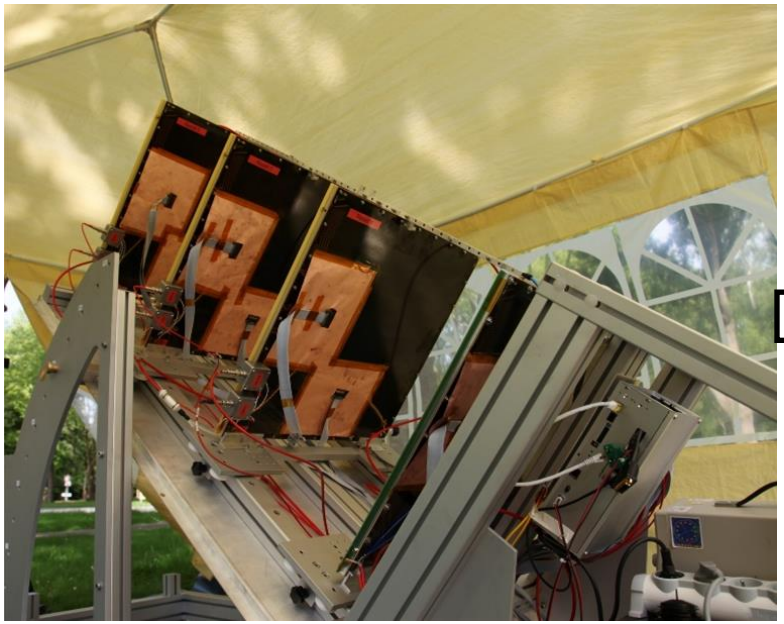
WATTO → SCANPYRAMIDS

- Telescopes : 1 → 3
- Chassis → Flight-case
- Detection plane: prototype (CERN) → serial (ELVIA-PCB company)
- Building time: 9 months → 3 months
- Weight : ~ 200 kg → ~ 130 kg
- Data: raw → raw + processing

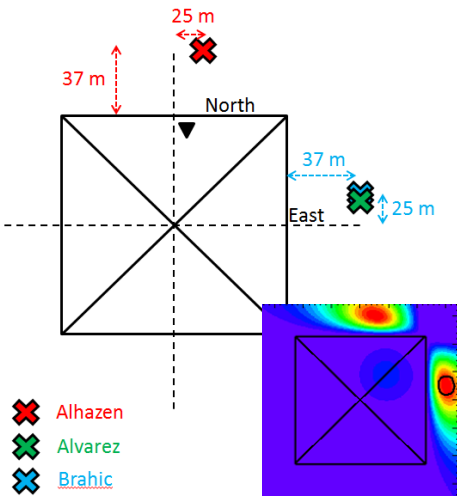


GIZA PLATEAU INSTALLATION

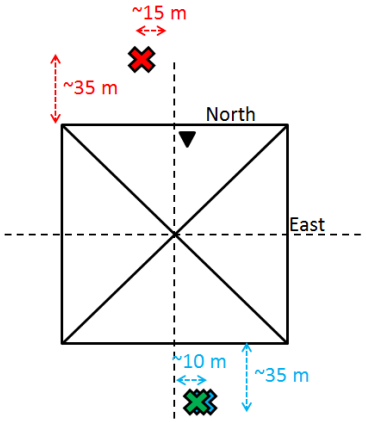
MEASUREMENT CAMPAIGNS

- 3 missions between 2016 & 2017

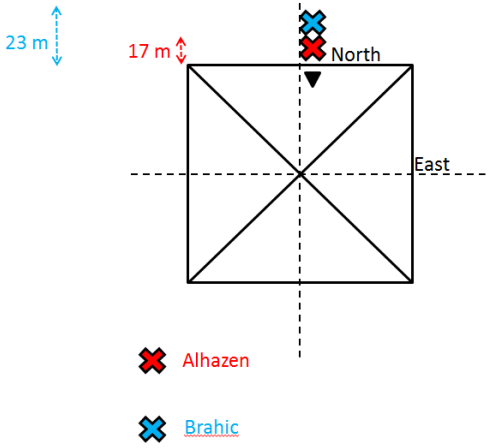
1st mission (jun-aug 2016)



2nd mission (jan-april 2017)



3rd mission 3 (may-jul 2017)



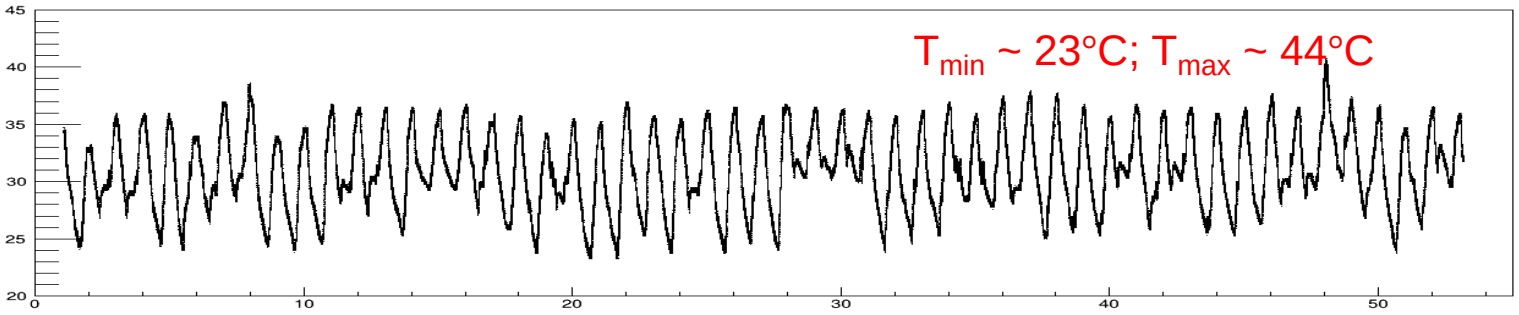
DATA TAKING

- Relatively smooth ☺

before

after

- Temperature variations (gas & electronics & mechanics)



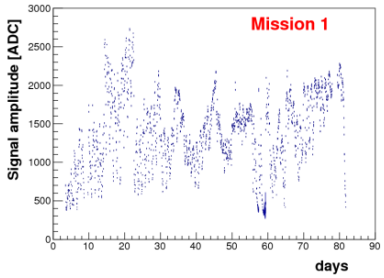
(instruments checked at Saclay between 2°C and 55°C)

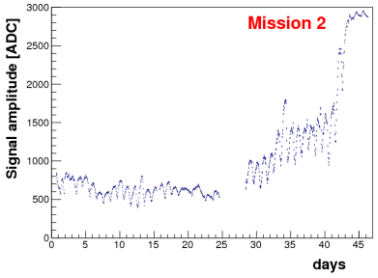
DATA TAKING

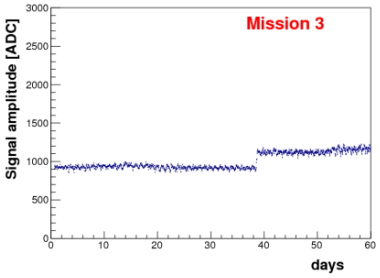
- Successive improvements of the instruments

Signal stability

(patented)







Monitoring of environmental conditions

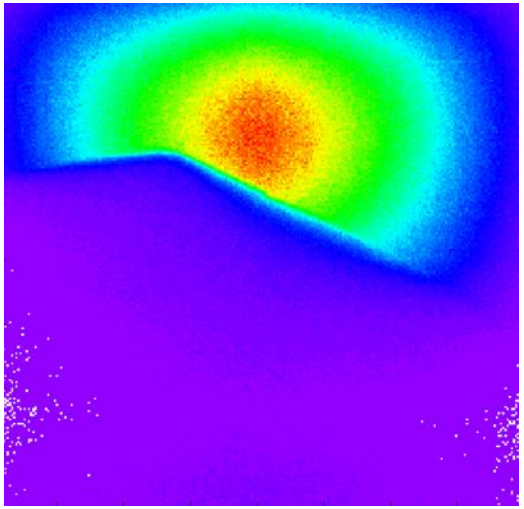
Full, online analysis on the nano-PC

ANALYSIS

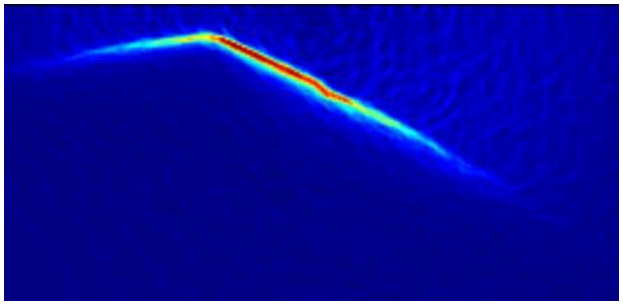
- Necessity to adjust photo and muo for comparison with 3D model

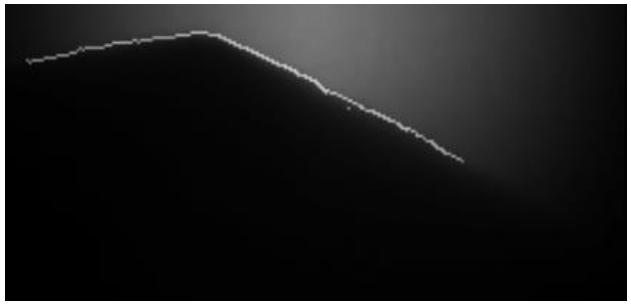
photo

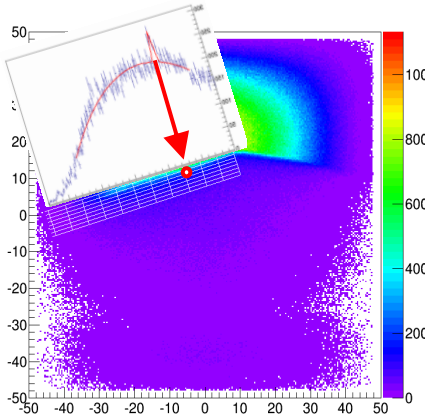
muo



- Requires edge detection (image filtering)

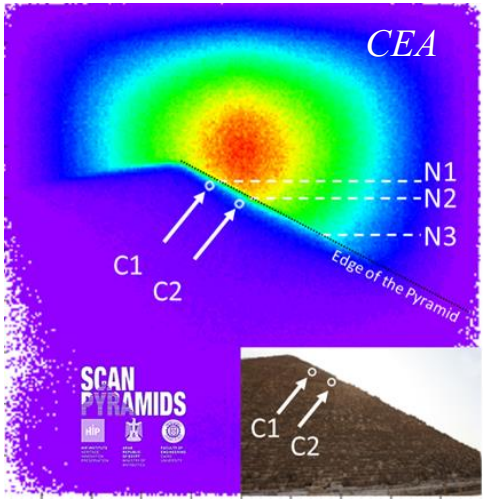


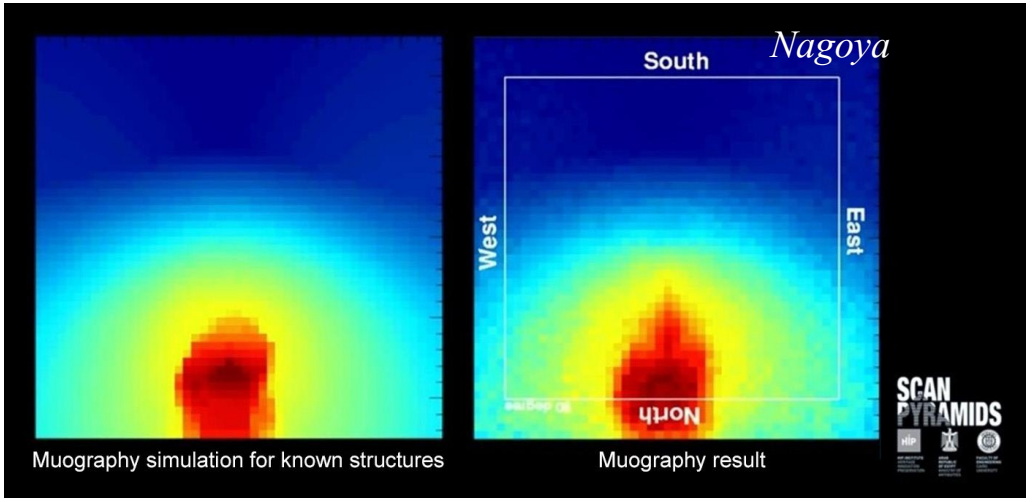


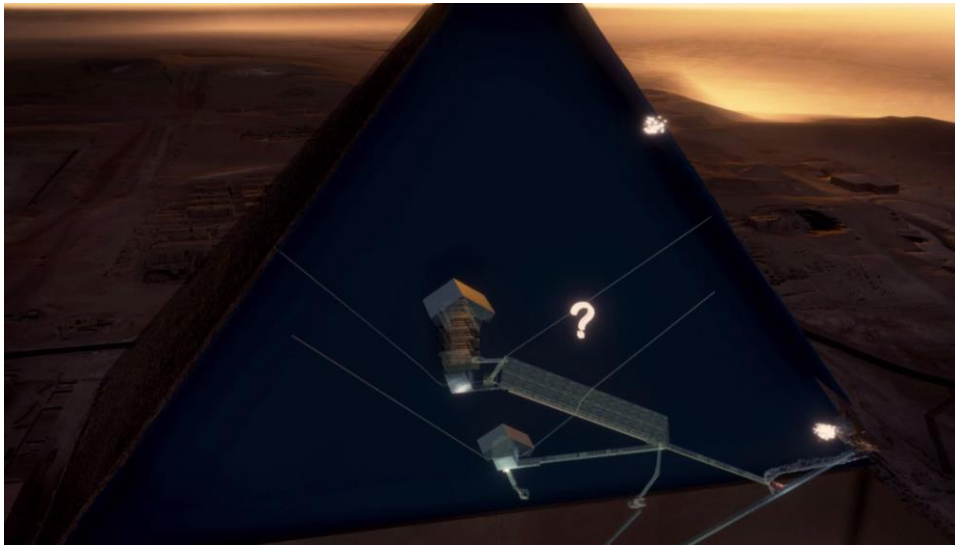


RESULTS – 2016

- October 2016: discoveries of 2 voids in the pyramid





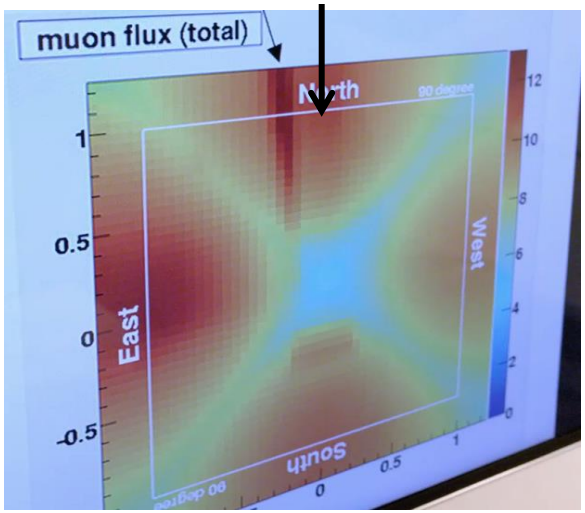


⇒ ***Question for egyptologists: what is the purpose of these voids?***

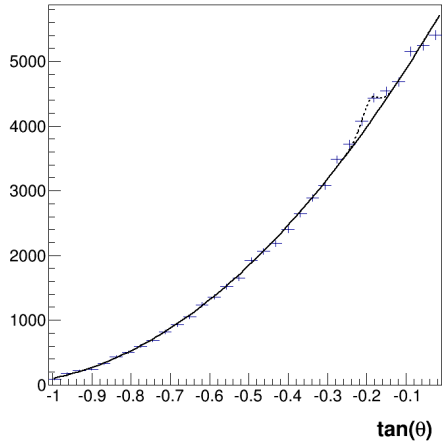
RESULTS – 2017

- Early 2017: 1st results from Nagoya emulsion in Queen's Chamber…

Significant muon excess close to the Grand Galery ⇒ **void**



Anomalies appearing also on KEK scintillator (Queen's Chamber), and on CEA telescope (North face)



- 3D model suggests that all these anomalies point to the same direction

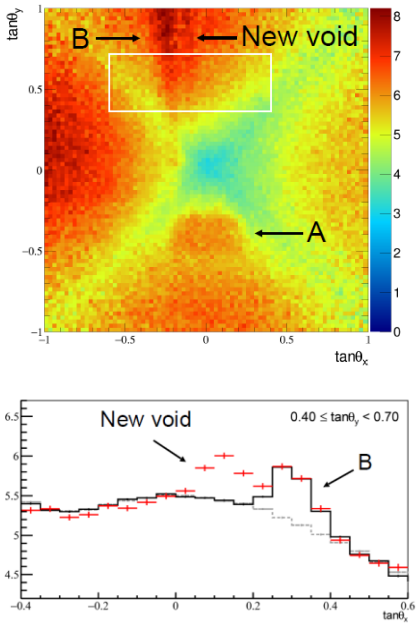
⇒ **Dedicated measurement campaign started**

- *Queen's Chamber: new emulsion from Nagoya and move of the KEK scintillator*
- *Outside: move of 2 telescopes in front of the North face Chevrons*

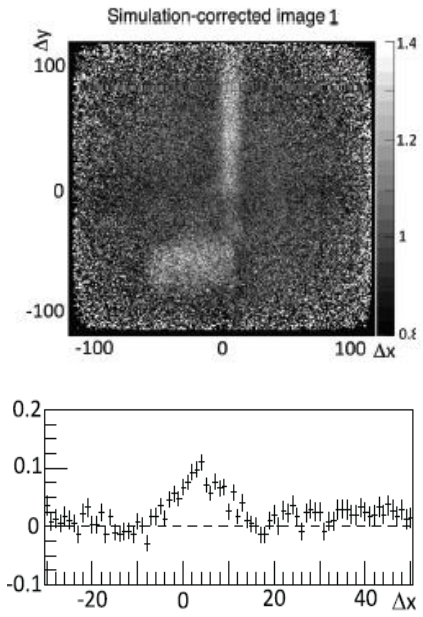
RESULTS – 2017 (FROM NATURE PAPER)

- All the measurements confirm a large void above the Grand Gallery

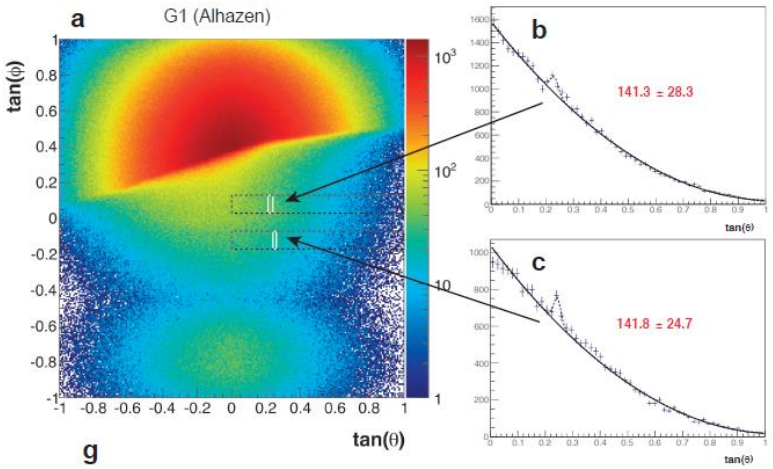
Nagoya



KEK

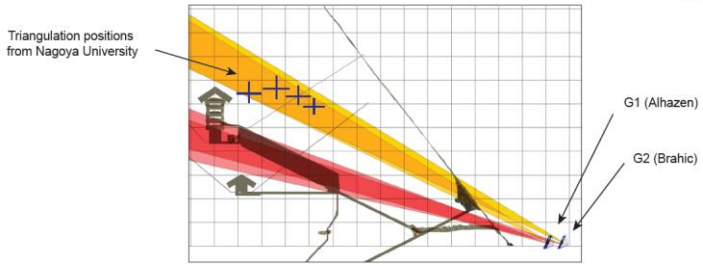


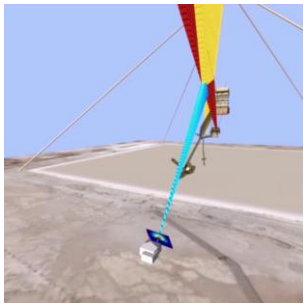
CEA



- *Only 2 such voids detected*
- *1st detection ever from outside of a deep structure*

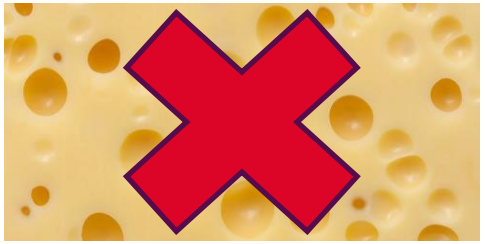
- Good triangulation with Nagoya and CEA instruments

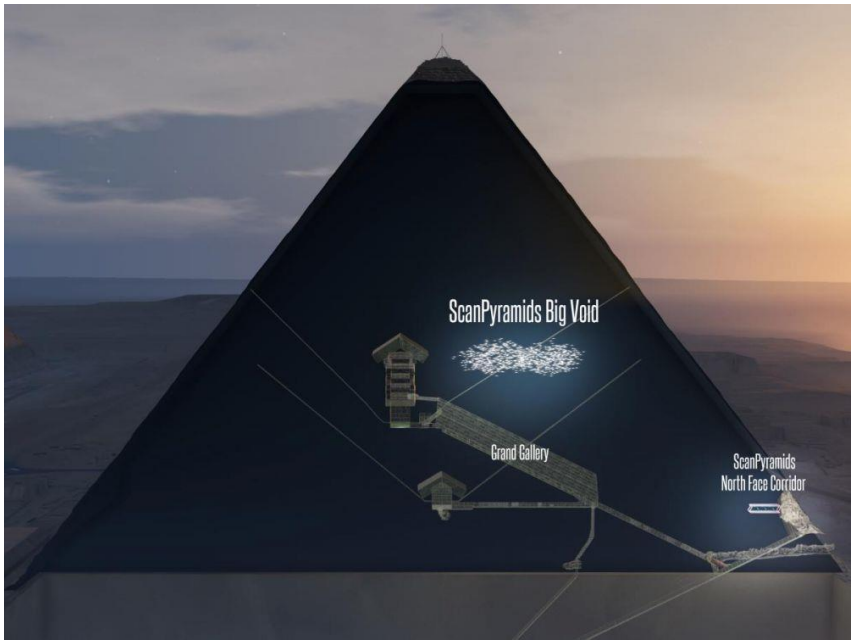


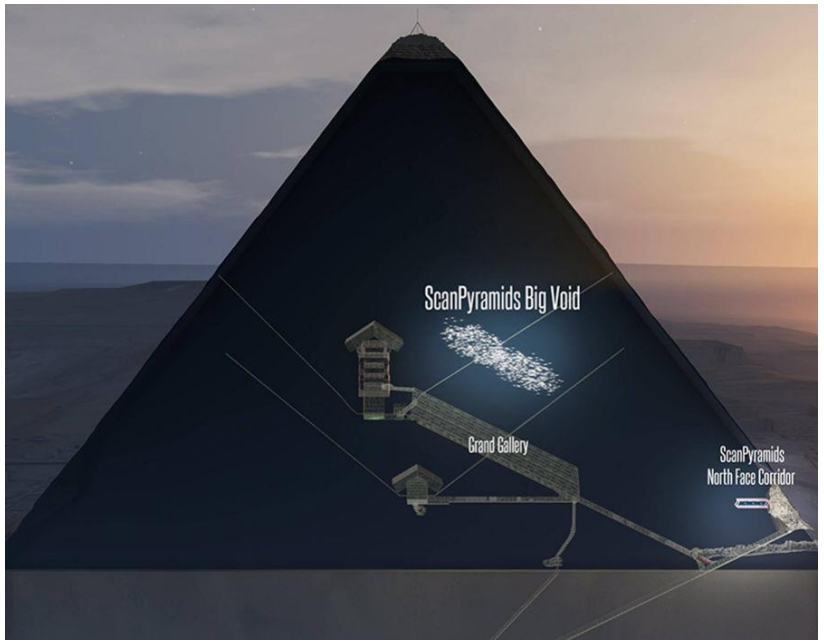


SCANPYRAMIDS BIG VOID

- Remarkable features of the ScanPyramids Big-Void:
  - *Within the same plane as all other knwon (big) structures*
  - *Large under-density, only at this place*



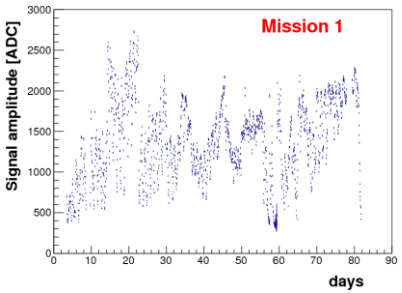


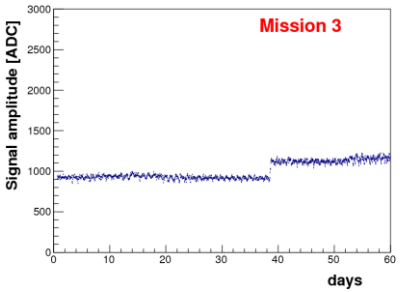


- *Volume estimate: several hundreds of m^3*
- *Lenght: > 30 m*
- *Inclined or horizontal…* ⇒ **More measurements needed!**

CONCLUSION

- MPGD robust enough for extreme condition applications in spite of gas





- Probably the best technology for precise muography

	Nuclear emulsion *Nagoya University*	Hodoscopes *KEK*	Gas detectors *CEA*
Angular Resolution	2-14 mrad	7-10 mrad	0.8 - 4 mrad
Angular Acceptance	45 degrees	34 - 45 degrees	45 degrees
Active area	30 cm x 25 cm / unit:	1.2 m x 1.2 m	50 cm x 50 cm
(for this analysis)	0.75 m x 0.6 m (NE1) 0.9 m x 0.5 m (NE2)		
Position Resolution	1 μm	10 mm	400 μm
Height	0.2 mm	1-1.5 m	60 cm
Power requirement	No	Yes (300W)	Yes (35W)
Data taking	Need development	Real time	Real time

- Technology transferred to an industrial

- Many more applications beyond archeology!

THANK YOU