

DE LA RECHERCHE À L'INDUSTRIE



SCAN PYRAMIDS



HIP.INSTITUTE
HERITAGE
INNOVATION
PRESERVATION

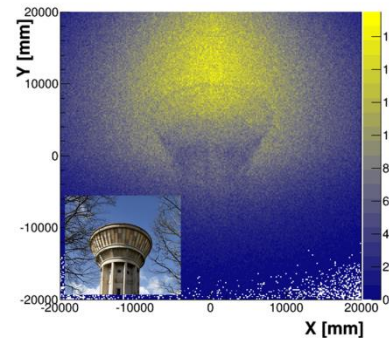


ARAB
REPUBLIC
OF EGYPT
MINISTRY OF
ANTIQUITIES



FACULTY OF
ENGINEERING
CAIRO
UNIVERSITY

An exotic use of MPPGD: muography of Egyptian pyramids



IRFU/SPhN: S. Procureur, S. Bouteille (PhD)

IRFU/Sédi: D. Attié, D. Calvet, P. Magnier, I. Mandjavidze, M. Riallot

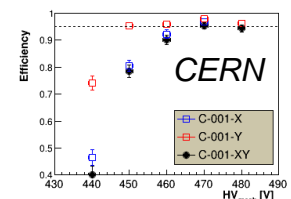
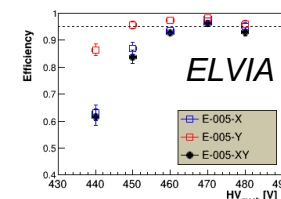
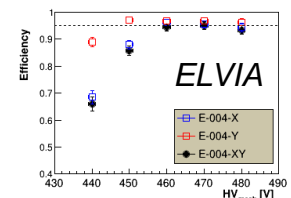
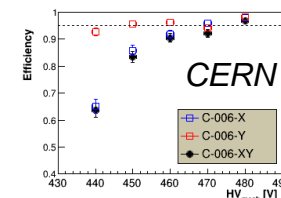
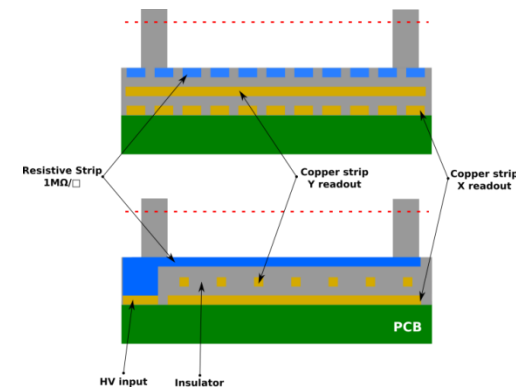
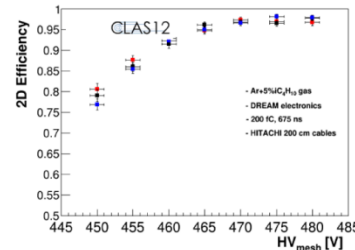
MPPGD workshop, 15/09/2016

→ development of 50x50 cm² Micromegas with *genetic multiplexing*

- Reduction of electronics (price, consumption) by factor of ~15
- Use of resistive strips to increase S/N and efficiency
- 2D strip readout
- CLAS12/DREAM electronics

→ first final prototypes available in 2015 (made @ CERN)

- $N \sim 2600$ e⁻, S/N ~ 60-100)
- 1.5 cm drift gap
- ~97% efficiency in 2D
- Ar-Iso-CF₄ (95-2-3) mixture (non flammable)
- 200 micron resolution ($\frac{L/N_{chan}}{40}$!)



→ know how transfer with ELVIA PCB company

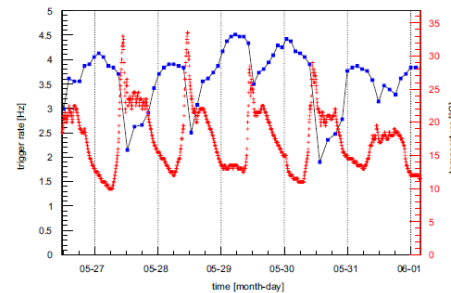
S. Bouteille et al., NIM A 834 (2016), 187 (1st 2D version)

→ building & validation of the first MM-based muon telescope

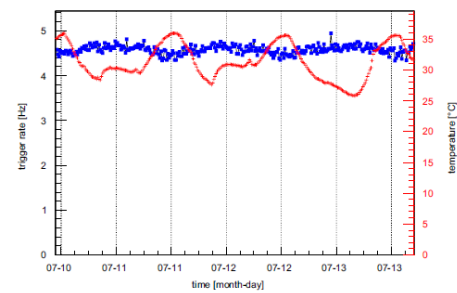
- Temperature fluctuations from 11 to 43°C
- Online feedback on T (P)
- Self-triggering mode
- Miniaturized electronics box
- 30 W of total consumption (bulb)
- Operated during 3.5 months...
- ... including 1.5 on solar boards + battery



Trigger rate and temperature

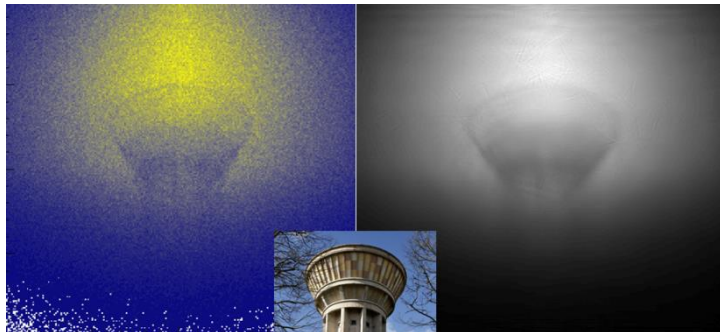


w/o T feedback

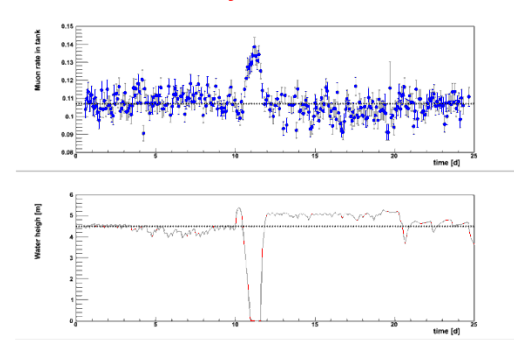


w T feedback

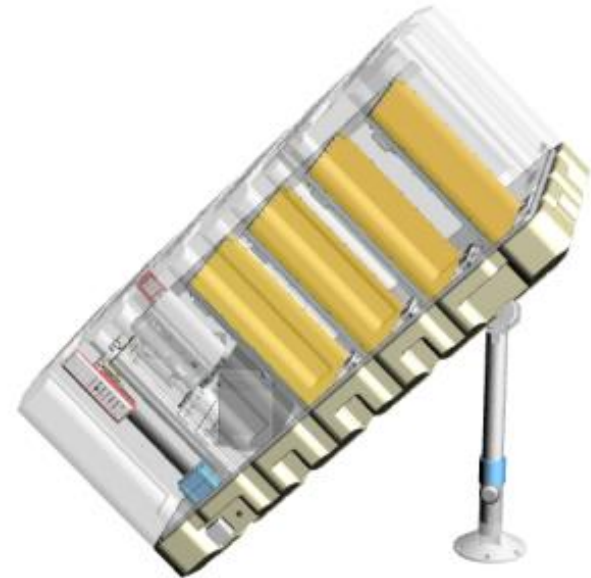
static



dynamic



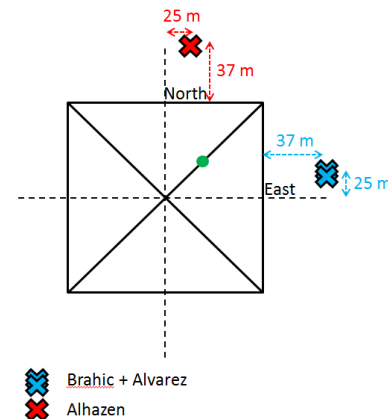
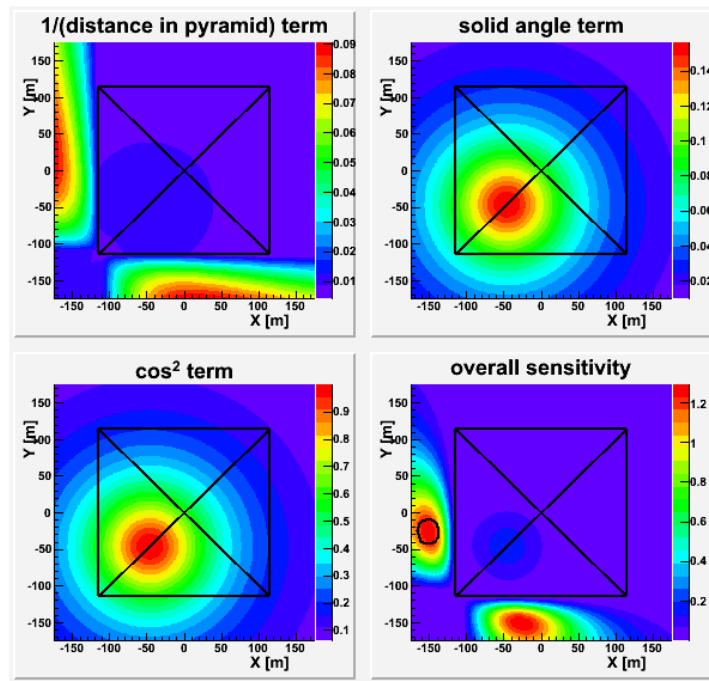
- Coordinated by Engineering faculty of Cairo & HIP Institute, under authority of antiquity ministry
- Imaging of 4 Egyptian pyramids with muons, thermal studies and drones
- Mission started in Oct. 2015 with 2 Japanese teams on muon program
 - *Emulsions & scintillators*
 - *Only inside pyramids*
- Proposition to install MM telescopes outside
 - *CEA joined the mission on April*
- Construction of 3 new telescopes of new generation
 - *4 detectors / telescope for redundancy*
 - *1 FEU with DREAM asics (512 channels)*
 - *Thermal protection*
 - *Improved components => less noise for self-trig.*
 - *Powered by 220V AC or solar boards (35 W)*
 - *150 Ah battery with regulator*
 - *3G connexion*
 - *Online data analysis (nano-PC)*
 - *2 TB hard disk for each telescope to store raw data*
 - *2 B5 bottles for each telescope (T2K gas)*
 - *Simulation to optimize the sensitivity*



Quite challenging schedule!

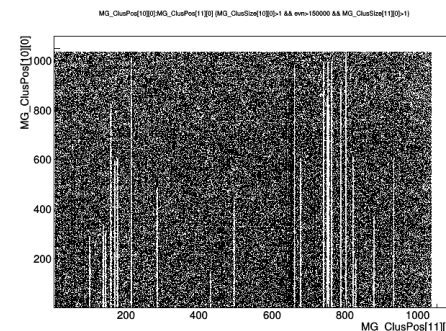
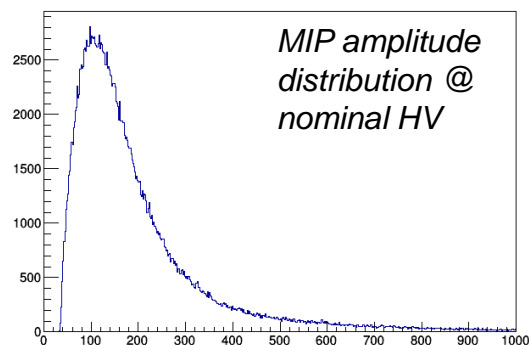
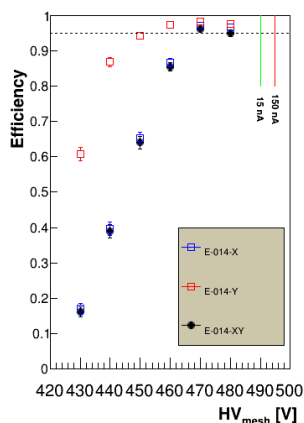
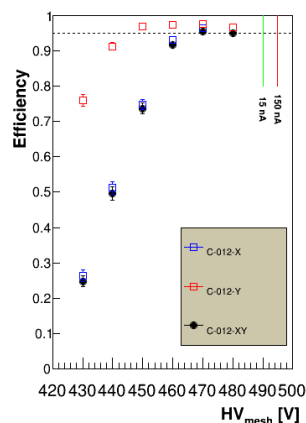
- Observe a known cavity on N-E edge to validate the performance
- Simulation were performed to optimize the sensitivity for this room

- *Distance between room and telescopes (solid angle) (the closer the better)*
- *Viewing angle (the higher the better)*
- *Ratio of stone and cavity lengths (the further the better)*



Already an enormous challenge: detection of a 3 m cavity in 20 m depth rocks, at 150 m distance!!!

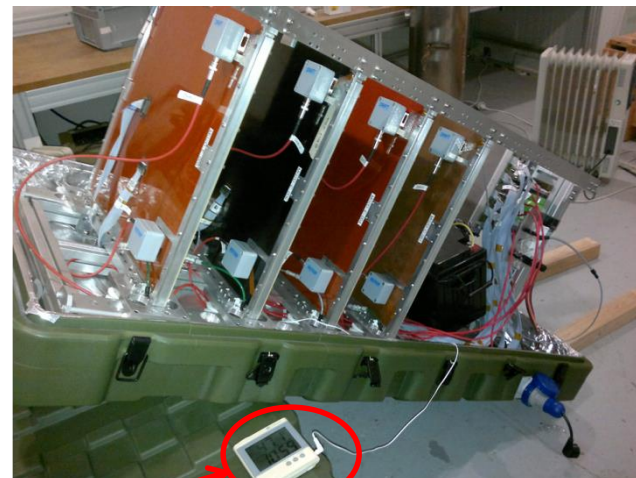
- Each detector was tested at Saclay before assembly
 - Efficiency
 - Spatial resolution
 - Gas tightness
- Outstanding commitment of ELVIA who built 2/3 of the detectors (8) in tight schedule
- All 12 showed good performance, with local defects on some (strip cuts)



→ Assembly at Saclay in fly-cases used for the transport & the acquisition



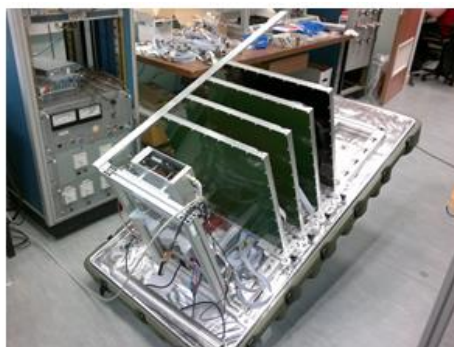
Snow!



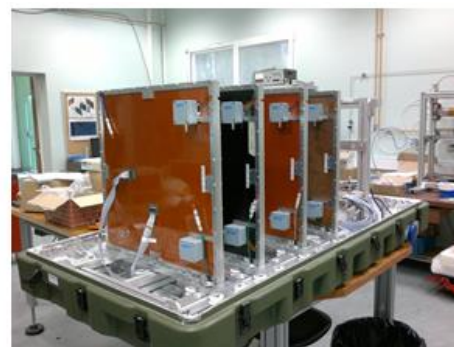
47.1 °C (whole setup tested up to 55°C)



Alhazen (n°1)



Alvarez (n°2)



Brahic (n°3)

→ Check tests after transportation, doublet assembly, final plugs



→ Transportation from University to Giza

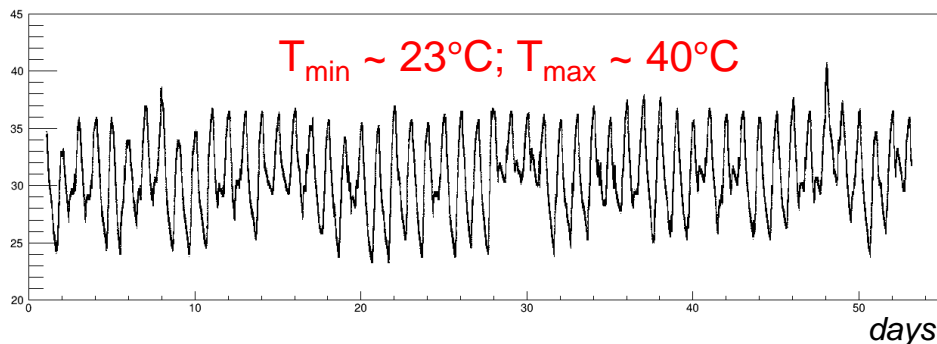


→ Telescopes under tents for safety: 2 on the East face, 1 on North

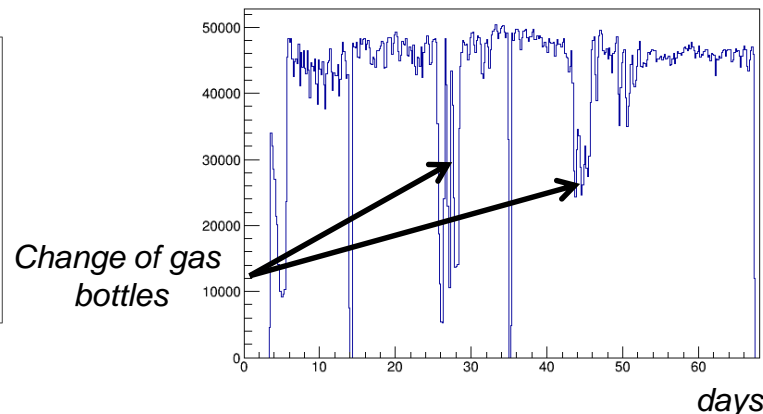


→ Each detector was operated during 2 to 3 months (gas autonomy)

- *Temperature evolution*



- *Number of reconstructed muons with time*



→ self triggering: at least 5 planes out of 8

- *Ensures at least 3 detectors, means signal from both doublets (lever arm)*

Relatively stable acquisition
(thanks to T,P feedback)

→ alignment performed early June

- *Resolution around 300 microns for perpendicular tracks, less than 3 mm from -40 to +40°*
- *3 mm resolution \Leftrightarrow 1 m uncertainty at 150 m*
- *Contribution of MS in telescope, fly-case and air yield a few tens of centimeters at 150 m*

→ overall statistics:

- *Alhazen (North): 30.8 million triggers (4.5 Hz)*
- *Brahic (East): 24.6 million triggers (4.2 Hz)*
- *Alvarez (East): 18.7 millions (3.3 Hz)*

~70% are good muon tracks

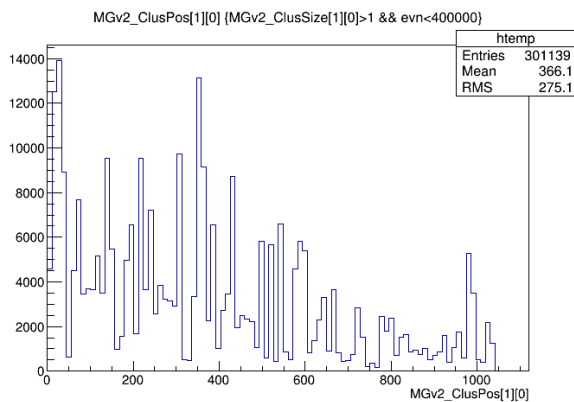
→ Some dead channels

- *Brahic: 5 on a single detector*
- *Alvarez: 4 on a single detector, 1 on a second one*

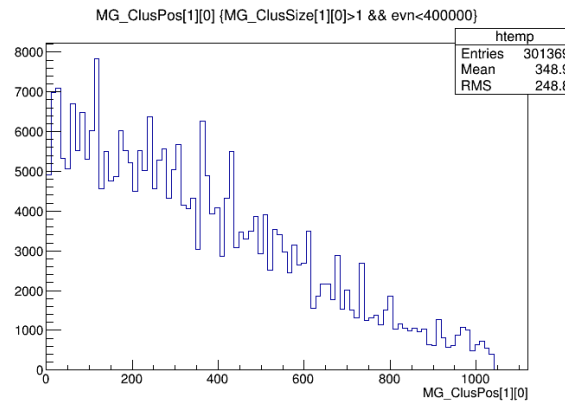
→ Reprocessing of raw data with new algorithm (old: biggest cluster search)

- *Convolute the strip amplitude pattern with Gaussian of sigma $\sim N_{char}/3$*
- *Consider the highest values as cluster seeds*
- *Grow the cluster seed allowing gaps with some criteria (based on number of new, unused channels in the cluster)*
- *Jump dead channels*

Muon position distribution in problematic Brahic plane



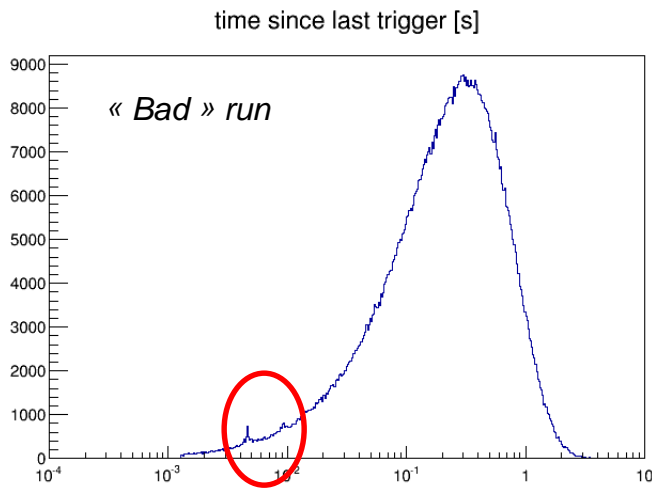
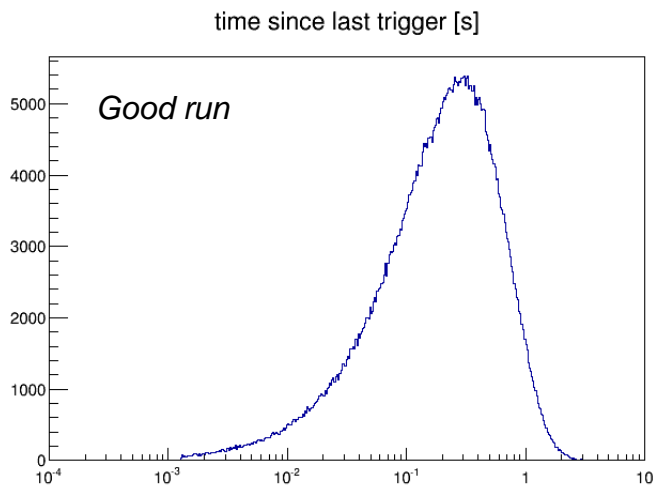
Old algo



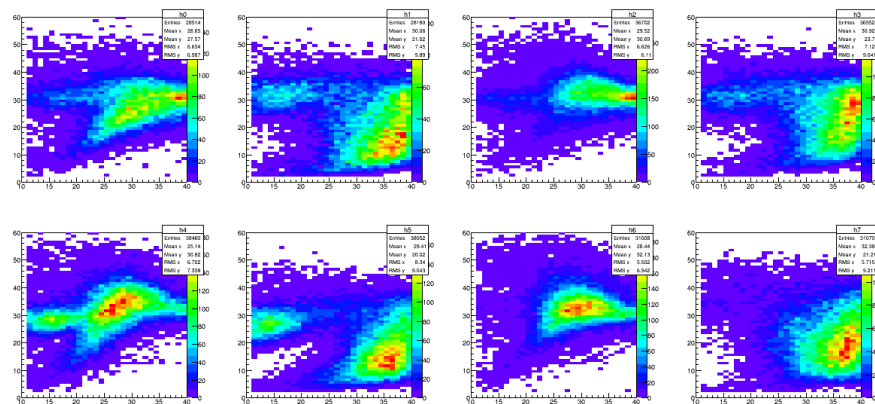
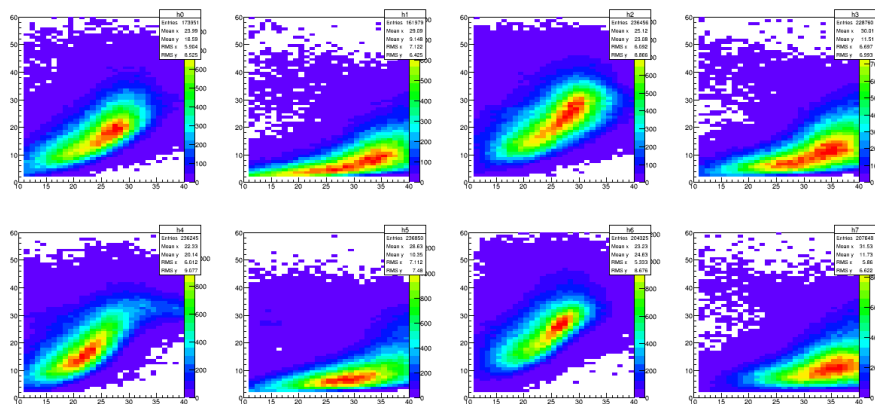
New algo

→ Some artefacts in the image are observed (in particular at its center)

- Largely due to small bursts of noise during some runs



- Also visible in N_{chan} vs TOT plots



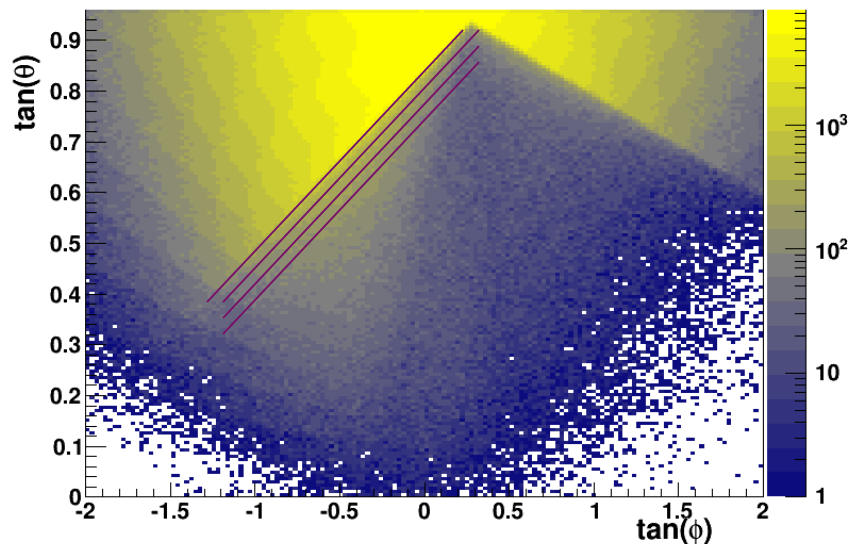
→ Misalignments appear with time, particularly on Alvarez

- *Not a day/night effect due to dilatation, but sudden misalignment followed by slow drift in time*
- *Need to understand the origin and re-align without changing direction*

→ Image treatment to find potential anomalies

- *Edge detection algorithm to check stability of telescopes in time*
- *Slices below the edge at different depths to localize muon excess (or deficit)*

→ Compare East and North projections to look for potential similarities



(Geant4 simulation of a perfectly homogeneous pyramid)

→ Fascinating experiment adventure

- *Btw, probably the first use of MPGD tracker in Africa (?)*
- *Proves that MPGD can have applications really far from our daily work*

→ Analysis is still ongoing, results should be soon available

→ Enormous thank to HIP institute, Cairo University...

- *Mehdi Tayoubi*
- *Hany Helal, Yasser Elshayeb*

→ ... and fantastic local team!

- *Vincent Steiger, Eric Van Laere, Philippe Bourseiller*
- *Hamada Anwar, Mostaffa Ezzy, Issam, Turbo, etc.,*

