ScanPyramids Muography Projects at Commissariat à l'Energie Atomique

Muographers 2017

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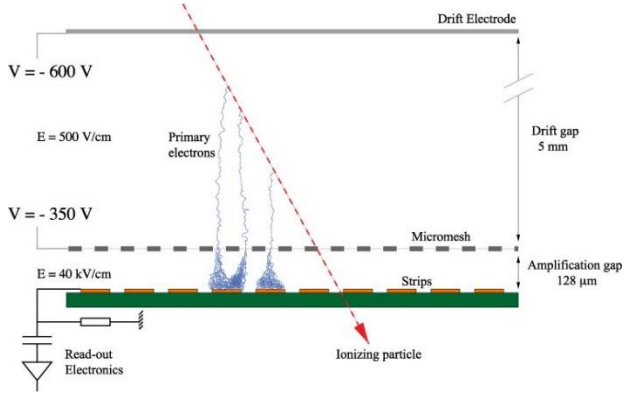
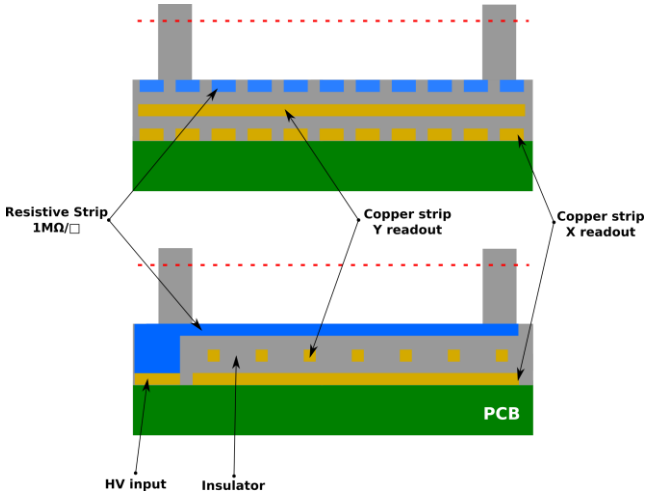
CEA/DRF/IRFU/DPhN | IRIS Instruments

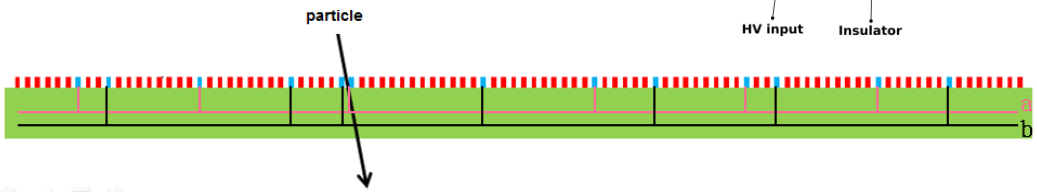
Instrument design

MultiGen 2D v2 detector

- Evolution of prototype
- Multiplexed resistive Micromegas with 2D strip readout
- Measured 2D efficiency above **96%**
  - Good homogeneity
- Efficiency plateau
  - Larger than prototype
- Degraded resolution (**300µm**)
  - Cluster size
  - Resistivity homogeneity
- Nearly **100% industrialized**
  - Only the resistive foil is made at CERN or Saclay
- **36 detectors** produced and tested







Telescope design

Enclosure	Flight case Thermal and EM shielding
Gas supply	2 10L premix bottles
Power supply	AC + truck battery
Power consumption	40W
Detectors	4 MultiGen 2D v2
Detector manufacturer	ELVIA industry
Weight	~130kg
Connectivity	3G
Storage	2TB (>90 days of data)

First ScanPyramids campaign

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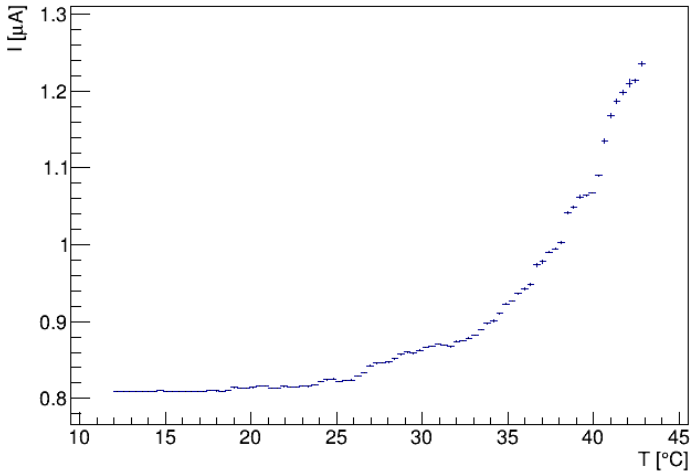
Context

- Participation was not foreseen
  - First discussions began in December 2015
- Complementary technology
  - Japanese scintillators and emulsions
  - Gas leaks incompatible with confined environment
- Image pyramid North-East edge
  - **Known cavity to detect**
    - Notch point of reference
  - Sensitivity from outside is better for the pyramid outer layer

Temperature tests

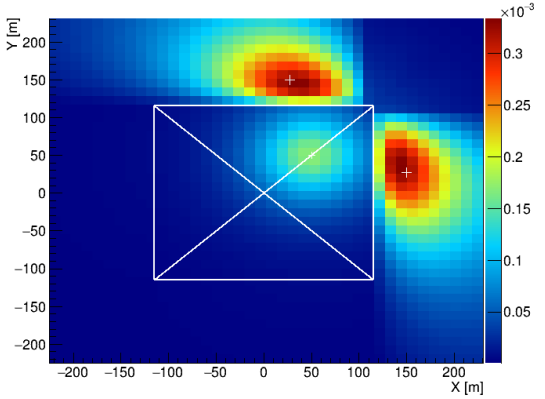
- Oven up to **55°C**
  - Reached maximum for electronics
  - Steady current above 30°C
    - Current leakage through the coverlay
    - Appears also with metallic Micromegas
  - Stable detector gain
- Outside down to 6°C
  - Test during hail shower

Temperature dependence of the detector current



Telescope installation

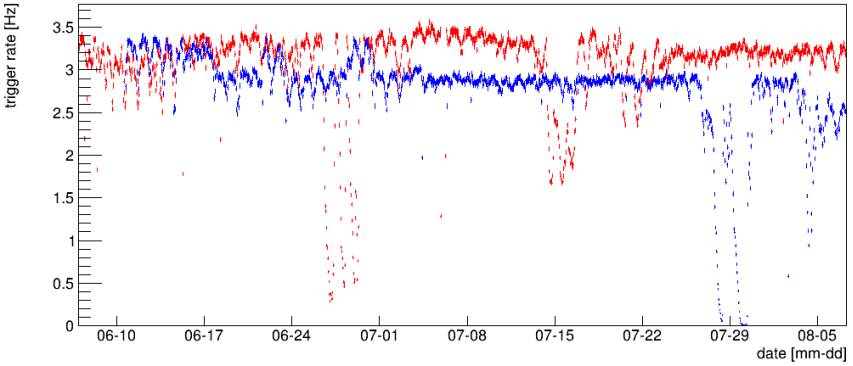
- Telescopes were shipped and stored at Cairo faculty of engineering
- One week of final configuration and setup
  - One day at the faculty
  - At Giza
- Telescope **placement optimized** for sensitivity
  - $\cos^2$ effect
  - Solid angle effect
  - Contrast effect ($\Delta\rho/\rho$)
- Telescopes placed inside tents for guard convenience



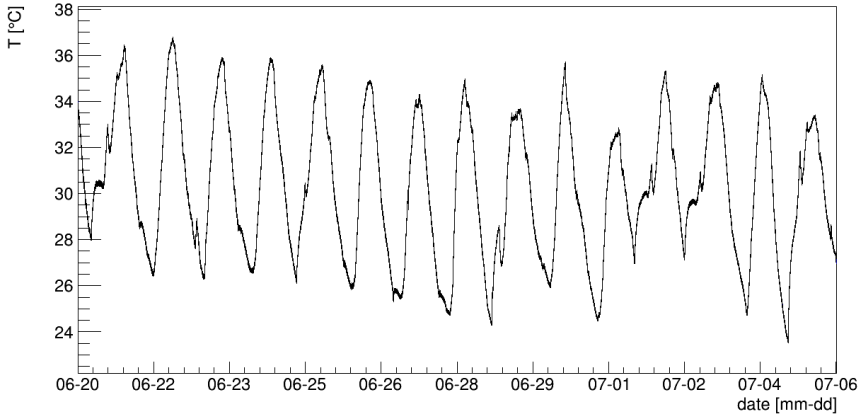
Sensitivity to the known chamber with respect to the point of view

Data taking

- Three months long
  - June 2016 to August 2016
- Stopped when gas bottles were exhausted
  - **<1L/h flow**
- Voltage T and P adjustments were complicated
  - Offsets : **T(Air) ≠ T(Gas)**
- Frequent 3G disconnection
  - Egyptian team rebooted connection several times a week
- Uneven gas flow due to T variations
  - Bubbling stopped at night



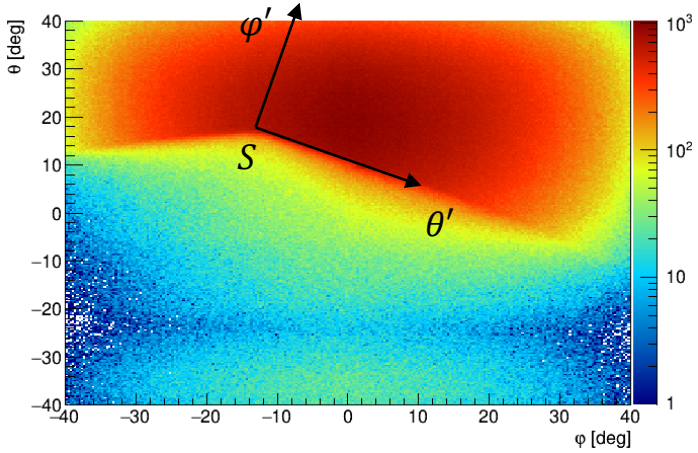
Triggering rate of two telescopes



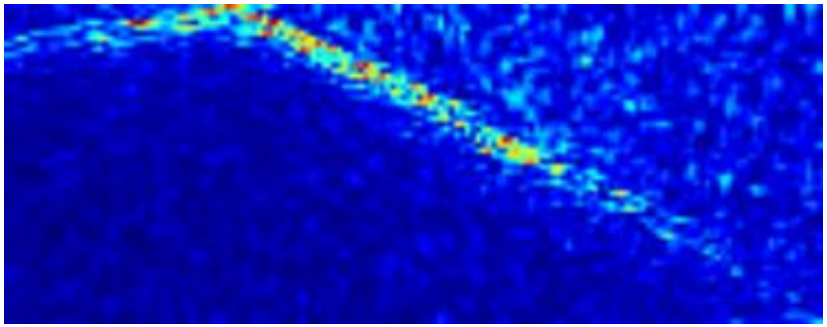
Temperature variation measured inside one telescope

Analysis (1/2)

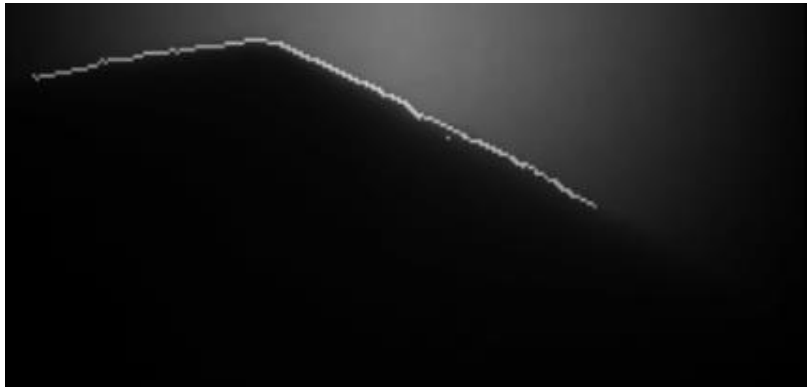
- Seeked signal can be seen through the muon flux gradient
- Computer vision inspired analysis
- Gradient calculation ~ applying filters
  - Convolution with kernel matrix
- Sobel gradient calculation
- Canny edge detection algorithm
  - **Precise edge positioning**
- Hints on known chamber



Muon flux angular distribution



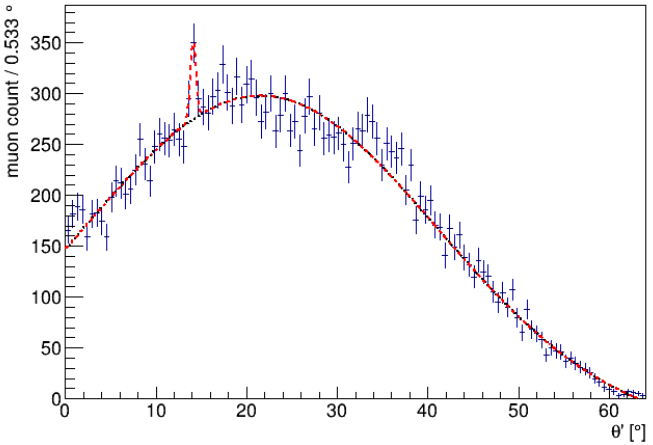
Sobel flux gradient of the edge region



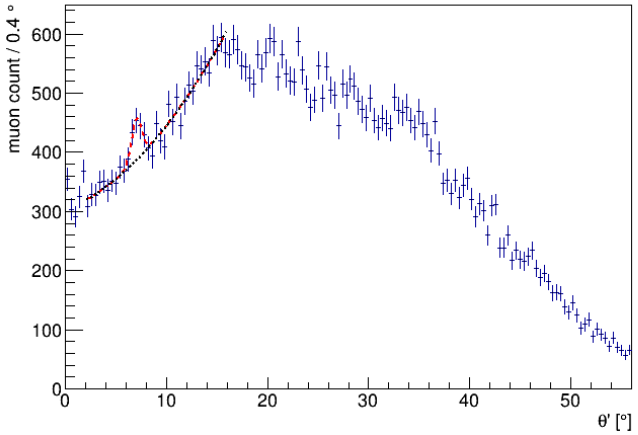
Detection of the pyramid edge with the Canny algorithm

Analysis (2/2)

- Slices parallel to the edge method
- Corresponds to **nearly constant contrast** zone
- Independent detection of the known cavity with two telescopes data
  - Combined excess of $144{,}6 \pm 22{,}5$ muons
  - **$6{,}4\sigma$ excess**
- Independent detection of a new cavity with two telescopes data
  - Combined excess of $129{,}1 \pm 22{,}7$ muons
  - **$5{,}7\sigma$ excess**



Known cavity muon excess measured by one telescope



Unknown cavity muon excess measured by one telescope

Second ScanPyramids campaign

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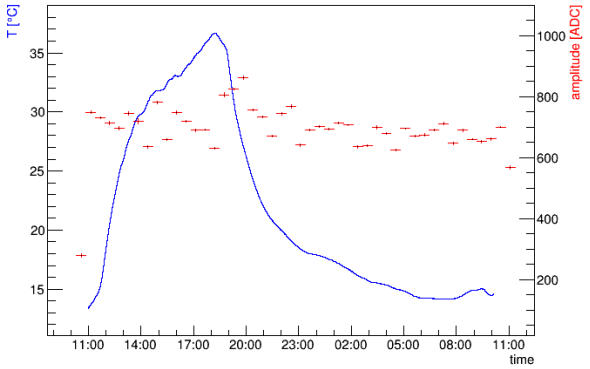
Goal

- At least 2 cavities exist on North-East edge
- Cavities may exist on all three other edges
  - Predicted by ramp theories
- 3 telescopes for 3 remaining edges
  - 1 on North
  - 2 on South

First campaign
Second campaign

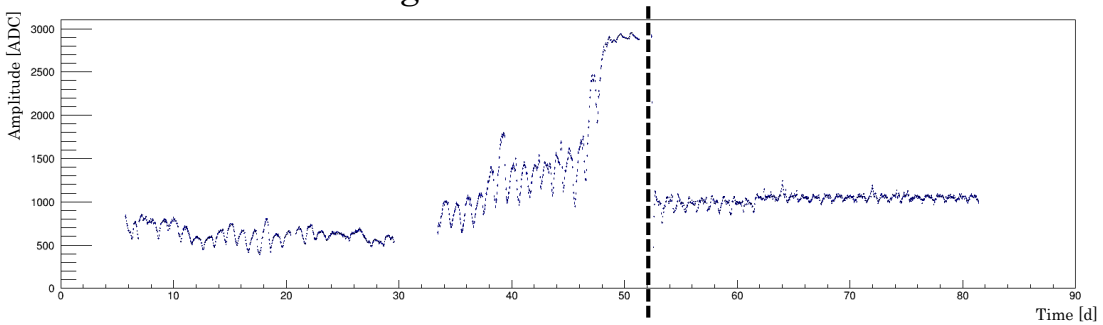
Telescope upgrades

- Gas monitoring
  - (T,P) probes inside the gas volume
- Detector changes
  - Installation of the best detectors in term of gas tightness
- Amplitude feedback
  - **Voltage dependence on signal amplitude itself**
  - $U(t + \Delta t) = U(t) - \alpha(S(t) - S_T)$
  - Use online tracking to filter computed amplitude
  - Greatly increased stability
  - Patented



Signal amplitude and temperature variations

- Switch from 3G to 4G dongles



Amplitude variation through time before and after the amplitude feedback implementation

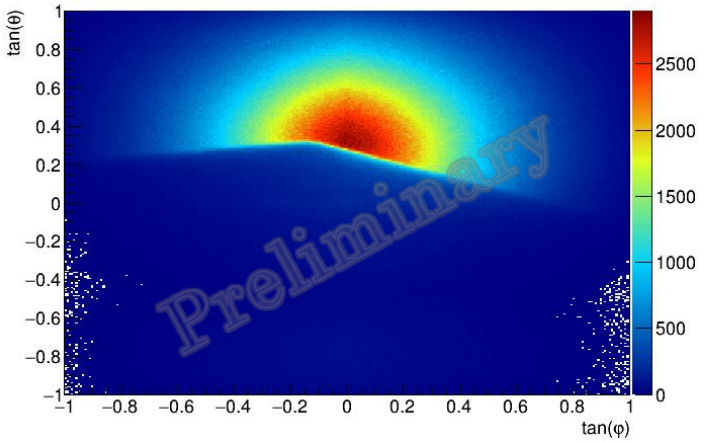
Data taking

- January 2017 to April 2017
- Sandstorms
  - **Tents torn off** several times
  - No telescope movements observed
- 3G connectivity problems remain
  - Humidity during the night ?
- Better voltage adjustments
  - First thanks to inner probes and less leaks
  - Then thanks to the amplitude feedback

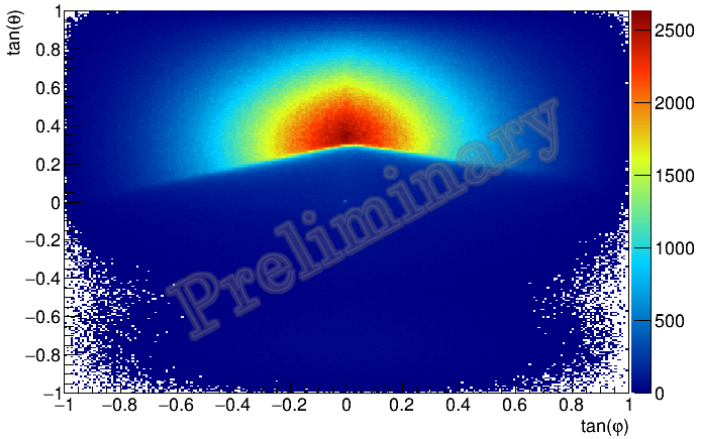
Analysis

- Same methods as previous missions
- Some anomalies found
  - Nothing significant enough
- Further analysis still ongoing
- Tends to disprove inner ramps theory

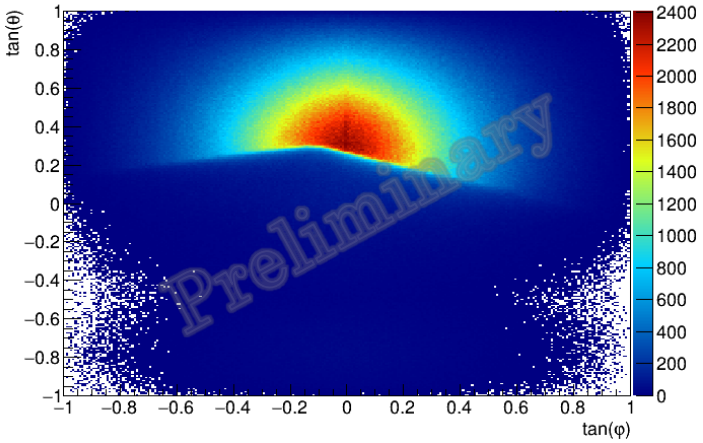
North-West edge muon flux map



South-West edge muon flux map



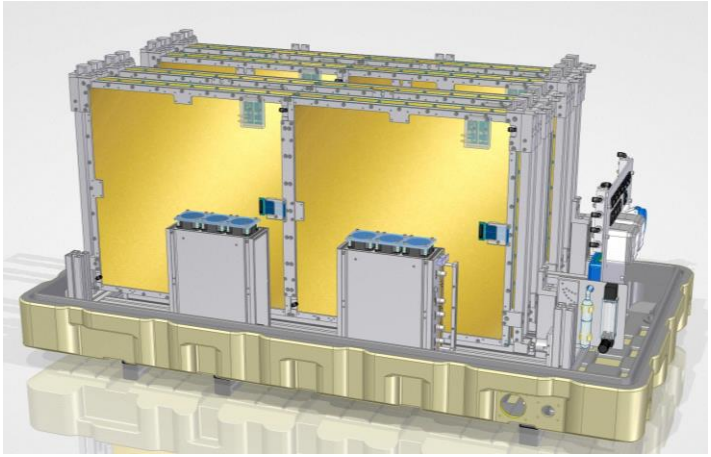
South-East edge muon flux map



Toward the future

MIMOSA

- Telescope collection surface upgrade
  - 0.25m² to 1m²
- Limit resource consumption increase
- Maintain transportability
  - Foldable design
- Detector upgrade
  - DLC resistive layer
  - Better resolution
  - **First tests are promissing**

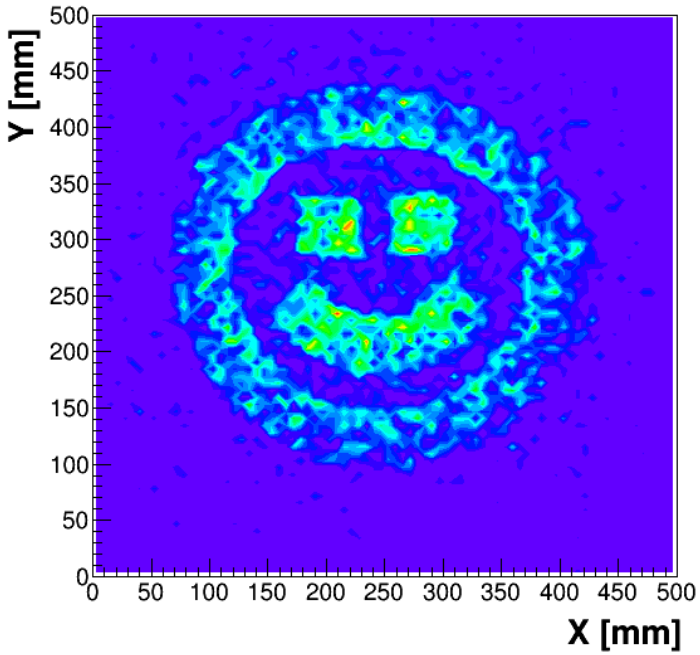


HVPS v2

- Dedicated card for high voltage and gas supply
  - Upgrade of existing design
- 5 HV power supply
  - Enough for 4 detectors
  - Made by CAEN
  - <0,4W each
- Up to 2 electronic flow controllers/meters operation
  - Allow for **semi-sealed operation**
  - Maintain overpressure inside the detectors
  - Made by Bronkhorst

Conclusion

- Three telescopes have been design, built and shipped to Egypt in less than 6 months
- They were successfully operated during two 3 monthes long data taking campaign
  - Enduring harsh conditions of the Giza plateau
- Proof that gaseous Micromegas detector are suitable for muographing campaigns in the wild
- These campaigns unveiled unknown an unknown cavity inside Khufu's Pyramid and maybe more in the future…



Thank you for your attention

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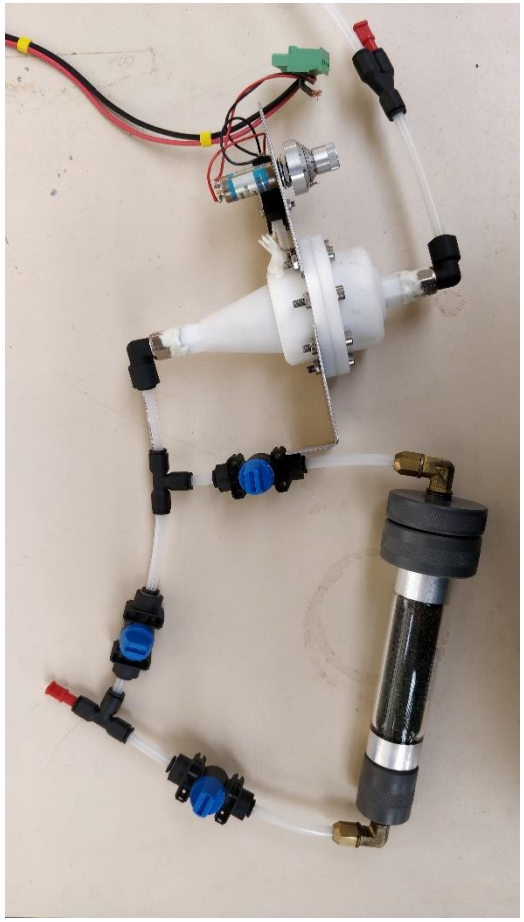
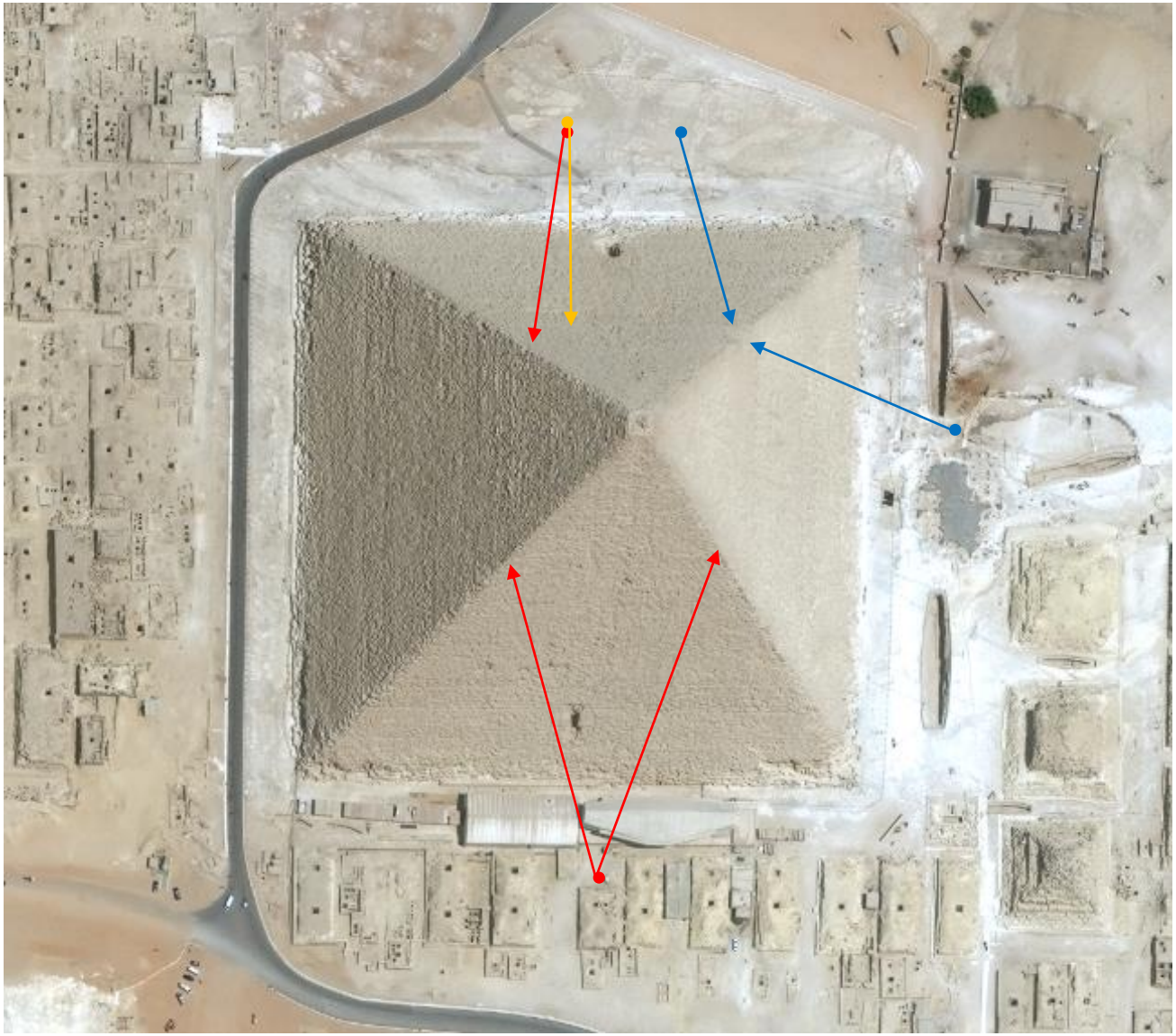
Backup

Toward sealed operation

- Gas tightness
  - Seals can be replaced by gluing
  - Better gas tightness at the cost of repairing capabilities
  - Down to **0,04mL/h leaks**
- Gas recycling
- Developed by HARPO collaboration
  - Circulating turbine
  - Gas filter
  - Remove contaminants (O2,H2O,…)
- Ongoing test
  - Detector material **outgassing**





First campaign
Second campaign
Third campaign