Micromegas: a versatile device for radiation detection and imaging applications

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Outline

Micromegas detector basics

Principle of operation

Evolving technology

Various types of Micromegas

Overview of (some) applications

Radiation detection

Timing

Other (imaging, accelerators, cultural heritage...)

MM @ AUTh

Summary

Current status and future steps

MM basics

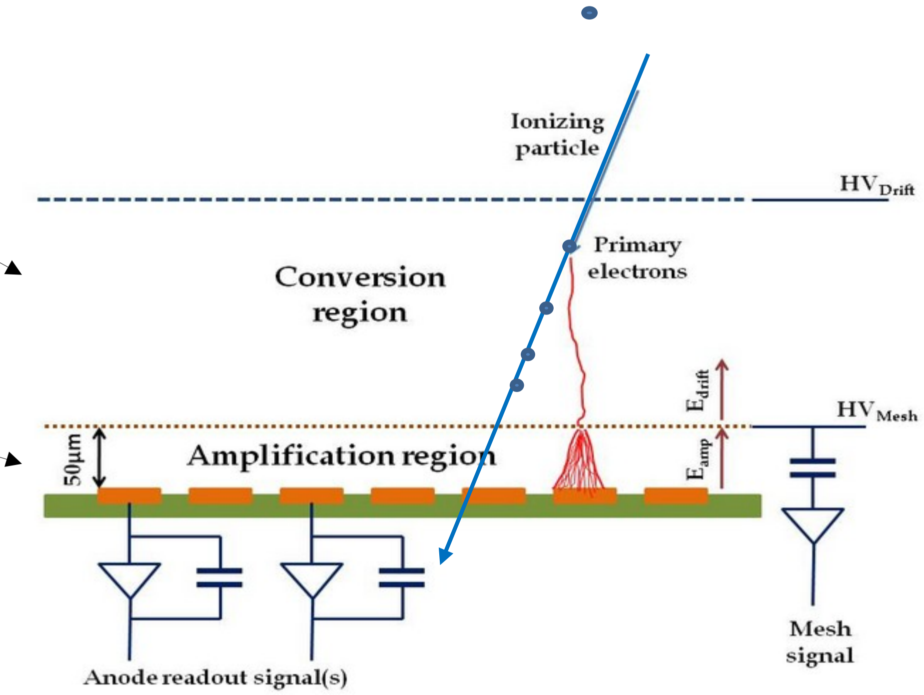
Typical Micromegas: Principle of Operation

Drift gap/Conversion region

Ionizing particles create electrons, which drift towards readout plane.

Amplification region

Avalanches/amplification, charge movement induces signals.



Characteristic advantages of the technology:

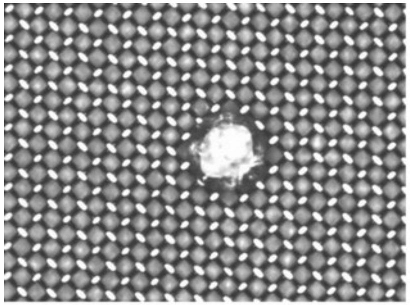
Simplicity, Granularity, Homogeneity, Scalability, High rate capabilities, Radiation hardness, Low cost

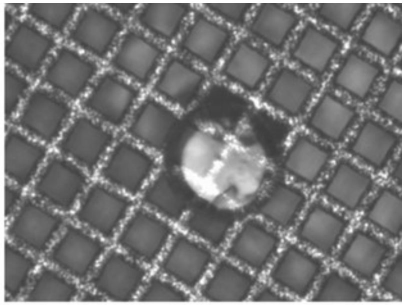
Y. Giomataris, P. Rebourgeard, J. Robert, G. Charpak, MICROMEGAS: A high granularity position sensitive gaseous detector for high particle flux environments, Nucl. Instrum. Meth. A 376 (1996) 29–35

MM Fabrication techniques: mesh

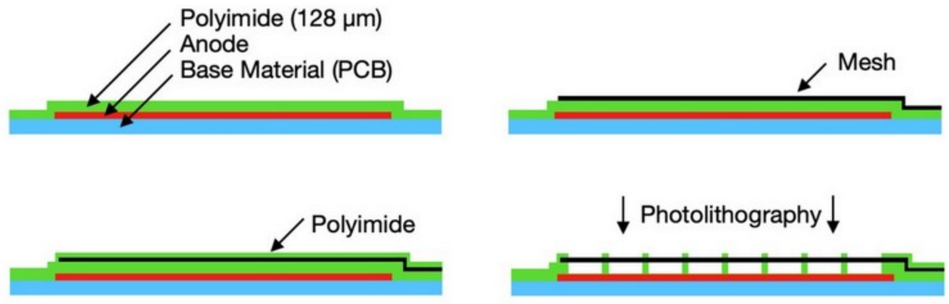
Micromegas detectors are built using different types of meshes depending on the fabrication technique/application

- flat meshes made of thin metallic sheets (4–10 μm), holes produced by micro-machining processes (electroforming, chemical etching etc.)
- mesh made of mechanically woven stainless-steel wires (18 μm up to 30μm typical wire thickness)


(a) Woven mesh


(b) Electroformed mesh

“Bulk” technology a big step for the industrialization/production of large scale MM



Principle: embedded metallic woven mesh on a Printed Circuit Board

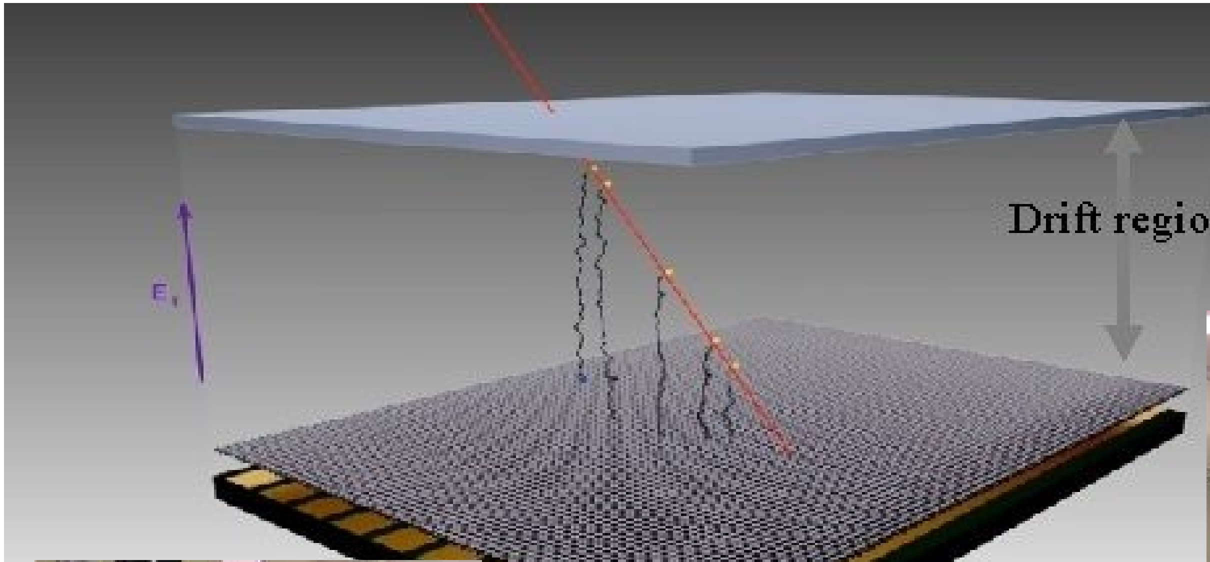
- in Microbulk MM, mesh, pillars and read-out are constructed in a single structure
- bulk technology is applied to the majority of today’s MM

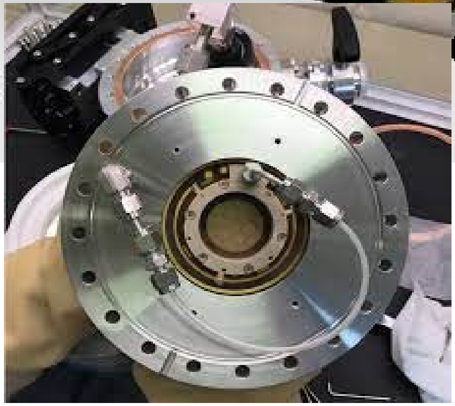
Micromegas in a bulk. Nucl. Instrum. Methods 2006, 560, 405–408

Micromegas: various applications

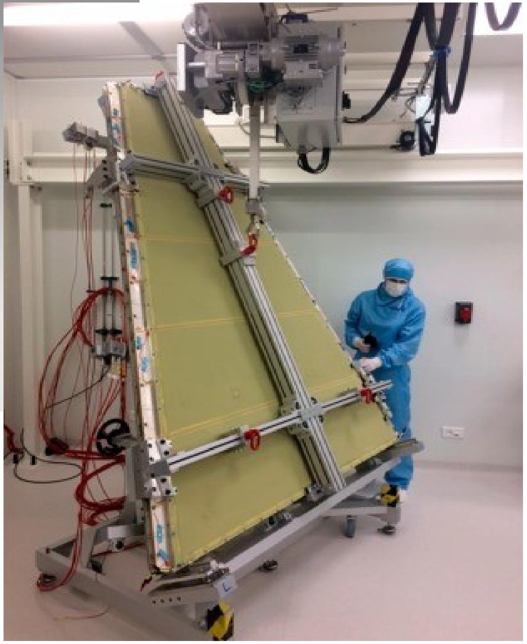
MM used in numerous experiments:

- particle physics (LHC/ATLAS)
- dark matter (CAST)
- neutrinos (T2K)
- astrophysics
- neutron TOF experiments (n_TOF)
- …





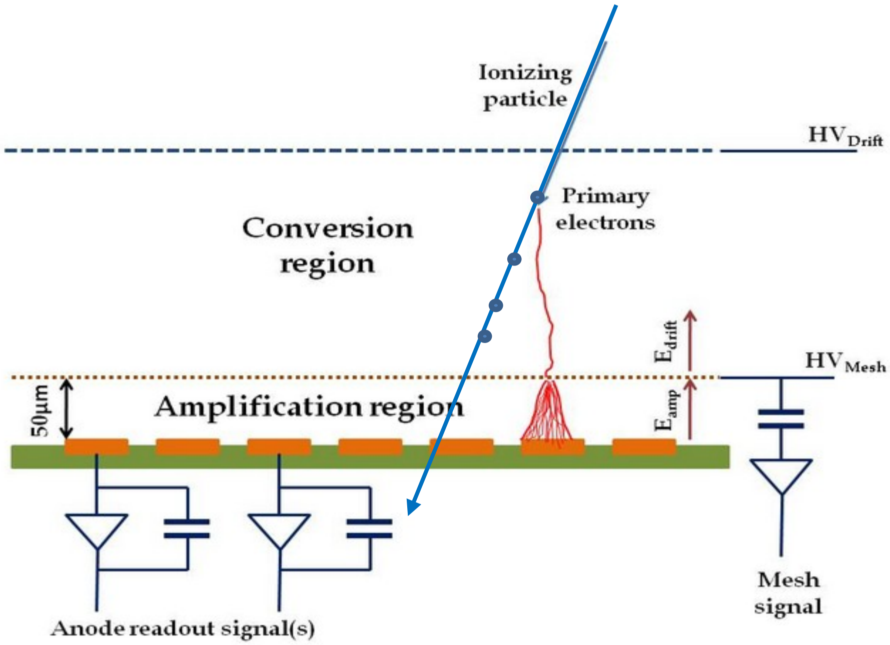
PICOSEC Micromegas for precise timing



LM1 Micromegas for ATLAS
New Small Wheel @ CEA – Saclay

Applications: Timing

Typical Micromegas: **Limitations**



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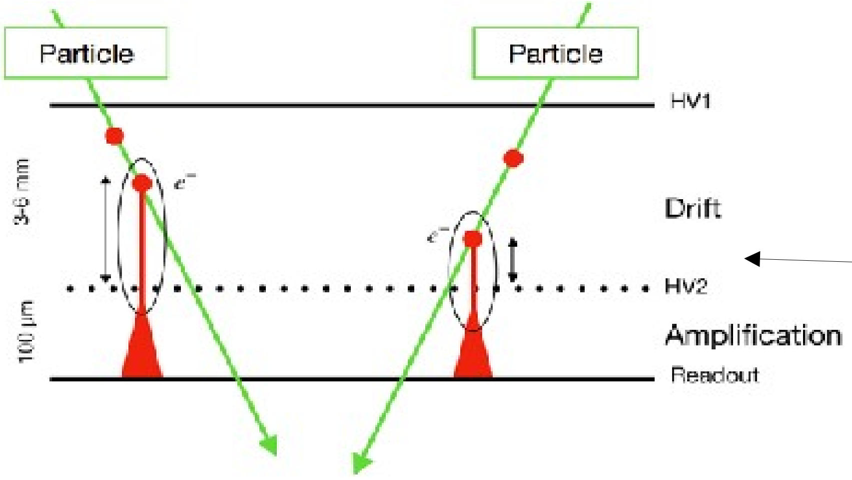
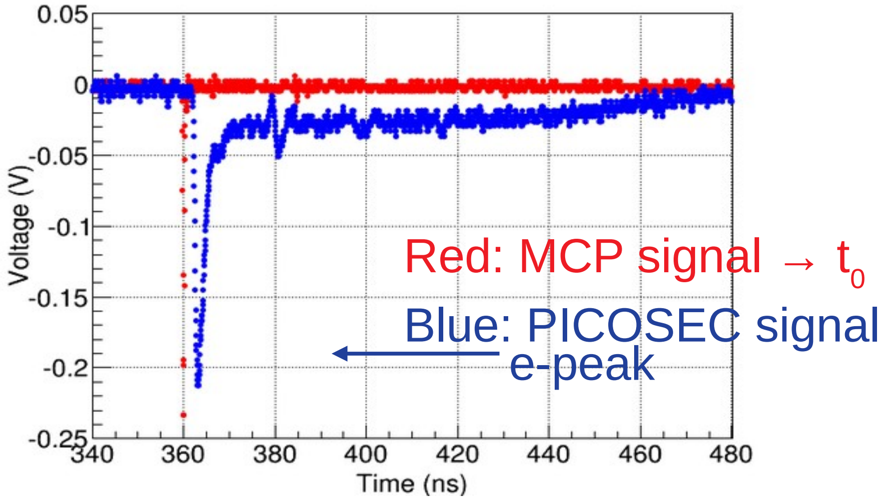


- Ionizations occur in different positions along the particle's trajectory → ~ ns time jitter for a 3-6 mm conversion region
- Diffusion effects

The PICOSEC concept



Red: MCP signal → t_0

Blue: PICOSEC signal

e-peak

Cherenkov radiator + Photocathode

- ✓ Particle produce Cherenkov light
- ✓ Photo-electrons emerge from photocathode
- ✓ Electrons amplified by a two-stage Micromegas

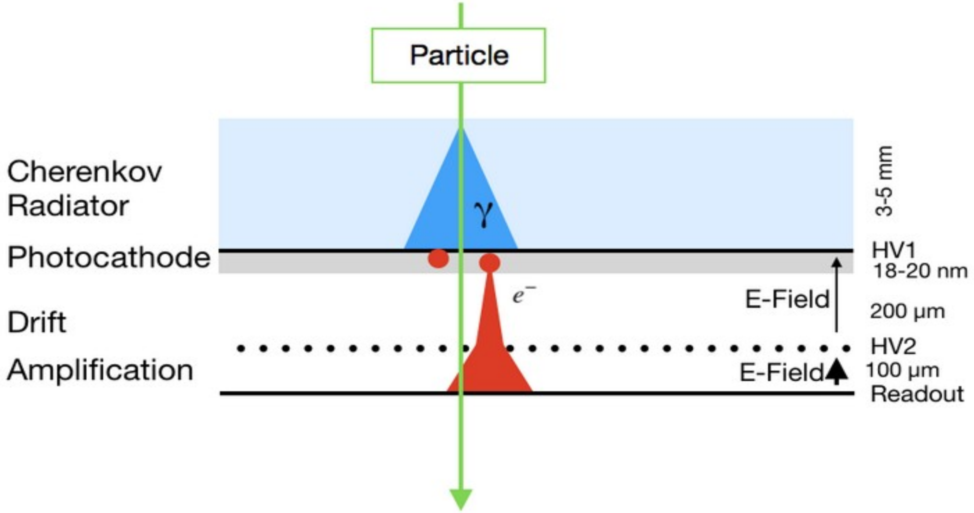
Signal components: Fast <1ns (electron peak) &
Slow ~100ns (Ion-tail)

Small drift gap (~200 μm) + High E-field:

- ✓ Pre-amplification possible
- ✓ Limited direct ionization
- ✓ Reduced diffusion impact

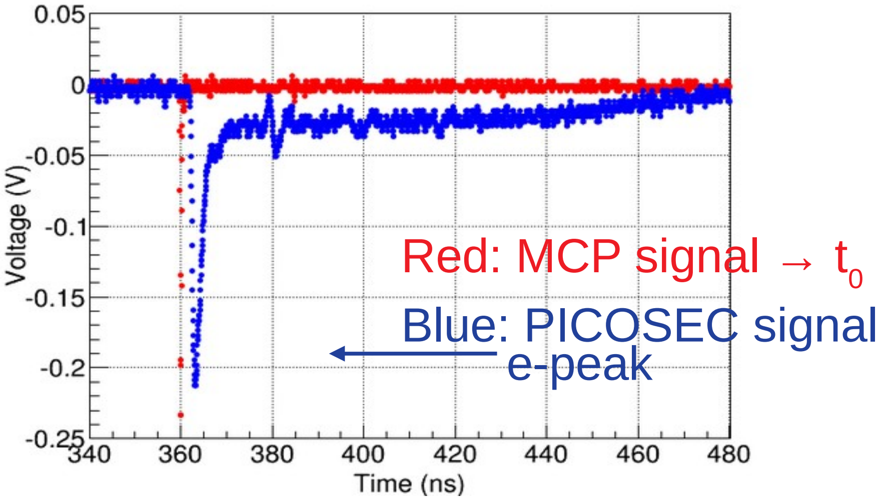
Cherenkov radiator/Photocathode:

- ✓ Photo-electrons emerging the photocathode simultaneously (fixed distance from the mesh)
- ✓ produce sufficient number of photo-electrons



Effect: improved timing resolution

The PICOSEC concept



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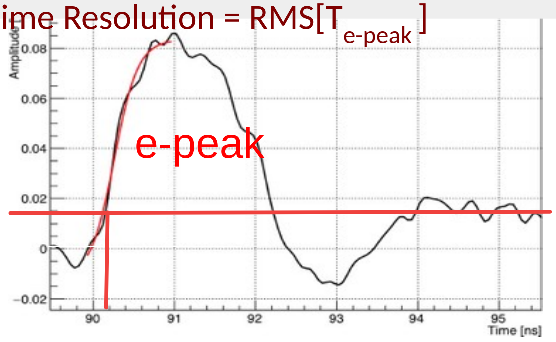
$T_{e\text{-peak}}$ = Signal Arrival Time (SAT)

* SAT of a sample of events = <$T_{e\text{-peak}}$ >

* Time Resolution = RMS[$T_{e\text{-peak}}$]

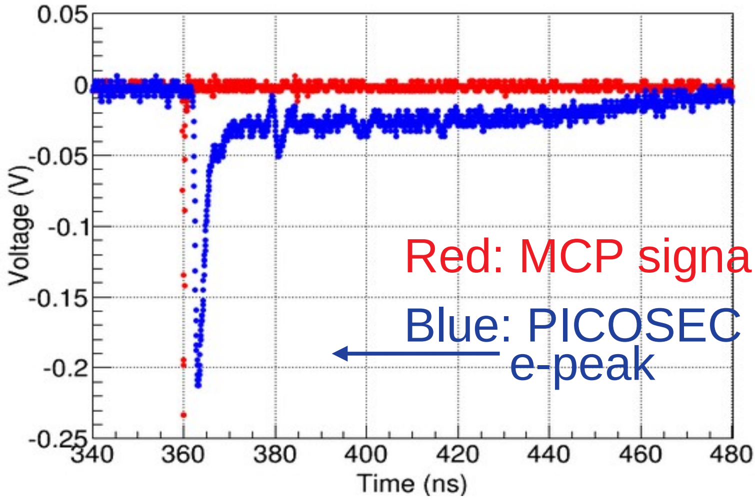


e-peak

$T_{e\text{-peak}}$ Time (ns)

J. Bortfeldt et al. PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detectorhttps://doi.org/10.1016/j.nima.2018.04.033

The PICOSEC concept



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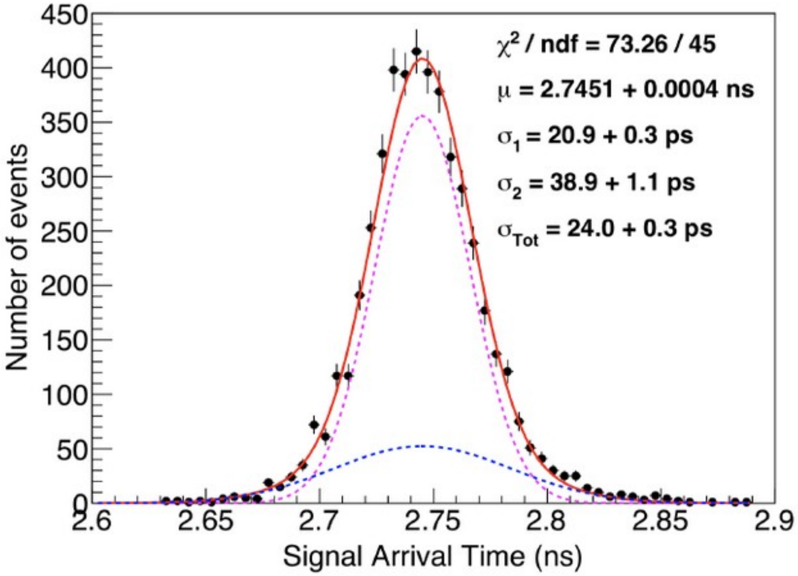

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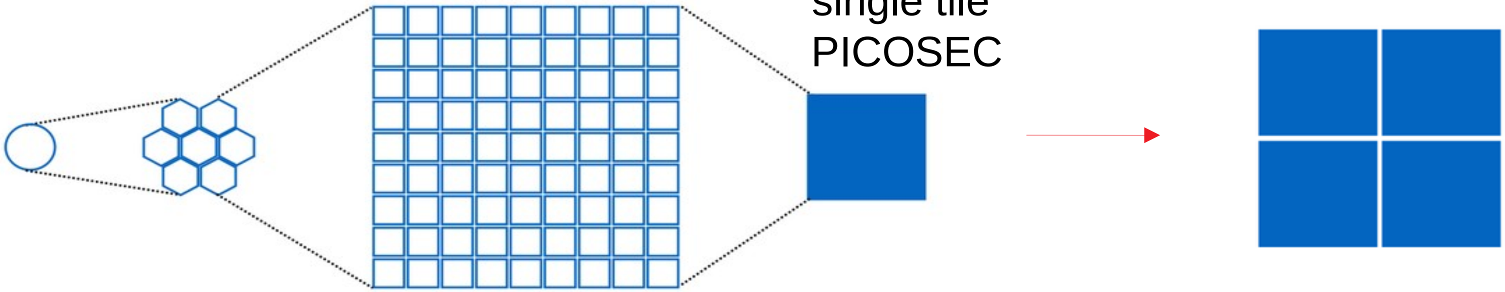
J. Bortfeldt et al. PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector, https://doi.org/10.1016/j.nima.2018.04.033

Towards large area coverage: modular design

S. Aune et al., Timing performance of a multi-pad PICOSEC-Micromegas detector prototype, https://doi.org/10.1016/j.nima.2021.165076



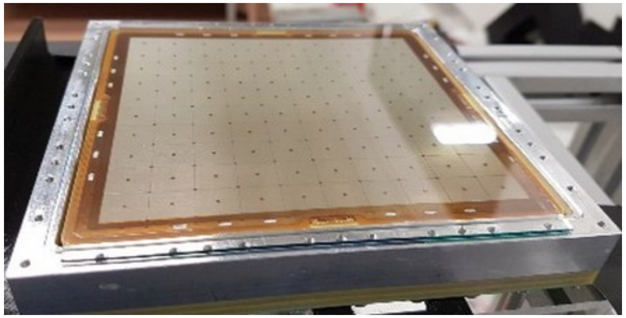
single cell PICOSEC

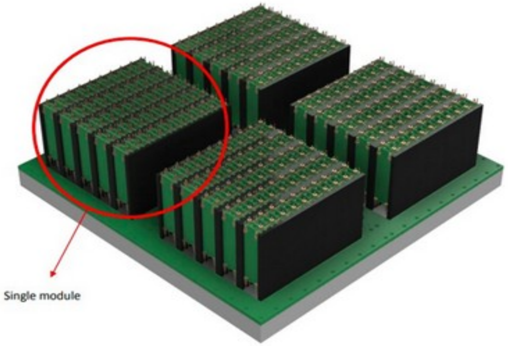
single tile PICOSEC

multipad PICOSEC

segmented PICOSEC detector

tile window pattern PICOSEC

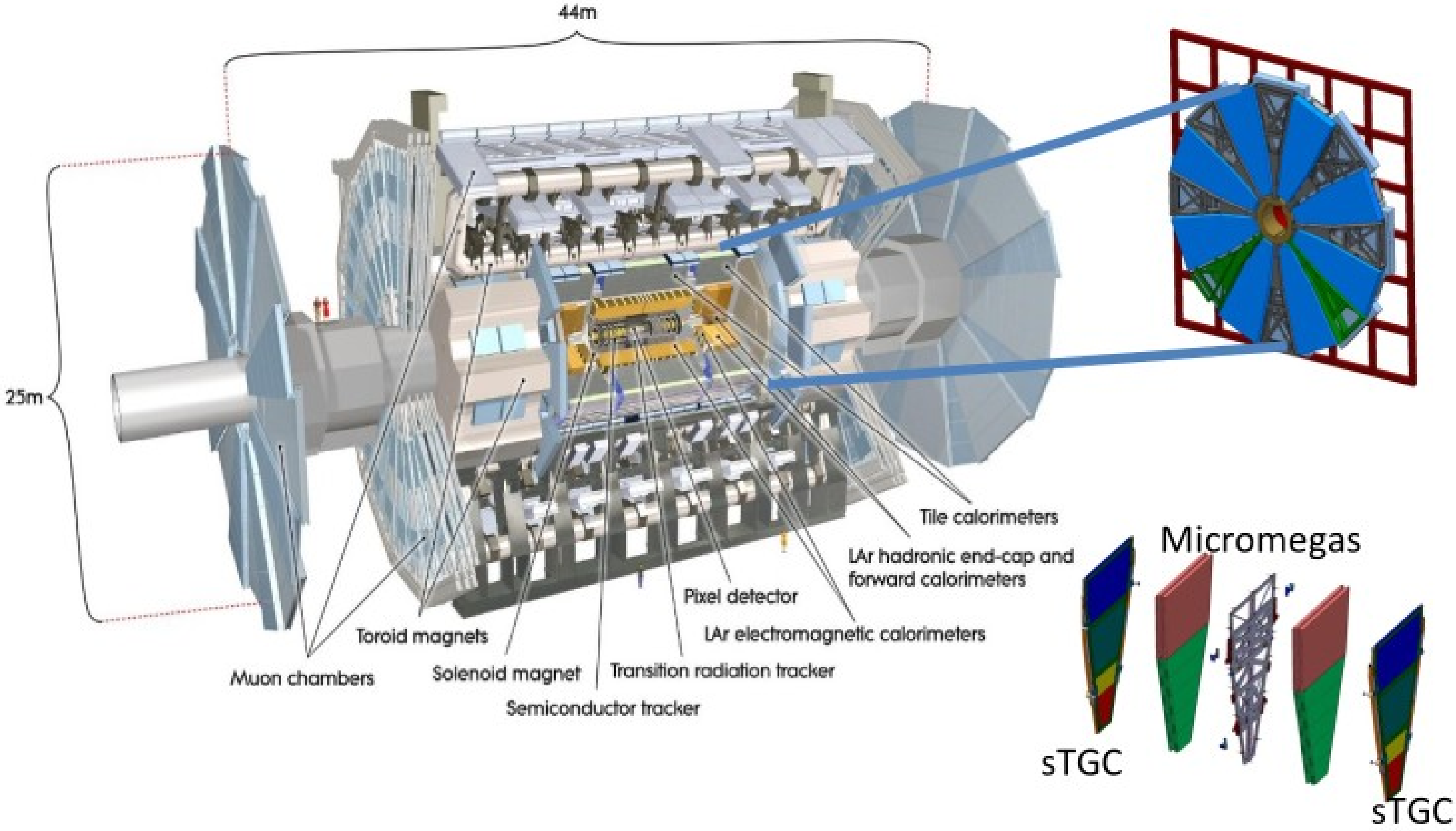




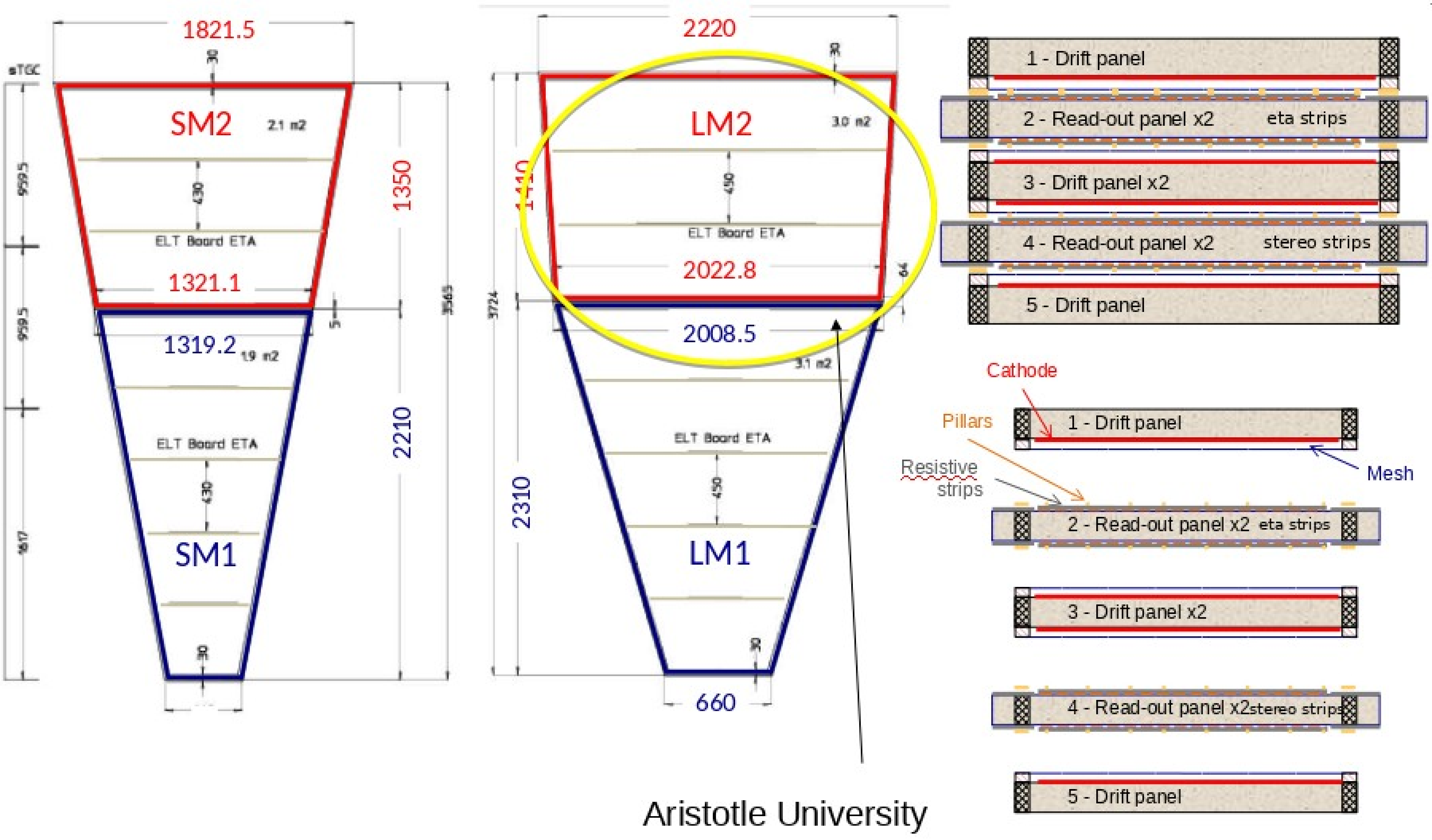
Schematics/photos not to scale

Applications: ATLAS New Small Wheel

Micromegas for ATLAS



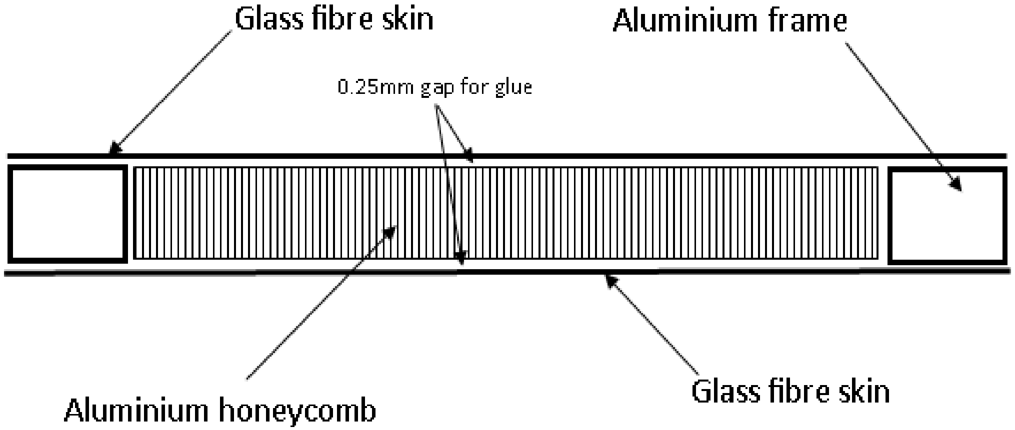
Micromegas wedge and module



NSW single panel construction basics

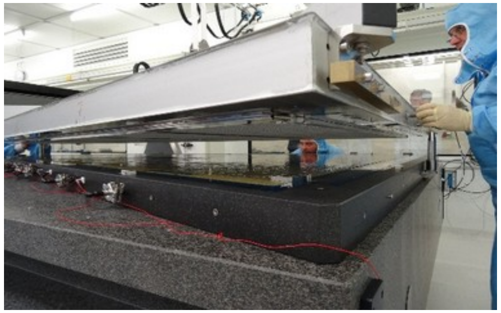
➔ Panel is a sandwich of two skins glued on a stiff plane without mechanical constraints

➔ It consists of two PCBs (500μm) with aluminum made honeycomb and frame in between



- Super – flat surfaces are required as reference planes
- Granite + Stiff – back or Double Vacuum tables methods applied
- Single or dual step processes

stiff – back



vacuum tables

https://www.youtube.com/watch?v=uLJ60sPjOHg

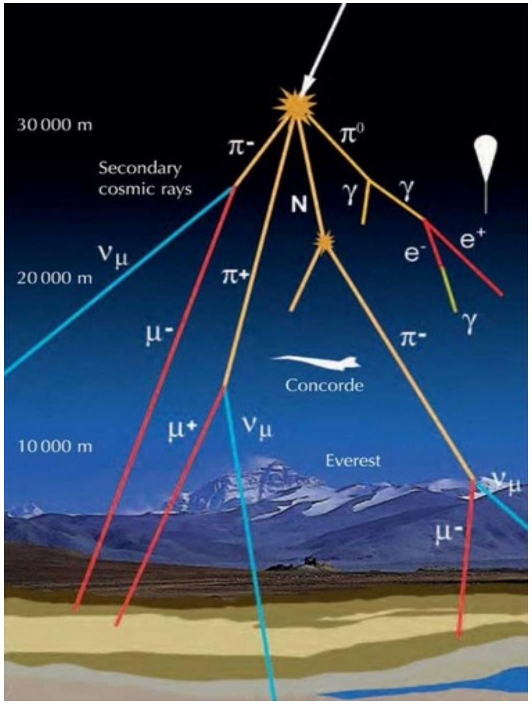
NSW single panel construction basics

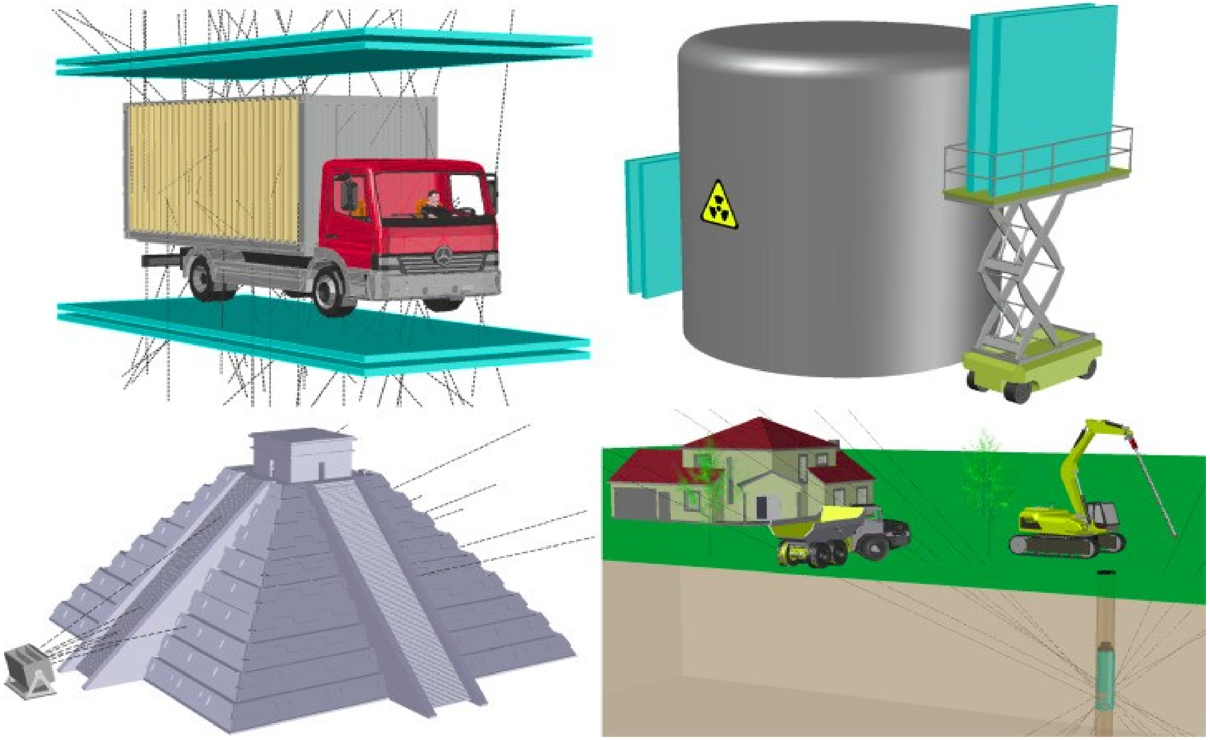
https://www.youtube.com/watch?v=goYfDWU1yws *https://www.youtube.com/watch?v=uLJ60sPjOHg*

Applications: Muography

Atmospheric muons as an imaging tool

Exploit the abundant natural flux of muons produced from cosmic-ray interactions in the atmosphere.





Applications

Investigation of large geological structures
Homeland security: cargo scanning, detection of heavy elements
Safeguards: e.g. characterization of encapsulated nuclear waste
Natural hazard monitoring: volcanos

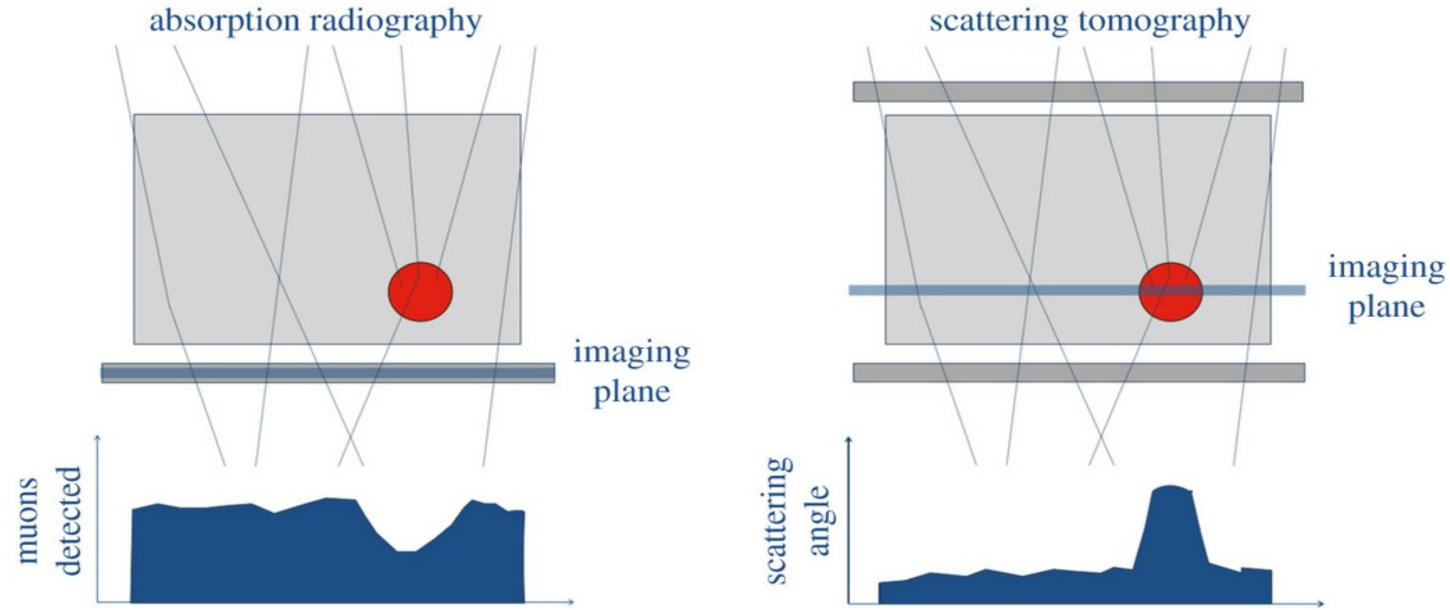
L.Bonechi et al. Review in Physics 5, 2020.

Muography: imaging based on muon detection

a non-invasive but penetrating imaging of density contrast using natural charged particles

Historical overview of Muography

- Thickness of a mountain: George (1955)
- Hidden chambers in Chephren (or Khafre) pyramid: Alvarez (1970)
- Volcanology: Nagamine (1995), Tanaka (2001), Diaphane collaboration (2008)

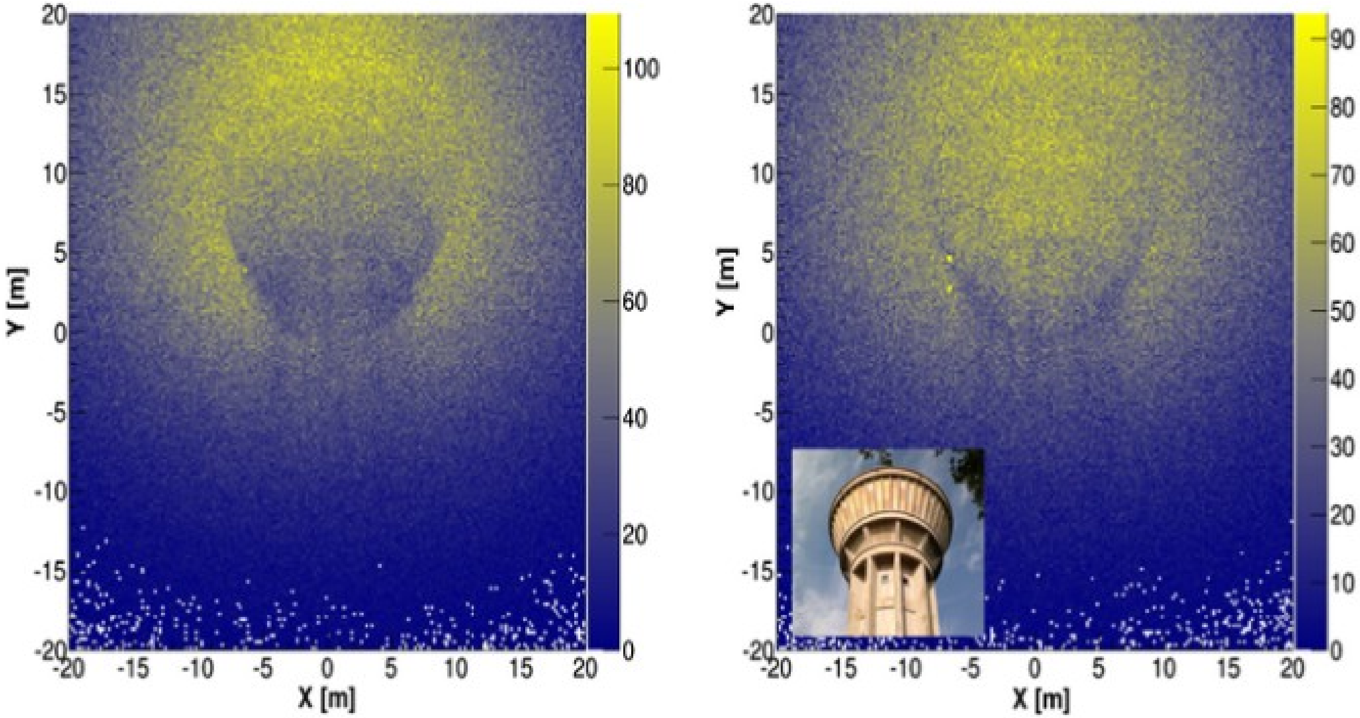


Imaging via absorption
principle is similar to conventional X-ray radiography

Imaging via scattering
analyze the angles of deflection before and after passing through a volume

Muography: imaging from muon flux

S. Procureur,. Muon imaging: Principles, technologies and applications, Nuclear Inst. and Methods in Physics Research, A 878 (2018) 169–179



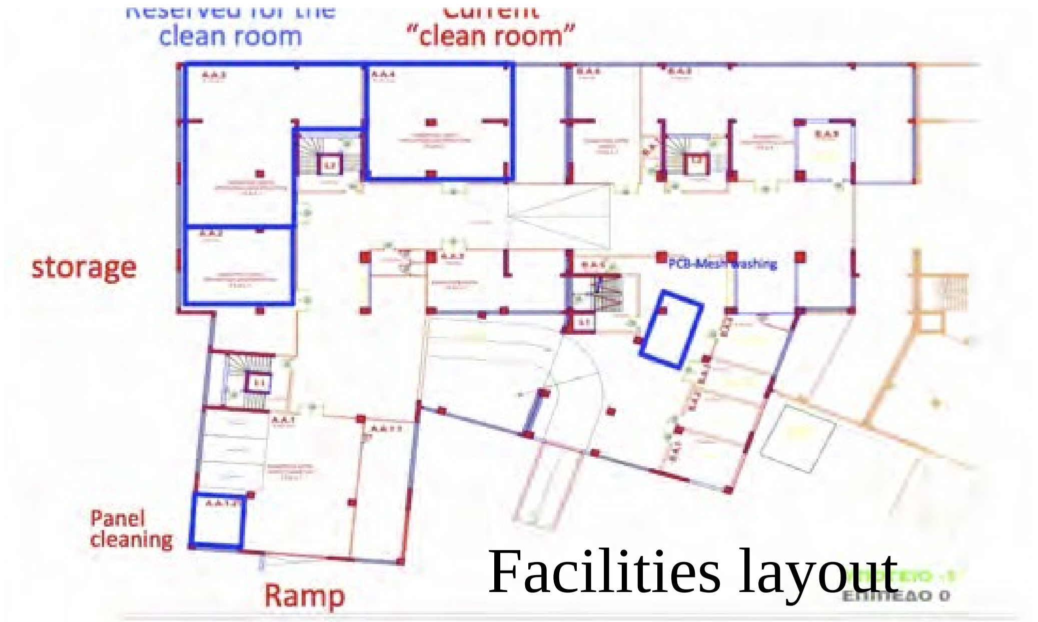
Raw muographies of the Saclay water tower, with (left) and without (right) water in the tank.

S. Bouteille, et al. A Micromegas-based telescope for muon tomography: The WatTo experiment, https://doi.org/10.1016/j.nima.2016.08.002

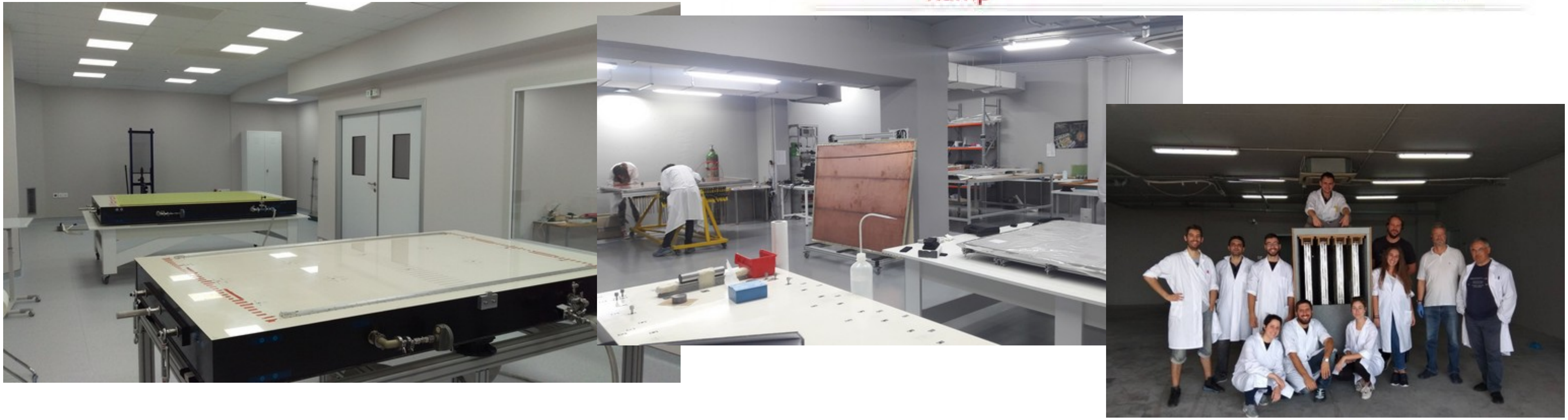
Micromegas @ AUTh

NSW drift panels construction @ AUTh

CIRI – AUTh



Facilities layout

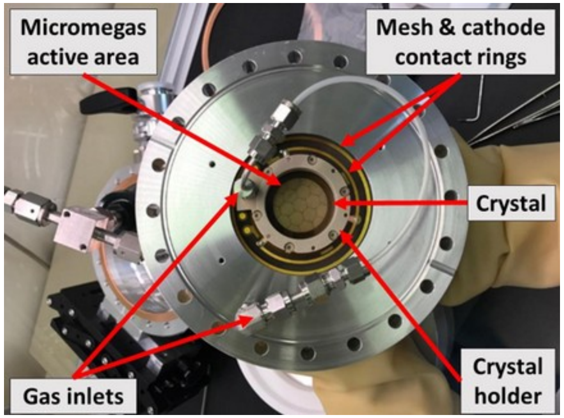


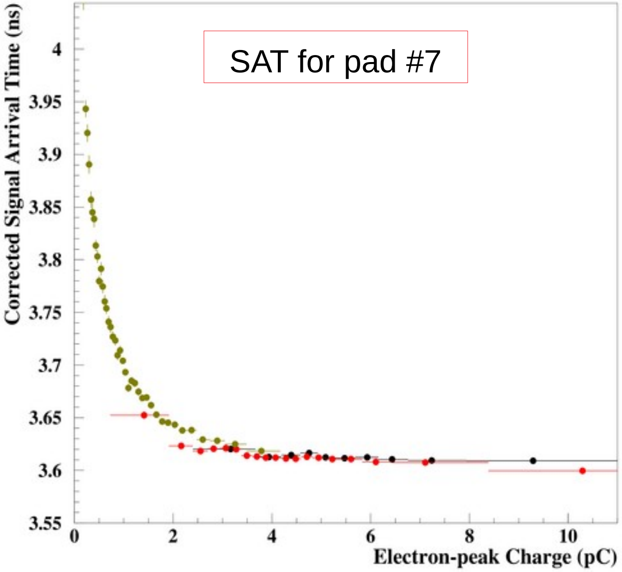
2016 – 2020 production line: delivered 105 MM drift panels

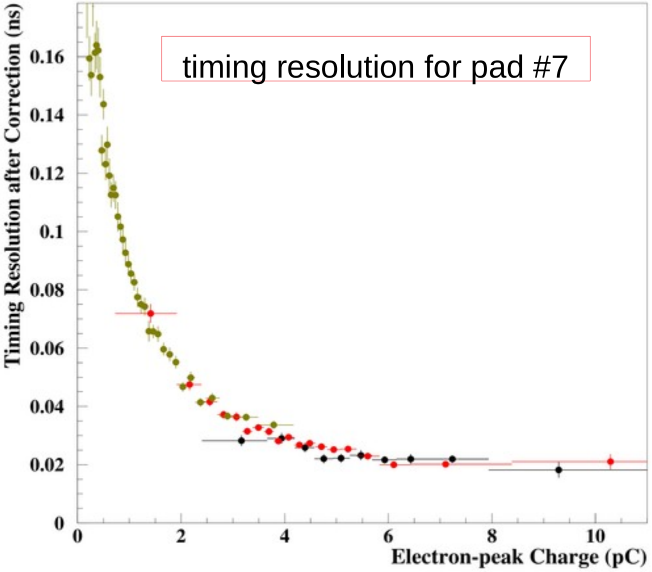
PICOSEC

Requirements aiming for a larger coverage detector
- Multi-channel capabilities (Cherenkov shared among pixel anodes)
- Robust photocathodes
- Resistive readout for spark quenching in amplification gap
- Detector optimization

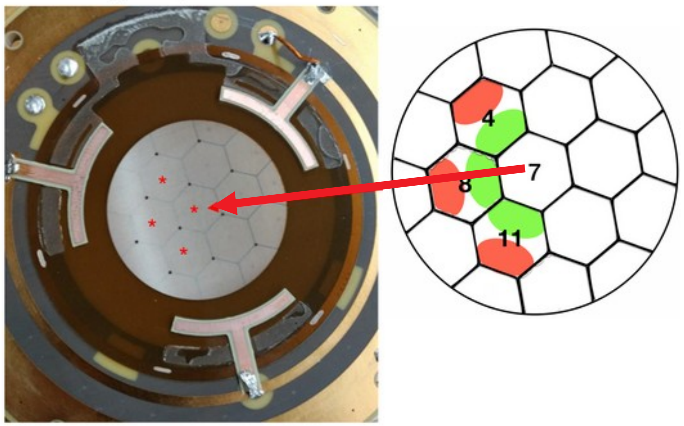
Similar detector configuration as the single – anode PICOSEC







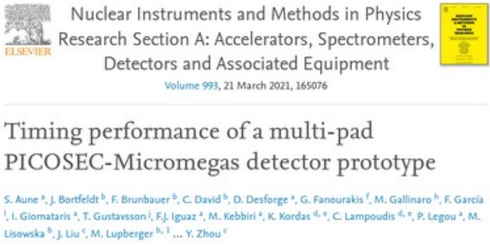
19 hexagonal pads 5mm side



0 < R < 2mm: full Cherenkov cone (3mm) inside a single pad surface

2 mm < R < 4.33 mm

4.33 mm < R < 7.5mm: full Cherenkov cone (3mm) mostly outside a single pad


Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 993, 21 March 2021, 165076

Timing performance of a multi-pad PICOSEC-Micromegas detector prototype

S. Aune [a], J. Bortfeldt [b], F. Brunbauer [b], C. David [b], D. Desforge [a], G. Fanourakis [f], M. Gallinaro [h], F. García [i], I. Giomataris [a], T. Gustavsson [j], F.J. Iguaz [a], M. Kebbiri [a], K. Kordas [d, e], C. Lampoudis [d, e], P. Legou [a], M. Lisowska [b], J. Liu [c], M. Lupberger [b, 1] ... Y. Zhou [c]

The “mini” Micromegas telescope (CIRI – AUTh)

12 x 10 cm^2

Scintillator 2

MM4

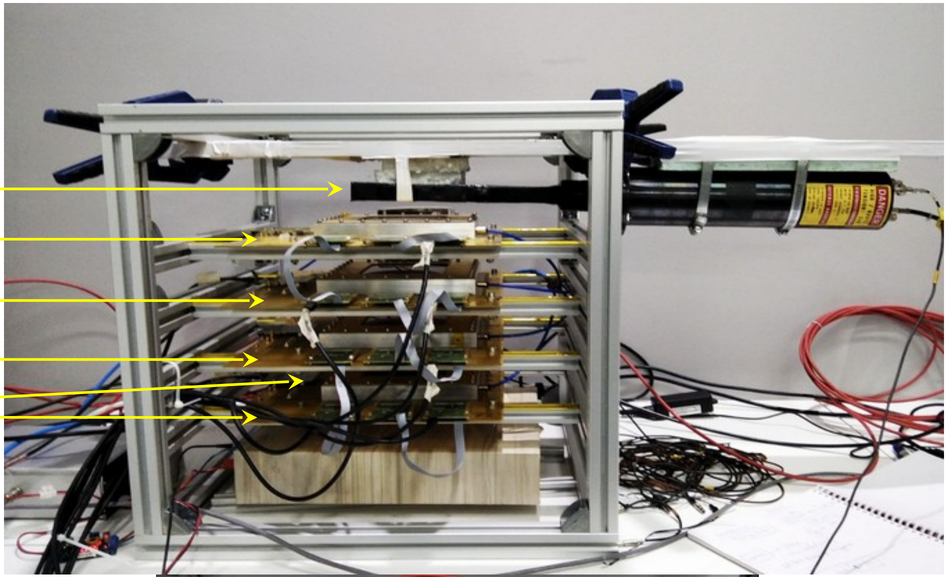
MM3

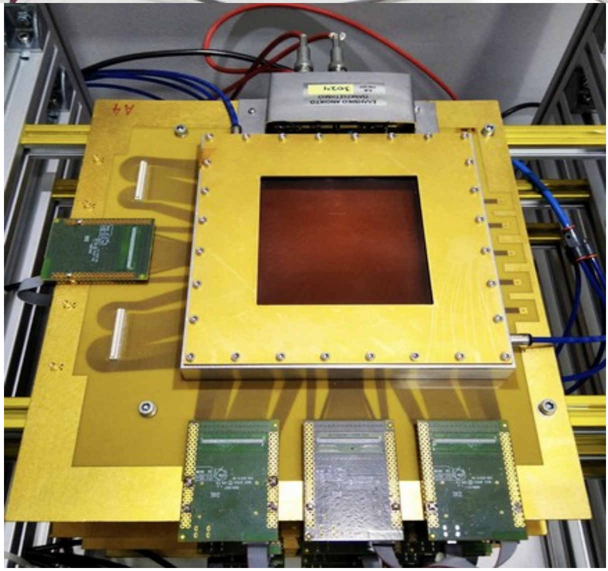
MM2

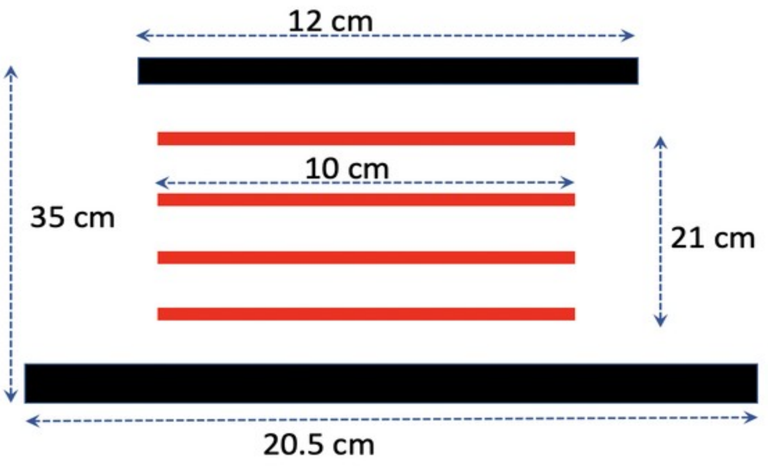
MM1

Scintillator 1

20.2 x 23 cm^2





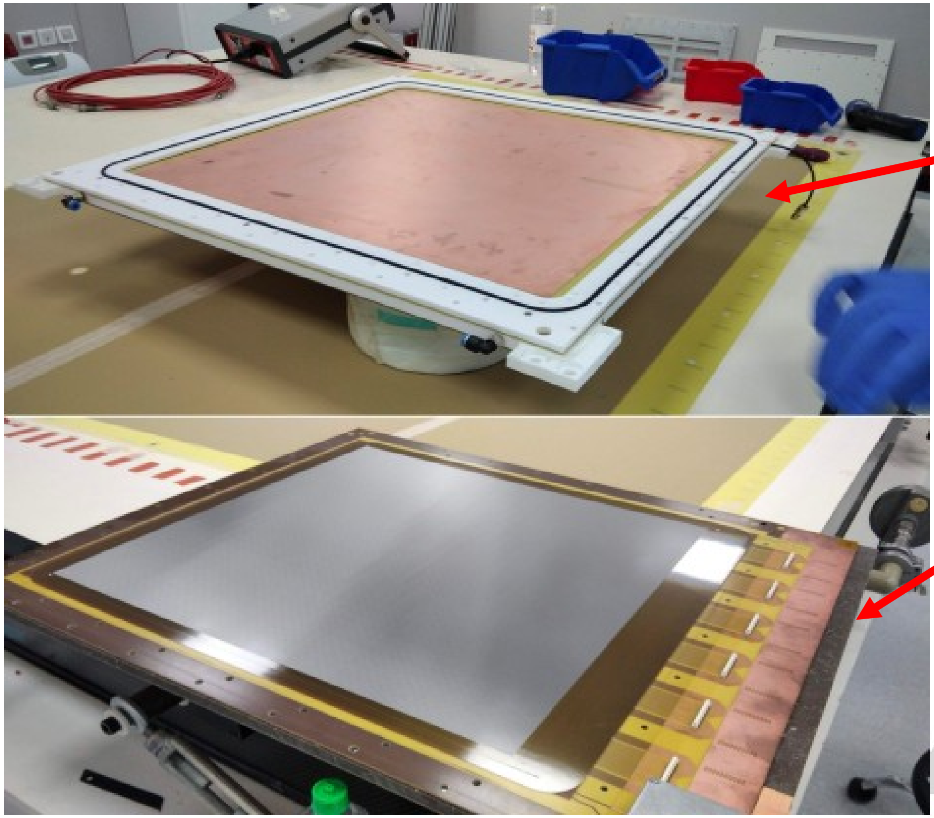


4 Micromegas (10 x 10 cm^2 active area)

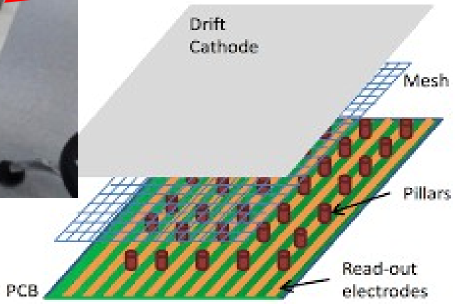
- anode board: XY 2-dimensional ~ 384 strips
- detection medium: Ar – CO$_2$ gas 93%-7%
- APV25 readout cards (x6 per XY plane)
- signal reception via SRS (Scalable Readout System)
- trigger using 2 scintillators in coincidence

MM Chambers

A single MM module consists of:



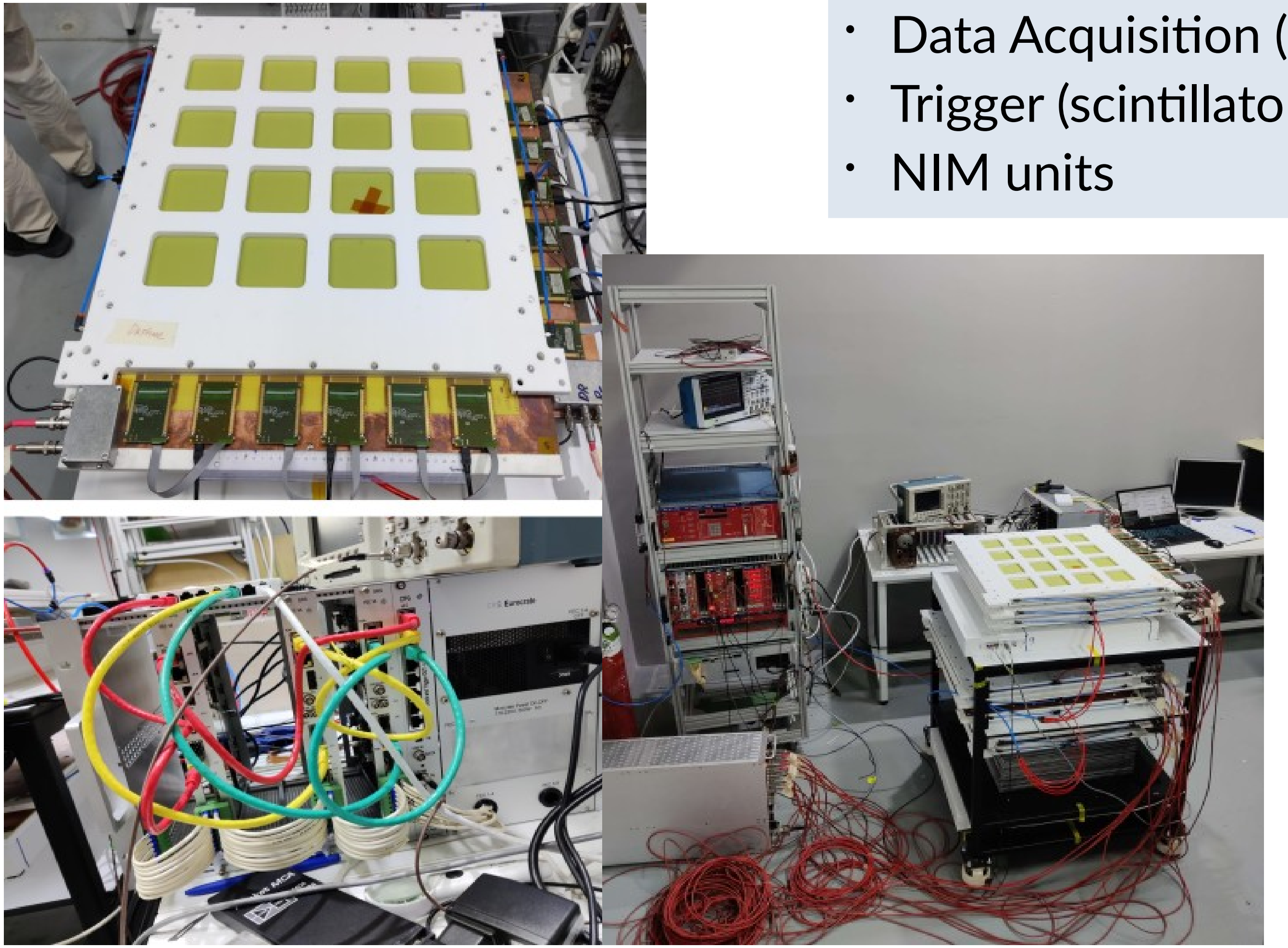
- A Drift panel
- Gas gap frame (with 2 o-rings) mounted on the Drift panel
- A Read-Out panel
  - Resistive BULK Micromegas on 2mm board
  - outer size 580mmx 700mm
  - active area 460mm x 460mm
  - 768 strips per detector
  - strip 0.45mm
  - 0.6mm pitch
  - 6 Panasonic connectors



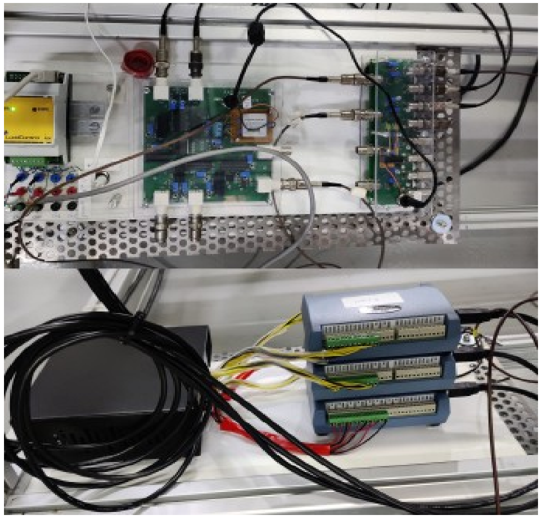
Individual MM chamber: Cosmic ray test bench I

Lab tests: module validation

- Power Supply (CAEN Mod. A4531)
- Data Acquisition (APV25 & SRS)
- Trigger (scintillators)
- NIM units

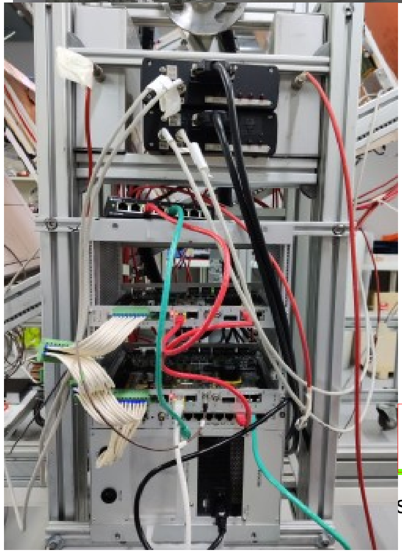


MM Telescope: full system installation



Custom made electronics (A. Tsirigotis H.O.U.)

Gas bottle



DAQ system

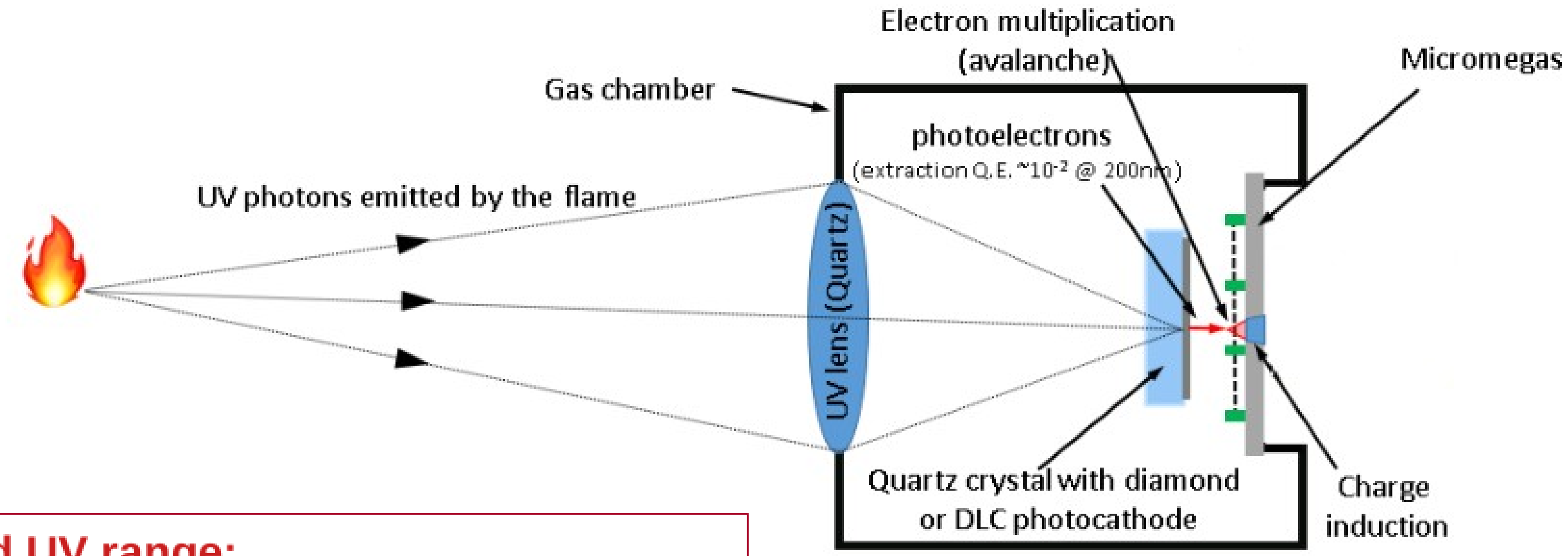
- Mounting of detectors
- Cables routing (Gas & HV)
- Mounting of peripherals (HV supplies, Gas bottle etc.)

MM Telescope at the Apollonia tumulus

- Power: Solar panels & power box
- Full system powered ON
- Addition of temperature sensors
- Telescope set @ 20 degs
- Test (trigger system + MM pedestal run)

EKATY project

MM photocathode studies: solar blindness



Solar blind UV range:

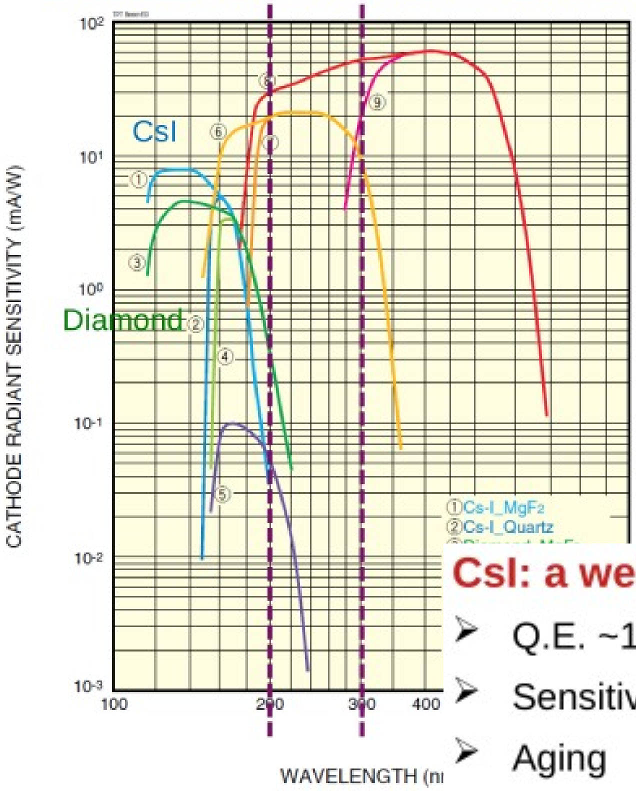
- The O_3 layer absorbs the solar irradiance bellow ~300 nm
- The atmosphere @ sea level is transparent down to ~200 nm
- The range 200 – 300nm is called “Solar blind”.
- Especially bellow ~250 nm no solar light reaches the earth’s surface. All light in the range can be associated to flames, explosions, electric discharges or other human activities

T. Papaevangelou et al., CEA – Saclay

MM photocathode studies

- Micromegas chamber (PICOSEC version)
- Use of UV lenses coupled to MM
- Photocathode is the critical component of the detector
- Best possible QE for ~200nm range
- Candidates: CsI, B4C, DLC...

QE of commercial phototubes by Hamamatsu (https://www.hamamatsu.com/resources/pdf/etd/Phototubes_TPT1001E.pdf)



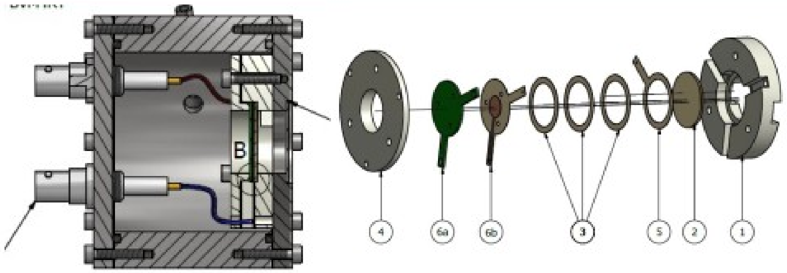
Ongoing work

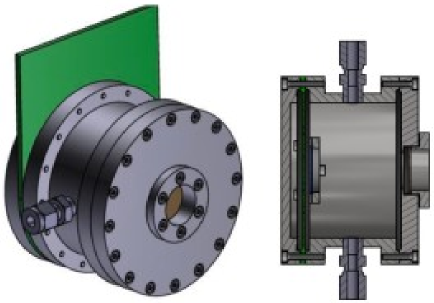
CsI: a well-know photocathode

- ➢ Q.E. ~1% @ 200 nm
- ➢ Sensitive to air exposure
- ➢ Aging

Search for alternatives:

- ➢ Compatible with operation in gas
- ➢ High efficiency
- ➢ Robustness / aging





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Summary

Micromegas: a detector for multiple applications

- High energy physics (e.g. ATLAS New Small Wheel)
- Rare event detection (e.g. CAST experiment)
- Neutron Data (e.g. n_TOF beam profile monitor)
- Nuclear physics and applications
- ...

Ongoing work to face new challenges

- New materials and/or engineering solutions to improve further performance and radiation hardness
- Optimization of gas mix uses
- Advances in readout electronics
- ...

Micromegas ≡ Yannis

“Celebrating Ioannis”: on the 5th of October 2023 at CEA – Saclay, we celebrated Ioannis Giomataris scientific impact on our community

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Thank you!