Caliste – MM: A Spectro-Polarimeter for Soft X-Ray Astrophysics

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The 4 faces of light in astrophysics

- **Imaging** : get precise information about the location of the source ("making pictures")

- **Spectroscopy** : get precise evaluation of the energy of the detected light

- **Timing** : study of the time variation of the intensity of the signal

- **Polarimetry** : ??

Polarimetry : Definition

- Light = Electromagnetic Wave
  → Carries oscillating electric field and magnetic field
- Electric and magnetic fields linked by Maxwell's equations
- **Polarimetry** = study of the orientation of the electric field of light
- Several polarization state possible : none, elliptic, circular, linear

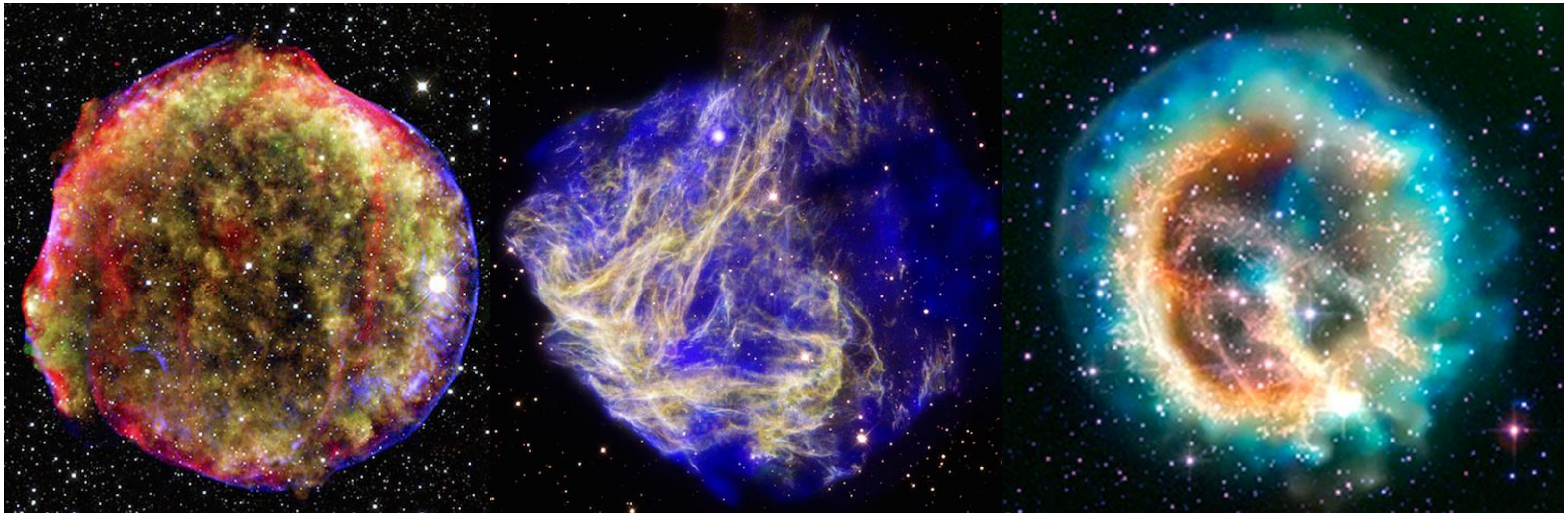
Circular

Linear

X-ray polarimetry : why ?

- **<u>Polarisation state influenced by the magnetic field of the source</u>**

→ Allows the study of intensity and direction of magnetic field in sources like Supernovae Remnants

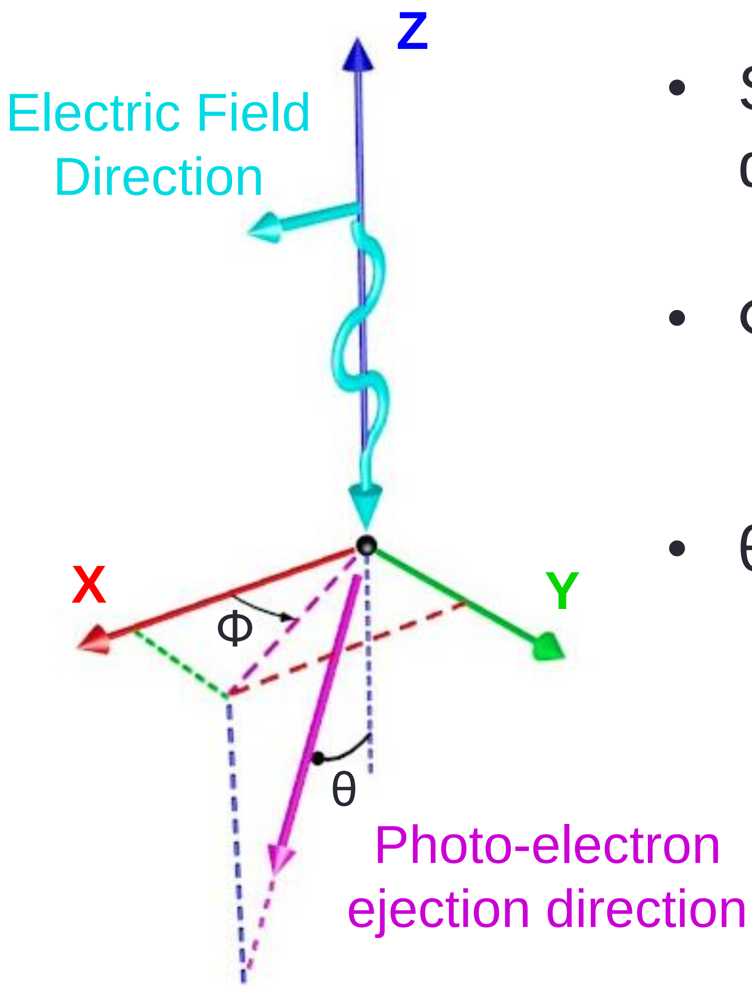


- **<u>Polarisation state influenced by the geometry of near objects</u>**

In X rays *low spatial resolution* (hard to make mirros for telescopes) and *small objects* (fast rotating neutron stars have diameter of ≈ 20 km, and are billions of kms away)

→ Polarimetry gives "indirect" information about the geometry of objects near the source

The Photo-electric effect

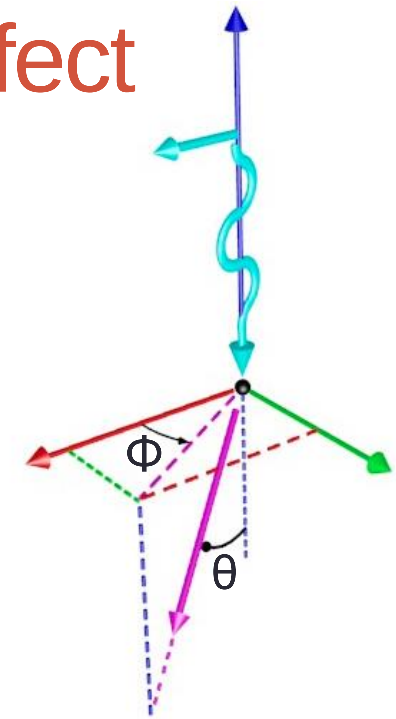


- Soft X-Rays (1 keV – 40 keV)
  detection done by photo-electric effect

- Φ = azimuth
  → 2D projection of the ejection angle

- θ = polar angle

Polarimetry with the Photo-electric effect



- Differential Cross-Section:

$$\frac{ds_{Ph}}{dW} = r_0^2 a^4 Z^5 \left(\frac{m_e c^2}{E}\right)^{\frac{7}{2}} \frac{4\sqrt{2}\sin^2(q)\cos^2(f)}{(1 - b\cos(q))^4}$$

- Probability modulated by $\cos^2(\Phi)$

→ **We want to recover Φ for each interaction to make a histogram → we want to recover the track of the photo-electron**

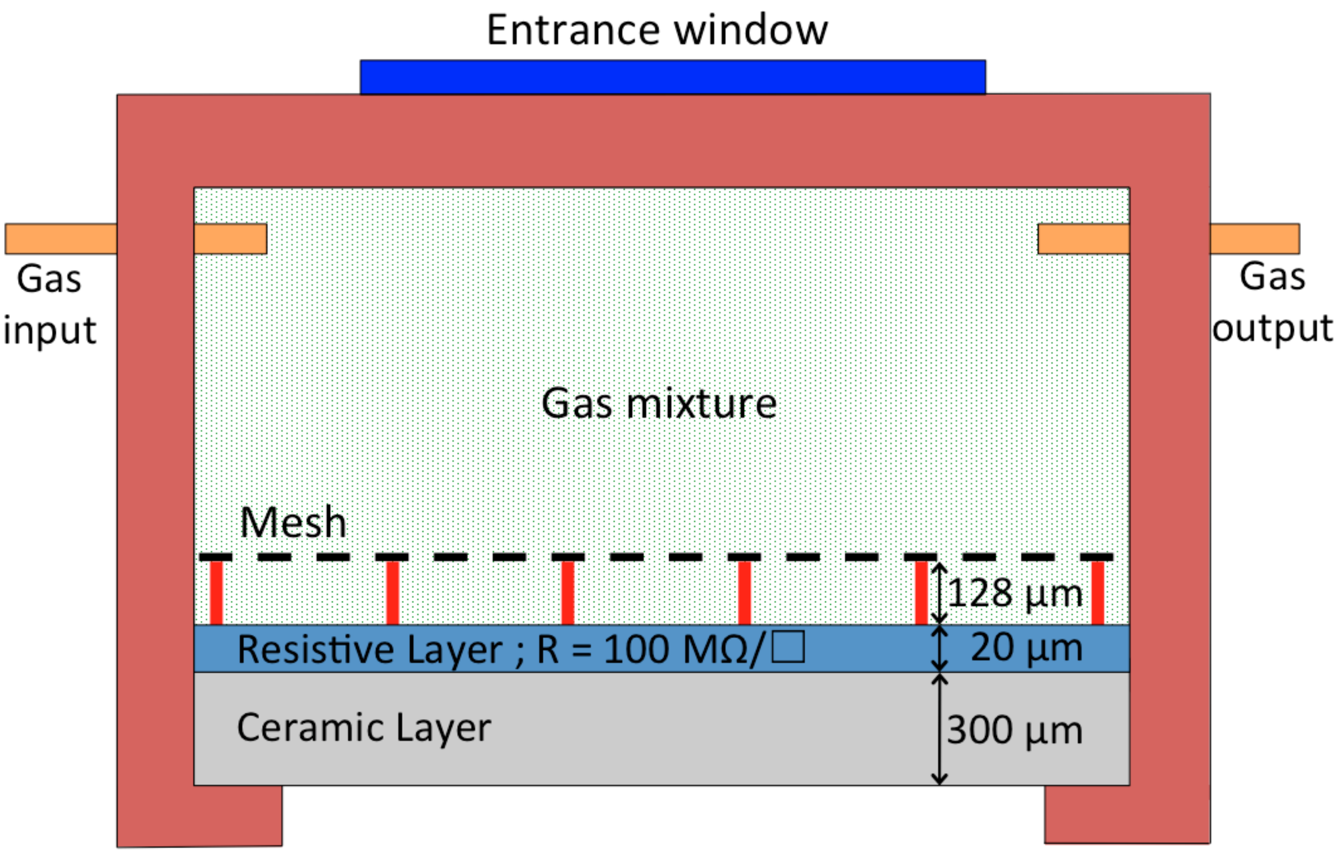
Need of an efficient material (high Z), but light enough to let the photo-electron recoil

→ **gas = perfect candidate**. But gaseous detectors are very sensitive to sparks : huge problem when detector in space

need of a new concept of detector if we want to send it into space


~5nm
~100um

Piggyback Micromegas (1)



- Bulk Principle
- Anode = resistive layer spread on ceramic plate

<u>No electronics inside the detector</u> : signal read through the ceramic

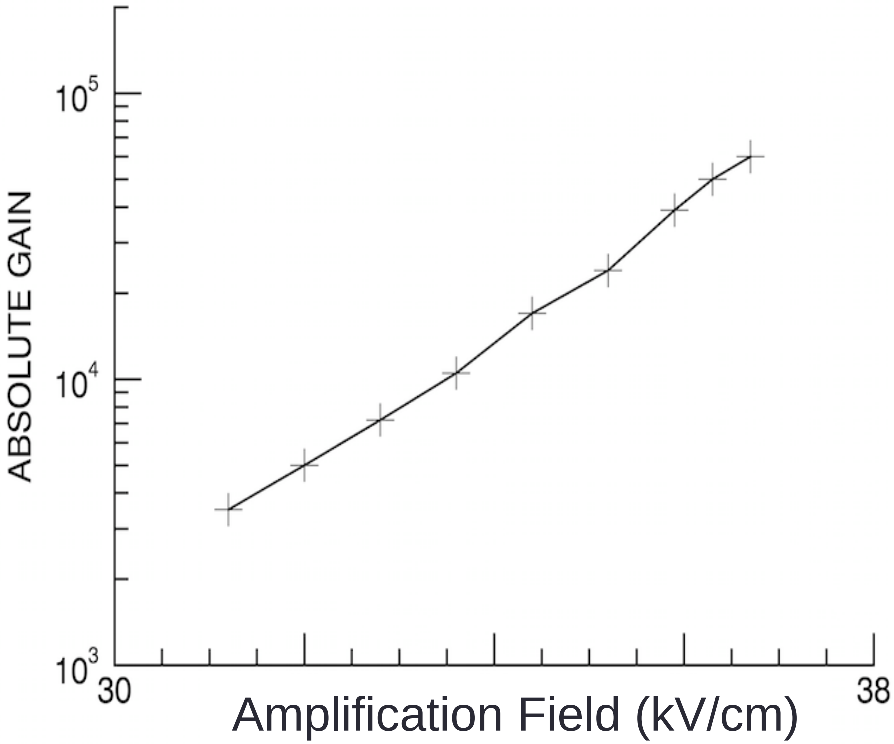
- ➢ Protection from Sparks thanks to resistive layer
- ➢ Interchangeable Electronics

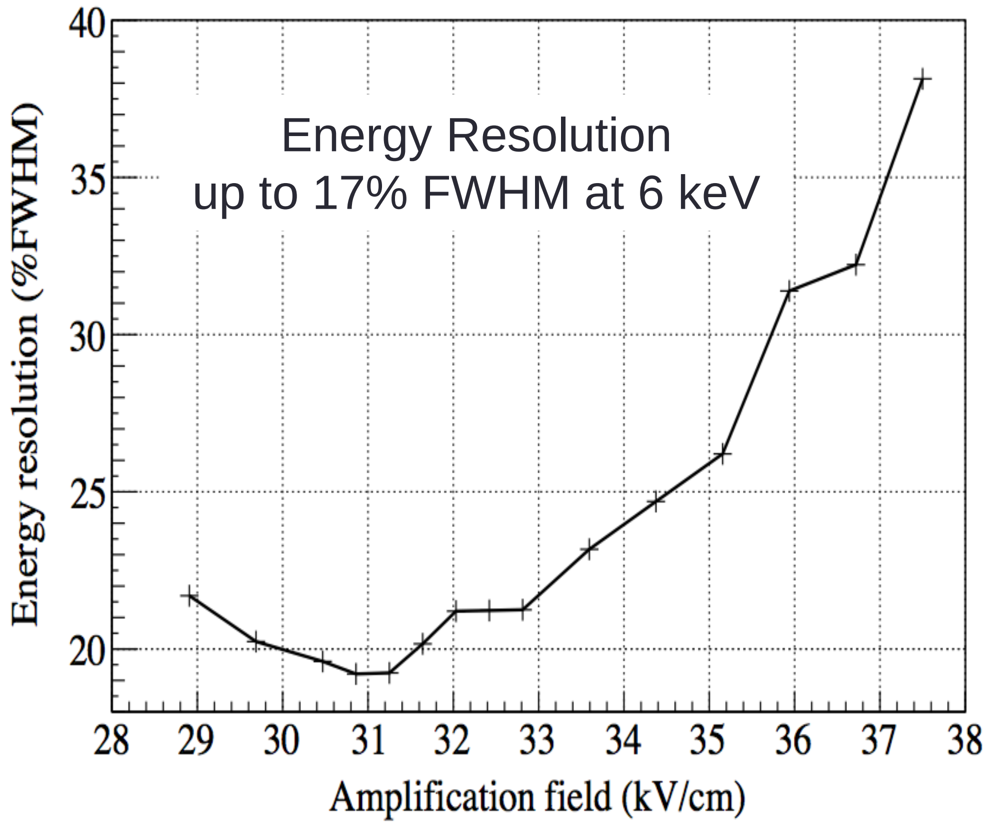
D. Attié et al., JINST 1305 (2013) P05019.

Piggyback Micromegas (2)

Source = ^{55}Fe (6 keV photons)
Argon – Isobutane 95% - 5%
Signal read on mesh

Gain between 10^3 and 10^5





Piggyback Micromegas (3)

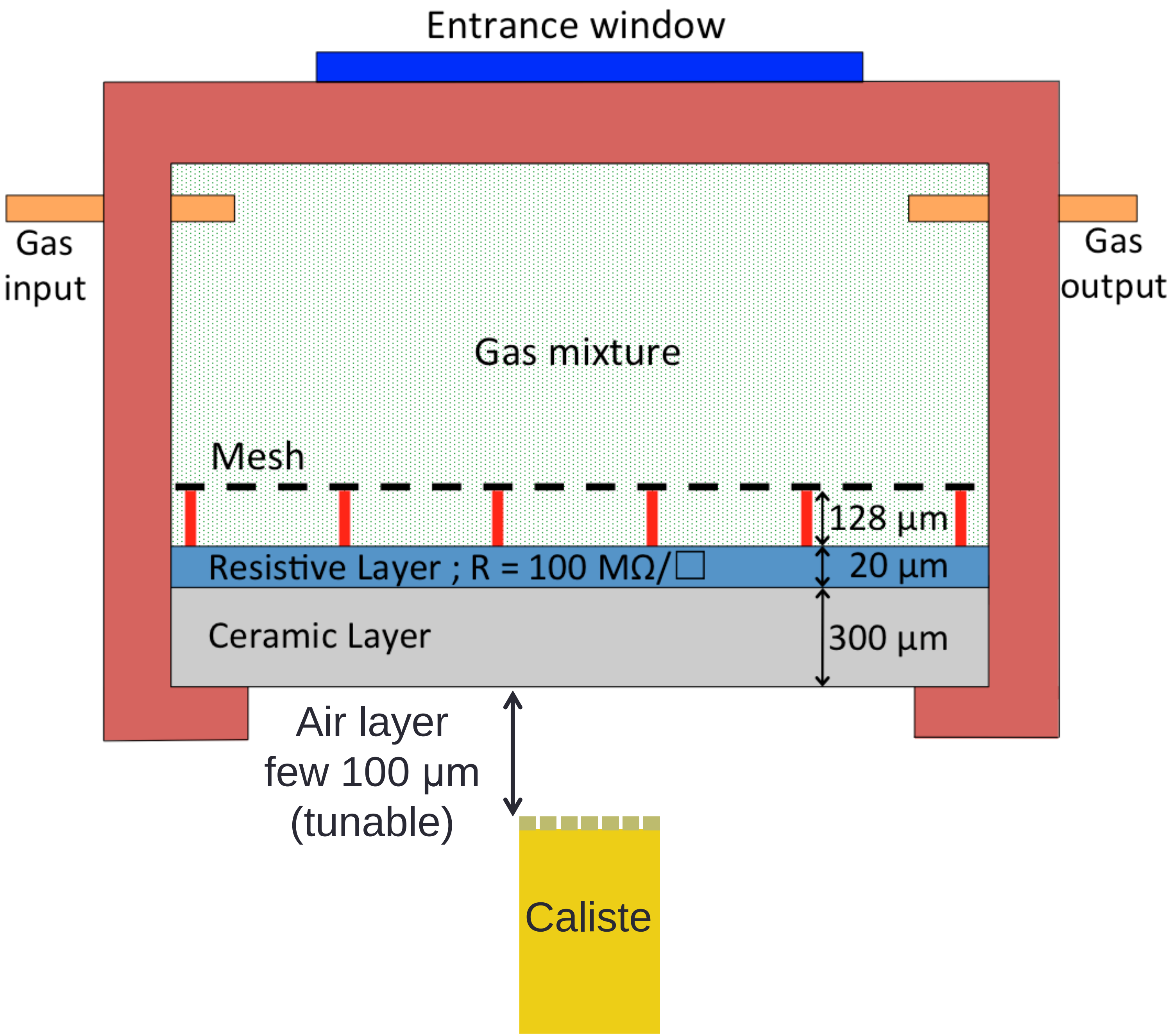
- Readout electronics must have some specificities:
  - Low Noise and sensitive enough to read the signal through the ceramic
  - Small pixels to recover the photo-electron’s track for polarimetry
  - Able to perform spectroscopy

Caliste

Initially for semiconductor space detectors

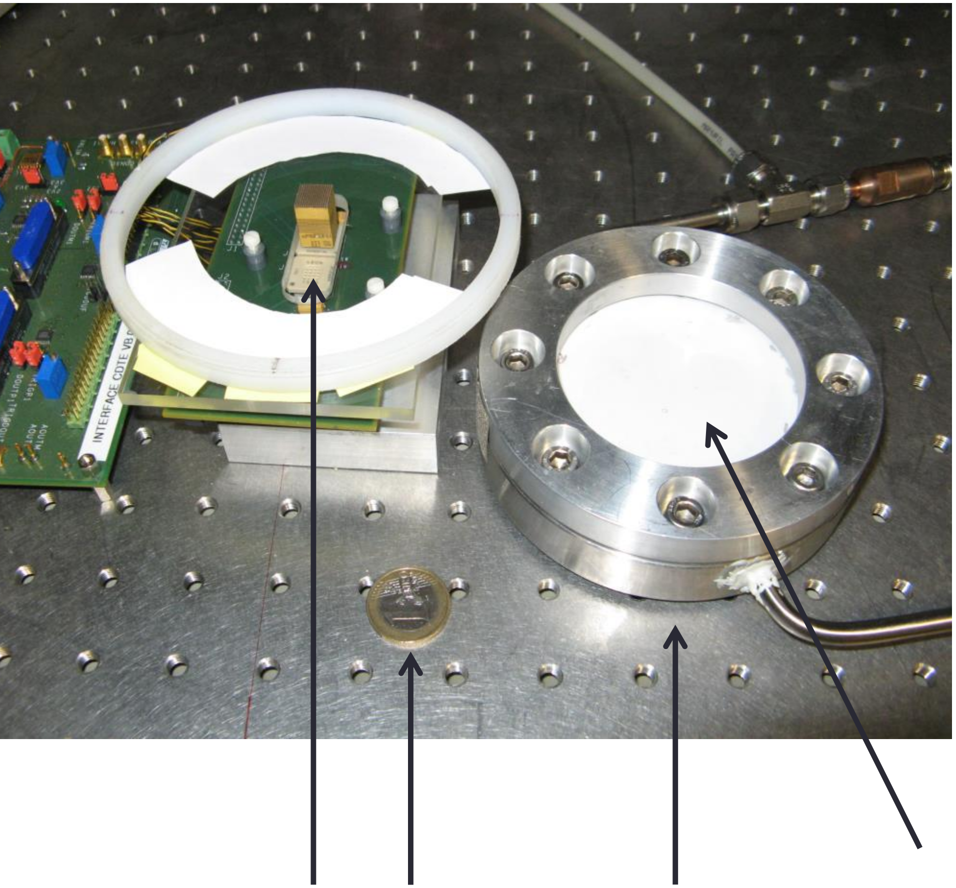
- 3D
- 10 x 10 x 20.7 mm^3 (Compact)
- 16x16 pixels : 8 ASICs of 32 channels
- Pixel Ø = 500 µm ; Pixel Pitch = 580 µm
- Consumption = 850 µW/channel (218 mW in total)
- Low Noise (ENC = 50 e^- rms)
- Space Qualified
- Self-Triggered

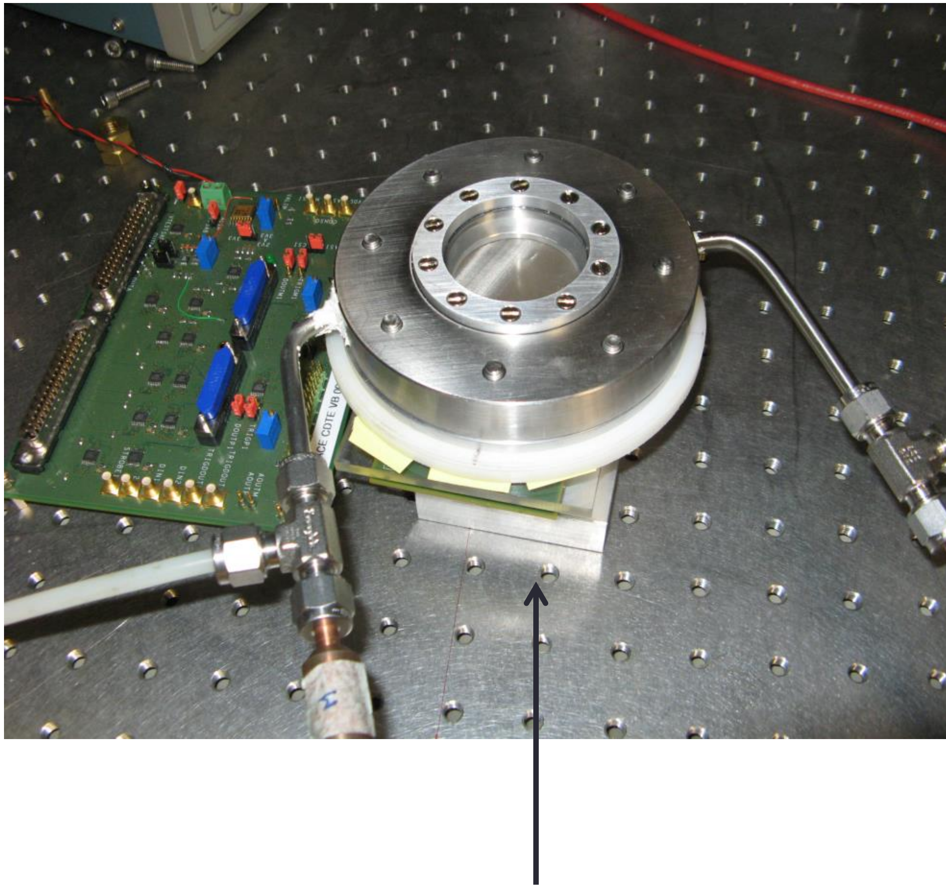
O. Limousin et al., NIMA, Vol.647 Issue 1 pp.46-54



Entrance window
Gas input
Gas output
Gas mixture
Mesh
128 µm
Resistive Layer ; R = 100 MΩ/□
20 µm
Ceramic Layer
300 µm
Air layer
few 100 µm
(tunable)
Caliste

SETUP Caliste-MM



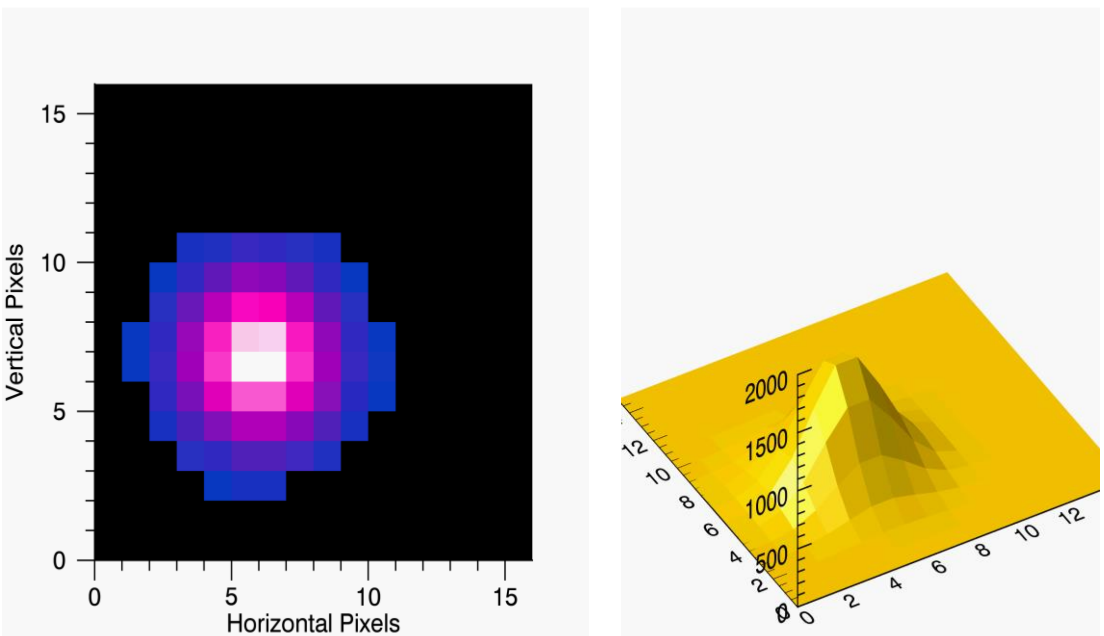


Caliste - MM: Events

Gas = Argon-Ethane 90% - 10%

Caliste at 500 µm from the ceramique: contactless configuration

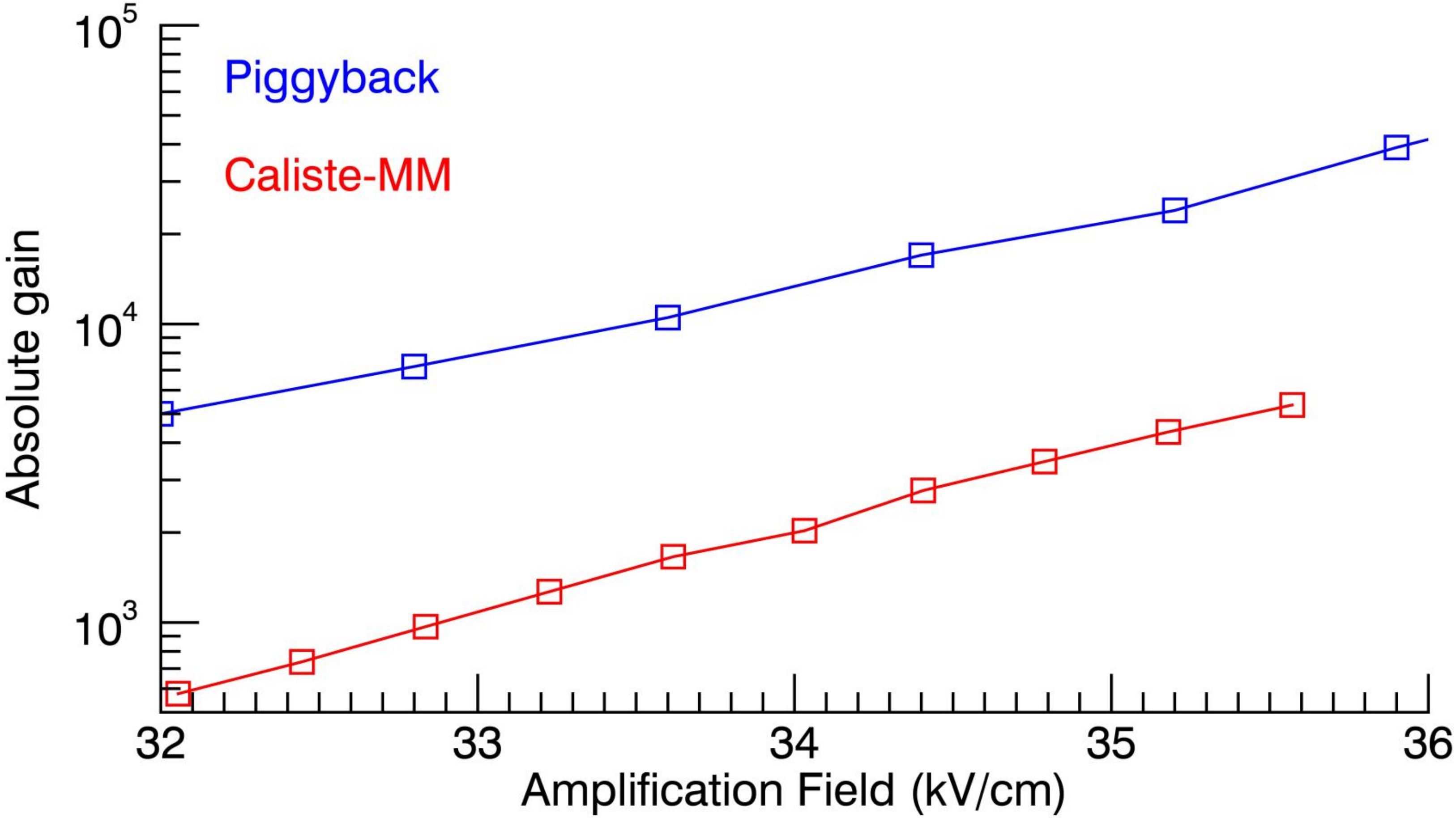
6 keV photons source



Typical events read on Caliste

P. Serrano et al., JINST 11 (2016) no.04, P0416

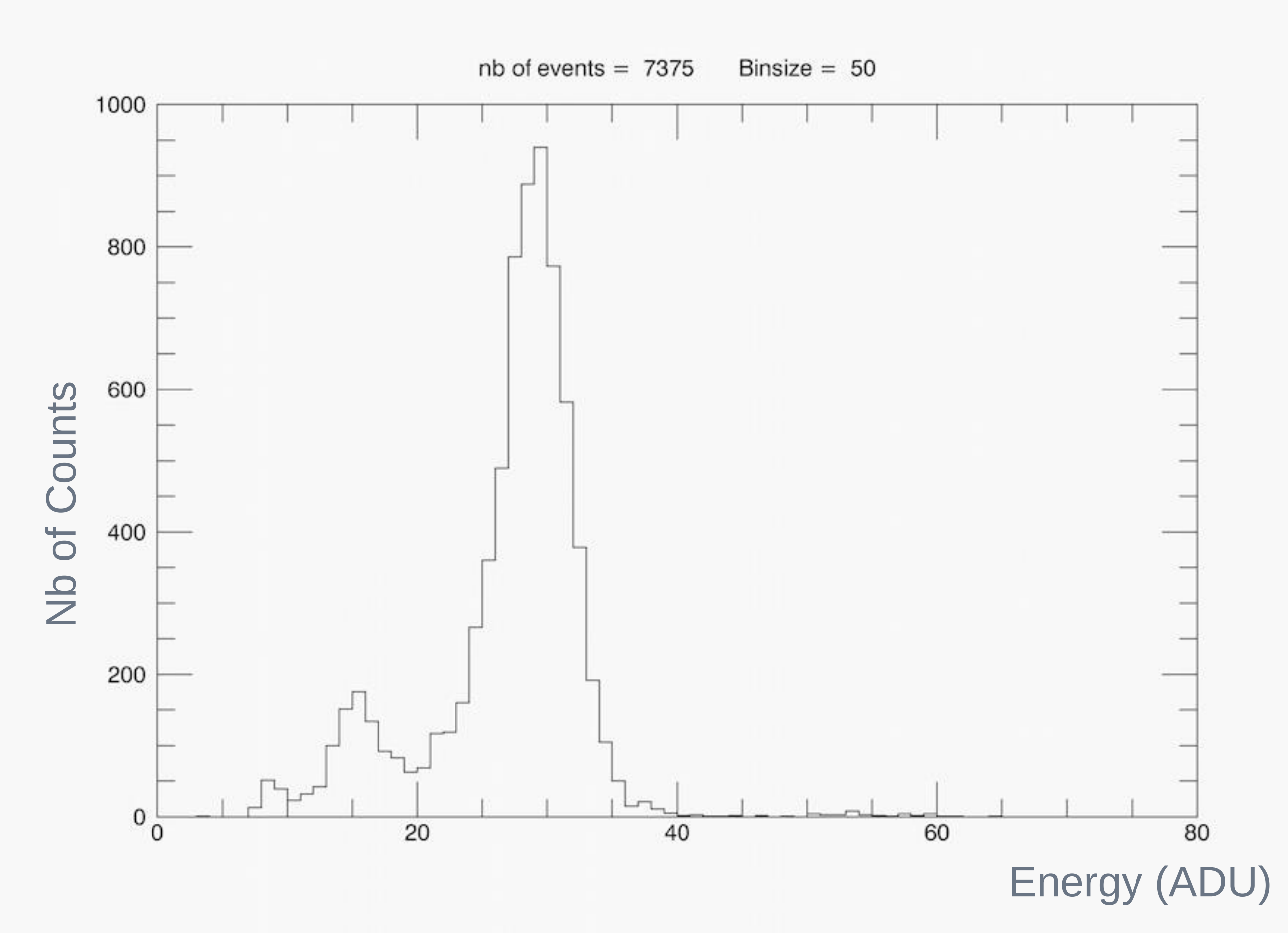
Caliste - MM: Gain



Gain of whole setup smaller

But still of around 10^3 thanks to high gain of Micromegas detectors

Caliste - MM: Spectroscopy



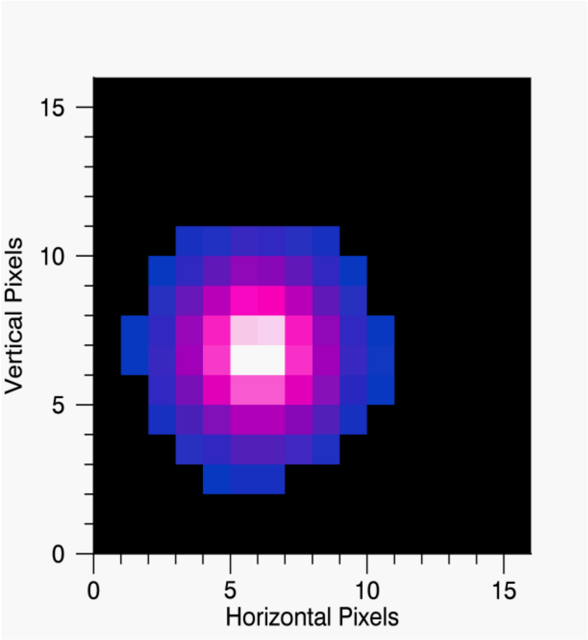
Resolution = 17.8% FWHM at 6 keV

As good as expected for a micromegas using a bulk technology

Having outer and contactless electronics does not degrade the energy resolution

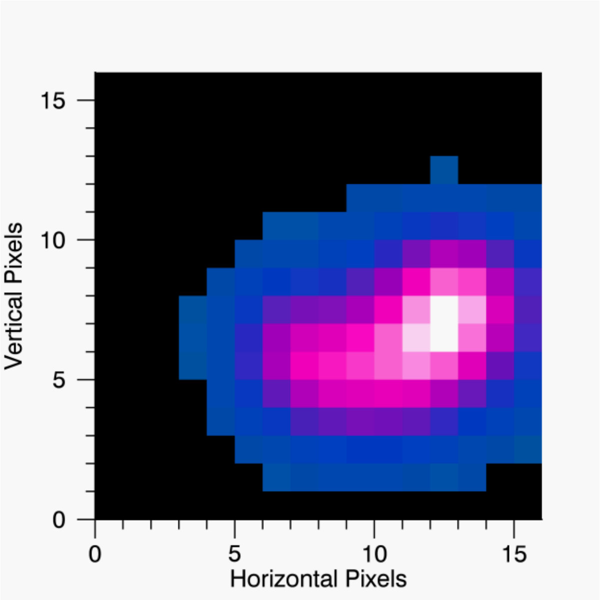
Caliste - MM: Polarimetry (1)

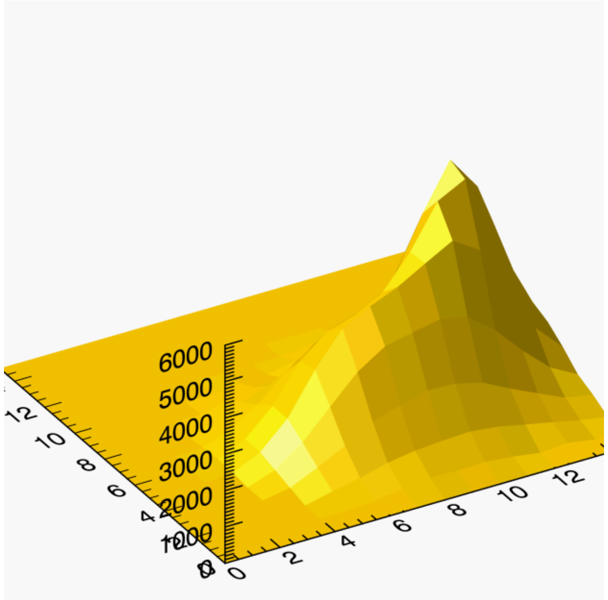
Photo-electron's track impossible to see in Argon



Caliste - MM: Polarimetry (2)

- Using a mixture of He-CO_2, 8keV source





Helium lighter than Argon: it lets the photo-electron recoil

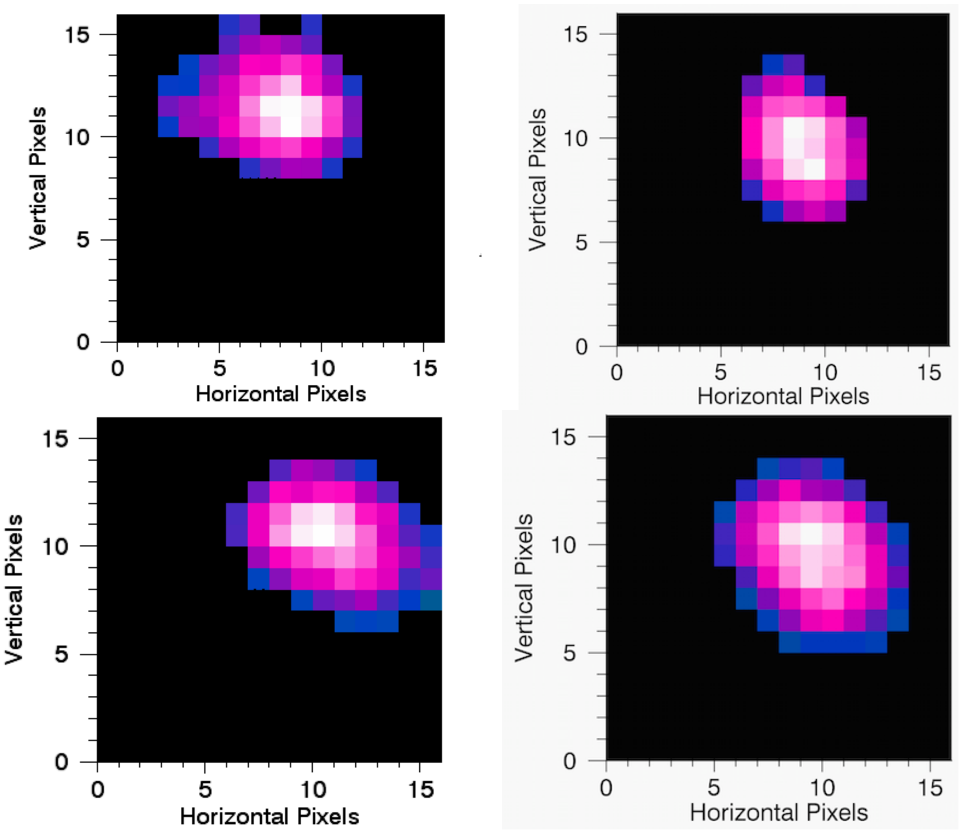
→ We can recover the track, and then perform a polarimetry measurement

Caliste - MM: The problems with Helium

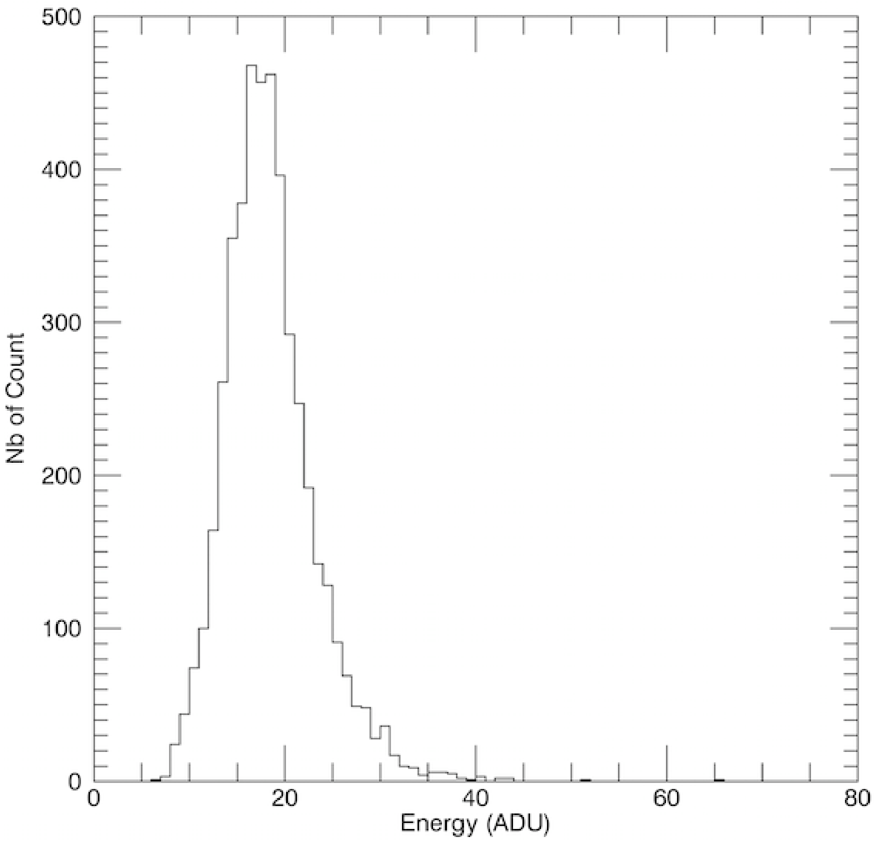
- Helium bad candidate for spectroscopy
- Helium too inefficient for photo-electric effect: efficiency depends on Z^5, and $Z_{He} = 2$ ($Z_{Ne} = 10$, $Z_{Ar} = 18$)
- Helium = bad candidate for astrophysics: very hard to contain and high leaking probability
- Idea: use Neon or Argon in low pressure conditions

Caliste - MM: Spectro-polarimetry

Mixture of **<u>Neon</u>**/Ethane/CF_4
P = 375mbar ; 6 keV source



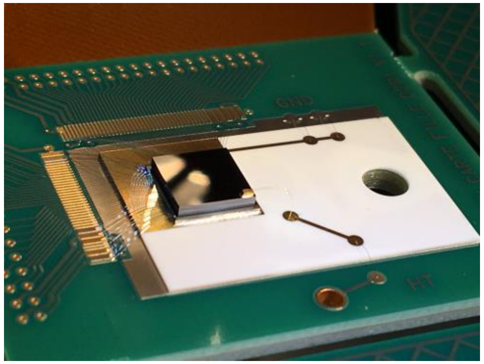
Visible tracks



Resolution ≈ 30% FWHM at 6 keV

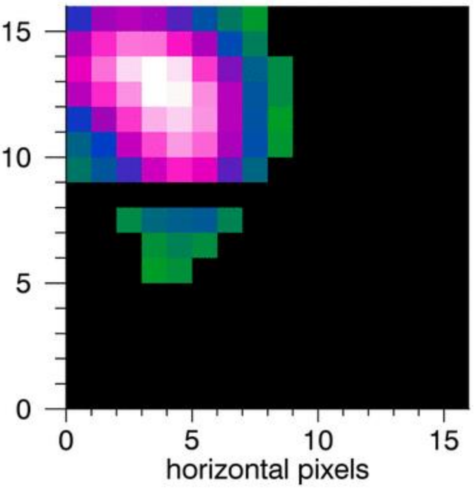
D^2R_1– MM

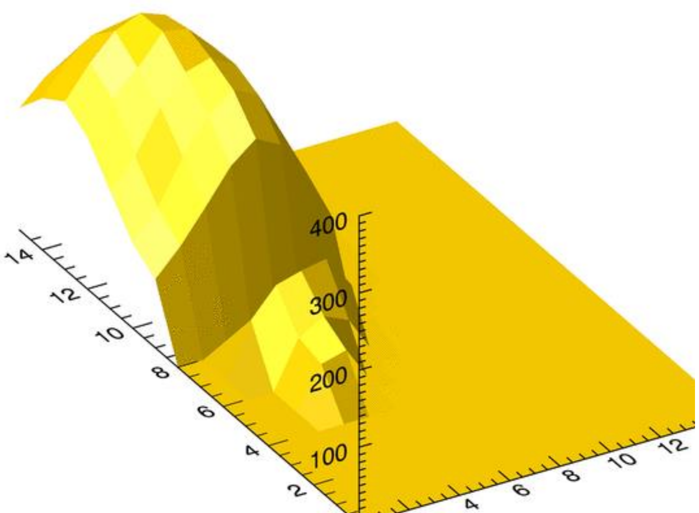
- One way to improve the results: to use the concept of non integrated electronics and use another one



D^2R_1 electronics, also inherited from semi-conductor detectors

16 x 16 pixels, low noise (25 e^- rms)
300 µm pixel pitch
→ **pixels 4 times smaller**





Helium mix
6 keV source

Nice tracks at 6 keV
(before, it was 8 keV)

Caliste - MM: Prospects

- Proof of concept of spectro-polarimetry with novel design of detector. Now needs to be improved

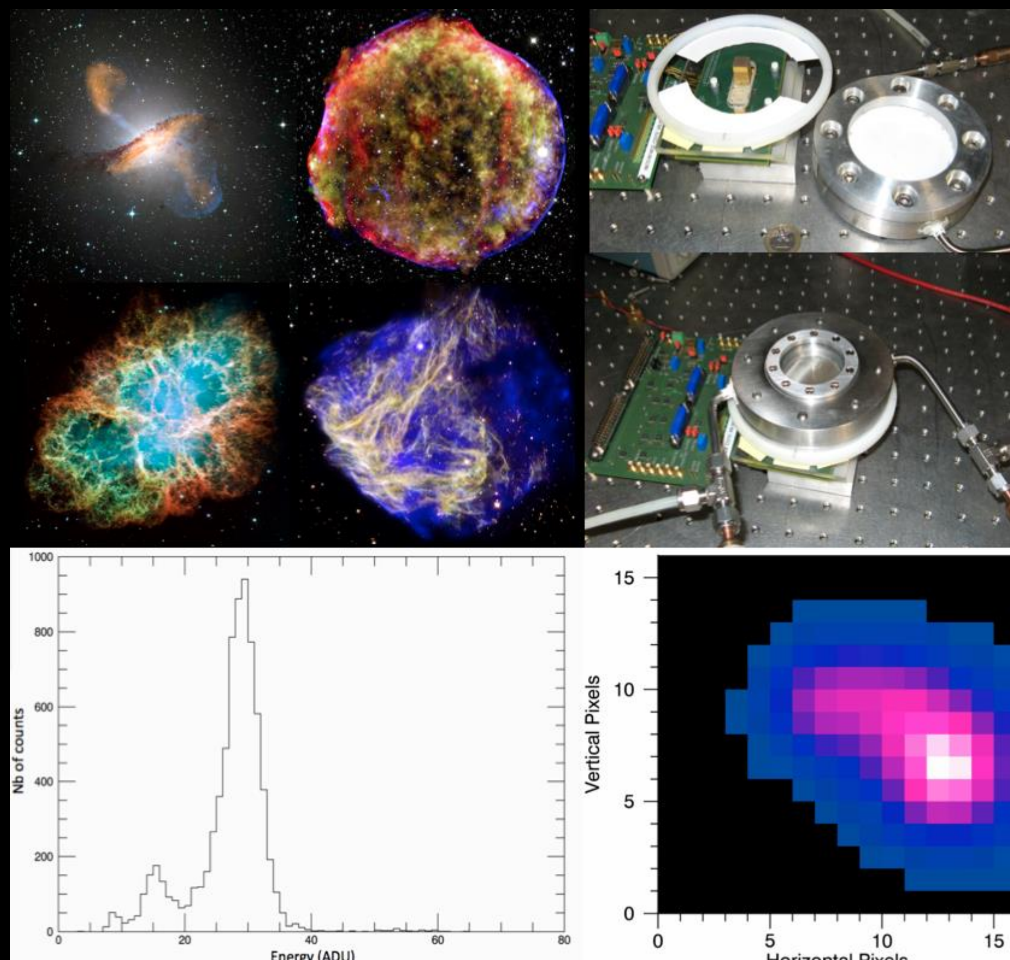
- Use of piggybacks with greater gaps (196 µm and 256 µm) will allow to reach higher gains at low pressure and recover better tracks

- Concept of completeley uncoupled and easily changed electronics proven

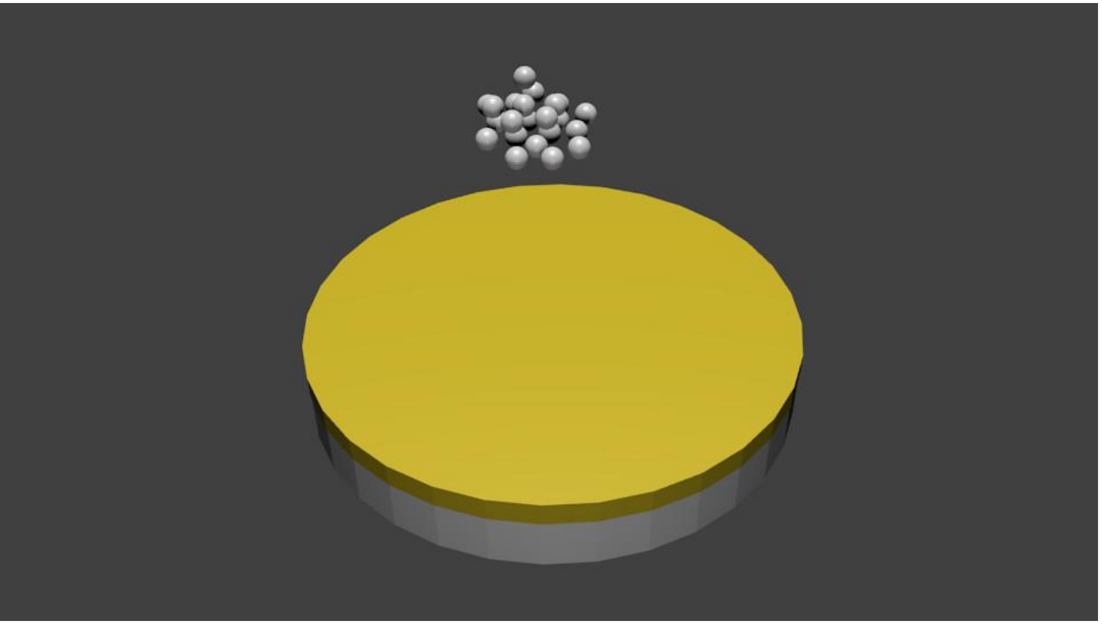
We can design a specific electronics more adapted (pixels' size, gain) without being worried of protecting it from sparks

- Measurement in a 100% polarized beam to measure modulation factor

Thank you



Back-up: Diffusion Model (1)



Charges arrive at the resistive layer of uniform potential

Diffusion inside the resistive layer

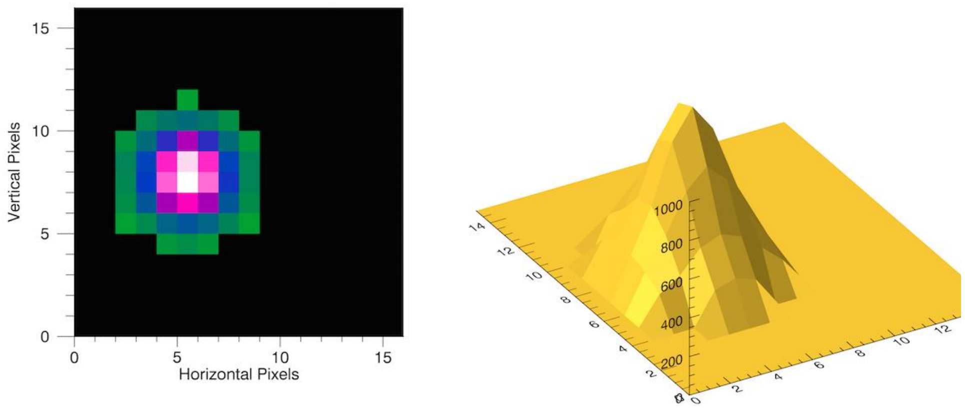
2nd Fick's Law give the equation of charge density :

$$\frac{\partial \rho}{\partial t} = D\left(\frac{\partial^2 \rho}{\partial x^2} + \frac{\partial^2 \rho}{\partial y^2}\right) \quad \text{with} \quad D = \frac{1}{R_{\square} C_S}$$

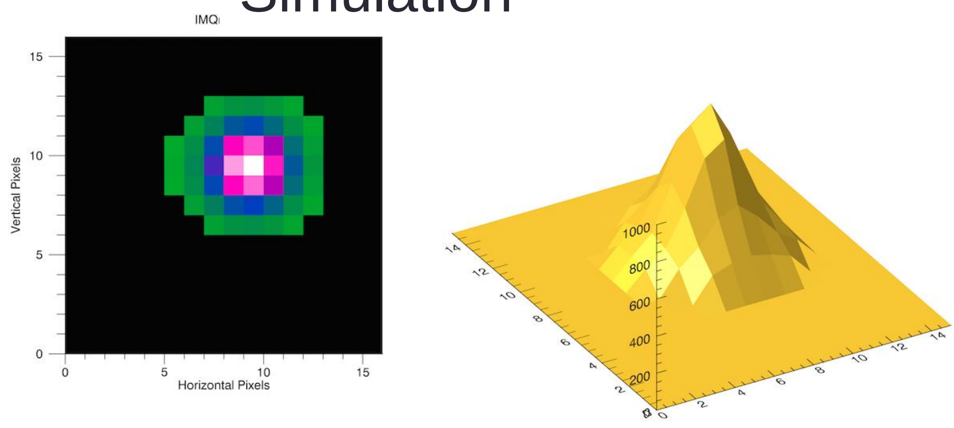
Back-up: Diffusion Model (2)

- We solve and calculate ρ
- Spatial integration to get charge Q read on each pixel
- We take the maximum on this charge on each pixel and convert into ADU units

Real Data



Simulation



- Good agreement in gain and event shape, but still some work to do : need to fit curve of gain with observable parameters (gain vs distance ; gain vs resistivity, etc..)

Back-up: Gain vs Distance