Status and First Acquisitions of the XEMIS2 Liquid Xenon Compton Camera for 3γ Imaging

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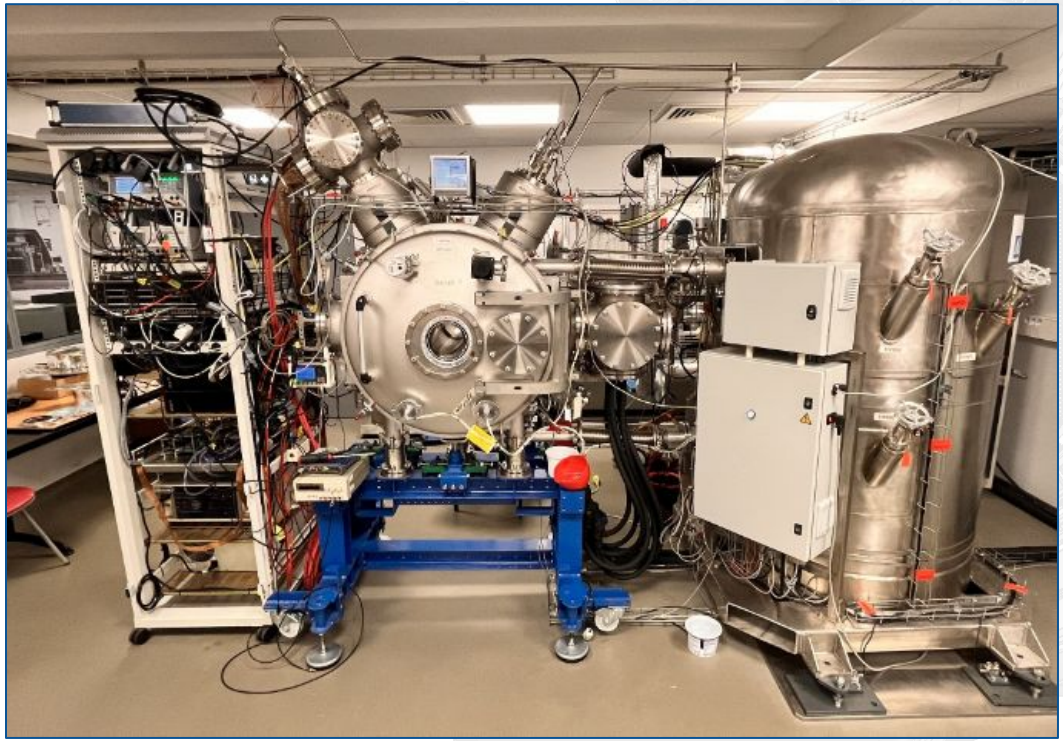
XEMIS2 (3γ imaging for small animal)



Goal : First image with the first compton camera with monolithic LXe

What is expected for medical imaging :

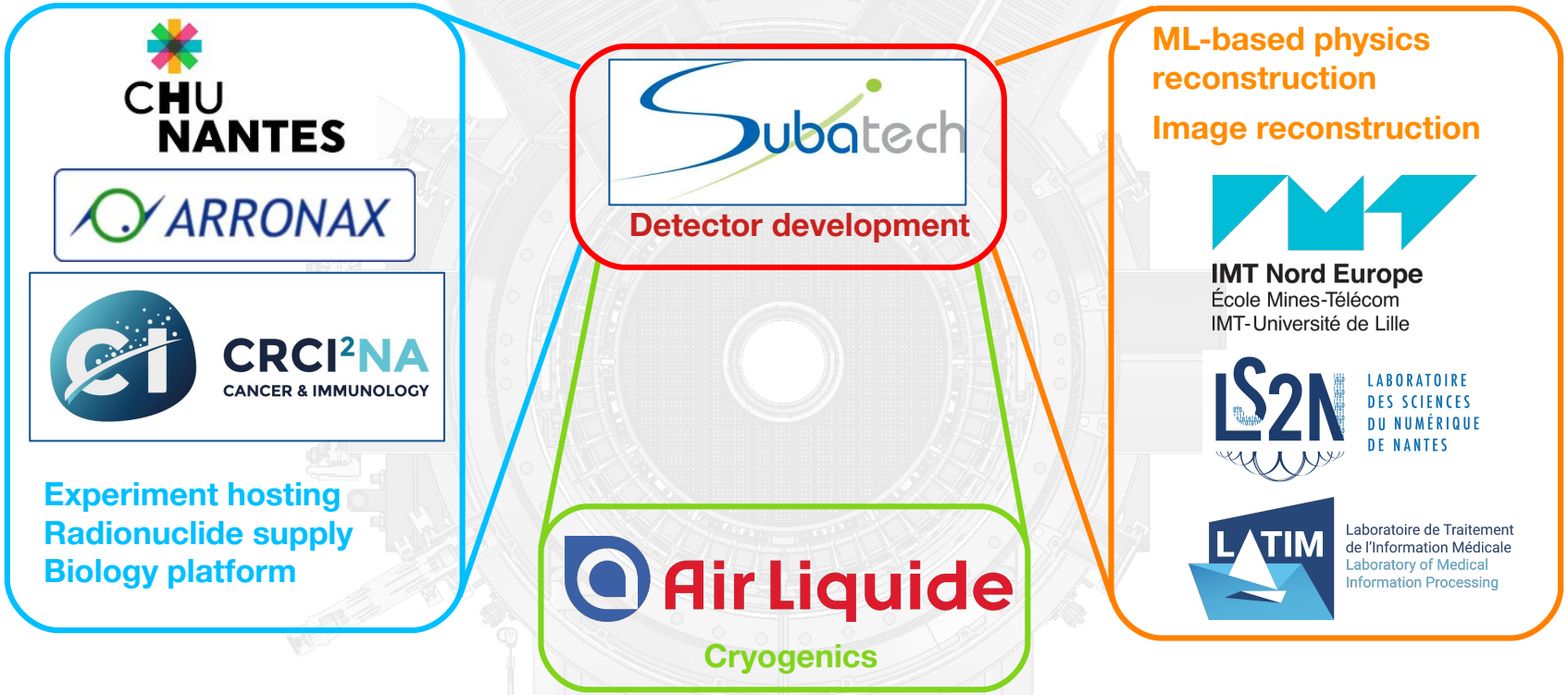
3-gamma : 100x less activity compared to PET/SPECT with 44Sc, same image contrast, same exposure time

PET : image possible

SPECT : first Compton images of new emitters (E_γ >400 keV)

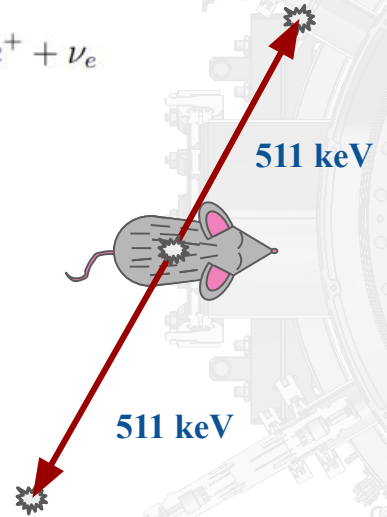
Experimental proof of concept : XEMIS2 for small animal at Nantes hospital (20 kBq, 20 min)

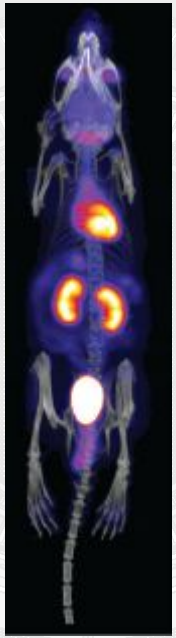
Approach : High detection efficiency monolithic Compton telescope with large field of view


CHU NANTES
ARRONAX
CRCI²NA
CANCER & IMMUNOLOGY
Experiment hosting
Radionuclide supply
Biology platform
Subatech
Detector development
Air Liquide
Cryogenics
ML-based physics reconstruction
Image reconstruction
IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille
LS2N
LABORATOIRE DES SCIENCES DU NUMÉRIQUE DE NANTES
LATIM
Laboratoire de Traitement de l'Information Médicale
Laboratory of Medical Information Processing

2 γ imaging (PET scan)

$$^{18}_{9}\mathrm{F} \rightarrow {}^{18}_{8}\mathrm{O} + e^{+} + \nu_e$$

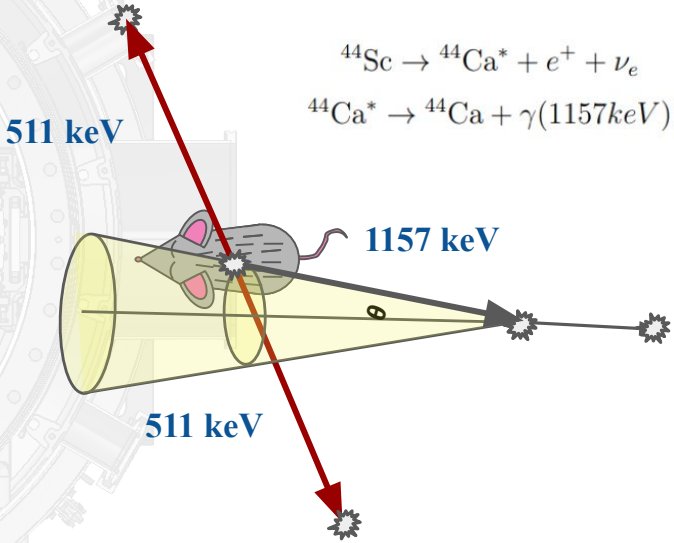




3 γ, Compton imaging (Xemis 2)

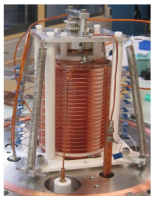
$$^{44}\mathrm{Sc} \rightarrow {}^{44}\mathrm{Ca}^{*} + e^{+} + \nu_e$$

$$^{44}\mathrm{Ca}^{*} \rightarrow {}^{44}\mathrm{Ca} + \gamma(1157keV)$$



$$\theta^{C} = arccos[1 - m_e c^2 \frac{E_{dep}}{E_i(Ei - Edep)}]$$

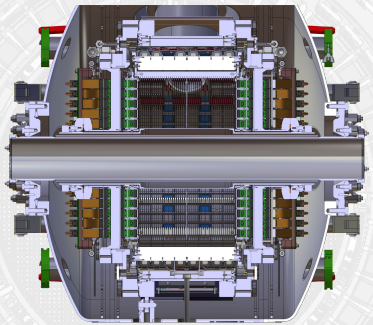
Used for ongoing R&D
Will be shipped to
Melbourne



XEMIS1
R&D Prototype

30 kg
6 (12) cm
drift TPC

Currently under commissioning

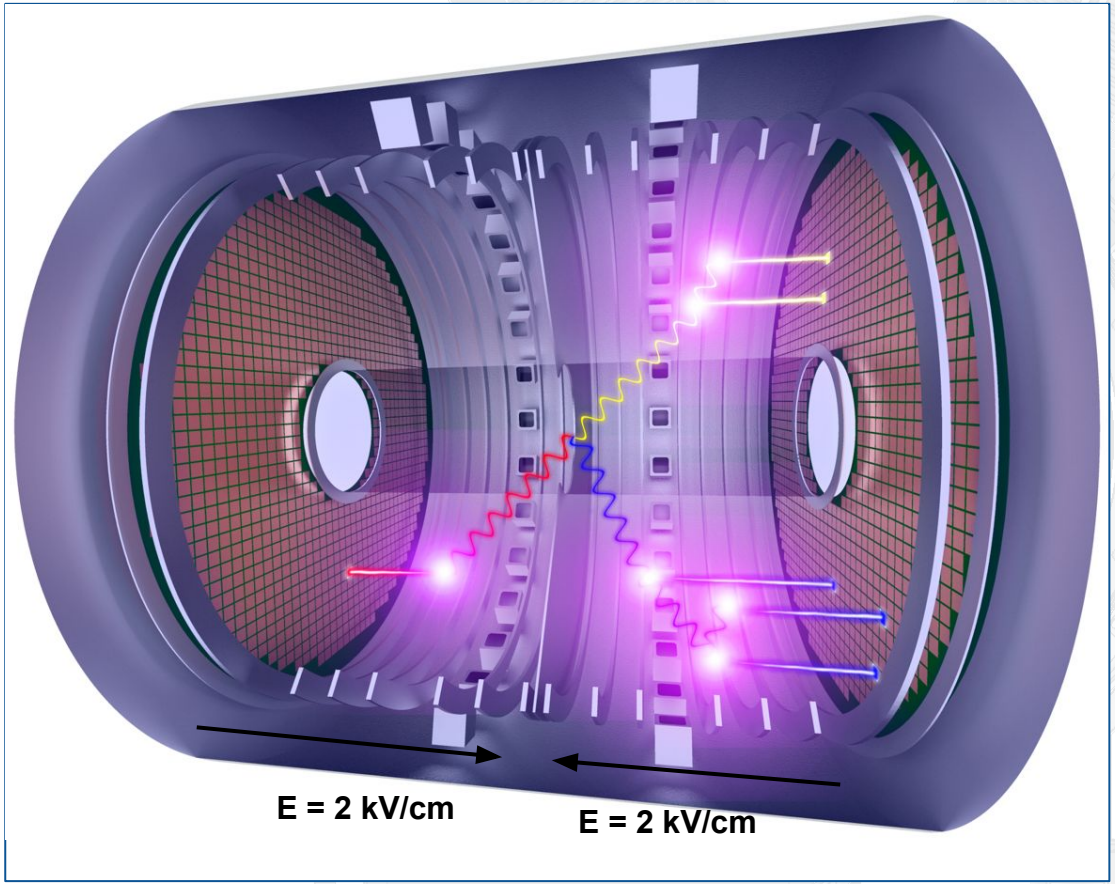


XEMIS2
Small animal imaging

200 kg
2 x 12 cm
drift TPC

2010 — **2026** — **Exploitation**

Introduction



- 2 x 32 PMTs 1 inch
- 2 x 9808 pixels
  3.1 mm x 3.1 mm
- 200 kg of LXe with
  70 kg of active
  volume
  at -100 °C

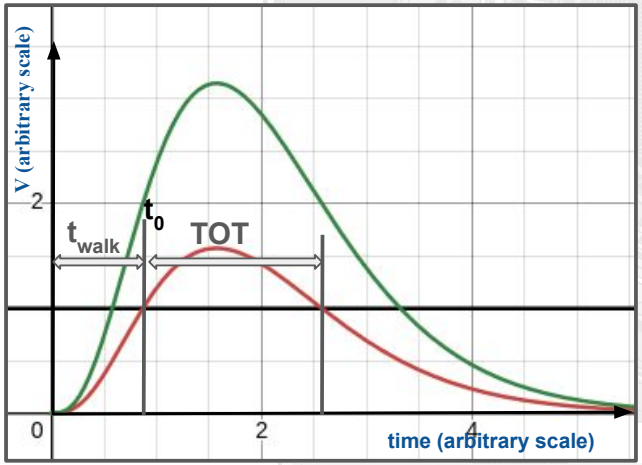
Xenon properties for cones reconstruction

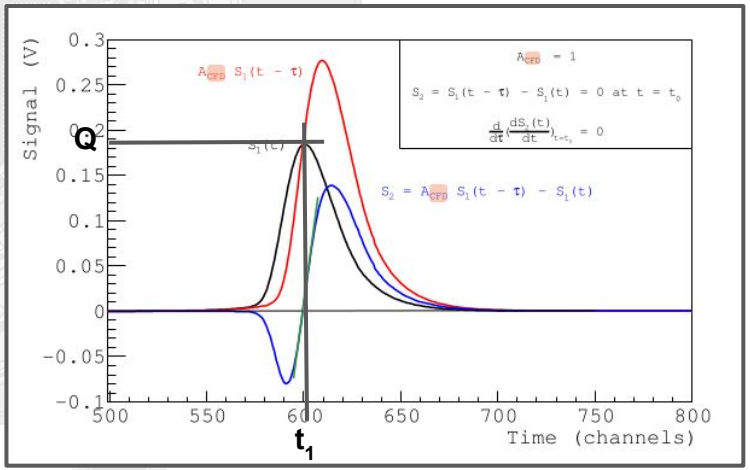
Raw Data, output of the camera

Files containing multiple signals:

- Light signals (t_0, Time Over Threshold (TOT), PMT_{id})
- Charge signals (t_1, Q, (x,y))

If you know v_d the drift speed of the electron (2.1 mm /µs at 2k V/cm)in LXe you have the z coordinate
=> $z = vd*(t_1 - t_0)$

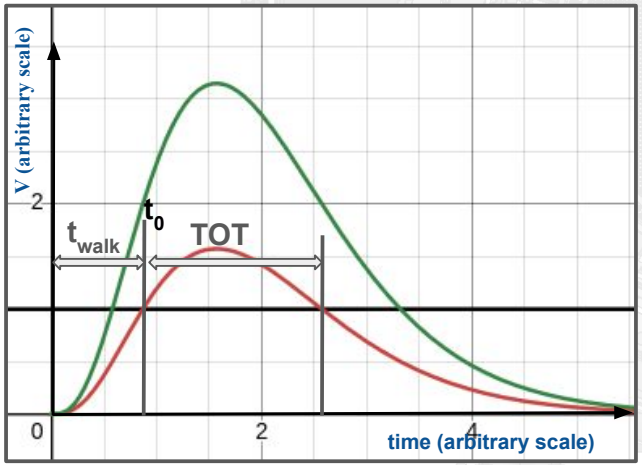




Light Calibration

Raw Data, output of the camera
Files containing multiple signals:

- Light signals (t_0, Time Over Threshold (TOT), PMT_{id})
- Charge signals (t_1, Q, (x,y))



Light Calibration

- Thresholds
- Gain
- ToT -> npe
- ToT -> walk

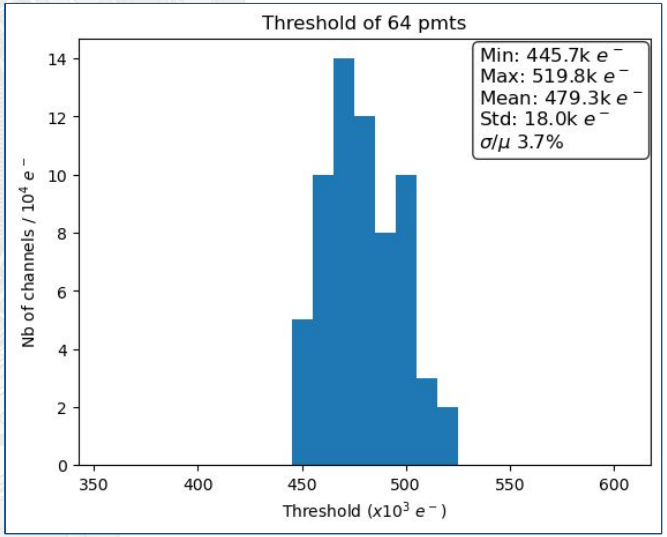
Light Calibration

Thresholds :

- The threshold is set to 1000 hit noise/s/pmt
- Software automated calibration :
  - ~5 min for 64 PMT
- 64 PMT successfully calibrated
- max rate data stored at 800k hit/s/pmt of without dead time
- each PMT is self triggered

<TH> = 480k (less than 500k expected)

$\sigma_{TH}/<TH>_{mean}$ ~4%



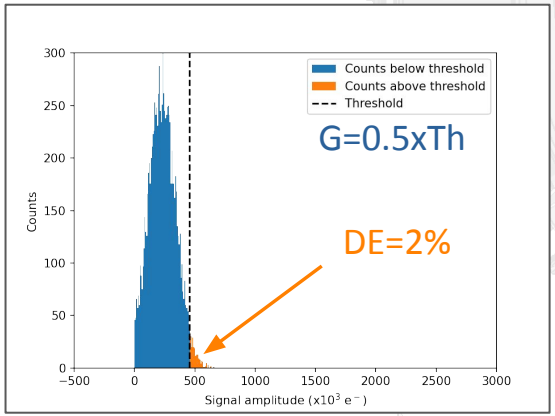
Light Calibration

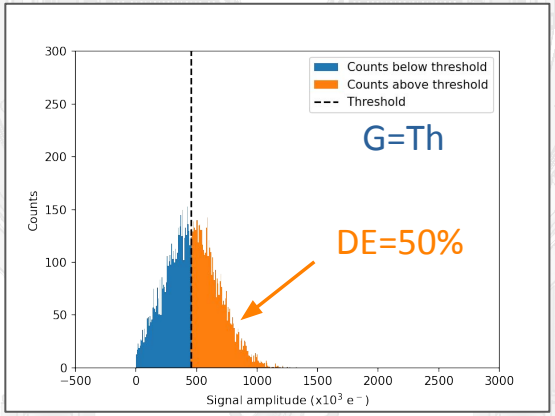
Gain :

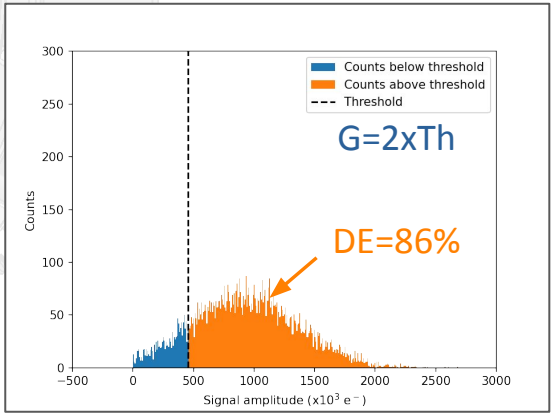
Sets the gain = threshold

→ threshold set to 1 PE

- **Gain adjusted with Single PE detection efficiency (DE)**
  → No ADC
- **Simulations with Gain~N (μ=G, σ=G/2)**
  (DE(G) ≠ S-curve as σ∝μ)



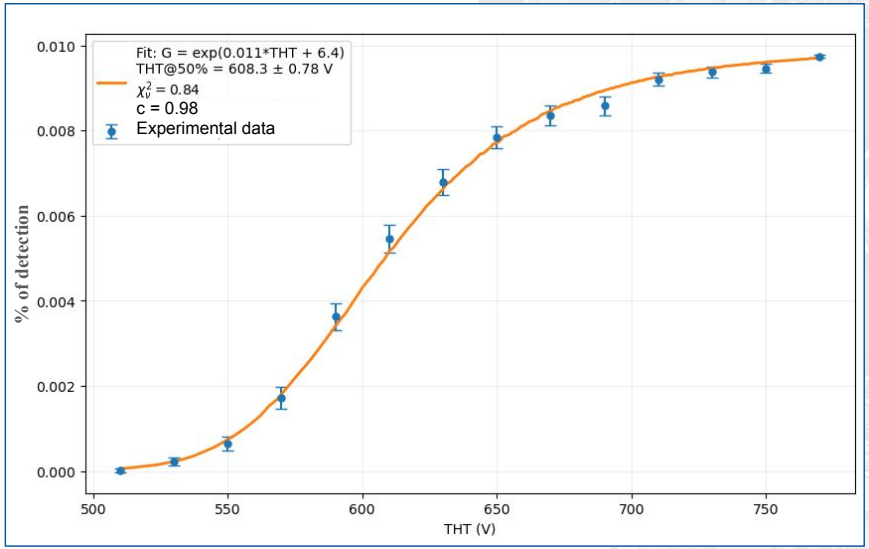


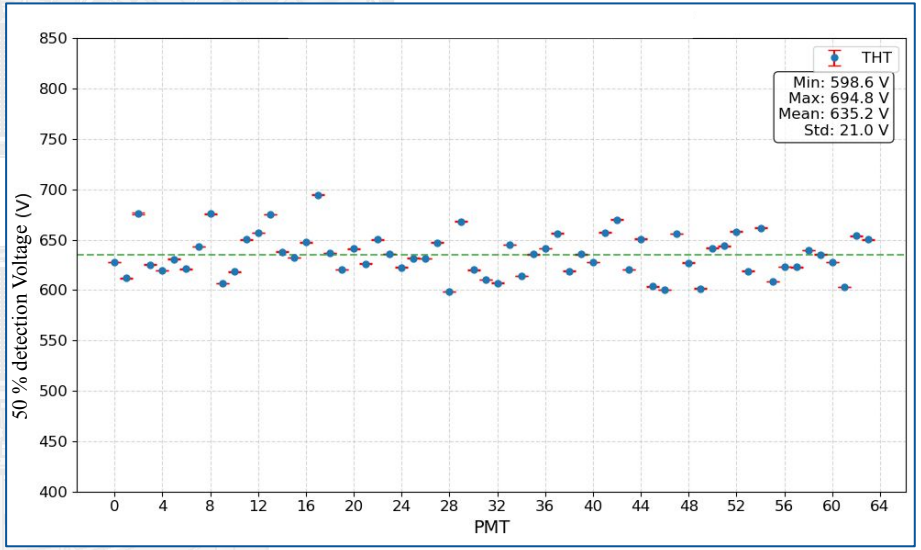


Light Calibration

Gain :

Low dispersion $\sigma_V/V_{mean} = 3\%$

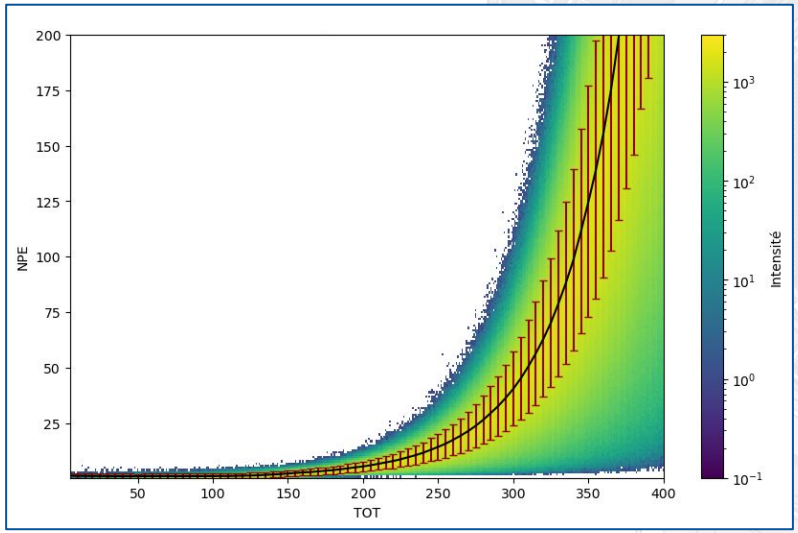




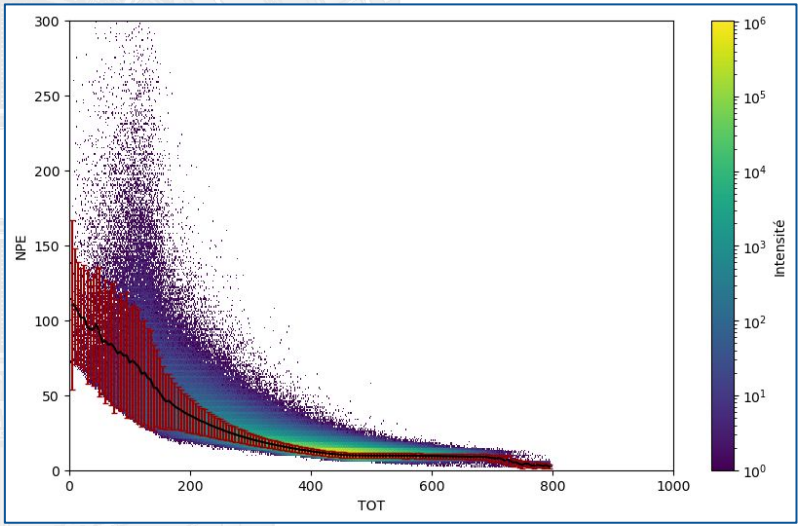
Light Calibration

From simulation based on data :

ToT -> npe



ToT -> Walk



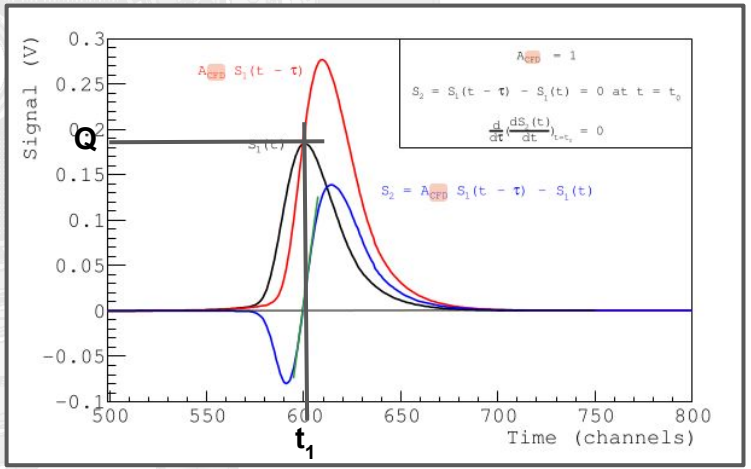
Charge Calibration

Raw Data, output of the camera
Files containing multiple signals:

- Light signals (t_0, Time Over Threshold (TOT), PMT_{id})
- Charge signals (t_1, Q, (x,y))

Charge Calibration

- Thresholds
- Sensitivity
- Time walk calibration



Charge Calibration

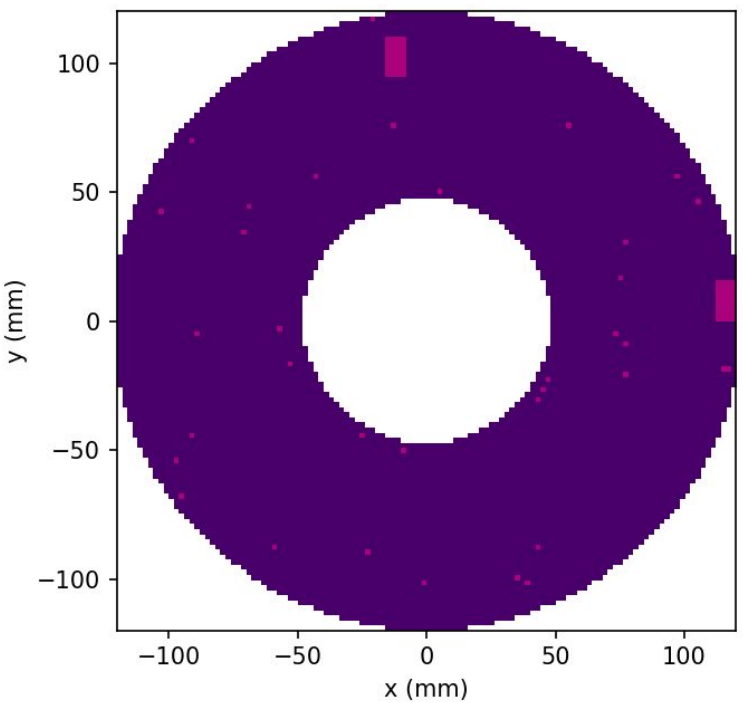
Thresholds (in electronic noise) :

Sets the threshold to 1k hit/s/pixel (~3σ)

Software automated calibration :
- ~5 hours for 20 000 channels

Channel loss : 1%
- channel disconnected
- baseline out of range

DAq is running at 1 kcps/pixel (auto-triggered)
→ 20 Mcps total on disk



Charge Calibration

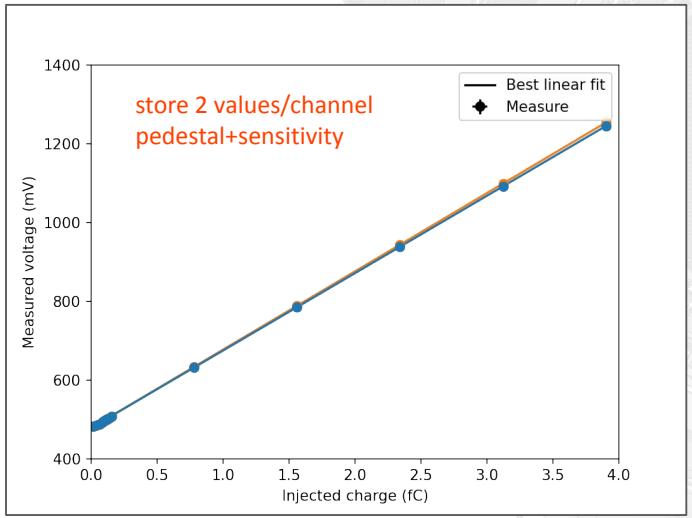
Sensitivity calibration :

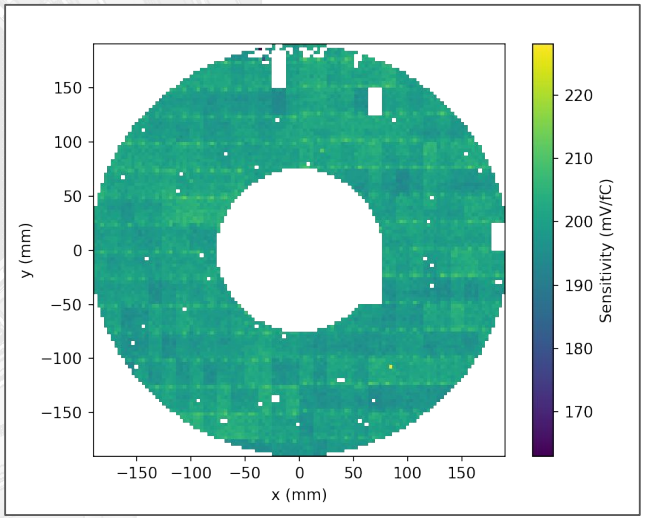
Procedure :

Measurement of $V_{mes}(Q_{in})$ + linear fit

Sensitivity :

- $\langle S \rangle = 200$ mV/fC,
- $\sigma_S / \langle S \rangle = 1.4\%$





Charge Calibration

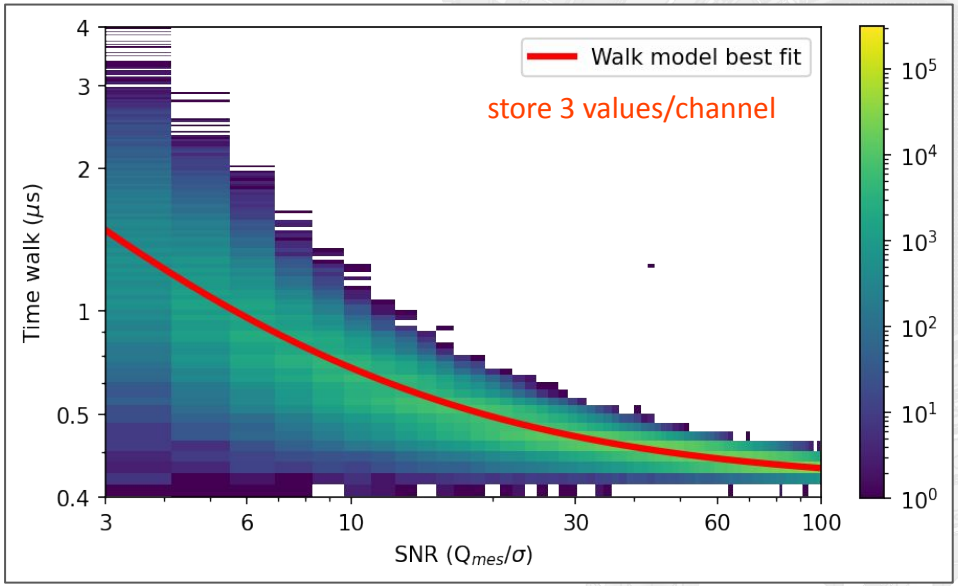
Time walk calibration :

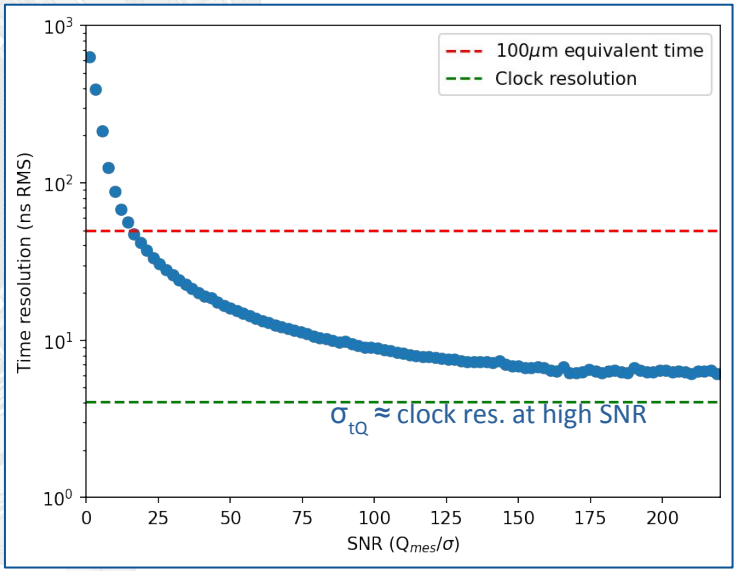
Procedure :

Measurement of $t_Q(Q_{in})$ + power law fit

σ_{tQ}=50 ns above ~40 keV

Equiv. to σ_Z=100 µm @ 2 kV/cm





Conclusion :

- The construction of the prototype is completed

- The light calibration :
  - 64 PMT calibrated with their electronics
  - gain of ~ 500k

- The Charge Calibration :
  - 98.5% of pixels calibrated
  - low noise ~ 100 e^-

- Acquisition is now possible storing TBs for 20 min acquisition

Perspective :

- End of calibration and commissioning in Fall 2026

  → Geometrical alignment with ^{137}Cs

  → Xenon purity assessment

- From Fall 2026 : First images with point source, phantom and small animal with medical radionuclides (^{211}At, ^{212}Pb, ^{44}Sc, …)