Réunion du GDR DI2I du 24 Juin au 26 Juin
IJCLab - Orsay

Contributions to the instrumental developments of the XEMIS2 camera, on-board scintillation measurements

Dingbang CAI - SUBATECH

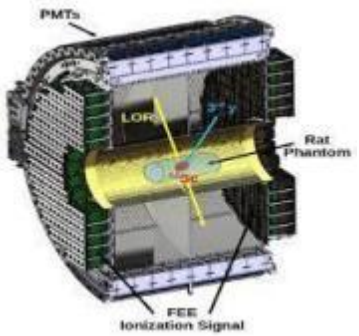


TABLE OF CONTENTS

XEMIS (Xenon Medical Imaging System)

✓ **3γ imaging**

(β^+, γ) emitter for functional imaging, e.g. ^{44}Sc

✓ **Liquid xenon Compton camera**

Time projection chamber (TPC)

- **Direct 3D location of the radioactive source**
- **Administered dose reduction &/or shorter acquisition time**

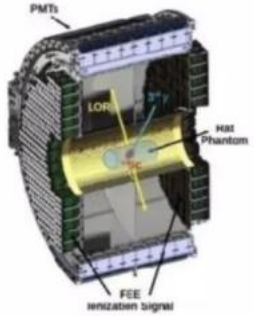
XEMIS1
R&D

XEMIS2
Small animal imaging

XEMIS3
Human body imaging

Done

30 kg LXe



200 kg
2 x 12 cm drift TPC

In progress

200 kg LXe

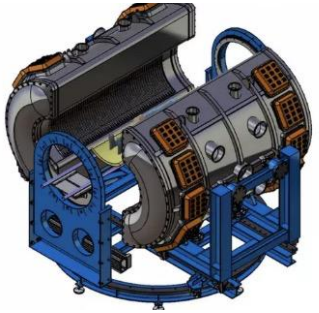
3γ : 20 kBq for 20 mins

100+ times less of injected activity

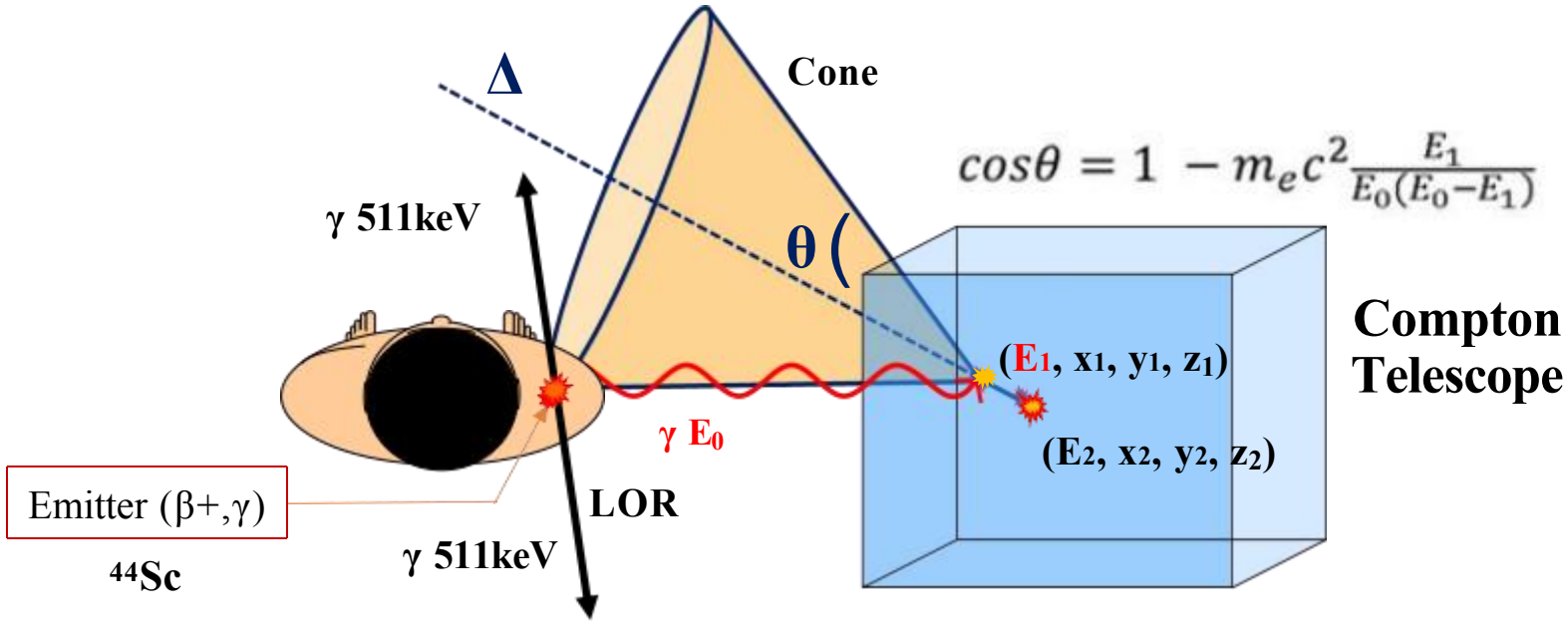
Large field-of-view
High sensitivity

Future

Few tons LXe



3γ imaging with Compton telescope

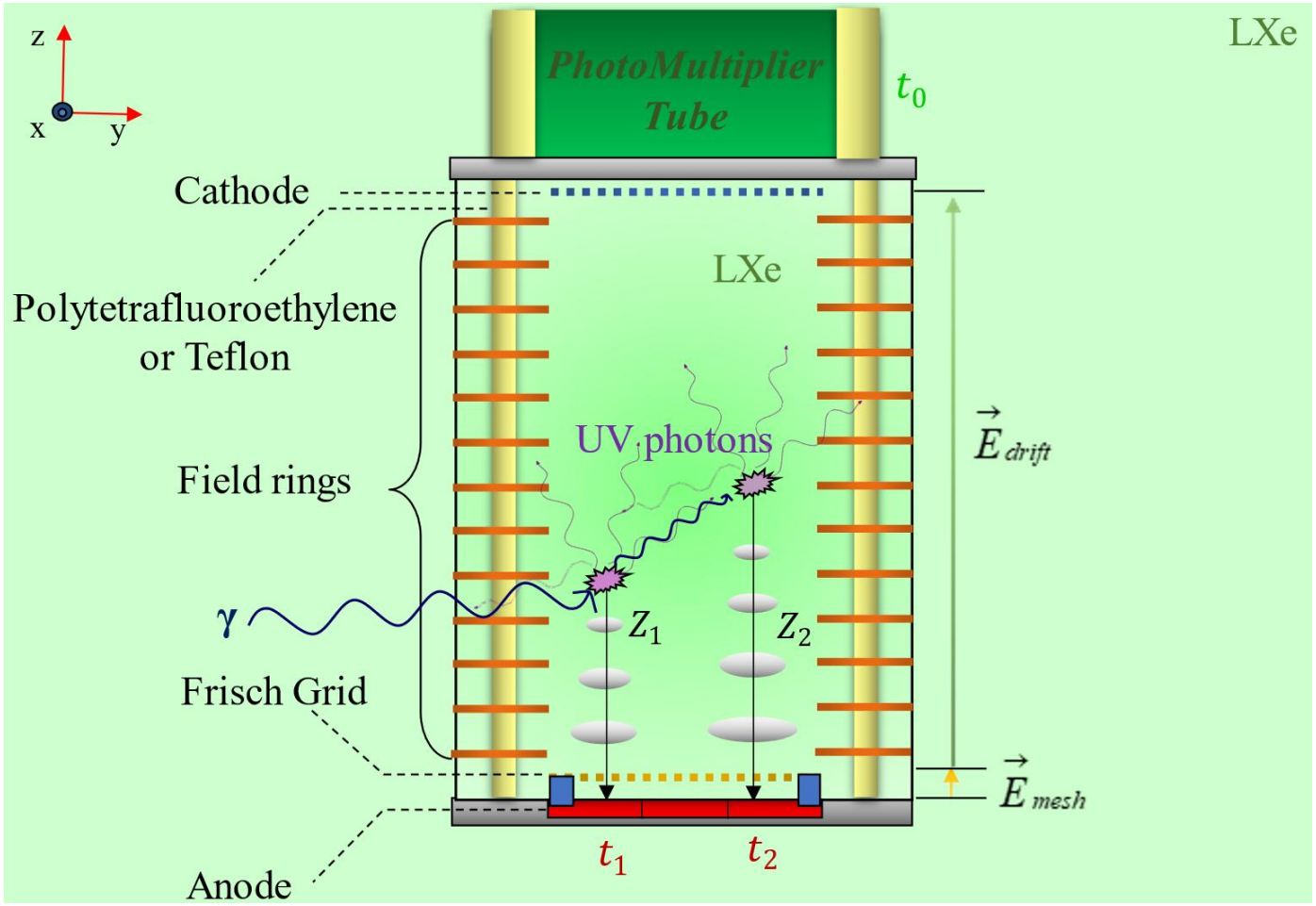


Reconstructed γ direction
- Spatial resolution ➡ cone axis (Δ)
- Energy resolution ➡ opening angle (θ)

Direct 3D location of the radioactive source: res. along LOR ~ 1 cm (FWHM)

Localisation 3D

Particle interaction in the active volume produces **prompt scintillation** light and **ionization electrons**



Scintillation light (PMT) : t_0

Ionization : **Energy + (x, y) + t_1**

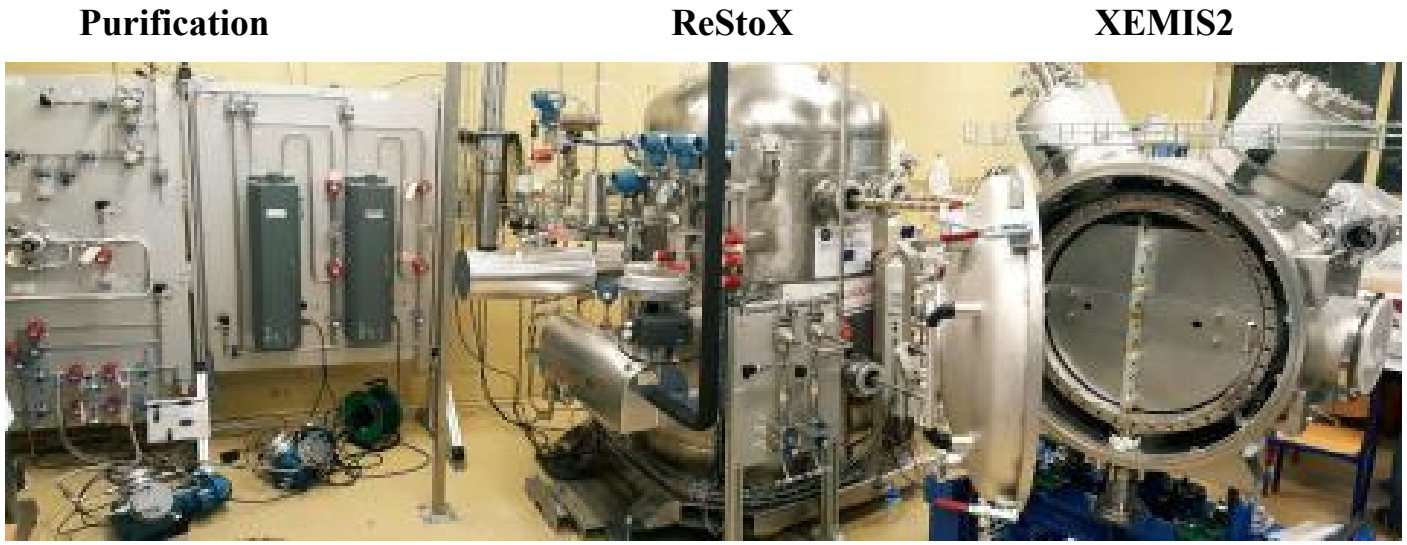
+

V_{drift} is known ~2.3 mm/µs under 2 kV/cm electric field : $Z = v_{drift}(t_1 - t_0)$

↓

Energy + 3D Positions of each interaction

XEMIS2: Small animals imaging



XEMIS2 at Nantes Hospital:

- **1st image: end of 2024**
- **preclinical researches: until 2025**

✓ **Operation Condition** (LXe):168 K at 1.2 bar abs (range of 6.7 K)

✓ **The ReStoX**: Fast recovery, safe storage and cooling Xe

✓ **Purification System:**

Removes electronegative impurities (N2, O2) :

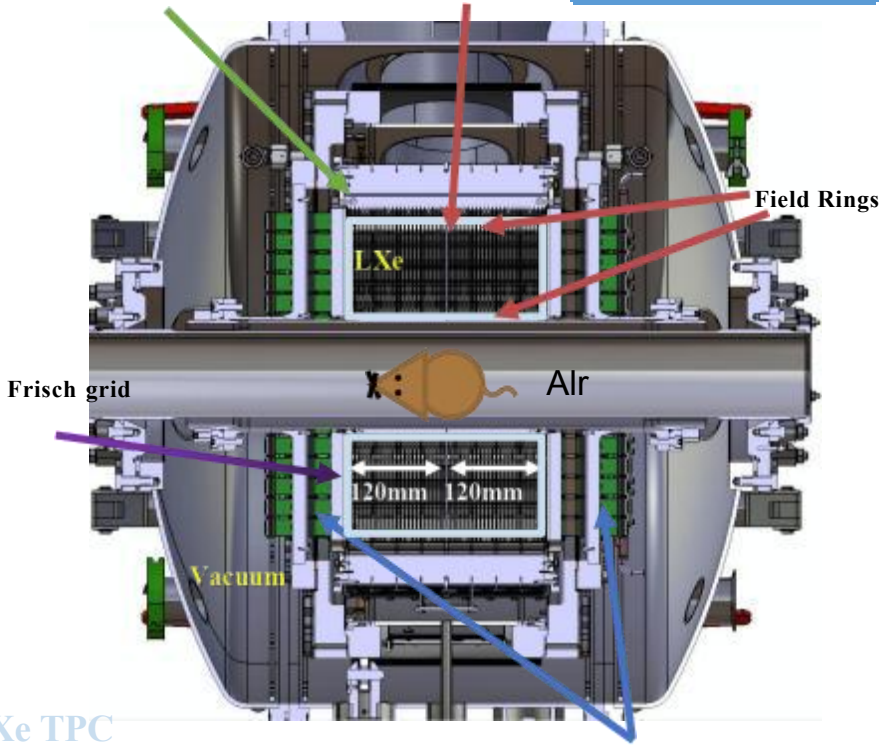
a) Prevents capture of drifting electrons before anode
b) Eliminates moisture to preserve UV scintillation light
c) Ensures high liquid purity for accurate ionization and scintillation signals detection

XEMIS2: Small animals imaging

Scintillation

64 PMTs in LXe

LXe: 200 kg

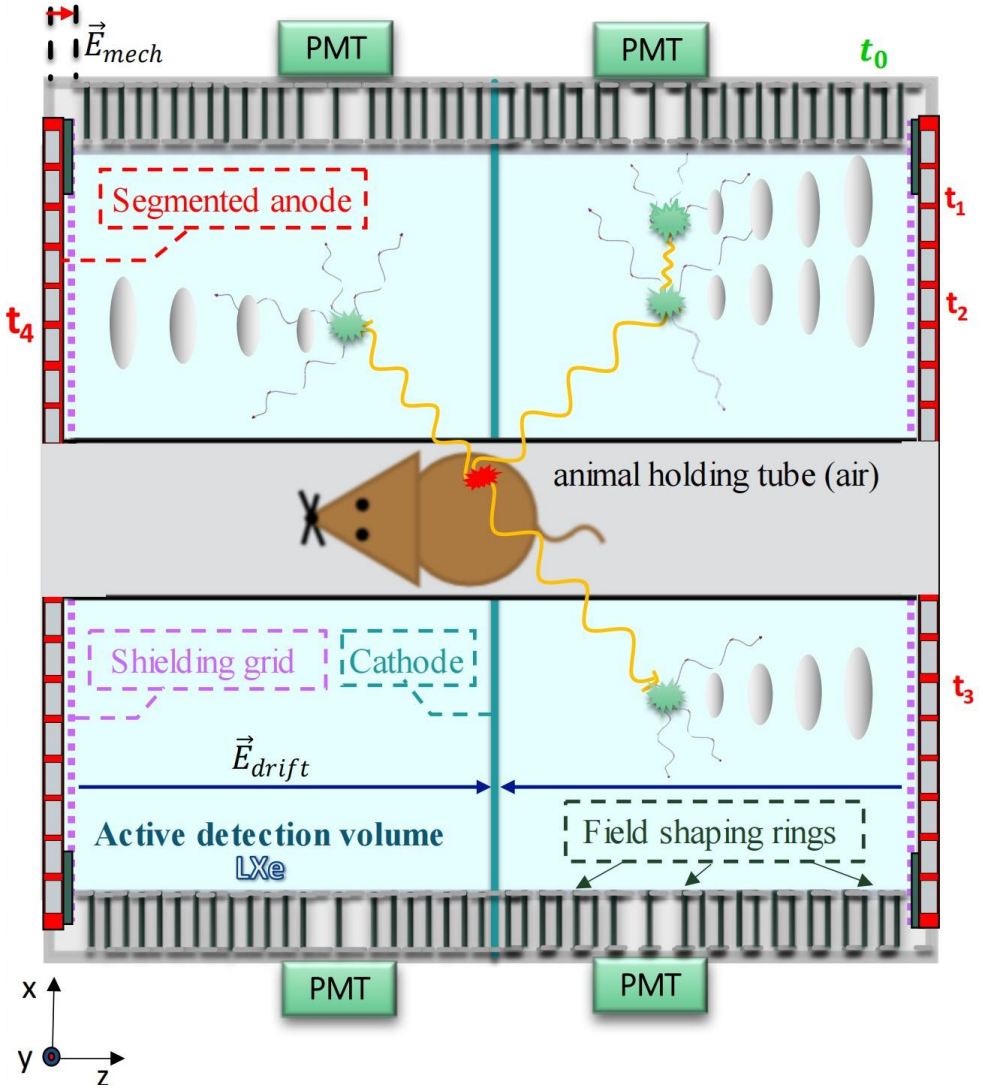


LXe TPC

Active volume
- axial : 2 x 12 cm
- radius : 7 -> 19 cm

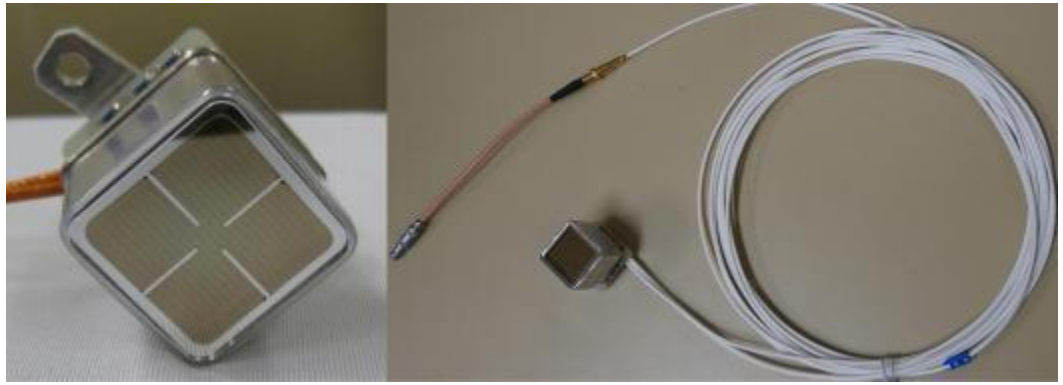
Ionization

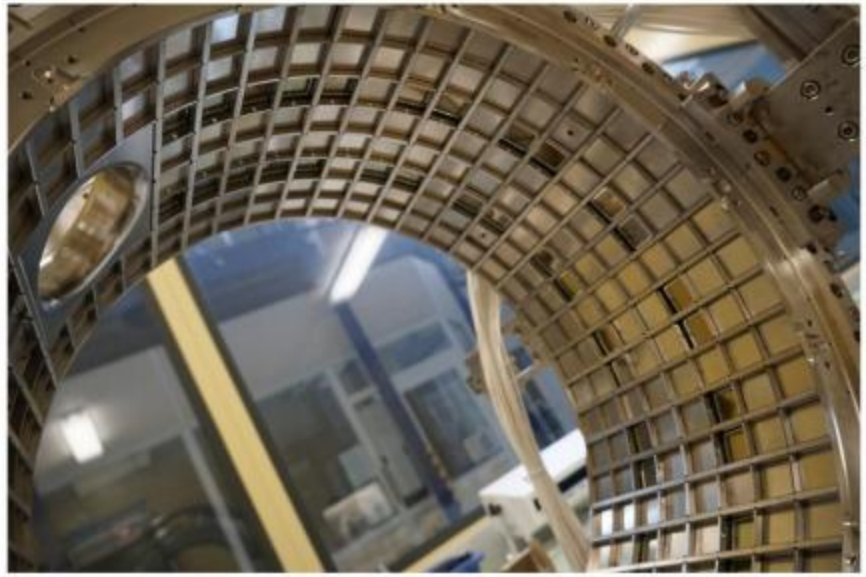
2.10^4 pixels: 3.1 x 3.1 mm



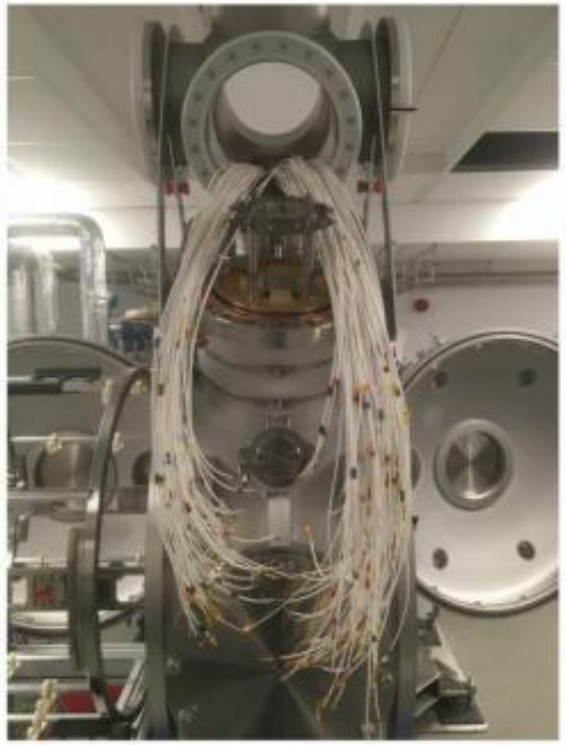
Scintillation light detection system

VUV-sensitive Hamamatsu R7600-06MOD-ASSY PMT





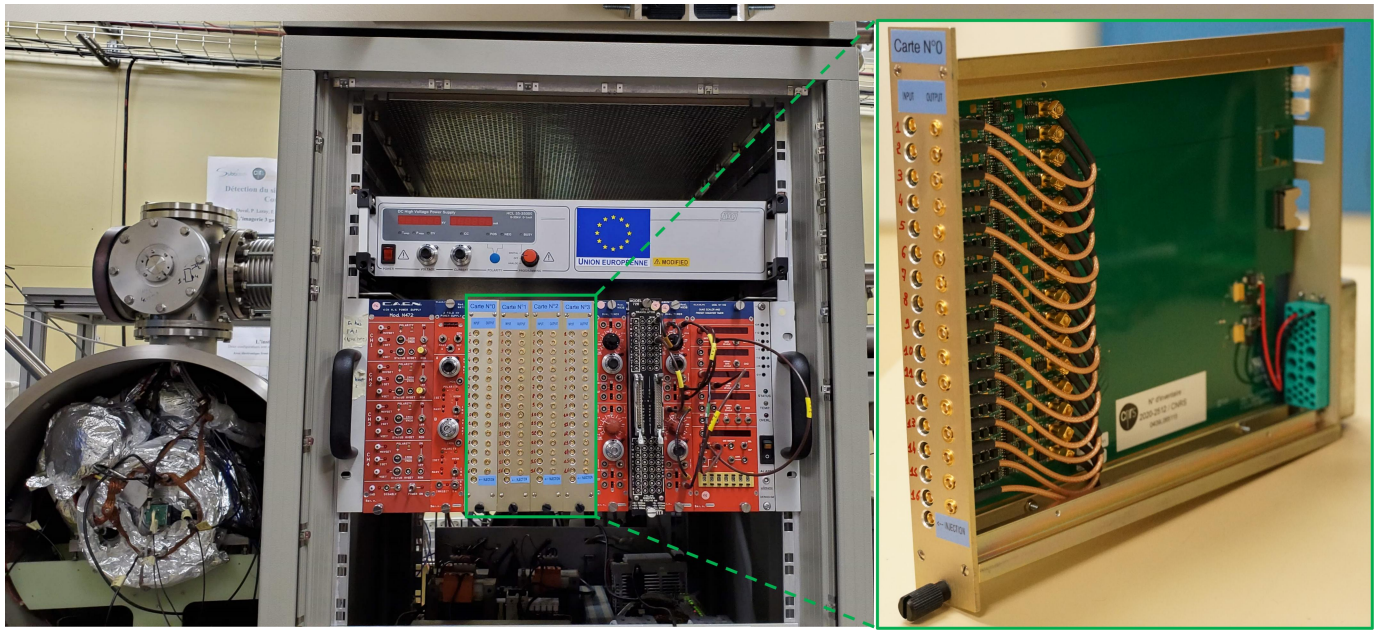
Installation in Nantes hospital

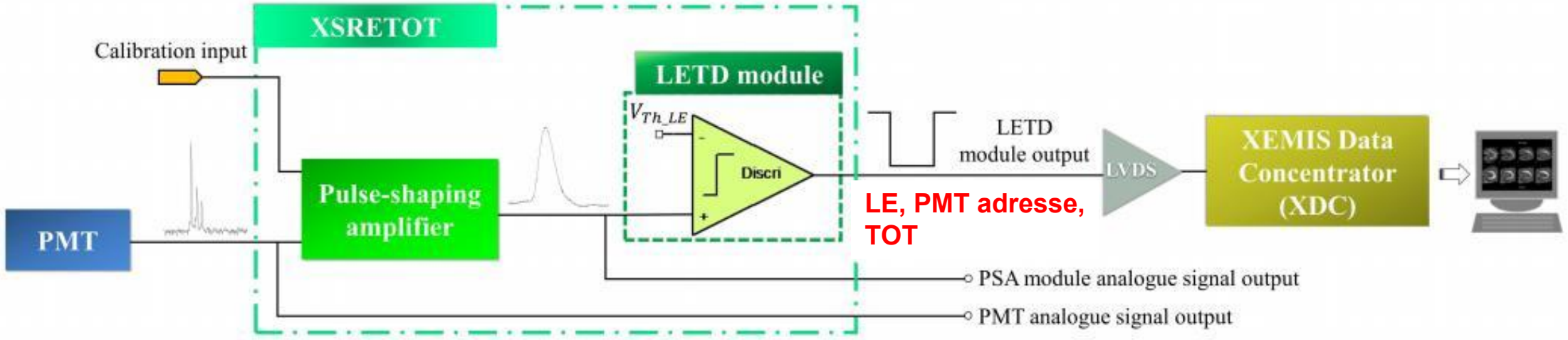


Scintillation light detection system

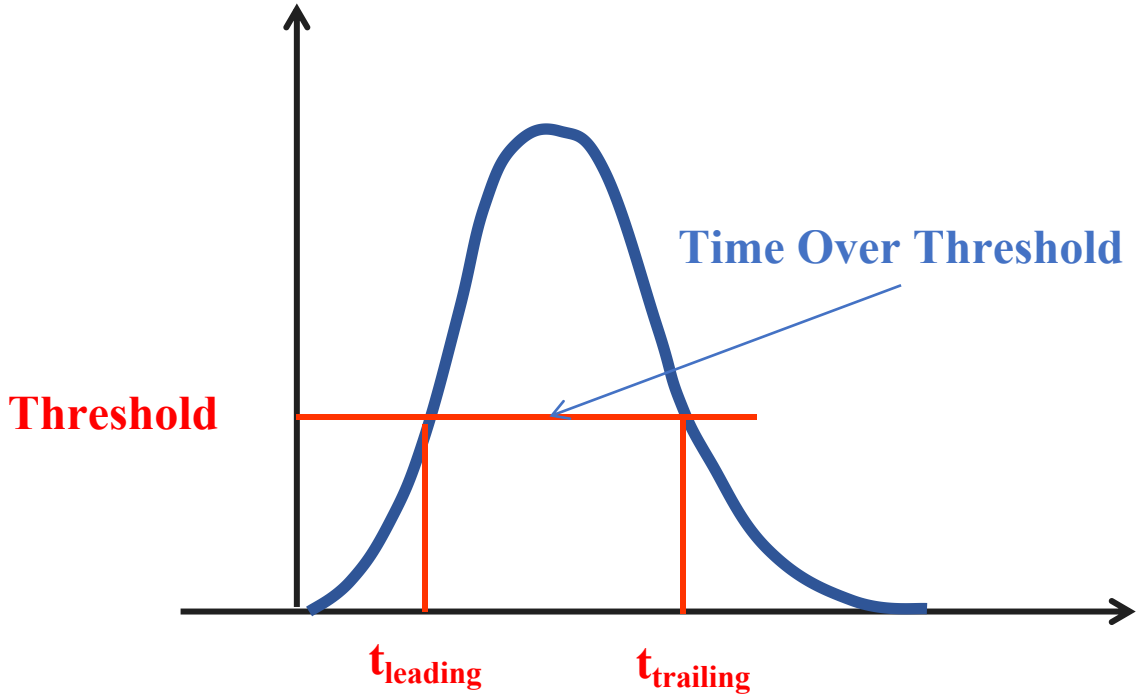
XSRETOT(**X**EMIS **S**cintillation **R**eadout for **E**xtraction of **T**ime **O**ver **T**hreshold)

LETD(**L**eading **E**dge **T**iming **D**iscrimination)
The leading edge of this logic pulse is used as the arrival time of the input PSA signal





Scintillation light detection system



Time Over Threshold (TOT):

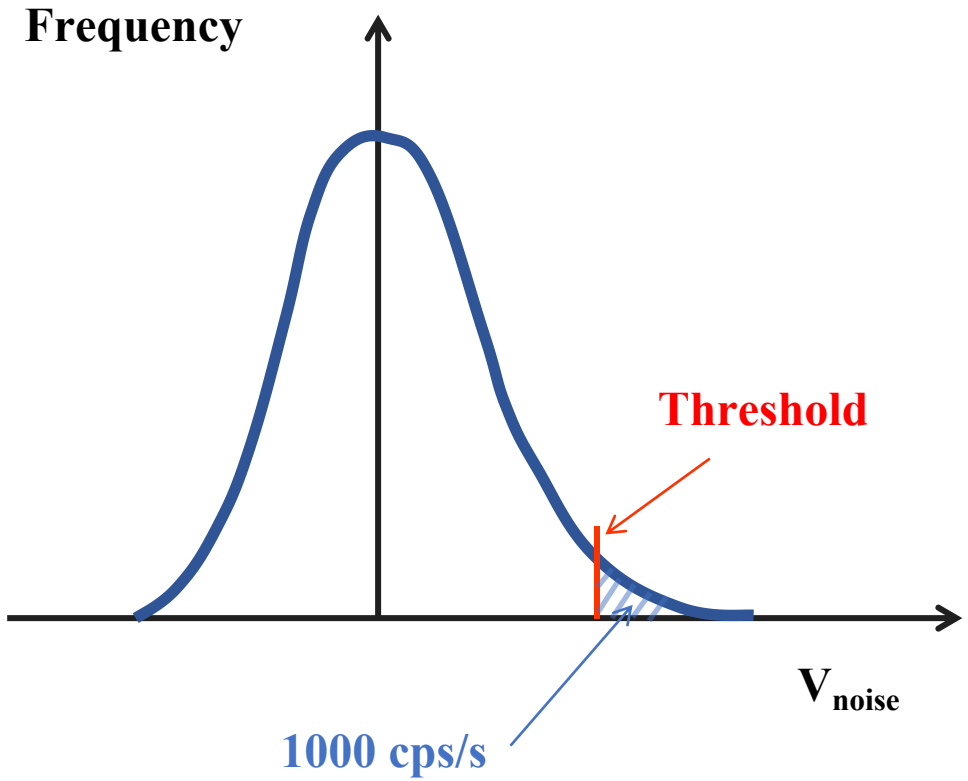
- ✓ Registers only signals exceeding the threshold.
- ✓ Efficient method for registering signal amplitude.

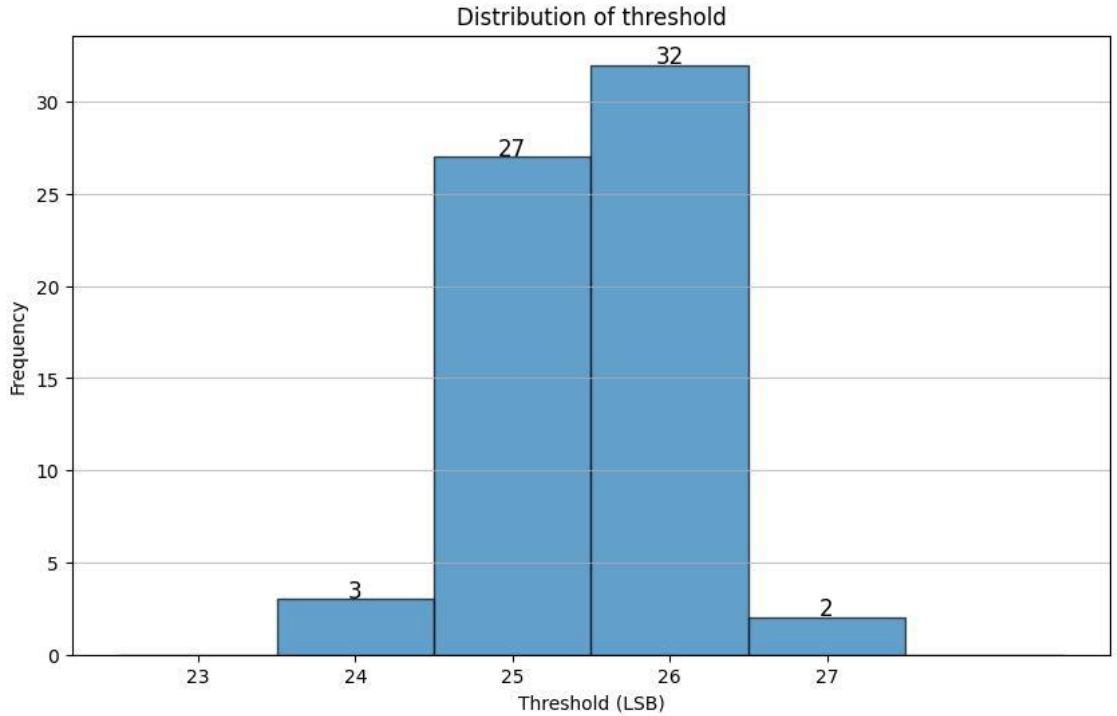
Requires calibration of TOT dependency as a function of signal amplitude.

Scintillation Calibration: 5 Steps

a) Threshold Calibration: 1000 cps/s
b) Threshold unit Conversion: Convert threshold units from Least Significant Bit (LSB) to charge (e-).
c) Photoelectron Approximation: Estimate the approximate number of photoelectrons from TOT
d) Time correction: time walk correction
e) PMT Gain Calibration: Gain PMT = Threshold

Threshold Calibration

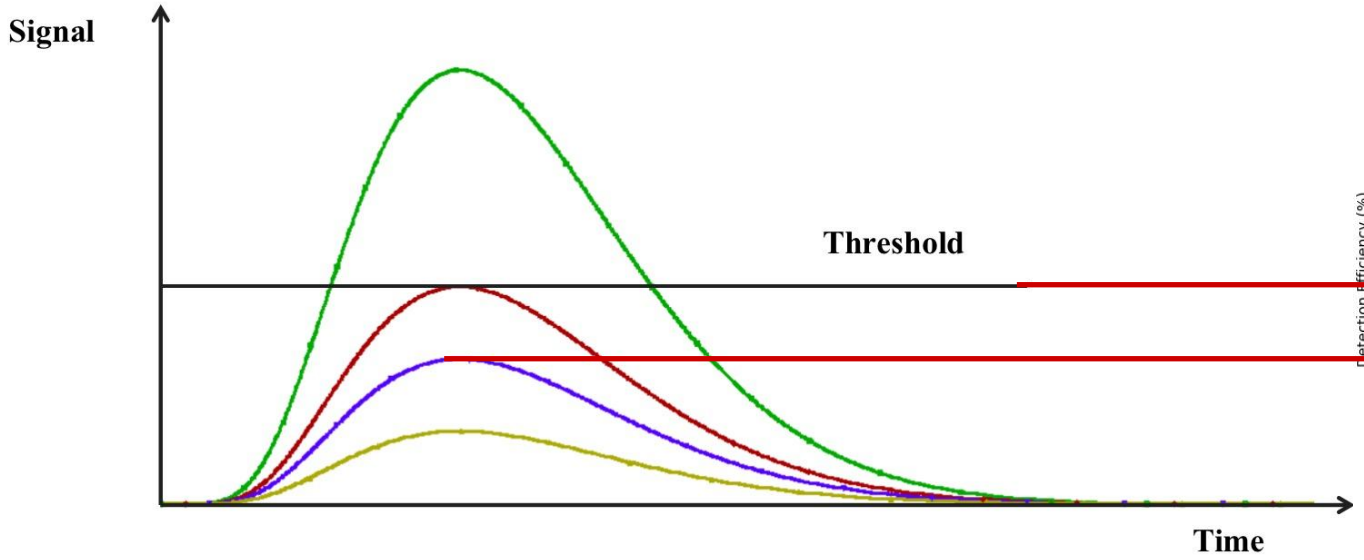


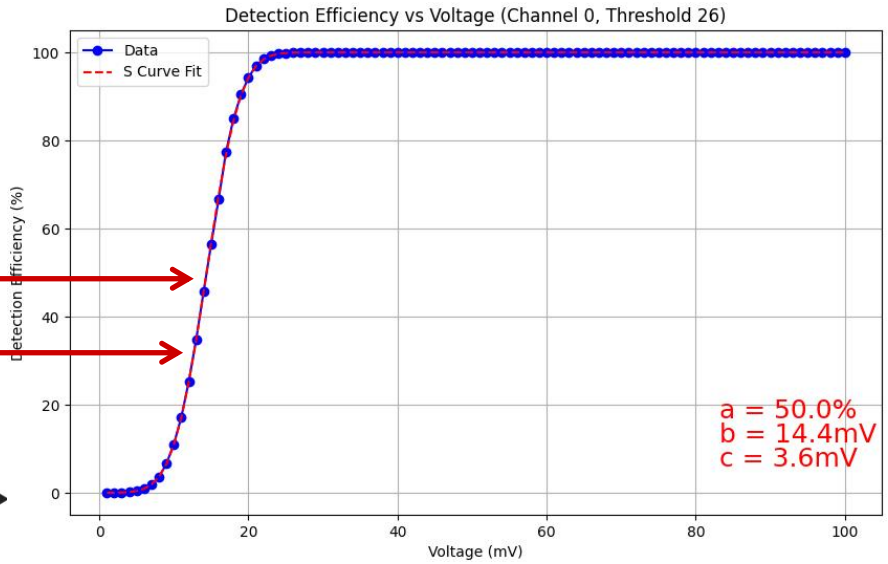


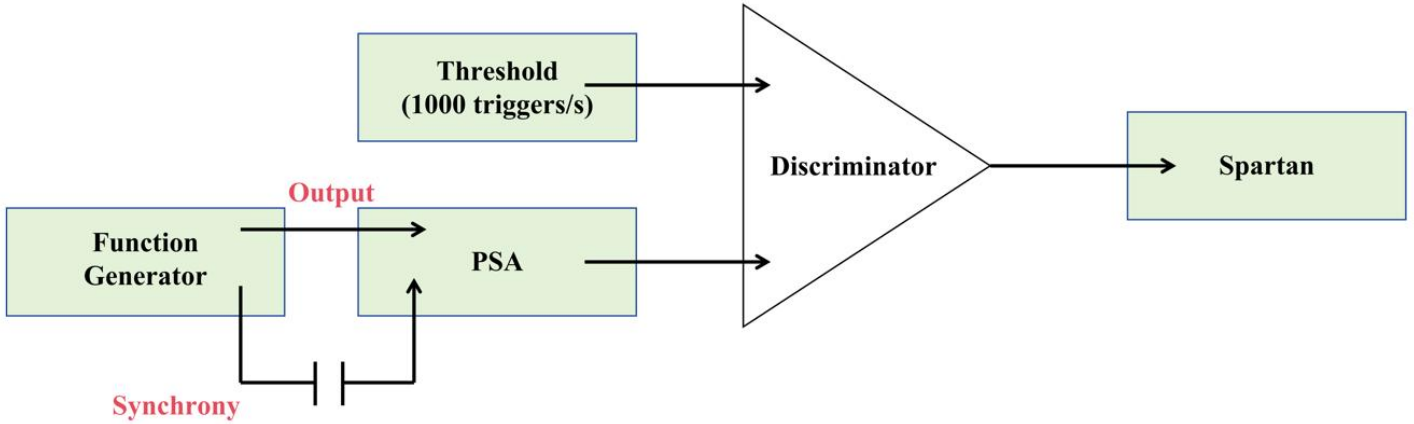
Objective: Find the threshold corresponding àwith 1000 cps/s for the 64 PMTs => Threshold = 4 * noise

The threshold is around 25 and 26 LSB

Conversion of the thresholds from LSB to charge



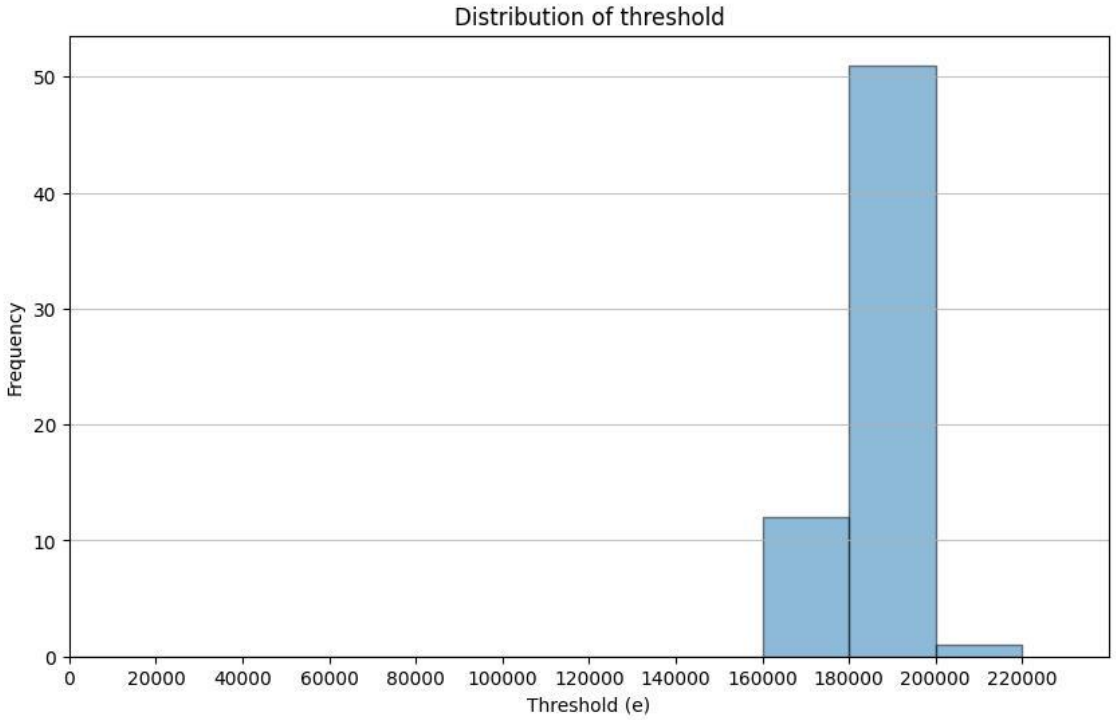


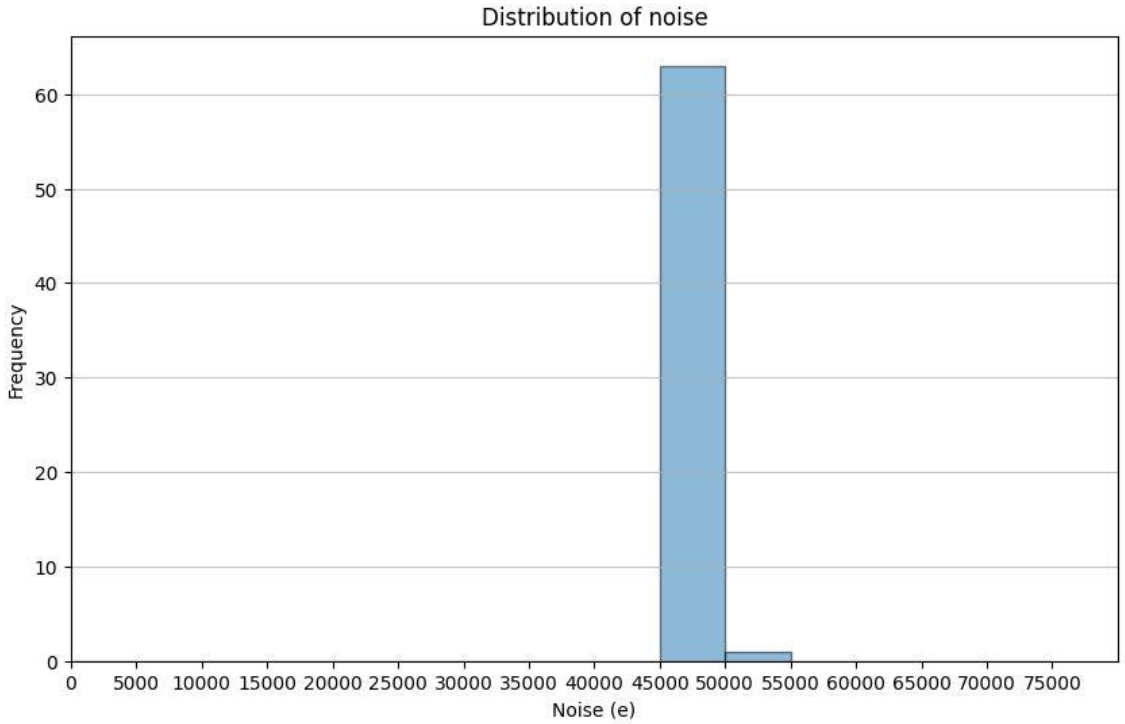


Q (Threshold) = 14.4 mV * 2.2 pF = 31.7 fC = 198000e

Q_{RMS} = 49500e

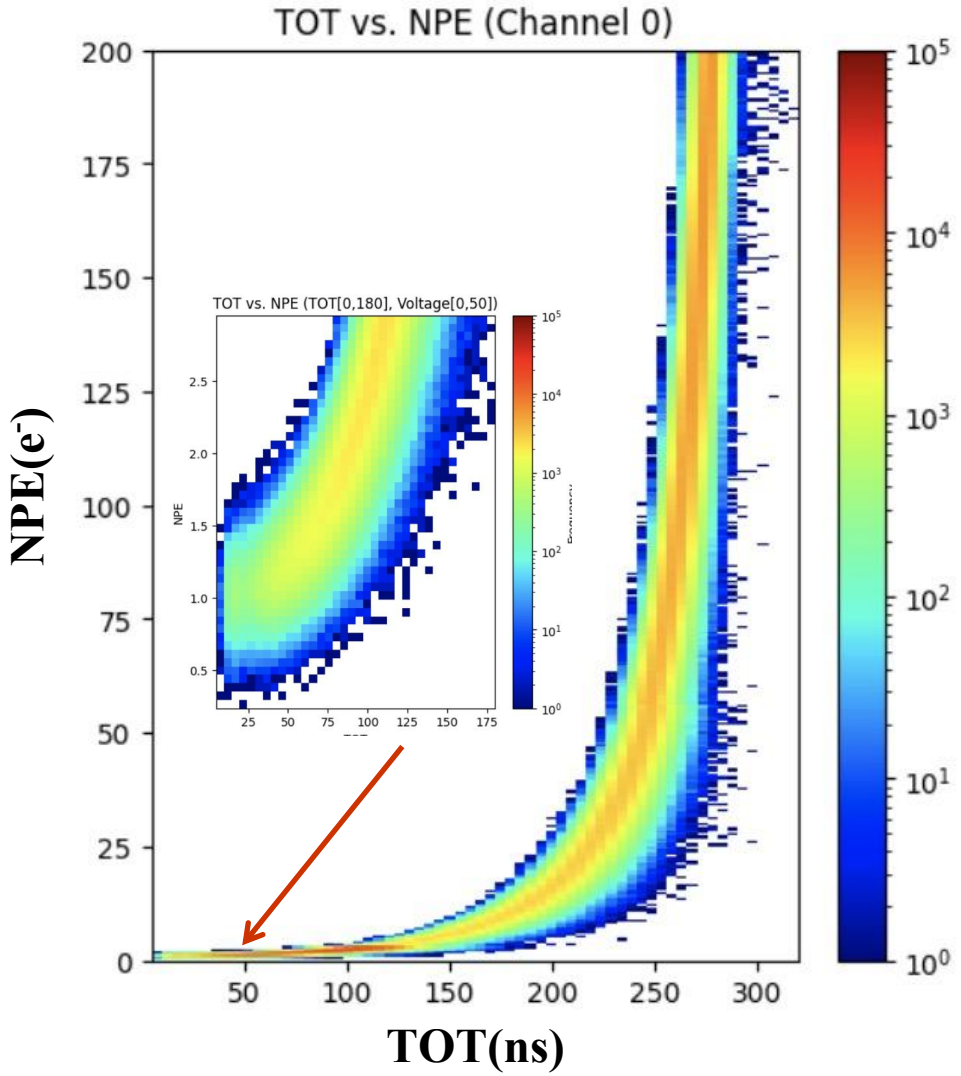
Conversion of the thresholds from LSB to charge

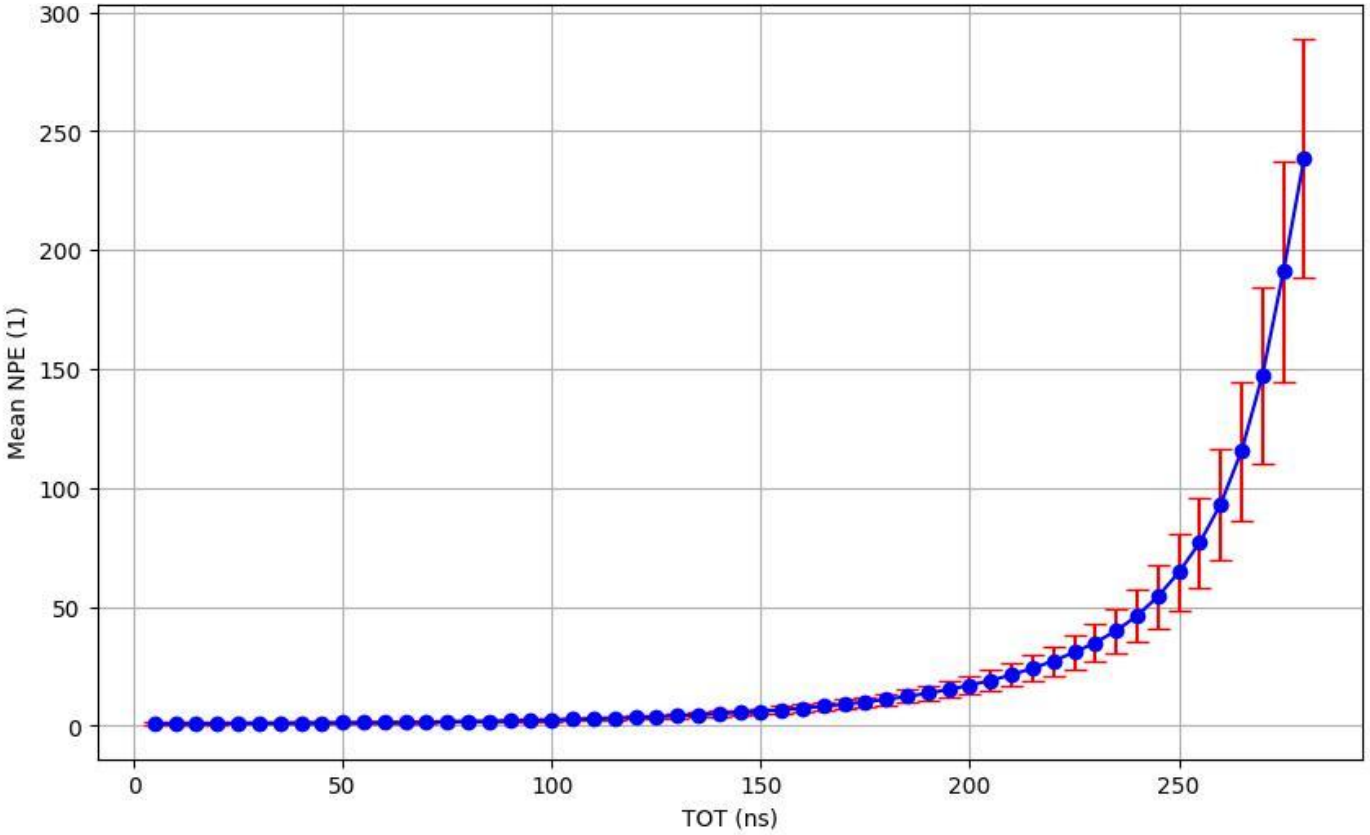




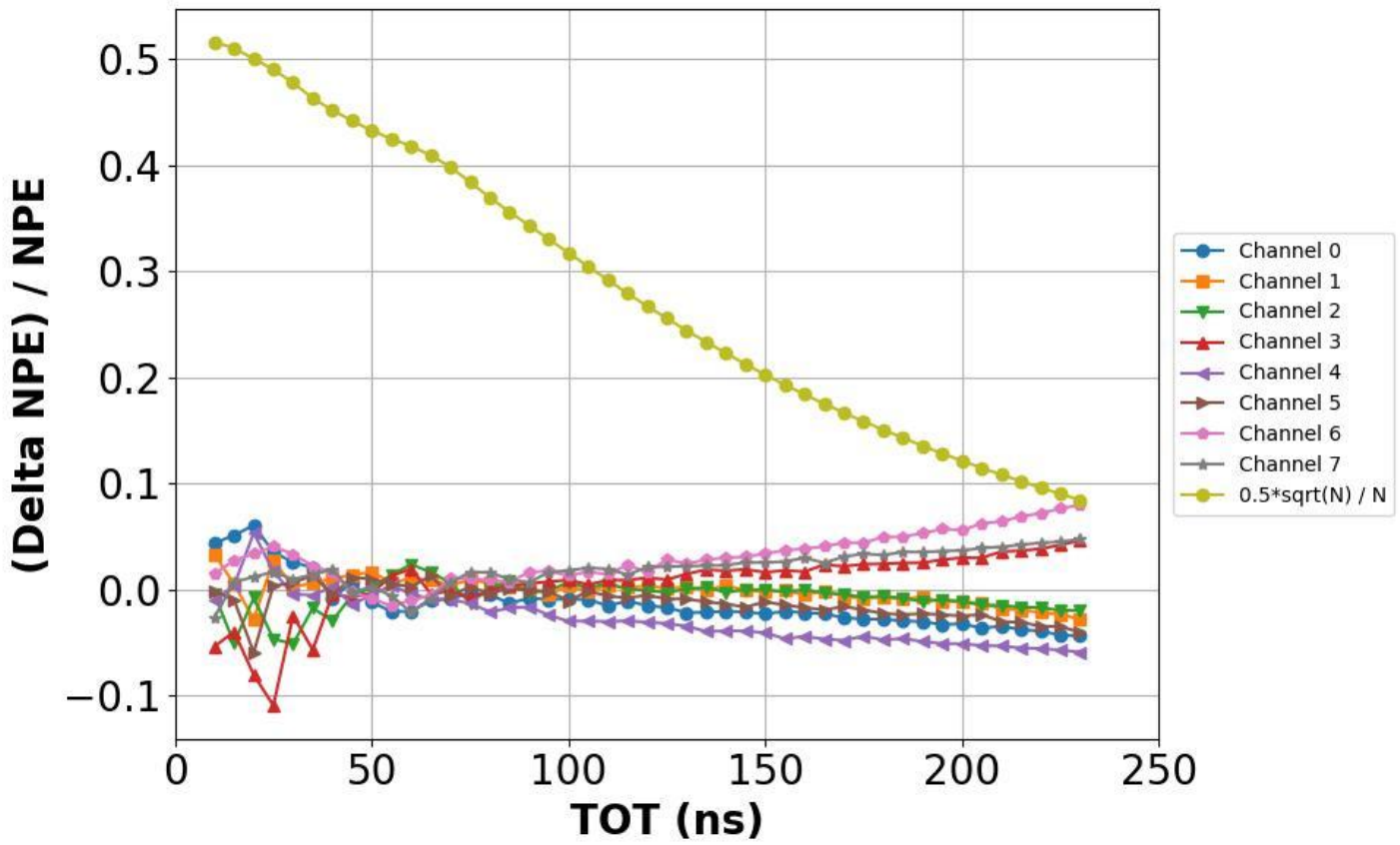
The threshold is between 160,000 electrons and 220,000 electrons with the noise in range of 45,000 electrons and 55,000 electrons.

Conversion of the TOTs to NPE



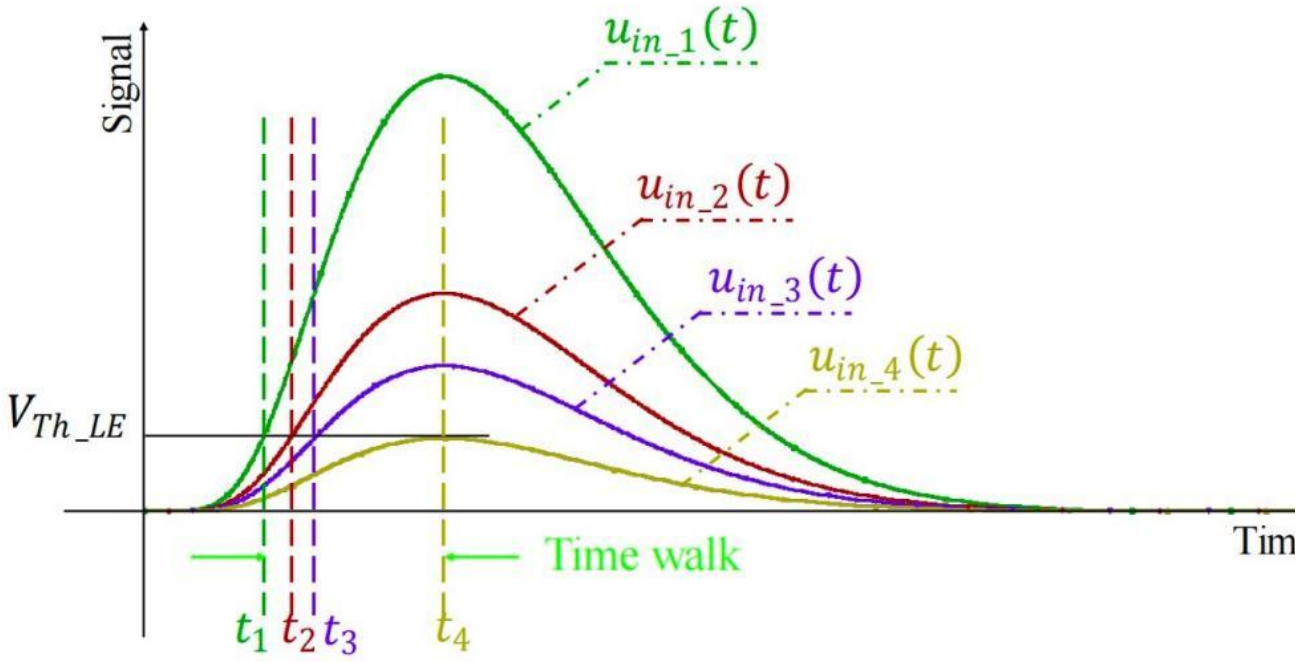


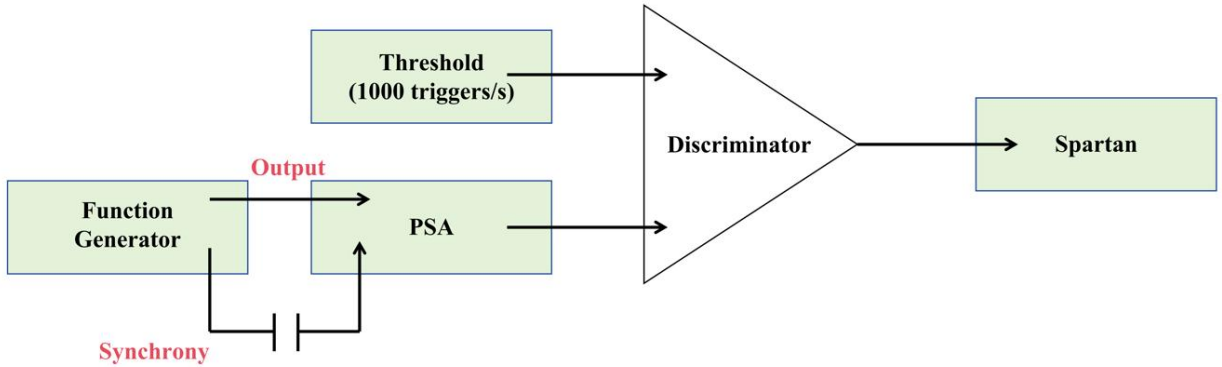
Conversion of the TOTs to NPE

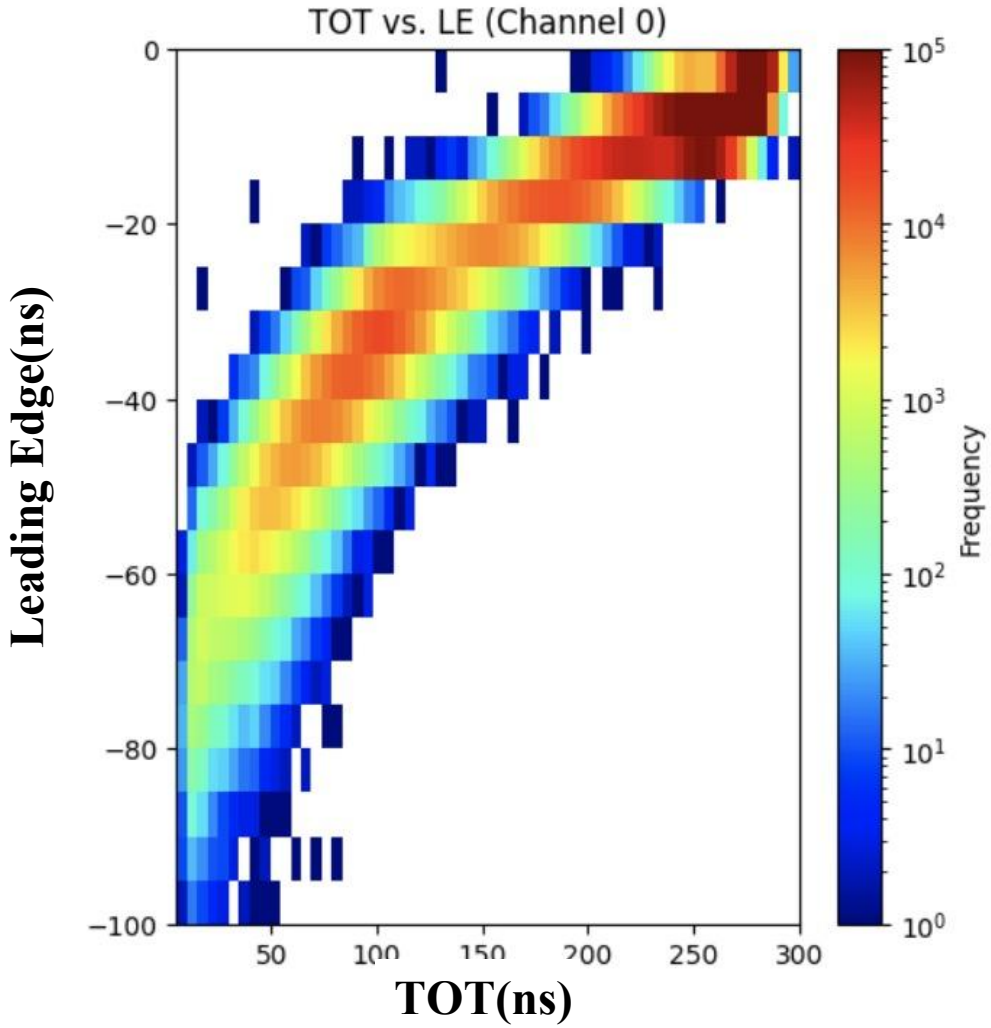


- The difference between each channel and the mean curve are within ± 10%,
- The fluctuations in the PMTs gain for the XEMIS2 in operation can be represented by the formula: 50% * sqrt(N)/N., where N denotes the number of detected events.

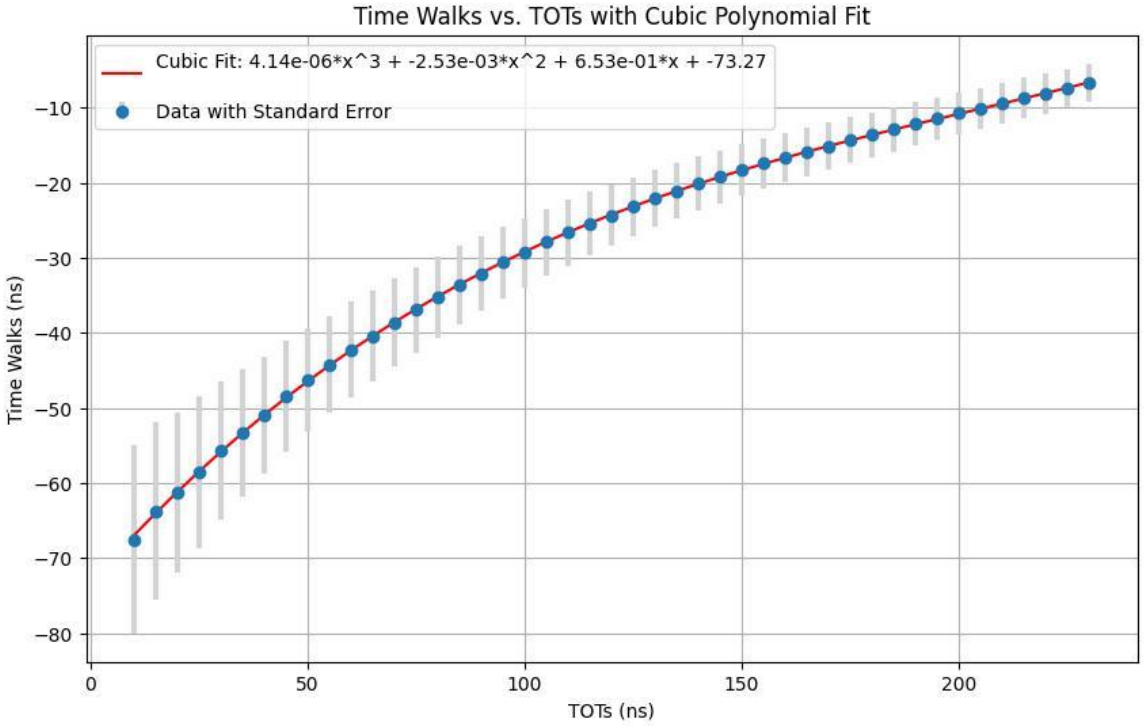
Correction of Time Walk

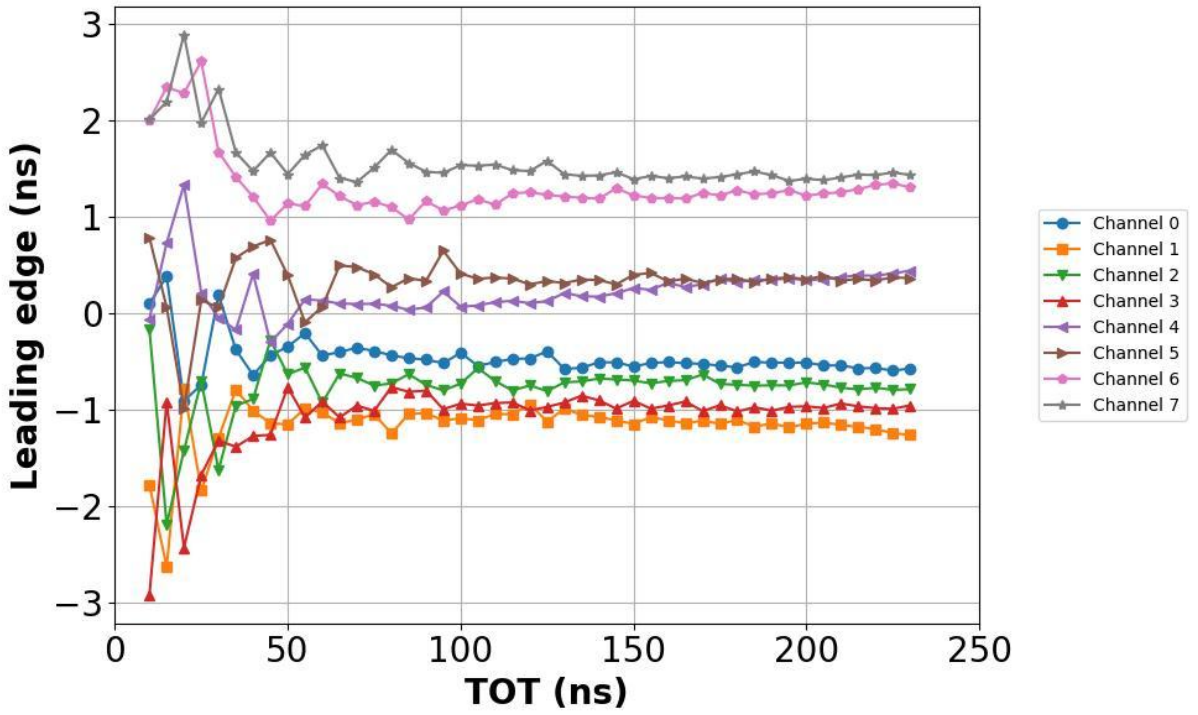




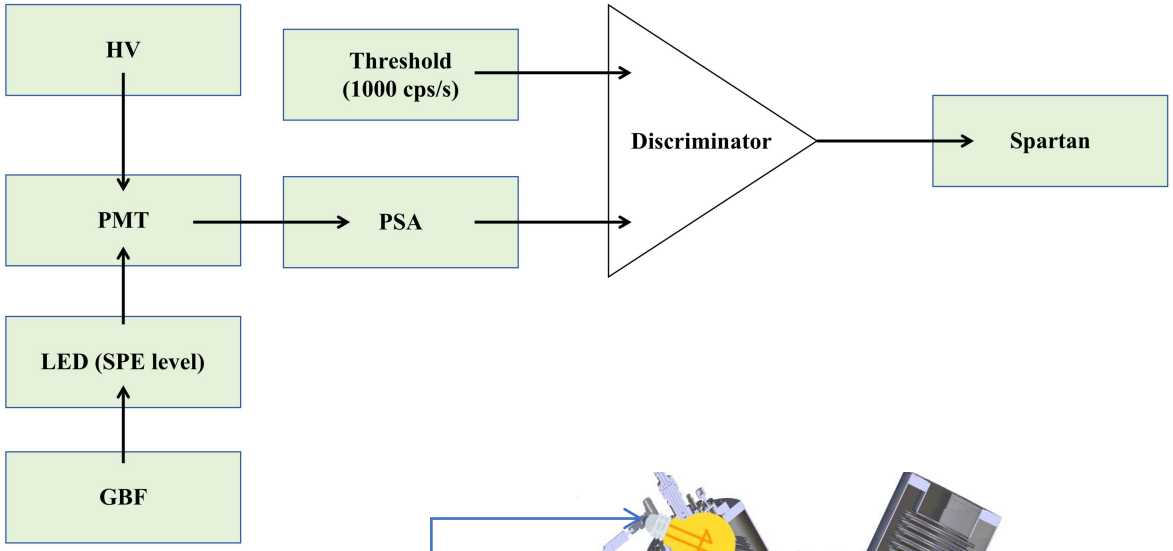


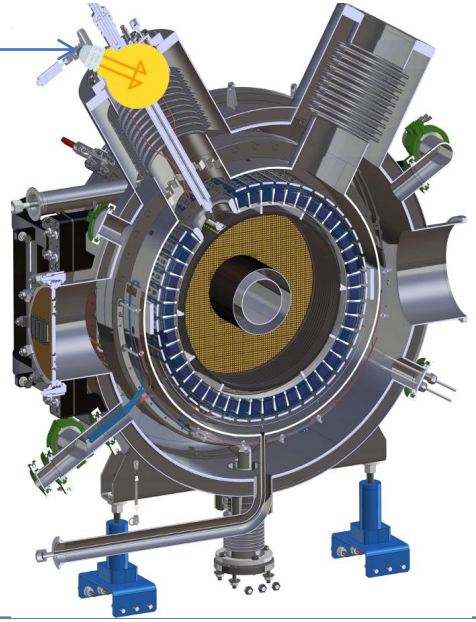
Correction of Time Walk

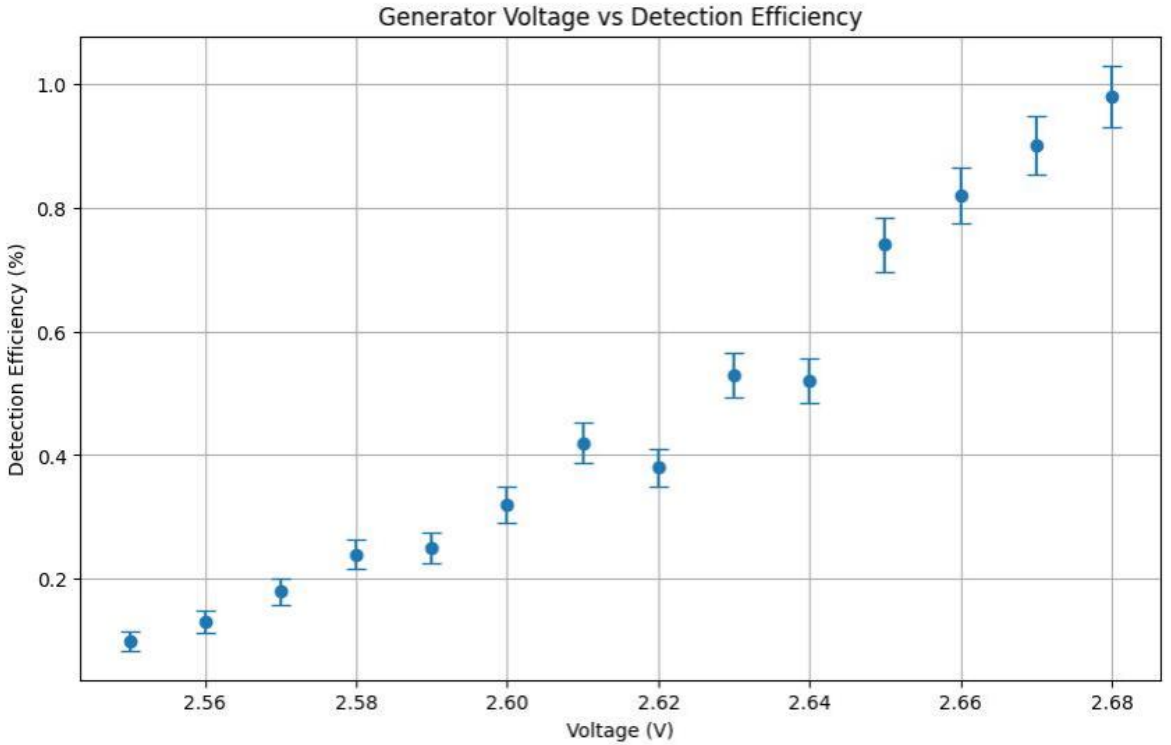




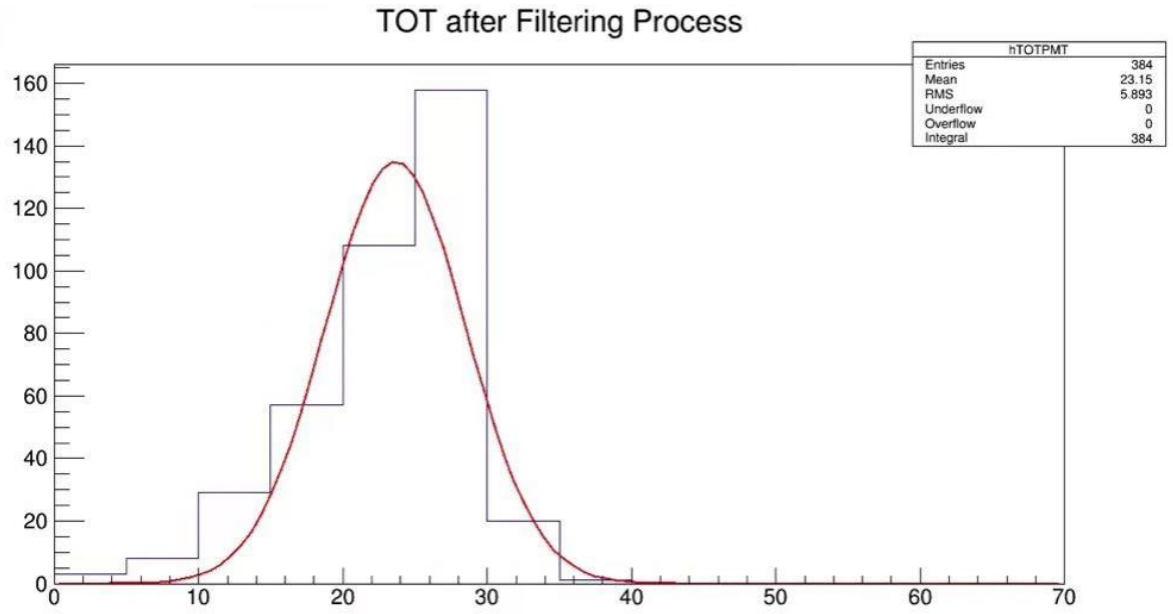
PMT gain calibration

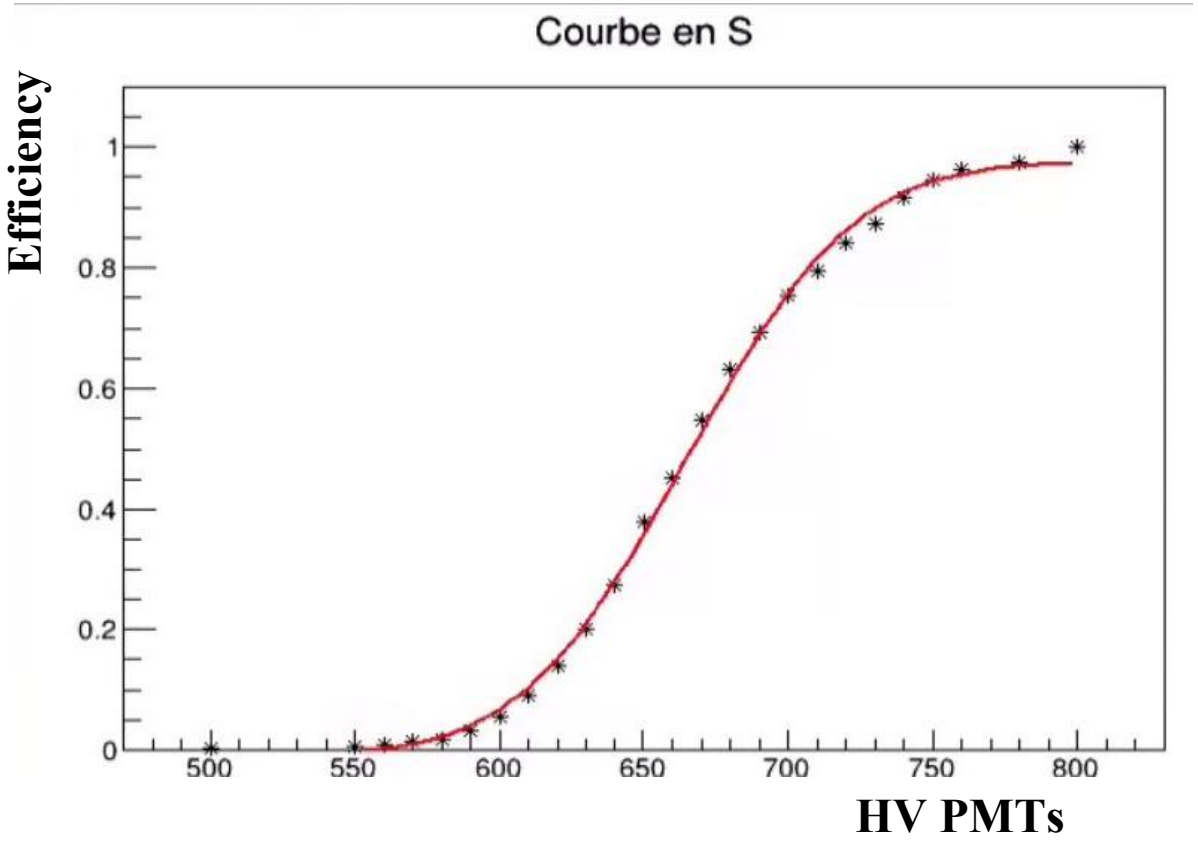






Calibration du gain PMT

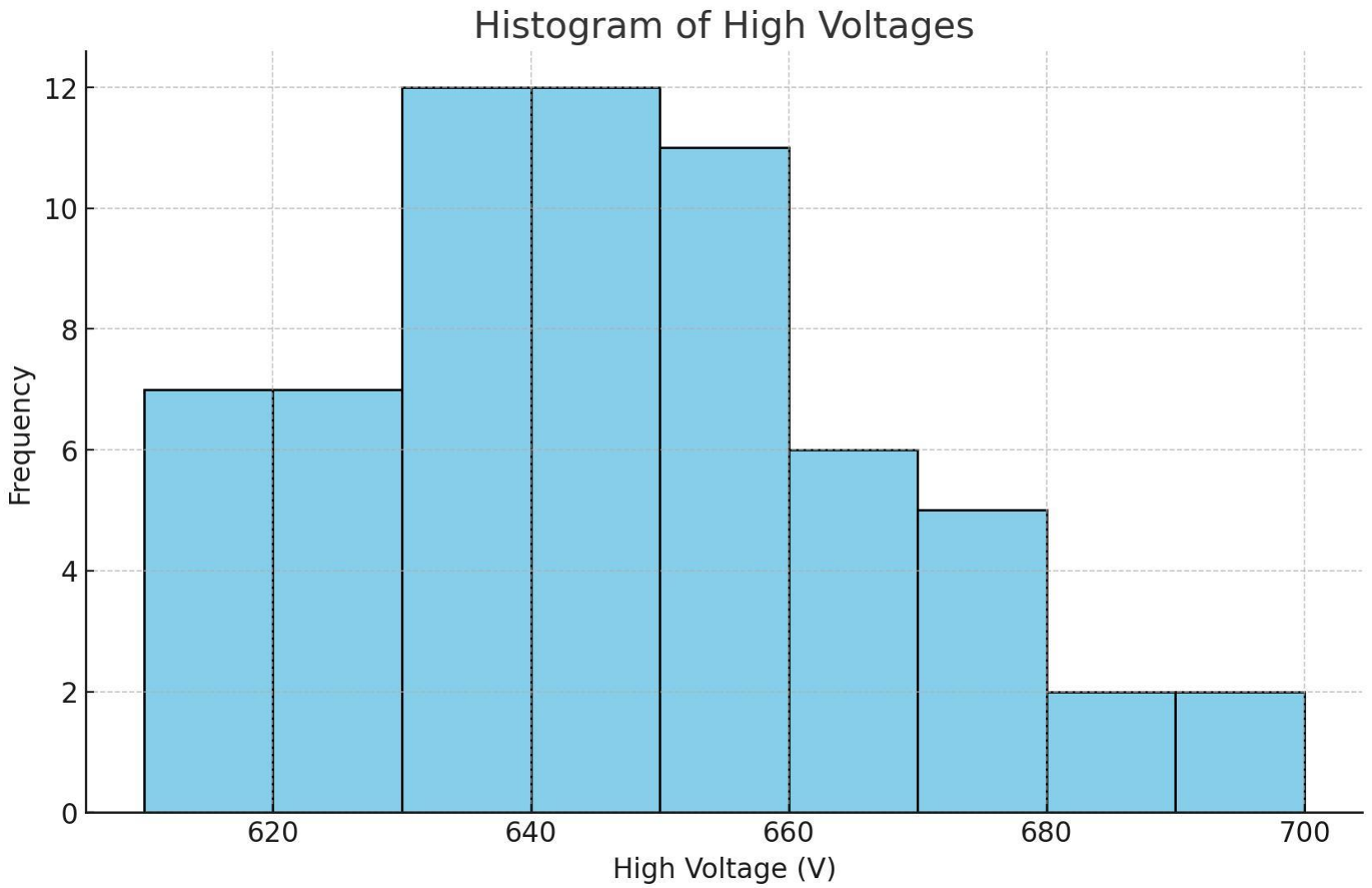




Majority of physical events with a mean TOT of 23 ns
(A TOT of 23 ns corresponds to approximately 1 NPE from the third steps.)

Objective: Control the HV so that the PMT gain matches the threshold (e-)

Calibration du gain PMT



Conclusions and outlook

- ✓ The method for calibrating the light signals is ready.
- ✓ The automation of the method is also ready.
- ✓ The calibration process for the loads is currently under development.
- ✓ XEMIS2 will be operational by the end of this year.
- ✓ XEMIS2 also search for the additional applications, such as MOX fuel, Proton Therapy...

THANK YOU ！