8th SYMPOSIUM ON LARGE TPCs FOR LOW-ENERGY RARE EVENT DETECTION

XEMIS: a single-phase liquid xenon TPC for 3gamma medical imaging

Lucía Gallego Manzano

6/12/2016

XEMIS: XEnon Medical Imaging System

Low activity Medical Imaging (~20 kBq)

3γ imaging

Radioisotope (β^+, γ) for functional imaging: **^{44}Sc**

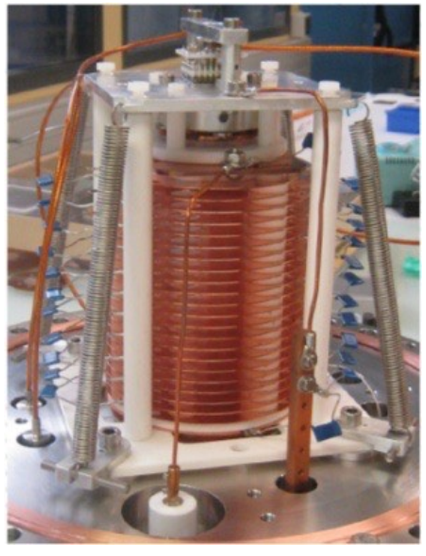
Liquid xenon Compton camera

Time projection chamber (TPC)

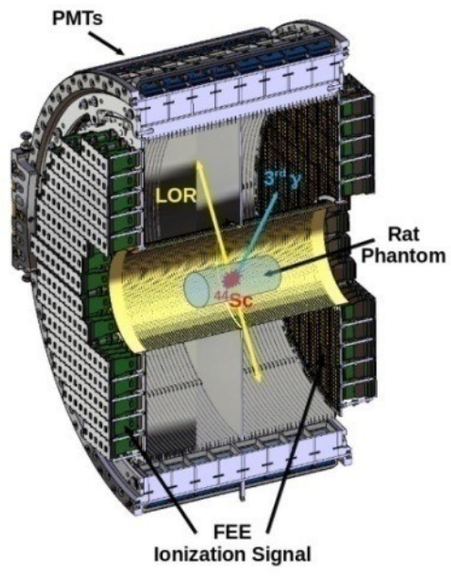
XEMIS1
R&D

XEMIS2
Small animal imaging

XEMIS3
Whole body imaging



30 kg
12 cm drift TPC



200 kg
2 x 12 cm drift TPC

From 2020

LXe clinical camera

- Neurology: ~250 kg
- Paediatrics: ~700-800 kg
- Whole body: few tons

Outline

1. 3γ Imaging

2. XEMIS1: R&D

3. XEMIS2: Small animal imaging

4. ReStoX: Recovery and Storage of xenon

5. Overview

Principle of the 3γ Compton Imaging

- Radioisotope (β^+,γ) emitter in coincidence: ^{44}Sc — β^+ (E_{max} = 1.472 MeV), γ (E_0 = 1.157 MeV), $T_{1/2}$ = 4 h

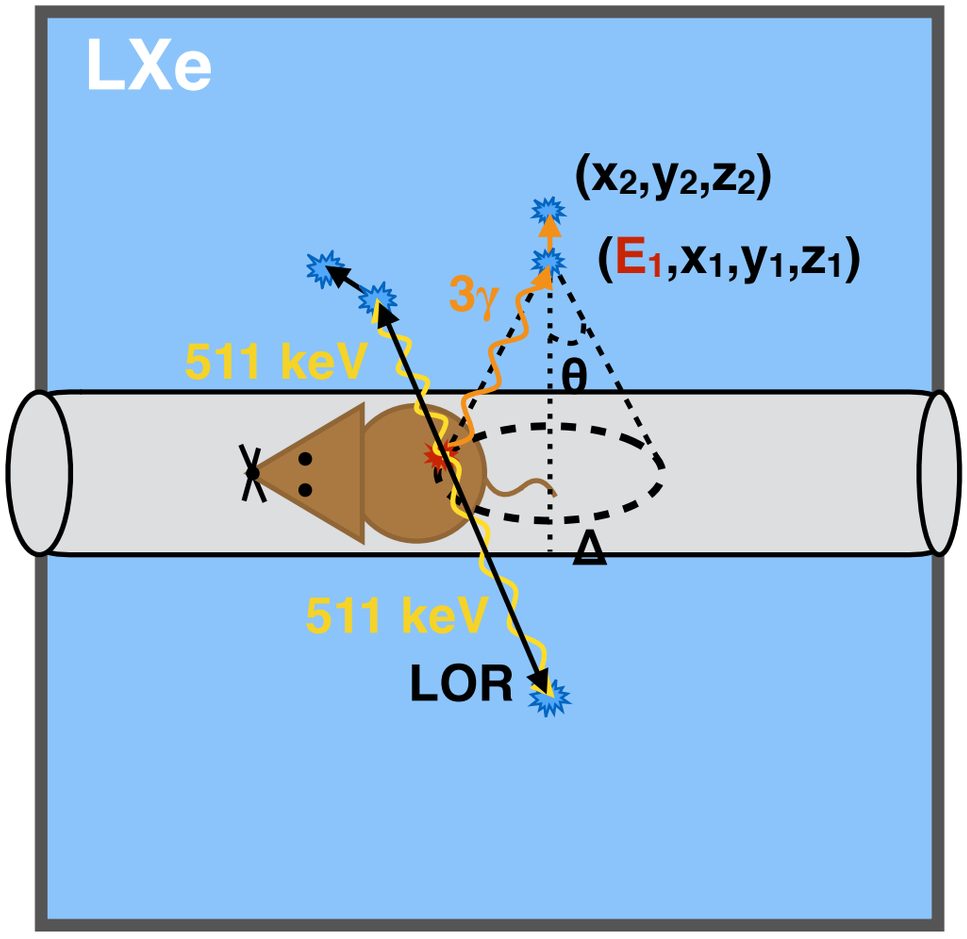
- Direct 3D reconstruction of the source:

Line of response (LOR) + Compton cone

- Reconstructed γ direction:

Compton kinematics

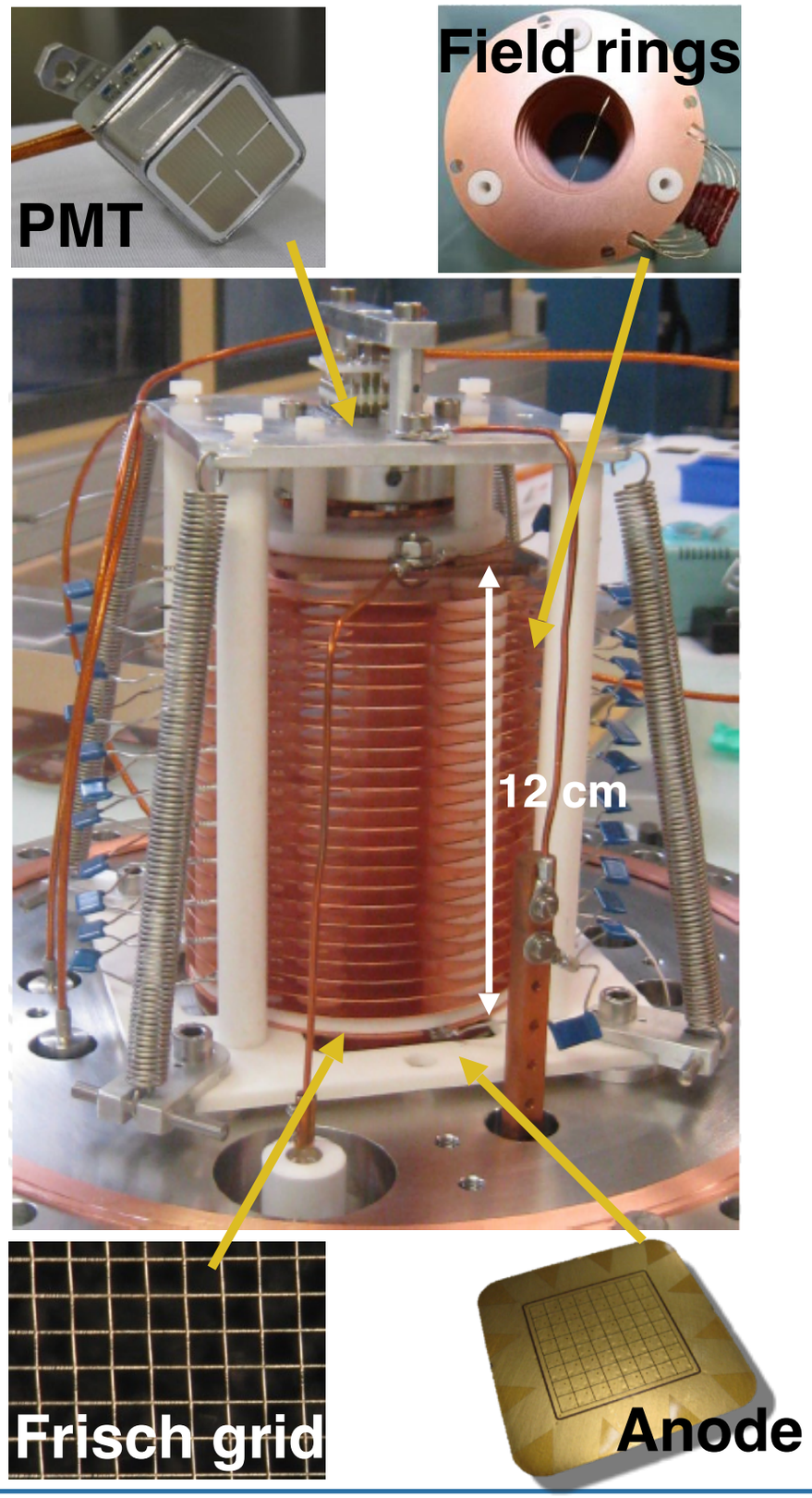
$$\cos\theta = 1 + m_e c^2 \left(\frac{1}{E_\gamma} - \frac{1}{E_1} \right)$$



Spatial resolution ⇒ axis Δ of the cone
Energy resolution ⇒ opening angle θ

- Direct 3D location of the radioactive source
- Administered dose reduction &/or shorter scan times

XEMIS: LXe Time Projection Chamber



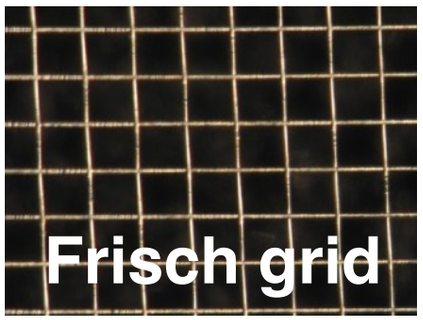
XEMIS1: R&D prototype

- 30 kg ultra pure LXe
- Active volume 12 (6) x 2.5 x 2.5 cm^3
- Field shaping rings (23)
  Homogeneous drift field up to 2.5 kV/cm
- 1” square UV sensitive PMT → Trigger
- Segmented anode (2.5 x 2.5 cm^2 active) in 64 pixels
- Frisch grid

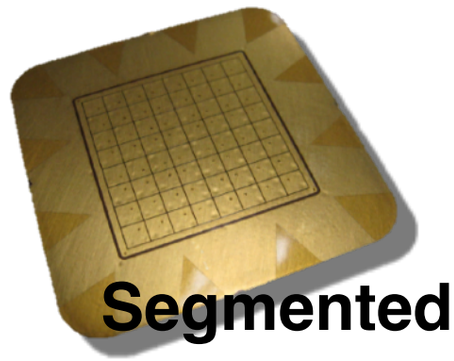
Energy + 3D Positions of each interaction

Gridded Ionization Chamber

Ionization signal affected by:



- Transparency of the grid
- Efficiency of the grid



- Small pixel effect: induction in non-collecting pixels

Grid	Pitch	Thickness	Bar thickness
500 LPI	50.8 μm	5 μm	12 μm
200 LPI	127 μm	5 μm	24 μm
100 LPI	254 μm	50 μm	25 μm
70 LPI	362 μm	5 μm	18.5 μm
50.3 LPI	505 μm	60 μm	30 μm

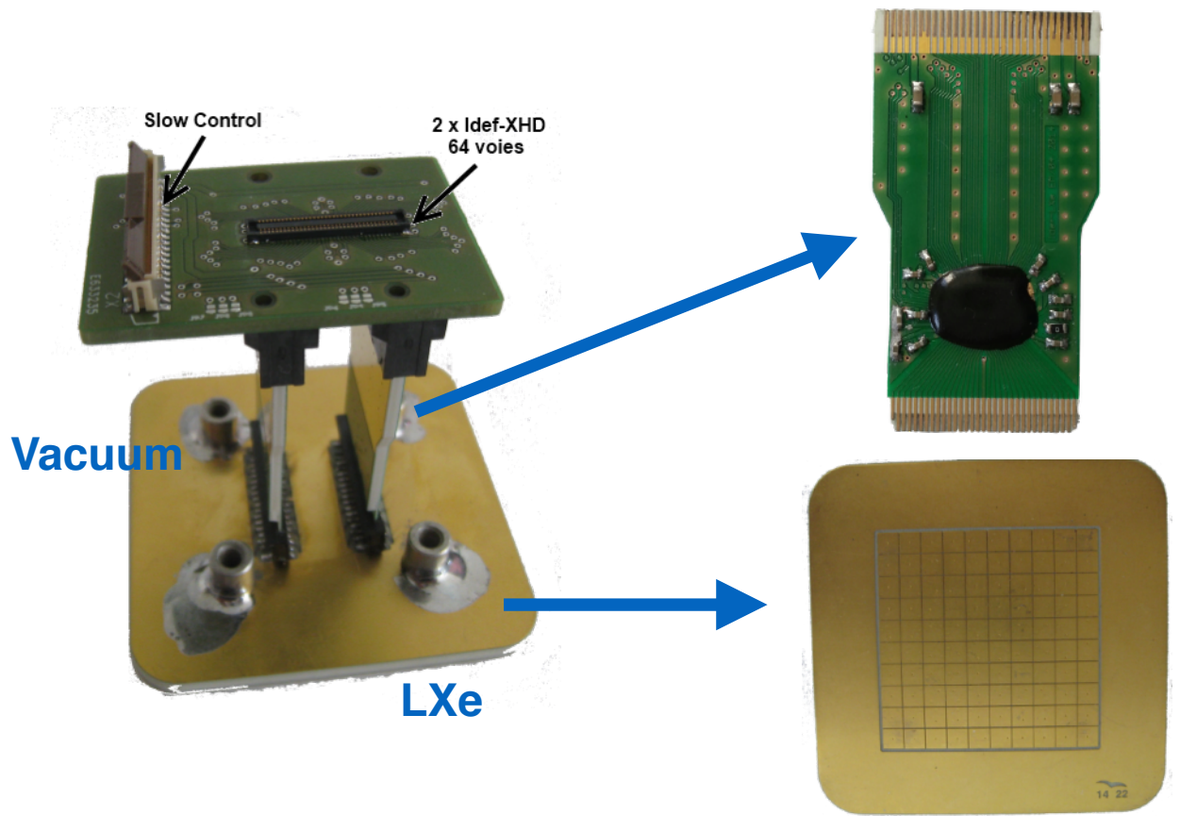
Gap grid-anode
1 mm
500 μm
125 μm

XEMIS1: Ionization Signal Readout

IDeF-X HD LXe Asics Gevin et al. 2006

Developed for CdTe @ IrFU

Adapted by Subatech for LXe



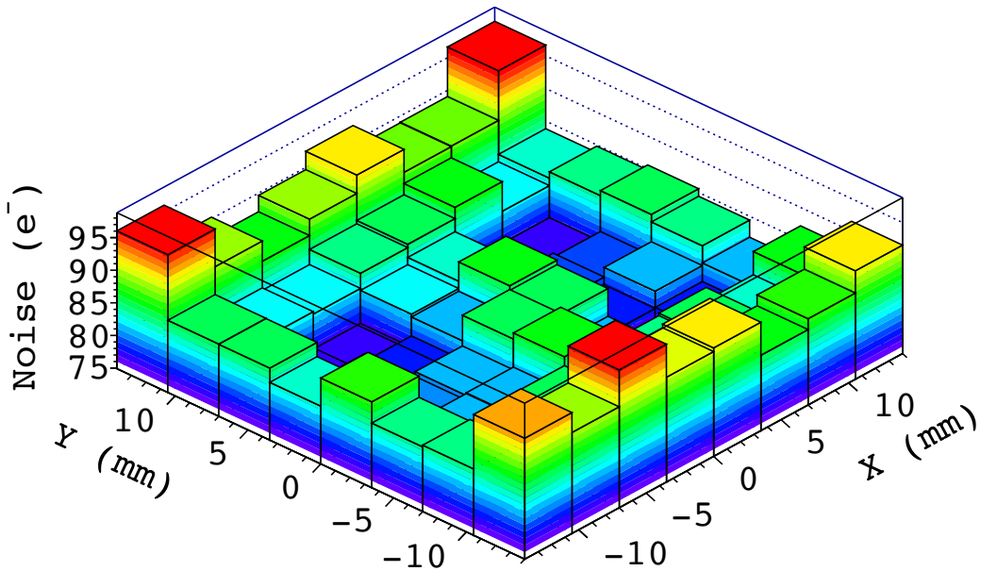
Anode 64 pixels
3.1 x 3.1 mm²

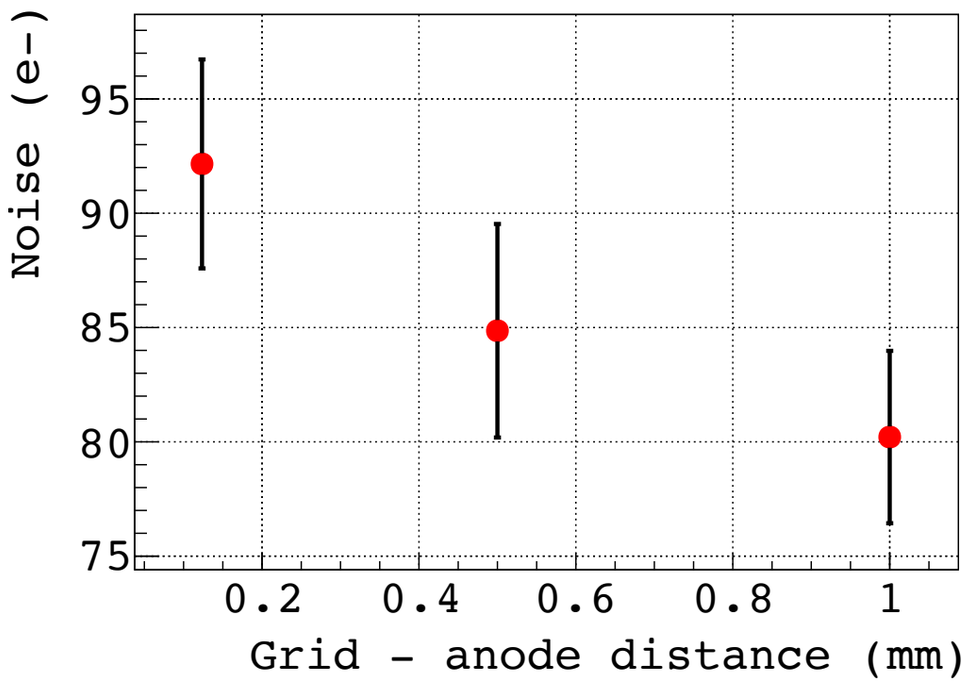
- Ultra low noise front-end electronics
- 32 channels per IDeF-X HD LXe
- Two chips → **one channel per pixel**

Good linearity and stability

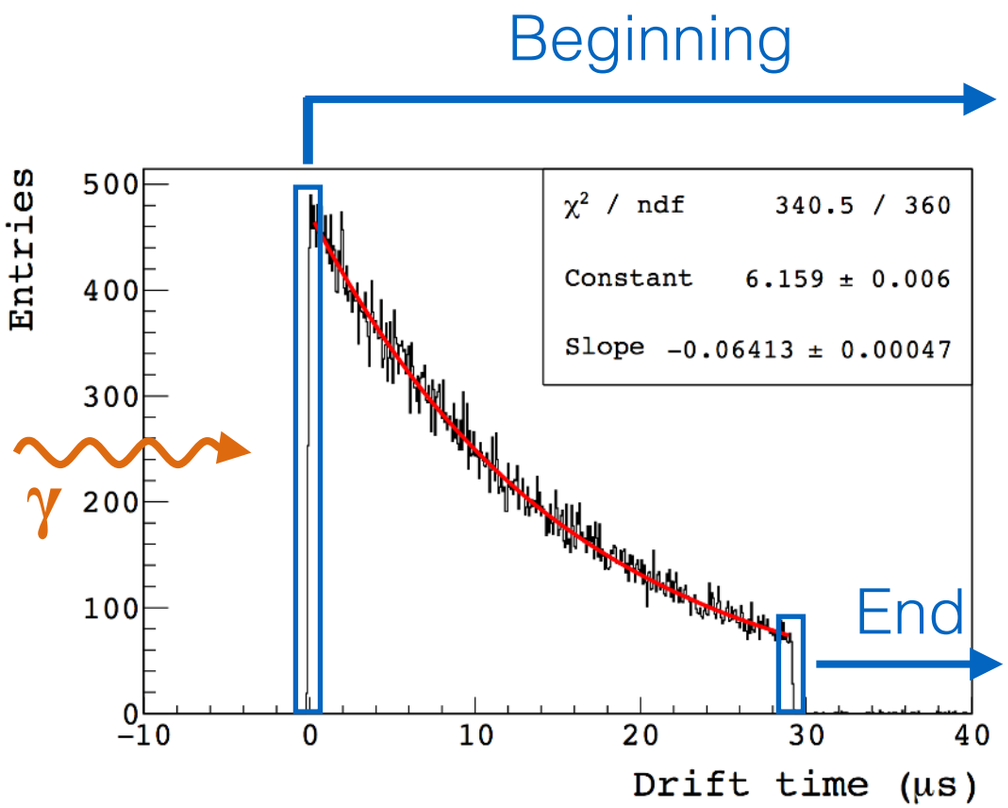
Noise < 100 e⁻ (at LXe Temp)

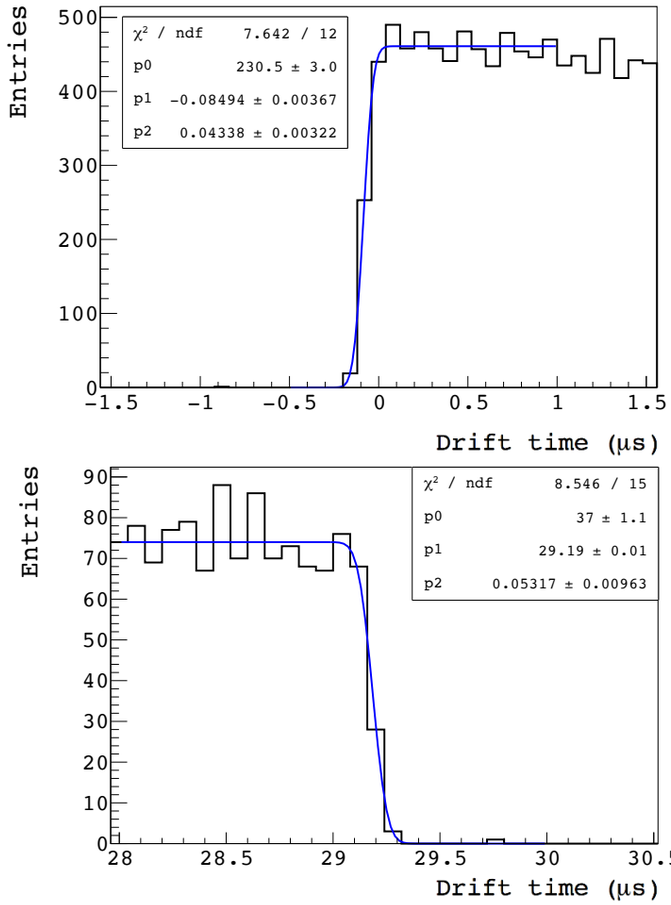
511 keV (@1 kV/cm) ⇒ 27200 e-





XEMIS1: Ionization results @511 keV

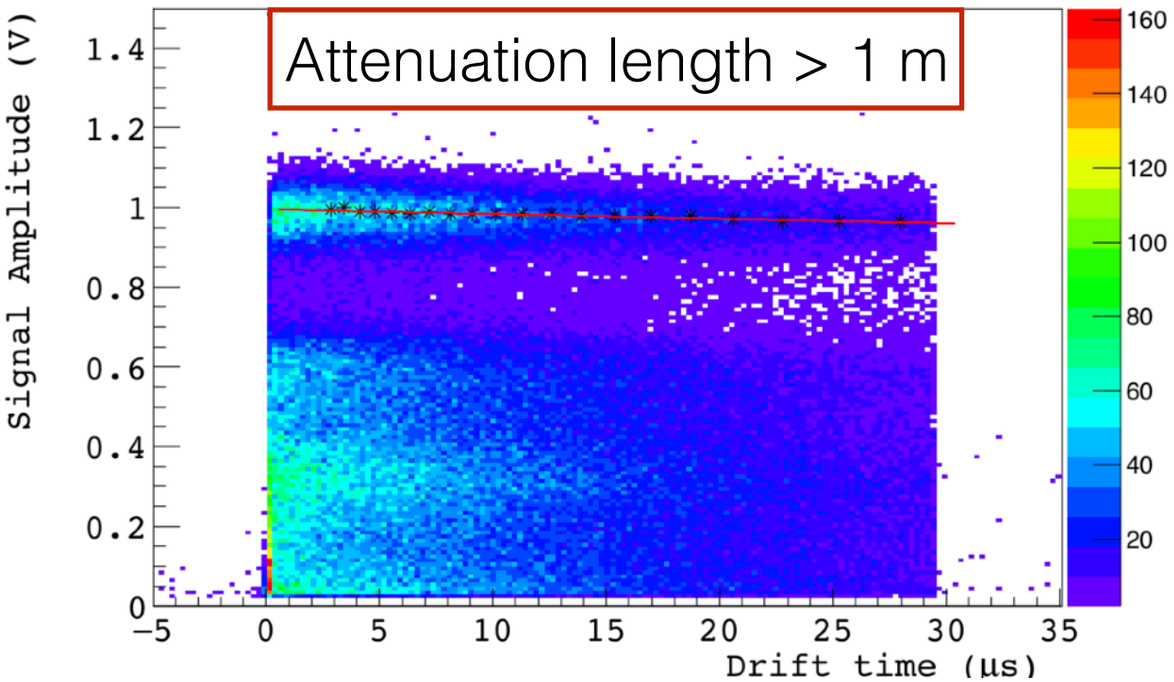


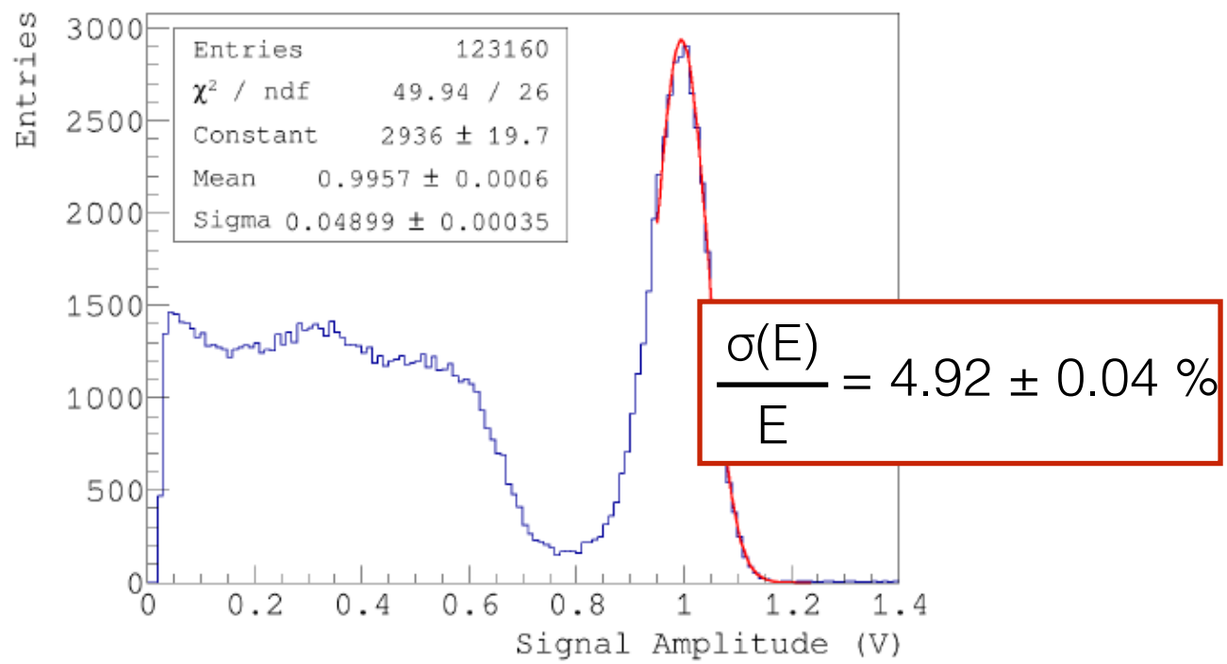


^{22}Na (20 kBq):
$E_{max}\beta+$= 545 keV, E_γ= 1.274 MeV

1 kV/cm

Drift time resolution: ~ 50 ns
DOI resolution: ~ 100 μm

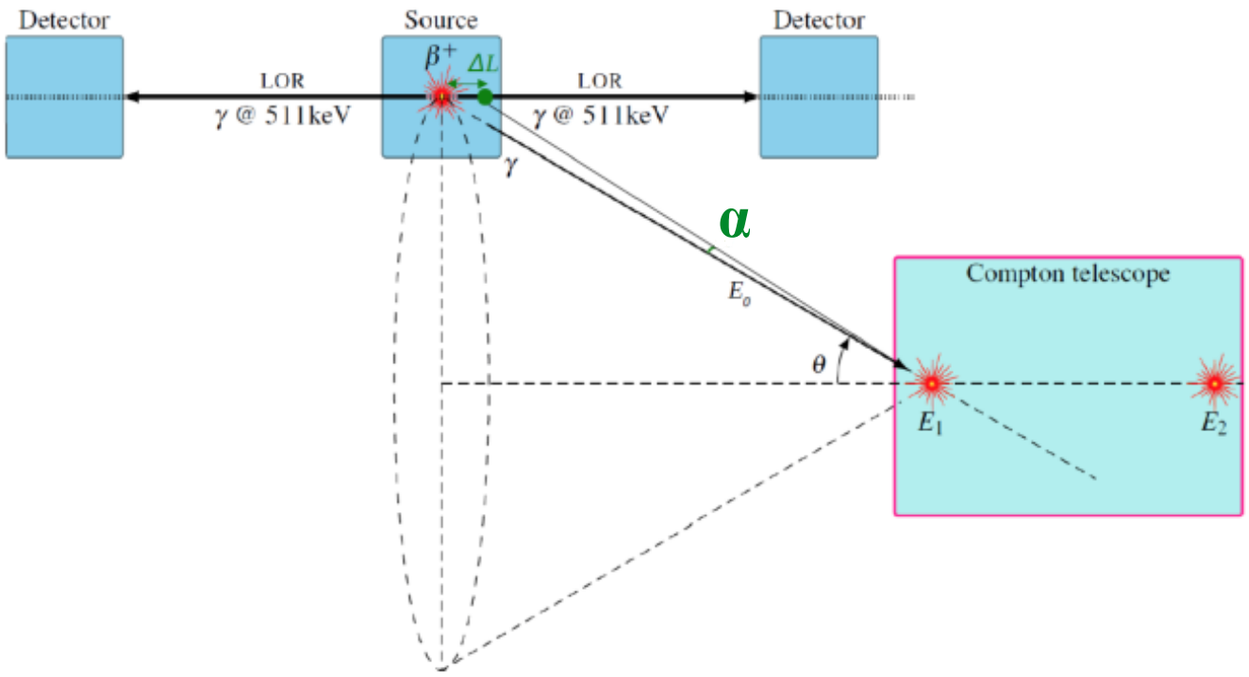




$$\frac{\sigma(E)}{E} = 4.92 \pm 0.04\ \%$$

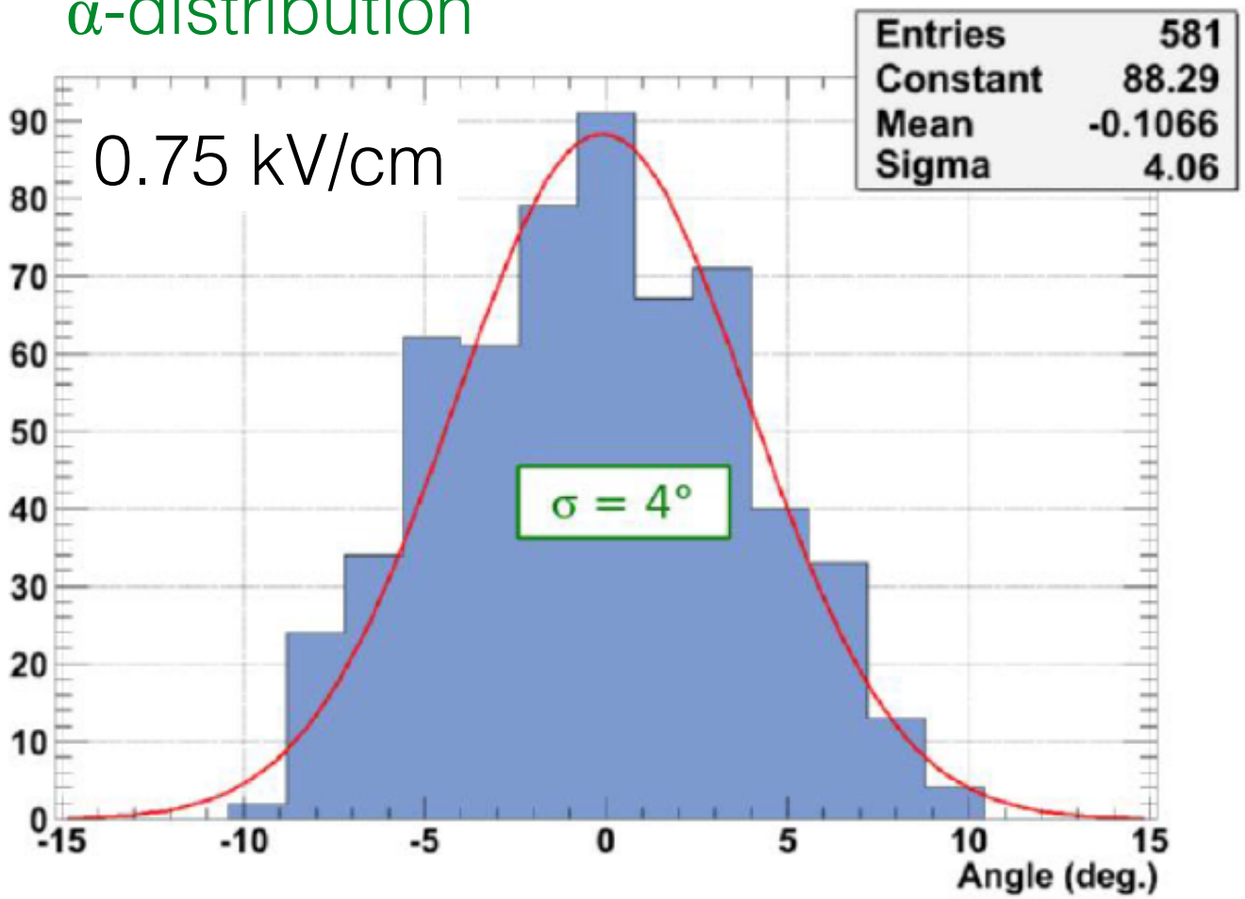
XEMIS1: Resolution along the LOR

ΔL resolution along the LOR → α



$$\cos\theta = 1 + m_e c^2 \left(\frac{1}{E_\gamma} - \frac{1}{E_1} \right)$$

α-distribution



Gallego et al., NIMA (2015)

- Angular resolution limited by active area of XEMIS1
- Improvement expected at higher electric field
- XEMIS2 is the key

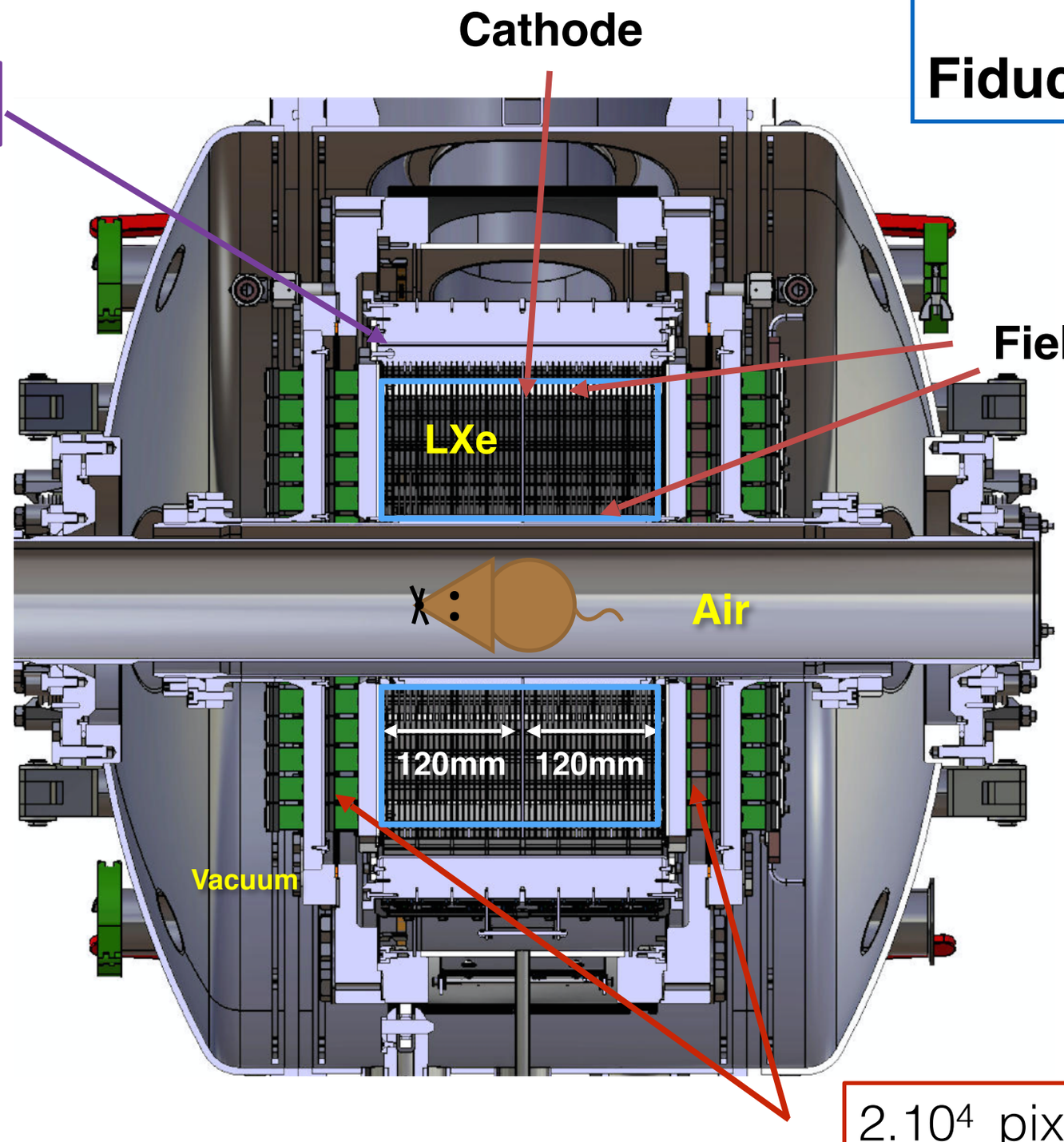
Equivalent to ΔL = 8.2 mm (FWHM) for a 5 cm distant source

XEMIS2

LXe: 200 kg
Fiducial volume ~24 L

Scintillation

380 x 1” PMTs in LXe



High Purity LXe
at 1.2 bar (168 K)

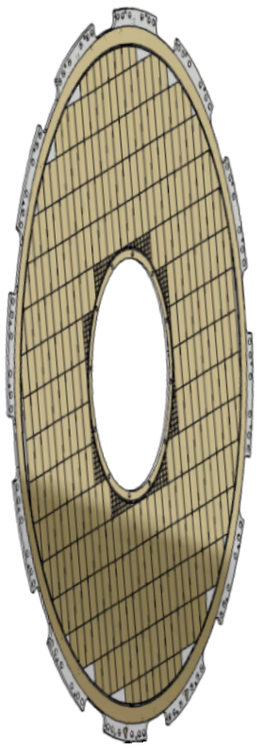
LXe TPC

Active volume
- axial : 2 x 12 cm
- depth : 12 cm
- r_{min} : 7 cm

Ionization

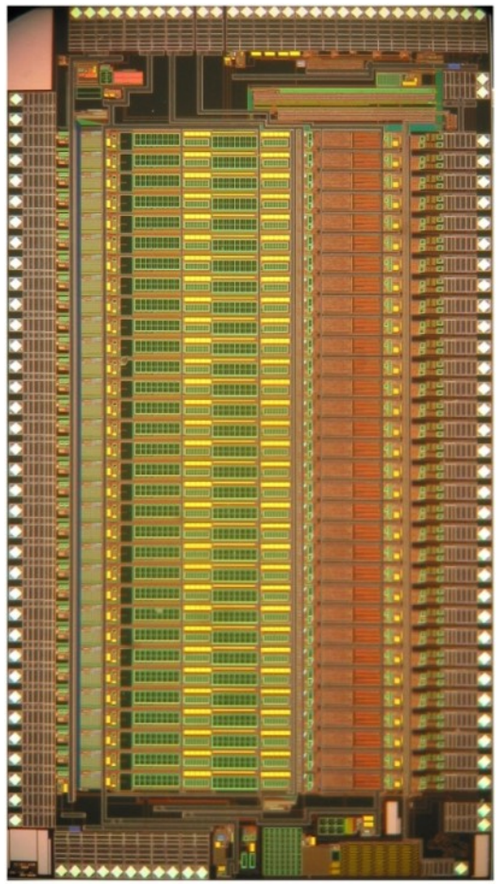
2.10^4 pixels - 3.1 x 3.1 mm^2
Ultra low noise FEE

XEMIS2: Ionization Signal Readout



32 x Pixels

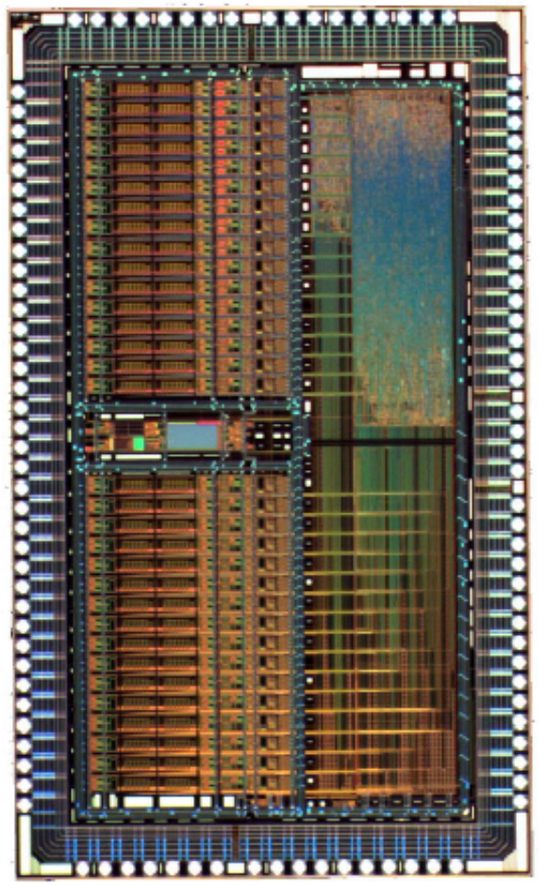
IDeF-X HD_LXe
Imaging **De**tector **F**ront-end



IRFU - SUBATECH

x32

XTRACT: Xemis **T**PC **R**eadout for **A**cquisition of **C**harge and **T**ime



Amplitude

Time

Address

Trigger

Read

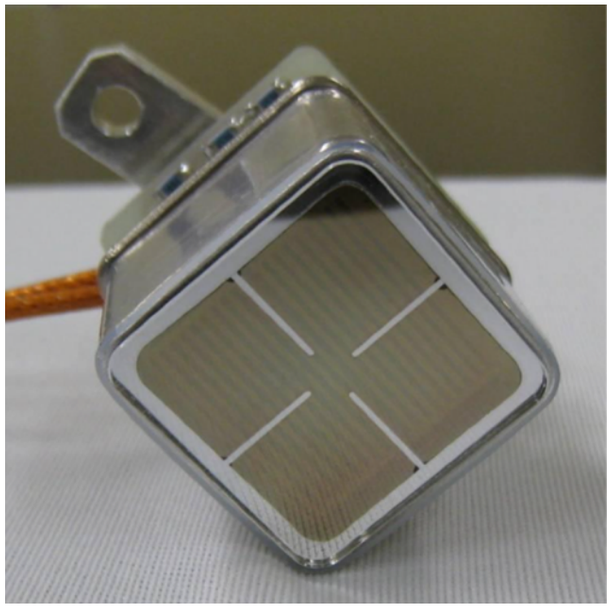
MICHRAU - SUBATECH

~20000 electronic channels
Challenge: continuous read-out with negligible dead-time

XTRACT v1 is on test since summer 2016. Final version expected for 2017

XEMIS2: Light Signal

Hamamatsu R7600 1” PMT



- Used as time measurement for the charge signal readout and interaction volume determination
- Developed to work at LXe temperature
- **Phase 1: 64** x 1” PMTs inside LXe covering 8 sectors in Φ
- **Future upgrade: 380** x 1” PMTs → complete coverage of the active zone

XEMIS2: Recovery and Storage of Xenon

ReStoX:
Recovery and **St**orage system **o**f **X**enon

- Double walled vacuum insulated stainless steel cryostat
- Compact (210 kg capacity)
  - storage
  - distribution
  - recovering
- Safe
  - from room temp. to -110 °C
  - 71 bar design pressure
- Ultra pure LXe at 1.2 bar
  - ppb impurities level

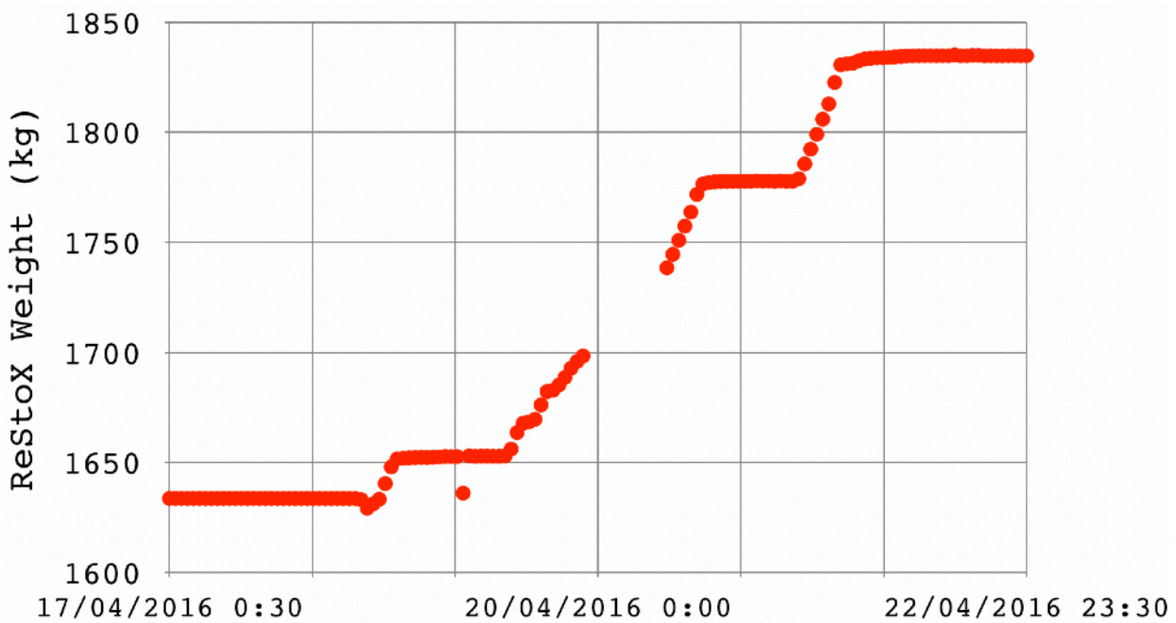
AIR LIQUIDE ADVANCED BUSINESS & TECHNOLOGIES

Subatech

XEMIS2: Recovery and Storage of Xenon

Liquid nitrogen cooling system

5000 L LN_2 at 3 bar abs



Successful injection & liquefaction of 200 kg of xenon inside ReStoX

Nitrogen line

Aluminium Exchanger

High thermal inertia

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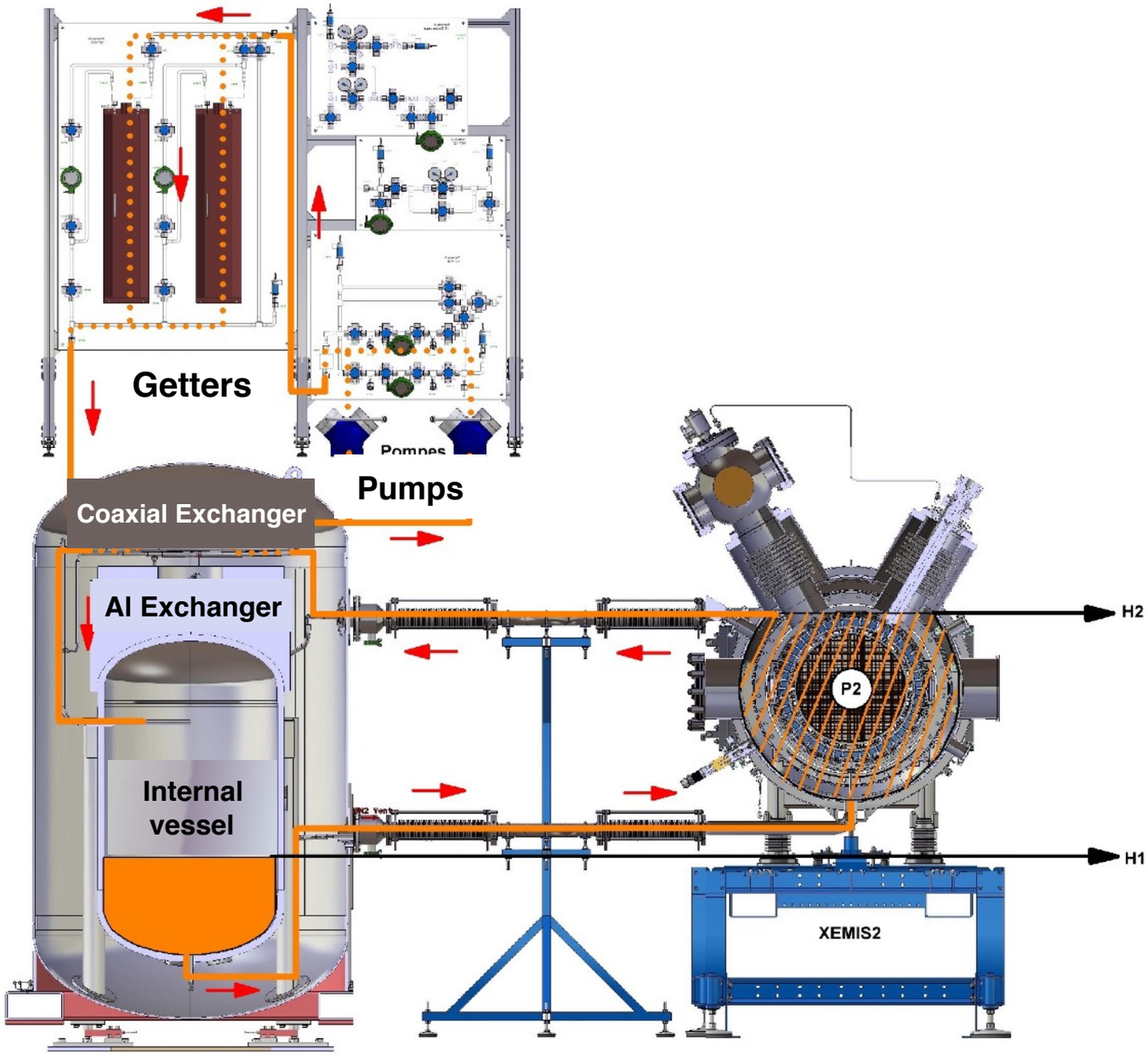
Subatech

XEMIS2: purification and re-circulation

Closed loop

Reversible transfer ReStoX - XEMIS2

- LXe injection from ReStoX to XEMIS2
- Purification & circulation: 30 Nl/min
- Recovery from XEMIS2 to ReStoX



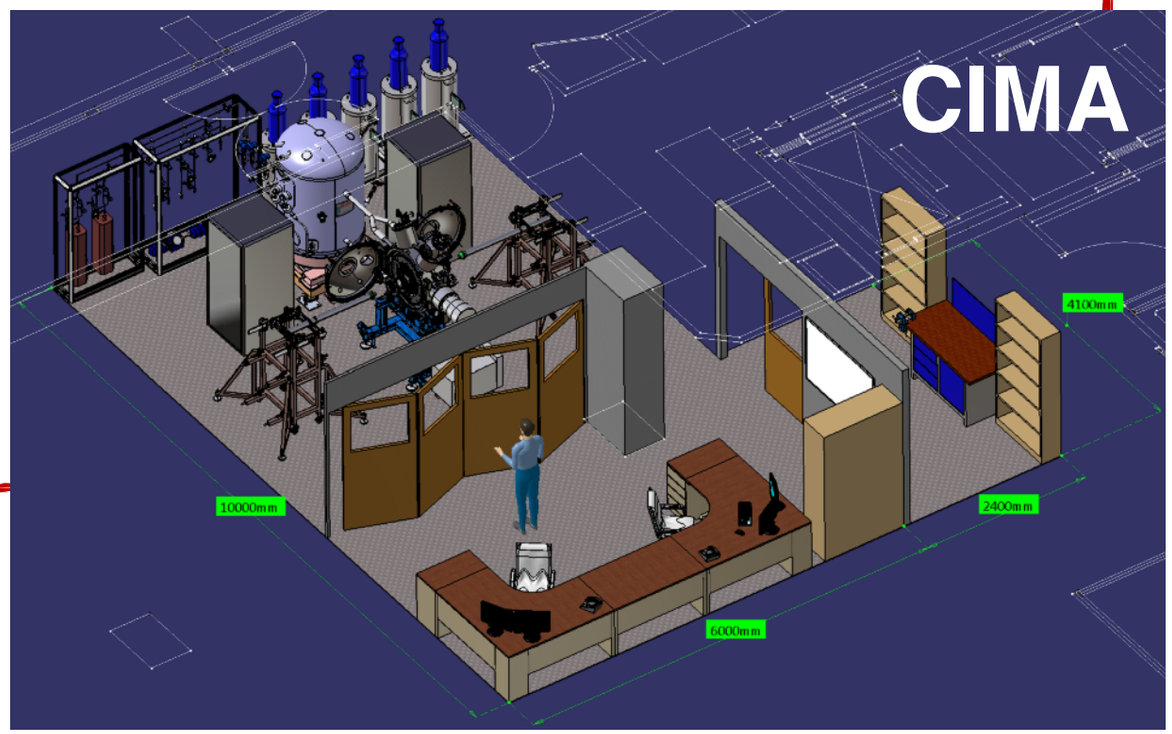
Conclusion

“Technical” proof of the XEMIS project feasibility

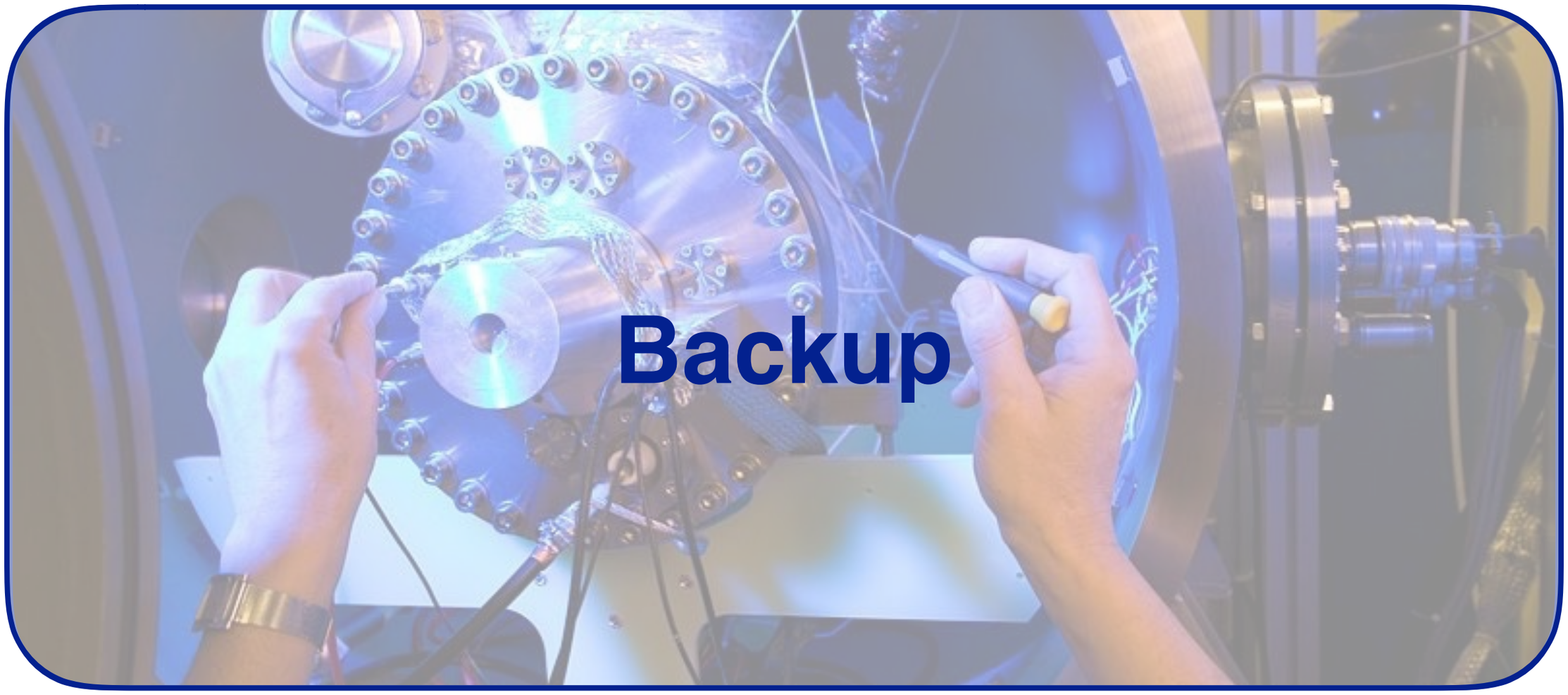
- Validation thanks to the XEMIS1 prototype
- Promising results for the 3γ imaging technique
- Development of new technologies & fundamental research

Small animal imaging prototype XEMIS2

- Commissioning at Subatech: 2016
- Installation at Nantes Hospital: 2017
- First 20 kBq image: 2017
- Preclinical researches: til 2020



Thank you for your attention

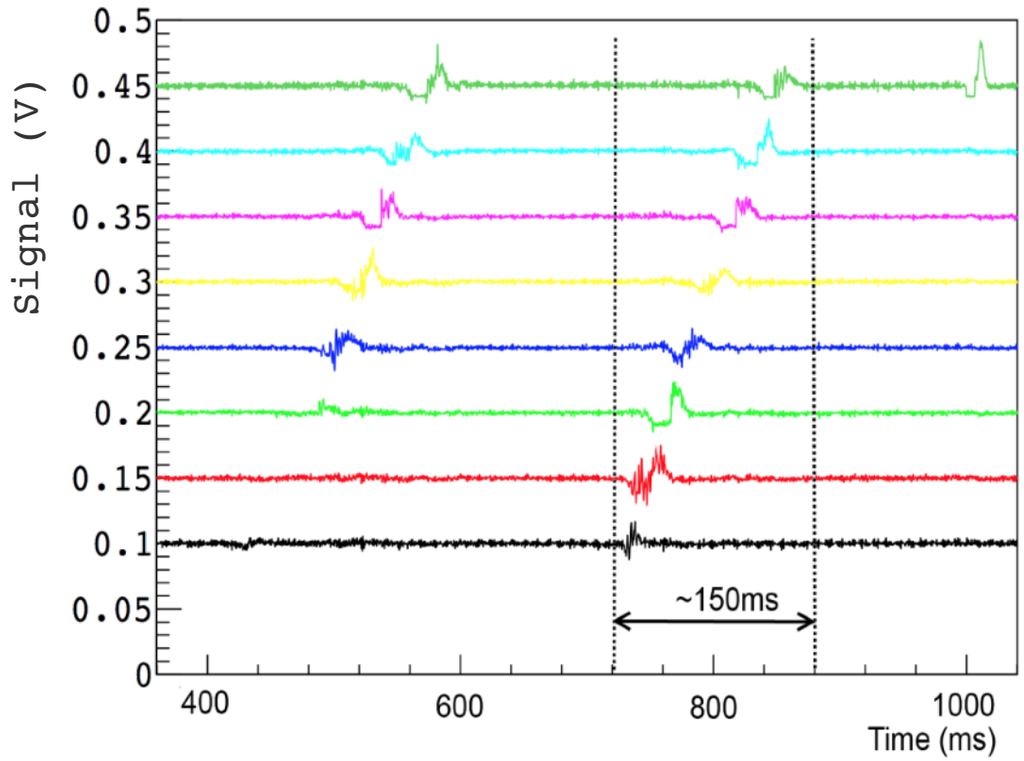


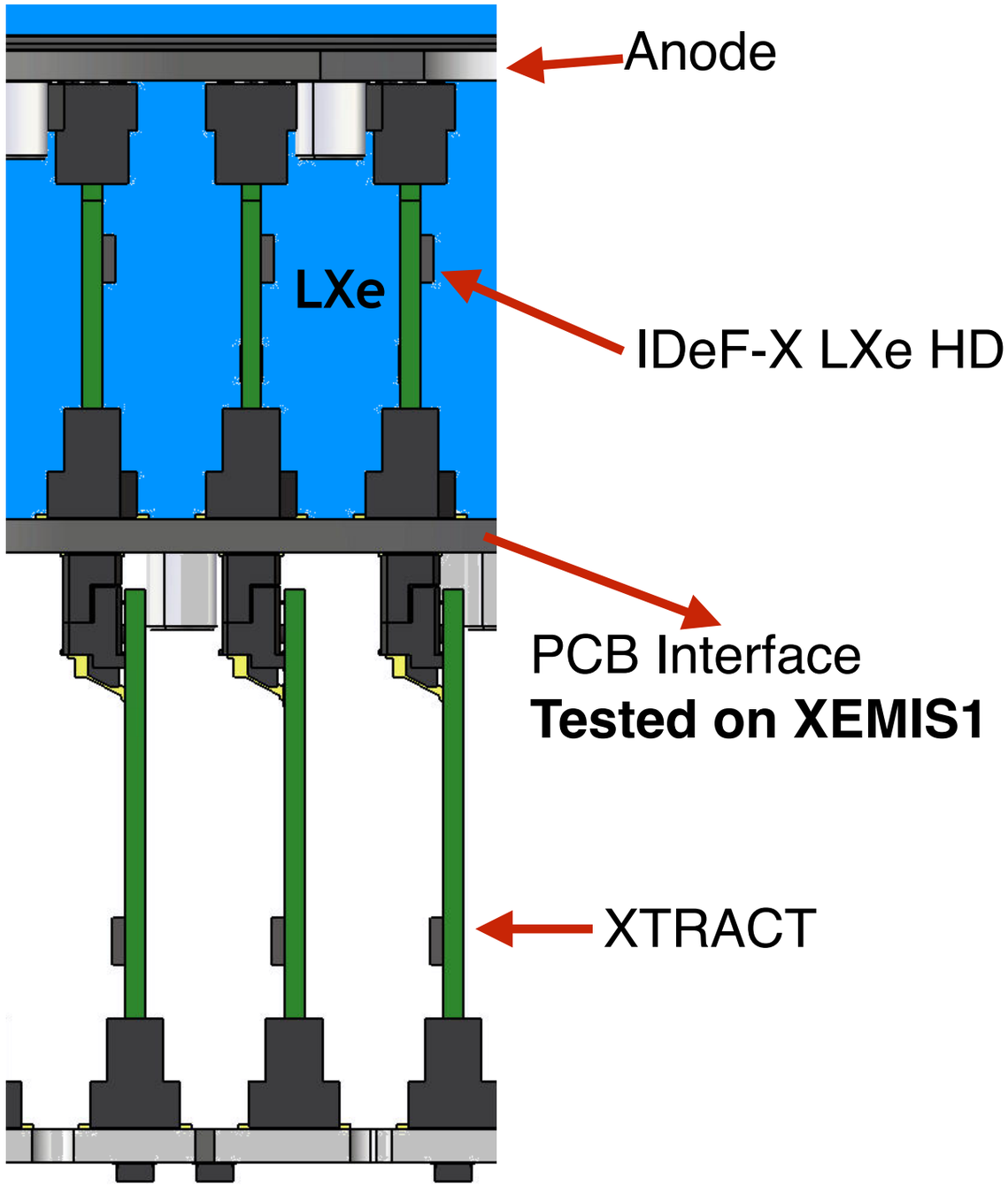
Backup

IDeF-X – XTRACT Coupling

Reduce presence of bubbles in the LXe:

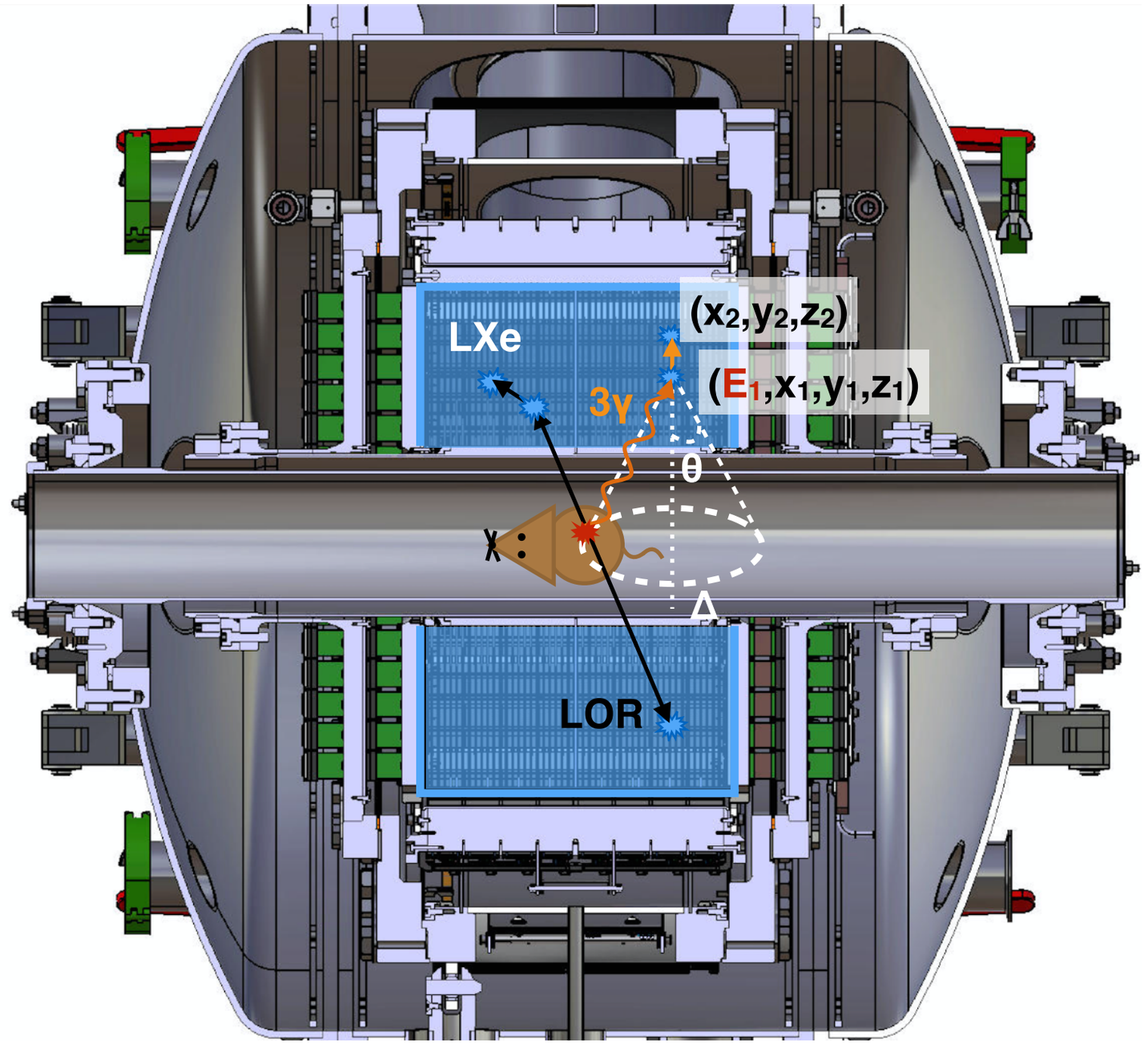
- IDeF-X Cooling with LXe
- XTRACT Cooling by conduction





3γ Imaging with XEMIS

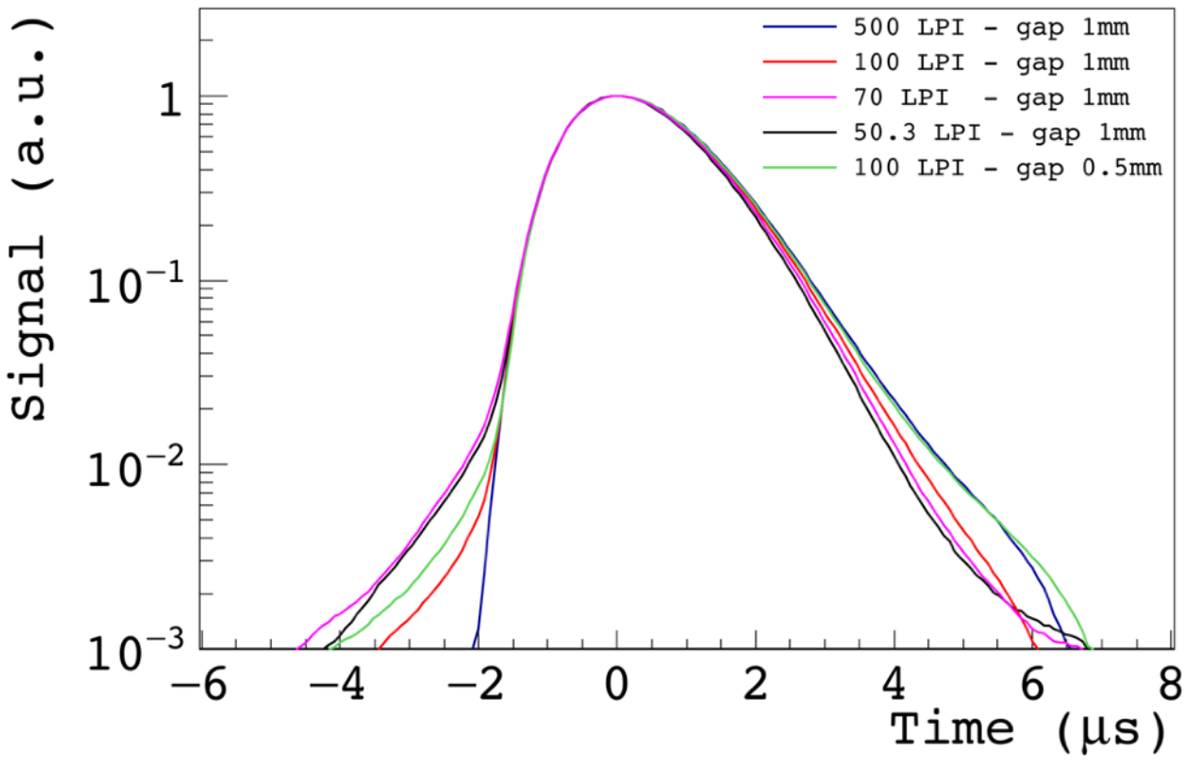
XEMIS2: A monolithic LXe cylindrical camera for small animal 3γ Compton imaging



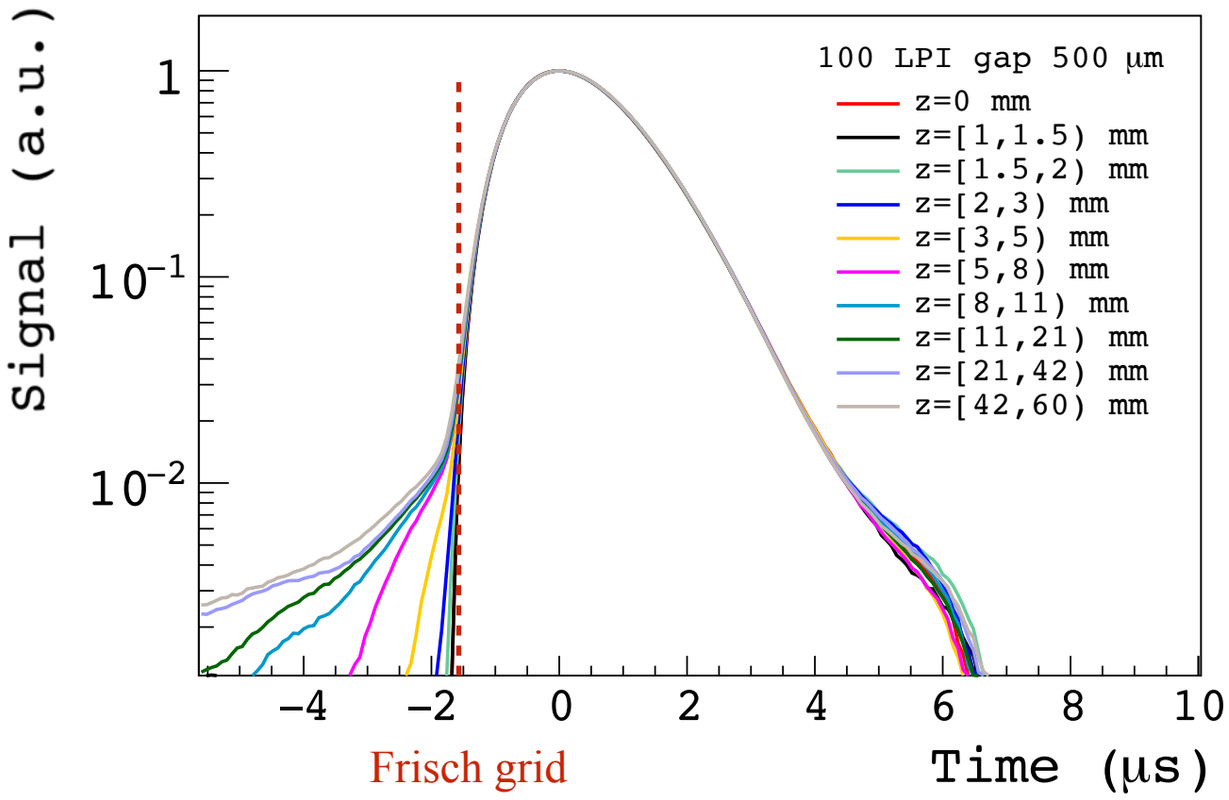
Frisch Grid Inefficiency & Ballistic Deficit

2. Frisch grid Inefficiency:

Signal depends on the type of grid



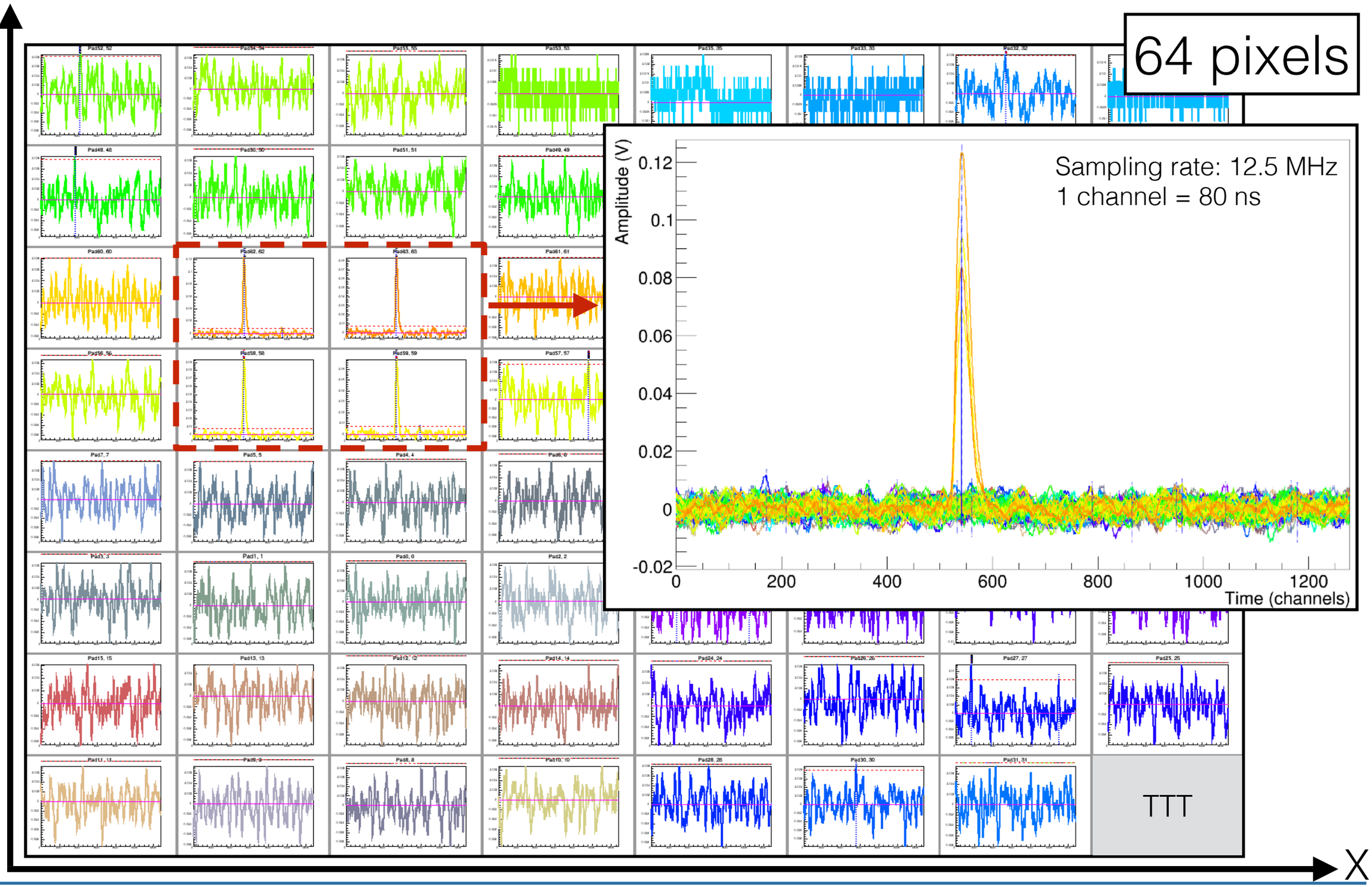
Signal depends on the position of the interaction



Grid	Pitch	Thickness
500 LPI	50.8 μm	5 μm
100 LPI	254 μm	50 μm
70 LPI	362 μm	5 μm
50.3 LPI	505 μm	60 μm

Event Topology @ 511 keV

Event reconstruction: Compton scattering/**photoelectric effect** identification



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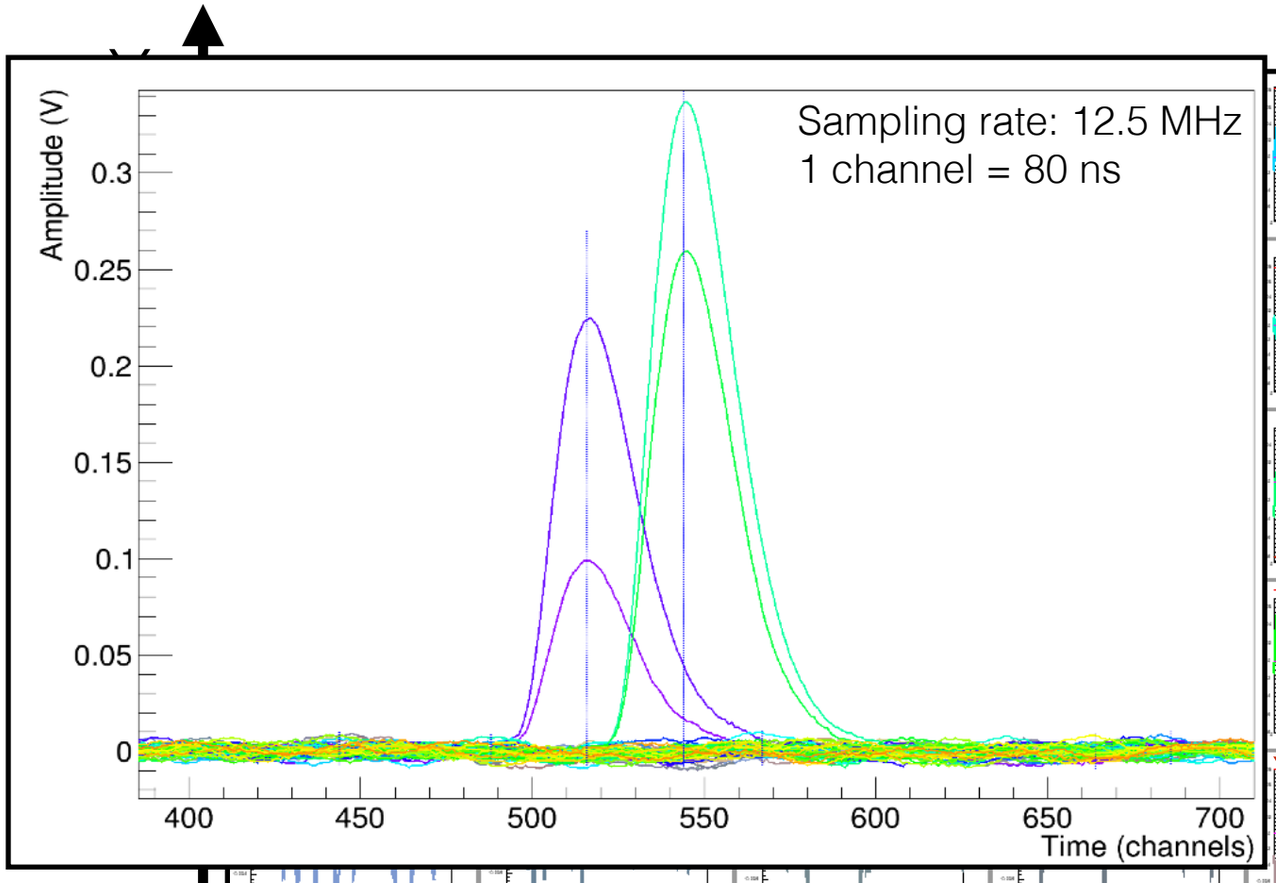
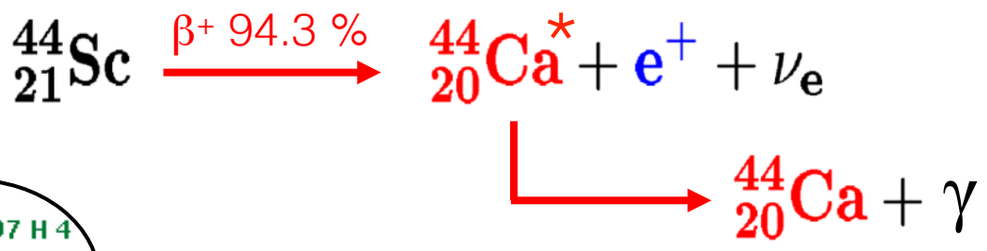
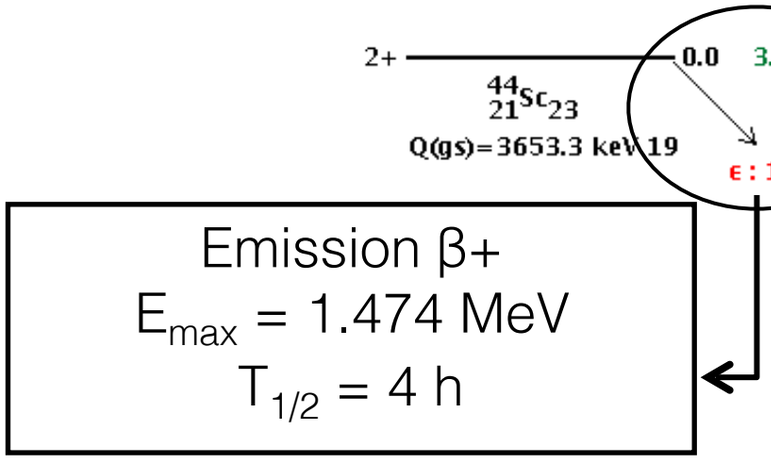


Scandium-44

Good **β+ / γ** emitter radionuclide for 3γ medical imaging: **^{44}Sc**

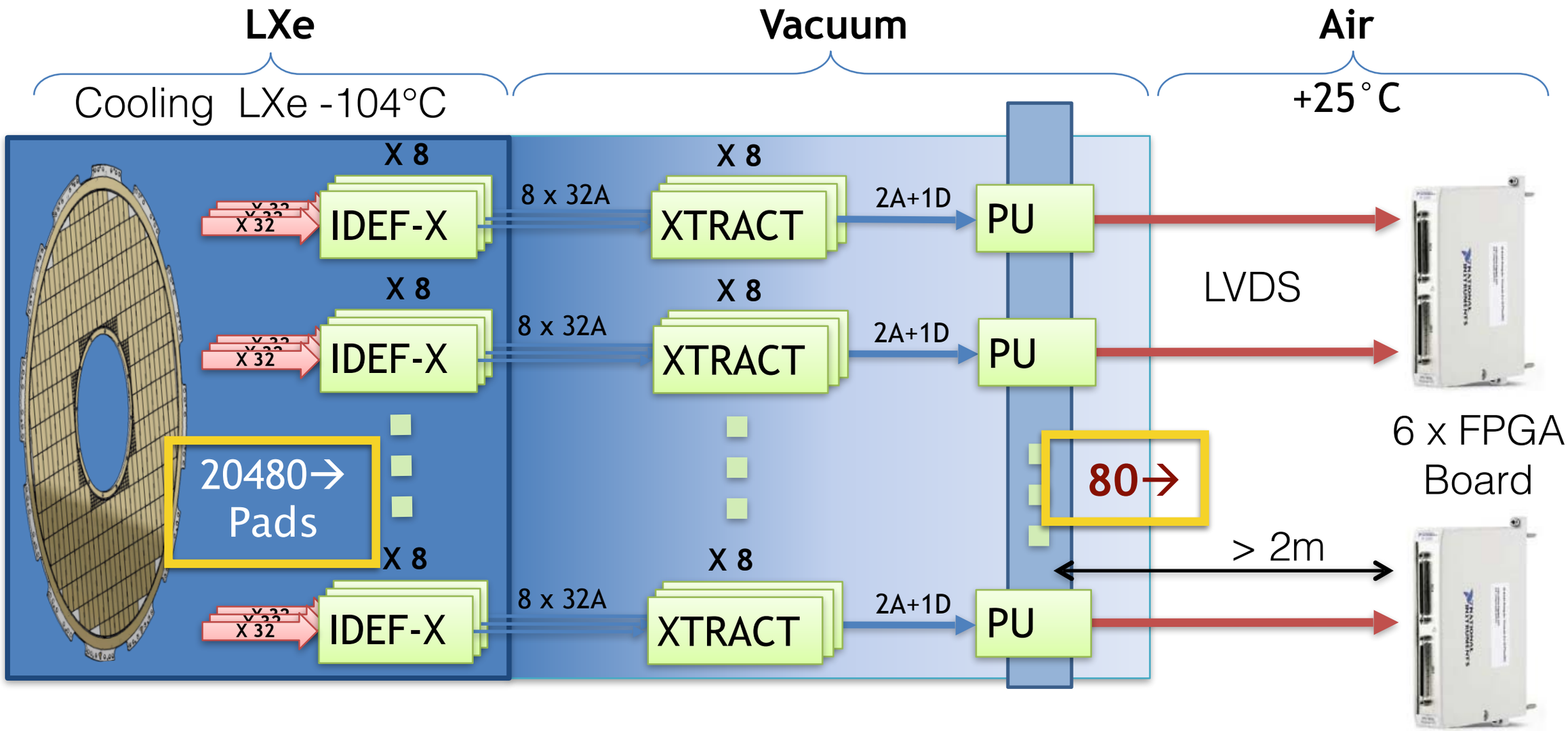




~100% emission of a
1.157 MeV γ

R&D {
- ^{44}Sc production: ARRONAX cyclotron
- Radiopharmaceutical labeled with ^{44}Sc: CRCNA

XEMIS2: Ionization Signal Readout



640x IDeF-X
(32W) 50mW/chip
T_{Idef-X} = -100°C

640x XTRACT
(32W) 50mW/Chip
T_{Xtract} > -80°C

80 x PU
(40W) 500mW/PU
T_{PU} > -40°C