GROUPE XENON

Subatech

Mi2b

GDR MI2B Assemblée Générale

6-7 Décembre 2017

Université Caen-Normandie

MP XEMIS2: Liquid Xenon Compton Camera for 3γ medical imaging

Dominique THERS on behalf of XEMIS project

Subatech (IMT-Atlantique, In2p3/CNRS, Nantes University)

AIR LIQUIDE

Instituts thématiques Inserm Institut national de la santé et de la recherche médicale

CENTRE HOSPITALIER UNIVERSITAIRE DE NANTES

ANR

IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom

cnrs

UNIVERSITÉ DE NANTES

INSTITUT NATIONAL DU CANCER

Nantes Métropole

Région PAYS DE LA LOIRE

Cancéropôle Grand ouest

MICRHAU

XEMIS: XEnon Medical Imaging System

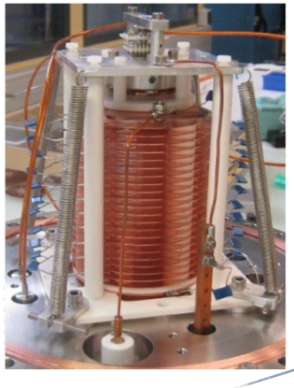
Motivation: Personalized Medicine

↪ Concept: Low activity medical imaging (~ 20 kBq)

↪ Principles:

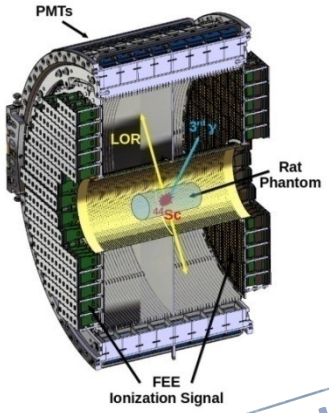
- 3γ imaging: (β^+, γ) emitter for functional imaging, e.g. **^{44}Sc**
- Liquid xenon Compton telescope: Time projection chamber (TPC)

XEMIS1	XEMIS2	XEMIS3
R&D	Small animal imaging	Whole body imaging



30 kg

DONE



200 kg

Underway

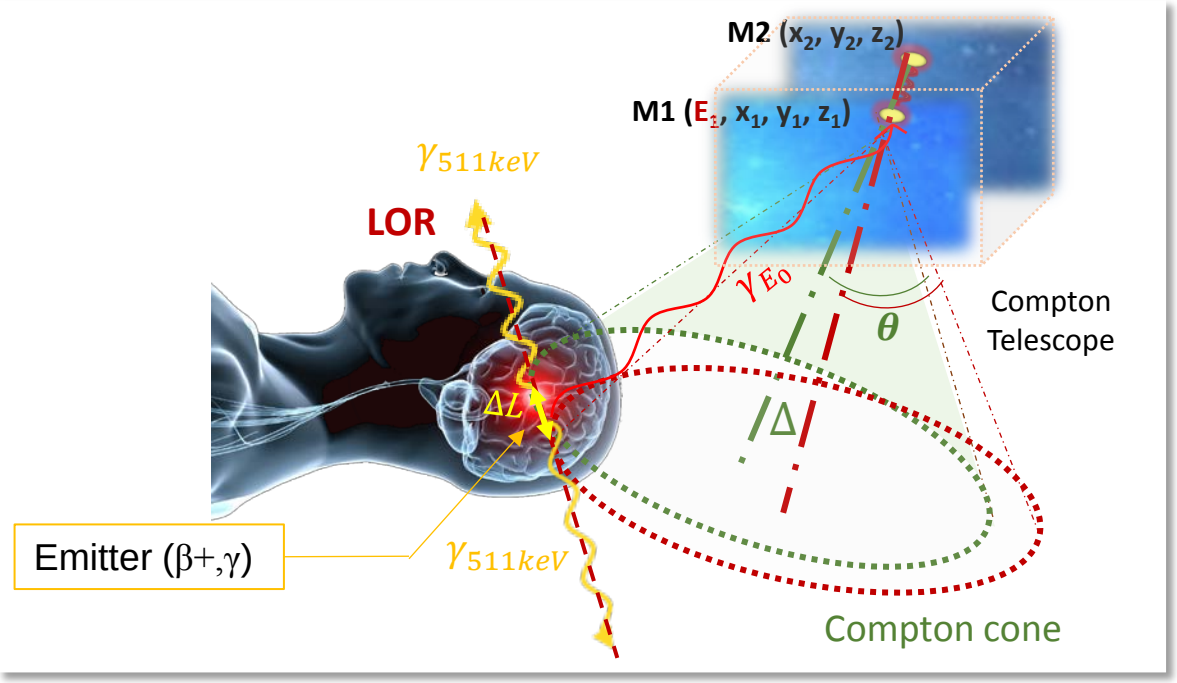
LXe clinical camera

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

Future

3γ Compton Imaging

- Direct 3D location of the radioactive source: res. along LOR ~ 1 cm (FWHM)
- Administered activity reduction &/or shorter scan times: 100 times less



- Position of the source:

↪ Line of Response (LOR) & Compton Cone

- γ direction reconstruction :

↪ Compton kinematics

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

Spatial Resolution
↪ Axis of the cone **Δ**
Energy Resolution
↪ Opening angle θ

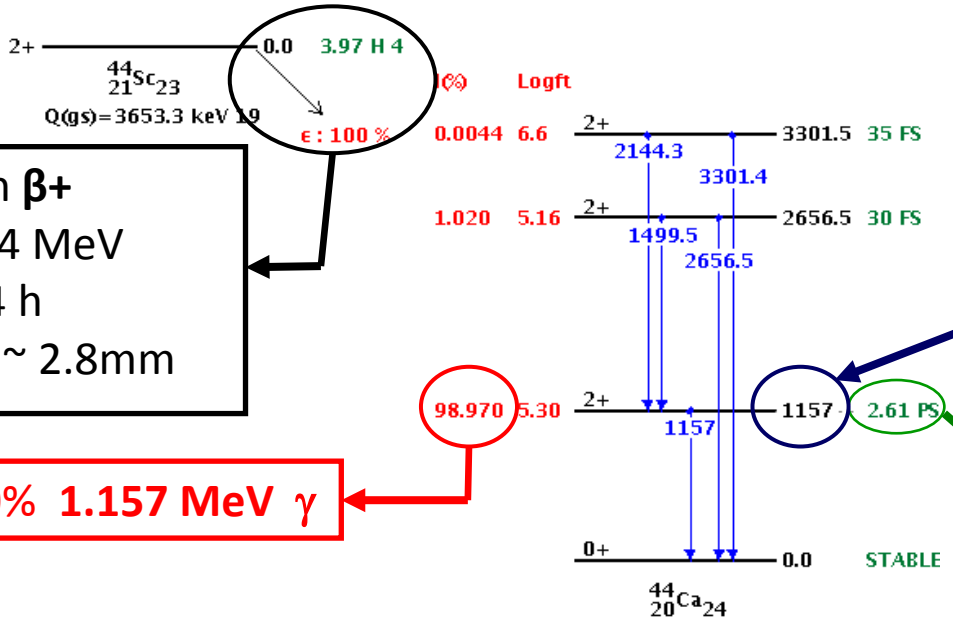
Both new radiopharmaceutical and new camera technology !

3γ imaging with ^{44}Sc

^{44}Sc is the best candidate

$$^{44}_{21}\mathrm{Sc} \xrightarrow{\beta^+\ 94.3\ \%} {}^{44}_{20}\mathrm{Ca}^* + e^+ + \nu_e$$

$$^{44}_{20}\mathrm{Ca}^* \rightarrow {}^{44}_{20}\mathrm{Ca} + \gamma$$



Emission **β+**

E_{max} = 1.474 MeV

$T_{1/2}$ = 4 h

Range in H_2O ~ 2.8mm

B.R. ~ 100% **1.157 MeV** γ

Good for Compton imaging

Fast emission
Precise time coincidence

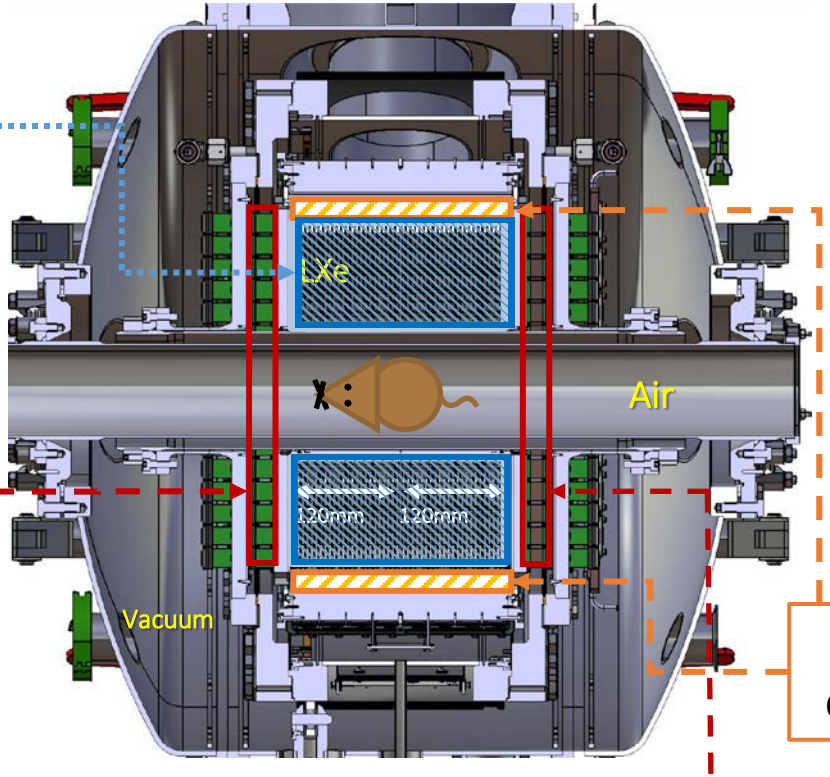
- **Production: ARRONAX** cyclotron
- **Radiopharmaceutical : CRCINA/INSERM**

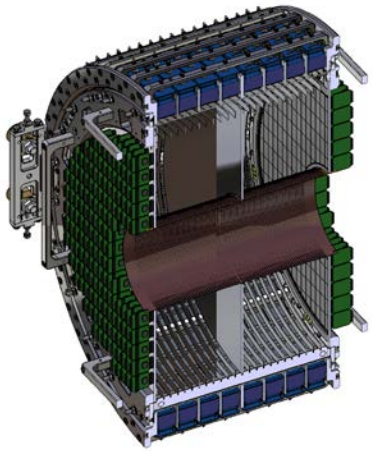
Ready for tests with [^{44}Sc]-DOTA

XEMIS2: Small Animal Imaging Camera

LXe TPC

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





Ionization

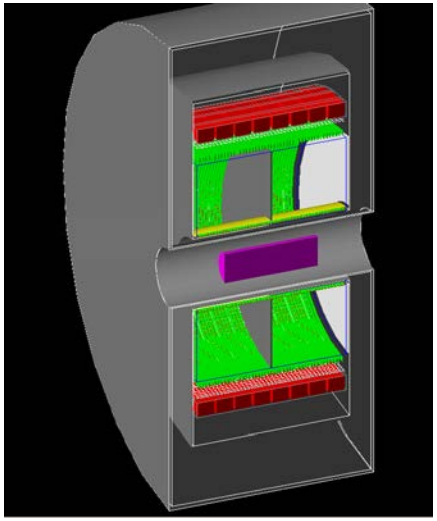
2 x 10^4 3.1 x 3.1 mm^2 pixels with ultra-low noise cold FEE

Scintillation

64 x 1'' PMTs in LXE covering 16 sectors in ϕ

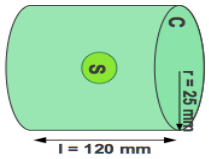
High Purity LXe
at 1.2 bar (168 K)
LXe: 200 kg
Fiducial volume ~24 L

XEMIS2: Simulation / 3γ Image reconstruction



MOUSE PHANTOM

- **Cylinder:**
  - **radius = 2.6 cm**
  - **length = 12 cm**
- **Sphere:**
  - **radius = 5 mm**



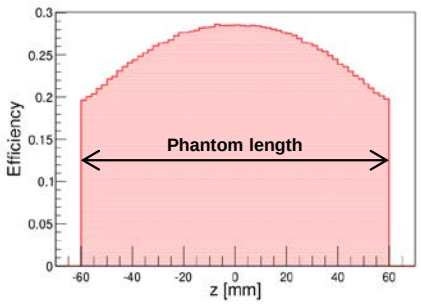
SOURCE

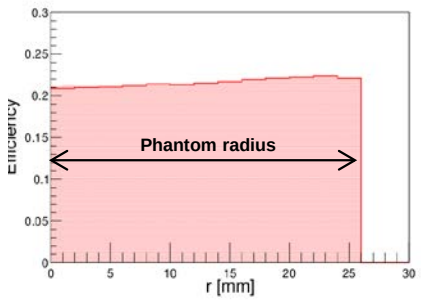
- ^{44}Sc
- **Total: 20.0 kBq**
- **Hot Sphere: 0.5 kBq**

Contrast = 15

Detectable Event Fraction

Quite uniform response of the detector!

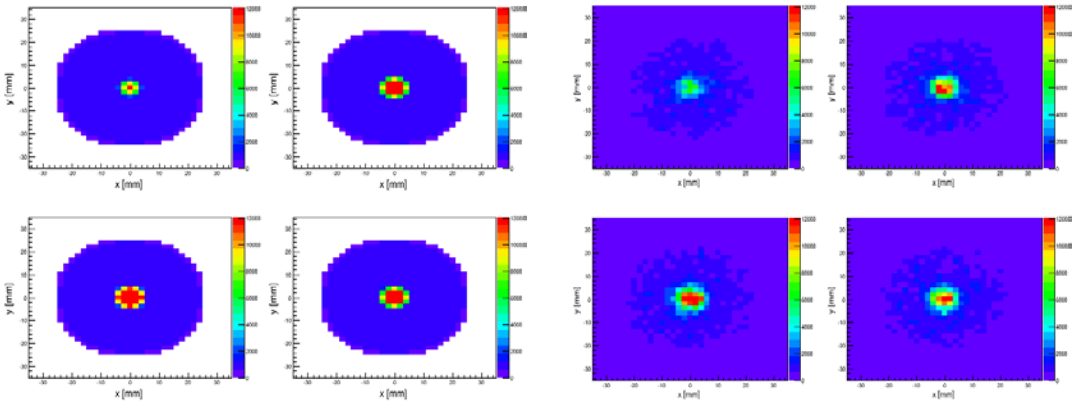




XEMIS2 expected image 20 kBq, 20 mns

Simulated true distribution

Reconstructed image



Expected resolution: [2-3 mm] all over the field of view

Ready with a lot of works for the future …

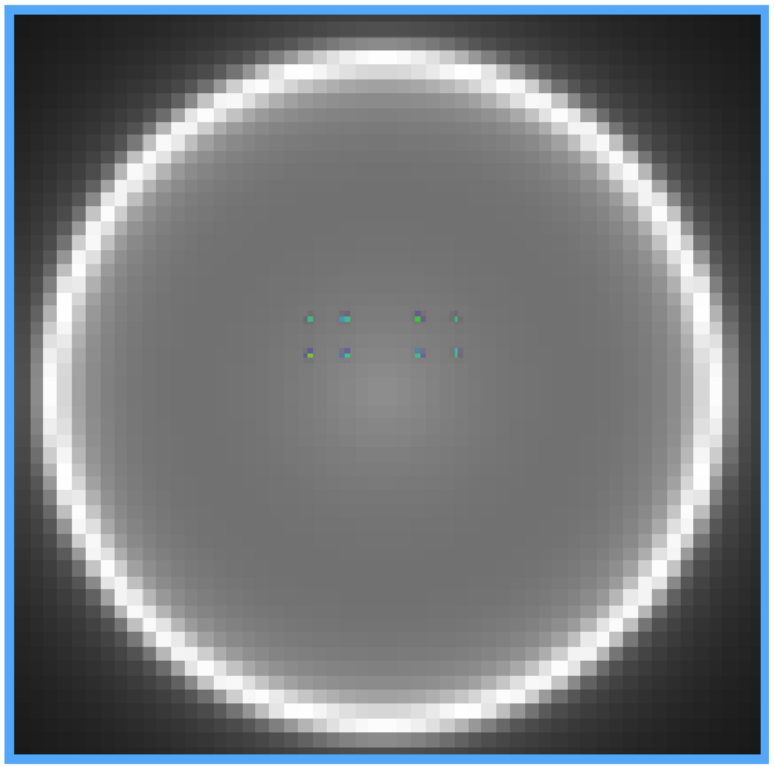
XEMIS2: additional modality

Team ACTION @Latim, Brest

PET Reconstruction using CASToR

(Customizable and Advanced Software for Tomographic Reconstruction)

http://www.castor-project.org



PhD: Reconstruction with the 3 gamma camera XEMIS2

Debora Giovagnoli

PET Reconstruction, using only the two ⟵annihilation photons from Sc44

- The SONIC-GATE project is positioned in the interface between the conception/construction of innovative imaging devices aiming to provide new improved patient specific information and the development of innovative approaches for the exploitation of multi-source data.

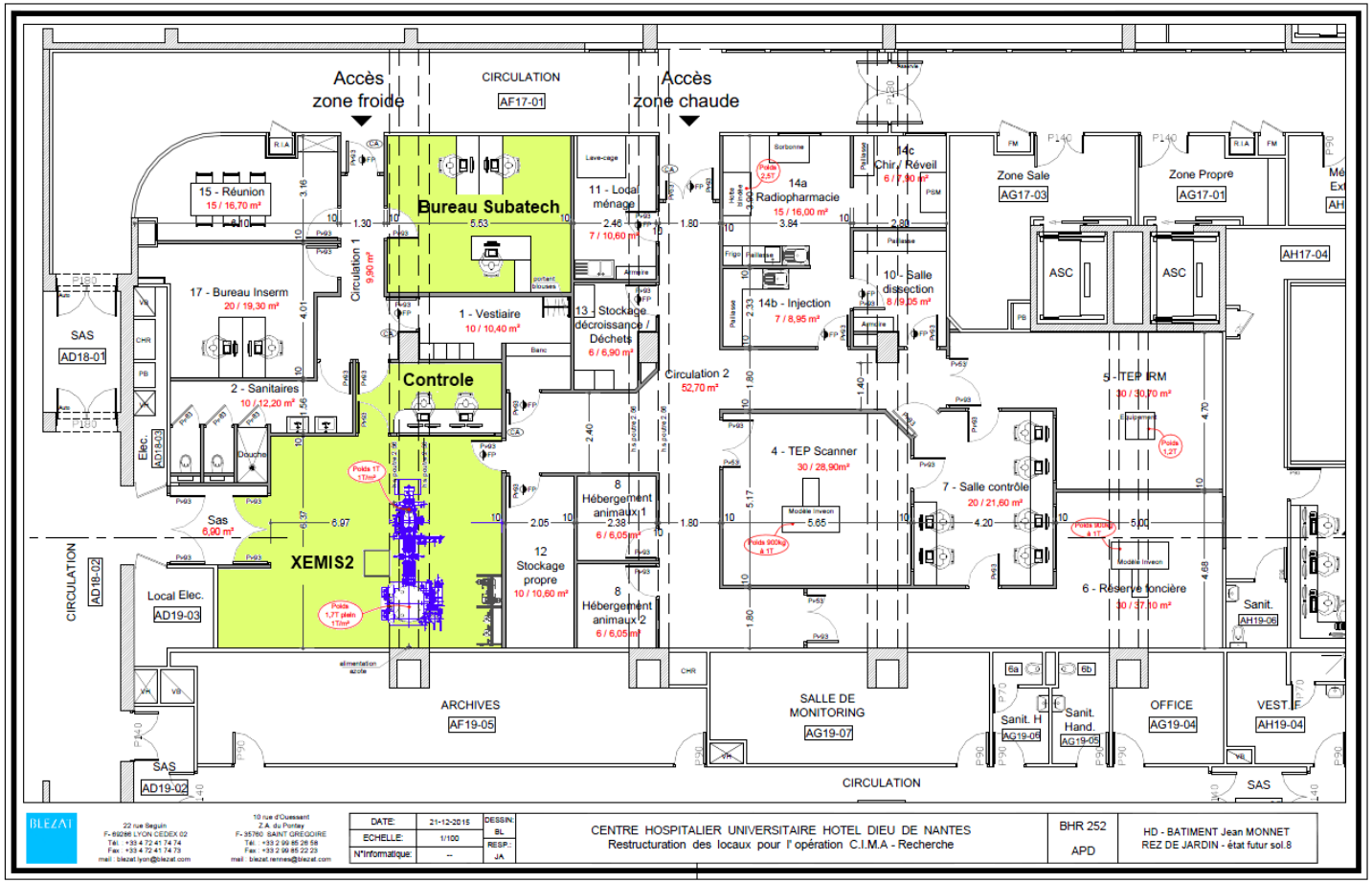
- The SONIC-GATE project brings together partners in the fields of innovative detection system development for medical devices and simulation dedicated to biomedical applications.

- Hosting Institute : IMIV (Orsay).
  structuration around simulation/detector développements

- IMIV/IMNC (Orsay): SiPM
- LaTIM/Subatech (Brest, Nantes): XEMIS
- CREATIS/IPNL (Lyon): Solid Compton Camera
- IPHC (Strasbourg): cmos Dosimeters

AAPG ANR 2018 : first round selection for mid of february

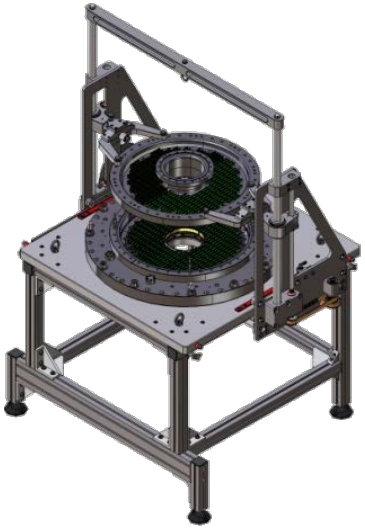
XEMIS2 @ CIMA



~ 100 m^2 for the camera and control rooms

Ready for the installation soon : strong administrative exchanges btw CHU and Subatech. Common agreement is under achievement.

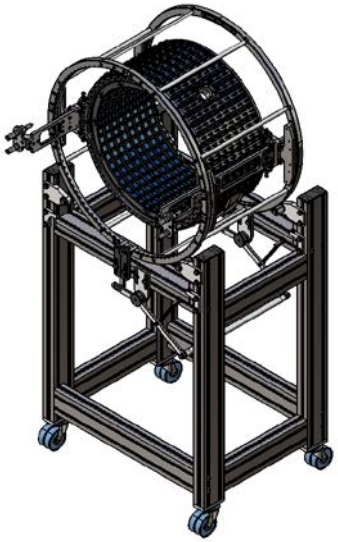
XEMIS2: Mechanical construction tools



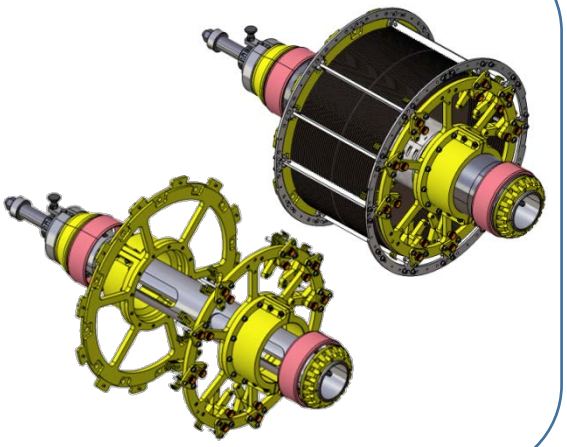
Installation / Extraction des brides et traversées

Transfert sur l'outillage d'installation sur cryostat

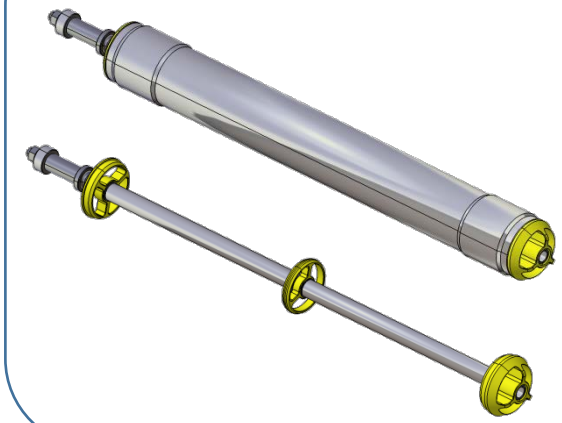
Outillage d'installation des Photomultiplicateurs



Outillage des anneaux de champs

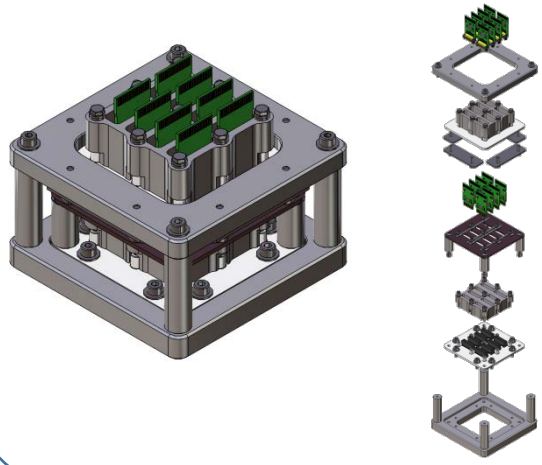


Outillage du tube Air / Vide

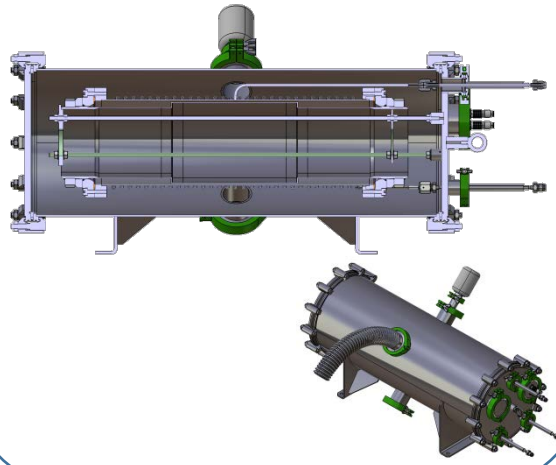


XEMIS2: Mechanical test bench

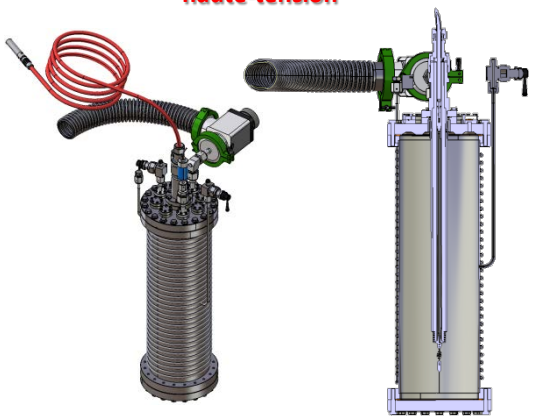
Implantation de l'électronique



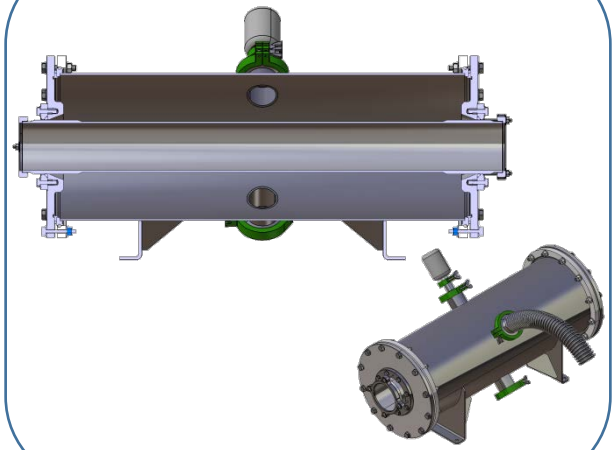
Etanchéité centrale xénon et Vide



Distribution de la très haute-tension

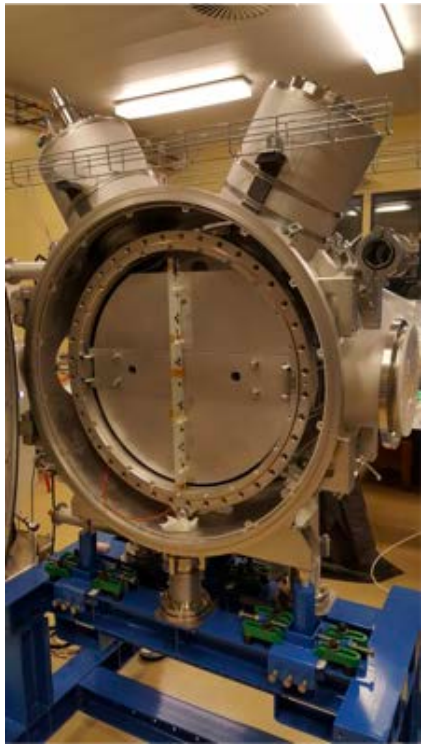


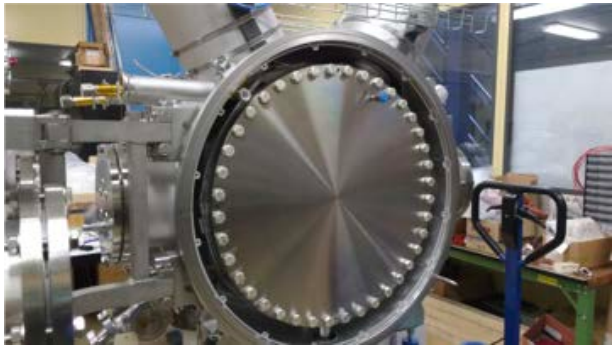
Etanchéité centrale air et Vide

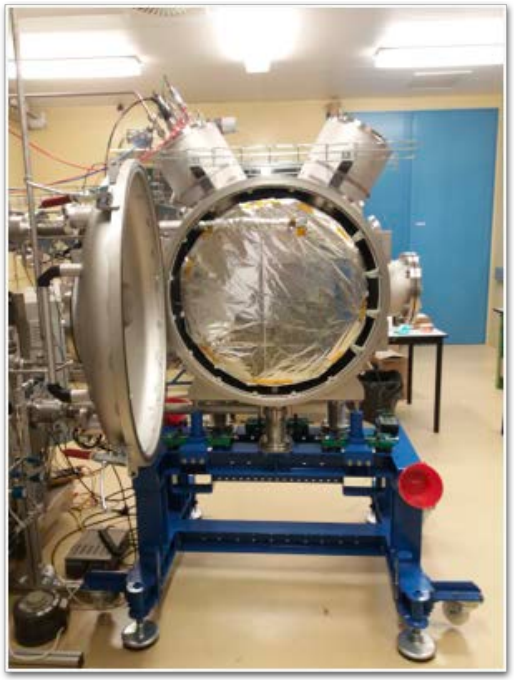


Contrôle du collage circuit de traversées

XEMIS2: Assembling







ReStoX: Recovery and Storage of Xenon

ReStoX: Recovery and Storage system of Xenon

- Compact (210 kg capacity)
  - storage
  - distribution
  - recovering
- Safe
  - from room temp. to -110 °C
  - 71 bar design pressure
- High cooling power (up to 10 kW)
- Ultra pure LXe at 1.2 bar
  - ppb impurities level

Scientific collaboration:

AIR LIQUIDE

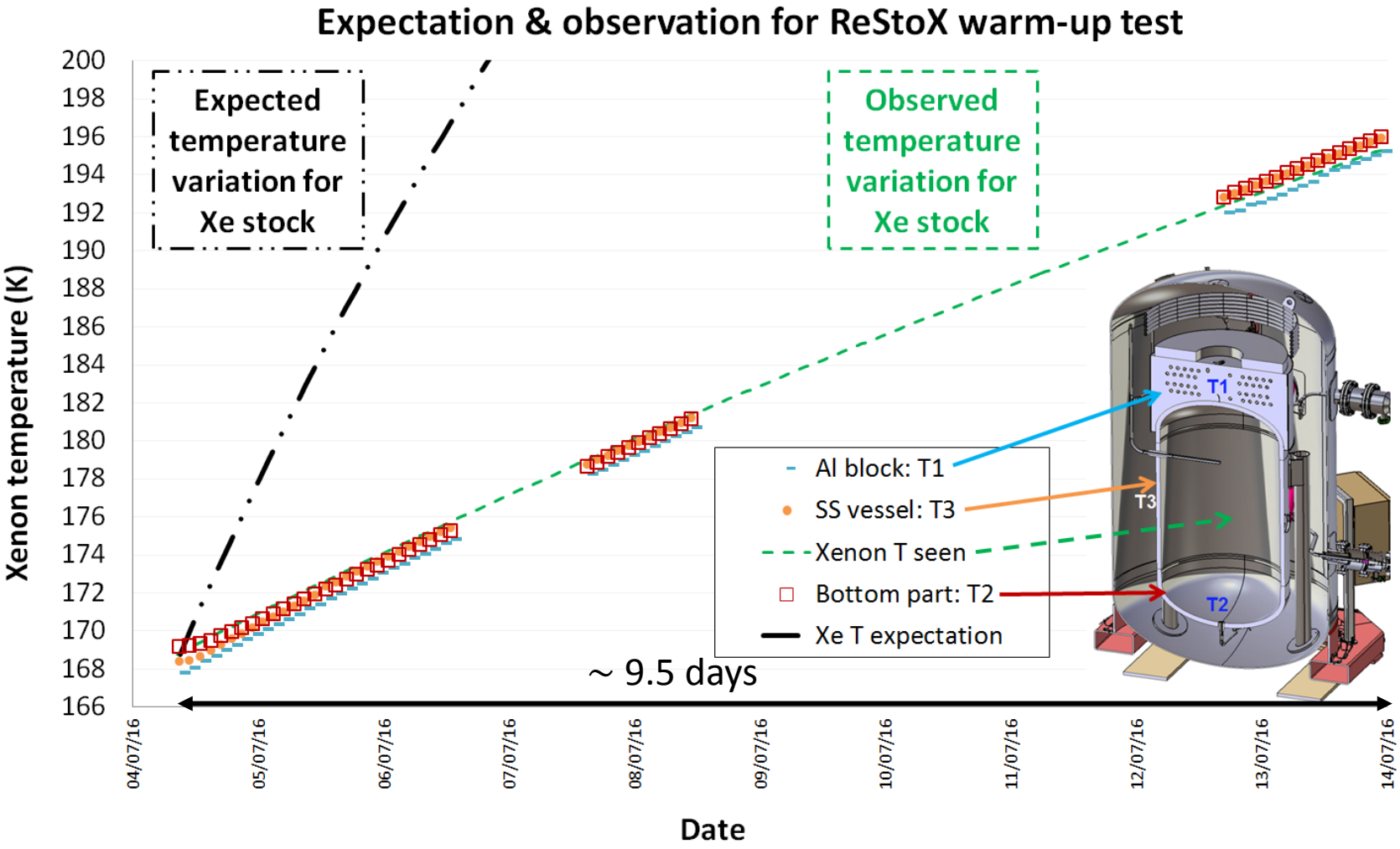
XEMIS2 Facility

Purification ReStoX XEMIS2

XEMIS2 at Nantes Hospital:

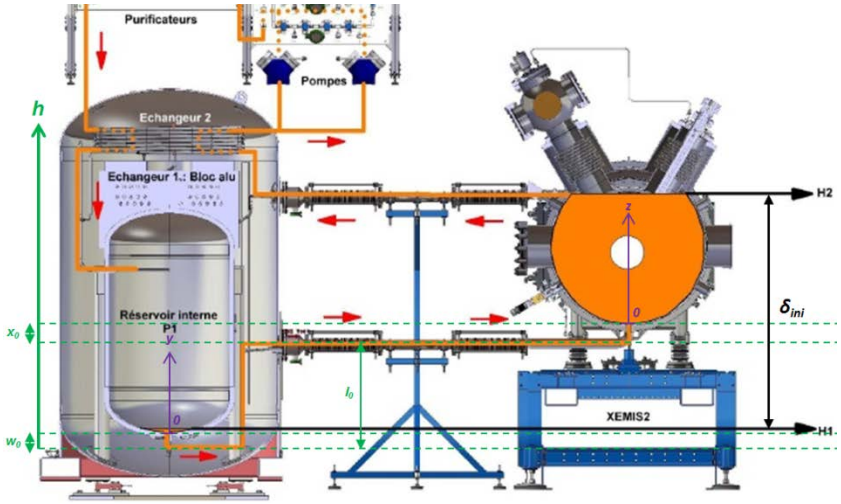
- 1st image: 1st semester 2018
- preclinical researches: until 2020

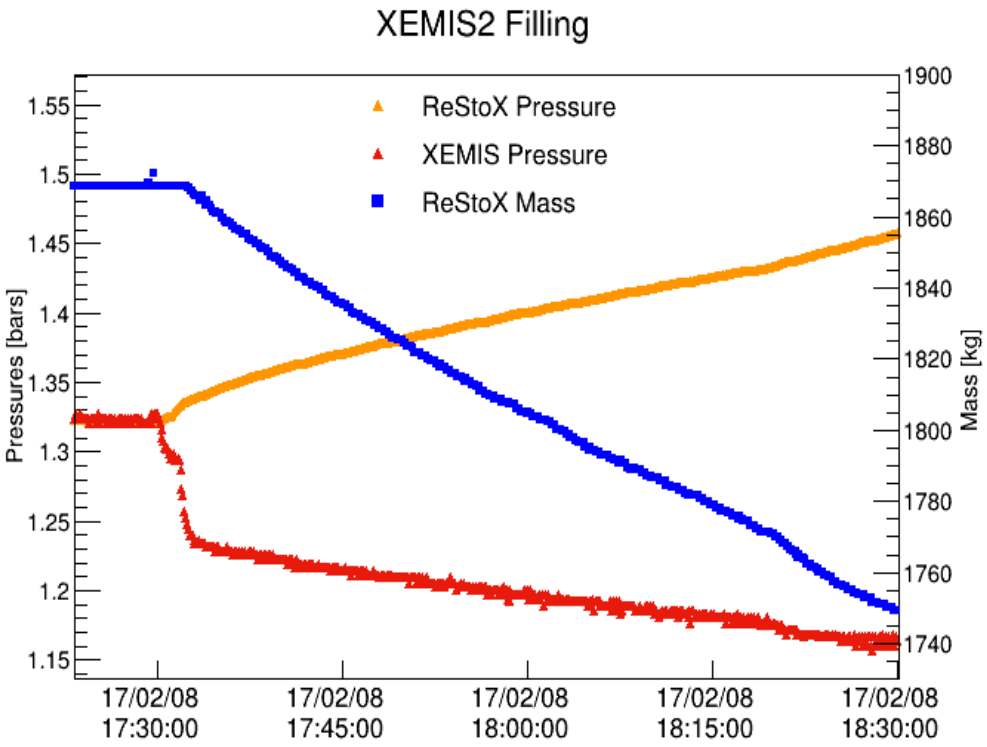
XEMIS2: ReStoX Commissioning



Without LN_2, RT should be reached in ~ 1 year

Commissioning: Filling of XEMIS2

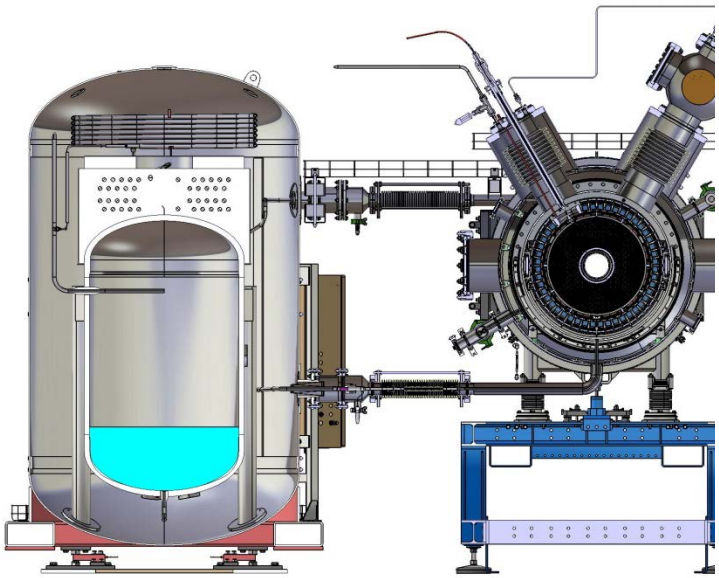


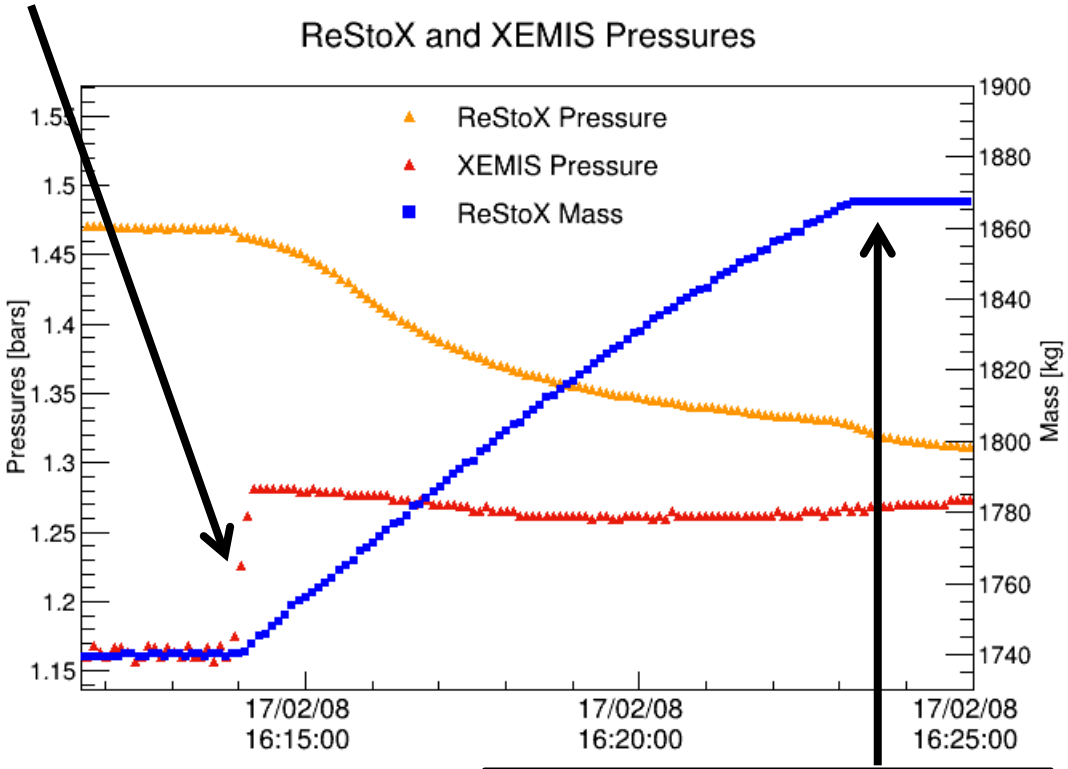


125 kg filled in ~ 1 hour at 30 nl/mn thanks to the pump.
GXe continually pass through getters

Commissioning: Gravitational Recovery

↪ Bypass of the circulation circuit, direct connection of gaseous phases
↪ LN2 valve closed on ReStoX



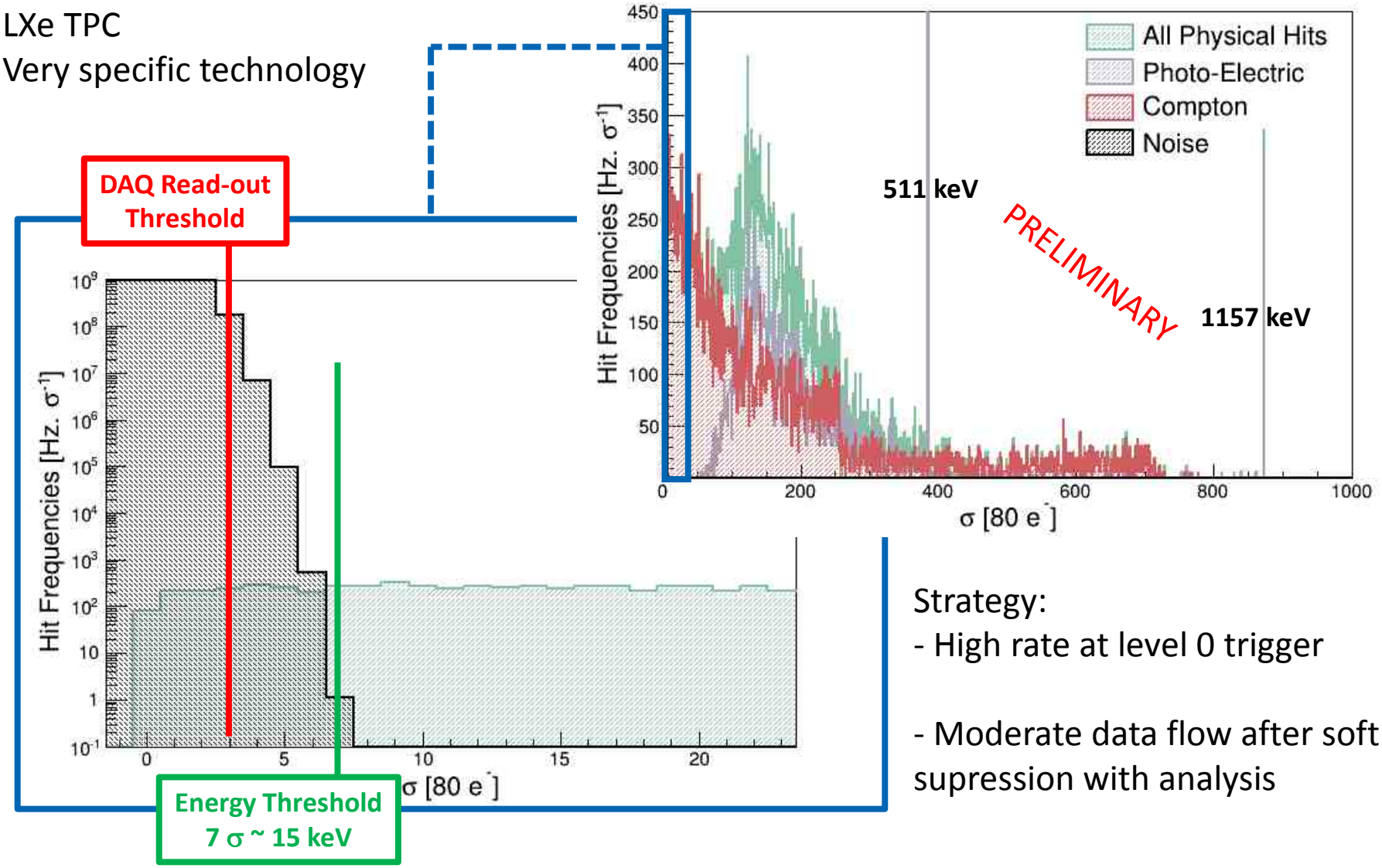


End of LXe Recovering

125 kg recovered in less than 9 mn ! (without cooling power)

XEMIS2: Data flow

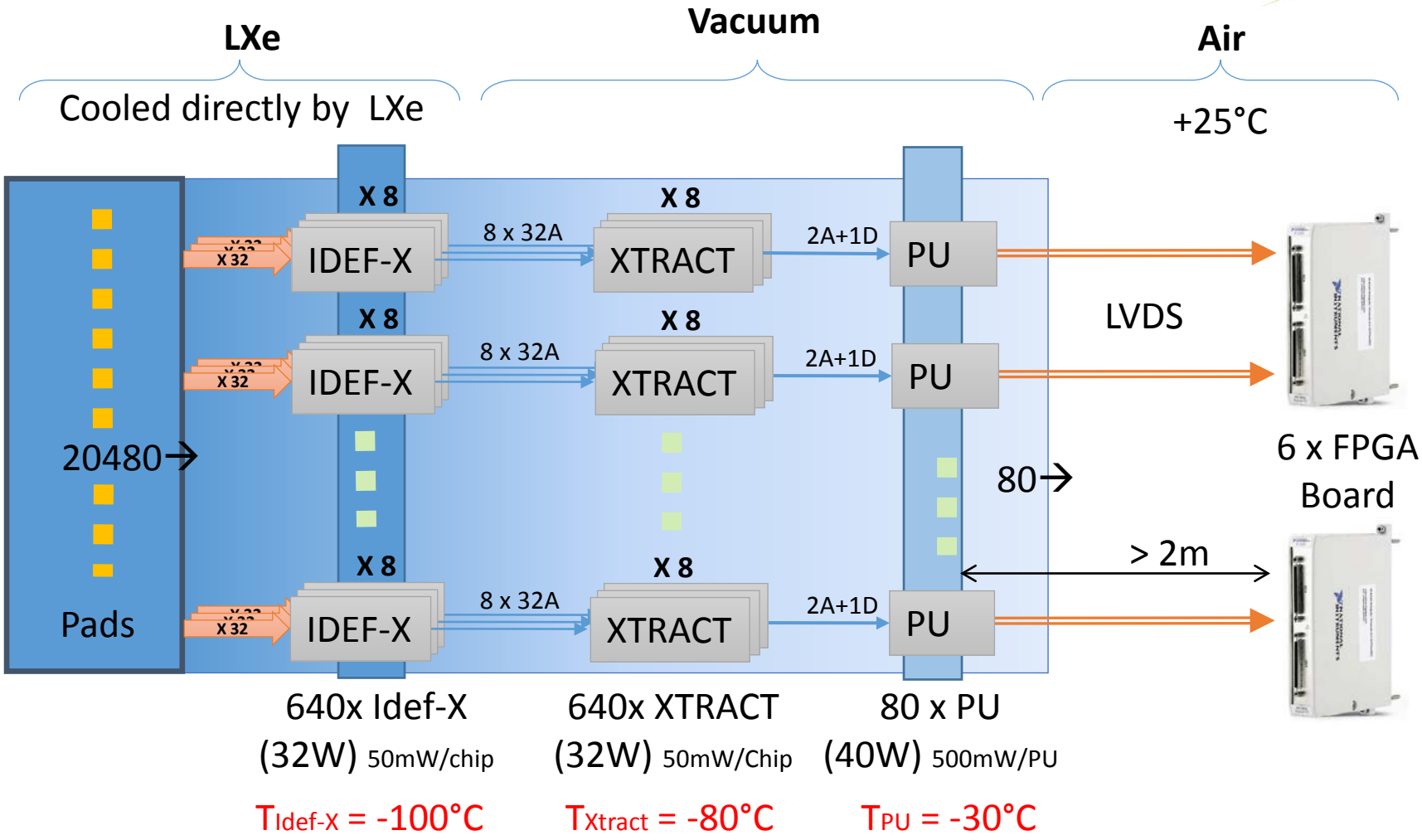
LXe TPC
Very specific technology



Strategy:
- High rate at level 0 trigger

- Moderate data flow after soft zero supression with analysis

XEMIS2: DAQ development

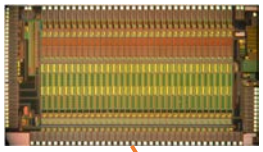


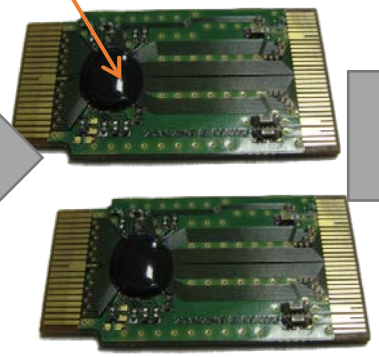
Challenge: Continuous read-out with negligible dead-time

Goal: record on disc ~10^4 charge and time signals/pixel/s

XEMIS2: DAQ details

IDEF-XHD_Lxe
IRFU – SUBATECH

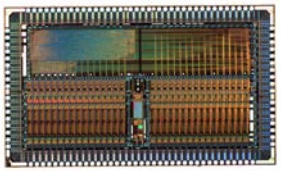


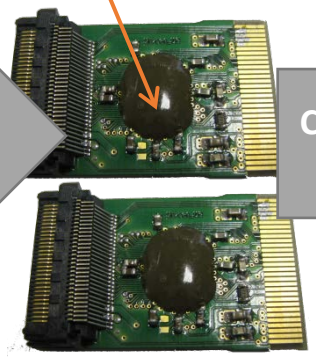


20480 Pixels

640 x cards in production

640 x XTRACT_V2
MICHRAU - SUBATECH

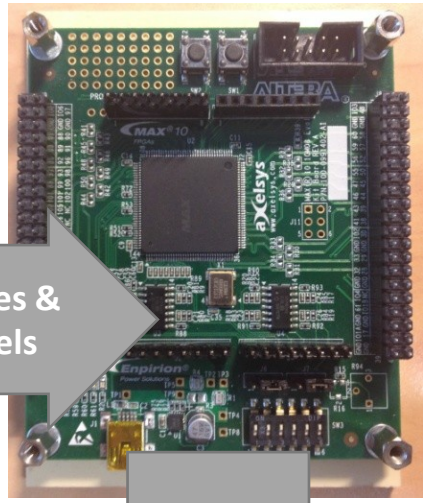




Amplified charges

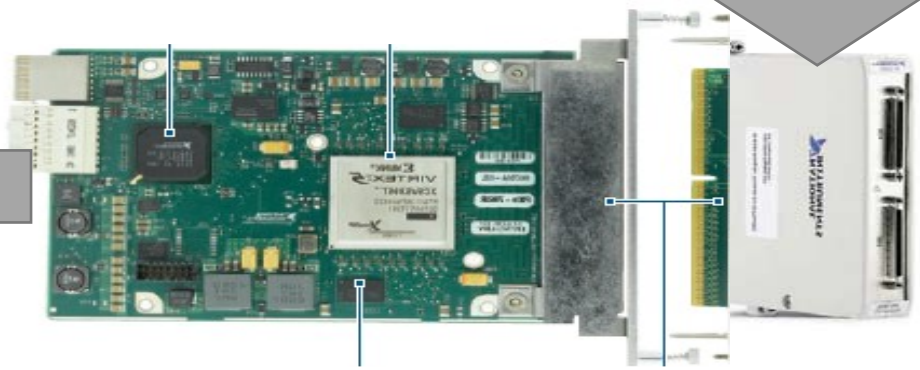
Cards & Asics in test

80 x PU (in test)
SUBATECH



Charges , Times & Affected Pixels

LVDS Transfert

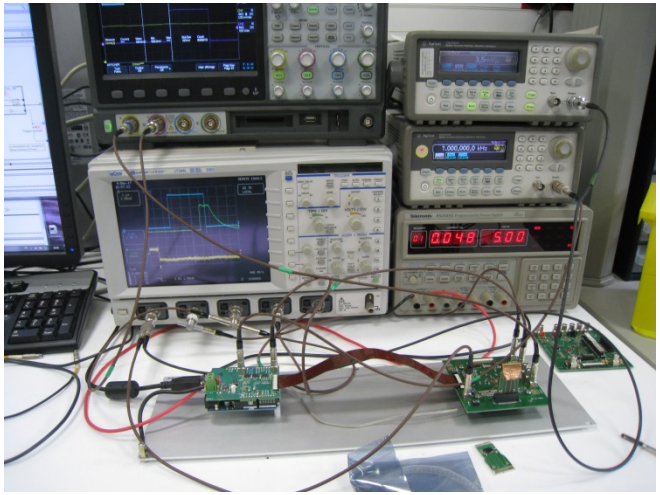


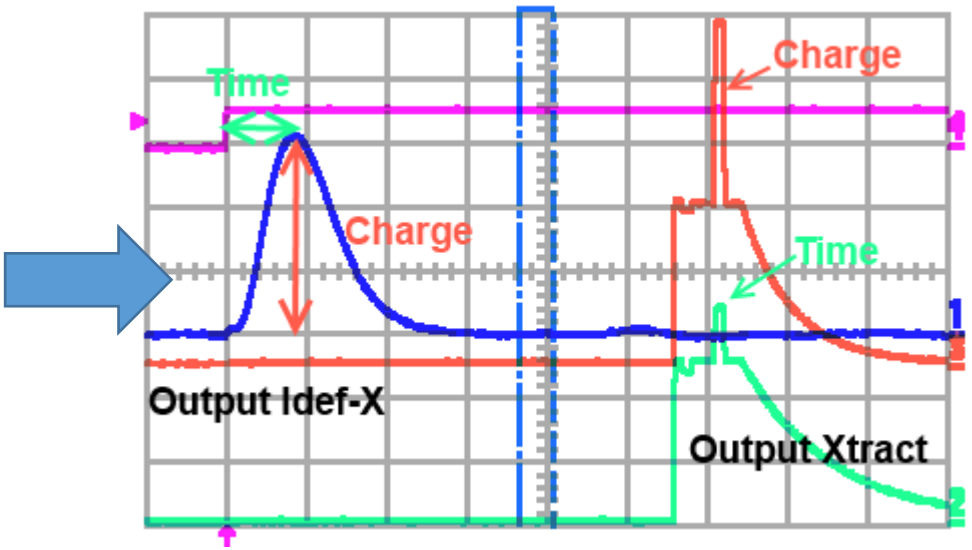
6 x FlexRIO NI (in evaluation)

500MB/s

Raid Disk
~800MB / 20min

XEMIS2: DAQ test bench





- Time & Charge measurements of affected pixels (CFD)
- Self-triggered by XTRACT
- ENC noise : 80 electrons
- Dynamical range : up to 80 000 electrons for charge
- Continuous 12 Hz overall synchronisation for better than 40ns time resolution expected
- Data flow : up to 10M hitted pixels/s with negligeable dead time
- ~800GB Storage in 20 minutes with real time files for each 80 ms.
- Online soft additional zero supression under development for 10 GB storage goal.

Work on progress in parallel with the installation at CIMA

Summary

- 3γ imaging can be a new medical modality thanks to LXe technology
- Big challenges and innovations for the camera design
- XEMIS2 is under construction and it will demonstrate the potential of LXe for medical imaging
- Expected image qualities are very promising:
  - very low injected activity
  - good spatial resolution all over the FOV
  - reduced acquisition time on a large FOV

LXe technology is scalable: design of large whole body camera could be investigated.