# Revue calorimétrie et photodétecteur pour l'imagerie médicale

Sara Marcatili

LPSC – Laboratoire de Physique Subatomique et Cosmologie

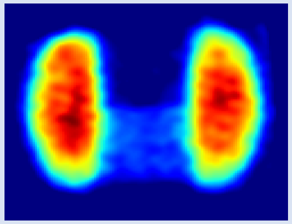
# Imaging instrumentation at IN2P3

Nuclear imaging

X-ray Imaging

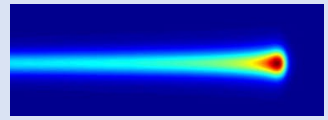
## $\gamma$ camera and SPECT

Single Photon Emission Computed Tomography



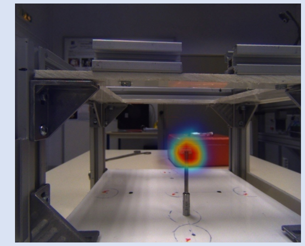
$E\gamma$ = 0.1 ÷ 1 MeV
Photoelectric

## Prompt Gamma Imaging



$E\gamma$ = 1 ÷ 10 MeV
Compton + Pair P.

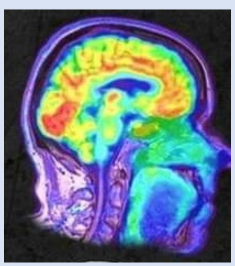
## Environmental applications



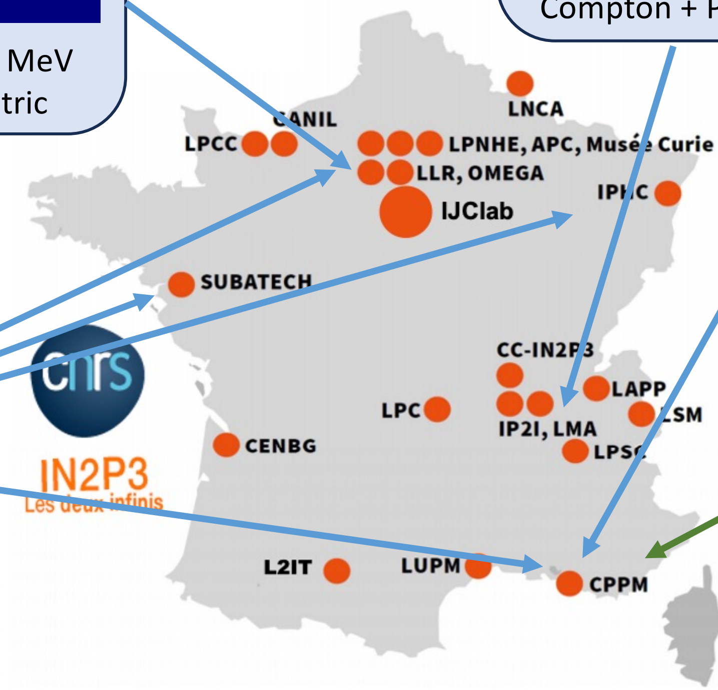
$E\gamma$ > 1 MeV
Compton

## PET

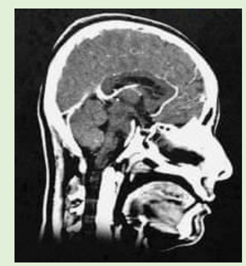
Positron Emission Tomography



$E\gamma$ = 511 keV
Photoelectric

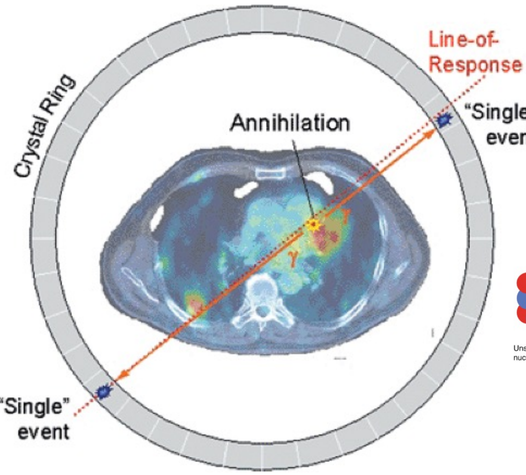


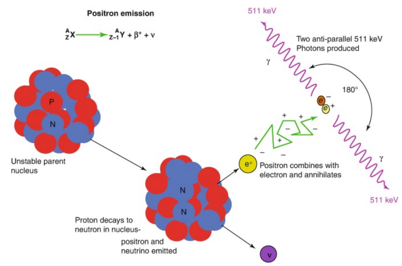

## X-ray imaging



$E_X$ < 200 keV
Photoelectric

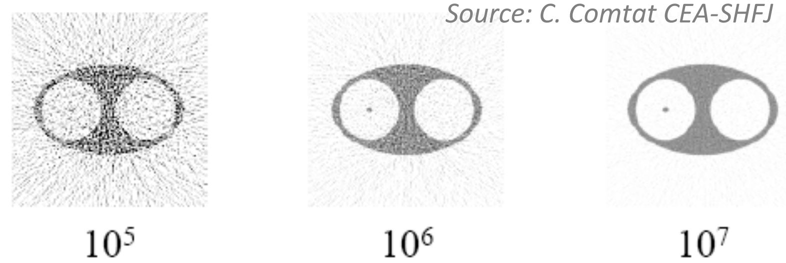
# Positron Emission Tomography




More events, better images… higher dose !

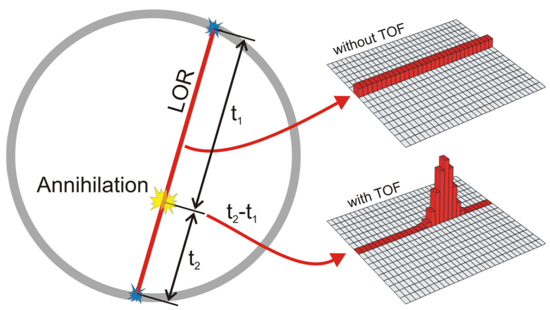
*Source: C. Comtat CEA-SHFJ*




## Many strategies to increase sensitivity

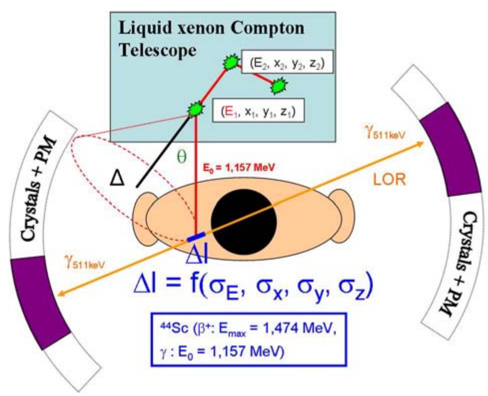
### 10 ps – PET

- <1.5 spatial resolution on the LOR
- No need for tomographic back-projection
- 14-fold improvement in SNR
- or 20-fold dose reduction



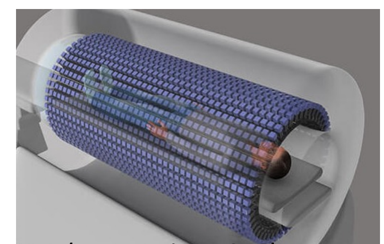

### 3 $\gamma$ PET

- 44-Sc: $\beta$+ emitter + 1.157 MeV $\gamma$
- LOR / Compton cone intersection
- Shorter scans or lower dose




### Whole body PET

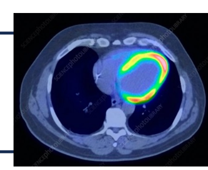
- Currently < 1% of available signal collected
- Lower dose
- Study of systemic disease



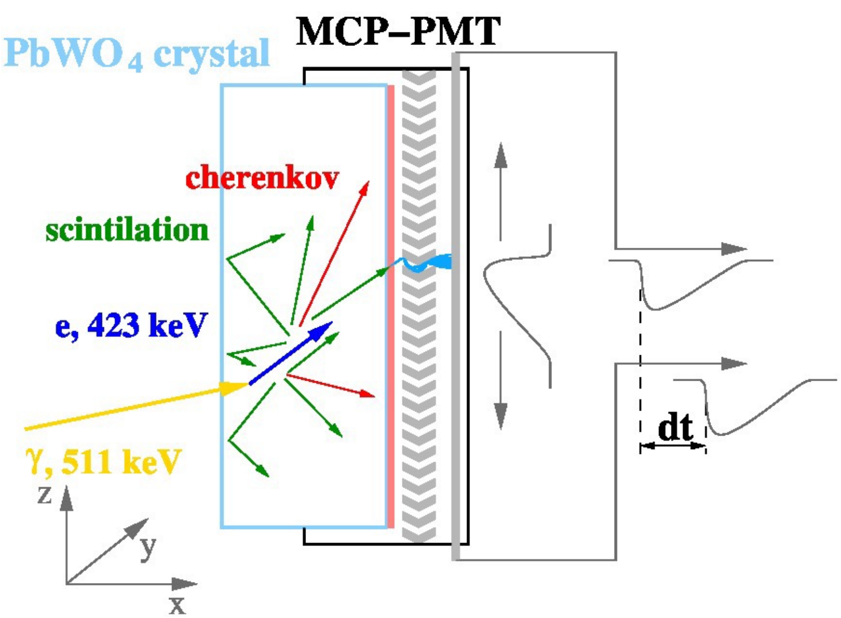
*Explorer project, S. Cherry*

**Hybrid imaging (PET/CT – PET MRI)**

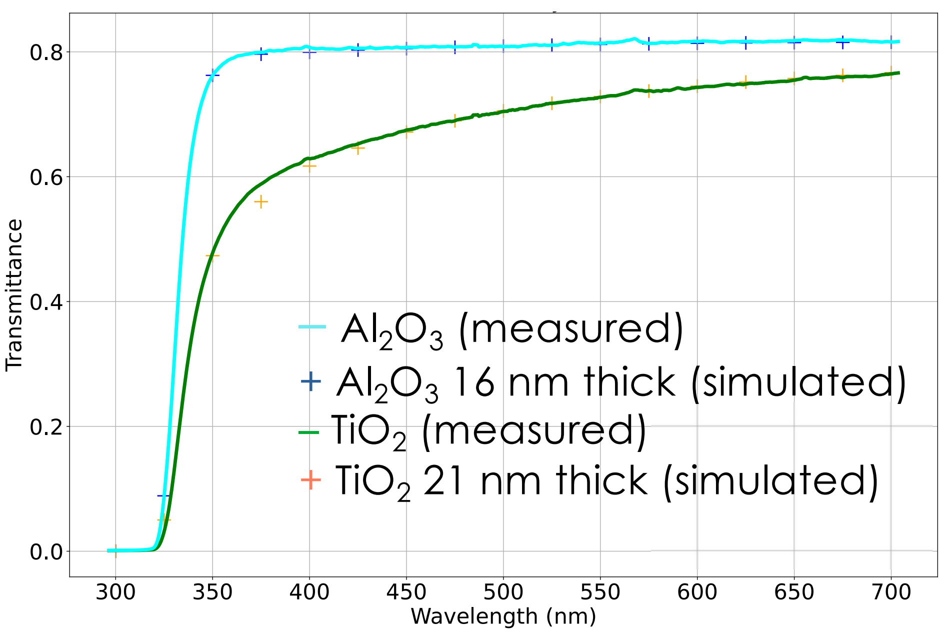
Combining functional and morphological information



# Development of scintronic MCP-PMT detection modules for fast timing




- Detection of scintillation and Cherenkov photons emitted in PWO
- Direct deposition of a photocathode (n ~2,7) on the crystal surface (n ~2,3)
- Encapsulation within a Micro-Channel Plate Multiplier Tube (MCP-MT)
- Coincidence Time resolution (CTR) ~20 ps FWHM (excluding MCP-MT)




D. Yvon *et al.* JINST 15 (2020) P07029

Modelisation of light transmission through surfaces with thin film optical coating in Geant4

L. Cappellugola *et al.* in Conf. Rec. IEEE NSS/MIC'2021
C.-H. Sung, L. Cappellugola et al. accept. in NIMA 2023

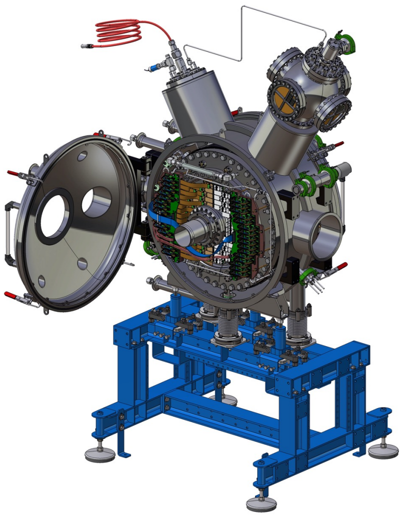
Update of the optical light transport of Geant4 version 11.1 to model optical coating

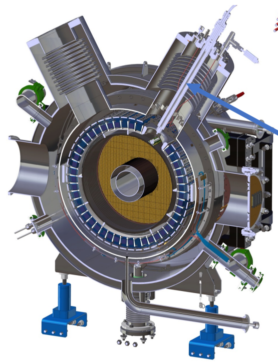
L. Cappellugola *et al.* Technical Forum Geant4, 2022

# 3 $\gamma$ PET: XEMIS2 (Xenon Medical Imaging Systems)

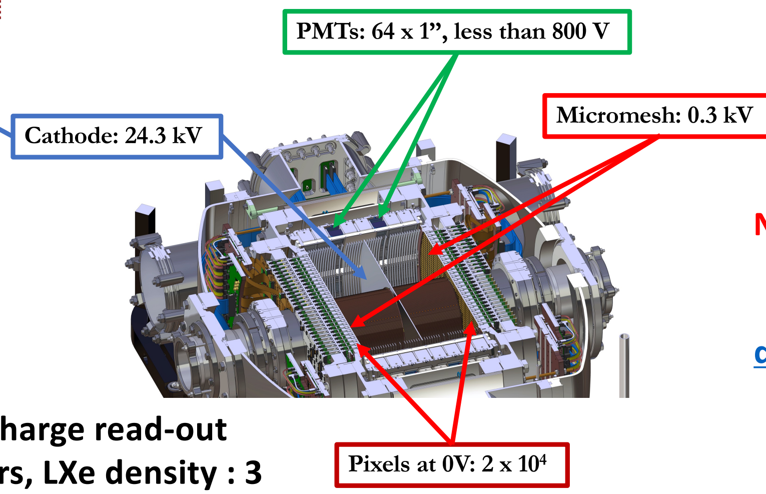
IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom · Nantes Université · cnrs · Subatech

**XEMIS prototypes are made of single phase LXe TPC**





Charge and light generated by LXe $\gamma$ interactions
Very Large acceptance for small animal : 24 cm axial FOV
Thickness : 12 cm LXe in radius
Very precise : 0.1 mm 3D resolution on Compton interactions




**Around 10 FTE/year since 5 years in Subatech Tech teams and Xénon group**

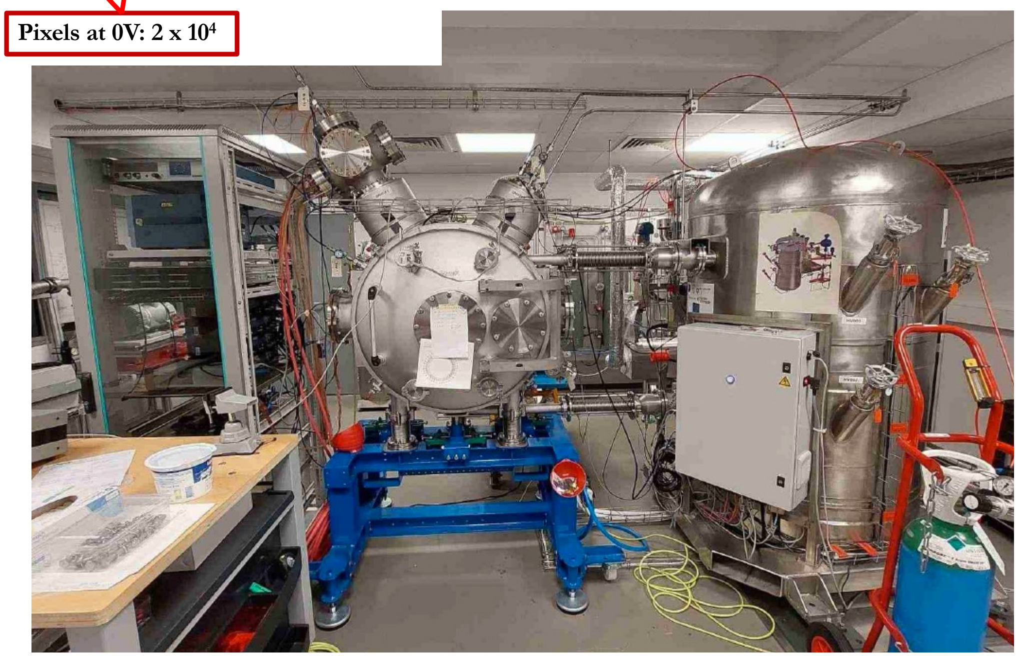
**New In2p3 colleagues very welcome**
Contacts :
jean-luc.beney@subatech.in2p3.fr
dominique.thers@subatech.in2p3.fr

20000 analogical electronics channels for charge read-out
Working conditions : LXe@-100 °C, P@1,2 bars, LXe density : 3

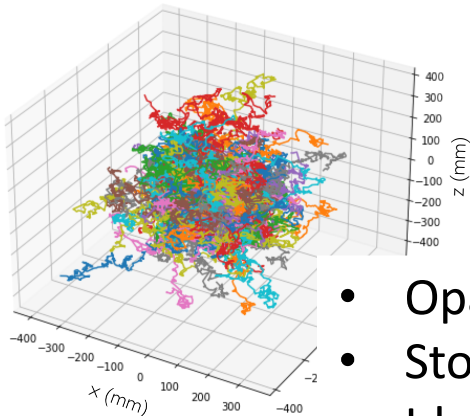
**First LXe Compton Telescope designed for small animal Medical Imaging**

**Installed at "Nantes Centre" CHU in the CIMA Building**

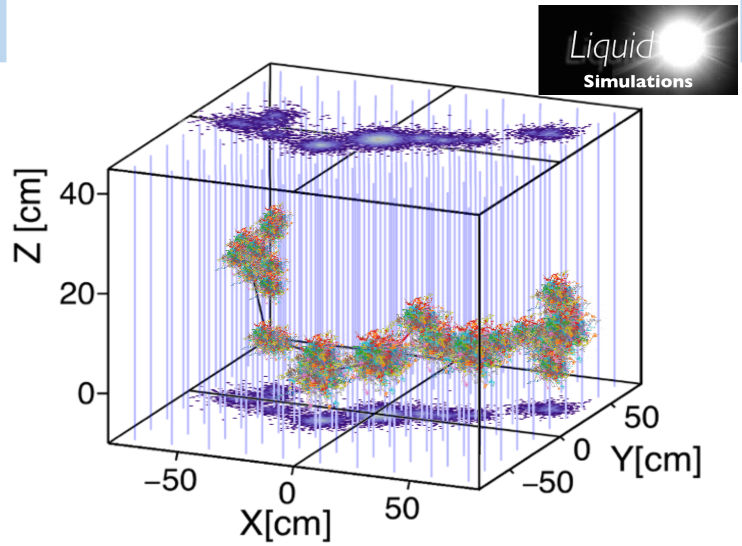
**XEMIS2 construction scheduled : closing this year**

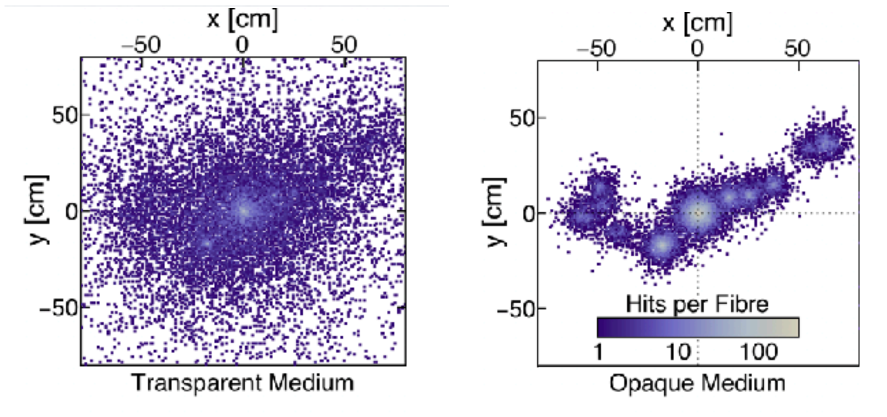


# Whole Body PET with LiquidO

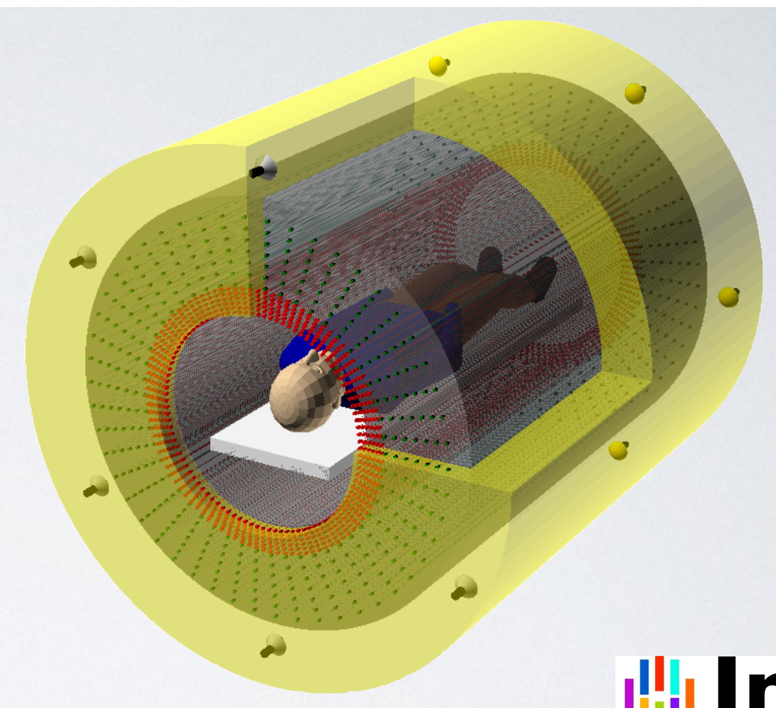



- Opaque scintillator
- Stochastic light confinement
- Identify each $\gamma$ interaction point




Goal



## LPET-OTech Consortium

M. Bongrand[d], C. Bourgeois[aα], D. Brasse[*b], D. Breton[aα], M. Briere[aα], A. Cabrera[†aα], V. Chaumat[aα], A. Dahmane[b], R. Gazzini[aα], D. Giovagnoli[b], F. Haddad[d], A. Hourlier[b], G. Hull[aα], P. Lanièce[aβ], F. Lefevre[d], P. Loaiza[aα], J. Maalmi[aα], Y. Mellak[c], T. Merlin[c], R. Mastrippolito[aβ], C. Marquet[‡aα], L. Ménard[aβ], D. Navas-Nicolás[aα], P. Pillot[d], L. Simard[aα], D. Stocco[d], M.-A. Verdier[aβ], D. Visvikis[c], and F. Yermia[d]

Inserm LATIM IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis Subatech

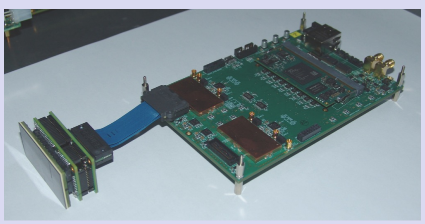
# Instrumentation en imagerie TEP préclinique

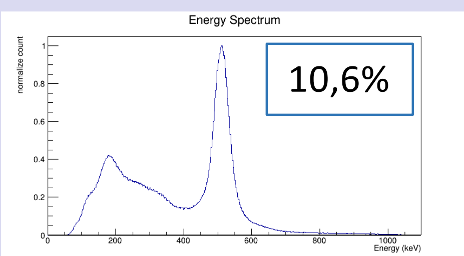
## Imagerie TEP/CT

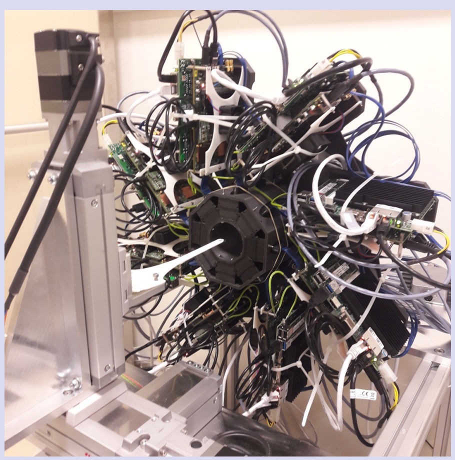
Projet région/BPI
Collab. Inviscan, Streb&Weil
Labelisé pôle Biovalley

**Module de détection (25x50mm²):**
*23x96 LYSO:Ce, 0.98x0.98x8mm³*
*32 voies électroniques*

**Système:**
*2 anneaux de 8 modules chacun*





## Base commune de développement

Matrice SiPM de type S13361-3050
ASIC Imotep2
Système de mesure multivoies (charge & temps)
Multiplexage par réseau de résistances
Virtex 5 / Gbit Ethernet

**D Brasse (david.brasse@iphc.cnrs.fr)**
V Bekaert, F Boisson, N Chevillon, C Fuchs,
X Fang, J Sahr,
R Sefri

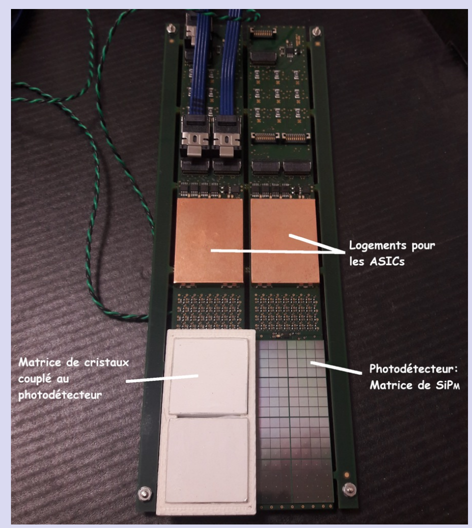
## Imagerie TEP/IRM

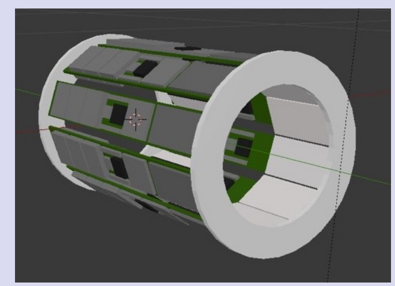
Projet CPER I2MT
Collab. Laboratoire Icube

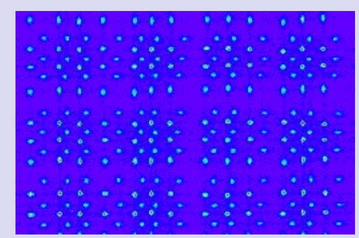
Contraintes:
compacité & champ magnétique

**Module de détection (25x50mm²):**
*Double couche*
*33x68 LYSO:Ce, 0.66x.66x4mm³*
*32 voies électroniques*

**Système:**
*1 anneau de 10 modules*





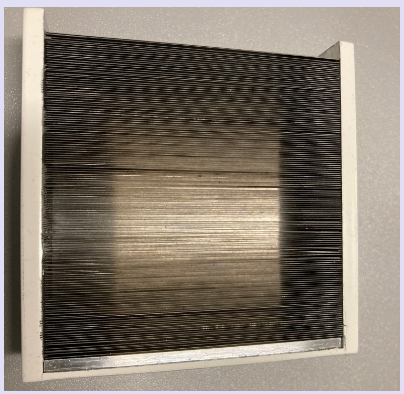

Courtesy of F Boisson, D Brasse

# Instrumentation en imagerie TEMP préclinique

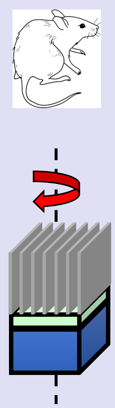
**Base commune de développement**
PMT H9500 256 voies
ASIC Imotep1
Système de mesure multivoies (charge & temps)
Virtex 5 / Gbit Ethernet

**F Boisson (frederic.boisson@iphc.cnrs.fr)**
V Bekaert, D Brasse, N Chevillon,
C Fuchs, X Fang, J Sahr, R Sefri

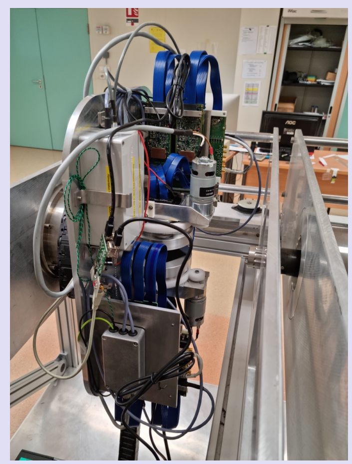
De trous à lames parallèles



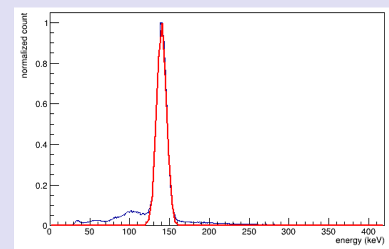
Amélioration de l'efficacité de 0,02 to 1%



Spin-rotation



1D -> 2D : nécessité de reconstruction dédiée




Efficacité : 0,6 % (@25mm)
$R_E$: 10,3 % (@140 keV)
FOV: 50x50 $mm^2$

Vers l'information 3D

Etude des performances intrinsèques : 2 cristaux CeBr3 (avec réflecteur ou revêtement noir)
Utilisation de réseau de CNN pour la correction de linéarité
Mise en place d'algorithmes et de protocoles dédiés aux acquisitions et reconstructions 3D

# Gamma camera THIDOS for dose monitoring in Internal Radiotherapy

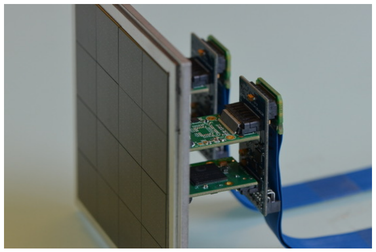
IJCLab Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

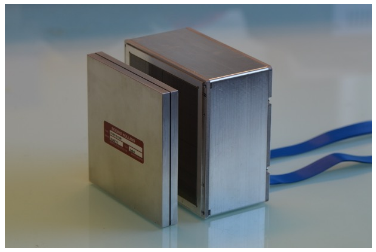
## OBJECTIFS

- THIDOS : proposer de nouvelles approches instrumentales (caméra ambulatoire) et méthodologiques (analyse des incertitudes liées au calcul de la dose, système expert) visant à renforcer le contrôle de la dose délivrée lors du traitement à l'iode radioactif des maladies thyroïdiennes

## MATERIELS & METHODES

### Optimisation de l'ensemble scintillateur/photodétecteur



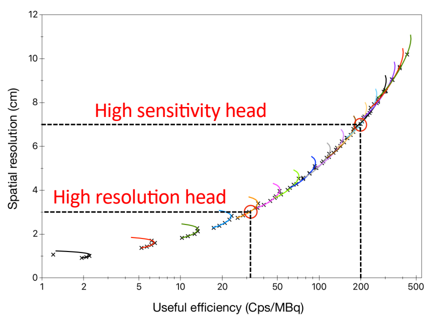


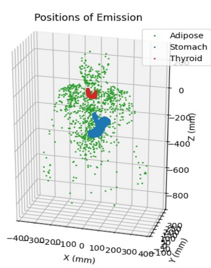
Matrice de SiPMs et électronique miniaturisée (PETSys Electronics)

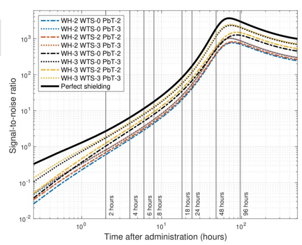
- Scintillateur monolithique CeBr3
- Méthodes de reconstruction avancées

### Optimisation du collimateur haute-énergie et du blindage

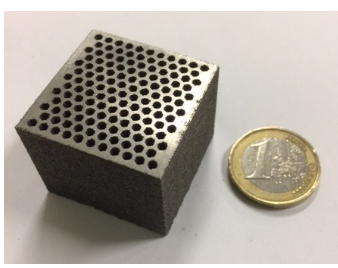
Simulation Monte-Carlo (GATE)

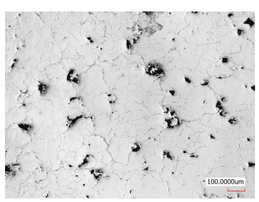



Etude des paramètres d'impression 3D tungstène par fusion laser sélective (collaboration UTBM, ICB, Belfort)

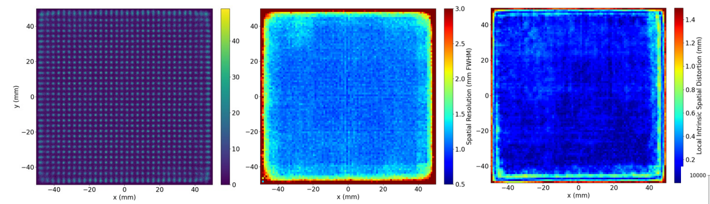




## RESULTATS

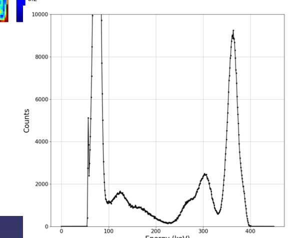
- Développement du prototype clinique de la caméra ambulatoire (10x10 $cm^2$)
- Conception et validation d'un réseau Bayésien pour l'estimation de l'incertitude sur la dose absorbée (IRSN)

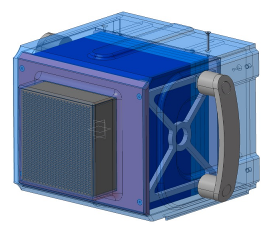
Reconstruction par réseau de neurones convolutif profond

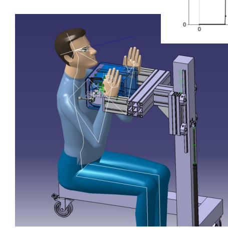


Résolution spatiale ~ 1 mm et distorsion sub-millimétrique

Résolution énergétique < 8%   @356 keV



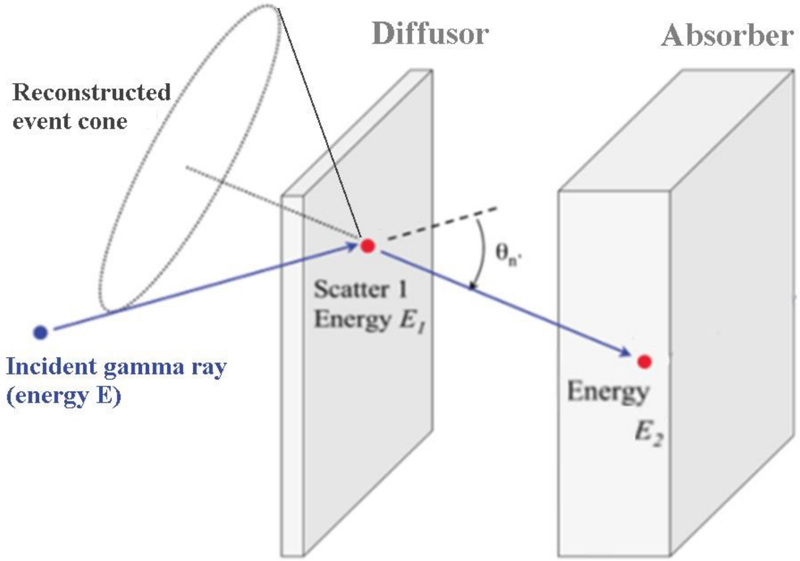





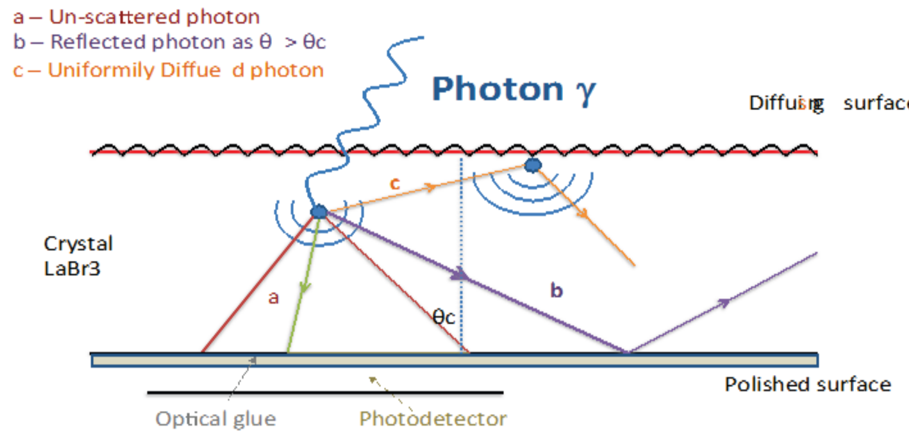
**Support financier**

Plan Cancer (AAP Physicancer, INSERM, 296 k€, 2019-2022) et AP-IN2P3

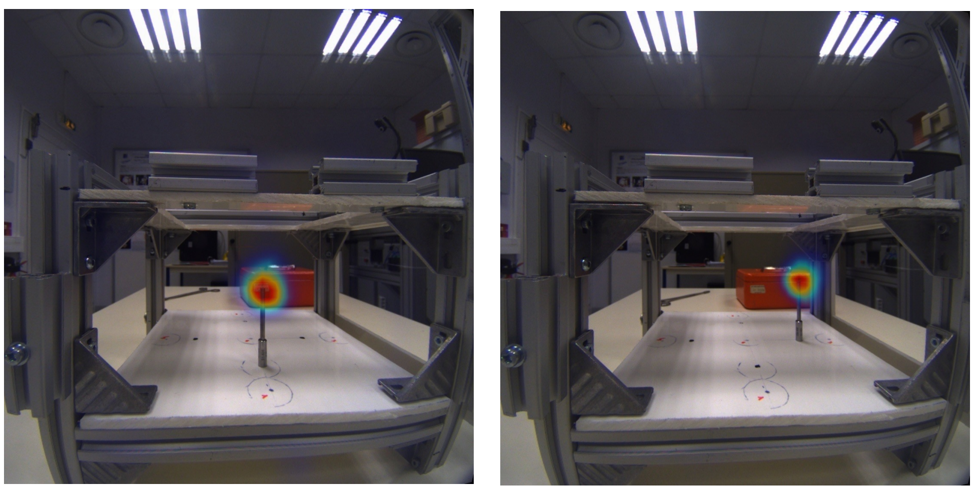
Detectors: monolithic $LaBr_3$ detectors readout by digital SiPM matrices (Philips)

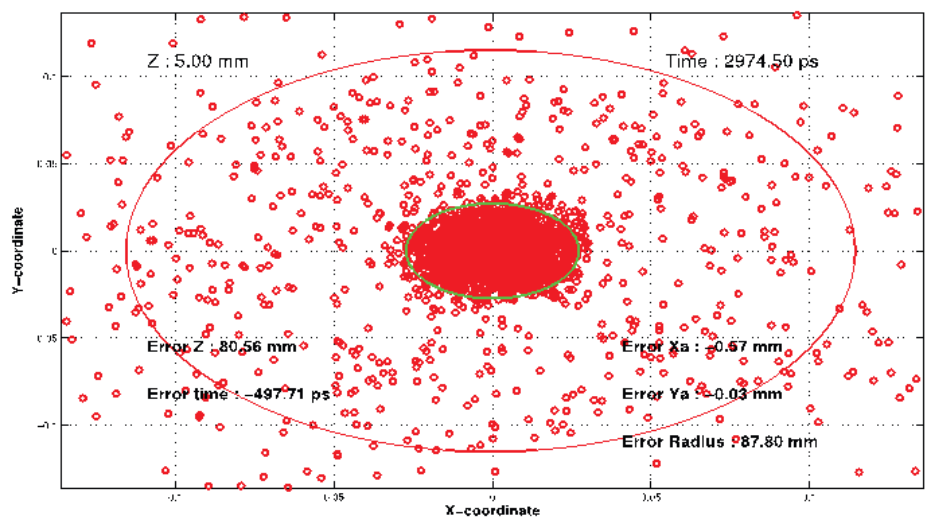



Depth of Interaction

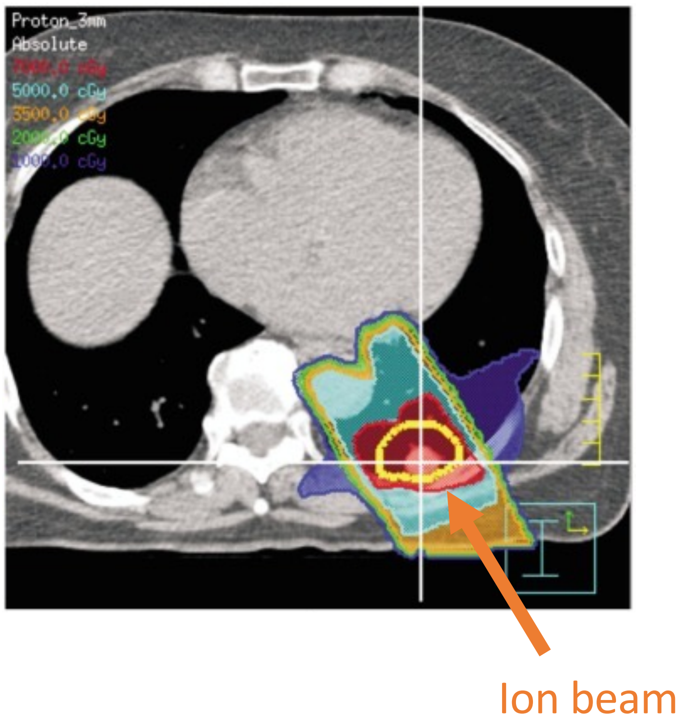


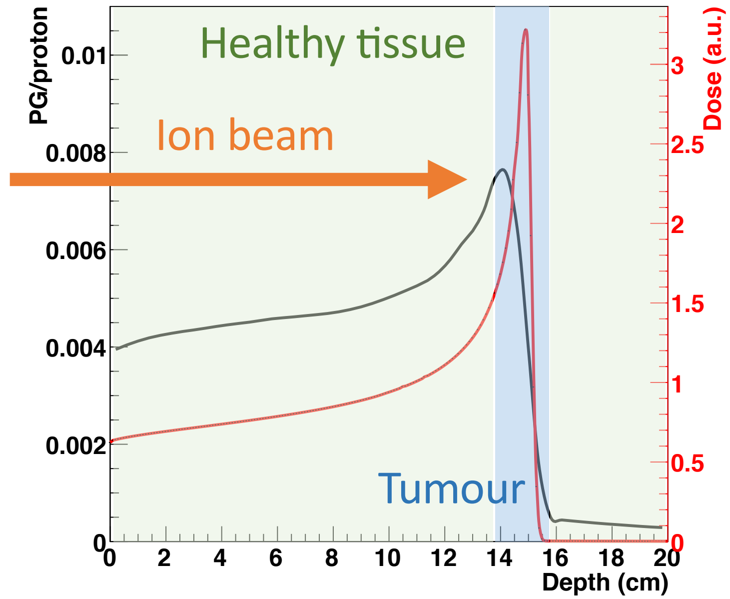

Detection of a Germanium source






A. Iltis and H. Snoussi. J. Imaging 1 (2015) 45-59




Many source of errors (patient's positioning, anatomical changes…) impose the use of safety margins

=> Reduced treatment efficacy

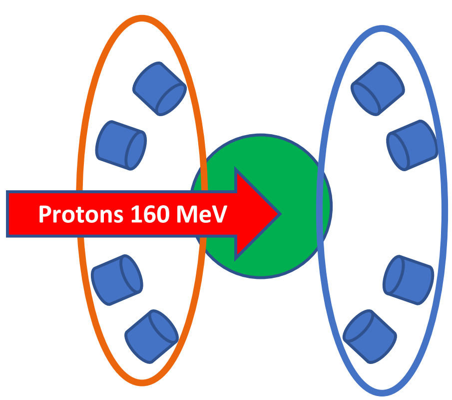
# Prompt Gamma Energy Integral (PGEI)

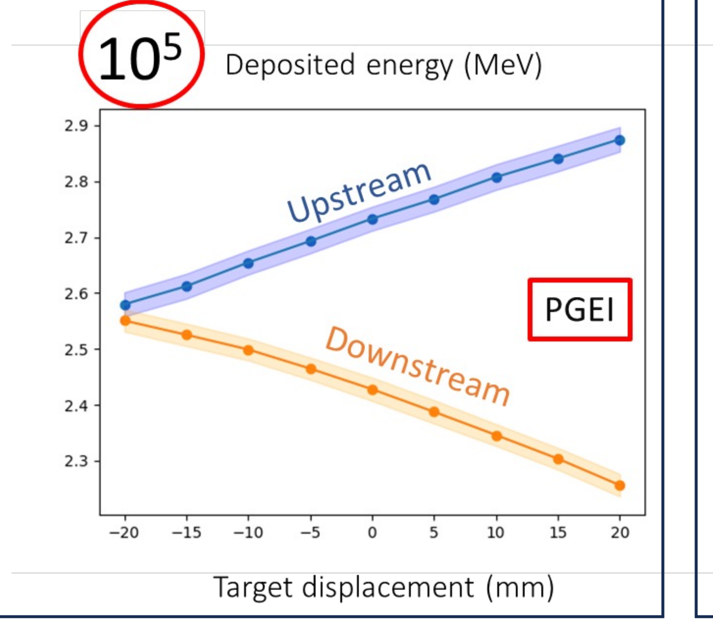
- Detection of many simultaneous photons by large scintillators
- Integral of detected energy: PGEI method
- Fast scintillators : $PbWO_4$ , to keep linear response at high energy deposit

LPSC Grenoble · iP2i Les 2 Infinis Lyon · Antoine Lacassagne Centre de lutte contre le cancer, unicancer Nice · CREATIS · ARRONAX

## GATE simulation

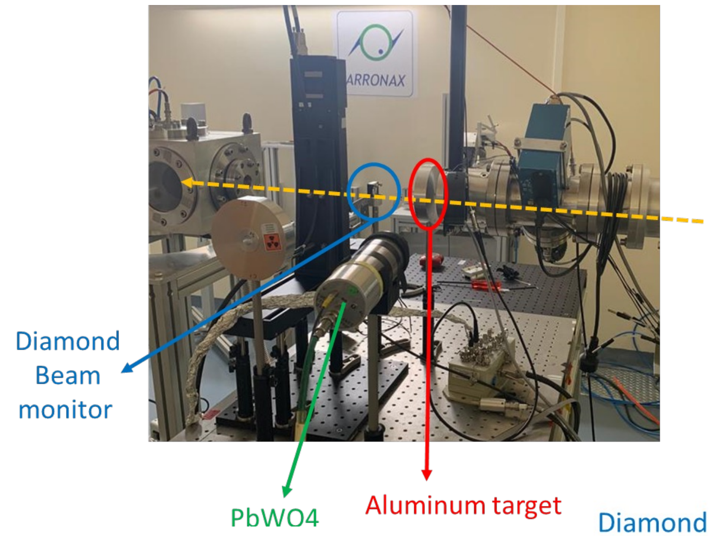
- Spot of $1.5\times10^7$ protons
- 5 cm radius LaBr3 detectors

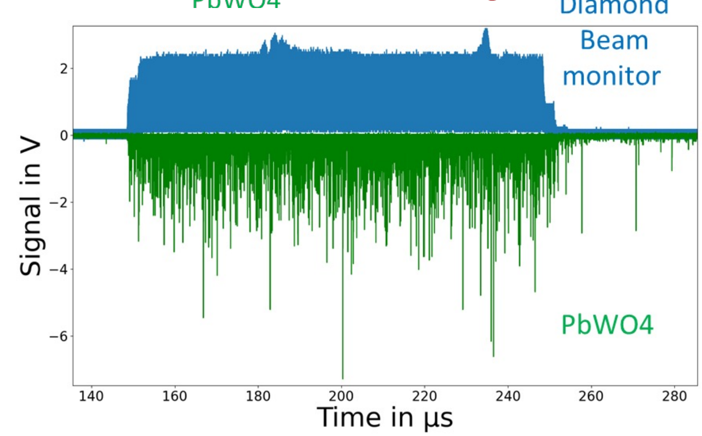


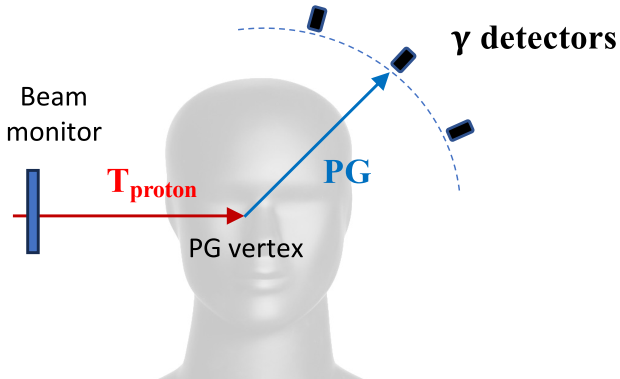

## Experiment

(68 MeV pulsed alpha beam, 2 μA)



# Time-of-flight Imaging ARrAy (TIARA)



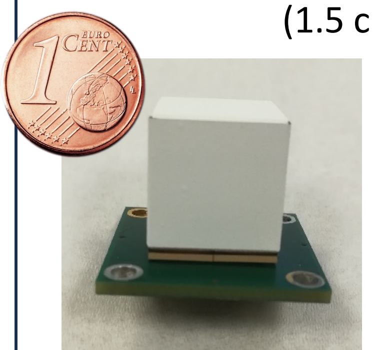

## GOAL

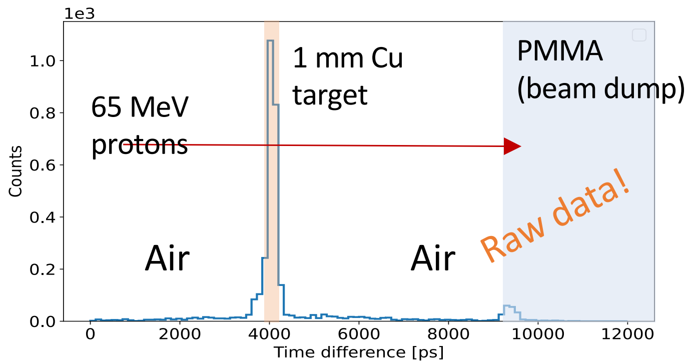
- 30 γ detectors to achieve a uniform target coverage
- Detection efficiency ~0.5%
- Targeted coincidence time resolution ~100 ps RMS
- Dedicated reconstruction for PG vertex

$$TOF = T_{proton}(r_v) + \frac{1}{c}\|r_d - r_v\|$$

### TIARA γ module (Cherenkov)

$(1.5\ \text{cm})^3$ PbF2 coupled to SiPMs

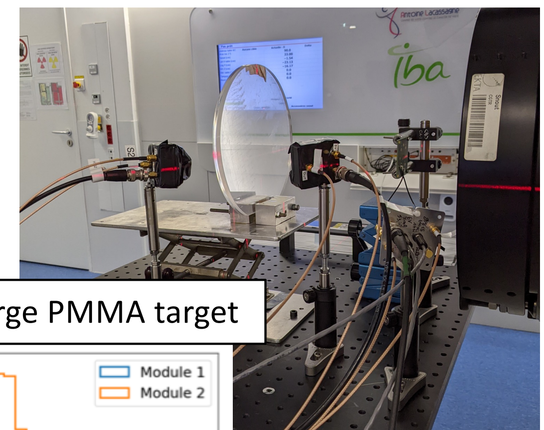




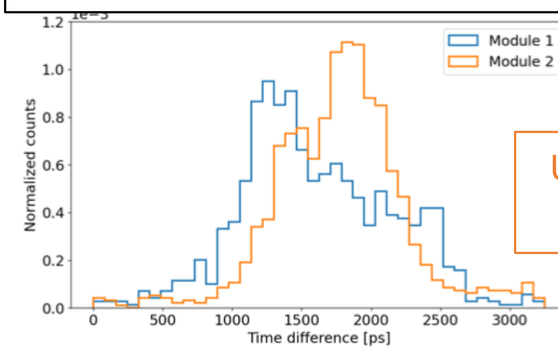

**Prototype v.4**: Time resolution ~ 100 ps RMS

### Experiment on clinical accelerator

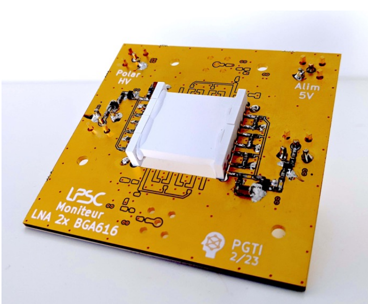
CTR = **112 ps RMS**
at 148 MeV, SPR



PG TOF profile from large PMMA target




Uniform sensitivity all over the range



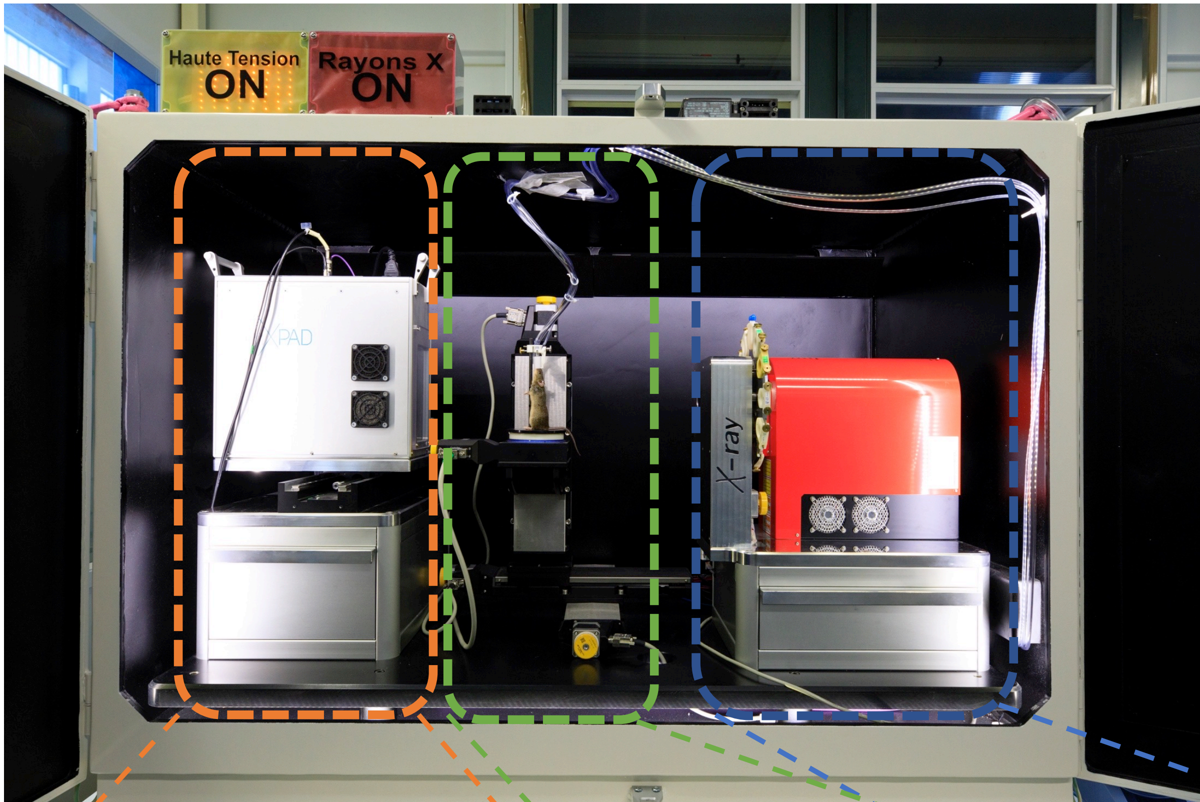
### Beam monitor

~ $4\text{cm}^2$ plastic scintillator readout by SiPMs

**Prototype v.0** (test with 148 MeV)
Time resolution = 52 ps RMS
Spatial resolution = 2.5 mm RMS

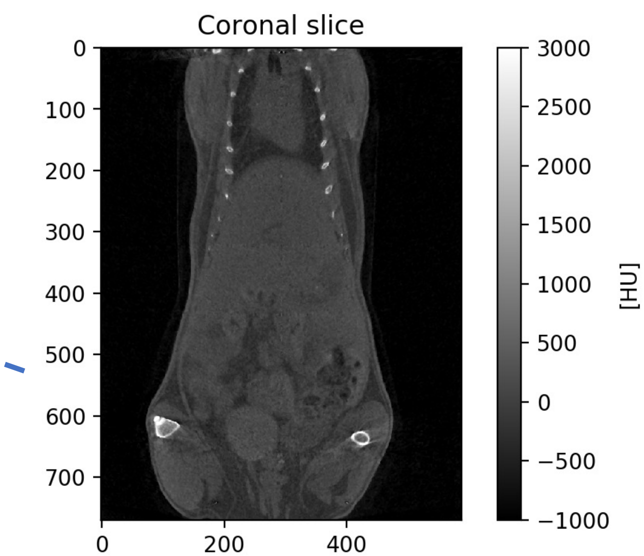
PGTI
PROMPT GAMMA TIME IMAGING
erc
European Research Council
Established by the European Commission

# X-ray PC-CT prototype PIXSCAN




F. Cassol *et al.* BPEX 2 (2016) 025003
- ✓ A. Dawiec (2011) PhD
- ✓ H. Ouamara (2013) PhD
- ✓ M. Dupont (2014) PhD
- ✓ C. Kronland-Martinet (2015) PhD
- ✓ M. Hamonet (2016) PhD
- ✓ F. Cassol (2018) HDR

F. Cassol et *al*. iScience 21 (2019) 68-83
- ✓ L. Portal (2018) PhD




Detector (imXPAD)
- ➢ 500,000 XPAD3/Si hybrid pixels 130 x 130 µm$^2$
- ➢ 500 µm thick

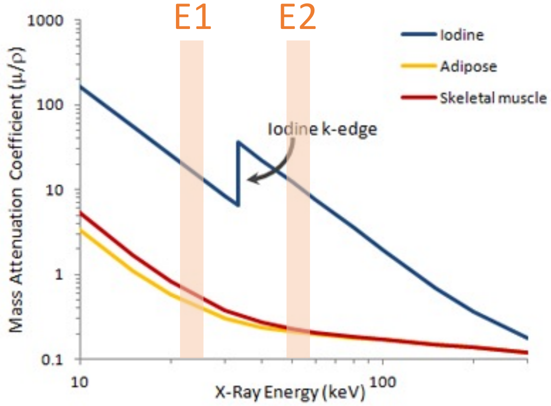
Animal support
- ➢ 3-axis motion + rotation
- ➢ Minerva gas anesthesia system

X-ray tube (Hamamatsu)
- ➢ 40 to 150 kV
- ➢ filter wheel


*Courtesy of C. Morel*

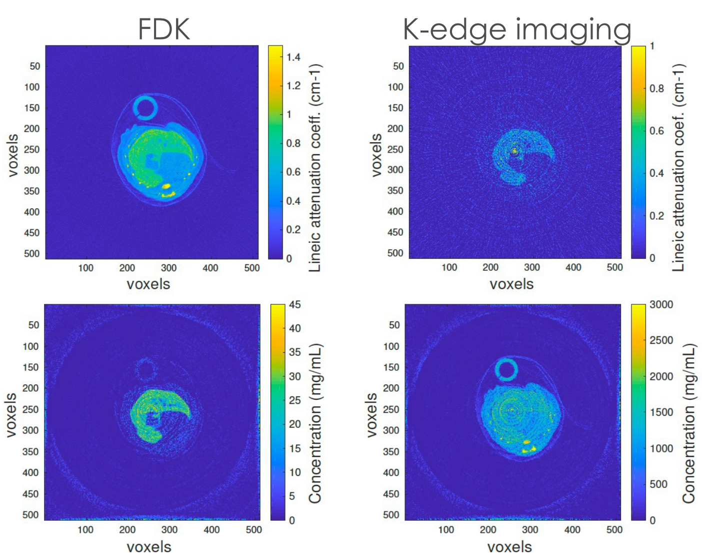
# K-edge X ray imaging

**K-edge imaging:**
Dual energy acquisition below and above the k-edge




## Detector (imXPAD)

- 70,000 **XPAD3/CdTe** hybrid pixels
- 130 x 130 µm², 700 µm thick
- **ProMeSCT** dedicated reconstruction



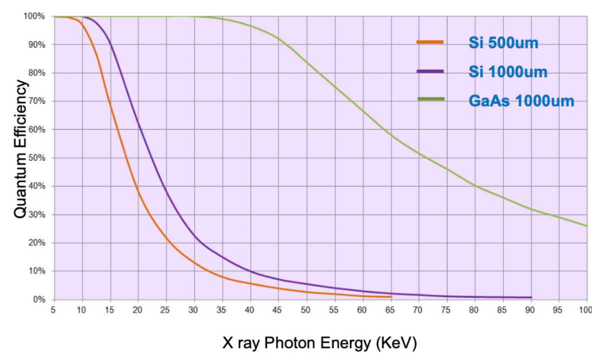

ProMeSCT Barium     ProMeSCT $H_20$

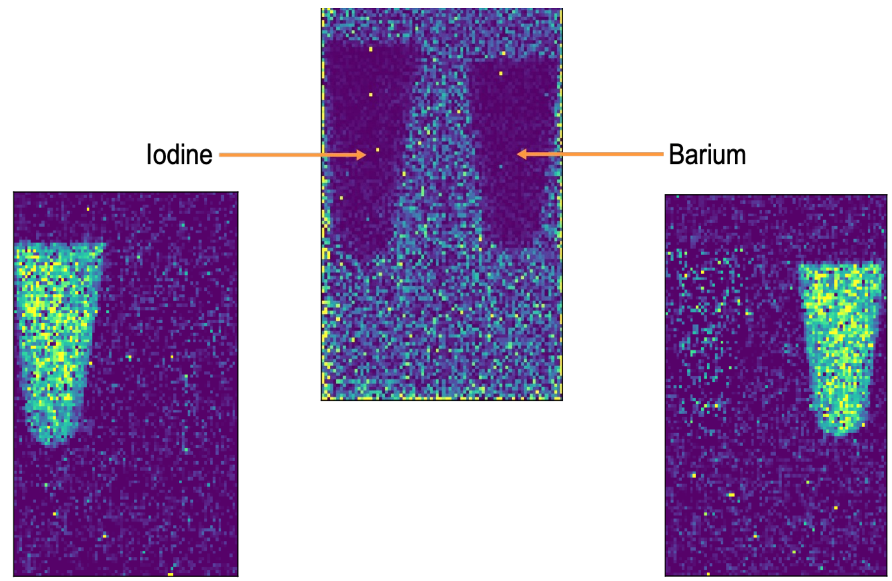
I2M - UMR CNRS 7373

S. Tairi *et al.* IEEE TRPMS 5 (2021) 548-558

## Detector (Cegitek <- imXPAD)

- 9600 **XPAD3/GaAs** hybrid pixels
- 130 x 130 µm²
- 1000 µm thick




Institute Marseille Imaging
Aix Marseille Université

Cegitek Innovation

## Questions ?