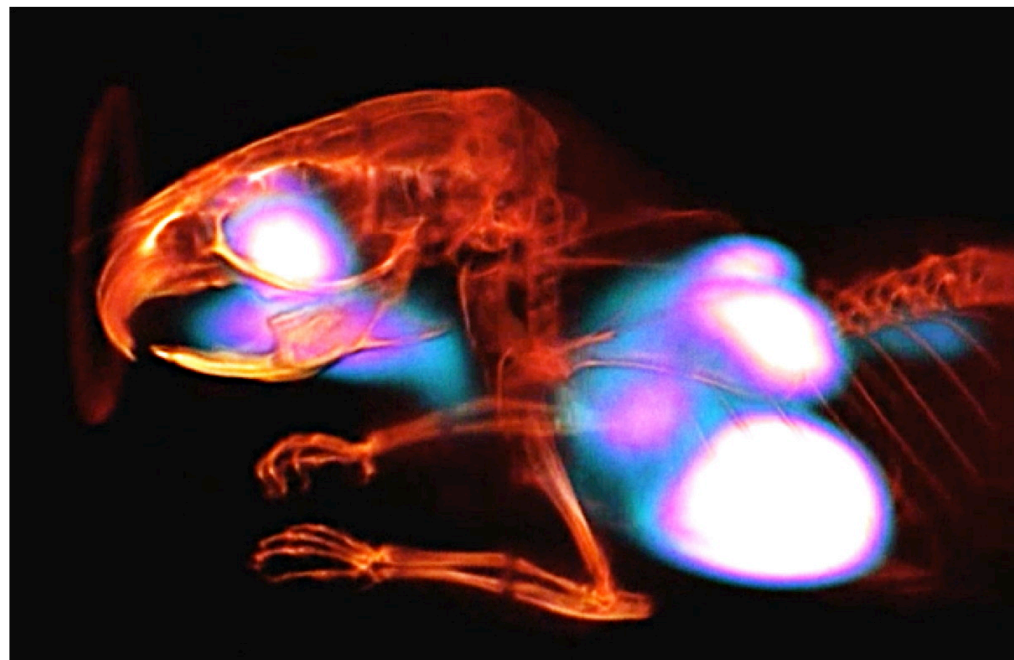




Equipe de recherche



imXgam – imagerie X et gamma



- GDR Modélisation et Instrumentation pour l'Imagerie Biomédicale



- Centre Européen de Recherche en Imagerie Médicale



- Institut d'Imagerie pour la Biologie et la Médecine de Marseille

PC-CT

- FLAP*VAP (AMIDEX interdisciplinaire) ← PC-CT@PIXSCAN-FLI (CERIMED)
- SELF PorTrait (Fondation arc) ← PC-CT@PIXSCAN-FLI (CERIMED)
- MultiX (CIFRE Detection Technology) ← Modélisation MC pixels CdTe dans Geant4

Sondes beta⁺

- MAPSSIC (IN2P3) ← sonde IC

Caméras gamma

- ClearMind (ANR) ← Modélisation MCP-PM dans Geant4 et GATE
- AAIMME (ANR) ← Caractérisation détecteurs ClearMind sur tomXgam
- CCP (CNRS Déclic) ← R&D sonde Compton peropératoire

Hadronthérapie

- PGTI (ERC)/TIARA (PCSI) ← Modélisation détecteur TIARA dans G4 + problème inverse

CERN DRDs

- DRD4 (IN2P3?) ← Modélisation détecteur Tcherenkov (WP4) pour mesures TOF
- DRD6 (IN2P3?) ← Développement scintillateurs X-luminescent (ScintCal) pour mesures TOF

Fast timing

Composition de l'équipe + budget annuel

- **Liste des membres de l'équipe :**

- **3 permanents** (1.8 FTE)

- Christian MOREL, PU —responsable scientifique
- Yannick BOURSIER, MCU
- Mathieu DUPONT, IR-chercheur (0,8 FTE) —coordinateur technique

- **3 post-docs**

- X, ERC PGTI, 24 mois, printemps-25
- X, ANR AAIMME, 12 mois, automne-26
- X, DRD4, 24 mois, demande EAOM24 IN2P3

- **2 doctorants**

- Alicia GARNIER, PGTI/TIARA, CNRS/IN2P3, 2022-25
- Mélissa LEROY, CIFRE/DT, 2023-26

- **5 ITs**

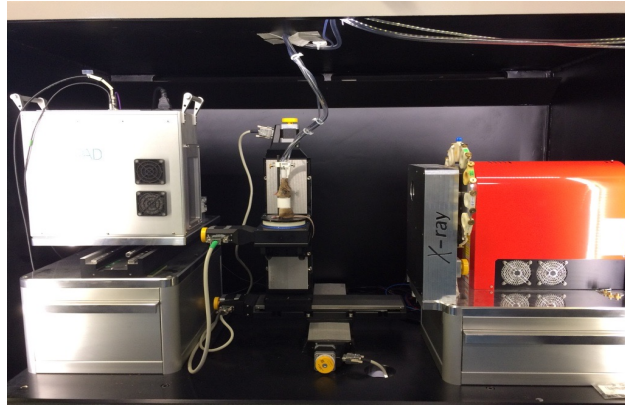
- Fabrice GENSOLEN (MAPSSIC) 5%
- Téo WEICHERDING (MAPSSIC, ClearMind) 3,75%
- Patrick PANGAUD (MAPSSIC) 5%
- Jean-Philippe LOGIER (PC-CT, ClearMind, AAIMME) 12,5%
- Jérôme LAURENCE (MAPSSIC) 5%

- **Budget annuel de soutien de base de l'équipe :**

- Soutien de base alloué par le CPPM en 2024 : 12 k€

- **Collaborations**
 - Collaborations **OpenGATE**, CERN **Crystal Clear** (RD-18), CERN DRD 4 et 6
 - PGTI (LPSC, CPPM, CAL)
 - MAPSSIC (IJCLab, IPHC, CPPM, CERMEP)
 - ClearMind (CEA-IRFU, IJCLab, CPPM)
 - AAIMME (CEA-DM2S, CEA-IRFU, IJCLab, INRIA, CPPM)
 - FLAP*VAP (C2VN, CERIMED, ICR, CRCM, CPPM, iDEAL)
 - SELF PorTrait (CRCM, CPPM, I2M)
- **Participations à l'enseignement, à la communication, à la vulgarisation**
 - Fêtes de la science
 - 13 minutes
- **Responsabilités hors projets**
 - COMEX CERIMED, COPIL Hub FLI Marseille, Conseil d'institut IMI (C. Morel)
 - G4 Oversight board (C. Morel)
 - OpenGATE SC (M. Dupont)
 - Crystal Clear SC (C. Morel)
- **Organisations d'écoles, de workshops, conférences, etc.**
 - Biomedical Imaging School (AMU, Univ Tübingen, UNIL), Cargèse, 2023 (Morel)
 - R&D Seminar — « IMAGING 2022 », Institute Marseille Imaging (Morel)
 - Workshop on Compton Cameras, GDR MI2B, Marseille, 2021
 - Formation CNRS « Python data analysis for GATE simulations » 2019 (Dupont)

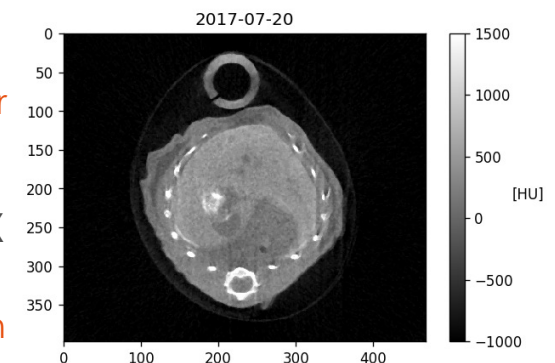
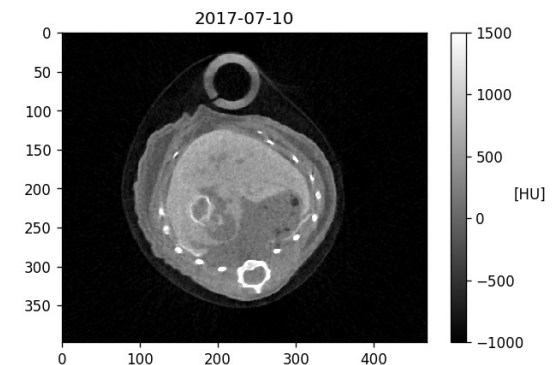
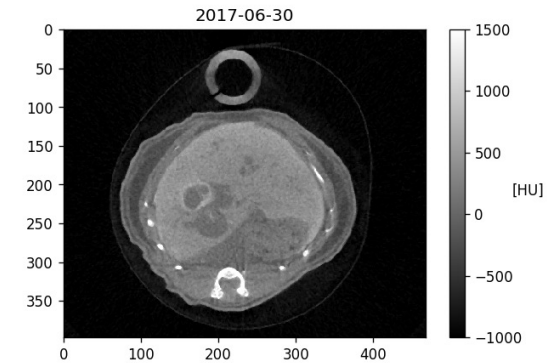
Photon Counting-CT



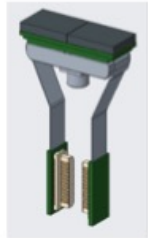



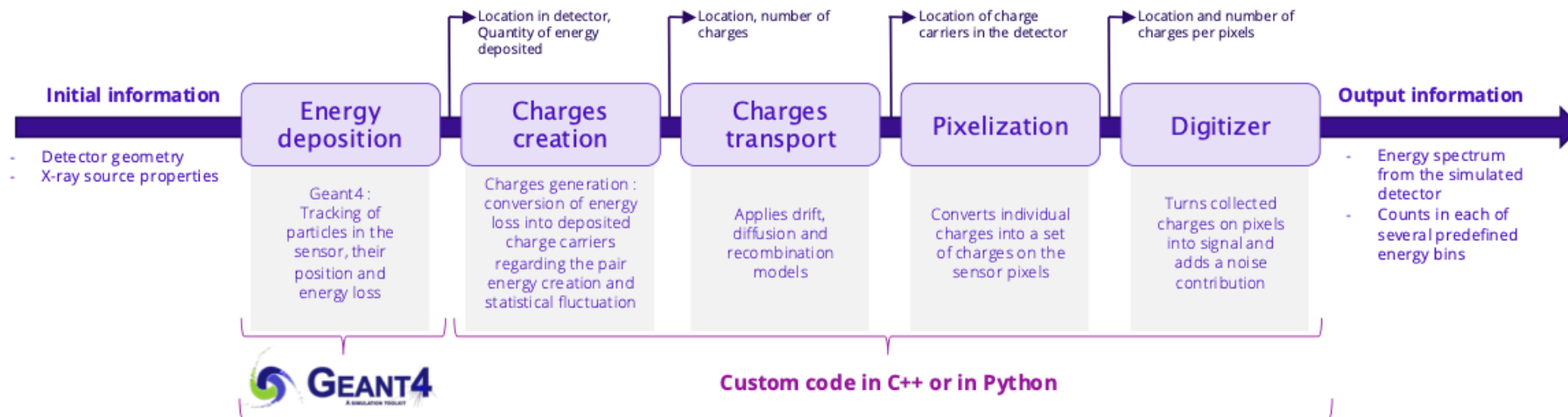
PIXSCAN-FLI PC-CT prototype



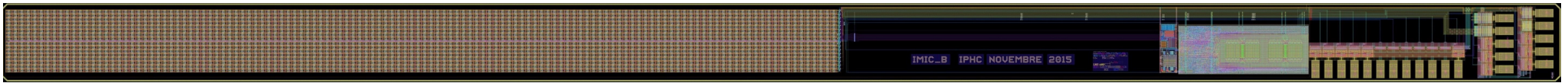
- Suivi de la croissance de tumeurs du foie et de leur réponse au traitement chez la souris
 - Thèse **Loriane Portal** (BDO CNRS/Région, 2018) -> IDL
 - F. Cassol, L. Portal *et al.* *iScience* 21 (2019) 68
 - Thèse **Floriane Cannet** (MITI, 2024) -> CERIMED
- Décomposition en matériaux de base par des méthodes proximales à métrique variable
 - Thèse **Souhil Tairi** (BDO CNRS/Région, 2019) -> Institut Fresnel
 - S. Tairi *et al.* *IEEE TRMPS* 5 (2021) 548
- SELF PorTrait (CRCM, CPPM, I2M), Fondation arc (2024-2026)
 - Recherche des vulnérabilités aux stades précoces et avancés pour cibler des cellules cancéreuses et immunitaires dans des modèles de cancer du foie
- FLAP*VAP (C2VN, CERIMED, ICR, CRCM, CPPM, iDEAL), AMIDEX interdisciplinaire (2024-2026)
 - [¹⁸F]F-fluorinated apelin for PET vasculomonitoring of APJ expression



	Amptek : XR-100T-CdTe	DT : X-Card ME3	DT : Prototype	CPPM : XPAD3-Si
Detectors				
Characteristics	<ul style="list-style-type: none"> • Mono-pixel detector • 3 mm pitch • Cadmium Telluride • 1 mm thickness 	<ul style="list-style-type: none"> • Linear detector of 128 pixels • 800 μm pitch • Cadmium Telluride • 2 mm thickness • Up to 128 bins 	<ul style="list-style-type: none"> • 2D Matrix • 2x 24x36 pixels • 350 – 400 μm pitch • Cadmium Zinc Telluride • 2 mm thickness • Up to 8 bins 	<ul style="list-style-type: none"> • 2D Matrix • 130 μm pitch • Silicon • 500 μm thickness



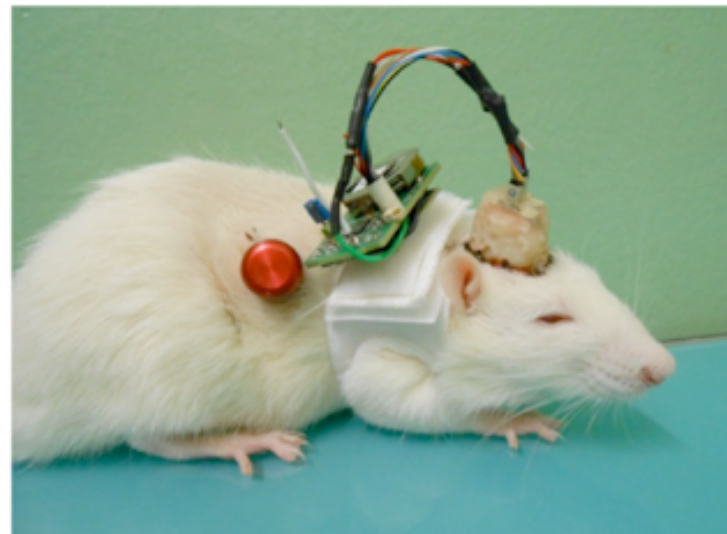
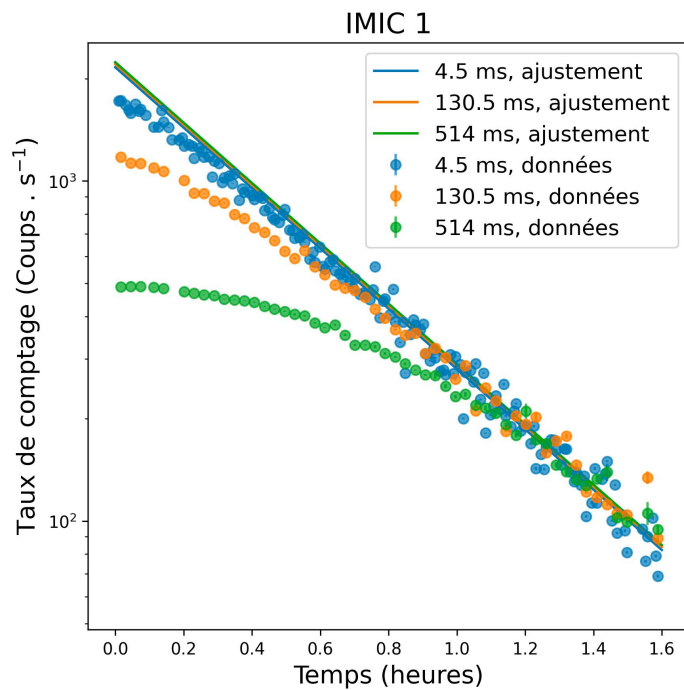
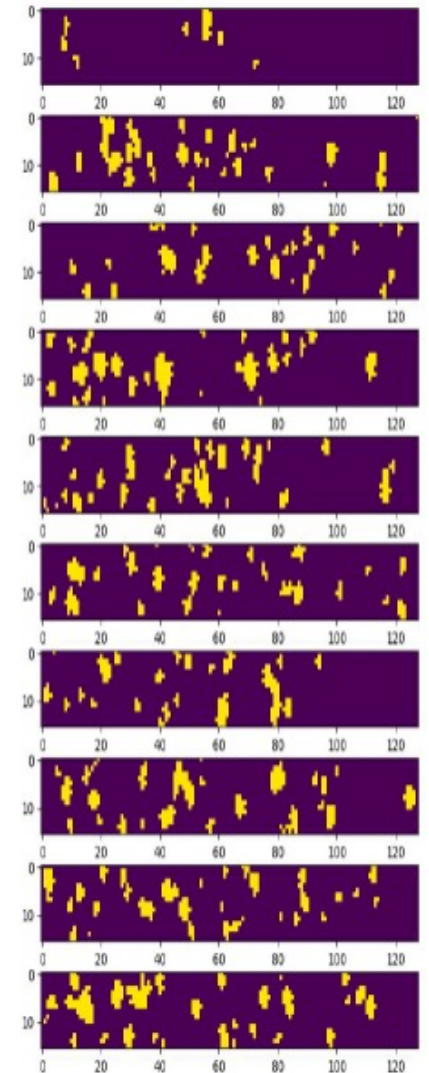
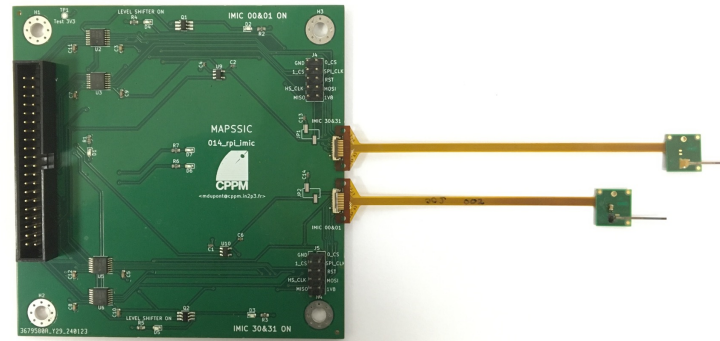
Sonde IC bêta⁺ : MasterProjet MAPSSIC (IJCLab, IPHC, CPPM, CERMEP)



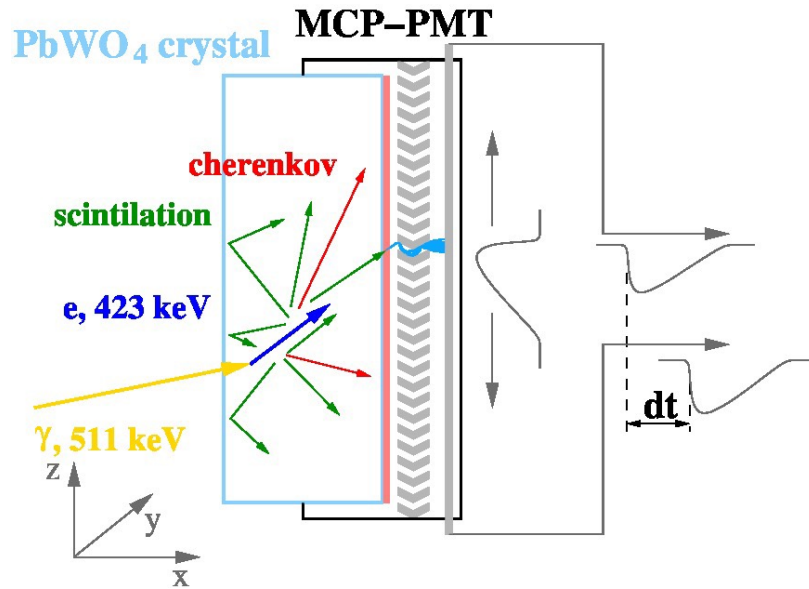
- 0.61 x 12 x 0.25 mm³ implantable needle consisting of 2048 (16 x 128) pixels 30 x 50 μm²
- Based on a FE amplifier of ALPIDE (**AL**ice **P**ixel **D**etector)
- ¹⁸F sensitivity (simulated) : 0.8 cps/(Bq/mm³)
- Low power (55 nW/pixel)

Au CPPM :

- Capot + carte tête
- Acquisition sans fil (carte sac à dos)



Development of scintronic MCP-PMT detection modules for fast timing applications (CEA-Irfu, CPPM, IJCLab)



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

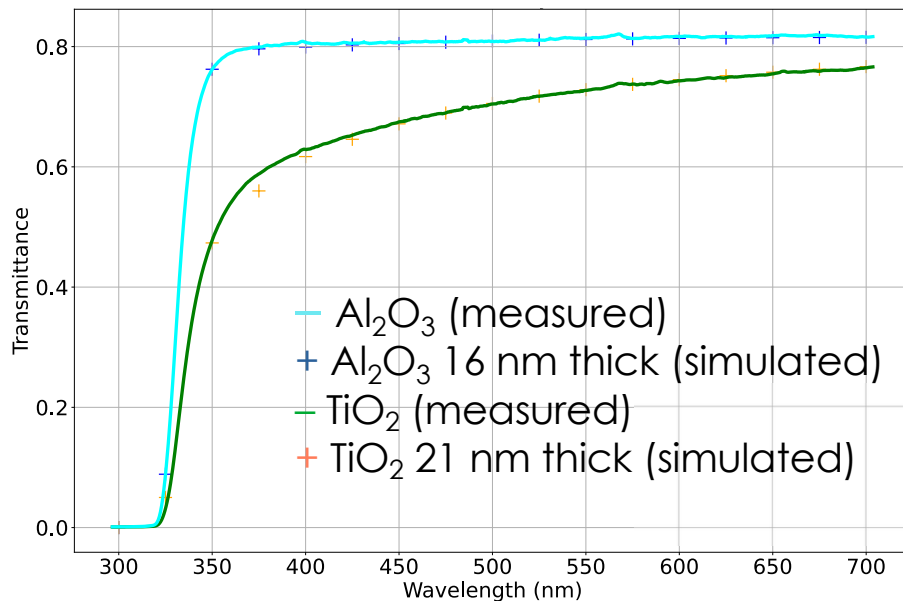
- D. Yvon *et al.* JINST 15 (2020) P07029

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.* NIMA 1048 (2023) 167905

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

- L. Cappellugola *et al.* Technical Forum Geant4, 2022
- Thèse **Laurie Cappellugola** (BDO CNRS/Région, 2023) -> DQPRM



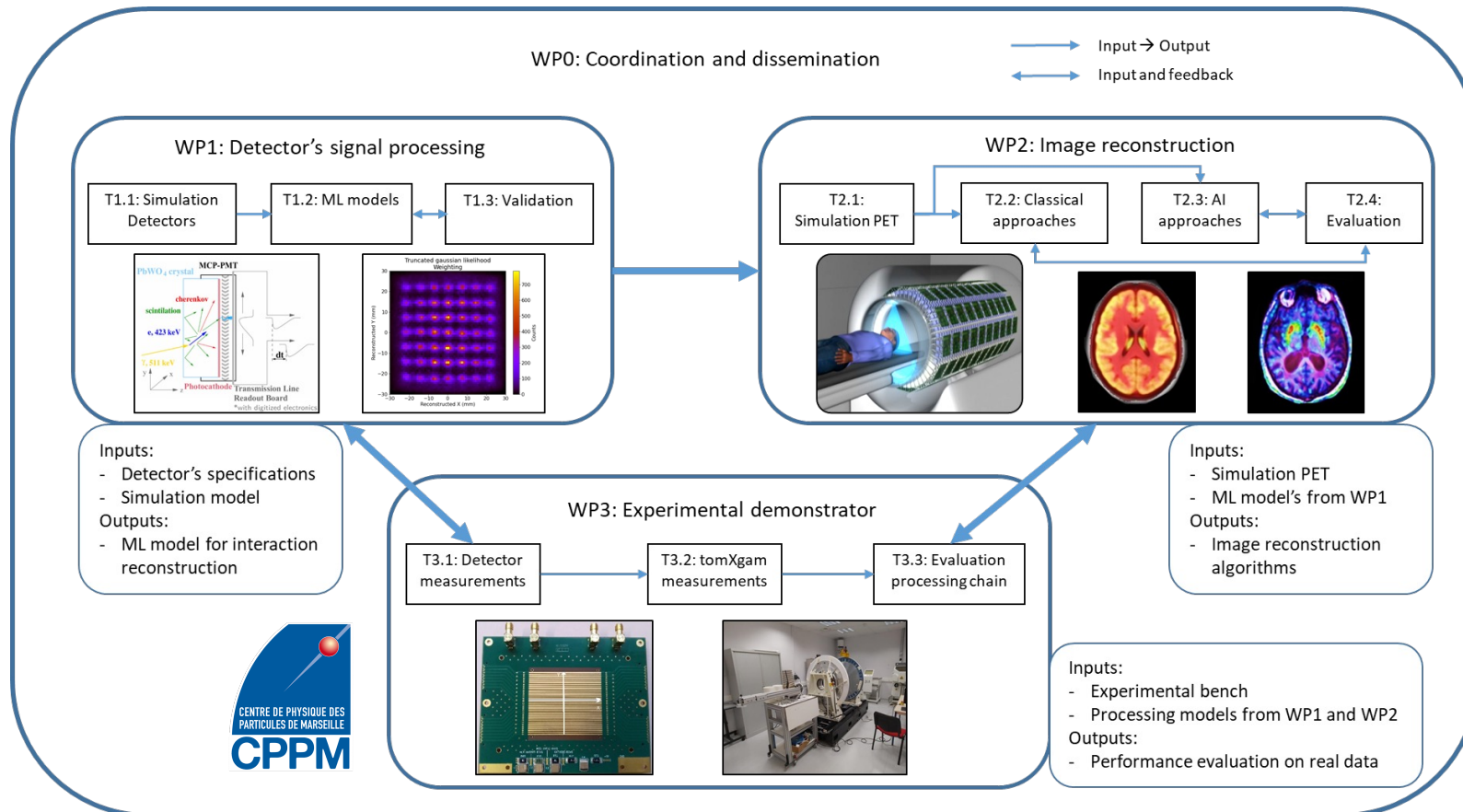
Apprentissage Automatique pour l'Imagerie Moléculaire et la Médecine du future
ANR-24-CE45-7518 – durée : 46 mois – budget total : 583 k€ – budget CPPM : 114 k€

Objectif du projet :

Développer des méthodes IA pour lever ces verrous numériques

Spécificités :

- IA de confiance : méthodes de quantification des incertitudes pour l'aide à la prise de décision
- Validation sur des données expérimentales



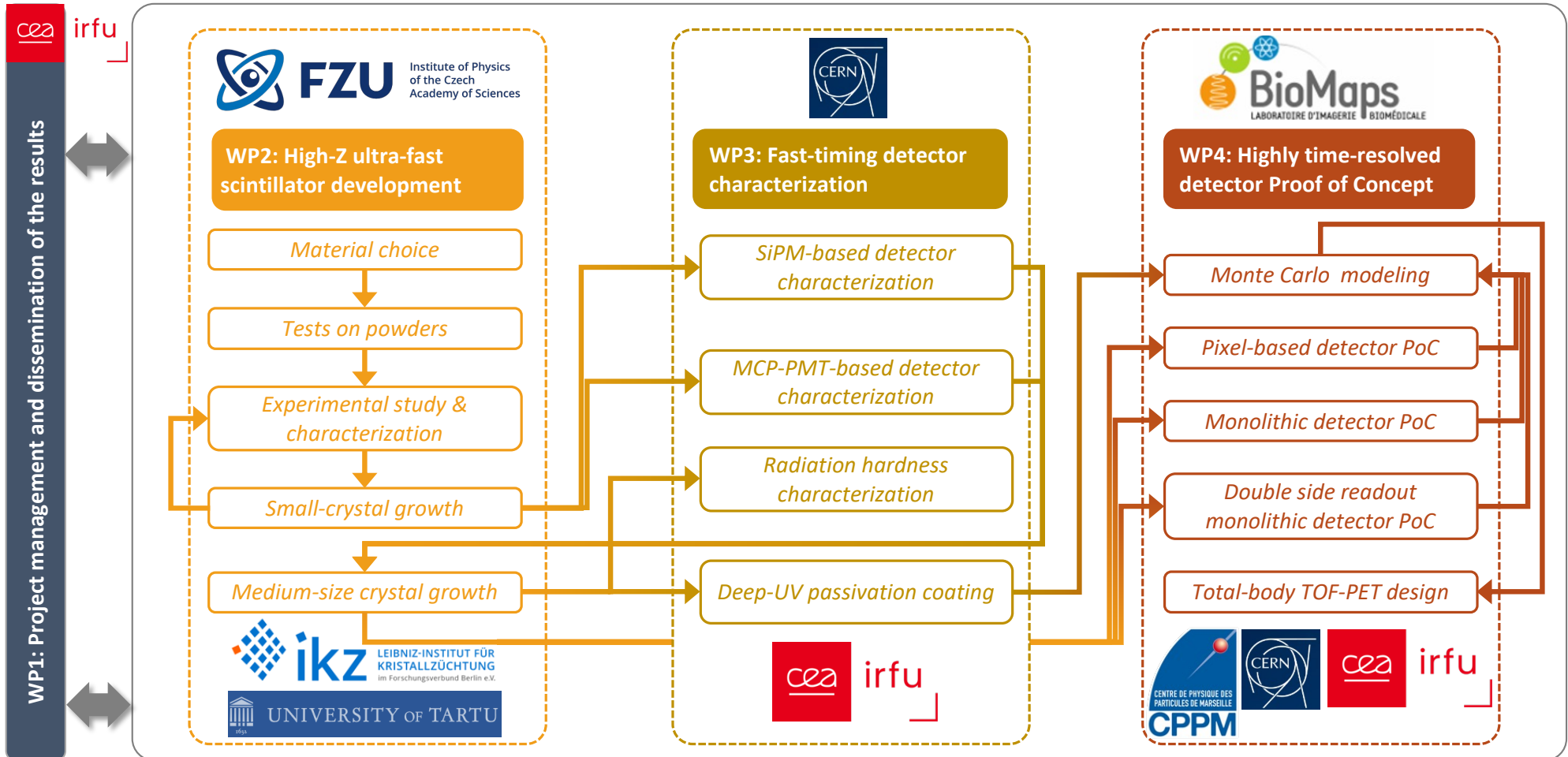
Chronography



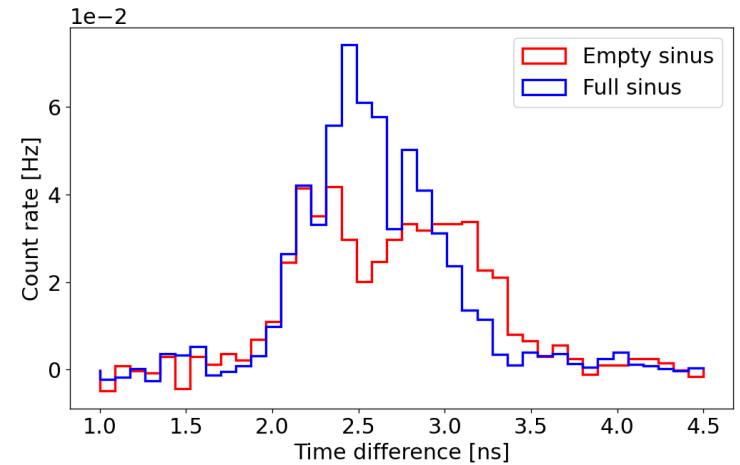
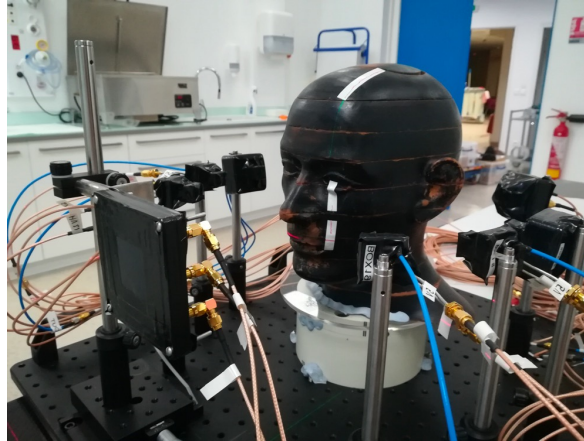
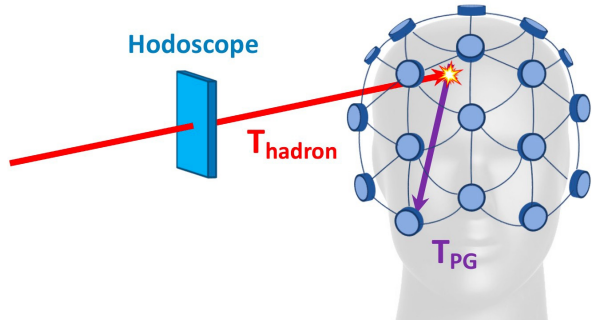
Cherenkov and cross-luminescence timing for highly time resolved ionizing radiation detectors for physics and society
EIC Pathfinder Open 2024 – rated: 3.95/5.00 – resubmission in 2025



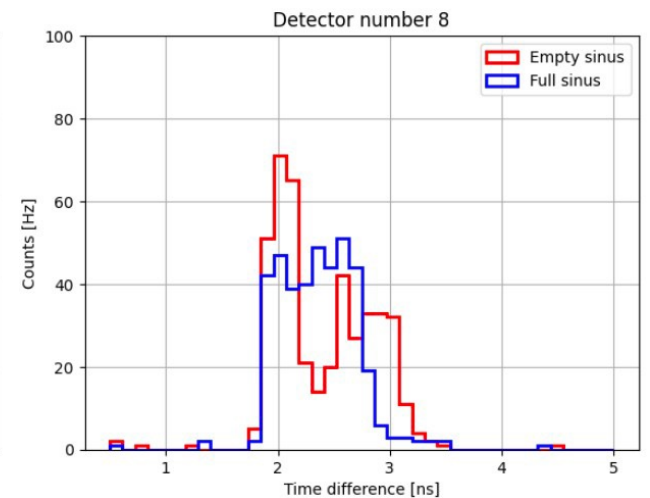
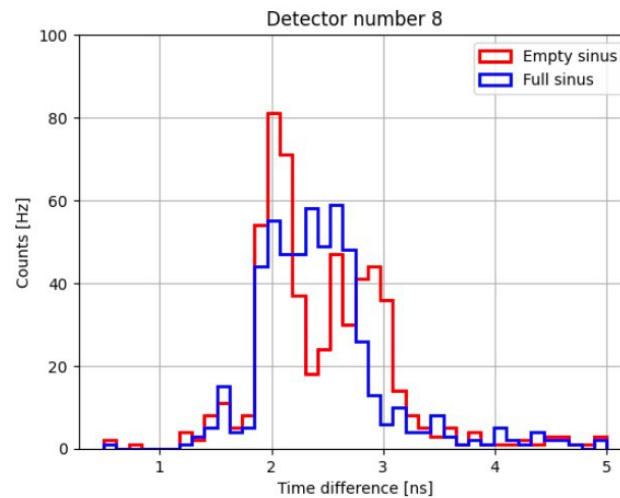
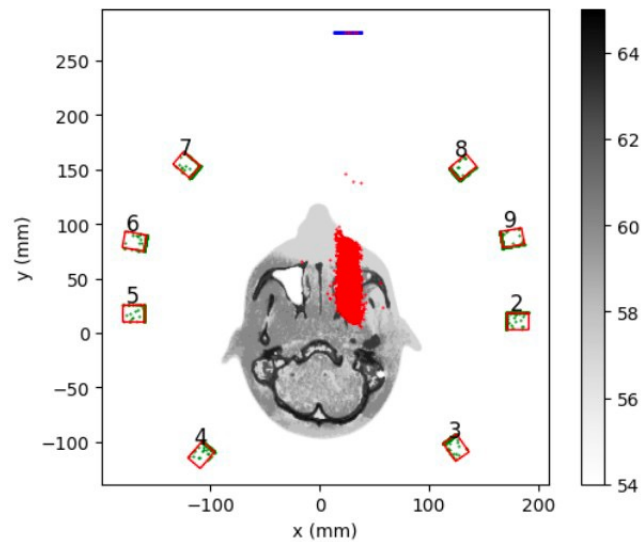
Functional & non-functional requirements



PGTI (ERC)/TIARA (PCSI)



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

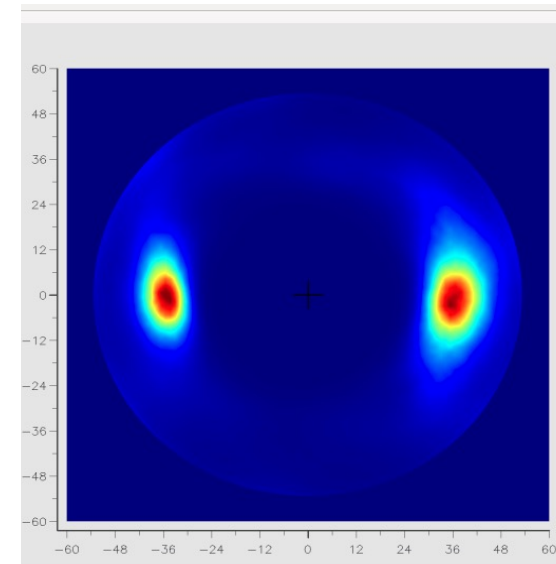
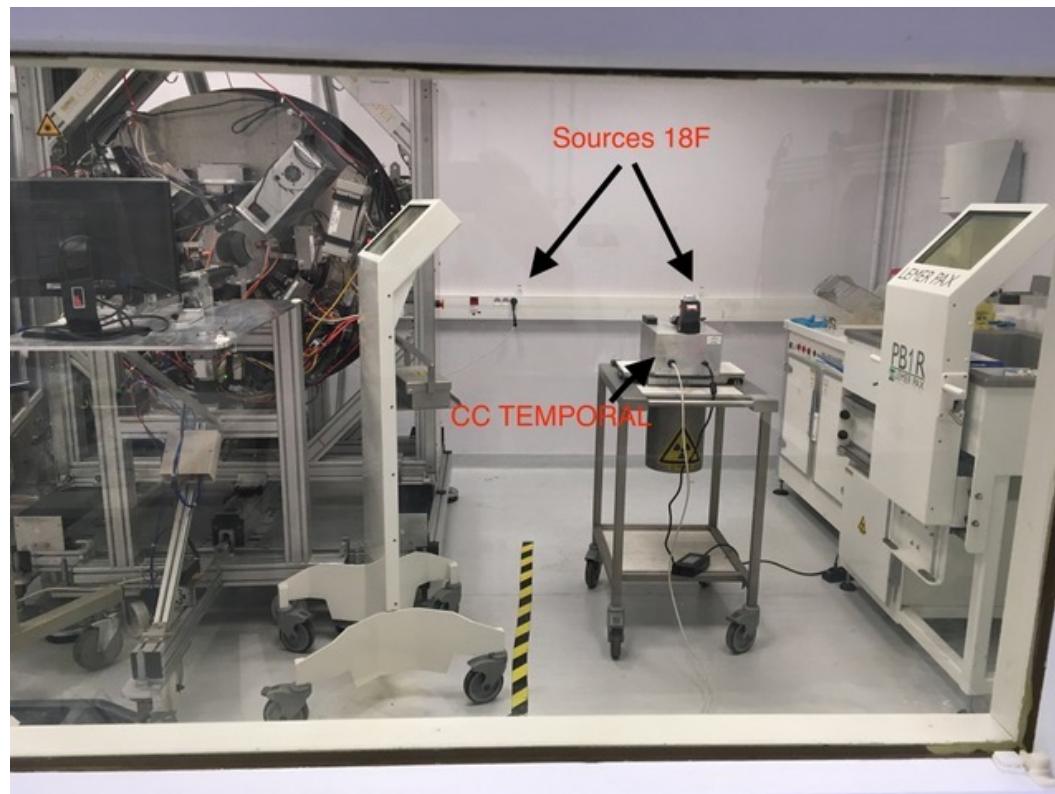
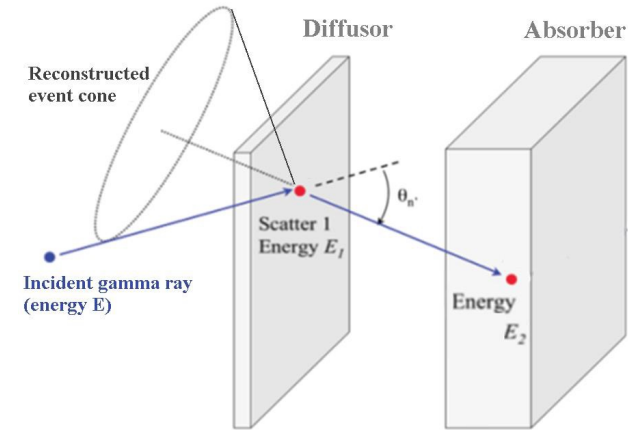


Red: vertices positions
Blue: interaction with the beam monitor
Green: Interaction with the TIARA detector

Thèse **Alicia Garnier** (CNRS/IN2P3, 2022-2025)
Thèse **Adélie André** (U. Grenoble-Alpes, 2022-2025)
ERC Staring Grant **Sara Marcitili** (LPSC, 2023-2027)

Characterization of the Temporal Compton camera using Philips dSiPM

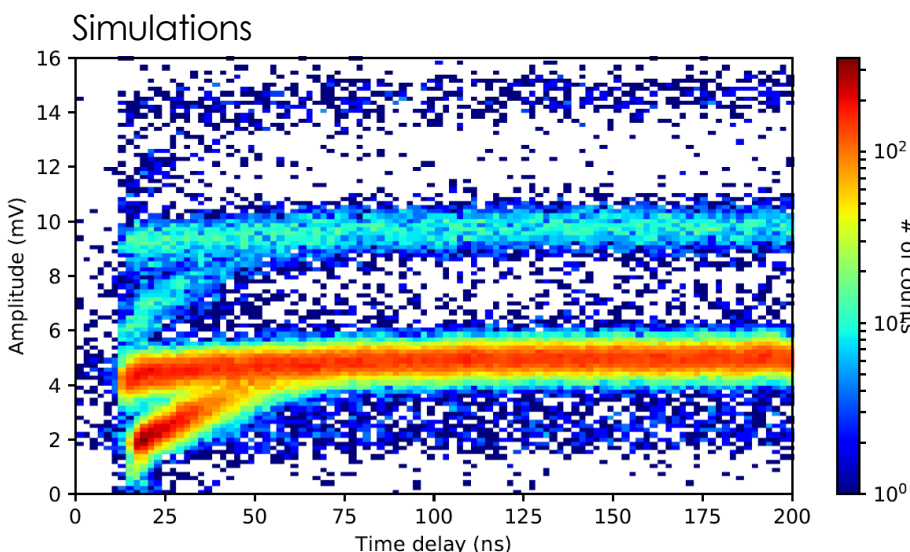
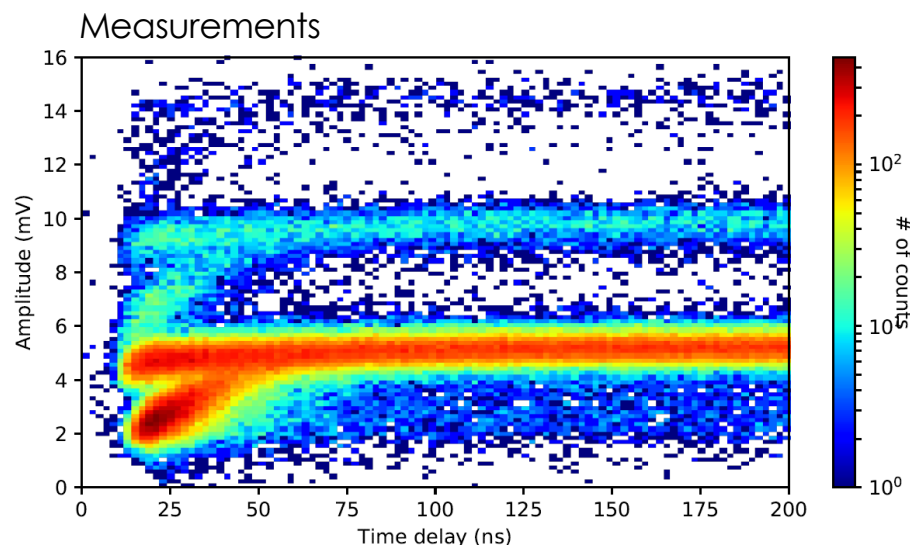
- Angular resolution (ARM): $(21.3 \pm 0,4)^\circ$
- Intrinsic efficiency: $\sim 8\%$ (measured), 11.2% (simulated)
- Thèse **Brahim Mehadji** (AMU, 2021) -> Associate Prof. UC Davis



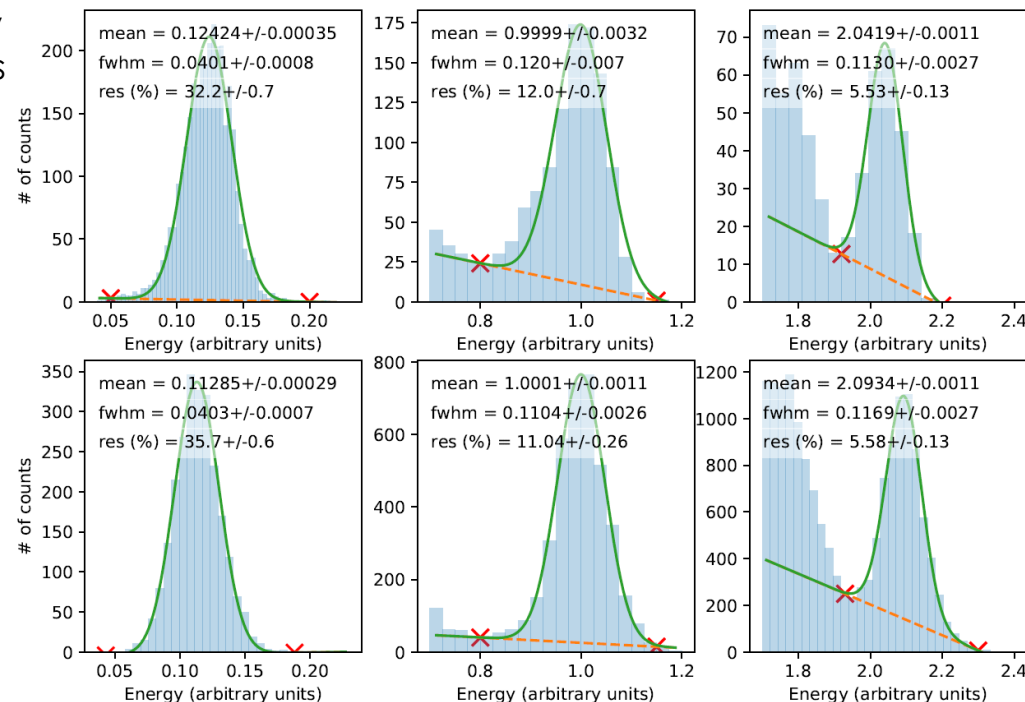
Source 1 : -30 cm — source 0 : 30 cm
Source-camera distance_ : 60 cm

B. Mehadji *et al.* JINST 17 (2022) P09025

MPK MPPC S13360-3050 characterization as proposed by J. Rosado and S. Hidalgo in JINST 10 (2015) P10031 and its GATE simulation



Measurements



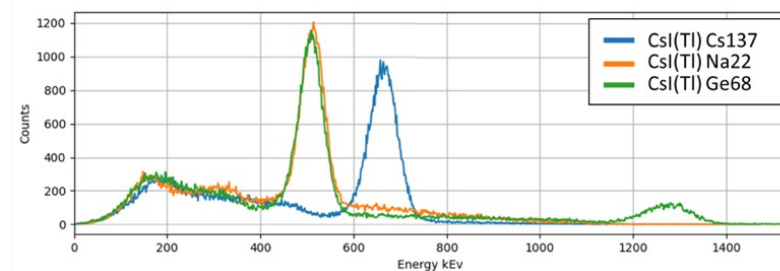
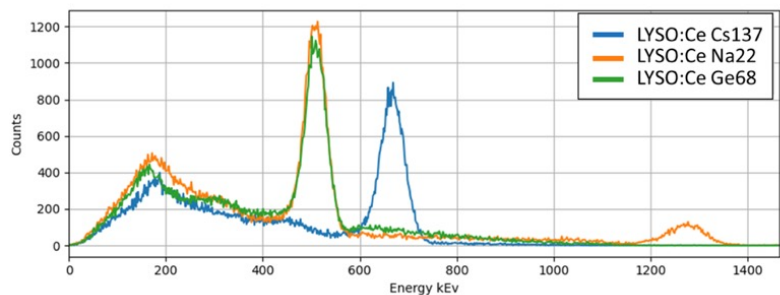
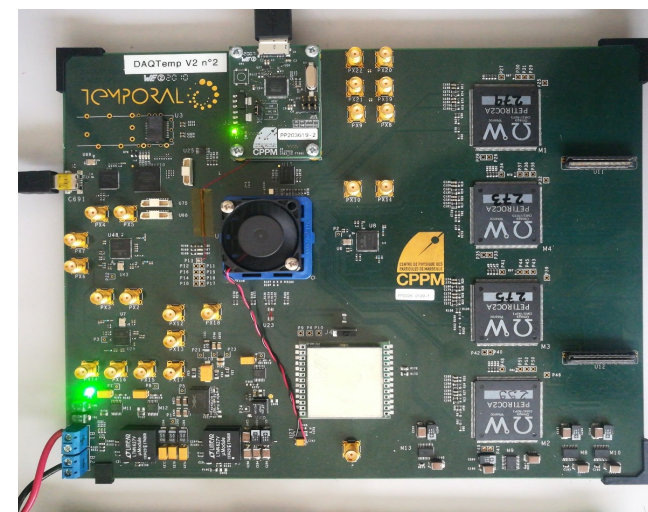
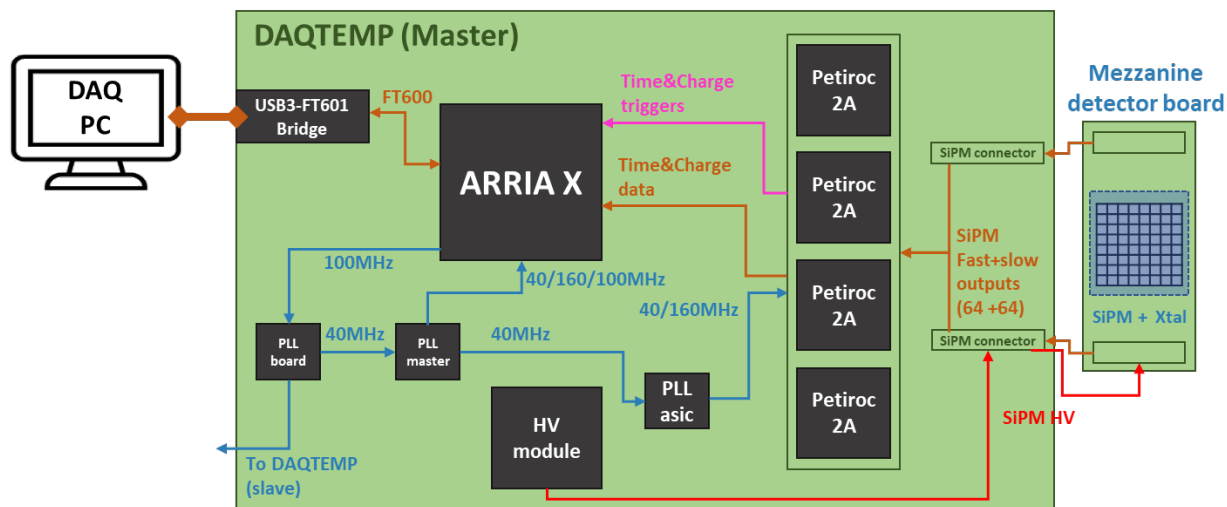
Simulations

E (keV)	Measurements		Simulations		Relative diff. (%)	
	pos.	res. (%)	pos.	res. (%)	pos.	res.
60	0.11	32.6 ± 0.7	0.11	32.9 ± 0.5	0	0.9
511	1.00	13.5 ± 0.8	1.00	13.3 ± 0.3	0	1.5
1275	2.48	8.6 ± 0.6	2.49	8.5 ± 0.7	0.4	1.2

B. Mehadji *et al.* NIMA 1048 (2023) 167905

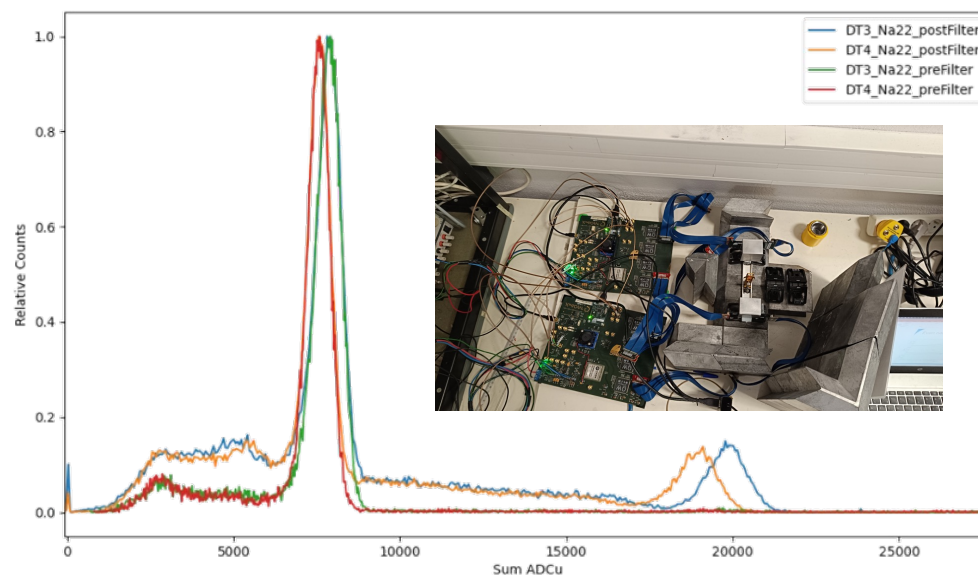
Detailed Monte Carlo simulation of a 3 x 3 x 5 mm³ LYSO crystal readout by a MPK MPPC S13360-3050CS

Development of the DAQTemp readout board

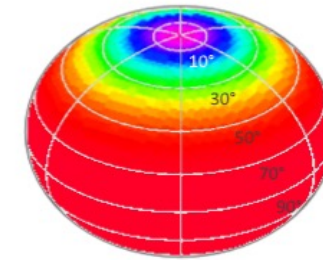
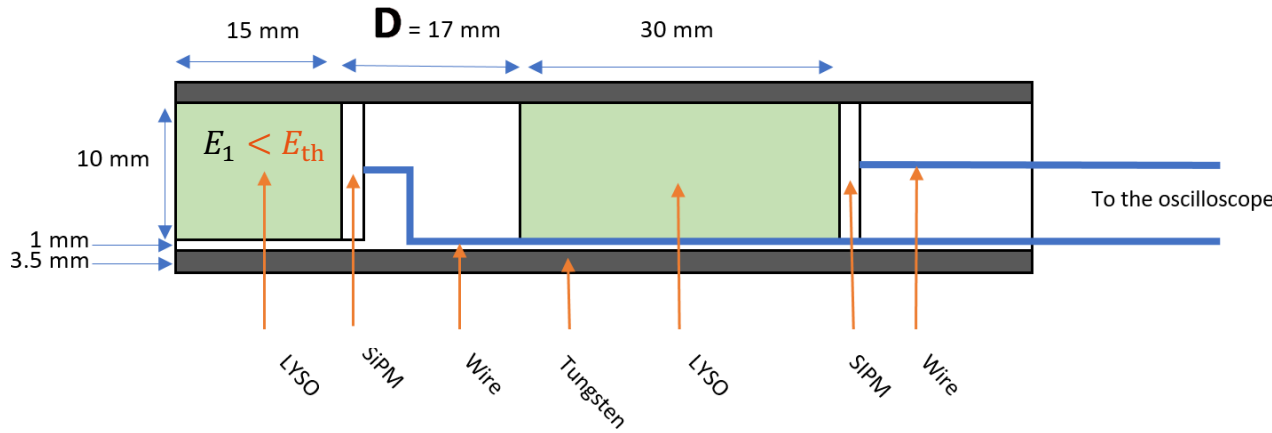


Energy [keV]	CsI(Tl) resolution (FWHM)	LYSO resolution (FWHM)
511	11.4 %	9.8 %
662	10.5 %	8.6 %
1275	8.8 %	6.8 %

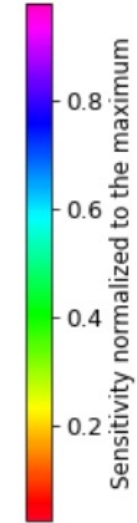
- ❑ SiPM array SensL model ARRAYJ-30035-64-PCB with 64 (8 x 8) SiPMs 3 x 3 mm²
- ❑ LYSO or CsI(Tl) 26,7 x 26,7 x 20,0 mm³ crystals



CCP: Compton Collimated Probe

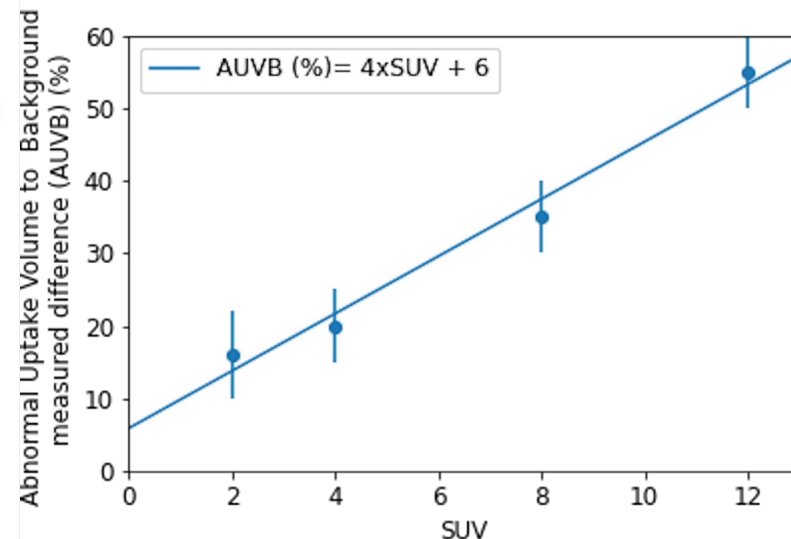
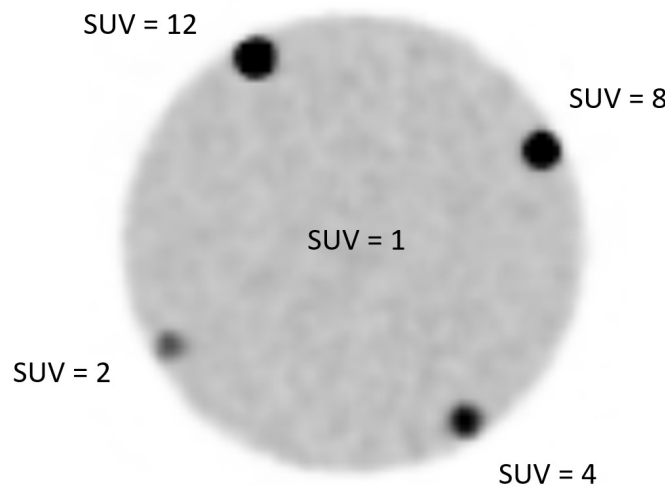


Compton Probe



$$\theta_{\max} = \arccos \left(1 - \frac{E_{\text{th}}}{E} \frac{m_e c^2}{E - E_{\text{th}}} \right)$$

B. Mehadji, et al. JINST 19 (2024) T08002
 B. Mehadji, M. Dupont et al. PCT/EP2024/075264
 CNRS Déclic 2023-2024



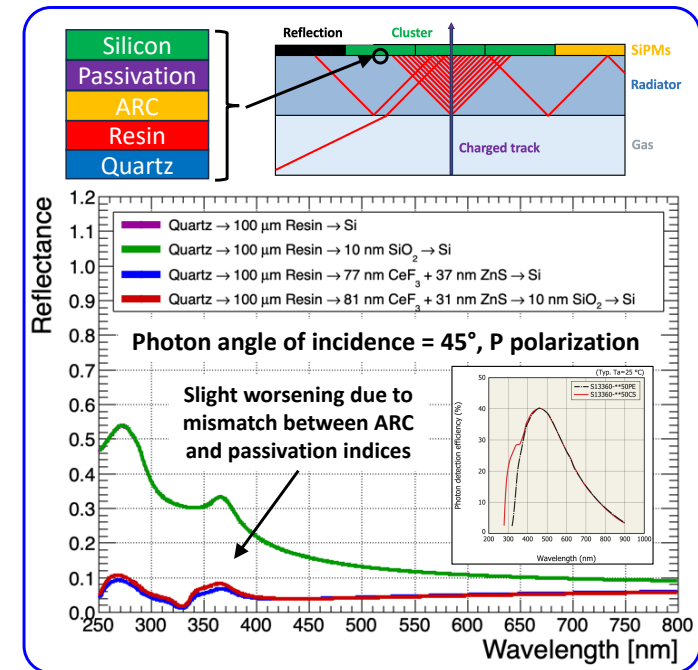
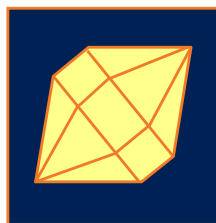
DRD4: R&D for Photon Detectors and Particle identification Techniques

- WG1: Photon Detectors
- WP4: Time of Flight Detectors
 - ❑ Task4.1: Study the coupling of a thin Cherenkov radiator to a single-photon detector array for TOF of charged particles (Task leader: C. Morel)
 - ❑ High precision timing (~10 ps) using high refractive index solid Cherenkov radiators coupled to SiPMs arrays or MCPs



DRD6: R&D on Calorimetry

- ❑ ScintCal: Scintillator material for future Calorimeter



Courtesy: Nicola Nicassio (INFN Bari)

PC-CT

- Déménagement de **PIXSCAN-FLI** au CERIMED en déc. 2023 et recrutement de Floriane Cannet sur un poste d'IR Carnot STAR au CERIMED
- Financement du projet **SELF PorTrait** par la fondation arc pour 36 mois (2024-2026)

Sonde bêta+

- Continuation projet **MAPSSIC** financé par la MITI en 2022 (30 k€) et 2023 (15 k€)

Fast timing

- Prolongation du projet ANR **ClearMind** jusqu'au 30 juin 2025
- Financement du projet ANR PRC **AAIMME** — Geoffrey Daniel (PI), CEA-DES, durée : 48 mois (2025-2028)
- Soumission du projet européen EIC Pathfinder Open 2024 **Chronography**
- Prolongation du projet PCSI **TIARA** jusqu'au 30 avril 2024
- ERC Starting Grant **PGTI** — Sara Marcatili, LPSC (2023-2027)
- Participation aux DRDs 4 (**TOF Detectors**) et 6 (**ScintCal**) du CERN
- Prolongation projet **TEMPORAL (II)** jusqu'au 30 nov. 2024
- Prématuration projet **CCP** (Collimated Compton Probe) financé par DECLIC (2023-2024), 10 k€

Publications

- C. Sequera, F. Cannet *et al.* **Lipid and cell cycling perturbations driven by the HDAC inhibitor romidepsin render liver cancer vulnerable to RTK targeting and immunologically active**, *subm. to Nat. Comm.* (2024)
- F. Cannet *et al.* **Tracing specificity of immune remodelling associated with distinct anticancer treatments in mice**, *subm. to iScience* (2024)
- A. André *et al.* **A fast plastic scintillator for low intensity proton beam monitoring**, *accepted in IEEE TRPMS* (2024)
- B. Mehadji *et al.* **Beta+ surgical radio-guidance using a small Compton-angles collimation probe**, *JINST* **19** (2024) T08002
- A. Galindo-Tellez *et al.* **First ClearMind gamma detector prototype for TOF-PET imaging**, *JINST* **19** (2024) P07037
- S. El ketara *et al.* **Characterization of IMIC, an implantable needle-shaped positron sensitive monolithic active pixel sensor for preclinical molecular neuroimaging**, *NIM A* **1064** (2024) 169456
- J. Nuyts, M. Defrise, C. Morel and P. Lecoq **The SNR of time-of-flight positron emission tomography data for joint reconstruction of the activity and attenuation images**, *PMB* **69** (2024) 015011
- C.-H. Sung *et al.* **Detailed simulation of the ClearMind prototype detection module and event reconstruction using artificial intelligence**, *NIM A* **1053** (2023) 168357
- M. Jacquet *et al.* **A high sensitivity Cherenkov detector for prompt gamma timing and time imaging**, *Sci. Rep.* **13** (2023) 3609
- B. Mehadji *et al.* **Monte Carlo simulation of a scintillation crystal read by a SiPM with GATE**, *NIM A* **1048** (2023) 167905

Brevet

- B. Mehadji *et al.* **System for detecting gamma rays or X-rays with improved collimation**, *PCT/EP2024/075264* (2024)

Conférences

- A. Garnier *et al.* **A Monte Carlo Simulation for Prompt Gamma Time Imaging**, IEEE NSS/MIC'2024, Tampa, FL, USA (poster)
- Y. Boursier *et al.* **Spectral CT reconstruction with ProMeSCT: results on real data from PIXSCAN**, CT 8th Meeting 2024, Bamberg, Germany (poster)
- A. Cherni *et al.* **An alternating algorithm for Prompt Gamma Time Imaging with the TIARA project**, IEEE NSS/MIC 2023, Vancouver (virtual), Canada (oral)
- A. Cherni *et al.* **An alternating approach to reconstruct prompt gamma distribution and hadron velocity profiles from Time-Of-Flight measurements**, ion 2023, London, U.K. (oral)
- A. Cherni *et al.* **Optimisation alternée pour la localisation des rayons gamma prompts et l'estimation du profil de vitesses en hadronthérapie**, GRETSI 2023, Grenoble, France (poster)
- F. Cannet *et al.* **Preneoplastic behaviours in hepatocellular carcinoma: cellular and molecular traits in quiescent versus evolving lesions**, EMIM 2023, Salzburg, Austria (poster)

Thèses

- Floriane Cannet, **Apprentissage profond pour l'imagerie CT spectrale par comptage de photons et conception de traitement sur des modèles murins de cancers du foie**, Aix-Marseille Université, mars 2024
- Laurie Cappellugola, **Modélisation Monte Carlo d'un détecteur scintronique à haute résolution spatio-temporelle couplé à un tube multiplicateur à galette de micro-canaux**, Aix-Marseille Université, juillet 2023

HDR

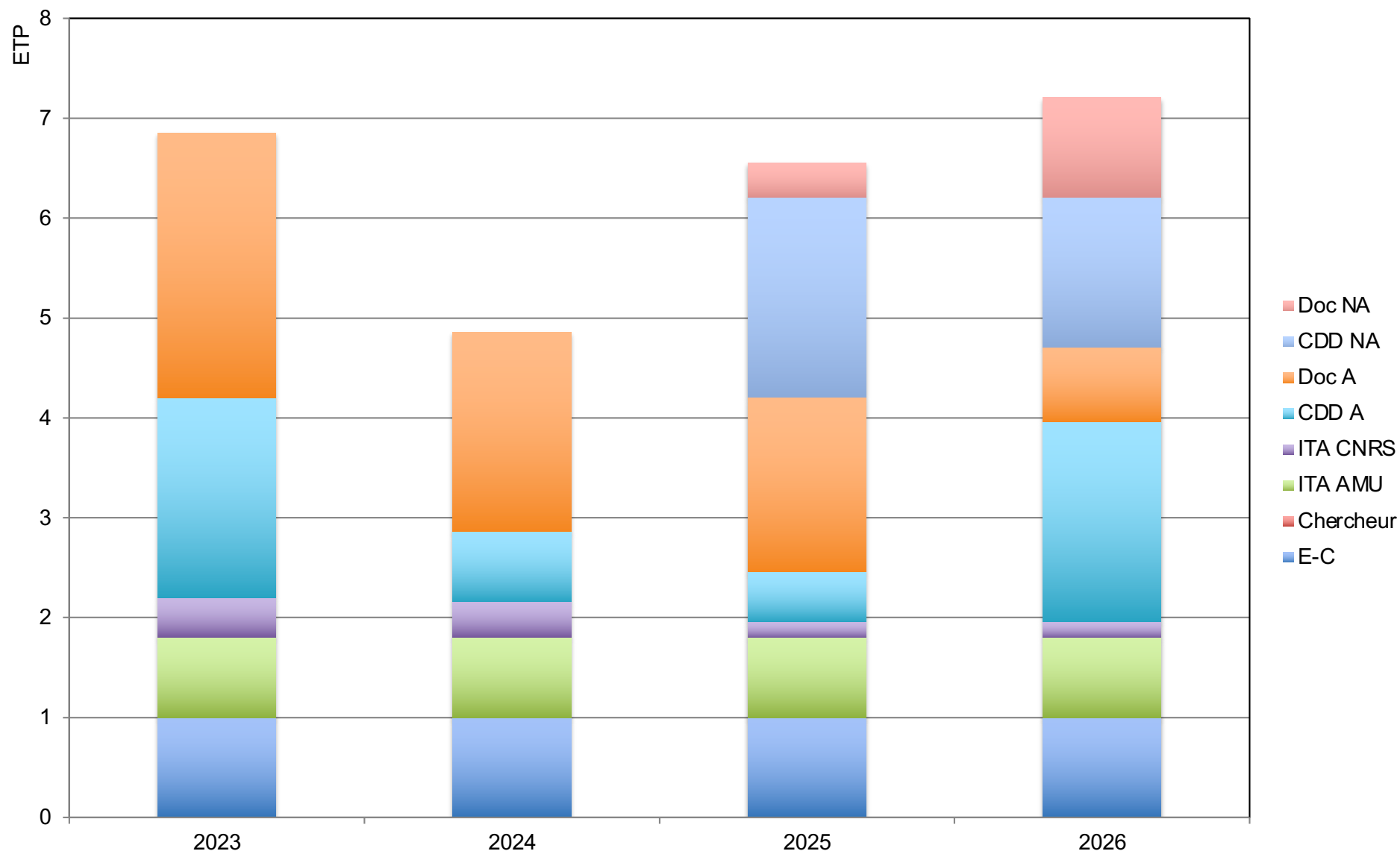
- David Tisseur, **Contribution aux contrôles et aux mesures non destructifs par rayonnements ionisants**, Aix-Marseille Université, juin 2023

- PC-CT
 - Simulation de la réponse de détecteurs à comptage de photons (thèse **Mélissa Leroy**)
 - **FLAP*VAP** (AMIDEX interdisciplinaire) **SELF PorTrait** (Fondation arc)
- Sonde bêta+
MAPSSIC
 - Développement de la communication sans fil vers la nouvelle IMIC
 - Réalisation carte d'acquisition embarquée (**Mathieu Dupont, Téo Weicherding**)
- Fast timing
ClearMind (ANR) **AAIMME** (ANR) **Chronography** (resoumission EIC Pathfinder Open)
 - Mise en œuvre de modules MCP-PMT sur tomXgam (**post-doc ANR 12 mois**)
 - Modélisation optique de détecteurs scintillateurs (**doctorant Chronography ?**)**PGTI** (ERC Starting Grant Sara Marcatili, LPSC)
 - Modélisation Monte Carlo du détecteur TIARA (thèse **Alicia Garnier**)
 - Développement de l'algorithme d'imagerie temporelle des gamma prompts (**post-doc 24 mois PGTI**)**DRD4** (IN2P3?)
 - Tâche 4.1 du WP4 *Study the coupling of a thin Cherenkov radiator to a single-photon detector array for TOF of charged particles* (**post-doc IN2P3 24 mois ?**)**CCP** (prématuration CNRS Déclic)
 - Prématuration d'une sonde Compton collimatée peropératoire (**post-doc PREMAT 18 mois ?**)

Feuille de route par projet/thématique

PC-CT	2023	2024	2025	2026	2027	2028	
PIXSCAN-FLI		exploitation au CERIMED thèse Floriane Cannet (03.24) -> IR Carnot @ CERIMED					
FLAP*VAP (AMIDEX INTERDISCIPLINAIRE 2024-2026) SELF-PorTrait (ISERM FONDATION ARC 2024-2026)		TEP et PC-CT hépatocarcinome PC-CT hépatocarcinome					
MultiX (THESE CIFRE 2023-2026) DETECTION TECHNOLOGY/CPPM		modélisation pixels CdTe thèse Mélissa Leroy (10.26)					
Sonde bêta+	2023	2024	2025	2026	2027	2028	
MAPSSIC (MITI 2022-2023) IJCLab/IPHC/CPPM/CERMEP		capot/carte tête + DAQ sans fil					
Fast timing	2023	2024	2025	2026	2027	2028	
ClearMIND (ANR PRC 2020-2025) IRFU/CPPM/IJCLab		MC couches minces + IHM tomXgam thèse Laurie Cappellugola (07.23)					
AAIMME (ANR PCR 2025-2028 ?) DES/IRFU/BioMaps/INRIA/CPPM		acquisition de données sur tomXgam post-doc tbc					
Chronography (EIC Pathfinder Open 2026-2029 ?) IRFU/BioMaps/U-Tartu/FZU/DKZ/CERN/CPPM (WP3 DRD6)					modélisation détecteur scintronique thèse tbc		
TIARA (INSERM PCSI 2021-2024) LPSC/CPPM/CAL		Prompt Gamma Time Imaging postdoc Afef Cherni (04.24)					
PGTI (ERC Starting Grant 2023-2027) LPSC/CPPM		modélisation Monte Carlo détecteur TIARA thèse Alicia Garnier (09.25) + post-doc tbd					
T4.1 DRD4 (CERN DRD 2024-2026 ?) CPPM/INFN Bari/CERN/FBK/Istanbul		modélisation Tcherenkov TOF detectors post-doc IN2P3 tbc					
TEMPORAL II (PIA ANDRA 2022-2024) Damavan/Weeroc/CPPM		carte DAQTemp v2 CDD Giovanni Brajato (04.24)					
CCP (CNRS DECLIC 2023-2024) CPPM/AP-HM		prématuration sonde collimatée Compton peropérateur post-doc CNRS PREMAT tbc					

Plan de charge/catégorie de personnels



- **Strengths:**

- **Interdisciplinarity** <- nuclear/health and nuclear/energy
- **Multi-disciplinarity** <- from detector to tomographic reconstruction
- **Know-how** <- hybrid pixels, nuclear instrumentation, data acquisition, inverse problems, AI, GATE/Geant4
- **Skills of the technical services** <- electronics, mechanics, informatics
- **Infrastructure** <- imaging room, clean room, irradiation devices

- **Weaknesses:**

- **Subcritical human resources** <- 2 E-C et 1 IR (80%) for 1,8 permanent FTE including only 1 HDR for 3 PhD students et 2 post-docs on average and no CRCN/DR CNRS

- **Opportunities:**

- **Local environment** <- UAR CERIMED, Institute Marseille Imaging
- **National environment** <- France Life Imaging (FLI), GDR MI2B
- **Funding** <- ANR, MITI, A*Midex, IMI, PIA FLI, PIA ANDRA

- **Threats:**

- **Lack of attractiveness due to lack of career opportunities** <- no keyed CRCN in Section 01 since 2017
- **Rare discipline** <- less than 10 PU at the national level
- **Seniority of the team leader**
- **Disappearance** -> transfer R&D on imaging with ionizing radiations to other AMU UMRs, particularly to Fresnel Institute