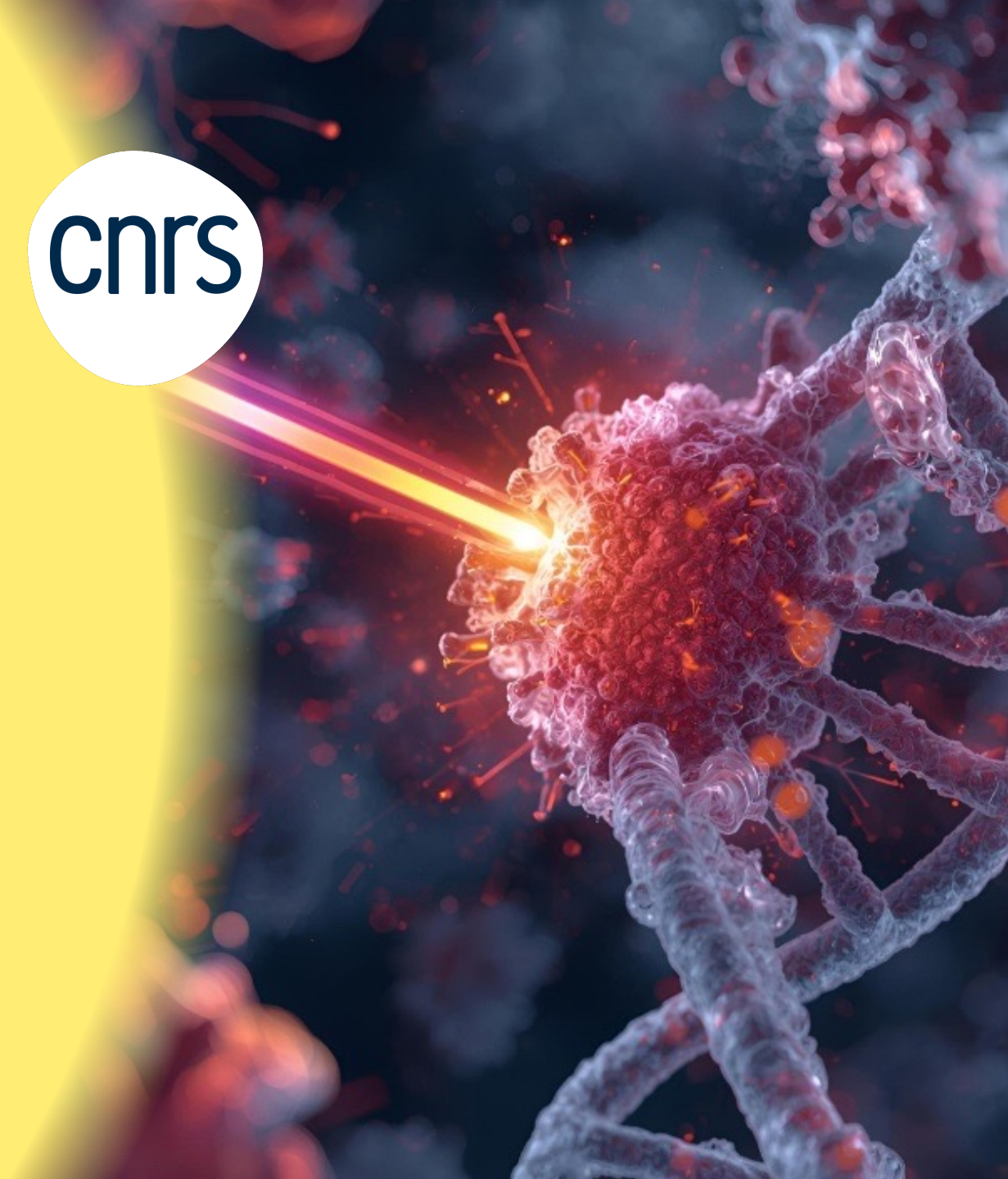
in2p3.cnrs.fr

Master projet Hadronthérapie

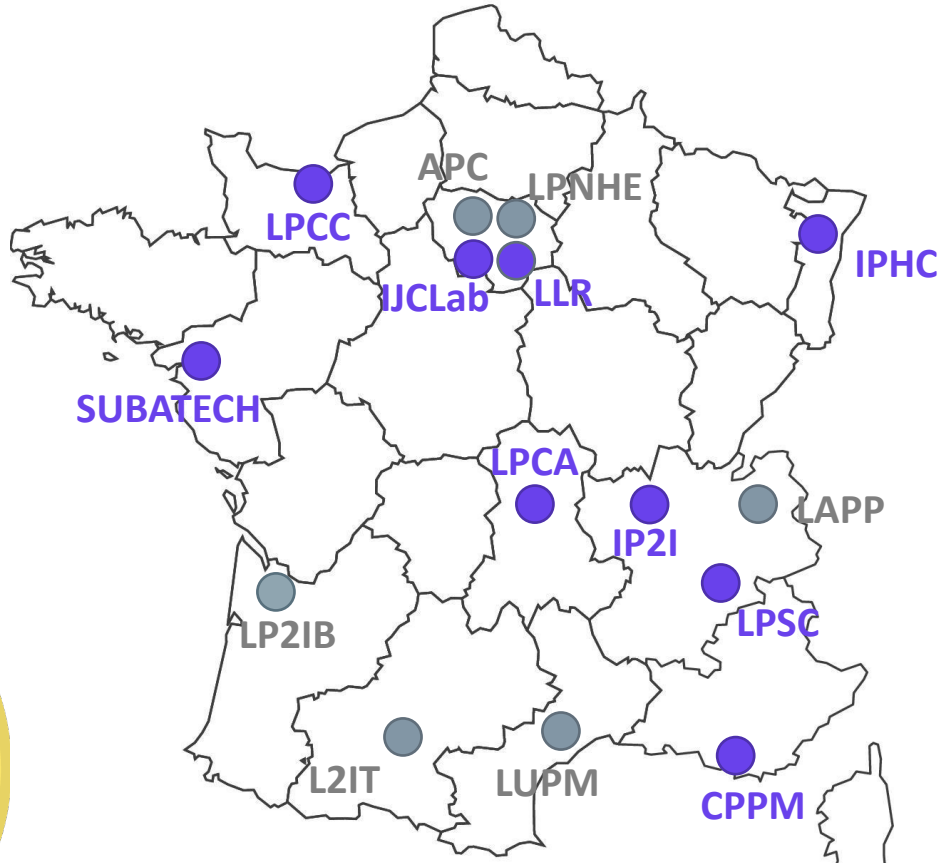
AG du GdR Mi2B
Marseille, 29 Juin – 1 Juillet 2026

Responsables scientifiques :
Sara MARCATILI, Marie Vanstalle,
Claire Rodriguez-Lafrasse, Juliette Thariat
on behalf of Hadrontherapy IN2P3 project
Responsable technique :
Stéphane Higueret



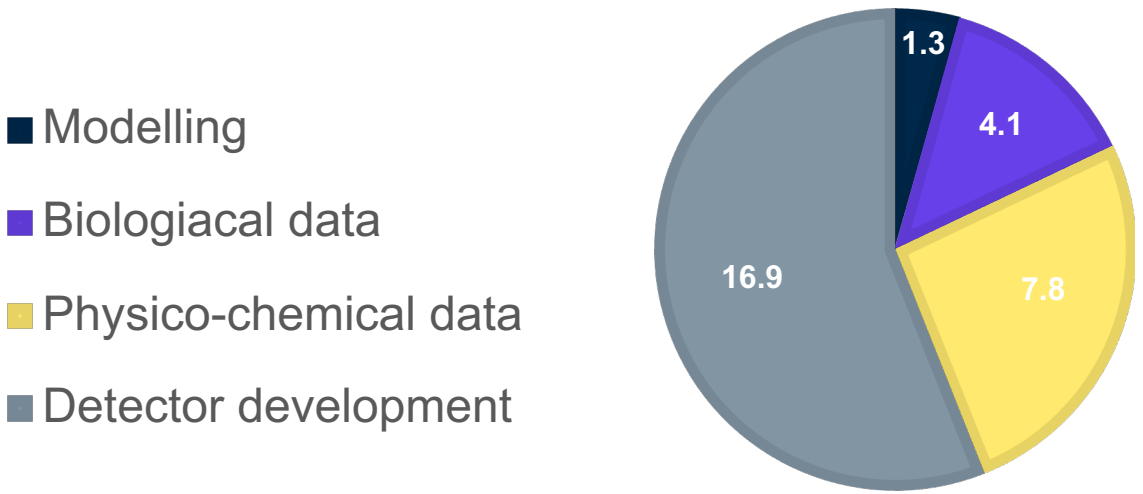
Hadrontherapy at IN2P3: key figures

9 IN2P3 labs involved
30 FTE/year @in2p3 + other collaborating institutes
90 persons involved (researchers and engineers)
19 subprojects



CNRS Nuclei & Particles labs involved in Hadrontherapy applications

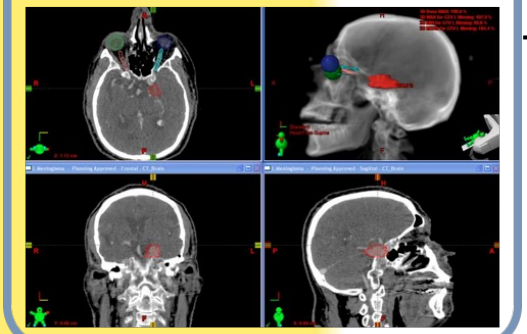
FTE/YEAR AT IN2P3



Research in Hadrontherapy

Imaging

Define tumoral/targeted volume



Treatment planning system (TPS)

Treatment

Dose calculation model

- Physical processes
- Biological processes
- Chemical processes

Irradiation control

- Beam
- Range/dose on-line
- Dose QA

Final goal: improve hadrontherapy treatments

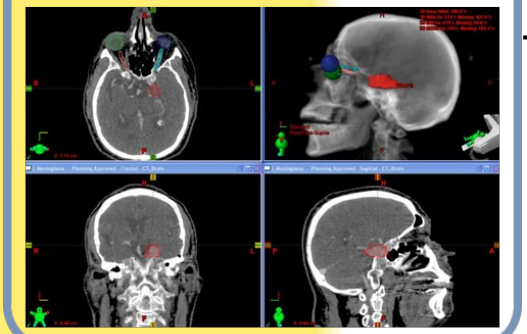
Fundamental research

Translational research

Research in Hadrontherapy

Imaging

Define tumoral/targeted volume



Treatment planning system (TPS)

Treatment

- WP1
- WP2
- WP4
- WP3

Axis 1: Fundamental research

- Dose calculation model
- Physical processes
- Chemical processes
- Biological processes

Axis 2: Translational research

- Irradiation control
- Beam
- Dose
- Range

NUCLÉAIRE & PARTICULES

WP1
Multiscale, multidisciplinary modelling of radiation effects

Coordinator:
Juliette Thariat

Task 1.1 Nano- and micro-metric maps of energy deposition and free radicals *(Coord. E. Testa, IP2I)*
Related projects: NanOx/GATE

Task 1.2 Biological and predictive models of tumour growth *(Coord. M. Badoual, IJCLab)*
Related projects: MODERATO

Task 1.3 Clinical data-driven modelling of NTCP and radio-resistance *(Coord. J. Thariat, LPCC)*
Related projects: aRTwin

3 sub-projects

WP2
Measurement of nuclear and physico-chemical data

Coordinator:
Marie Vanstalle

Task 2.1 Nuclear data measurements *(Coord. M, Vanstalle, IPHC)*
Related projects: CLINM, FOOT

Task 2.2 Chemical data measurements *(Coord. Q. Raffy, IPHC)*
Related projects: Radiolysis

3 sub-projects

WP3
Control of irradiation delivery

Coordinator:
Sara Marcatili

Task 3.1 Beam monitoring *(Coord. M-L. Gallin-Martel, LPSC)*
Related projects: PEPITES@CNAO, N2 Beam profiler, Diamond Hodoscope, MATRIX

Task 3.2 Dose delivery characterisation *(Coord. A-M. Frelin, GANIL)*
Related projects: SCICOPRO, Micro-scintillator

Task 3.3 Range monitoring and tissue composition *(Coord. S. Marcatili, LPSC)*
Related projects: CLaRyS-S2C2, TIARA, XEMIS, vpgTLE

10 sub-projects

WP4
Hadron interactions with biological targets: from cells to patients

Coordinator:
Claire Rodriguez-Lafrasse

Task 4.1 Production of biological data for simulation models *(Coord. A-S. Wozny, IP2I)*
Related projects: MODERATO, SIMUBIO

Task 4.2 Biological advantages of ions on radio-resistant and hypoxic tumours *(Coord. C. Rodriguez-Lafrasse, IP2I)*
Related projects: BIOHADRON

Task 4.3 Combinatorial approaches using ion therapy and other treatments *(Coord. F. Chevalier, CIMAP)*
Related projects: COMBION

3 sub-projects

WP1. Multi-scale, multi-disciplinary modelling of radiation effects

NUCLÉAIRE & PARTICULES

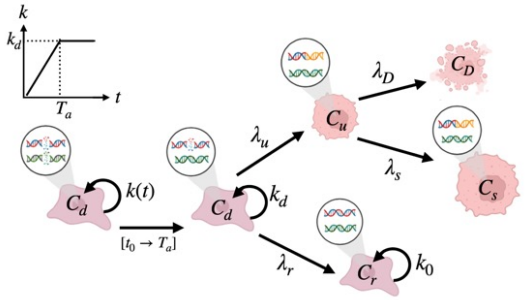
B. Dais's talk

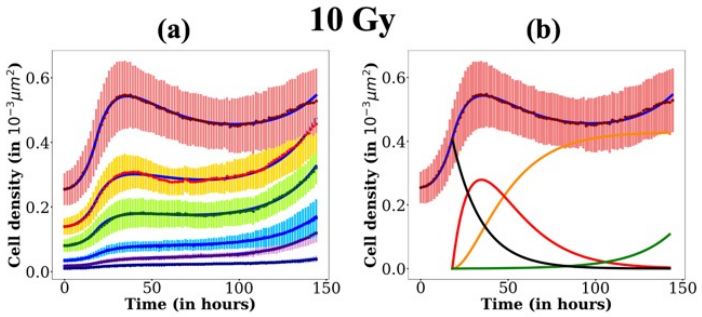
MODERATO

Beyond the Linear Quadratic model: introducing time and space dependency.

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

- Development of compartment model to access different cell populations (damaged, repaired, senescent cells, etc …).
- Multi-parametric fit of cell culture data.





Experiment: points with error bars
Model: solid curves
C_d: damaged cells
C_u: unrepaired cells
C_r: repaired cells
C_s: senescent cells
$C=C_d+C_u+C_r+C_s$ ***(Total cell population)***

NanOx/ GATE

NanOx is a model for predicting cellular and biological doses based on nanometric and micrometric maps of energy deposits and free radicals distributions.

- Development of BioDoseActor for HT applications in GATE.
- Computational speed-up for future integration into TPS.

LPC Particules Plasmas Univers applications Laboratoire de Physique de Clermont

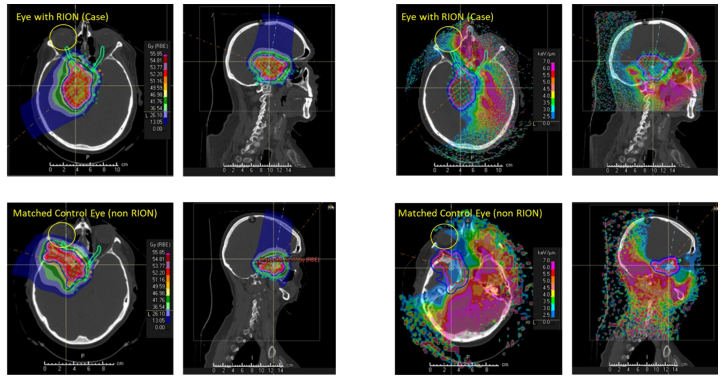
iP2i LES 2 INFINIS LYON

aRTwin

LPC CAEN

Experimental and clinical data-driven modelling of normal tissue toxicity and tumour radio-resistance.

- Extended clinical database: structural and functional assessment with toxicity classification.
- Real photons and protons plans + simulated ion plans.
- Development of NTCP data driven (ML) model.



Final goal: Integrated multi-ion, patient specific digital twin to simulate radiation effects under varying treatment conditions.

WP1. Multi-scale, multi-disciplinary modelling of radiation effects

NUCLÉAIRE & PARTICULES

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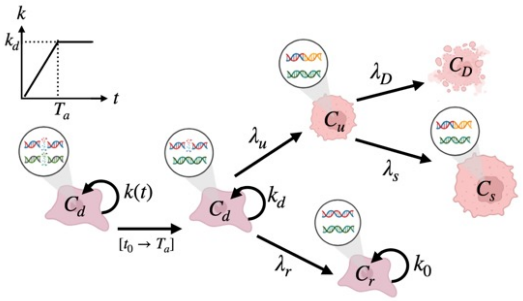

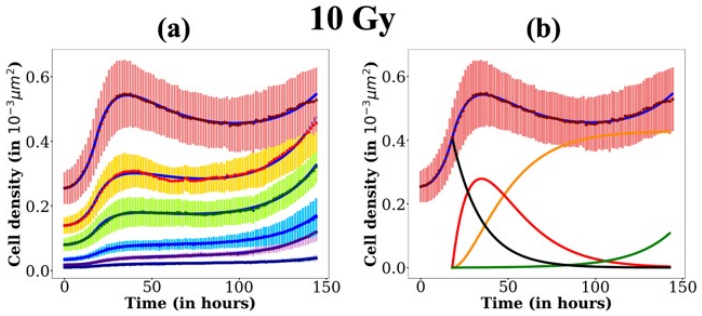

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aRTwin

Experimental and clinical data-drive modelling of normal tissue toxicity and radio-resistance.

- Extended clinical databas onal assessment with toxi
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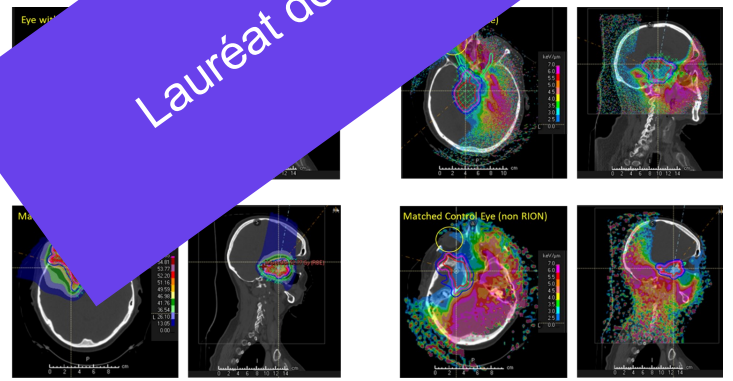
- Developmen model.

Lauréat de l'AaP FEDER



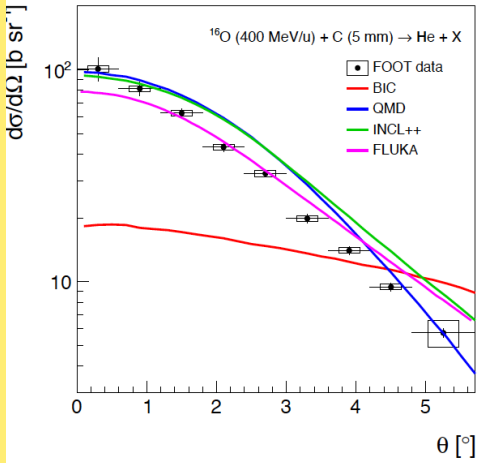
Final goal: Integrated multi-ion, patient specific digital twin to simulate radiation effects under varying treatment conditions.

WP2. Measurement of nuclear and physico-chemical data

- Measurement of nuclear cross section to improve dose calculation models
- Experimental validation of Geant4-DNA

FOOT

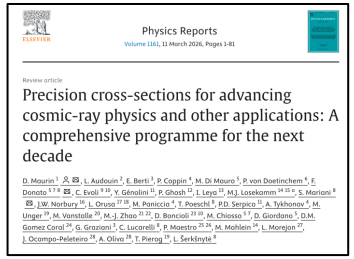
Measuring double differential cross-section for hadrontherapy with 5% accuracy



Multi-detector setup International collaboration with INFN laboratories

- Première publication de sections efficaces différentielles $^{16}O \rightarrow {}^{12}C$ (5mm) @ 400 MeV/u. R. Ridolfi et al., Phys. Rev. C **112**, (2025) **014610**

- Publication d'une feuille de route sur les mesures de sections efficaces de la cosmologie jusqu'aux applications (FOOT & CLINM notamment) dans Physics Reports : Maurin et al., 2026.


Physics Reports
Volume 1161, 11 March 2026, Pages 1-81

Review article

Precision cross-sections for advancing cosmic-ray physics and other applications: A comprehensive programme for the next decade

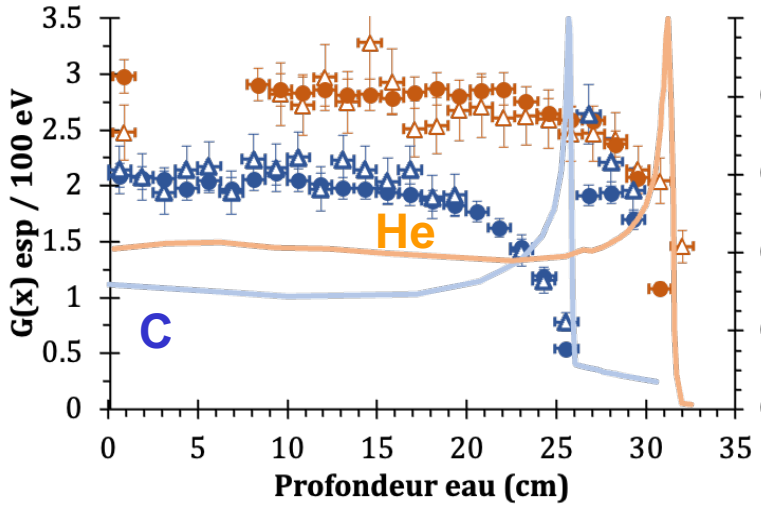
D. Maurin [1], L. Audouin [2], E. Berti [3], P. Coppin [4], M. Di Mauro [5], P. von Doetinchem [6], F. Donato [7,8], C. Evoli [9,10], Y. Génolini [11], P. Ghosh [12], I. Leya [13], M.J. Losekamm [14,15], S. Mariani [8], J.W. Norbury [16], L. Orusa [17,18], M. Panicciá [4], T. Poeschl [6], P.D. Serpico [11], A. Tykhonov [4], M. Unger [19], M. Vanstalle [20], M.-J. Zhao [21,22], D. Bancoid [23,24], M. Chiosso [8,7], D. Giordano [7], D.M. Gomez Coral [25], G. Graziani [1], C. Lucarelli [8], P. Maestro [25,26], M. Mahlein [14], L. Morejon [27], J. Ocampo-Peleteiro [28], A. Oliva [29], T. Pierog [19], L. Serksnyte [6]

Radiolysis and CLINM

Q. Raffy's talk

- Study of LET effects, dose rate effects, oxygen effects on radiolysis of biomolecules + comparison to simulations.
- Study of radiolysis products in the fragments area (after the Bragg peak) and impact of secondary particles on indirect effects.

⇒ Measurement of yields of radiolysis species



WP4. Hadron interactions with biological targets: from cells to patient

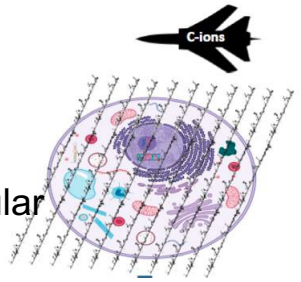
Standardised data to support simulation models
Understand molecular and cellular mechanism responsible for higher RBE of ions

C. Rodriguez Lafrasse's talk

SIMUBIO & BioHADRON

Characterization of the biological responses of tumoral cells (2D and 3D models) and pre-clinical models (in-ovo or in-vivo irradiations) to ions (protons, heliums, carbons).

- Production of biological data for simulation models
- Characterization of the biological advantages of ions in radioresistant and hypoxic tumors: study of nuclear and cytosolic DNA, mitochondrial parameters, proteostasis, cellular signalling, immune activation and cell death



COMBION

Combinatorial approaches using ion therapy alongside other treatments, studied in-cellulo, in-ovo & in-vivo.

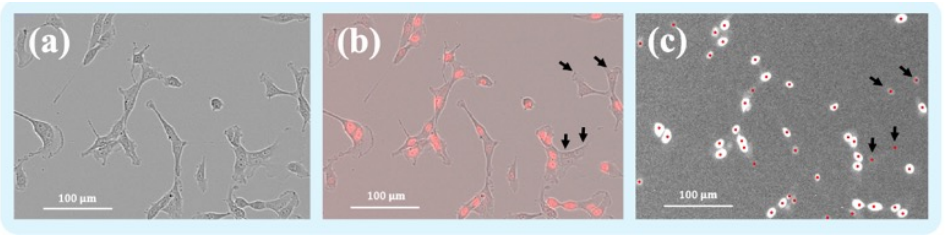
- Inhibitors of proliferation pathways (focus on KRAS inhibitors)
- Proteasome inhibitors
- DNA repair inhibitors

B. Dais's talk

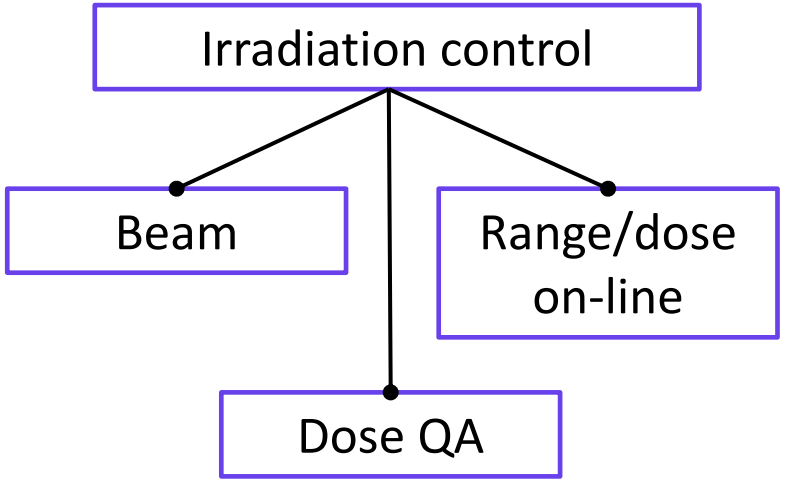
MODERATO

Multi-scale biophysical modeling of the effects of irradiation on cells in their microenvironment

- Cell culture time-lapse imaging (10 days)
- Different environments (i.e. cell density, hypoxia, nanoparticles…)
- Protons, ions and X-rays
- Development of a tracking software to analyse the faith of individual cells



WP3. Control of irradiation delivery



Essential elements of hadrontherapy optimisation:

- Feed TPS with accurate physical data (beam+dose)
- Allow quantification in preclinical experiments (beam+dose)
- On-line monitoring and eventually feedback to TPS (beam+range)

WP3. Control of irradiation delivery: beam monitoring

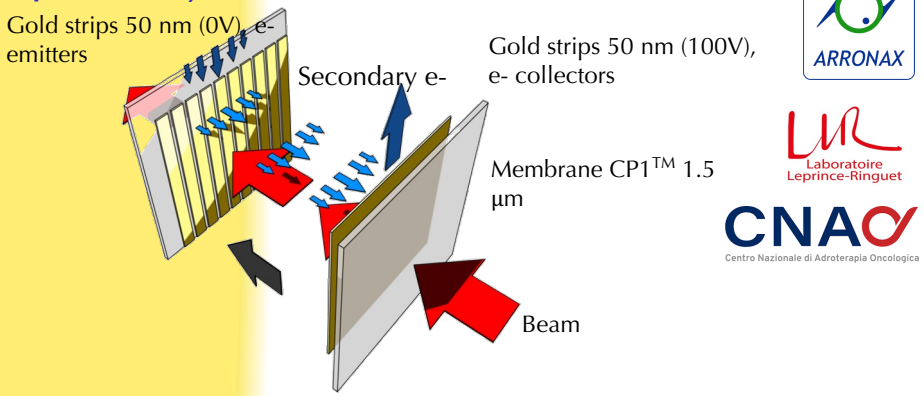
NUCLÉAIRE & PARTICULES

Non perturbative detectors

PEPITES @ CNAO

C. Thiebaux's talk

Nearly transparent (10->5 nm WET) distant (few m upstream) detector based on SEE.



ARRONAX

Laboratoire Leprince-Ringuet

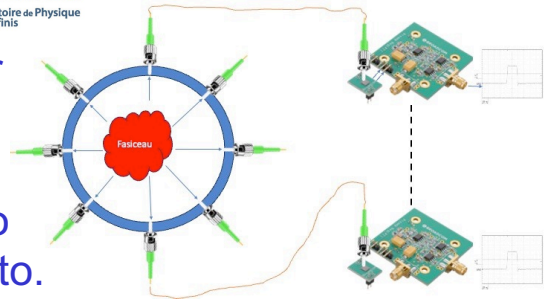
CNAO Centro Nazionale di Adroterapia Oncologica

N2 Beam Profiler

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

L. Hardoin's talk

Transparent detector based on air as scintillating medium. Conceived for in-vitro experiments at BioAlto.



Fast detectors with large dynamic range (& FLASH applications)

Diamond Hodoscope

LPSC Grenoble | Modane

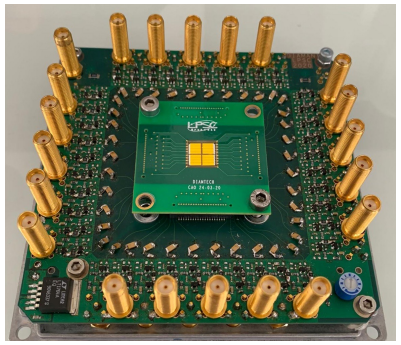
Subatech

ARRONAX

Many diamond-based detectors developed in the team. Hadrontherapy dedicated prototype focuses on:

- timing (~ 100 ps for single –nearly – MIPs)
- compatibility with high count rates (100 MHz).

+ radiation resistant



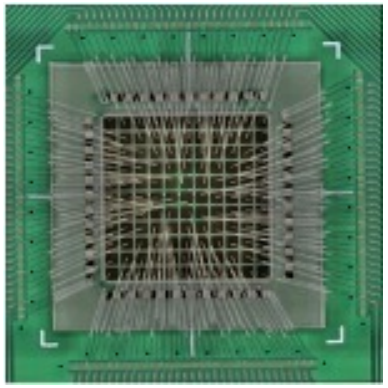
75 ps RMS time resolution

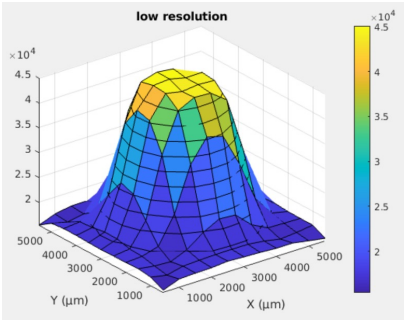
MATRIX

GaN based detector for real-time beam imaging.

- Temporal structure analysis for FLASH.
- Sensitivity below 1 pA for radiolysis studies.

+ can be grown in large areas





- Current prototype: 11x 11 GaN PIN diodes on Sapphire substrate
- Goal: 128x128 matrix

IPHC Institut Pluridisciplinaire Hubert CURIEN Strasbourg

CRHEA

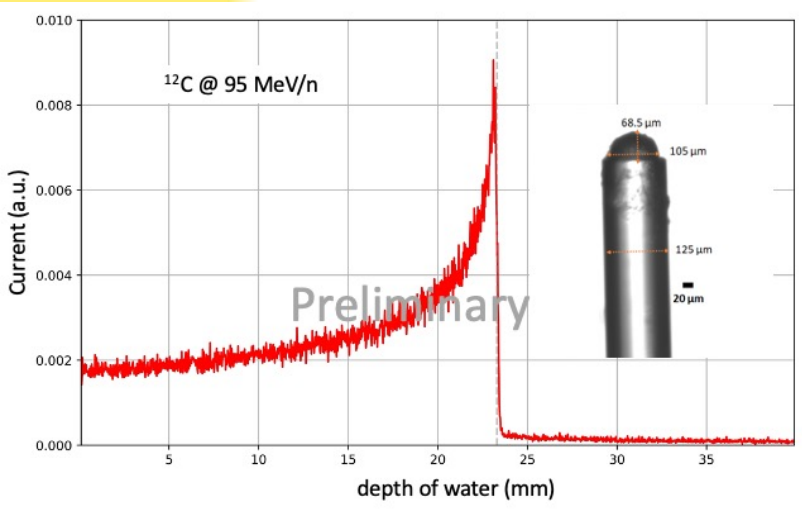
DeSIs

WP3. Control of irradiation delivery: dosimetry

Scintillation detectors as an alternative to Ionization Chambers

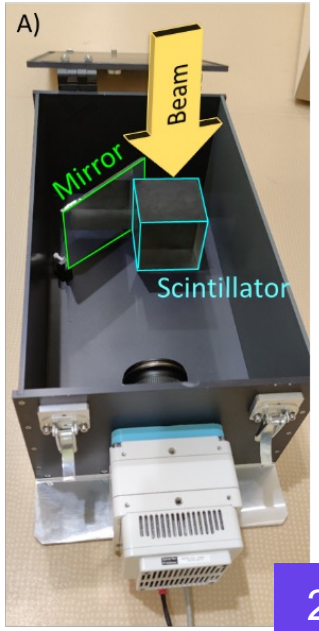
Micro-scintillator

Micro-scintillator (inorganic) for LET and micro-dosimetry measurement.

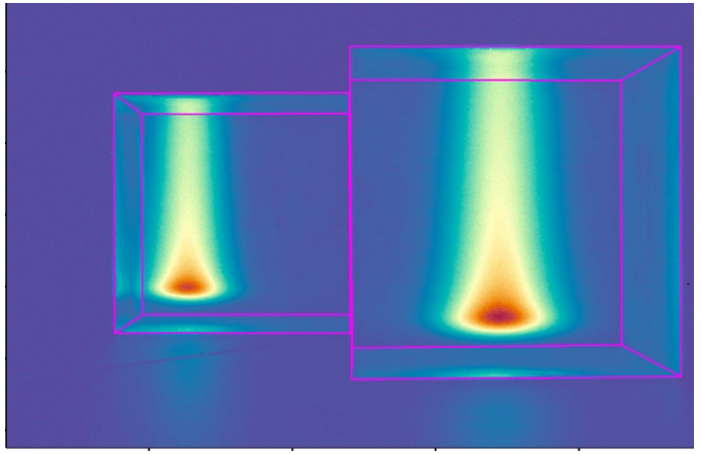


SCICOPRO

3D spatio-temporal dose deposition in PBS and its correlation with biological effects. Detector based on a monolithic organic scintillator cube.



- PBS image in a single acquisition
- Very high spatial resolution



2027: Study of AI methods in optical biases correction and reconstruction - TwinRISE European Project

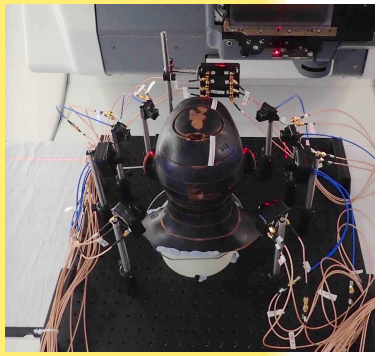
WP3. Control of irradiation delivery: on-line monitoring

NUCLÉAIRE & PARTICULES

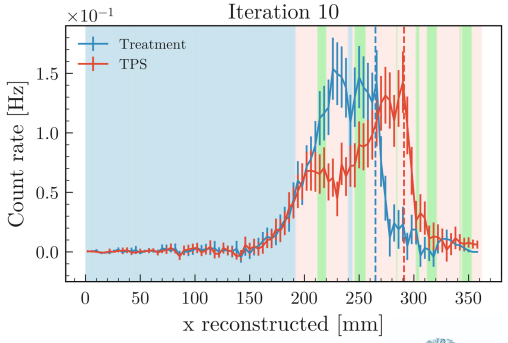
TIARA

C. Abid's talk

From PG TOF distribution to PG vertex distribution



Detection of anatomical variations with the TIARA setup



vpgTLE

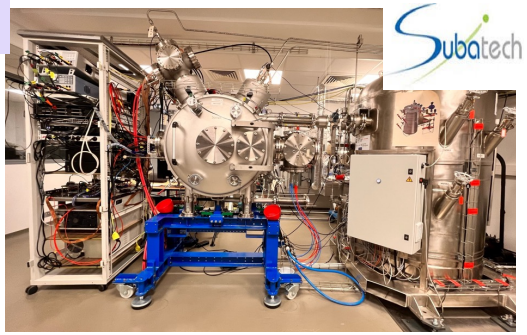
Sinergy with TIARA for the fast simulation of PGs in GATE

XEMIS2

Y. Ramsi's talk

3 γ imaging detector based on liquid Xe technology

MC study for feasibility as a range monitoring device

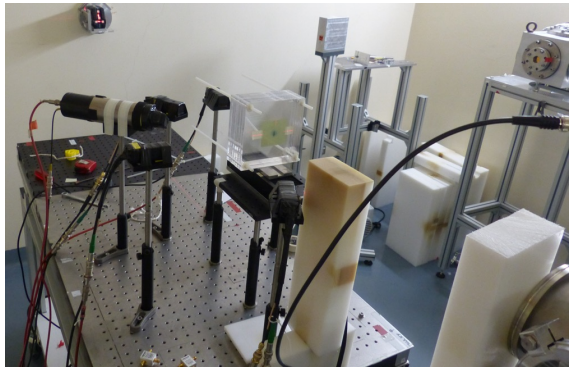


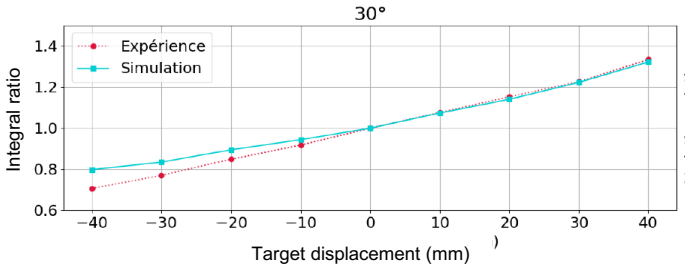
CLaRyS S2C2

Energy integration of secondary radiation with high intensity pulsed beams from CAL-Proteus One

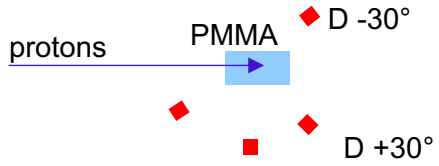
PbWO4 scintillators+ fast PMTs. ASIC QDCs developped at LPSC

68 MeV protons at ARRONAX
(longitudinal target displacement)

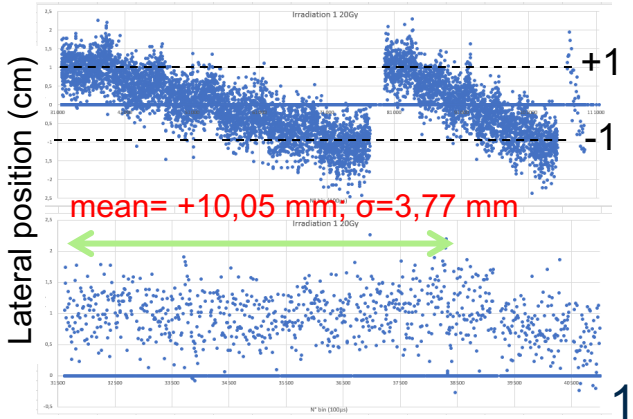




140 MeV protons at P1 - CAL
(transverse target displacement)



Irradiation 2x2 cm^2 20 Gy

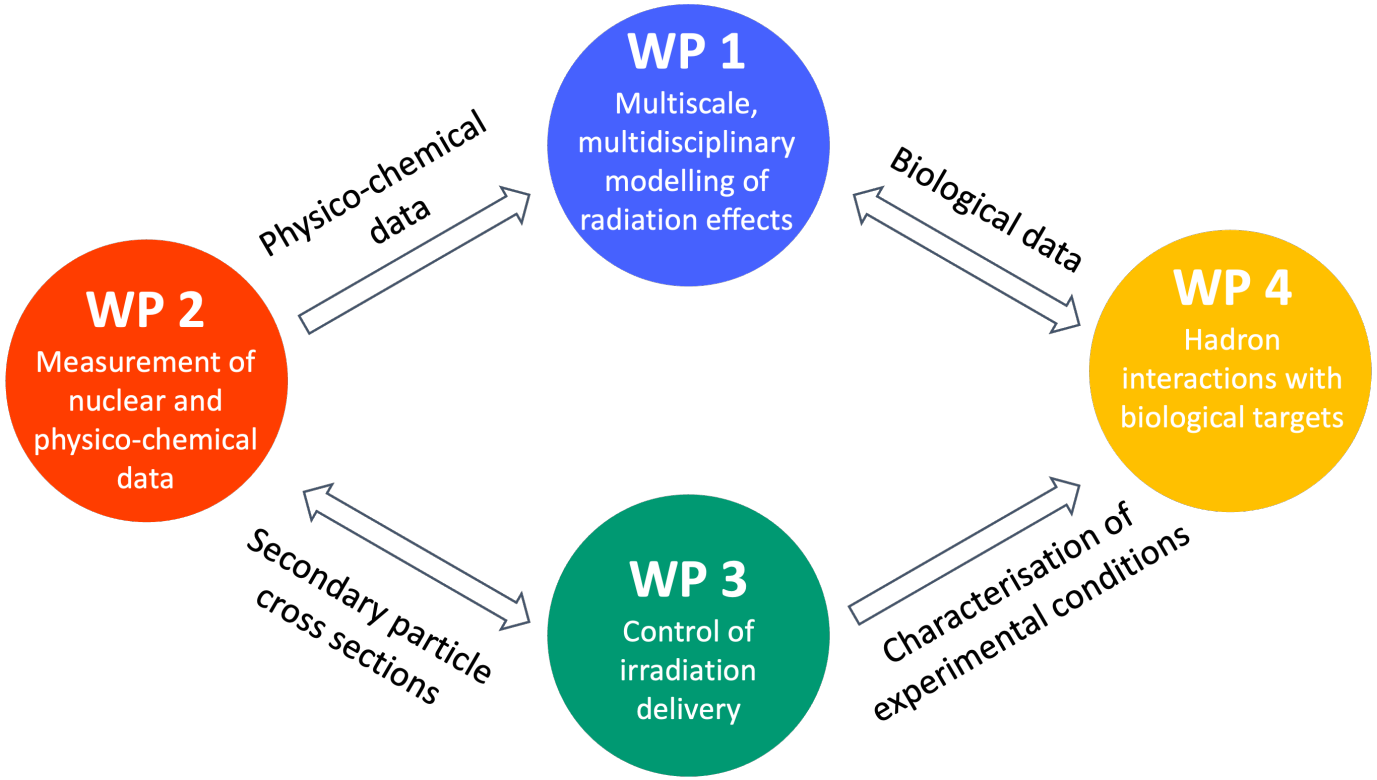


NUCLÉAIRE & PARTICULES

Conclusions and perspectives

- **MP récent, construit sur des projets existants à l'IN2P3**
  - Financements souvent mono-équipe sur AaP
  - Collaboration hors IN2P3 existantes

  - Lieu d'animation pour encourager les collaborations inter-équipes (réponse à AaP communes)
  - Proposition: Workshop en ligne en Septembre (evento dans les prochains jours)



NUCLÉAIRE & PARTICULES

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- **Projets très dépendants du temps faisceau**
  - Accord IN2P3 – **CAL** arrivé à terme

  - Accord IN2P3 – **CNAO** : renouvellement et renforcement des collaborations existantes
    - Beam/range monitoring – PG imaging (**PEPITES**, TIARA)
    - Radiobiology (**BioHadron**)
    - TPS – radiolysis (**CLINM**)
    - BNCT – neutrons measurements (to be discussed)

  - Accord IN2P3 - **CYCLHAD**

- **Accord cadre IN2P3 – INFN** signé en 2026: opportunité pour des futures collaborations

- Premier **poste de CR** depuis 2016 sur les activités inter-disciplinaires

MP Hadrontherapy at the Particle Therapy Co-Operative Group (PTCOG) conference

Michael Goitein Awards, Biology
Claire Rodriguez-Lafrasse

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Additional slides

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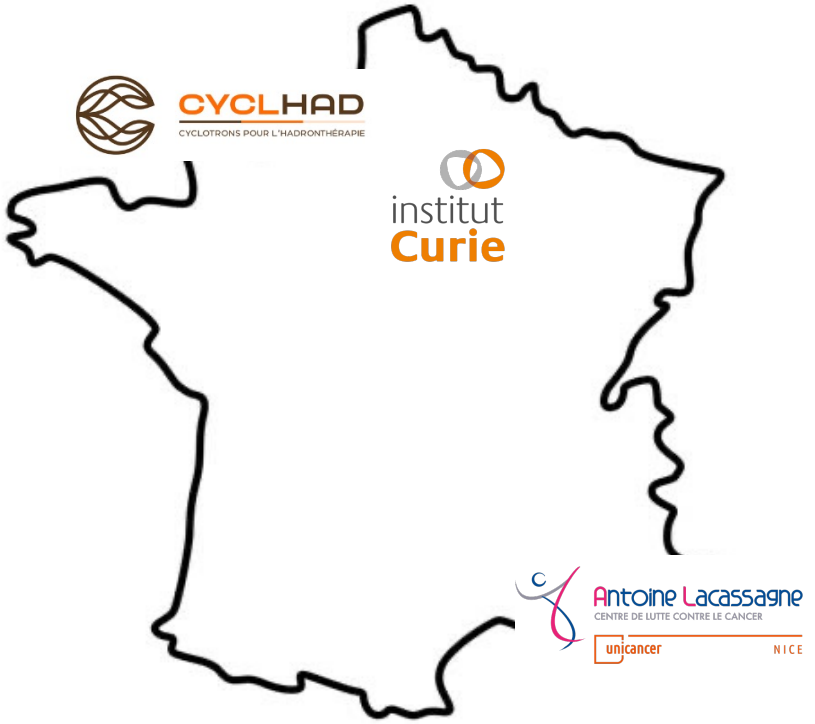
Irradiation facilities

Main platforms & collaborations



French Hadrontherapy facilities

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Current collaborations

Multi-scale modelling

French:
CREATIS, LIRIS, TIMC, ISMO, CFB

International: GATE collaboration

Platforms: CPO, RadEx, BioAlto

Physico-chemical data

French:
Icube, IBMP, Icans, Aerial-CRT

International: CNAO, CNRS, QST-Himac, **INFN**, Geant4 collaboration

Platforms: CAL, CNAO, GANIL, CYRCE, GSI, HIMAC…

HT project

Irradiation control

French:
IP Paris, DIAMFAB, CHREA, CLCC, CINAM, CREATIS, ARRONAX

International: CNAO, Ruhr University, WGPTC, Roma Tor Vergata

Platforms: CAL, CNAO, GANIL, ARRONAX, CYCLHAD, BioAlto…

Biological data

French:
ARRONAX, IAB, CEA, CLCC

International: CNAO, NIRS, IFIN-HH

Platforms:
CAL, CNAO, ARRONAX, GANIL

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Project name	Primary IN2P3 lab	PI
Nanox	IP2I Lyon	E.Testa/M. Beuve
MODERATO	IJCLAB Orsay (Paris)	M. Badoual
aRTwin	LPCC Caen	J. Thariat
CLINM	IPHC Strasbourg	M. Vanstalle
FOOT	IPHC Strasbourg	C. Finck
Radiolysis	IPHC Strasbourg	Q. Raffy
PEPITES	LLR Palaiseau (Paris)	M. Verderi
N2 Beam Profiler	IJCLAB Orsay (Paris)	Q. Mouchard
Diamond hodoscope	LPSC Grenoble	M-L. Gallin-Martel
MATRIX	IPHC Strasbourg	S. Higueret
SCICOPRO	GANIL Caen	A-M. Frelin
Micro-scintillator	LPCC Caen	M. Rousseau
CLaRyS-S2C2	LPSC Grenoble	D. Dauvergne
TIARA	LPSC Grenoble	S. Marcatili
XEMIS/SMART	SUBATECH Nantes	N. Beaupere
vpgTLE	IP2I Lyon	E. Testa
SIMUBIO	IP2I Lyon	A-S. Wozny
BioHADRON	IP2I Lyon	C. Rodirguez-Lafrasse
COMBION	CIMAP Caen	F. Chevalier

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WP synergies