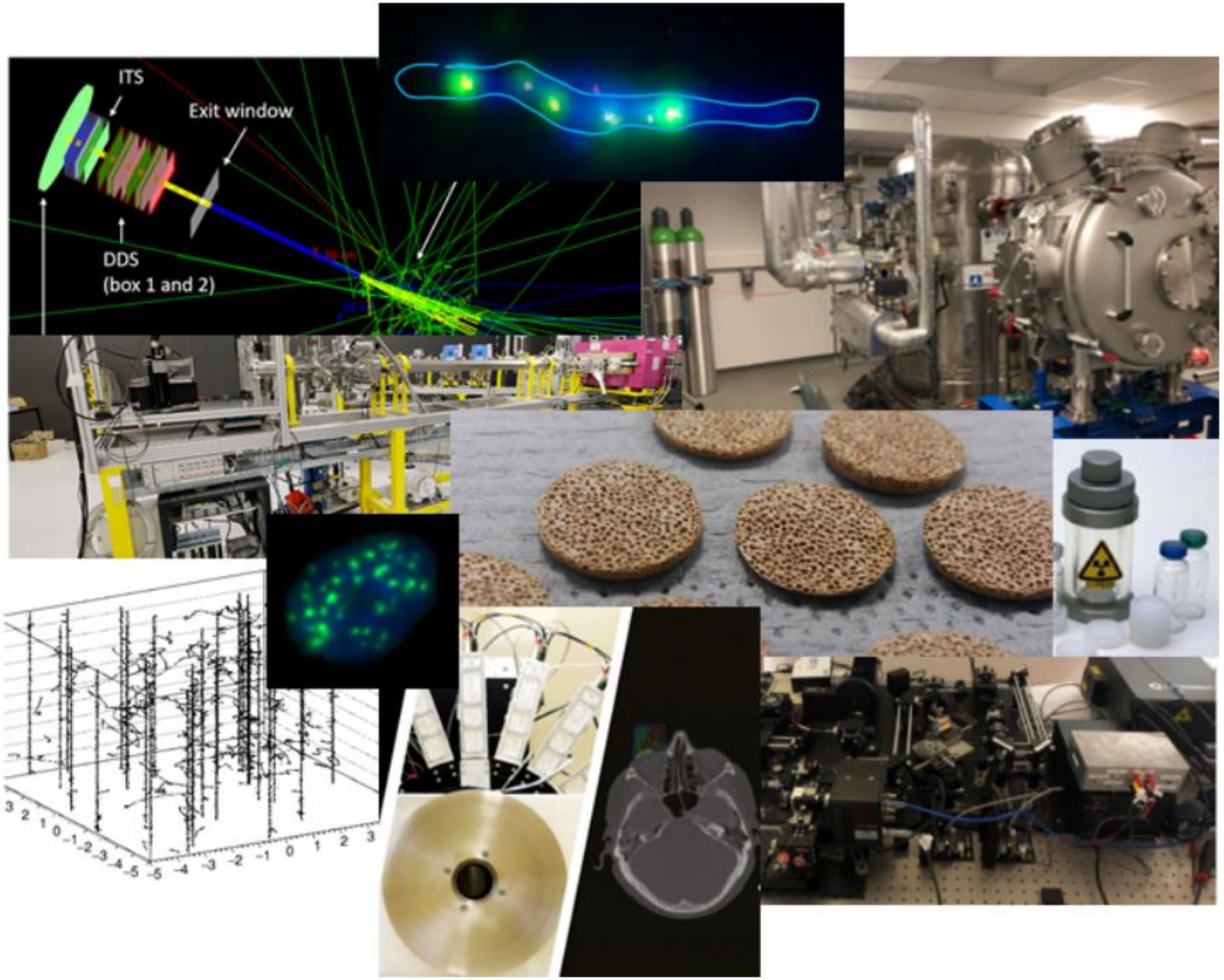


GT10

Nuclear technologies for life sciences

Denis Dauvergne & Lydia Maigne
On behalf of GT10 collaborators

Plan

- Introduction

- 4 Science Drivers: scientific questions, 10-year projects
  - 1: Improve therapeutic efficiency through innovative irradiation modalities
  - 2: Develop innovative medical imaging toward personalized medicine
  - 3: Develop efficient multiscale and open source simulations
  - 4: Develop novel radioisotope production toward therapy and/or diagnostics

- Recommandations

Introduction
GT10 « Nuclear sciences for Health »

- COPIL GT10: S. Incerti, D. Dauvergne, F. Farget, L. Maigne, C. Morel, M. Rousseau, H. Seznec

- September – October 2019: call for contributions

  About 30 contributions

- 5 February 2020, Strasbourg, **« Séminaire Thématique GT10 »** https://indico.in2p3.fr/event/19756/

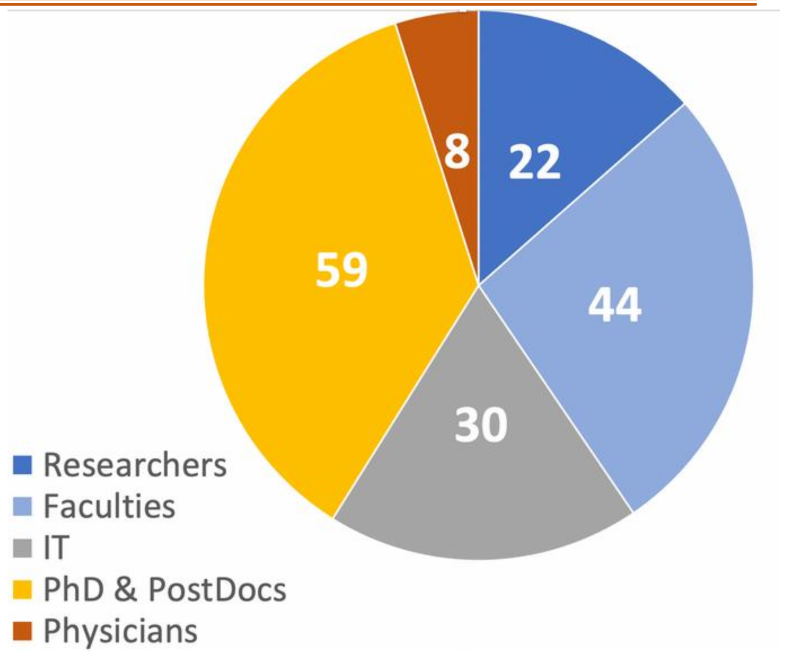
  66 participants, 18 presentations

- May 2020: redaction of report

Introduction
Innovative Nuclear Techniques for Health at IN2P3

- **12 laboratories**
- **GDR MI2B**: created in 2004 – renewed in 2020 (INSB deputy)

- "**Innovative Nuclear Techniques for Health (INTH)**" research program gathering the community
  - **Common goal: use of ionizing radiation** to **observe and understand living organisms**, for **therapeutic and diagnostic purposes** (e.g. in the fight against cancer).
  - **IN2P3 skills**: simulation, production of beams and radionuclides, instrumentation for imaging and dosimetry
  - Several teams of **biologists and clinicians have joined IN2P3 laboratories** (e.g. CENBG, IP2I, IJCLab, LPC, LPC-Caen, IPHC ...)
  - **Network of national irradiation facilities**, associated to common instrumentation and **development of biophysical models**

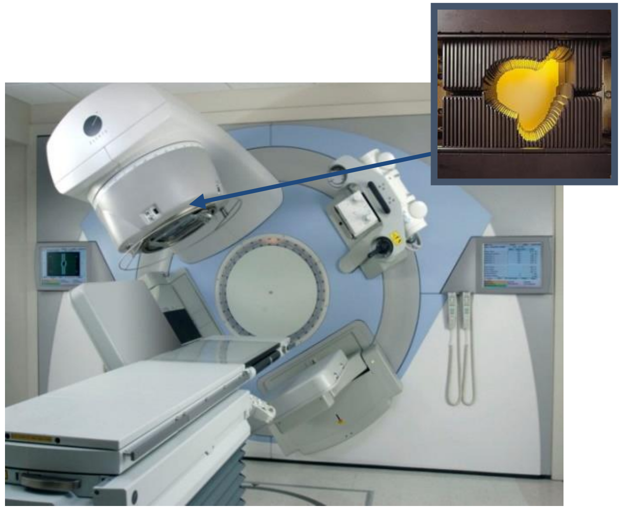


Science Driver 1

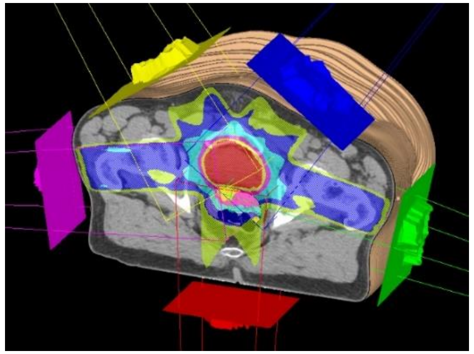
Improve therapeutic efficiency through innovative irradiation modalities

SD1 Improve therapeutic efficiency through innovative irradiation modalities

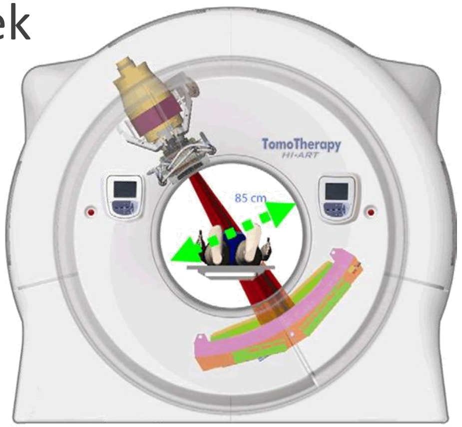
- ``Conventional '' radiotherapy (>95%)
  - **Particles**: X-rays 6-25 MV, electrons 3-18 MeV (surface tumors)
  - **Machines**: clinical electron accelerators - multileaf collimator - embedded imaging systems
  - **Time fractionation**: 2 Gy/session, 5 sessions/week
  - **Dose**: 40-70 Gy, (Dose rate: 30-70 mGy/s)



Standard clinical accelerator with embedded imaging systems



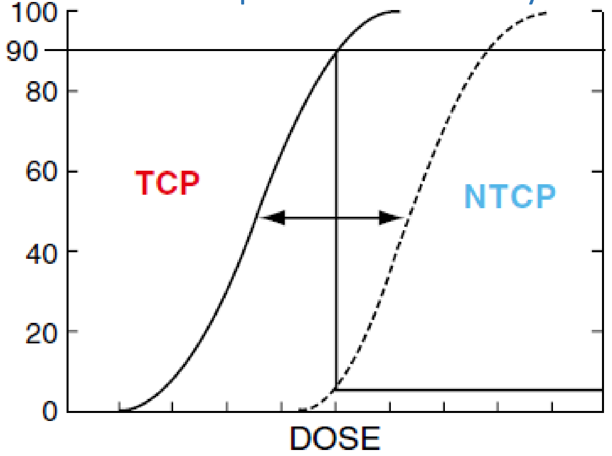
Intensity-modulated irradiation



Tomotherapy

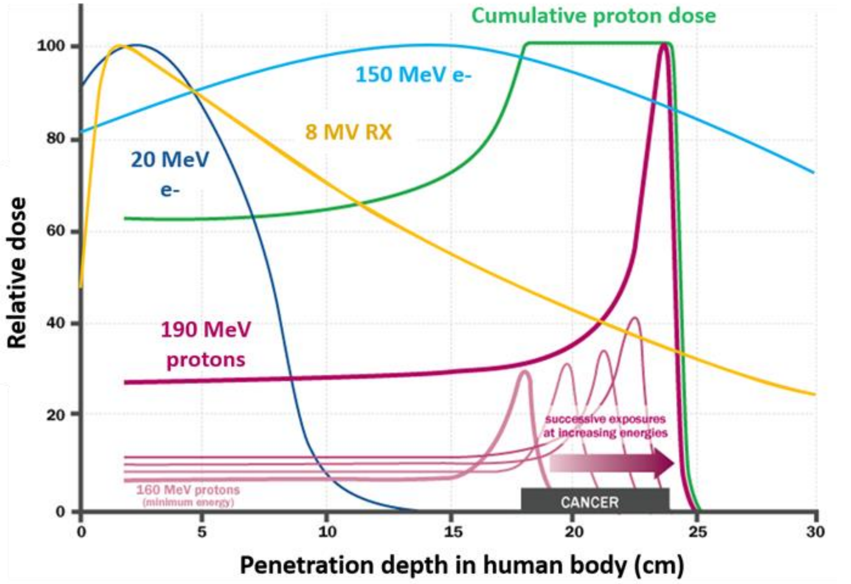
Cyber-knife

Tumor Control Probability vs Normal Tissue Complication Probability

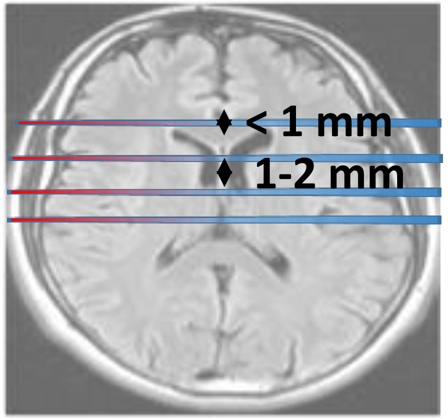


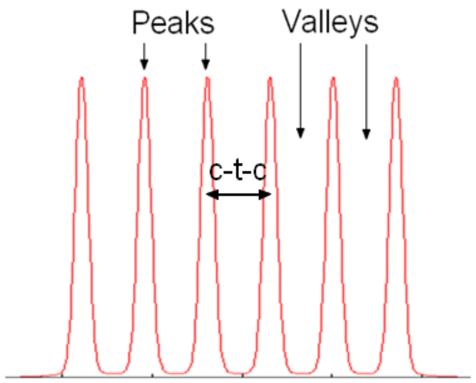
SD1 Improve therapeutic efficiency through innovative irradiation modalities

- Innovative irradiation modalities
  - **Hadrontherapy -** ballistic precision and high LET particles
    - Proton therapy became clinical standard (PBS, gantries, …)
    - Carbon and light ions (He, Li, O…):
      - 4 centers in EU: 6000 patients (36000 worldwide) in 2019
      - Higher RBE, smaller straggling than protons



  - Spatial fractionation
    - **Proton minibeams** were initiated at IN2P3
    - X-ray **microbeams** (MRT): veterinary translation (ESRF)
    - VHEE: (> 10^2 MeV) keeps spatial tayloring in depth
    - → Increased dose tolerance of healthy tissues





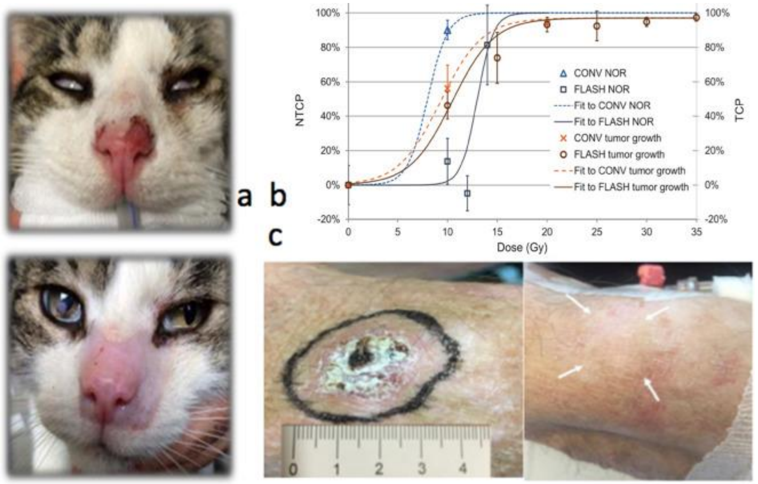
Heterogeneous dose profiles

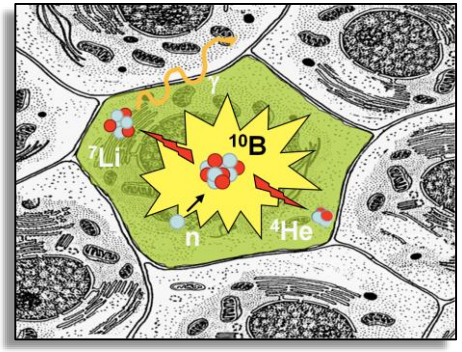
SD1 Improve therapeutic efficiency through innovative irradiation modalities

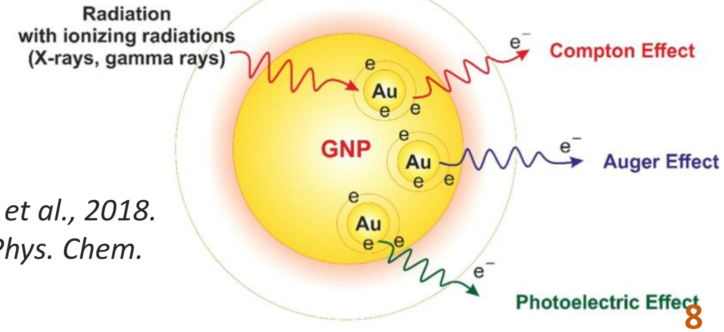
- Innovative irradiation modalities
  - Hypo-fractionation with high fluxes: **FLASH therapy**
    - First observation with electrons (Favaudon et al, 2014)
    - Confirmed with high- and low-energy X-rays
    - Under study with protons

    → Better normal tissue tolerance >40 Gy/s, irradiation time <100-200 ms
  - Drug-assisted targetting
    - **AB-BNCT**: renewed interest with accelerator-based irradiation
    - **Local dose enhancers** (high-Z, nanoparticles, PDT-nanoscintillators…)
    - Internal **vectorized therapies** (alpha-beta emitters)
  - Combination with other modalities (immunotherapy)

Mazal et al., 2020. British J Rad







Borran et al., 2018. Rad. Phys. Chem.

SD1 Improve therapeutic efficiency through innovative irradiation modalities

A unique offer for complementary irradiation modalities in France

protons and light ions (He, C, O…), photons from **synchrotron** X-rays to high-energy, **pulsed beams** of high energy electrons, with **FLASH** irradiation capability, radioisotopes, neutron sources.

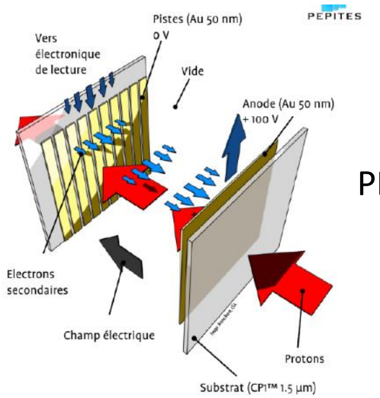
Challenges for radiobiology and for a versatile dosimetry, some of them being in the research field of IN2P3

- Prediction of radiobiological effectiveness of radiation through multi-scale simulations **Geant4 with Geant4-DNA and GATE**;
- Need for online, and possibly real-time control of the treatment quality;
- Development of strategies for patient-data based models for personalized treatment efficiency modelling;
- Acquisition of nuclear data to improve the precision of the effective dose during hadrontherapy treatments.

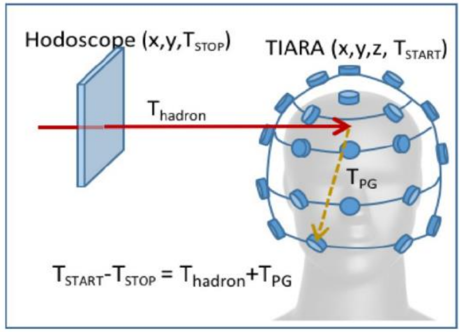
SD1 Improve therapeutic efficiency through innovative irradiation modalities

10-years project

- **Development of new-dose delivery modalities**
  - FLASH irradiation (CYRCé – ARRONAX) : **MP Dosiflash, FLASHMOD**
  - Hadrontherapy (protons at CAL-Nice, light ions: ARCHADE, CNAO…)
    - Basic physical data
    - Radiobiological data → Biophysics models (NanOx, G4-DNA)
    - Radioactive ions?
  - VHEE ?
  - Targeted radiotherapies & ab-BNCT: neutron & radioisotope production with dose modelling (PICTURE project)
- **Specific instrumentation**
  - Beam monitors
    - Flash (Dosiflash)
    - Spatially fractionated beams
    - Fast timing (Diamtech)
    - Microdosimeters
  - Online control
    - Thidos (gamma camera targeted therapy)
    - Prompt gamma range verification (CLaRyS – TIARA)
  - Clinical data collection and processing: PMRT



PEPITES (LLR)



TIARA (LPSC-CPPM-CAL)

Diamond: Diamtech (LPSC-Arronax-Subatech)

Science Driver 2

Innovative medical imaging toward personalized medicine

SD2 Innovative medical imaging toward personalized medicine

- Recent evolutions in medical imaging
  (provided by industry)
  - PET imaging:
    - Whole body PET
    - Time of Flight
    - Dual modality PET/MRI
  - Single Photon (SPECT) imaging
    - Increased efficiency

- Remaining challenges
  Improve sensitivity to get better images at lower dose and faster

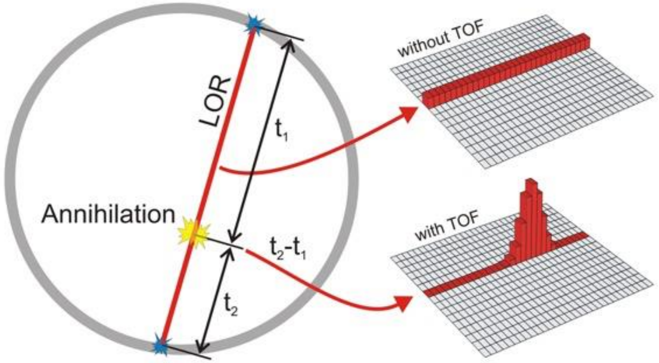
Total-Body PET EXPLORER Project

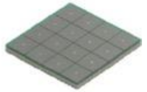
R D Badawi et al. (2019)

VERITON camera 12 CZT heads

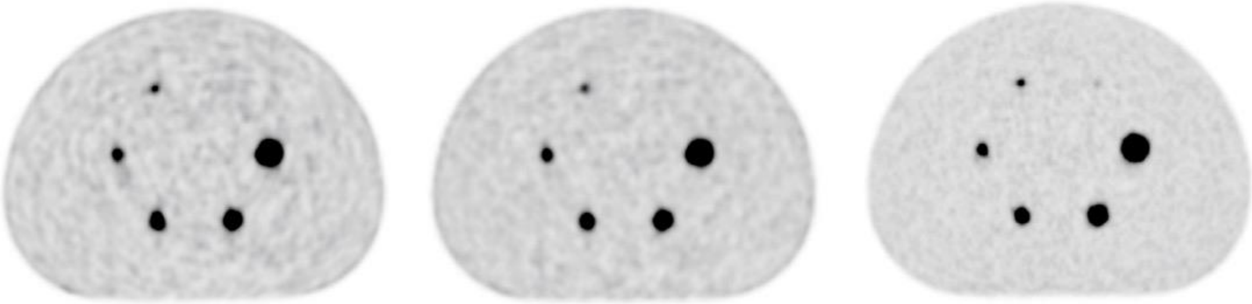
SD2 Innovative medical imaging toward personalized medicine

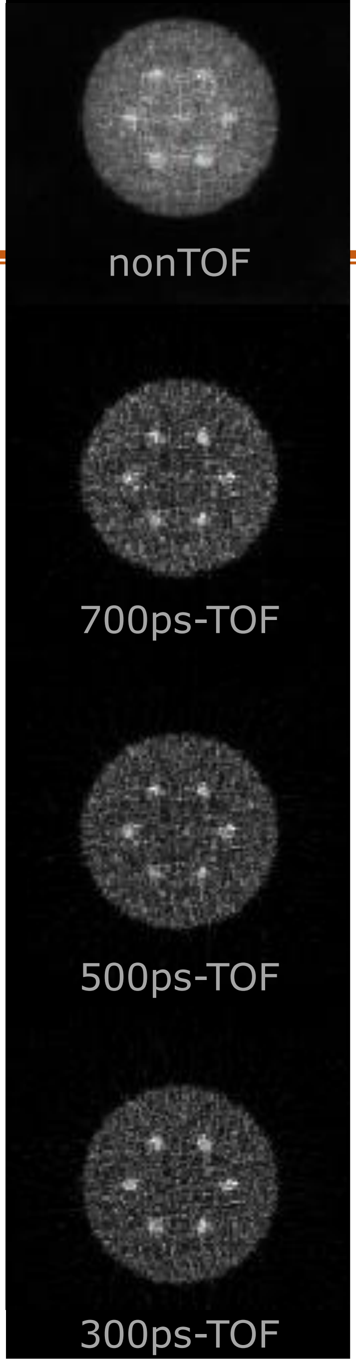
Time-Of-Flight (TOF)-PET





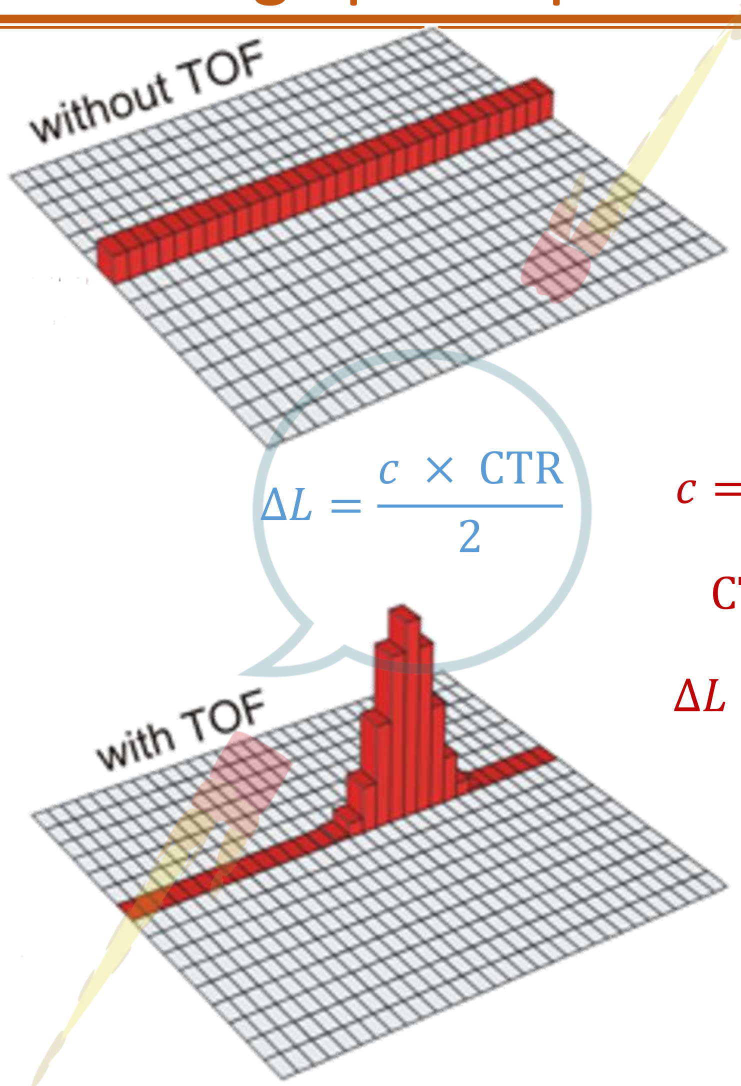
$$\left(\frac{SNR_{TOF}}{SNR_{nonTOF}}\right)^2 = \frac{2D}{c \times \mathrm{CTR}}$$





M. Conti and B. Bendriem, Clinical and Translational Imaging (2019) 7:139–147

Case for setting up a 10 ps challenge: a step toward reconstruction-less TOF-PET

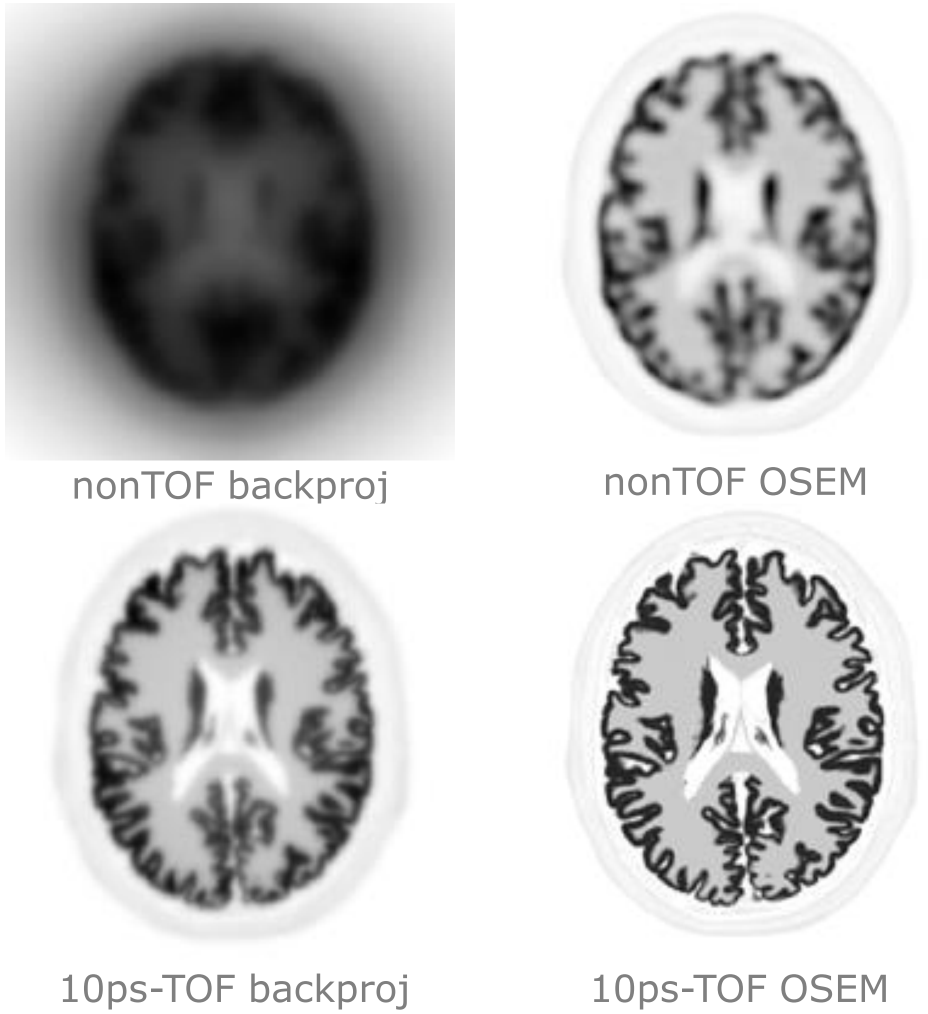


$$\Delta L = \frac{c \times \text{CTR}}{2}$$

$c = 30\ \text{cm ns}^{-1}$

$\text{CTR} = 10\ \text{ps}$

$\Delta L = 1.5\ \text{mm}$

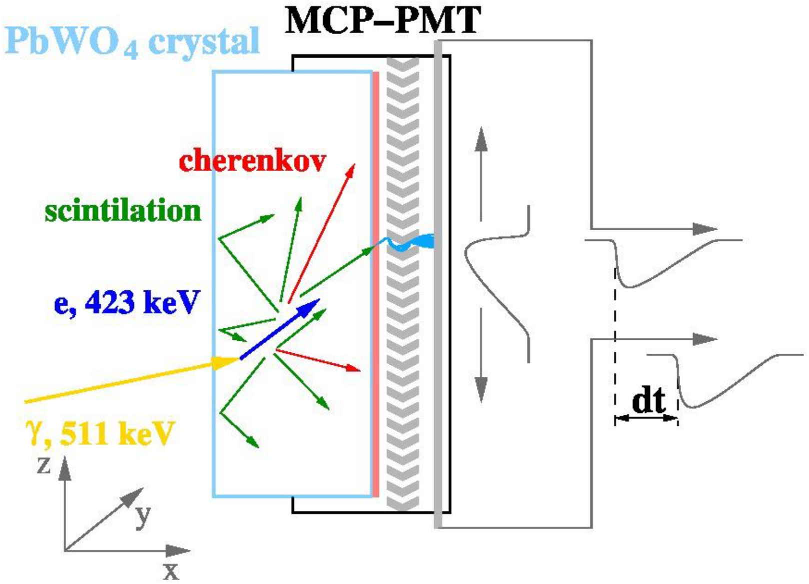


M. Lecoq, C. Morel and J. Prior, Il Nuovo Cimento 43 C (2020) 2

SD2 Innovative medical imaging toward personalized medicine

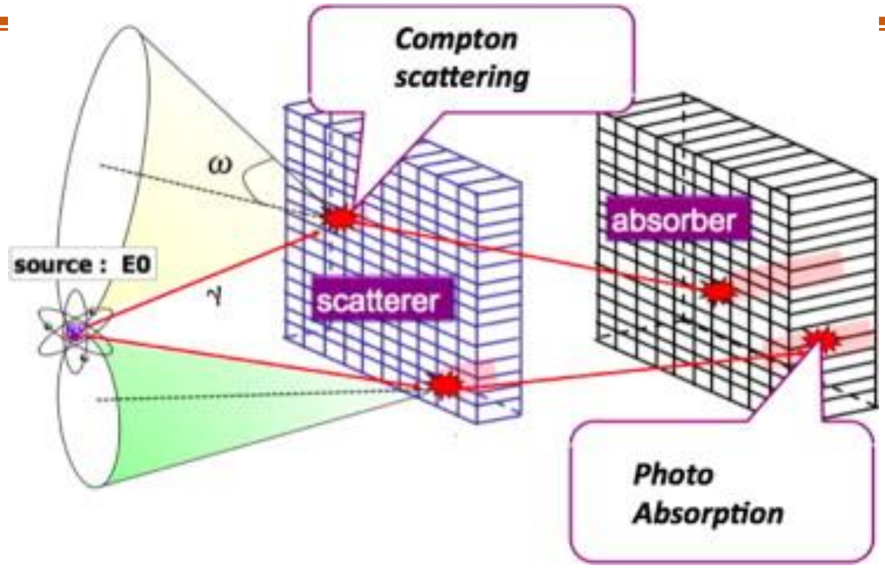
Development of a scintronic crystal for very fast gamma ray imaging applications

- Detection of Cherenkov and scintillation light in PWO
- Direct deposition of a photocathode (n ~2,7) on the surface of PWO (n ~2,3)
- PWO surface used as entrance window of an MCP-MT
- Read out transmission lines on both ends
- Spatial resolution on the gamma ray interaction point of ~ mm^3 in 3D
- CRT ~20 ps FWHM (excluding MCP-MT contribution)



SD2 Innovative medical imaging toward personalized medicine

Compton imaging



Y. Nakamura et al. NIM A 2013

Requirements for Compton telescope:

- Angular resolution ~ 1 deg
- Spatial resolution ~ 1 mm
- Good energy resolution for electron recoil (Compton scattering)
- Distance between 2 interactions large enough
- Angular resolution limited by Doppler Broadening (low Z scatterer)

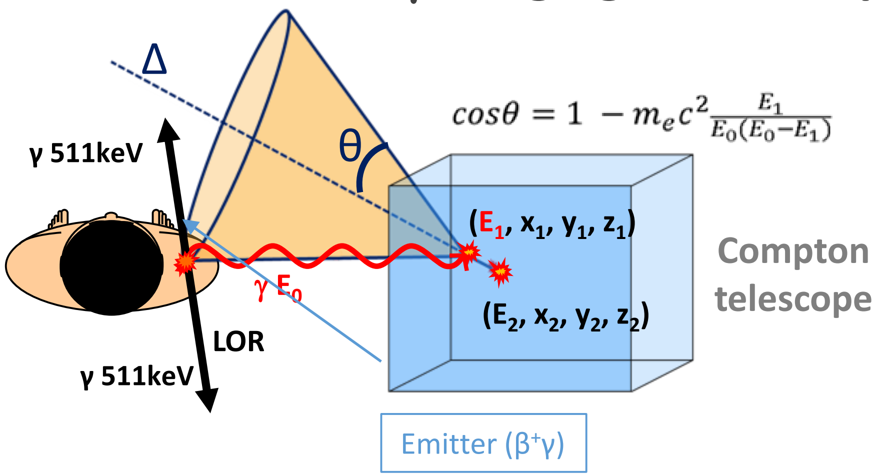
Application to Medical Imaging:

- High flux (source activity)
- High detection efficiency
- Energy of γ is known
- Source distribution 3D reconstructed from Compton cones

- Not only stimulated by medical applications, but also for other applications such as nuclear dismantling and waste management
- Strategic reflection to be undertaken at IN2P3, which involves instrumentation, reconstruction and application aspects
- Organization of a workshop on CC by the GDR MI2B Nov 30 – Dec 1 2021

SD2 Innovative medical imaging toward personalized medicine

3γ imaging with Compton telescope

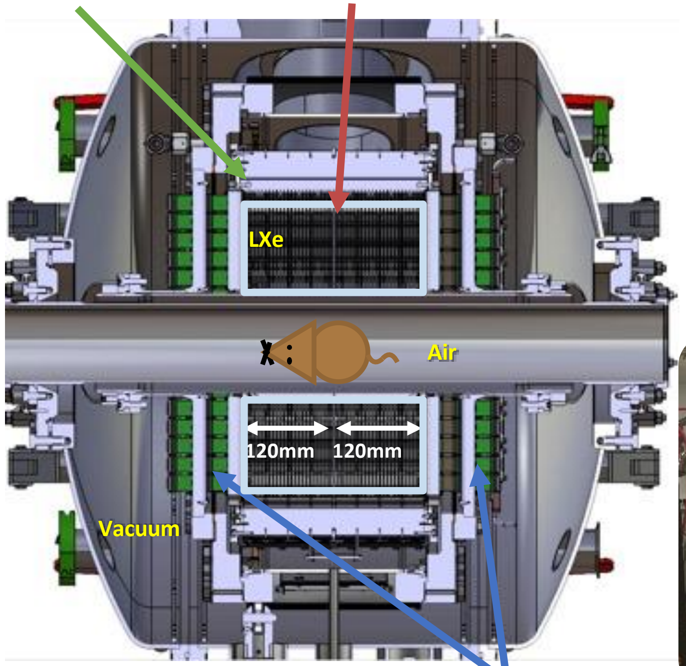


Reconstructed γ direction { Spatial resolution: cone axis (Δ)
Energy resolution: opening angle (θ)

- Direct 3D location of the radioactive source: res. along LOR ~ 1 cm (FWHM)
- Reduction of injected activity: 100 times less

➢ **Both new radiopharmaceutical and new camera technology !**

XEMIS2 – small animal imaging



In CHU-Nantes

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

20000 pixels: 3.1 x 3.1 mm

-> XEMIS3 – clinical imaging

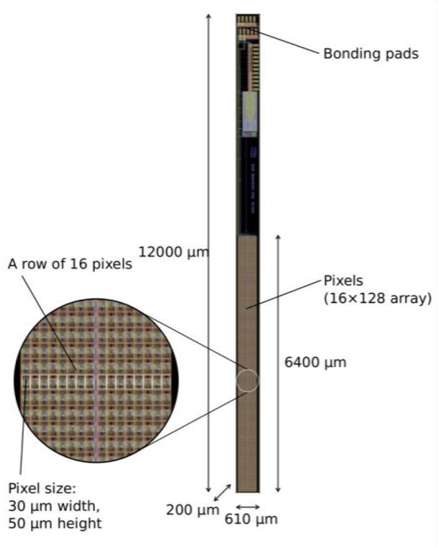
SD2 Innovative medical imaging toward personalized medicine
Interventional imaging

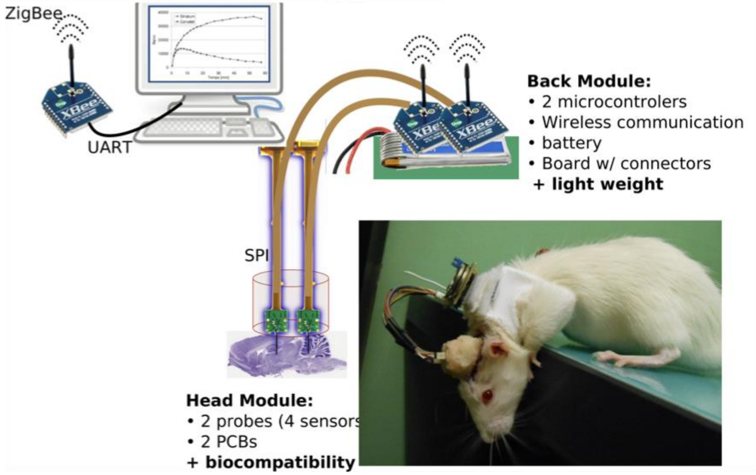
Intracerebral imaging of β^+

MAPSSIC Project

IJCLab, CPPM, IPHC

- Short range of β+ allows measurement of local concentration of radiotracer
- High sensitivity to β^+



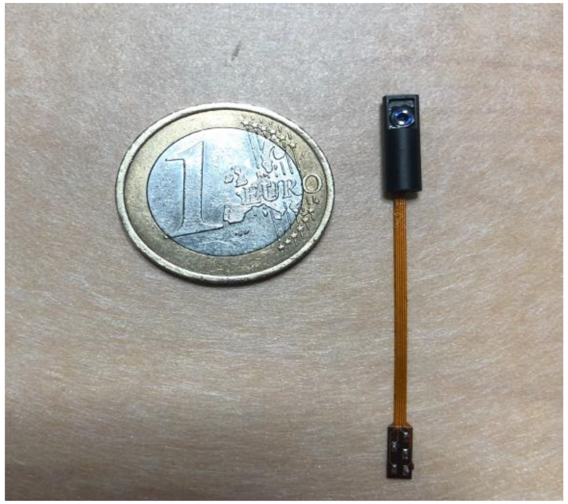


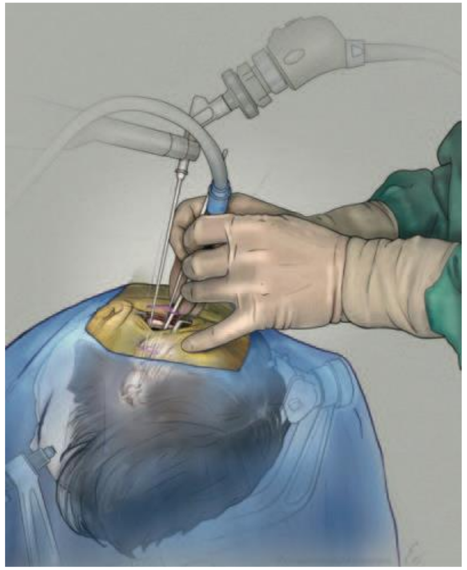
Multimodal non-linear endomicroscopy

IMOP Project

IJCLab

- Fluorescence lifetime spectroscopy of living tissues using a double-clad photonic crystal fiber
- Development of an innovative miniature biocompatible scanning device
- CNRS-Innovation: next start-up creation





SD2 Innovative medical imaging toward personalized medicine
Interventional imaging

Strategies

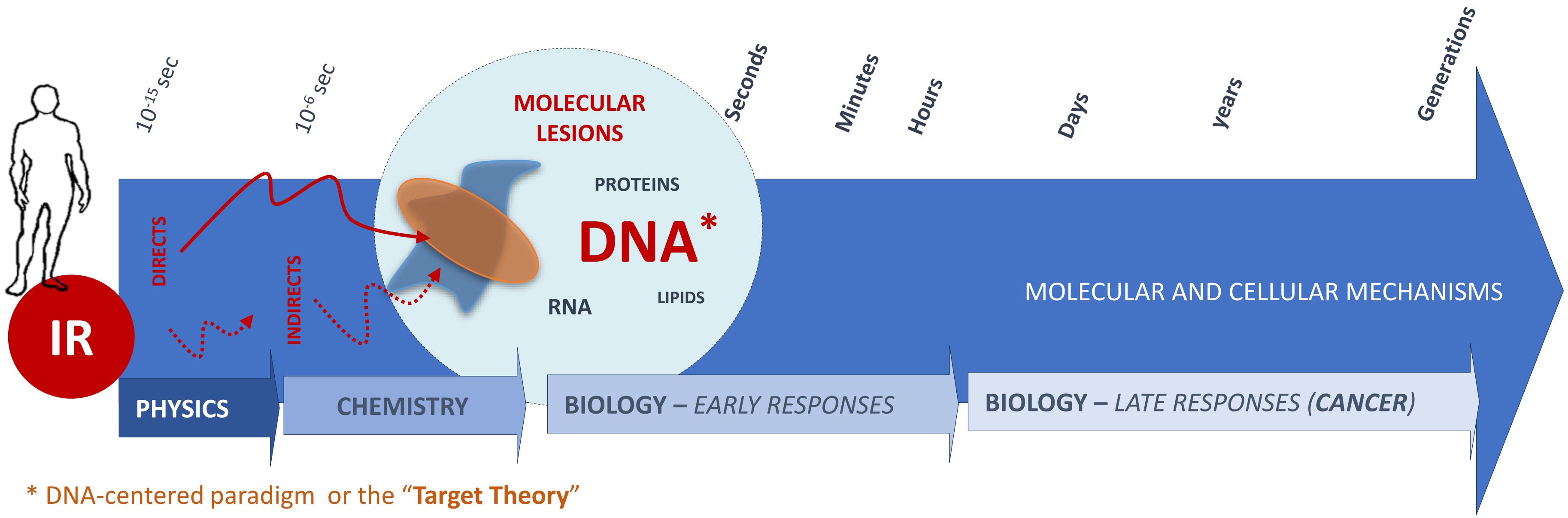
- Towards high temporal resolution (paradigm breakthrough)
- Explore Compton imaging
- Interventional imaging
    - Miniaturization
    - Multi-modality
    - Multi-scale (molecular imaging)
    - Multi-organ
- Valorization

Science Driver 3

Develop efficient multiscale and open source simulations

SD3 Develop efficient multiscale and open source simulations

Radiation Biology – Open questions



* DNA-centered paradigm or the "**Target Theory**"

- **DNA** was considered as **the main target of Ionizing Radiation**
- **Ionizing radiation** produces **DNA damage**
- **Relationship** between **DNA damage, mutations** and **cancer development**
  - **- DNA-centered paradigm, known as "the target theory"**
  - **- Linear no-threshold model**.

Non-Targeted Effects** occur **when IR energy has not been deposited exclusively in DNA
*Distinct classes of NTE : **genomic instability, bystander effect, adaptive response, low dose radiation-induced hypersensitivity**.*

SD3 Develop efficient multiscale and open source simulations

Radiation Biology – Goals

Dosimetry → **Simulation, mathematics, computing sciences** → **characterize the energy deposit at different biological levels & time scales**

Modeling → **Optimization process to** improve RT **accuracy** **&** **estimation of their risks** → improve RT **response for different modalities** **understand their consequences in oncogenesis**

Approach → **validate a multidisciplinary and multimodal approach integrating the chain of physical, chemical and biological events** triggered by well-characterized irradiation conditions within emerging cancer models

(such as spheroids-3D models, *C. elegans*…)

Complete mechanistic understanding of IR biological impacts at a **molecular** **cellular** **organism levels**

SD3 Develop efficient multiscale and open source simulations

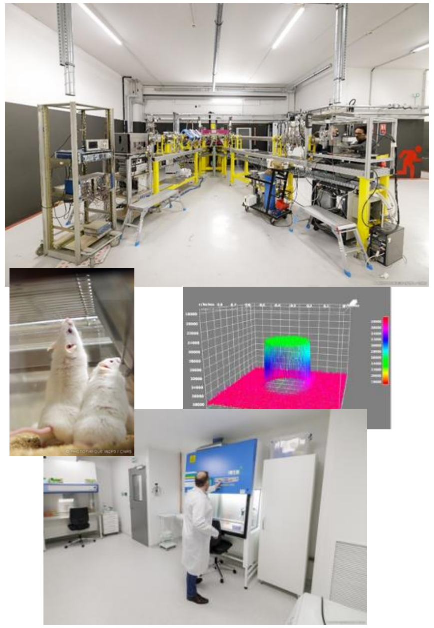
ResPlaNDIr: Specific and well-characterized technical Environments

AIFIRA

Biology Lab L2, CENBG

Nuclear microprobe
Protons, alpha
< 3 MeV

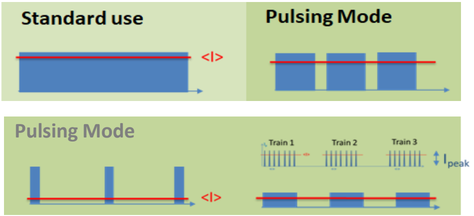
CYRCé

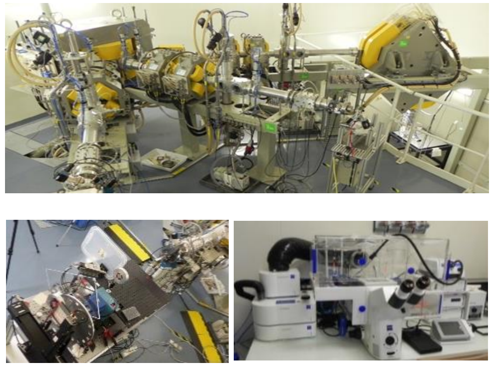


Biology Lab L2, in vitro in vivo, animalry, small-animal PET

25 MeV protons
2 to 23 mm irradiation field
Dose rate: 10^{-3} Gy/s to 100 Gy/s

ARRONAX

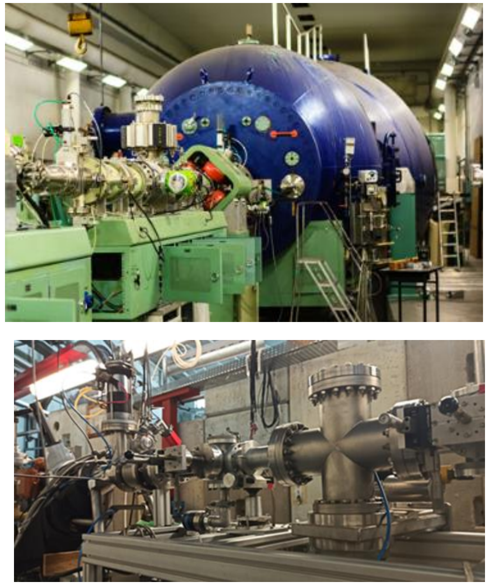




Cell irradiation facility
Time-lapse microscopy

Pulsed beams
(100 Gy/T with 10µs < T < min)
Protons, alpha, < 70 MeV
Photons, Low-high Energy

ALTO



Radiograaff Cell irradiation facility

Protons <28 MeV, alpha, lithium and heavier ions

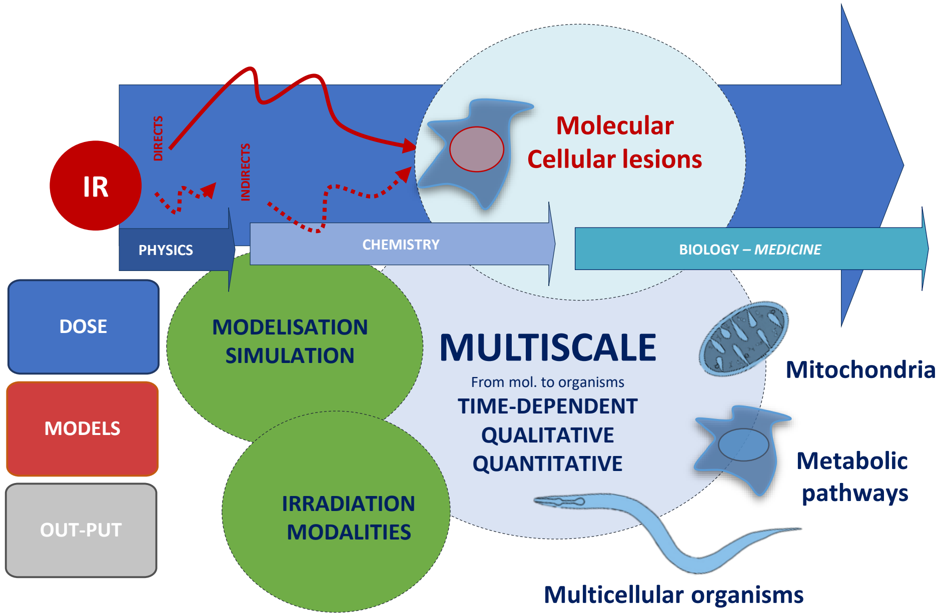
LSM

GANIL Spiral2

Carbon ions 95 MeV/u

SD3 Develop efficient multiscale and open source simulations

Radiation Biology Conclusions



▸ Radiation Biology - *Needs*

▶**Technical development**
Detection, …
High-resolution time-lapse microscopy, …
▶**Expertises**
Physics, Chemistry, Biology, Computing sciences (Big Data, AI), Bio-informatics
Nanosciences/Nanotechnologies, Microfluidics
▶**Interdisciplinary**
Long-term support (team, facilities,…)

Radiation Biology @ IN2P3

▶**active** and **dynamic** research domain
▶**several teams involved and integrated in collaborative networks**
INSB, INSERM, CEA, ESA, IRSN, INRA, universités
▶**Interdisciplinary** (Physics, med. Phy., chemistry, biology,…)

Specific and highly well-characterized facilities

▶AIFIRA, ARRONAX, CYRCé, LSM,GANIL…
▶Open to other communities
▶**Technological transfer**
(Ex: nuclear microprobe/IRSN,…)
▶From **physics to biology with installation of dedicated laboratory (L2)**

Strong interactions with "modeling/simulation" community

▶Strong needs to experimental validation of numeric tools
▶From **molecule to organism (multiscale)**

Emerging concept and strategies Proof of concept - originality

▶Mitochondria
▶Multiscale radiation biology
▶C. elegans
▶Genomics (bio-info), data collection (meta-analysis)

SD3 Develop efficient multiscale and open source simulations
Multi-scale modeling of Irradiation effects on Life

Elementary processes:
- Ionization
- Excitation
- Fragmentation
- Radical production

Sub cellular structures

Nano dosimetry

Death,cycle arrest
Migration /metastases
Mechanical properties
Morphology

Micro dosimetry

Evolution of tumour
- Growing
- Control
- Vascularisation

Bystander

Organ motion
Patient morphology
Cancer induction

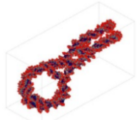
Biological dose

Molecules

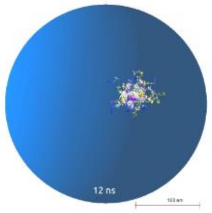
Cell

Clusters of cells / Organ

Patient

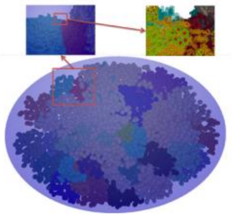


Delage et al. 2015

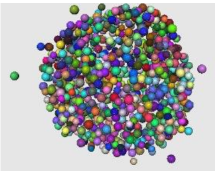


J. Comput. Phys. 274 (2014) 841-882

LPCHEM code

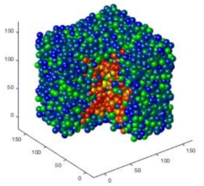


Sc. Rep. 7 (2017) 11923

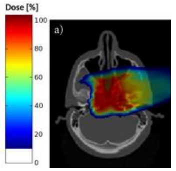


cpop.in2p3.fr

MSB



Dufour A et al, (2018), Modeling the dynamics of oligodendrocyte precursor cells and the genesis of gliomas, *PLoS Comput Biol.*, **14**, e1005977.



NanOx

PMRT

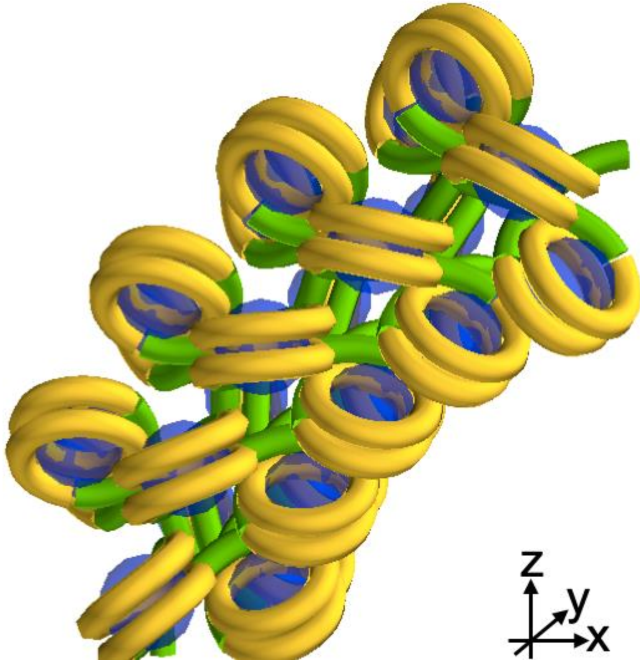
GEANT4-DNA

Open source and open access toolkits

GATE

SD3 Develop efficient multiscale and open source simulations

GEANT4-DNA
A SIMULATION TOOLKIT



The unique open source and open access simulation toolkit for micro/nano dosimetry and radiation biology

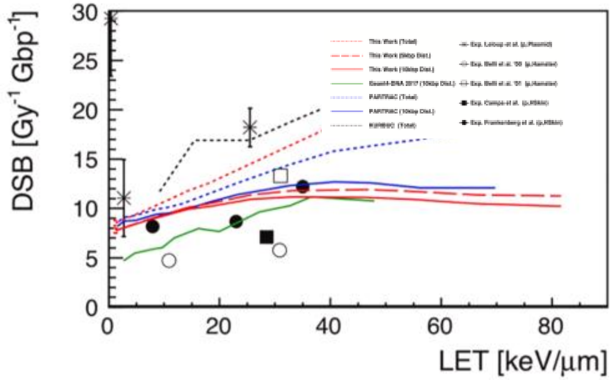
- **Long term development** fully included in Geant4 releases
- International collaboration composed of 53 collaborators (3 IN2P3 labs)
- **Coordinated by IN2P3/CNRS** since 2008
- Funded by regular support from institutions and international calls
- Fruitful involvement in international conferences & tutorials
  - Geant4 International User Conference at the Physics-Medicine-Biology frontier » series of conferences initiated by IN2P3 in 2005
  - Annual international tutorials
- High rank and highly cited publications (104 since 2007)

DEVELOPMENT ACCESSIBLE TO OTHER TOOLKITS, PARTICULARLY TO GATE

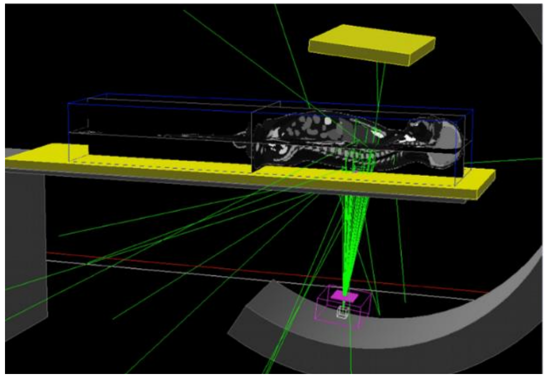
SD3 Develop efficient multiscale and open source simulations

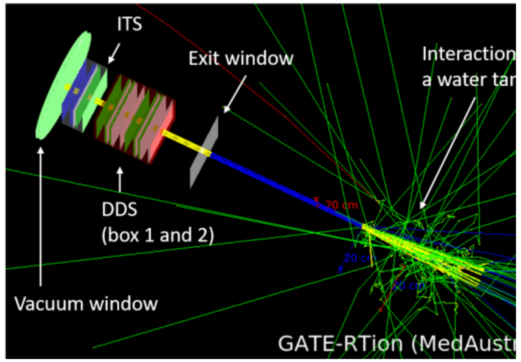
Geant4-DNA: Highlights and future challenges

- **Recent highlights**
  - Accurate Track Structure simulations of electrons and ions in **liquid water**
  - New cross section models for electrons and protons in **DNA components**
  - New cross section models for electrons in **gold nanoparticles**
  - **Prediction of early DNA damage** in human cell following two approaches
- **Challenges**
  - Track structure simulations in **biological medium**
  - Improve physico-chemistry and chemistry models for radiolysis simulations
  - Simulation of **late effects** of radiation
    - Full set of realistic biological geometry: DNA fibers, cell populations….
    - Repair and survival models
  - Improve **computing performance**
    - GP-GPU, AI (neural networks)



SD3 Develop efficient multiscale and open source simulations





An open source and open access simulation platform for medical physics

- **Long term development** based on Geant4 toolkit
- International collaboration composed of 27 members: laboratories (**6 IN2P3 labs**), companies and clinics
- **Very large community of users** (more than 2000 users)
- **Newly coordinated by IN2P3/CNRS** since 2018
- Funded by regular support from institutions and international calls
- Fruitful involvement in international conferences, workshops & tutorials
  - 2 tutorials /year + Tutorials in medical physics master programs
- High rank and highly cited publications
  - 2 PMB citation prizes in 2009 and 2015 for the 2 collaboration papers

A PLATFORM TO GATHER INNOVATIVE DEVELOPMENTS FOR THE FUTURE CHALLENGES IN MULTI-SCALE SIMULATIONS

SD3 Develop efficient multiscale and open source simulations
GATE: Highlights and future challenges

- **Highlights**
  - Validated **quality insurance** of preclinical and clinical beams
  - Integration and validation of biophysical models to tackle relative biological effectiveness in hadrontherapy
  - New developments to assess **microdosimetry** & **nanodosimetry**

- **Challenges**
  - Improve biophysical models
    - Better combine MCTS simulation outputs to macroscopic simulations
    - Use AI to train the models for different types of cells
  - Adapt or develop new biophysical models for new techniques
    - FLASH, mini-beam therapy, VHEE, IRT, NP…..
  - Combine the models to tumoral growth simulations
  - Combine to statistical analysis of clinical data

Science Driver 4

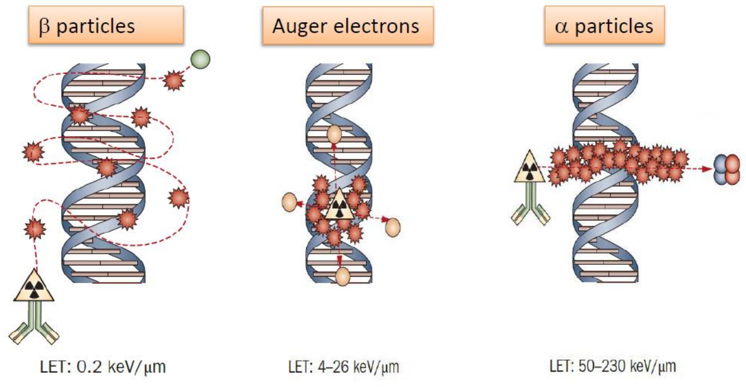
Develop novel radioisotope production toward theranostics

SD4 Develop novel radioisotopes production toward theranostics

- **Develop personalized treatments based on the vectorization of nuclear medicine probes to address new targets**
- The development of radioisotopes subdivided into five research and development activities:
  - Research for alternative production pathways of theranostic pairs
  - Identification and production of high LET radioactive emitters
  - Study of the chemical properties of these radionuclides in view of their absorption in molecular vectors
  - Development of high power targetry
  - Development and exploitation of isotope mass separator

SD4 Develop novel radioisotopes production toward theranostics

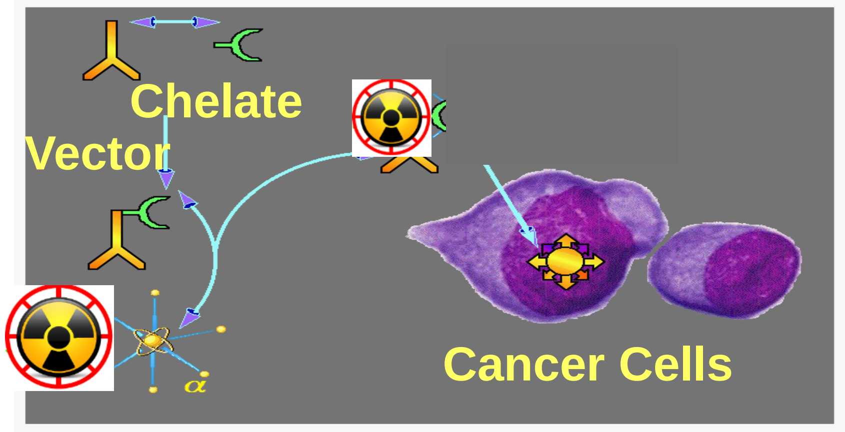
- **In Nuclear medicine, radionuclides are used:**
  - for **imaging and diagnosis**
    - **SPECT** (X, γ)
    - **PET** (β+)
  - for **therapy (α, β-,e-Auger)**



Pouget et al, *Nat. Rev. Clin. oncol.* **2011**, *8*, 720

- In most cases, **a vector molecule is needed** to target the cells or tissues of interest.

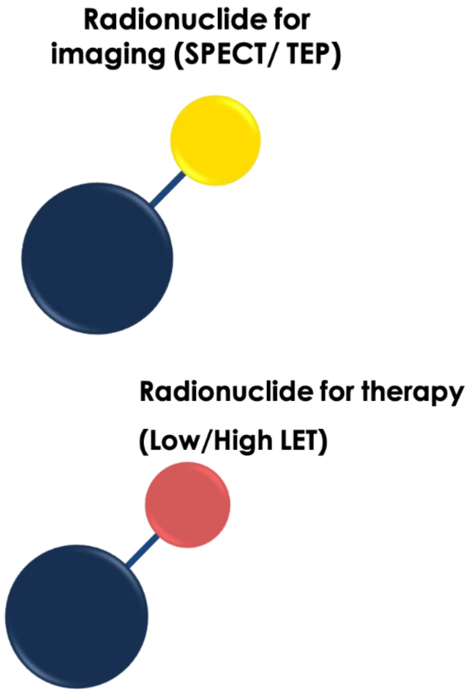
- Nuclear medicine needs radionuclide **with different decay radiations, LET, Chemical properties , Half-lives…**



SD4 Develop novel radioisotopes production toward theranostics

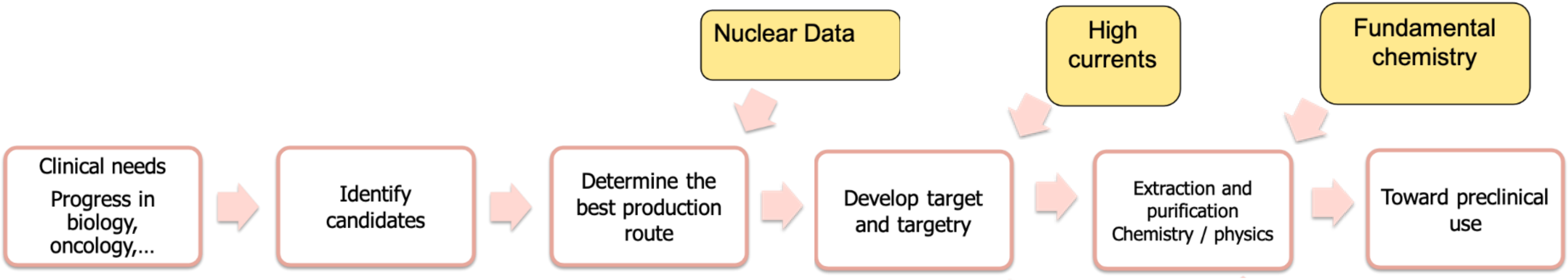
- Theranostic approach: A strategy to personalize treatment
  - The Right Drug To The Right Patient For The Right Disease At The Right Time With The Right Dosage

- Nuclear Medicine is well suited for the Theranostic approach
- **Which radionuclides?**
  - **Radionuclides of the same element**
    (**^{44}Sc/^{47}Sc**, ^{64}Cu/^{67}Cu, **^{124}I/^{131}I**, ^{155}Tb or ^{152}Tb/^{161}Tb/^{149}Tb …)
  - **Radionuclides** with comparable properties
    (**^{68}Ga/^{177}Lu**/^{225}Ac, ^{211}At/^{18}F ,^{211}At/^{123,124}I…)
  - **Radionuclide** with radiations for both imaging and therapy
    (^{117m}Sn, ^{64}Cu…)



SD4 Develop novel radioisotopes production toward theranostics

- Radionuclide production:

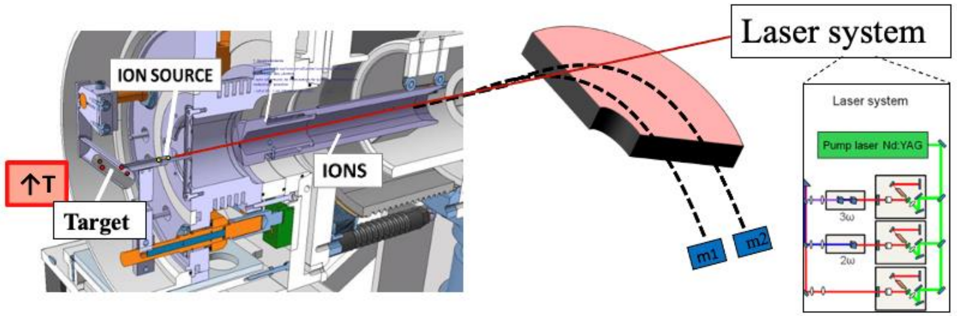


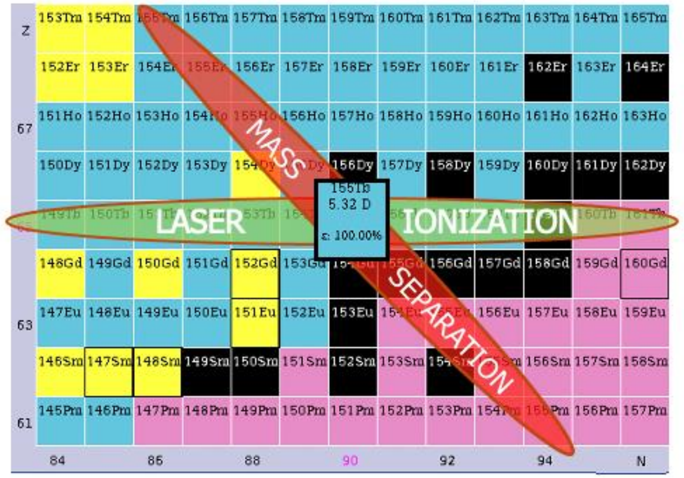
- Most important factors: **purity** and **quantity**
- Nuclear Physics and radiochemistry can help by developing **efficient large scale** production of **high purity** radionuclides (innovative or not)
- Cross section measurement, engineering for production, radiochemistry, radiobiology, preclinical test (vectorisation…)

SD4 Develop novel radioisotopes production toward theranostics

- Most important factors: **purity** and quantity

  Laser resonance ionization coupled to mass separation can increase product purity when chemistry is useless.





➢ Project SMILE(Séparation en Masse couplée à l'Ionisation Laser pour des applications Environnementales et en Santé)

- Goal: increase efficiency with a dedicated optimized system
- Foreseen Applications: enriched material, environmental analysis, radionuclide separation

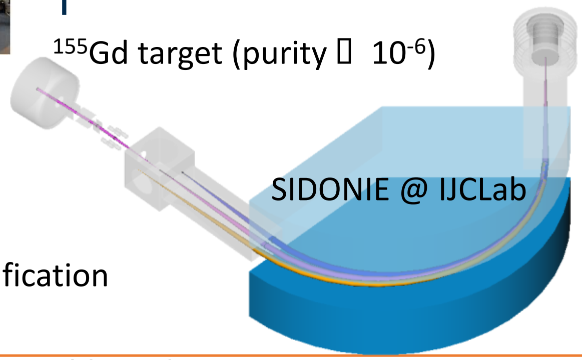
➢ ANR TTRIP (Tools for Tb RadioIsotopes Production for nuclear medicine)

- ^{155}Tb study
- use of a magnetic separator for production of precursor (high enriched target)
- development of new chelator for Tb

^{155}Gd (p,n)^{155}Tb

^{155}Gd target (purity □ 10^{-6})

^{nat}Gd

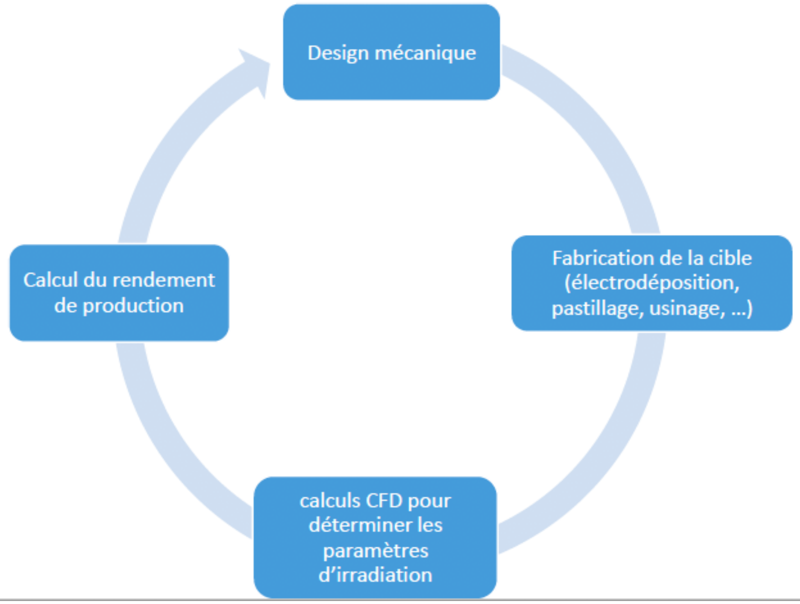


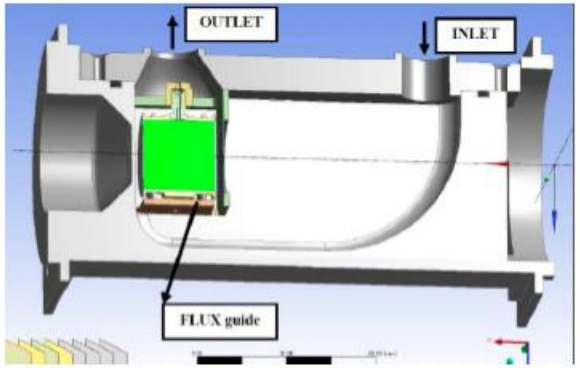
simplified radiochemistry purification

chelation in mild conditions

SD4 Develop novel radioisotopes production toward theranostics

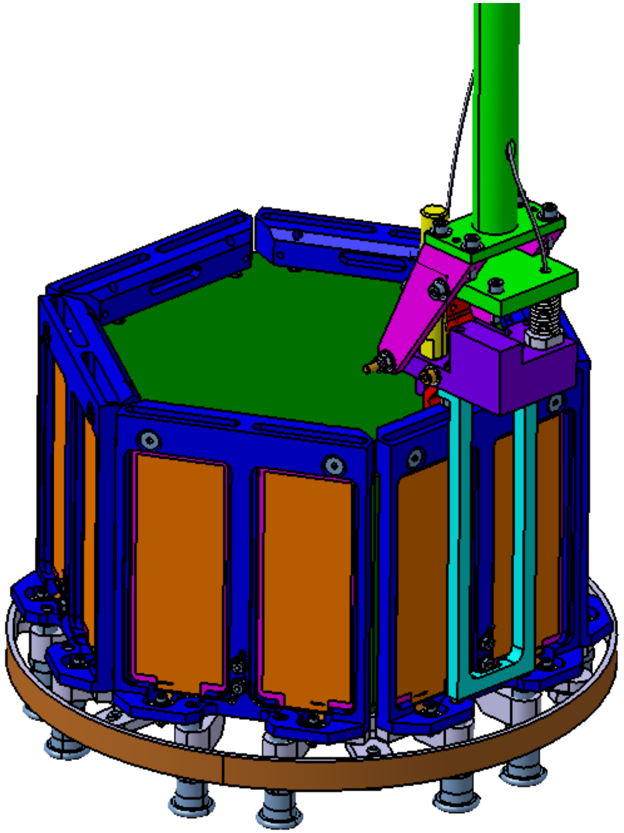
- Most important factors: purity and **quantity**
  - To produce enough radiosiotopes we need to use high intensity beams.
  - For a (new) radioisotope production we need to
    - Identify the nuclear reaction to be used
    - Chose the energy range
    - Chose a chemical form
    - Determine the thickness of targets and thermal load
  - Example : production of strontium-82 at ARRONAX
    - 140 μA at 70 MeV routinely
  - Target remains the blocking point





SD4 Develop novel radioisotopes production toward theranostics

- Most important factors: purity and **quantity**
  - High power target:
  - Example of the ANR REPARE:
    - to study the different production pathways of astatine-211: direct pathway with an alpha particle beam or indirect pathway with a lithium beam (SPIRAL2).
  - Prototype of a 10 kW solid rotating target
  - R&D for Liquid target
  - Long term goal: produce ^{211}At and other innovative radioelements for R&D (including potentially clinical trials) at SPIRAL2 and ARRONAX



Recommendations

1. Strengthen IN2P3 central leading role in radiation biology in France

Physicists, radiobiologists, internal irradiation platforms, know-how in dosimetry, multi-scale simulation and modelling, the GDR as structuring network

Recommendations

2. Reinforce collaboration links with key national or international partners

CNRS: INSB, INP, INSIS,

INSERM, IRSN, CEA

RadiotransNet: preclinical research in radiotherapy

IBC@FAIR (International Biophysics Collaboration), ENLIGHT (Network hadrontherapy)

Recommendations

3. Multi-disciplinary **career opportunities are essential to stimulate excellent young scientists**.

Wo do attract excellent and motivated students, thanks to various fundings.

However, the lack of long-term perspective is a serious issue.

Inter-disciplinary research is made by researchers from multiple different disciplines

Recommendations

4. Long-term sustainability of IN2P3 irradiation platforms.

5. Challenging collaboration opportunities

- on platforms: AIFIRA, ARRONAX, CYRCé, GANIL, Tandem-ALTO
- and treatment centers (ARCHADE, CAL-Nice, CPO, CNAO).

Recommendations

6. Support the leading role of IN2P3 within international open-science collaborations Geant4, GATE and Geant4-DNA

Both collaborations are now lead by IN2P3 scientists.

Engineering resources, supported by IN2P3, are needed to maintain this leadership

Recommendations

7. SD1: Innovative radiotherapies challenges : Instrumentation & platform development and access to get data for modelling fundamental mechanisms

8. SD1: New strategies for online treatment control are needed, including accelerator technology developments (GT07).

9. SD4: Efficient methods for radioisotopes production (GT02).

10. SD2: Overcome limitations in the performance of medical imaging modalities.

11. SD1,2,3: Contribute to the national initiatives of health-data collection and sharing.

Recommendations

Science Drivers:
1: Improve therapeutic efficiency through innovative irradiation modalities
2: Develop innovative medical imaging toward personalized medicine
3: Develop efficient multiscale and open source simulations
4: Develop novel radioisotope production toward therapy and/or diagnostics

1. Strengthen IN2P3 central leading role in radiation biology in France
2. Reinforce collaboration links with key national or international partners (CNRS, INSERM, IRSN, CEA, RadiotransNet, IBC@FAIR...).
3. Multi-disciplinary **career opportunities are essential to stimulate excellent young scientists**.
4. Long-term sustainability of IN2P3 irradiation platforms.
5. Challenging collaboration opportunities on platforms: AIFIRA, ARRONAX, CYRCé, GANIL, Tandem-ALTO and treatment centers (ARCHADE, CAL-Nice, CPO, CNAO).
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9. Efficient methods for radioisotopes production (GT02).
10. Overcome limitations in the performance of medical imaging modalities.
11. Contribute to the national initiatives of health-data collection and sharing.

Transverse questions

GT10 contributes to fundamental questions
Common technological challenges with GT 2, 7, 8, 9