Interdisciplinary research @ in2p3, a (non-exhaustive) overview

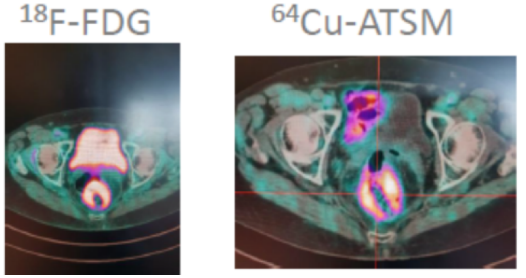
M. Vanstalle

22/06/2021

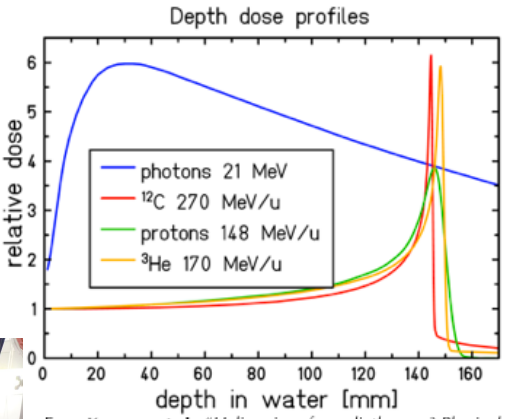
Workshop "Physique et Détecteurs à la frontière"

Applied physics for health – main questions

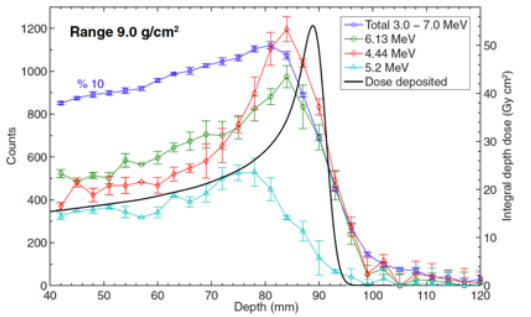
- Imaging:
  - Development of new radioisotopes for nuclear medicine
  - Multimodal imaging (PET, SPECT,..)
  - Improvement of imaging perfomance (PET, SPECT)



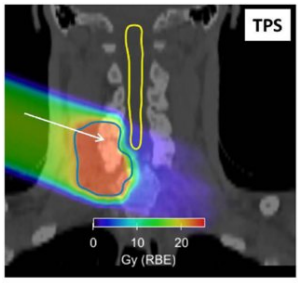
- Hadrontherapy & innovative radiotherapy:
  - Online treatment monitoring
  - Nuclear data for health
  - New beam delivery modes (FLASH, micro-beams, radioactive beams)



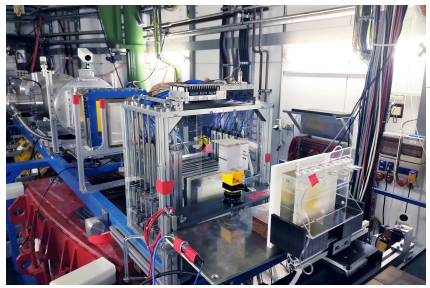
From **Kraemer et al.**, *"Helium ions for radiotherapy? Physical and Biological verifications of a novel treatment modality"*, Med. Phys. (2016).



From **Verburg et al.**, *"Energy- and time-resolved detection of prompt gamma-rays for proton range verification"*, Phys. Med. Biol. (2013).



From **Battistoni et al.**, *"The FLUKA code: an accurate simulation tool for particle therapy"*, Frontiers in Oncology (2016).



From **GSI website:** Setup for carbon ion FLASH experiment

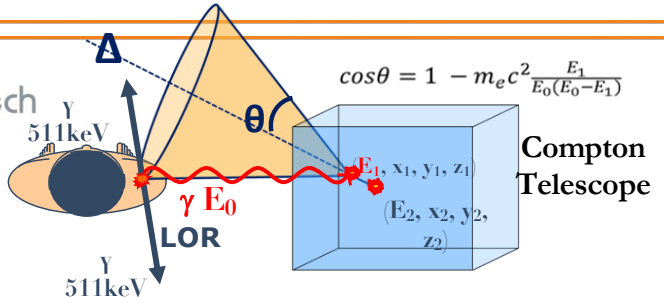
Actors (in2p3)

- 12 laboratories involved in applied physics for health

- Organized around GDR Mi2B

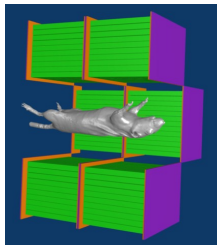
PET imaging

- XEMIS project: 3γ-imaging (from ^{44}Sc)
  - Direct 3D location of the radioactive source: res. along LOR ~ 1 cm (FWHM)
  - Reduction of injected activity: 100 times less

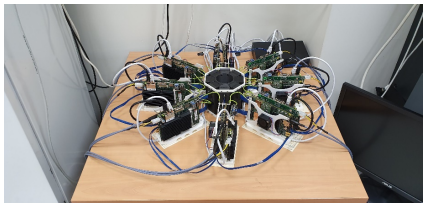


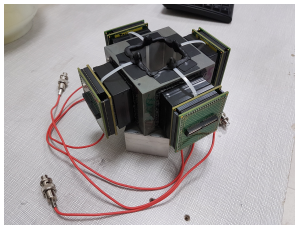
- ClearMind project:
  - Development of **scintronics crystal** for ultra-fast gamma imaging
  - Cherenkov photons detection and scintillation emitted by $PbWO_4$:Y
  - Collection efficiency enhancement on photocathode **by factor 4!**
  - Coincidence Resolving Time ~ **20 ps FWHM**

- Different geometrical approach:
  - DigiPET (dual layer approach, 2D)
  - Axial approach (2,5D)
  - JackPET (3D)
  - InsertPET (PET+MRI)



Modular DAQ development (ASICs IMOTEP + FPGA)





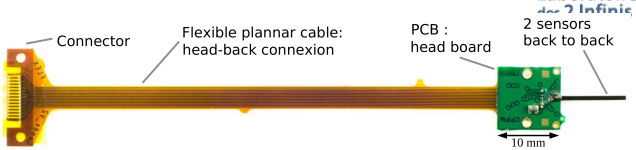
SPECT imaging & in-vivo imaging

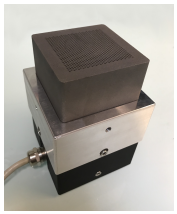
- What is the impact of collimating choice in SPECT performances?

  * **SPECT prototype:**
    - $CeBr_3$ detectors
    - DAQ (IMOTEP + FPGA)
    - Collimation à lames parallèles (g=2mm, H=20mm)

- In-vivo imaging:

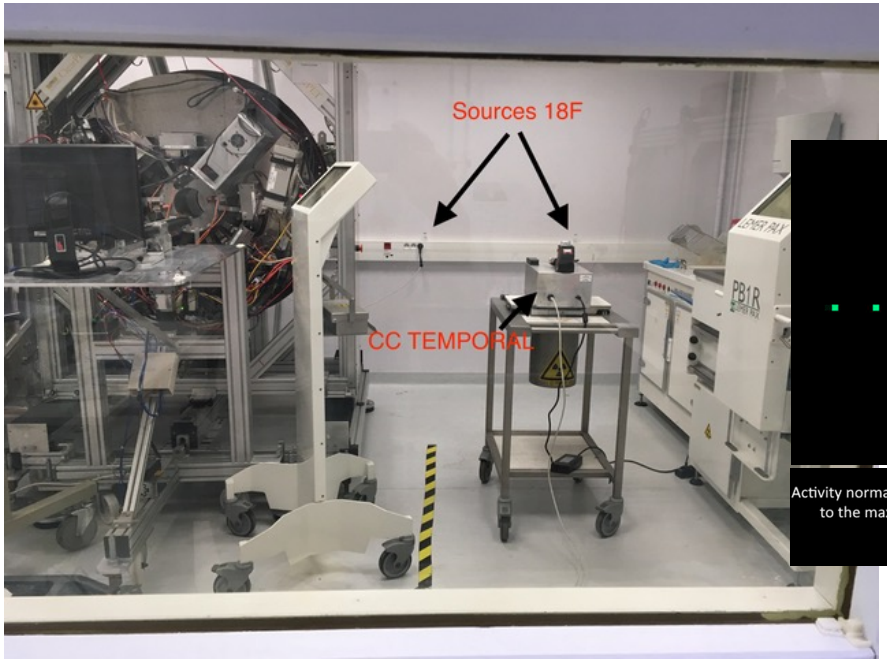
  * CMOS probe for beta detection
  * Multimodal optical endomicroscopy for in vivo diagnosis of brain tumors
  * Ambulatory gamma-camera of high resolution for thyroid diseases

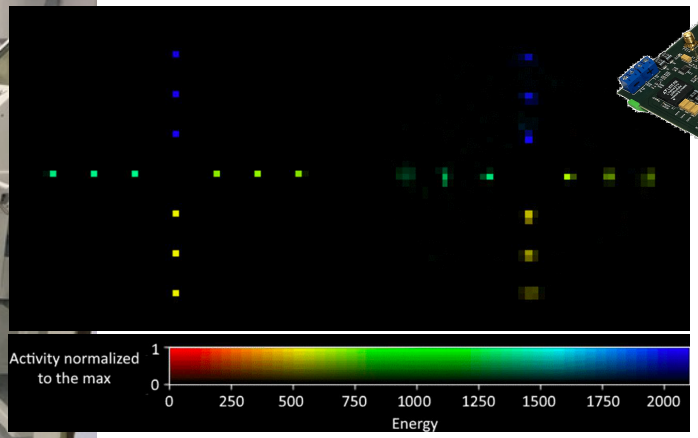


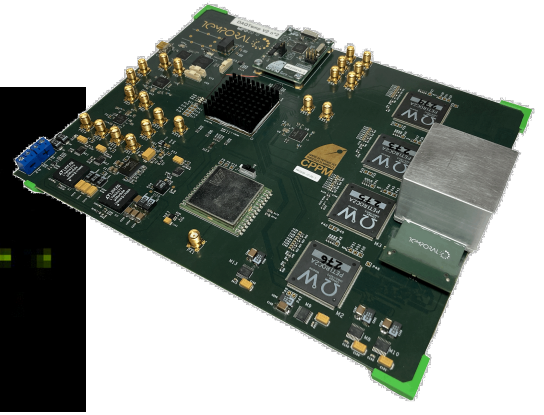


Imaging for nuclear dismantling

- TEMPORAL project Compton camera (and DAQTemp)
  - $CeBr_3$ crystals coupled to SiPM (modelised in GATE)
  - Reconstruction with MLEM-like algorithm
  - Acquisition card developed for SiPM readout with ASIC PetiROC

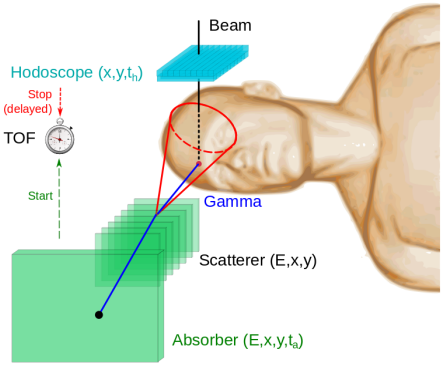


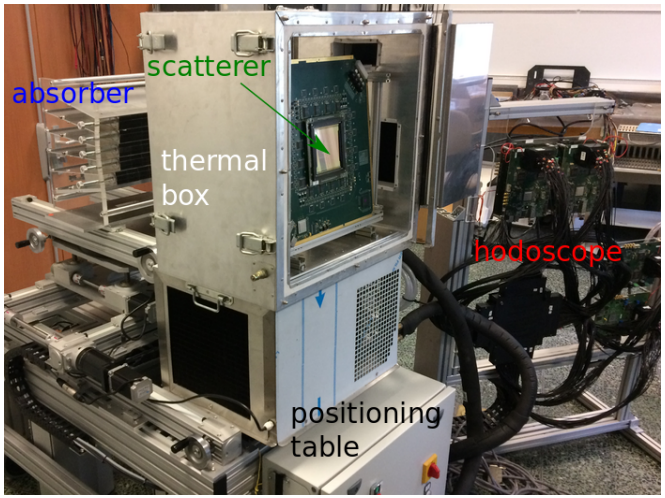




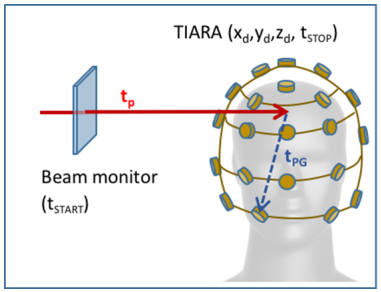
Online treatment monitoring – prompt-γ

- CLaRyS project:
  - **Compton camera** with hodoscope (line reconstruction + TOF) + 2-mm thick silicon detectors + BGO absorbers ⟹ **detection efficiency enhancement** wrt collimated camera (factor 50!)
  - Hodoscope: diamond detector (100 ps TOF resolution with 68 MeV protons)
  - Prospects:
    - TEMPORAL detectors: $CeBr_3$ + SiPM ⟹ Reconstruction of the interaction point + improvement of time resolution (CC absorber)
    - Future integration in the CLaRyS acquisition system thanks to the front-end board developed in CPPM



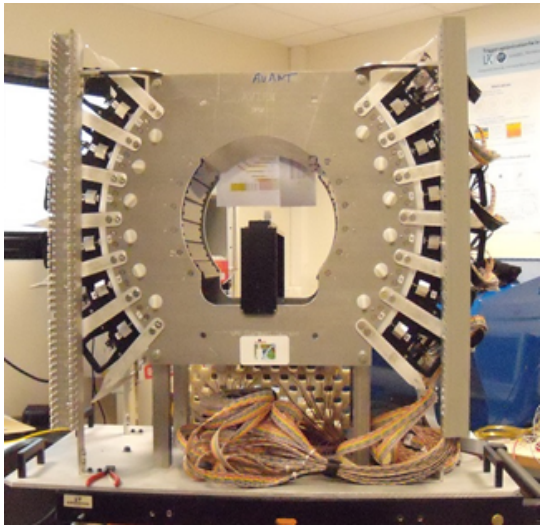


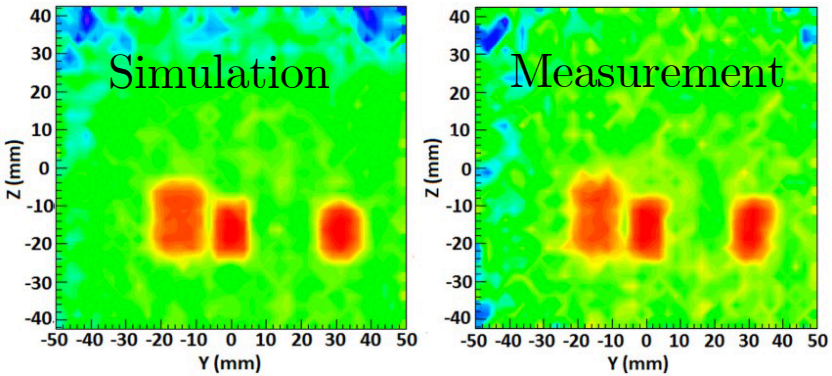
- TIARA project (a ToF Imaging ARray for hadrontherapy):
  - Cherenkov + SiPM
  - 30 pixels of ~ 1 cm^3

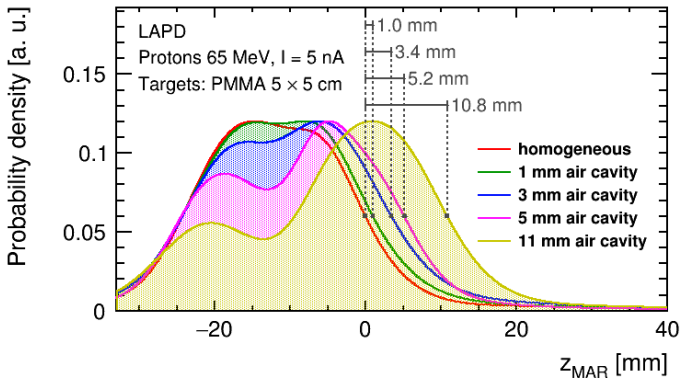


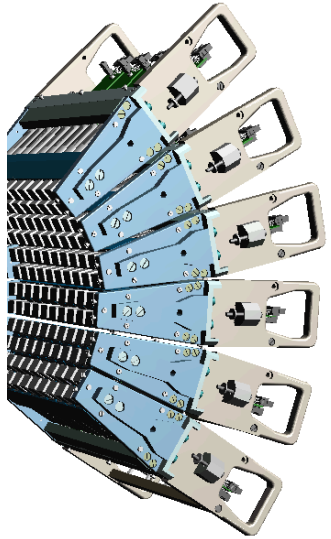
Online treatment monitoring - PET

- LAPD (Large Acceptance Pixelised Detector), developed @ LPC Clermont
  - 12 modules of LYSO+PMT, 2×120 channels
  - Performances:
    - Energy resolution: 14% @ 511 keV (FWHM)
    - CRT: 3.4 ns
  - Prospects:
    - Unfortunately, no more fundings, but detector available and operational!
    - SOBP tests, heterogeneous media...



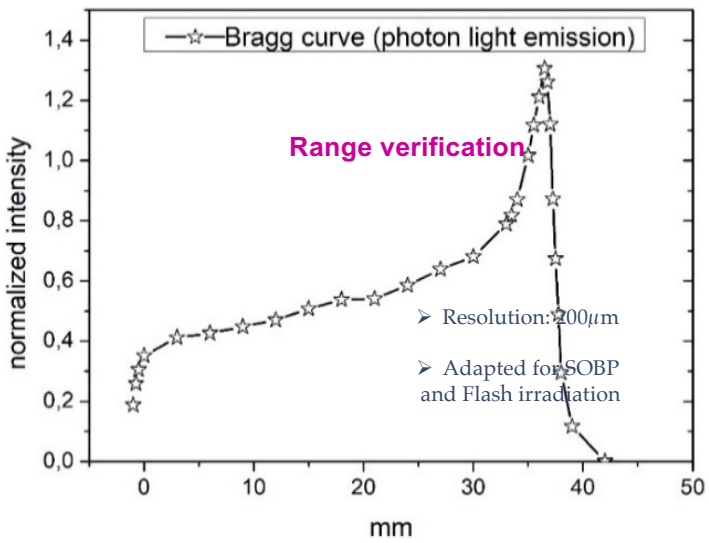


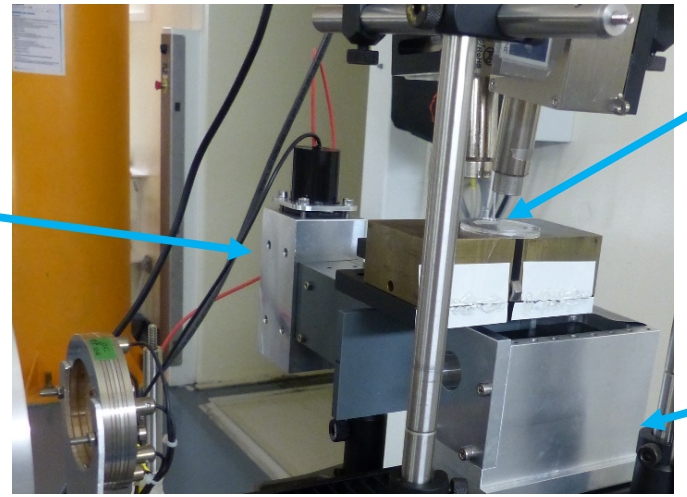




Bragg peak monitoring

- Detection of UV (from transparent medium) and X-rays from bremsstrahlung (from opaque medium) during treatment ⟹ range verification of the Bragg peak



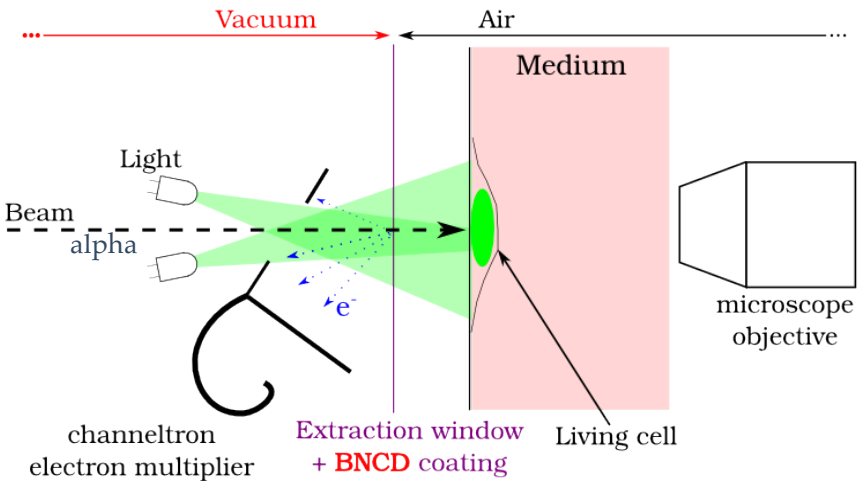


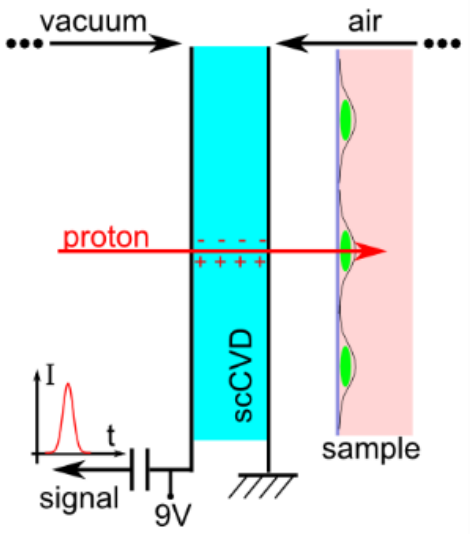
- Prospects:
  - Tests with SOBP (Spread-Out Bragg peaks)
  - Heterogeneous media

From **Ralite et al.**, "*Bremsstrahlung X-rays as a non invasive tool for ion beam monitoring*", Nuclear Instruments and Methods in Physics B (2021).

Beam monitoring

- Ultra-thin detectors for low energy beams
  - AIFIRA beam line: protons and α @ 3 MeV ⟹ How to monitor low energy ions delivered to the sample?
  - Two detectors developed in collaboration between CENBG and CEA-LIST:
    - Secondary electrons emitter for α beams (400 nm-thick)
    - Monocrystal diamonds for protons (2 µm-thick)

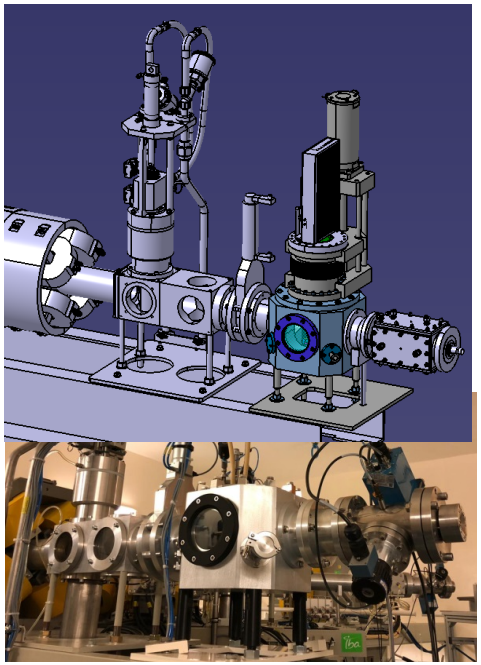


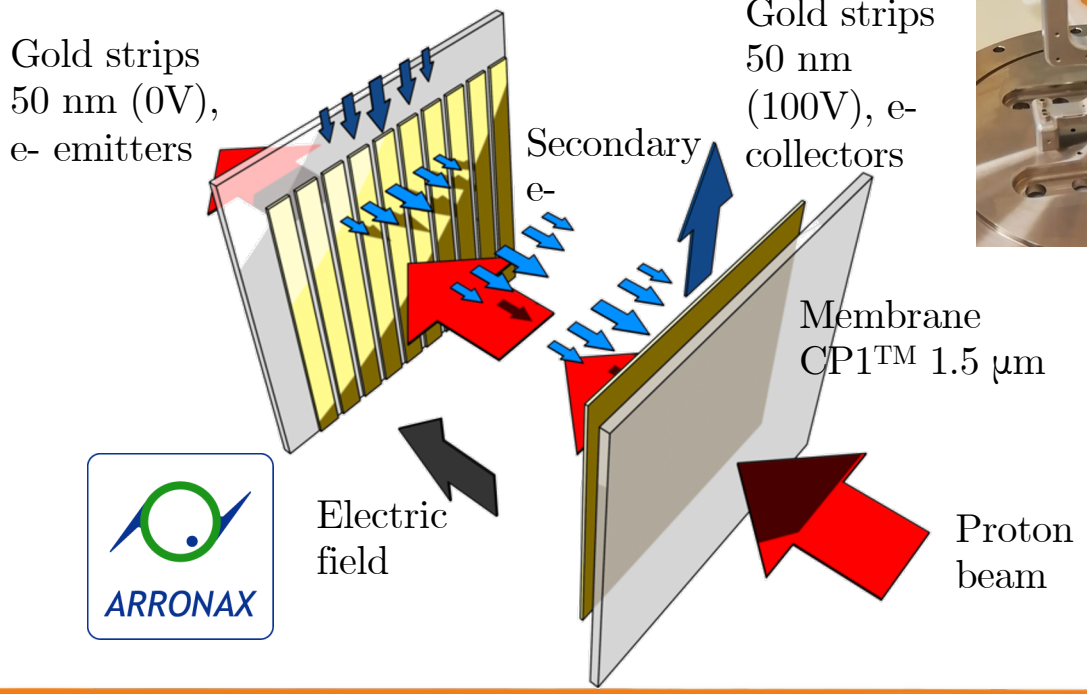


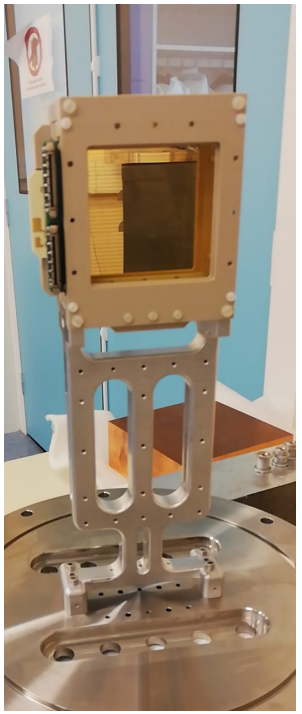
Beam monitoring

Laboratoire Leprince-Ringuet

- PEPITES (Profileur à Electrons secondaires pour Ions ThérapeutiquES)
  - Secondary electrons emitter, thickness < 10 µm WET
  - Monitoring of proton beam around 100 MeV, 1 pA-10 nA
  - Will be installed on ARRONAX
  - Good candidate for beam monitoring in **FLASH therapy!**

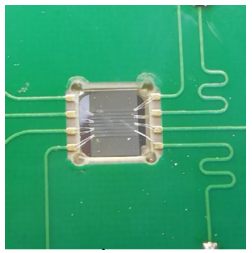


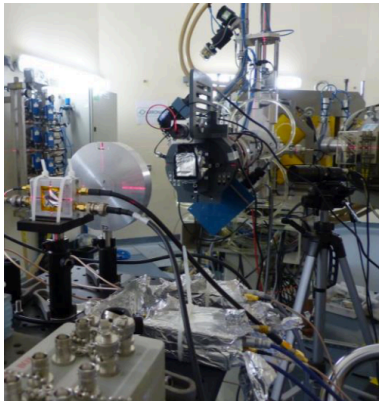


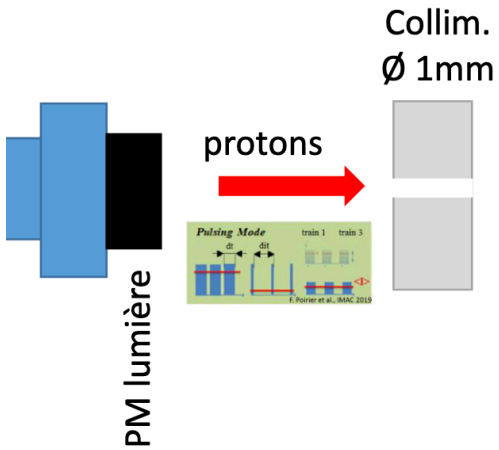


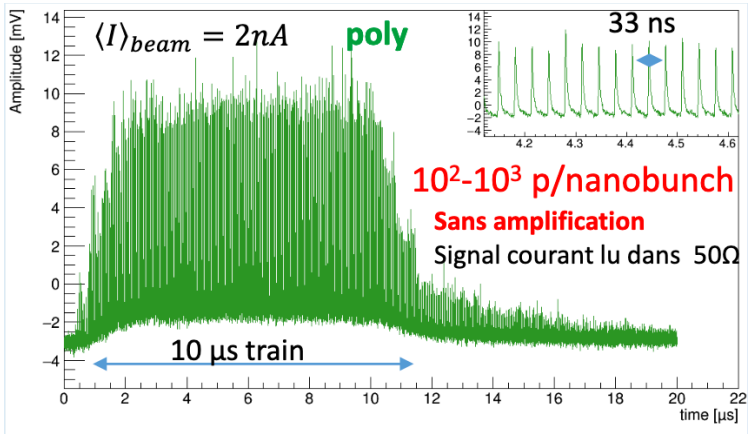
Beam monitoring

- Beam monitoring with diamond detectors
  - Monitoring of X-ray micro-beams (synchrotron)
  - Beam monitoring of pulsed ion beam for FLASH therapy (e.g., Radiograaff platform)

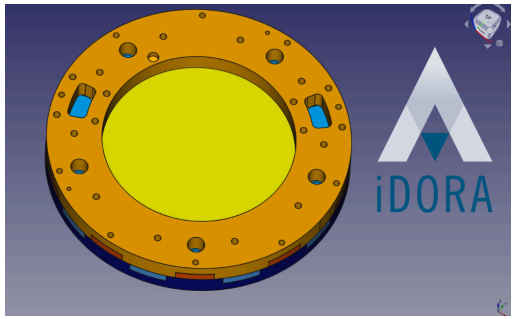






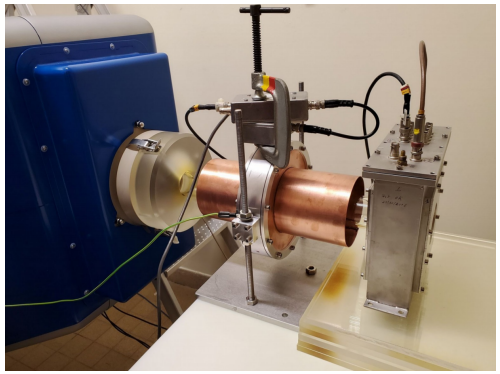


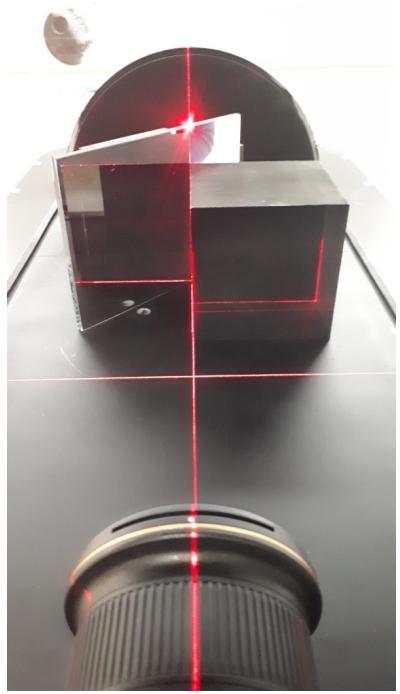
- Beam monitoring with nanometric ionization chamber for FLASH therapy + adapted electronic (iDORA)
  - Reducing the ionization yield of a 500 factor
  - 800 µs timing response

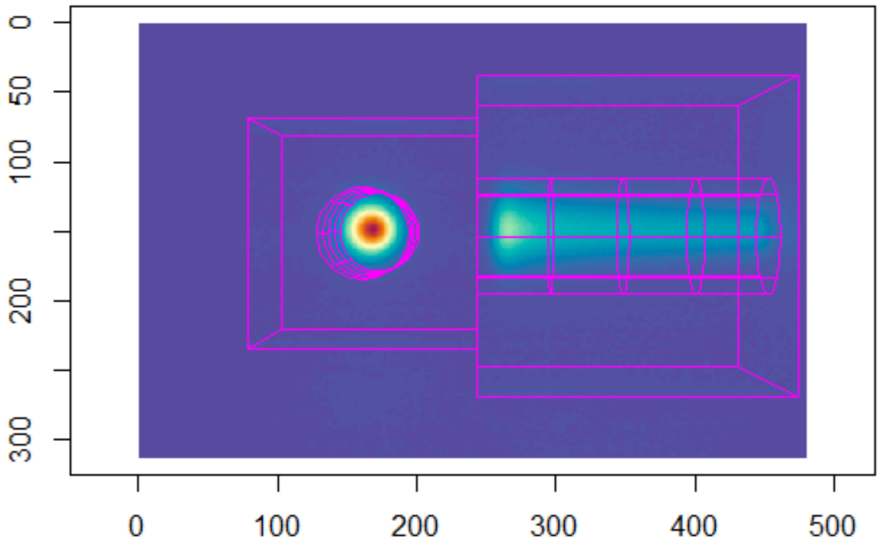


Beam monitoring

- Beam monitoring and dosimetry with BCT
  - Tested for FLASH therapy with electrons 5-7 MeV (orsay)
- 3D dose monitoring for protontherapy
  - Ultra-fast camera to reconstruct 3D dose profile
  - Quality control of IBA S2C2

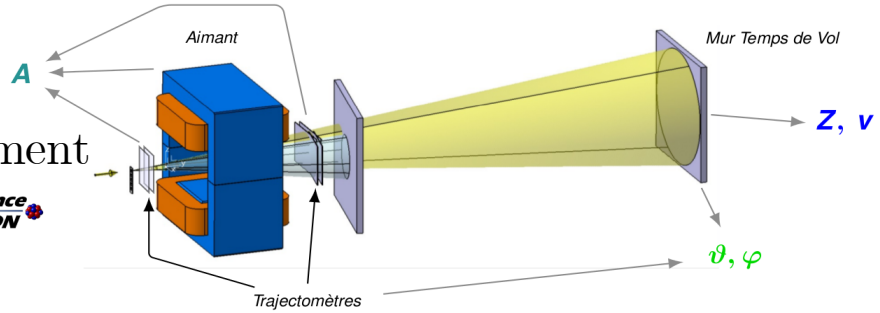




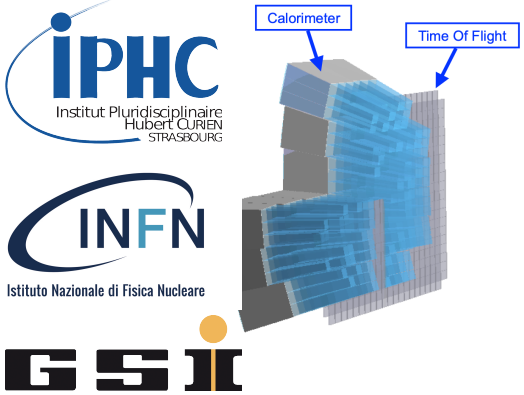


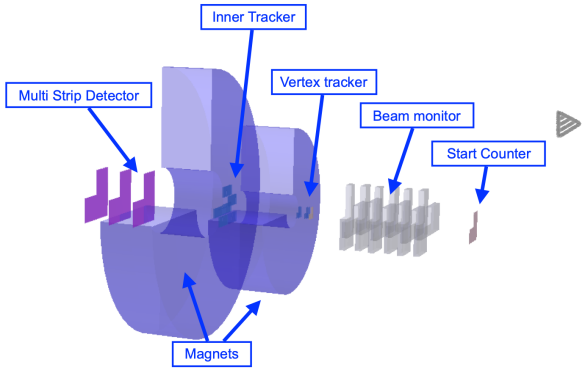
Nuclear data for hadrontherapy & space

- FRACAS spectrometer for cross-section measurements on ARCHADE accelerator
  - ToF wall of 75 YAP:Ce crystals
  - PPAC electrodes for beam monitoring
  - Gaseous trackers (uRWell, MWPC) development



Conception S.Salvador



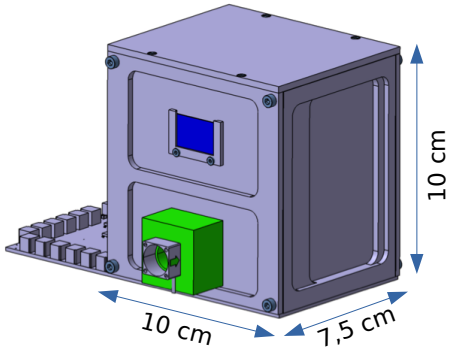


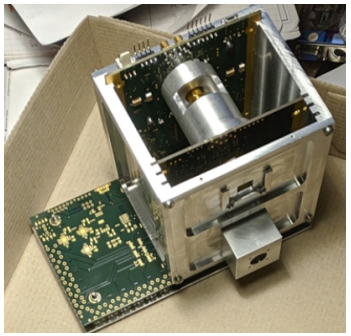
- FOOT (FragmentatiOn Of Target) experiment
  - IPHC involved in vertex detector + inner tracker development

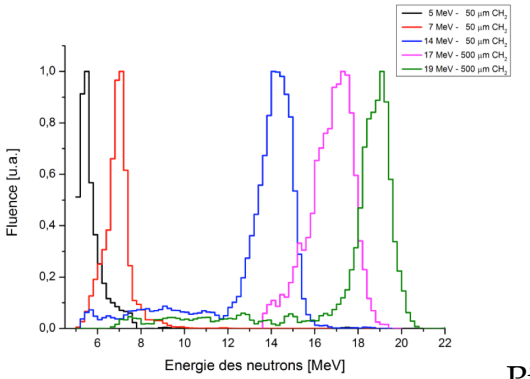
- CLINM (Cross-sections of Light Ion and Neutron Measurements) :
  - Measurement of impact of secondary particles on biomolecules
  - ΔE-ToF telescope (plastic scint. + $CeBr_3$) for charged particles identification
  - Neutrons measured by RPT (Recoil Proton Telescope)

Nuclear data for hadrontherapy & space

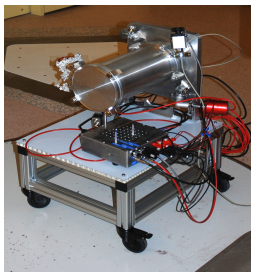
- Neutron spectrometry by RPT (Recoil Proton Telescope)
  - Energy reconstruction of neutrons between 5-50 MeV
  - Compact device, real-time, high fluence (10^8 n/s/cm^2)
  - Recoil protons reconstructed by CMOS (FastPIX) tracker

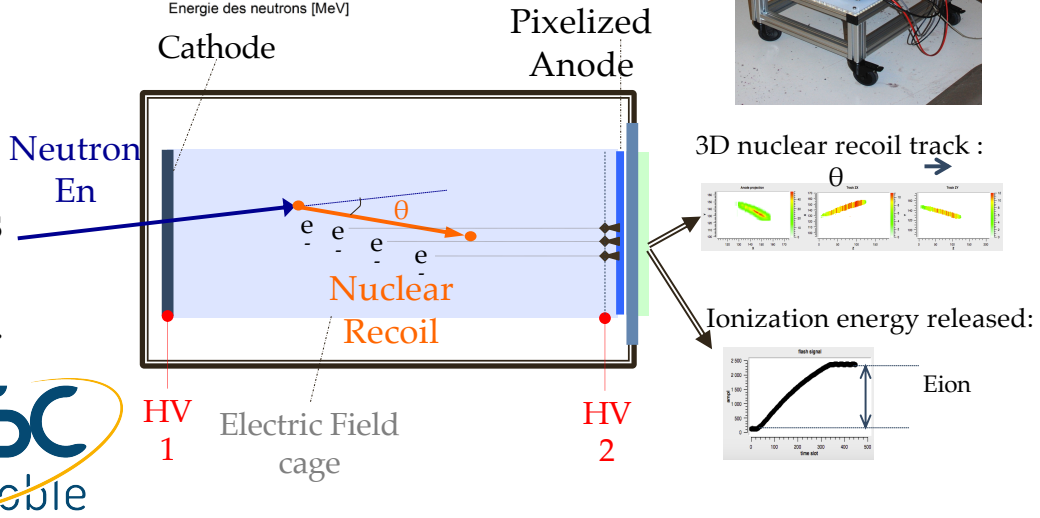






- Neutron spectrometry MIMAC-FastN detector
  - Energy reconstruction of neutrons with Θ and Eion (+IQF)
  - Adding a B_4C foil on cathode ⟹ "active phantom" for BNCT





Acknowledgements

Backup slides

M. Vanstalle

About the platforms...

- Platforms were installed in several labs

- For charged particles:
  - **AIFIRA platform**: low energy p & α (3 MeV), micro-beams irradiation ⟹ detector characterization (diamonds micro-dosimeters, CMOS-detectors for neutrons...)
  - **ARRONAX** pre-clinical platform with p & α up to 70 MeV, to study FLASH irradiation effect
  - **Radiograaff** (developed at IP2I, now moved at IJClab), p <3.5 MeV
  - **Cyrcé**, p @ 25 MeV
  - GANIL
  - CAL