

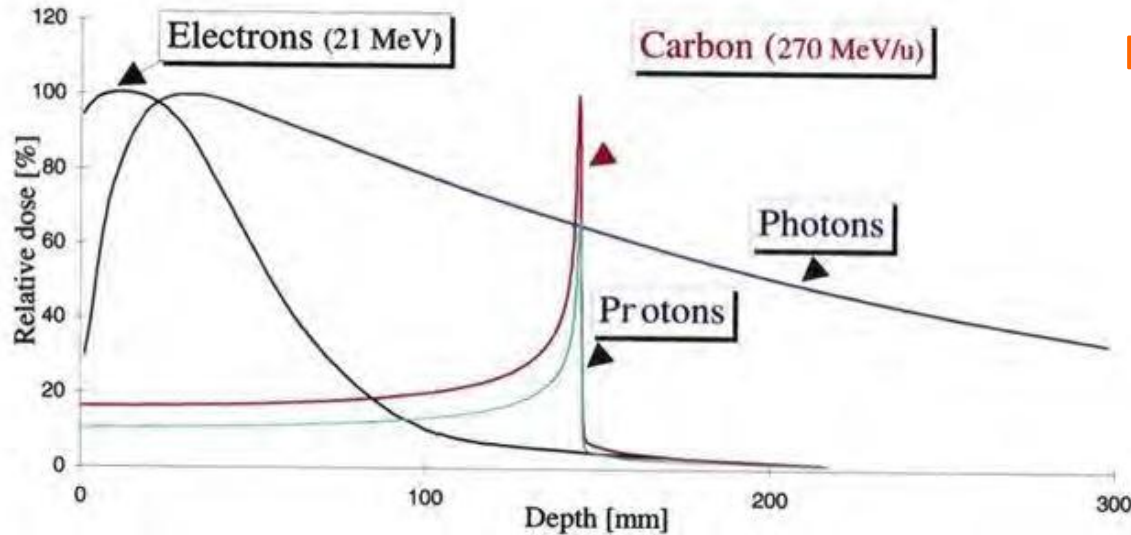
DEvelopment and testing of Medical physics instrumentation (DENIM)

**Antoni Ruciński¹, Victor Merza², Marcin Pietrzak¹, Jan Gajewski¹, Renata Kopeć¹,
Marc Antoine Verdier³, Quentin Mouchard³, Louis Hardouin³, Philippe Lanièce³**

1 CCB Krakow proton therapy center, Institute of Nuclear Physics PAN

2 (a) Department of Physics, Instituto Superior Técnico, Lisbon University, (b) Centre for Nuclear Sciences and Technologies, Instituto Superior Técnico, Lisbon University

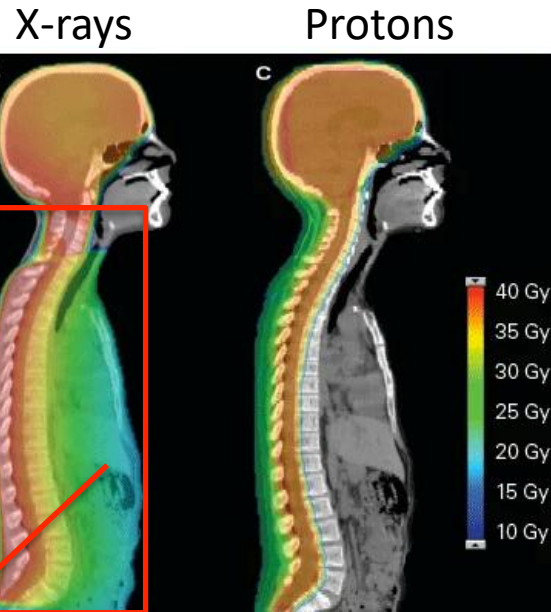
3 (a) Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France (b) Université Paris Cité, IJCLab, F-91405, Orsay, France



Dosimetric properties of light ions:

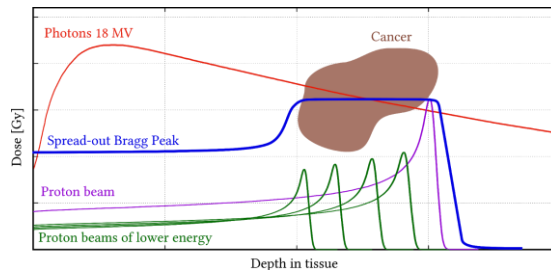
- Steep dose gradient
- Limited dose to the surrounding healthy tissues
- Toxicity reduction with comparable target coverage with respect to X-rays

Ions have better ballistic properties



Dose distribution in a patient

X-rays don't stop!



Dosimetric properties of light ions:

- Steep dose gradient
- Limited dose to the surrounding healthy tissues
- Toxicity reduction with comparable target coverage with respect to X-rays

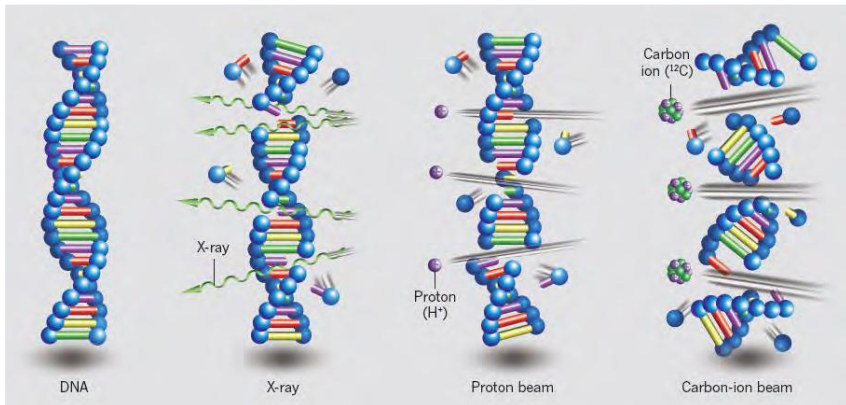
Therapeutic recommendations:

- Deep seated tumours
- Pediatric tumours

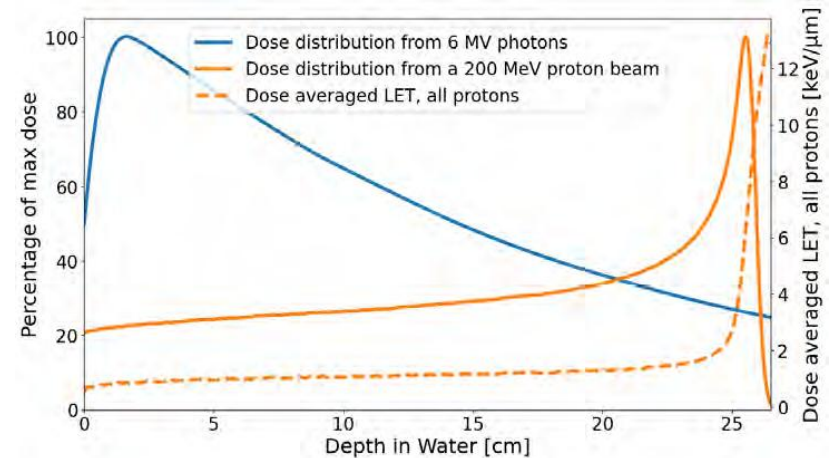
Radiobiological properties of light ions:

- Higher Linear Energy Transfer (LET): energy delivered per unit length $\text{keV}/\mu\text{m}$
- More serious DNA damage induced
- Higher relative biological effectiveness (RBE)
- Higher efficacy on radioresistant tumours

The same dose not lead to the same biological effect

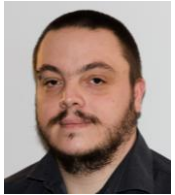


Marx, V. Sharp shooters. *Nature* **508**, 133–138 (2014). <https://doi.org/10.1038/508133a>





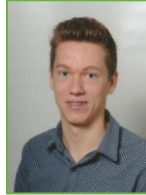
IJC Lab



Marc Antoine Verdier



Quentin Mouchard



Louis Hardouin



Philippe Lanière



zoom

Budget: 0 EUR
4/5x Zoom meetings /year

CCB IFJ PAN



Victor Merza



Marcin Pietrzak



Jan Gajewski



Renata Kopeć



Antoni Ruciński

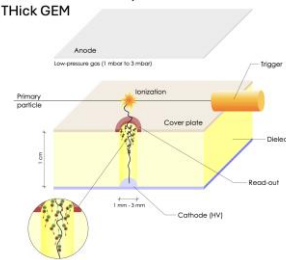
• Common interests:

- Condensed history and track structure simulations: Scientific committee of GATE (Geant4/Geant4-DNA) collaboration
- Radiobiological response to ionizing radiation in micro- and nano-scale
- Detector development for beamline modeling and characterization of radiation quality

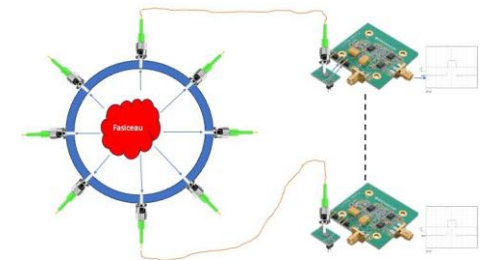


Courtesy of Jan Gajewski

"THGEM": THick GEM



Victor Merza PhD project



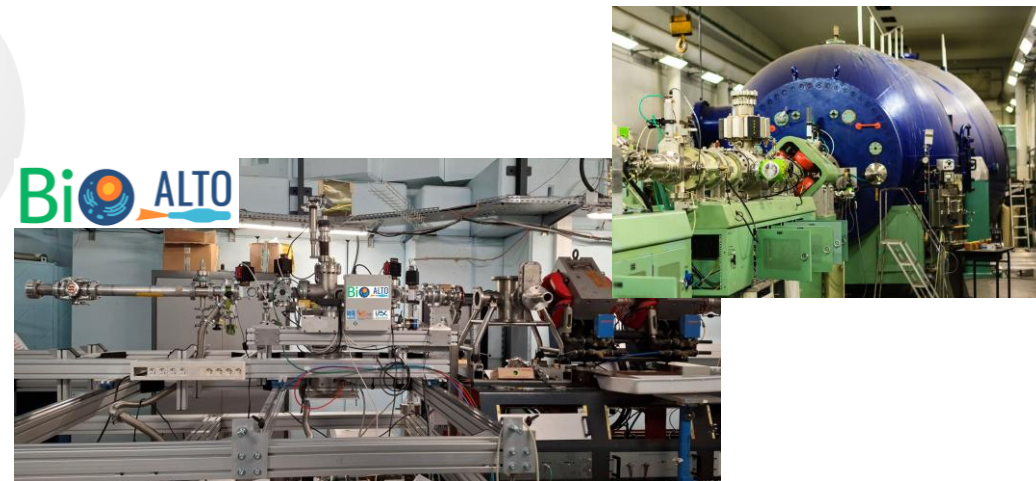
Louis Hardouin PhD project

- CCB Kraków proton center



- Scanned clinical proton pencil beams at 70-230 MeV/u operated at therapeutic, low, and FLASH beam rates
- Access to proton beams in Gantry rooms for experiments
- Anonymized patient data for TP studies and protocol development
- Radiobiology labs equipped to perform in vitro experiments (from 2023)

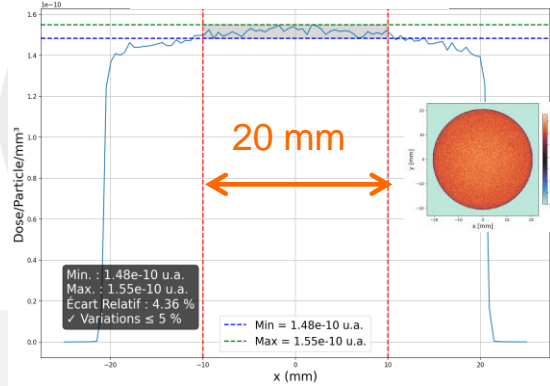
- BioALTO platform



- An experimental platform at ALTO for pre-clinical hadron therapy research
- Wide range of ions and energies: 4-25 MeV/u protons ; 4 – 11 MeV/u helium ; 7 MeV/u Carbon ; 8 MeV/u Oxygen
- Continuous beam / additional pulsed beam possible (100 ns to 100 μ s)
- Possibility of carrying out relative biological effectiveness (RBE) studies for all ions of interest for future hadron therapy treatments



Louis Hardouin intership project



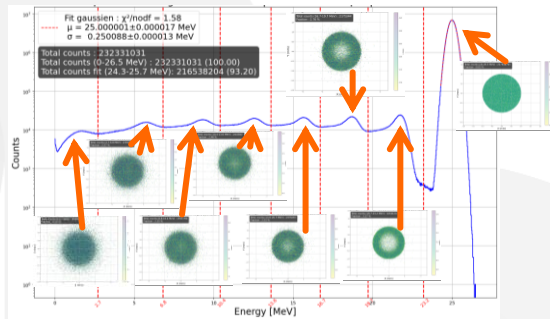
Design office @IJCLab



→ beam line upgrade
(interoperability with ALTO,
improved beam monitoring, etc.)

Irradiation conditions for radiobiology:

- ✓ Monoenergetic beams (< 0.1 MeV)
- ✓ Homogeneous irradiation field ($> 95\%$)
- ✓ Precise dose delivery ($> 95\%$)
- ✓ Precise dose rate ($> 95\%$)
- ✓ Beam repeatability and reproducibility
- ✓ Strict schedule compliance (cell survival)



→ Optimisation of beam transport
(scattering, collimation, etc.)

2026:

- ❑ Continued upgrading of the line during the ALTO shutdown
- ❑ Installation and commissioning of new detectors (Faraday cup, diamond detector, beam profiler, etc.)
- ❑ Commissioning of the beam line at the end of 2026
- ❑ opening of the line for irradiation at the beginning of 2027

- **Development of a compact ion-counting detector for nanodosimetry (ND) applications**
 - **ND:** Prediction of DNA damage frequency and complexity through the specification of the **nanoscopic ionization pattern** of radiation
 - **Clinical applications of ND:** Miniaturized detectors required
 - A **low-pressure gas-based ND detector** is under development (Fig. 1)

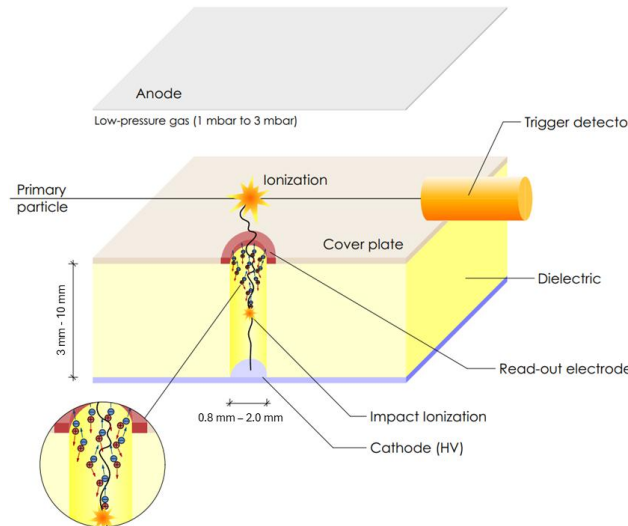
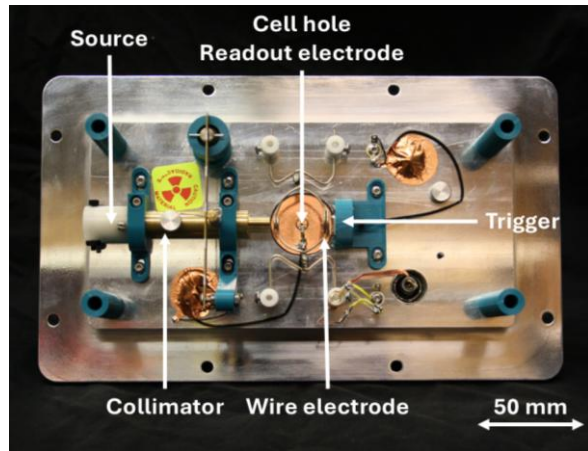


Fig. 1: **Left:** Top interior view of the nanodosimeter. **Right:** Illustration of the detector working principle.

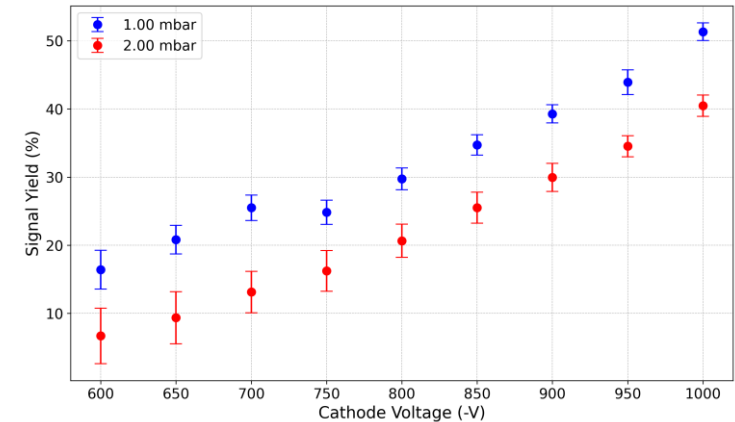


Fig. 2: Measured signal yields using an Am-241 source in 1 mbar & 2 mbar propane gas for the stated cathode voltages.

First experimental results using propane gas and an Am-241 source/4.6 MeV alphas are promising (Fig. 2): High signal yields

- **Development of a compact ion-counting detector for nanodosimetry (ND) applications**

Computational characterization:

- Radiation transport and ND quantities: **Geant4-DNA** (Fig. 3)
- Detector performance incl. charge multiplication and transport: **Garfield++**

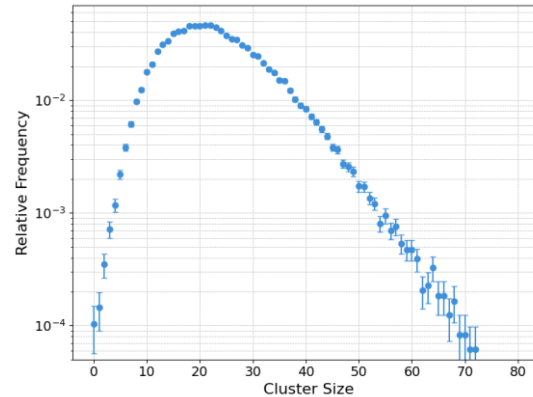
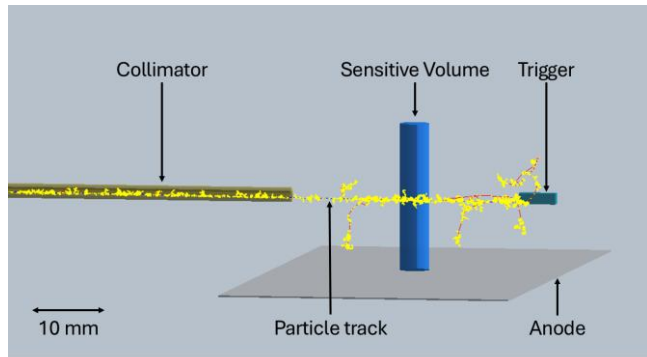


Fig. 3: **Left:** Geant4-DNA model of the current experimental setup. **Right:** Simulated frequency distribution of the ionization cluster size in the detector's sensitive volume for 4.6 MeV alpha particles.

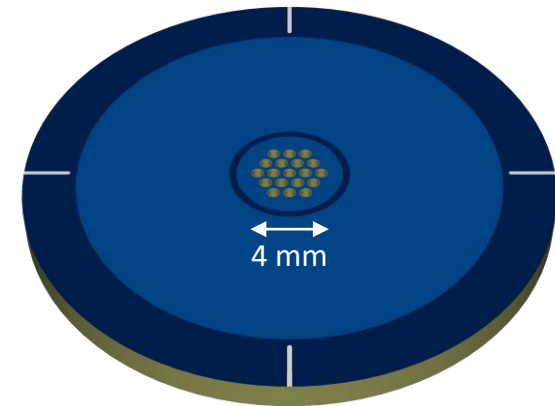
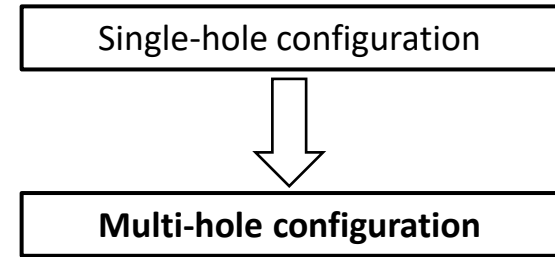
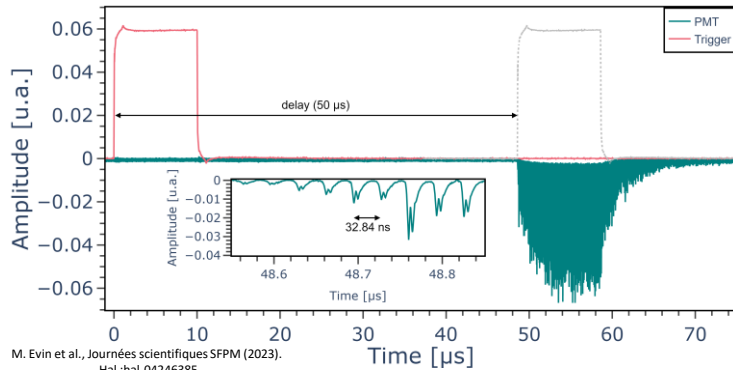


Fig. 4: Multi-hole configuration of the detector featuring independent sensitive cells to count the number of produced ions in the sensitive volume.

⇒ Tests of new detector configuration at the **BioALTO** beamline planned

- **Development of a non-disruptive beam monitoring based on the fluorescence of nitrogen molecules in the air**

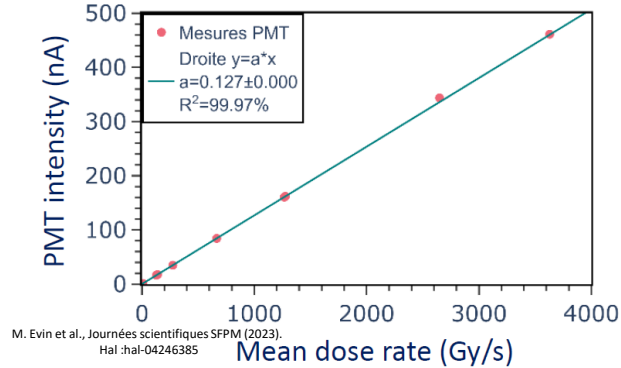
Monitoring the temporal structure of the beam



M. Evin et al., Journées scientifiques SFPM (2023).
Hal :hal-04246385

- Monitoring the temporal structure of 68 MeV proton beam (30.45 MHz) with pulsing beam system

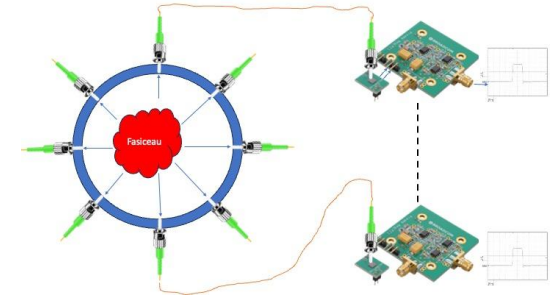
Monitoring of beam fluence/dose



M. Evin et al., Journées scientifiques SFPM (2023).
Hal :hal-04246385

- Linear response of PMT to fluence/dose over a wide range up to several thousand Gy

Monitoring the geometric structure of the beam



- Using **SiPM/fibres** instead of PMT (compact design - width < 2cm)
- **ring-shaped** detector configuration

2026:

- Development of a monitor prototype (temporal structure and the fluence)
- Modelling the detector response (GATE simulation)
- Irradiation tests at low-medium energies (BioALTO) and at clinical energies (CCB)



- **In 2023, we have initiated discussions on common interests:**
 - The BioAlto Health Pole and CCB teams have shown synergetic and complementary interests, expertise, and infrastructure (irradiation facilities, Monte Carlo simulation methods, and detector development). We defined complementary project objectives.
 - We request 2k€ per facility per year (8k€ in total for 2 years) for travelling required to detail specific research goals => we used 0k€ sparing resources for consulting for proof-of-concept experiments.
- **In 2024, we performed preliminary simulations of:**
 - Condensed history Monte Carlo simulations of BioAlto beamline for proton and helium beams and its characterisation with TimePix detector
 - Condensed history and truck structure simulations of the response of a GEM-based nanodosimetric detector in proton and helium BioAlto beams

➔ demonstrating the feasibility of the proposed projects.
- **In 2025, we improved our developments:**
 - Optimisation of the bioALTO platform (delay in commissioning)
 - Characterisation of the nanodosimetry detector and design of a new prototype adapted to BioALTO
 - Launch of a project for a new detector designed to visualise and quantify the BioALTO beam and the CCB beam
 - Participation in staff exchange grant application (NAWA proposal)



- In 2026/2027:
 - Collaboration meeting in Orsay and in Krakow
 - Joint request for irradiation time at BioALTO (end-2026 – 2027) and CCB (last quarter of 2026)
 - More detailed simulations of beamline and detector setups
 - Jointly respond to other grants to accelerate achieving the long-term research goals

Thank you for your attention!