



MATRIX : A GALLIUM NITRIDE ARRAY FOR PROTON IMAGING

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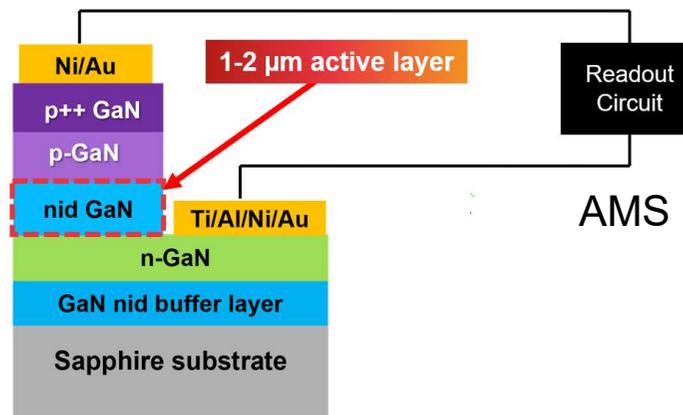
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Why Gallium Nitride ?

- GaN is resistant to high energy irradiation (strong bonds): in literature up to flux 10^{14} protons/cm²
- Other GaN detectors exist (UV light, x-ray, neutrons, alpha particles..)
- Big wafers are available for GaN growth
- Matured fabrication methods from LED / high-power electronics technology
- Disposable

	C-Si	4H-SiC	GaN	Diamond
Band gap (eV)	1.12	3.26	3.4	5.45
Wafer size	30 cm (11.8")	20 cm (8")	20 cm (8")	10 cm (4")
Displacement energy(eV)	13	22-35	19-22	35-50



Types :
 → 1x128 linear
 → 2x64
 → 11x11 Matrix
 → 32 x 128

A GaN detector is possible



Measurement setup with linear stages

- Current range
100 pA to 25 nA
- Energies
tunable with
diffuser wheel
(Al thickness)
- Detector is
biased with $V \approx 0$ V

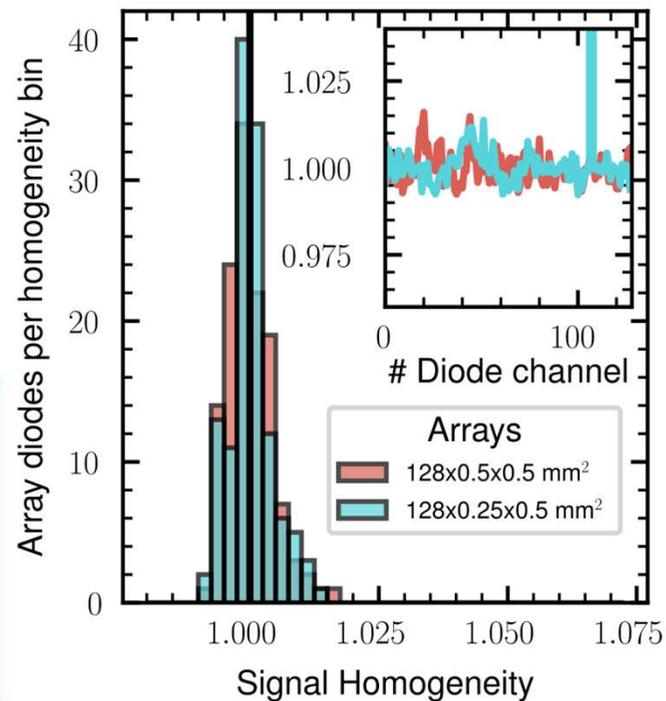
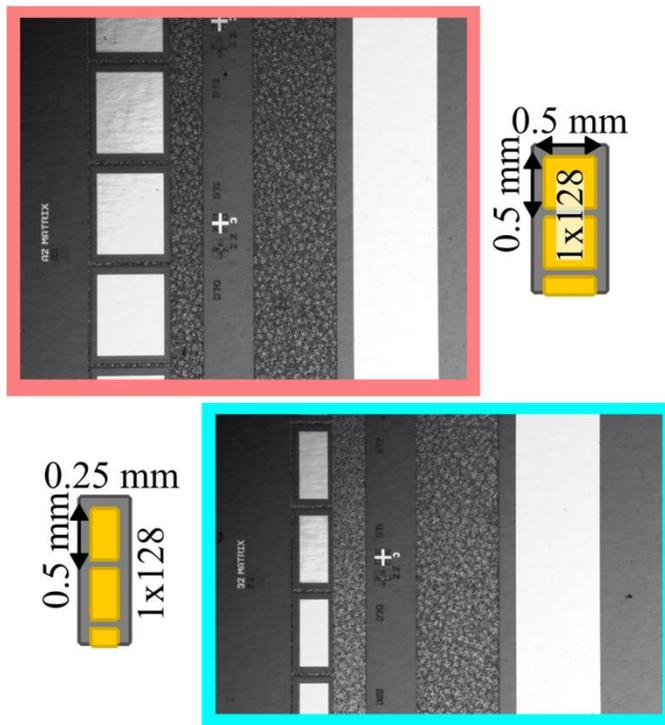
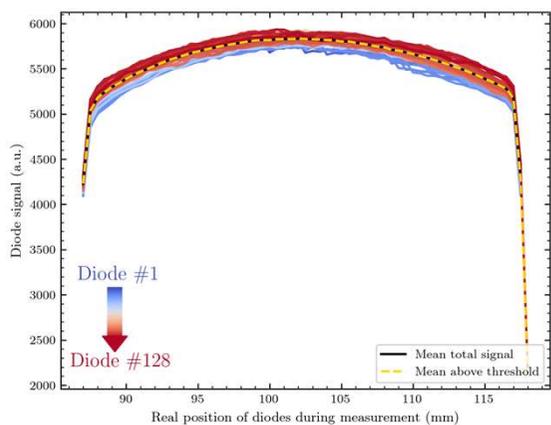
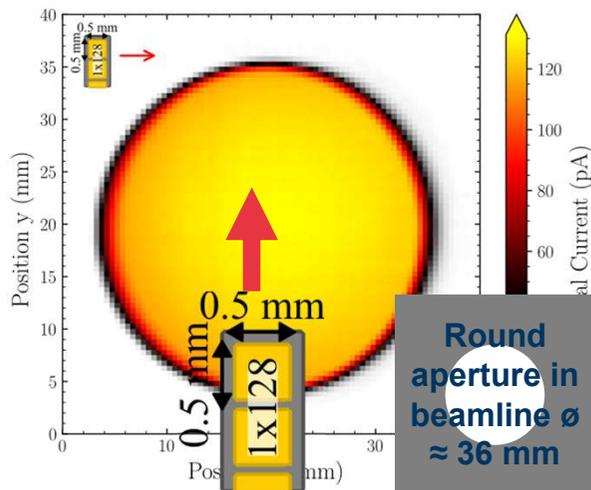
Phantom to image



Data Processing – Image generation



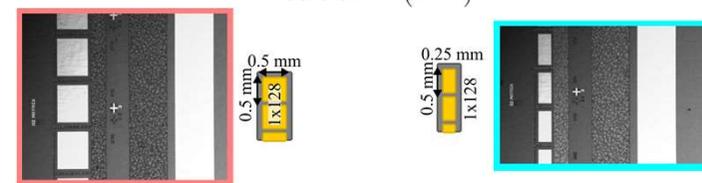
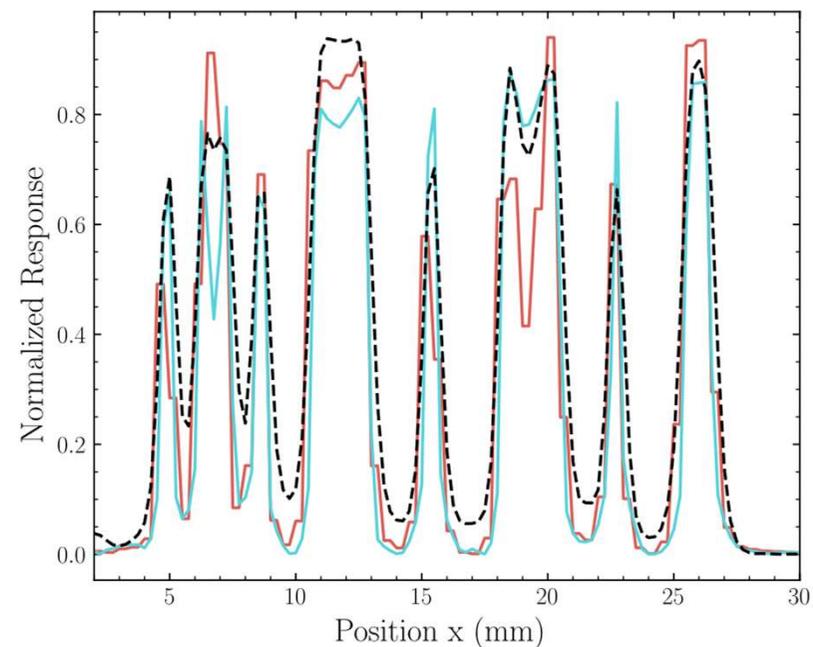
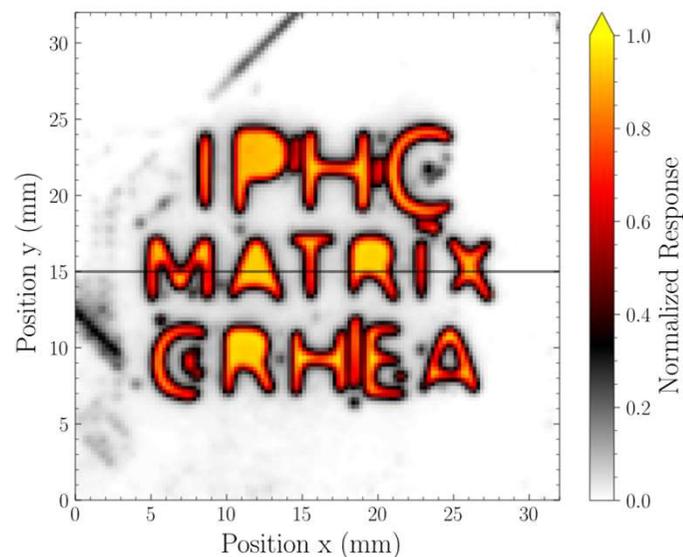
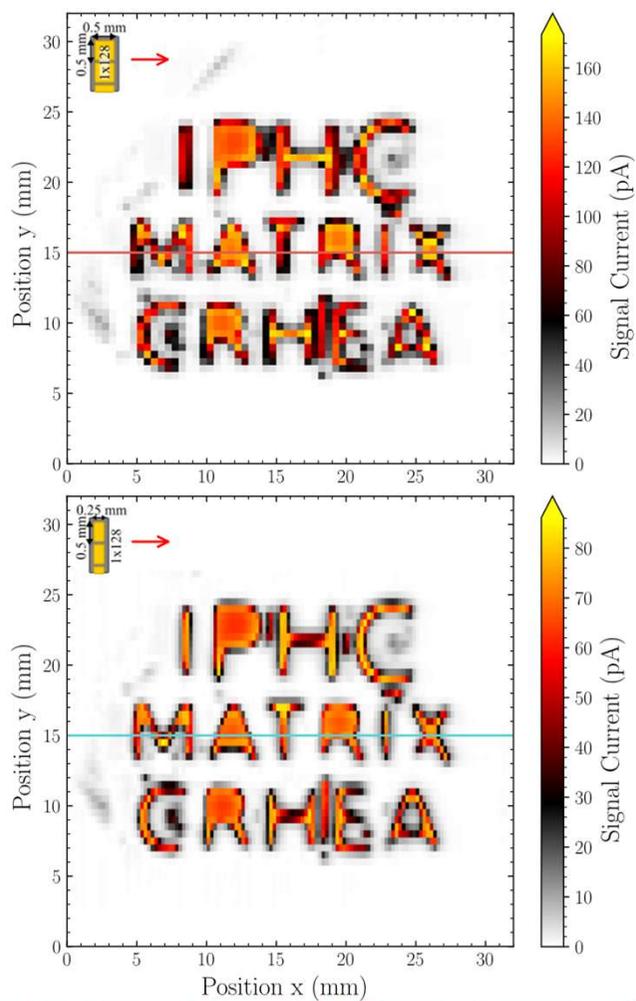
Response homogeneity



➤ 255/256 pixels are working! - yields ≈ 100 %

➤ Response inhomogeneity < 2 %

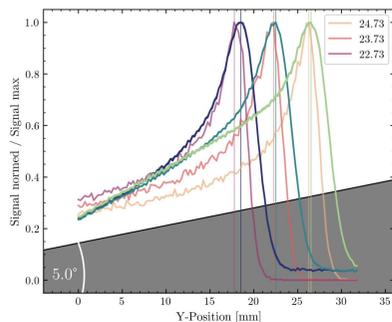
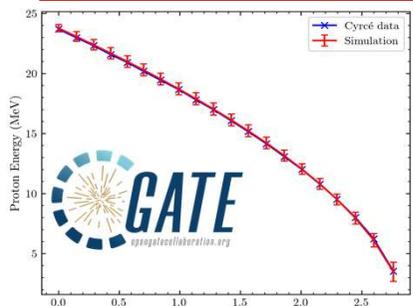
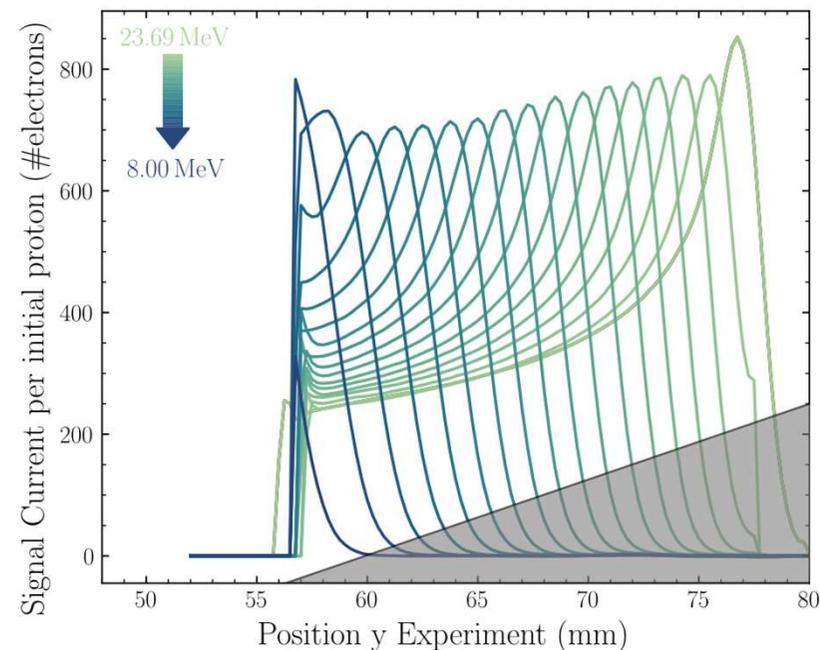
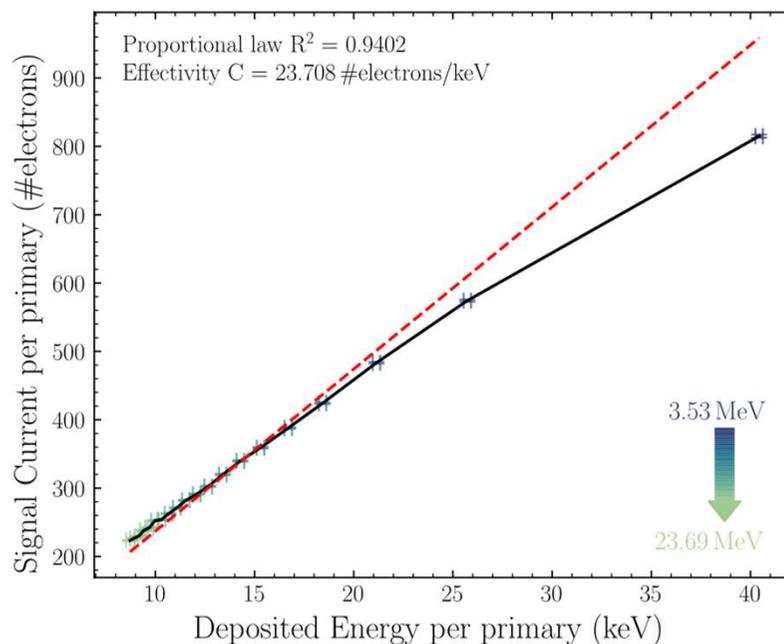
Imaging quality comparison



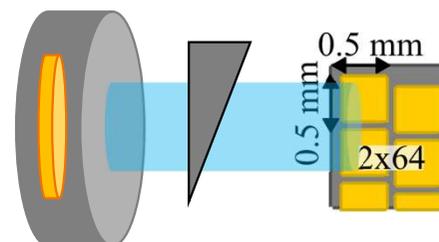
Bragg peak in active layer → Energy measurement



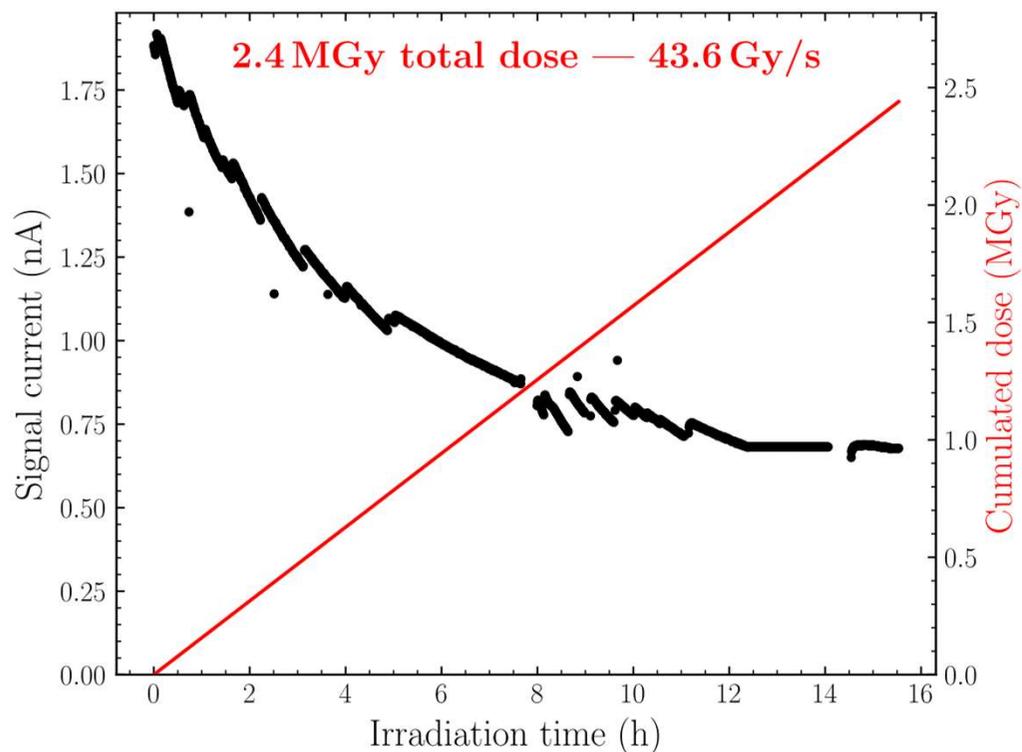
Experimental response



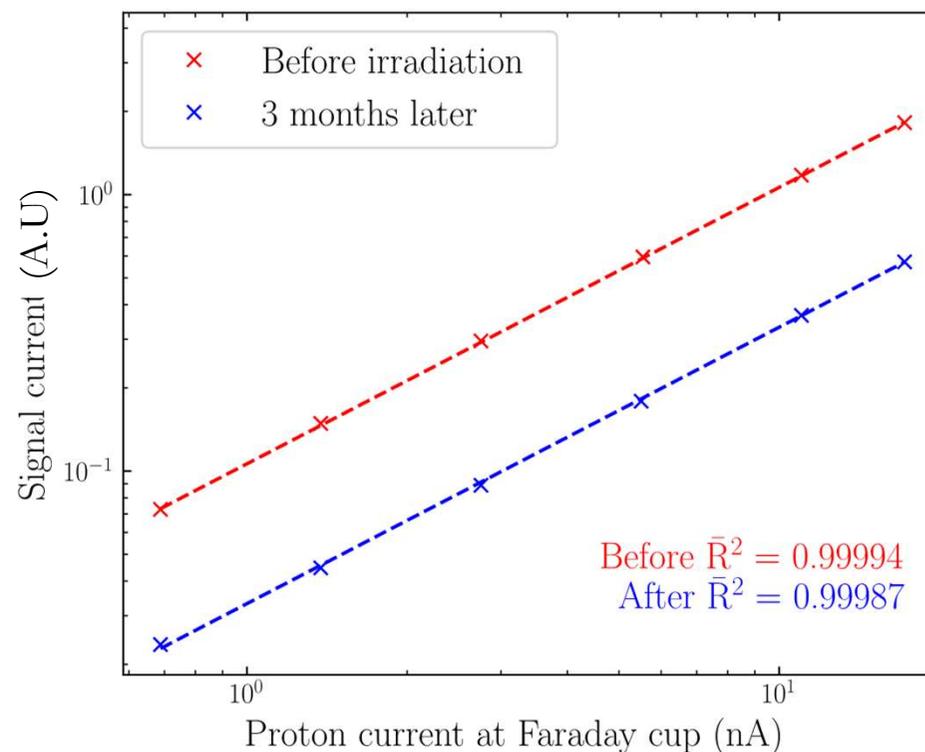
Energy resolution (8 diodes for 1 MeV) < 125 keV



Radiation hardness (single diode)



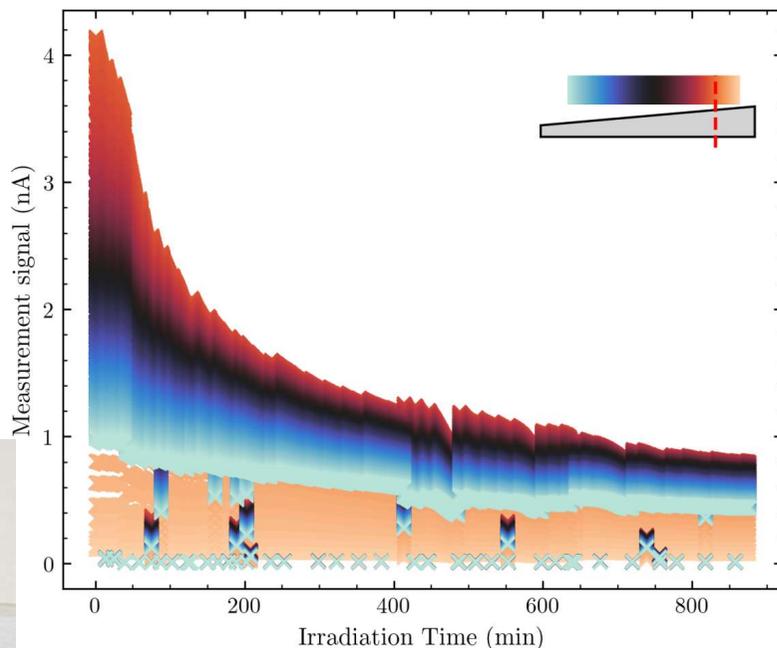
Detector survives dose of > 50k patient treatments!



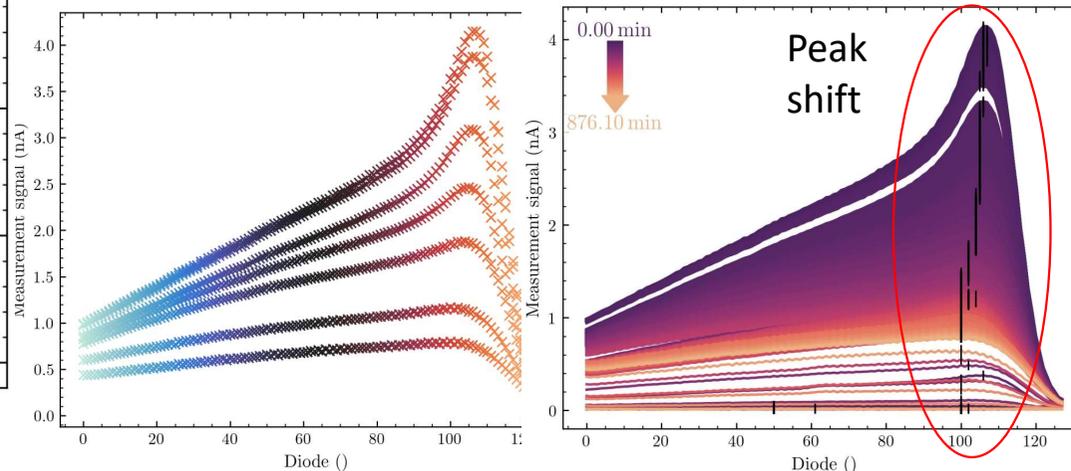
Linearity remains excellent!

Radiation hardness (→ in depth study, in progress)

Linear array of 128 diodes



Dose deposition : diodes behind the wedge
 For a proton of 25 MeV, $E_{dep} \approx 8.8 \text{ keV}/\mu\text{m} \approx 2.3 \text{ MGy}$
 For lower proton of $\approx 10 \text{ MeV}$, $E_{dep} \approx 20 \text{ keV}/\mu\text{m} \rightarrow 5.3 \text{ MGy}$
 For even higher energy depositions and protons closer to Bragg peak ($E_{dep} \approx 120 \text{ keV} / \mu\text{m} @ 2 \text{ MeV}$) $\rightarrow 32 \text{ MGy}$



5° wedge (PEEK)

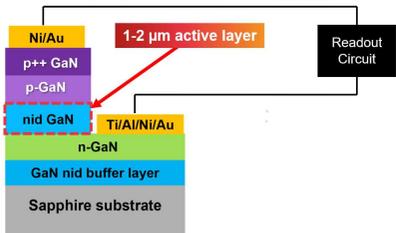


How is the damage developing with higher doses :

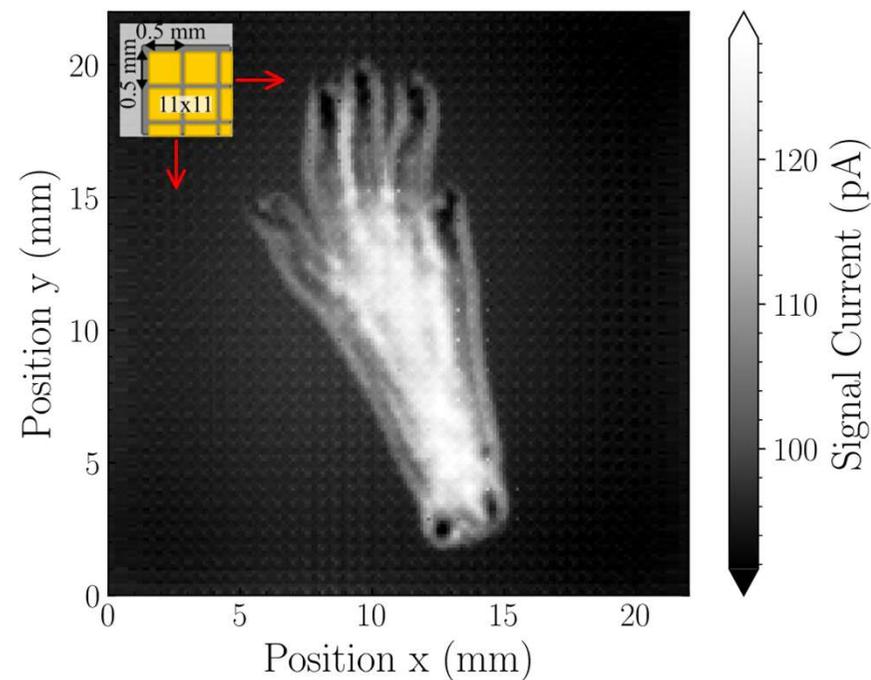
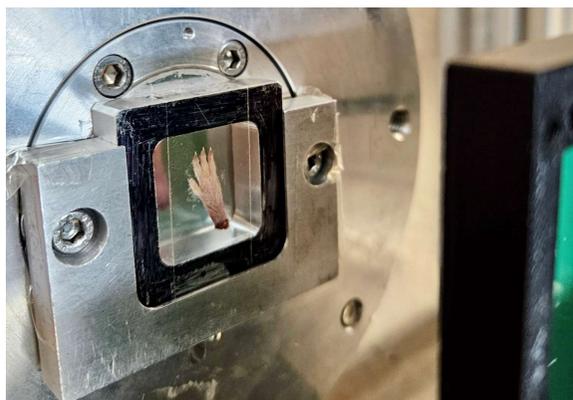
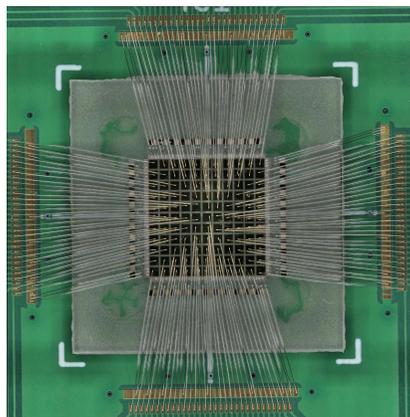
Signal decrease got far less previously towards the 2.5 MGy total dose

→ damage in the **Bragg peak** is not heavily amplified

→ to be investigated : damage proportional to simulated energy deposition or if close to the Bragg peak, damage is higher cause of larger share of inelastic proton interactions

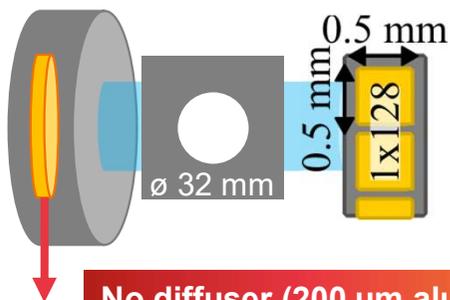
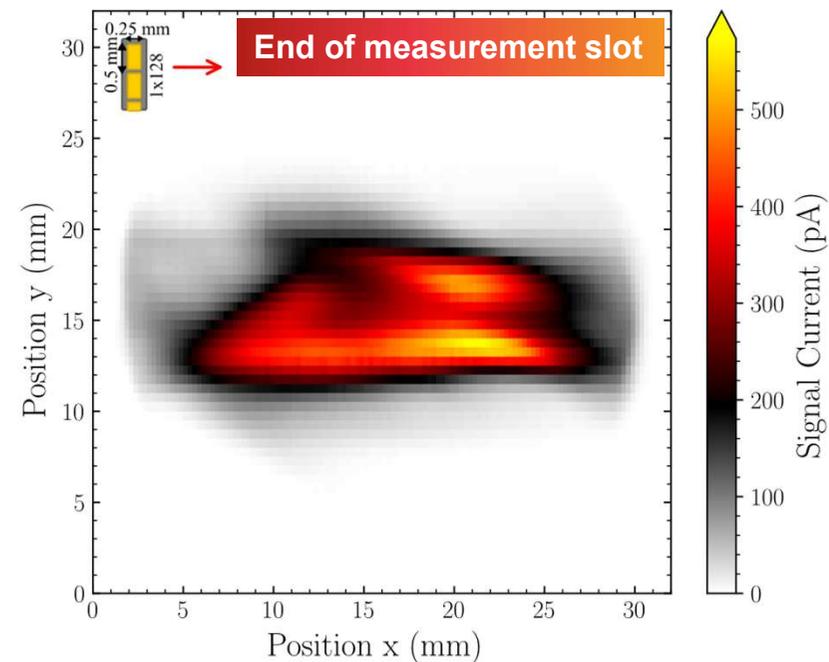
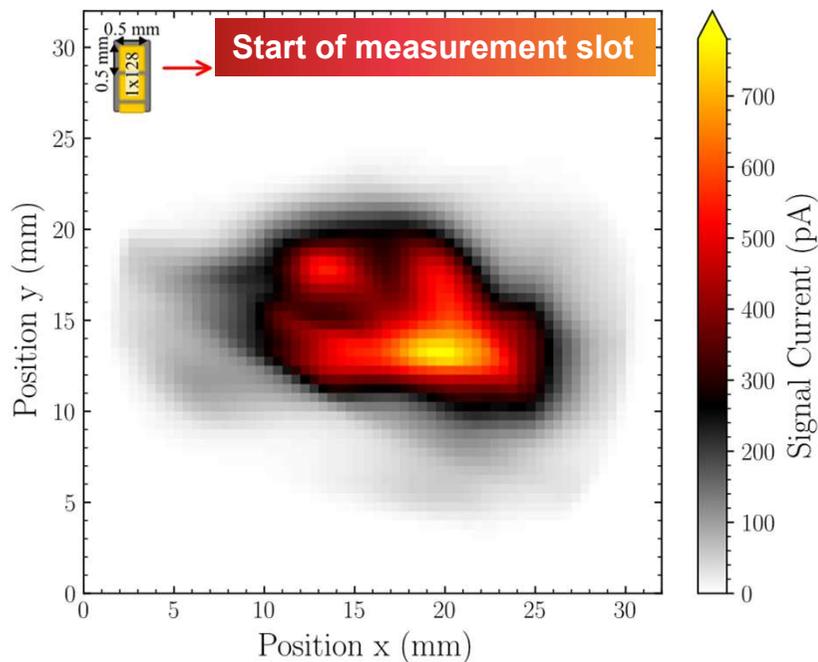
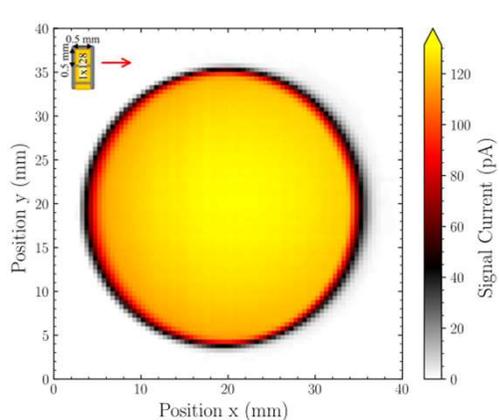


Radiography of biological tissue



Mouse tissue was obtained in accordance with ethical guidelines; the animal was not sacrificed solely for this study.

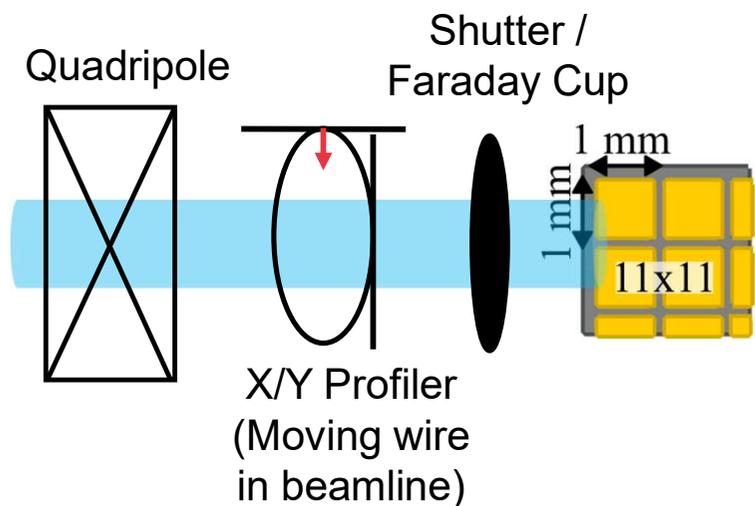
Undiffused Beam



No diffuser (200 µm aluminium) in beamline

Undiffused beam changes dependent on intensity and collimation
 ➤ Can the timescale of such a change be resolved?

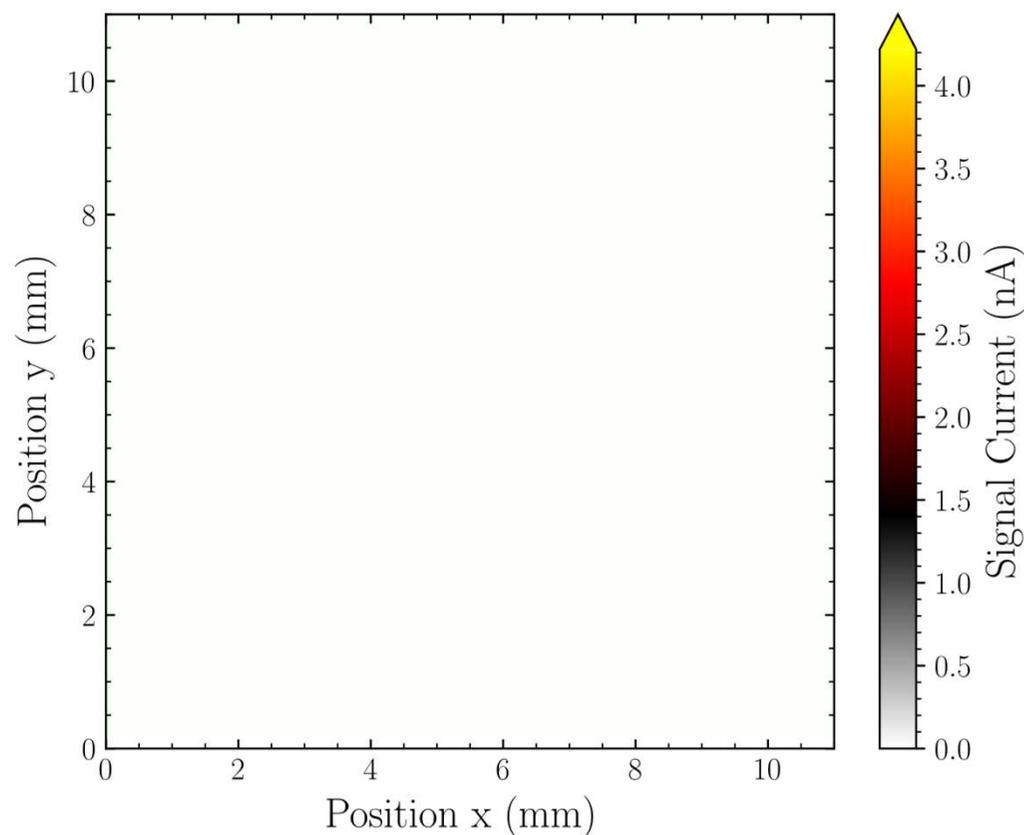
Beam Monitoring (3D: x,y, time)



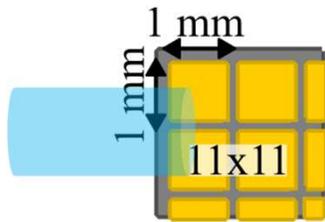
Movie key facts:

- Displayed length shortened by factor 50
- Effectively 60 fps displayed

1. Shutter open
2. Changes of beam collimation
3. Beam Profiling (wire moving inside beamline)

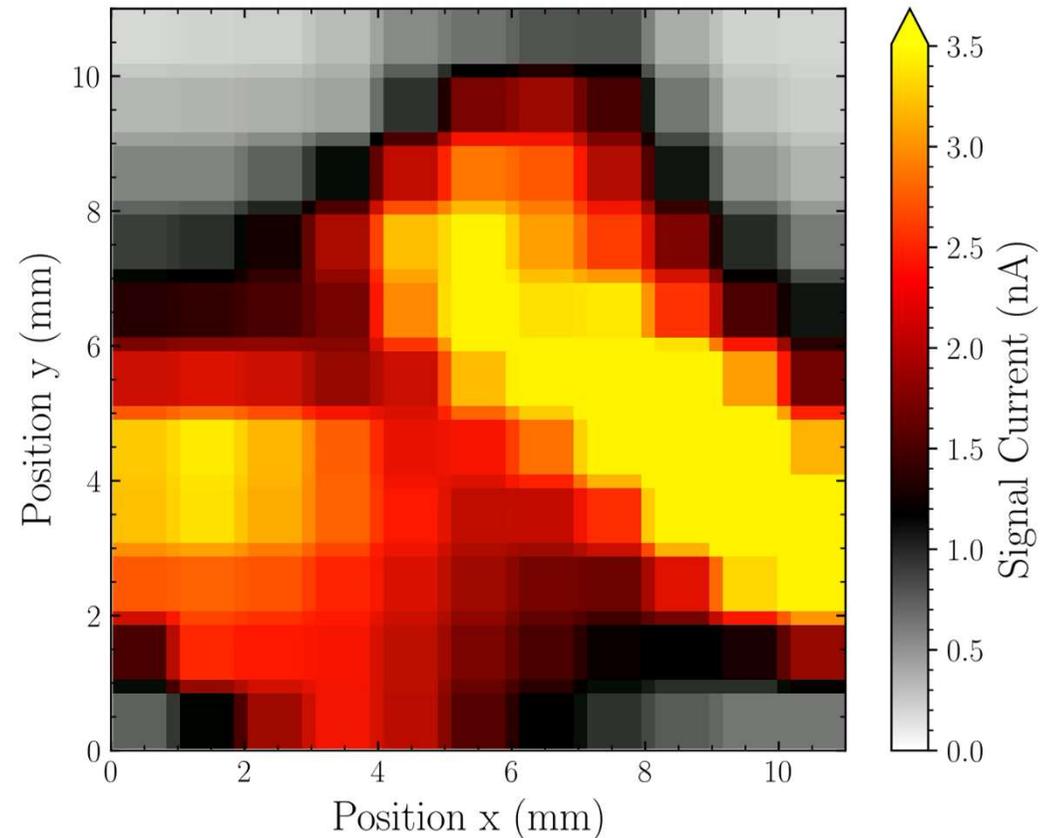


Time resolution in ms range → to be improved

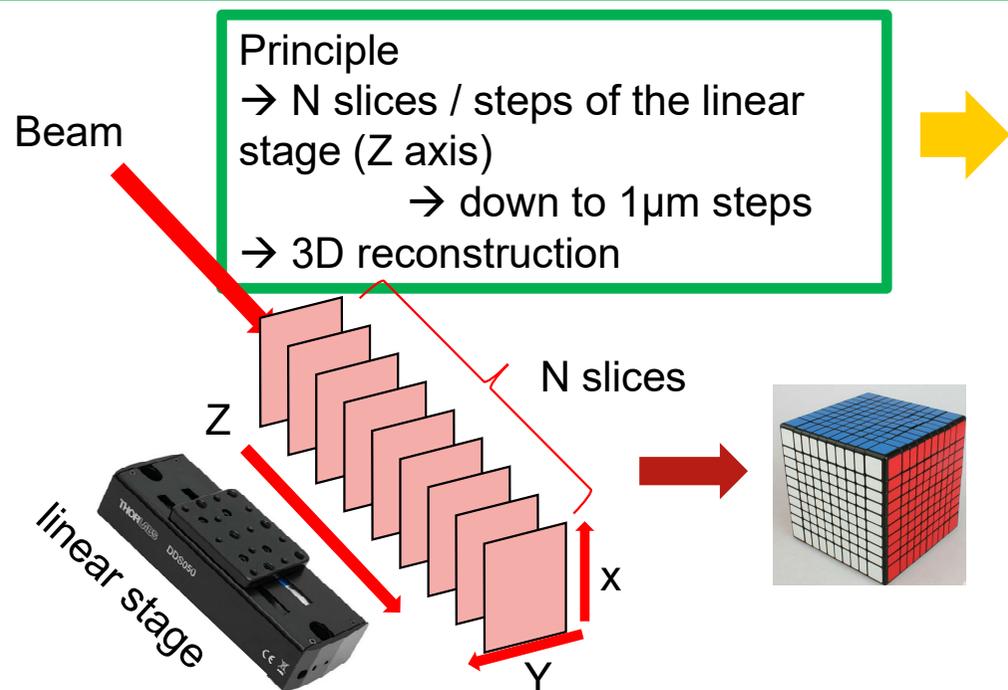


Movie key facts:

- Displayed length stretched by factor 20
- Effectively 50 fps displayed
- Time window between two frames: 1ms
- No active changes in collimation



From 3D to 4D prot(hadr)on Beam Imaging !

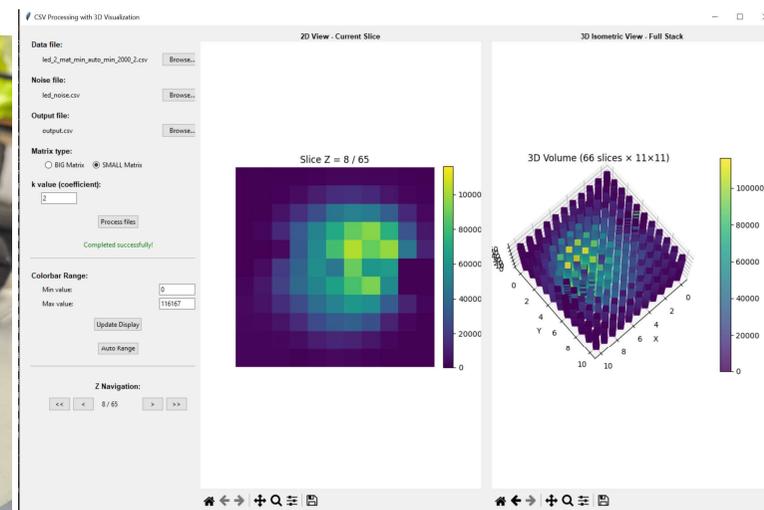
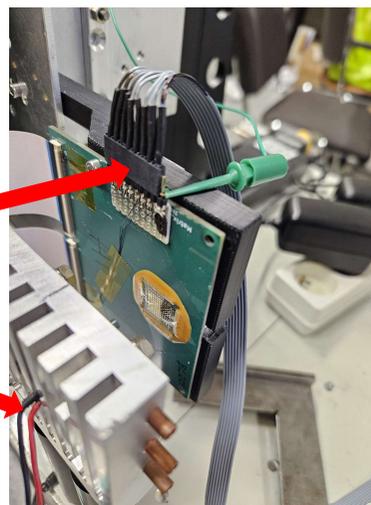


Principle
→ N slices / steps of the linear stage (Z axis)
→ down to 1 μ m steps
→ 3D reconstruction



Purpose
→ Micro imaging for extracted beam
→ Beam density along Z
→ Diffusion ...
→ Protons @ AIFIRA facility
→ Protons @ AGLAE (Louvre)
IBIC analysis
→ Cyncé (protons)
→ CNAO (hadrons : C)

Test bench
→ μ controller (synchronisation), Z axis
→ UV diode (310nm) tricky, very short service life
→ 2 OWIS linear stages (Y, Z)

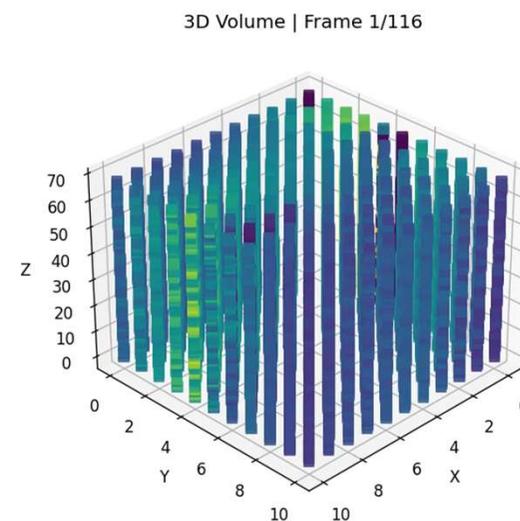
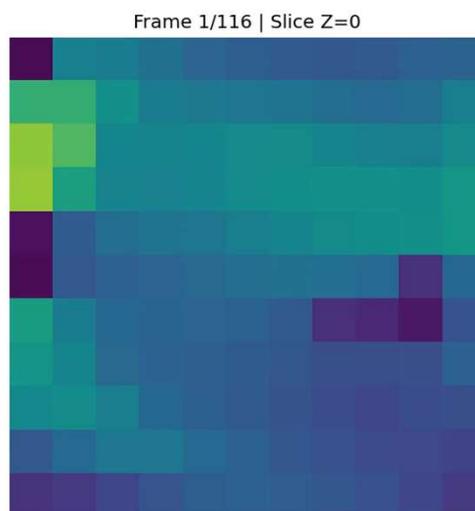


Cyrcé 4D proton Beam Imaging (02 / 26)

Current magnet adjustment by operator (focusing, sliding, ..)



First slice, $z = 0$

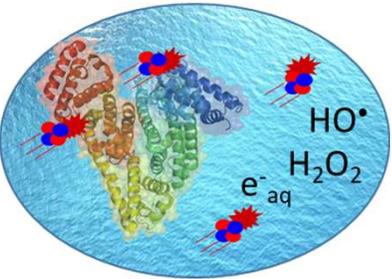


Beam

Work in progress ...

Application 1 : Radiolysis of Biomolecules (Radiochem, IPHC)

courtesy of Q. Raffy (IPHC, Strasbourg)

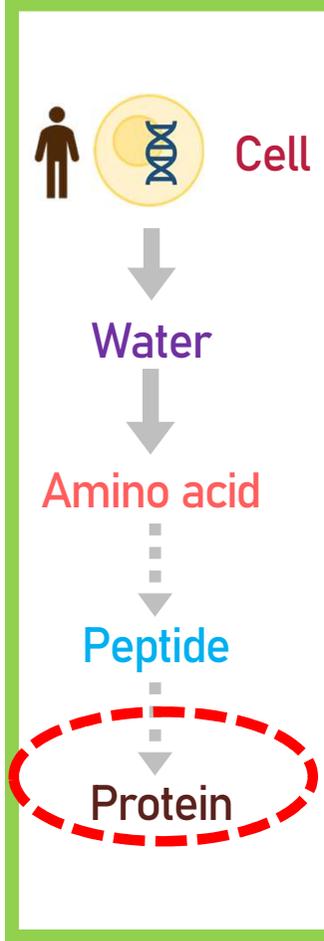


Water radiolysis
Radiolysis of biomolecules

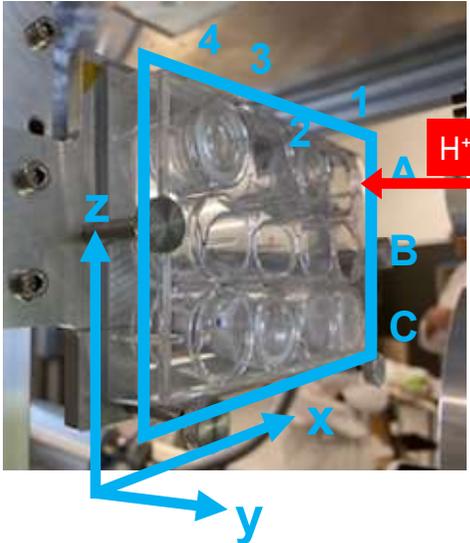
Radiolytic yield G :

$$G = 100 \cdot \frac{N_{\text{species/ion}}}{E}$$

In species per 100 eV



Radiolysis cells and support design
Mobile plate with 12 positions in front of the beam line



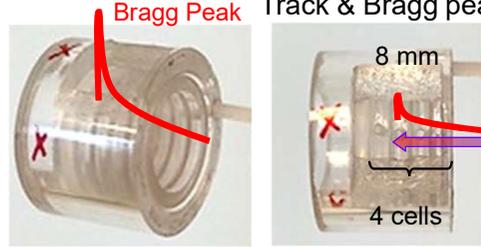
H⁺ 24 MeV

Determination of Radiolytic yields G:
→ **Determination of the dose (critical)**

➔ **Matrix, beam current / energy monitoring (linearity pA to nA)**

- pA – 1 nA (long time exp.)
- 100 nA (short time exp.)

H⁺ (24,05 MeV) : 5,83 mm in water
irradiation setup



Cell configurations
H⁺: 4 x 2 mm cell
Volume : 226 µL
1 cell in the "Fragments" region



Applications cont'd

Application 2 : Beam monitoring (IBA)

Industrial irradiation facilities

AERIAL (labcom, IPHC)

→ High energy E-beam and X-rays (feerix)

x-ray beamline (5 MeV, 7 MeV)

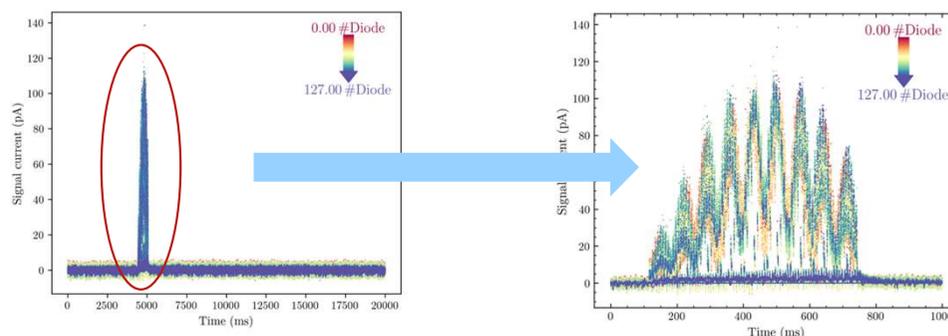
electron beamline (10 MeV, maximum power 10 KW)

Aerial feerix®



Application 3 : Flash therapy, beam structure

- CAL, Nice
- WPE



WPE Essen, proton therapy center,
04/2025 (beam bunch)

Temporal resolution measurement of
the proton beam

→ Down to μs (one diode is enough)

Application 4 : Real time imaging (Treatment plan)

- Improving resolution from 1mm → $< 500\mu\text{m}$

MATRIX

Outlook

- More measurements in proton beam (CAL, WPE)
 - Physics simulations cont'd
 - IBA comparison (ion. chambers, 1mm res.), pencil beam
 - On going GATE simulations
- AIFIRA, ... extracted beam monitoring
- 2D array (k x 128) multiplexed, ~36 cm²
- CS IN2P3 / Master project – Hadrontherapy (WP3)
- AD readout circuit



Compact setup

Readout constraint (bottleneck)

→ FPGA Board (COTS), Ethernet transmission



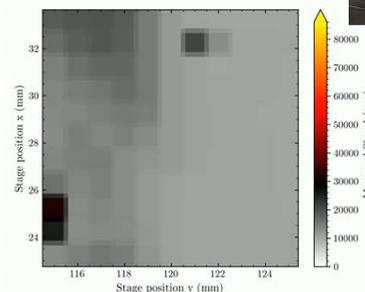
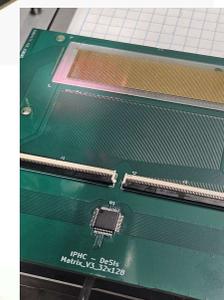
Mimas A7



AMS Chip



> 8 fp/s (32 x 128)



• Hadrontherapy, CNAO (500 MeV)





Team effort

IPHC, Strasbourg

L. The-Duc

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A. Wieck

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C. Bäumer

L. Parschat

CAL, Nice

J. Hérault

P. Hofverberg

M. Vidal

CRHEA, Nice

J.-Y. Duboz

M. Siviero

M. Hugues



wpe West German
Proton Therapy Centre
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CENTRE DE LUTTE CONTRE LE CANCER
unicancer NICE



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Université
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franco-allemande
Deutsch-Französische
Hochschule

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