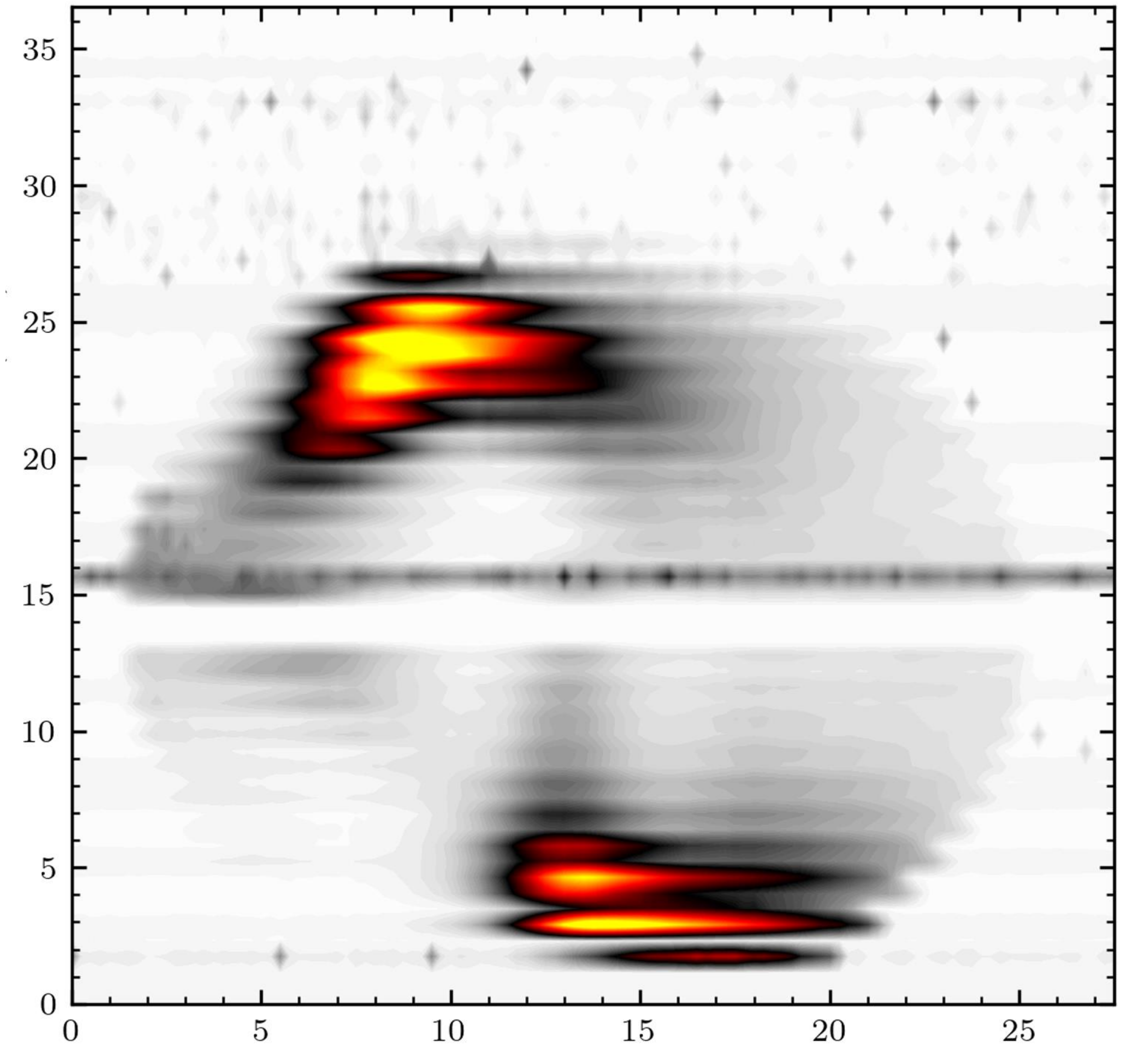
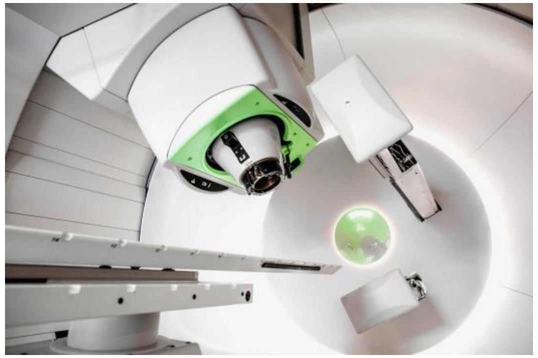
MATRIX : VERS DE L‘IMAGERIE PROTONS





West German
Proton Therapy Centre
Essen

Stéphane Higueret – GDR DI2I – IJCLab

26.06.2024

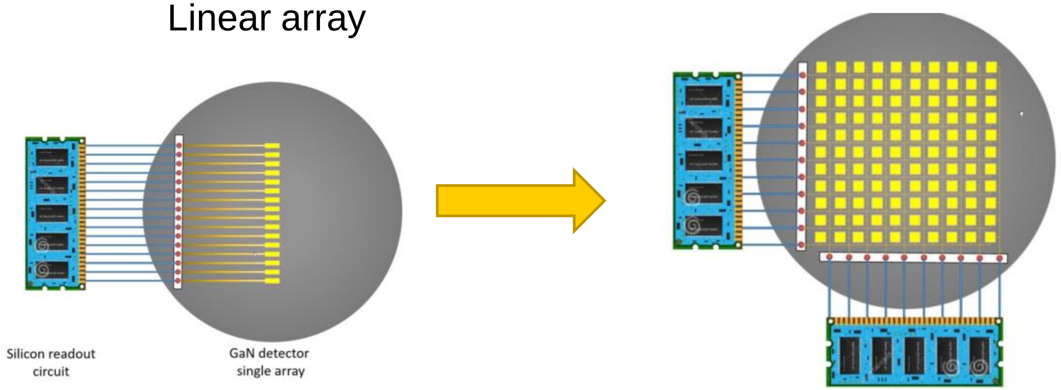
MATRIX : GaN diode array for proton monitoring and imaging

ANR
- CRHEA, Nice : GaN design
- CAL, Nice : test facility, MEDICYC proton line, 65 MeV, Proteus One, 230 MeV
- Ruhr-University, Bochum : GaN tests
- West German Proton Therapy Center, Essen : test facility, 230 MeV

→ IPHC, Strasbourg (from the detector to the signal)

Roadmap :
- GaN diode selection / process
- Laser / proton beam tests → selection (yield)
- DAQ (cots if possible)
- Linear array of 64 diodes
- Proton beam tests
- Matrix (11x11) diodes
- MATRIX (128 x 128)
- Applications

Linear array



2-D imaging array
36 cm^2 (500 μm^2 diode)
128 x 128 diodes
Current integration from the chip

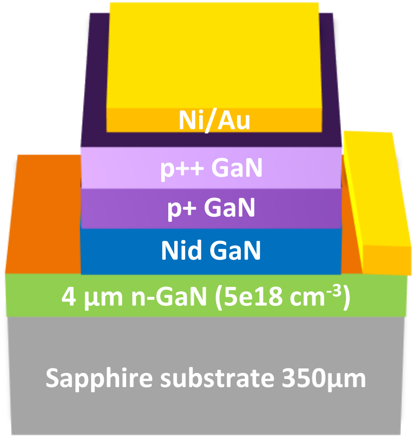
Why GaN ?

	Bandgap (eV)	Breakdown field (MV/cm)	Electron mobility (cm^2/Vs)	Thermal conductivity (W/mK)	Radiation hardness	Large area (industry)	Cost
SiC	2.36-3.23	3.5	900	320	+	+	-
GaN	3.4	3.4	1500	1300	+	+	-
Si	1.1	10	3000	230	-	+	--
Diamond	5.47	0.3	1500	2130	+	-	+

☺

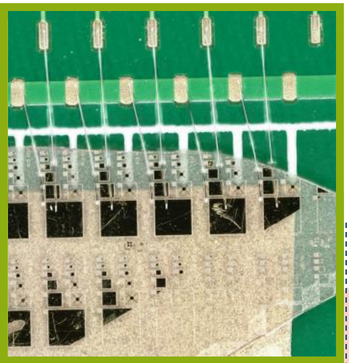
INVESTIGATING DIODES STRUCTURES (500 µm² diode)

courtesy of M. Siviero (CRHEA)



Substrate:

- Sapphire cheaper than GaN
- GaN has no lattice mismatch

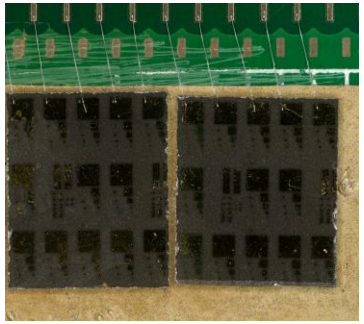


PIN on sapphire

10µm nid GaN

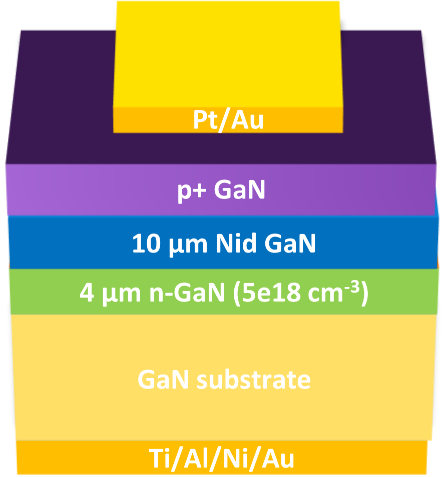
PIN on GaN

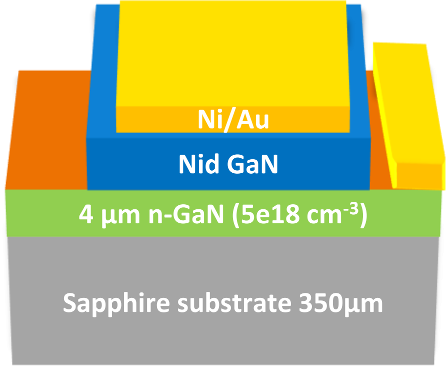
10µm nid GaN



PIN diodes:

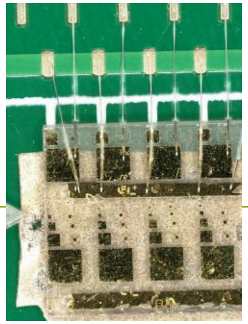
- require Mg+ doping





Schottky diodes:

- No Mg+

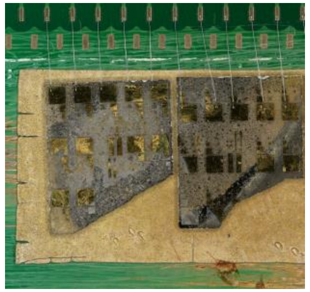


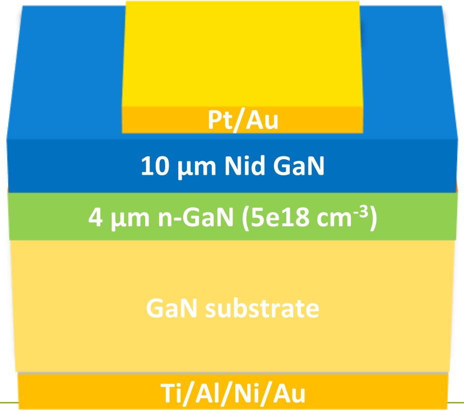
Schottky on Sapphire

1,2,4,10µm nid GaN

Schottky on GaN

10µm nid GaN





MATRIX

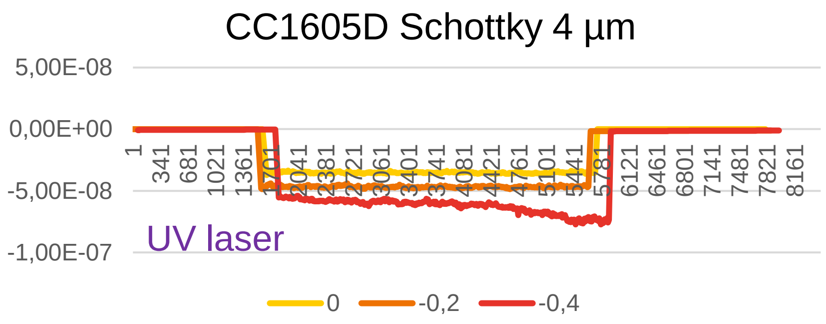
INVESTIGATING DIODES STRUCTURES cont'd

Substrate: no effect observed on the dark current nor the response to protons
Sapphire substrates needed for medium and large size arrays → 3'' wafers
⇒ **Sapphire substrate**

Pin shows :
- higher responses
- lower dark current
- less response instability
- higher process yield than Schottky diodes

⇒ **pin diodes**

courtesy of J-Y. Duboz (CRHEA)



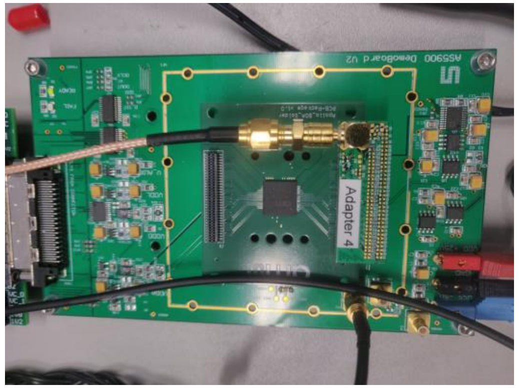
Thickness of undoped active region :
- Schottky: no clear trend among samples with L=1-2-4-10µm
- pin: samples with L=1-2-4-10µm.
  Similar results for 2 and 10µm. 4µm to be measured
  10µm very difficult to process

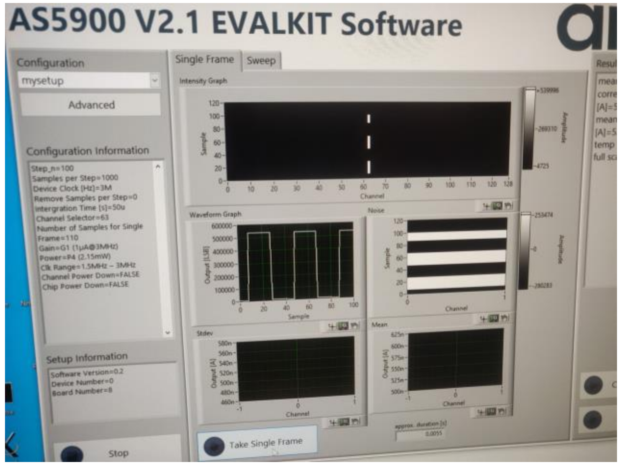
⇒ **Thickness will be in the range 1-2µm**: processing yield is a key issue for arrays !

ACQUISITION SYSTEM

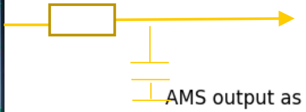
COTS (Market survey)

- N channels (~128)
- Current input (up to 1ms), low noise
→ Xray imaging (radiotherapy)
    - Analog devices (in progress)
    - AMS-OSRAM (NDA)
        - AS5900 – 26 bit 128 Channel Low Noise Current-to-Digital

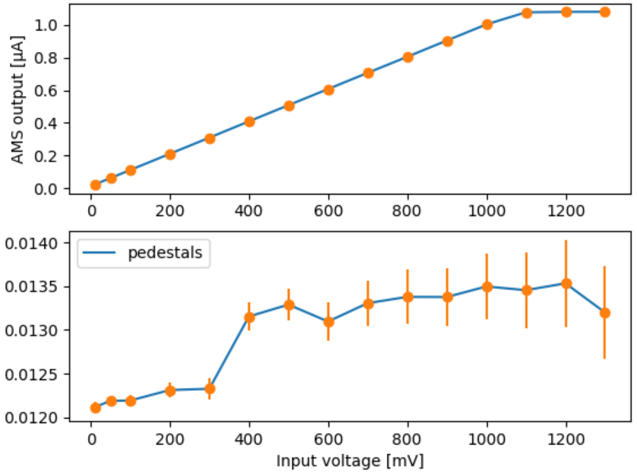


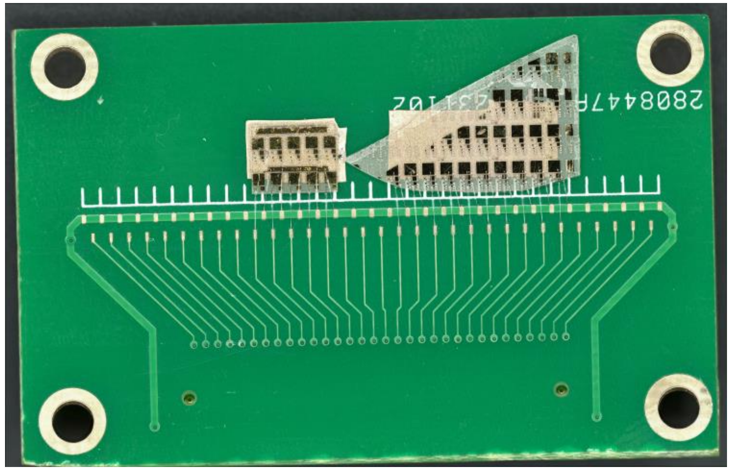


Closed software : biaising, etc.



AMS chip



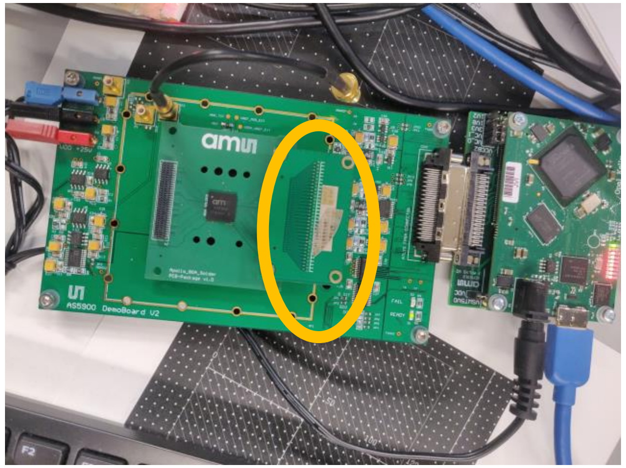


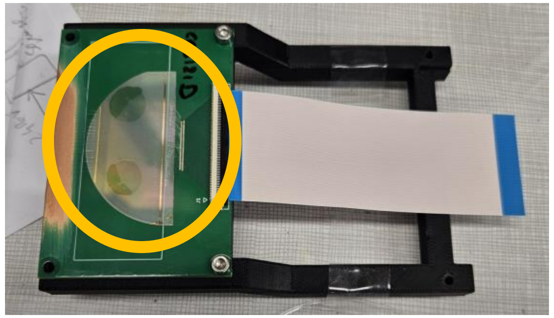
14 channels :

- average of 10000 tests, 10s
- 1ms integration time
- 9 pin diodes 1606D0
- 5 Schottky diodes 1517A2
- Mean of mean : 422 pA ☺
- Std : 350 fA

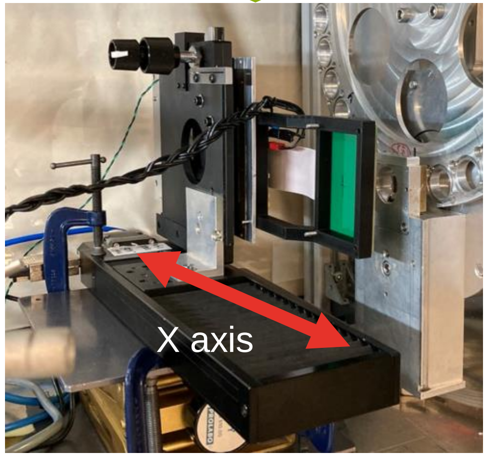
2 dead channels

EVOLUTION OF THE SETUP

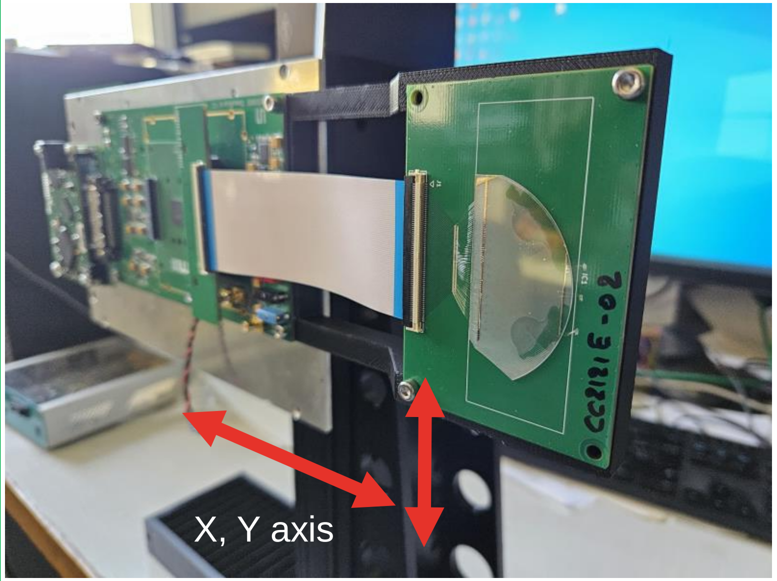




FROM



TO

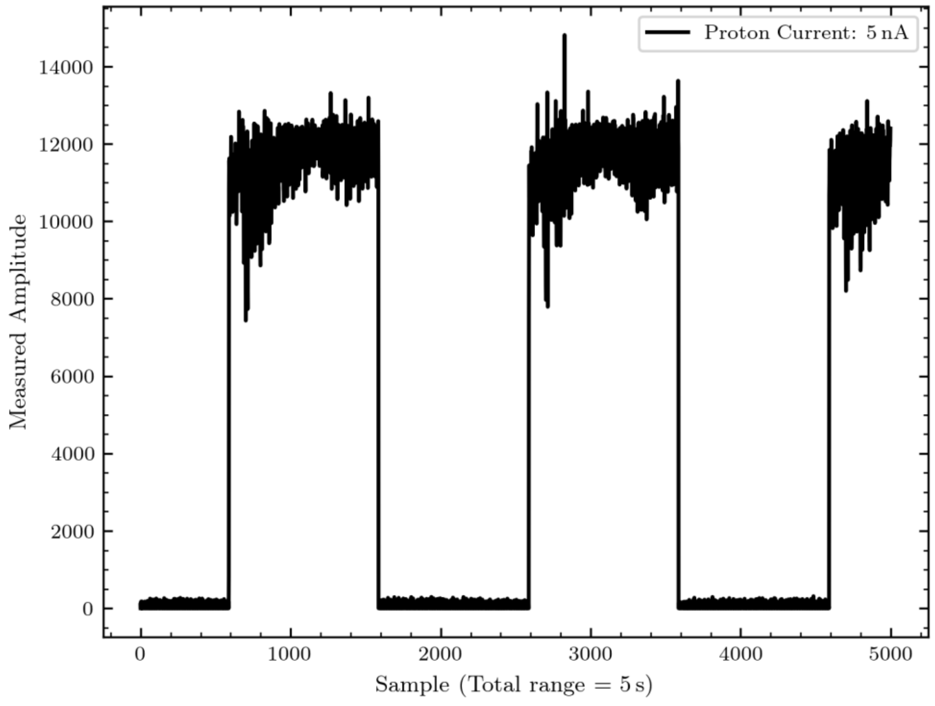


CYRCE EXPERIMENT

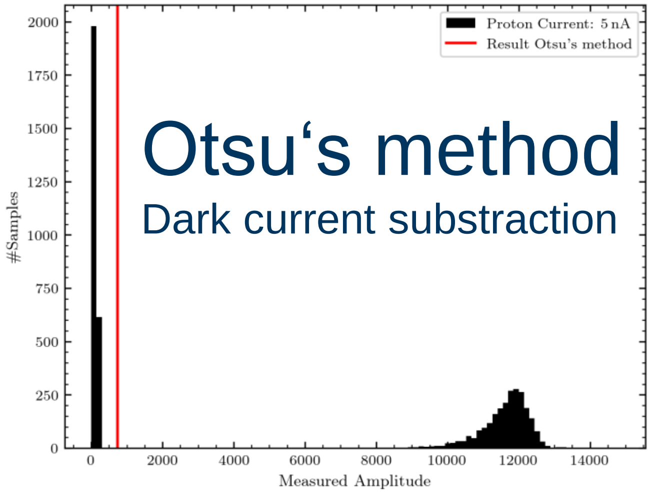
- Proton beam with a frequency of 85 MHz or half 42 MHz
- fA to 100 nA (25pA – 10nA , our experiment)
- Beam Modulated On/Off with 1 s pulse duration
- Option to use a diffuser in proton beam line (makes beam more homogenous)
- Diodes read out by AMS Test Kit
- 1D line array of 64 diodes
- Stage allows 2D imaging

CYRCÉ

Diode response : time structure

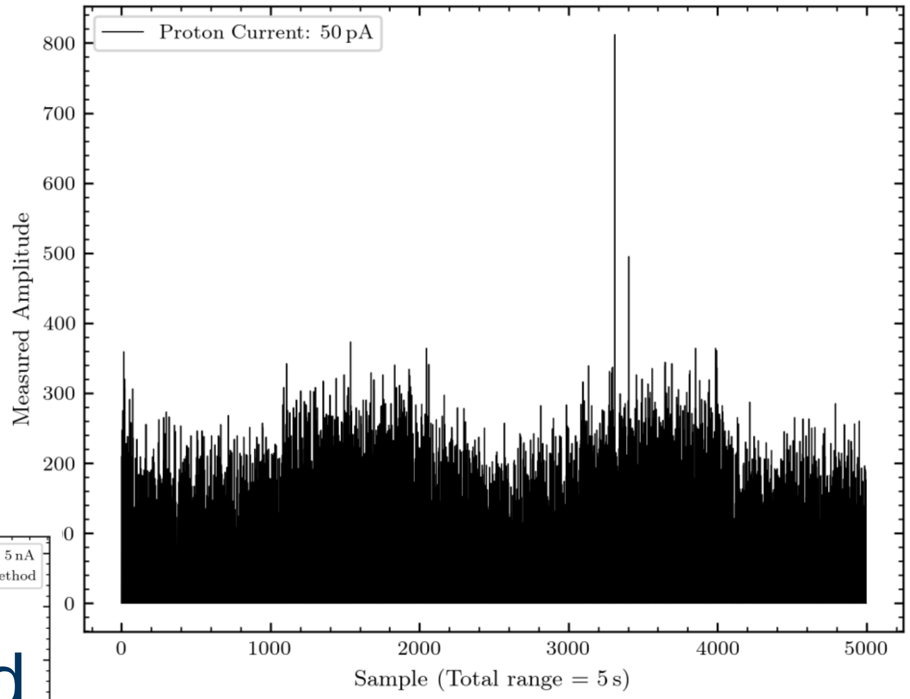


On/Off with 1 s pulse duration



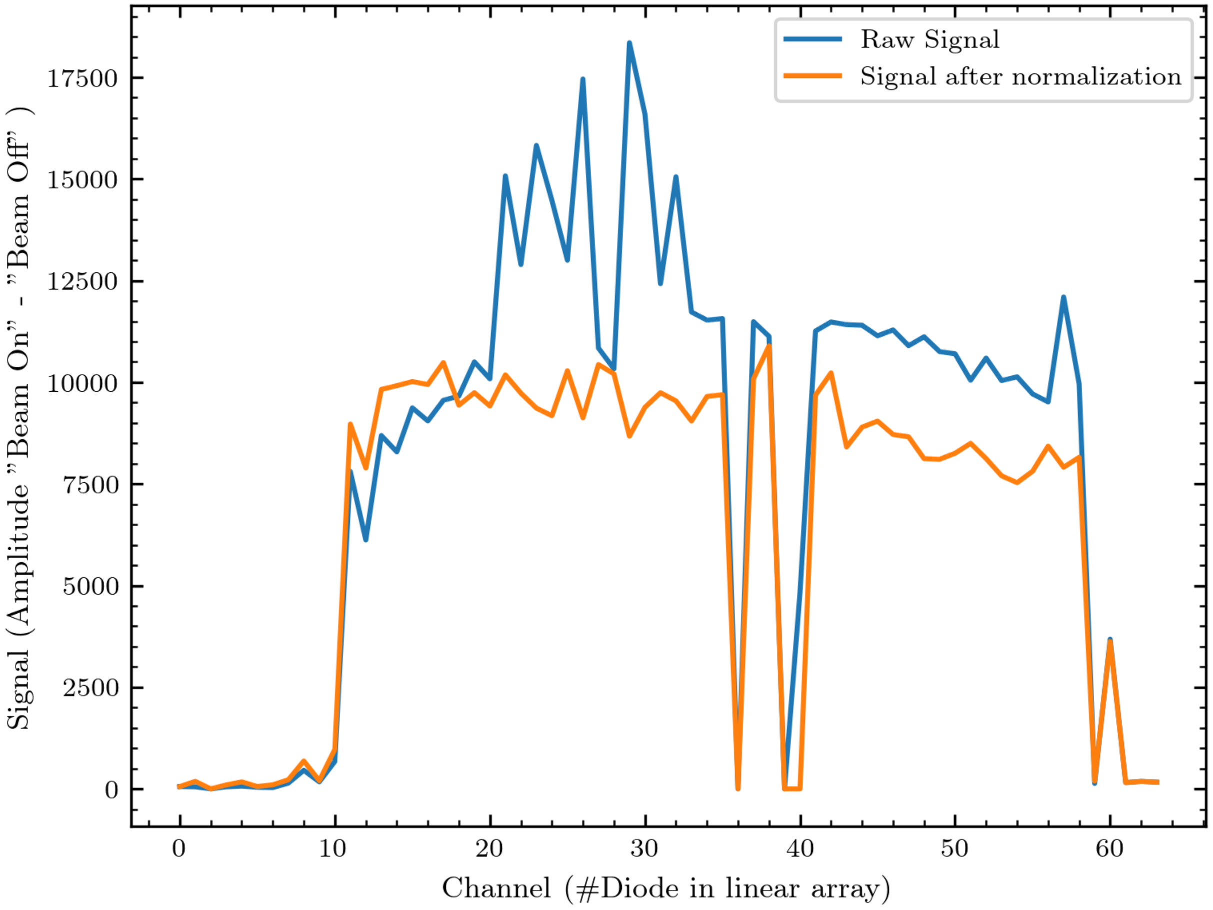
Otsu's method

Dark current substraction

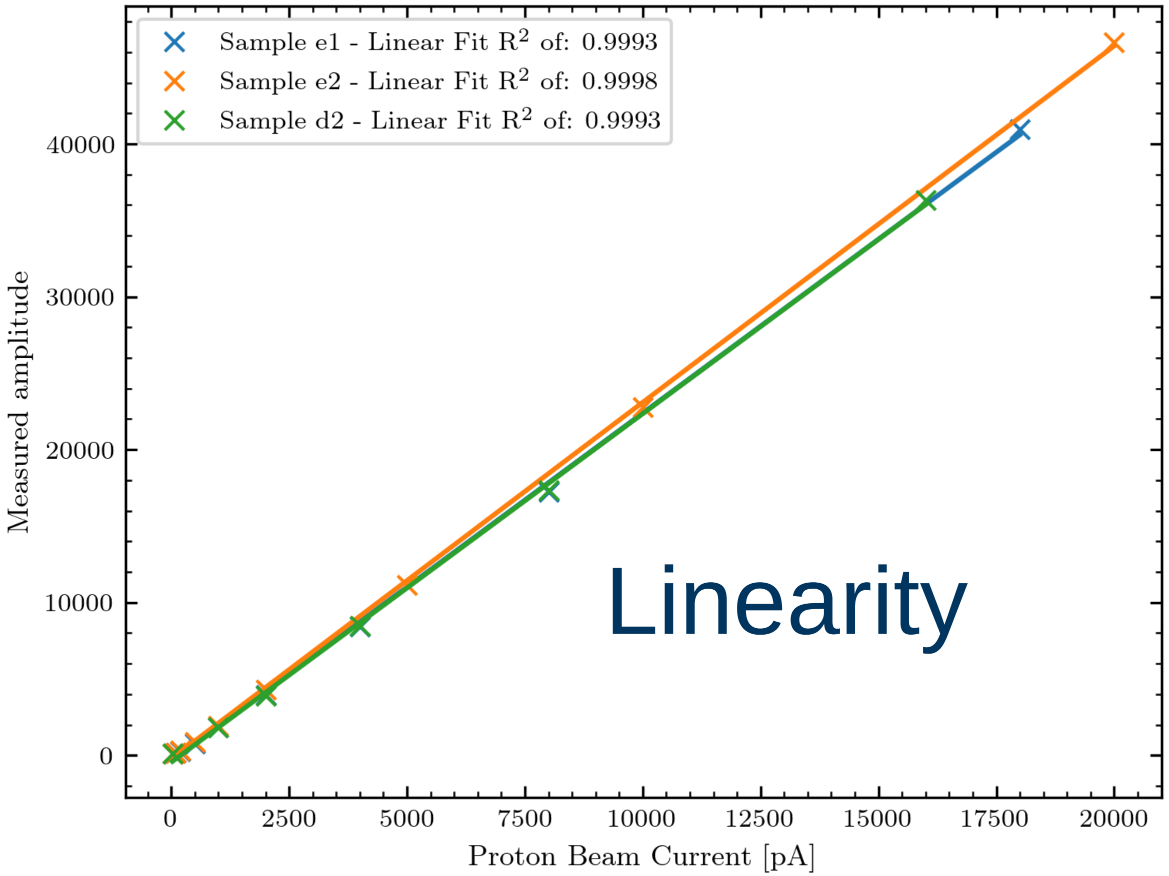


Normalizing the response (@5 nA)

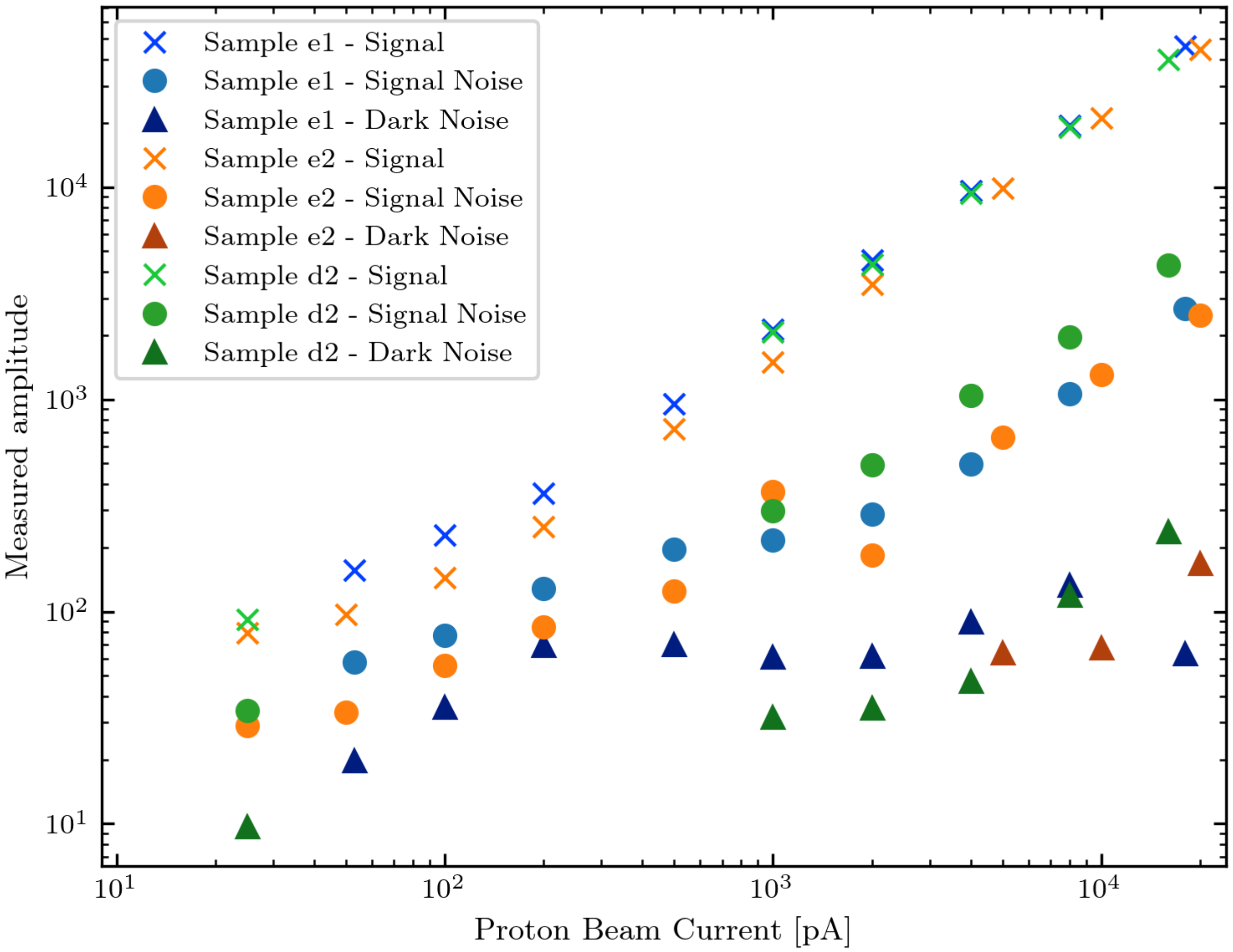
courtesy of N. Broda (RUB)



3 dead channels



Signal and noise for different diode structures (e1, e2, d2)



SENSITIVITY

CC2121 pin diode 1µm nid GaN

AMS :

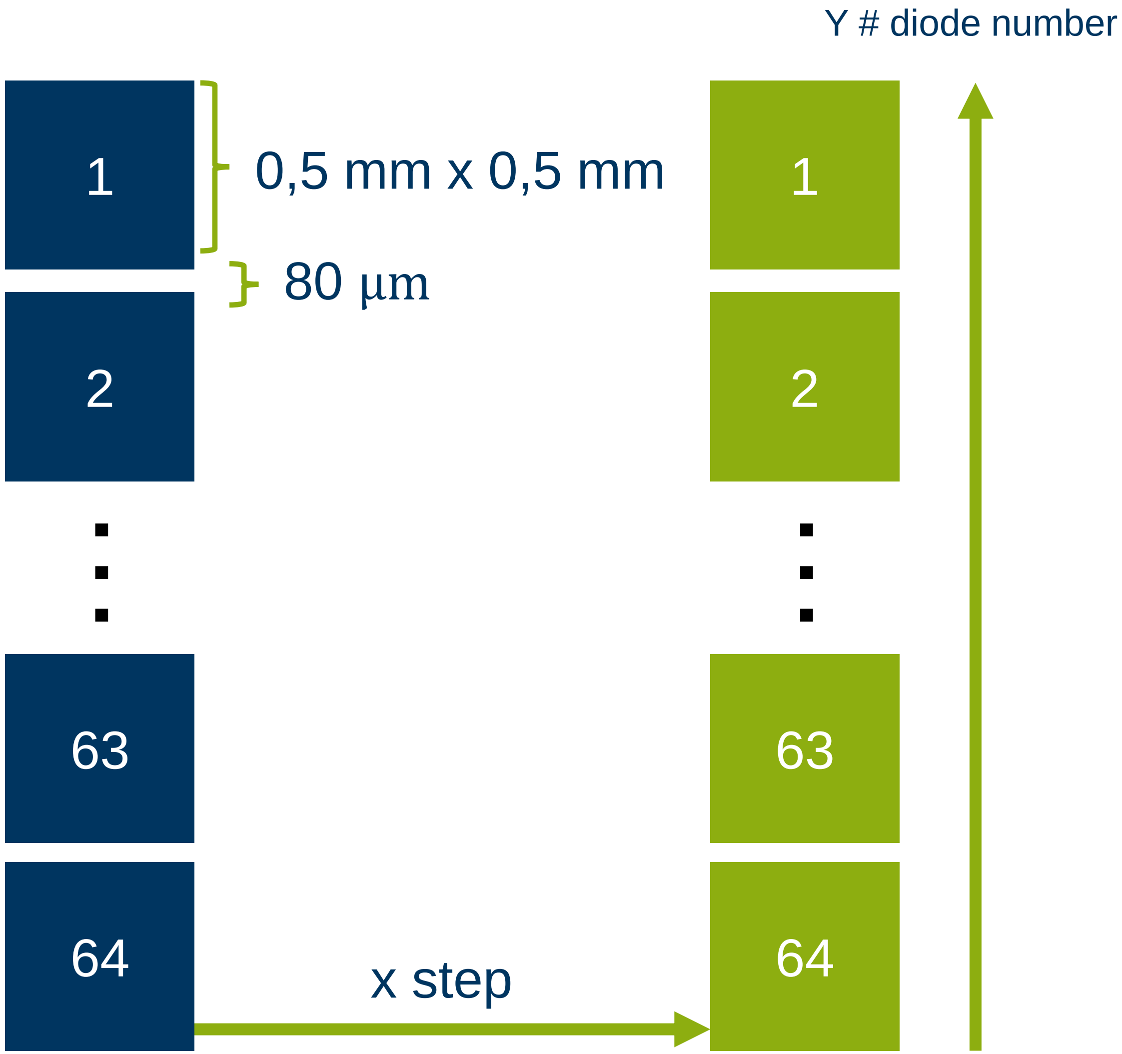
Min detect. proton current density : 3 pA / cm^2

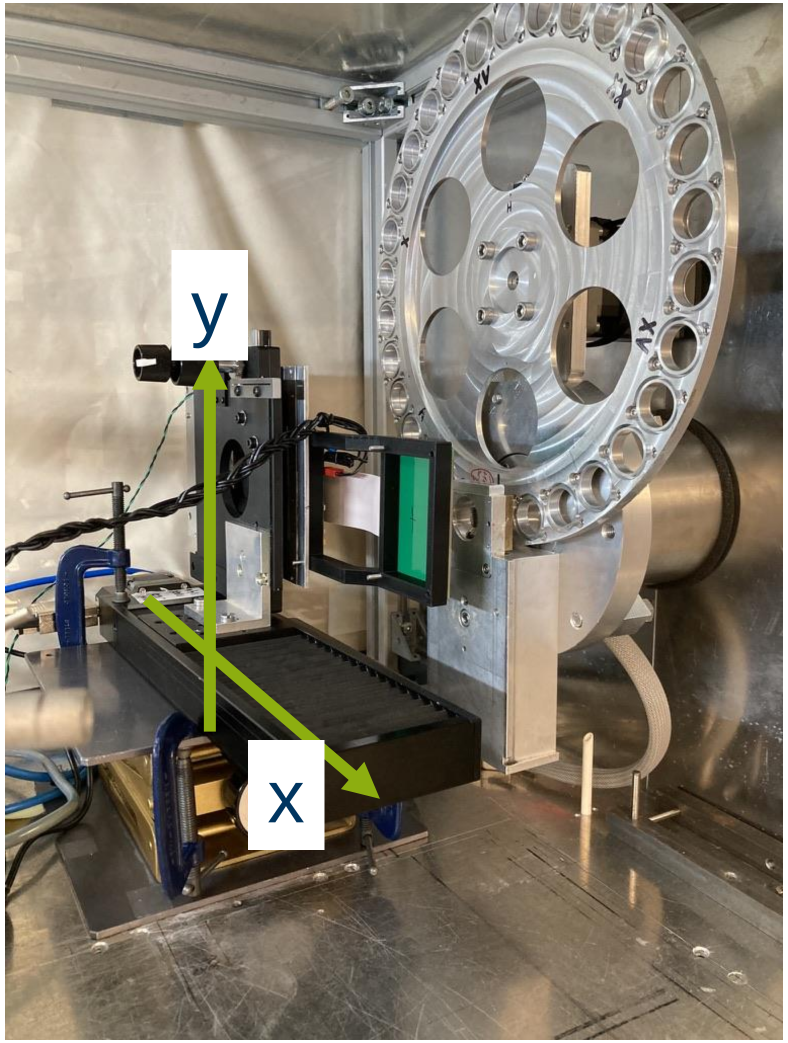
Min detect. proton current in the diode : 7.5 fA

Nb: 1.6 fA = 10000 protons / s

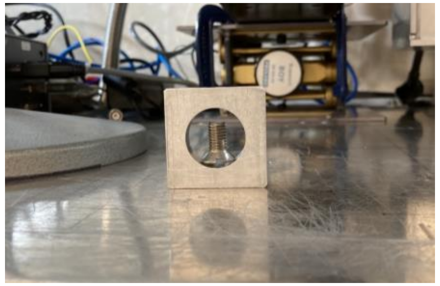
MATRIX

Proton beam imaging



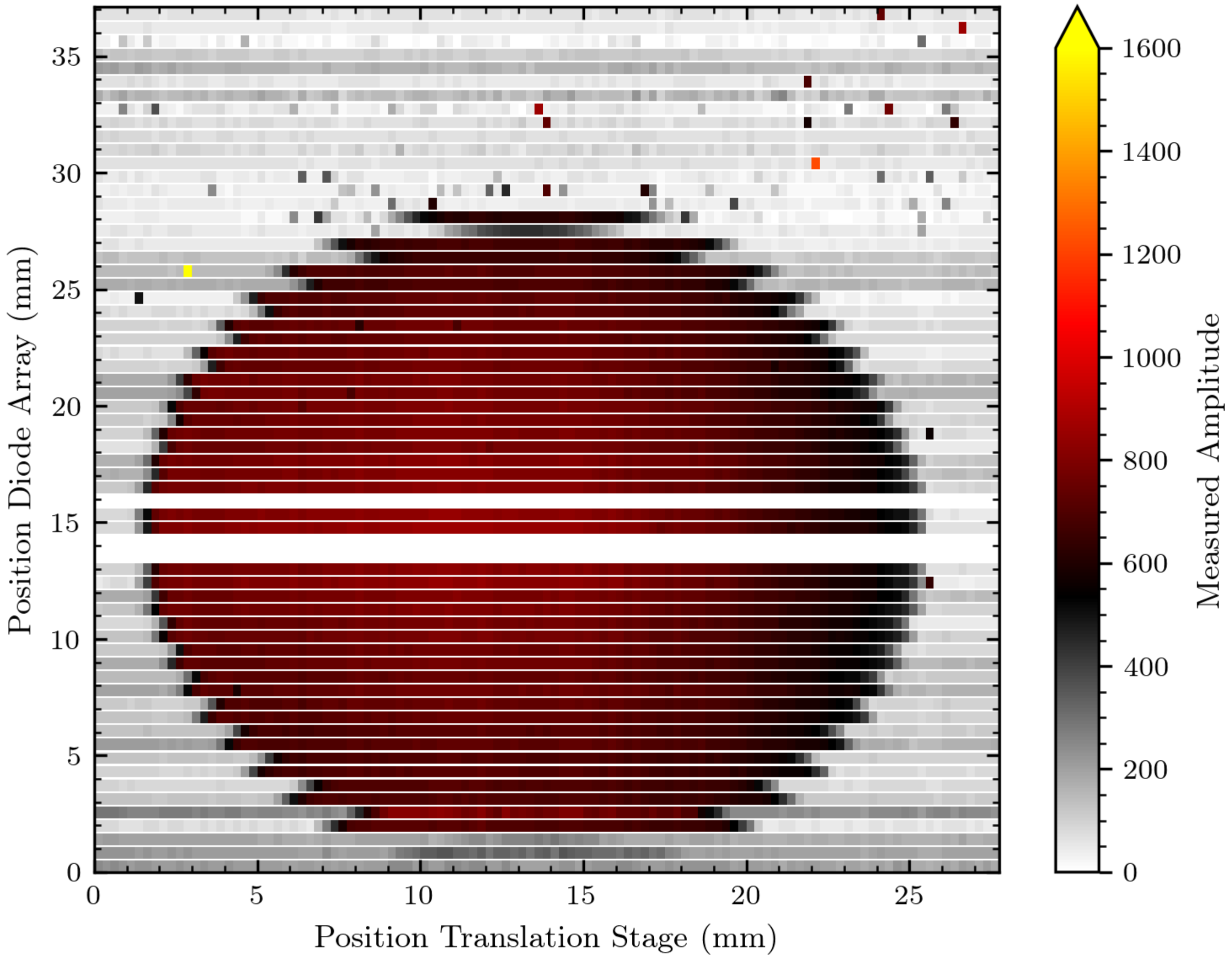


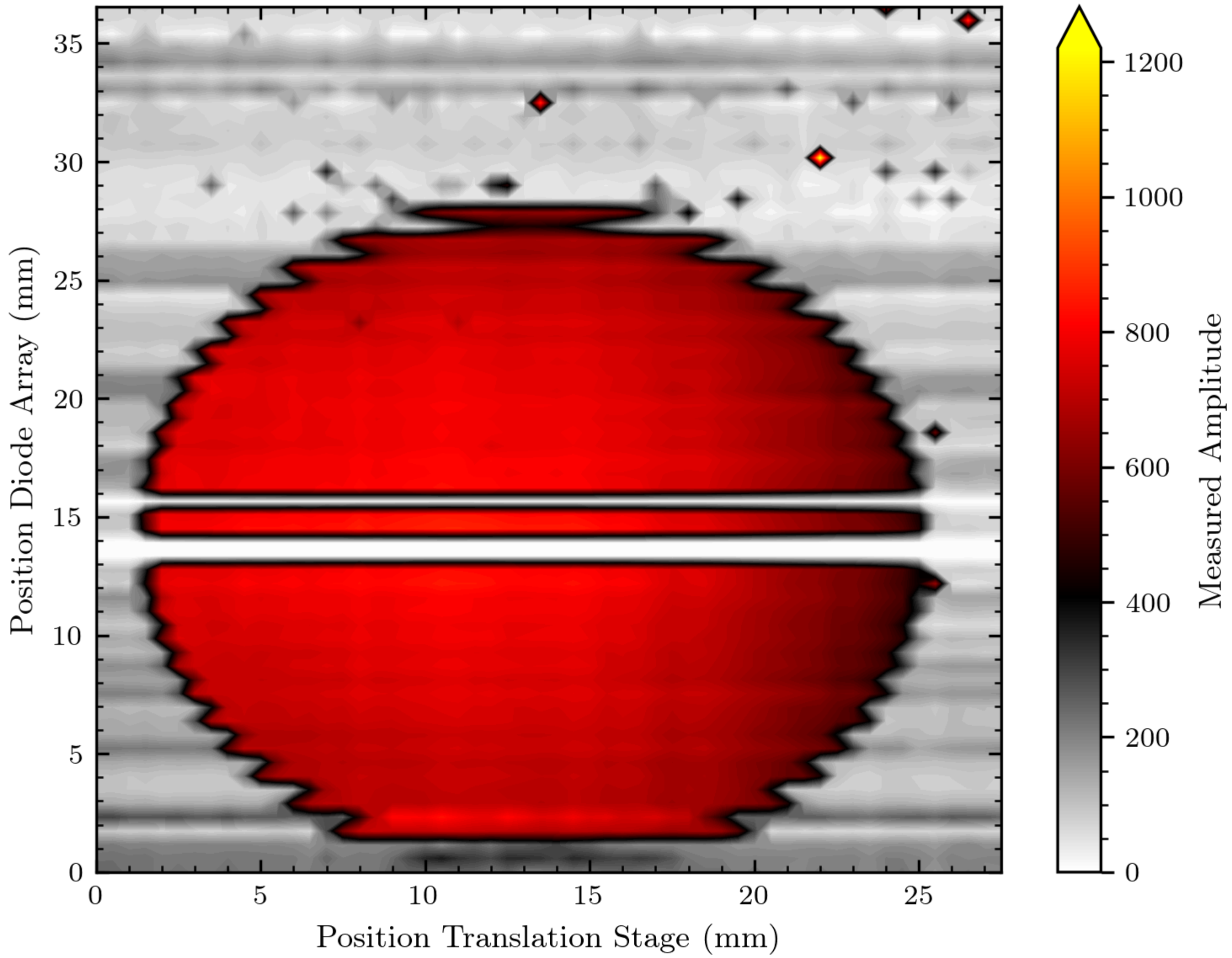
Empty round collimator imaging



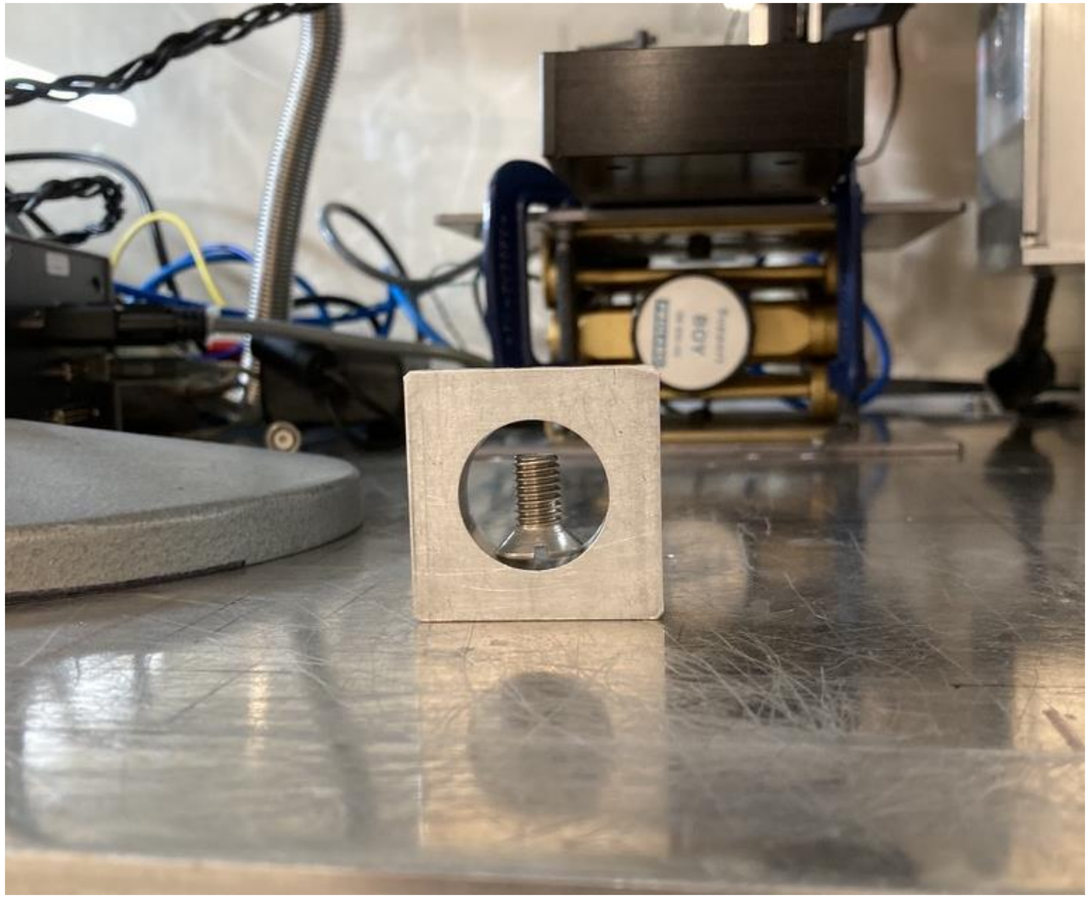
Imaging – real Image vs interpolated

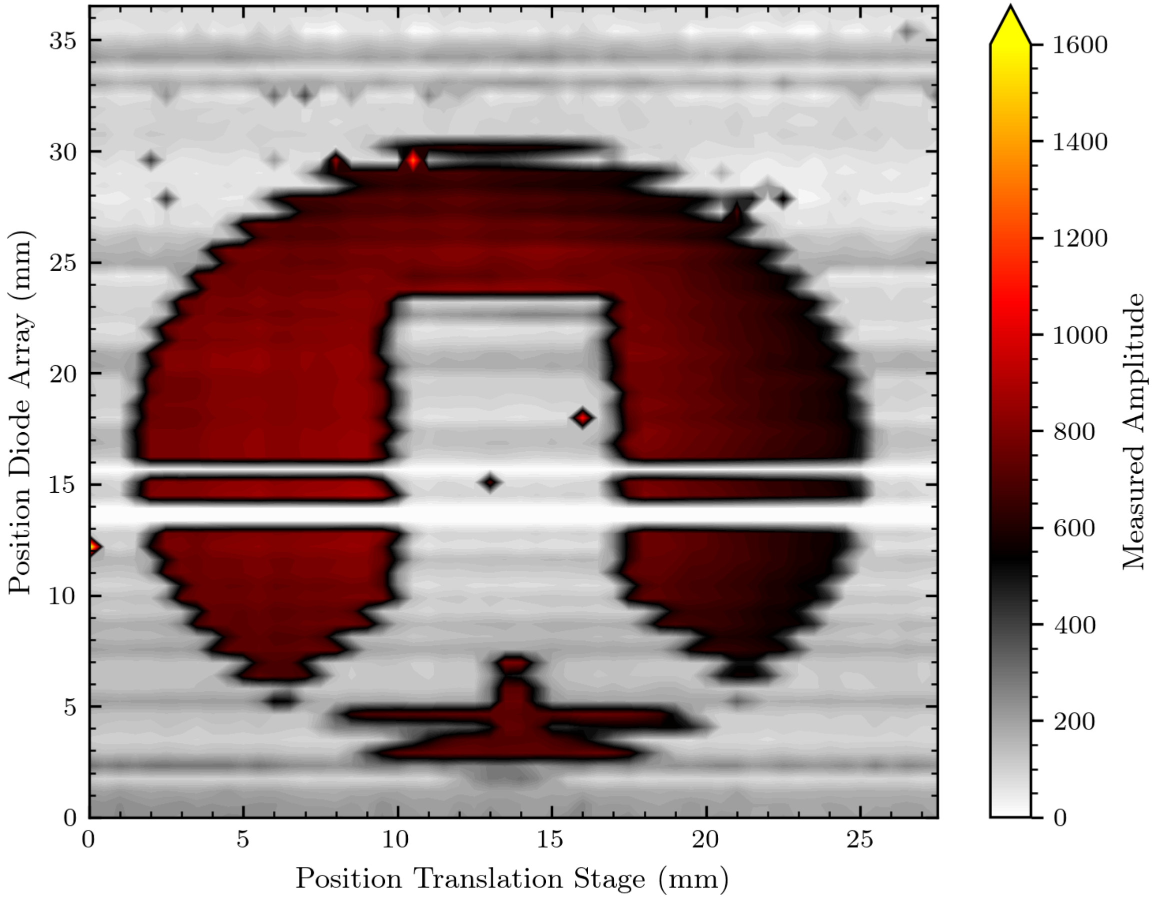
courtesy of N. Broda (RUB)





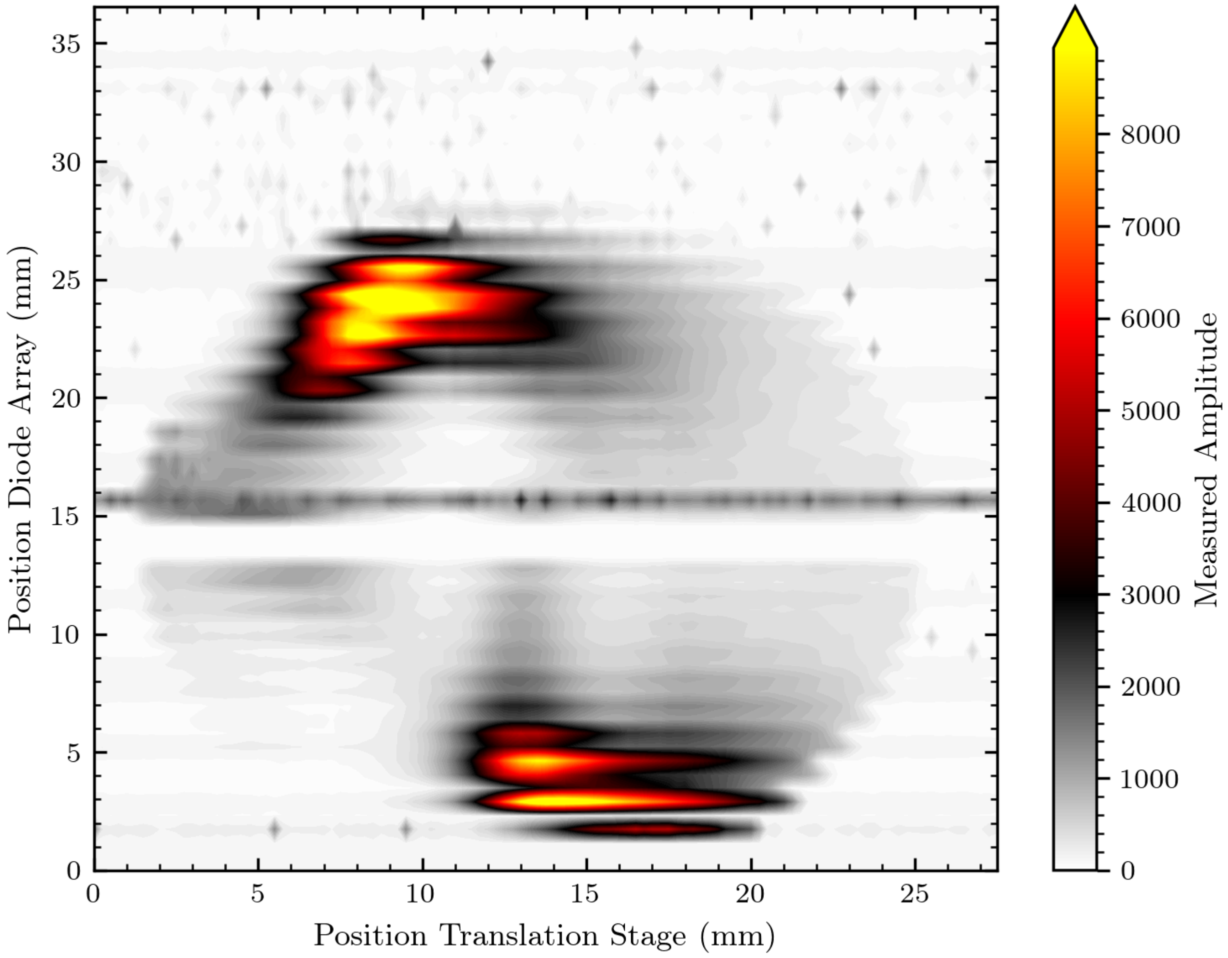
A (turn of the) screw





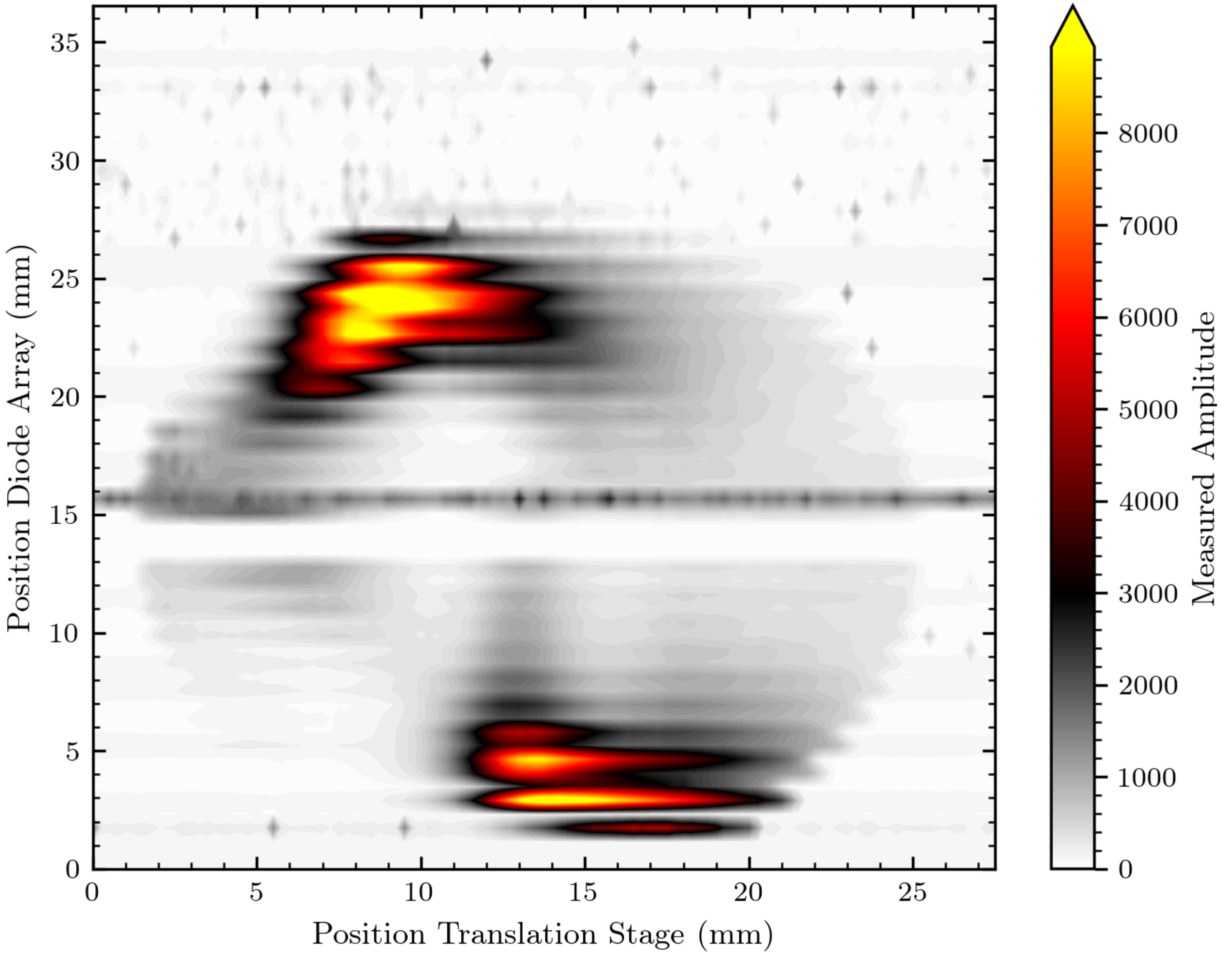
MATRIX

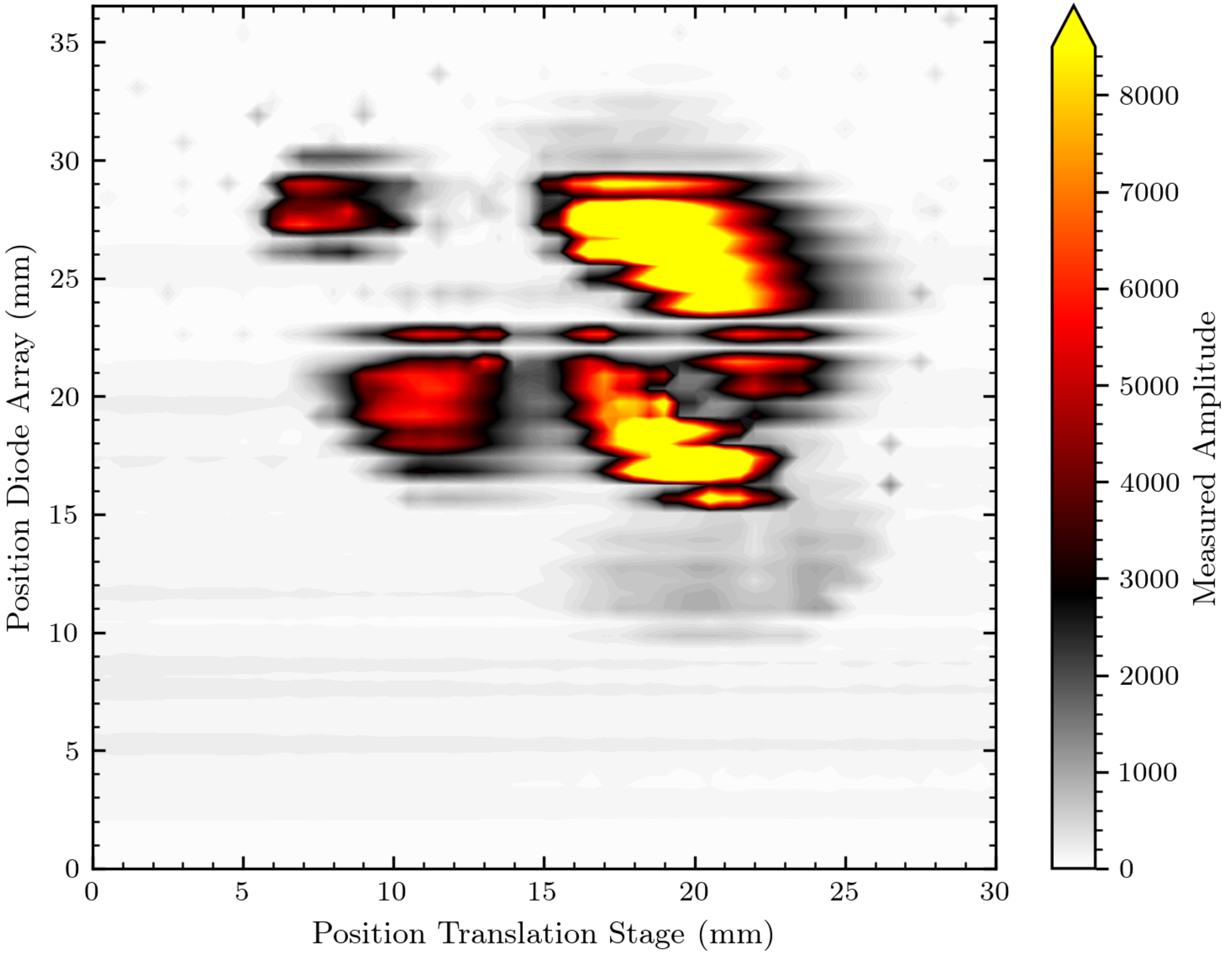
Beam image without diffuser (Al, 40 µm)



MATRIX

Beam structure 28 days later

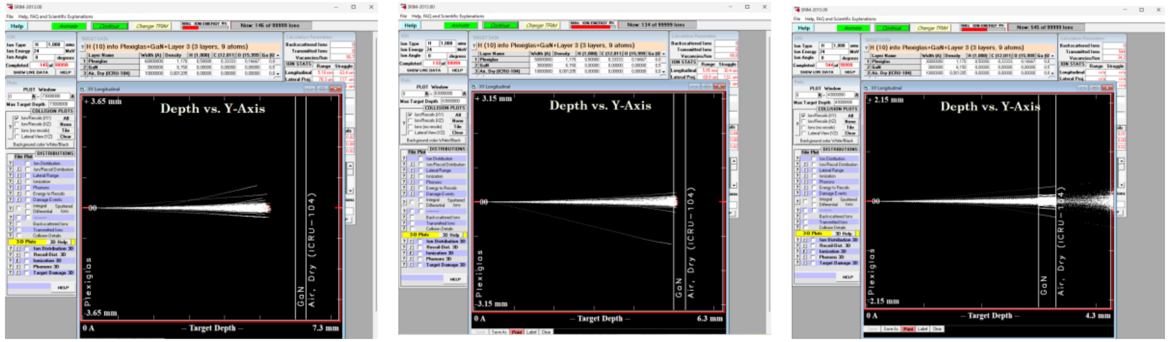




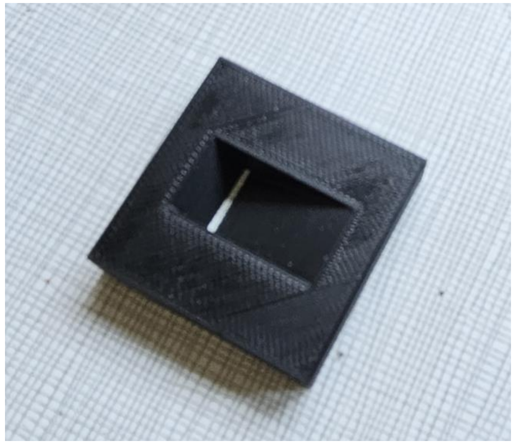
Application 1 : Beam energy monitoring ☺

Ongoing analysis 19/06/24

SRIM simulation

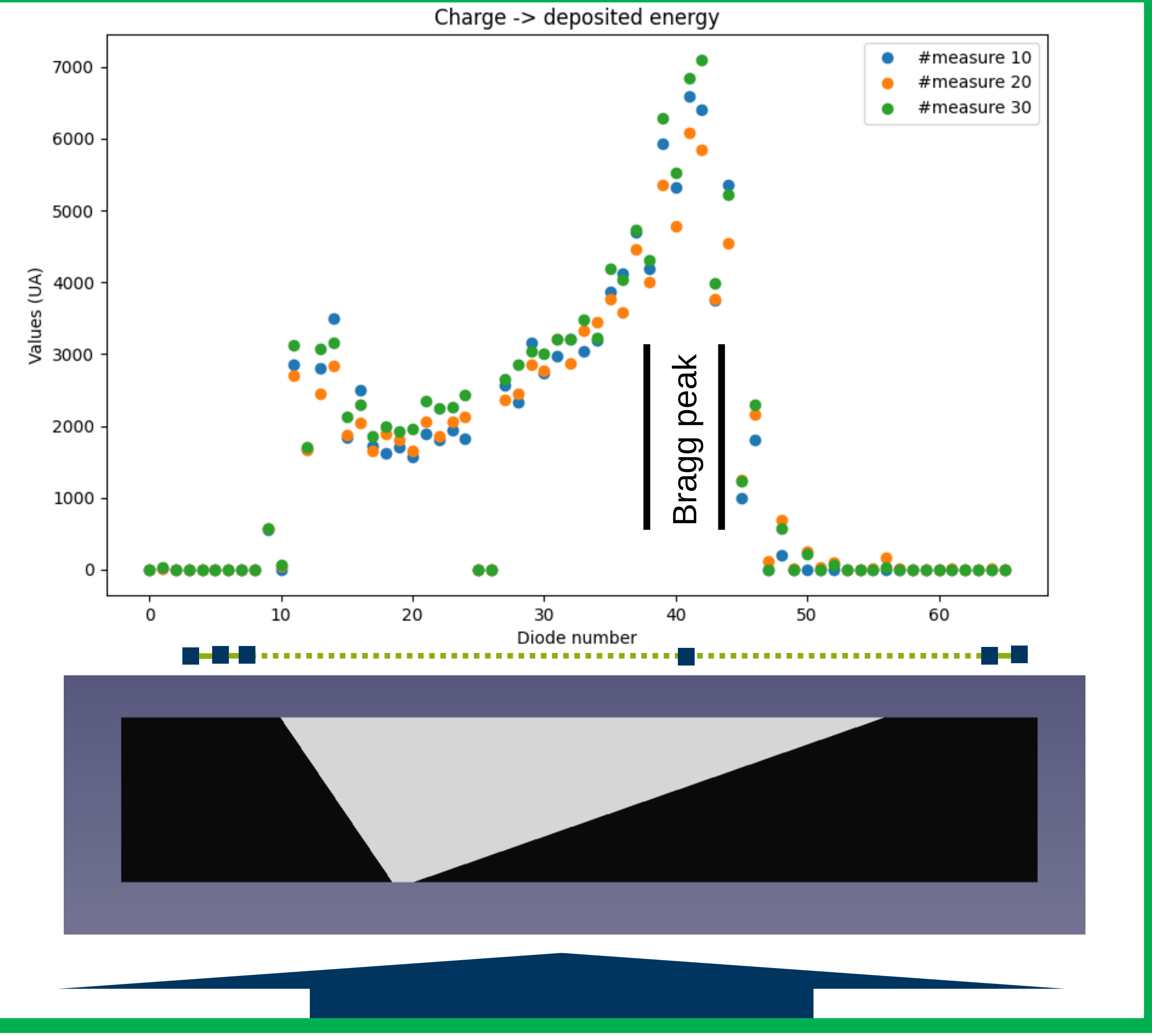


Bragg peak



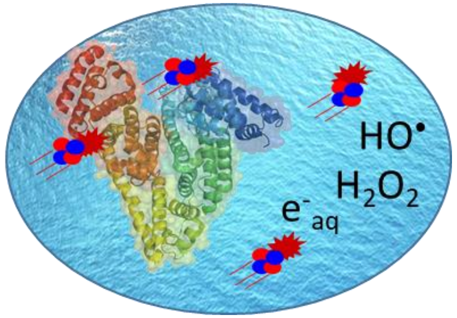
3d printed trapezoid (various shapes)

Cyrcé Proton beam



Application 2 :Radiolysis of Biomolecules (Radiochem, IPHC)

courtesy of Q. Raffy (IPHC, Strasbourg)



Water radiolysis
Radiolysis of biomolecules

Radiolytic yield G :

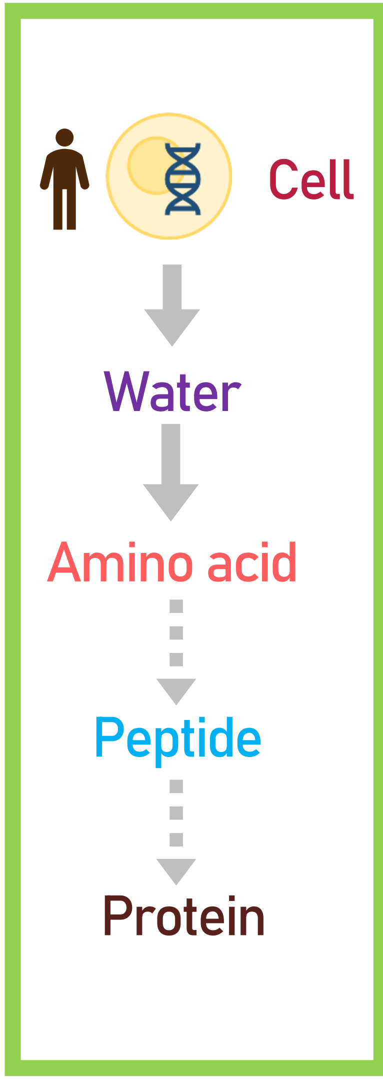
$$G = 100 \cdot \frac{N_{species/ion}}{E}$$

In species per 100 eV

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

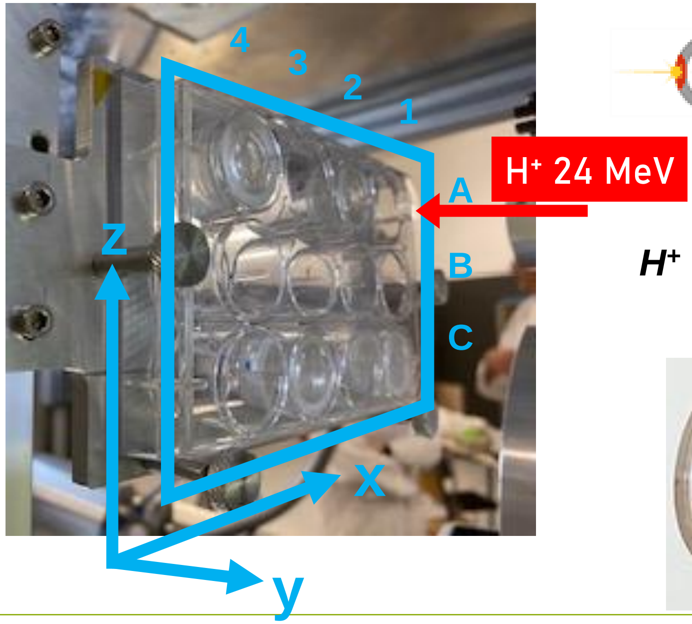
Matrix, beam current monitoring (linearity pA to nA)

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



Radiolysis cells and support design

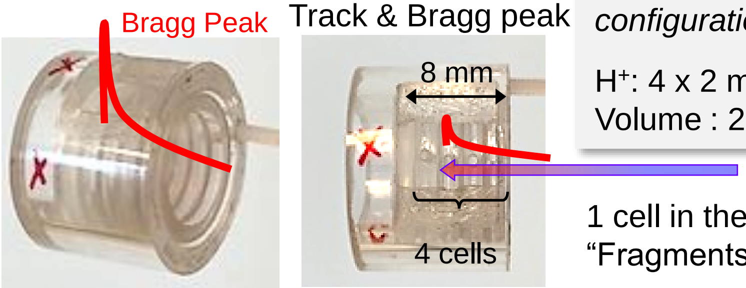
Mobile plate with 12 positions in front of the beam line



CYRCÉ

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

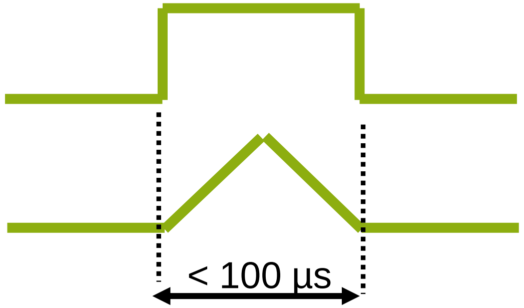
MATRIX

Application 3 : 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)

Application 4 : Flash therapy, beam structure

- CAL, Nice
- WPE ?



temporal resolution measurement of the proton beam
(one diode is enough)

Outlook

- **More measurements in proton beam (CAL, WPE)**
  - Physics simulations
  - IBA system comparison (ionisation chambers, 1mm res.), pencil beam
- **Hadrontherapy (SiC), CNAO (500 MeV)** CNAO The National Center for Oncological Hadrontherapy
- **Optical setup for diode excitation (laser)**
  - Easier studying of AMS circuit parameters (fine tuning), capacitance, …
- **Further process of data analysis (relation to image processing)**
- **2D array (11 x 11) and (k x 128) multiplexed**
- **Analog device testing**

TEAM EFFORT

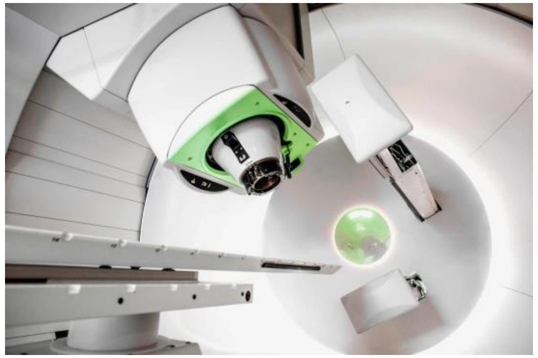
IPHC, Strasbourg
L. The-Duc
C. Wabnitz
N. Arbor
S. Higueret

RUB, Bochum
A. Wieck
N. Broda

WPE, Essen
C. Bäumer
L. Parschat

CAL, Nice
J. Hérault
P. Hofverberg
M. Vidal

CRHEA, Nice
J-Y. Duboz
M. Siviero
M. Hugues
L. Lesourd



West German Proton Therapy Centre Essen

CRHEA

RUB

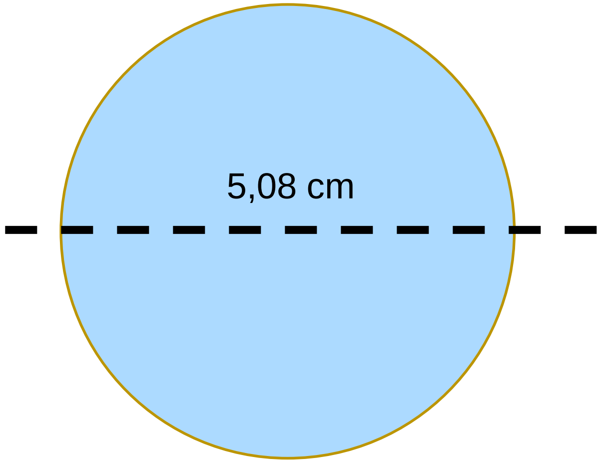
MATRIX

Antoine Lacassagne
CENTRE DE LUTTE CONTRE LE CANCER
unicancer NICE

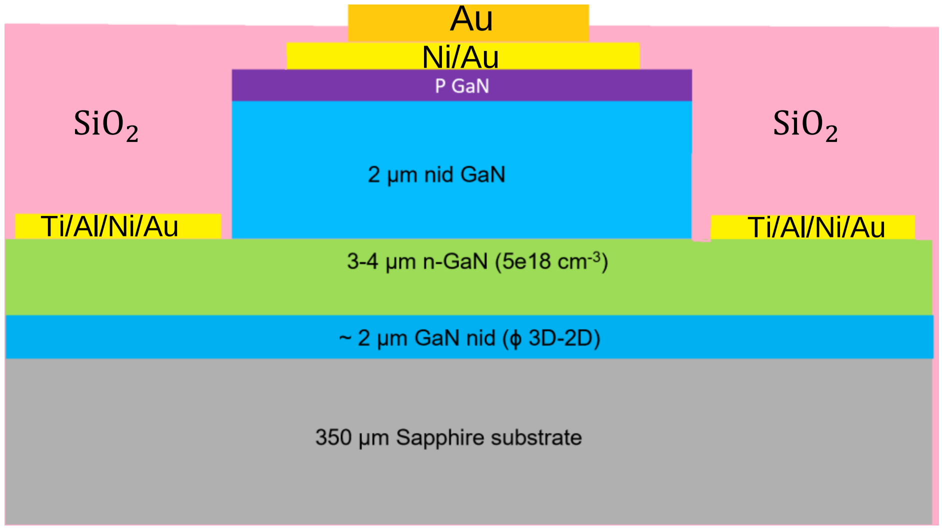
IPHC
Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

Université franco-allemande
Deutsch-Französische Hochschule

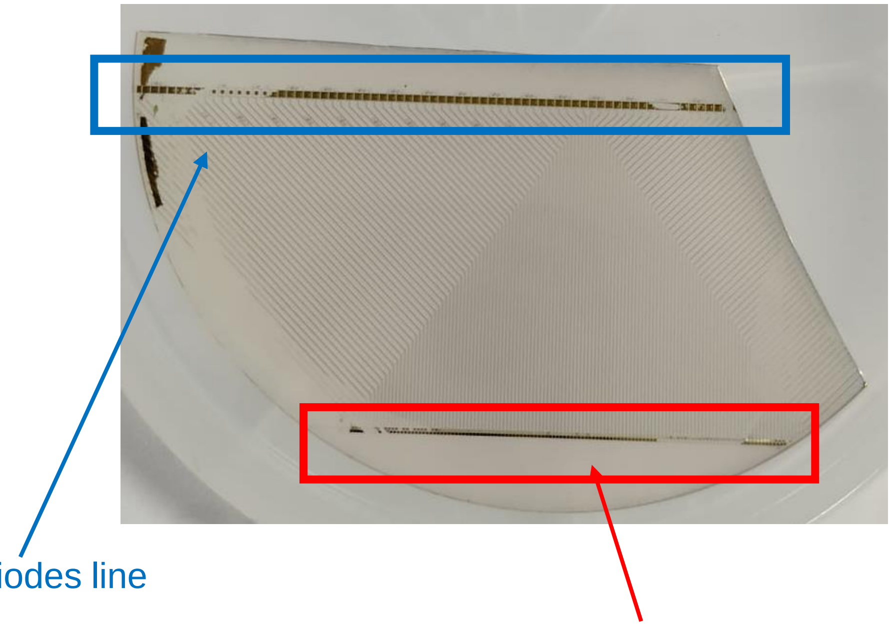
CC1606-02 (½ of a 2 inches wafer)



PIN DIODE

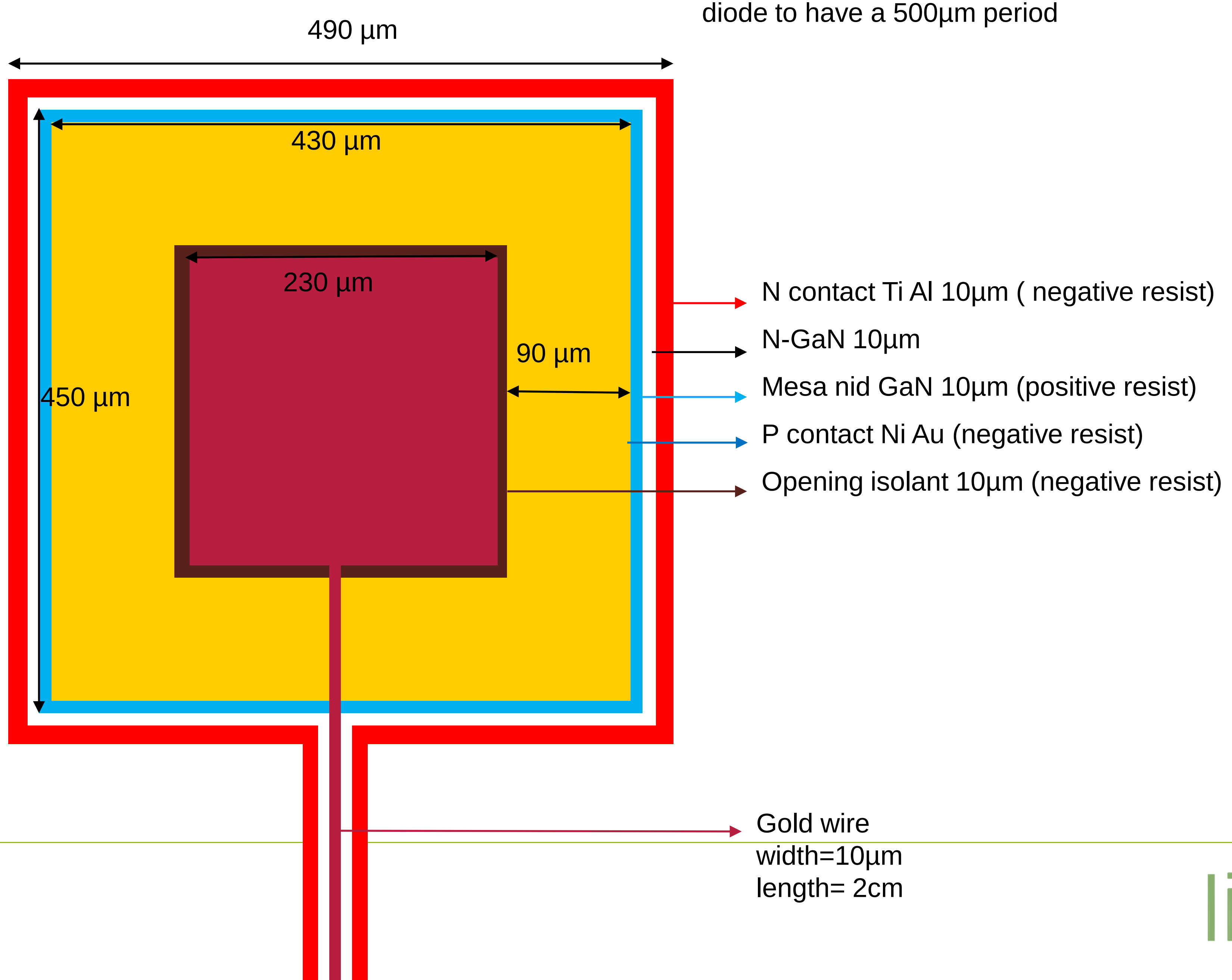


Diode cross section



Mask – single diode plan view

Distanced 10µm from the next diode to have a 500µm period



MATRIX

Mask – single diode side view