FIRST GaN DETECTOR ARRAY FOR HIGH ENERGY PROTON BEAM IMAGING

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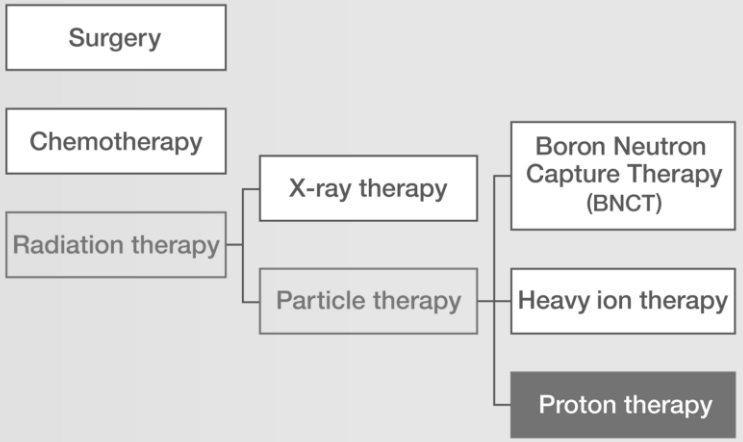
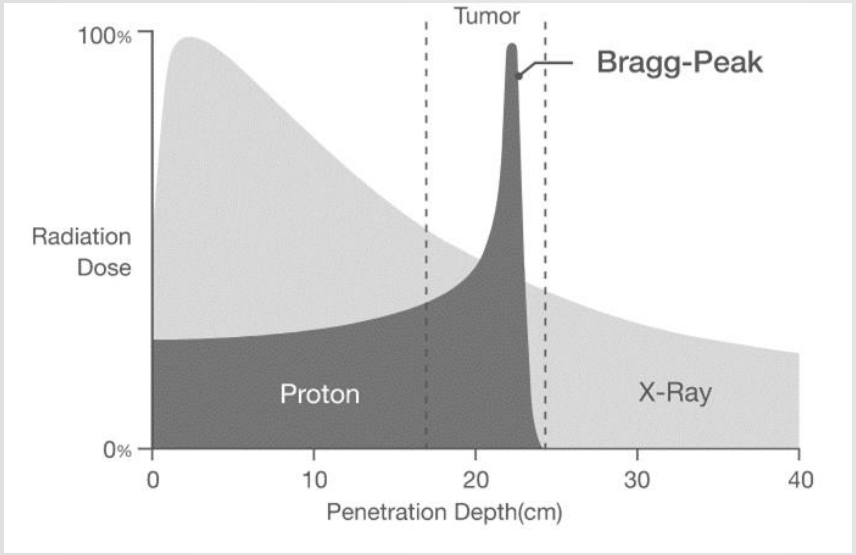
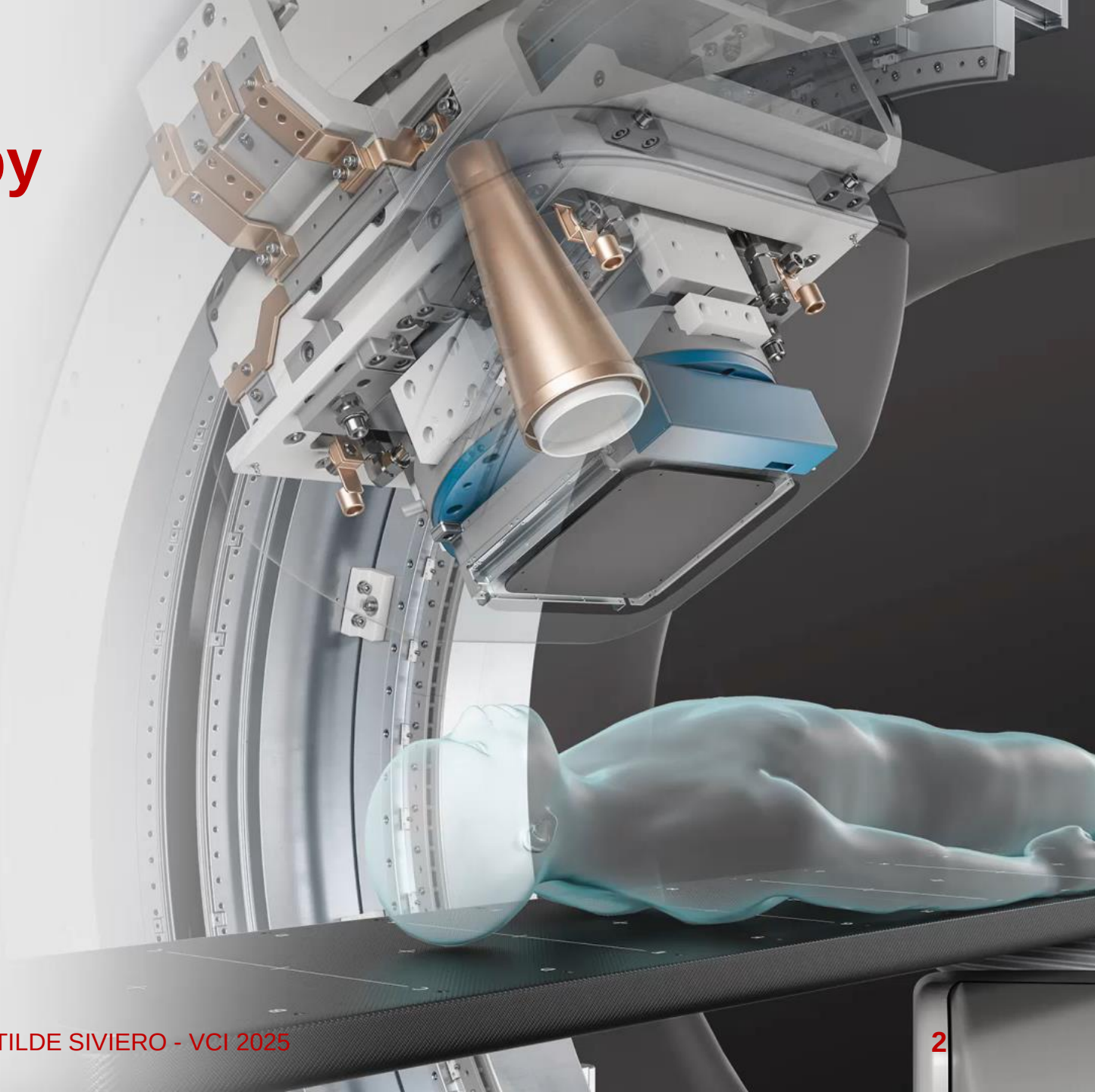
Context: Proton therapy







Detectors applications

QA = quality assurance

- Beam profiles
- Beam energy measurement
- Beam stability

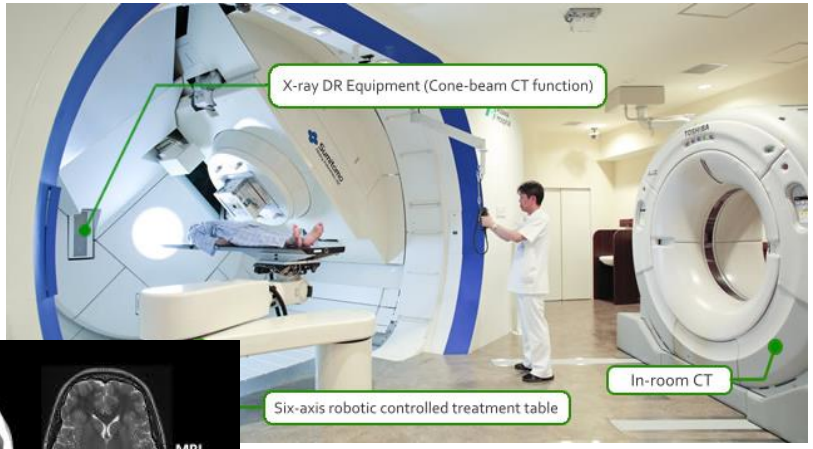
Good devices already in the market

Imaging before treatment is fundamental (traditionally x-rays).

Conversion from photon range and proton range introduces an uncertainty of 3%

Proton imaging provides direct visualization of the proton beam path, ensuring more accurate localization of tumors.

There is a current lack of proton CT scanners ready for clinical use.



GaN for proton detection

Already existing detectors for protons in proton therapy:

- Ionization chambers (e.g. MatriXX by IBA) → limitation: spatial resolution (500μm – 1mm)
- Scintillators coupled to CCD (e.g. Lynx from IBA) → saturation at high proton currents
- calorimeter+scintillators → (only literature for proton therapy) long imaging times, image elaboration
- Silicon detectors (faraday cups, silicon strips, silicon pin diodes) → degradation after irradiation

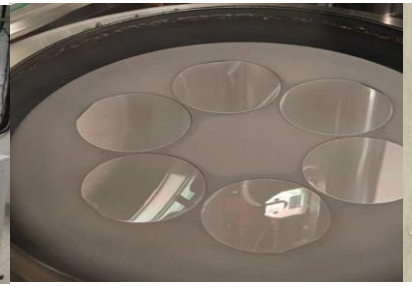
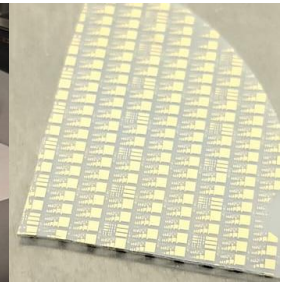
A GaN detector:

- GaN is resistant to high energy irradiation (strong bonds)
- Other GaN detectors exist (x-ray, alpha particles..)
- Big wafers are available for GaN growth
- The silicon electronics must stay out of the irradiation area

	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

GaN diodes for proton beam monitoring

CRHEA *Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications*

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PAPER

GaN Schottky diodes for proton beam monitoring

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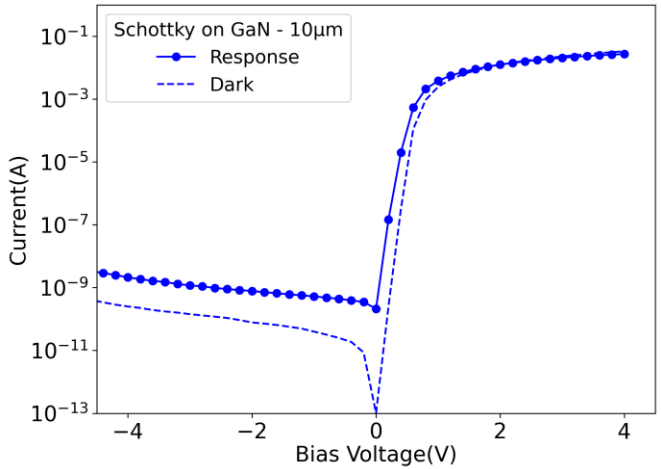
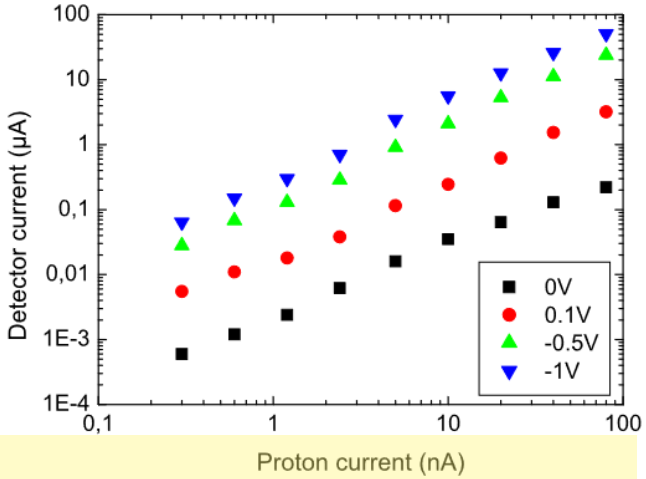
Abstract

We have demonstrated that GaN Schottky diodes can be used for high energy (64.8 MeV) proton beam monotoring. Such proton beams are used for tumor treatment, for which accurate and radiation resistant detectors are needed. GaN Schottky diodes have been measured to be highly sensitive to protons, to have a linear response with beam intensity and fast enough for the application. Some photoconductive gain was found in the diode leading to a good compromise between responsivity and response time. The imaging capability of GaN diodes in proton detection is also demonstrated.

- ✓ GaN is a radiation resistant material
- ✓ Irradiation generates a proton-response in the GaN diodes
- ✓ The response is linear when changing protons current

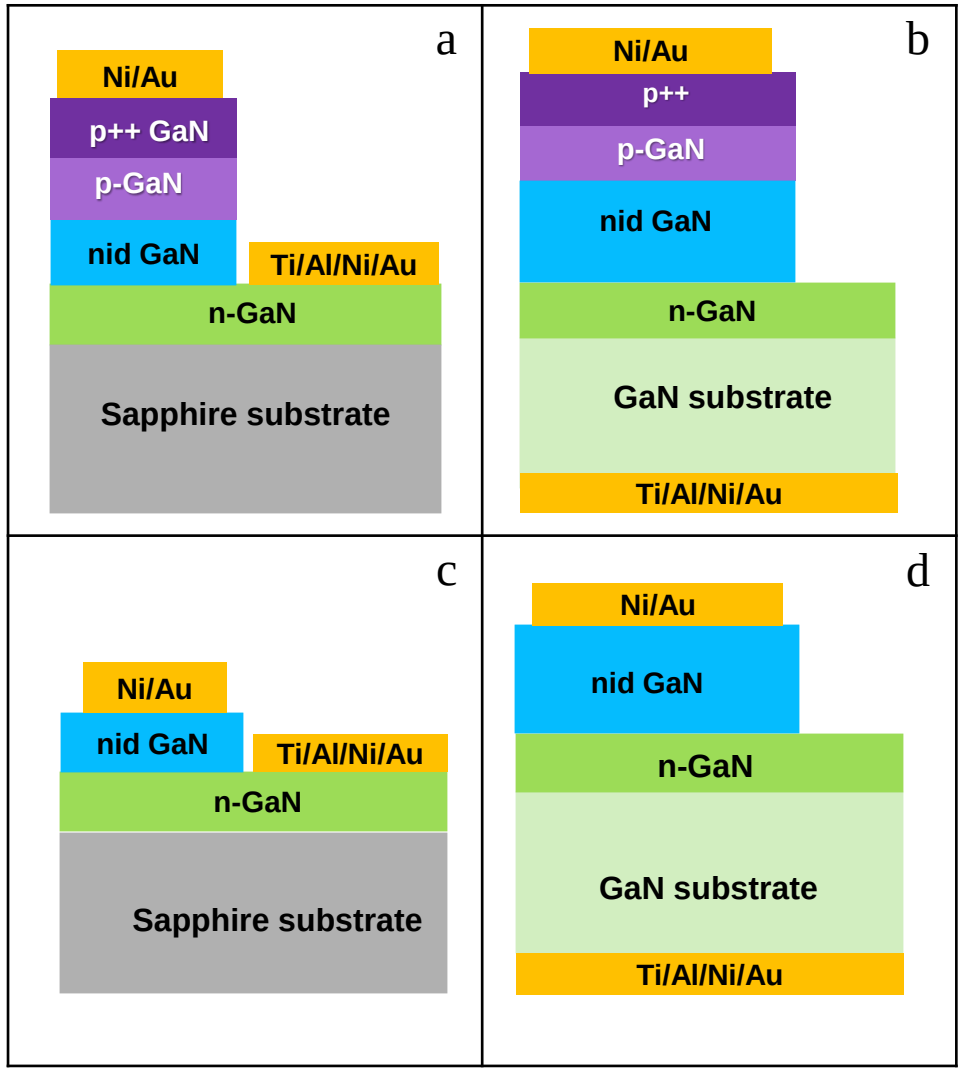




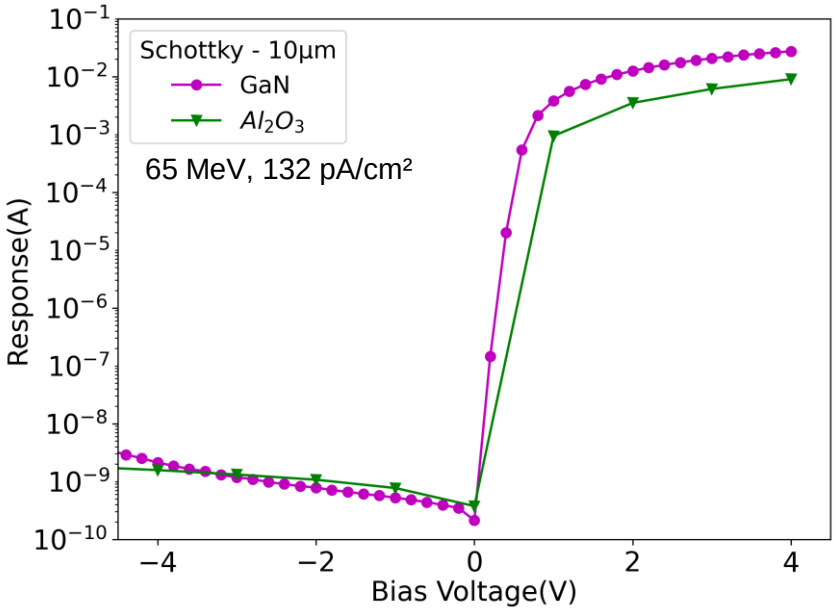
We can make a proton detector with Gallium Nitride!

GaN diodes comparative study for high energy proton detection

- Single diode optimization :
  1. substrate,
  2. geometry (schottky/ pin),
  3. layer thickness
- Proton irradiation @CAL, Nice (65 MeV, 132 pA/cm²)
- A bias voltage is applied -2V – +4V (out of irradiation area)



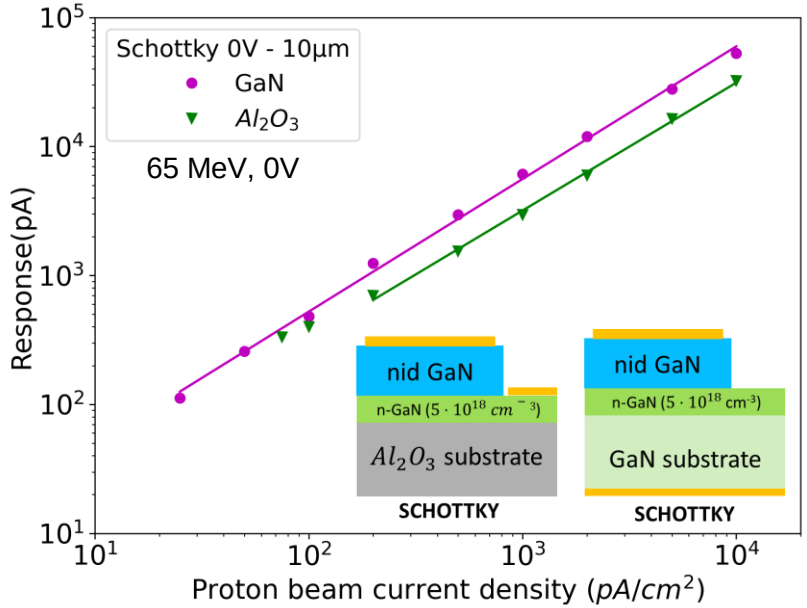
Substrate



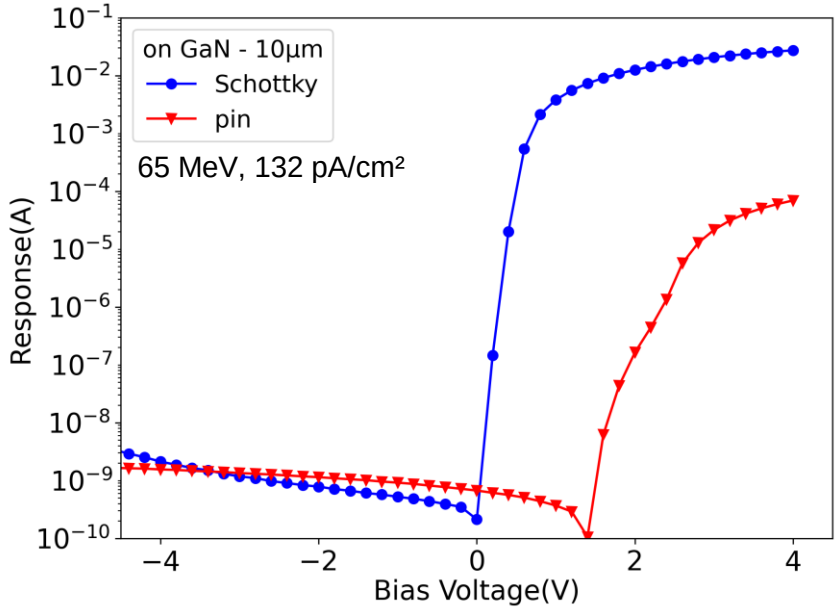
- No significative difference in the substrates
- Sapphire is cheaper
- Sapphire wafers are available up to 8 inches for GaN MOCVD growth

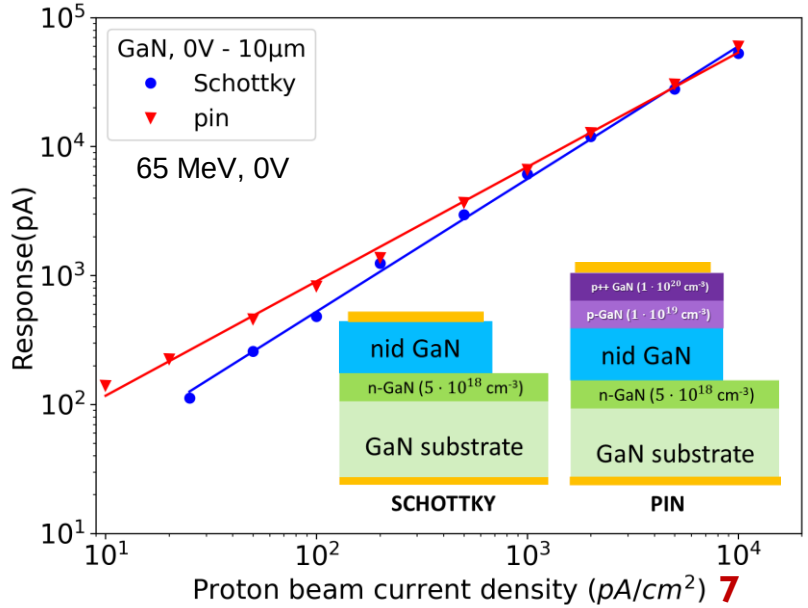
- Pin diodes have higher response at 0V

- Linearity close to 1

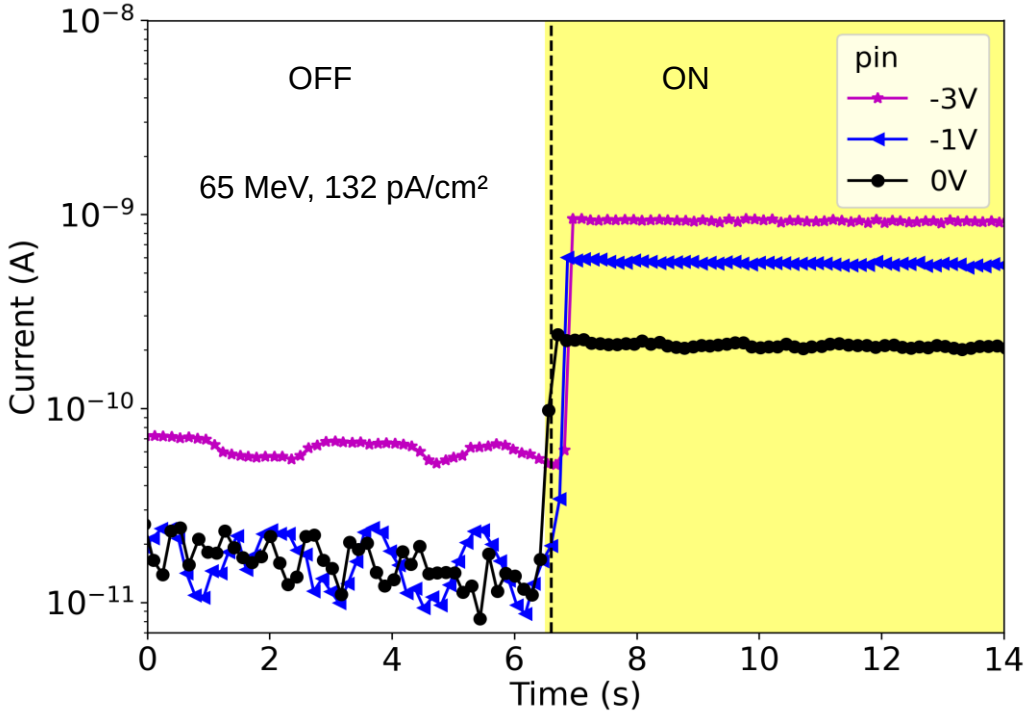


Schottky - pin



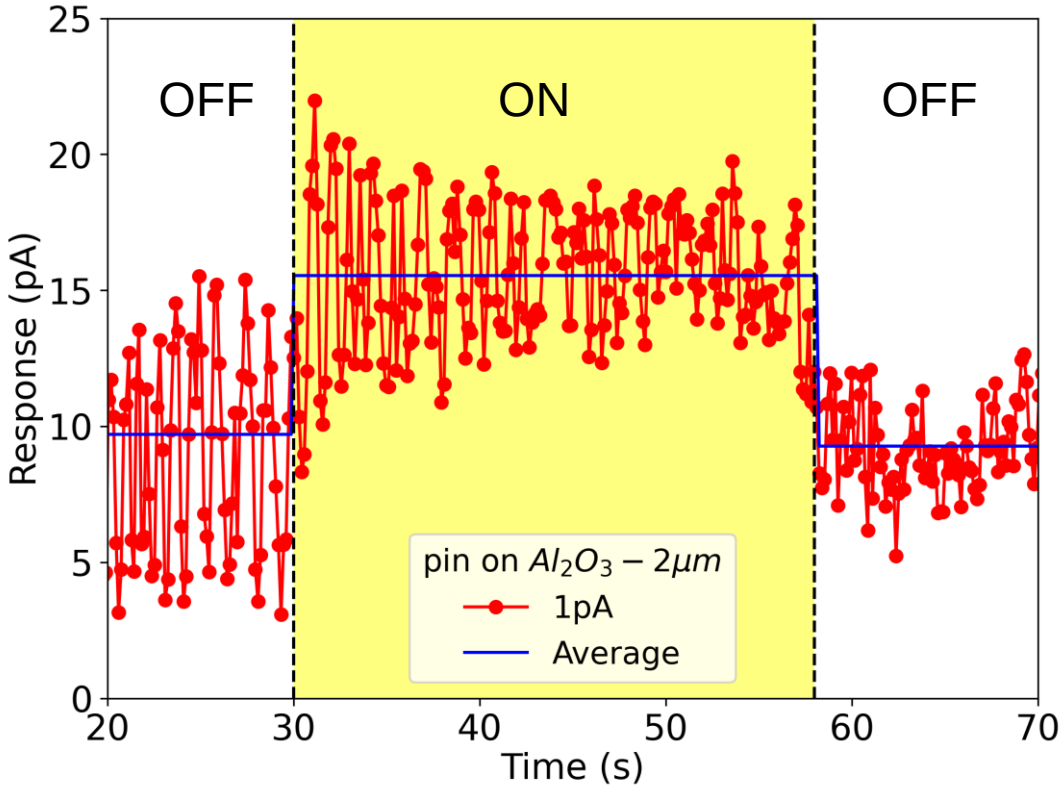


OFF - ON transient



Short OFF-ON transient, mostly limited by setup (measurement every 0.25 s)

Low proton current density sensitivity

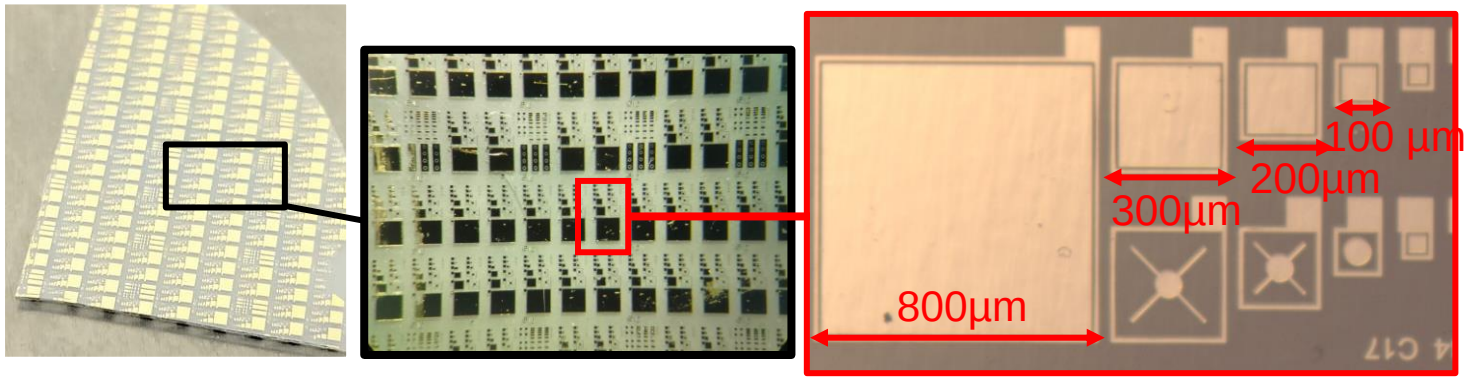


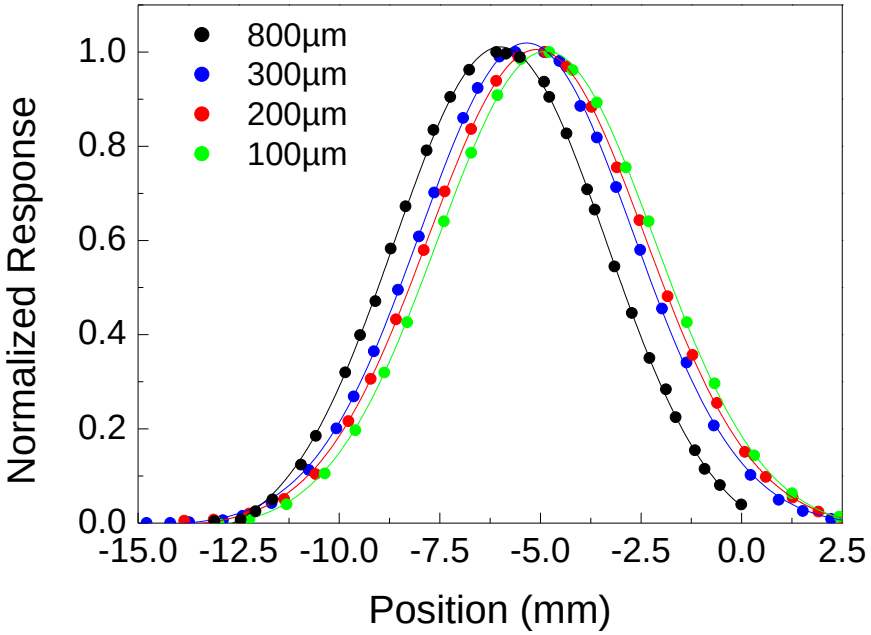
proton current of 1pA, corresponding to 1.3 pA/cm^2

- noise of 2.7pA
- minimum detectable proton current density: $\frac{noise}{response}$*proton current density = **0.63 pA/cm^2**

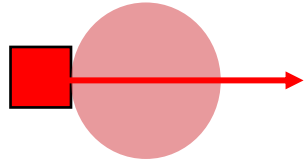
Low proton current sensitivity is fundamental for proton imaging

Single element testing

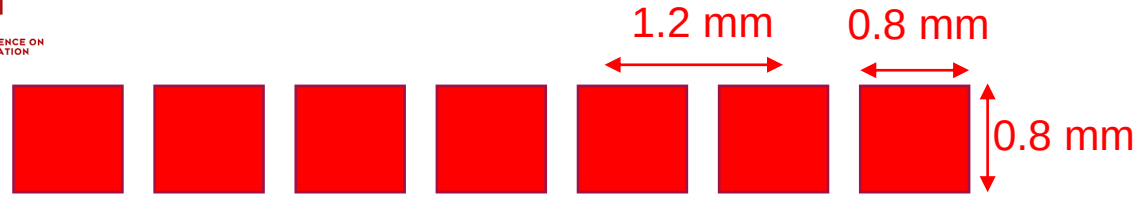




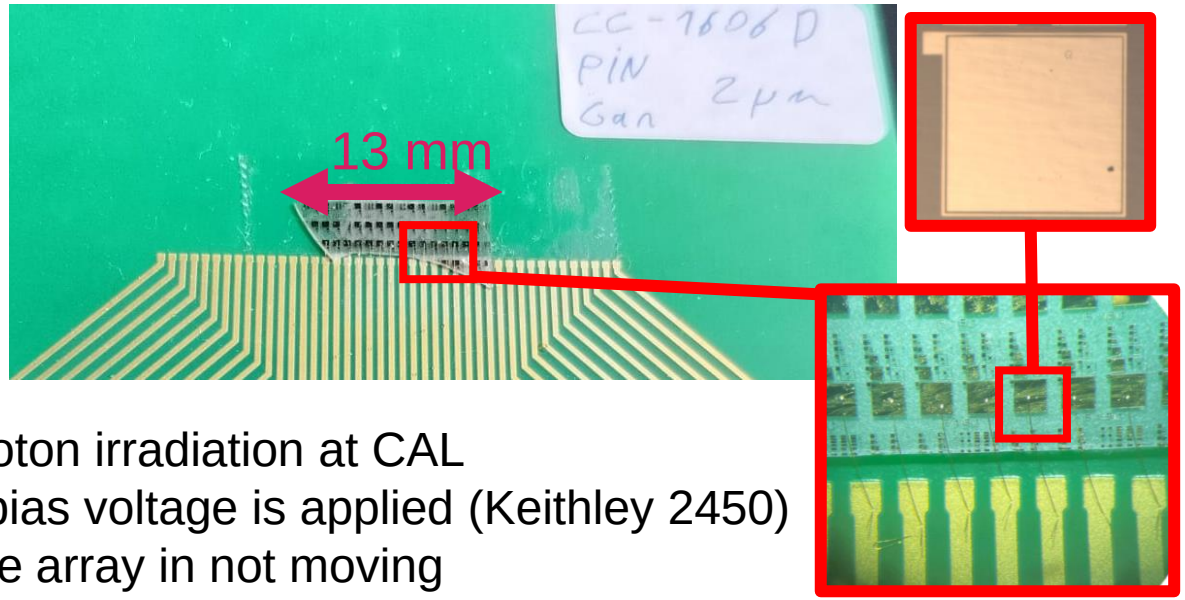
- Proton irradiation (CAL, Nice, 65 MeV)
- A bias voltage is applied (out of irradiation area)
- Measurement in air, no vacuum, no cooling
- IV curves, time response, linearity, profiles
- Several diodes dimensions tested (very easy to reduce diodes dimensions down to 20µm)



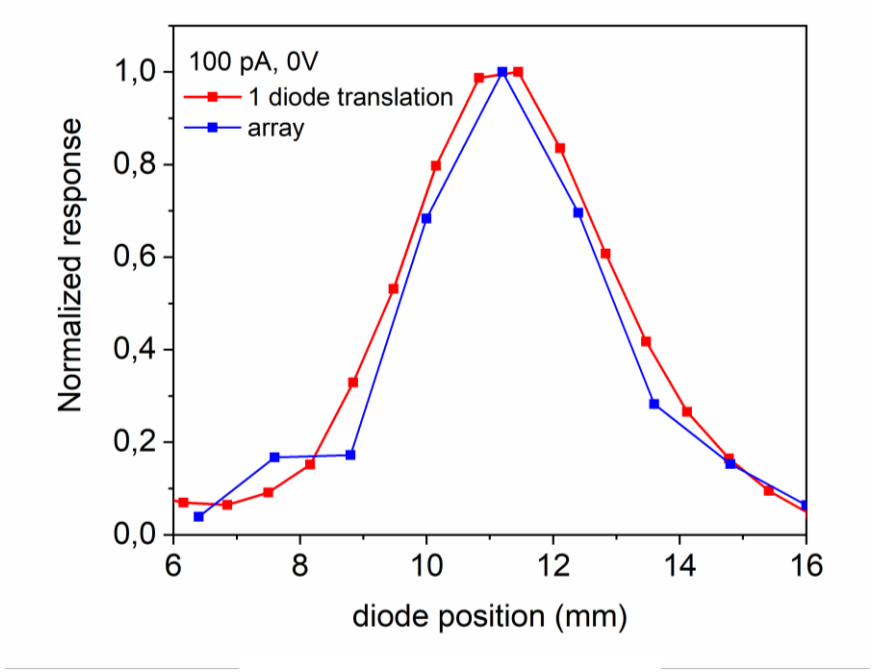
1 diode translation:
the diode is translated to cross the entire proton beam

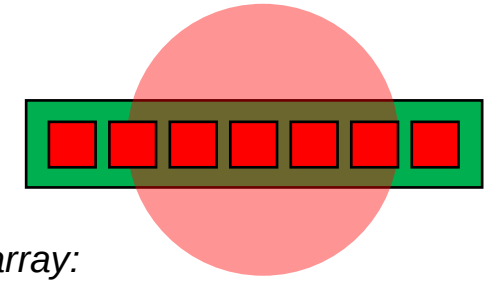


One line of 9 pixels

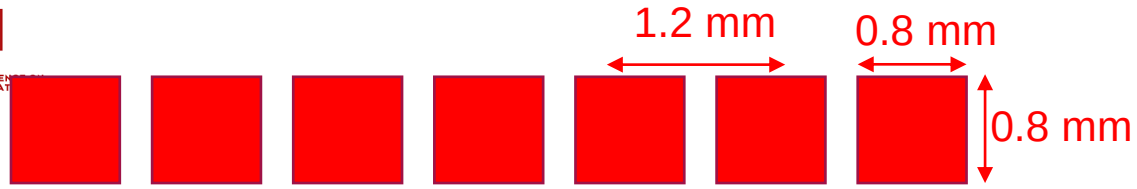


- Proton irradiation at CAL
- A bias voltage is applied (Keithley 2450)
- The array in not moving
- The array is centered
- Non simultaneous measurement

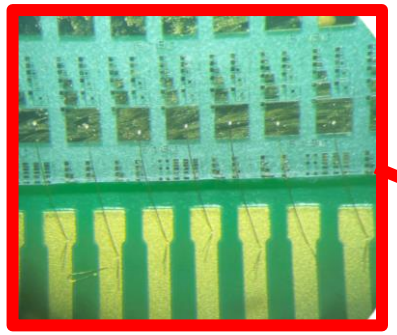




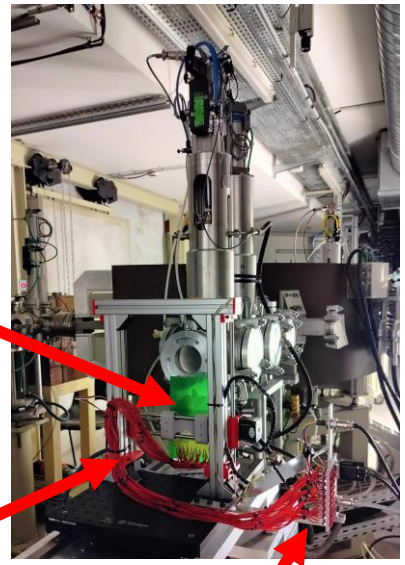
diodes array:
The array is centered in the proton beam, and all diodes are measured



One line of 11 pixels + scanner



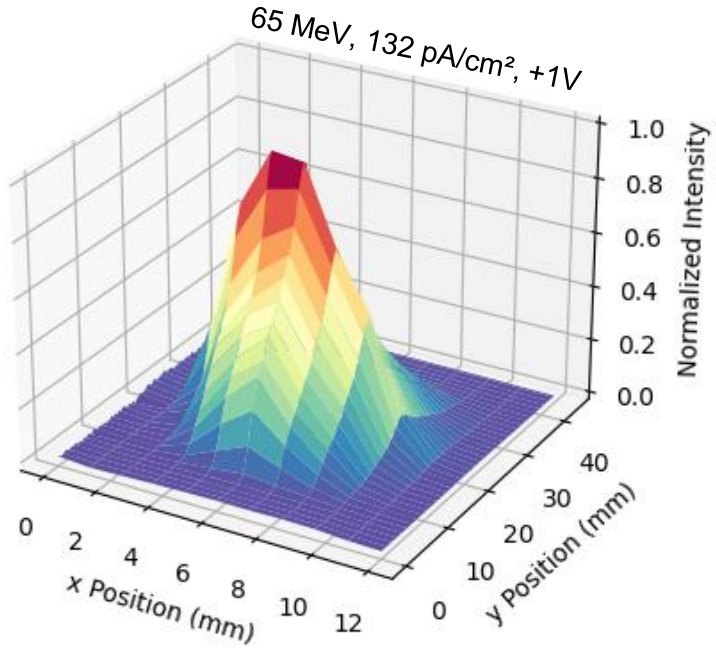
11 diodes of 800 µm (13 mm)

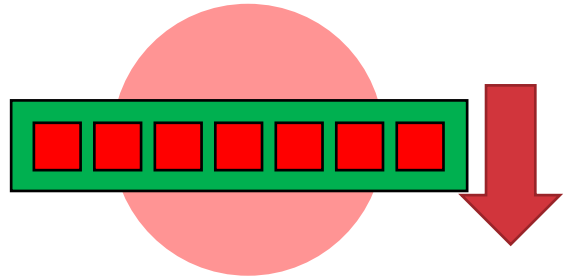


Translation stage

Keithley 2450 to apply a bias and read signal (out of irradiation area)

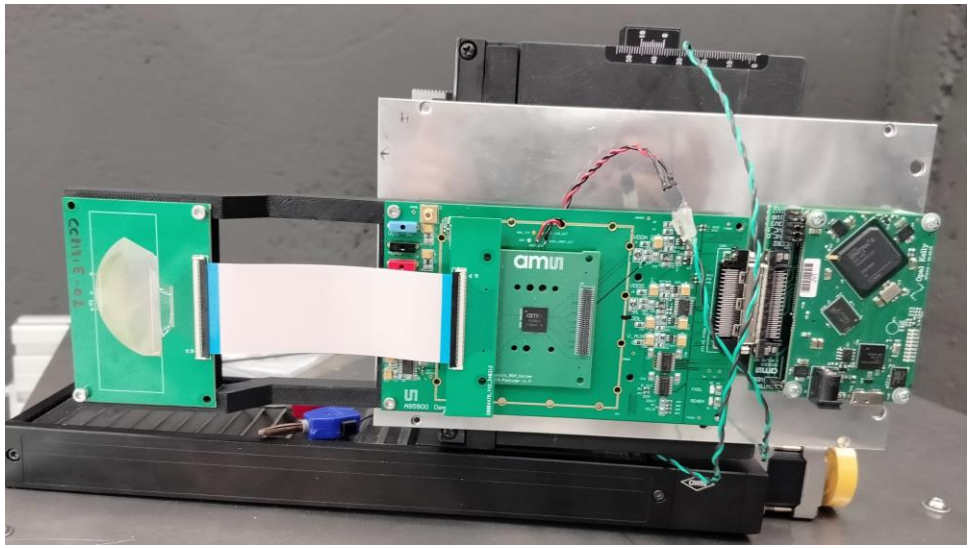
- Irradiation at CAL (65 MeV)
- Non simultaneous measurement
- Measurement time: 15 minutes





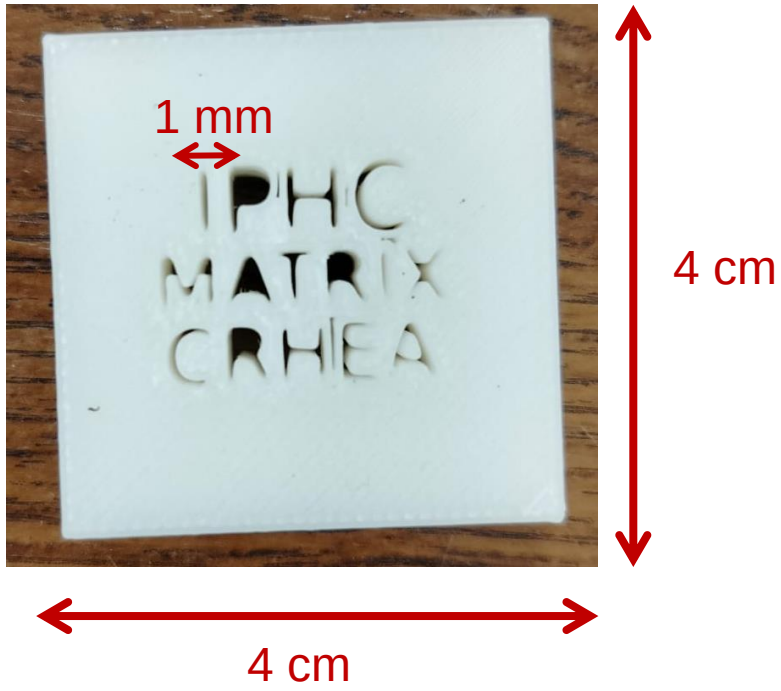
diodes array:
The array is centered in the proton beam, and all diodes are measured during a translation

One line of 128 pixels + scanner



A new read-out system (OSRAM AMS)
Simultaneous measurement of 128 diodes

How do we image an object now?

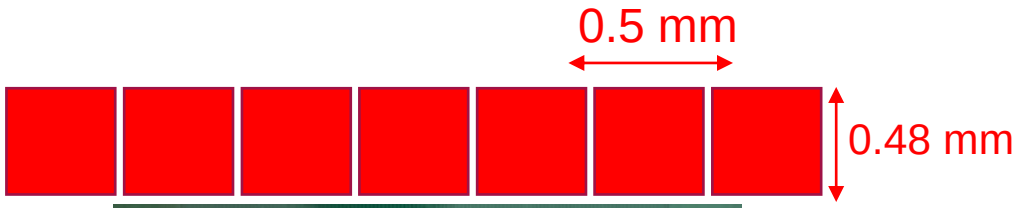


3D printed polymeric object

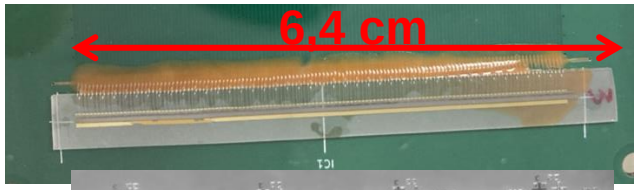
1. We need to cover a big surface
2. We need millimetric resolution

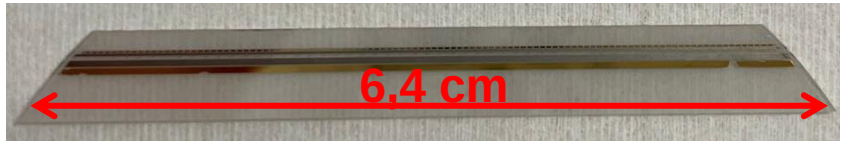
Linear detector + vertical translation

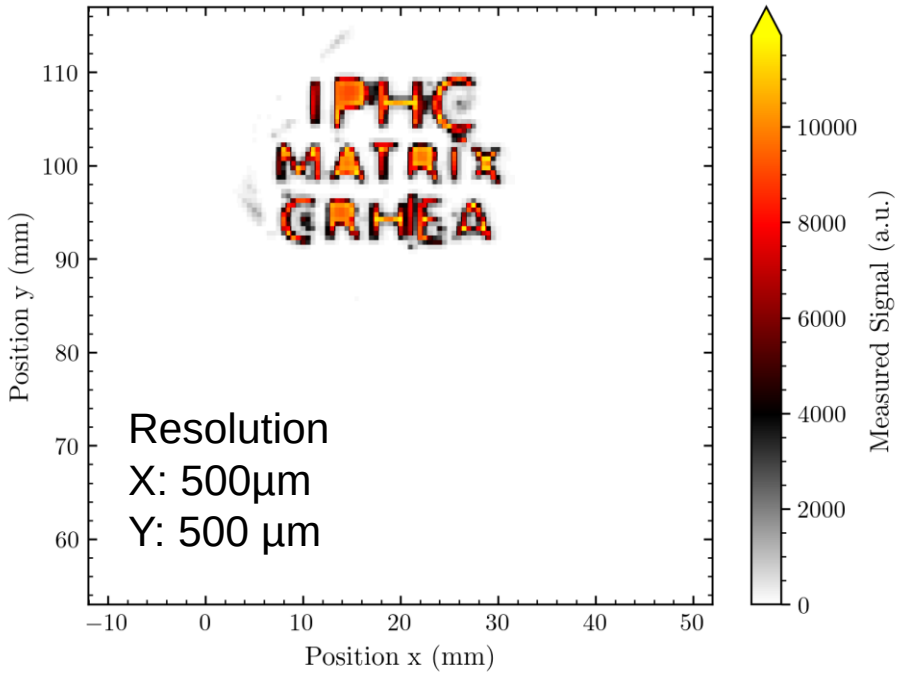
One line scanning with 128 pixels

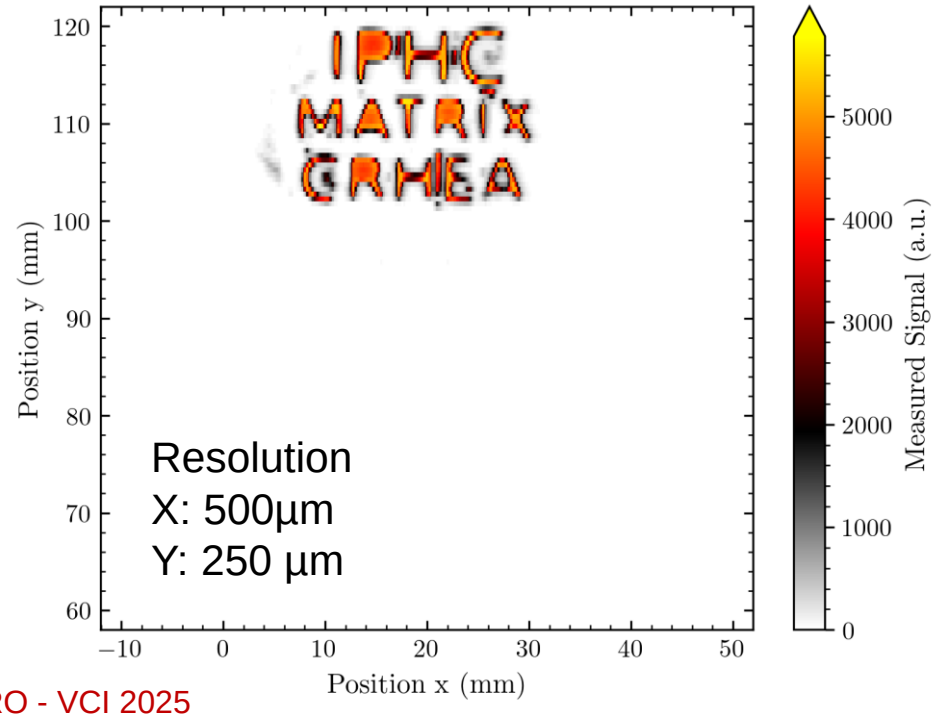


- **Linear arrays fabricated on 3 inches wafers**
- **Response uniformity 98%**



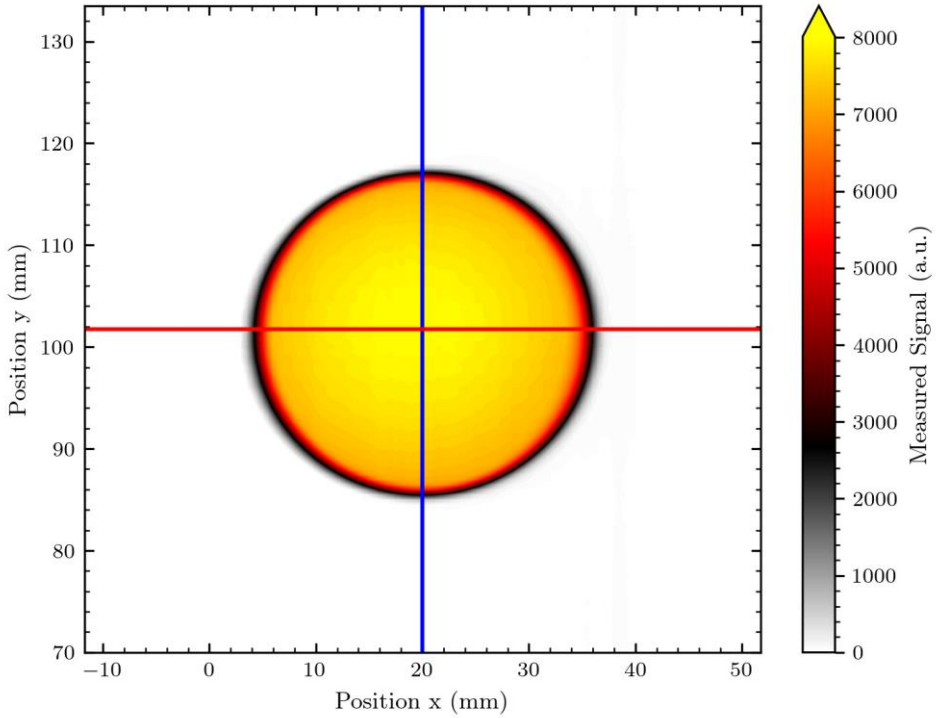


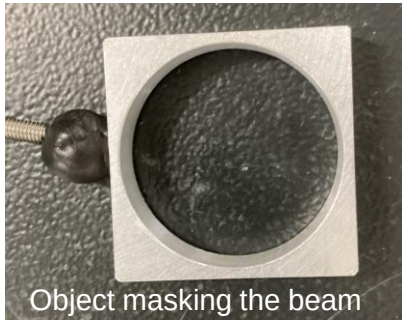




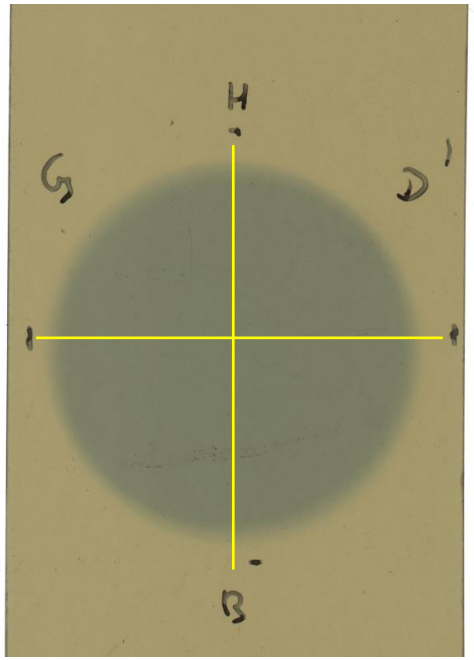
Preliminary Gafchromic film comparison

GaN detector

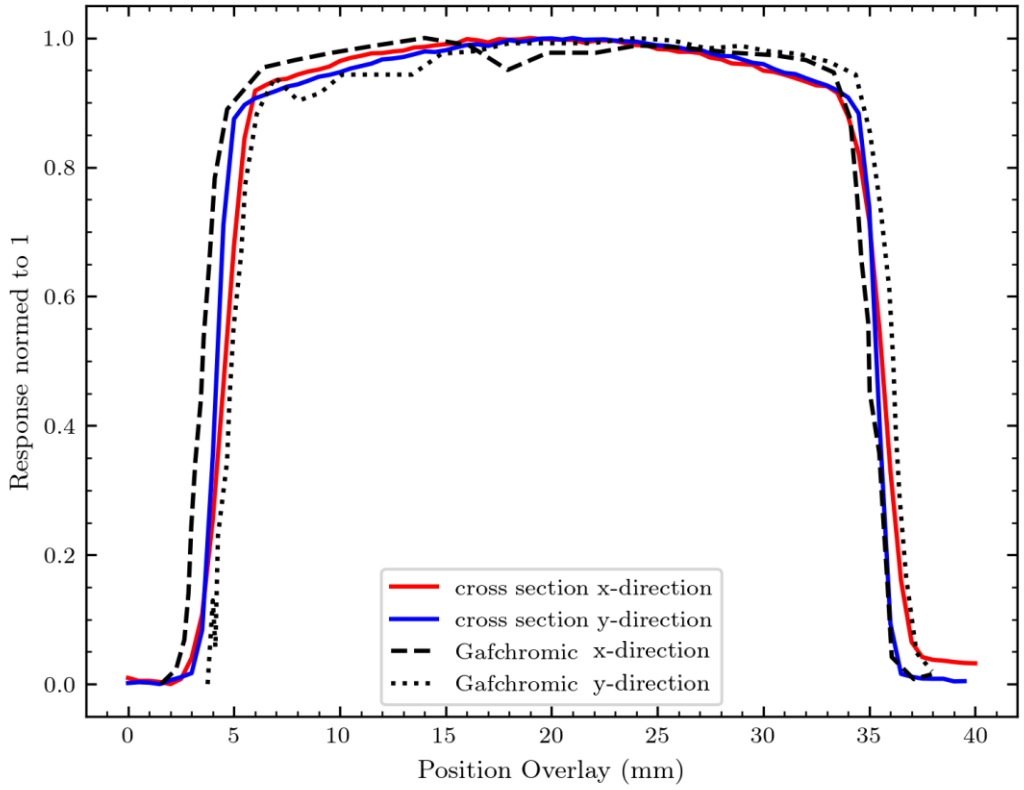



Object masking the beam

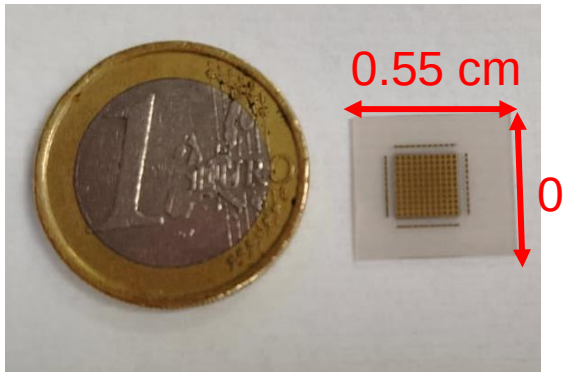
Gafchromic film:

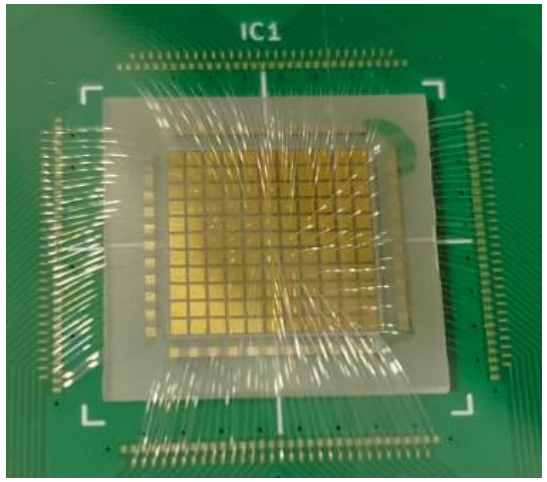


Measurement with different current and time than on the detector



The first 2D matrix





One shot image – just like a photo, or videos

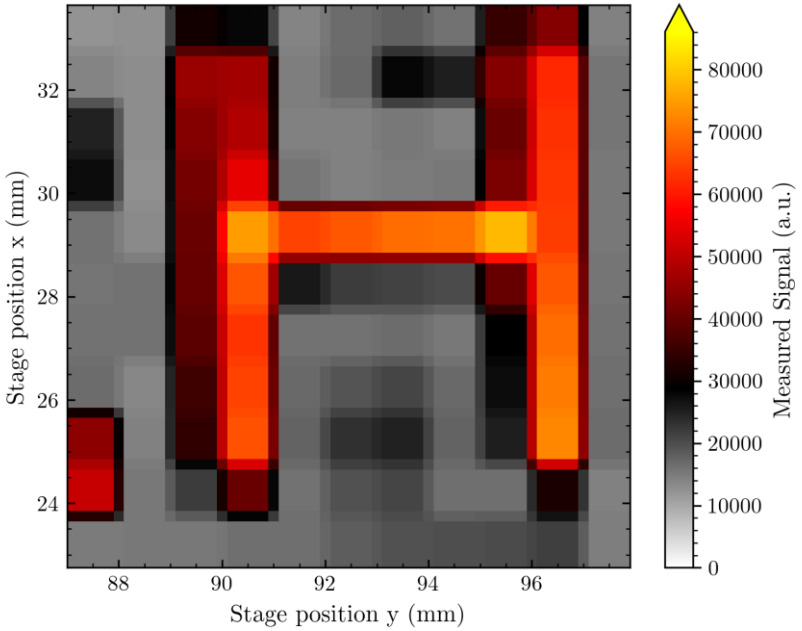
Scanning can be used to have high resolution images

0.5 mm resolution

11x11 pixels

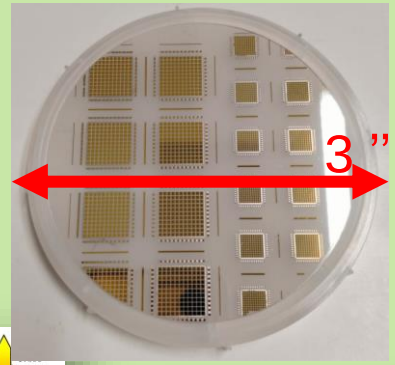
It can be upscaled (changing the electronics)

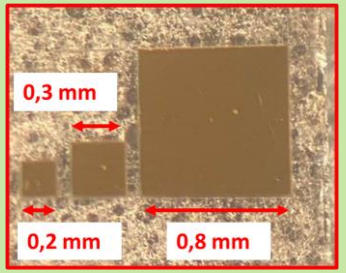
One shot one image (before corrections):

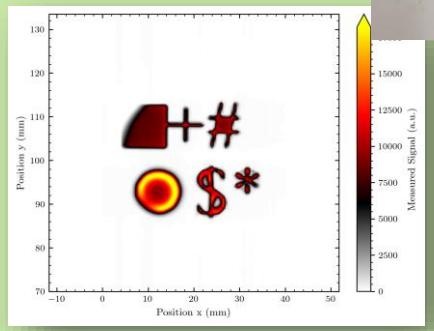


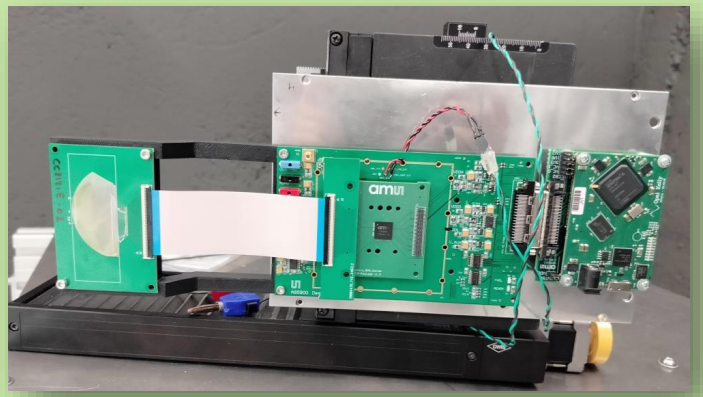
Conclusions

1. Microelectronics fabrication procedures: micrometric pixels (easy to down scale to 10µm)
2. Fabrication possible on big wafers
3. Response uniformity of 98%
4. Very compact detector
5. First proton radiographies
6. With no translation <1s
7. GaN is very robust – no sign of degradation so far









Perspectives

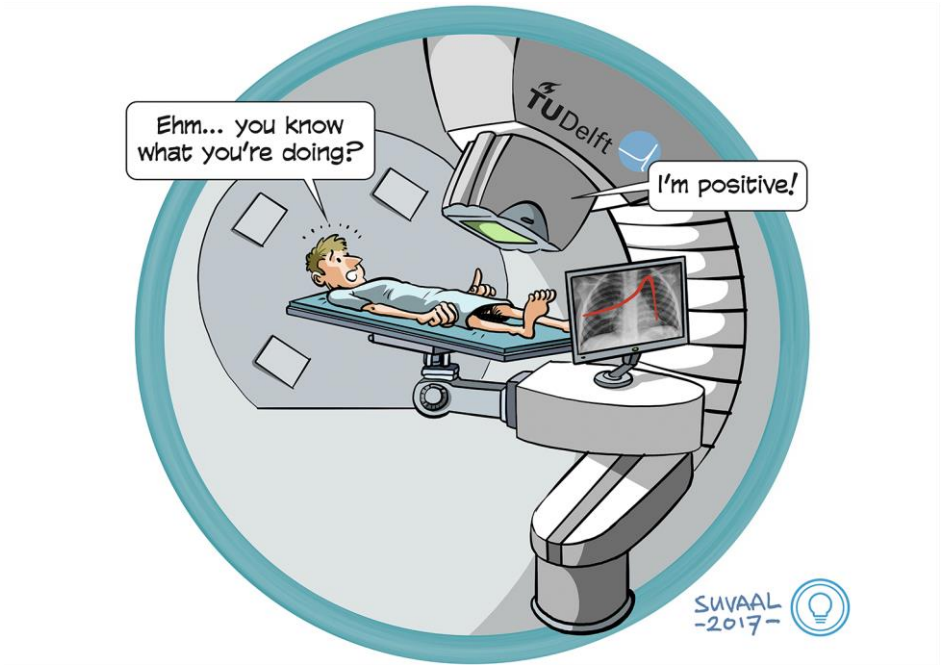
In progress:

- Real time video of proton imaging
- 2D passive matrix 128xN (line-column scheme-reading)
- Proton energy measurement

Next:

- Degradation studies
- Characterization in different proton beam lines (200 MeV)
- Investigation of time resolution for application to flash therapy (ms)

THANK YOU FOR LISTENING



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