ANEMONE

hAdroN bEam MONitoring by pErovskite based detectors

Durata esperimento: 2 anni

Area di ricerca: Rivelatori

Responsabile nazionale: Laura Basiricò (INFN- sezione Bologna)

Unità partecipanti:

- **INFN Bologna section (INFN-BO)**
- **Laboratori Nazionali del Sud (LNS)**
- **INFN Firenze section (INFN-FI)**

Motivation & Objectives

MAIN AIM:

Development of the first **PEROVSKITE (Hybrid and Inorganic) film-based real-time direct detector for PROTONS and IONS**, as **beam monitor** for **hadron therapy** and as beam test tool for high-energy experiments, realized on flexible substrate.

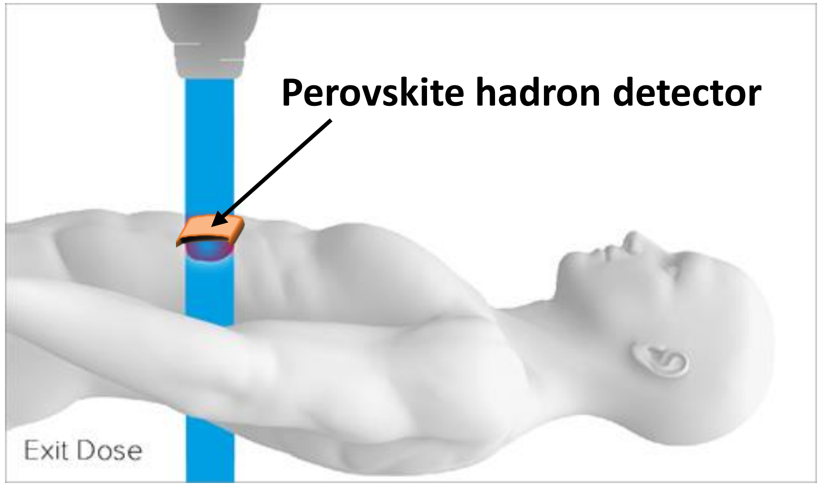
TASKS:

i) **Unravel the interaction of charged particles** with nanostructured **hybrid and inorganic perovskite** films to design novel detectors.

ii) **Design and optimization** of the most performing PVK-based active layer (hybrid and inorganic) and detector layout for hadron detection.

iii) **Test under relevant proton/ion irradiation and dosimetric characterization** (at TIFPA, CNAO, LNS facilities) for beam monitoring application during hadrontherapy treatments.

REAL-TIME BEAM MONITORING FOR HADRONTHERAPY

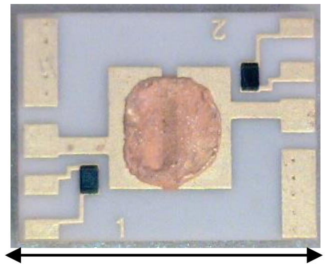


Background: Perovskites for X-ray detectors

INFN-FI→ CSN5 experiment

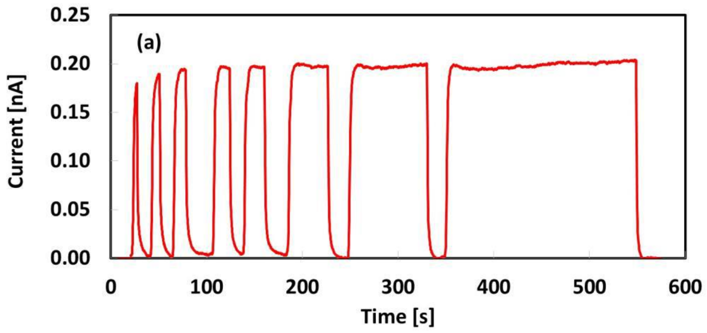
PERO2: Development of medical dosimetric systems based on PEROvskite materials

- **Inorganic perovskite $CsPbBr_3$** thin film based **X-ray** detectors

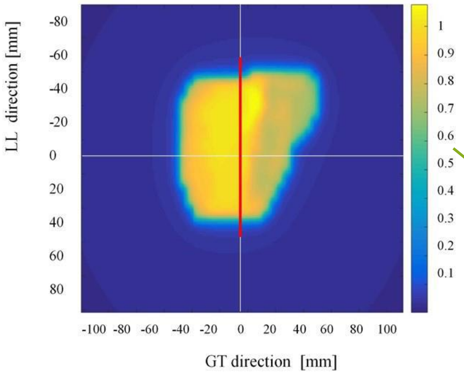


1.7 cm

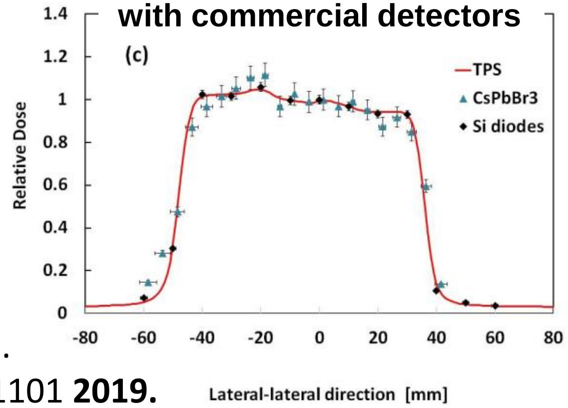
Current signal under repeated X-ray pulses



TPS map of doses



Dose profile comparison with commercial detectors

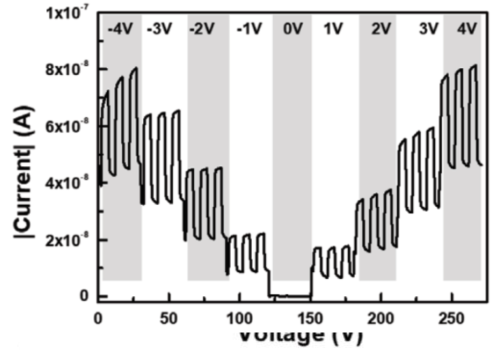


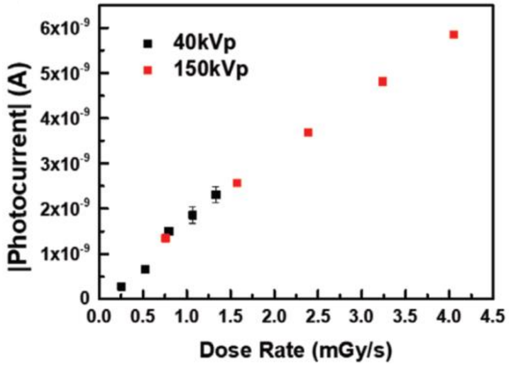
Bruzzi, M. et al., *Front. Phys.* **2021**, 9.
Bruzzi, M. et al., *APL Materials* 7 051101 **2019.**
Bruzzi, M. et al., *Energies* **2020**, 13 (7), 1643.

INFN-BO (TTLab)→ POR-FESR Emilia Romagna

FORTRESS: Flexible, large-area patches for real-time detection of ionizing radiation

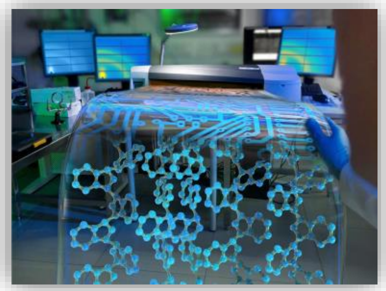
- **Hybrid lead halide perovskite** thin film based **X-ray** detectors on flexible substrates

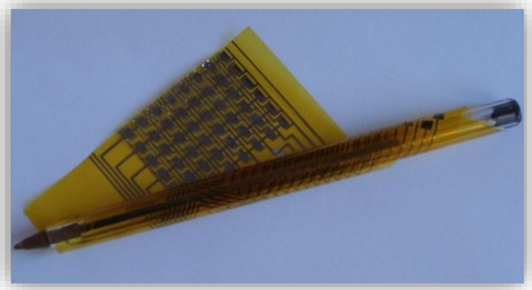




Basiricò, L. et al., *Adv. Mater. Techn.*, **2021**, 6(1), 2000475.
Ciavatti, A. et al. *Adv. Func. Mater.*, **2021**, 31(11), 2009072.
Demchyshyn S., **Basiricò, L.** et al. *Advanced Science*, **2020**, 7(24), 2002586.
Basiricò, L. et al. *Adv. Func. Mat*, **2019**, 29 (34), 1902346.

Why Thin Films?





Easy chemical tailoring

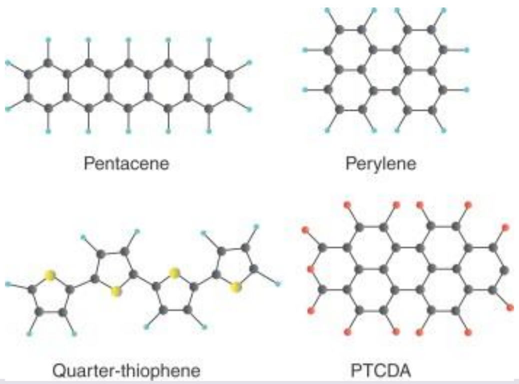
Low-cost large-area printing techniques

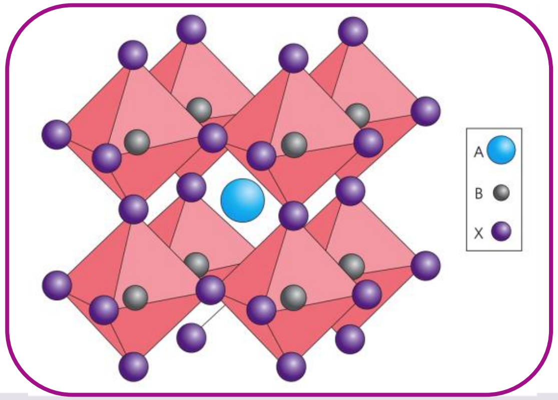
Light-weight and flexible

Low Power consuming

Wearable

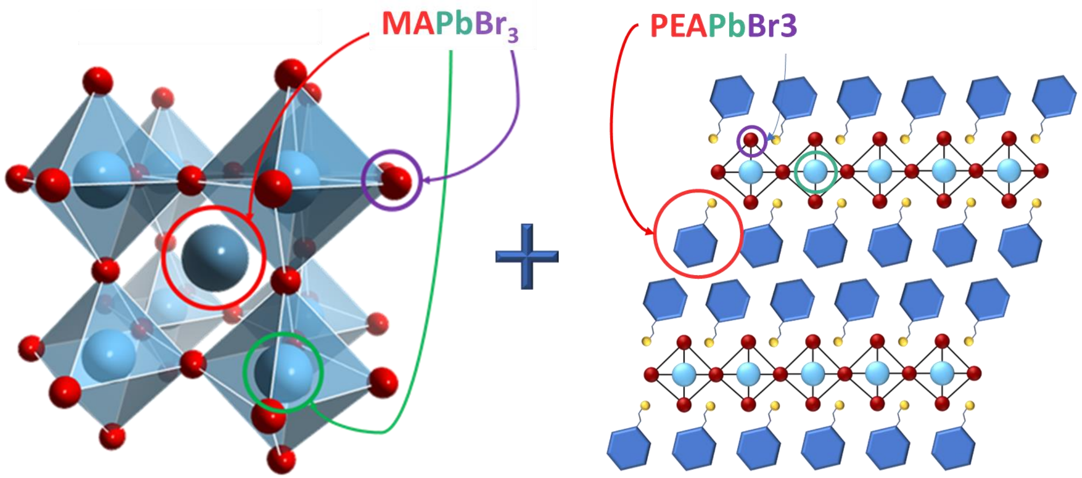
Organic semiconductors



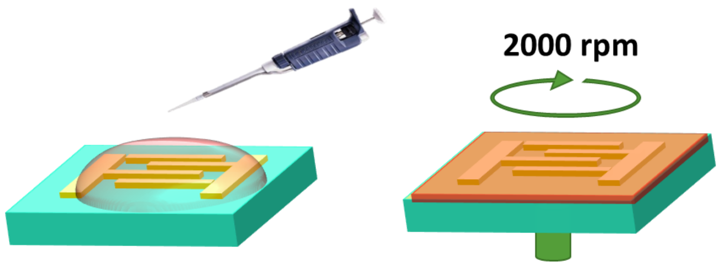


Perovskite

INFN-BO: Mixed 3D/2D Hybrid organic-inorganic halide perovskite: $MAPbBr_3$/ PEA_2PbBr_4

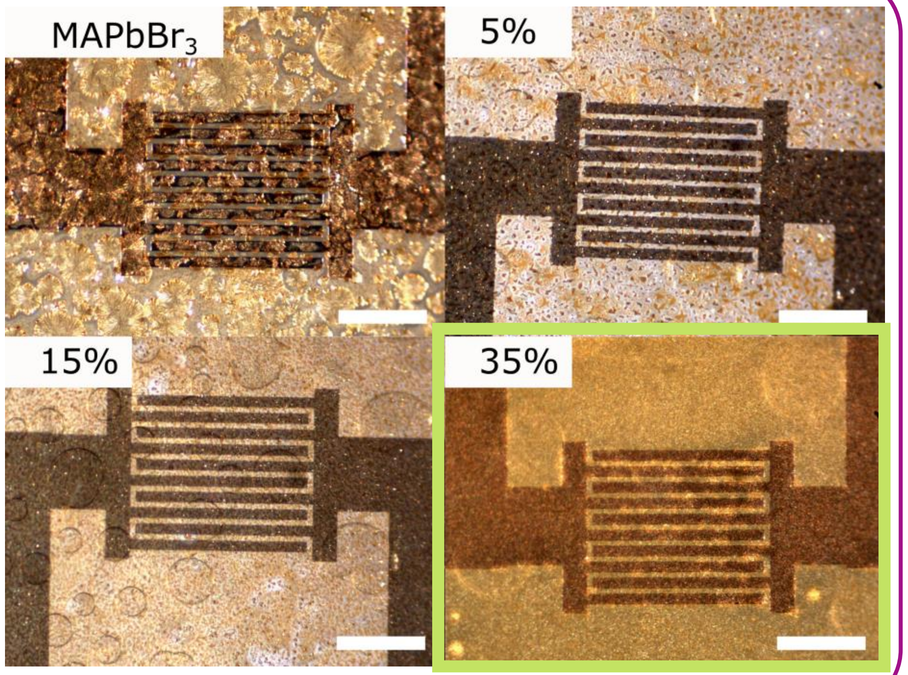


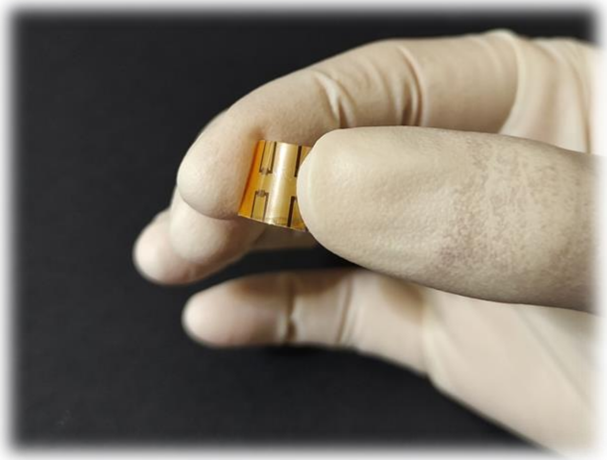
- Higher stability to environment and bias stress
- Higher film coverage and uniformity
- Lower dark current
- Thickness increased to 4 µm



35% $MAPbBr_3$/ PEA_2PbBr_4 on 125 µm PET foil

Recipe Optimization

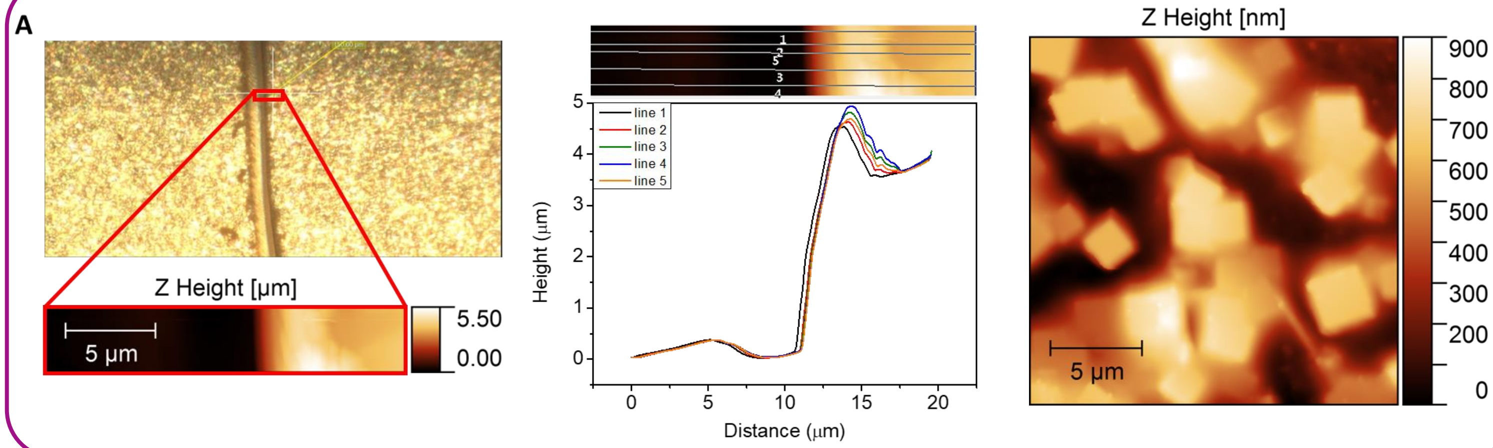




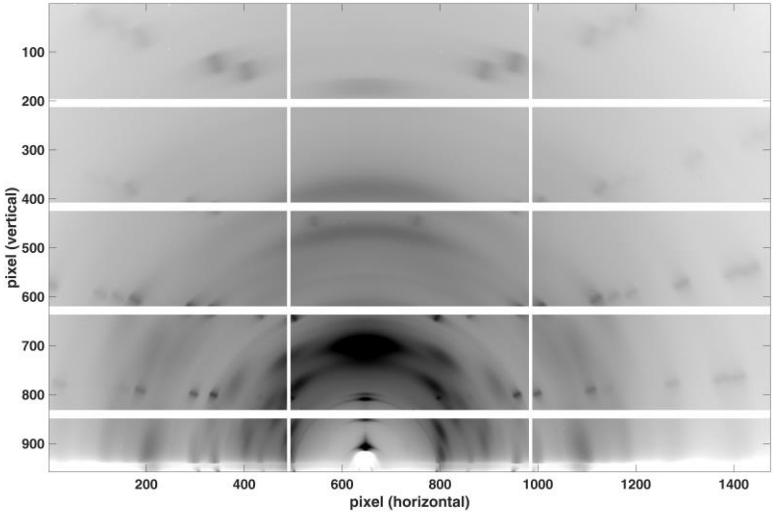
Good coverage of the active area

AFM Characterization

4 µm thick layer

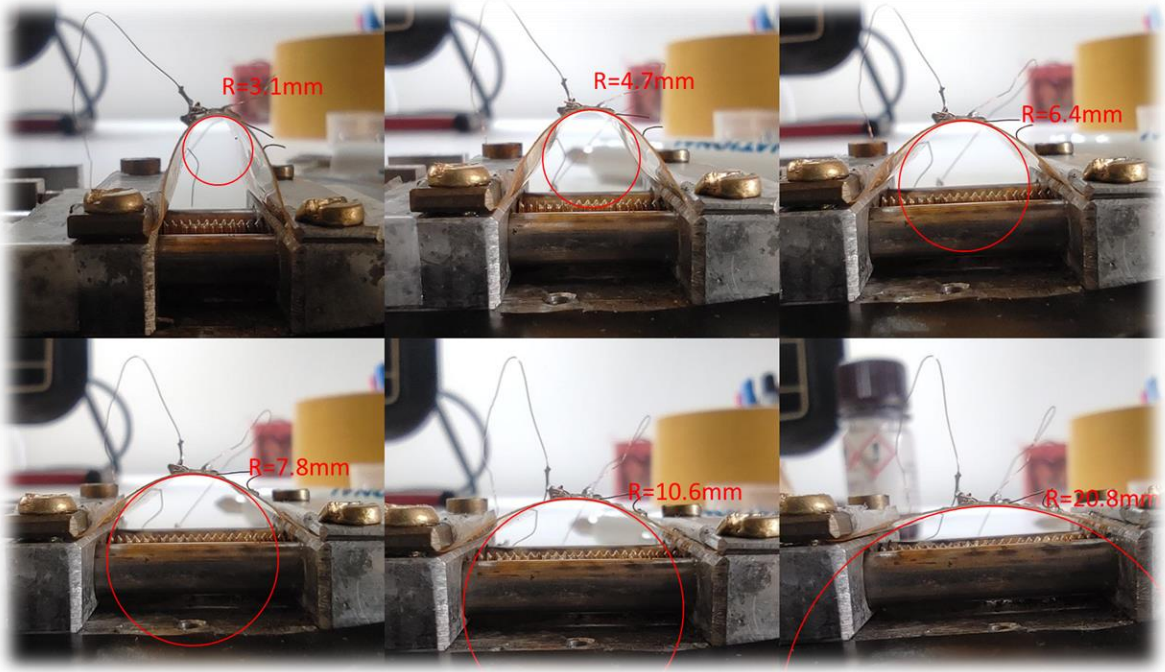


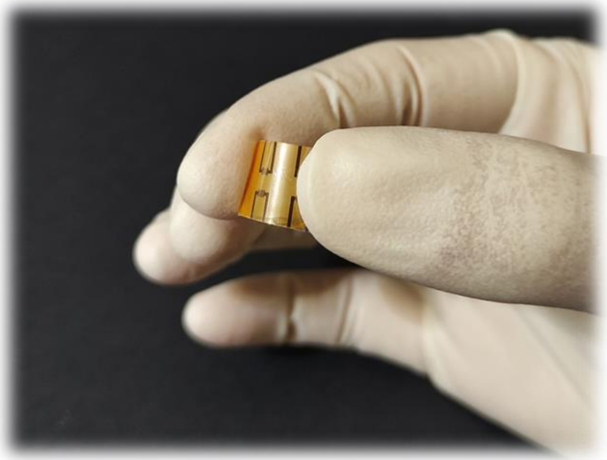
Structural Characterization



G-XRD Characterization@ELETTRA

Crystal structure in accordance with SoA





- **Ohmic behaviour**
- **Flexible device**
- **Stable down to R=3.1mm**
- **Stable over multiple cycles**

Current (A)

$3x10^{-10}$
$2x10^{-10}$
$1x10^{-10}$
0
$-1x10^{-10}$
$-2x10^{-10}$
$-3x10^{-10}$

Flat
20.8mm
10.6mm
7.8mm
6.4mm
4.7mm
3.1mm
Flat

-10 -5 0 5 10

Voltage (V)

Current (A)

$3.0x10^{-10}$
$2.0x10^{-10}$
$1.0x10^{-10}$
0.0
$-1.0x10^{-10}$
$-2.0x10^{-10}$
$-3.0x10^{-10}$
$-4.0x10^{-10}$

Pristine
After 5 cycles
After 10 cycles
After 20 cycles
After 50 cycles

R=4.7mm

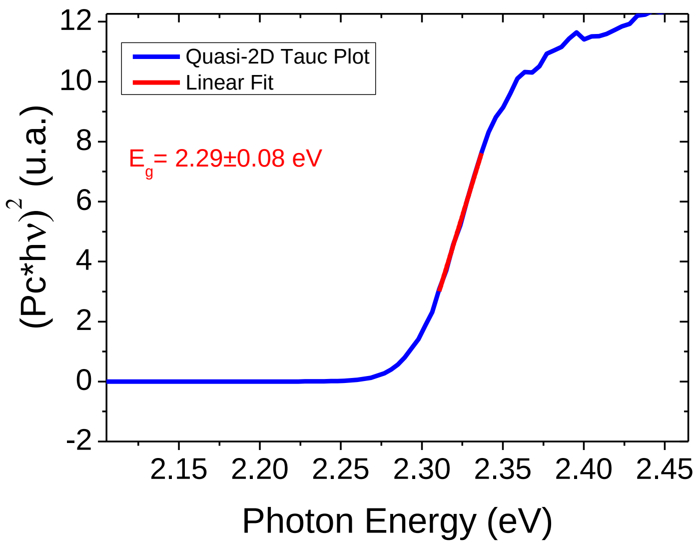
-10 -5 0 5 10

Voltage (V)

Mechanical strain

$$\epsilon_{top} = \frac{t_s + t_d}{2R}$$

Optoelectronic Characterization



Experimental determination of energy gap

E_G =(2.29 ± 0.08) eV

W_{mixed} ≈ 6.38 eV

→ Theoretical max sensitivity: S_{Vmixed} = 533 nC $Gy^{-1}mm^{-3}$

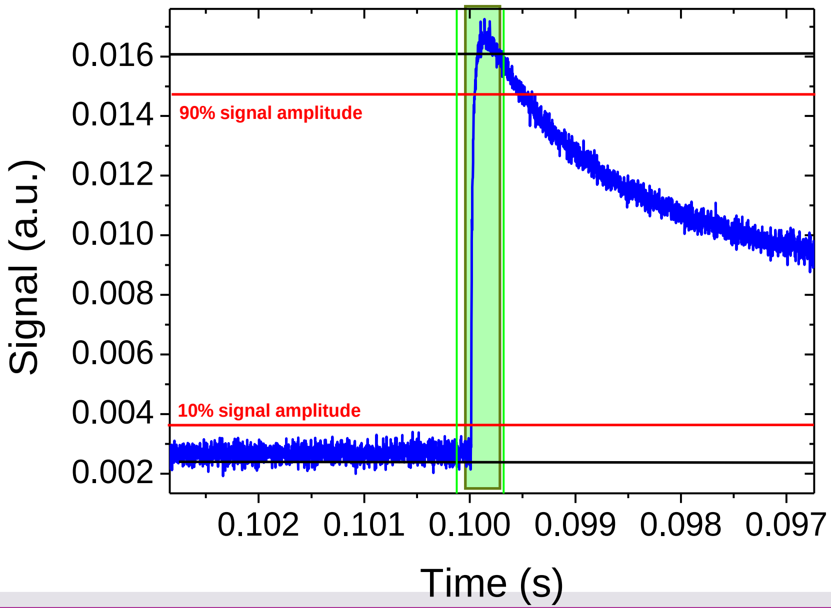
Silicon: 637 nC $Gy^{-1}mm^{-3}$
Diamond: 217 nC $Gy^{-1}mm^{-3}$

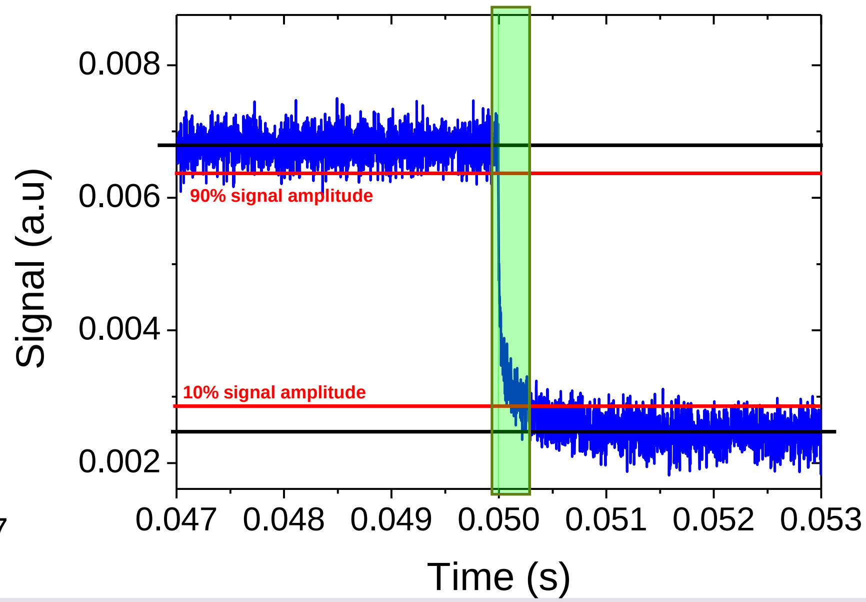
Benchmark materials for on-line dosimeters

Time Response under 375 nm LASER

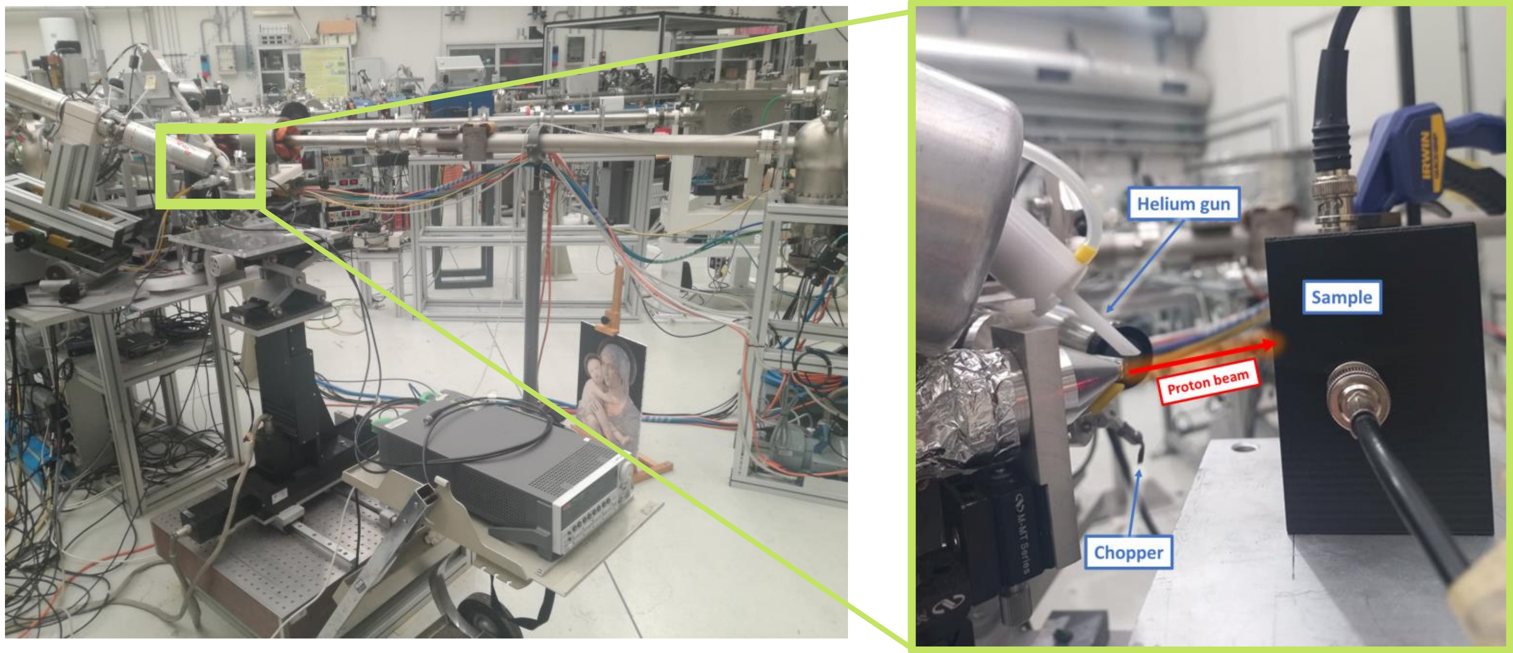
Rise Time τ = 32 μs

Fall Time τ = 275 μs

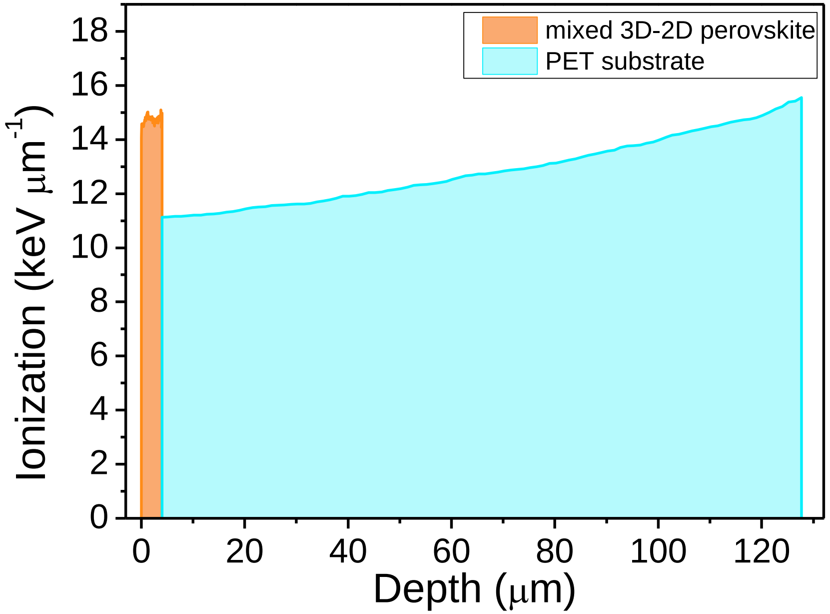




Tests under proton irradiation (5MeV @ LABEC)



Istituto Nazionale di Fisica Nucleare
LABORATORIO DI TECNICHE NUCLEARI
PER L'AMBIENTE E I BENI CULTURALI

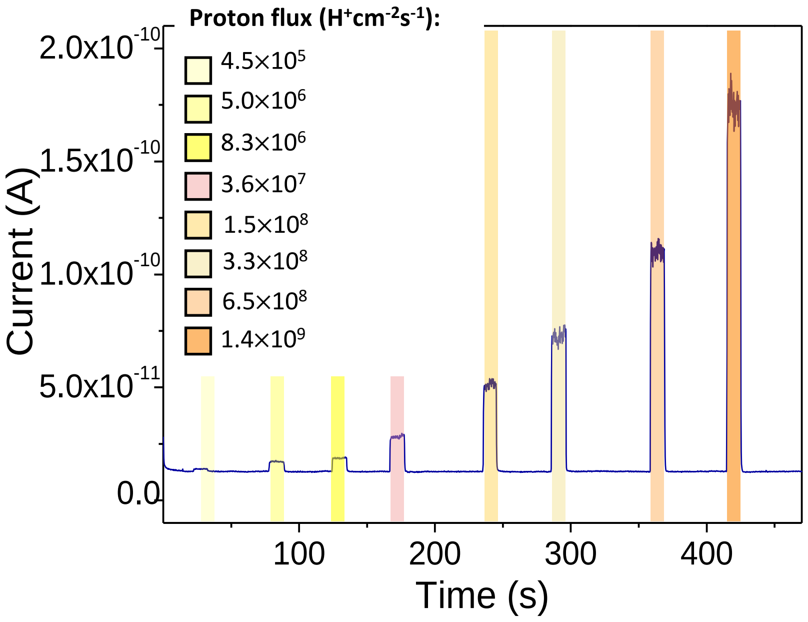


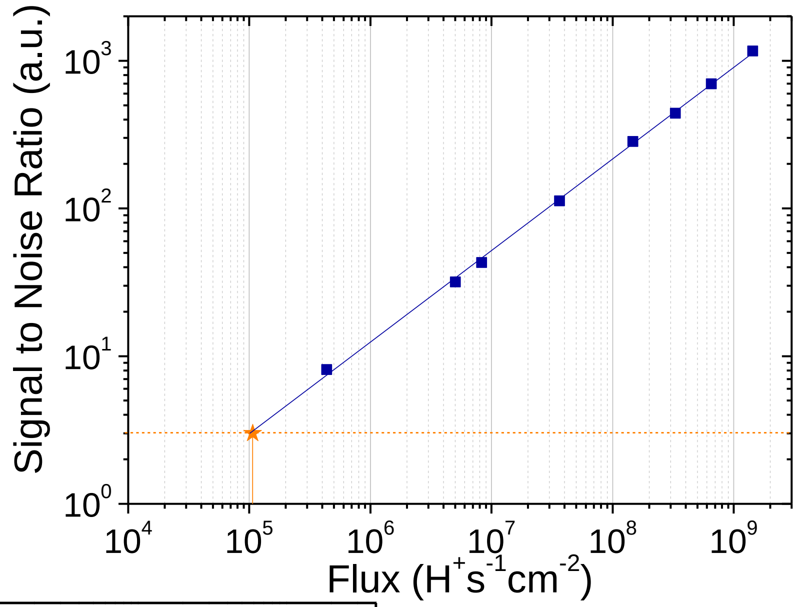
5MeV proton Beam extracted into atmosphere, provided by the 3 MV Tandetron accelerator

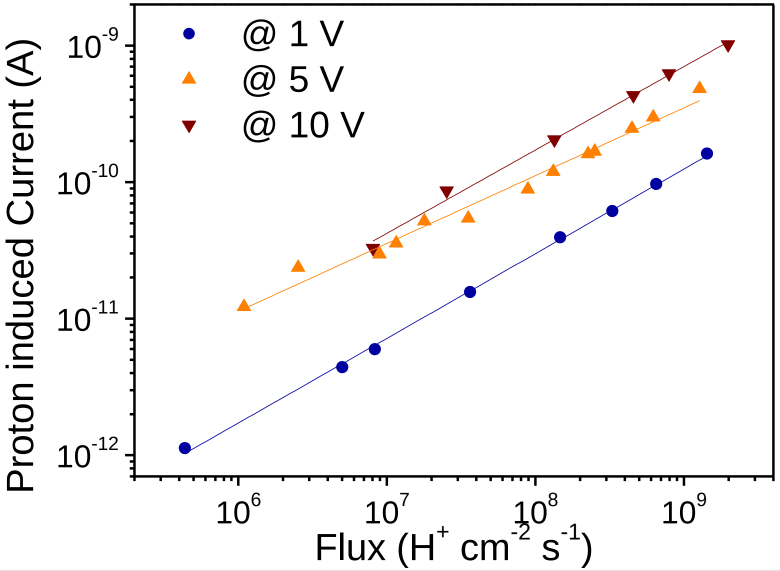
proton flux in the range [10^5 – 10^9] H^+ s^{-1} cm^{-2}
proton beam current: 0.01 pA - 49 pA

SRIM simulation shows 59 keV of enegy released in 4μm perovskite and 1550 keV in the 125μm PET

Tests under proton irradiation (5MeV @ LABEC)





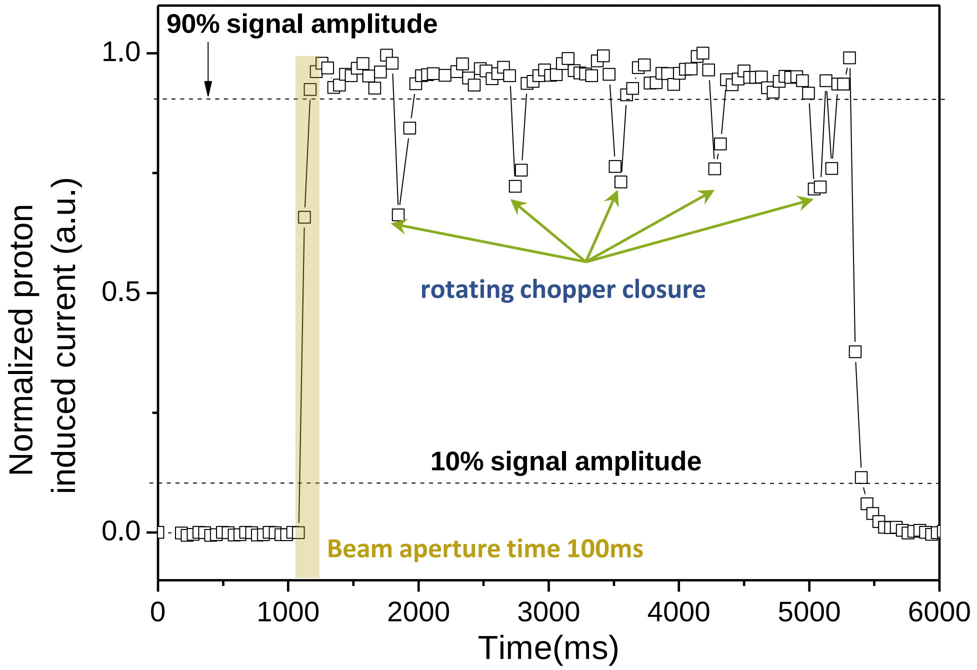


- Real time detection
- Response scales with proton flux
- LoD at 1V as low as **$(1.06 \pm 0.03) \times 10^5$ H$^+$s^{-1}cm^{-2}** corresponding to 729.2 ± 0.2 µGy s^{-1}
- Sensitivity up to (290 ± 40) nC Gy^{-1}mm^{-3}

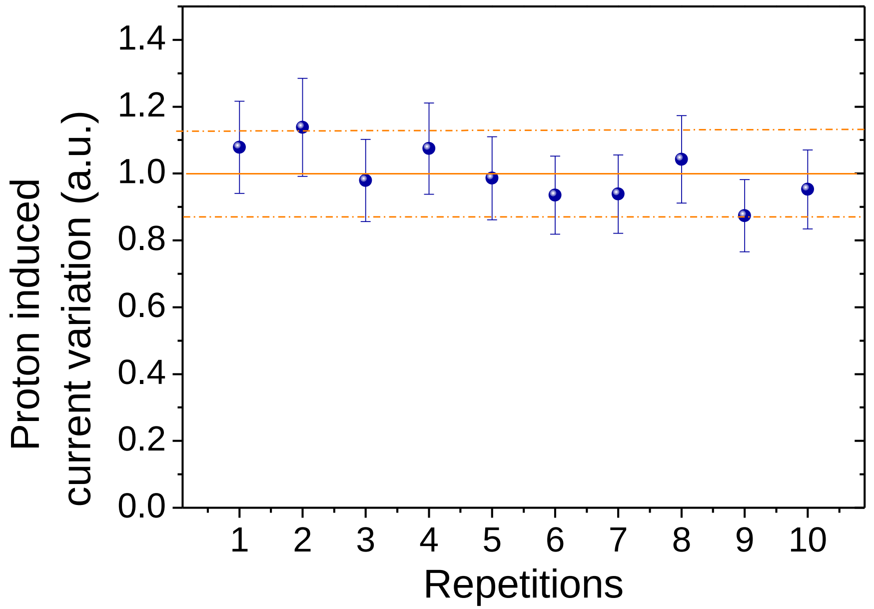
lower than the theoretical value → incomplete collection of the charges produced in the film, possibly due to trapping effects in the device's channel

Stability and rad tolerance

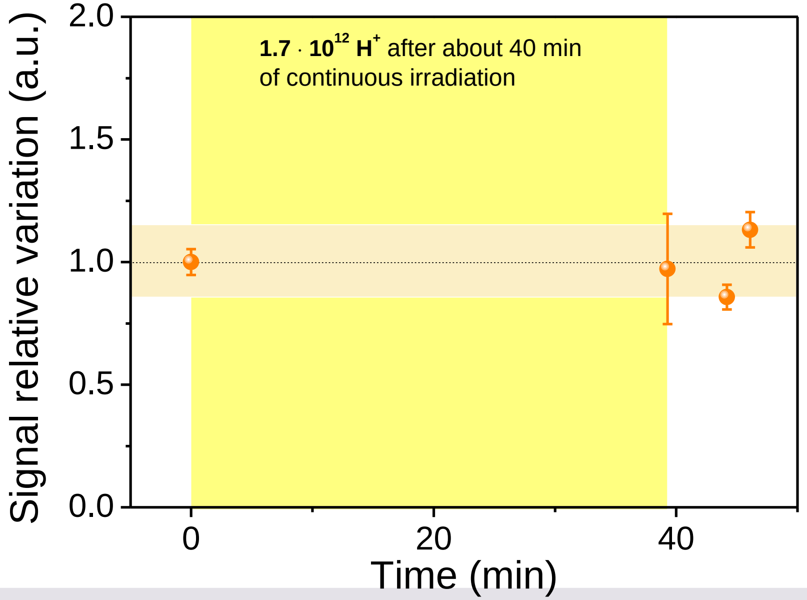
Time response



Basiricò et al. Adv. Sci. 2022, 2204815



- 10 repetitions of 10 s irradiation cycles
- Signal variation within 12% with respect to the mean value

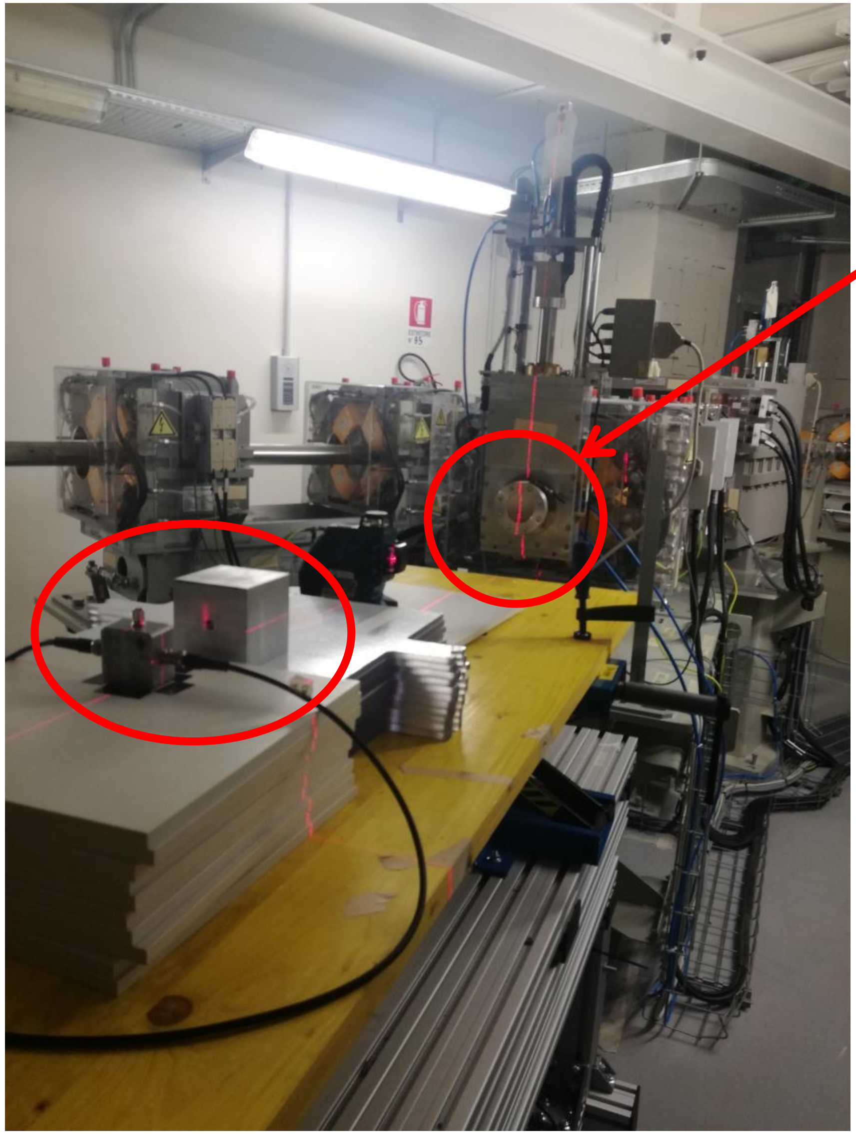


maximum variation of 14% after 40 min irradiation tests, corresponding to a total of 1.7×10^{12} protons impinging on the beam spot area

Tests under proton irradiation (70-228 MeV @ TIFPA)

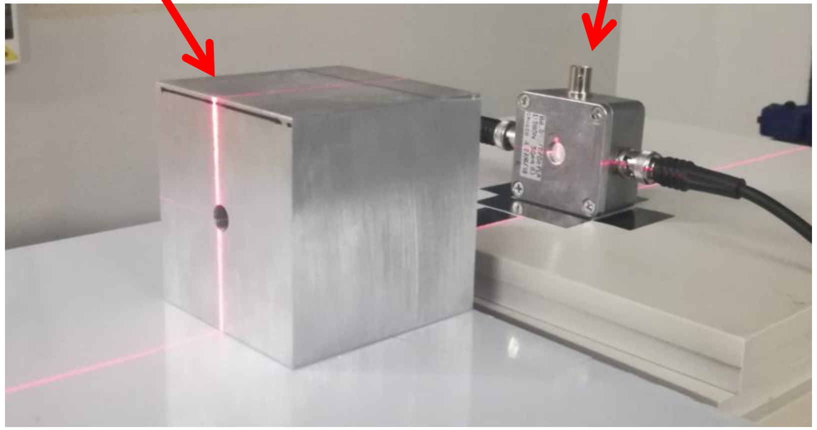
TIFPA
Trento Institute for Fundamental Physics and Applications

PROTON BEAM



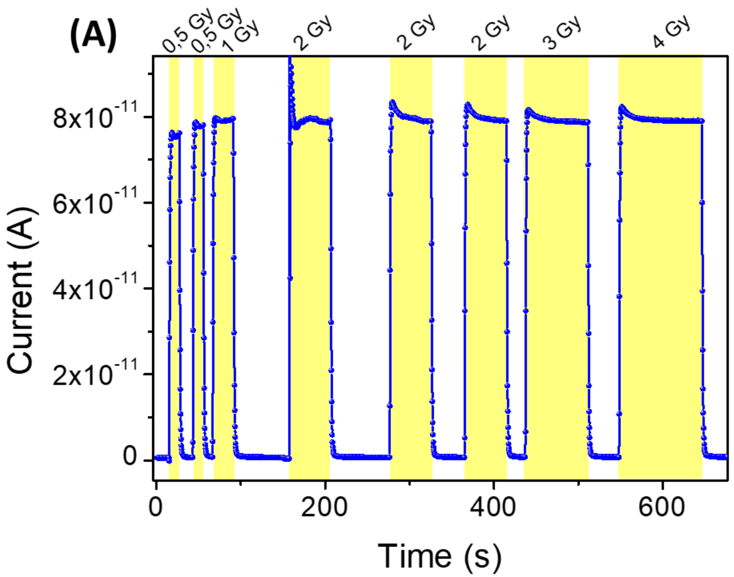
SAMPLE

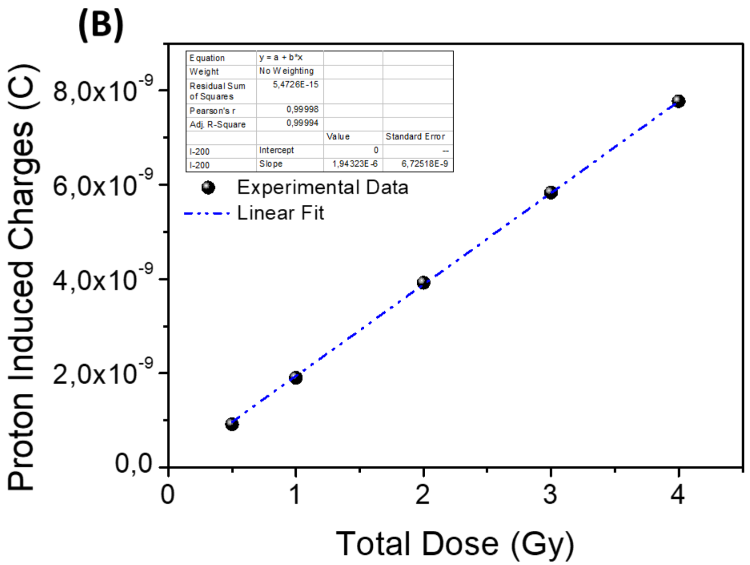
COLLIMATOR



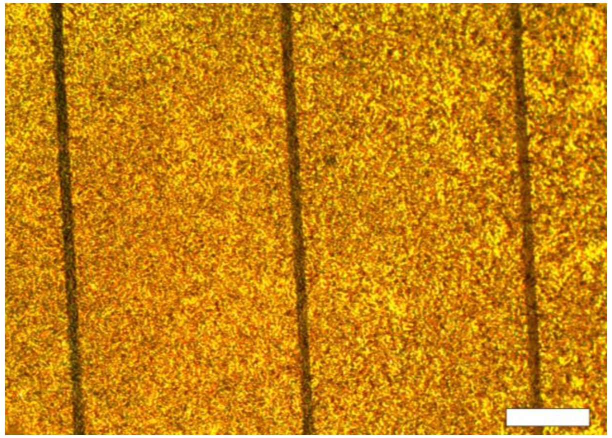
Tests under proton irradiation (70-228 MeV @ TIFPA)

Data analysis still ongoing but… promising preliminary results:





- Sharp real time response to 70 MeV proton beam
- Linearity with dose
- Pure 2D perovskite on Kapton (growth optimization in glovebox). Lower dark current; higher stability; high coverage; thickness up to 8 µm

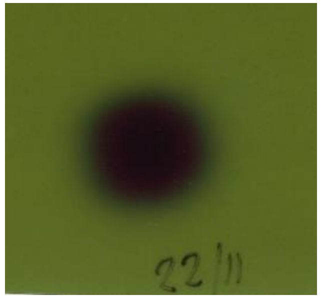


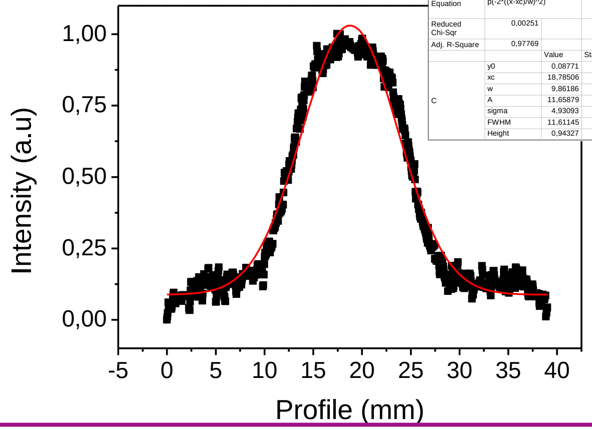
Still under analysis:

- Dose rate linearity
- Radiation hardness up to 2 kGy

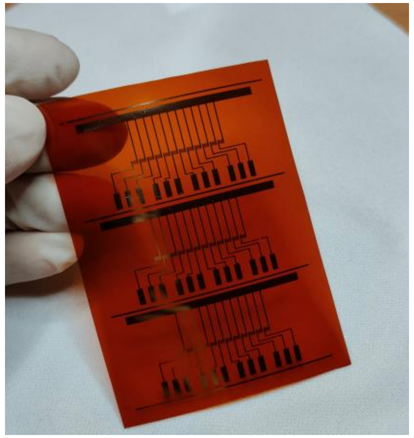
ToDo2023

PoC trasversal beam monitoring





Model	Gauss		
Equation	y=y0 + (A/(w*sqrt(PI/2)))*exp(-2*((x-xc)/w)^2)		
Reduced Chi-Sqr	0,00251		
Adj. R-Square	0,97769		
		Value	Standard Error
C	y0	0,08771	0,0029
	xc	18,78506	0,02605
	w	9,86186	0,06744
	A	11,65879	0,0929
	sigma	4,93093	
	FWHM	11,61145	
	Height	0,94327	

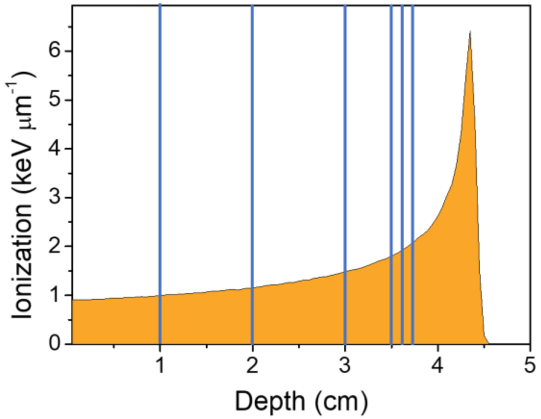


BEAM-TIME @TIFPA REQUESTED July2023-March2024

BEAM-TIME @LABEC SCHEDULED March2023; July2023

BEAM-TIME @ CNAO?

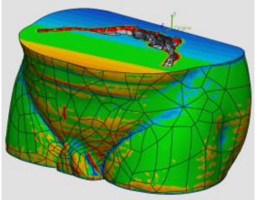
PoC longitudinal dose profile

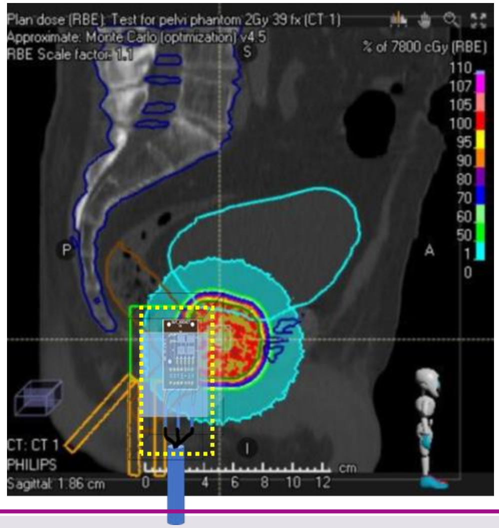


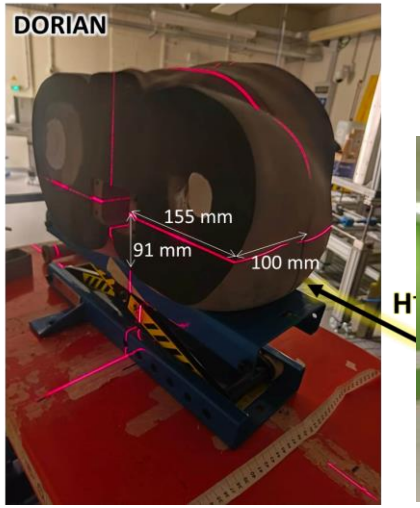
Different thickness of water equivalent absorber slabs

Complete dosimetric characterization

- Dose rate dependence
- Test inside antropomorphic phantom



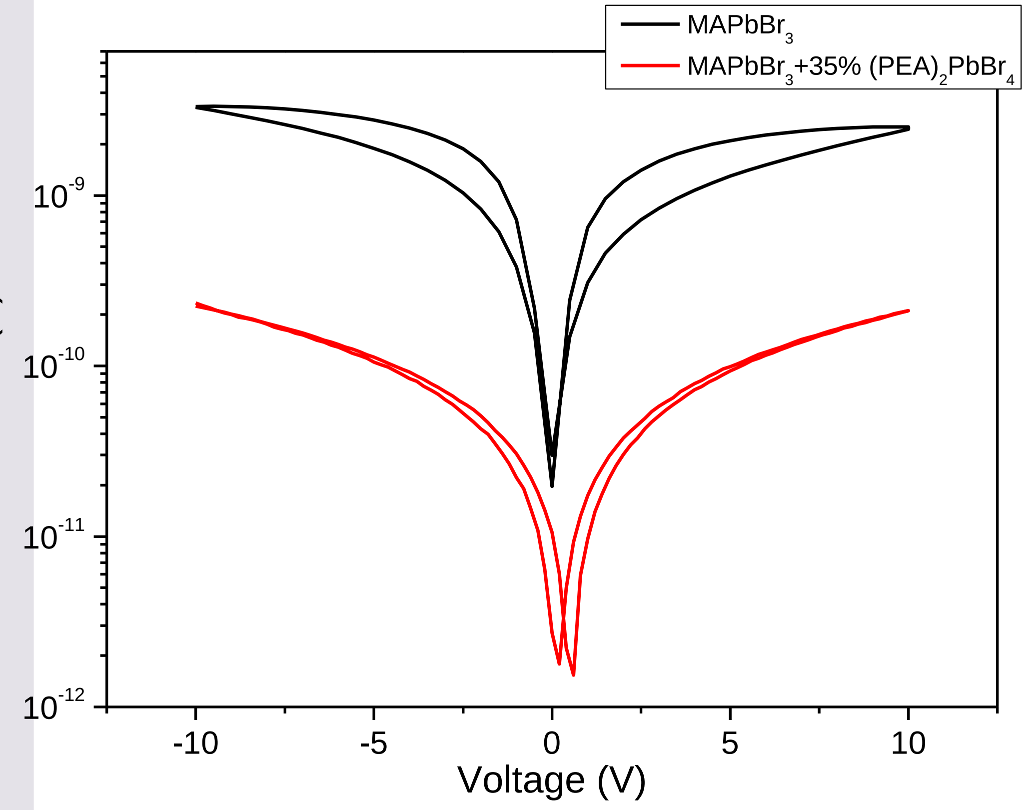




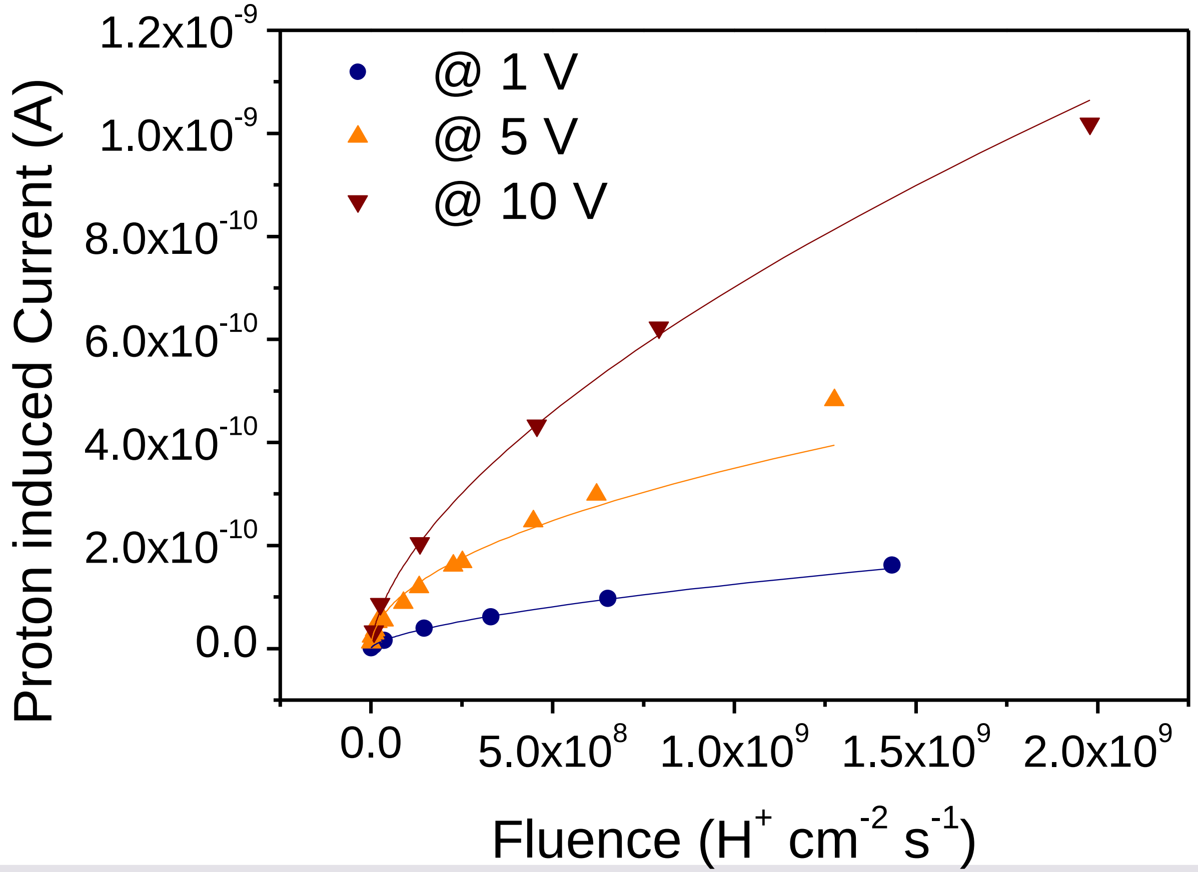
- Test in Gantry?

THANK YOU FOR ATTENTION

BACKUP SLIDES



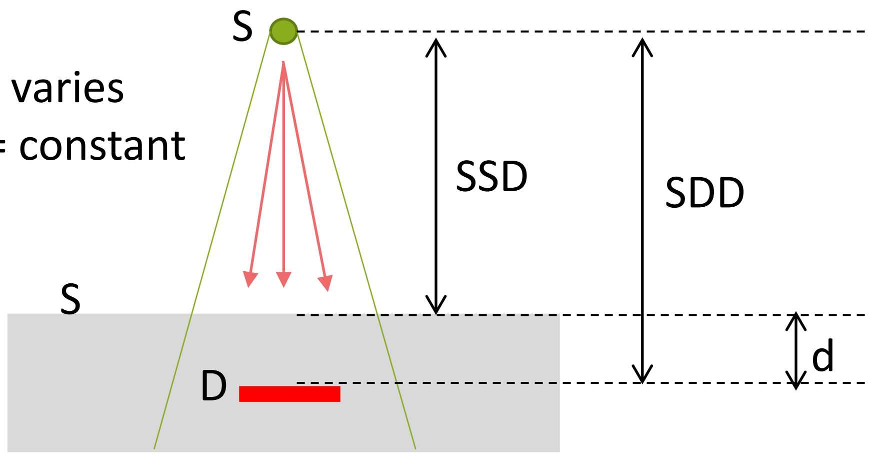
MAPbBr$_3$
MAPbBr$_3$+35% (PEA)$_2$PbBr$_4$
10^{-9}
10^{-10}
10^{-11}
10^{-12}
-10
-5
0
5
10
Voltage (V)



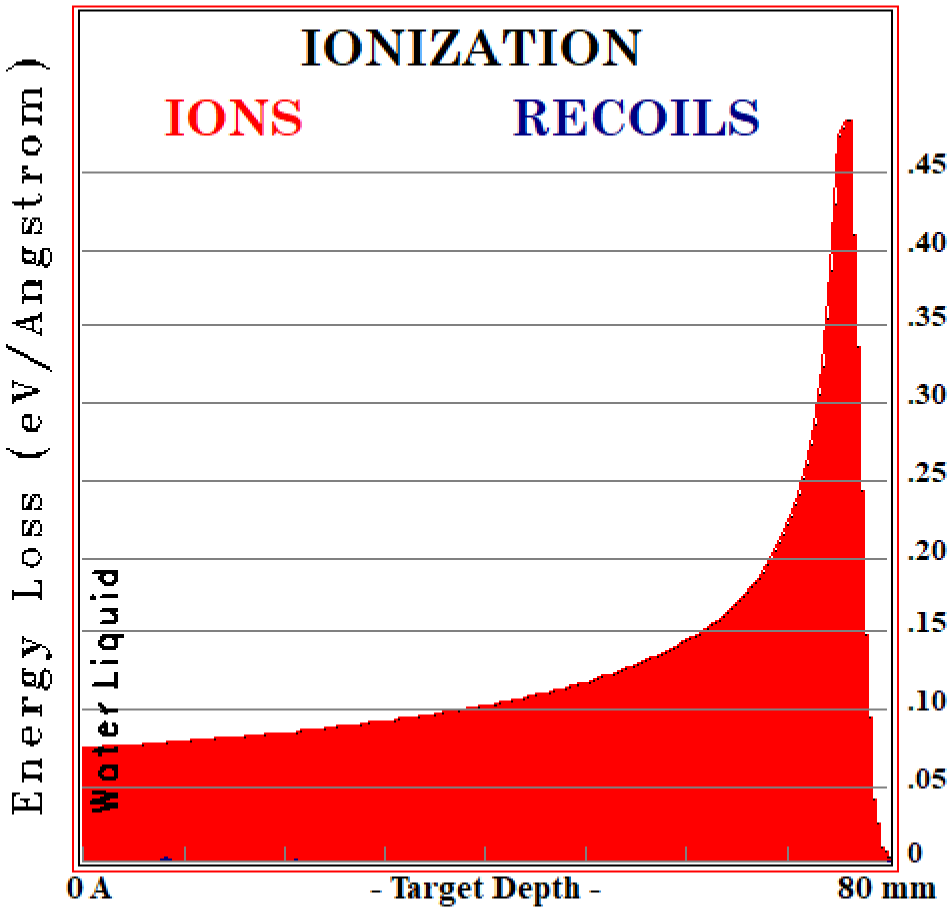
@ 1 V
@ 5 V
@ 10 V
Proton induced Current (A)
$1.2x10^{-9}$
$1.0x10^{-9}$
$8.0x10^{-10}$
$6.0x10^{-10}$
$4.0x10^{-10}$
$2.0x10^{-10}$
0.0
$5.0x10^{8}$
$1.0x10^{9}$
$1.5x10^{9}$
$2.0x10^{9}$
Fluence (H^+ cm^{-2} s^{-1})

1) Esperiemnto Acque Solide – **TPR MEASUREMENT**

SSD = varies
SDD = constant



d max = 8 cm
Protoni @ 100 MeV

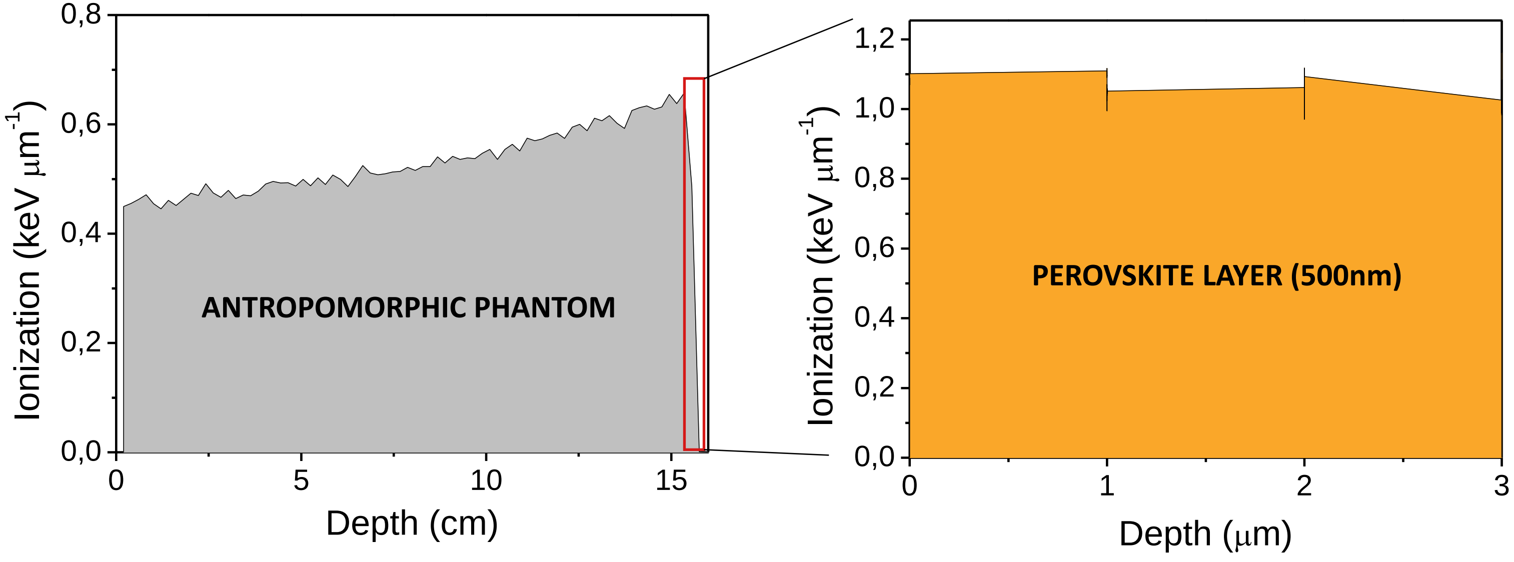


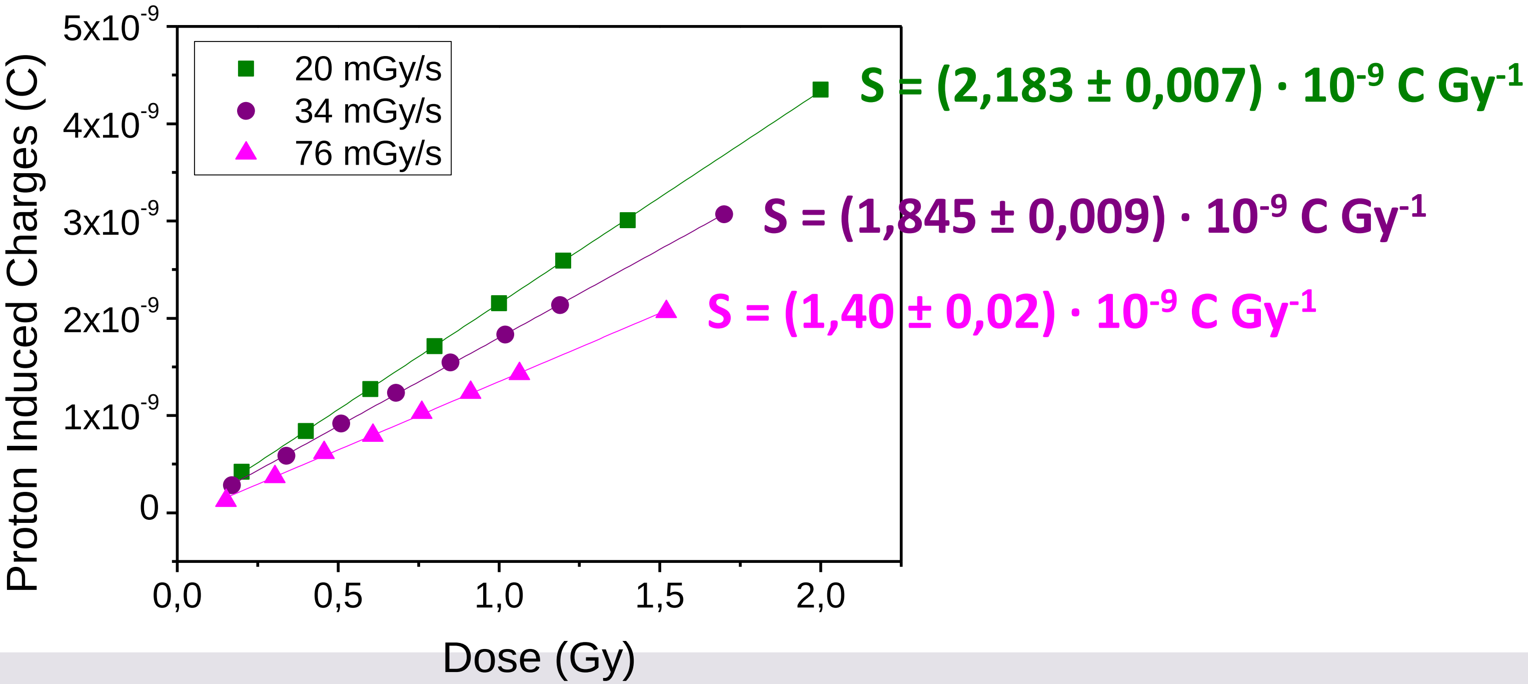
2) RADIATION HARDNESS

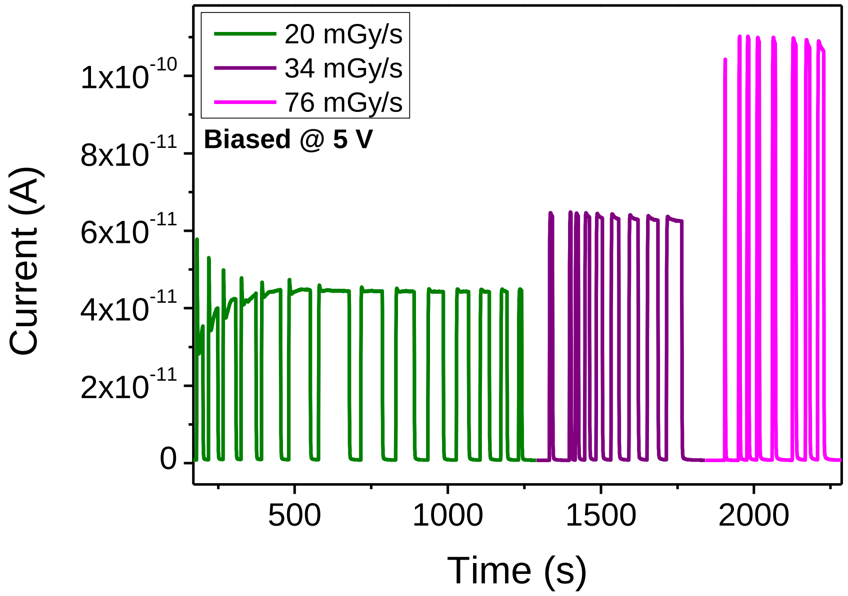
Pre e post irraggiamento
IV real-time
Photocurrent Spectroscopy
AFM

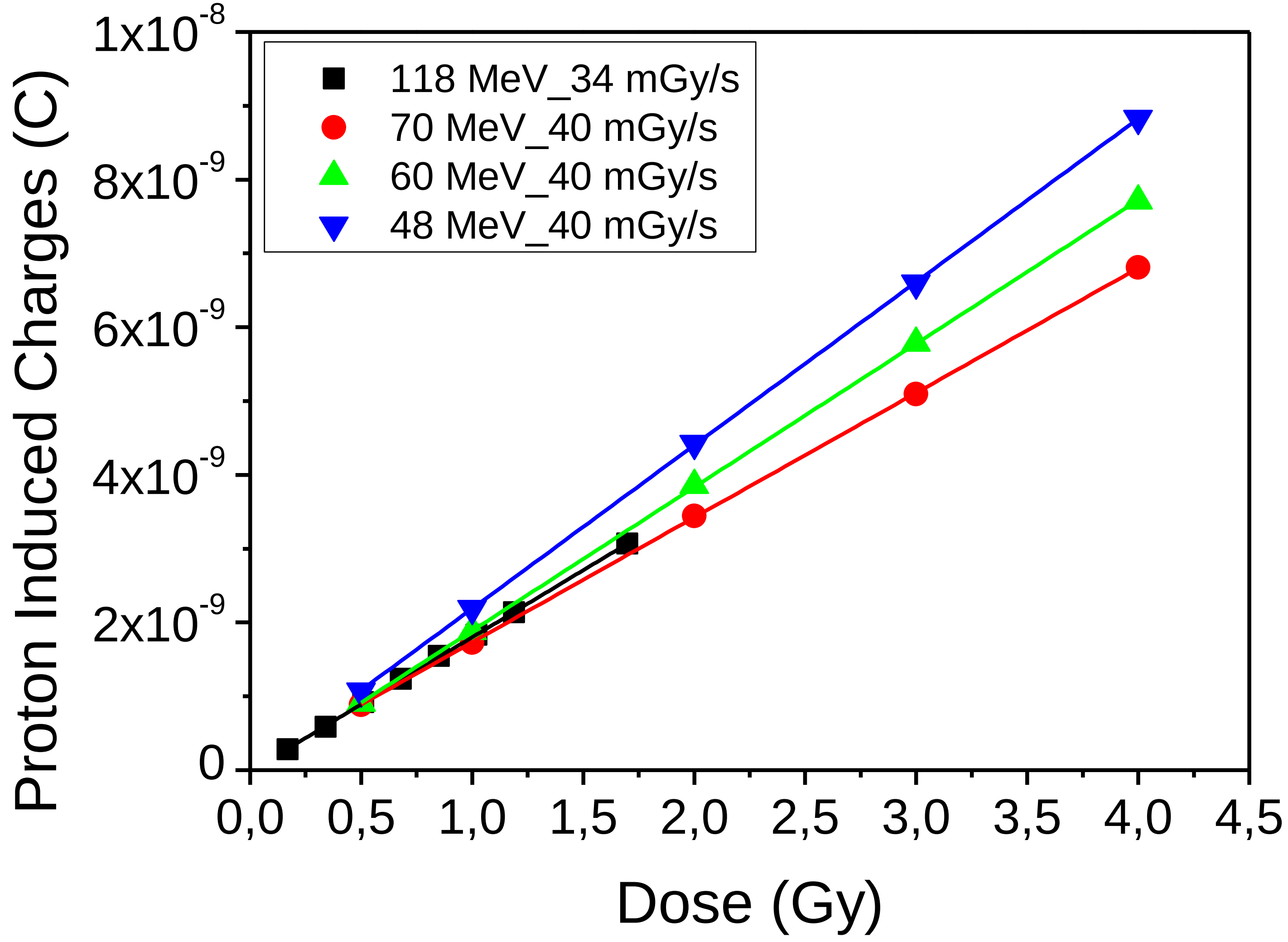
Direct Detection of Protons @ TIFPA by PERO 2D – based detectors

High Energy protons @ TIFPA
LET = 1 keV µm^{-1}
118 MeV protoni incidenti sul sample
201 MeV all'uscita dalla sorgente
FLUXES ([5; 8.5; 19] 10^8 H^+ s^{-1})
Sensitivity= (2,183 ± 0,007) nC Gy^{-1}









Dependence on energy