Design of a new amorphous Silicon-based Flat Panel Detector for Particle Therapy

[1]Khalil El Achi, [1]Eduardo Cortina Gil,
[2]Alexis Warnier, [2]Victor De Beco, [2]Severine Rossomme
[1]Université Catholique de Louvain, Louvain-la-Neuve, Belgium
[2]IBA Dosimetry, Louvain-la-Neuve, Belgium

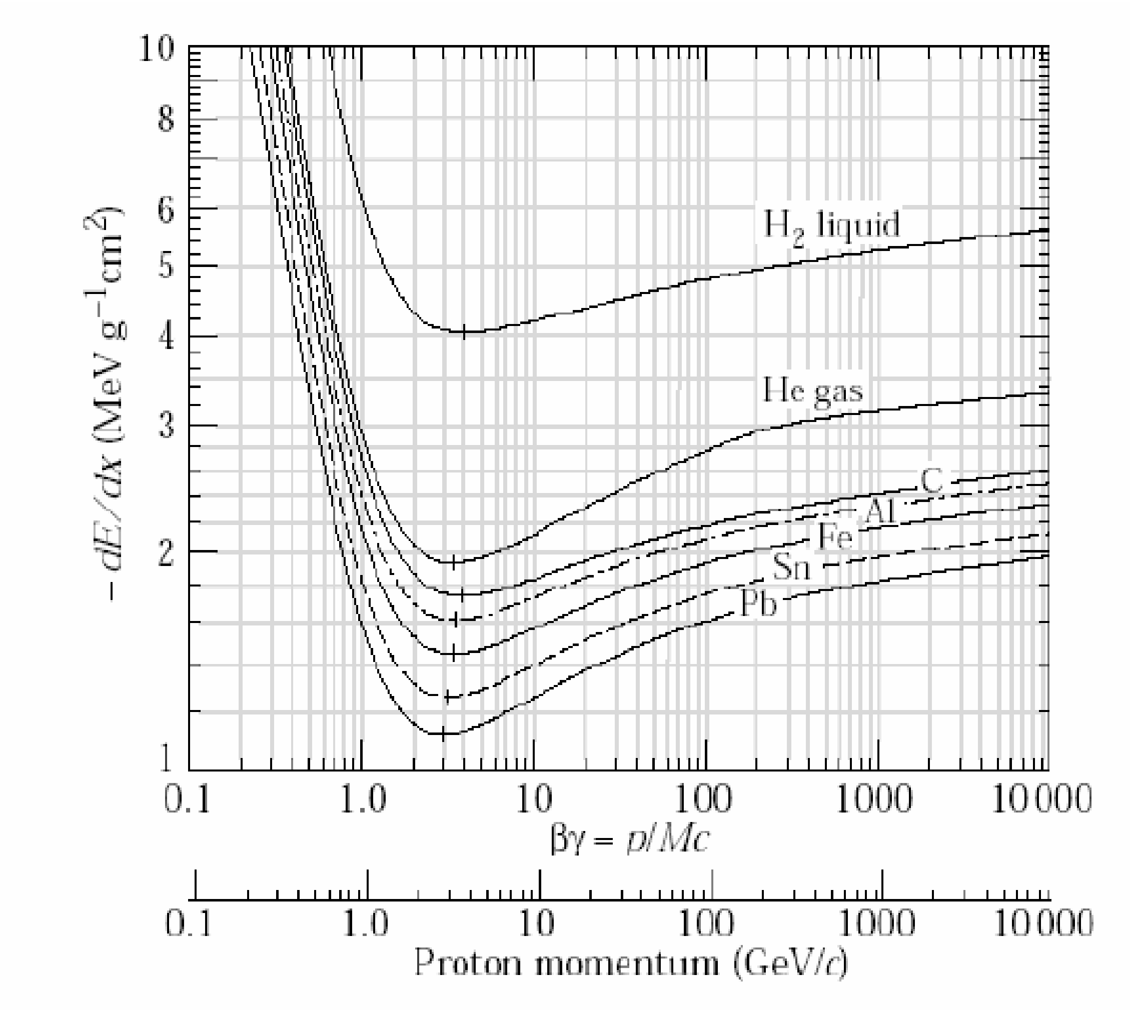
UCLouvain

Proton Stopping Power

- The energy loss of different particles is characterized by the Bethe-Bloch equation,

$$-\frac{dE}{dx} = K \cdot \frac{z^2}{\beta^2} \cdot Z \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2 \gamma^2}{I}\right) - \beta^2\right]$$

- The energy loss depends on the initial energy of the particle beam and the density of the medium.
- Proton's stopping power increases as the particle slows down and maximizes at the end of the trajectory.
- This special behavior is exploited to treat chronic cancers and tumors that are difficult to treat with surgical and pharmaceutical procedures [1].

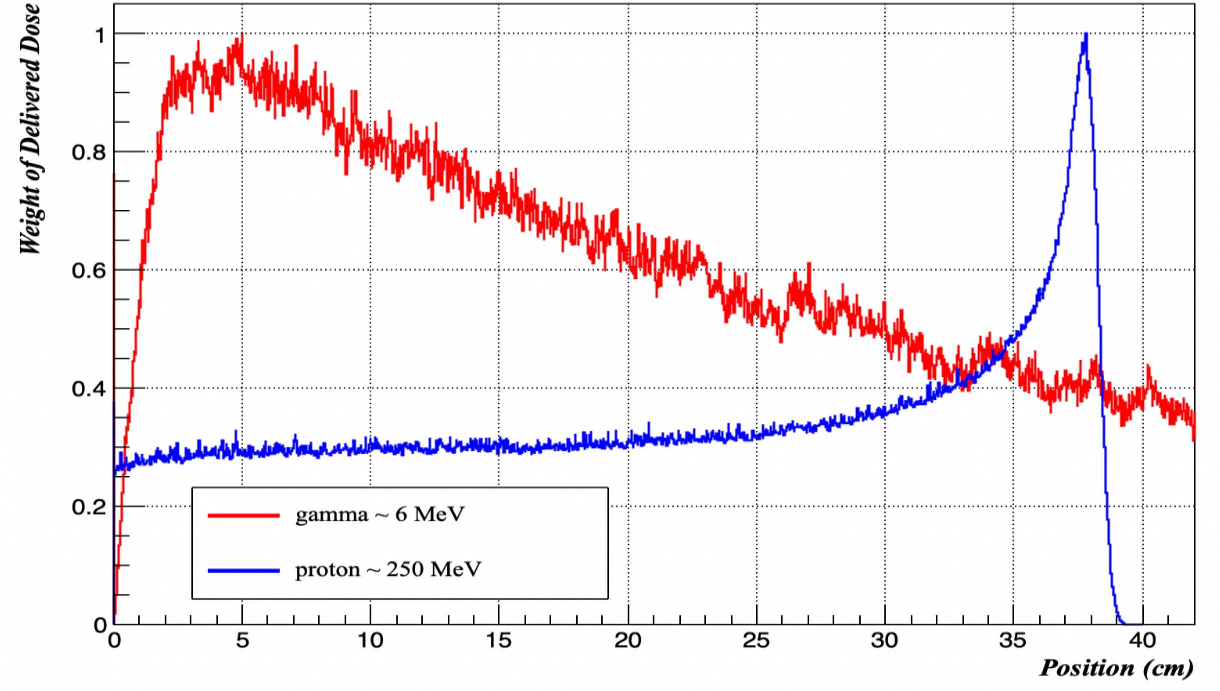


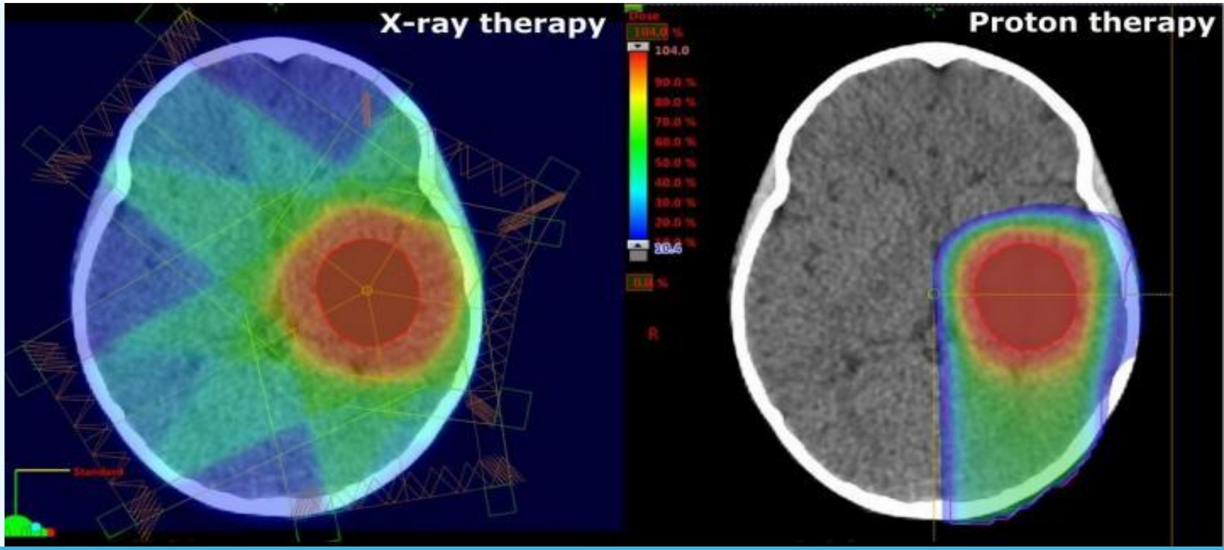
[1] Durante, M., Orecchia, R., & Loeffler, J. S. (2017). Charged-particle therapy in cancer: clinical uses and future perspectives. Nature Reviews Clinical Oncology, 14(8), 483-495.

Proton Therapy (PT) and Conventional Radiotherapy (RT)

- Proton therapy:
  - ❖ Utilizing highly accelerated protons of range 60 – 250 MeV
  - ❖ Particles penetrate the tissue and deposit the lethal dose to a small region
  - ❖ Preserving healthy cells located around the tumor

- Conventional Radiotherapy
  - ❖ Ɣ-rays of energy range 6 – 25 MeV
  - ❖ Most common form of radiation treatment
  - ❖ Dose delivered around the tumor
  - ❖ Significant non-lethal dose delivered all around the tumor [2]





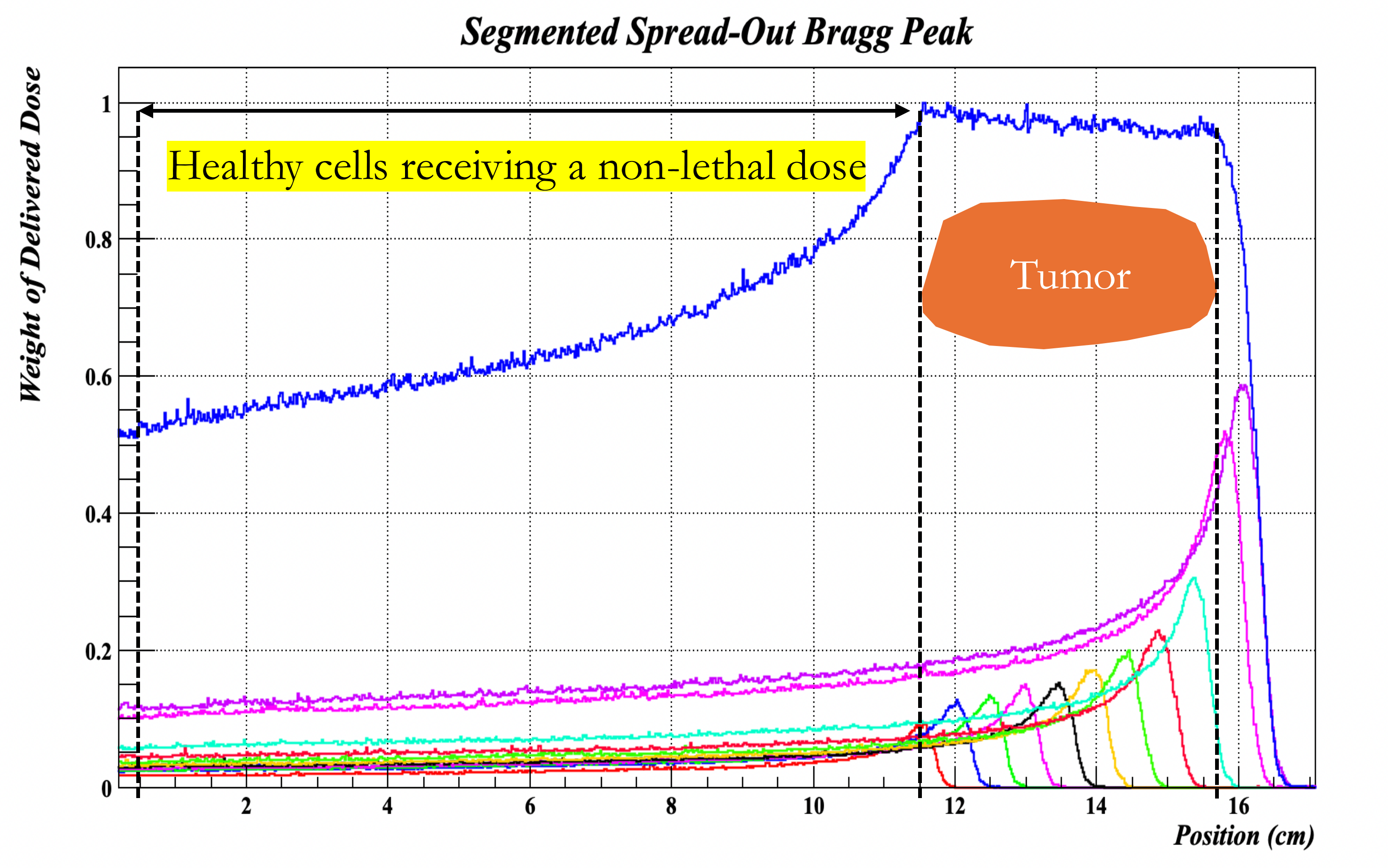
[2] E. C. Halperin, "Particle therapy and treatment of cancer," The lancet oncology, vol. 7, no. 8, pp. 676–685, 2006.

Spread Out Bragg Peak (SOBP)

- ❖ By superpositioning the different segmented Bragg peaks concerning energy and dose, a consistent dose can be delivered to the tumor region.
- ❖ By setting the minimum and maximum energy needed, depending on the penetration depth
- ❖ Where the range of protons in water follows the close power-law relationship:

$$R_{proton} = \alpha E^{P_0}$$

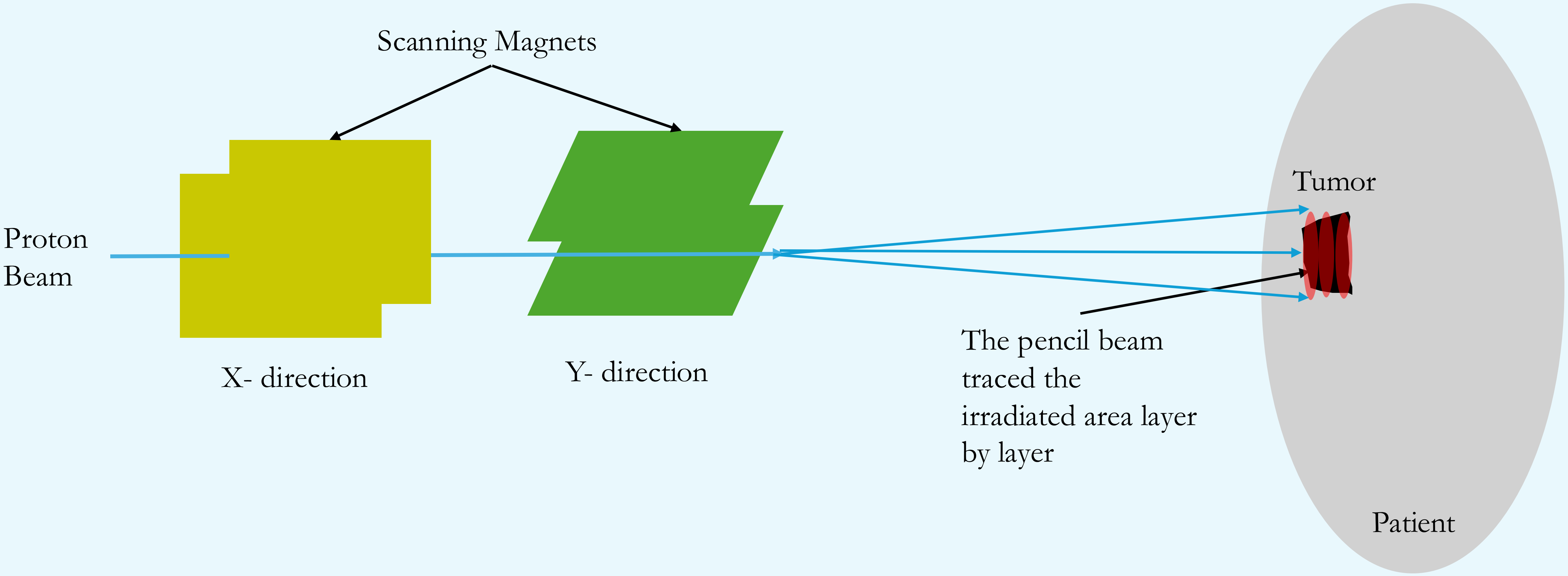
Where R is the range in water, E is the energy of the proton beam, $\alpha = 0.0022$, and $P_0 = 1.77$ [3].



[3] Jette, D., & Chen, W. (2011). Creating a spread-out Bragg peak in proton beams. *Physics in Medicine & Biology*, *56*(11), N131.

Proton therapy delivery techniques – Pencil Beam Scanning (PBS)

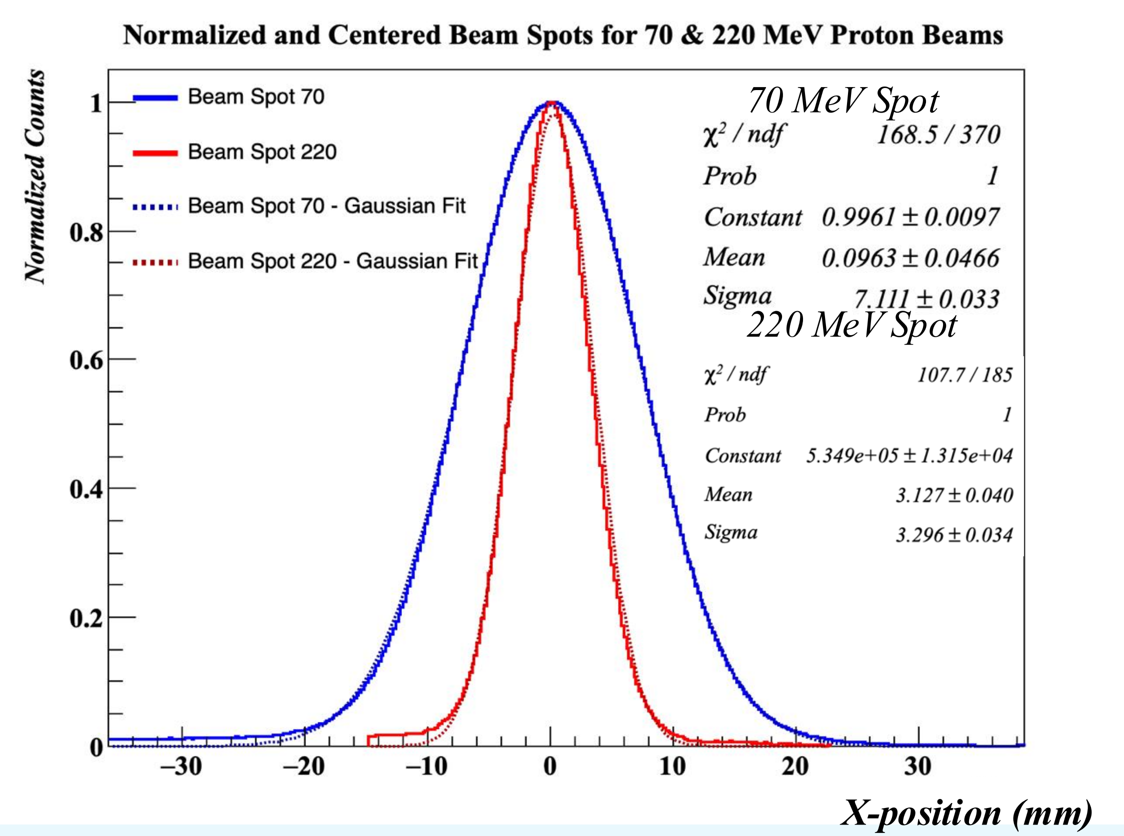
- The modern proton therapy delivery technique, where the proton beam is magnified and steered by a set of magnets.
- Has the capacity for Ultra-High-Dose Rate (UHDR) proton FLASH therapy [4]



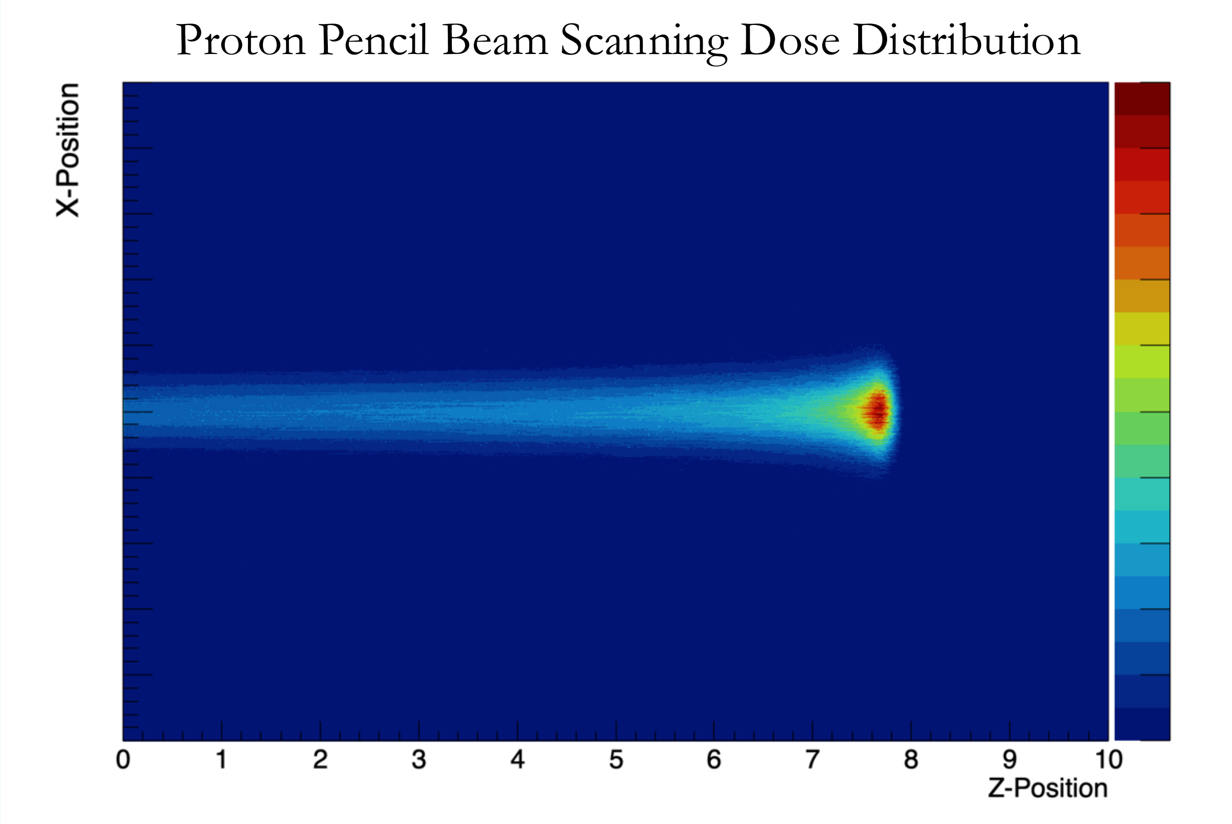
[4] B. Lin, D. Huang, F. Gao, et al., "Mechanisms of flash effect," Frontiers in Oncology, vol. 12, p. 995 612, 2022.

Proton therapy delivery techniques – Pencil Beam Scanning (PBS)

- The beam delivers the dose to a magnified spot depending on the energy of the beam
- The beam spot has a Gaussian profile with:
  - $\sigma_{70} = 7.11\ mm$
  - $\sigma_{220} = 3.3\ mm$

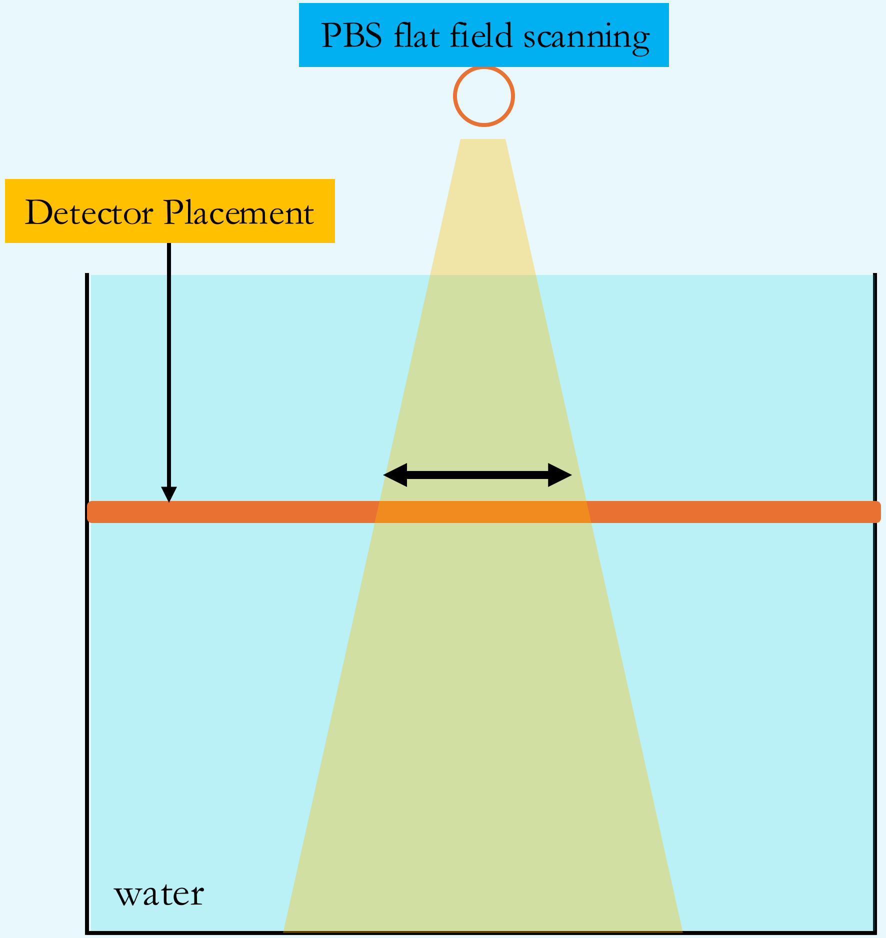


*acquired by IBA Sphinx Compact Detector



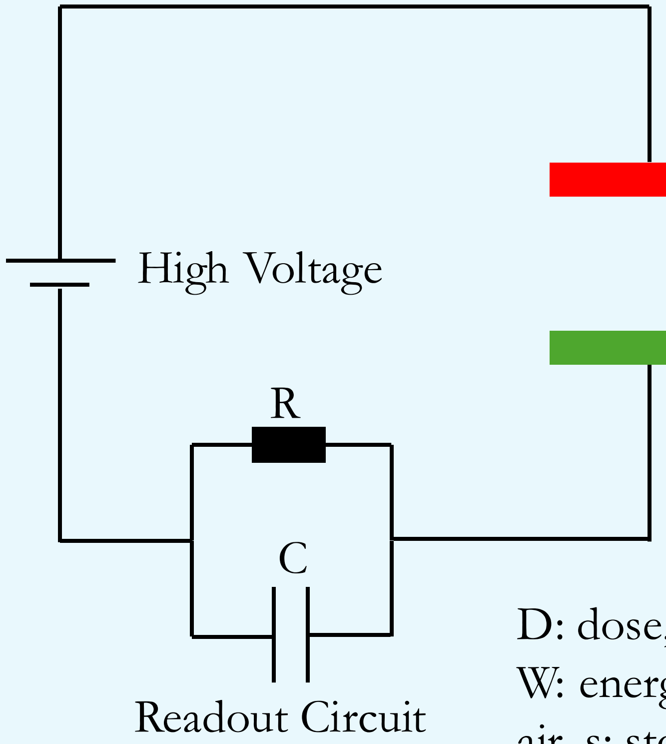
*Simulated with Geant4

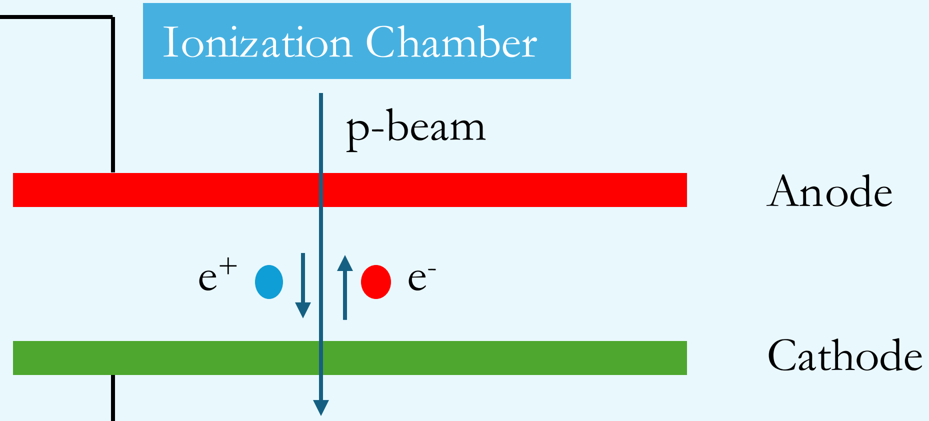
- To accurately deliver the dose, quality assurance practices have to be done
- Medical Dosimetry:
  - Irradiating a particle detector with the treatment plan, to verify the delivered dose



Patient-Specific Quality Assurance (PSQA) - Ionization Chambers

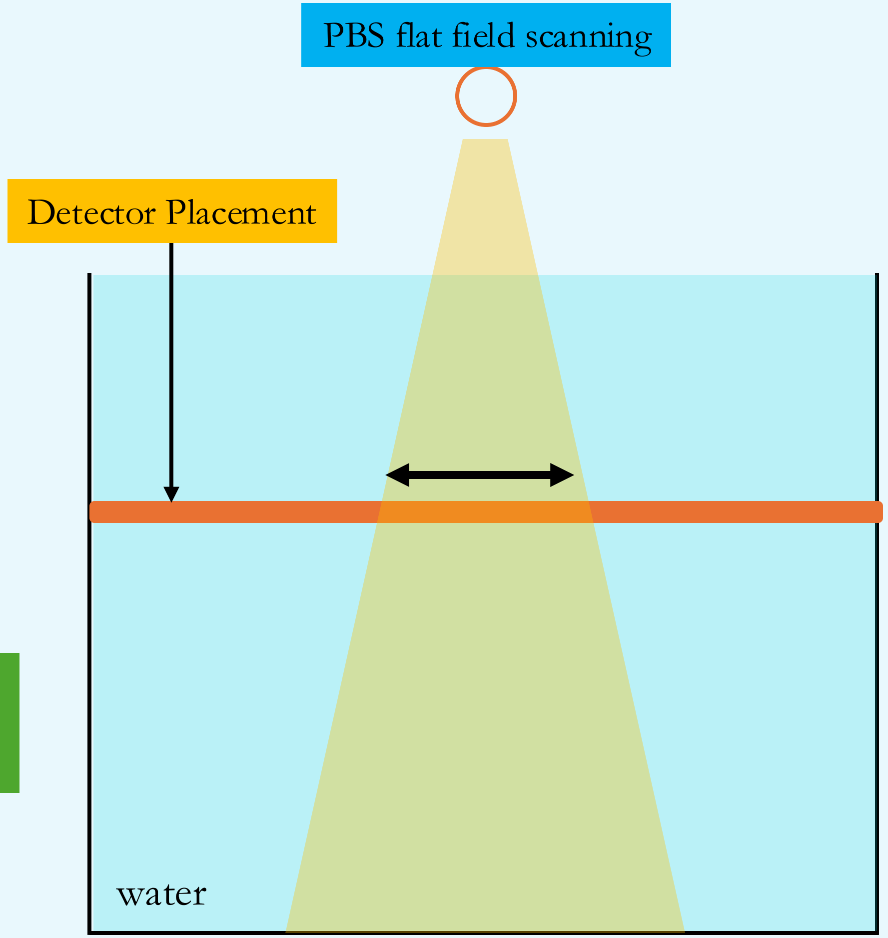
- To accurately deliver the dose, quality assurance practices have to be done
- Medical Dosimetry:
  - Irradiating a particle detector with the treatment plan, to verify the delivered dose





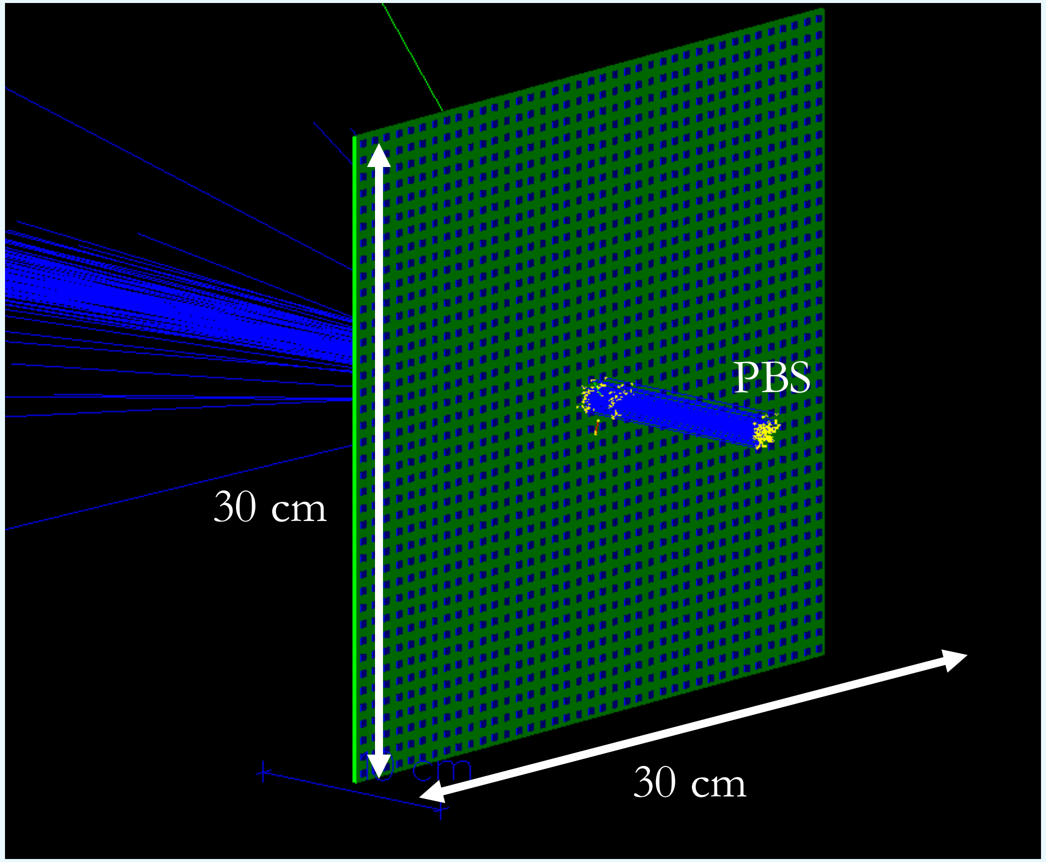
$$D_{air} = \frac{E}{m} = \frac{Q\,W}{\rho\,V} \rightarrow D_{water} = D_{air}\frac{s_w}{s_{air}}$$

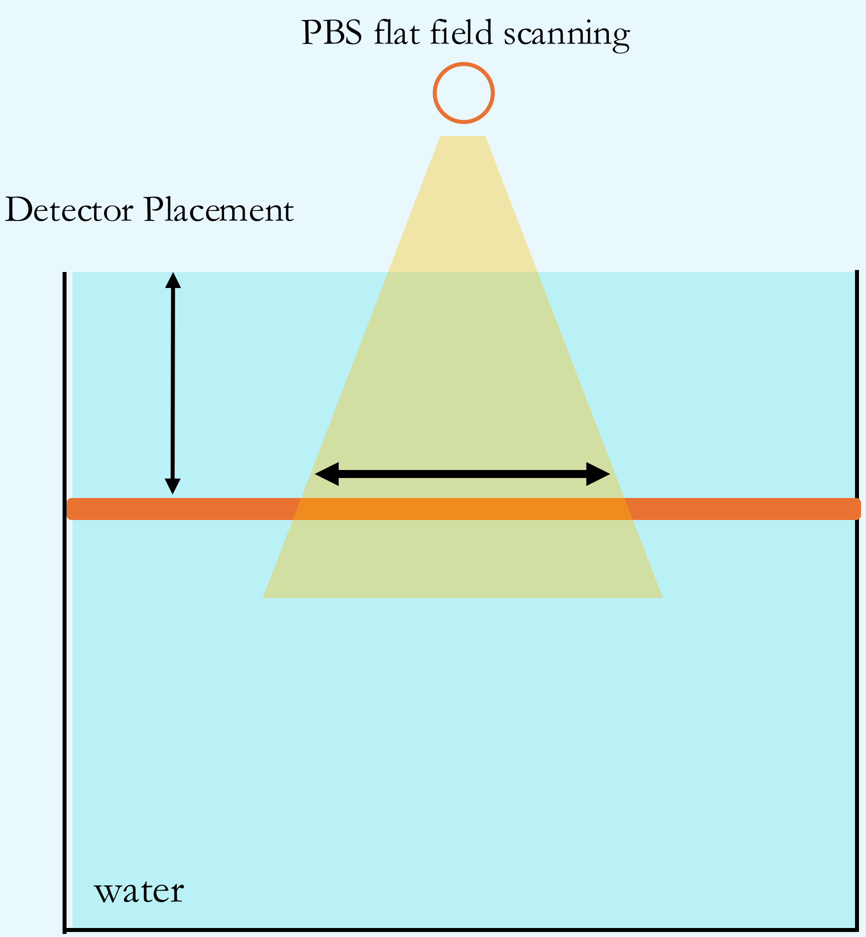
D: dose, E: energy, m: mass, Q: charge in detector, W: energy needed to create one electron/ion pair in air, s: stopping power



- ❖ To accurately deliver the dose, quality assurance practices have to be done
- ❖ Medical Dosimetry:
  - ❖ Irradiating a particle detector with the treatment plan, to verify the delivered dose

Flat-panel detectors, made of segmented air cylinders, provide both dosimetry and dose map construction. But with a limited resolution of ~ 6 mm





Semiconductor-based Detectors

Semiconductor detectors are characterized by:
- ❖ High radiation resistance
- ❖ Increase image resolution ~ 0.2 mm
- ❖ Fast acquisition and signal generation [5]

aSi Flat Panel Detectors for X-ray Imaging

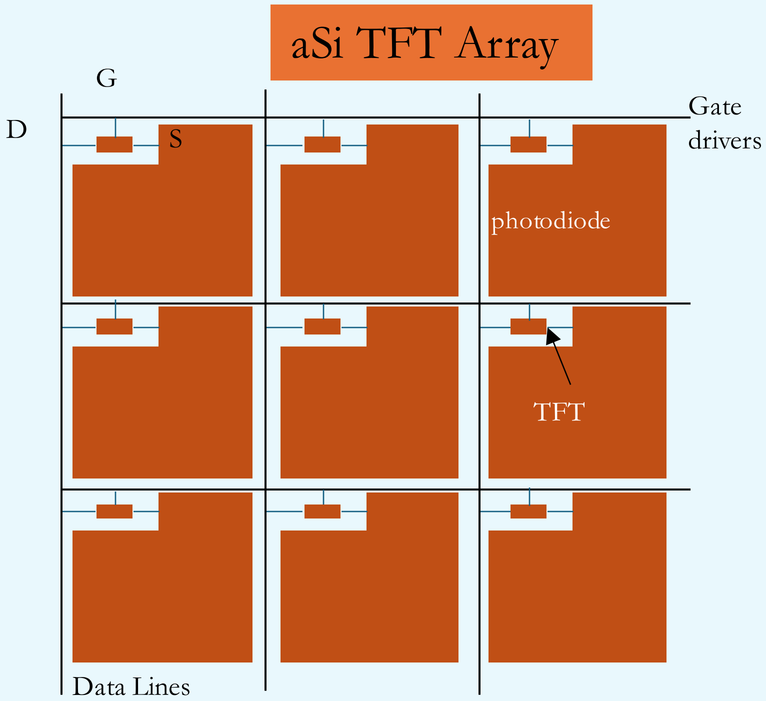
CMS Silicon Pixel Tracker

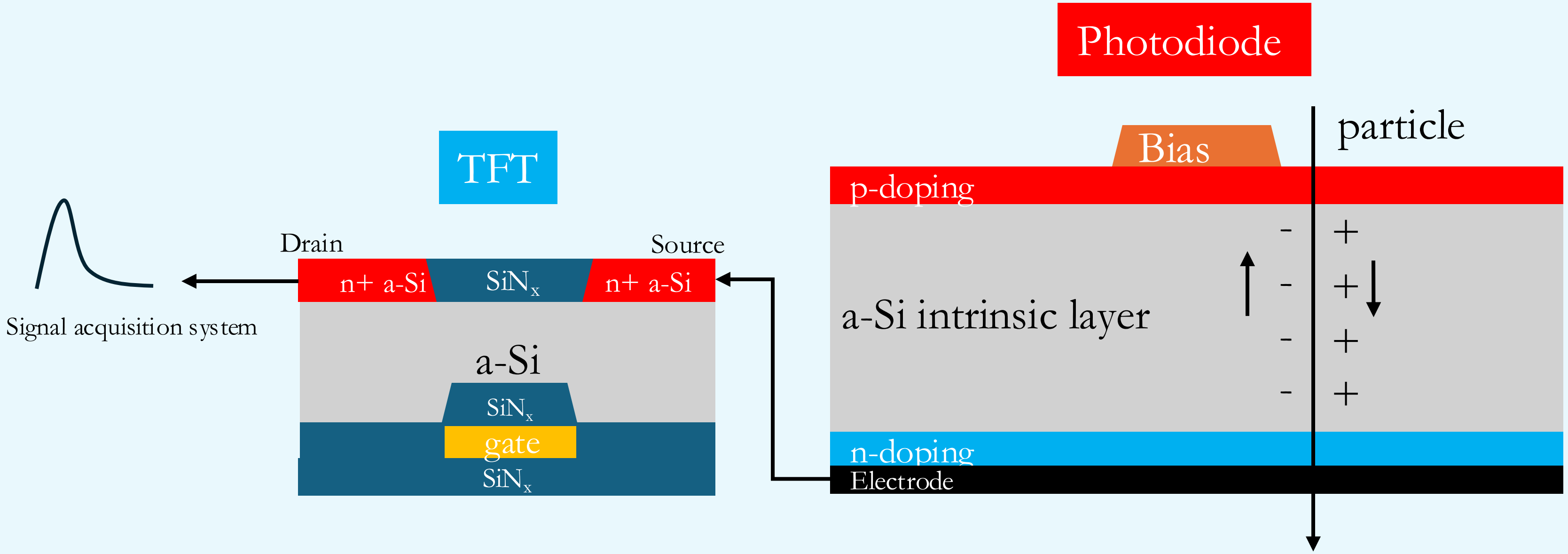
[5] N. Wyrsch and C. Ballif, "Review of amorphous silicon based particle detectors: The quest for single particle detection," Semiconductor Science and Technology, vol. 31, no. 10, p. 103 005, 2016.
[6] H. Schindler, R. Veenhof, Garfield++ | simulation of ionisation based tracking detectors, 2018, URL http://garfieldpp.web.cern.ch/garfieldpp/

Amorphous Silicon (a-Si) based TFT Flat Panel Detectors

a-Si Thin-Film-Transistor (TFT) Array consists of:

- PIN Photodiode, which produced the current signal on the bottom electrode
- Connects to the source of the TFT. When the insulating gate activates, the charges drift towards the drain and charge into a storage capacitor
- Simulated in COMSOL, interfaced with Garfield++ [6], for understanding the specific characteristics of the pixel





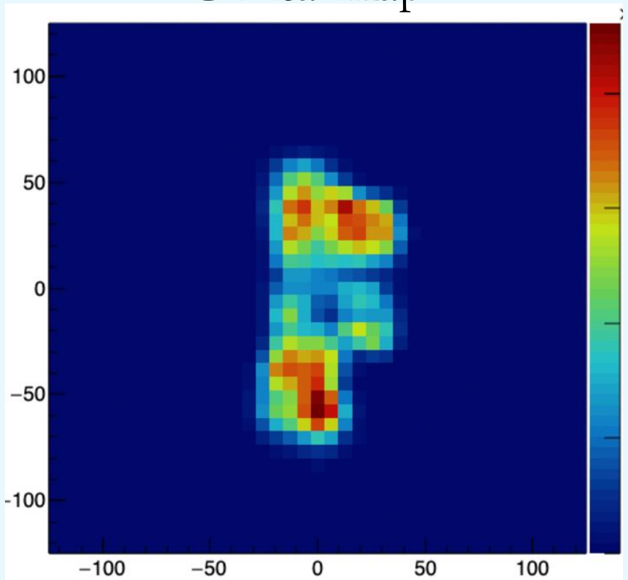
[5] N. Wyrsch and C. Ballif, "Review of amorphous silicon based particle detectors: The quest for single particle detection," Semiconductor Science and Technology, vol. 31, no. 10, p. 103 005, 2016.

[6] H. Schindler, R. Veenhof, Garfield++ | simulation of ionisation based tracking detectors, 2018, URL http://garfieldpp.web.cern.ch/garfieldpp/

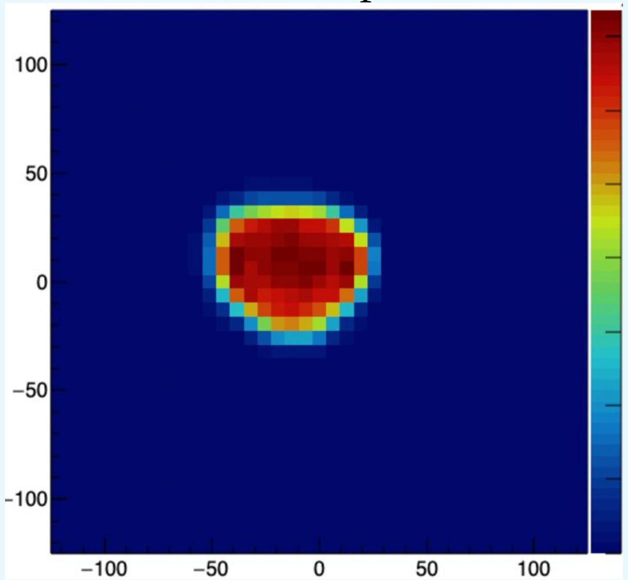
Image acquired by
IBA MatriXX Resolution

❖ Array of Ionization chambers

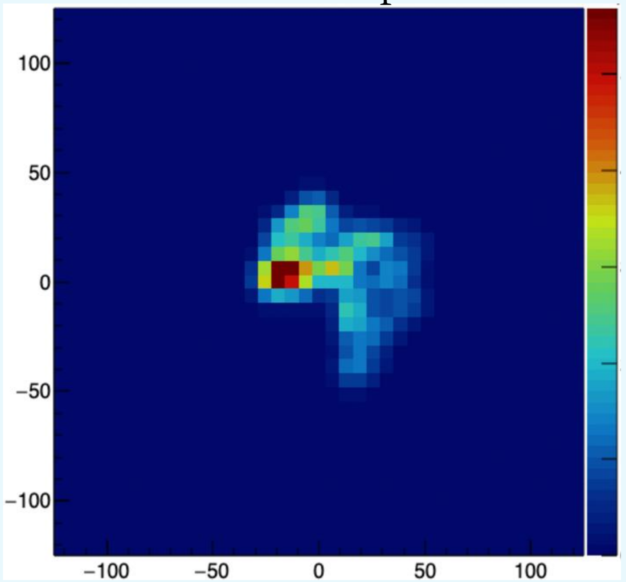
Clinical Map 1



Clinical Map 2



Clinical Map 3



Clinical Map 1 | Clinical Map 2 | Clinical Map 3

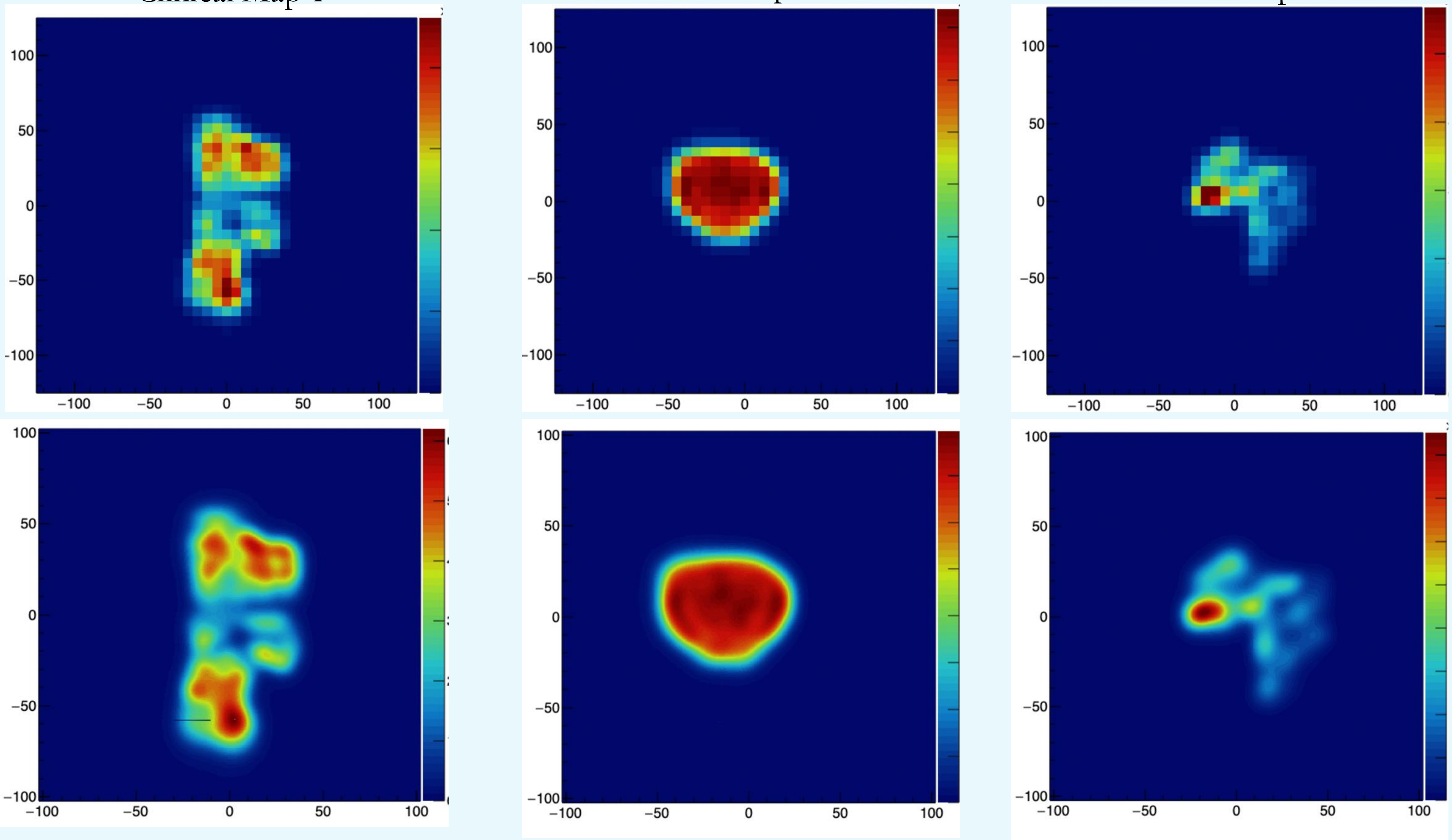


Image acquired by
IBA MatriXX Resolution
- ❖ Array of Ionization chambers

Images acquired by
IBA Sphinx Compact
- ❖ aSi TFT Panel

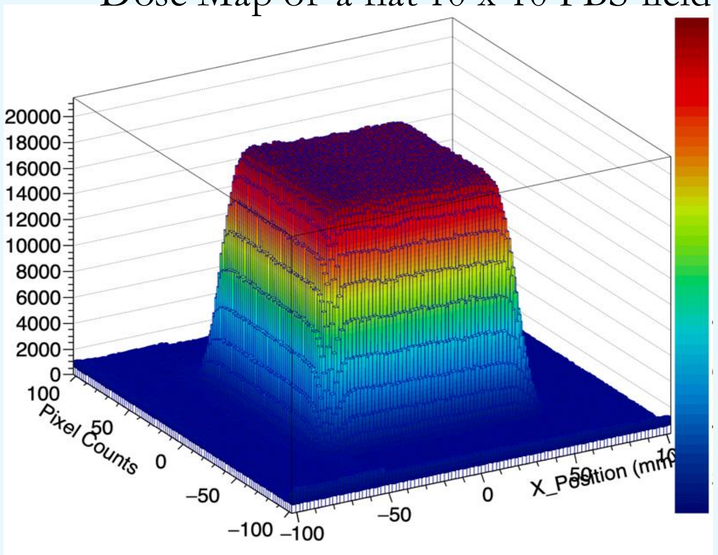
Comparison of small field dosimetry detectors

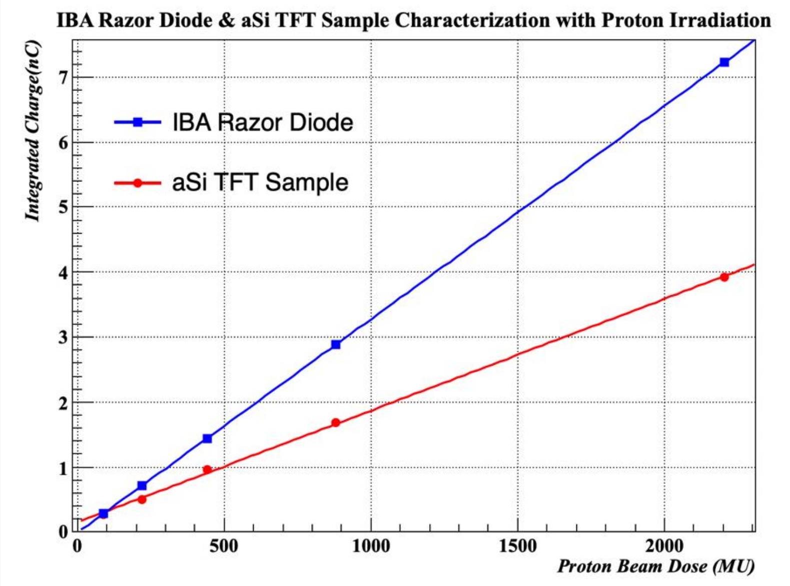
- To understand the different behavior of crystalline-based (c-Si) and amorphous-based (a-Si) silicon detectors under different particle beams.
- The IBA Razor Diode and a small a-Si TFT array were irradiated with a flat 10 x 10 proton PBS with different doses.

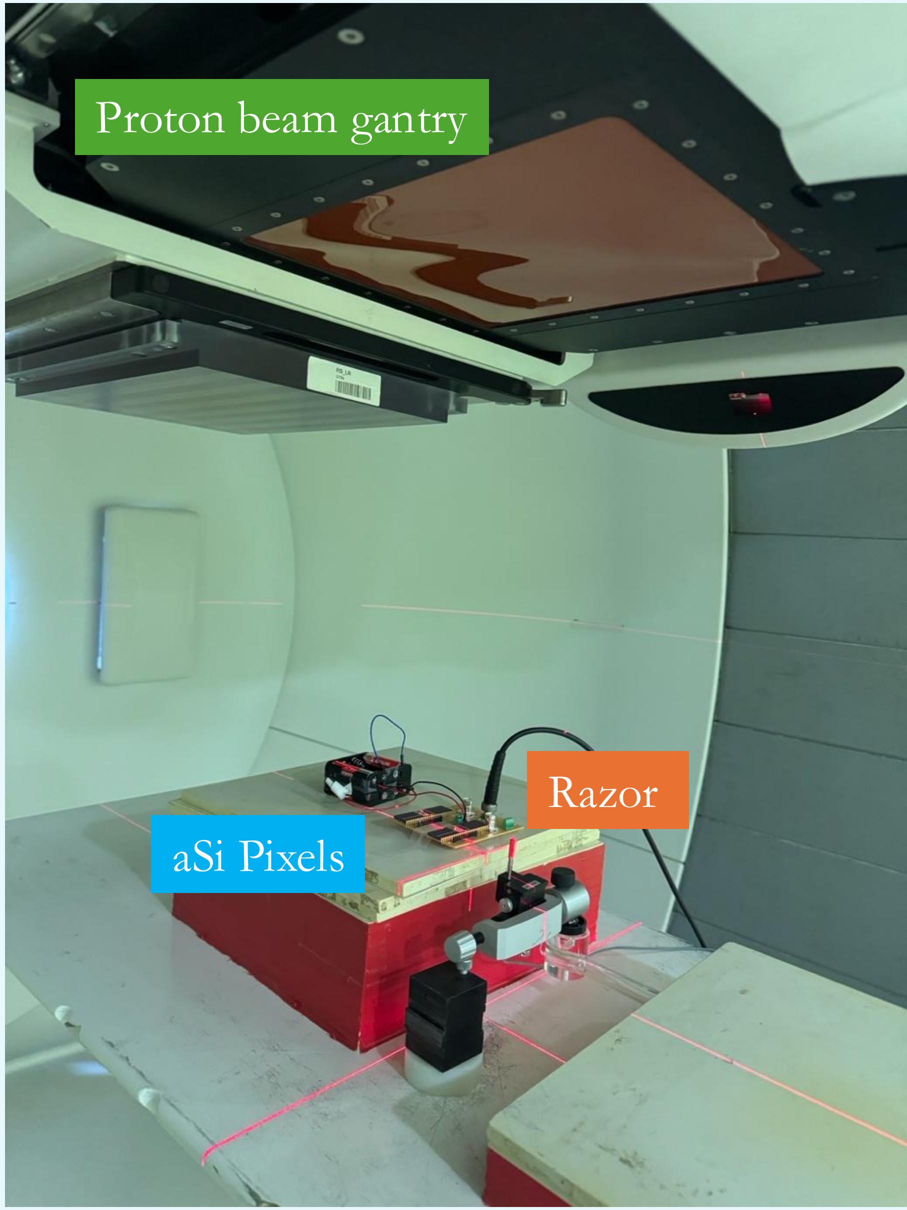
- Both diodes exhibited pristine charge linearity, without showing any saturation at high-proton doses.

- Diodes will be further tested with proton and electron FLASH dose levels.

Dose Map of a flat 10 x 10 PBS field

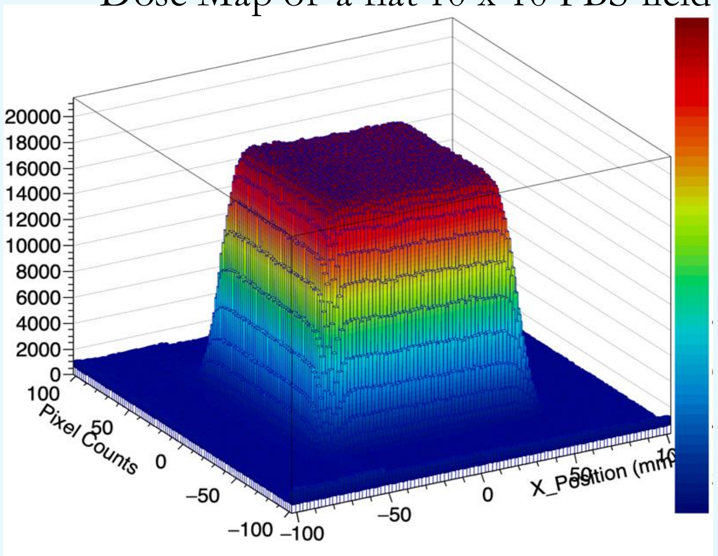


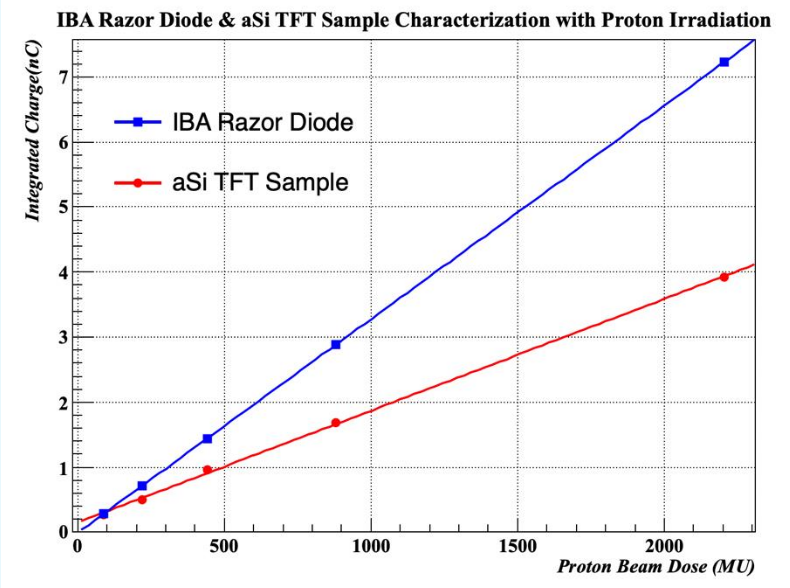


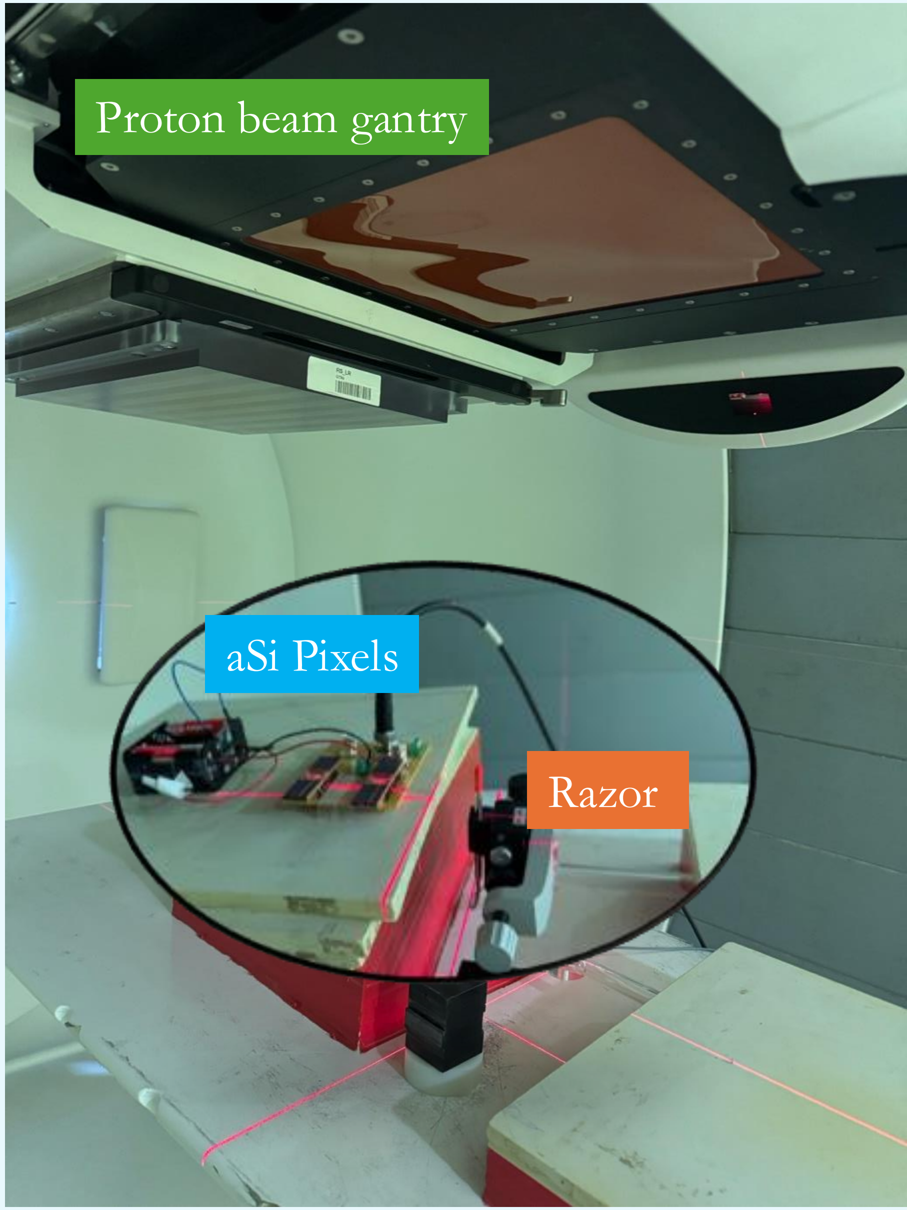


Comparison of small field dosimetry detectors

- ❖ To understand the different behavior of crystalline-based (c-Si) and amorphous-based (a-Si) silicon detectors under different particle beams.
- ❖ The IBA Razor Diode and a small a-Si TFT array were irradiated with a flat 10 x 10 proton PBS with different doses.





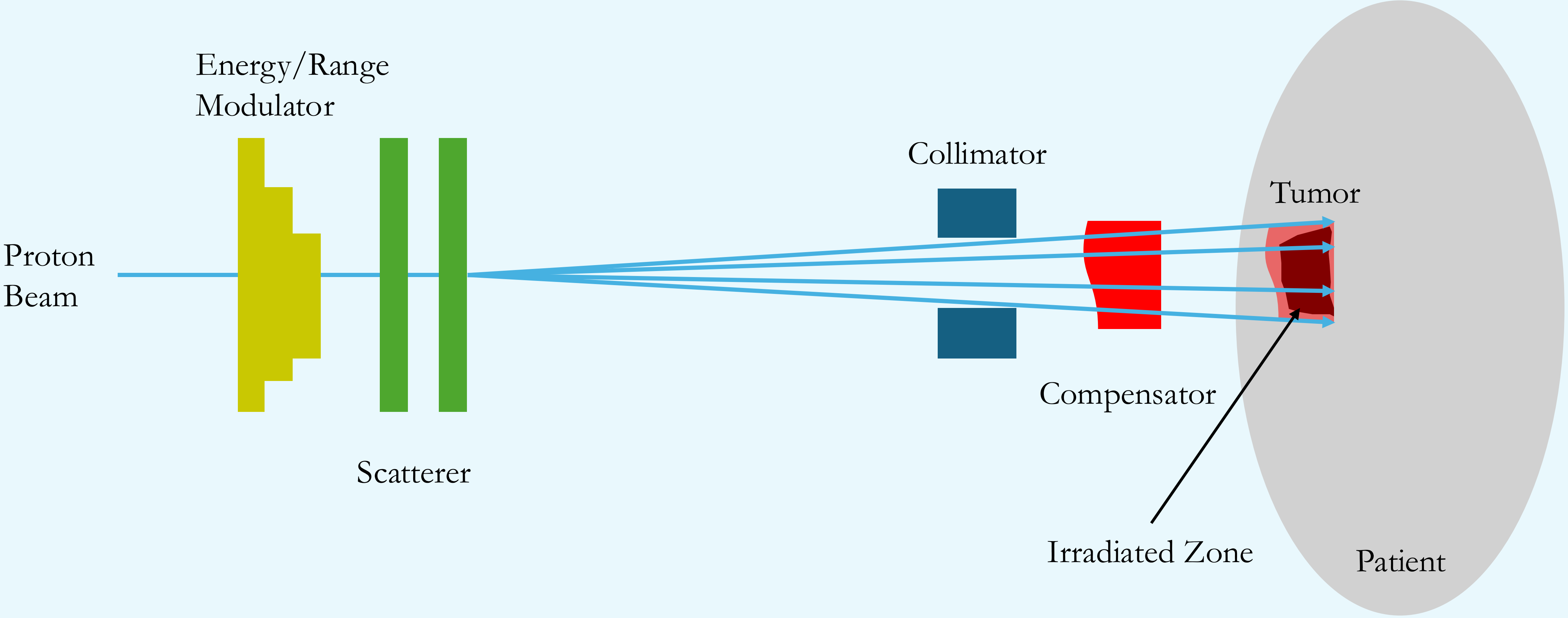


- ❖ Both diodes exhibited pristine charge linearity, without showing any saturation at high-proton doses.
- ❖ Diodes will be further tested with proton and electron FLASH dose levels.

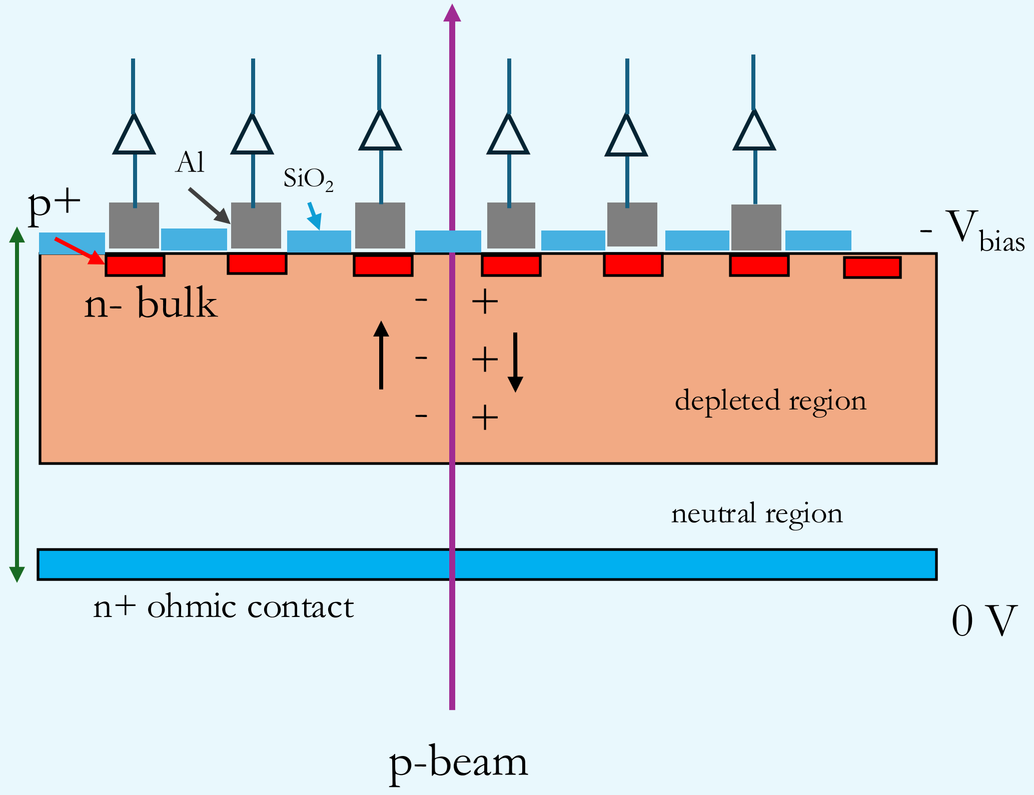
BACK-UP SLIDES

Proton therapy delivery techniques – Conventional Scattering

A monoenergetic Proton Beam operates at the highest energy, while the modulator changes the energy per delivered dose. Where a compensator is placed, according to the shape of the tumor



PN – Diodes



PIN – Diodes