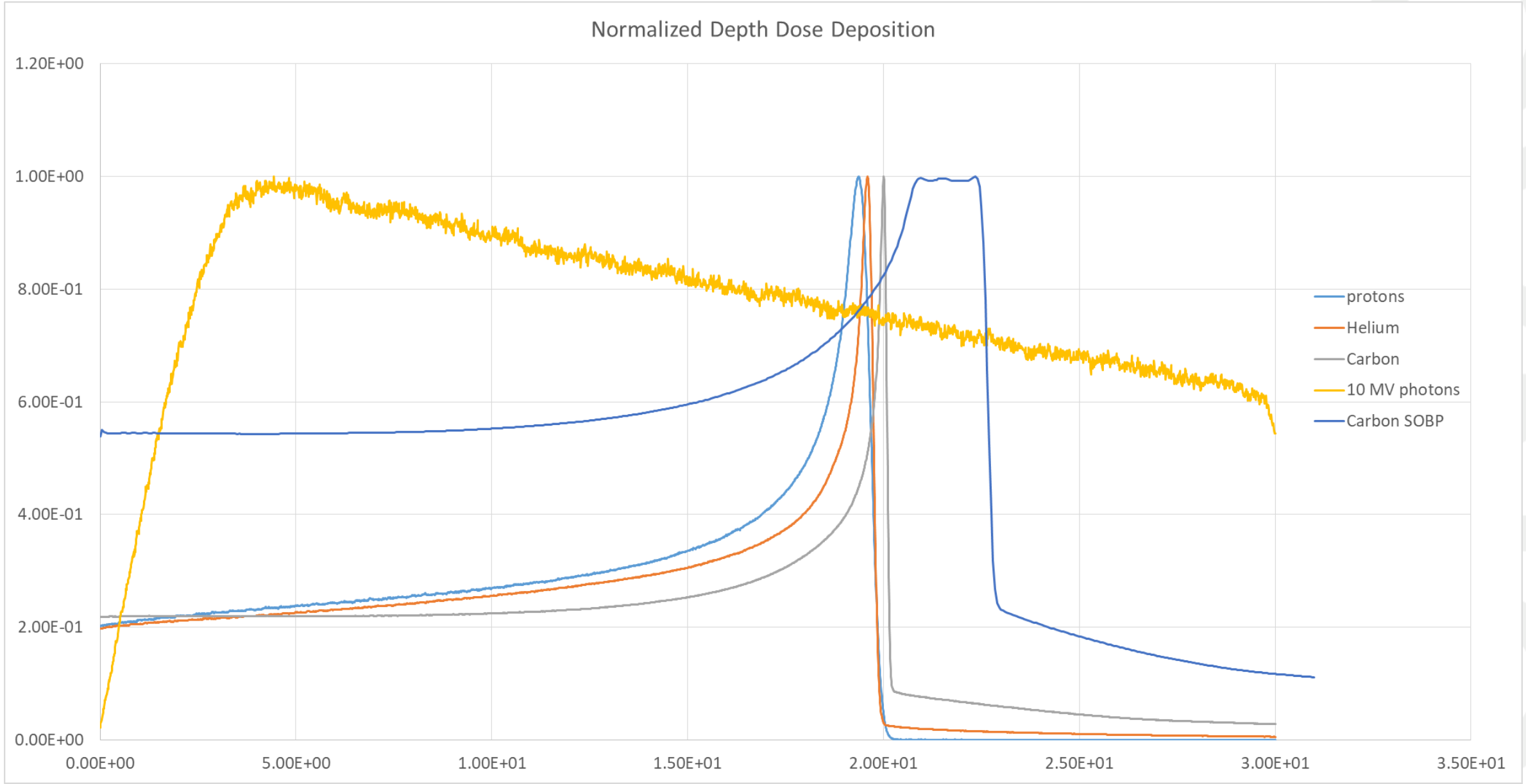
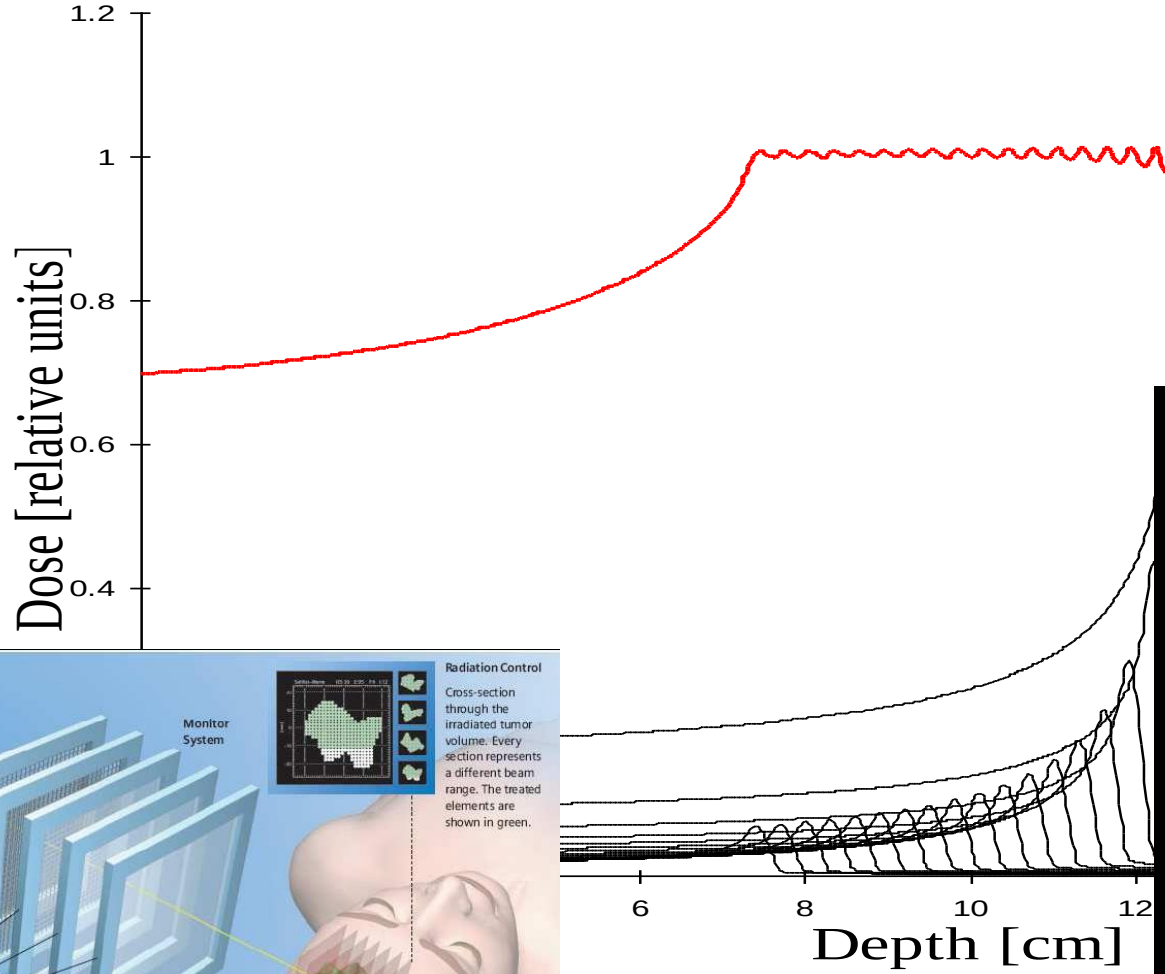
Why range verification

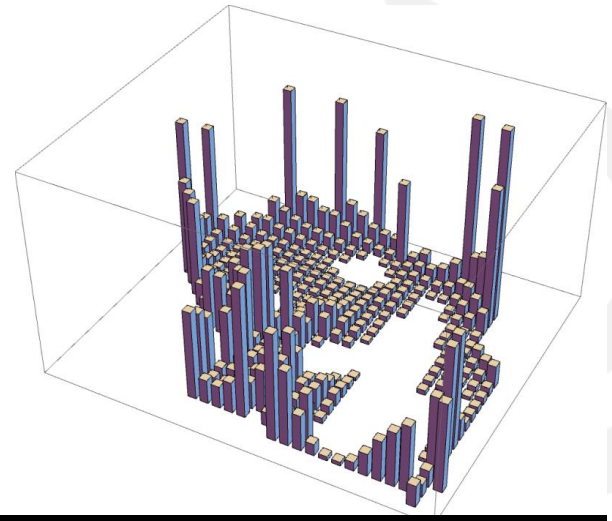
M. Pullia

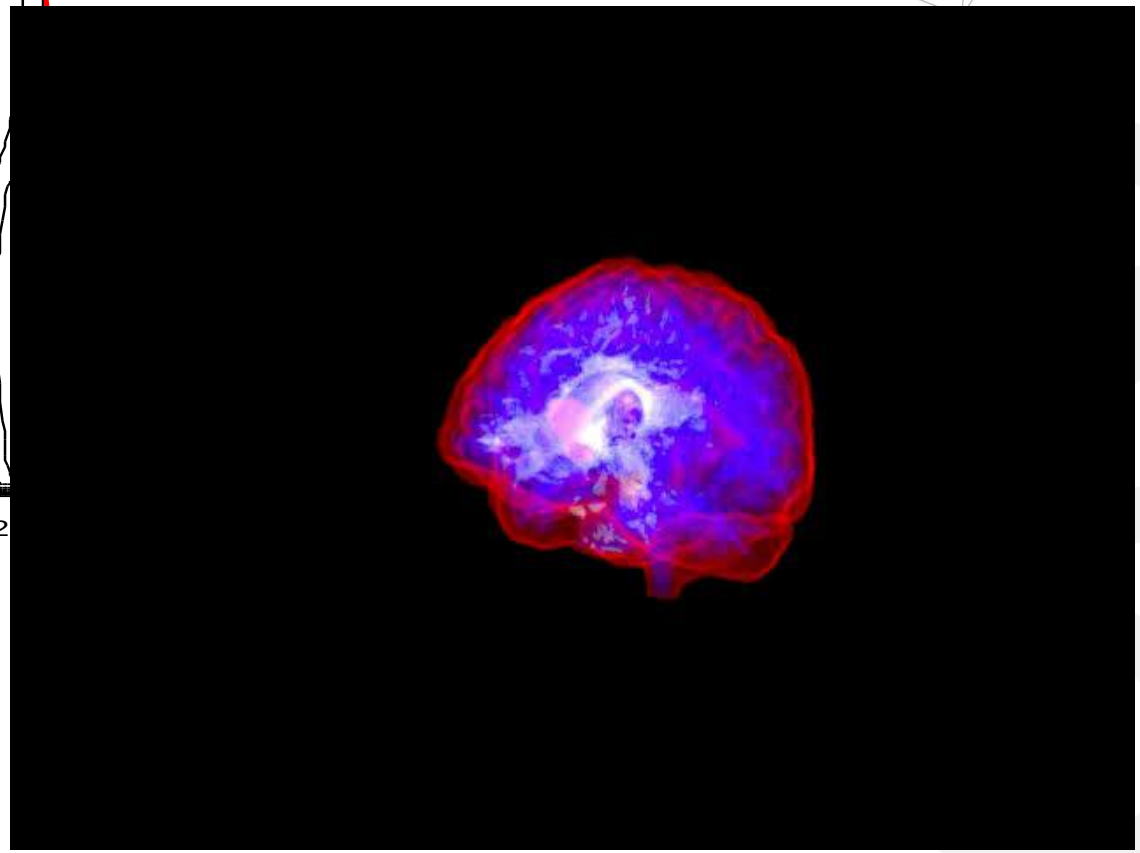
Hadrontherapy and Bragg peak

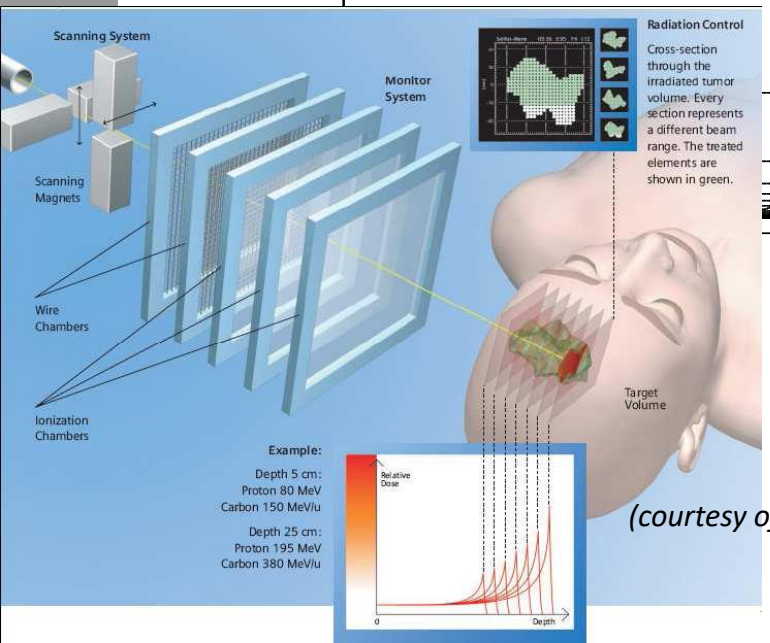


Active beam delivery





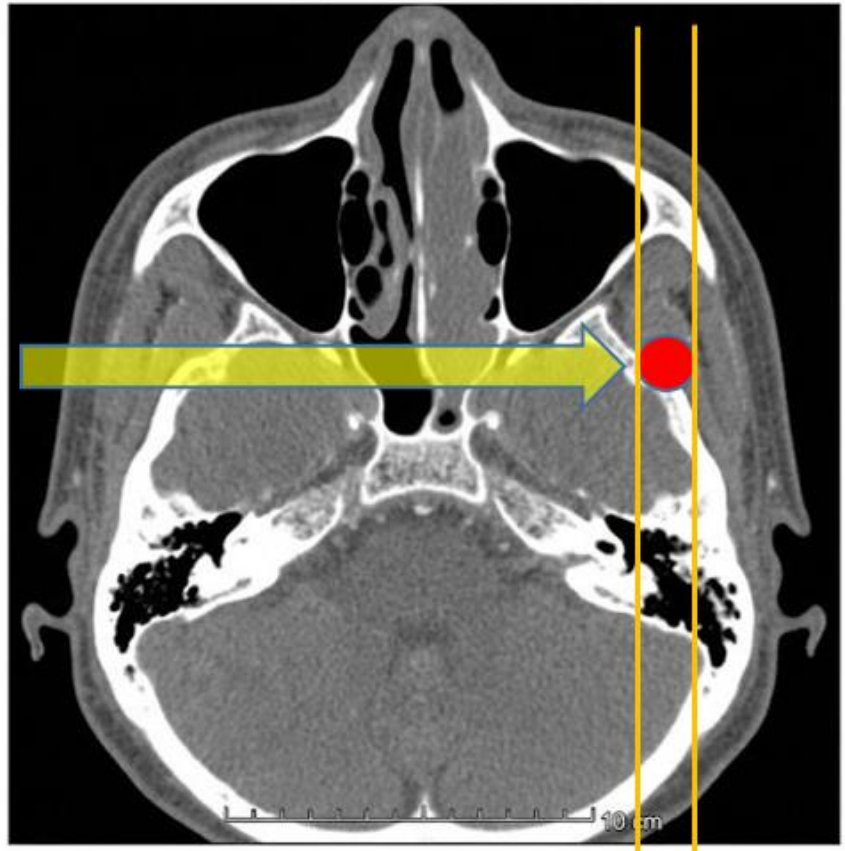


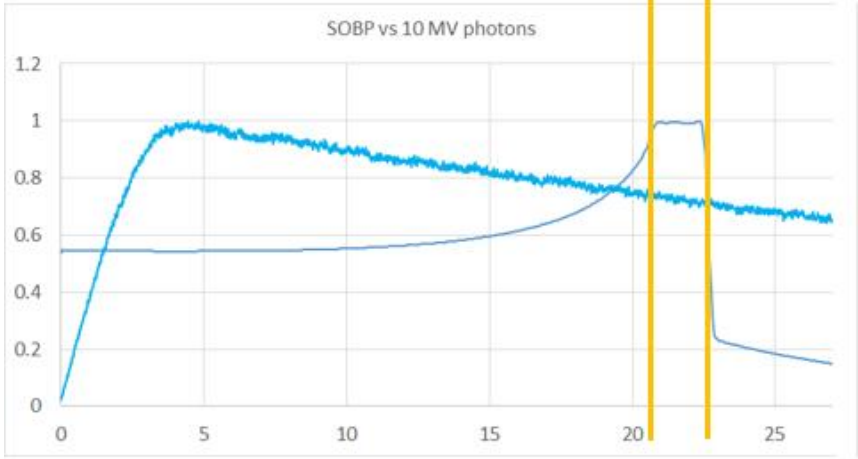


(courtesy of Siemens Medical)

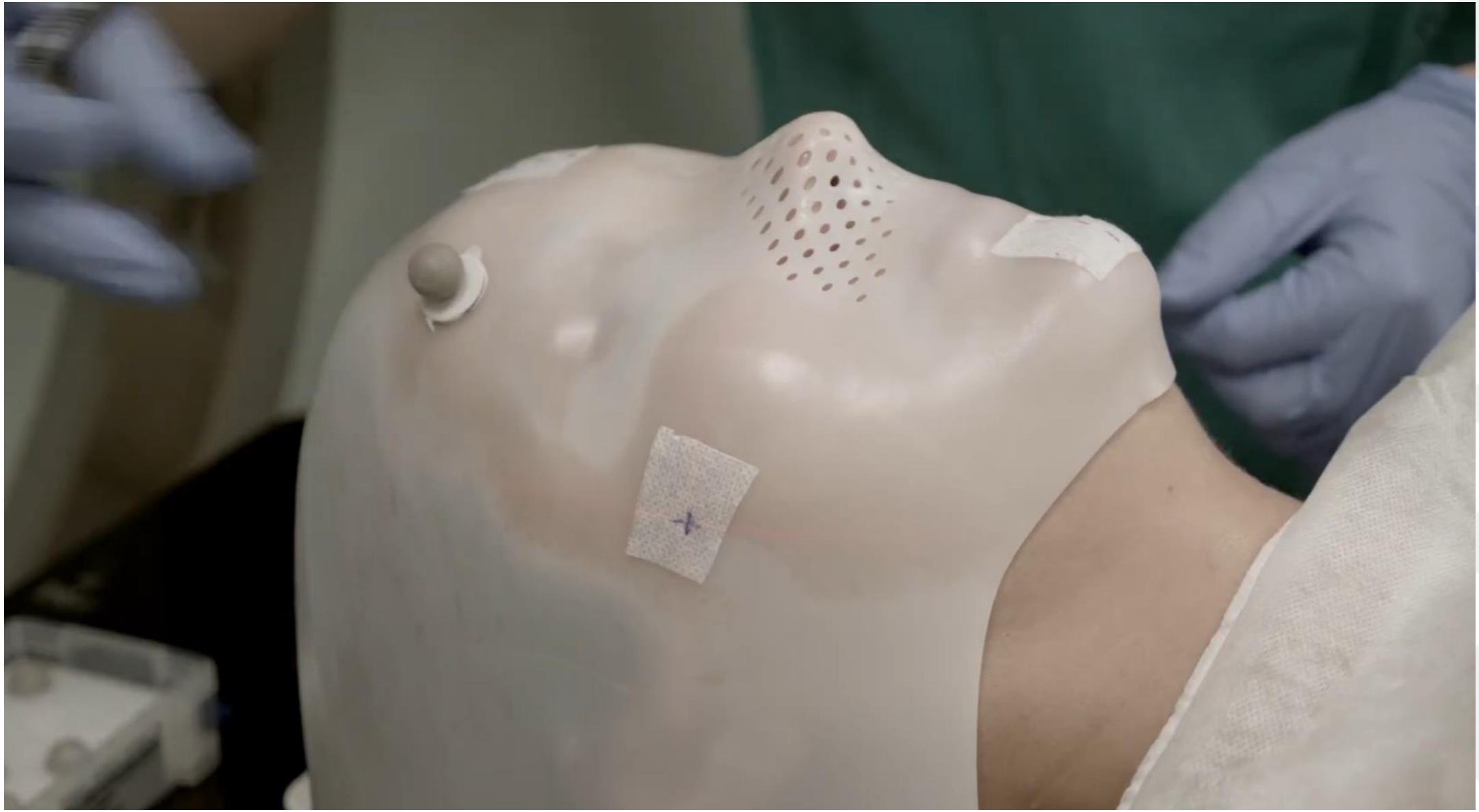
Precise delivery of the dose

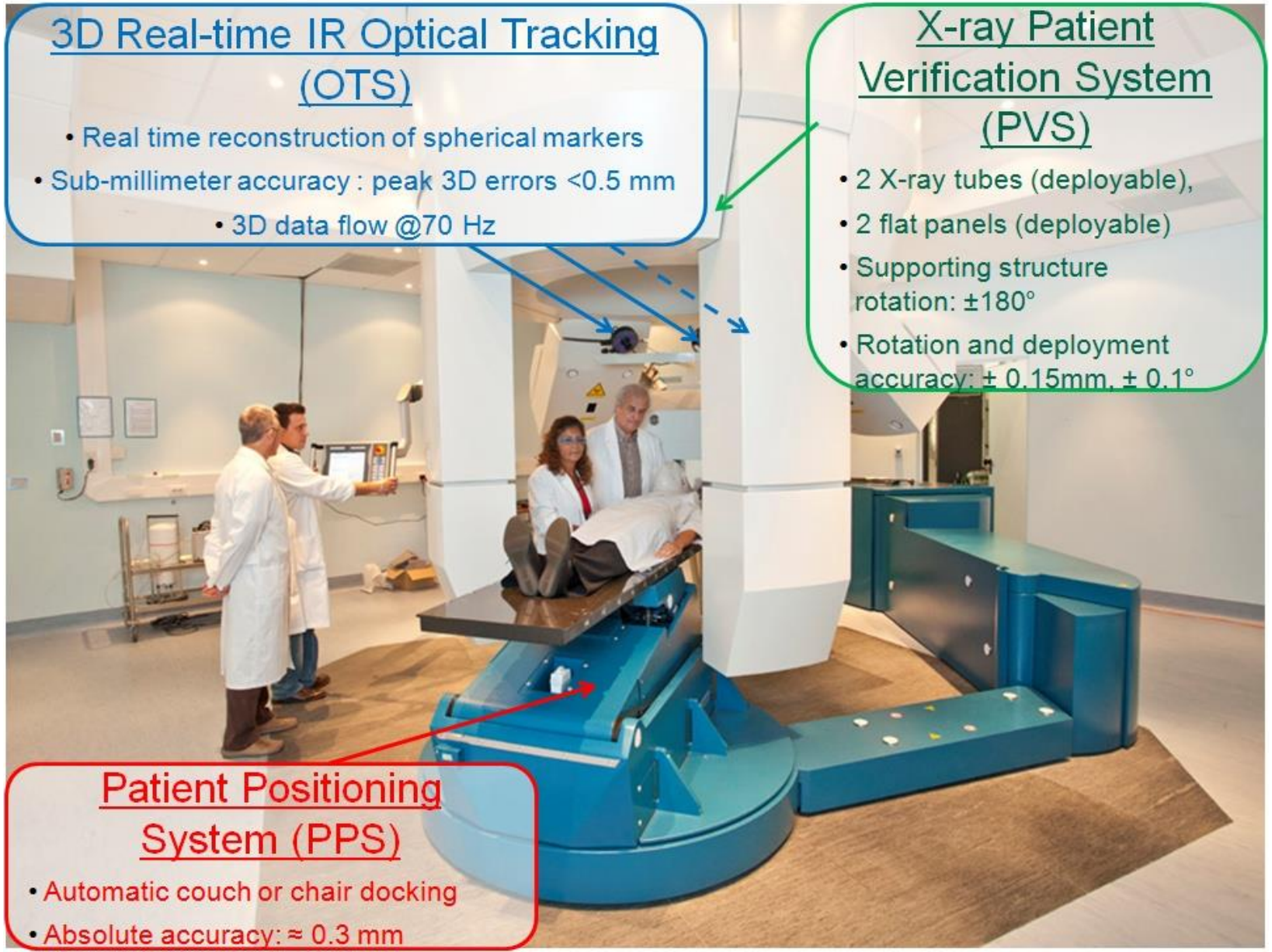
- The target (patient) has to be known with the same precision
- The plan is made on the planning CT with the patient in that position
- A treatment can last up to two months
- Everyday the patient has to be repositioned in the exact same position





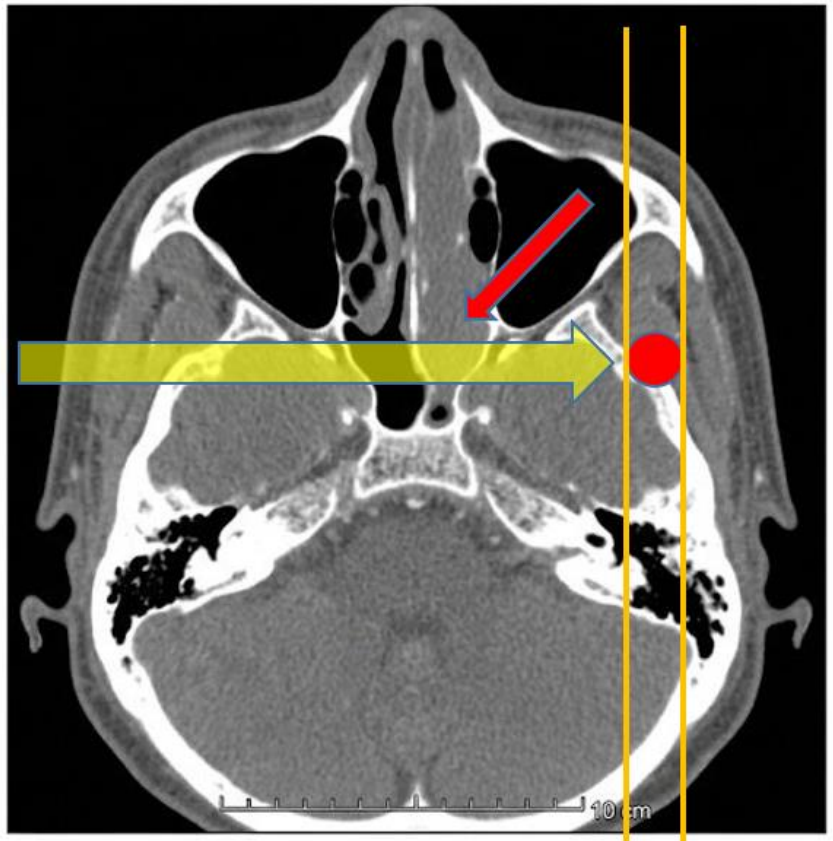


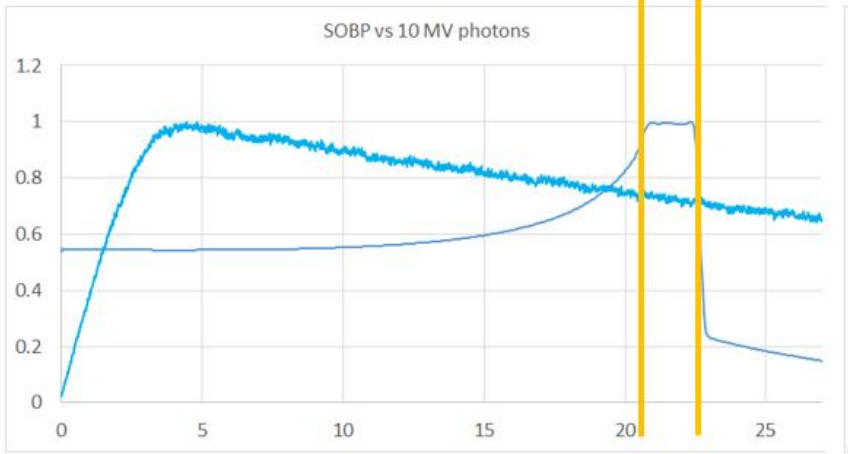



3D Real-time IR Optical Tracking (OTS)
• Real time reconstruction of spherical markers
• Sub-millimeter accuracy : peak 3D errors <0.5 mm
• 3D data flow @70 Hz
X-ray Patient Verification System (PVS)
• 2 X-ray tubes (deployable),
• 2 flat panels (deployable)
• Supporting structure rotation: ±180°
• Rotation and deployment accuracy: ± 0.15mm, ± 0.1°
Patient Positioning System (PPS)
• Automatic couch or chair docking
• Absolute accuracy: ≈ 0.3 mm

- CT Hunsfield units to SPR error up to 3%
- Anatomical changes are possible
- Inter fraction
- Even intra fraction

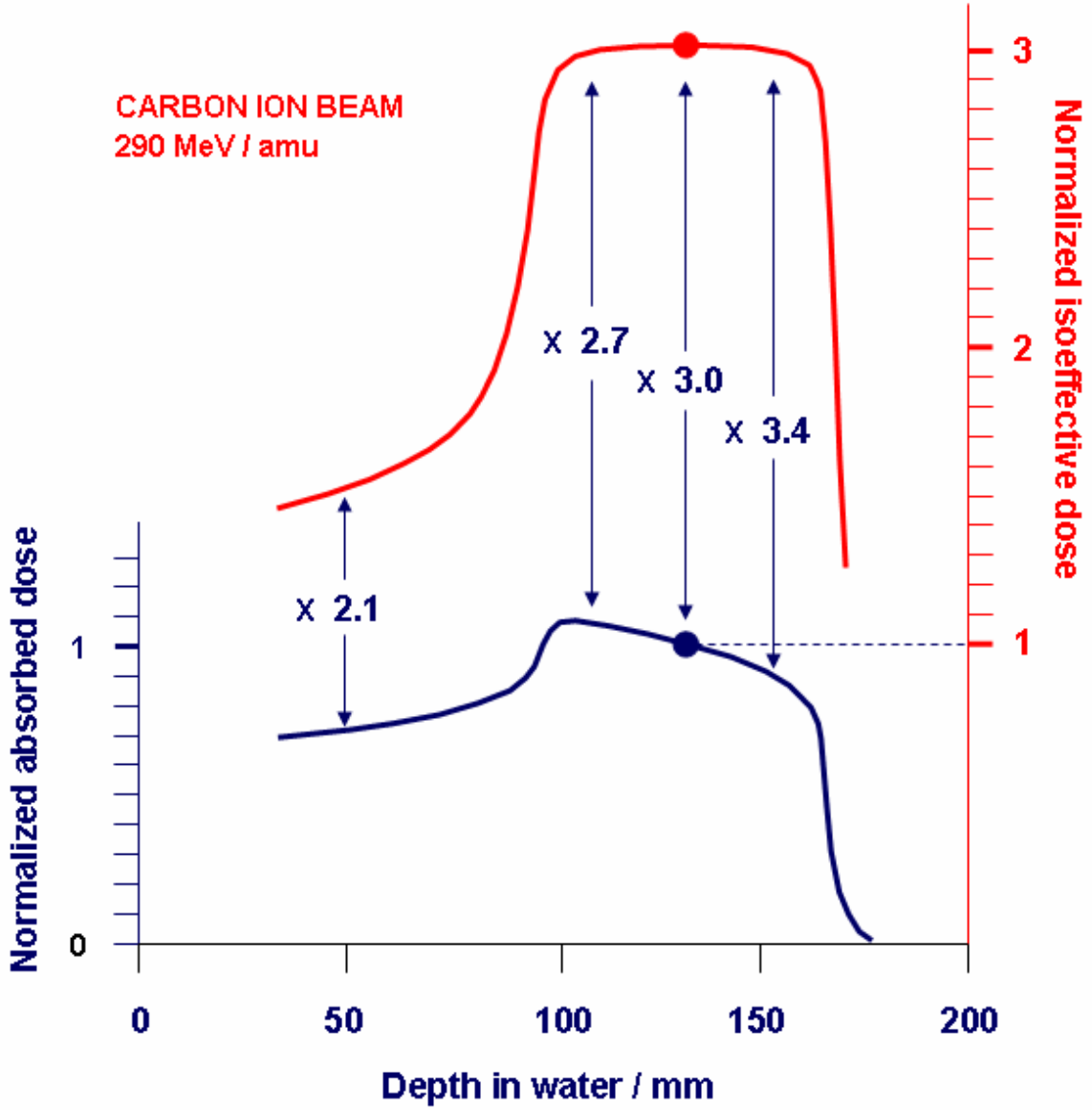
- Adaptive therapy





Radiobiology (out of scope)

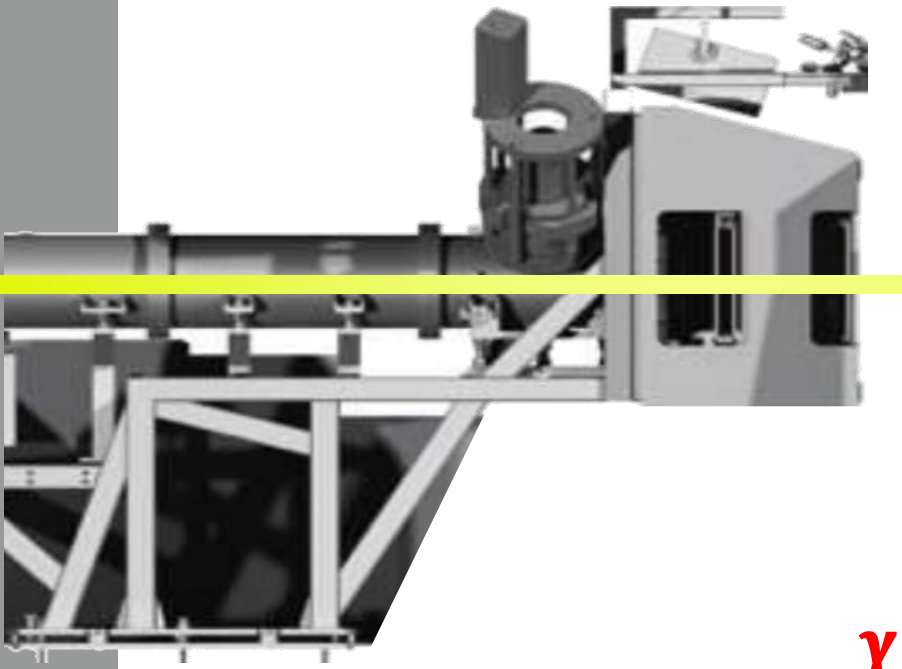
- RBE
- LET
- Oxygenation
- Bio Adaptive Therapy

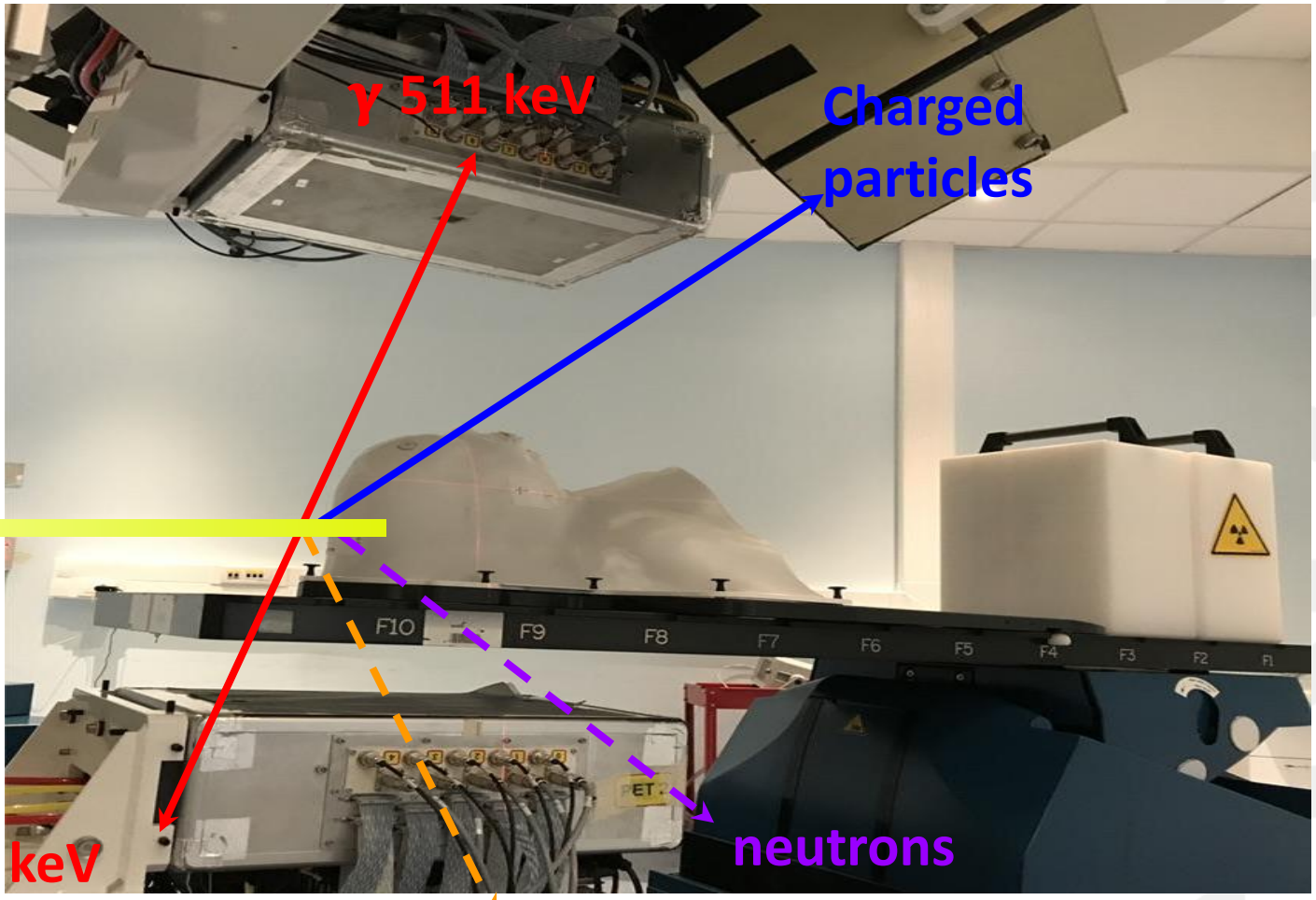


Range verification

Range monitoring

Online pet acquisition





Clinical trial: 37 patients, data analysis in progress

Range verification by prompt gamma

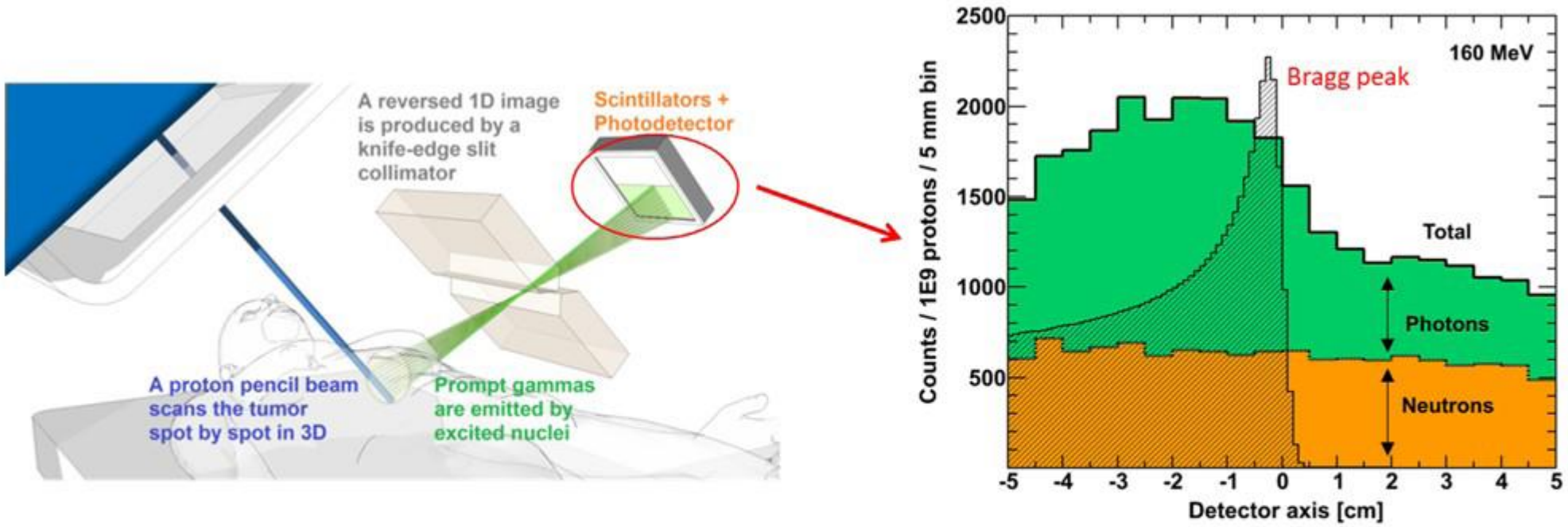


Fig.1. Principle of prompt-gamma measurement through a 1D imaging camera. The measured profile of gamma rays shows correlation with the fall-off of the Bragg peak. Contribution from secondary radiation, as neutrons shown in the figure, do not show relevant correlation and contribute mainly to background noise.

Collaborazione Polimi

POLITECNICO
MILANO 1863

Prompt Gamma Imaging alternative collimators

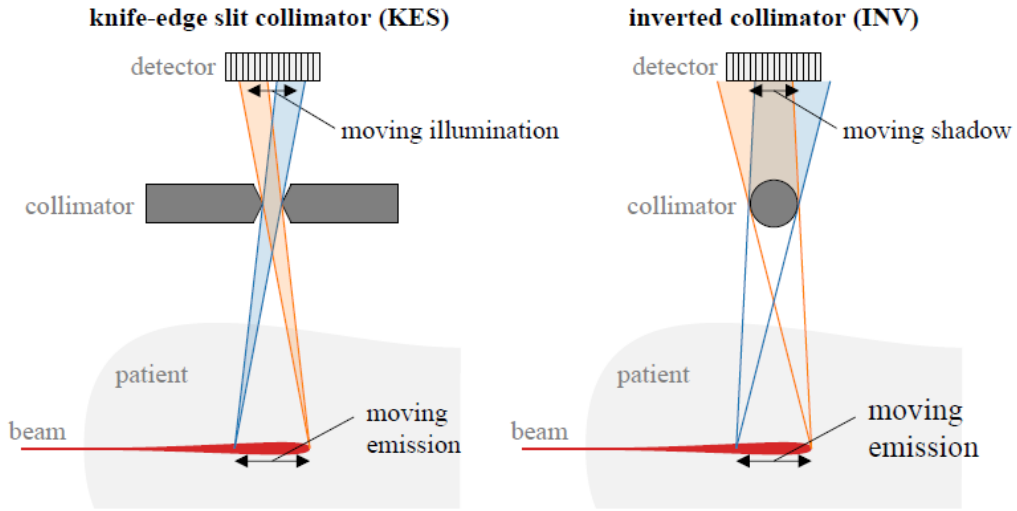
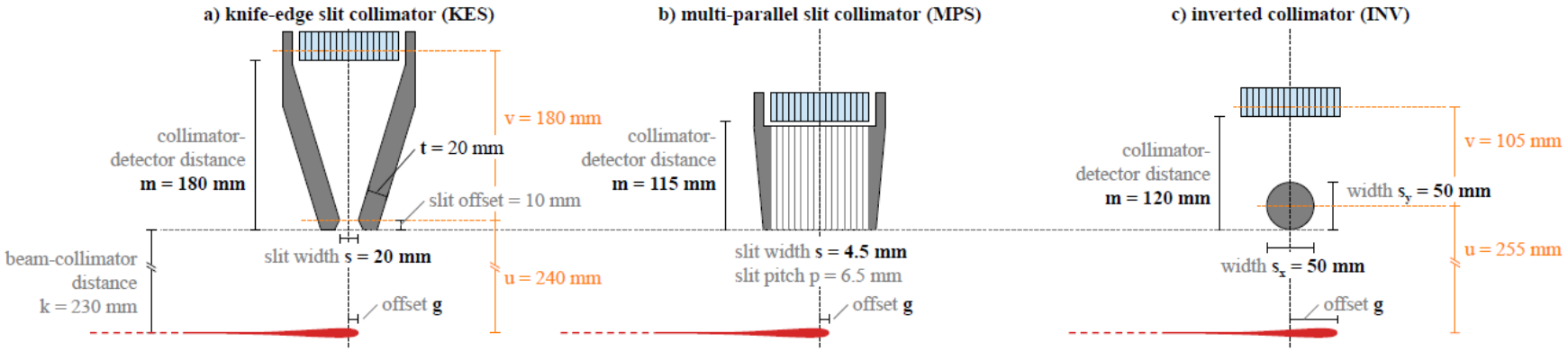


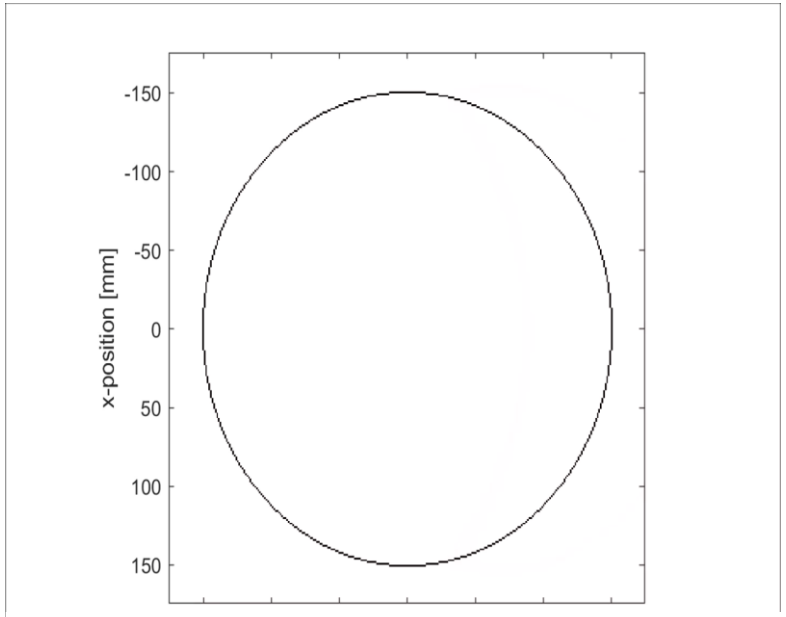
Figure 5. Sketch of the idea of the inverted collimator compared to the knife-edge slit collimator.

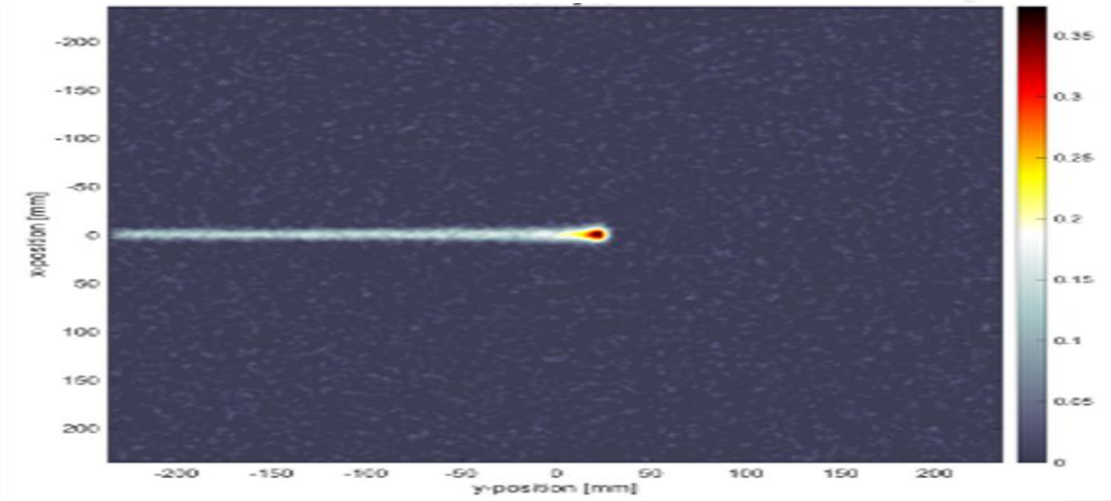


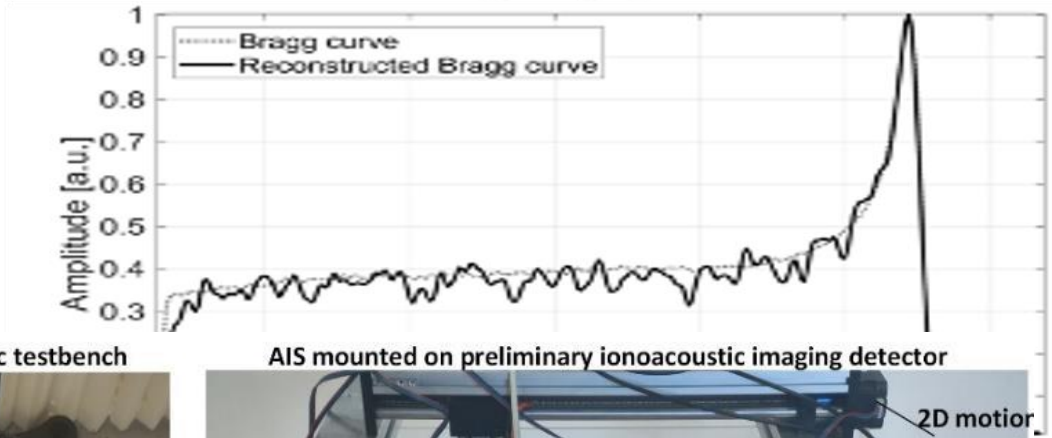
Urban et al, *Study of a novel inverted collimator concept for prompt-gamma-based range verification in proton therapy using a hybrid simulation approach*. Accepted for publication on PMB 2026

POLITECNICO
MILANO 1863

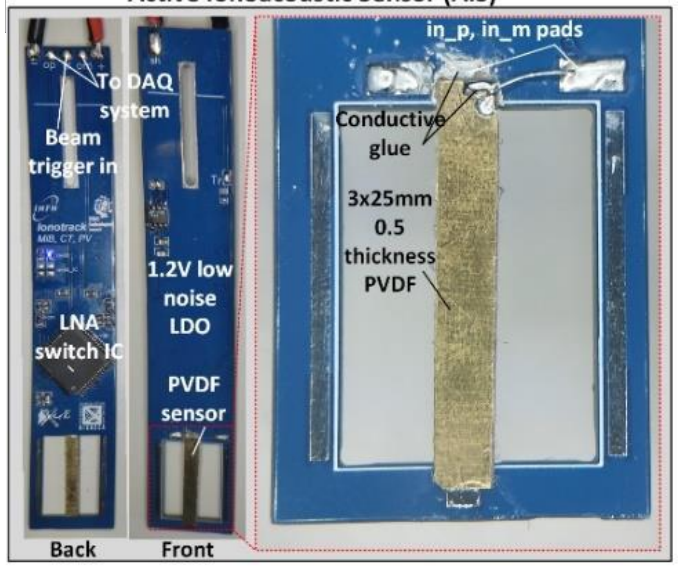
ionoacoustics



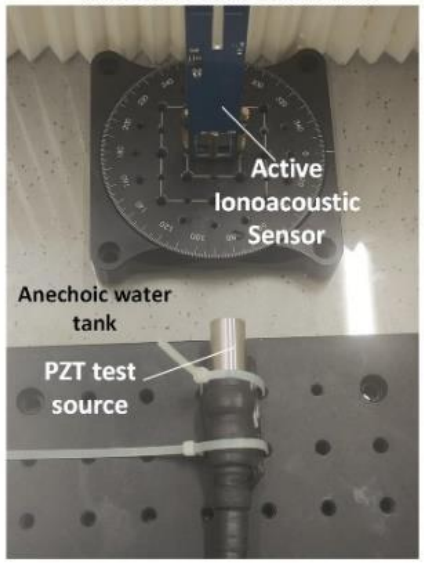




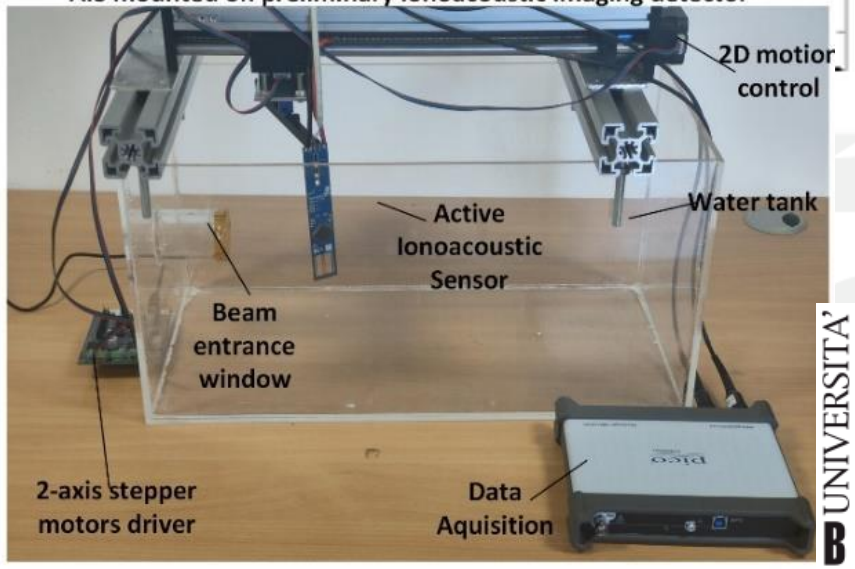
Active Ionoacoustic Sensor (AIS)



AIS on acoustic testbench



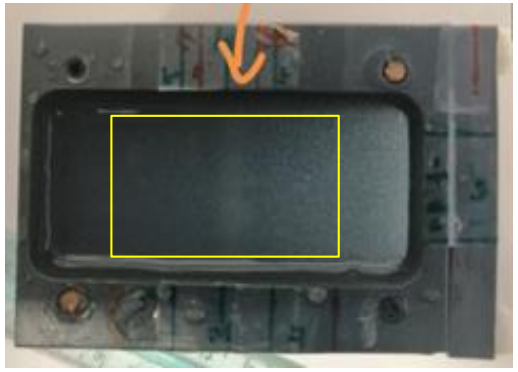
AIS mounted on preliminary ionoacoustic imaging detector

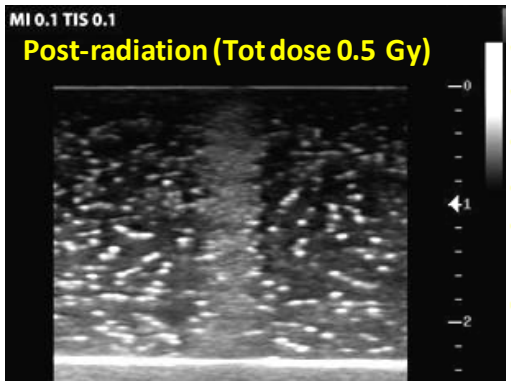


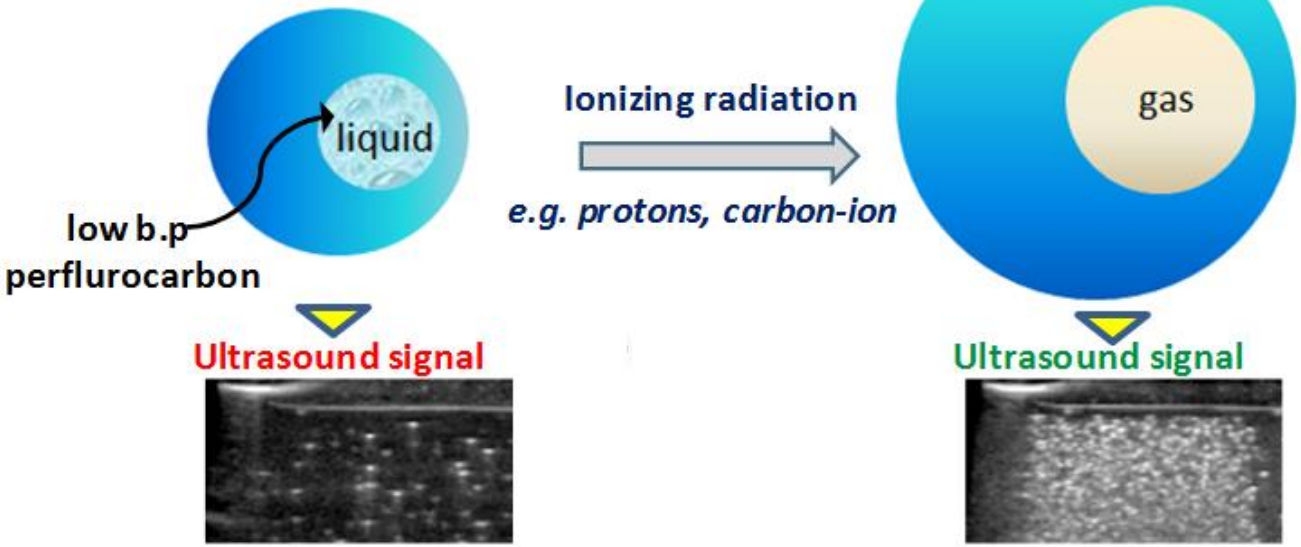
UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

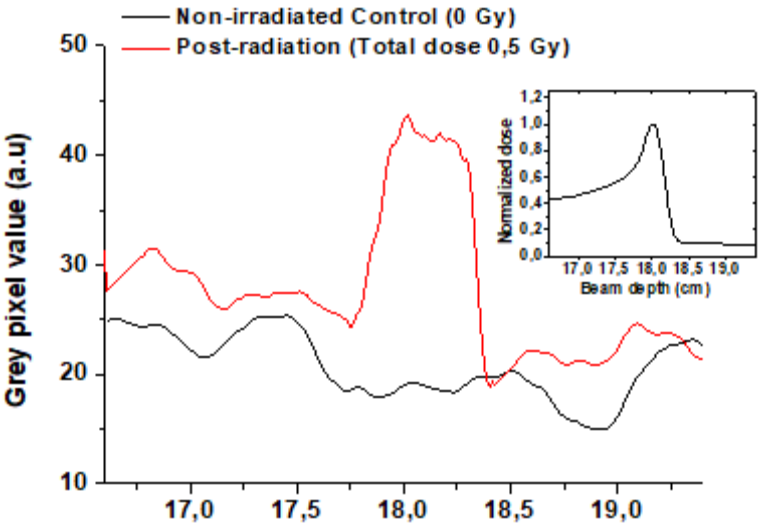
Nanodroplets













Dipartimento di Scienze e Tecnologie Chimiche,
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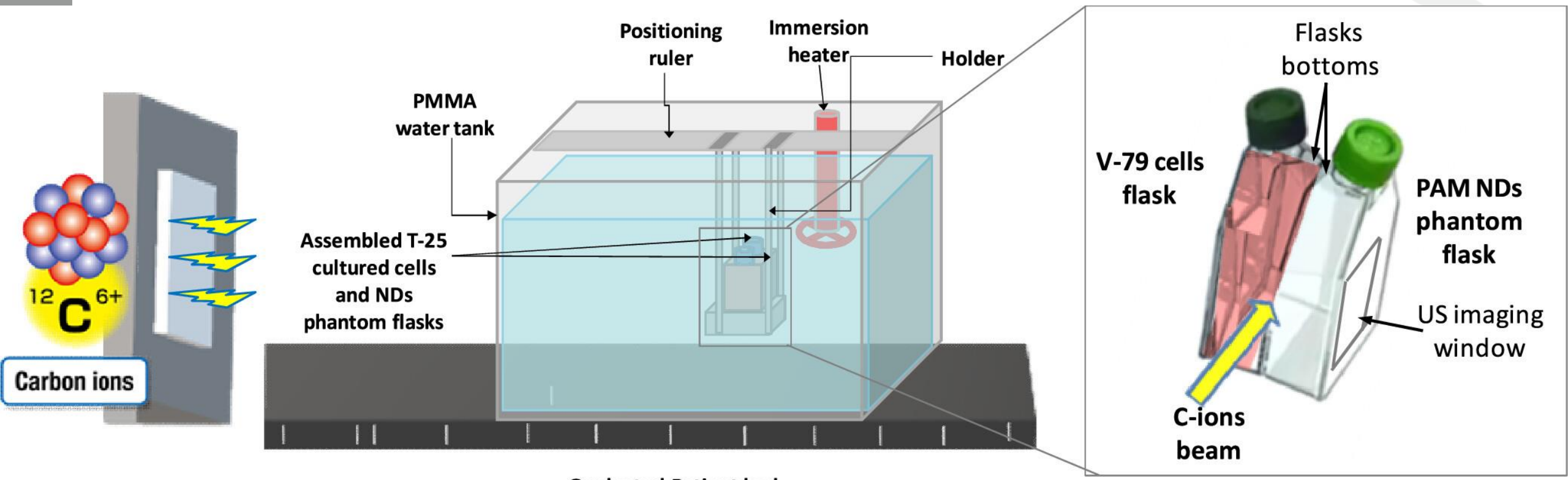
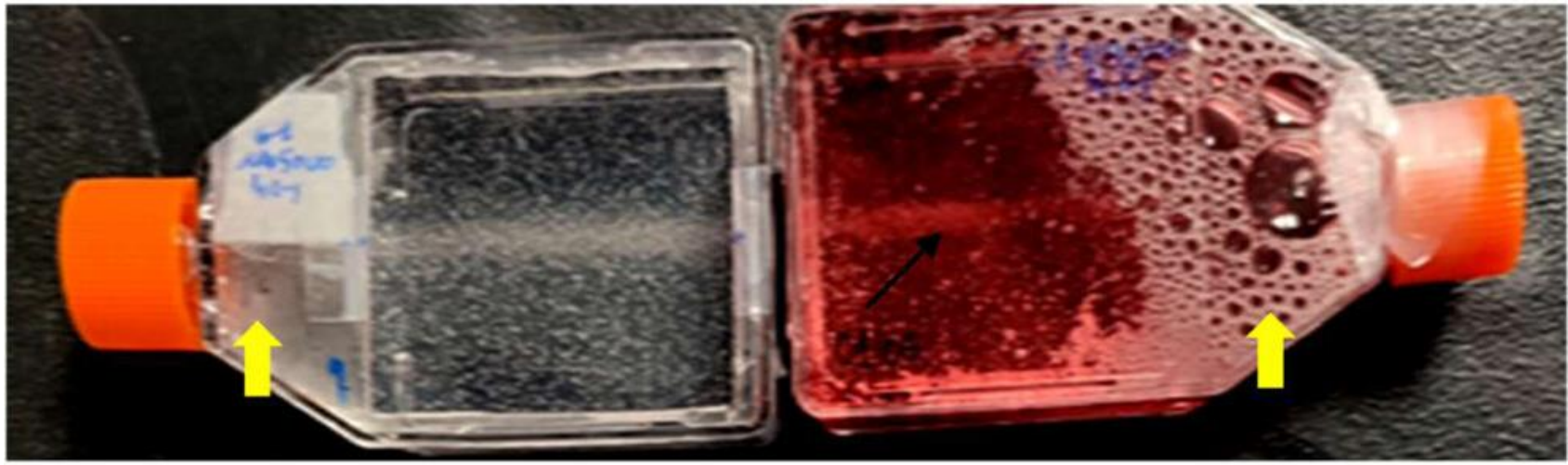
INFN sez. Roma Tor Vergata

Toumia, Y., Pullia, M., Domenici, F. et al. “Ultrasound-assisted carbon ion dosimetry and range measurement using injectable polymer-shelled phase-change nanodroplets: in vitro study”. Sci Rep 12, 8012 (2022). https://doi.org/10.1038/s41598-022-11524-x

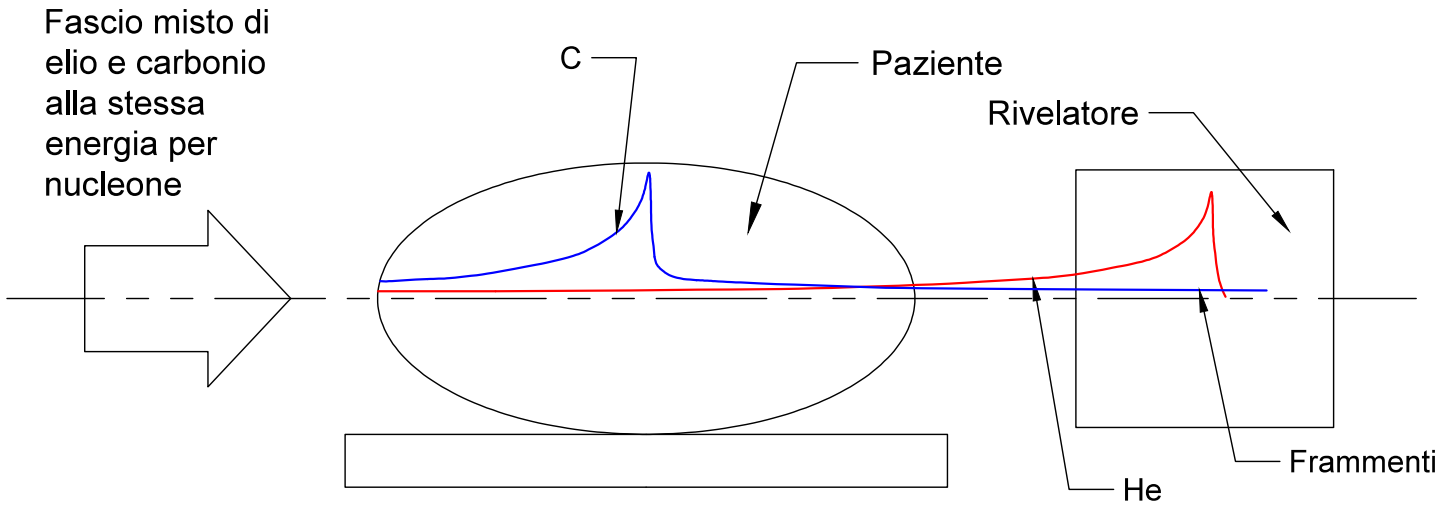




Yosra Toumia, Marco Pullia, Alexandra Charalampopoulou, Alessandra Vitaliti, Fabio Domenici, Michele Ferrarini, Angelica Facoetti, and Gaio Paradossi, Perfluorobutane Nanodroplets for the Selective Sensing and Range Verification of Carbon-Ion Radiotherapy: In Vitro Evaluation on Cells, ACS Omega 2025 10 (27), 29154-29165, DOI: 10.1021/acsomega.5c01785

INFN Istituto Nazionale di Fisica Nucleare

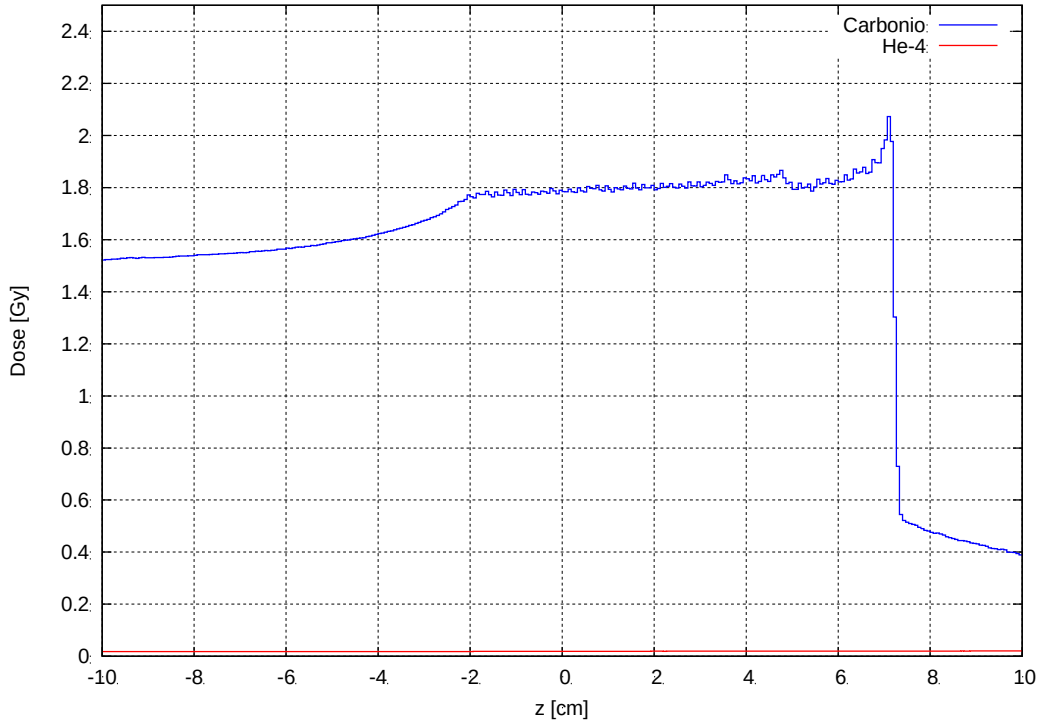
Mixed Beams HeCheck



Proof of principle

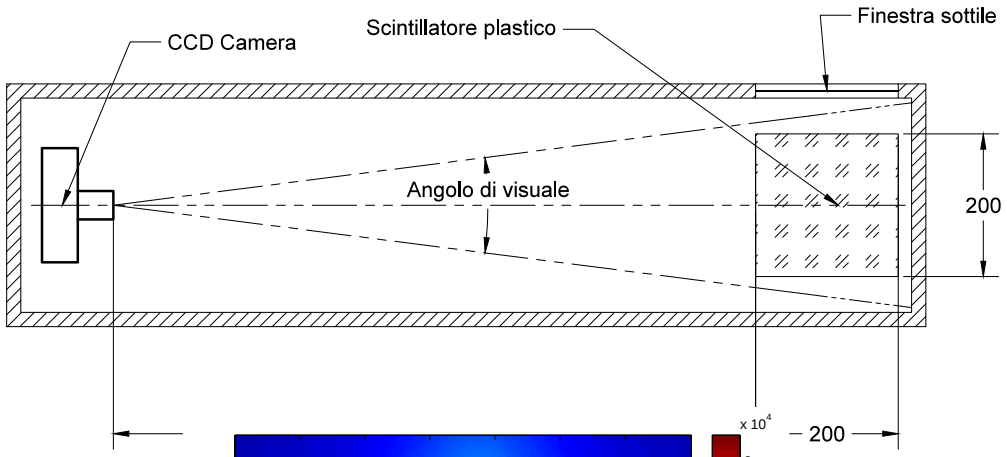
He 10% in number wrt C

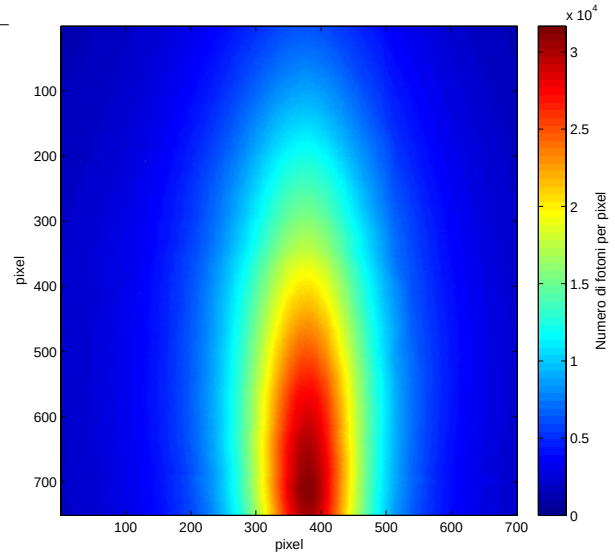
1% in dose



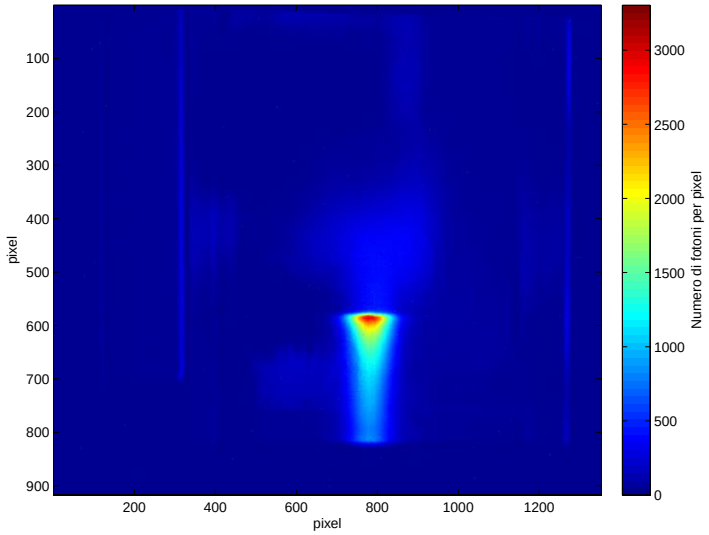
https://doi.org/10.1002/mp.13219

HeCheck

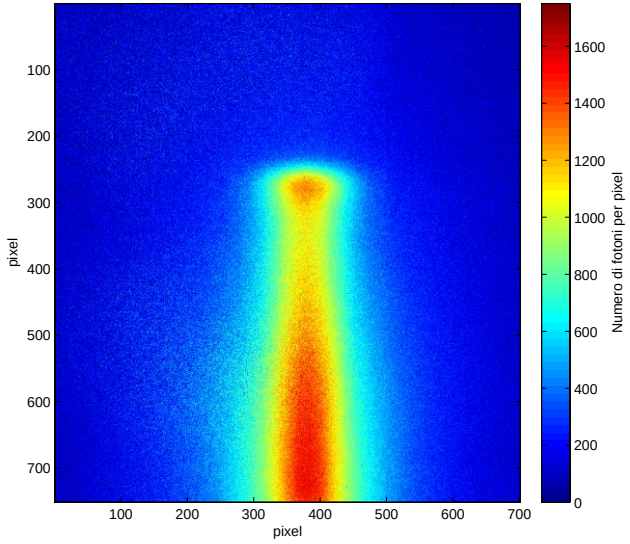




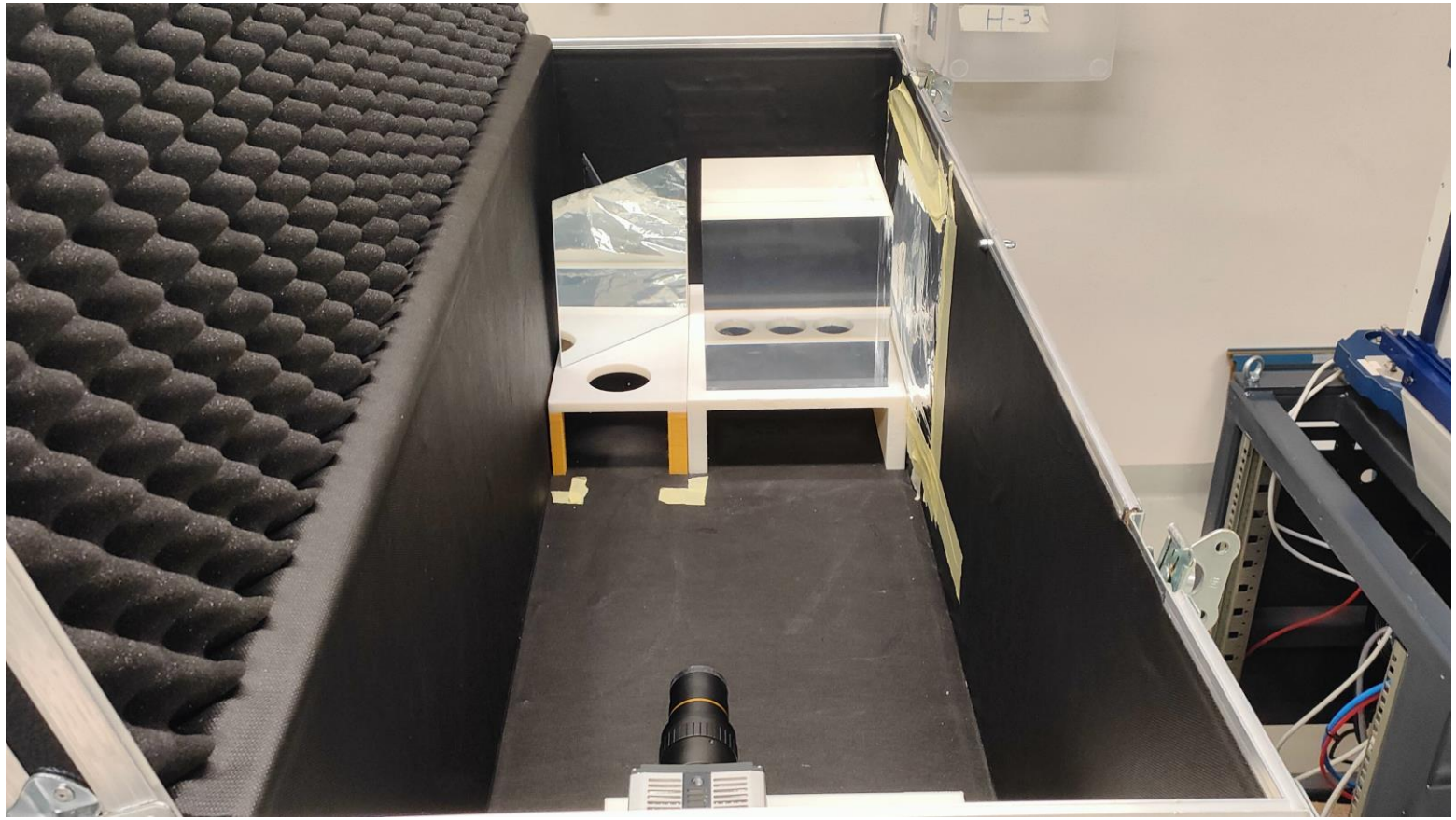
Fragments from 5x10^7 C ions at 280 MeV/u.



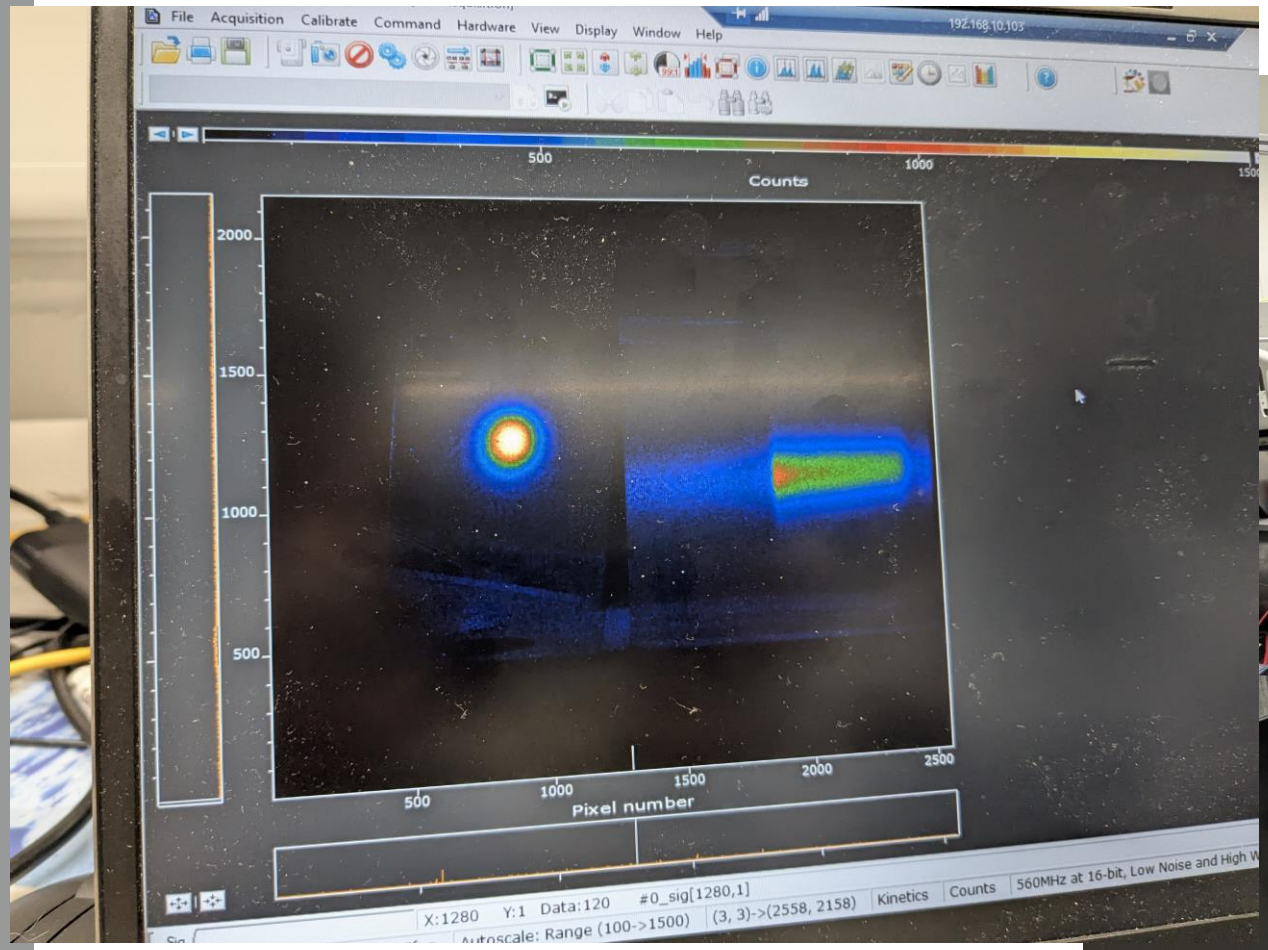
Protons, 81 MeV, 5x10^5 particles.



Protons (5x10^5) and carbon (5x10^6)


H-3

Test at GSI


File Acquisition Calibrate Command Hardware View Display Window Help
192.168.10.103
Counts
500
1000
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Pixel number
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Kinetics
Counts
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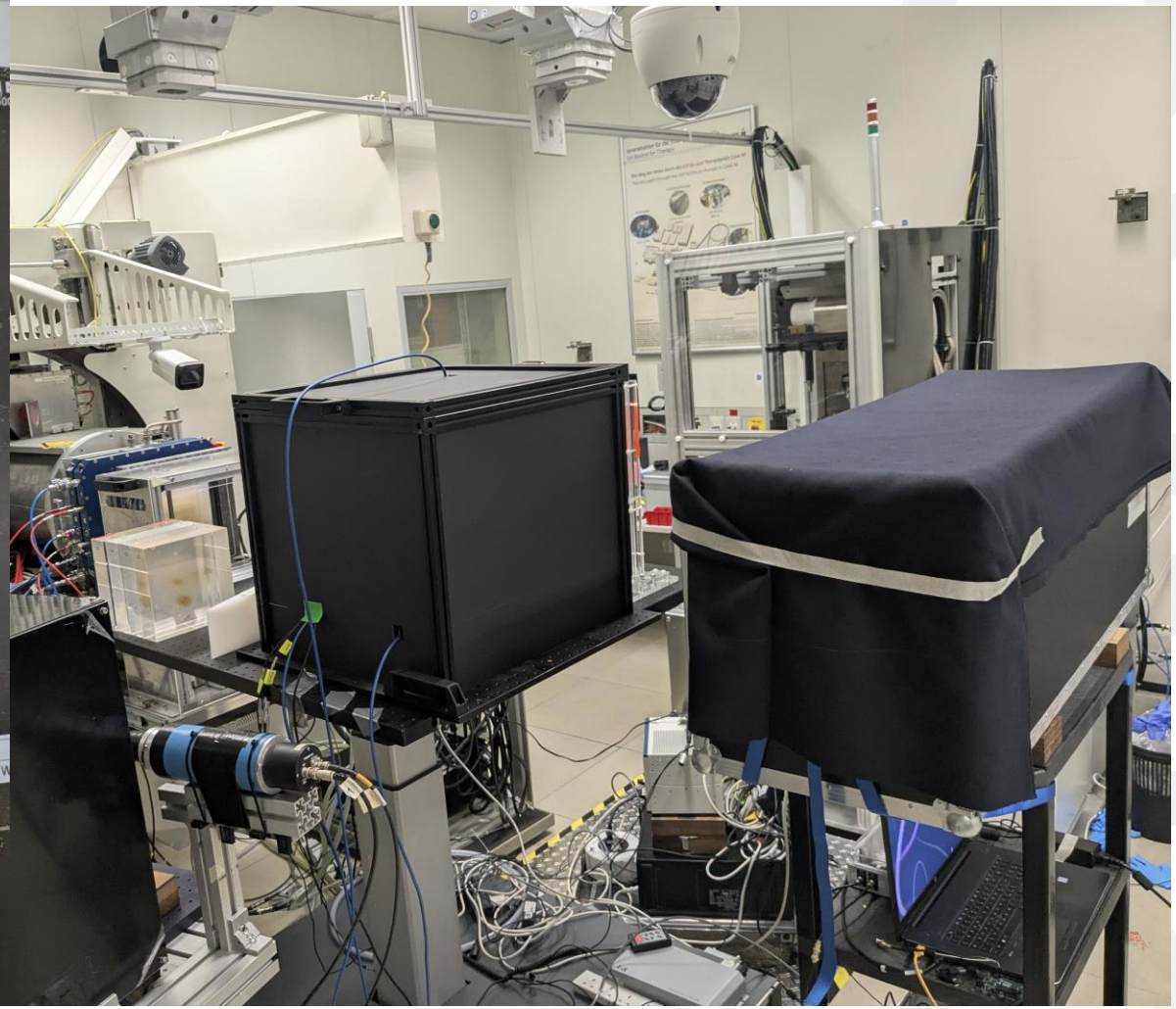
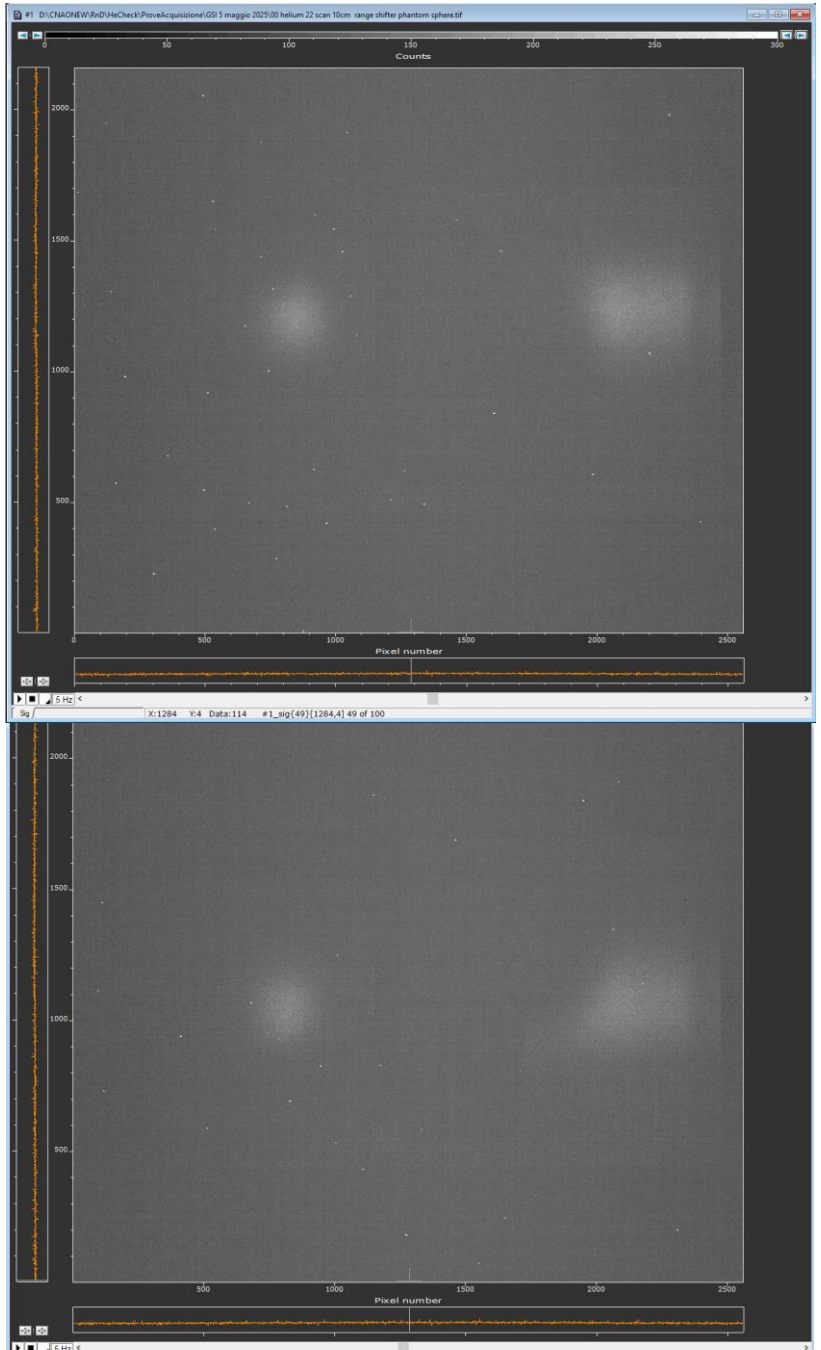
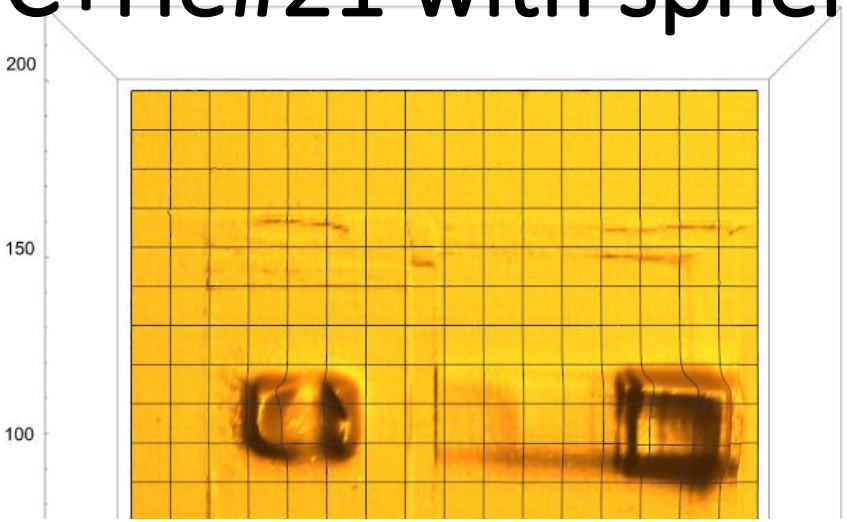
Autoscale: Range (100->1500)

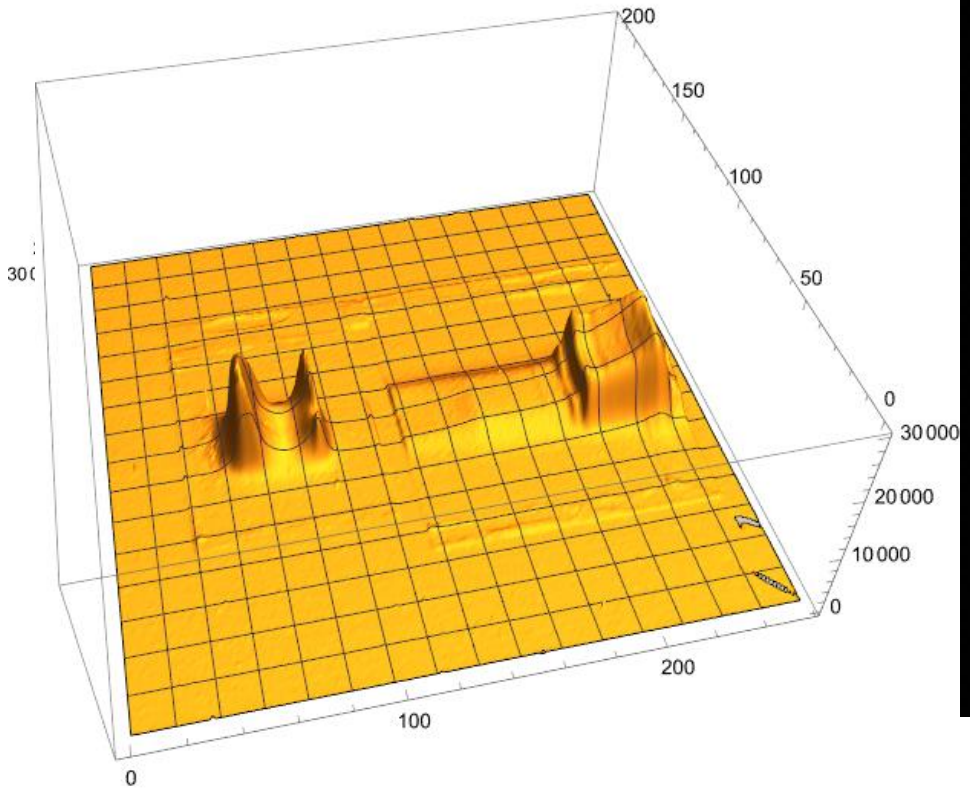


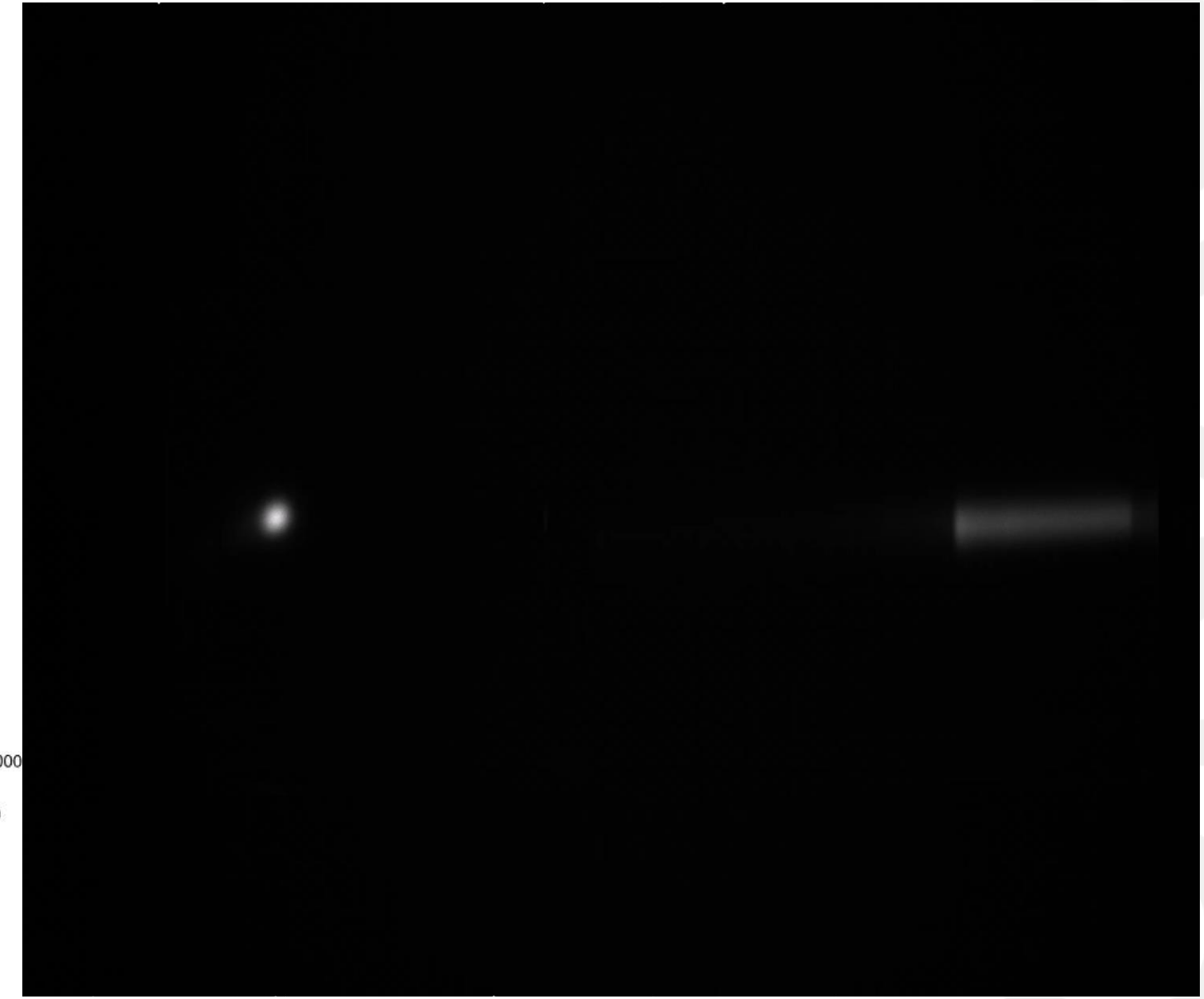

Counts
Pixel number
Pixel number


MOBIL
PTZ 2
2025-05-07 13:31:35
PTZ 3
Nozzle

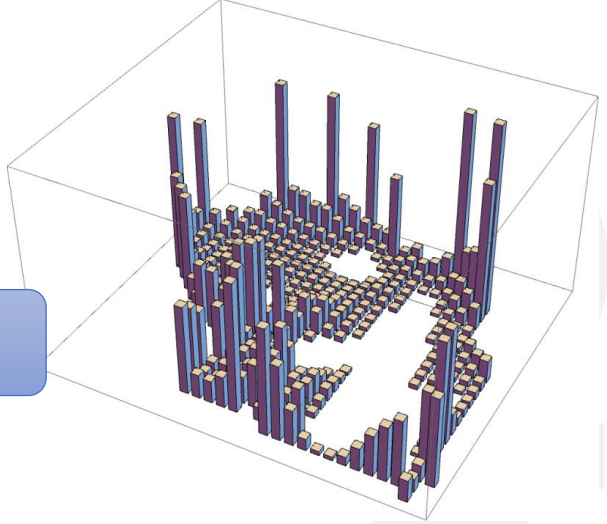
C+He#21 with sphere, no range shifter



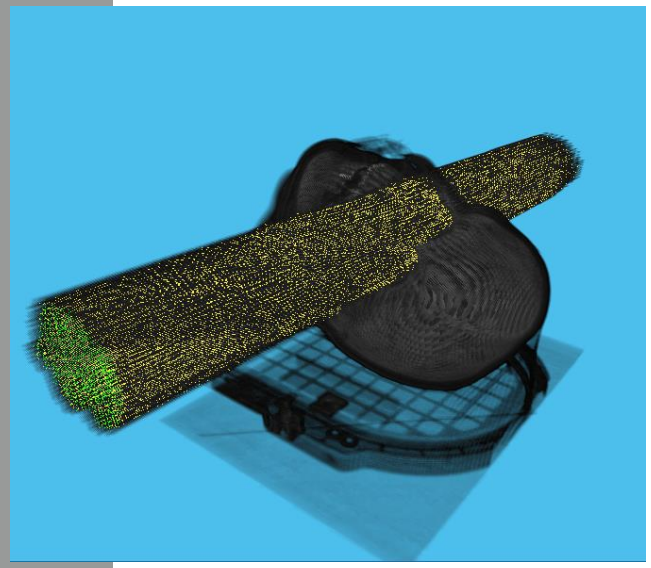




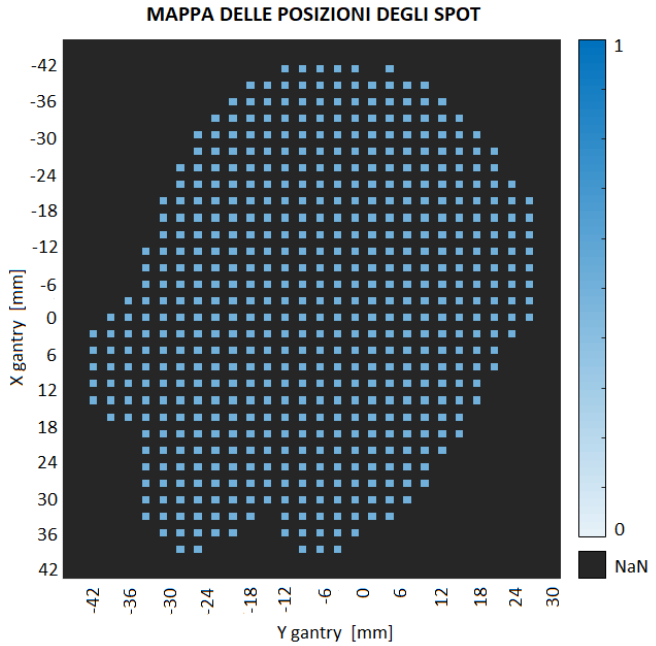
Irradiation simulation on CT



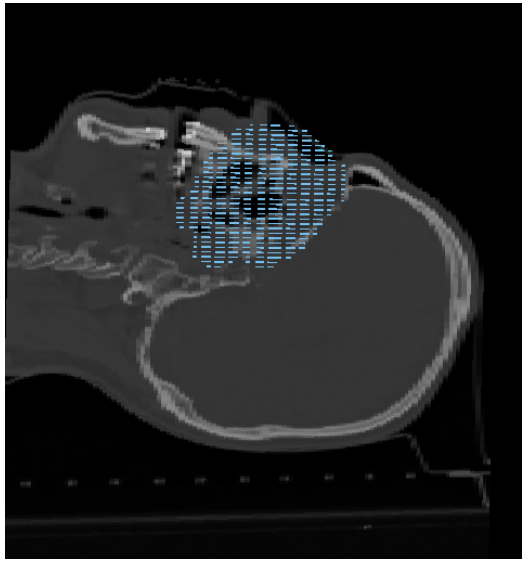
Rendering 3D del fascio erogato

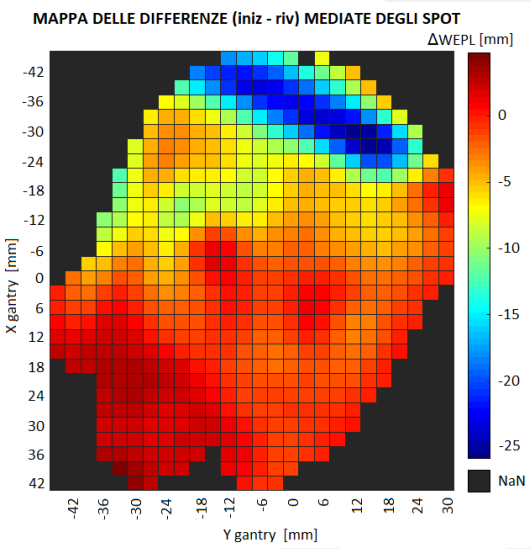


Profilo del fascio in sezione

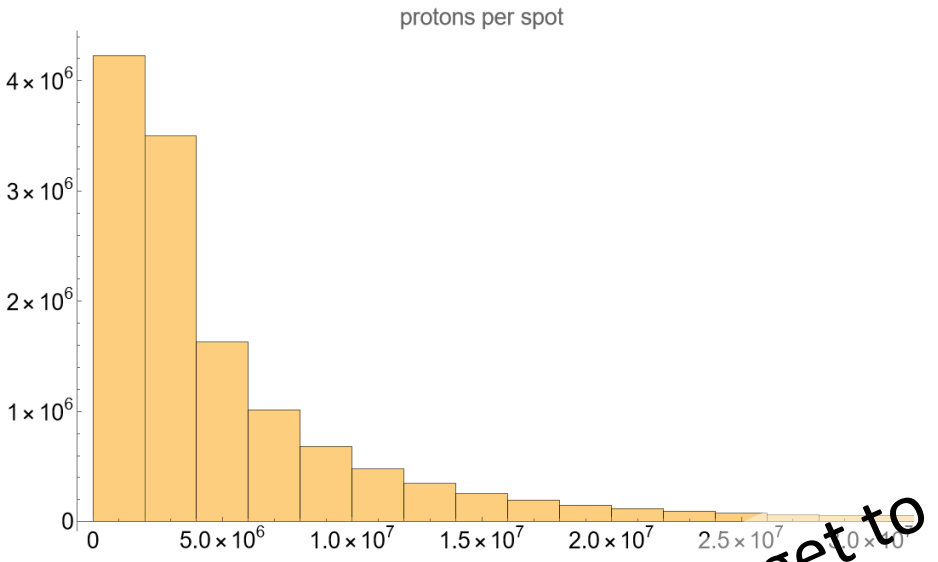


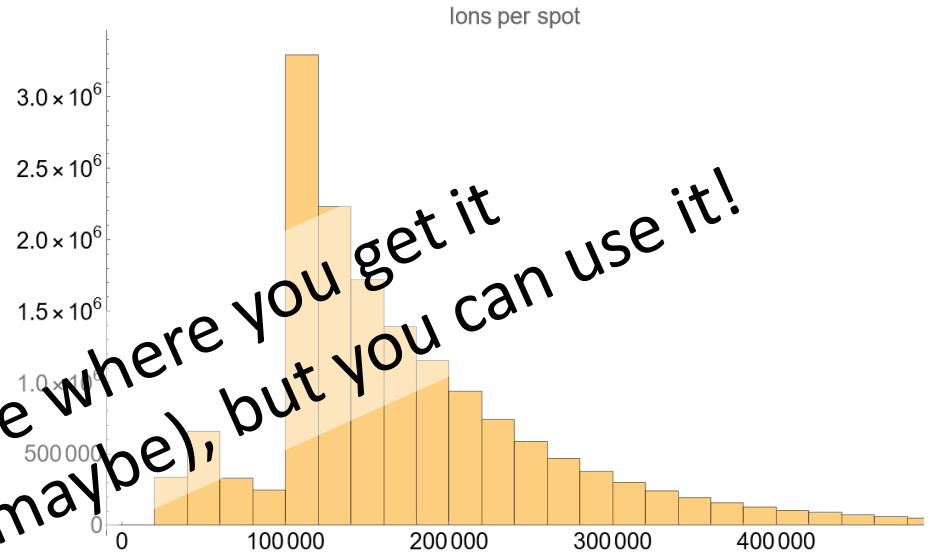
Fetta CT con il profilo del fascio





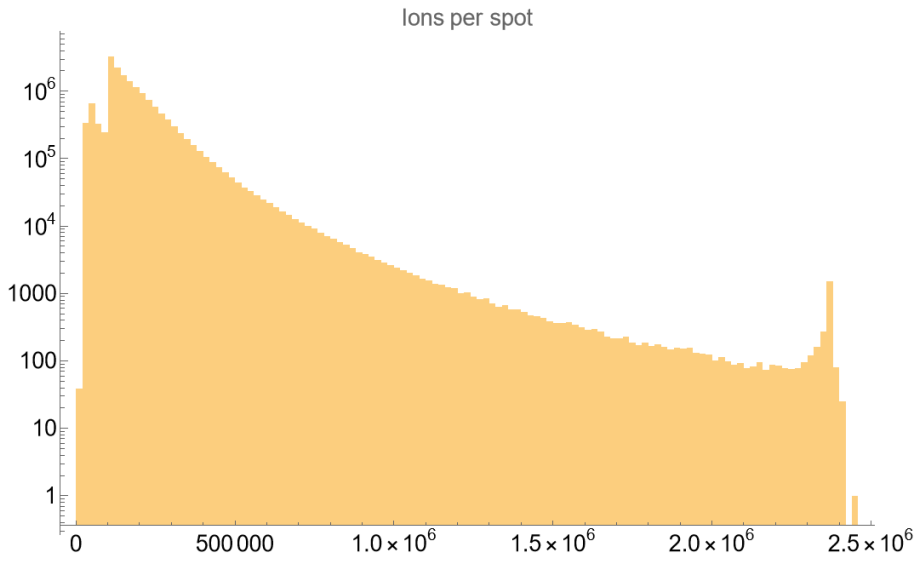
Number of particles per spot at CNAO (2024-25)





Thus you don't get to choose where you get it
and how much you get it (maybe), but you can use it!





And now let’s enjoy this fantastic workshop!

CNAO

“If you think research is expensive, try disease!”

Mary Lasker