The Dose Profiler tracker: an online Particle Therapy monitor

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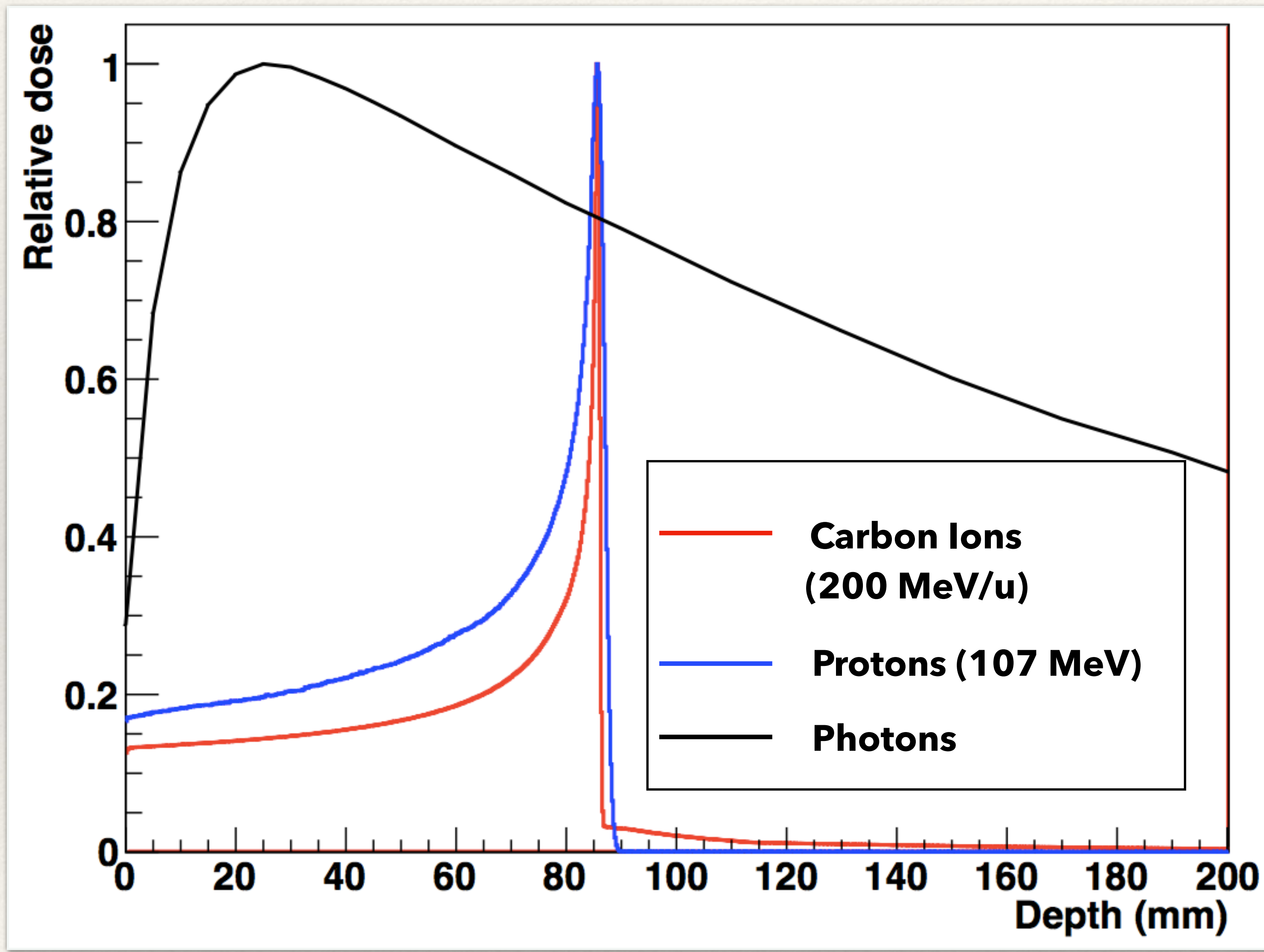
Particle Therapy (PT)

PT is a modern technique of non-invasive radiotherapy mainly devoted to the treatment of tumours untreatable with surgery or conventional radiotherapy.
It uses charged particle beams to release energy into the tumour volume causing the diseased cells apoptosis.

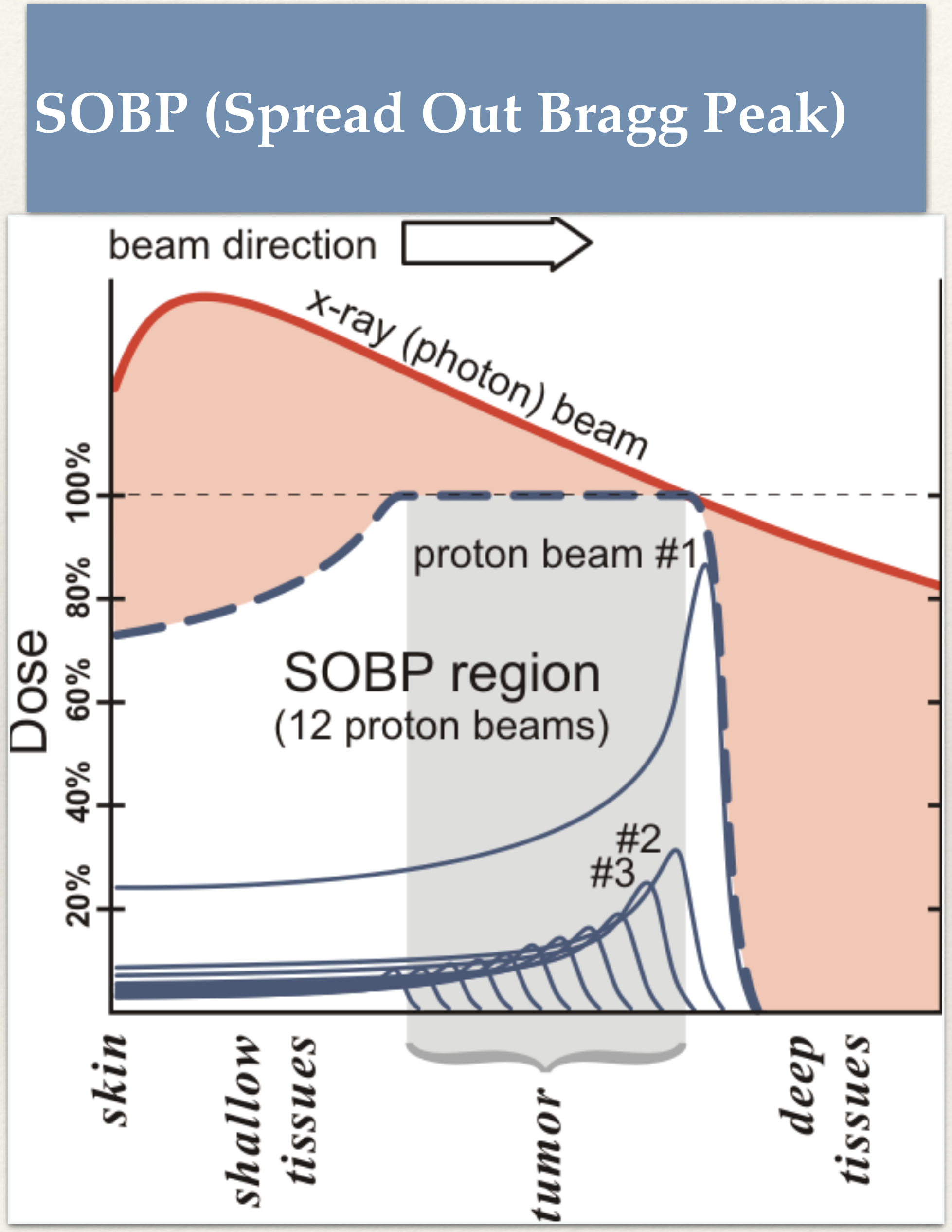


The **biological damage** is related to the **released energy**, **ionization density** and **type of projectile used**.

$$D = \frac{dE}{dm} \qquad \left[1Gy = 1\frac{J}{Kg}\right]$$

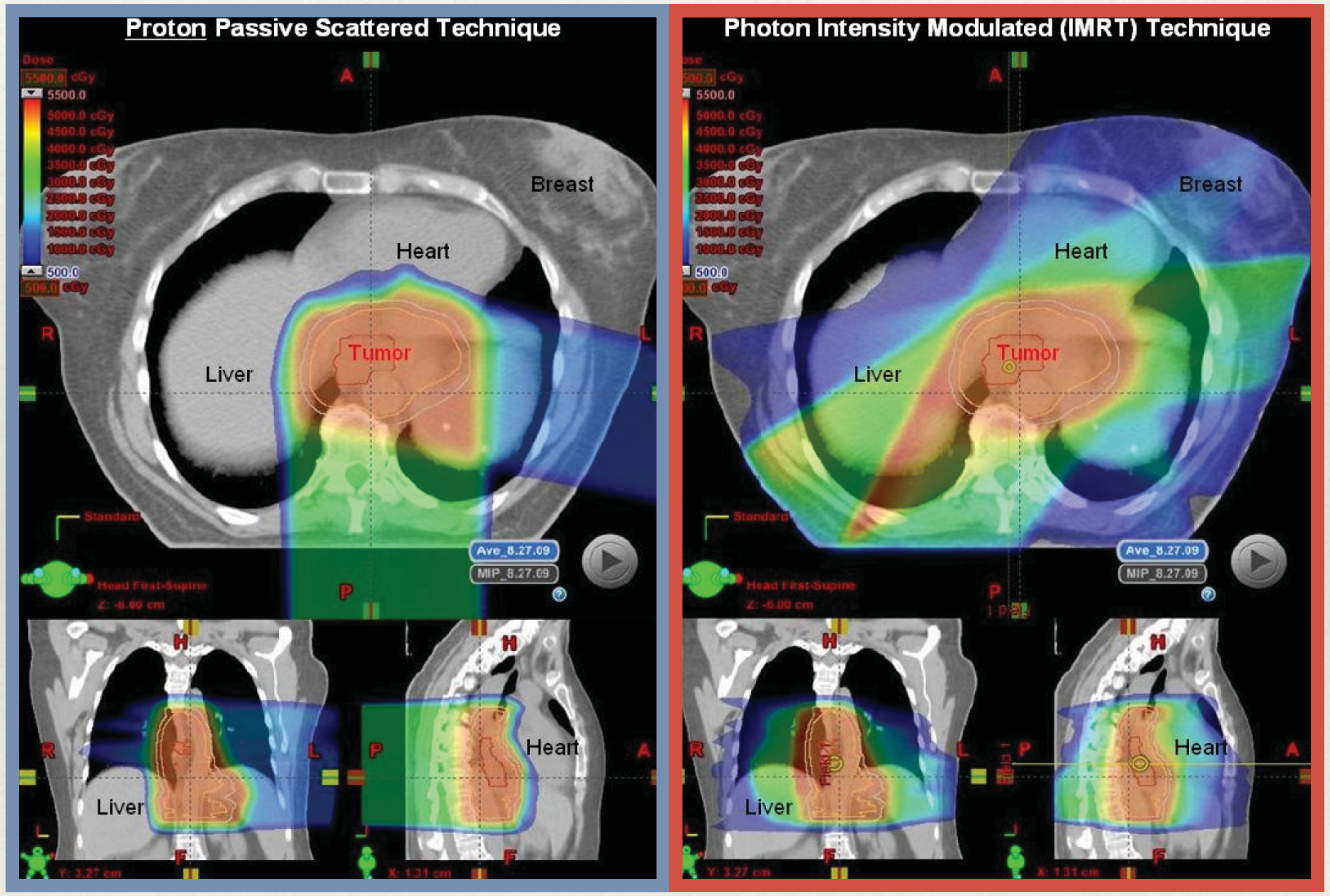
Particle Therapy (PT)

To cover the entire tumor volume, an overlap of beams at different energies is used obtaining a wider irradiation profile:



proton treatment (2 proton beams)

photon treatment (5 photon beams)

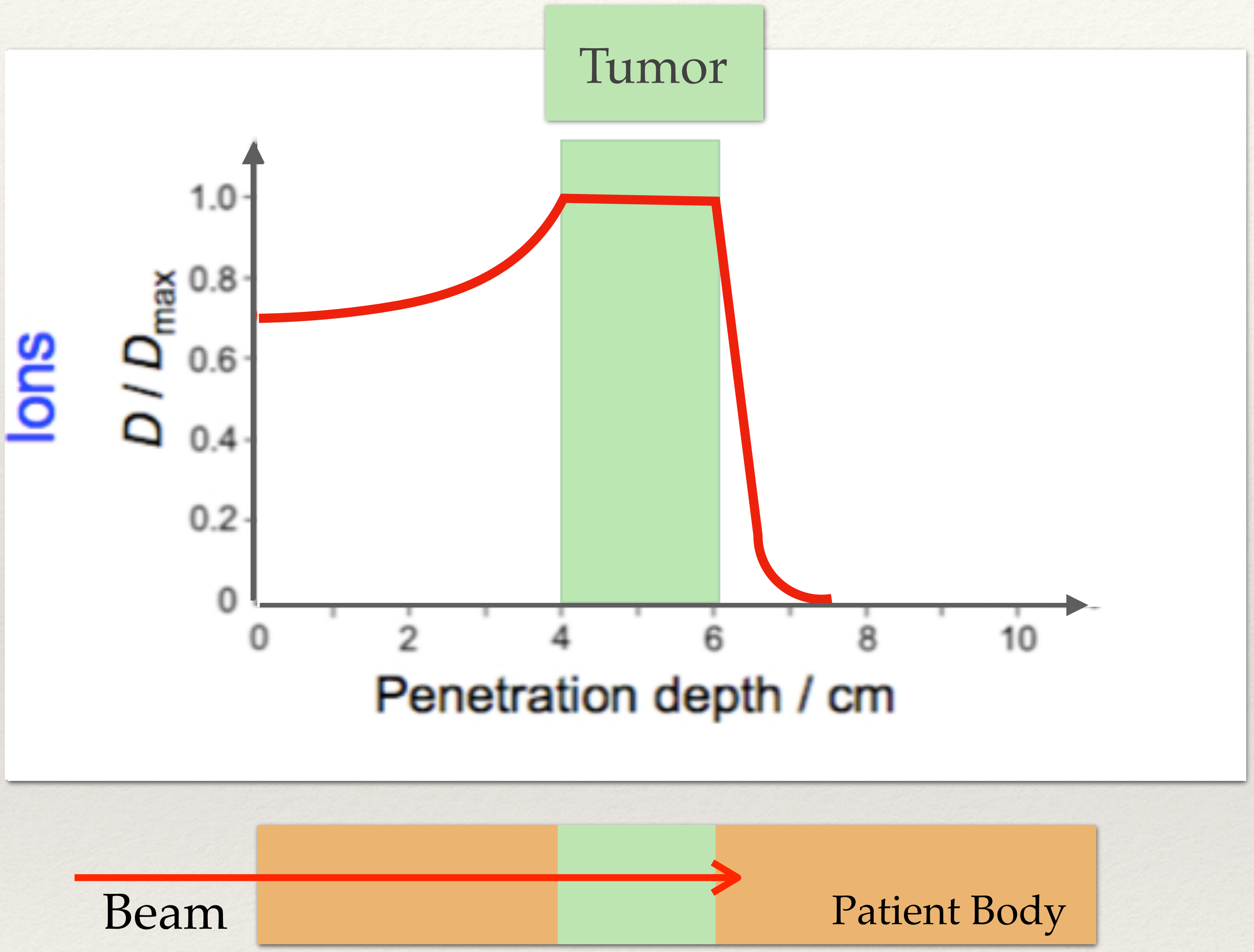


S. H. Lin, in Cancer, Volume 3 (2011), pp. 490-4101

Range Monitoring

high sensitivity in range variations

(patient mispositioning, uncertainties on the CT Hounsfield number conversion, anatomical density variation…)



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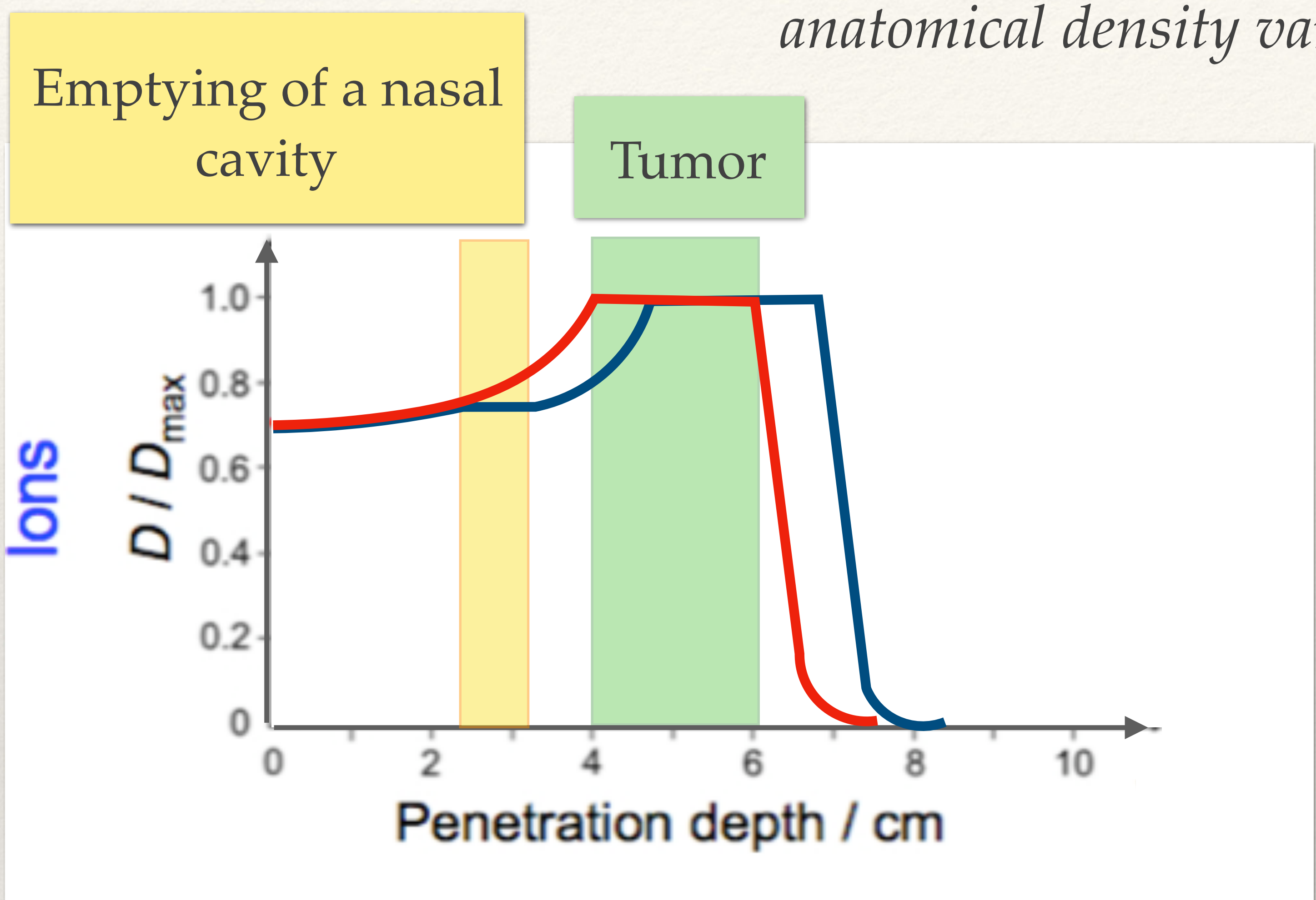

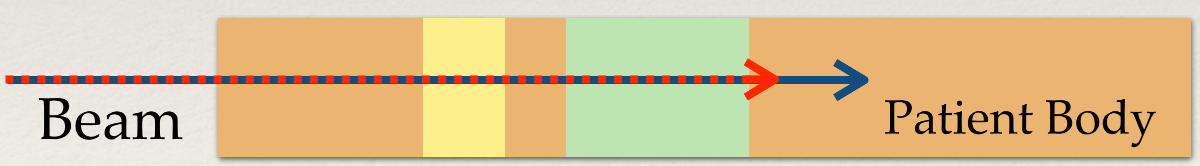

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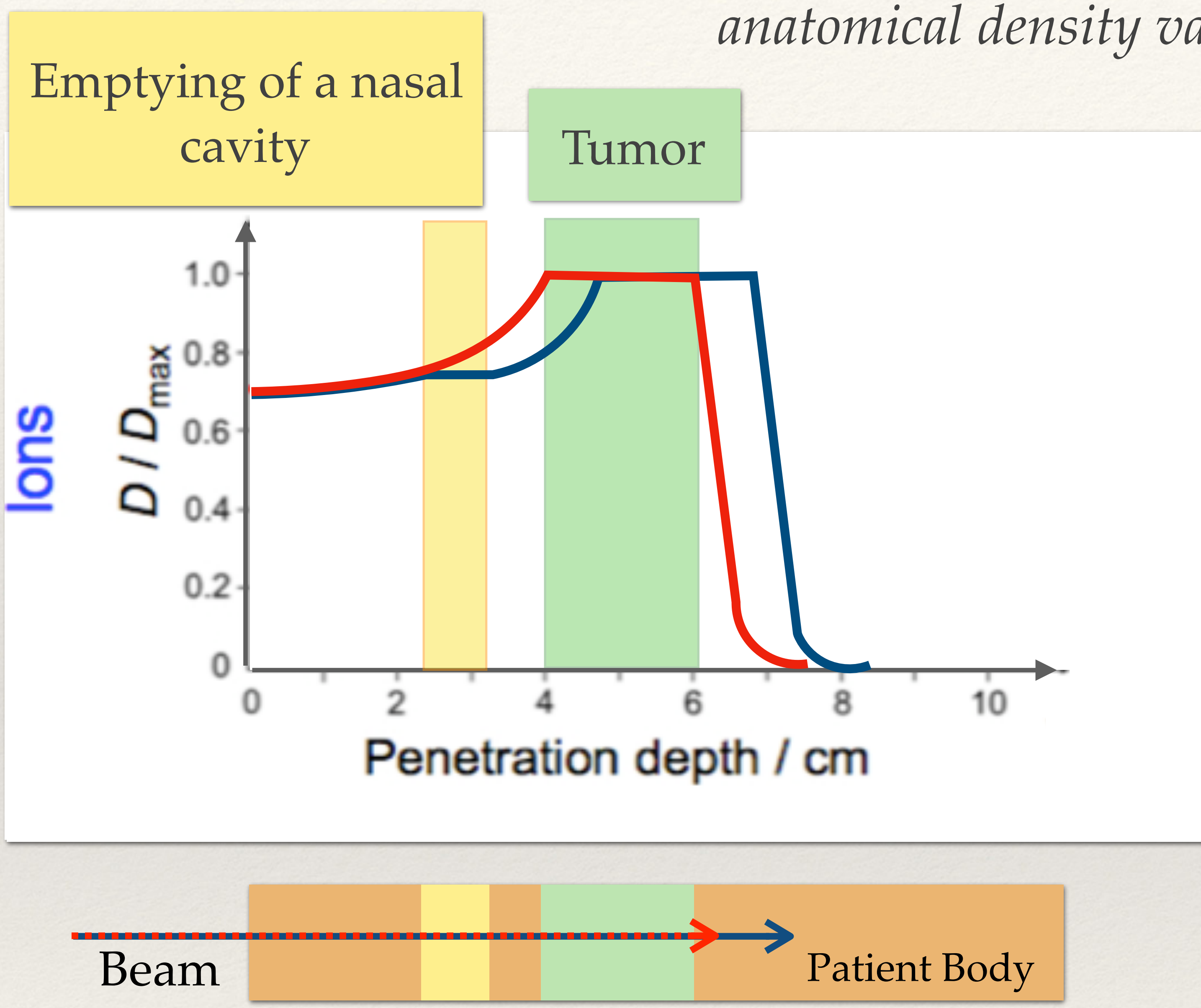
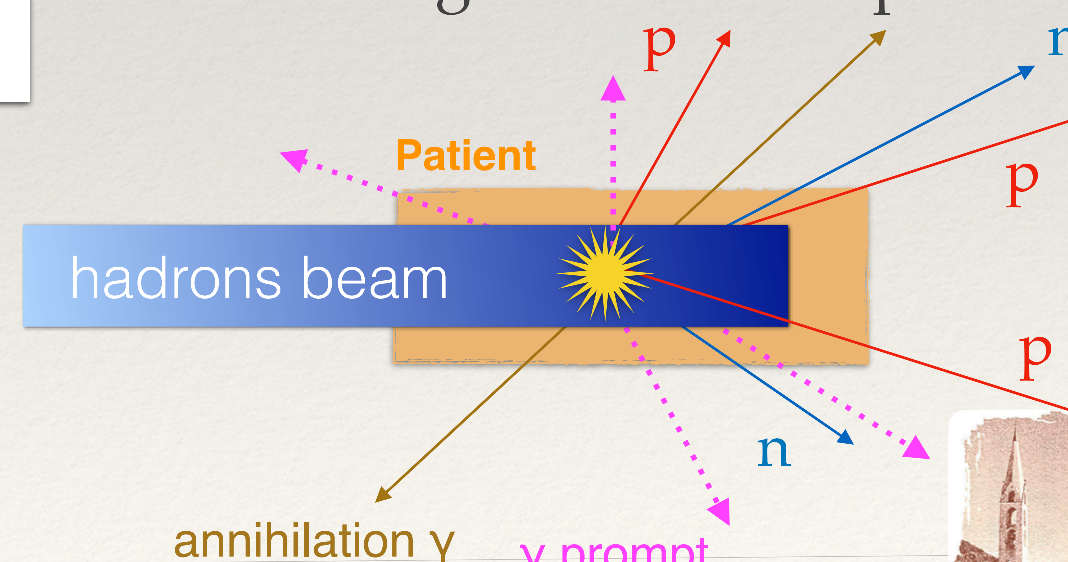


- An ideal PT beam range monitor should give **feedback** during the treatment (**online**)
- The beam is completely absorbed into the patient tissues -> a monitoring system must rely on **secondary particles** produced in nuclear interactions and coming out from the patient



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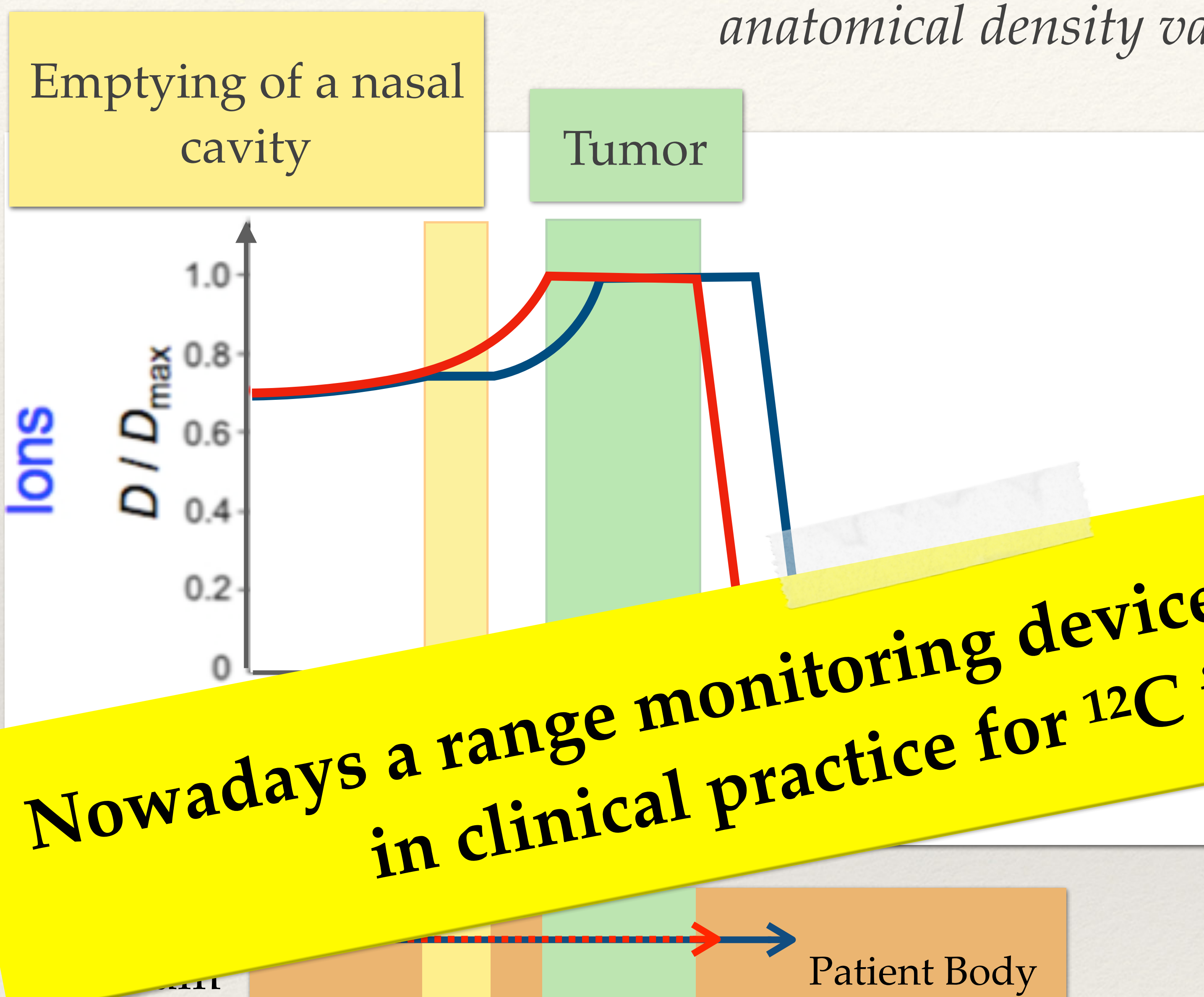

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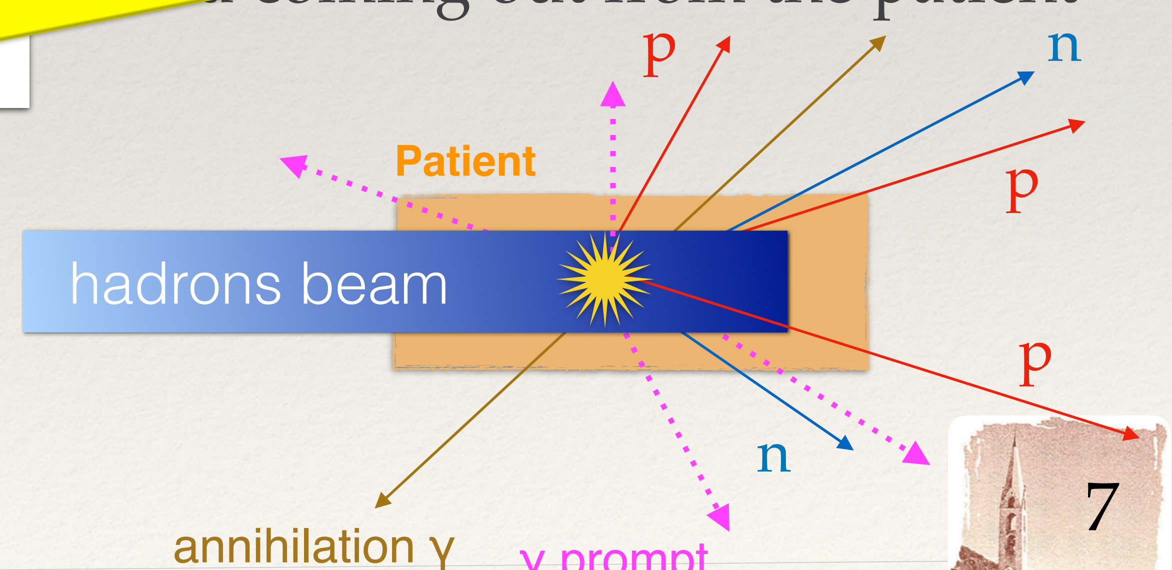


Nowadays a range monitoring device operable routinely in clinical practice for ^{12}C is missing

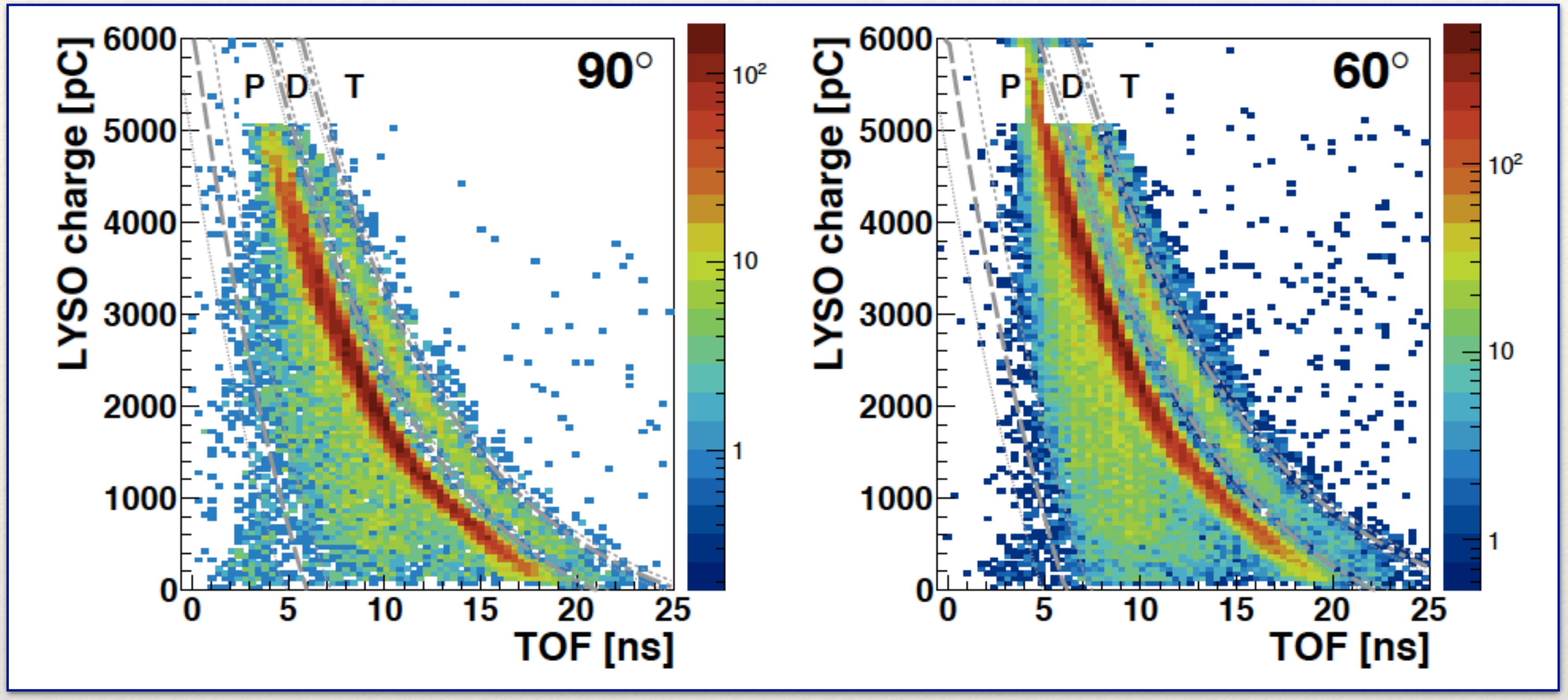
Charged secondary particles based monitoring

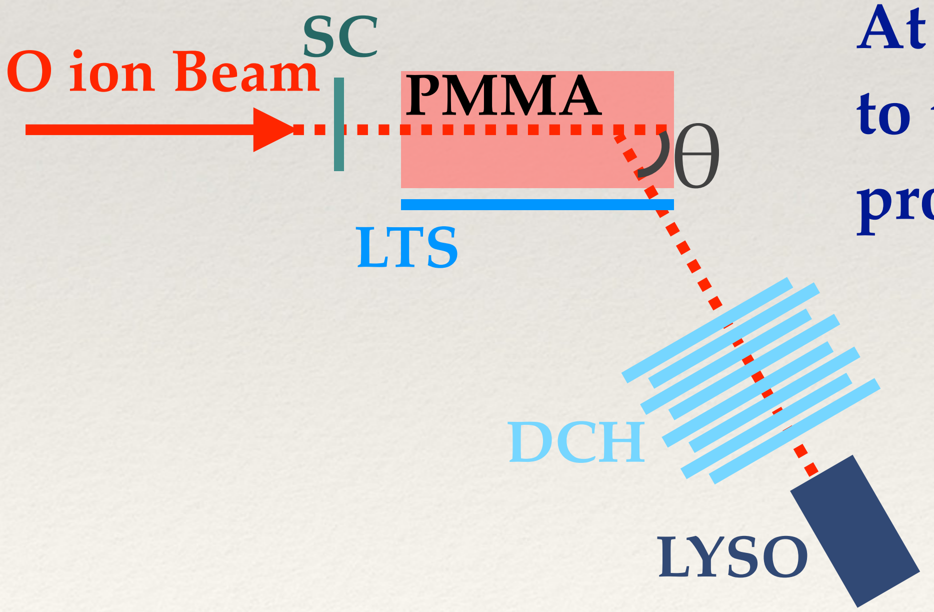
Detection with **charged secondary particles**:

Advantages

- Easy to detect (high efficiency, small background)
- Easy to track
- Significant production in PT treatments with C and O ions

O ion beam on a PMMA target





At large angles with respect to the beam direction mainly protons (P) are produced

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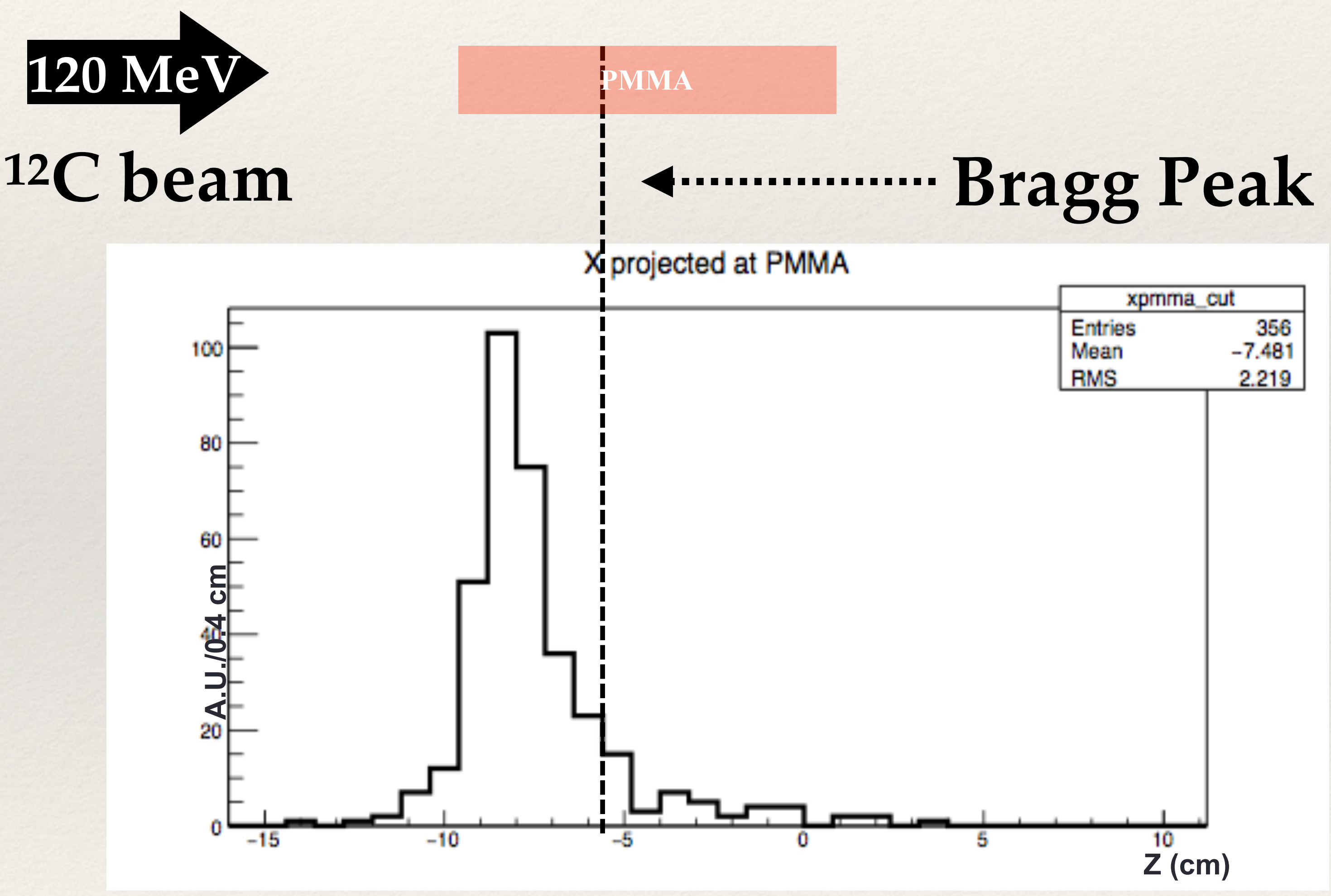
Correlation with the Bragg peak



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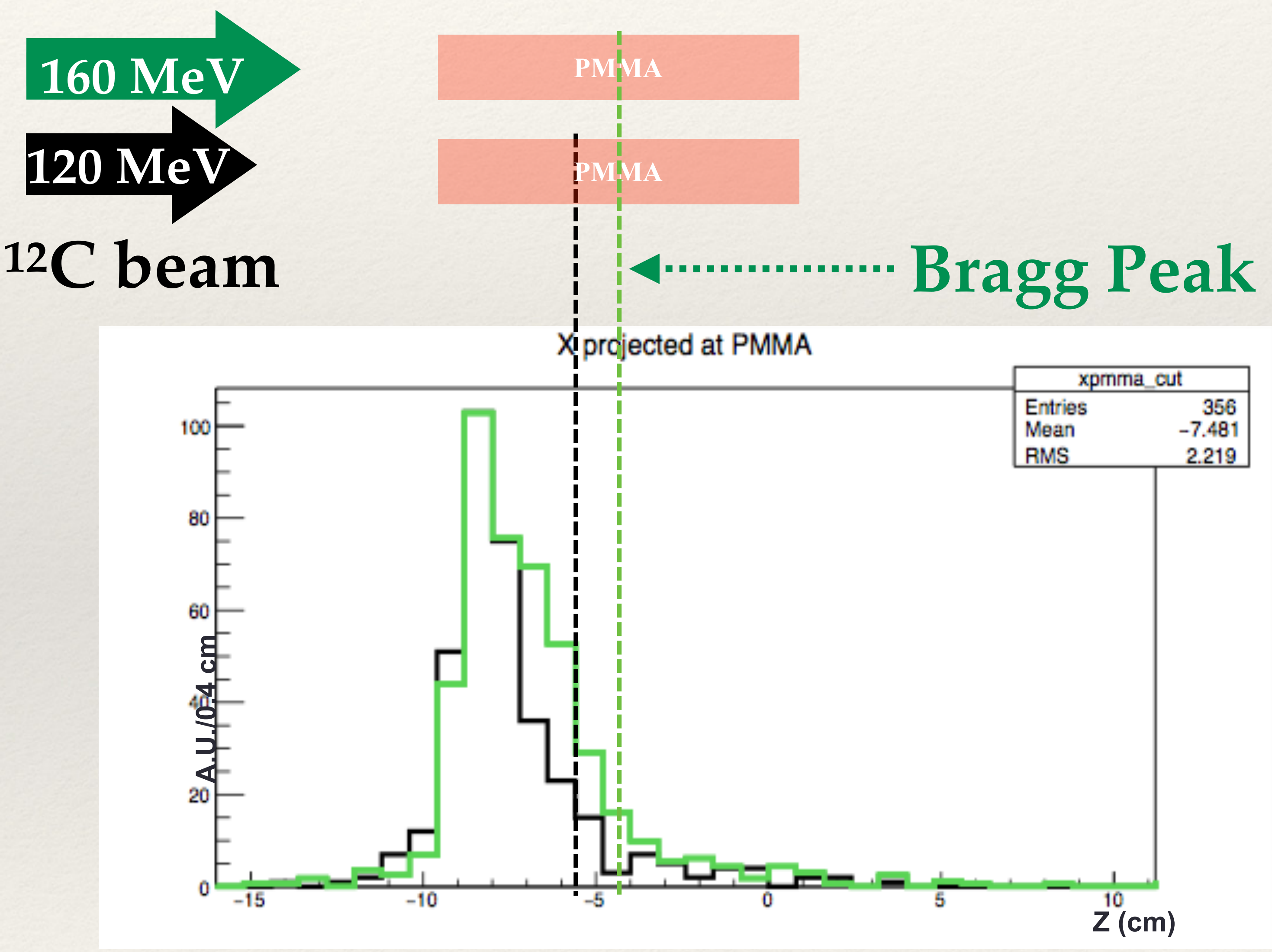

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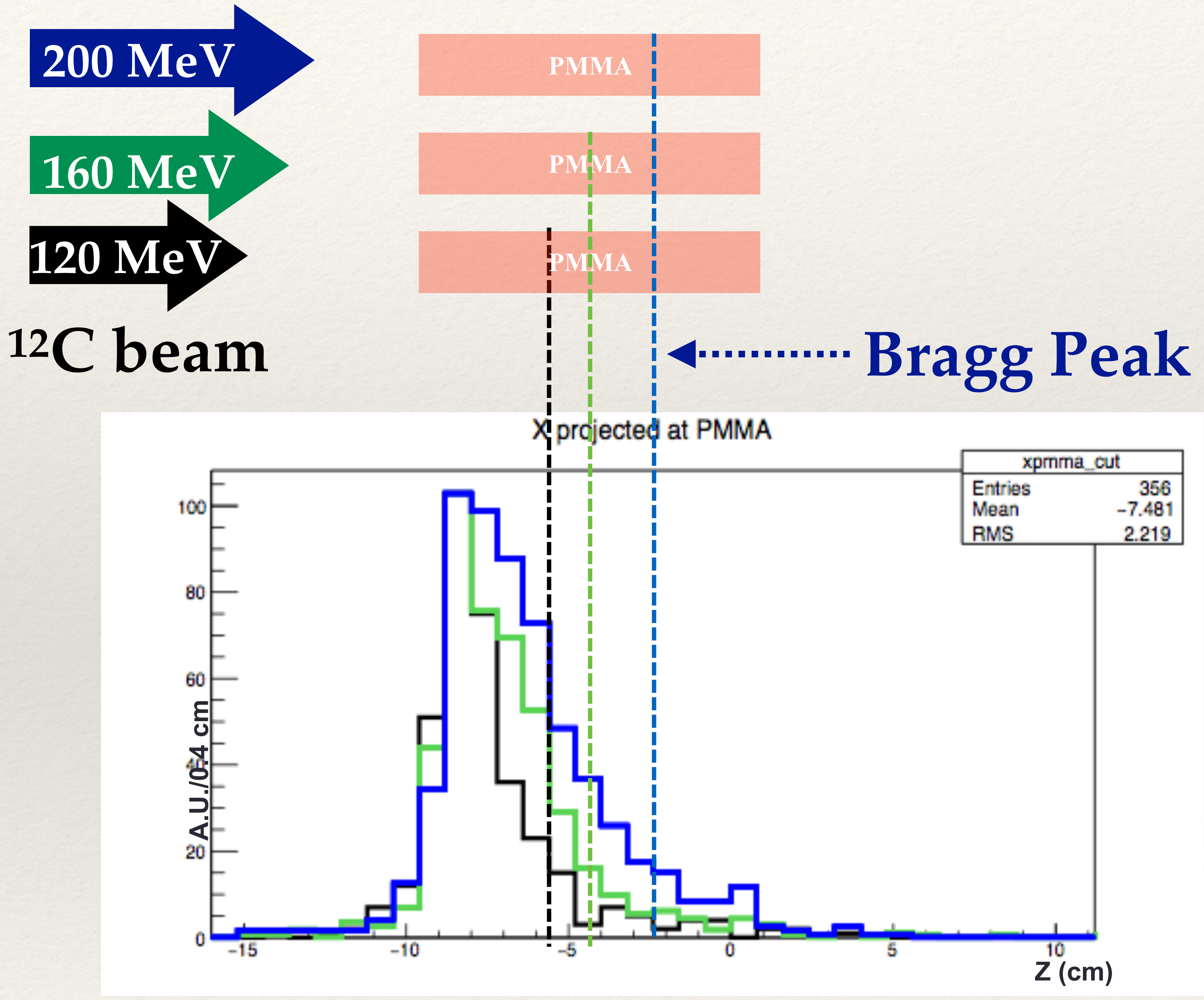

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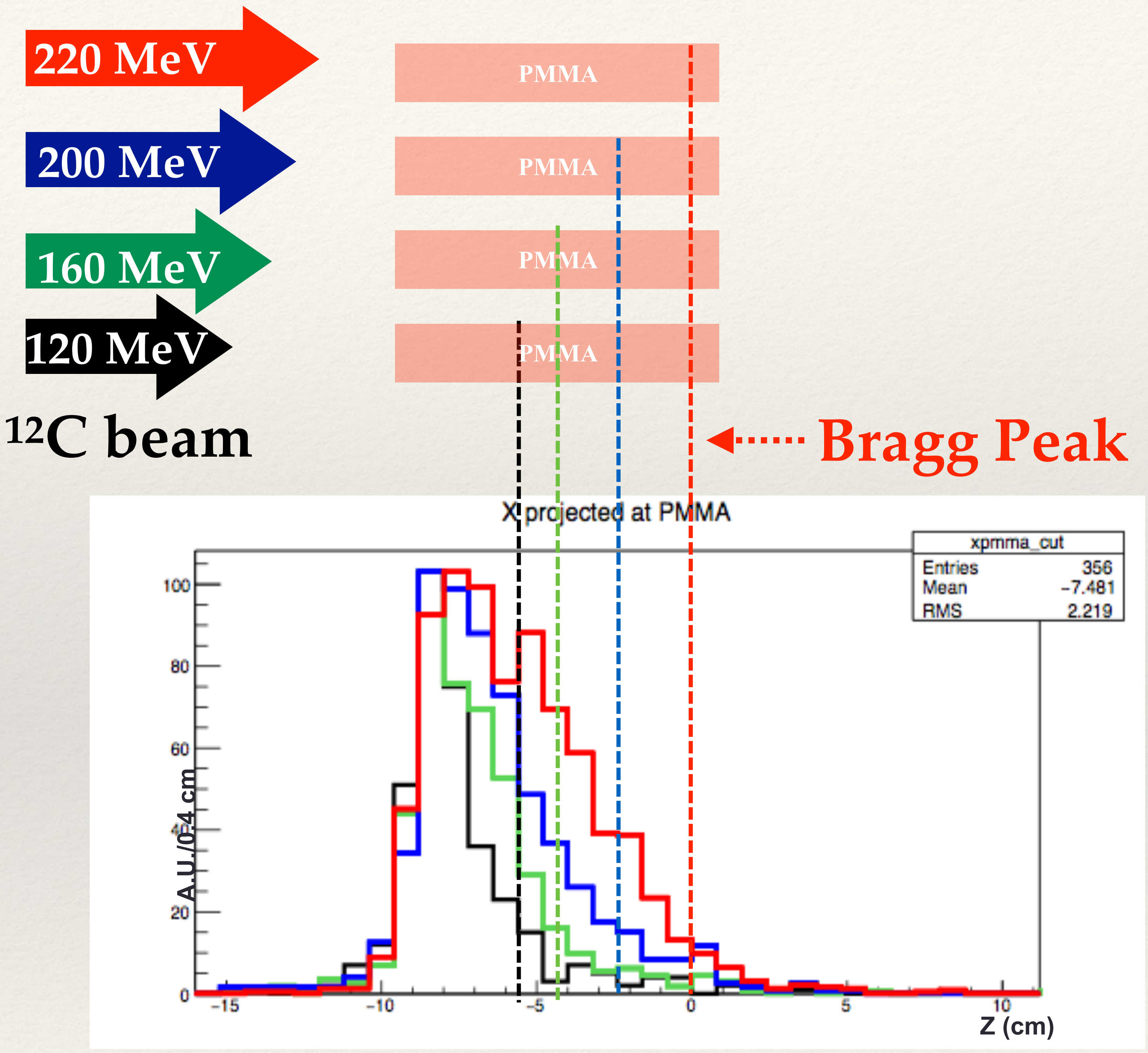
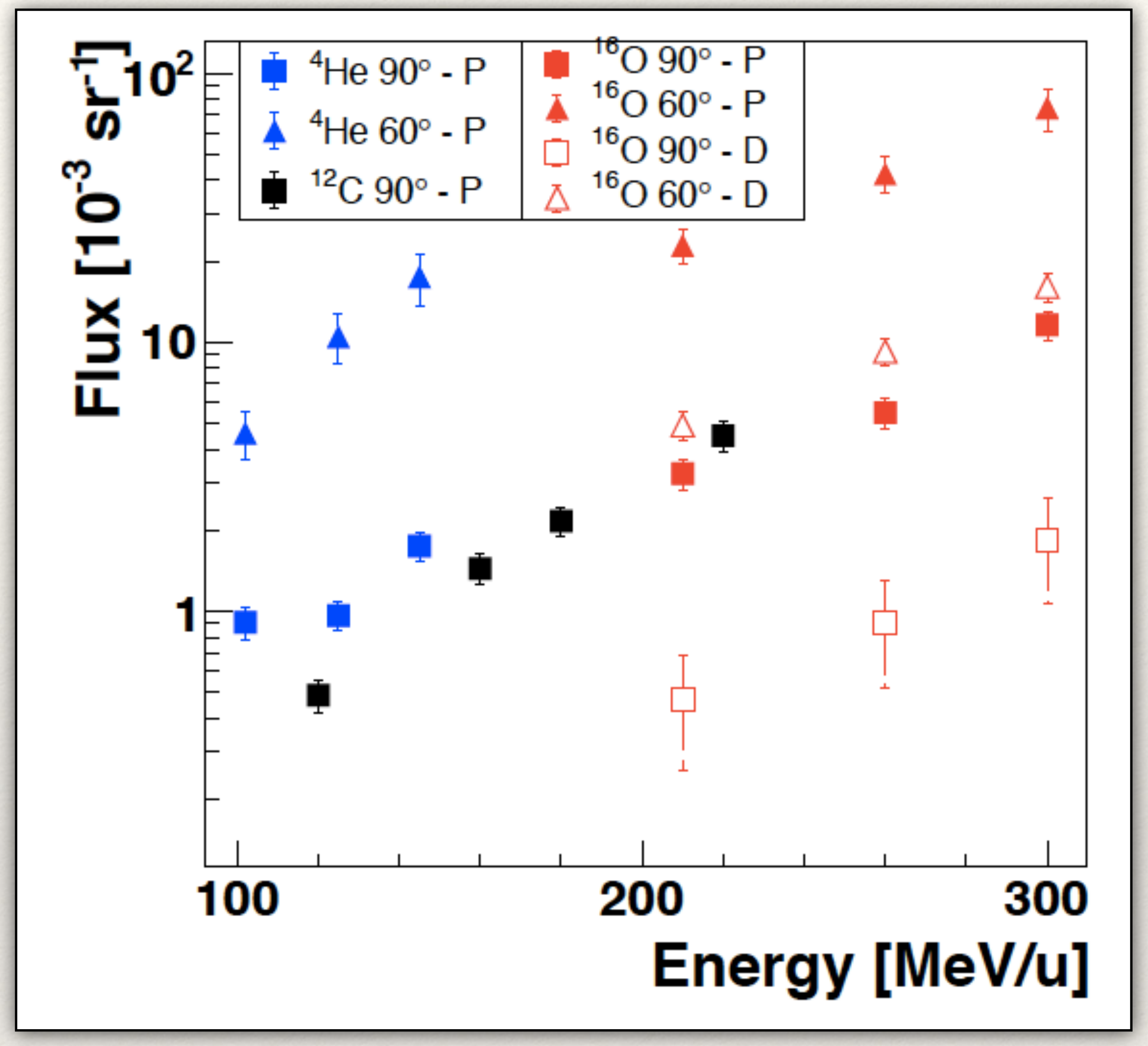


Charged secondary particles based monitoring

Detection with **charged secondary particles**:

Challenges

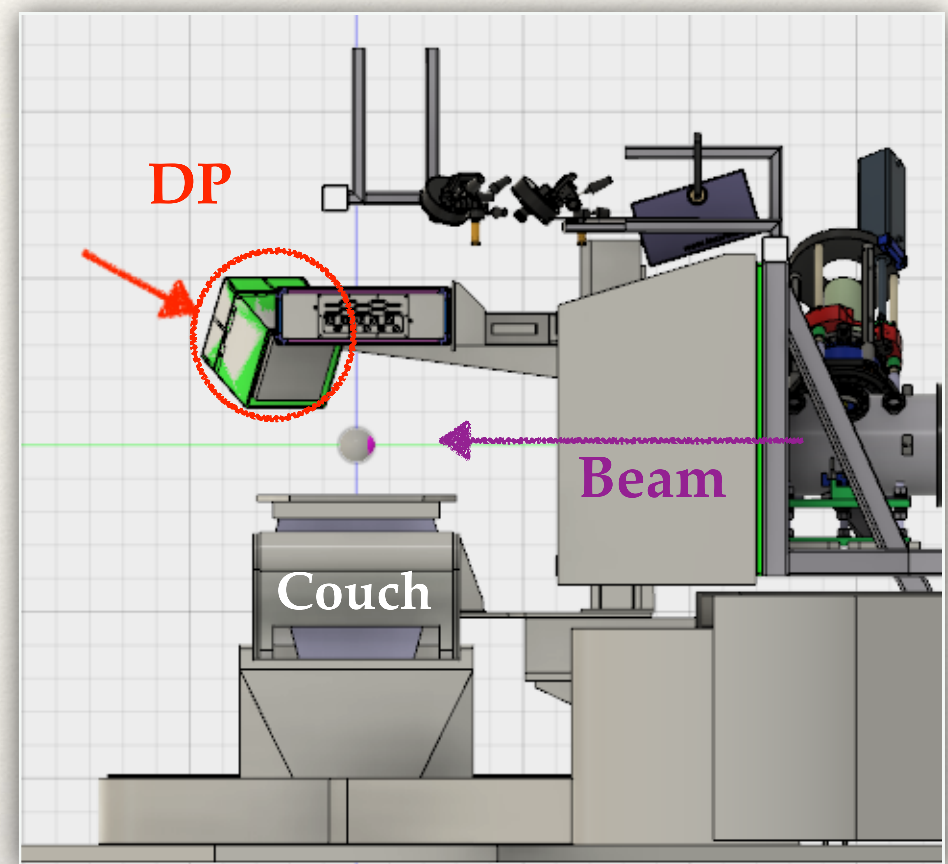
- Charged fragments suffer from absorption and multiple scattering interactions in matter (patient body)
- Maximize the statistics at large angles wrt beam direction



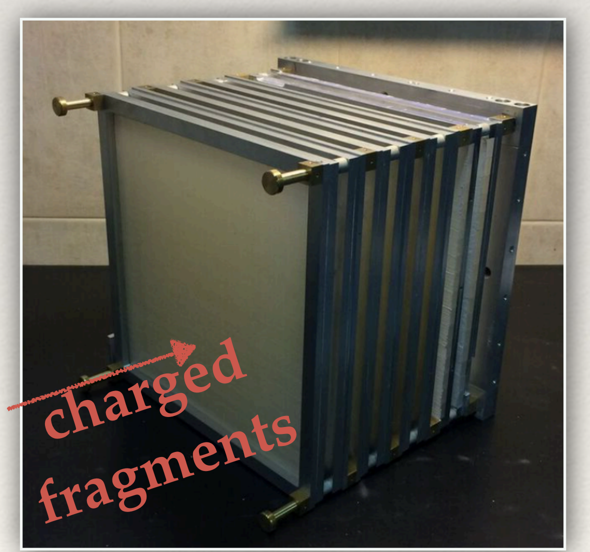
A significant flux of charged particles is observed with C and O beams with energy of interest for PT applications

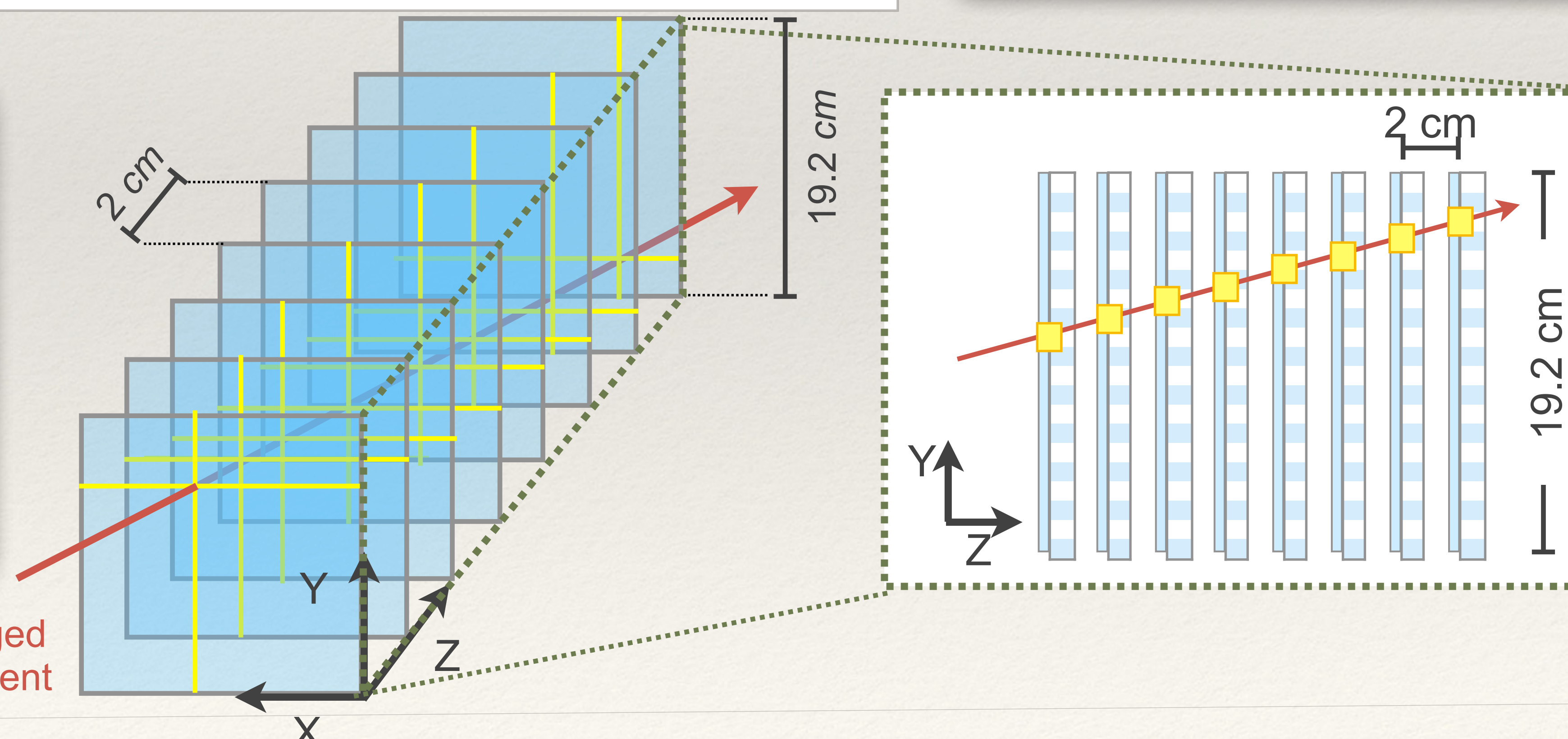
Dose Profiler

Developed within the **INSIDE** project at **CNAO** with a PET device for a bi-modal simultaneous approach: **charged fragments** and ß+ emitters detection tailored respectively for **carbon** and proton **treatments monitoring.**



- **8 planes**, each one composed of 2 orthogonally oriented **scintillating fibres** layers (500x500 μm^2)
- Readout: **SiPM**
- **3072 channels**



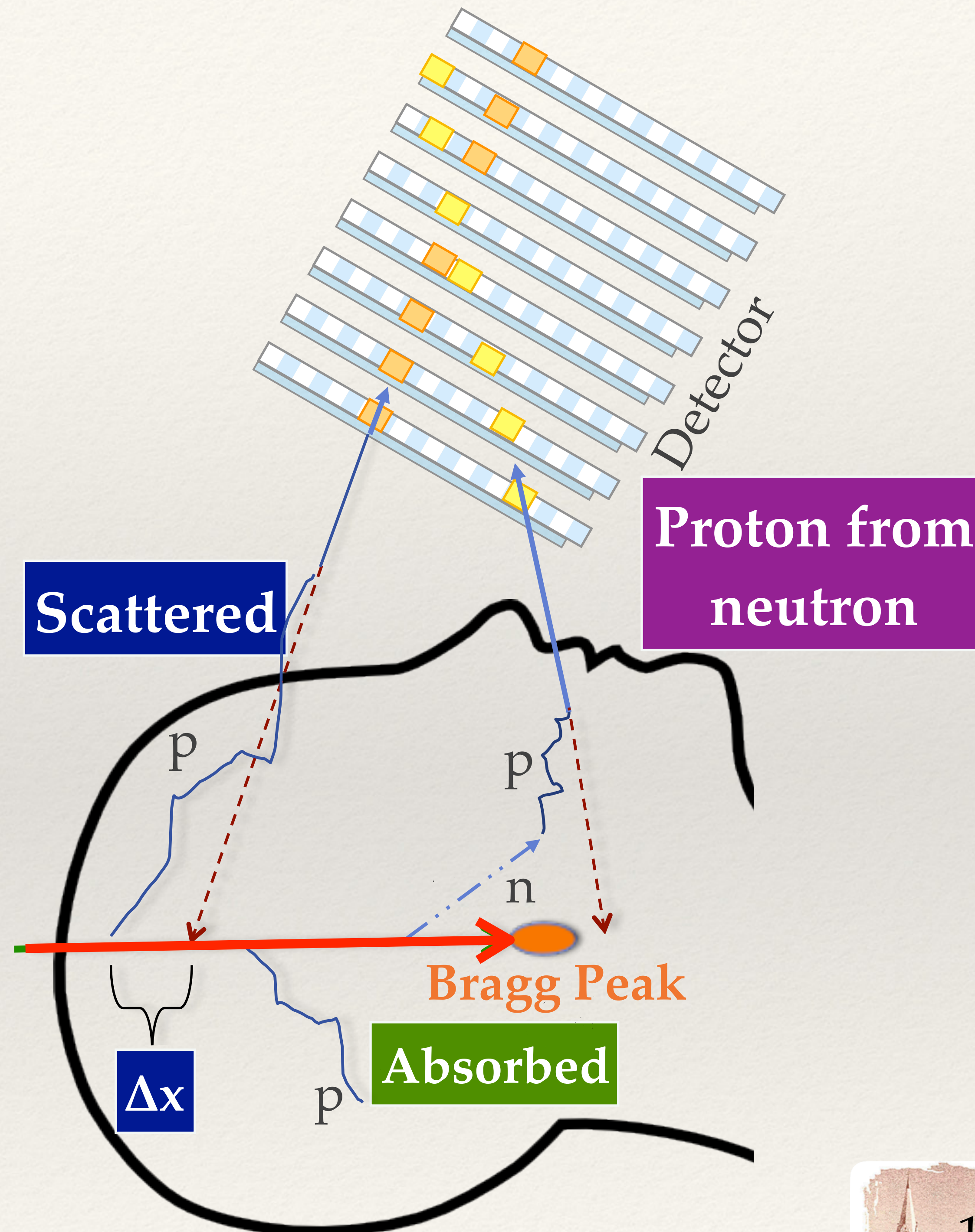


Matter Effect

The effect of the fragment interaction undergone by the fragments in the patient has to be properly taken into account to correlate the emission profile and the beam range.

The reconstructed emission distribution is affected by several effects:

- **the resolution is limited by the multiple scattering in the patient. Typical resolution on Δx is of the order of 6-8 mm;**
- **a proton can be absorbed depending on the crossed material and on emission energy, which in turn depends on the emission angle and the beam energy at the emission point;**
- **a neutron can generate uncorrelated protons**



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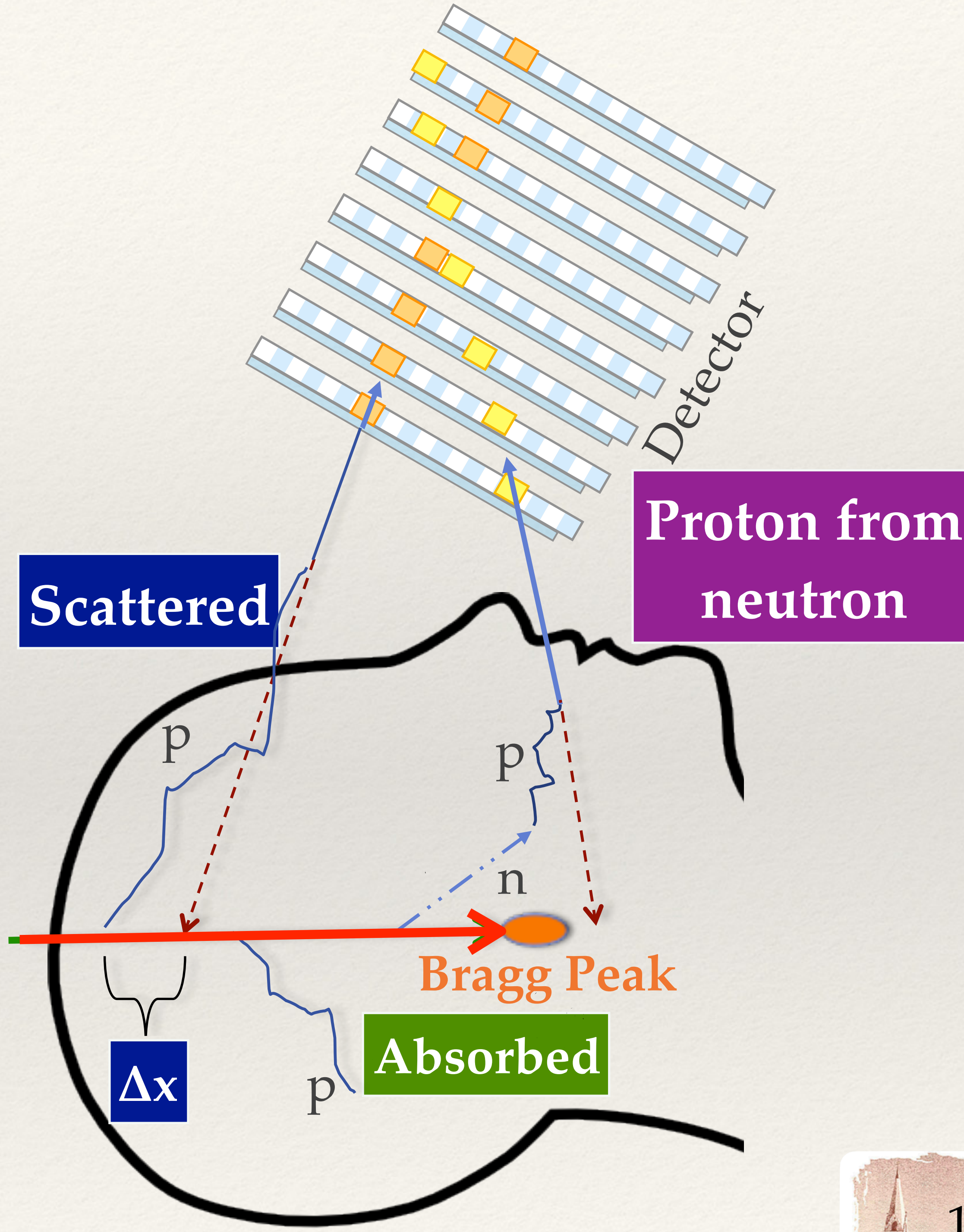
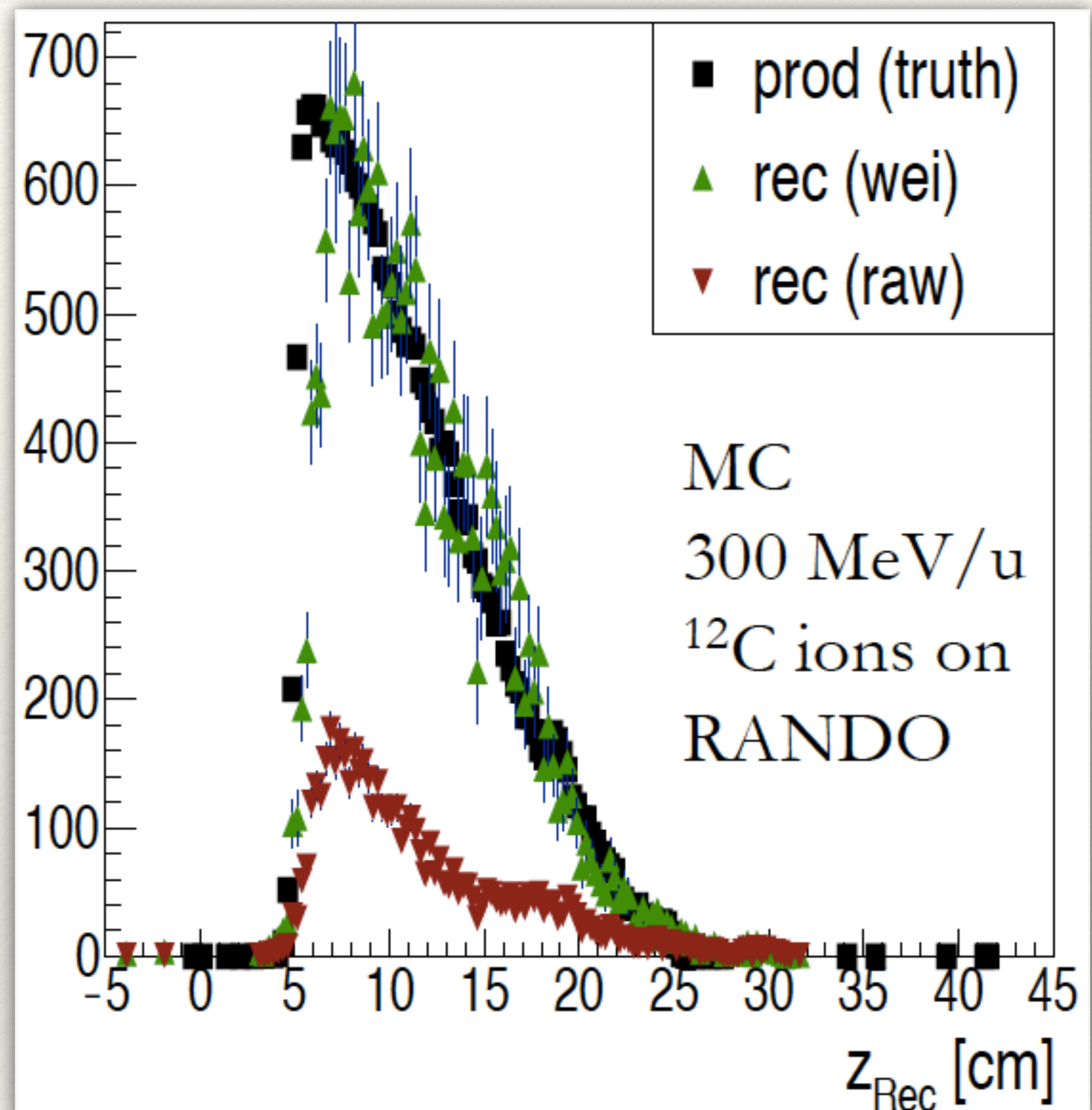
Approaches to minimize and correct the matter effect:

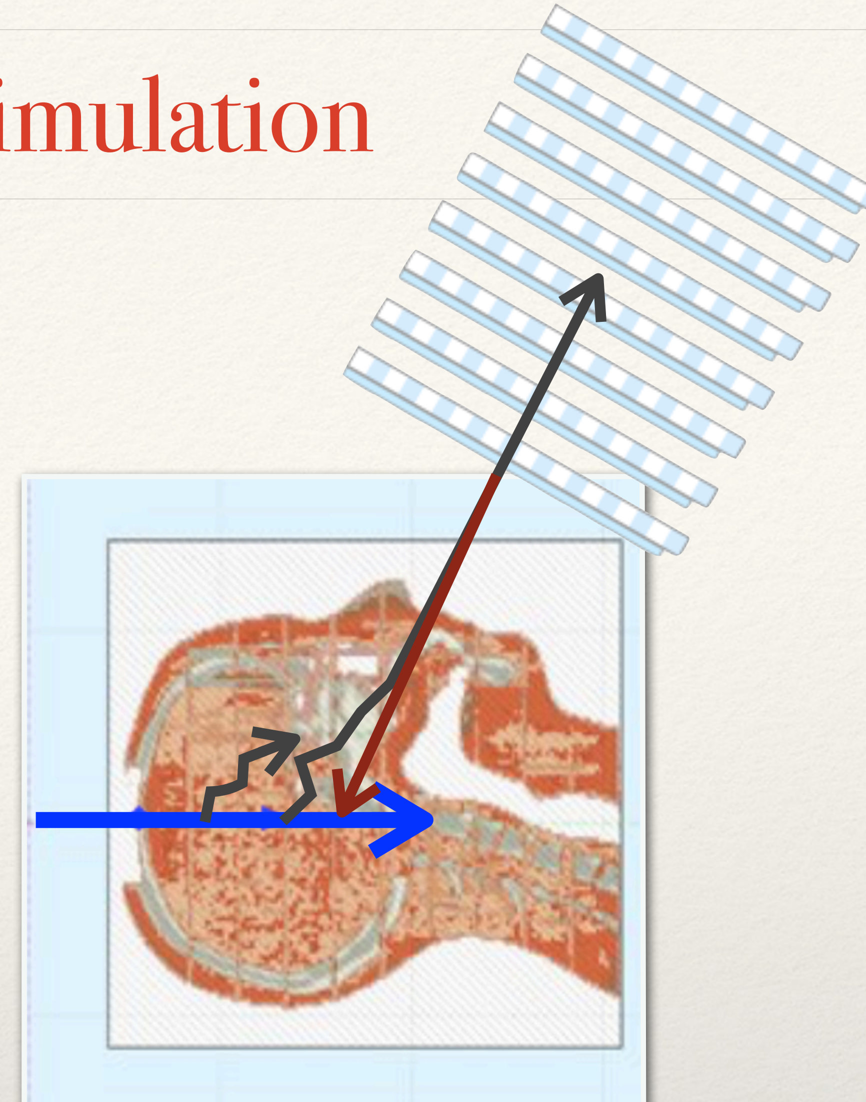
Detector at **large angle** (60-90° wrt beam direction): better resolution (parallax error due to beam size) usually less material to escape patient

MC simulation to evaluate the probability of each track to escape the patient in function of the beam energy at proton emission point and of the weighted path crossed by the proton.



Matter Effect - MC simulation



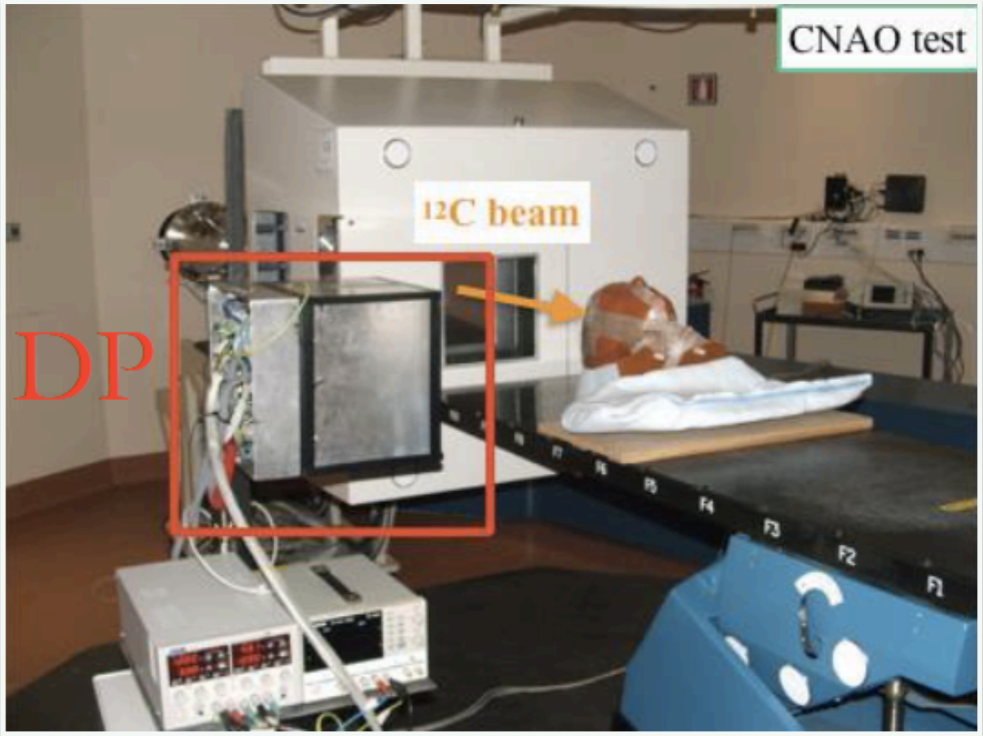


RANDO® : anthropomorphic phantom, whose density is modeled to properly mimic the human head tissues.

For each **proton detected**, MC used the CT info to compute the path of the proton and then **reweight the track**-> recover the **emission shape.**

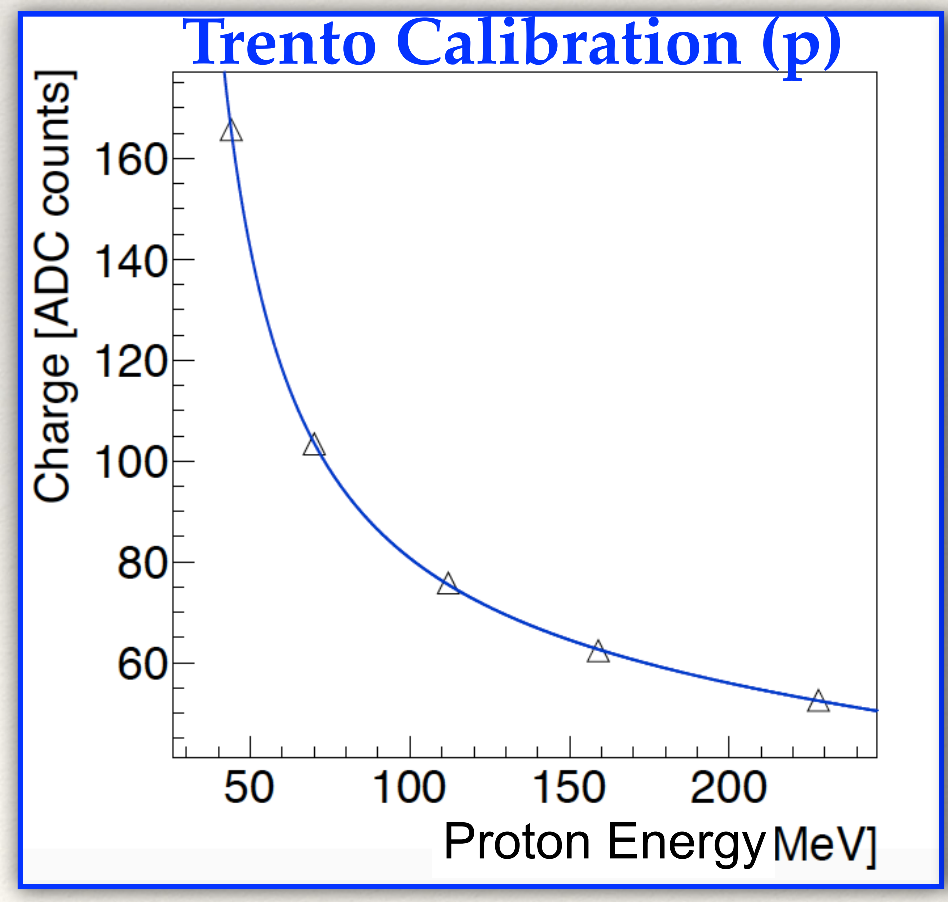
To evaluate the unfolding matrix, the detector's resolution has been implemented using informations from data.

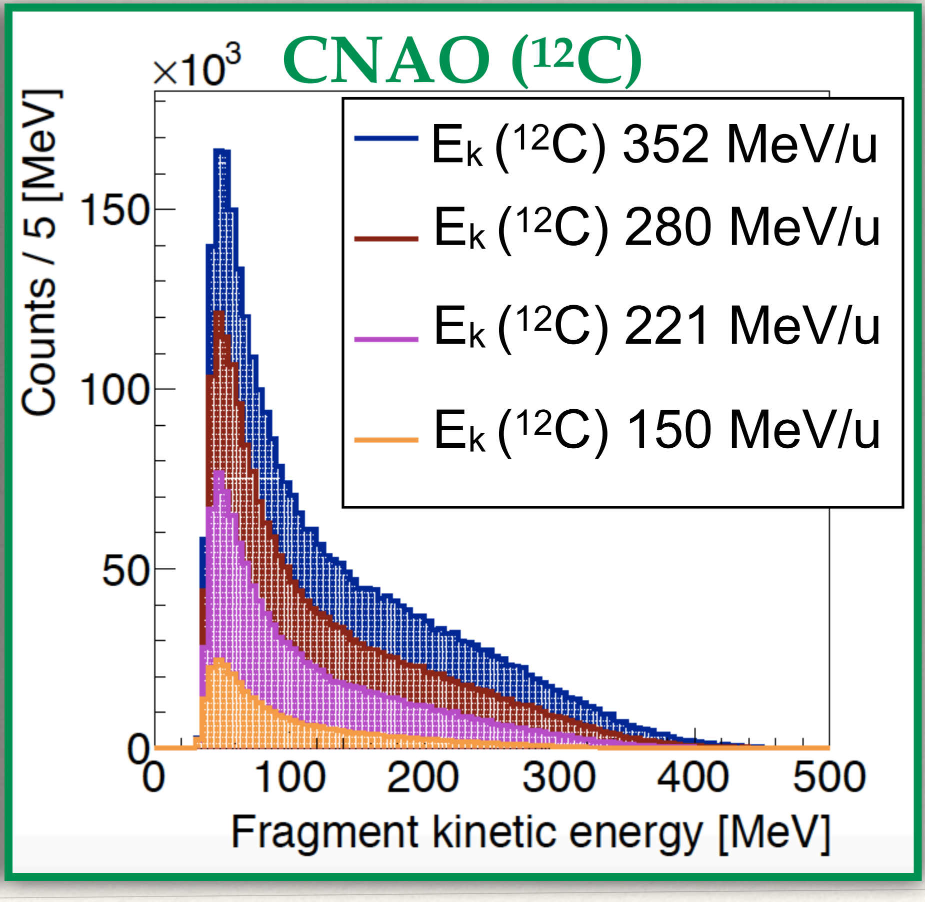
Test @ CNAO



The DP has been assembled in may 2017 and it has undergone a performance characterization using the **Trento Proton Therapy Centre**. Since it has been characterized, it has been tested @ **CNAO** to check the operation in 'clinical like conditions'.

The interaction of beams of different energies has been studied using different targets and the RANDO® phantom.

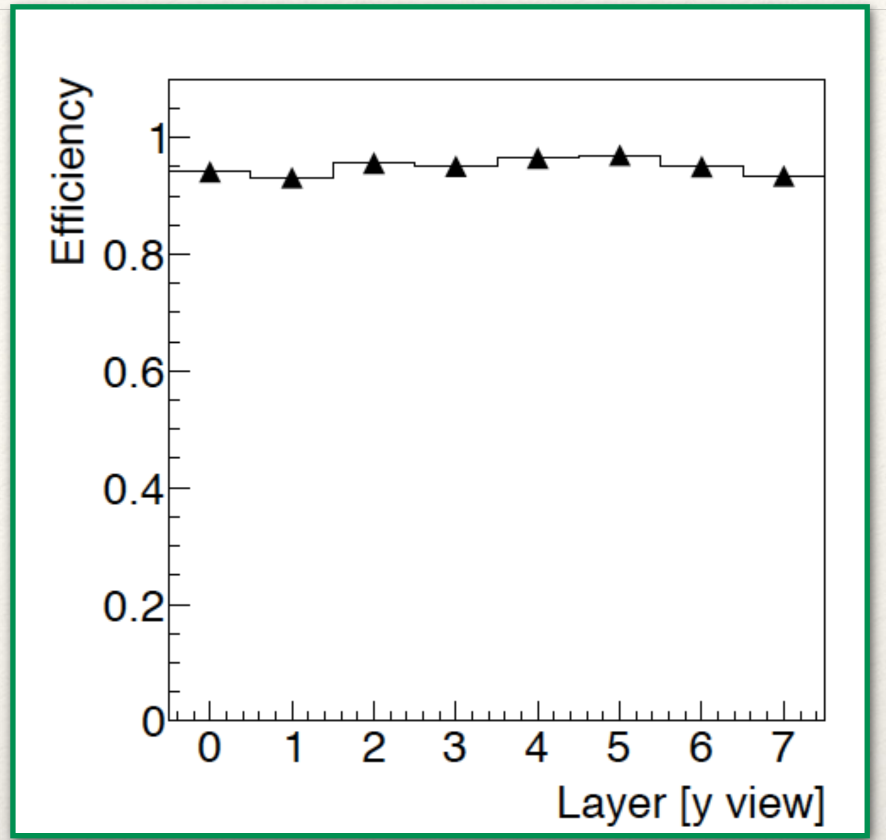




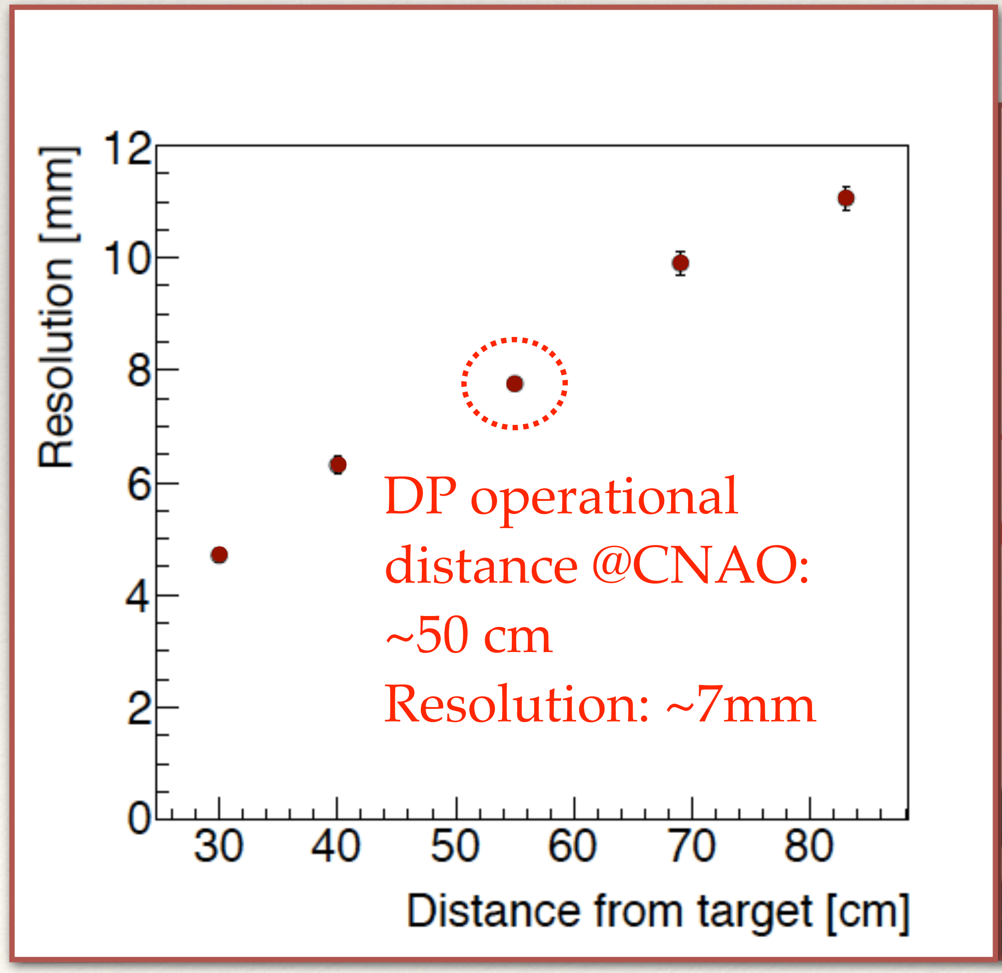
The average kinetic energy of the fragments is in the 100-120 MeV range. The 50 MeV cut is caused by the trigger (the proton need to have enough energy to cross 7 fibre layers)

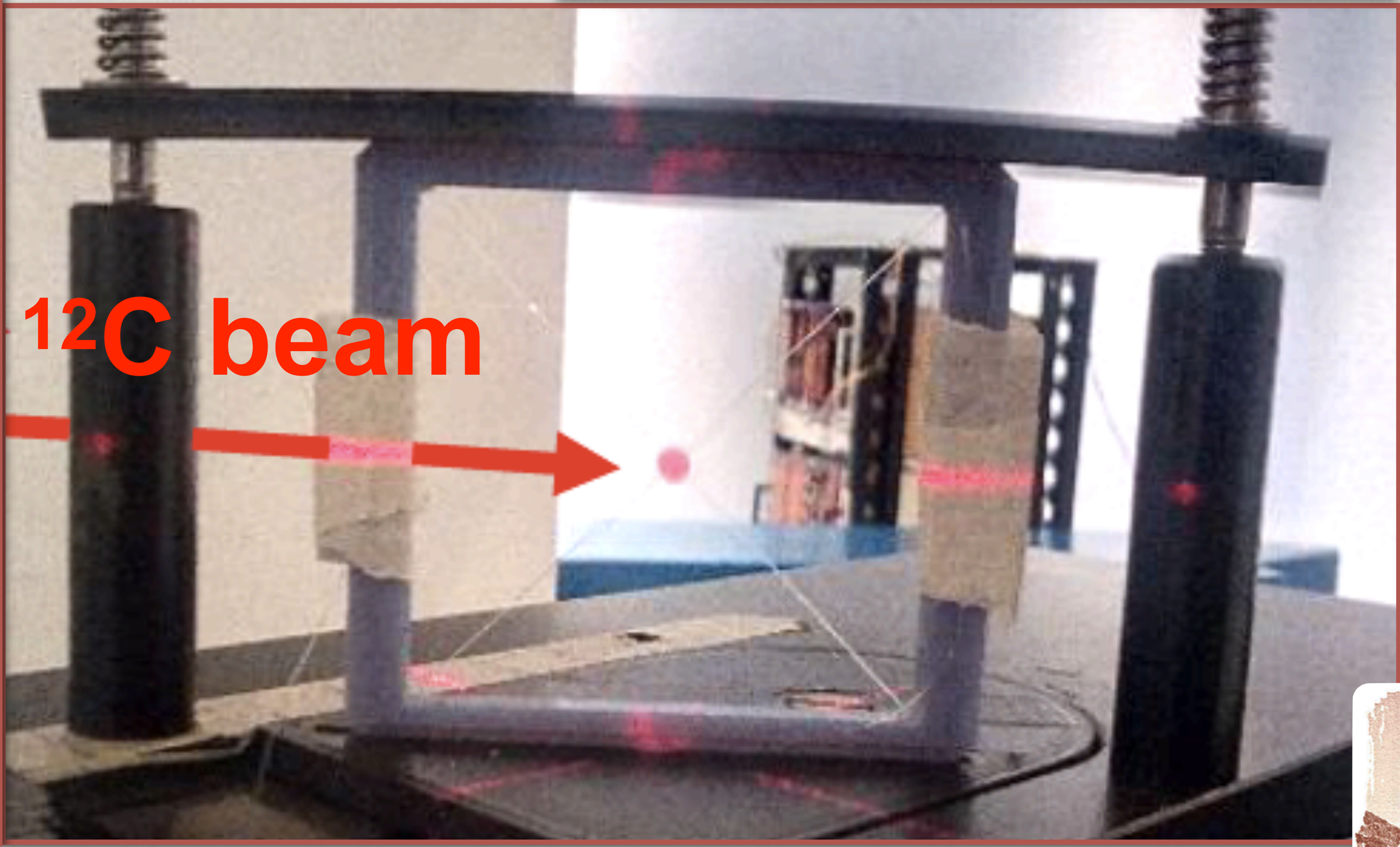
DP performance

The measured **efficiency** (~90%) matches the expected value when the fibre cladding and inter-layer alignment are taken into account.



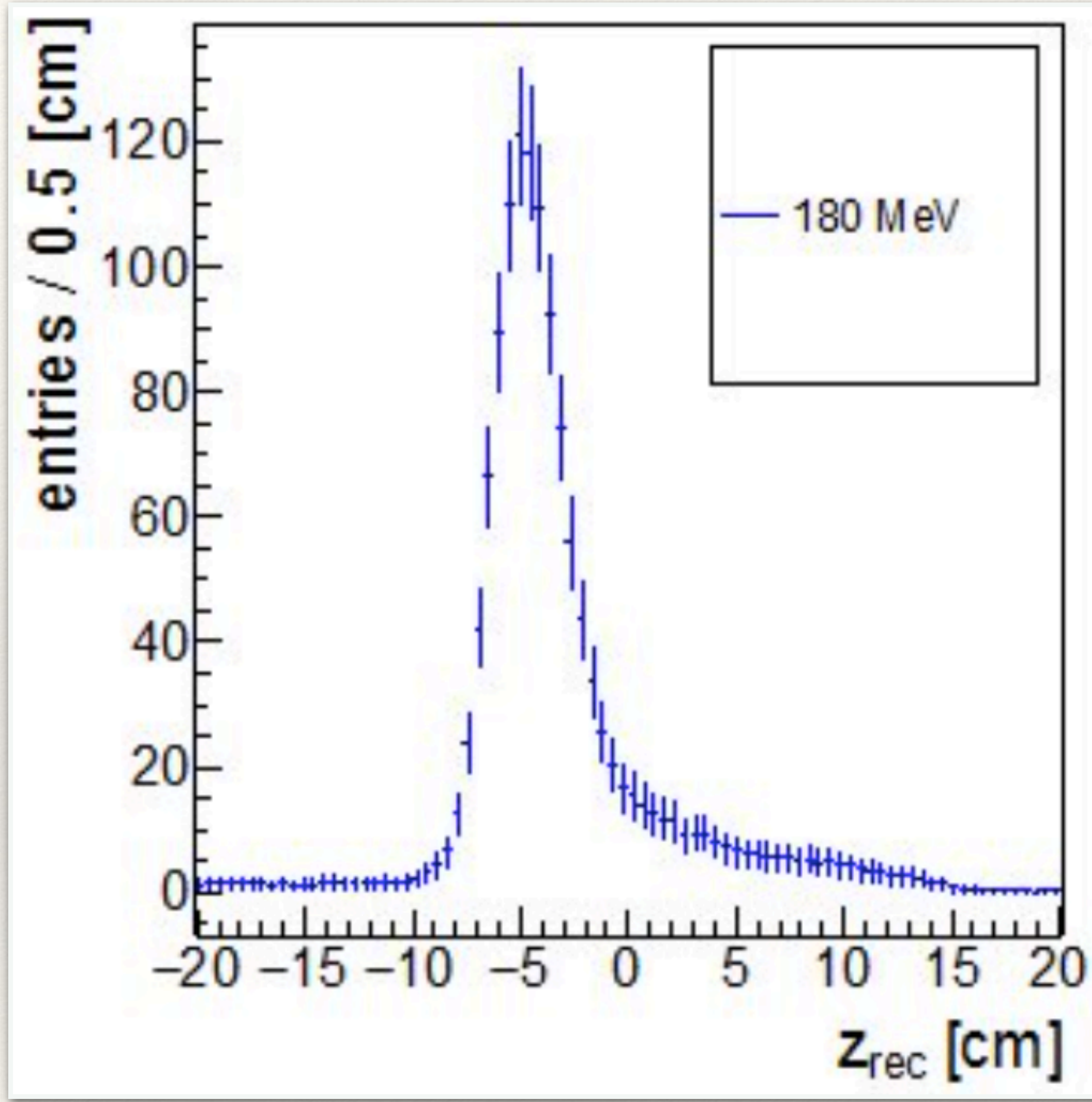
The **'per-track' resolution** has been evaluated using a small (4 *mm* diam.) plastic spherical target.

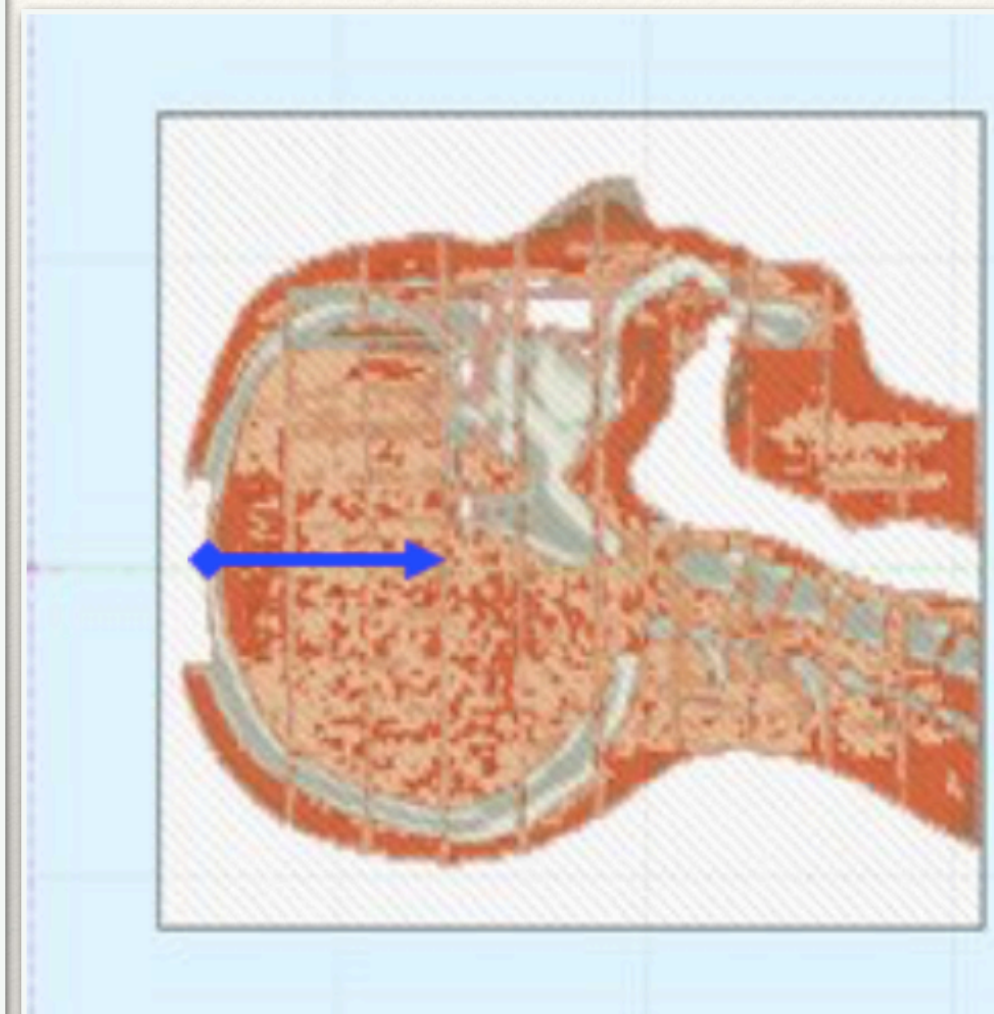




Charged Emission Profile in Rando®

Real data from a test beam @CNAO





^{12}C range: **180 MeV: 7*cm***; **220 MeV: 10*cm***; **280 MeV: 15*cm***

The results are shown for the statistics (number of fragments) expected to be produced in **~1 cm² area**

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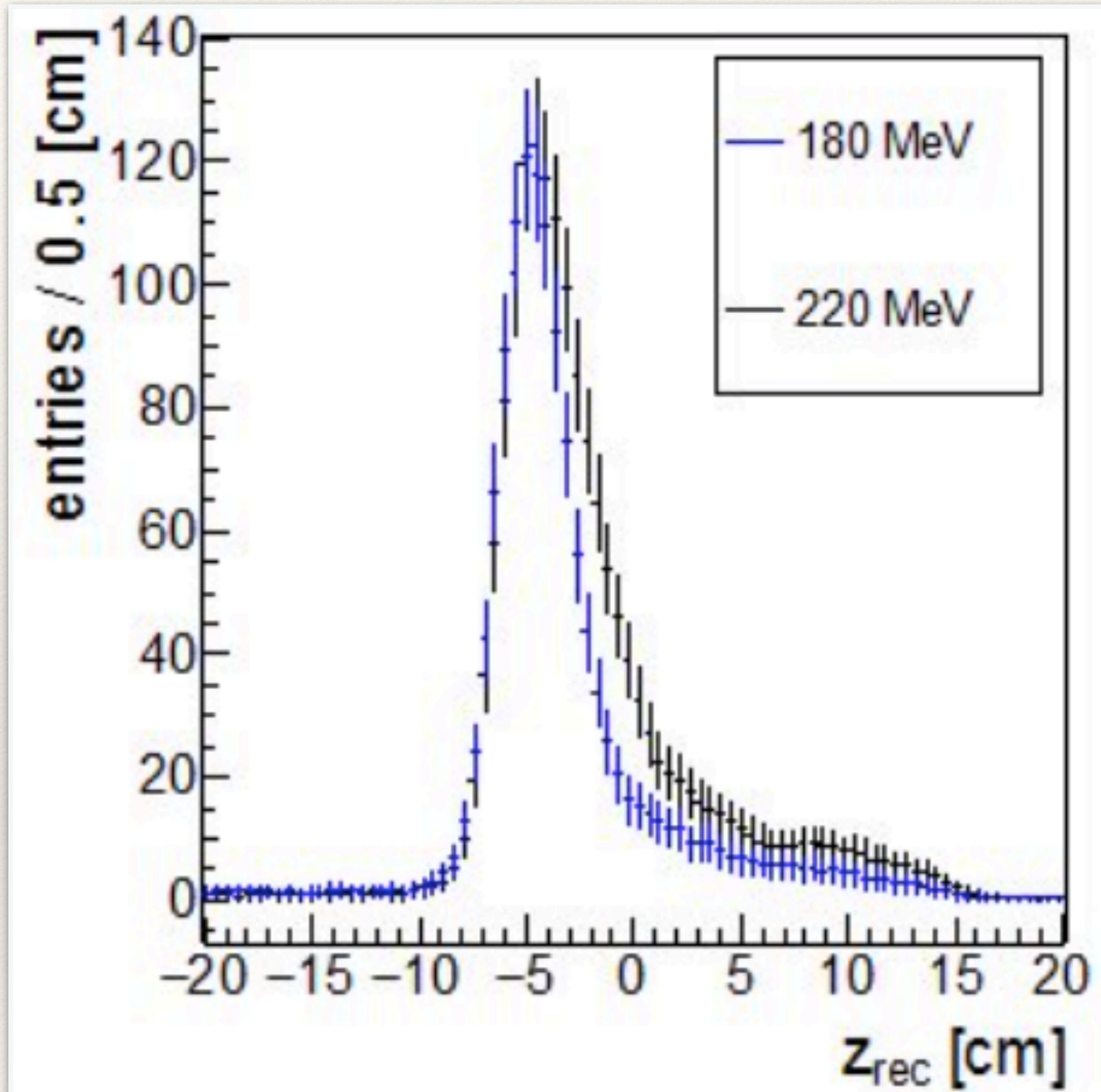

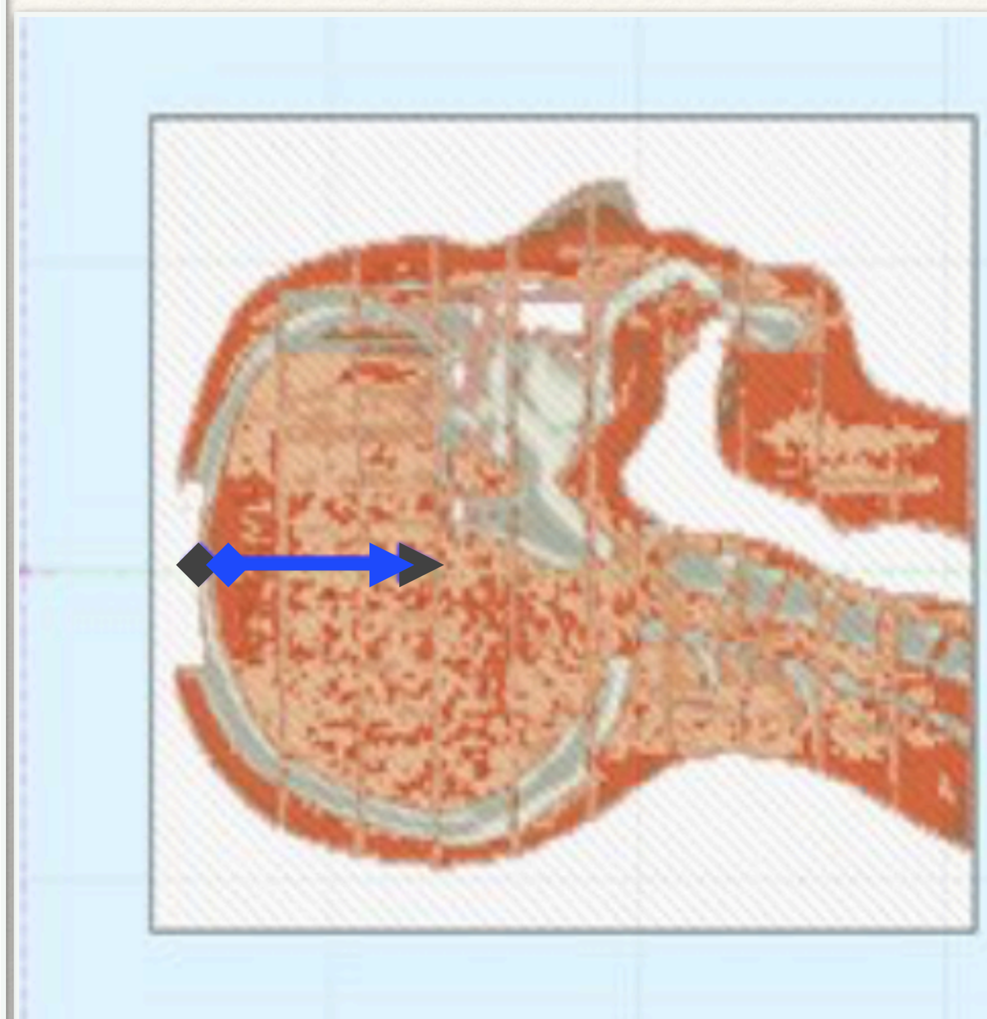

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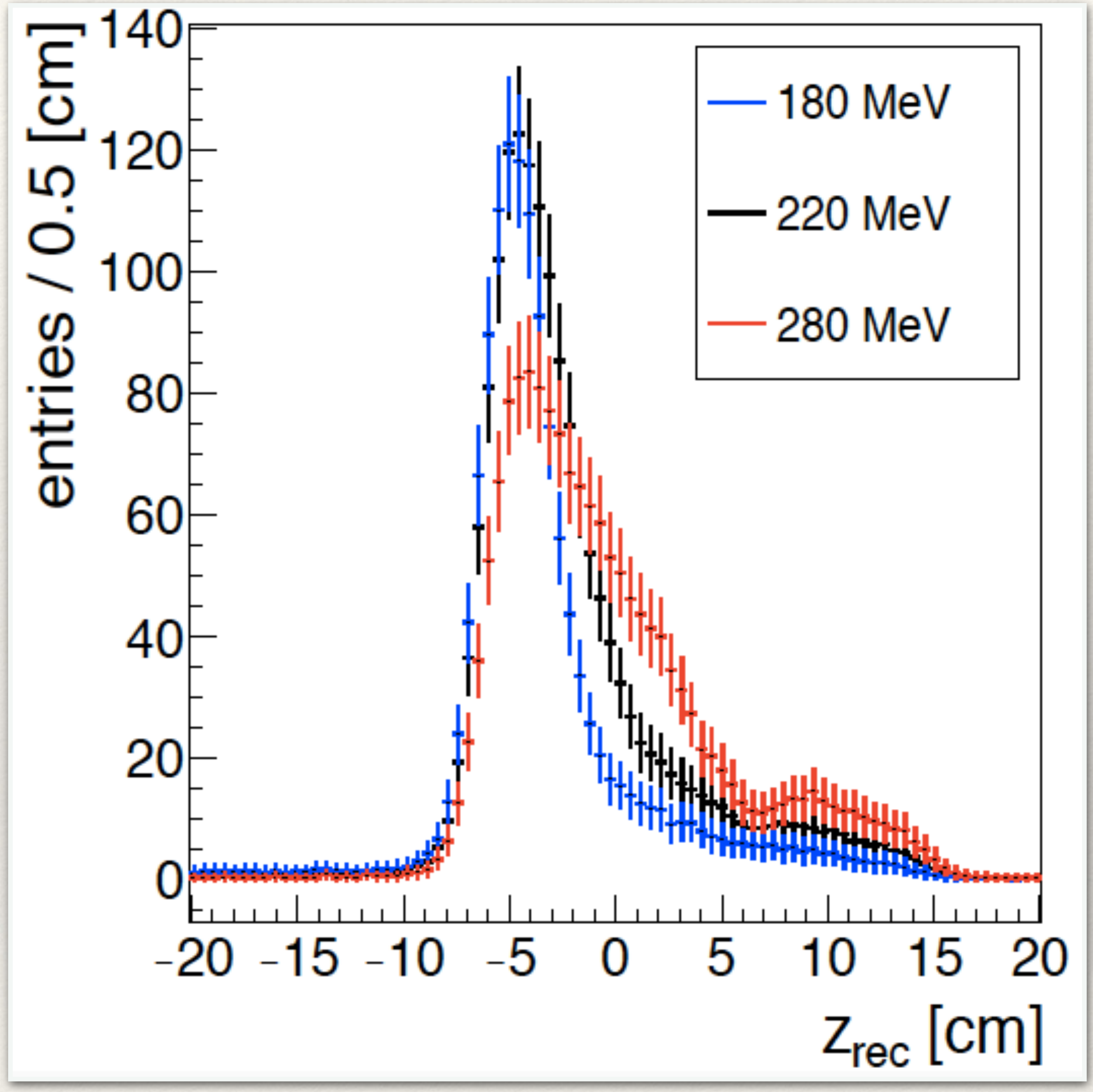

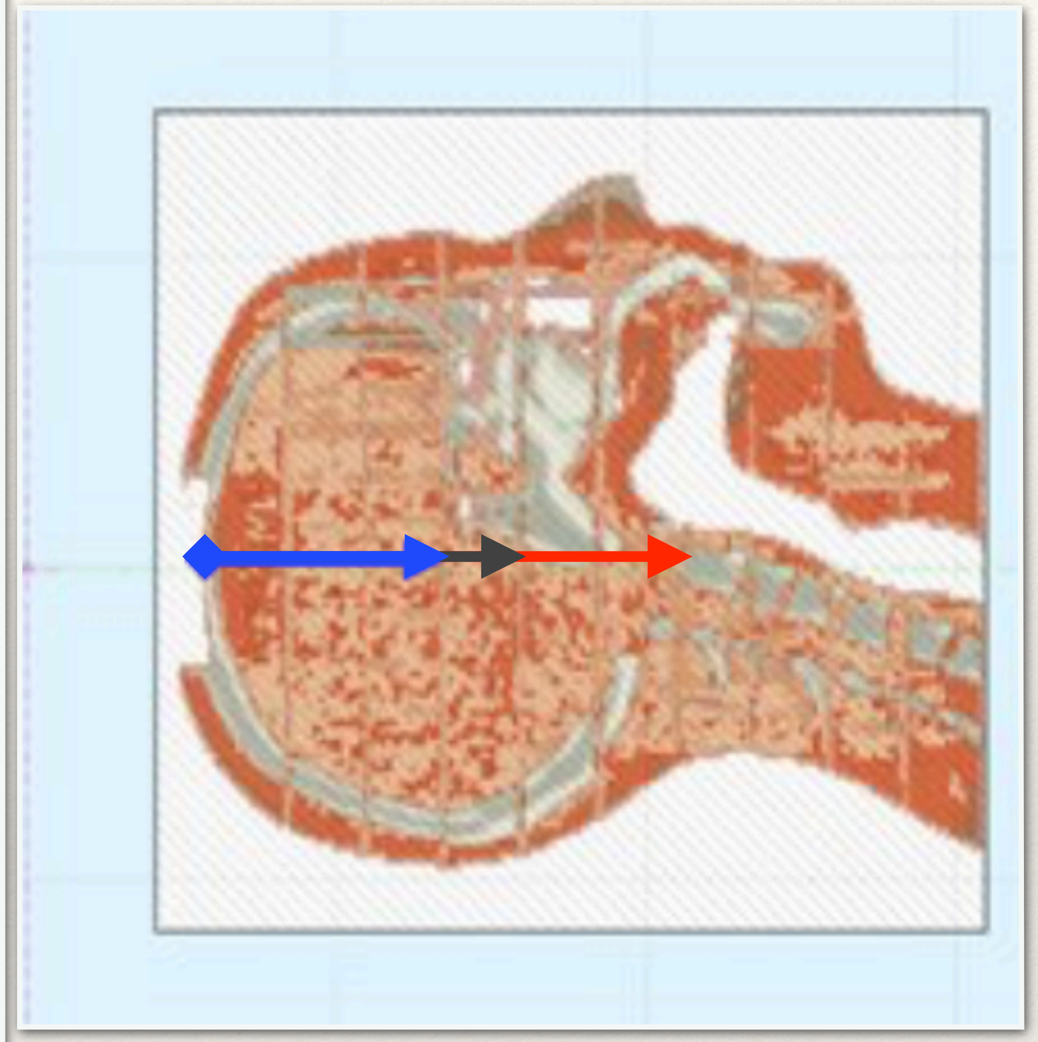

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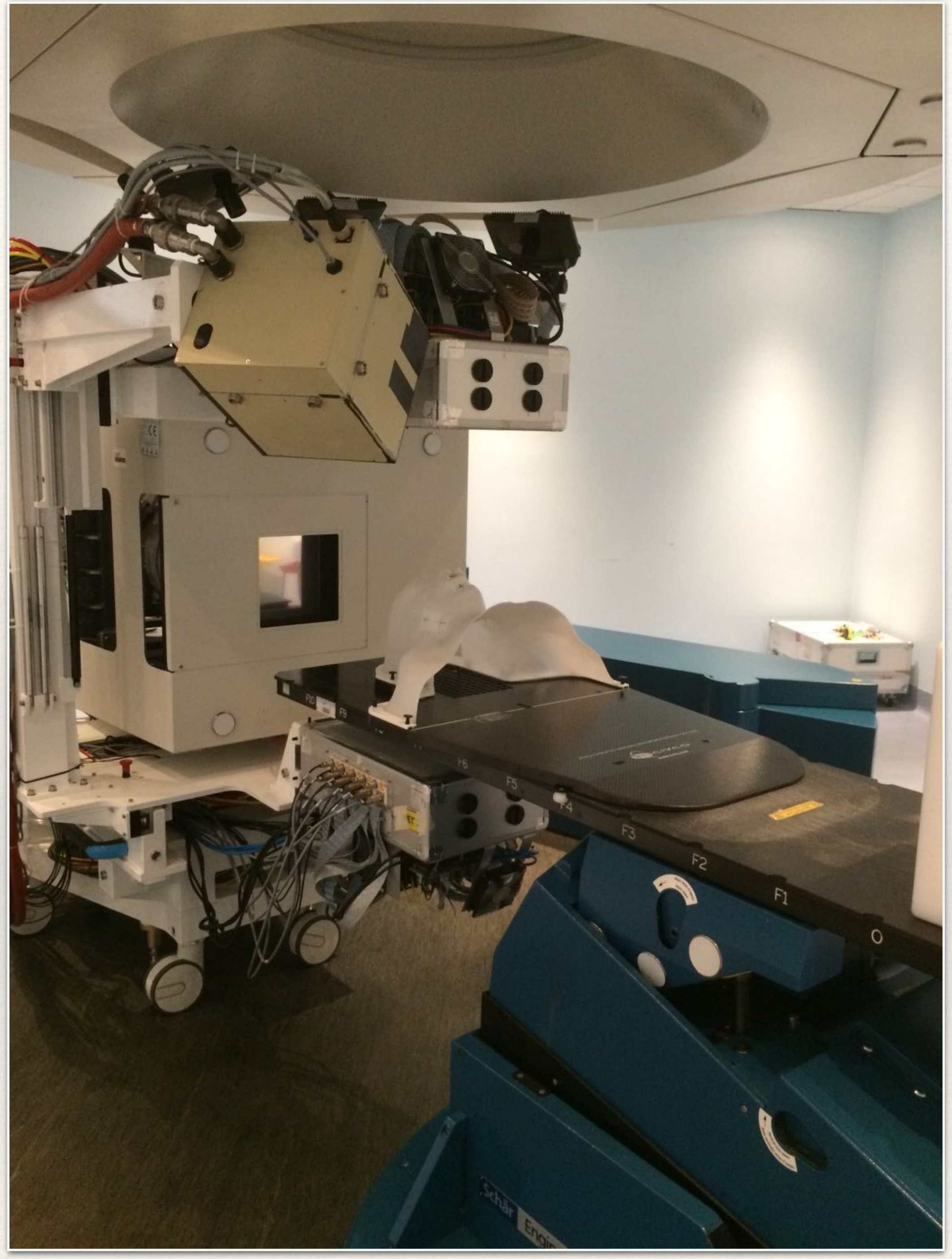
Conclusion

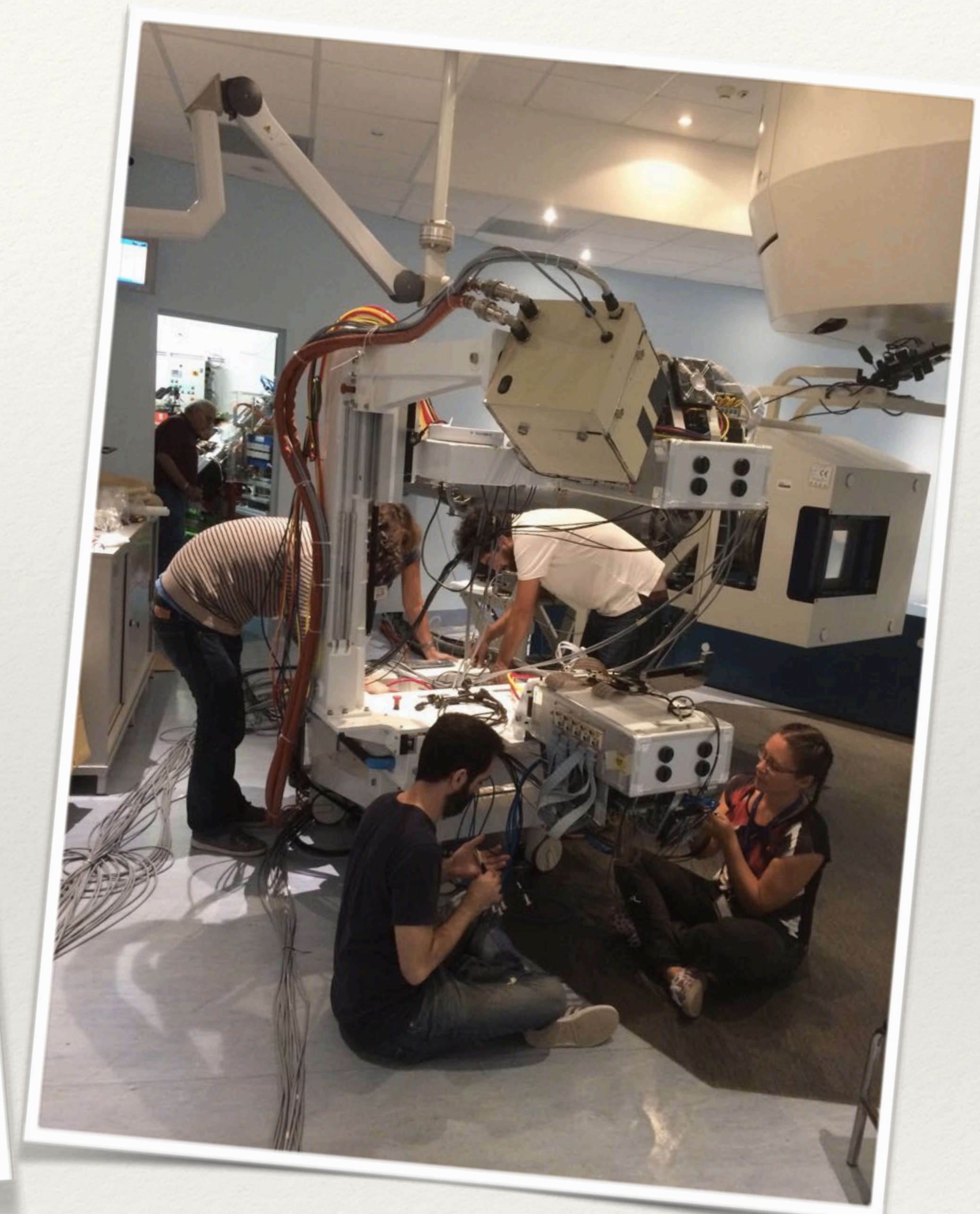
- The Dose Profiler fibre tracker is operational and matches the design expectations (resolution and efficiency);

- Clinical trial at CNAO (bi-modal operation with PET heads) will start in a few months;

- Data collected during the treatment will be analyzed offline, finalizing the matter studies, and a final word on the BP monitoring precision achievable in clinical conditions with this technique will be said.



Thanks!



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