MC codes and Range Monitoring in Particle Therapy: the case of secondary charged particles

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on behalf of RDH & INSIDE collaborations

Outline

Particle therapy & MC codes: monitoring with secondary charged particles

INSIDE – Dose Profiler – data acquisition - FLUKA full simulation

Real time procedure

- Proton emission point determination:
- Attenuation of the secondary charged particles emission profile (re-weighting procedure)

The on-line operation (FRED)

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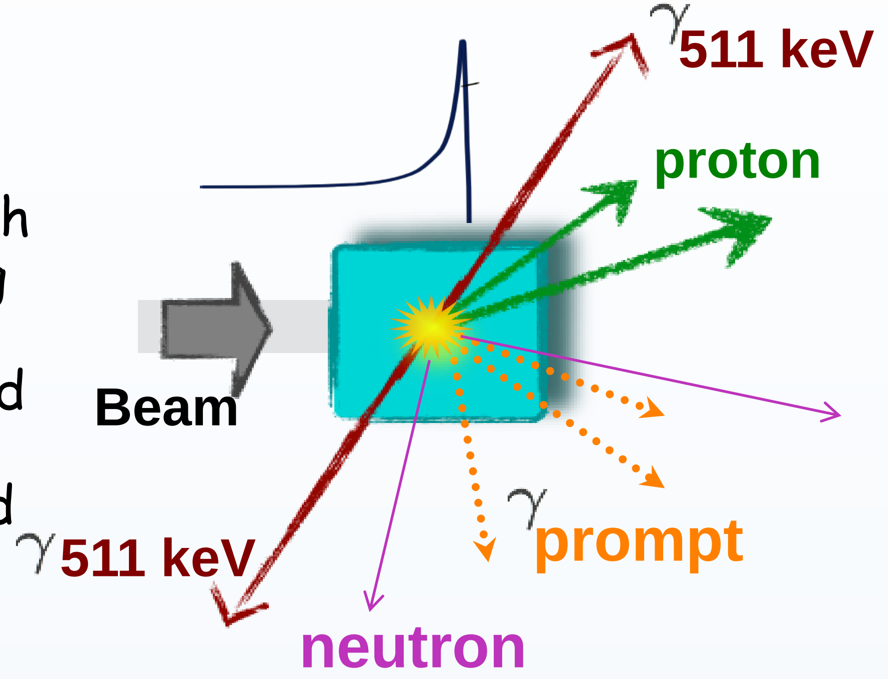
Particle therapy & MC codes: monitoring

Particle therapy **planning** gets fundamental information from MC codes. Its millimetric precision needs the assurance of the **successfulness of the treatment session**.
Range monitoring of primary beam would be important for many reasons: patient mis-positioning, organ motion, anatomical density variation, uncertainties in CT/Hounsfield number conversion…

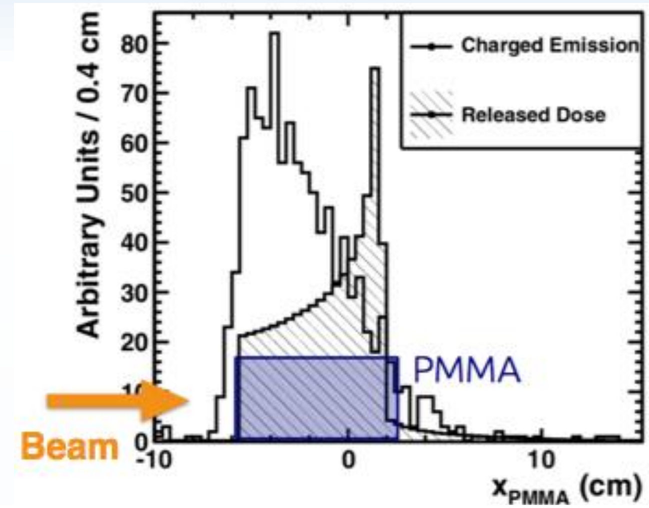
Different **range monitoring techniques** are under development exploiting secondary particles which are generated in the patient during the treatment: prompt gammas, annihilation gammas from β^+ induced activity, **charged fragments**.
The **yield** of produced particles and their **propagation** in the human tissue must be studied with MC codes.



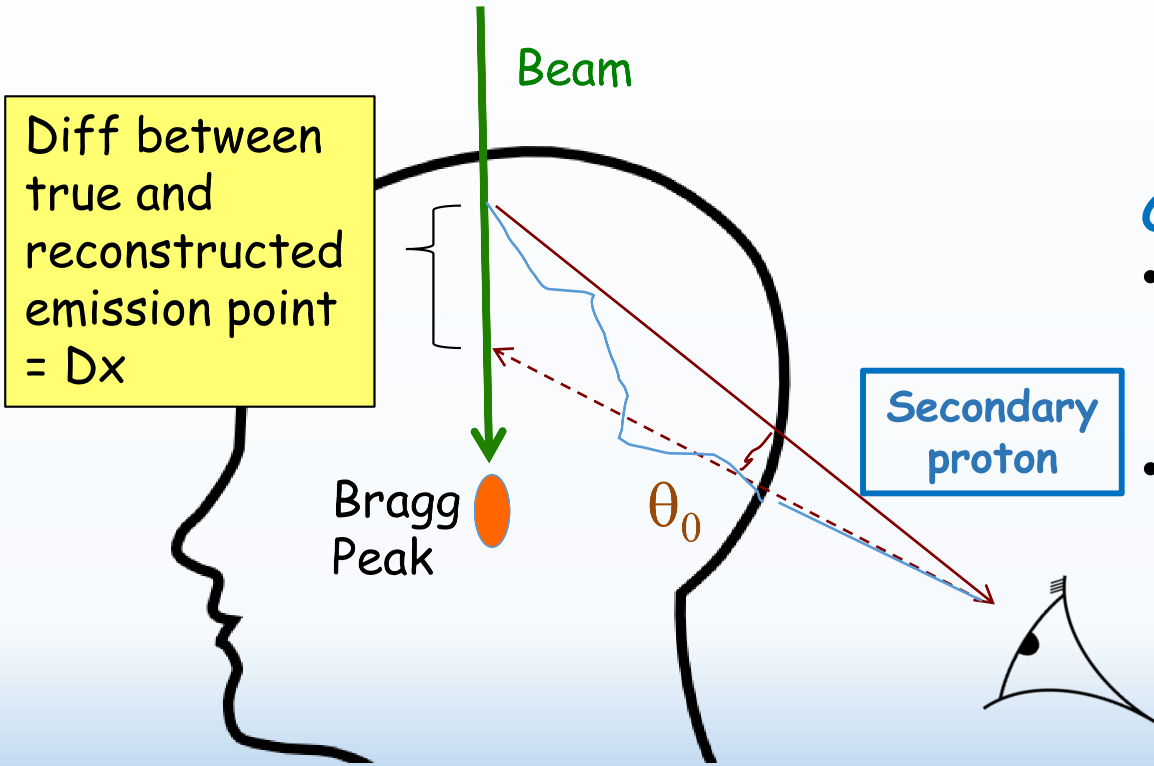
Monitoring with secondary charged particles

PRO

- The detection efficiency is almost 100%
- Can be easily back-tracked to the emission point -> can be correlated to the beam profile & BP
- They are forward peaked
- Enough energy to escape from patient



L. Piersanti et al., Phys. Med. Biol. 59 (2014) 185



CONS

- **Attenuation** of the signal due to energy loss in the patient
- **Multiple Scattering** inside the patient -> worsen the back-pointing resolution

→ **MC study is essential**

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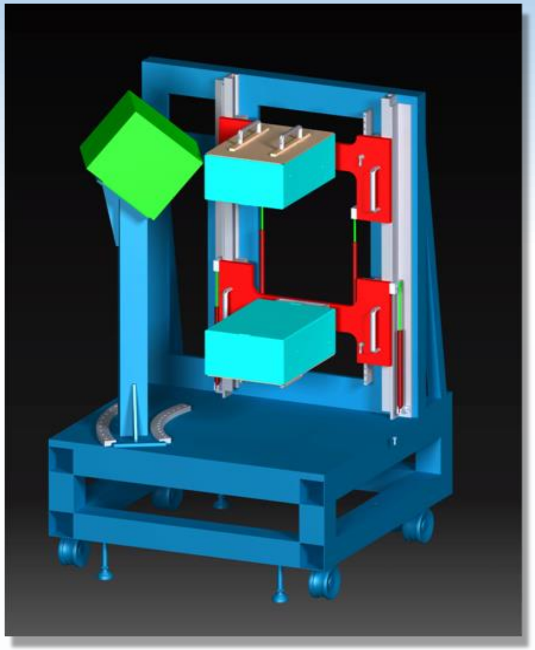
The InSide Project @ CNAO

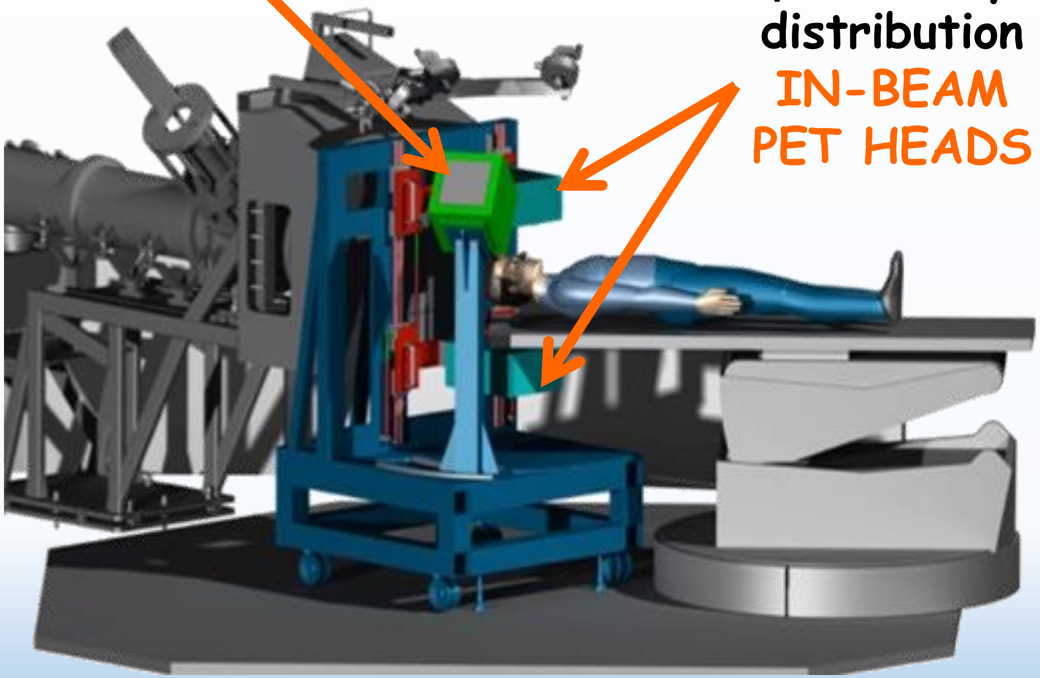
INnovative Solutions for In-beam DosimEtry in Hadrontherapy



proton emission
Tracker +
Calorimeter =
DOSE PROFILER

β^+ activity distribution
IN-BEAM PET HEADS

E.Fiorina, ID 143

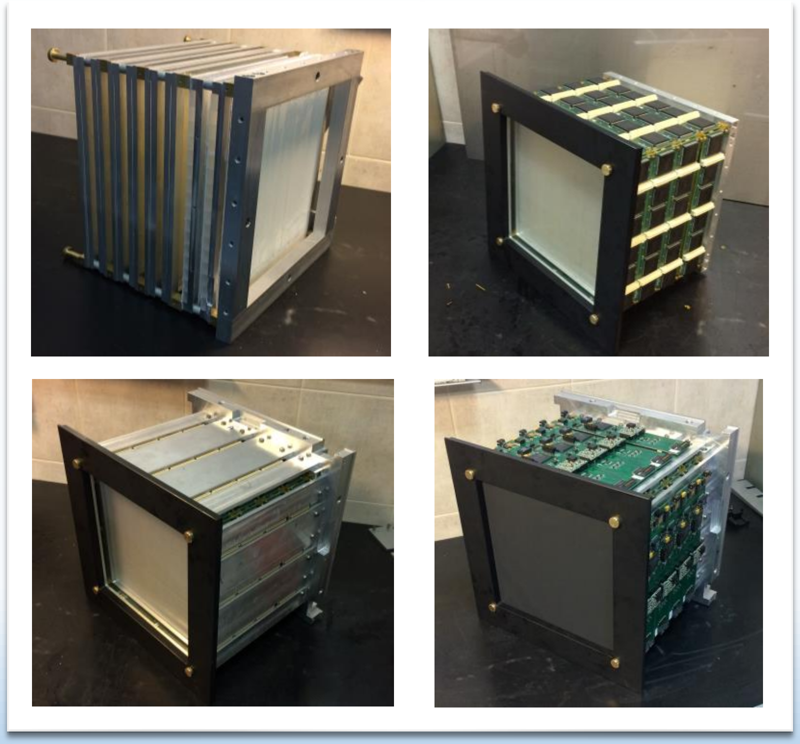


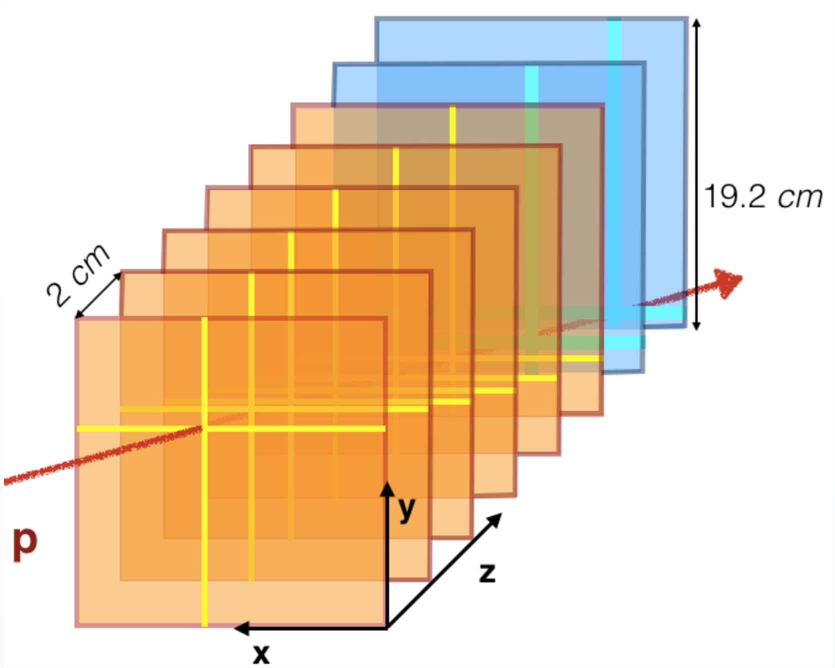
- **Integrated in treatment room** of Centro Nazionale di Adroterapia Oncologica (CNAO)
- Operate **in-beam**
- Give an **IMMEDIATE feedback** on the particle **range**

The Dose Profiler (DP)

A detector named Dose Profiler (DP), able to track secondary charged fragments (mainly protons) emitted at large angles with respect to the beam direction, is under construction and test.

Tracker: 6 planes of 2 orthogonally oriented layers of **scintillating fibers**. SiPMs Read Out (1 mm^2).

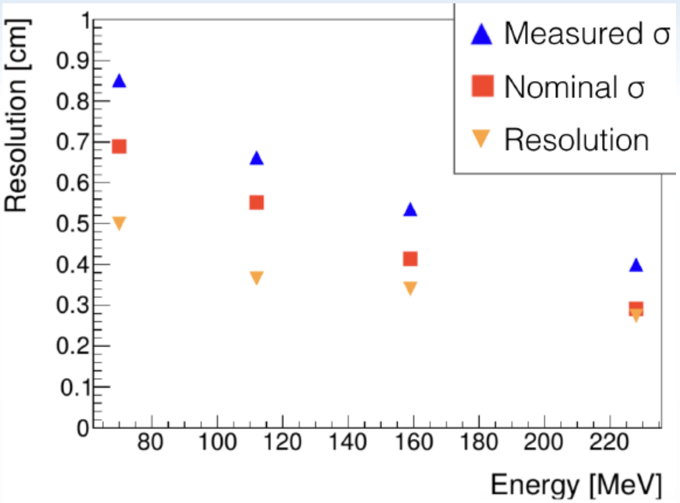


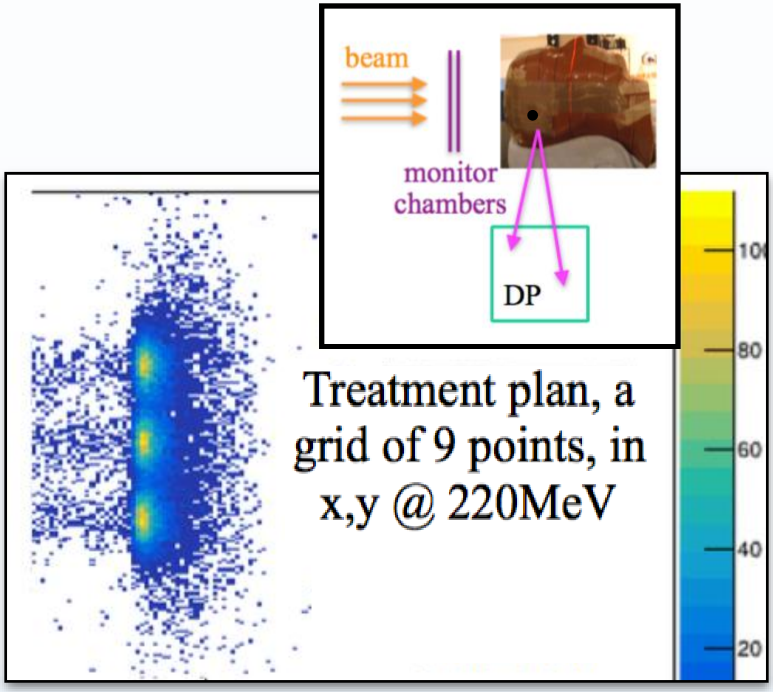


Energy measurement: 2 planes of 2 orthogonally oriented layers of segmented thicker **plastic scintillators** (6 mm)

Data taking campaign

The detector tested @ Trento Proton Center
Proton beam of E = 40-220 MeV
Beam size @ isocenter: 3-7 mm.
STS1, STS2 plastic scintillators (1 cm) for external trigger
Detector resolution: $\sigma_{DP} = \sqrt{\sigma^2_{Meas} - \sigma^2_{Prod}}$

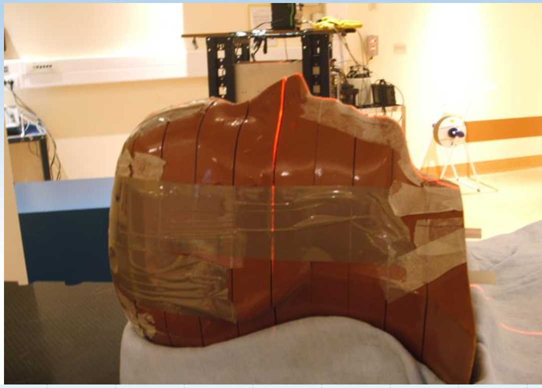


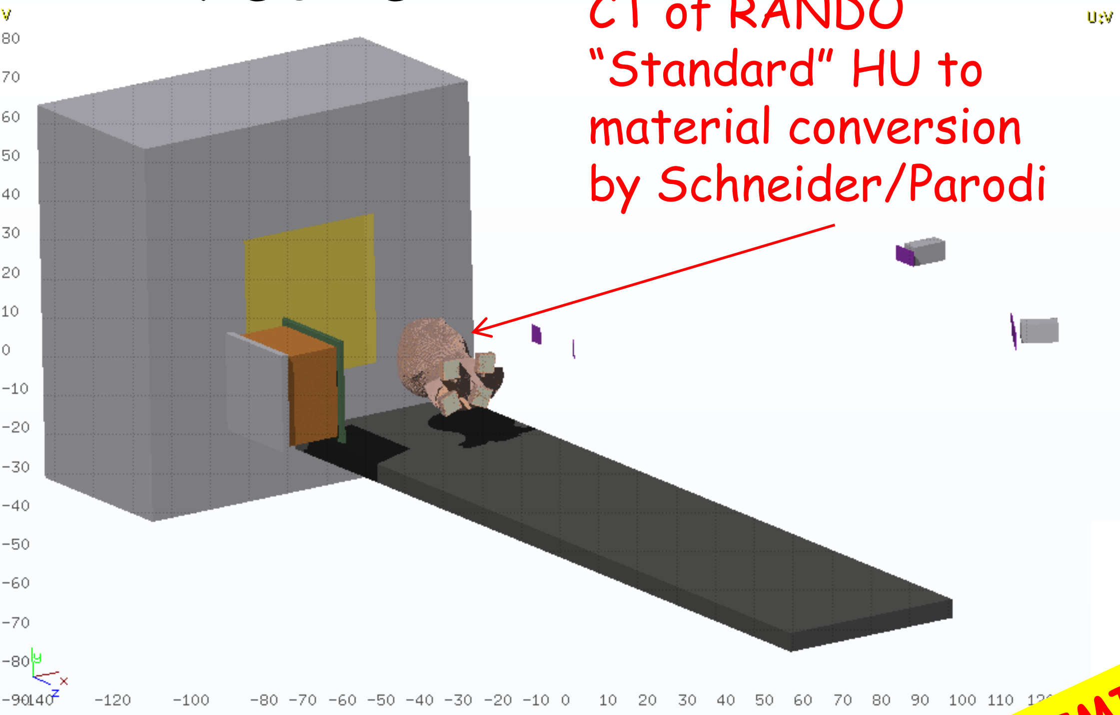


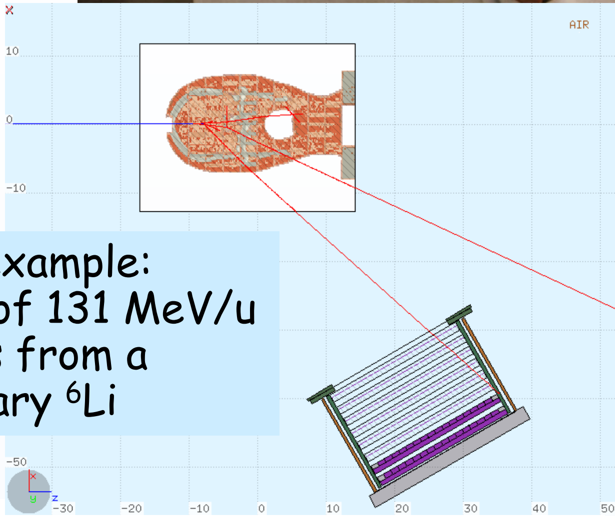
Test performed @ CNAO: both PET and DP systems have acquired data.
^{12}C beam of energies: 115, 151, 221, 352 MeV/u
Thin target (charged fragments cross section @ 60°-90°) PMMA, graphite, scintillator (polyethylene)
→ MC cross section model improvement
Thick PMMA target
RANDO phantom → MC feasibility study

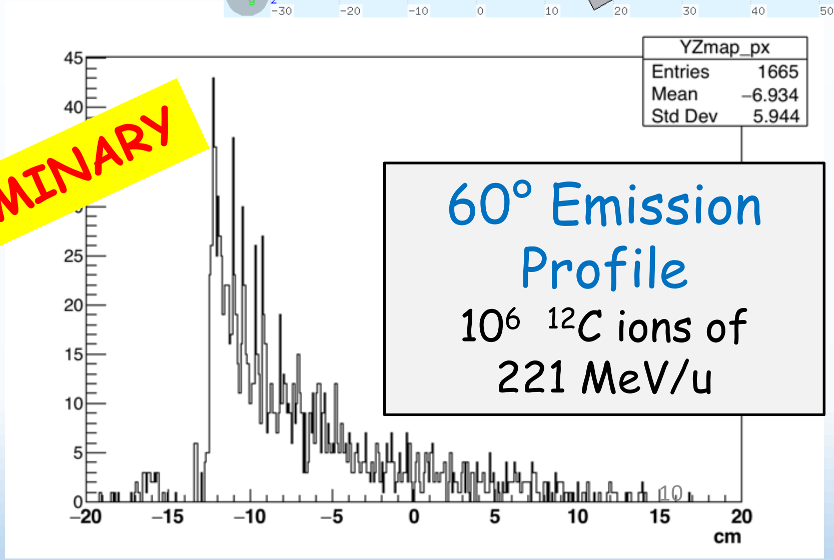
Feasibility study with MC FLUKA

A very preliminary simulation of a ^{12}C beam on RANDO + DP









The MC predictions seams to confirm us on the feasibility of the technique

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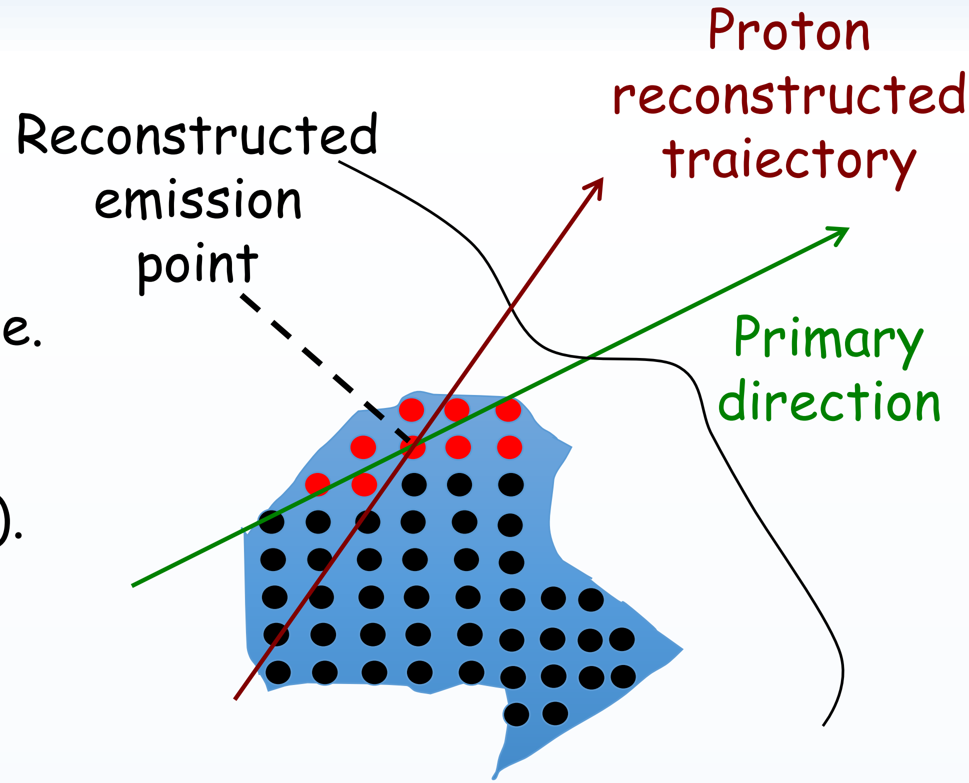
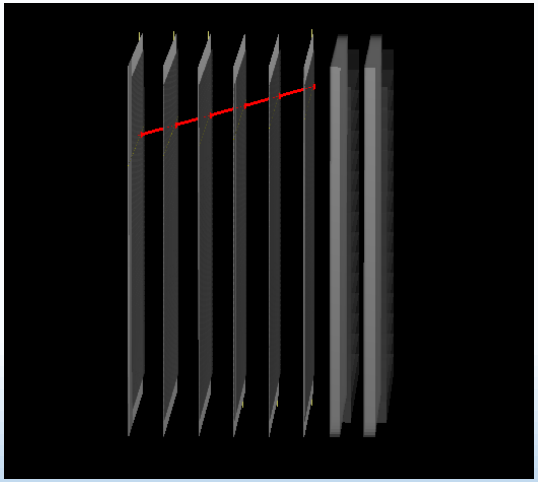
DP real time hardware/software procedure

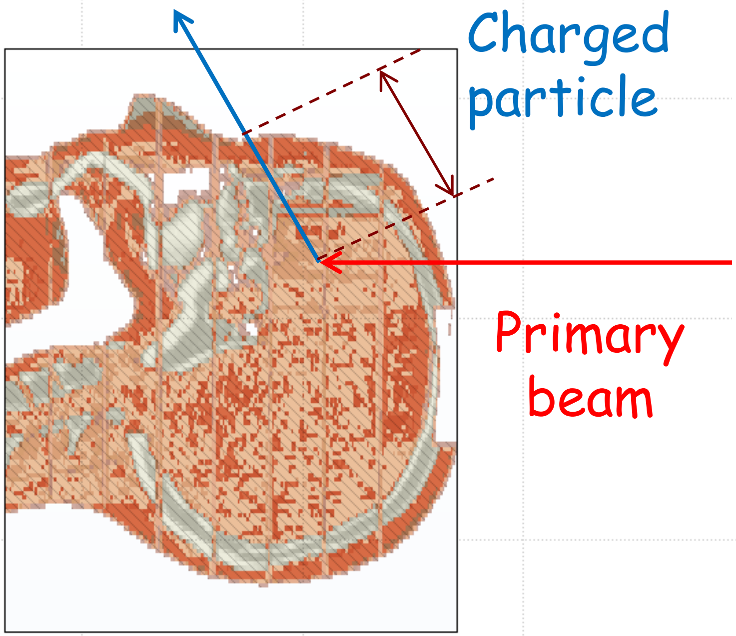
Reconstruction of the emission point: primary beam and track reconstructed directions are necessary.
The DP tracks the emitted particle.
The primary beam direction and position from the Rasterplan (interface with the Dose Delivery).
An hardware interface is under construction .





A new track reconstruction performed by means of a Kalman filter algorithm is under study and optimization (GenFit code).

DP real time hardware/software procedure



For a correct interpretation of the signal, it is necessary to **evaluate** and **compensate** the amount of material crossed by each proton track inside the patient.

Patient CT is managed by a fast interaction/tracking code (on GPU).

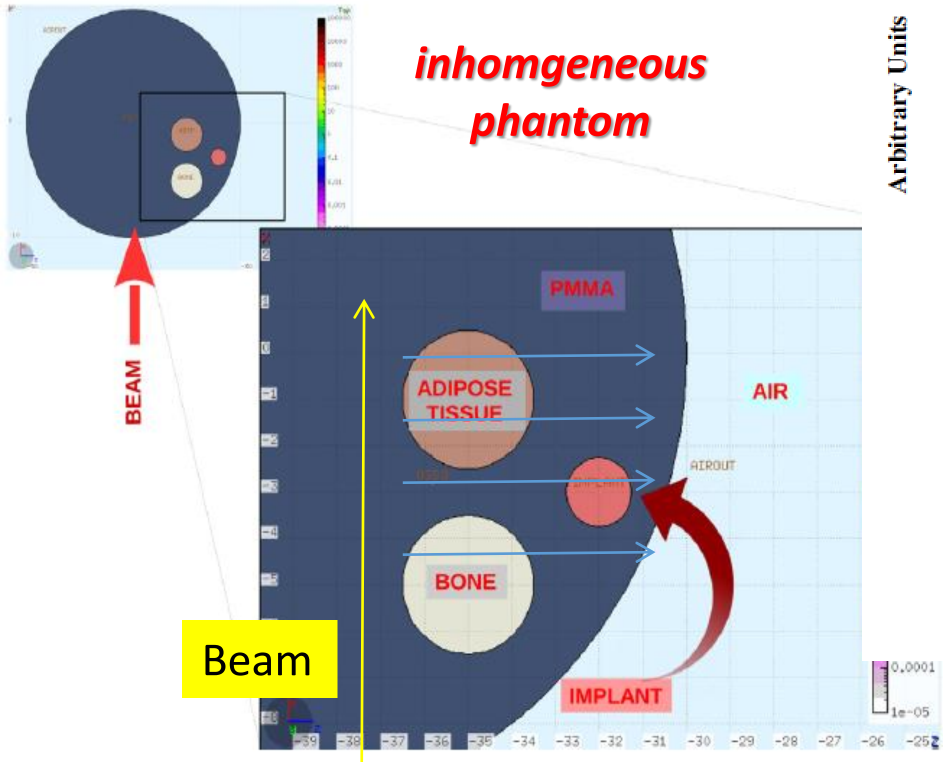
The **attenuation** of the secondary charged particles emission profile due to the crossed material is studied and parametrized with the FLUKA MC code.

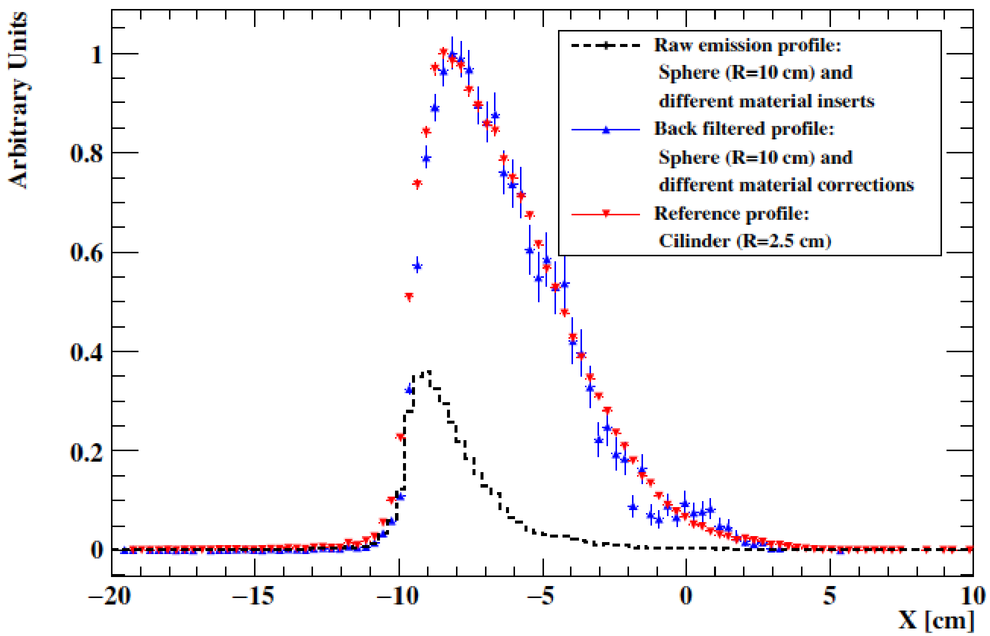
Traini et al., *Design of a new tracking device for on-line beam range monitor in carbon therapy,* Physica Medica 34 (2017) 18-27

Re-weighting procedure

By means of the **attenuation study** of the proton emission shape for different material thicknesses, we get a method to correlate the shape detected by the profiler coming out from the patient with the **B**ragg **P**eak position.

We apply to each reconstructed track a weight which takes into account the thickness and density of the material crossed by the proton.





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The on-line operation

The on-line operation of DP requires real-time back-tracing and reconstruction of the amount of material crossed in the patient by each detected proton.
This task will be accomplished using FRED (**F**ast pa**R**ticle th**E**rapy **D**ose evaluator) , a fast GPU-MC code developed to recalculate and optimize ion beam treatment plans within minutes.

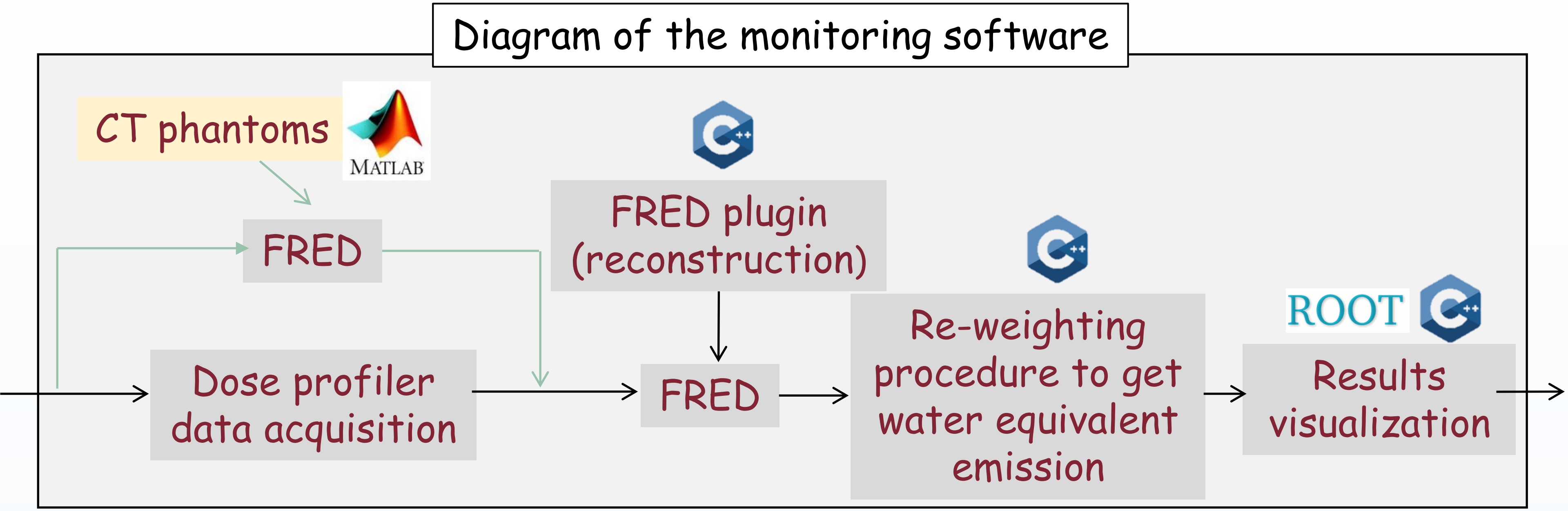
		Primary/s	μs/primary
FLUKA	1 CPU	0.75 K	1340
FRED	1 CPU	15 K	68
FRED	1 GPU*	800 K	1.35

A. Schiavi et al., *Fred: a GPU-accelerated fast-Monte Carlo code for rapid treatment plan recalculation in ion beam therapy*, Phys. Med. Biol. **62** (2017) 7482-7504

* LAPTOP: Apple MacBook Pro with one AMD Radeon R9 M370X

See A. Schiavi talk:
Fred: A new GPU-based fast-MC code and its applications in proton beam therapy
previous session (Parallel MC implementations)

The on-line operation



Conclusions

MC codes contribute on Range Monitoring in Particle Therapy by means of secondary charged particles in many points of the procedure:

Feasibility study

The yield of produced particles and their propagation in the human tissue must be studied with MC codes, as well as the estimation of the flux magnitude in the detectors (FLUKA)

Signal interpretation

Back-tracking has to be performed with MC codes to take into account the attenuation in matter and the Multiple Scattering which the charged particle undergoes passing through the patient (GenFit).
The attenuation of the secondary charged particles emission profile due to the crossed material has been studied and parametrized with MC codes (FLUKA)

Fast process for real time operation

A fast MC code (FRED on GPU) has to be used to manage the previous on-line operation during the treatment

Thank you

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