Dose Profiler simulation update

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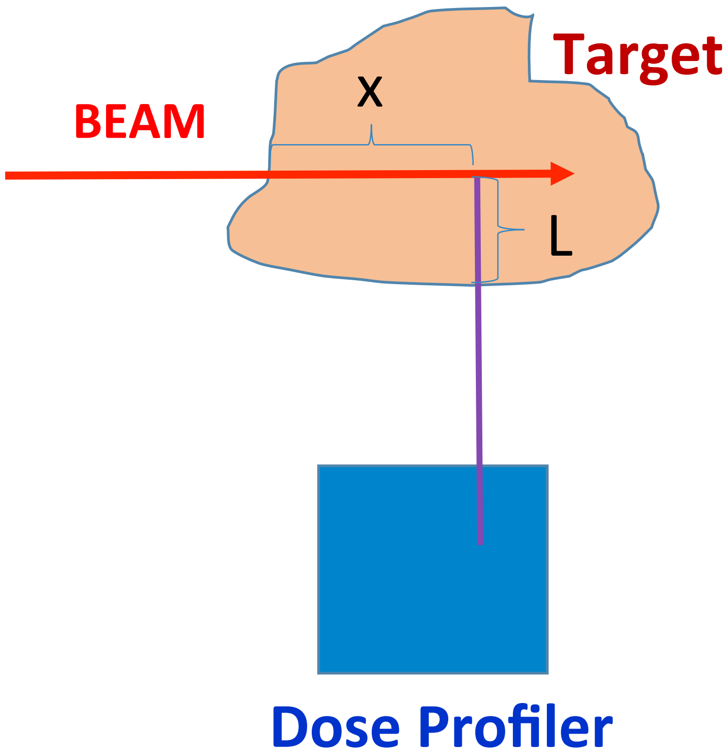
Reminder from January's meeting:

- Key question: how to make use of emission profile detected in a complex geometry
- in other words: how to take into account different shapes and materials



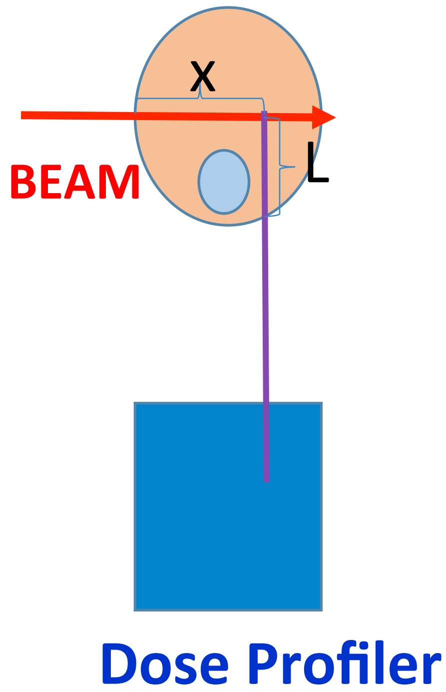
With the parameters fitted
as a function of thickness ***Par(L)***,
we get a parametrized
DFD (**D**ouble **F**ermi-**D**irac) distribution
f_{DFD} ***(Par(L) , x)***
where ***x*** is the reconstructed emission point of the track (charged secondary particle)

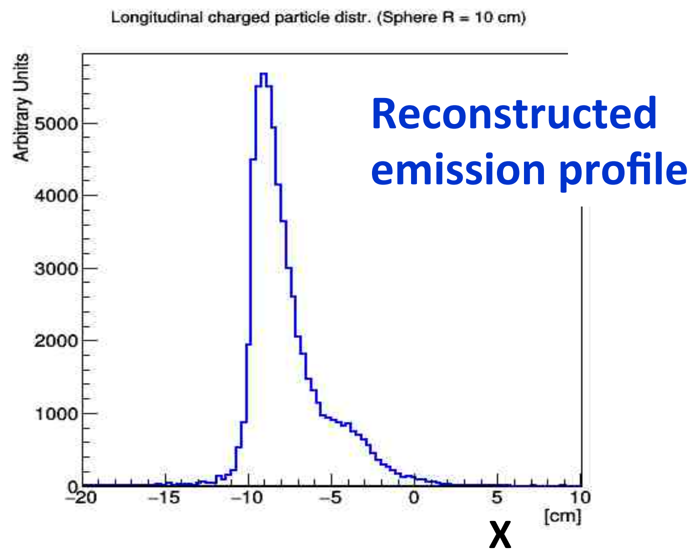
Taking as reference distribution the one obtained from the cilinder with R=2.5 cm,
we can define a weighting function ***w(Par(L) , x)*** *:*

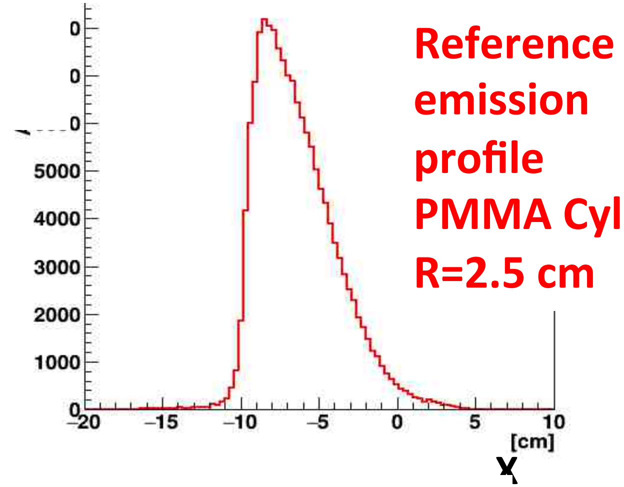
w(Par(L) , x) = *fDFD (Par(L) , x) /fDFD (Par(2.5 cm) , x)*

We get the thichness ***L*** of crossed material from the geometry (patient CT) and reconstructed track informations (emission point and direction).

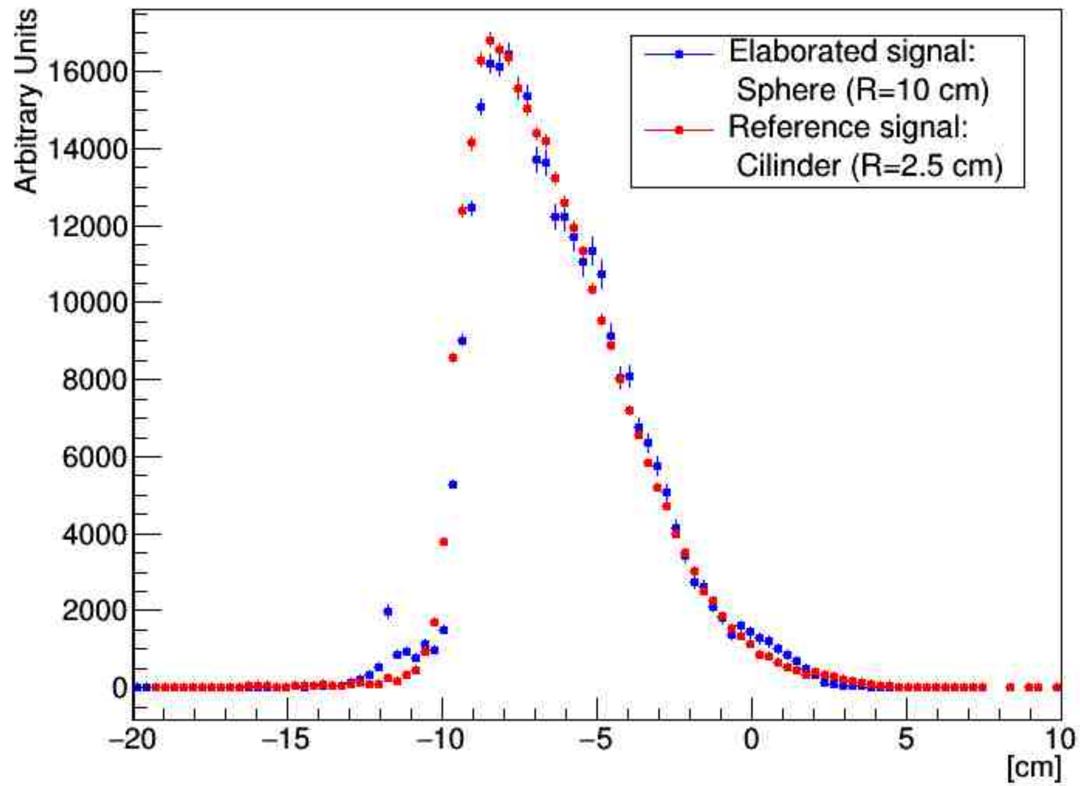
Known the thickness ***L*** and the reconstructed emission point ***x*** on the beam axis, we associate a weighting value ***1/w(Par(L) , x)*** which converts the emission profile to the reference one (cilinder R = 2.5 cm)







Result of the application of the weighting function



New developments

- So far the correction was valid a-priori just to correct for different thickness and density. What if elemental composition changes?
- Our generator was developed only for PMMA, how to make it general? (In partcular how to apply it to Water?)

Two different Corrections:

- **Thickness** correction

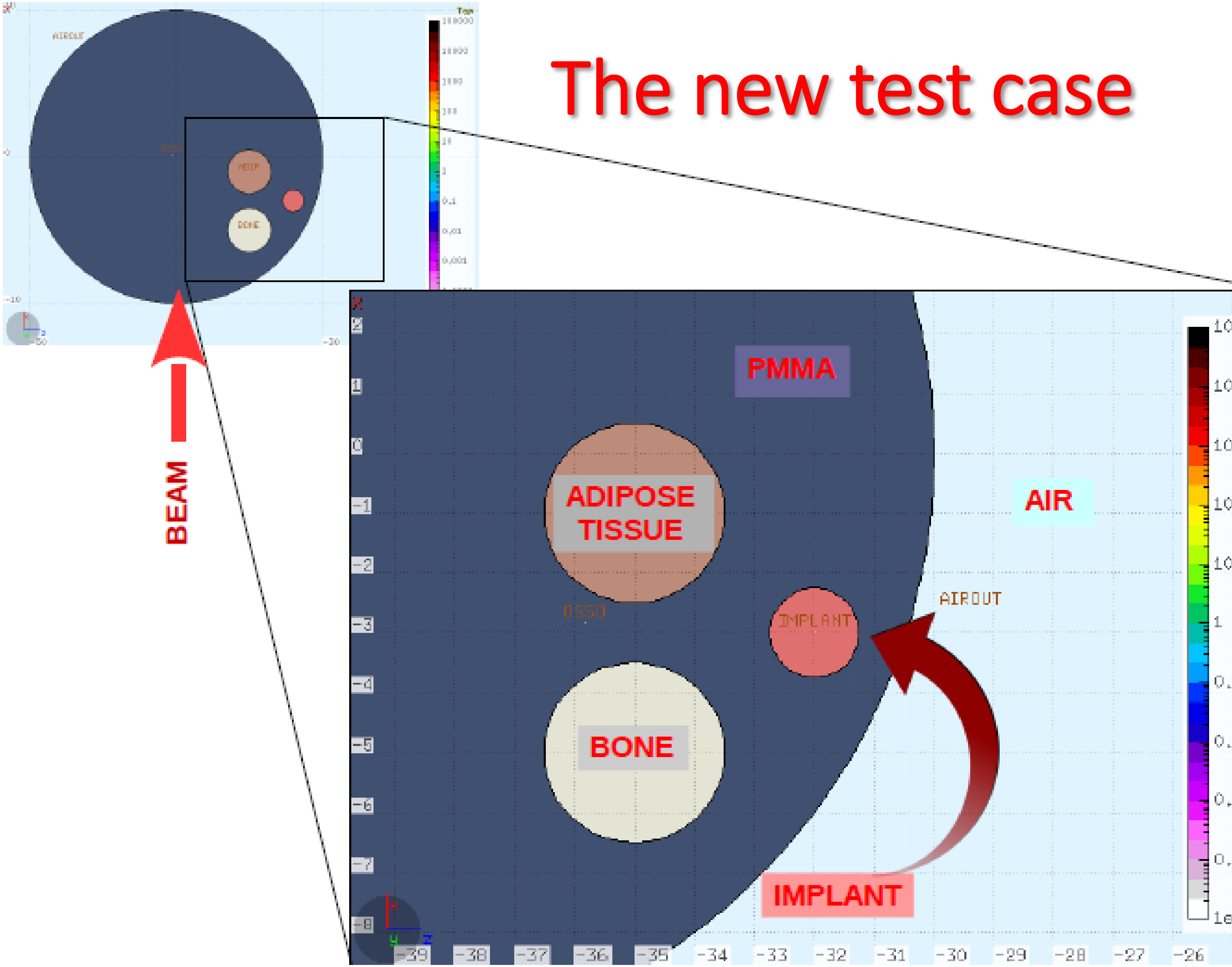
$$w(x,l) = \frac{f(x,l_0)}{f(x,l)} \qquad f(x) = p_0 \cdot \frac{1}{1+\exp(\frac{x-p_1}{p_2})} \cdot \frac{1}{1+\exp(\frac{x-p_3}{p_4})} + p_5$$

- For materials different from PMMA, to take into account for **different densities ρ_{mat}** and **different material chemical composition**, the thickness l is multiplied by the factor

$$F_{mat} = \frac{\rho_{mat}\frac{Z_{mat}}{A_{mat}}}{\rho_{PMMA}\frac{Z_{PMMA}}{A_{PMMA}}}$$

where ***Z*** is the atomic number and ***A*** is the mass number of the compound material.

The new test case



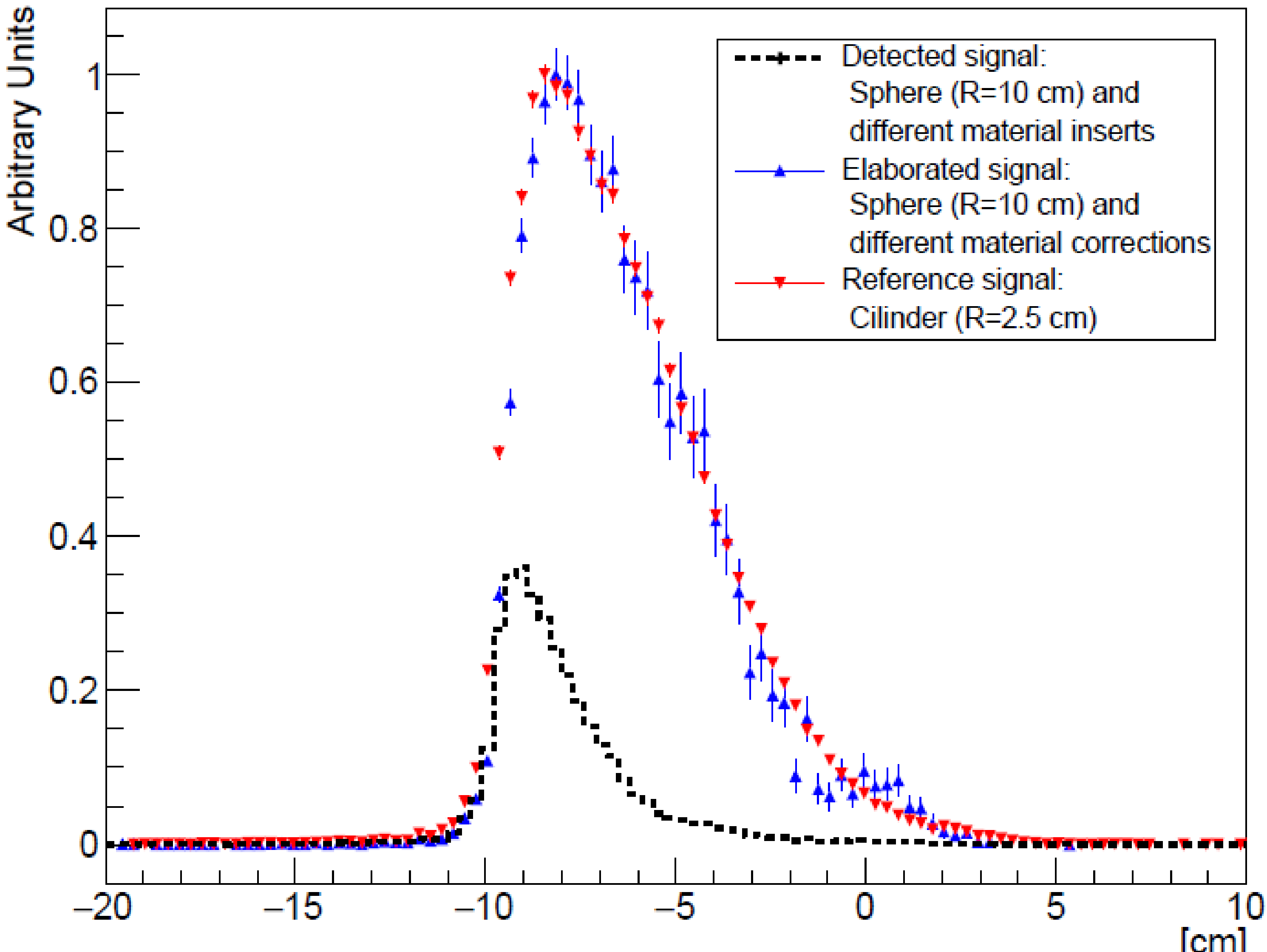
Material	Density $[g/cm^2]$	Z/A	Average Excitation energy [eV]
PMMA	1.190	0.539	74.00
Adipose tissue	0.926	0.557	63.22
Bone	1.816	0.517	104.05
Metallic implant	2.466	0.482	107.67

Material	Chemical composition (%)									
	H	C	N	O	Na	P	S	Cl	Mg	Ca
PMMA	53.3	33.3		13.3						
Adipose tissue	11.6	68.1	0.2	19.8	0.1		0.1	0.1		
Bone	3.9	17.9	4.1	42.9	0.1	9.6	0.3		0.2	21.0
Metallic implant	3.4	15.5	4.2	43.5	0.1	10.3	0.3		0.2	22.5

Table 1: Material properties and composition as parametrized by [18, 19, 20]

Complete correction applied

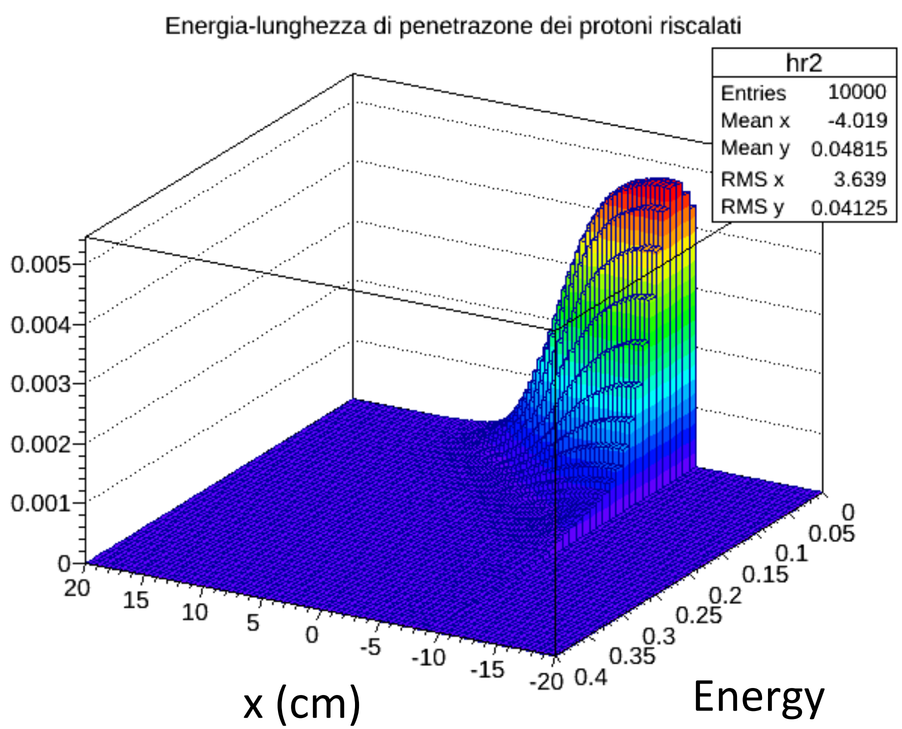
The number of primary ^{12}C ions considered in the simulation is the one necessary to cover 1 cm^2 of the distal slice (220 MeV/u) of a raster scanning treatment plan delivering 1 Gy of physical dose in 3×3×3× cm^3 in water starting at a depth of 7 cm.

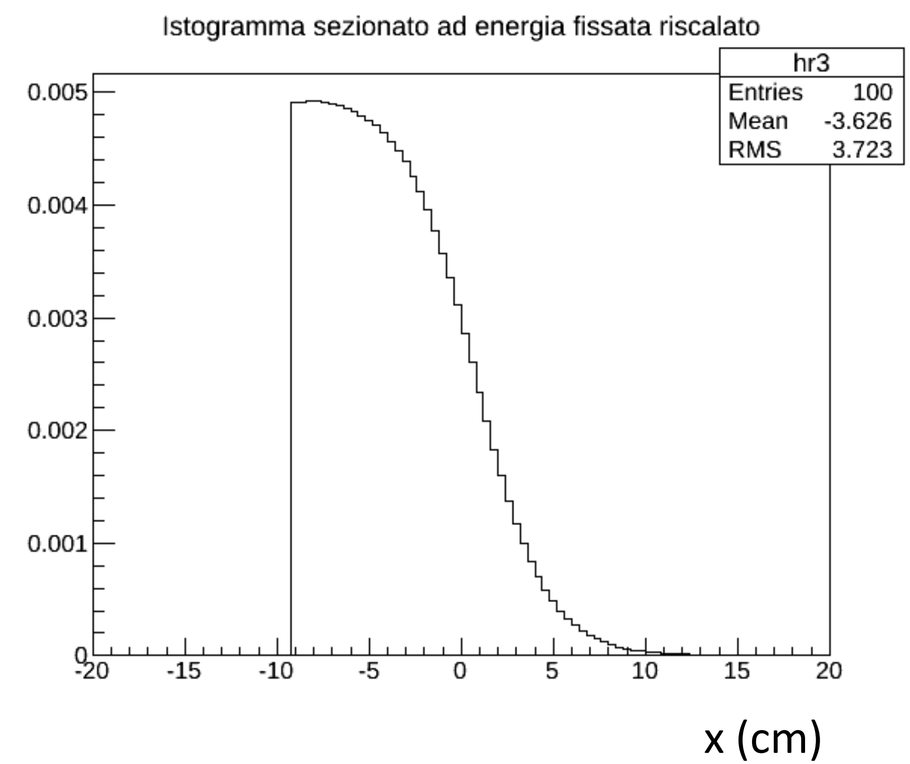


Improvement of generator

- The first version was built starting from the emission profile of measured protons as emerging from R = 2.5 cm of PMMA: with the help of MC and taking into account the functional form described above, an extension to R~0 is now available
- Making use of the already discussed dependences on density and elemental composition we are now able to adapt the distributions as a function of x and E in PMMA to any material or to any non-homegeneous situation

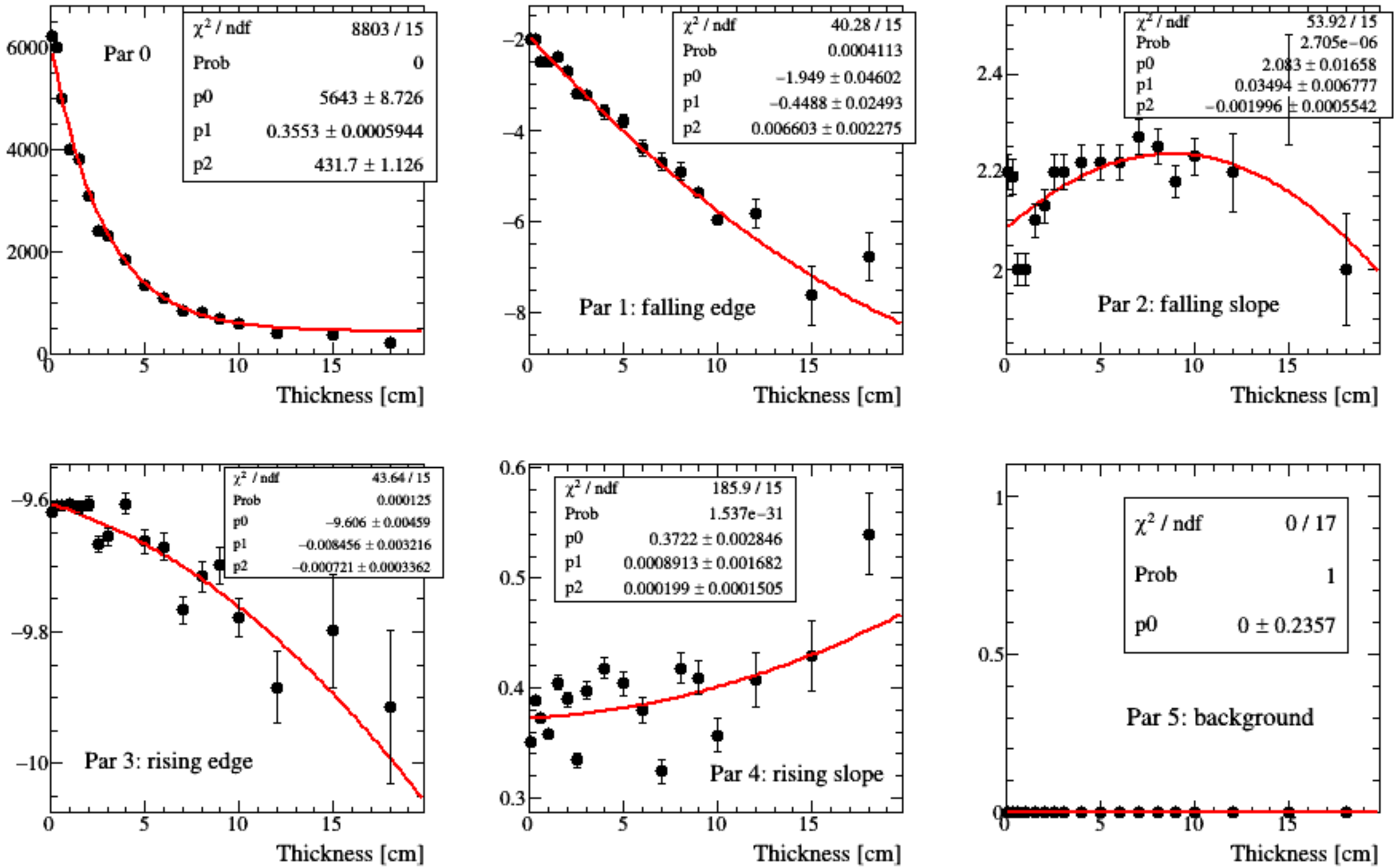
New fast generator starting in WATER originating from the beam axes (R=0)



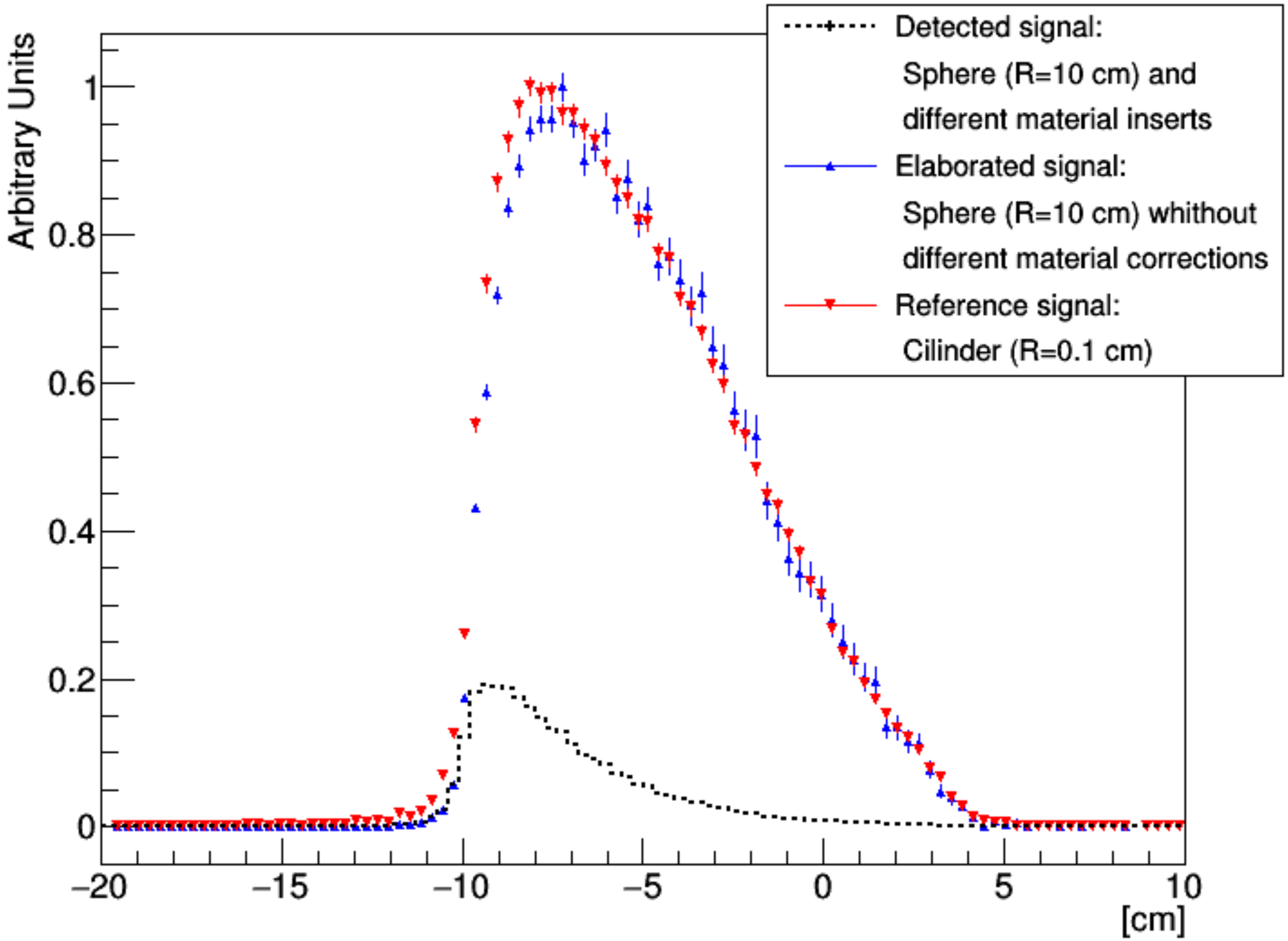


Evolution of 5 parameters of f(x) for different material thickness

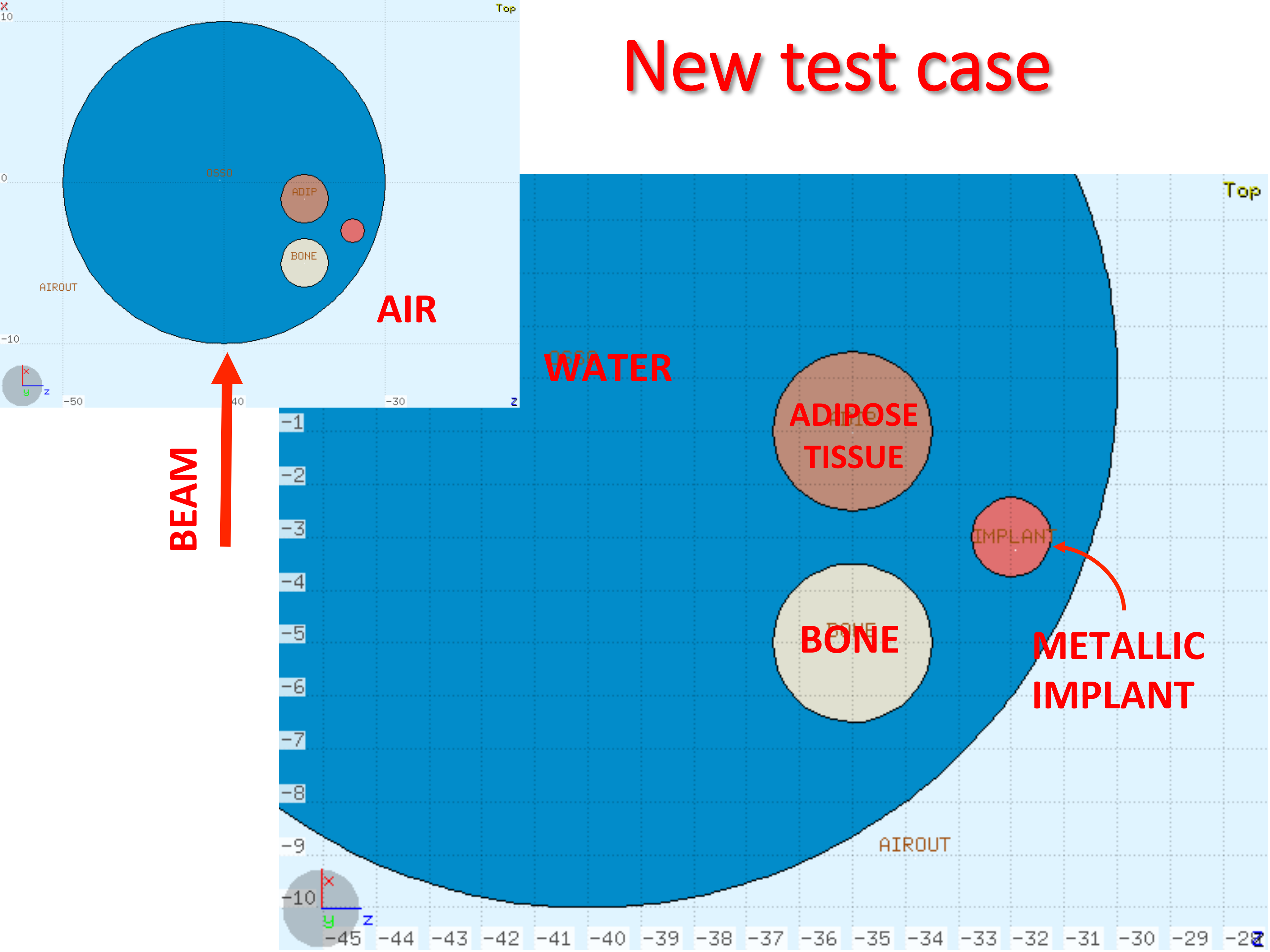
Example:from 0.1 cm to 18 cm <u>in water</u>



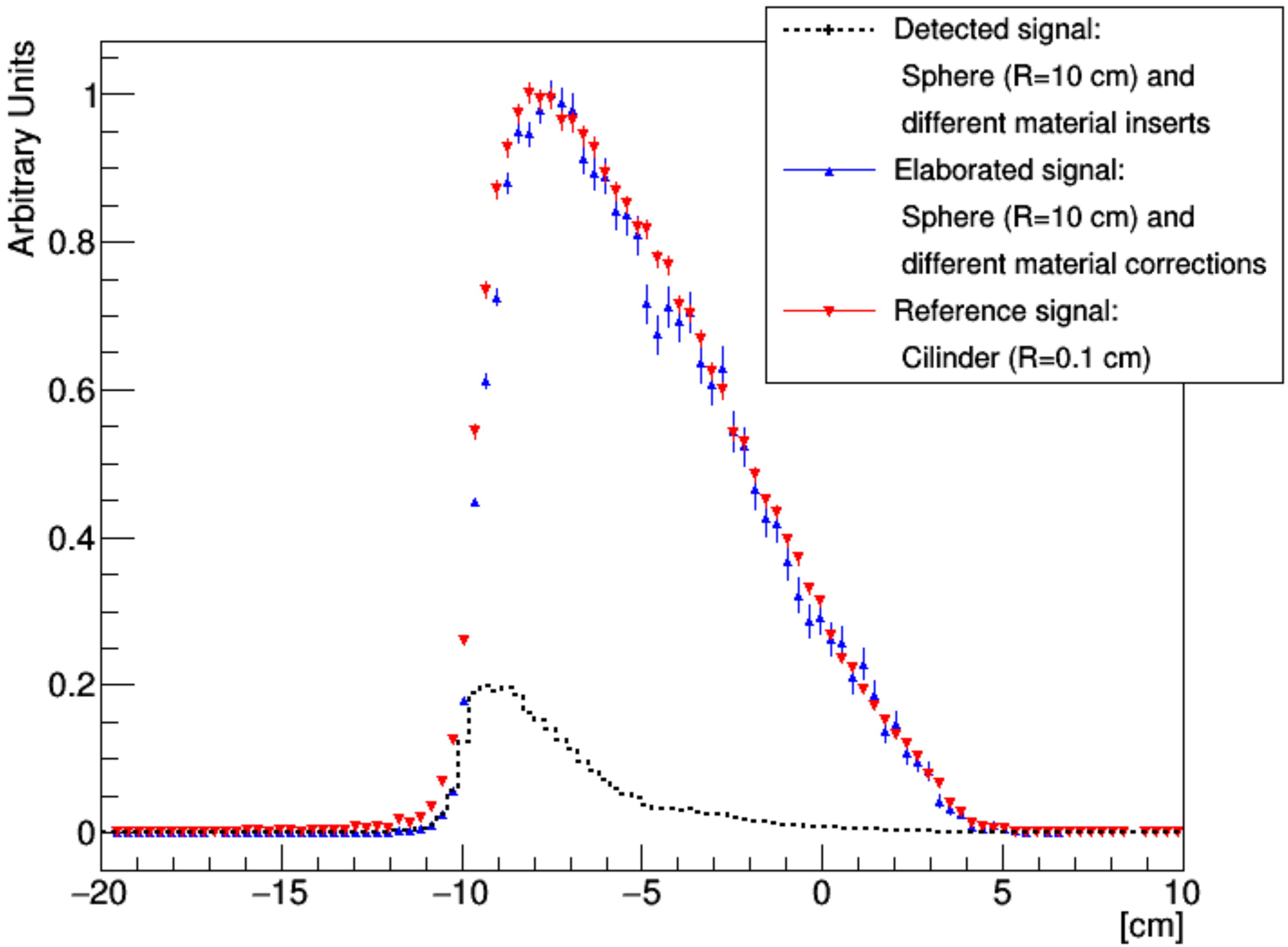
Reconstruction of the emission shape at beam level starting from the detected shape emerging from a homogeneous WATER sphere



New test case



Reconstruction of the emission shape at beam level starting from the detected shape emerging from a WATER sphere <u>***with different material inserts***</u>



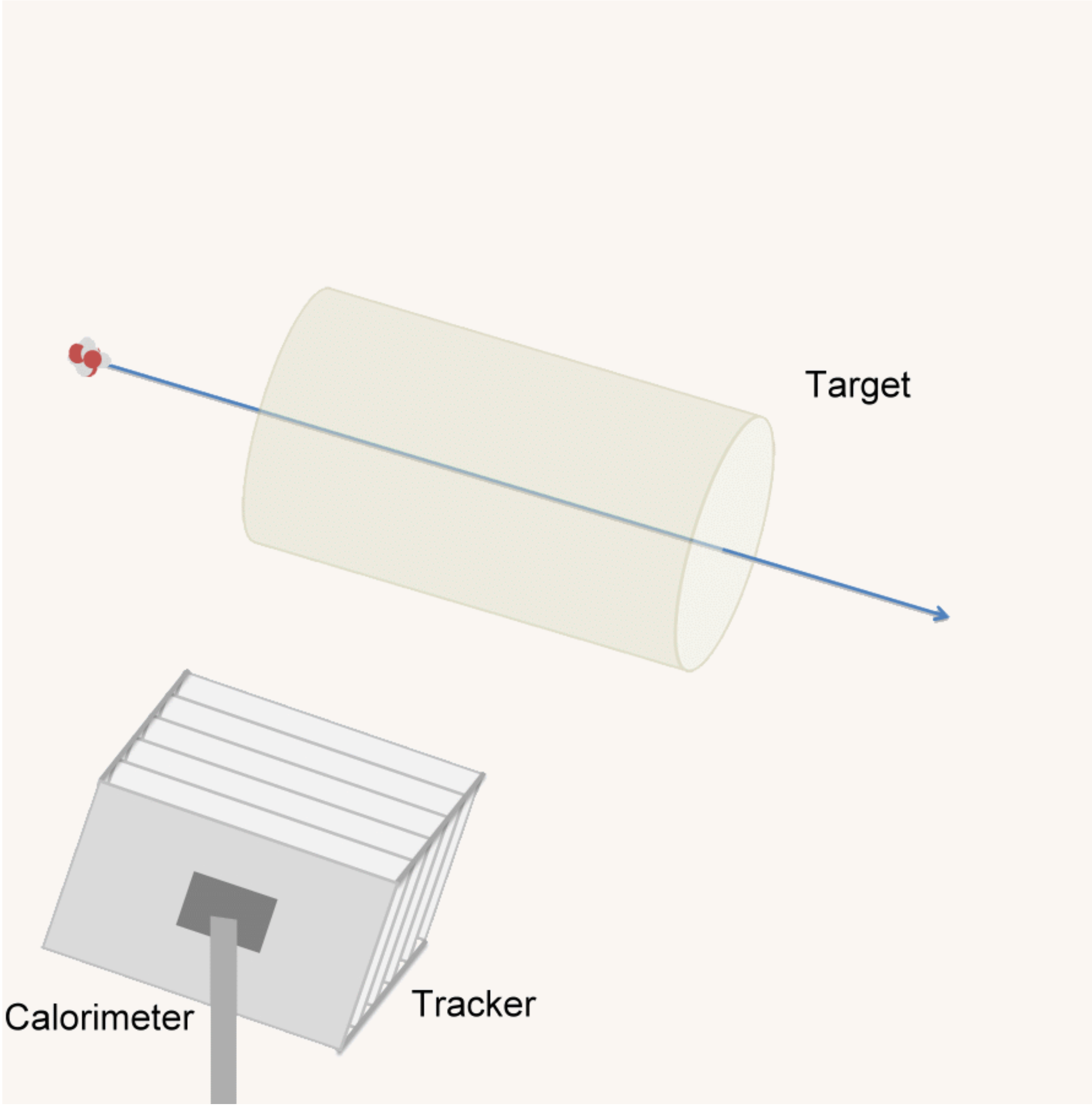
Towards the use in clinical practice: use of fast MC

We developed a plugin for FRED (a fast-MC simulation software for ray tracing, RDH-WP11) to reconstruct the fragmentation pattern of the beam in a real patient case and take into account in real time of all corrections needed in a non-homegenous case in order to reconstruct the actual range of primary beam

Input:

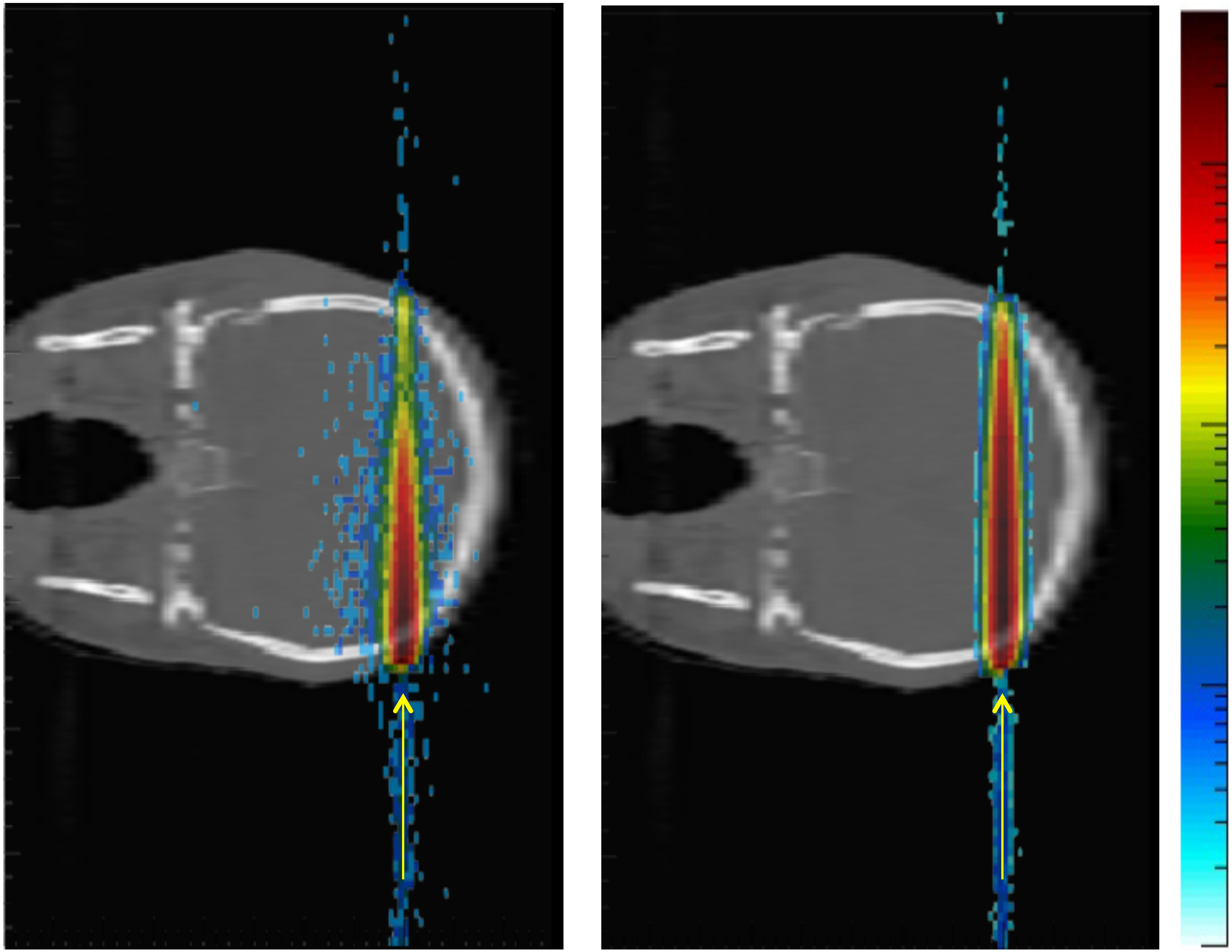
a) CT of the patient, the relative detector position and the on-line info about position and direction of primary beam.
b) Secondary particles' position, energy and velocity direction supplied by the tracker + calorimeter

FRED backtracks every particle until it reach the «minimum approach position» with respect to primay beam. Once it is done, FRED «interprets» the data to find the actual range.


Target
Calorimeter
Tracker

Emission Profile of Reconstructed secondary particles

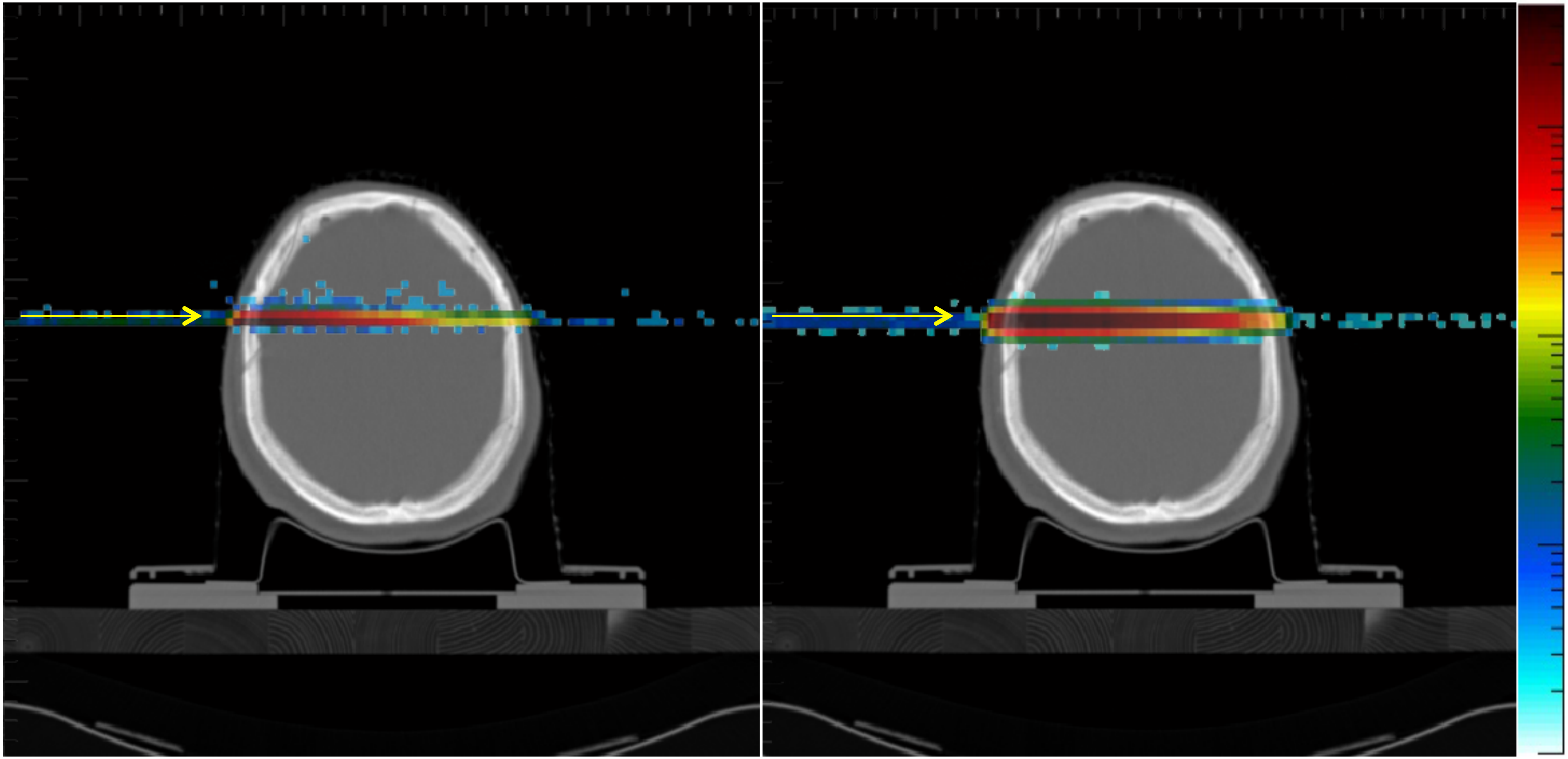
Emitted secondary particles as resulting from FRED backtracking



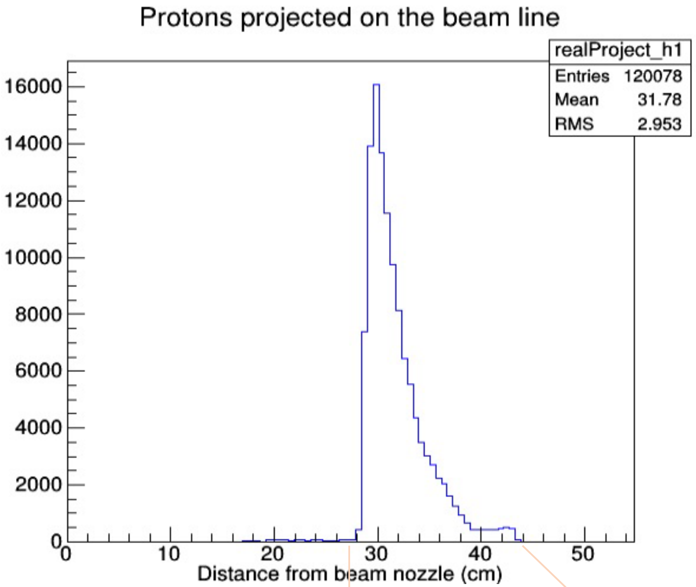
C220 MeV beam on a real CT (head)
[XZ view]

Emission Profile of Reconstructed secondary particles

Emitted secondary particles as resulting from FRED backtracking



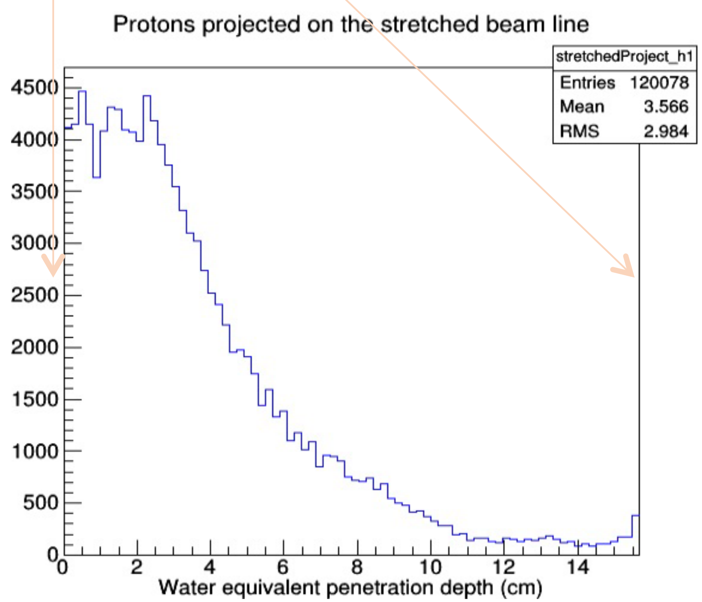
C220 MeV beam on a real CT (head)
[XY view]

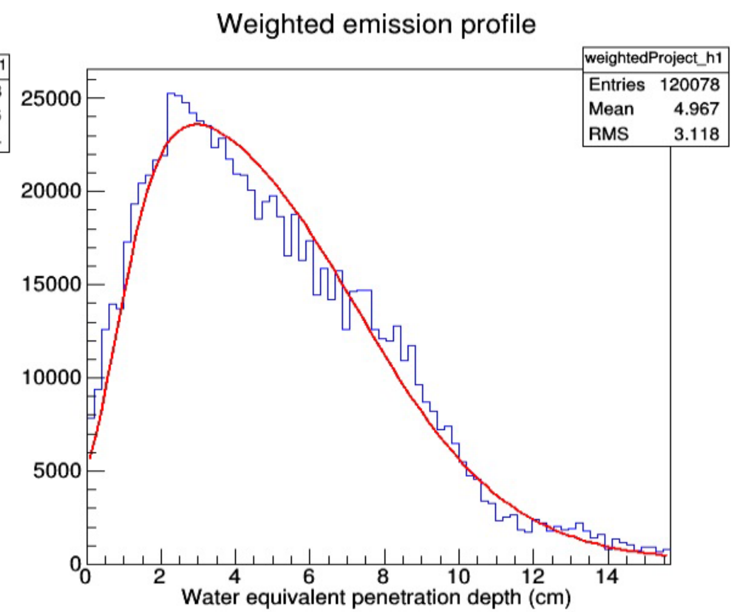


The same weighting technique introduced at January's meeing is used:

- **To translate the «penetration depth» in «water equivalent penetration depth»**
- **To consider how many secondary particles may be trapped in the target**

The red line is the reference emission profile for which we know the BP position (= range)





C220 MeV beam on a real CT (head)
[beam line projection]

Other topics

- Dose Profiler presented in February at the 14th Vienna Conference on Instrumentation (S. Muraro). Proceedings available on-line
- Paper on Dose Profiler ~ready for submission to Physica Medica