Reconstruction of the emission profile of secondary charged particles for a variable thickness of the material

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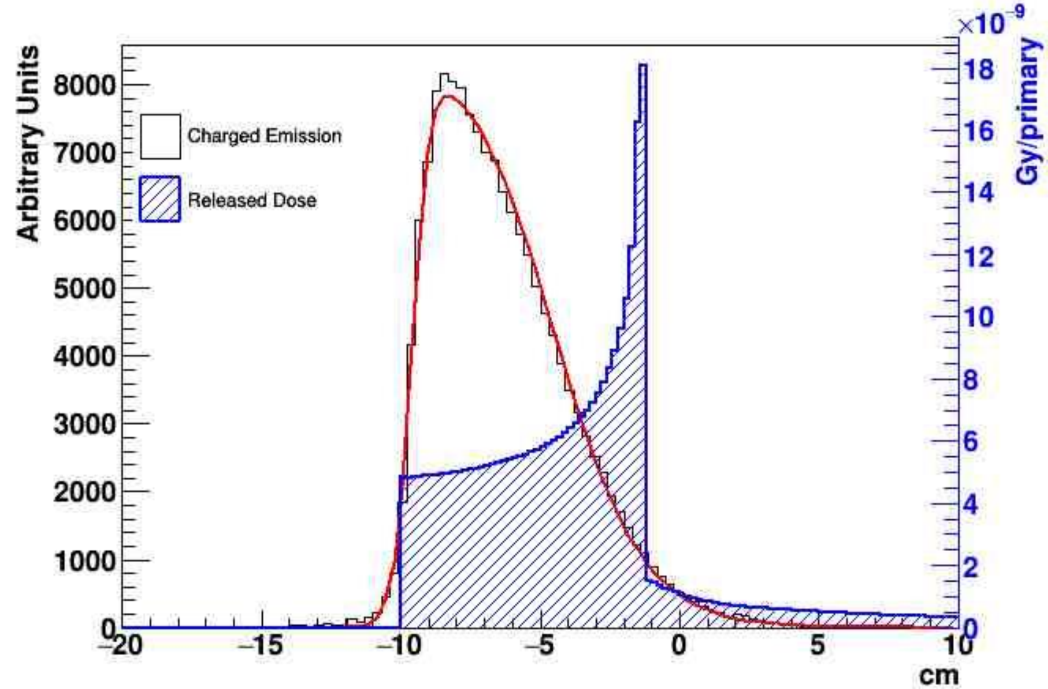
1) Problem: On-line dose monitoring by means of secondary charged particles emission profile.
2) Method to compensate variable thickness
3) How we developed the method
4) Application to exemplifying cases
5) How to proceed towards a more general case

Problem:

On-line dose monitoring by means of secondary charged particles emission profile.

We can correlate the emission profile with the Bragg peak position.

L. Piersanti et al. Phys. Med. Biol. 59 (2014) 1857



^{12}C beam of 220 MeV/u on PMMA target: secondary proton emission profile and released dose

We learned how to do it (exp. + MC) for the thickness of 2.5 cm of PMMA but **the emission prifile depends on the crossed material thickness!**

The yield of the secondary protons produced by the beam interaction with the patient tissue undergoes an **attenuation process** in the crossed material (dE/dx).

The resulting profile detected by the Dose Profiler is modified with respect to the emission one.

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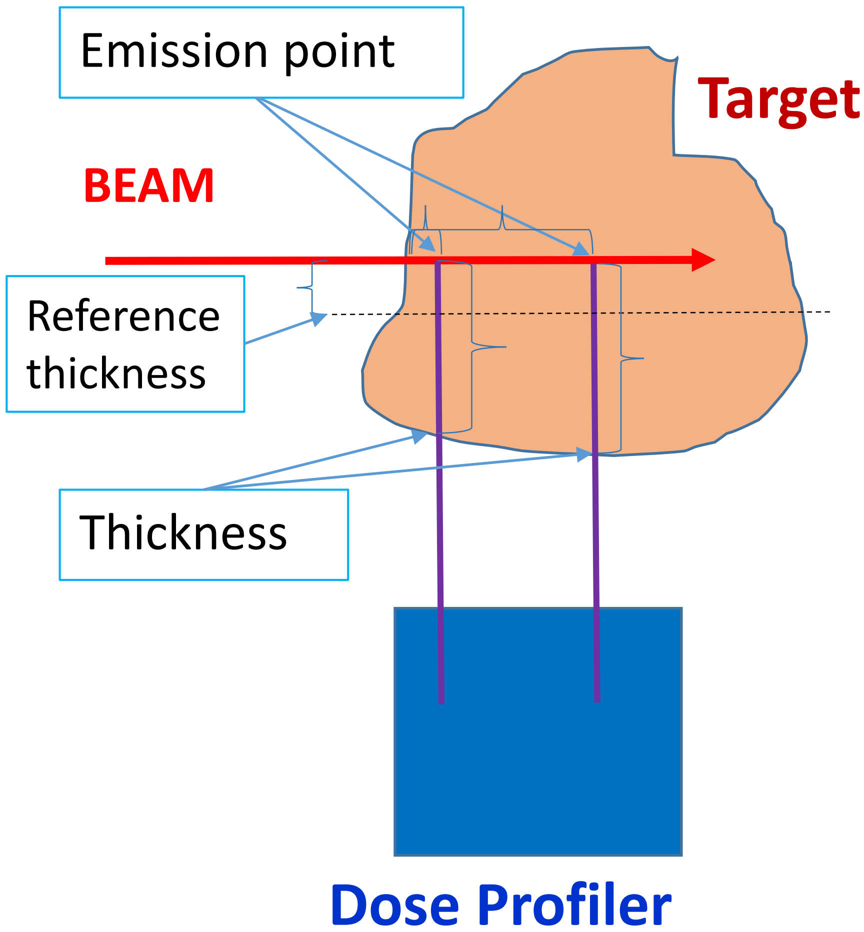
Method:

We can evaluate, by means of MC simulations, for given material thicknesses, how the emission profile changes because of the attenuation along the path towards the Dose Profiler.

By <u>comparing the emission profile of a known thickness with the emission profile of our reference thickness</u> (2.5 cm), we can build a **weighting factor** to be applied to each reconstructed track to modify its contribution to the emission profile on the basis of the crossed thickness.



Known the thickness of crossed material (CT of the patient) and the reconstructed emission point on the beam axis, we associate a weighting value which convert the profile to the reference one (cilinder R = 2.5 cm).

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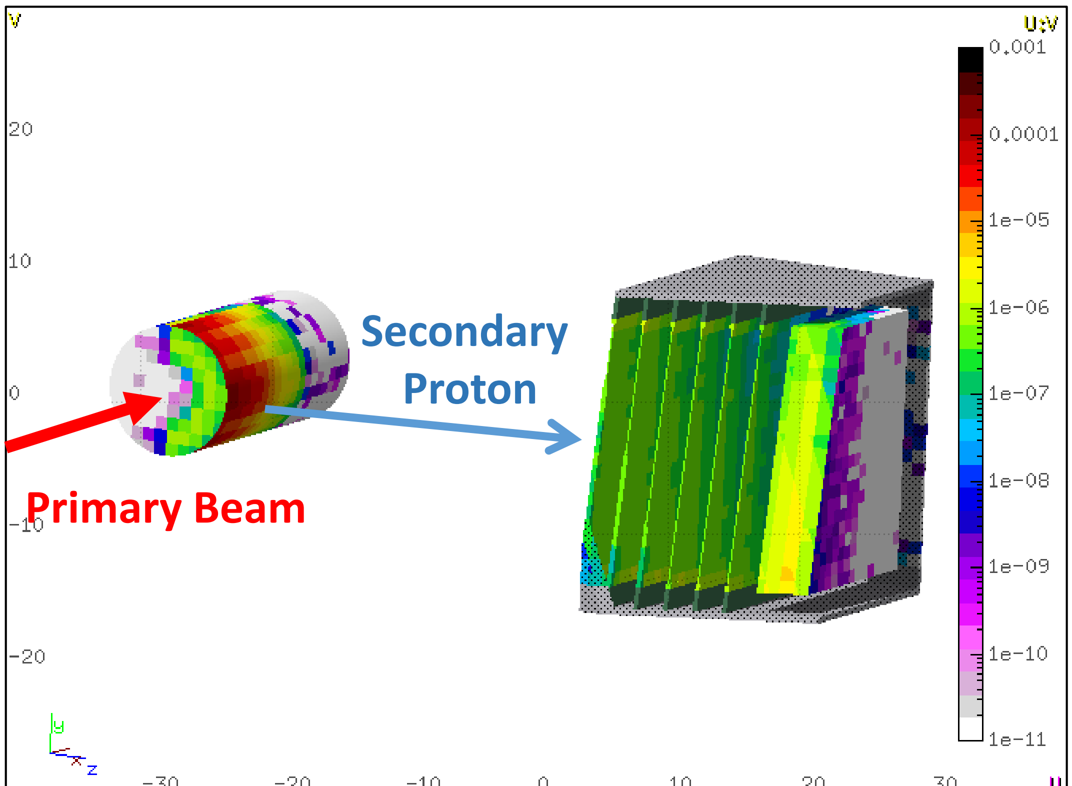
How we developed the method

We used a parametrized secondary proton generator to evaluate for different thicknesses the proton flux attenuation in PMMA.

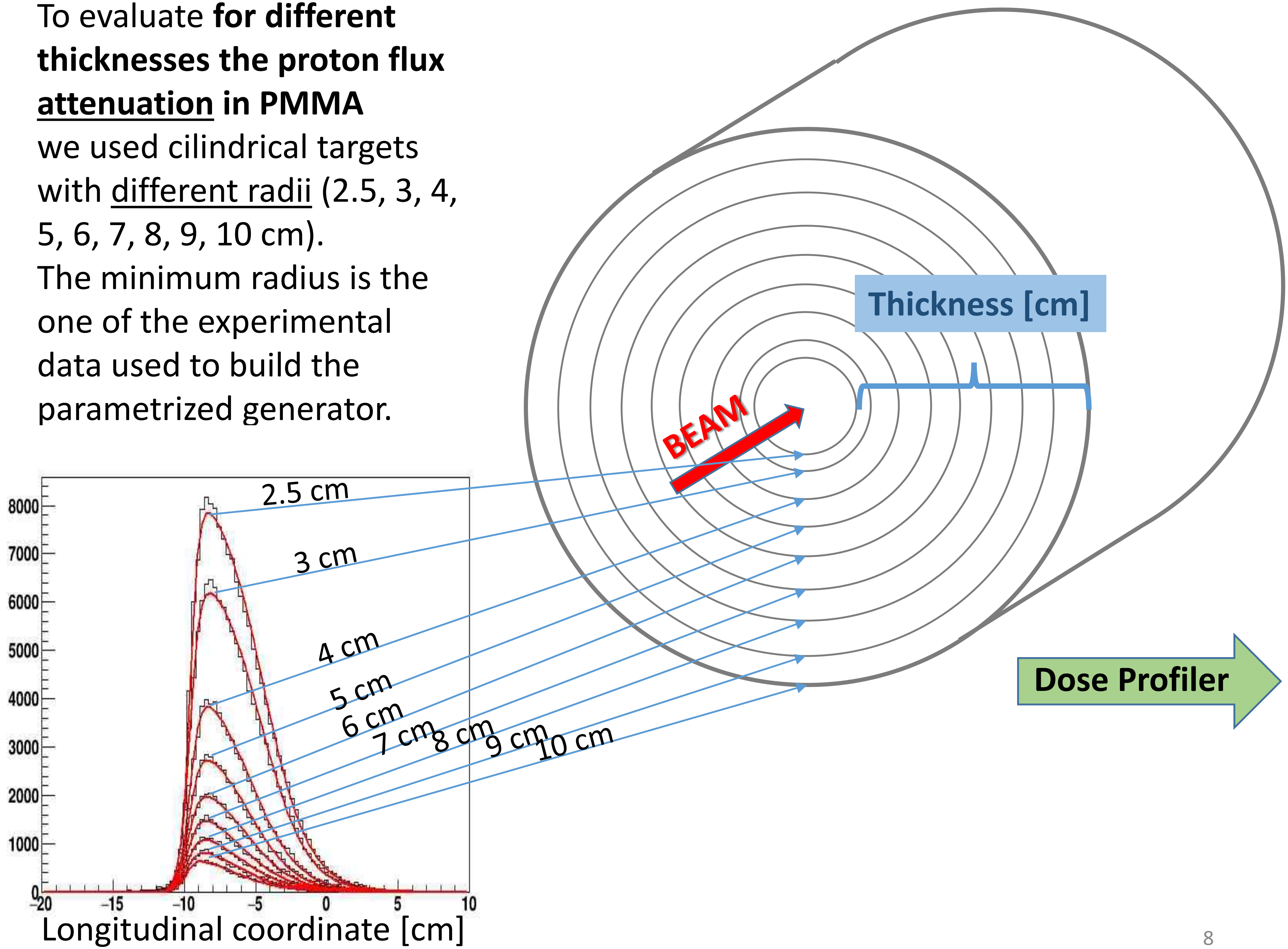


Parametrized proton generator

Protons come out towards the Dose Profiler direction:

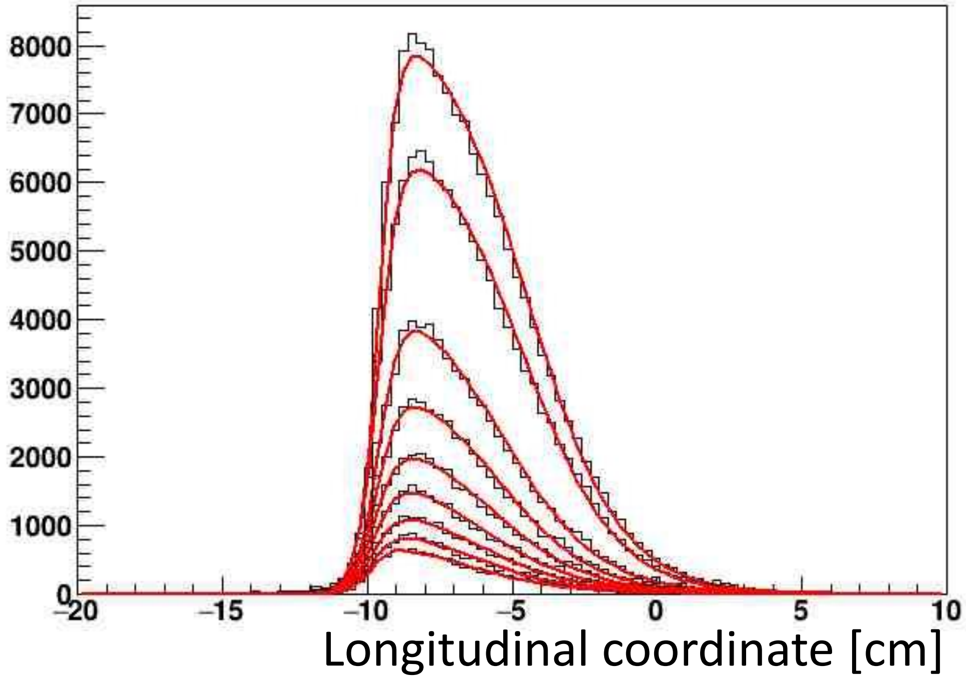
- ~ 90° with respect to the beam axis
- Spectrum based on the experimental data taken with a ^{12}C ion beam of 220 MeV/u on PMMA. Thickness 2.5 cm.
- cilindrical target

To evaluate **for different thicknesses the proton flux <u>attenuation</u> in PMMA** we used cilindrical targets with <u>different radii</u> (2.5, 3, 4, 5, 6, 7, 8, 9, 10 cm). The minimum radius is the one of the experimental data used to build the parametrized generator.



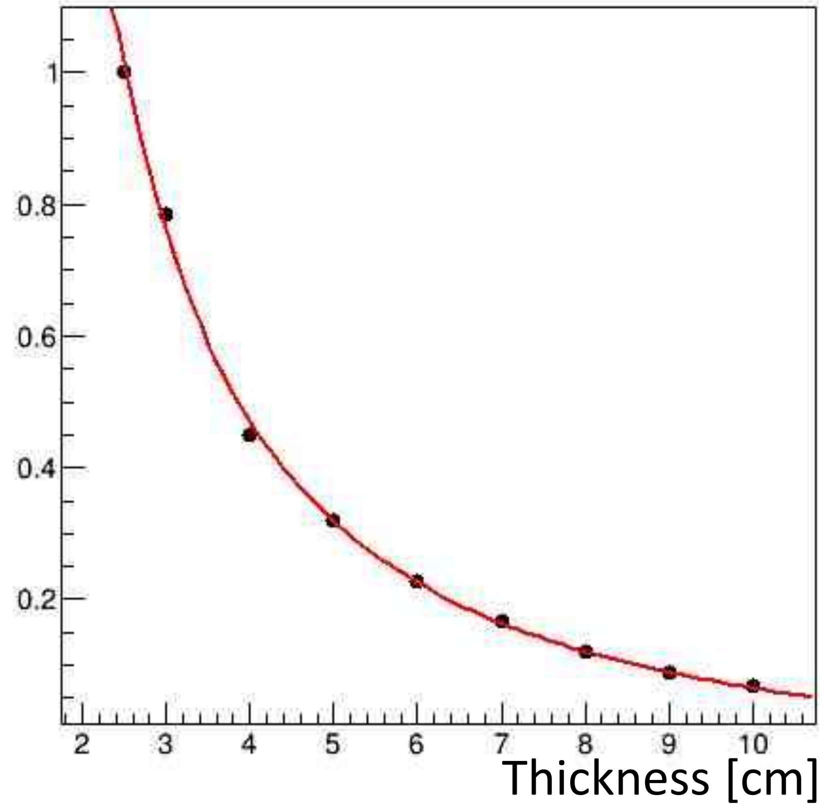
Attenuation as a function of thickness

Reconstructed secondary proton emission profile for different PMMA thicknesses (2.5, 3, 4, 5, 6, 7, 8, 9, 10 cm)



Proton attenuation factor in PMMA.

^{12}C 220 MeV/u



How we developed the method

Each **emission profile** is well fitted with the Double Fermi-Dirac function.

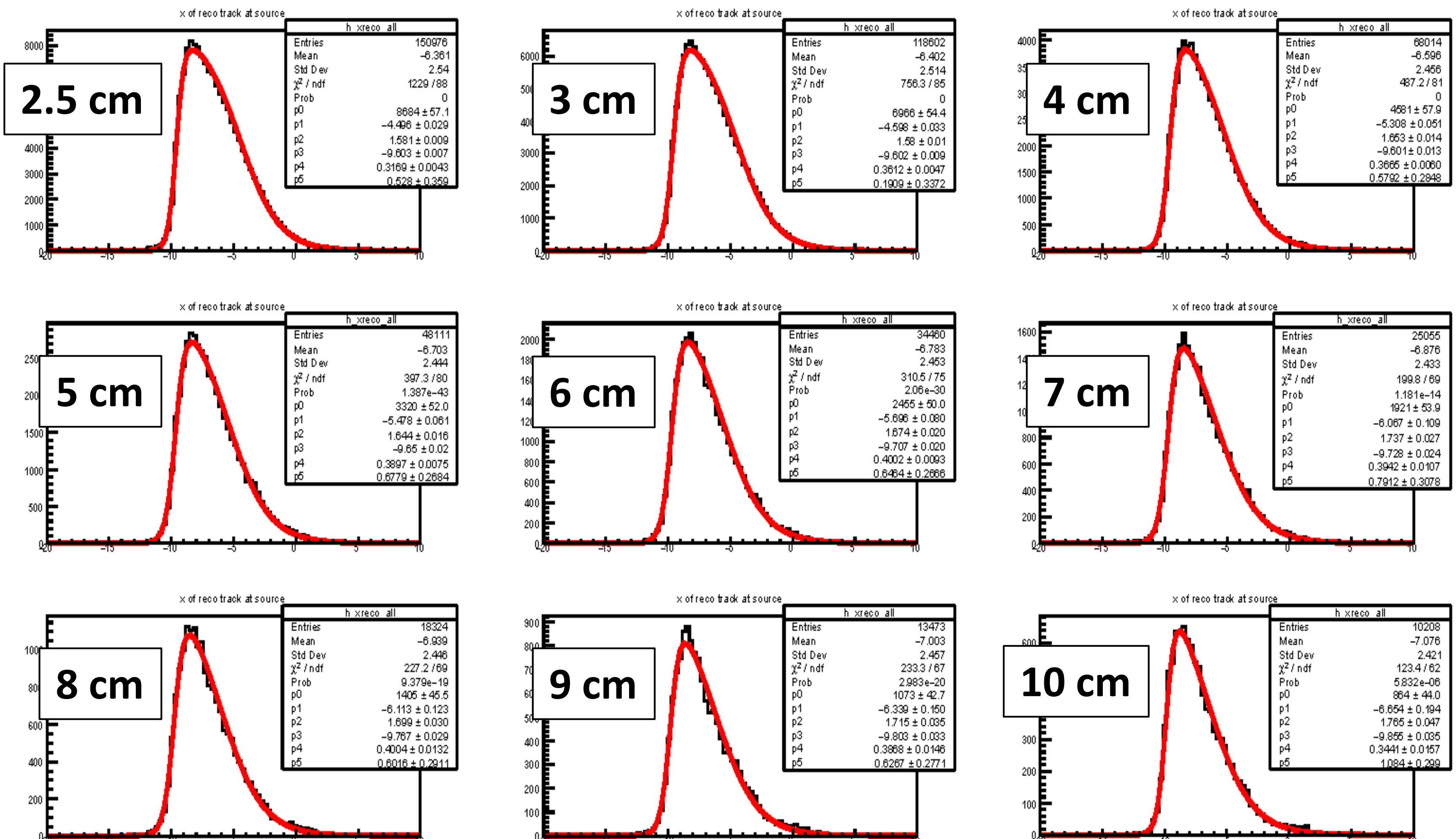
The Double Fermi-Dirac function

$$f(x) = p_0 \frac{1}{1+\exp\left(\frac{x-p_1}{p_2}\right)} \frac{1}{1+\exp\left(-\frac{x-p_3}{p_4}\right)} + p_5$$

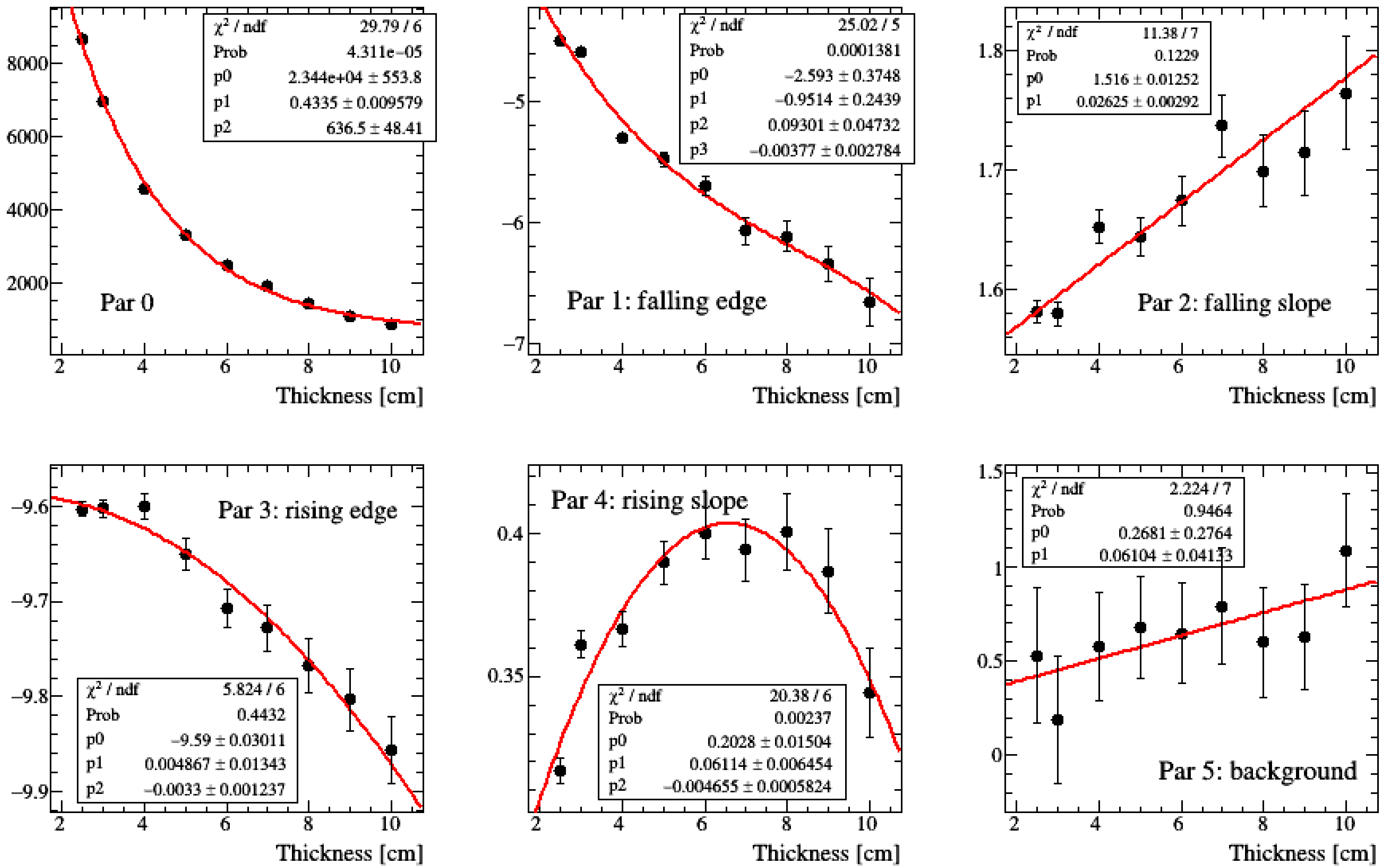
The evolution of the different **parameters** as a function of thickness
can be easily evaluated by fitting

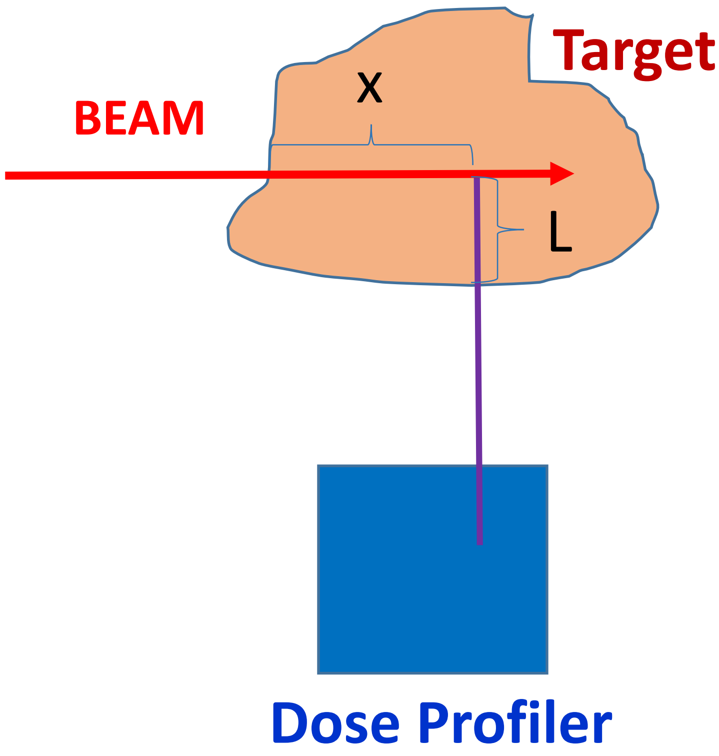
Fits with the Double Fermi-Dirac function

Secondary proton emission profile from ^{12}C @220 MeV/u as detected by the Dose Profiler for different PMMA thicknesses (2.5, 3, 4, 5, 6, 7, 8, 9, 10 cm)



Fits of the Double Fermi-Dirac distribution parameters VS PMMA thickness for ^{12}C @220 MeV/u





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)*** :

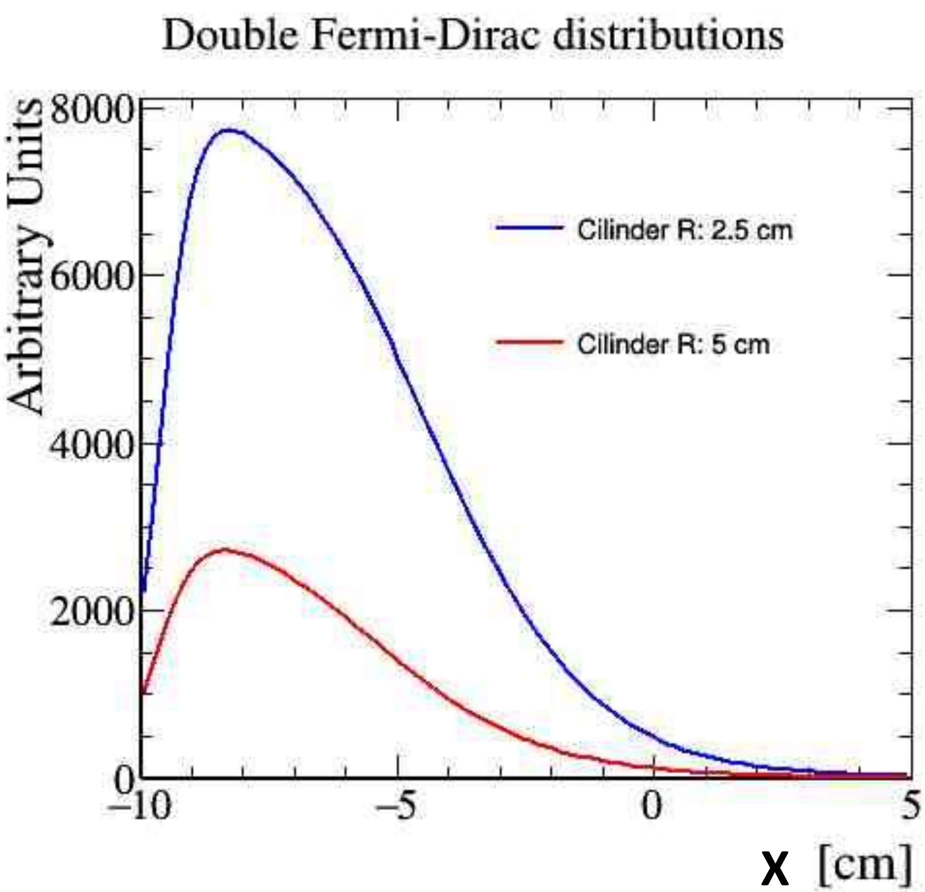
$$w(Par(L)\,,\,x) = \frac{f_{DFD}\,(Par(L)\,,\,x)}{f_{DFD}\,(Par(2.5\ cm)\,,\,x)}$$

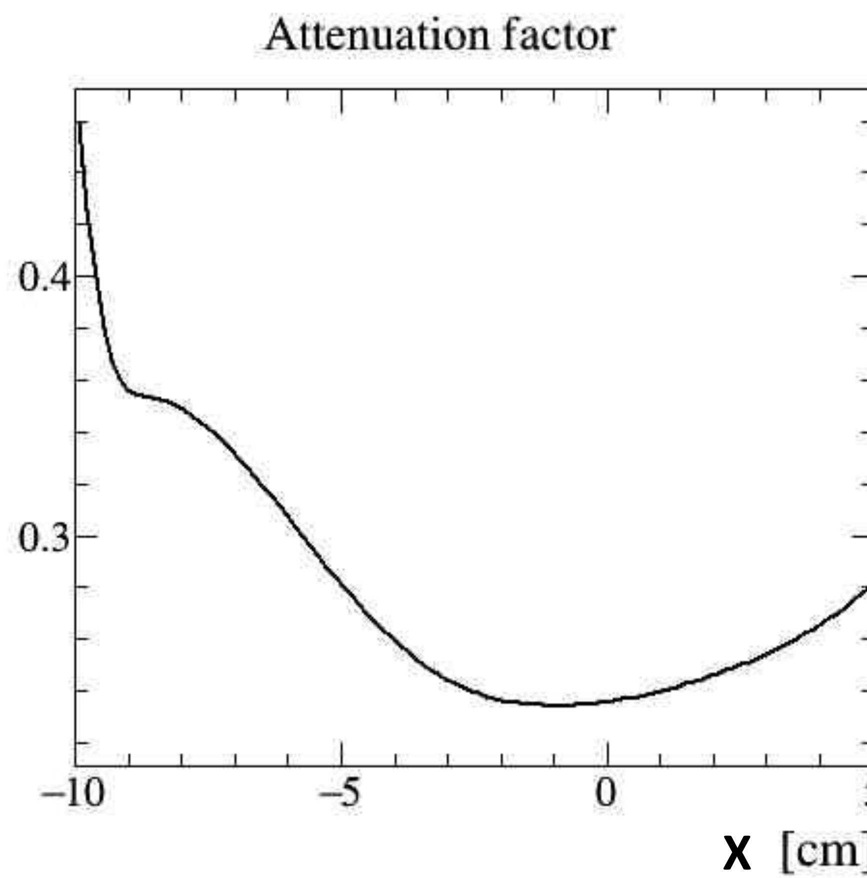
We get the thichness ***L*** of crossed material from the geometry (patient CT) and reconstructed track informations (emission point and direction).

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)

From Cilinder R = 5 cm to Cilinder R = 2.5 cm

$$w(Par(L), x) = \frac{f_{DFD}(Par(L), x)}{f_{DFD}(Par(2.5\ cm), x)}$$





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Application to exemplifying cases

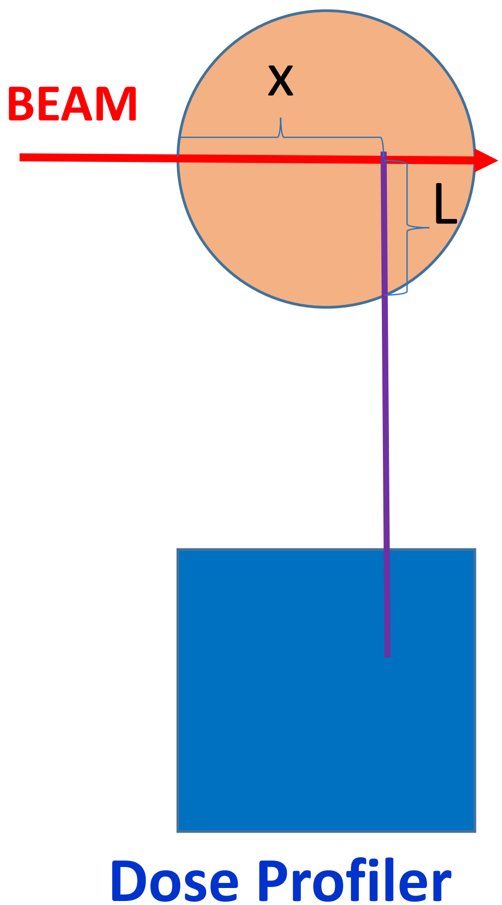
1. ***homogenous PMMA Sphere***:

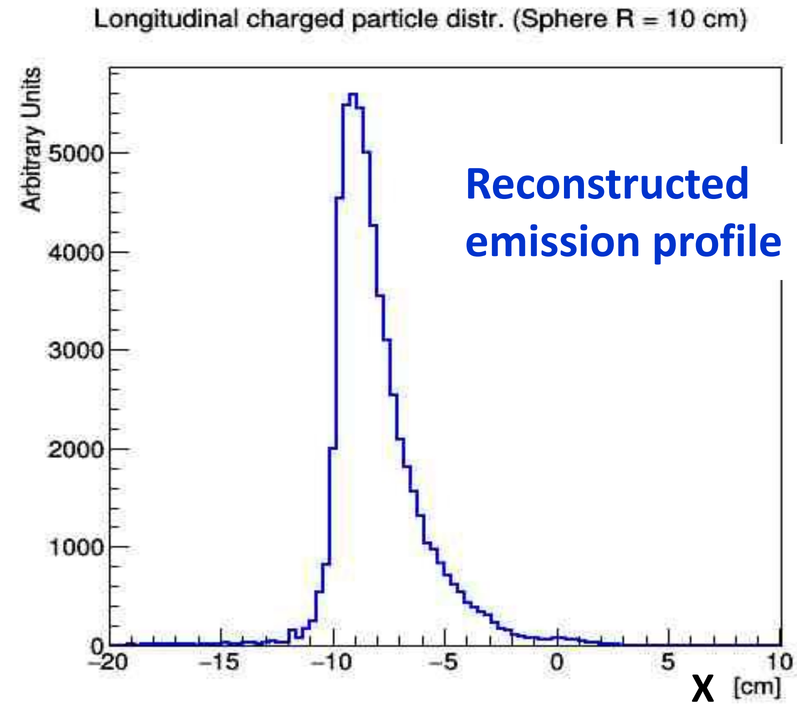
   variable thickness

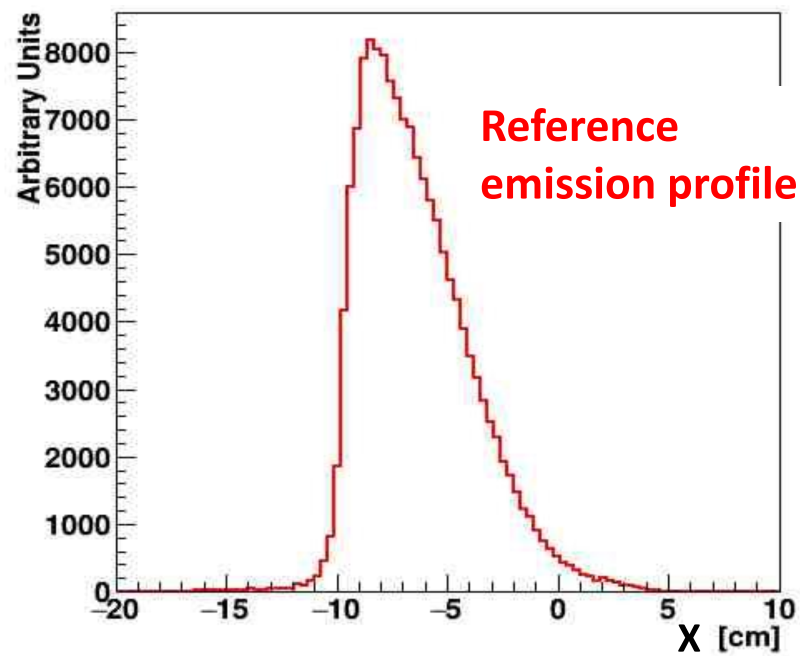
2. ***inhomgeneous PMMA Sphere containing a smaller sphere of "light" PMMA*** (half density with respect to the standard PMMA):

   variable thickness and material density

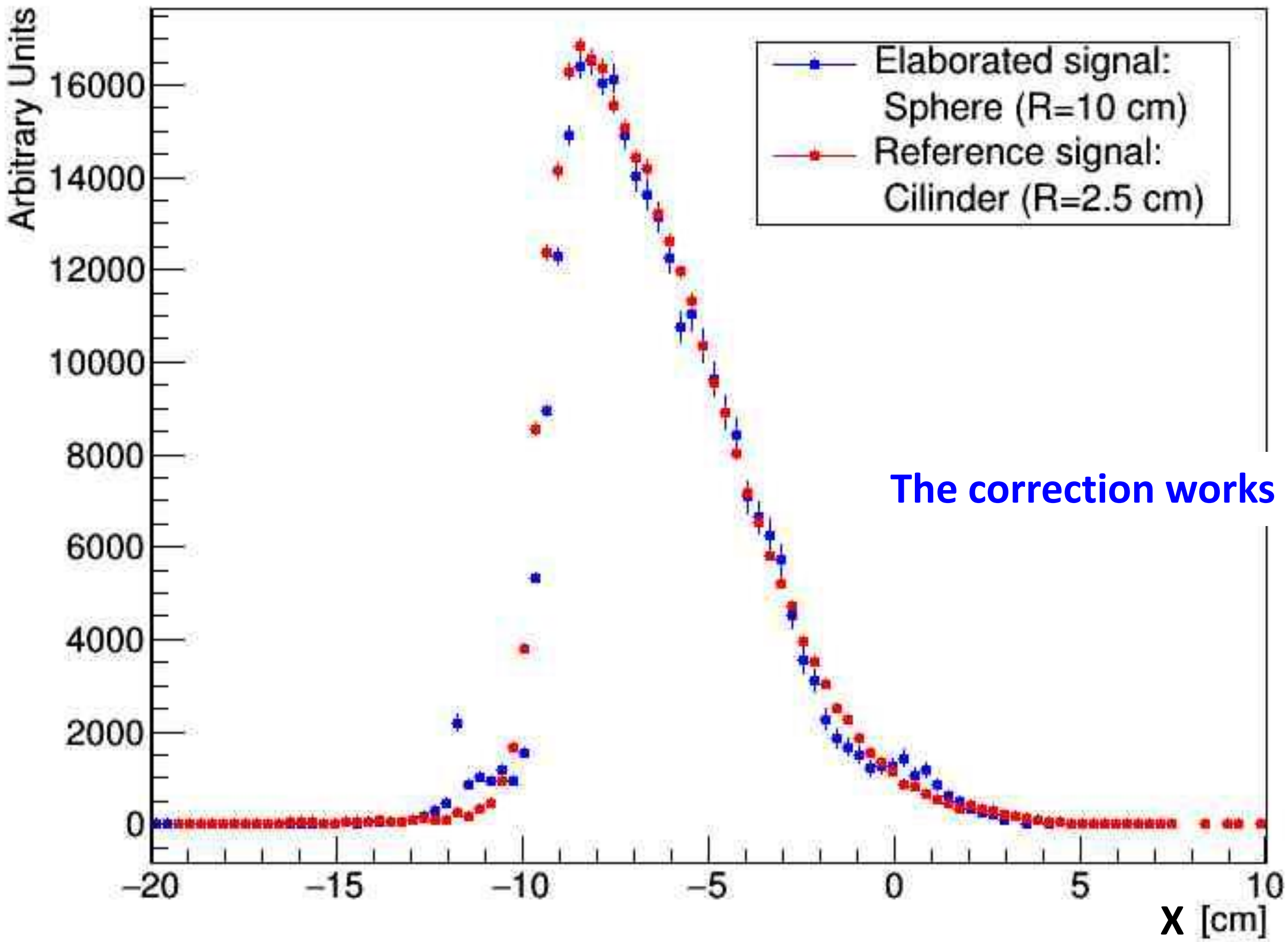
1) homogeneous PMMA sphere R = 10 cm





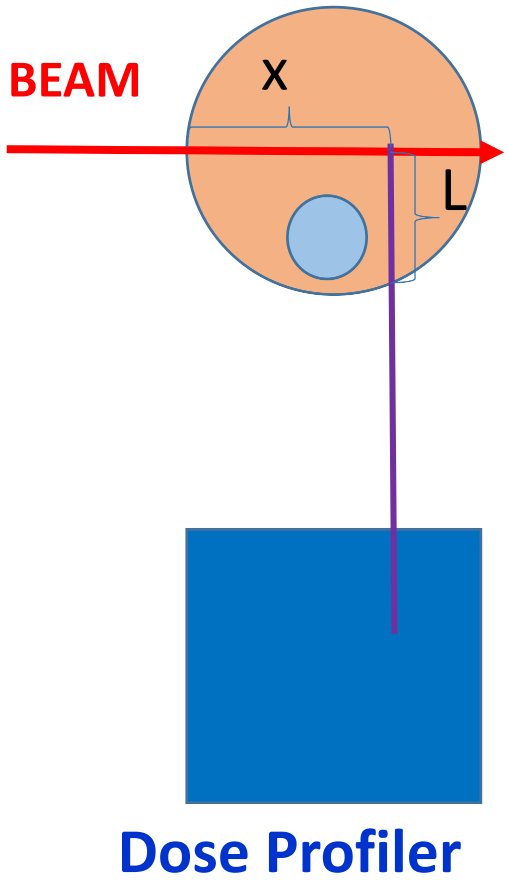


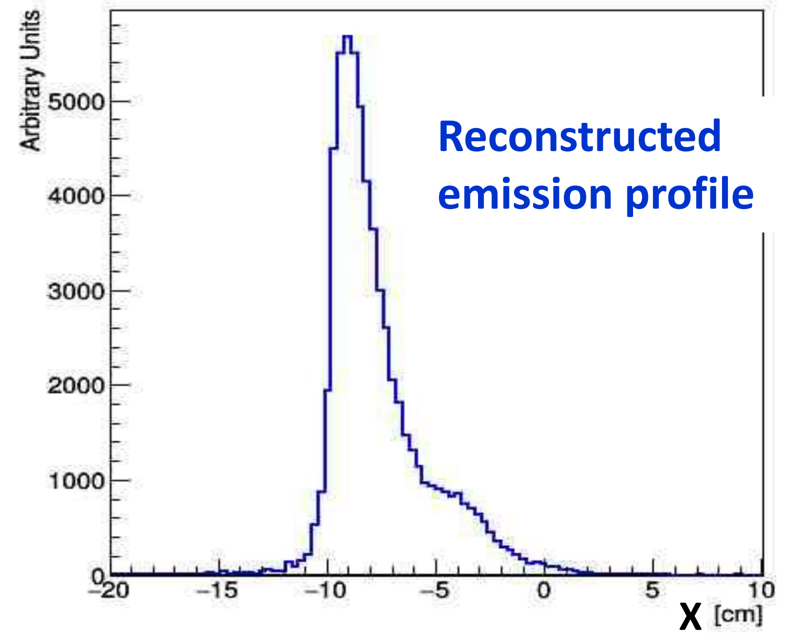
Result of the application of the weighting function

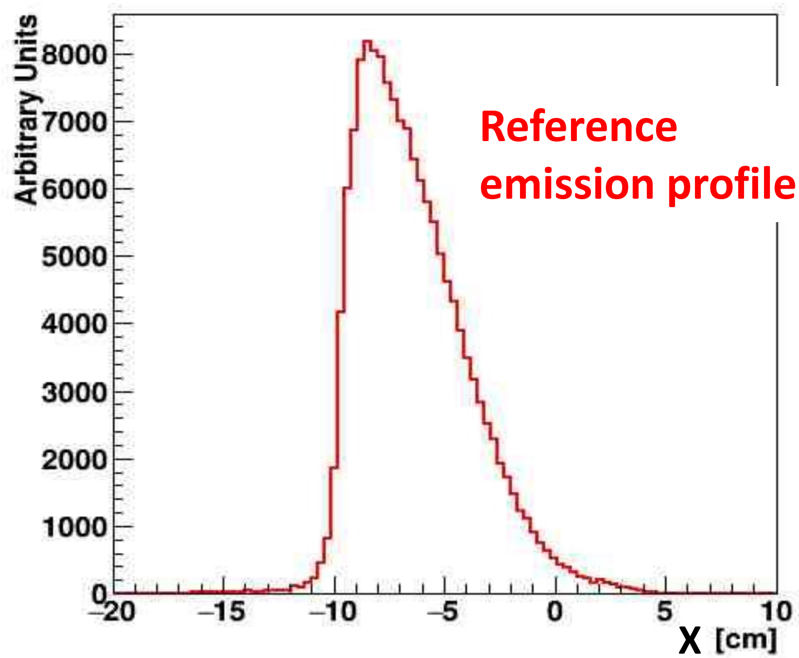


The correction works

2) inhomgeneous PMMA sphere containing a smaller sphere of "light" PMMA *(half density with respect to the standard PMMA)*







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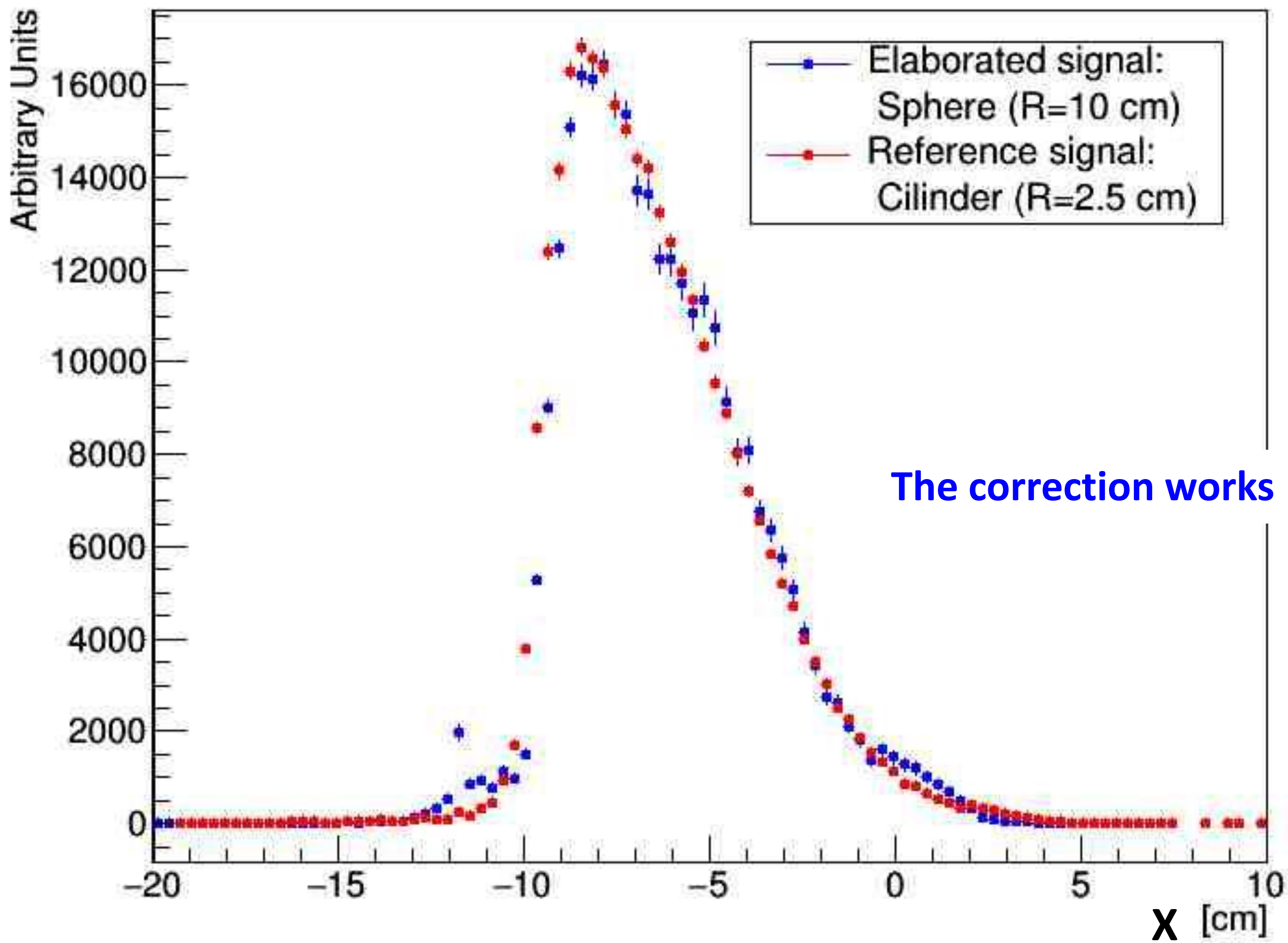

The correction works

Conclusions:

It seems that **the method is working as expected** and provides a way to **compare expectations and measurements in real time**

For a given beam and geometry (CT of patient), we can **build** the shape of **the expected** outcoming secondary protons **emission profile in a fast analytical way**

(for this purpose we can recur to ***W****ater* ***E****quivalent* ***P****ath* ***L****ength corrections to transform all materials to water)*

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How to proceed towards a more general case

- Analyze various inhomogeneus targets with **different material composition and increasing complexity**

- Evalute the **variations in the longitudinal development of the emission profile** when the beam crosses different material composition and density applying the **WEPL** correction