Solid state instrumentation for microdosimetry

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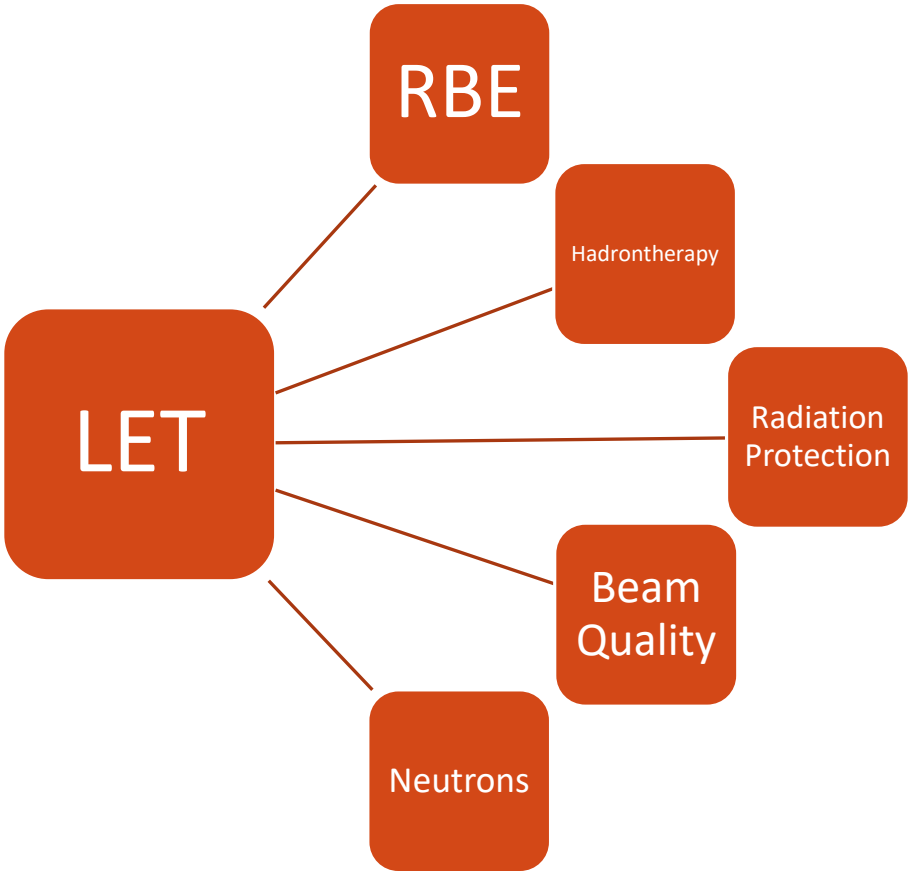
Presentation outline

- Motivation
- Experimental setup and methods
- CNM (INM-CESIC)/USC detectors
- Experiments with first version of the detector (p^+, ^{12}C)
- Experiments with second version of the detector (p^+, ^{12}C)
- Concluding remarks

Motivation



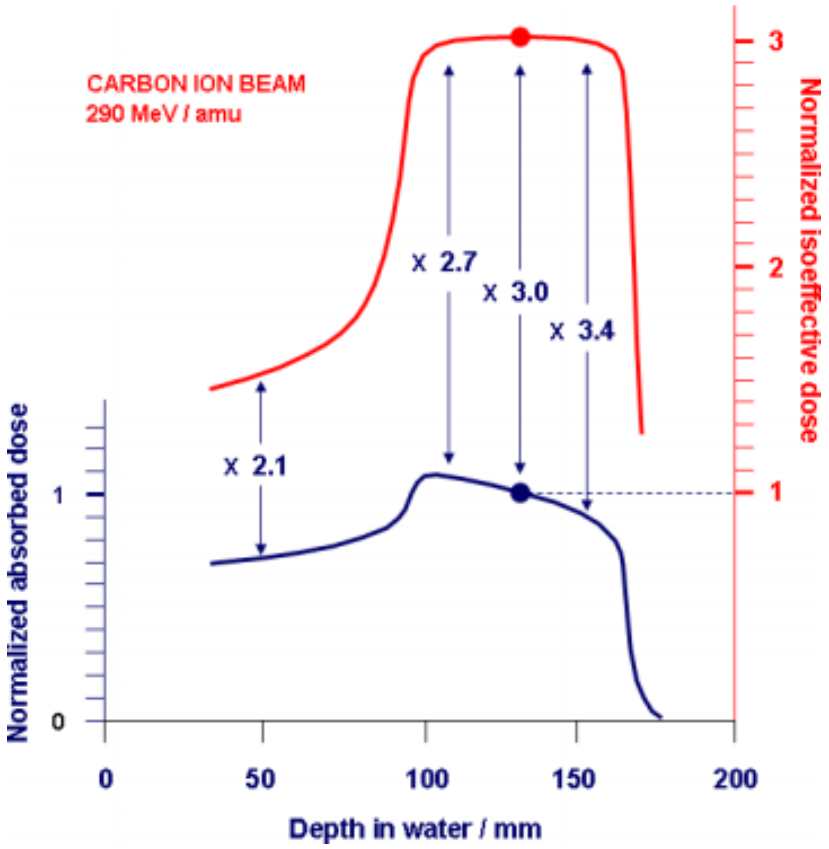
- Dose/specific energy is the standard magnitude for expression of the exposition to radiation.
- BUT radiobiological effects are not described through dose only!

$$H = \int Q(L)\, D(L)\, dL$$

$$Q(L)\ ?$$

- LET/lineal energy related magnitudes are not available in current instruments.

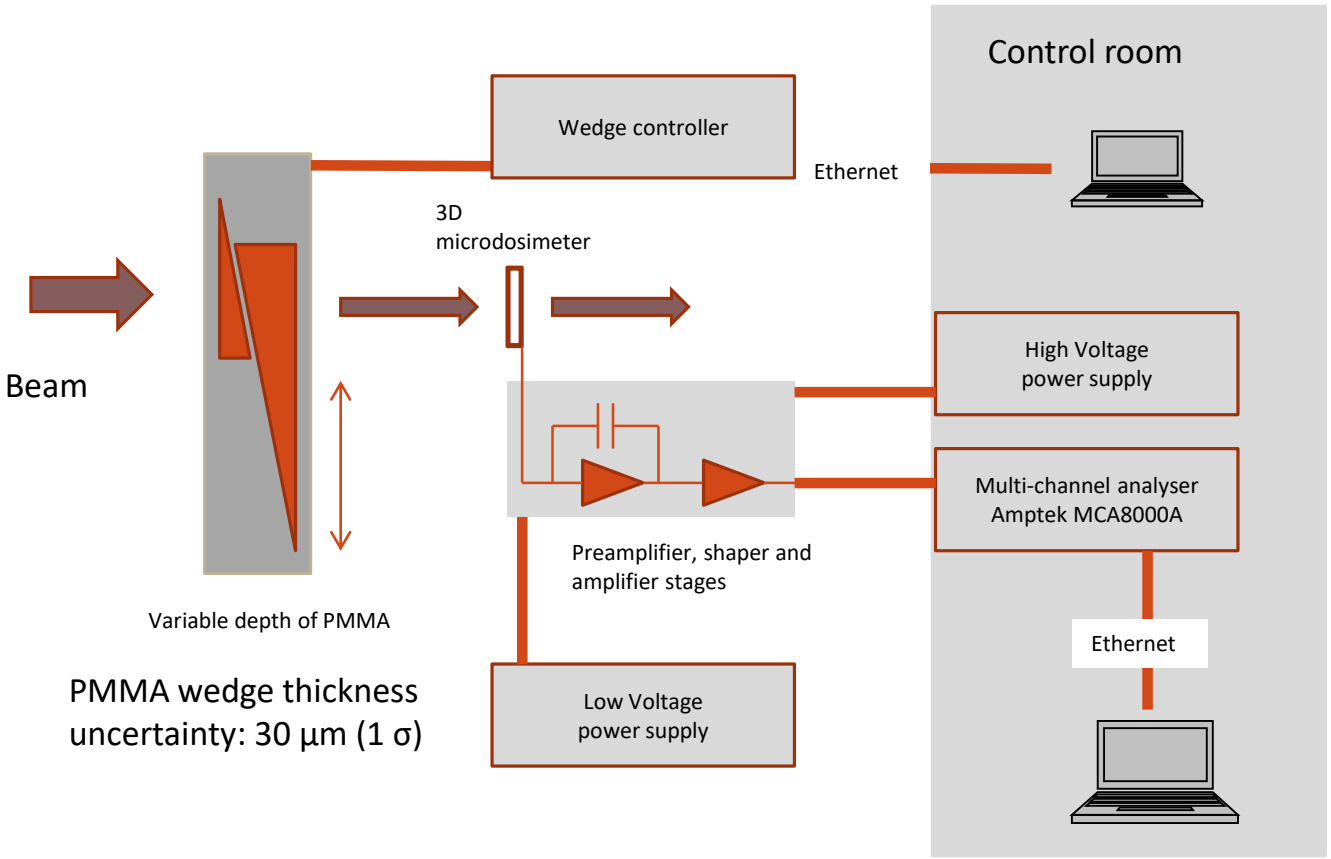
Motivation



Source: Relative Biological Effectiveness In Ion Beam Therapy. Technical Report Series TRS-461.

- Different kinds of radiation yield different results on living tissue at the same physical dose.
- The RBE is a comparison between the effects of a given radiation and a reference radiation at the same physical dose.
- RBE depends on physical dose, radiation quality, target tissue, fractioning…
- Using RBE a biological dose can be established.
- TEPCs/Silicon detectors are used for this task

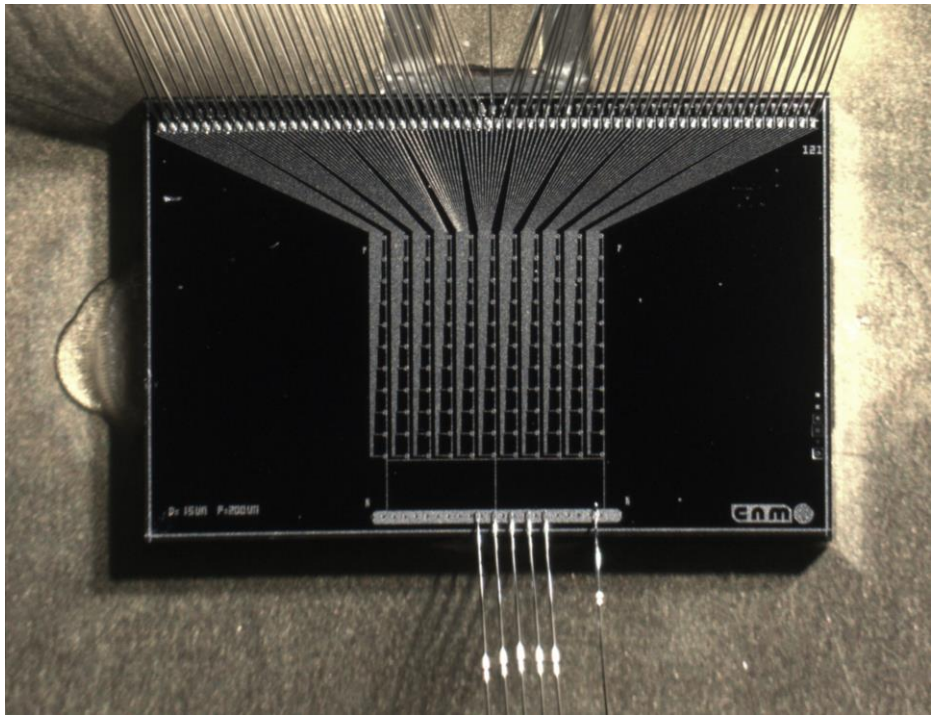
Experimental setup



Methods

- Energy deposition spectra over several depths of Lucite (PMMA).
- Results compared with Monte Carlo simulations.
- Three parameter χ^2 minimisation.

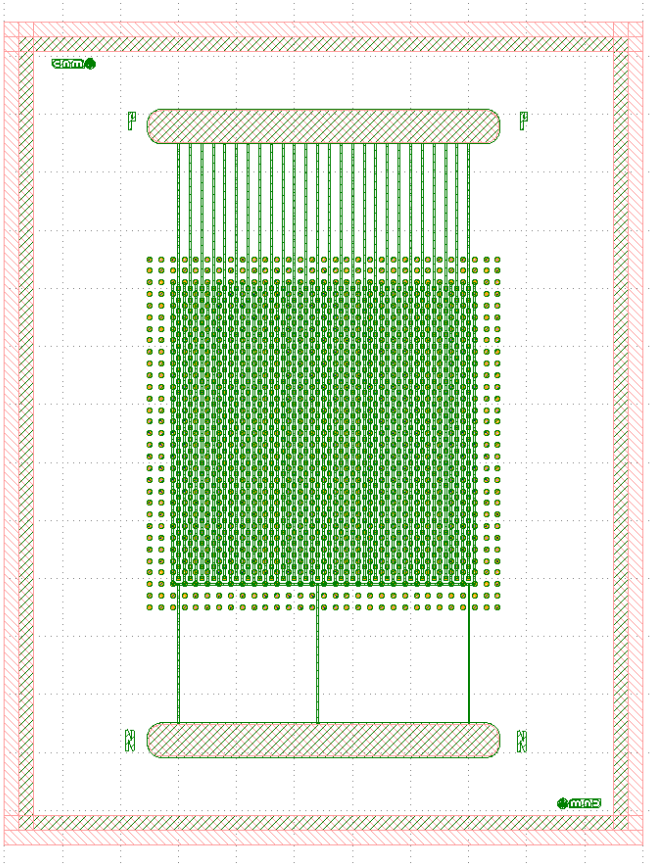
$$\chi^2 = \sum_i \left(\frac{\left(N * \left\langle y_{f/d}^{exp}(z_i + L) \right\rangle + C_0 - \left\langle y_{f/d}^{MC}(z_i) \right\rangle \right)^2}{U_{total}^2} \right)$$

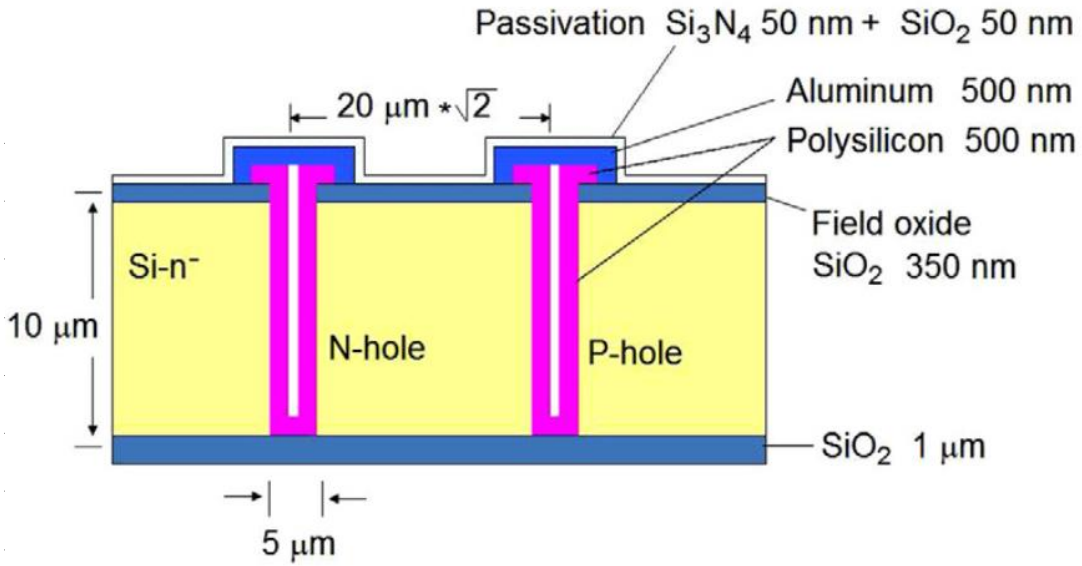


Monte Carlo simulations

- Simulations were performed with FLUKA (and GEANT4).
- For FLUKA: Hadrontherapy settings with a shorter step in the scoring region.
- 10^6 primary histories simulated.
- No detailed simulation of the beamline.
- Detailed geometry of the detector and experimental setup.

Detector – First version

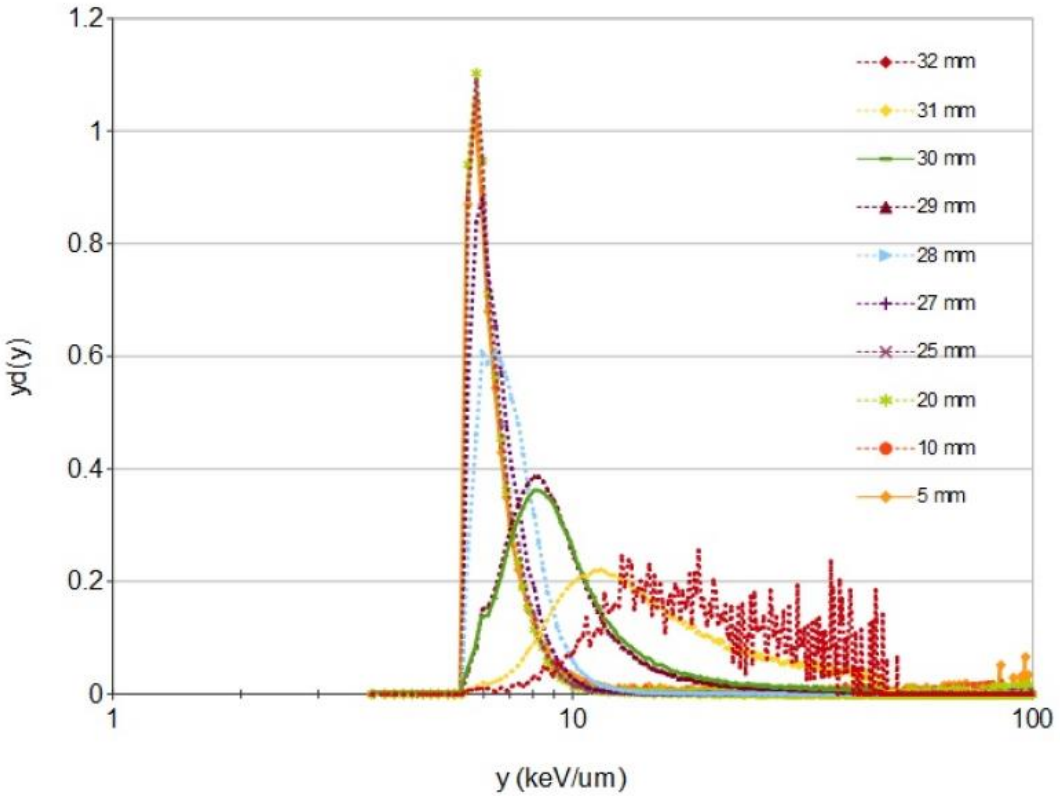




- Tests with first version of the microdosimeter.
- Performed on May 2014.
- Compared with GEANT4 and FLUKA MC.

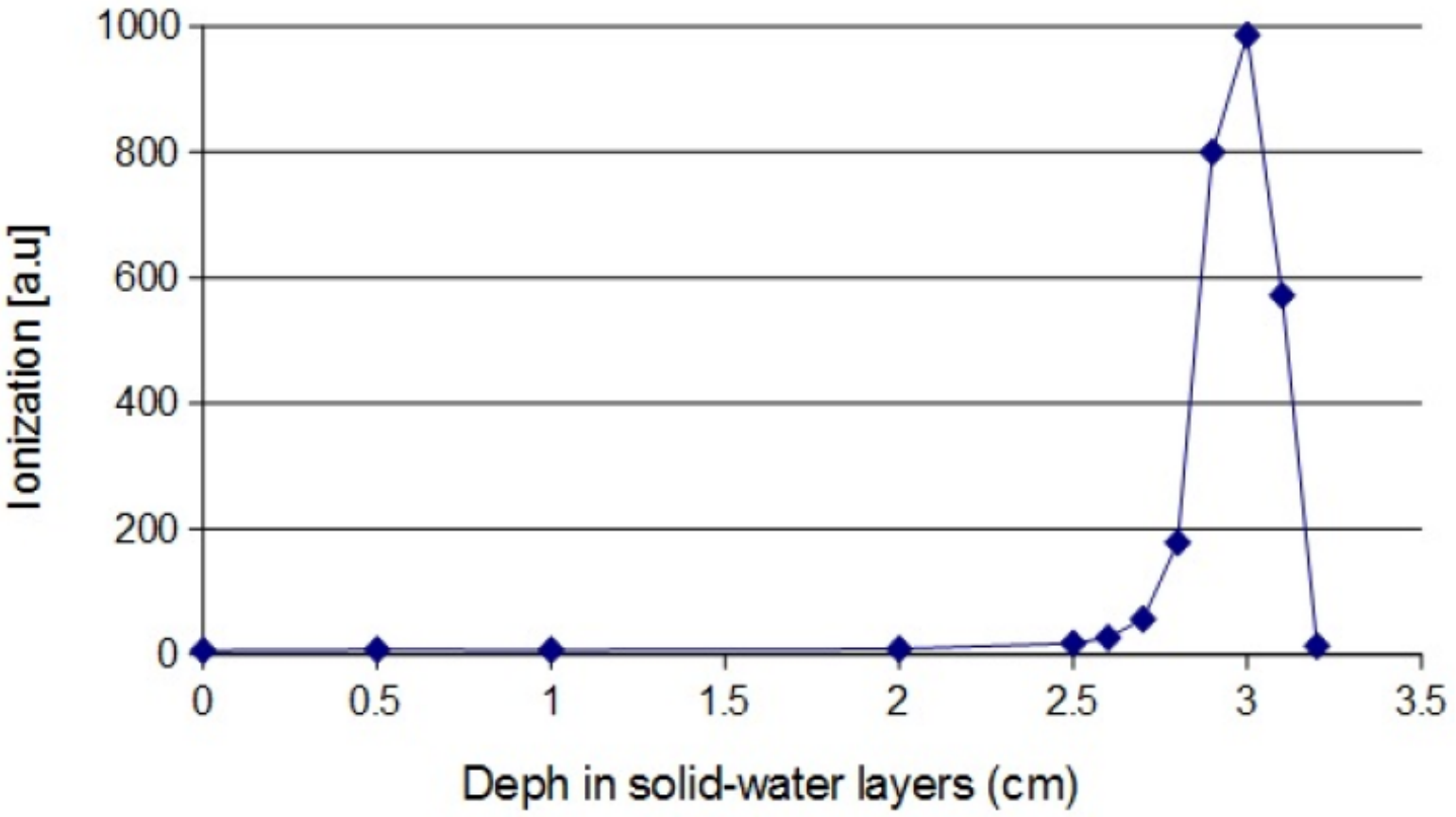
CRC Proton test (Column detector)

- 62 MeV proton beam from CYLONE-110 cyclotron at Centre de Recherches du Cyclotron (CRC) at Louvain-la-Neuve (Belgium).
- Measurement of microdosimetric distributions at several thicknesses of solid water slabs.
- Reconstruction of the Bragg peak from total ionization of the detector normalized to air ionization.



Source: C. Guardiola, C. Fleta, J. Rodríguez, M. Lozano and F. Gómez, "Preliminary microdosimetric measurements with ultra-thin 3D silicon detectors of a 62MeV proton beam," *Journal of Instrumentation*, Vol 10, Jan. 2015

CRC Proton test (Column detector)



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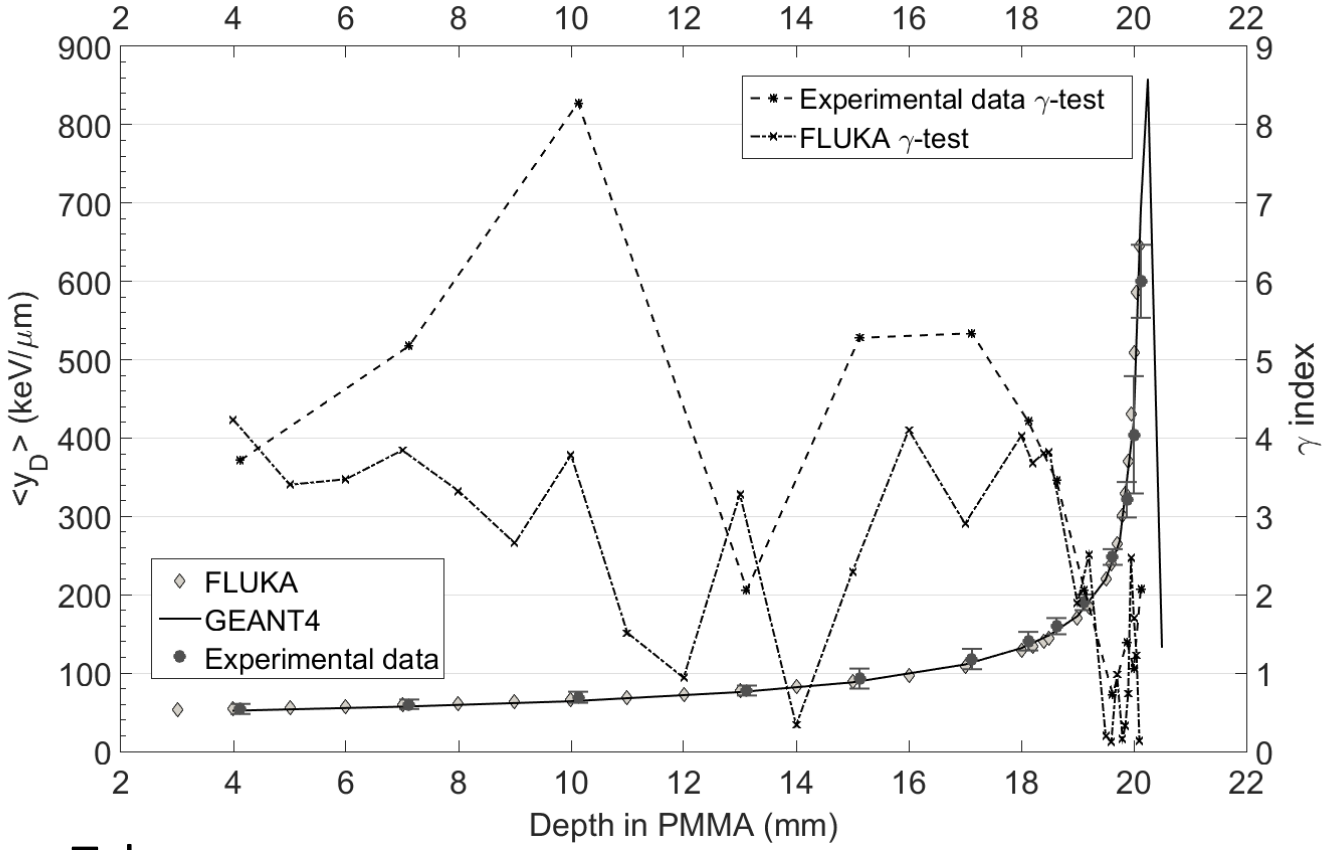
Test at GANIL – Carbon Ions (Caen, France)



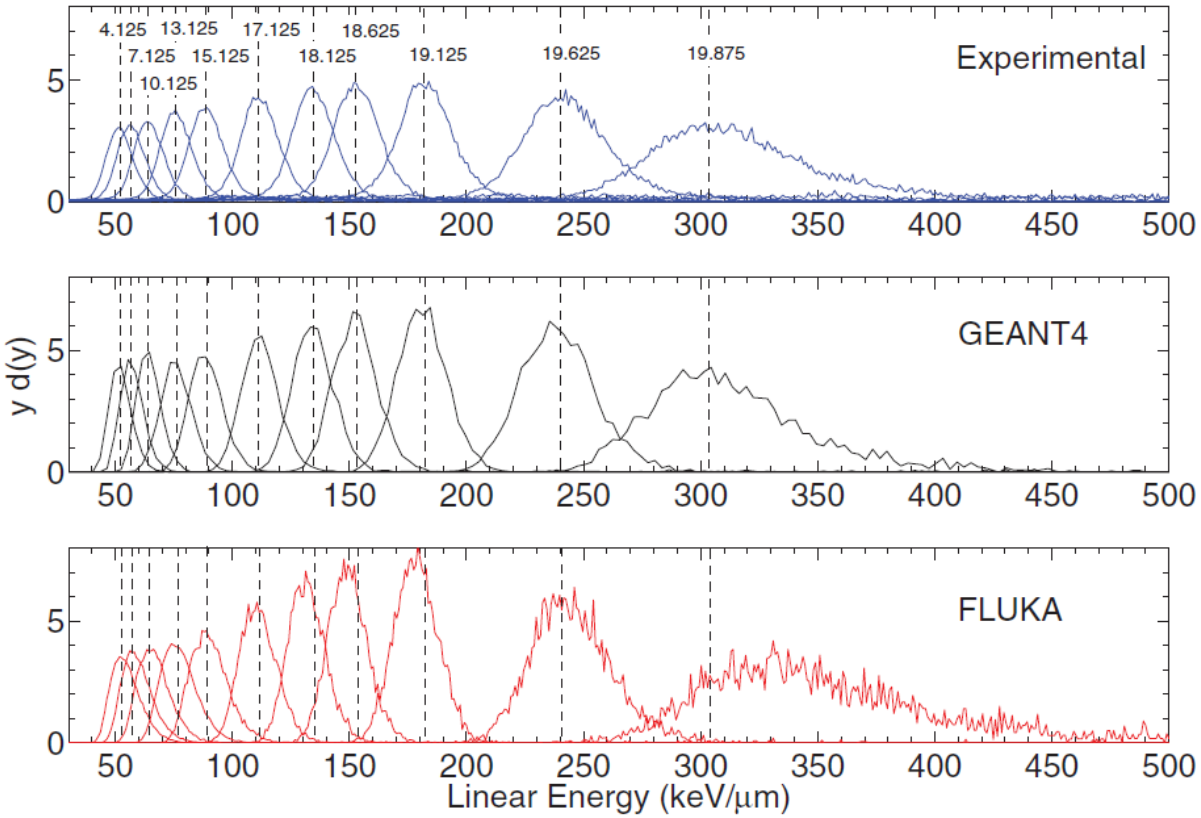
Tolerances: Δz= 30μm; Δy= 0,54 keV/μm

Source: F. Gomez et al. Phys. Med. Biol. **61** (2016) 4036

- 94.98 AMeV ^{12}C ion beam.
- Approximately 10^5 particles per second

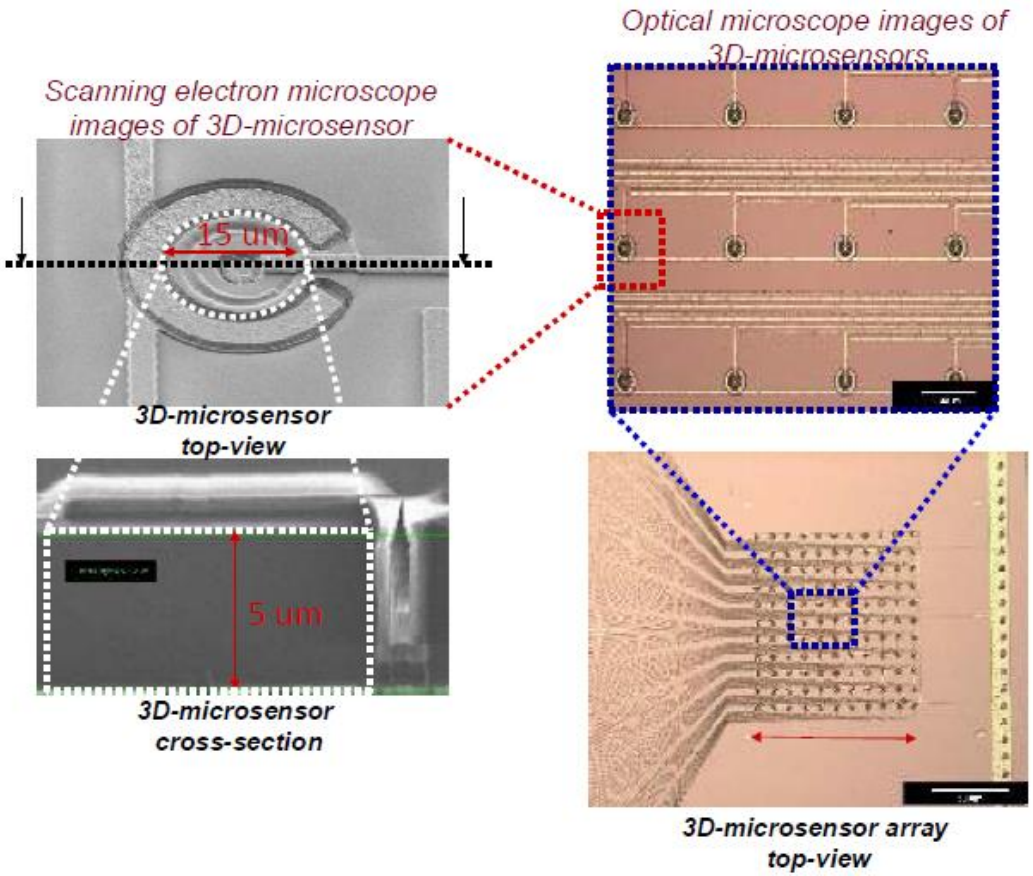
Test at GANIL – Carbon Ions (Caen, France)

- GEANT4 simulation matches very well the experimental spectra.
- FLUKA does not have a very good agreement, but this was solved changing the simulation parameters.
- Nevertheless, the peak values are good in both simulations.



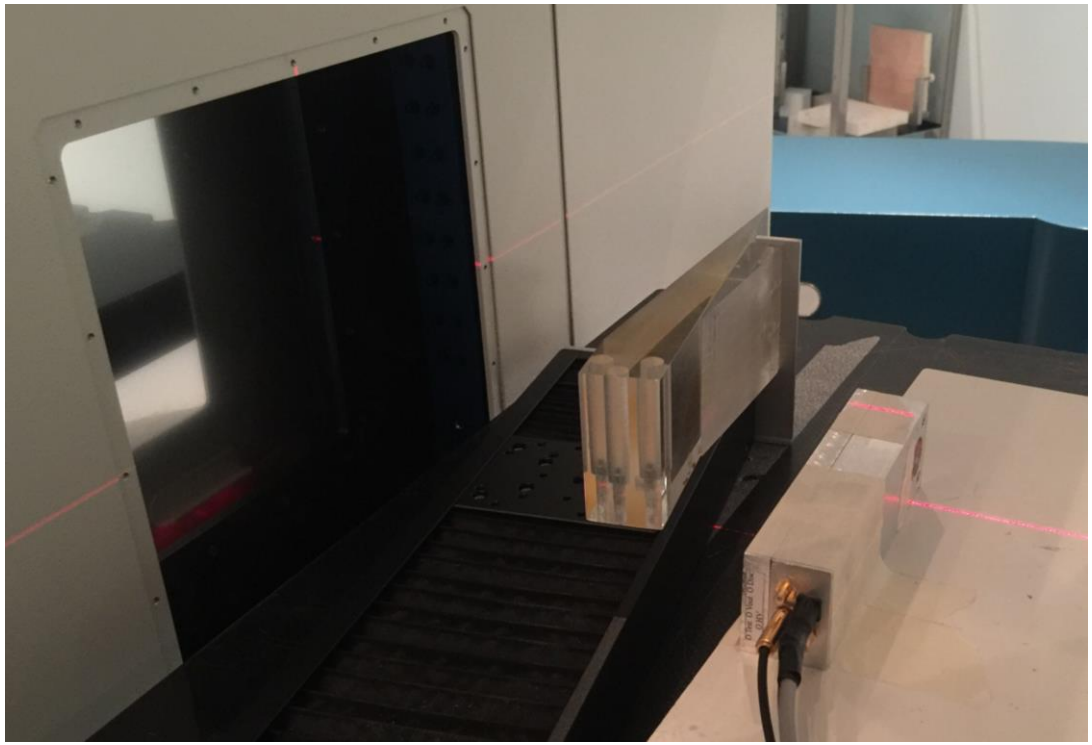
Second version of the detector

- The new version of the microdosimeter was tested at CNAO.
- Microdosimetric spectra for both proton and carbon ions.
- Tests at clinical intensity.



Guardiola C. et al., Patent ref: PCT/ES2015/070056

Tests at CNAO – Carbon Ions (Pavia, Italy)



- Test performed on December 9-10, 2016 in treatment room 1 at Fondazione CNAO.
- ^{12}C ions with 115.23 MeV/u at nominal intensity $\left(10^7 \ {}^{particles}/_{spill\ cm^2}\right)$.
- N=10^9 particles.
- Results compared with FLUKA Monte Carlo.

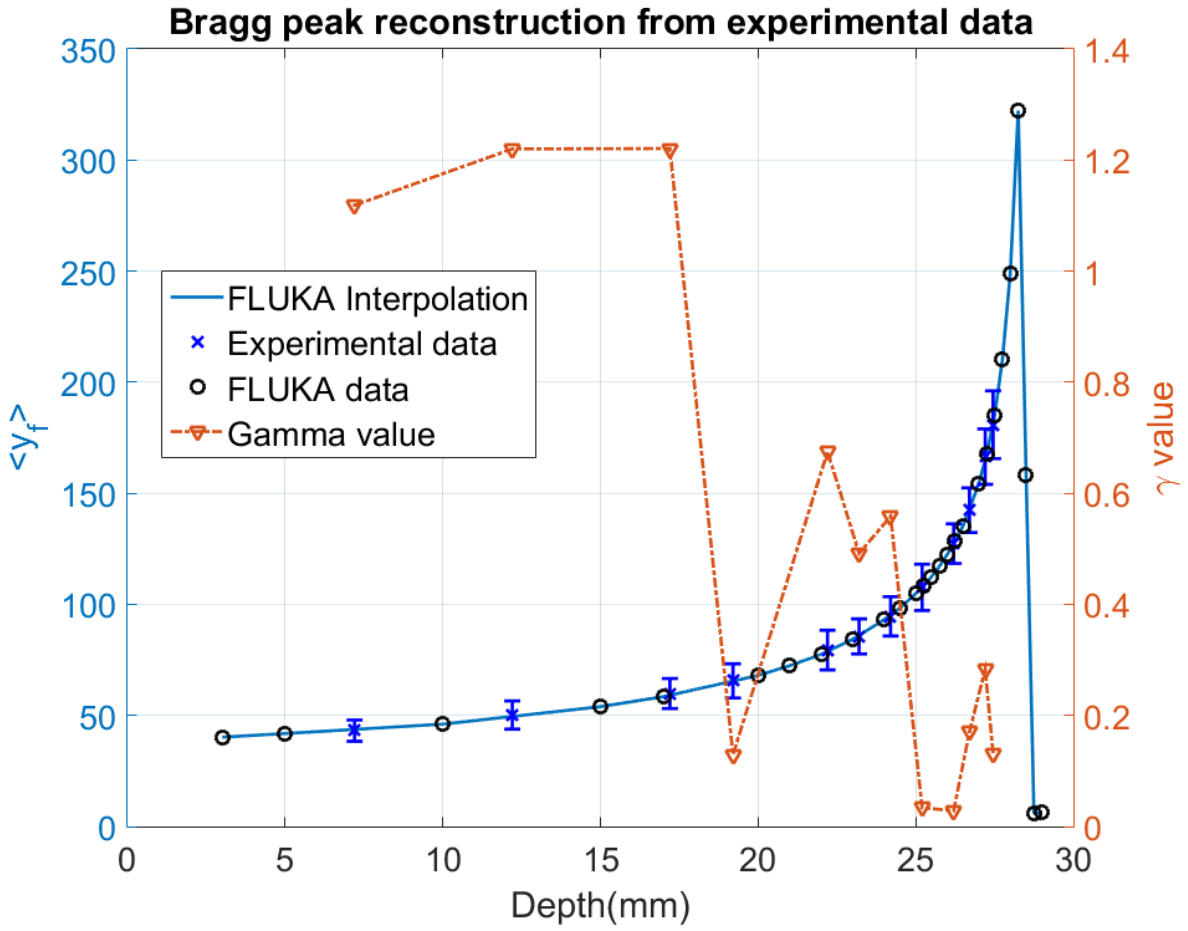
Carbon test results – Bragg Peak

- Results show an excellent agreement with Monte Carlo simulations.

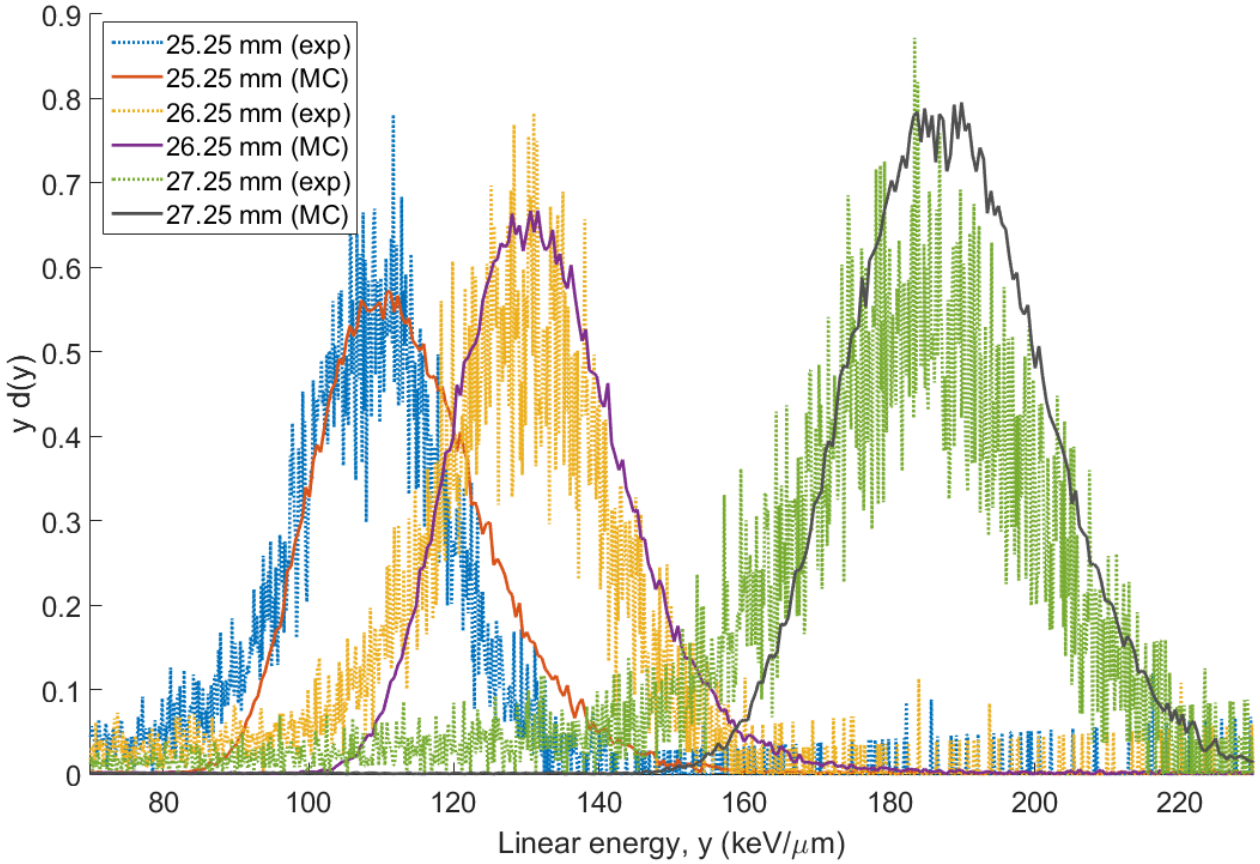
- N_{min}=0.8592 keV/(µm*ch)
- C0=-2.7619 keV/µm
- L= 2.2027 mm

- Gamma-index tolerances: 0.1 mm and 0.5 keV/µm

- Gamma-index takes values less than 1.3, specially near the Bragg peak region.



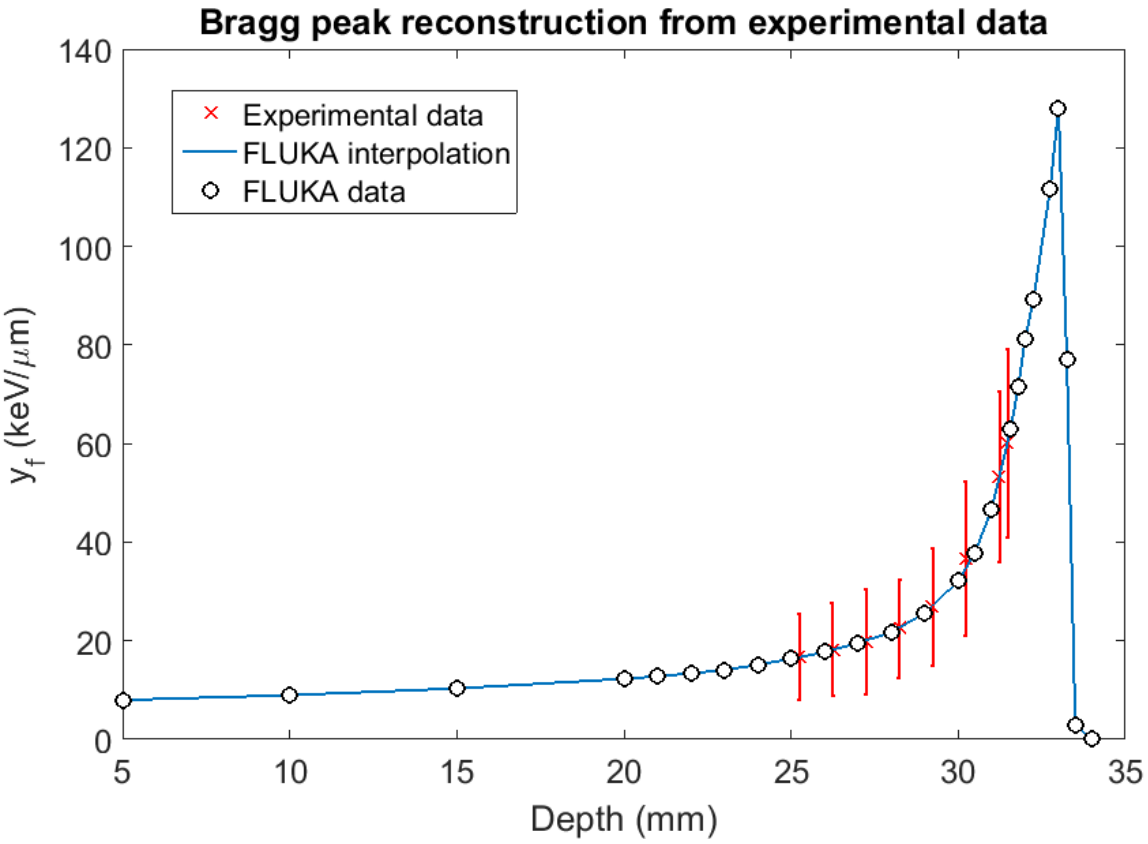
Carbon test results – Spectra



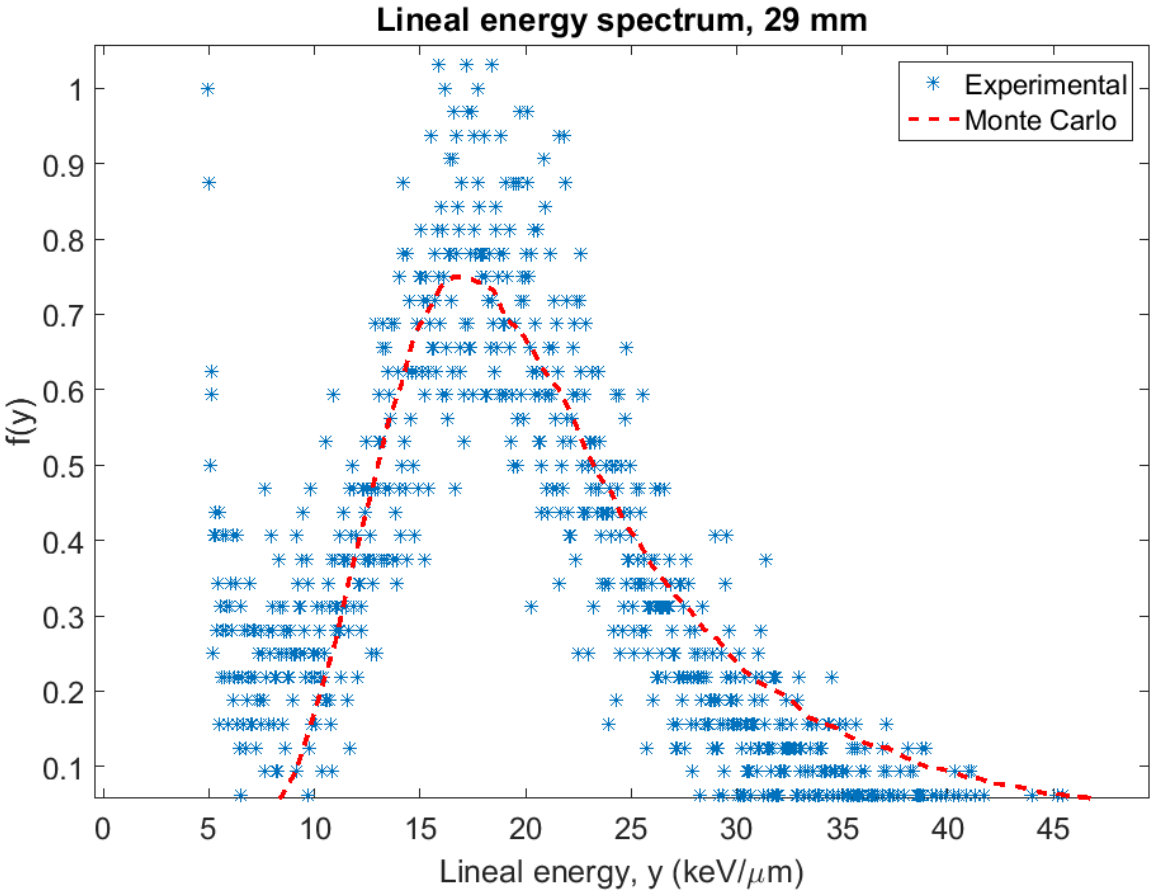
- Good agreement with beam particle distribution.
- Partial charge collection in un-depleted sensor volume due to low bias voltage adds counts in the low-y area.

Proton test results

- Test performed on January 10, 2017 in treatment room 1 at Fondazione CNAO.
- 66.34 MeV protons.
- Test performed at nominal intensity $\left(10^7 \ {}^{particles}/_{spill\ cm^2}\right)$.
- N_{min}= 0.3423 keV/(µm*ch)
- C0= 5.3235 keV/µm
- L= 1.2383 mm



Proton test results – Spectrum



- Good agreement on proton spectrum
- As before, there are some problems with partial charge collection in the detector area.

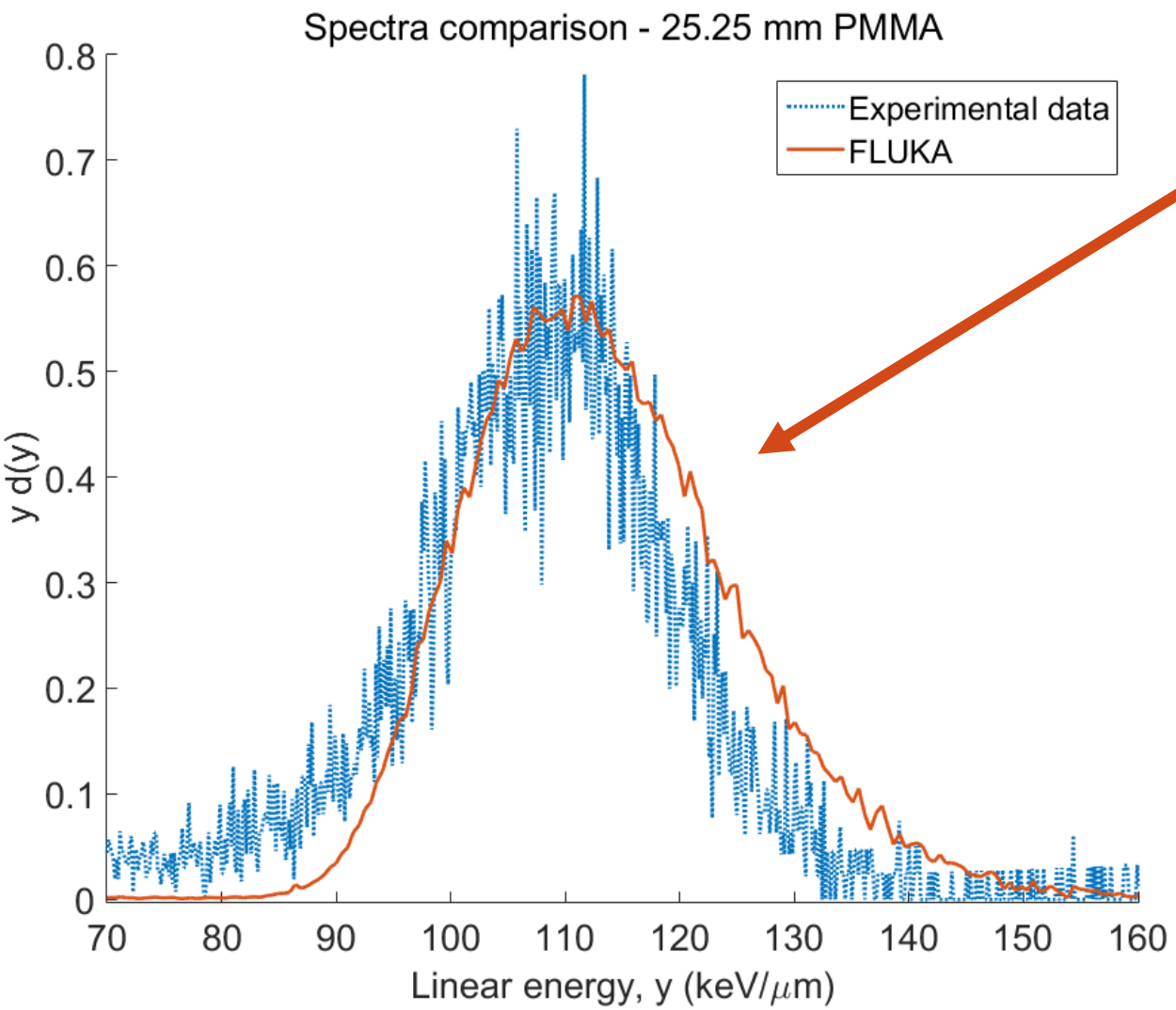
Concluding Remarks

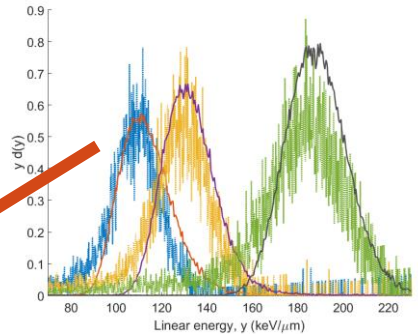
- There was a very good agreement between experimental and simulated spectra.
- This detector can quantify LET or linear energy distributions on clinical beams allowing calculation of RBE and commissioning on said beams.
- The detector is capable of measuring in clinical conditions, under nominal fluence rate.
- There is still some room for improvement in the new versions of the detector and the electronics, regarding the low-energy part of the spectrum.

J. Prieto-Pena and F. Gomez acknowledge funding from Spanish MINECO project DPI2014-57645-R. J. Prieto-Pena also acknowledges funding from a Barrié Foundation pre-doctoral research grant.

THANK YOU FOR YOUR ATTENTION ANY QUESTIONS?

Carbon test results – Spectra





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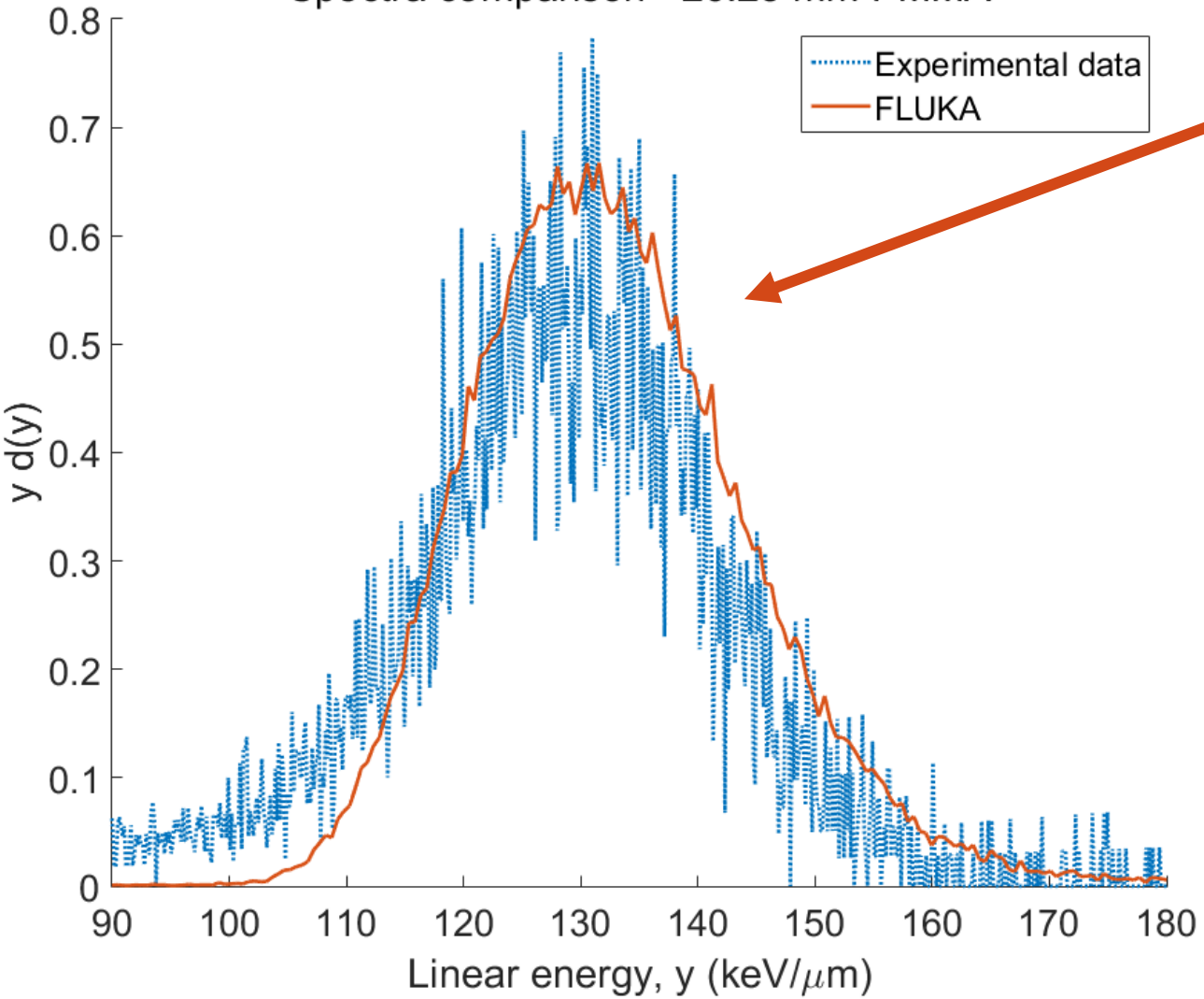

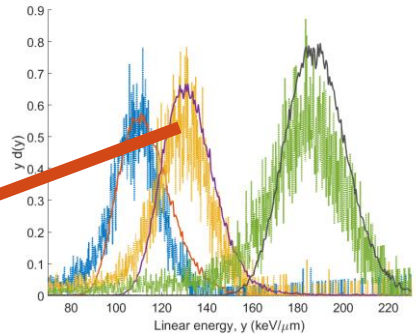

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