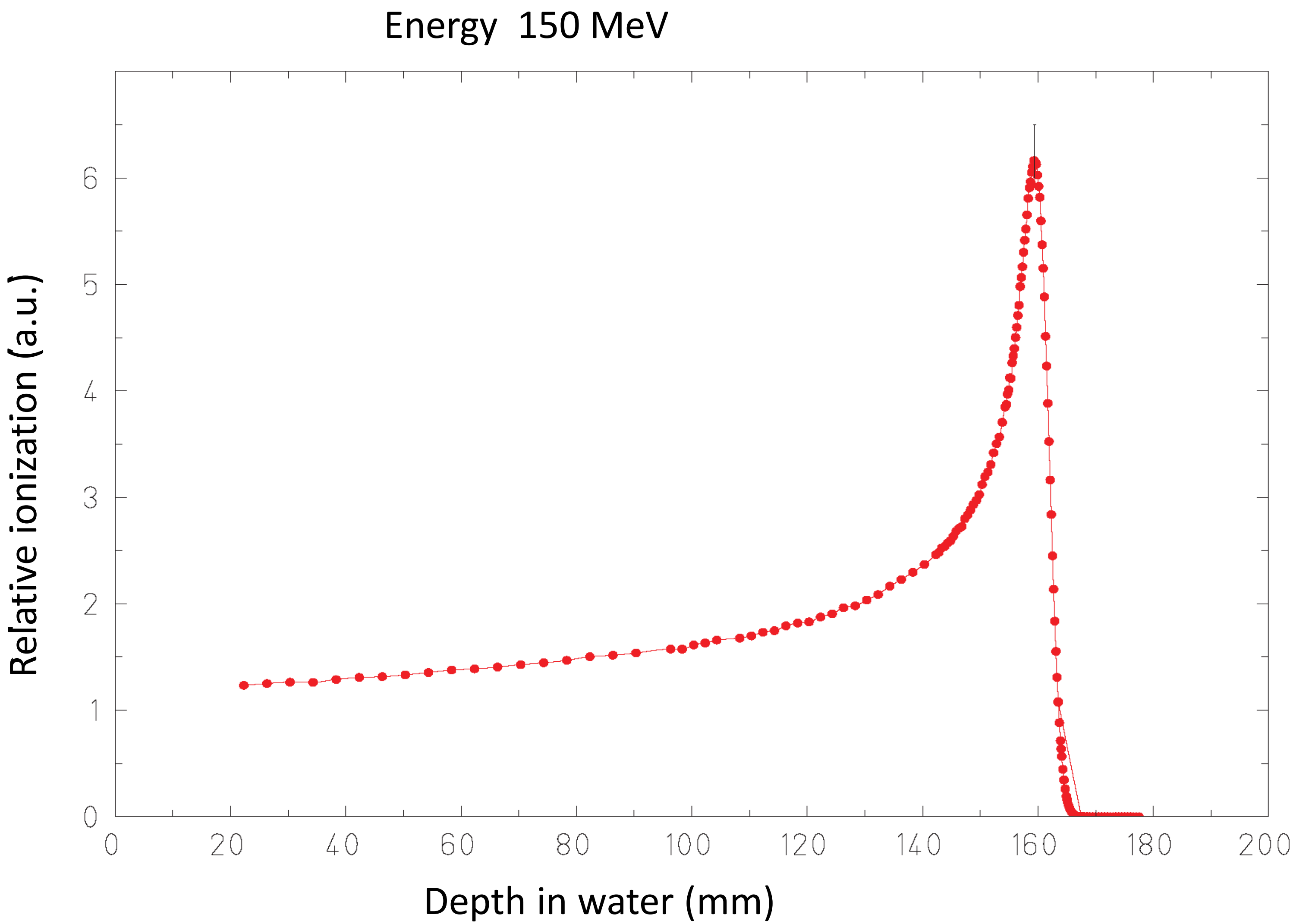
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289485.

Proton beam optimization for dosimetry studies with radiochromic films and ionization chambers at the 3 MV Tandem Accelerator

Cristina Battaglia

Introduction (1)



Provided by D. Schardt

Introduction (2)

3MV Tandem accelerator provides proton beams of maximum energy of 6 MeV.

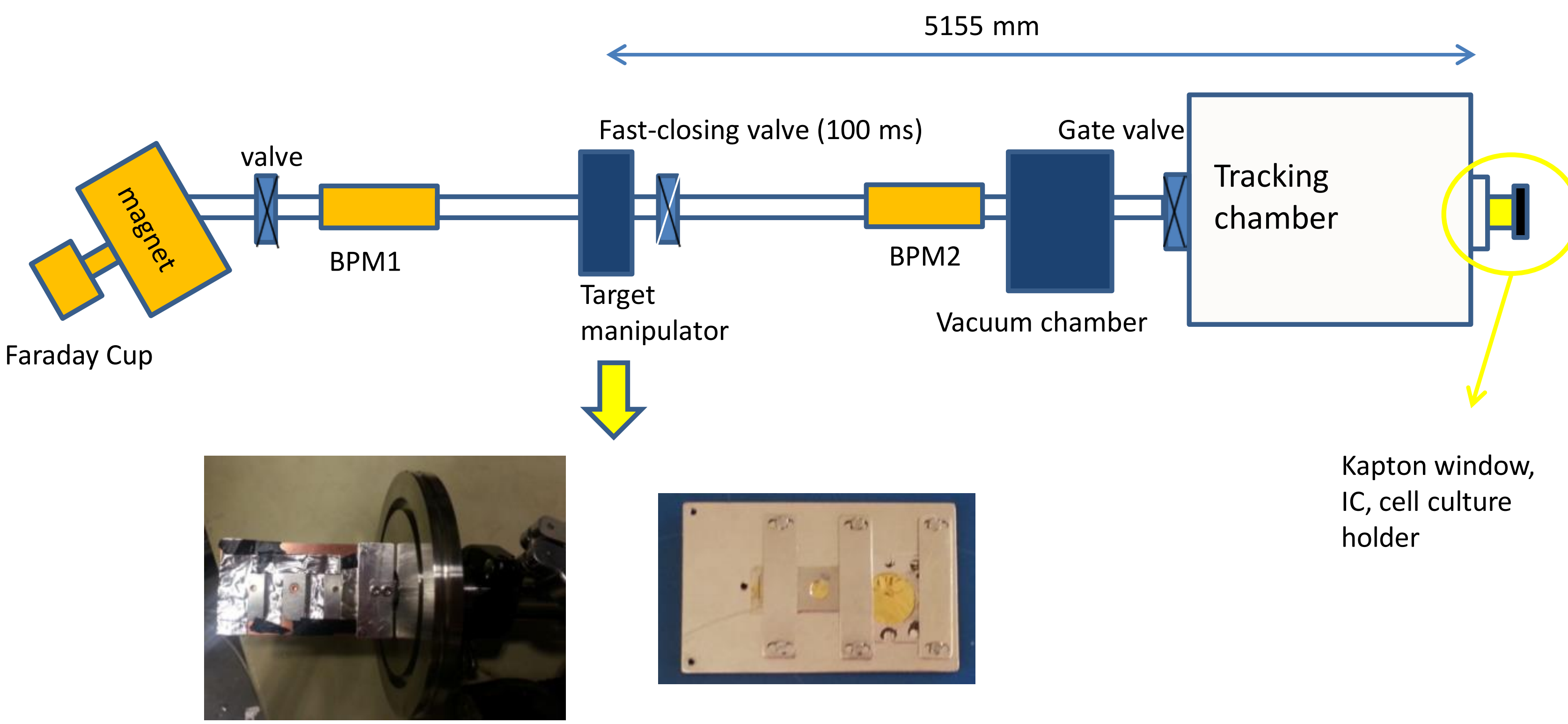
Useful for radiobiology and dosimetry studies

In this work:

- Optimization of the beam line for dosimetry studies
- Radiochromic films (Gafchromic EBT3) calibration in dose for protons
- Study of the proton dosimetry outside and inside the Bragg peak region with EBT3 films and ionization chamber

Experimental setup: beamline

- *Au targets (thickness 2.0 and 5.4 mg/cm^2) to scatter and obtain a homogenous beam profile onto the samples.*
- *Fast-closing valve (100 ms) used as a beam-shutter.*

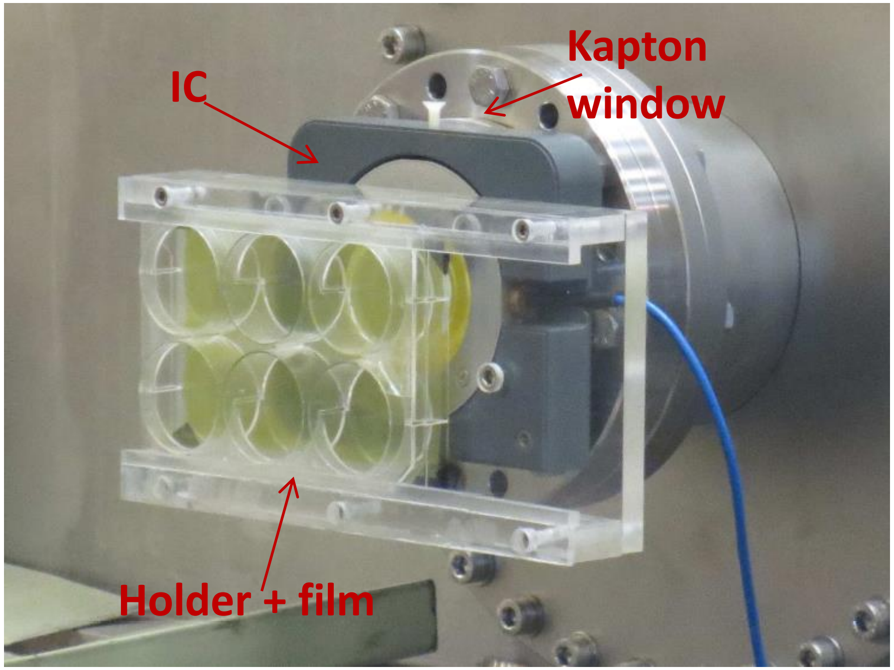


Experimental setup: beamline (2)

- *Thin vacuum exit window (kapton, thickness 50 µm, diameter 44 mm, $\Delta P \approx 10^{-6}$ mbar).*

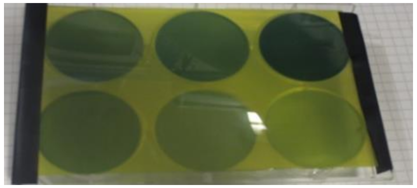
- *Ionization chamber (IC) (three parallel electrodes 7.5 µm thick, two air gaps 6.5 mm, operated a*t V_{IC}=400 V*) to measure the proton fluence and monitor the dose, connected to a Keithley electrometer (model 6514).*

- *Holder with six positions designed for biological samples and also used for films.*



EBT3 Gafchromic films

Characteristics:



Irradiated film with six amounts of dose.

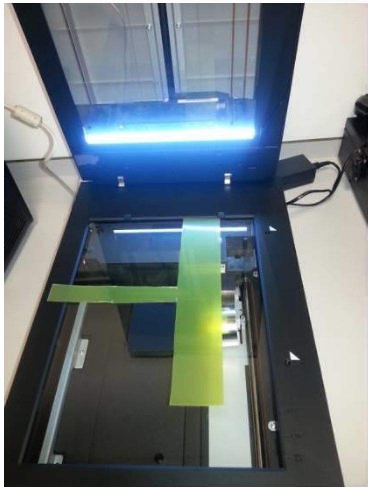
Polystyrene 125µm
Active layer 28 µm
Polystyrene 125µm

Transversal view: EBT3 technology

For photons and electrons:

- Under ionizing radiation, the sensitive gel layer polimerizes, and the film turns blue.
- Symmetric construction.
- ~~Energy independence.~~ ***Not always for protons!***
- High spatial resolution (25µm).
- Tissue equivalence.
- No chemical, thermal or optical development.

Analysis device & software



Epson perfection V700 photo scanner

- Transmission mode
- 48-bit RGB (Red Green Blue) mode.
- No colour correction activated.
- Tiff image acquired.
- 75 dpi (dots per inch resolution).

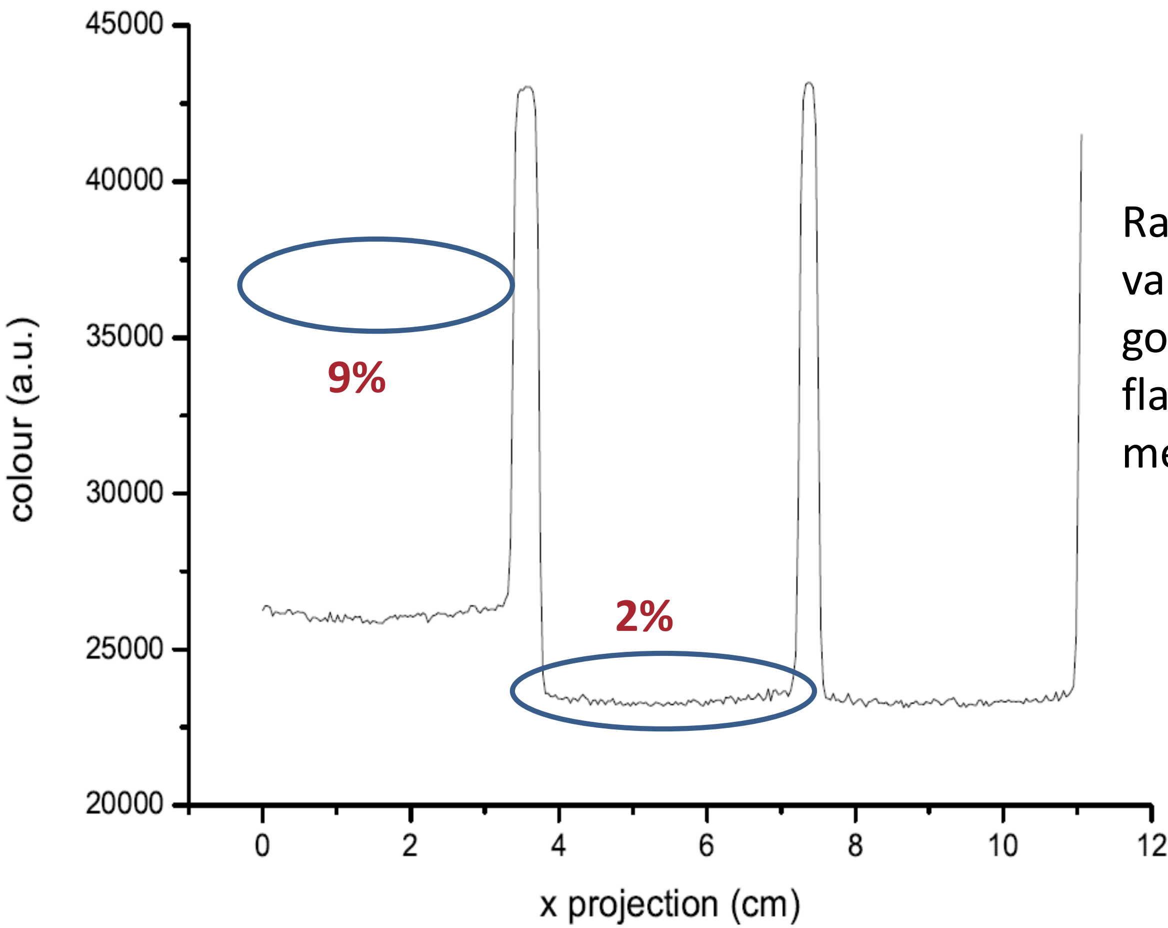
Image J: software of public domain for Java image processing

Used for EBT3 analysis in terms of:

- ✓ beam profile checking;
- ✓ absorbed dose calibration of the radiochromic films.

Beam profile study

Preliminary analysis of radiochromic films to identify the best Au scatterer

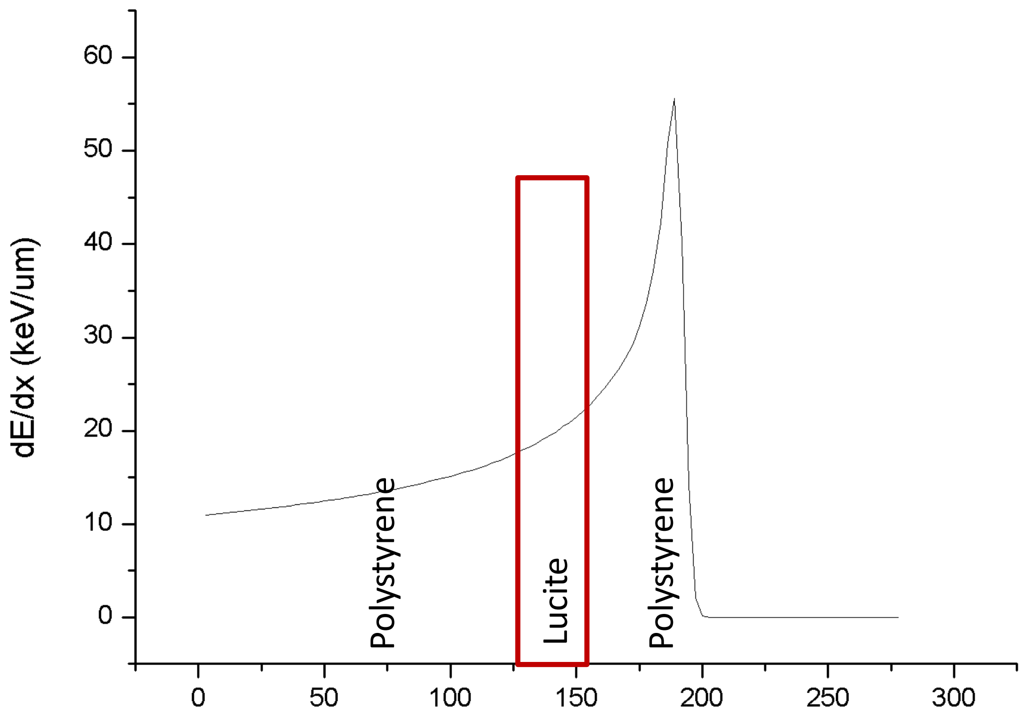


Raw response for three values of irradiation with a gold target of 2.4 mg/cm^2: flat profile, *suitable* for the measurements

Dose calibration

Calibration with photons

Irradiation with protons



D(cGy)

Standard protocol*:

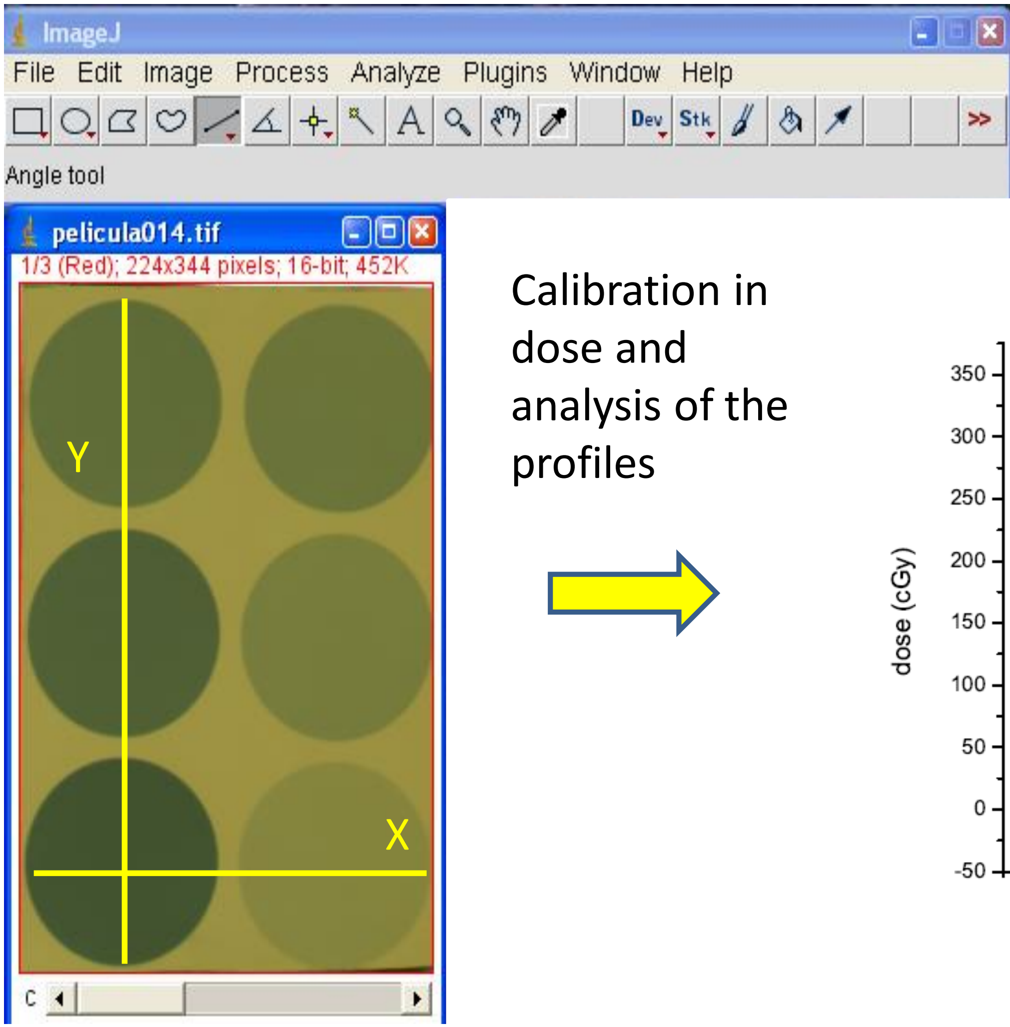
- Photons delivered by a 6MV clinical linac (at Virgen Macarena Hospital).
- Source to Surface Distance of 100 cm + 1.5 cm of solid water above the film.

Under these conditions 100MU correspond to 100cGy

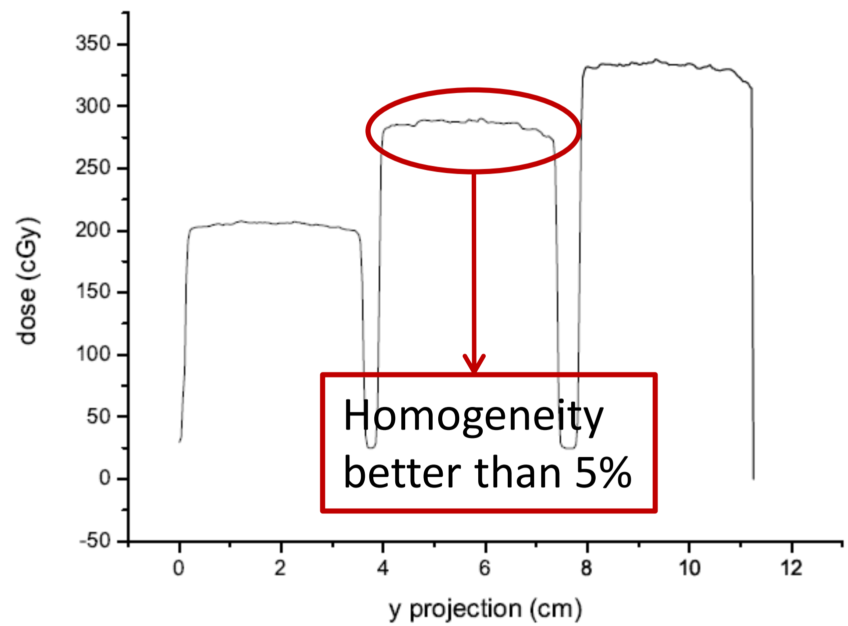
Below Bragg peak energies, the dose calibration with *photons* is valid also for *protons (similar Linear energy transfer, LET, outside the Bragg peak).*

*R. Arráns, et al., Rev. Fis. Med, 2009; 10(2):83-104.

Results: dose profile



Calibration in dose and analysis of the profiles



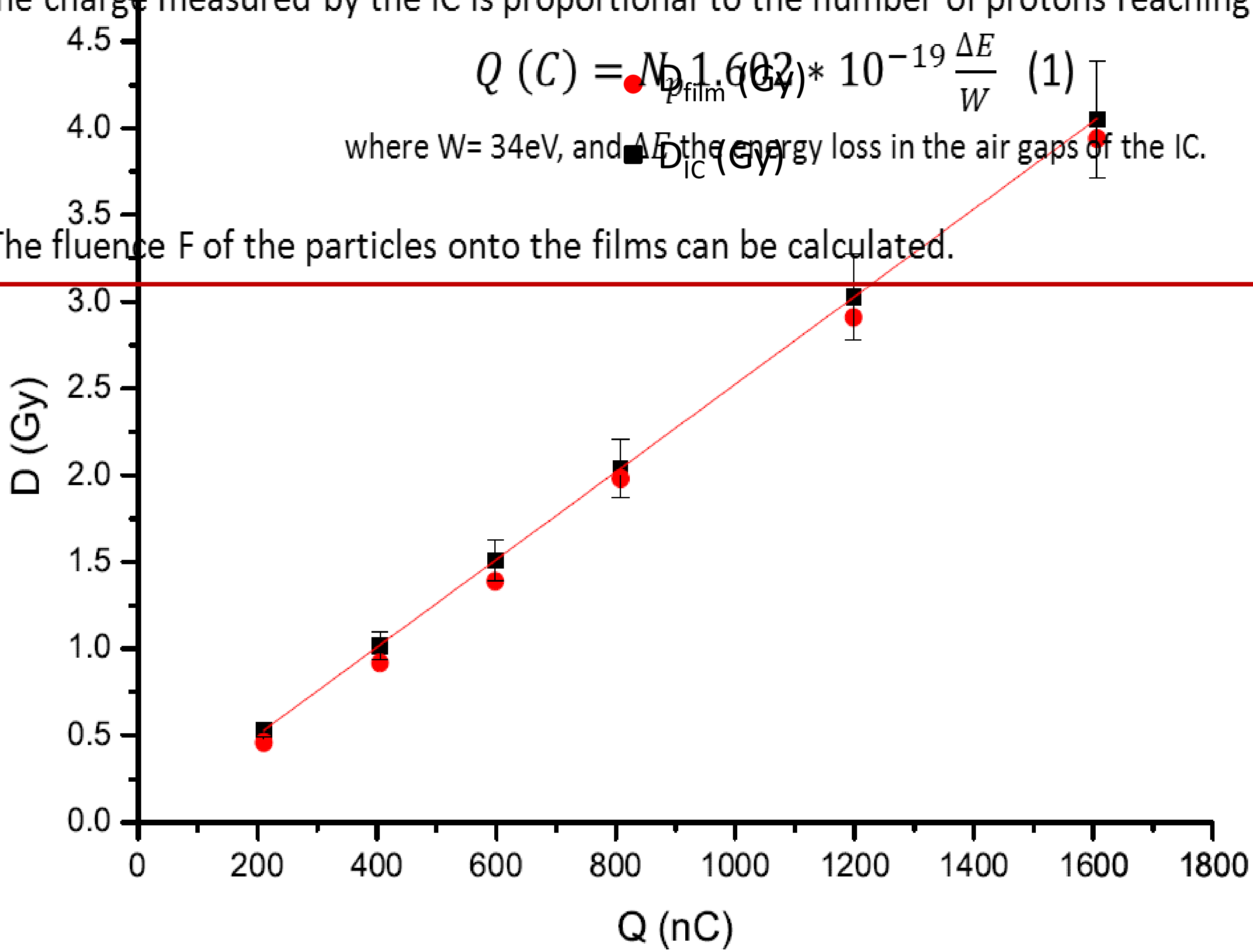
Results: D_{IC} vs D_{EBT3}

- The charge measured by the IC is proportional to the number of protons reaching it.

$$Q\ (C) = N_p 1.602 * 10^{-19} \frac{\Delta E}{W} \quad (1)$$

where W= 34eV, and ΔE the energy loss in the air gaps of the IC.

- The fluence F of the particles onto the films can be calculated.



Moving to the Bragg peak

What do we expect?

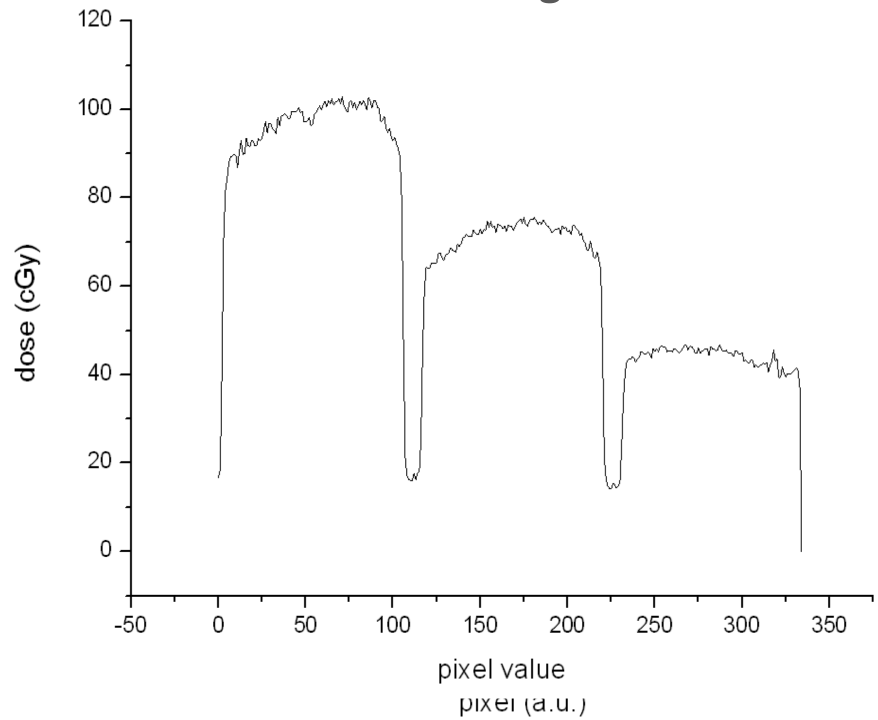
LET increases: the dose calculated by the IC is not equivalent to the calibrated film dose

Passive degradation with mylar foils

The beam optics does not change: the energy can be varied by small steps, very quickly, without touching the accelerator settings: the homogeneity in the beam profile is mantained

Changing the accelerator terminal voltage

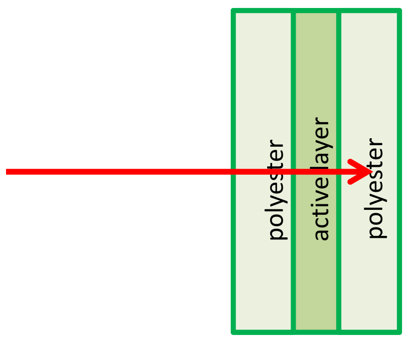
Passive degradation

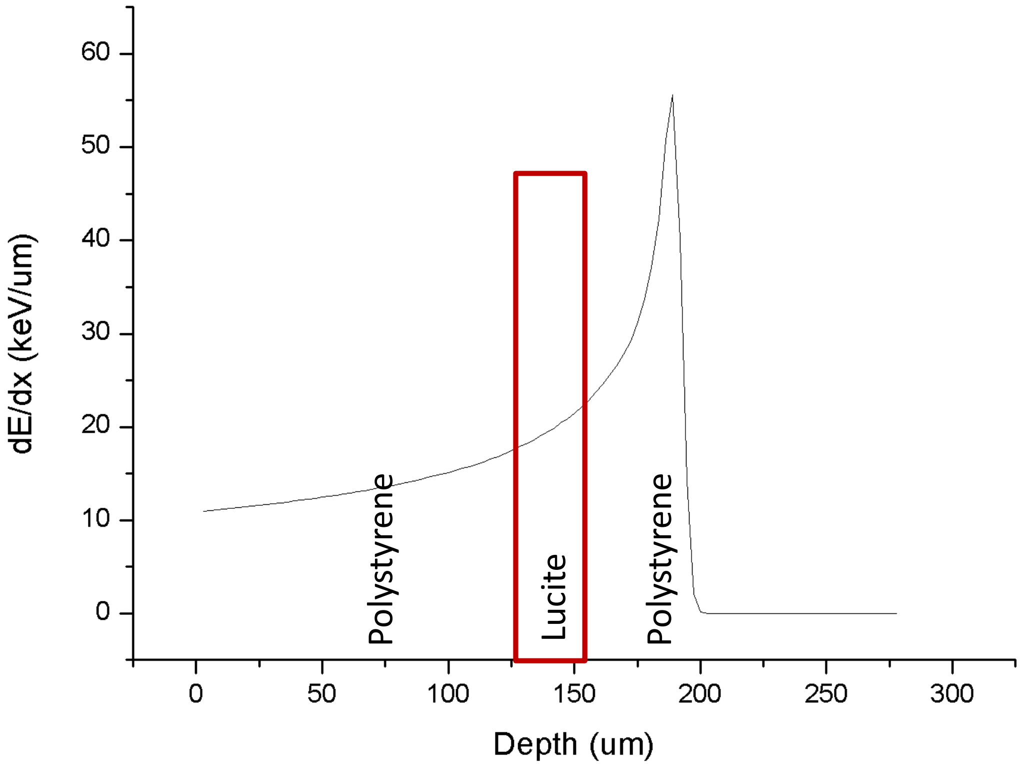


Bragg peak position: out

Bragg peak position in the EBT3 film: transversal view

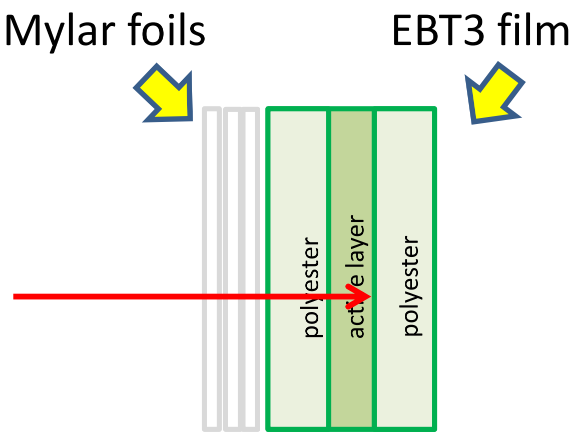
Experimental conditions: nominal energy of the accelerator E= 5.233 MeV, current of the order of 10 nA

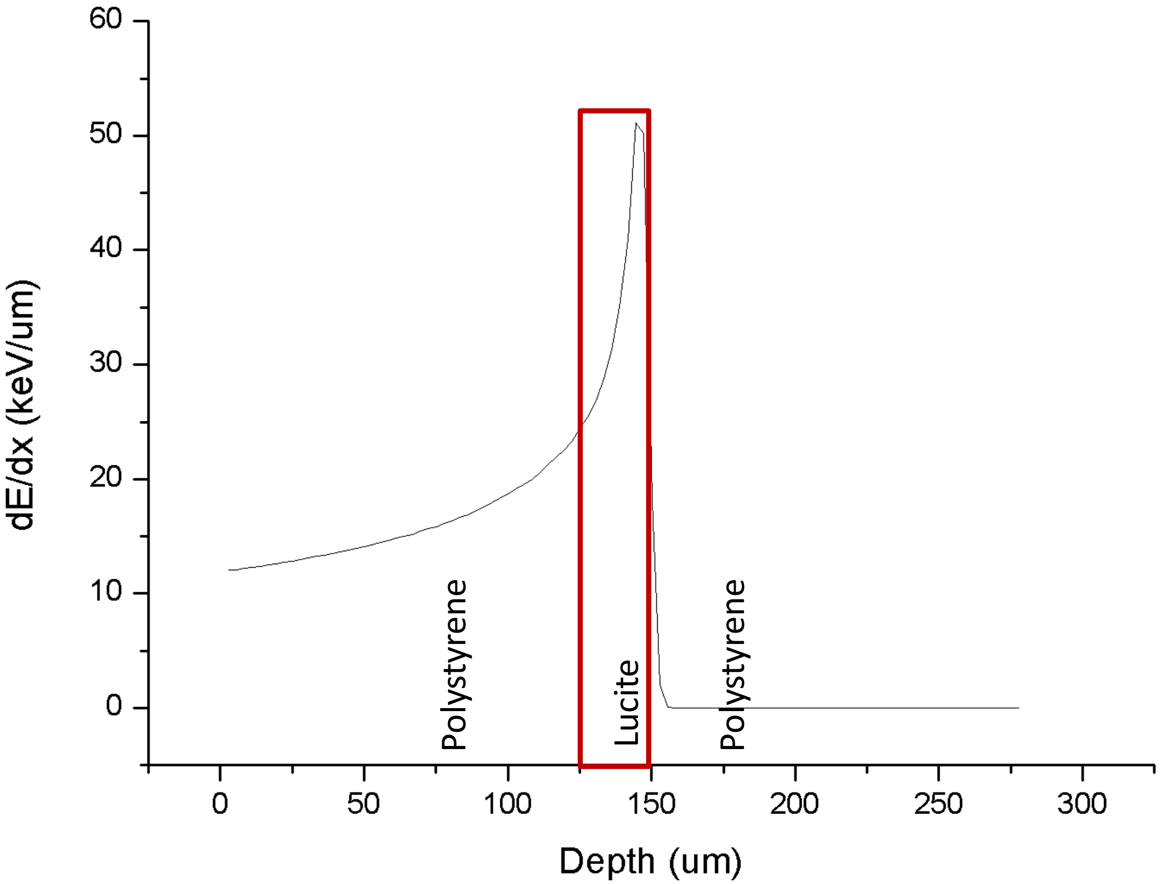




Monte Carlo simulation with SRIM2008 code

Bragg peak position: in





Monte Carlo simulation
with SRIM2008 code

Saturation effect

Radiochromic film saturation: ***quenching effect***

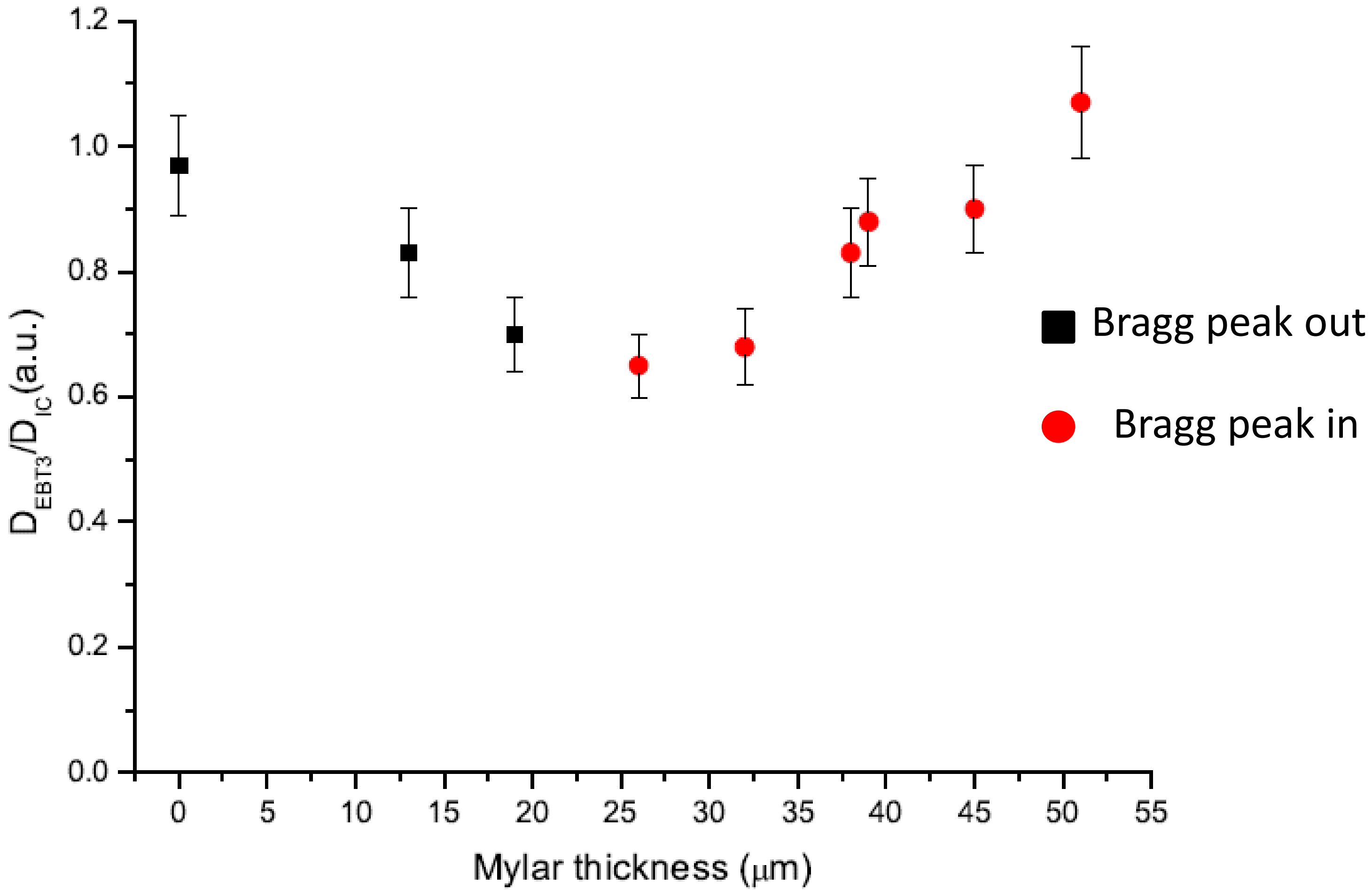
D_{EBT3}/D_{IC}	Mylar thickness (μm)
0.97 ± 0.08	0
0.83 ± 0.06	13
0.70 ± 0.08	19
0.65 ± 0.06	**26**
0.68 ± 0.08	**32**
0.83 ± 0.06	**38**
0.88 ± 0.08	**39**
0.90 ± 0.08	**45**
1.07 ± 0.10	**51**

Mylar of different thickness to degrade the beam energy

When LET increases, the darkening of the film is not anymore proportional to the dose.

In high-dose gradient region, the film becomes *sensitive to energy*, and another calibration method has to be implemented .

Saturation effect



Final remarks

- Optimization of a beamline dedicated to dosimetry studies at the 3 MV Tandem accelerator
- Dosimetry studies with a new technology of radiochromic films (EBT3 Gafchromic)
- Dosimetry outside the BP with EBT3 films is validated by the IC measurements
- EBT3 films cannot be used for dosimetry inside the BP, at this stage, since the quenching effect is occurring.

Next….

- Quantify the quenching factor for EBT3 for different values of energy
- Establish a protocol of dosimetry in the BP region (measurements and simulations)
- Cell irradiations to study the damage produced in the DNA.

Acknowledgement

Radiobiology collaboration

University of Seville, Spain: GETERUS group (M. A. Cortés Giraldo, M. I. Gallardo, J. M. Quesada), J. M. Espino (also CNA).

GSI, Darmstadt, Germany: D. Schardt

University Hospital "Virgen Macarena", Seville: H. Miras.

University of Granada, Spain: A. M. Lallena.

University Hospital "San Cecilio", Granada, Spain : D. Guirado.

Bibliography

[1] M. Muller, Diploma thesis, University of Darmstadt, 2004.

[2] R. Arráns, et al., Rev. Fis. Med, 2009; 10(2):83-104.

[3] F. Fiorini et al., Physica Medica 30 (2014) 454-461.

[4] S. Reinhardt et al., Radiat. Environ. Biophys. (2015) 54:71-79.

[5] D. Kirby et al., Phys. Med. Biol.55(2010): 417-433.

[6] S. Devic, Physica Medica (2011), 27, 122-134.

[7] A. Piermattei et al., Med. Phys. 27 (7), 2000, 1655-1660.

[8] J. Sorriaux et al., Physica Medica (2012), 1-10.

[9] L. Zhao and I. J. Das, Phys. Med. Biol. 55 (2010), N291-N301.

[10] H. Alnawaf et al., Journal of Applied Clinical Medical Physics, 13 (2012).

[11] I. Daftari et al., Phys. Med. Biol. 44 (1999), 2735-2745.

Any questions?