Proton therapy: real-time prompt gamma imaging and microdosimetry

Andrey Morozov[1], Jorge Sampaio[1,2], Hugo Simões[1], Pamela Teubig[1,2], Patrícia Gonçalves[1,3], Paulo Crespo[1,4]

1 LIP LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSCA EXPERIMENTAL DE PARTÍCULAS
2 Ciências ULisboa Faculdade de Ciências da Universidade de Lisboa
3 TÉCNICO LISBOA
4 1290 UNIVERSIDADE D COIMBRA

Highlights

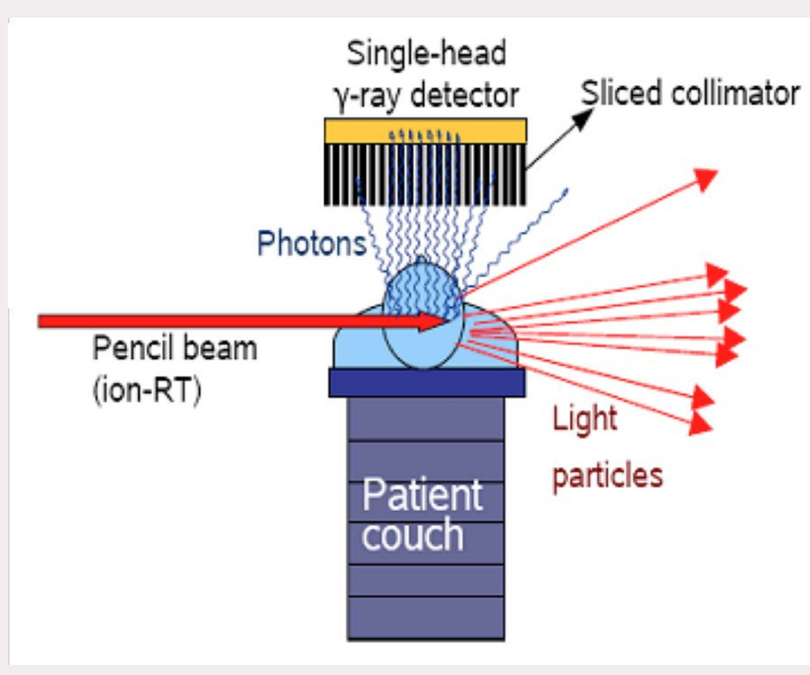
- According to [1], the number of patients treated with particle therapy (protons and carbon ions) varies between **0.018%** (Italy) and **0.035%** (France) of the country's population. This leads, in the worst-case scenario, to **1 800 patients/year treatable with particle therapy in Portugal.**
- A not so conservative approach states that in Portugal there are around 55000 new cancer patients/year of which about 50% will be treated with radiotherapy (27 500 patients/year). It is expected that 12% to 15% of those will benefit from proton therapy: **3 300 patients/year** [2].
- **Technologies for cancer therapy** with charged particle beams are in a phase of advanced development and **have been strongly supported by CERN** and adopted by the most renowned international centres for oncological treatment and research. In addition, there are **recent developments in the fields of micro and nanodosimetry and radiation damage at the DNA level**, including the application of the **CERN originated Geant4 simulation toolkit Geant4-DNA extension** [3] for modeling of biological damage induced by ionising radiation at the DNA scale
- Given the numbers above, **a proton therapy facility is under advanced planning in Portugal.** This proposal aims at the development of a beam monitoring technique that provides feedback on the dose deposition along the beam track, including the most important verification of the location of the Bragg peak. This requires deep knowledge in MC simulations, treatment planning, dosimetry with proton beams, and operation of the cyclotron, among others. Work on this project will also contribute to the formation of a community of experts in proton therapy in Portugal.

1. Orthogonal prompt-gamma imaging (O-PGI)

- **Why O-PGI?**

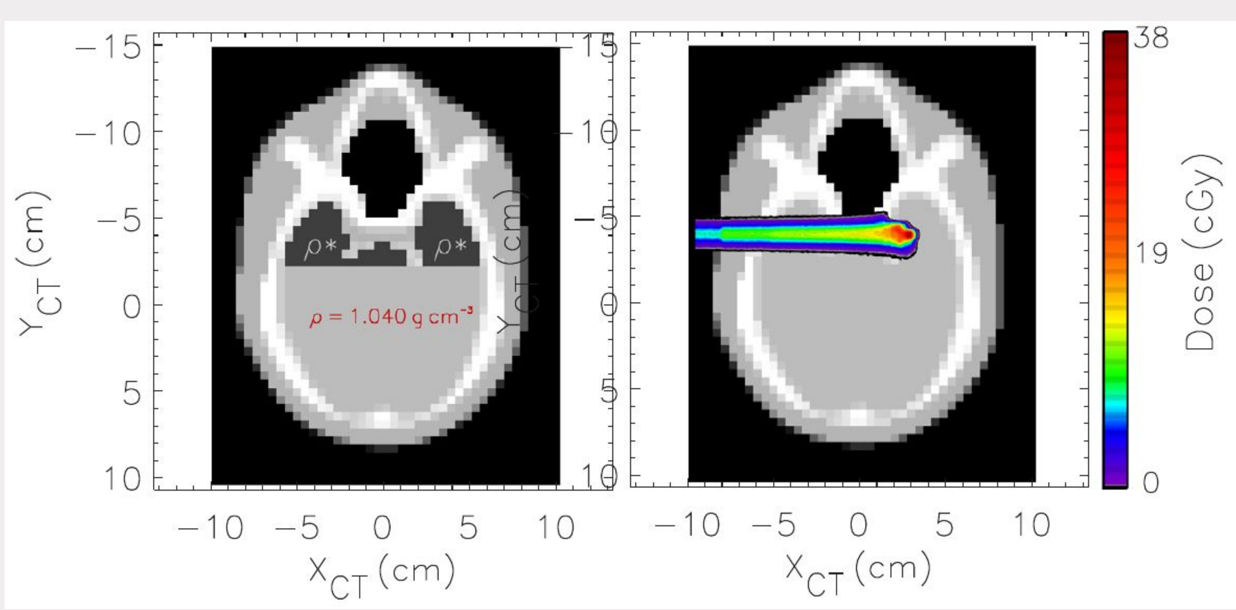
- Dose discrepancies either at the plateau and more importantly at the Bragg peak may arise due to:
  - Patient mis-positioning on a fractionated regime (or not)
  - Filling/emptying of body cavities
  - Tumor movement due to breathing cycle or bowel movements
  - Tumor regression/progression
  - Weight gain/loss
  - Different positioning of the child's vertebra in total body irradiation on a day-to-day basis
  - Formation of edema due to fractionated irradiation

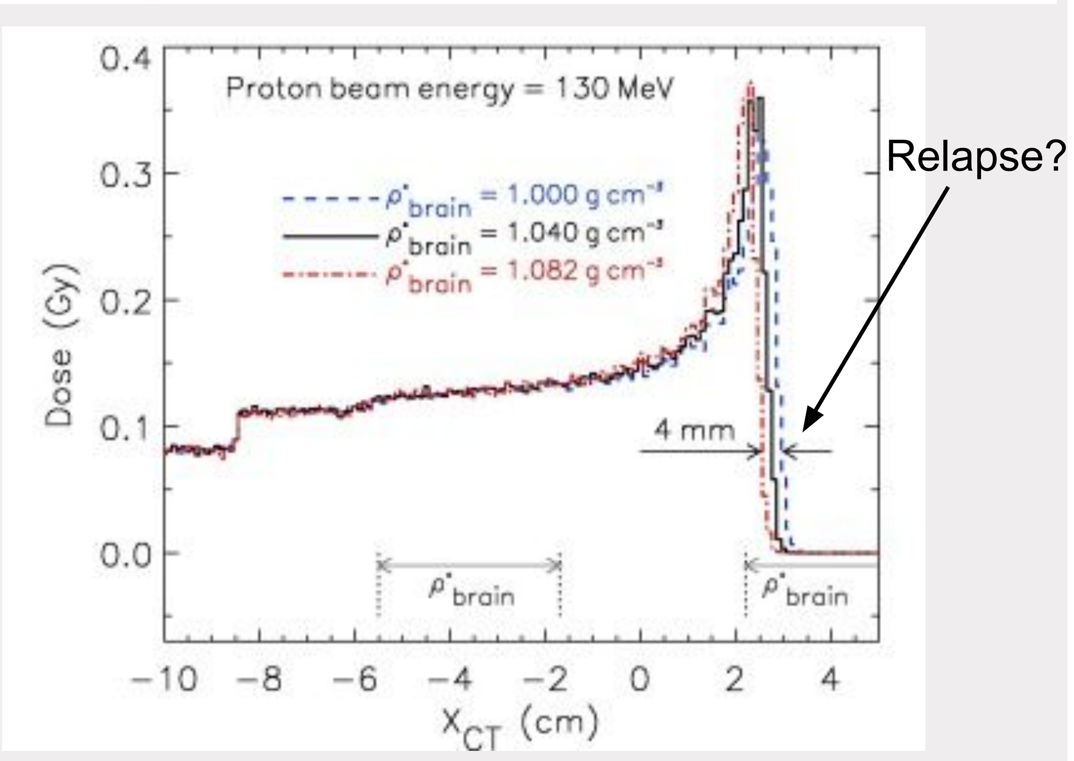
- The O-PGI technique for monitoring PT treatments: detection of prompt γ emitted perpendicularly, as a result of proton-nuclear interactions within the body during PT [4]



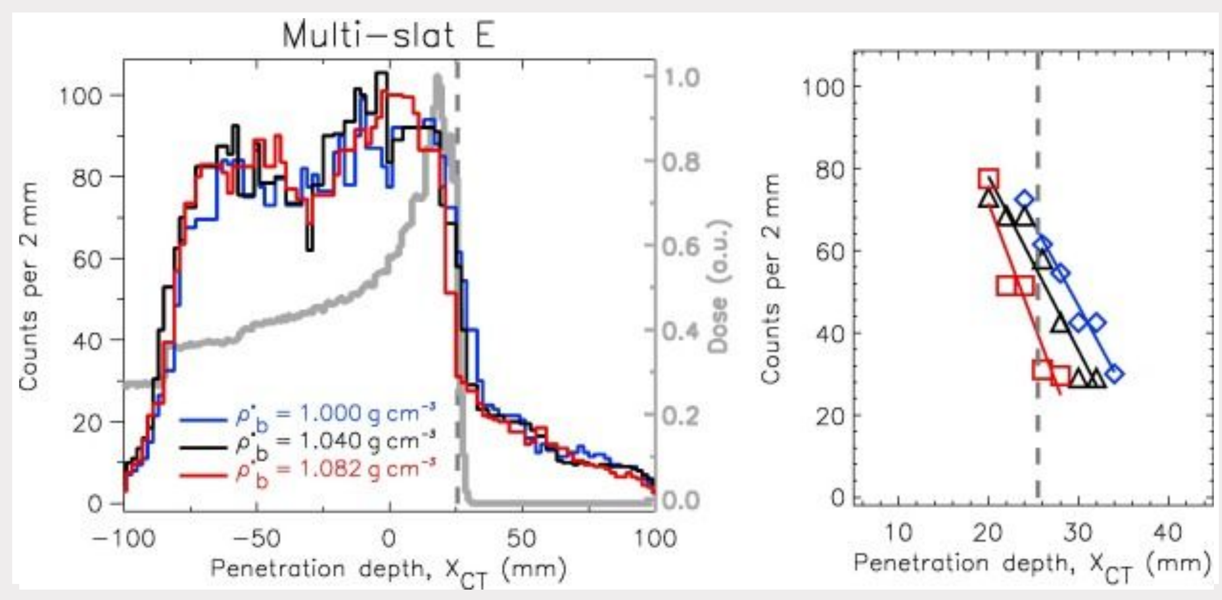
2. First simulation results (CERN's Geant4)

- **Conjecture: brain edema?**

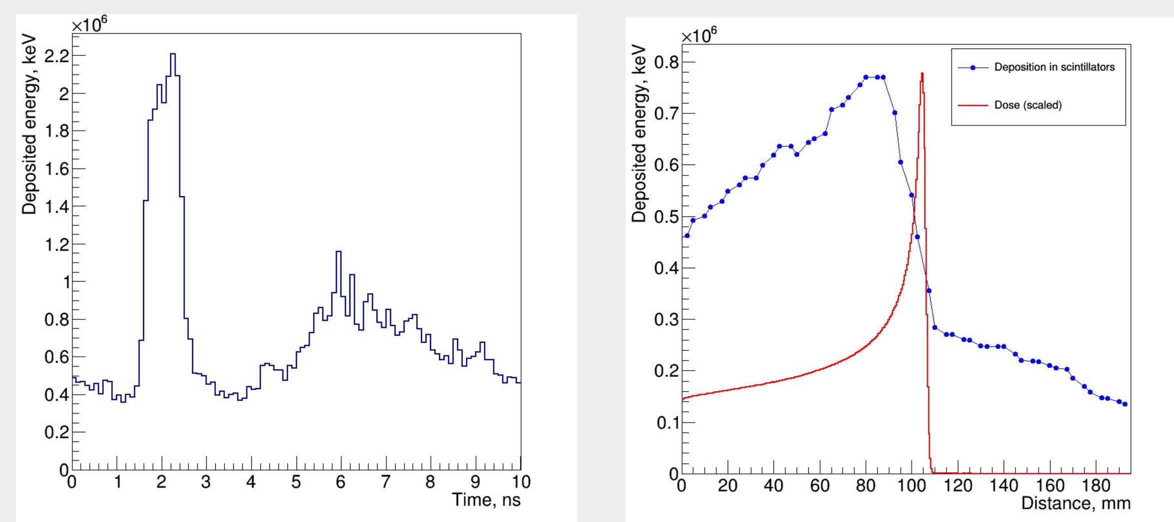




- The slice-collimated profiles (Fig. below) allow a linear regression to separate Bragg peaks only 2 mm apart (no scintillators considered in the simulation at this stage).



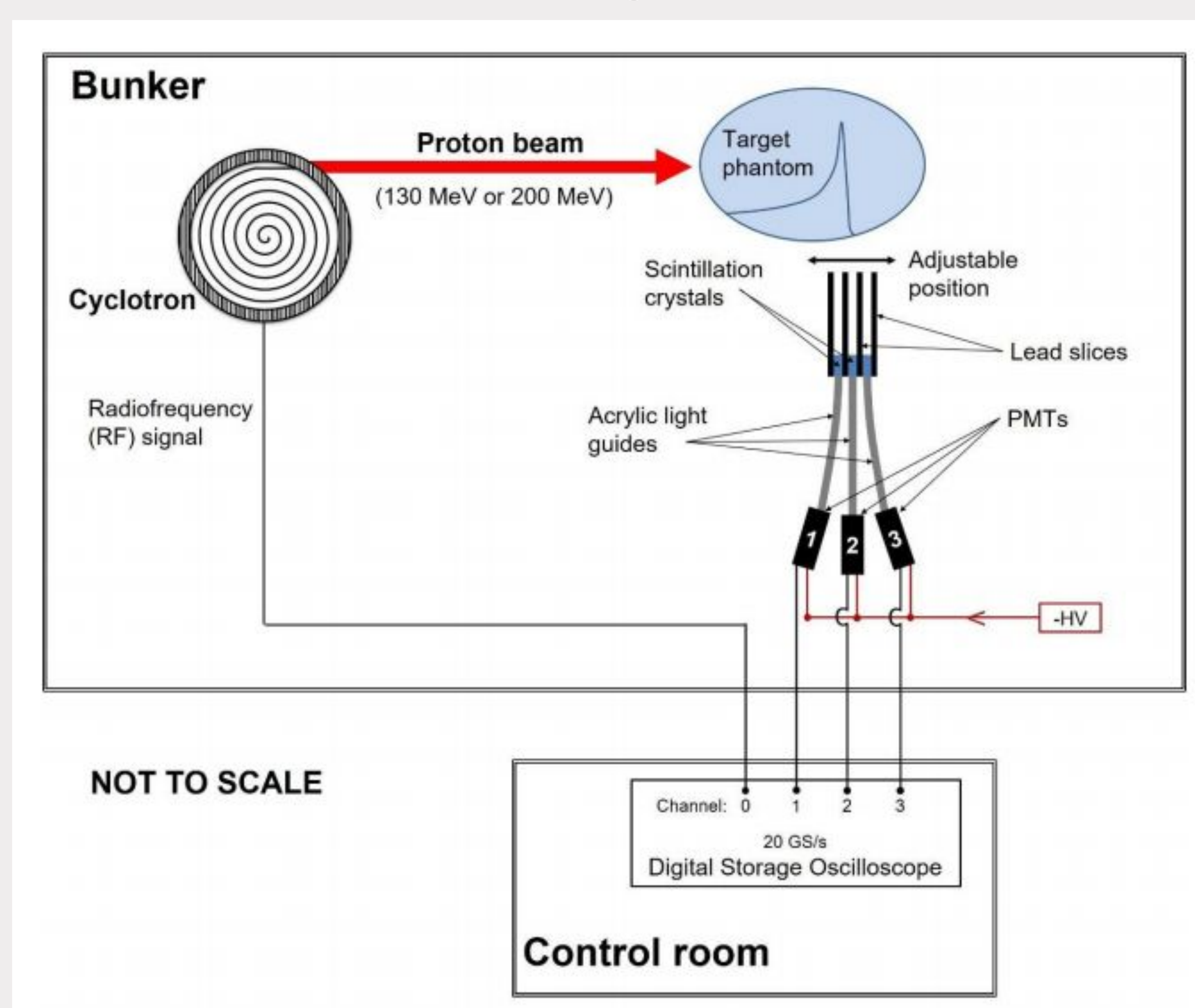
- **Ongoing work**
  - Geant4 simulation [5-7] taking into account the energy deposition in the GSO scintillators. Profile obtained with TOF rejection of all late-arriving particles shown below.



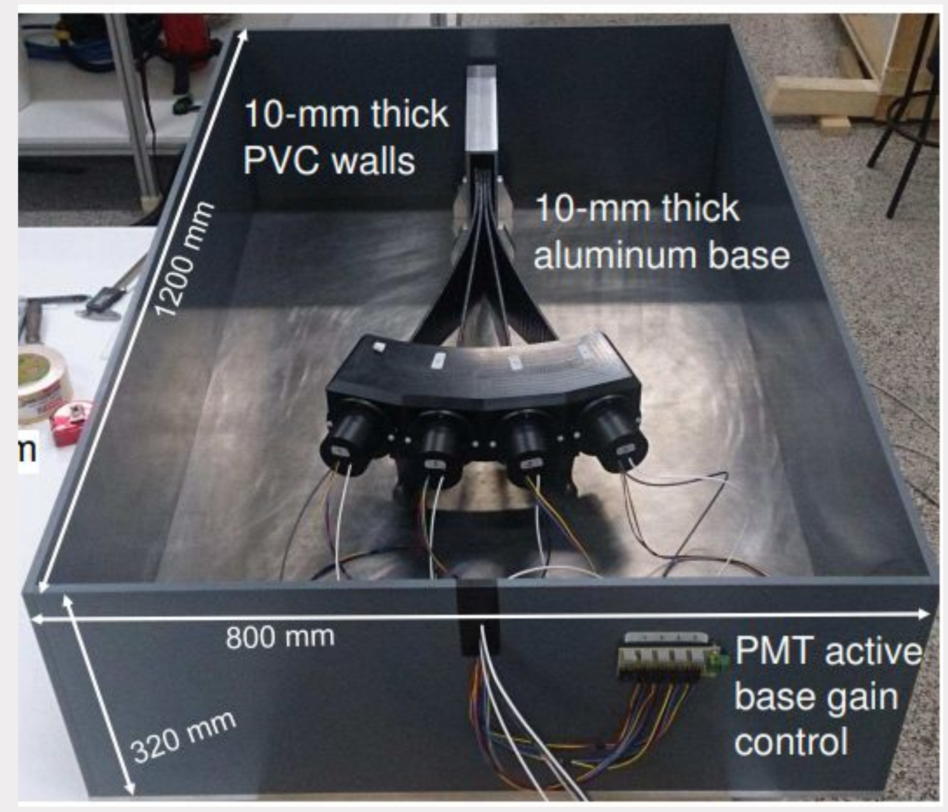
- **Planned work**
  - Include optical photons and photon detector in the MC;
  - Optimize shifting-TOF
  - Consider neutron + all particles interactions in the sensor
  - Consider new PT challenges (CT adapted to Geant4):
    - Pediatric TBI (total body irradiation); moving targets (e.g. lung, bowel); and others (e.g. patient mispositioning on a day-to-day basis)

3. Planned experiment for MC validation

- Already have scintillators, collimator, lightguides, and PMTs. **Oscilloscope missing.**

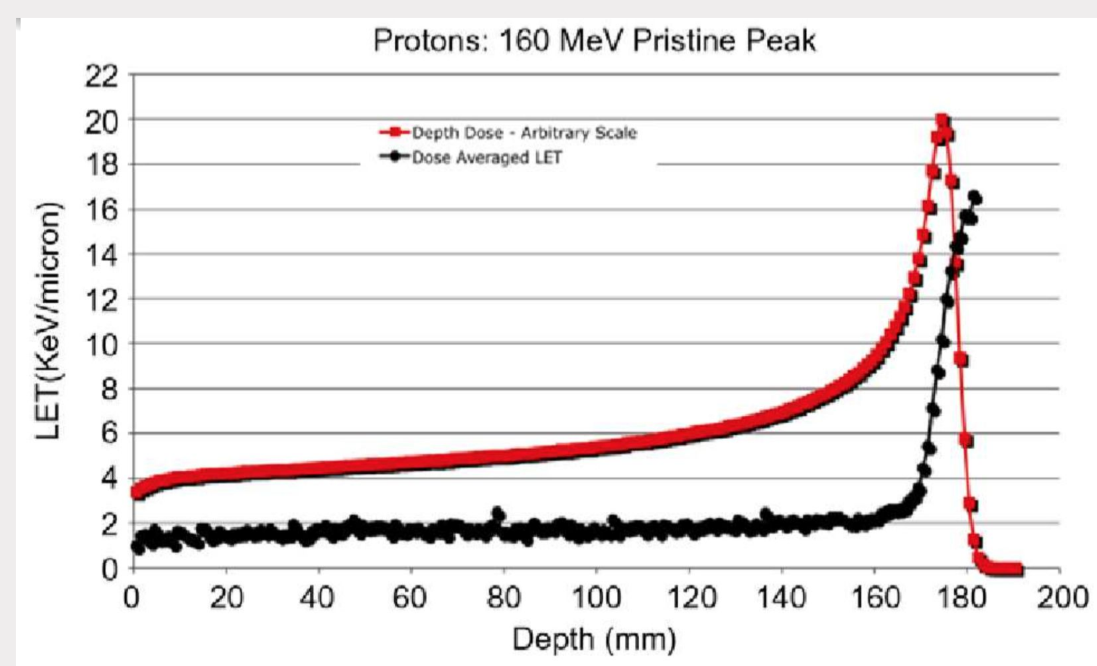


- First version of a validation prototype (already constructed) to be tested at PCTHolland facility (within this proposal)



4. Microdosimetry

- **Open issues**
  - Is proton RBE equal to 1.1?
  - What is the impact, to therapy, of the rise of the LET in the distal edge?



- **Planned work**
  - Optimize the response of a small portable radiation detector based on 3D silicon diodes to tackle particle range uncertainty at the subcellular scale;
  - Study materials and thicknesses for layers to emulate a tissue-equivalent detector;
  - Build a prototype with high potential for technology transfer to industry through programs like ATTRACT in collaboration with the USC.

References:

[1] Hirohiko Tsujii, *J Phys: Conf Ser.*, 777, 012032, 2017
[2] Prof. Dr. João Seco, German Cancer Research Centre, private communication
[3] S Inocenti, Int. J. Model. Simul. Sci. Comput. 1, 157-178, 2010 (http://geant4-dna.org/)
[4] P. Cambraia Lopes et al., Phys Med, 54: 1-14, 2018
[5] S. Agostinelli et al., NIM A, 506(3):250-303, 2003
[6] J. Allison et al., IEEE TNS, 53(1):270-278, 2006
[7] J. Allison et al., *NIM A*, 835:186-225, 2016

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Corresponding address: **Paulo Crespo (crespo@lip.pt) • LIP • Physics Department • University of Coimbra • 3004-516 Coimbra • Portugal**
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