Particles and Health Advances in Imaging in Proton Radiotherapy

Hugo Simões On behalf the ORimag group from LIP-Coimbra



LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS



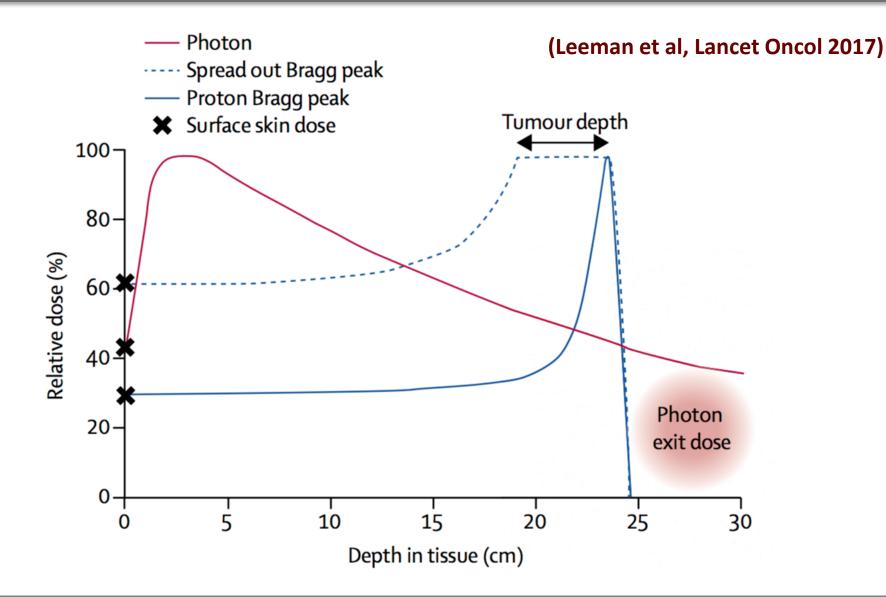
FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE DE COIMBRA

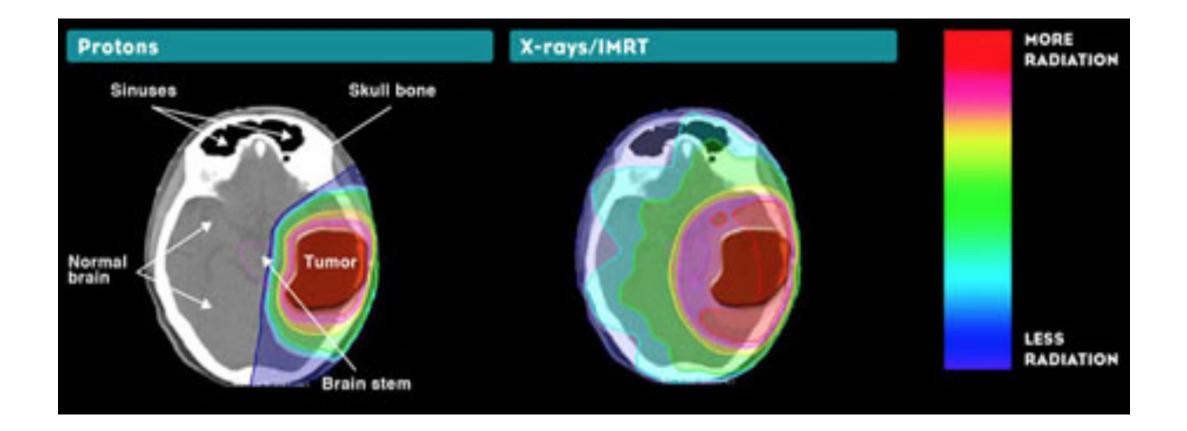
LIP training internship LIP – July 2nd, 2025

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Advances in Imaging in Proton Radiotherapy

- 1. Motivation
- 2. Rationale for in-vivo imaging in proton radiotherapy (RT)
- 3. The multi-slat concept for prompt-gamma imaging (PGI) in proton RT
- 4. In-beam time-of-flight PET for proton RT

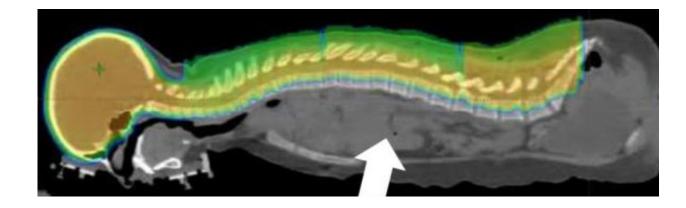




(Proton Therapy Today 2019)

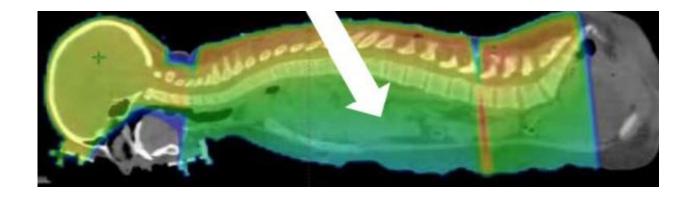
The protons stop!

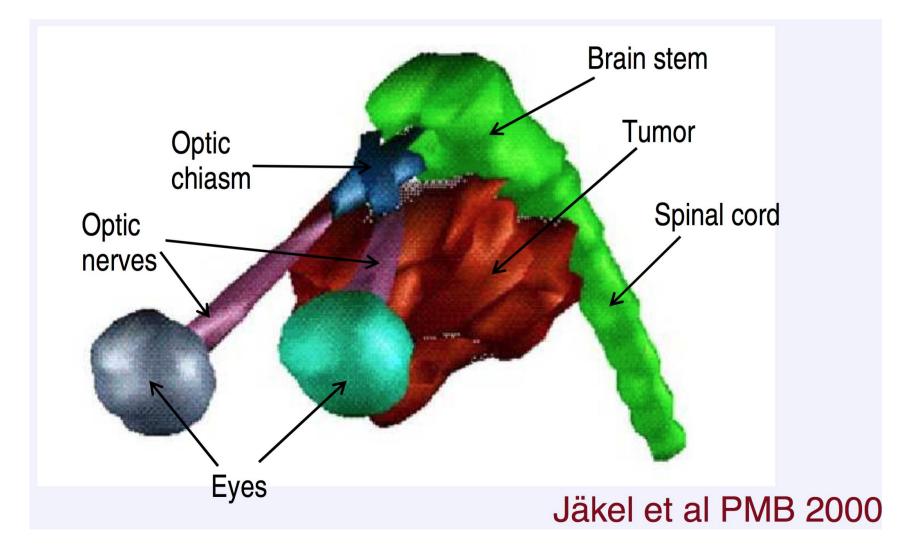
The depth at which this occurs depends on their initial energy.



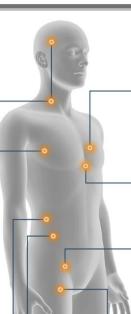
X-rays do not stop!

They continue to pass through the surrounding tissue.





1. Motivation: Proton therapy clinical benefits



Lung

56% relative reduction in incidences of grade 3 esophagitis

50% reduction in relative risk of recurrence

Higher radiation dose to the tumor while reducing risks of overall side effects

64% relative increase in 5-year overall survival

Esophageal

3 to 4-day reduction in average hospital stay
5.1-22.8% overall reduction in pulmonary complications
68% relative reduction in wound complications

Prostate

4.9% higher overall 5 year survival rate

35% less radiation to bladder and 59% less radiation to the rectum

Proton patients are almost twice as likely to report **treatment had NO IMPACT on their quality of life** compared to surgery, conventional radiation, and brachytherapy

Half as many incidences of long term (2+ years) moderate or severe bowel problems

42% reduction in relative risk of developing a secondary malignancy

Significantly fewer reports of gastrointestinal, genitourinary, endocrine, or "other" complications

Rectal/Anal

More than 50% reduction in radiation dose to critical structures including bone marrow

Overall 31% relative reduction in occurrence of secondary cancers after treatment

PROVISION CARES

*References available upon request. Results from separate studies compared in some instances. The benefits of proton therapy for each individual patient will vary based on their individual diagnosis. A personal consultation with a proton-trained physician is recommended in all cases.

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7

(Hepatocellular) 58% higher overall survival rate (2 years)

Bile Duct 54% higher overall survival (4 years)

Sarcoma 49-75% reduction in complications

(Hepatocellular)

no breast tumor recurrence at 5 years

Brain/Head & Neck

nasal and paranasal sinus cavity cancers

Delivers 8-18 times less overall radiation

50-83% less relative risk of heart attack or

another major coronary event depending on age

97% of partial breast irradiation patients experience

50% reduction of clinically significant radiation doses to the heart

90% of cases result in good to excellent cosmetic outcomes at 5 years

quicker return to normal function

nasopharyngeal cancer

oropharyngeal cancer

Breast

to the heart than IMRT

45% reduction in overall risk of needing a feeding tube for

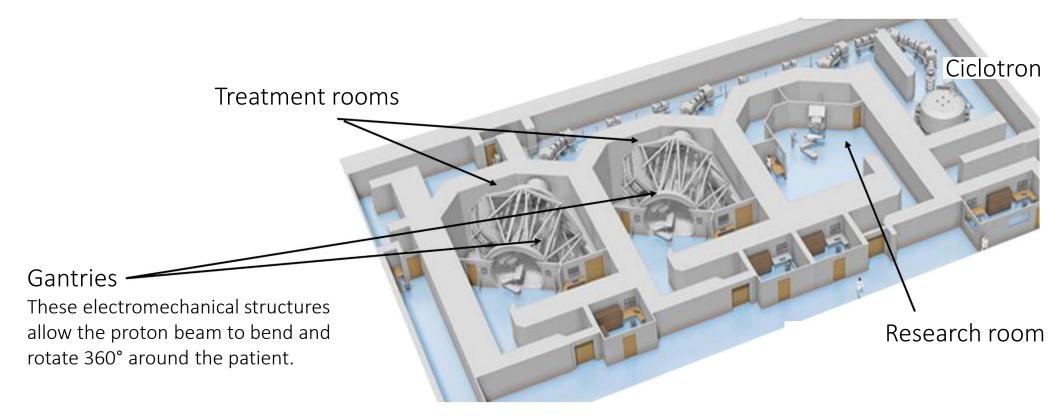
27% reduction in overall risk of needing a feeding tube for

44% increase of relative 5-year disease free survival rate for

50% overall increase of disease control for **chordomas Less side effects** during first 3 months after treatment.

50% less likely to have secondary tumor from treatment

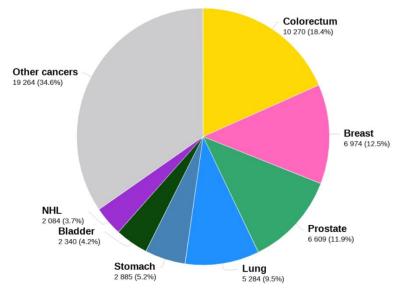
1. Motivation: A proton therapy facility in Portugal?



https://iba-worldwide.com/proton-therapy/proton-therapy-solutions/proteus-plus

1. Motivation: A proton therapy facility in Portugal?

Incidence of different types of cancer in Portugal



Estimated number of new cases in 2018, Portugal, all cancers excl. NMSC, both sexes, all ages

Total : 55 710

Estimated number of patients recommended for proton therapy: 15% of patients recommended for radiotherapy (50% of the total): around **4200/year**

1. Motivation: A proton therapy facility in Portugal?

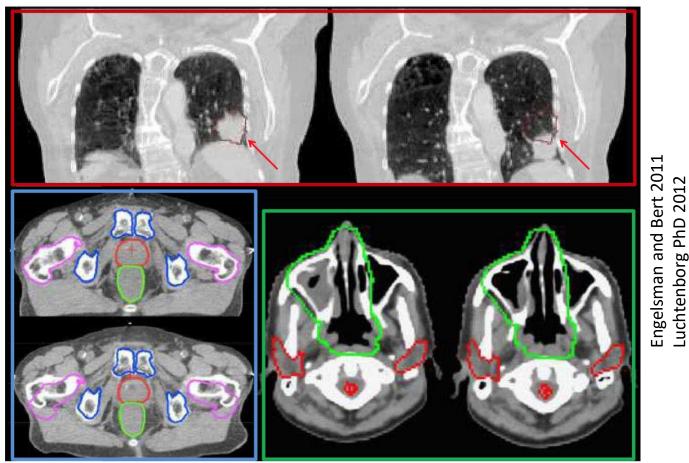
IPOPORTO **()** SNS 24 808 24 24 24 LOGIN BEM-ME-KER 🛞 Q LINHA DIRETA 225 084 000 PT 24 Outubro 2024 **PRIMEIRO-MINISTRO ANUNCIA CENTRO NACIONAL DE** PROTONTERAPIA NO IPO PORTO Portugal vai ter um centro de terapia do cancro com protões instalado no Instituto Português de Oncologia do Porto (IPO Porto). O anúncio foi feito hoje pelo primeiro-ministro, Luís Montenegro, na cerimónia de assinatura do acordo de compromisso com a Fundación Amancio Ortega (FAO), o IPO Porto e o Governo português para a criação do primeiro Centro Nacional de Protonterapia (CNP) em Portugal, e no Serviço Nacional de Saúde (SNS).

A cerimónia contou com a presença da Ministra da Saúde, Ana Paula Martins, o Ministro Adjunto e da Coesão Territorial, Manuel Castro Almeida.

O desafio lançado pelo IPO do Porto à FAO, com o envolvimento e empenho do Governo de Portugal, irá permitir a concretização, num horizonte de 3 a 4 anos, da criação do Centro Nacional de Protonterapia, um projeto de desígnio nacional.

2. Rationale for in-vivo imaging in proton RT

Morphologic changes / patient positioning



Very high conformality provides high-precision and highly accurate RT, but need for RT imaging also increases

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2. Rationale for in-vivo imaging in proton RT

Beam verification approaches:

Positron Emission Tomography (PET)

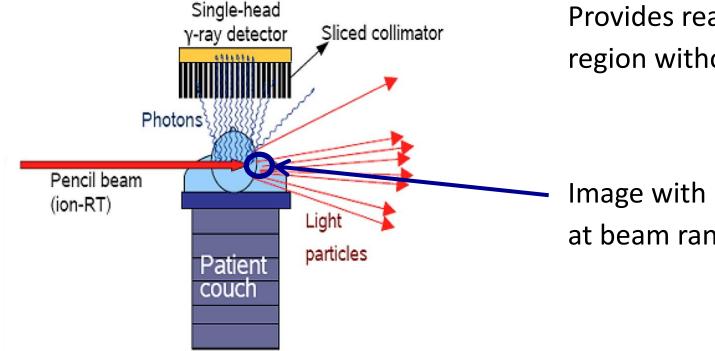
•Interaction of the beam with the body generates positron emitters, such as $^{15}\text{O},\,^{11}\text{C},\,^{13}\text{N}$

•PET scanners can be used to verify beam range by comparing the reconstructed image with the simulated activity distribution

Prompt Gamma (PG) imaging

•Beam also generates prompt gammas with the energy sufficient to escape the body without interactions

•Measured distribution of the emission positions can be compared with the simulation to verify the beam range



Provides real-time images of selected region without rotation of beam source.

Image with prompt gammas "stops" at beam range

(Cambraia Lopes et al, Physica Medica 2018)

Y_{CT} (cm)

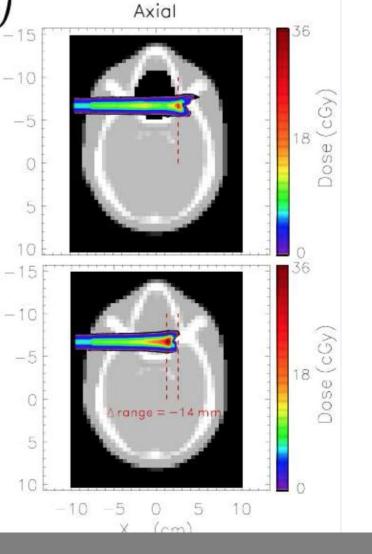
 $\gamma_{\rm CT}({\rm cm})$

3.1 Filling of nasal cavity

Head irradiation (NCAT)

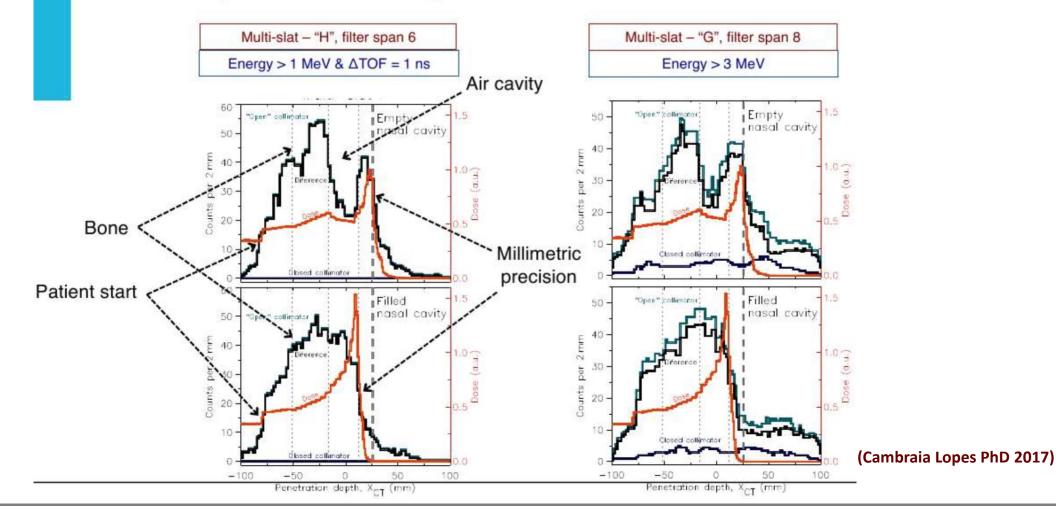
① Sphenoid region

- Treatment plan:
 - Irradiation of a hypothetical tumor located in the sphenoid bone region
 - o Empty nasal cavity (air-filled)
- Compromised treatment:
 - Filled nasal cavity with PMMA-like material
 - Under-range shift of 14 mm
 - Possible causes:
 - Patient cold → presence of mucus
 - Response after irradiation → edema, tissue swelling
 - Tumor growth



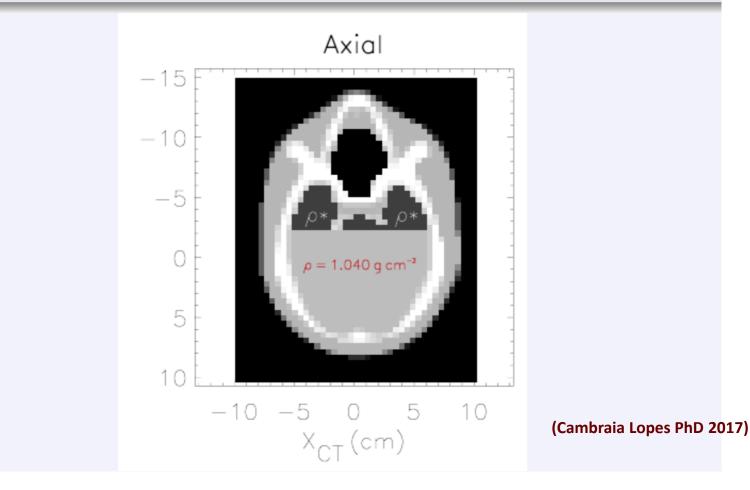
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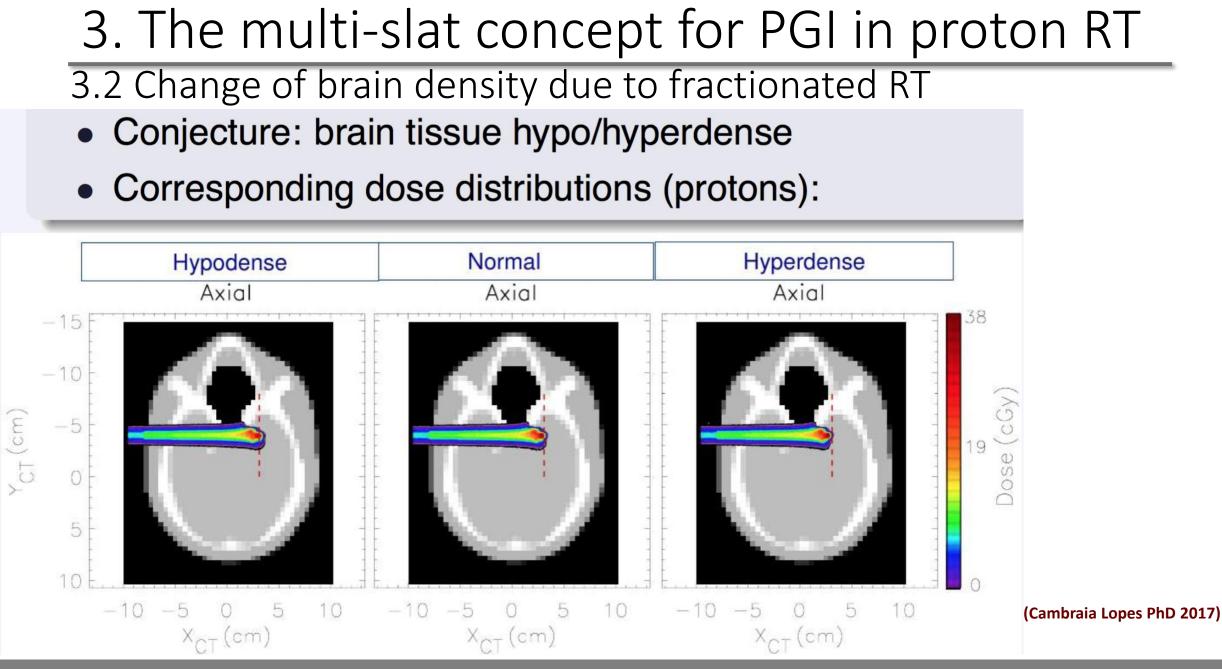
1 Sphenoid region Collimated PG profiles



3.2 Change of brain density due to fractionated RT

• Conjecture: brain tissue hypo/hyperdense due to fractionated RT Denham et al Radiother Oncol 2002

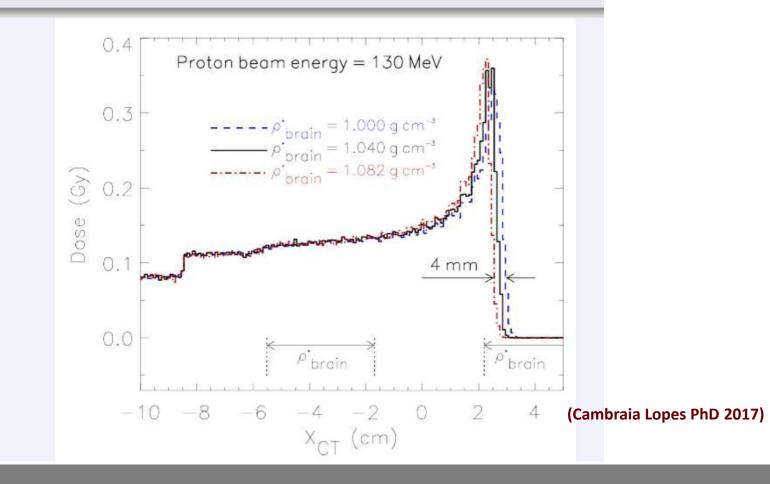


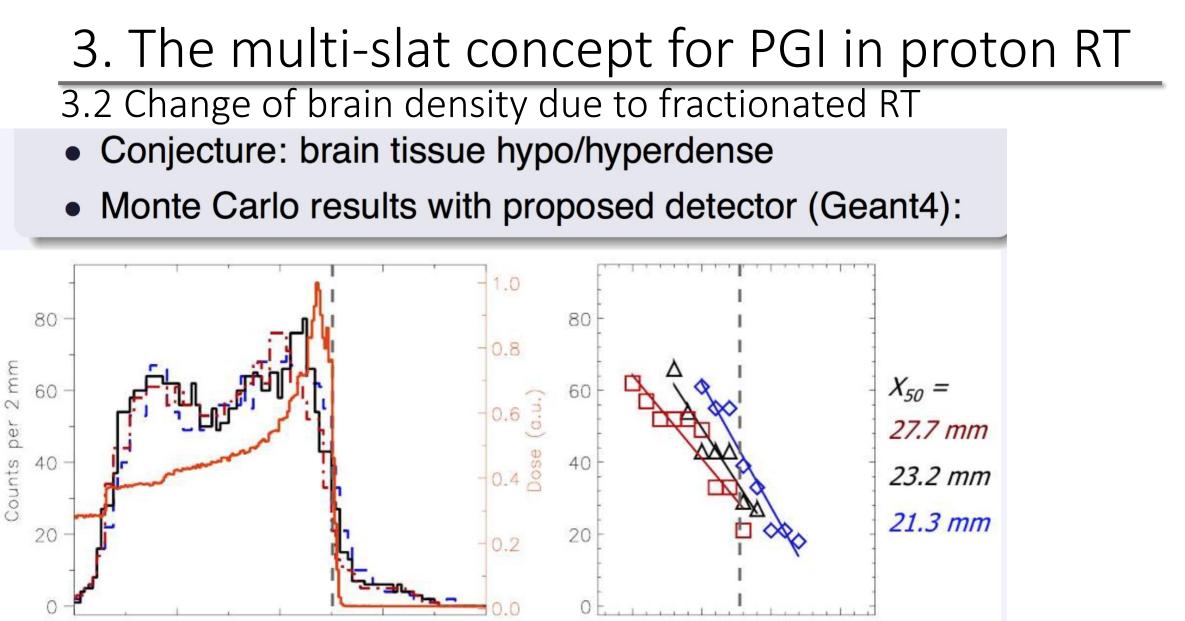


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3.2 Change of brain density due to fractionated RT

- Conjecture: brain tissue hypo/hyperdense
- Corresponding dose profiles (protons):





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Penetration depth, X_{CT} (mm)

10

30

40

(Cambraia Lopes PhD 2017)

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-100

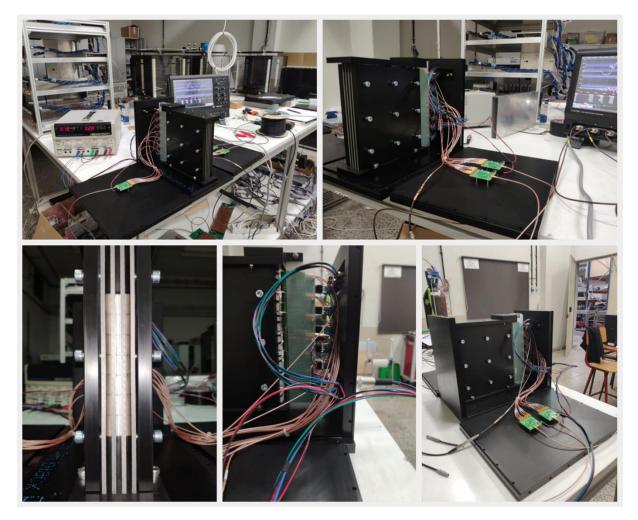
-50

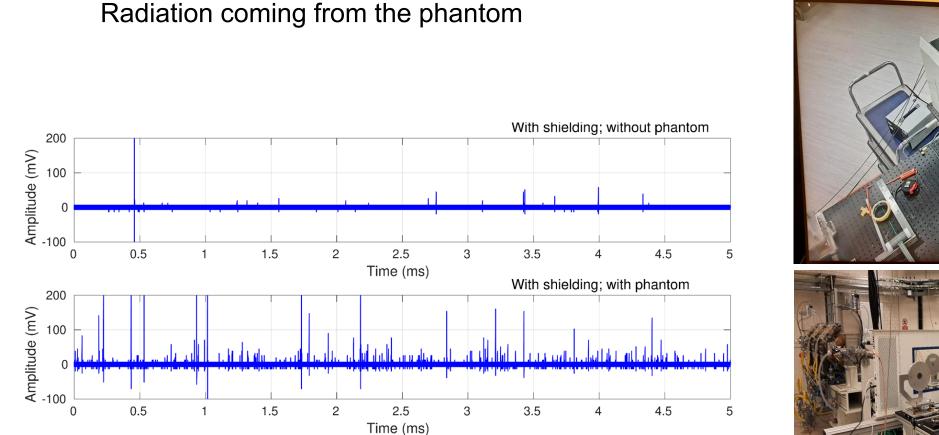
Penetration depth, X_{CT} (mm)

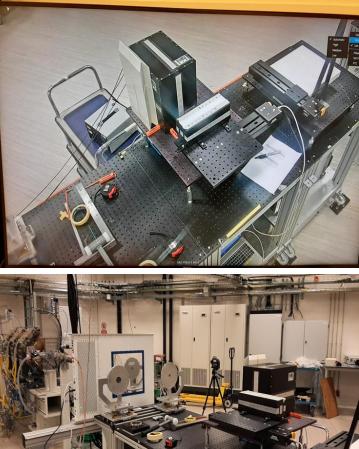
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Small-scale multi-slat O-PGI prototype

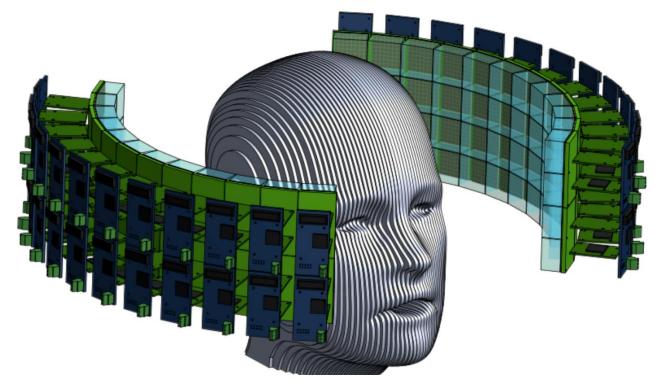




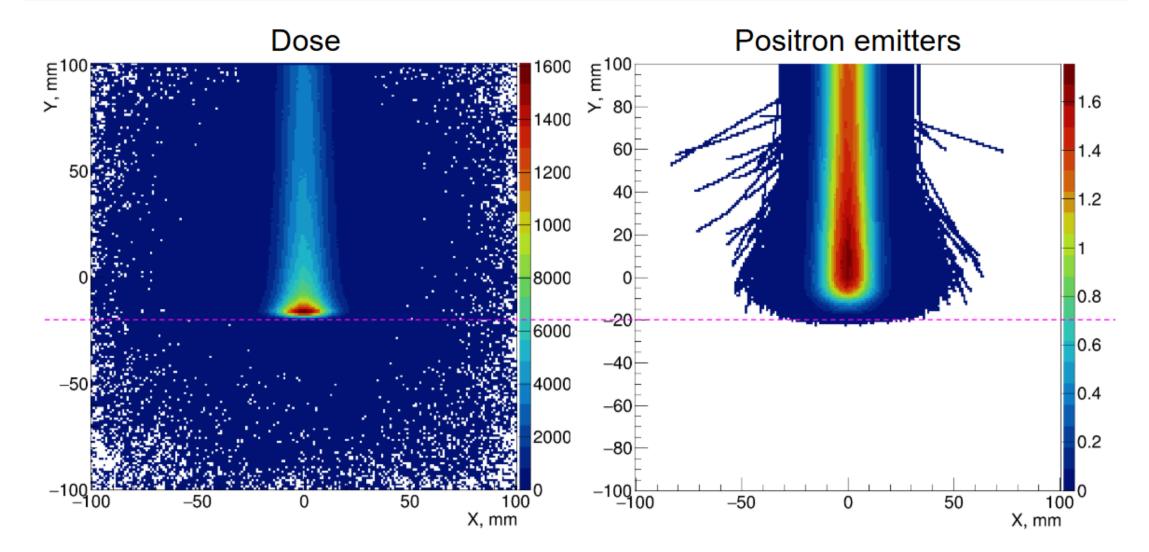


TOF-PET for Proton Therapy (TPPT) – In-beam Time-of-Flight (TOF) Positron Emission Tomography (PET) for proton radiation therapy

Consortium between PETsys Electronics (Lisbon), LIP (Lisbon & Coimbra), ICNAS-UC, IST, Un. Texas at Austin, USA, MDACC (Houston), USA



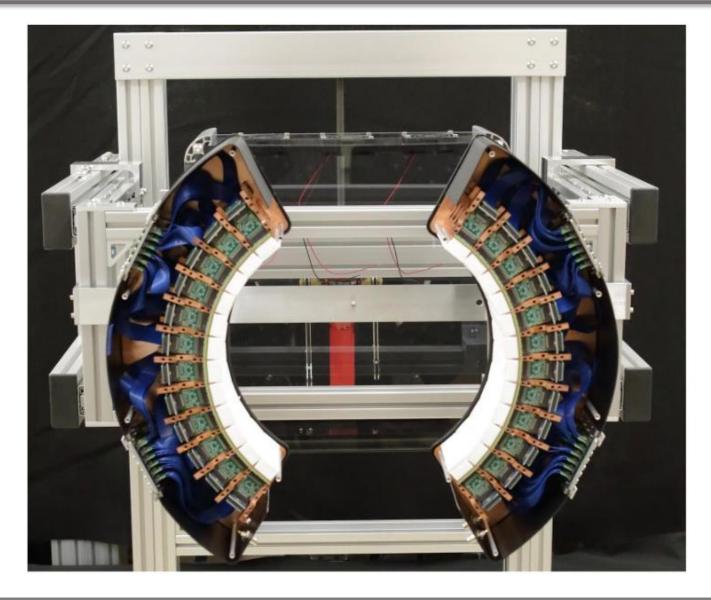
Coincidence time resolution of 200 ps FWHM (corresponds to Gaussian with 3 cm FWHM)

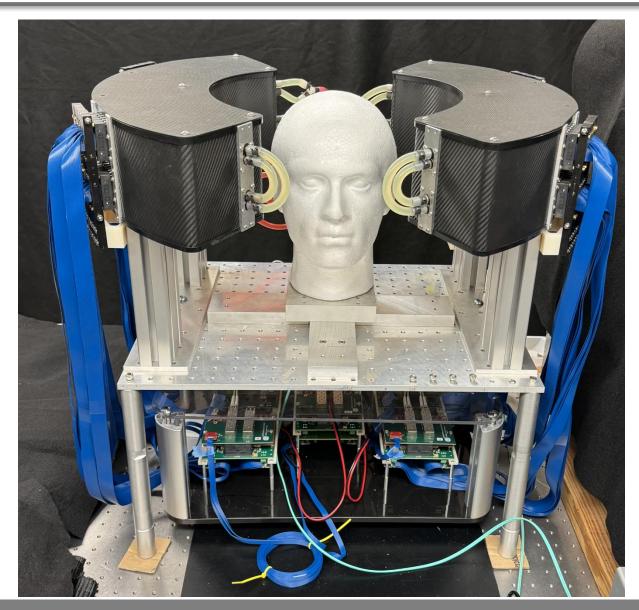












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Thank you for your attention