Particles and Health

Advances in Imaging in Proton Radiotherapy

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On behalf the ORimag group from LIP-Coimbra

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS

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UNIVERSIDADE DE COIMBRA

LIP training internship

LIP – July 2nd, 2025

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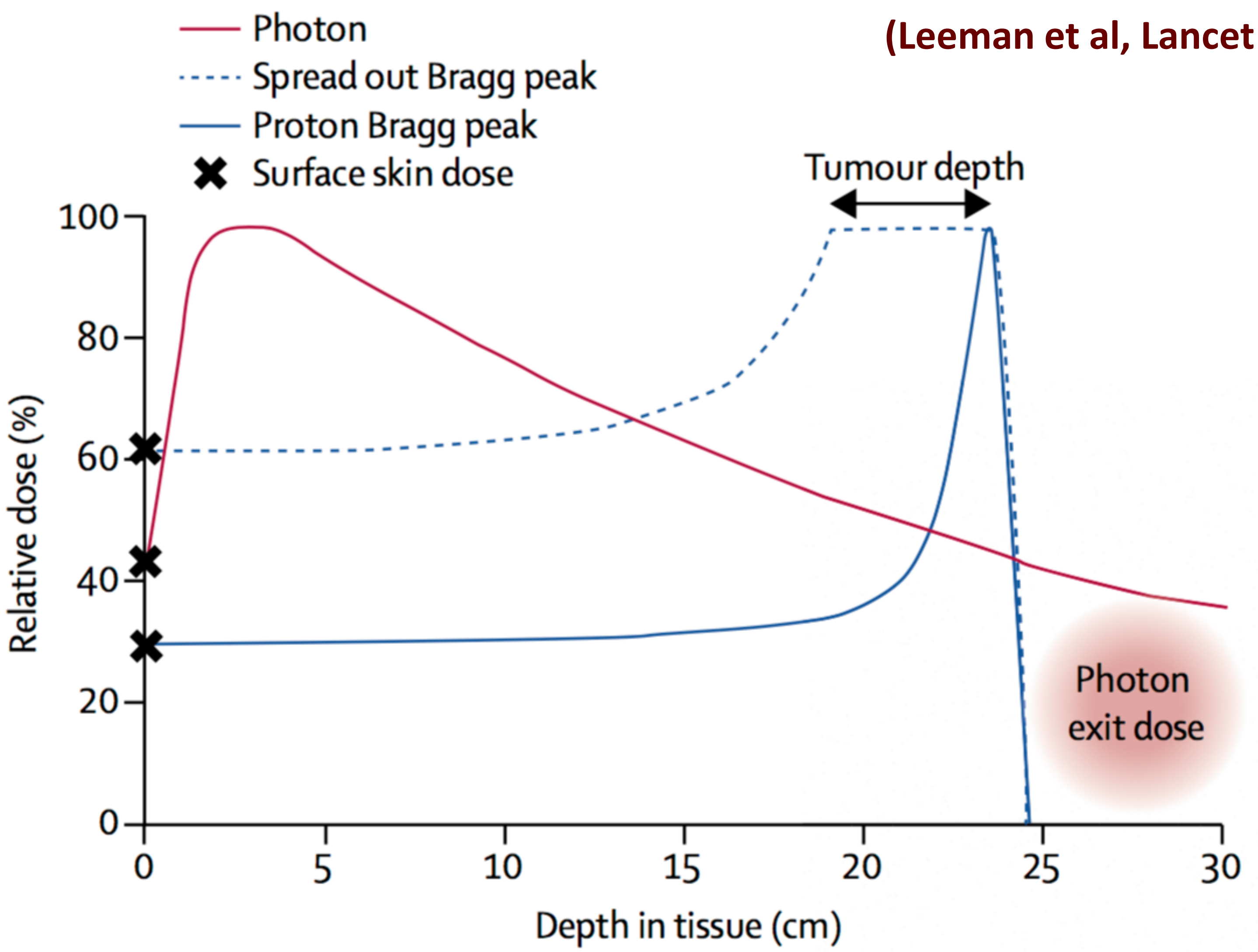
Outline

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

1. Motivation: Proton therapy physical advantage over photons

(Leeman et al, Lancet Oncol 2017)



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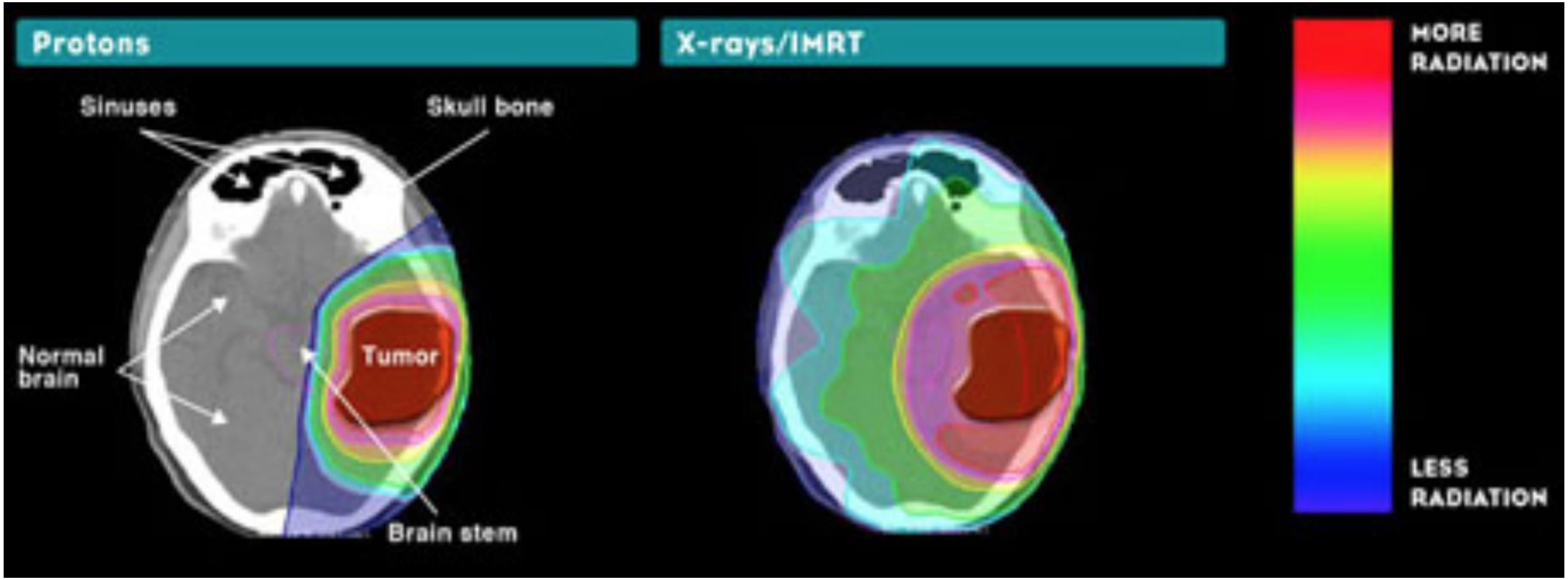

(Proton Therapy Today 2019)

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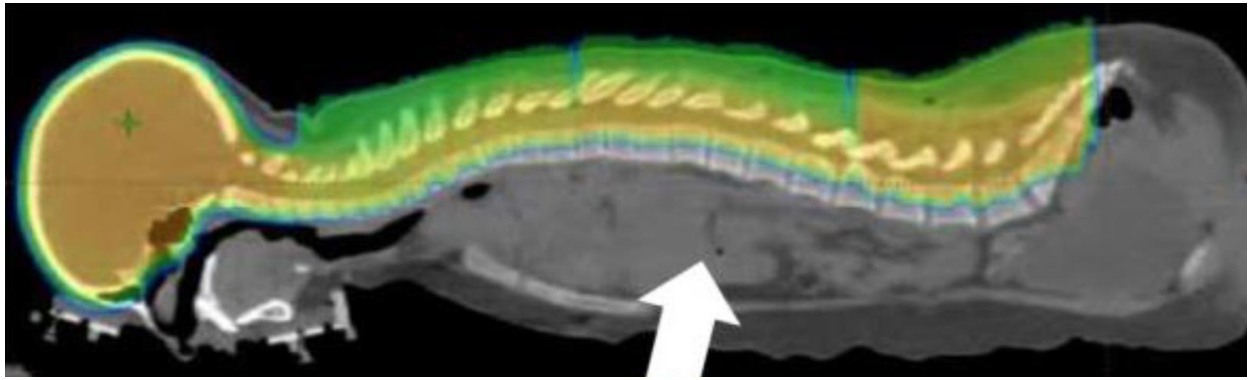
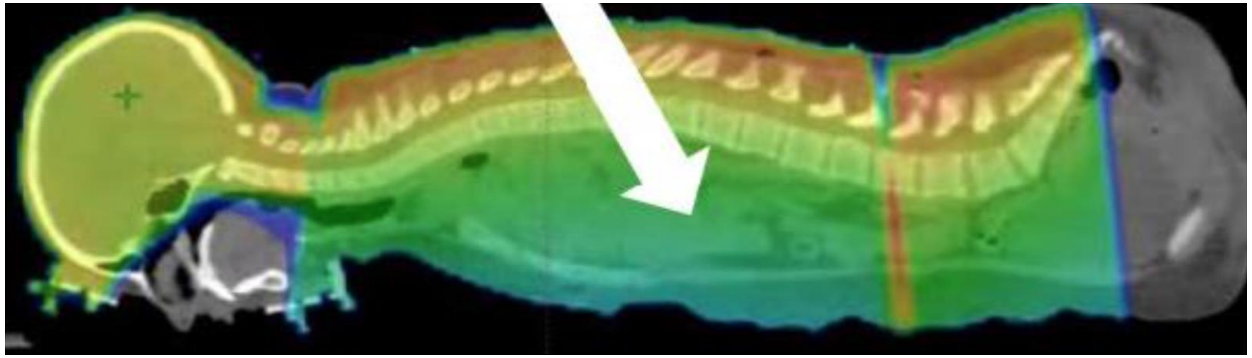


The protons stop!
The depth at which this occurs depends on their initial energy.



X-rays do not stop!
They continue to pass through the surrounding tissue.

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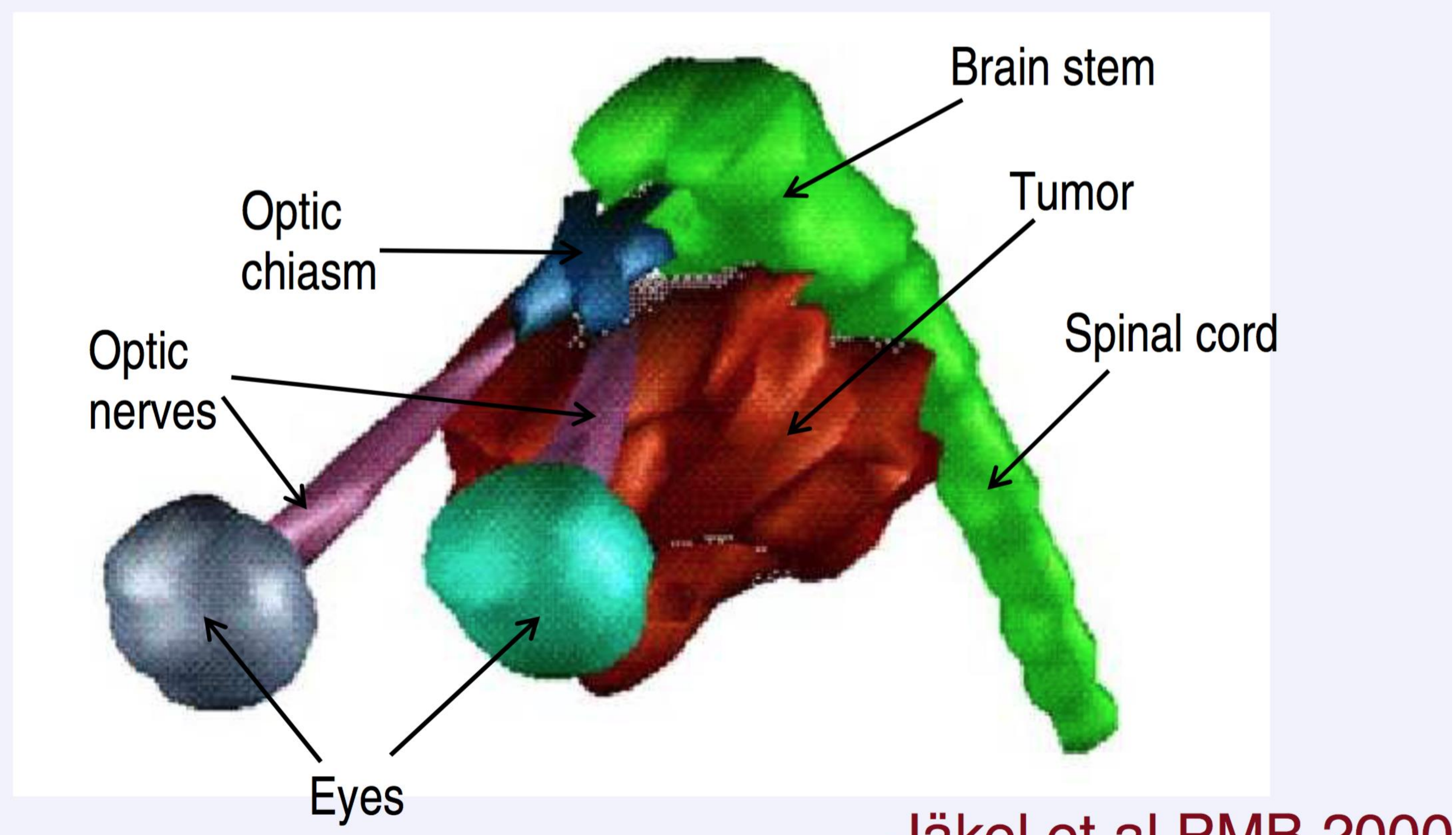
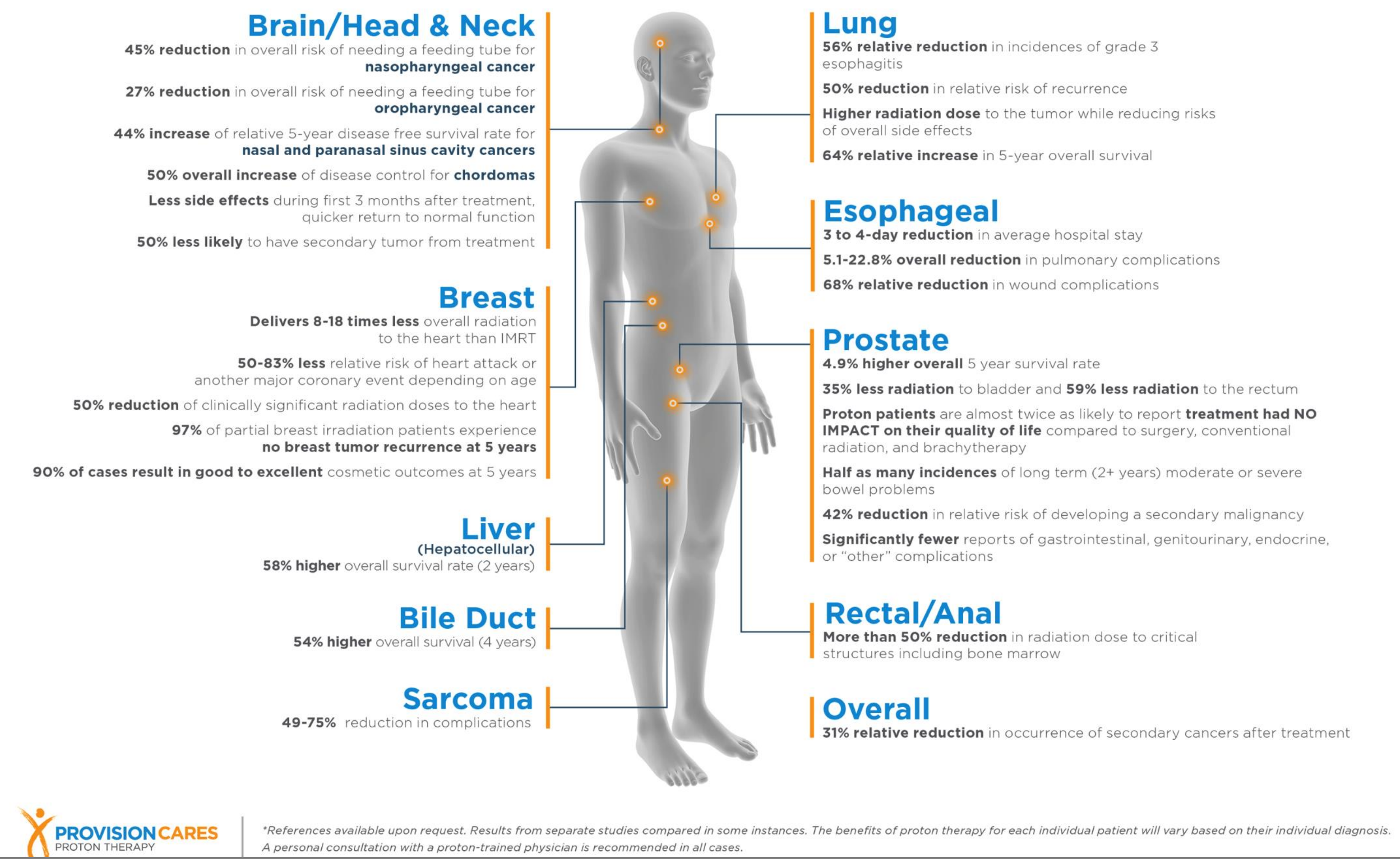
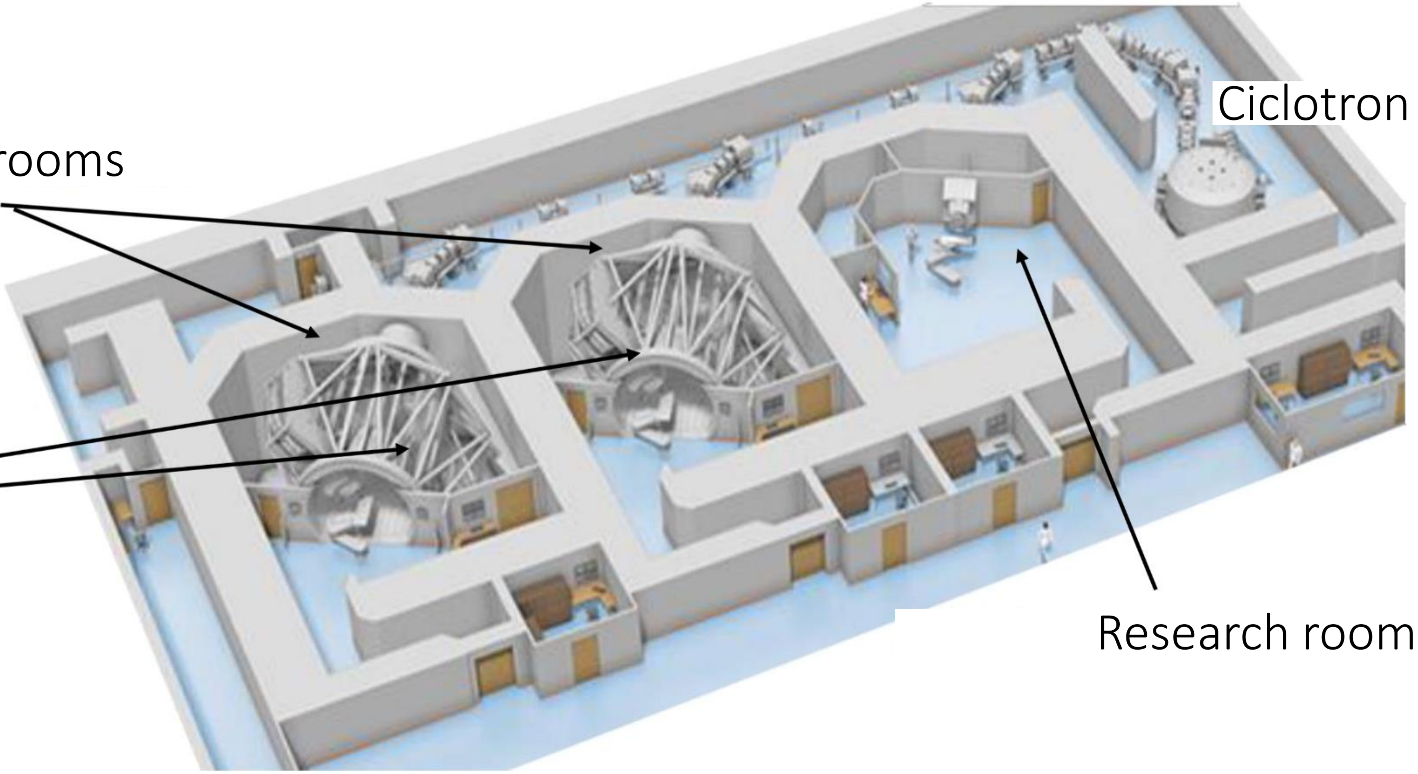


Jäkel et al PMB 2000

1. Motivation: Proton therapy clinical benefits



1. Motivation: A proton therapy facility in Portugal?



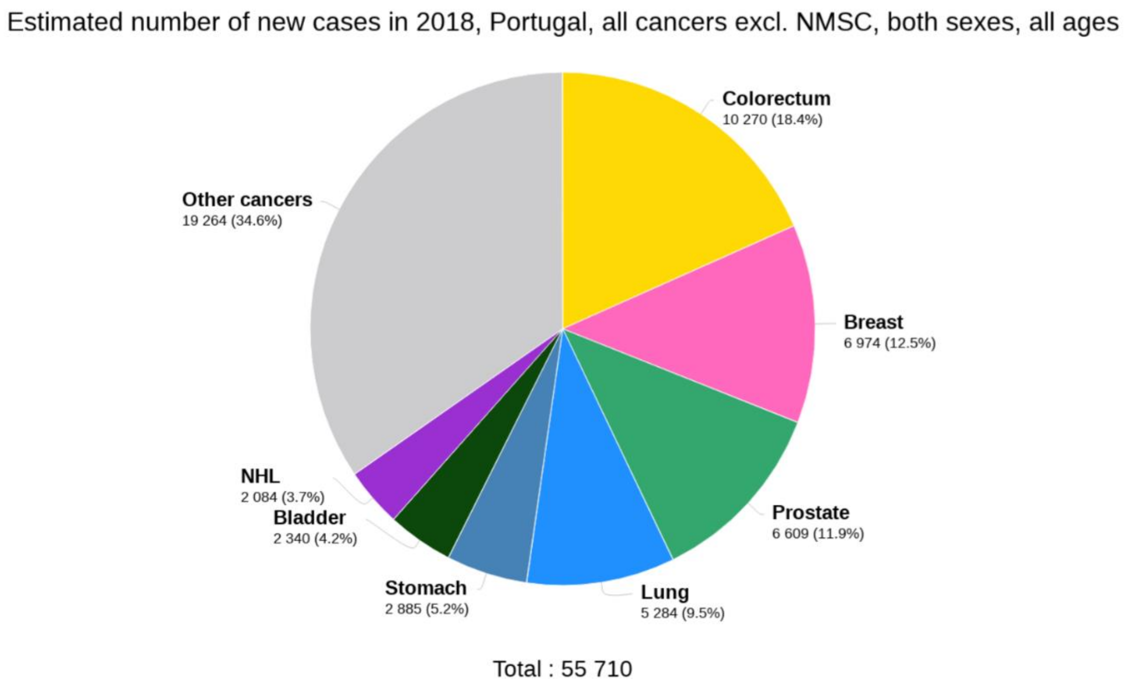
Gantries

These electromechanical structures allow the proton beam to bend and rotate 360° around the patient.

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

1. Motivation: A proton therapy facility in Portugal?

<u>Incidence of different types of cancer in Portugal</u>



<u>Estimated number of patients recommended for proton therapy:</u>

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

1. Motivation: A proton therapy facility in Portugal?

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24 Outubro 2024

PRIMEIRO-MINISTRO ANUNCIA CENTRO NACIONAL DE PROTONTERAPIA NO IPO PORTO

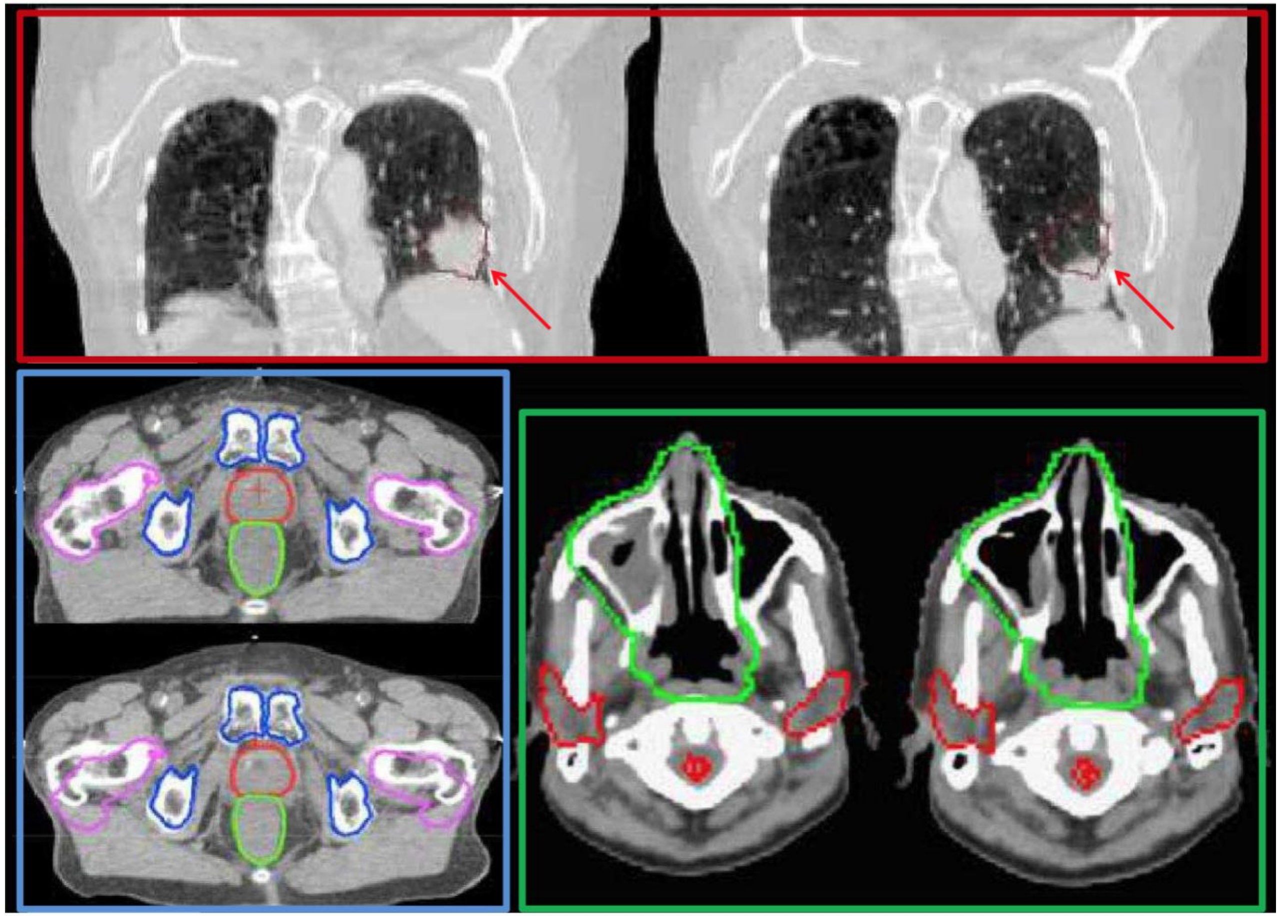
Portugal vai ter um centro de terapia do cancro com protões instalado no Instituto Português de Oncologia do Porto (IPO Porto). O anúncio foi feito hoje pelo primeiro-ministro, Luís Montenegro, na cerimónia de assinatura do acordo de compromisso com a Fundación Amancio Ortega (FAO), o IPO Porto e o Governo 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



Engelsman and Bert 2011
Luchtenborg PhD 2012

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

2. Rationale for in-vivo imaging in proton RT

Beam verification approaches:

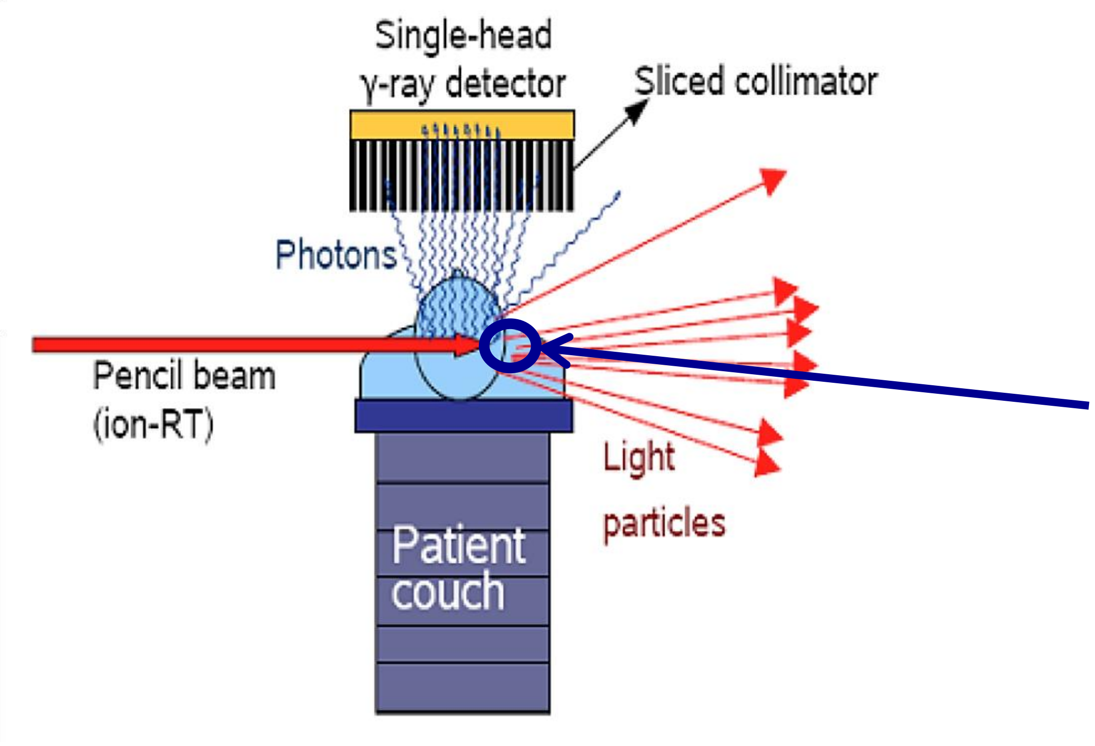
Positron Emission Tomography (PET)

- Interaction of the beam with the body generates positron emitters, such as ^{15}O, ^{11}C, ^{13}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

3. The multi-slat concept for PGI in proton RT



(Cambraia Lopes *et al*, Physica Medica 2018)

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

Image with prompt gammas "stops" at beam range

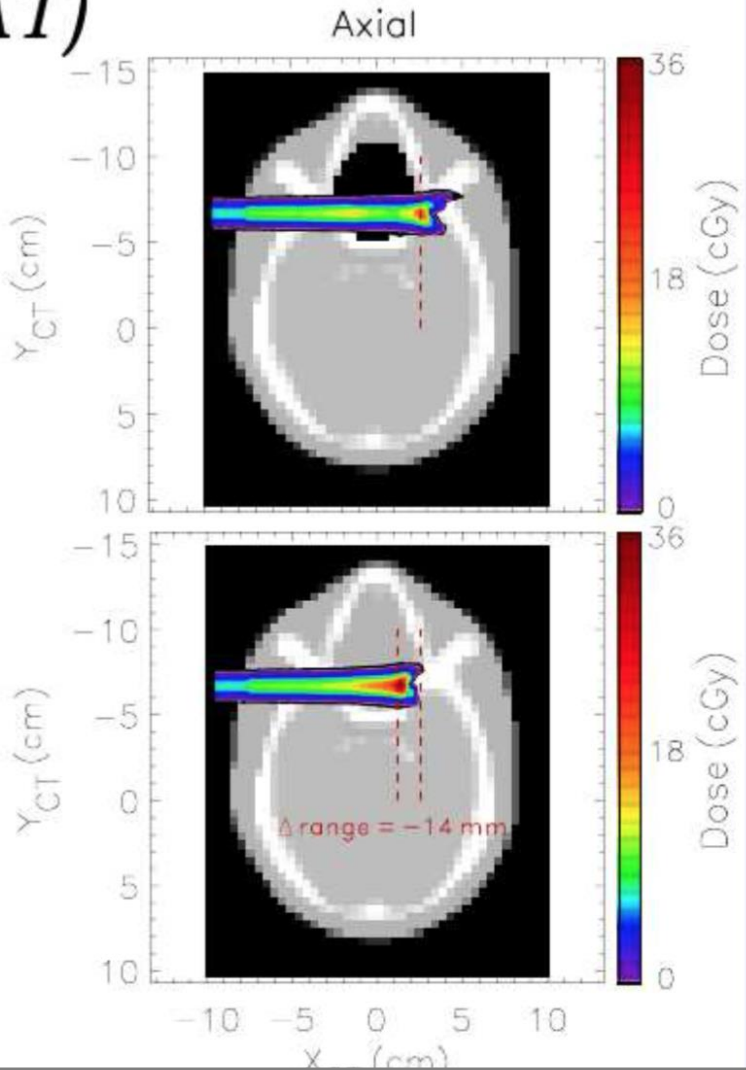
3. The multi-slat concept for PGI in proton RT

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
  - **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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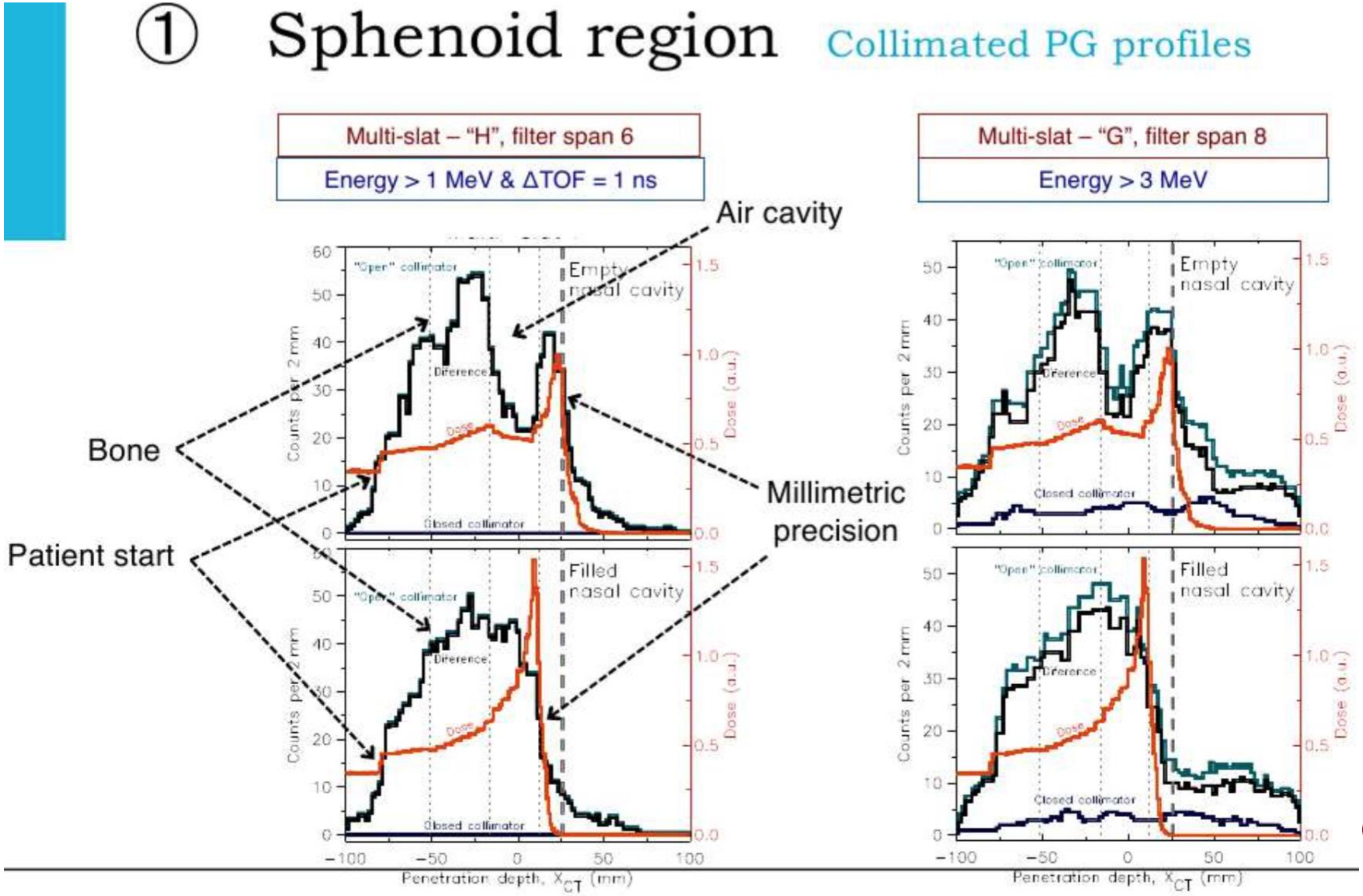
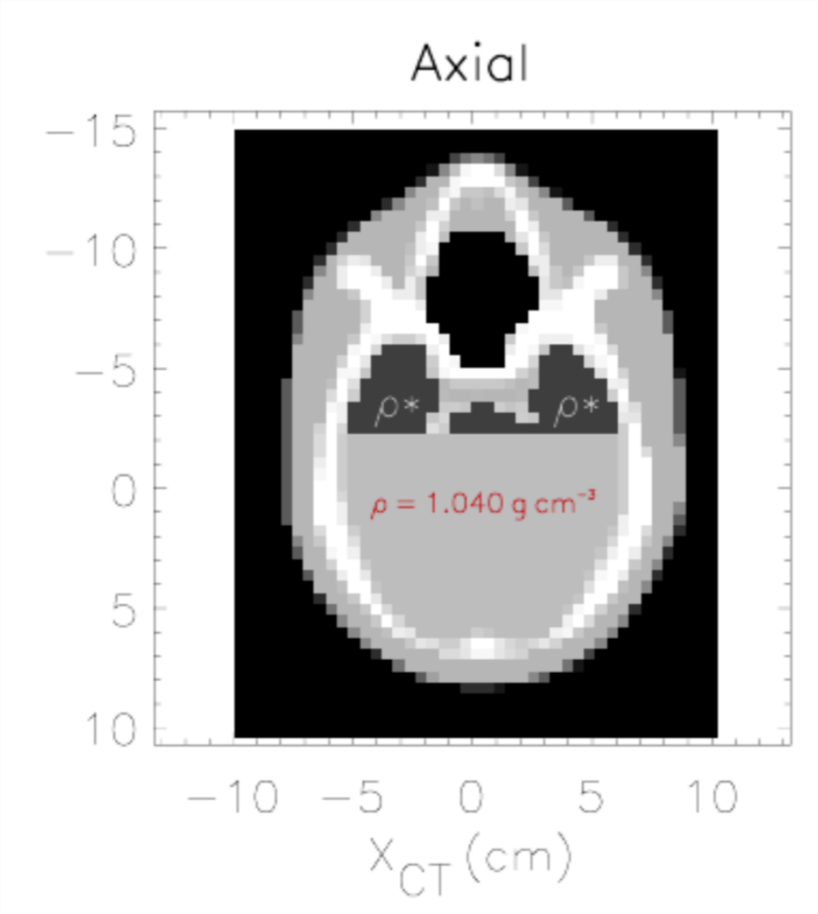


(Cambraia Lopes PhD 2017)

3. The multi-slat concept for PGI in proton RT

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



(Cambraia Lopes PhD 2017)

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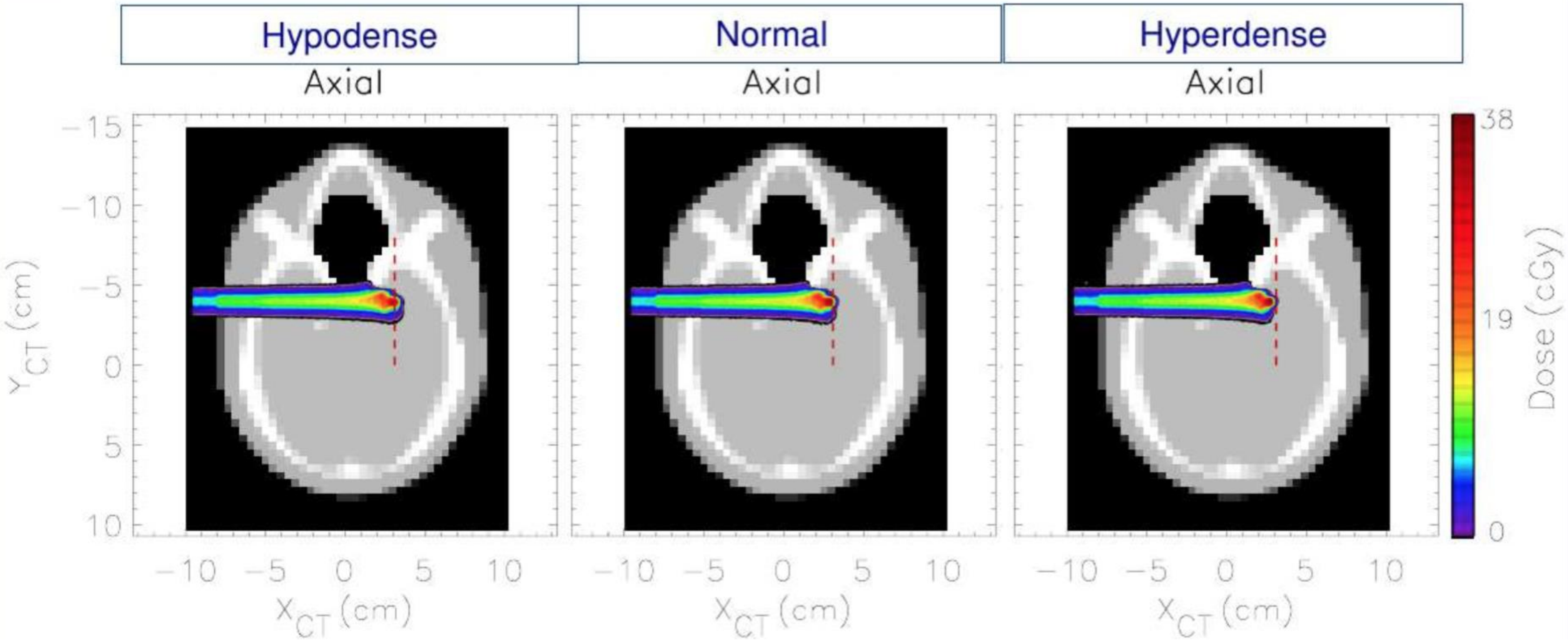
- Corresponding dose distributions (protons):



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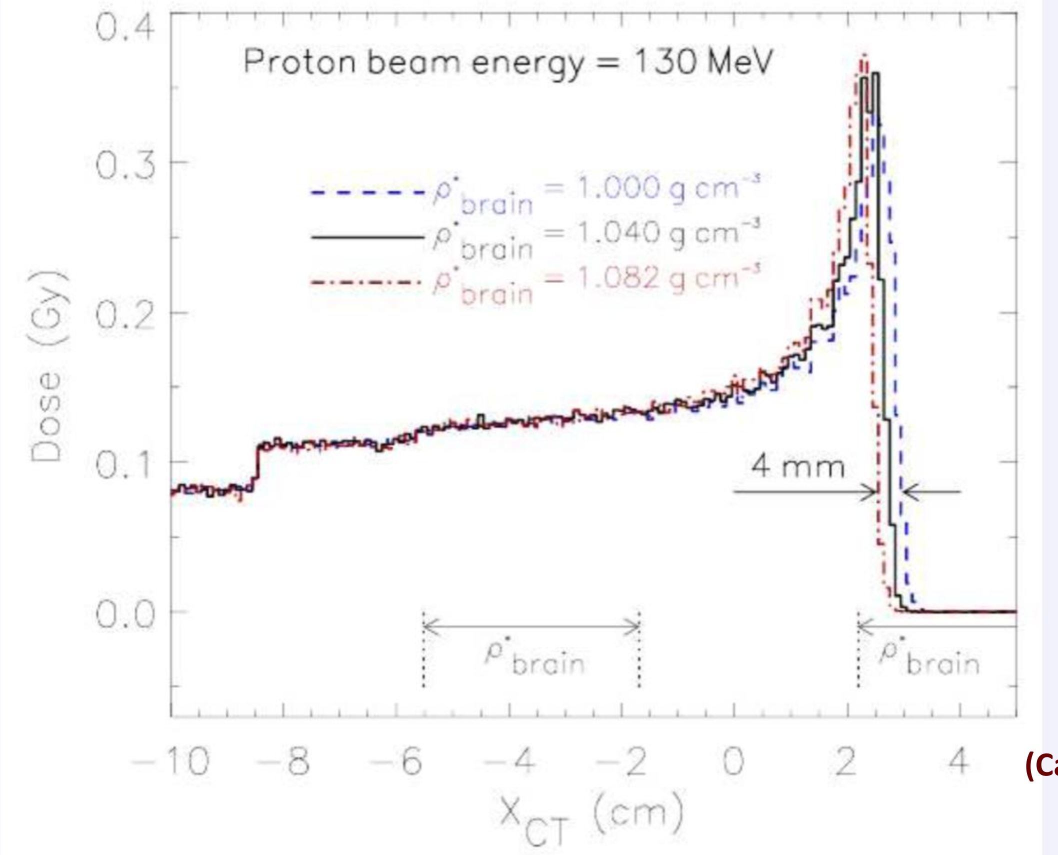

(Cambraia Lopes PhD 2017)

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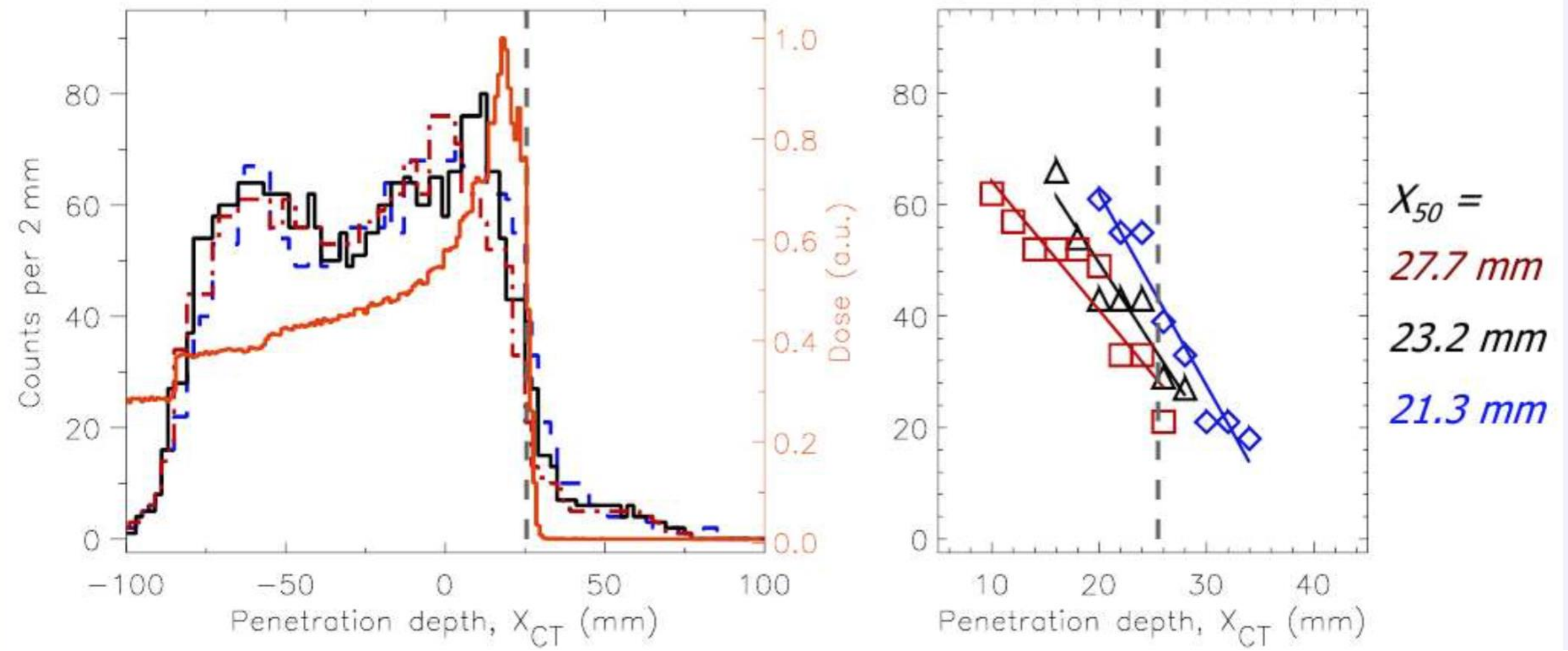
- Monte Carlo results with proposed detector (Geant4):



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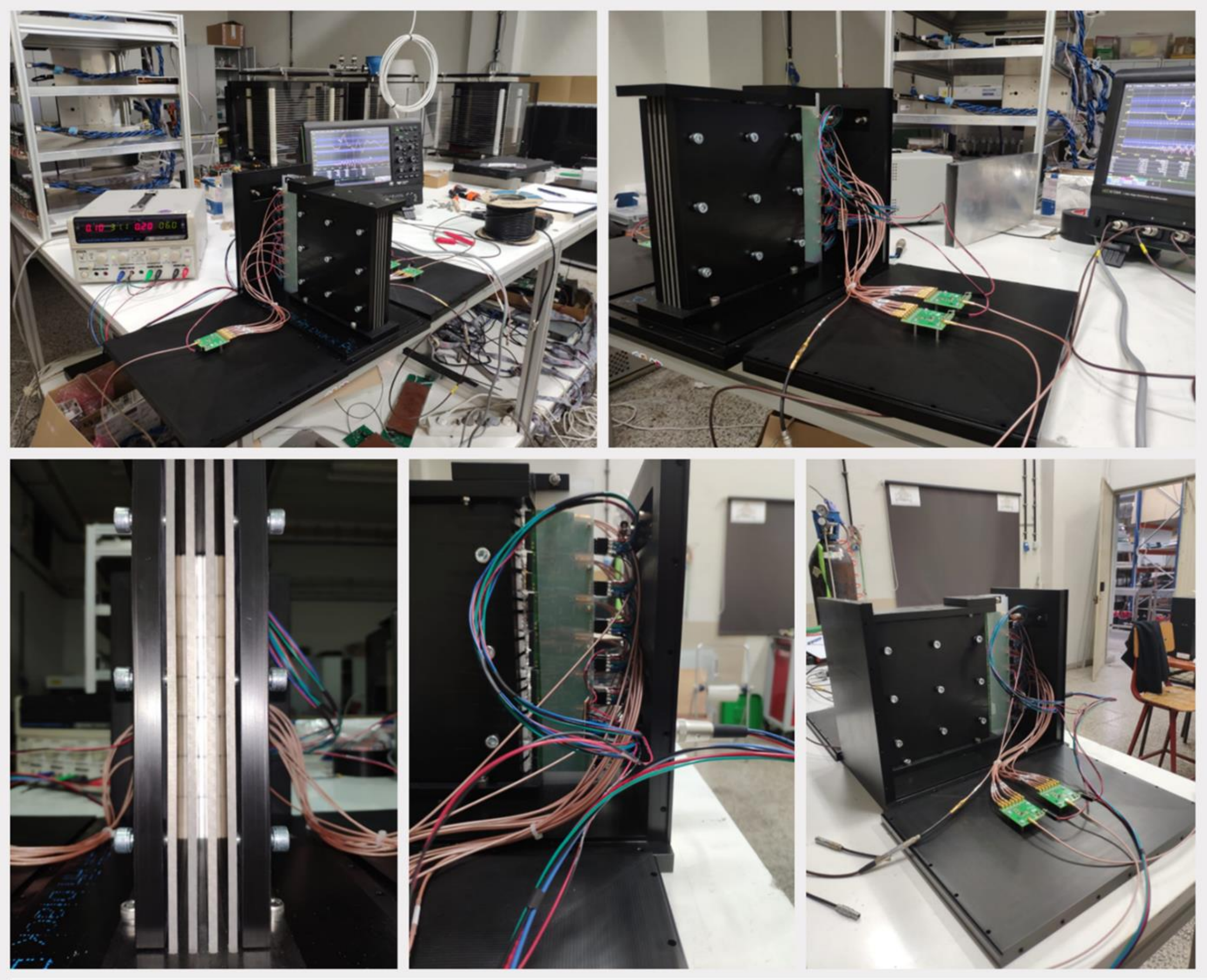
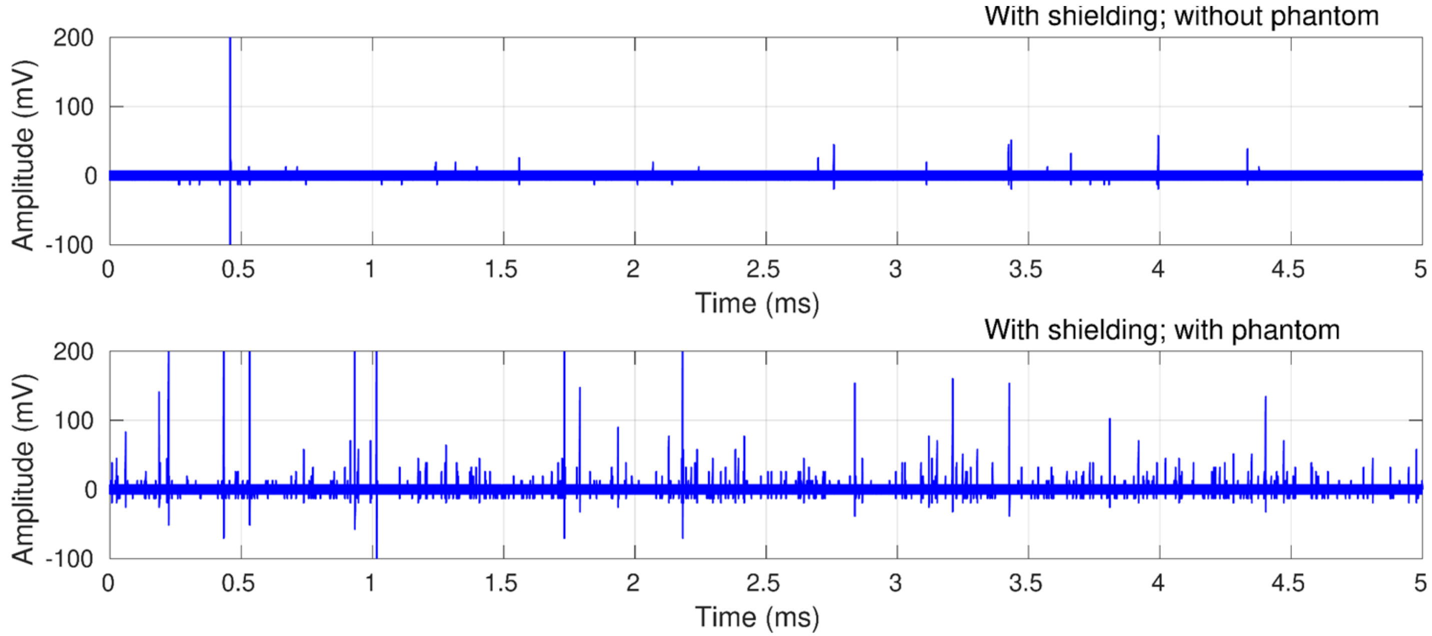
3. The multi-slat concept for PGI in proton RT

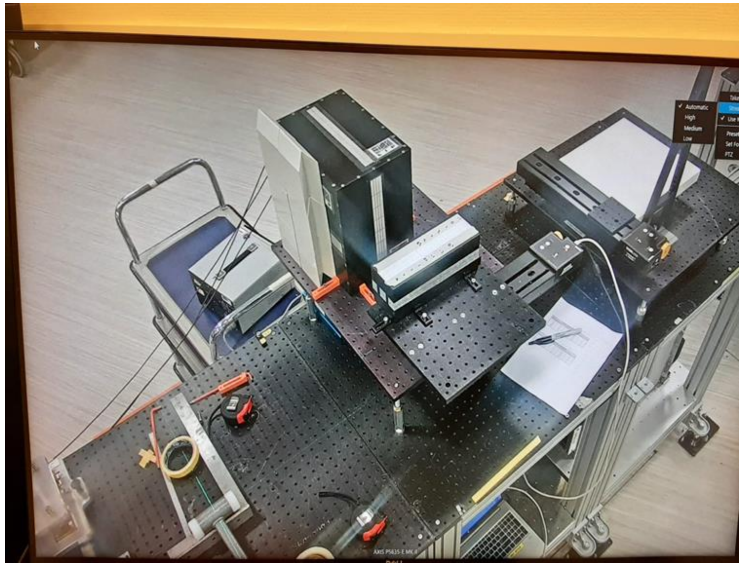
Small-scale multi-slat O-PGI prototype

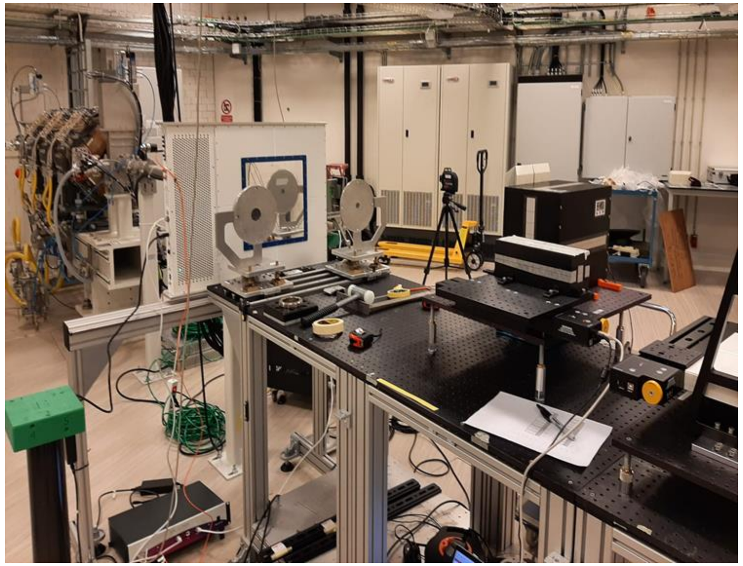


3. The multi-slat concept for PGI in proton RT

Radiation coming from the phantom



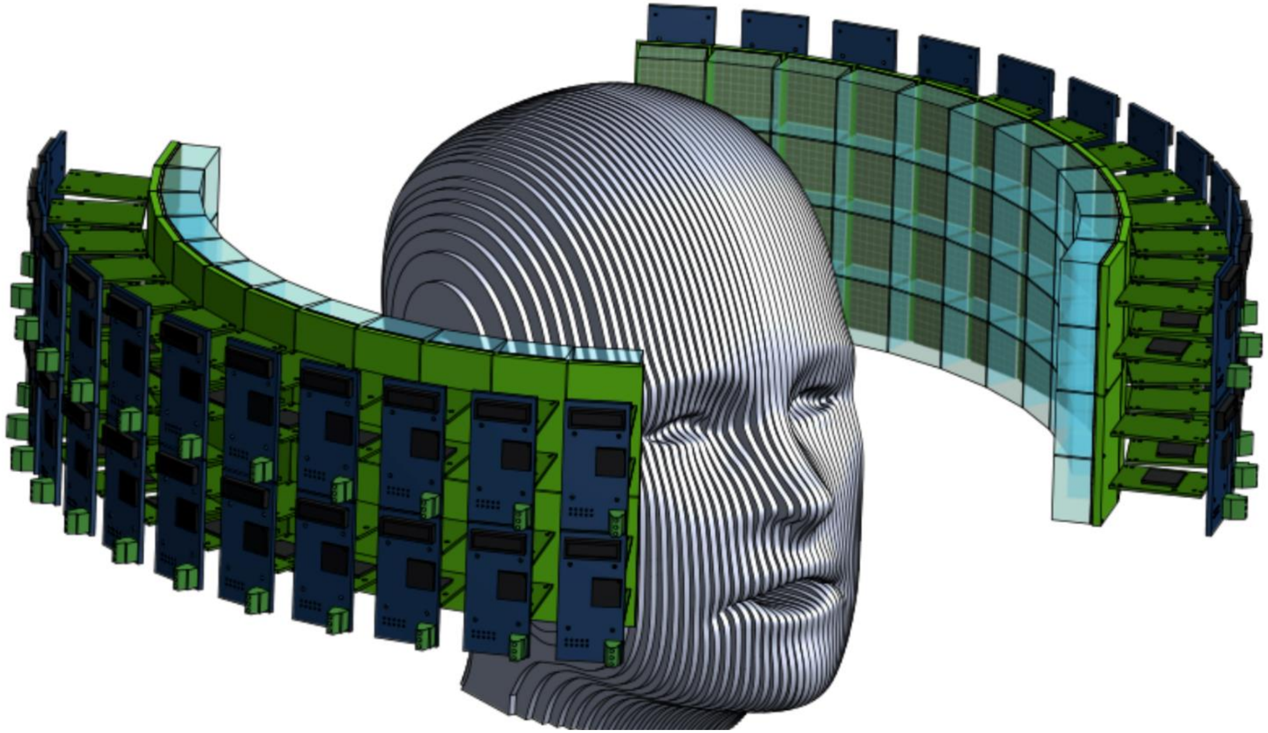




4. In-beam time-of-flight PET for proton RT

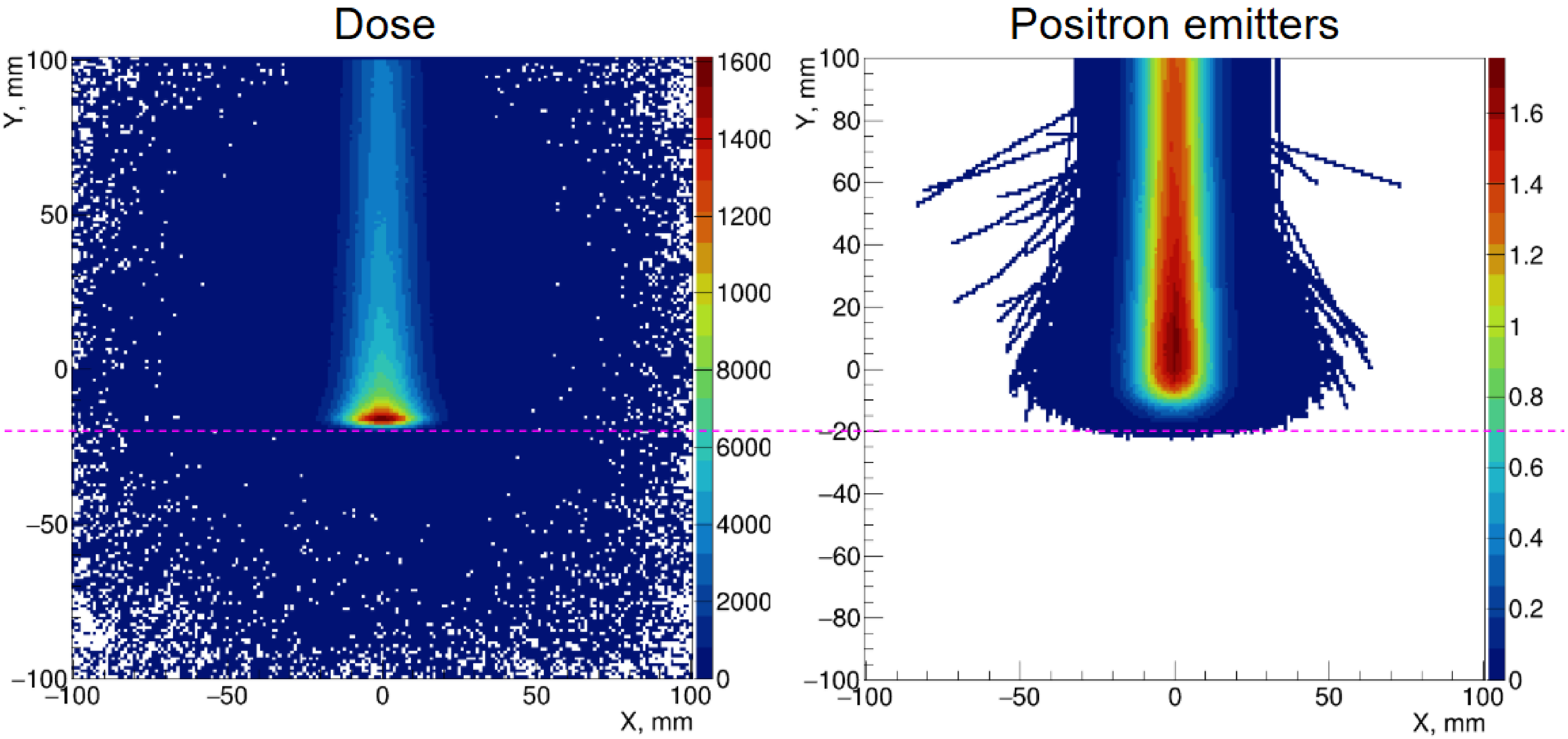
TOF-PET for Proton Therapy (TPPT) – In-beam Time-of-Flight (TOF) Positron Emission Tomography (PET) for proton radiation therapy

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)

4. In-beam time-of-flight PET for proton RT



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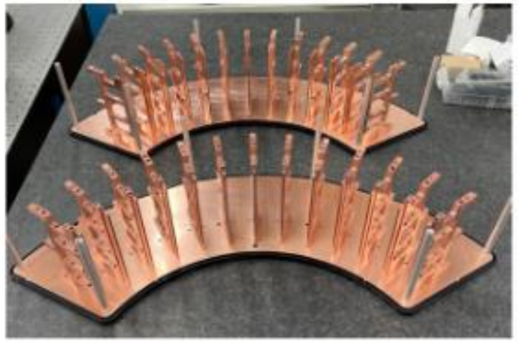

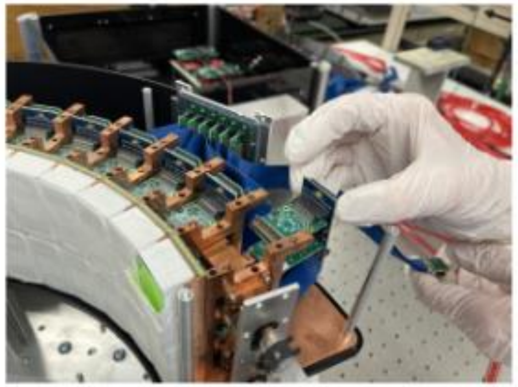

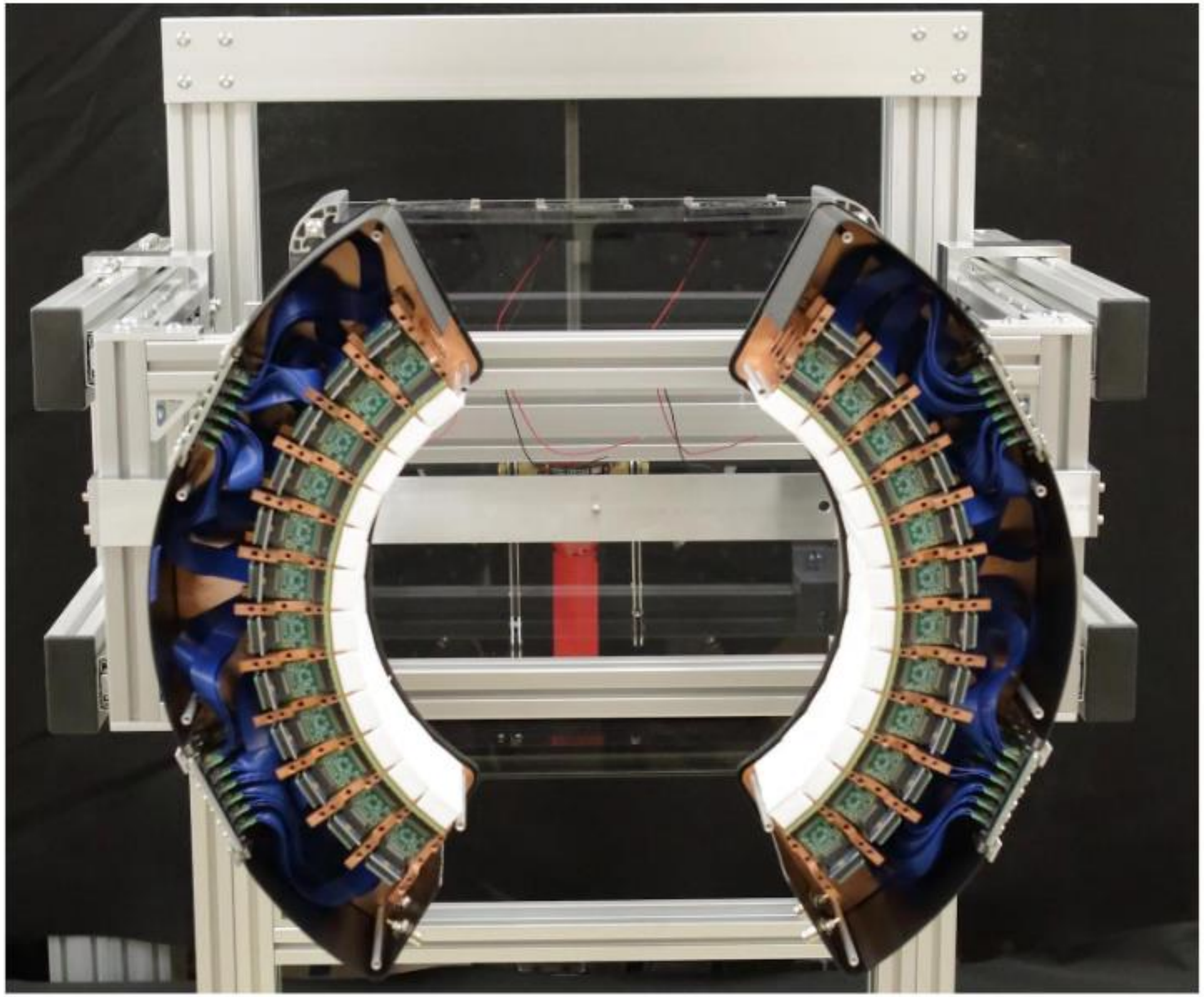

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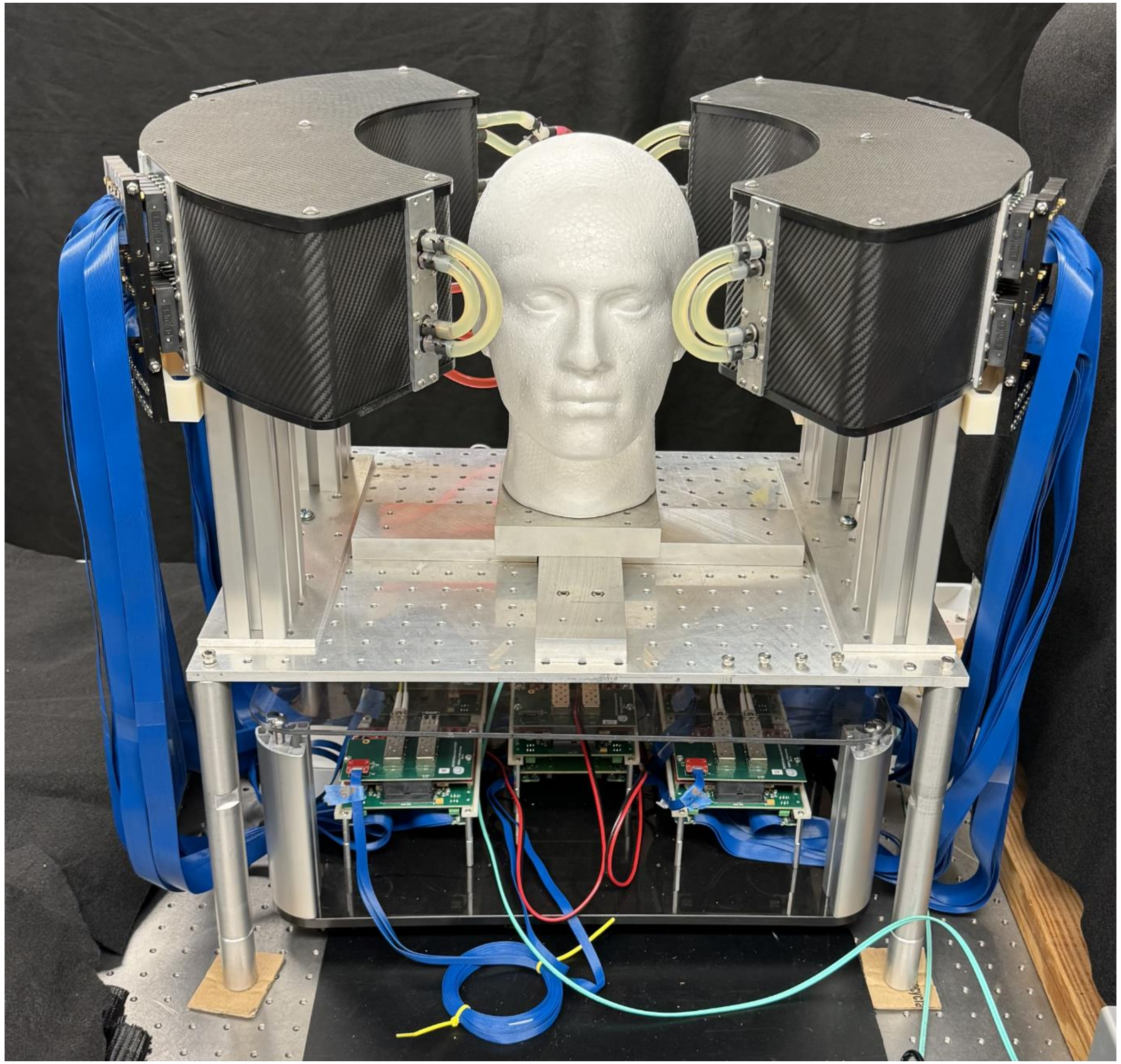

Thank you for your attention