Particle Physics Techniques Applied to Health

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LIP training internship

LIP – July 14th, 2022

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Outline

I – Advances in Nuclear Medicine

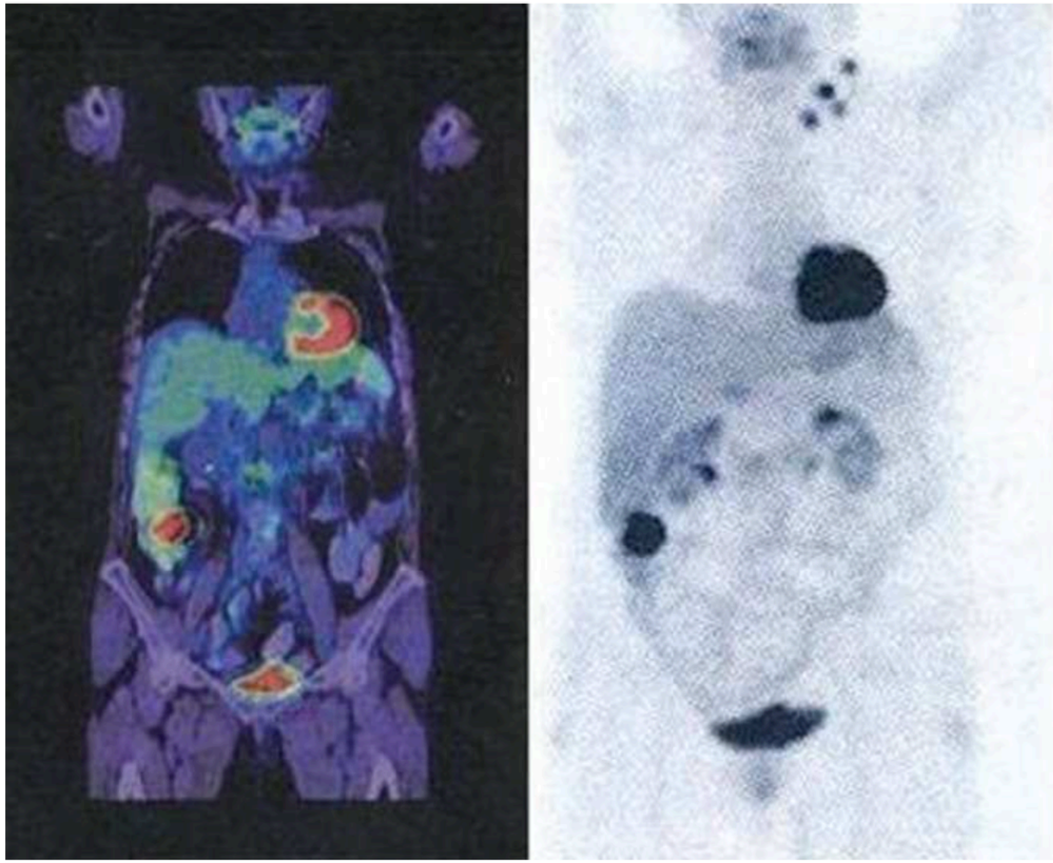
1. RPC-based TOF-PET
2. Development of New Gamma Cameras

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

Rationale is based on state-of-the-art of PET (positron emission tomography):

- Technique experiences growing utilization in nuclear medicine, e.g. for diagnostic/screening/staging of oncologic, neurologic, and cardiac disease.

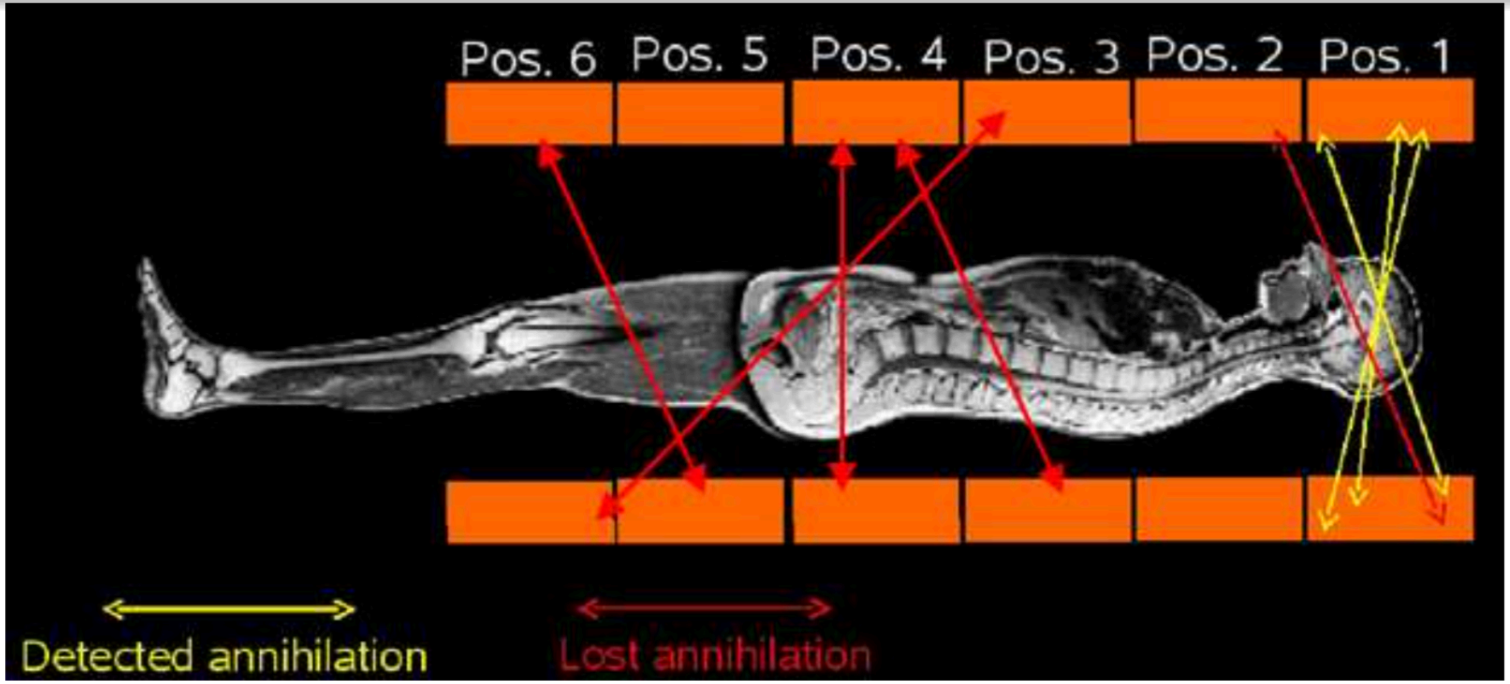


- E.g. Palmisano et al. Saudi J Gastroenterol 2011
- F, 64 a., symptoms: palpable supracavicular, ganglionic adenopathies, asthenia, anorexia.
- PET-based diagnostic: adenocarcinoma of the ascendent colon.

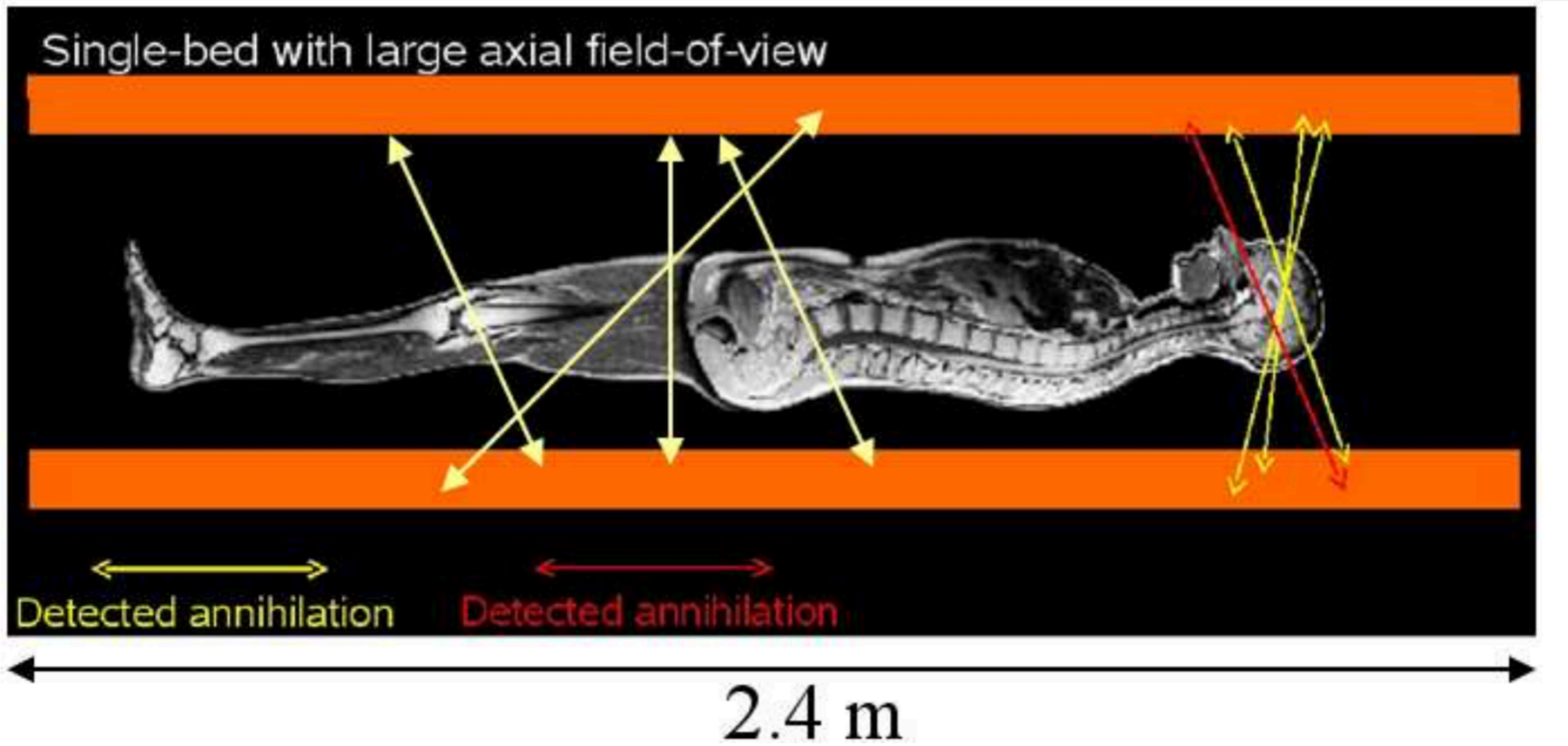
I - 1. RPC-based TOF-PET

Rationale:

- PET technology is extremely costly (millions of €); patient examinations are equally costly (ca. 4000 €), lengthy in time, morphologically imprecise, often inconclusive when imaging small lesions (detectability, sensitivity, and specificity); and the patient bears a non-negligible amount of radiation dose.



I - 1. RPC-based TOF-PET



I - 1. RPC-based TOF-PET

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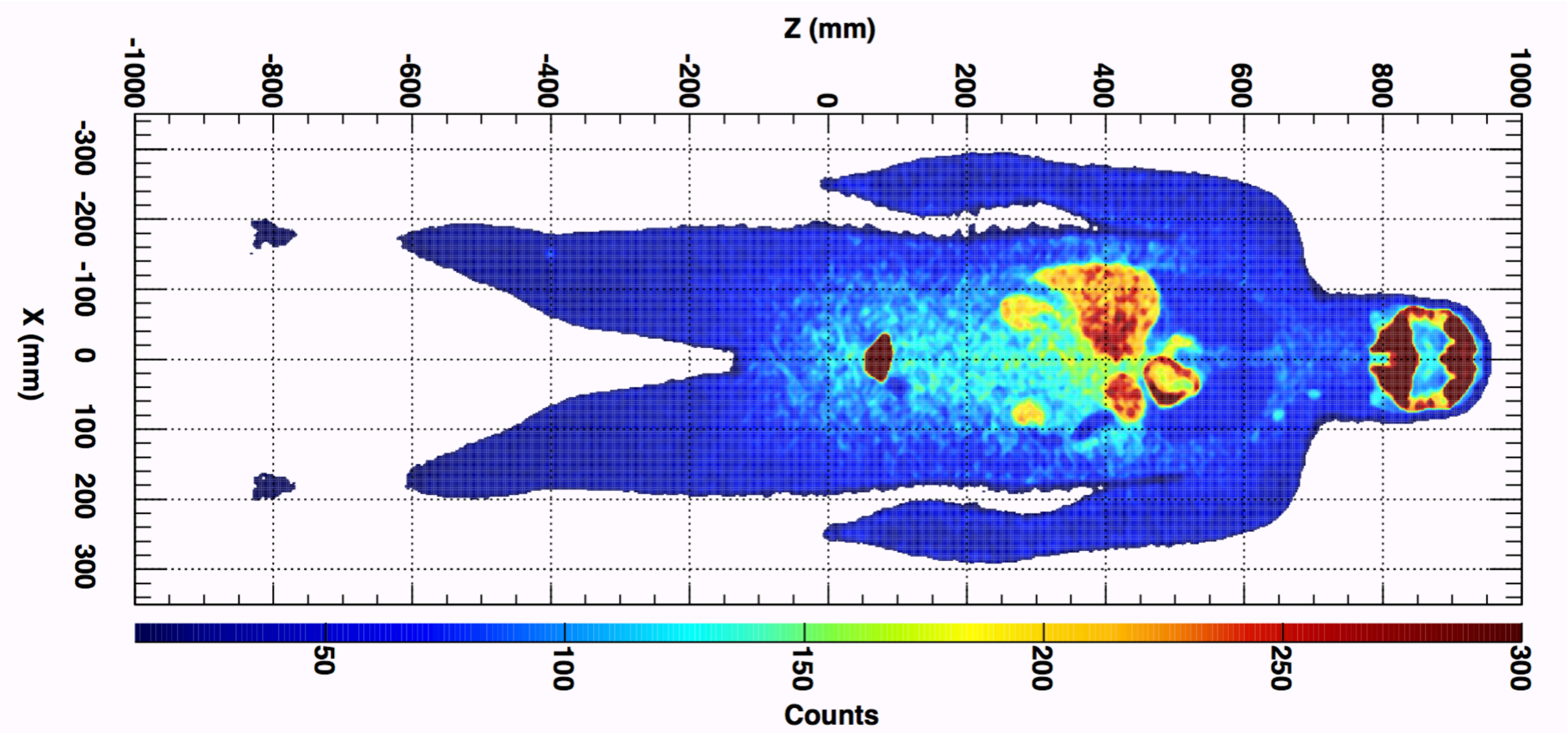
Implementation (software):

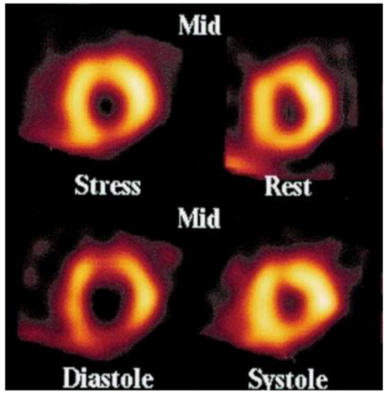
- R&D in simulation and reconstruction



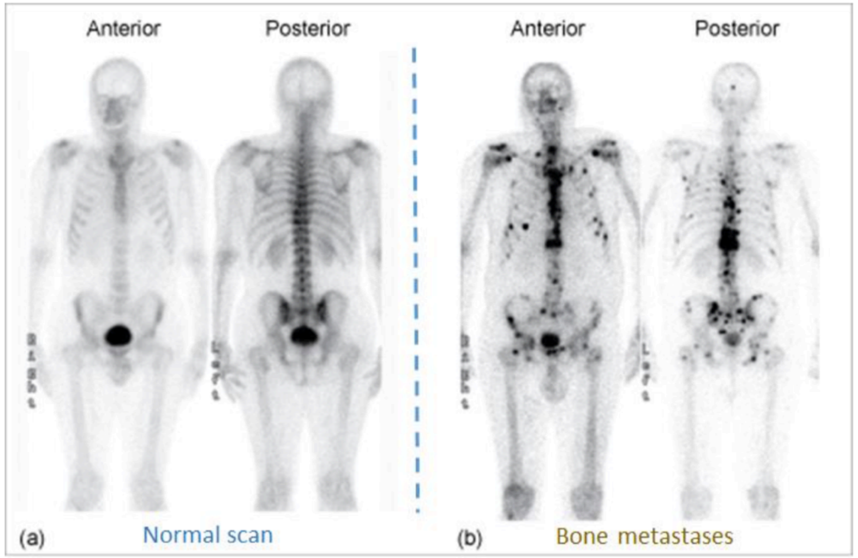
I - 2. Development of New Gamma Cameras

- Collaboration between Laboratório de Instrumentação e Física Experimental de Partículas, **LIP** and the University Hospital of Coimbra – **Nuclear Medicine Department**
- Gamma cameras are used to perform **scintigraphy**: a medical imaging modality used to obtain functional images. E.g. cardiology, pneumology, oncology (staging of tumors, evaluate therapeutic response)

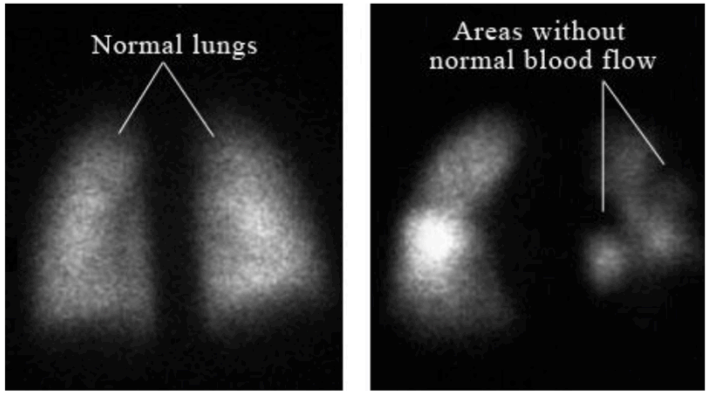
Heart study



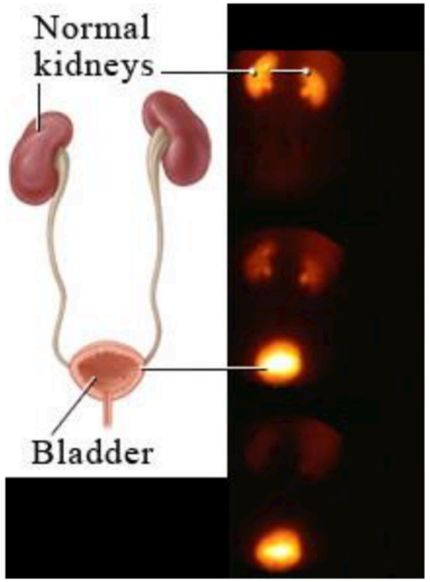
Bone scans



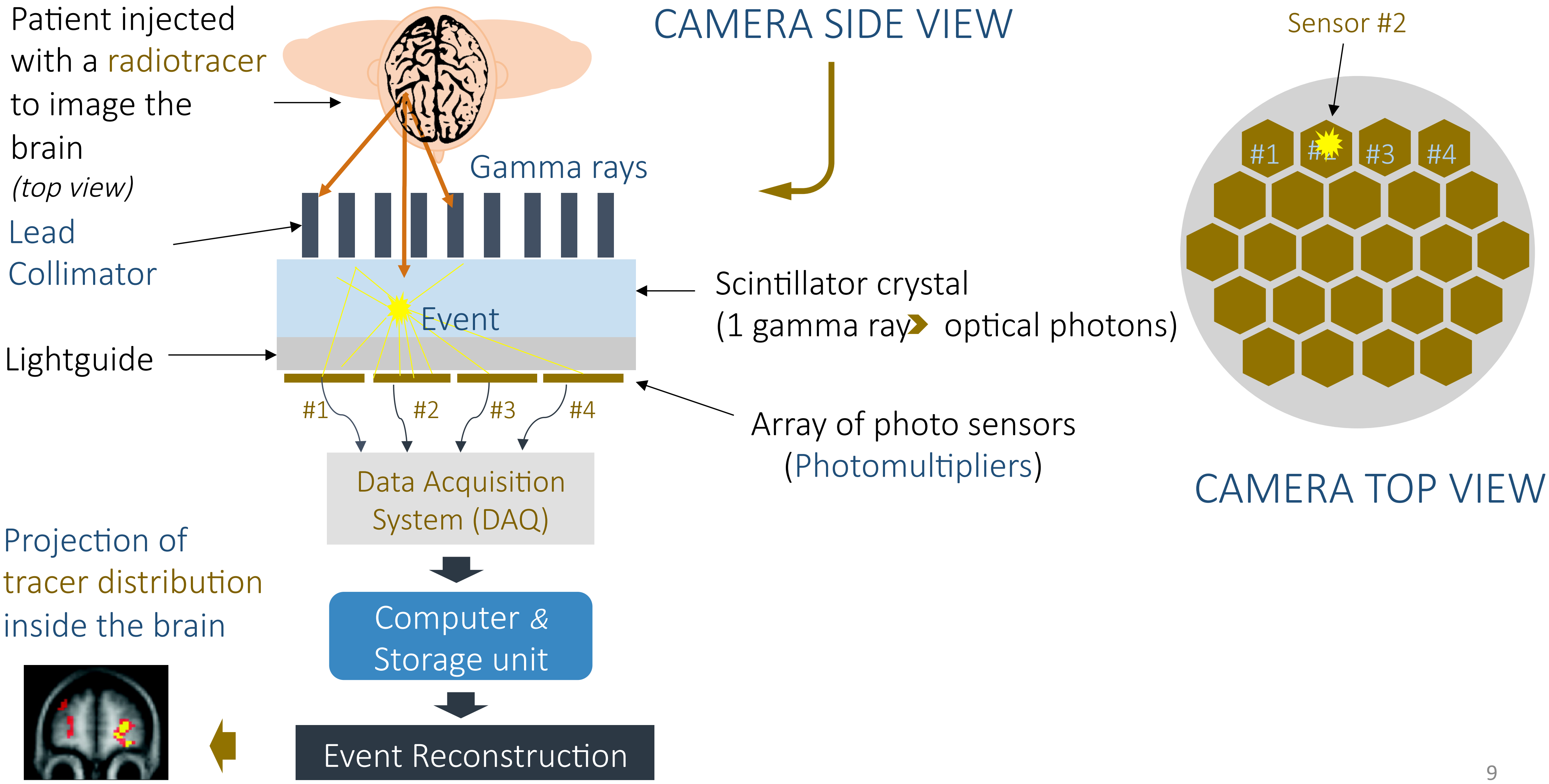
Lung scintigraphy



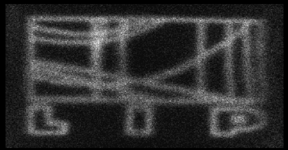
Kidneys study



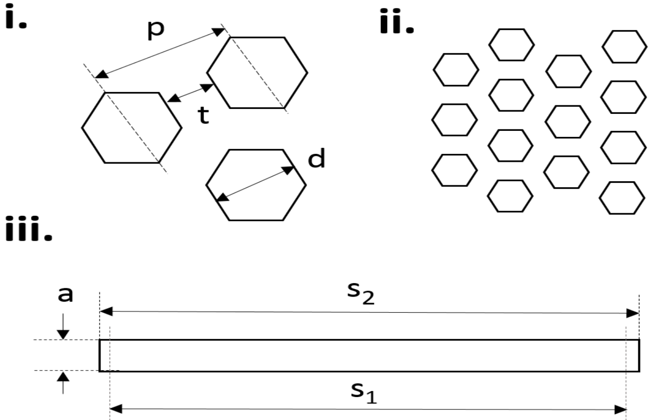
Gamma camera working principle



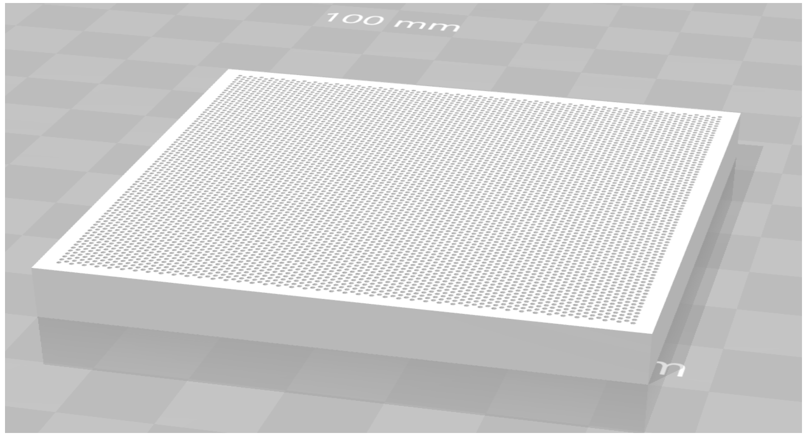
Collimators prototypes

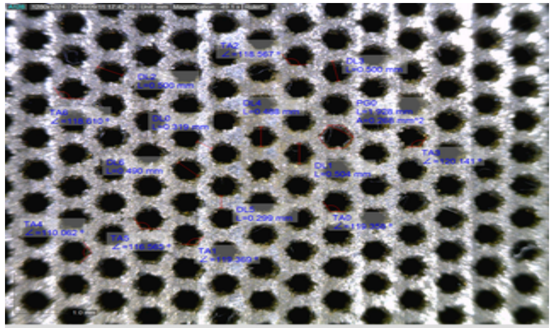


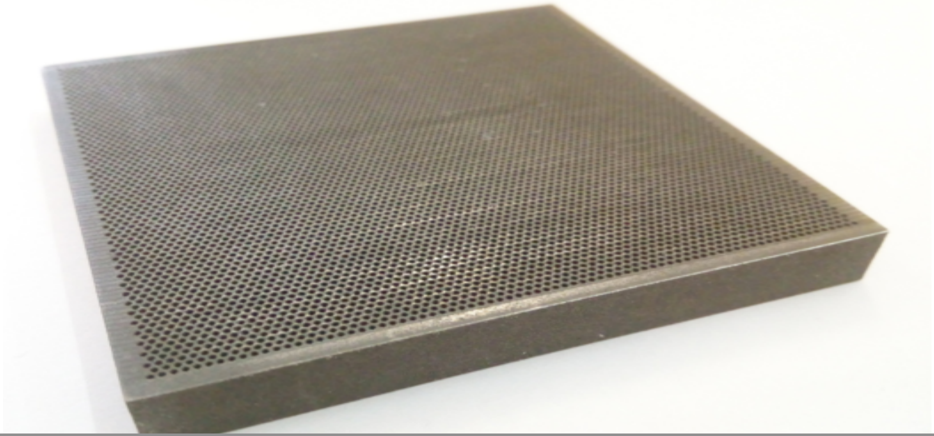
Parallel-holes collimator (hexagones 0.5 mm “diameter)



Made of tungsten using Selective laser melting







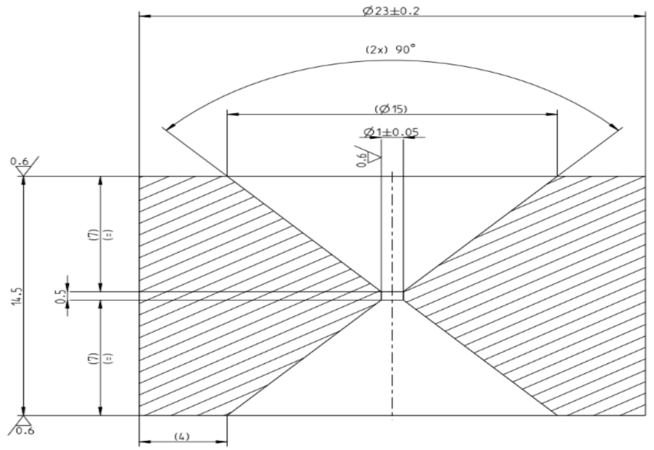
- **Specification** by João Marcos
- **Designed** by Eng. Rui Alves (LIP mechanical workshop)
- **Manufactured** by M&I Materials

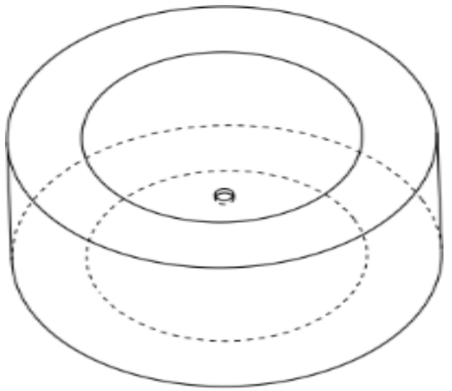
Collimators prototypes

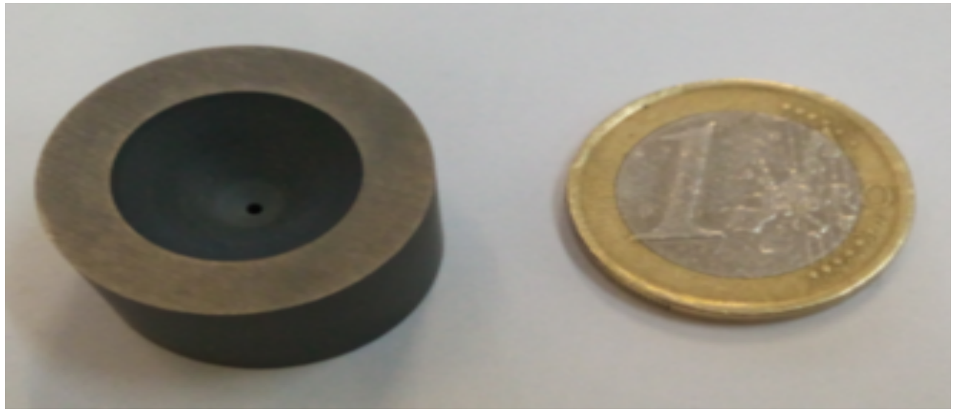
Pinhole collimator (1 mm hole, 0.5 mm channel edge height)

Made of Tungsten alloy (95.5% W, 4.5% Co)

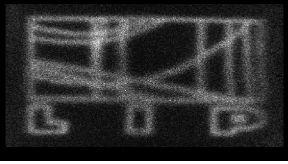
- **Specification** by João Marcos
- **Designed** by DURIT (Albergaria-a-Velha)
- **Manufactured** by DURIT







Phantom imaging



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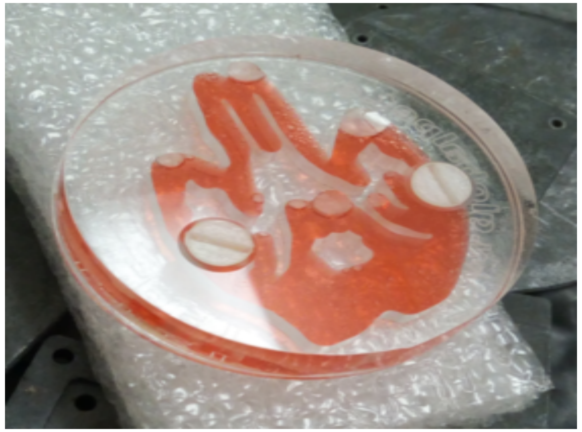
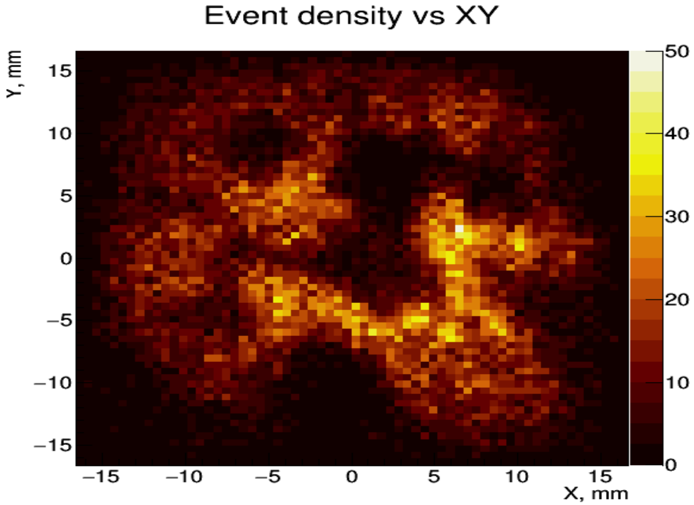
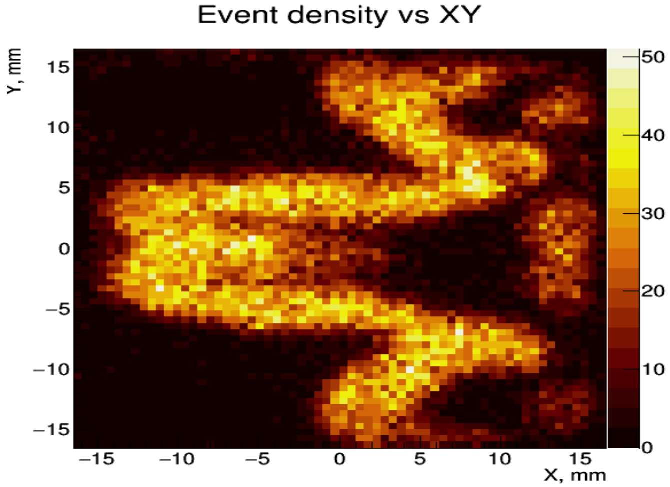
Brain slice phantom



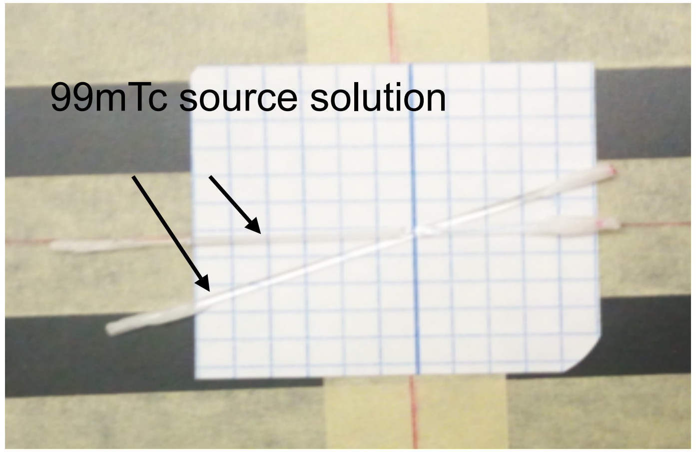
Pinhole collimator

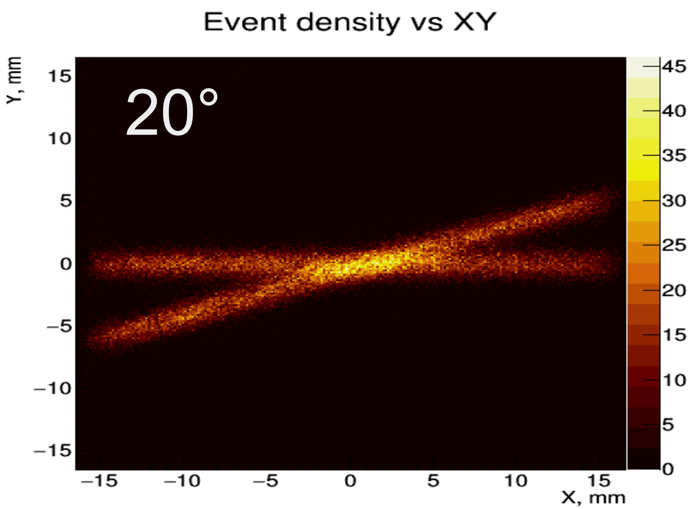


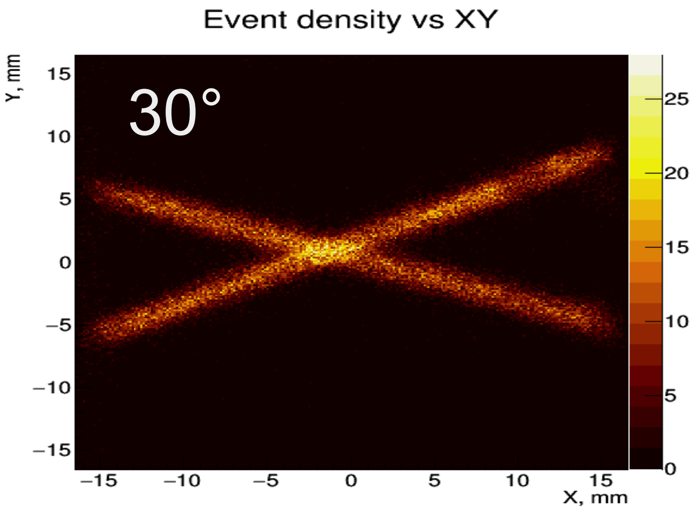
Parallel-hole collimator



Crossed capillary tubes phantom

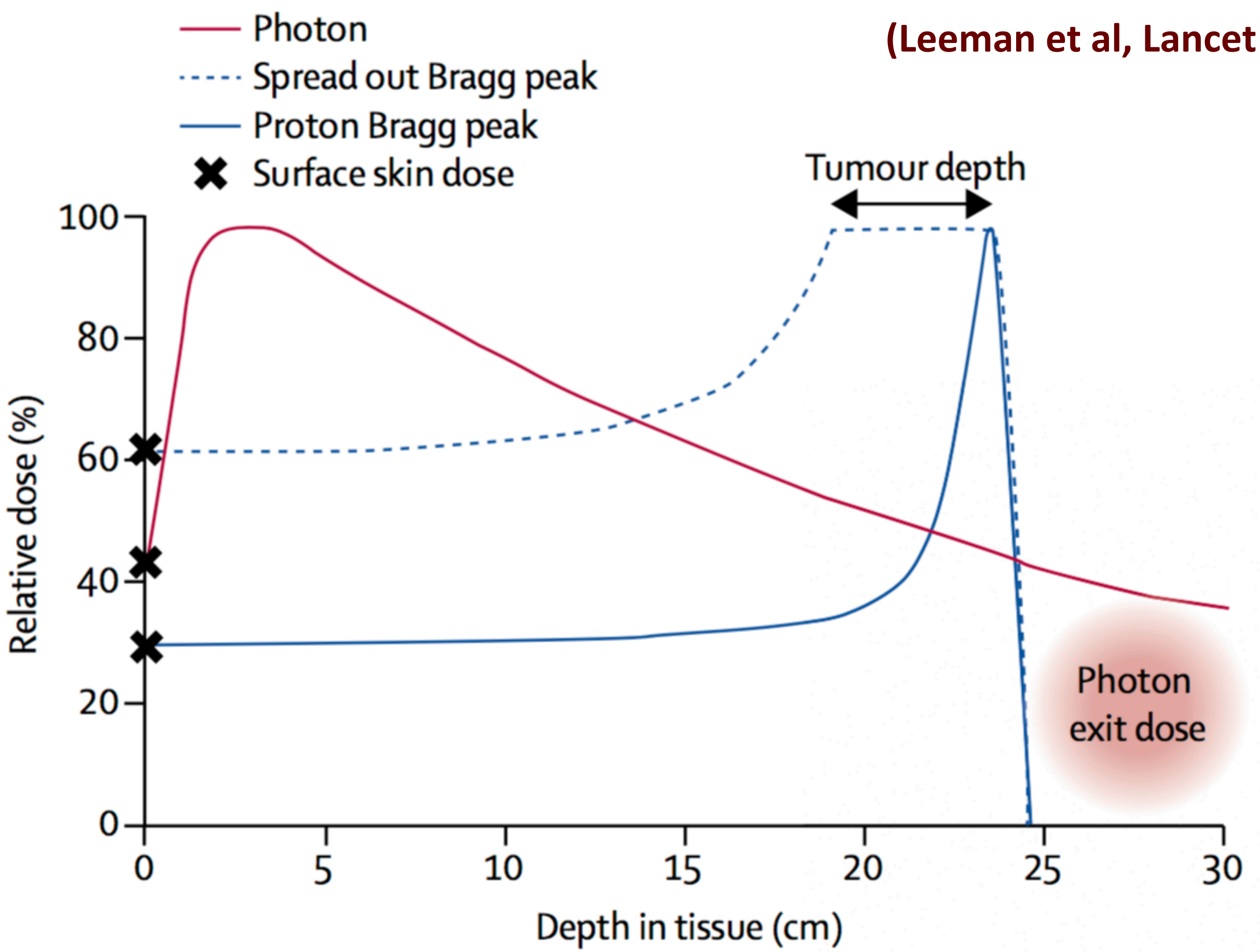




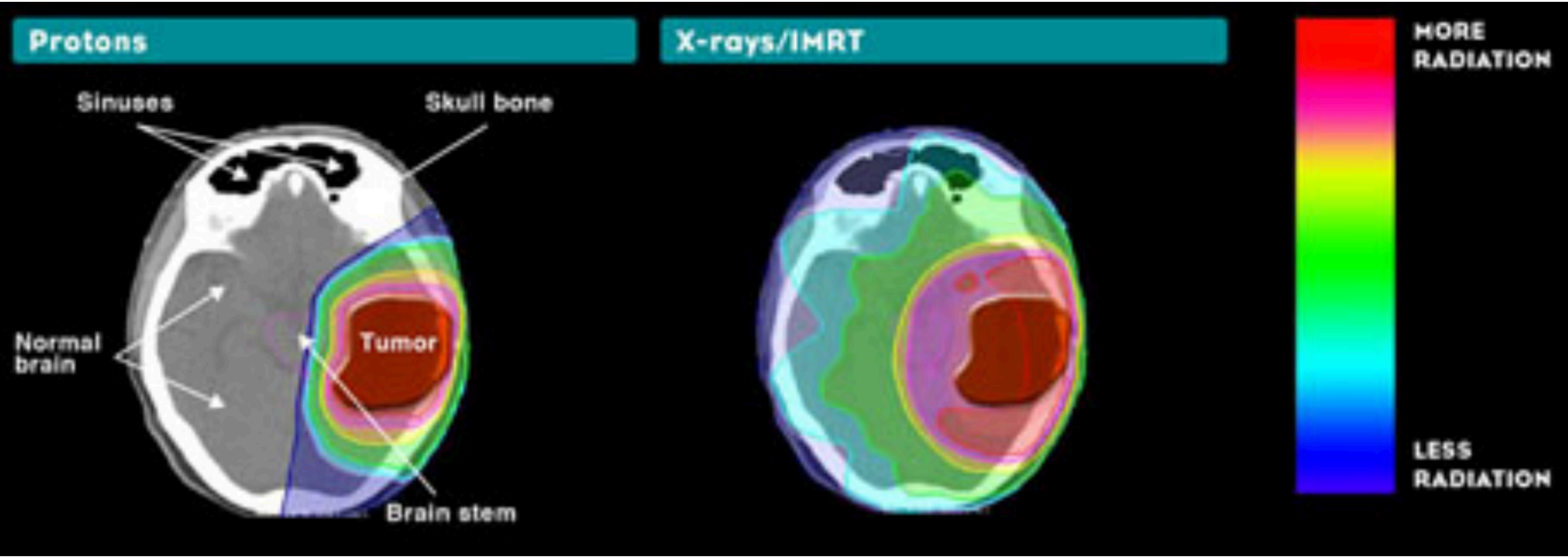


II - 1. Motivation: Proton therapy physical advantage over photons

(Leeman et al, Lancet Oncol 2017)

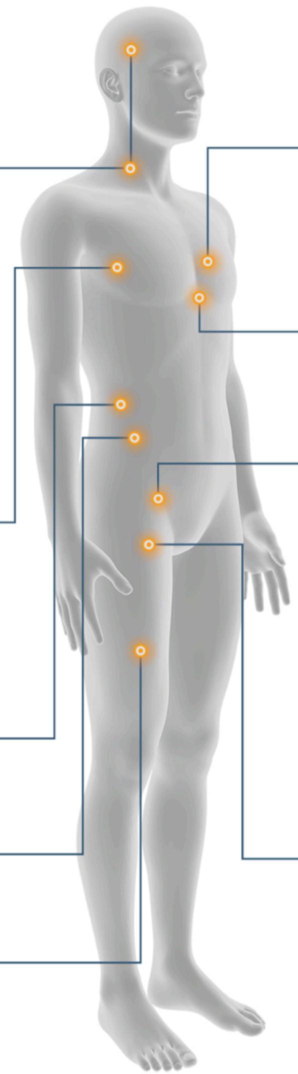


II - 1. Motivation: Proton therapy physical advantage over IMRT



(Proton Therapy Today 2019)

II - 1. Motivation: Proton therapy clinical benefits



Brain/Head & Neck

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

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

44% increase of relative 5-year disease free survival rate for **nasal and paranasal sinus cavity cancers**

50% overall increase of disease control for **chordomas**

Less side effects during first 3 months after treatment, quicker return to normal function

50% less likely to have secondary tumor from treatment

Breast

Delivers 8-18 times less overall radiation to the heart than IMRT

50-83% less relative risk of heart attack or another major coronary event depending on age

50% reduction of clinically significant radiation doses to the heart

97% of partial breast irradiation patients experience **no breast tumor recurrence at 5 years**

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

Liver

(Hepatocellular)

58% higher overall survival rate (2 years)

Bile Duct

54% higher overall survival (4 years)

Sarcoma

49-75% reduction in complications

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

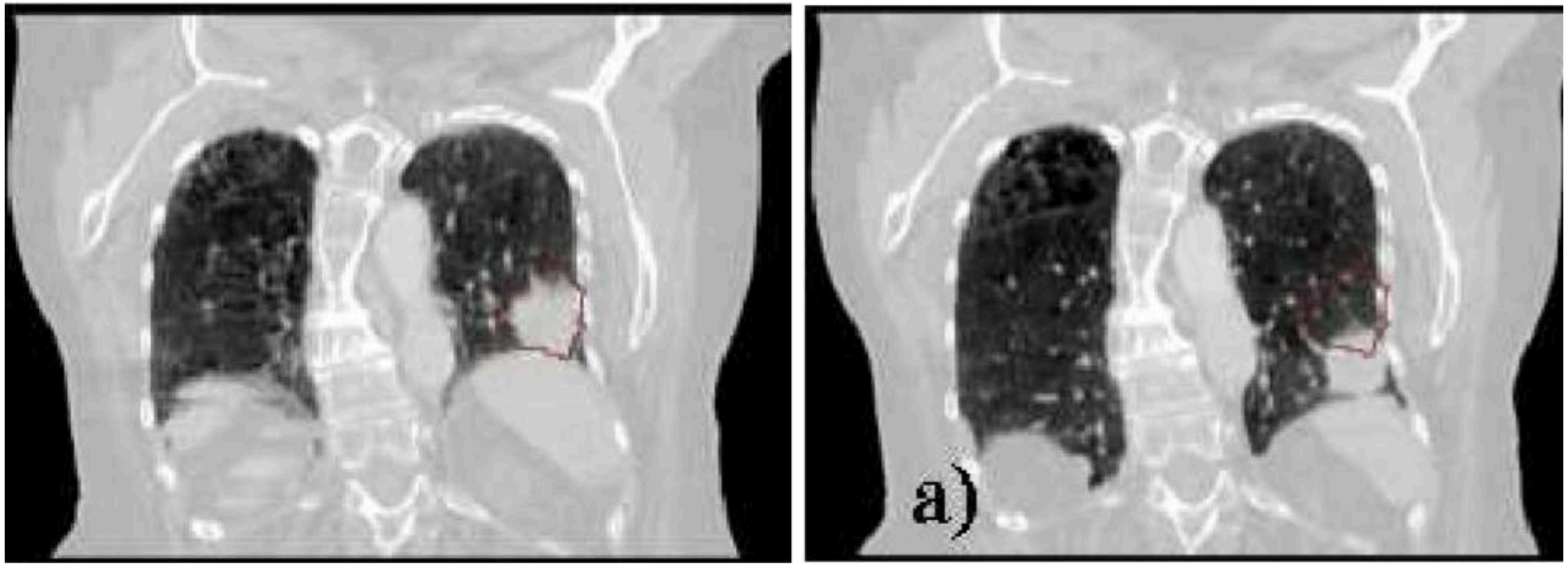
PROVISION CARES
PROTON THERAPY

**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.*

II - 2. Rationale for in-vivo imaging in proton RT

Target volumes and organ motion: tumor displacement

- Breathing (intrafraction)

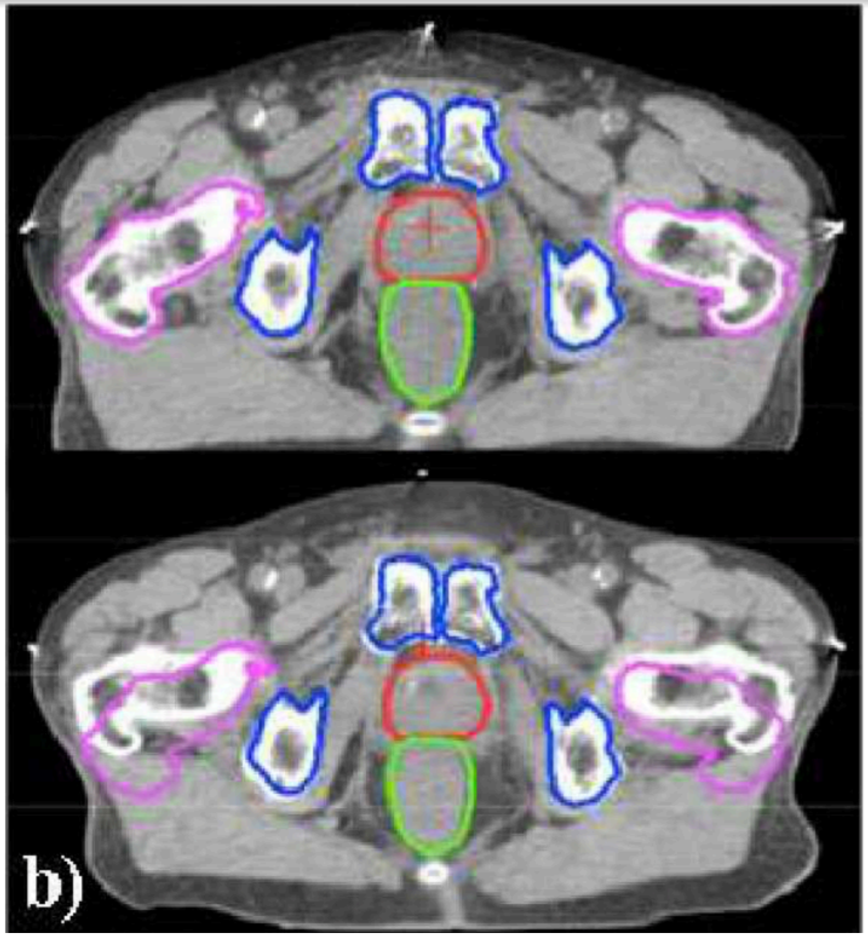


Engelsman and Bert 2011
Lüchtenborg PhD 2012

II - 2. Rationale for in-vivo imaging in proton RT

Target volumes and organ motion: patient displacement/deformation

- Mispositioning (interfraction)



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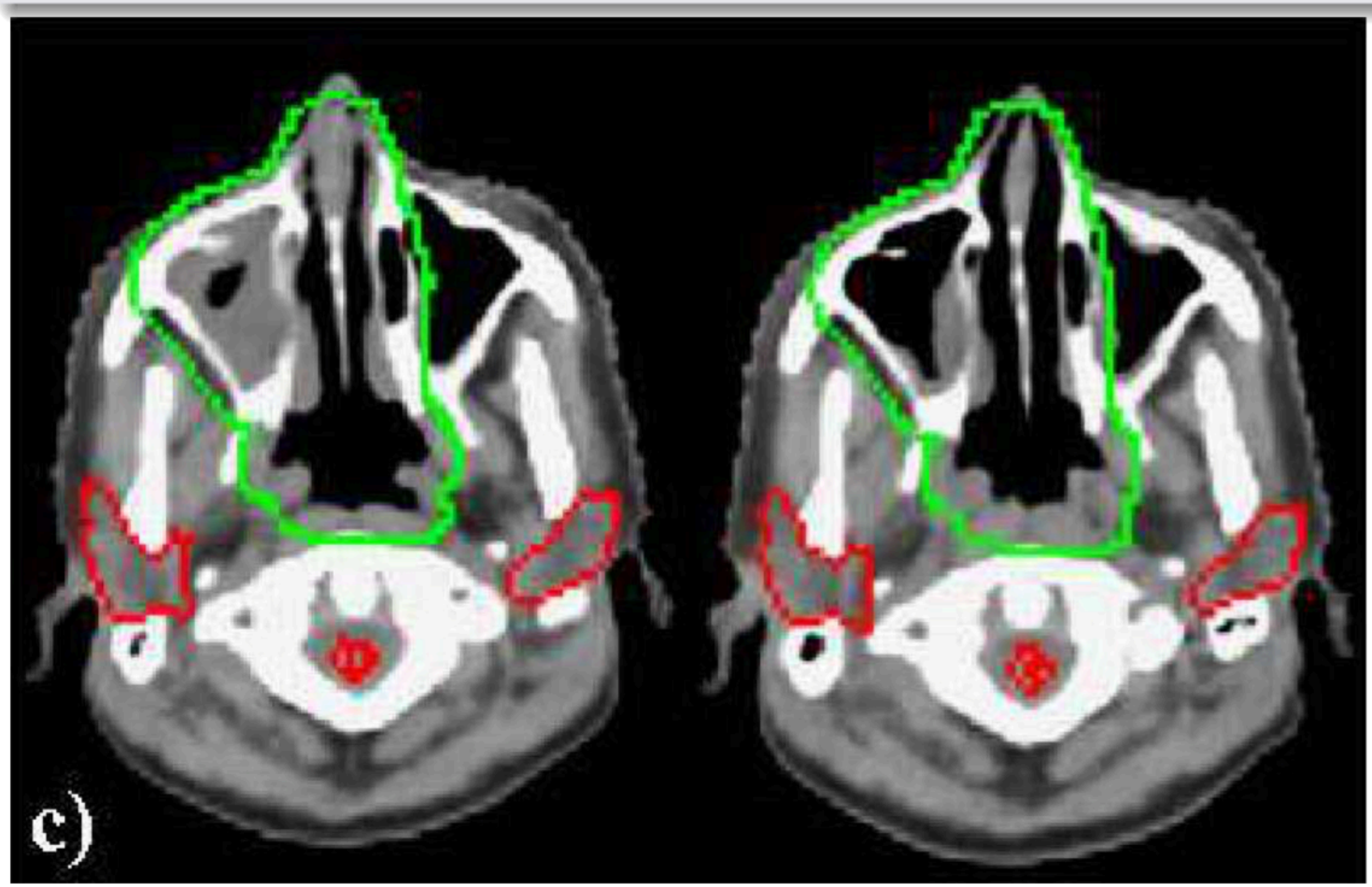
Lüchtenborg PhD 2012

II - 2. Rationale for in-vivo imaging in proton RT

Target volumes and organ motion: cavity filling/wall thickening

- Tissue-density modification (interfraction)



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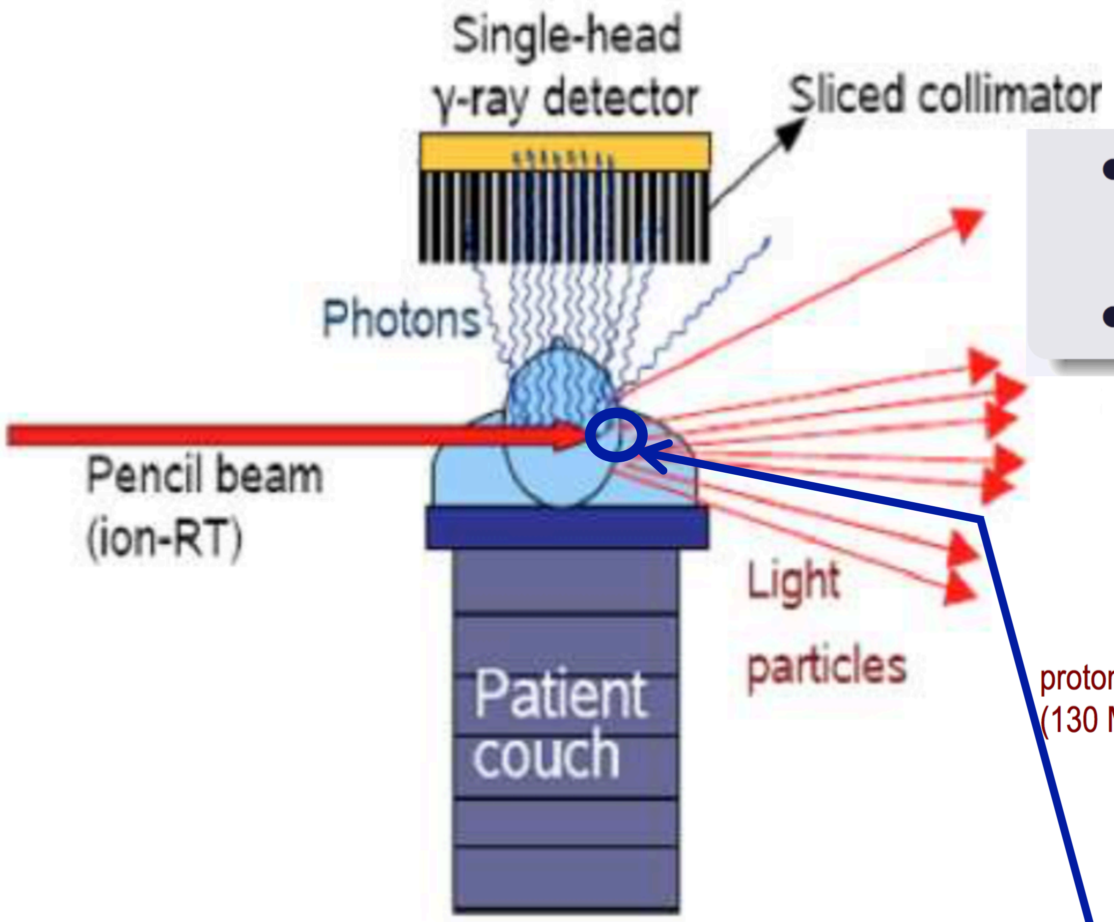
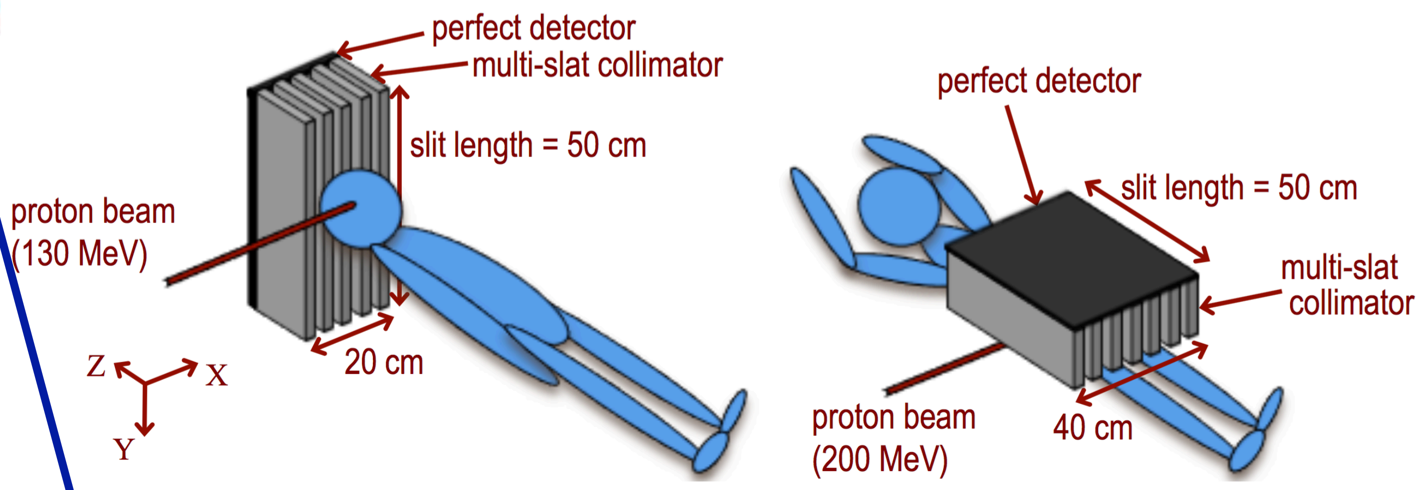
II - 3. The multi-slat concept for prompt-gamma imaging in proton RT



- Head irradiation: nasal cavities (cavity filling) and pituitary (change in brain density)
- Pelvic irradiation: prostate (patient mispositioning)



(Cambraia Lopes PhD 2017)

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

Image with prompt gammas "stops" at beam range

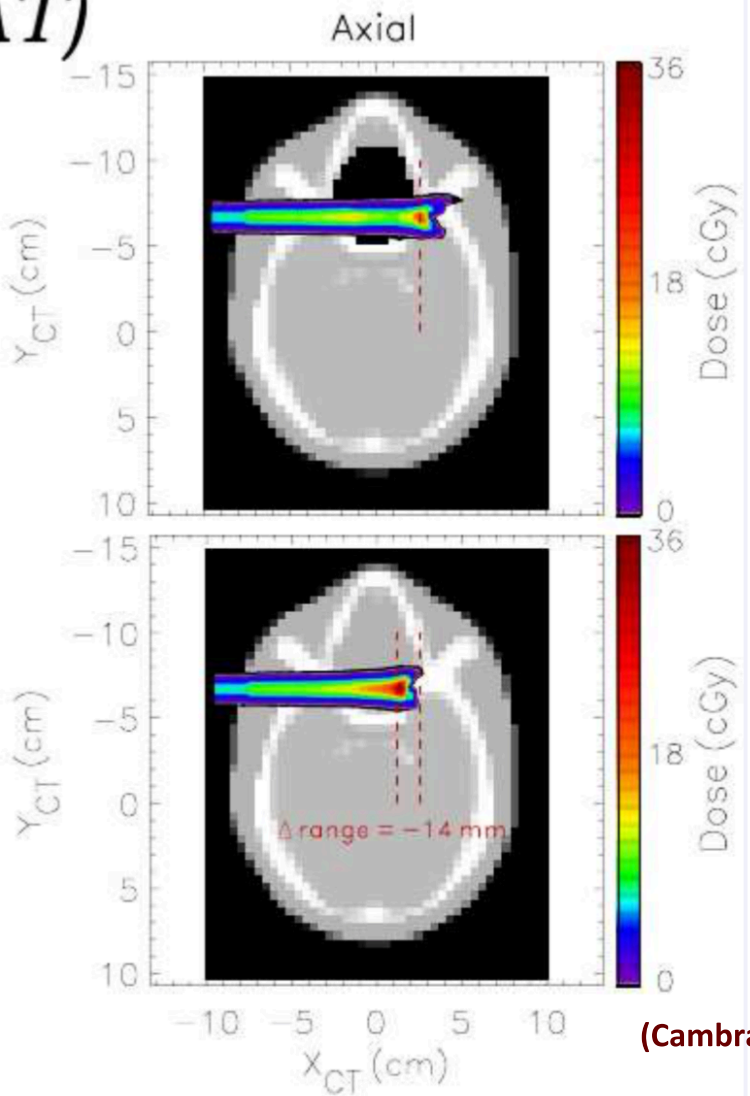
II - 3. The multi-slat concept for prompt-gamma imaging in proton RT

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



(Cambraia Lopes PhD 2017)

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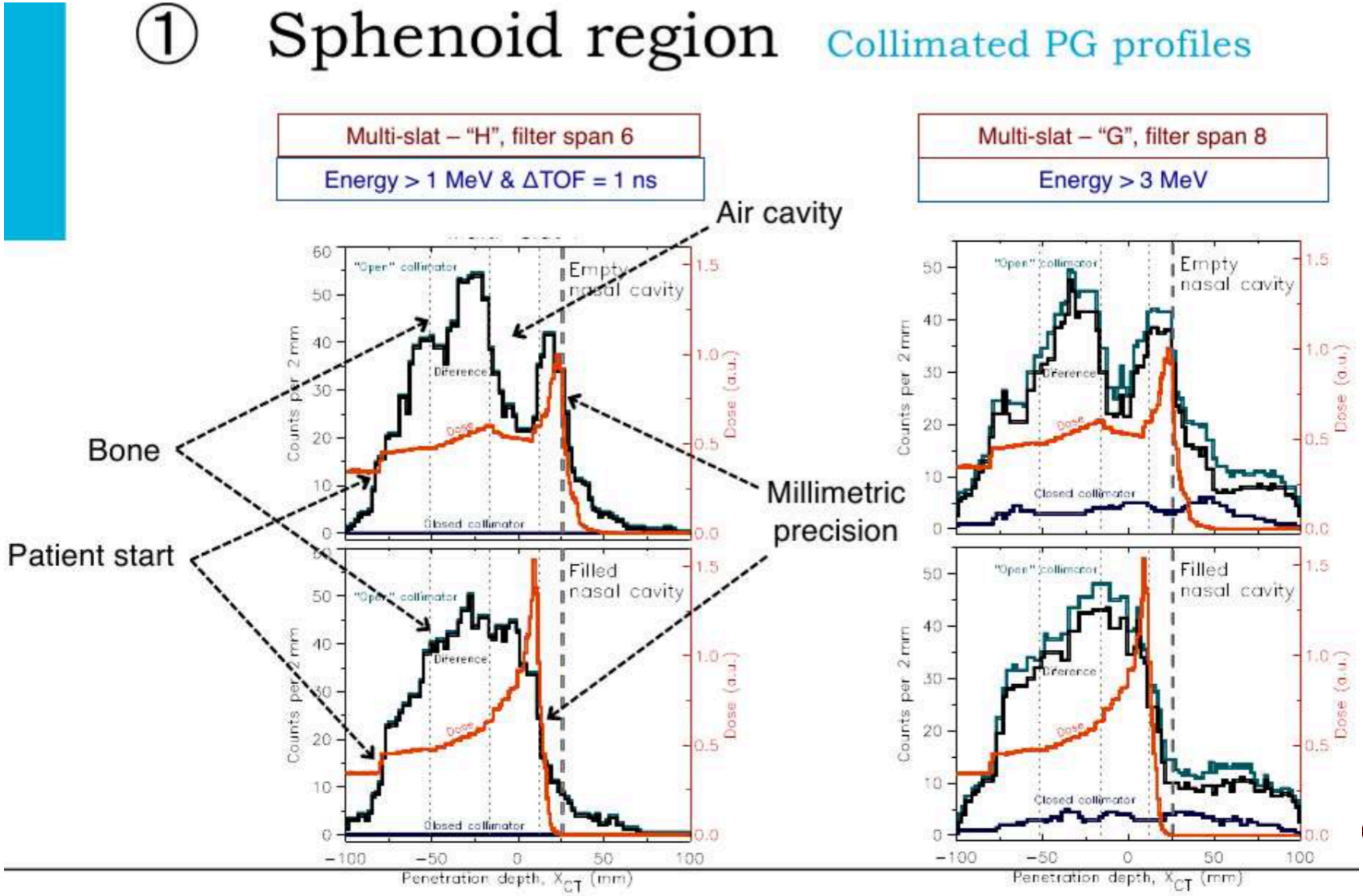
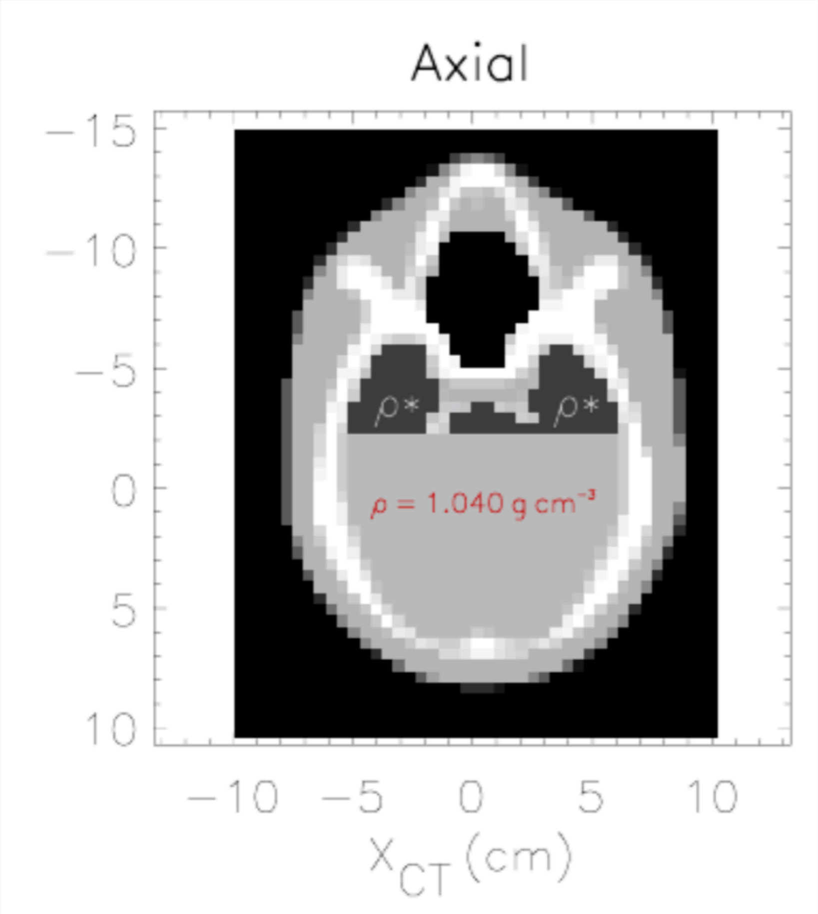


(Cambraia Lopes PhD 2017)

II - 3. The multi-slat concept for prompt-gamma imaging 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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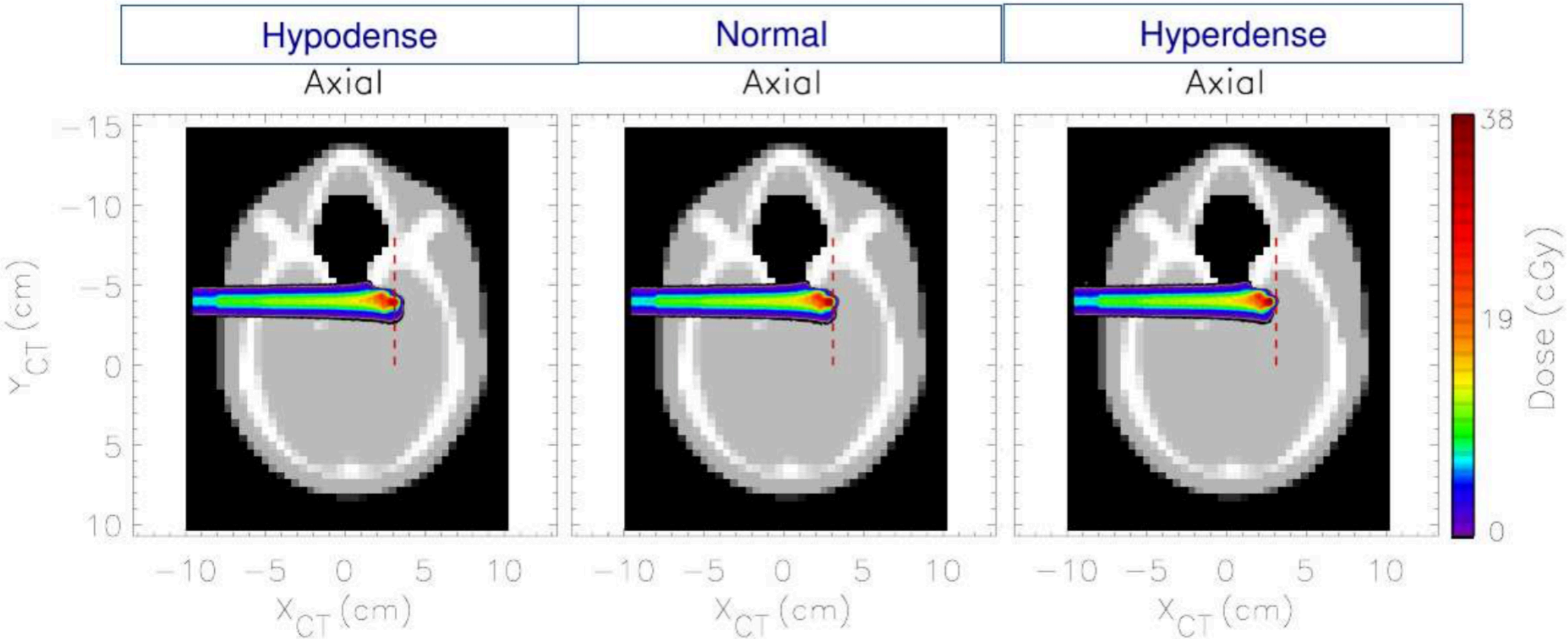
- Corresponding dose distributions (protons):



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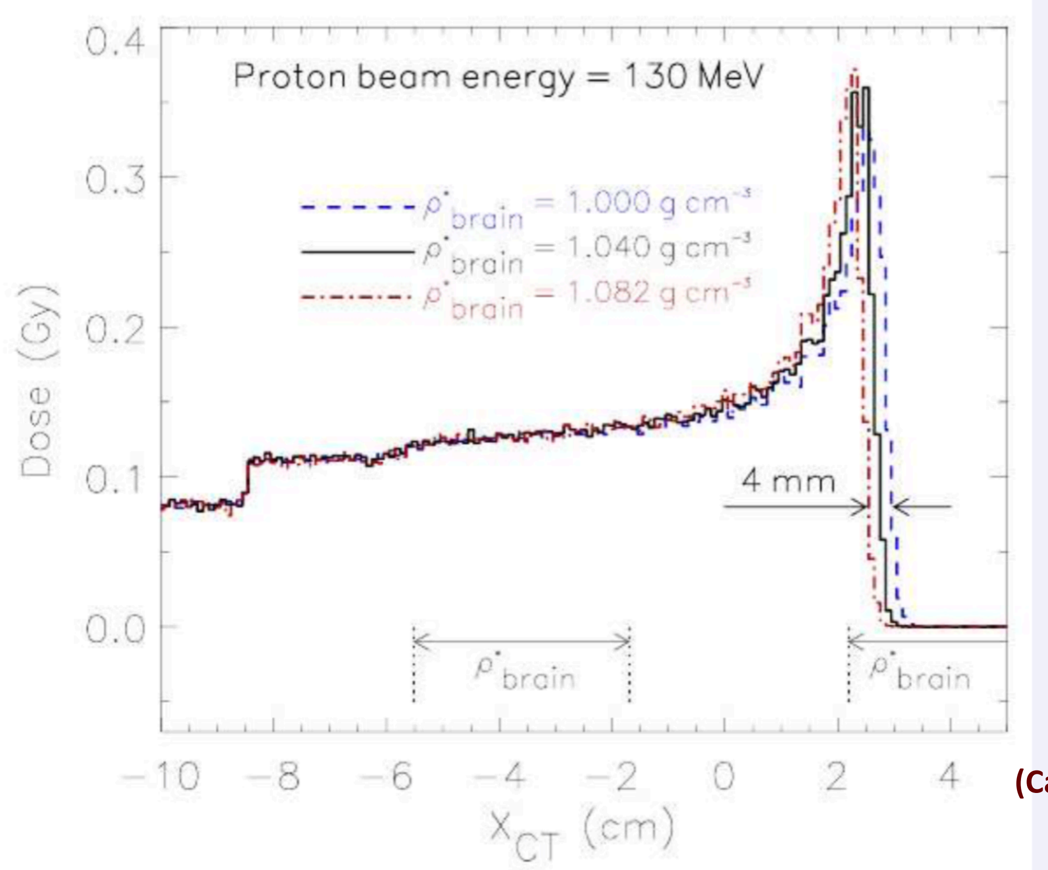
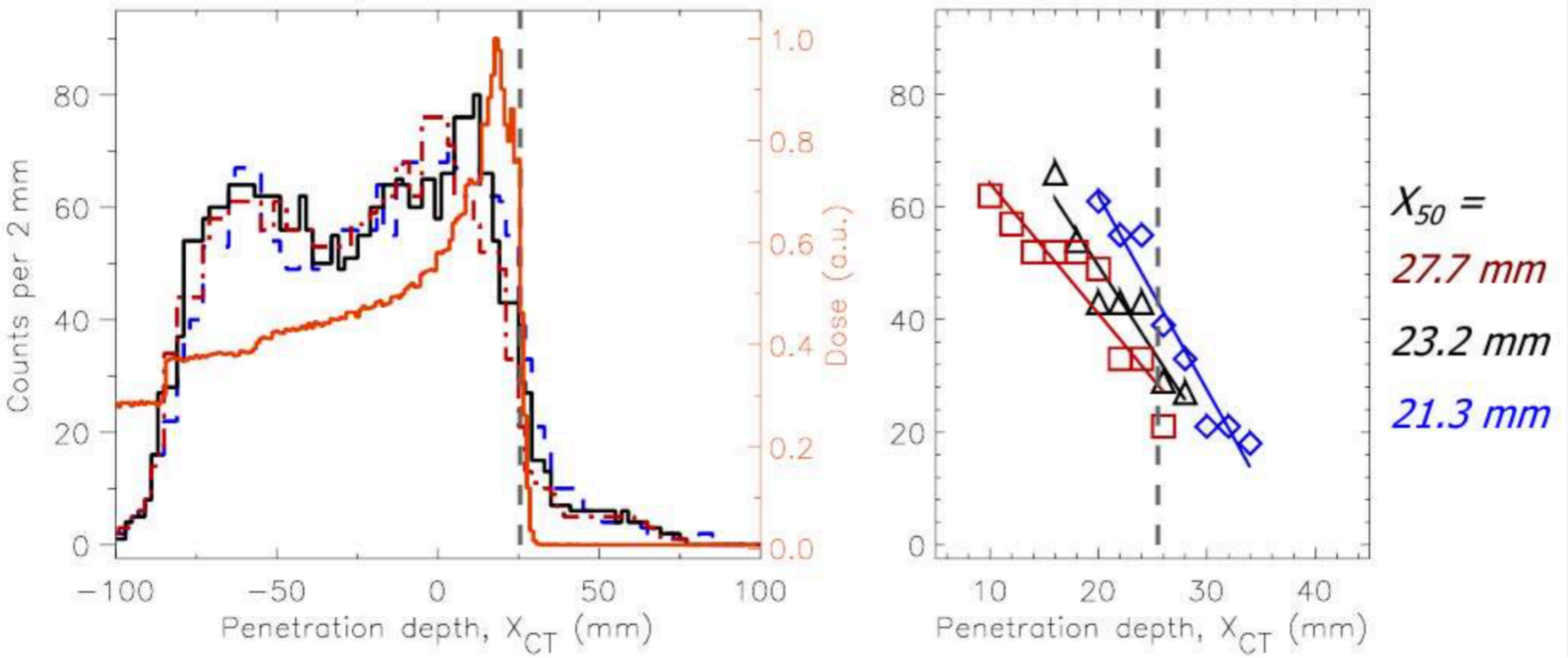


(Cambraia Lopes PhD 2017)

II - 3. The multi-slat concept for prompt-gamma imaging in proton RT

3.2 Change of brain density due to fractionated RT

- Conjecture: brain tissue hypo/hyperdense
- Monte Carlo results with proposed detector (Geant4):



(Cambraia Lopes PhD 2017)

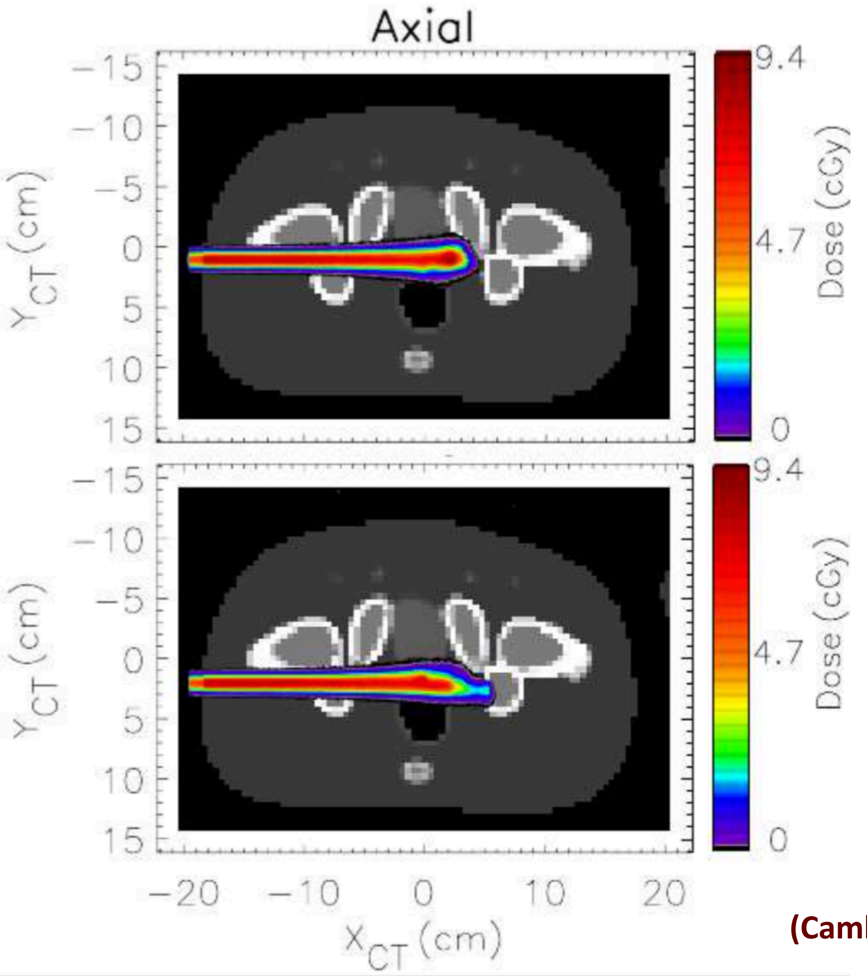
II - 3. The multi-slat concept for prompt-gamma imaging in proton RT

3.3 Prostate: patient mispositioning

Pelvis irradiation *(NCAT)*

Prostate

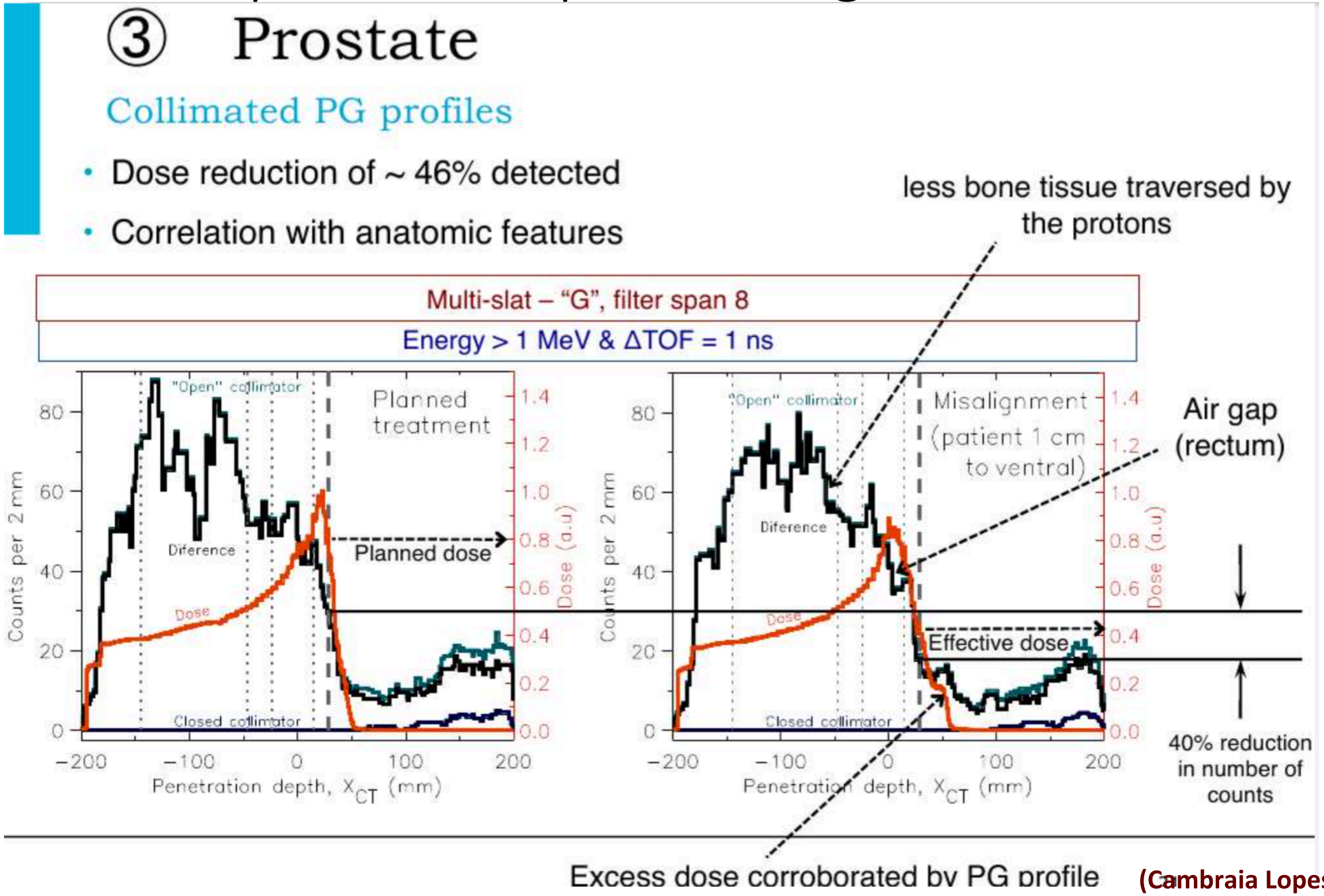
- Treatment plan:
  - Irradiation of a hypothetical tumor in the prostate
- Compromised treatment:
  - **Misalignment**
    →Patient 1 cm to ventral
  - Dose proximal displacement
    → tumor underdosage
  - Possible causes:
    - Mispositioning
    - Patient weight change



(Cambraia Lopes PhD 2017)

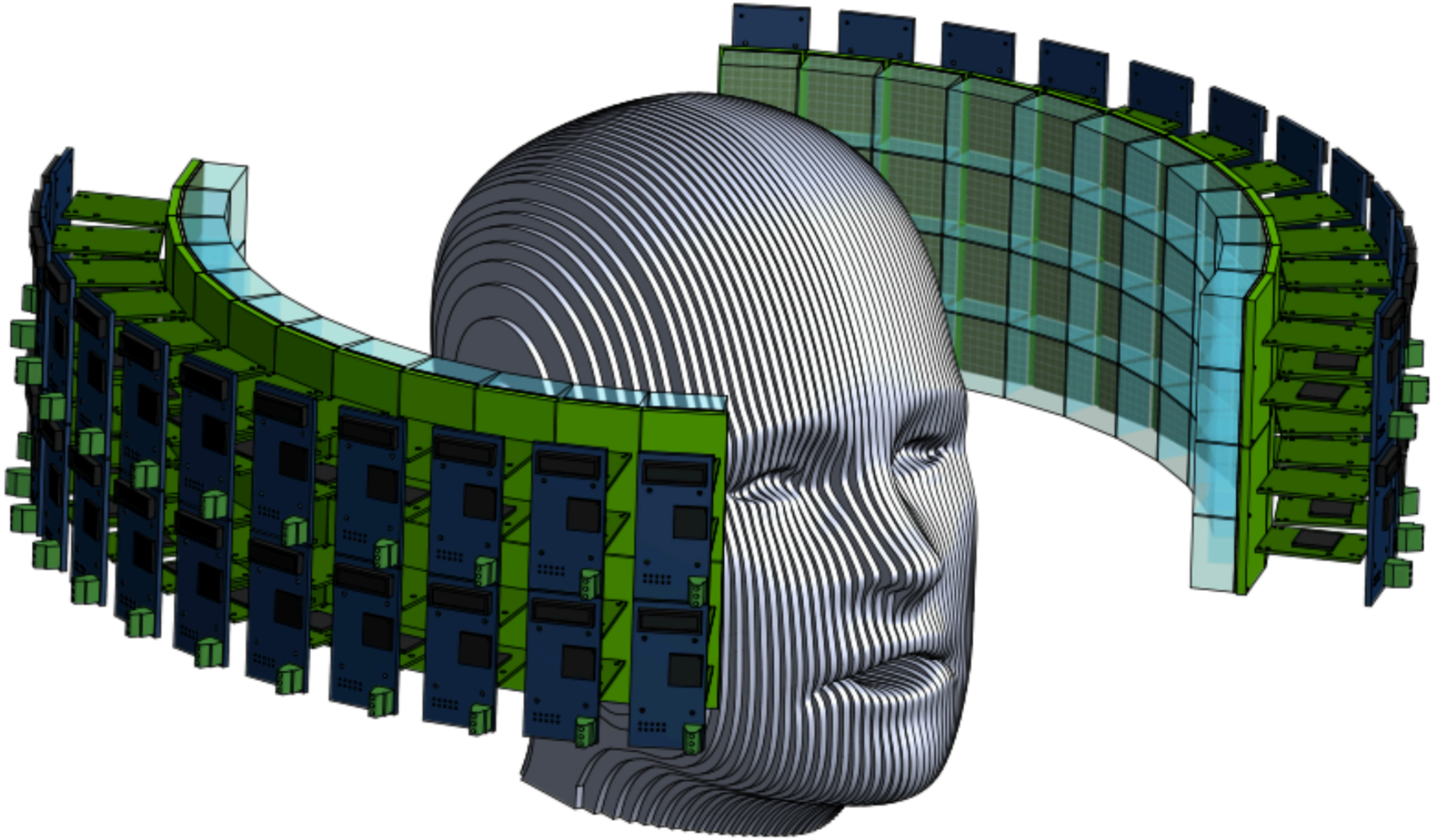
II - 3. The multi-slat concept for prompt-gamma imaging in proton RT

3.3 Prostate: patient mispositioning



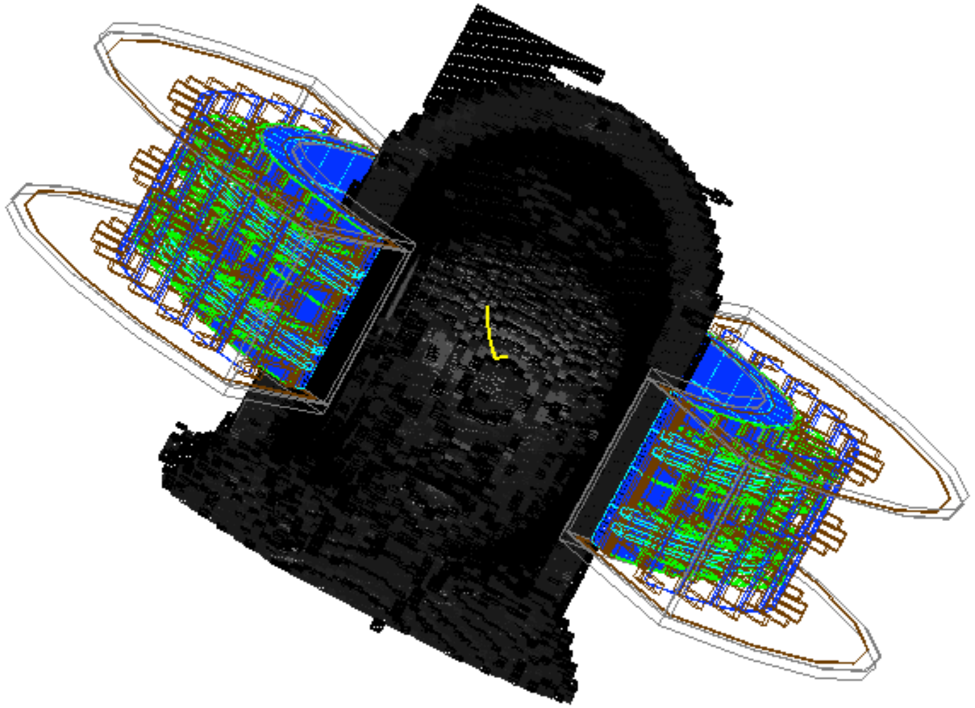
(Cambraia Lopes PhD 2017)

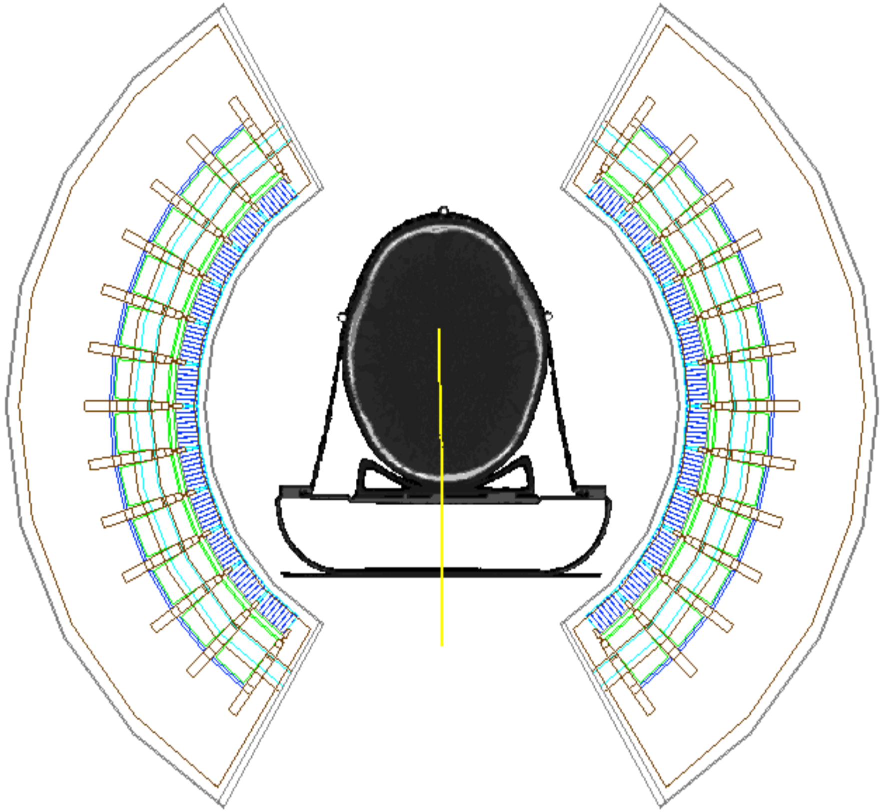
II - 4. In-beam time-of-flight PET for proton RT



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

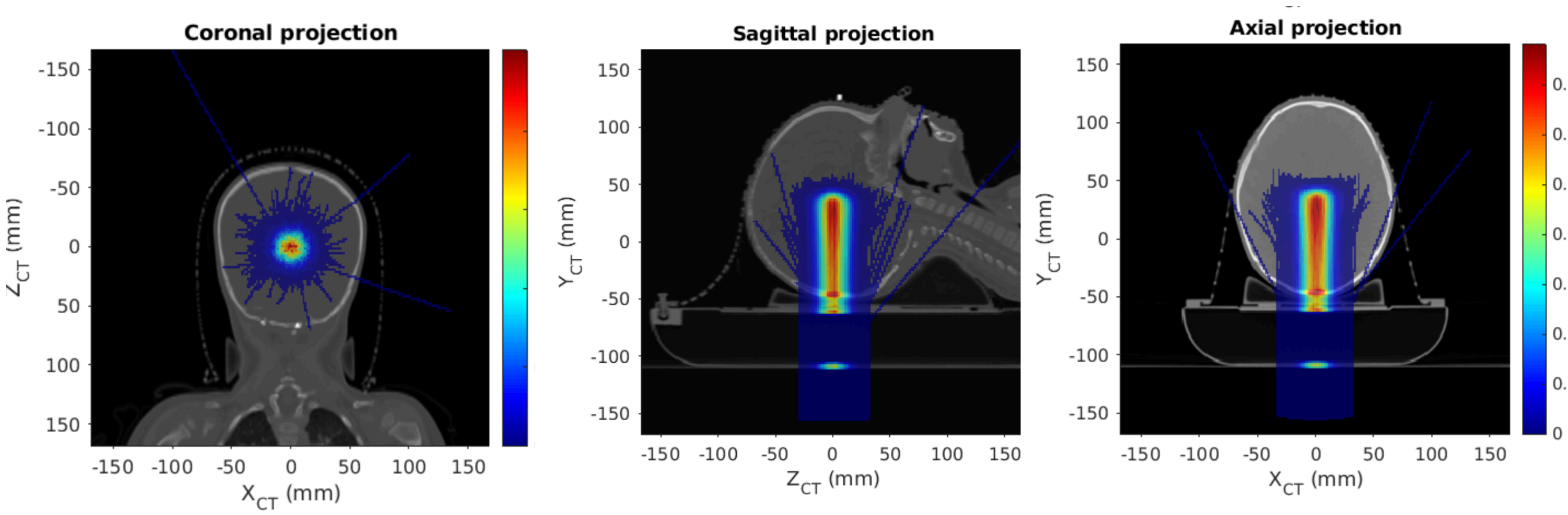
A full simulation with an arbitrary single beamlet





Starting position: (0, -155, 0)
Direction: Y (gantry angle of 180 degrees)
Energy: 131 MeV
Beamlet spread size: 8.42 mm sigma
Beamlet duration: 4 ms

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



Thank you for your attention

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COMPETE 2020 PROGRAMA OPERACIONAL COMPETITIVIDADE E INTERNACIONALIZAÇÃO

PORTUGAL 2020

UNIÃO EUROPEIA Fundos Europeus Estruturais e de Investimento