In-Vivo Monitoring in Proton Radiotherapy with Prompt Gamma Multi-Slat Imaging: a Realistic Monte Carlo Study

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New Horizons for Nuclear Sciences and Technologies in Portugal: health and cancer applications

C[2]TN: Center for Nuclear Sciences and Technologies – April 27th, 2018

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Outline

1. LIP competences
2. Motivation
3. Rationale for in-vivo imaging in proton radiotherapy (RT)
4. The multi-slat concept for prompt-gamma imaging in proton RT
5. Case study (Monte Carlo) pertinent to proton RT: Achieving 2 mm resolving power in head irradiation

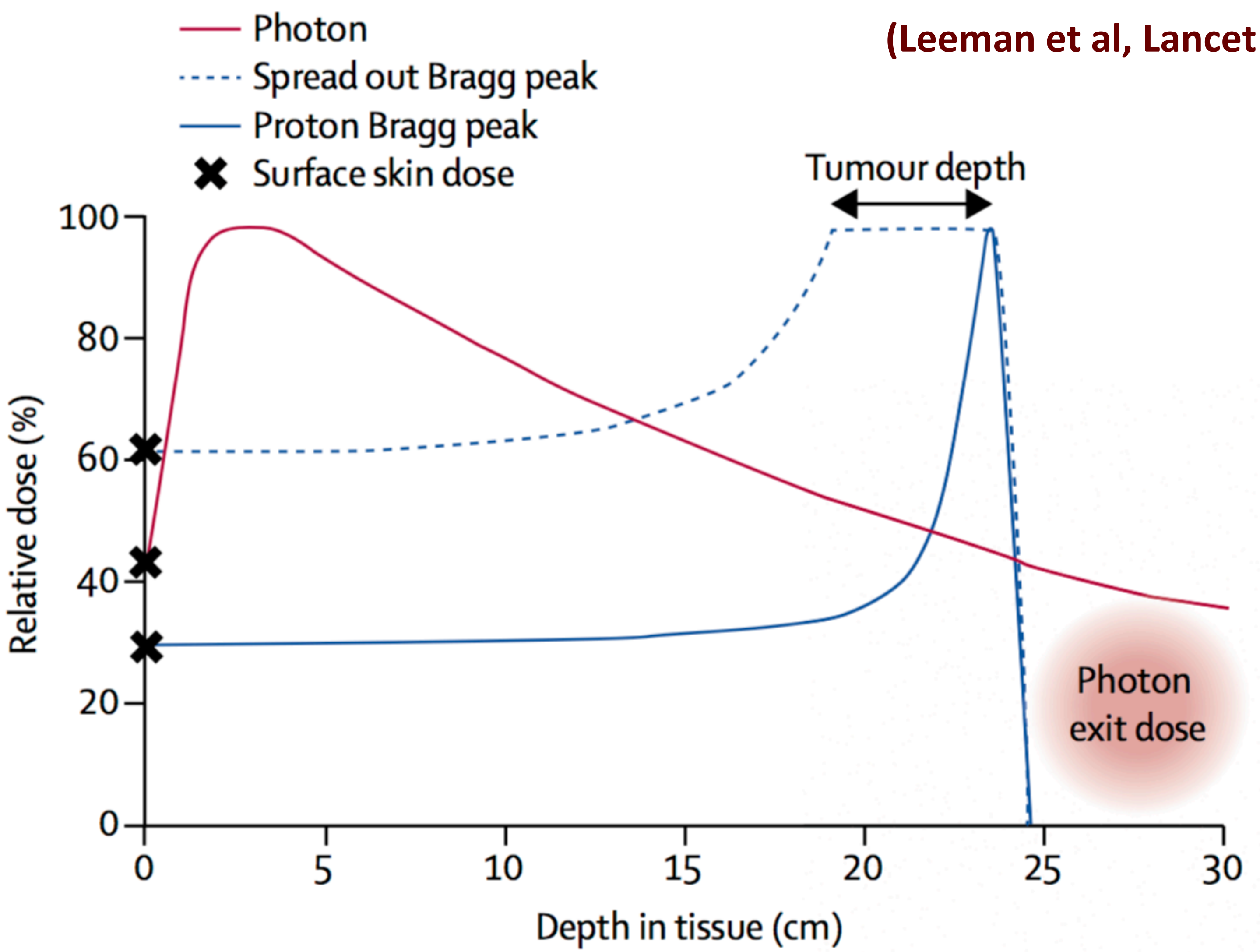
   Acknowledgments

1. LIP competences

- Monte Carlo simulation in Medical Physics
- Imaging in Nuclear Medicine and in Radiotherapy
  - Instrumentation
  - Simulation
  - Electronics (from front-end to fast data acquisition)
- Dosimetry
- Distributed computing (e.g. the GEANT4 simulations presented here took several thousands of hours of parallel computing)
- Detector laboratory
- High-precision mechanical workshop

2. Motivation: Proton therapy physical advantage over photons

(Leeman et al, Lancet Oncol 2017)



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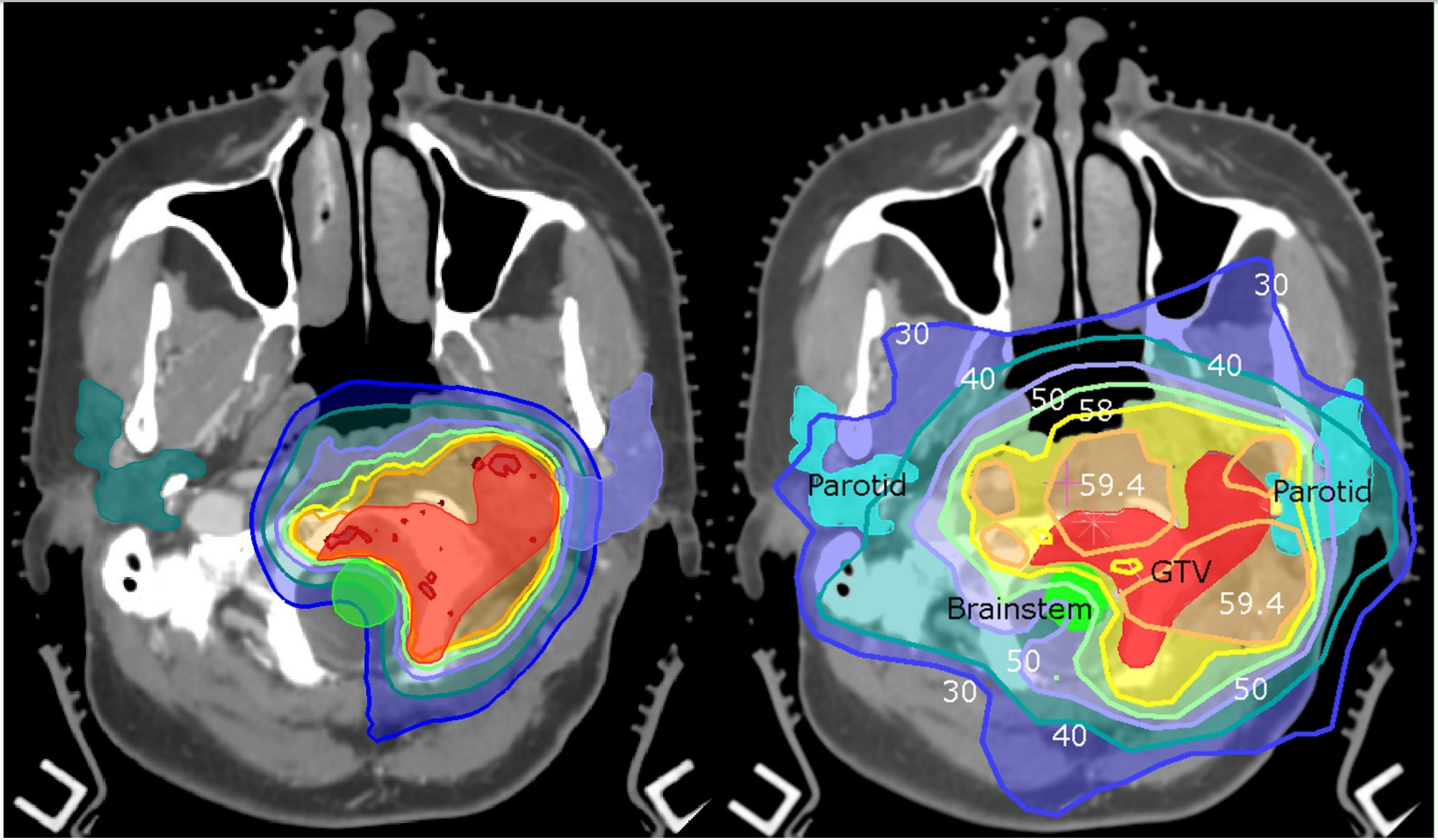


(Proton Therapy Today 2014)

2. 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)

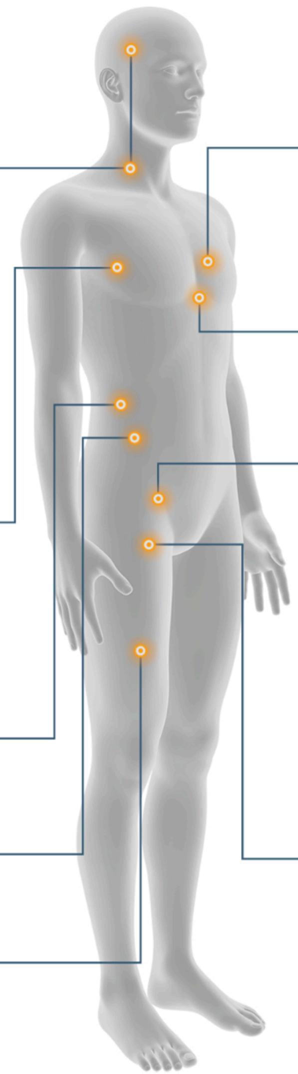
58% higher overall survival rate (2 years)

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

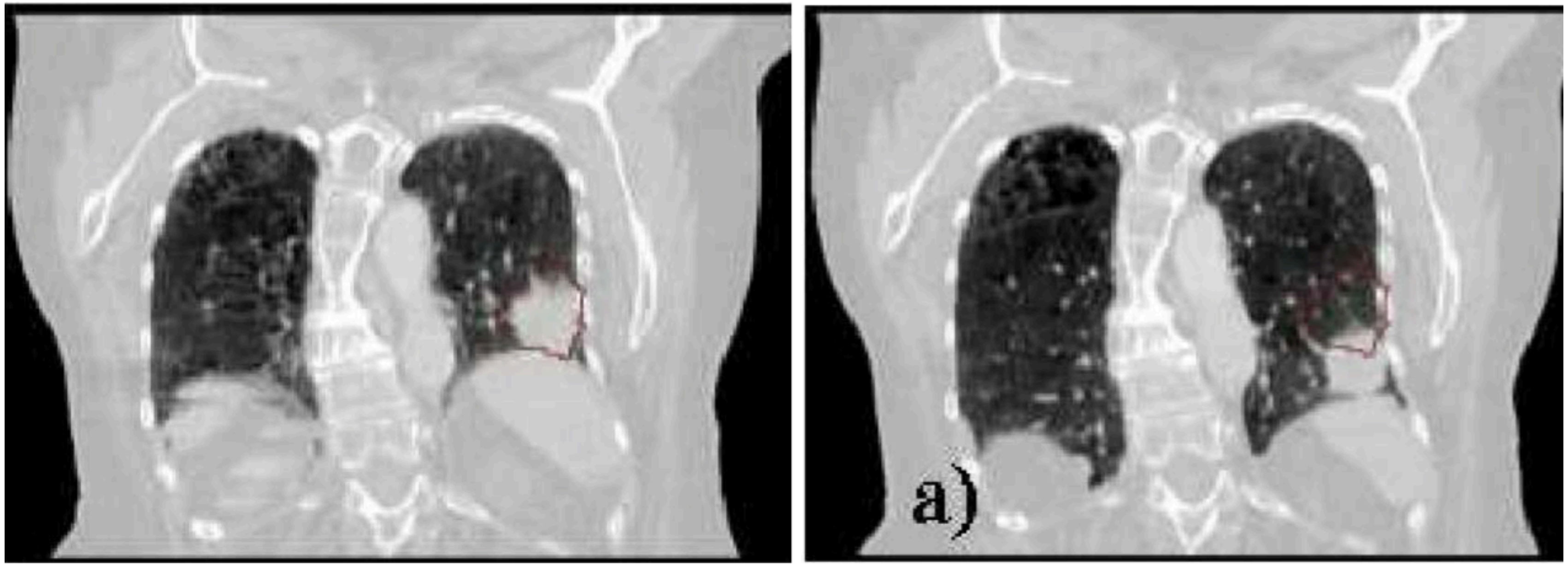
PROVISION CARES
PROTON THERAPY

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.

3. Rationale for in-vivo imaging in proton RT

Target volumes and organ motion: tumor displacement

- Breathing (intrafraction)

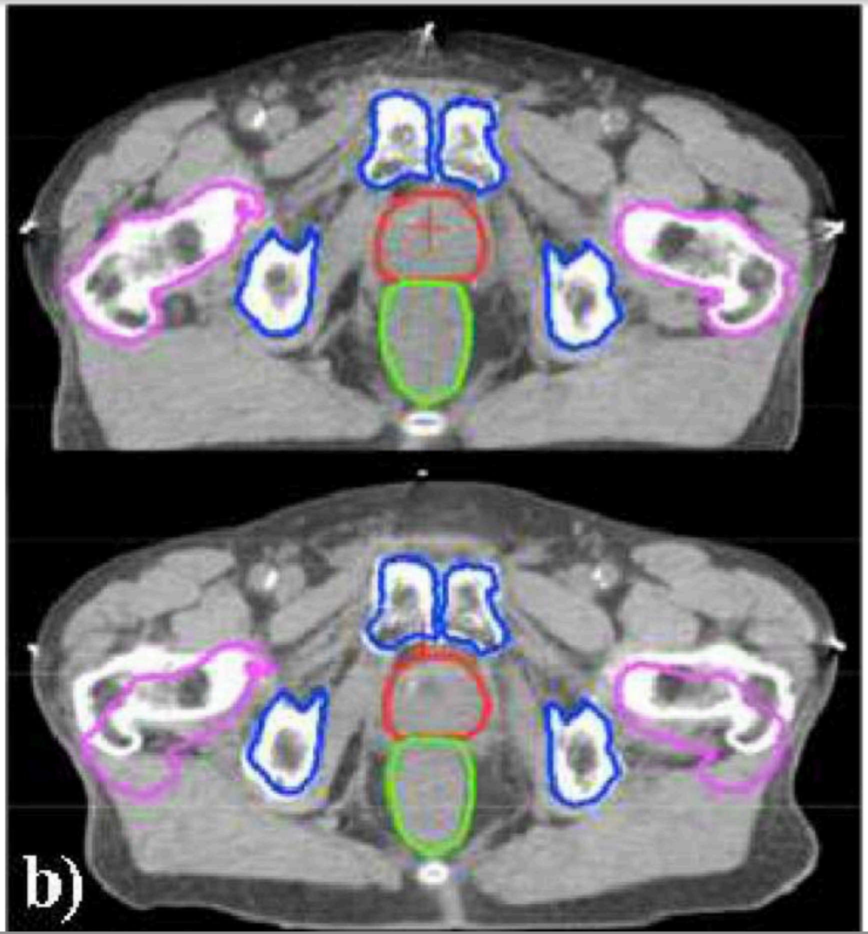


Engelsman and Bert 2011
Lüchtenborg PhD 2012

3. Rationale for in-vivo imaging in proton RT

Target volumes and organ motion: patient displacement/deformation

- Mispositioning (interfraction)



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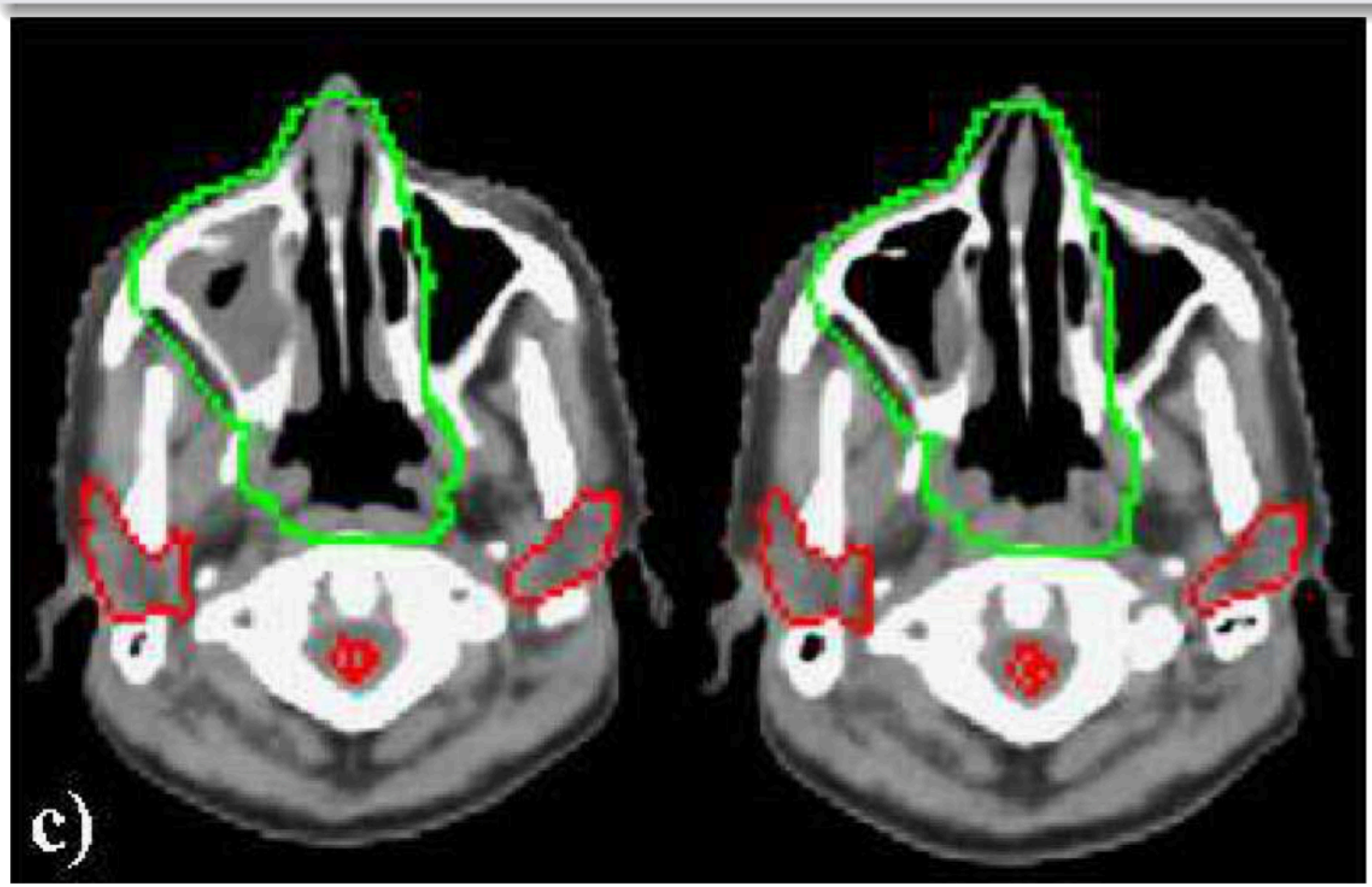
3. Rationale for in-vivo imaging in proton RT

Target volumes and organ motion: cavity filling/wall thickening

- Tissue-density modification (interfraction)



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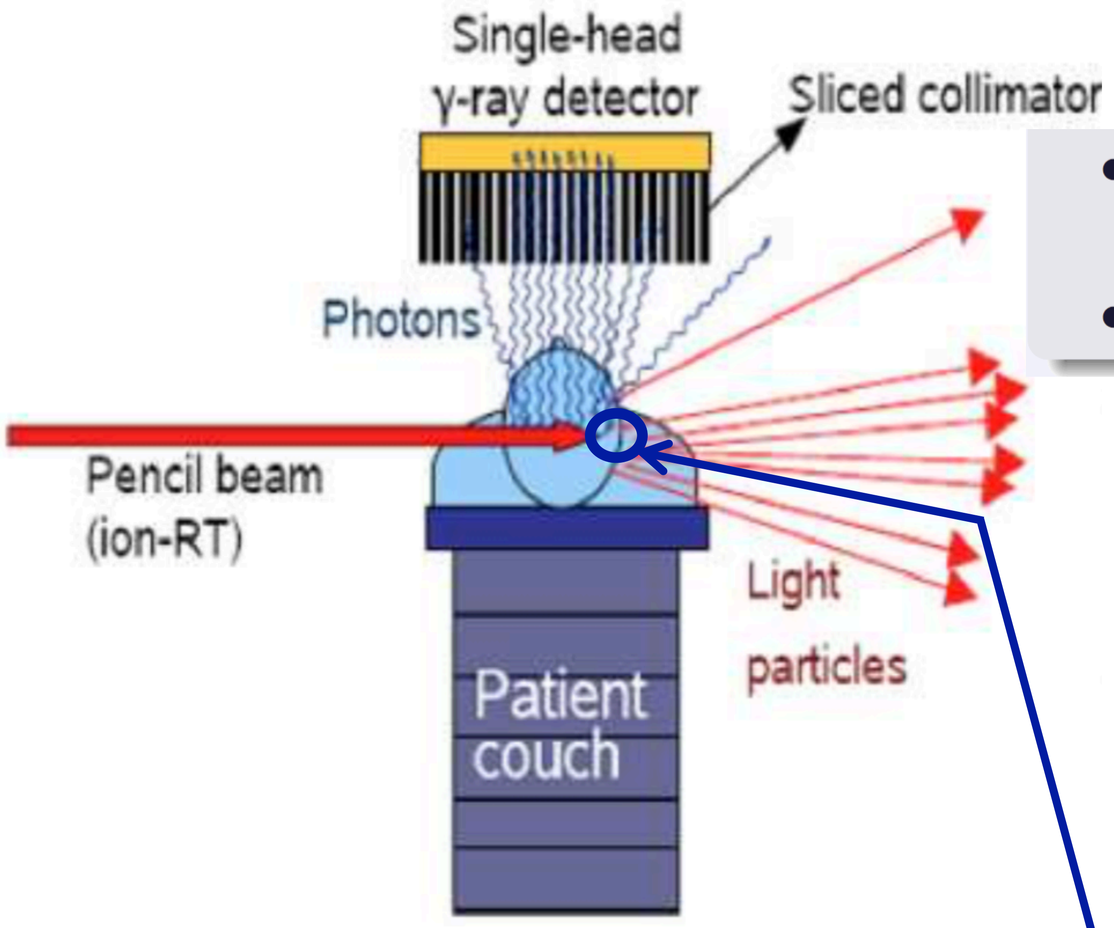
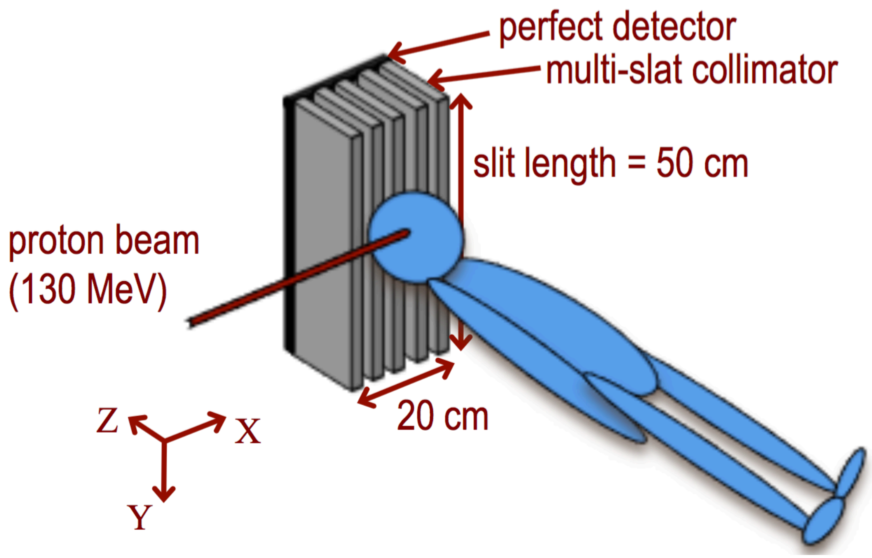
4. The multi-slat concept for prompt-gamma imaging in proton RT



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



(Cambraia Lopes PhD 2017)

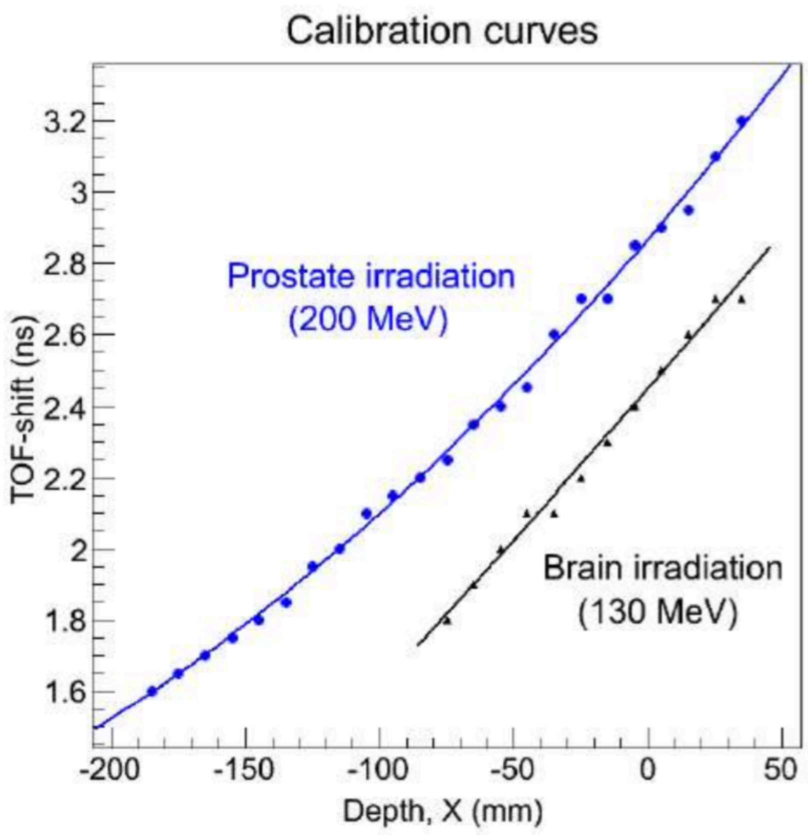
Provides real-time images of selected region without rotation of beam

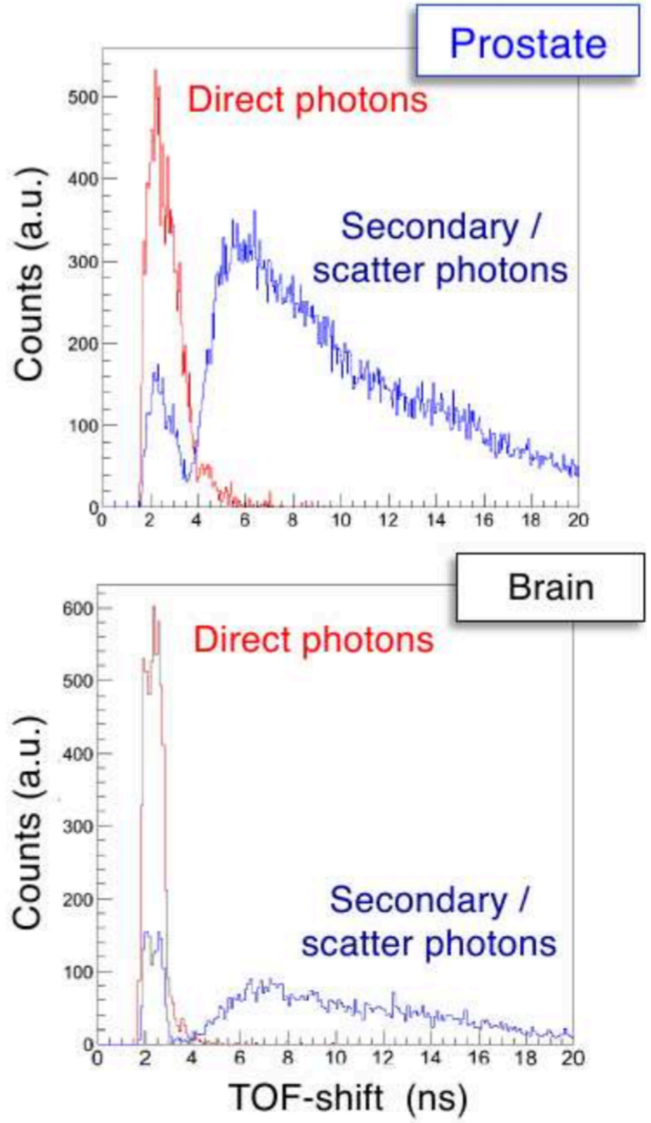
Image with prompt gammas "stops" at beam range

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

Data analysis

Shifting Time-of-Flight (TOF) selection





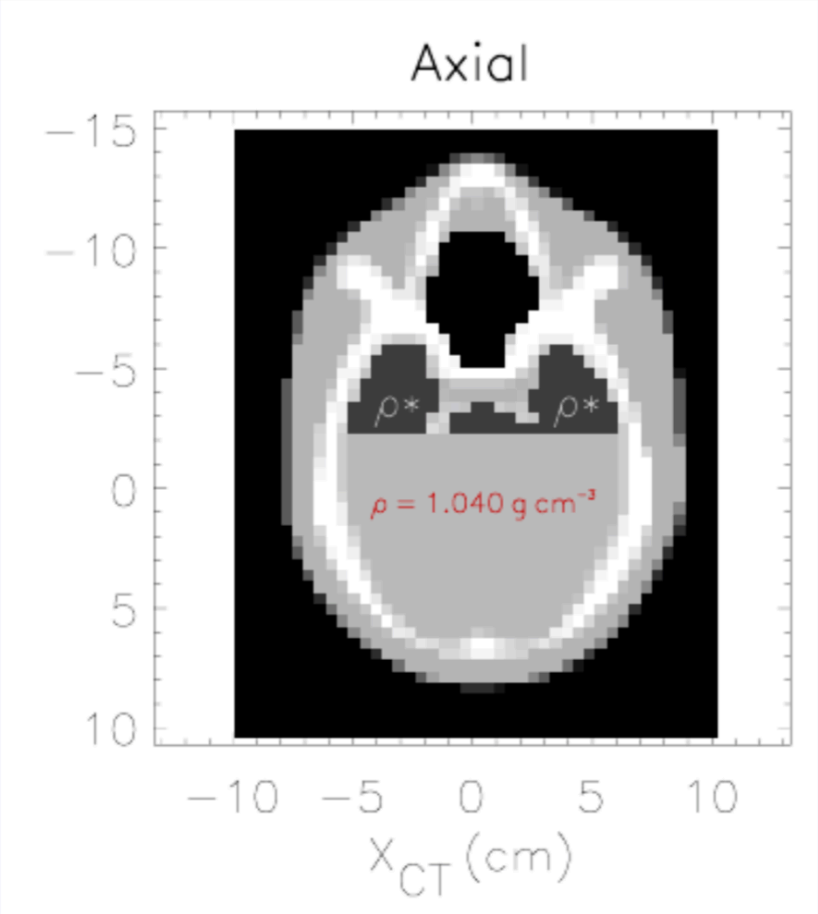
→ Method according to Biegun et al. PMB 2012

(Cambraia Lopes PhD 2017)

5. Case studies (Monte Carlo) pertinent to proton RT

5.1 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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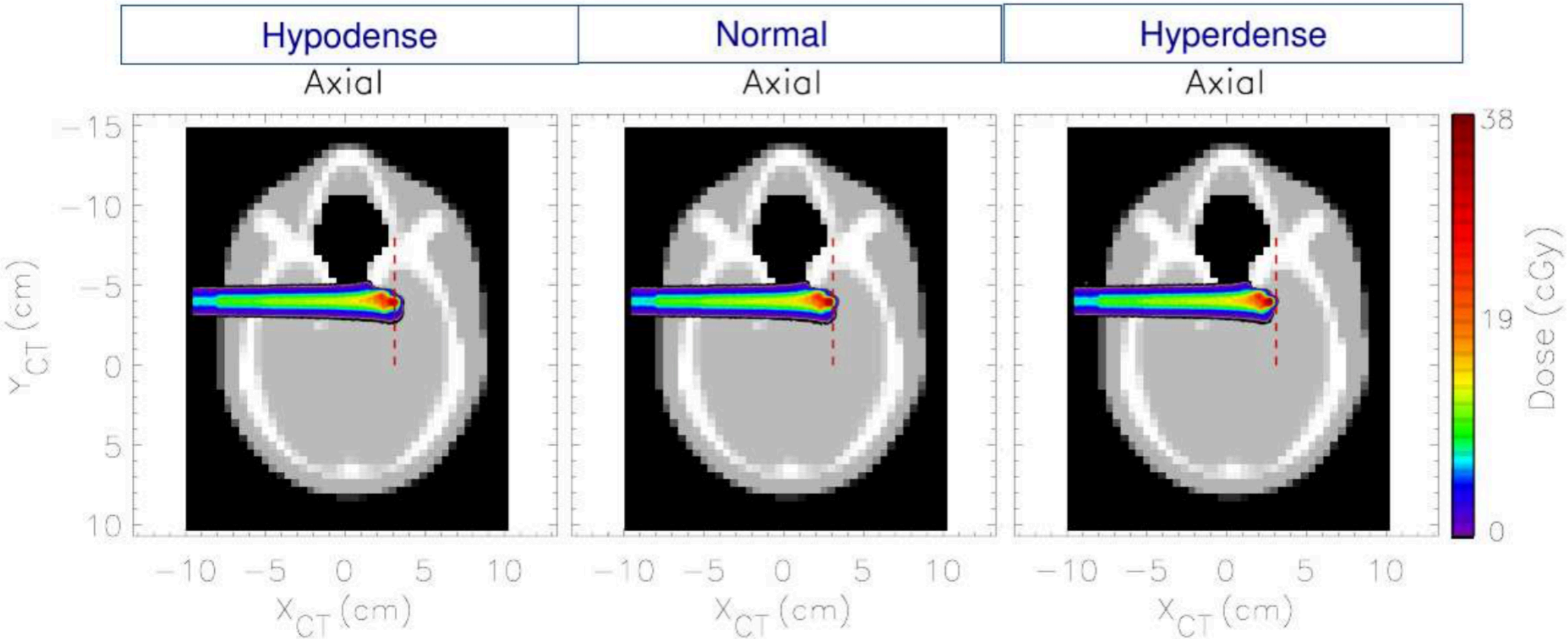

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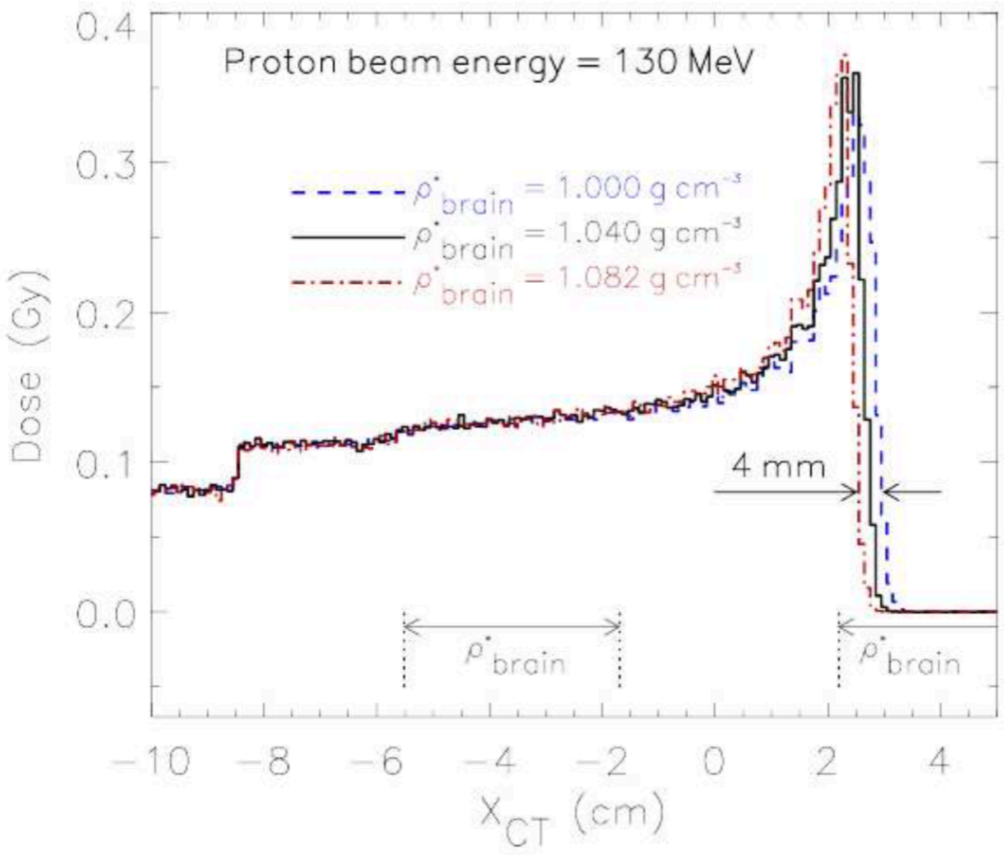

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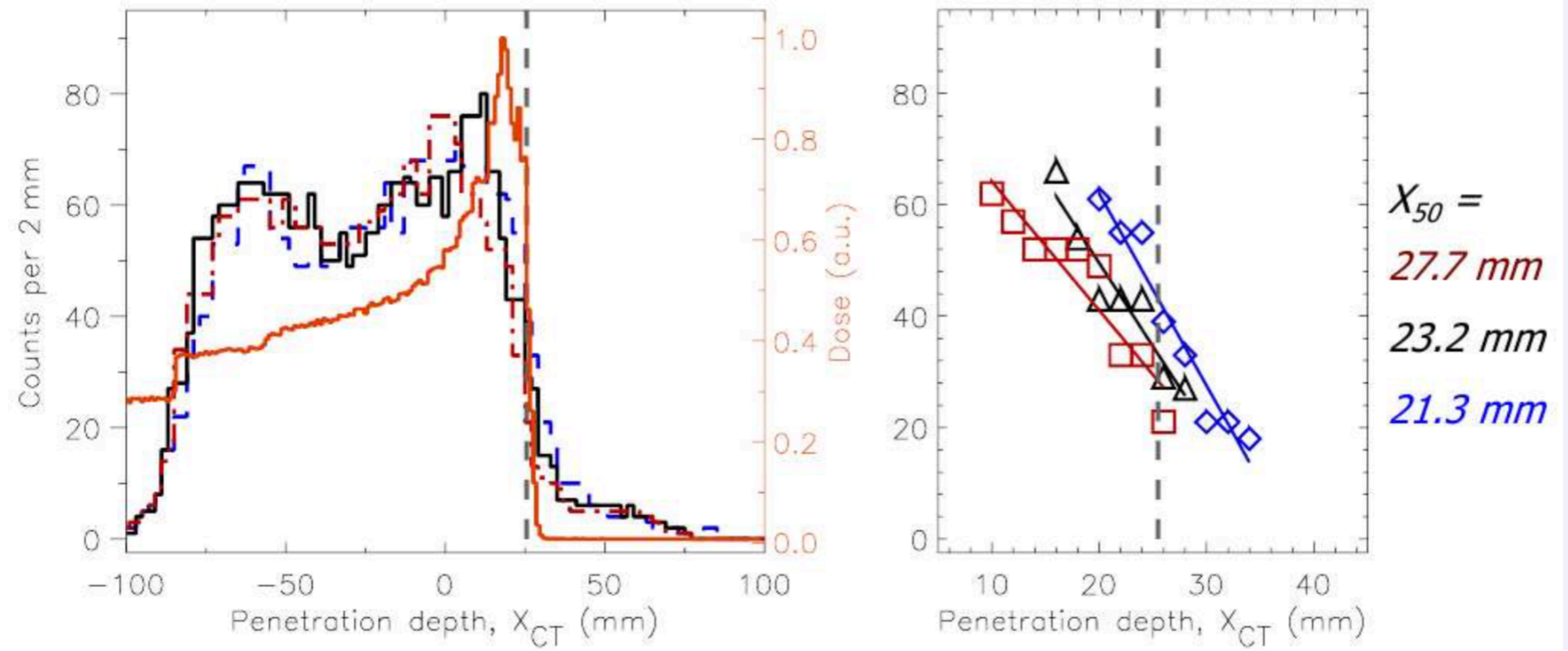
- Monte Carlo results with proposed detector (Geant4):



(Cambraia Lopes PhD 2017)

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UNIÃO EUROPEIA Fundo Social Europeu

POPH PROGRAMA OPERACIONAL POTENCIAL HUMANO