# The Promises and Challenges of Proton Therapy

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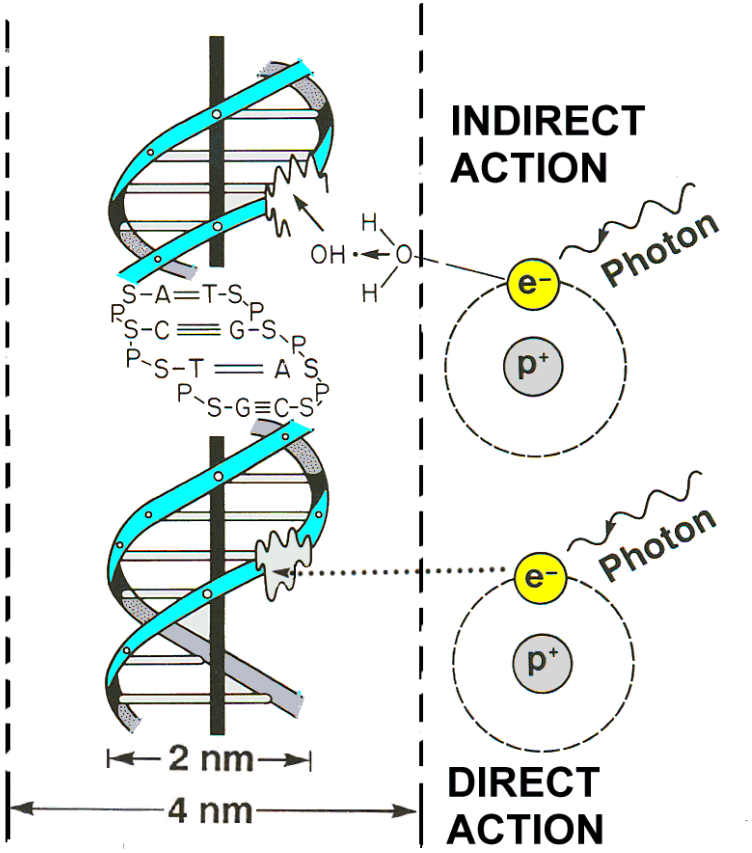
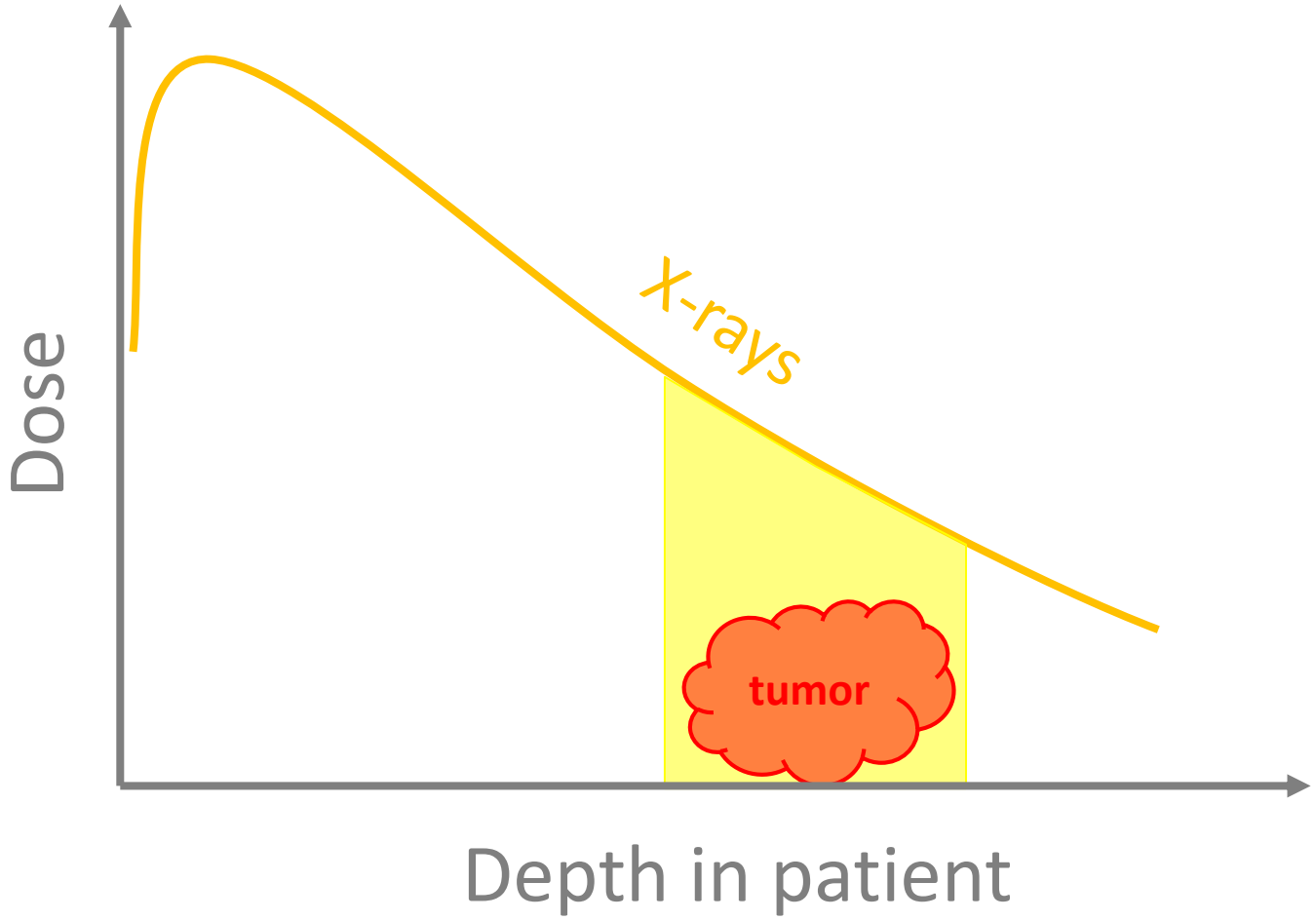
# The Role of Radiotherapy

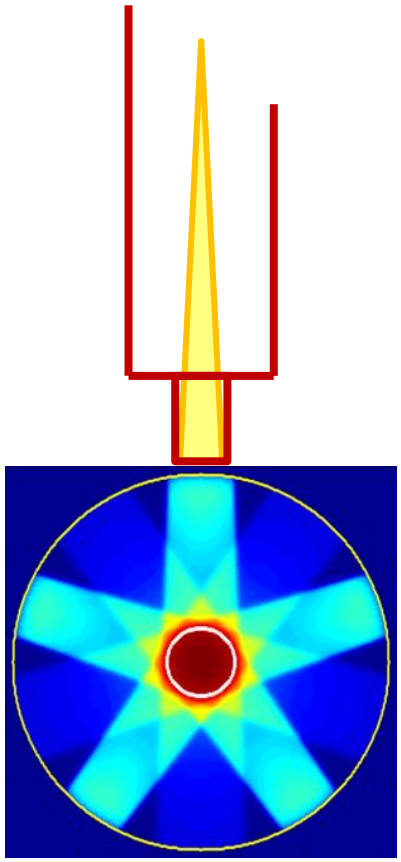


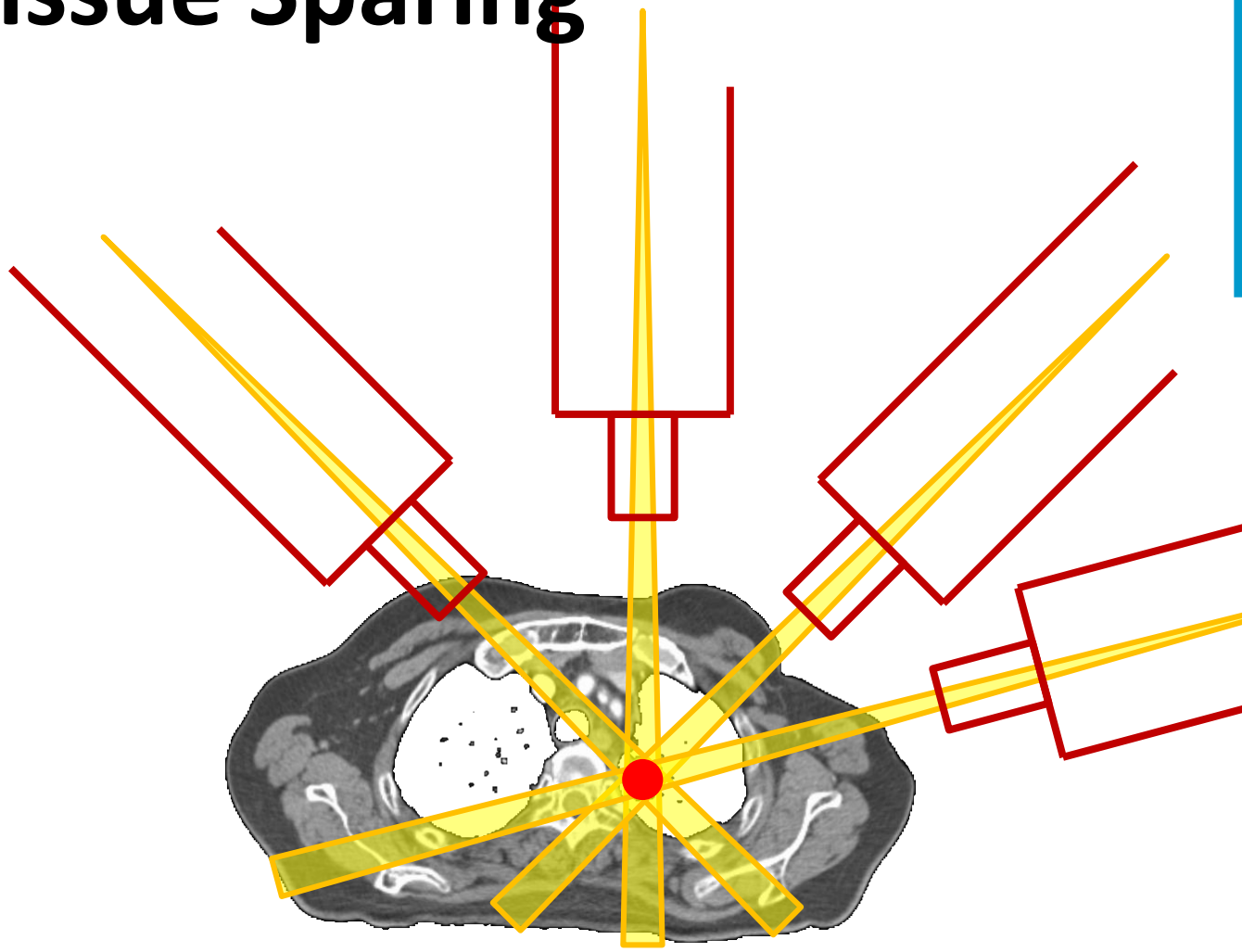

- 45% of cancer patients receive radiotherapy
- For the main tumor sites (breast, lung, prostate, and rectum) the percentage is even higher (50-80%)
- Radiotherapy can be applied as monotherapy, but also in a combined modality setting with chemotherapy and surgery

# X-ray Dose in Patient

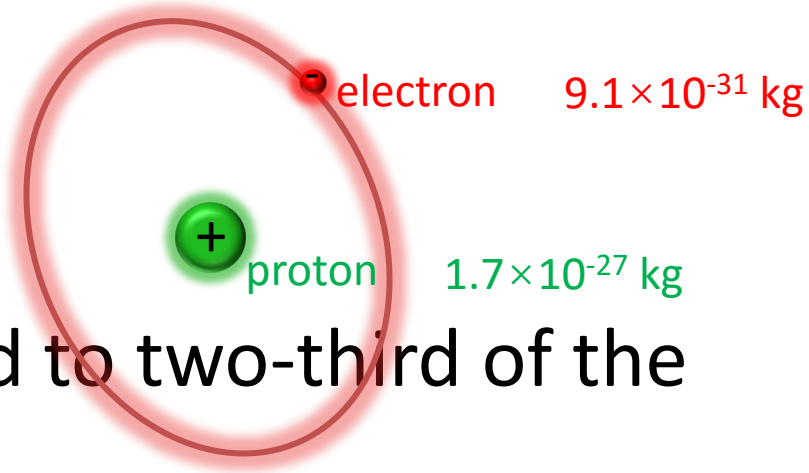


# Healthy Tissue Sparing



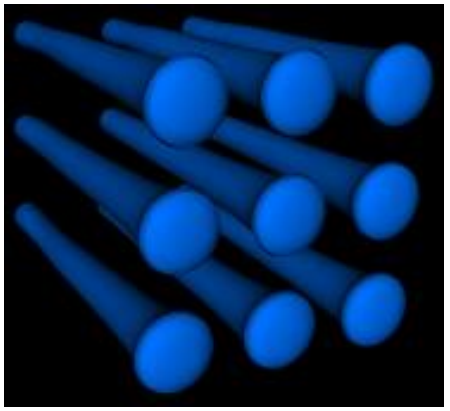


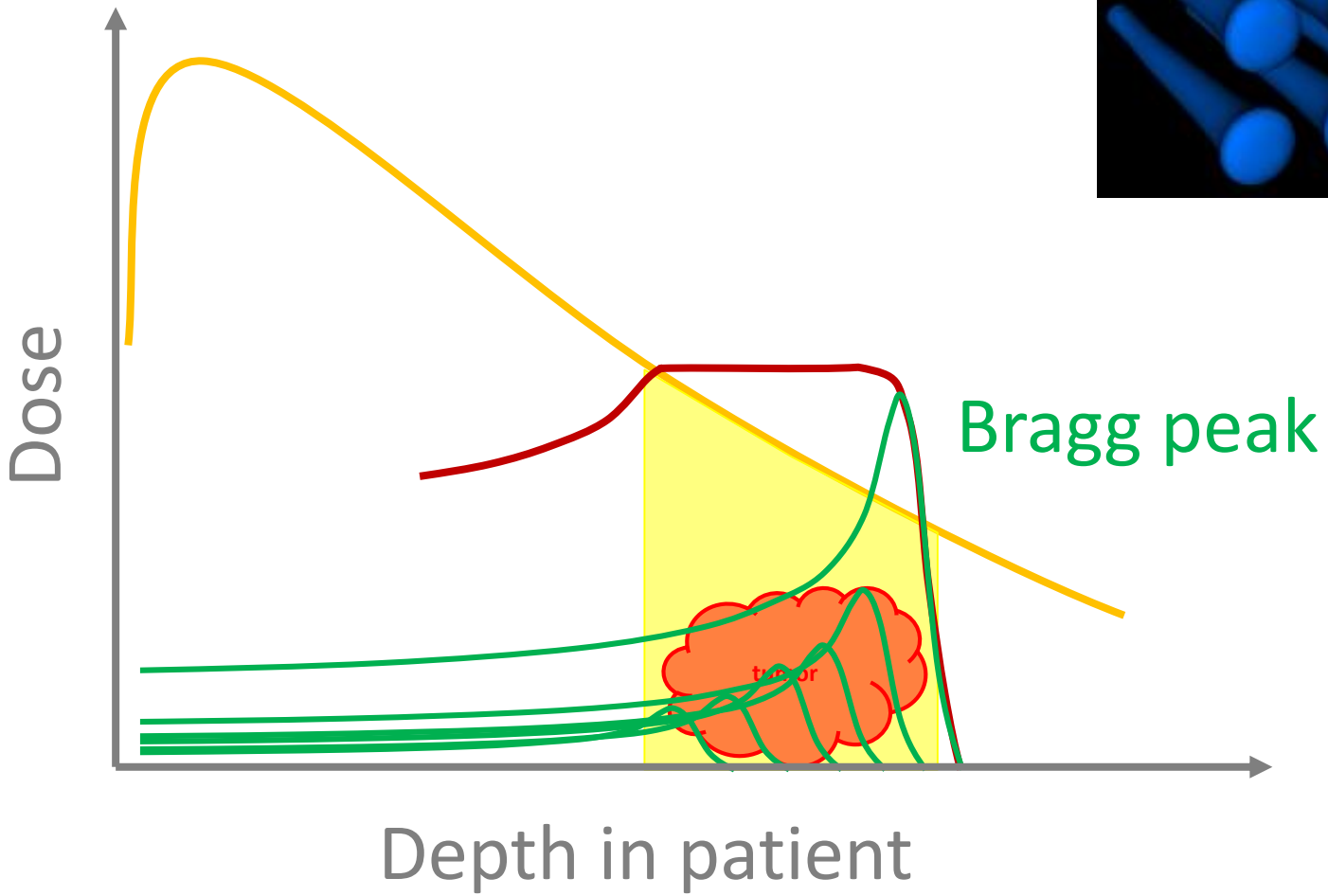
# Proton Beams



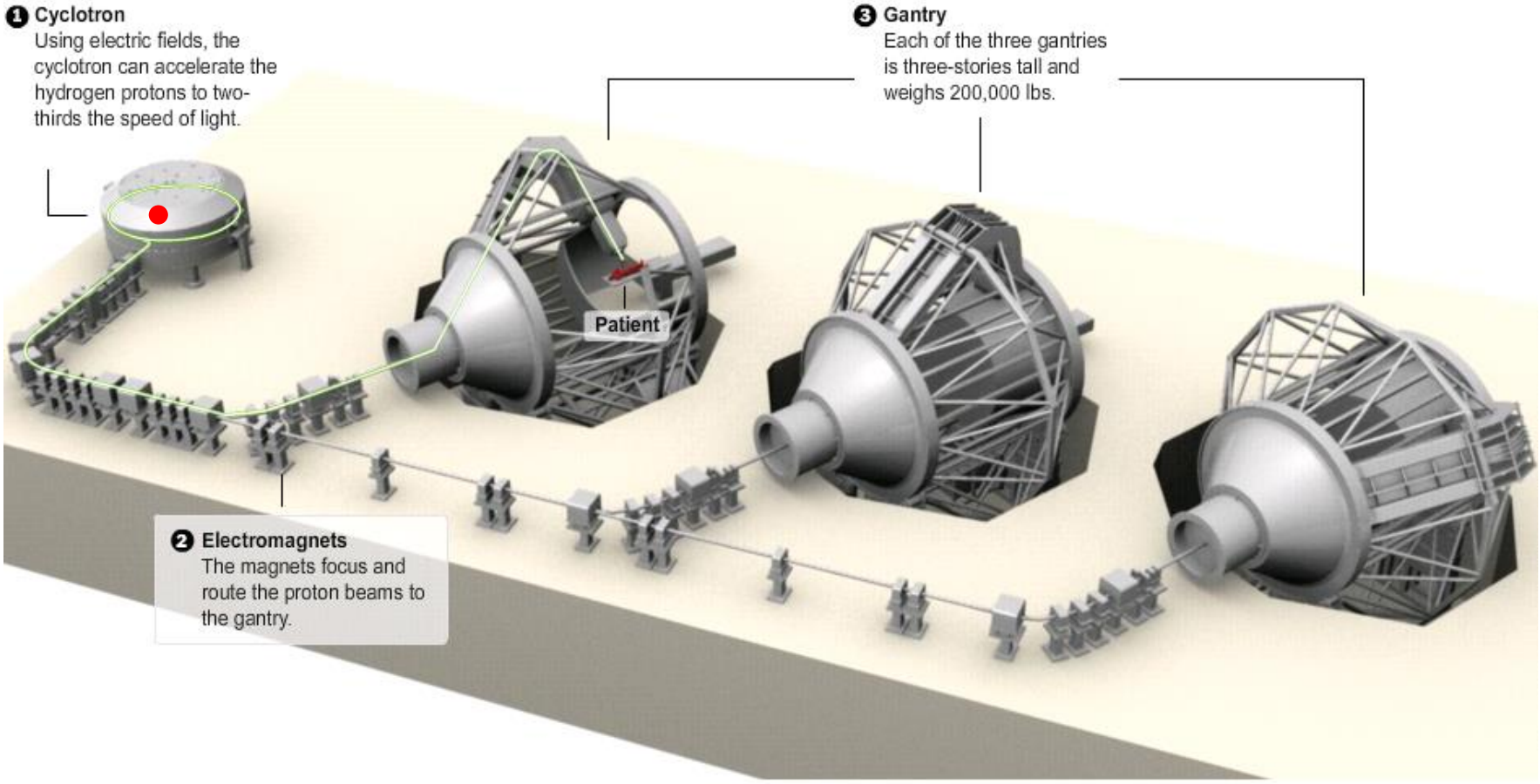

1. Protons are accelerated to two-third of the speed of light.
2. Initially, small amount of energy is transferred to electron clouds.
3. Protons are slowing down.
4. The slower the particles, the greater the linear energy transfer and dose deposition is.

# X-rays vs. Protons



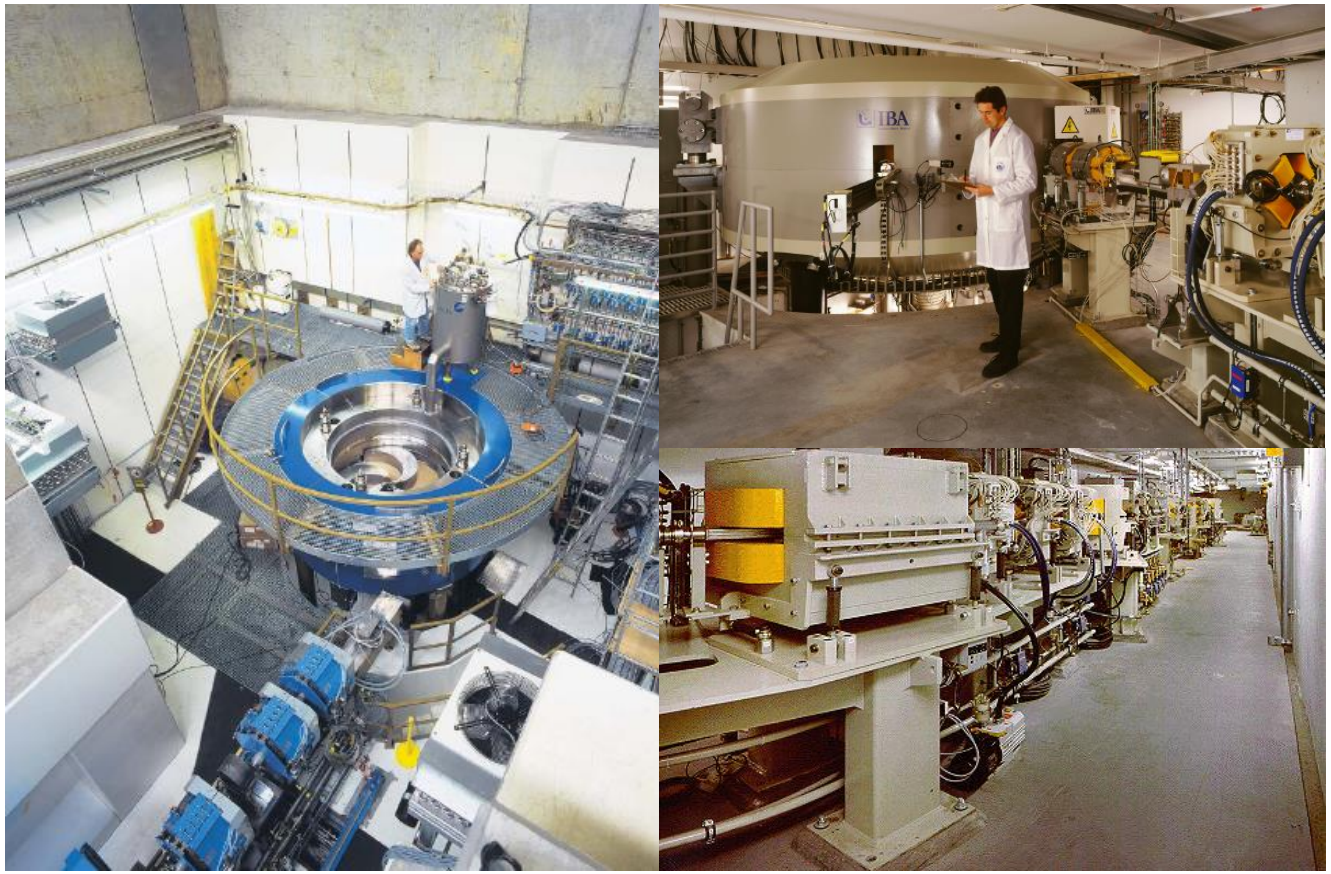


# Proton Therapy Center

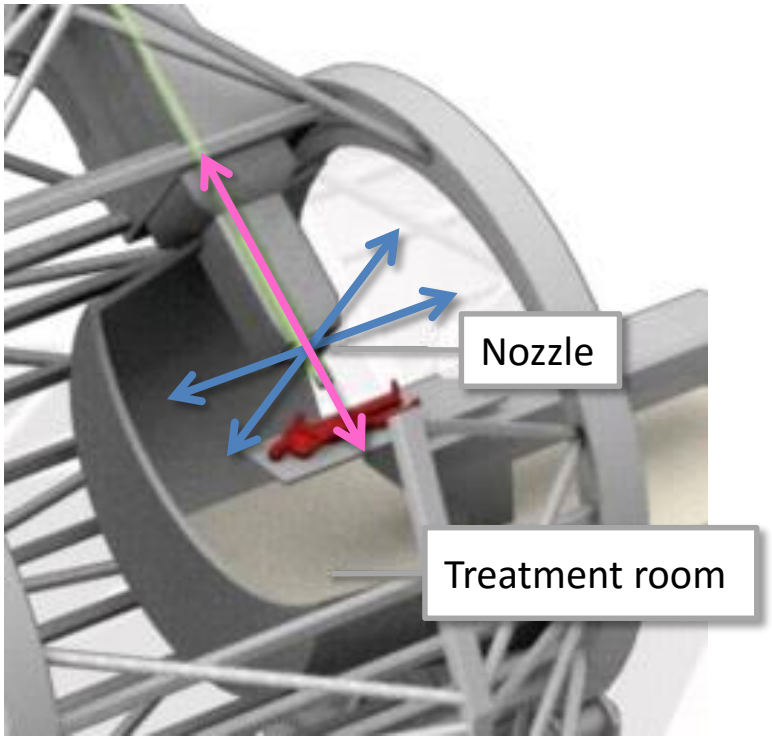


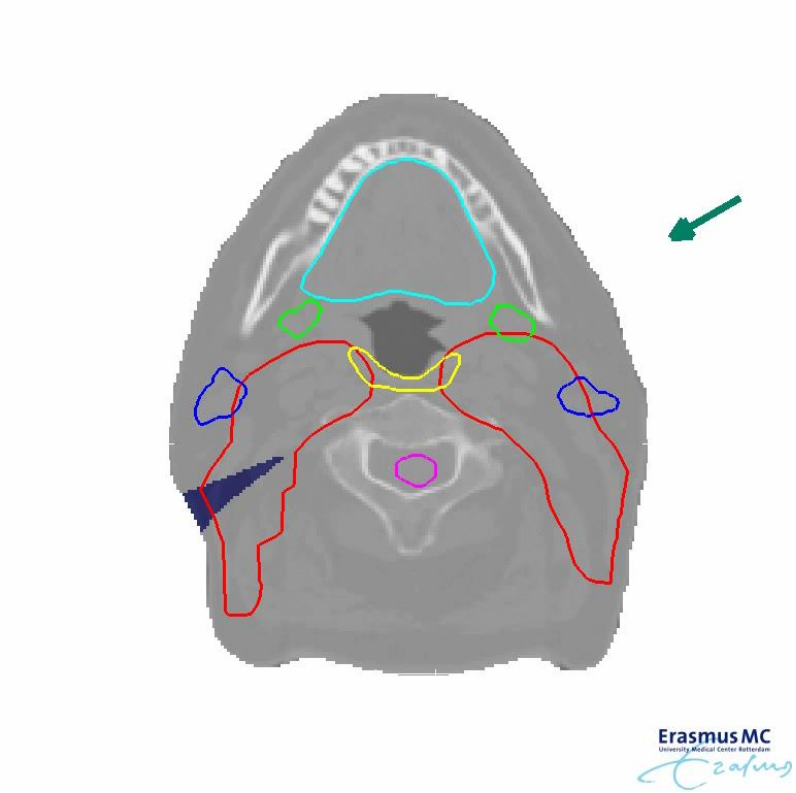

Bron: Vu Nguyen / The New York Times

# Cyclotron and Beamline

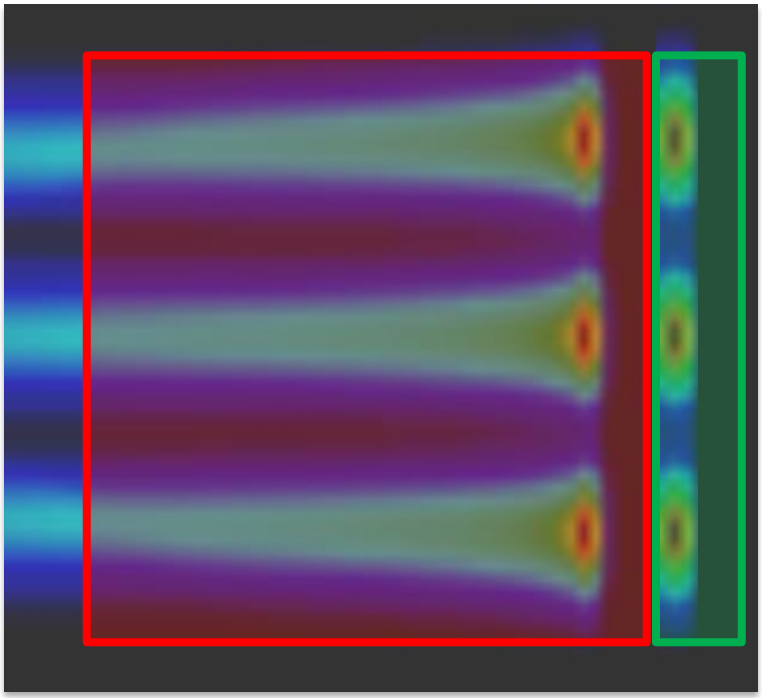


# Pencil beam scanning



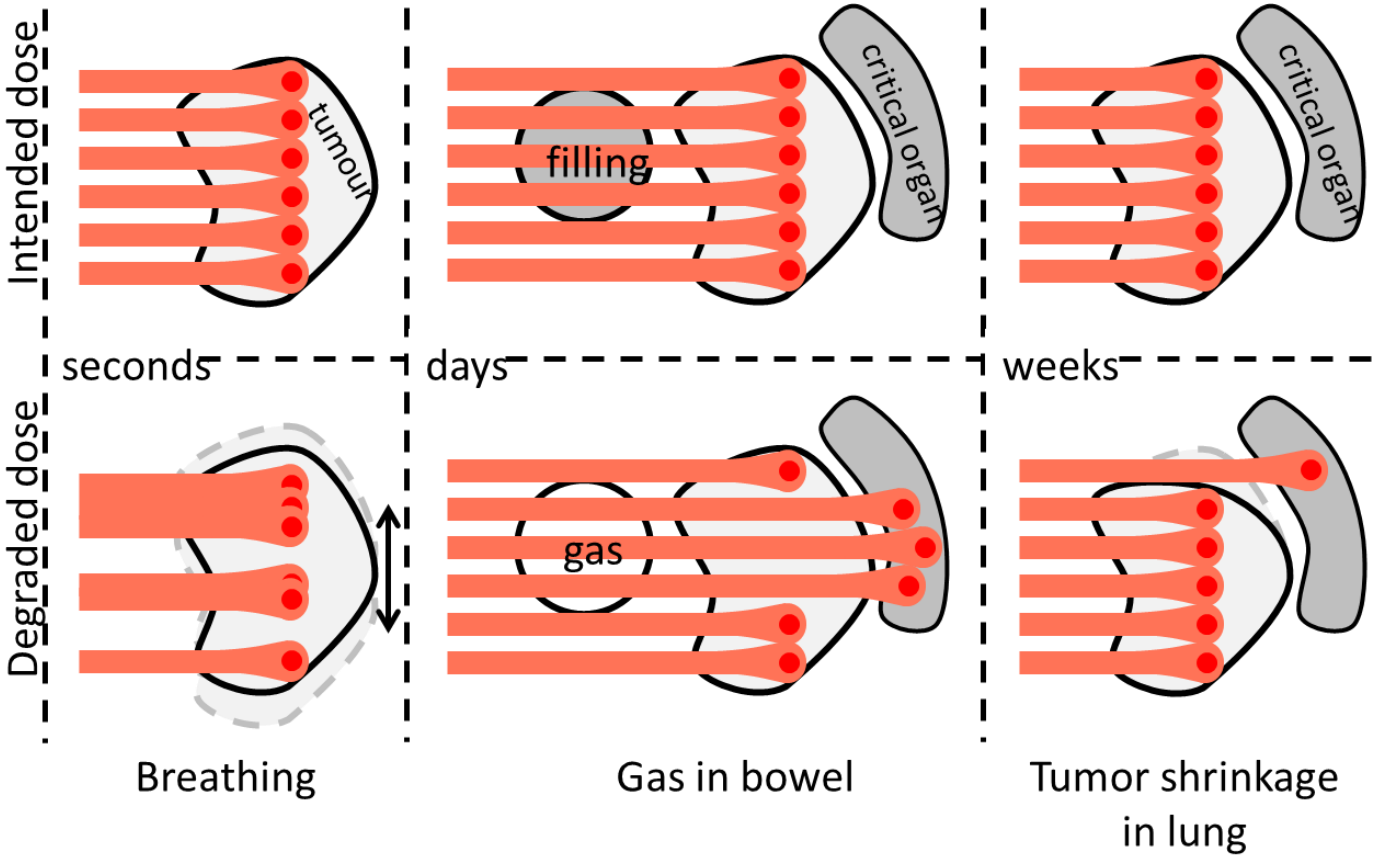



# Protons Stop, But Where?

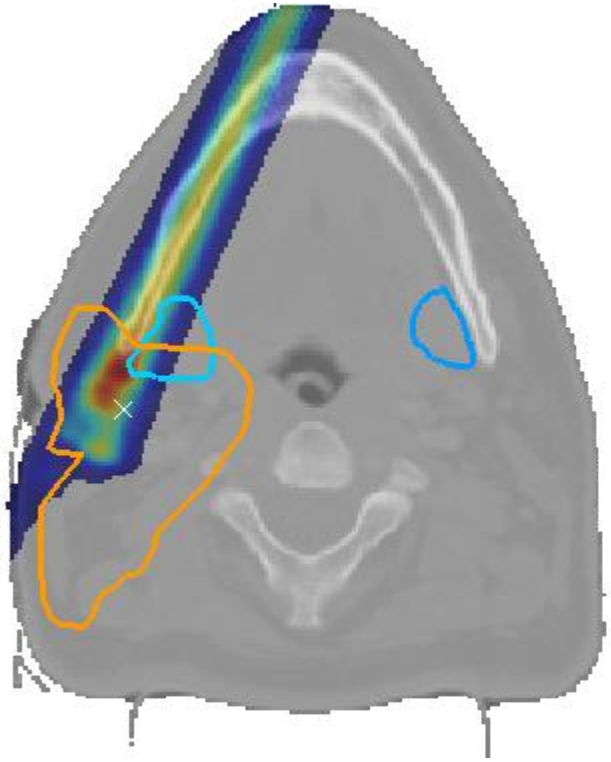


- Dose calculation uncertainties (stopping power)
- Patient setup variation that induce range errors
- Internal organ motion (interplay effects)
- Anatomical changes

# Dose Degradation in Proton Therapy

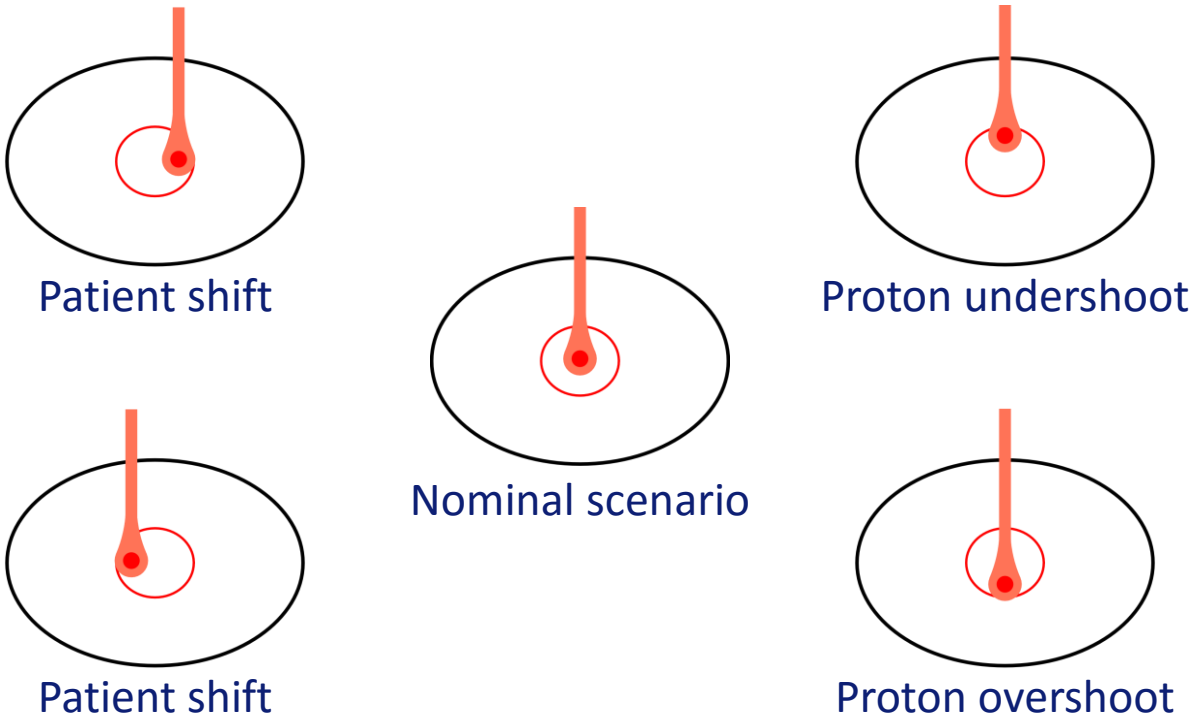


# Patient Setup And Dose



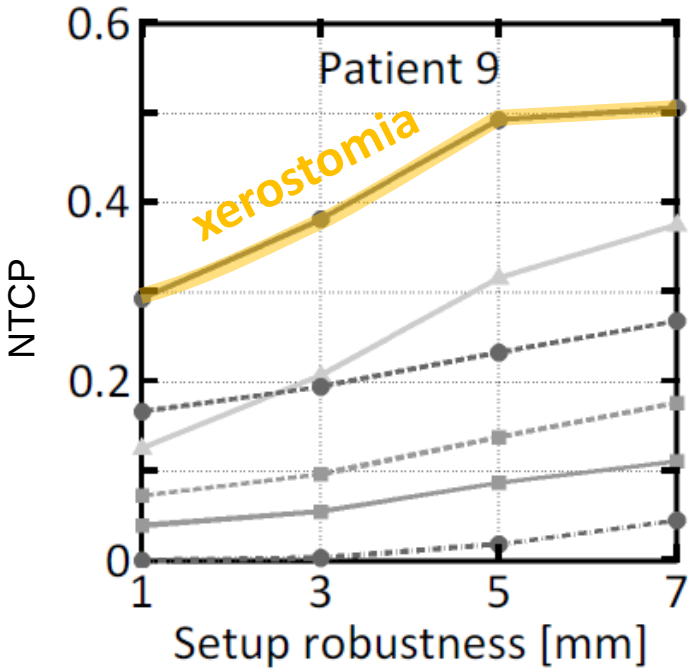
A Kraan, S van de Water et al.

# Robust Against Errors



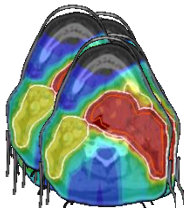

van de Water S et al. Physics in Medicine and Biology 2013;58:6969-83

# The Prize to Pay

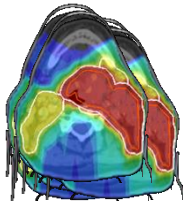




Iris van Dam et al., manuscript in preparation

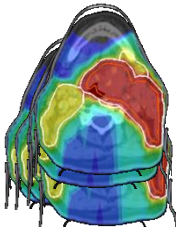
# Time Consuming Simulations



1st treatment



2nd treatment



3rd treatment

X 10,000 treatments

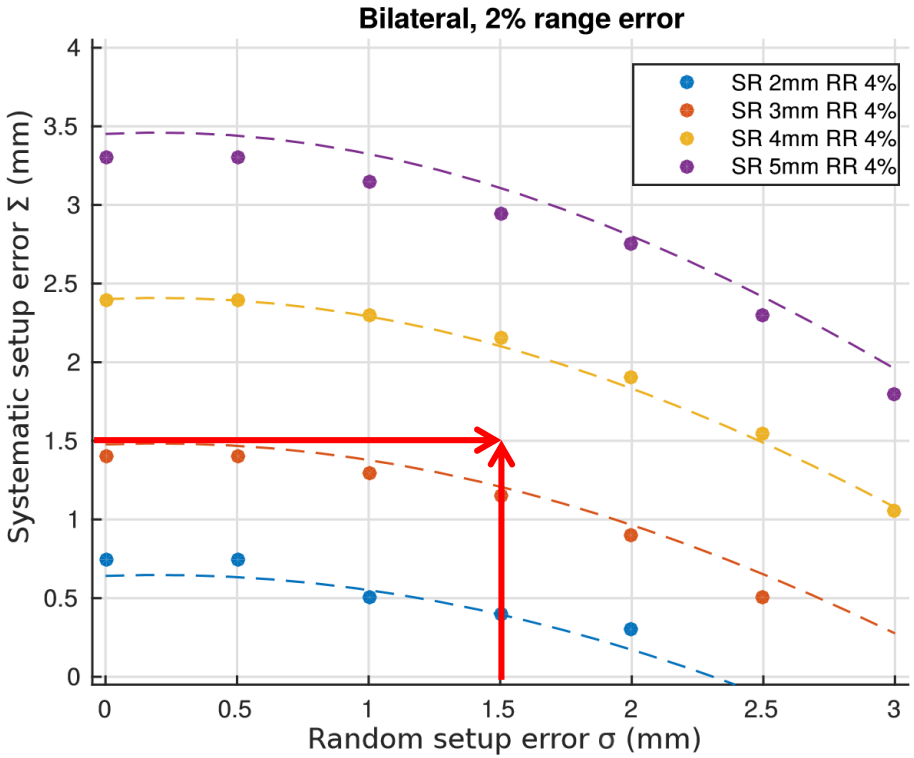
# Polynomial Chaos Expansion Method

- Expected dose for entire fractionated treatment course analytically derived for a given systematic setup error (μ) and range error (ρ) and random setup error distribution (σ)

- **Assuming normally distributed errors (1 standard deviation)**
  - Systematic setup error (Σ)
  - Random setup error (σ)
  - Systematic range error (ρ)
- **Obtain robustness settings that result in adequate CTV coverage**
  - setup robustness **α** mm
  - range robustness **β** %

Sebastian van der Voort et al., manuscript submitted

# Setup Robustness Recipe

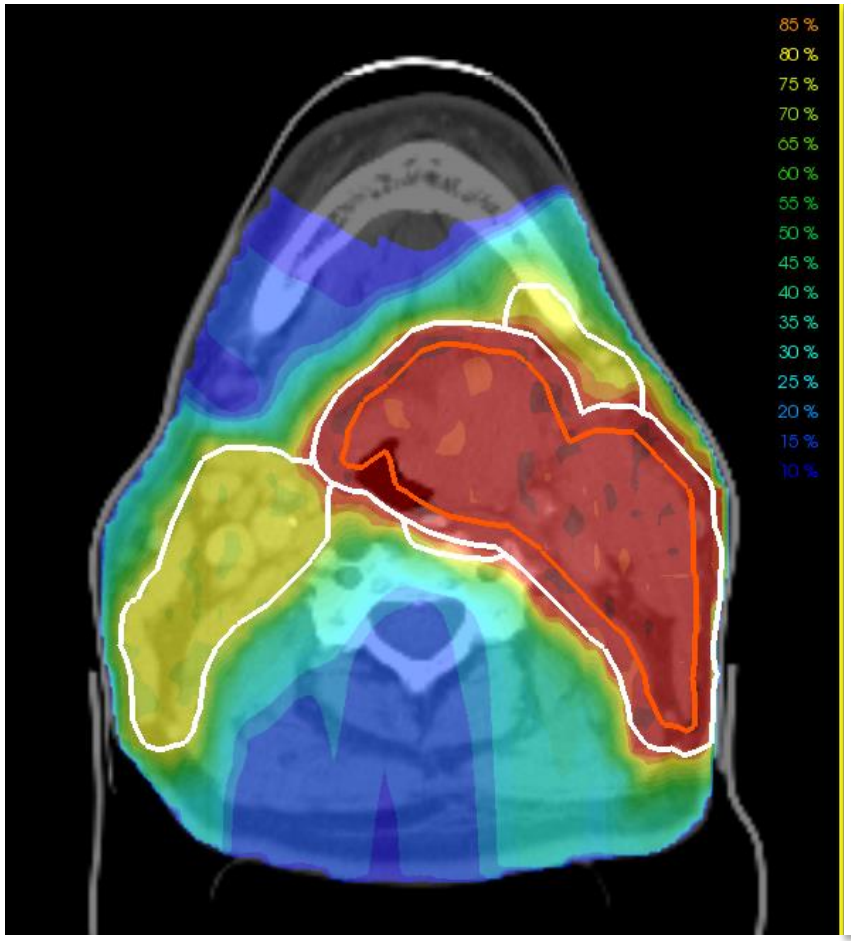



Sebastian van der Voort et al., manuscript submitted

# Anatomic Changes

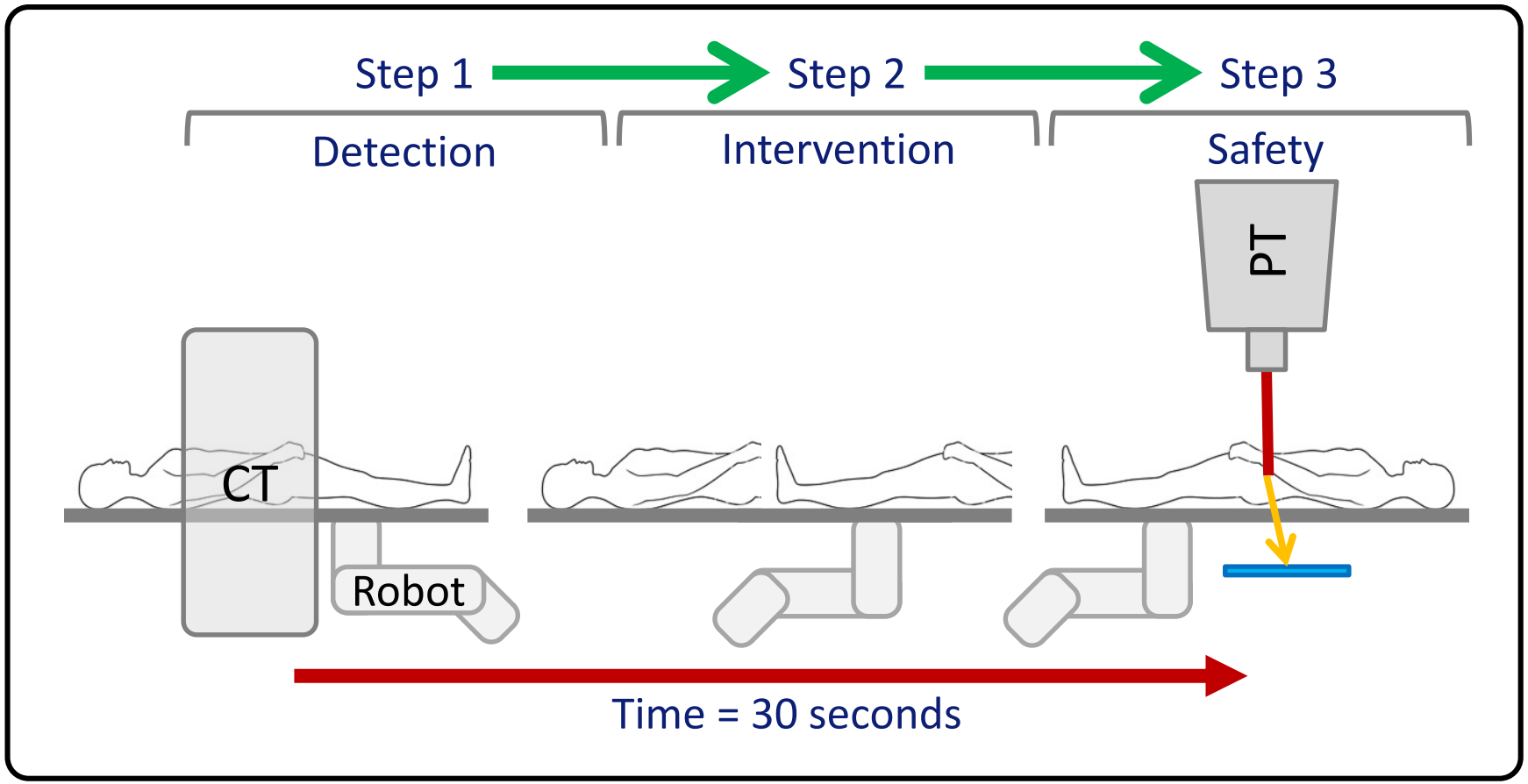

E Vasquez-Osorio et al. IJROBP 2008; dx.doi.org/1016/j.ijrobp.2007.10.063

# Dosimetric Changes




A Kraan et al. IJROBP 2013; dx.doi.org/10.1016/j.ijrobp.2013.09.014

# ADAPTNOW




ADAPTNOW project, Medical Delta collaboration funded by ZonMw and Varian

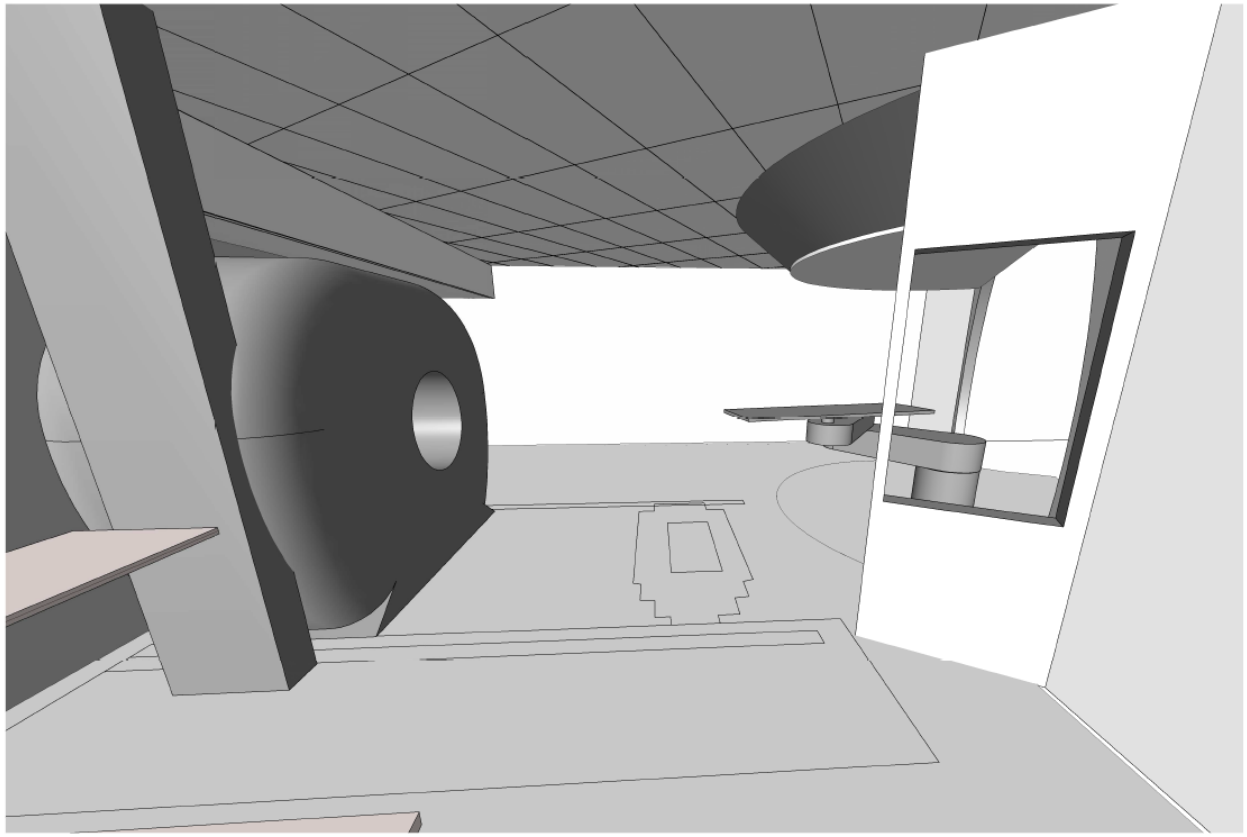
medical delta

Erasmus MC
Universitair Medisch Centrum Rotterdam

LUMC
Leids Universitair Medisch Centrum

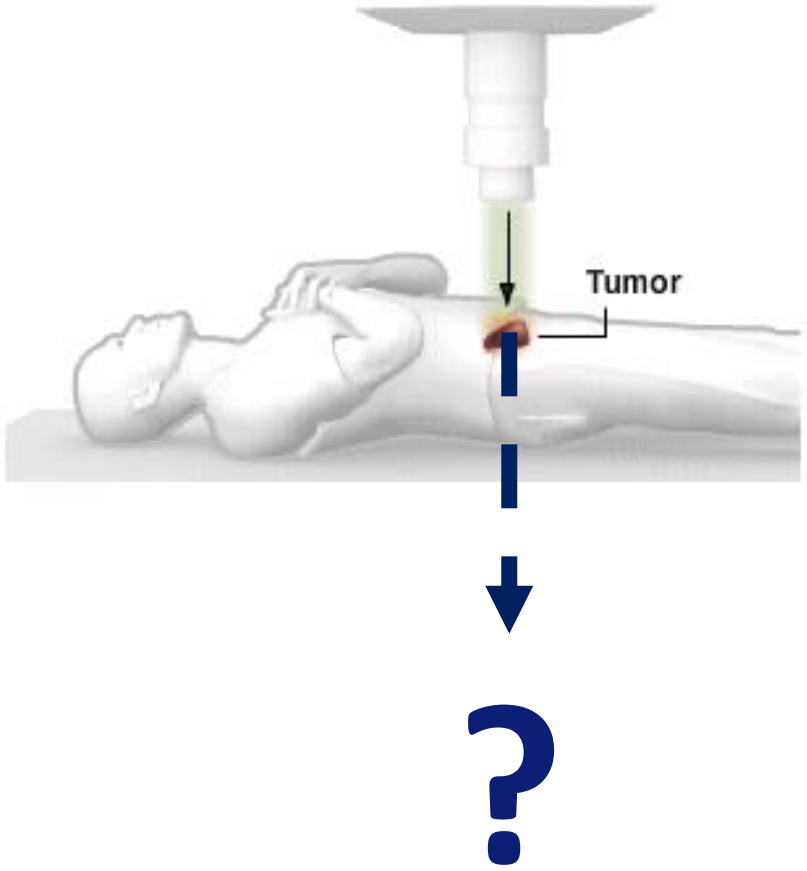
TU Delft

# In-room CT Scanner

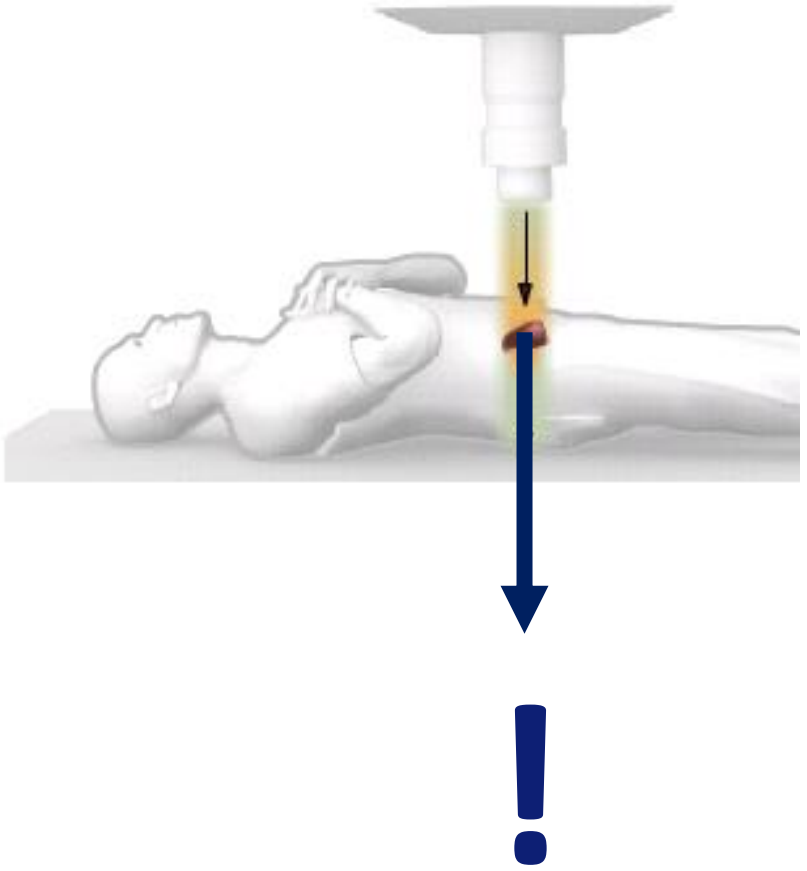


# Dose Verification

## Protons

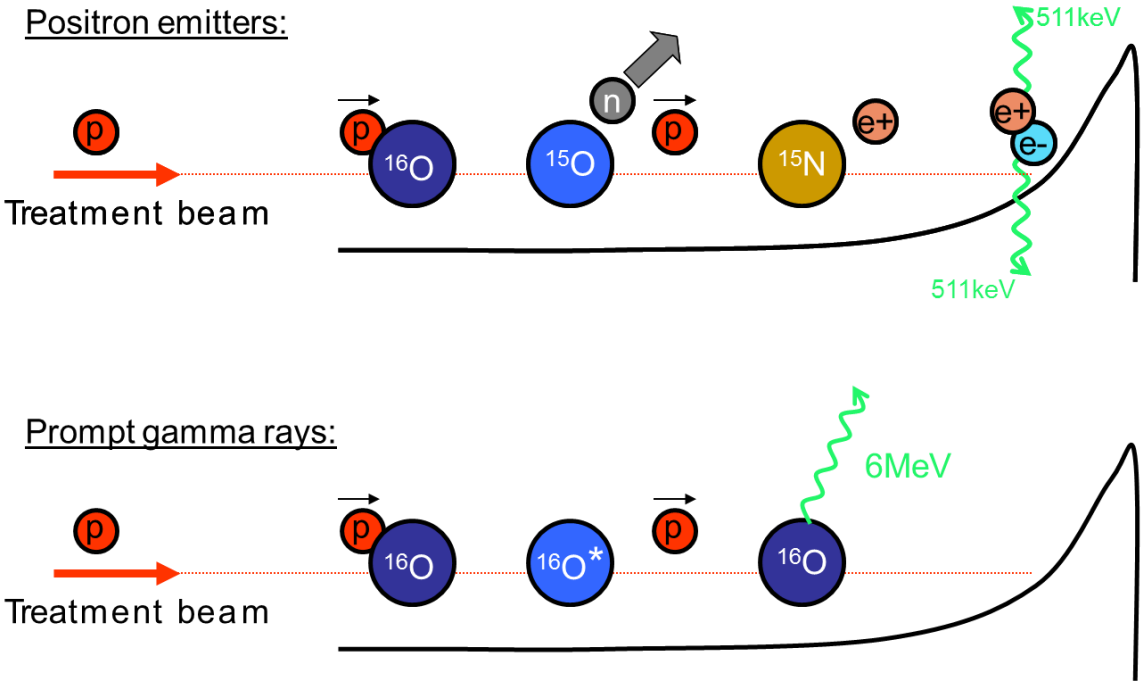



## X-rays



# In-Situ Dose Imaging

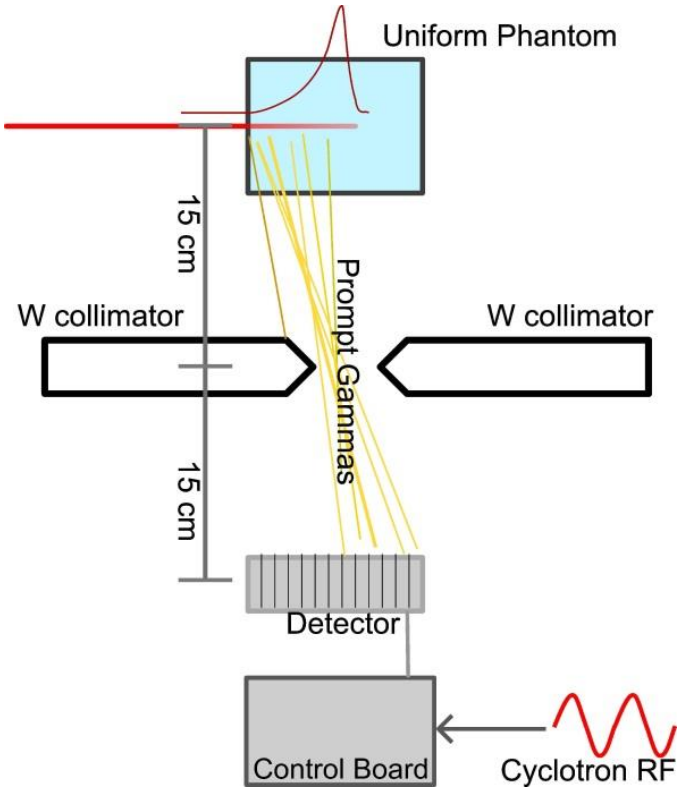
Human body > 90% Oxygen, Carbon, Hydrogen and Nitrogen

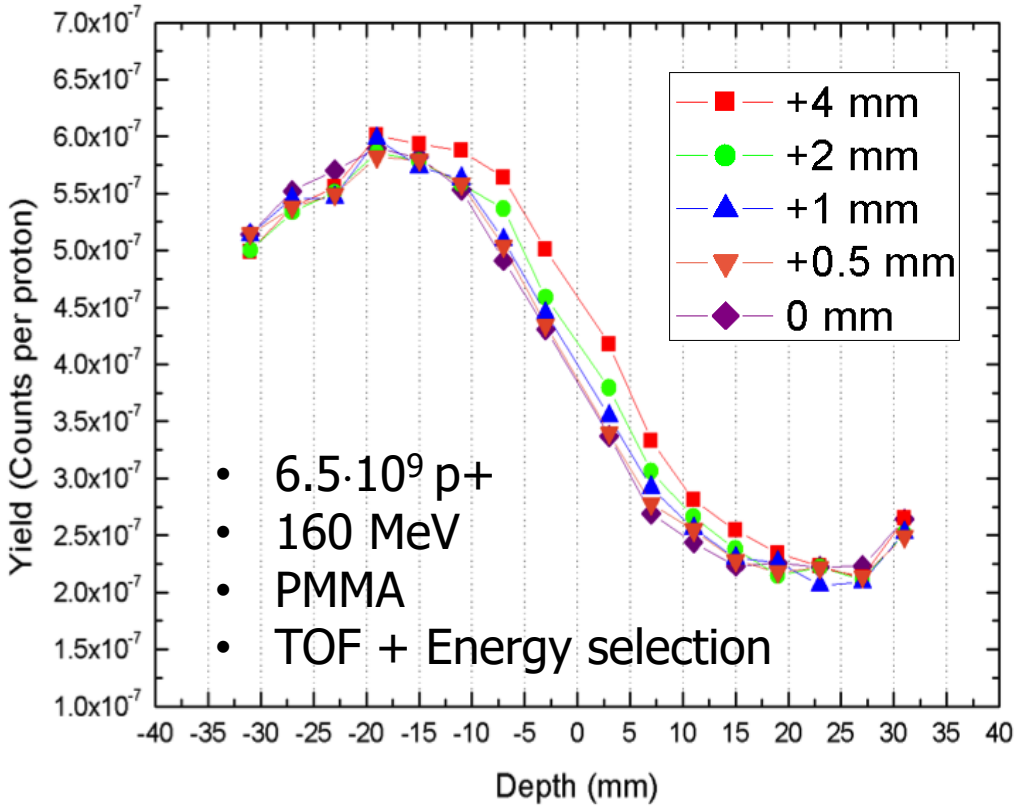



By D Schaart, ISoToPE project, Delft-Groningen collaboration funded by NIG-FOM

# Prompt gamma results

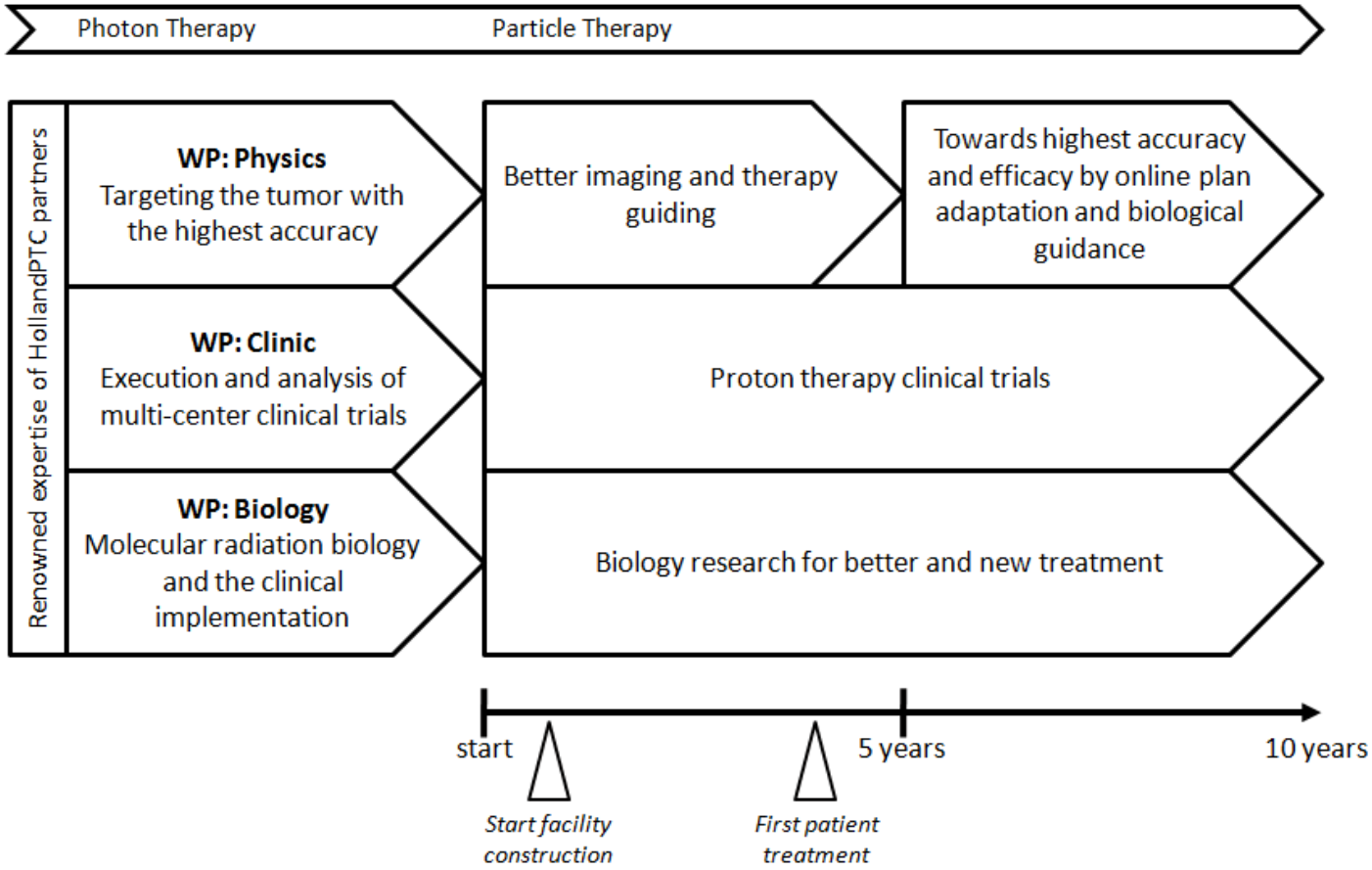
measured profile near Bragg peak
with TOF and energy selection




P.C. Lopes et al, Phys Med Biol 60, 6063-6085, 2015

# Research Goals



# Conclusions