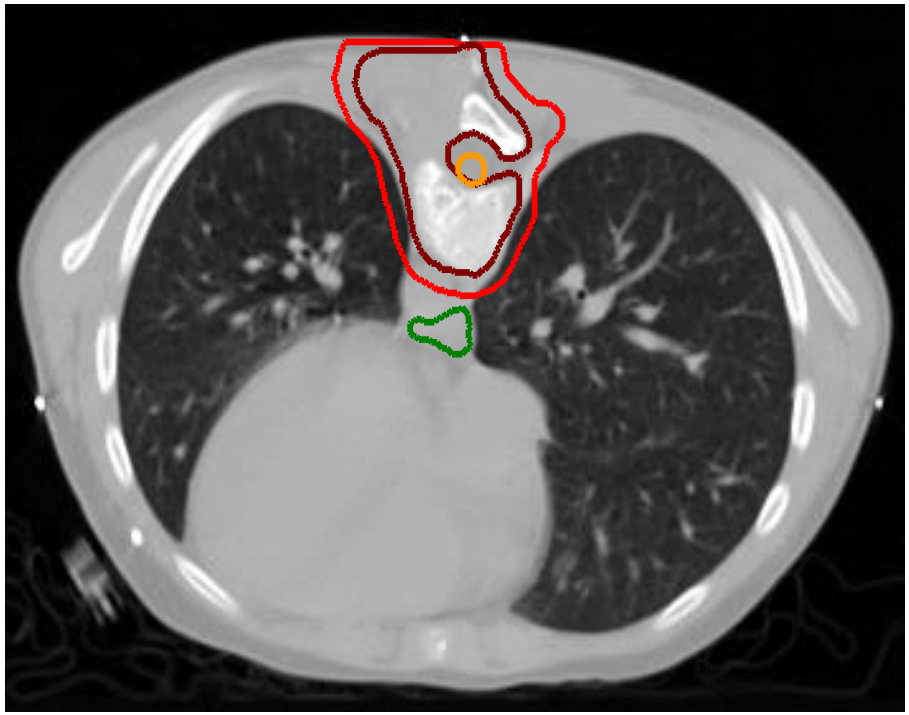
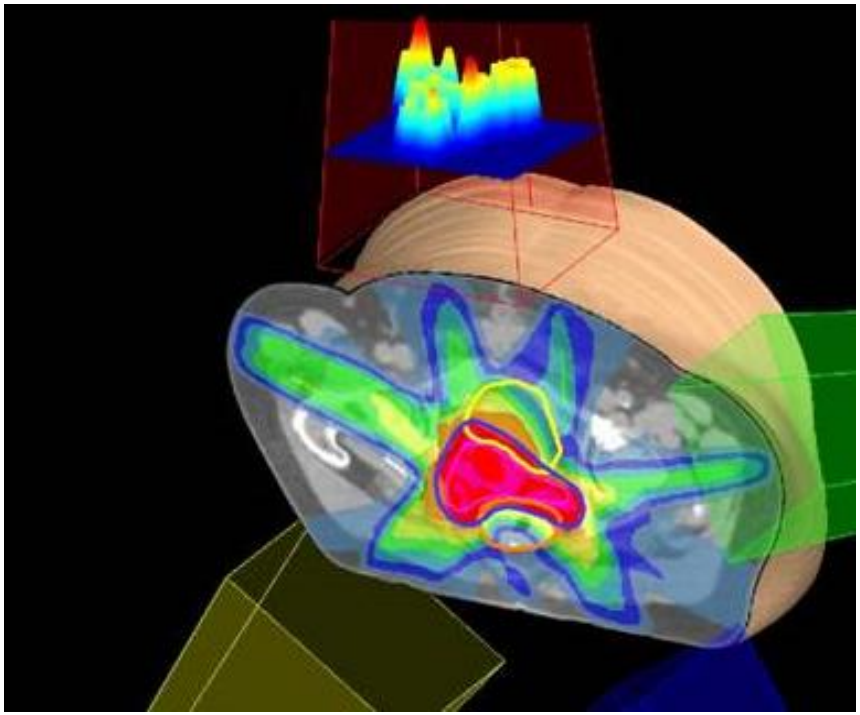
# Physics and Mathematics of radiotherapy planning

Introduction





# Cancer treatments

What types of cancer therapy are there?

# Cancer treatments

Types for cancer therapy:

Mainstay:

- Surgery
- Radiotherapy
- Chemotherapy
  - Cytostatic drugs
  - Targeted therapies
  - Immunotherapy

Niche / Experimental:

- Oncolytic viruses
- High focused ultra sound
- ...

# Cancer treatments

How many cancer patients receive radiation?

# Cancer treatments

How many cancer patients receive radiation?

**As a rule of thumb: about 50%**

Note: Most treatments are multi-modality

(Few patients receive radiation only)

# High level view on radiotherapy

Radiotherapy means irradiation with ionizing radiation

**Hierarchy of processes:**

ionization of atoms / molecules in the tissue
(physical processes) **Physics**

Damage to DNA molecules
(chemical processes, formation of free radicals) **Chemistry**

Induction of cell death / damage
(biological processes on cellular level, triggering of apoptotic pathways, repair processes) **Biology**

cancer cure / side effects in healthy tissues
(macroscopic effects on tissue / organ level) **Medicine**

# Radiotherapy planning process

1. Patient is diagnosed
2. CT scan is performed

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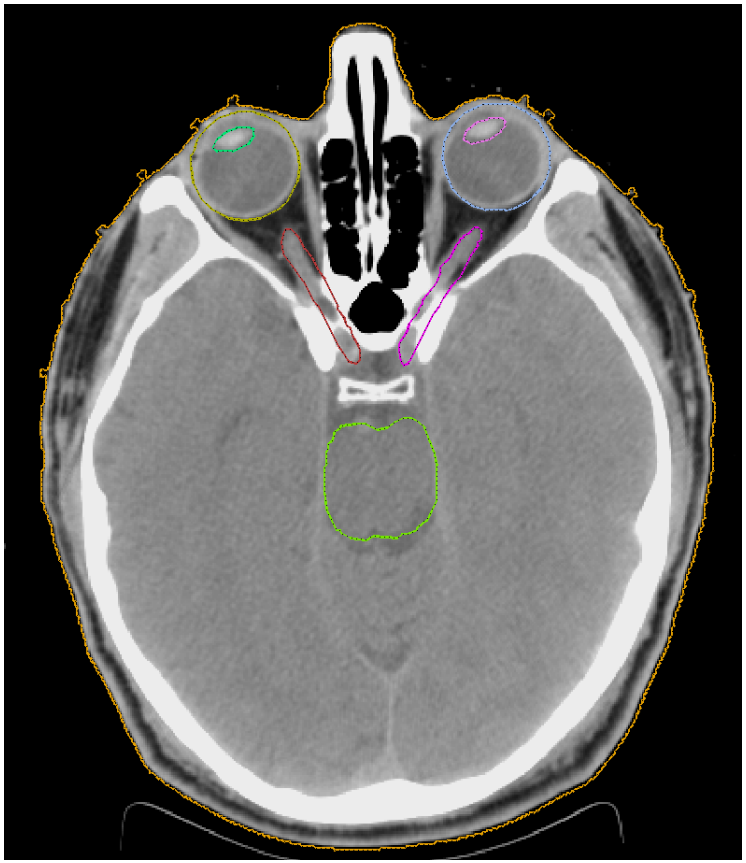

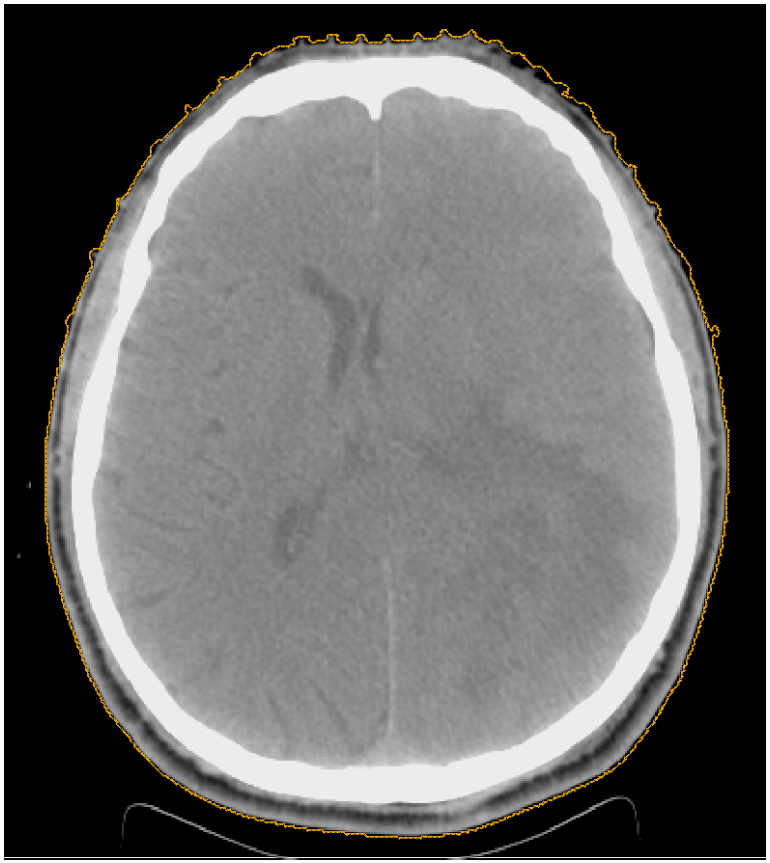

# Radiotherapy planning process

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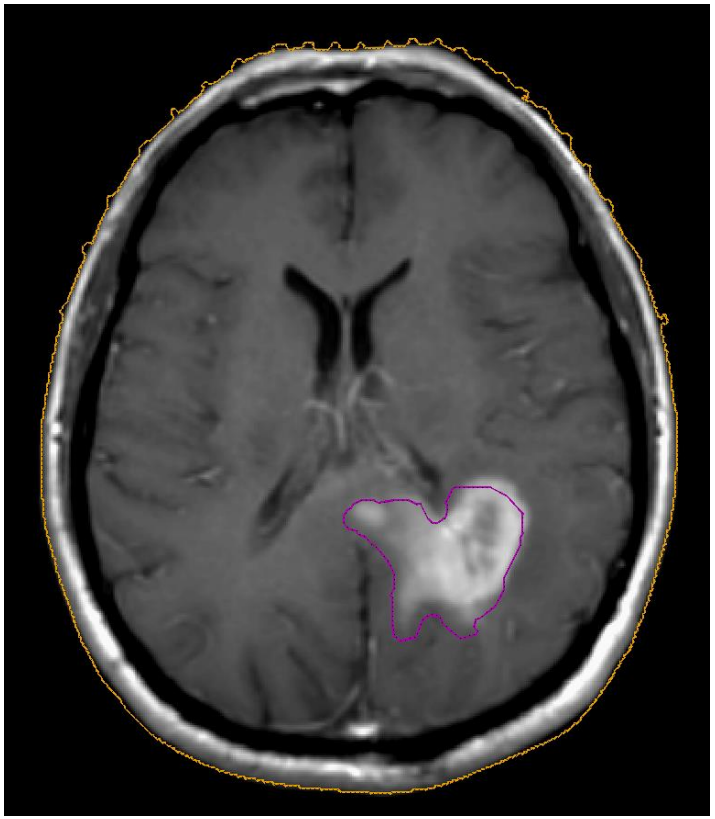
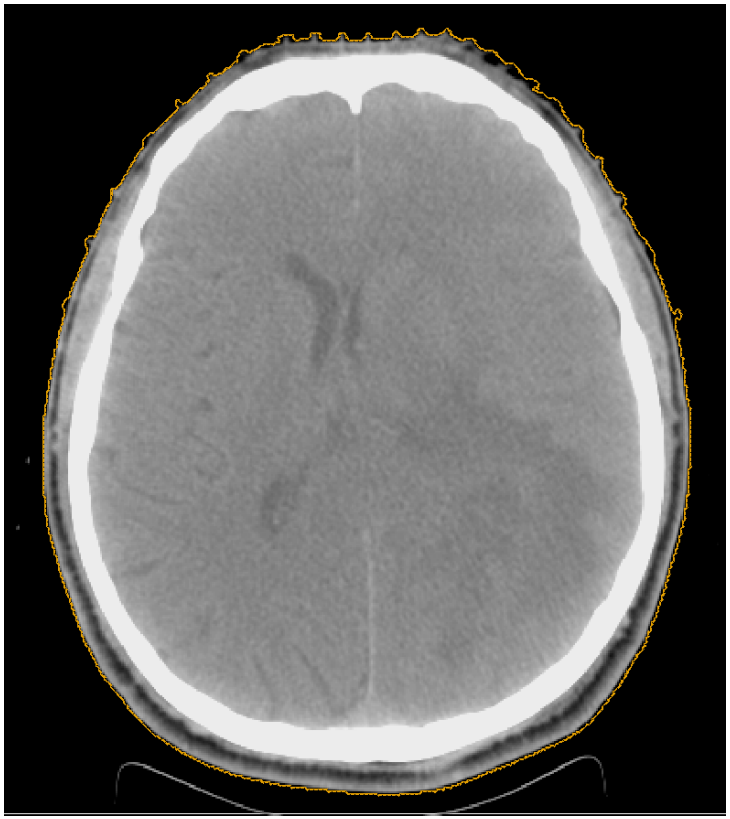
2. CT scan is performed (possibly MRI, PET in addition)



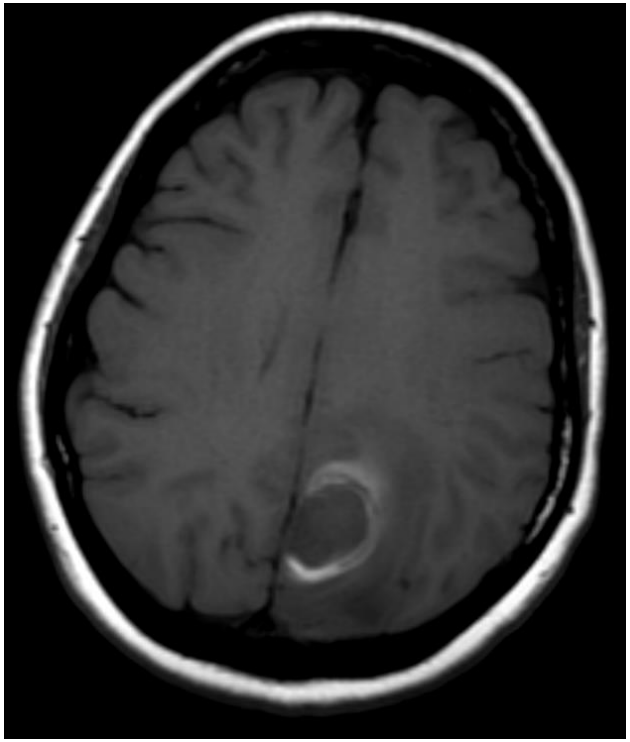
T1 weighted MRI



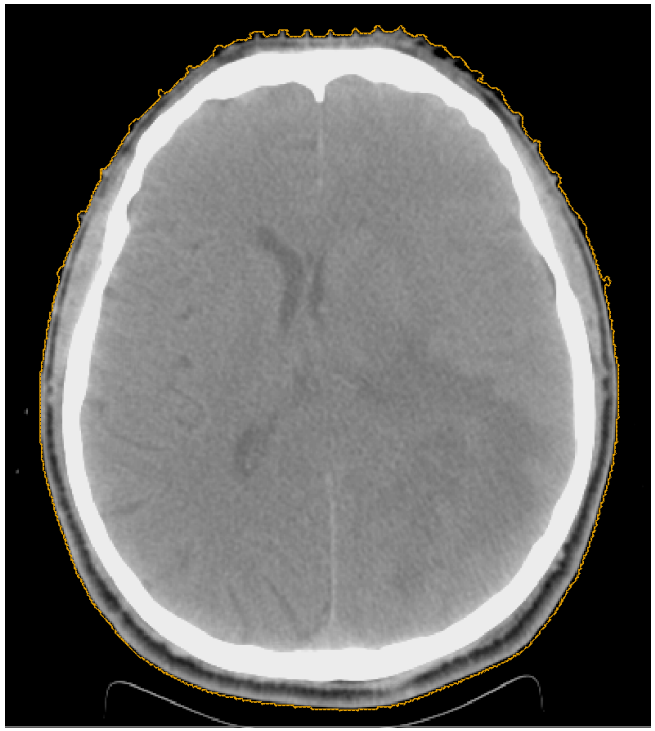
CT

# Radiotherapy planning process

1. Patient is diagnosed
2. CT scan is performed (possibly MRI, PET in addition)
3. CT and MRI images are registered

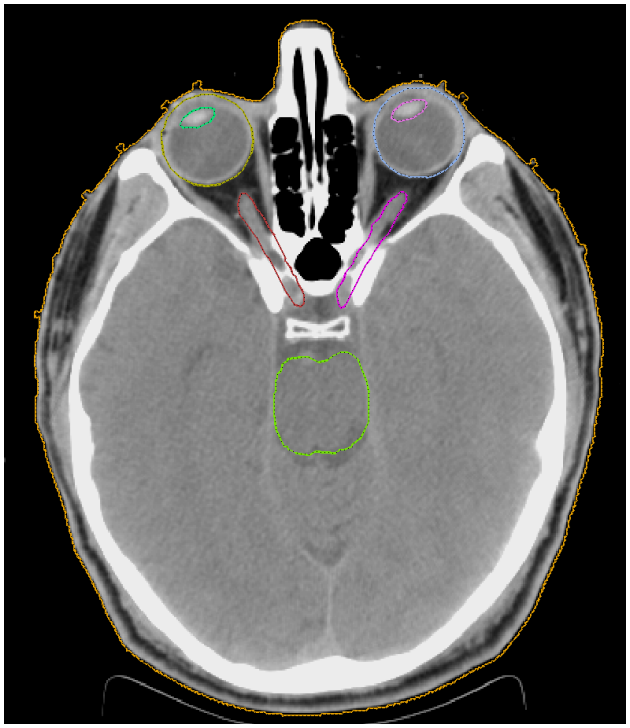


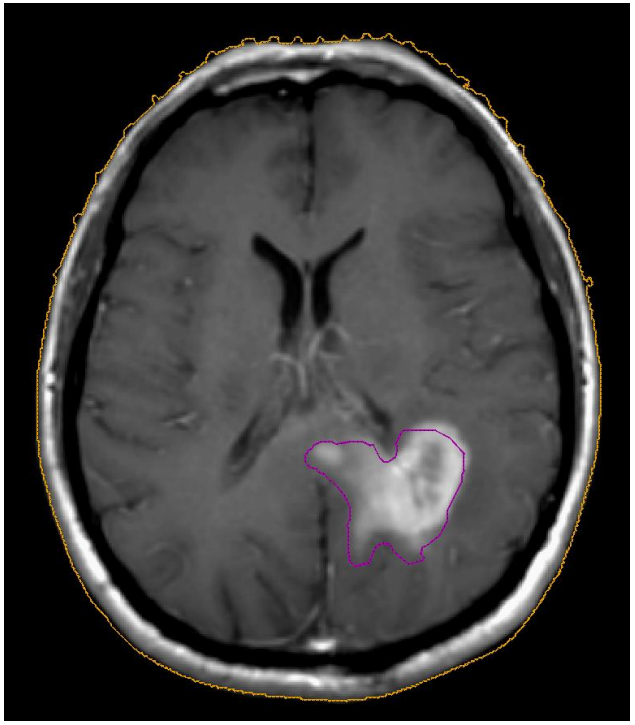
translation
rotation
deformation



# Radiotherapy planning process

1. Patient is diagnosed
2. CT scan is performed (possibly MRI, PET in addition)
3. CT and MRI images are registered
4. Tumor volume and radiosensitive organs are segmented





Glioblastoma

# Radiotherapy planning process

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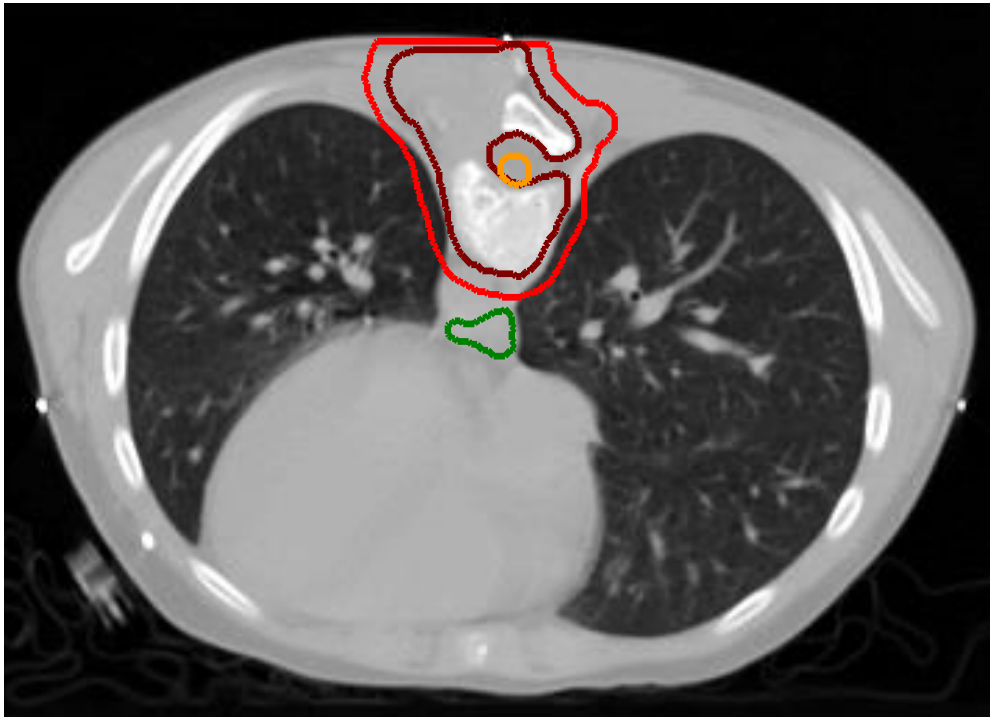

Spinal metastasis

# Radiotherapy planning process

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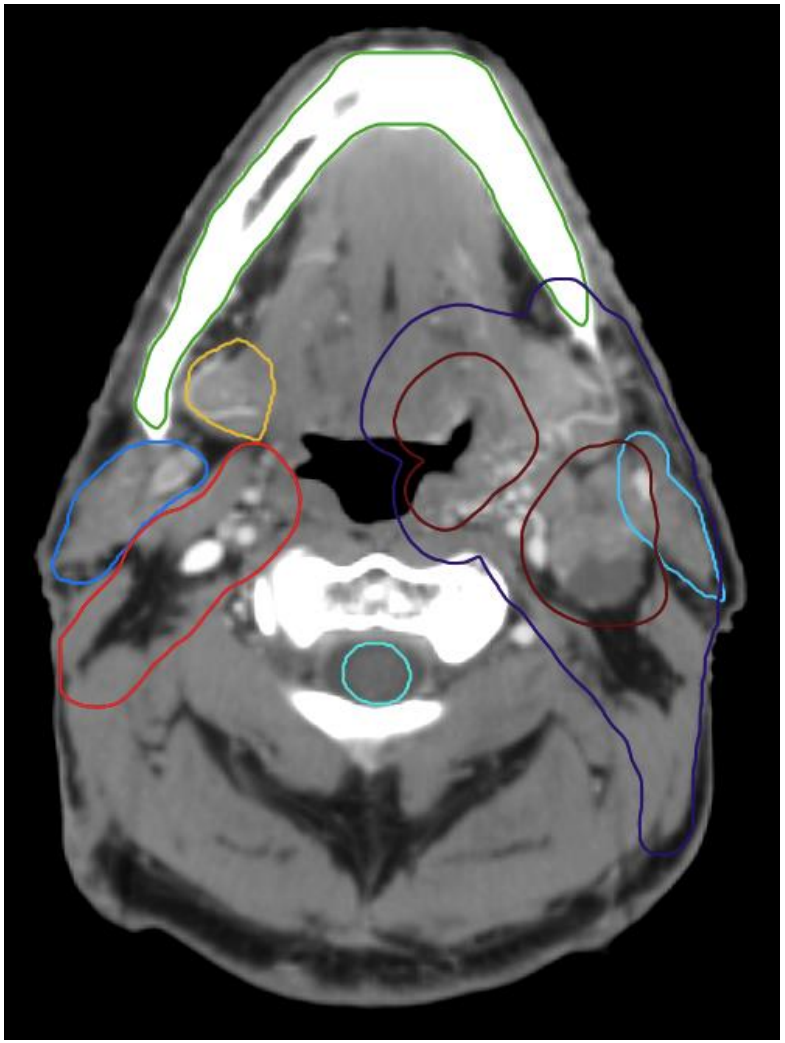


Head & neck tumor

# Radiotherapy planning process

1. Patient is diagnosed
2. CT scan is performed (possibly MRI, PET in addition)
3. Images are registered
4. Tumor volume and radiosensitive organs are delineated
5. A radiotherapy treatment plan is created

# Goal

**Goal:**

**Deliver therapeutic radiation dose to the tumor and minimize dose to normal tissue**

# Dose

**Dose**

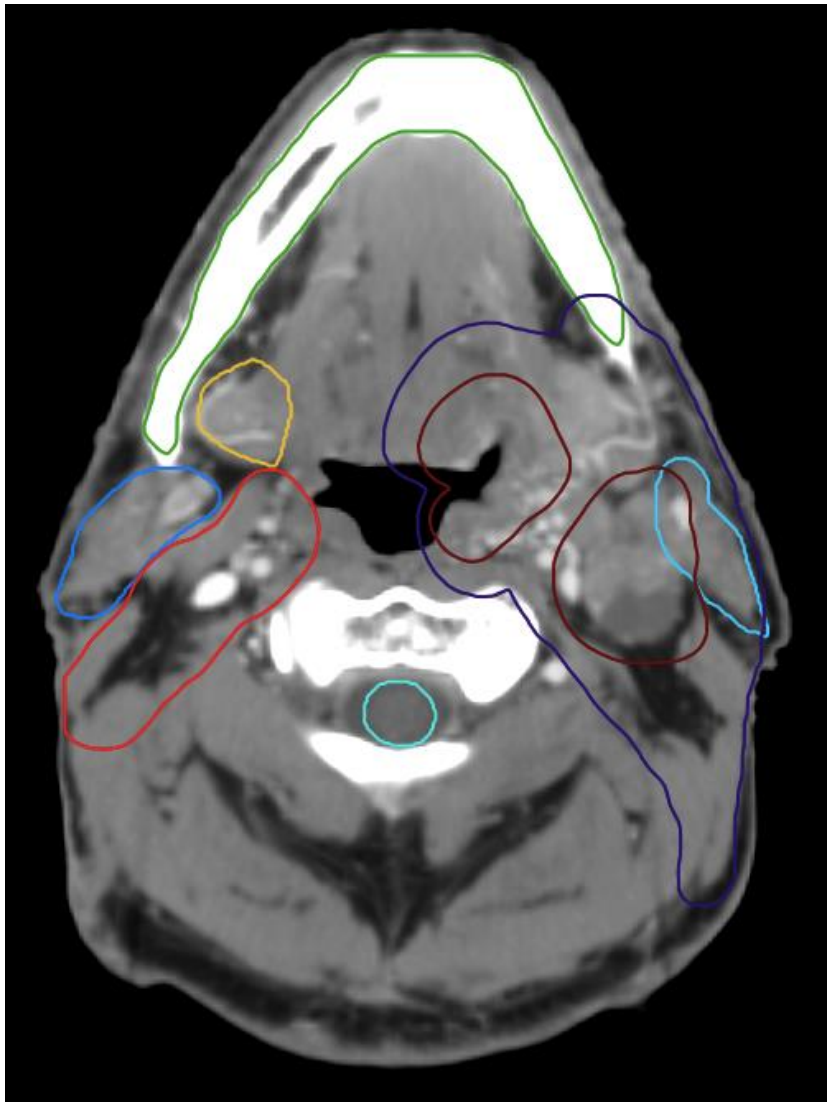
**Physical measure for the amount of radiation that affects a part of the patient**

Physical definition: absorbed energy per unit mass

**Dose distribution**

**3D distribution of dose inside the patient**

# Clinical prescription

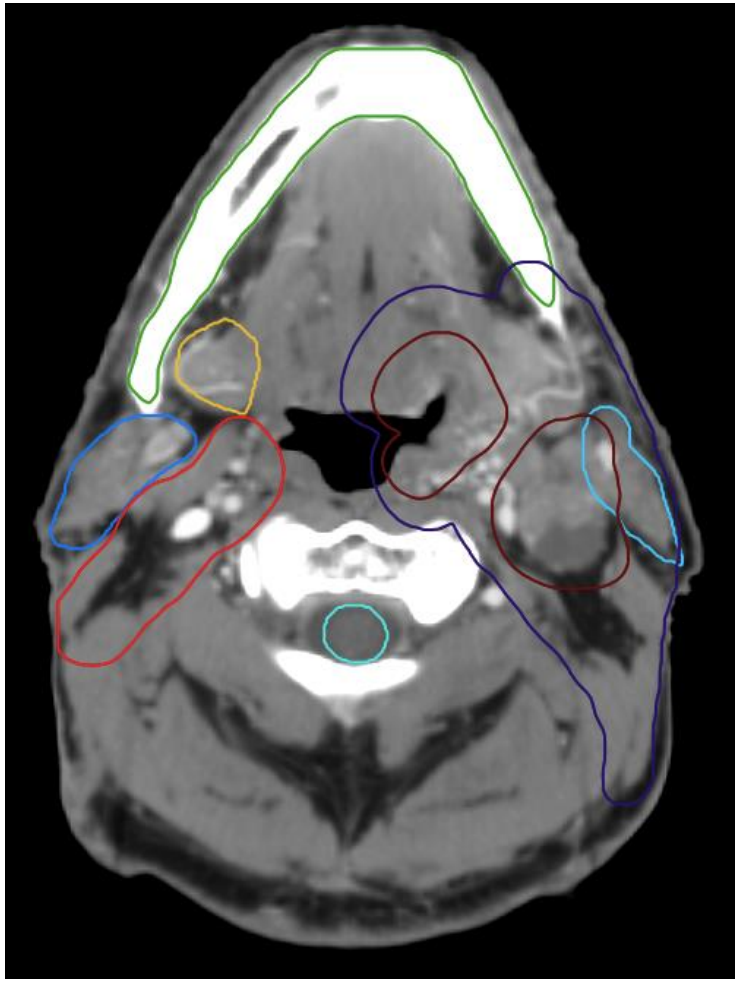


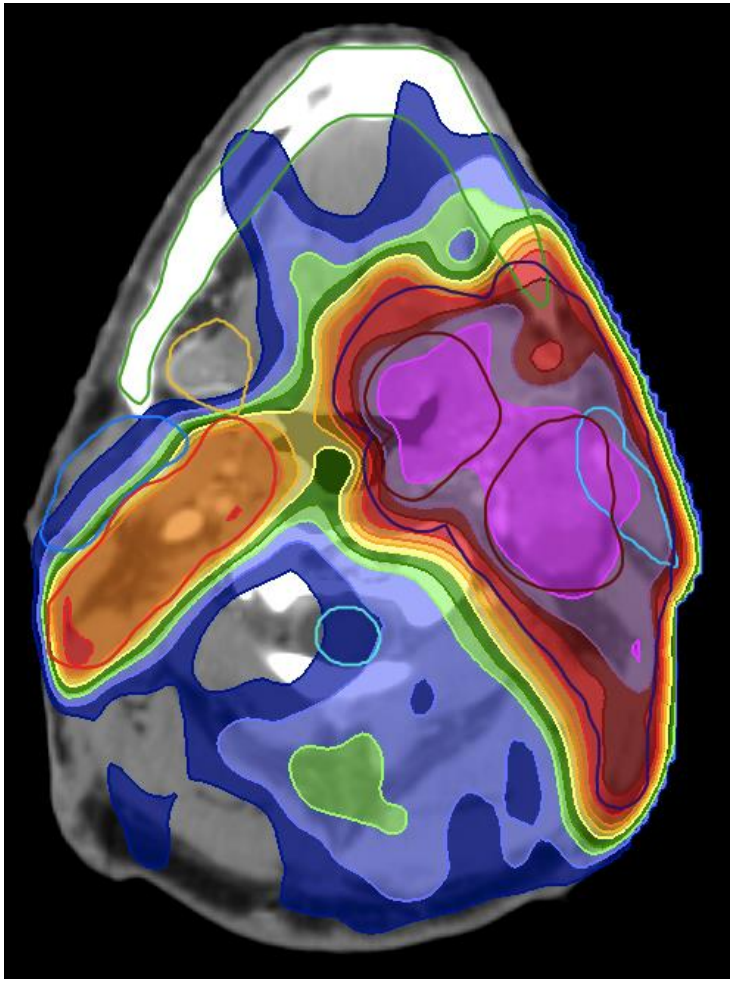
physician provides

- prescription dose
- normal tissue dose constraints

- 70 Gy to the tumor
- mean dose to the parotid gland less than 25 Gy

# Dose distribution





# Treatment planning

**How can a desired dose distribution be achieved with external radiation beams?**

# Content

## Treatment planning system

**Dose calculation**

Physics

Interactions of radiation in tissue

How much dose does each part of the patient receive for a given radiation field?

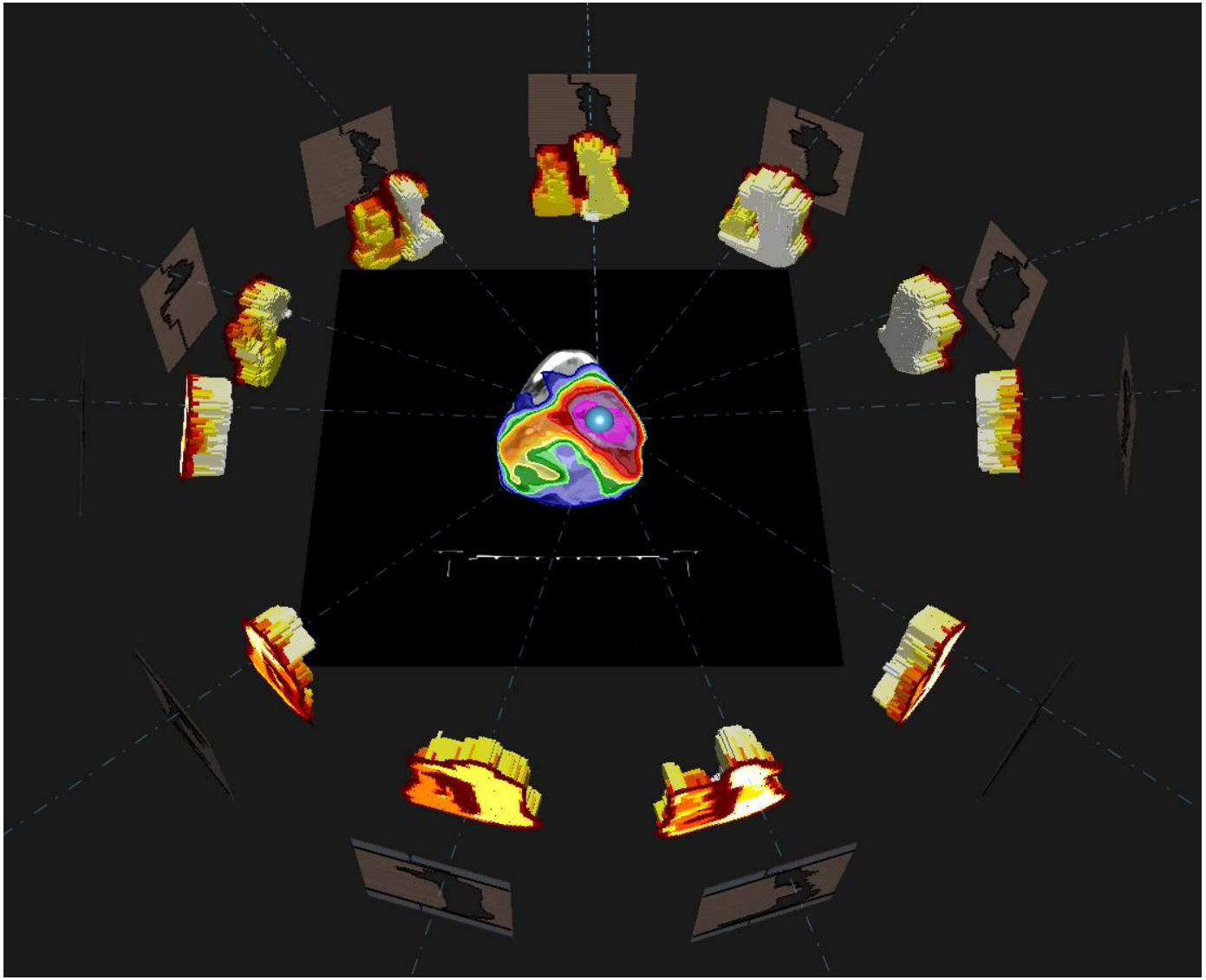
**Plan optimization**

Mathematics

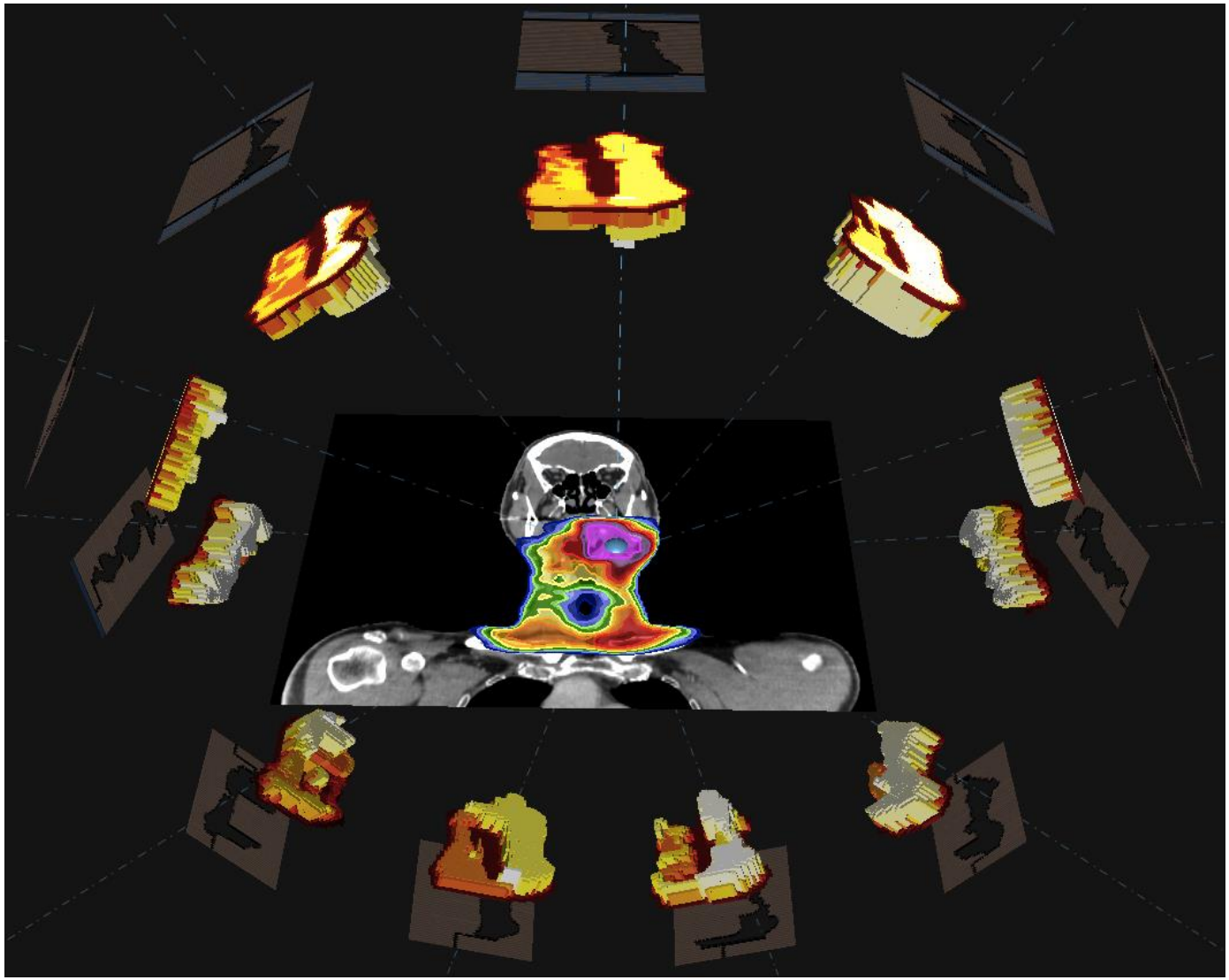
Mathematical optimization algorithms

What are the best possible radiation beams?

# Illustration



# Illustration

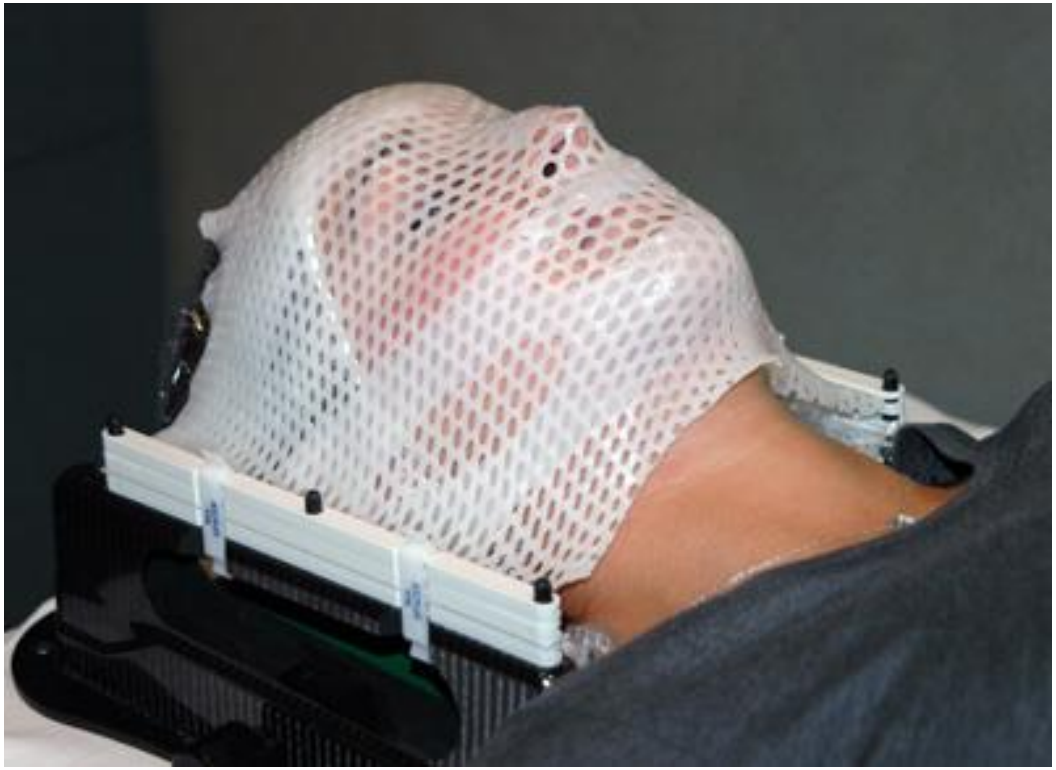


# Radiotherapy planning process

1. Patient is diagnosed
2. CT scan is performed (possibly MRI, PET in addition)
3. Images are registered
4. Tumor volume and radiosensitive organs are delineated
5. A radiotherapy treatment plan is created
    - physician provides prescription dose
    - treatment planner chooses incident beam directions
    - determines radiation fields
    - calculates final dose distribution
    - physician reviews/approves plan
6. Some QA is performed, dose measurements
7. Treatment starts

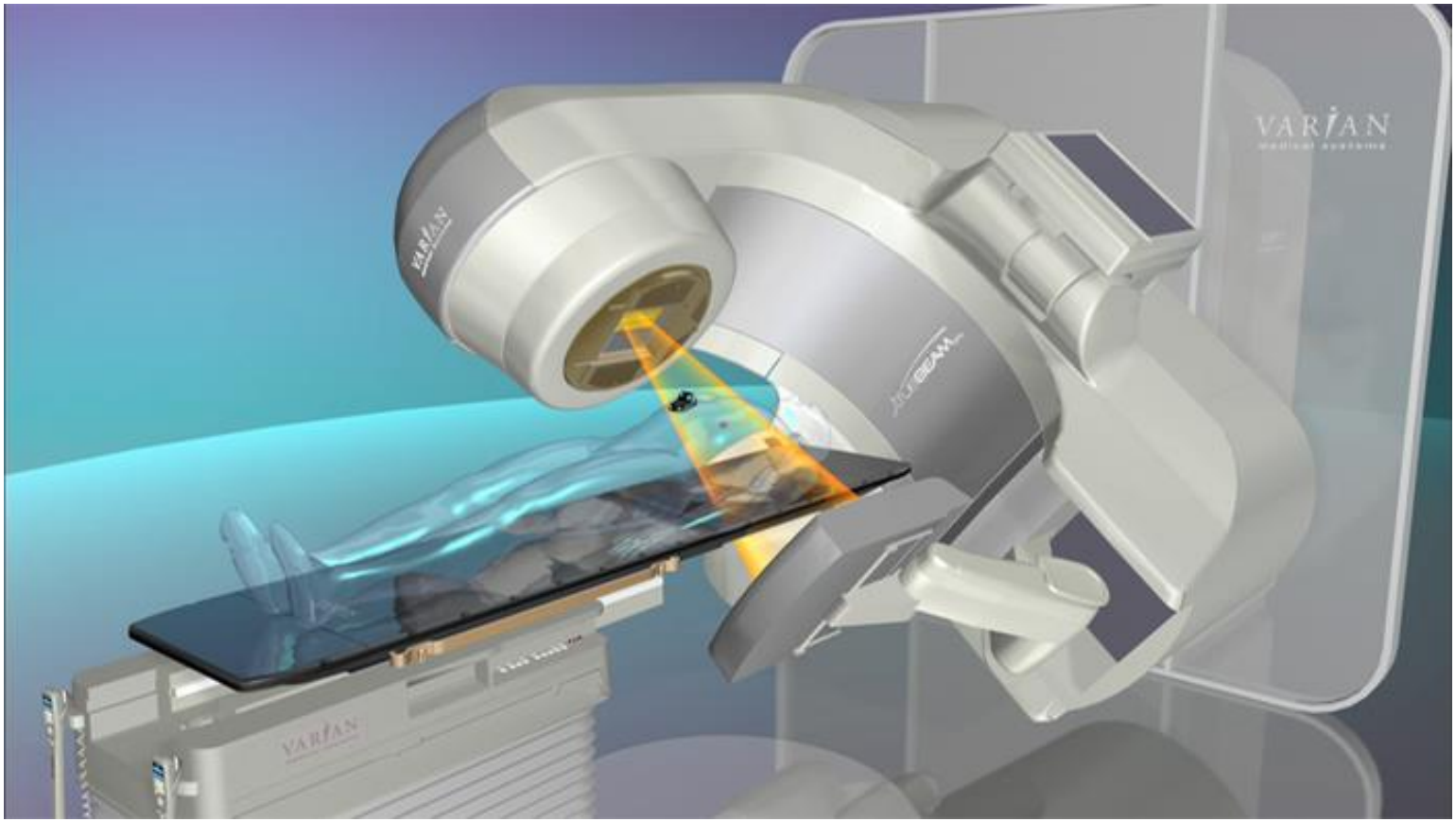
# Radiotherapy treatment process

1. Patient enters the treatment room
2. Patient is positioned relative to the treatment beam
    - position lasers
    - X-ray imaging
    - fixation devises



# Radiotherapy treatment process

2. Patient is positioned relative to the treatment beam
3. Patient is irradiated (typically over several weeks)




Linac

# Radiotherapy treatment process

Cyber knife

# Types of irradiation

# Types of irradiation

**Vast majority of treatments:**

High energy X-rays 1 ... 10 MeV

**Some superficial tumors (e.g. breast cancer):**

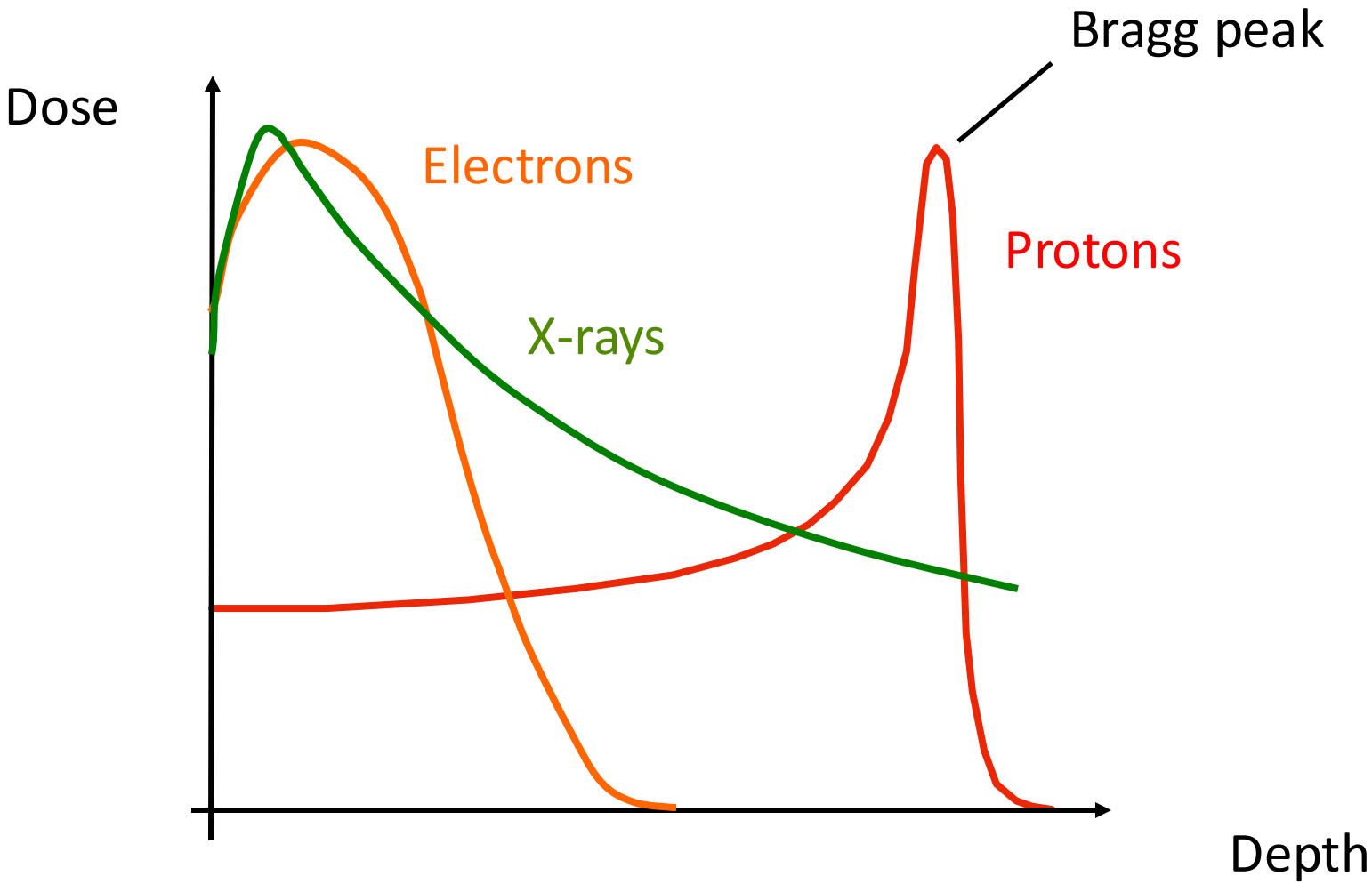
Electrons 6 ... 18 MeV

**in the order of 100 centers world-wide**
(http://ptcog.web.psi.ch)

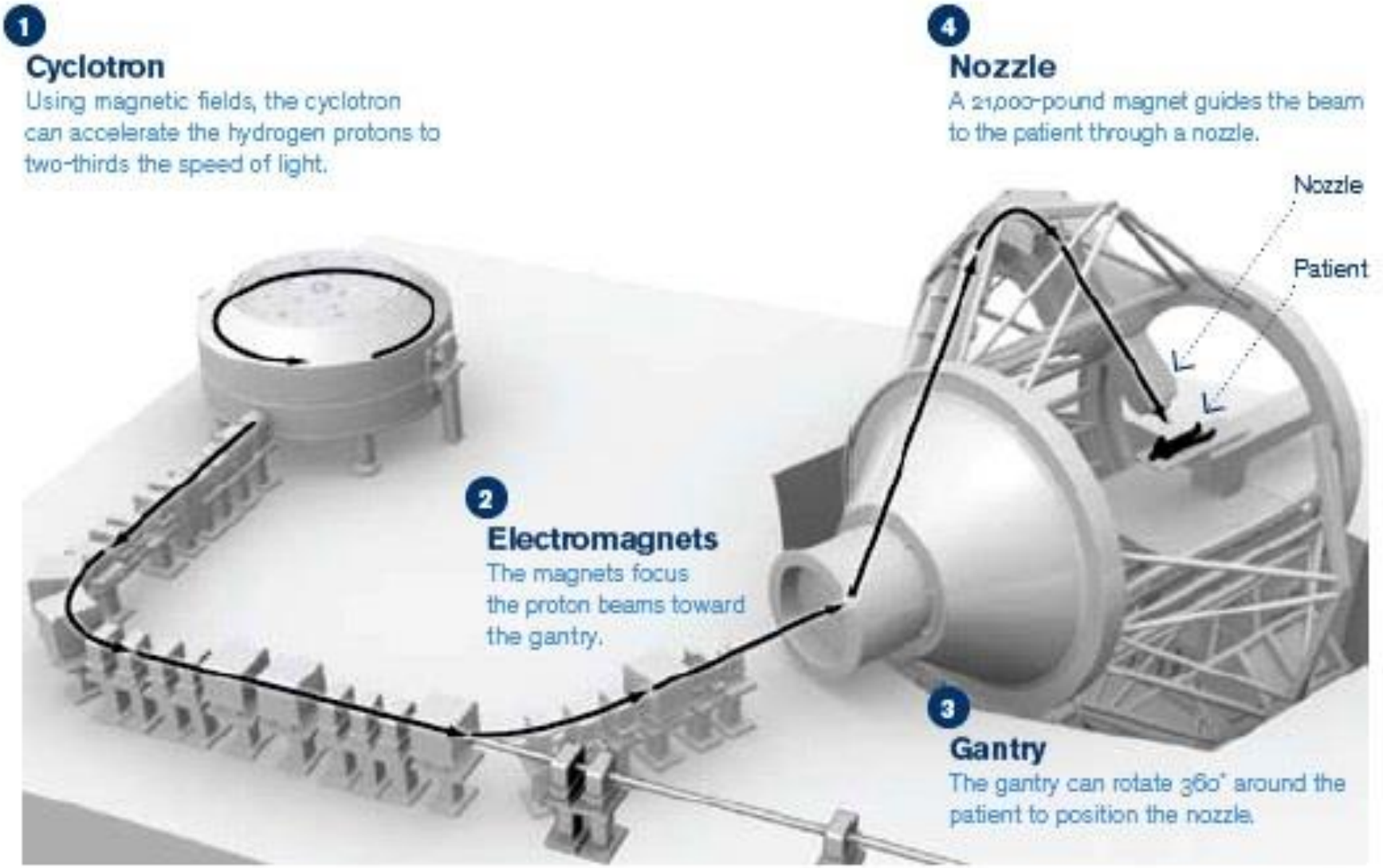
Protons 250 MeV

# What is the advantage of Protons?

**The proton depth dose curve**



# What is the problem with Protons?



# Other particle types

**Currently in use:**

Carbon ions (5 Japan, 2 Germany, 1 Italy, 1 China, 1 Austria)

**In the past:**

Neutrons (few centers operating for selected tumors)

Pions

He, Ne, O

**Funny ideas:**

Anti-Protons

# Course overview

# Syllabus

| | |
|---|---|
| 17.09.2025 | Introduction |
| 24.09.2025 | Photon interactions |
| 01.10.2025 | Pencil beam algorithm |
| 08.10.2025 | Convolution-Superposition algorithm |
| 15.10.2025 | Proton interactions |
| 22.10.2025 | Proton depth dose curve |
| 29.10.2025 | Proton pencil beam algorithm |
| 05.11.2025 | Fluence map optimization 1 |
| 12.11.2025 | Fluence map optimization 2 |
| 19.11.2025 | Direct aperture optimization |
| 26.11.2025 | Advanced treatment plan optimization methods |
| 03.12.2025 | USZ Visit |
| 10.12.2025 | Advanced treatment plan optimization methods |
| 17.12.2025 | Current research topics in treatment planning |

# Relation to other classes

Medical Physics 1, Manser

Interactions in matter, radiation sources, dose measurements

Medical Physics 2, Manser

clinical dosimetry, beam characteristics, treatment planning

MAS (ETH)
Medical Physics

Physics against cancer, Lomax/Schneider

Overview

## Specialized / In-depth lectures

Monte-Carlo in Medical Physics, Fix/Stampanoni

Therapeutic applications of particle physics, Lomax

Physics and Mathematics of radiotherapy planning, Unkelbach

# Exercises

Main goal:

Implement the main components of a radiotherapy treatment planning system in Python

- dose calculation algorithm
- treatment plan optimization algorithm

- in two dimensions (one slice of a CT)
- otherwise relatively realistic

# Exercises

unless stated otherwise,

- assignments are due two weeks after they are handed out

  (questions can be discussed after one week)

- submit Python files, possibly brief report
- solutions will be presented in class by one of you

# Grading

Two components:

| | |
|---|---|
| Homework assignments | pass/fail |
| Final oral exam | grade |

# Literature

Treatment planning in Radiation Oncology

Khan, Gibbons, Sperduto (Editors), Wolters Kluwer, 2016