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THESSALONIKI

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Introduction to Particle Therapy

Aristeidis Mamaras,

Aristotle University of Thessaloniki, AUTh & CERN

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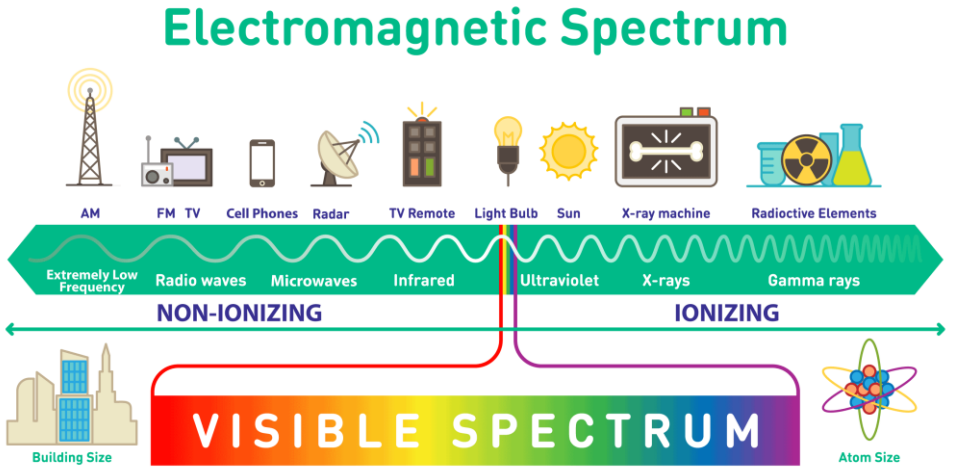
1. What is Radiation Therapy?

- uses ionizing radiation to produce DNA damage to cancer cells
- its goal is to kill or “control” the cancer cells and at the same time spare healthy cells
- different modalities are in use:
  - conventional radiation therapy
    - electrons
    - photons
  - particle therapy
    - hadrons: mainly protons, neutrons also possible
    - Ions: mainly carbon ions



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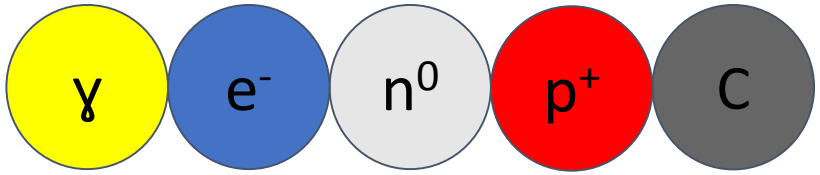
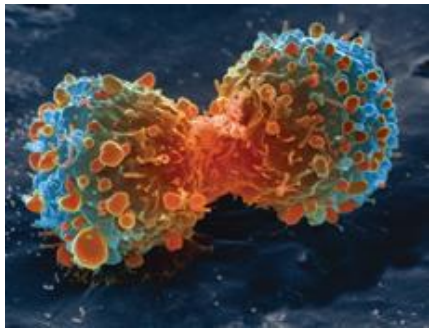


[1] Medium – Electromagnetic spectrum. Accessed from https://medium.com/@tajamulfayaz621/electromagnetic-spectrum-b80002a65665.

2. Cancer

- is uncontrolled cell proliferation and cell rampant growth
- cancer may spread to other parts of the body
- over 100 different types, individual



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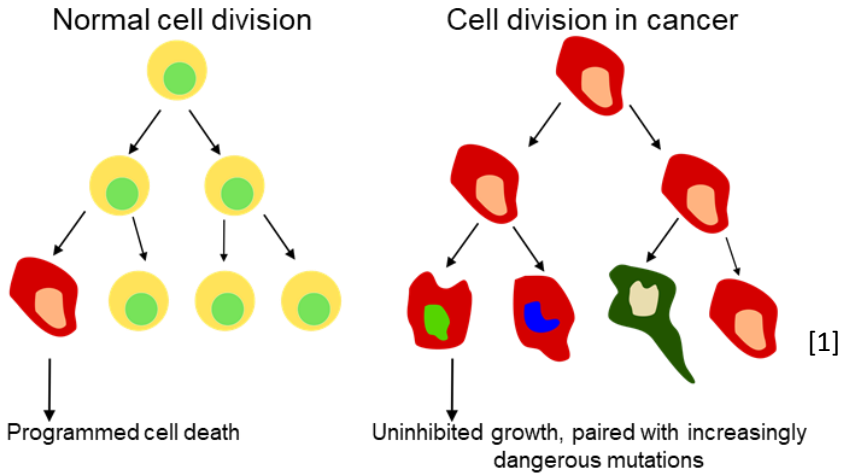
Cancer cell of a lung tumor during cell proliferation

Theory of cancer formation:
(random) mutation levers out normal programmed cell death
→ cells need to be removed / killed "manually" for treatment

healthy cells vs. cancer cells

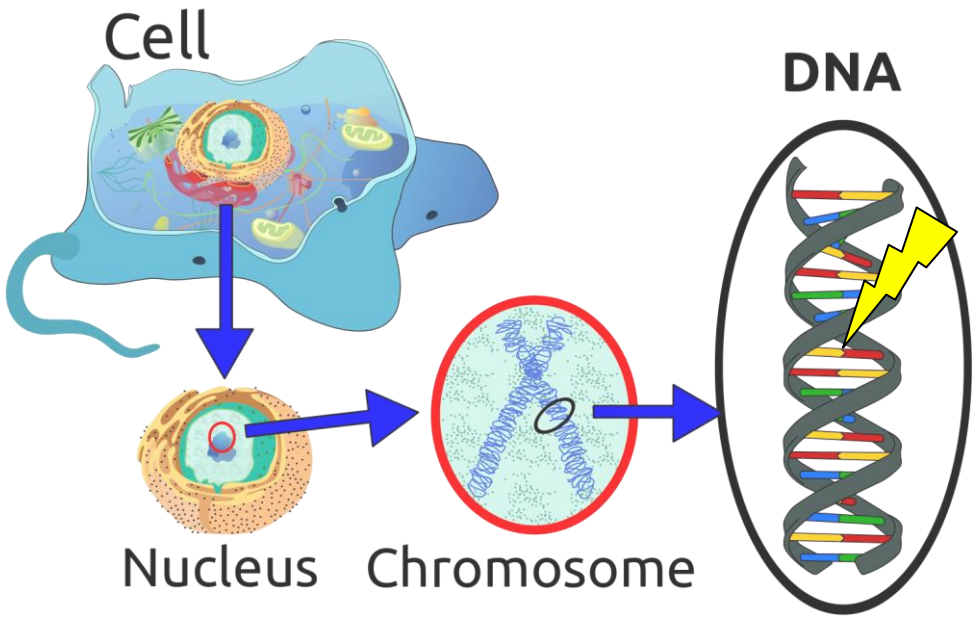


[1]

[1] Garak76, Suhadi Jorhaa'ir (https://commons.wikimedia.org/wiki/File:Zellteilung_normal_im_Gegensatz_zu_Krebs.svg), „Zellteilung normal im Gegensatz zu Krebs"
[2] fineartamerica - Lung Cancer Cell Division. - Accessed from https://fineartamerica.com/featured/lung-cancer-cell-division-sem-steve-gschmeissner.html?product=metal-print on 12.02.2021. Lettering was adapted.

3. Radiotherapy - Biology

> 50% of all cancer patients receive radiotherapy [1]



[2]

Physical phase: 10^{-18} to 10^{-14} s

Elementary physical interactions between ionizing radiation and atom

Chemical phase: 1ms to ~ min

Reactive radicals react with molecules of the cell and change their chemical composition

Biological phase: after 1s to years

Cell death, loss of function of the organism

Serial organs: e.g. spinal cord

Parallel organs: e.g. lung

[1] Atun R. Jaffray et. al, Expanding global access to radiotherapy. Lancet Oncol., 2015

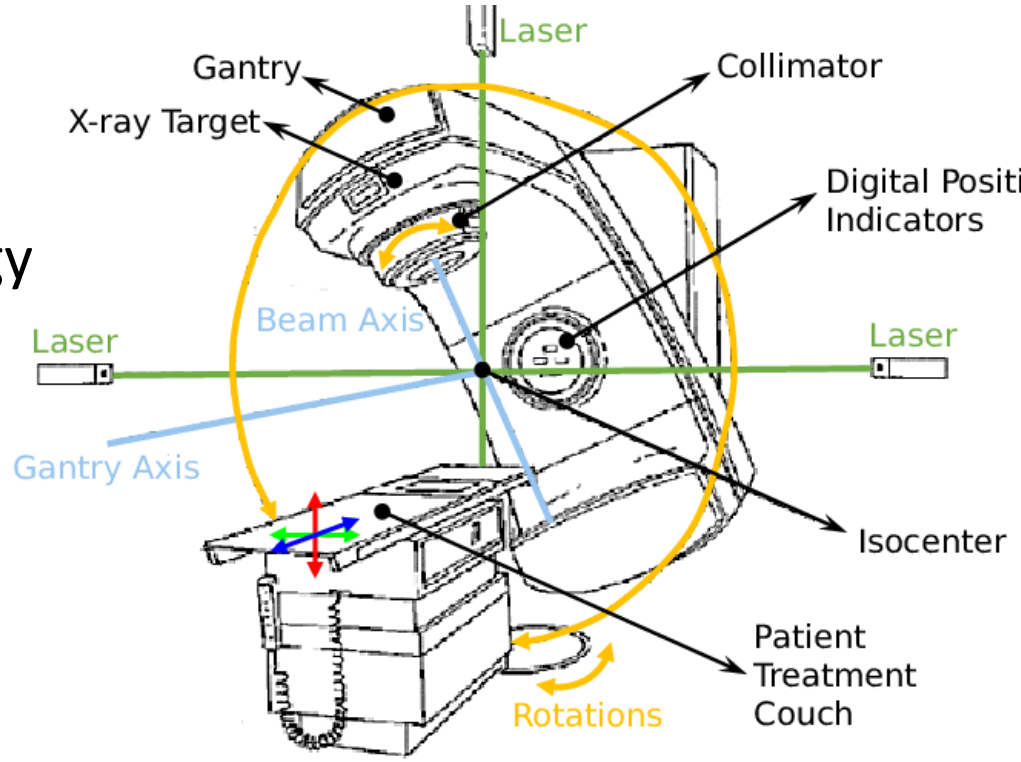
[2] Sponk, Tryphon, Magnus Manske, User:Dietzel65, LadyofHats (Mariana Ruiz), Radio89 (https://commons.wikimedia.org/wiki/File:Eukaryote_DNA-en.svg), „Eukaryote DNA-en“, https://creativecommons.org/licenses/by-sa/3.0/legalcode

4. Conventional radiation therapy

- Uses photons: massless, no electric charge and travel always at the speed of light
- no “acceleration”, but frequency dependent energy

How to generate? We can accelerate electrons!

- accelerated electrons hit a target
- electrons lose energy due to “bremsstrahlung” **high-energy photons**



[1]

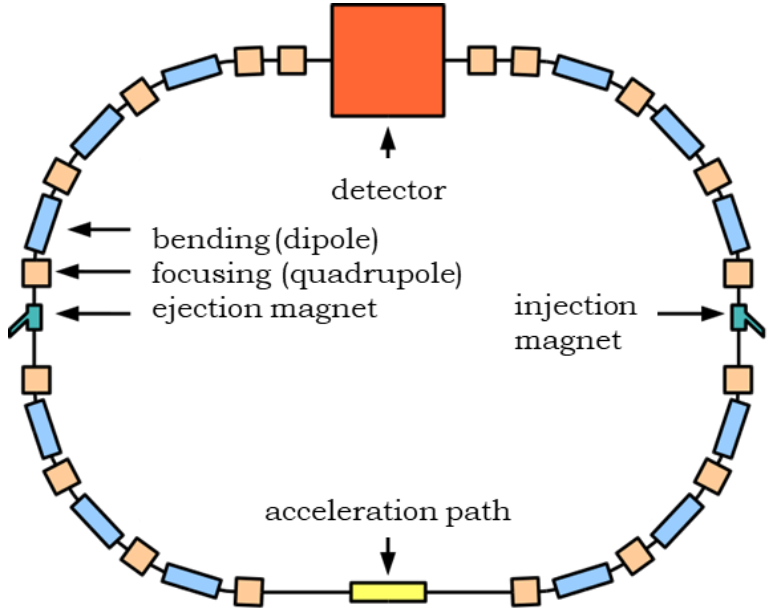
- gantry: moves the radiation source around the patient
- coach: rotates the patient

[1] ResearchGate – Schematic depiction of a linear accelerator (LINAC) used in External Beam Radiation. Accessed from https://www.researchgate.net/figure/Schematic-depiction-of-a-linear-accelerator-LINAC-used-in-External-Beam-Radiation_fig1_334378462.

5. Particle therapy – particle accelerator

How do we accelerate high energy protons or ions?

- acceleration with electric fields
- linear or **circular accelerator**
  (depending on the required energy)
  → e.g. Large Hadron Collider LHC (CERN)
- the bigger the particle‘s mass,
  the more energy, power and size is needed
  for its acceleration
- big and expensive accelerators are needed



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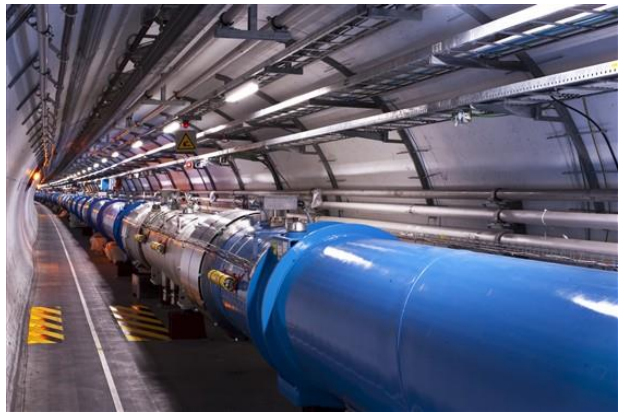

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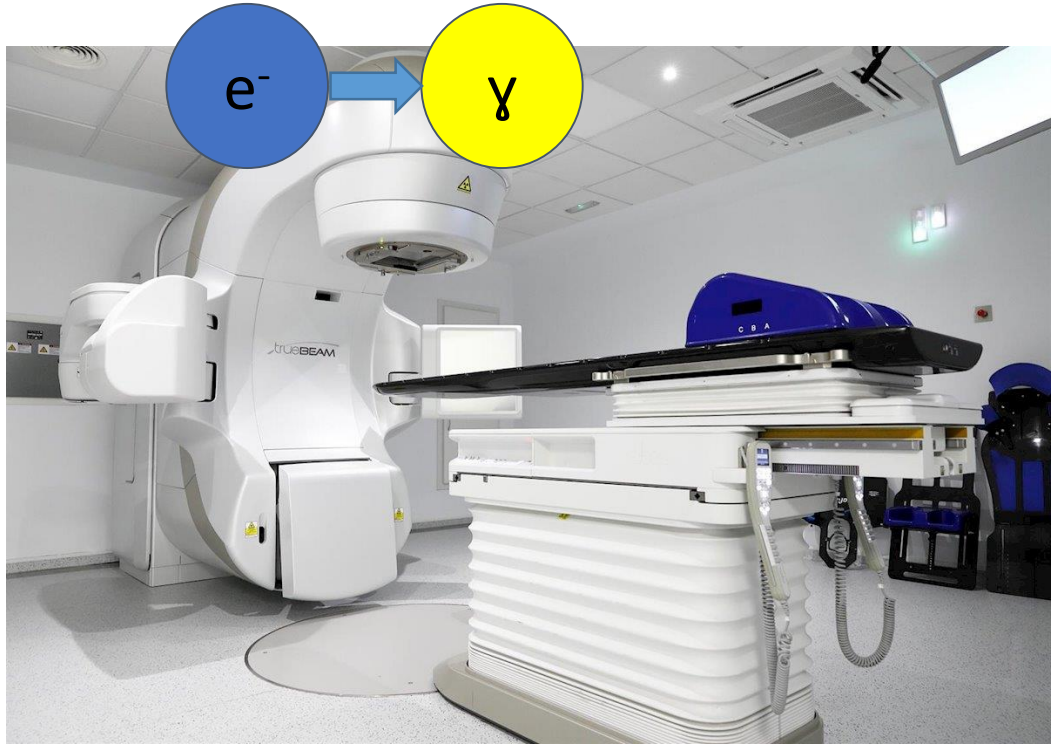
[1] Maximilien Brice (https://commons.wikimedia.org/wiki/File:CERN_LHC.jpg), https://creativecommons.org/licenses/by-sa/4.0/legalcode
[2] No machine-readable author provided. Florian DO assumed (based on copyright claims). (https://commons.wikimedia.org/wiki/File:Storage_ring_de.svg), „Storage ring de“, lettering was adapted, https://creativecommons.org/licenses/by-sa/3.0/legalcode

6. Machines



LINAC – Linear accelerator

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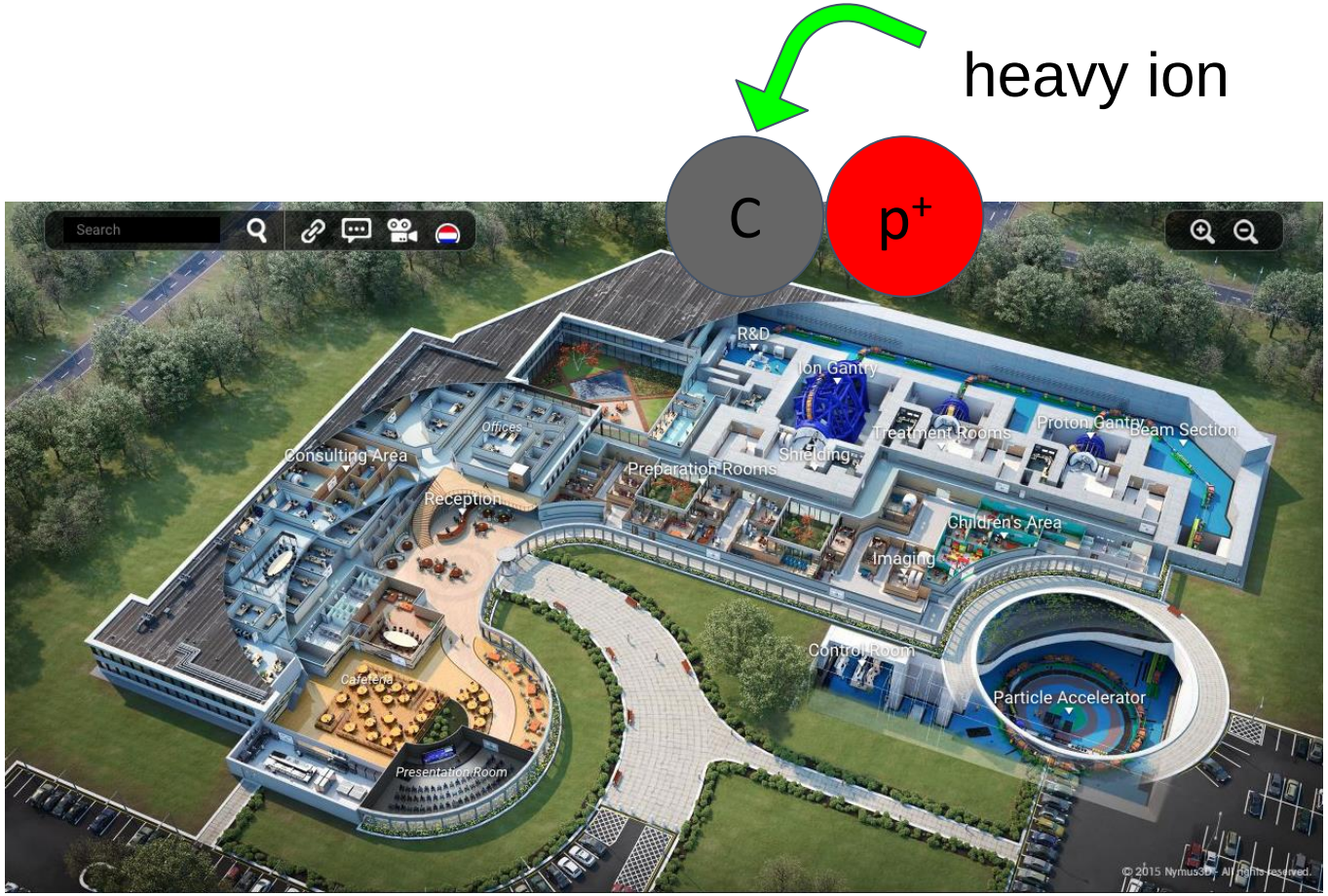


Circular accelerator

$$$$$$

6. Machines

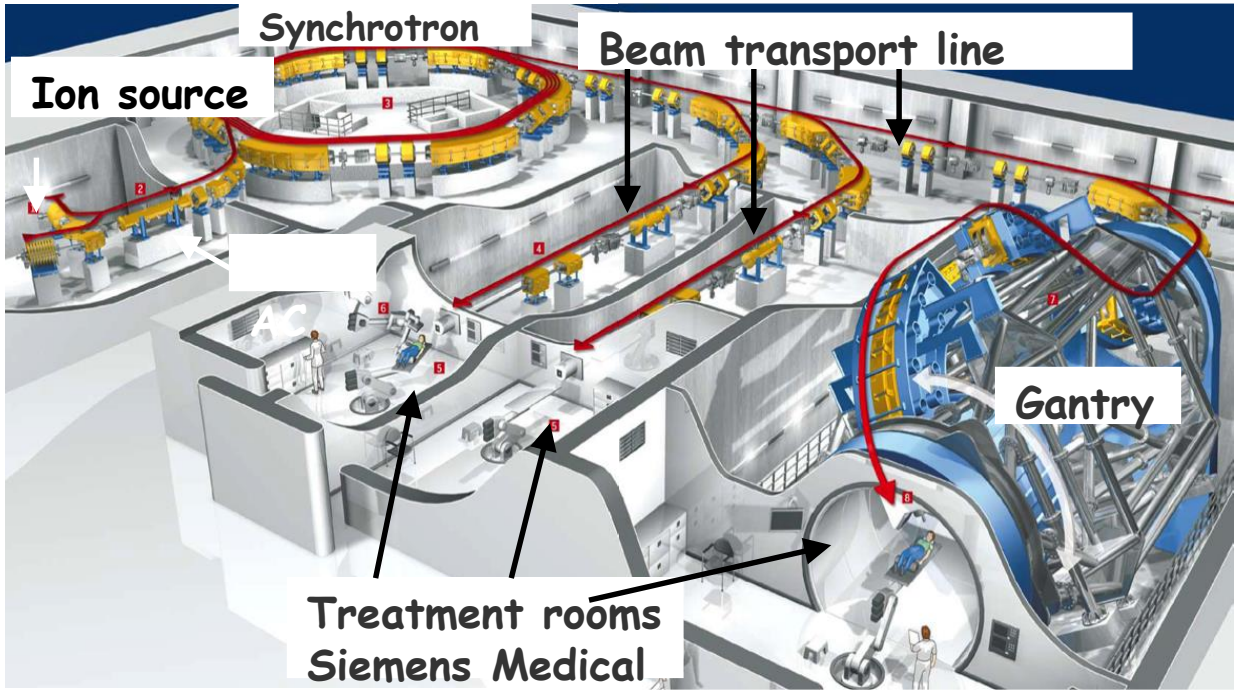
All particle treatment centers have static beam lines

Some of them have rotating gantries (common for protons, but only 2 in the world that work with carbon ions).

The system of reference or “center” is usually placed in the tumour (in the **isocenter**).

We will work with the rotating gantry.

Heidelberg Ion-Beam Therapy Center (HIT)



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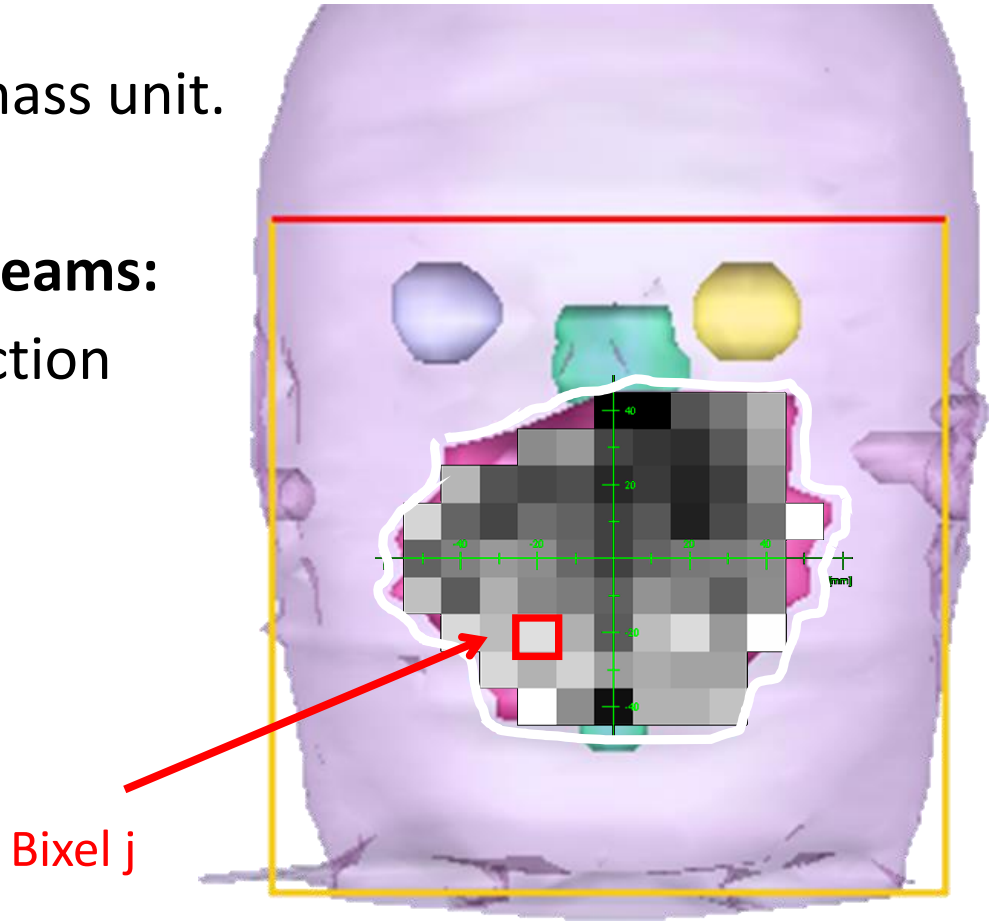
[1] Universitätsklinikum Heidelberg – HIT Broschüre - HIT Ionentherapieanlage. Accessed from https://www.klinikum.uni-heidelberg.de/fileadmin/hit/dokumente/HIT_Broschuere.pdf on 12.02.2021

7. Important concepts

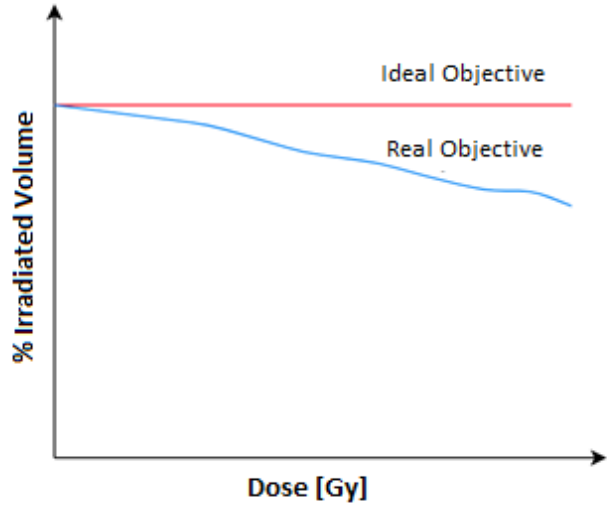
- **Absorbed dose**: ionizing energy absorbed per mass unit.
  It is measured in Gray (1 J/kg = 1 Gy).
- **Intensity modulation for photons with pencil beams:**
  Pencil beams form “pixel” in the beam cross-section
  (or the fluence, respectively)
  = “bixel” (**B**eam + P**ixel**)
  We weight all pencil beams
  (more/less photons) differently

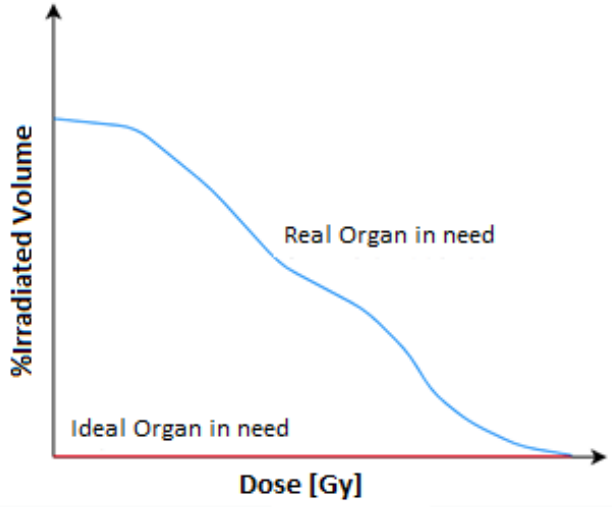


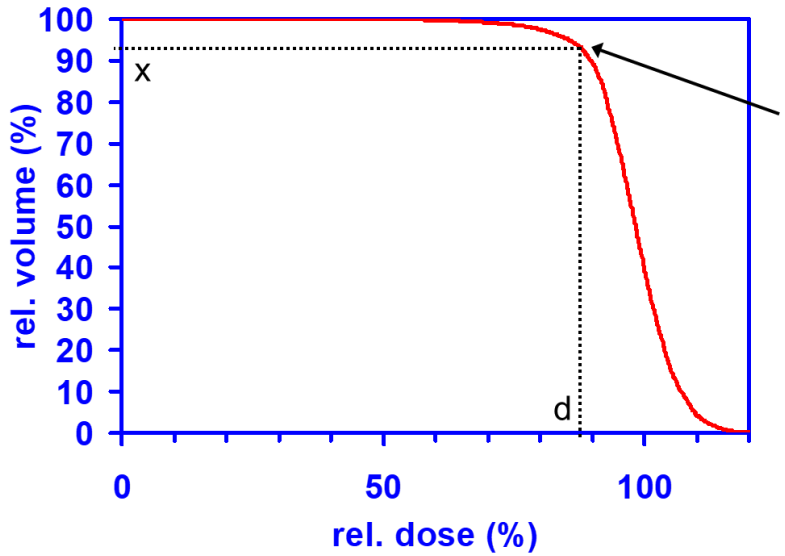
7. Important concepts

- **DVH**: dose-volume histogram.

In the ideal case, only the tumor is irradiated without affecting other (healthy) tissues.



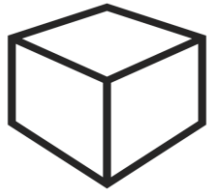




x% of the volume obtains at least d% of the prescribed dose

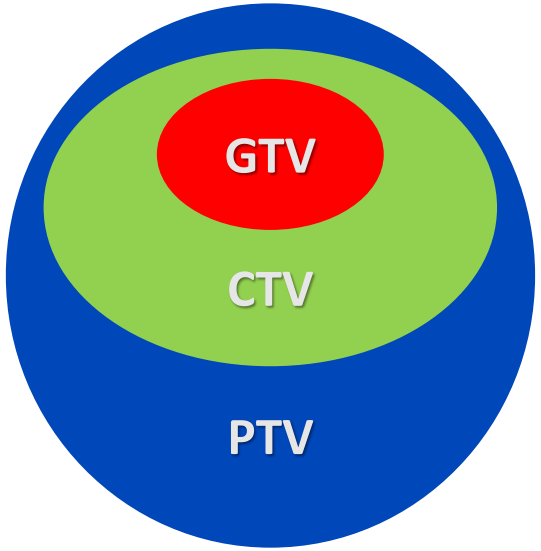
7. Important concepts

- **RBE:** Relative biological effectiveness. Factor that compares the biological effectiveness of (the biological damage caused by) one type of ionizing radiation (e.g. particle radiation) to the biological effectiveness of a reference radiation (e.g. photon radiation) .
- **Voxel:** volume pixel. A voxel is a volume element. It is the basic building block of a volumetric description of an object.
- **VOI:** volume of interest.
- **OAR:** organ at risk.



7. Important concepts

- **Gross Tumour Volume (GTV).**
  - Tumour volume that is visible on the images.
- **Clinical Target Volume (CTV).**
  - Volume of the tissue including the GTV and regions where invisible tumour tissue is expected.
- **Planning Target Volume (PTV).**
  - Includes the GTV and CTV as well as a safety margin to take uncertainties into account.



Thank you very much for your attention!