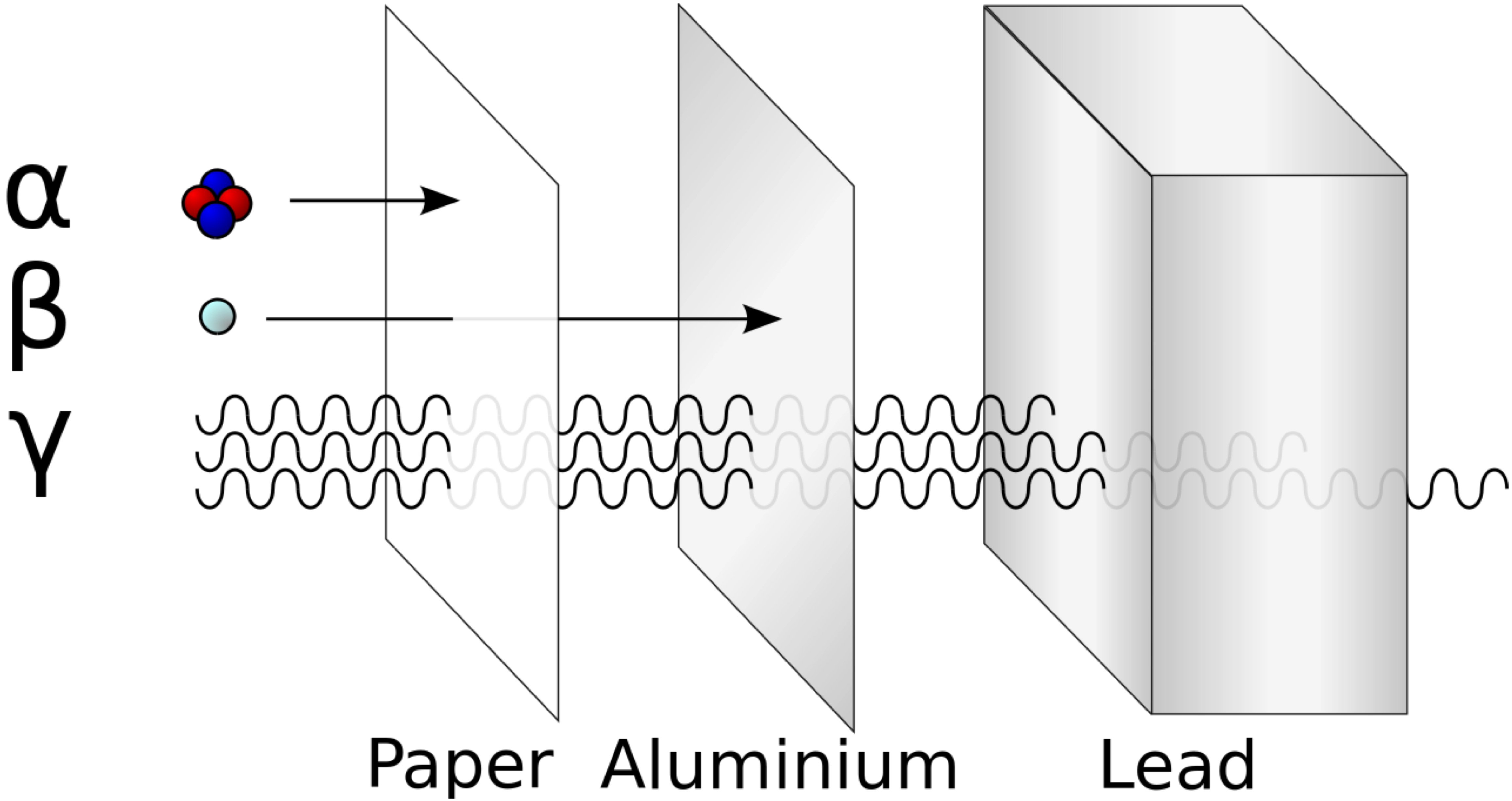
Proton therapy
- coming to Norway in 2023

Common types of cancer therapy

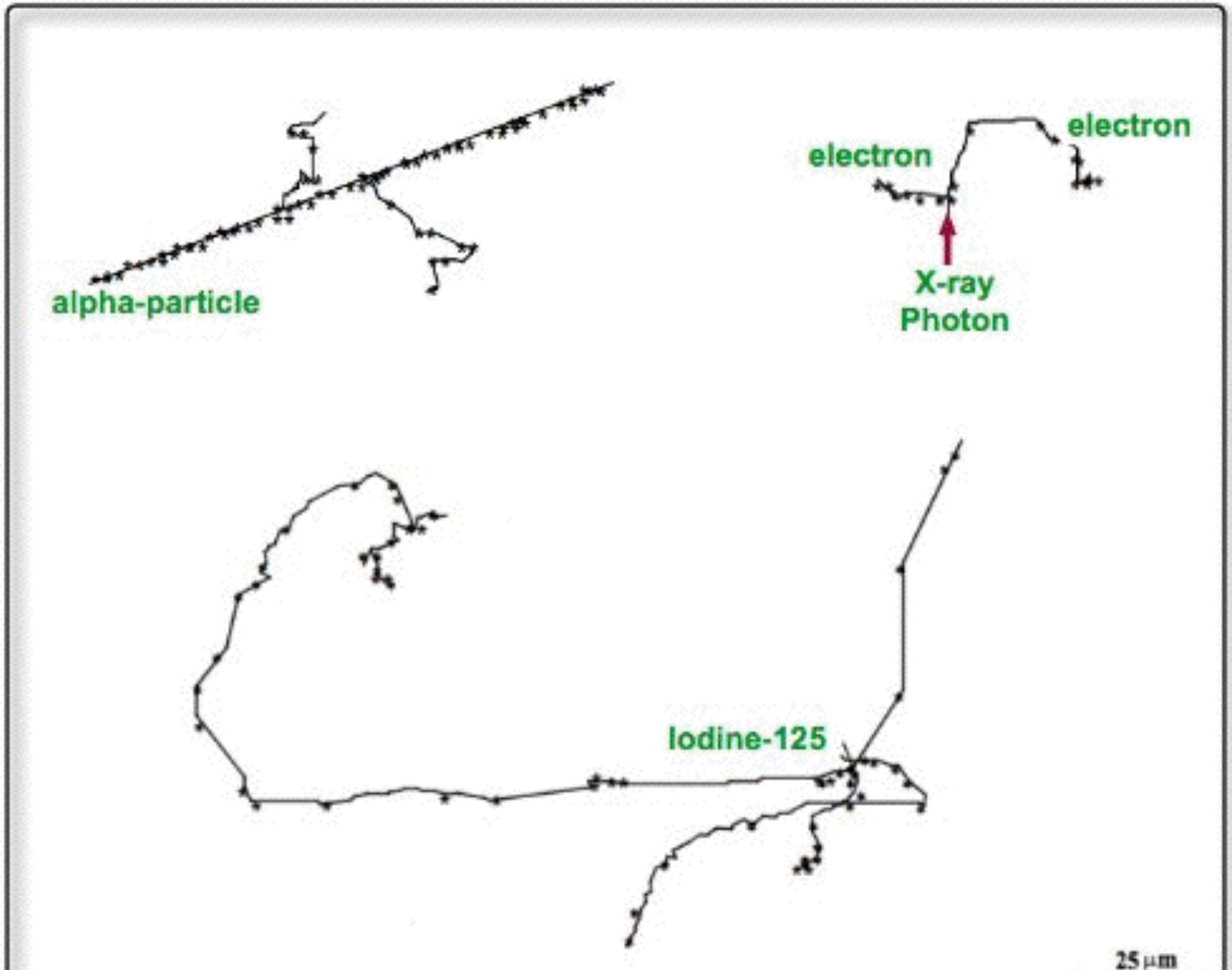
- Surgery
- Chemotherapy
- Radiation therapy

Radiation therapy works because ionization is bad for cells

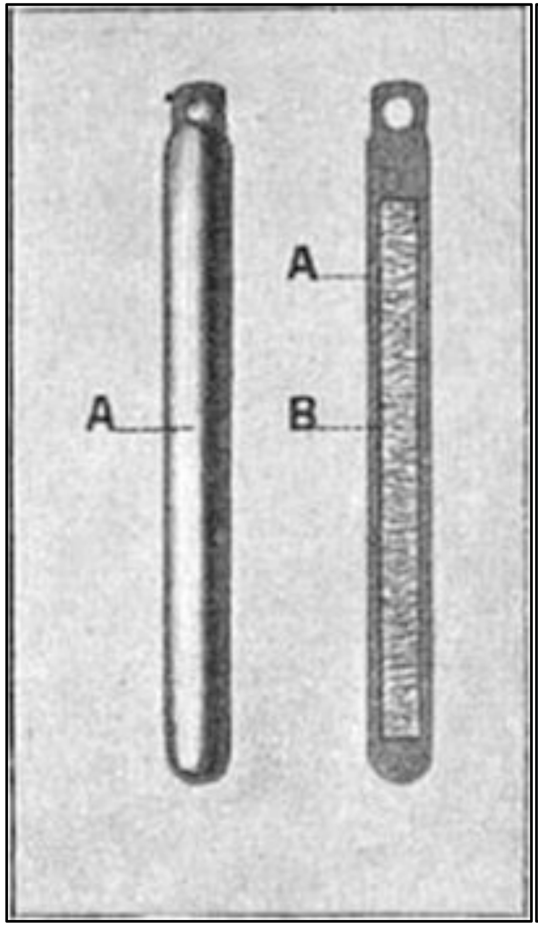
- Charged particles, like electrons and protons, ionize directly
- Photons ionize indirectly by interacting with the electrons in matter


α
β
γ
Paper
Aluminium
Lead

Examples of tracks (in human tissue)



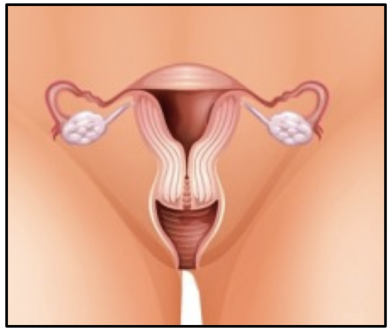
In the beginning, there was radium



Applying radium to skin cancer in 1898 (?).

Sources were also implanted into patients!

- In 1903 Margaret Cleaves introduced gynecological brachytherapy
- Weak sources meant you could only treat if you could get the source close to the cancer tissue



Margaret A. Cleaves
Source: U.S. National Library of Medicine

http://dx.doi.org/10.1016/j.brachy.2007.08.009

Cobalt therapy (still commonly used today)

- Nuclear reactors made it possible to produce strong Cobalt-60 sources
- 1949: First production of such a source for medical applications
- Produces to gamma ray energies

The first cobalt machine in Italy, 1953.

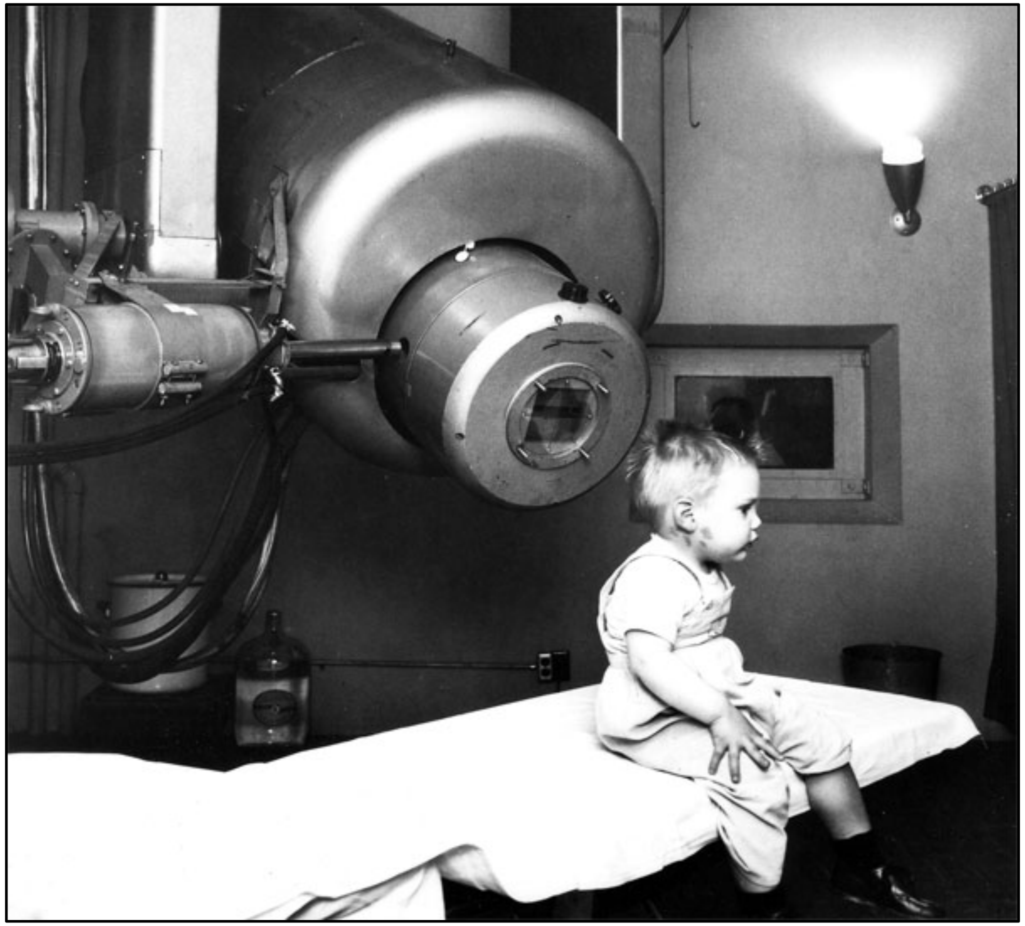
Image source: http://www.valsuganacultura.it/atomicadellasalute/album-08-foto08.html

Medical Linear Accelerators
(almost only type in Norway)

Images courtesy of Department of Radiation Oncology, Stanford

The original medical linac, installed in 1956, at Stanford in operation.

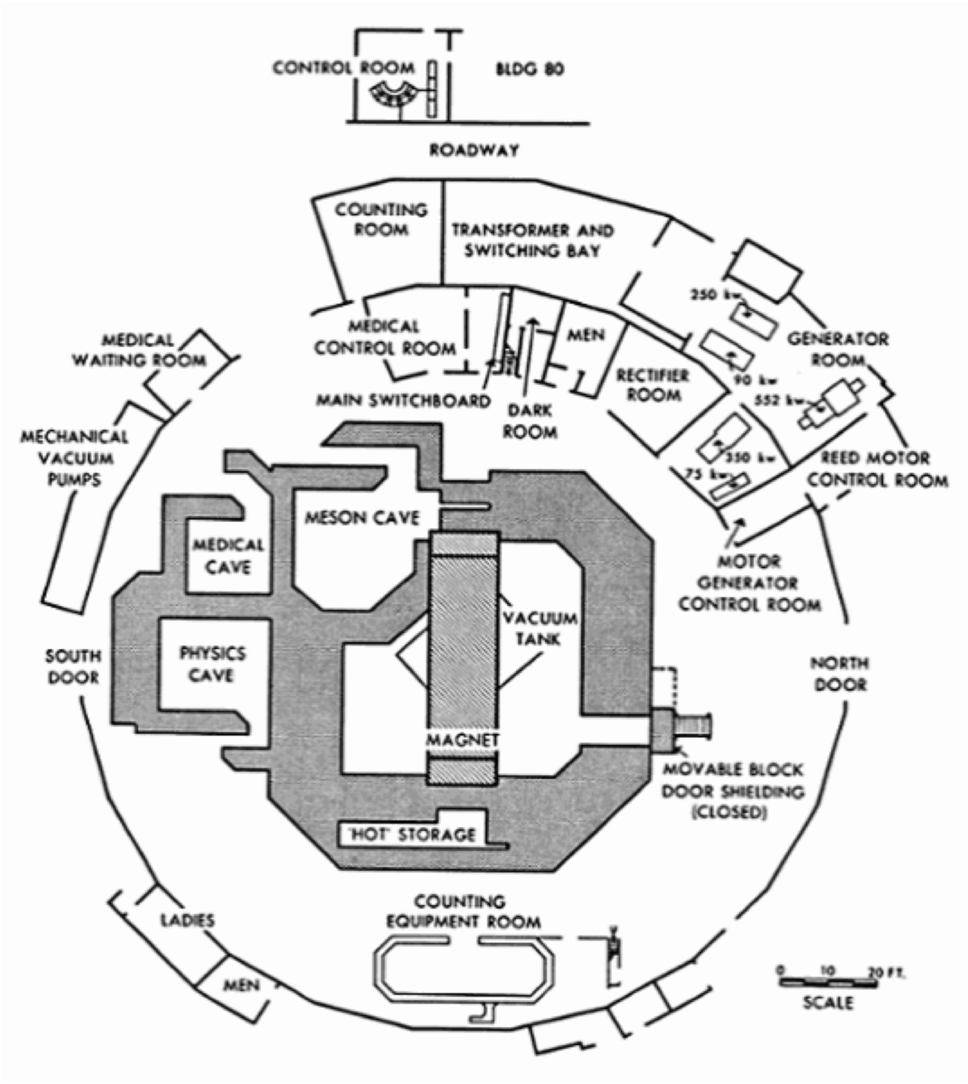
Images from Stanford news April 18, 2007



The first patient to receive radiation therapy from the medical linear accelerator at Stanford was a 2-year-old boy.

First proton tests in Berkeley in 1954

- The 184-inch synchrocyclotron delivered up to 100 MeV protons
- The first tests were carried out in 1954
- seminal work on brain tumor treatment was carried out there

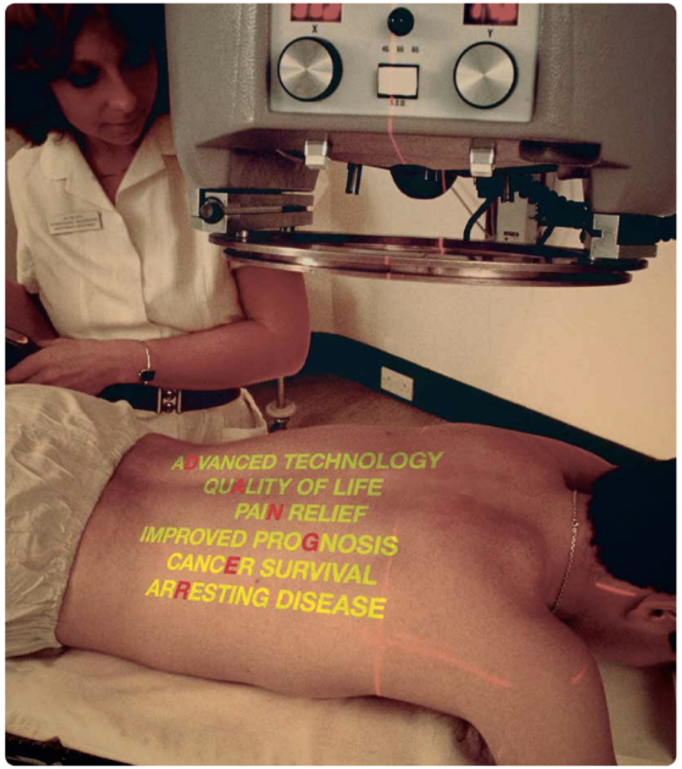


Synchrocyclotron Building

Image: LRL Accelerators The 184-Inch Synchrocyclotron, Lawrence National Laboratory
Source: The Gutenberg Project: http://www.gutenberg.org/files/33397/33397-h/33397-h.htm

The goal in Norway is that 52% of the patients should receive radiation treatment[1]

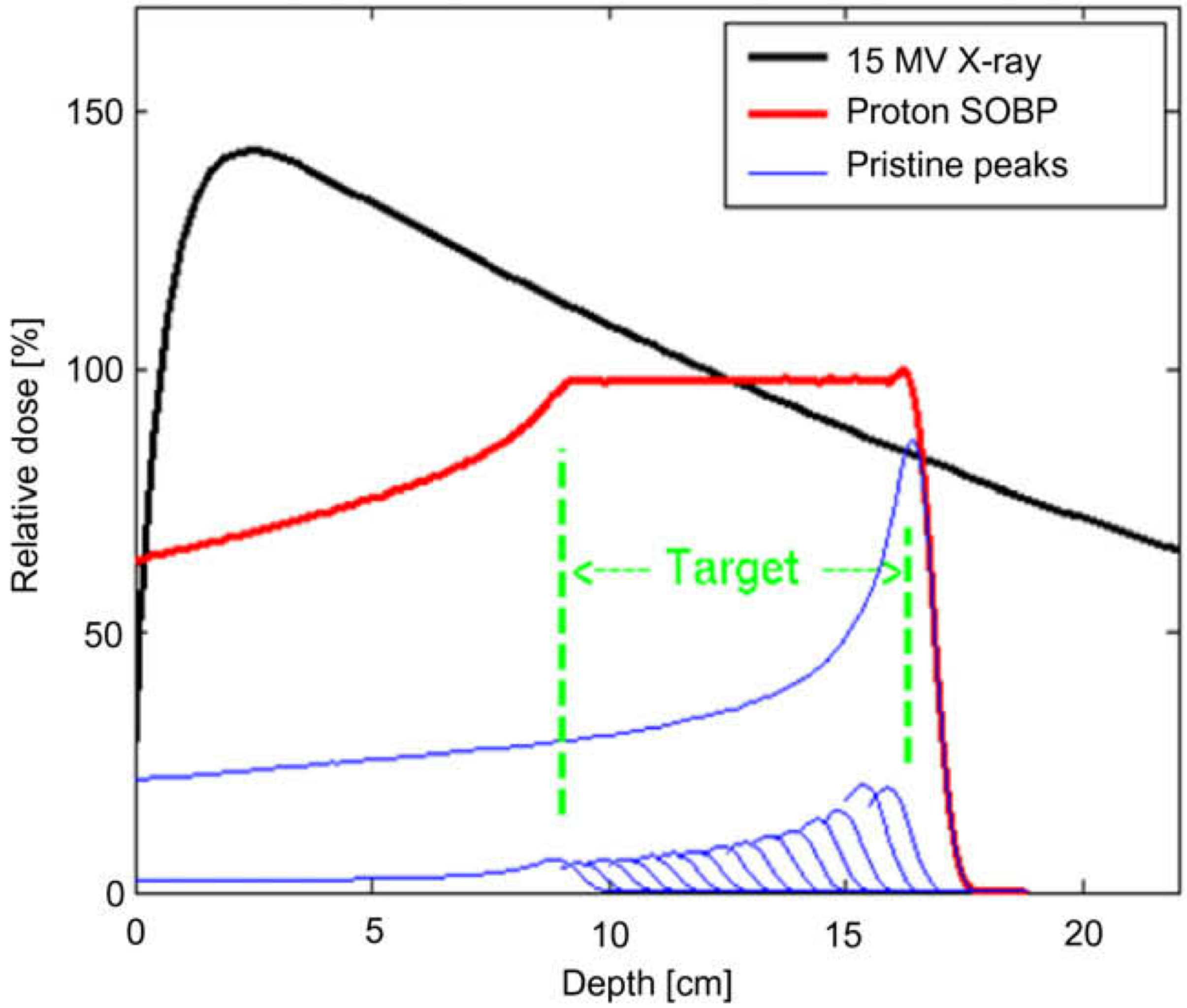
- Less than 30% of patients in Norway with cancer receive radiation therapy[2]
- Reasons: Lack of capacity (and possibly worry about long term effects of radiation)
- Proton therapy is expected to provide treatment to at least 15% of cancer patients[3]



CMO ANNUAL REPORT 2006

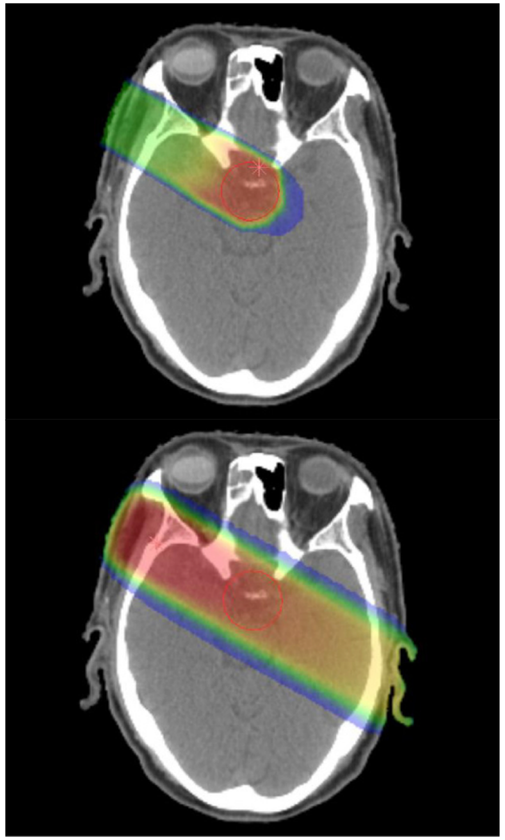
[1]Delaney G et al. The role of radiotherapy in cancer treatment:
Estimating optimal utilization from a review of evidence-based clinical guidelines. Cancer, 2005, 104:1129–1137. DOI: 10.1002/cncr.21324
[2]Private communication professor emeritus Sophie Dorothea Fosså and
kronikk hos Aftenposten 10 Mars 2004 http://www.aftenposten.no/norge/All-stralebehandling-gir-noen-bivirkninger-515039b.html
[3]Konseptfase - etablering av protonbehandling i Norge, report from Helsebygg, August 2016. URL: https://helse-bergen.no/seksjon/styret/documents/2016-08-31/konseptrapport%20konseptfase%20%E2%80%93%20etablering%20av%20protonbehandling.pdf

Protons vs. photons



H. Suit et al., "*Proton vs cabon ions in the definitive radiation treatment of cancer patients*", Radiotherapy and Oncology **95** (2010)

protons

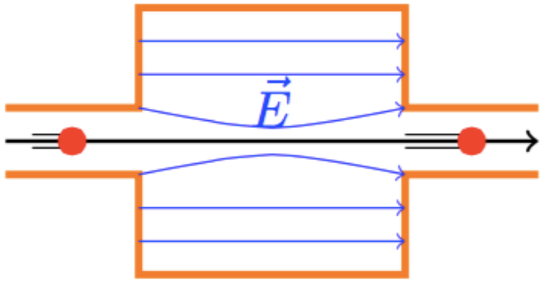


photons

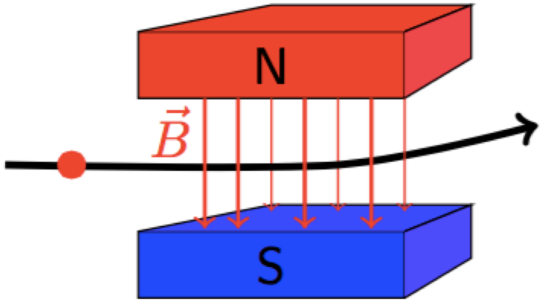
Tatsuya Ohno, "*Particle radiotherapy with carbon ion beams*", The EPMA Journal **4:9** (2013)

Main components of a particle accelerator

- Accelerating structures



- Magnets to steer the particles
  (mainly focusing and bending/analyzing)



- Collimators to absorb part of the beam
  (cut off stray particles or "shape" the beam)

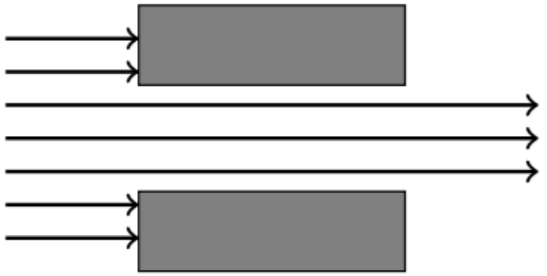


Illustration by Kyrre Sjøbæk

Cyclotron
(the cheaper solution)

- Constant guiding magnetic field
- Constant-frequency electromagnetic field

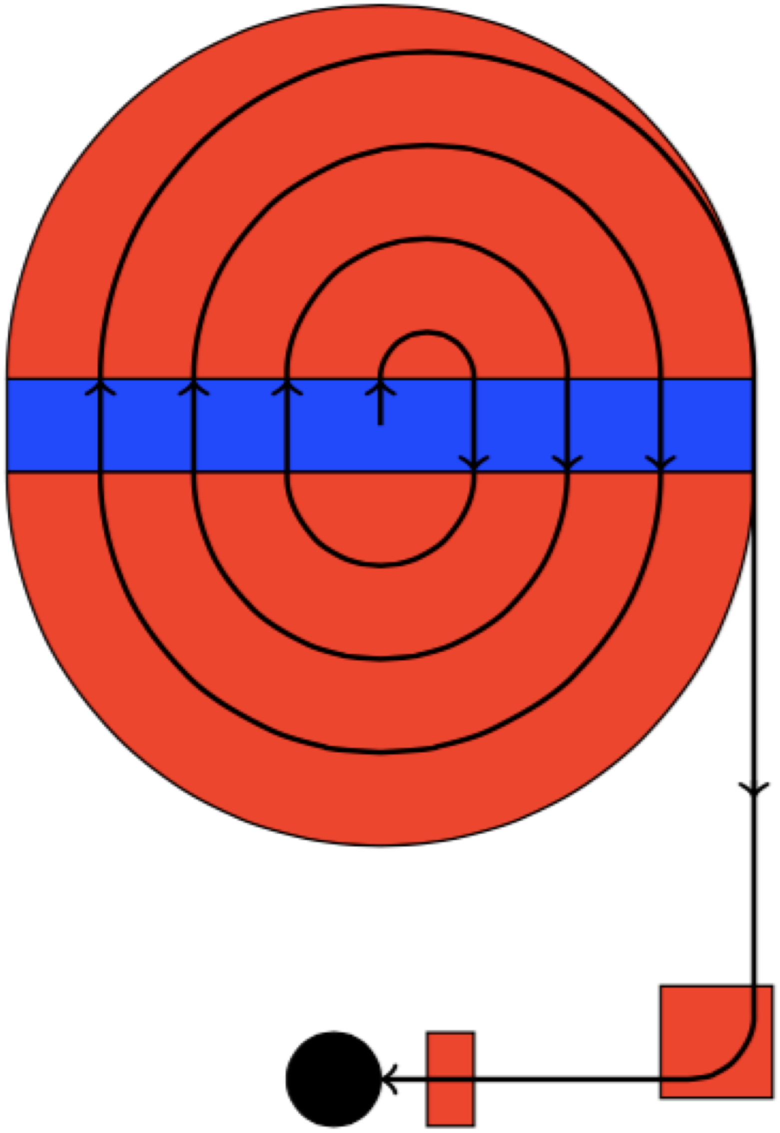
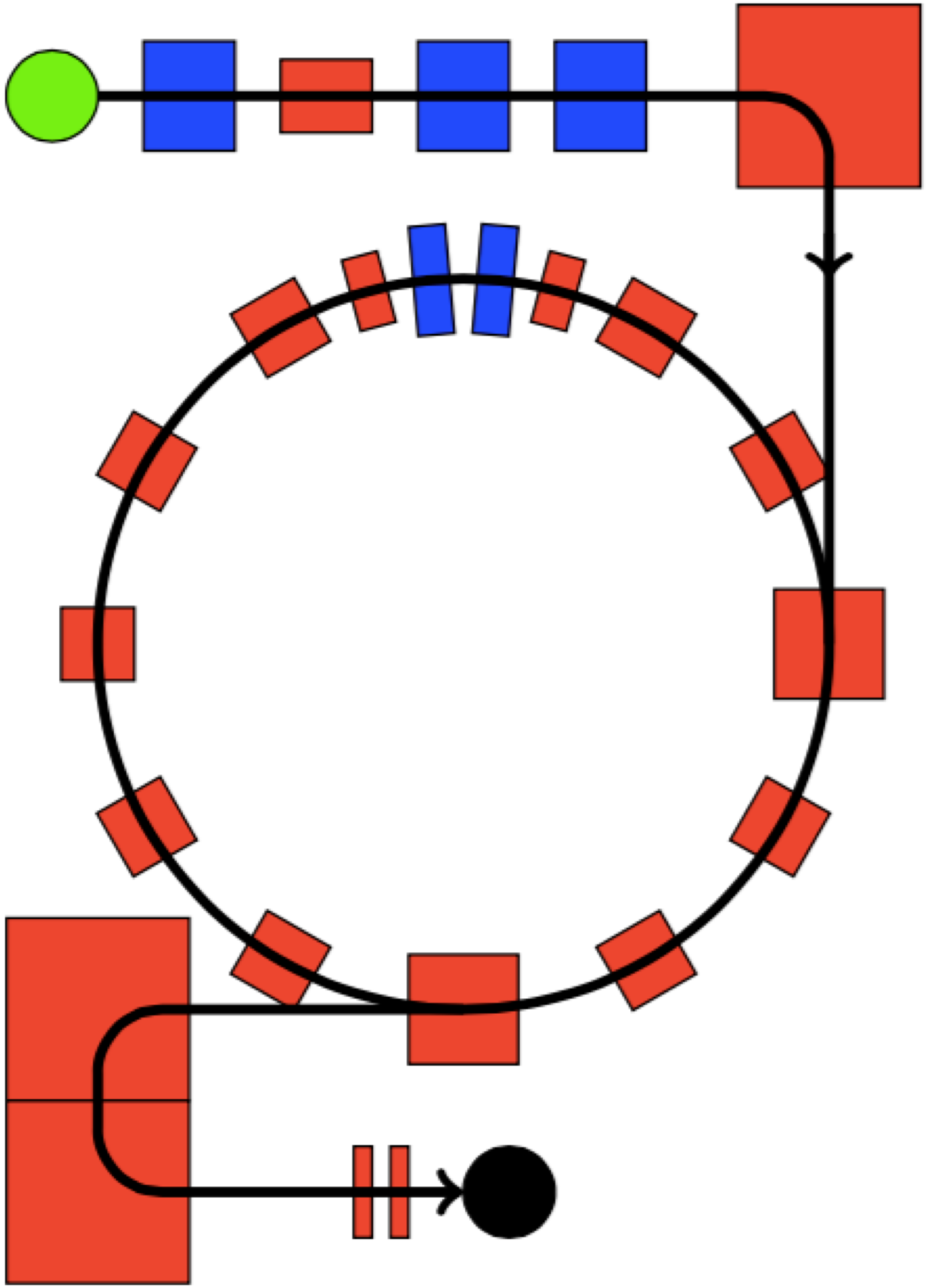


Illustration courtesy of Kyrre Sjøbæk

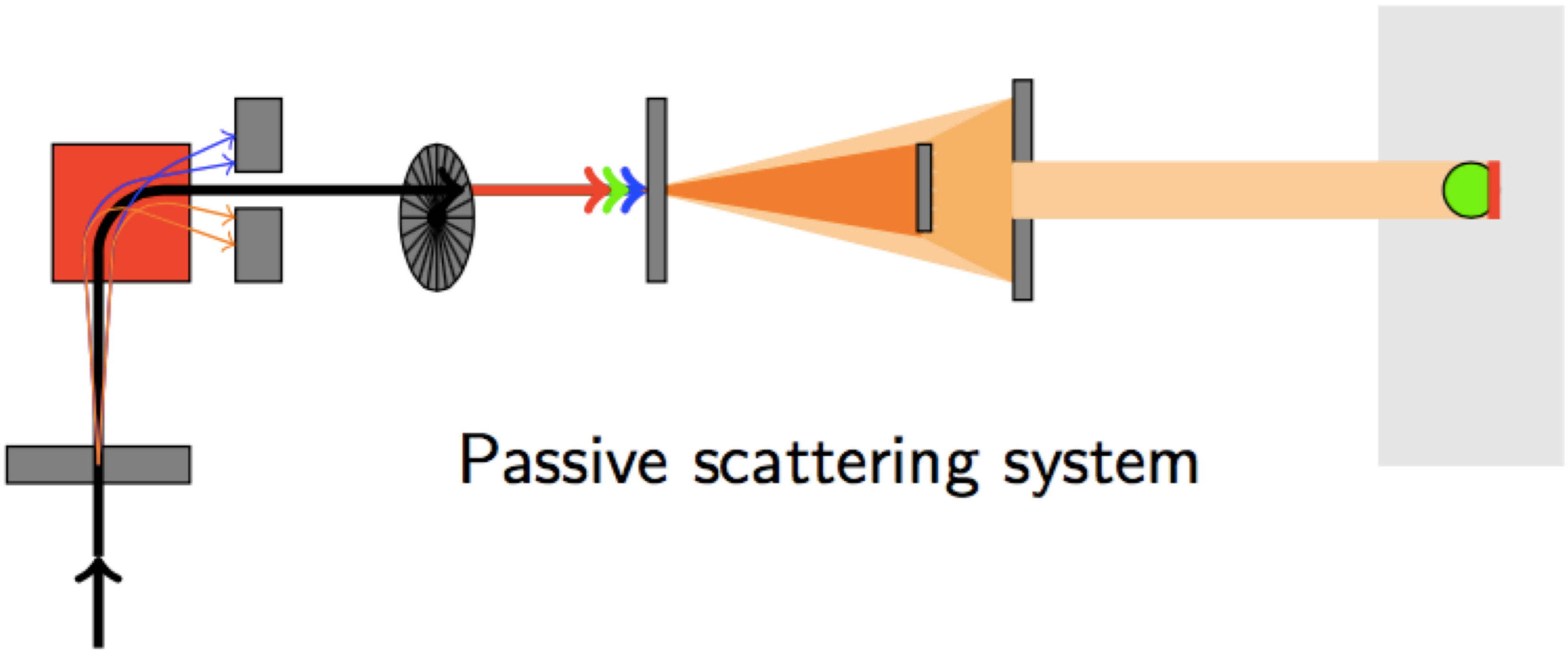
$$f = \frac{qB}{2\pi\gamma m}$$

Synchrotron

- The magnetic field varies in time
- The frequency of the electromagnetic field is also sometimes varied
- Typically the diameter is about 10 – 30 m.



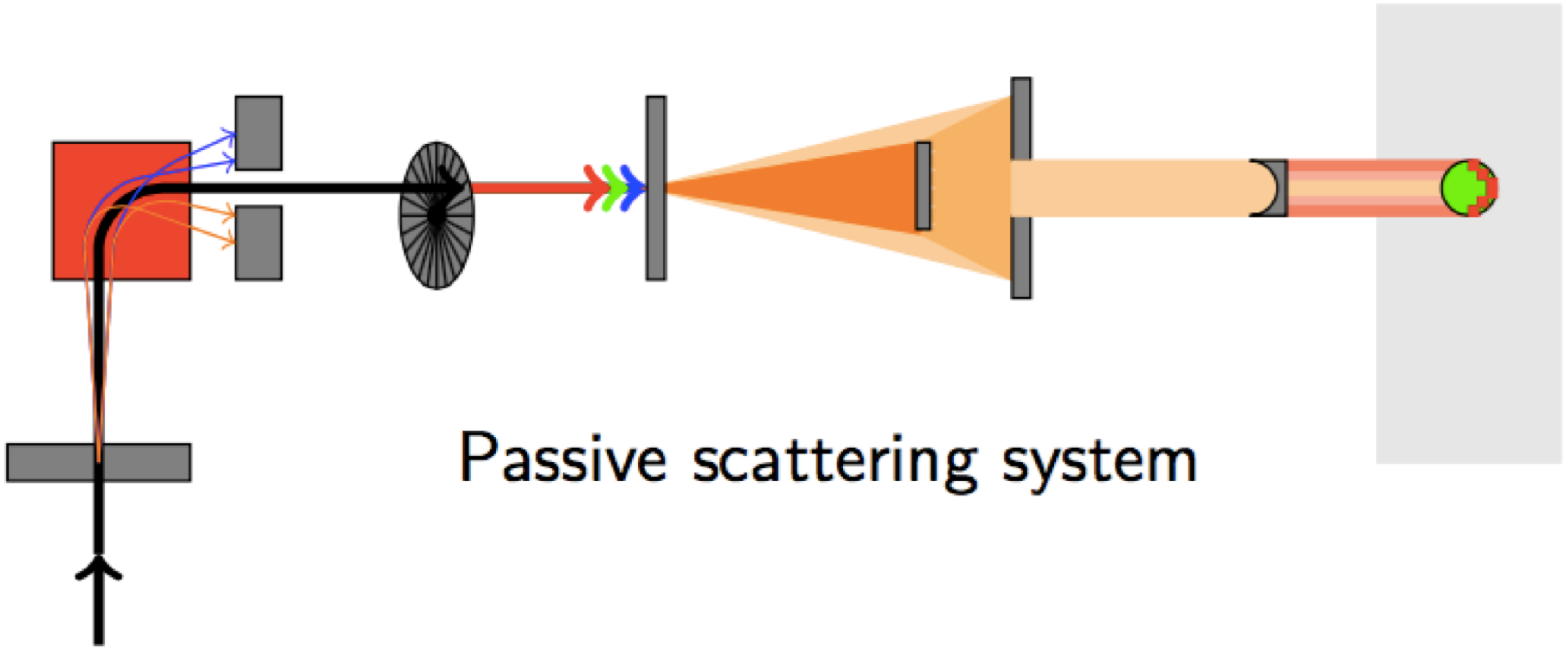
Scattering: Match tumor shape



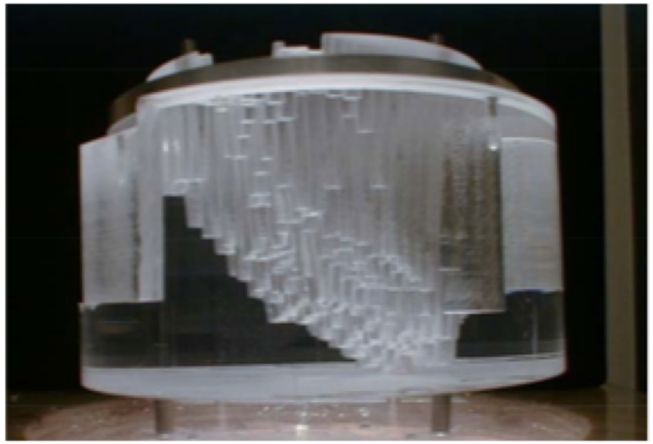
Hui Liu, Joe Y. Chang, "*Proton Therapy in Clinical Practice*"

Figure courtesy of Kyrre Sjøbæk (from his trial lecture 14th October 2016)

Scattering: Range compensator



Passive scattering system



Roelf Slopema, "*Basic Physics of Proton Therapy*", (Lecture)

Figure courtesy of Kyrre Sjøbæk (from his trial lecture 14th October 2016)

Active scanning by a pencil beam

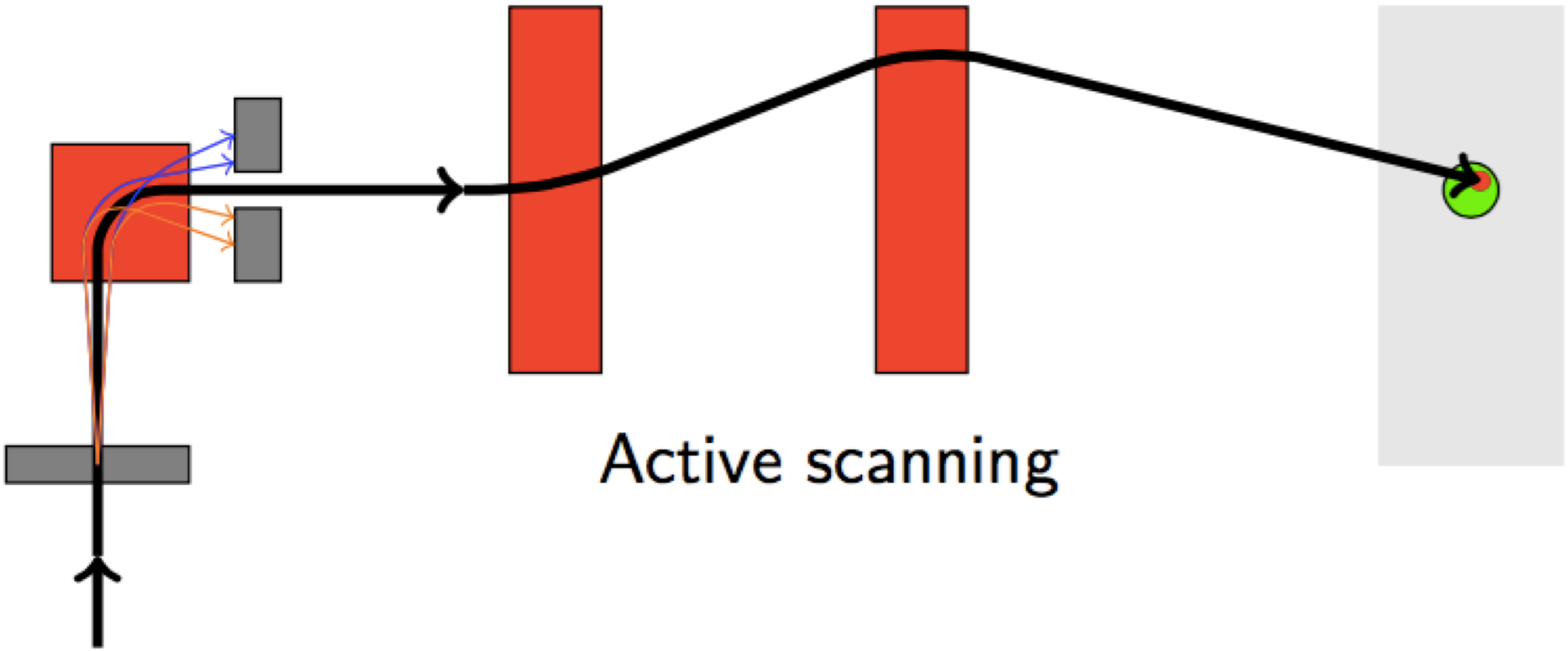
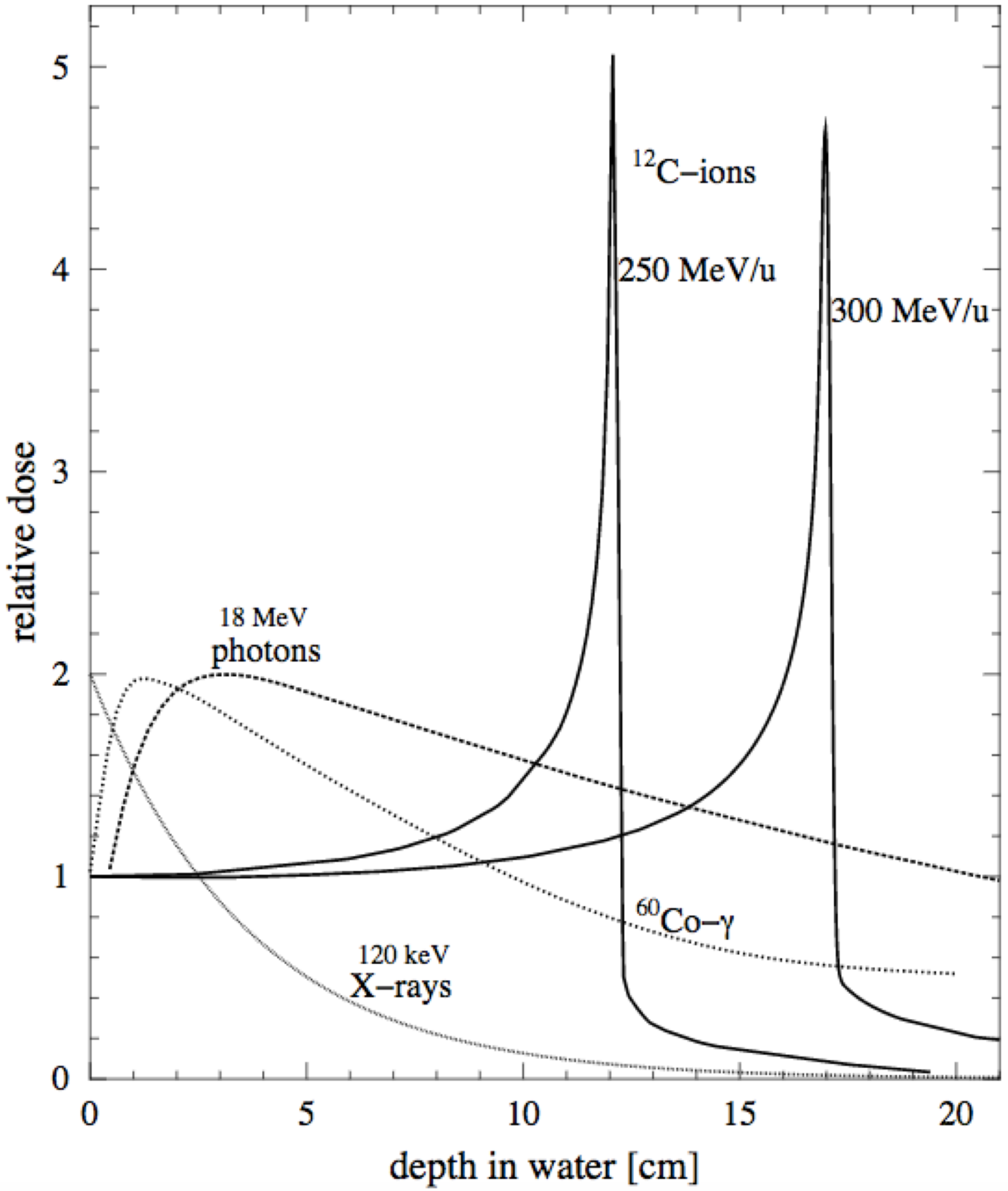


Figure courtesy of Kyrre Sjøbæk (from his trial lecture 14th October 2016)

Comparison of the depth dose profiles

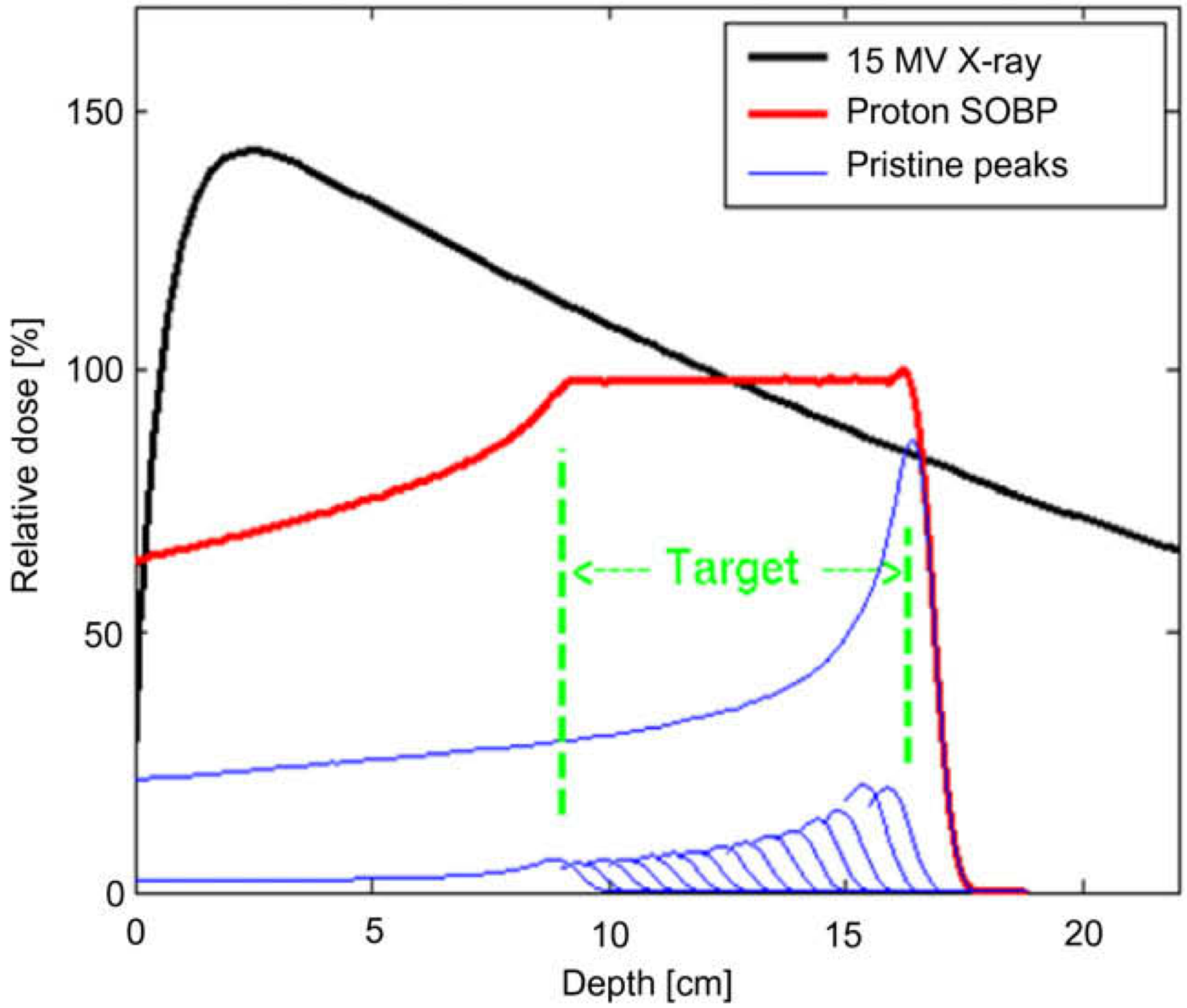
X-rays, Co-gamma and Röntgen-Bremsstrahlung with carbon ions of 250 MeV/u and 300 MeV/u



G. Kraft, "Tumor Therapy with Heavy Charged Particles";
URL: http://bio.gsi.de/PUBS/TumortherapyHCP_partA.pdf

Protons vs. photons

SOBP: Spread-out Bragg Peak



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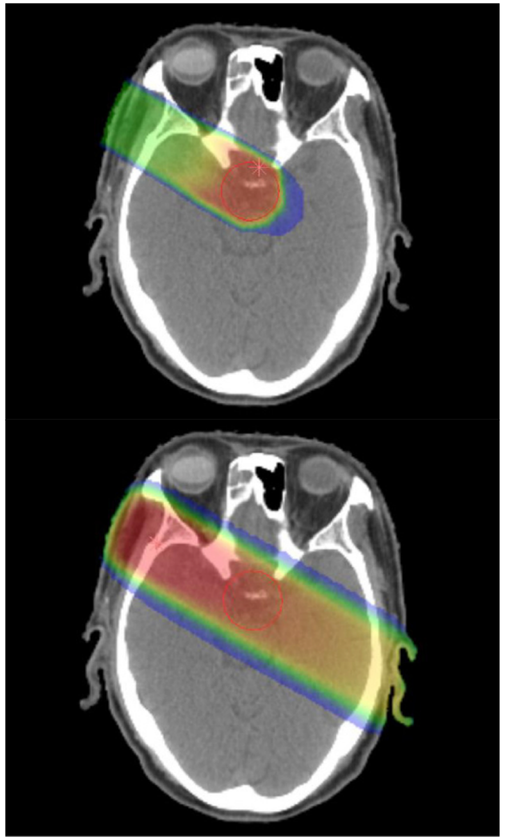
protons



photons

Tatsuya Ohno, "*Particle radiotherapy with carbon ion beams*", The EPMA Journal **4:9** (2013)

Proton vs. photons

Pros of protons

- Can deliver radiation dose more accurately
- Less dose to healthy tissue
- The total dose is split up in fewer fractions

Pros of photons

- Cheaper
- Simpler planning
- Well understood by medical community
- Sometimes irradiating larger volumes is a good thing

Modelling

Output of a Monte Carlo based code is used as input to commercial software Treatment Planning System

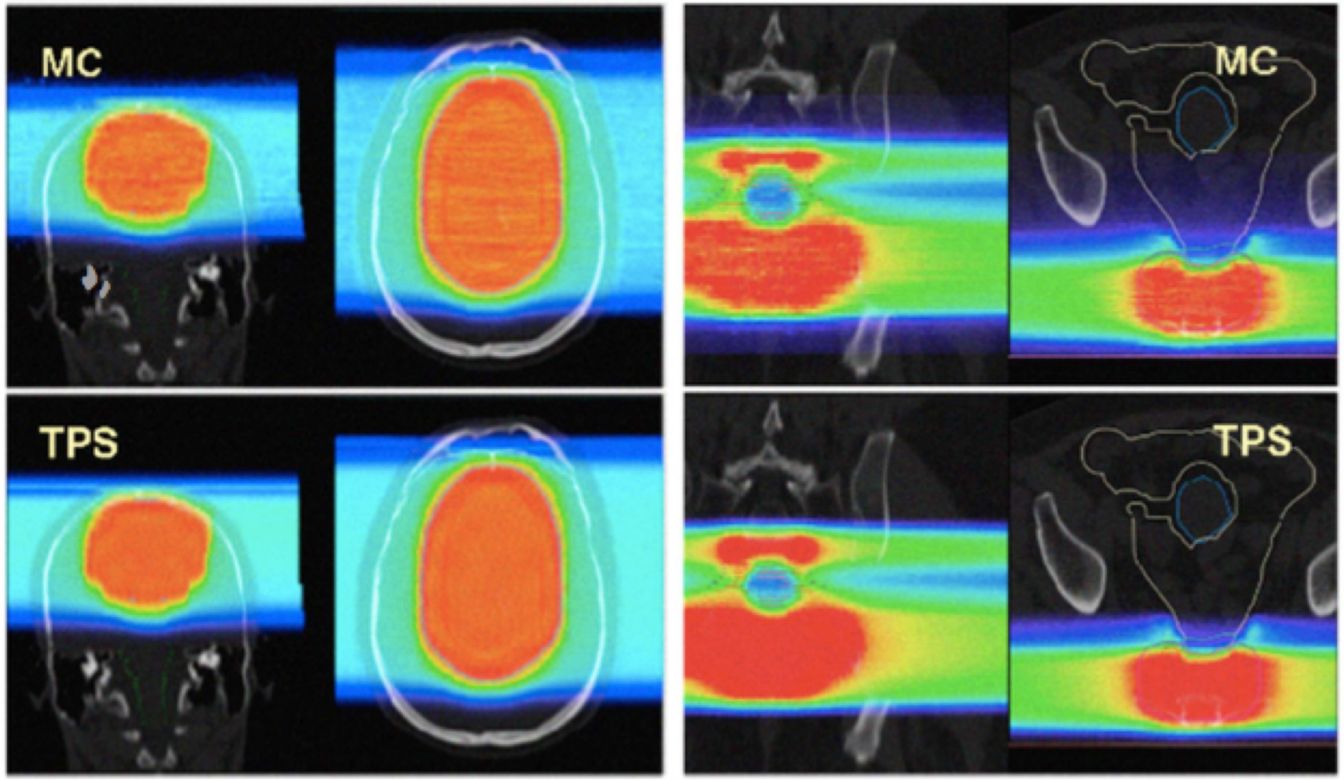


Fig. 4 Example of MC forward dose calculations (upper row) in comparison to the clinical TPS (bottom row) for the fraction absorbed dose of a two-field proton treatment of an head-and-neck tumour (left) and for the fraction RBE-weighted dose of a two-field carbon ion treatment of a pelvic tumour (right). The dose is shown in absolute scale (same colour wash range) overlaid onto the patient CT (gray scale).

[1]K. Parodi et al, IEEE Nuclear Science Symposium Conference Record (2011) http://ieeexplore.ieee.org/document/6153641/
GitHub repository for code https://github.com/hibtc

Other codes used in other places for modelling:

Geant4, MCNPX, PHITS and SHIELD-HIT

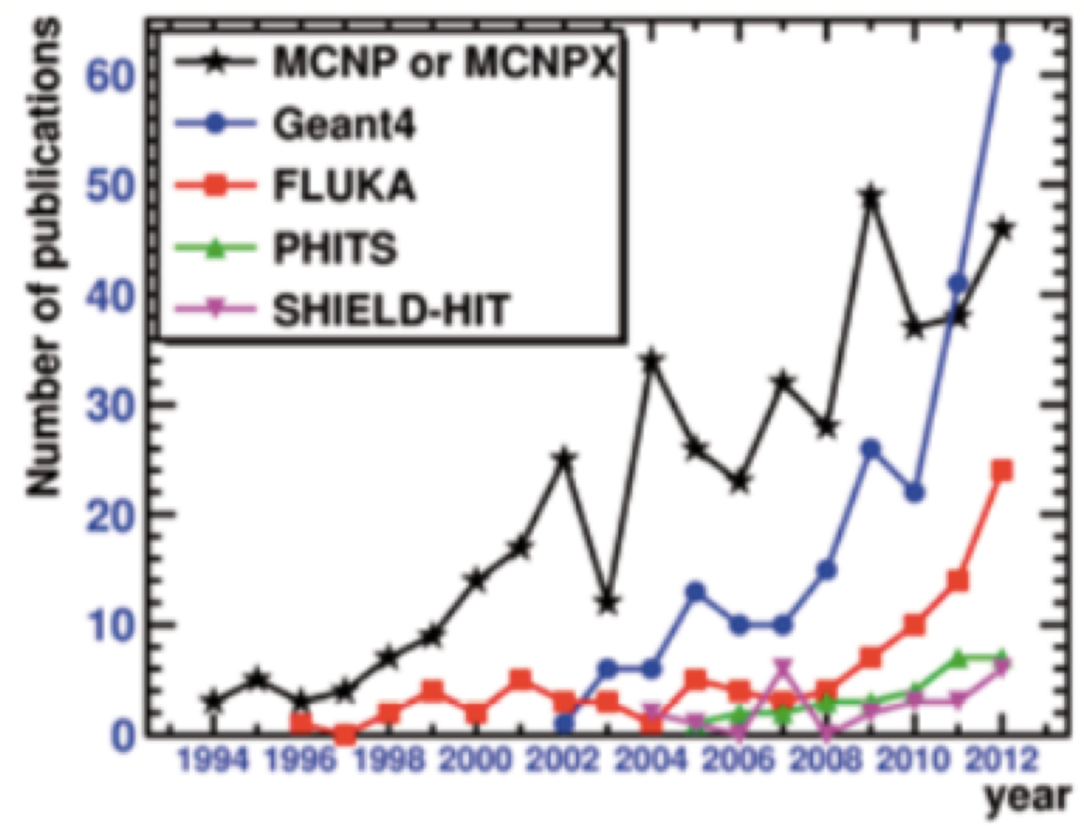


Figure 8.1. Annual number of publications related to hadrontherapy, where respective Monte Carlo codes/tools were used. Estimated from the Web of Science database (Thomson Reuters) in October 2013.

Source: Nuclear Physics European Collaboration Committee (NuPECC) "*Nuclear Physics for Medicine*" (2014 report)