# Medical activities

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Session on Application and Exploitation

# Medical physics

- Prevention, diagnostics, and treatment of disease using physics
- Imaging with X-rays, PET, Computed Tomography, ...
- Radiation treatment with external beam, nuclear medicine, …
- Health physics – dosimetry, radiation protection, …

# Proton therapy in Norway

From refs. 1, 2, and 3

- Two centers under construction: Oslo (Radiumhospitalet) and Bergen (Haukland)
- First patient planned in 2024
- Oslo: 3 gantries, 2 for patients and 1 for research
- Bergen: 2 gantries, 1 for patients and 1 for research

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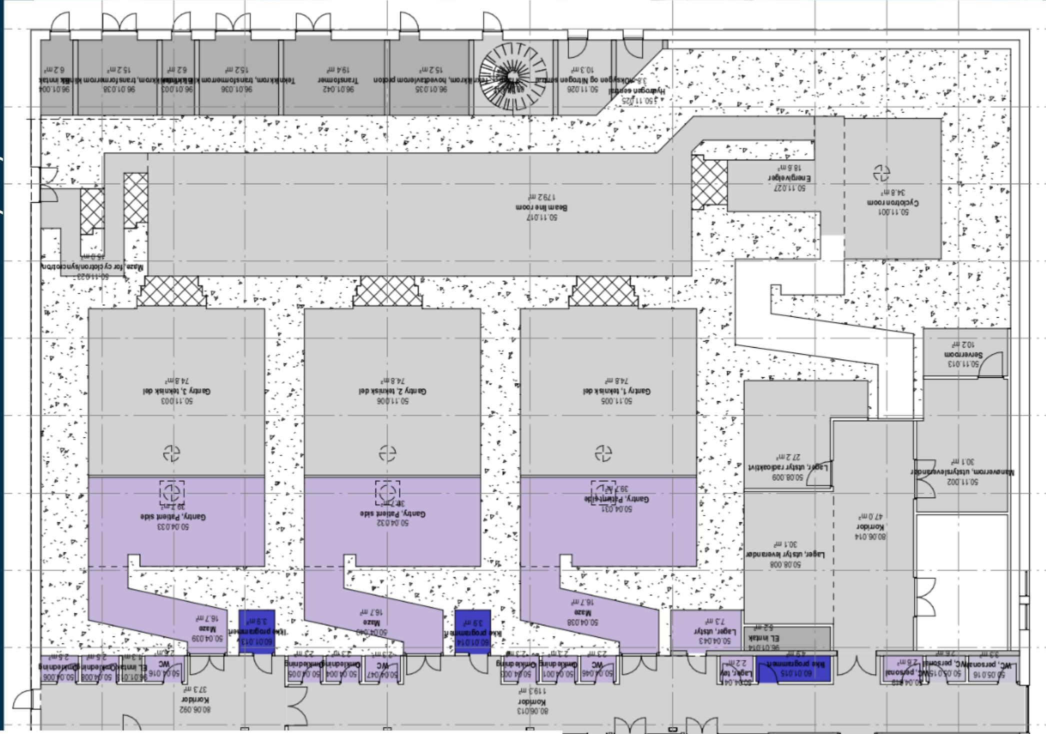

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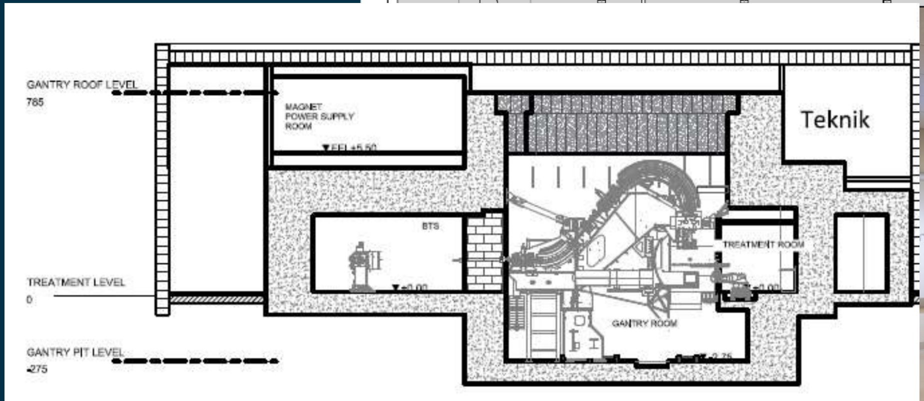
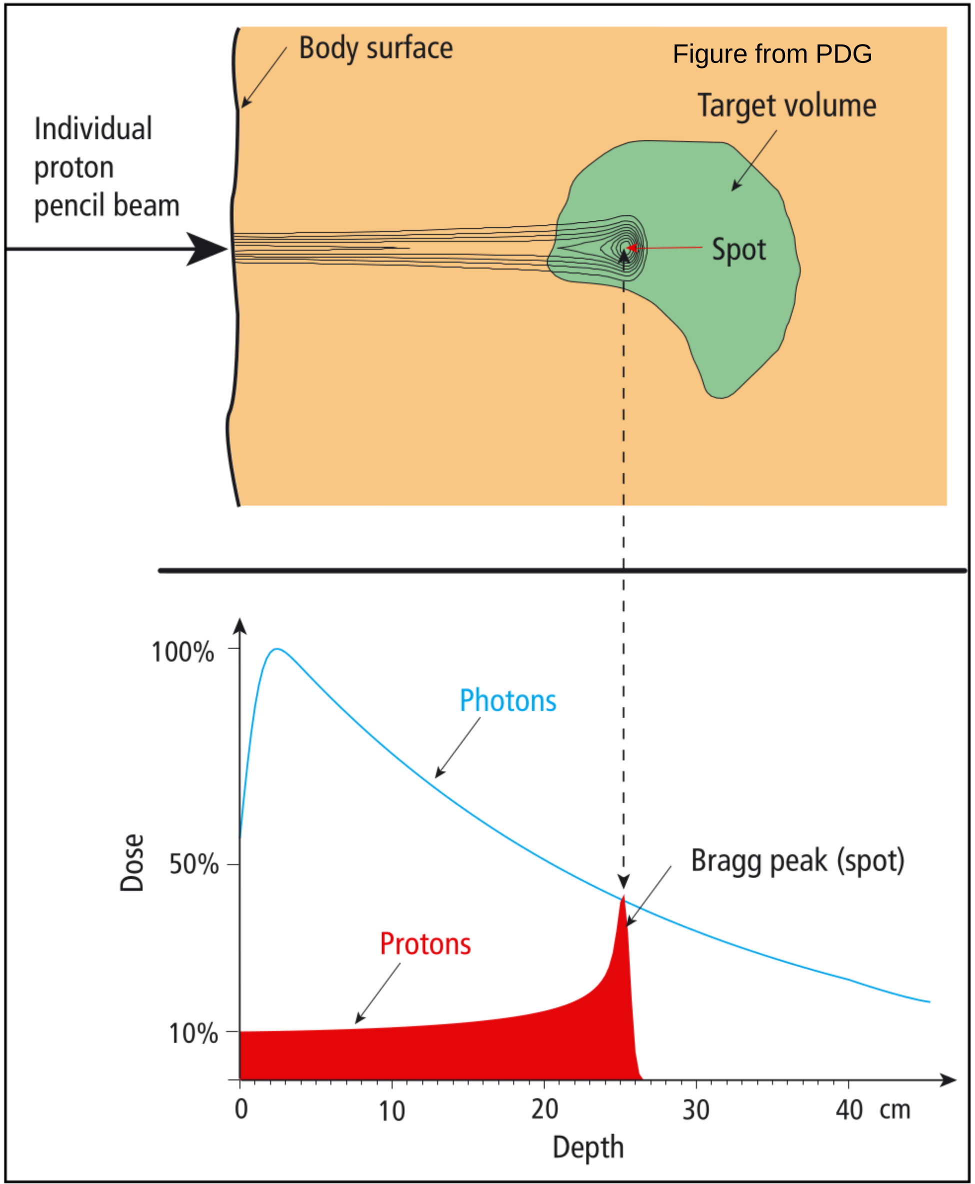



SECTION THROUGH GANTRY ROOM

# Proton Therapy

- Method of external beam radiotherapy
  - Mostly used against cancer
  - EBRT today mostly with Photons
- Protons stop at a predictable range
- Deposit lots of energy near the end of their track
- Can be more precise than photons, which are commonly used today
  - Less damage to nearby tissues → Diminished side effects
  - **But:** Need to be careful to match beam energy and material density in order to stop at targeted depth

Figure from "Proton therapy at the Paul Scherrer Institute", 2011



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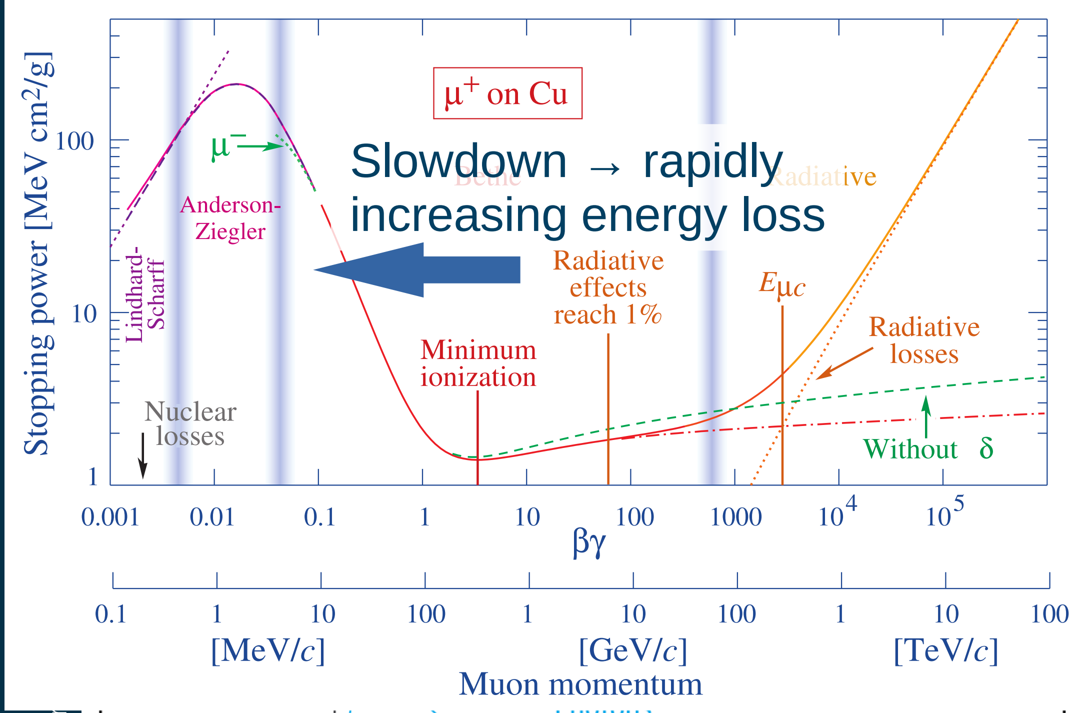


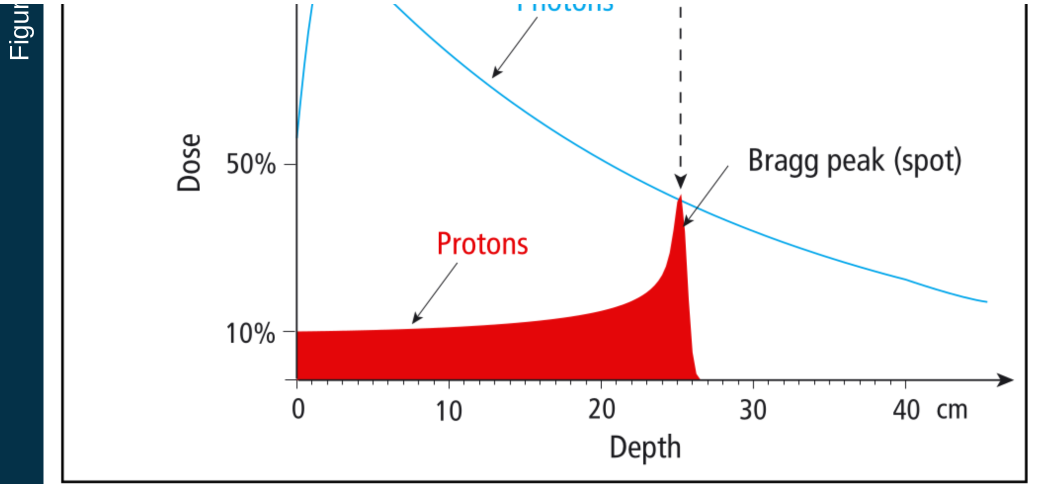

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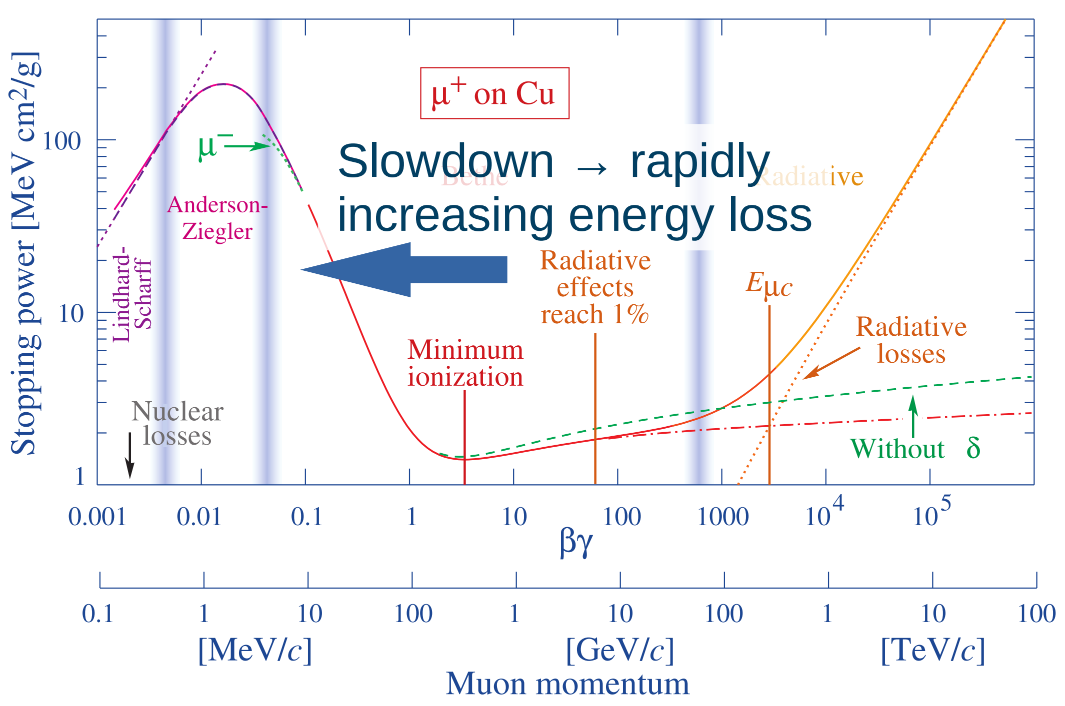
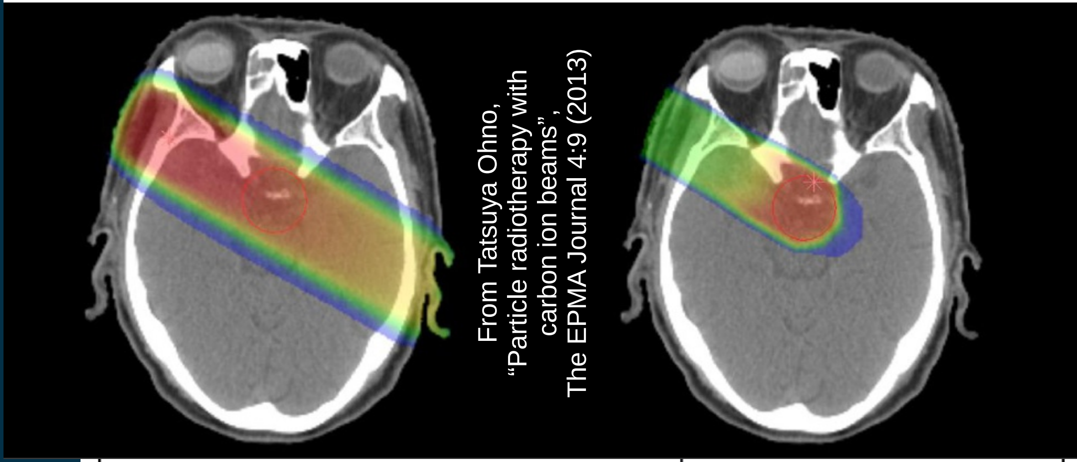


From Tatsuya Ohno, "Particle radiotherapy with carbon ion beams", The EPMA Journal 4:9 (2013)

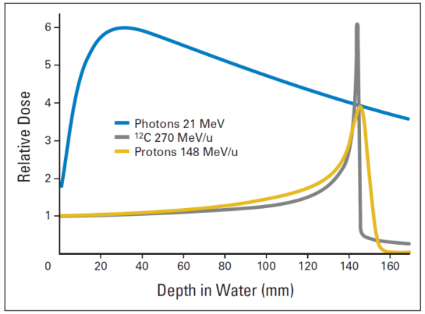
# NorCC involvement with medical technology

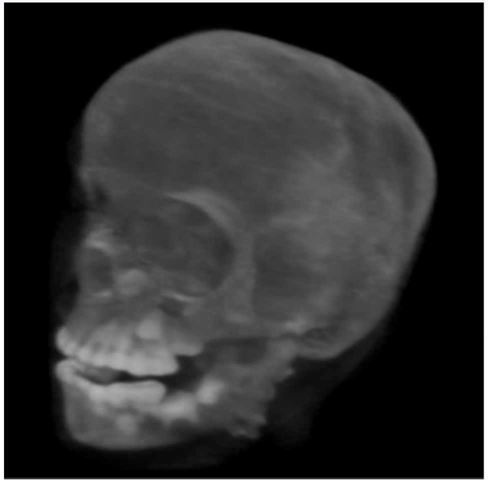
NorCC is involved in several
medical applications of CERN technology

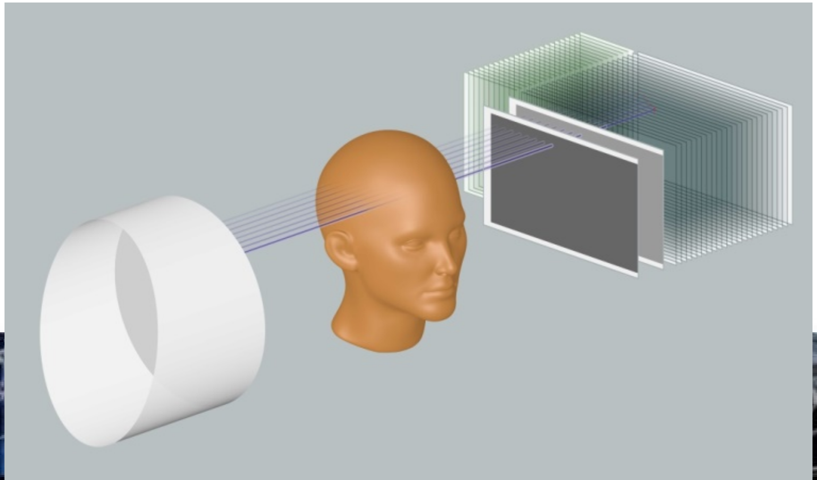
- ProtonCT, IFT@UiB
- VHEE and FLASH, CERN/UiO
- Strong focusing of proton beams for sharp dose profiles, UiO
- ISOLDE Medicis, CERN/UiO (separate talk)
  + medical-relevant research at UiO cyclotron

# Medical Physics – imaging with particles

- Clinical prototype of a proton CT
  - Key advantage/challenge with particle therapy – the Bragg peak position
  - Proton Computed Tomography system for
    - Treatment planning
    - Real-time monitoring of dose deposition

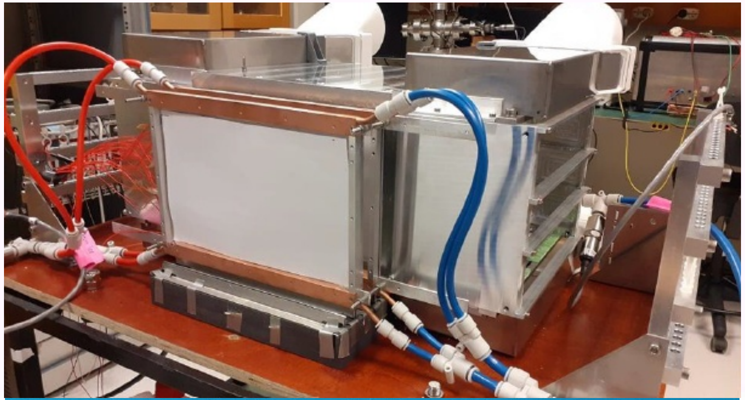


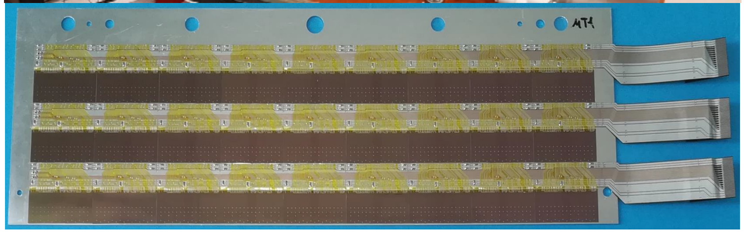





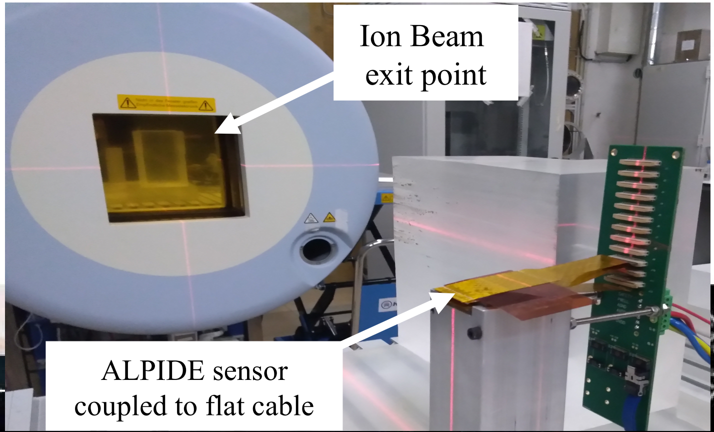
# The Bergen pCT project

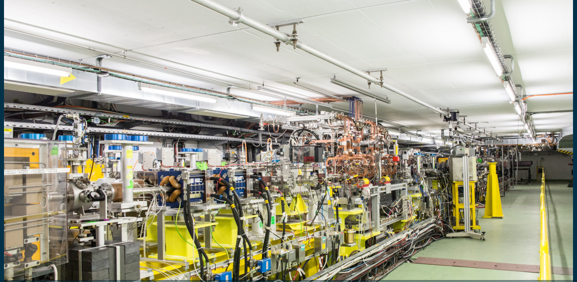
- Development of a proton CT system for the Bergen proton therapy facility
  - Hardware
  - Pixel detectors and readout electronics
  - Online software
  - Event reconstruction and tomography (including ML)
  - Beam tests and data analysis
  - Simulation of the clinical performance





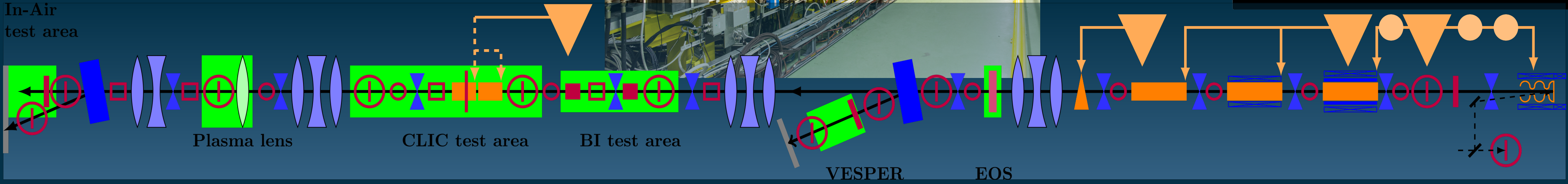
Heidelberg Ion-Beam Therapy Center





**Beam parameters**

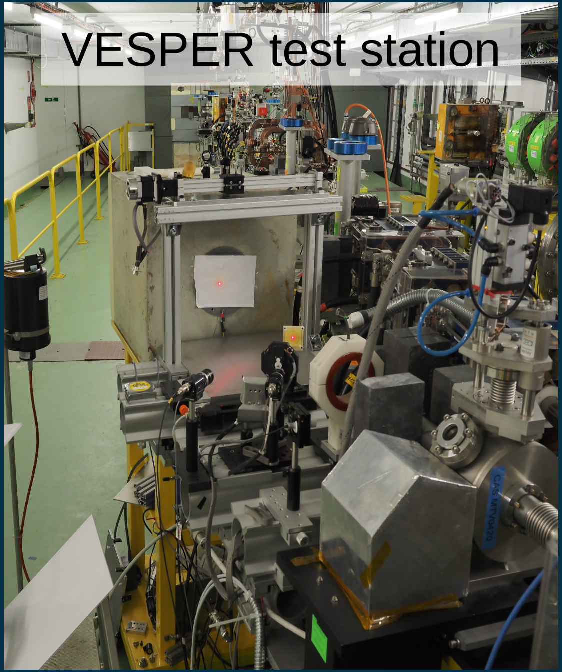
- 60-200 MeV electrons
- 10 pC – 50 nC / pulse
- 1-10 pulses/second
- Pulse length 1 ps – 50 ns



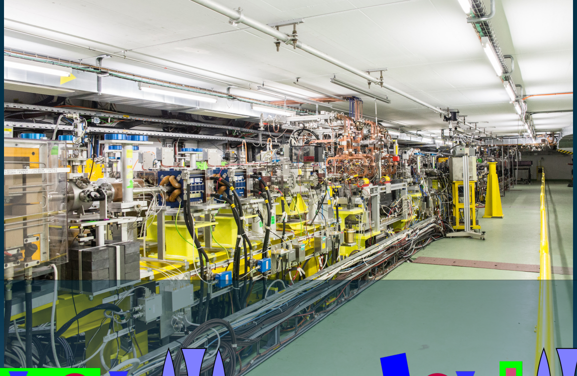

- CLEAR = CERN
  Linear Accelerator for Research
  - Based on the former
    CLIC test facility (CTF3)
- User facility:
  - Changing experiments on a
    ~weekly basis
  - Users from out- and inside CERN
- Diagnostics, data acquisition, and beam manipulation devices already installed
- Separated from rest of CERN accelerator complex → Ran through LS2

- Deep collaboration with accelerator group @UiO
- Examples of experiments:
  - Beam tests of plasma lens, beam position monitors
  - Irradiation of electronics, functional tests for radiation environments
  - Tests of novel radiotherapy schemes (e.g. FLASH in collaboration with CHUV): Technology and effects
- Electrons → Clean radiation environment, little activation

See refs. 1 and 2



CLEAR



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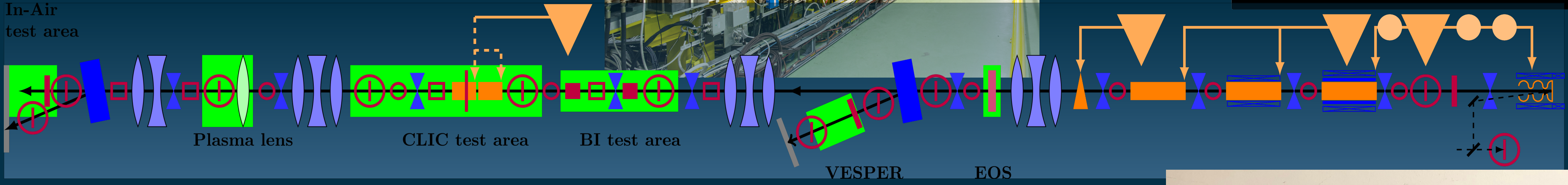


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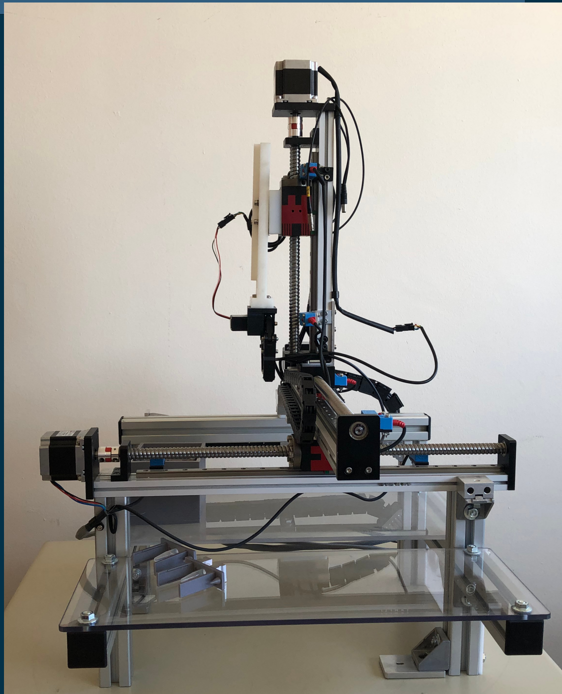
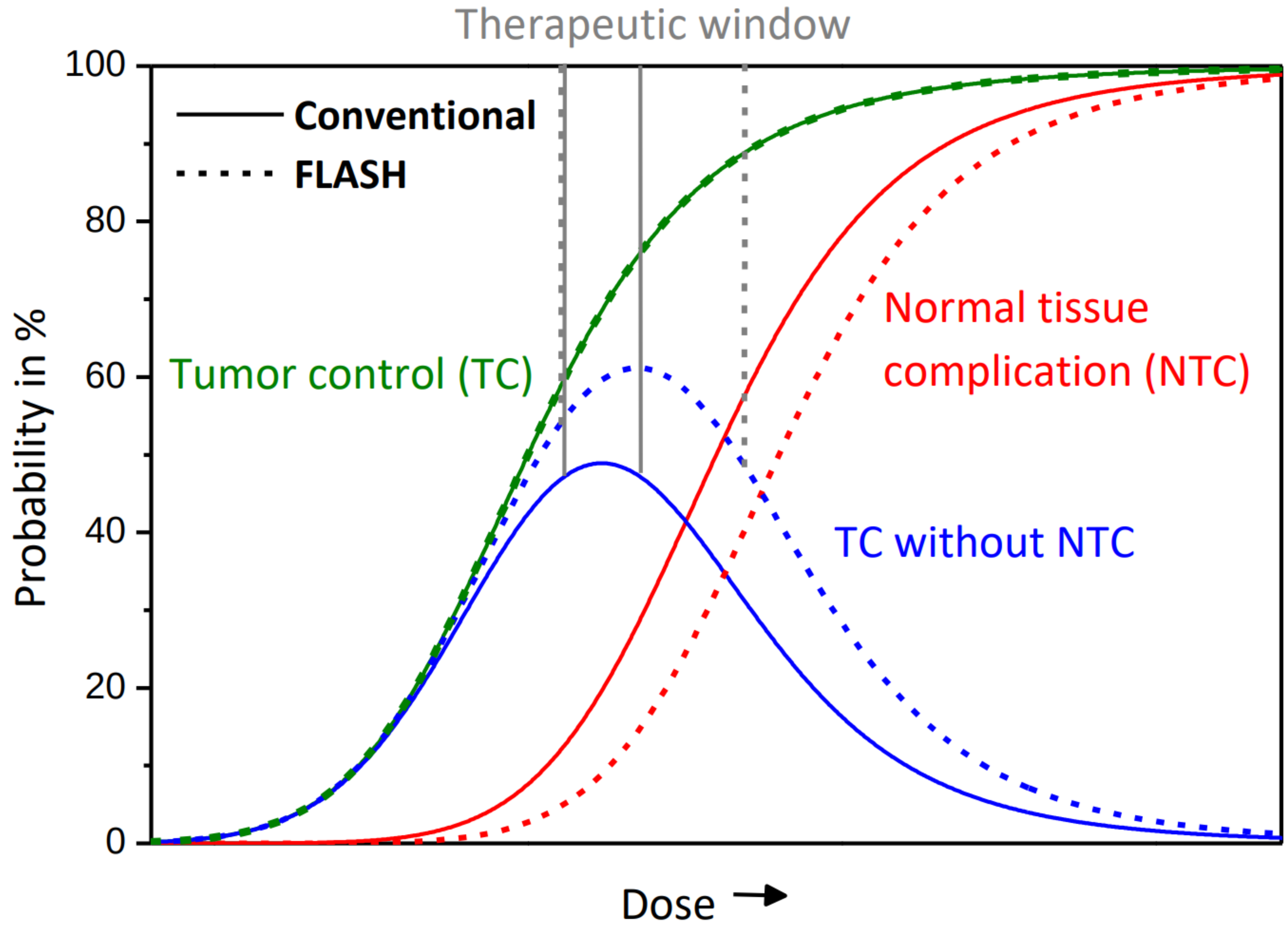


# UHDR and FLASH RT

- Ultra-high dose rate (UHDR) Radiotherapy (RT) > 40 Gy/s vs 0.1 Gy/s (conventional)
- FLASH effect:
  - Reduced toxicity
    => healthy tissue sparing
  - Maintained tumour control


A. Schüller et al., The European Joint Research Project UHDpulse - Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates, Physica Medica 80 (2020) 134-150.

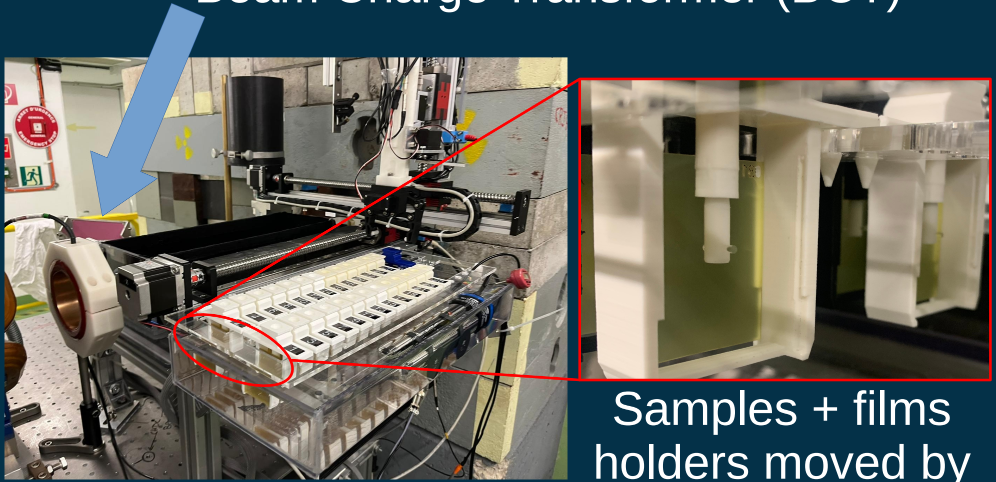



A. Schüller, Dosimetry for Radiation Therapy and Diagnostic Radiology, International Conference on Medical Accelerators and Particle 4Therapy, 2019, Seville

# FLASH and Dosimetric Challenges

- Clinical translation requires reliable and predictable dose delivery
  - Existing real-time dosimeters (e.g. ion chambers) saturate at UHDR
  - Passive dosimeters (e.g. radiochromic films) are reliable but impractical

Beam Charge Transformer (BCT)



Samples + films holders moved by custom robot

# FLASH and Dosimetric Challenges

- Clinical translation requires reliable and predictable dose delivery
  - Existing real-time dosimeters (e.g. ion chambers) saturate at UHDR
  - Passive dosimeters (e.g. radiochromic films) are reliable but impractical
- In addition to novel detectors and ion chambers, a complementary solution based on beam diagnostics is being investigated at CLEAR
  - Correlation between e.g. BCT and film depositions for varying charge, depth in water phantom, conv. VS FLASH
  - Robotic system with multiple sample holders developed for CLEAR combined with IdeaSquare's laser cutter allows for efficient preparation and irradiation of multiple films
  - Irradiated films are scanned using a photo scanner.
  - RGB pixel values of resulting images are extracted and the optical density of a single colour channel $x$ is the channel's pixel value divided by the 16 bit RGB colour space: $ODx = \log(x/65535)$.
  - The dose distribution is determined by inversion of the calibration function, which has the form $ODx = a + b/(D - c)$ where $D$ is the dose.

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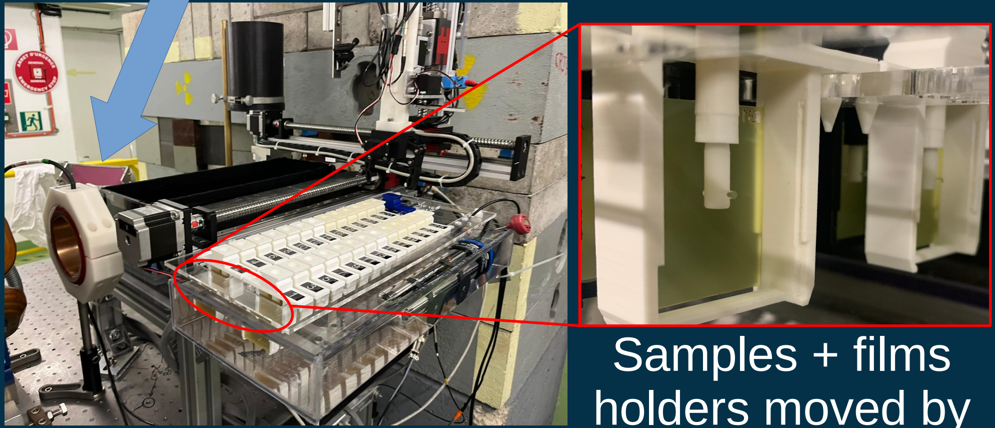

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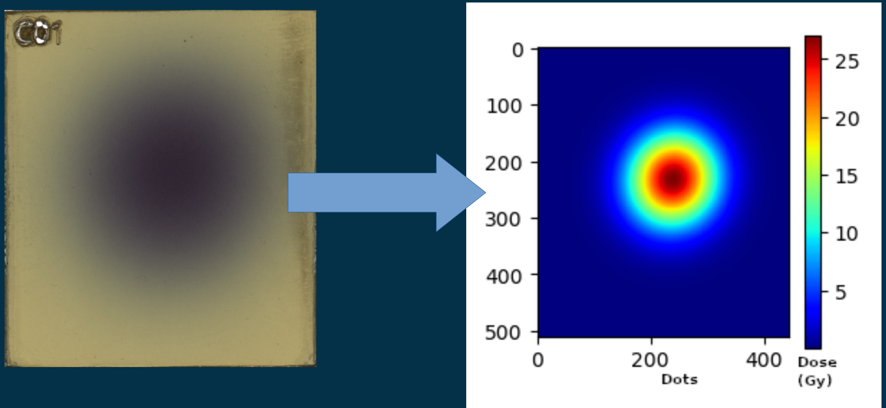
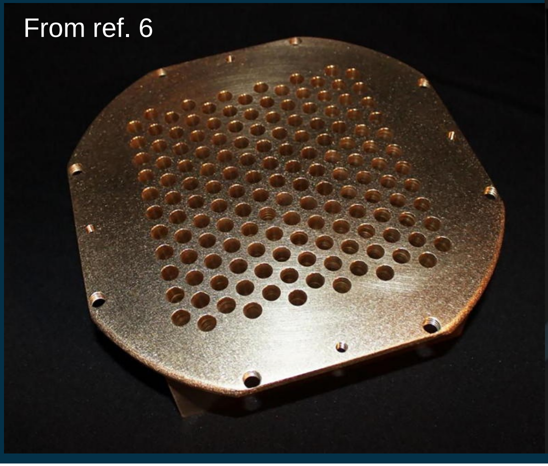
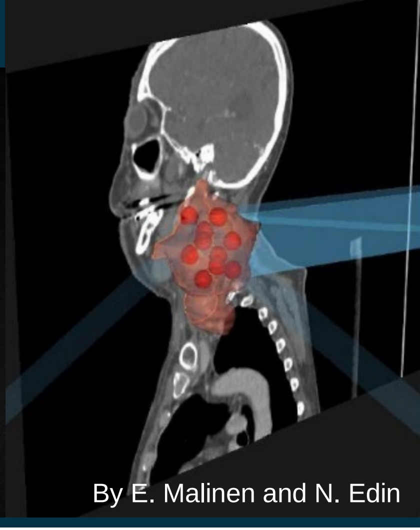
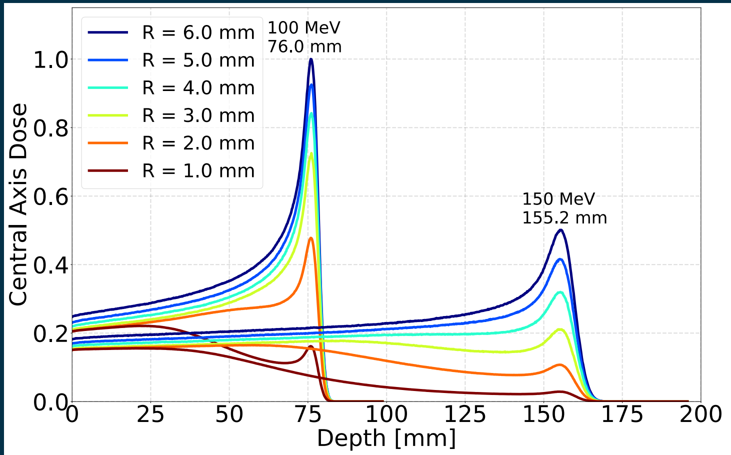


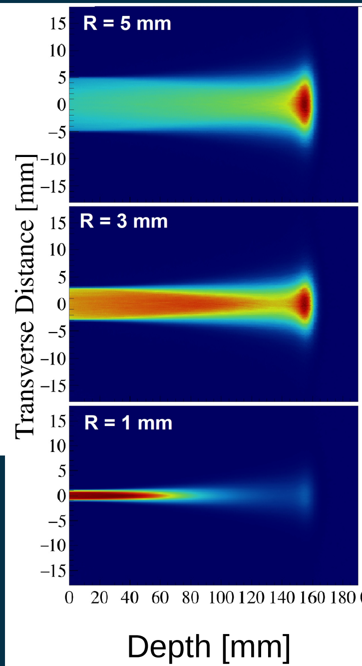
# Sharp dose profiles

- Typical pencil beam radius for spot scanning is approx 5 mm
- Sometimes, we want a smaller beam...
  - To go close to sensitive organs
  - For GRID / spatially fractionated proton therapy
- Very narrow beams are difficult to control with collimation alone
  - Beam widens with depth due to multiple scattering
  - Dose at Bragg peak < dose at skin!


From ref. 6


By E. Malinen and N. Edin

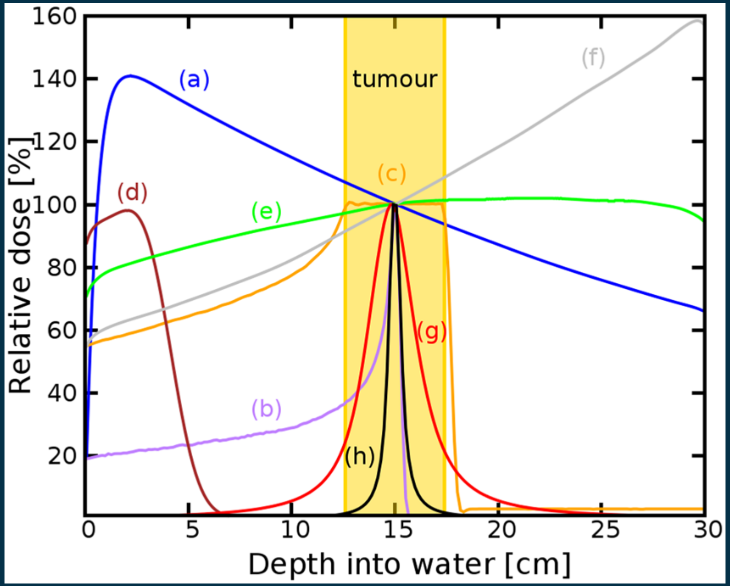


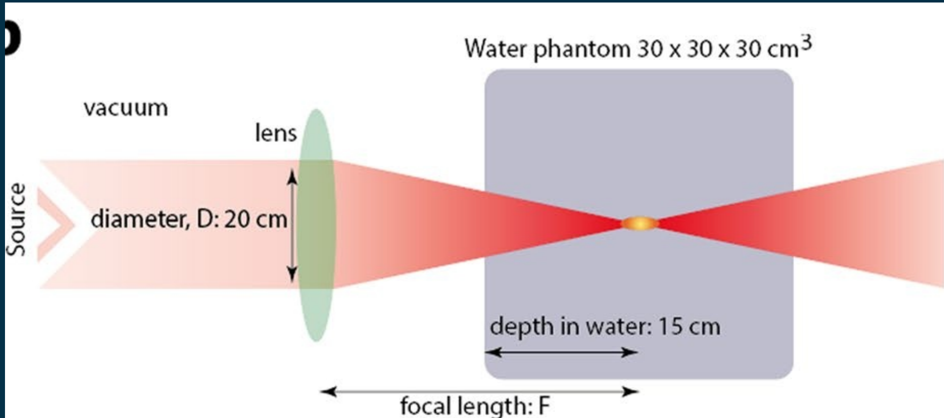

From ref. 7

# Beam shaping for VHEE: Tests at CLEAR

- VHEE = Very High Energy Electrons
  - ~200 MeV
  - Much higher than conventional electron therapy → More penetrating
- Electron dose distribution normally not conformal [(d) and (e)]
  - Geometrical focusing can peak the dose (g)
- Tests with focusing was done at CLEAR
  - Demonstrated peaked dose distribution from VHEE




(a) 6 MV Photons, (b) Bragg peak 147 MeV protons, (c) spread-out Bragg peak, (d) 10 MeV electrons, (e) collimated 200 MeV electrons, (f) collimated 2 GeV electrons, (g) 200 MeV electrons focused at 15 cm, (h) 2 GeV electrons focused at 15 cm. For comparison, each curve is normalised to the dose at the reference depth (15 cm) apart from the 10 MeV electron beam, which is normalised to its peak dose. Curves (a–f) correspond to a Gaussian beam with full-width-at-half-maximum (FWHM) diameter of 15.9 cm, matching the size of the focused beams (curves g,h) at the phantom entrance.




Figures from ref. 4 and 5

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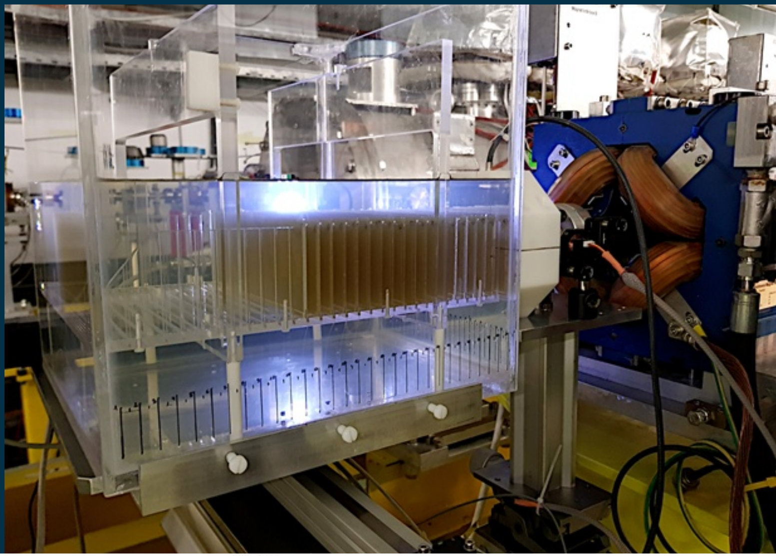
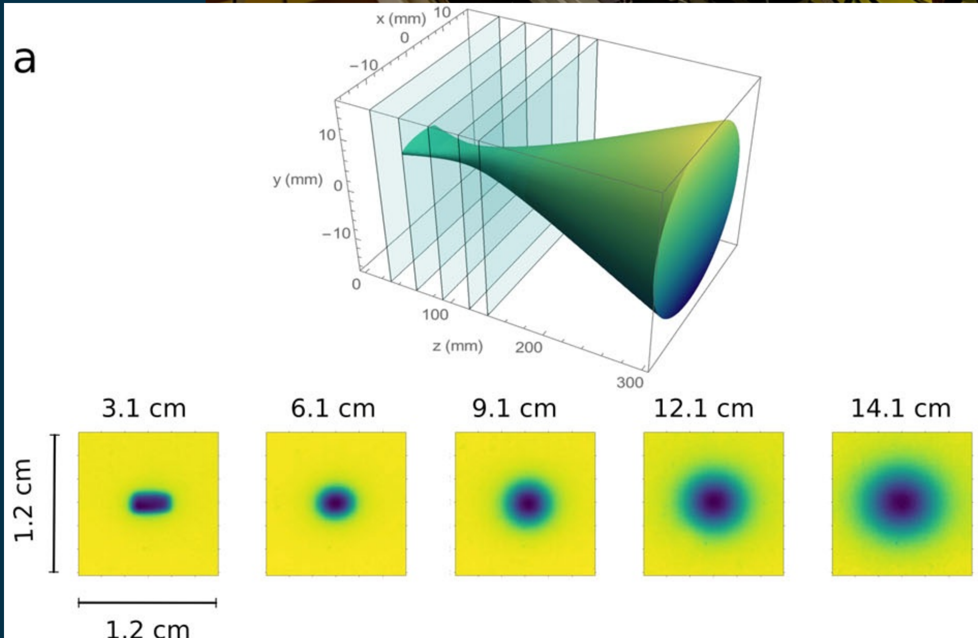
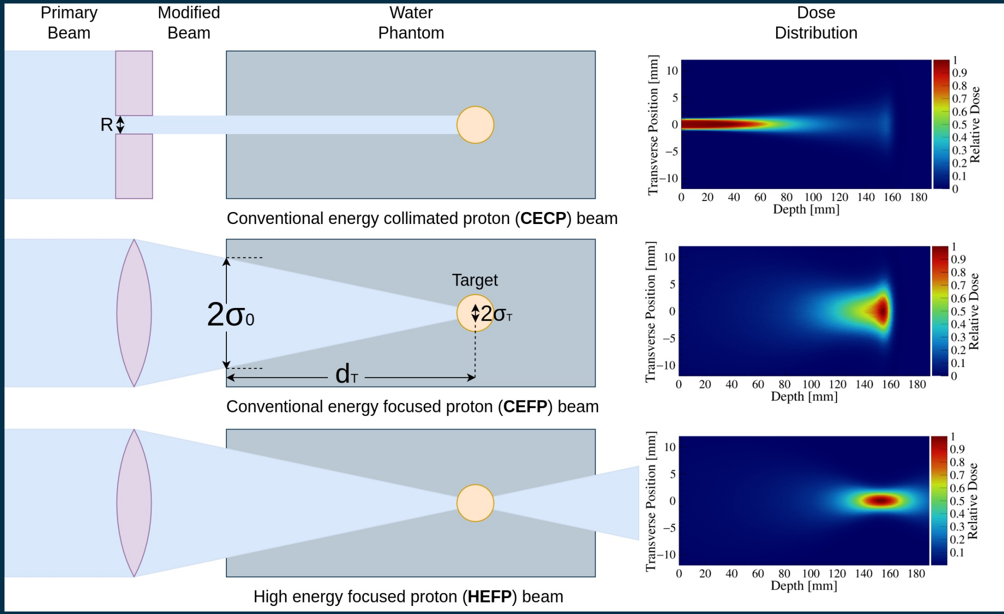





Figures from ref. 4 and 5

# Strongly focused proton beam for high precision

- We can also apply geometric focusing to proton beams
- Get Bragg peak + increased relative track density at target
- Much reduced dose on the surface due to lower track density
- Minimum achievable spot size still controlled by MCS
  - RMS beam size 3.2 mm at 155 mm, 1.8 mm at 73 mm
- Even smaller spot sizes are possible with high energy beams
  - Higher energy → Less MCS, submillimetric spots are possible
  - No Bragg peak
    - Insensitive to density
    - Reduced peak dose, nonzero dose behind target
  - Movable in 3D using only optics
  - Could be interesting for small spots requiring very high precision
- Next challenge is to design and hopefully test magnetic optics to achieve this
- Studied in collaboration with UiO biophysics group

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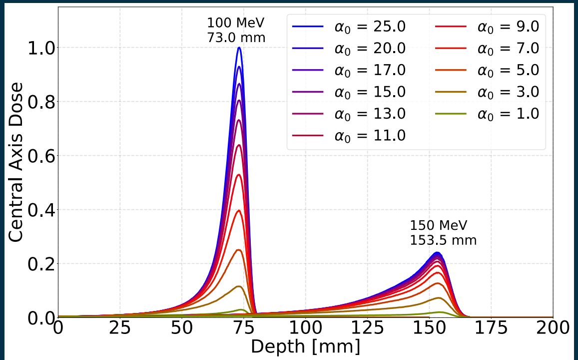


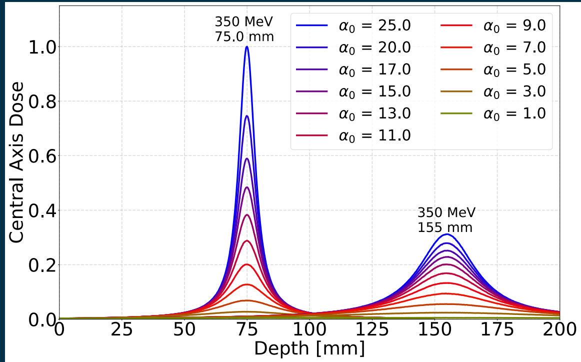

# Conclusions

- Technology for particle physics and particle accelerators have important medical applications
- People at NorCC is studying several of these
  - Imaging with protons
  - FLASH/UHD and specialized dosimetry
  - High-precision irradiation
- Two proton therapy centers under construction in Norway make this especially relevant now

# References


1) Yngve Vogt, “Verdens mest moderne stråleterapi mot kreft på vei til Norge,” Apollon, Aug. 20, 2020. Accessed: Aug. 31, 2021. [Online]. Available: https://www.apollon.uio.no/artikler/2020/3_protonterapi.html
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