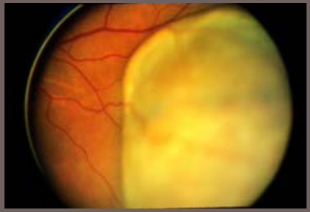
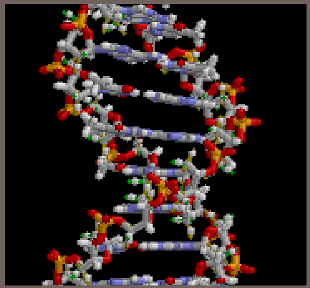
Cancer Radiotherapy with particle beams

Dr. Cornelia Hoehr

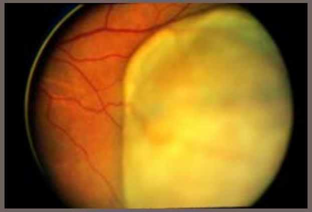


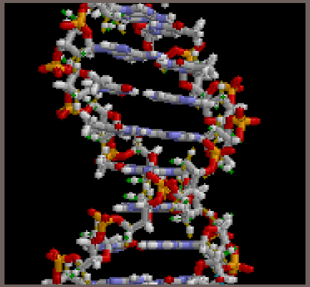


Cancer Radiotherapy with particle beams

- Cancer treatment
- Ionizing radiation
- Different Radiotherapy options
- Radiotherapy @ TRIUMF
- State-of the art Radiotherapy

Dr. Cornelia Hoehr





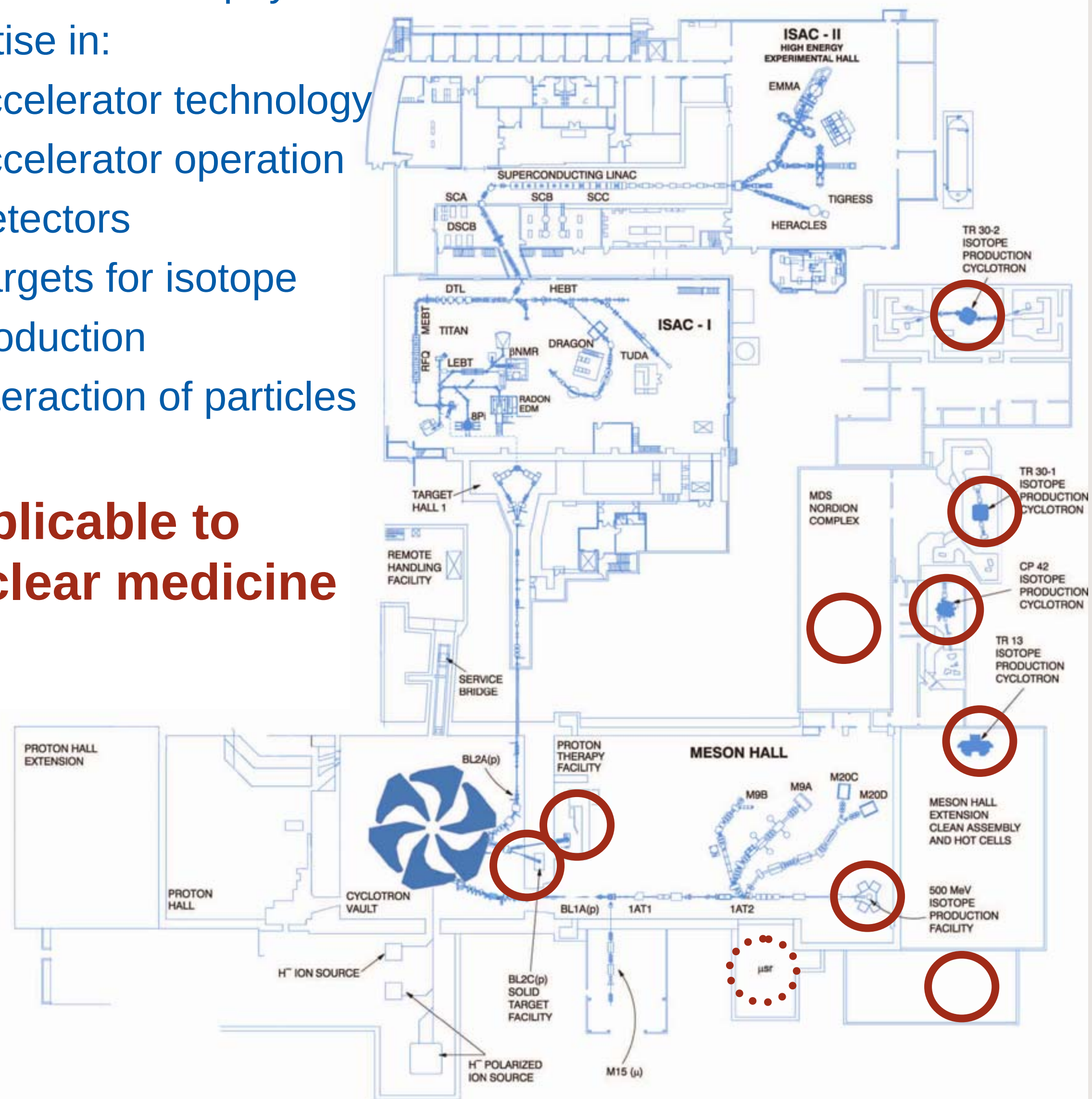
Nuclear Medicine @ TRIUMF

TRIUMF - nuclear physics lab.

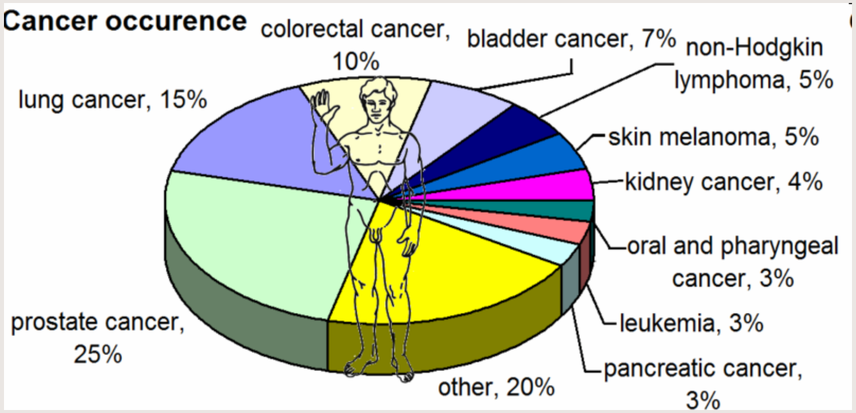
Expertise in:

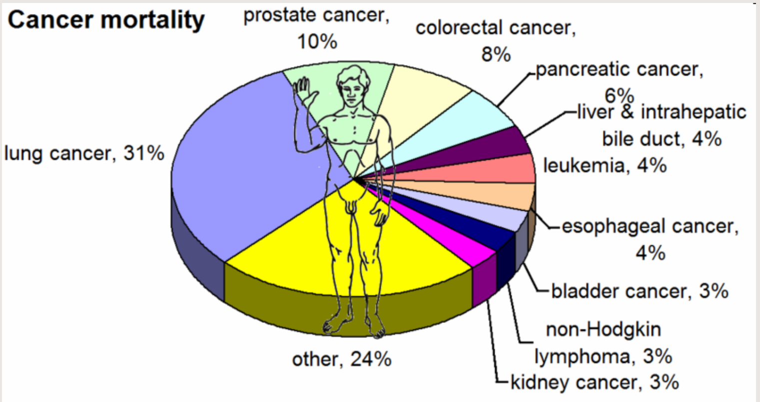
- Accelerator technology
- Accelerator operation
- Detectors
- Targets for isotope production
- Interaction of particles

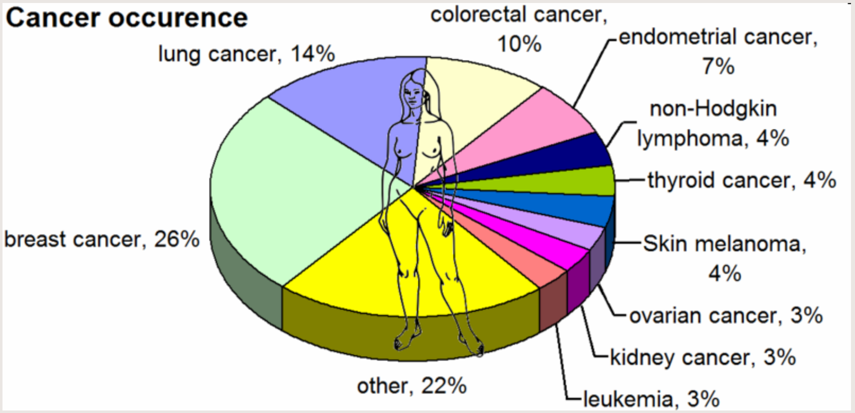
Applicable to nuclear medicine

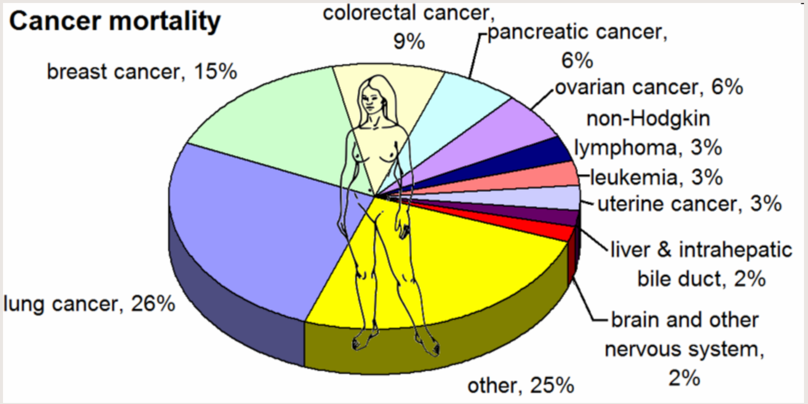


Cancer


Cancer occurence
colorectal cancer, 10%
bladder cancer, 7%
non-Hodgkin lymphoma, 5%
lung cancer, 15%
skin melanoma, 5%
kidney cancer, 4%
oral and pharyngeal cancer, 3%
leukemia, 3%
prostate cancer, 25%
pancreatic cancer, 3%
other, 20%


Cancer mortality
prostate cancer, 10%
colorectal cancer, 8%
pancreatic cancer, 6%
liver & intrahepatic bile duct, 4%
lung cancer, 31%
leukemia, 4%
esophageal cancer, 4%
bladder cancer, 3%
non-Hodgkin lymphoma, 3%
other, 24%
kidney cancer, 3%


Cancer occurence
colorectal cancer, 10%
endometrial cancer, 7%
lung cancer, 14%
non-Hodgkin lymphoma, 4%
thyroid cancer, 4%
breast cancer, 26%
Skin melanoma, 4%
ovarian cancer, 3%
kidney cancer, 3%
other, 22%
leukemia, 3%


Cancer mortality
colorectal cancer, 9%
pancreatic cancer, 6%
breast cancer, 15%
ovarian cancer, 6%
non-Hodgkin lymphoma, 3%
leukemia, 3%
uterine cancer, 3%
liver & intrahepatic bile duct, 2%
lung cancer, 26%
brain and other nervous system, 2%
other, 25%

TRIUMF

Cancer

If you were to develop cancer:

Surgery – to remove the tumor

Chemotherapy – to kill the tumor with drugs (fast-dividing cells)

Radiotherapy **– to kill the tumor with radiation**

*** External beam therapy – photons, neutrons, protons**

*** Internal therapy – brachytherapy (radioactive isotopes)**

Success: Tumor control vs. complications

Destroy/remove tumor without damaging healthy or normal tissue nearby

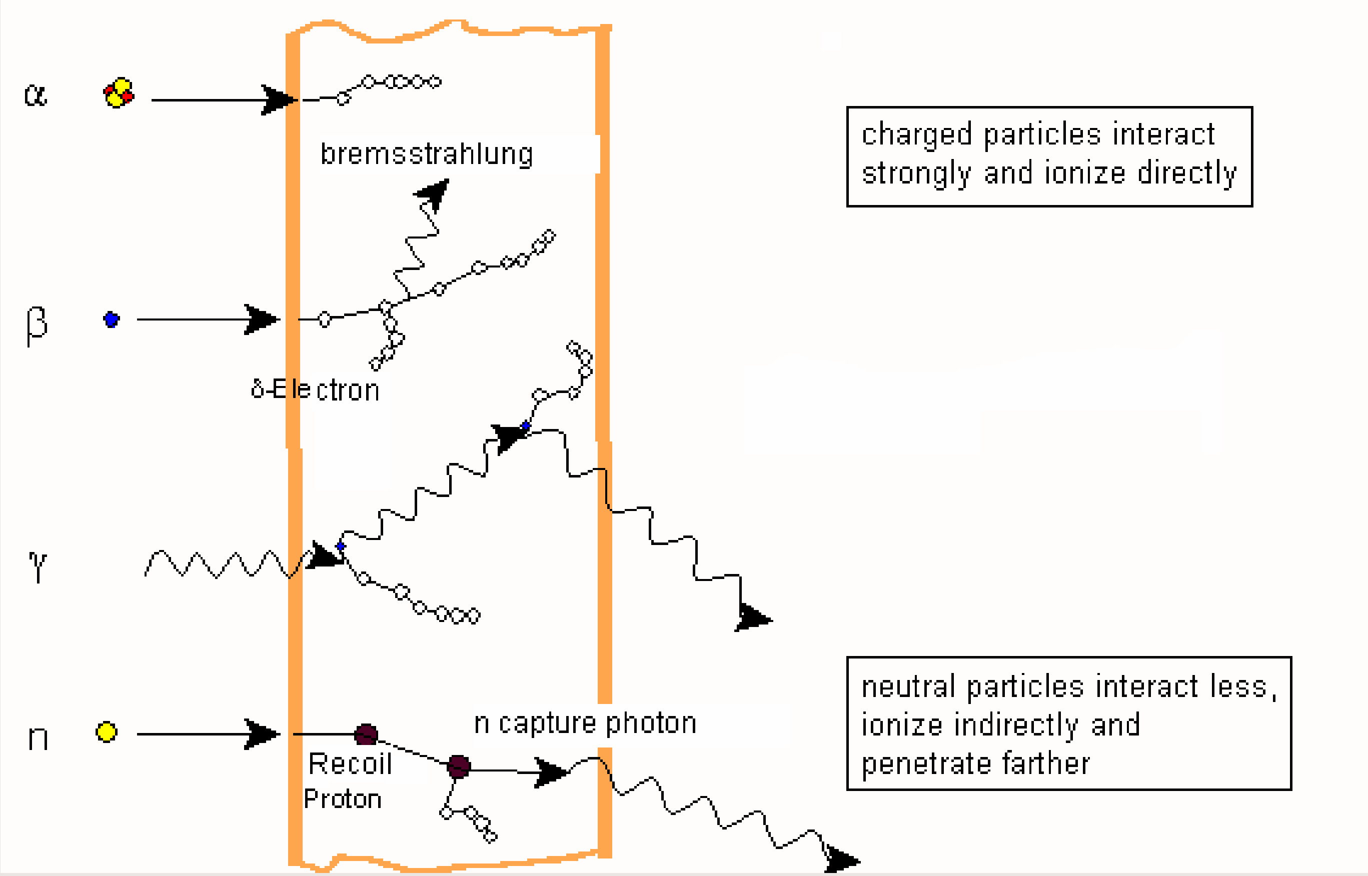
Cancer

Some numbers:

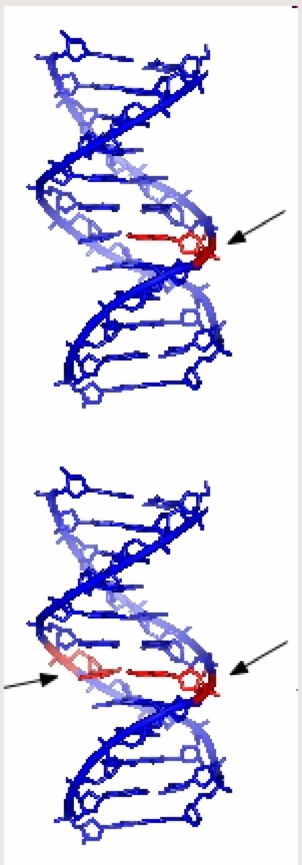
- **0.4%: develop cancer per year in US**
- **25%: probability to die of cancer in industrialized countries**
- **45%: of cancer patients can be cured**
- **50%: of those 45% are treated with radiation therapy, alone or in combination**
- **65%: diagnosed with localized tumor**
- **70%: of patients receive radiotherapy**
- **80%: of radiotherapy is with photon beams**

Source: IAEA technical report series No. 461 (2008)

Ionizing Radiation



DNA break

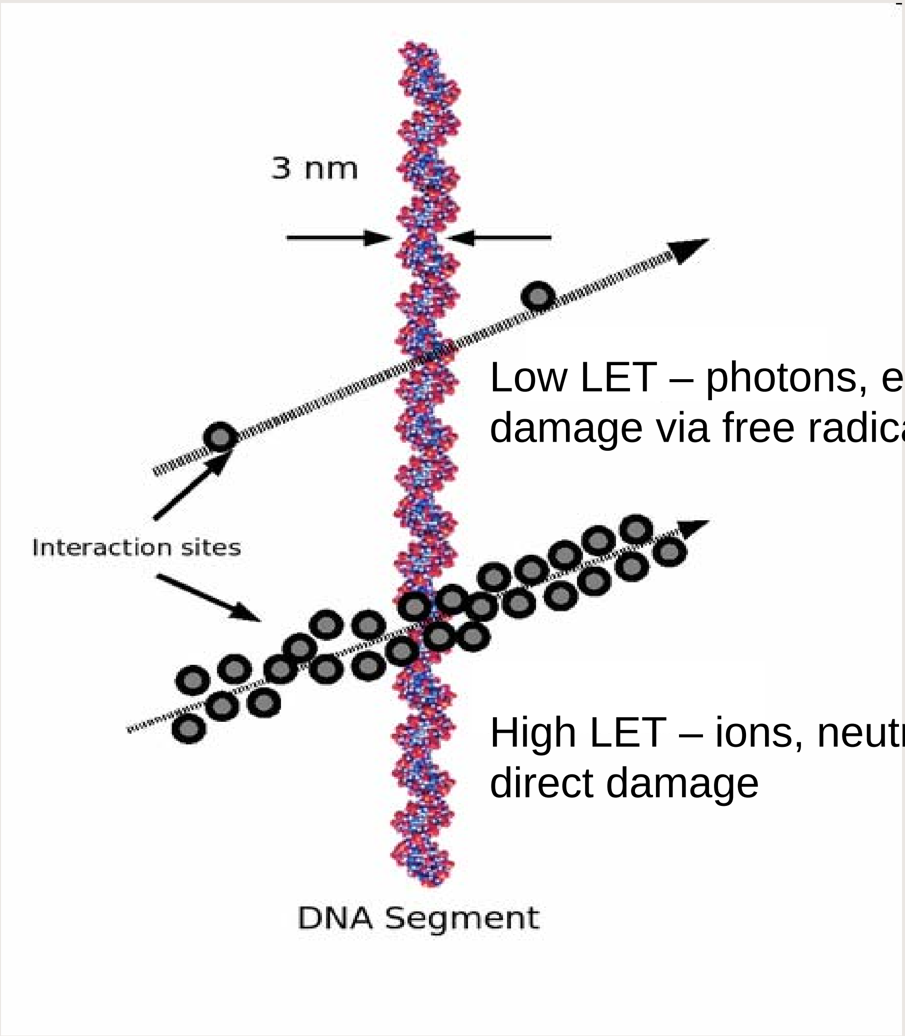


- DNA (Deoxyribonucleic acid): genetic instructions for development and functioning
- Cell needs information from DNA for survival

- Single helix break easy to repair
- Double helix break more difficult to repair
- Cell can not survive

- Radiotherapy: as many double helix breaks in cancer cells as possible with as few double breaks as possible in healthy cells

LET – Linear Energy Transfer

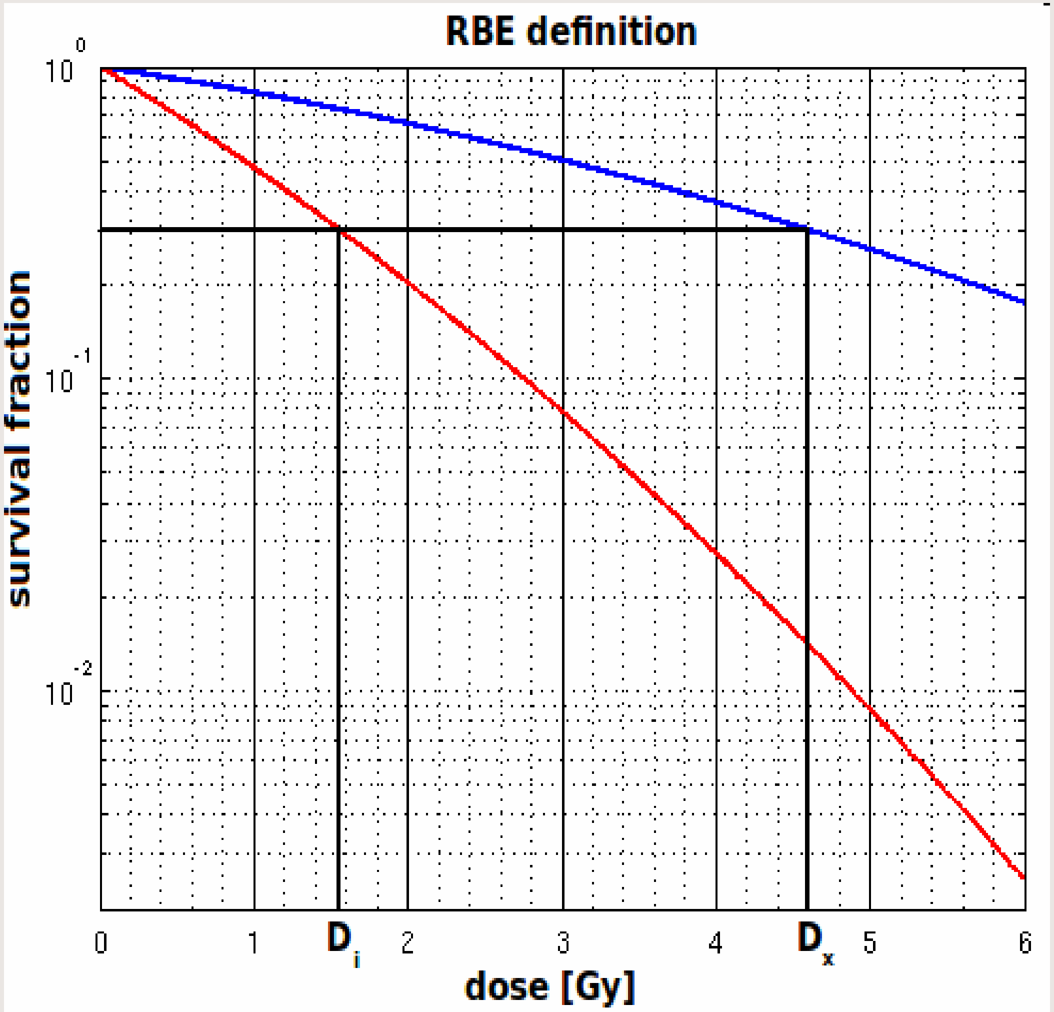


Low LET – photons, electrons, protons, indirect damage via free radical formation

High LET – ions, neutrons, direct damage

Linear Energy Transfer (LET): Energy transferred (ionization, secondary electrons) per unit distance

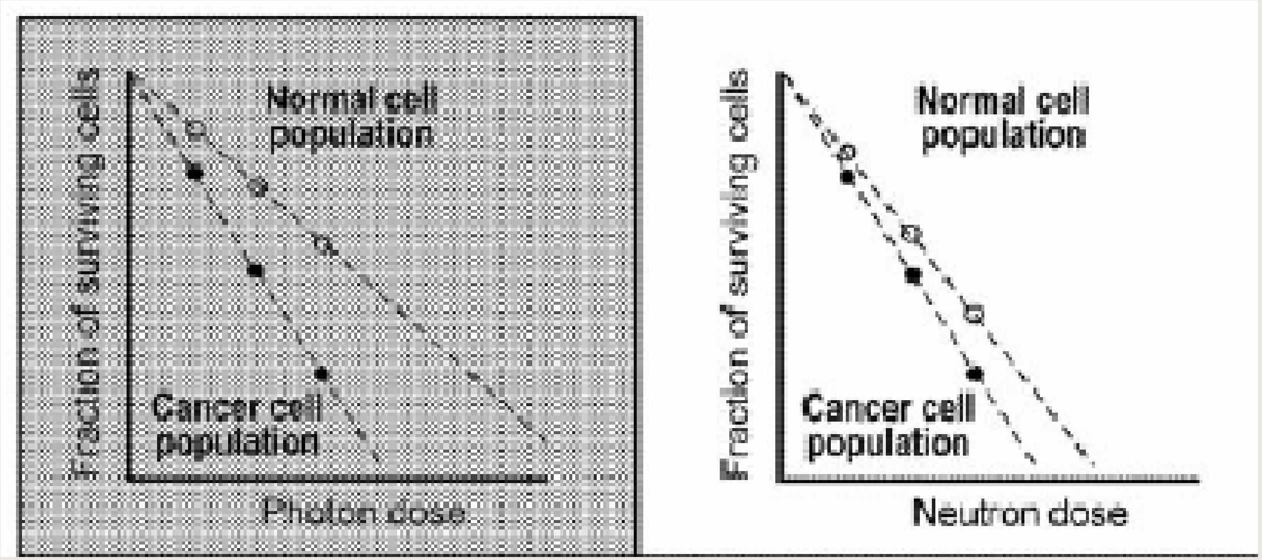
Relative Biological Effectiveness



Definition of <u>R</u>elative <u>B</u>iological <u>E</u>ffectiveness: $RBE = D_X/D_i$

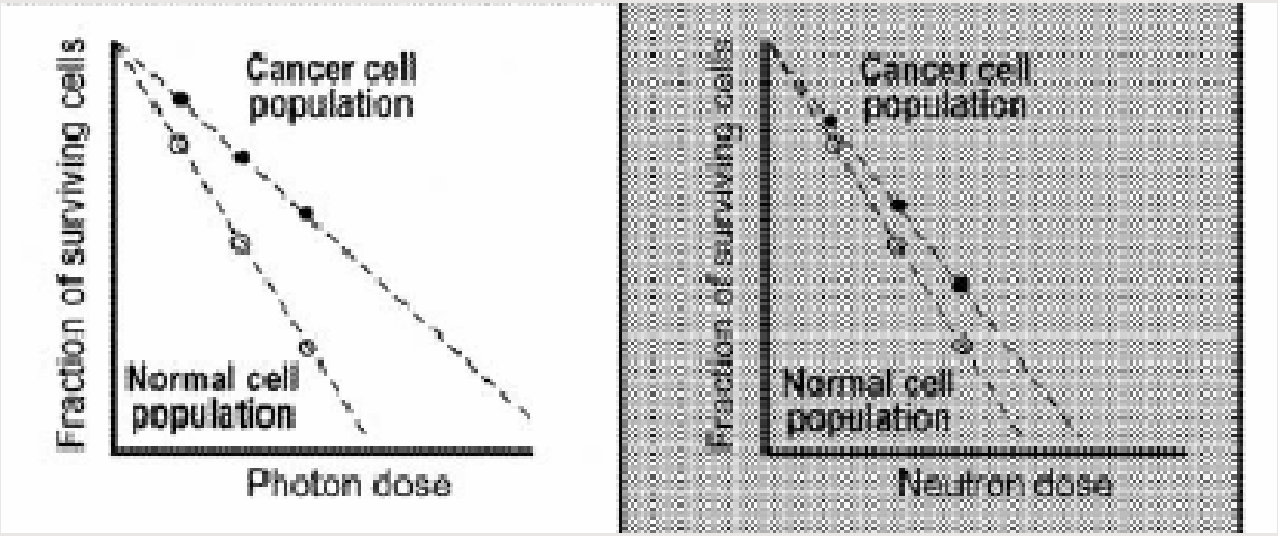
Data for CHO-K1 cell line irradiated by photons (blue curve) and carbon ions (red curve).

Choice of Treatment



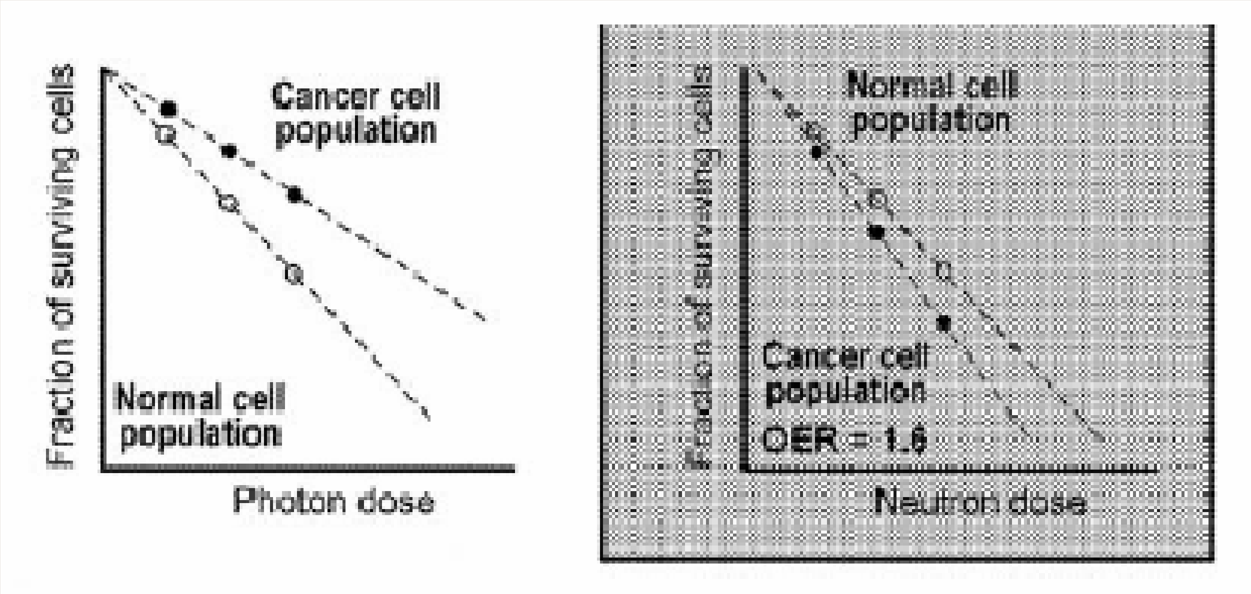
IAEA technical report series No. 461 (2008)

Choice of Treatment



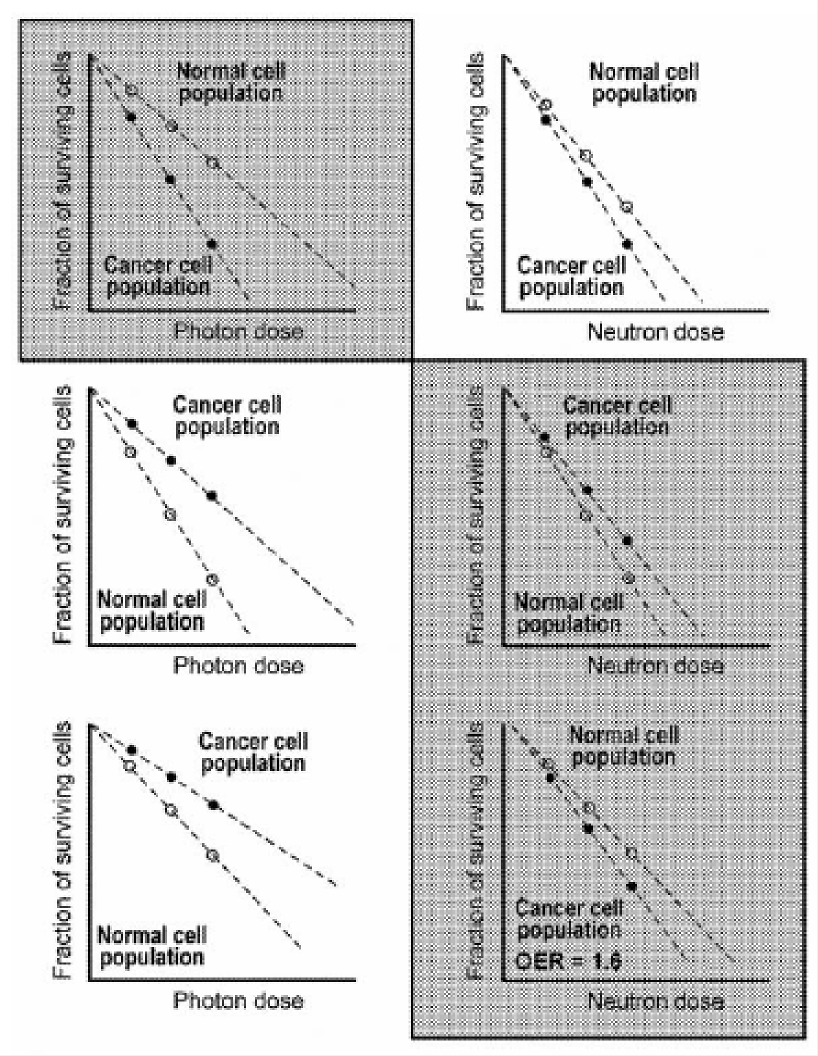
IAEA technical report series No. 461 (2008)

Choice of Treatment



IAEA technical report series No. 461 (2008)

Choice of Treatment



- Radiosensitivity of cancer cell
- Repair ability of healthy tissue
- Size of tumor
- Fractions

IAEA technical report series No. 461 (2008)

Electron Volt

Energy unit

1 eV = $1.602*10^{-19}$ J

Amount of kinetic energy gained by an electron accelerated through 1 V electrical potential (E=qU)

Electron Volt

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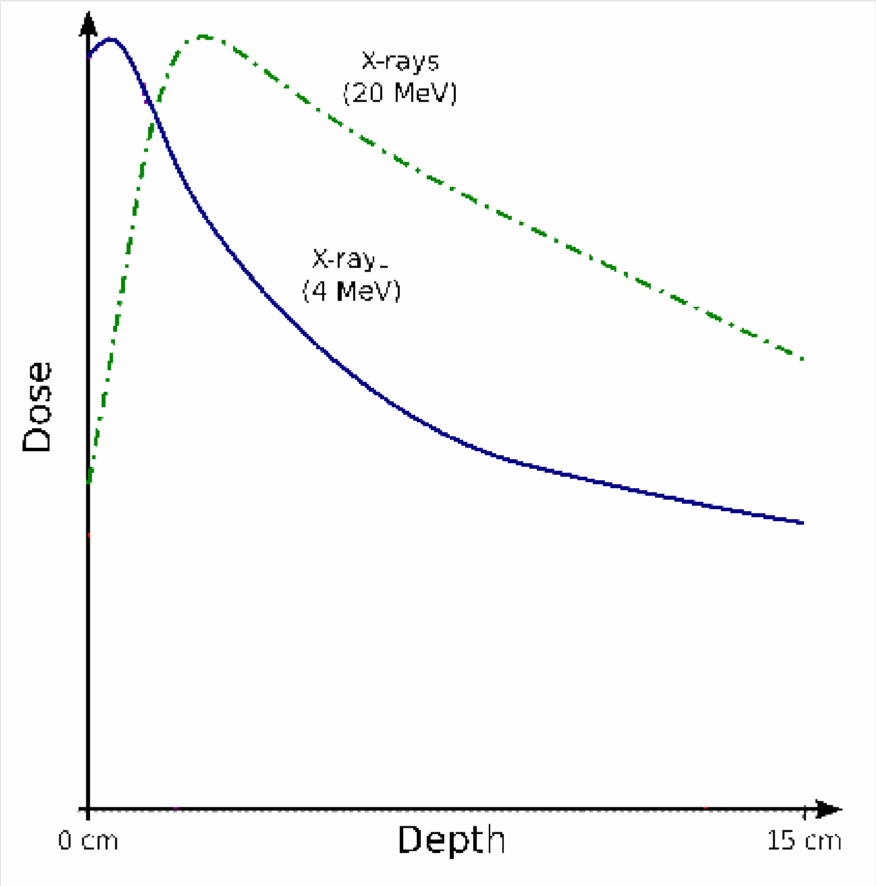
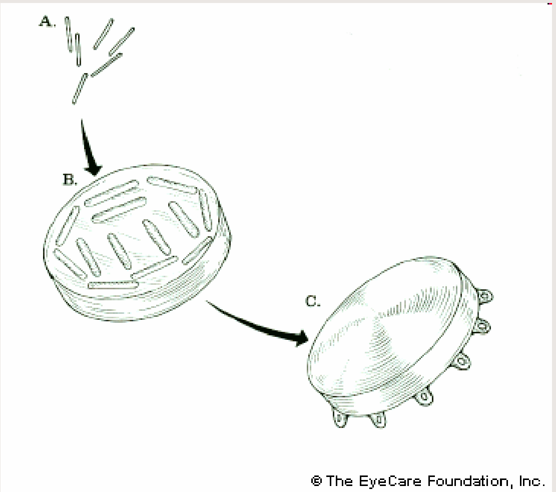
External: Photon treatment



- Cost-efficient, easy set-up, very common
- Many techniques to minimize dose to healthy tissue (multiple beams, wedges, intensity modulation…)
- Dose does not stop after tumor
- Low LET

Internal: Brachytherapy

From the Greek word *brachys*, meaning "short-distance“, most isotopes used are gamma emitters

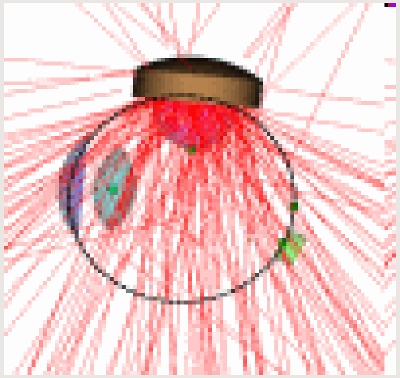


Advantages

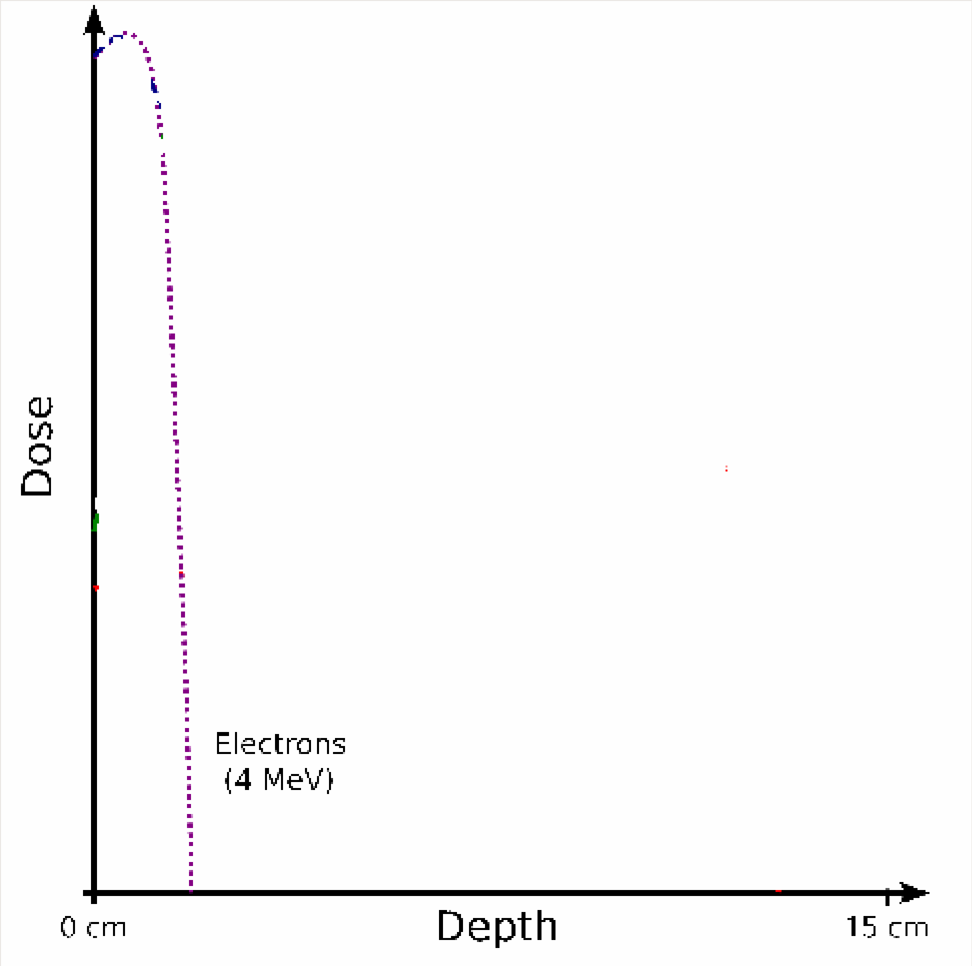
- Very localized
- Can have shorter treatment times
- Moves with tumor
- Can be permanent or temporary

Disadvantage

- High dose to medical personnel
- Dose not homogeneous (in some cases 40% of dose can be deposited in 15% of tumor)
- Tumor-size dependent



External: Electron-beam treatment



- Mostly used for tumors close to skin
- Low LET

External/internal: Neutron treatment

- Boron neutron-capture therapy (BNCT)

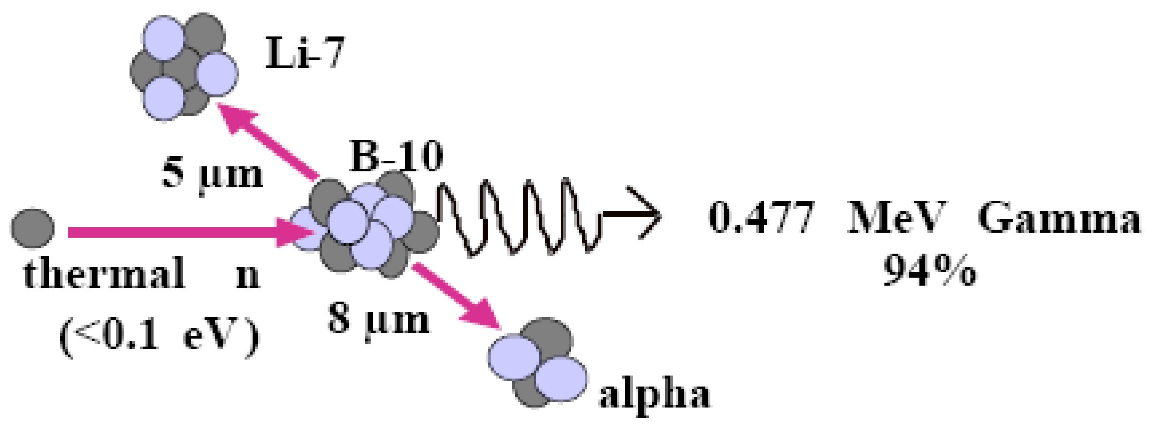


Fig. 1. Nuclear reaction utilized in BNCT. A ^{10}B nucleus absorbs a thermal neutron and promptly emits a back to back ^{7}Li ion and a ^{4}He (alpha) particle. The combined range of 12–13 µm is similar to mammalian cell dimensions.

- BNCT (thermal <0.1eV)
- Only experimental (treatment for hours)
- Tracer development still in beginning

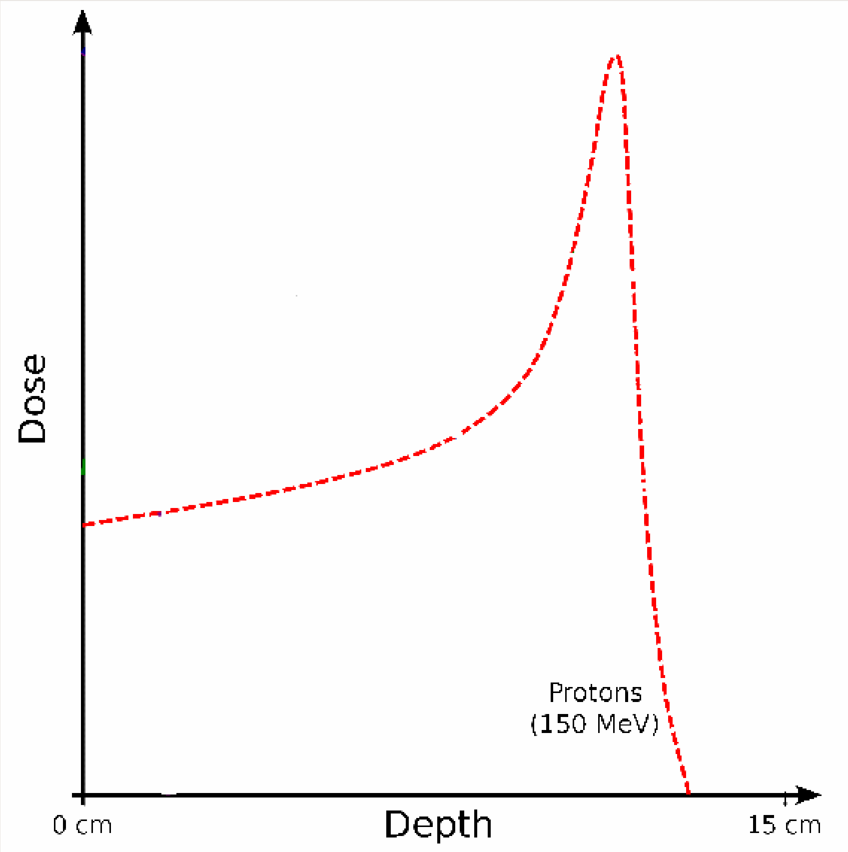
External: Ion-beam therapy

Advantage

- Less dose to surrounding tissue (Bragg peak)
- Very homogeneous tumor dose
- High control over position of Bragg peak (low to high LET)

Disadvantage

- Need higher-energy accelerator
- 250MeV for 30cm in human tissue
- Expensive



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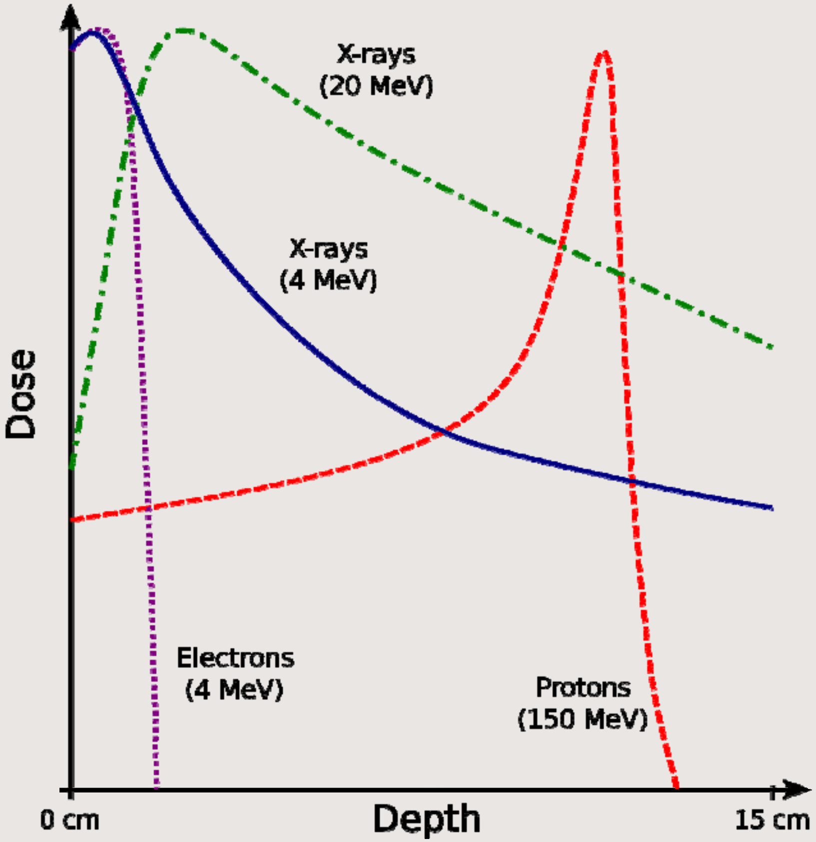
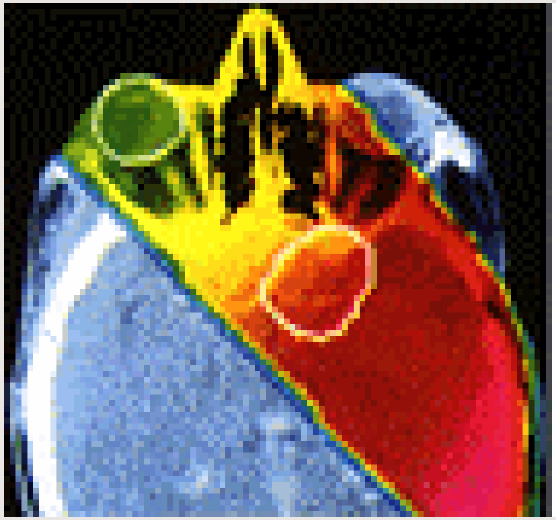
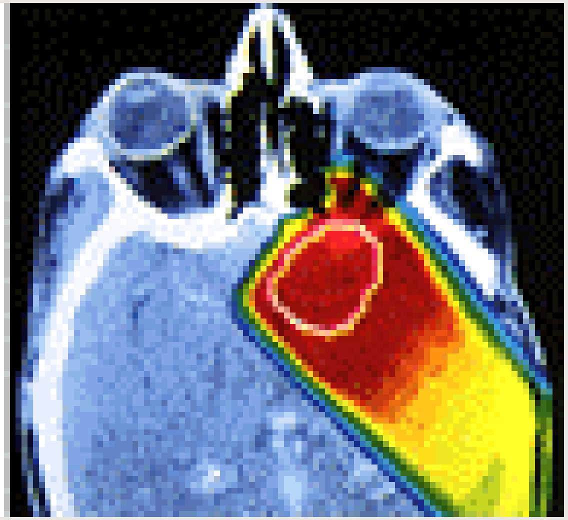


X Rays vs. Protons

Highest dose - red
Lowest dose - yellow

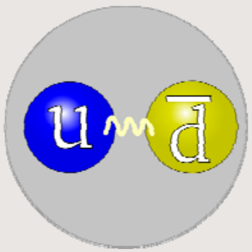


X rays

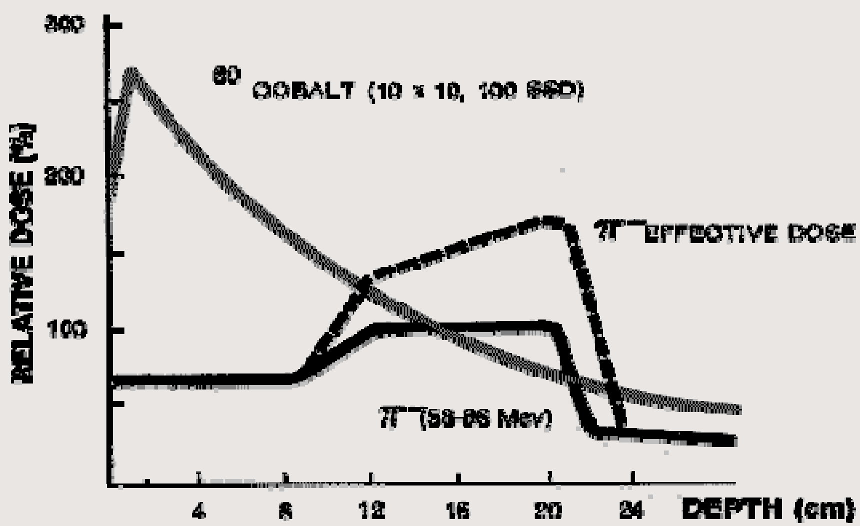


Protons

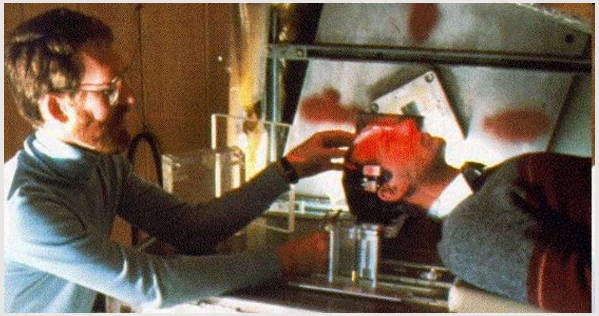
External: Pion-beam treatment



- Pion - subatomic particle, meson
- In nuclei, glue to hold protons and neutrons
- Some are charged
- Have Bragg peak, little damage to surrounding tissue, high LET in Bragg peak
- Lots of damage at Bragg peak (‘pion star’)



Pion-beam treatment at TRIUMF



• Study from 1980 – 1994 (over 300 patients), one of only three in the world
• Brain tumors (glioblastoma) and prostate cancer

• Result of study: no advantage over conventional photon therapy

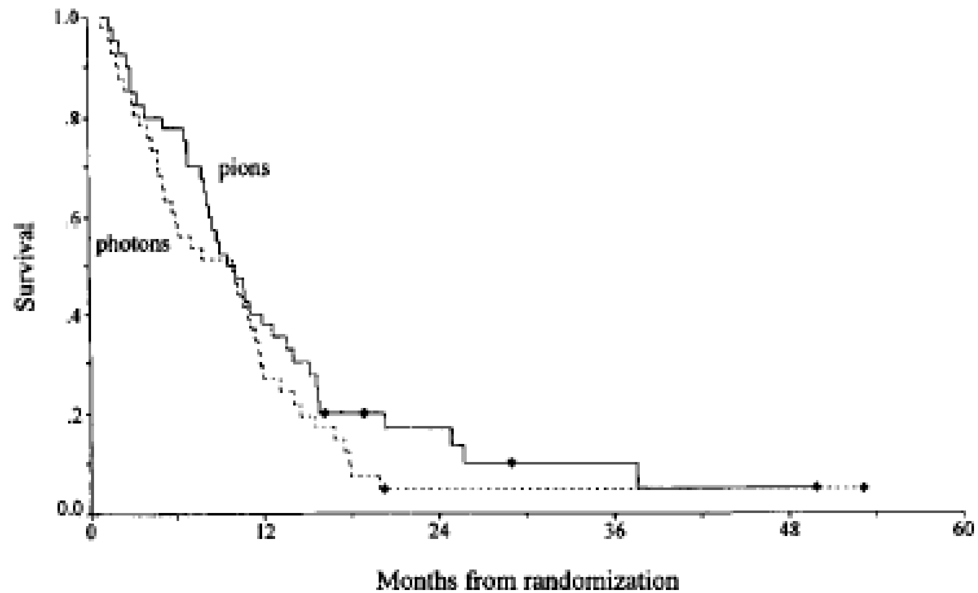
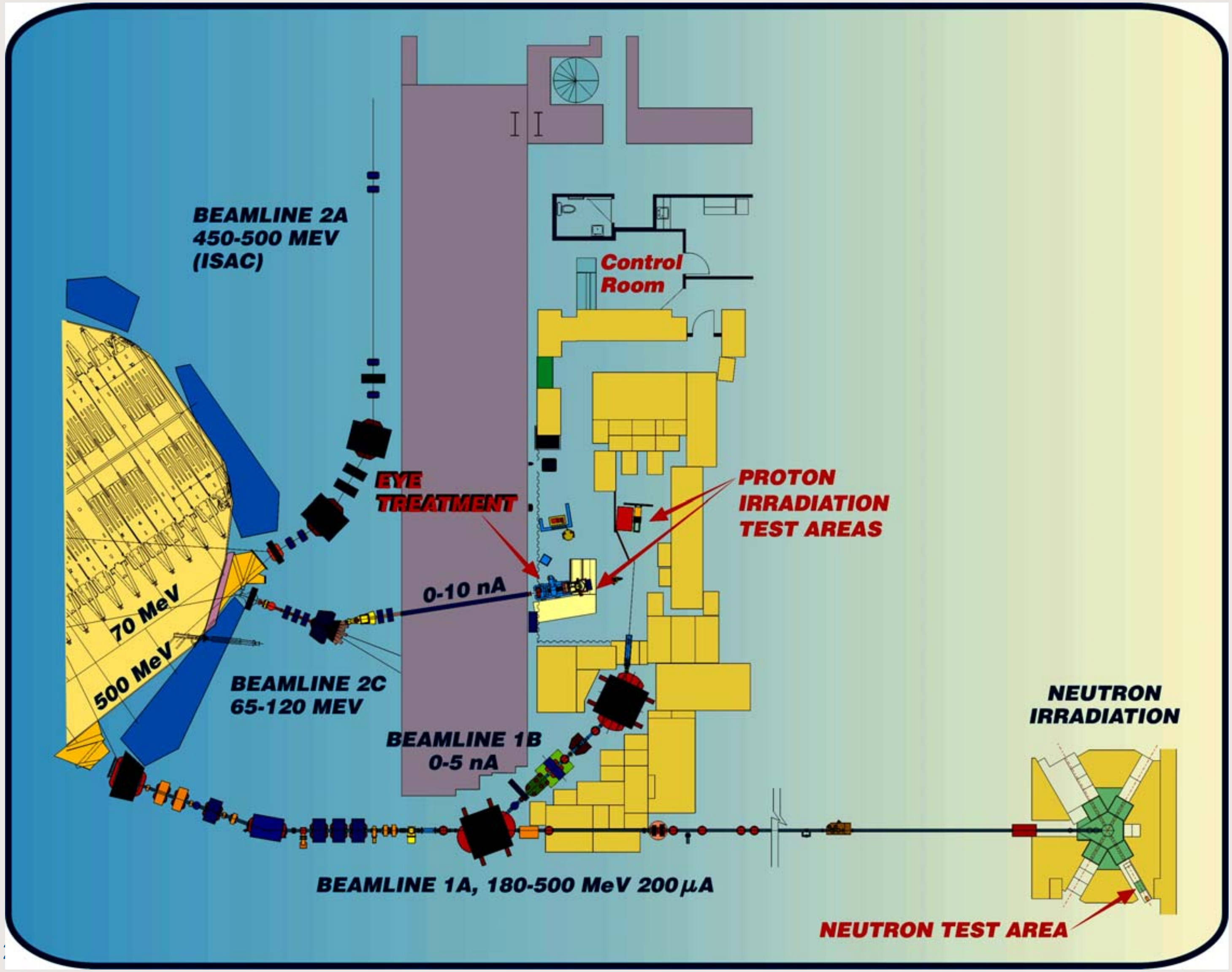


Fig. 2. Overall survival for both treatment groups. Median survivals are: photons, 10 months; pions, 10 months. Log rank: $p = 0.22$.

Int. J. Radiation Oncology Biol. Phys. **37** 491 (1997)

TRIUMF

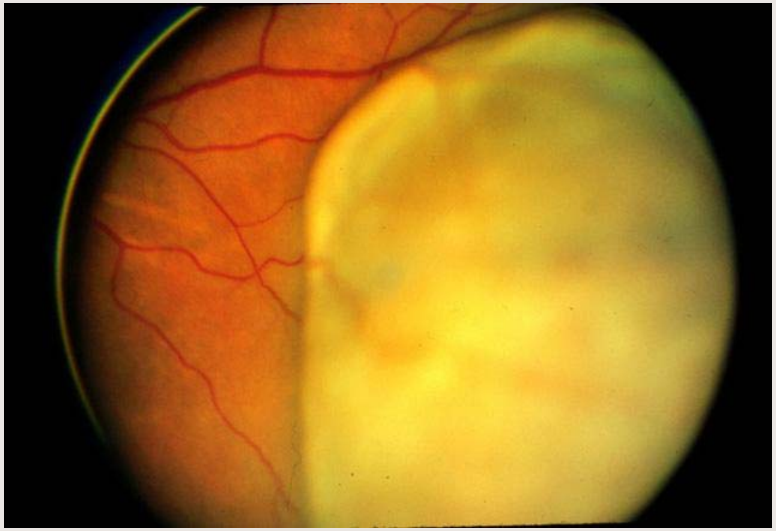
Proton Therapy at TRIUMF



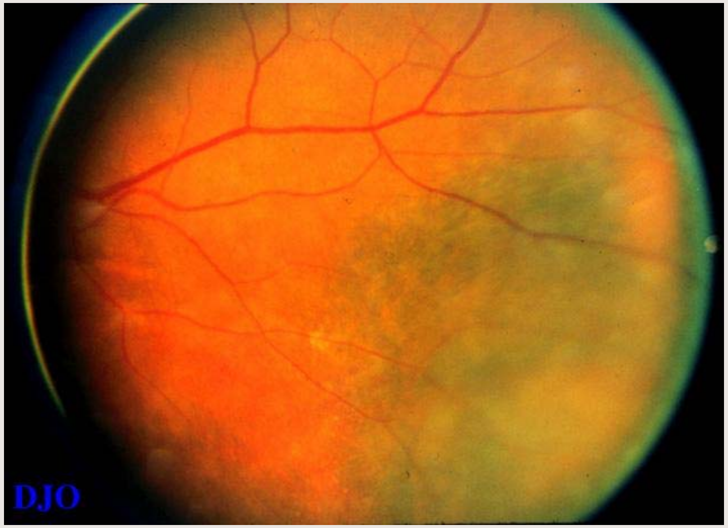
Ocular Melanoma

Frequency: 5 -6 cases/year per million population

Treatment protocols: Radioactive plaque therapy
Charged-particle radiotherapy
Enucleation

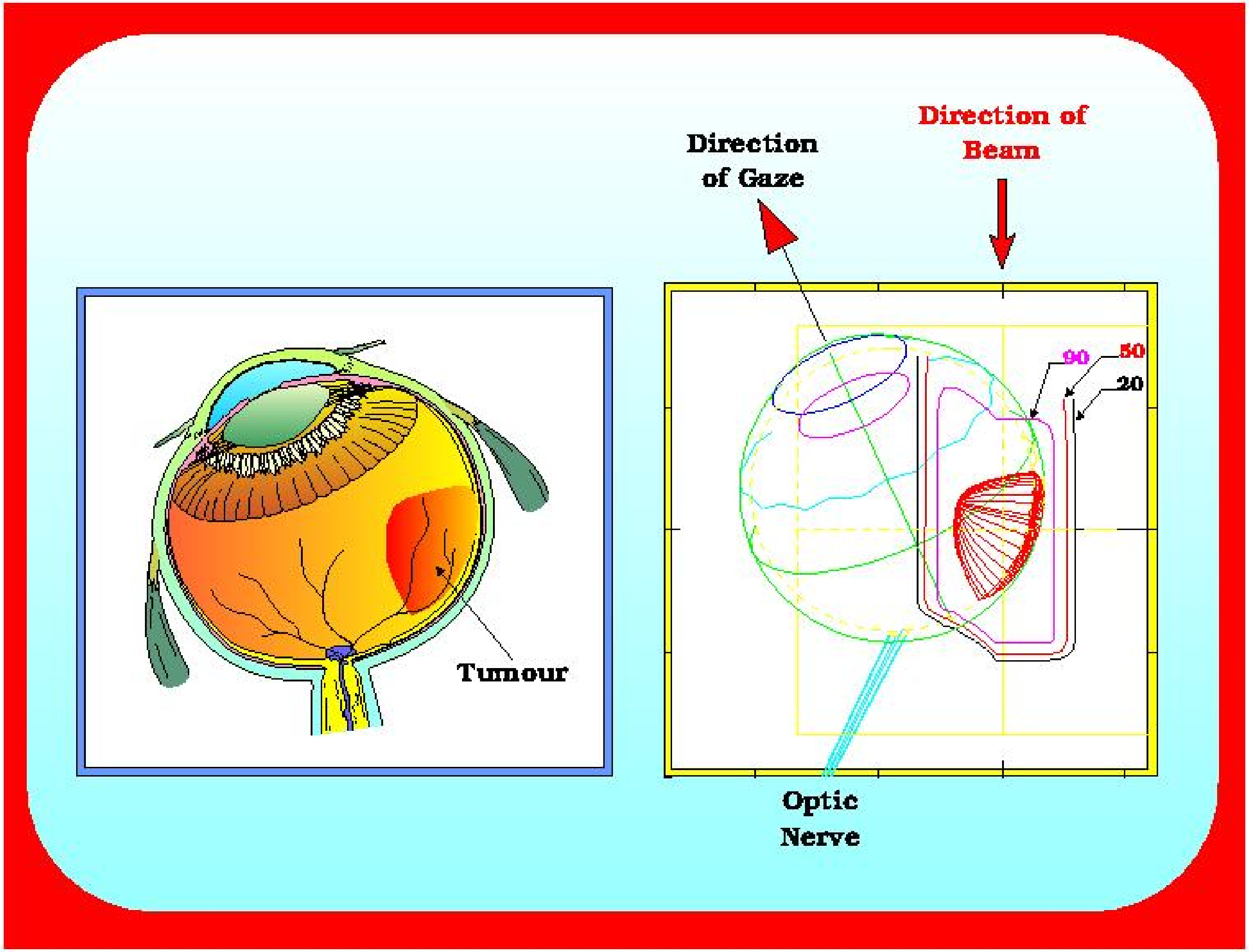


Uveal Melanoma before proton beam treatment

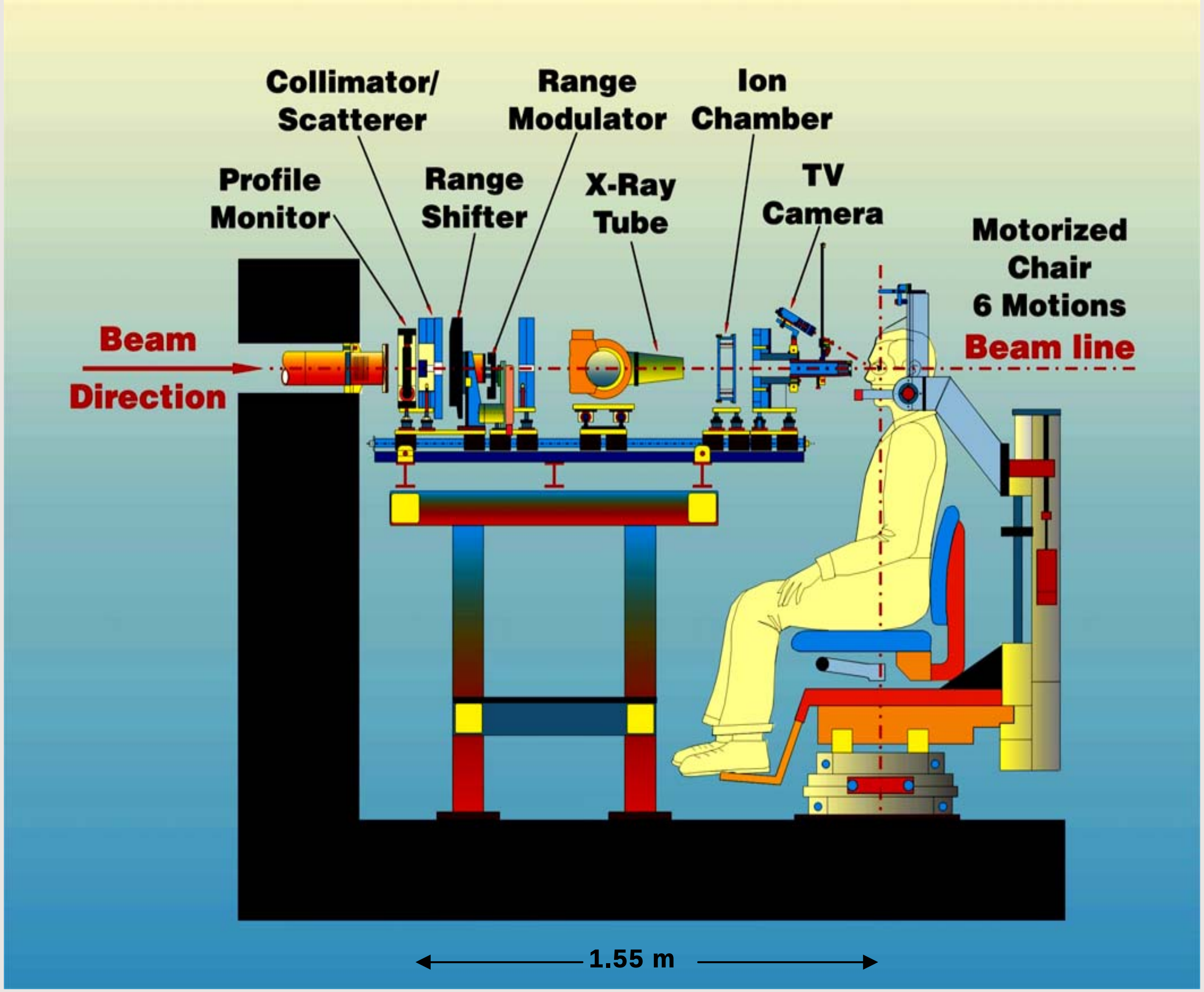


Uveal Melanoma after proton beam treatment

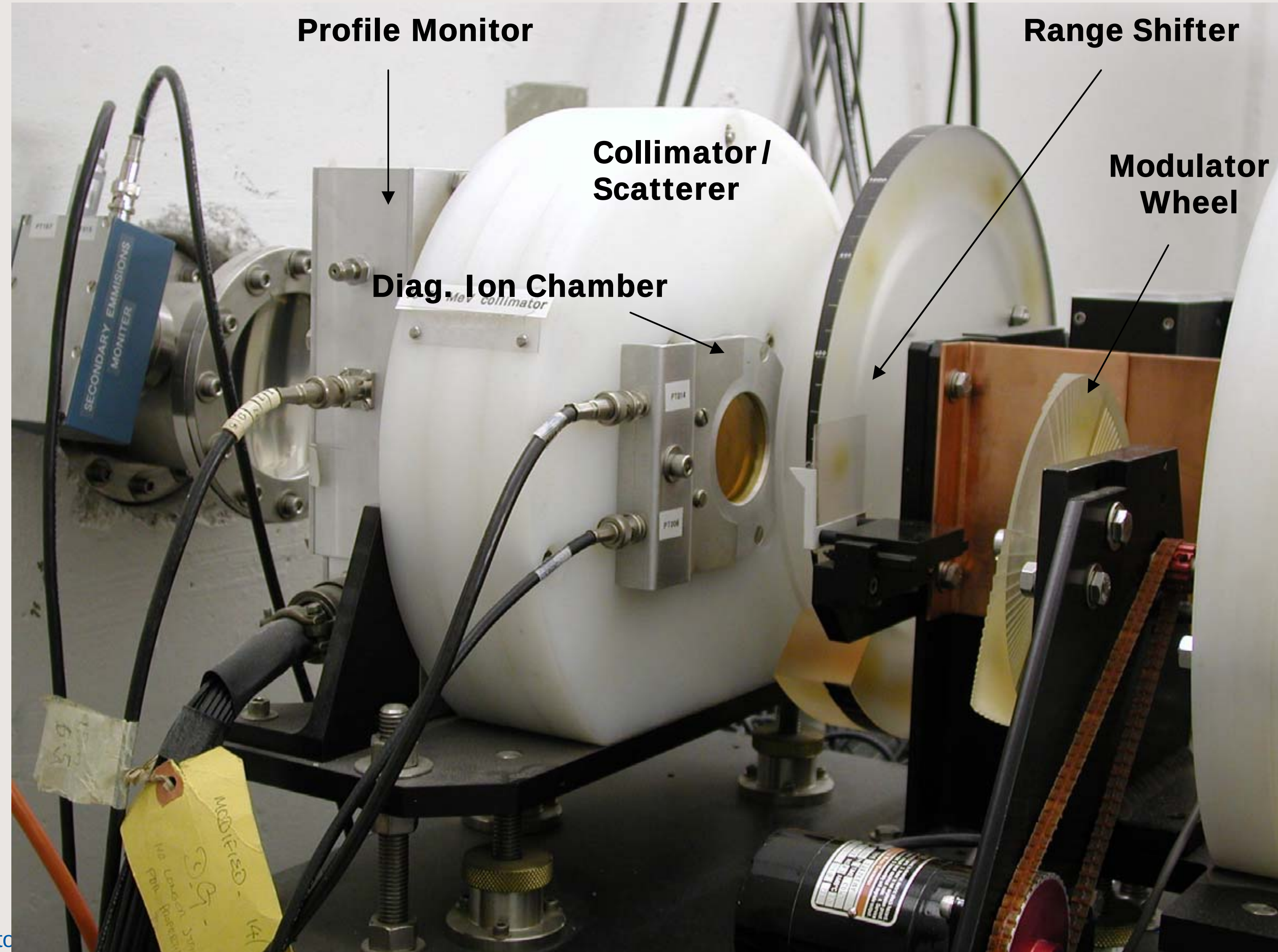
Treatment Planning



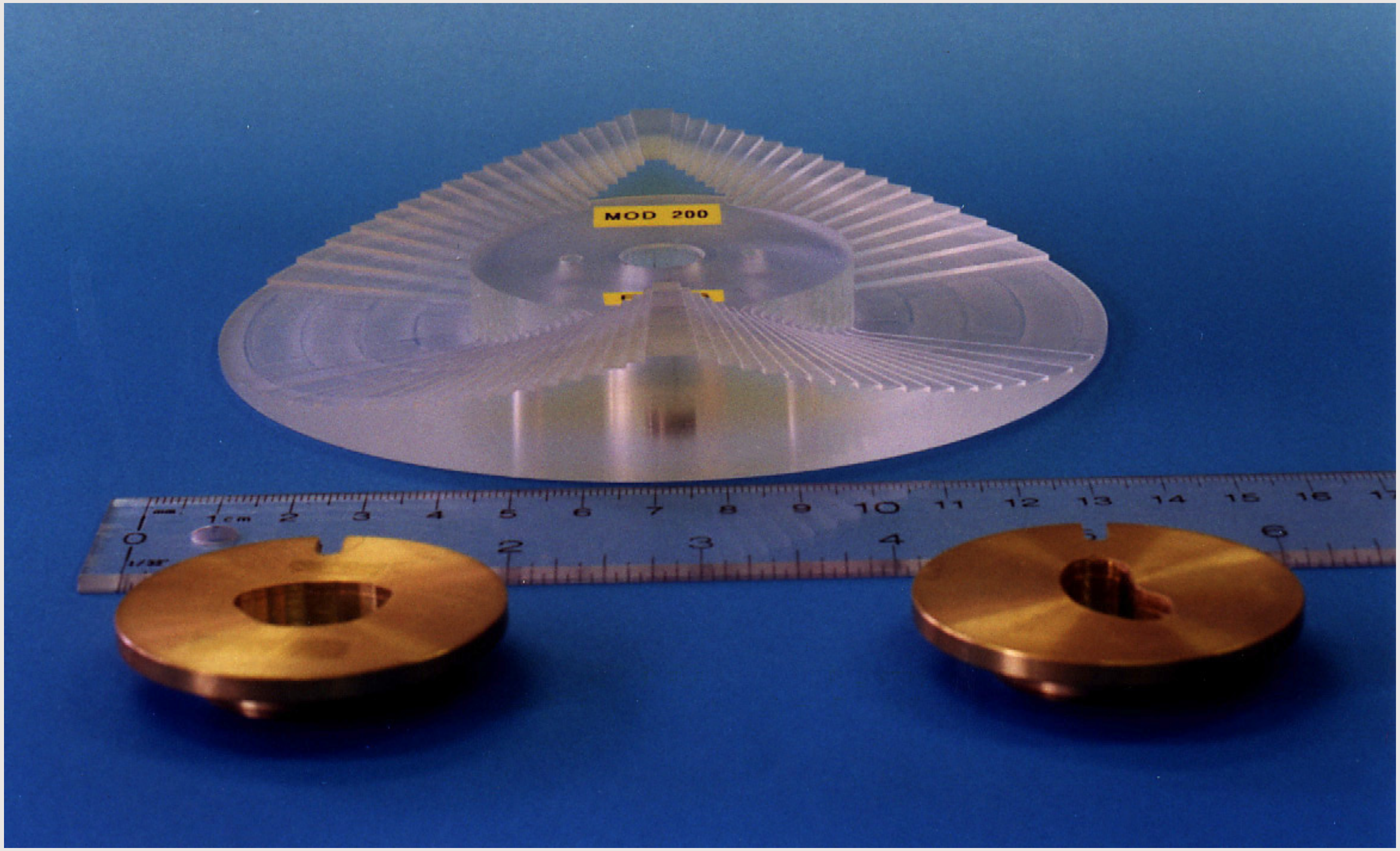
Beamline


Collimator/
Scatterer
Range
Modulator
Ion
Chamber
Profile
Monitor
Range
Shifter
X-Ray
Tube
TV
Camera
Motorized
Chair
6 Motions
Beam line
Beam
Direction
1.55 m

Beamline

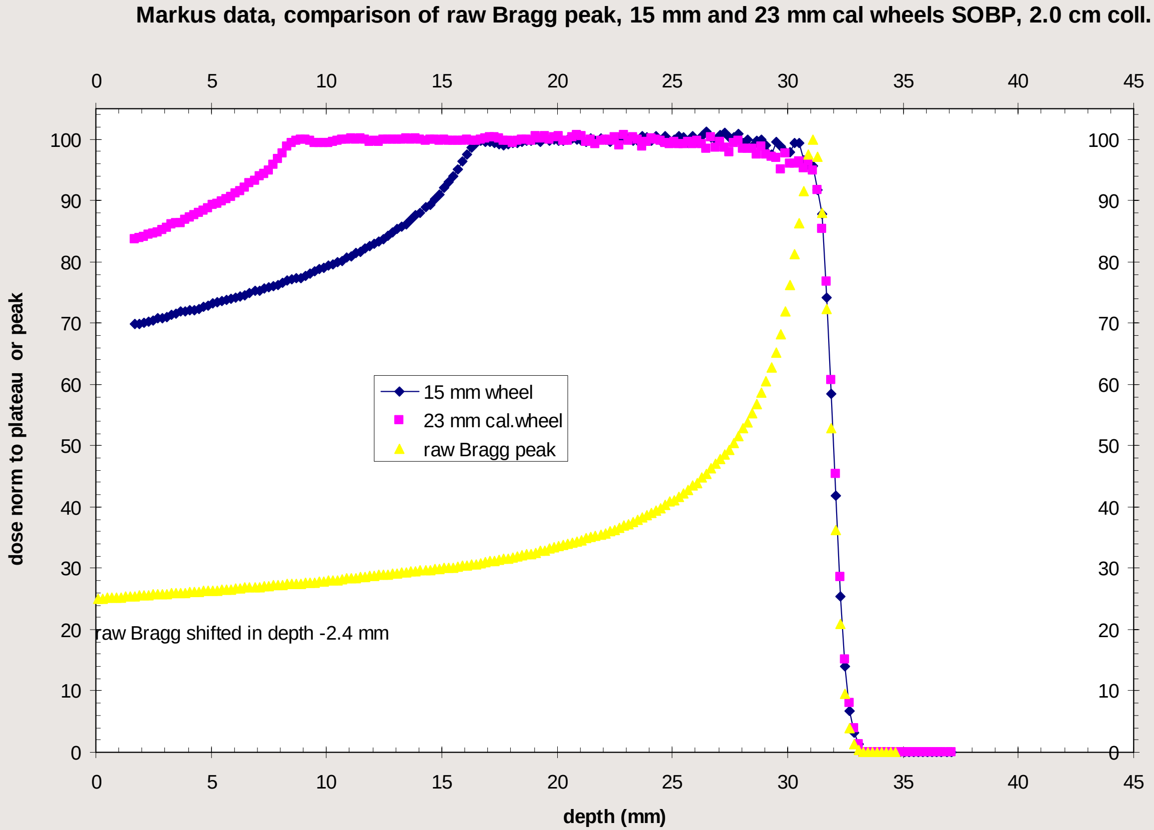

Profile Monitor
Range Shifter
Collimator / Scatterer
Modulator Wheel
Diag. Ion Chamber
SECONDARY EMMISIONS MONITER

Modulator and Collimator

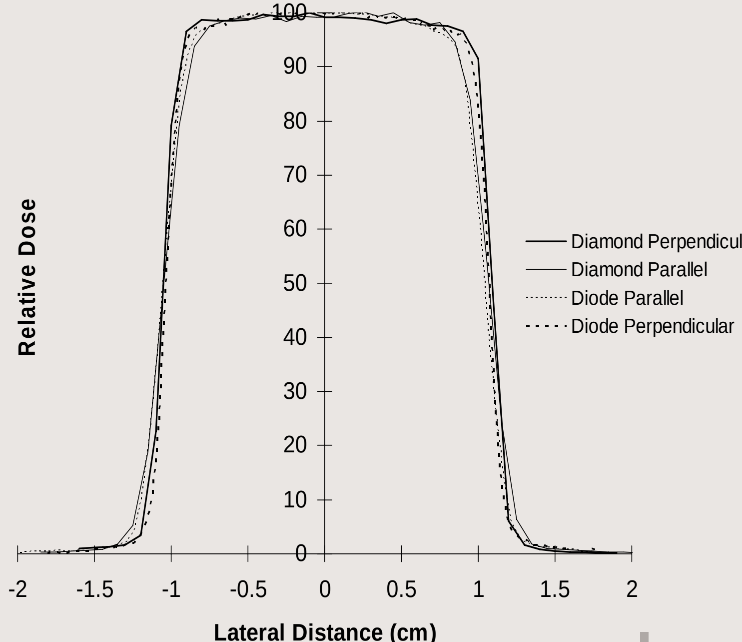


Modulators: 5 mm to 27 mm in 1 mm increments (depth control)
Brass collimators (lateral control)

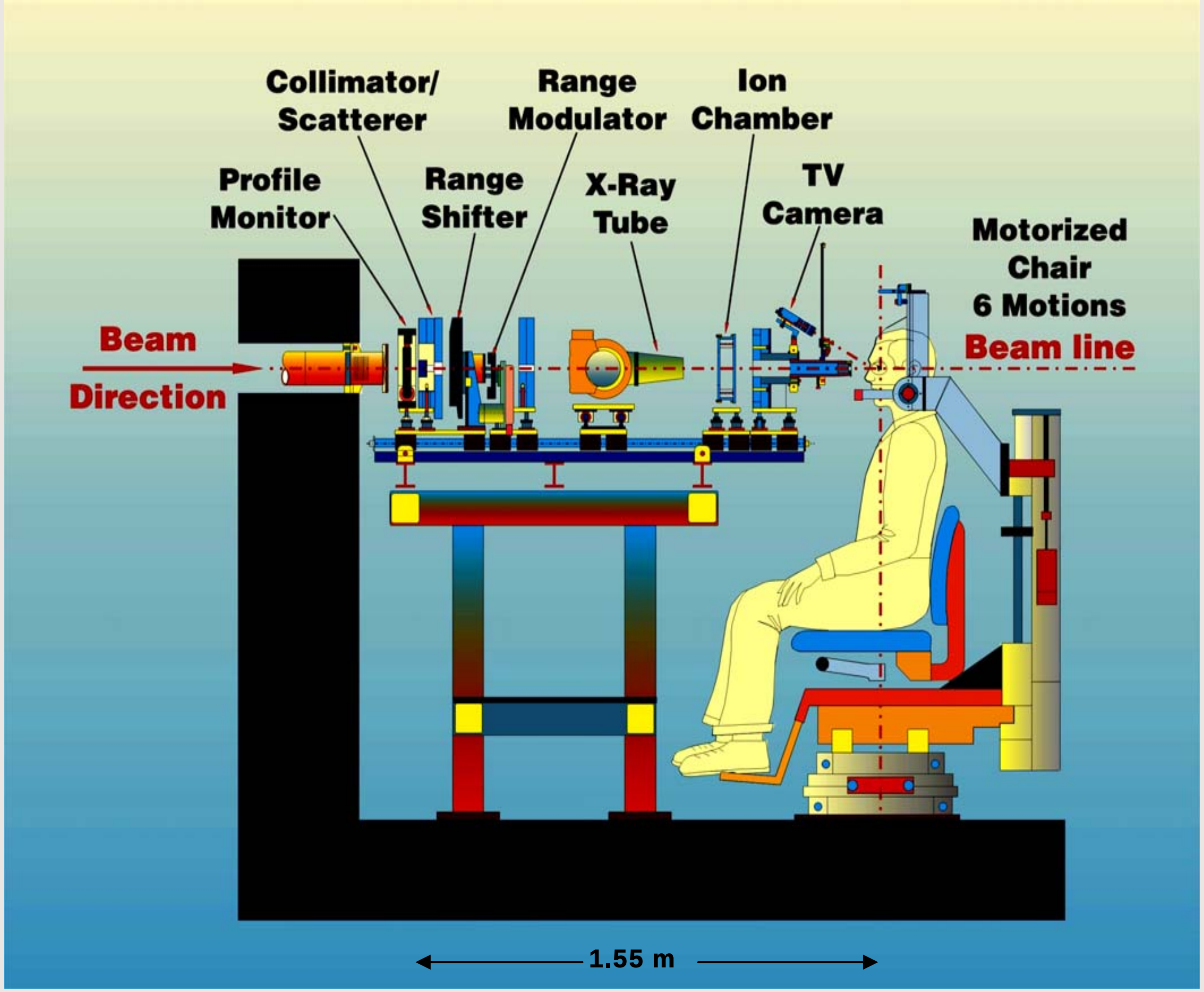
Beam Profile



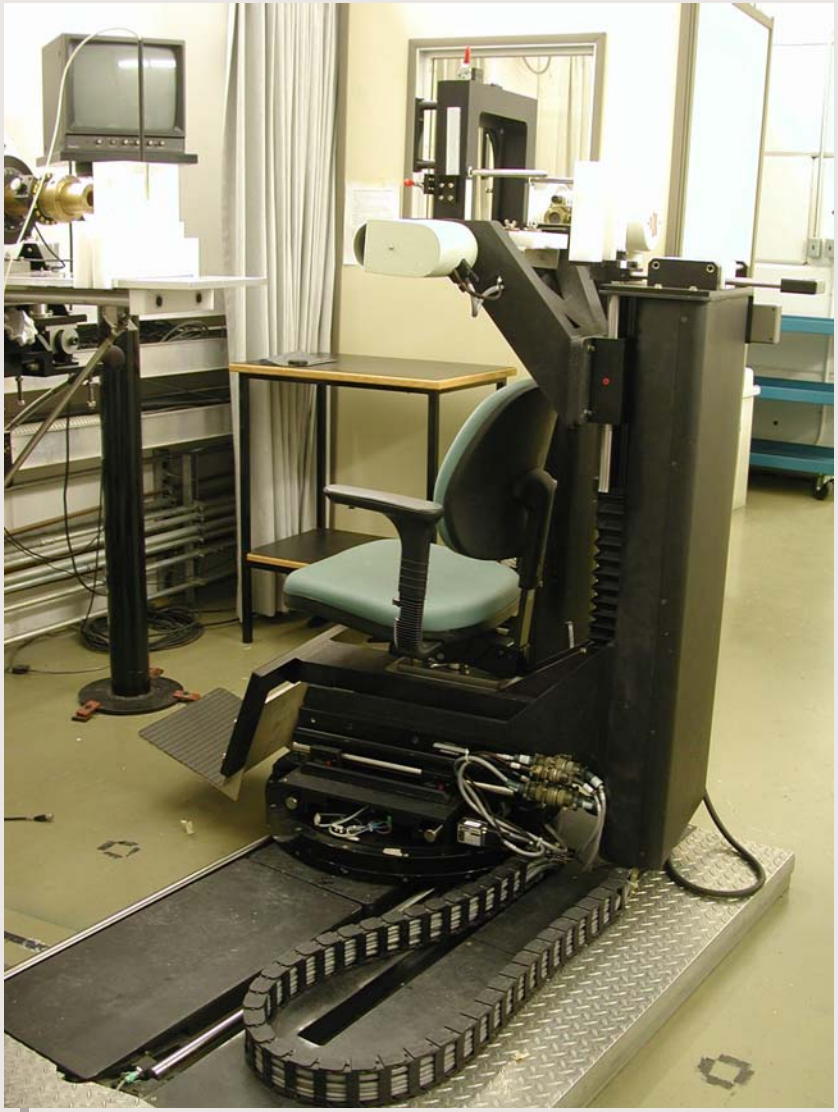
- Mono-energetic proton – Bragg peak at the end of its range
- Modulate energy – Spread Out Bragg Peak (SOBP)
- Maximum dose to tumor – minimize dose to nearby sensitive structures



Beamline


Collimator/
Scatterer
Range
Modulator
Ion
Chamber
Profile
Monitor
Range
Shifter
X-Ray
Tube
TV
Camera
Motorized
Chair
6 Motions
Beam line
Beam
Direction
1.55 m

Patient Set-up



Treatment Chair

6 motorized motions

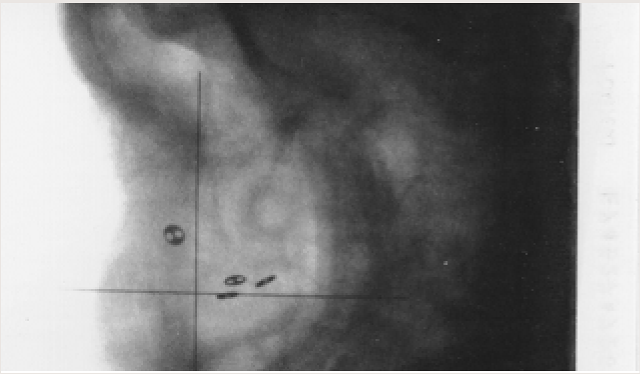
X, Y, Z, K, θ, Φ

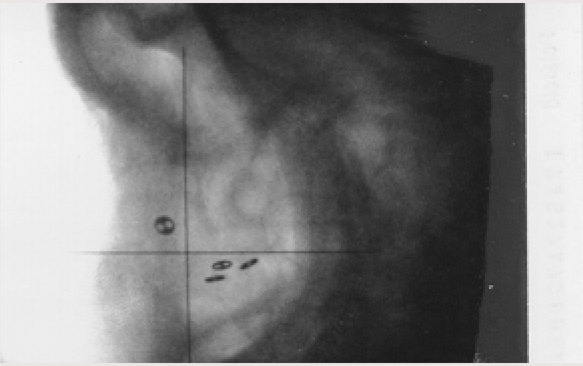
Patient Set-up

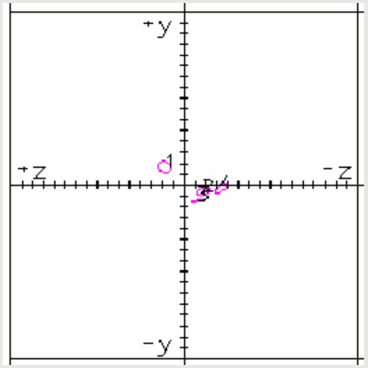
First set-up

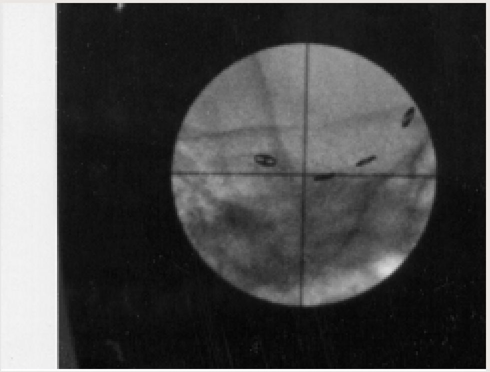
Second set-up

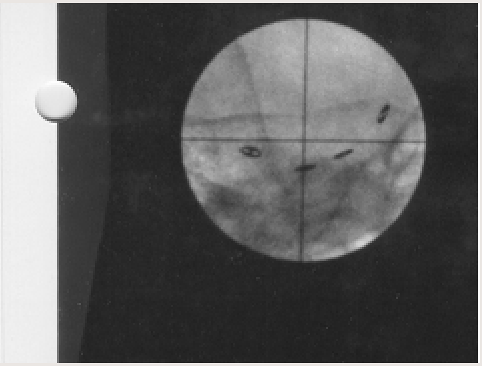
Treatment plan

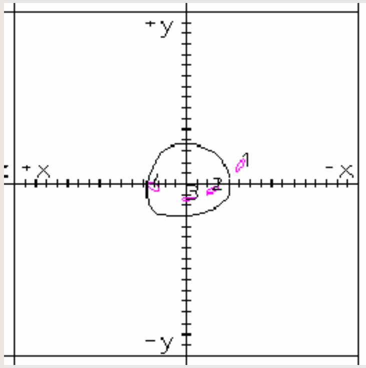












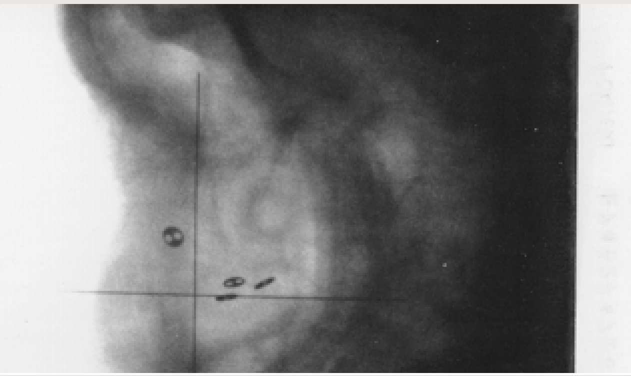
Treatment: four days in a row, around 90 seconds each

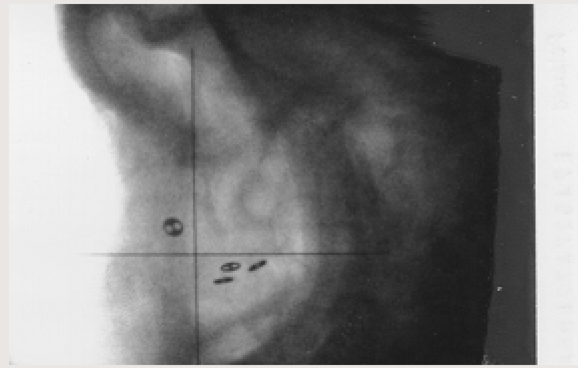
Patient Set-up

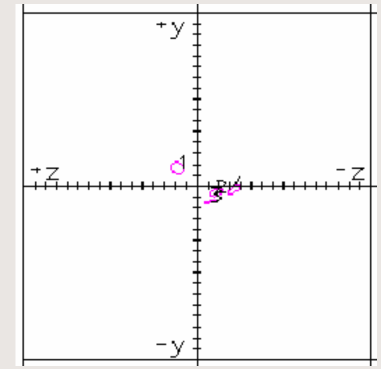
First set-up

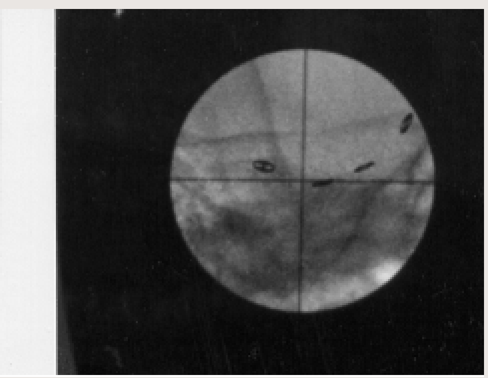
Second set-up

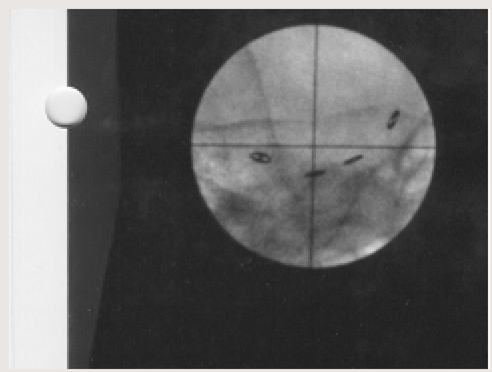
Treatment plan

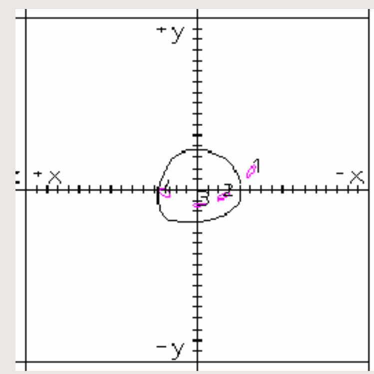












Statistics: 147 patients, average 10/year, ages 14-80, median 57
Tumor control >95%, survival rate (>5 years) 80%

Collaboration

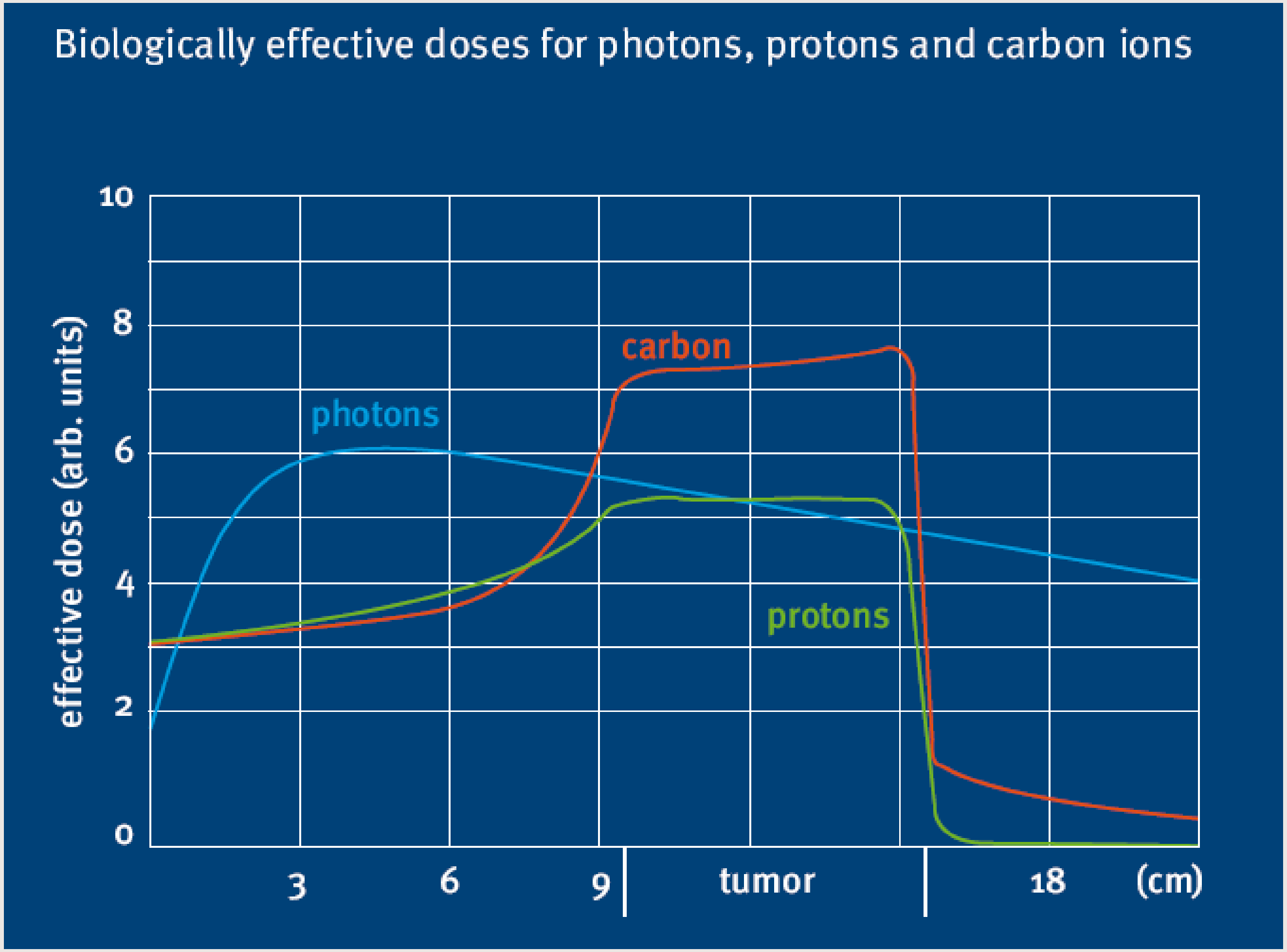
UBC Eye Care Centre

BC Cancer Agency
CARE & RESEARCH

TRIUMF

Dr. Ewart Blackmore

Heavy Ions



HIT website

Heavy Ions

H. Suit et al. / Radiotherapy and Oncology 95 (2010) 3–22

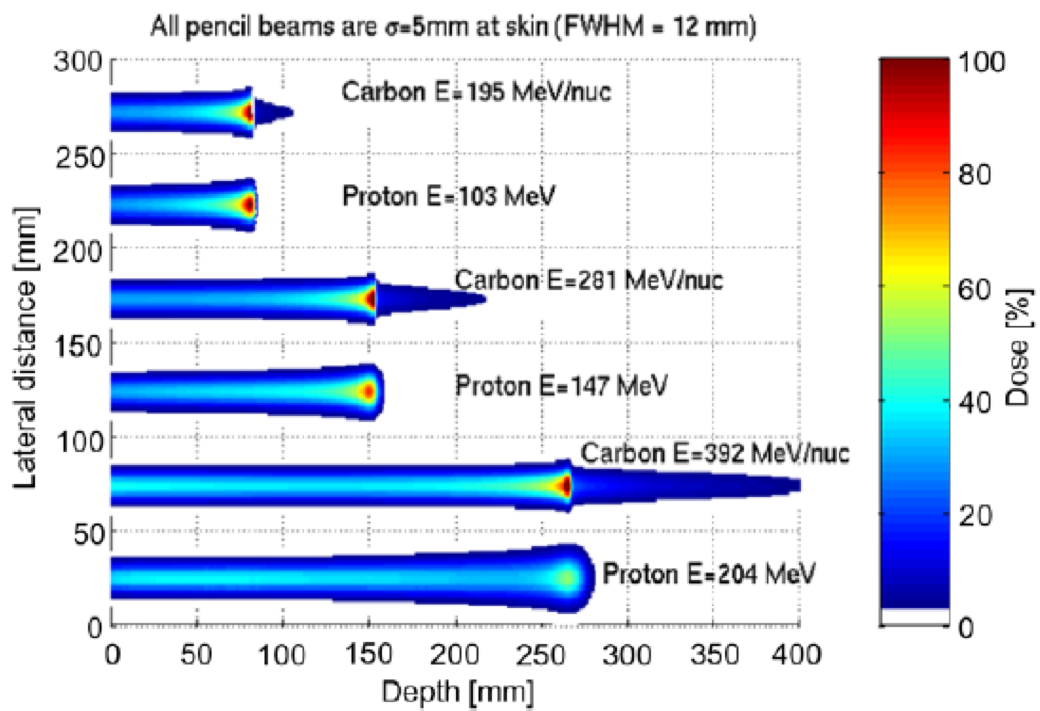


Fig. 4. Display of the penetration of fragmentation tails of 195 MeV, 281 MeV and 392 MeV ^{12}C beams. This contrasts with no tail for proton beams of energies of 103 MeV, 147 MeV and 204 MeV.

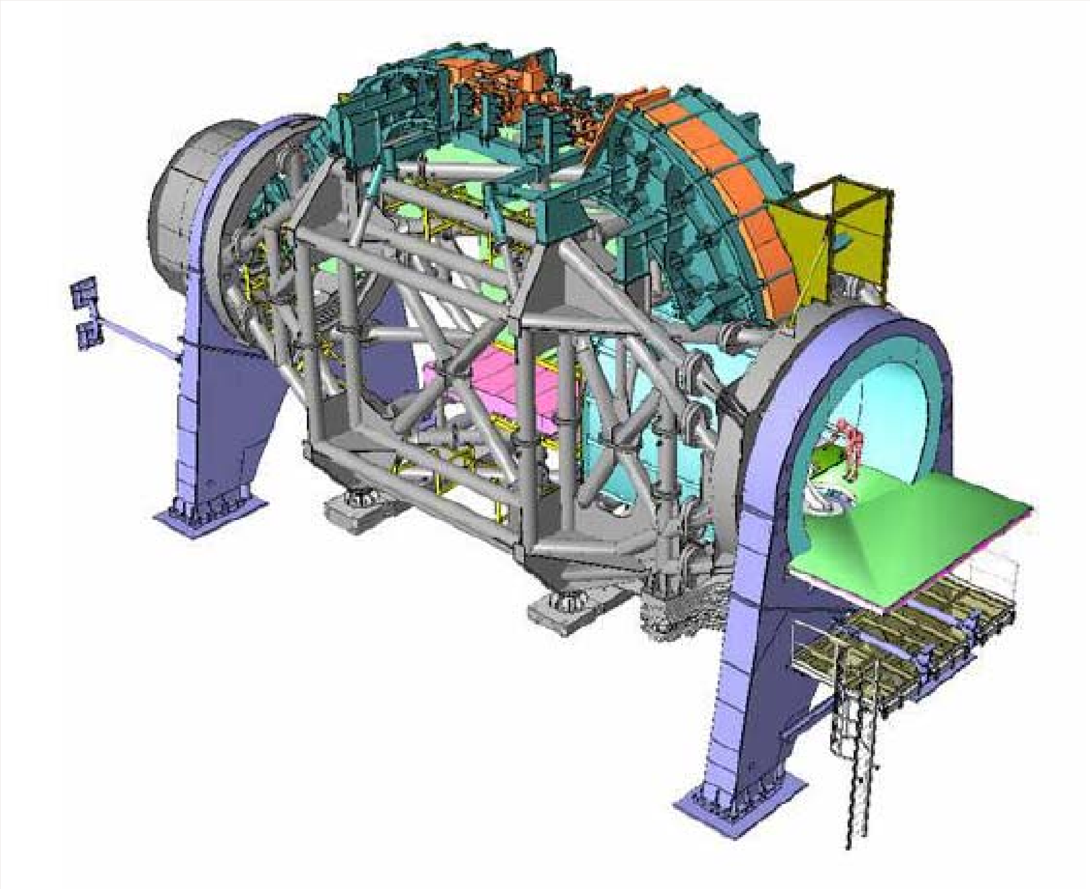
HIT in Heidelberg

Heidelberger-Ionenstrahl-Therapiezentrum

- Active raster scan via magnets
- Depth between 20 mm and 30 cm
- Protons and heavy ions
- Three beam lines
- Two ion sources

HIT website

Heavy-Ion Gantry

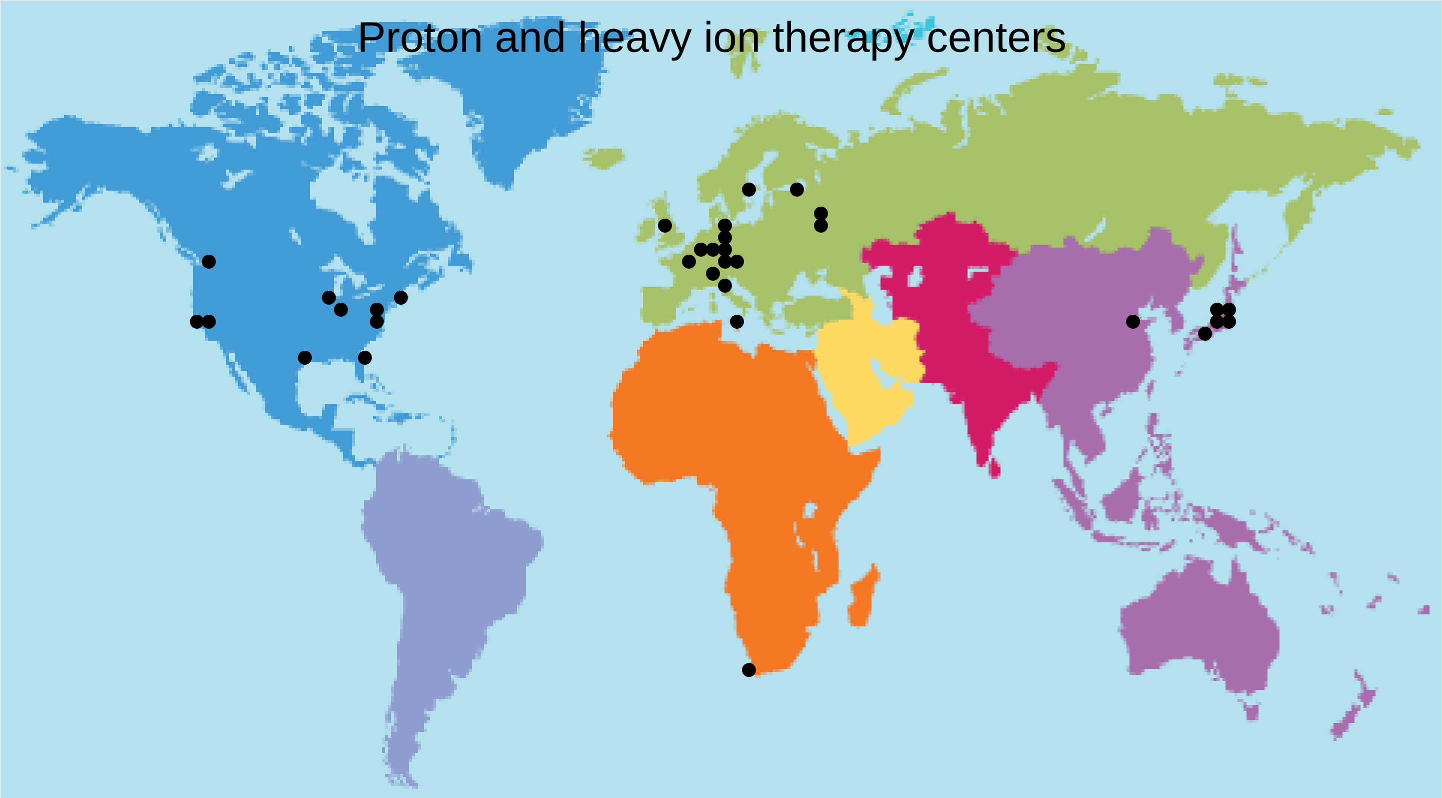


First heavy-ion gantry

- 25 m long
- 13 m diameter
- Total weight 670 tons
- Movable 600 tons

HIT website

Around the World



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