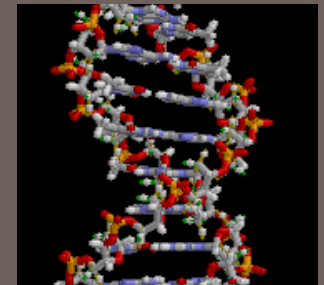
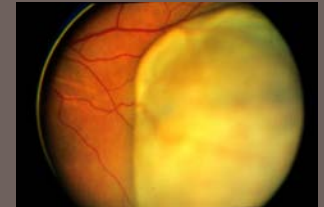


Cancer Radiotherapy with proton beams

Dr. Cornelia Hoehr | Research Scientist | TRIUMF



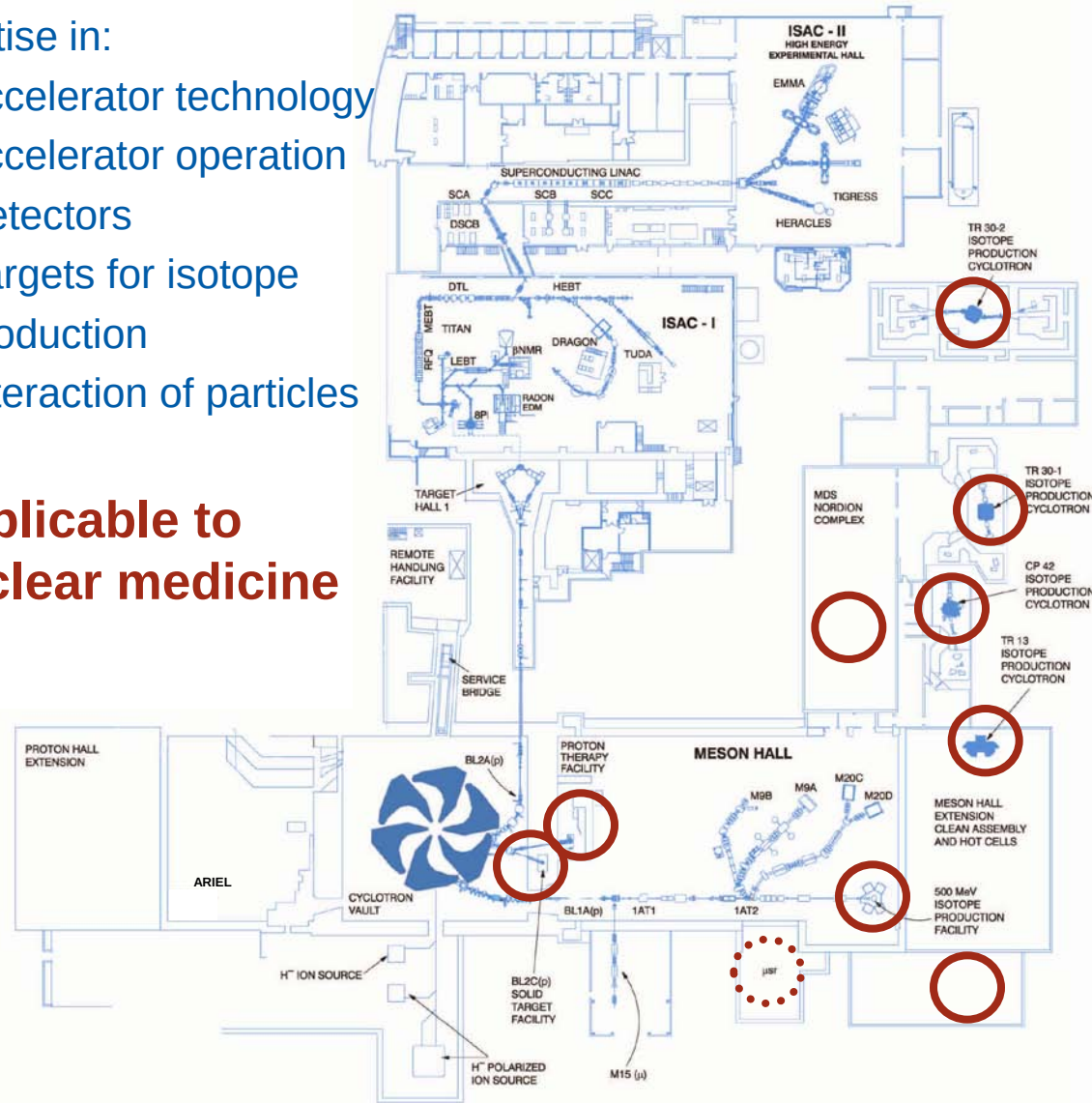
Nuclear Medicine @ TRIUMF

TRIUMF - nuclear physics lab.

Expertise in:

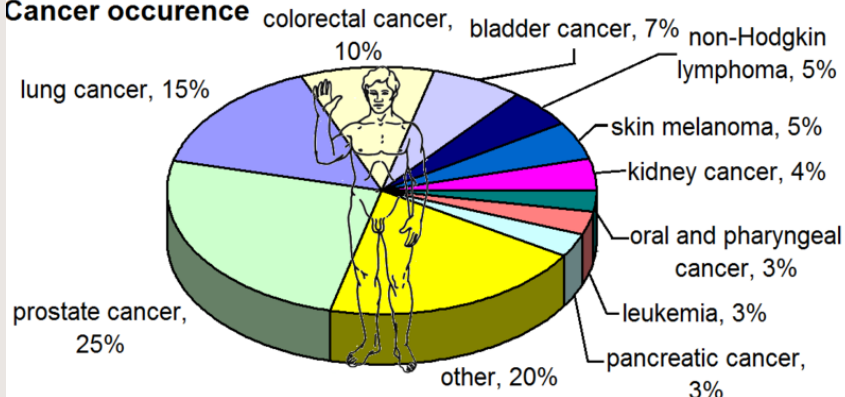
- Accelerator technology
- Accelerator operation
- Detectors
- Targets for isotope production
- Interaction of particles

**Applicable to
nuclear medicine**

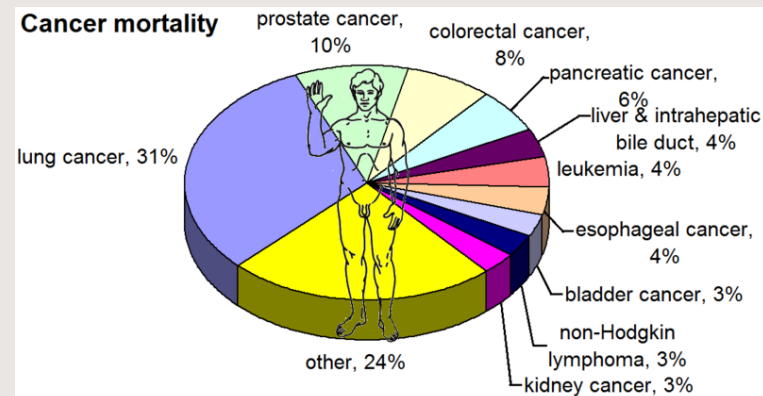


Cancer

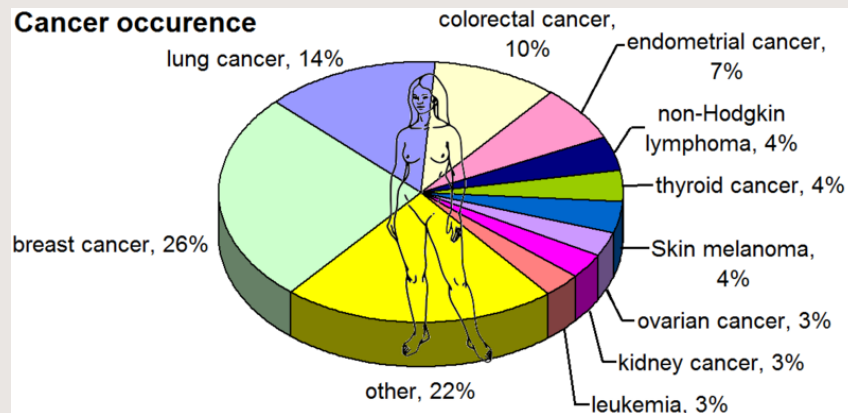
Cancer occurrence



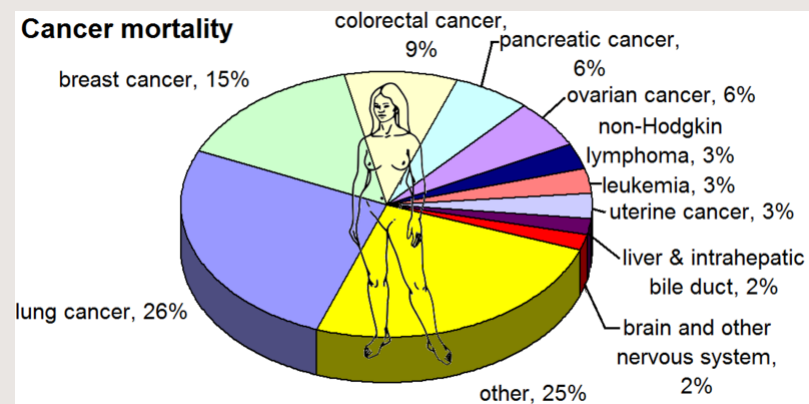
Cancer mortality



Cancer occurrence



Cancer mortality



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

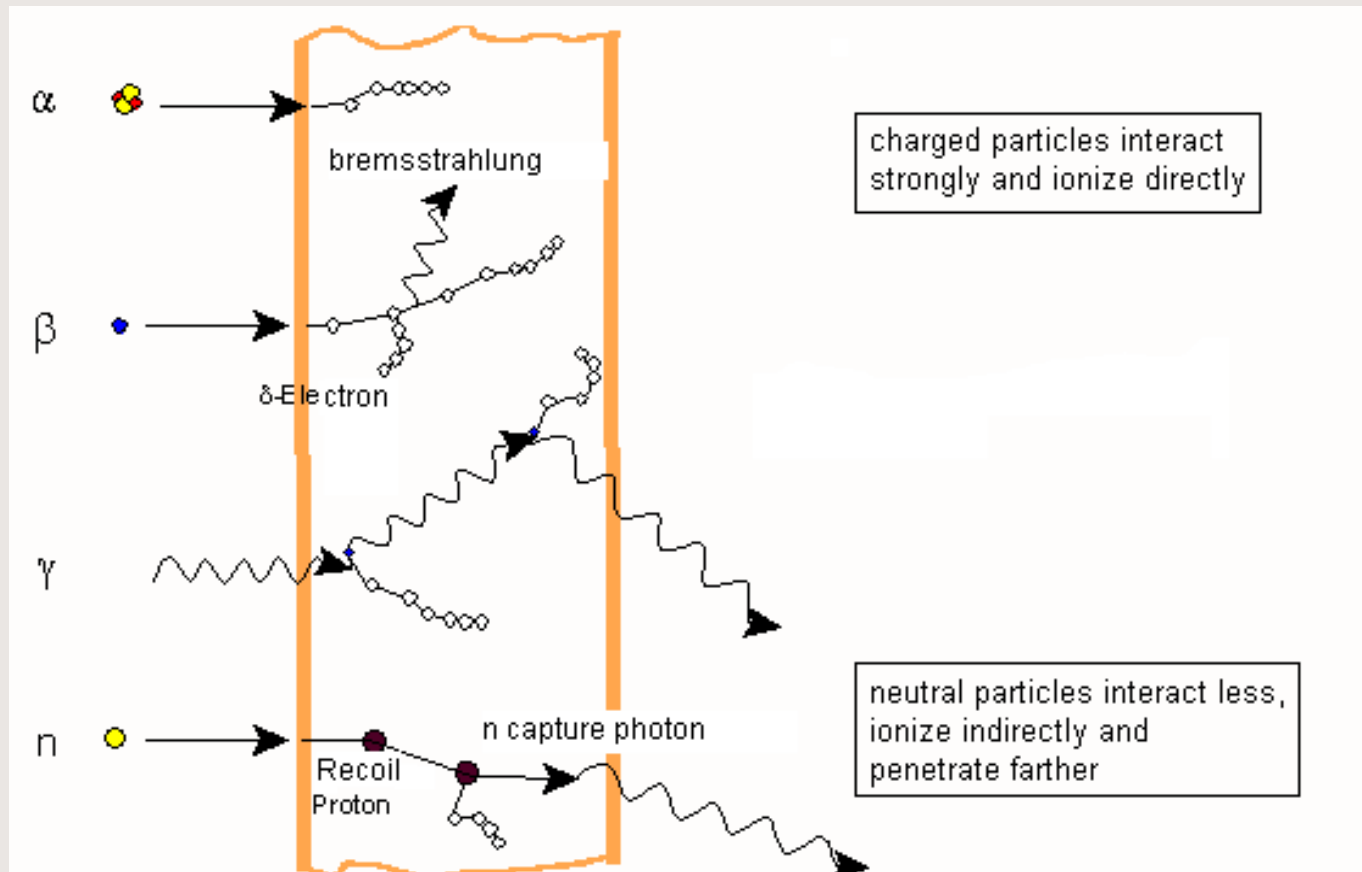
- * External beam therapy – photons, neutrons, protons

- * Internal therapy – brachytherapy (radioactive isotopes)

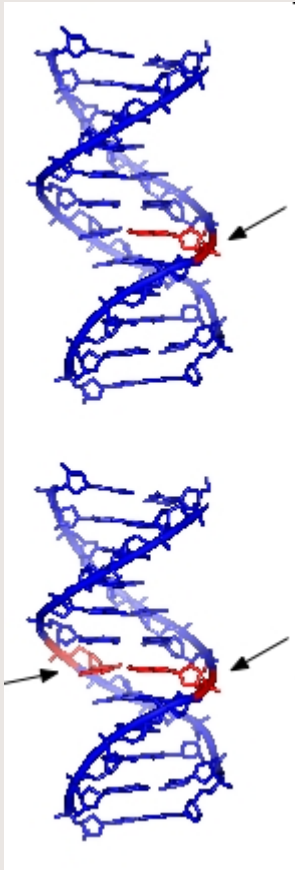
Success: Tumor control vs. complications

**Destroy/remove tumor without damaging
healthy or normal tissue nearby**

Ionizing Radiation

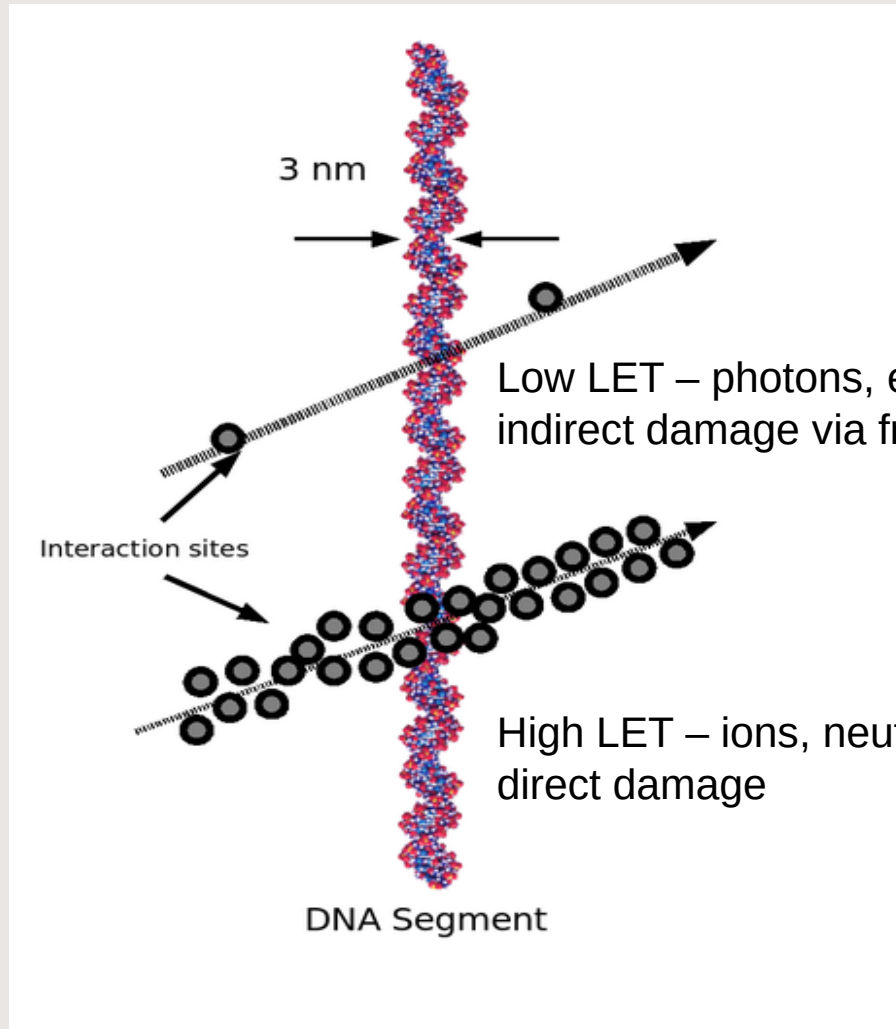


DNA break



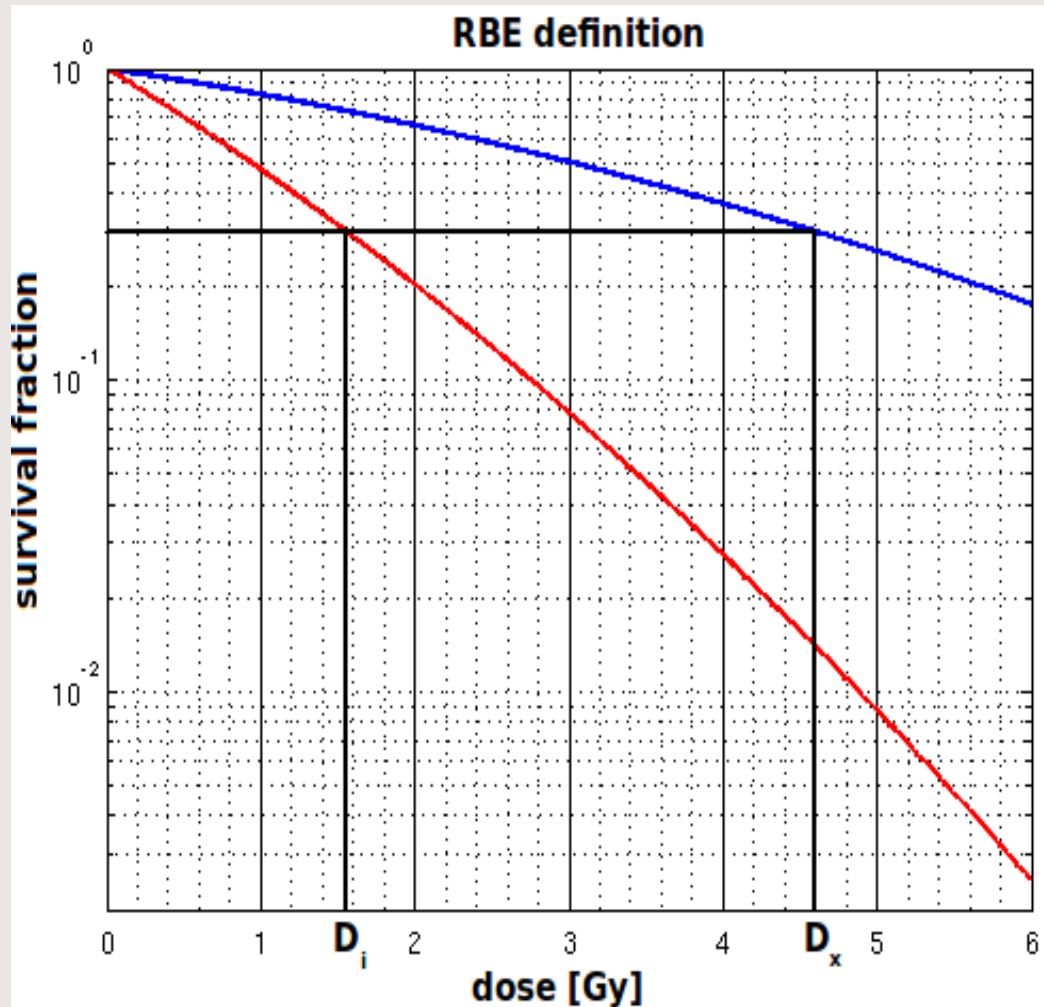
- DNA (Deoxyribonucleic acid): genetic instructions for development and functioning
- Cell needs information from DNA for survival
- Single helix break easy to repair
- Double helix break more difficult to repair
- Cell can not survive
- Radiotherapy: as many double helix breaks in cancer cells as possible with as few double breaks as possible in healthy cells

LET – Linear Energy Transfer



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

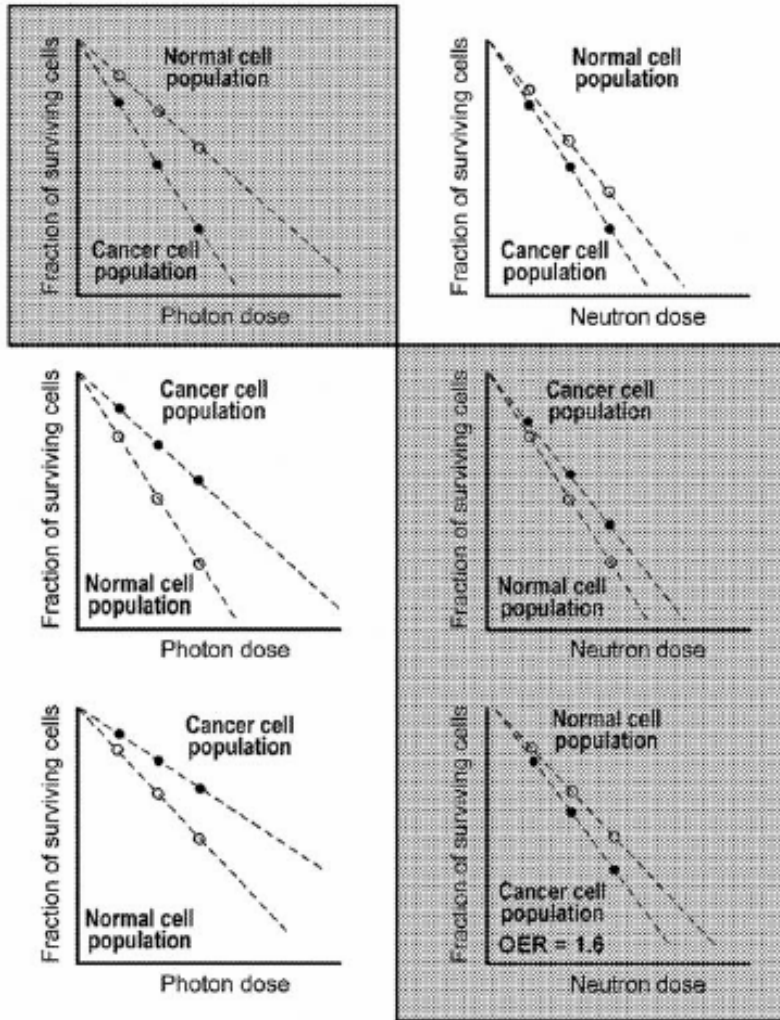
Relative Biological Effectiveness



Definition of Relative Biological Effectiveness:
 $RBE = D_x / D_i$

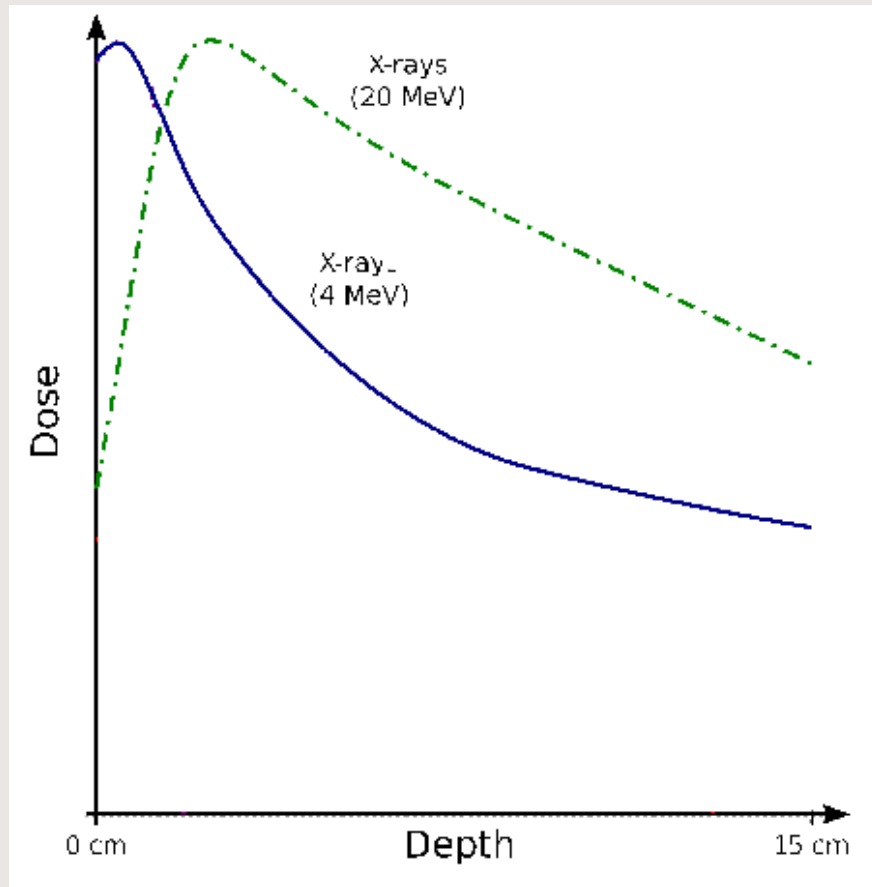
Data for CHO-K1 cell line irradiated by photons (blue curve) and carbon ions (red curve).

Choice of Treatment



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

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

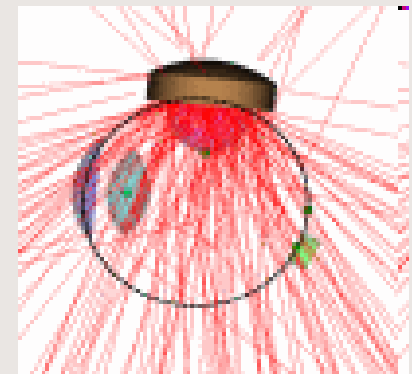
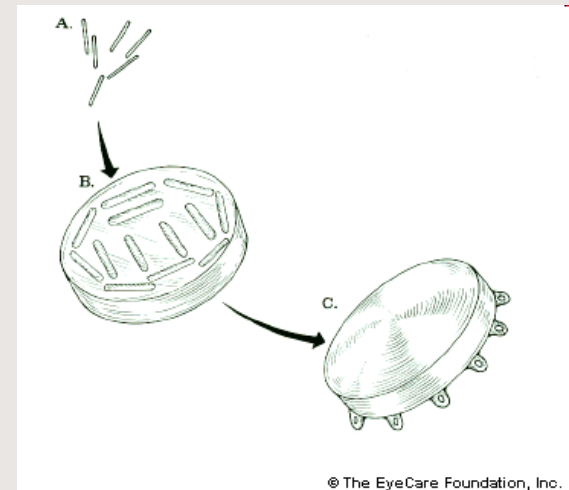
From the Greek word *brachys*, meaning "short-distance", most isotopes used are gamma emitters

Advantages

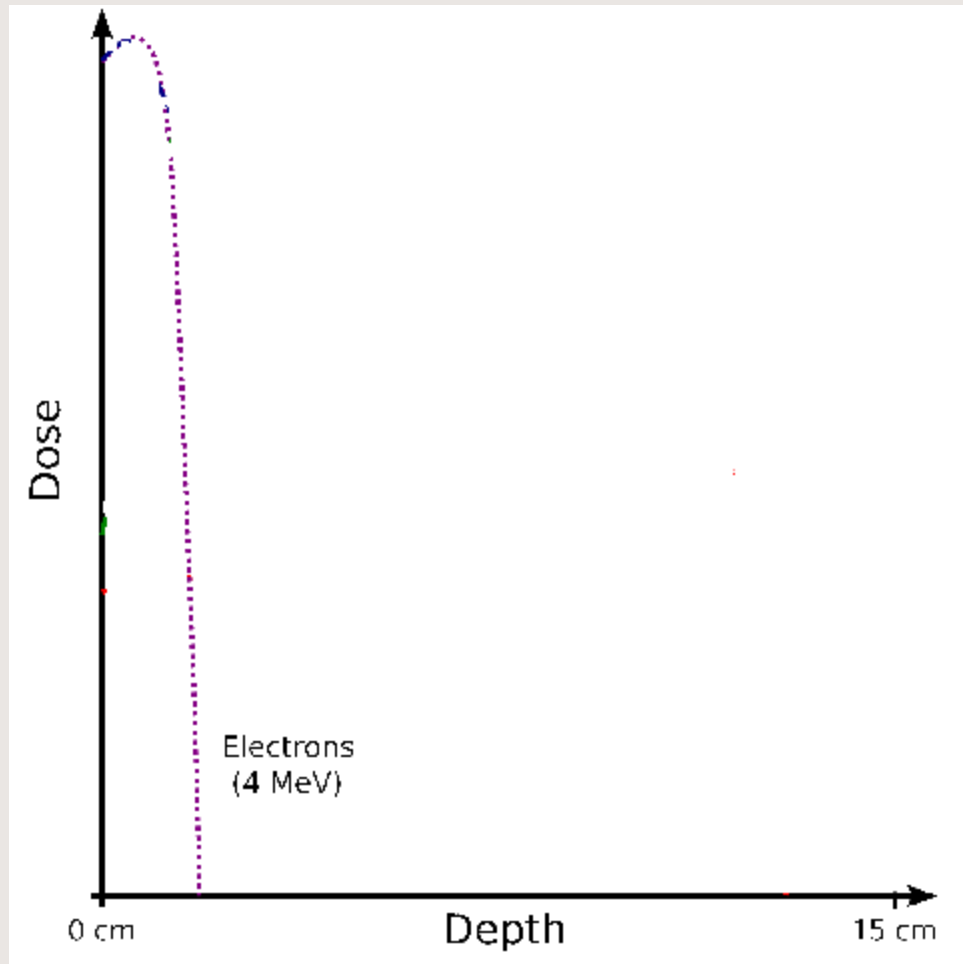
- Very localized
- Can have shorter treatment times
- Moves with tumor
- Can be permanent or temporary

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



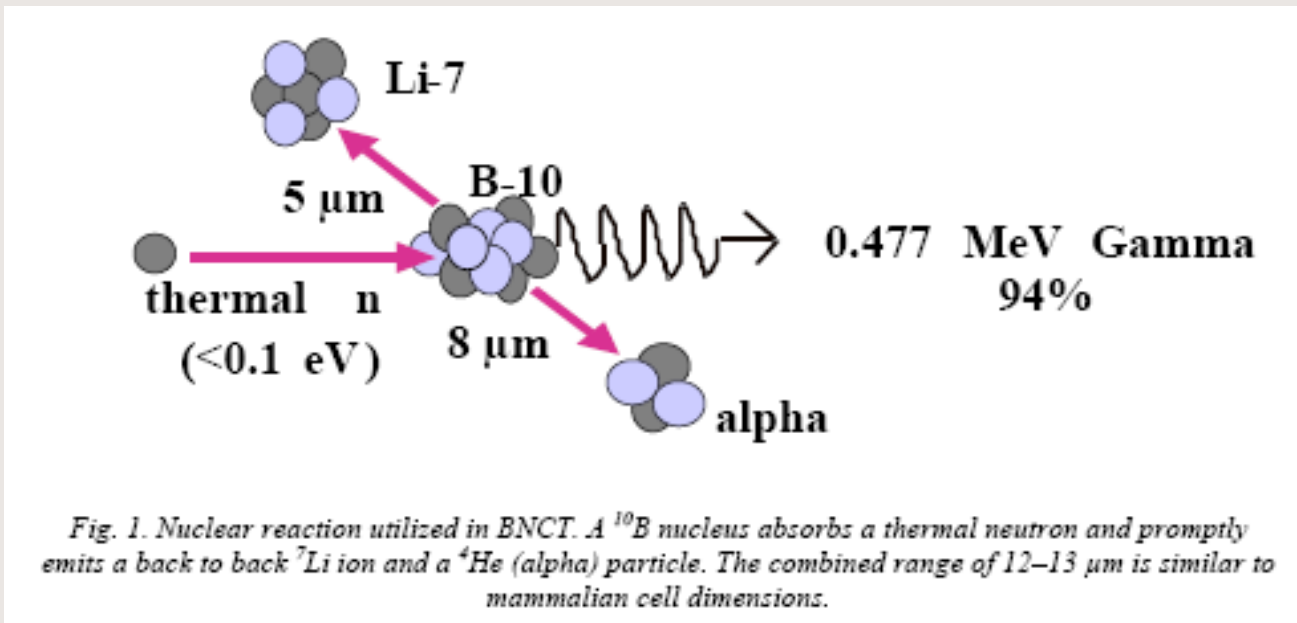
External: Electron-beam treatment



- Mostly used for tumors close to skin
- Low LET

External/internal: Neutron treatment

- Boron neutron-capture therapy (BNCT)



- BNCT (thermal $<0.1\text{eV}$)
- Only experimental (treatment for hours)
- Tracer development still in beginning

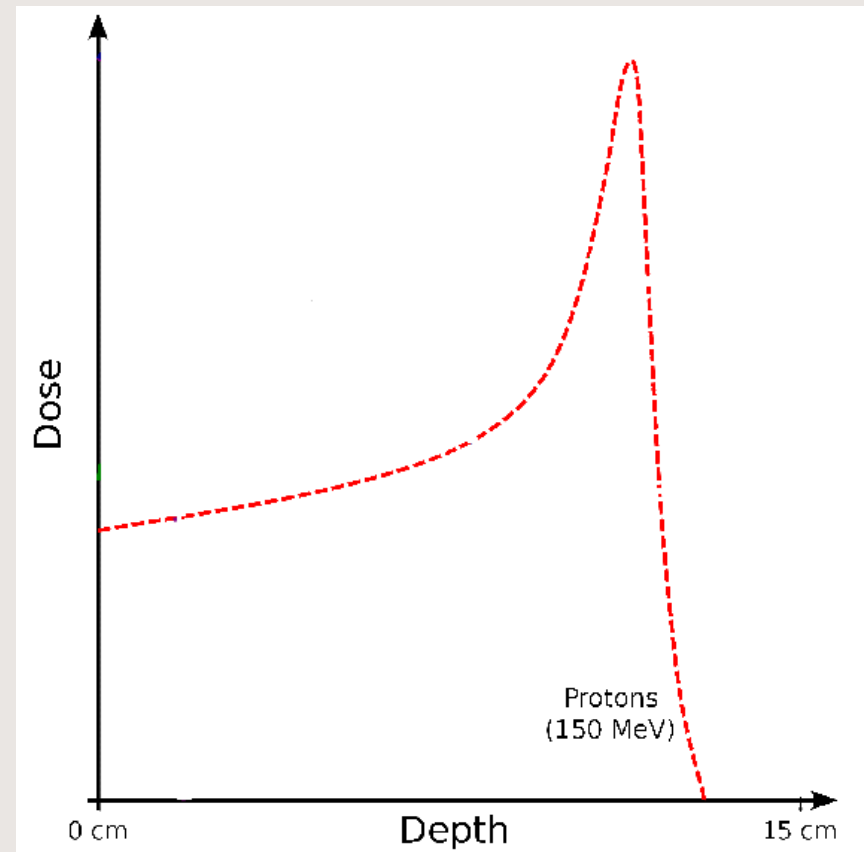
External: Ion-beam therapy

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



Bethe – Bloch equation

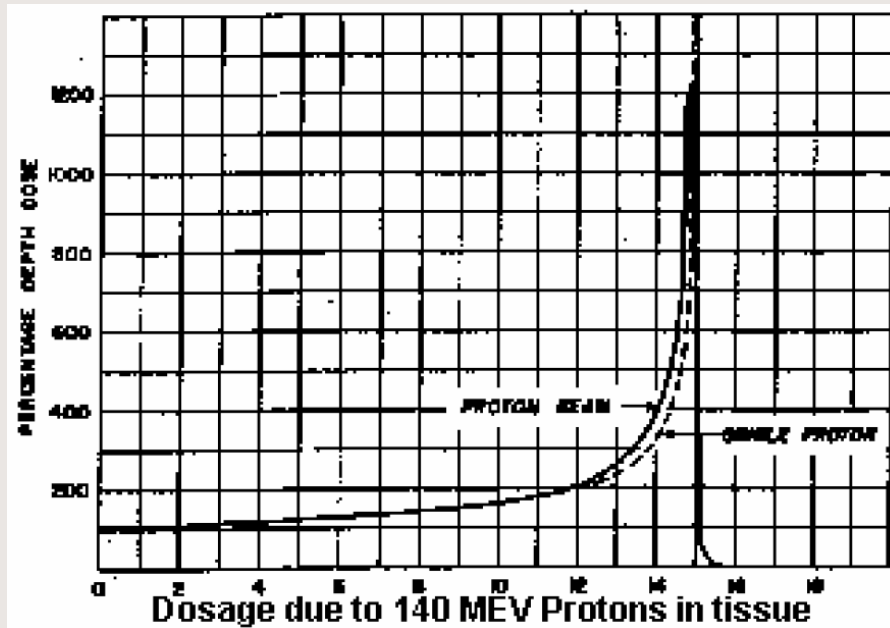


Hans Bethe,
1930 and 1932

$$-\frac{dT}{dx} = \frac{4\pi e^4 z^2}{m v^2} Z \ln \frac{2m v^2}{E},$$

Zur Theorie des Durchgangs schneller
Korpuskularstrahlen durch Materie,
Annalen der Physik. vol. 397, pp. 325-400,
1930

Robert Wilson – father of proton therapy



Radiological Use of Fast Protons,
Radiology vol. 47, pp. 487-91, 1946

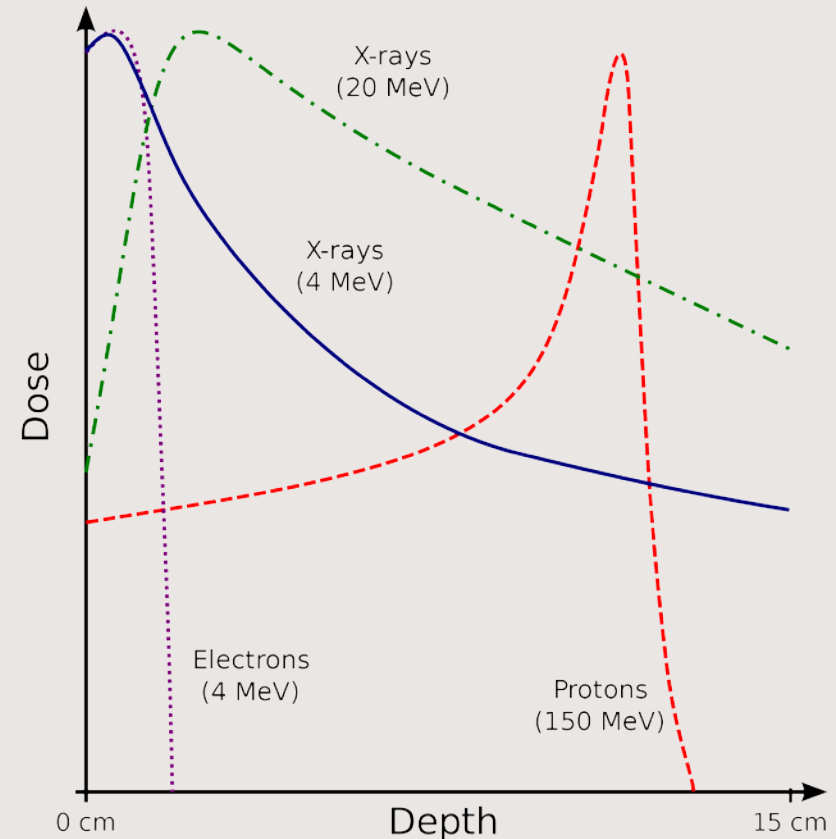
External: Ion-beam therapy

Advantage

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

Disadvantage

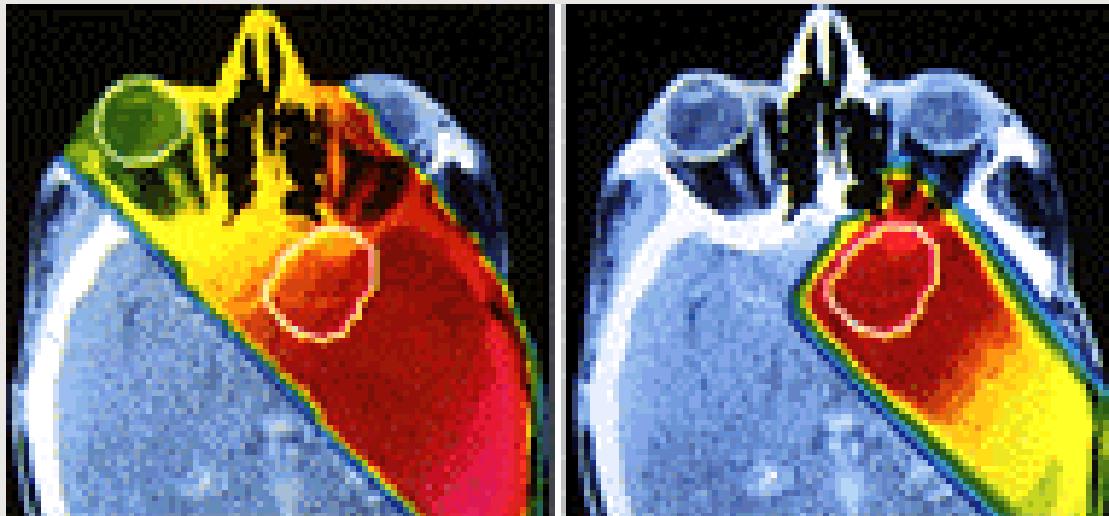
- Need higher energy accelerator
- 250 MeV for 30 cm in human tissue
- Expensive



X Rays vs. Protons

Highest dose
- red

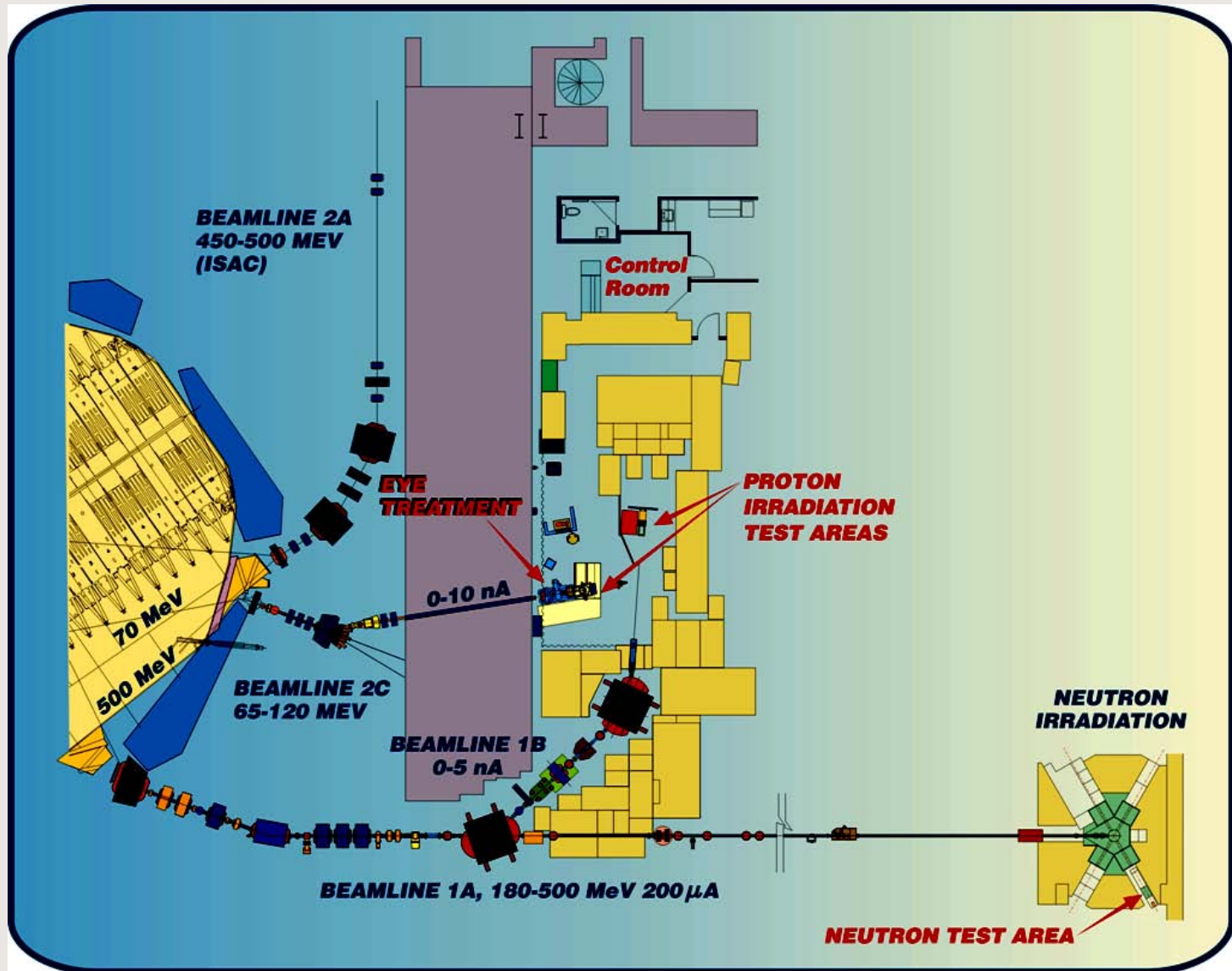
Lowest dose
- yellow



X rays

Protons

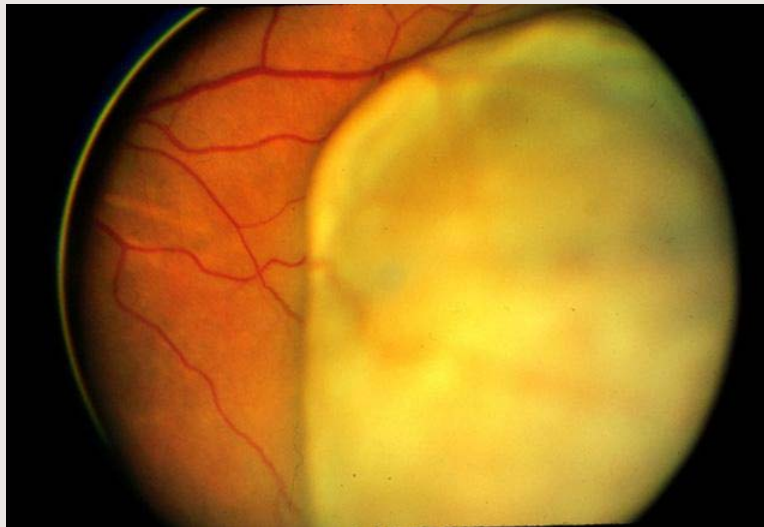
Proton Therapy at TRIUMF



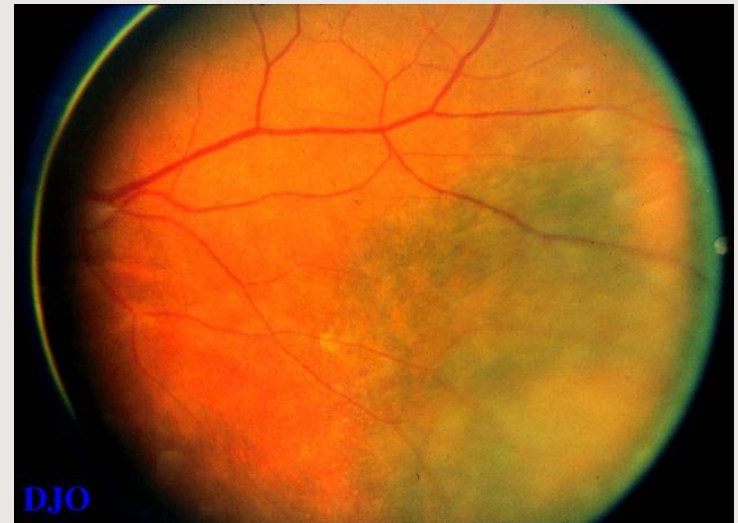
Ocular Melanoma

Frequency: 5 -6 cases/year per million population

Treatment protocols: Radioactive plaque therapy
Charged-particle radiotherapy
Enucleation

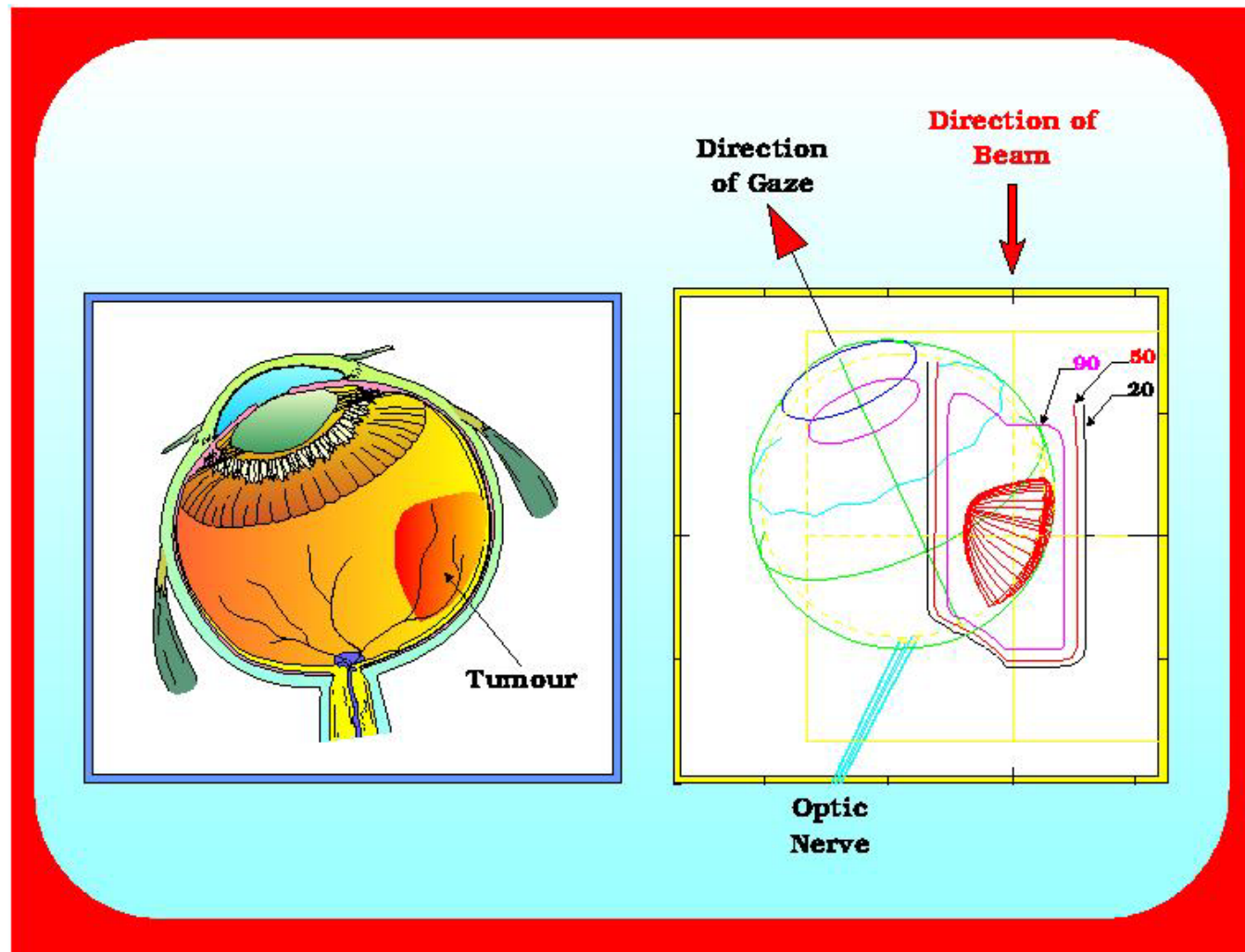


Uveal Melanoma before
proton beam treatment

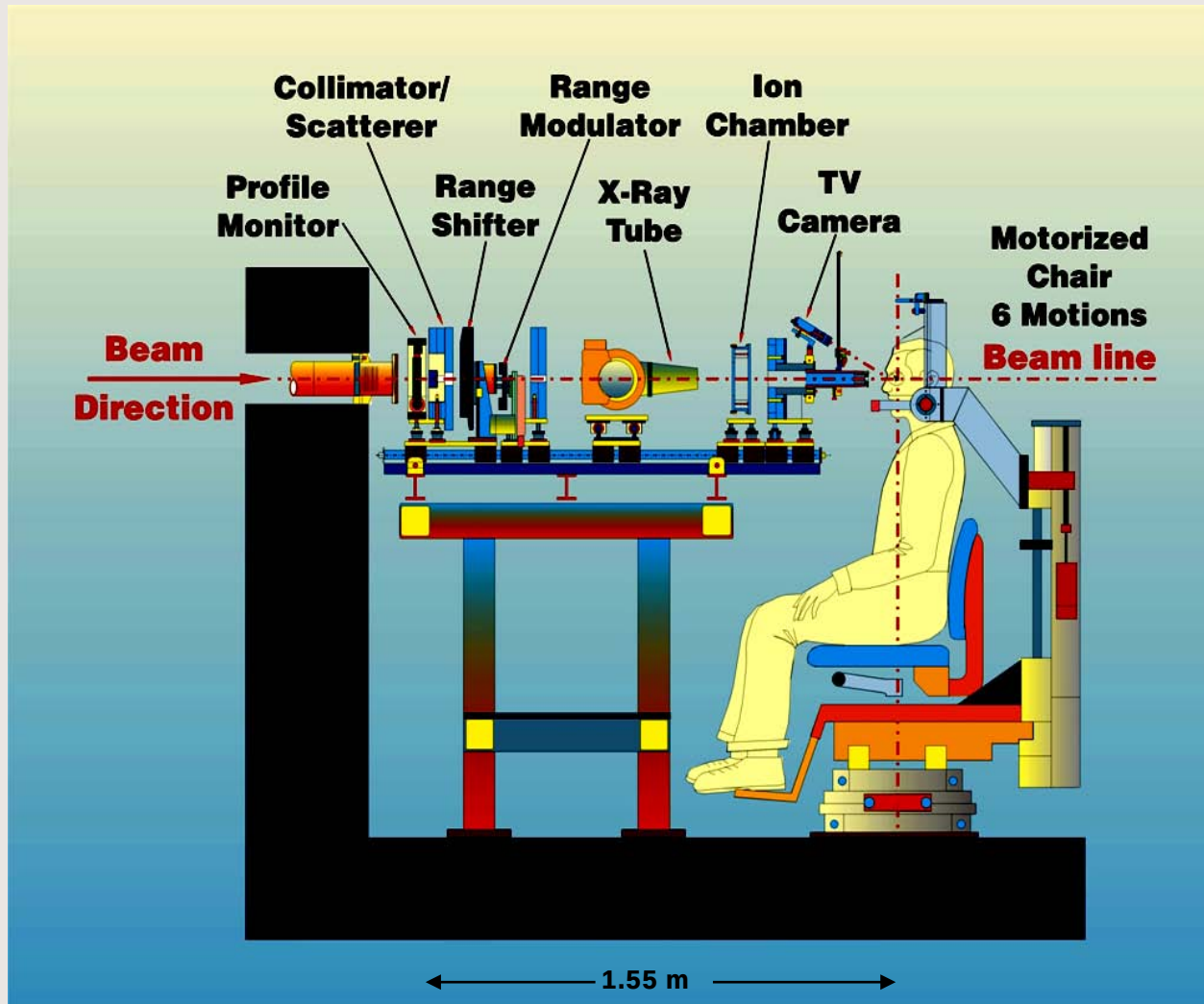


Uveal Melanoma after
proton beam treatment

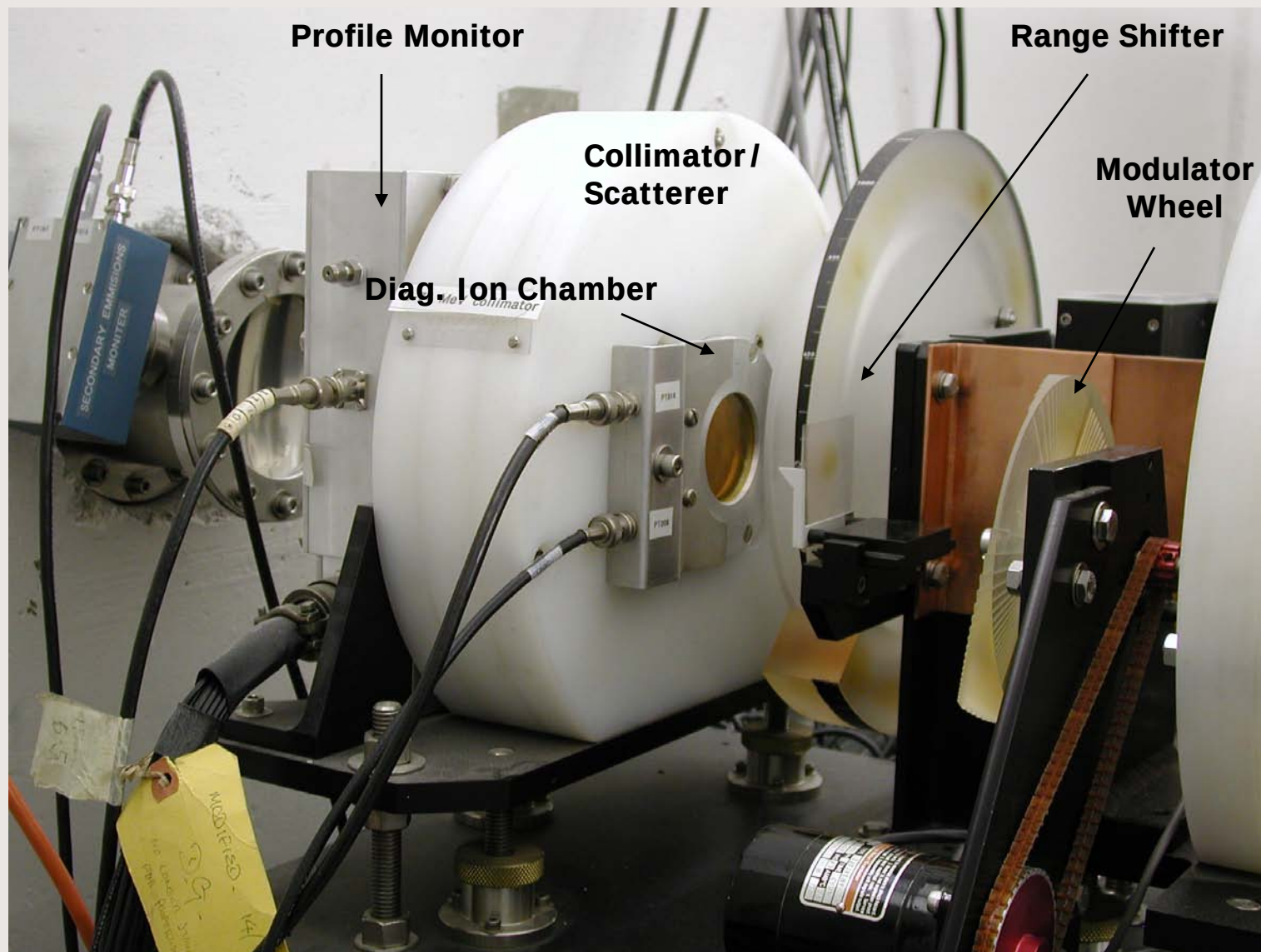
Treatment Planning



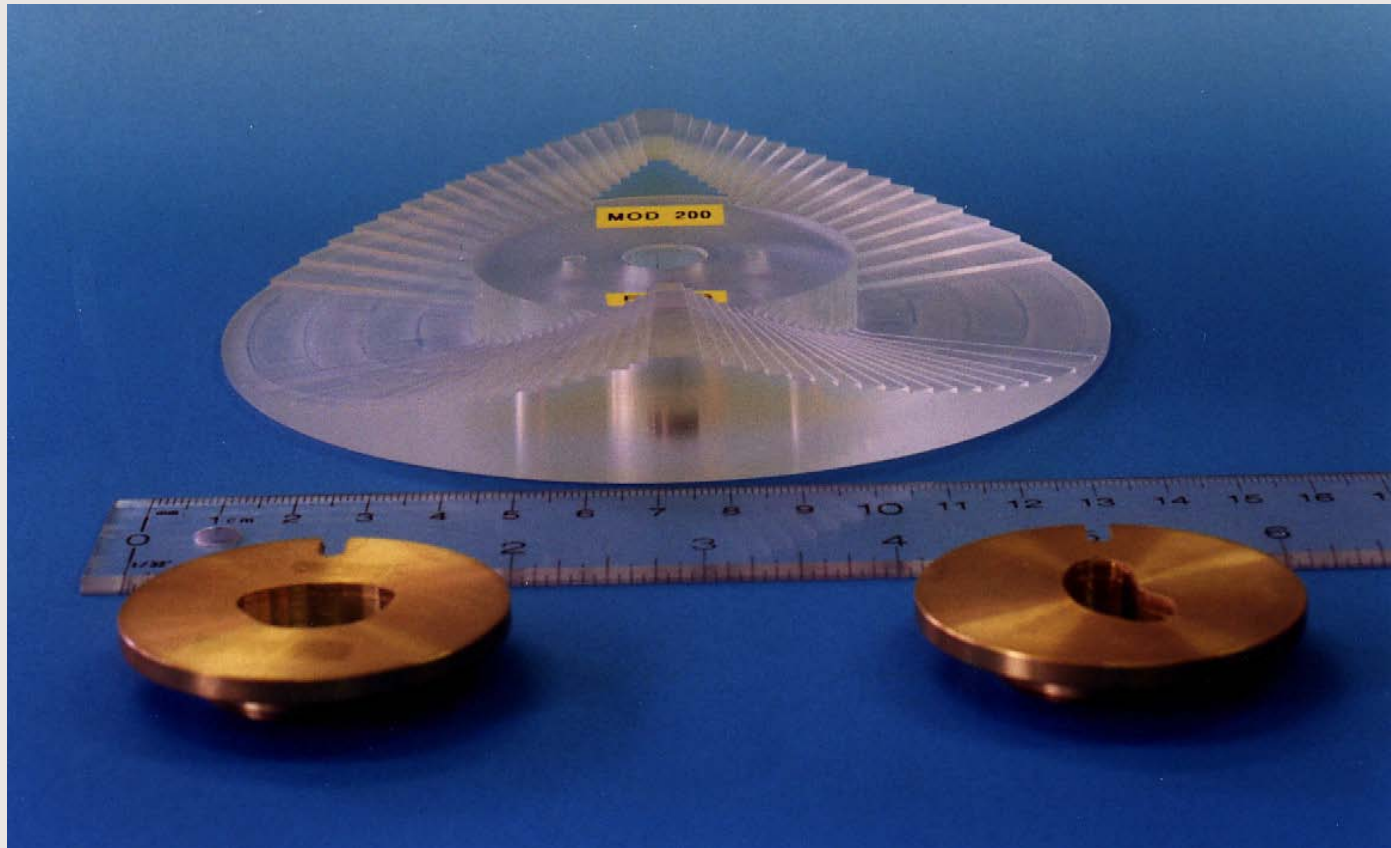
Beamline



Beamline



Modulator and Collimator

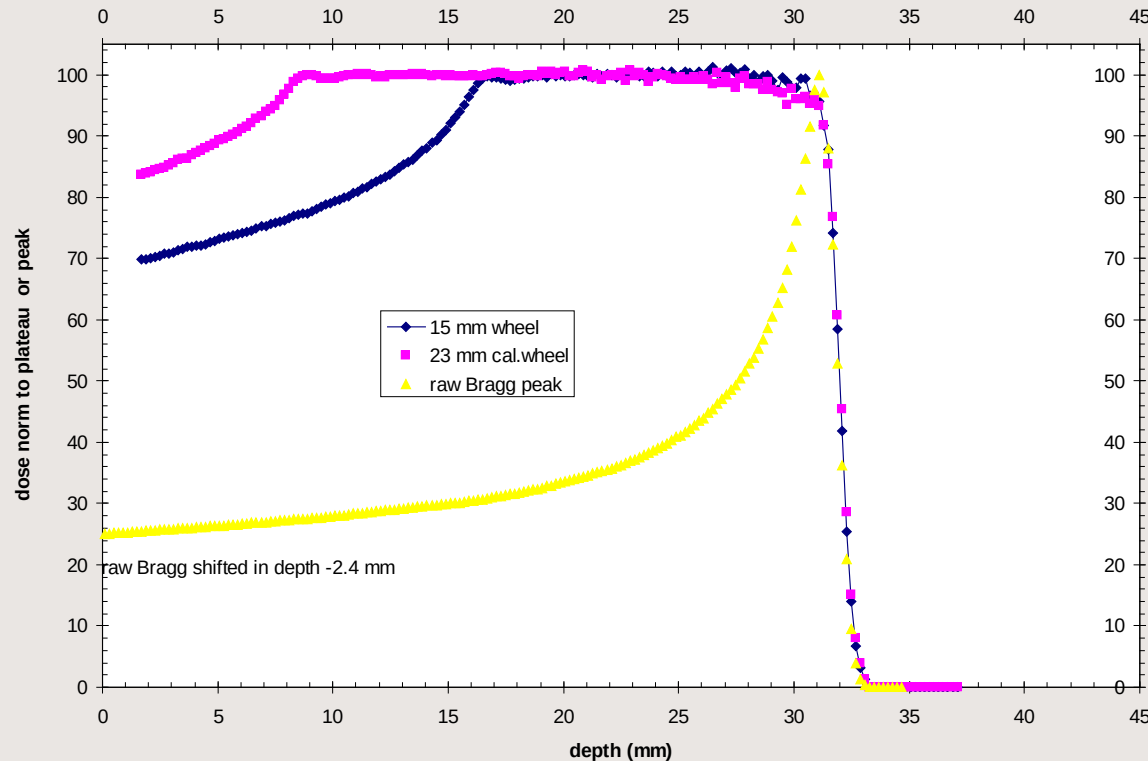


Modulators: 5 mm to 27 mm in 1 mm increments (depth control)

Brass collimators (lateral control)

Beam Profile

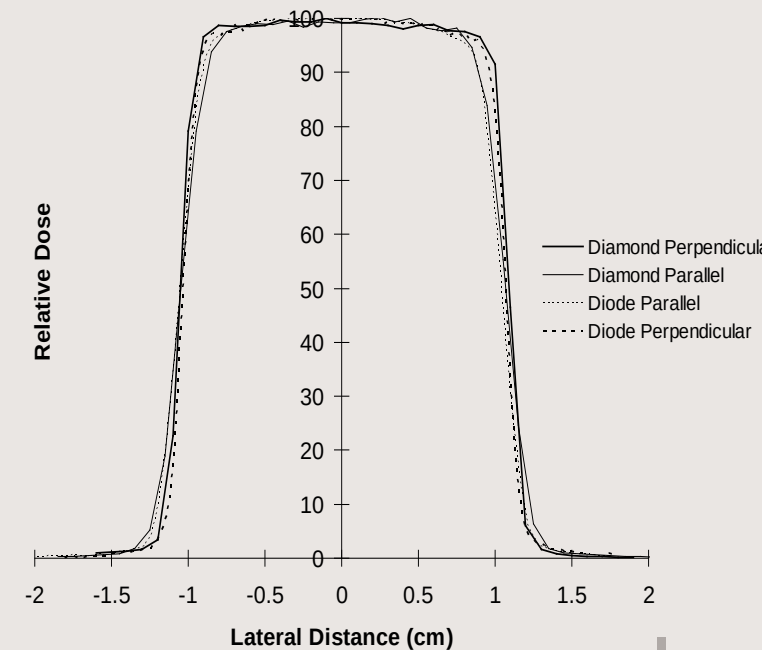
Markus data, comparison of raw Bragg peak, 15 mm and 23 mm cal wheels SOBP, 2.0 cm coll.



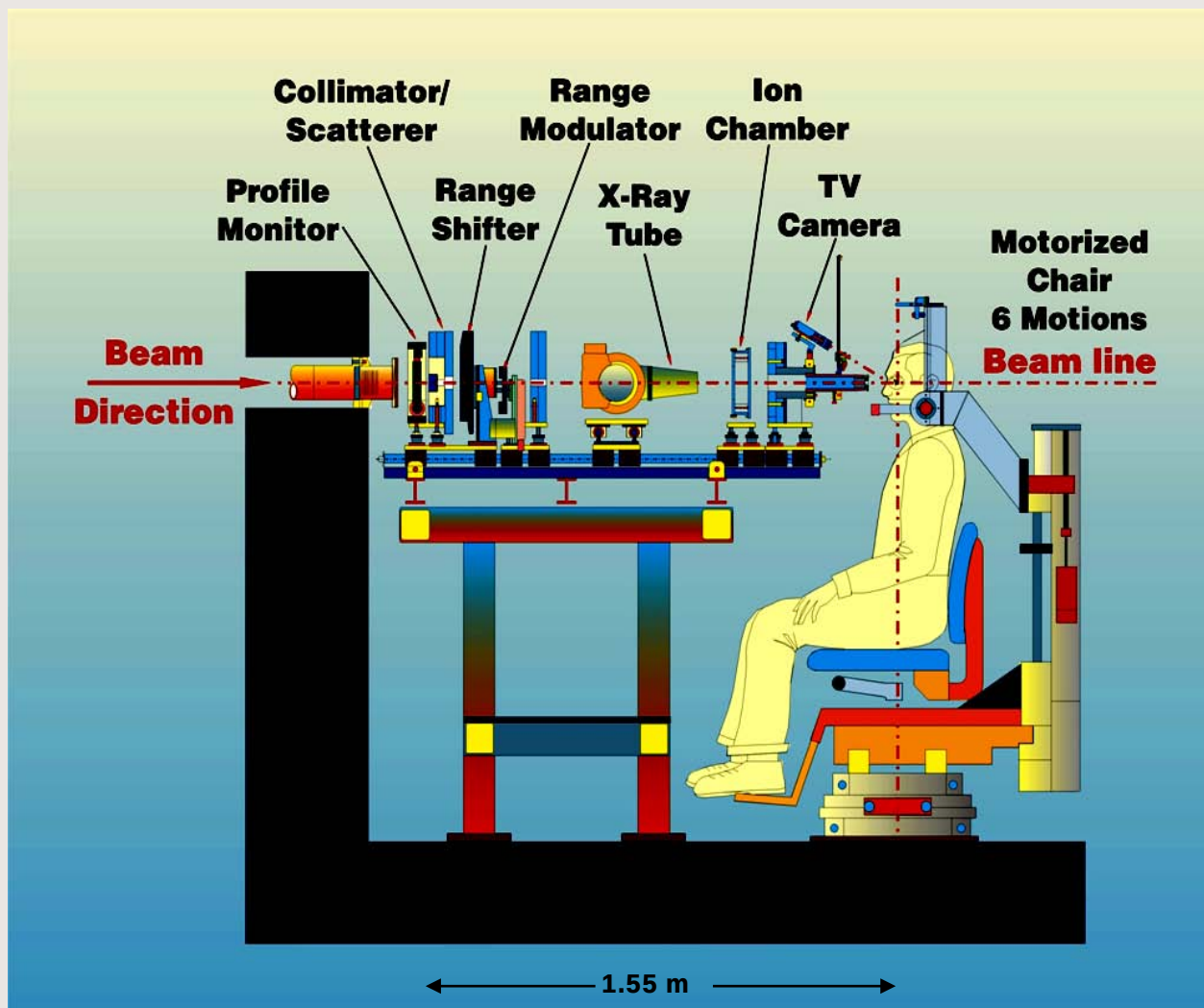
Mono-energetic proton – Bragg peak at the end of its range

Modulate energy – Spread Out Bragg Peak (SOBP)

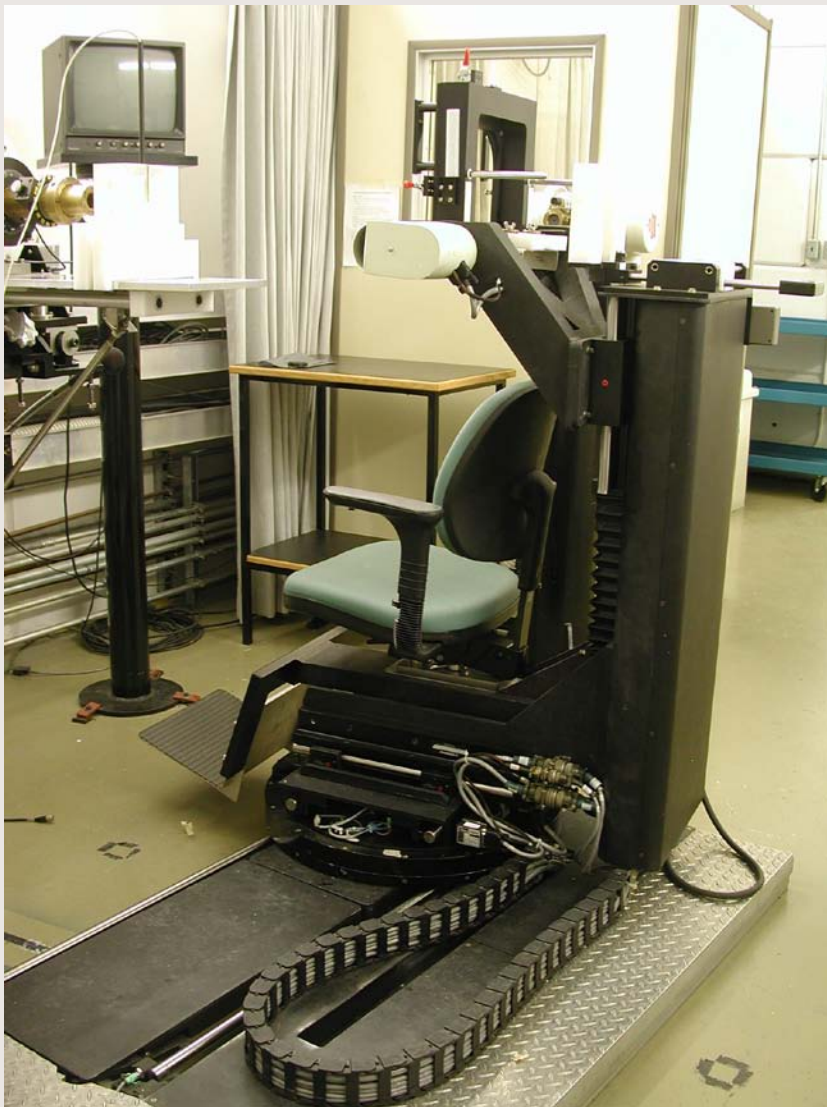
Maximum dose to tumor – minimize dose to nearby sensitive structures



Beamline



Patient Set-up



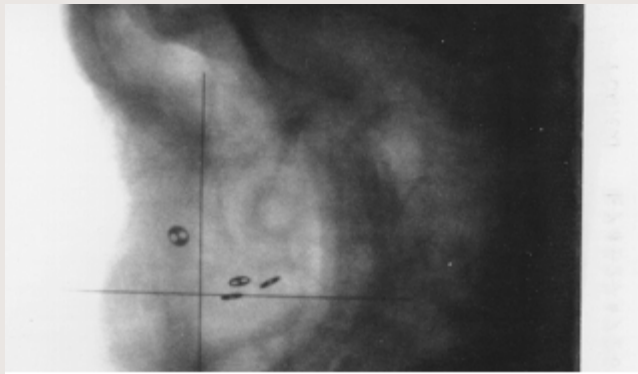
Treatment Chair

6 motorized motions

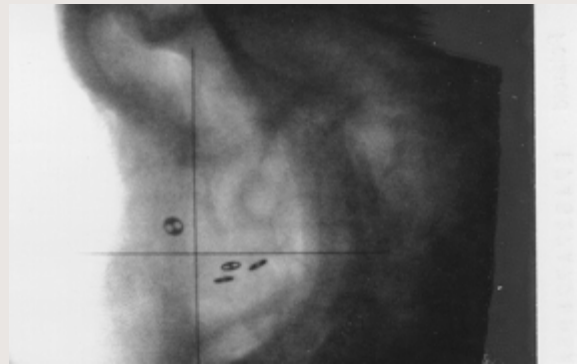
X, Y, Z, K, θ , ϕ

Patient Set-up

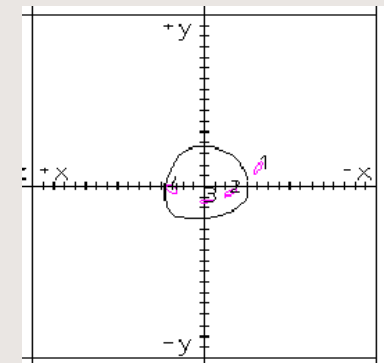
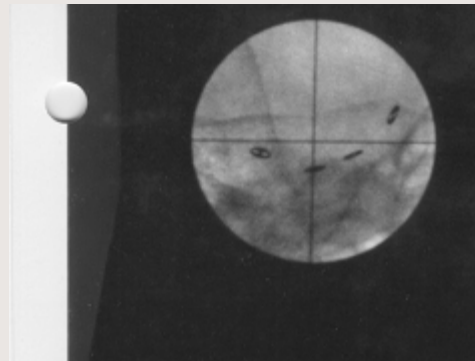
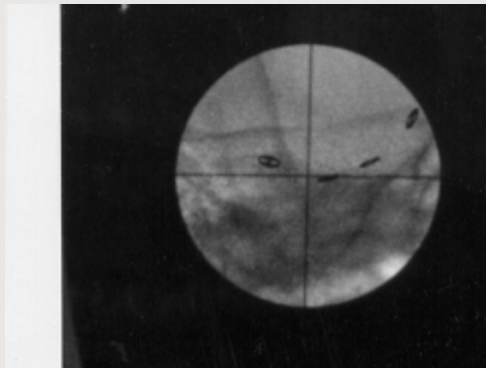
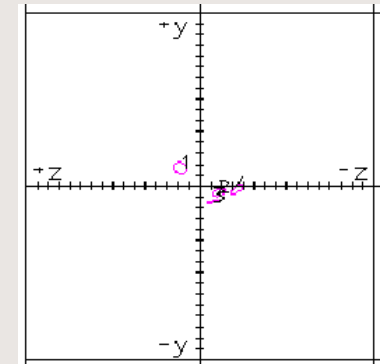
First set-up



Second set-up



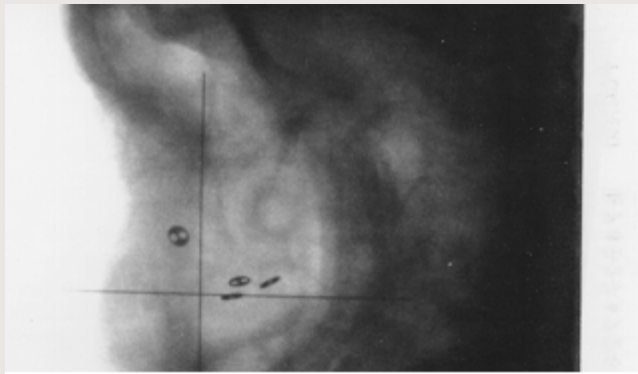
Treatment plan



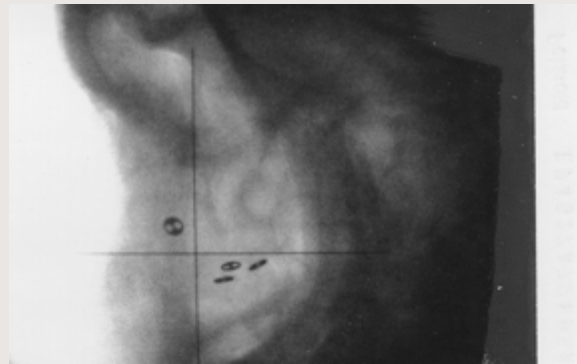
Treatment: four days in a row, around 90 seconds each

Patient Set-up

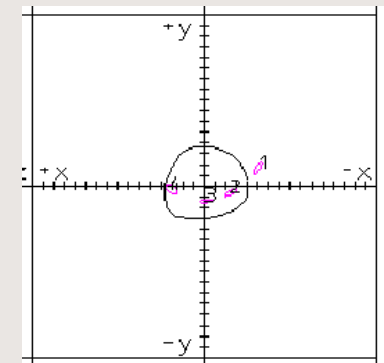
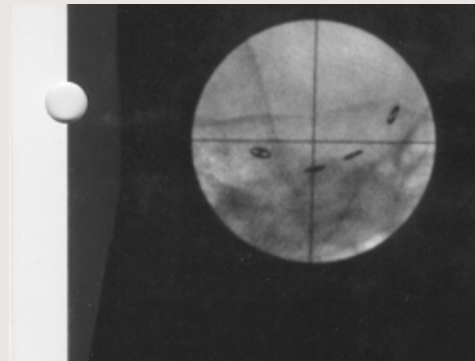
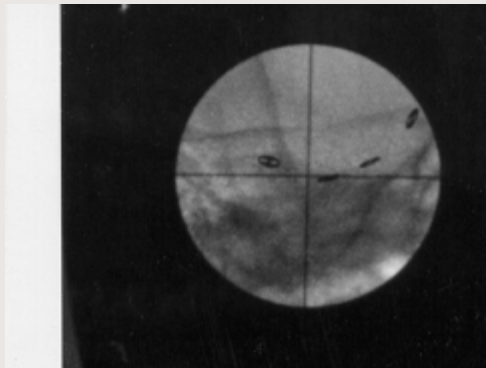
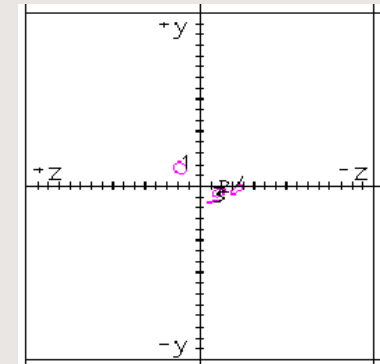
First set-up



Second set-up



Treatment plan



Statistics: 183 patients, average 9/year, ages 14-80, median 57
Tumor control >95%, survival rate (>5 years) 80%

Collaboration



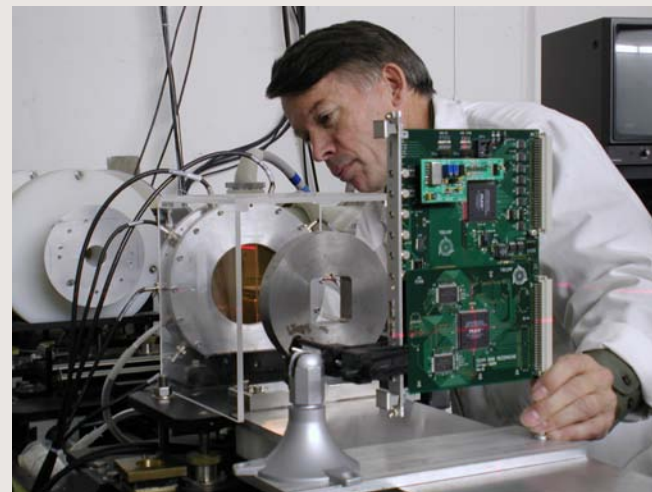
Eye Care Centre



BC Cancer Agency
CARE & RESEARCH



TRIUMF



Dr. Ewart Blackmore

Around the World

