Introduction to Particle Therapy

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Particle Therapy Masterclass (PTMC)

15 March 2024

Disclosure

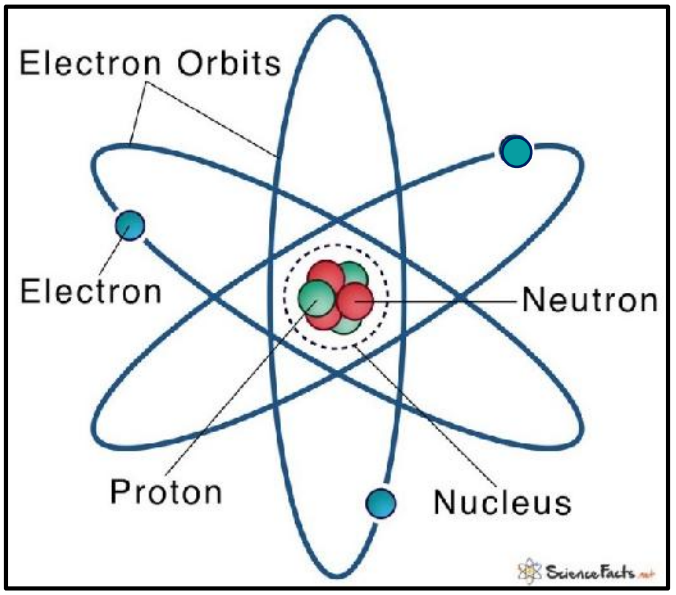
- **None.**
- **All the images used for educational purpose only.**

Outline

- Introduction
- Radiation Therapy
- Rationale for Particle Therapy
- Proton Therapy
- Proton Therapy Centre, ACTREC, TMC
- Basic Sciences – Applications
- Summary

Introduction – Matter & Energy

- Matter is any substance that has mass and volume.
- Form – Solid, Liquid, Gases.
- The atom is the smallest unit of matter.
- Constituents of atom – Proton, Neutron and Electron
- Mass defect = Mass of atom – Mass of constituents
- The energy equivalent to the mass defect of an atom is known as the binding energy of the atom.
- This energy required to separate the atom into its constituent parts.



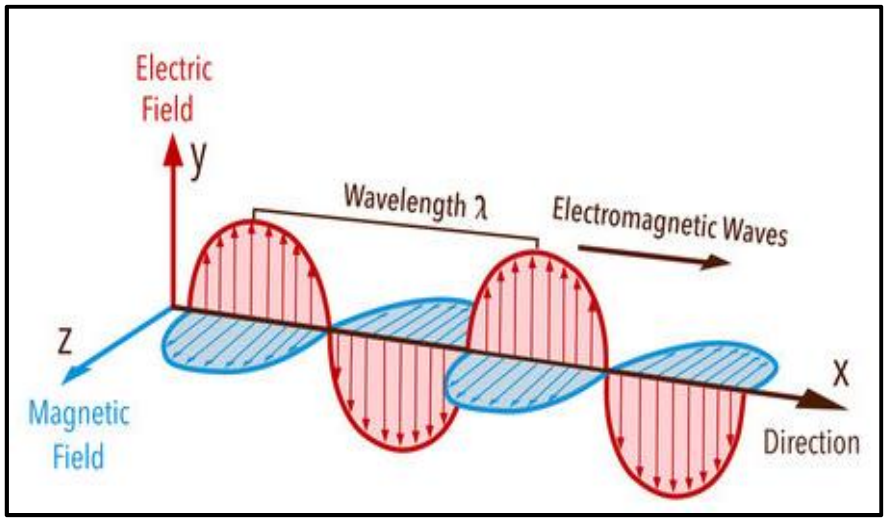
Electron
Proton
Neutron

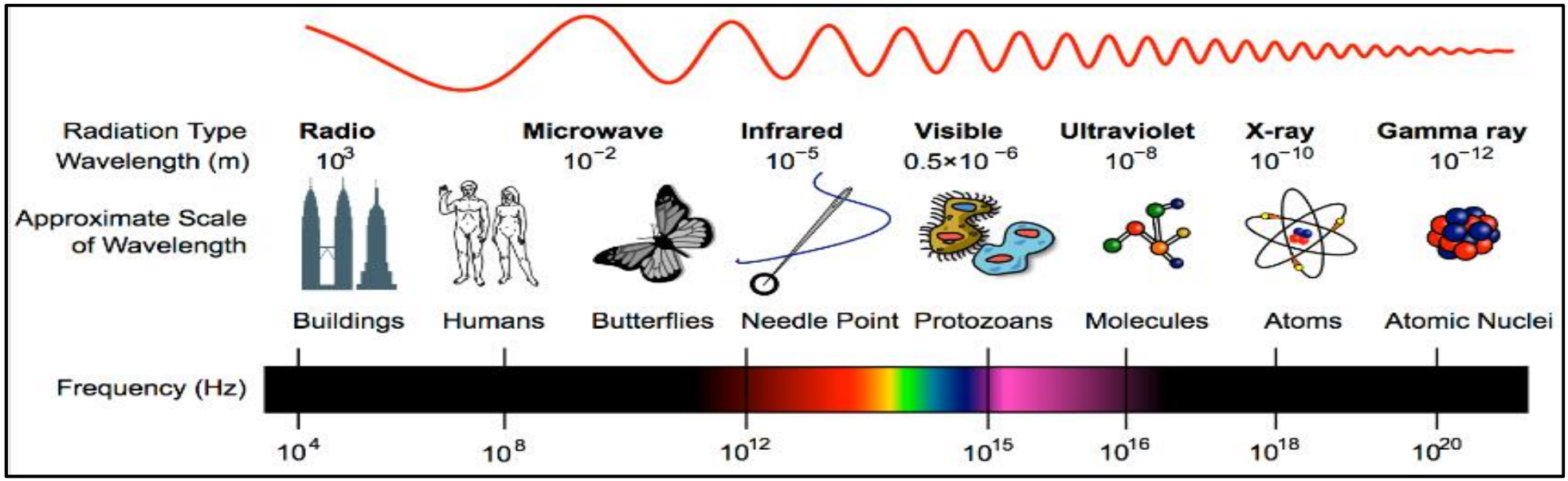
$$E = mc^2$$

Introduction – Matter & Energy

- **Energy is the ability to perform the work.**
- **Form – Heat & Light**
- **Conserved quantity.**
- **Propagation mode - Conduction,**

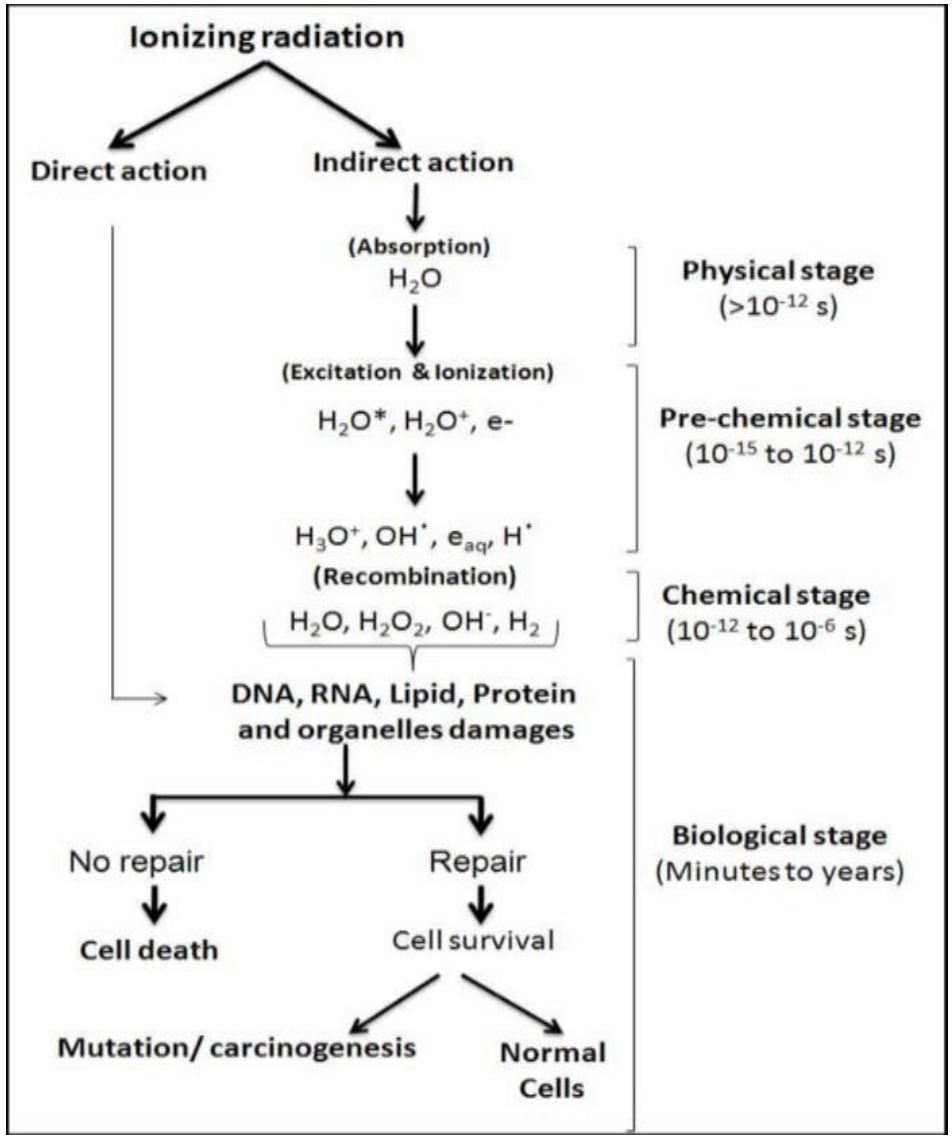
  Convection & Radiation





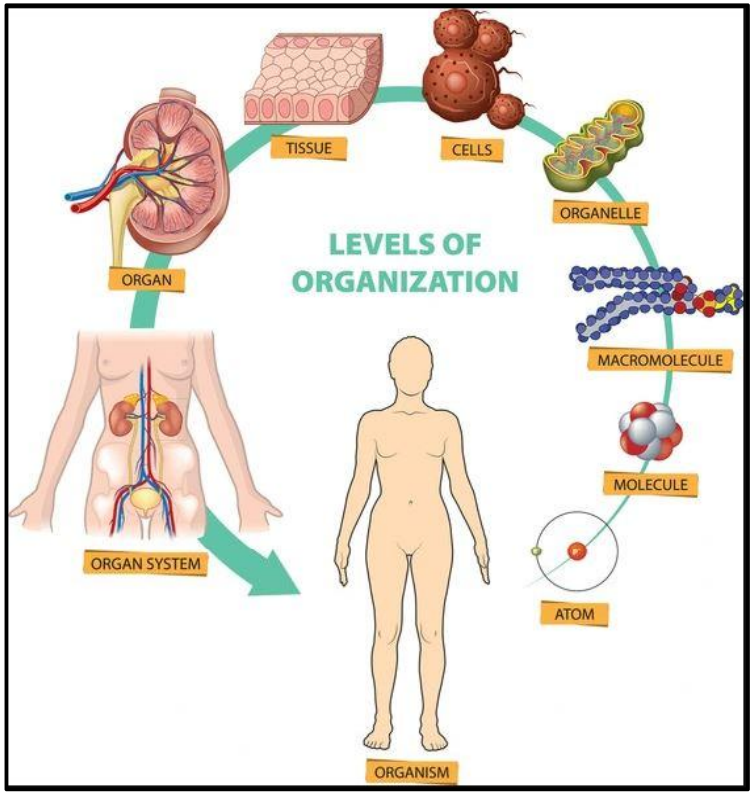
Introduction – Radiation

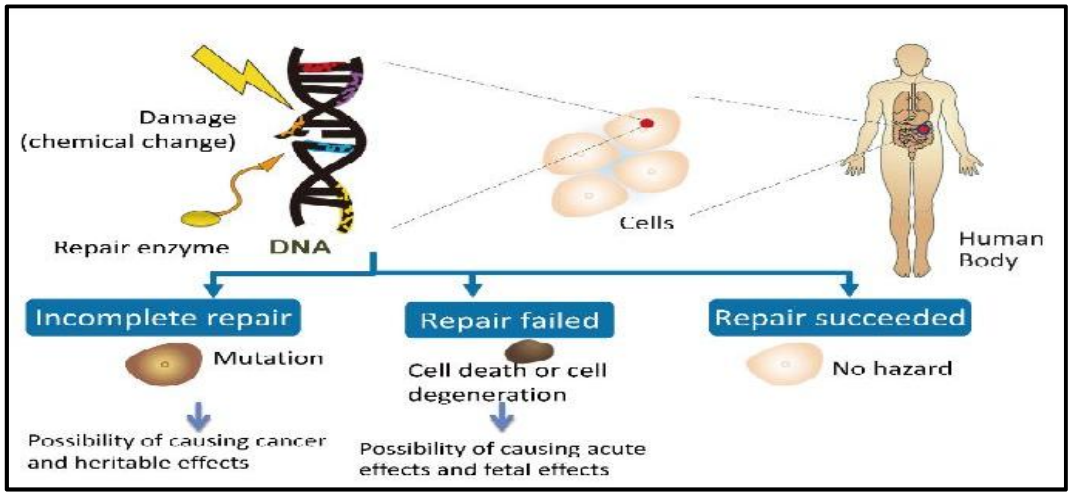
- **Non-ionizing radiation – can not ionize matter.**
- **Ionizing radiation – can ionize matter (results an ion pair i.e. free electron and ion)**
- **Radiation deposits energy in the matter.**
- **(Radiation dose unit i.e. 1 Gray = 1Joule / kg)**
- **Deposited energy damage the cell DNA.**
- **Aim – to deposit dose within the tumor to cause maximum damage while sparing the surrounding normal tissues.**

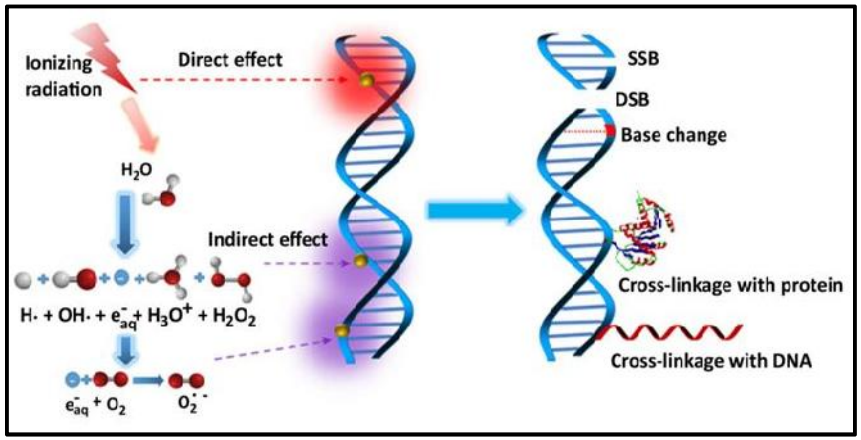


Introduction – Radiation effects

- **Cells are the units of life.**
- **Their controlled growth and properties are in balance with entire organism.**
- **A tumor originates when single normal cells mutate and develop into cancer cells.**
- **Mutations produce defects in the cellular regulatory mechanisms.**

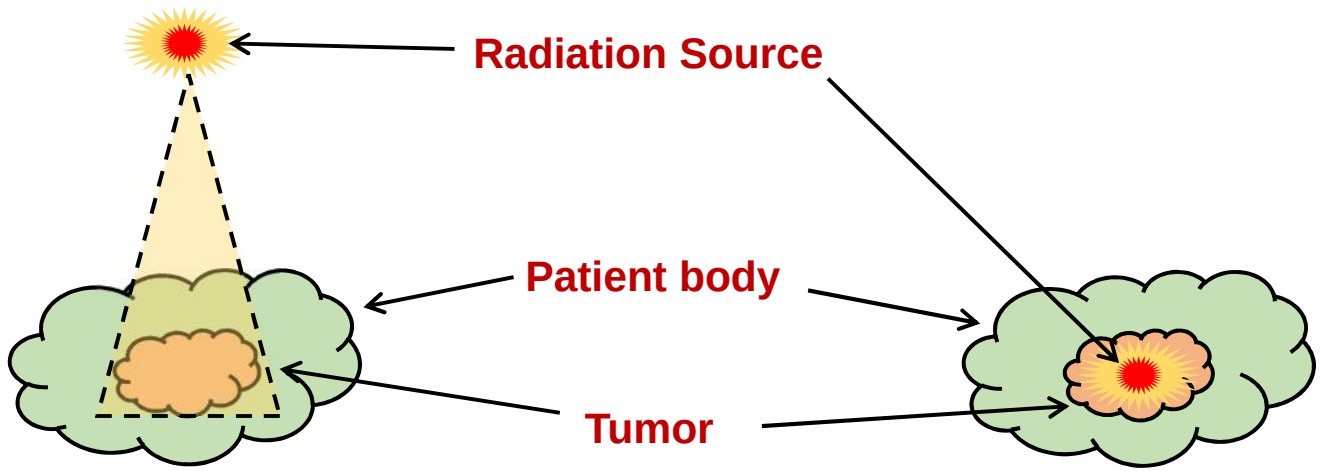






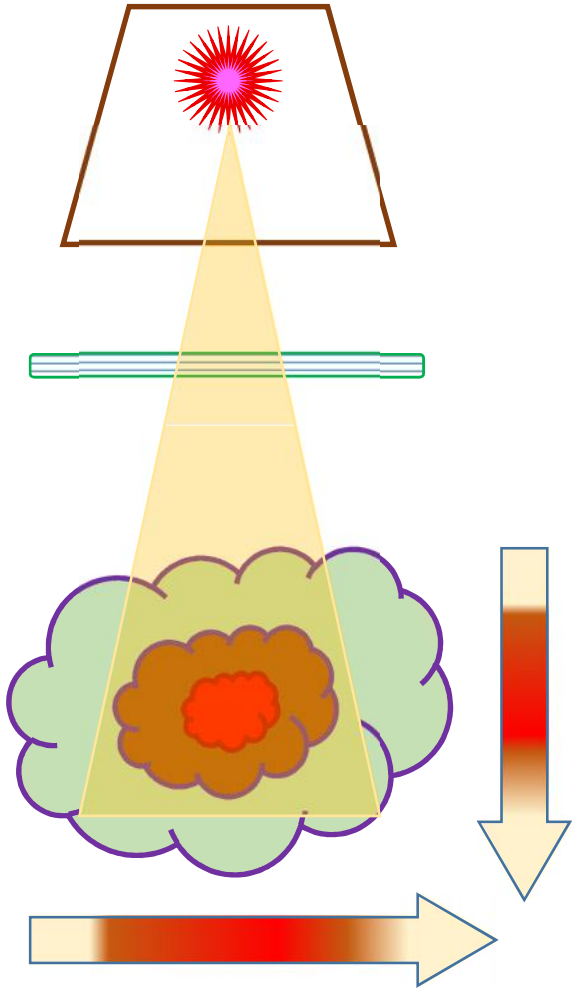
Radiation Therapy (Radiotherapy)

- **Radiation Therapy is a type of cancer treatment that uses high energy radiation beam to treat / destroy the cancer cells.**
- **Radiation damages genetic materials called DNA inside the cancer cells.**
- **Two types –**
  - ✓ **External Beam Radiation Therapy – Radiation source is away from body**
  - ✓ **Brachytherapy – Radiation source near / inside the body**

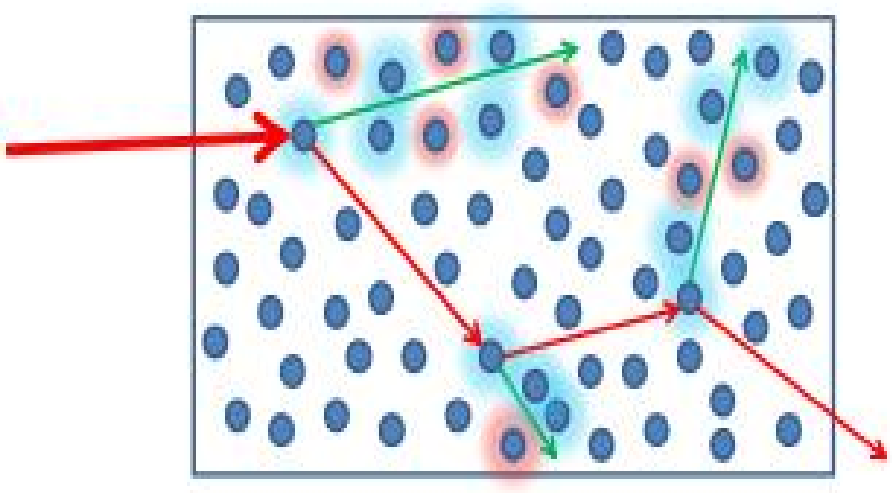


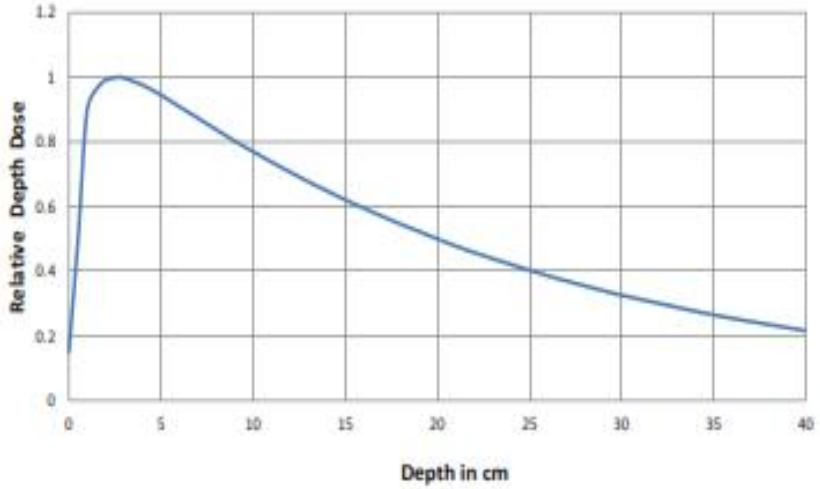
Radiation Therapy – External Beam Radiation Therapy

- **Goals of Radiotherapy**
  - ✓ Deliver the Prescribed Dose
  - ✓ Deliver the Prescribed Dose Distribution
  - ✓ Deliver the Distribution to the right place
- **Need of Radiotherapy**
  - ✓ Beam with appropriate energy/range
  - ✓ Beam with appropriate timing
  - ✓ Beam control provision and Dose distribution measurement
  - ✓ Provision to confirm right place
  - ✓ Deliver beam at that right place



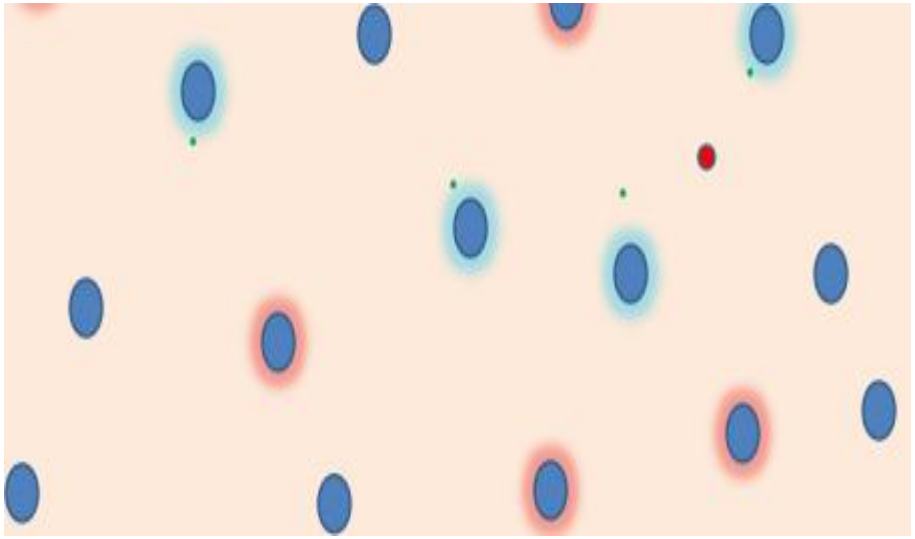
Radiation Therapy – External Beam Radiation Therapy

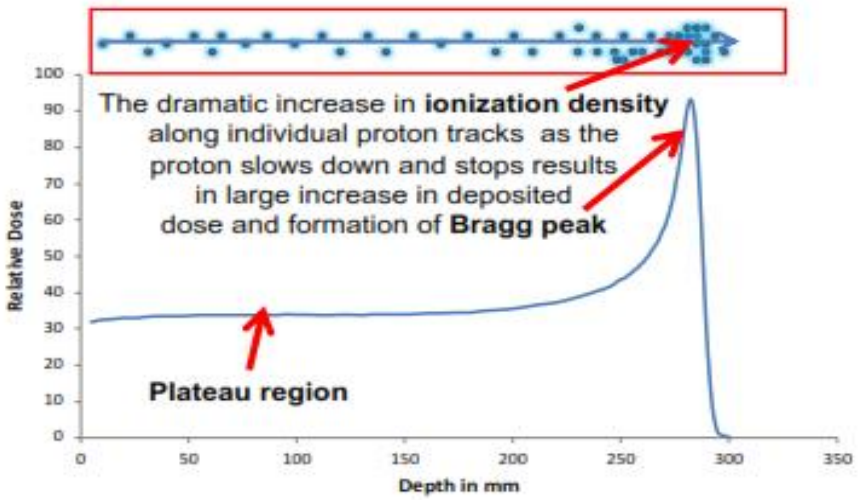




- **X-rays / Gamma rays are uncharged, ionize matter as they pass through by an indirect process.**
- **The X-rays/Gamma rays used in radiation therapy most of these interactions occur through a process known as the Compton effect.**
- **The result of the radiation nature of these interactions is that X-ray beam is exponentially attenuated.**

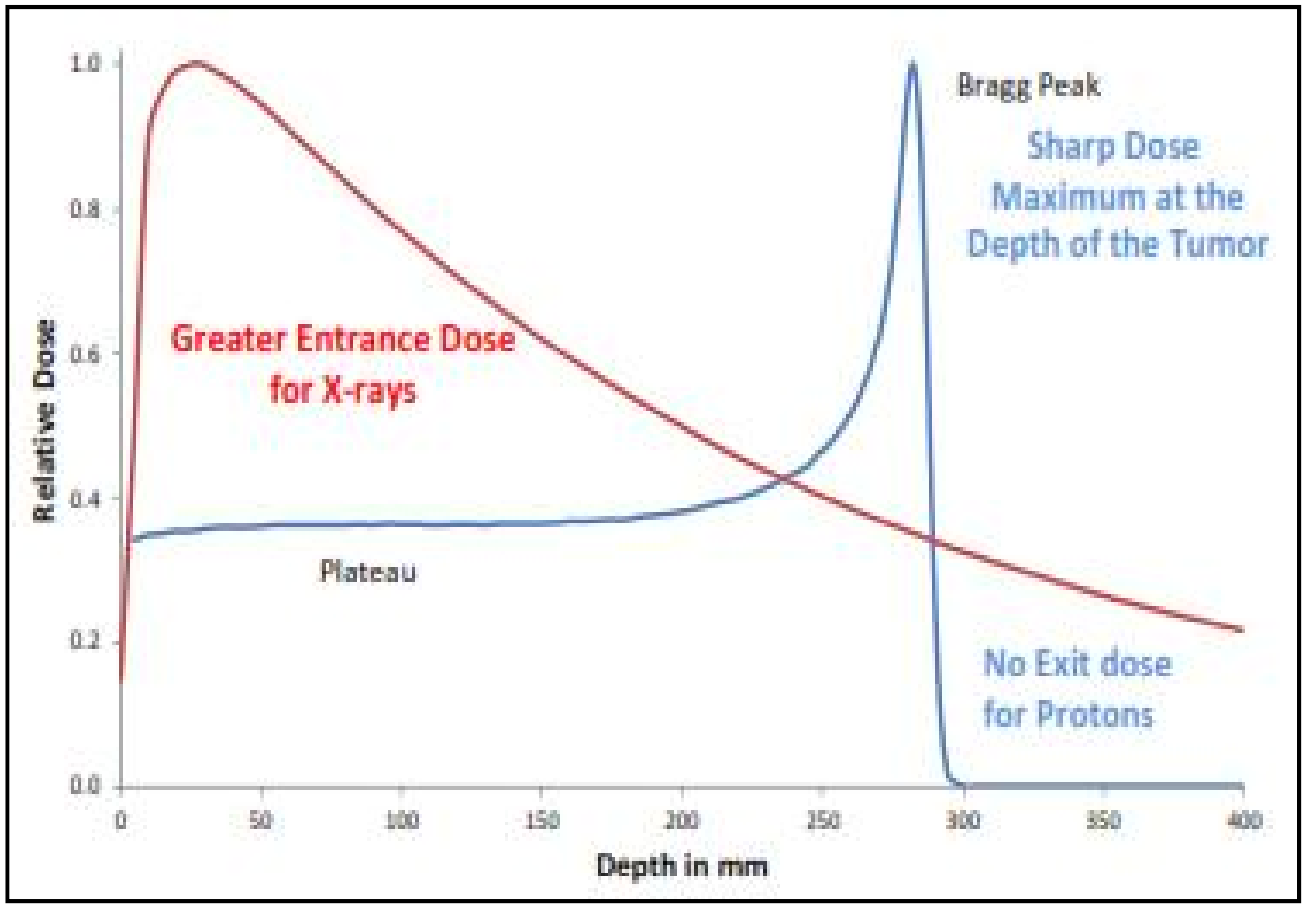
Radiation Therapy – External Beam Radiation Therapy

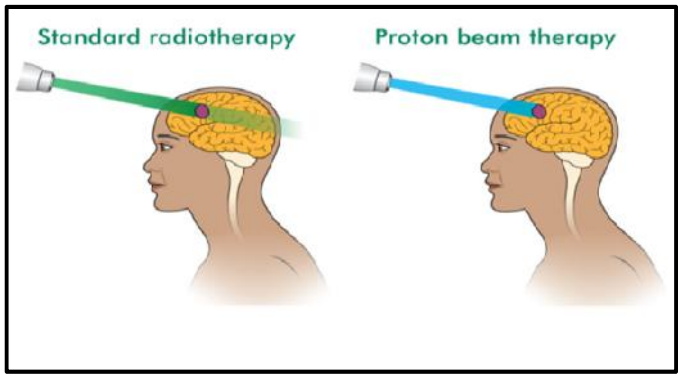


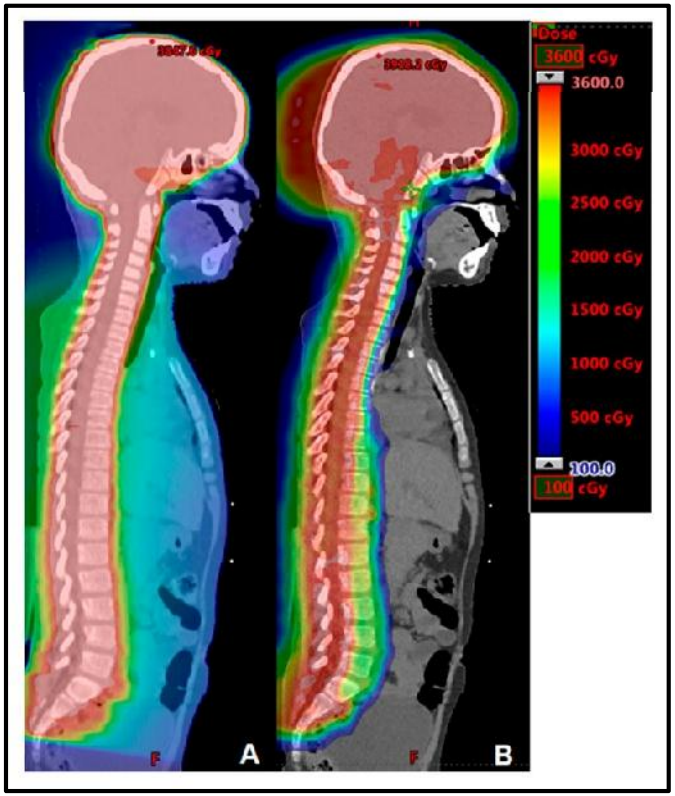


- **As the proton moves through water the coulomb force causes water molecules to be excited or ionized.**
- **Each interaction causes the proton to lose a small amount of energy (¼ 30keV). Thus, a 230 MeV proton may undergo close to 10 million interactions before losing all its energy and stopping.**
- **As the proton slows the time during which the coulomb force exists between the proton and the molecules increases, proton losses more energy in a given track length.**

Rationale for Particle Therapy

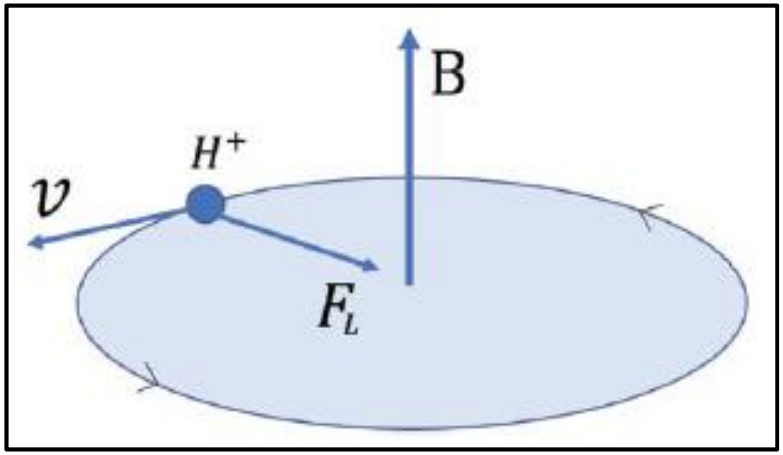


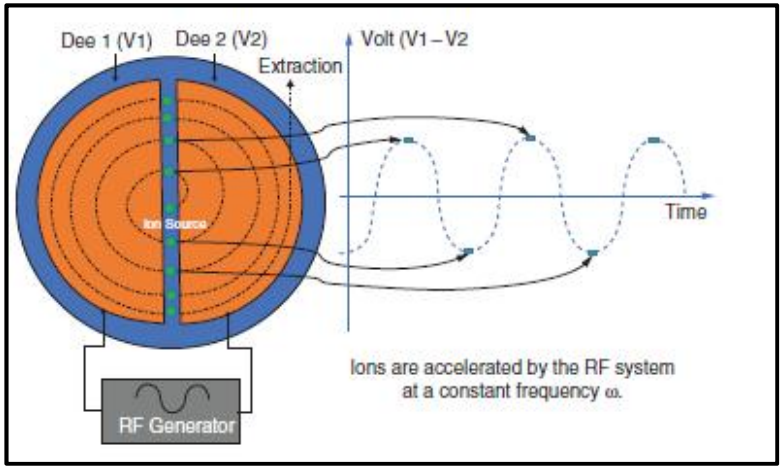




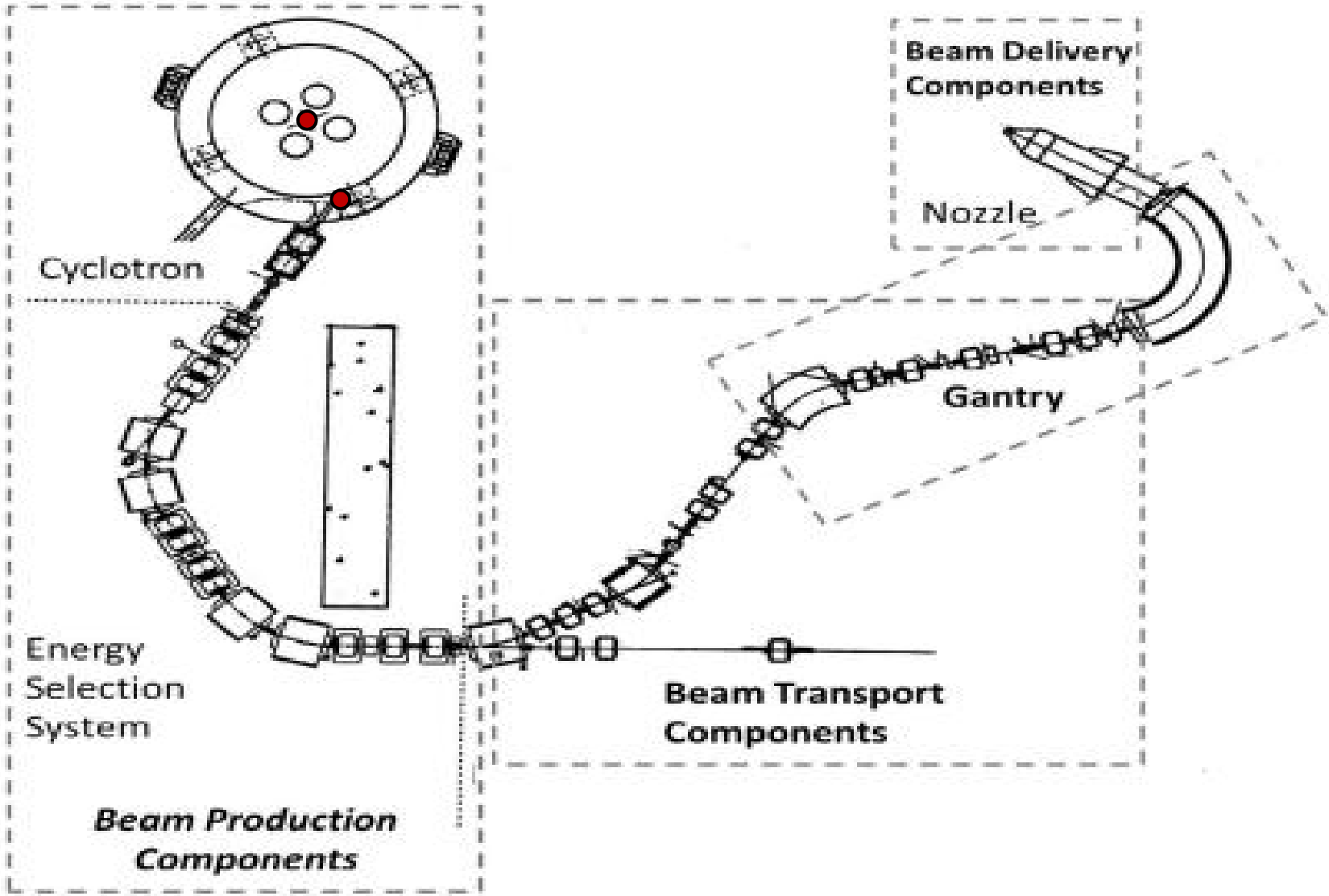
Proton Therapy

- A charged particle moving through a magnetic field will turn in a circular path
- A charged particle is accelerated by an electric field
- Centripetal Force $F_C = mv^2/r$, Lorentz Force $F_L = qvB$
- $mv^2/r = qvB$
- Rotational Frequency $\mu = v/r = qB/m$
- Cyclotron –
- Two semicircular disks called dees.
- The frequency of RF generator is equal to the rotational frequency of the particles
- The particles reach their maximum energy at the outer most trajectory and then exit the cyclotron.

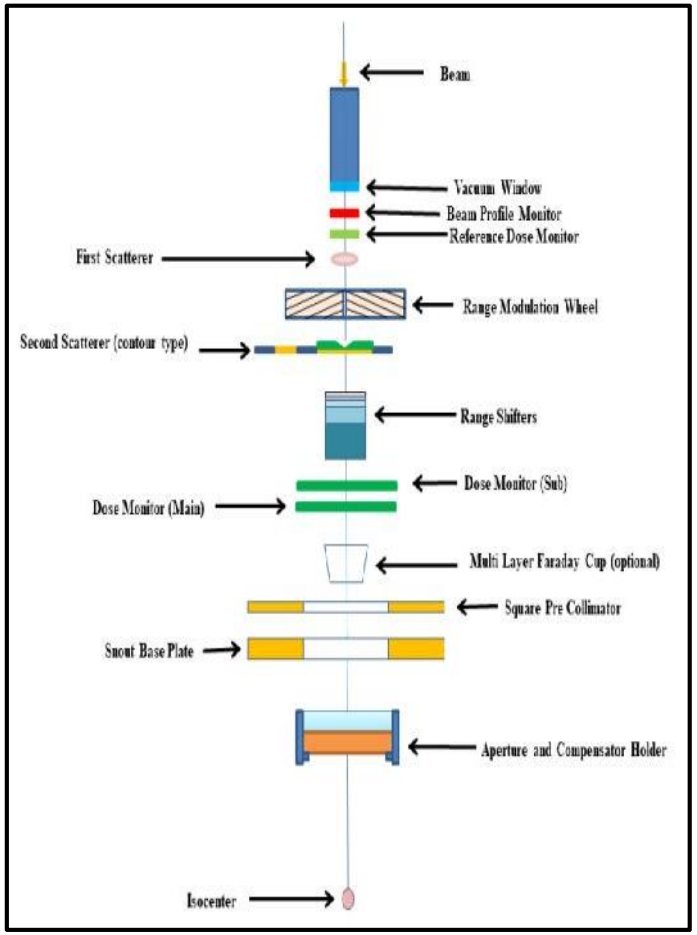




Proton Therapy

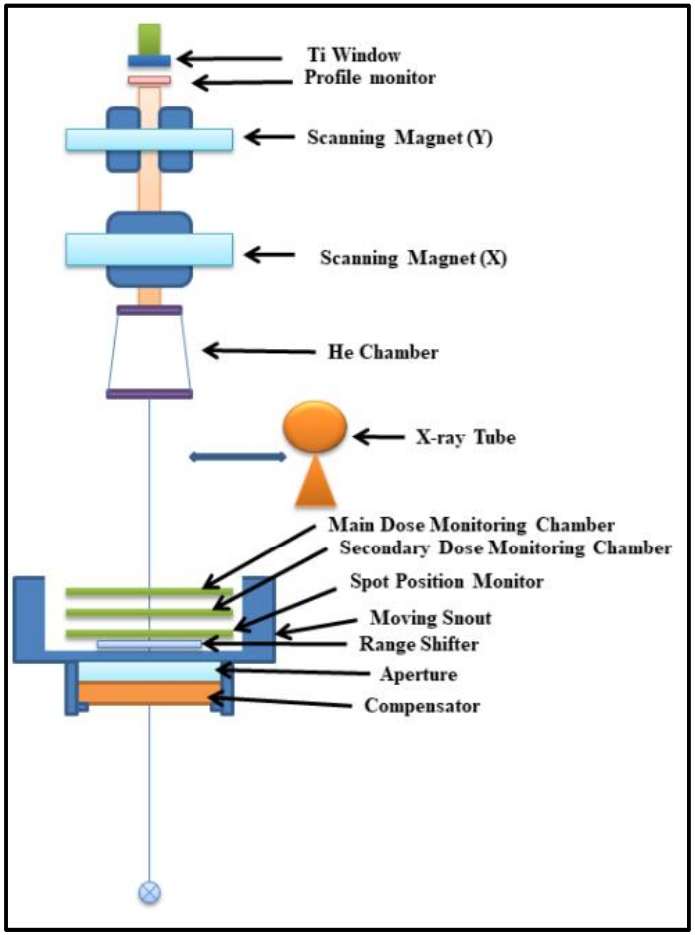


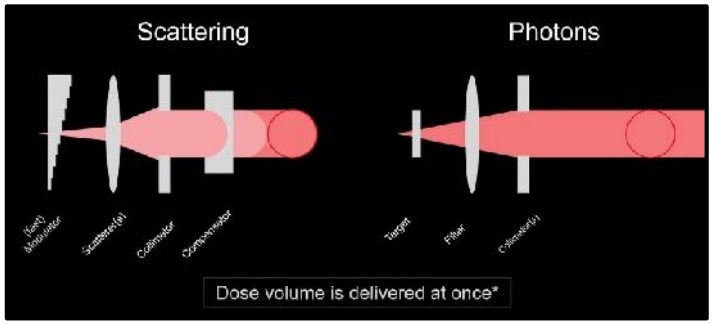
Proton Therapy

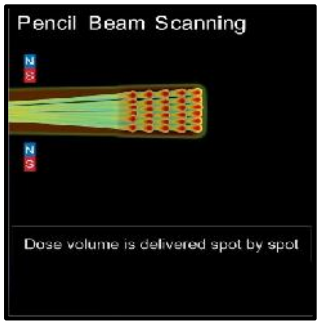


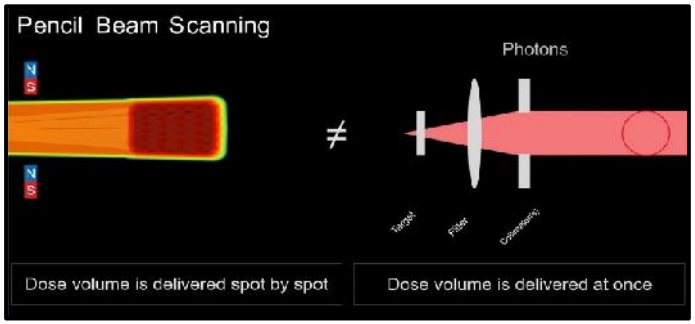
Scattering

Scanning

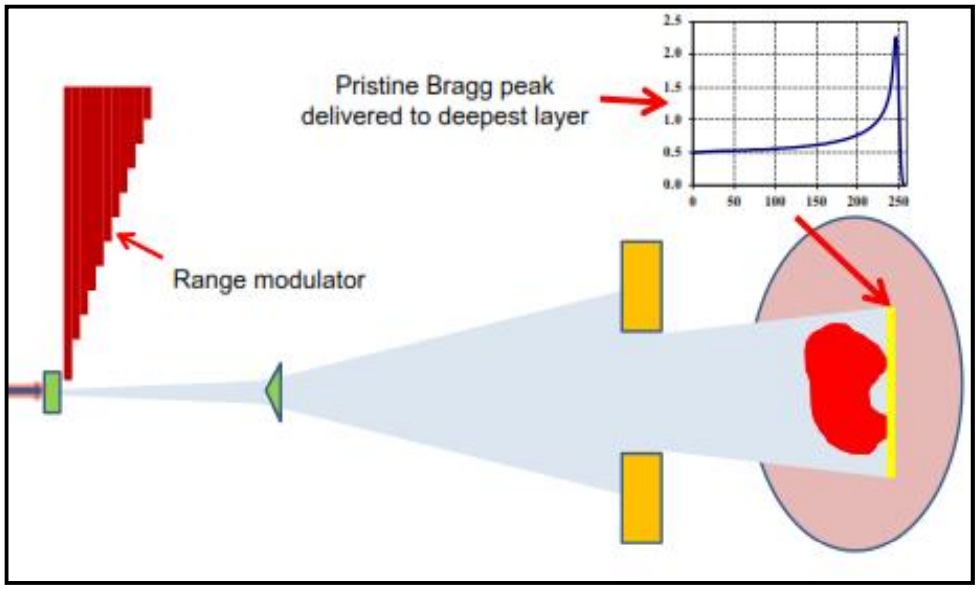


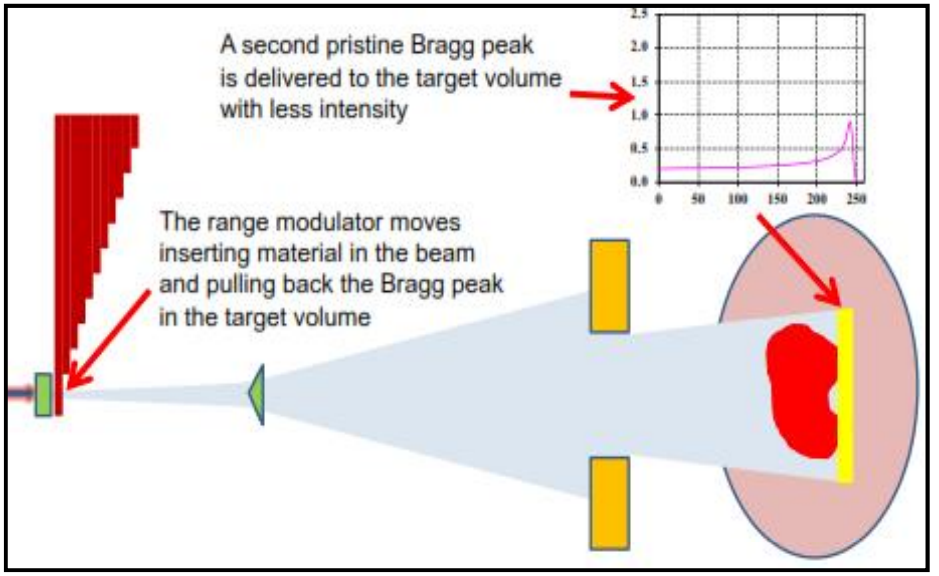


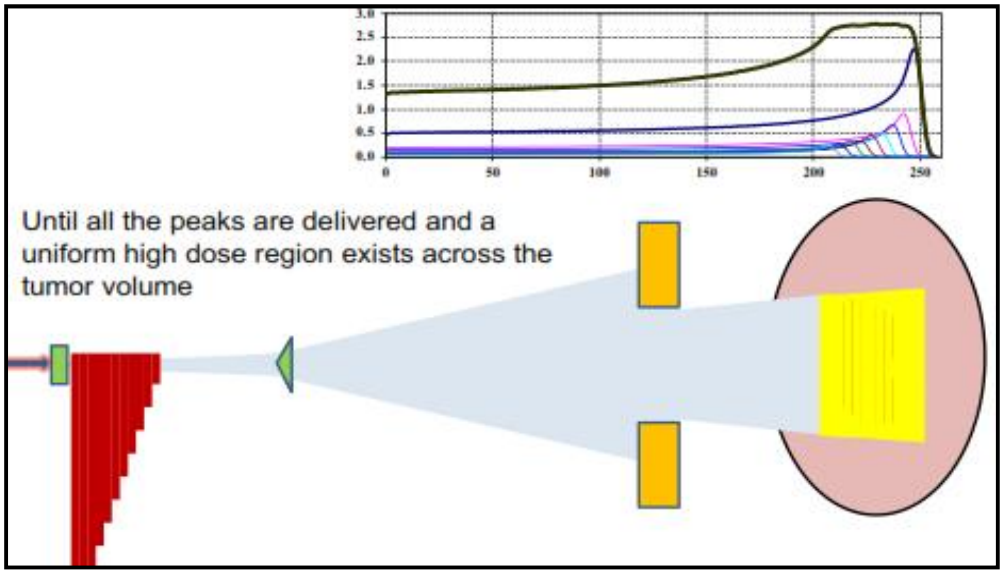


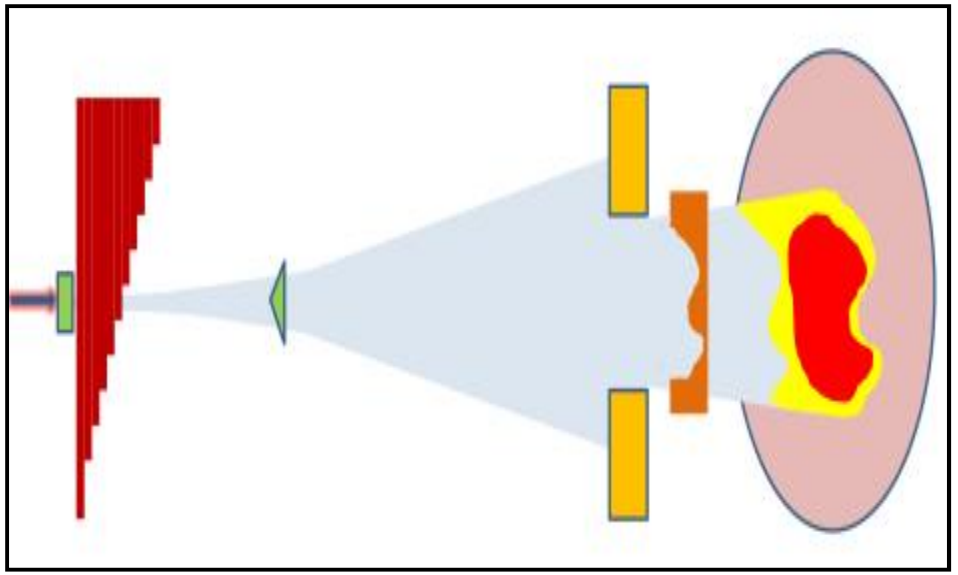


Proton Therapy – Scattering

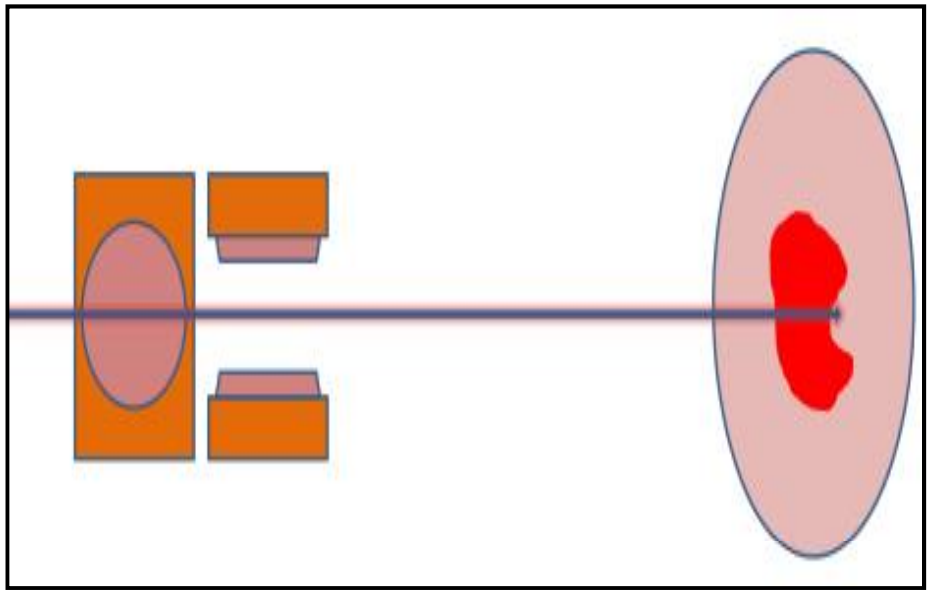


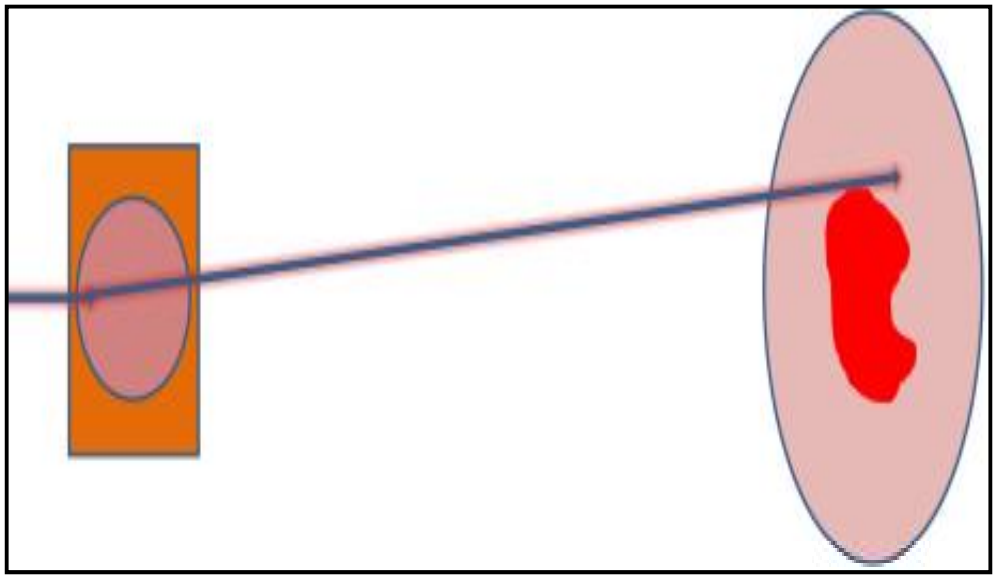


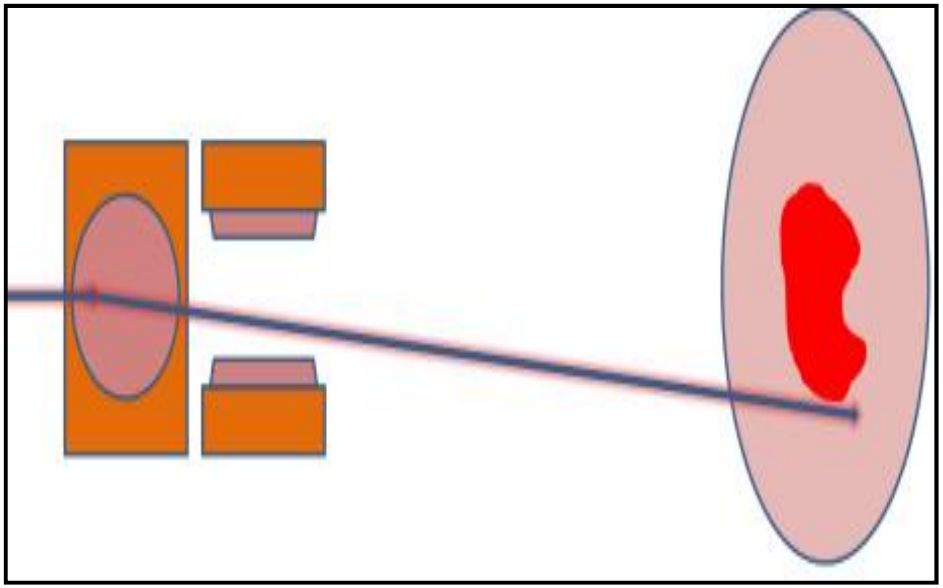


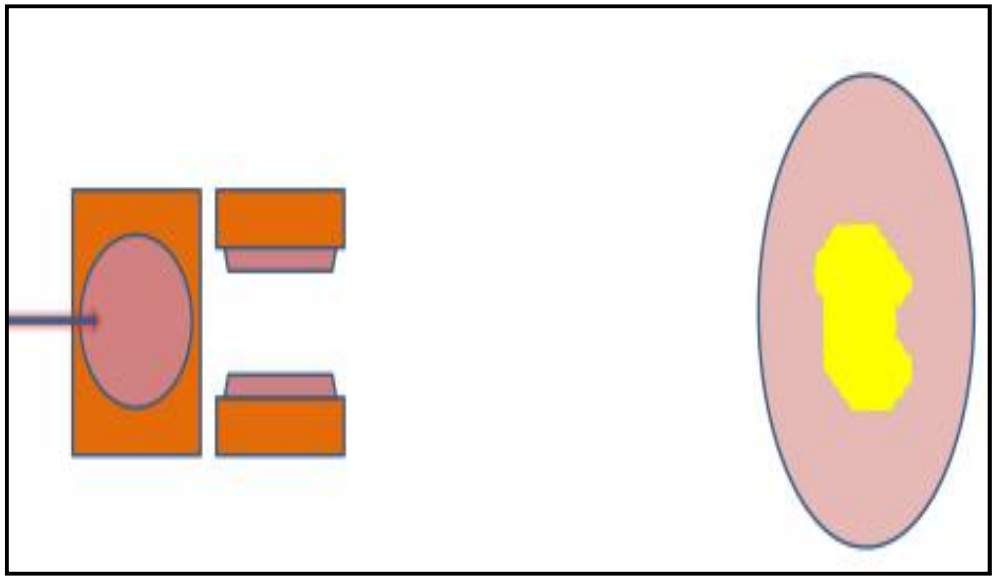


Proton Therapy – Scanning

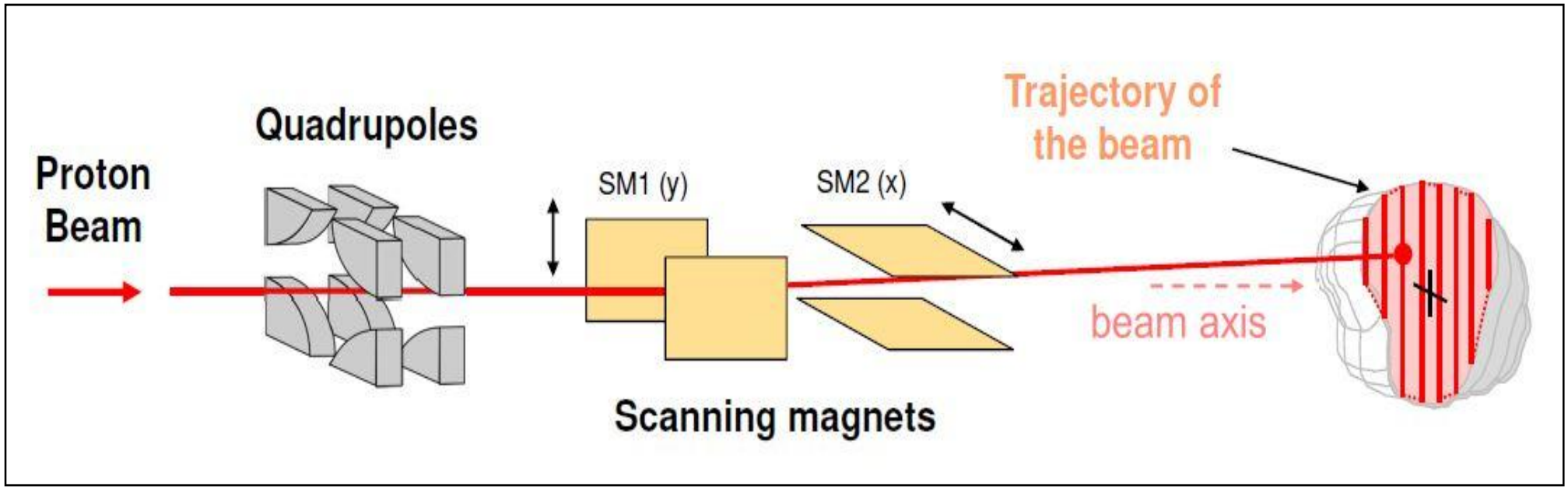


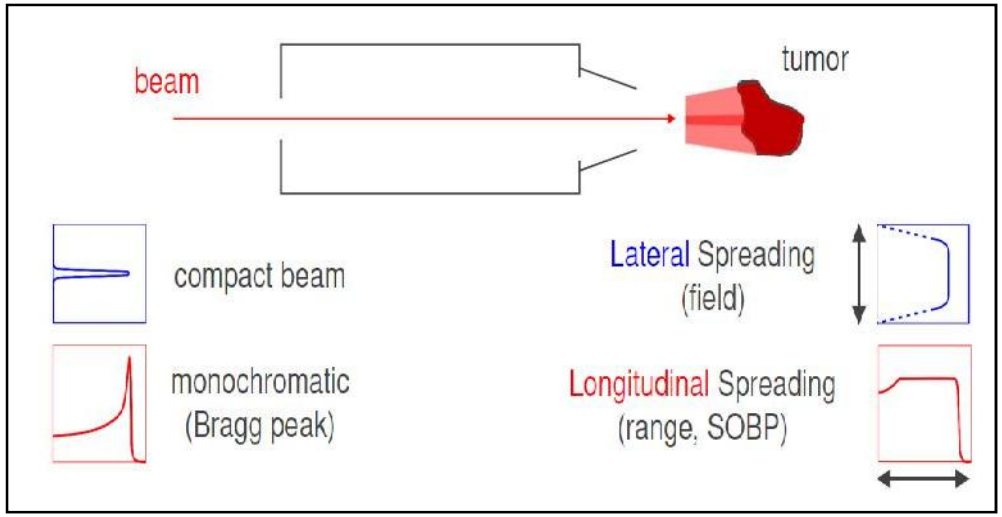


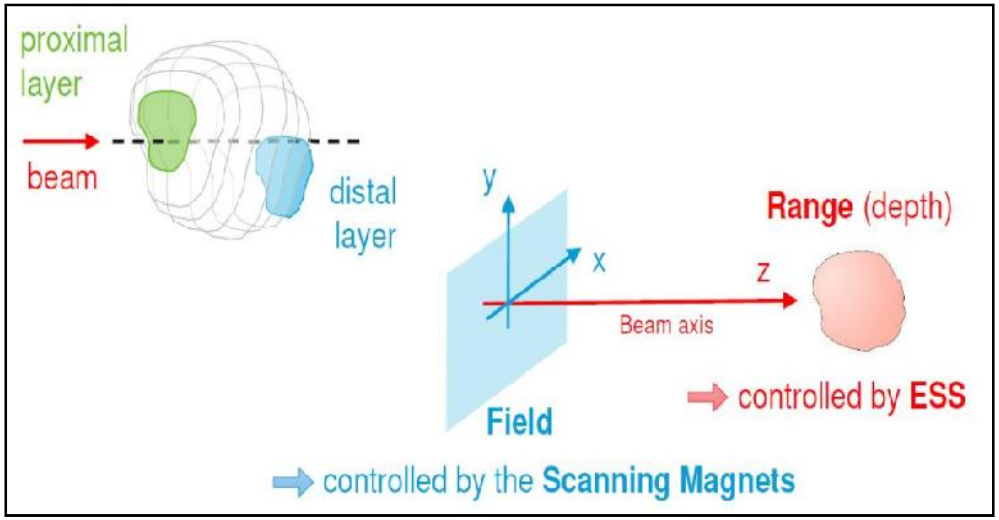




Proton Therapy

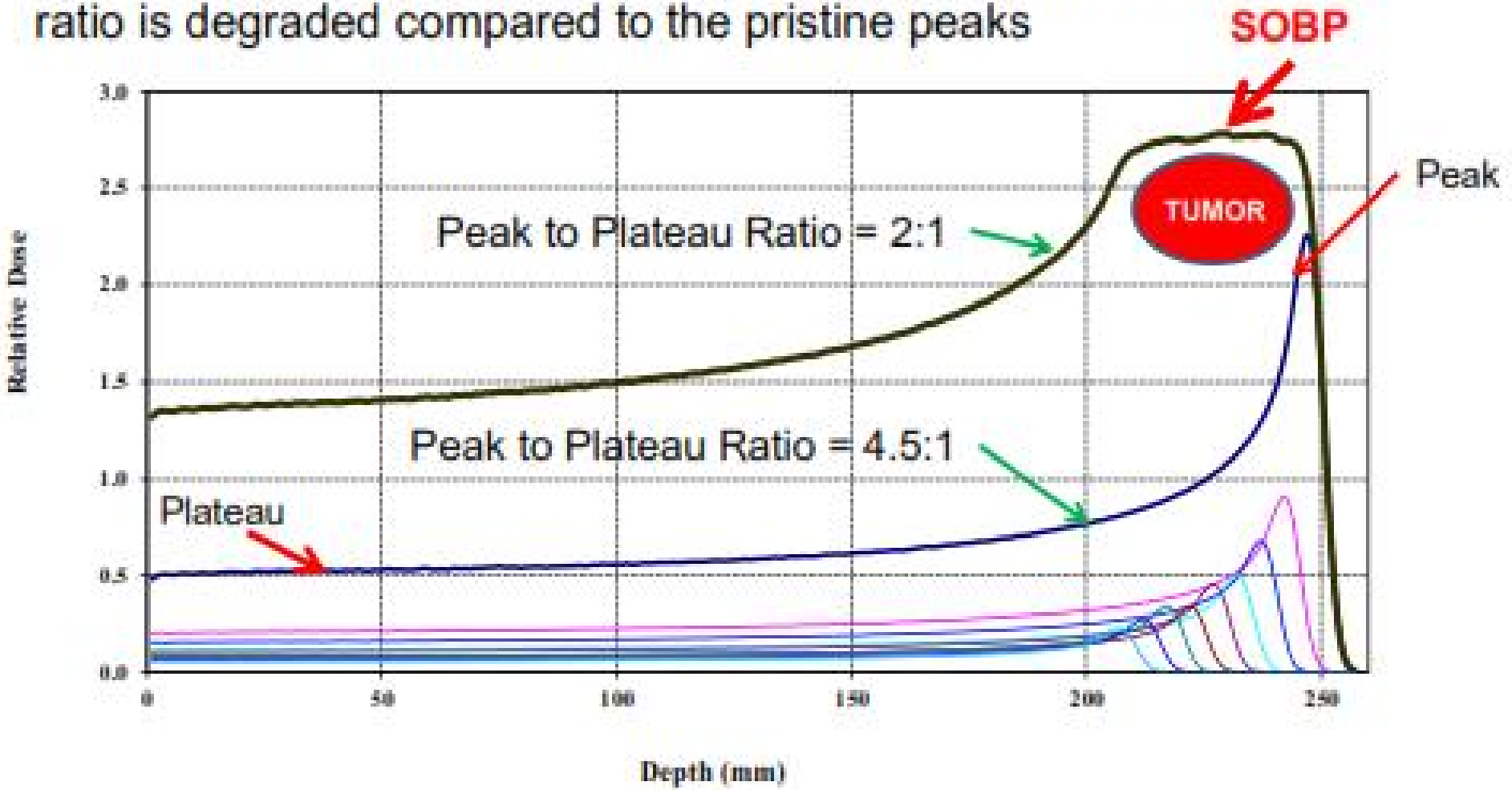




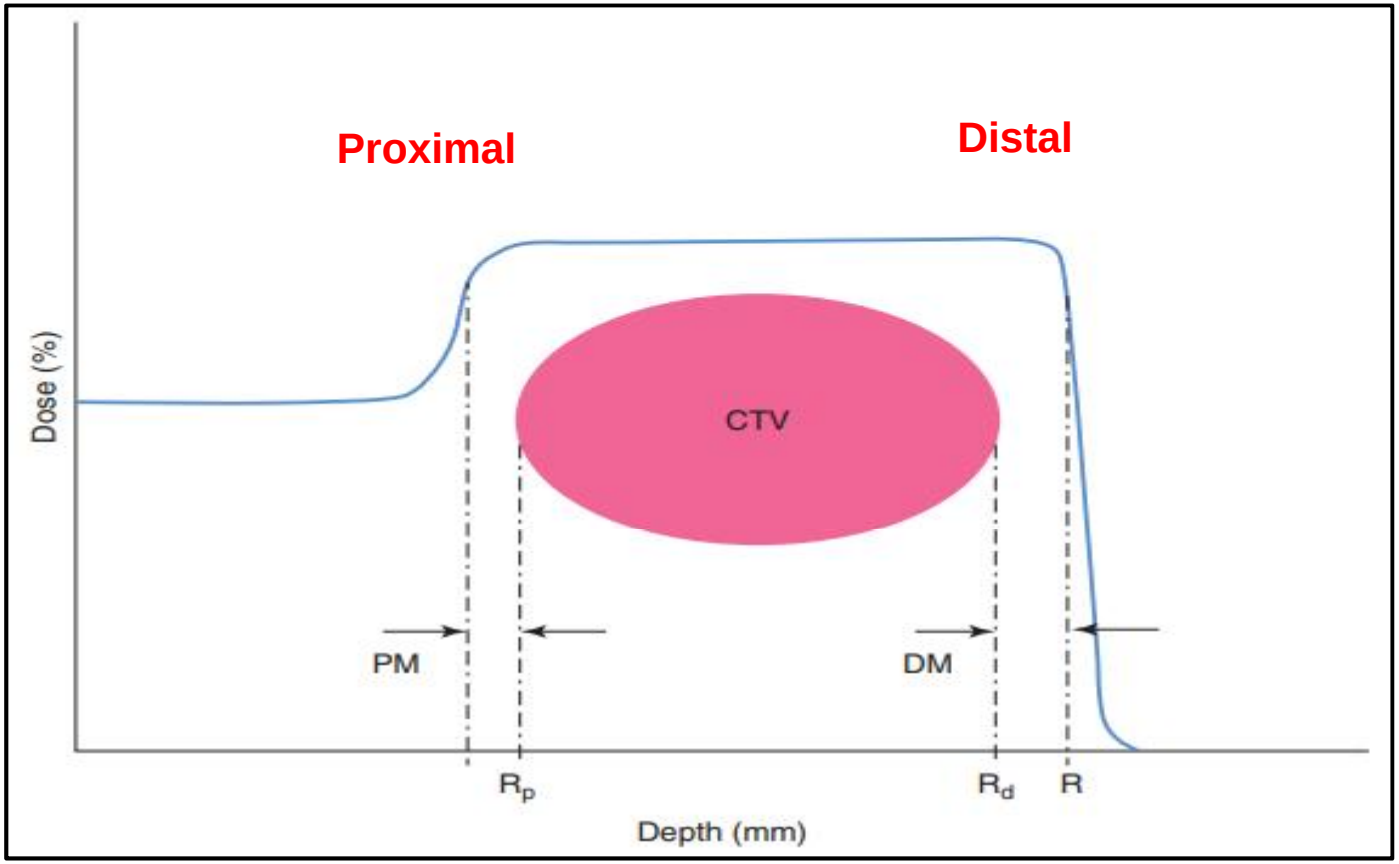


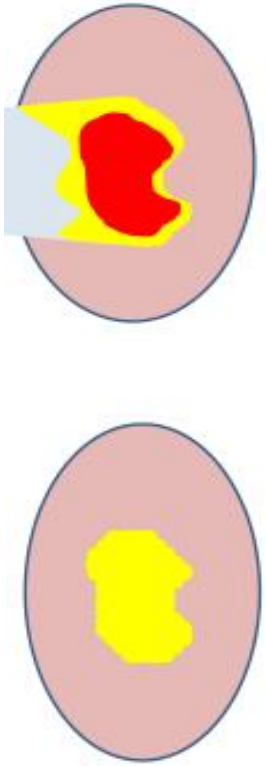
Proton Therapy – SOBP

- The SOBP has flat dose distribution across the tumor volume
- A result of the summing process is that the peak to plateau dose ratio is degraded compared to the pristine peaks



Proton Therapy – SOBP





- **Uniform dose distribution can be delivered over the volume of the tumor.**
- **Scattering method unable to conform the radiation dose to the proximal edge of the tumor.**
- **Scanning method produce greater conformal dose distribution to the tumor shape.**

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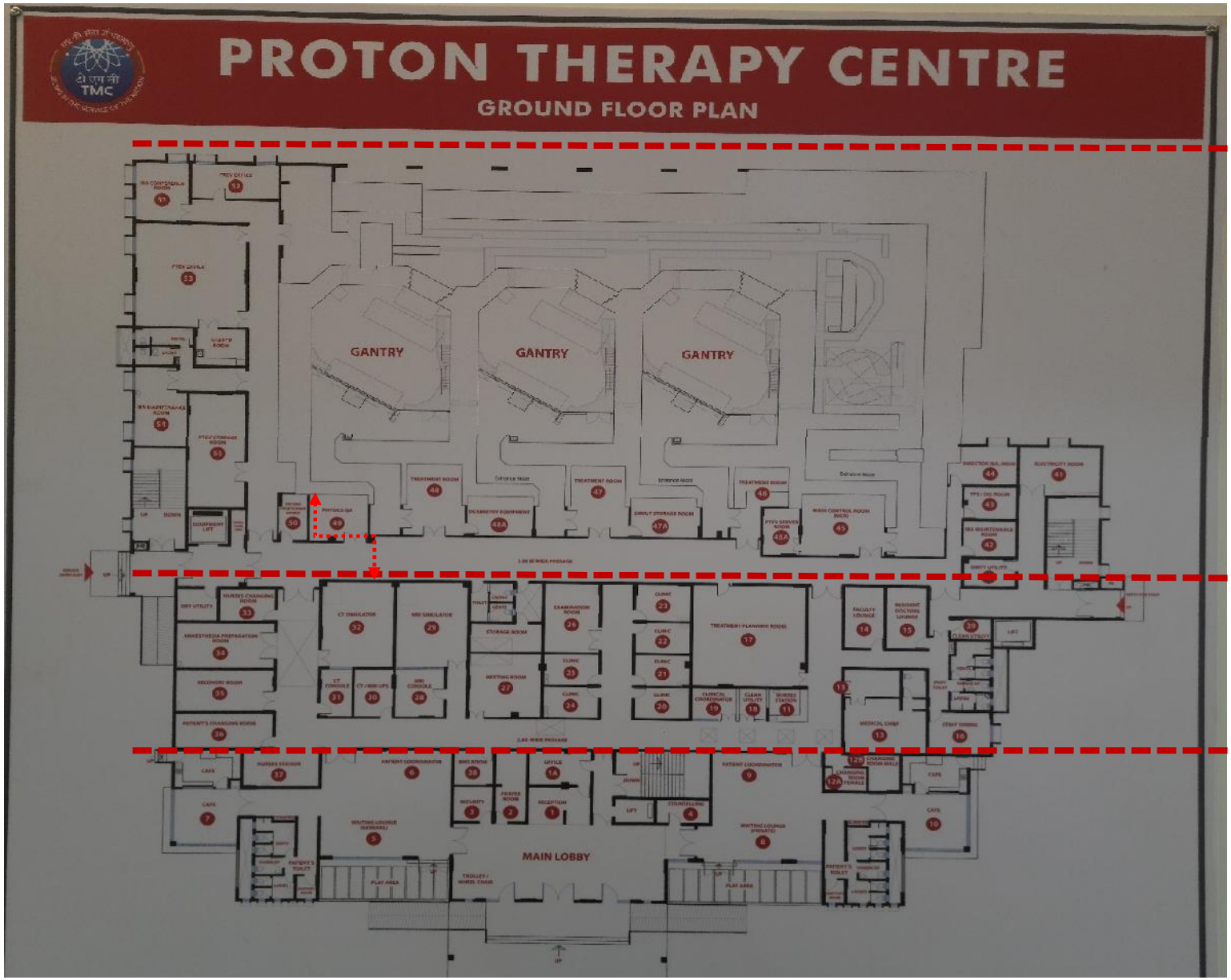
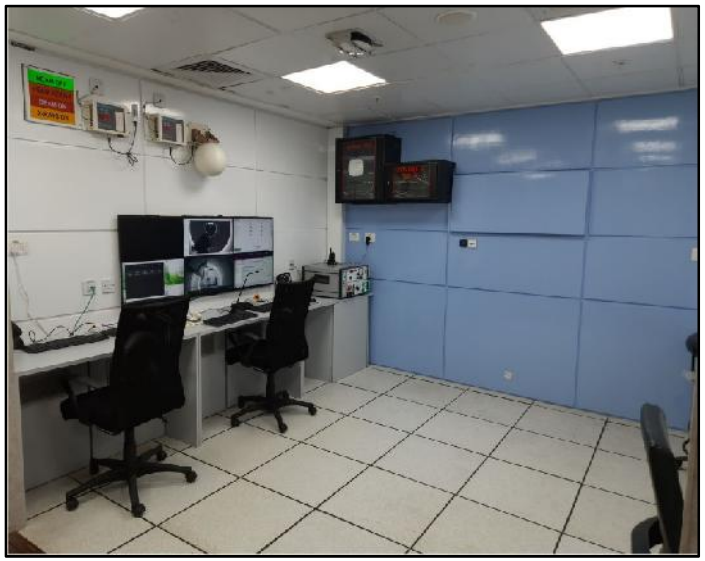


Proton Treatment Area

Clinical Service Area

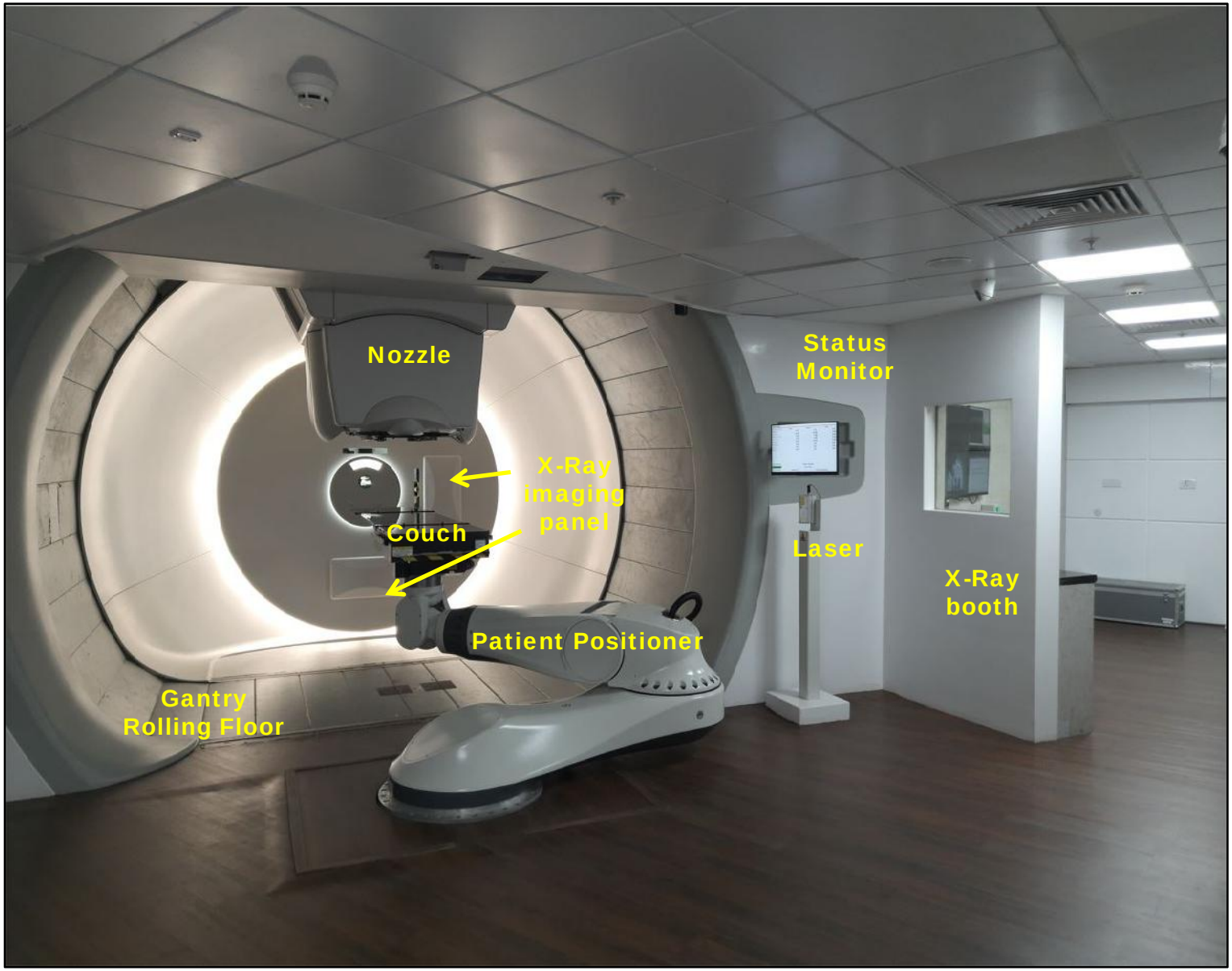
Patient Waiting Area

Proton Therapy Centre, ACTREC, Kharghar



1. Control Console
2. Double Maze Entrance
3. IR Safety Barrier
4. GTR3 Room
5. In-Room X-ray Booth

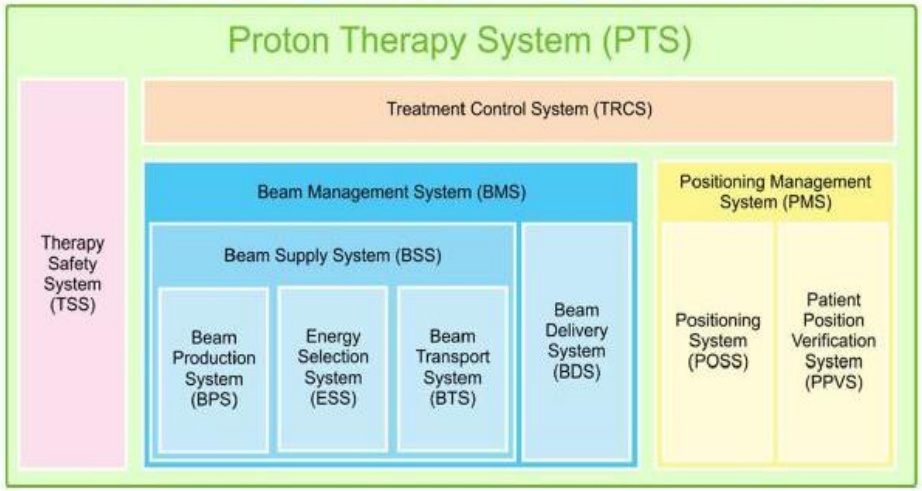
Proton Therapy Centre, ACTREC, Kharghar



- Gantry
- Couch
- Lasers
- X-ray Imaging
- Nozzle

Proton Therapy System

C230 – Key Values



Energy (fixed)	230 MeV
Typical Maximum Extracted Beam Current	300 nA
Average Extraction Efficiency	Better than 50 %
Maximum extracted beam emittance (1σ) (horizontal)	11 π mm.mrad
Maximum extracted beam emittance Unnormalized (vertical)	12 π mm.mrad
Turn on/turn off time by ion source (20% to 80%)	15 µs
Transit time from ion source to patient	45 µs
Turn off time by RF interlocks	10 ms
Turn off time by mechanical beam stopper	600 ms
External magnet diameter	434 cm
Total magnet height	210 cm
Total weight	220 tons
Average Magnetic Field at center / valley / extraction	1.76 T / 0.9T / 2.188 T
Accelerating Voltage Frequency	106.1 MHz

Proton Therapy System – Beam Transport Line

1. Cyclotron with Energy Selection System (ESS)
2. Beam Transport System (BTS)
3. Beam Entry in GTR1 and GTR3

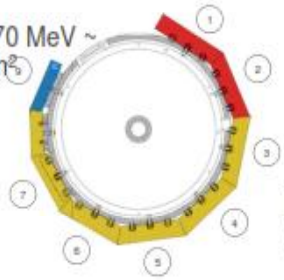
Proton Therapy System – Beam Monitoring

Beam Production System (C230)

- 230 MeV Fixed Energy;
- Isochrononous Cyclotron;
- Central region extracts protons from the Ion Source into the median plane of the Cyclo where the protons are accelerated to the required energy

Energy Selection System: Degrader

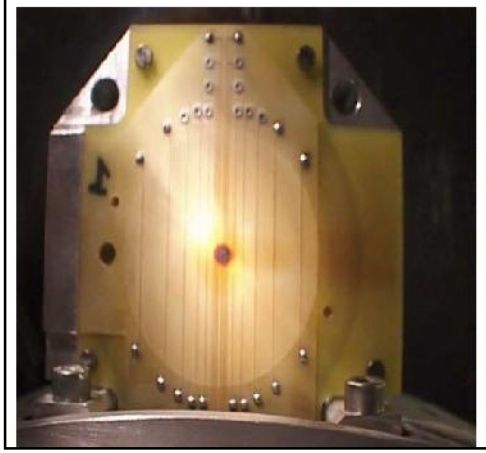
- Energy of protons out of C230: 230 MeV ~ Range 32g/cm^2
- Degrader:
  - Variable thickness block with of different materials (continuous selection of Energy)
  - Reduction down to 100/70 MeV ~ Range 7.7g/cm^2 /4.1g/cm^2



Energy Selection System (ESS)

Beam Profile Monitor

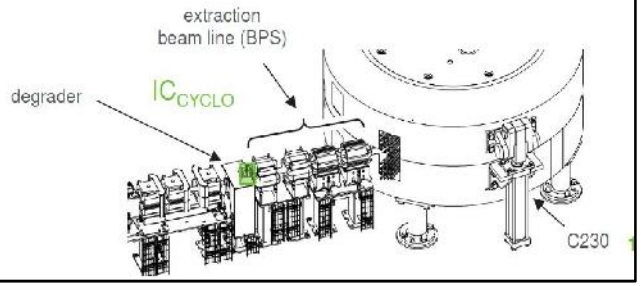
example: BPM on a straight line (telescope)



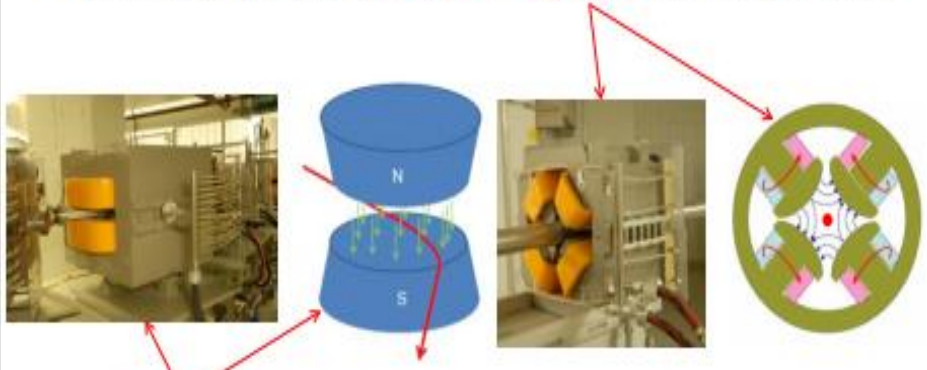
Proton Therapy System – Beam Delivery System

Ionization chambers in Proteus® PLUS

- There are 4 Ionization chambers in a Proteus® PLUS with a DN:
  - IC_{CYCLO} 05.21.33.0000 – end of the extraction beam line – 3 integrals, measure the beam current at the output of BPS
  - IC1 Wired 05.38.57.0000 – entrance of BDS – X & Y strips (12 each)
  - IC2-3 PBS Dedicated 05.38.17.0000 – exit of BDS – X & Y strips (64 each) + 2 integrals

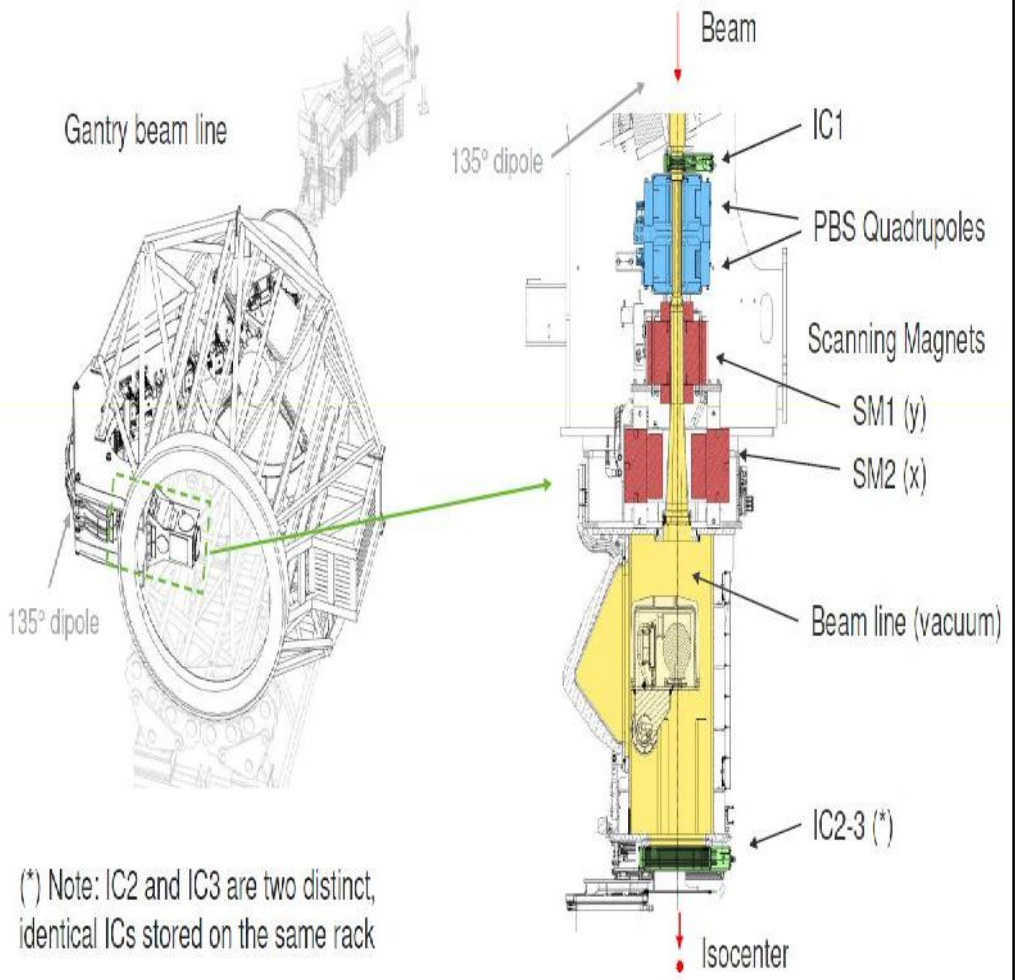


- The magnets are either quadrupole magnets which focus the beam.



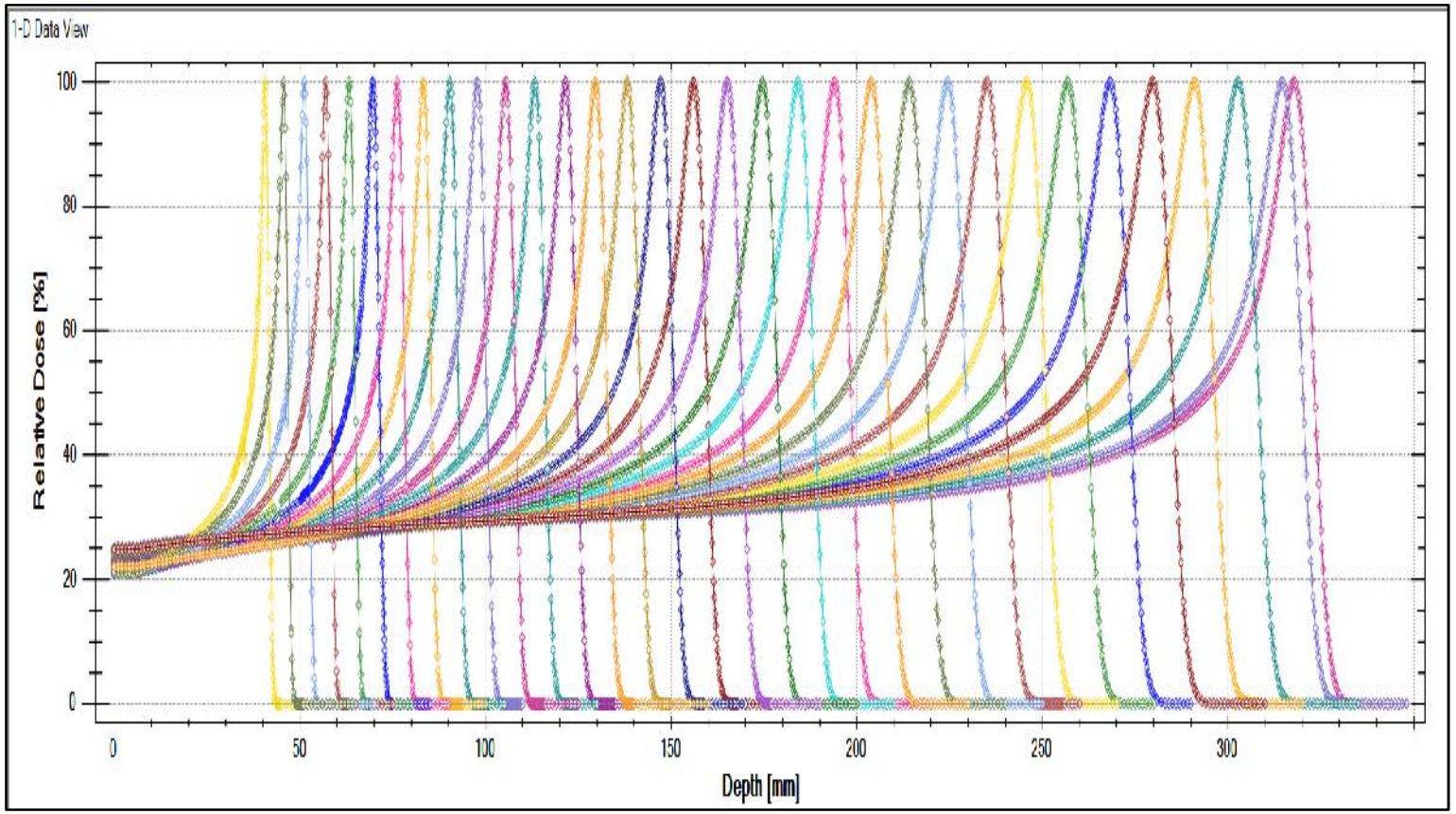
- Or dipole magnets which bend the beam

Beam Delivery System (BDS) - PBS Dedicated Nozzle



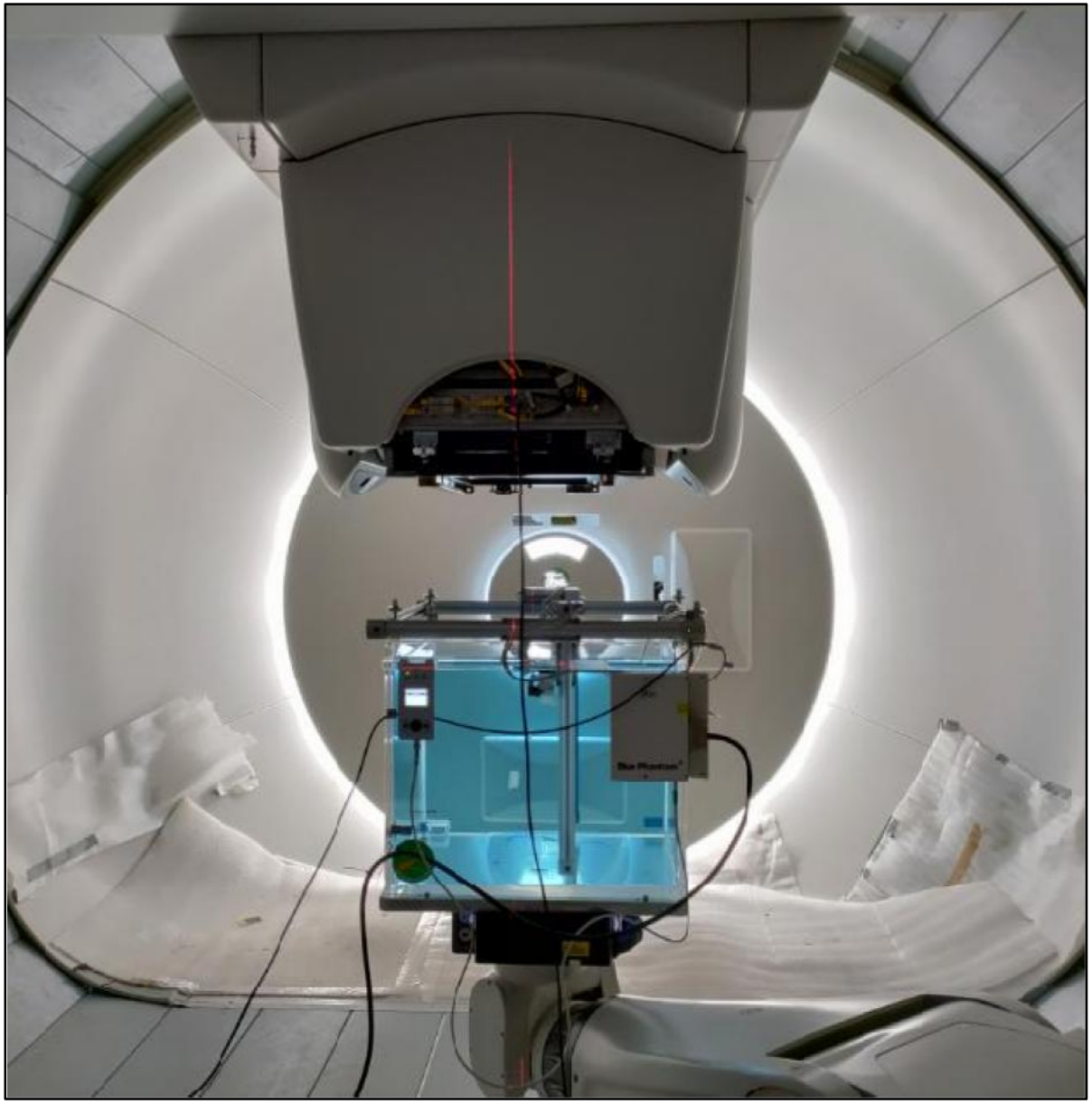
Proton Therapy – Energy/Range

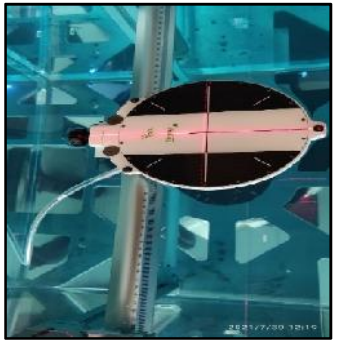
- **Lower energy, less penetrating beams have sharper Bragg peaks than higher energy beams. This phenomenon known as range straggling which increases with depth of the beam penetration.**



Integrated Depth Dose (IDD)

Proton Therapy – Energy/Range

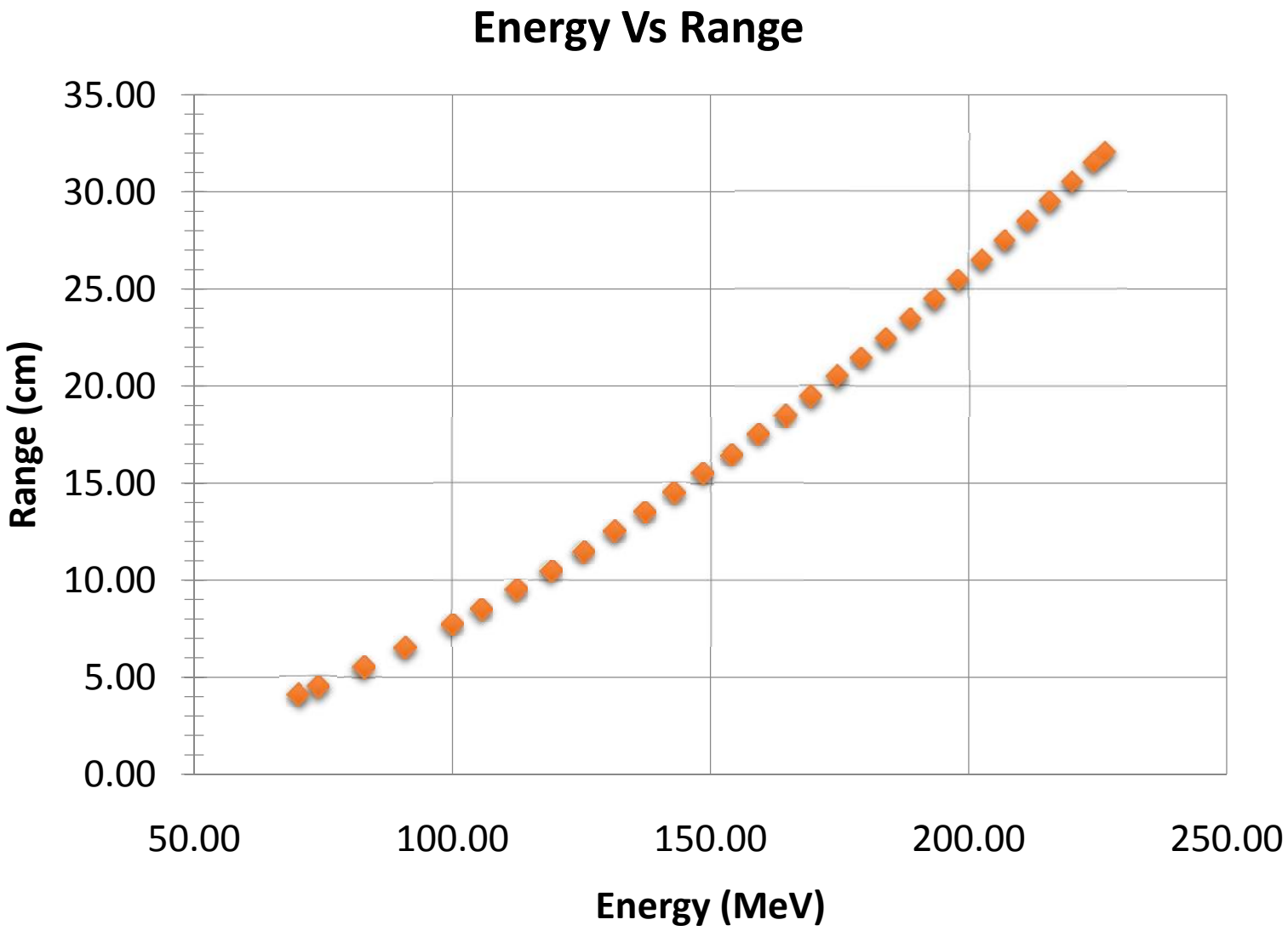




Stingray Ion chamber

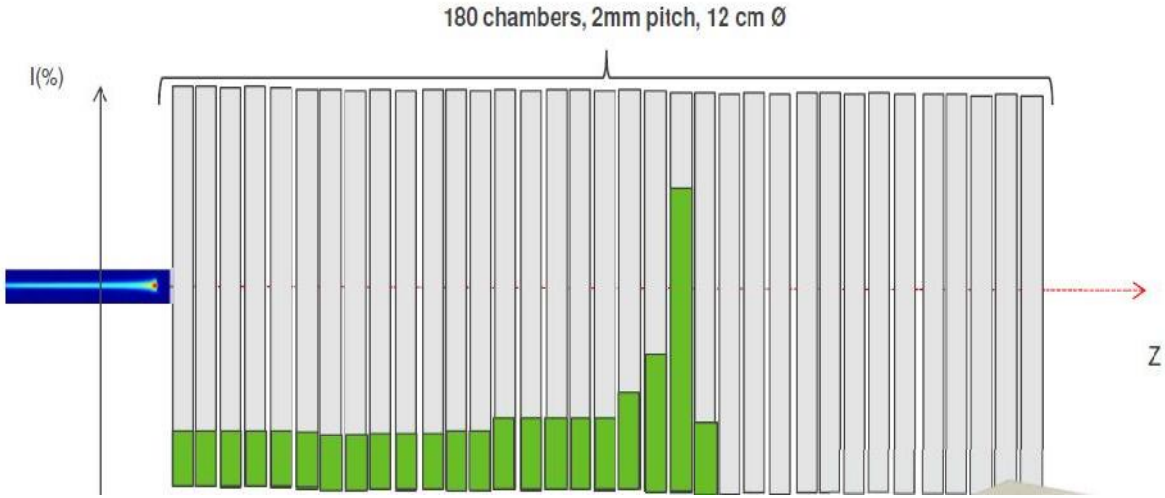
Proton Therapy – Energy/Range

Energy (MeV)	Range (cm)
70.18	4.10
73.92	4.50
82.69	5.50
90.80	6.50
100.01	7.72
105.58	8.50
112.42	9.50
118.97	10.50
125.26	11.50
131.34	12.50
137.23	13.50
142.94	14.50
148.50	15.50
153.91	16.50
159.20	17.50
164.37	18.50
169.44	19.50
174.40	20.50
179.27	21.50
184.05	22.50
188.76	23.50
193.39	24.50
197.94	25.50
202.43	26.50
206.86	27.50
211.23	28.50
215.54	29.50
219.79	30.50
224.00	31.50
226.08	32.00



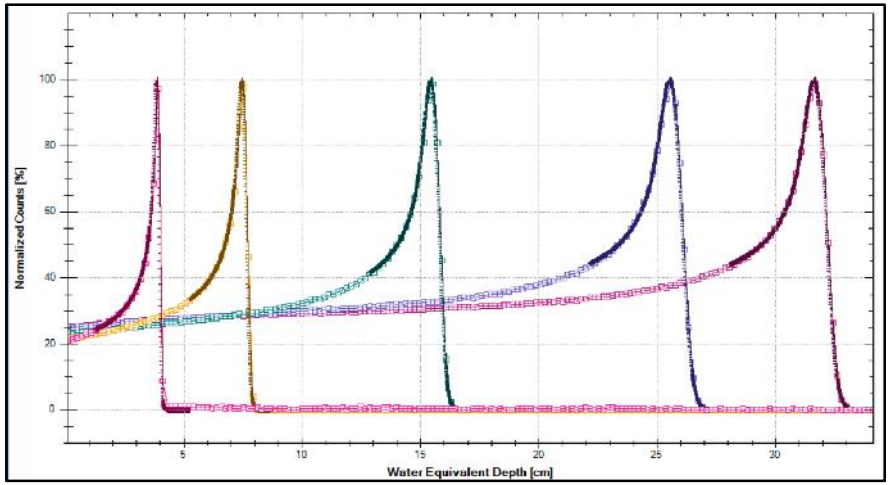
Proton Therapy – Energy/Range Verification

Giraffe

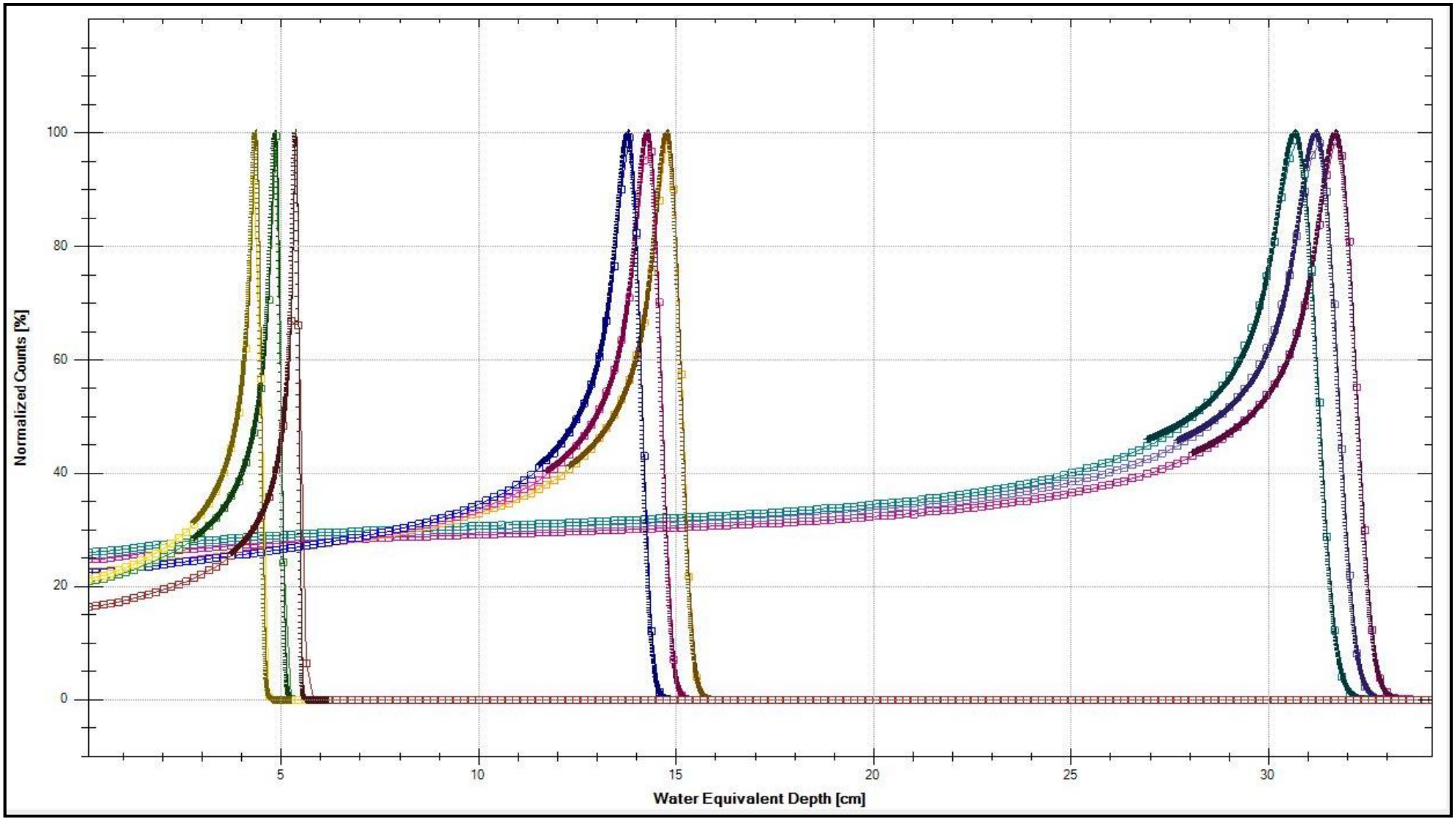


Technical highlights

- **Large electrode Ø12cm for spot beam delivery**;
- No reference chamber necessary;
- 180 chambers with 2 mm pitch;
- Range shifter for 1mm resolution;
- WE material;
- Proton Beams Energy up to 230MeV

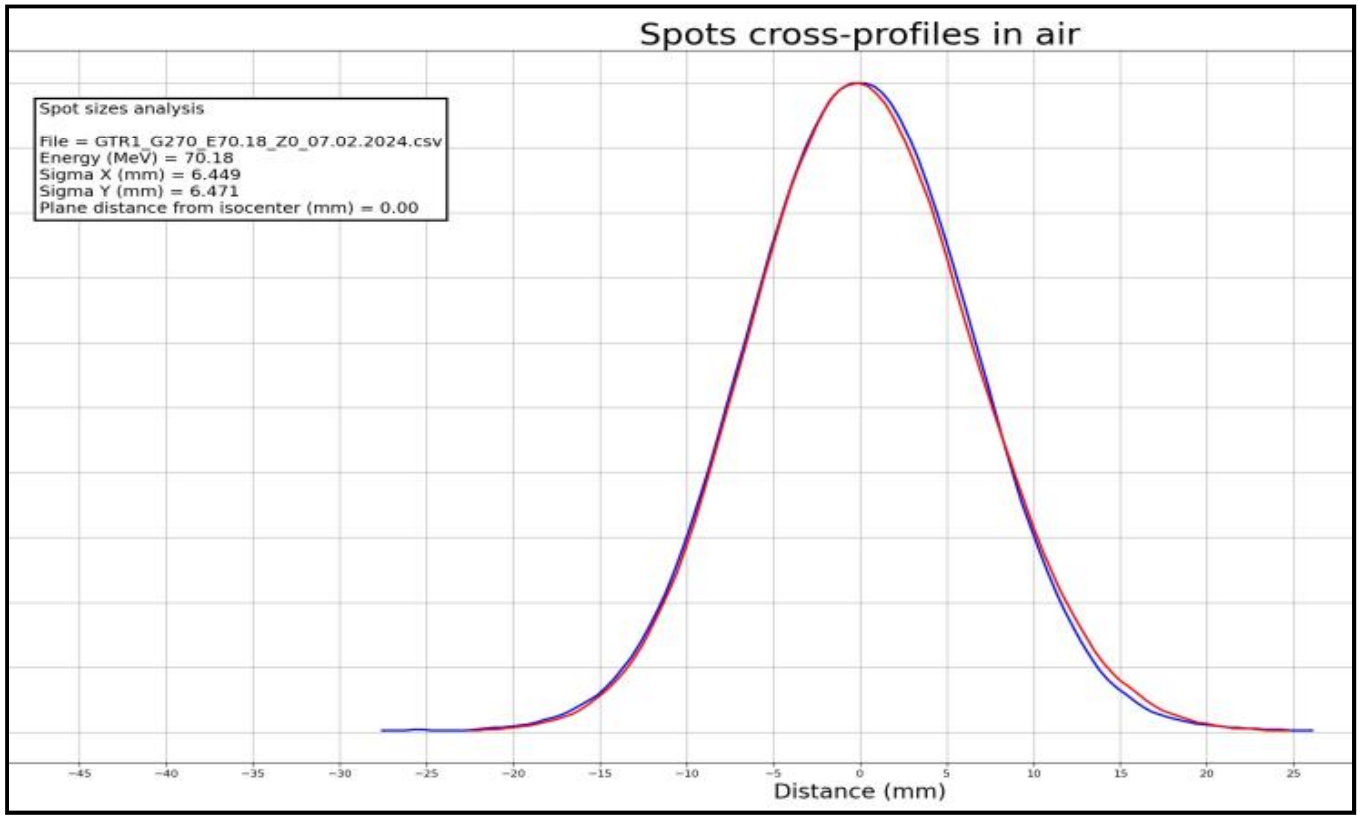


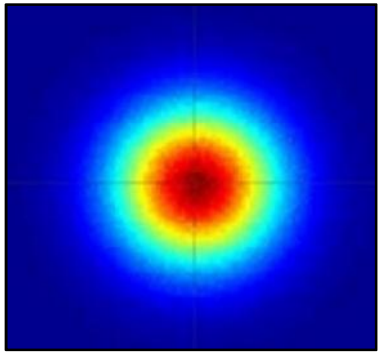
Proton Therapy – Range Pull-back accuracy

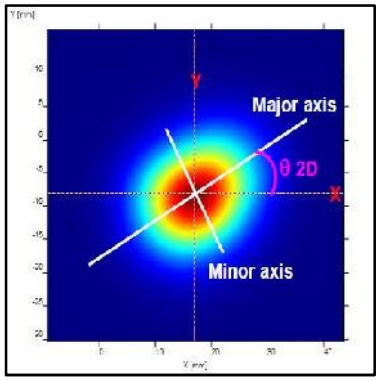


Proton Therapy – Spot Size

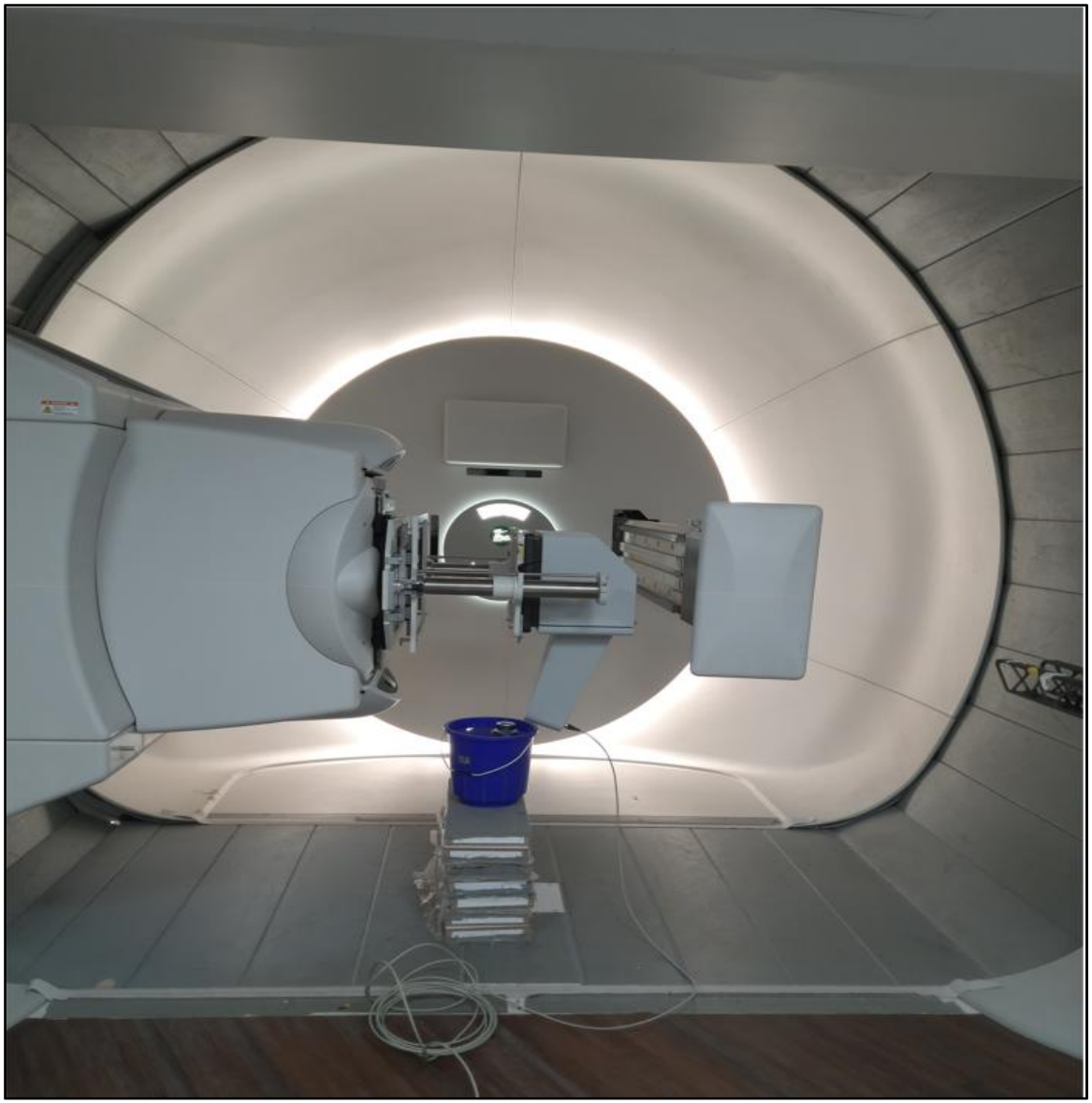
- **2D Spot profile in air and it is a function of distance along center axis (CAX).**
- **2D Gaussian Function**
- **Full Width Half Maximum (FWHM) = 2.355 * Spot Size**

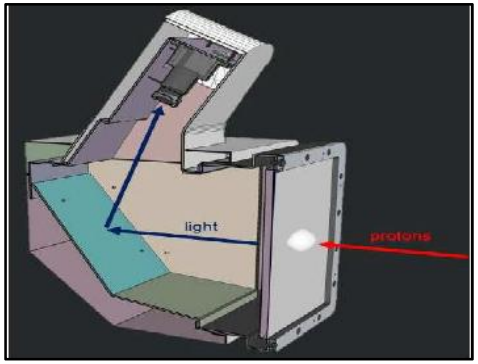






Proton Therapy – Spot Size

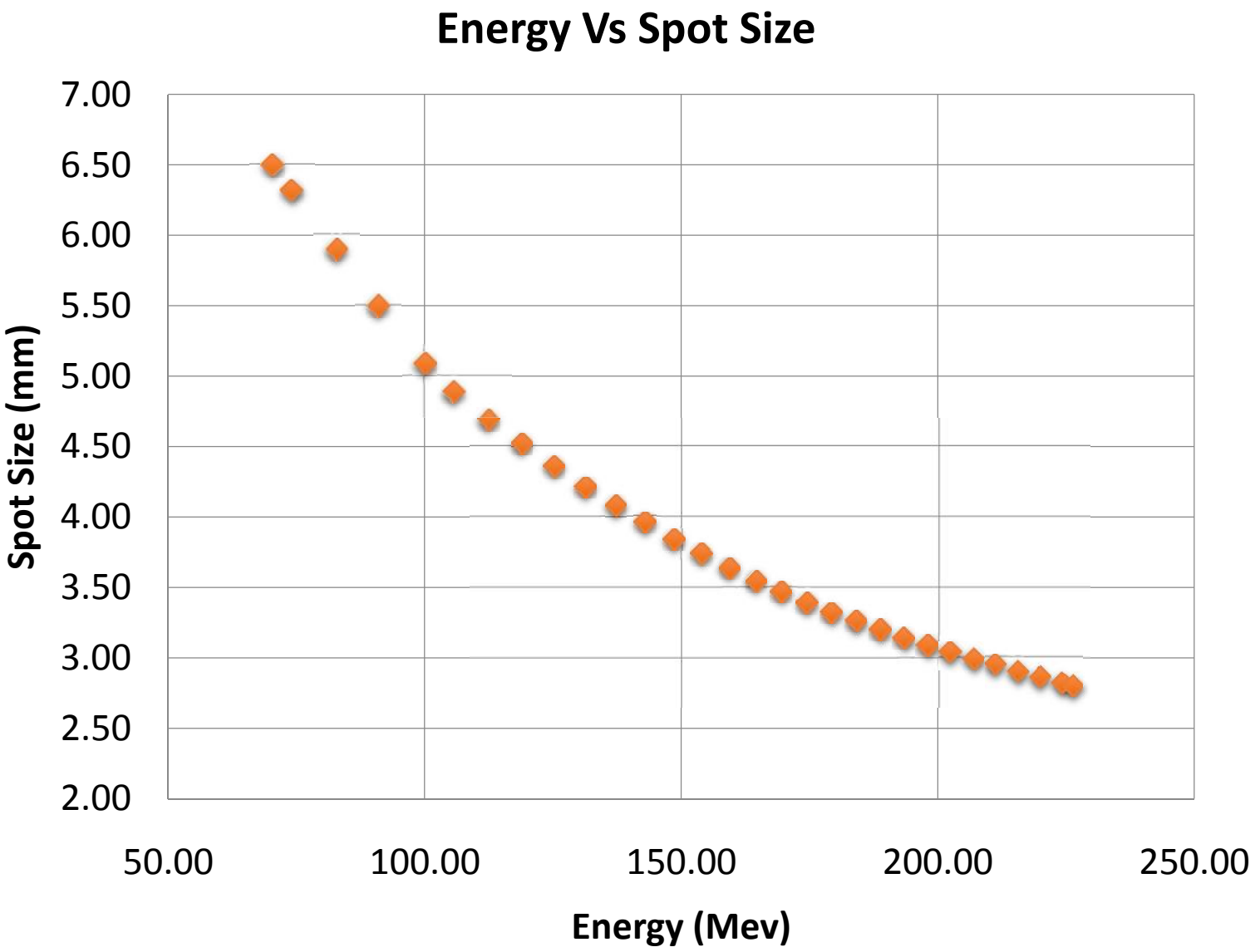




Lynx

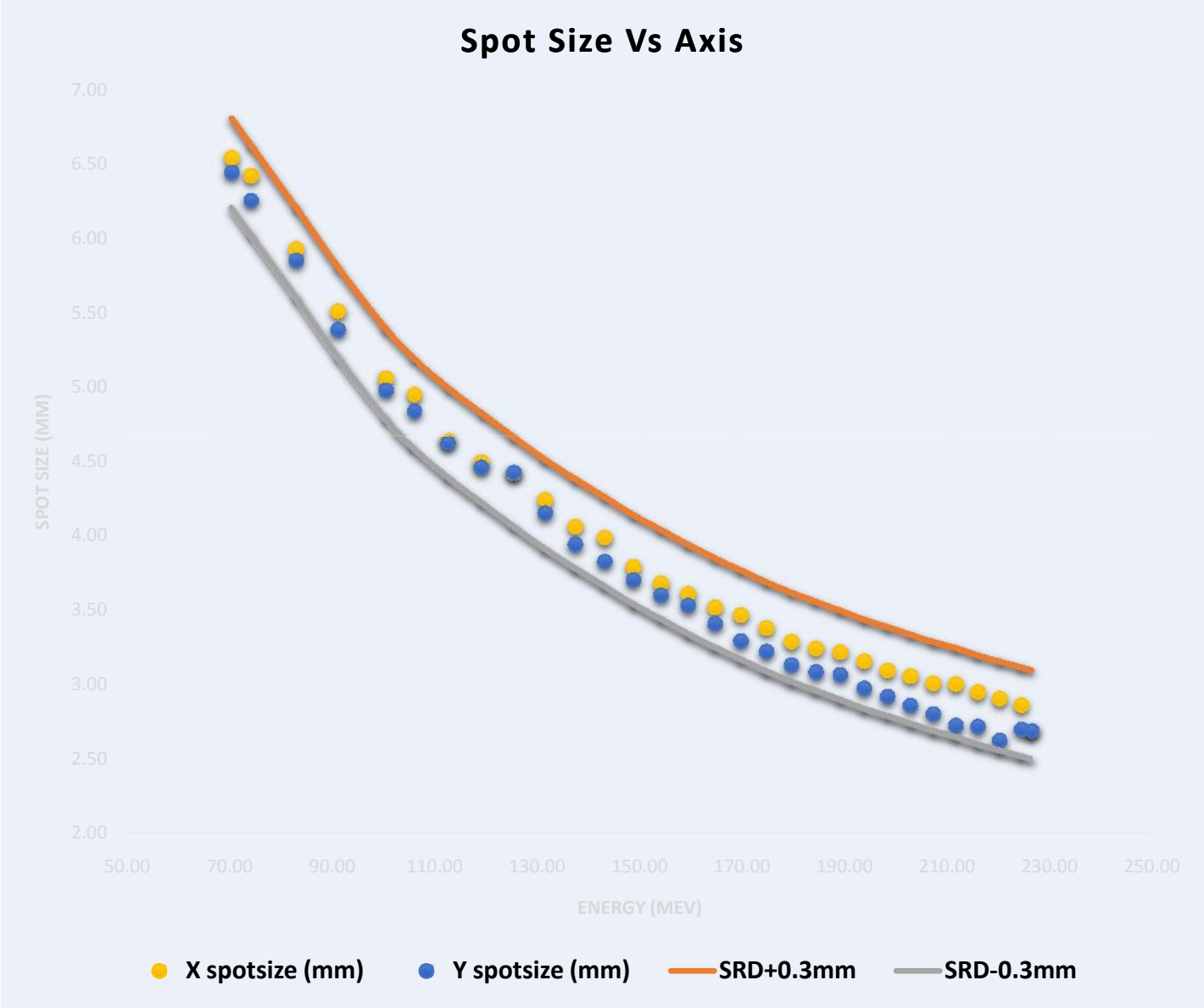
- Scintillation screen (Gadolinium based)
- CCD camera , sampling of 7 images/sec
- Resolution: 0.5 mm
- Field size: 30x30 cm^2
- Weight 10Kg
- Export in .dcm or .ilx
- Ethernet connection
- Nozzle mount (holder for IBA nozzle) or on patient table

Proton Therapy – Spot Size



Energy (MeV)	Baseline Spot size (mm)
70.18	6.50
73.92	6.32
82.69	5.90
90.80	5.50
100.01	5.09
105.58	4.89
112.42	4.69
118.97	4.52
125.26	4.36
131.34	4.21
137.23	4.08
142.94	3.96
148.50	3.84
153.91	3.74
159.20	3.64
164.37	3.55
169.44	3.47
174.40	3.39
179.27	3.32
184.05	3.26
188.76	3.20
193.39	3.14
197.94	3.09
202.43	3.04
206.86	2.99
211.23	2.95
215.54	2.90
219.79	2.86
224.00	2.82
226.08	2.80

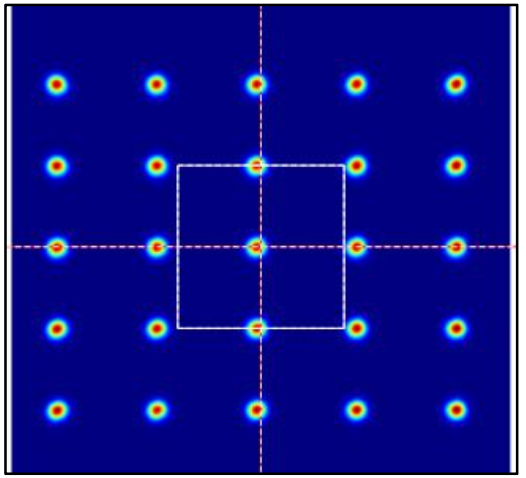
Proton Therapy – Spot Size



Energy (MeV)	X spotsize (mm)	Y spotsize (mm)
70.18	6.54	6.44
73.92	6.42	6.25
82.69	5.93	5.85
90.80	5.51	5.39
100.01	5.06	4.98
105.58	4.95	4.84
112.42	4.64	4.62
118.97	4.50	4.46
125.26	4.42	4.42
131.34	4.24	4.15
137.23	4.06	3.94
142.94	3.99	3.83
148.50	3.80	3.71
153.91	3.68	3.60
159.20	3.61	3.53
164.37	3.52	3.41
169.44	3.47	3.30
174.40	3.39	3.23
179.27	3.29	3.14
184.05	3.25	3.09
188.76	3.22	3.07
193.39	3.16	2.98
197.94	3.10	2.93
202.43	3.06	2.87
206.86	3.02	2.81
211.23	3.01	2.73
215.54	2.96	2.73
219.79	2.91	2.63
224.00	2.87	2.71
226.08	2.69	2.69

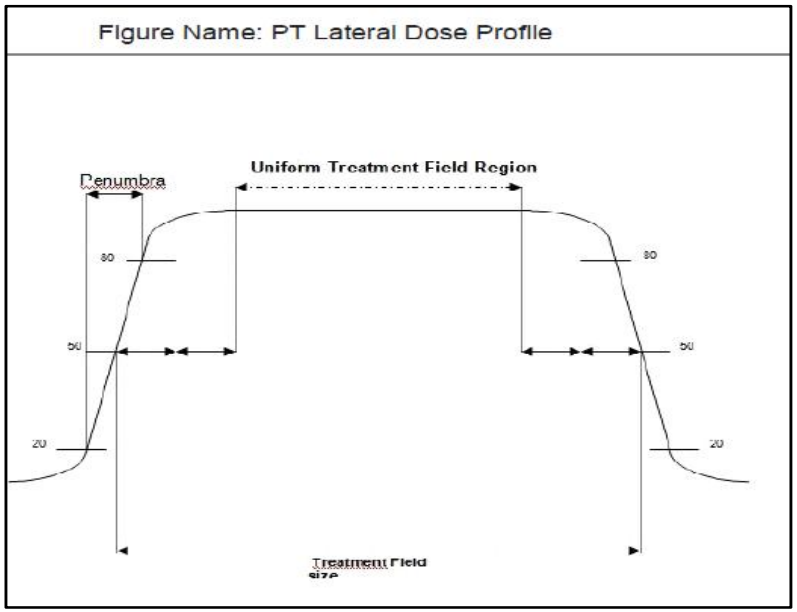
Proton Therapy – Spot Size

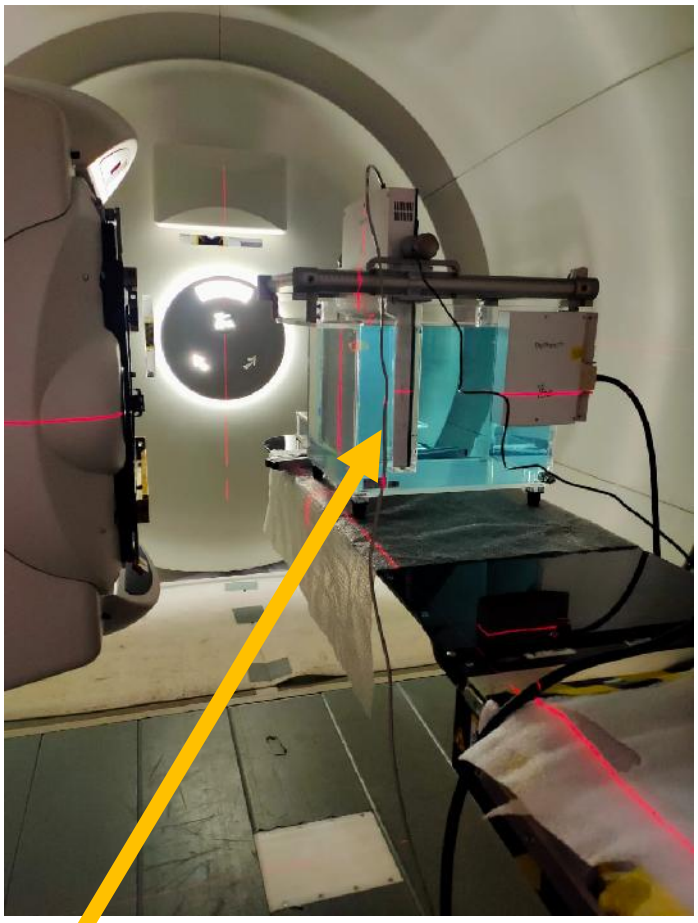
Test:	**Test 6.3.9 : Tolerance on spot size value as a function of Scanning amplitude compared to the central spot size value**
	Test 6.3.10: Centroid relative spot position accuracy in a layer
Equipment:	**Lynx 2D Scintilator Detector (Sr no. 71130) with myQA FastTrack software**
Method:	**The Lynx 2D detector attached to the gantry head. 25 spot pattern for each energy were irradiated at 12 gantry angles.**
	All 25 spots data analysed. The results were compared with the specified tolerance. The variation for each energy is recorded.
Tolerance:	**Test 6.3.9: 10% or ±0.5 mm**
	Test 6.3.10: ±10% of Sigma or ±1 mm



Gantry Angle (deg)	Energy (MeV)	Position	central spot size [mm]	Max. positional error in the layer (mm)	Max. position error compared to central spot size [%]	Max. spot size [mm]	Diff. between Max. spot size and central spot (mm)	Percentage difference of max. spot size (%)	Min. spot size [mm]	Diff. between Min. spot size and central spot (mm)	Percentage difference of min. spot size (%)	Max. centroid relative positional error in a layer (% diff.)	Max. centroid relative positional error in a layer (absolute diff.) (mm)	Max. spot size variation in the layer (% diff.)	Max. spot size variation in the layer (Absolute diff.) (mm)
G0	226.2	X	2.89	0.214	7.4%	2.89	0.01	0.24%	2.85	0.04	1.5%	9.3%	0.46	3.6%	0.24
		Y	2.73	0.214	7.8%	2.75	0.02	0.46%	2.72	0.01	0.6%				
	200	X	3.08	0.251	8.1%	3.09	0.01	0.25%	3.04	0.05	1.5%				
		Y	2.96	0.189	6.4%	2.99	0.03	1.00%	2.92	0.03	1.0%				
	150	X	3.82	0.356	**9.3%**	3.83	0.01	0.29%	3.75	0.07	1.8%				
		Y	4.02	0.170	4.2%	4.05	0.03	0.67%	3.97	0.06	1.4%				
	100	X	5.16	**0.465**	9.0%	5.21	0.05	0.97%	5.02	0.14	2.7%				
		Y	5.01	0.170	3.4%	5.02	0.02	0.31%	4.96	0.05	1.0%				
	70.18	X	6.74	0.381	5.7%	6.74	0.01	0.09%	6.50	**0.24**	**3.6%**				
		Y	6.52	0.310	4.8%	6.52	0.00	0.00%	6.42	0.10	1.6%				

Proton Therapy – SOBP



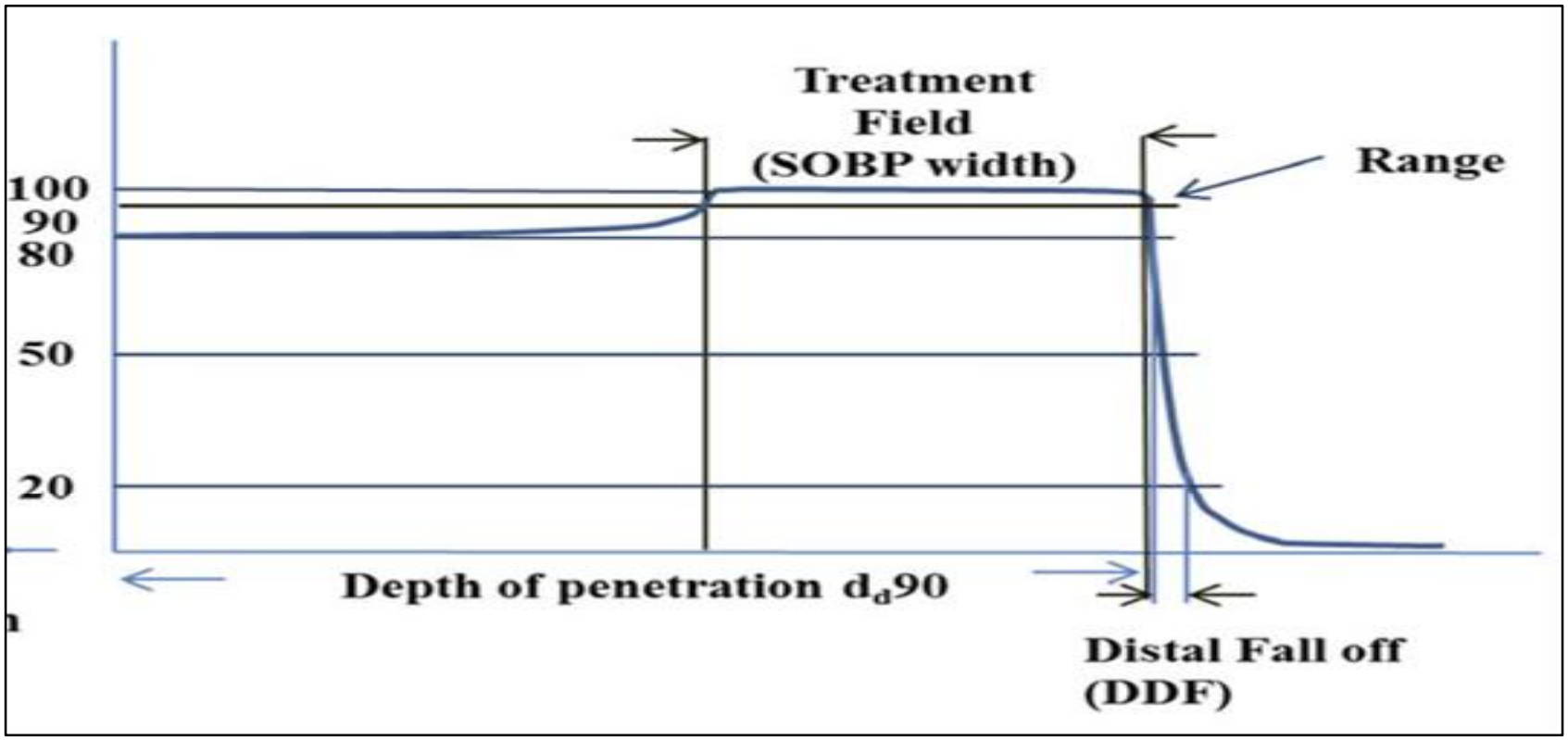


Uniformity = (Max-Min) / (Max + Min)

Tolerance : ± 3 %

Tool Used : DigiPhant with MatrixxPT

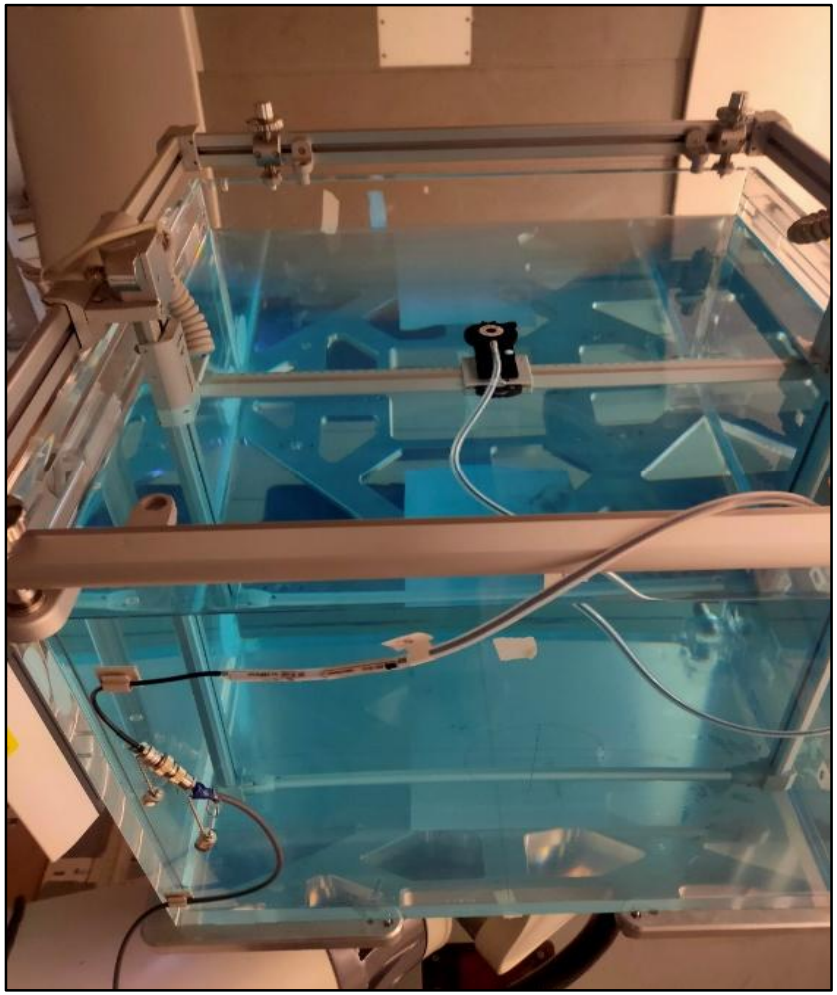
Proton Therapy – SOBP



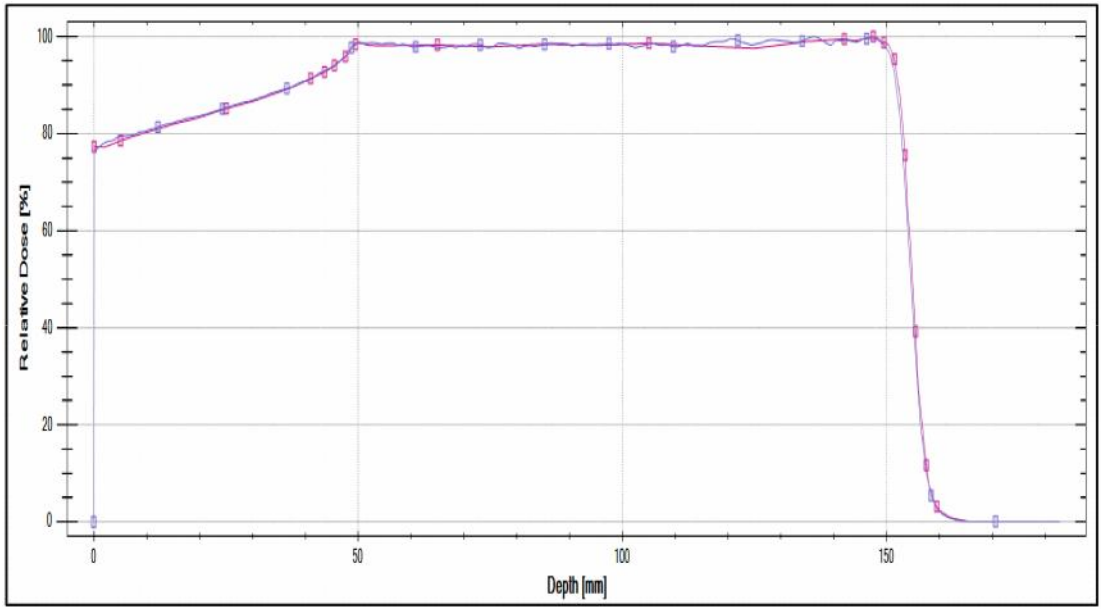
Cube Name	Measured Dose Max in central 80% of SOBP	Measured Dose Min in central 80% of SOBP	Uniformity (%)
Low Range	99.3	97.58	**0.87%**
Mid Range	99.73	99.01	0.36%
High Range	99.07	98.25	0.42%

Tolerance : ± 3 %

Proton Therapy – SOBP



RFA Setup



Low Range SOBP Analysis done by My QA Accept

Applications of Radiation

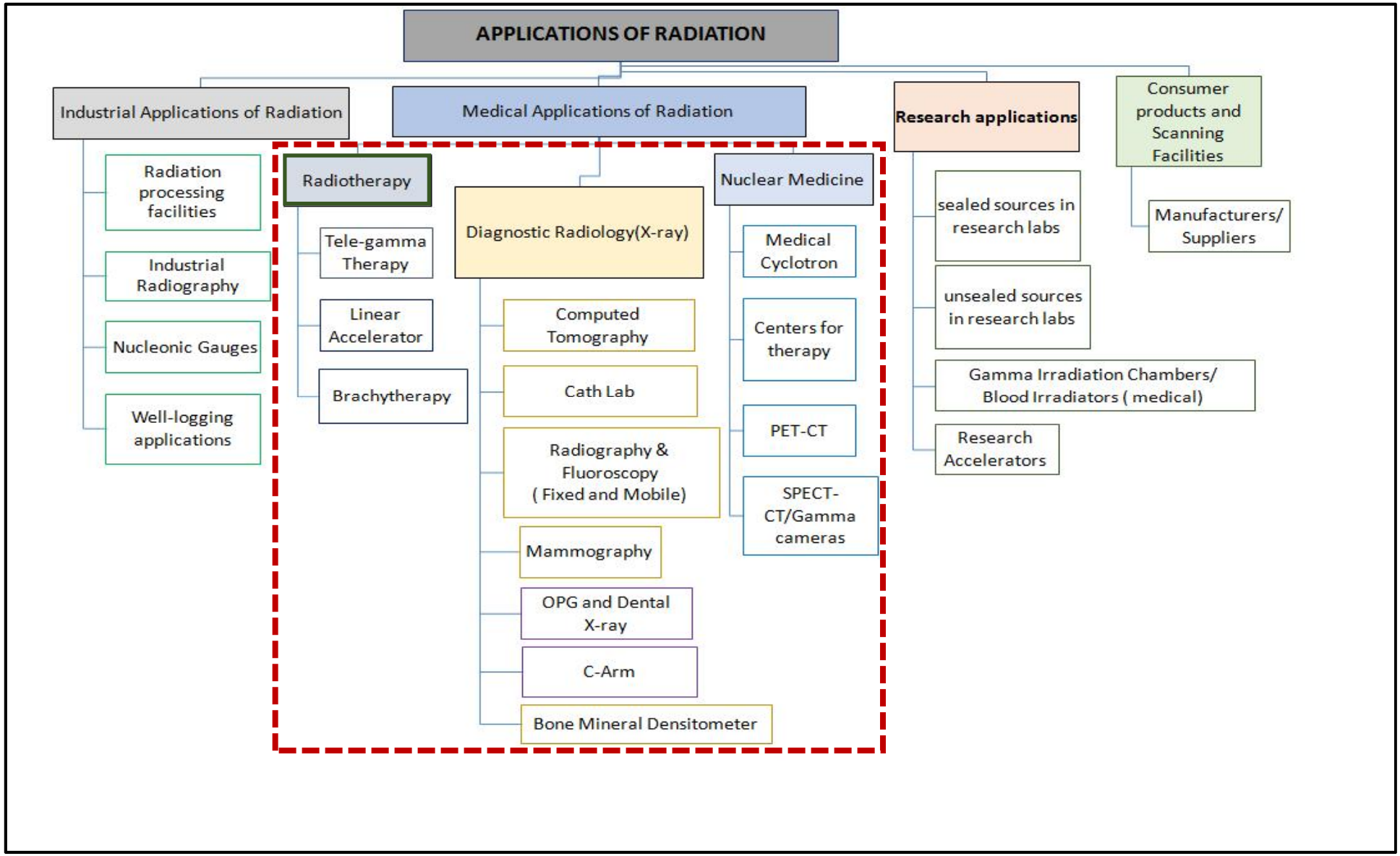


Image Source - www.aerb.gov.in

Basic Sciences – Applications

- **Physics – Radiation generation, detection and measurement.**
- **Biology – Radiation effects on living organisms.**
- **Chemistry – Chemical changes of matter.**
- **Mathematics – Computation and Simulations.**
- **Computers – Treatment Planning and Processing devices.**

Summary

- **Proton Therapy demands high precision and accuracy for its accurate dose delivery.**
- **The robust validations and routine quality assurance ensures the best quality treatments delivery to the patients.**
- **Continuous learning and adaption required for this advance and complex technology.**
- **The basic sciences study and its understanding are the building block of its use in any applications.**
- **The advance technical developments needs more skills adaption from future career point of view.**

Thank You