# Advances in Proton and Heavy Ion Treatment

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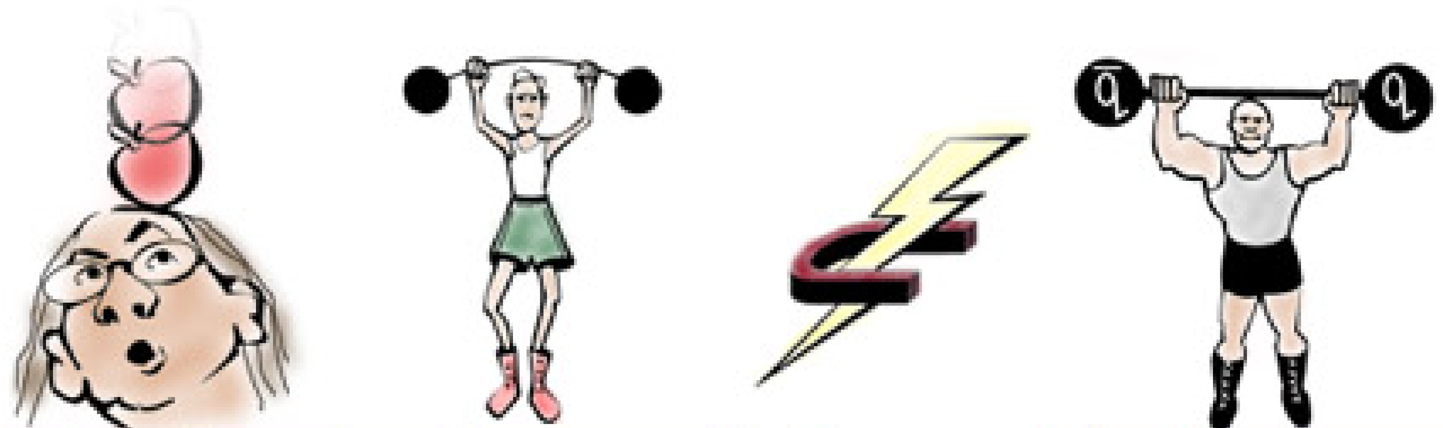
# Outlines

- Interactions in nature and particle classification
- Physics of Protons and Heavy Ions
- How does a cyclotron work?
- Monarch Cyclotron and OUHSC Cancer Center

# Interactions in Nature



| | Gravity | Weak (Electroweak) | Electromagnetic (Electroweak) | Strong |
|---|---|---|---|---|
| Carried By | Graviton (not yet observed) | $W^+$ $W^-$ $Z^0$ | Photon | Gluon |
| Acts on | All | Quarks and Leptons | Quarks and Charged Leptons and $W^+$ $W^-$ | Quarks and Gluons |

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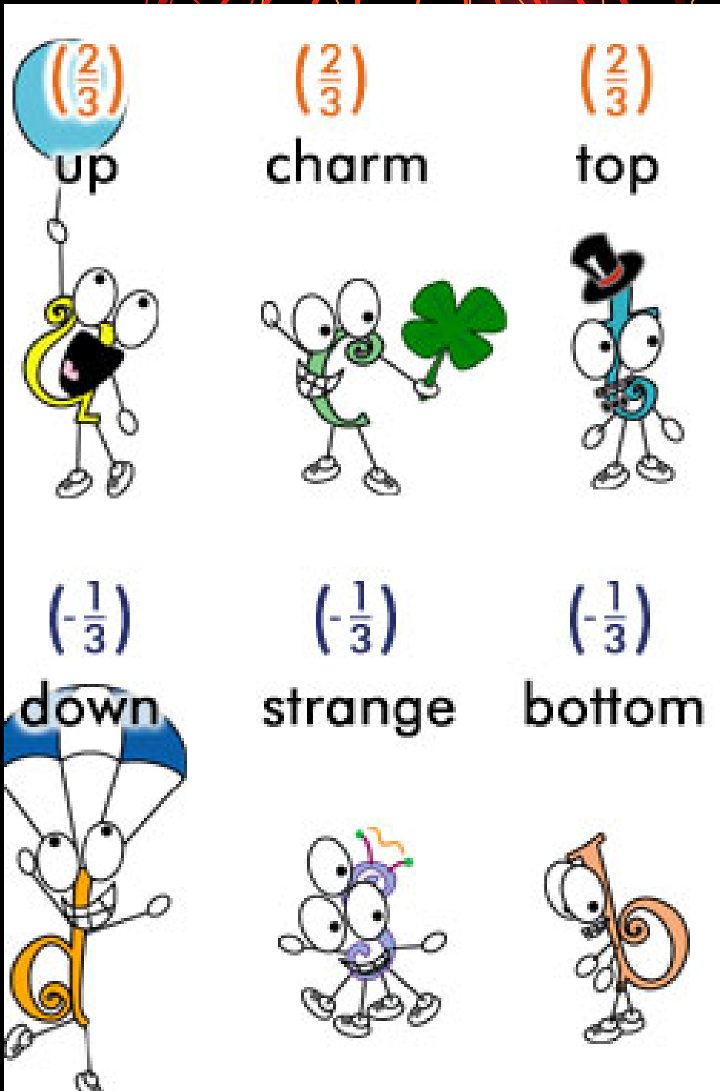
# Quarks and hadrons

There are 6 quarks and 6 anti quarks having fractional Electric charge

Composite particles made of quarks are hadrons

Proton Charge = 1



# Leptons

- The other type of matter particles are the **leptons**.

- There are six leptons, three of which have electrical charge and three of which do not. They appear to be point-like particles without internal structure. The best known lepton is the **electron** (e-).

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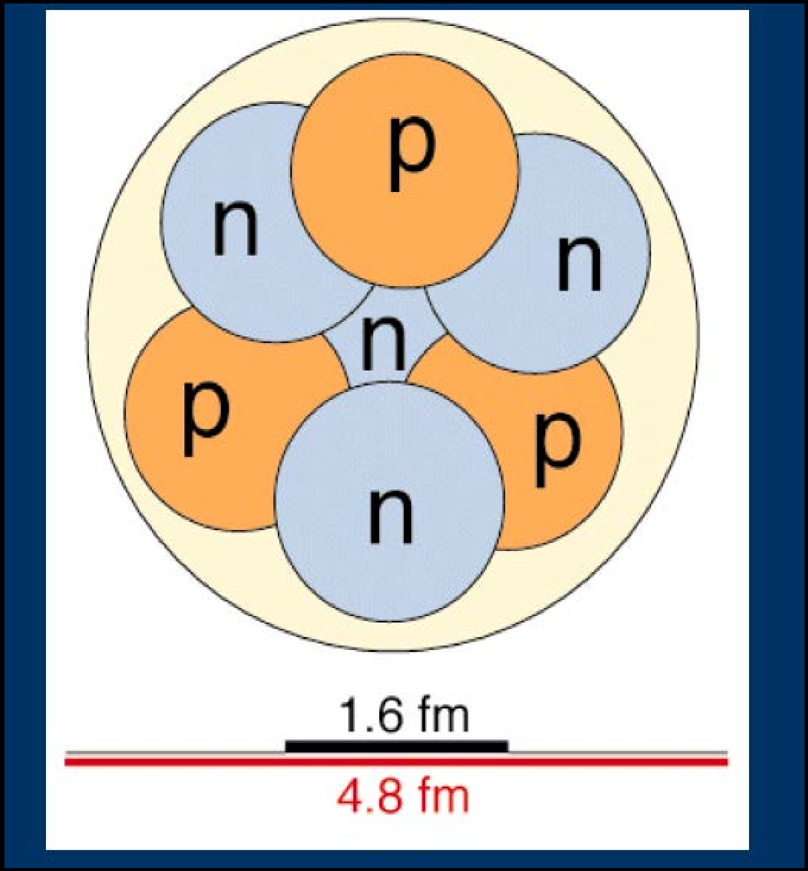
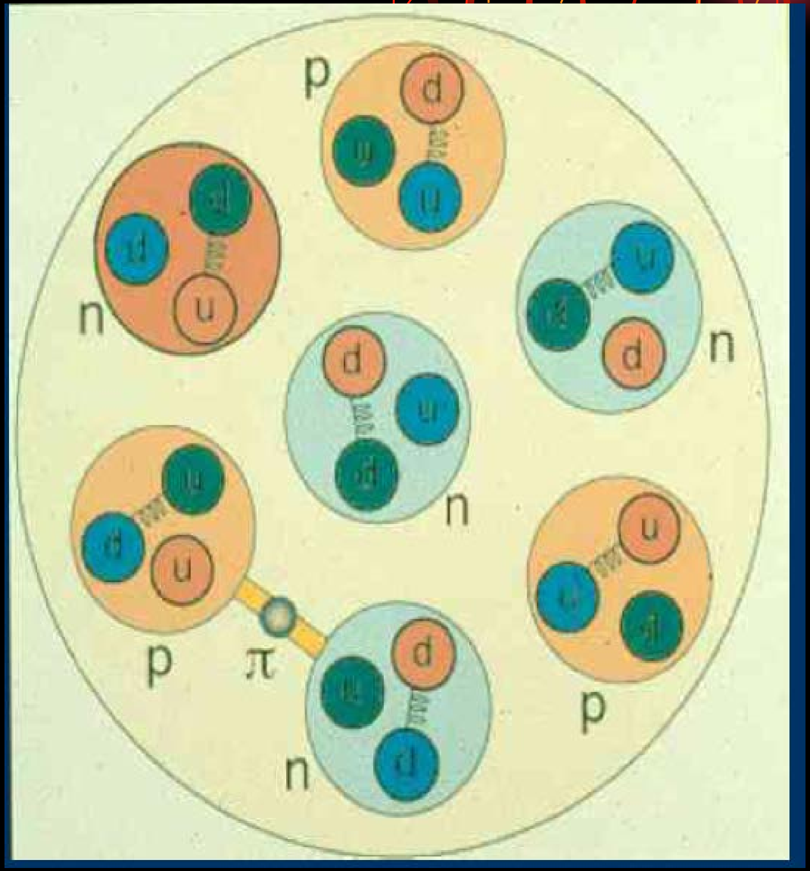
# Nucleus is made of neutrons and protons, when they are composite of quarks



# Hadron Therapy

- Beam of particles are made up of quarks and anti quarks

- Proton
- Neutron
- Pion
- Anti-proton
- Light and Heavy Ions

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# History of Protons and Heavy Ions

1919 Rutherford proposed existence of protons

1930 E. O. Lawrence built first Cyclotron

1946 Robert Wilson proposed proton therapy

1954 Tobias et al treated first patient with proton at LBL

1957 First patient was treated with helium ion at LBL

1961 Kjellberg et al treated patients with proton at HCL

1972 MGH received first NCI grant for proton studies at HCL

# History of Protons and Heavy Ions

1975 First patient was treated with neon ion at LBL

1991 First hospital-based proton facility at LLUMC

1992 Heavy Ion therapy program closed at LBL

1975 – 1992 433 patients were treated at LBL with neon ion

1994 Patient treatments with carbon ions at HIMAC, Japan

1996 Patient treatments with carbon ions at PSI, Switzerland

1997 Patient treatments with carbon ions at GSI, Germany

# History of Protons and Heavy Ions

<u>2012</u>

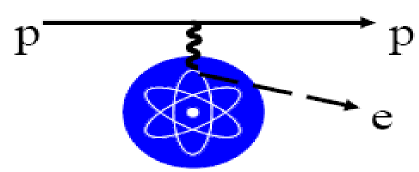
36 proton (12 in USA) and 6 carbon ion facilities worldwide treating patients; treated over 93000 patients with proton and over 10000 patients with carbon ion

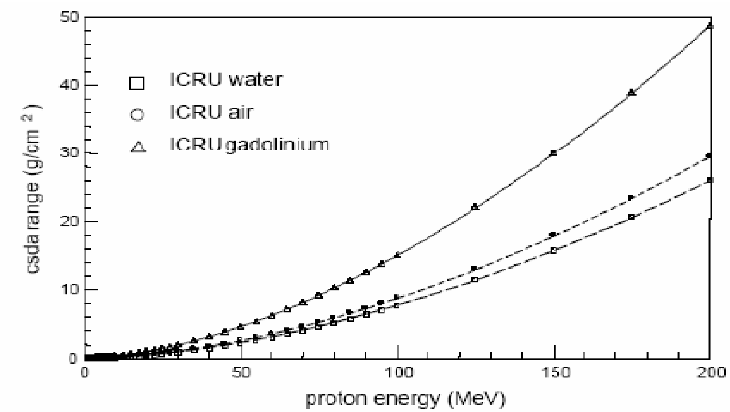
<u>2013</u>

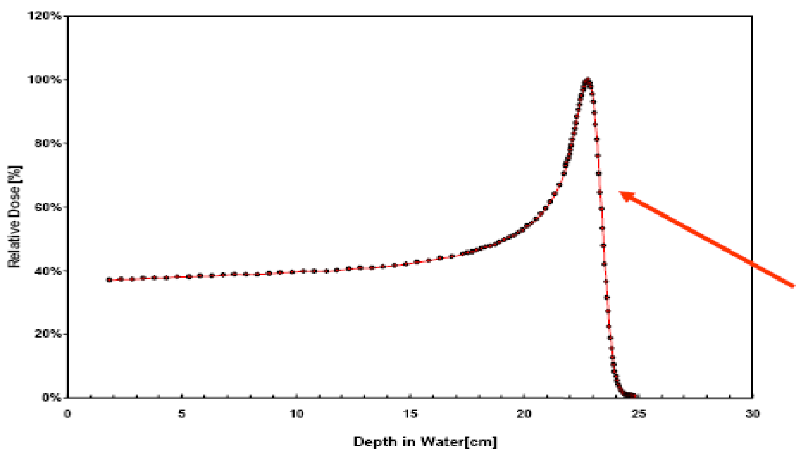
35 proton and 5 carbon ion facilities worldwide are currently being planned

# Proton Physics

## Electromagnetic energy loss of protons



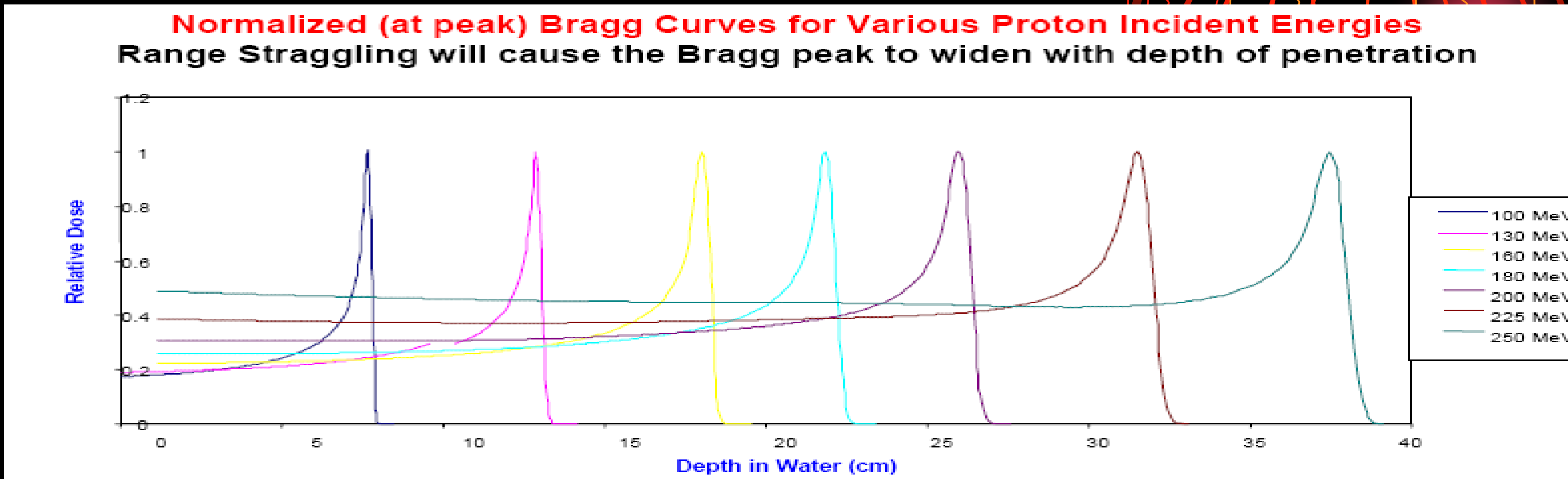



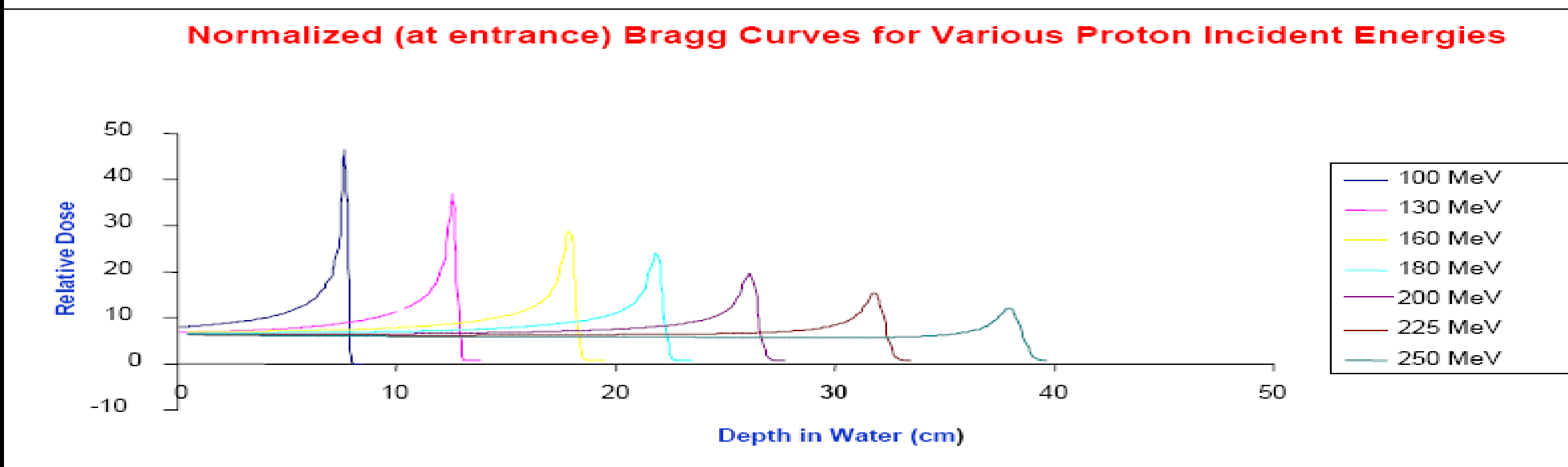

**Mass Electronic Stopping Power is the mean energy lost by protons in electronic collisions in traversing the distance dx in a material of density ρ.**

$$S/\rho = 1/\rho[dE/dx] \propto 1/v^2$$

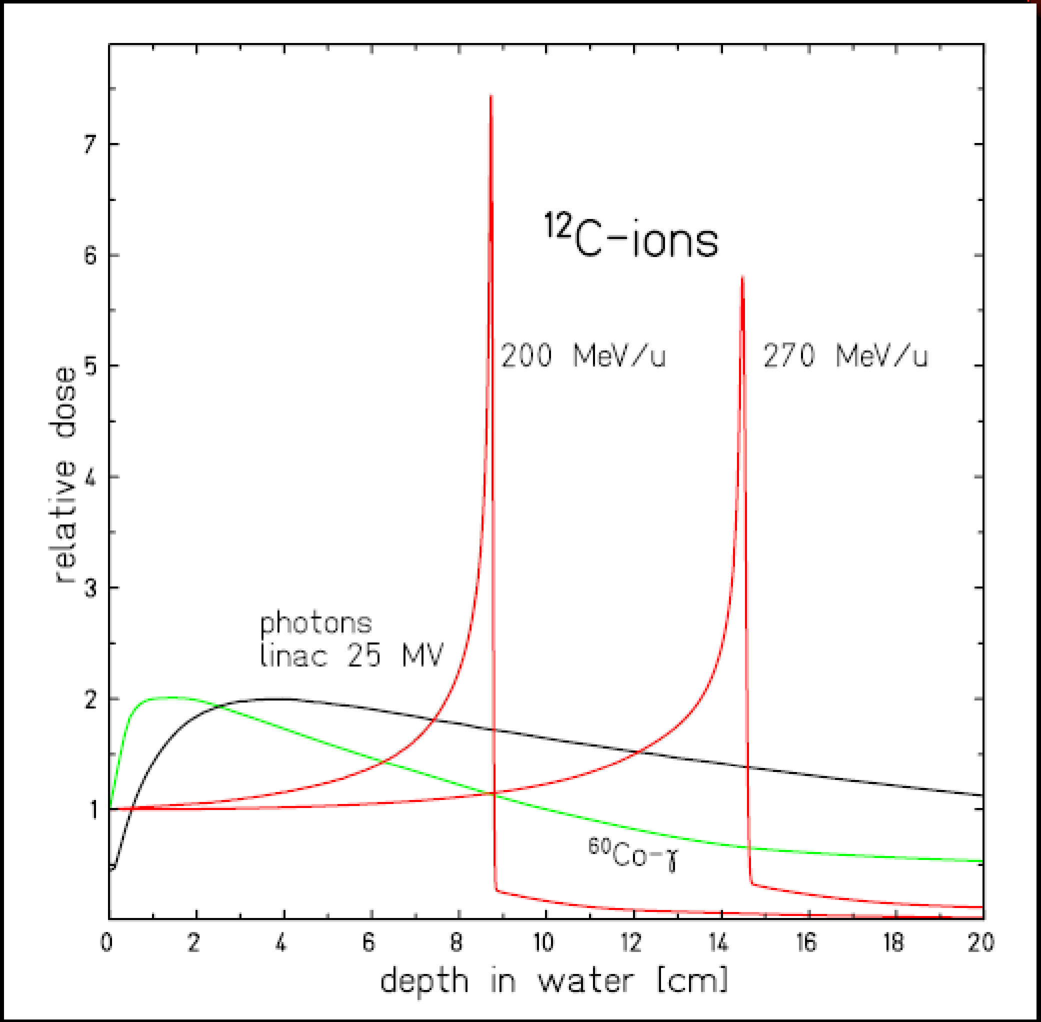
**Where v = proton velocity**

# Normalized Bragg peaks



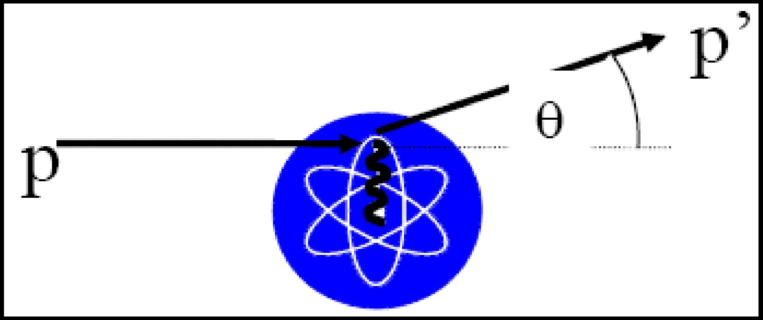



# Normalized Bragg peaks (carbon ions)



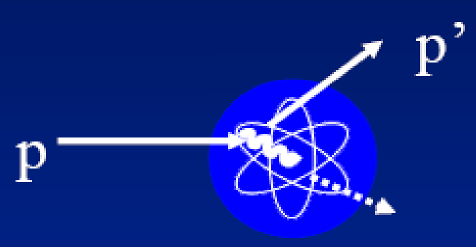

Schardt and Elsasser, 2010

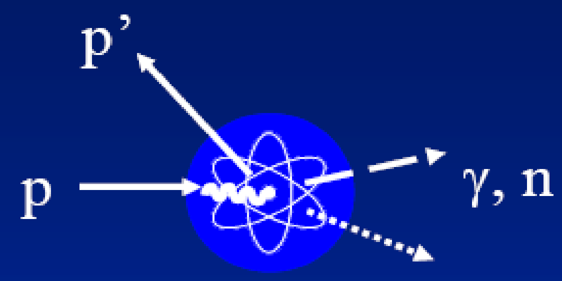
# Proton Physics (EM Interactions with proton)




Protons scatter due to elastic coulomb interactions with the target nuclei.

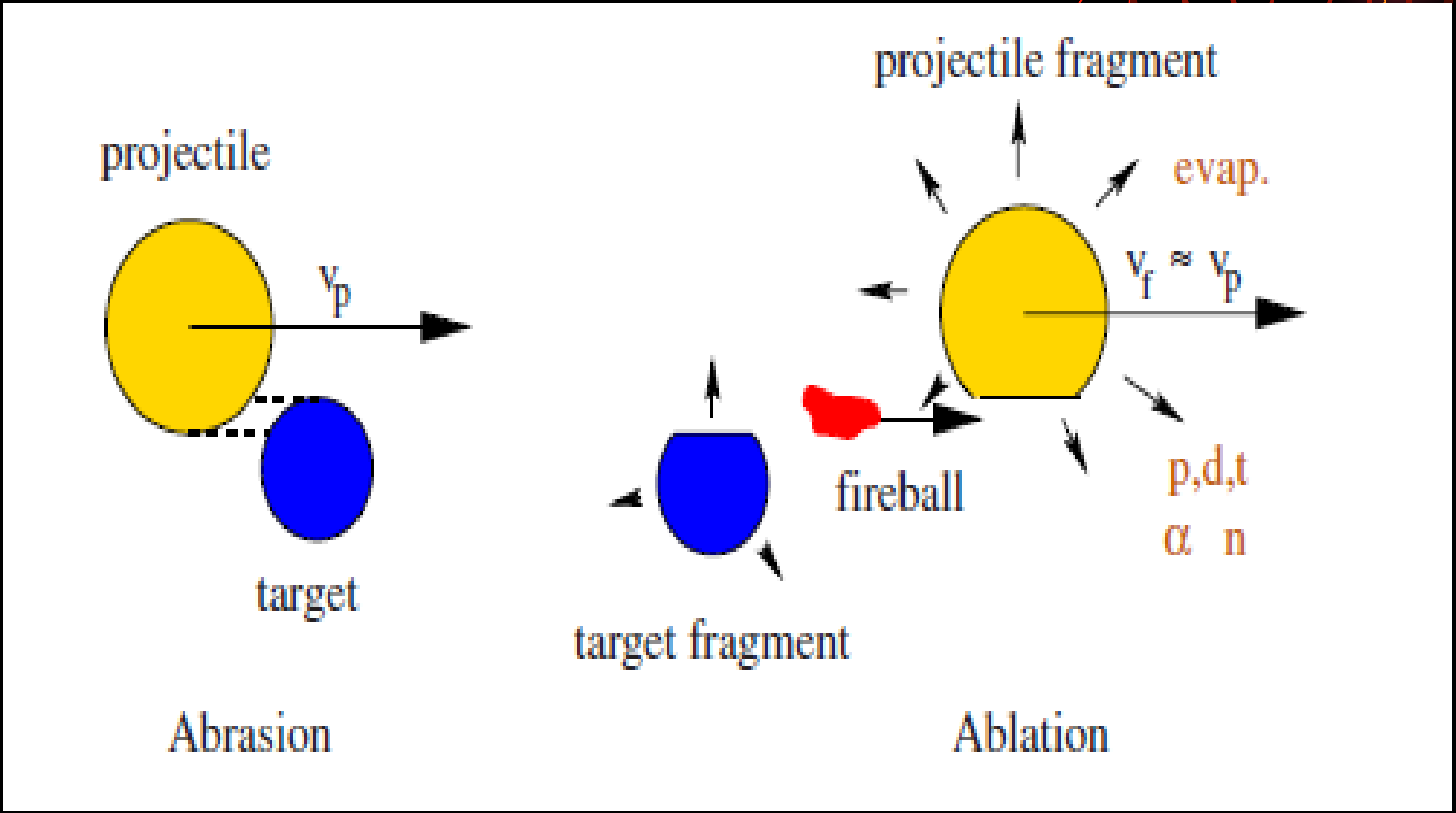
# Nuclear interactions of protons



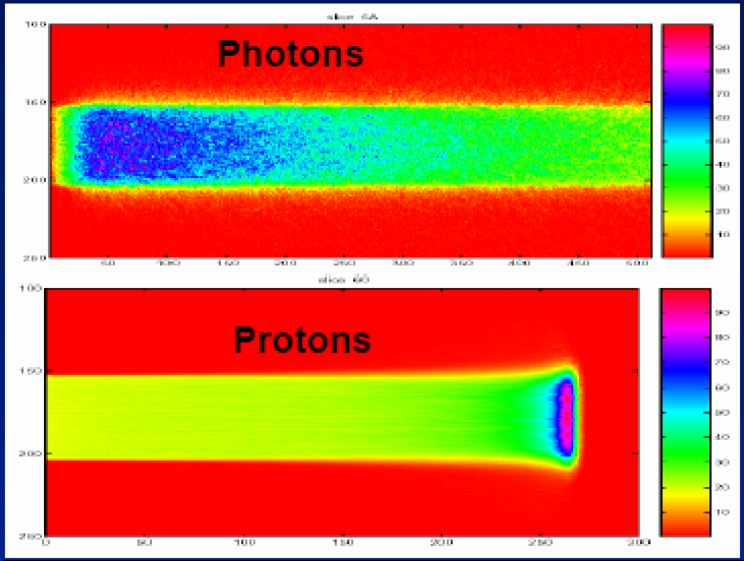

- A certain fraction of protons undergo nuclear interactions, mainly on $^{16}O$
- Nuclear interactions lead to secondary particles and thus to local and non-local dose deposition (neutrons!)
- In passive scattering systems neutrons are produced in the first and second scatterers, modulation wheel, aperture, range compensator in addition to those produced in the patient.

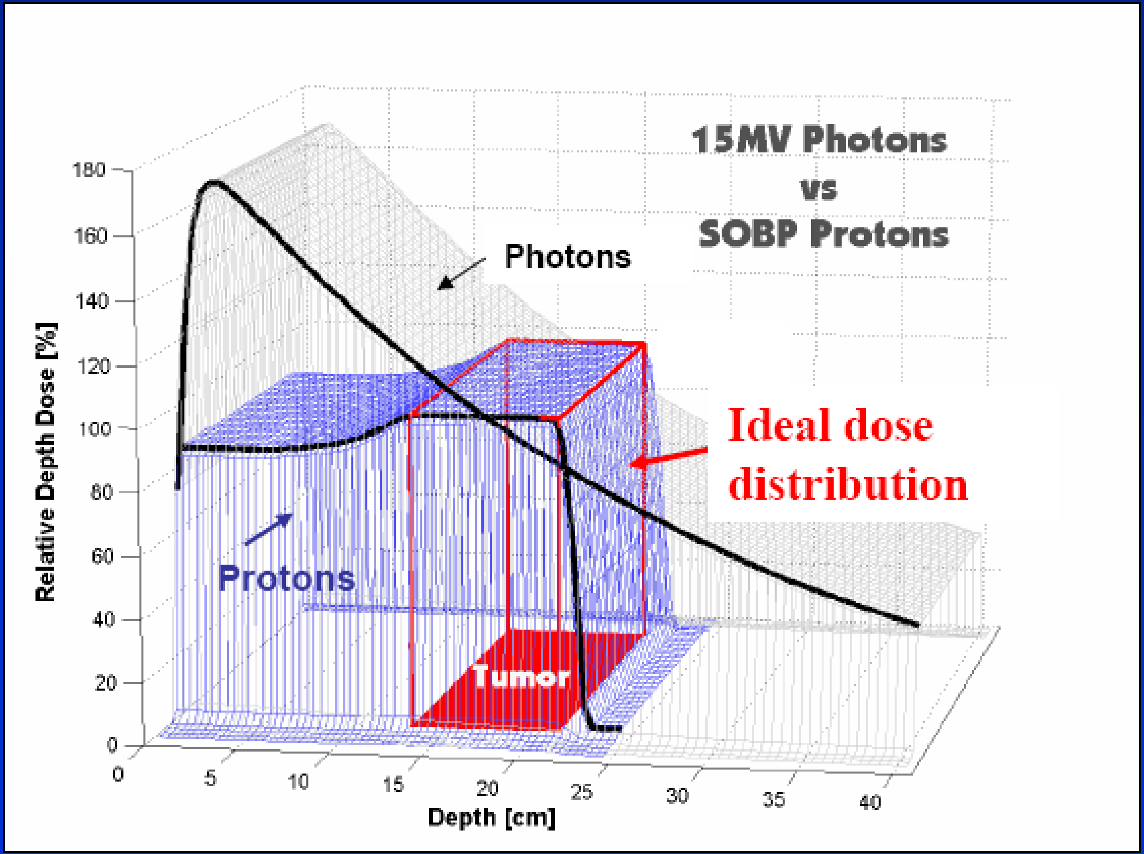
# Heavy ion Fragmantation




Schardt and Elsasser, 2010

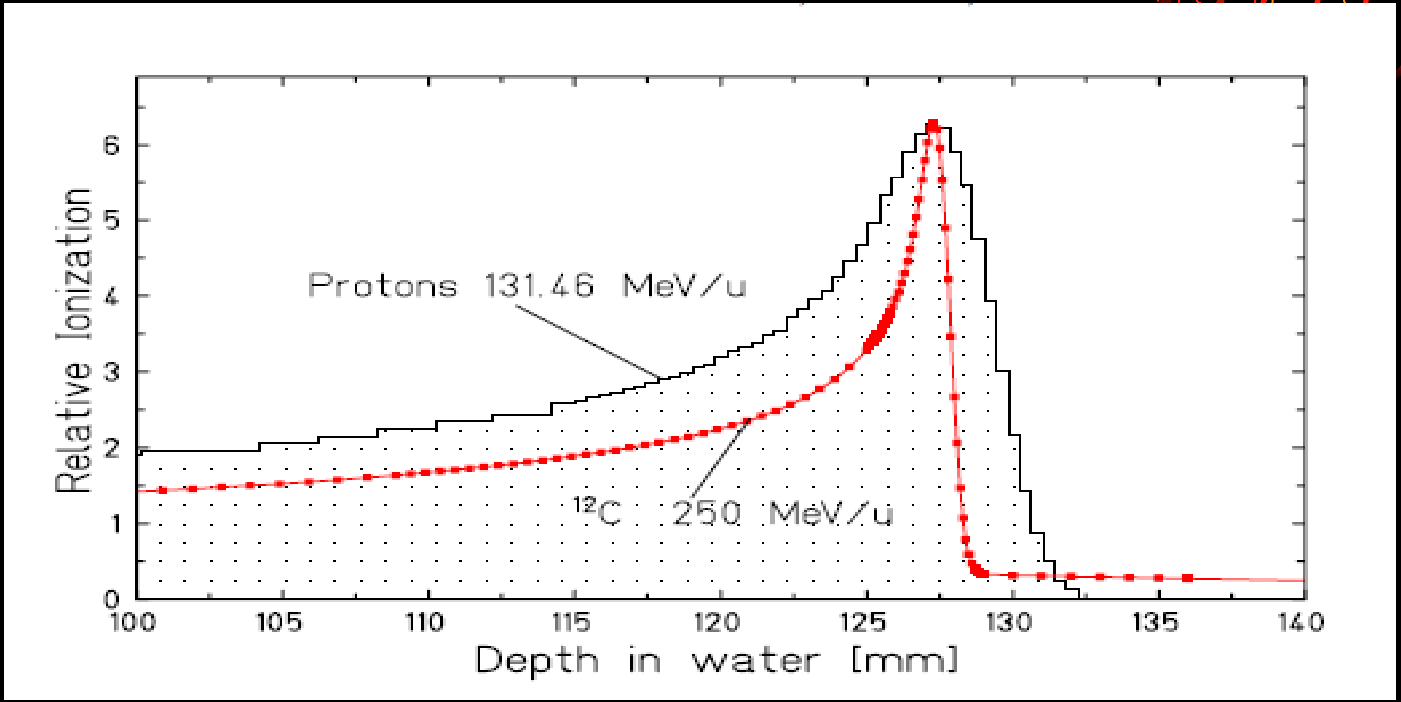
# Fundamental Things to Remember about Protons



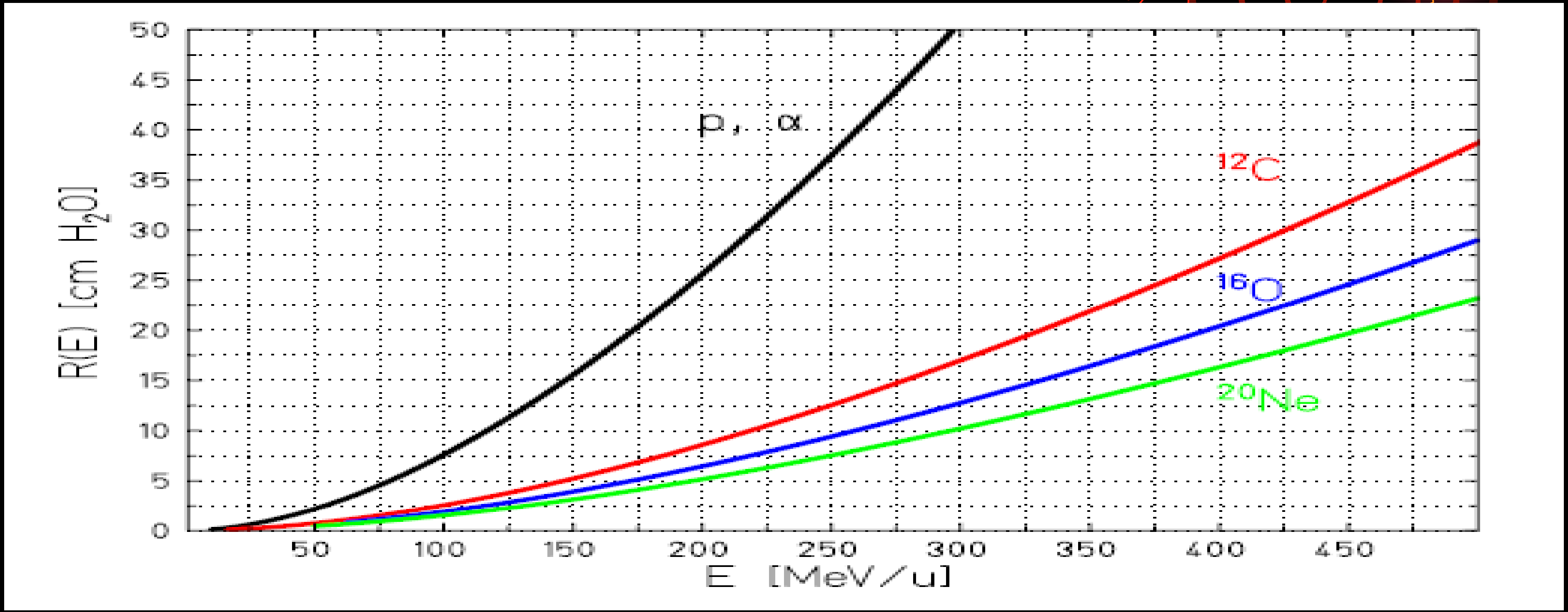

- Protons Stop!
- Photons don't stop.
- Proton dose at depth (target) is greater than dose at surface.
- Photon dose at depth (target) is less than dose at $d_{max}$.

# Bragg peaks of protons and carbon ions




Schardt and Elsasser, 2010

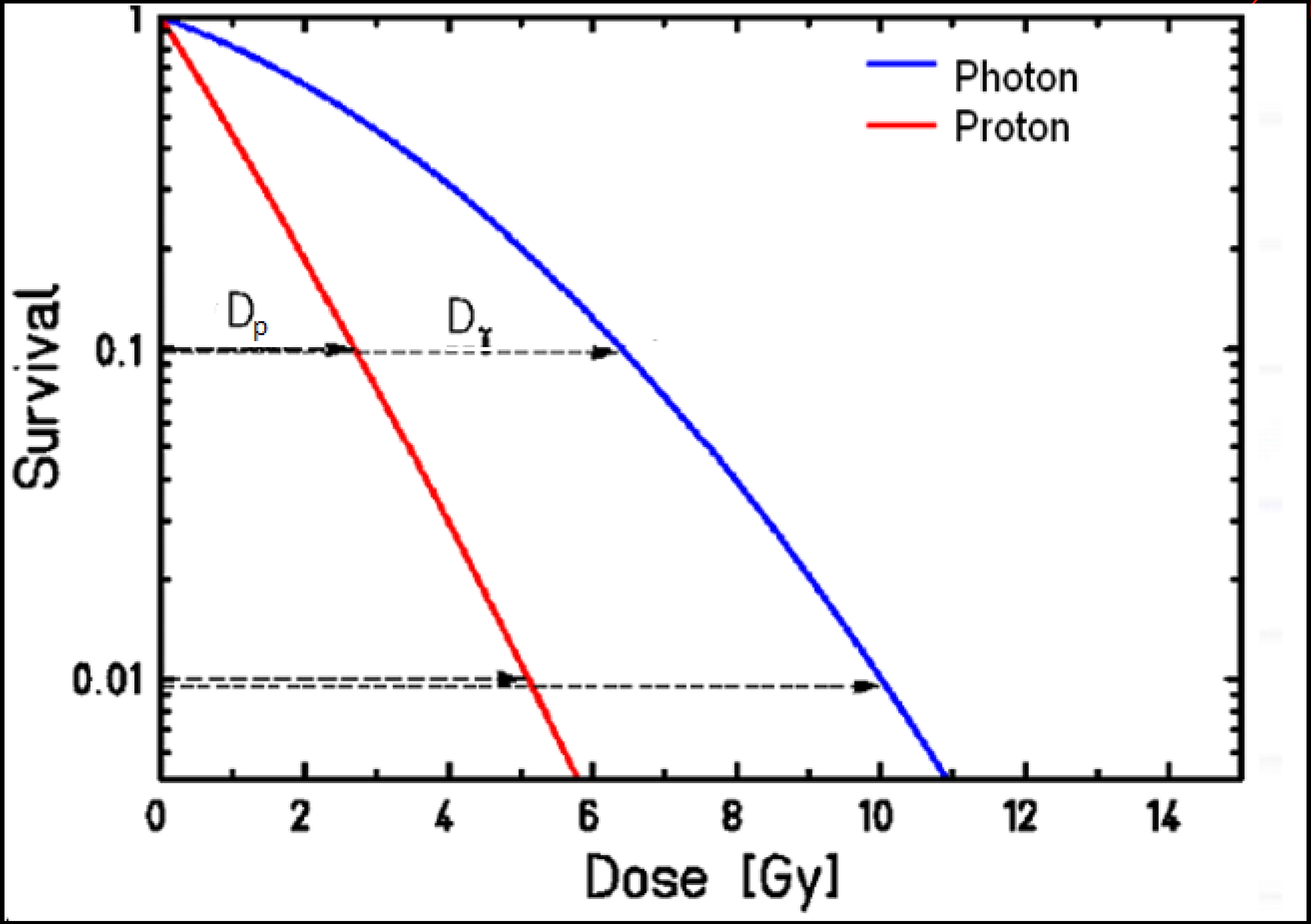
# Ranges in water (proton, carbon, neon etc.)




175 MeV proton, 325 MeV/U carbon, 450 MeV/u neon have 20 cm range in water.

Schardt and Elsasser, 2010

# Radiobiological Properties (RBE)

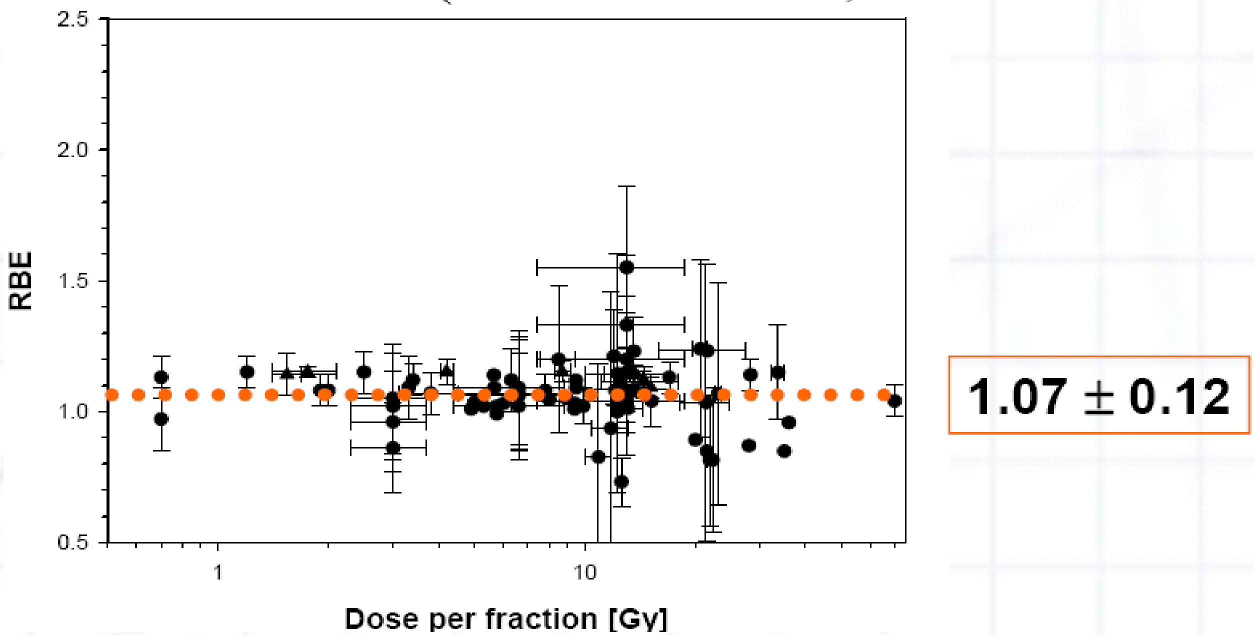



$$RBE = \frac{D_\gamma}{D_p}$$

# Clinical RBE = 1.1 (proton)

*Protons*

RBE values *in vivo* (center of SOBP; relative to $^{60}$Co)




**Mice data: Lung tolerance, Crypt regeneration, Acute skin reactions, Fibrosarcoma NFSa**

Paganetti et al.: *Int. J. Radiat. Oncol. Biol. Phys.* 2002; 53, 407

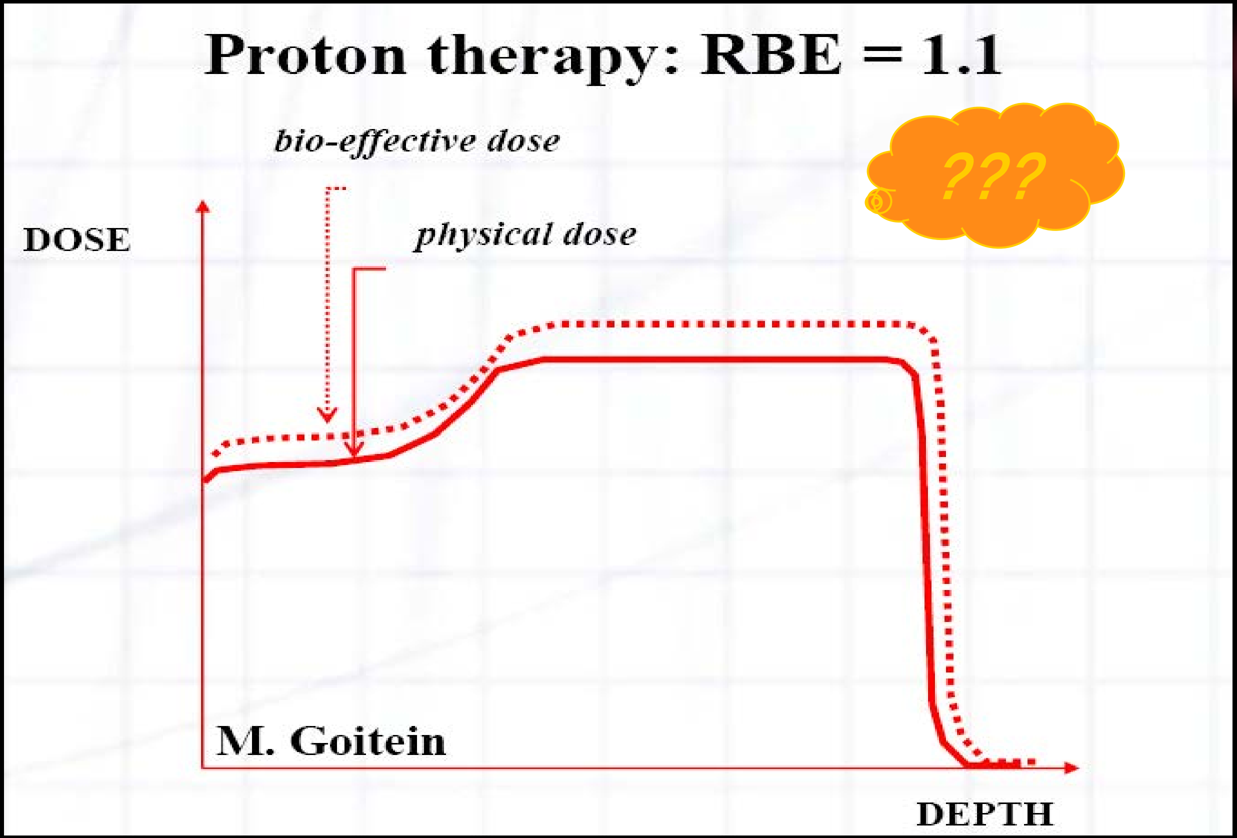
MGH 1811 MASSACHUSETTS GENERAL HOSPITAL CANCER CENTER

H. Paganetti AAPM meeting 2009

HARVARD MEDICAL SCHOOL

# Clinical RBE = 1.1 (proton)

H. Paganetti AAPM meeting 2009



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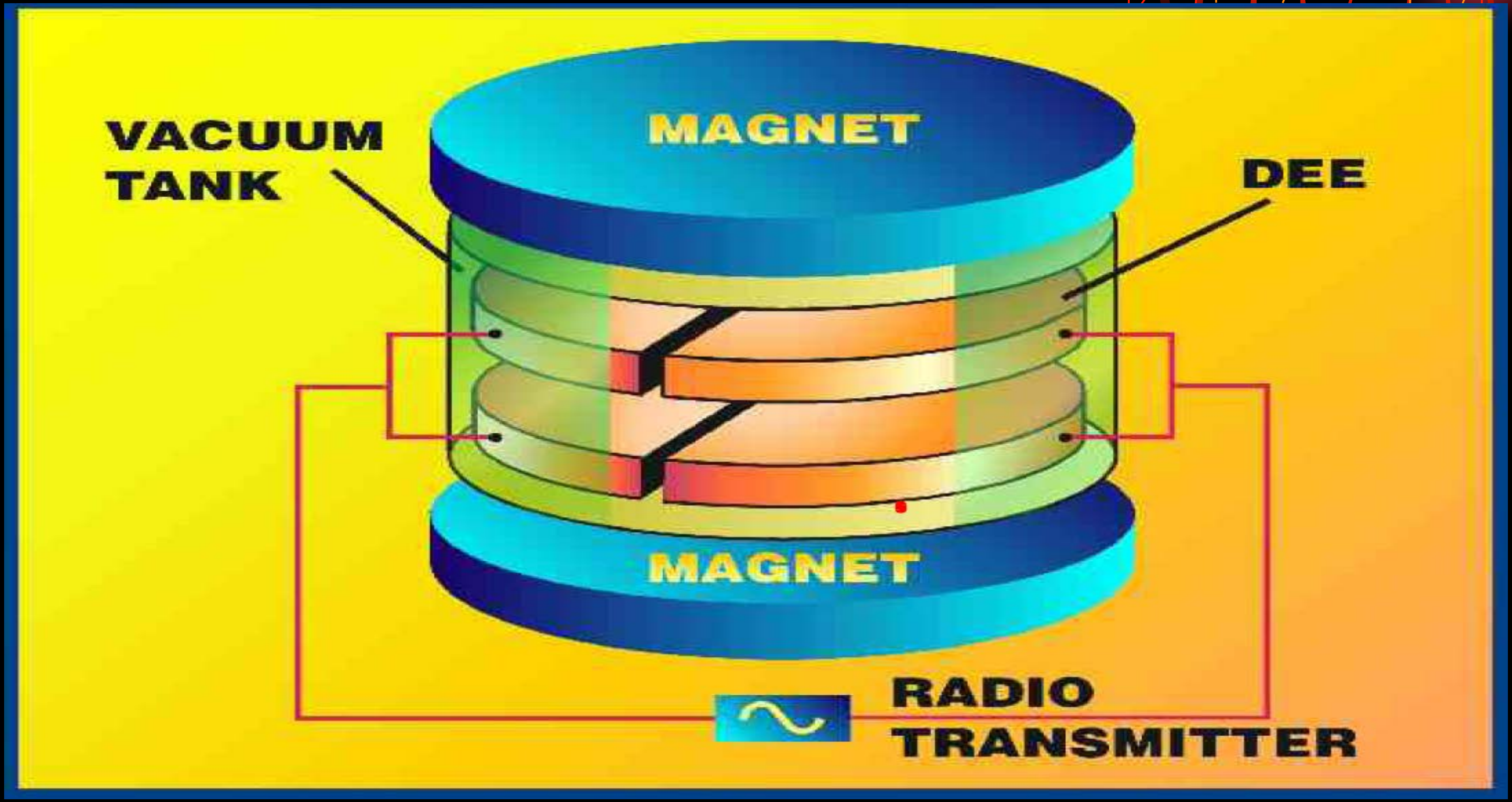
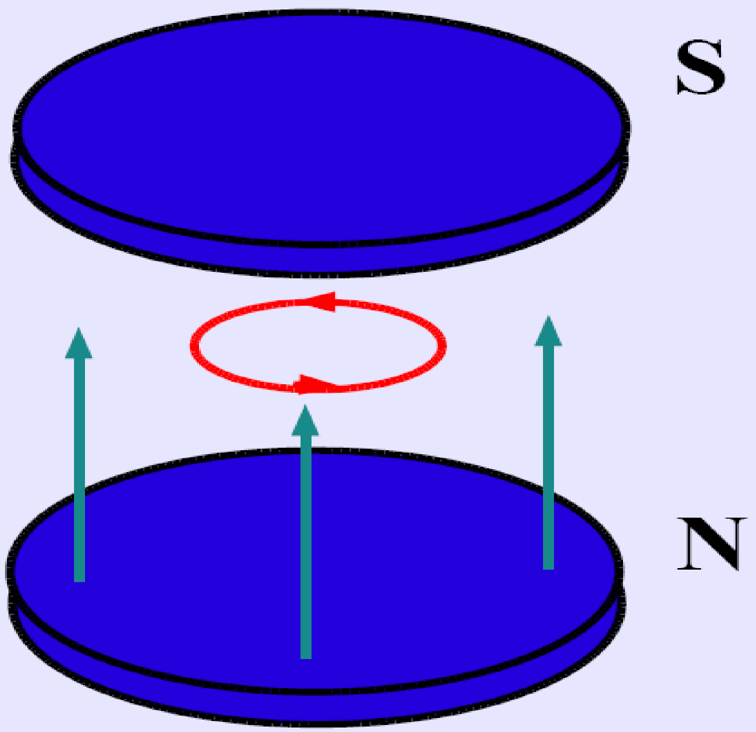
# How does a cyclotron work?

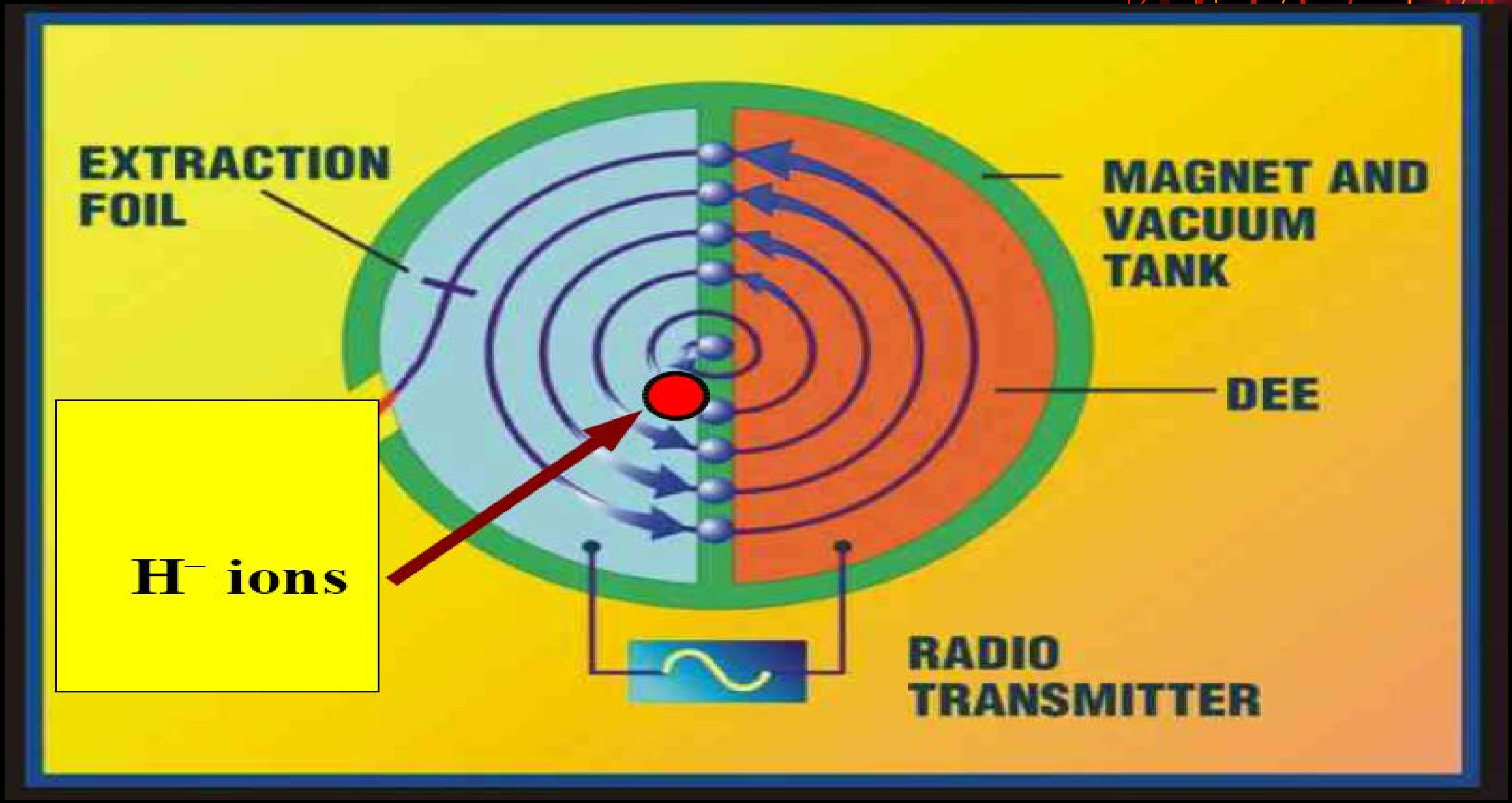


# Cyclotron

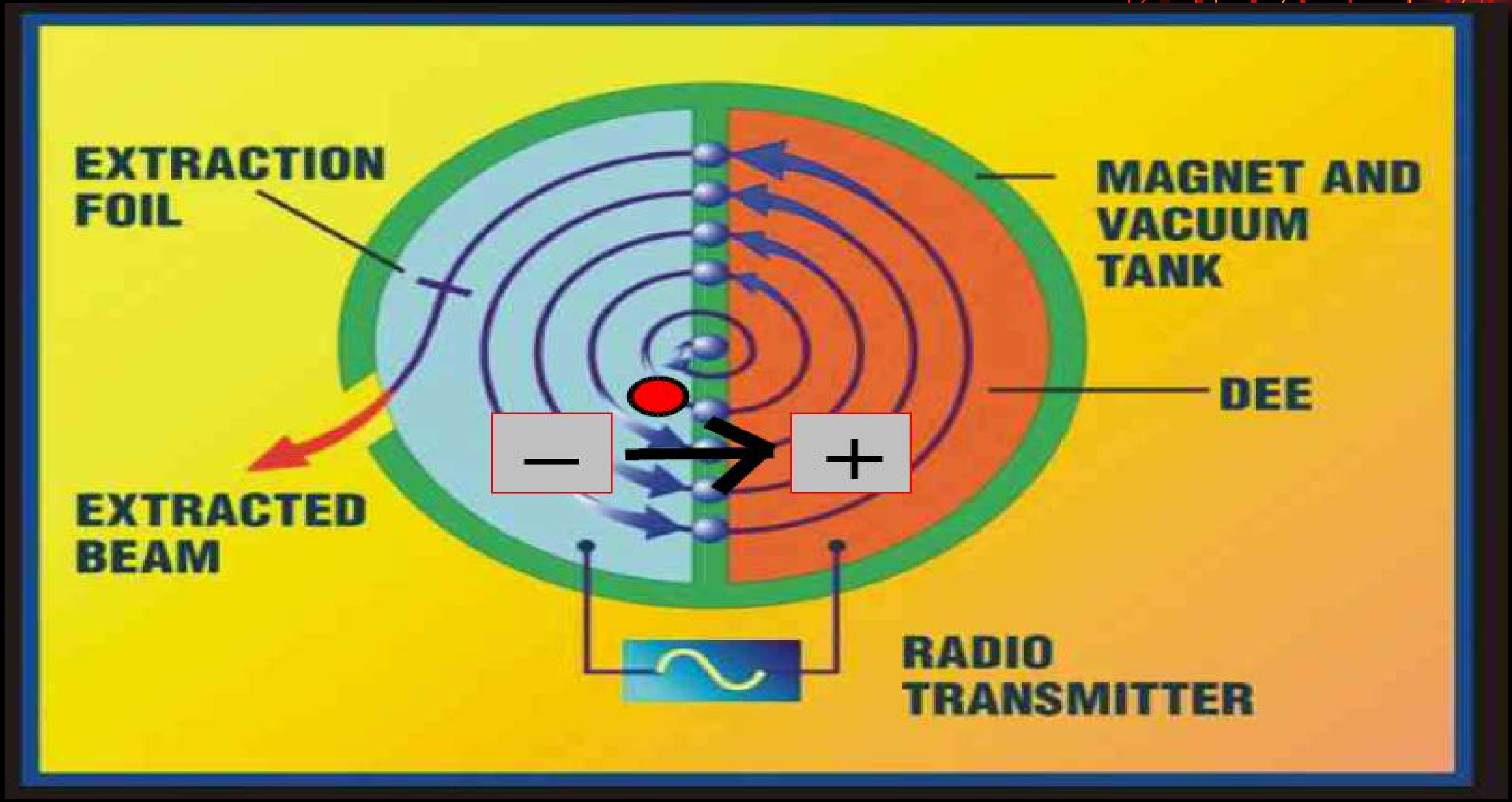
The magnetic field makes these ions move in circular orbits.
The higher the momentum of the ion, the larger the radius of the orbit.



# 1. Inject H– ions near centre of the cyclotron



# 2. High voltage on Dee's accelerate H– ions



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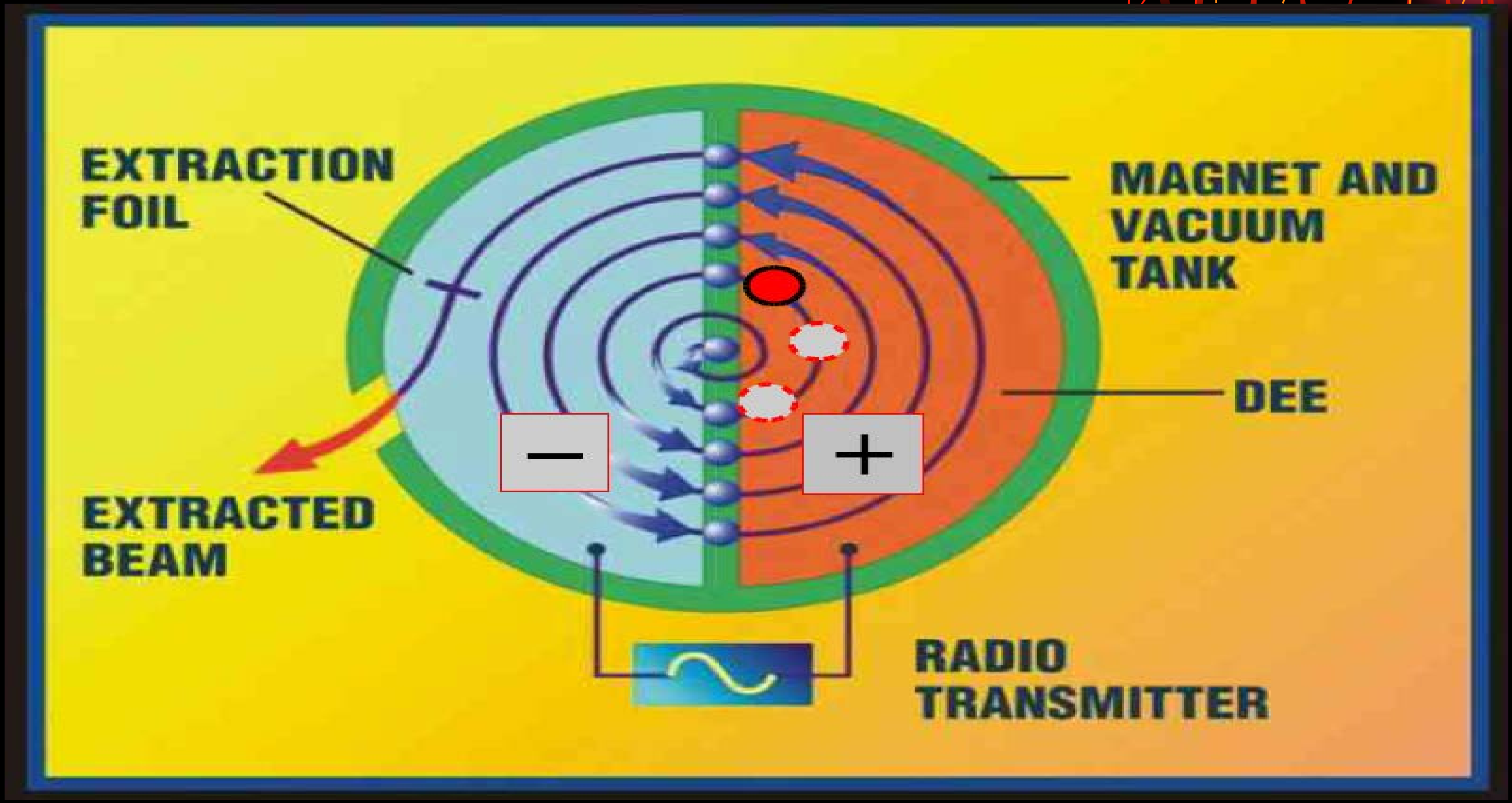
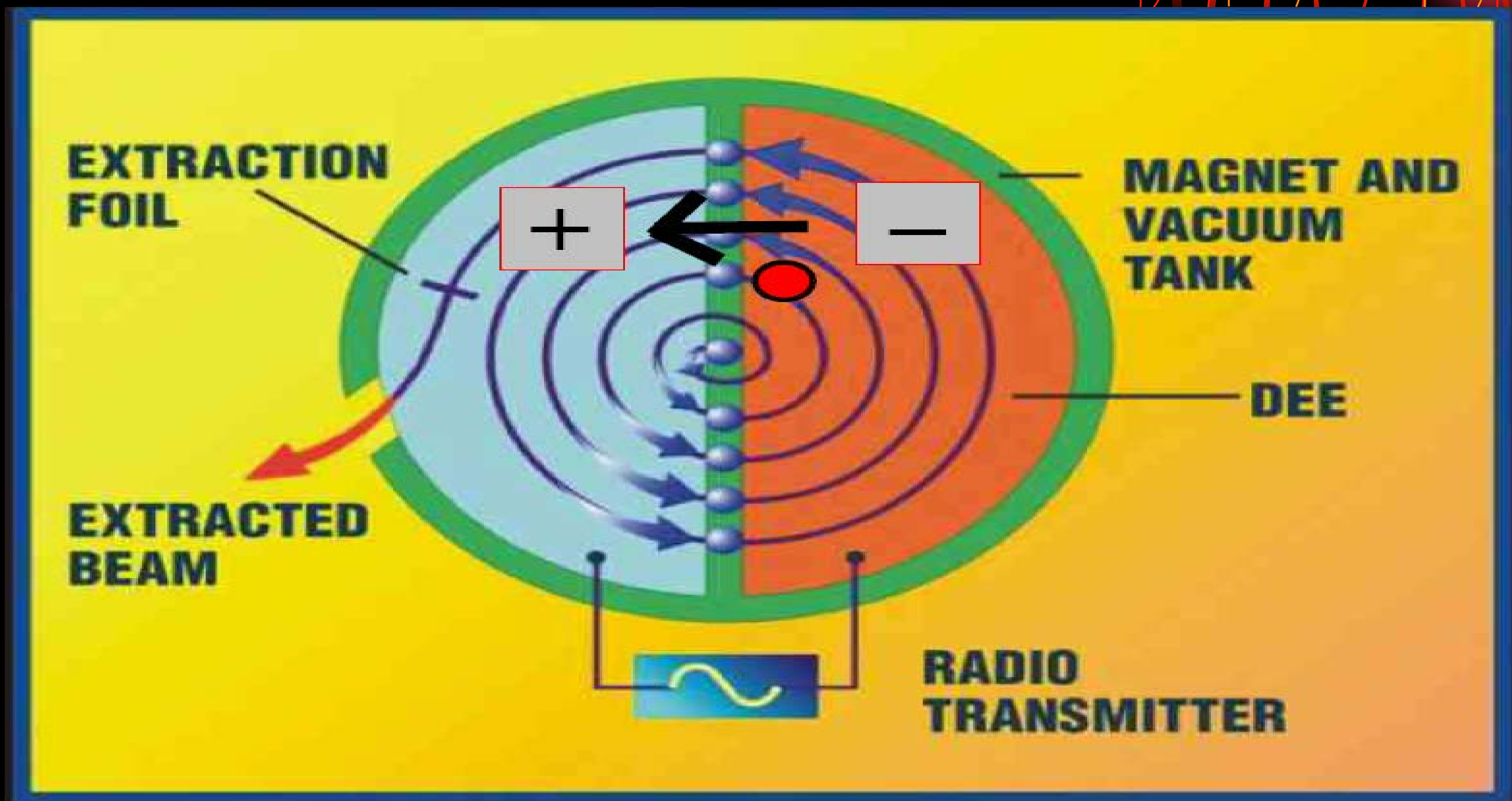
# 3. H– ions orbit through 180 degrees

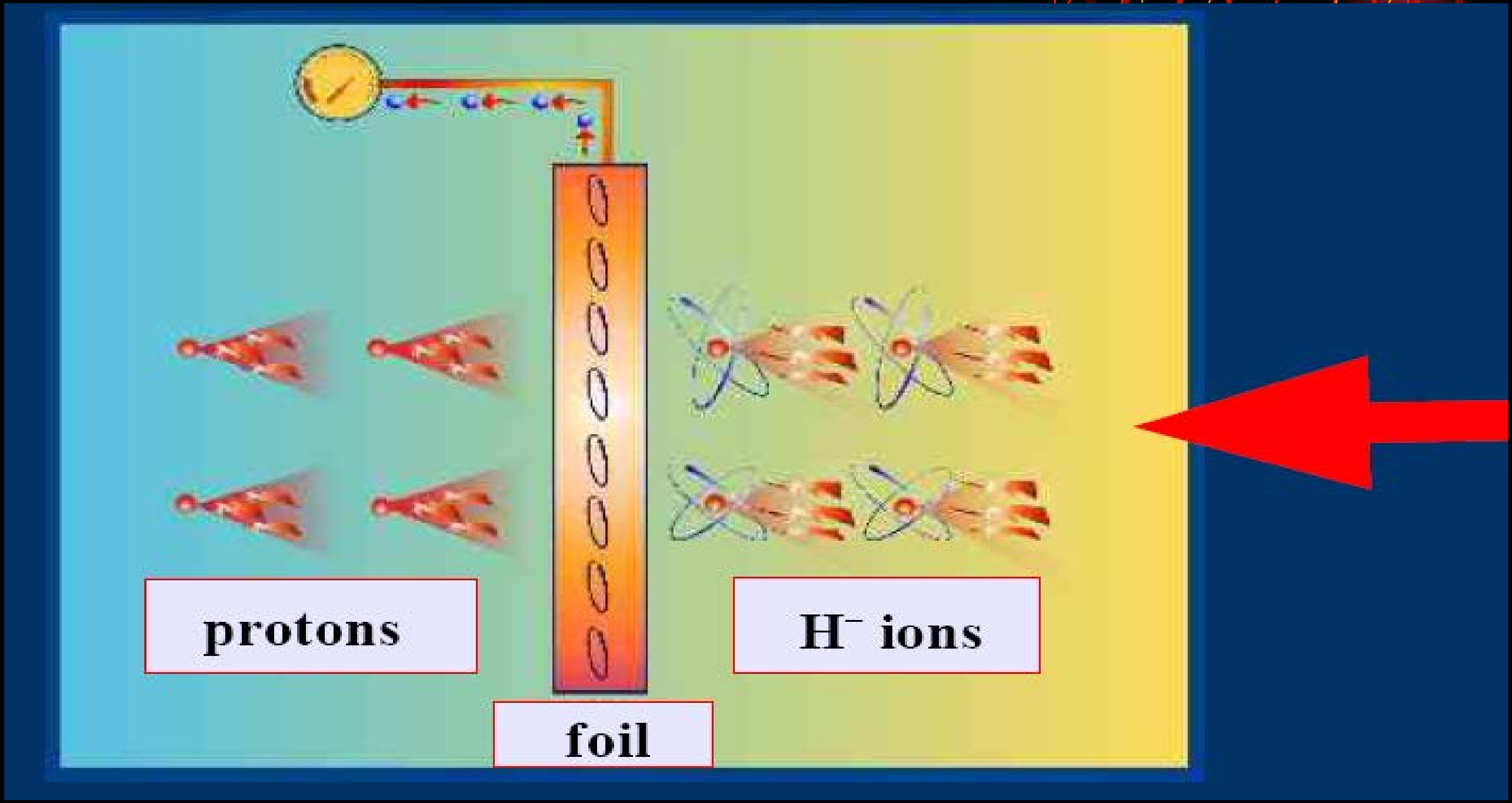


# 4. Dee's switch voltage and ions get accelerated again

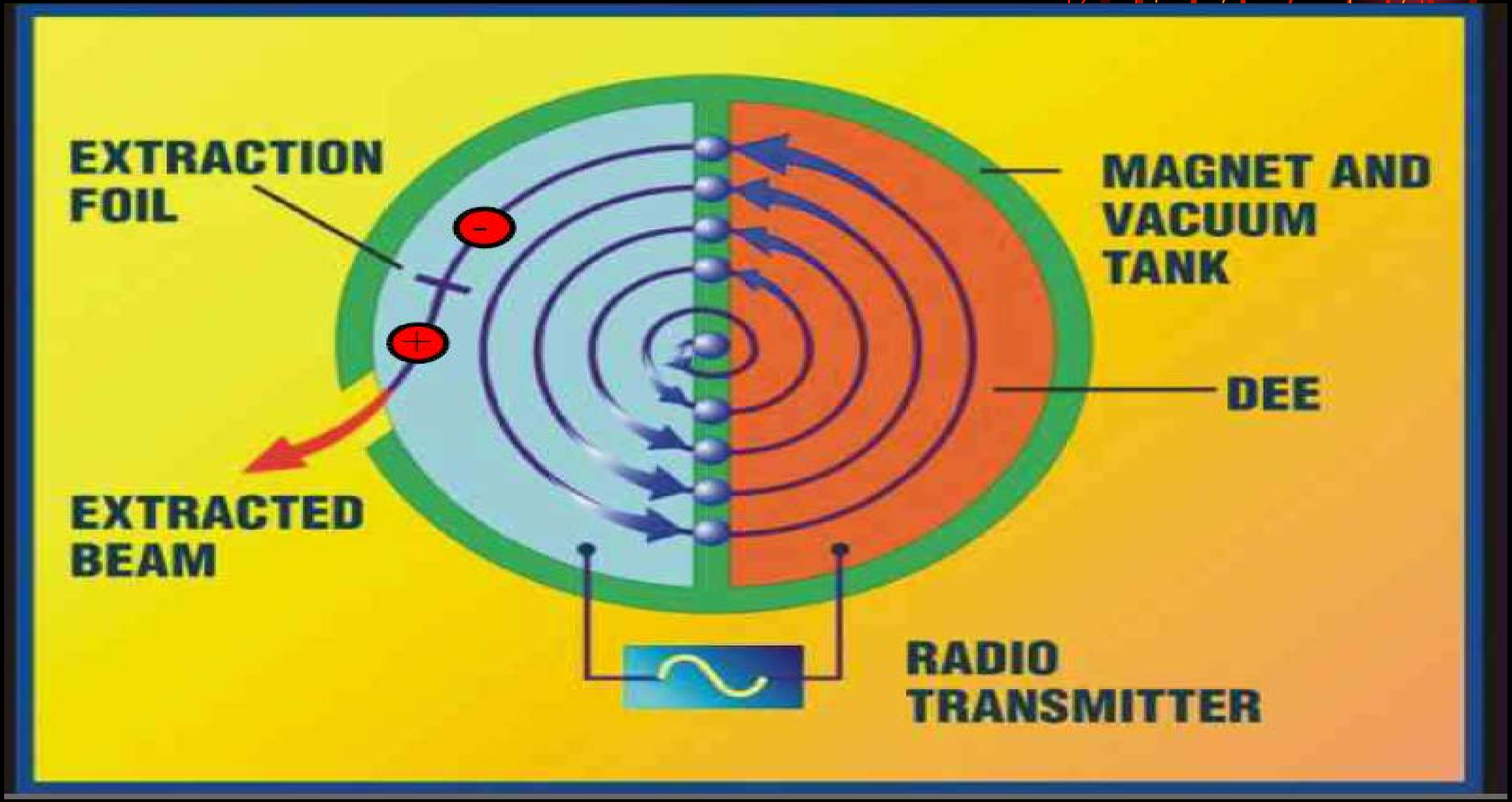


5. This cycle is repeated about several hundred times. The ions follow a spiral trajectory of increasing radius, until they hit the extraction foil.

When the H- ion hits the graphite extraction foil, its two orbital electrons are ripped off by the collision, and the H– ion becomesan H+ ion, i.e. a proton.



6. The ions change from – to + when they hit the extraction foil. The direction of the magnetic force also changes, and this ejects the ions out of the cyclotron



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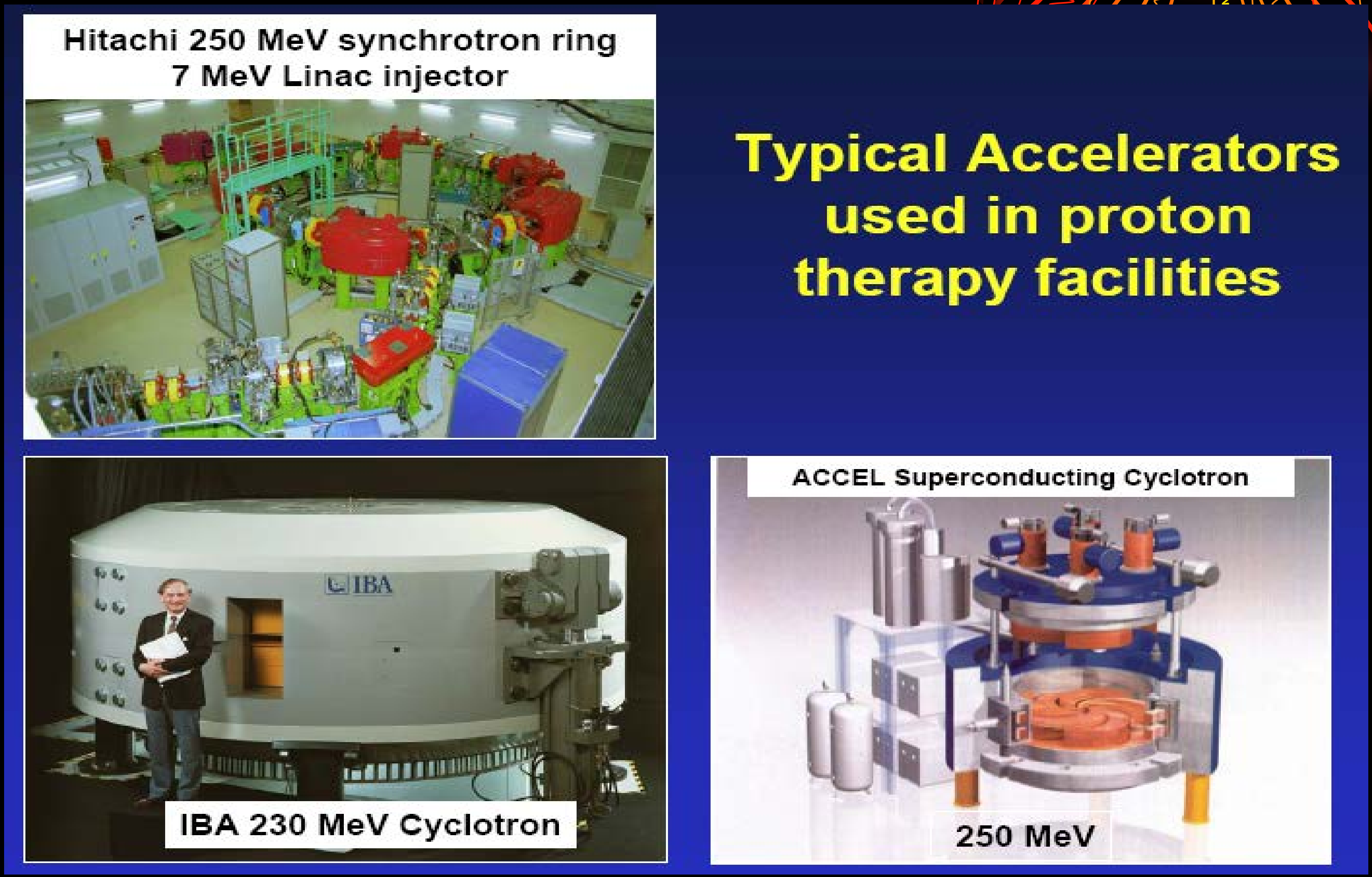
# Typical Accelerators



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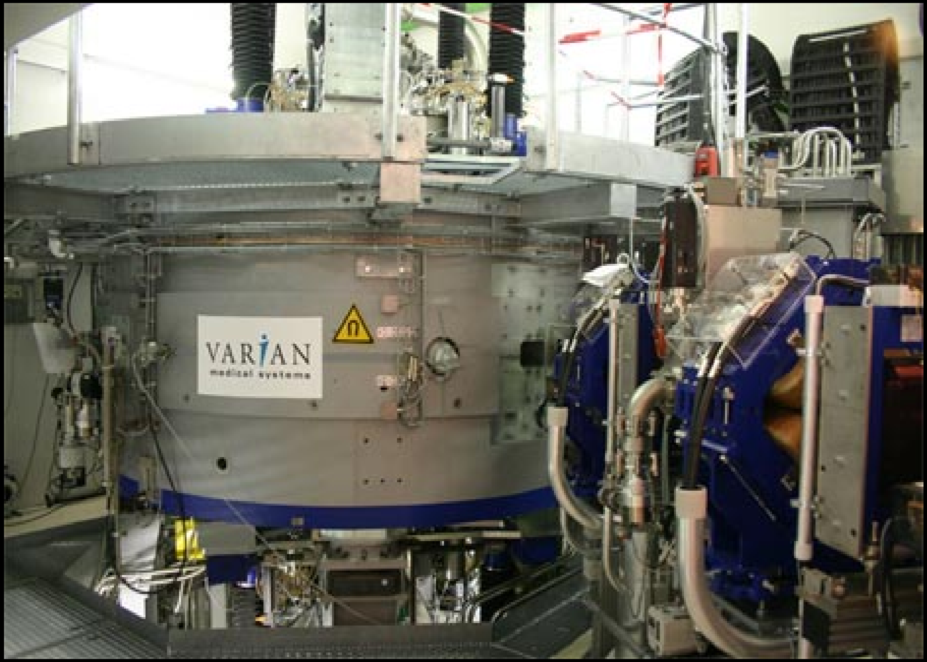


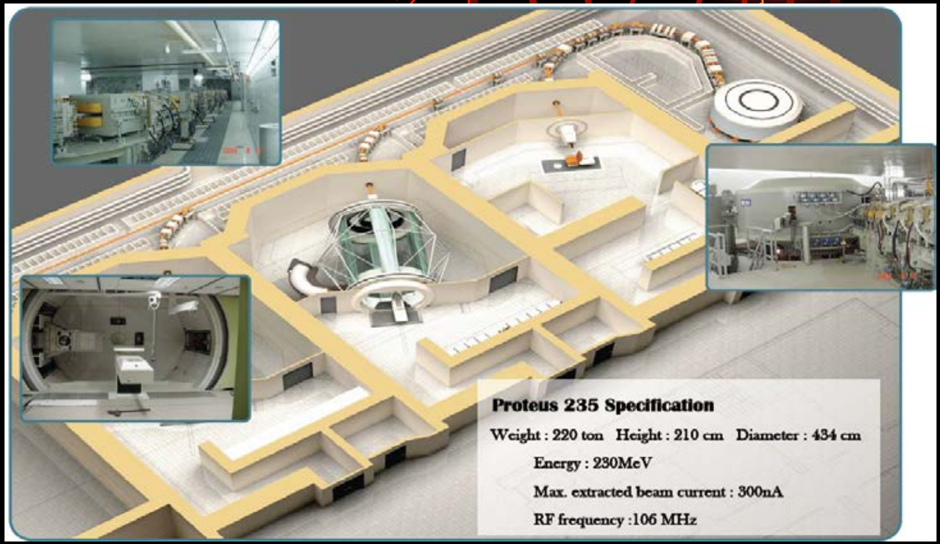


Korean Cancer center proton therapy

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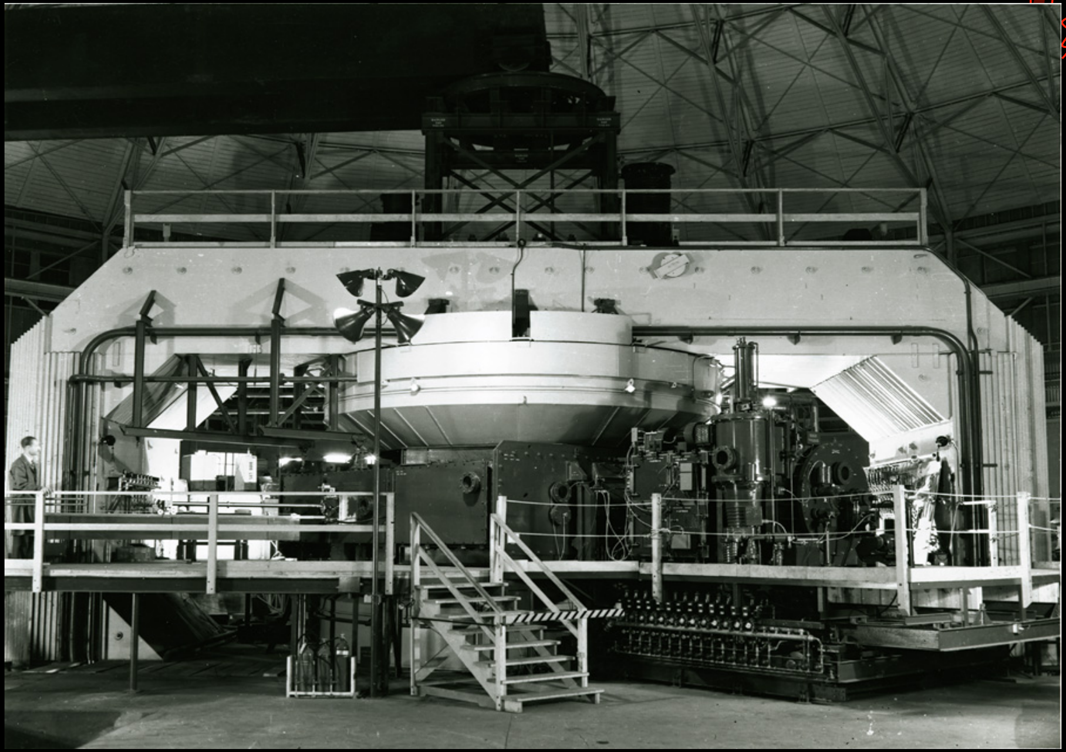
# Berkeley – 184” synchrocyclotron at LBL



1947 – investigations using 160 MeV protons begins
First patient with proton (1954), with helium (1957) and
with neon (1975) and closure (1992); 433 patients treated with heavier ions (most of them with 670 MeV/u neon beams). Total of 2340 patients treated throughout LBL program

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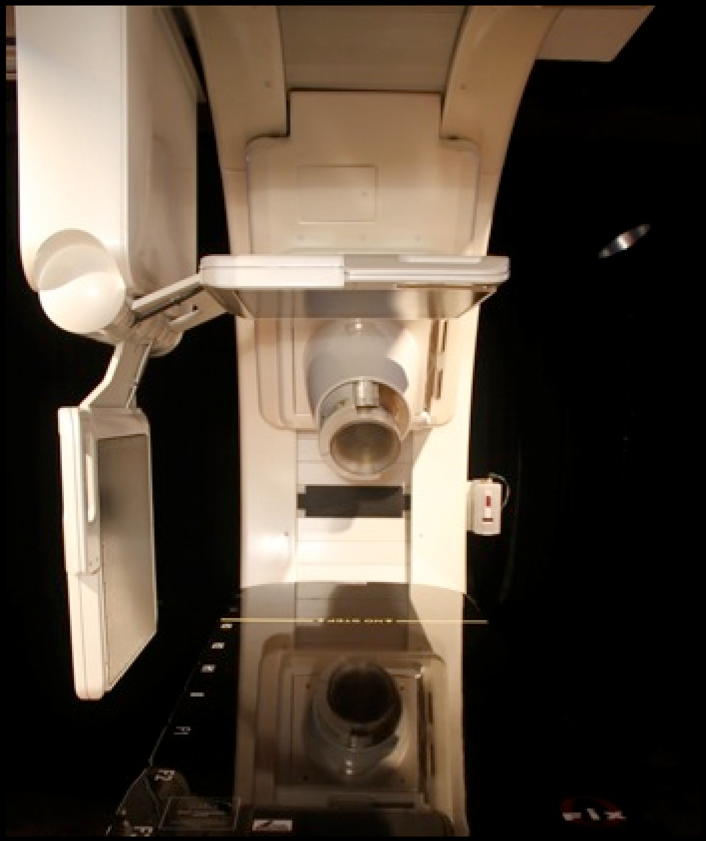
Still River SYSTEMS

# Next Generation Proton Therapy Platform



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# MONARCH250 Compact Proton Therapy

- **Build upon current Proton Therapy proven technology**
  - Based on proven technologies from existing centers (HCL, NEPC, LLUMC)
- **Incorporate modern superconducting magnet technology**
  - Reducing system size and cost, and improving reliability
- **Integrated with well established clinical systems**
  - Delivering state-of-the-art patient care: Radiographic and Cone Beam CT IGRT, Robotic Couch, Treatment Planning, R&V
- **Pass along Proton Therapy system manufacturing cost reduction to cancer care centers**
  - Giving physicians and patients greater access to proton therapy

Still River SYSTEMS

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# Still River's Next Generation Proton System

- Modern proton therapy platform
- Single Room Solution – Multiple Room Option
- Advanced clinical treatment capabilities

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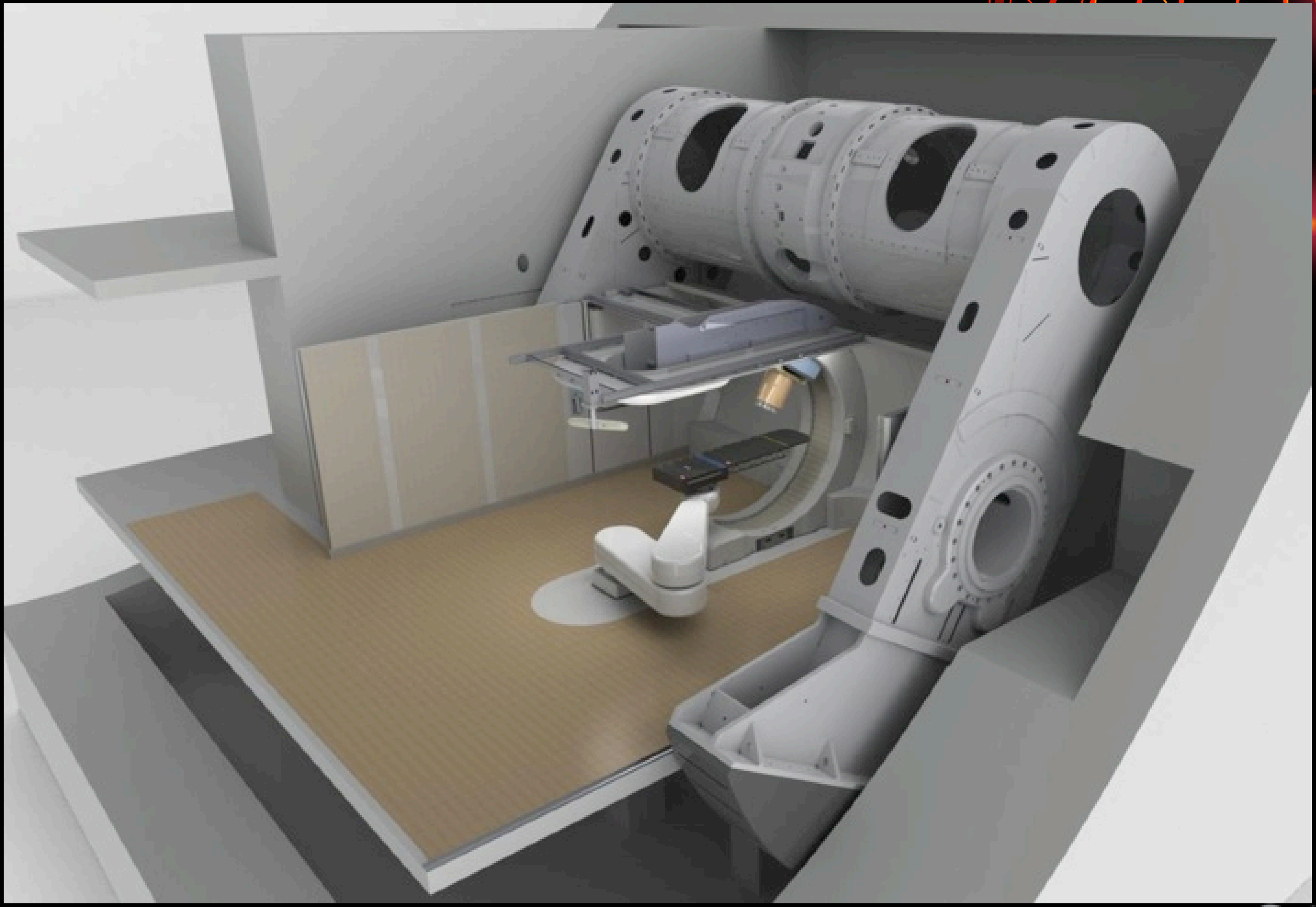

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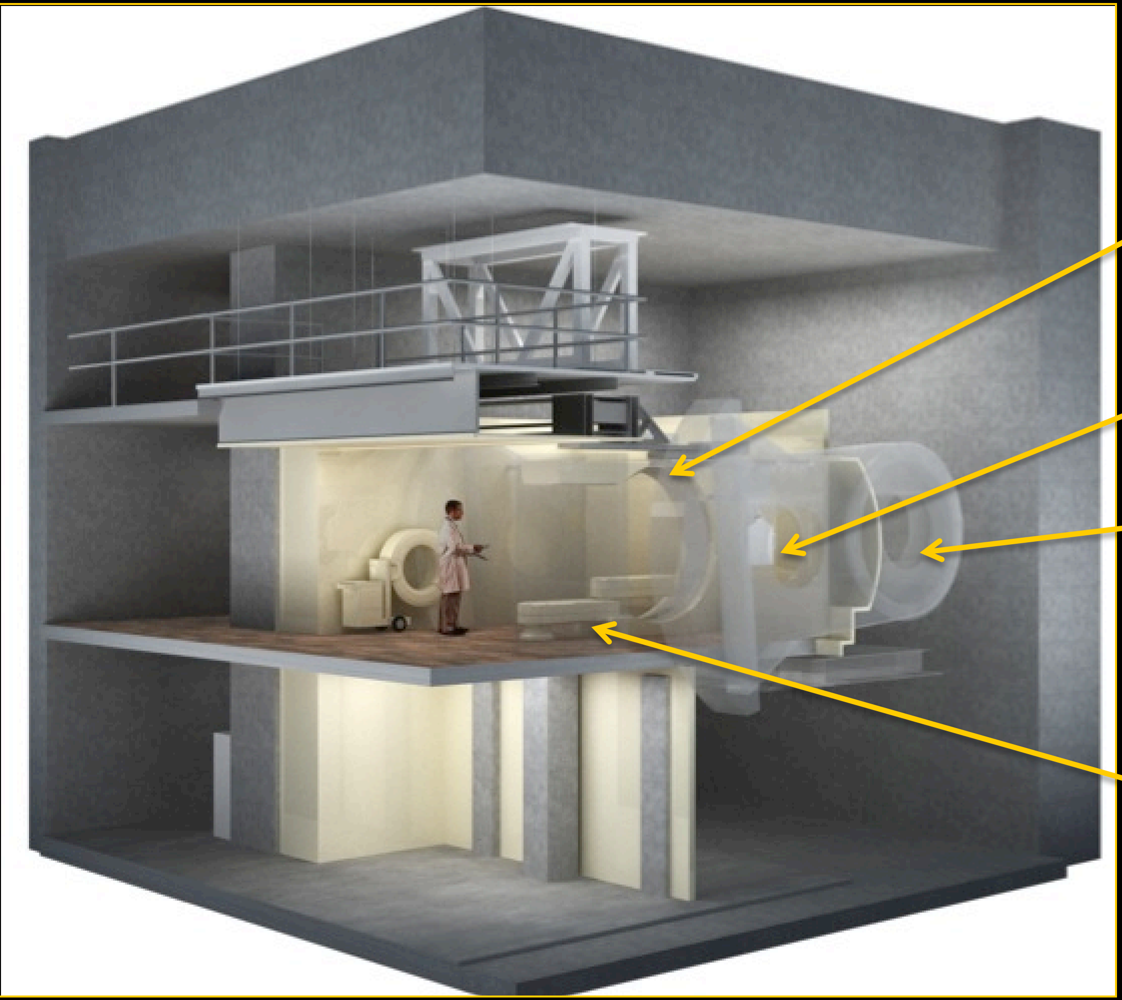

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# Superconducting Synchrocyclotron

A 10 Tesla Superconducting Magnet enables a smaller, lower cost gantry mounted Cyclotron.

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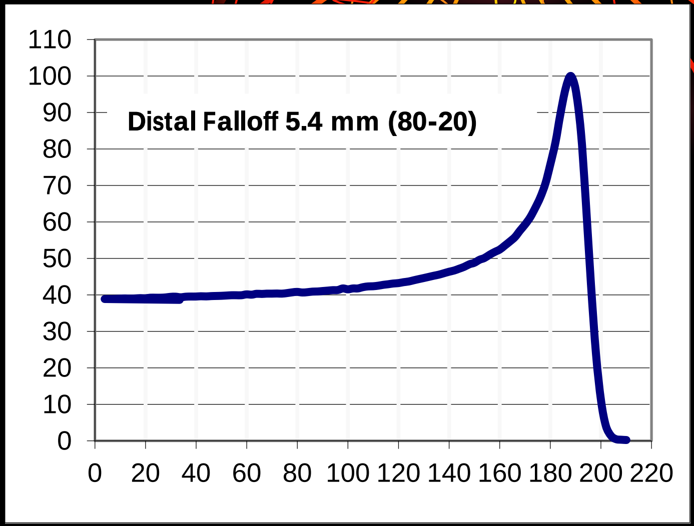
# A Robust Focused Beam

## 50+ years of Clinical Life Testing (>100 hours of beam)




"One push button" Tx delivery - similar to conventional RT protocol

- Energy: 254 MeV
- Dose Rate: 2 to 4 Gy/min
- Final Spot Size: 1.3 x 1.3 mm σ
- 80-20 Distal fall off = 5.4 mm
- Head leakage measured below 0.1% (Q=10)

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**Total Gantry Rotation: 190 deg.**

**Total Couch Rotation: 270 deg.**

→ **Provide all clinically used beam angles**

**(AP/PA; Left/Right Lateral; Angled/Oblique/Tangential)**

# Clinical Integration

Clinical Workflow Identical to IMRT/IGRT including 1st CBCT

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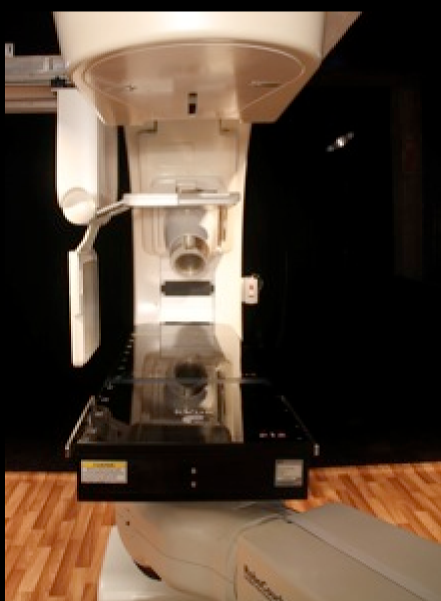
# Clinical Integration

## Clinical Workflow Identical to IMRT/IGRT including 1st CBCT

Digital X-ray (2D/3D)



3D – CBCT

(Medtronic)


# Clinical Integration

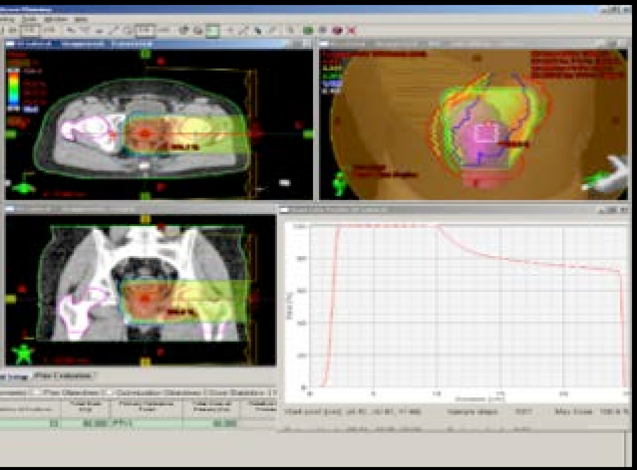
## Oncology Information System and TPS

Treatment Planning: Eclipse, CMS, Pinnacle

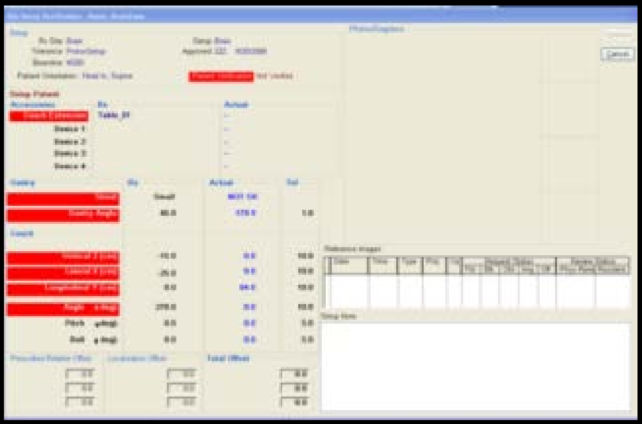
Oncology Information System: IMPAC or ARIA

- Workflow identical to conventional linear accelerator
- Schedule, treat, verify and record

TPS



R&V Integration



Treatment Console

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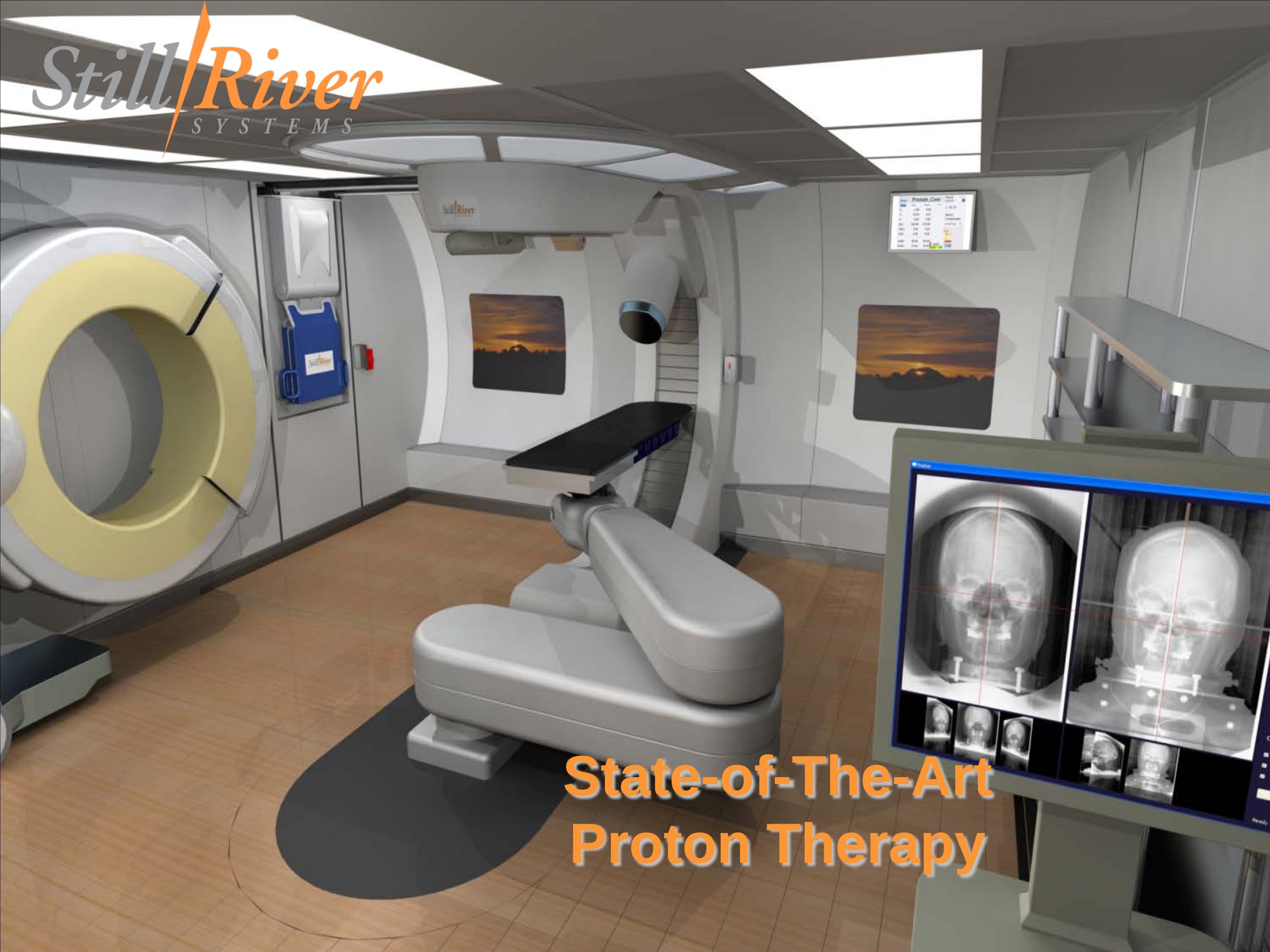
# The compact MONARCH$^{250}$ Proton Therapy System

# Proton Therapy


Still River
SYSTEMS
State-of-The-Art
Proton Therapy

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# MONARCH 250

## Installed One Room at a Time - Single Room or Multiple Rooms

- **Most Reliable Approach**
  - One cyclotron per each room
  - No remote beam steering or transport requirements
- **Most Efficient Approach**
  - No beam waiting
  - Patient treatment room can be interchanged
- **Most Economical Approach**
  - Conventional staff / workflow requirements (no cyclotron room)
  - Room investment can be staged

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# MONARCH 250

## Staff Requirements

- Similar requirements to high volume dedicated Linac IMRT / IGRT vault
  - 1.5 medical physicists
  - 1.5 dosimetrists
  - 4.0 therapists
  - Allocate all other fixed personnel (MD, Dept Mgr, etc)
  - Assume RCB and Final Aperture outsourced
- Total 7 "variable" staff per work shift and per vault

"Conventional Staffing → Integrated workflow"

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