



Dose Delivery Concepts

Marco Donetti



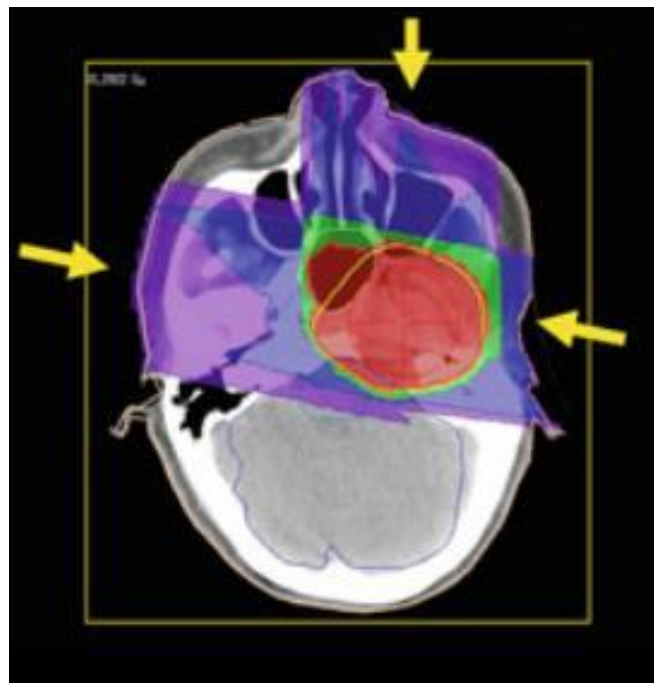
CAS 2015 - Accelerator for Medical Applications

fondazione **CNAO**
Centro Nazionale di Adroterapia Oncologica

What we have to do

Deliver the dose....

- with the desired spatial distribution
- in the right place
- inside the target volume

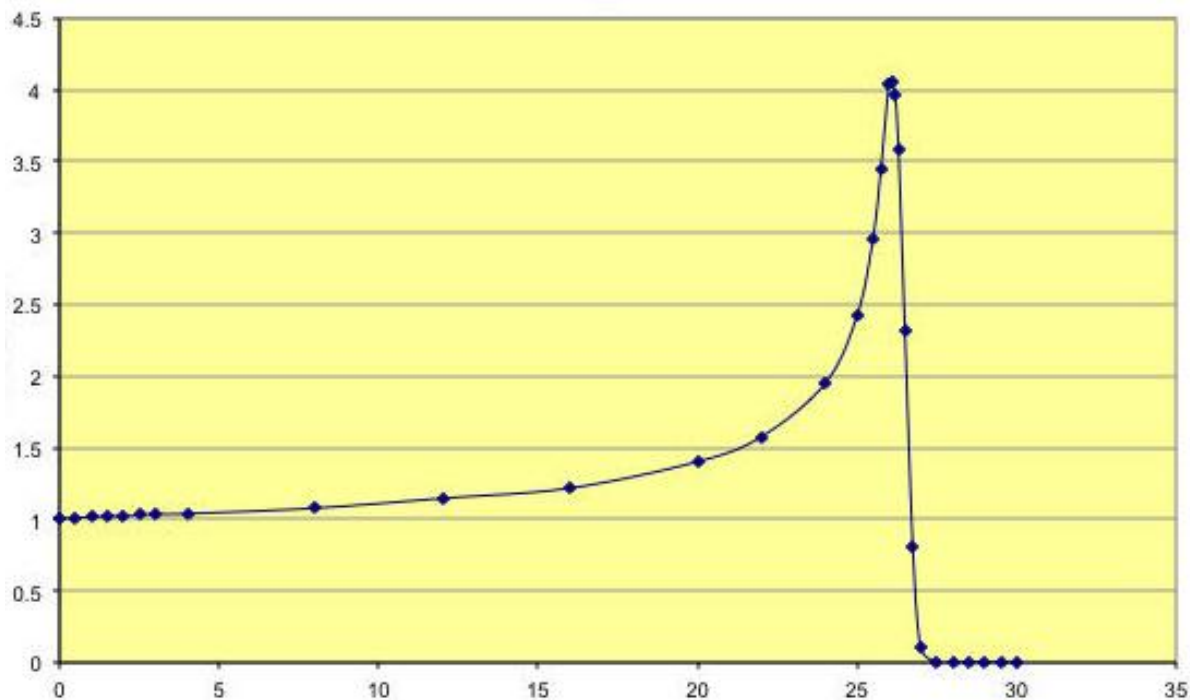
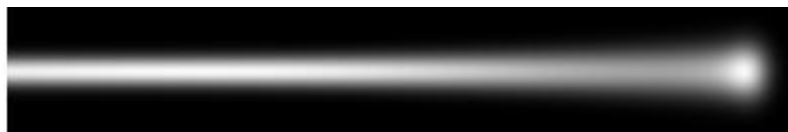


What do we need?

- requirements
- accelerator
- transport lines
- beam delivery
- patient positioning system
- position verification system
- treatment planning system
- oncological information system
- safety

Is a beam enough?

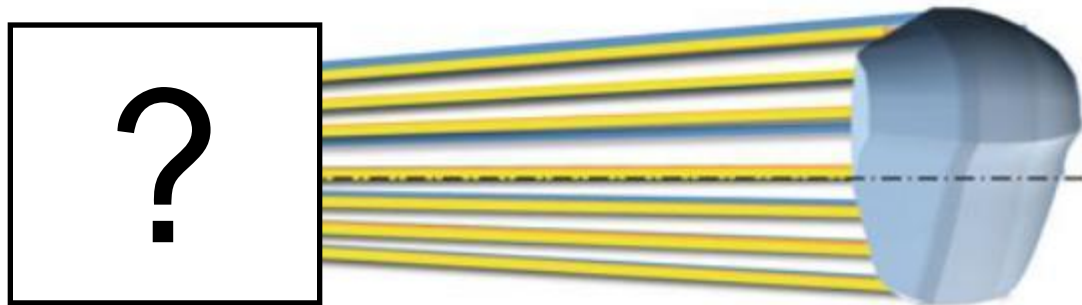
The beam is too narrow and the Bragg peak is too sharp to be used as it is



3D beam spread out

We can obtain it with:

- energy variation
- particle direction modification



Particles

Protons:

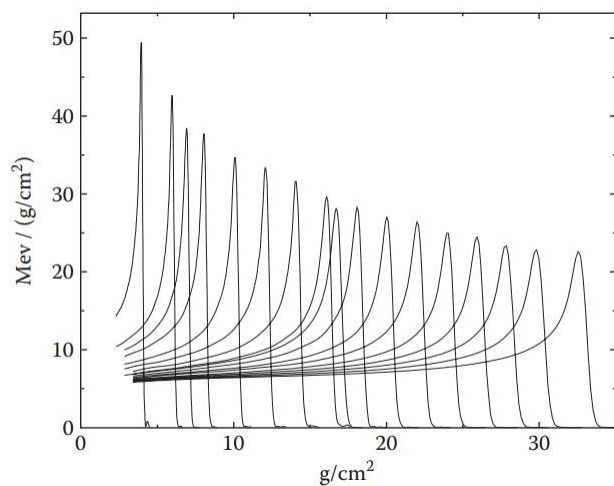
- similar to photons
- cheap
- well known
- constant RBE
- no fragments

Carbon ions:

- radioresistant tumor
- expensive
- not constant RBE
- fragments
- better trajectories

Proton-Carbon

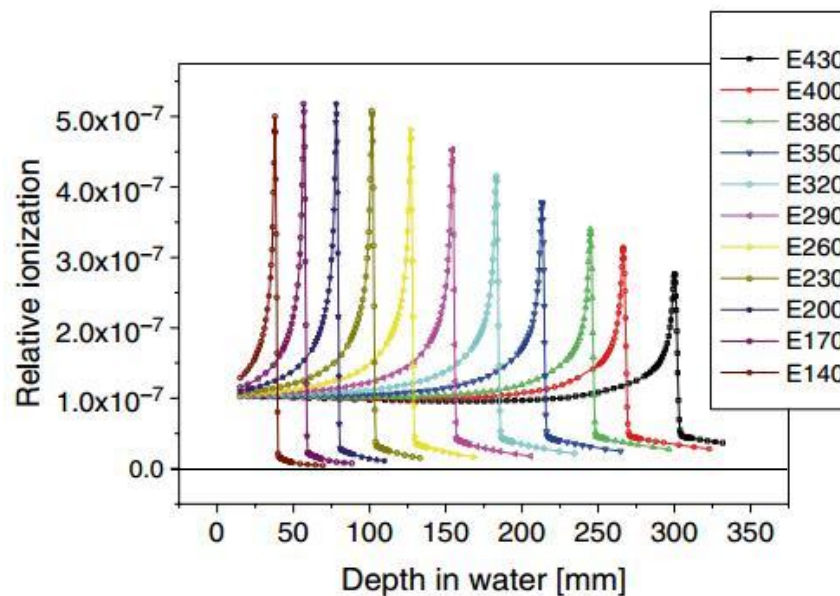
Proton



$$E_c = 60 - 250 \text{ MeV}$$

$$B\rho = 1.1 - 2.4 \text{ Tm}$$

Carbon



$$E_c = 120-400 \text{ MeV/u}$$

$$B\rho = 3.2 - 6.3 \text{ Tm}$$

Accelerators

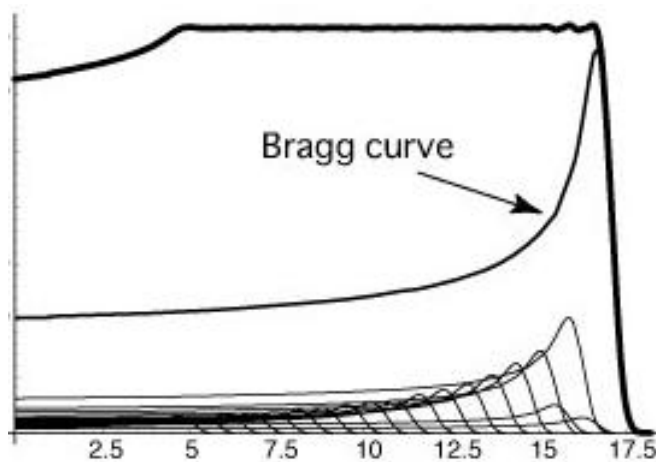
Cyclotron:

- fixed energy
- stable beam current
- continuous beam
- small
- protons only

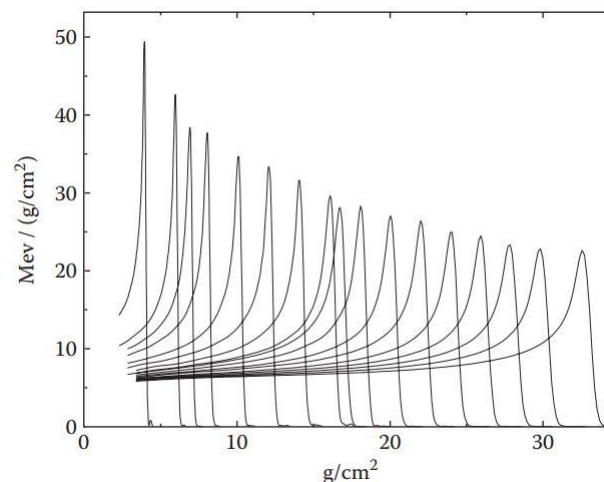
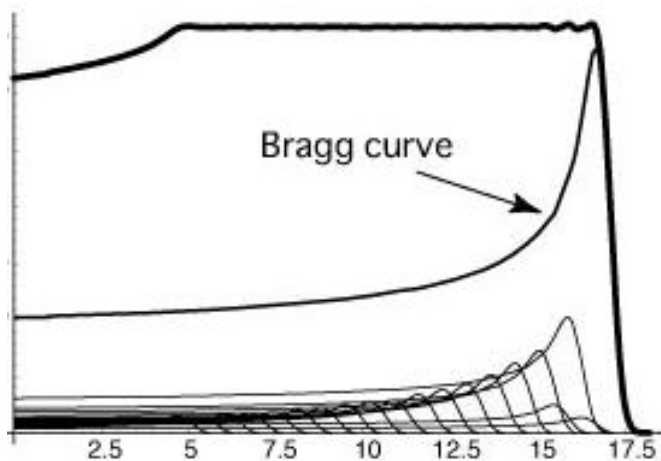
Synchrotron:

- variable energy
- not stable beam current
- pulsed beam
- large (for ions)
- protons and heavy ions

Spread Out Bragg Peak



Longitudinal spread



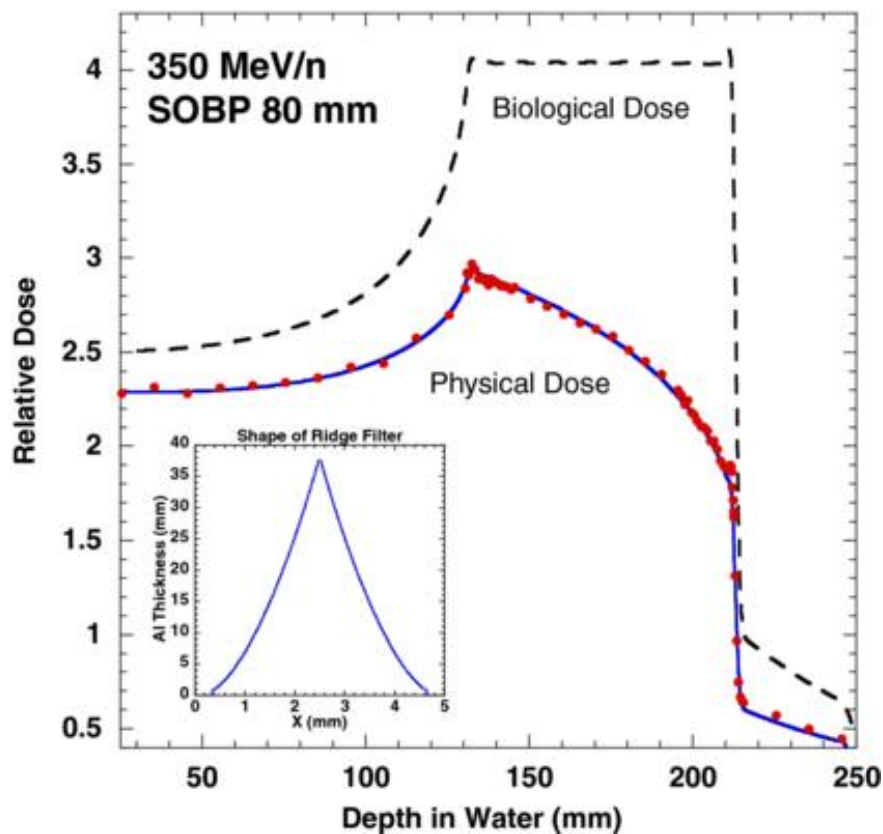
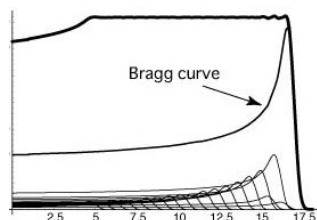
Passive:

- Ridge filter

Active:

- layer stacking
 - energy from accelerator
 - energy change in beam line
- modulation wheel

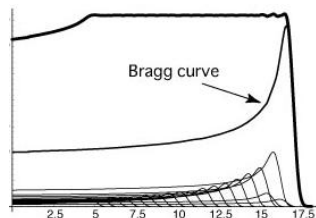
Ridge filter



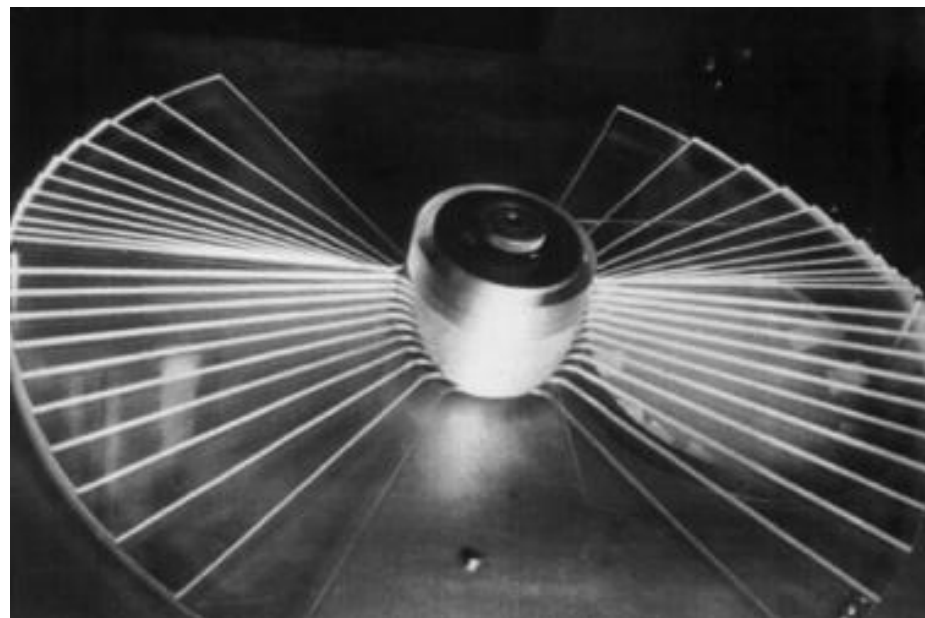
Passive

A laterally spread flat beam is used
Every SOBP has a ridge filter

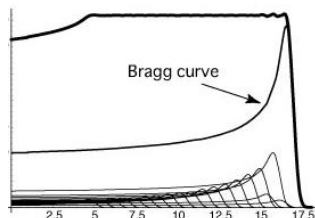
Modulator wheel



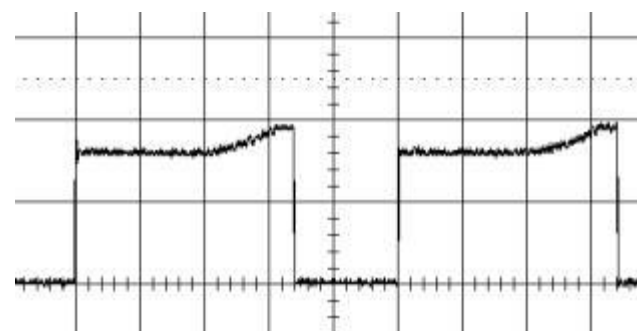
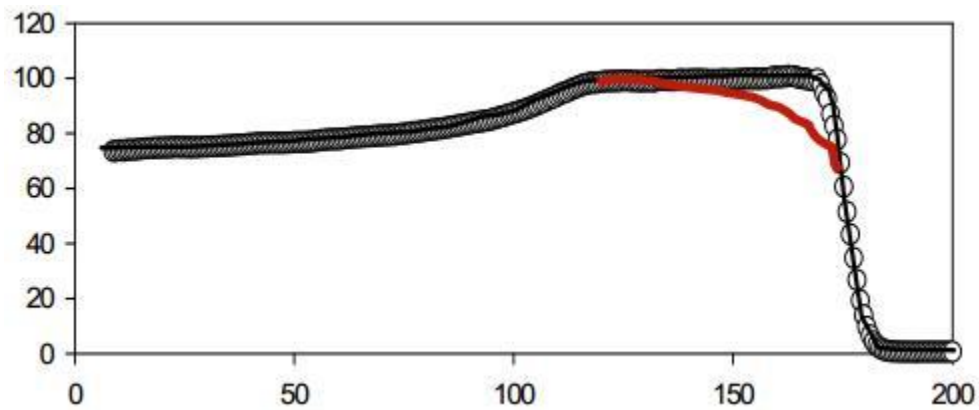
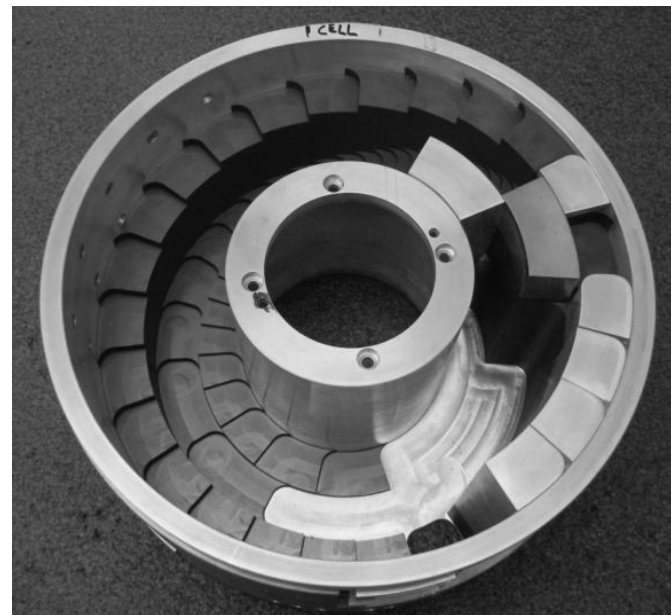
The peak weight is proportional
to the angle of the step
One modulator for one
modulation depth
Almost passive



Modulator wheel



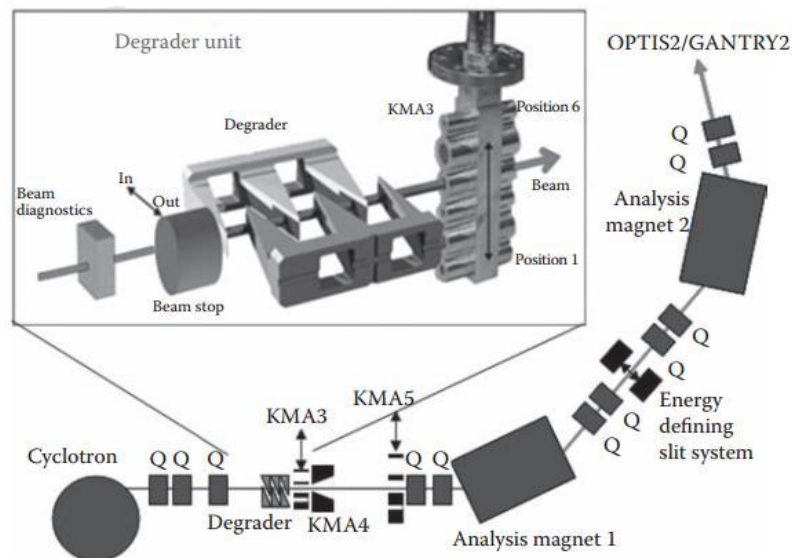
Controlling the beam intensity
and beam on/off
Not really passive



Layer stacking

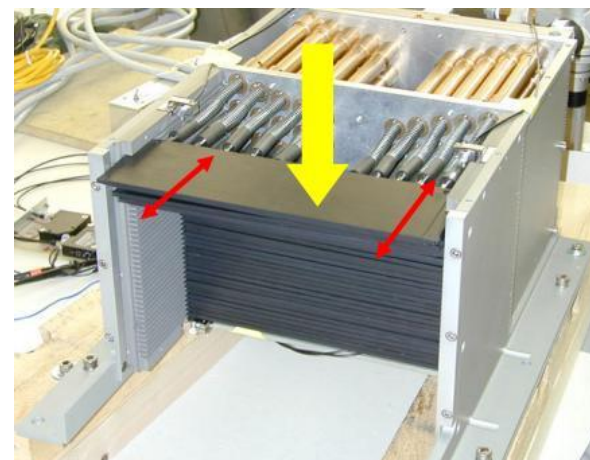
With beam:

- extraction from synchrotron
- degradation on beam line

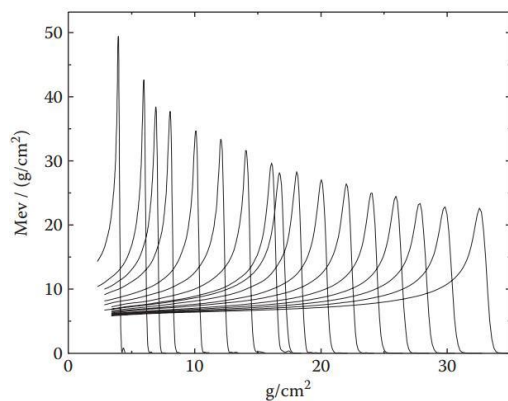


Mechanically:

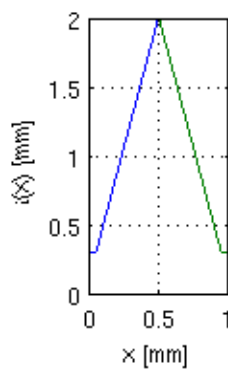
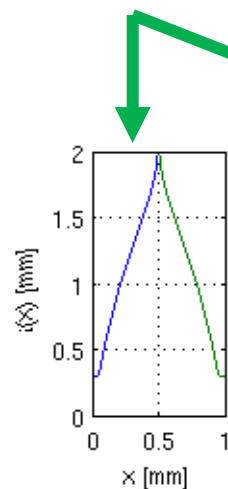
- range shifter



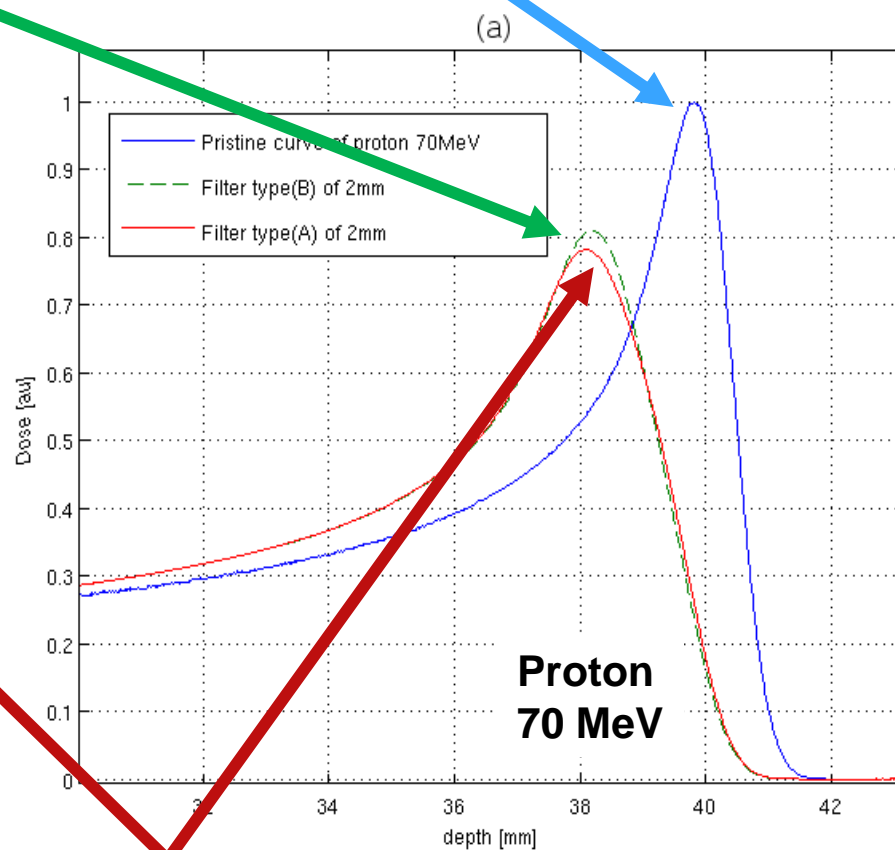
Ripple filter



Gaussian



Bragg peak



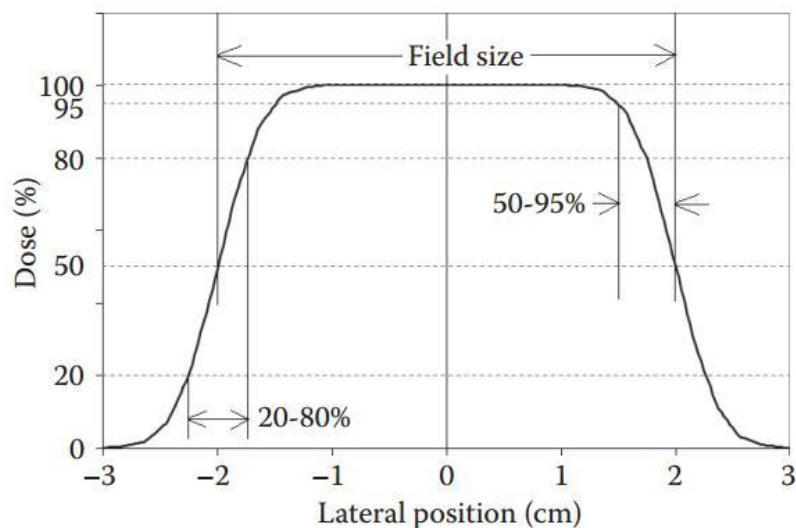
Simple geometry

Lateral spread

Scattering: Scanning:

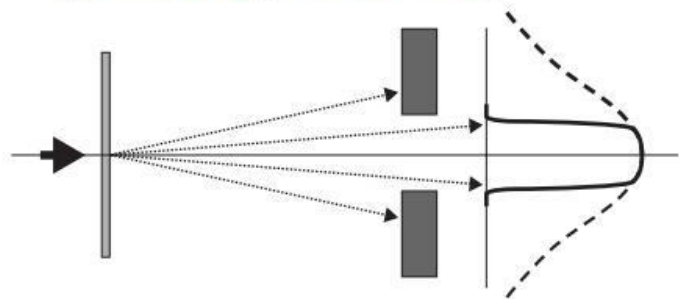
- single
- double
- pencil beam
- uniform
- wobbling

Penumbra

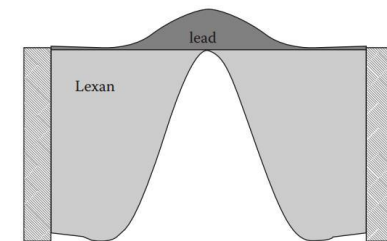
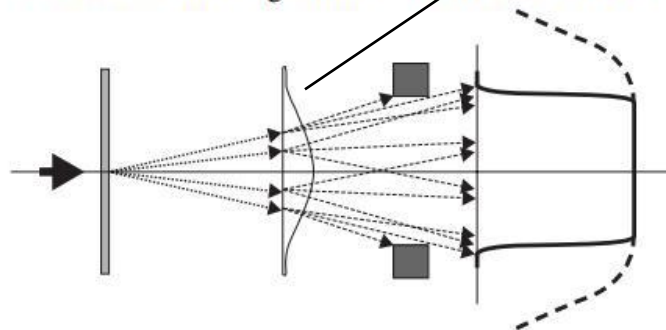


Scattering

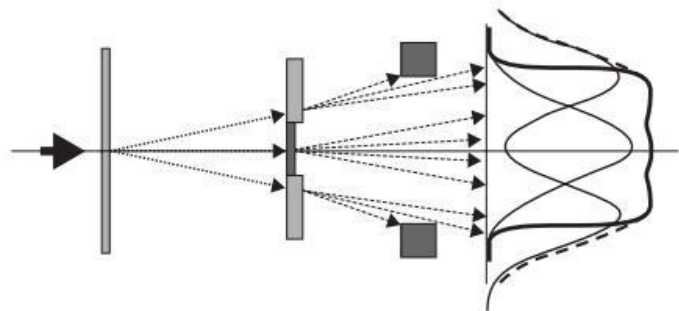
Single Scattering with flat scatterer



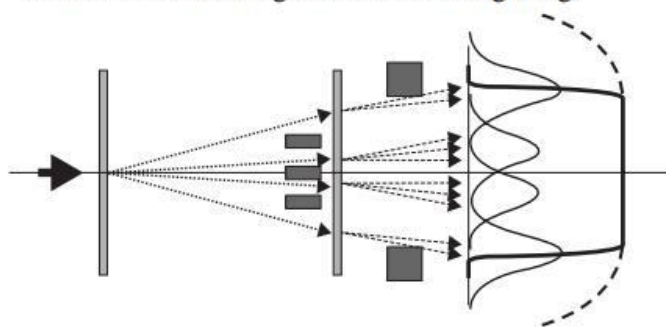
Double Scattering with contoured scatterer



Double Scattering with dual ring

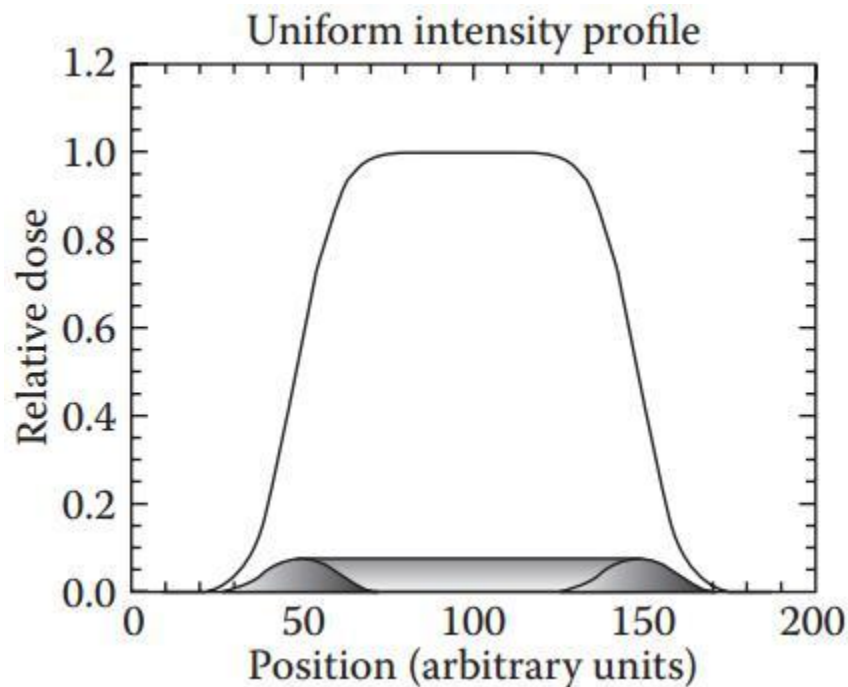


Double Scattering with occluding ring



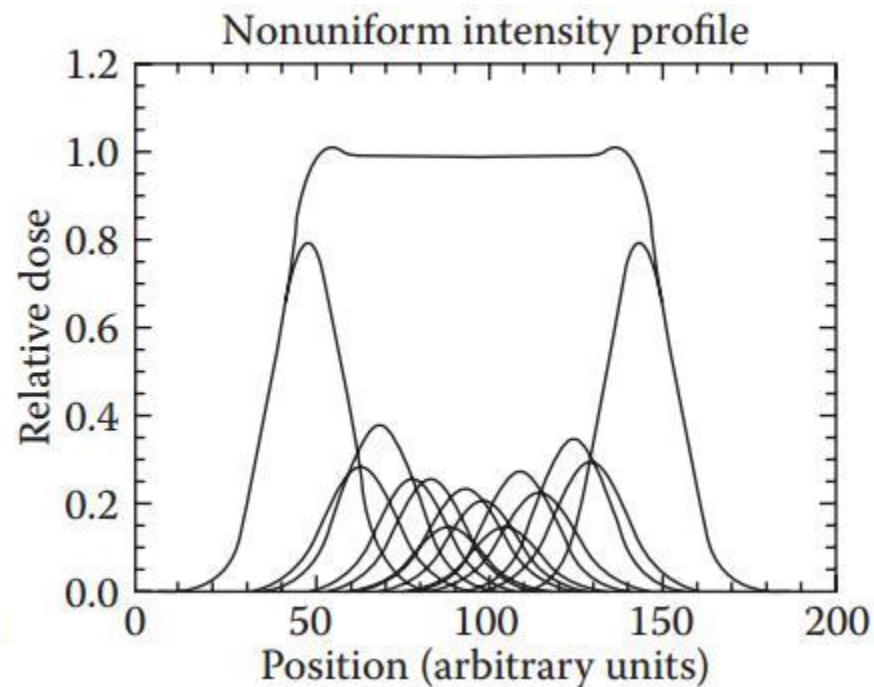
Scanning

Uniform



Gaussian is good!!

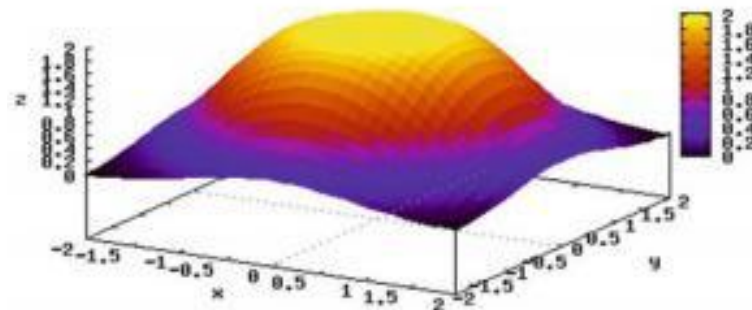
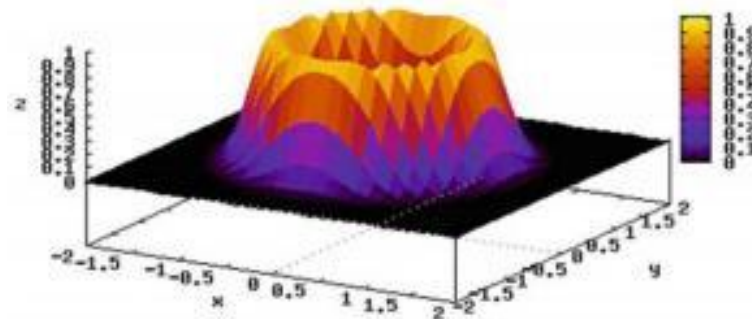
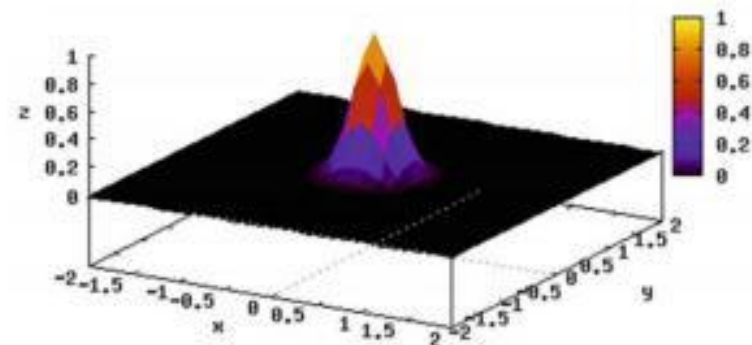
Discrete



FWHM = 2.35σ
Penumbra $\geq 1.1 \sigma$

Wobbling

Scanning + Scattering



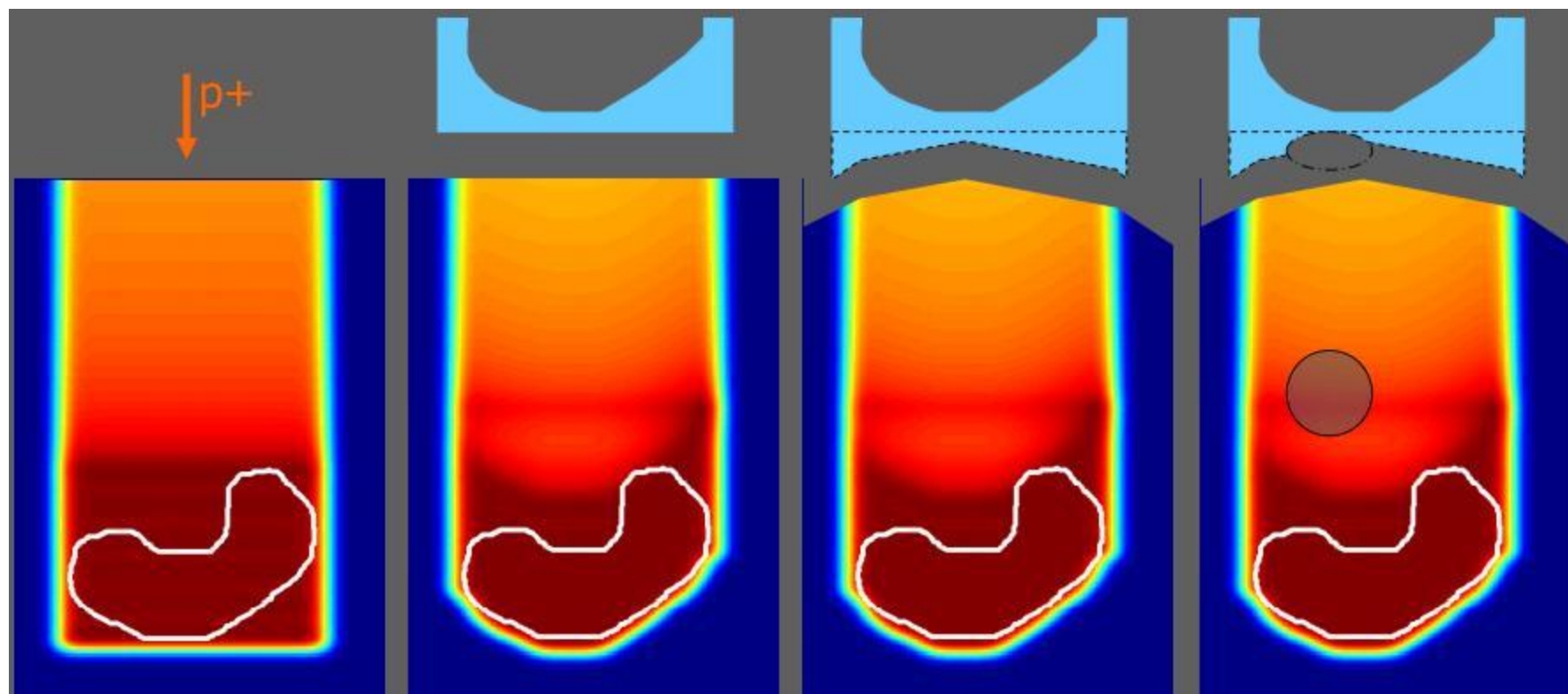
3D dose distribution

3D box

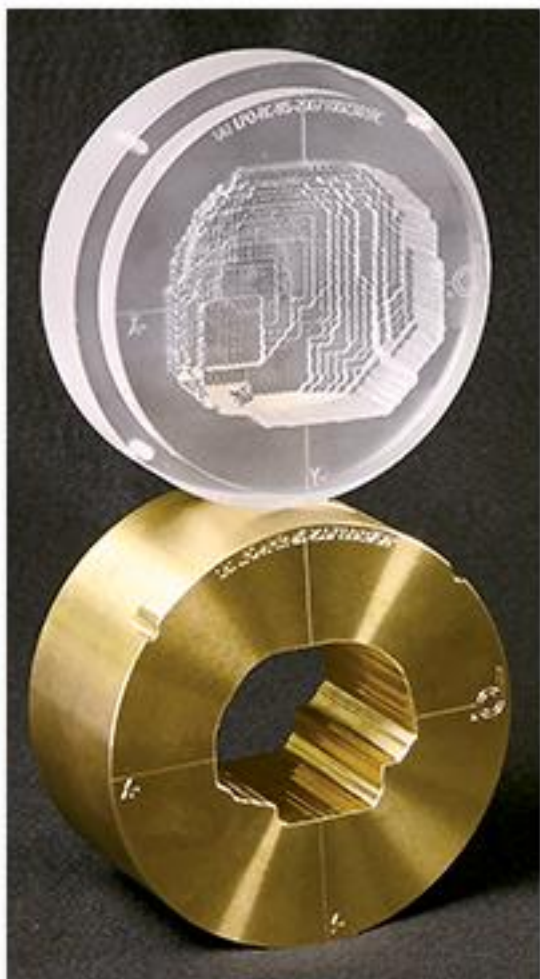
Shape distal end

Shape entrance

Inhomogeneities

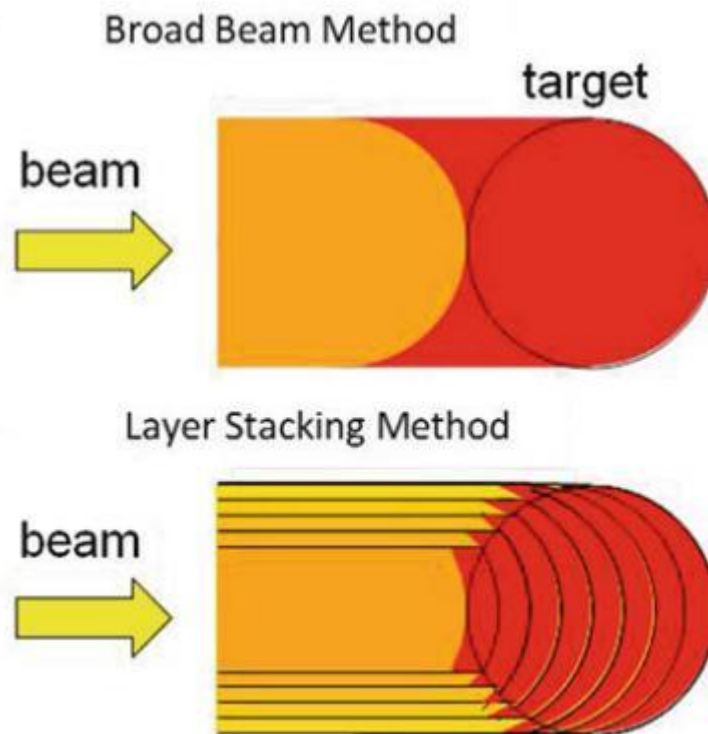


Collimators and compensator



In any 3D dose spread
without pencil beam scanning

Multileaf collimator



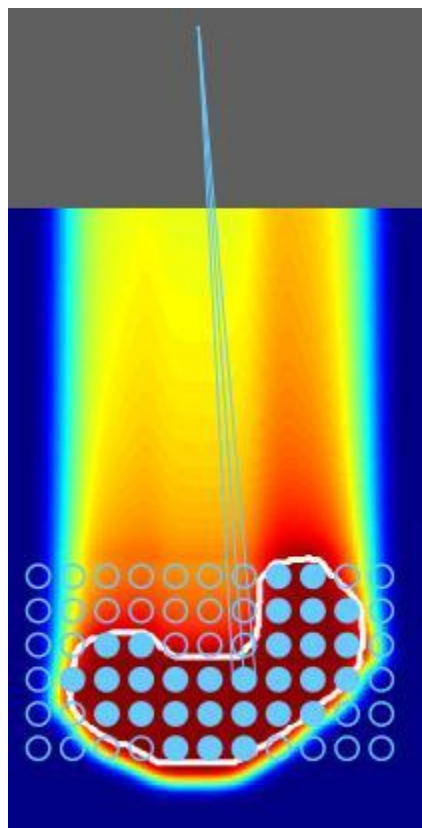
Small ridge + range shifter

Pencil beam scanning

Volume divided in 3D spot positions

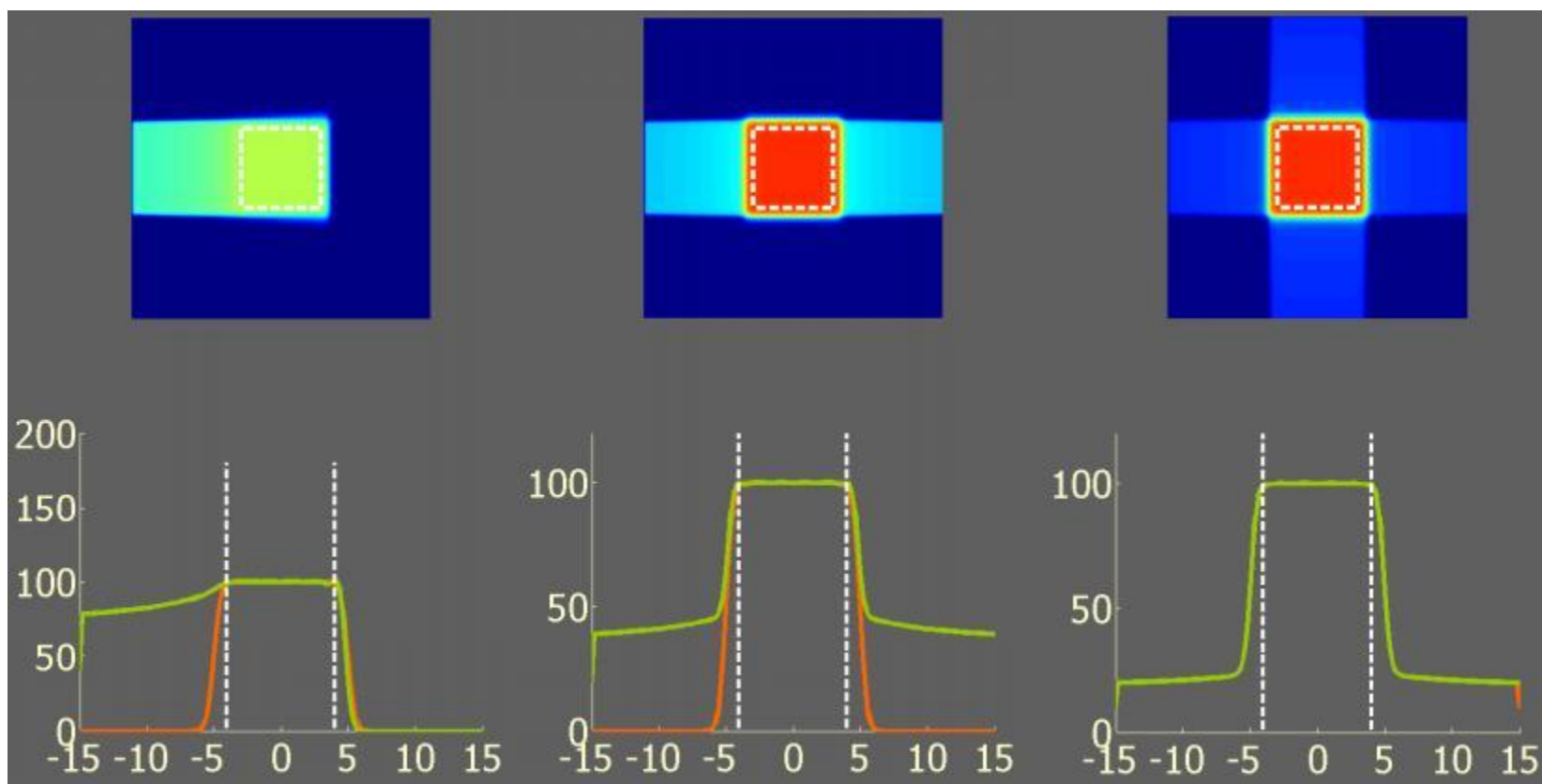
- z by energy
- x,y by scanning

Spots with \neq number of particles



- spot scanning
- raster scanning

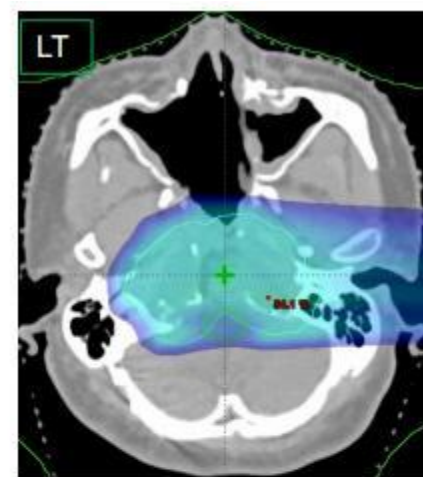
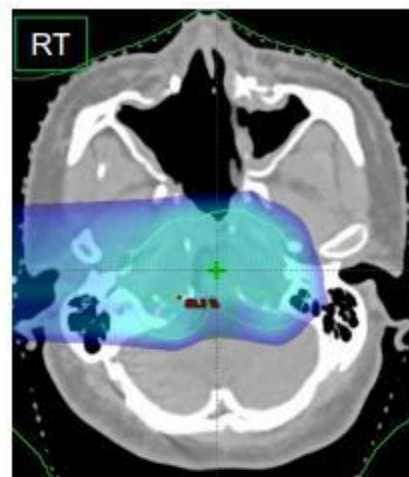
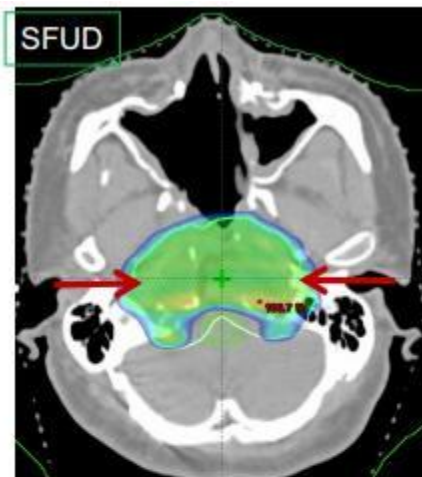
Multi fields



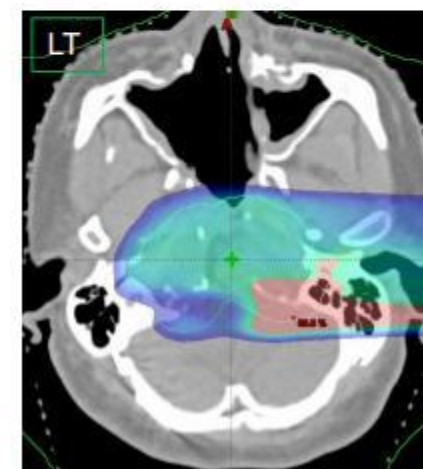
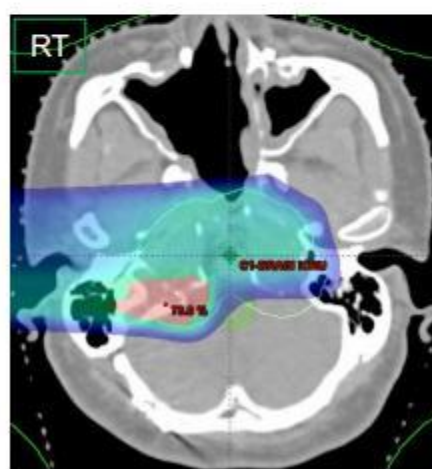
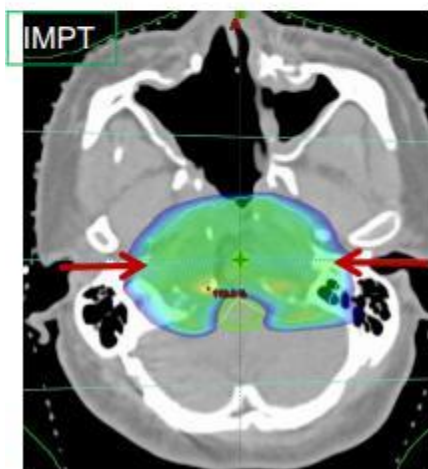
Treatment plan

For pencil beam

Single
Field
Optimization

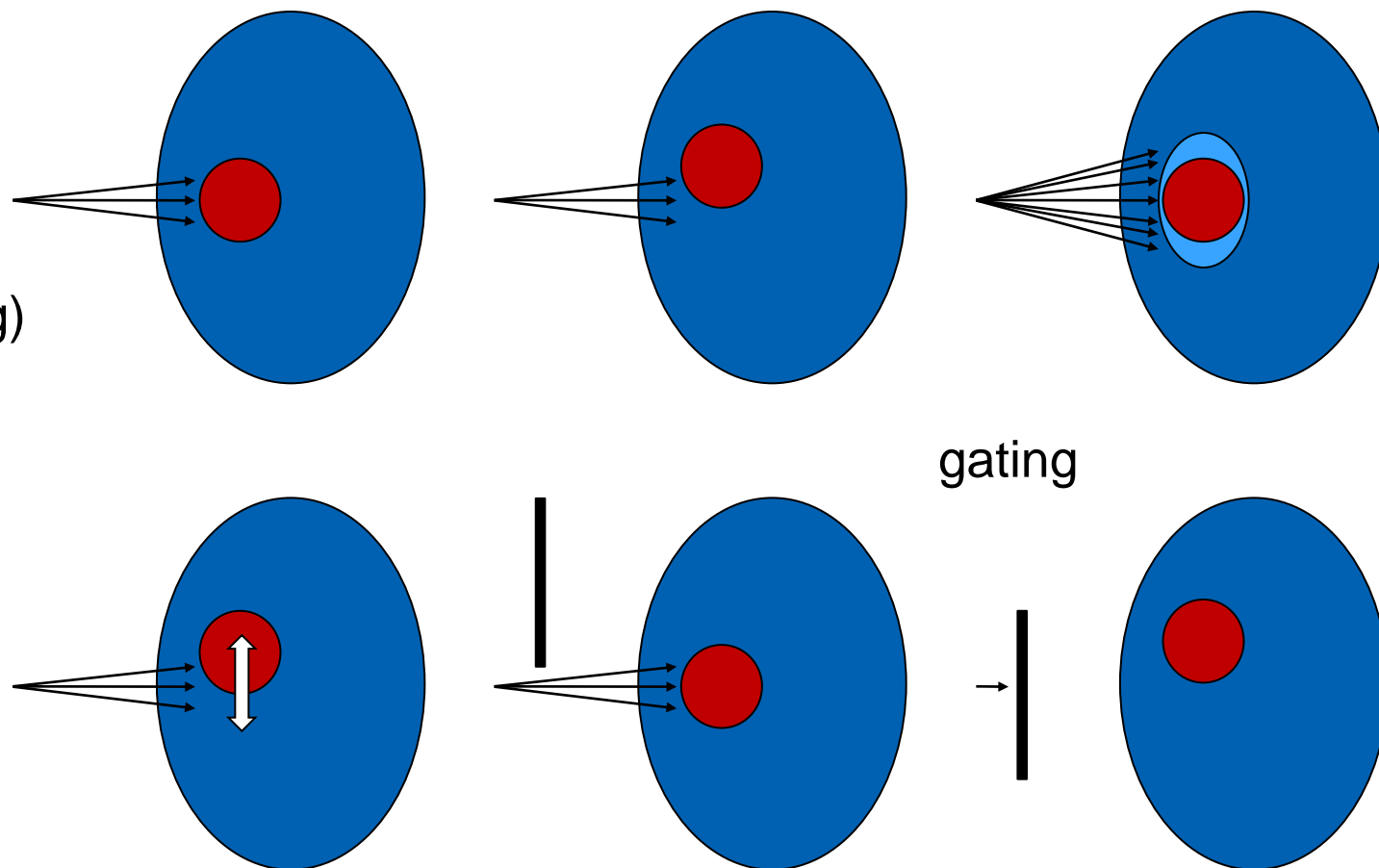


Multi
Field
Optimization



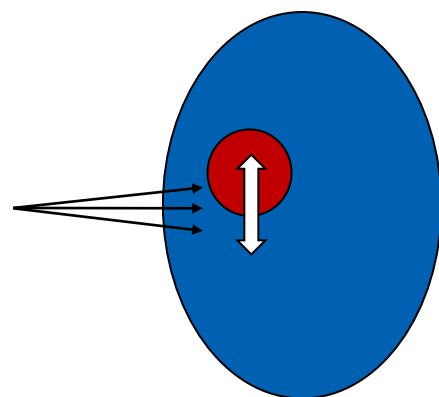
Moving target

Scattering
Wobbling
Uniform
(Fast scanning)

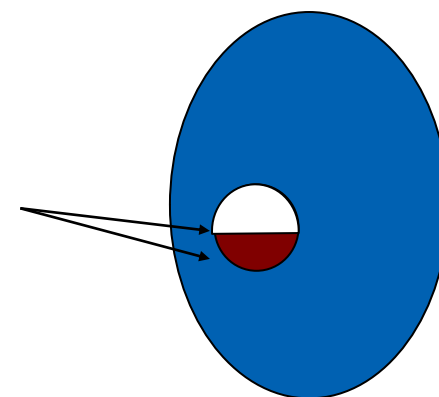
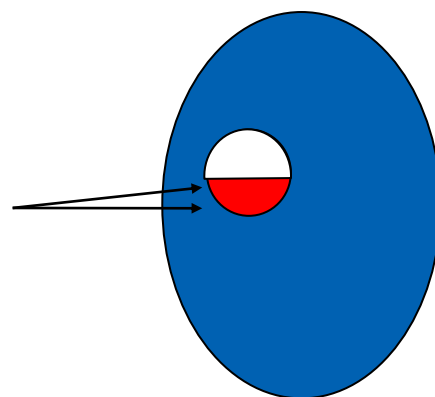


Moving target

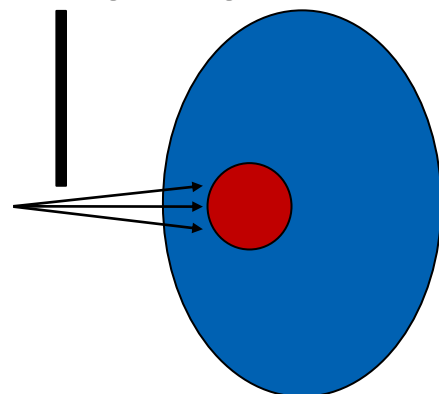
Pencil
Beam
Scanning



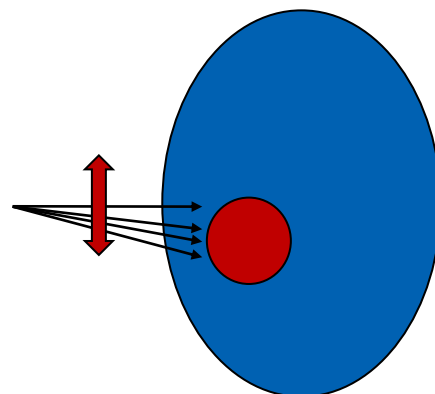
Interplay effect



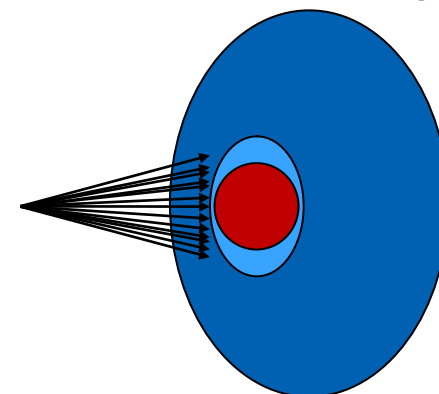
gating



guided



rescanning



Particles

Protons:

- similar to photons
- cheap
- well known
- constant RBE
- no fragments

Carbon ions:

- higher RBE
- expensive
- not constant RBE
- fragments
- better trajectories

Accelerators

Cyclotron:

- fixed energy
- stable beam current
- continuous beam
- small
- protons only

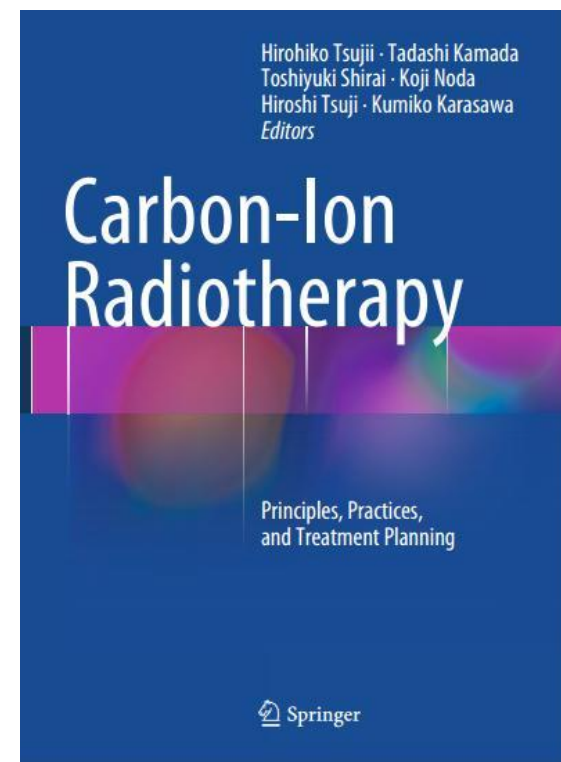
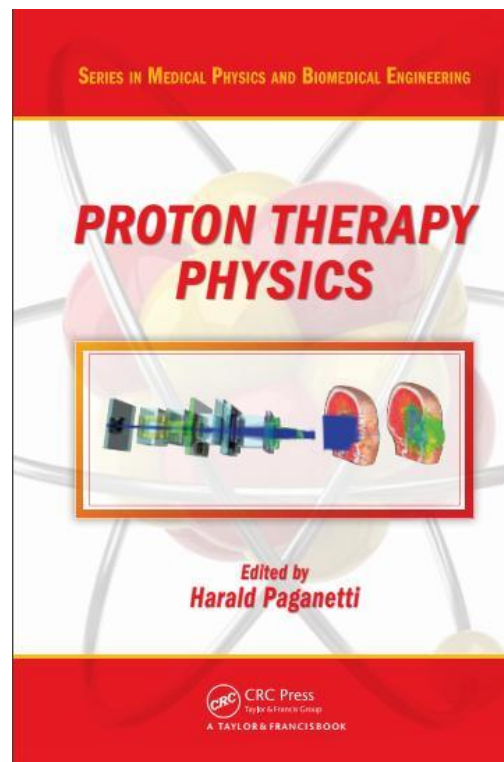
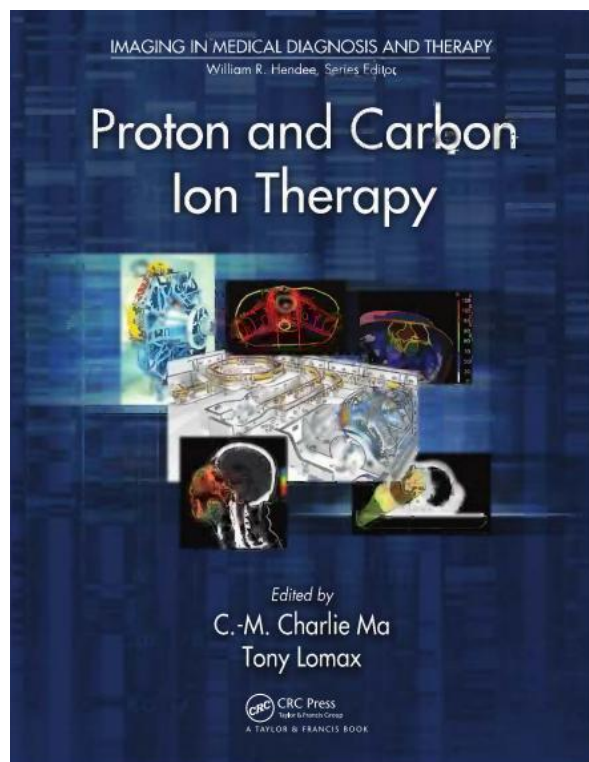
Synchrotron:

- variable energy
- not stable beam current
- pulsed beam
- large (for ions)
- protons and heavy ions

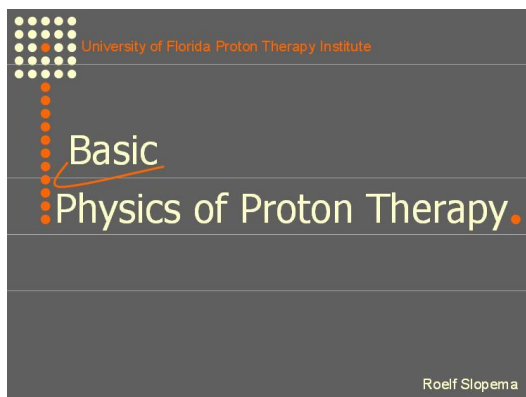
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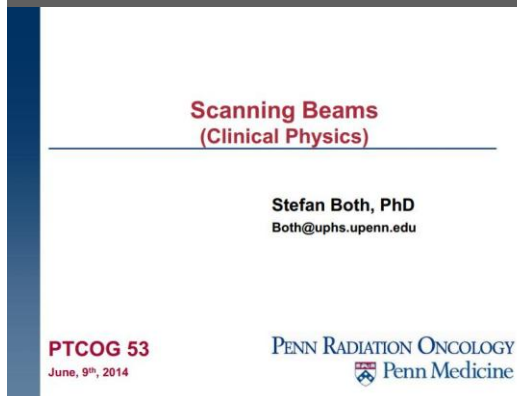
Books



Presentations



Roelf Slopema
AAPM Symposium
May 8-9, 2009, Baltimore, MD, USAR



Stefan Both
PTCOG53 Educational Workshop
June 9-11, 2014, Shanghai, China



Thank you for your attention

