Fast scanning techniques for cancer therapy with hadrons

–

a domain of cyclotrons

Marco Schippers,
David Meer, Eros Pedroni

(thanks to all collegues in the proton therapy field)

PSI PAUL SCHERRER INSTITUT

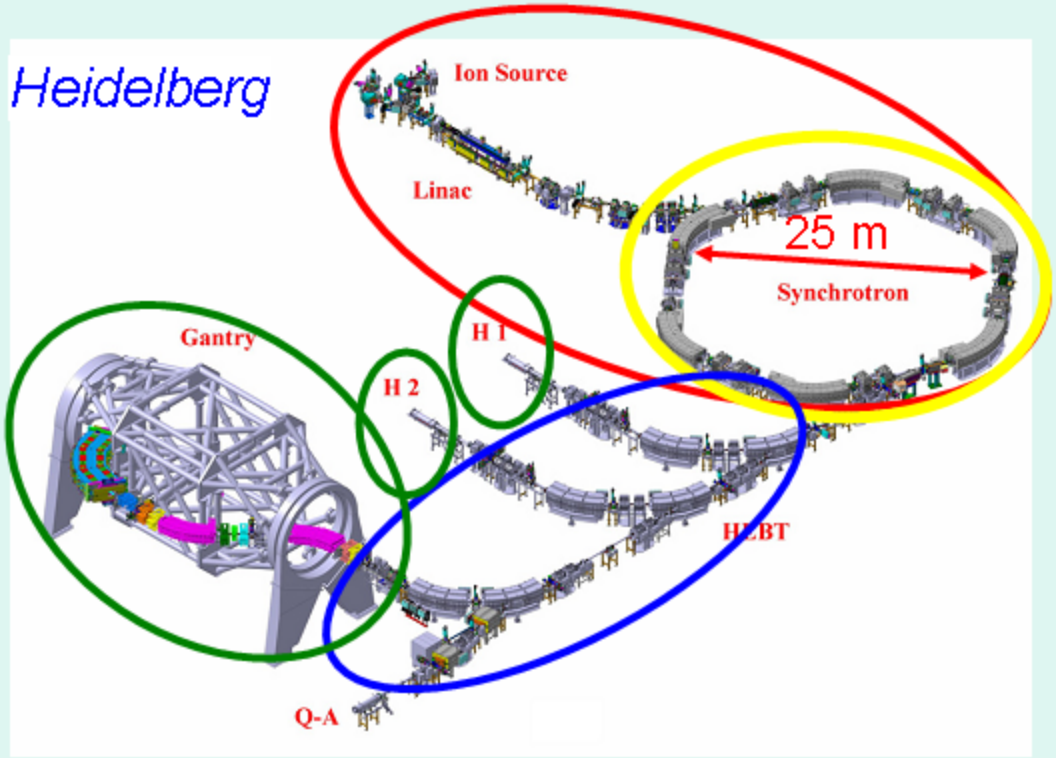
Hadron therapy facility

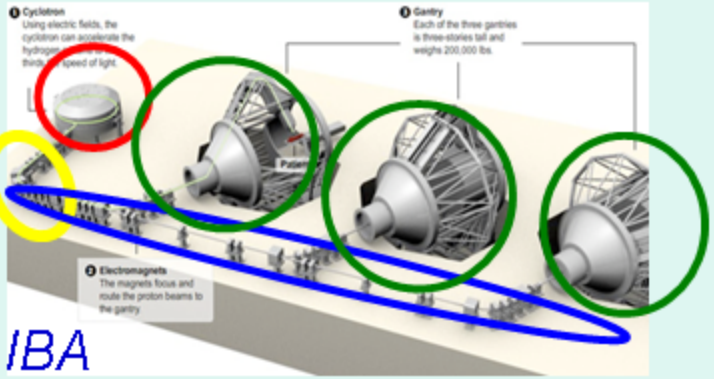
accelerator

energy selection

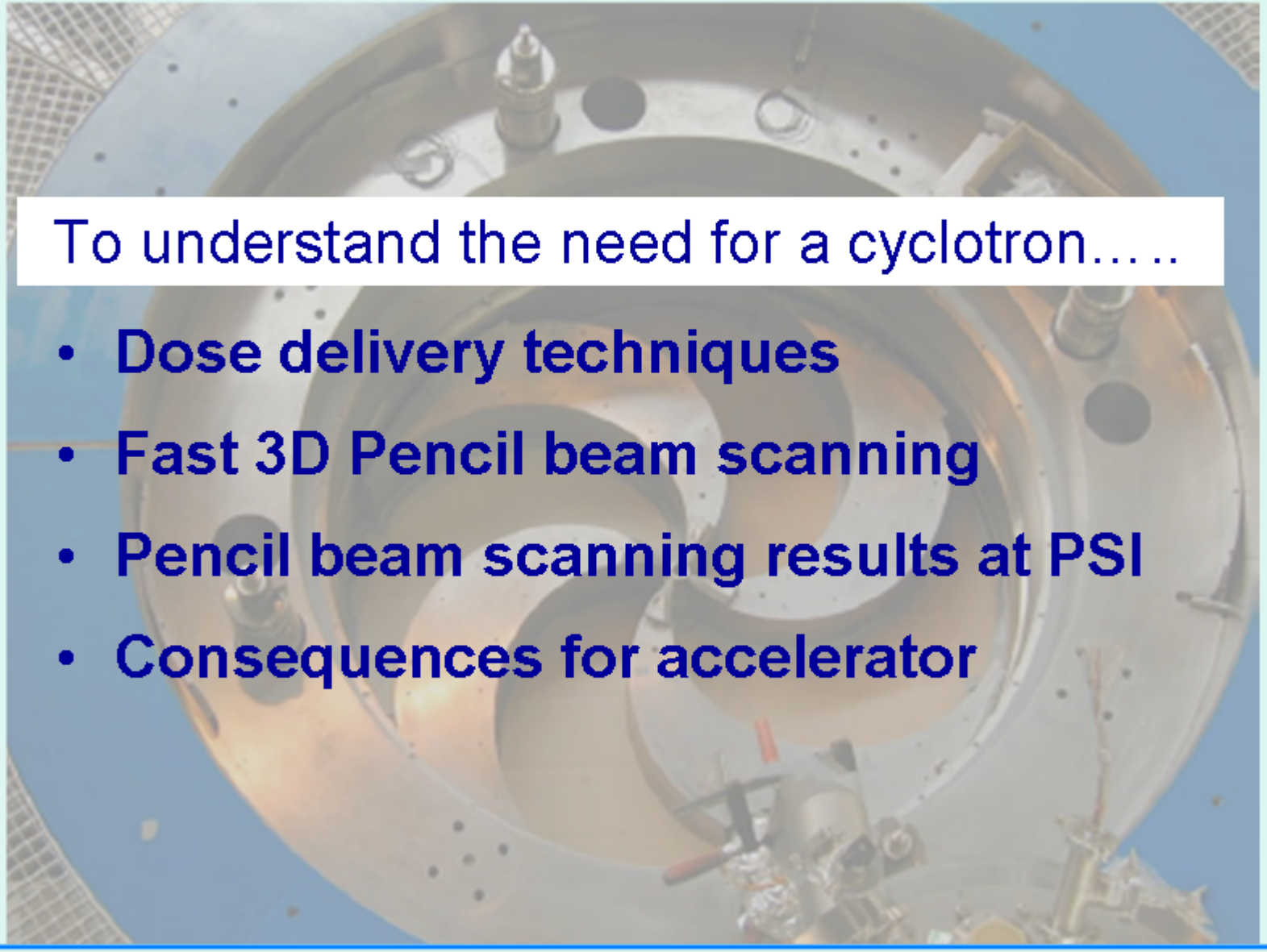
beam transport

gantry / fixed hor. line





Fast scanning: a domain of cyclotrons

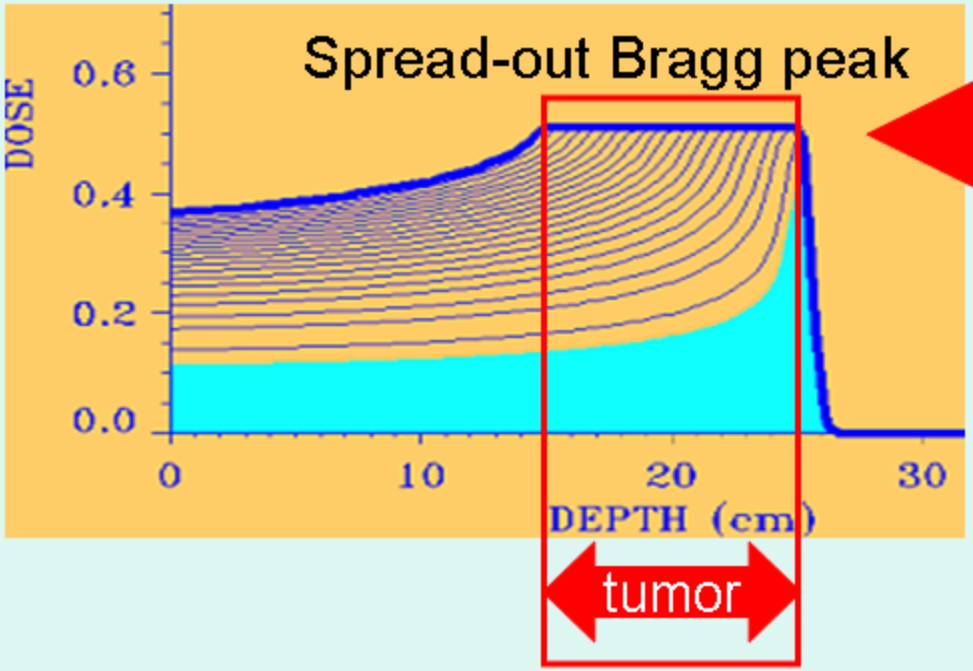


To understand the need for a cyclotron…..

- **Dose delivery techniques**
- **Fast 3D Pencil beam scanning**
- **Pencil beam scanning results at PSI**
- **Consequences for accelerator**

Dose delivery techniques

Dose delivery techniques: **Depth**



Range

Tumor **distal edge**

→ Range

→ Maximum Energy

per field → „slow“ (sec)

Tumor **thickness**

→ spread-out Bragg peak

→ energy modulation

During trmt → „fast“ (<0.1 sec)

Methods:

1) at accelerator
2) just before patient (in “nozzle”)

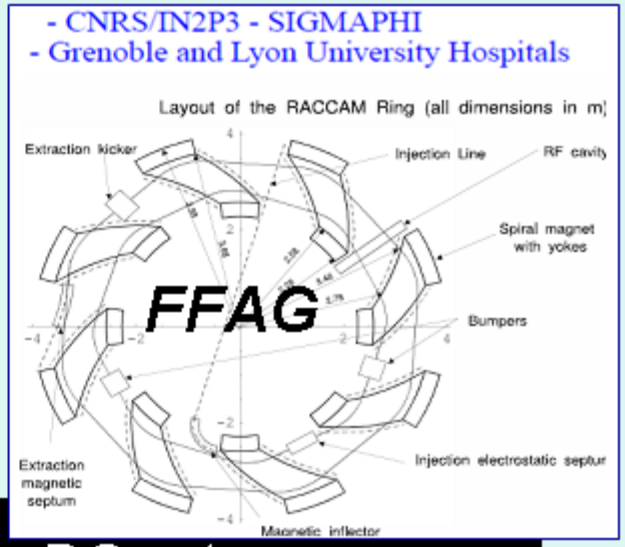
Dose delivery techniques: **Depth**

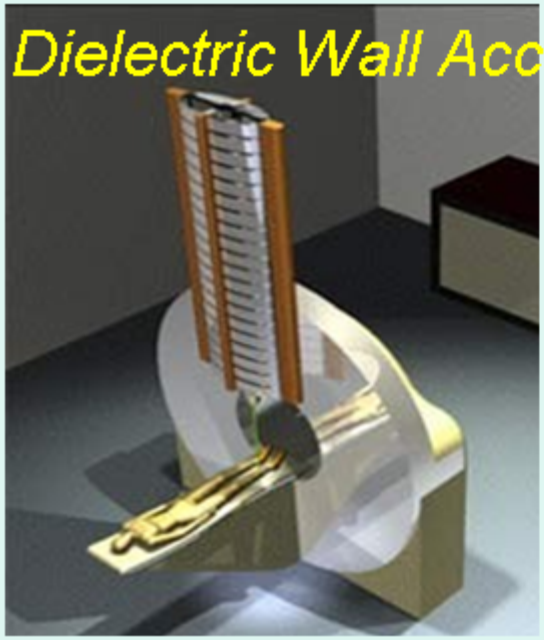
Vary energy at accelerator:

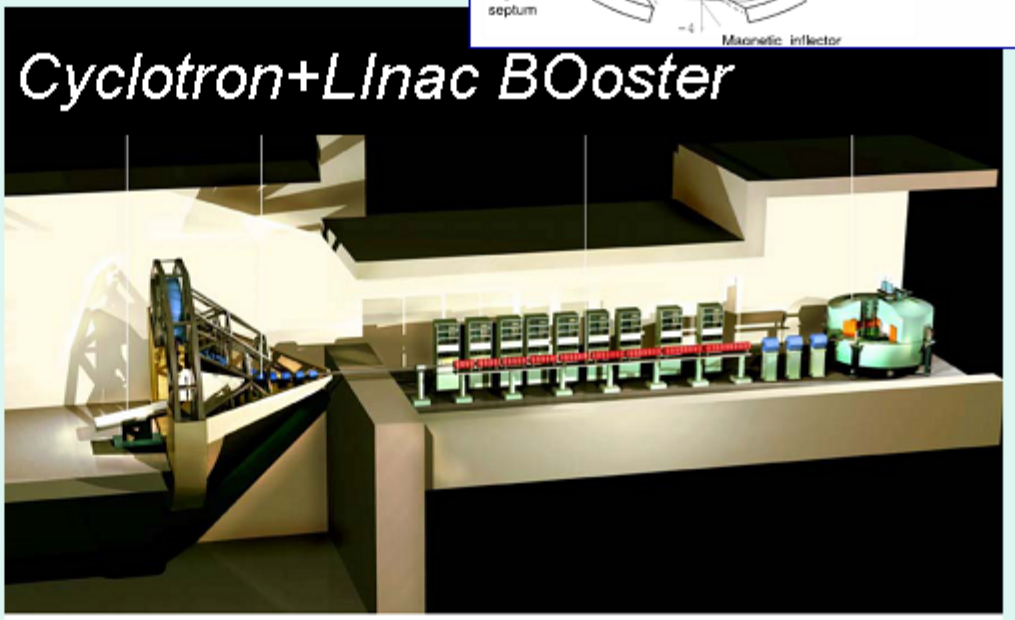
FFAG, Linear accelators:

- Pulsed machines
- Energy adjustable per pulse

Suitable for E-modulation
if Energy and **Dose** are correct at **each** pulse



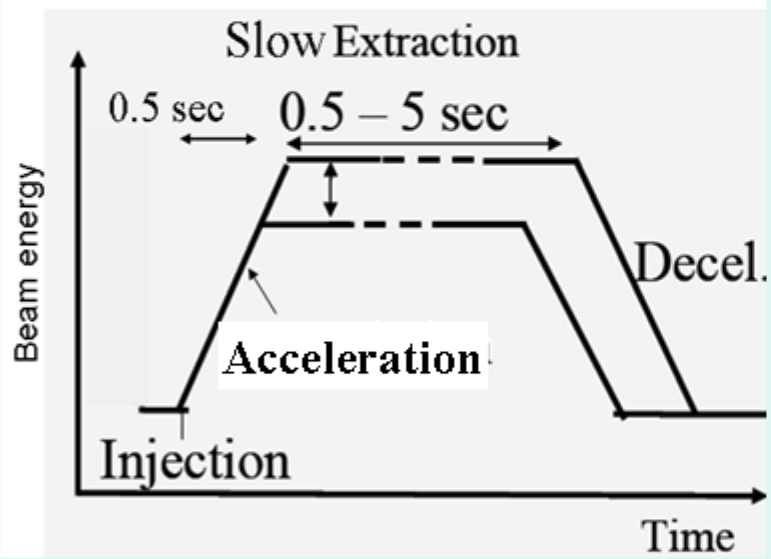




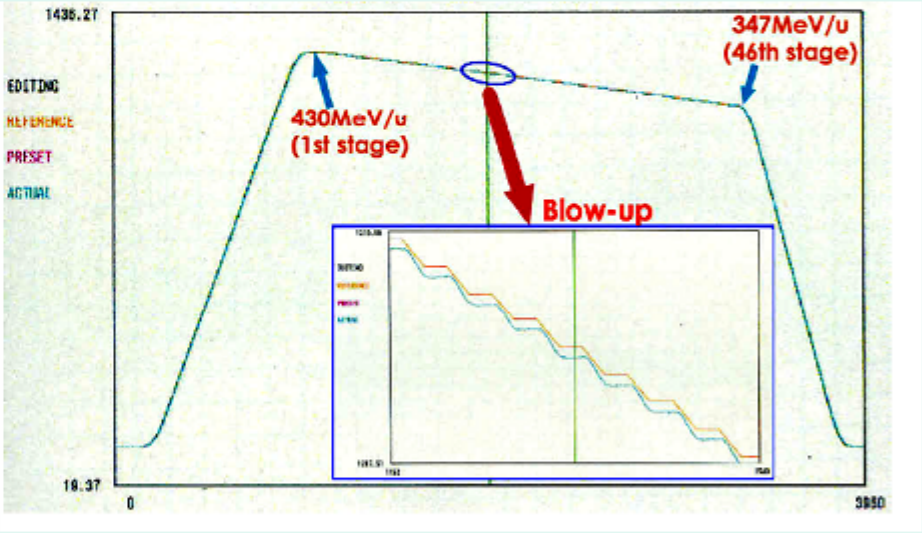
Dose delivery techniques: **Depth**

Vary energy at accelerator: **synchrotron**

Vary energy at each spill:



Vary energy during a spill:



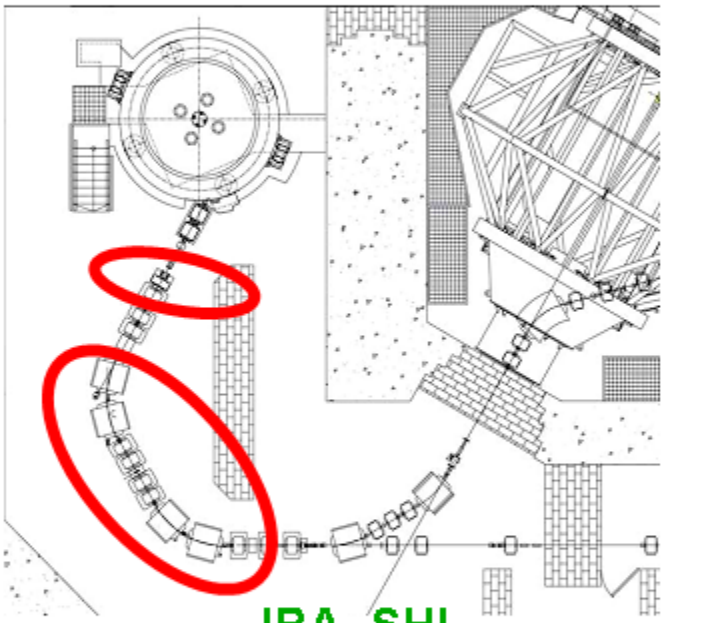
Iwata et al., IPAC'10, Kyoto, Japan MOPEA008

➔ Sets range

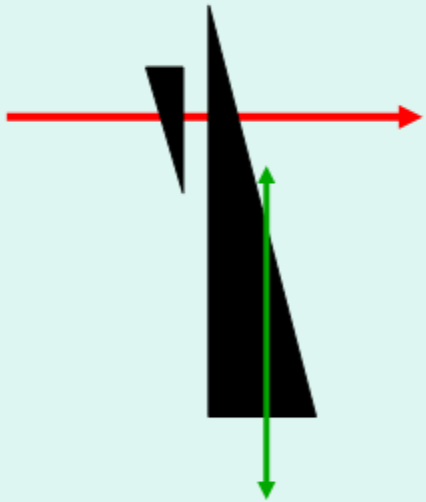
➔ **Additionally**: Fast energy modulation in nozzle

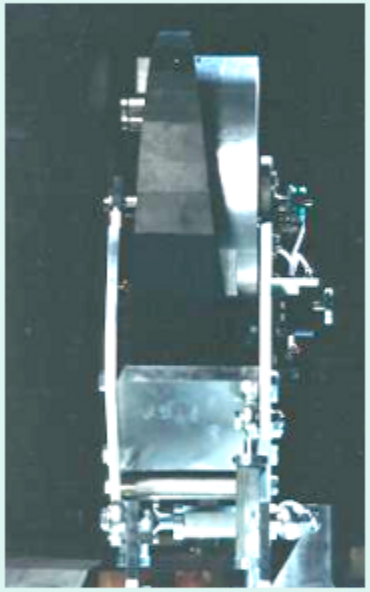
Dose delivery techniques: **Depth**

Vary energy at accelerator: **cyclotron**



IBA, SHI





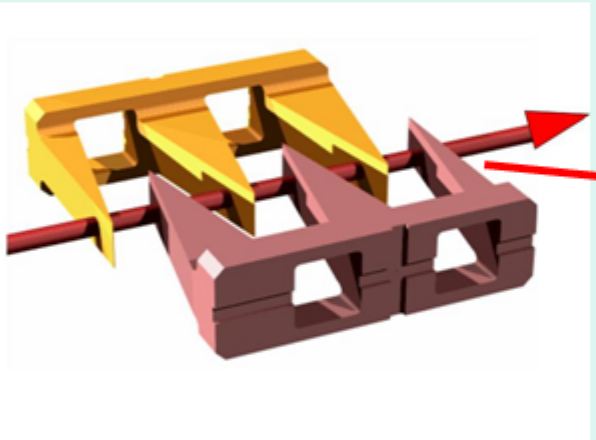
Rolled-up wedge degrader
220-70 MeV (IBA)

➔ Sets range
➔ **Additionally**: Fast energy modulation in nozzle

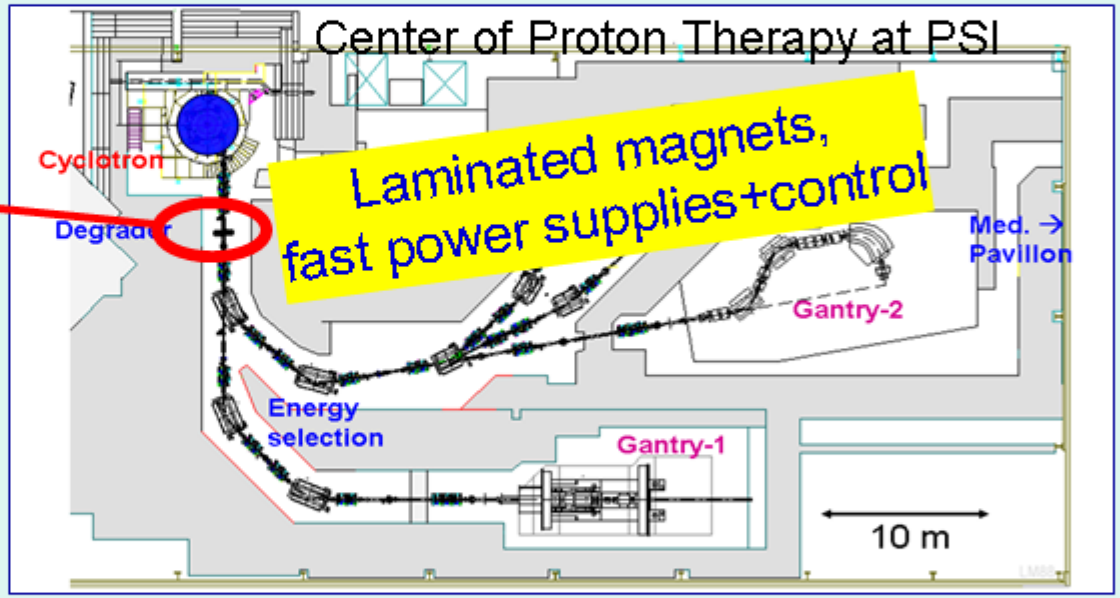
Dose delivery techniques: **Depth**

Vary energy at accelerator: **cyclotron**

PSI and VARIAN: **fast** degrader + laminated magnets



Multiple wedge degrader
238-70 MeV



→ 5 mm ΔRange in 50 ms

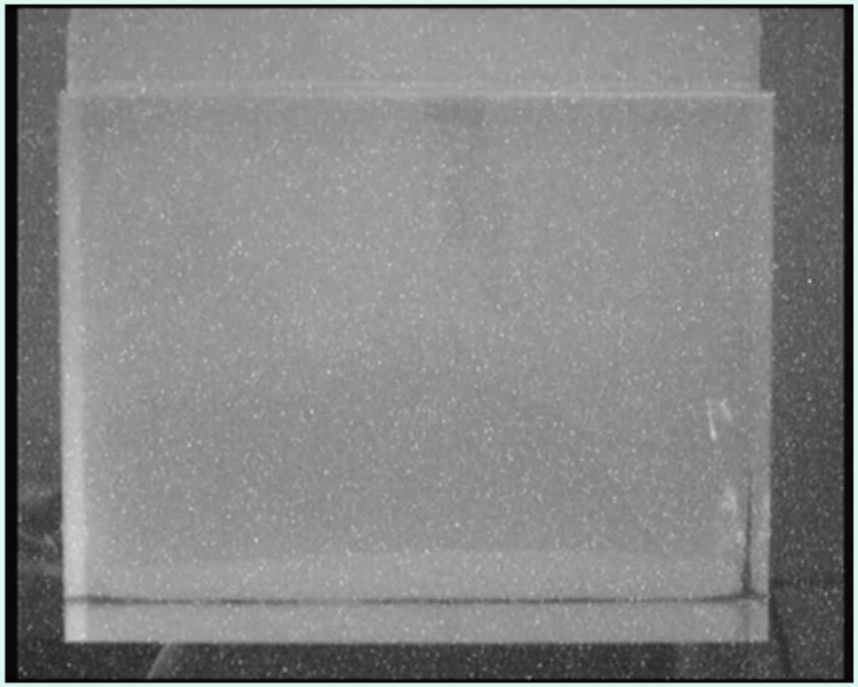
Gantry-2: No Additional energy modulation in nozzle

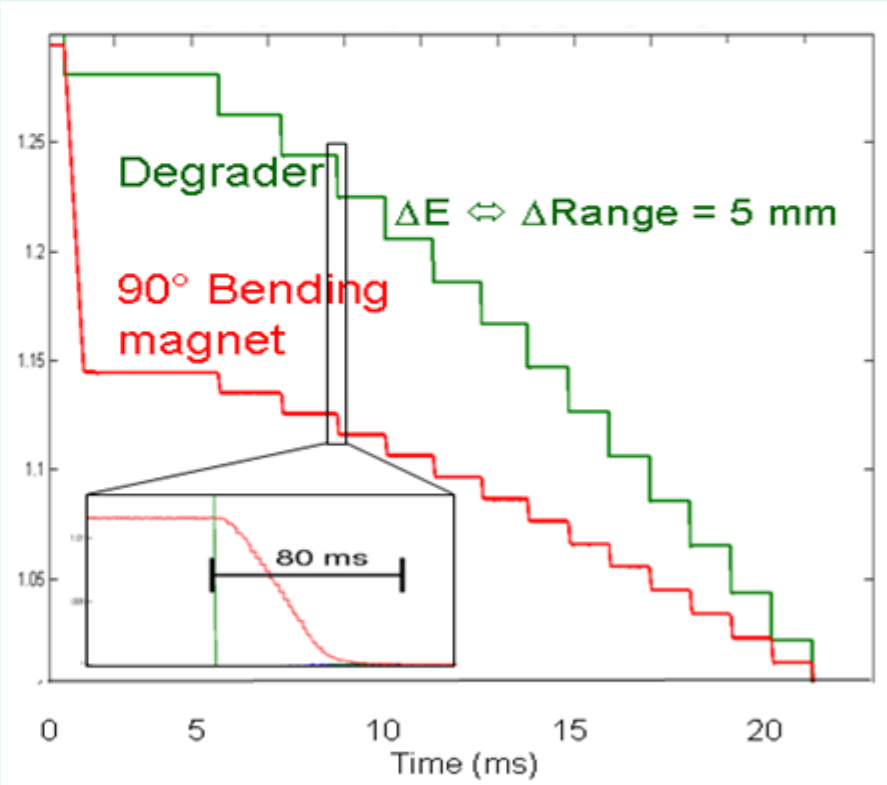
Dose delivery techniques: **Depth**

PSI fast degrader system: in depth 5 mm in 80 ms

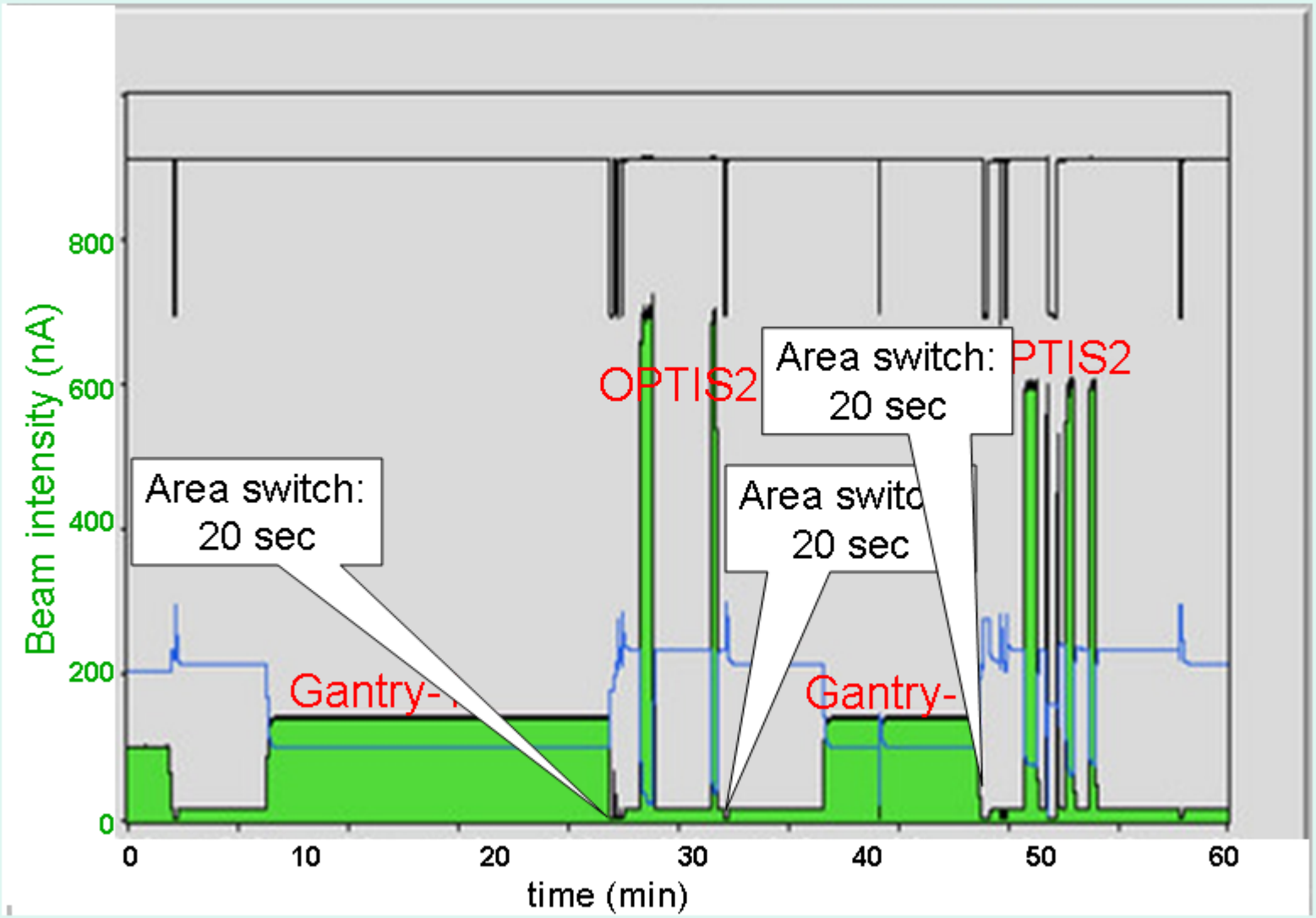
→ fast treatment

→ fast treatment area switching



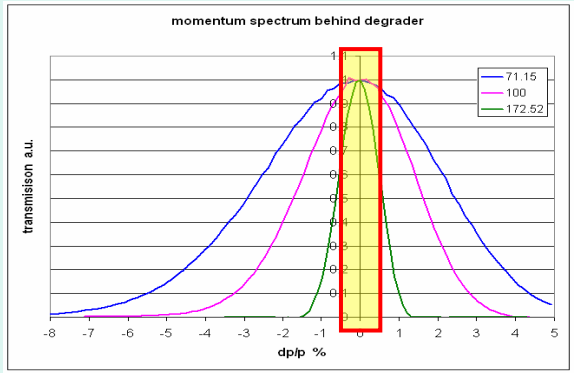


Fast magnets: quick area switching



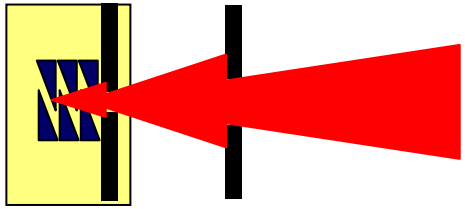
Dose delivery techniques: **Depth**

Degrader purpose: **decrease** energy



however: - **energy spread** increases

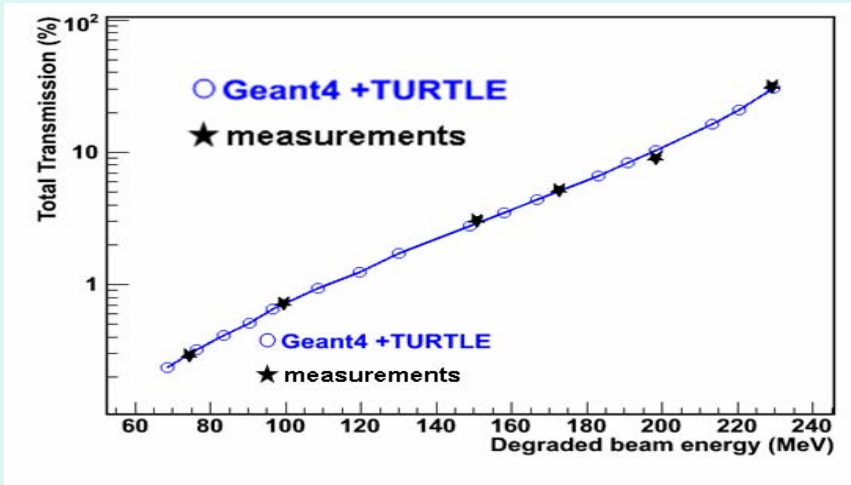
degrader system



Collimators define

transmitted beam size

- **beam size** increases due to multiple scattering
- **beam loss** due to nuclear reactions in degrader



Van Goethem et al., Phys. Med. Biol. 54 (2009)5831

Dose delivery techniques: **Depth**

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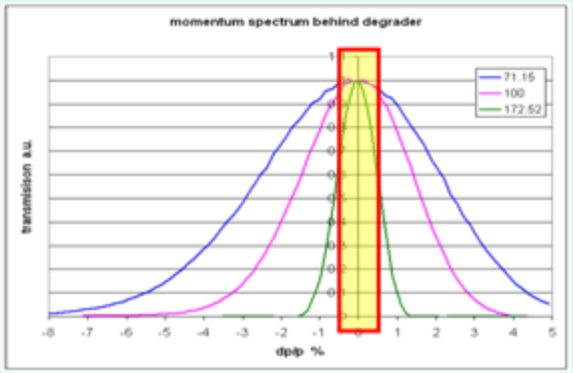

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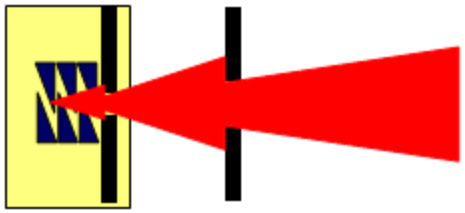

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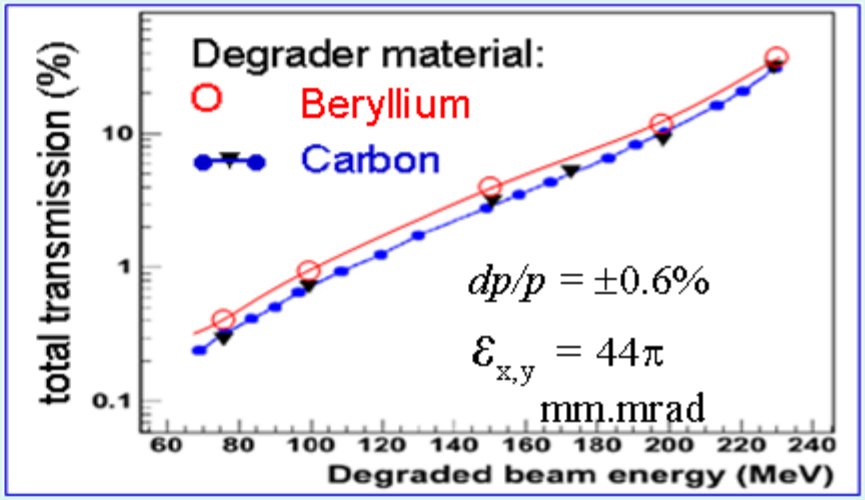

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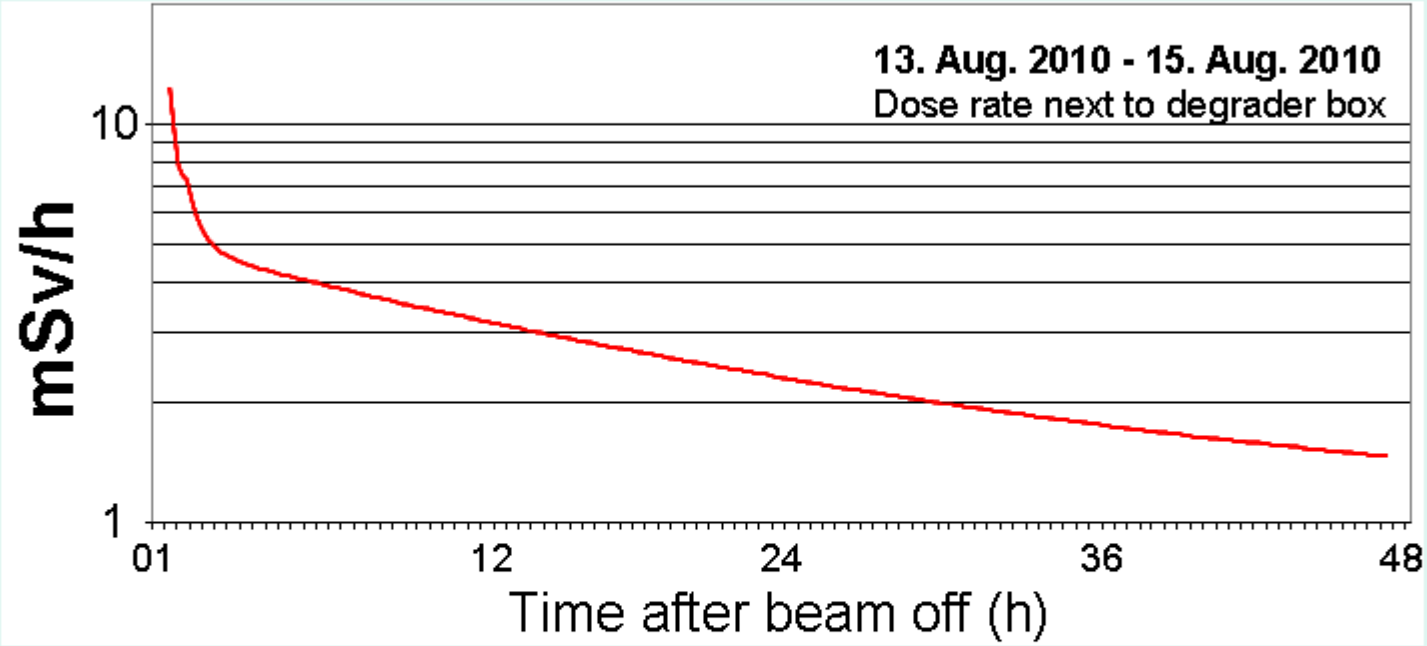
➔ Beam intensity from cyclotron must be high enough

Dose delivery techniques: **Depth**



Degrader and collimator: careful material choice

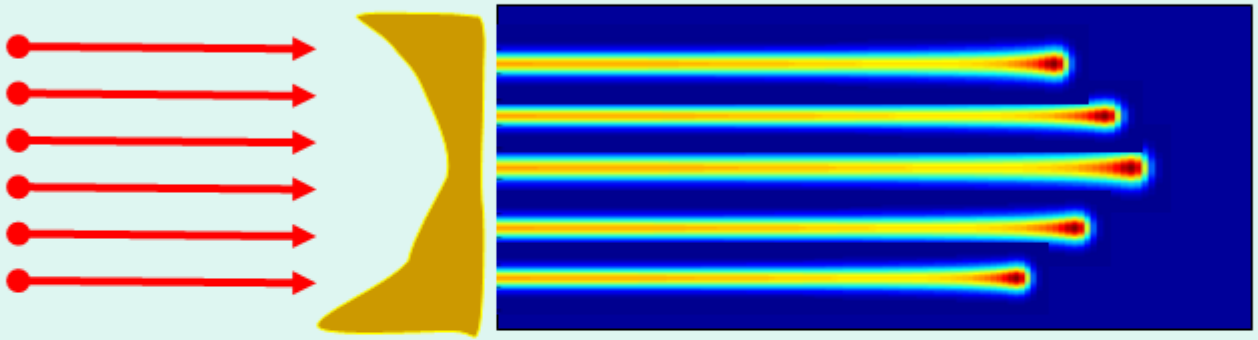
=> Activation decays quickly

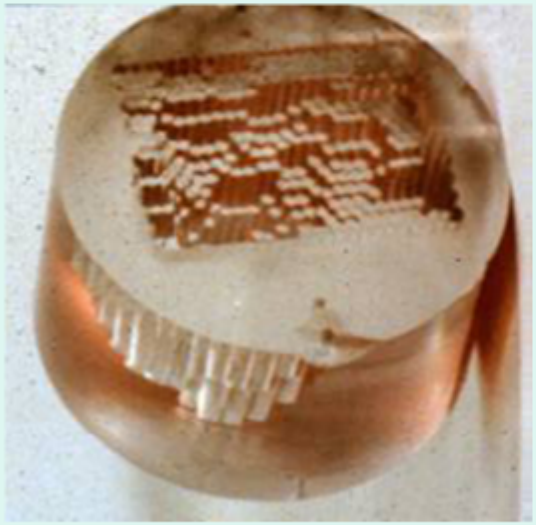
=> Amount of activated material is limited

Dose delivery techniques: **Depth**

Vary energy in nozzle (cyclotron and synchrotron)

Max penetration depth: bolus or compensator



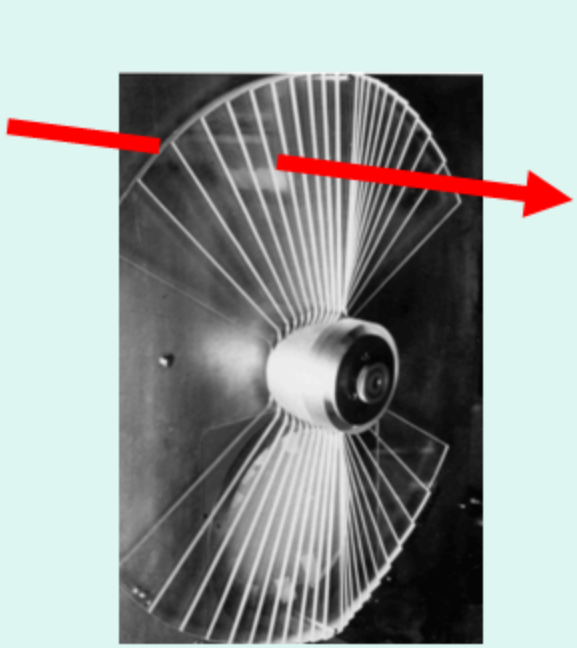


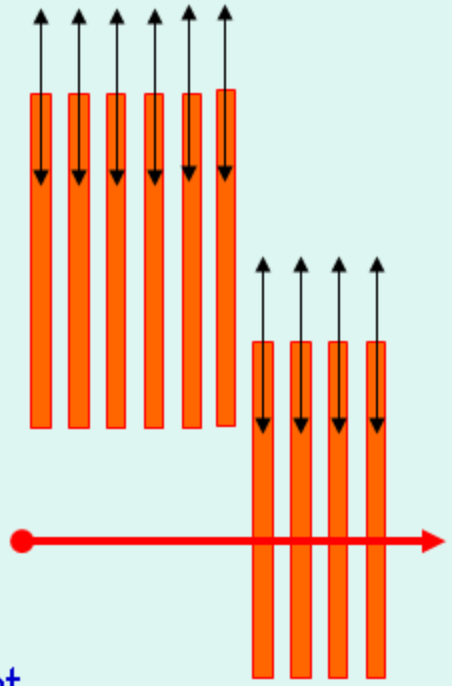
But: material in front of patient
- increases scatter → unsharp edges
- enter treatment room to change parts

Dose delivery techniques: **Depth**

Vary energy in nozzle **(cyclotron and synchrotron)**

Energy modulation: rotating wheel or insertable plates

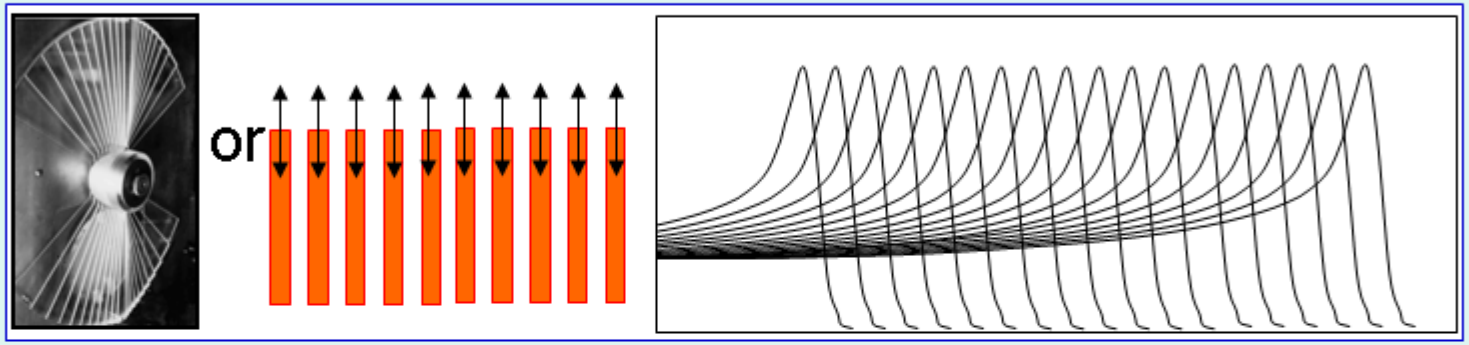




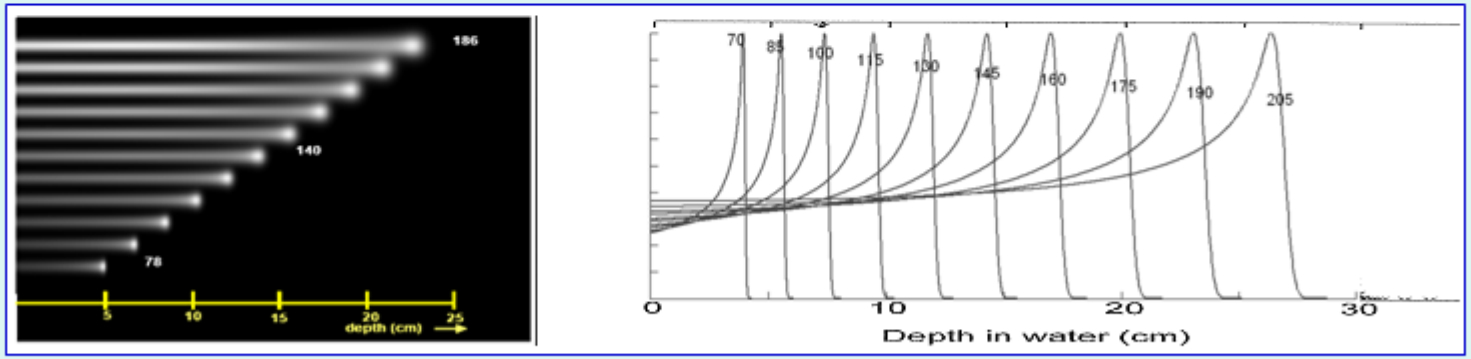
But: material in front of patient
- increases scatter → unsharp edges
(- enter treatment room to change parts)

Dose delivery techniques: **Depth**

Energy modulation in nozzle: no beam analysis

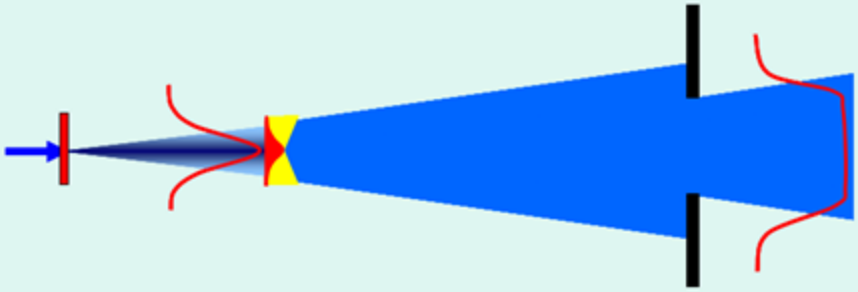


Energy modulation upstream: includes beam analysis



Dose delivery techniques: **lateral**

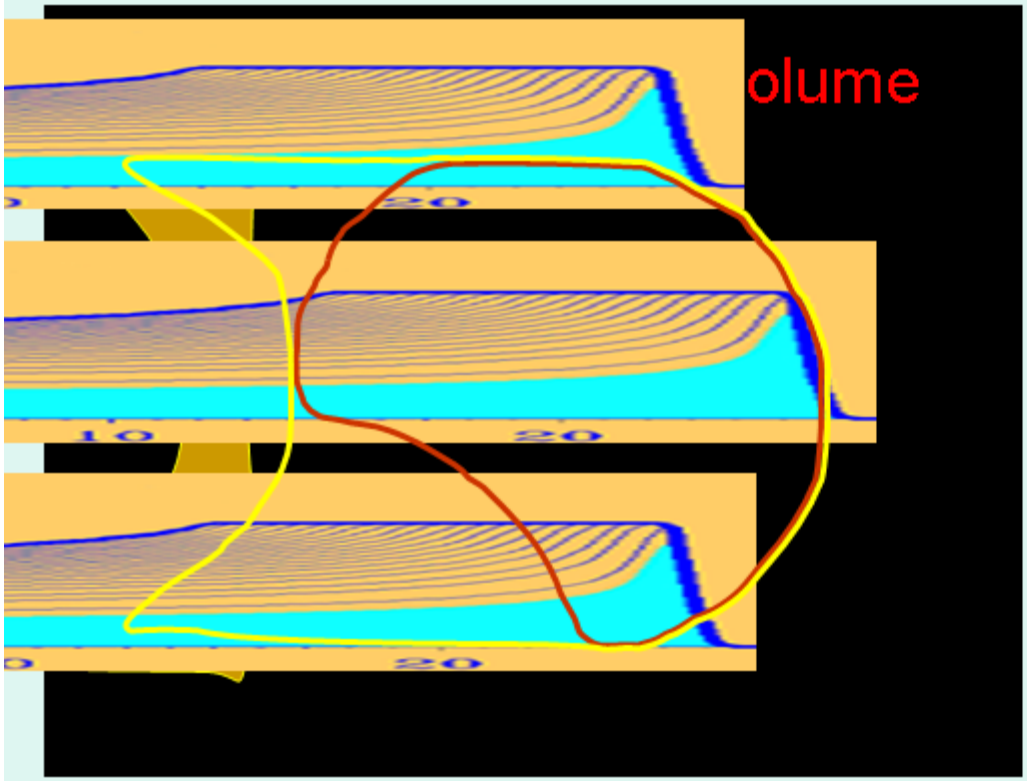
Scatter technique



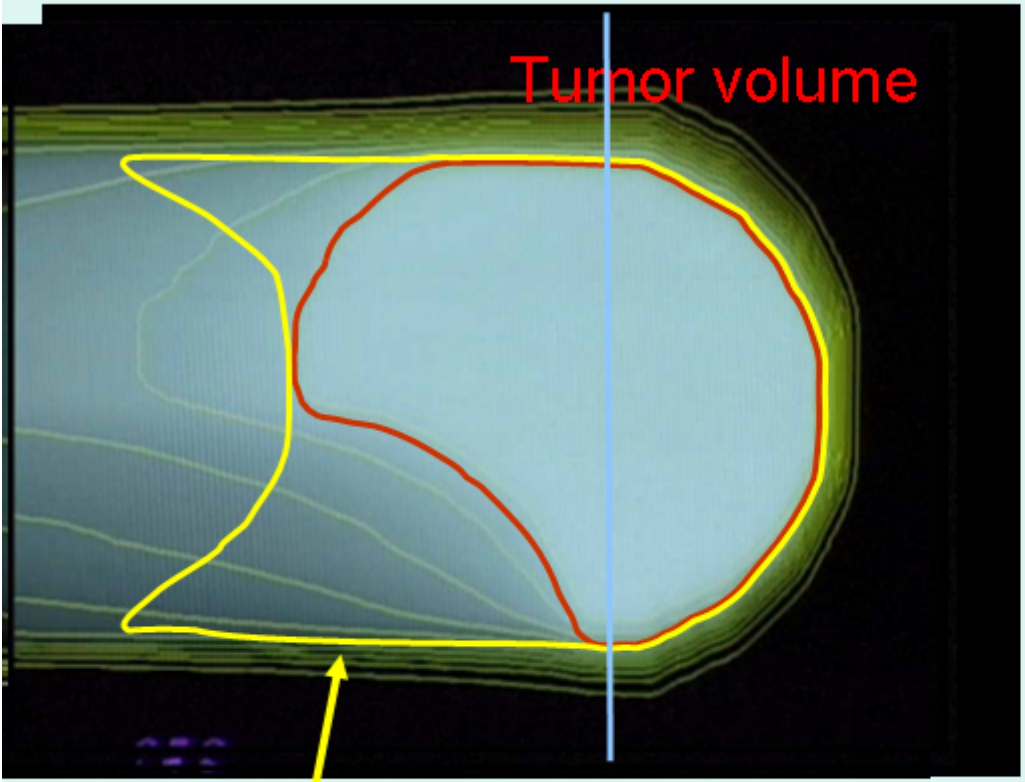
Scatter system

Collimator

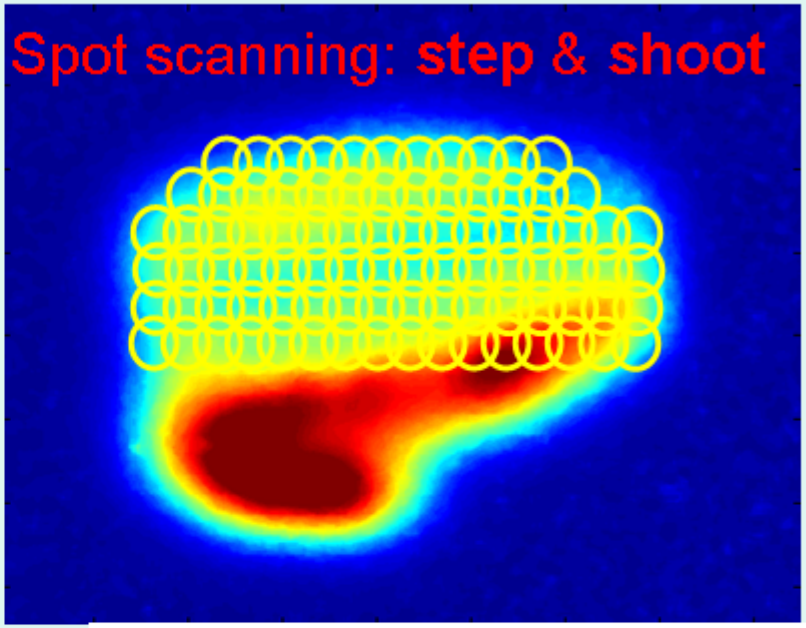
Scattered beam



Spot scanning



Dose distribution of scattered beam

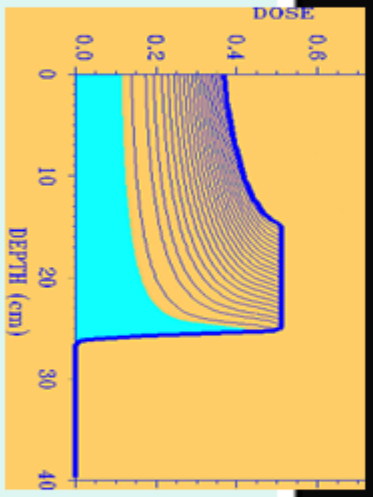


Beam size 7 mm FWHM
5 mm steps
10'000 spots/liter (21 x 21 x 21)
Dose painted only once
~1 Gy / liter/minute

Requirements for accelerator:

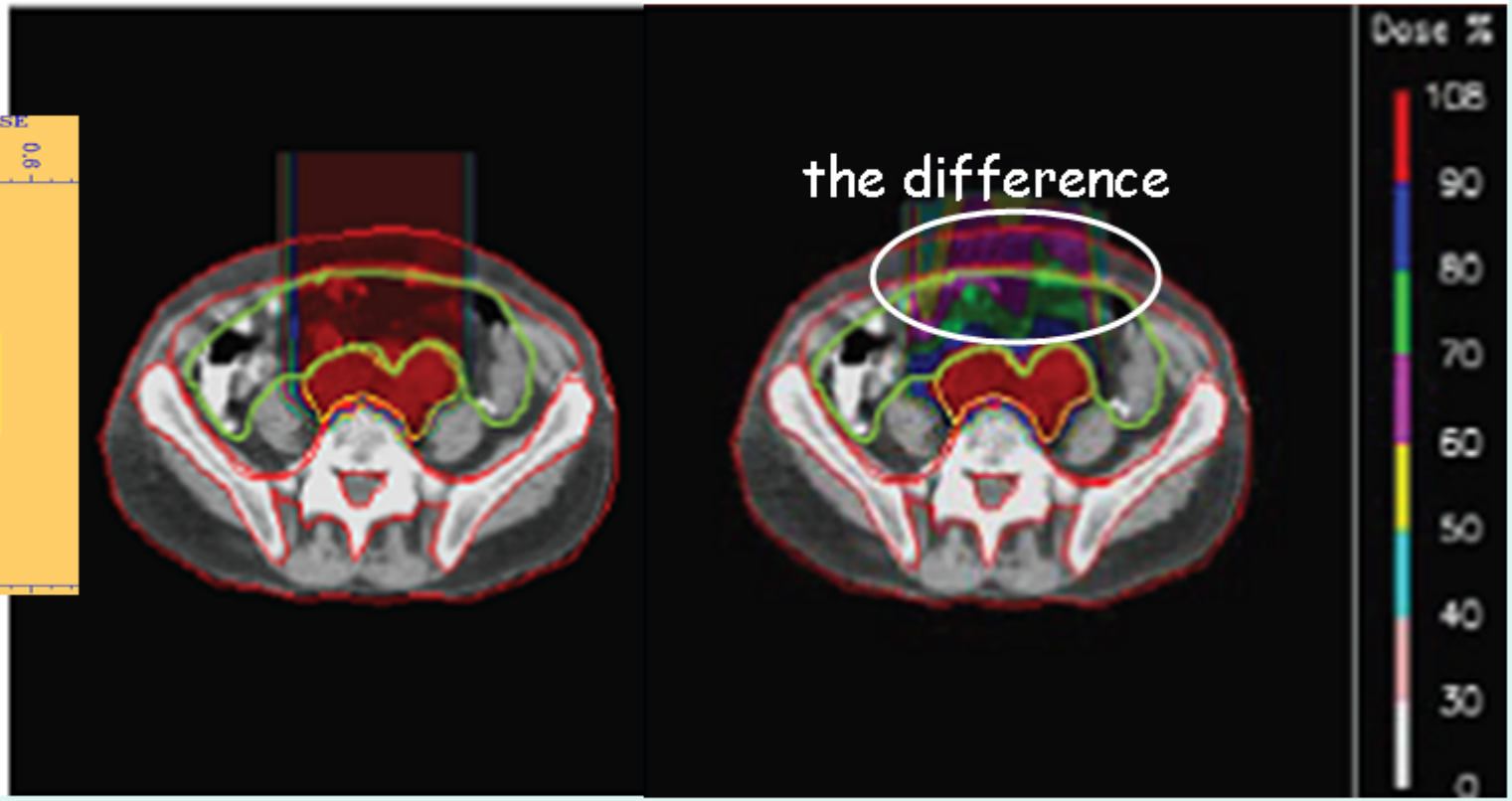
- stable beam position

Scattering – Scanning

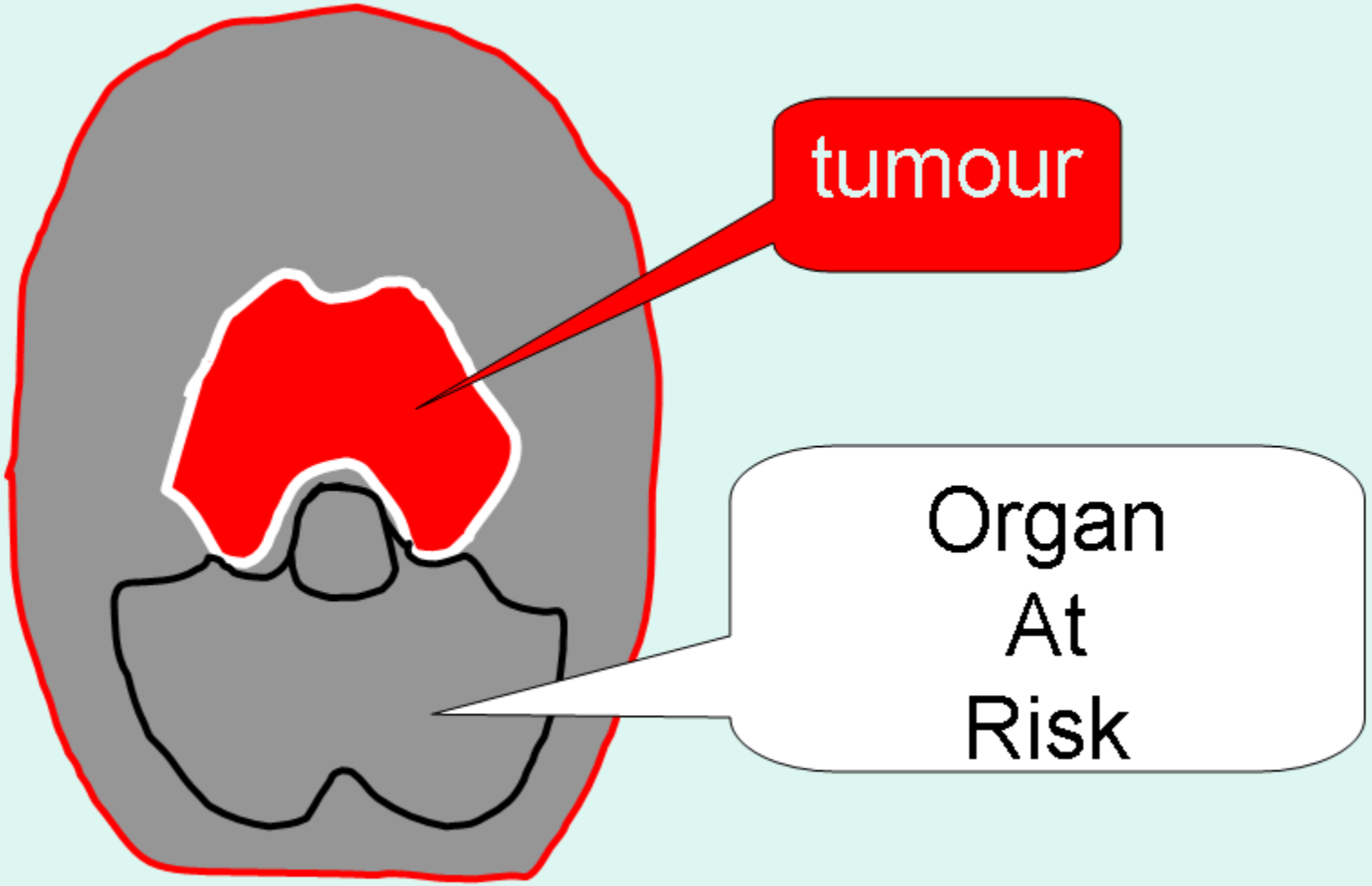


Scattered beam

Scanned beam



Intensity Modulated Proton Therapy



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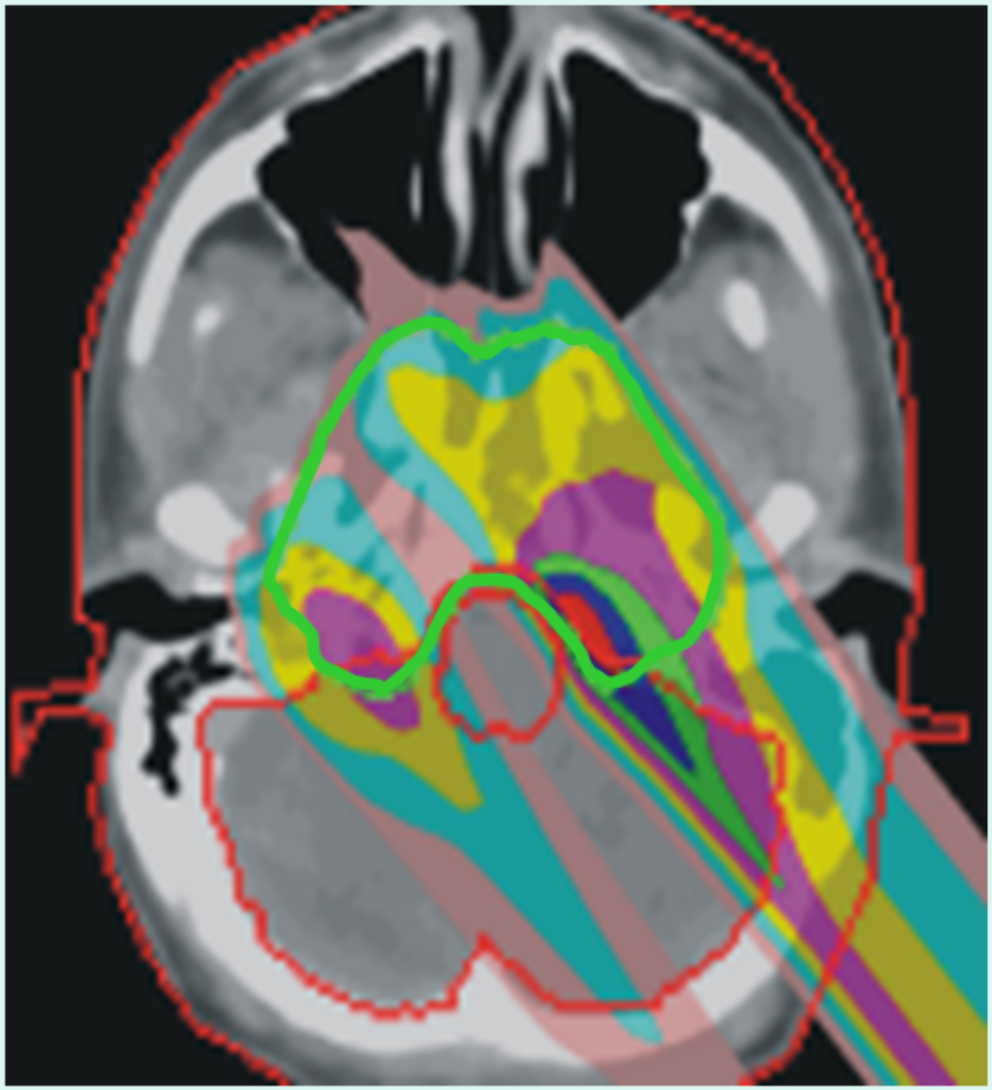

calculation made
by T.Lomax, PSI

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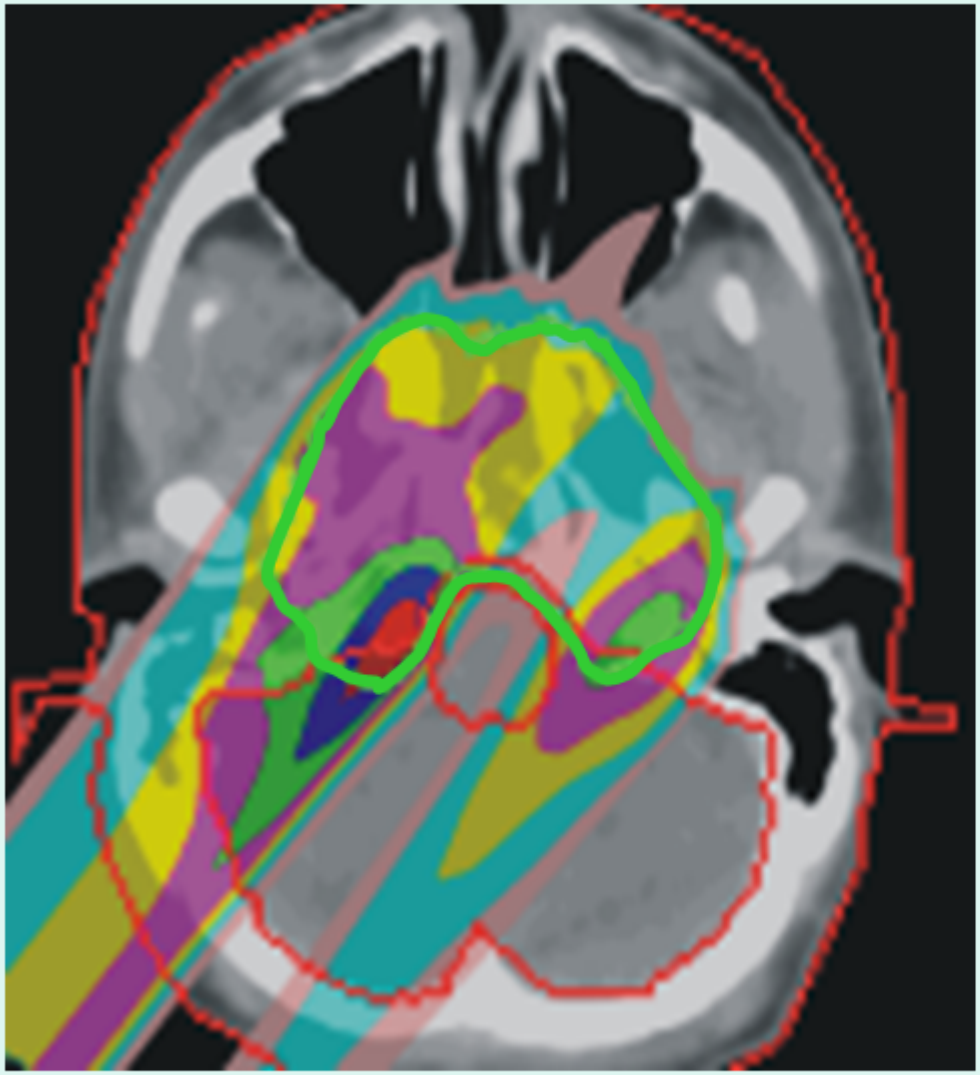

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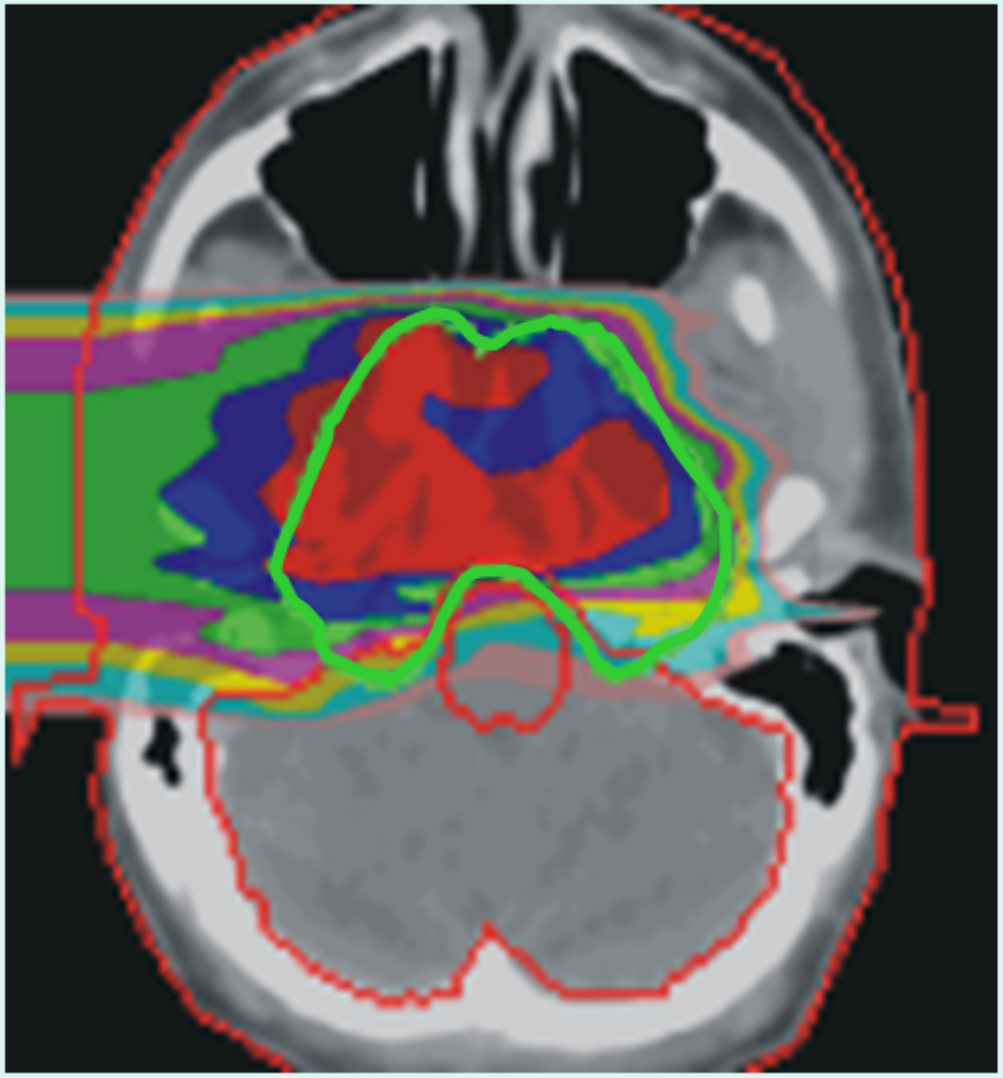

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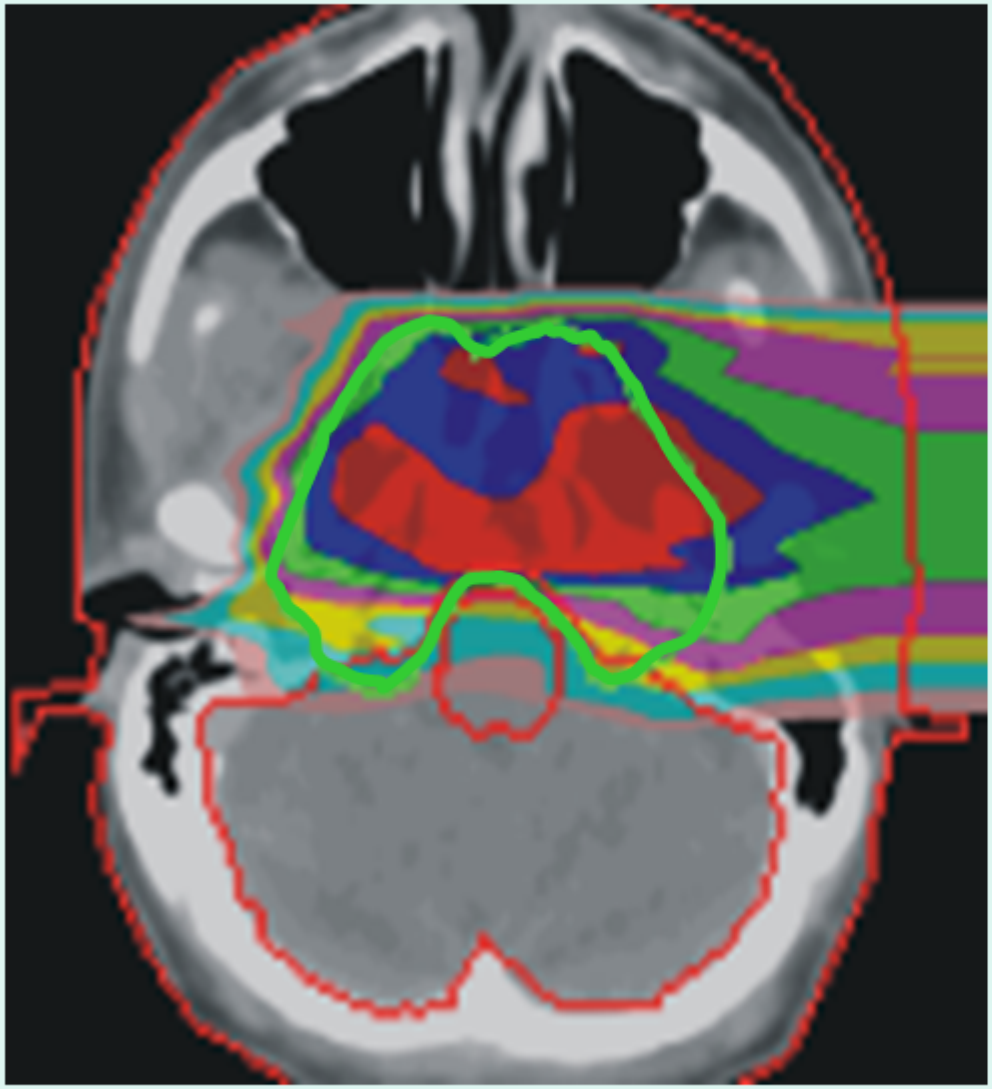

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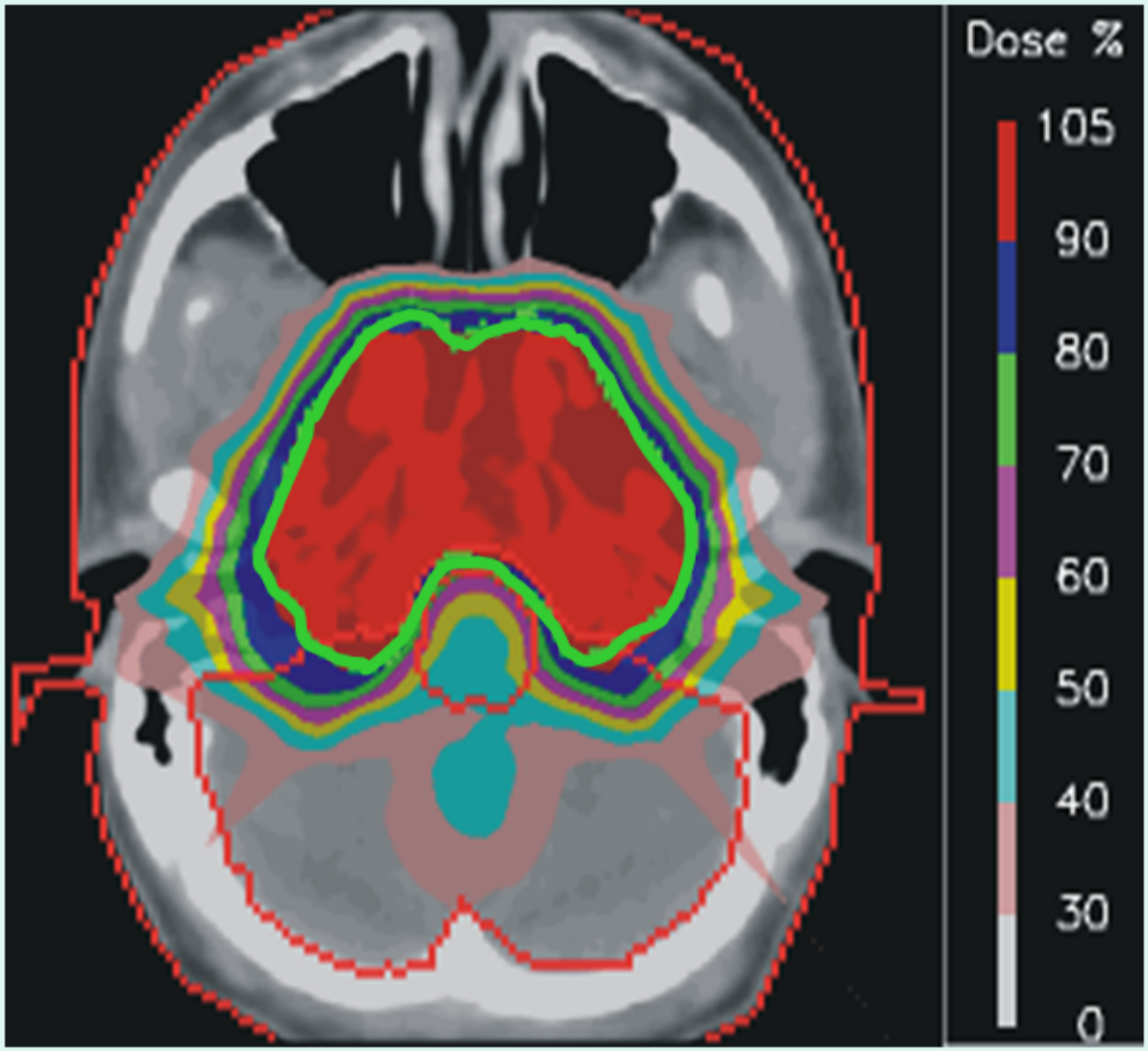
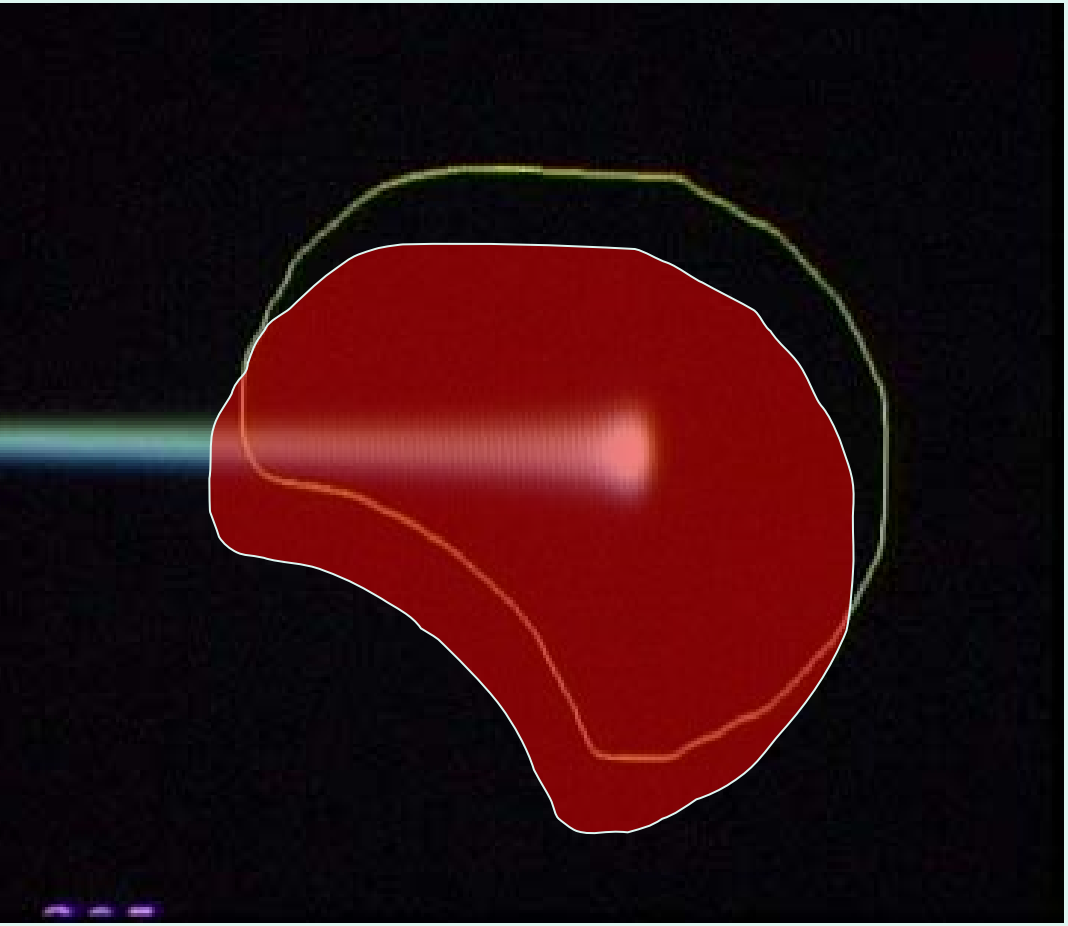


Total dose
of all 4
beam directions

calculation made
by T.Lomax, PSI

The problem in dynamical treatments:

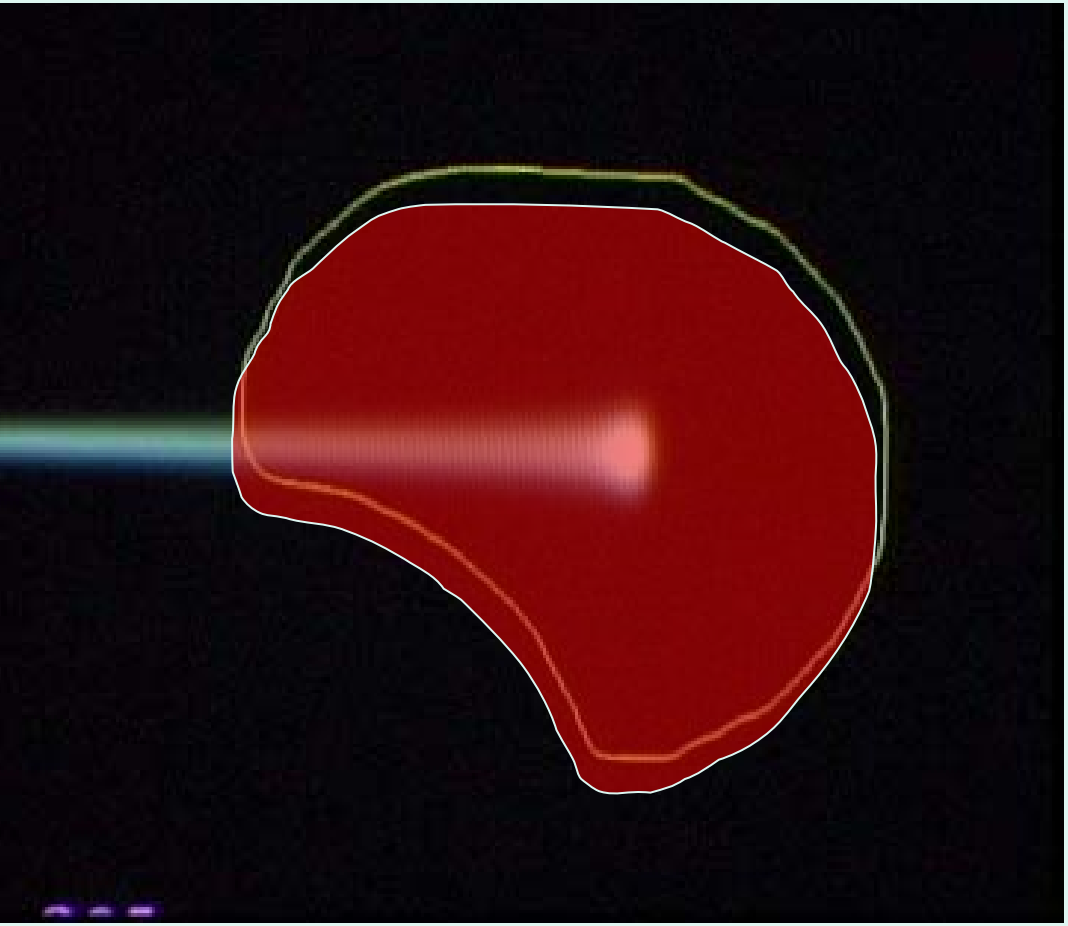
Organ movement



➔Danger to underdose and overdose

The problem in dynamical treatments:

Organ movement

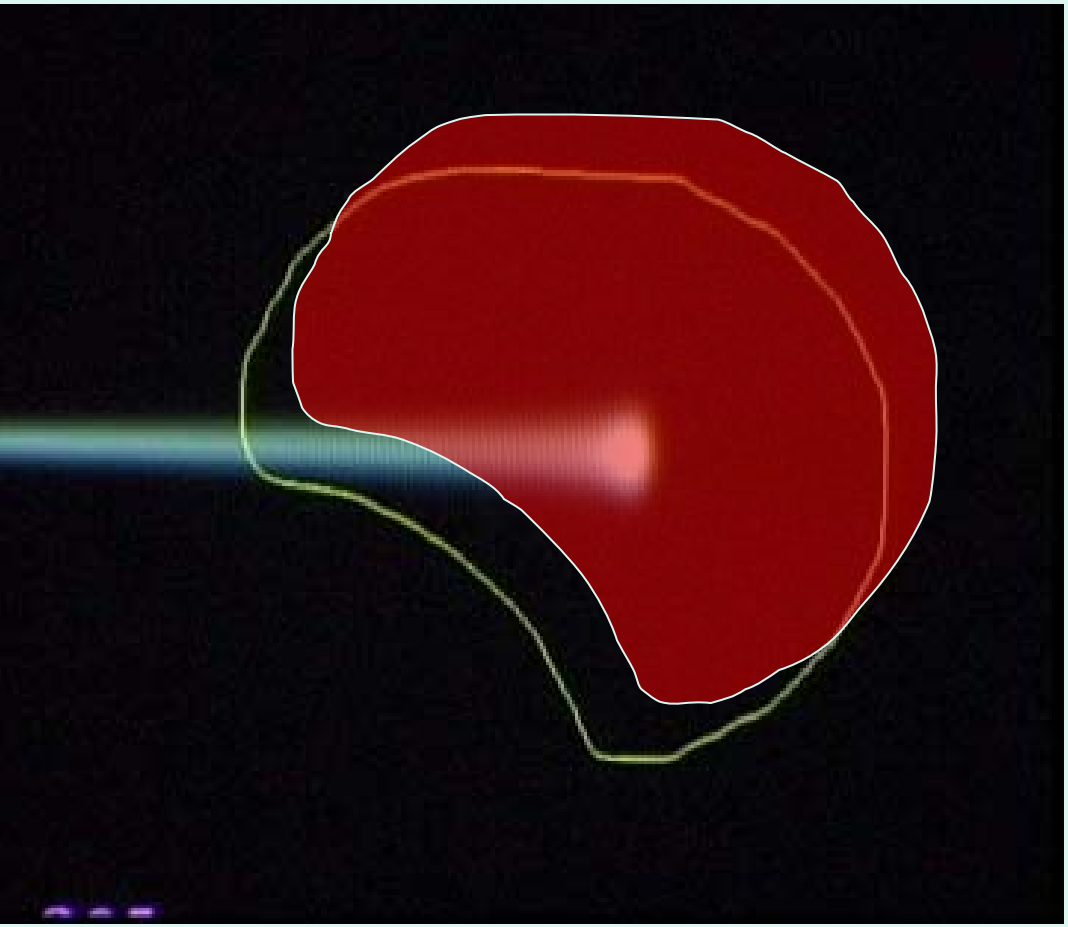


➔Danger to underdose and overdose

Solutions:

The problem in dynamical treatments:

Organ movement



➔Danger to underdose and overdose

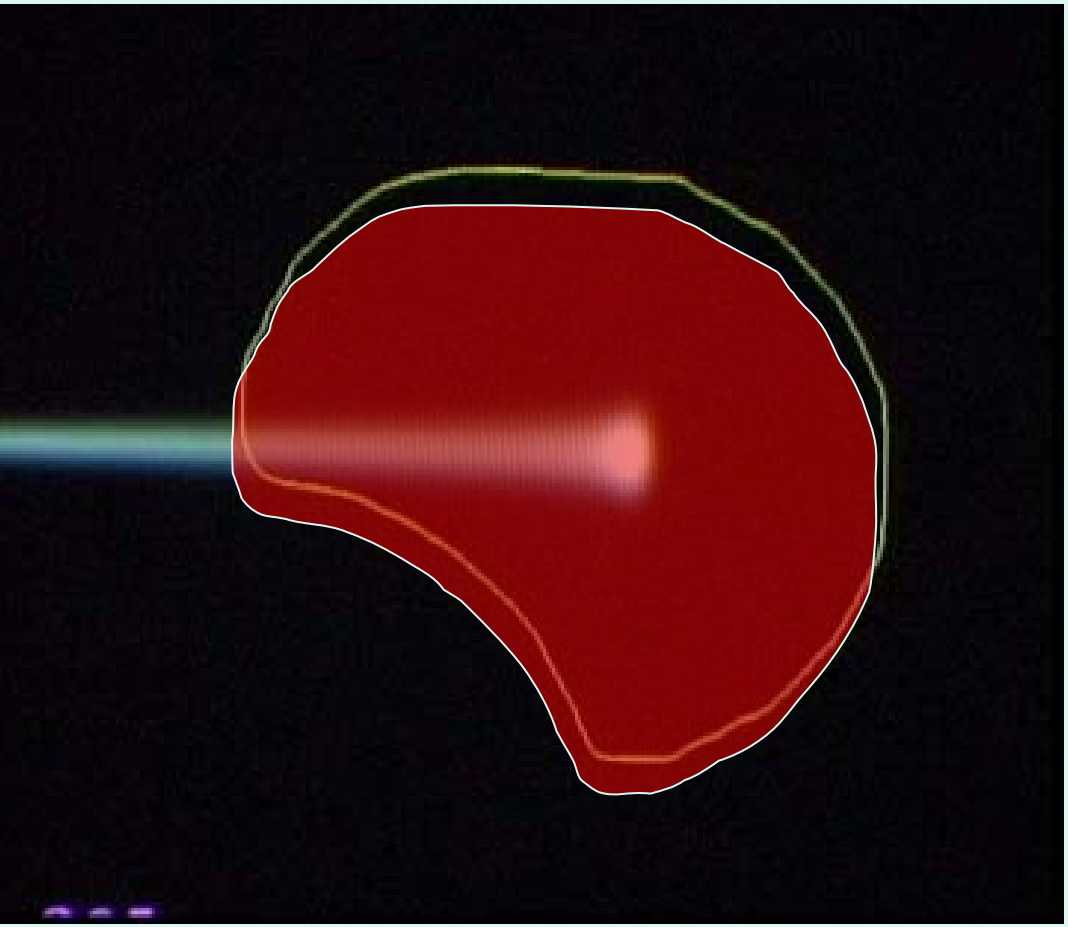
Solutions:

- Beam gating
- Multiple scans of tumour
- „follow“ tumour

⇒increase scan speed laterally + in depth

The problem in dynamical treatments:

Organ movement



➔Danger to underdose and overdose

Solutions:

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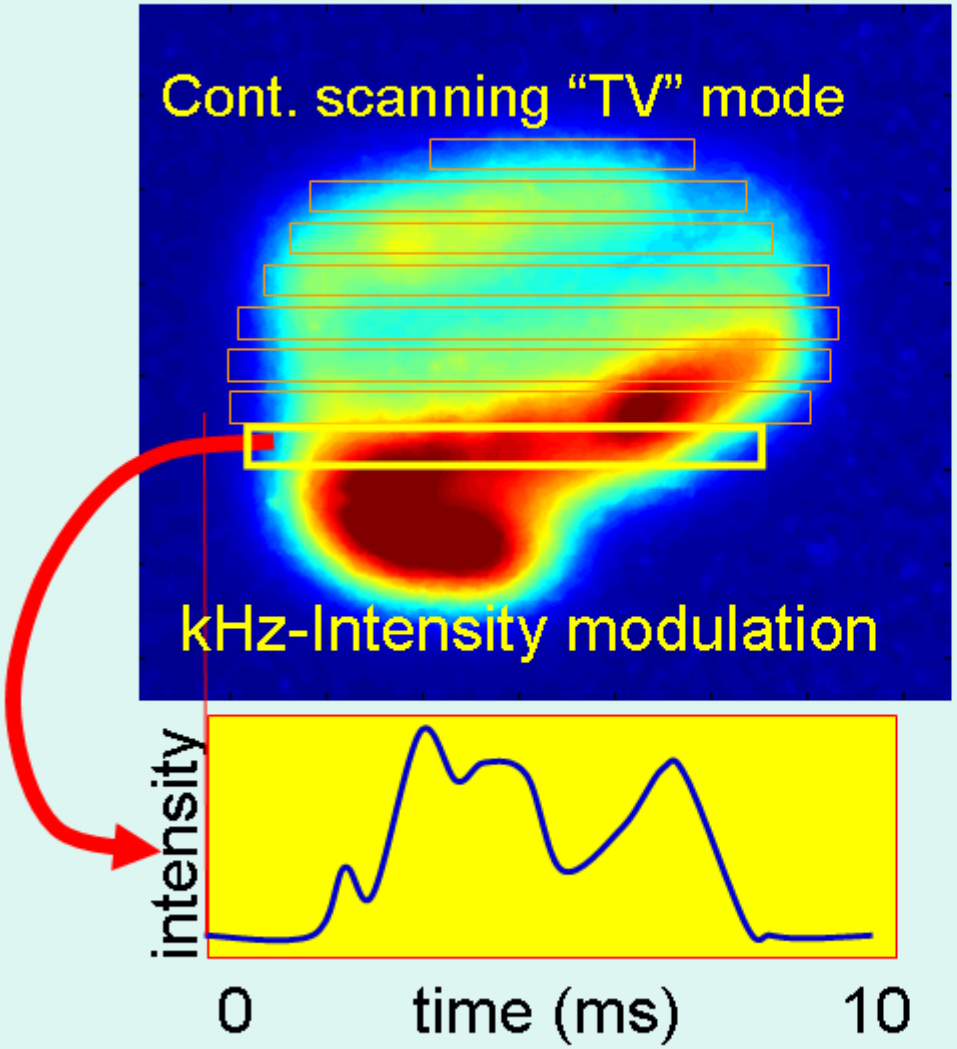
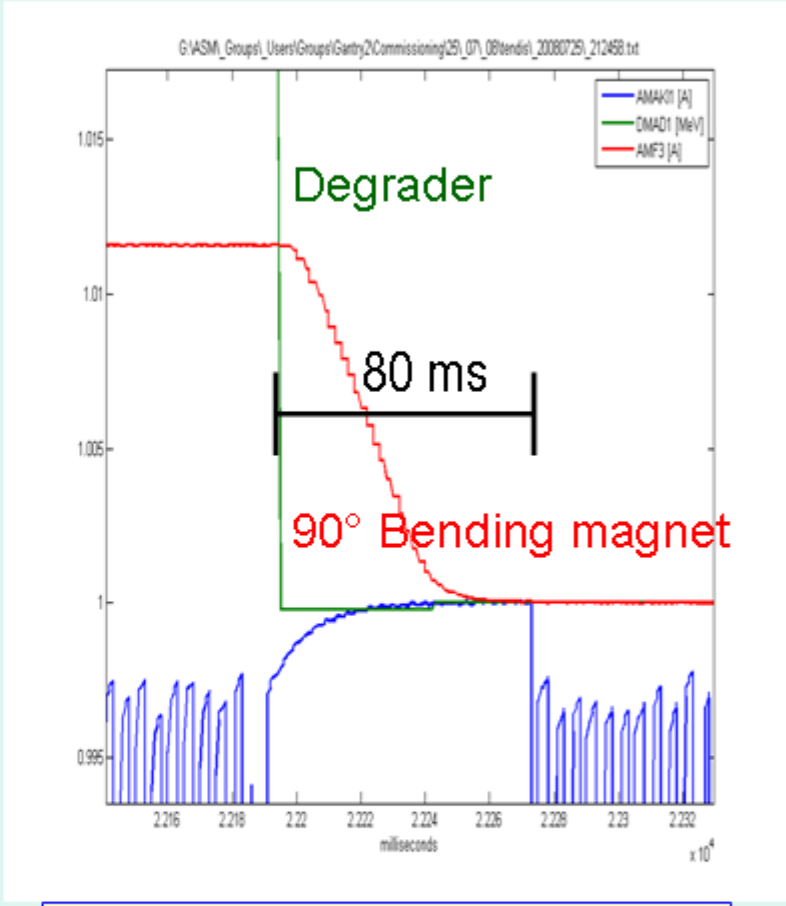
- „follow“ tumour

⇒increase scan speed laterally + in depth

Fast pencil beam scanning in 3D

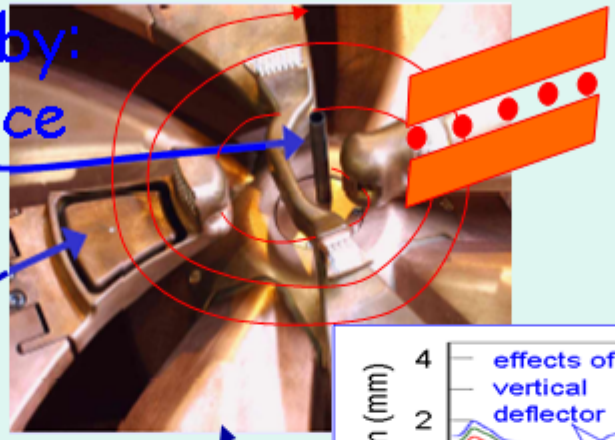


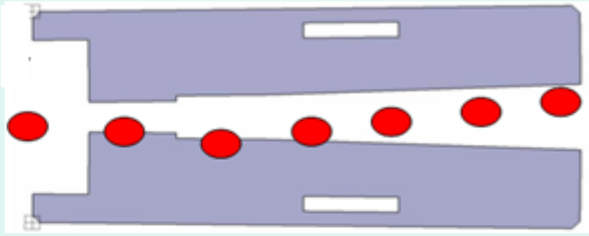


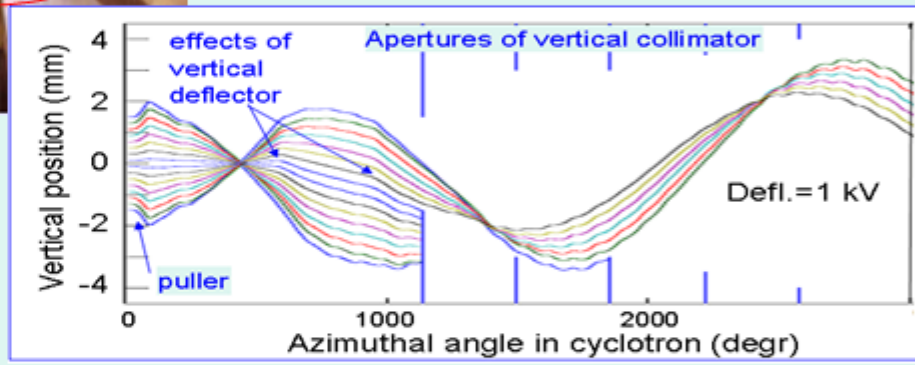
- **7 s for a 1 liter** volume.
- Target repainting:
- 15-30 scans / 2 min.

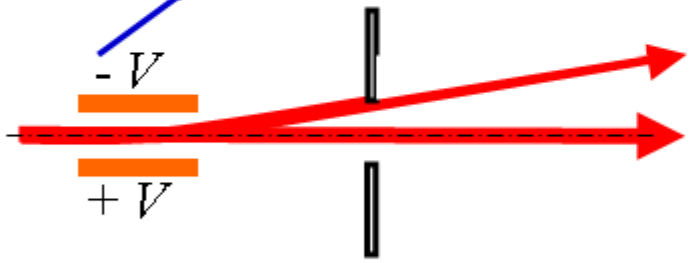
Intensity control

Max. intensity set by:
proton source

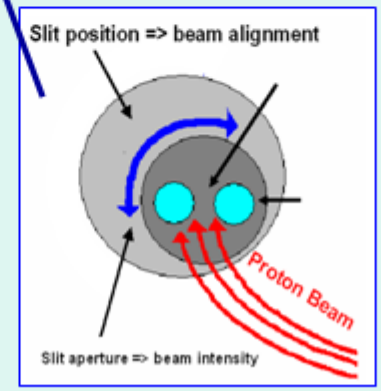






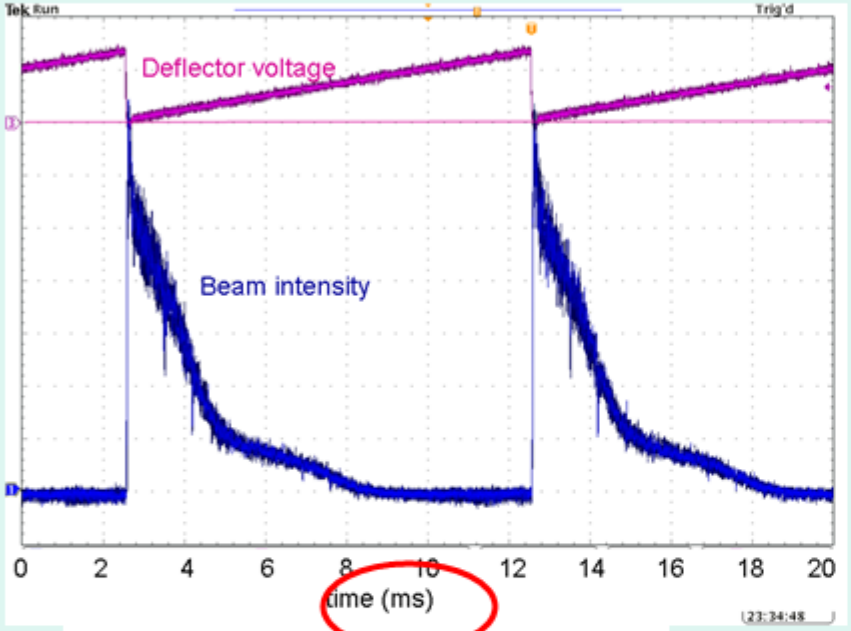


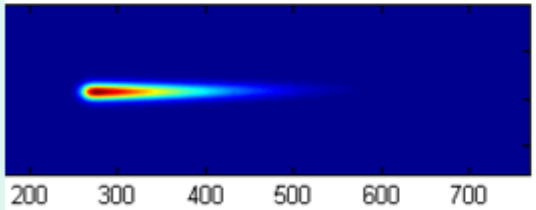
Deflector plate:
sets requested intensity
- within 50 μs
- 5% accuracy

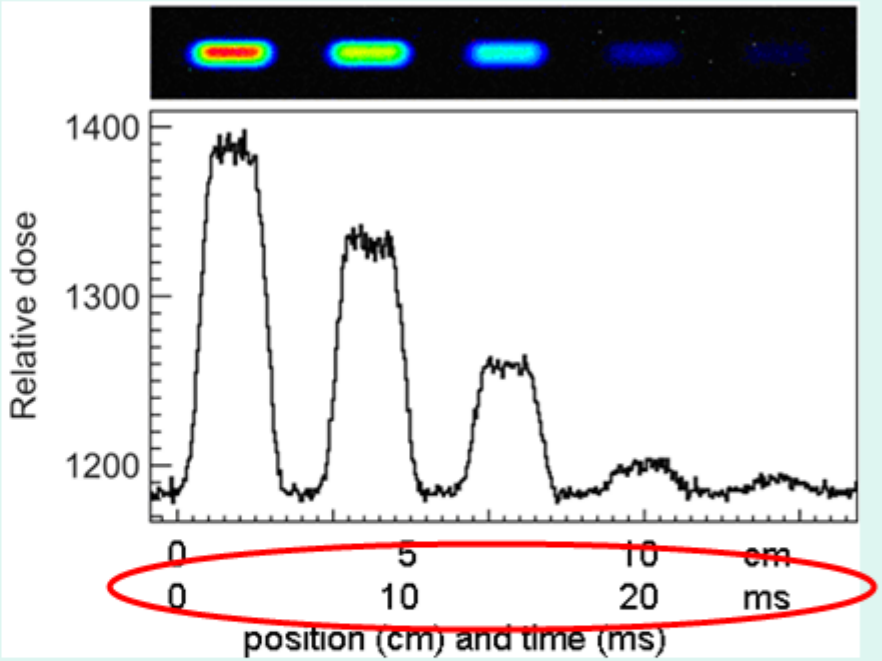


+ slits

Intensity (Vdefl) → intenisty modulation

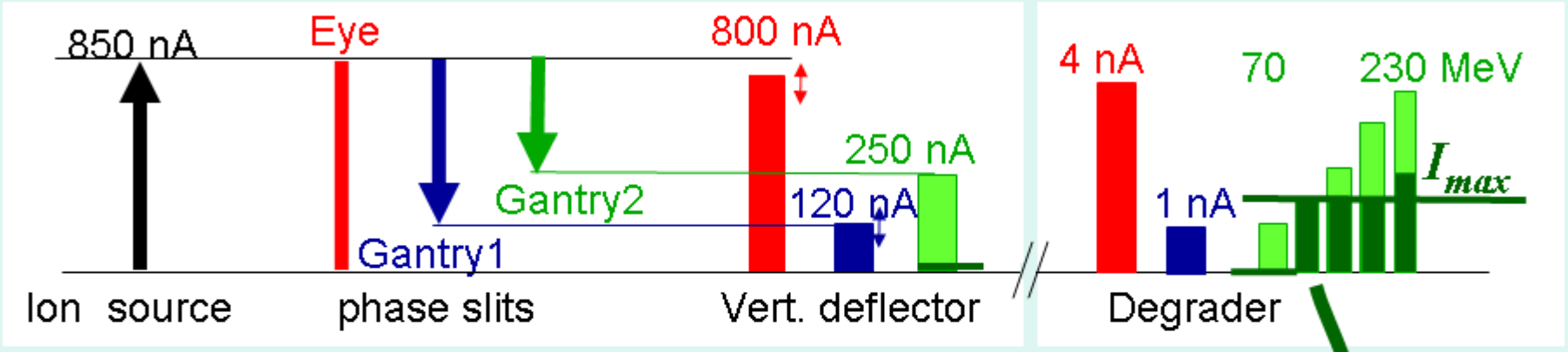


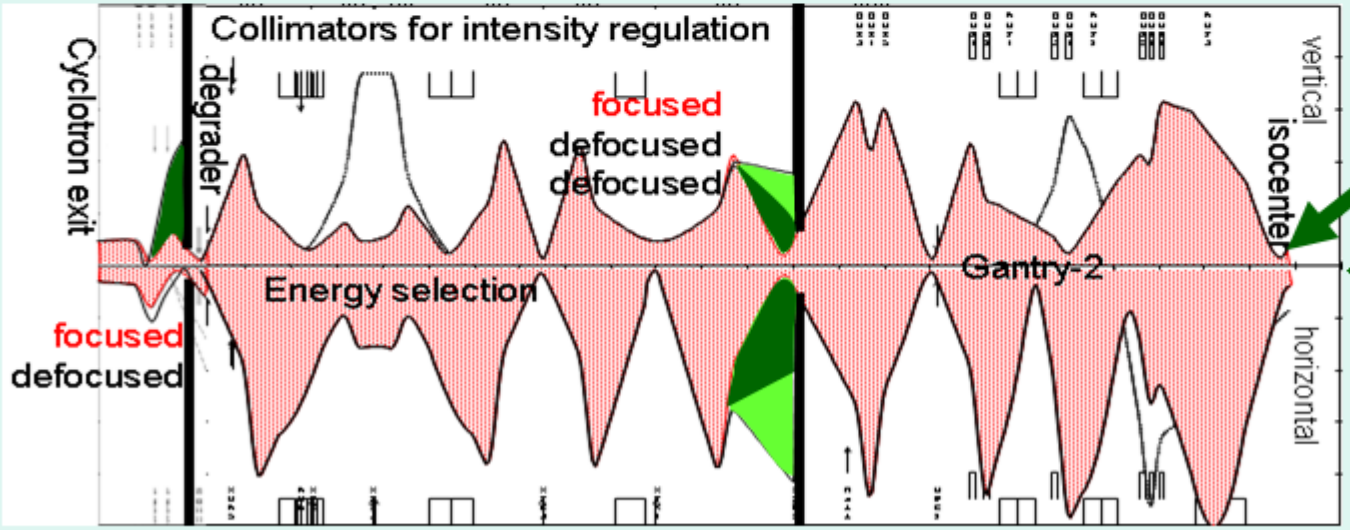




Intensity correction for Transmission(E)

Fast intensity regulation over factor 20 needed.



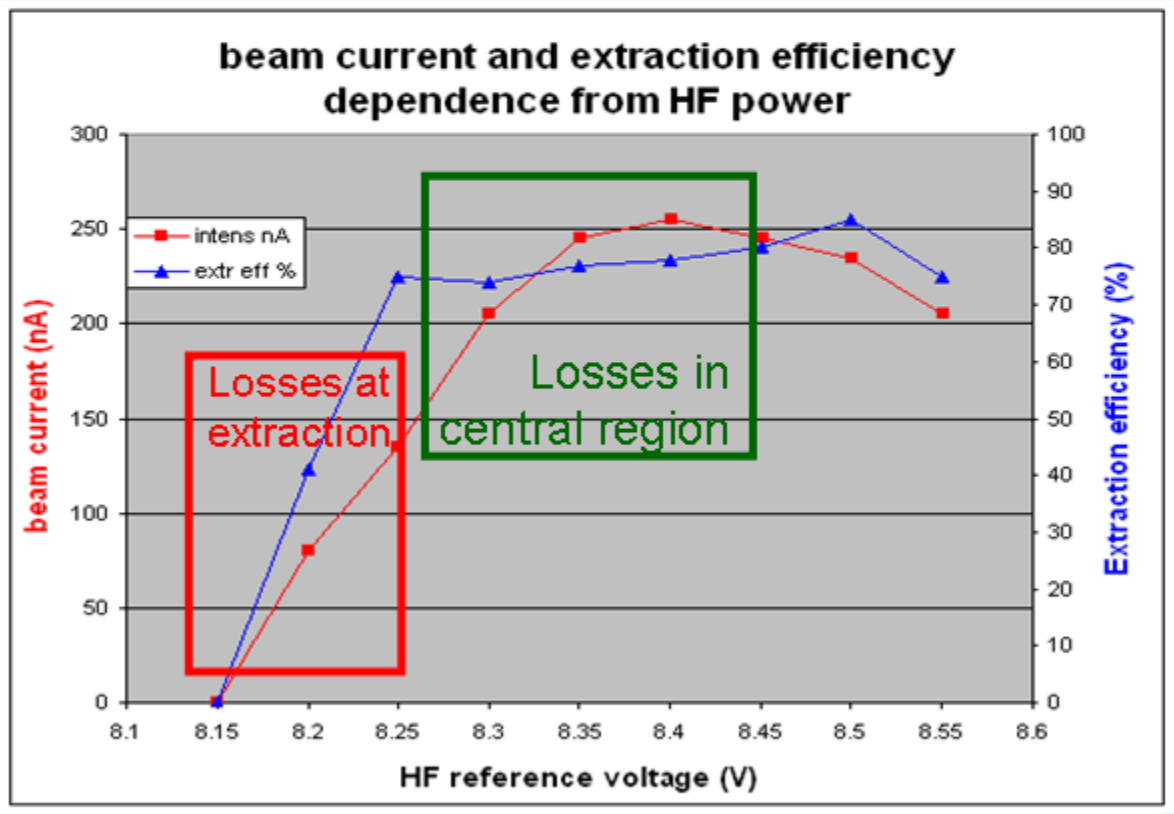


„quick and dirty"
brute force

Project coming up: Fast change of Imax

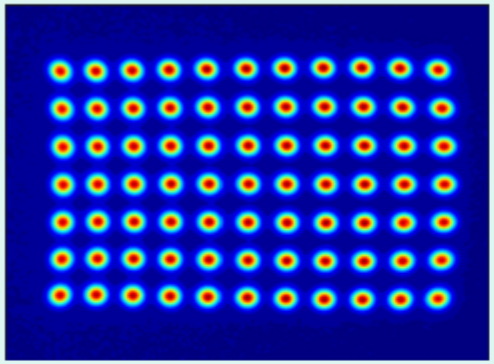
Regulation of beam intensity over factor 20 needed.

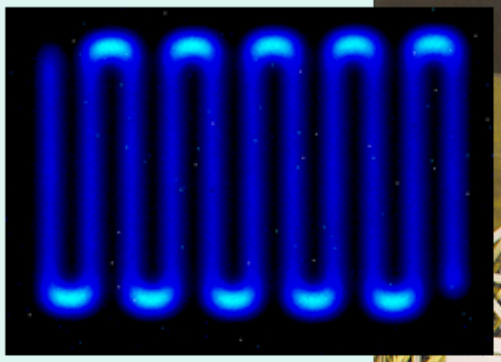
Idea: vary HF power in stead of Qpole defocusing



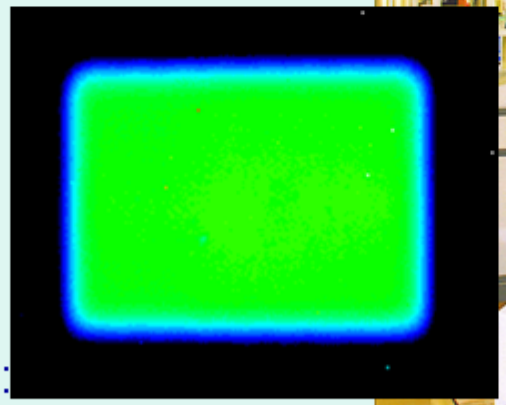
Study started to increase window of high extraction efficiency

PSI Gantry-2: fast 3D scanning

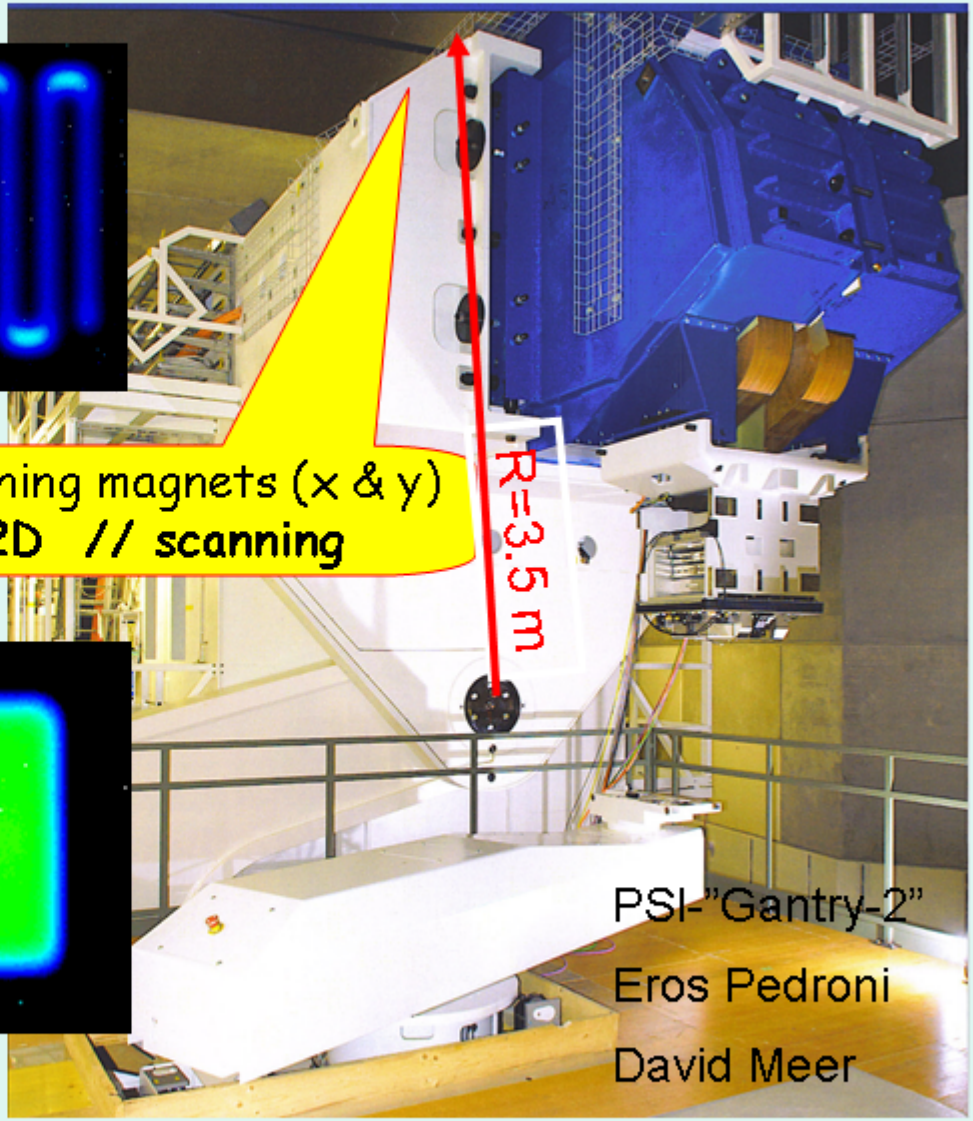




σ=3-4.5 mm over 230-100 MeV



Fast rescanning demo:
500 planes of 6x8 cm in depth < 1 min.



Requirements for accelerator

Only one conclusion….

Fast pencil beam scanning

- reliable, robust, easy to tune
- enough intensity
- stable beam position
- CW beam
- stable beam intensity
- fast control of beam intensity
- fast control of beam energy
- small pencil beam
- controlled by user (tune library)