Accelerators for Medical Application

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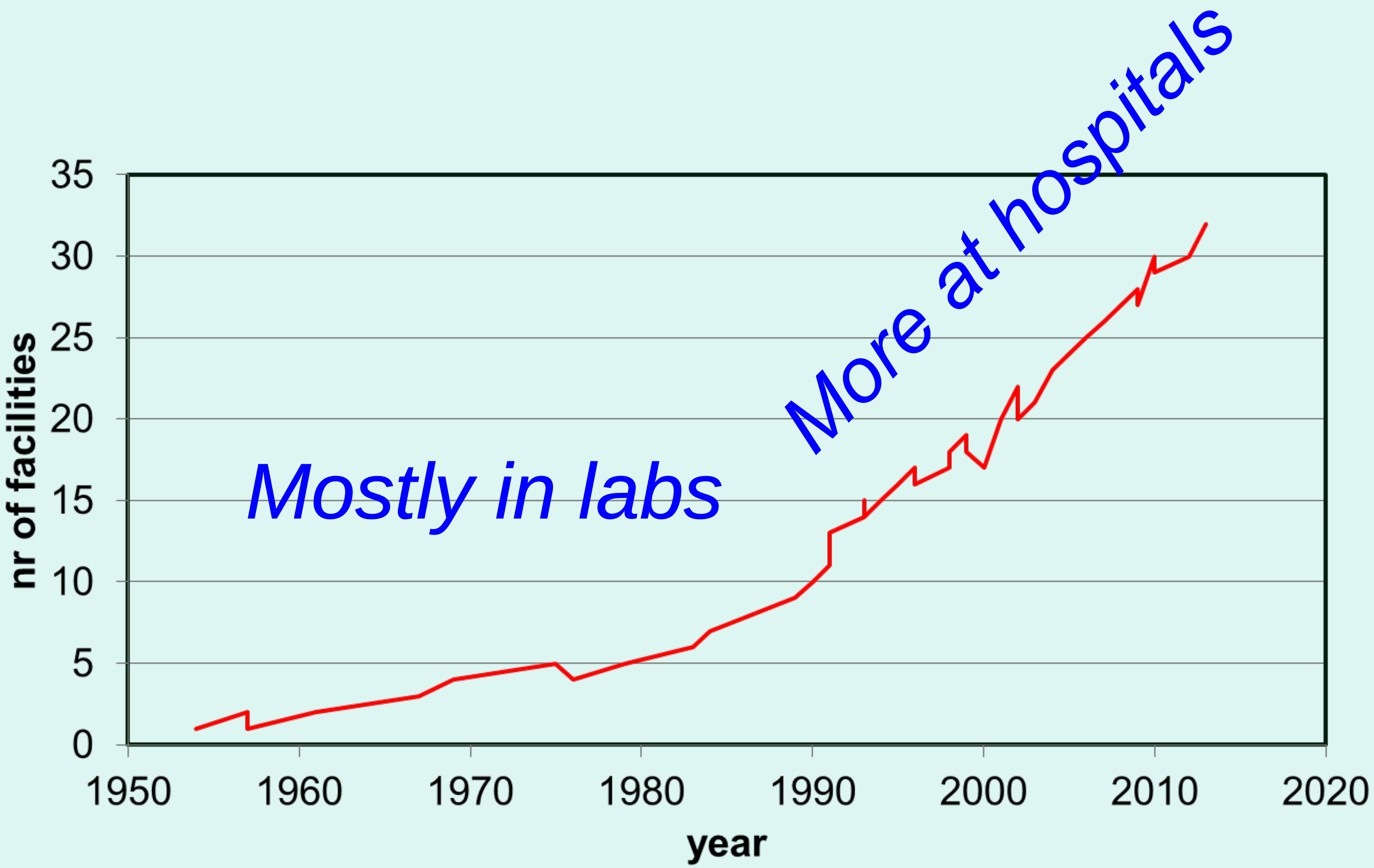
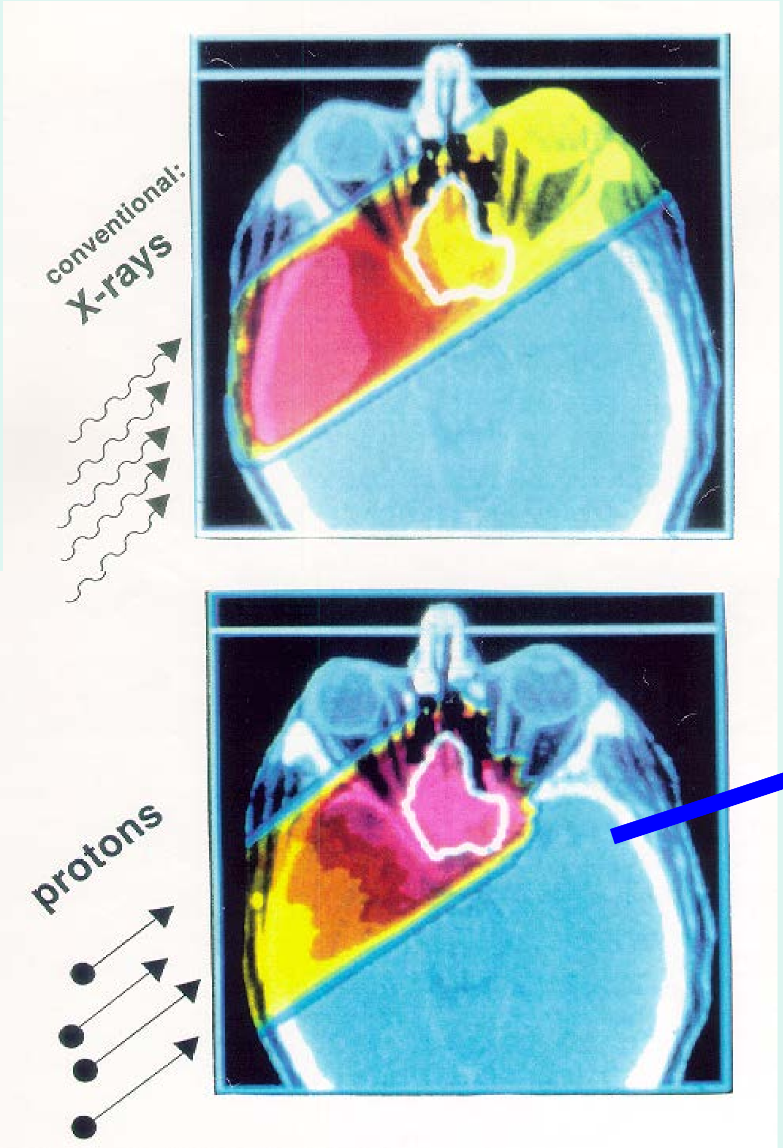
Contents

- Introduction: proton therapy
- How to apply the radiation dose
- Accelerators and beam transport
- Operational aspects
- Safety

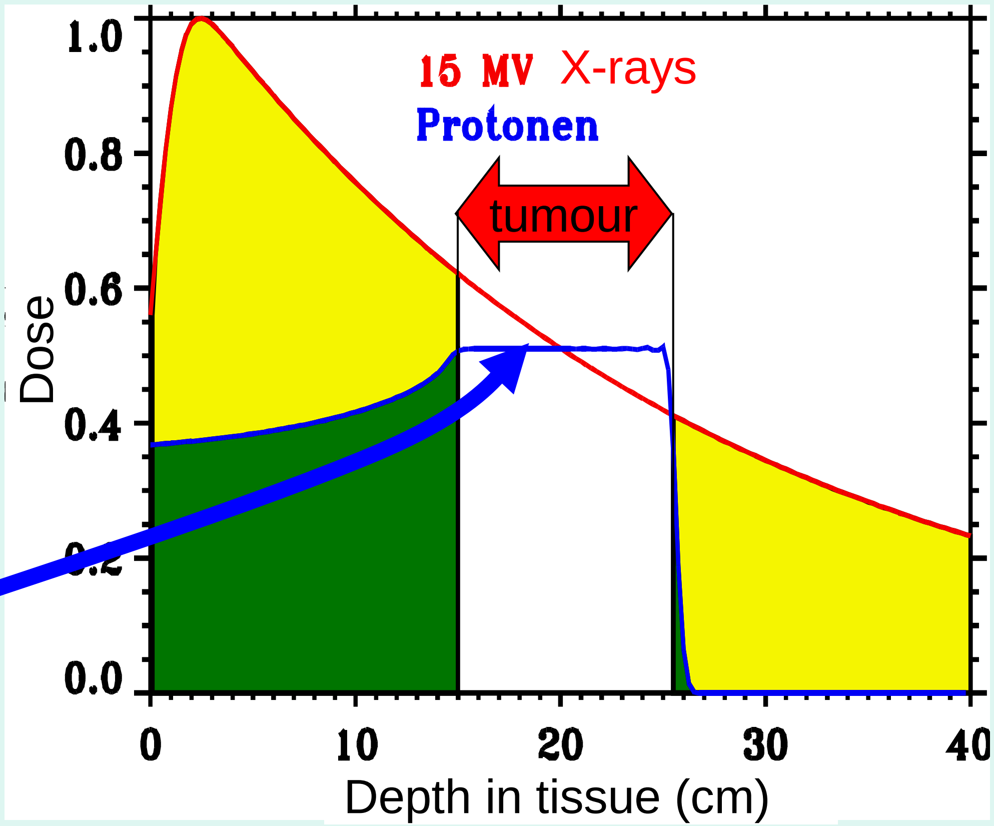
The boost in particle therapy



X-rays vs. Protons



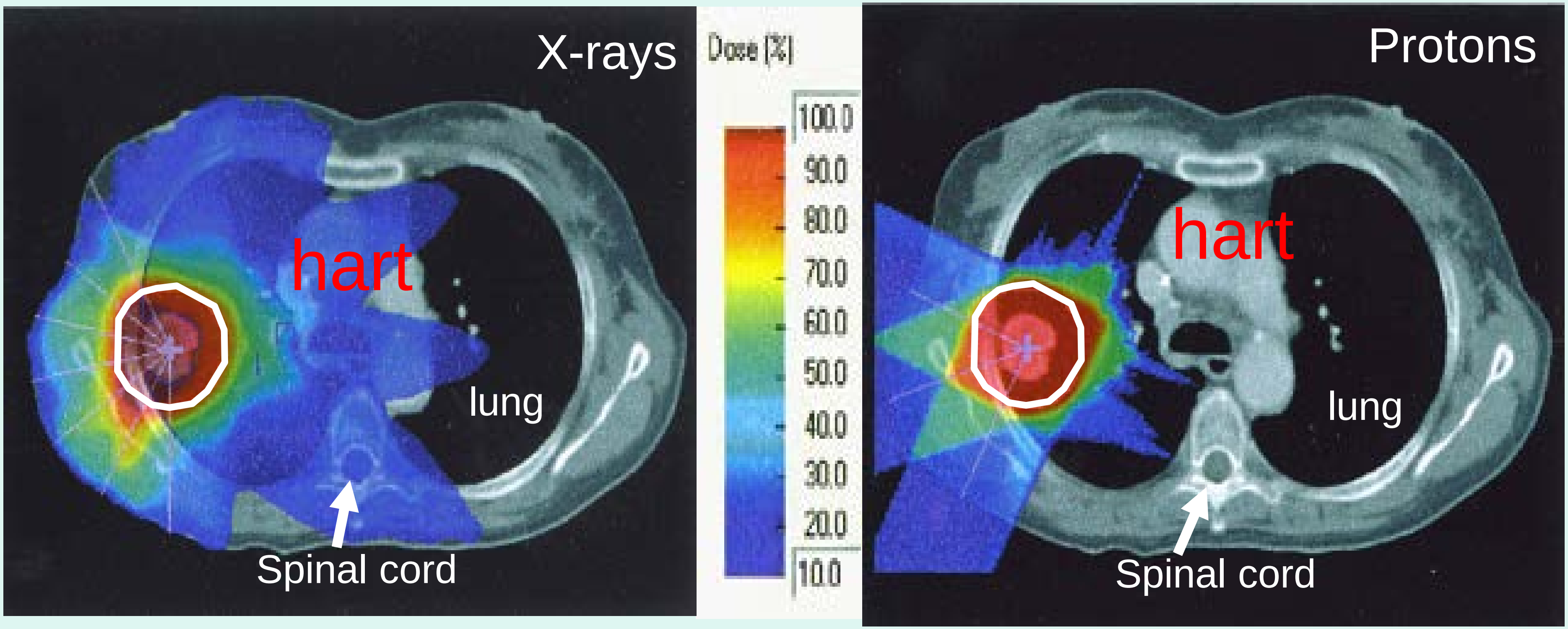
Depth-dose curve:



X-rays vs. Protons

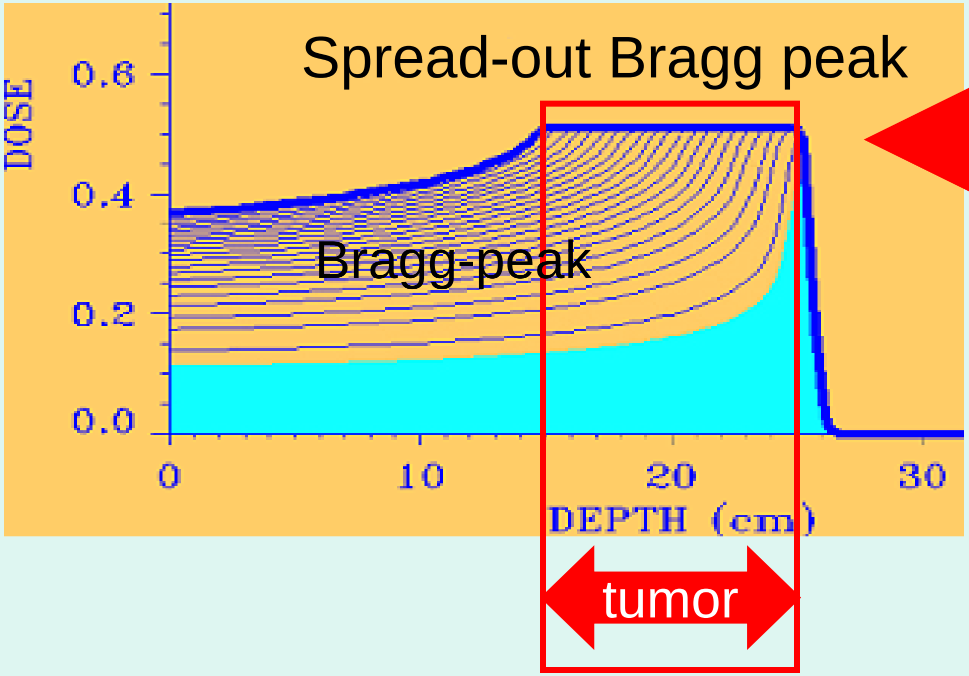
X-ray beams (IMRT)
from 7 directions

Proton beams
from 3 directions



pictures: Medaustron

Dose delivery techniques: **Depth**



Tumor **rear edge**

→ Range

→ Maximum Energy

per field → „slow“ (sec)

Tumor **thickness**

→ spread-out Bragg peak

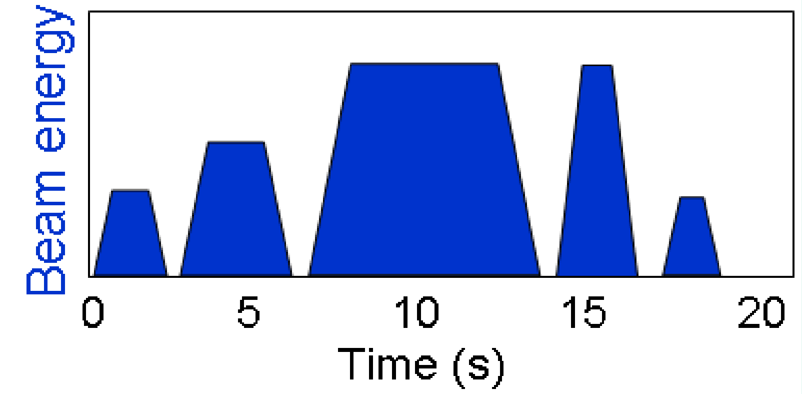
→ energy modulation

During trmt → „fast“ (<0.1-0.2 sec)

Dose delivery techniques: **Depth**

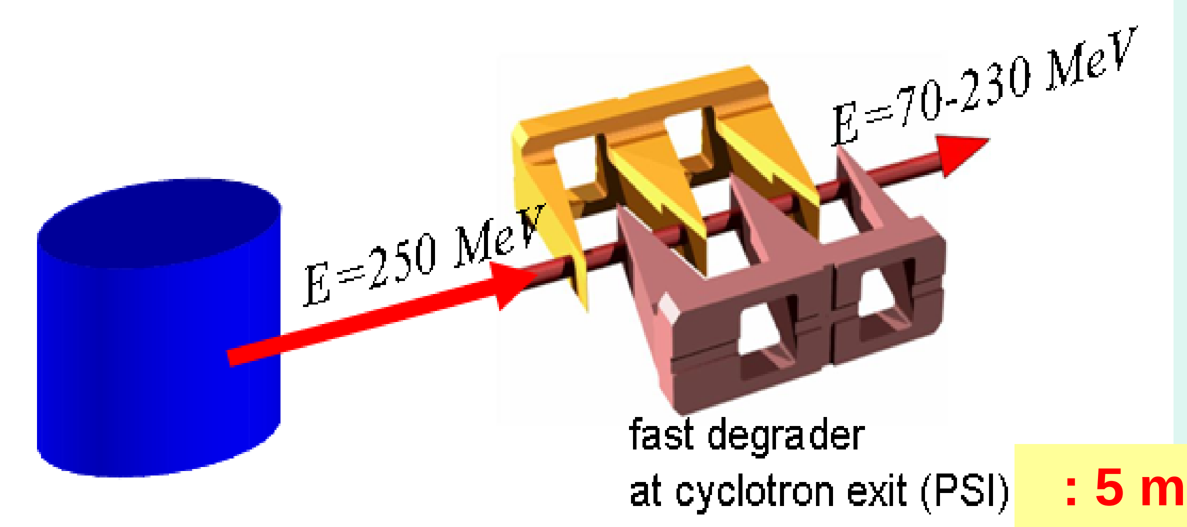
Vary energy at accelerator

Synchrotron: Set energy at each **spill:**



- ➔ Sets range only
- ➔ energy modulation in nozzle

Cyclotron has fixed energy => slow down (degrade) to desired energy



➔ Sets range

And, if fast enough

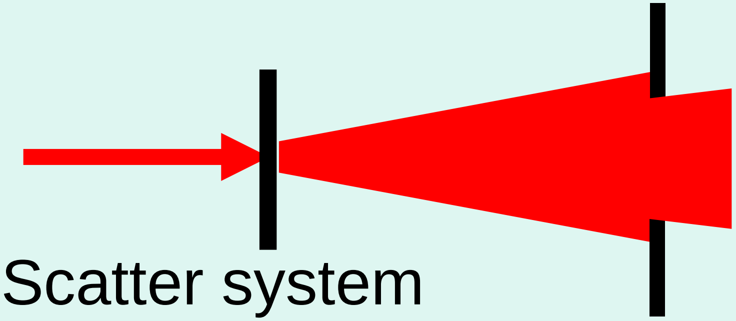
+ fast magnets:

➔ also energy modulation

: 5 mm ΔRange in 100-200 ms

Dose delivery techniques: **lateral**

Scatter technique

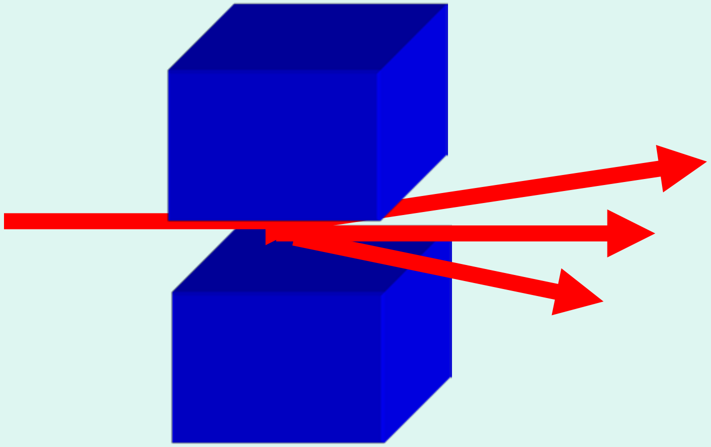


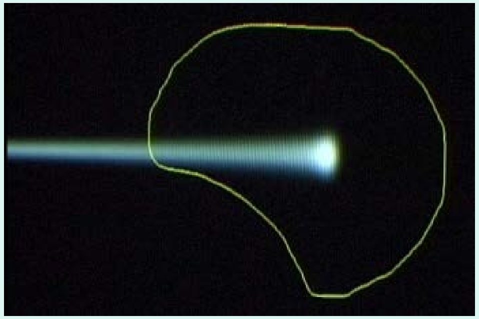
Scatter system

Collimator

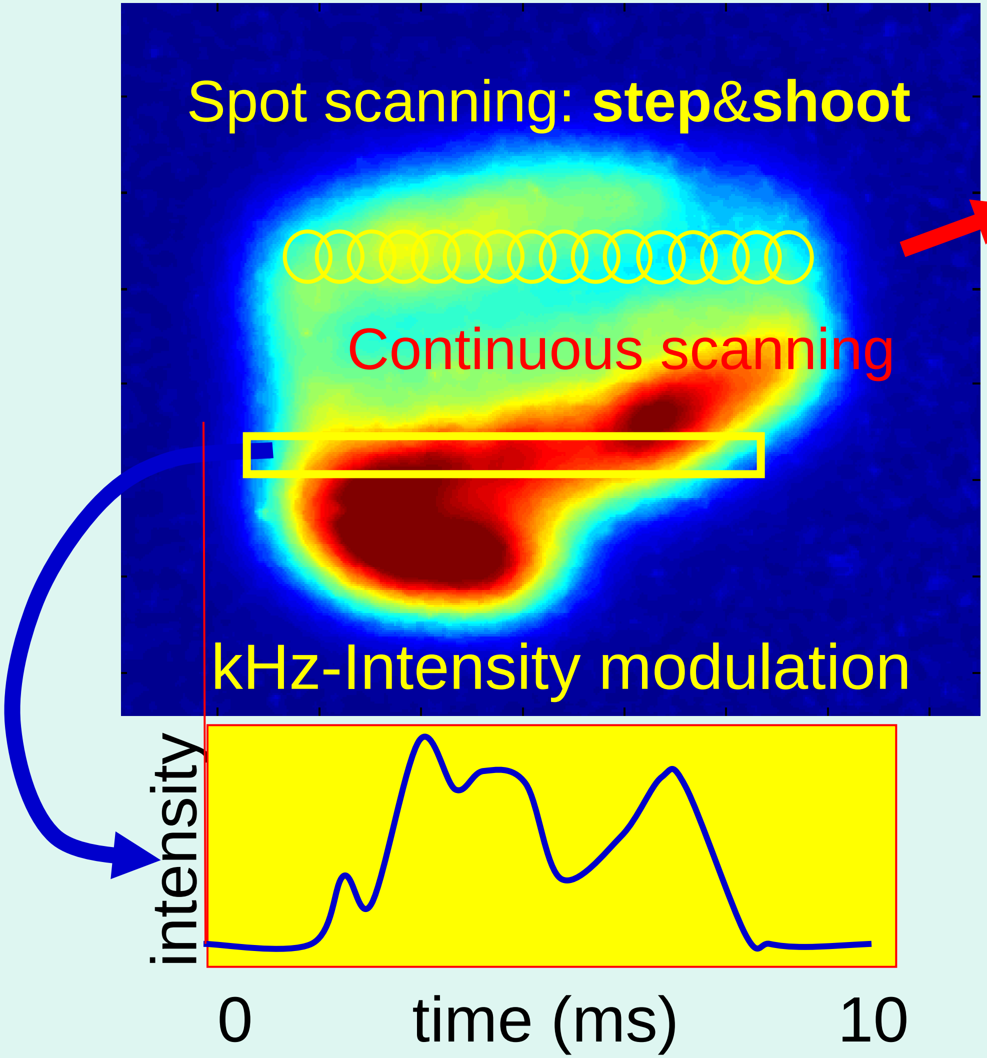
Best dose distribution

pencil-beam scanning





Pencil beam scanning



Requirements for accelerator:

- stable beam position

allows fast target **repainting**:
15-30 scans / 2 min.

Requirements for accelerator:

- stable beam position
- continuous and stable beam
- fast adjustable beam intensity
- fast adjustable beam energy

Present accelerator choice

e.g:

Boston

Florida

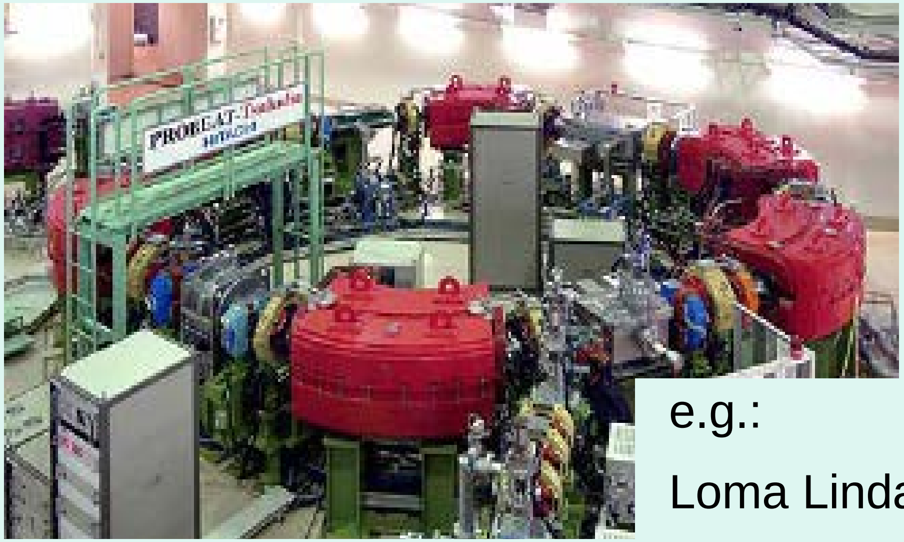
Seoul

Wanjie

PSI

München

Orsay



e.g.:

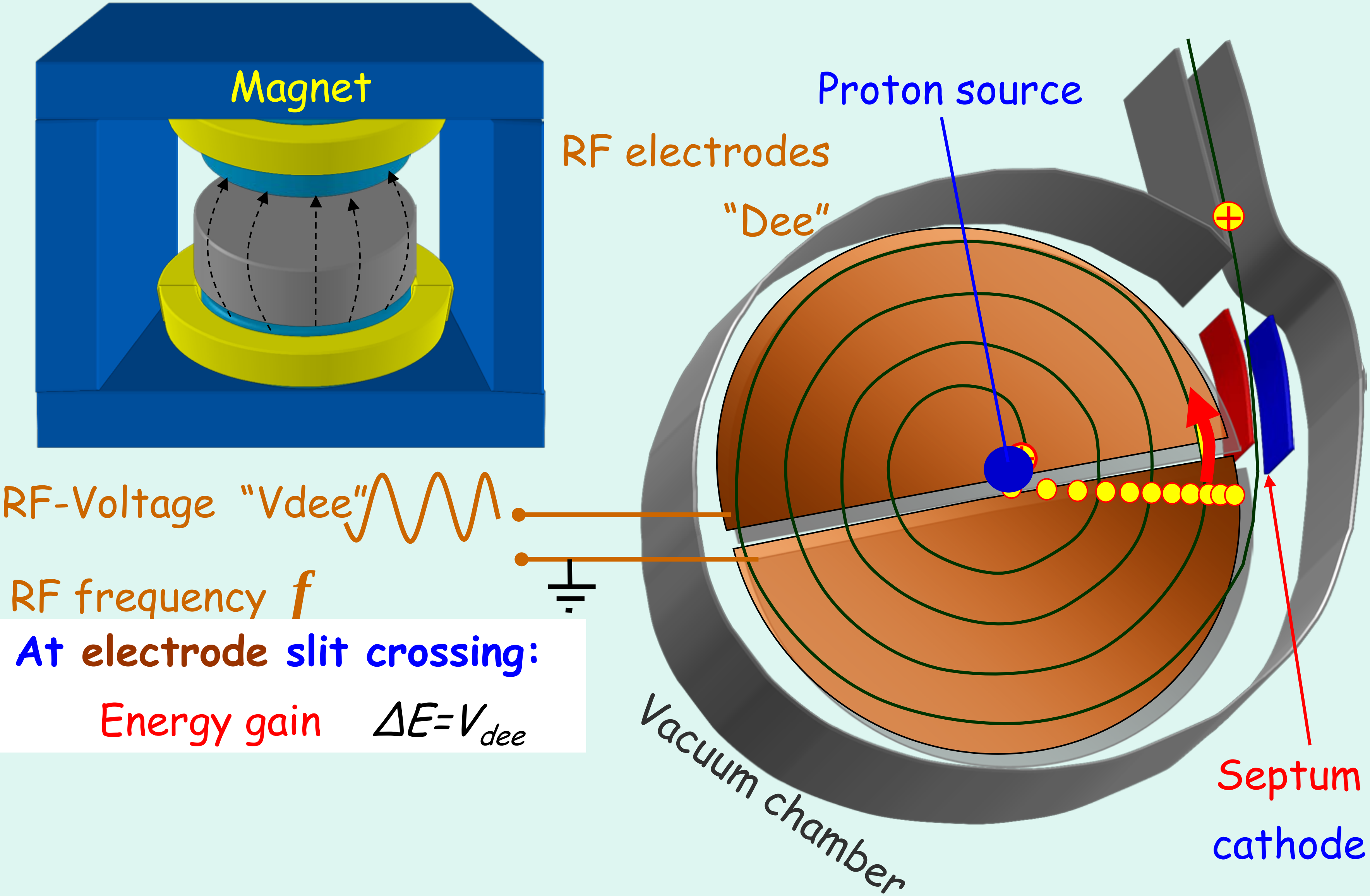
Loma Linda

Houston

Tsukuba

	cyclotron	synchrotron
Protons	in use, ∅3.5-5 m	in use, ∅8-10 m
Carbon ions	in design, ∅6 m	in use, ∅25 m

Cyclotron (1930)



At electrode slit crossing:

Energy gain $\Delta E = V_{dee}$

250 MeV proton cyclotron (Varian)

Closed He system

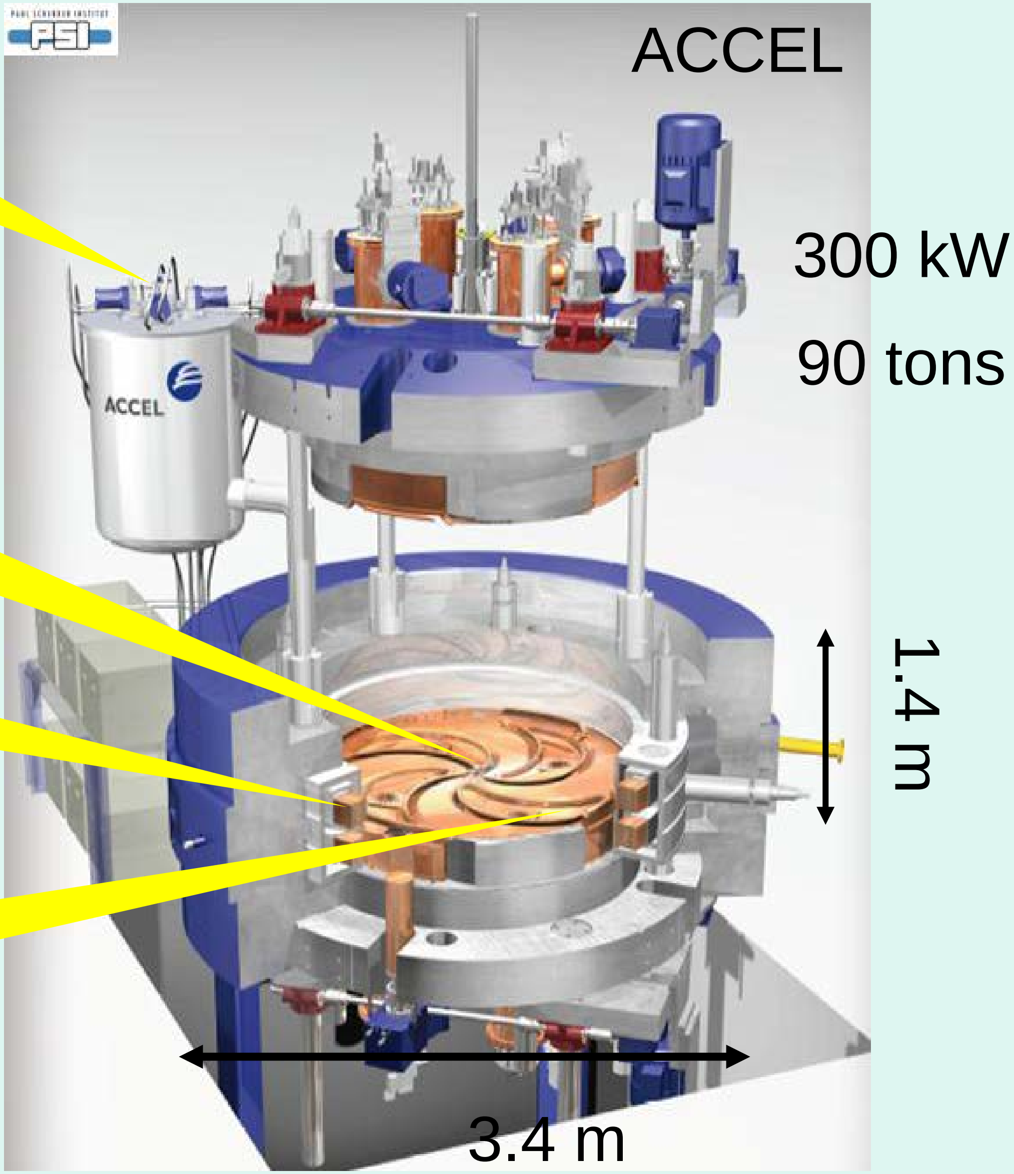
4 x 1.5 W @4K

Proton source

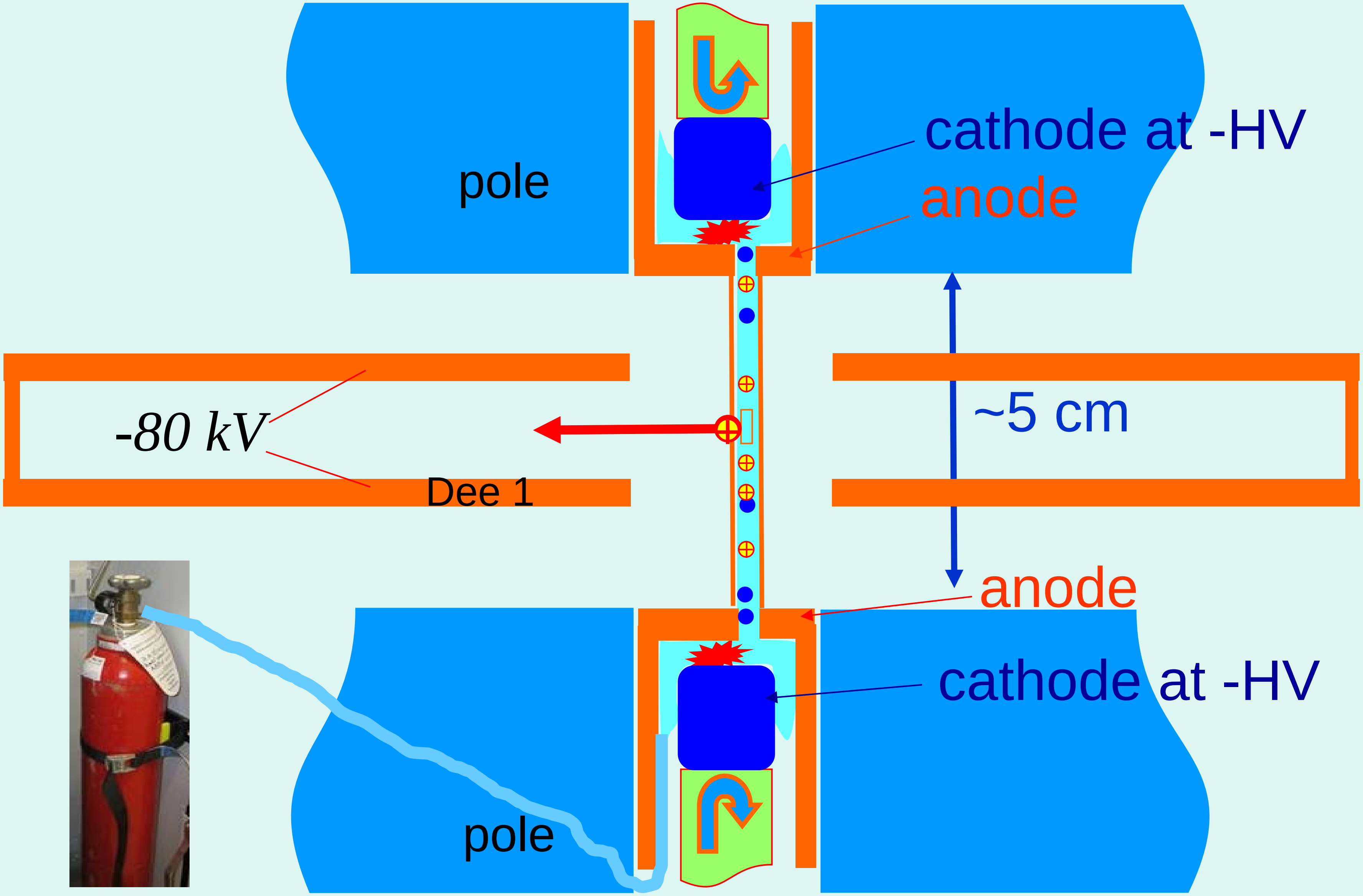
superconducting coils
=> 2.4 - 3.8 T

4 RF-cavities

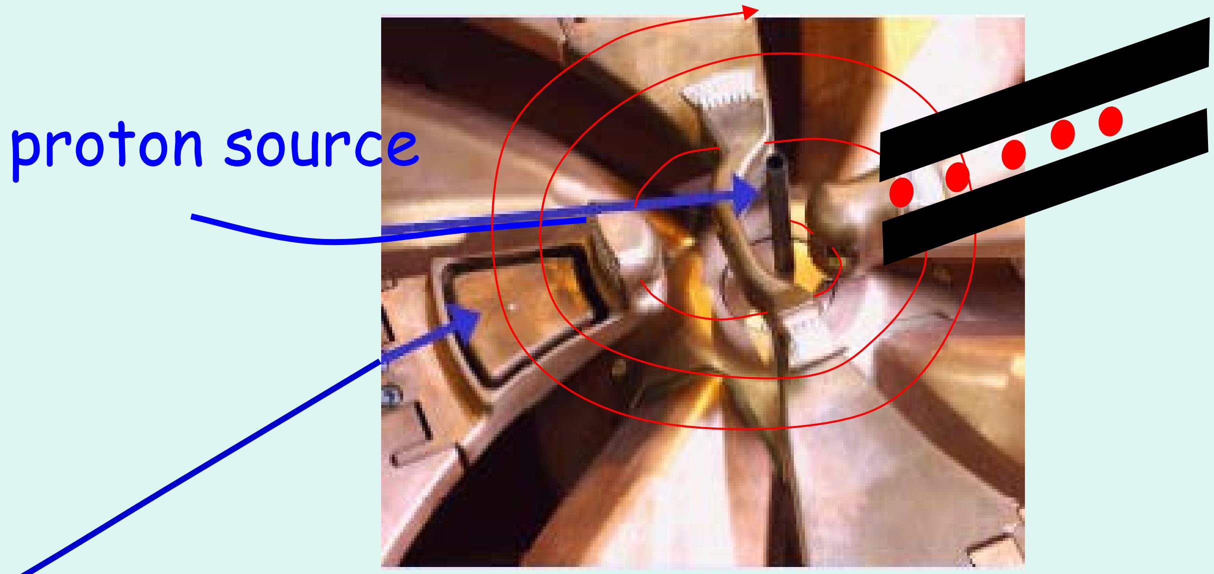
~100 kV on 4 Dees

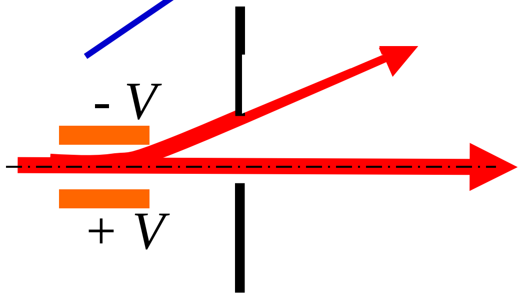


Internal proton source



On/off in Cyclotron (at PSI):





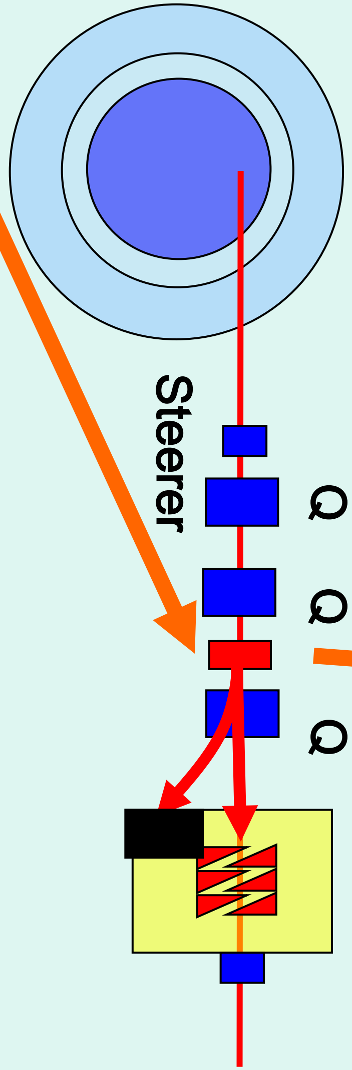
Deflector plate:
sets intensity
- within 50 µs
- 3% accuracy

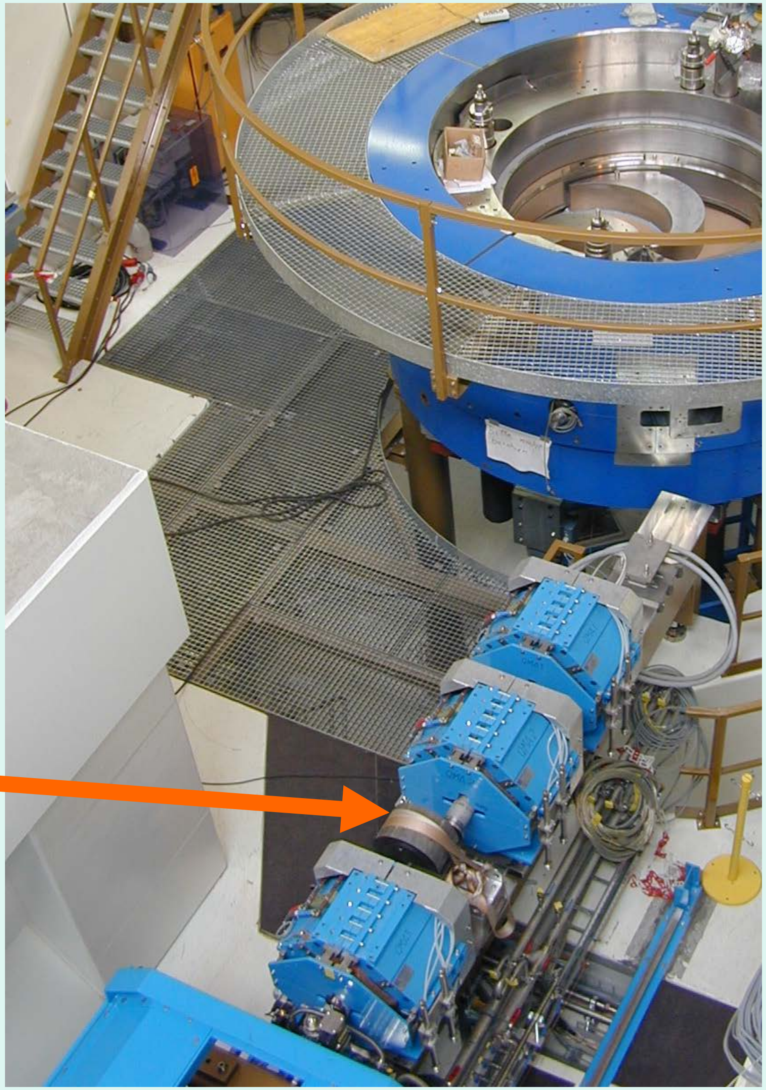
Possible ON / OFF:

- RF Voltage low or off
- Ion Source off
- Deflector plate 2 kV

Beam on/off at PSI

Fast kicker magnet: **beam on/off**





(Dis)advantages of a cyclotron

=> An isochronous cyclotron provides:

+ high intensity (if desired)

+ accurate and adjustable intensity

+ continuous beam

+ fast Energy change with degrader

Disadvantages:

- degrader needed

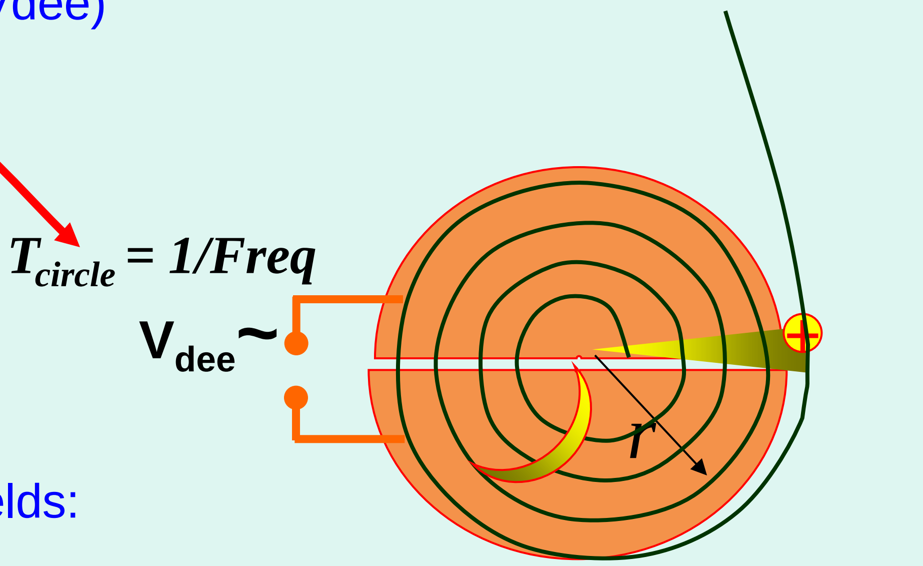
- activation

- one particle type (protons)

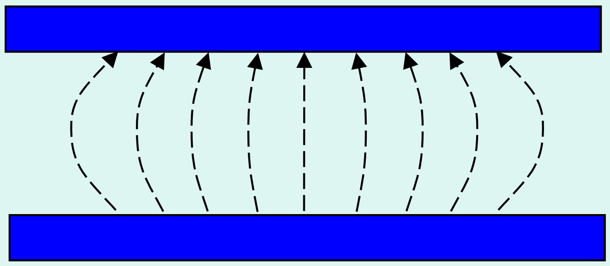
Small cyclotron; strong field

Cyclotron works while: T_{circle} independent from radius:
(particles move in pace with Vdee)

$$T_{circle} = \frac{2\pi . m}{q . B}$$



<u>However:</u> at very strong magnetic fields:



- m = mass
- B = magnetic field
- q = charge

$\Rightarrow$ Magnetic field decreases with radius $\Rightarrow T_{circle} \uparrow$

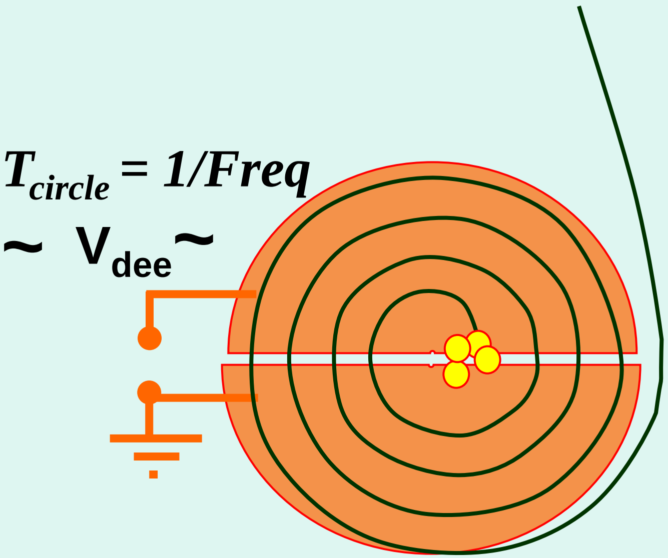
Synchro-Cyclotron

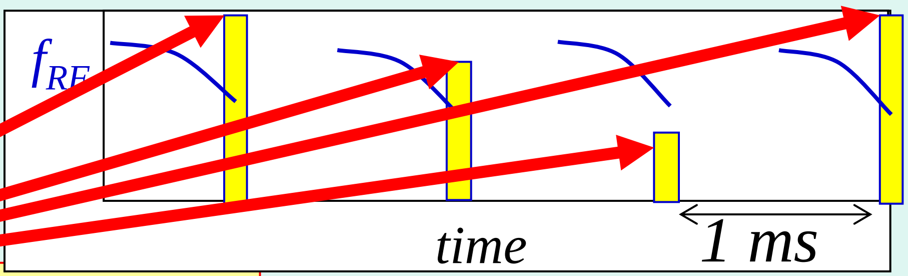
Remedy to **compensate**

increase of T_{circle} :

Decrease f_{RF} with radius and extract

Repeat 1000 x per sec





Each pulse: set intensity at source **within ms**

(=> typ 10-30% accuracy)

Synchro-Cyclotron

MEVION medical systems

iba **S2C2**

First beam extracted in May 2010

First beam at IBA in 2013

Synchrotron (1945)

Extraction into beam line

Ring:

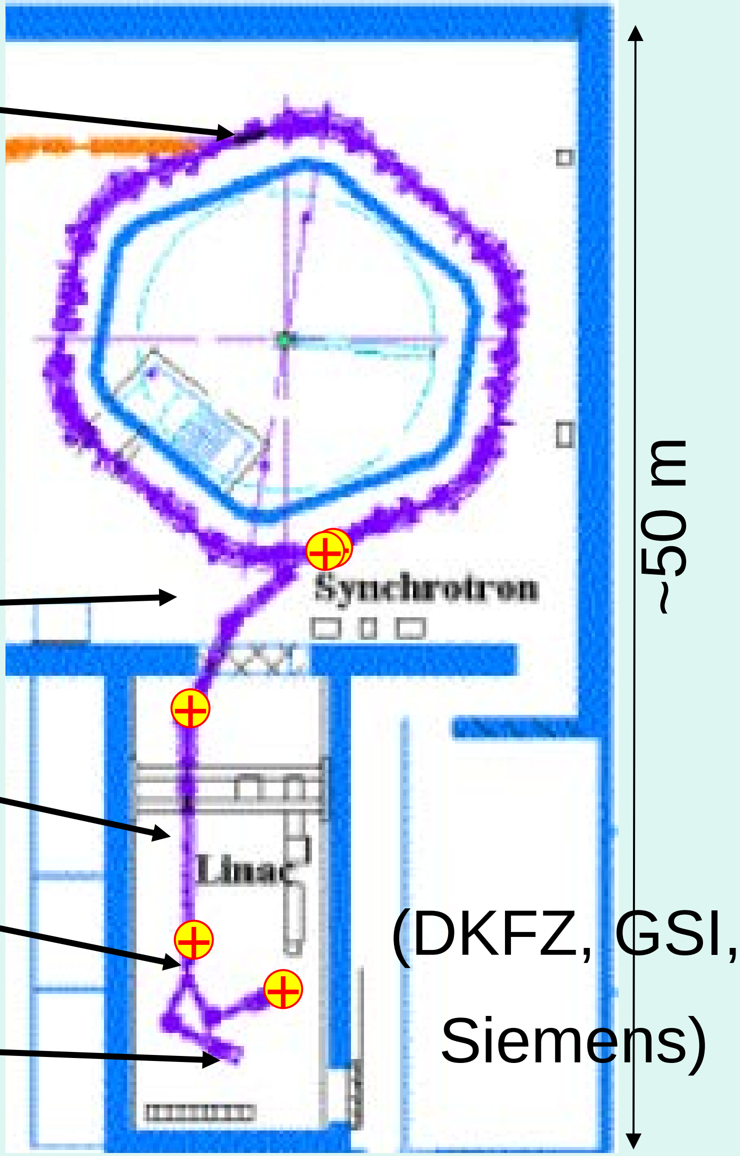
- acceleration to desired E
- storing of the beam

Injection in ring at 7 MeV/nucl

2 linear accelerators in series

Magnet to select ion source

Ion sources for different particles

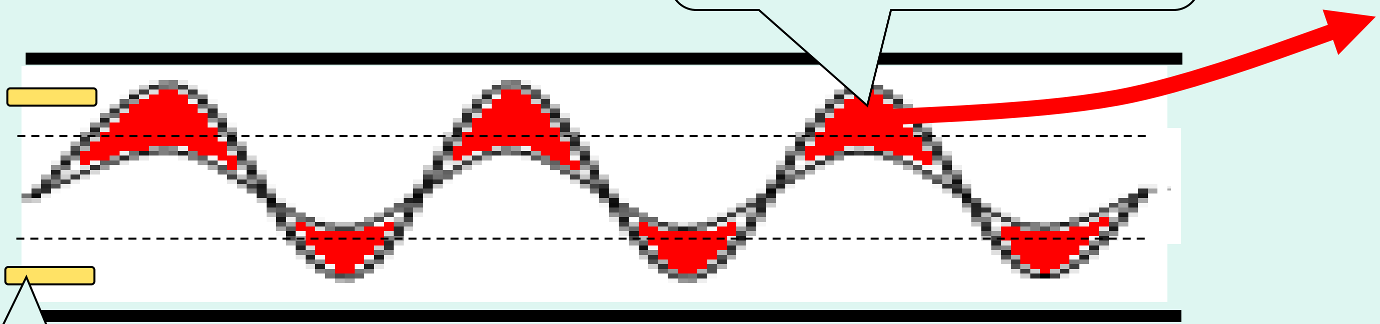


Extraction

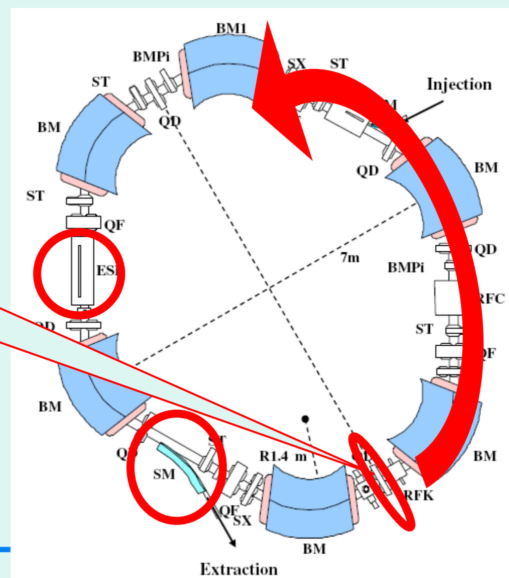
Extraction by RF-Knock Out

(first demonstated by Hitachi)

Unstable orbits
→ extracted



RF kicker: increases emittance (beam size)



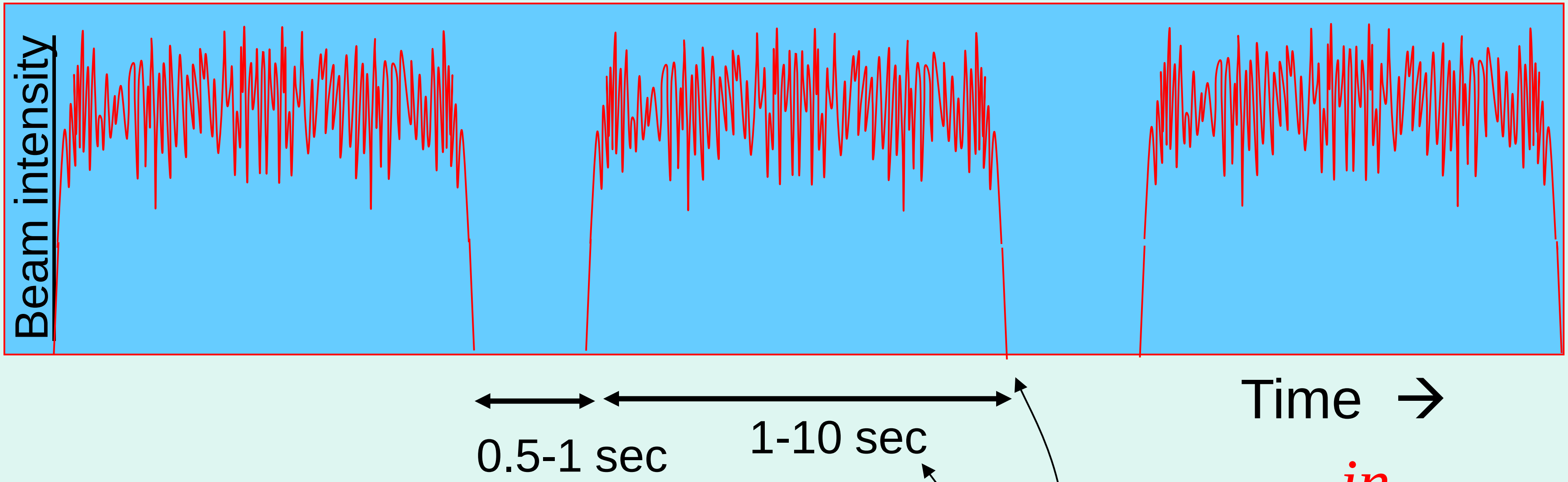
With RF-knock Out:

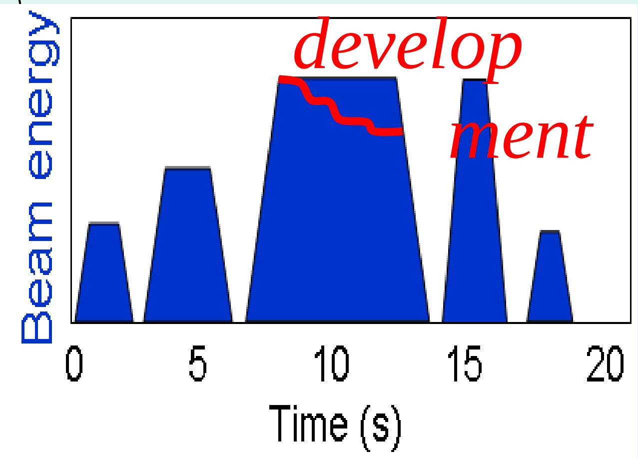
position and size

of extracted beam

remain constant

Synchrotron beam structure in time





"spill" time

- fill ring with ~10^{11} particles
- accelerate to desired energy
- extract slowly during 1-10 sec
- decelerate and dump unused particles

(Dis)advantages of a synchrotron

=> a synchrotron provides:

+ high energy (if desired)

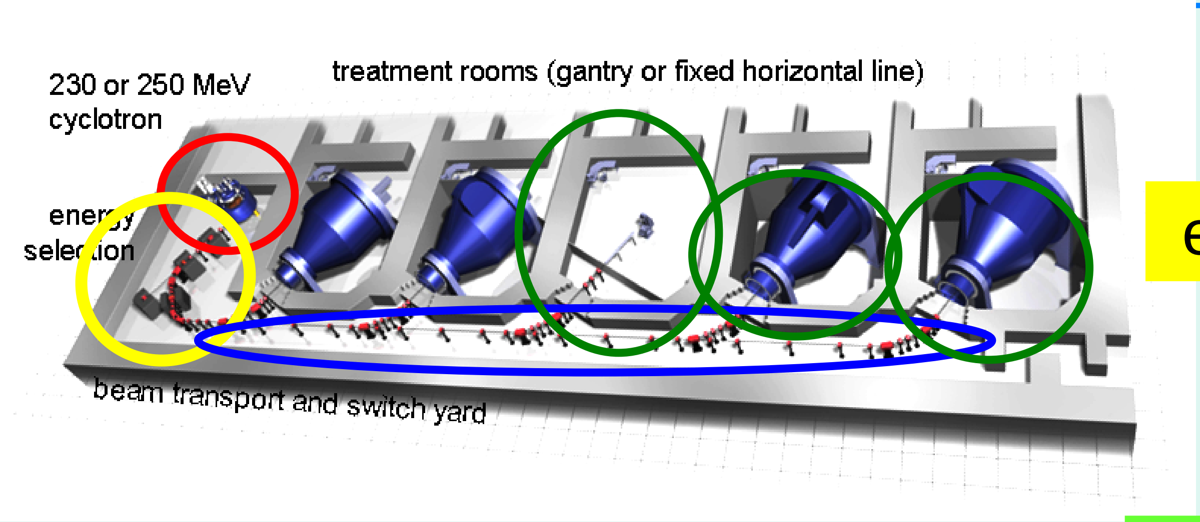
+ any particle

+ low radioactivity

Disadvantages:

- limited average intensity (ring filling)
- spill structure => low average dose rate
- energy change: wait for next spill (in development)
- noisy beam intensity

Particle therapy facility

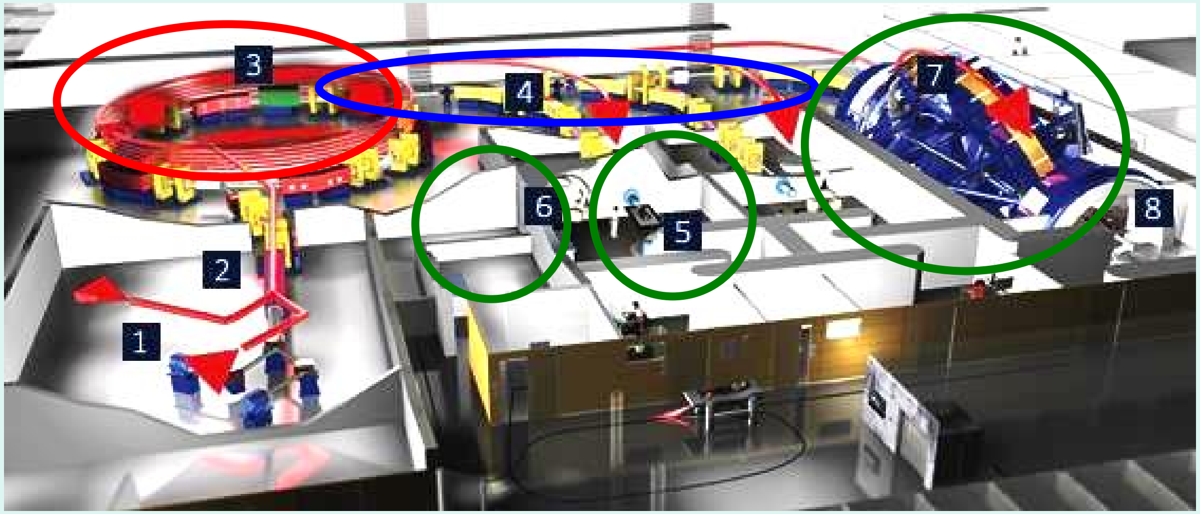


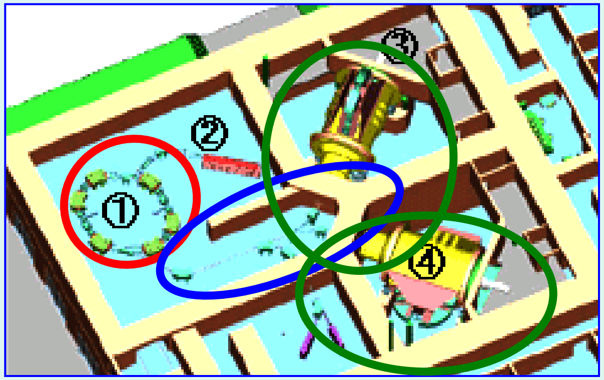
accelerator

energy selection

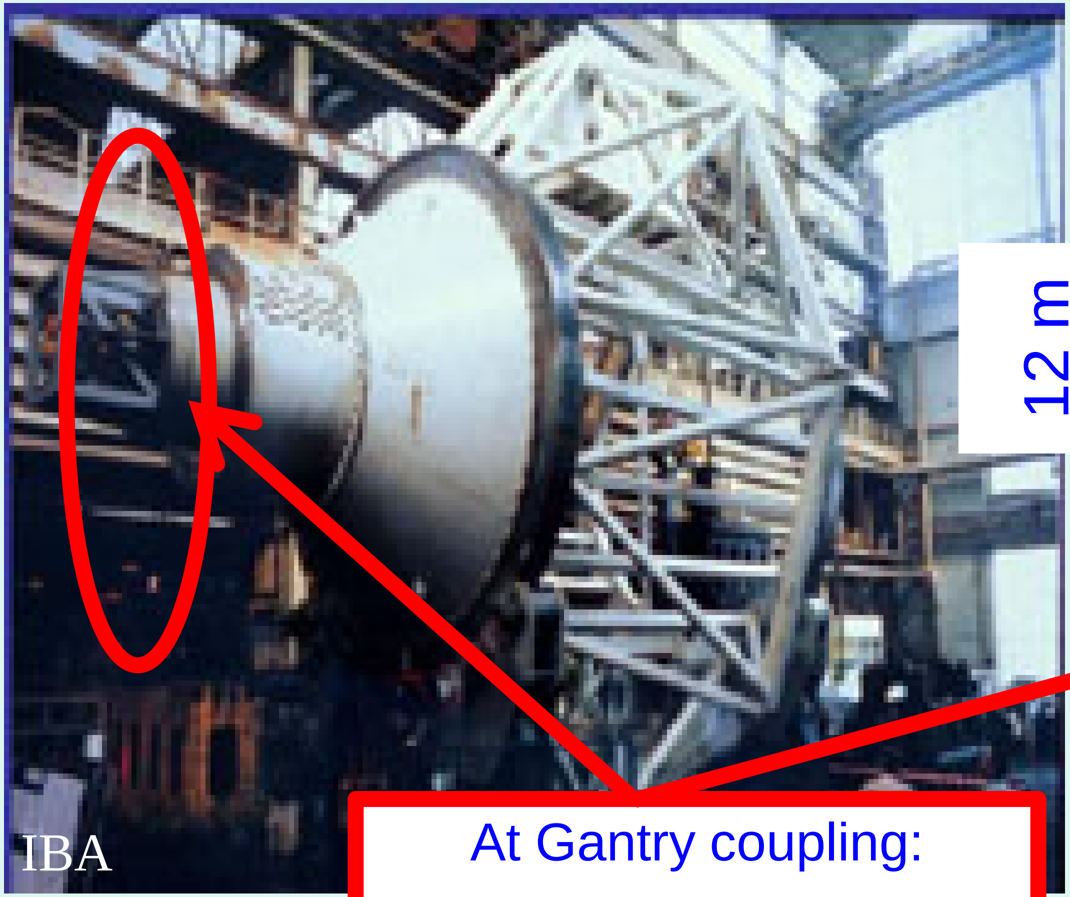
beam transport

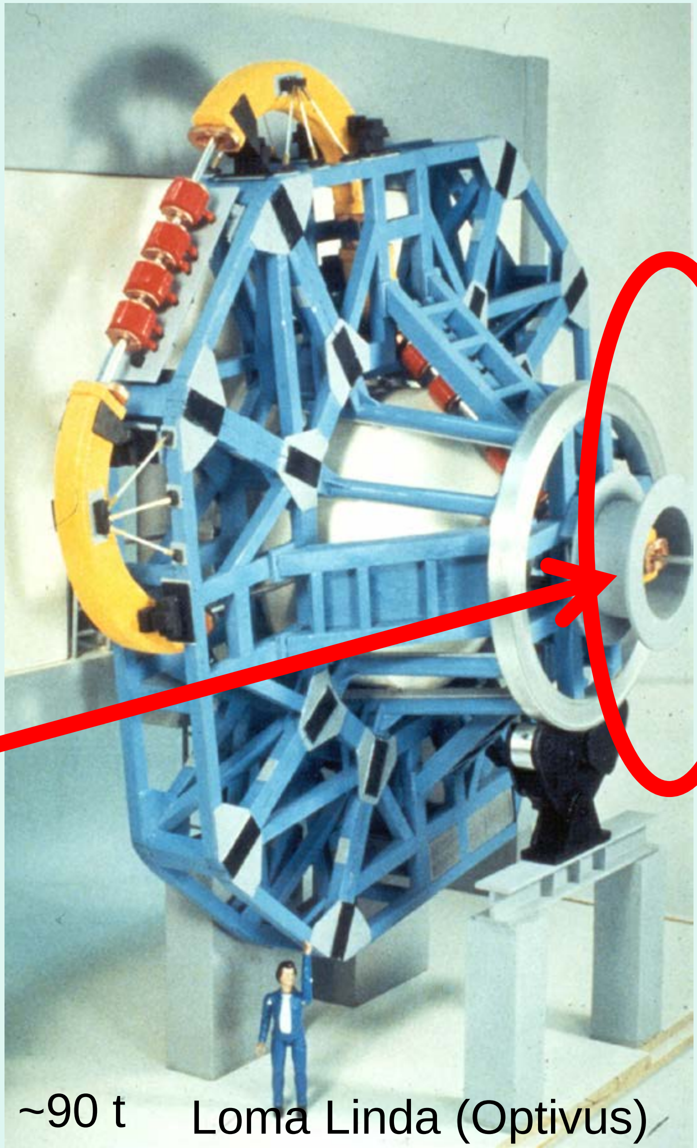
gantry / fixed hor. line





Gantries

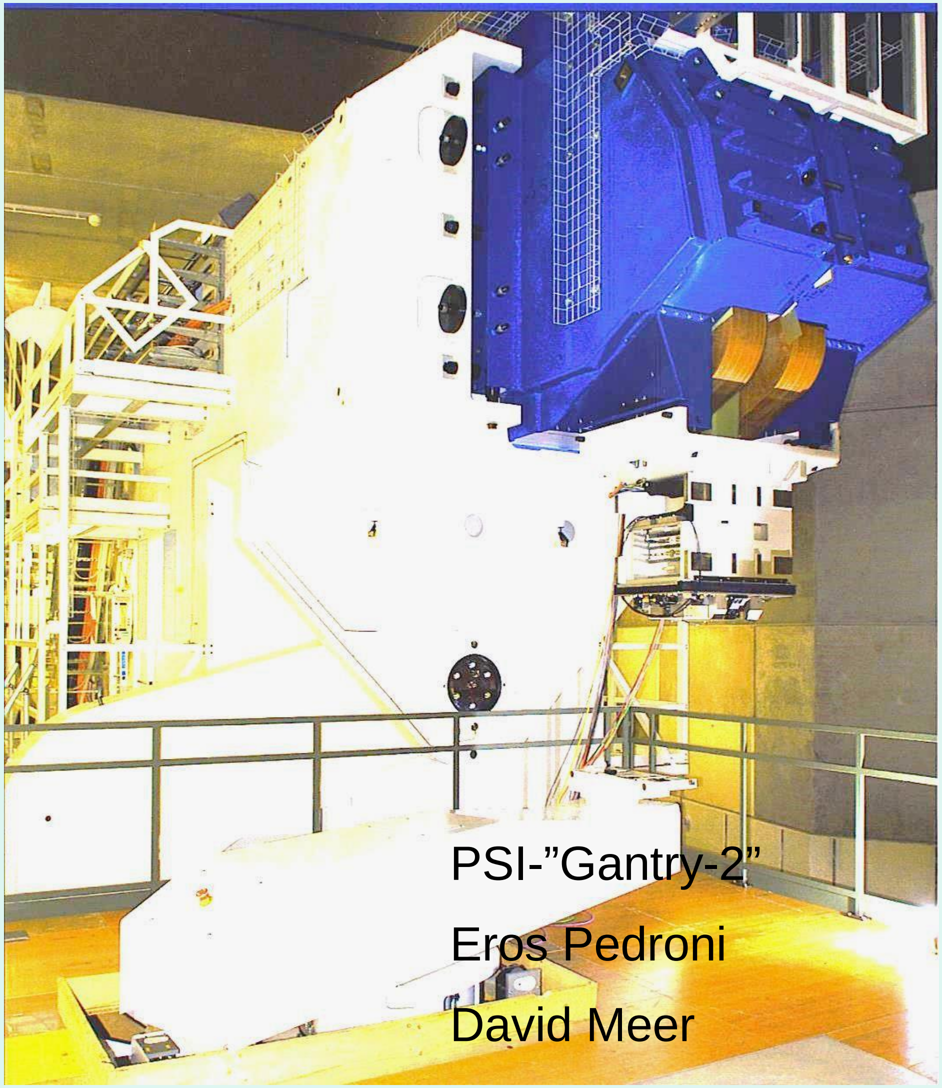


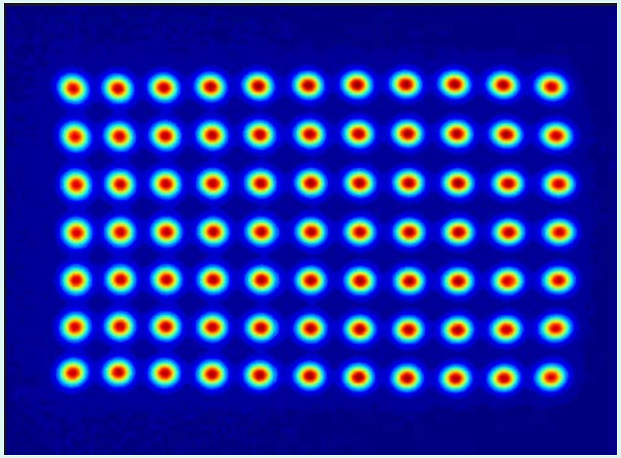


At Gantry coupling:

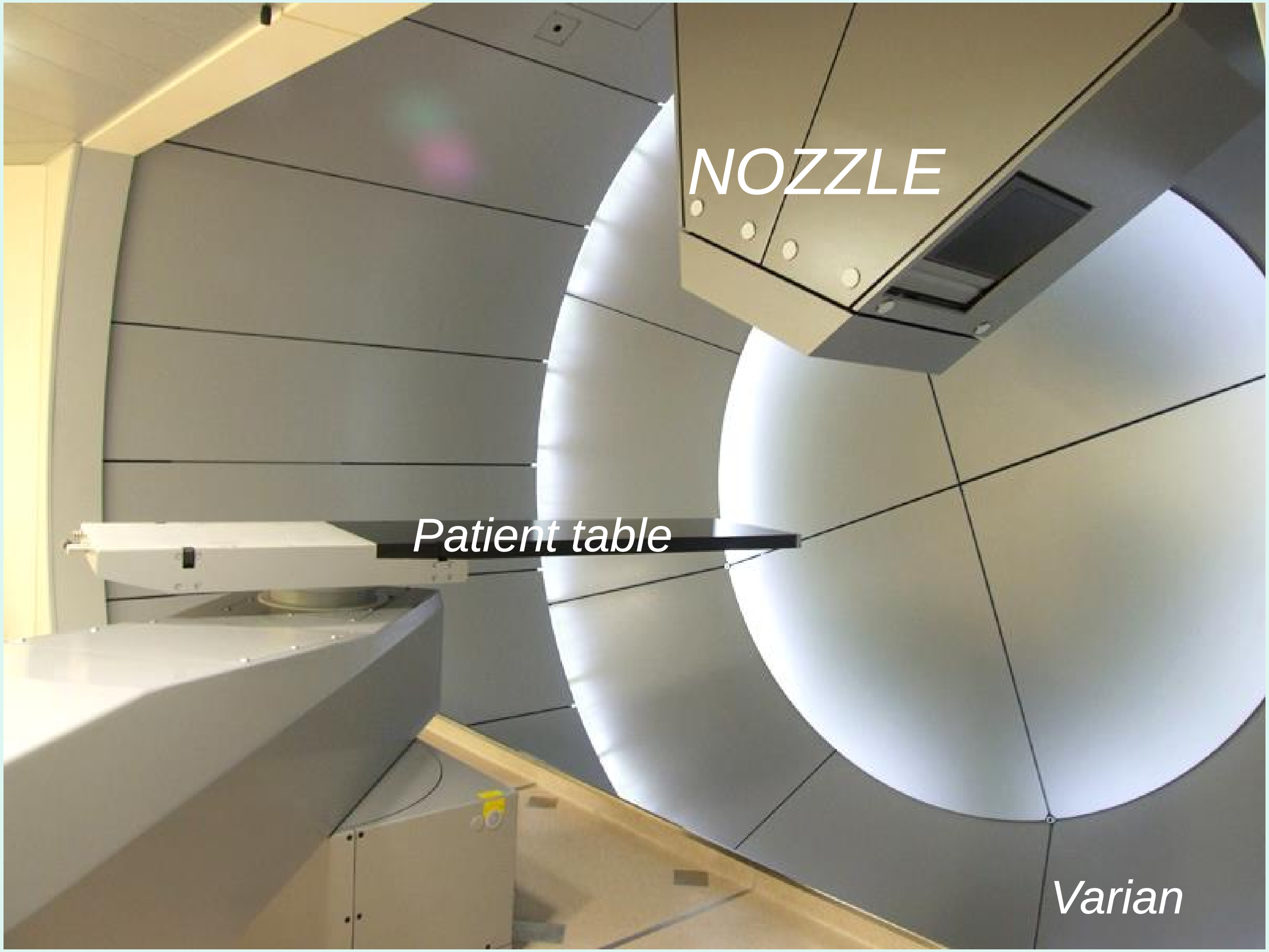
- Phase space symmetric
- No dispersion

PSI Gantry-2: fast 3D scanning





Gantry as seen from patient side



Acc.Lab <-> Hospital

Operators

Technicians

Experienced workshops

More improvised actions

New settings need more procedures

(operator) radiologist operates

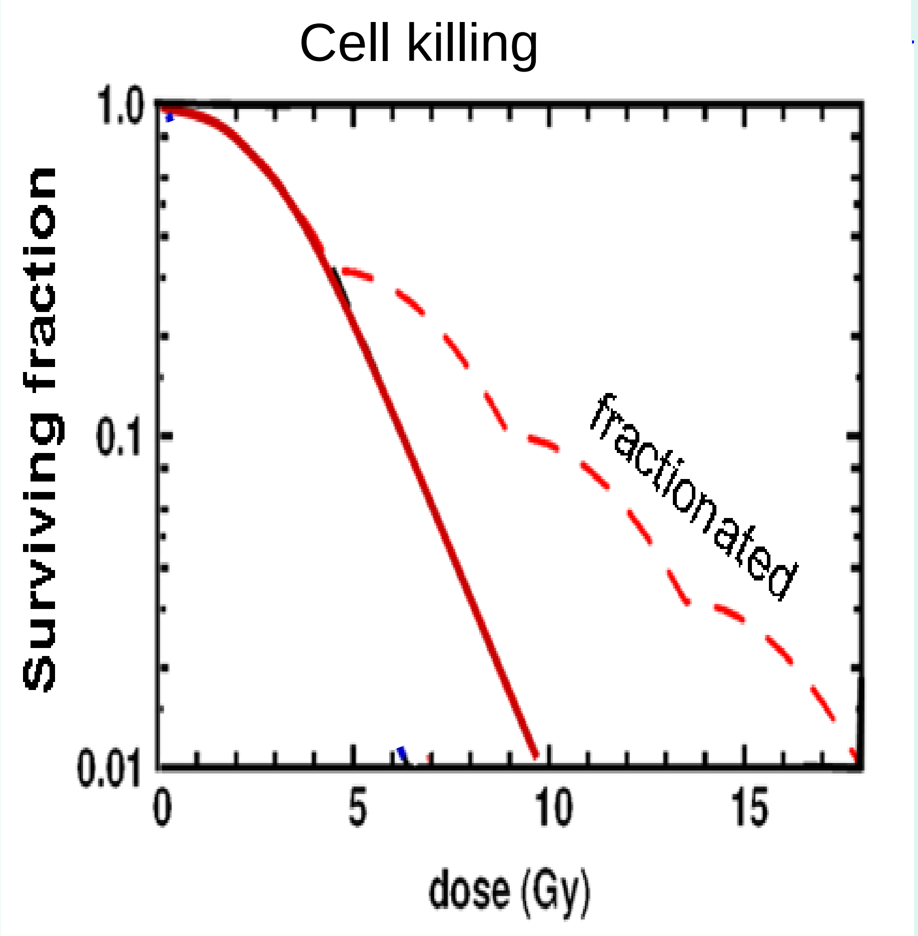
Technicians:only small repairs

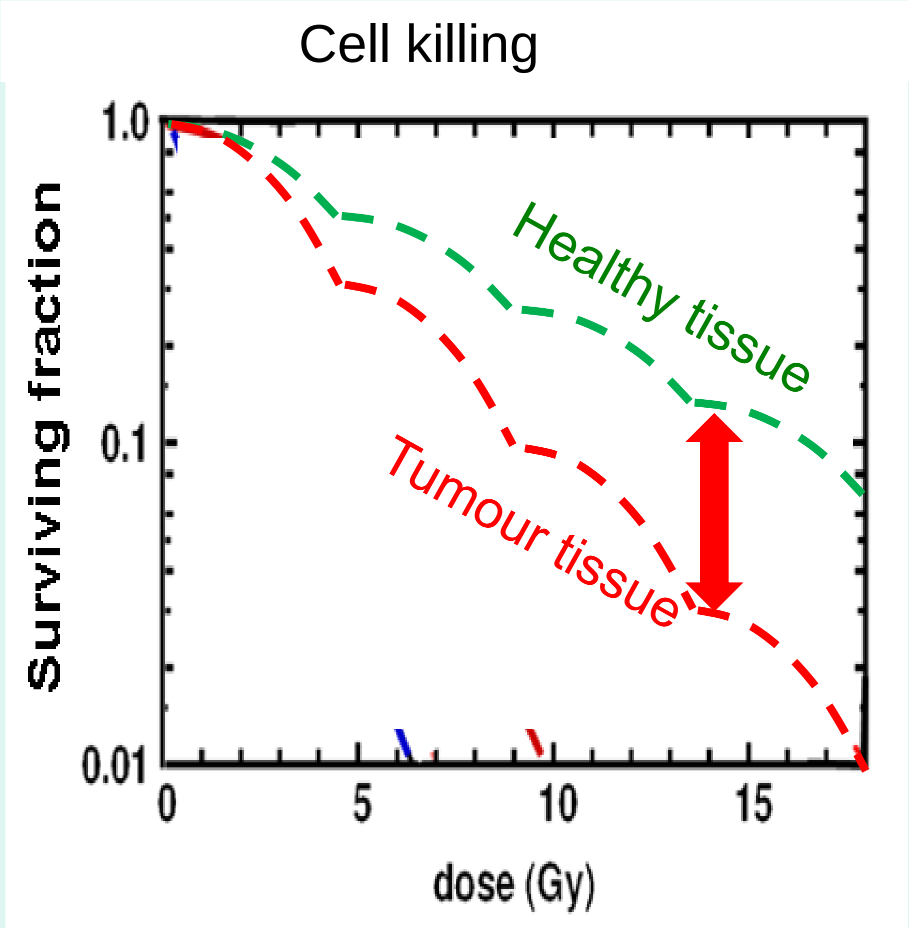
Service by equipment company

CE/FDA-certification: PROCEDURES

Fractionated treatment

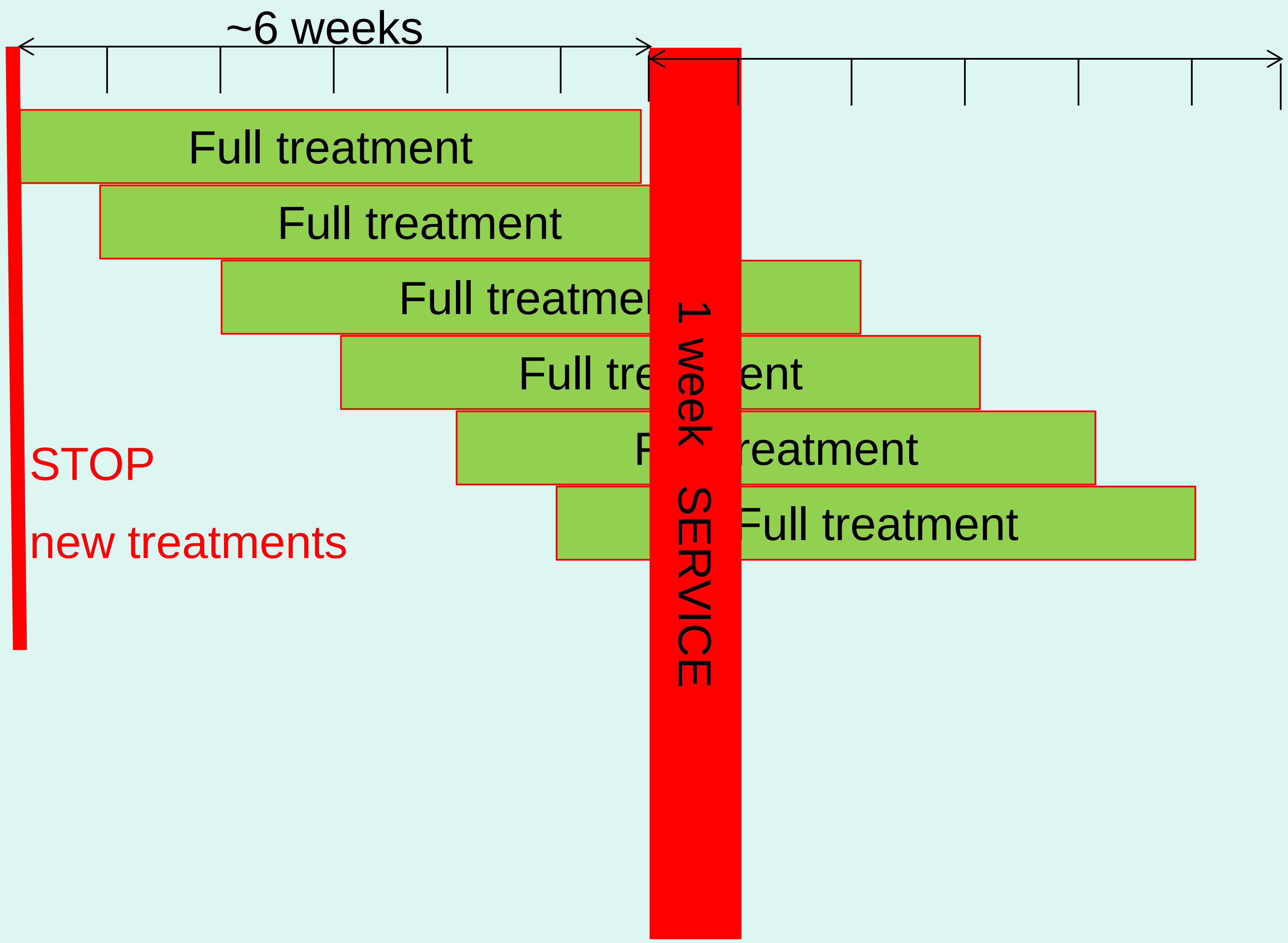
to spare healthy tissue



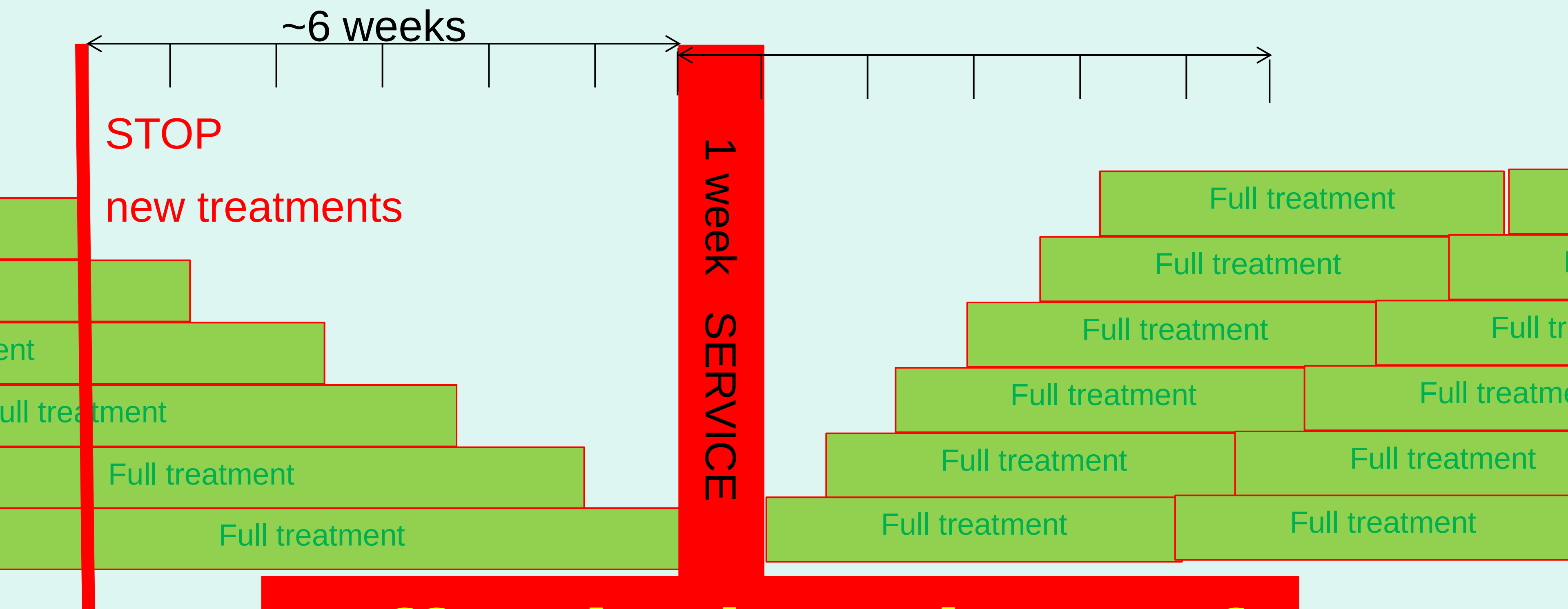


But: DO NOT interrupt treatment for more than 3-5 days

Operational aspects



Operational aspects



Effectively: a loss of

8-10 weeks

Operational aspects

So…

no long services =>

- well scheduled short services
- know what to do
- easy access

=> low dose level needed

=> many prepared spare parts

Operational aspects

- Dose application within 1-2 %: REPRODUCIBILITY

  => beam intensity, on/off, positioning accuracy
- «just retune and do a test»: NOT allowed
- Operational MODES: THERAPY / SERVICE
- Operation by medical staff
- Multiple treatment rooms => MASTERSHIP concept

with (CE / FDA) certification:

- **Procedures** for designing / building / repair / testing
- **Standardized** documentation
- Only **certified** staff for certain tasks

Safety <-> Availability

At Psi: **Separate interlock systems**:

More **special** for treatments

Machine interlocks:

all components technically OK

Area access & area dose:

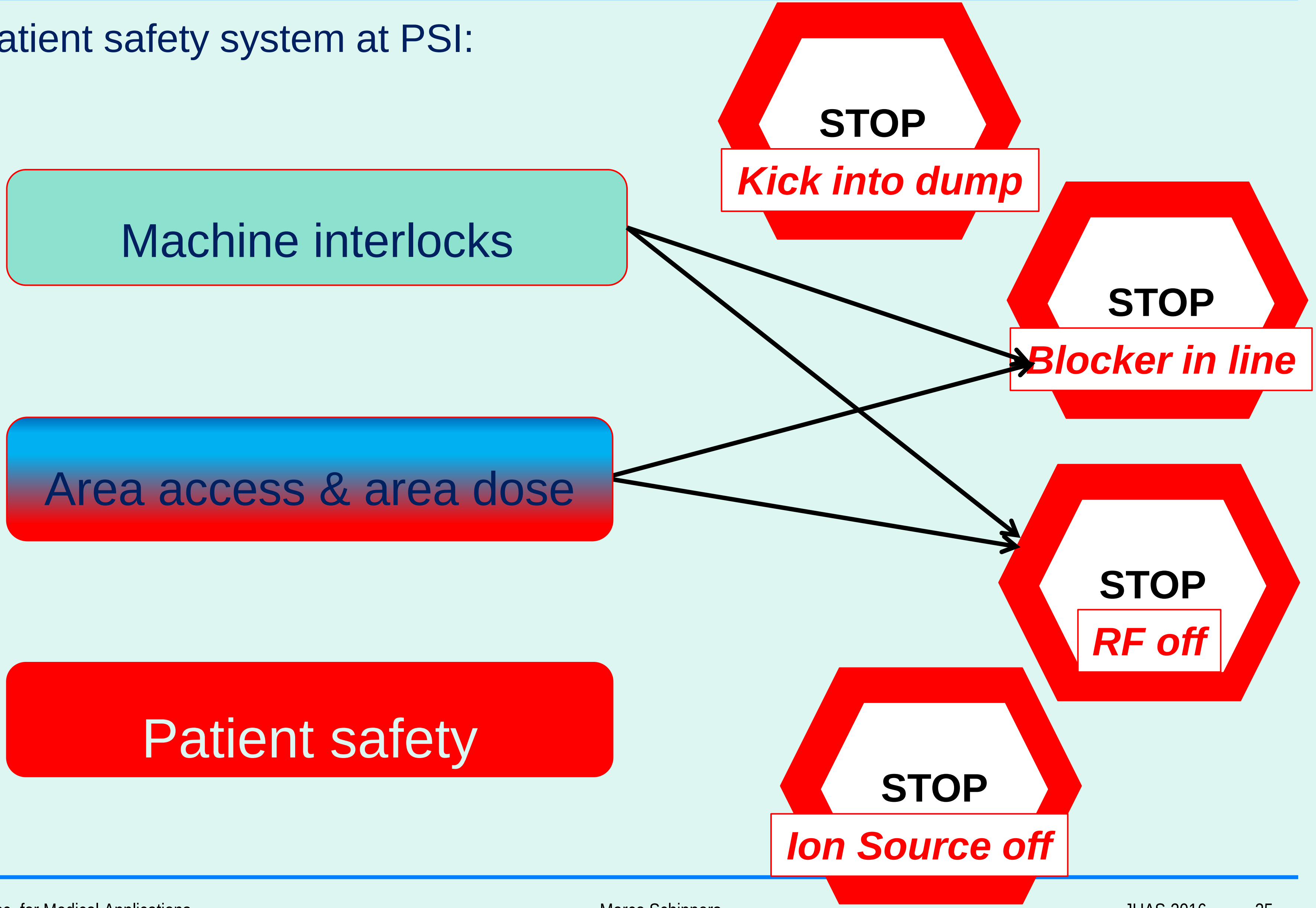
Doors closed, dose rate < µSv/h

Patient safety:

Dose delivery as planned

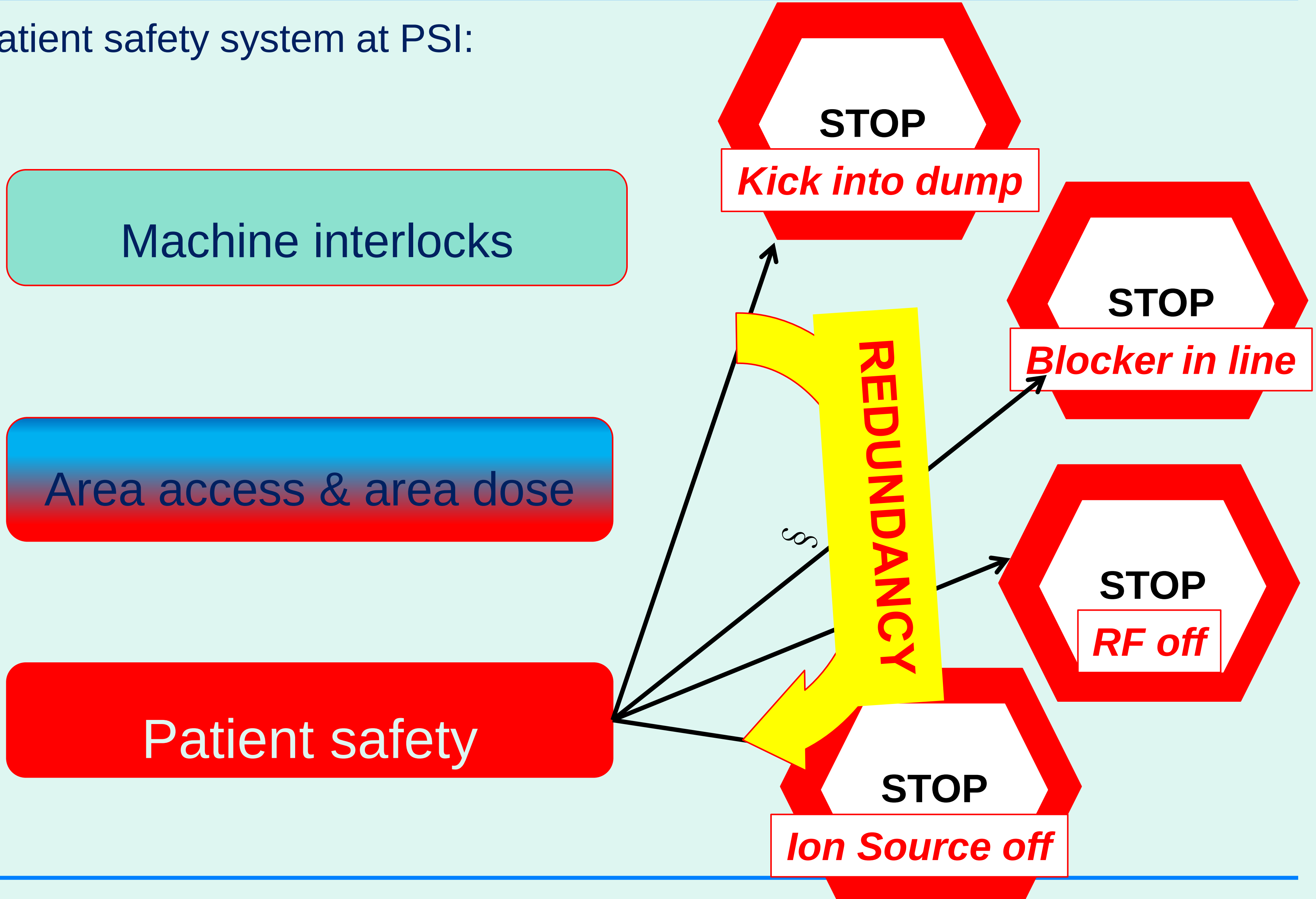
Hierarchy of Interlock signals

Patient safety system at PSI:

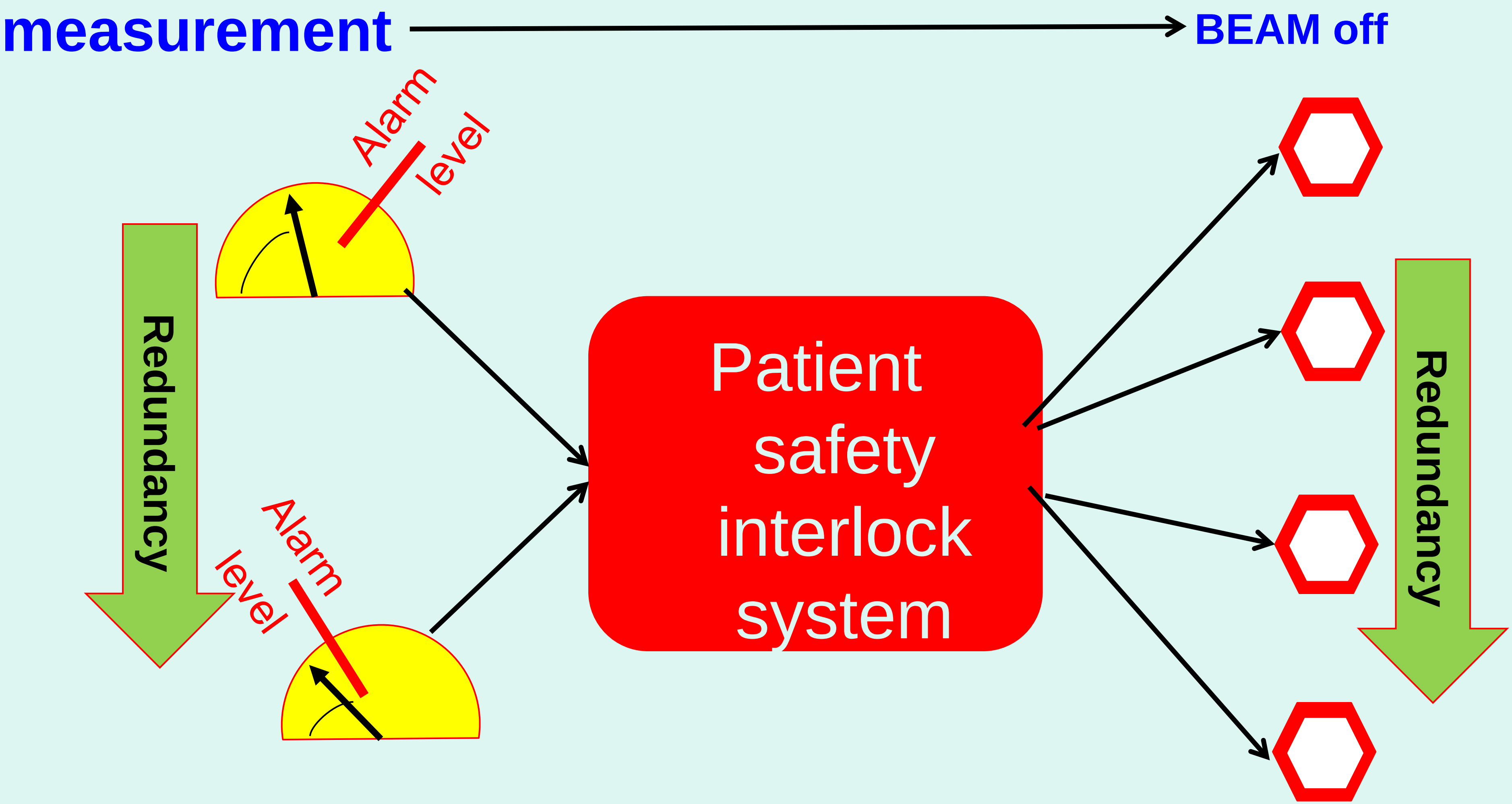


Hierarchy of Interlock signals

Patient safety system at PSI:



Redundancy


measurement
BEAM off
Alarm level
Alarm level
Redundancy
Patient safety interlock system
Redundancy

Operation: non-accelerator experts

What has happened ?

Strong need for ERGONOMIC display of: **Status**

Instructions

SUMMARY

Accelerators for Medical Application:

What is so special?

- **Technics**: dedicated, but not on the limit ….but…
  Reliable, Reproducible, Reliable, Reproducible

- **Operation**: by non accelerator experts
  strictly according procedures
  NO long services or shut downs

Control and safety:

VERY DEDICATED and SPECIAL :

Reliable, redundant, but not too sensitive

first scanning gantry : PSI, 1996

Gantry: Eros Pedroni

Tumours in kids: Beate Timmermann, Gudrun Goitein

Thank you !!