PAUL SCHERRER INSTITUT

Marco Schippers, Paul Scherrer Institut, Villigen

Developments in Particle Therapy using Nuclear Science and Technology

Helsinki, NUSPRASEN workshop, November 26, 2019

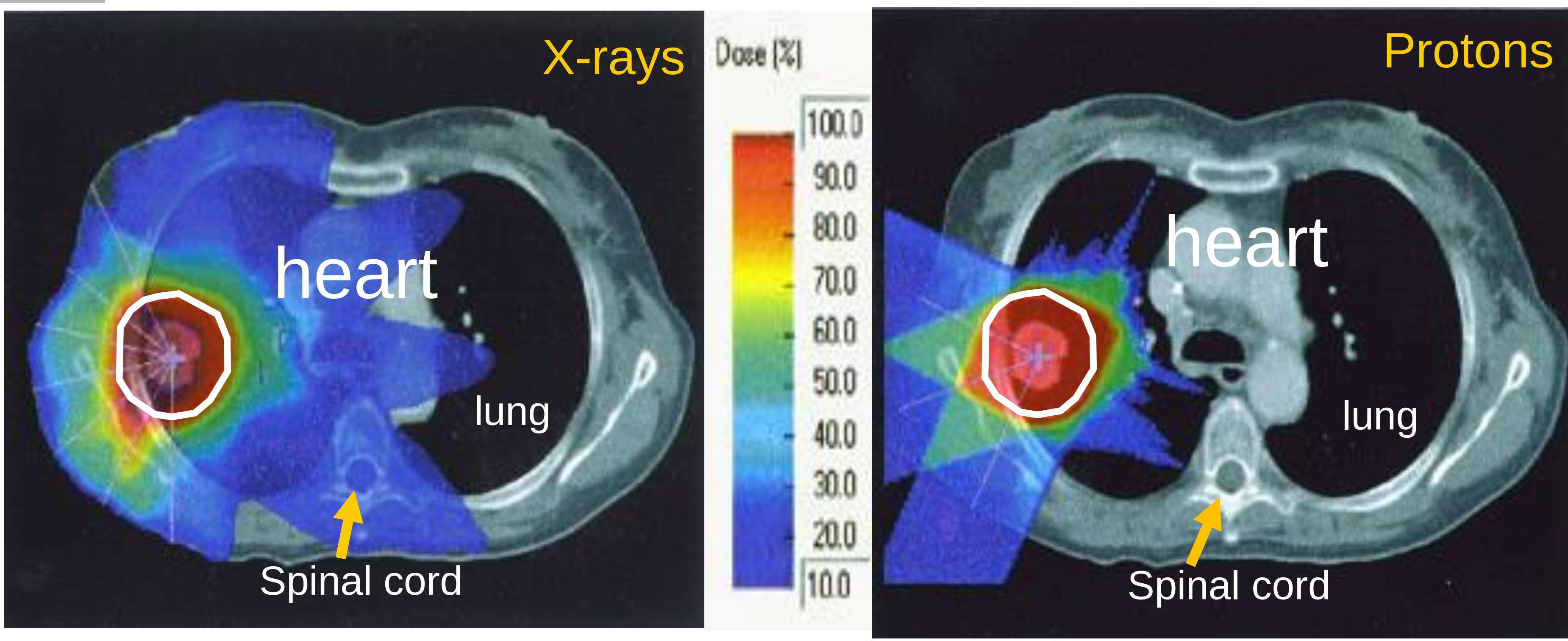
OUTLINE

- Proton Therapy
- Recent developments in dose delivery and p.th.-accelerators
- Current major topics of research:
  - Treatment when organs are moving
  - High intensity
  - Proton range determination

Why Particle therapy?

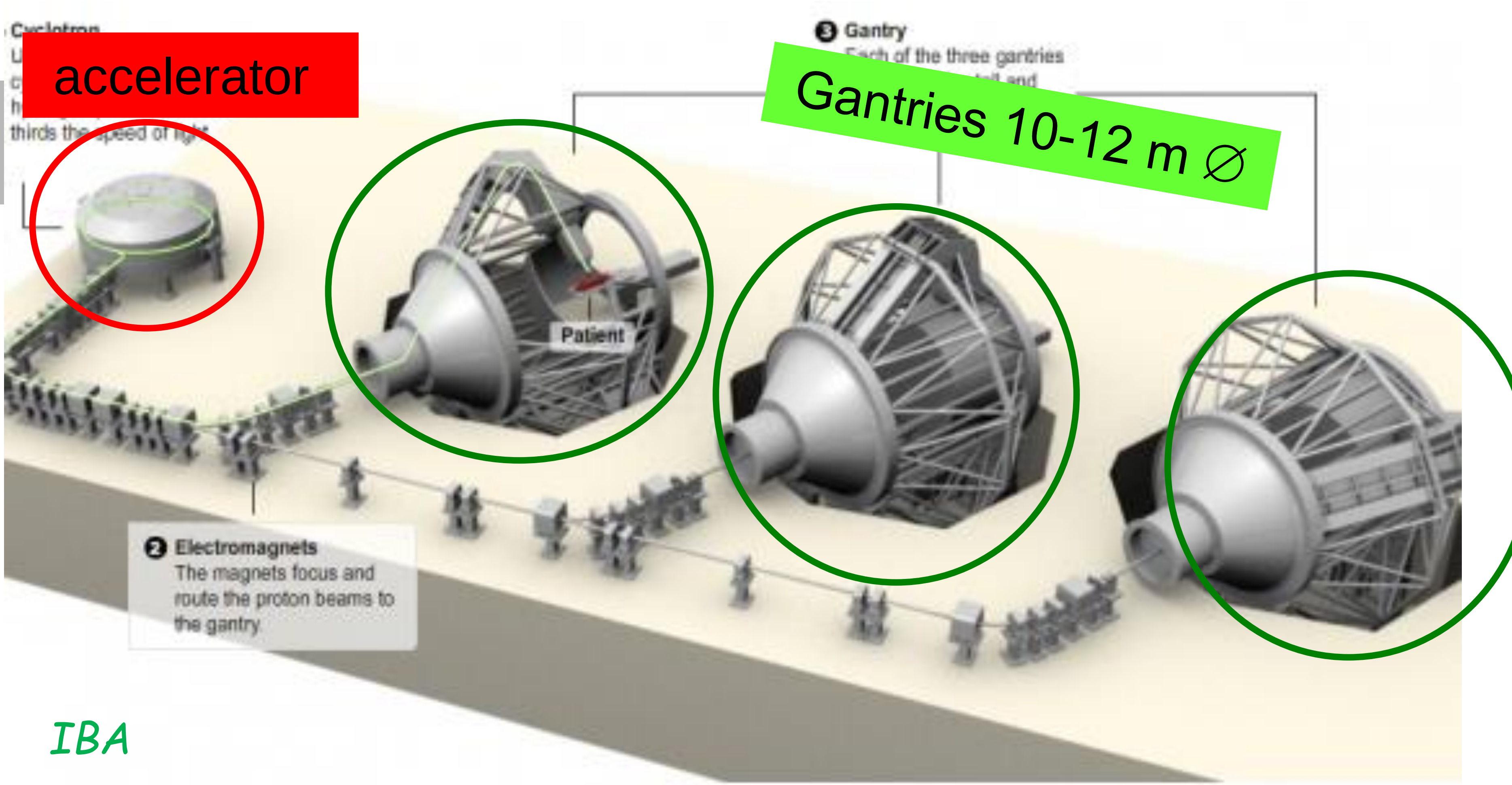
X-ray beams
from 7 directions

Proton beams
from 3 directions



pictures: Medaustron

Proton therapy facility



Accelerators for Proton therapy

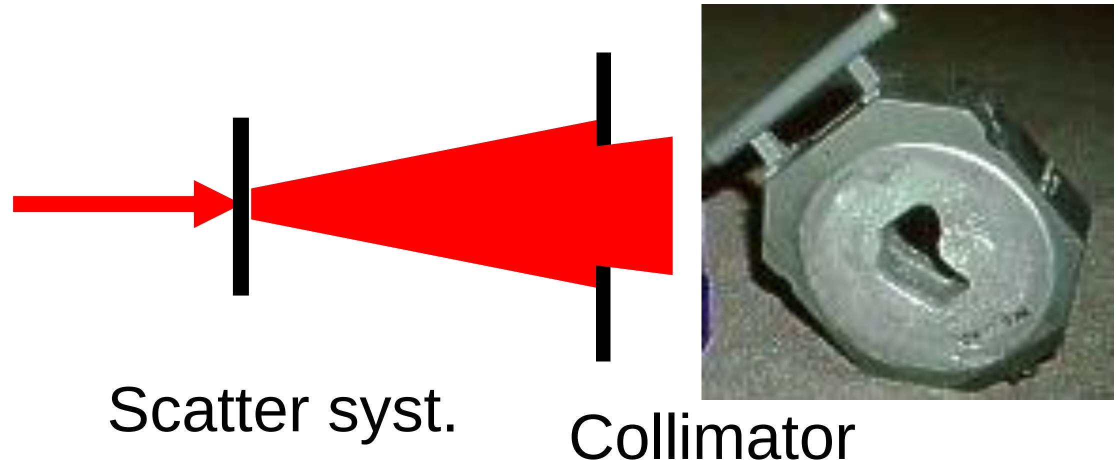
Cyclotron

Synchrotron

Recent Developments
in
dose delivery and **accelerators**

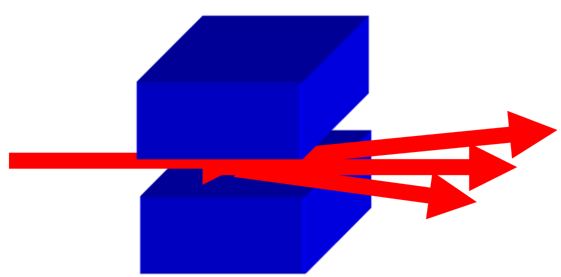
Dose delivery techniques

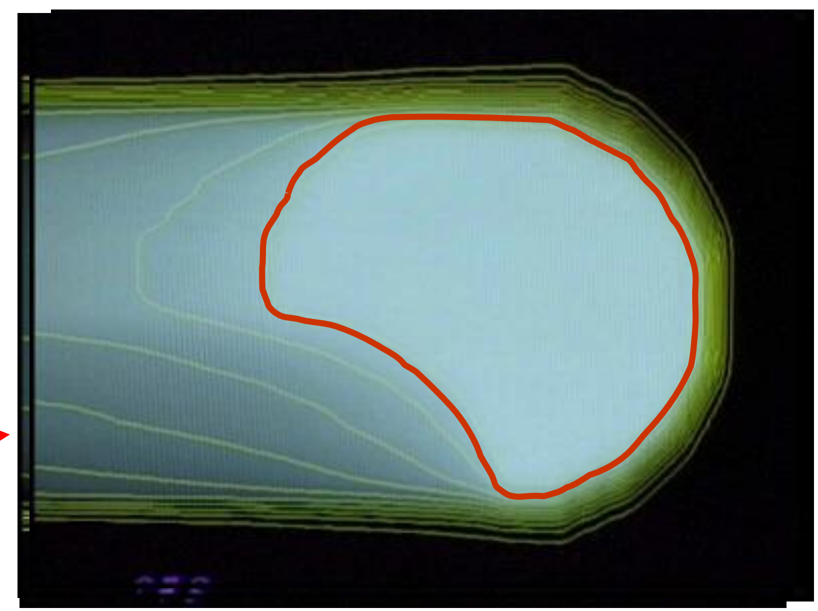
Scatter technique:



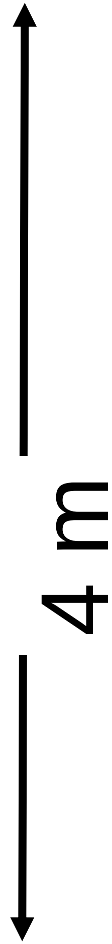
From nucl physics lab:

Pencil Beam Scanning





compact "Gantry-1" at PSI (1996)



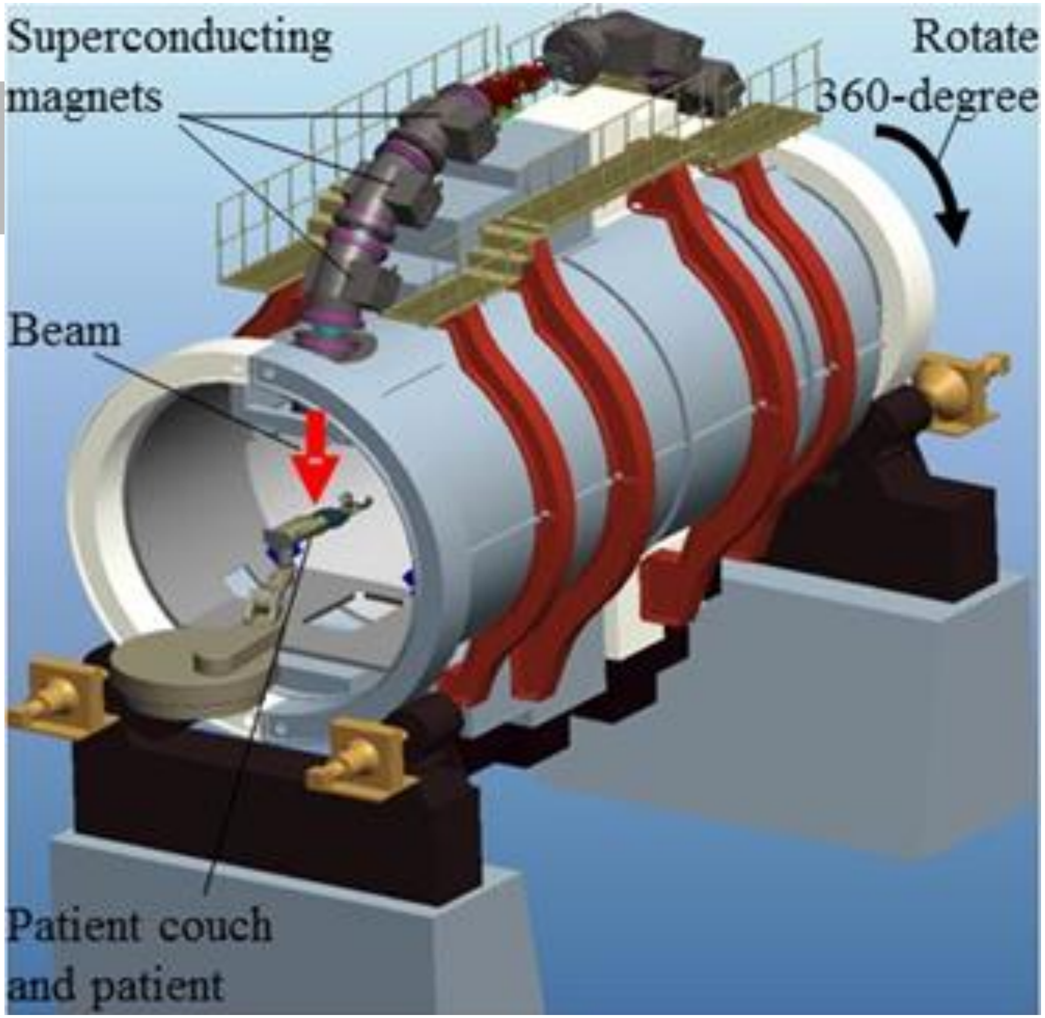
Typical Gantry ~1996…

Roberts Proton Therapy Center

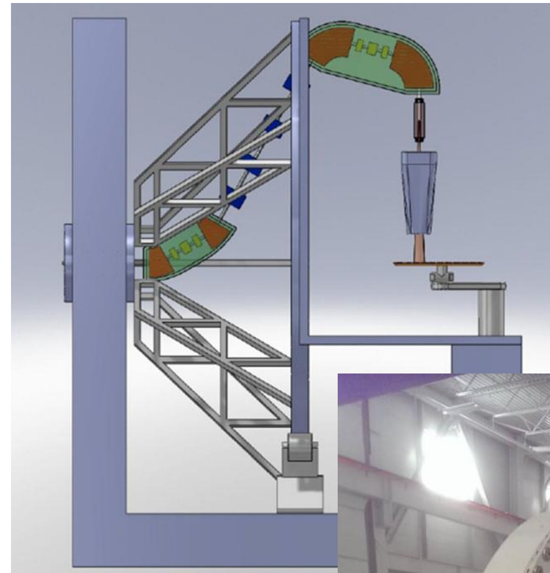
Philladelphia

Schär Engineering - Munich

NEW: gantries with SC magnets



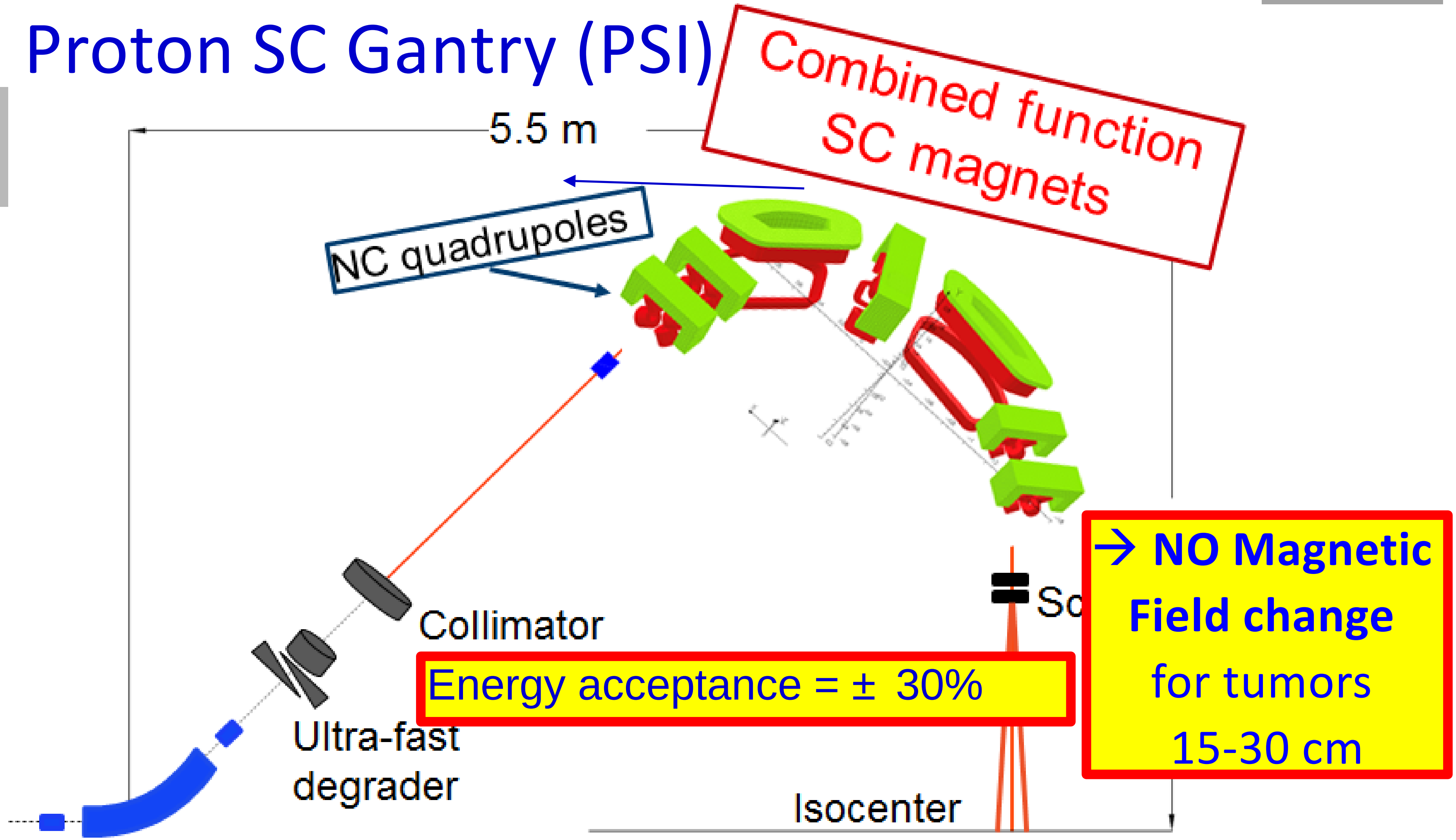
Toshiba, NIRS



ProNova

NEW: optics in SC gantry design

Proton SC Gantry (PSI)



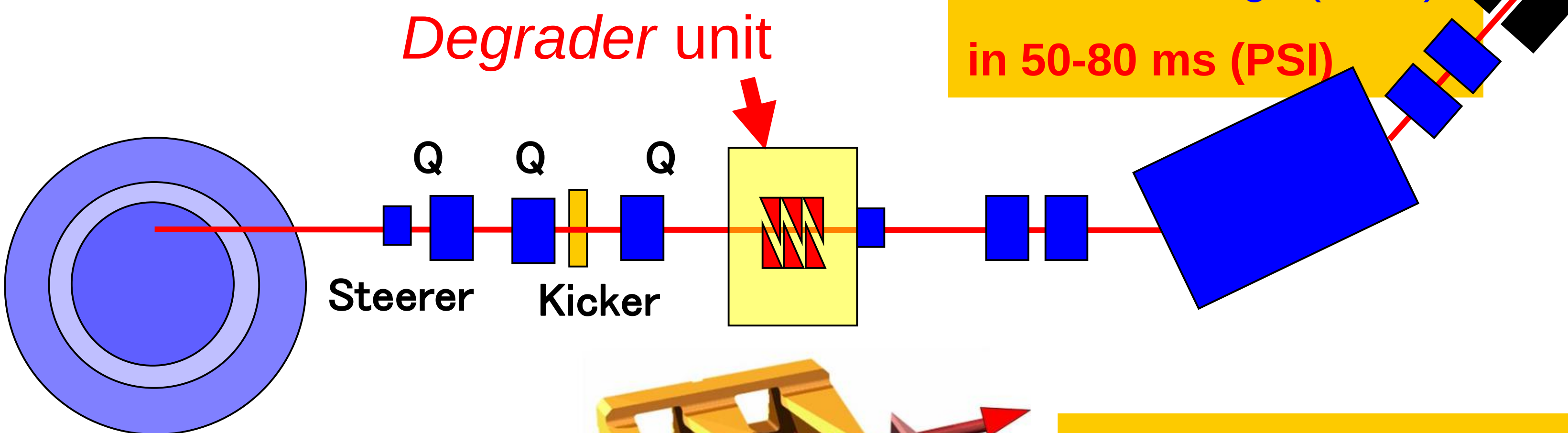
Vary depth: adjust beam energy

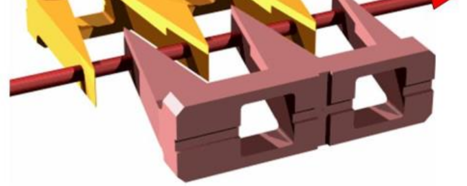
E– changes with Cyclotron

All following magnets:

1% field change (5mm)

in 50-80 ms (PSI)





graphite

multi-wedge degrader

→ 238-70 MeV

recent development:

Gaphite → **Boron Carbide**

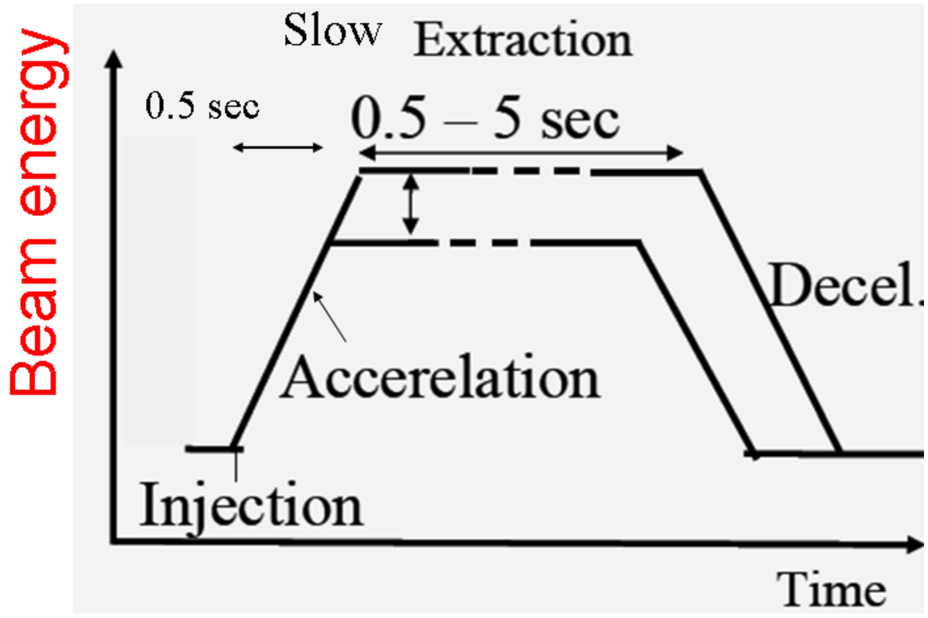
Less scattering→ less losses at low E

Vary depth: adjust beam energy

E-changes with Synchrotron

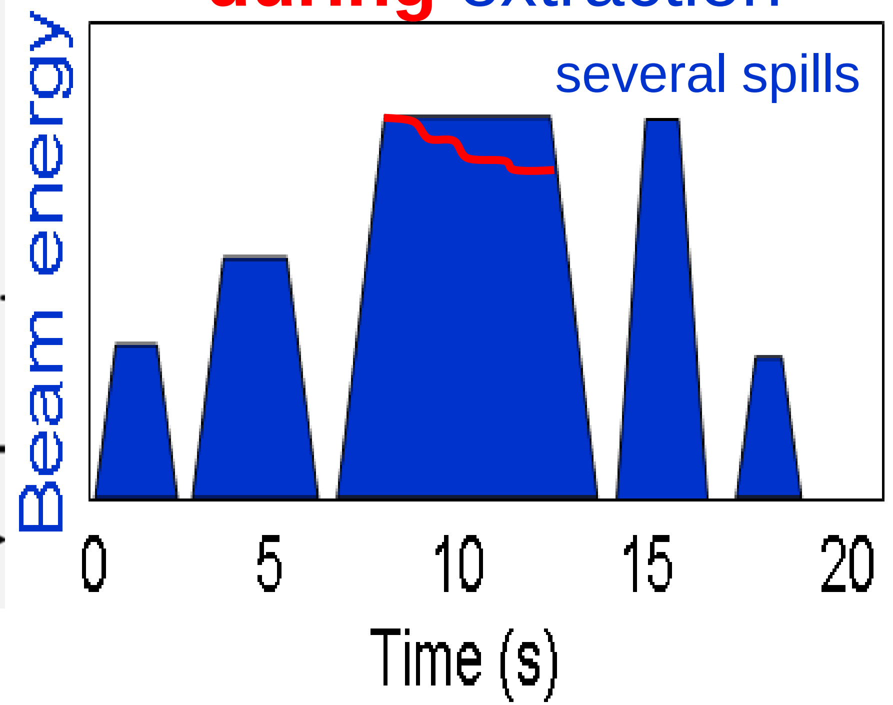
Energy is set per spill

1 spill:



recent development:

Energy **adjustable during** extraction



NIRS: Y. Iwata et al., MOPEA008, Proc. IPAC'10

cyclotrons in proton therapy

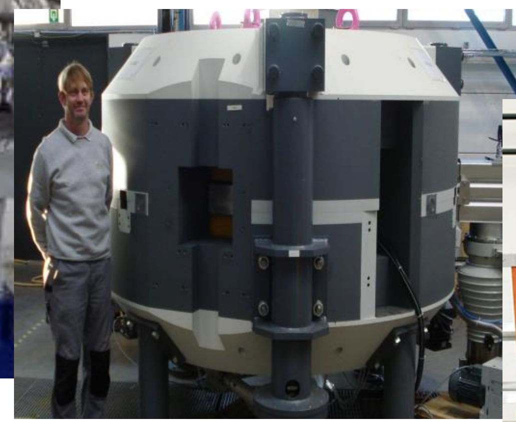
IBA (1996) , SHI

Isochronous Cyclotron

Varian (2005)

Isochronous Cyclotron

Superconducting Coils



IBA (2018)

Synchrocyclotron

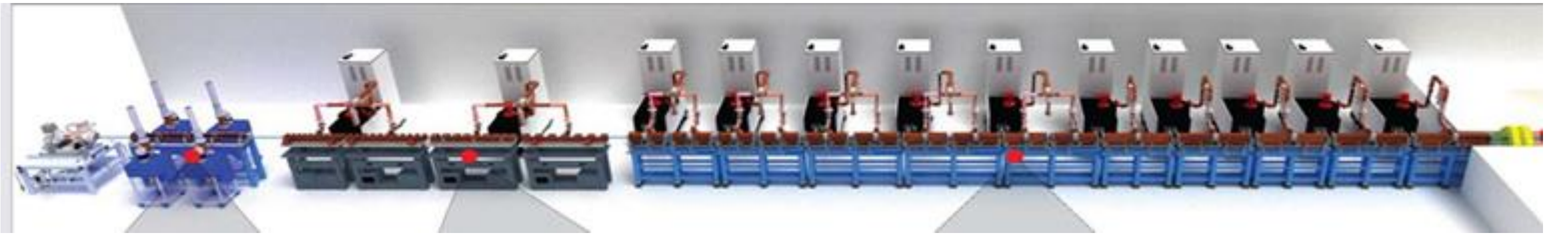
MEVION (2013)

Synchrocyclotron

Pulsed beam:
Limits speed in dose delivery

In Production: Linac 230 MeV

Spin-off from TERA and CERN:



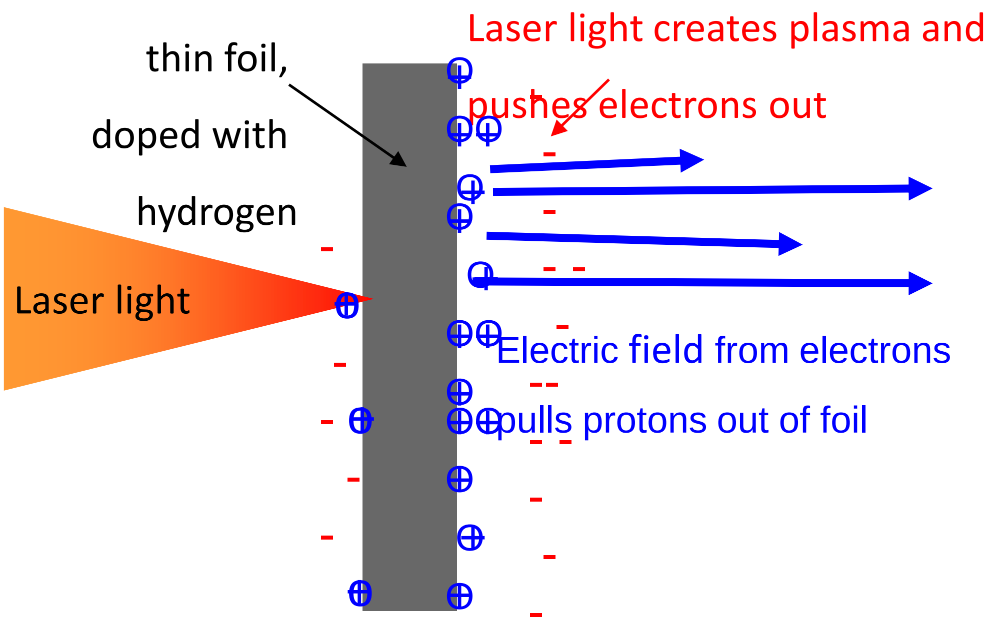
Coupled Cavity Linac →230 MeV

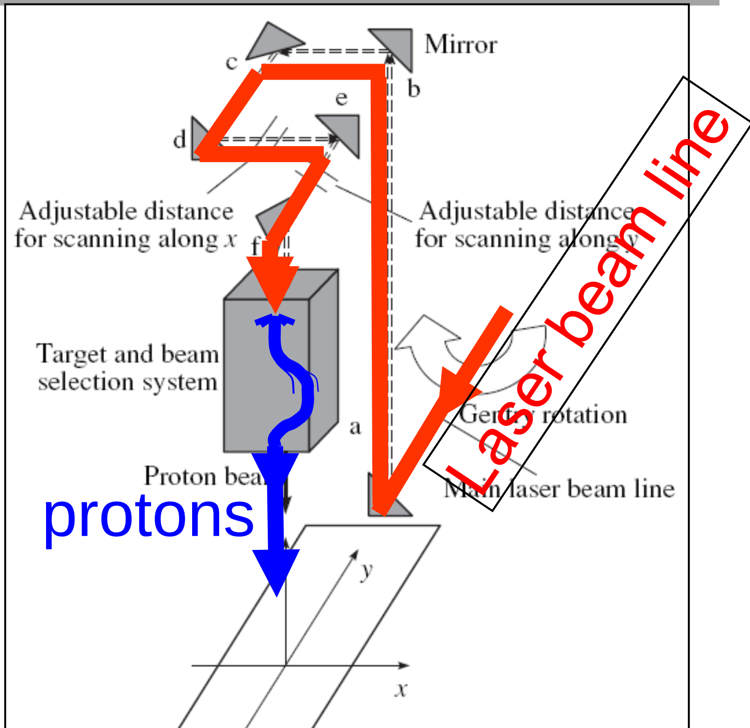
E-change by:

switching on/off power of cavity units

AVO, ADAM: A. Degiovanni et al. 2016

Laser driven proton accelerator





now used:

6x10^{17} W/mm^2

Pulsed at low rate

But: **more research needed** for:

- 100x more power (for Ep)
- MUCH higher pulse rate
- better energy spectrum

Current major topics of research

Treatment with moving organs

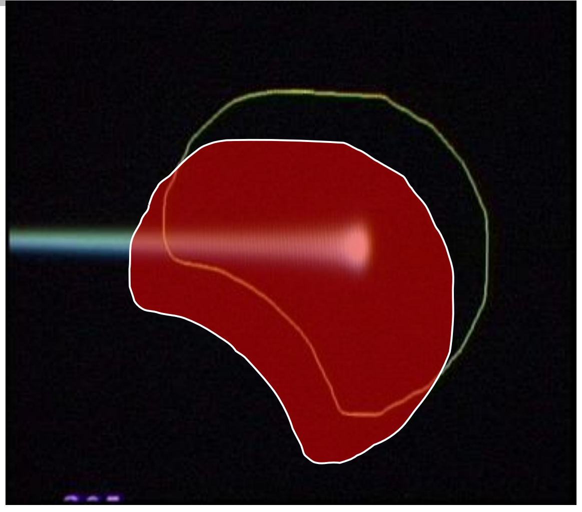
High intensity + verification

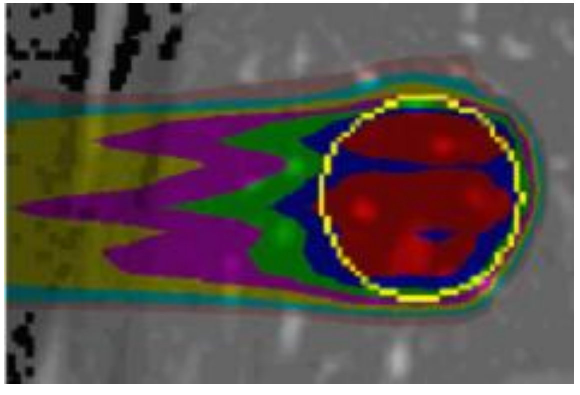
Range determination

organ / tumor motion

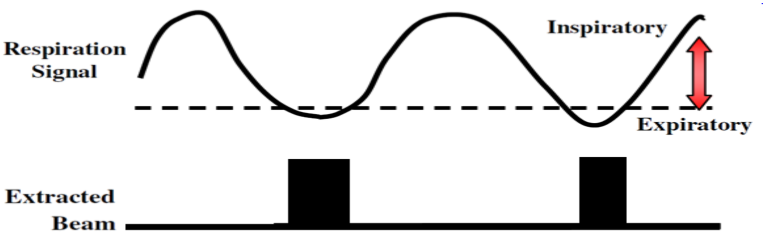
Possible solutions:

Organ motion



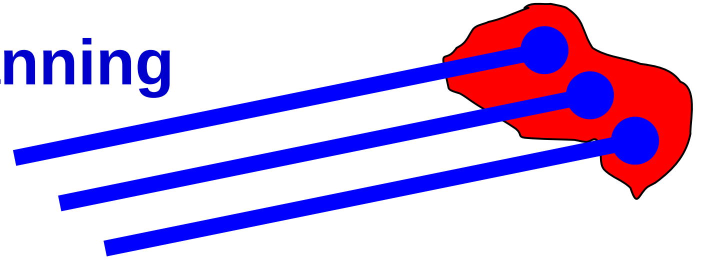


- **Gating**

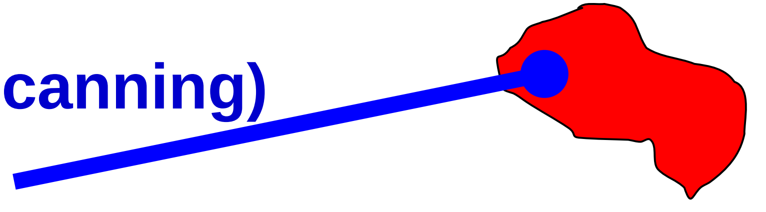


- **Adaptive scanning**

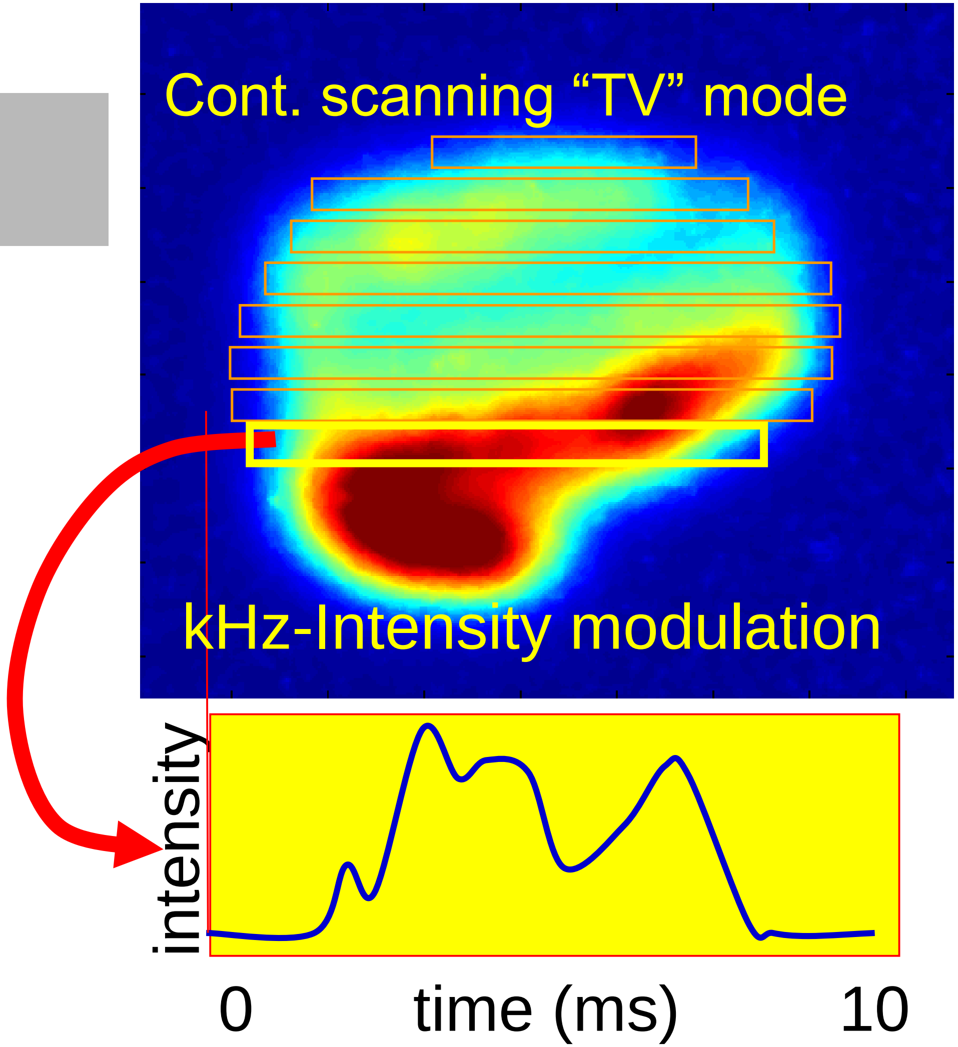
  (tumor tracking)

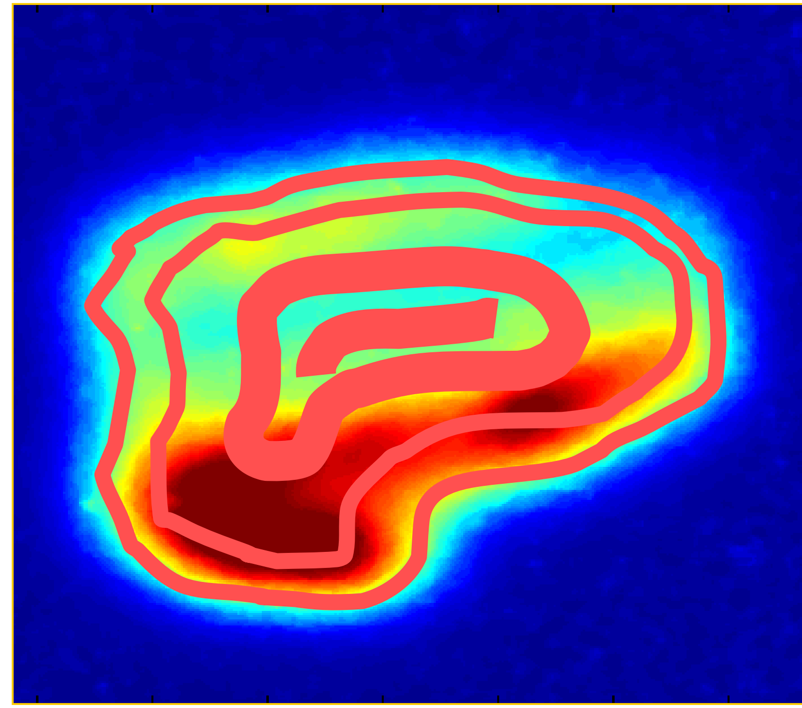


- **Fast (+ rescanning)**



Fast pencil beam scanning





7 s for a 1 liter volume.

Current major topics of research

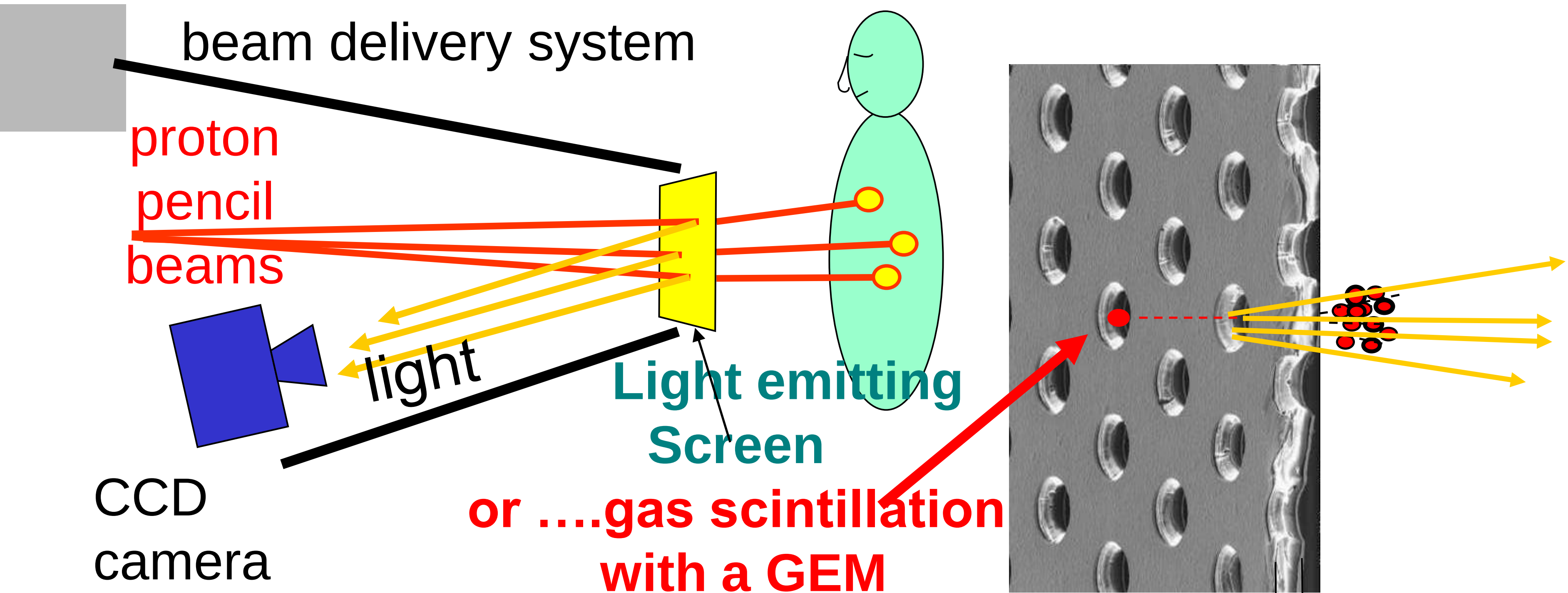
High intensity:

- Reduces motion problems
- FLASH irradiation: 0.03 Gy/s → 40 Gy/s

To be modified:

- Source / accelerator / beam transport
- How to verify?

scanning beam monitor



Advantages of gas scintillation:
No quenching at low E
Very fast (μs)

Sjirk Boon (1996), Enrica Seravalli (2003)

Current major topics of research

Particle range in tissue

Particle beams are sensitive to

- CT Hounsfield number → Stopping Power accuracy
- Organ motion
- Change of patient's anatomy

→ **Uncertainty in range in patients ~3%**

….. but impossible to measure range directly

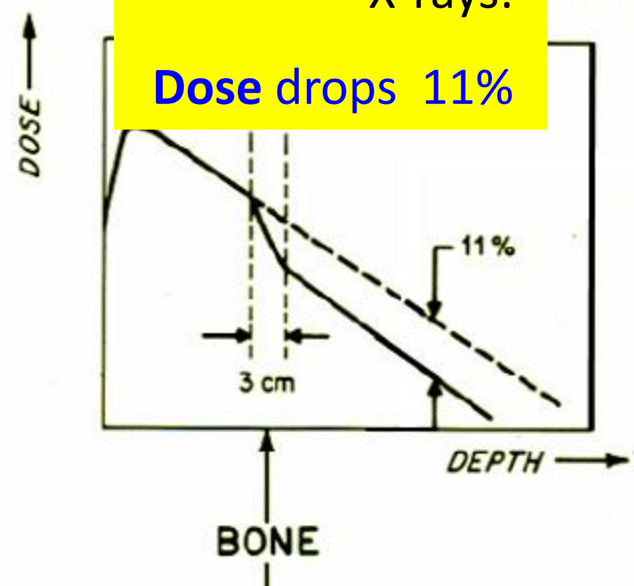
→ **Various methods** are in development

Proton range in tissue

Effect of: 3 cm bone

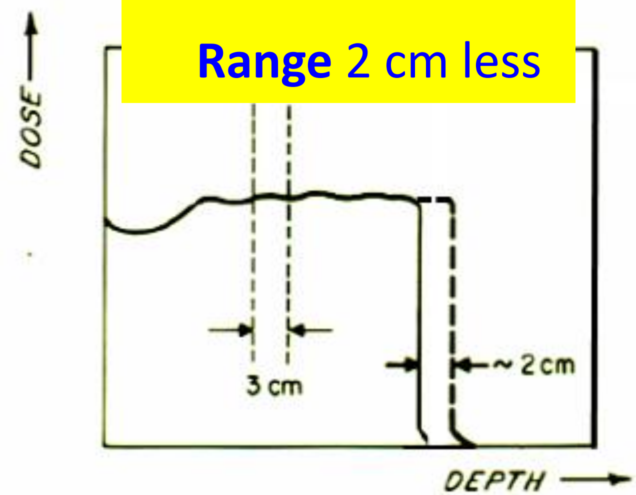
X-rays:

Dose drops 11%

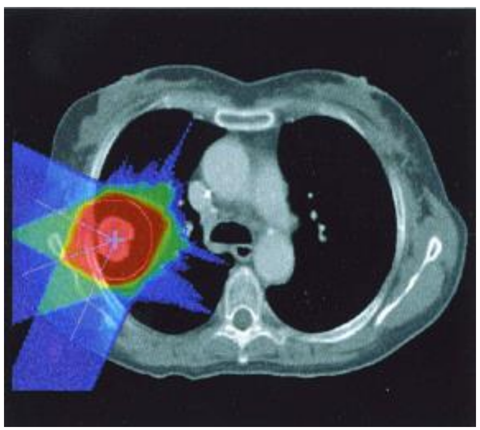


protons:

Range 2 cm less



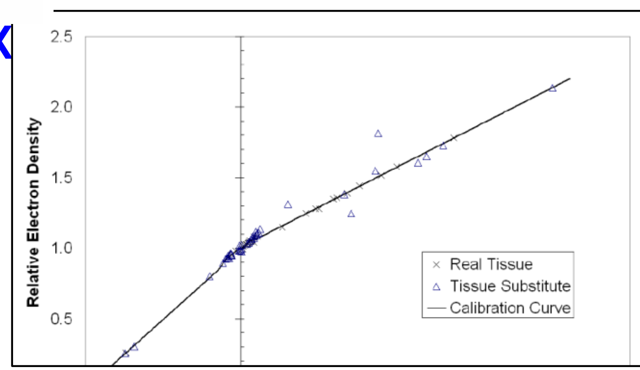
Effect of: CT



CT images: based on **X ray interaction.**

→ Calibration to stopping power is needed

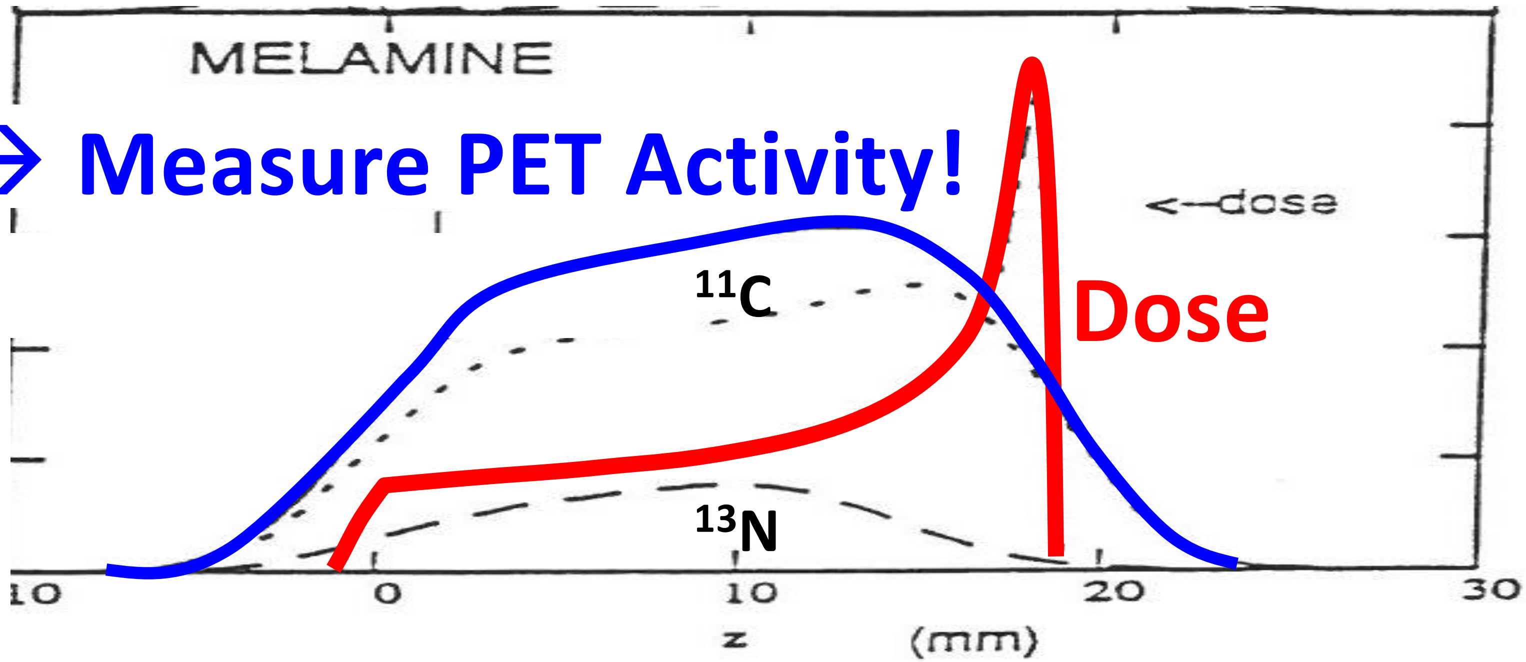
→ **Range error from CT calibr ~1%**



CT - Hounsfield nr

Range measurements

→ **Measure PET Activity!**



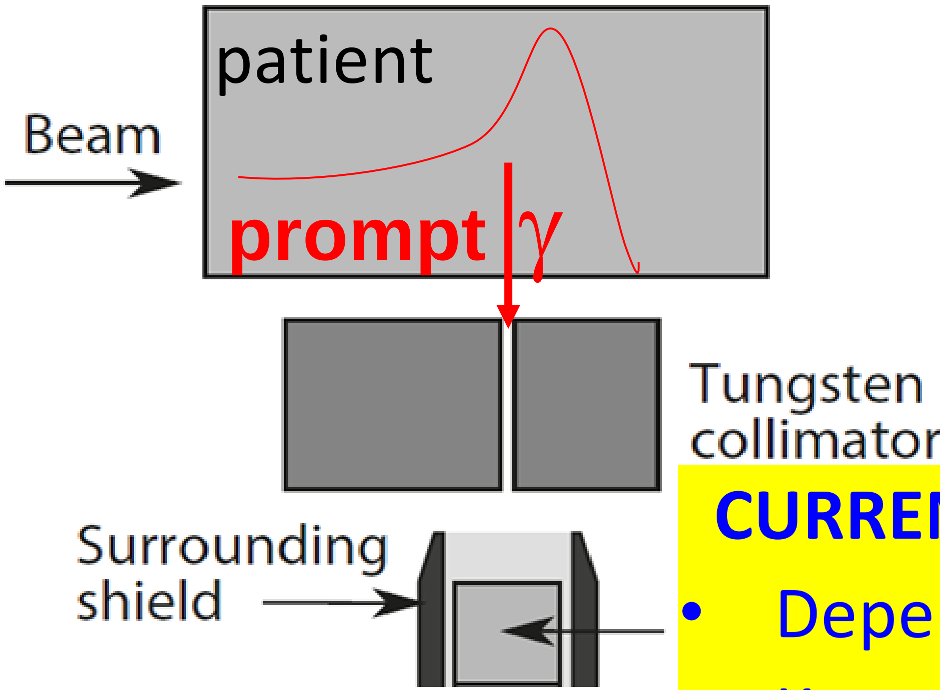
Paans and Schippers, IEEE 40(1993)1041

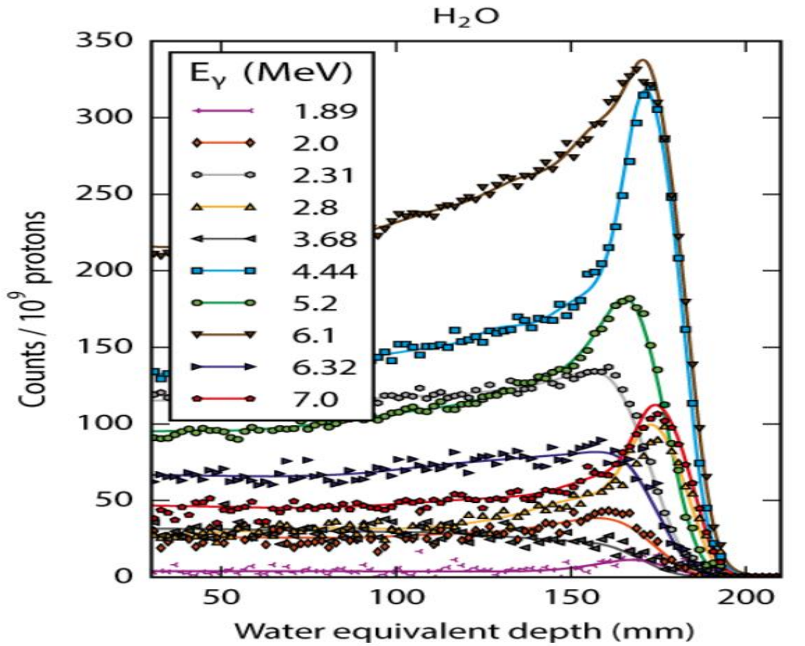
CURRENT STATUS:

- Need to know tissue constituents and predict PET signal
- Compare measured signal with prediction
- → accuracy ~3mm
- but new developments are coming……

Range measurements

npt γ-ray spectroscopy





Measured discrete prompt γ-ray yields along

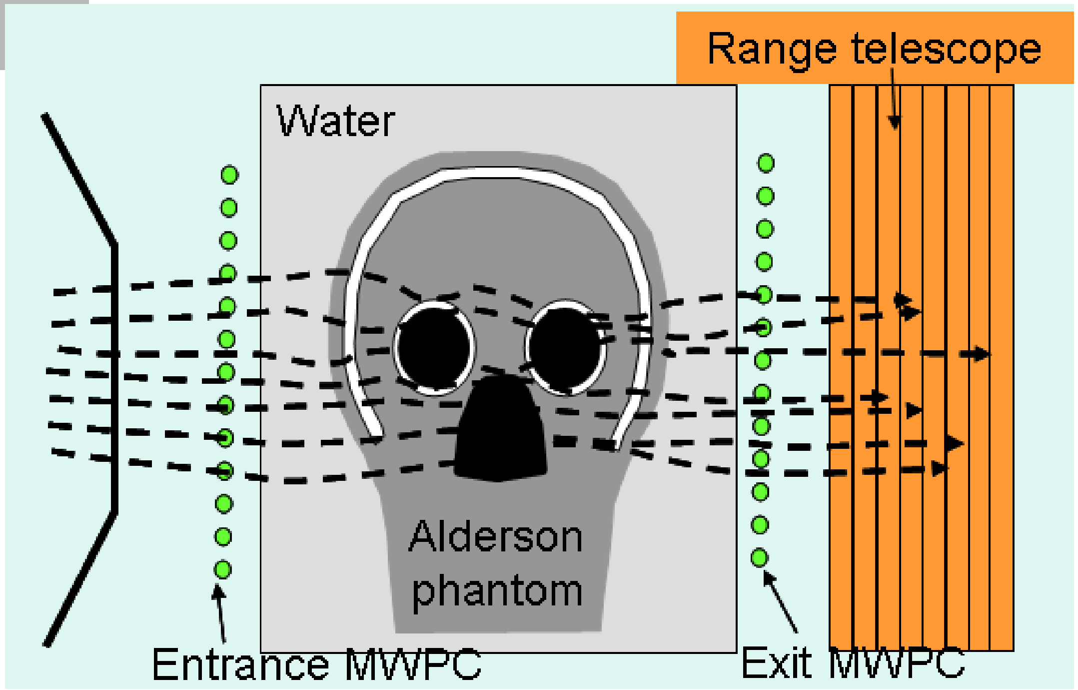
CURRENT STATUS:

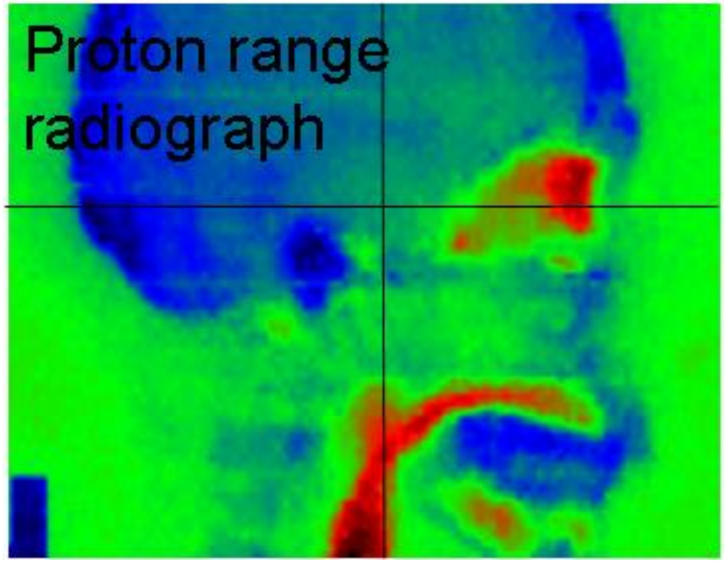
- Dependent on Eγ selection
- Know tissue constituents
- Accuracy of range **change**: ~1mm

e.g.: Verburg et al., PMB 60(2015)1019

Range measurements

Proton radiography





U.Scheider and E.Pedroni
Med. Phys. 22(1994), 353

Mumot et al, PMB (2010).

CURRENT STATUS:

- Range accuracy: ~1%
- Proton CT: → 3D stopping power

Conclusions

What developments are needed and where can Nuclear Technology contribute?

• Lower price (50%)	← (SC) Magnets + Acc.
• Faster (x …100)	← Acc. + **Nucl techn.**
• Motion detect., imaging	← **Nucl. Techn.**
• Range detection	← **Nucl. Techn.**

But take care when implementing new developments:

- Do not propose a solution looking for a problem
- Proven idea → clinic takes 10-20 years
- Long term (>20 yr) commitment: service / upgrades…

PAUL SCHERRER INSTITUT

Thank you for your attention