State of the Art in Medical Imaging and what is the Future

ENLIGHT Annual Meeting
Geneva, Switzerland, July 11, 2014

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Institute of Radiooncology

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...ology

OncoRay National Center for Radiation Research in Oncology Dresden
TECHNISCHE UNIVERSITÄT DRESDEN
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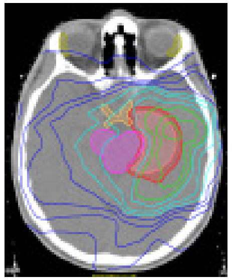
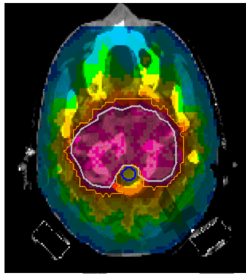
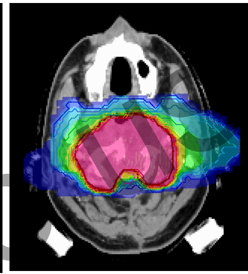
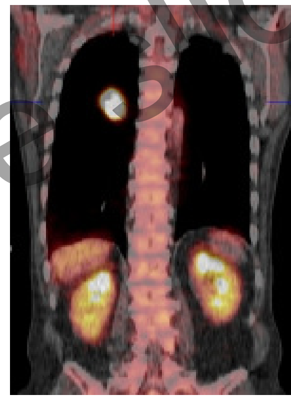
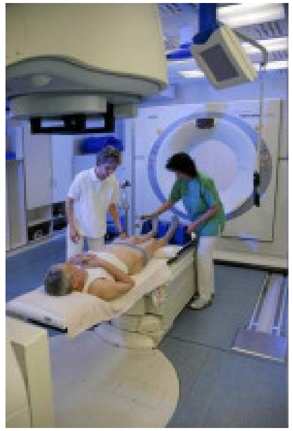
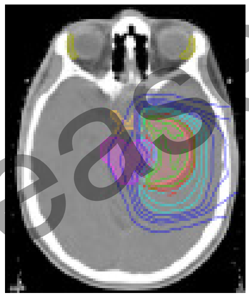
Universitätsklinikum Carl Gustav Carus

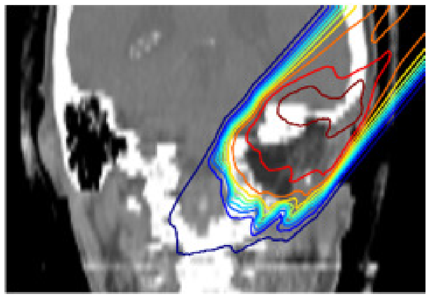
Outline



1. State of the art
2. In-room imaging: X-rays
3. Magnetic resonance imaging and radiotherapy
4. Particle beams: The in-vivo range problem
5. Summary





1. State of the art

Tomographic imaging in medicine

Transmission CT

X-ray CT
+ anatomy (skeleton)
+ resolution (x, y, z, t)
- soft tissue contrast
- function but radiomics
- dose

US
+ anatomy
+ no dose
- function
- low SNR

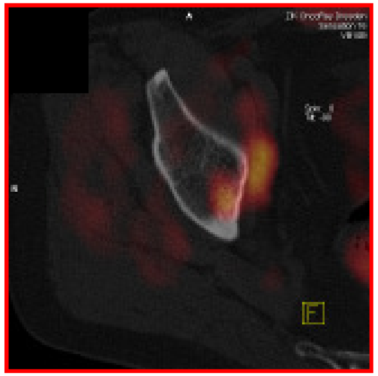
Combining everything with everything:
PET/CT, SPECT/CT, US/PET, MR/PET

Emission CT

MRI
+ anatomy (soft tissue)
+ function
+ no dose
- [limited resolution (x, y, z, t)]
- bone imaging
- limited *B* (3 T)

PET
+ function
+ sensitivity
- limited resolution (x, y, z, t)
- slow
- dose

SPECT
+ function
+ low costs
- sensitivity (Anger camera)
- limited resolution (x, y, z, t)
- slow
- dose

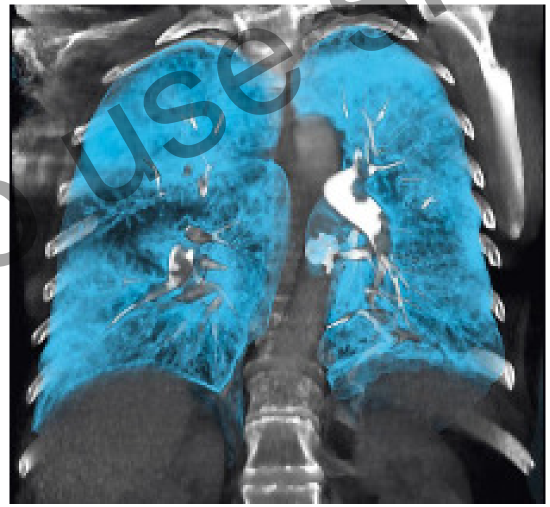


Courtesy: N. Abolmaali, OncoRay Dresden

1. State of the art

CT: Spatial and time resolution

- 64 … 320 detector rows (2 × 192)
- Slice thickness 0.33 … 0.6 mm
- In-plane resolution: ≤ 2.3 lp/mm, pixel: 0.22 mm (0.24 mm)
- Tube rotation time ≥ 0.25 s, time resolution ≥ 66 ms
  dual source (180° → 90°), two 120 kW generators
- Volume coverage with one rotation: 4 … 16 cm
- Maximum scan speed: 730 mm/s



Example: Thoracic imaging w/o breathhold (dyspnea)

- Scan time: 0.7 s
- Rotation time: 0.25 s
- Scan length: 294 mm
- Spatial resol.: 0.24 mm
- Eff. dose: 1.2 mSv

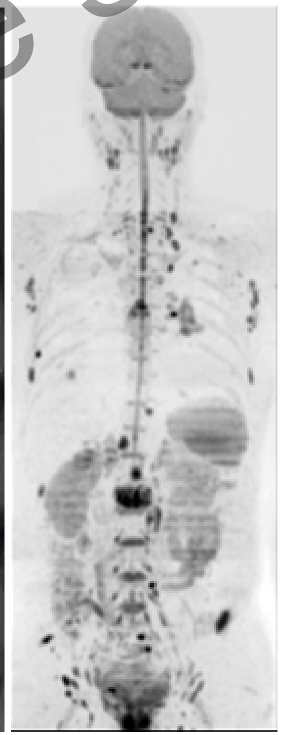
www.healthcare.siemens.com/computed-tomography/computed-tomography/, Med. Faculty Mannheim at Heidelberg University

1. State of the art
MR: Soft tissue contrast and function

- B ≤ 3 T
- Imaging volume: axial: ≤ 400 mm,
  transax: ≤ 550 mm
- Slice thickness: ≥ 0.3 mm
- In-plane resolution, pixel: 0.5 mm
- Time resolution: ≥ 10 ms
  (single planes, MR “fluoroscopy“)
- Time and spatial resolution at MRI: SNR dependent (5 µm in plane)

MRI:
mDiXON sequence
36 s

CT:
727 mm scan
1.44 s



Bone metastases
DWIBS
4.5 × 4.7 × 5.0 mm^3

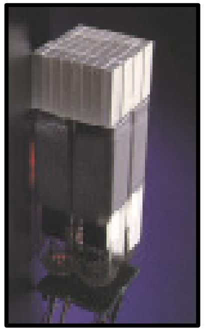
www.healthcare.philips.com/main/products/mri/..., www.healthcare.siemens.com/computed-tomography/computed-tomography/...

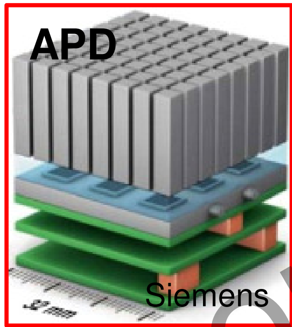
1. State of the art

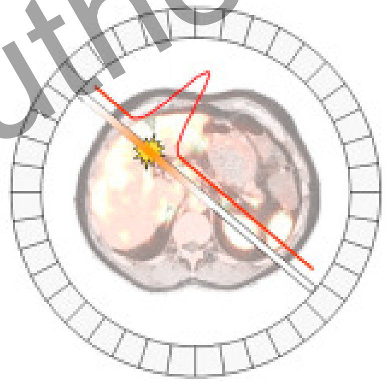
PET: Function, detectors and TOF

- Today only hybrids: PET/CT or MR/PET
- Imaging volume: axial: ≤ 260 mm, transaxial: ~ 500 mm
- Crystal material: LSO, LYSO, GSO, BGO
- Crystal dimensions: 4 × 4 ×20 mm^3
- Crystal number: ≤ 30,000
- Time resolution: ~ 500 ps (TOF reconstruction)

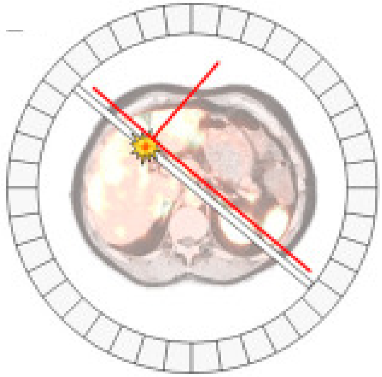
PMT



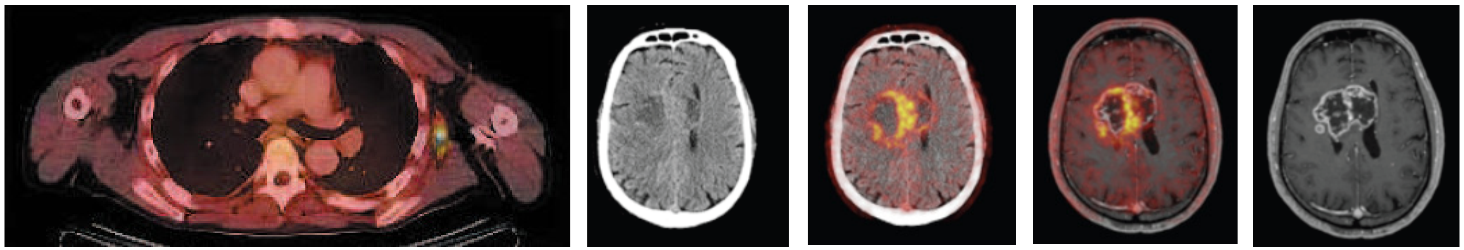




TOF: CRT = 500 ps



TOF: CRT = 20 ps



www3.gehealthcare.com/en/products/categories/pet-ct, Arbeitsausschuss PET der DGN, O. Ratib PHE 2012, Pichler e.a. EJN, 2008

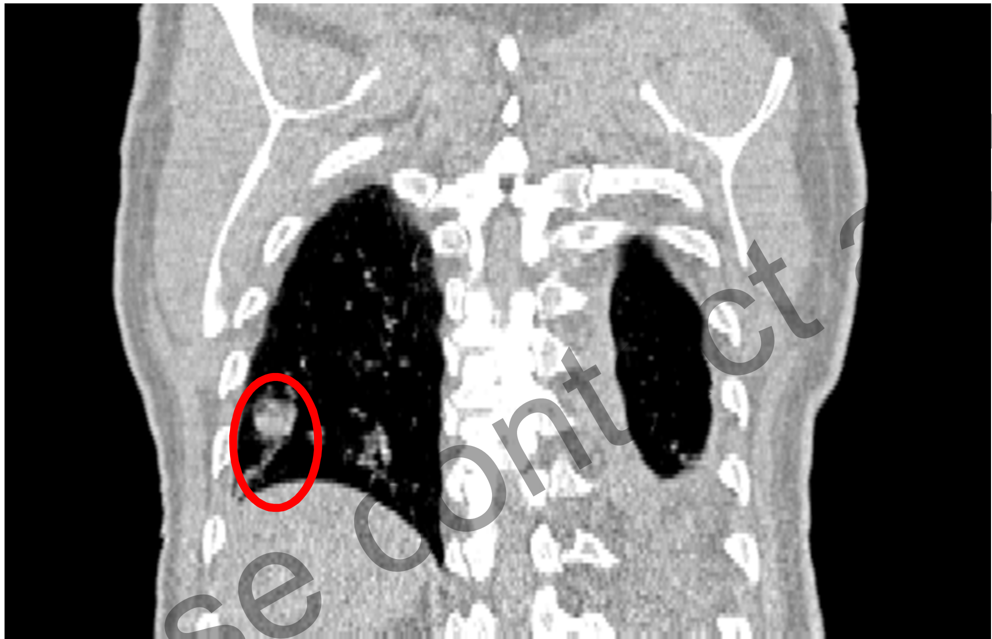
2. In-room imaging: X-rays

Patient positioning: steep dose gradients, selective RBE

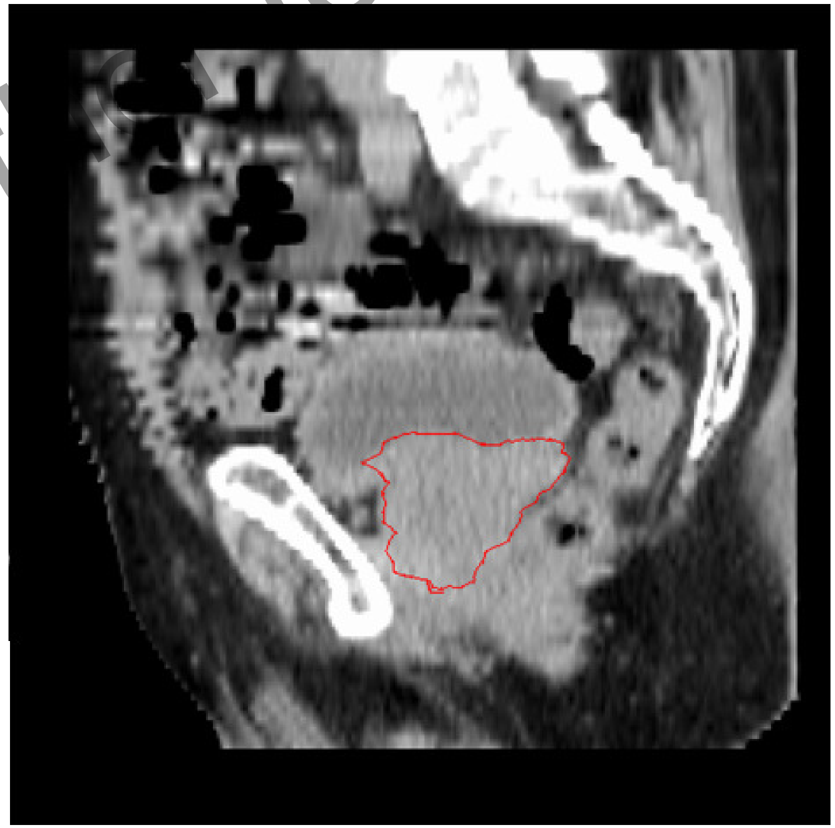
Challenge: precise positioning over ~ 30 daily fractions

The problem of daily patient positioning is multiplied by target movement

Intrafractional



Interfractional



Reduce the errors means:
Imaging, imaging, imaging, but how?

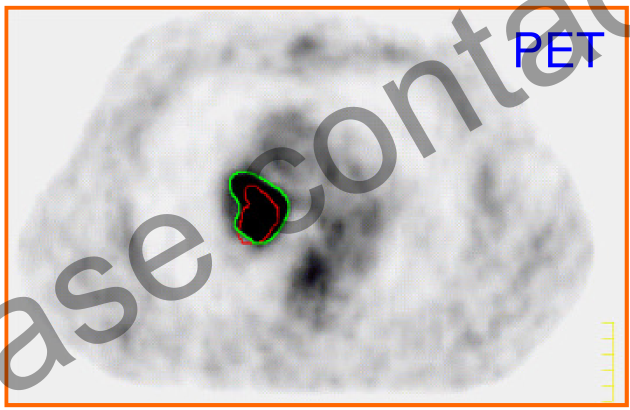
2. In-room imaging: X-rays
Requirements to in-room imaging

Obtain exact knowledge on

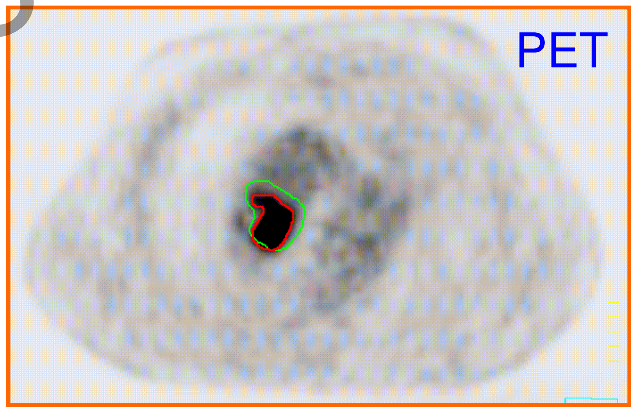
- patient position
- anatomy

in real time during dose delivery for

- reducing treatment margins
- interactive adaption of treatment on the basis of daily
  - assessment of changes in tumour volume
  - general response to therapy (e.g. loss of weight)



Before treatment



After dose delivery of 50 Gy

- Tumour volume reduction: 49.2 %
- Potential for tumour dose escalation

2. In-room imaging: X-rays

The situation before 2000

The observer | is blind

The sniper | is outstanding

What you do not see, you cannot hit, and what you do not hit, you cannot cure.

Wolfgang Schlegel

US Marine Corps, ID 001117-M-OW241-002

2. In-room imaging: X-rays

Electron linacs – state of the art in IGRT

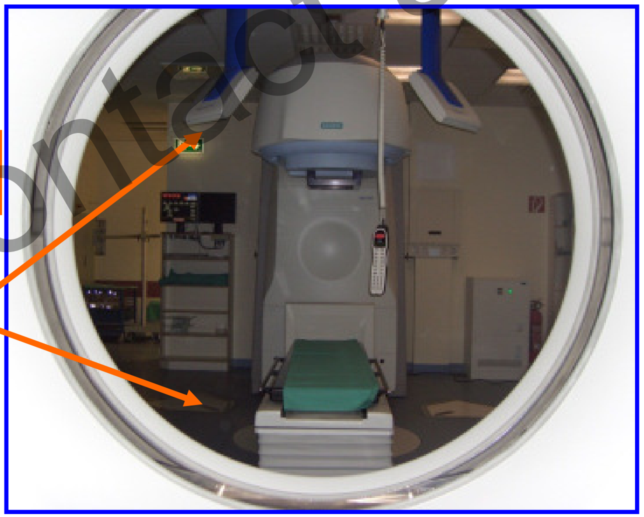
IR movement tracking

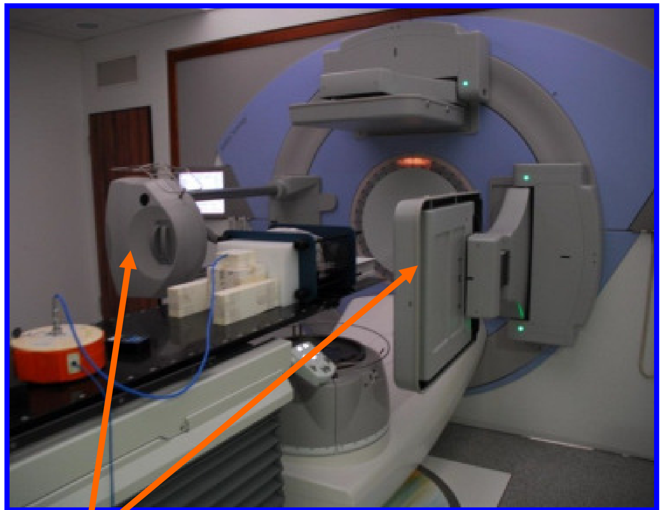
In-room CT on rails

e^--linac

MV cone beam CT

kV X-ray position control, flouroscopy





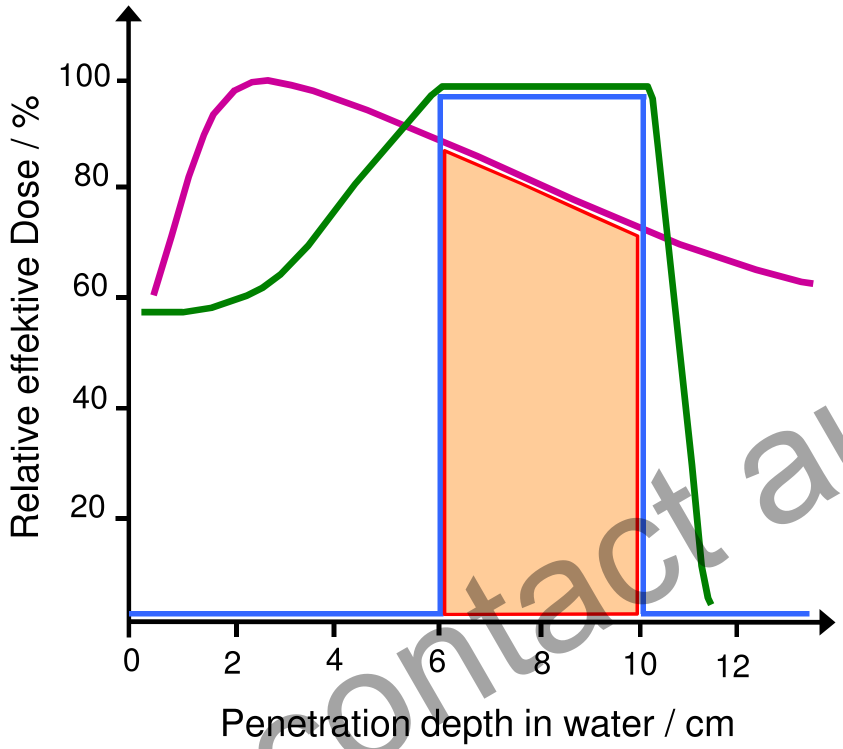
kV cone beam CT

Radiotherapy department, University hospital Dresden

Radiotherapy J. Distler, Bautzen

2. In-room imaging: X-rays

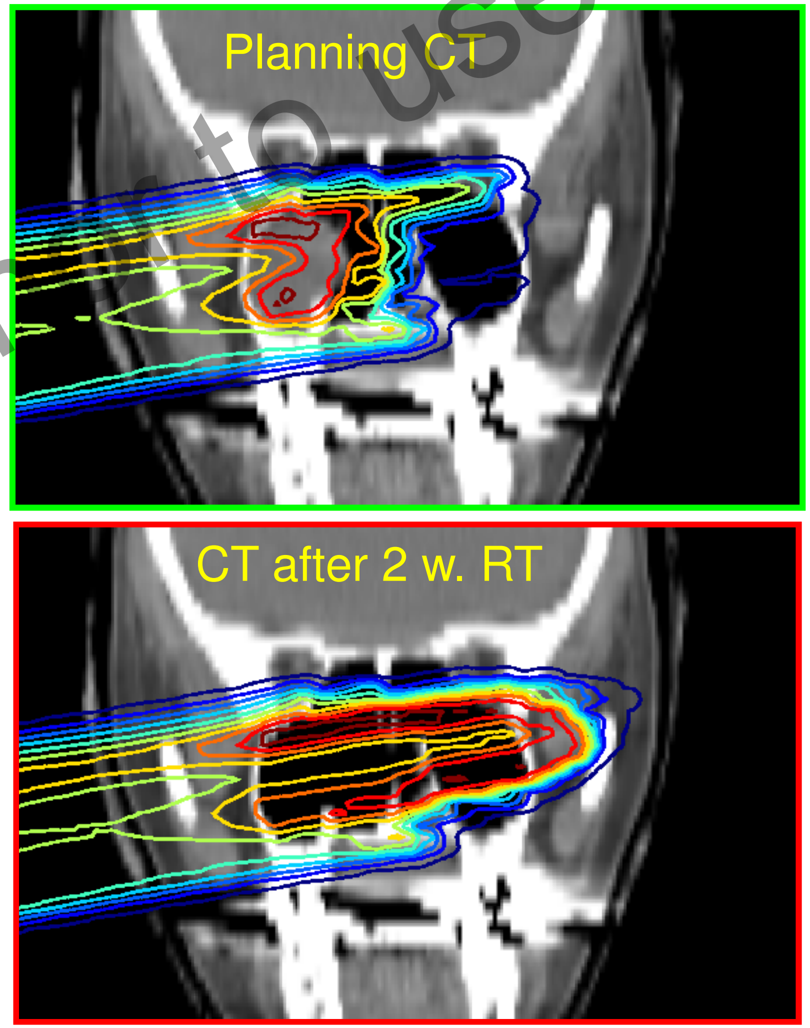
Error sensitivity of particle therapy: the finite range



Photons:
Ultrahard (15 MV) bremsstrahlung

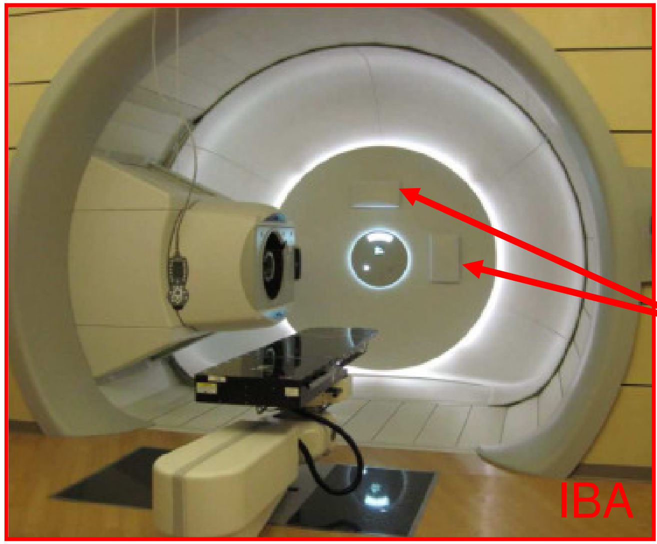
Protons: 90–120 MeV

Chordoma, ^{12}C, GSI Darmstadt



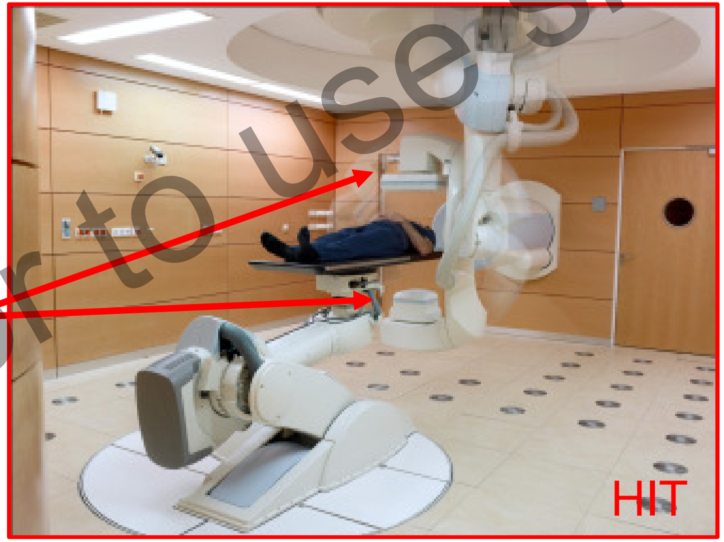
W. Enghardt et al.: Radiother. Oncol 73 (2004) S96

2. In-room imaging: X-rays
IGRT at particle facilities

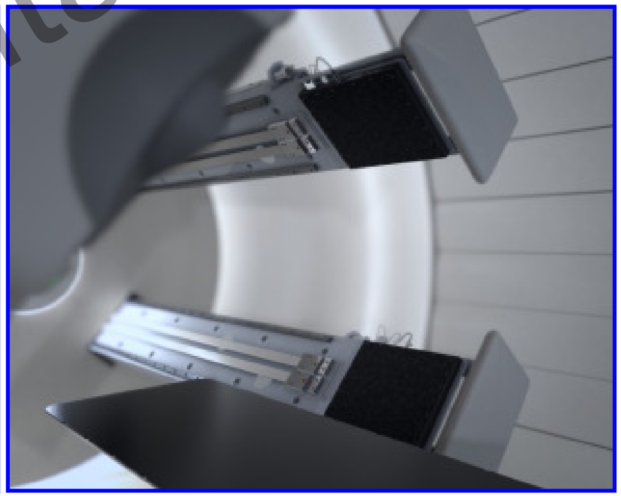


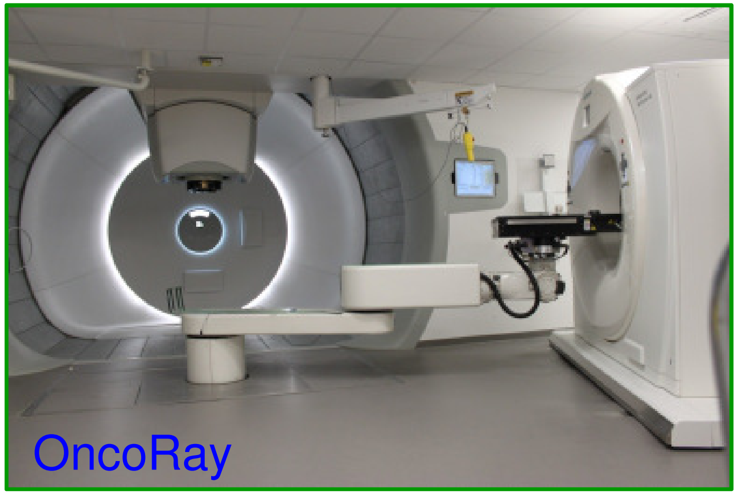
The state of the art (2014)

Orthogonal planar X-ray imaging



Things start to improve (2014):





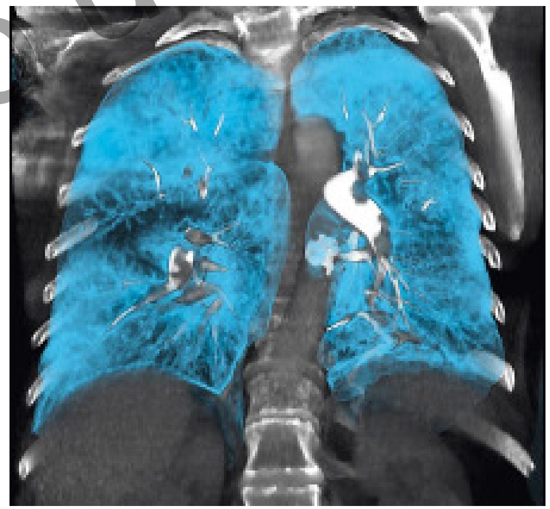
2. In-room imaging: X-rays
Dose considerations

IGRT dose values outside the target relative to scatter- and leakage dose $D_{leakage} \leq 0.2\ \%\ D_{target}$, NCRP 102 (1989), $D_{leakage} \leq 4$ mSv/fraction :

- Treatment planning (3D CT): 1 %
- Treatment planning (4D CT): 10 %
- CBCT (kV, MV): 5 – 30 %
- EPID (MV): 3 – 25 %
- Tomotherapy MV-CT: < 1 %
- Planar kV-radiography: < 1 %

Image based motion compensation:

- Breathing period: 6 s
- CT sampling frequency: 1/3 Hz
- Irradiation time: 2 min for 2 Gy
- Effective dose per fraction: 48 mSv
- Total effective dose per treatment:1.5 Sv ☹



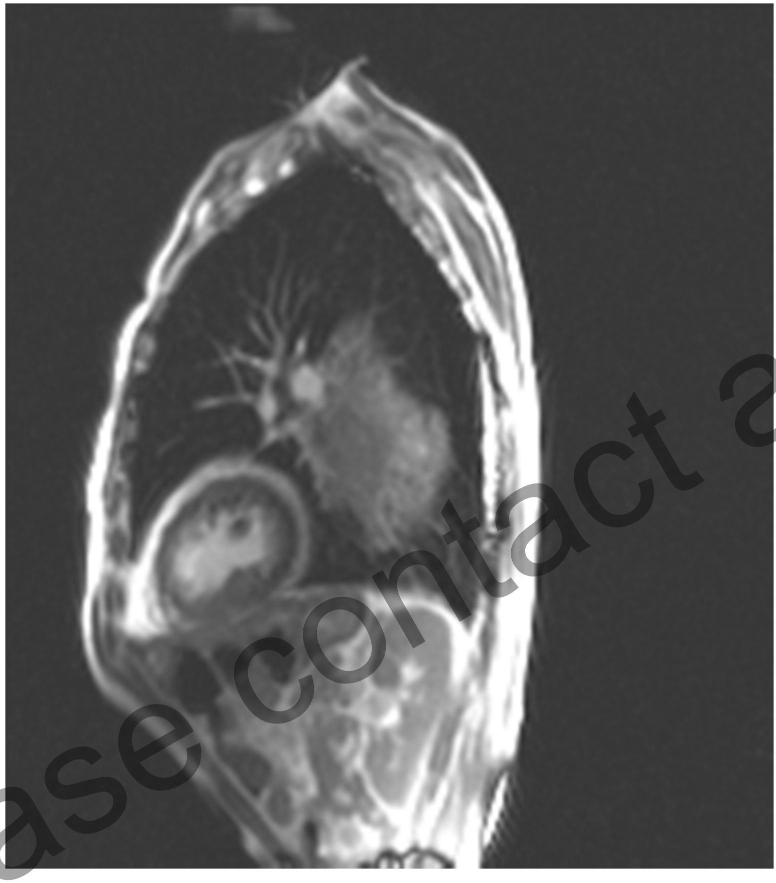
Example: Thoracic imaging w/o breathhold (dyspnea)

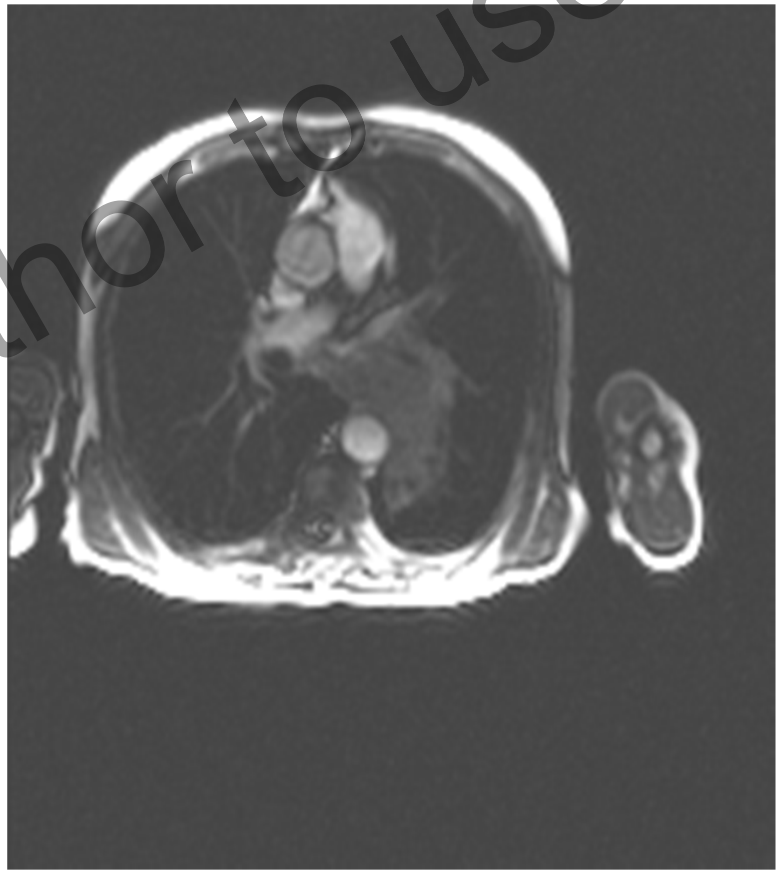
- Scan time: 0.7 s
- Eff. dose: 1.2 mSv

R.A. Hälg et al.: Med. Phys. 39 (2012) 7650-7661, M.J. Murphy et al.: Med. Phys. 34 (2007) 4041-4063

3. MRI and RT
Real-time MRI

… with an ordinary 1.5 T MRI scanner: time resolution 643 ms



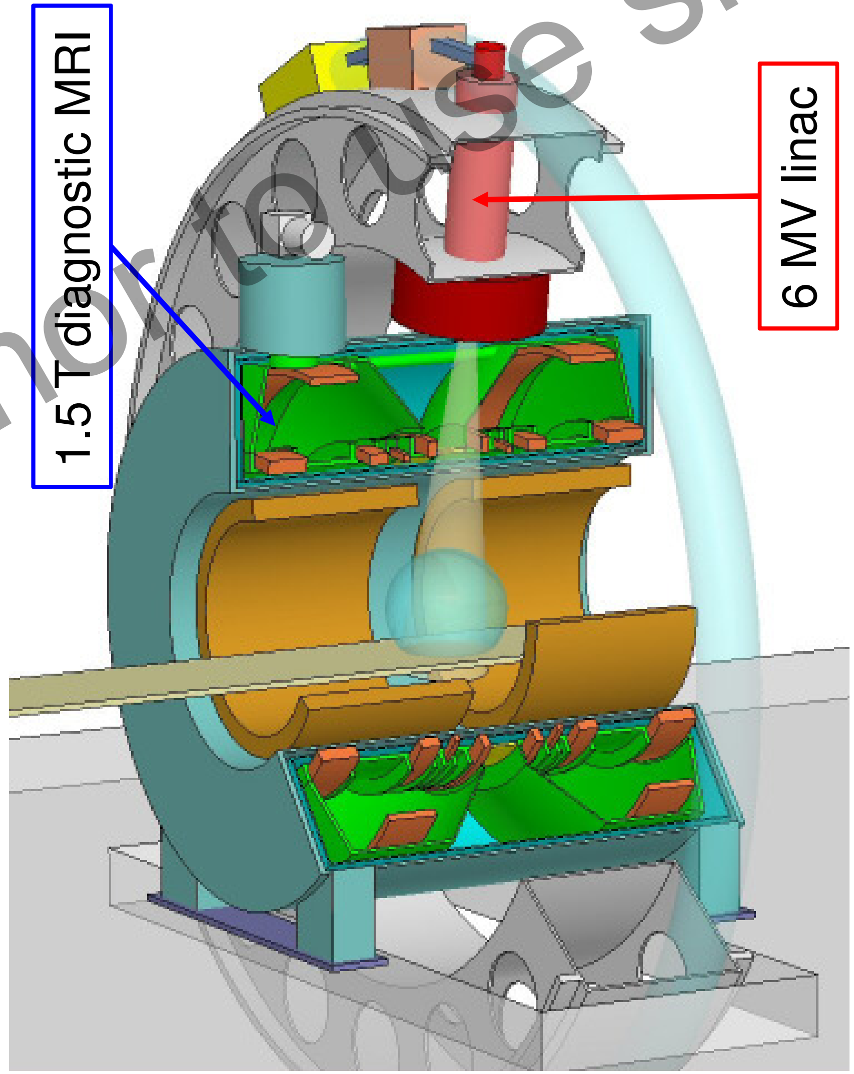


Single plane imaging, not volumetric

3. MRI and RT
The MRI-Linac: The Utrecht approach

University Medical Center, Utrecht, NL
Philips Research, Hamburg, GER
Elekta Oncology Systems, Crawley, UK
RaySearch Laboratories, Stockholm, S

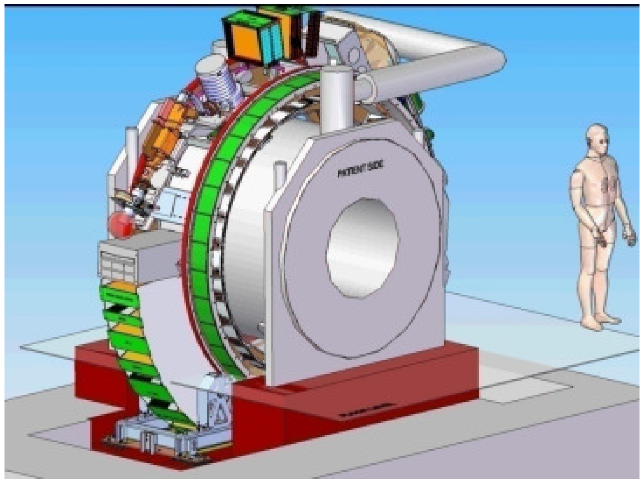
Apr. 5, 2014: Start of 1st clinical installation
At University Medical Center, Utrecht, NL



B.W.Raaymakers et al.: PMB 56 (2011) N207; B.W.Raaymakers et al.: PMB 54 (2009) N229, Courtesy: J. Lagendijk

3. MRI and RT
The potential

- Tumour characterization
- MRI simulation: delineation
- MRI guidance
  - MRI treatment guidance external beam
  - MRI guided brachytherapy
  - MRI guided HIFU (Highly Intensive Focused Ultrasound)
  - MRI guided protons !!!
  - MRI guided radioembolization
- MRI treatment response assessment

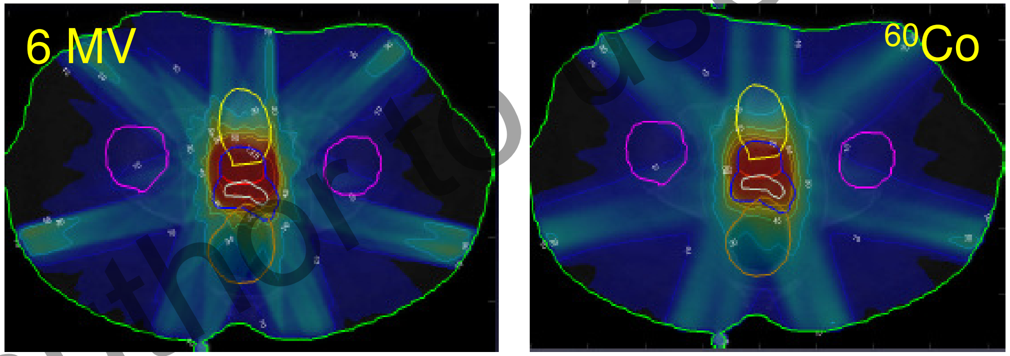


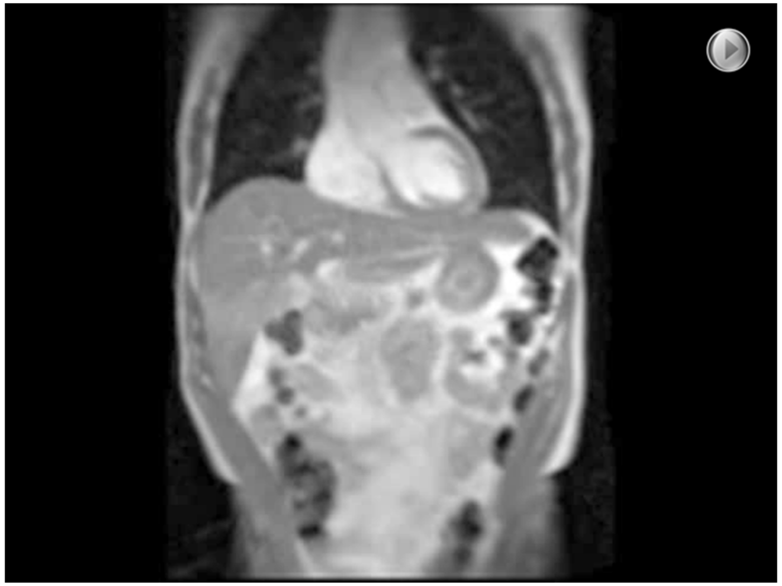
3. MRI and RT

MRI combined with an ^{60}Co source: The ViewRay approach

- 0,35 T split magnet MRI scanner
- 3 sources of ^{60}Co:
  - 500 TBq 750 cGy/min.
  - avoids RF interference
- adaptive treatment planning
- motion management

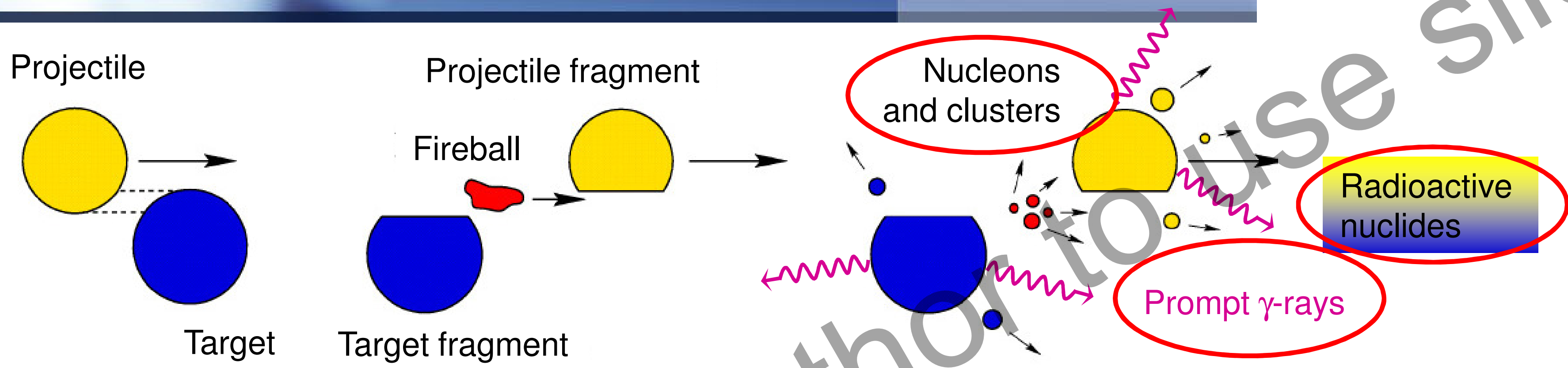
Prostate: 7 beams, dose distributions





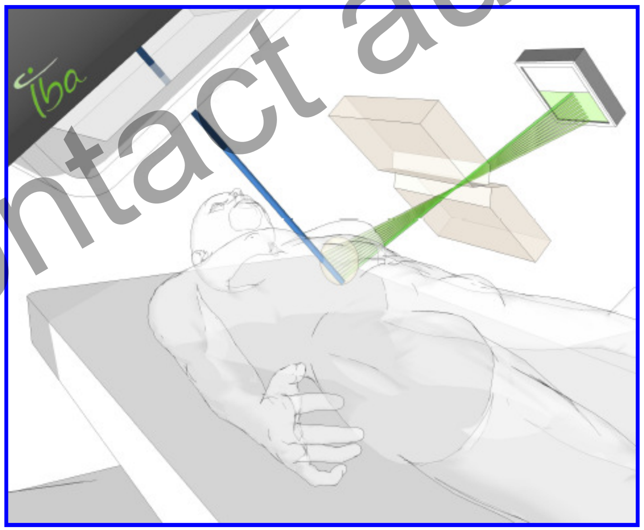
4. Particle beams: The in-vivo range problem

Nuclear interactions for real time range assessment

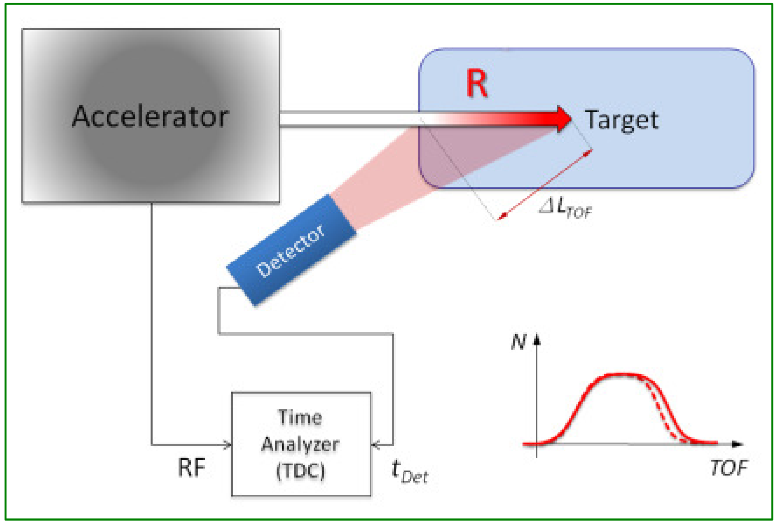


PT-PET

Prompt γ-ray imaging



Prompt γ-ray timing



Decreasing complexity

W. Enghardt et al.: NIM A525 (2004), J. Smeets et al.: Phys. Med Biol. 57 (2012), G. Pausch et al.: Patent pending

5. Summary

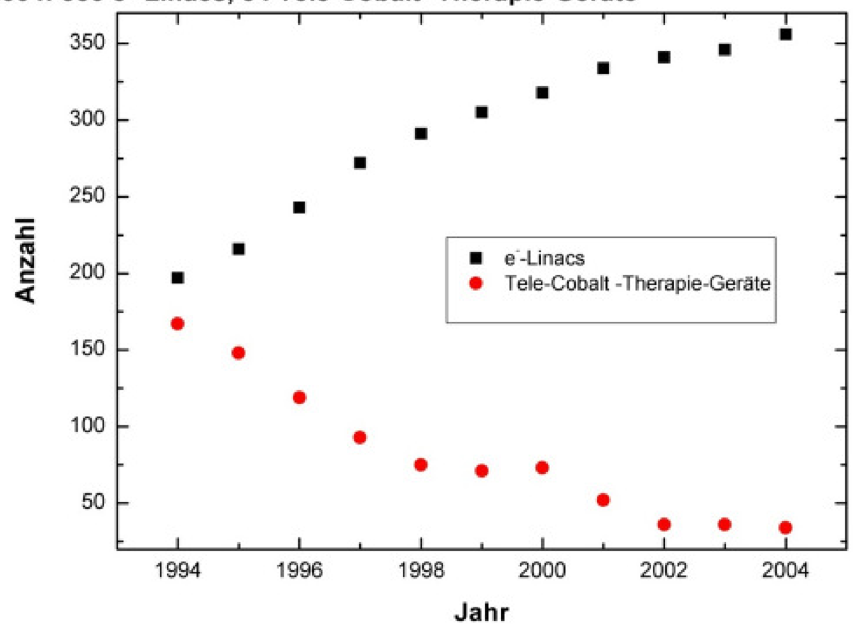
„Linear accelerators produce radiation distributions which are only slightly better than ^{60}Co. They are complicated and require back up services of well trained technicians or physicists. Their increased complexity over ^{60}Co will prevent them from being universally accepted.“
In H.E. Johns, J.R. Cunningham (1971) Physics of Radiology, 3rd ed., Thomas, Springfield, IL

Hahaha

- Real-time IGRT will be the future in RT: integration of irradiation and imaging
- X-ray IGRT delivers additional dose outside the target volume
- The basis of future real time IGRT will be magnetic resonance imaging
- Particle therapy requires range control:
  - in-beam PET
  - prompt γ-ray imaging
  - prompt γ-ray timing

Quelle: Statistisches Bundesamt, Gesundheitsbericht 2006

2004: 356 e⁻-Linacs, 34 Tele-Cobalt -Therapie-Geräte



Thank you