SIEMENS

Proven Outcomes Oncology Solutions

Particle Therapy

Fighting Cancer with Ion-Beams

Outline

- **Siemens**
- **Cancer**
- **Radiation Therapy and Biophysics**
- **Application of Ions**
- **The Siemens Med PT System**
- **Systems**
  - Accelerator
  - Service
  - IT
  - Positioning and Imaging
  - Gantry
  - BAMS
- **Heidelberg**

Group Sales in a Siemens-Comparison
Fiscal Year 2004/05

SIEMENS

	Sales in millions of Euros	Profit in millions of Euros
Communications	13.141	454
Siemens Business Services	5.373	-696
Automation and Drives	9.844	1216
Industrial Solutions and Services	5.390	139
Logistics and Assembly Systems	1.472	69
Siemens Building Technologies	4.415	181
Power Generation	8.061	951
Power Transmission and Distribution	4.250	212
Transportation Systems	4.190	45
Siemens VDO Automotive	9.610	630
Medical Solutions	7.626	976
Osram	4.300	465
Siemens Financial Services	10.148*1	319 *2
Siemens Real Estate	1.621	144 *2

*1 Total assets *2 Income before income taxes

Siemens Particle Therapy products and solutions are works-in-progress and require country specific regulatory approval prior to clinical use.

Siemens Medical Solutions
Sales According to Regions in Fiscal Year 2004/05

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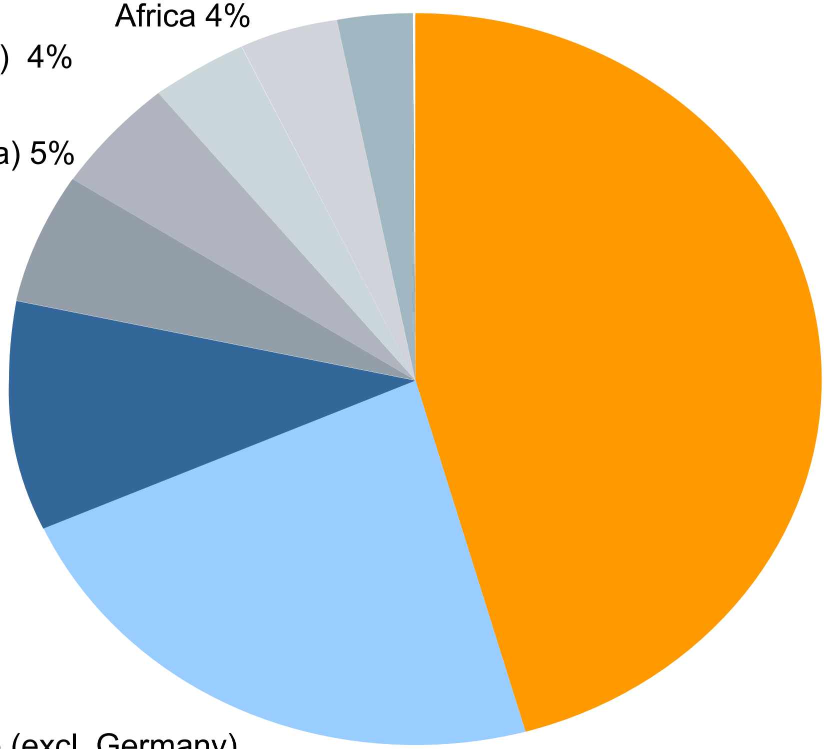
Basis Sales: 7.6 Bill. €



Employees

World	32,912
Germany (Erlangen/Forchheim)	8,457 (6,040)
USA	12,591

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Siemens Med and Particle Therapy –
Long-term Commitment in Oncology

SIEMENS

One leading vendor within oncology care

- Solution provider
- IMRT since 1997
- IGRT
- Oncology information systems
- Simulation systems

Installed base larger than 2000 linear accelerators

- Every day, 29,000 cancer patients are treated in the United States by Siemens linear accelerators

Headquarters facility in Concord, CA

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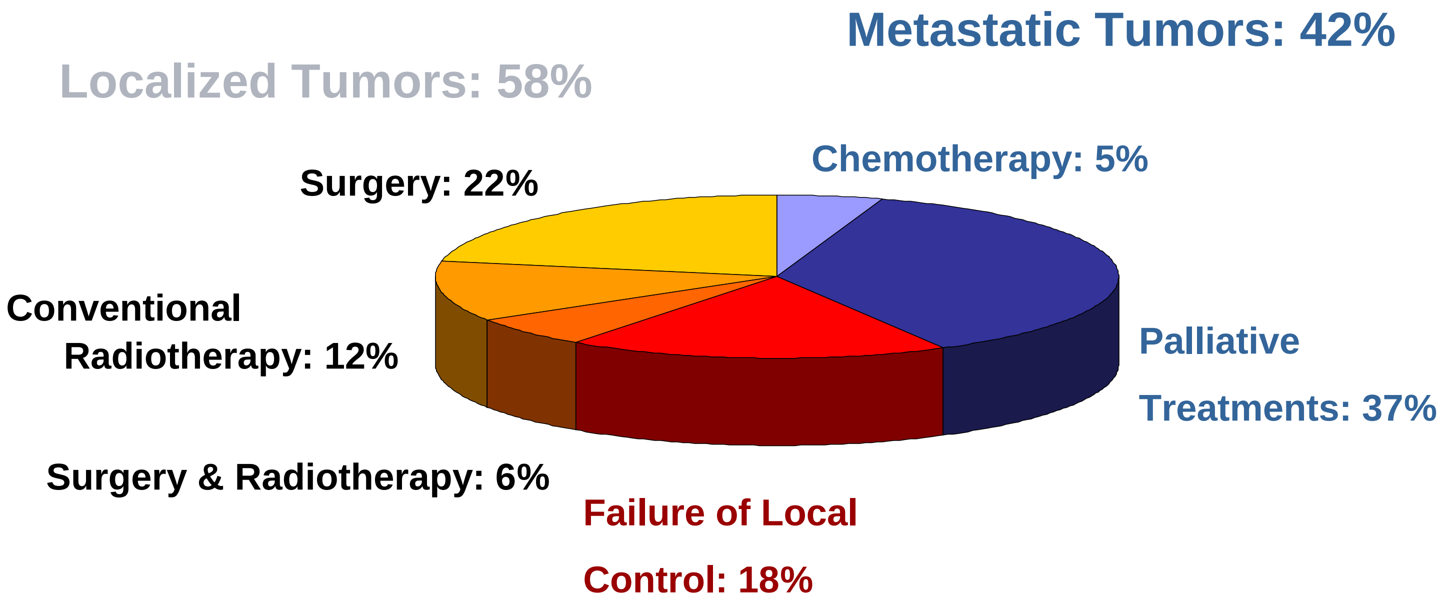
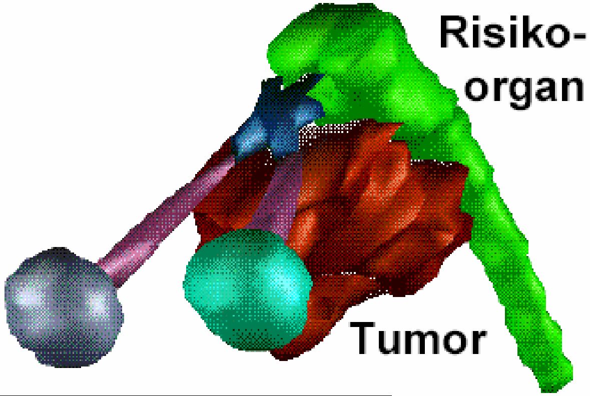
Cancer



- 2/3 of all patients: localized tumors
- 18% failure of local control => EU: 280.000 casualties/year
- Protons/Ions: heal 30.000 patients/year in the EU

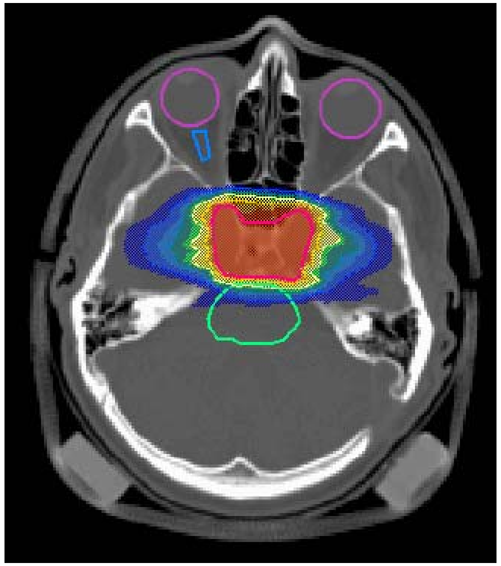
Indications for Therapy with Ions

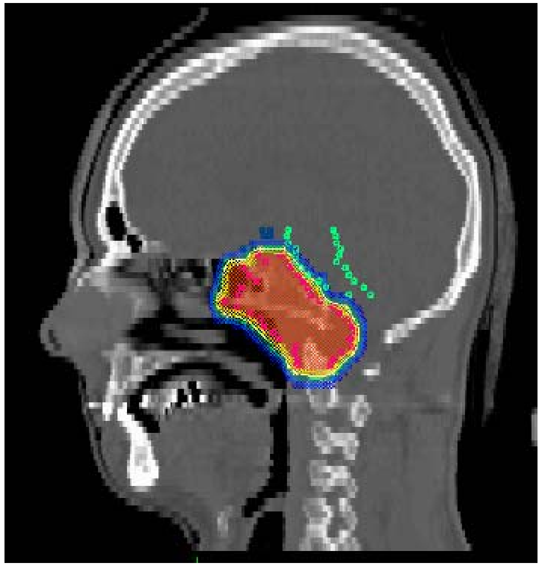
Characteristics:
Deep seated, radio-resistant,
hypoxic tumors
Close to “Organs at Risk”



Corurtesy: T. Haberer, HIT

Localisations:
- Brain
- Skull Base
- Liver
- Lung
- Prostata





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Depth-Dose-Profiles

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Medical Use of Ions

- **Invented by Wilson in 1946**

  How to shield proton-beams?

- **Results of more than**
  - 43,000 patients treated with protons and
  - 3,000 patients treated with carbon ions

Current State: „Boom“

- Diagnostics improved (CT and MRT)
- Beam Application techniques improved

Th. Haberer

LBL-33403
UC-406
Preprint

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Accelerator & Fusion
Research Division

Submitted to Review of Scientific Instruments

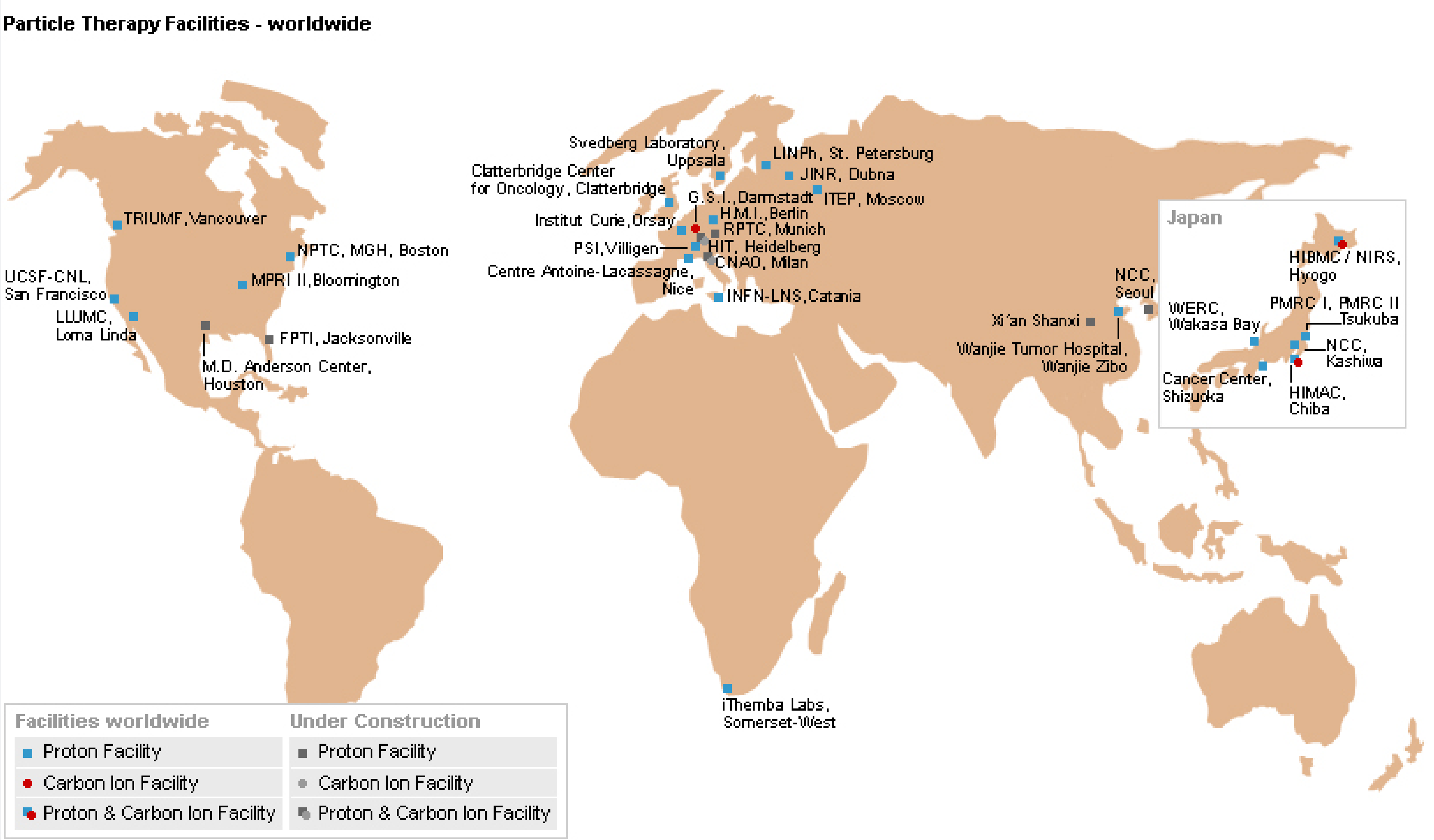
Instrumentation for Treatment of Cancer Using Proton and Light-Ion Beams

W.T. Chu, B.A. Ludewigt, and T.R. Renner

February 1993

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

Particle Therapy, worldwide



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Clinical Advantage of Particles –
Improved Dose Distribution

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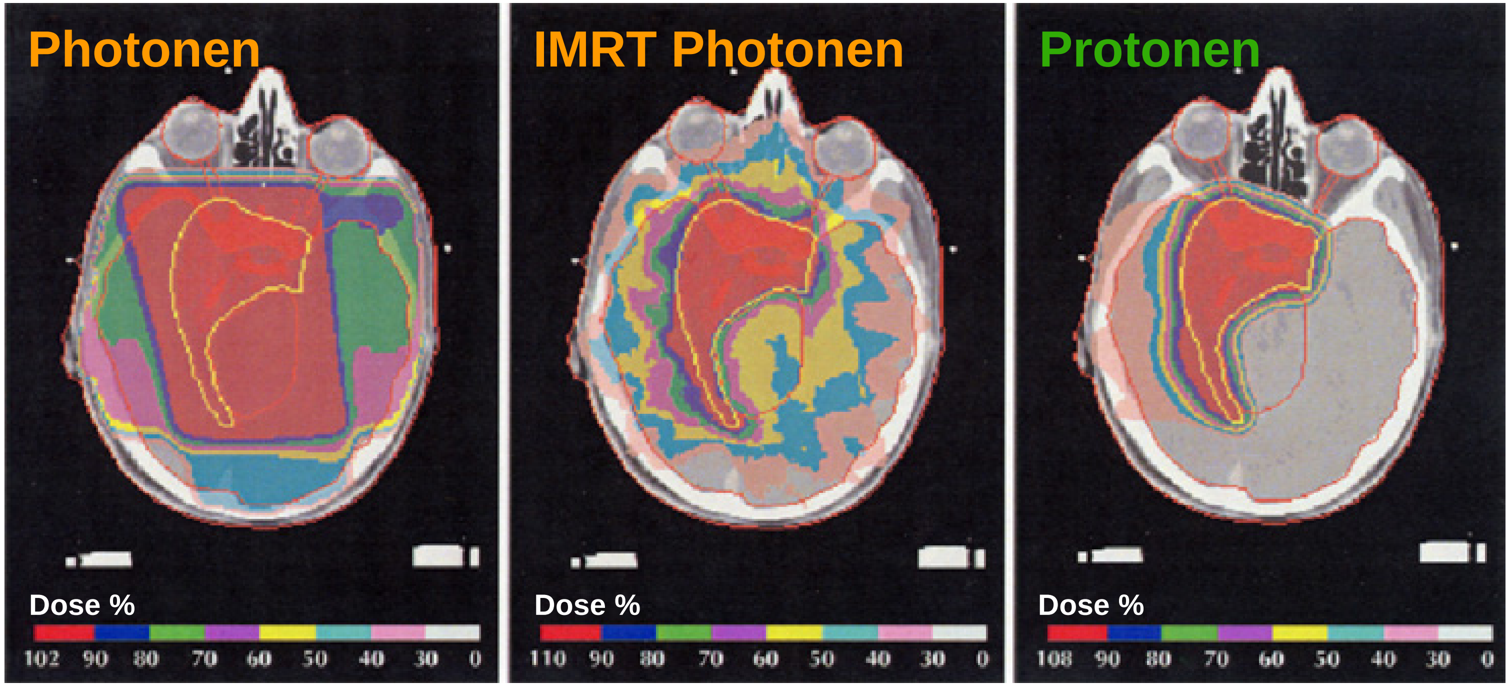
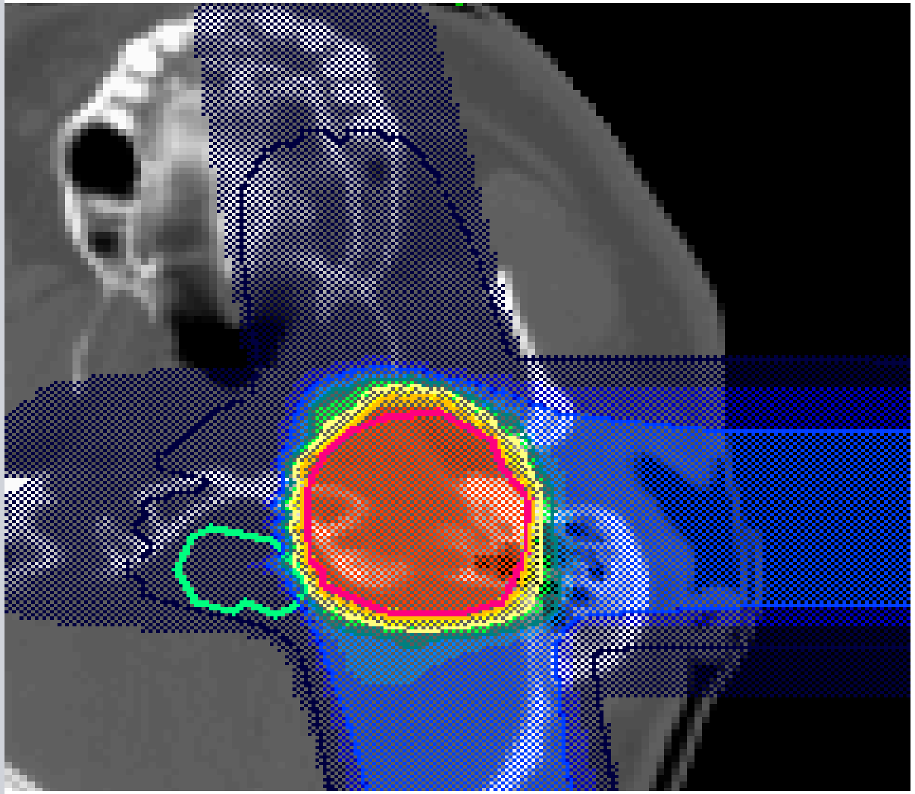


Radiotherapy Source: Anthony J. Lomax et al. Radiotherapy and Oncology 51 (1999) 257–271

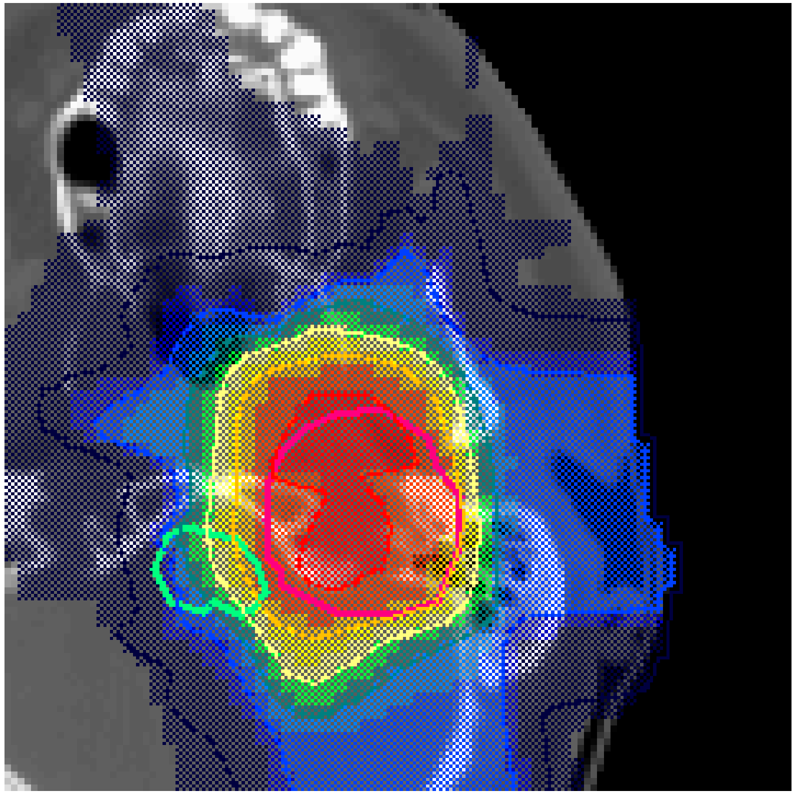
Comparison of Carbon Ions vs. Protons

Carbon



(GSI)

Protons

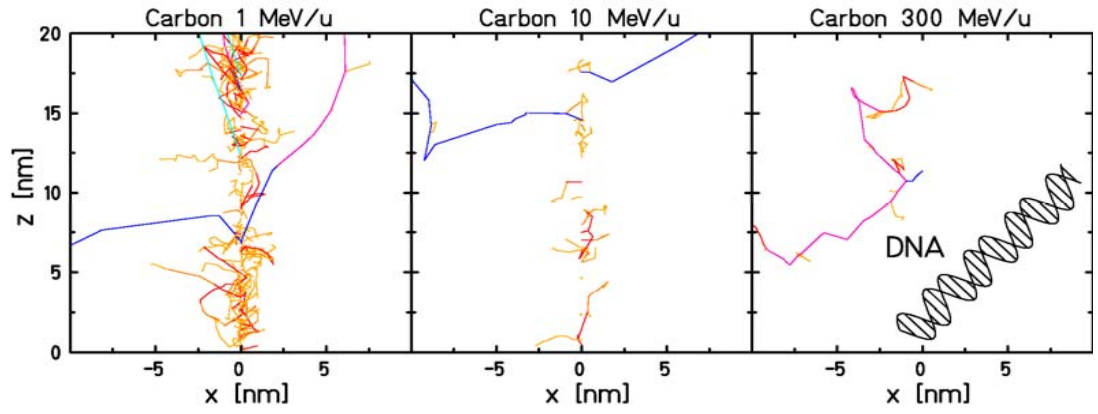


Capetown/ SA

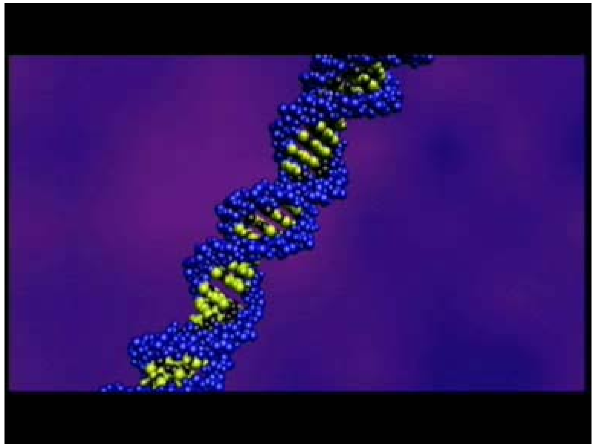
Double Strand Breaks

- Carbon ions produce non-reparable DNA damage
  due to double strand breaks (DSB)
  and clustered damages

- Protons produce mainly single strand breaks



Courtesy of M. Krämer, GSI (Gesellschaft für Schwerionenforschung)

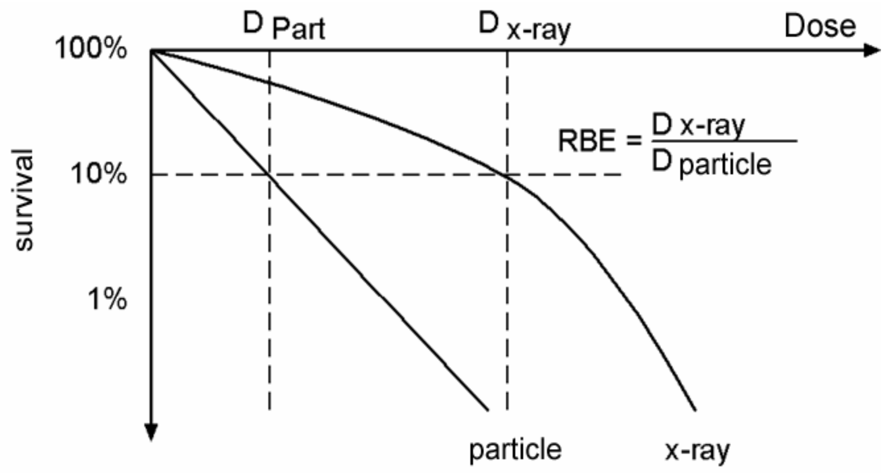


Why Carbon Ions?

RBE = Relative Biological Efficiency = $\frac{\text{Dose (X-ray)}}{\text{Dose (Particle)}}$

Particles need lower dose to gain the same biological effect (RBE > 1)

- **RBE approx. 1.1** for protons
- **RBE approx. 2–5** for carbon ions



Courtesy of G. Kraft / Prog. Part. Nucl. Phys. 45 (2000) S. 473 – S. 544

Benefit of the High RBE of Carbon Ions

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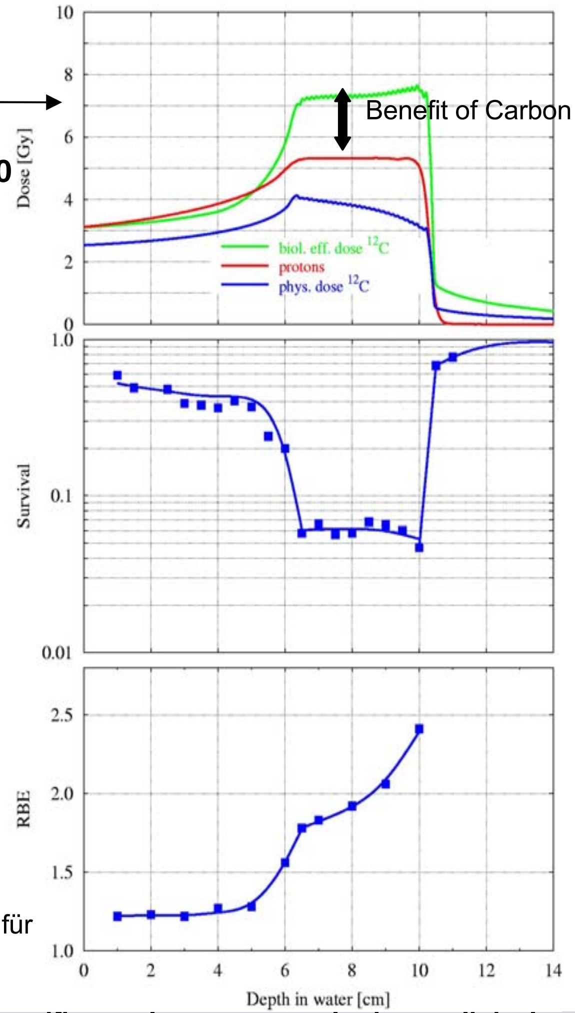
- Survival curve shows a high survival rate within the tissue outside the target volume (SOBP)
- RBE of protons = 1.1 for the complete field
- RBE for carbons is strongly increasing in the target volume (where the carbon ions stop)

RBE = Relative Biological Efficiency

$$= \frac{\text{Dose (X-ray)}}{\text{Dose (Particle)}}$$

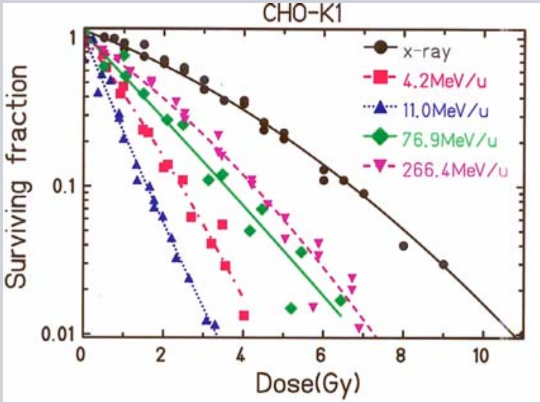
Proton depth dose normalized on same dose at z=0



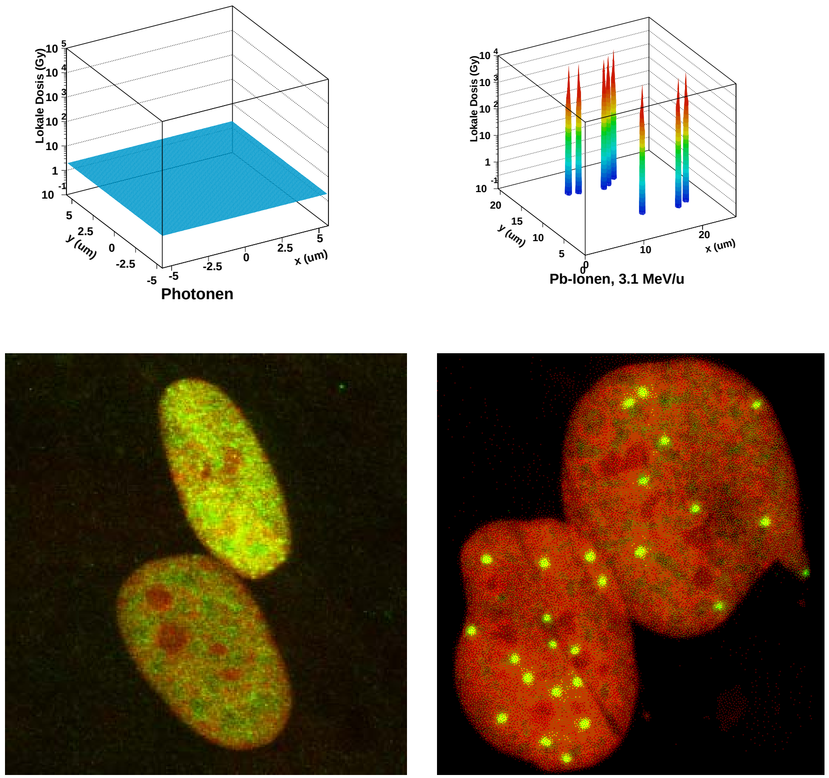
Courtesy of GSI, W. Weyrather (Gesellschaft für Schwerionenforschung)

Where does RBE come from?

- Microscopic dose is very high along the tracks for ions, especially at the end of the range (target volume)
- A few clustered damages (at the highdose track of ions) are more efficient for cell killing than many small damages (from photons or protons) due to cell repair



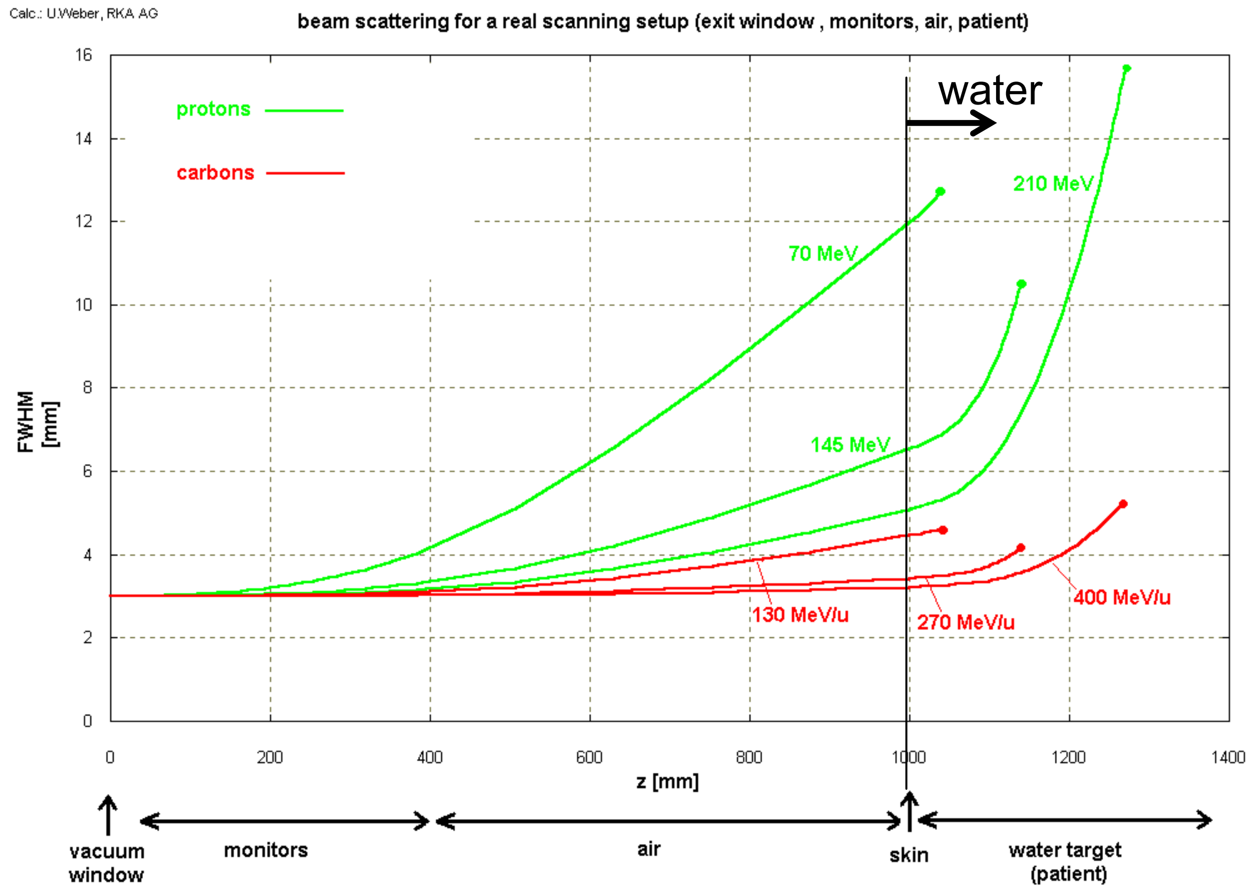
Photons/Protons **Ions (Pb)**



Jakob, B., Scholz, M., Taucher-Scholz, G., Radiation Research 154 (2000), 398–405

Beam Broadening

- Carbon beams are less affected by multiple scattering



Courtesy of GSI (Gesellschaft für Schwerionenforschung)

Production of Light Nuclei by Nuclear Fragmentation

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Advantages of protons and heavy ions:

- Finite ion range
- Inverted dose profile
- High biological effectiveness

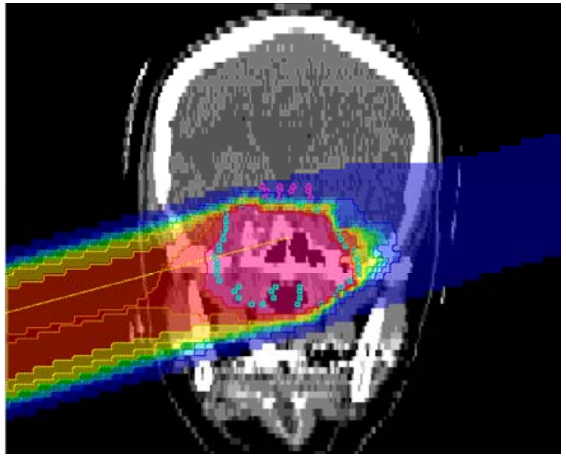
To consider in dose calculations:

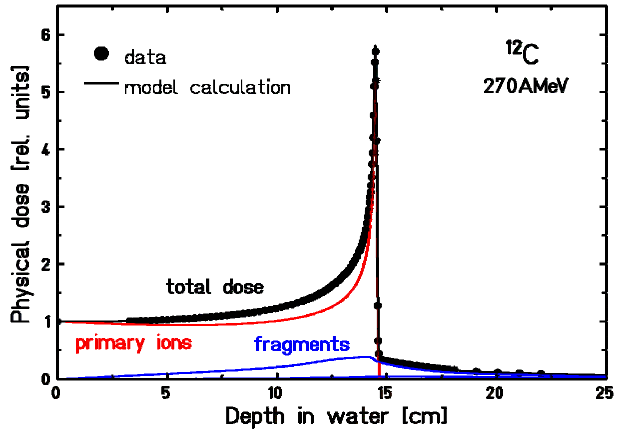
- Production of fragments in nuclear collisions (charged fragments,neutrons)
- Dose contribution of fragments along the whole penetration path
- Longer ranges of light fragments

$$R \propto \frac{A}{Z^2}$$

⇨ dose tail behind the Bragg-peak

* A: mass number, Z: atomic number



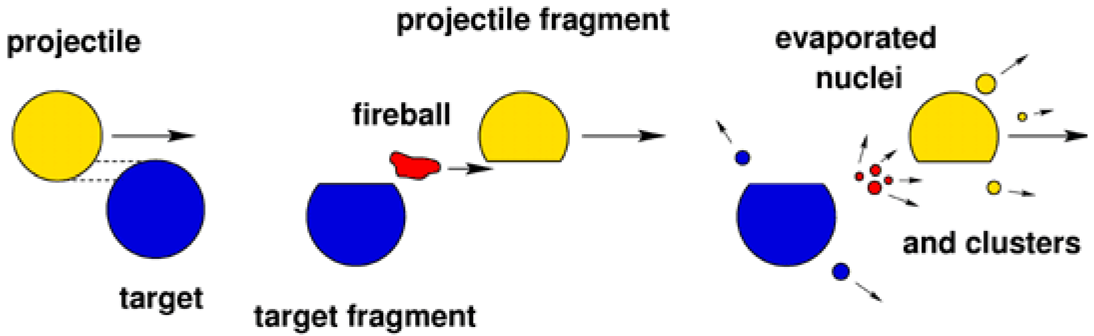


Courtesy of GSI (Gesellschaft für Schwerionenforschung)

Model of Nuclear Fragmentation

Nuclear collision can be described as a 2-step process:

1. Abrasion: Collision of projectile and target nucleus, abrasion of overlapping nuclei (fireball)
2. Ablation: Evaporation of light nuclei and clusters due to high excitation (protons, neutrons, alphas, photons)



Protons: Target fragmentation and scattering of primary protons
Carbon ions: Projectile and target fragmentation

Measurements: **Consistent picture, effect can be modeled**

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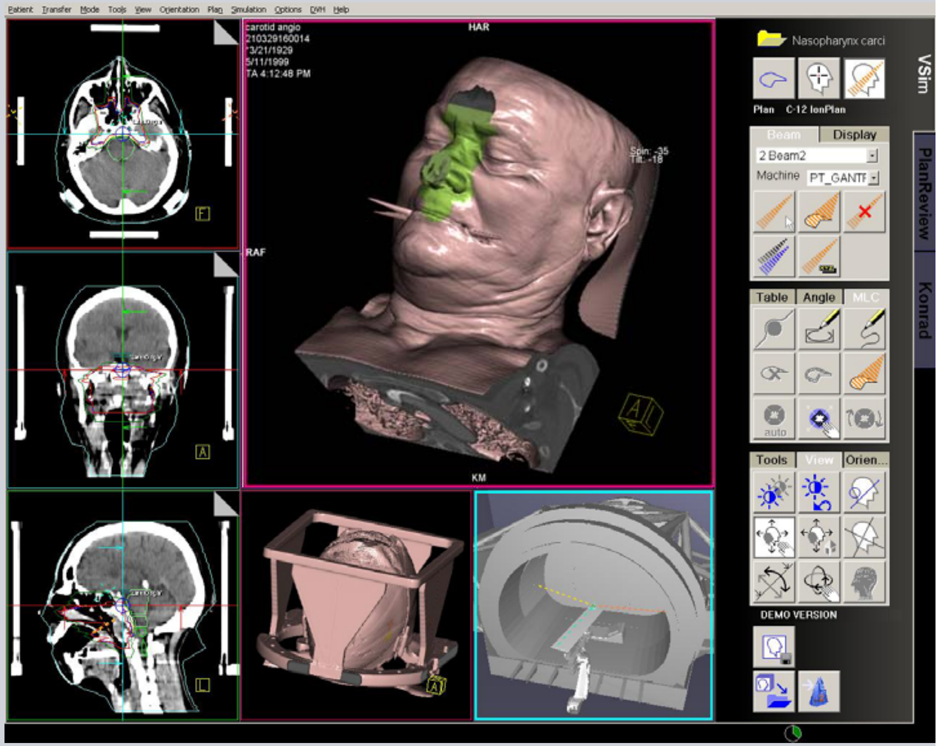
Treatment Plan Definition

- Treatment plan templates
- Comprehensive suite of beam definition tools, e.g.
  - BEV, REV, OEV
  - Manual and graphical beam definition
- Automatic beam splitting
- Beam patching
- Position verification image planning



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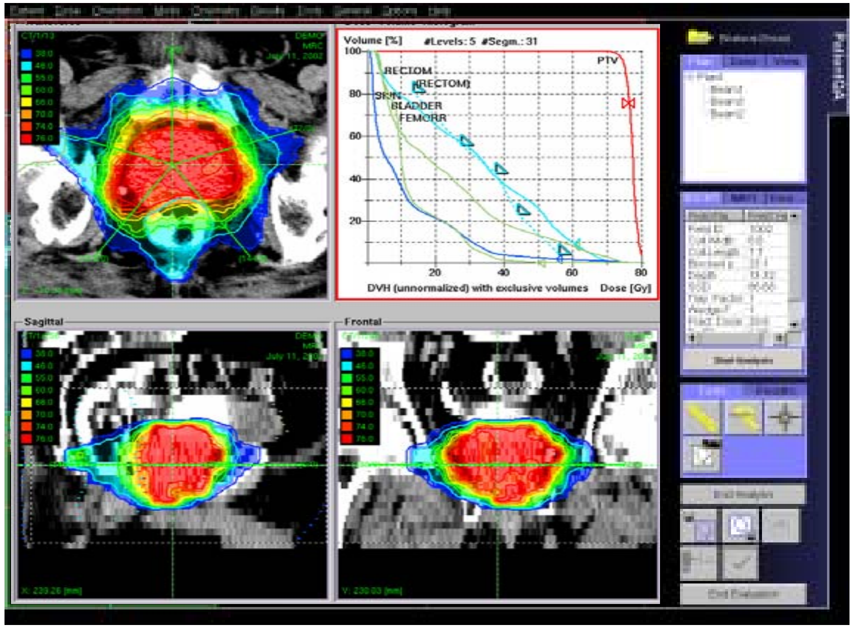
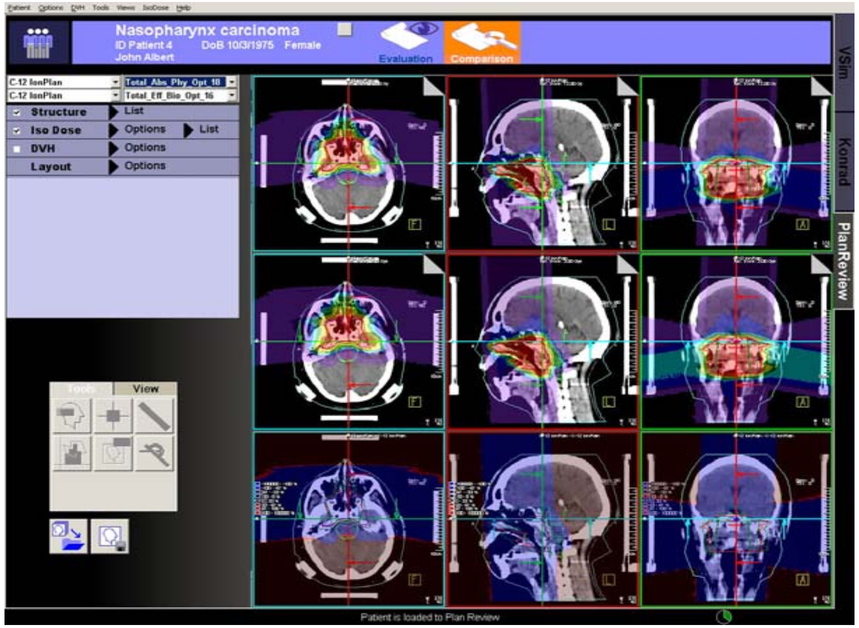
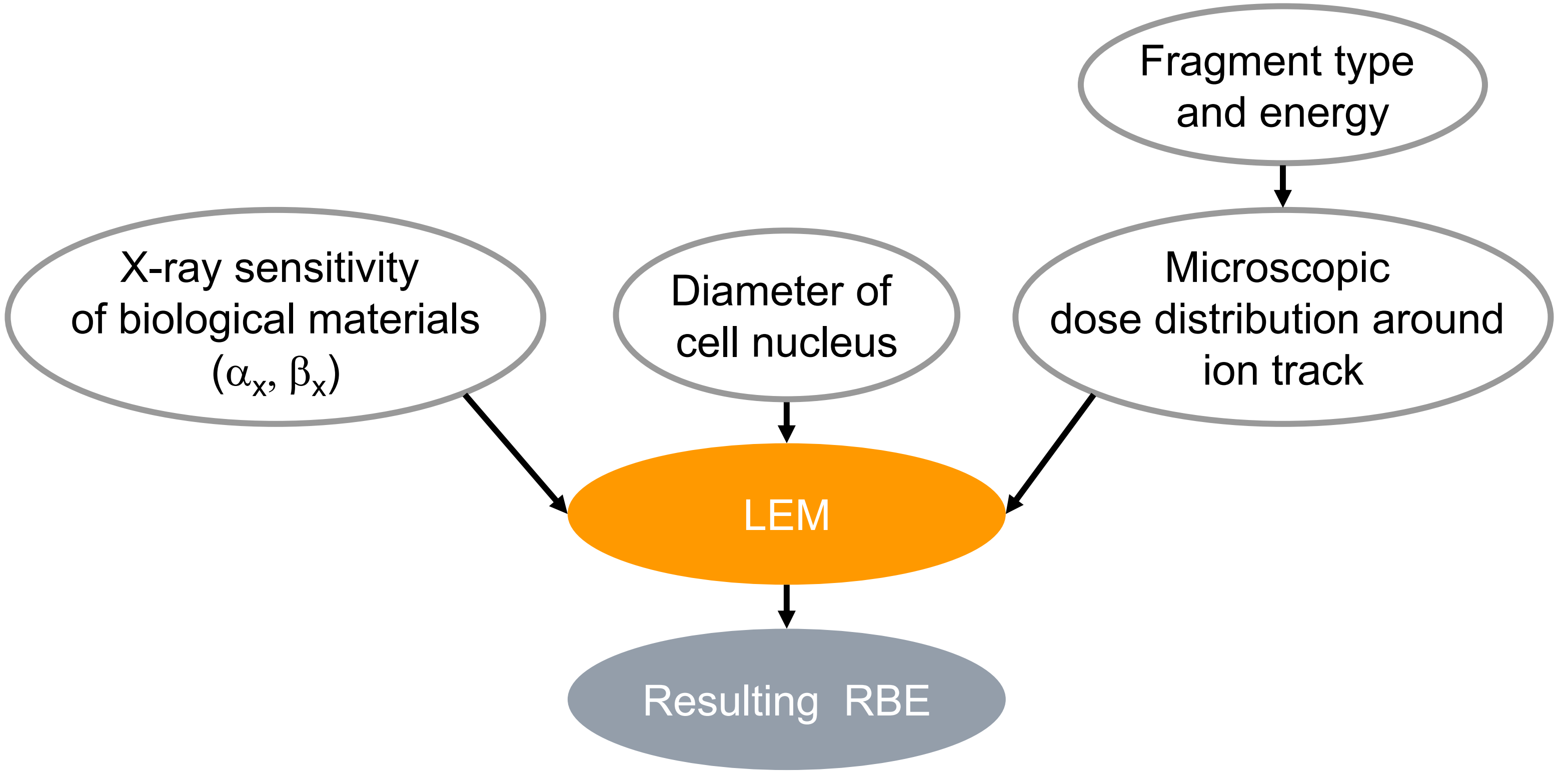
Treatment Plan Evaluation



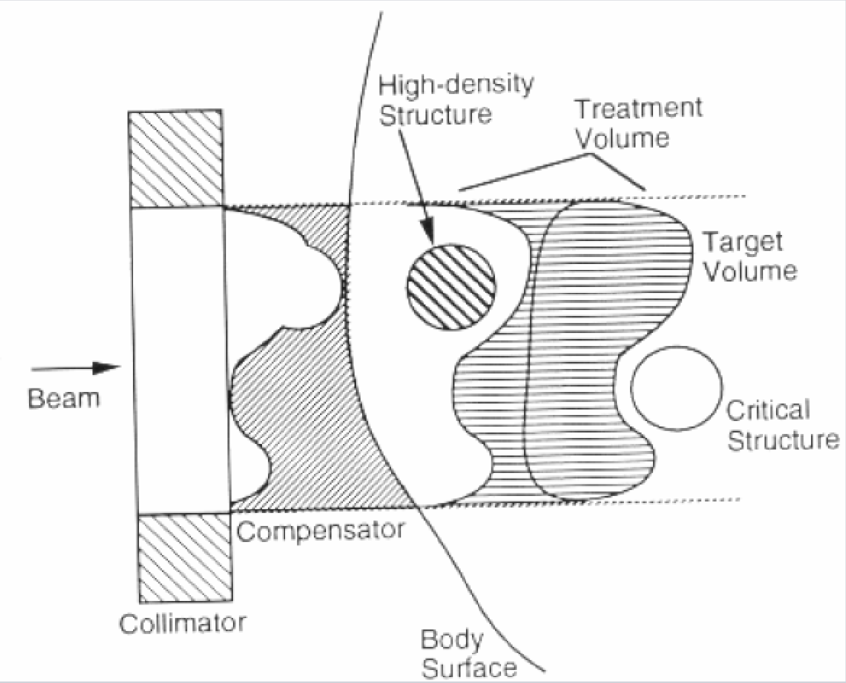


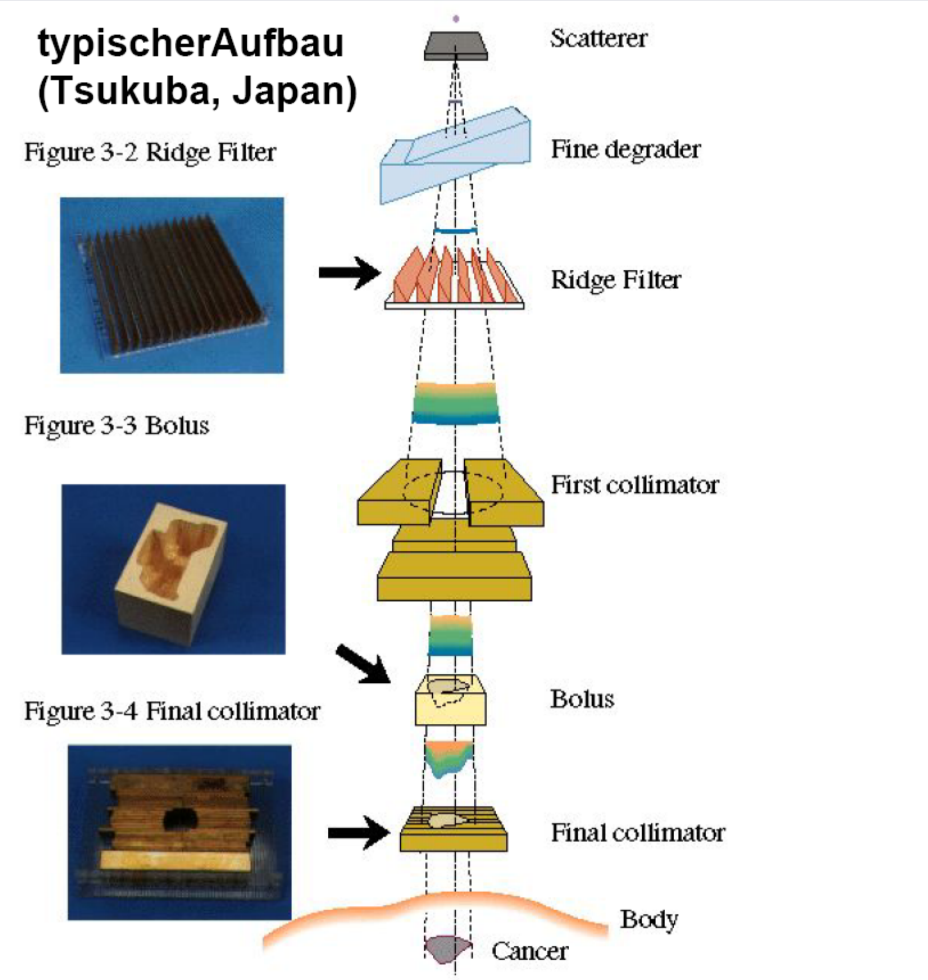
Local Effect Model (LEM)



Classical Particle Therapy

- Many widgets in Beam
- Complex setup
- Dose-distribution not optimal
- Patient-individual masks (Boli)





The GSI / Siemens System

- Active scanning with thin beams
- Depth-scans by energy => 3D rastering

Siemens Particle Therapy products and solutions are works-in-progress and require country specific regulatory approval prior to clinical use.

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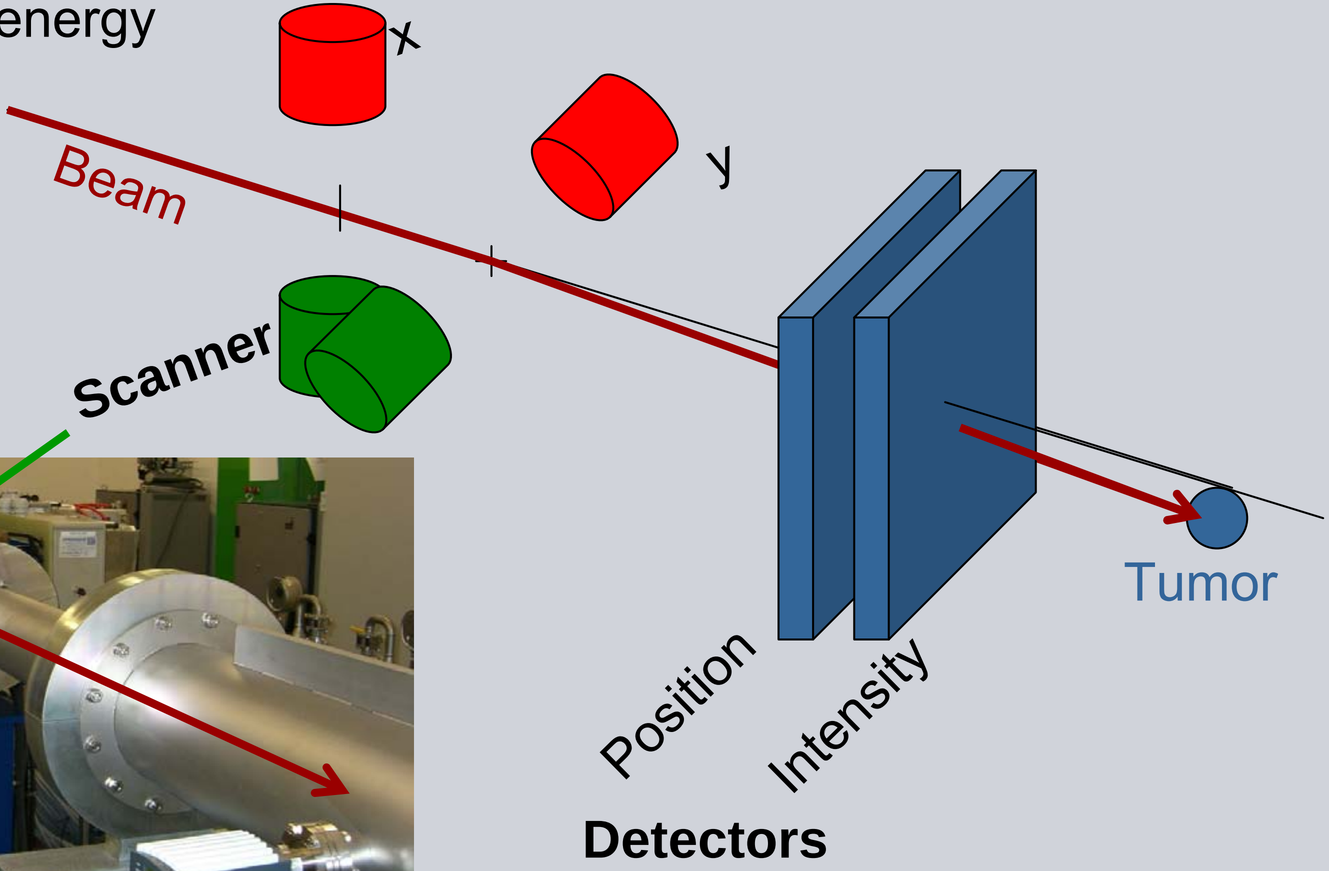
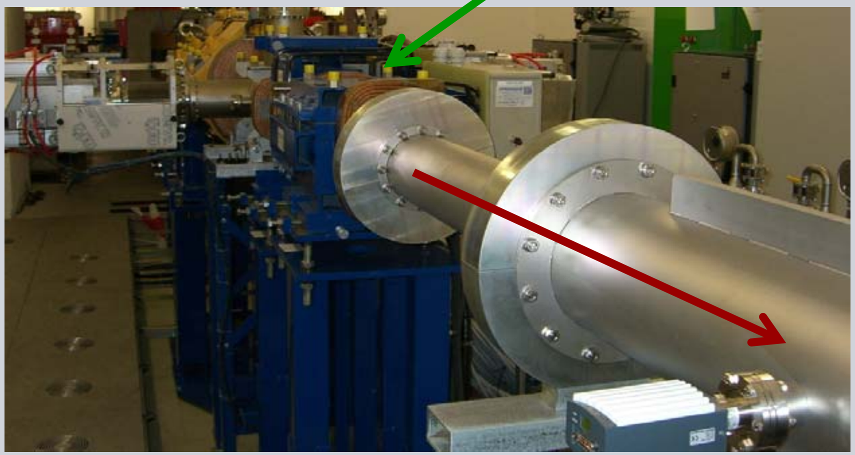
- Active scanning with thin beams
- Depth-scans by energy

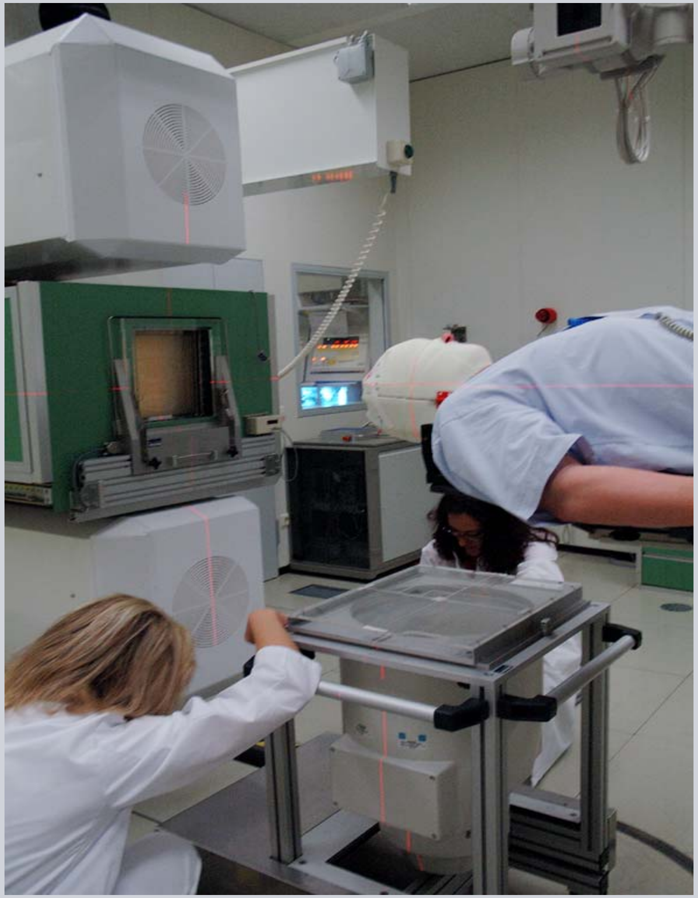
=> 3D rastering



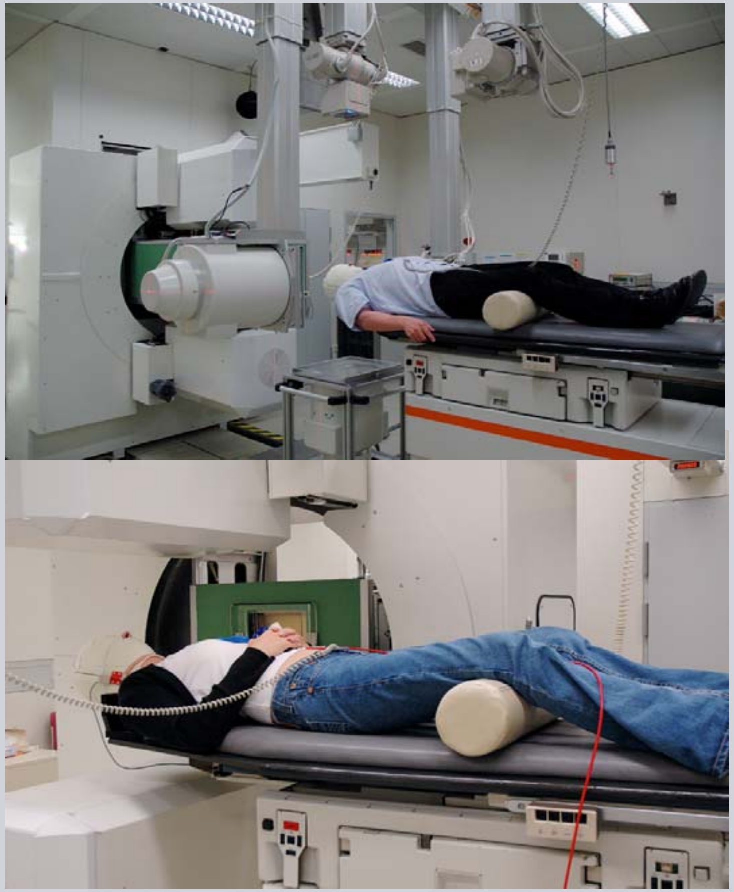
Cortesy HIT



GSI –
Treatment Room



Corurtesy: HIT



Corurtesy: HIT

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GSI –
Immobilization

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Corurtesy: HIT

Siemens Particle Therapy products and solutions are works-in-progress and require country specific regulatory approval prior to clinical use.

GSI –
Operating Console

Corurtesy: HIT

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SIEMENS

Our Cooperation Partners

- GSI* (Darmstadt, Germany)
  - synchrotron and raster scanning technology
  - treatment optimization (biological effects)
  - treatment planning software (ions)
  - knowledge transfer
  - Licences

PAUL SCHERRER INSTITUT PSI

dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

GSI Gesellschaft für Schwerionenfo in der Helmholtz-Gemeinschaft

MGH 1811 MASSACHUSETTS GENERAL HOSPITAL CANCER CENTER

DANFYSIK ws about us products & services ev

* Gesellschaft für Schwerionenforschung

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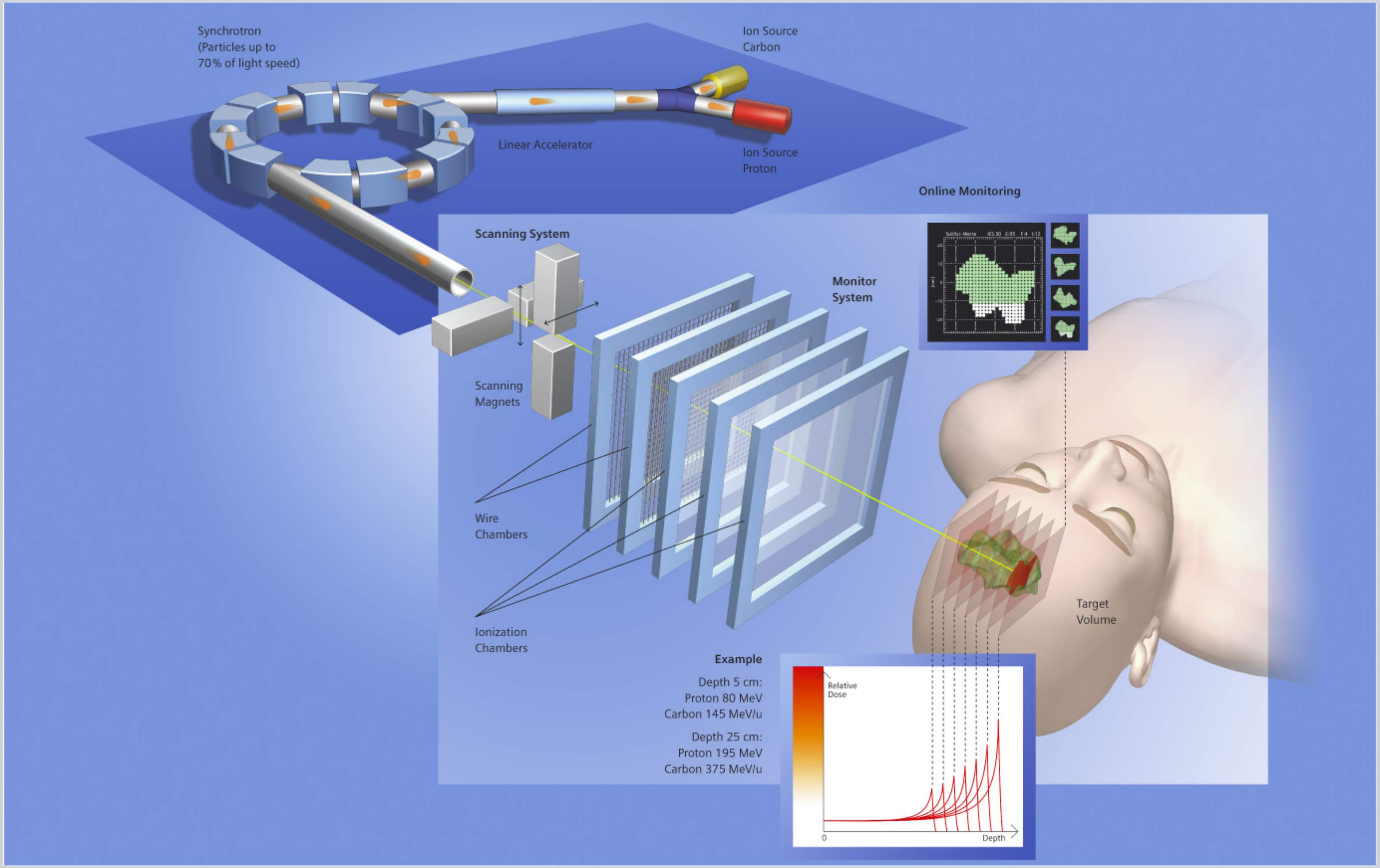
PT System Architecture/Principle



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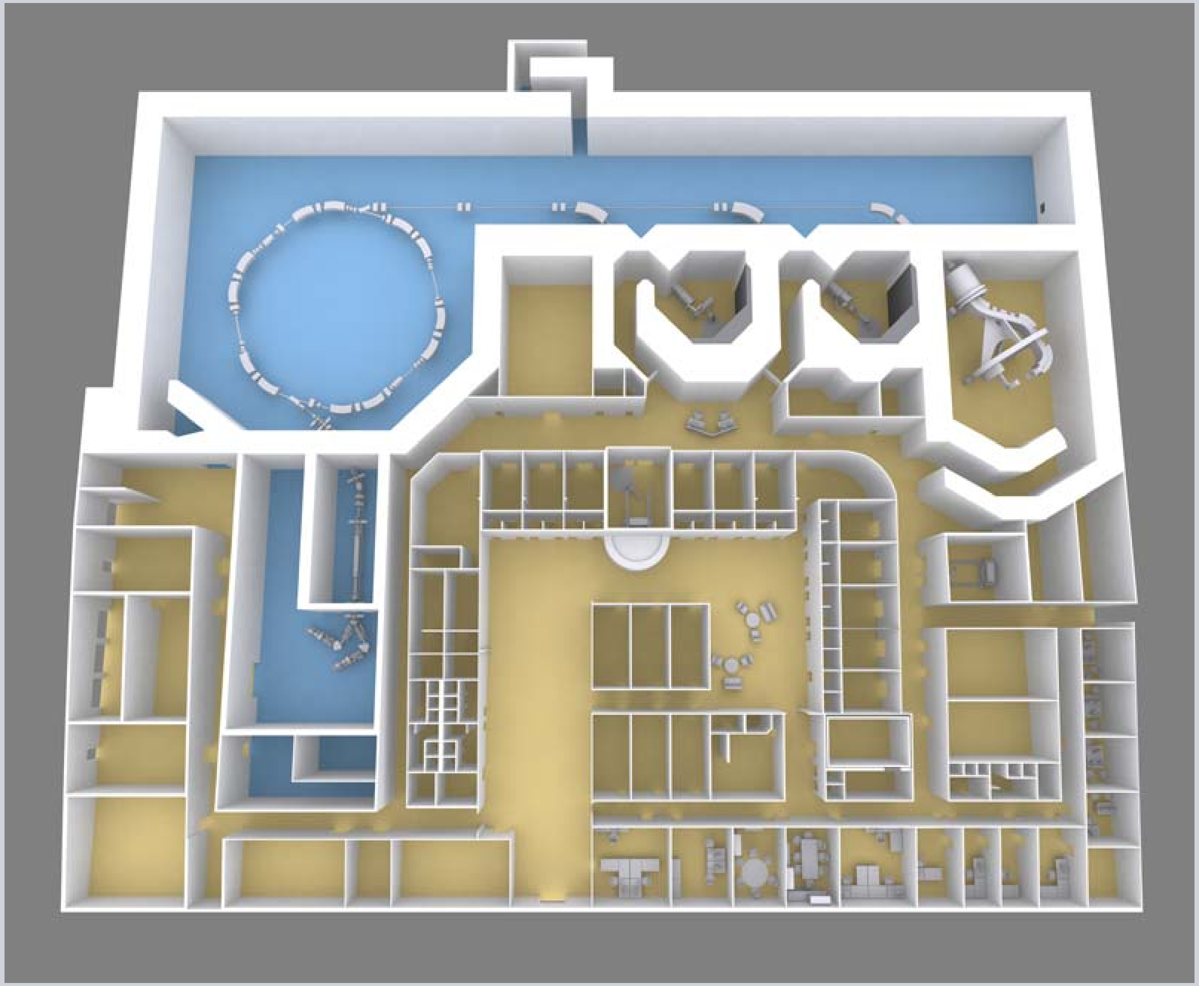

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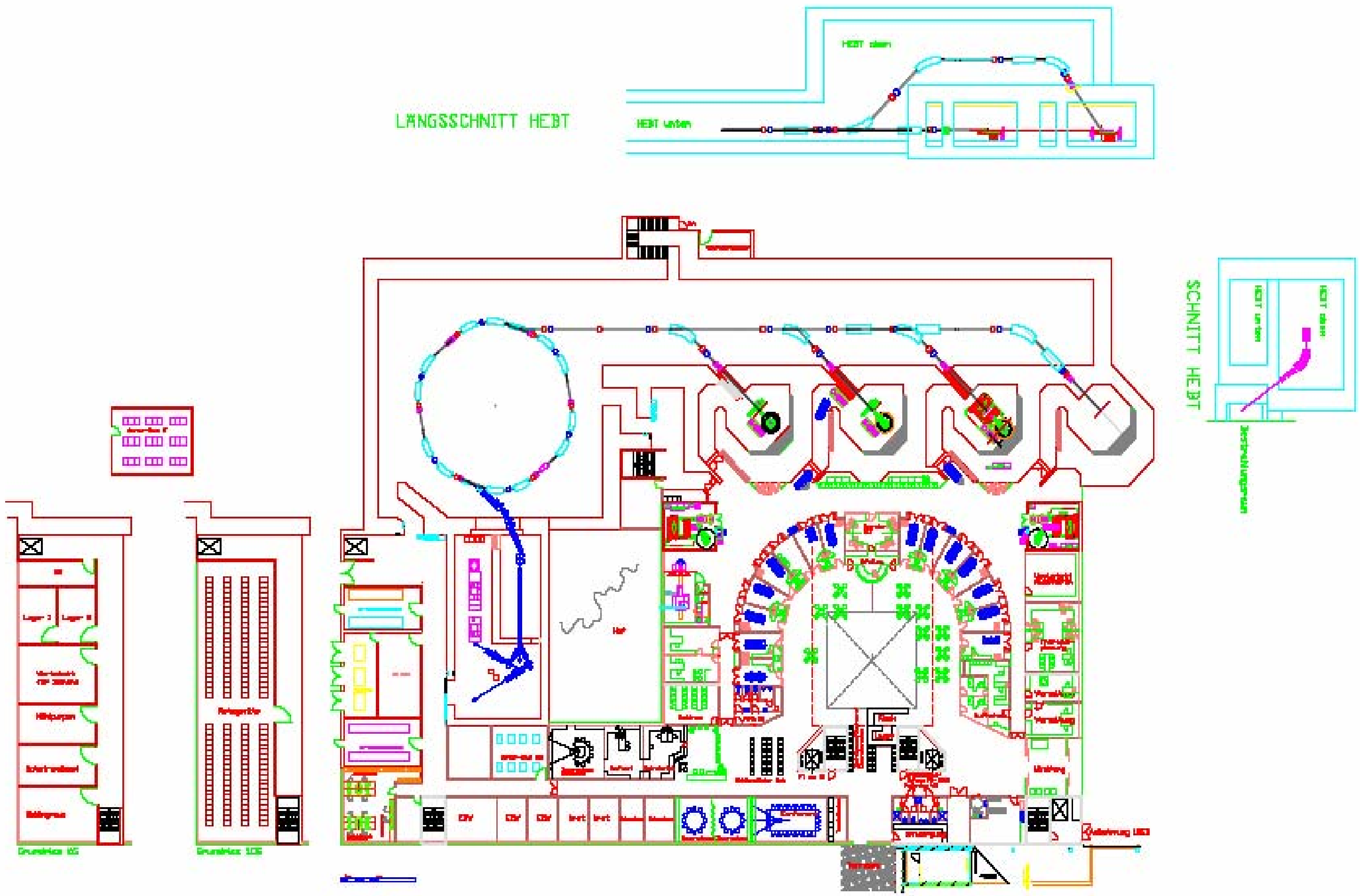
Rhön Klinikum AG –

Project Start - September 2006



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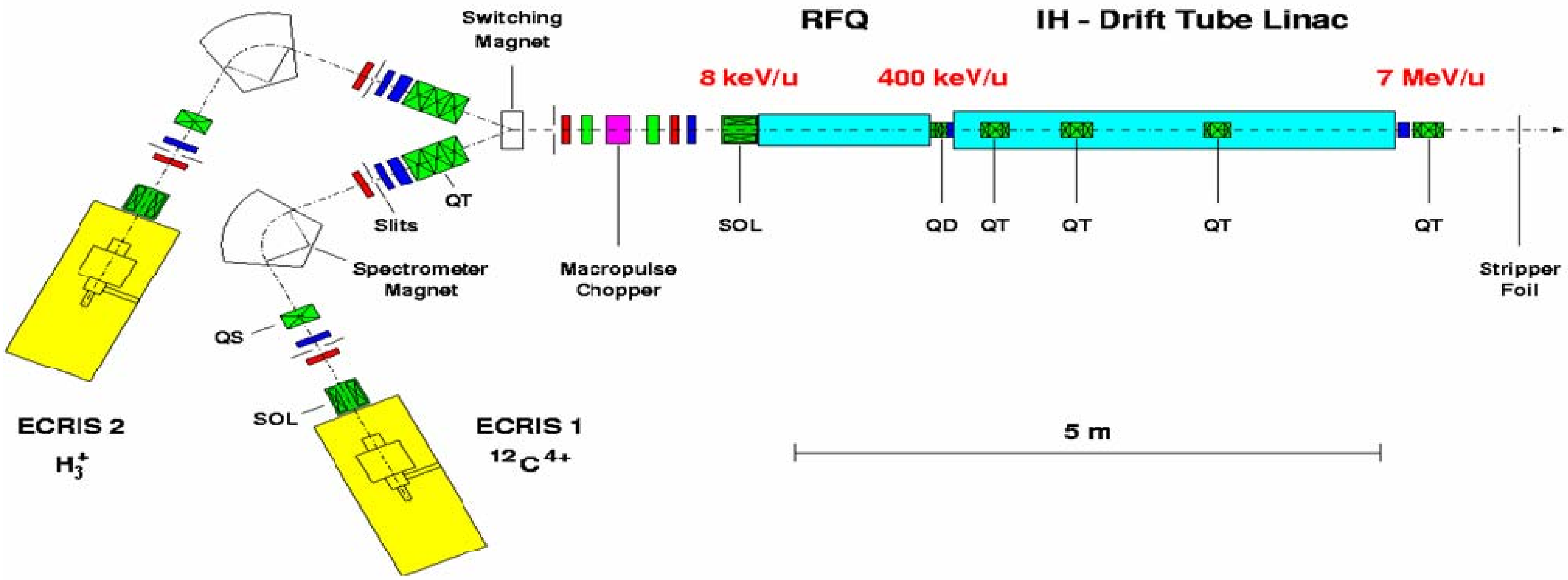
Siemens and Danfysik Cooperation

Danfysik

- Since 1964 engaged in the industrial and scientific area
- World renowned reputation in accelerator technology
    - Australian synchrotron project
    - Canadian Light Source
    - ANKA

Danfysik: Turn-Key supplier (exclusive) for the Siemens PT accelerator

Accelerator System Injector: Overview

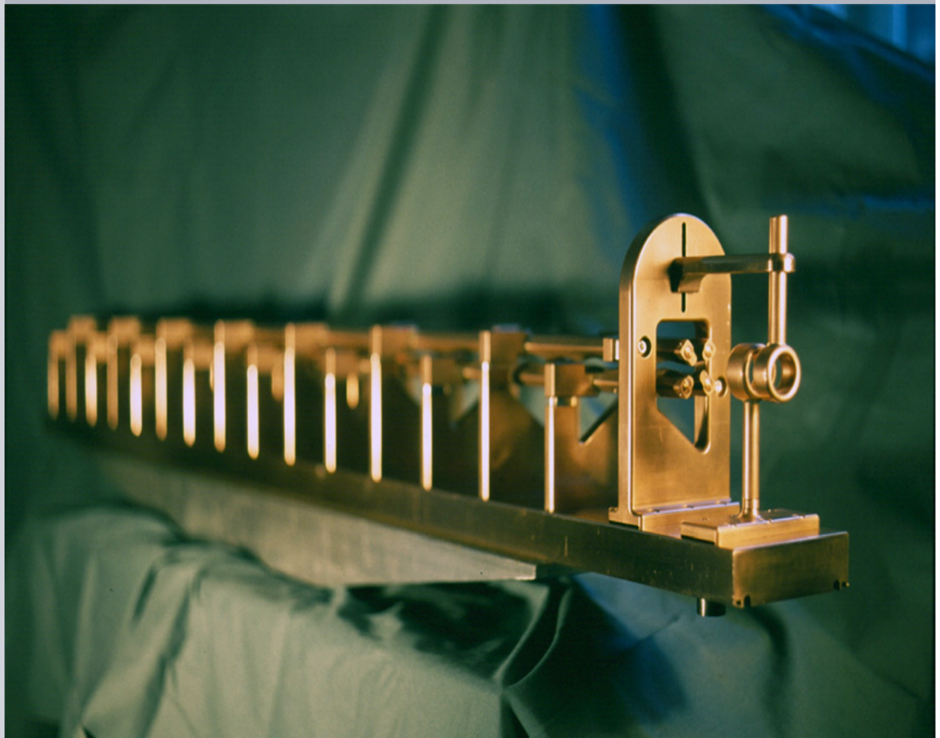


Courtesy of GSI (Gesellschaft für Schwerionenforschung)

Accelerator System RFQ

Function:

- Forms packets
  (necessary for loss free acceleration)
- Accelerates from 8 keV/u > 400 keV/u
- Patented with integrated rebuncher



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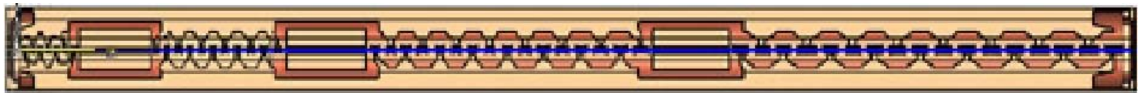
Accelerator System IH Drift Tube Linac

- 56 accelerating gaps within 3.8 m
- Accelerates from 400 keV/u to 7 MeV/u



Courtesy of GSI

Accelerator System
Synchrotron

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Acceleration range up to

- 430 MeV/u (Carbon)
- 250 MeV (Protons)
- (up to 300 mm depth in water)

Ramping Speed:

- 0.5 s till max. energy (Protons)
- 1.0 s till max. energy (Carbon)

Extraction time: 1...10 s

Intensity:

- 2 x 10^{10} protons/cycle
- 1 x 10^{9} carbon ions/cycle

Diameter: 22 m

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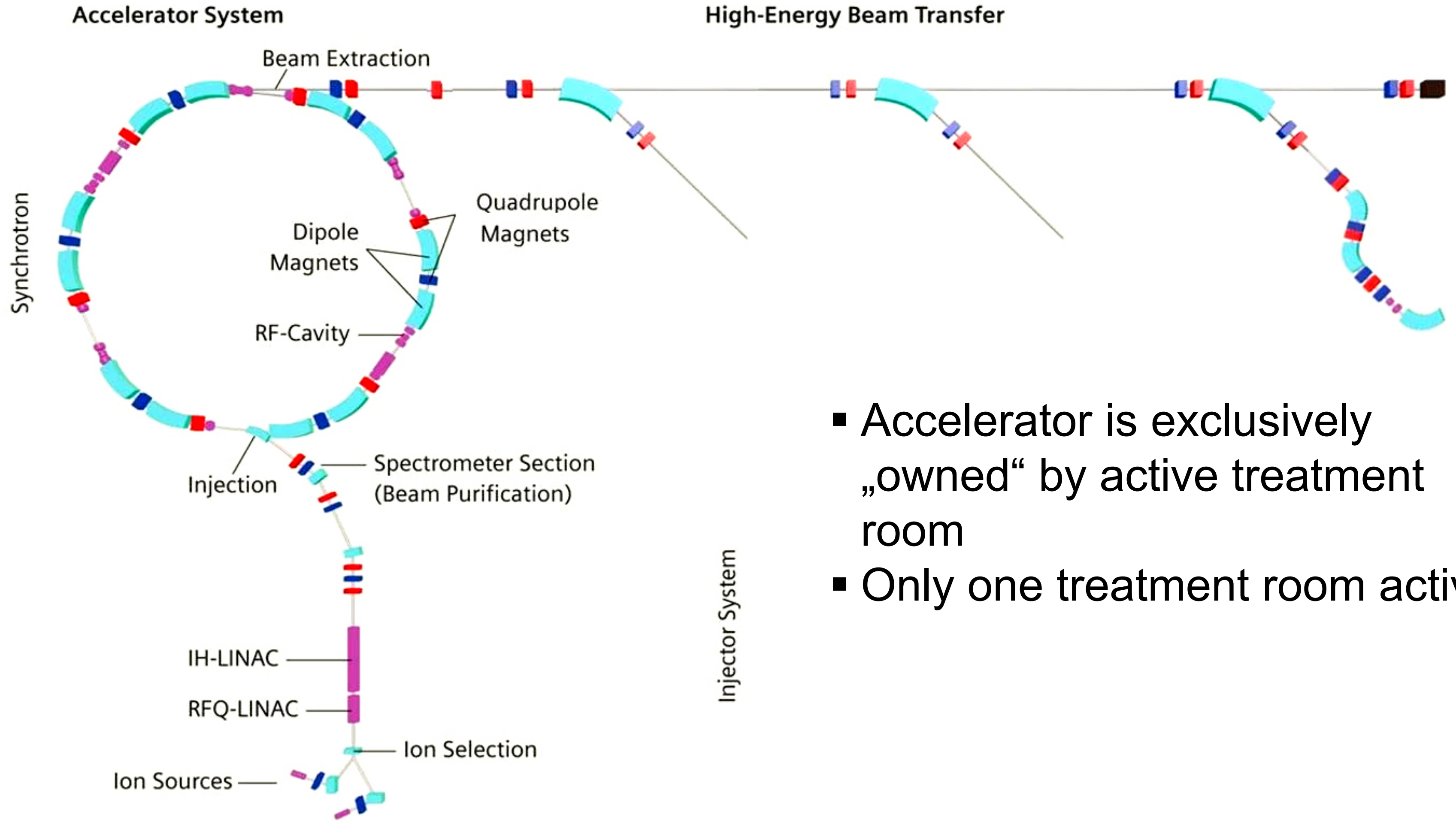
Accelerator and Beamlines

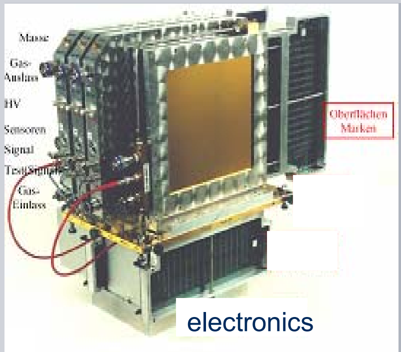


- Accelerator is exclusively „owned“ by active treatment room
- Only one treatment room active

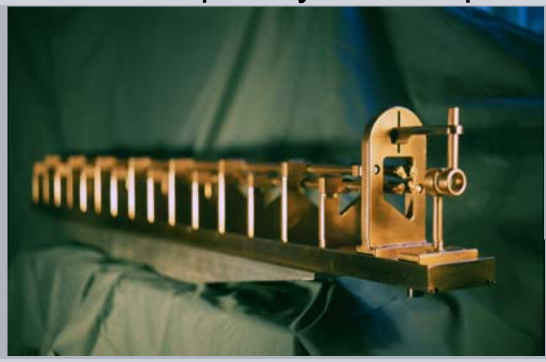
Reliability

- Standardized system modules
- Redundant beam profile measurement
- Redundant and diverse intensity measurement
- Proven technology: accelerator/synchrotron
- Fast spill abort (< 250 µs)

Detector block, GSI



Radio-Frequency-Quadrupole



IH Drift Tube Linac

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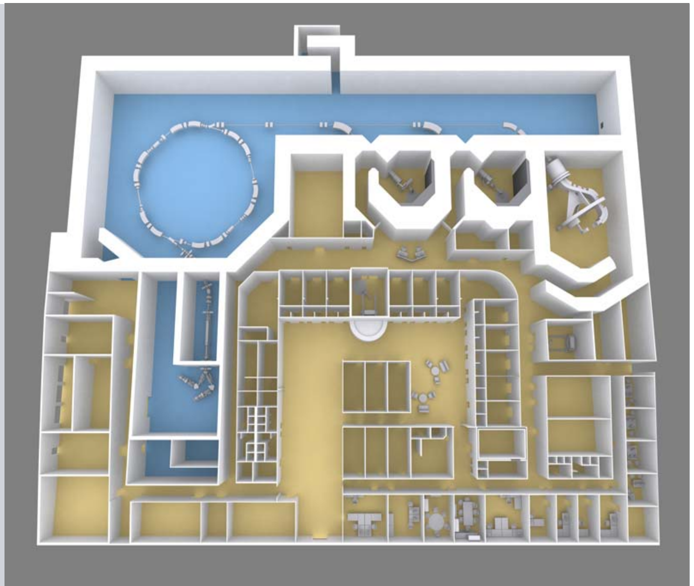
Service Solution PT
Meeting Customer Requirements

- On-site Expert Team around the clock
- Service Desk
- Constant (real time) System Monitoring
- Preventive Maintenance
- Critical Parts on-site
- Remote Support
- Service Coverage from Day 1 of Operation



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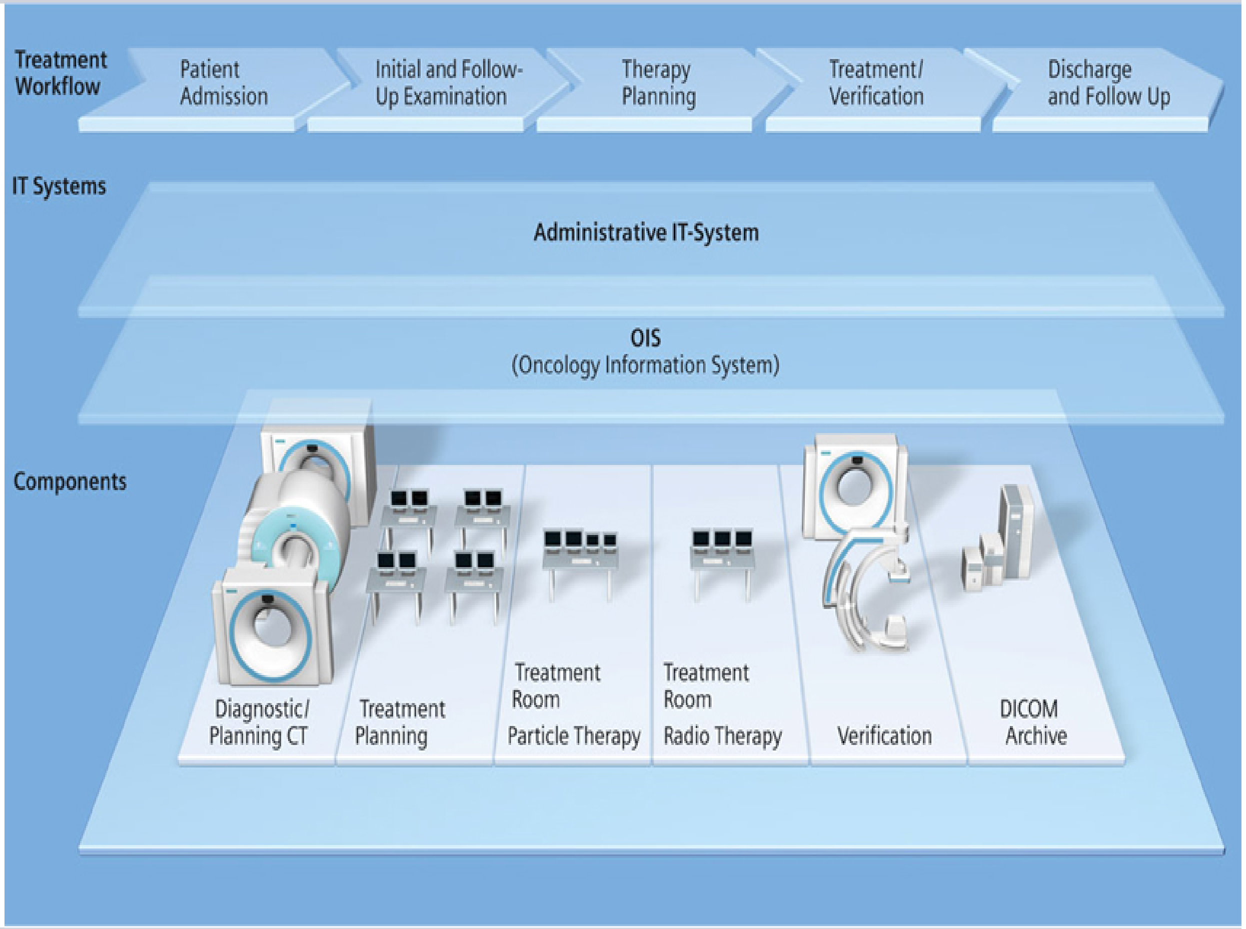
IT and Workflow

Integration of:

- Administrative IT-System
- OIS
- TPS
- Imaging Modalities
- DICOM-Archive
- Verification Systems
- Treatment Console



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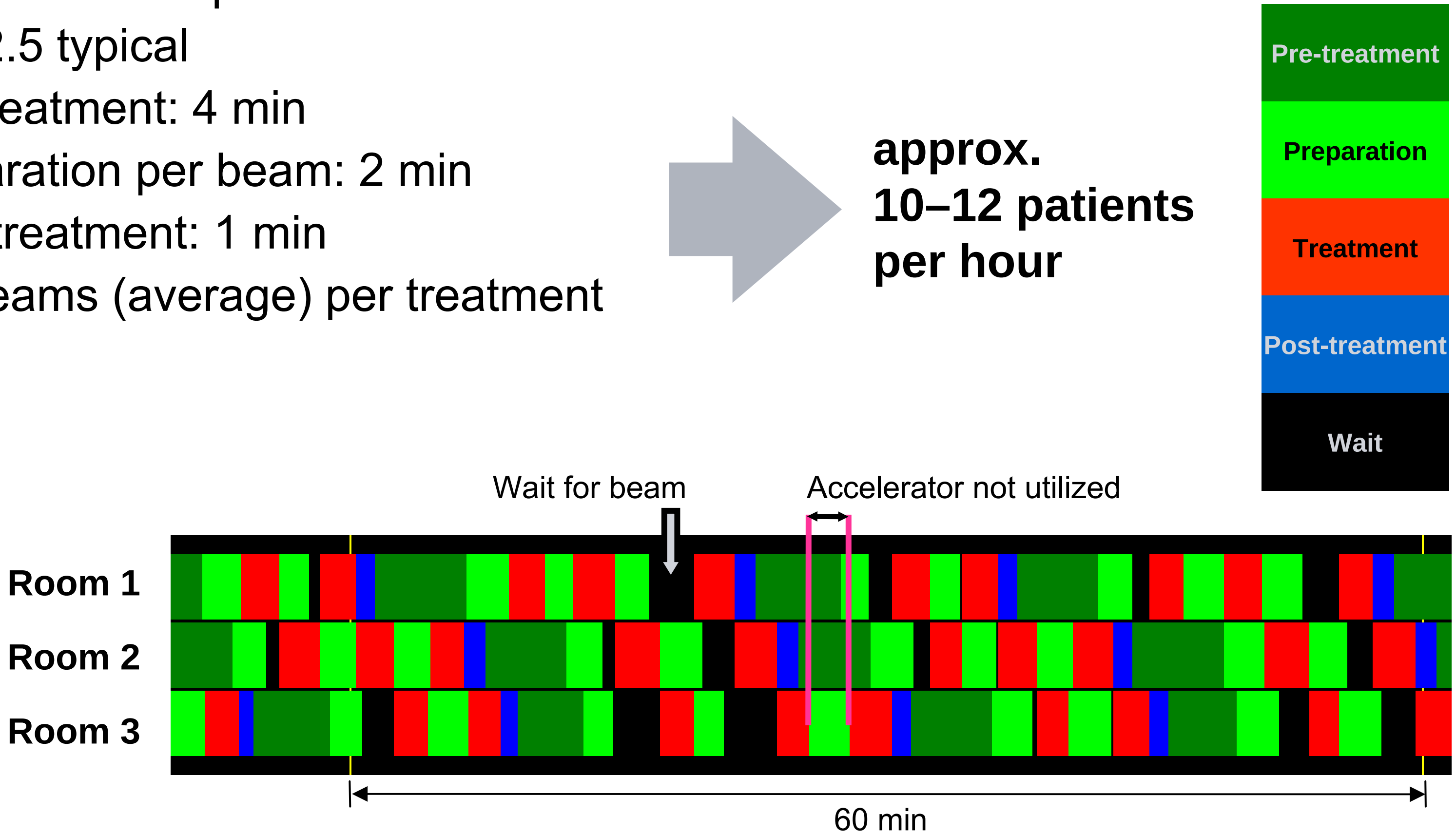
IT and Workflow

Simulation of Utilization of a Center with 3 Treatment Rooms

- Treatment time per beam:
  1.5 - 2.5 typical
- Pre-treatment: 4 min
- Preparation per beam: 2 min
- Post-treatment: 1 min
- 2.5 beams (average) per treatment

approx. 10–12 patients per hour



Source: U. Weber/ RKA

Outline

- **Siemens**
- **Cancer**
- **Radiation Therapy and Biophysics**
- **Application of Ions**
- **The Siemens Med PT System**
- **Systems**
  - Accelerator
  - Service
  - IT
  - Positioning and Imaging
  - Gantry
  - BAMS
- **Heidelberg**

SIEMENS

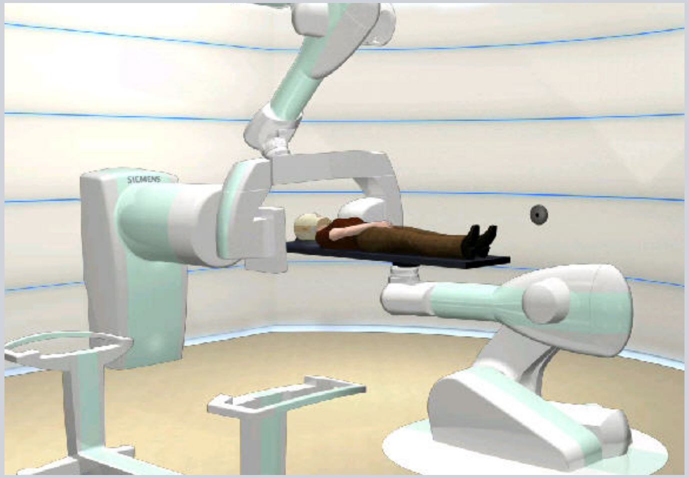
Patient Positioning

- Flexible patient positioning systems for fixed beam- and gantry rooms
- Solutions in conjunction with treatment planning and position verification
- Options to improve clinical workflow
- Options to expand range of applications
- Laser positioning marker

Siemens Particle Therapy products and solutions are works-in-progress and require country specific regulatory approval prior to clinical use.

Imaging

- Tailor made solutions for position verification in the treatment room
- Approved combinations for treatment planning
- Utilization of synergies of Siemens' diagnostic product portfolio for particle therapy applications
- Research on innovative topics with scientific and clinical partners



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SIEMENS

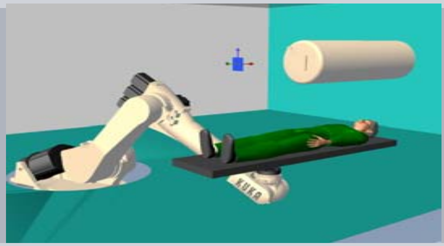
Robotic Treatment Table

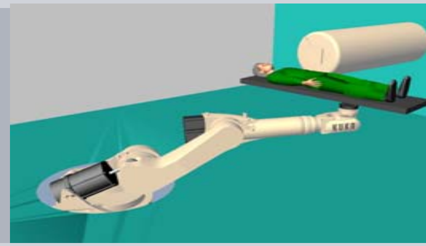
- **Excellent position capabilities with 6 degrees of freedom**
  linear (vertical, lateral, longitudinal)
  rotation (isocentric, roll, pitch)

- **High accuracy**
  Absolute within a sphere
  of R = 0.5 mm
  Relative ±0.1 mm

- **Reliability (industrial applications)**

- **Flexibility**
  table top
  chair
  QA phantoms
- **Automated procedures**
  treatment position
  loading position
  QA procedures





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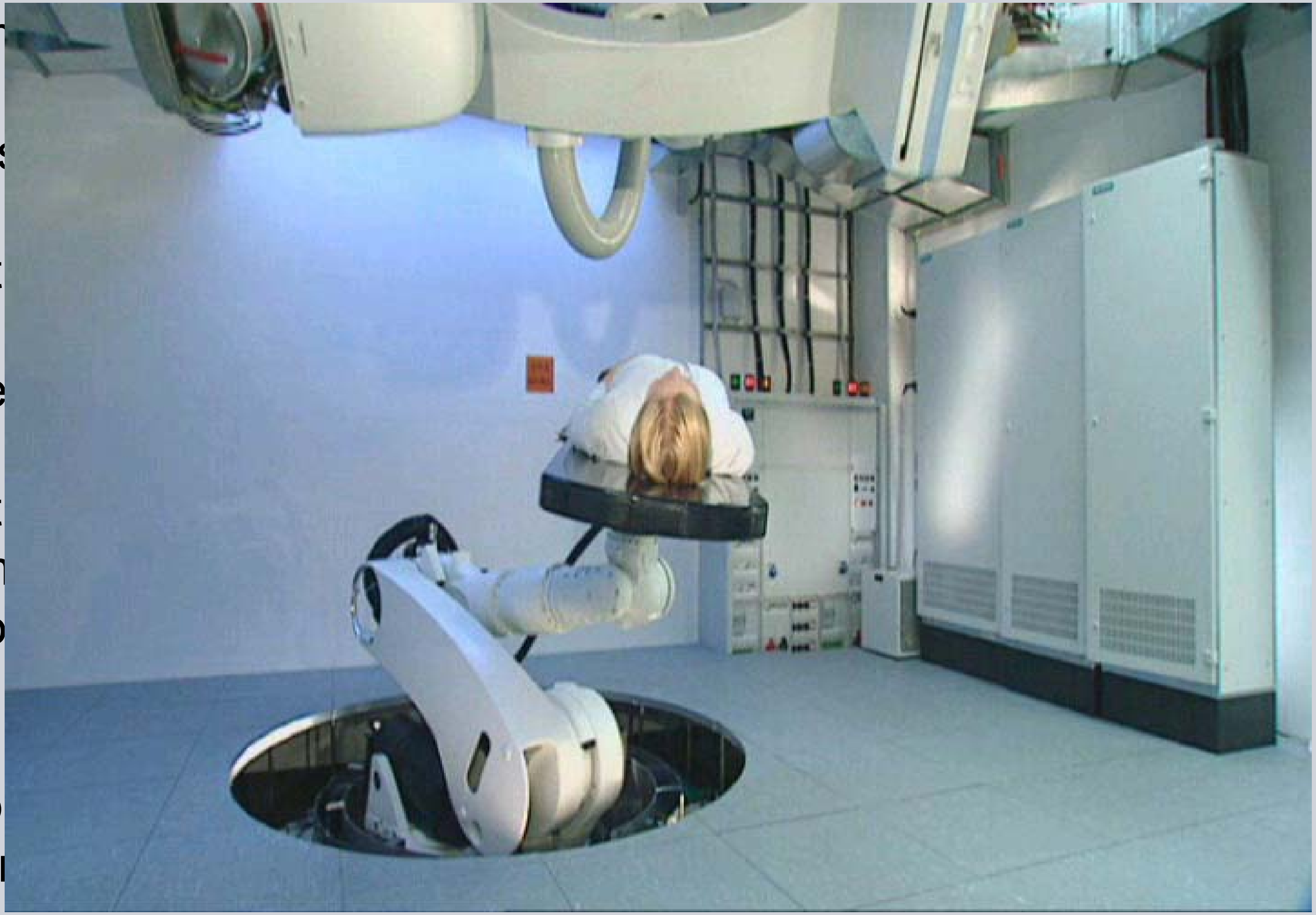
Robotic Treatment Table

- First system
- Start HIT ins
- Component
- System rele
- Same robot
  fixed bean
  gantry roo
  CT room
- Different ap
  specific roo



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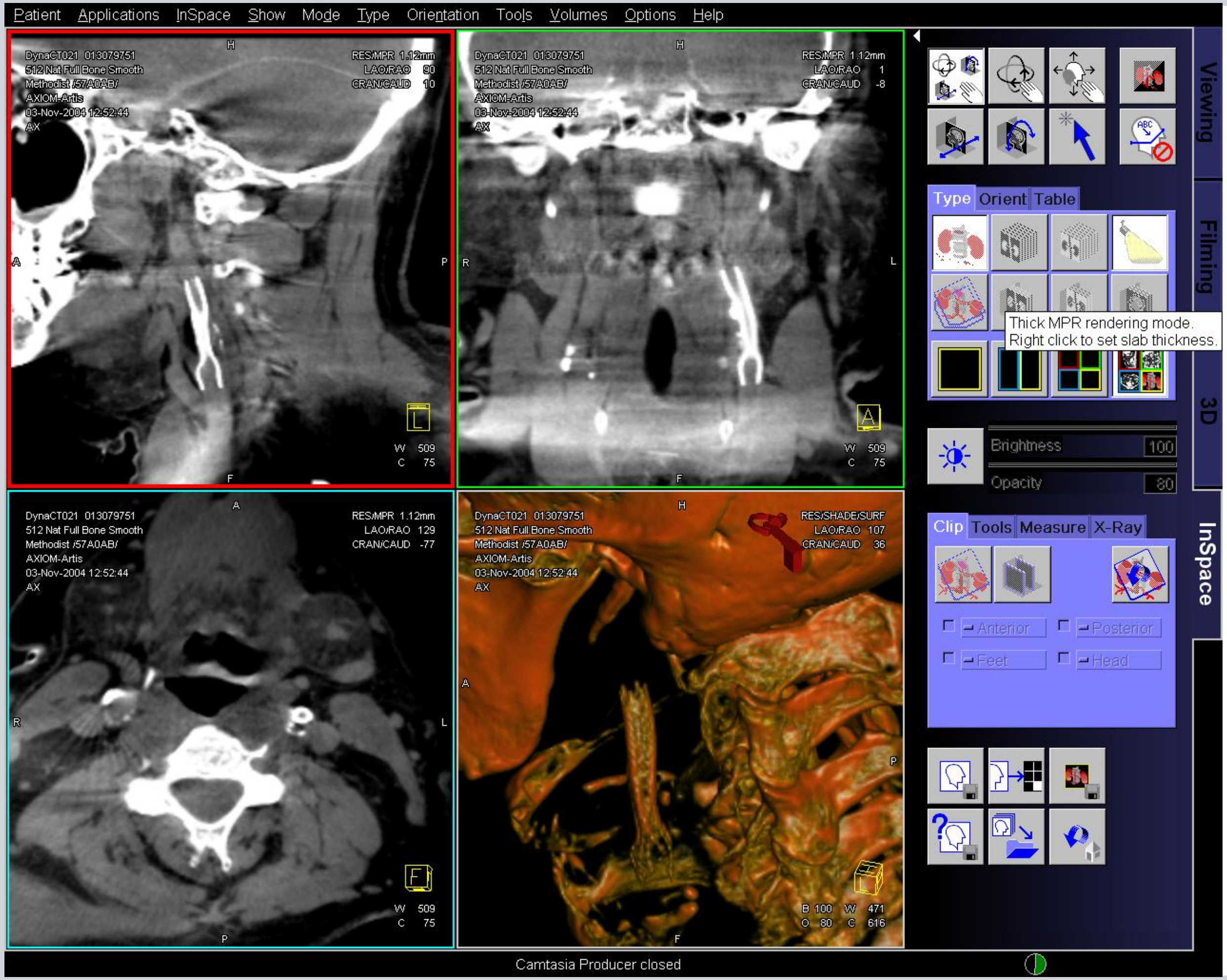
Dyna CT – Stent of the Carotis artery



3D imaging by non-CT systems!

Stent of the Carotis (538 Proj.):
Dr. Strother, Dr. Mavad
-> " CT-image like impression"

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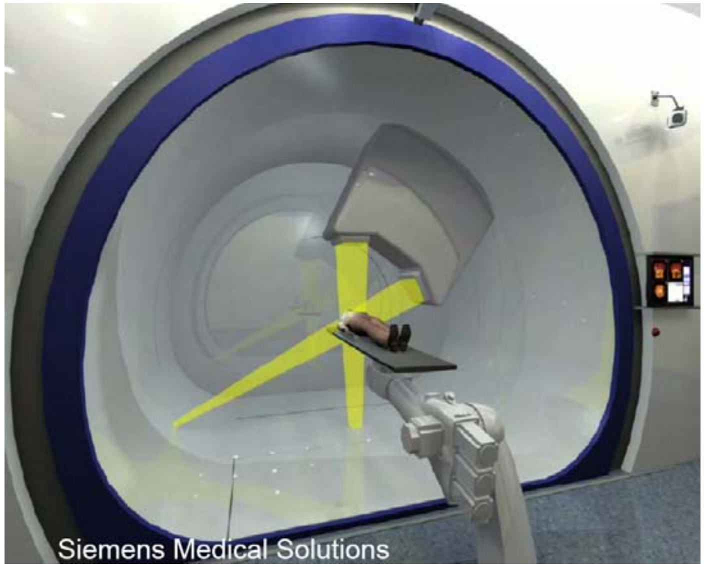
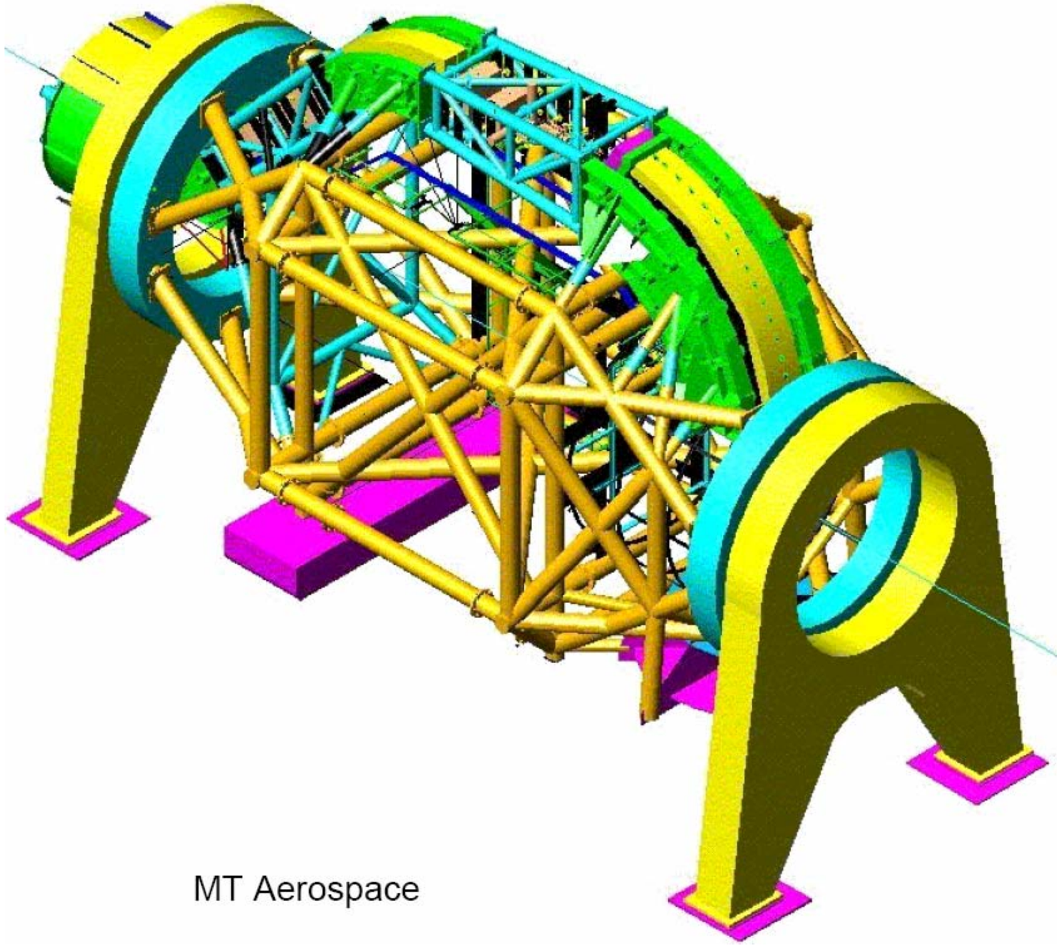
Gantries:
Turn the beam around the patient!

SIEMENS





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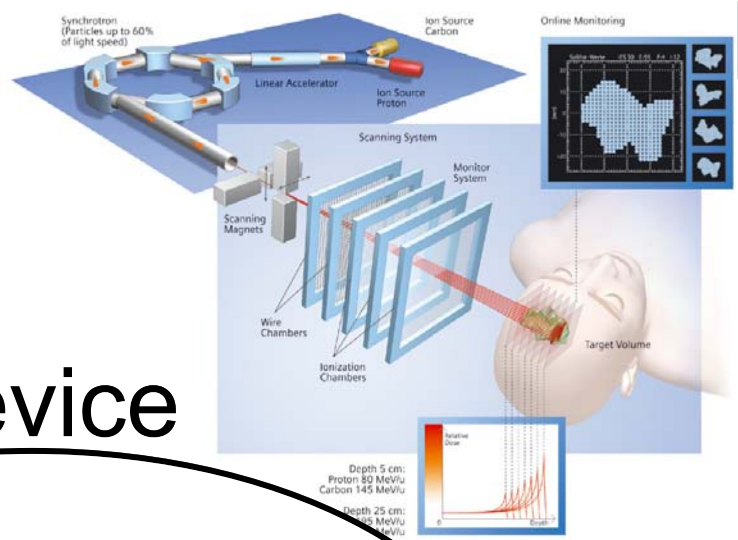
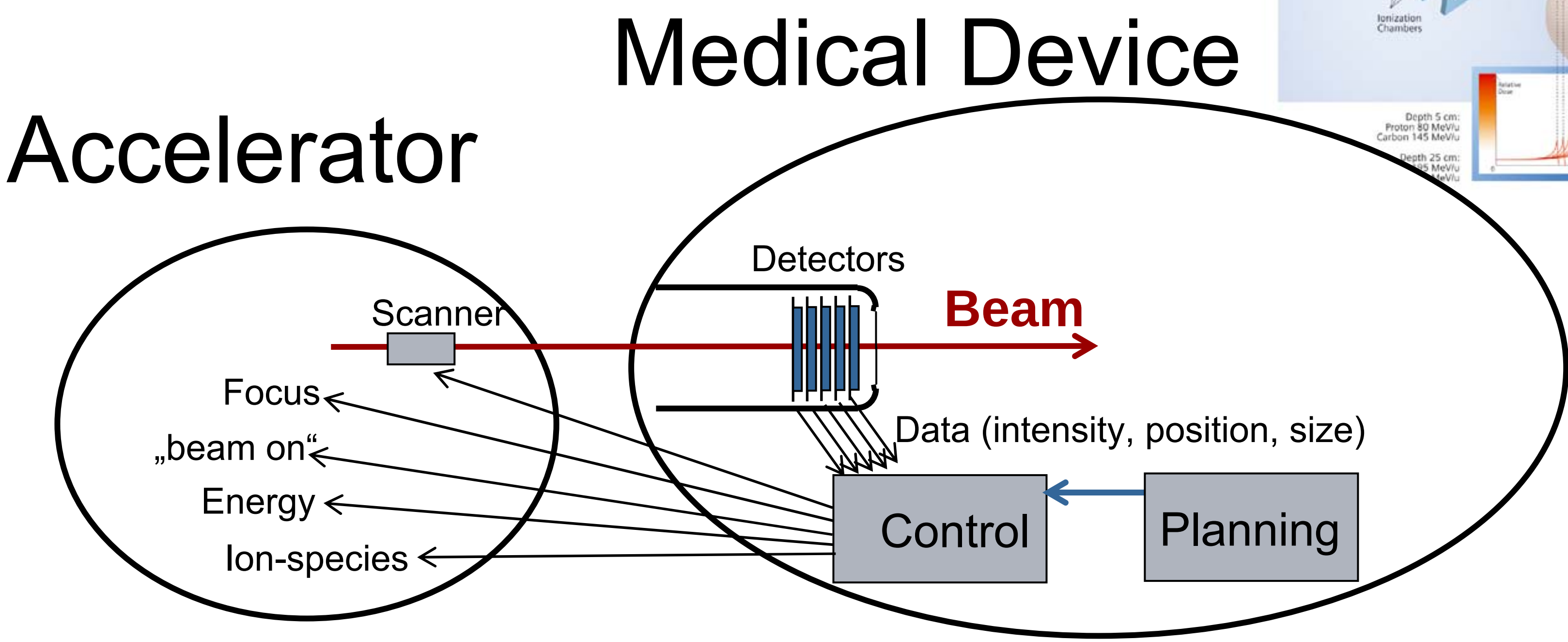
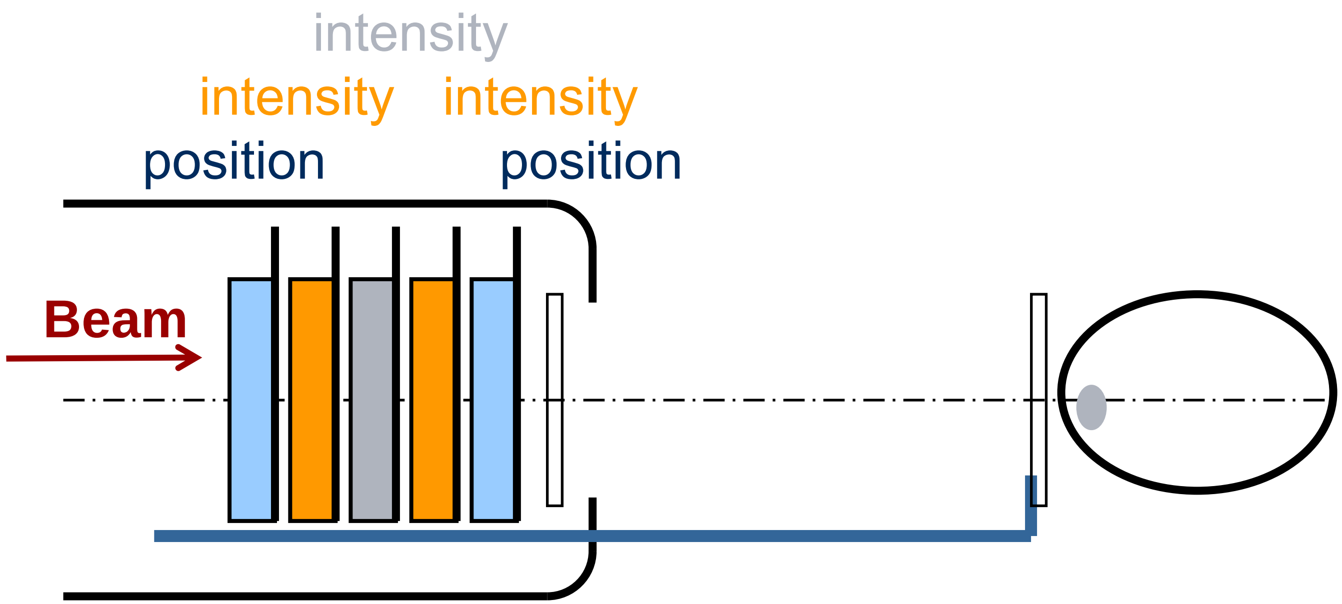
Safety Concept

Two Systems:
- Accelerator (technical)
- Medical Device





Detectors feedback for scanner



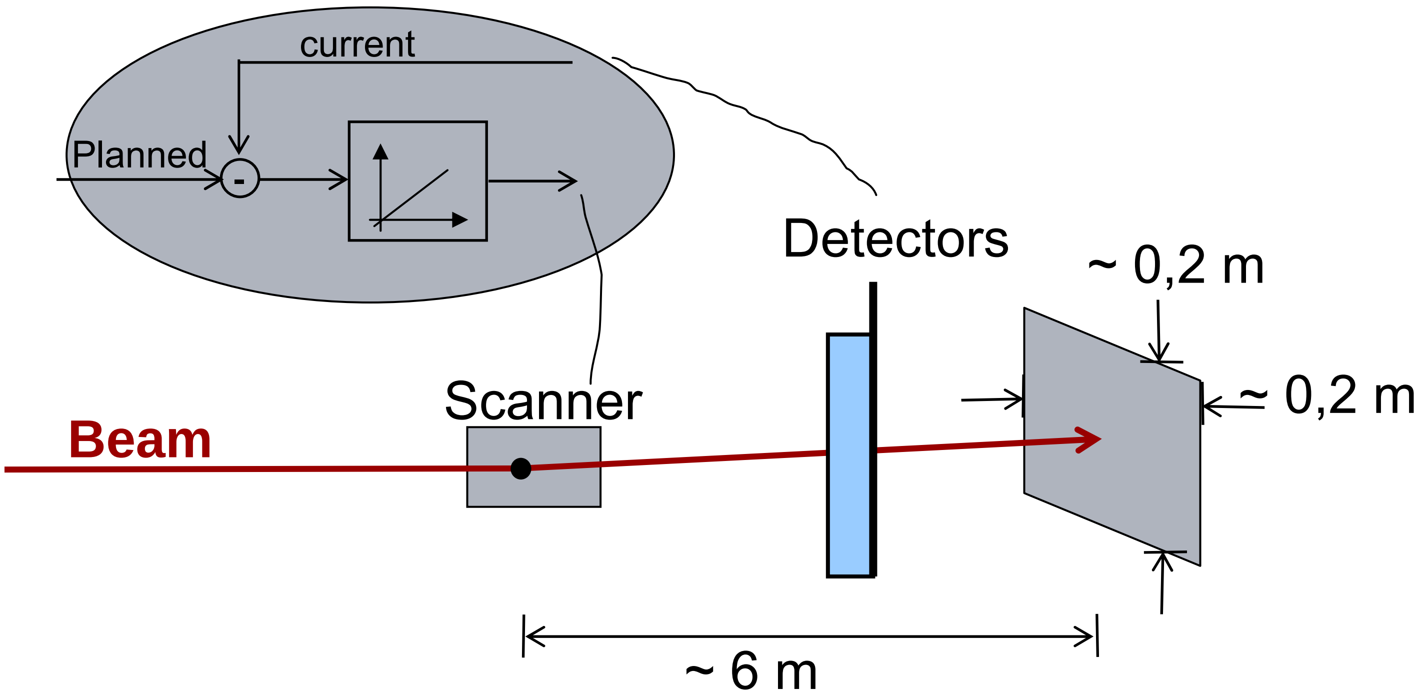
Ripple-filter
Optional:
Widen Iso-Energy-slices

Range-shifter
Optional:
Decrease depth @ E_{min}

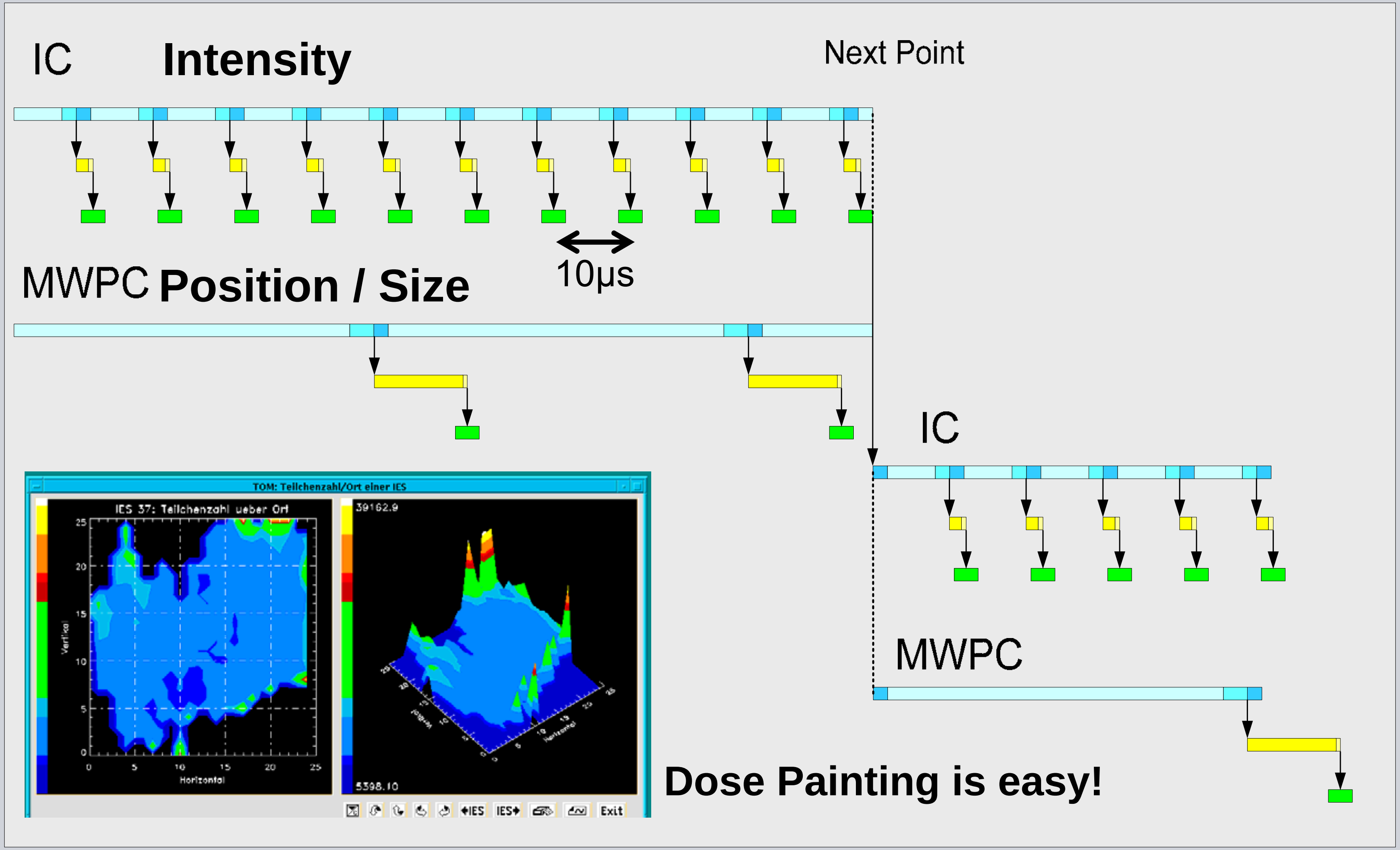
Modulators

Active Feedback

Measure	Control	
• Intensity	Irradiation time / voxel	(< 100µs)
• Position (x and y)	Scanner Current or Abort	(< 250µs)
• Size (x and y)	Abort	



Timing of a Voxel

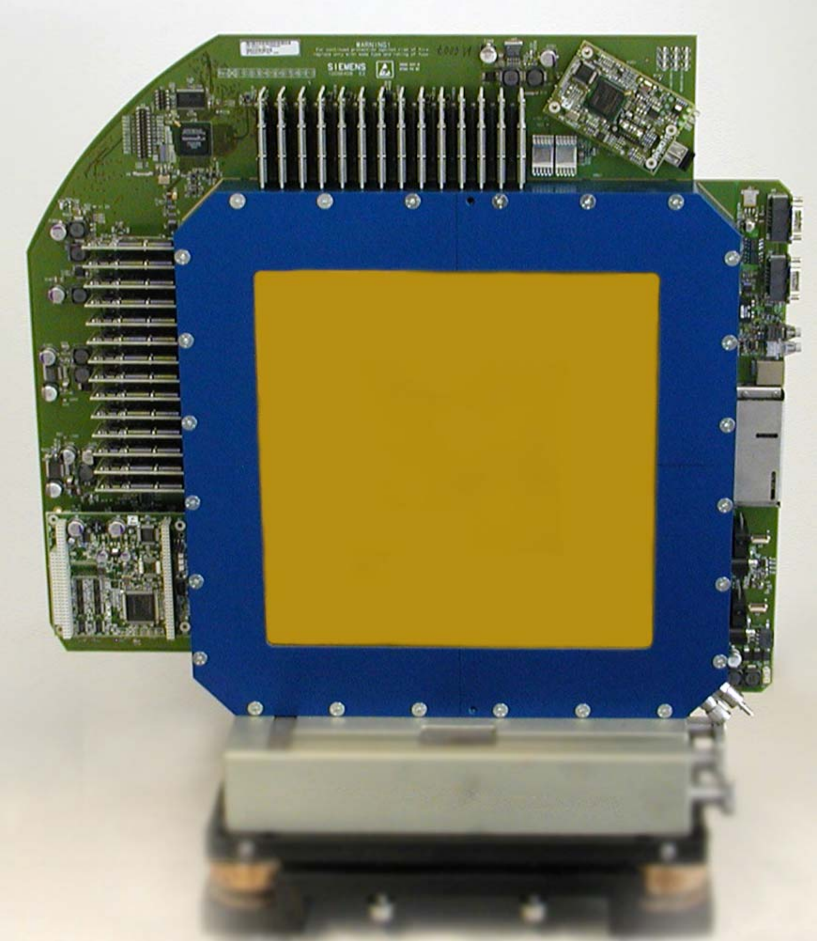


Position Sensitive Detectors

MWPC

- Medical Detector (MDD-conform)
- Series Product
- Built by Siemens Medical
- Full Integration of all aux. Systems!

- 112 channels / view
- > 200mm x 200mm apperture
- ≤ 0,2mm Resolution



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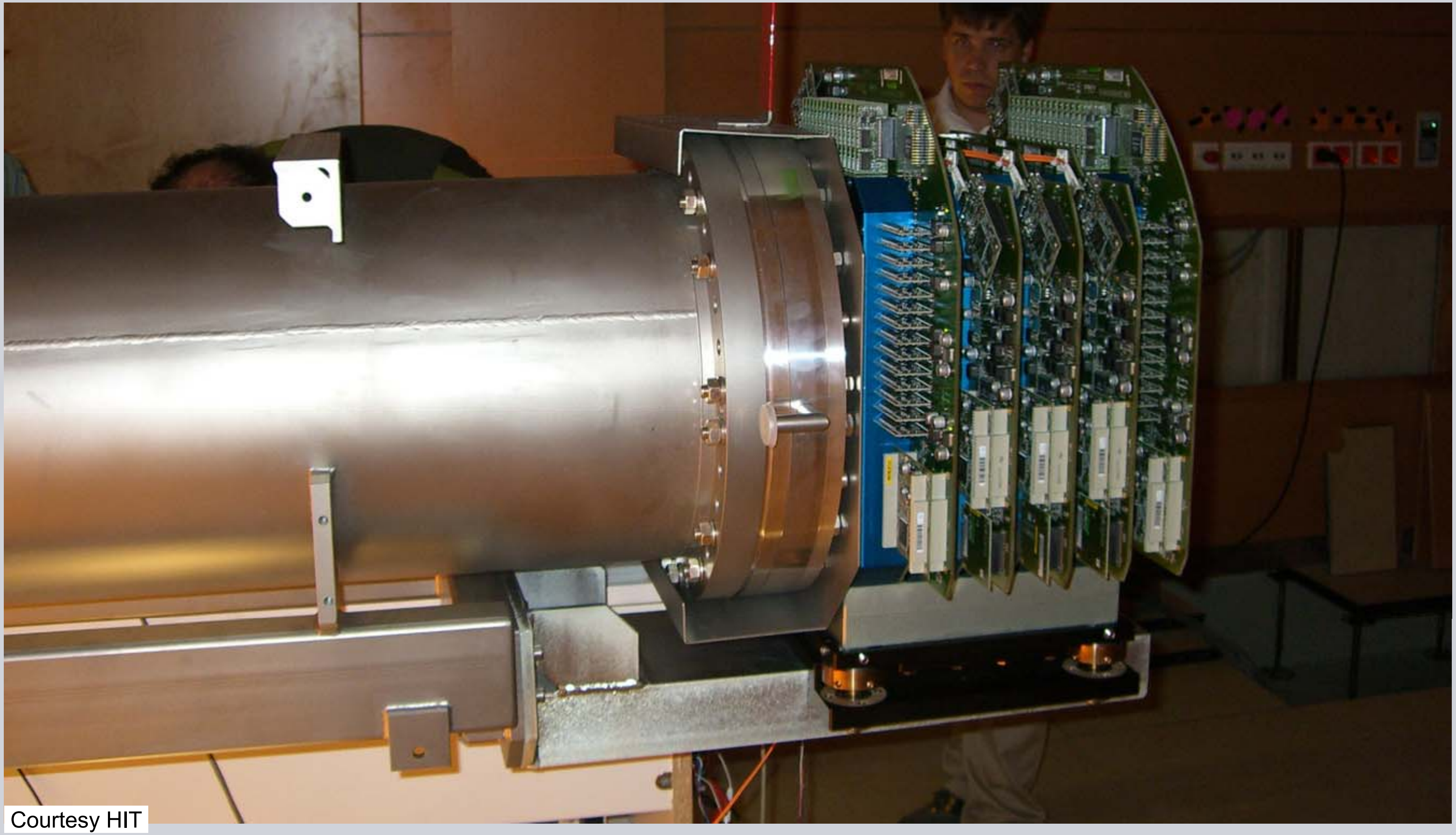
First Medical Detectors in Heidelberg


Courtesy HIT

SIEMENS

Heidelberg: Lenses, Scanner, Beamtube

Siemens Particle Therapy products and solutions are works-in-progress and require country specific regulatory approval prior to clinical use.

Heidelberg: Robot

Courtesy HIT

Siemens Particle Therapy products and solutions are works-in-progress and require country specific regulatory approval prior to clinical use.

SIEMENS

Heidelberg: Robot

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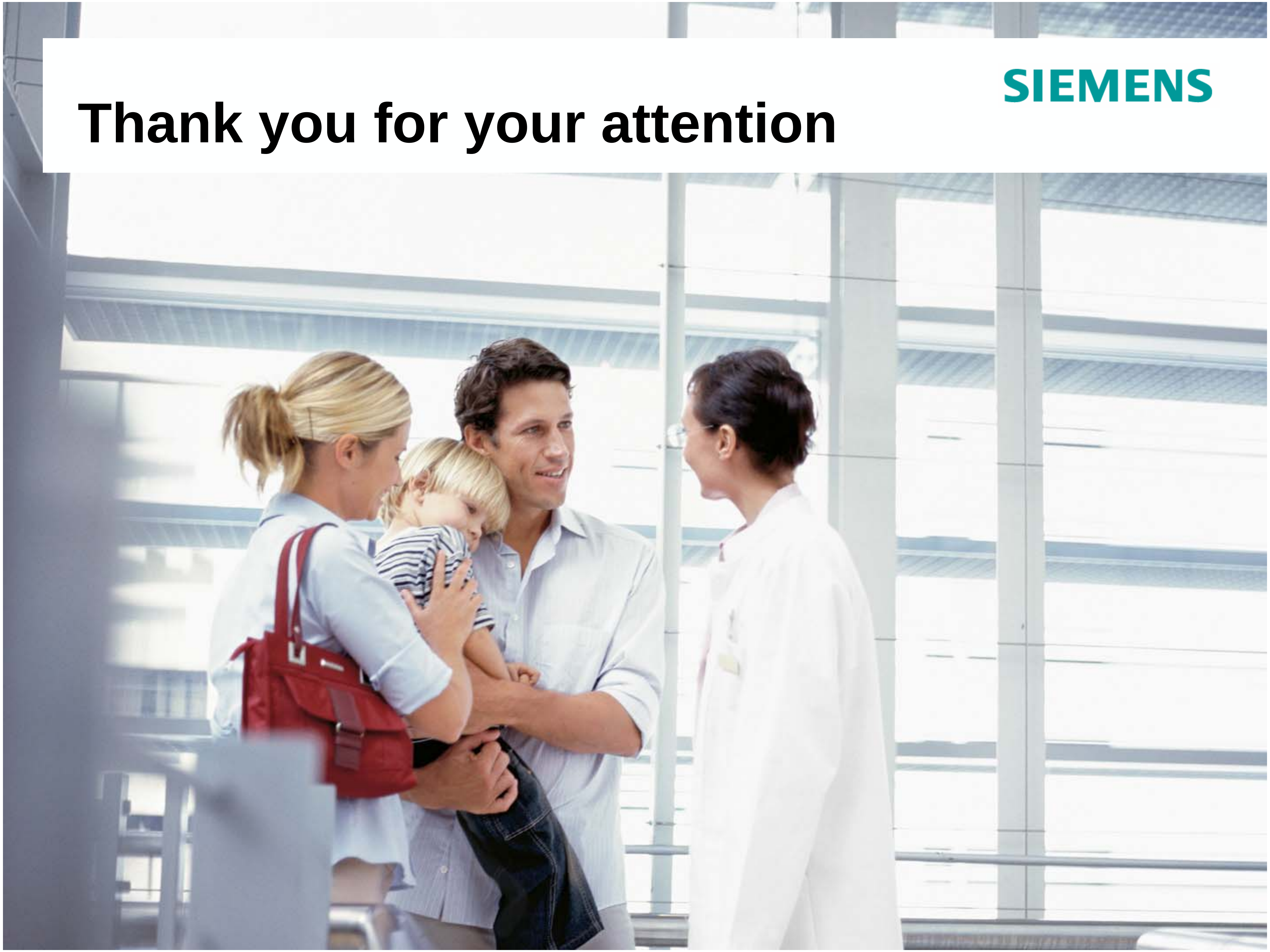
Thank you for your attention

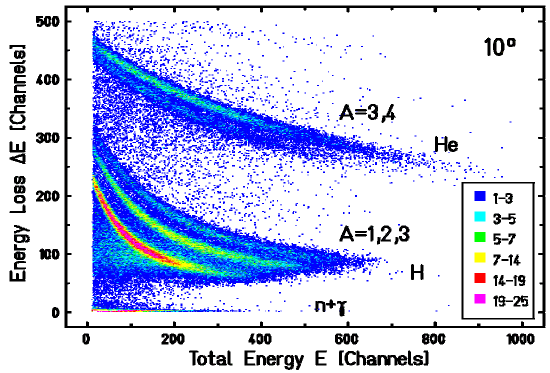
SIEMENS

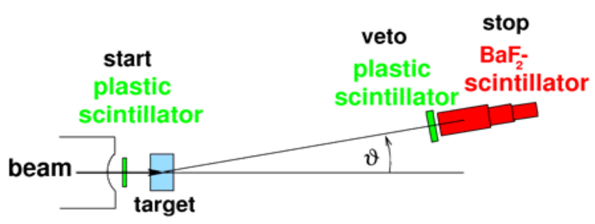


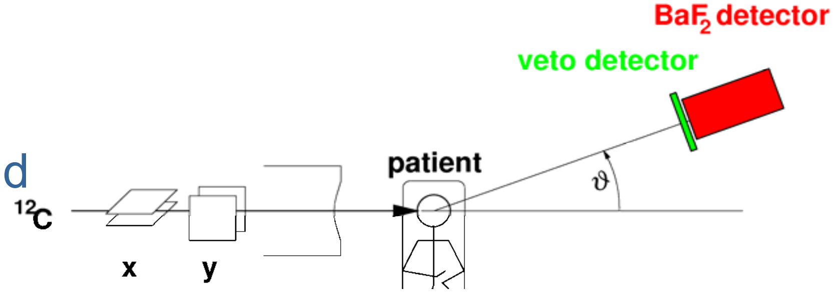
Experimental Arrangement

Measurements with water-equivalent targets

- Thick water target (12.78 cm)
  - ➔ stopping of primary ions (200 MeV/u, range: 8.57 cm)
- Time-of-flight measurements
  - ➔ determination of neutron energy
- Measurements from 0° to 30°
  - ➔ angular distribution of fragments
- BaF_2-detector-telescope
  - ➔ identification of isotope species
- Measurements in patient treatments
  - ➔ neutron and charged fragment yield behind the patient
  - ➔ angular distributions of fragments from 0° to 90°







Courtesy to GSI (Gesellschaft für Schwerionenforschung)

Siemens Particle Therapy products and solutions are works-in-progress and require country specific regulatory approval prior to clinical use.

SIEMENS

Energy and Angular Distribution

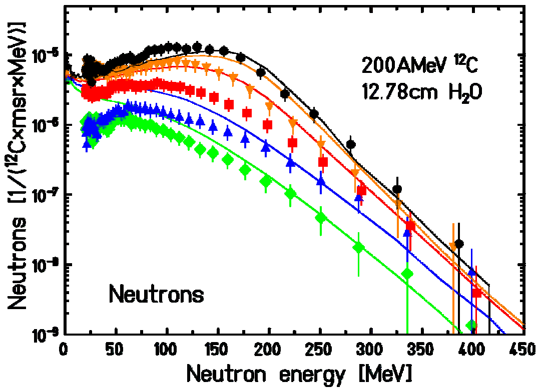
Angular distribution

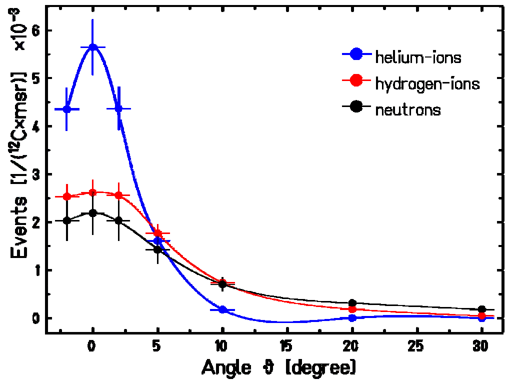
- Heavy fragments are forward focused
  - ➔ produced by projectile abrasion
- Lighter fragments are less focused
  - ➔ produced by evaporation

Energy distribution

- All fragments are forward focused
- Large maximum at small angles
  - ➔ projectile abrasion
- Exponential decay at high energies and maximum energies of fragments
  - ➔ evaporation from fire-ball/ projectile

Results from measurements in **patient treatment** are **comparable** to results obtained at the **water target** if the different irradiation
conditions are considered





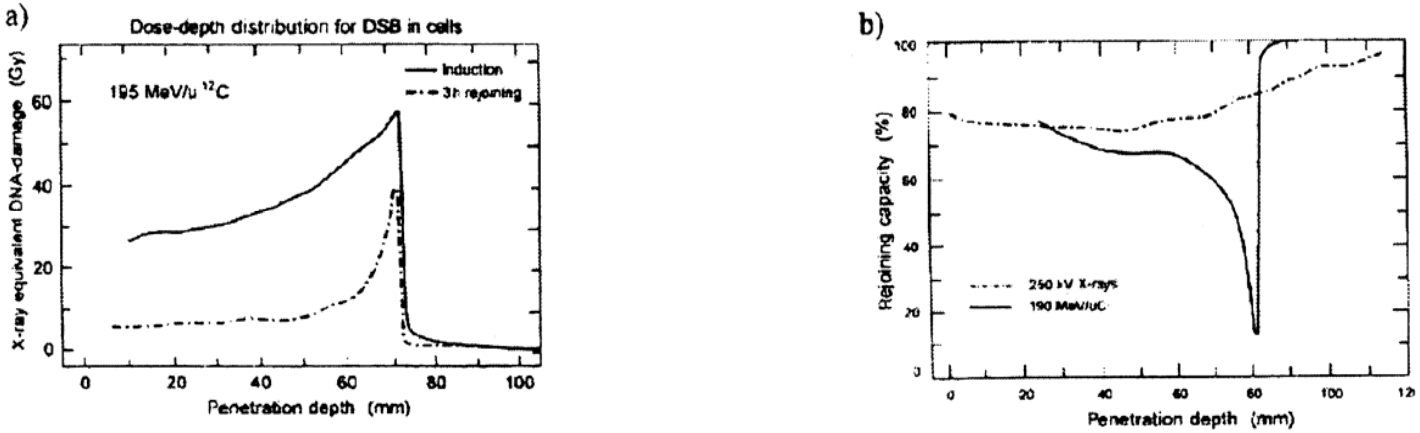
Courtesy to GSI (Gesellschaft für Schwerionenforschung)

SIEMENS

DNA Damage Versus Penetration Depth

The amount of double strand breaks immediately after exposure to 200 MeV/carbon ion and after additional incubation time of 3 h for DNA repair shown as a function of penetration depth.

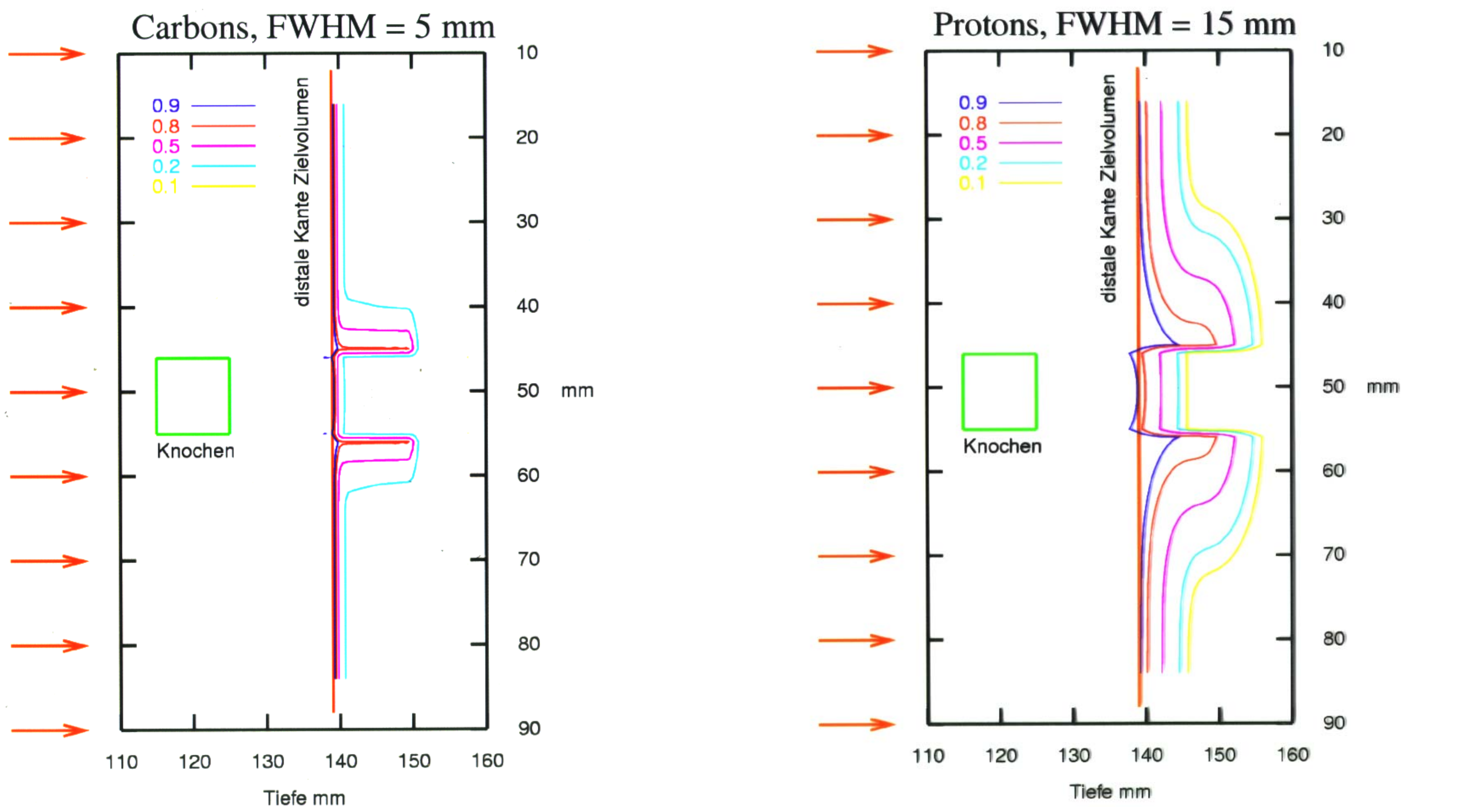
Comparison of rejoining after X-ray and particle exposure as function of penetration (G. Kraft)



Courtesy of GSI (Gesellschaft für Schwerionenforschung)

Advantages of Carbon Ions:
Edge Effect – Overrange Induced by Scattering

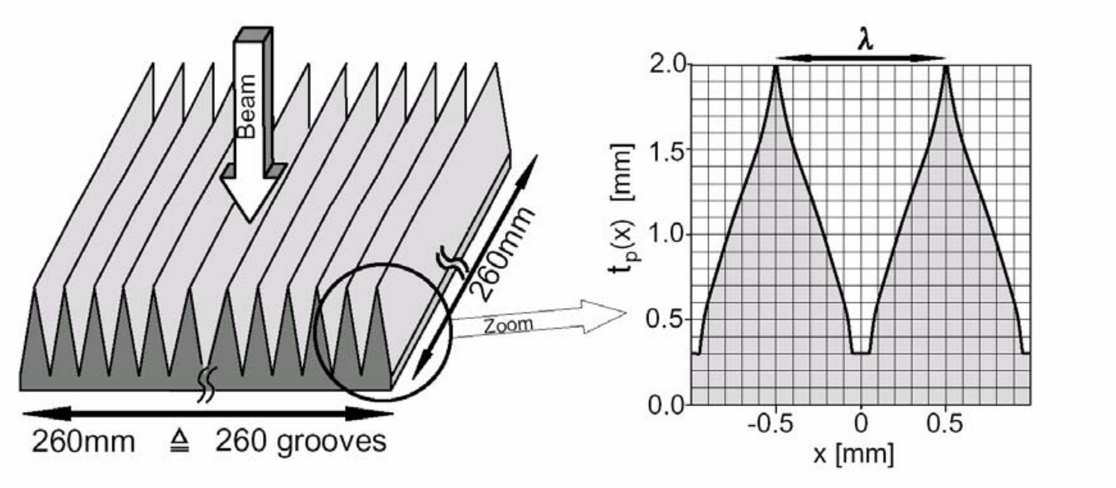
SIEMENS



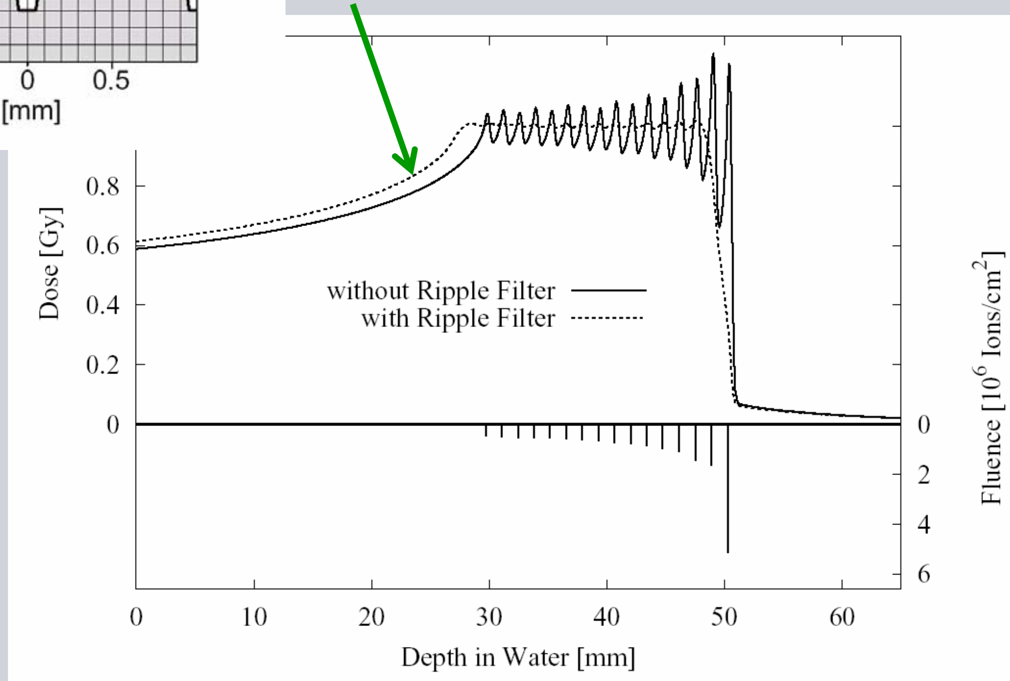
Courtesy of GSI (Gesellschaft für Schwerionenforschung)

SIEMENS

Ripple-Filter



Smooth curve with Ripple-Filter



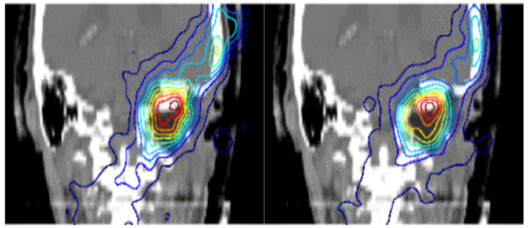
Future:
In – Beam PET

SIEMENS

Functional benefits:
- In vivo range verification helps to avoid incorrect treatments
- Potential as an enabler for extreme hypofractionation with pilot shot
- Improves the pysicians' confidence in the accuracy of their plans

Status:
- Using existing Siemens PET components (detectors, electronics, mechanics, SW and IT)
- Works in progress, research topic
- Research collaboration with FZR
- Feasibility study with FZR toevaluate PET performance parameters

Simulated positron distribution *Measured positron distribution*



W. Enghardt et al., FZR Dresden

SIEMENS

Correlation indication/treatment angle

	Sc. DEGRO	0°	45°	90°	90°+0°	90°+45°	0°+45°	0°+45°+90°	Gantry
Prostate	27%			X	X	X		X	X
Head & neck	19%			X	X	X		X	X
Brain	9%			X	X	X		X	X
Pediatric	9%	X	X	X	X	X		X	X
Abdomen	8%				X	X	X	X	X
Thorax	7%				X		X	X	X
Mamma	7%		X			X		X	X
Recurrent	4%	X	X	X	X	X	X	X	X
Uterus				X	X	X	X	X	X
Paraspinal	2%	X						X	X
Extremities	1%	X	X	X	X		X	X	X
Others	5%	X	X	X	X	X	X	X	X

Black: All tumors of this indication can be treated; **blue**: Most tumors of this indication can be treated