# IONTRIS Particle Therapy Systems: Marburg, Kiel and Shanghai

Heiko Rohdjeß
SIEMENS Healthcare Particle Therapy

## Outline

- Particle Therapy – Introduction
- IONTRIS System
- Projects
- HIT Heidelberg
- PTZ Marburg
- NRoCK Kiel
- ShaPHIH Shanghai
- Summary

## History of Particle Therapy

SIEMENS

Clinical Application

Clinical Research

Fundamental Research

Today: Commercial Vendors: IBA, Varian, Hitachi, Mitsubishi, Optivus, Siemens, …..

Particle therapy is applied in purely clinical centers, e.g.

- Francis H. Burr PTC, Boston; MD Anderson, Houston; University of Florida
- HIT, Heidelberg; Rhön Klinikum AG, Marburg; CNAO, Milano; RPTC, Munic
- HIBMC, Hyogo; NCC, Kashiwa; Shizuoka; PMRC, Tsukuba

1996/97 First tumor conform radiation with scanned beam – protons at PSI (Villigen, Switzerland), $^{12}$C-Ions at GSI (Darmstadt, Germany)

1993 First center for $^{12}$C-ions therapy in Chiba (Japan)

1990 First center for proton therapy in Loma Linda (USA)

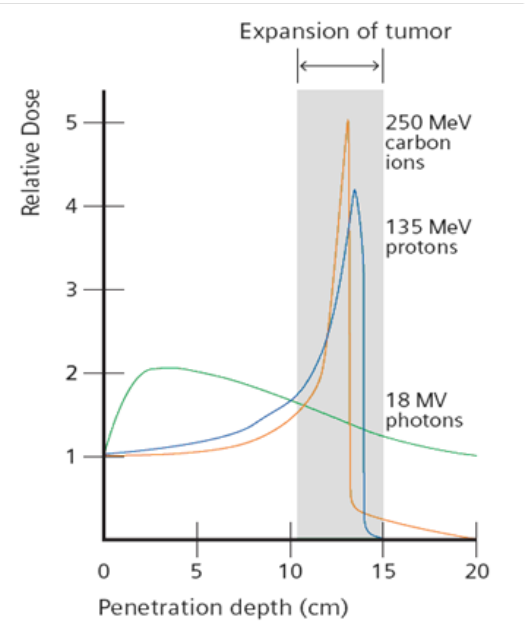
1975 LBL irradiated for the first time with ions (helium, carbon, neon)

1974 First proton therapy at the Harvard Cyclotron

1957 Uppsala started with proton treatment

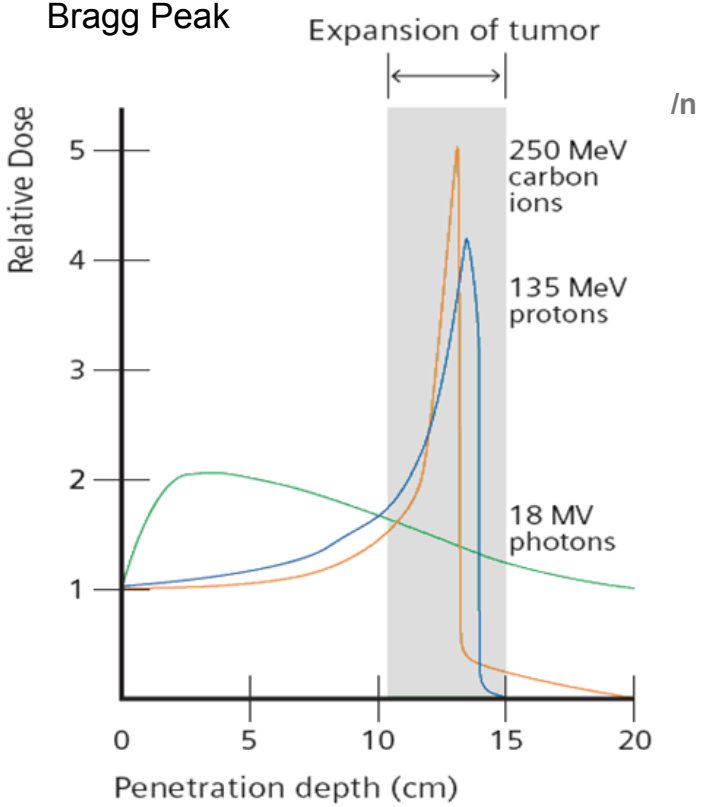
1954 LBL (Lawrence Berkeley Laboratory, USA) started radiotherapy for deep located tumors with protons

1946 R. R. Wilson proposed charged particles (p, ions) for applications in radiotherapy



# Particle Therapy vs. Conventional Radiotherapy with Photons

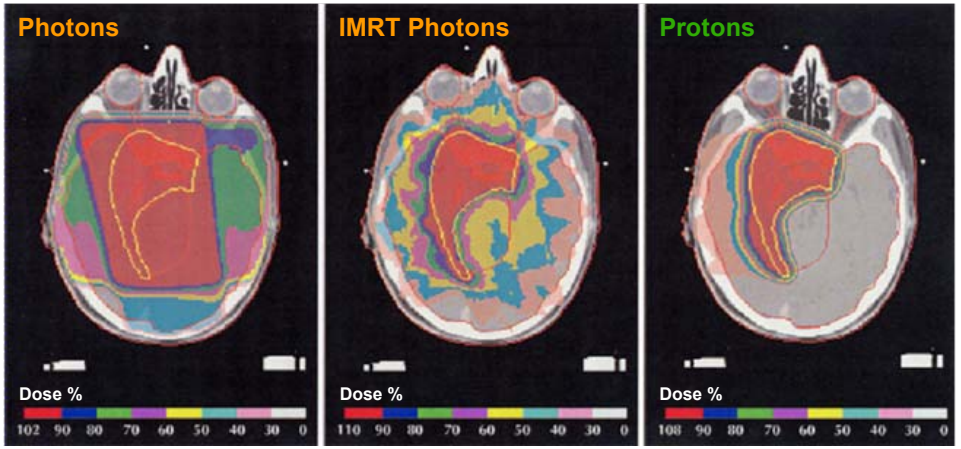
Bragg Peak




/n

Objectives

- Increase of uniformity and
- Reduction of integral dose
  → less adverse side effects, higher quality of life
- Improve local control rate (less recurrent tumors)
- Higher survival rate expected



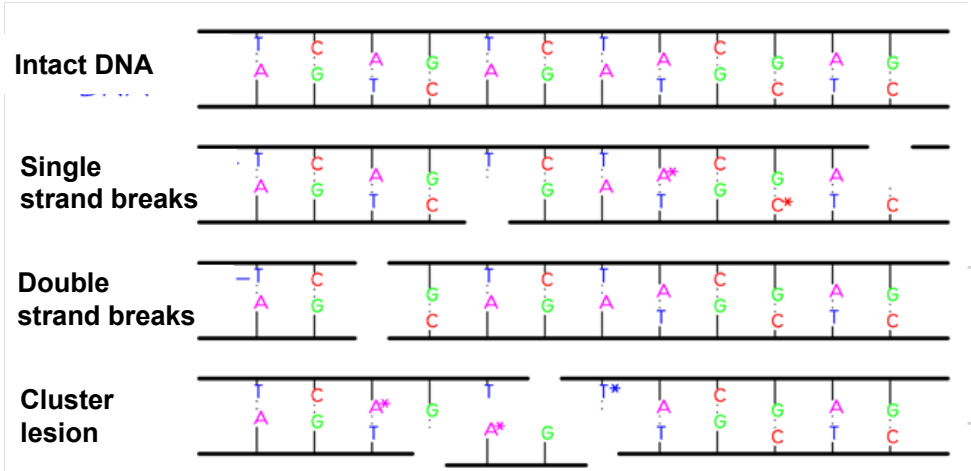

Courtesy of A. Lomax, Paul Scherer Institut, Villigen, Switzerland, - Data on file

## Carbon Ions / Biological Effectiveness

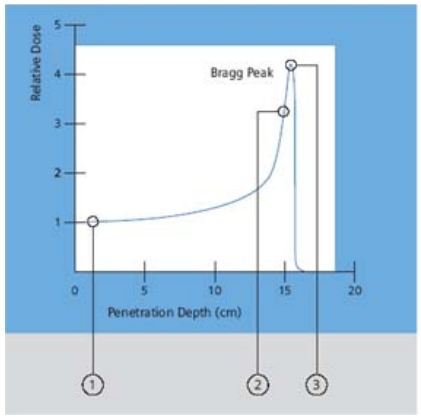
SIEMENS

- Photons and protons produce mainly single strand breaks
- Carbon ions produce also non reparable double strand breaks and clustered DNA damages in the region of the Bragg peak

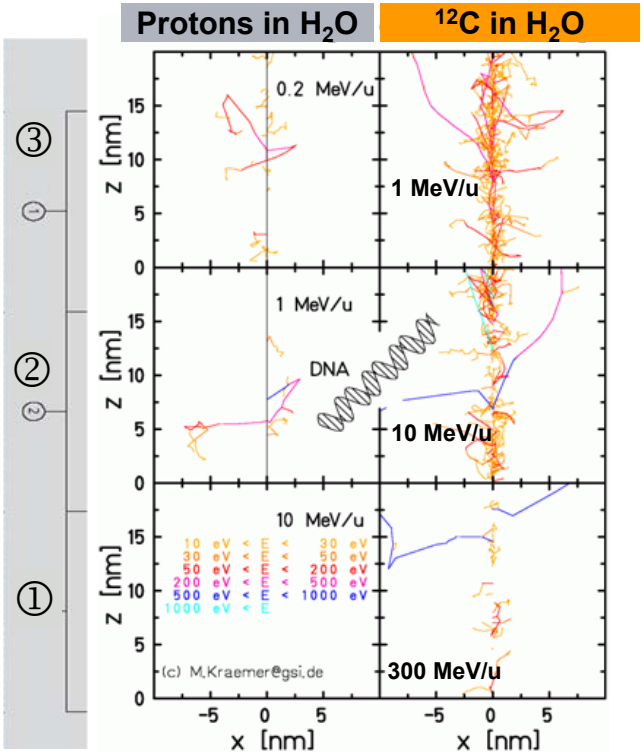
⇨Typical RBE in tumor region: 2 - 4




Courtesy of W. K. Weyrather, GSI, Darmstadt, Germany




Ionization density:
Density of electron-ion pairs along the particle track



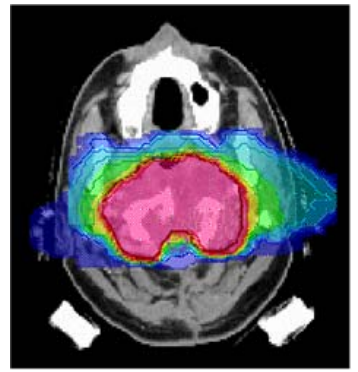

Courtesy of M. Krämer, GSI, Darmstadt, Germany
- Data on file -

## Advantages of Protons and Carbon Ions

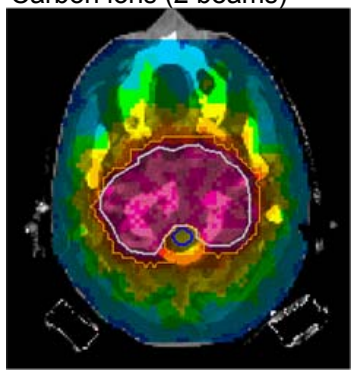
Higher target conformity due to physical characteristics of p and $^{12}C$
- High dose in tumor volume due to inverse dose profile
- Less scattering for $^{12}C$
- Reduced dose in organs at risk and healthy tissue

New applications thanks to the biological characteristics of $^{12}C$
- Radiation resistant tumors
- Slow growing tumors
- Hypoxic tumors

Clinical results
- Low toxicity – low integral dose (p and $^{12}C$)
- Higher tumor control rates, especially for the aforesaid tumors ($^{12}C$)
- Reduction of fractionation scheme possible ($^{12}C$)



Carbon ions (2 beams)



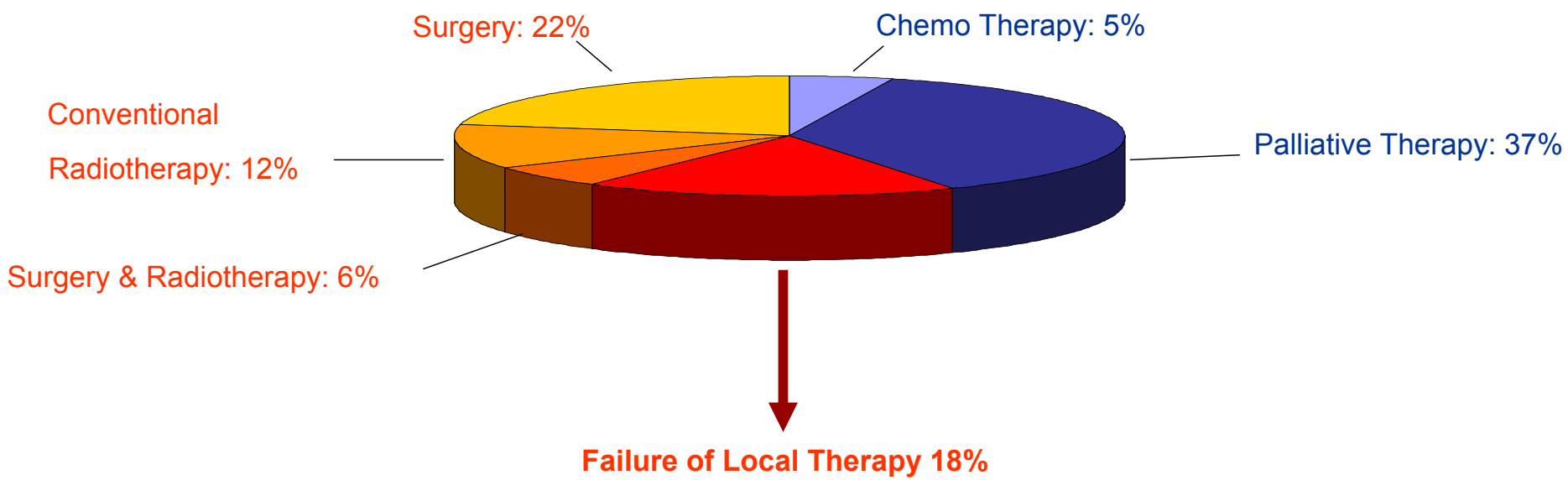
IMRT (9 beams)

Courtesy of the University Hospital, Heidelberg and GSI, Darmstadt

# PT: When “traditional therapy” is not enough

**Localized Tumors: 58%**

**Metastazised Tumors: 42%**




**Failure of Local Therapy 18%**

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## IONTRIS Particle Therapy Solution

## Example: NRoCK, Kiel

Footprint:
6000 m²

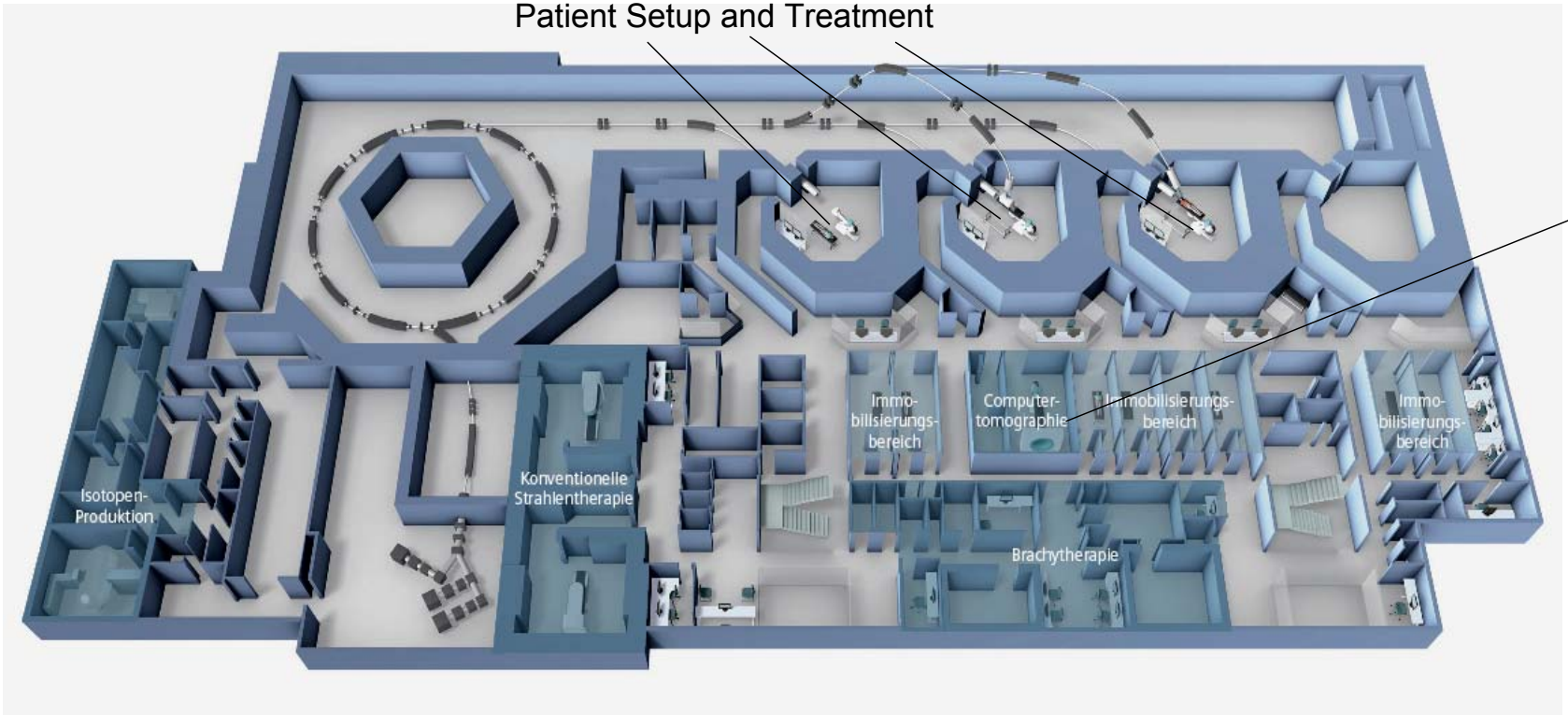
Concrete:
36.000 tons
(>5.000
trucks)

Steel:
5.500 tons

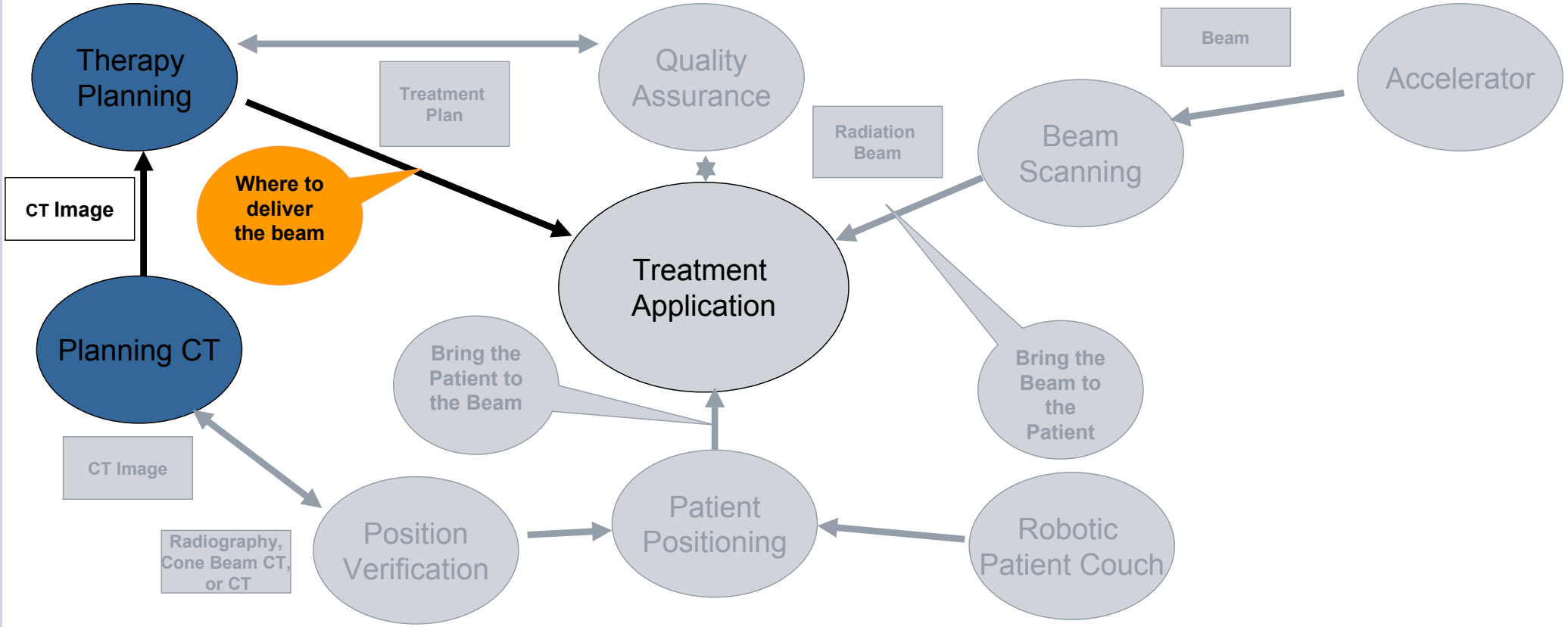
Cables:
more than 40
km

Power:
~ 5MVA

Treatment Rooms:
Patient Setup and Treatment

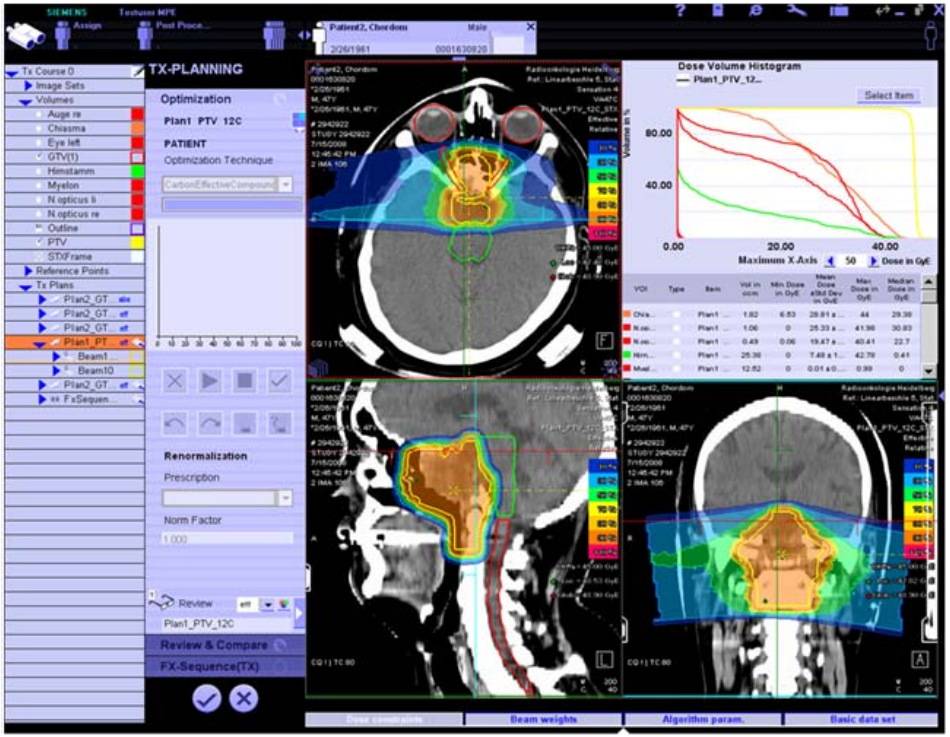



IT Integration:
Complete workflow from diagnostic to treatment planning, position verification and treatment



TPS Features

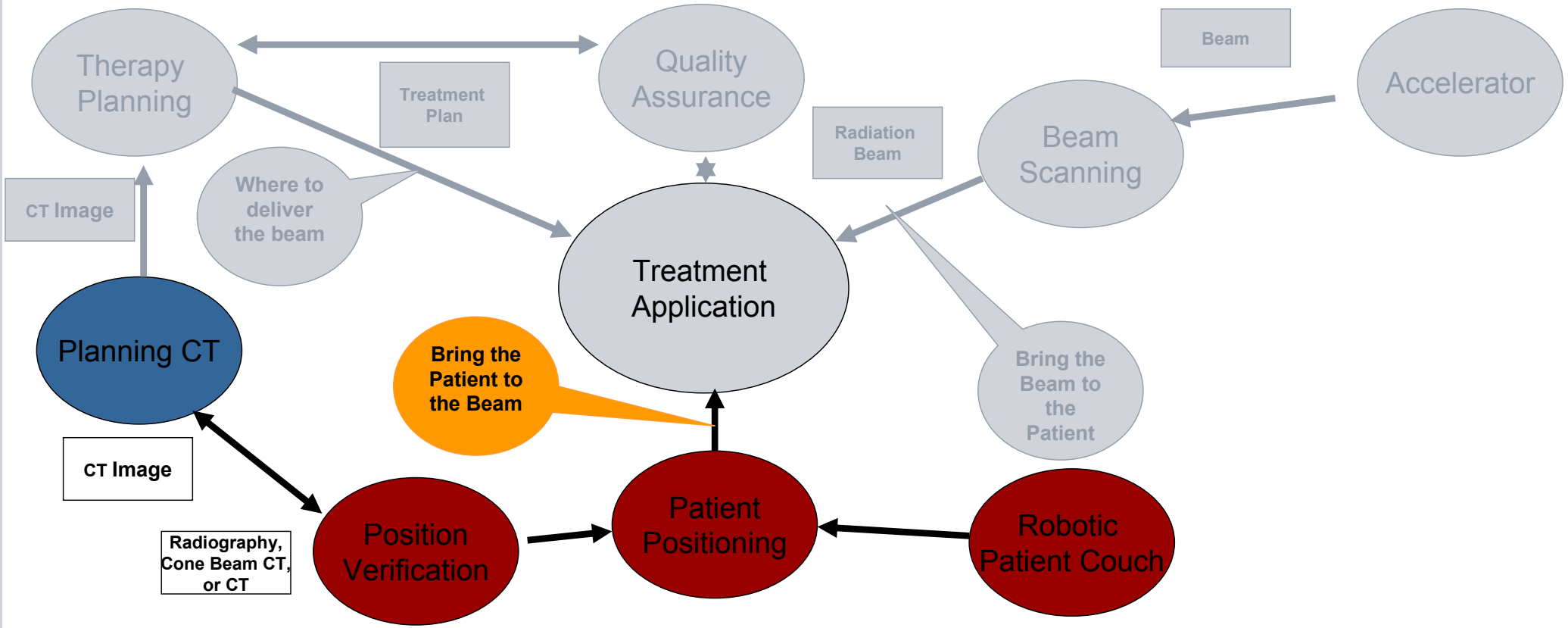
- Protons and carbon ions
- Workflow oriented
- DICOM RT and *syngo*® based (CE certified)
- Implementation of
  - LEM / TRiP for carbon ions (Cooperation GSI)
  - 2D pencil beam algorithm for protons (Cooperation DKFZ)




**Patient (Clivus Chordoma) - $^{12}$C Plan**
Courtesy HIT – SAG Session Jan 2009

# IONTRIS Particle Therapy Solution

## Patient Handling

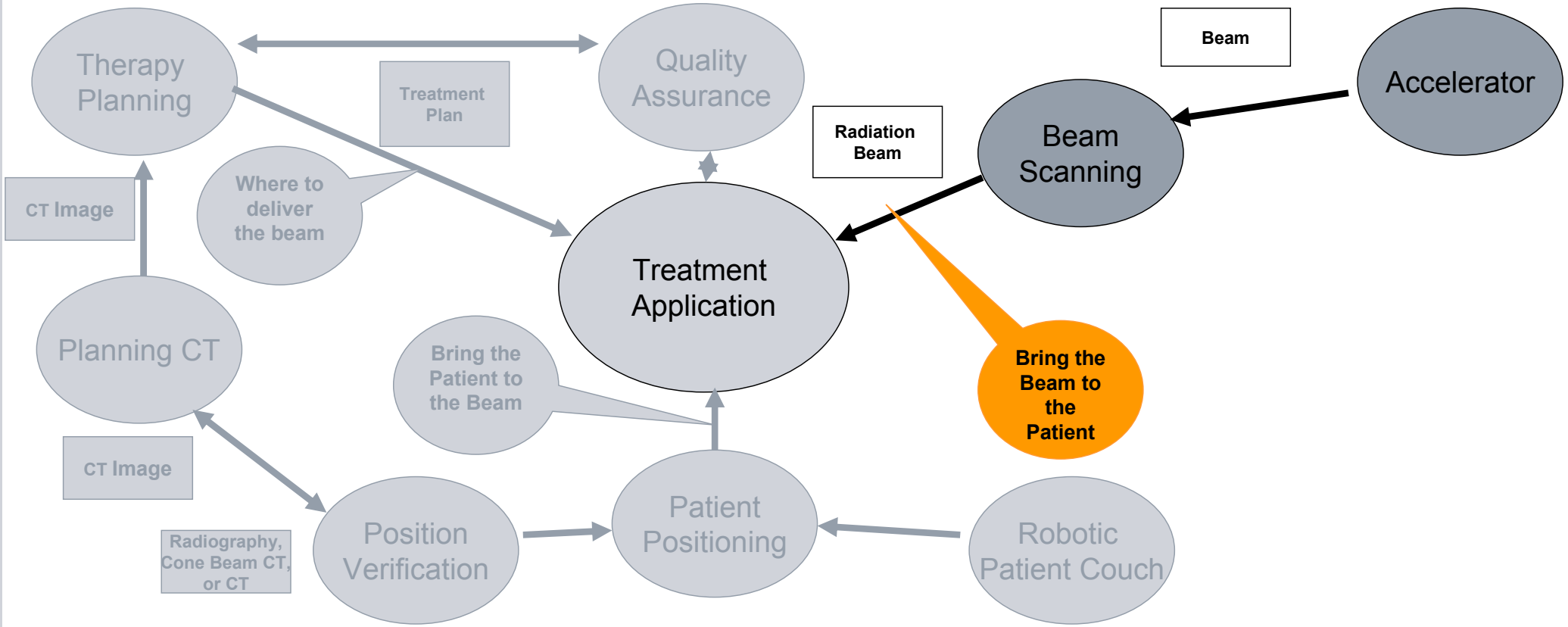


## Patient Handling: Robotic Systems

- Robotic patient positioning system
  - Identical in treatment and CT rooms
  - Position correction in 6 degrees of freedom (including roll & pitch)
  - High position accuracy independent from patient weight (carbon fiber boards)
- Workflow optimization
  - positioning according to treatment plan
- Robotic imaging system
  - Orthogonal x-ray and Cone beam CT
  - Position verification in every treatment position
  - High position accuracy in imaging position

# IONTRIS Particle Therapy Solution

## Accelerator



## Accelerator Key Parameters: Medical Beams

| Parameter | Protons | Carbon Ions | # |
|---|---|---|---|
| Energy<br>Range (2-30 cm) | ~50-250 MeV<br>1 mm steps | ~88-430 MeV/u<br>1 mm steps | ~300 |
| Max Intensity | $2\text{-}4 \cdot 10^{10}$ / Spill | $1 \cdot 10^{9}$ / Spill | |
| Intensity<br>Variation | 0.01 … 1<br>15 steps | 0.01 … 1<br>15 steps | 15 |
| Pencil Beam Width | 5 steps | 5 steps | 5 |
| Beam Lines | 4-5 | 4-5 | 4-5 |

Combinations/Beam Line: 45000

Medical Operating Mode

- Accelerator Control System acts as slave to the Treatment Control System
- Predefined beams are requested from a library according to treatment plan
- Model of Accelerator implemented in Control System

## Accelerator Development

In 2003 when PT started: Siemens was not known as an accelerator provider!

Strategy:

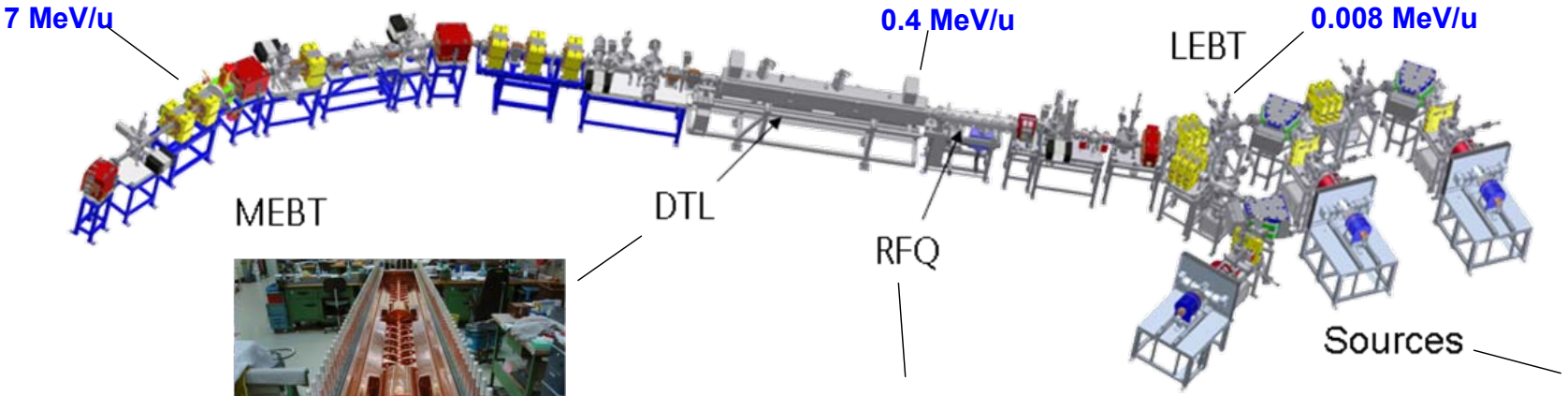
- Build an in-house core development team
- Technology-Transfer Contract with GSI: Access to
  - Accelerator Design for Heidelberg HIT Project
  - Experience from GSI Carbon Therapy Pilot Project
- Strong Industrial Partner with Accelerator Background
  - Danfysik AS, in 2008 major parts acquired by Siemens → part of Siemens AS, Denmark
- External Consultants

→ Design of the IONTRIS Accelerator System derived from the GSI design from HIT

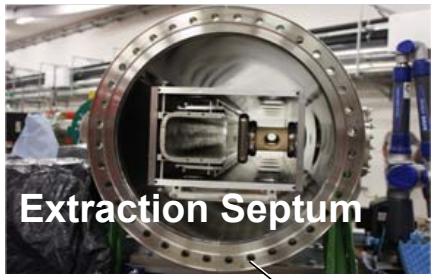
- New synchrotron lattice and HEBT layout, new Synchrotron RF cavity
- Same Ion Sources, Linac Design and Control System

# IONTRIS Particle Therapy Solution

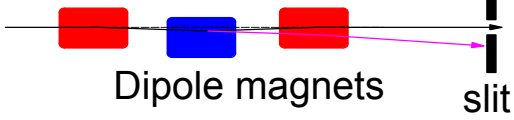
## Injector

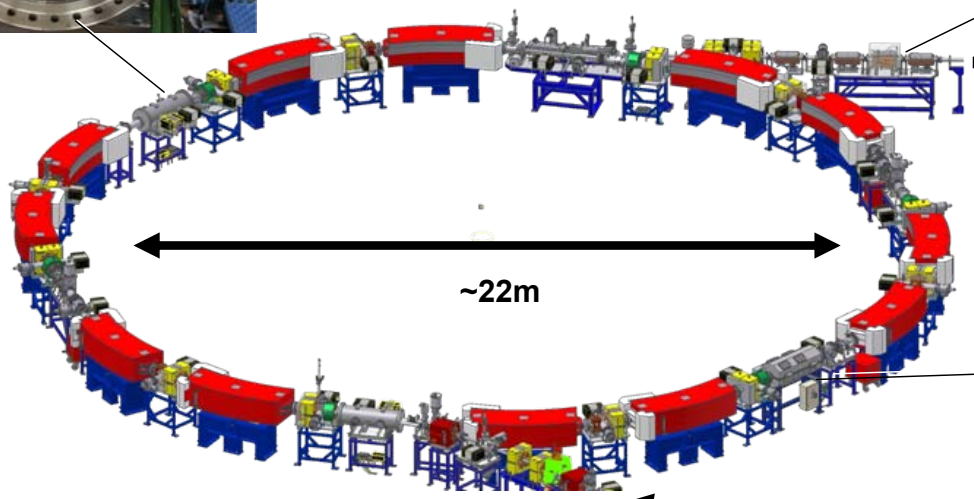



Courtesy: Pantechnic



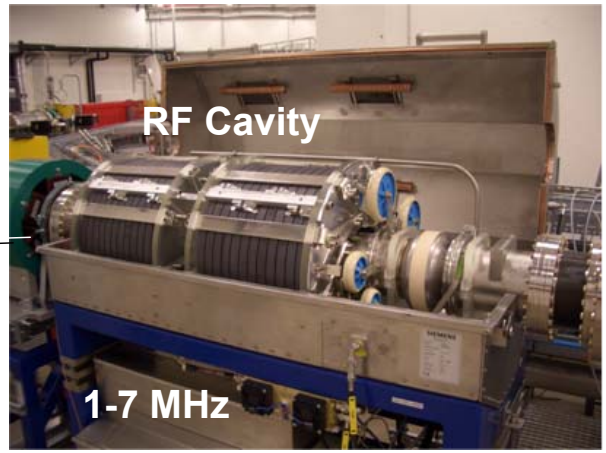

Magnetic Chicane: shutoff < 200 µs




*To Patient*

*From Injector*

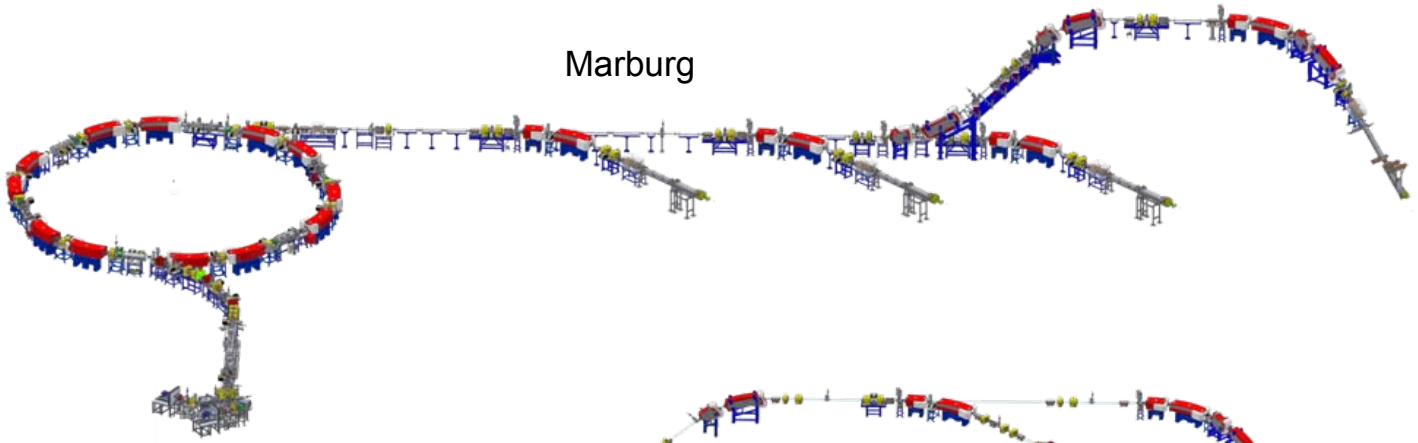


IONTRIS is a Product

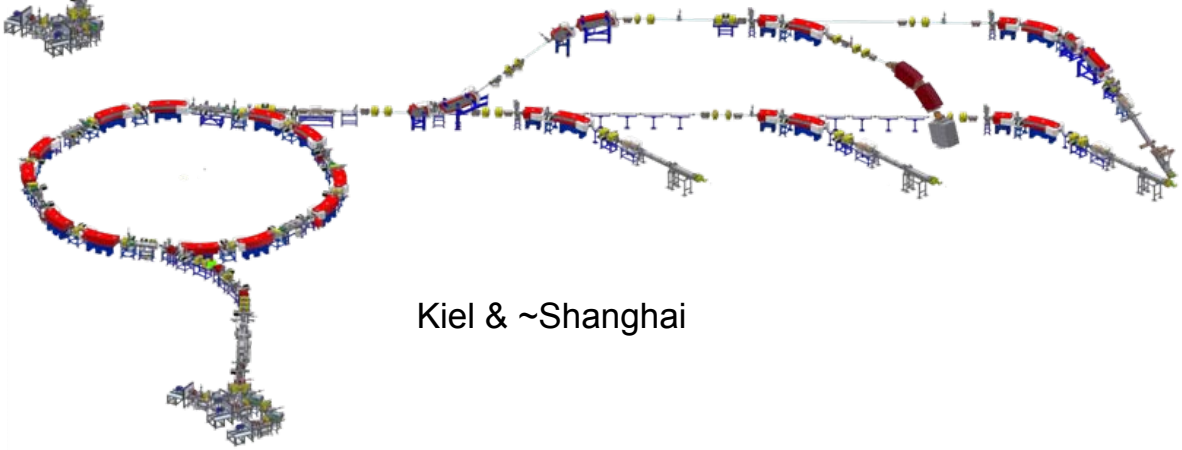
….but….

with project specific Variations!

Marburg

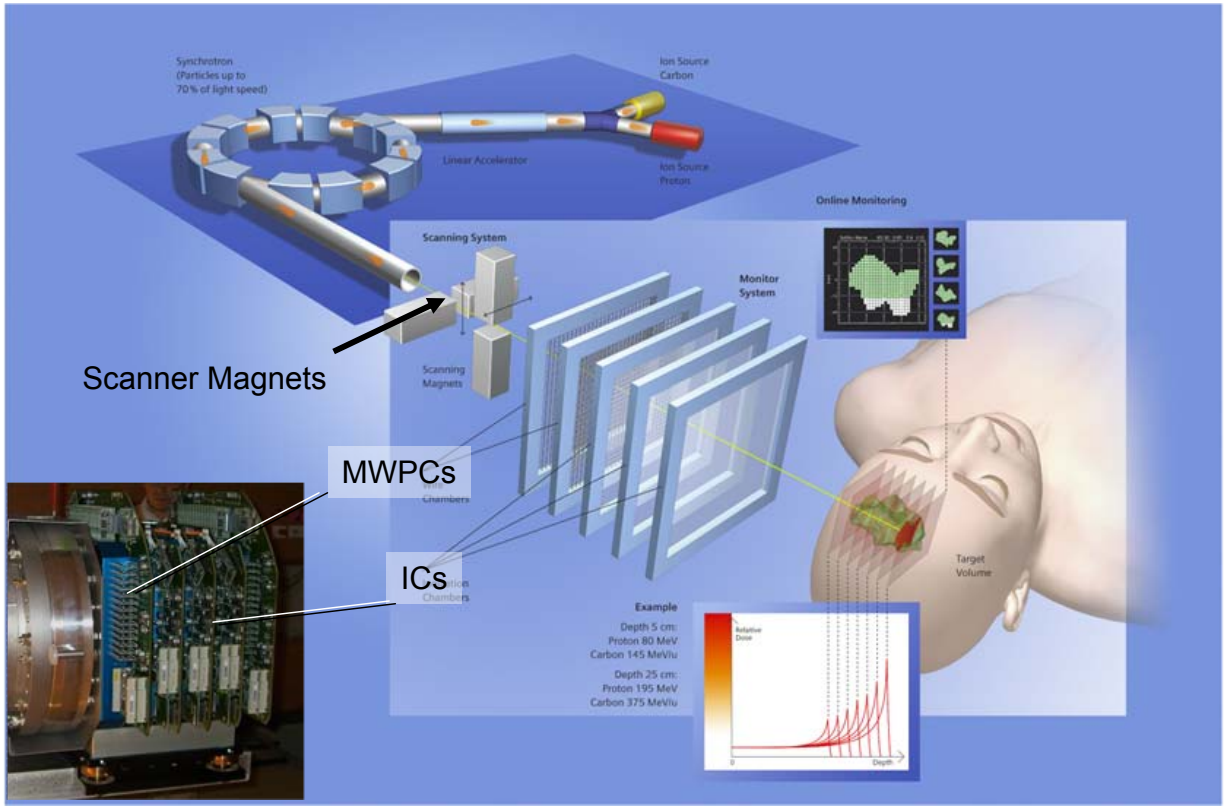


Kiel & ~Shanghai

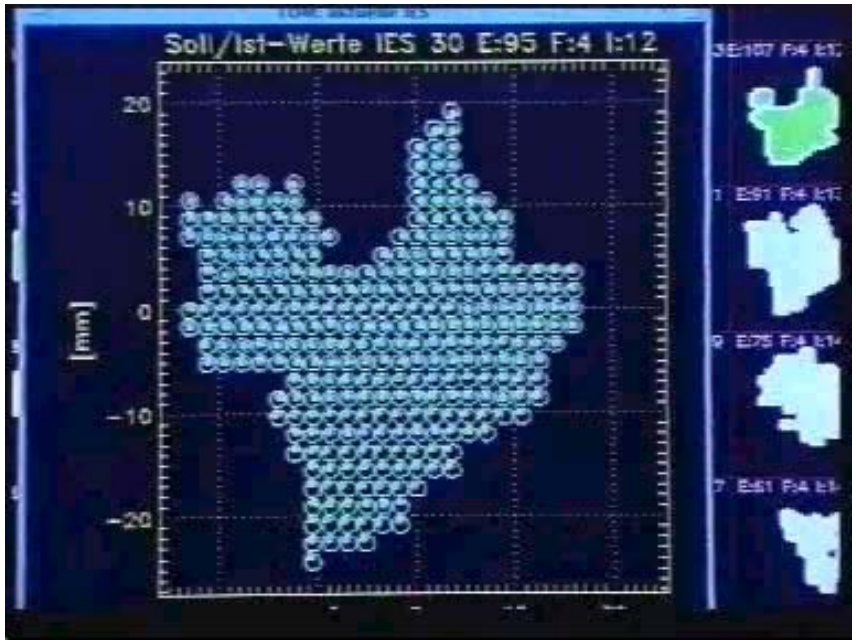


# IONTRIS Particle Therapy Solution

## Raster Scanning

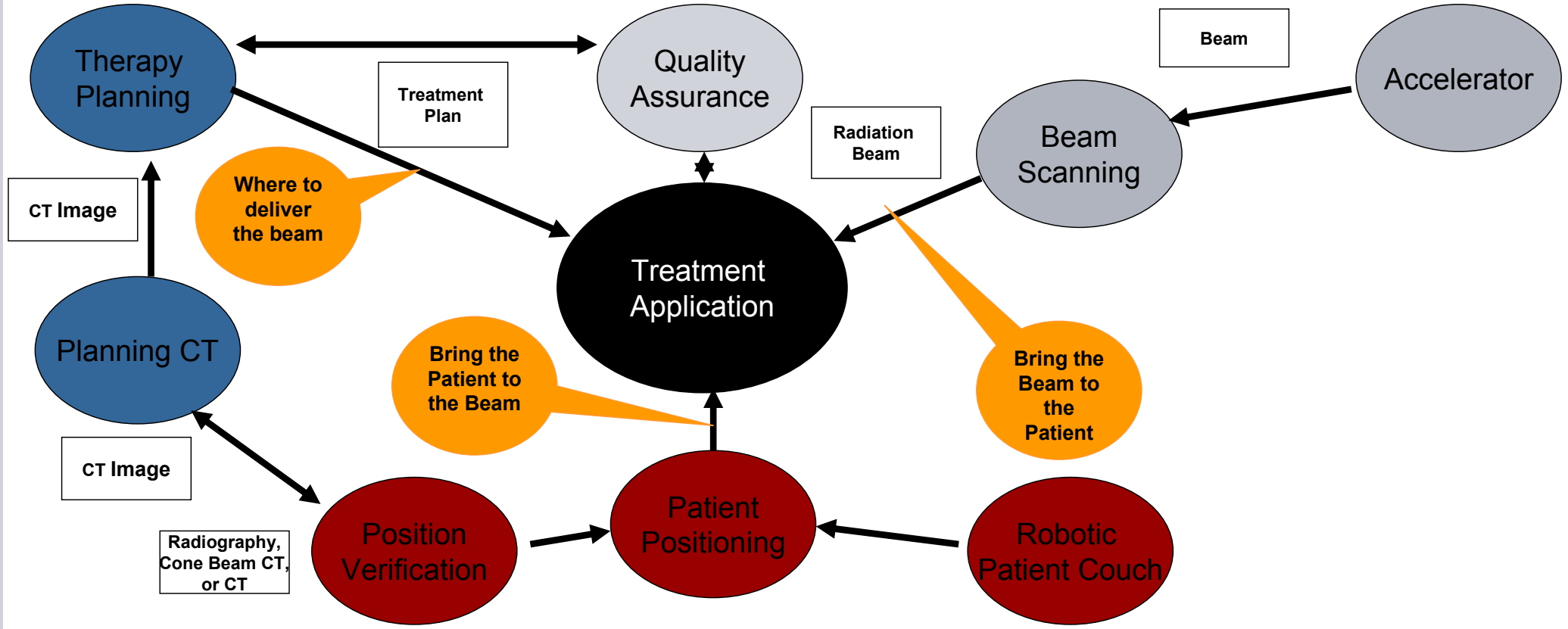



Courtesy of GSI



## IONTRIS Particle Therapy Solution

### The Whole Picture



## IONTRIS Particle Therapy Solution

## Where it comes together: Treatment Rooms

SIEMENS

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## Projects

## Past and Present

1 HIT Heidelberg University, Germany
Provide medical devices, workflow, treatment planning, and patient environment

2 PTZ Marburg University, Rhön Clinic, Germany

Provide turn-key solution for carbon and proton ion therapy

3 CNAO, Pavia, Italy
Provide treatment planning

4 NRoCK Kiel, University of Schleswig-Holstein, Germany

Comprehensive cancer center comprising Particle Therapy, conventional radiotherapy, brachytherapy and isotope production.

5 Shanghai Proton and Heavy Ion Hospital, China
Provide turn-key solution for carbon and proton ion therapy

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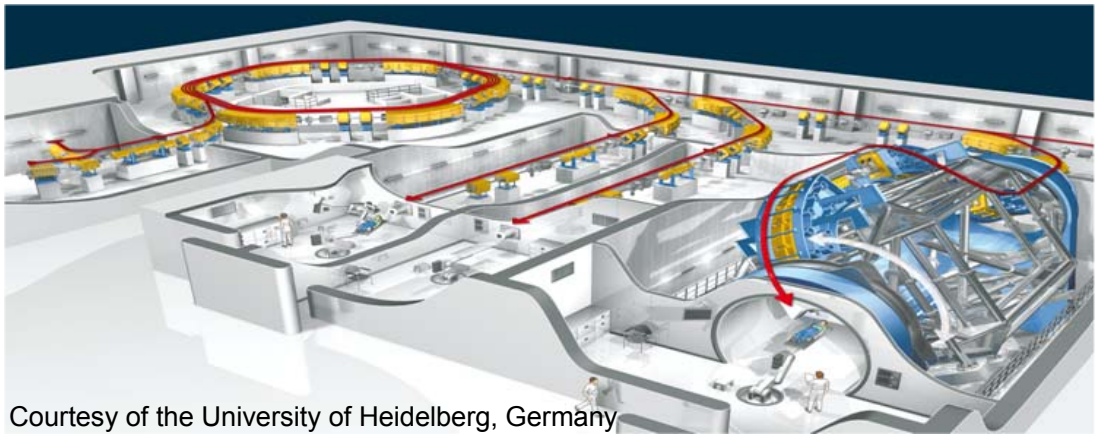
## University of Heidelberg - HIT

## Patient Environment



Courtesy of the University of Heidelberg, Germany

Accelerator system designed and delivered by GSI Gesellschaft für Schwerionenforschung mbH, Darmstadt

Patient treatment started Nov 2009 –
To date ~ 300 people have undergone treatment

Siemens supplied all components related to patient environment:

- Scanning and monitoring system
- Robotic patient positioner
- Imaging system (2D x-ray and CB CT)
- Therapy control system (TCS)
- Collaboration on TPS *syngo* ® PT planning

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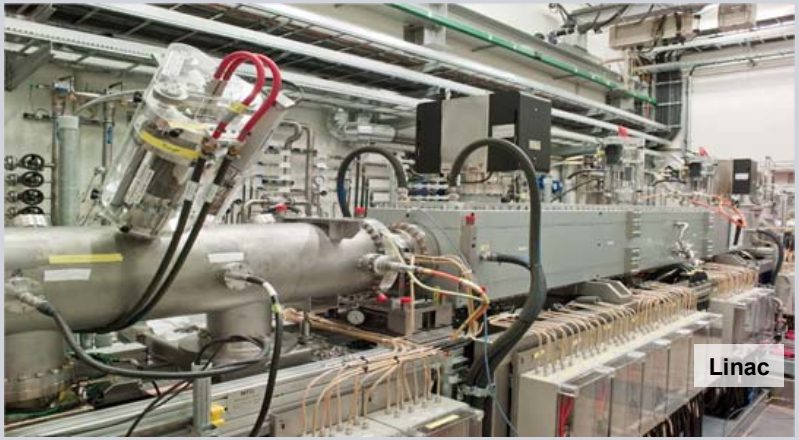
## University of Marburg / Giessen – Rhön Klinikum AG

## Photos


Sources and LEBT

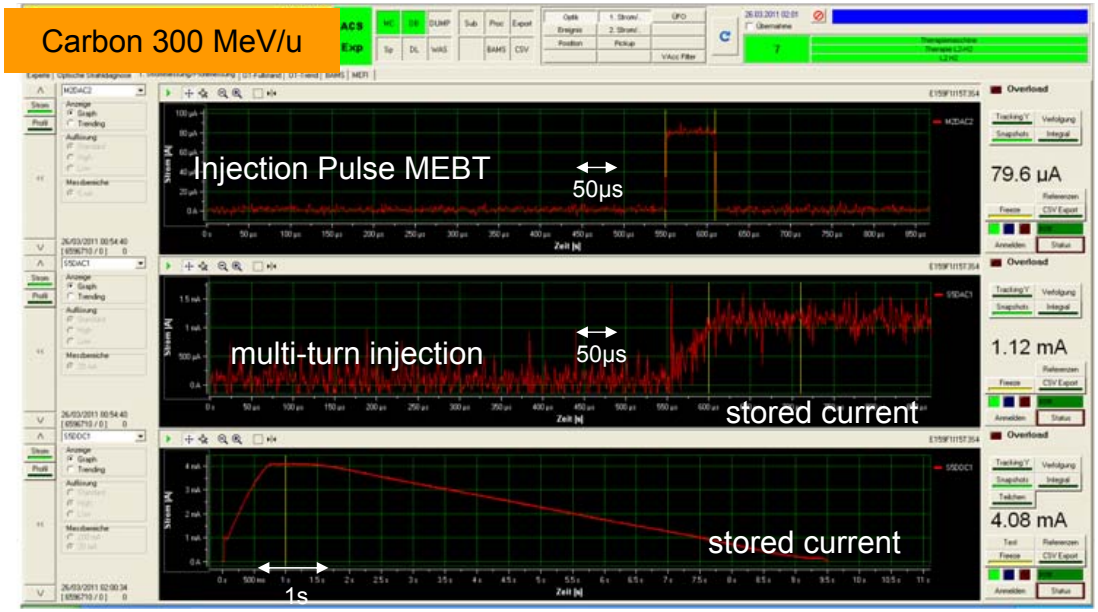

Linac


Synchrotron

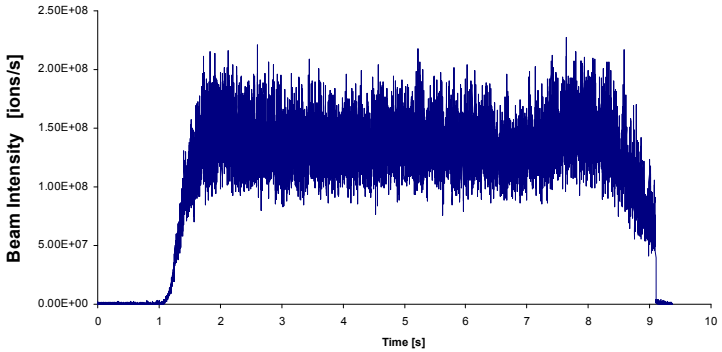

HEBT

## Injection, Acceleration and Extraction Control

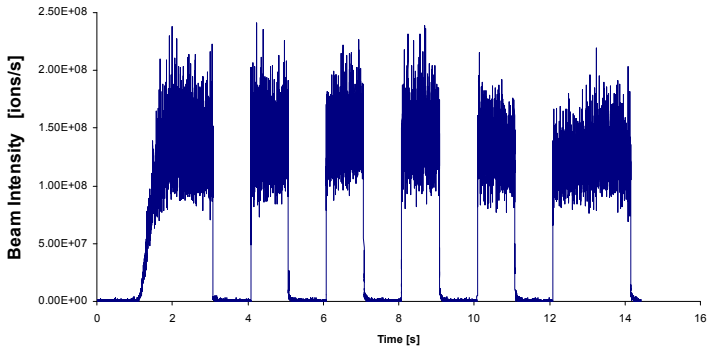
- Multiturn-Injection Scheme
- Slow Extraction Scheme with smooth spill profile
- Fast pausing and resuming extraction
  - Beam Gating (Breathing Motion)




**Time resolved intensity variation of a spill**

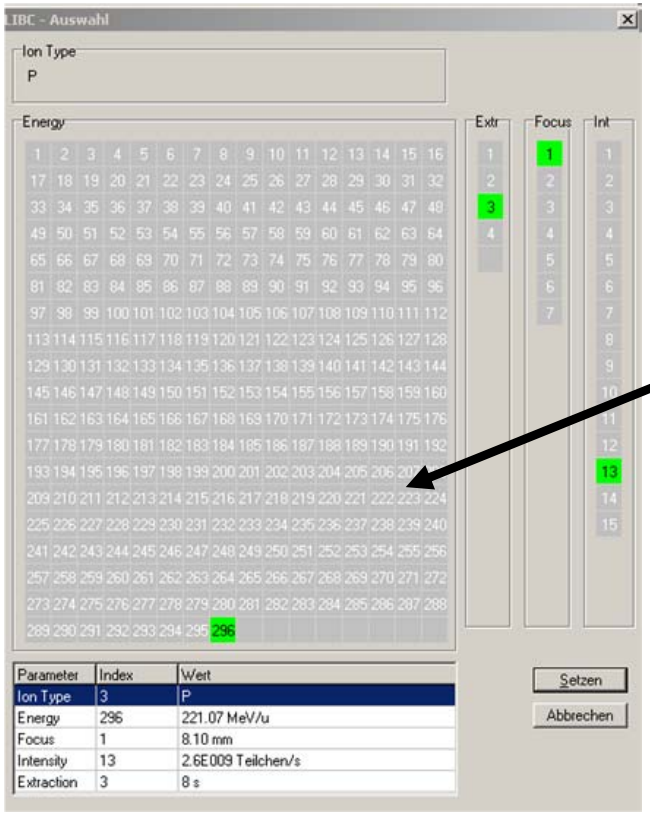



**Time resolved intensity variation of multiple spill pauses**



# Commissioning Status

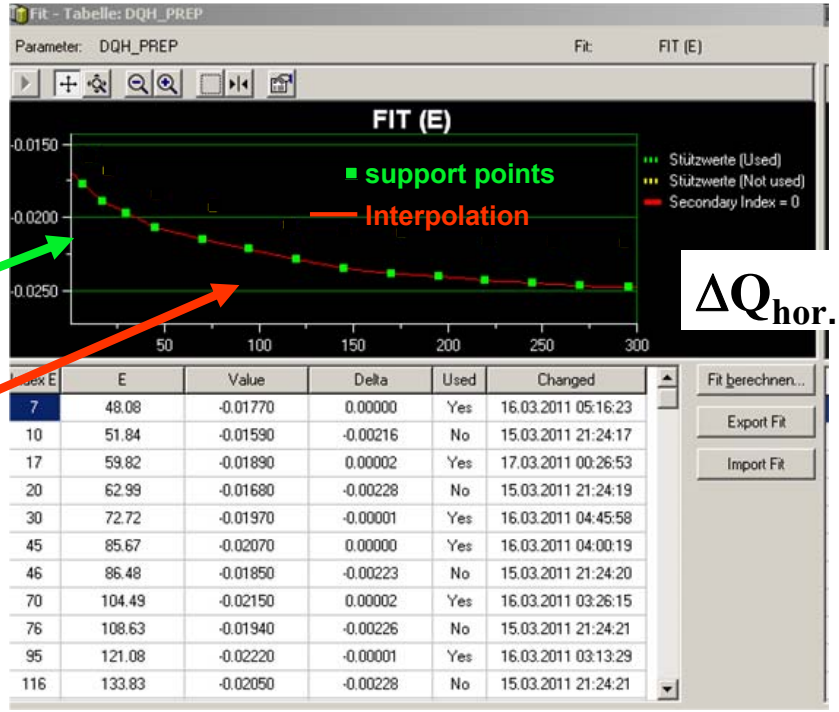
## Interpolation of steps




Commissioning of Beam Library

- Define strategy
  - E.g. what is const
  - What “knobs” to touch
- Fine-tune some beams
- Interpolate in between

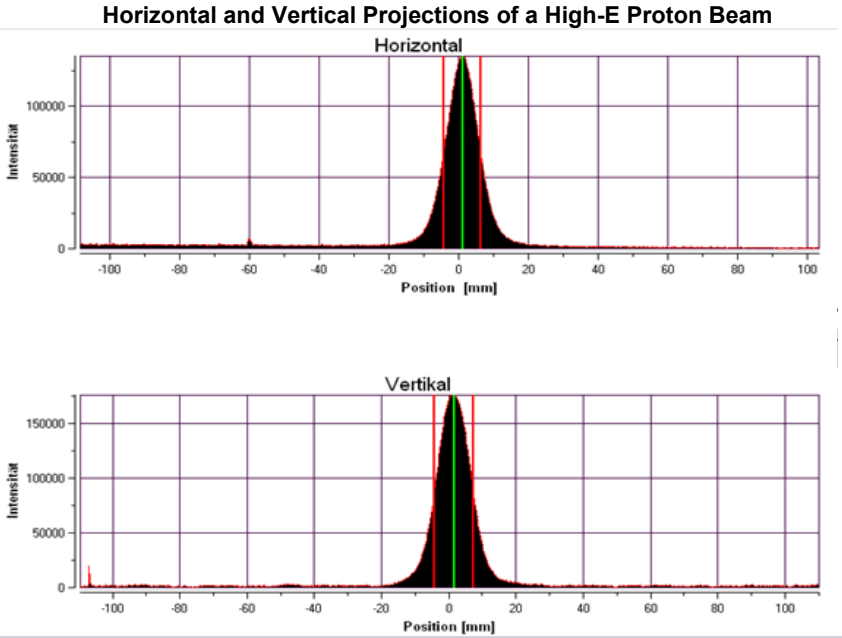
Example: horizontal tune shift prior to extraction



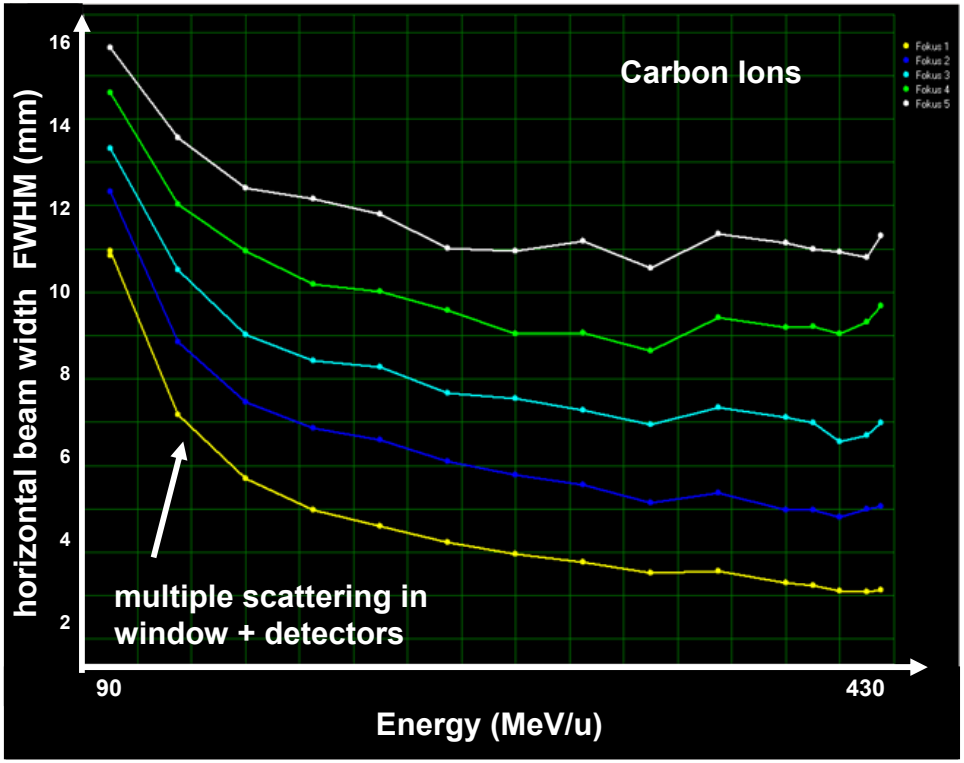
## Interpolation of steps

Example: Beam width at the isocenter

- Excellent reproducibility
- All foci (5), energies (~300), intensities (15) commissioned

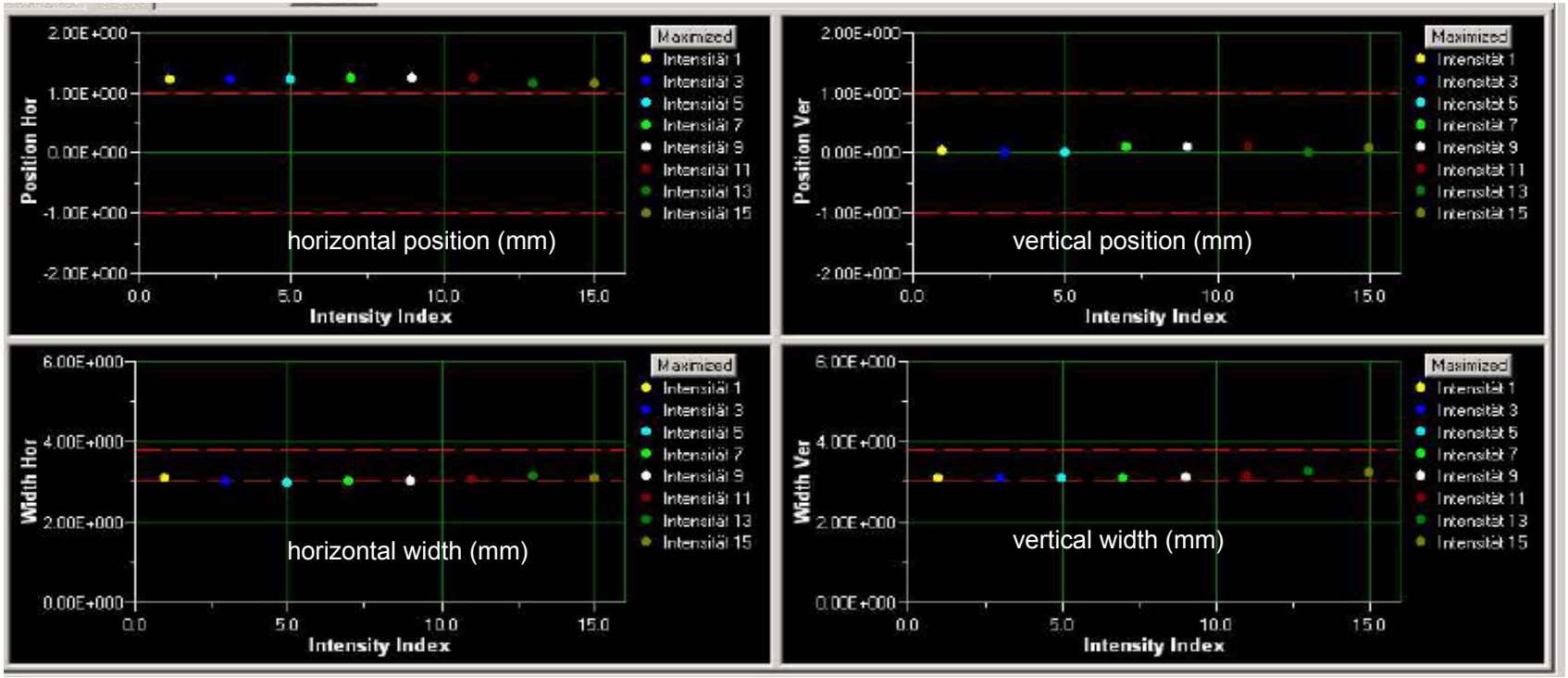



Scan of all foci over all E from available treatment beam library



## Commissioning Status

## Carbon beam properties vs. Intensity




intensity

$1x10^7$……$1x10^9$ particles/spill

## Commissioning Status

## System Integration

Example:
intensity modulated 2D raster-scan of arbitrary shapes

Status:

- Accelerator commissioning practically complete
- Formal testing ongoing, e.g. System Integration
- Final parameterization of the treatment delivery system ongoing

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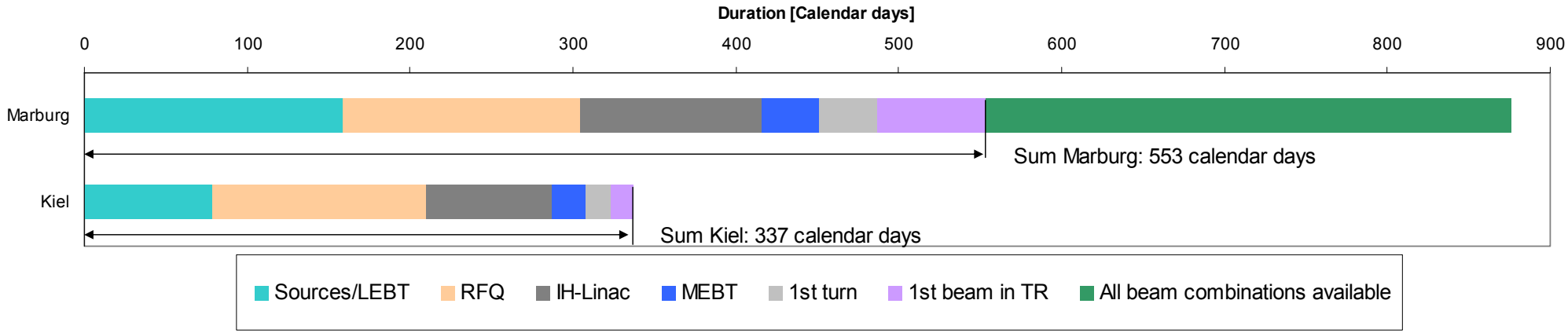
# North European Radiooncological Center Kiel - NRoCK

## Integrated Cancer Treatment Hospital


- Cancer treatment center with PT integrated as a department
- Patient care facilities
- Standard Treatment Options
  - Conventional Radiotherapy
  - Brachytherapie
  - PET Isotope production

# Project Duration Comparison

## Marburg vs. Kiel



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## Shanghai Proton & Heavy Ion Hospital (ShaPHIH)

上海质子和重离子医院项目

# Shanghai Proton & Heavy Ion Hospital (ShaPHIH)

上海质子和重离子医院项目

SIEMENS


Date: 14 Jan. 2011

Level 4 in construction.

Synchrotron area completed.

January | February | March | April | May | June | July

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## Summary

- Proton and Carbon ions offer new advantageous treatment modalities
- IONTRIS: fully-integrated solution for particle therapy
- PTZ Marburg: Full treatment beam library available for treatment delivery. Beam tests ongoing
- NRoCK KIEL: First beam in treatment room. Work progressing to commission beams
- ShaPhiP Shanghai: Shipments on schedule, building nearing completion.
- Build on knowledge from 4+ projects