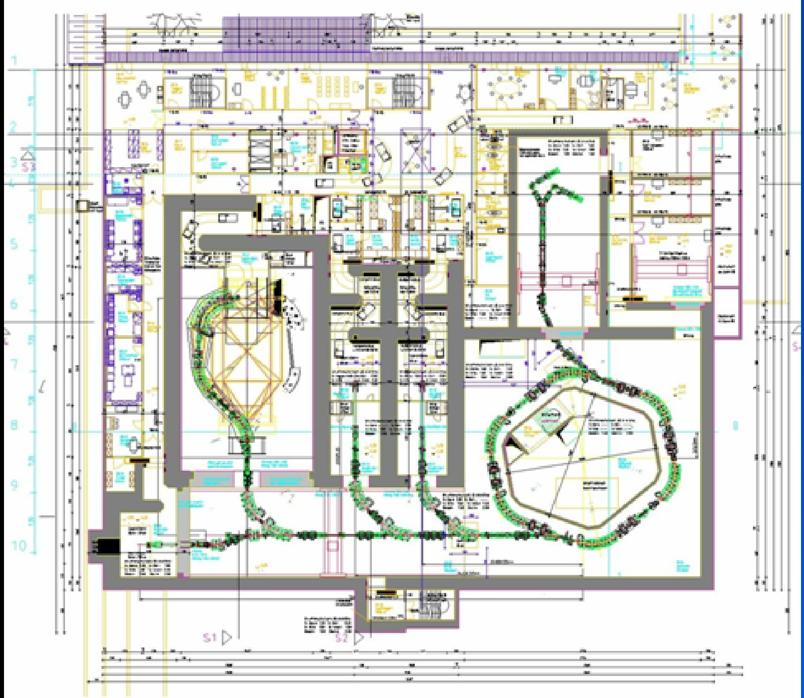
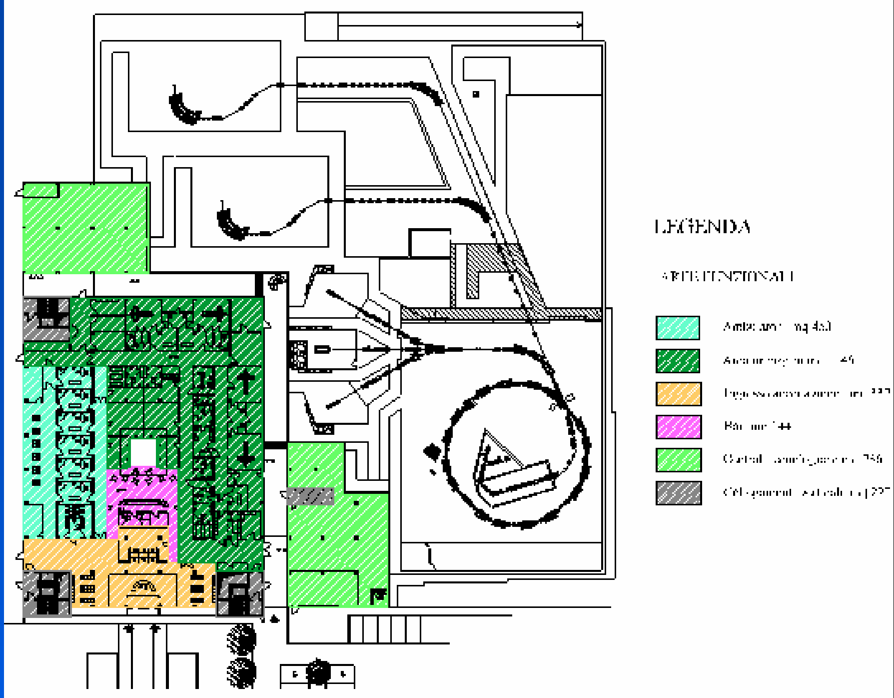




Status of the Hadron Therapy Centers at Heidelberg (HIT) and Pavia (CNAO)

Thomas Haberer

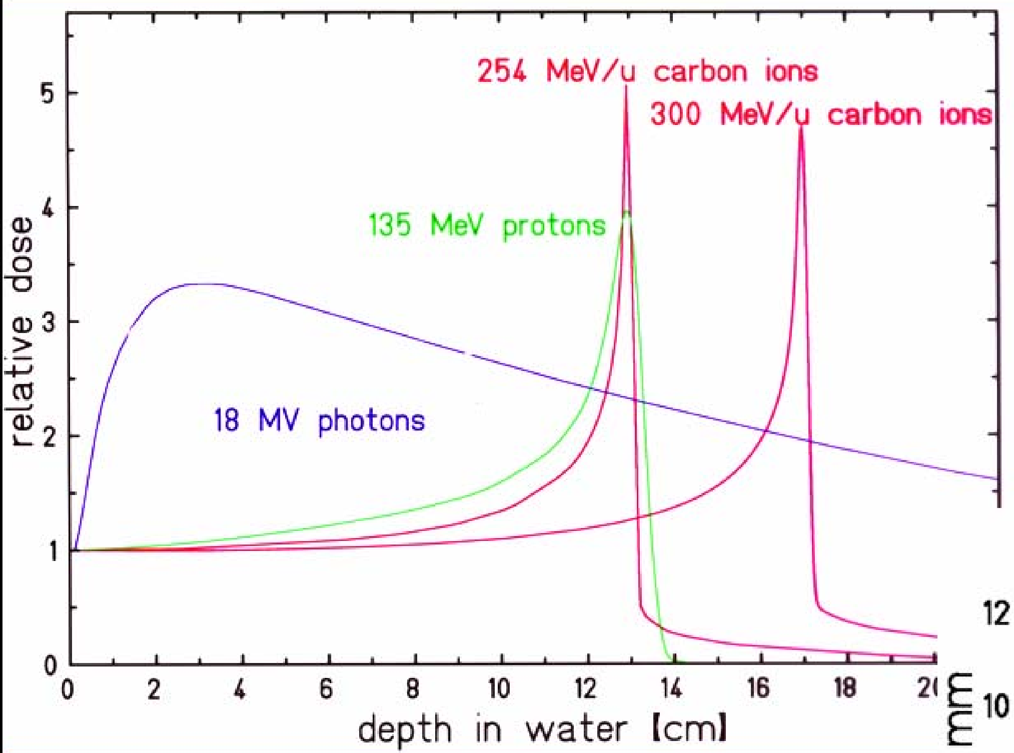
Heidelberg Ion Therapy Center

Outline

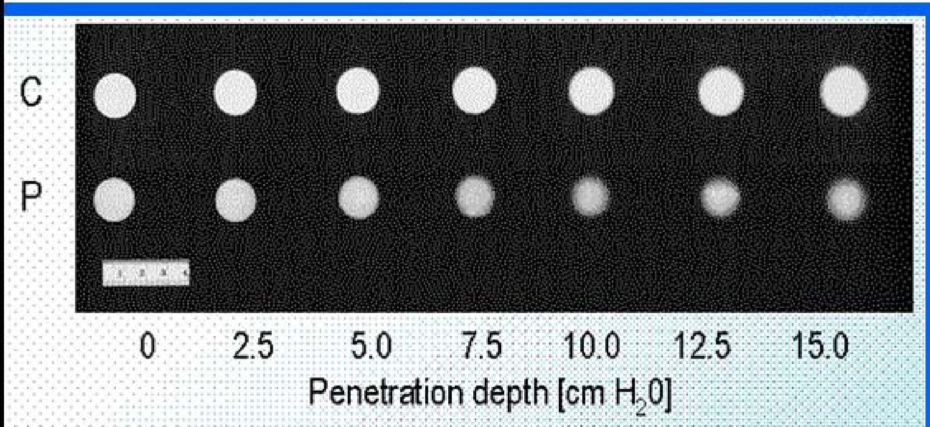
- Rationale
- Standard approach
- Advanced approach
- GSI pilot project
- HIT
- CNAO
- Outlook

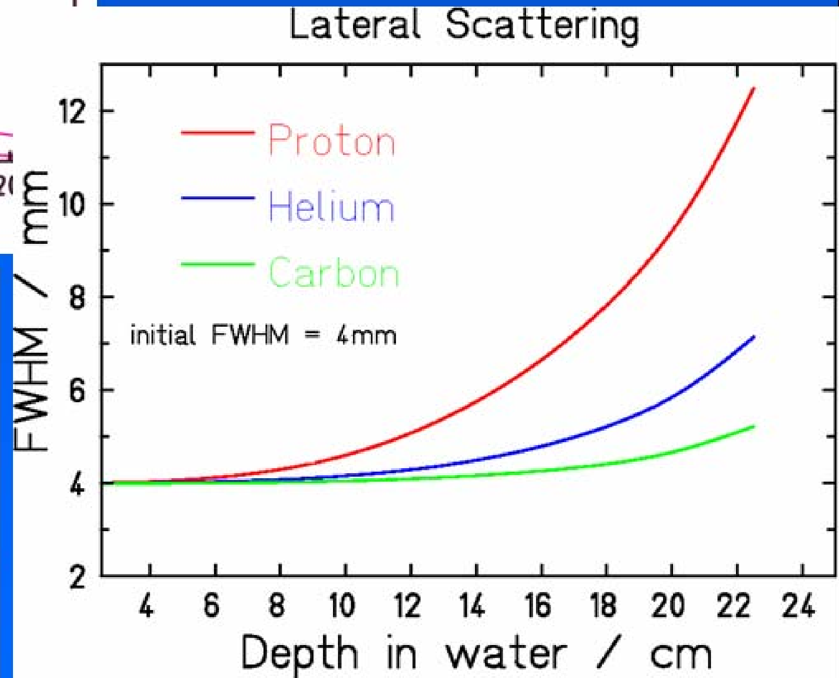
Heidelberg Ionenstrahl-Therapie Centrum

Rationale / Physics



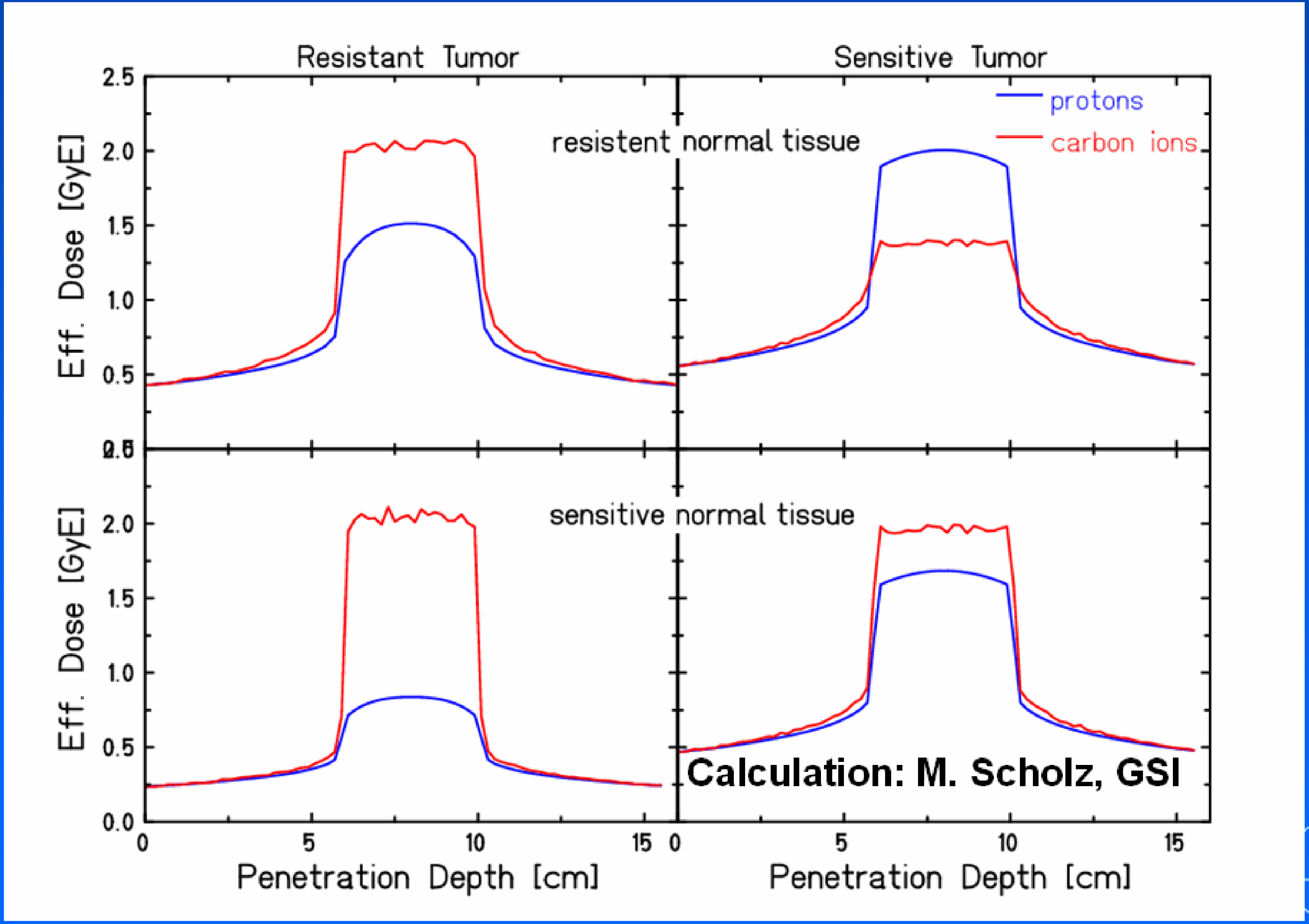
- inverted depth-dose distribution
- mild lateral scattering





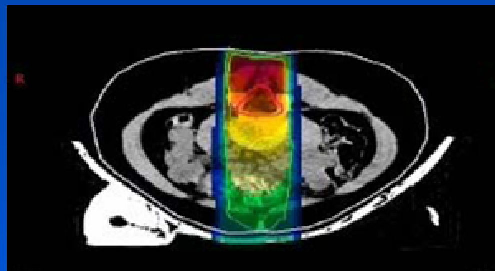
Rationale / Radiobiology

different ions and tissues

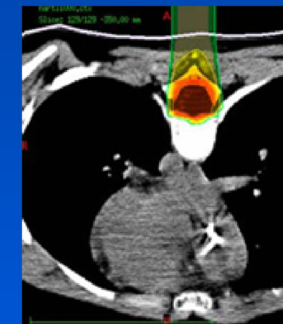


Medulloblastoma

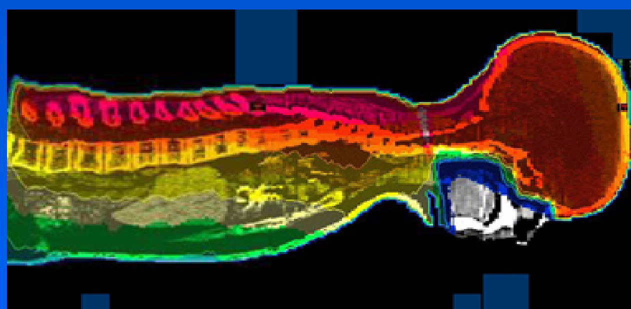
conventional

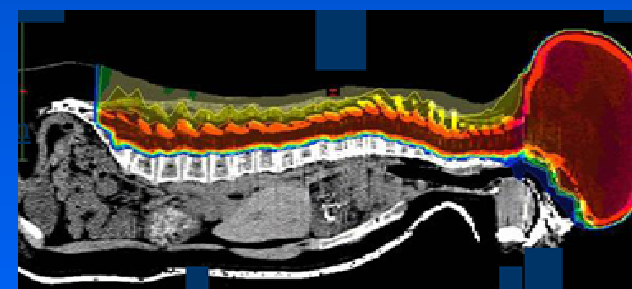


charged particles



Target dose 32 Gy/GyE





Dose comparison

22 Gy	bone marrow	< 1 GyE
18 Gy	heart	<.5 GyE
20 Gy	intestinal	<.5 GyE

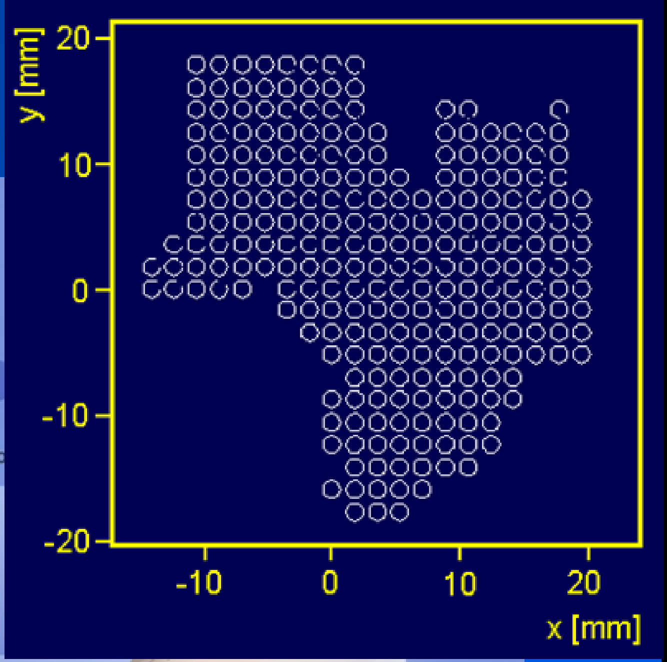
Dose Delivery Concept @ GSI/HIT

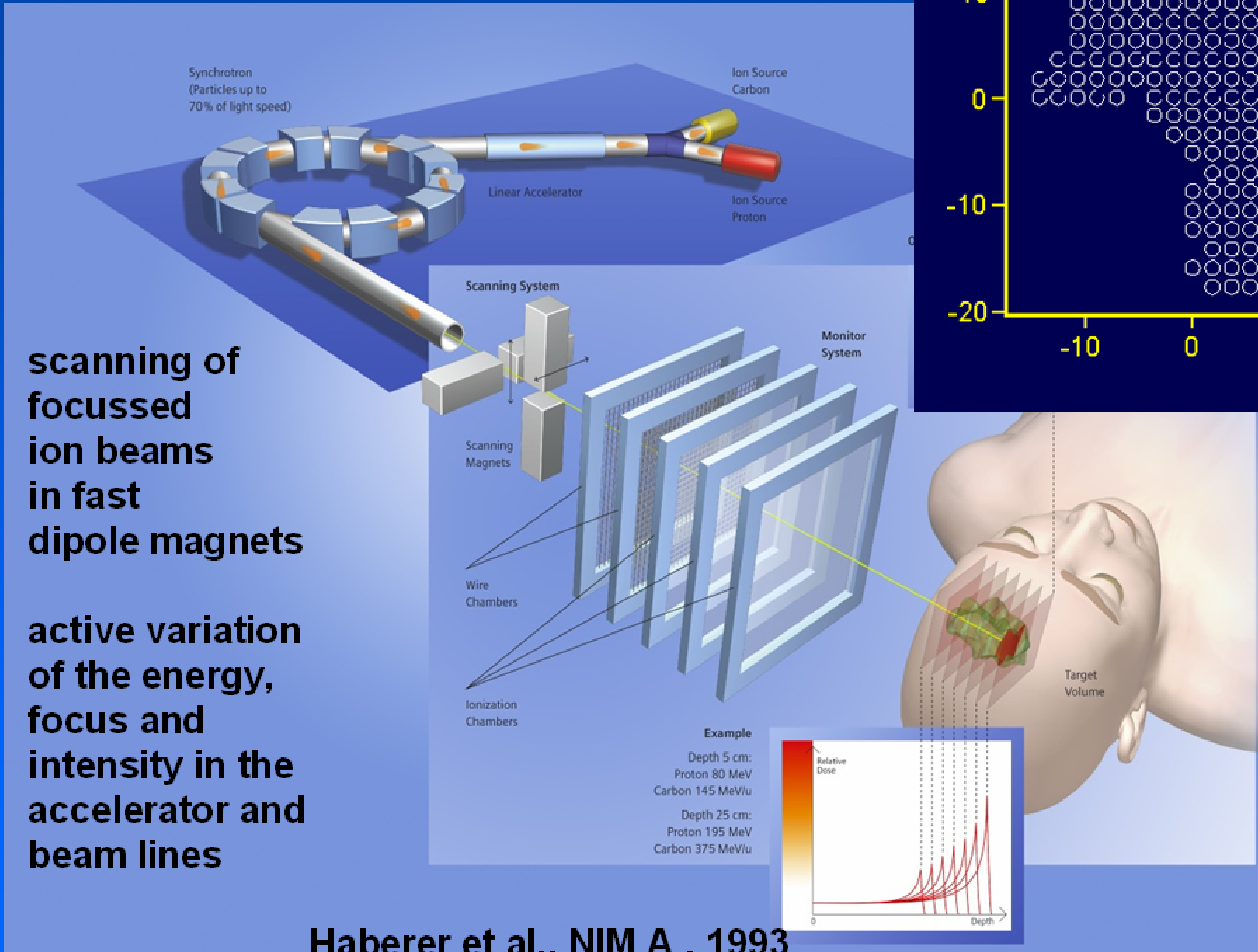
Idea:
Dose distributions of utmost tumor conformity can be produced by superimposing many thousands Bragg-peaks in 3D.
Sophisticated requirements concerning the beam delivery system, the accelerator, the treatment planning, QA, … result from this approach.

Realization:
Dissect the treatment volume into thousands of voxels. Use small pencil beams with a spatial resolution of a few mm to fill each voxel with a pre-calculated amount of stopping particles taking into account the underlying physical and biological interactions.

⇒ **Extreme intensity modulation via rasterscanning**

Rasterscan Method





scanning of
focussed
ion beams
in fast
dipole magnets

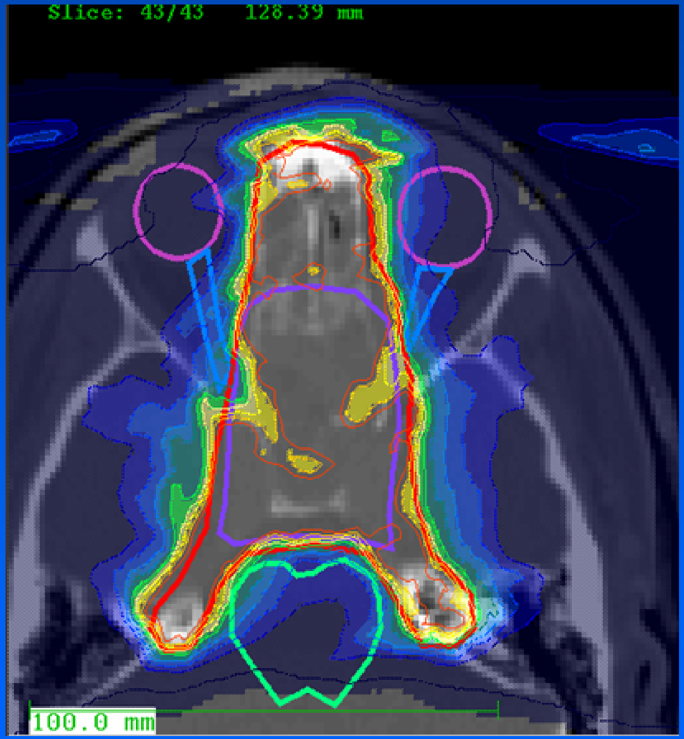
active variation
of the energy,
focus and
intensity in the
accelerator and
beam lines

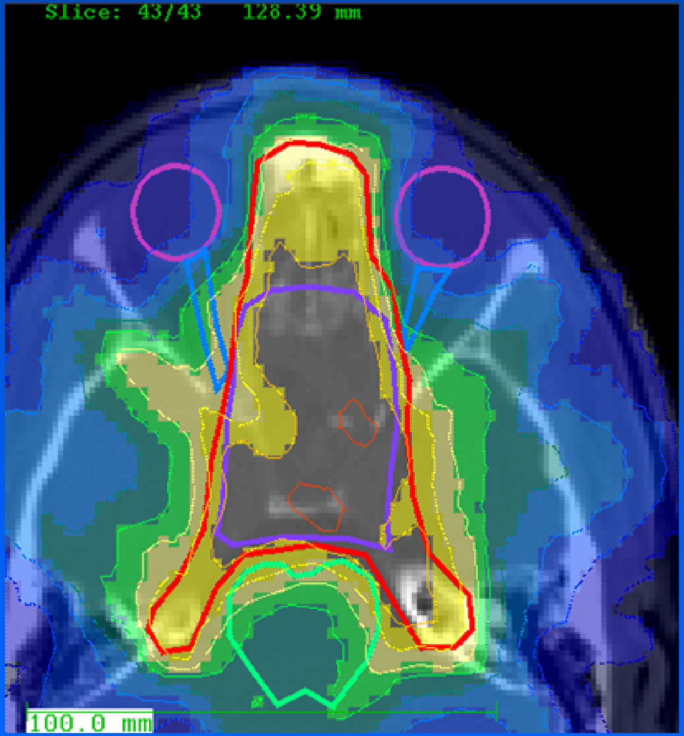
Haberer et al., NIM A , 1993

Scanned Carbon vs. Intensity Modulated Photons

scanned carbon
3 fields

intensity modulated photons
9 fields



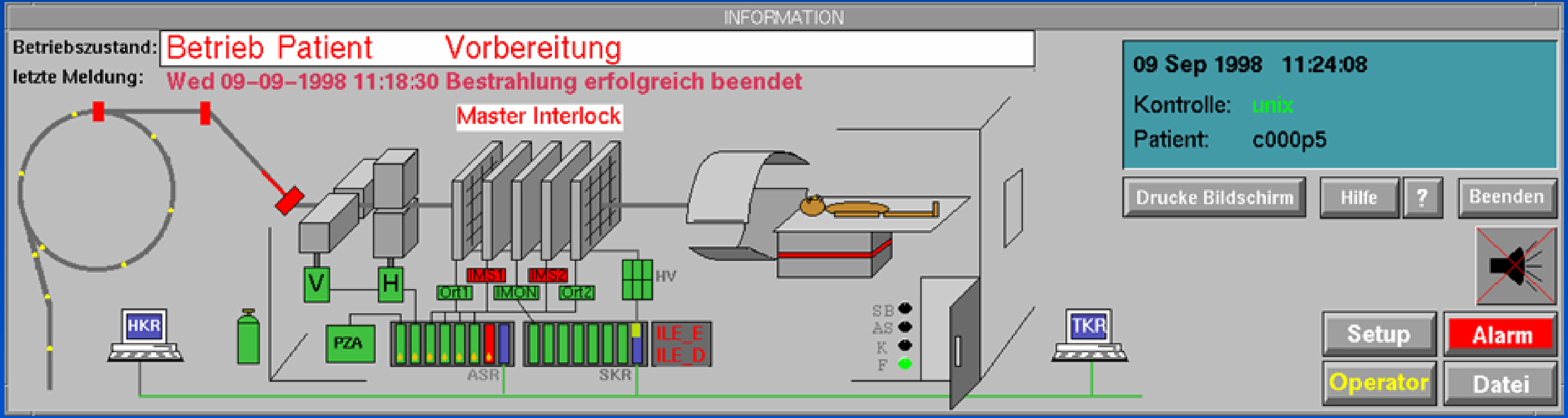


reduced integral dose
steeper dose gradients
less fields
increased biological effectiveness

courtesy O. Jäkel, HIT

HIT Heidelberg Ionenstrahl-Therapie Centrum

Key Developments @ GSI



- Scanning-ready **pencil beam library** (25.000 combinations):
  253 energies (1mm range steps) x 7 spot sizes x 15 intensity steps
- **Rasterscan method** incl. approved controls and safety
- **Beammonitors** follow the scanned beams (v <= 40 m/s) in real-time
- **Biological interactionmodel** (LEM) based on 25 years of radiobiological research
- Physical beam **transportmodel**
- **Planningsystem** TRiP
- **In-beam Positron Emission Tomography**
- **QA system**
- Prototype of the **scanning ion gantry**

RadioOnkologie
Universitätsklinikum Heidelberg

dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

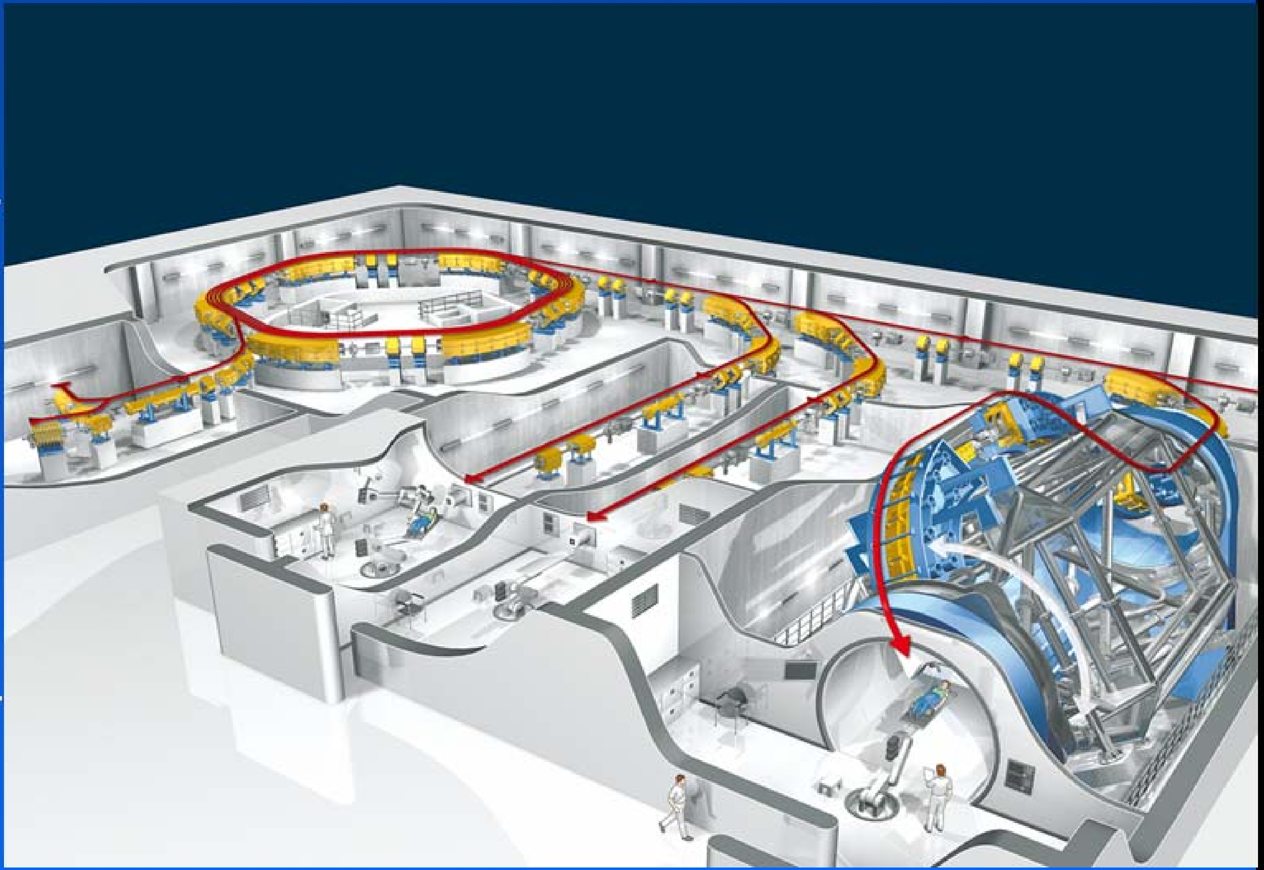
FZD Forschungszentrum Dresden Rossendorf

The Next Generation: HIT + CNAO

- combined Proton (low-LET) / Carbon (high-LET) facilities
- linac / synchrotron systems provide pencil beam libraries for highly tumour-conform scanning beam dose delivery

Heidelberg Ion Therapy Center

- compact design
- full clinical integration
- rasterscanning only
- low-LET modality: Protons (later He)
- high-LET modality: Carbon (Oxygen)
- ion selection within minutes
- world-wide first scanning ion gantry
- > 1000 patients/year > 15.000 fractions/year
- integrated R+D-infrastructure



Some Facts

- Effective area 5.027 m²
- Concrete 30.000 tons
- Constructional steel 7.500 tons
- Capital Investment 106 M€

Start of construction: November 2003
Completion of building and acc.: June 2006
Accelerator settings established: April 2008
First patient planned: 2^{nd} half of 2009

Project Partners:

- **University** pays, owns and operates the facility
- **GSI** designed the center and has built and commissioned the accelerator, trained a core team…
- **Siemens** supplies all components related to patient environment
- **GSI, DKFZ, Siemens …** are research partners

Some Facts

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Heidelberg Ionenstrahl-Therapie Centrum

IMPT → Beam Scanning

pencil beam library:

• **ions**	:	**p**	$^{3}He^{2+}$	$^{12}C^{6}$	$^{16}O^{8+}$
• **energies (MeV/u)**	:	**48**	**72**	**88**	**102**
(255 steps,1.0/1.5 mm)		**-220**	**-330**	**-430**	**-430**
• **beam spot size**	:	**4 – 10** (20) **mm , 2d-gaussian**			
(4 (6) **steps)**		(up to 20 mm for moving organ treatments)			

intensity variation: chopper system in front of the RFQ, variation factor: 1000

active energy variation: in the synchrotron + high-energy beam lines

beam size variation: quads directly in front of the scanning systems

beam extraction: established RF-knock-out method (Himac > 10 years) gives

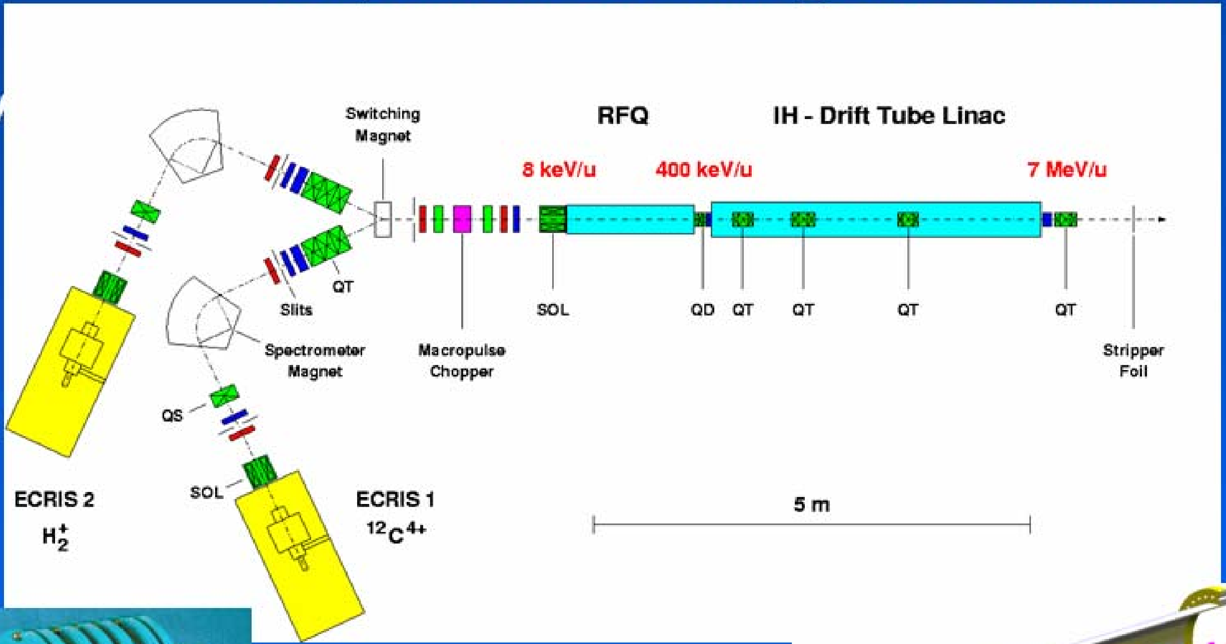
high stability in time, position and spot size

extraction switchable at flat-top level

HIT / Linac

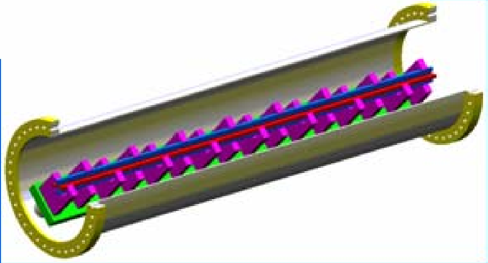
Cooperation: GSI + IAP@ Univ. Frankfurt/M.

- compact design
- proven technology
- fast change of the ion species
- fast intensity variation (1000-times)
- constant beam parameter

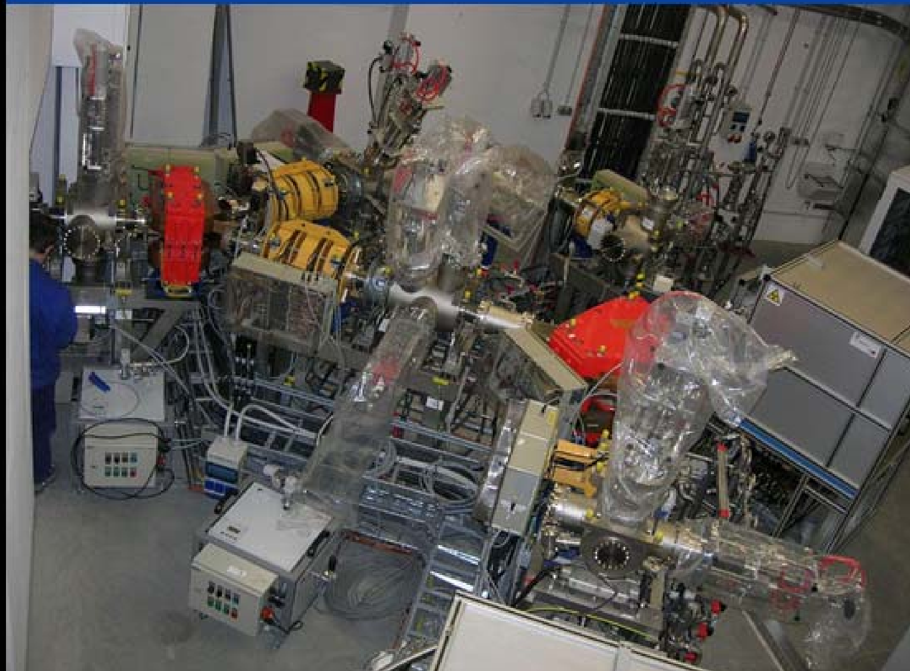


Ion source

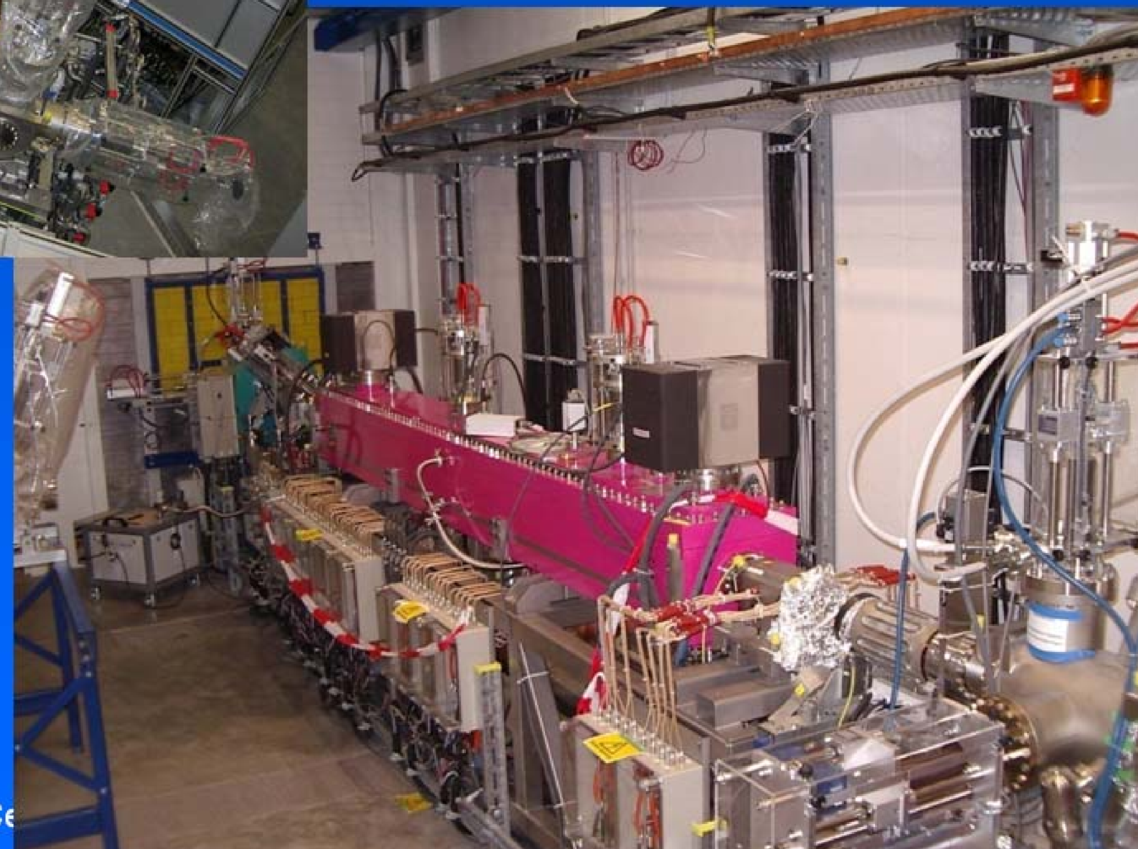
RFQ



Injector



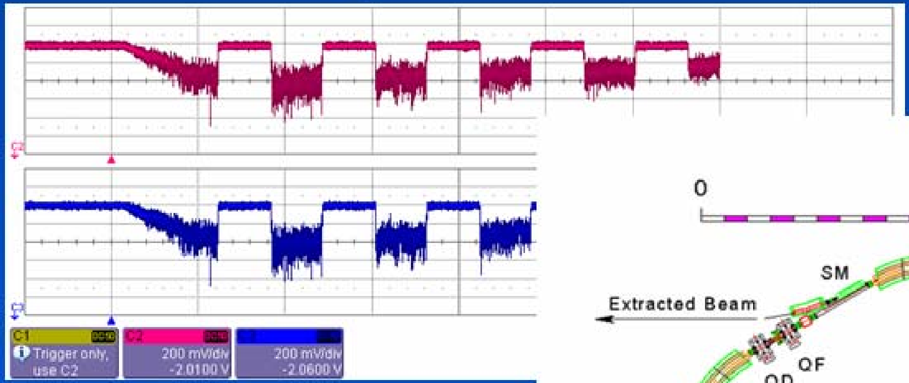
RFQ + IH-DTL



Ion sources

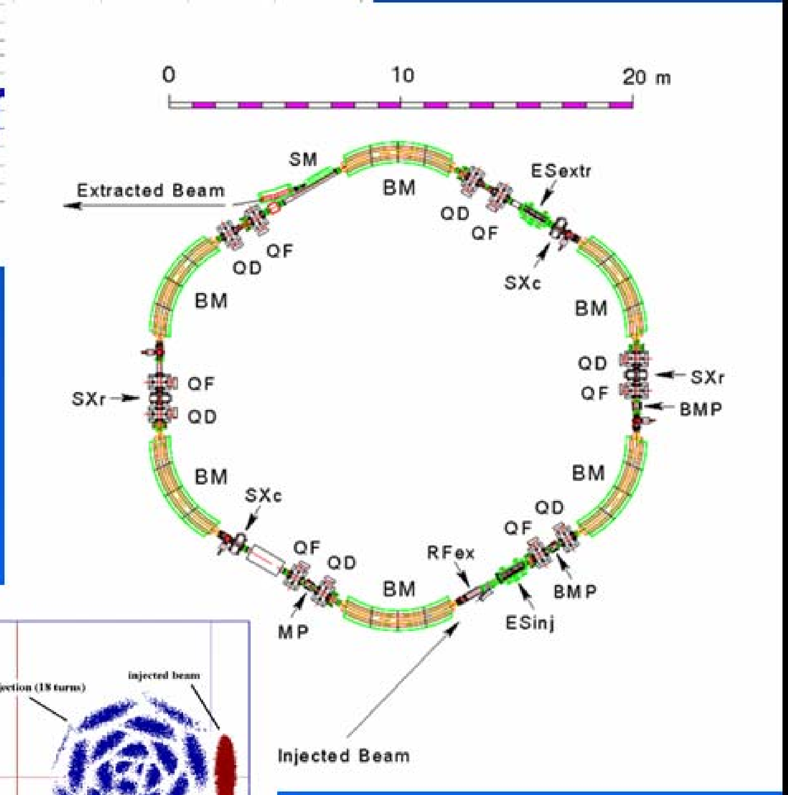
HIT / Synchrotron

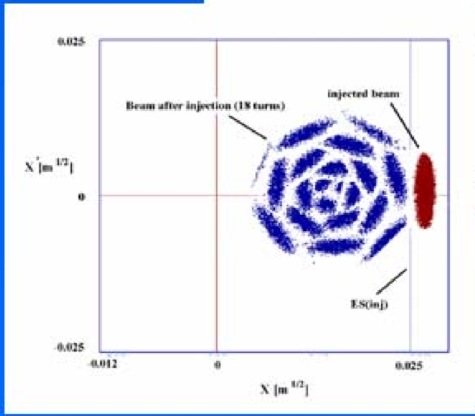
- compact design
- proven technology
- multiturn-injection => high intensities
- rasterscanning optimized, extremely flexible beam extraction
- fast variation of energy (range)



Multiple extraction

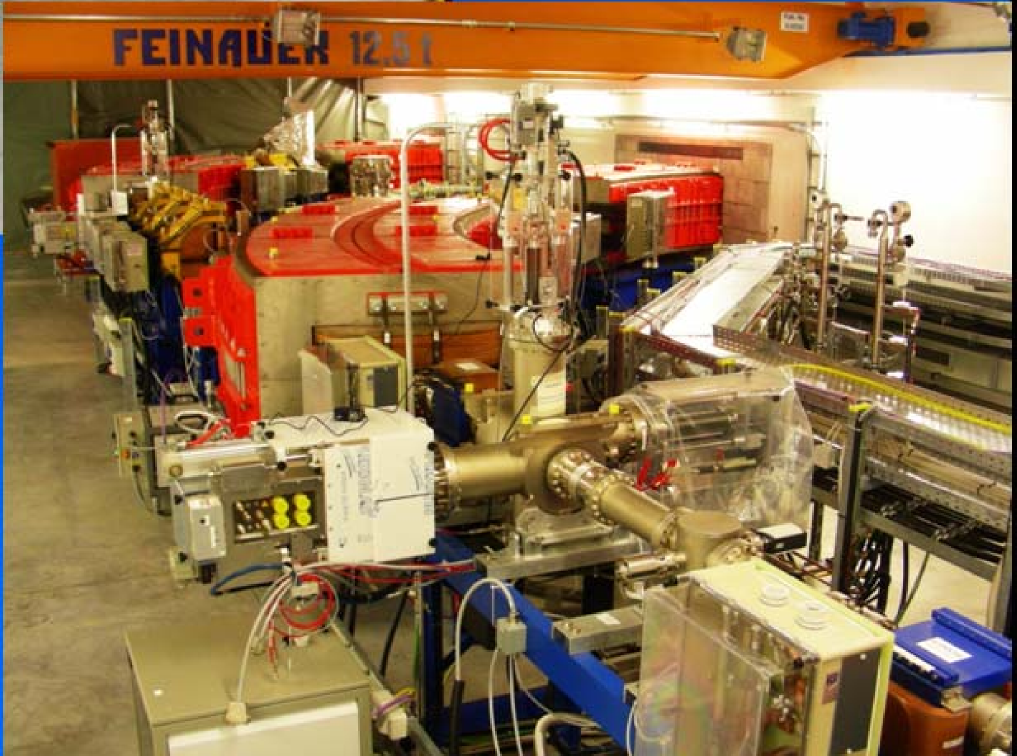
0,5 bis 10 sec





Multiturn injection

Th. Haberer, Heidelberg Ion Therapy Center



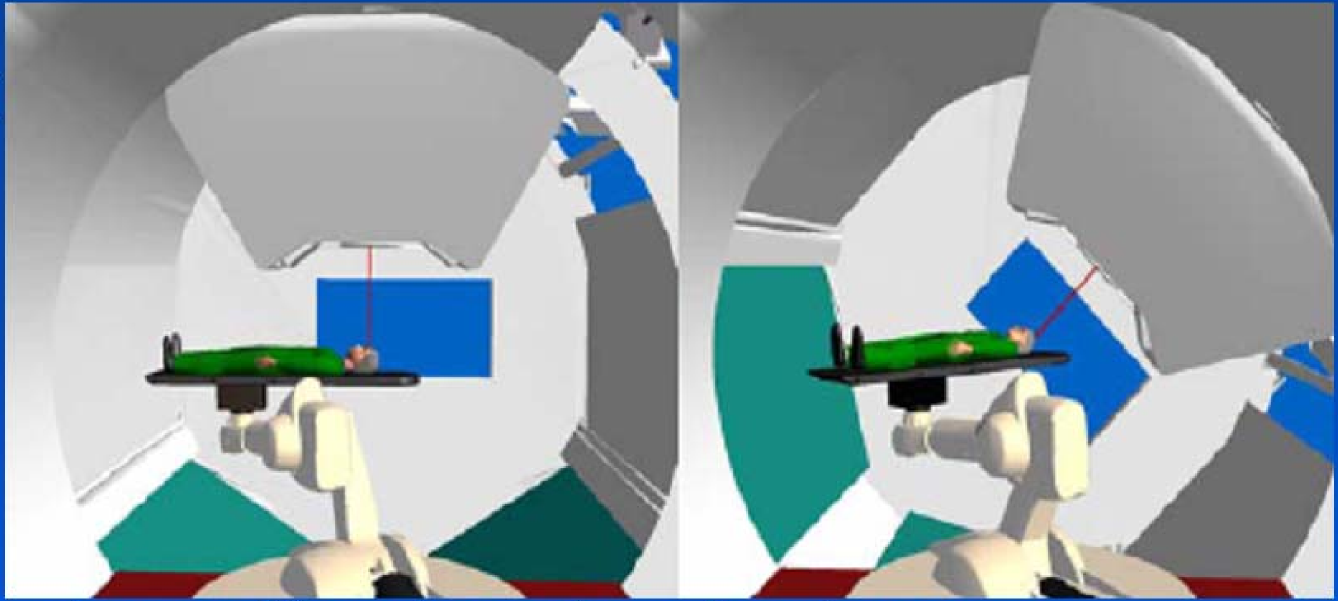
high energy
beam transport

synchrotron

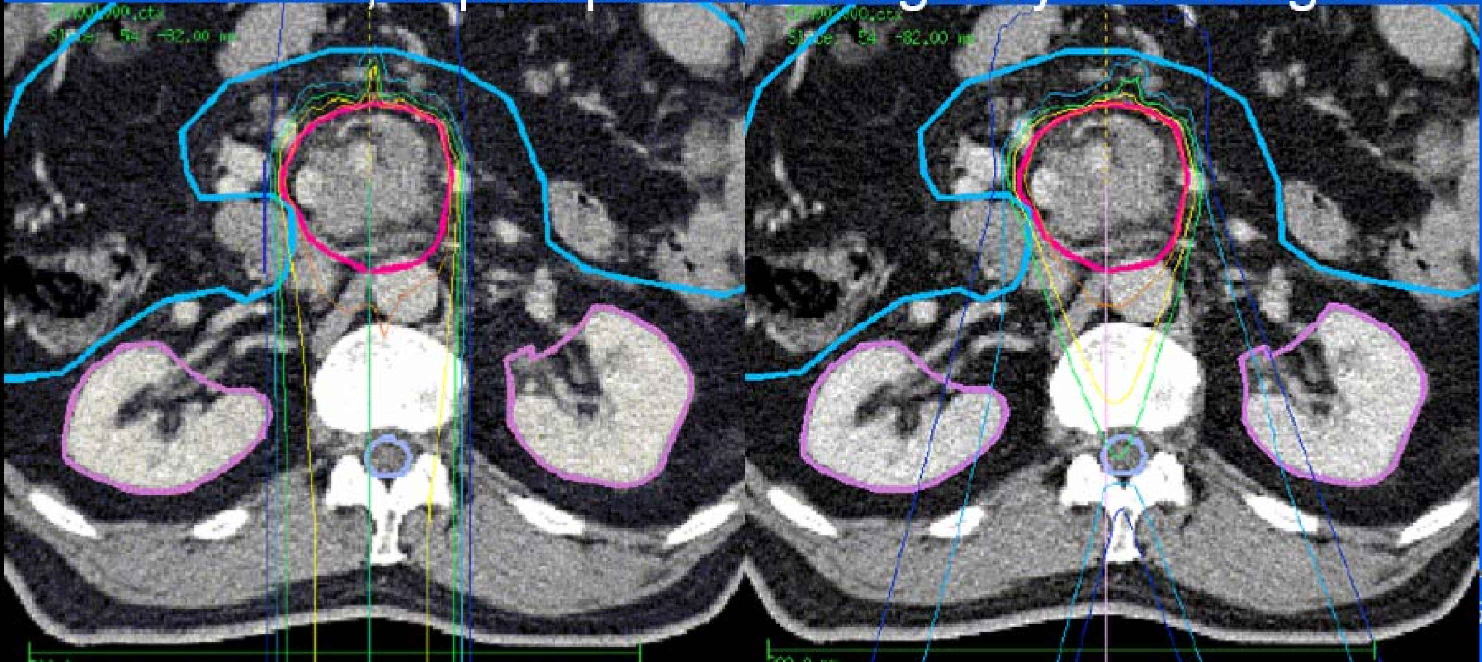
Th. Haberer, Heidelberg Ion Therapy Center

Motivation Gantry

Advantage of a rotating beamline

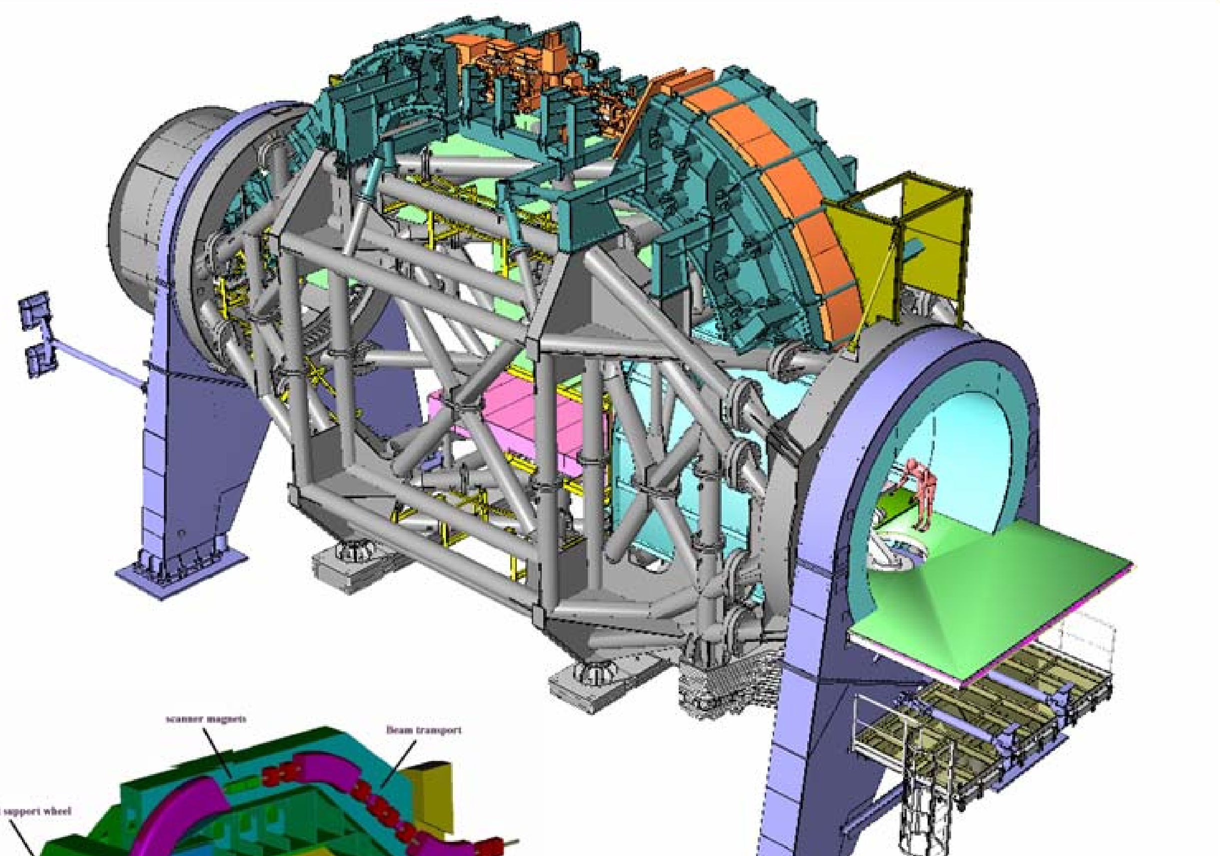


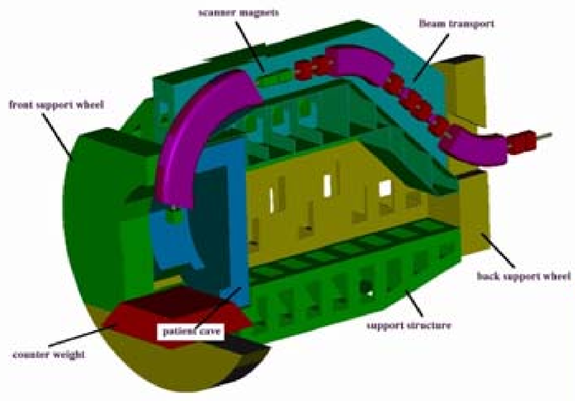
Pancreas, supine position via gantry advantageous



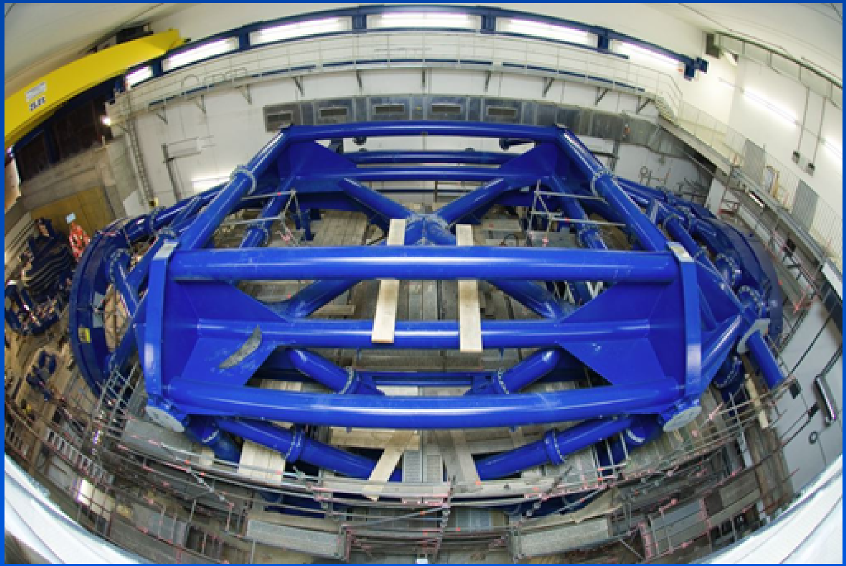
Scanning Ion Gantry

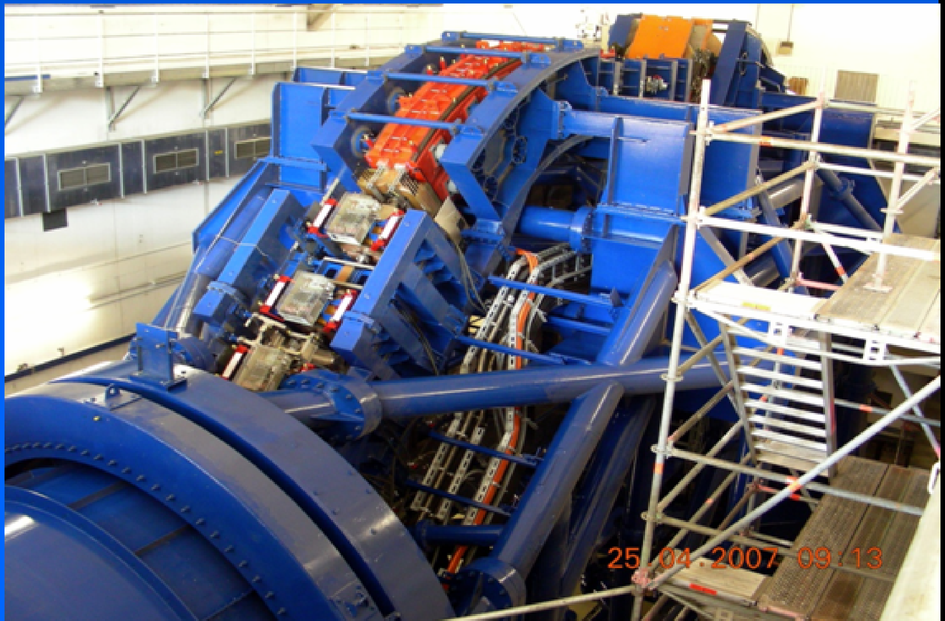
- optimum dose application
- world-wide first ion gantry
- world-wide first integration of beam scanning
- 13m diameter
  25m length
  600to overall weight
  0,5mm max. deformation
- prototype segment tested at GSI





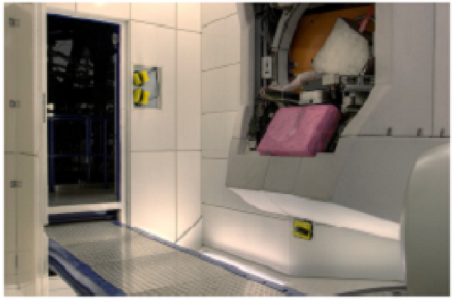
Mounting





Gantry / Medtech

Patient Gantry Room November 2007



Tilt floor, pending on Gantry position

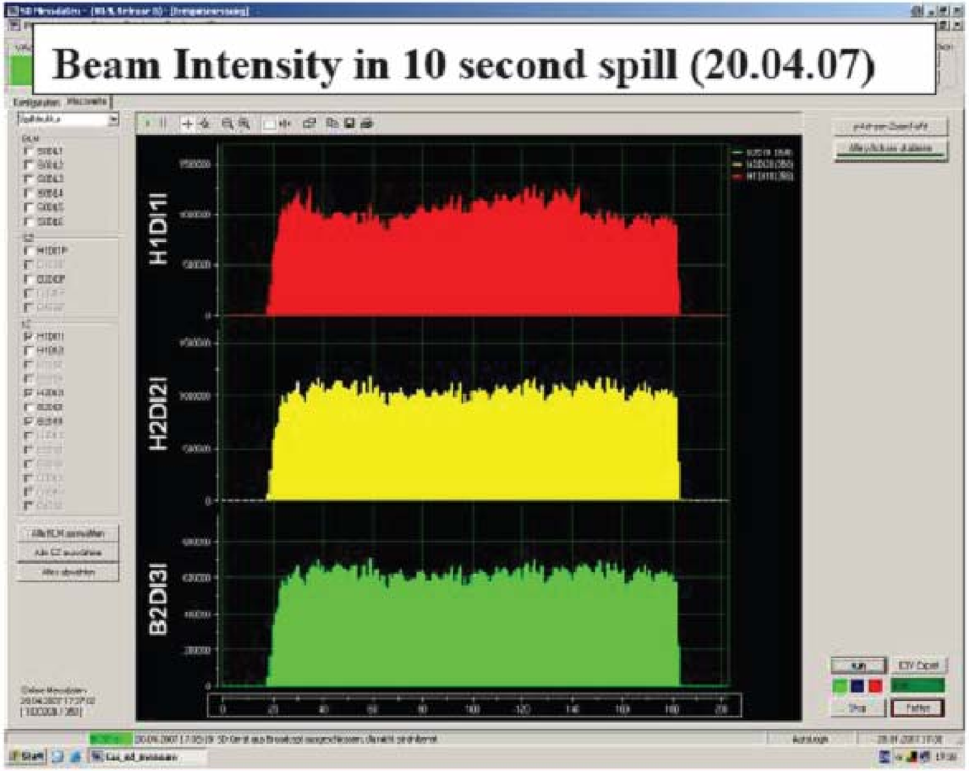
Nozzle

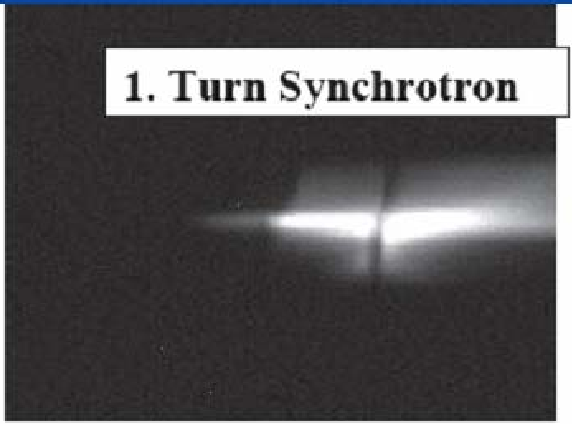
Bumber mats

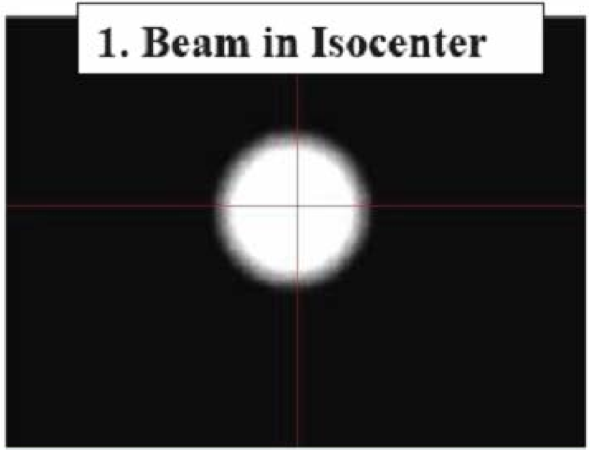
Patienttable, Roboter

Synchroton/HEBT Commissioning

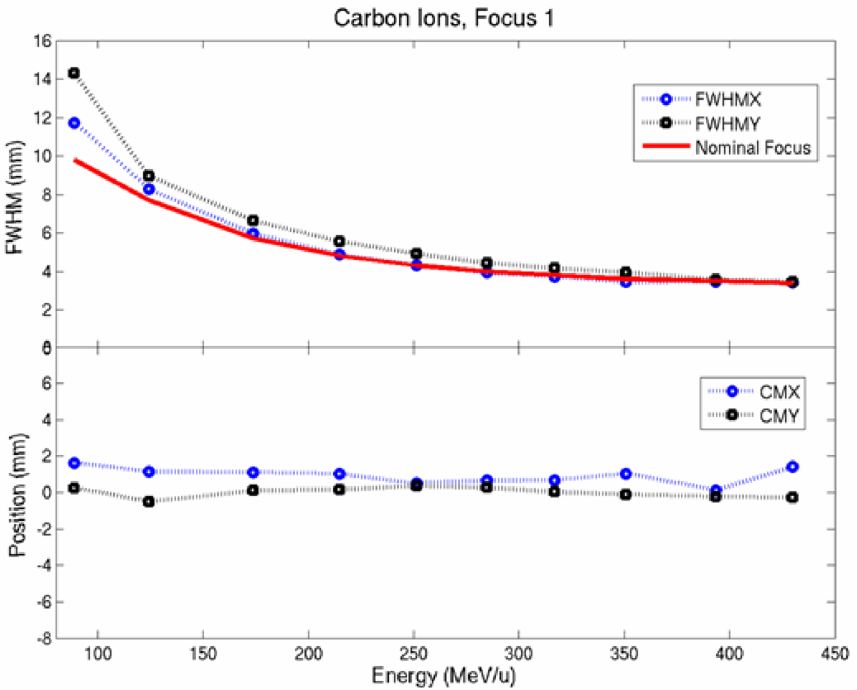
- **1. Turn in Synchrotron: Febr. 2007**
- **1. Beam in Cave: March 2007**

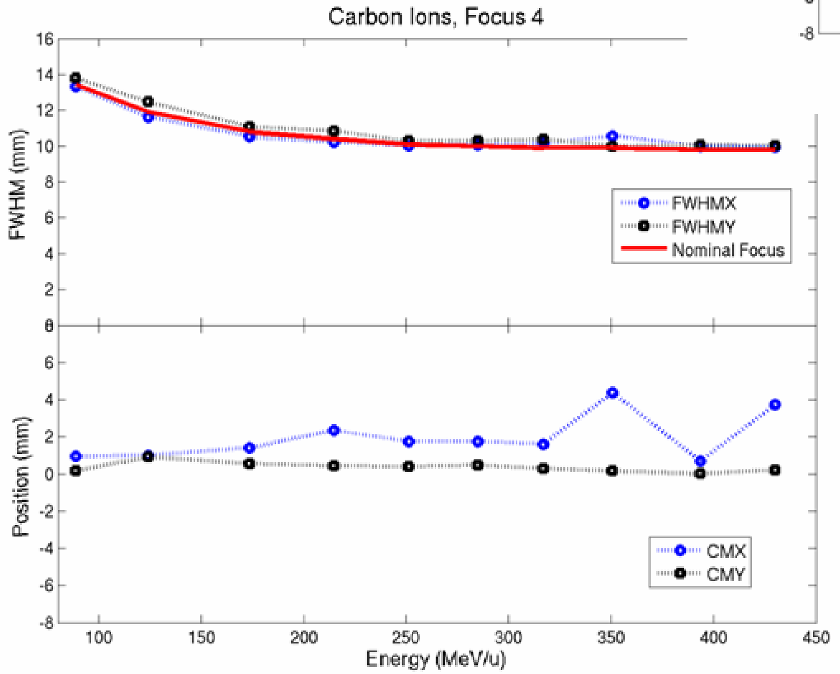






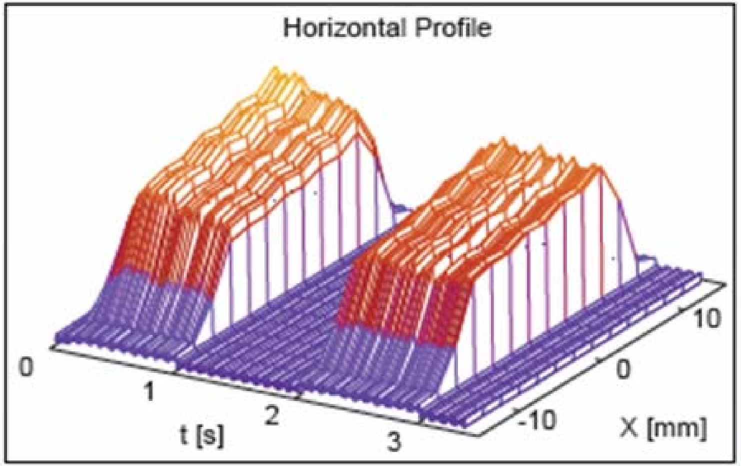
Status of pencil-beam libraries



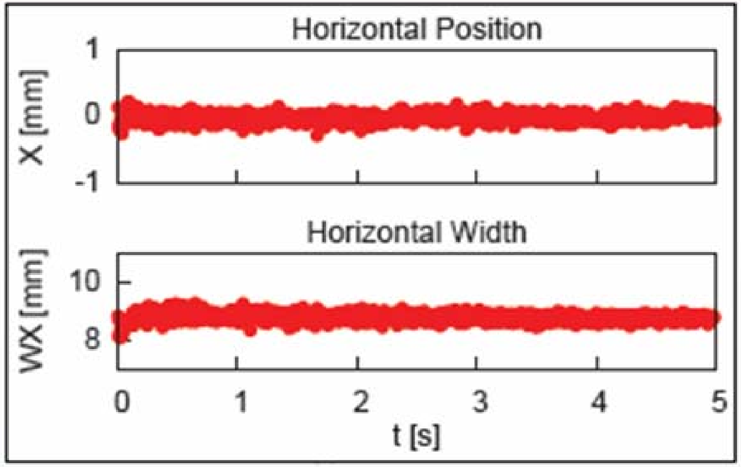


treatment quality since April 2008

Beam Stability



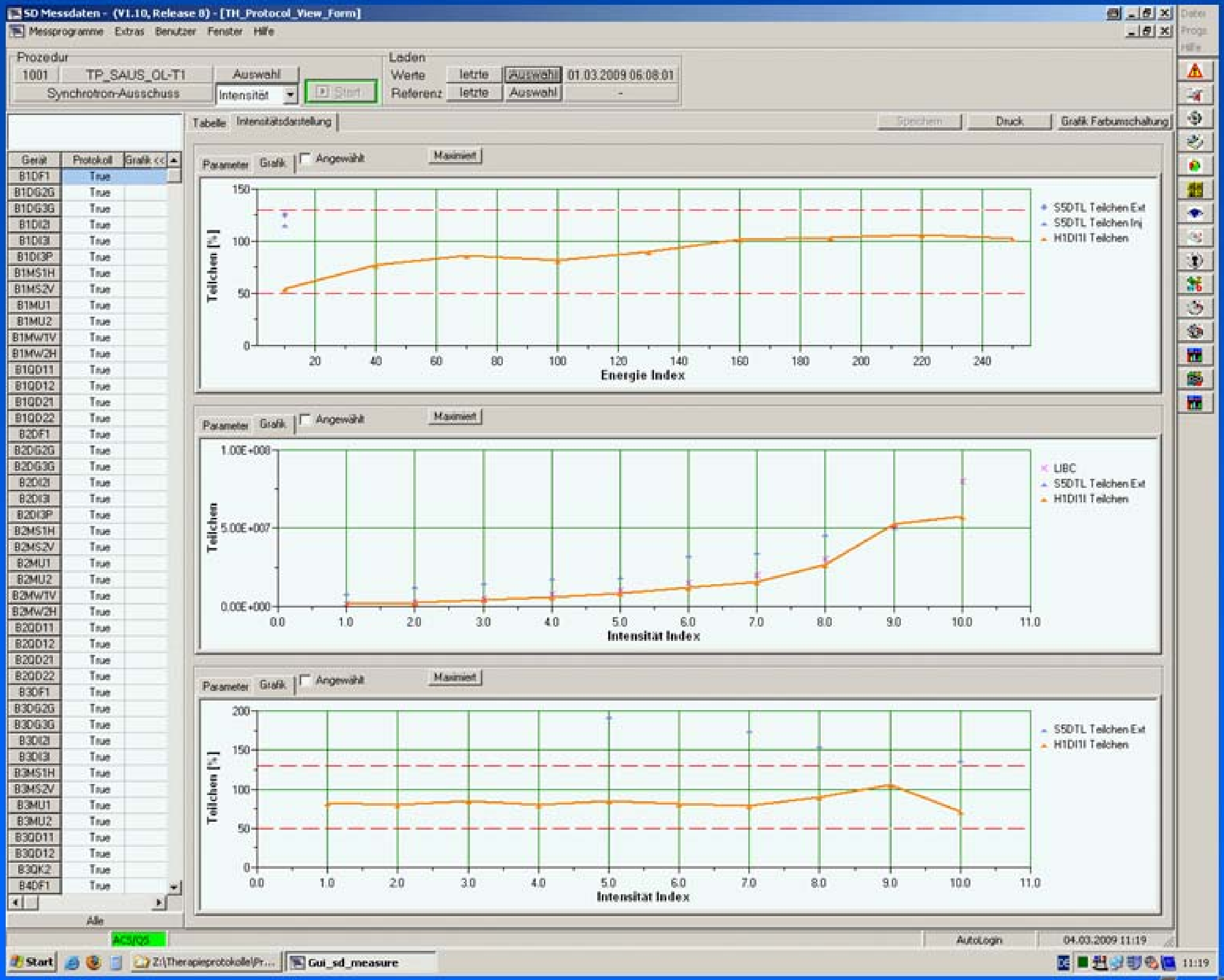
MWPC in beam line
(C, 250 MeV/u, one interruption)



Treatment monitoring system
(C, 250 MeV/u, no interruption)

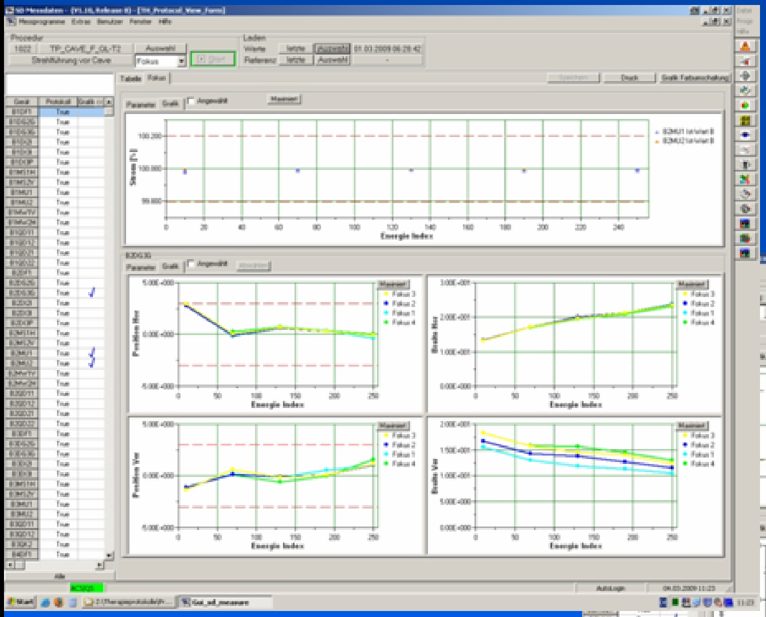
- Excellent stability of beam size and position at treatment place due to KO extraction (constant optics)
- No profile distortions due to spill interruptions
  ➔ Very homogeneous lateral dose distributions

Daily ACC-QA, March 2009

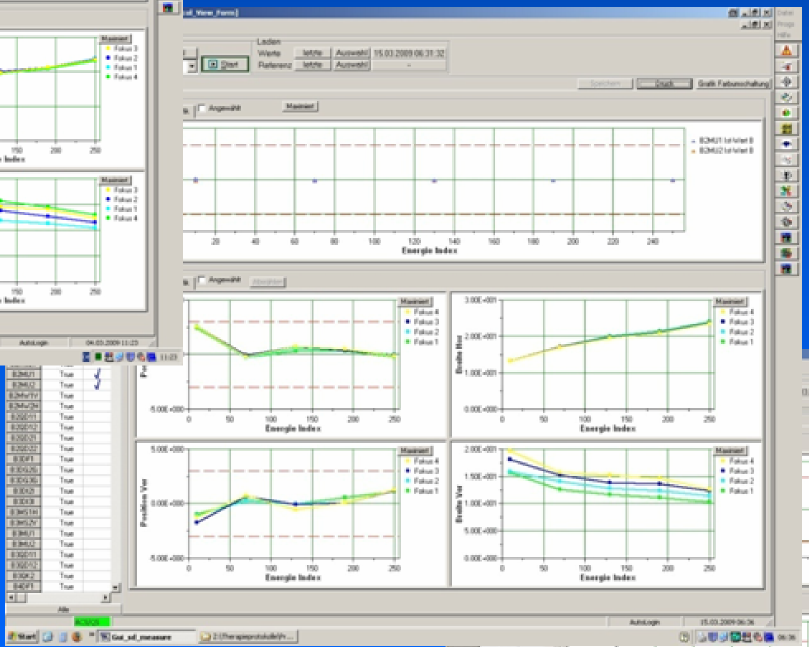


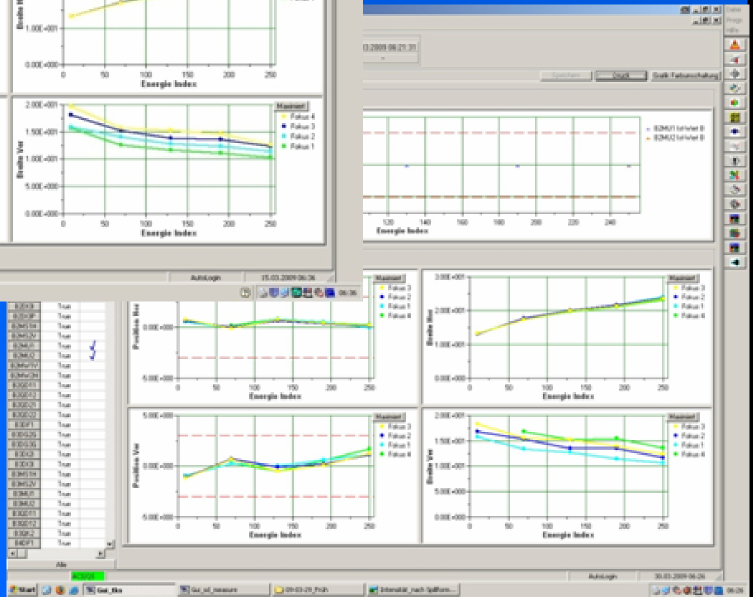
Th. Haberer, Heidelberg Ion Therapy Center

Daily ACC-QA, March 2009



March 2009:
1st, 15th and 30th





fixed beamline H2
at the scanning system:
current in bending magnet
beam position and size (hor/vert)

Th. Haberer, Heidelberg Ion Therapy Center

Accelerator Status

- **Sources, injector and synchrotron** fully commissioned for protons, carbon and oxygen (256 energies each)
- **H1 / H2**: pencil beam libraries (E F I) for protons and carbon in therapeutical quality reached in April, 2008

  outstanding beam quality: very high position and focus stability, small intensity fluctuations
- **R+D-cave**: protons, carbon and oxygen energy libs established
- **Gantry**: proof of principle for protons and carbon

  (representative settings in the full phase space (E F I α))
- **To do**: intensity upgrade (x3) under way (sources, LEBT, RFQ)
- **Operation scheme**:

  2007: 24 h / 5 days

  2008ff: 24 h / 7 days, 330 days, 2 shutdowns 14 days each
- **Availability** of the pencil beams @ H1/2: ≈ 98%

HIT Heidelberg Ionenstrahl-Therapie Centrum

Dose Delivery and Medical Equipment

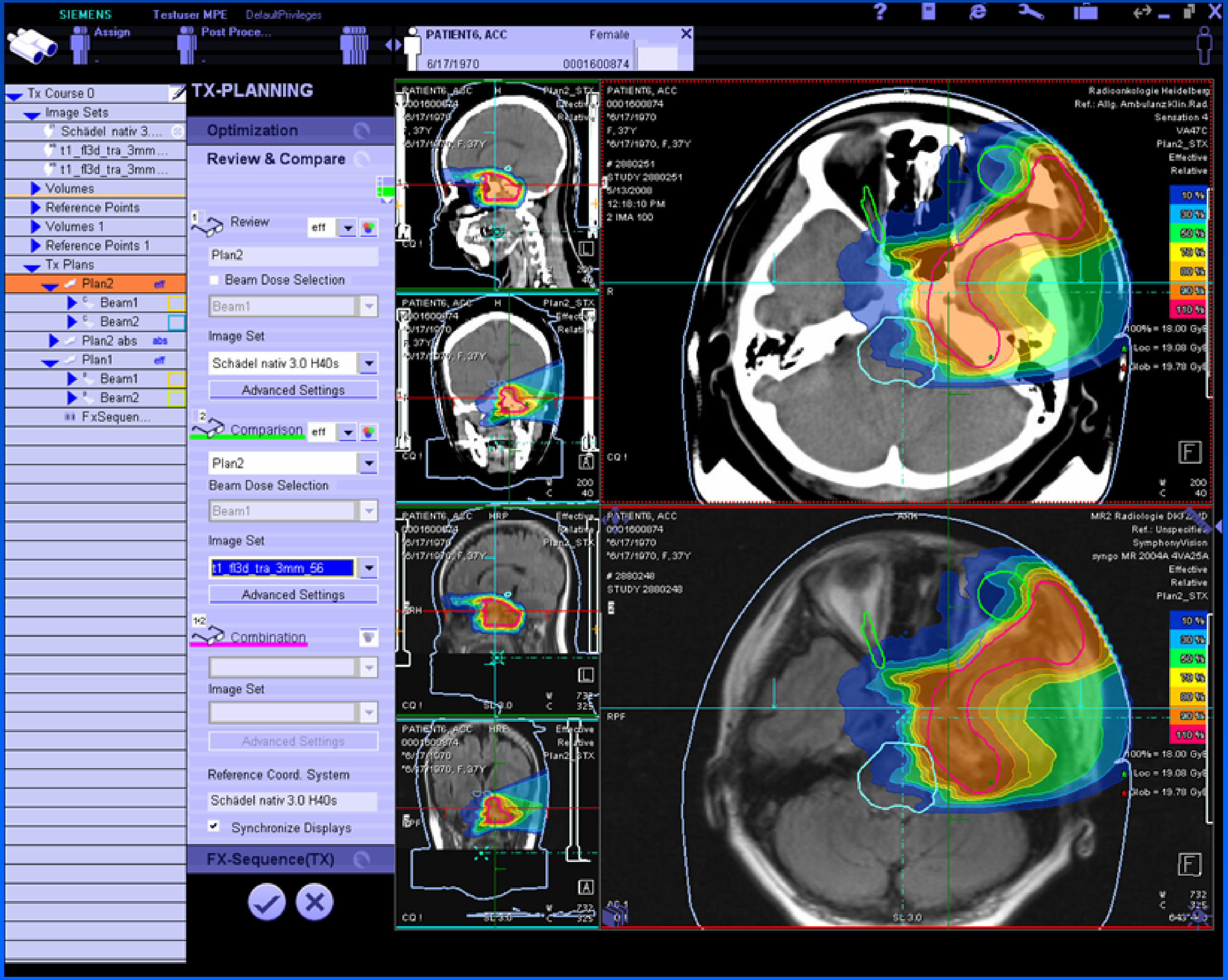
Identical patient positioning systems
- fixed beam
- Gantry

Workflow optimization
- automated QA procedures
- automated patient hand over from shuttle

Inroom position verification
- 2D
- 3D Cone beam CT

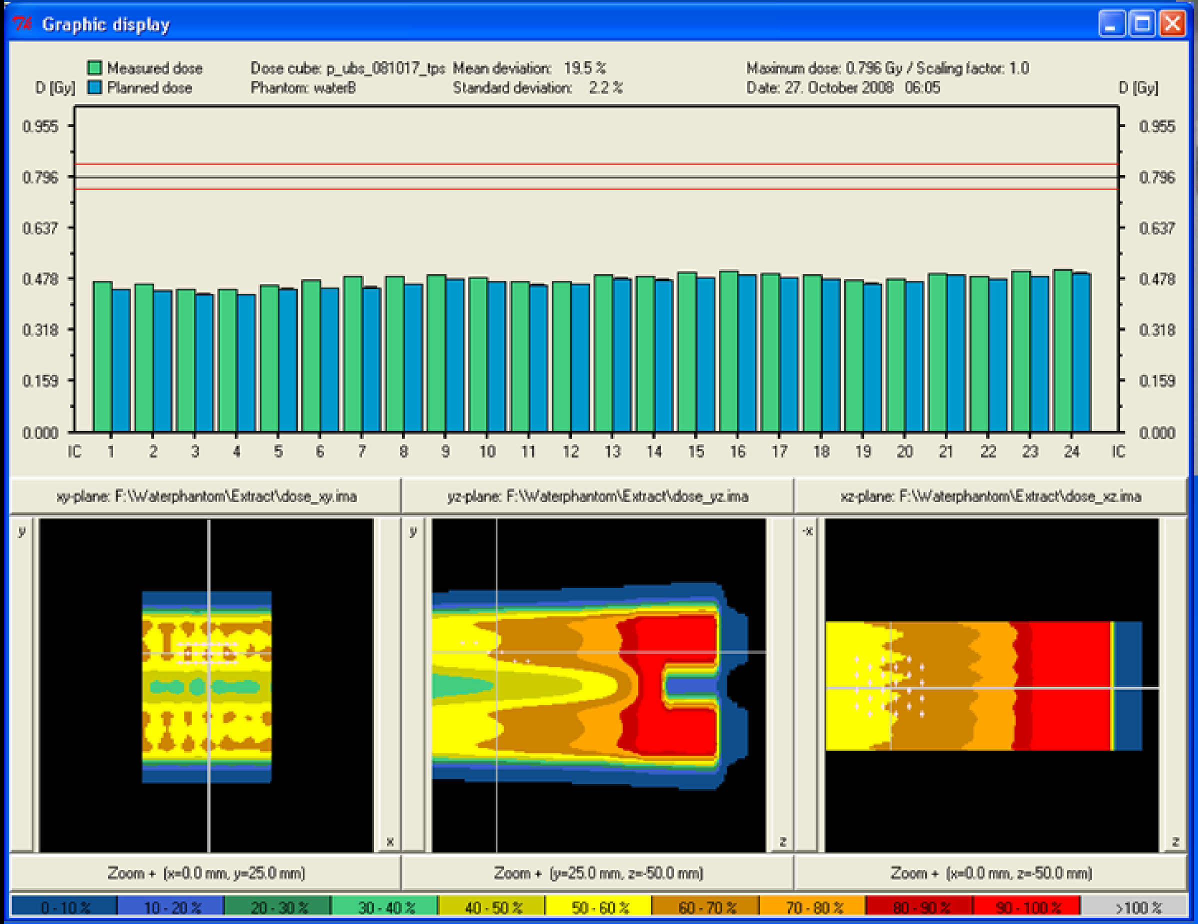
Open for future applications and workflows

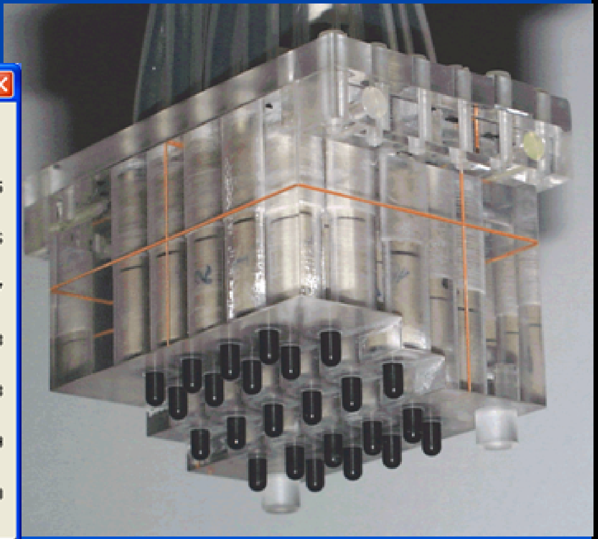
Treatment Planning System



Adenoid cystic carcinoma, plan mapped on CT and MR

Commissioning

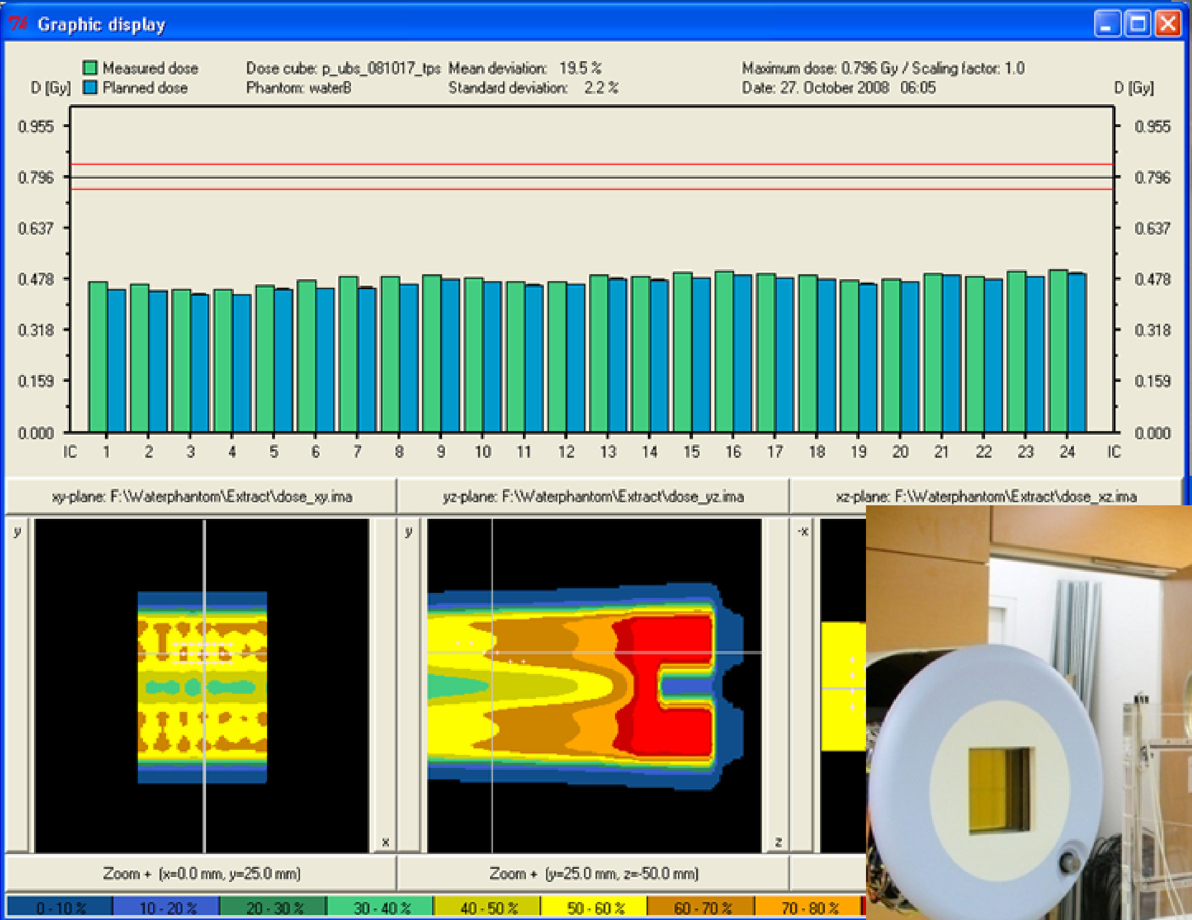


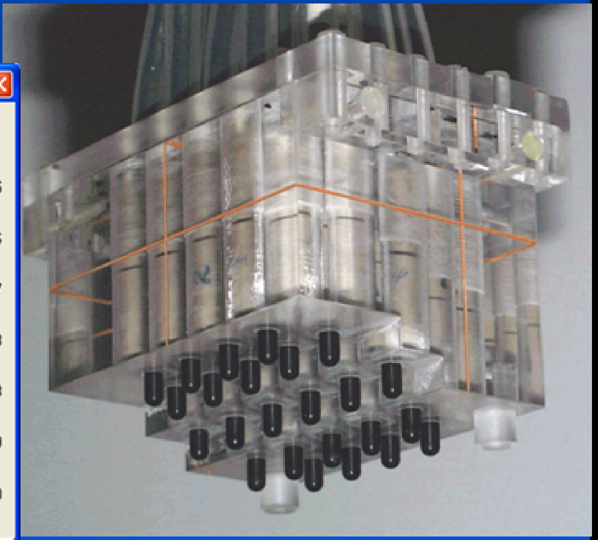


commissioning result, Protons @ H1:
3d dose delivery vs. treatment planning
24 thimble-type ICs in a water phantom,
standard deviation 2.2 %

HIT Heidelberg Ionenstrahl-Therapie Centrum

Commissioning






QA Table Top with Water Phantom

commissioning result, Protons @ H1:
3d dose delivery vs. treatment planning
24 thimble-type ICs in a water phantom,
standard deviation 2.2 %

Next Steps

- Stabilize the clinical workflow
- Finalize the bugfixing of the “kick-off-version”:

  system freeze in May 2009
- Perform the system integration and system tests (~3000 test cases) to fulfill the requirements of the Medical Device Directive (=> CE label)
- User training
- Approval for the full facility by the German authorities some weeks later

HIT
Heidelberg Ionenstrahl-Therapie Centrum

The HIT Gantry Rotates

HIT
Heidelberg Ionenstrahl-Therapie Centrum

HIT / Milestones

1998 / Aug	Proposal submitted
2000 / Dec	Technical proposal
2002 / Dec	Tendering documents
2003 / Spring	Tendering activities (acc.)
2004 / Autumn	Tendering act. (medtech)
2004 / May	Foundation stone
2005 / Oct	Installation of acc.comp.
2006 / Apr	Commissioning IQ + LEBT
2006 / Dec	Injector fully commissioned
2007 / Feb	1st turn in the synchrotron
2007 / Mar	1st beam at H1
2007 / Apr	1st gantry rotation
2007 / Dec	pencil beam libs for p, C in H1+2
2008 / Jan	1st beam at the gantry isocenter

fondazione CNAO

Created by the Italian Ministry of Health at the beginning of 2001

21st November 2001, the Board has been established

to build a Centre with two main goals:

→ **To treat patients using hadrontherapy**

→ **To perform clinical and radiobiological reasearch**

Material provided by Sandro Rossi (CNAO)

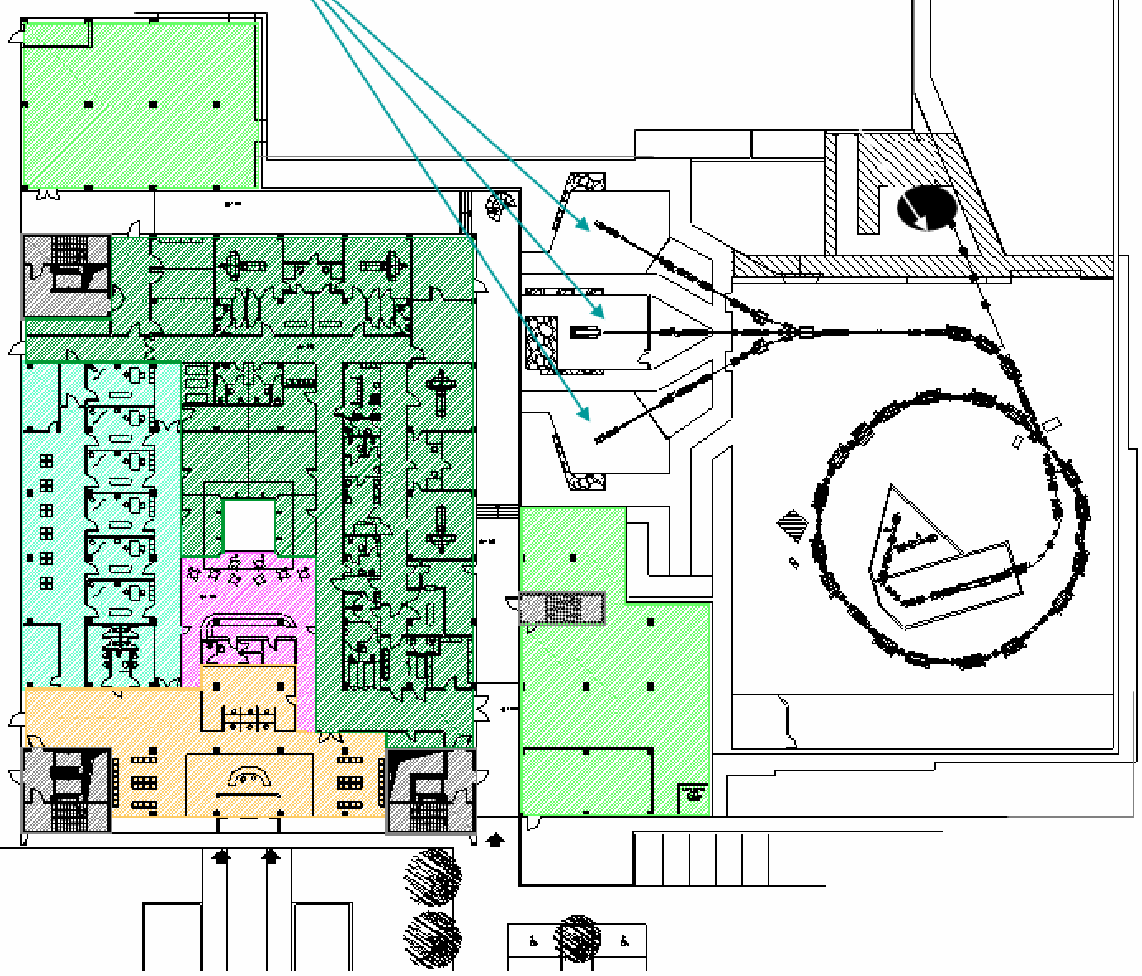
CENTRO NAZIONALE DI ADROTERAPIA ONCOLOGICA
CNAO – Pavia (Italy)

CNAO layout

Approved by CNAO Board

One experimental room

Three treatment rooms (3H+1V)



LEGENDA

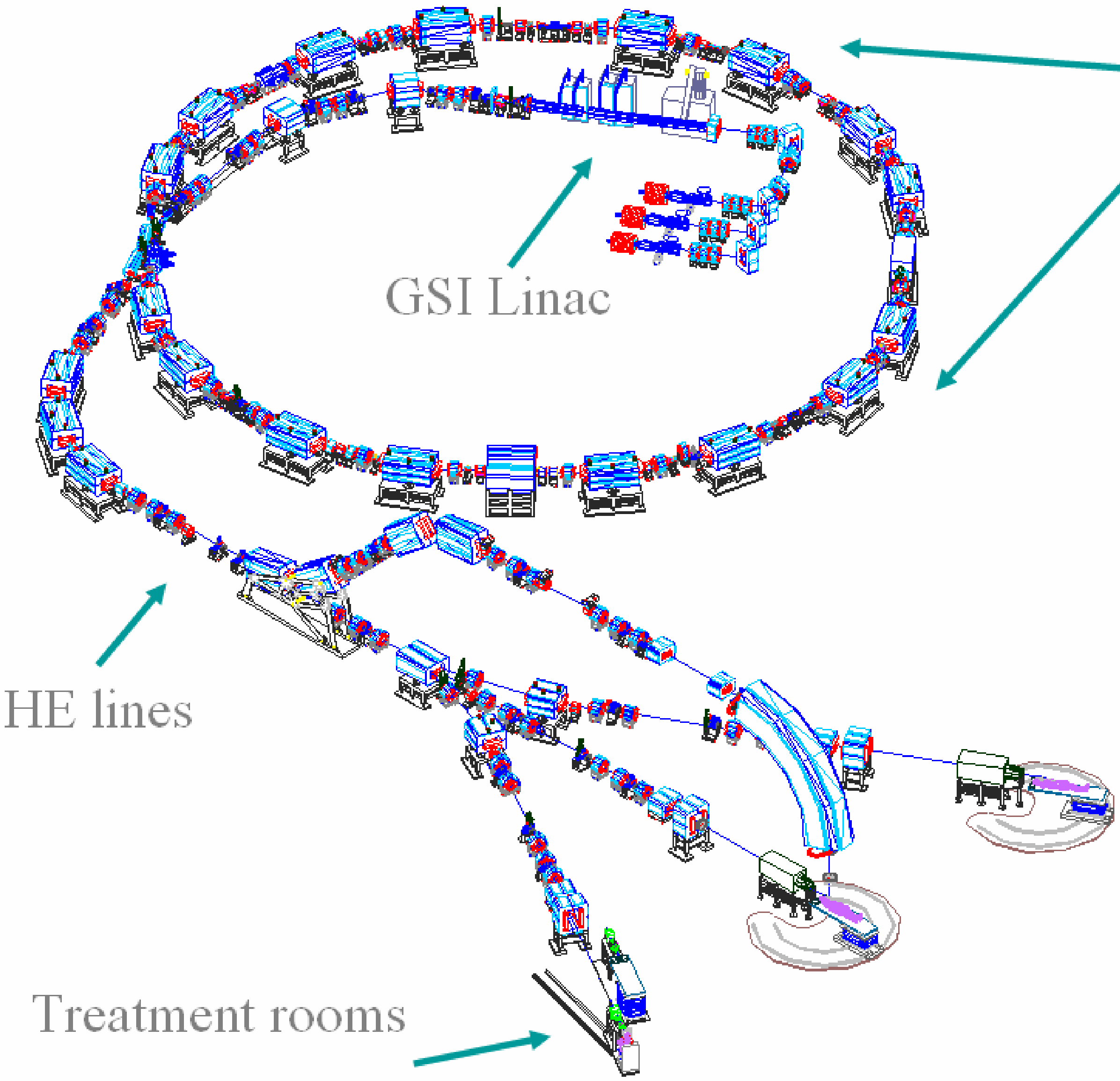
AREE FUNZIONALI

- Ambulatori mq 453
- Area immagini mq 1146
- Ingresso accettazione mq 337
- Bar mq 144
- Centrali tecnologiche mq 736
- Collegamenti verticali mq 227

Buildings and plants ready and CNAO people have moved to Pavia

The High Technology commissioning is ongoing

The heart of CNAO



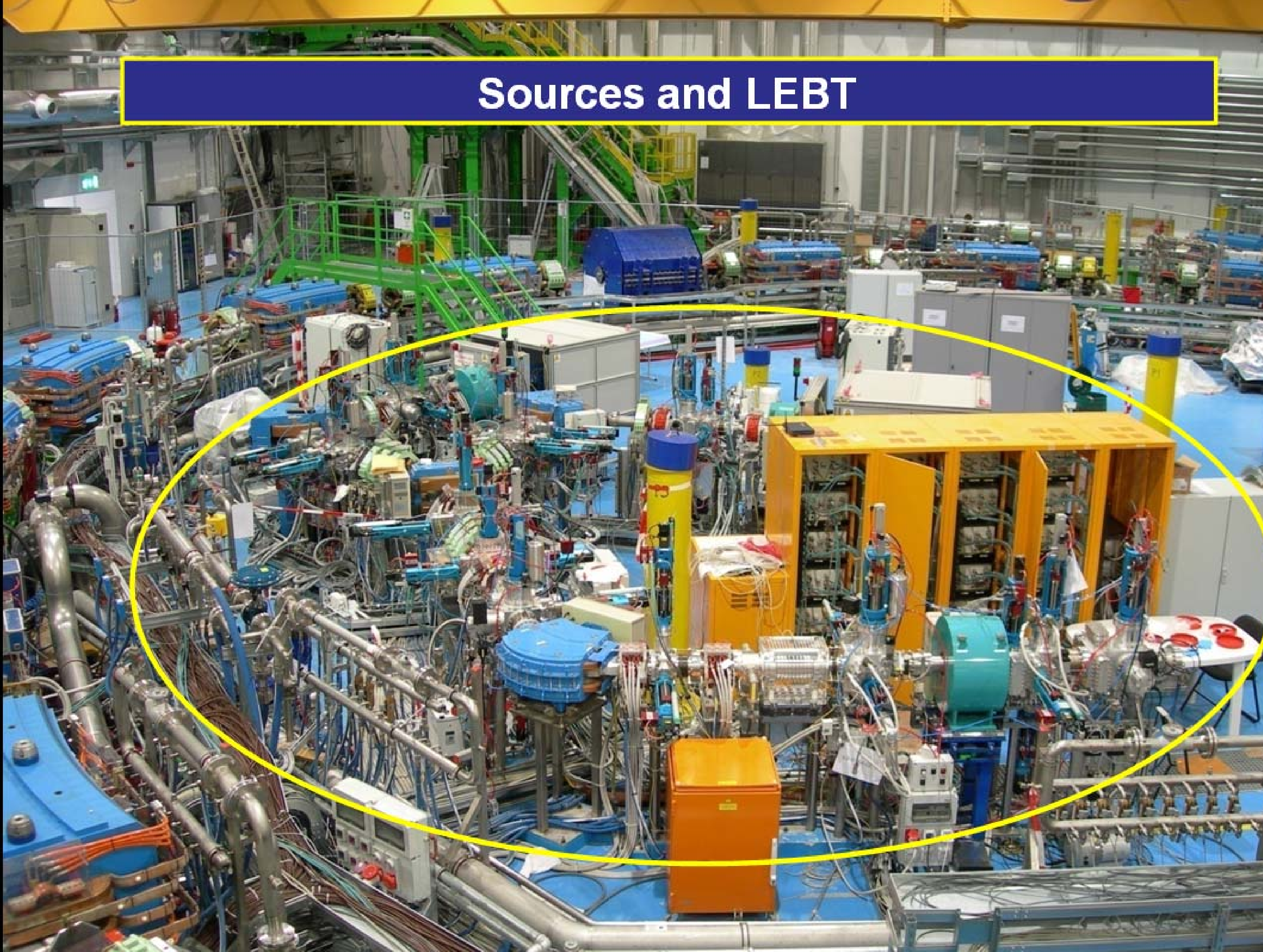
SYNCHROTRON

OPTIMIZED
for an hospital based facility (all Ion-therapy centres existing in the World adopt it):
- **Safety**
- **Efficiency**
- **Reliability**
- **Maintainability**

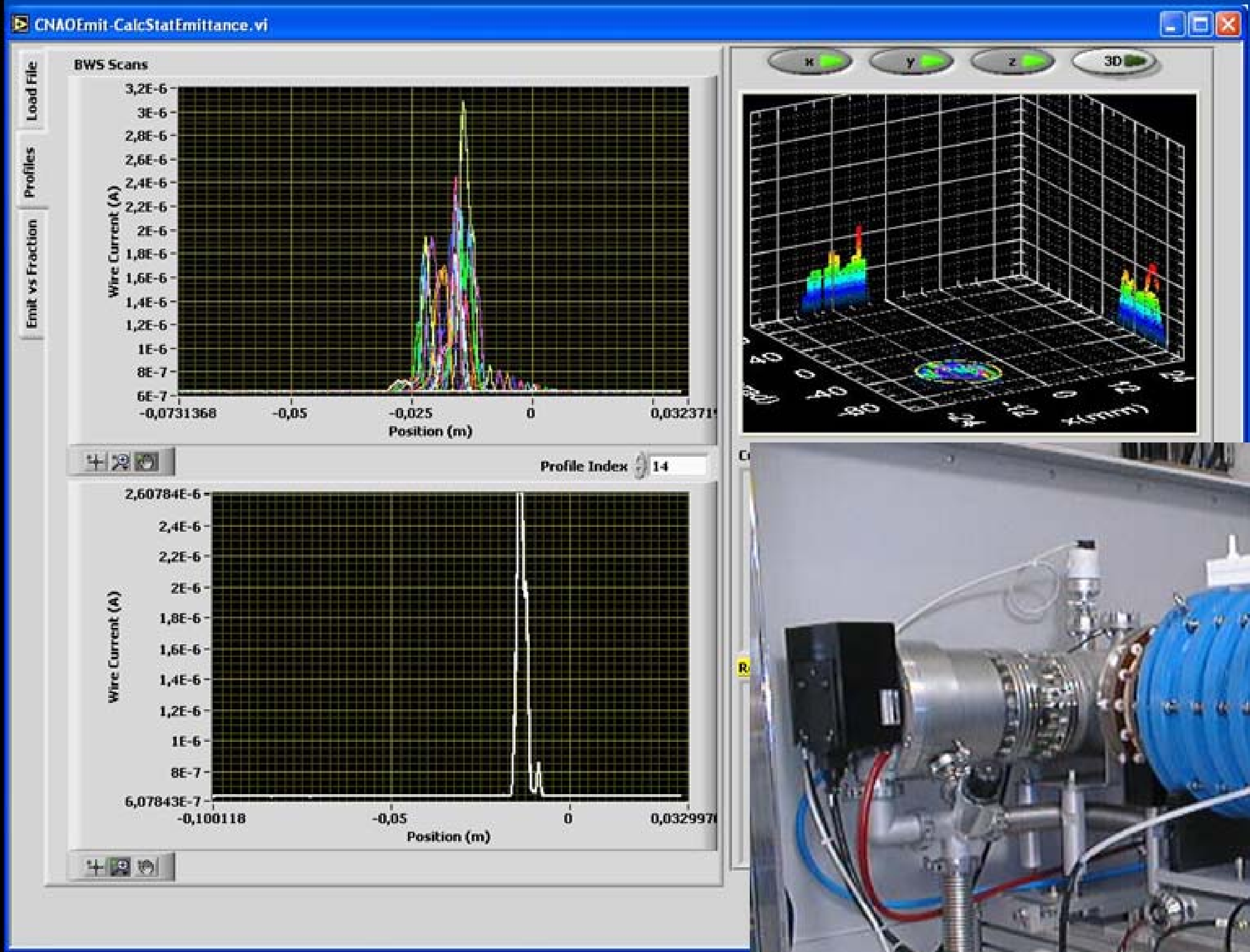
-Designed by

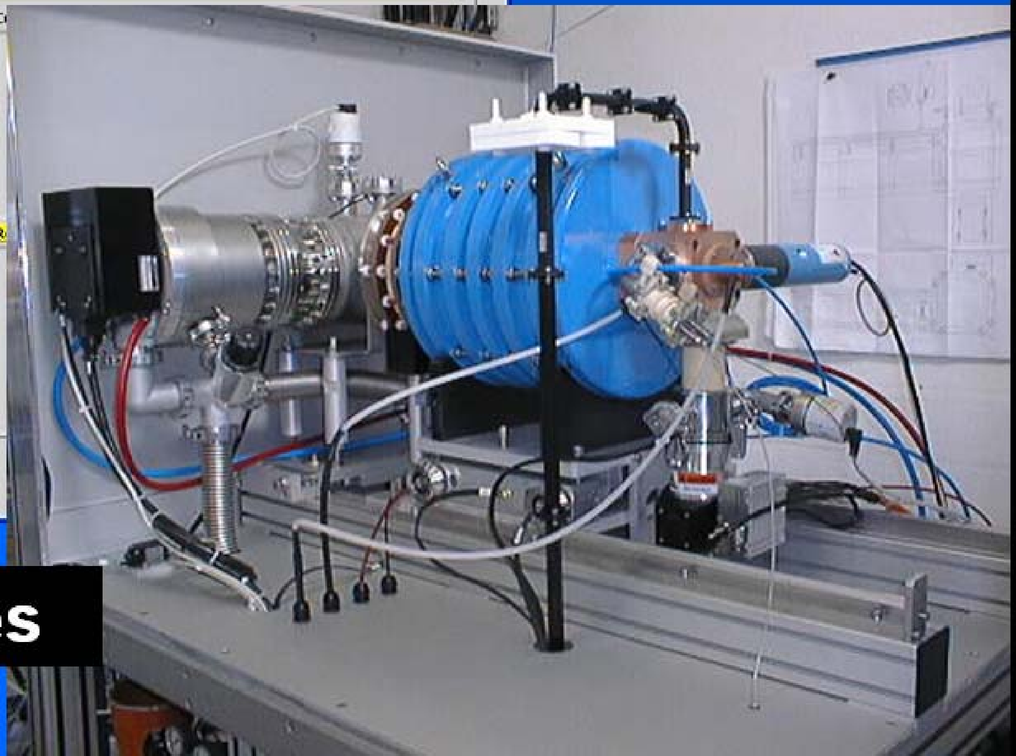
PIMMS/TERA

Sources and LEBT



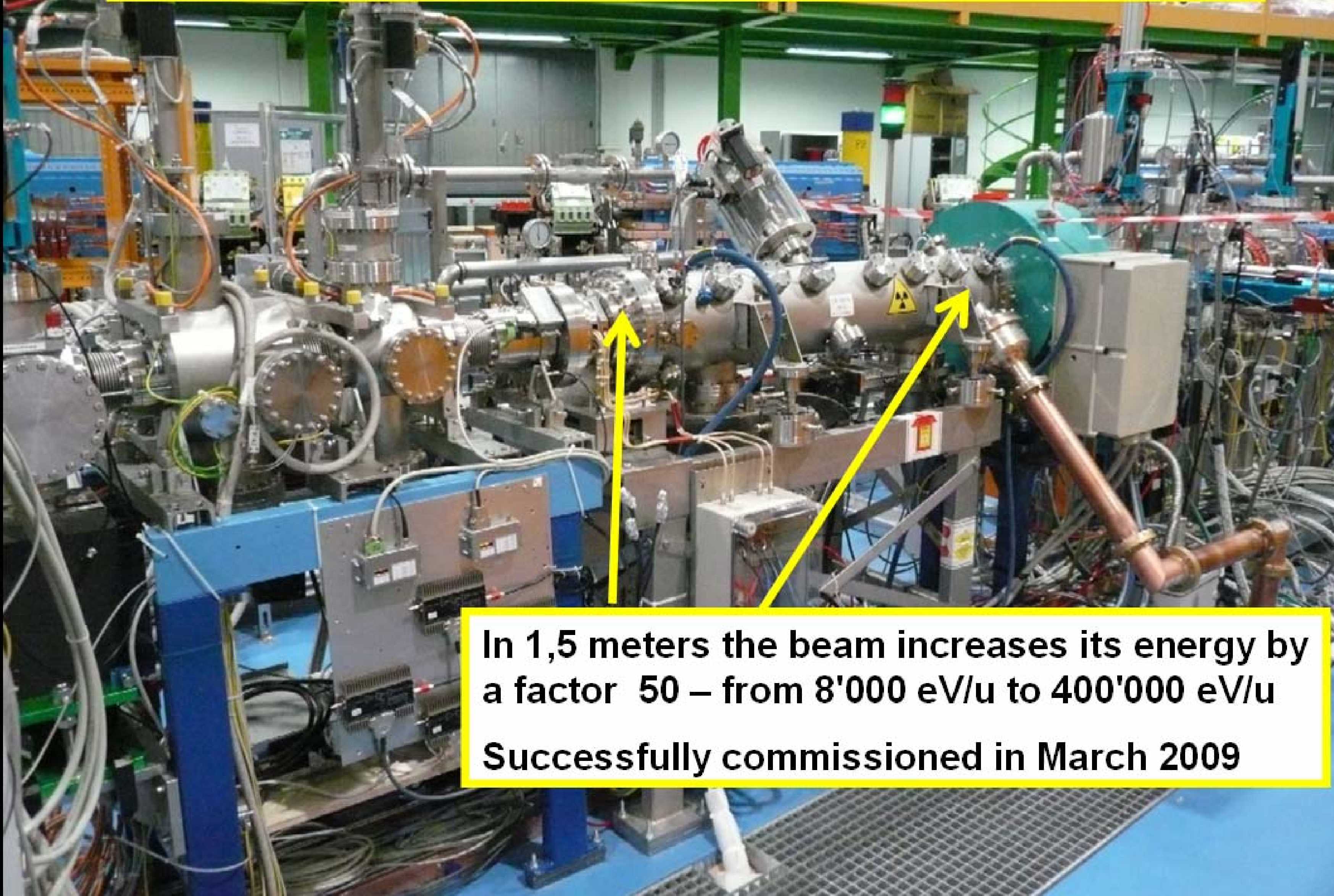
C^{4+}, 230 μA (design goal = 200 μA !)





ECR sources

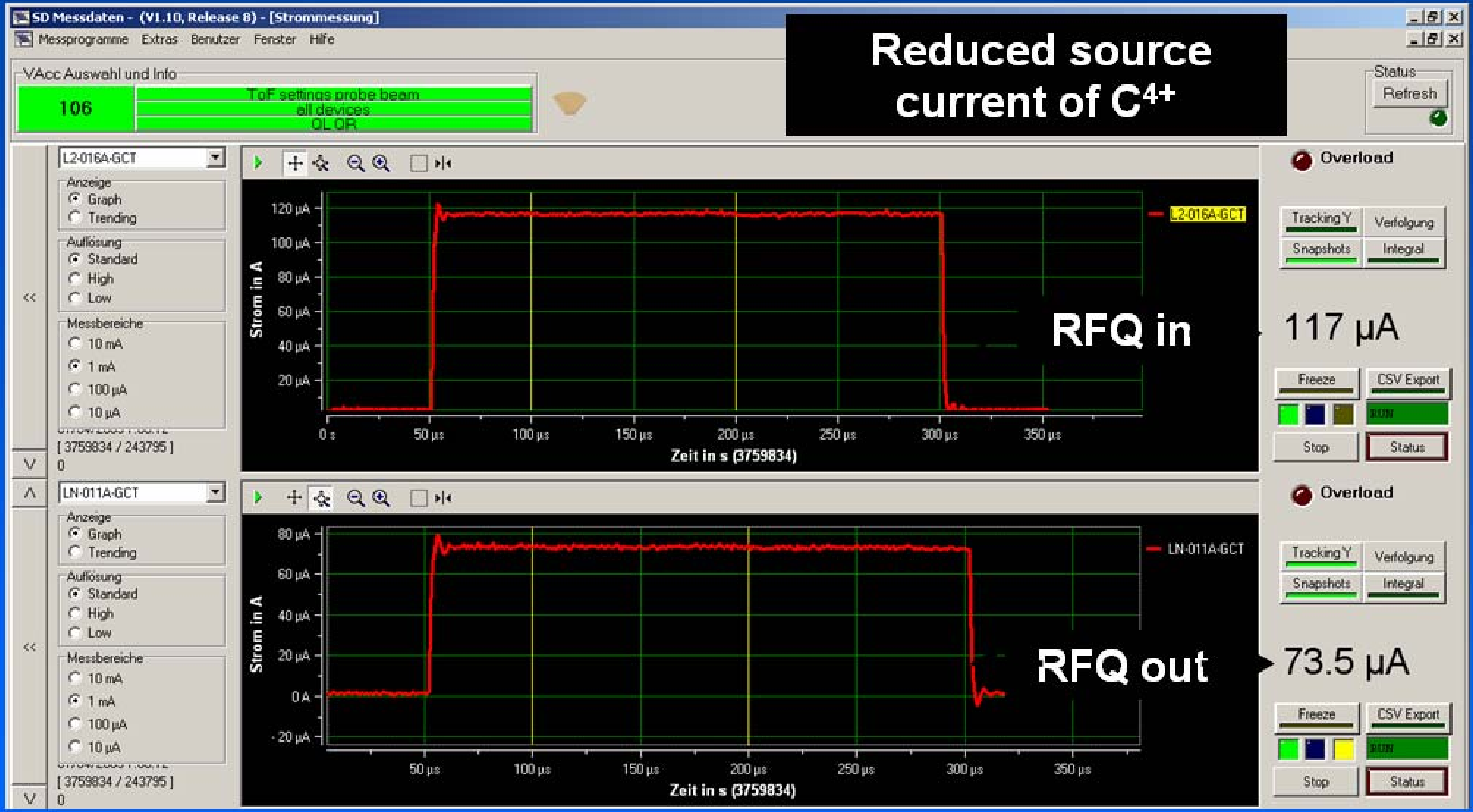
RFQ produced in collaboration with GSI



In 1,5 meters the beam increases its energy by a factor 50 – from 8'000 eV/u to 400'000 eV/u

Successfully commissioned in March 2009

RFQ commissioning completed



Transmission efficiency:

63%

Gross plan:
Start overall commissioning summer 2009
Start treatments in 2010

Heidelberg Ionenstrahl-Therapie Centrum

Outlook

- Particle therapy will cover the full spectrum of radiotherapeutical indications
- Per 10 million inhabitants one particle therapy facility may be required
- Treatments will be fully accepted by the health insurance systems