Tumor Therapy with Heavy Ions at GSI Darmstadt

D. Schardt GSI / Biophysik for the Heavy-Ion Therapy Collaboration

The GSI Pilot Project

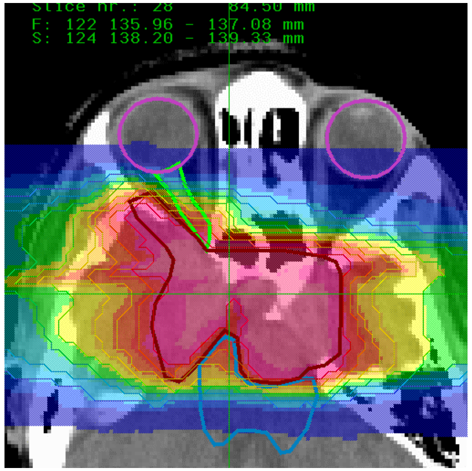
Treatment room at GSI

Interdisciplinary project
Univ. Clinics and Cancer Research Center Heidelberg
GSI Darmstadt, FZ Rossendorf (Dresden)

260 patients treated since Dec.1997
Local head/neck and spinal/sacral tumors

New clinical-based project HIT in Heidelberg
Operational in 2007

Patient immobilization



Treatment plan

Ion Beams in Radiotherapy

1946 R.R. Wilson, Radiology 47,487
„potential benefits of heavy charged particles in radiotherapy“

				patients
1957 - 92	^{4}He	184-inch SC	Berkeley	2054
1975 - 92	^{20}Ne	BEVALAC	Berkeley	433

Current ion-beam facilites:

1994	^{12}C	HIMAC	Chiba	1800
1997	^{12}C	SIS-18	Darmstadt	260
2003	^{12}C	HIBMC	Hyogo	30

Projects for clinical facilities in Austria, China, Germany, Italy…

Ion Beam Therapy Pilot Project at GSI

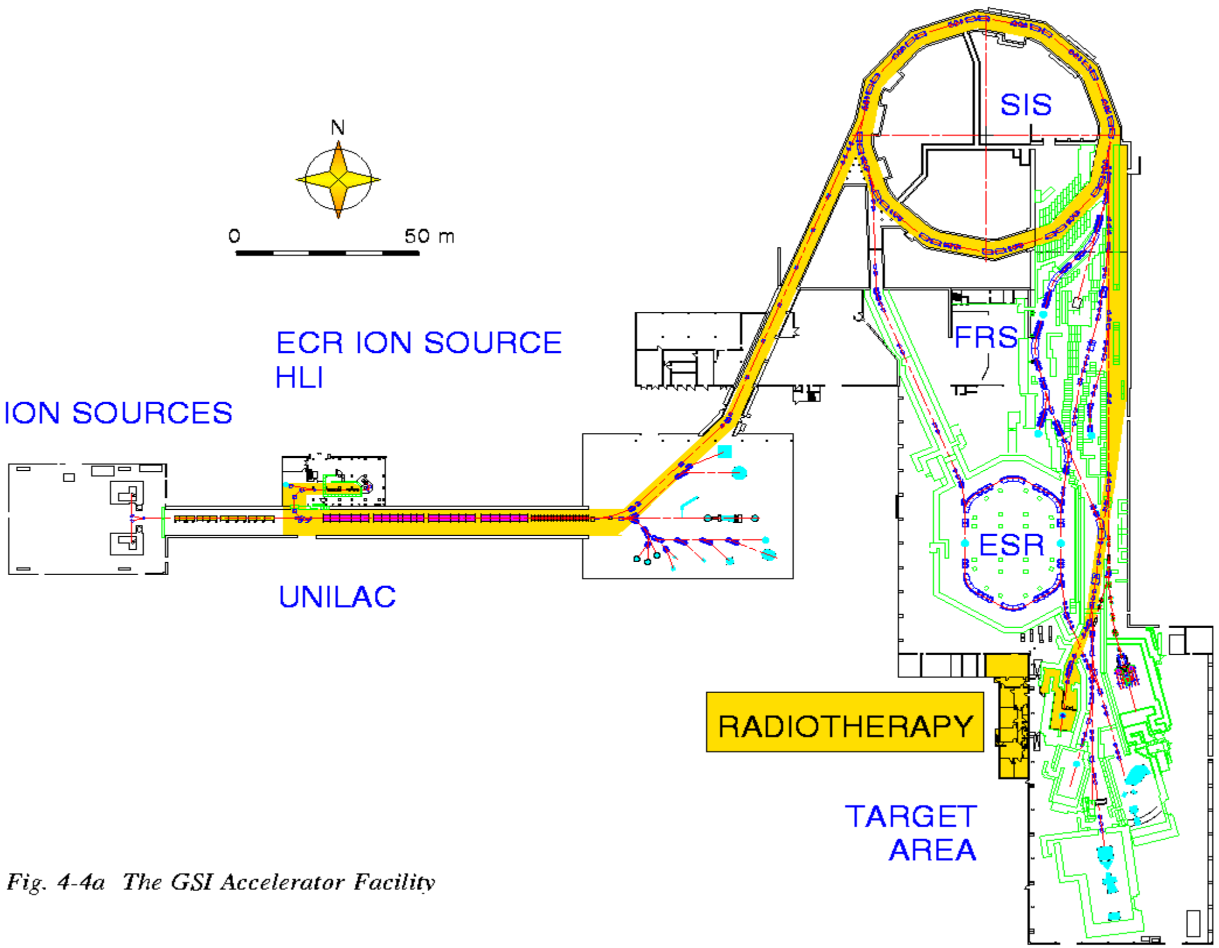


Fig. 4-4a The GSI Accelerator Facility

Ion Therapy Pilot Project at GSI

GSI Darmstadt - Radiol. Clinics Heidelberg-
DKFZ Heidelberg - FZ Rossendorf

Time Table

1993 – 1997	Construction phase
Dec. 1997	First patient treatment
1998 – 2007	Treatment of ~ 40 patients per year Tumors in head/neck and pelvic region
2007	End of pilot project

Future: HIT **H**eidelberg **I**on Beam **T**herapy
Clinical Operation 2007

Technical Data

Beam: ^{12}C ions 80 - 430 MeV/u

Intensity-controlled rasterscan system

Operation: 3 Treatment blocks of 20 d per year

→ Time sharing with physics experiments

Cost: 6 Million EUR (Investment)

Carbon Ion Radiotherapy

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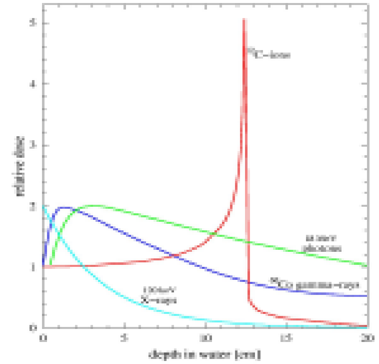
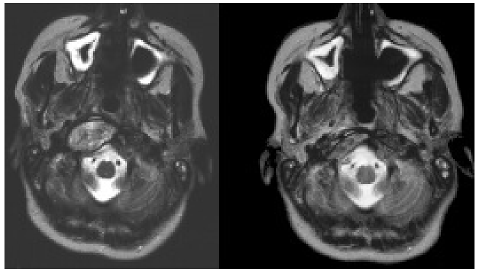
1. **Advantages of ion beam therapy**



2. **Clinical results**



3. **Status of the HIT-project**

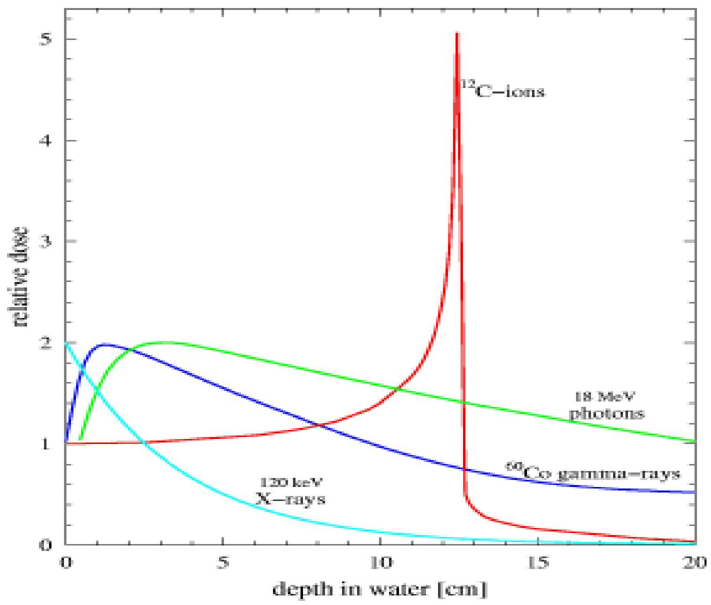
Clinical advantages of heavy-ion beams

- **Excellent depth-dose profile (Bragg curve)** *p, ions*
- **Increased biological efficiency** *only ions*
- **Tumor-conform treatment** *p, ions*
  beam scanning + energy variation
- **In-vivo range localisation** *(p), ions*
  Positron-emitting beam fragments (PET)

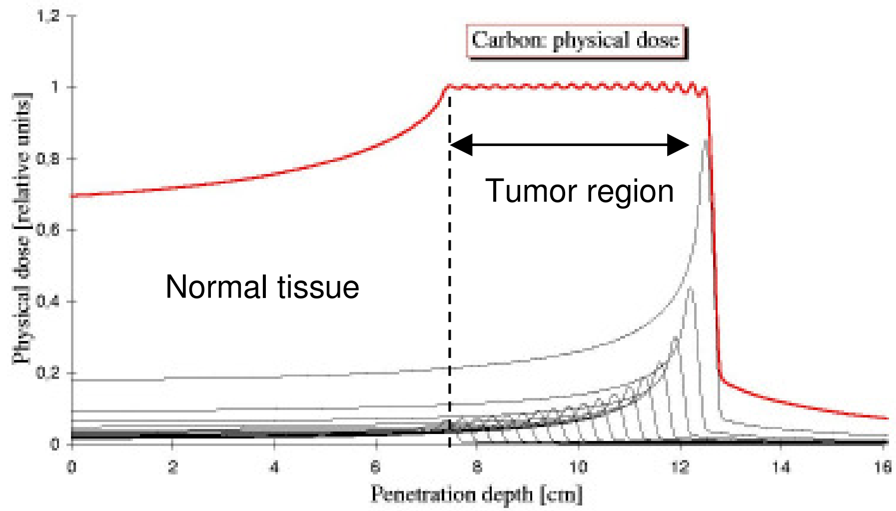
Clinically relevant properties of heavy-ion beams

➡ **Inverted depth-dose profile (Bragg curve)**

Unmodified Bragg peak



Extended target volume



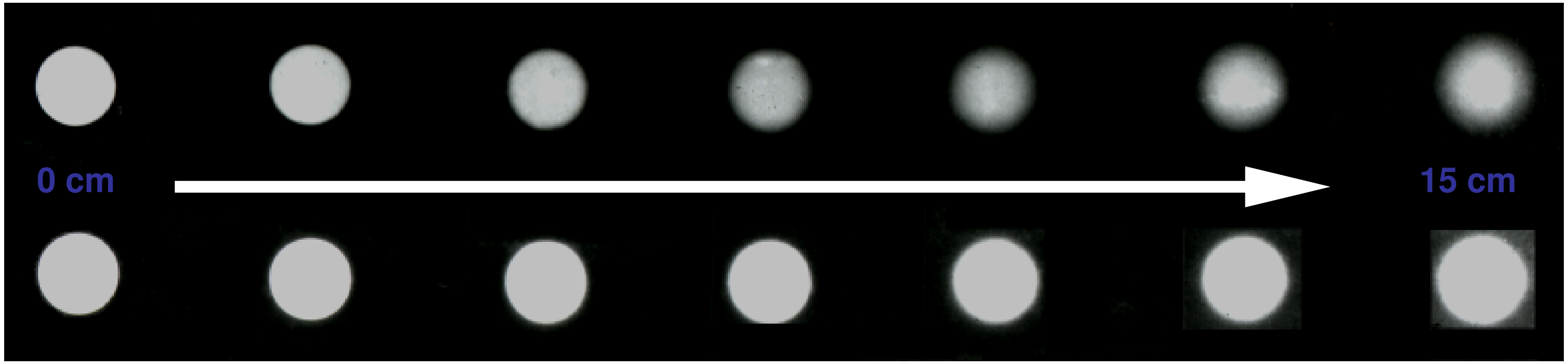
Typically 30 energy steps needed

for a ripple < 5%

Lateral beam spread

Film dosimetry, LBL Berkeley

Protons

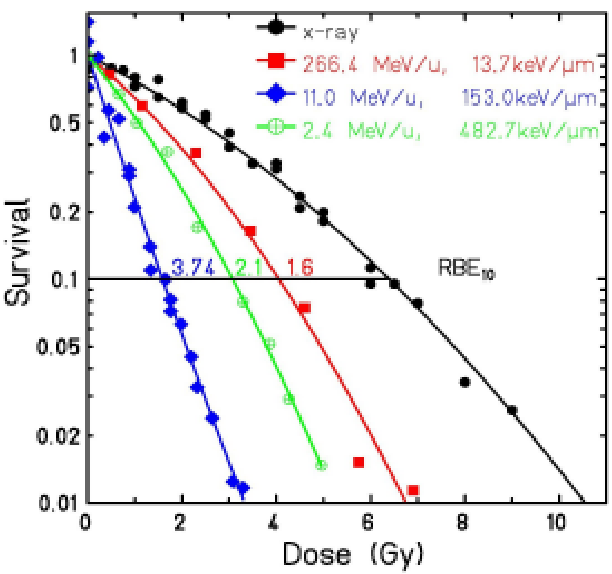


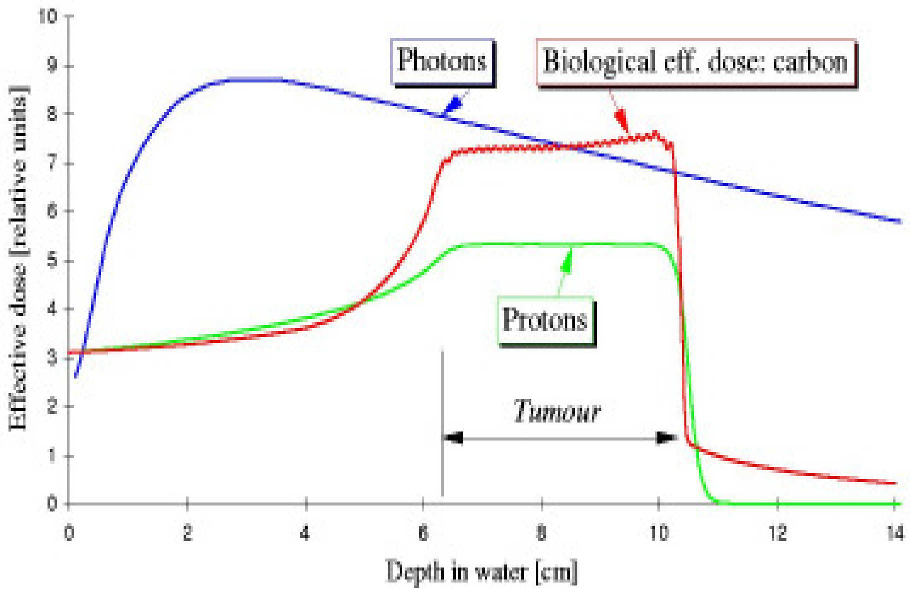
^{12}C ions

Clinically relevant properties of heavy-ion beams

➡ **Increased biological efficiency**

Survival curves
CHO cells

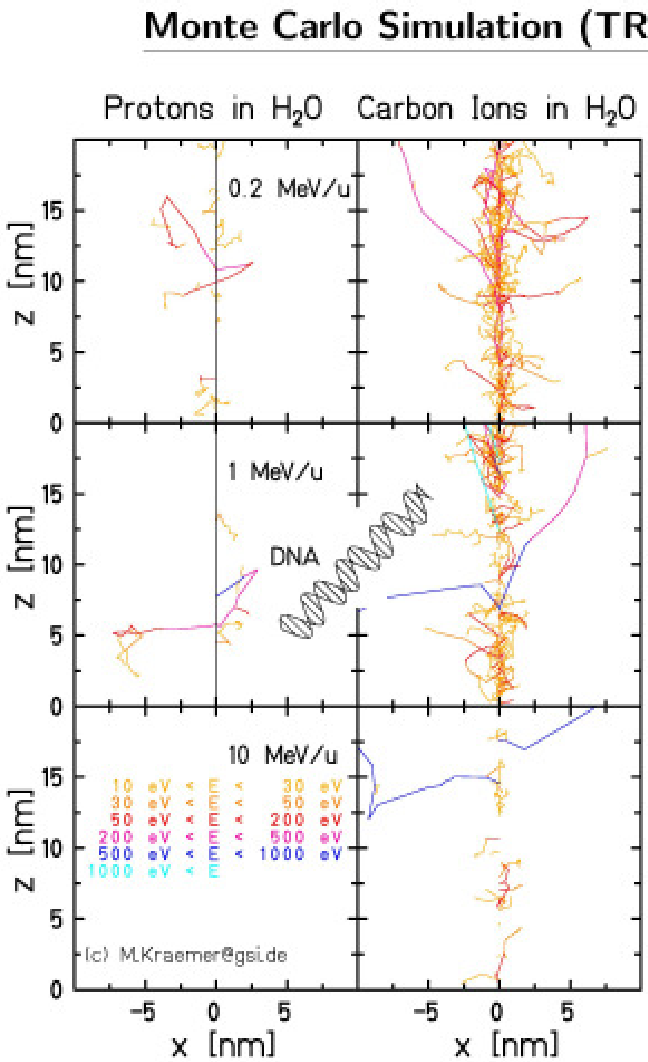




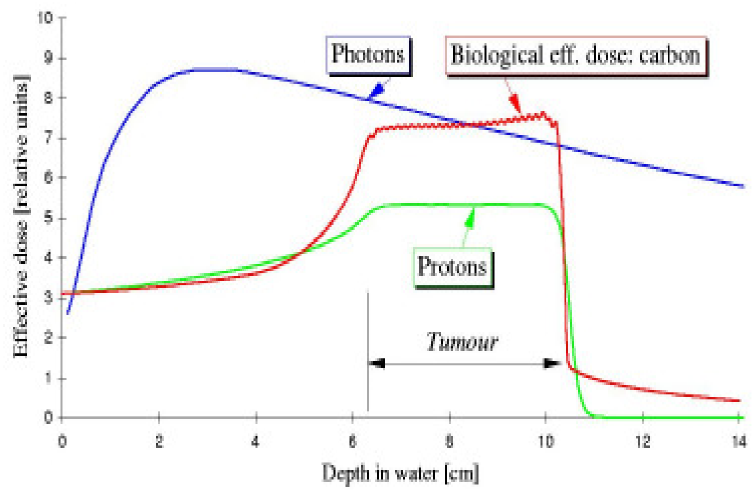
$$\mathrm{RBE} = \left[\frac{D_\gamma}{D_p}\right]_{\mathrm{Isoeffect}}$$

$$\mathrm{Biol.\,Effect} \propto \int f(Z,E)\cdot \mathrm{LET}(Z,E)\cdot \mathrm{RBE}(Z,E)\,dV$$

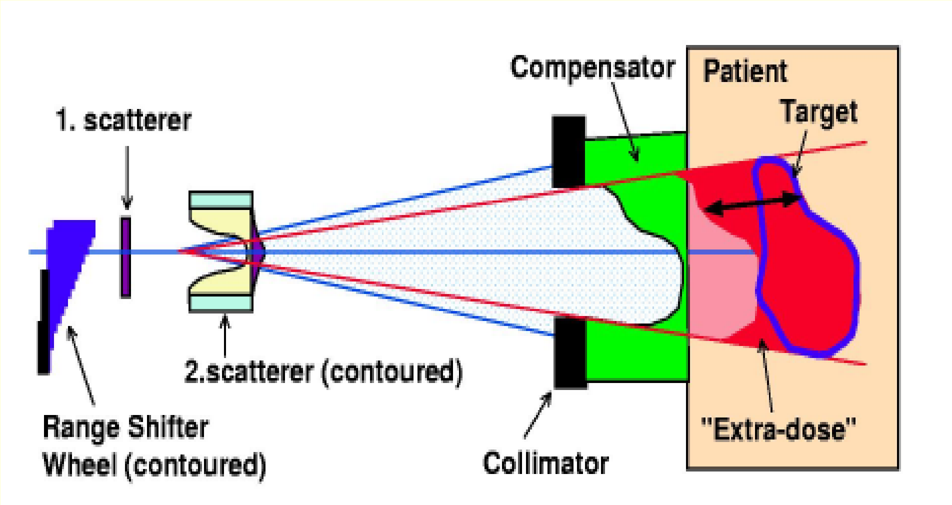
Track structure



➡ **Increased biological efficiency**



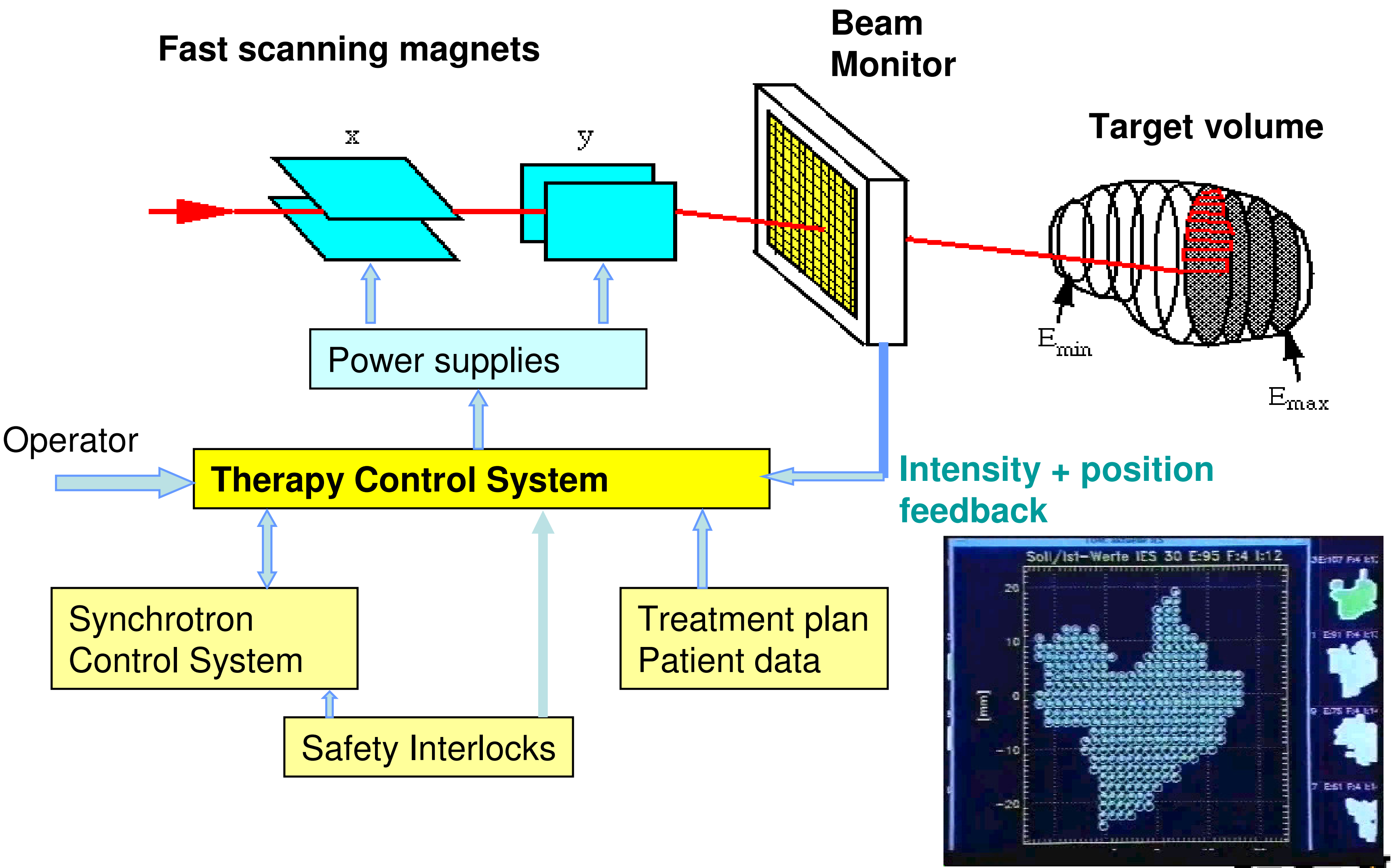
Beam delivery systems



passive system

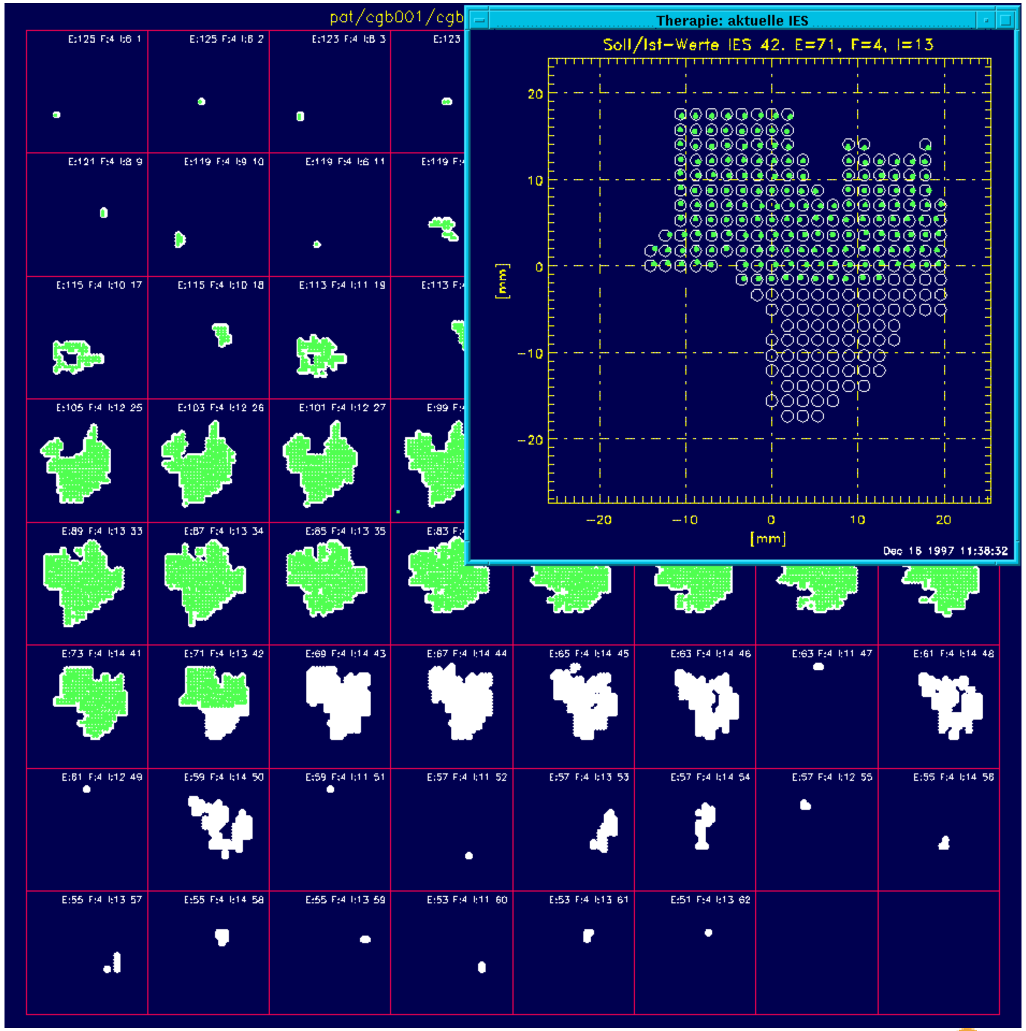
➡ **much better: Intensity-controlled beam scanning**

Intensity-controlled raster scan

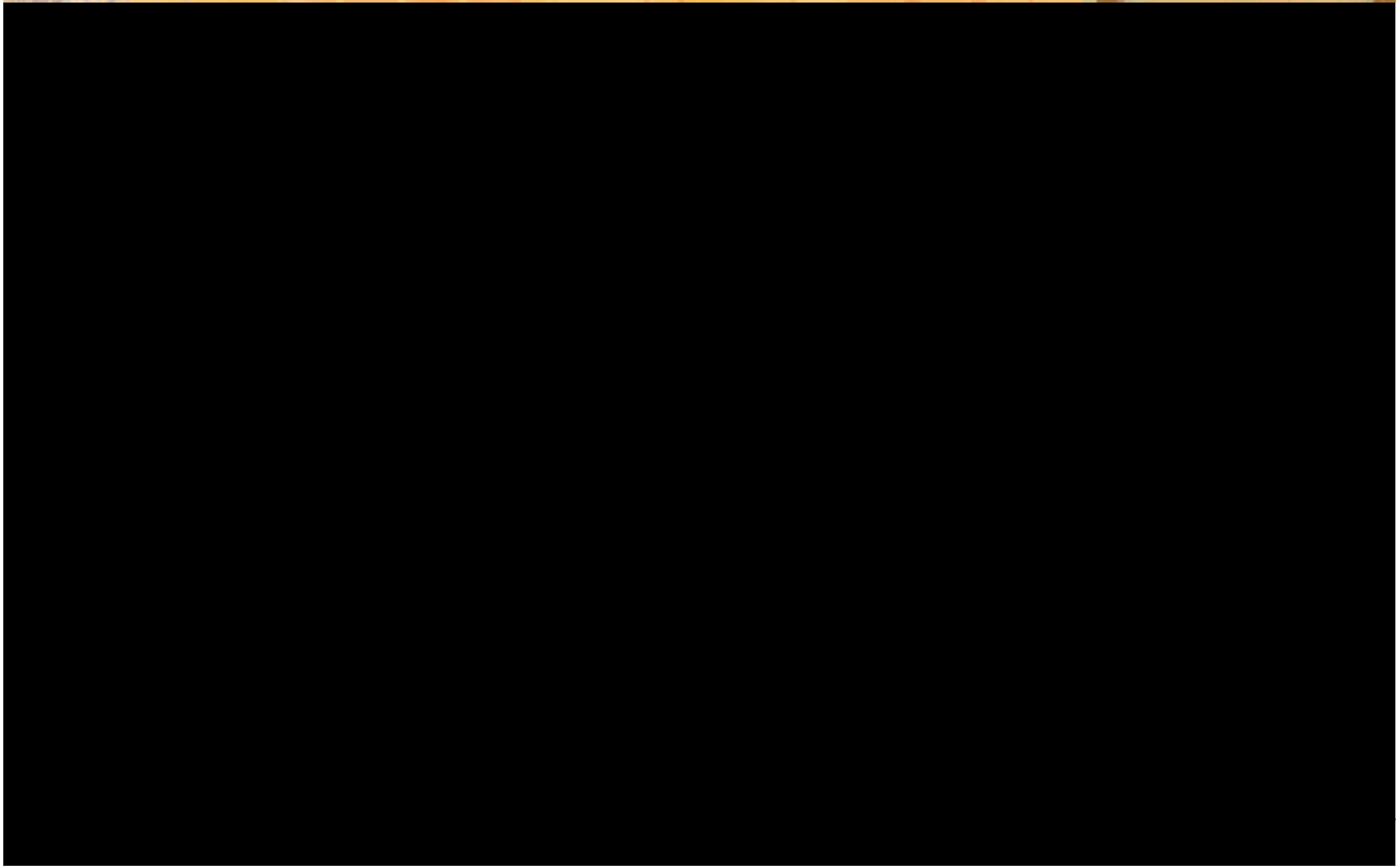


Therapy Online Monitor (TOM)

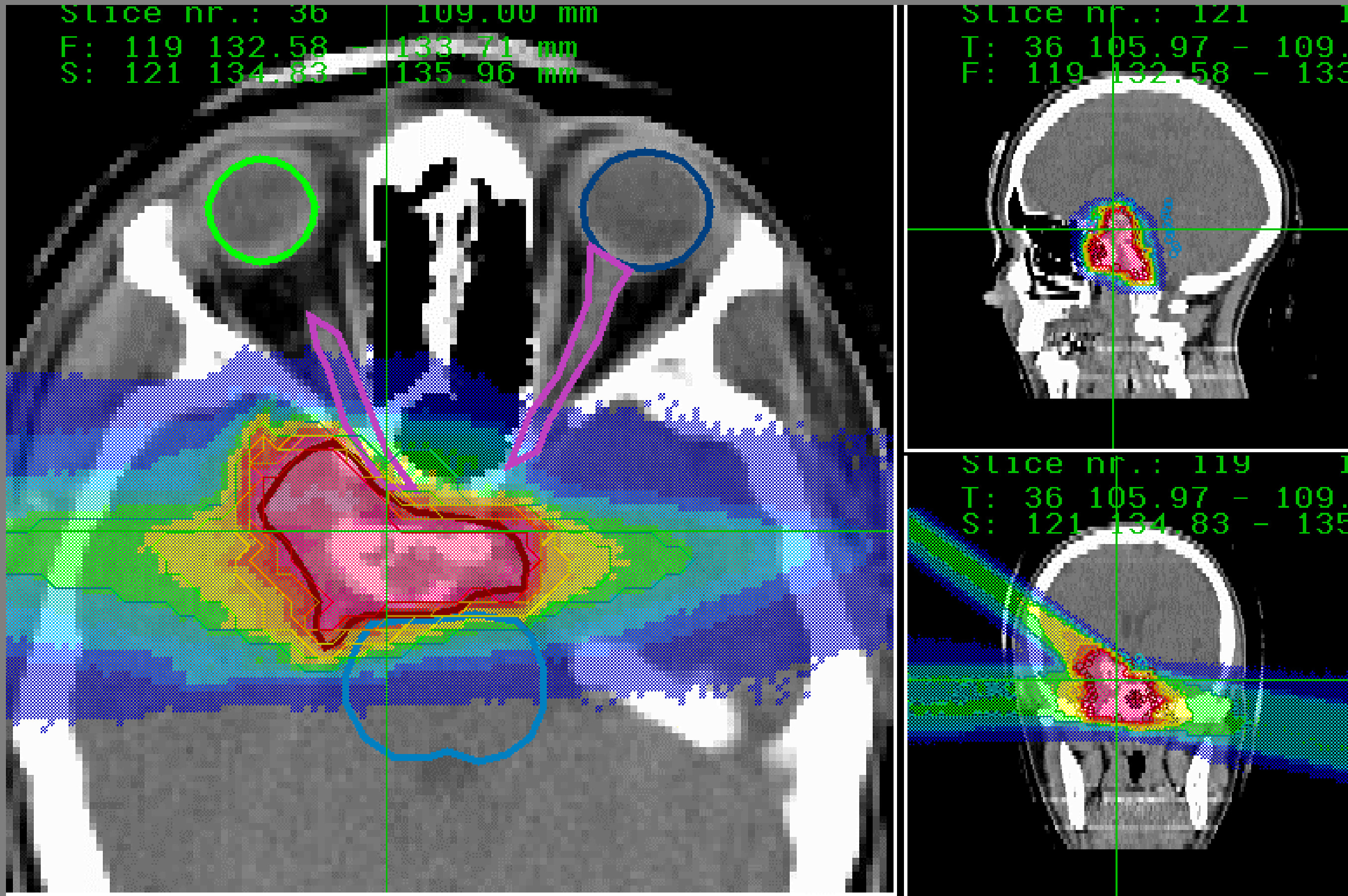
- Iso-Energy slices
- typ. 20.000 beam positions in a treatment plan
- Beam position checked every 150 µs



Rasterscan irradiation

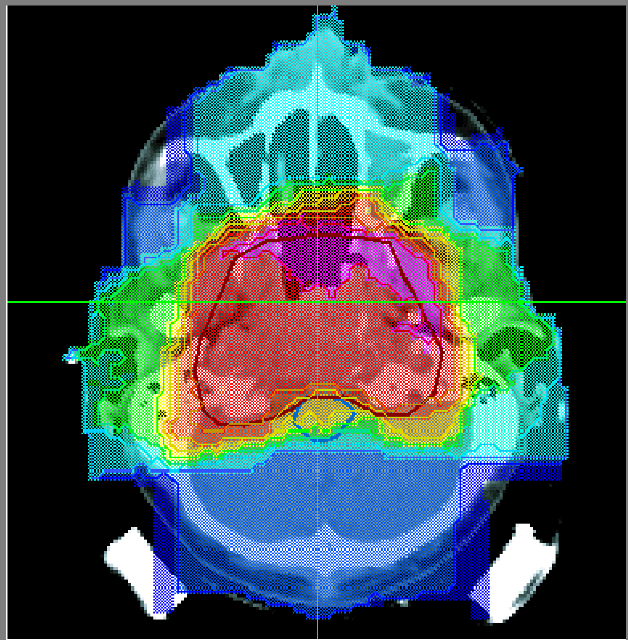


Treatment plan for a Chondrosarcoma, Carbon beam 3 fields

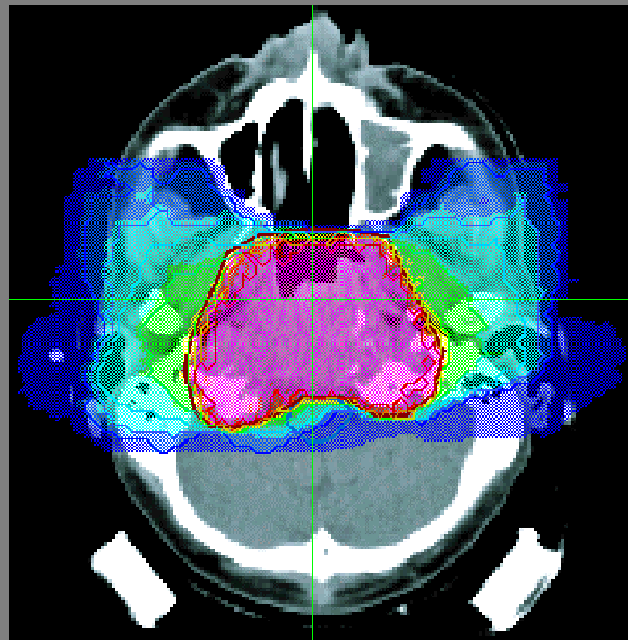


Tumor-conform irradiation

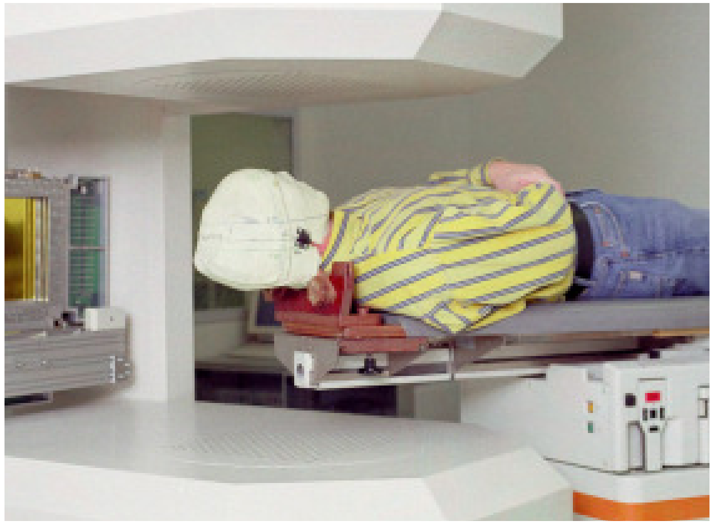
Photons 4 fields



Carbon ions 2 fields

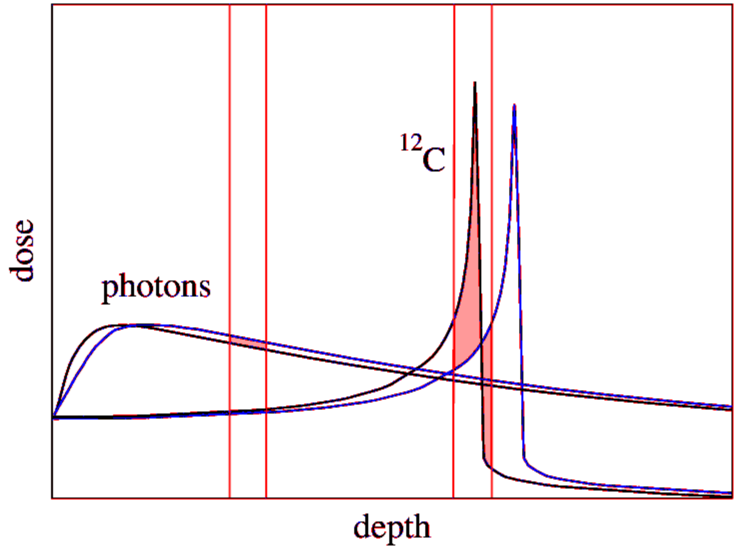


Extension to moving targets

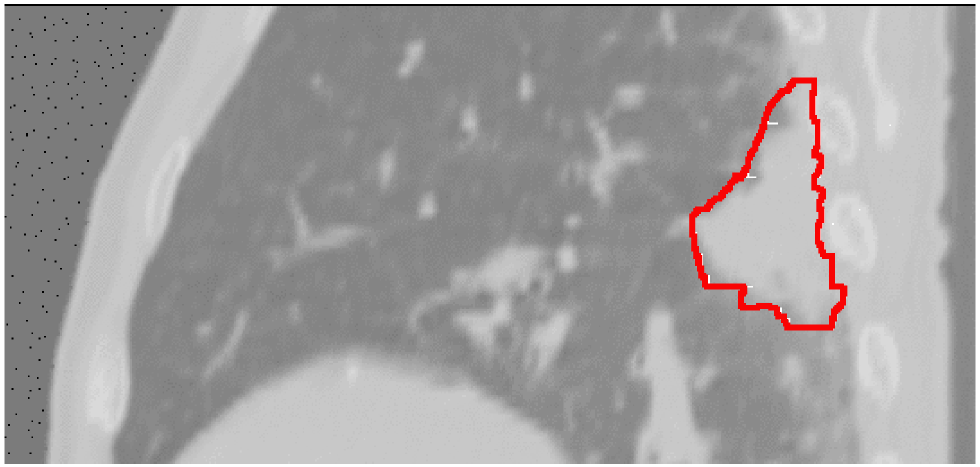


precision of stereotactic fixation:

1mm in the head to
3mm in the pelvic region

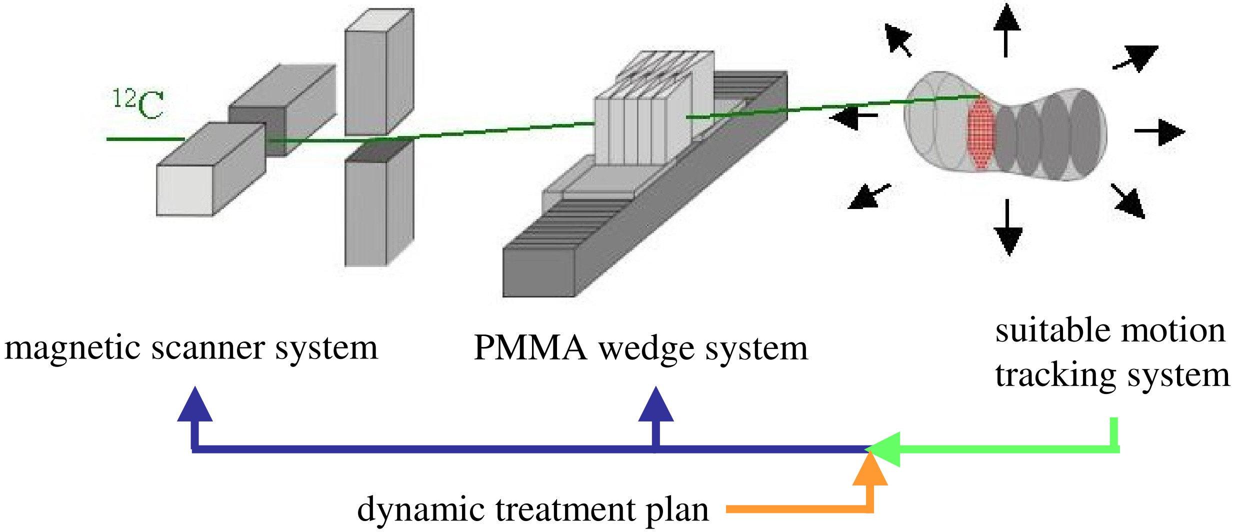


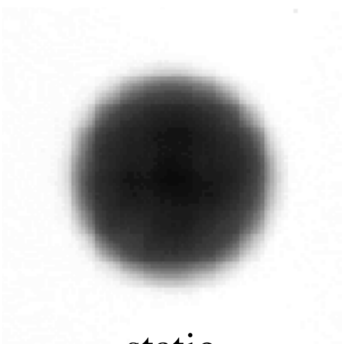
for ions: variations in radiological path length extremely important



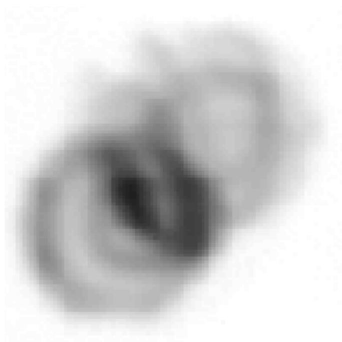
not feasible for regions with internal motion
e.g. respiration in thorax and abdomen

3D online motion compensation (3D-OMC)

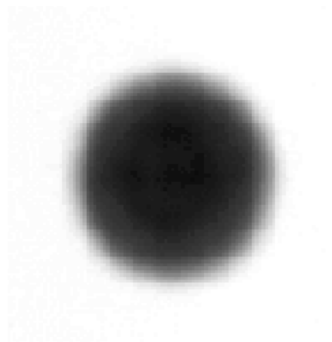




static



moving,
non-compensated



moving,
compensated

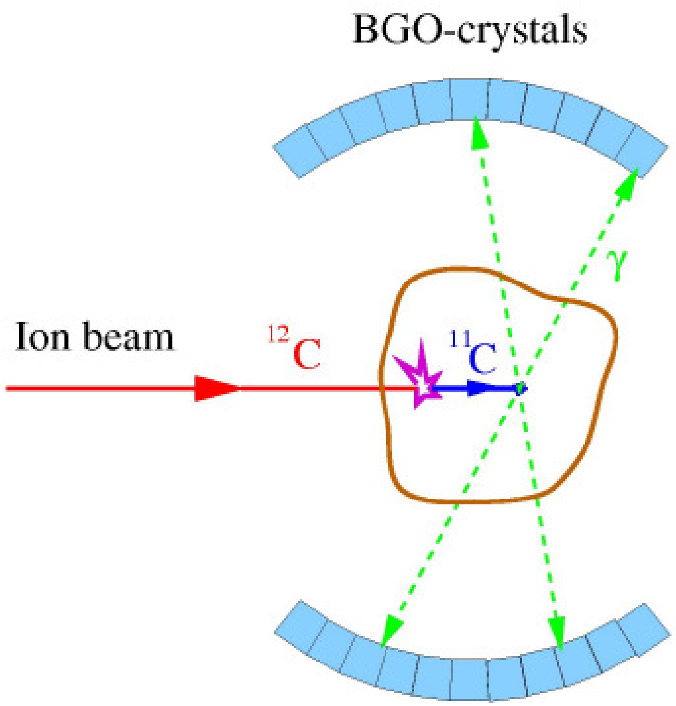
➢ real-time, highest precision

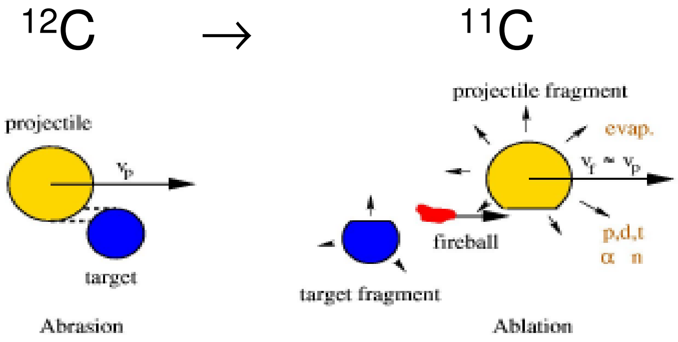
Verification of beam delivery

➧ **In-beam PET monitoring**

In-beam PET-Monitoring

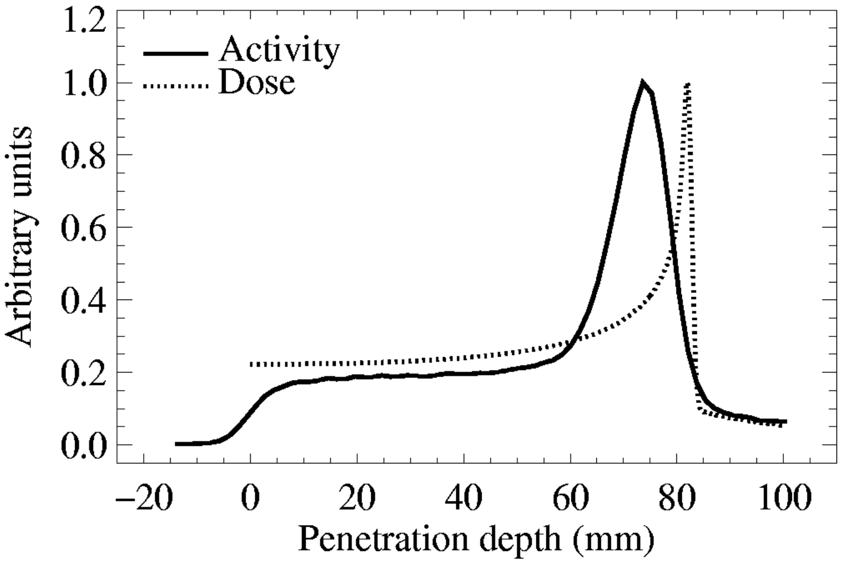
Formation of positron-emitters by projectile fragmentation



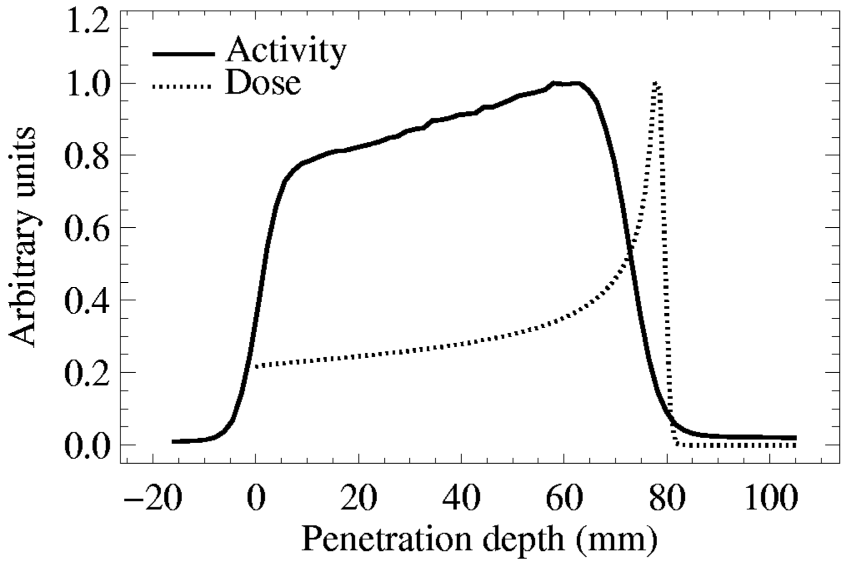


In-beam PET-Monitoring

carbon ions



protons

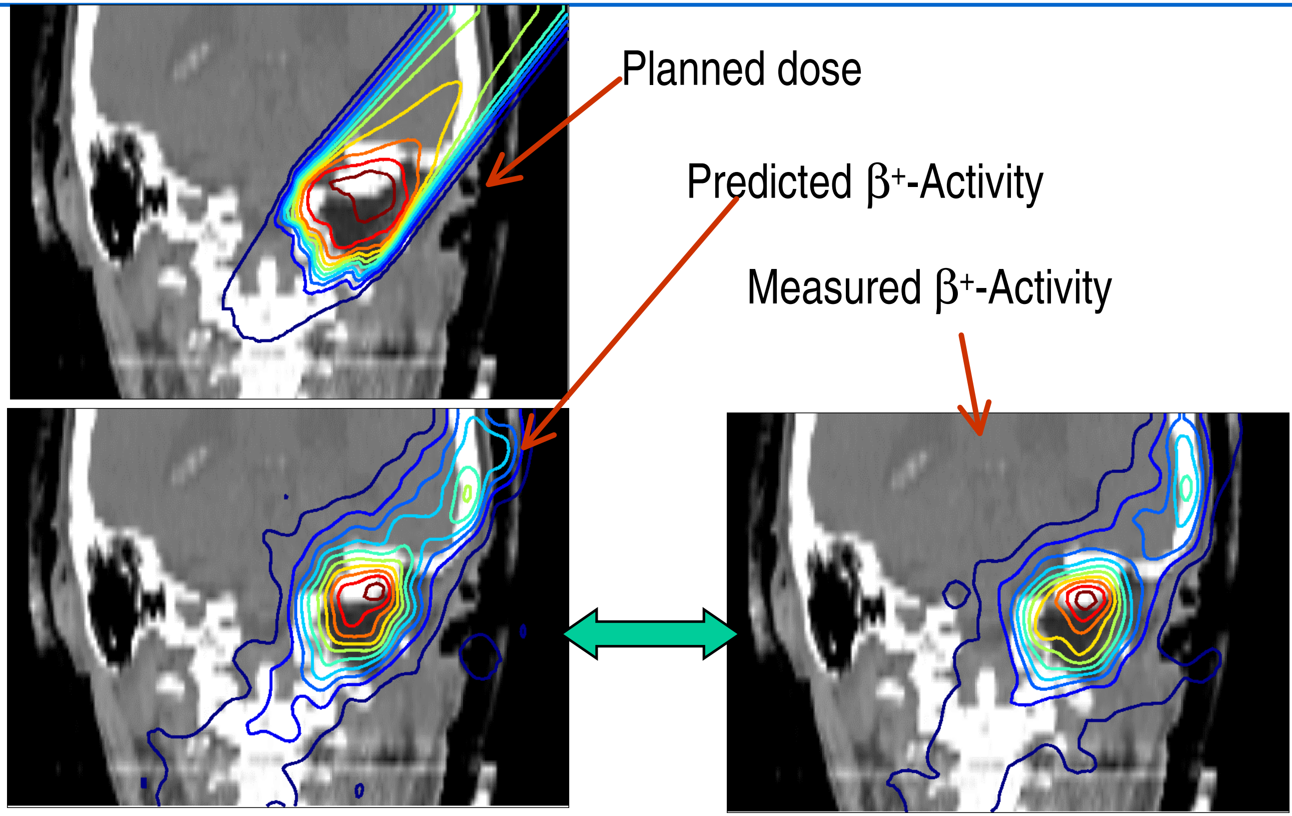


Activity density:
~ 200 Bq cm^{-3} Gy^{-1}

Compare with tracer imaging:
10^4 – 10^5 Bq cm^{-3},
even 10^6 Bq cm^{-3} (mice PET)

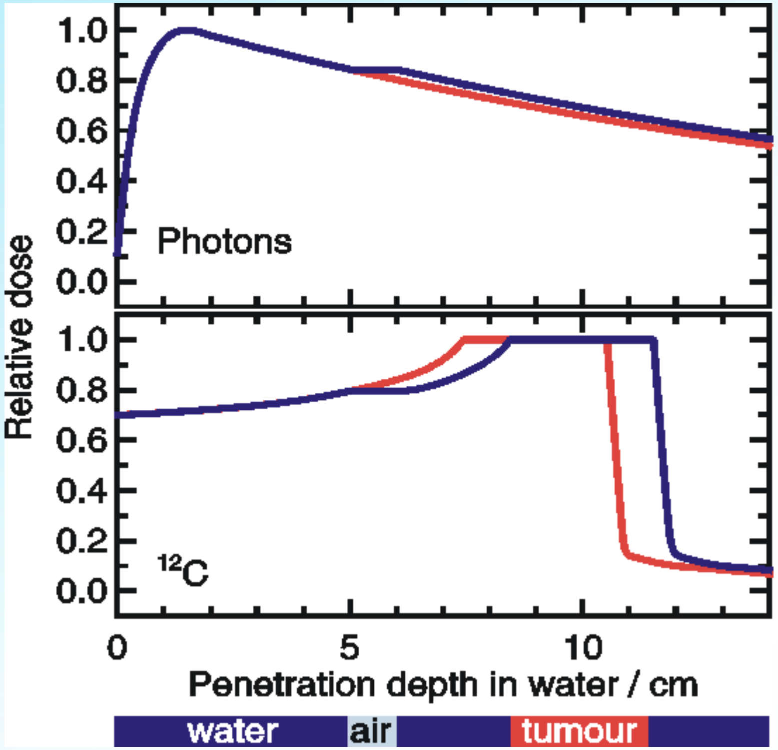
In-beam PET monitoring of carbon ion therapy at GSI

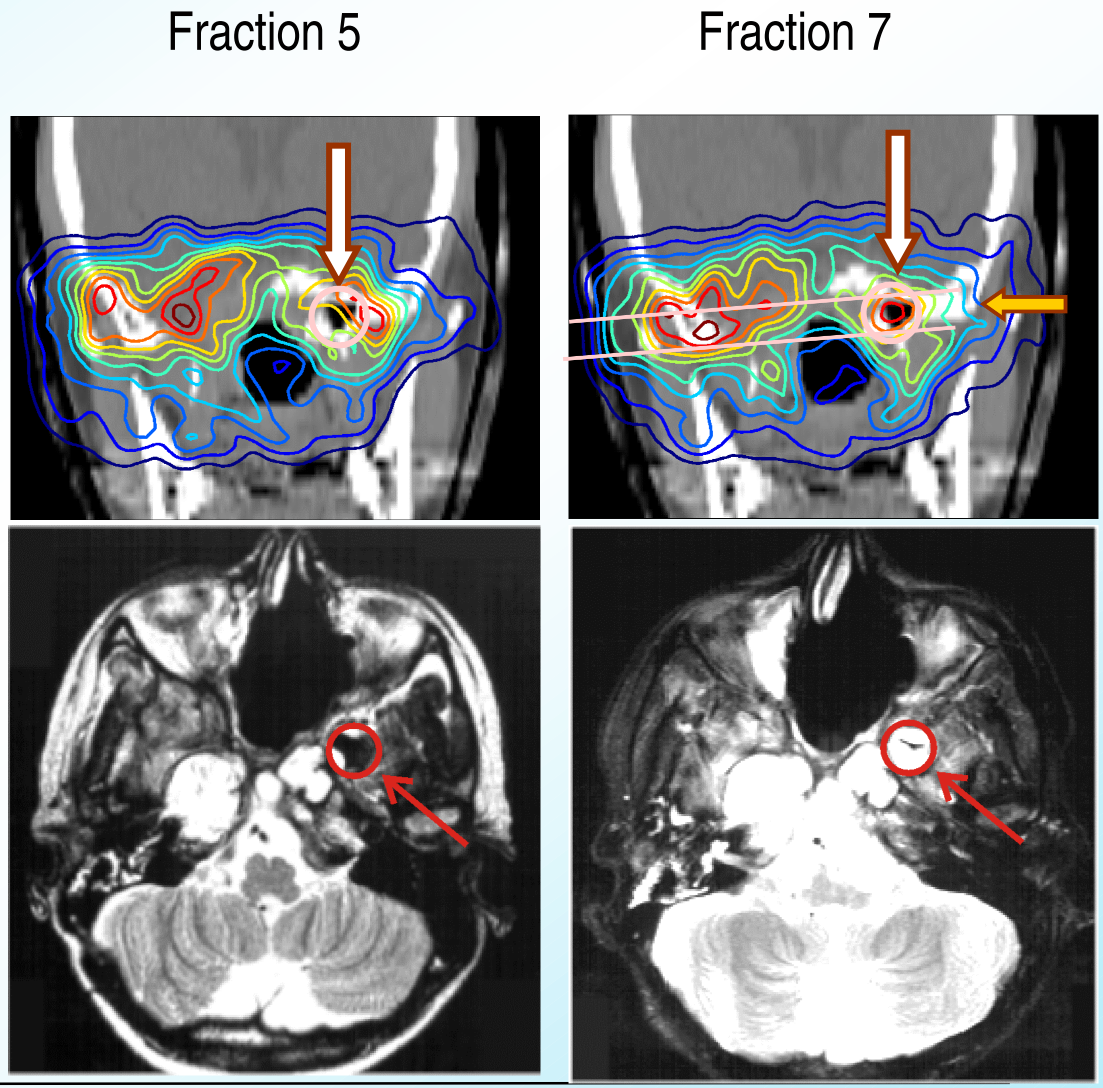
W. Enghardt et al., Nucl. Phys. A 654, 1999



- Control of the carbon ion range
- Verification of field position
- Detection of deviations between real and planned treatment (misalignments or local anatomical changes) => Effect on dose?

Clinical results:
The detection of tissue density modifications





Local density modifications:

- filling of cavities with mucus
- tissue reduction after surgery
- slight mispositioning

Clinical results

- Tumor regression
- Local tumor control
- Side effects

Patient treatments

12/2003 n=205

chordoma / chondrosarcoma SB	**81/42**	**123***
sacral / spinal chordoma / CS		**22**
Adenoid cystic carcinoma		**30**
Other skull base tumors		**15**
Reirradiations skull base		**15**

***67 treated within phase I/II study**

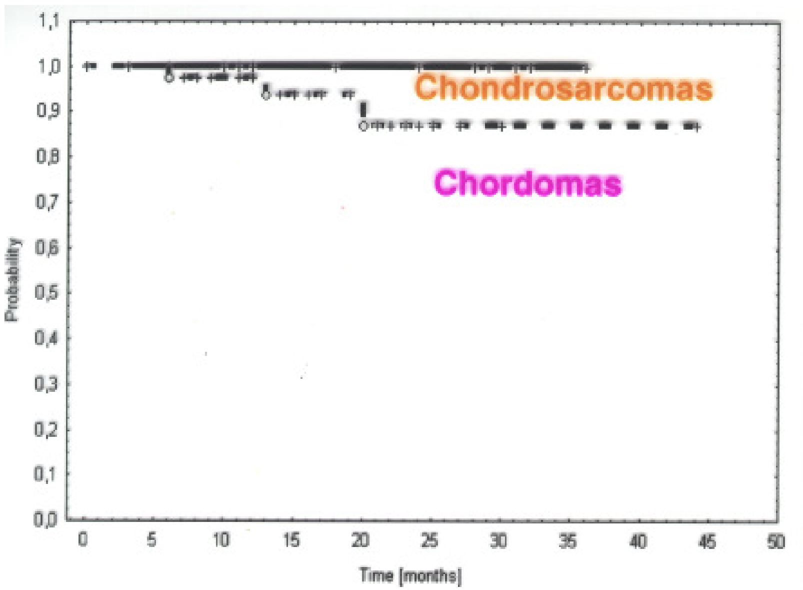
Chordomas / Chondrosarcomas
Results of Radiation Therapy

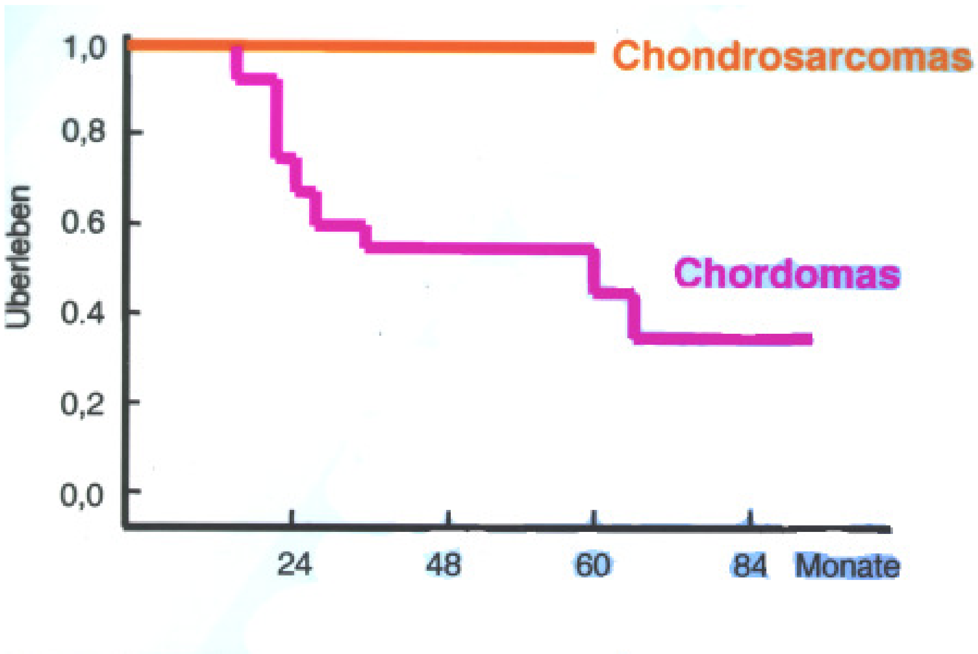
Author, year	n	RT	local control
Romero, 1993	18	conv.RT	17% (CH)
Debus, 2000	45	FSRT	50%/5y (CH) 100%/5y (CS)
Munzenrider, 1999	519	Prot. (+ Phot)	73%/5y (CH) 98%/5y (CS)
Castro, 1994	223	He	63%/5y (CH) 78%/5y (CS)
Noel, 2001	67	Prot + Phot	71%/3y (CH) 85%/3y (CS)
Schulz-Ertner, 2003	67	C12	81%/3y (CH) 100%/3y (CS)

Local tumor control

Carbon

photon IMRT





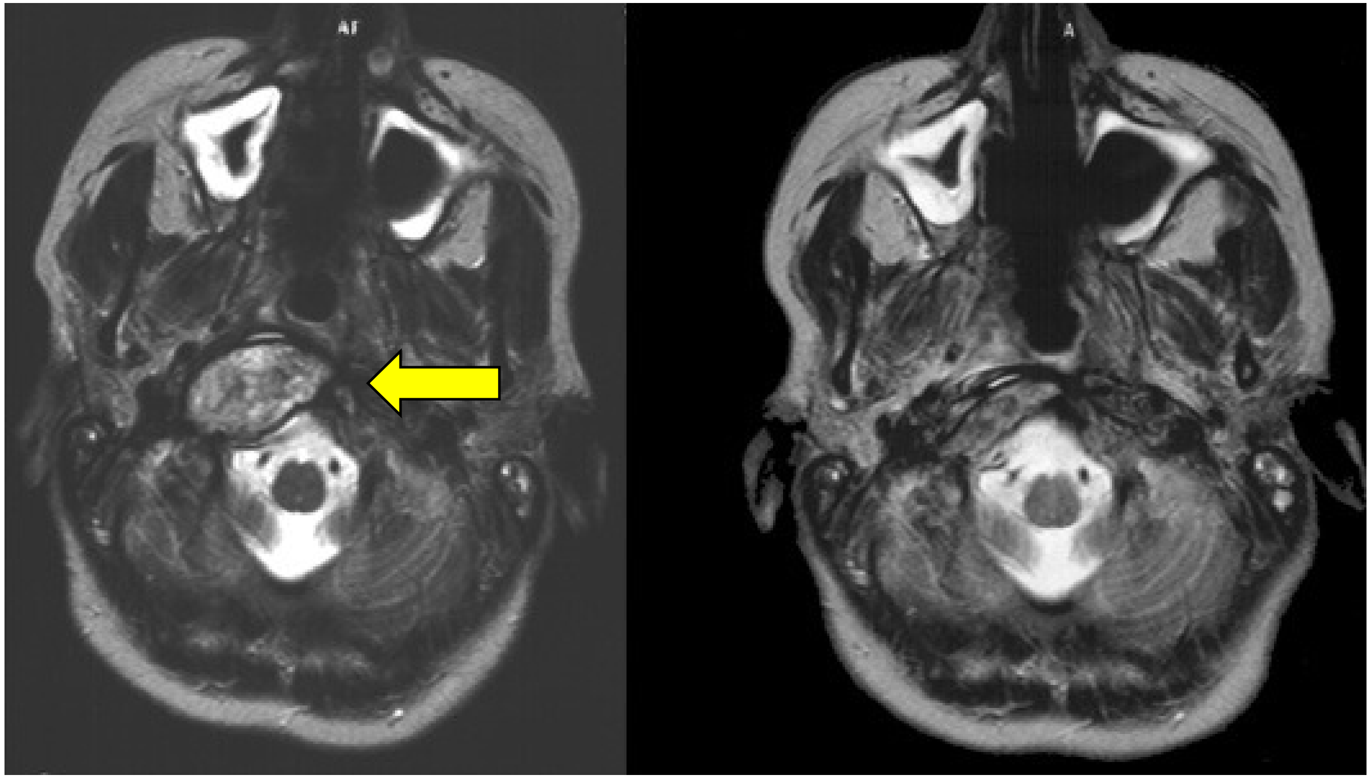
Debus et al., 5/2000

Tumor regression

Prior to therapy

3 months after carbon ion therapy
total tumor dose 60 GyE

Tumor regression (Chordoma)

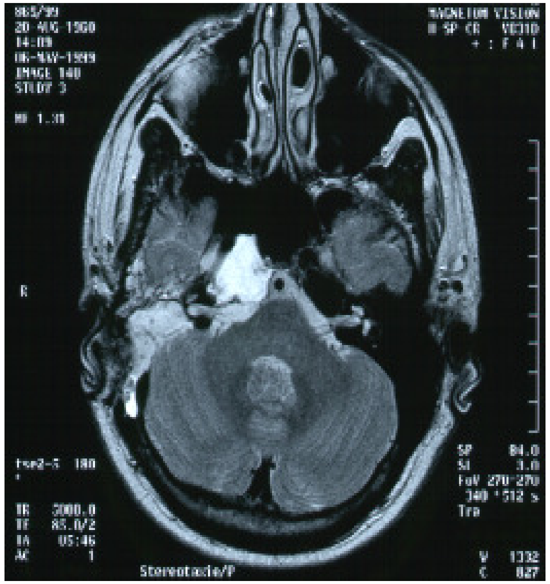


Prior to therapy 6 weeks after treatment

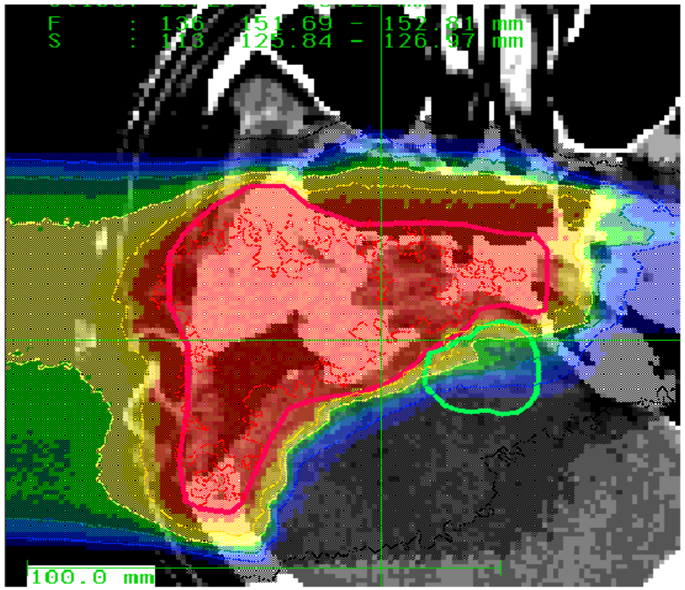
Petroclivale Chondrosarcoma

Prior C12-RT

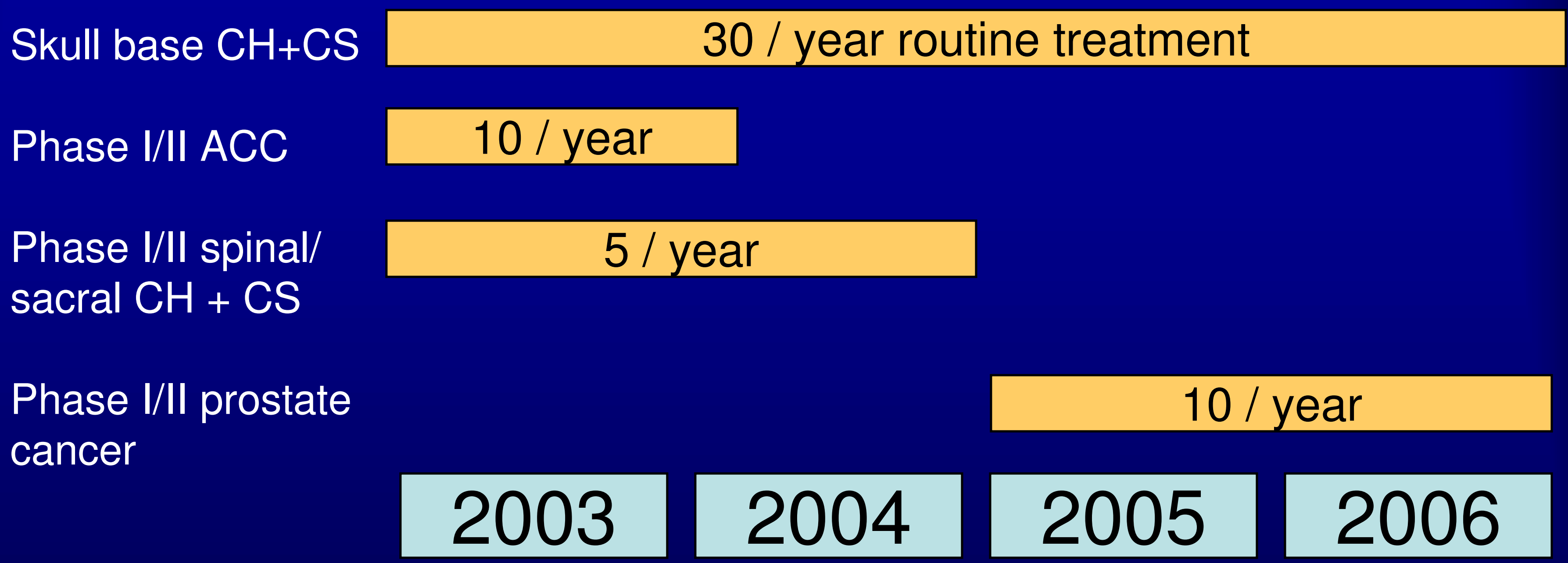
6 weeks after C12-RT



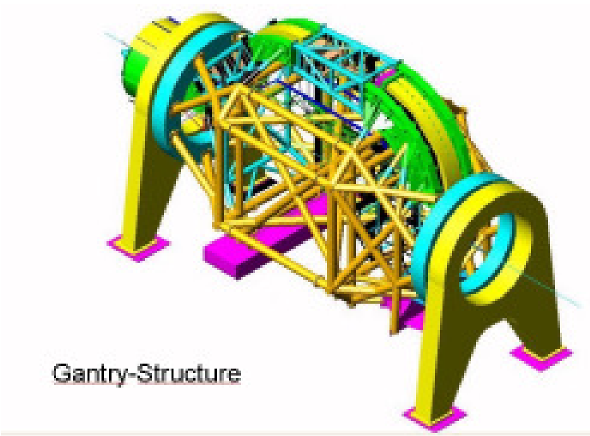
Recurrent Chordoma
60 GyE



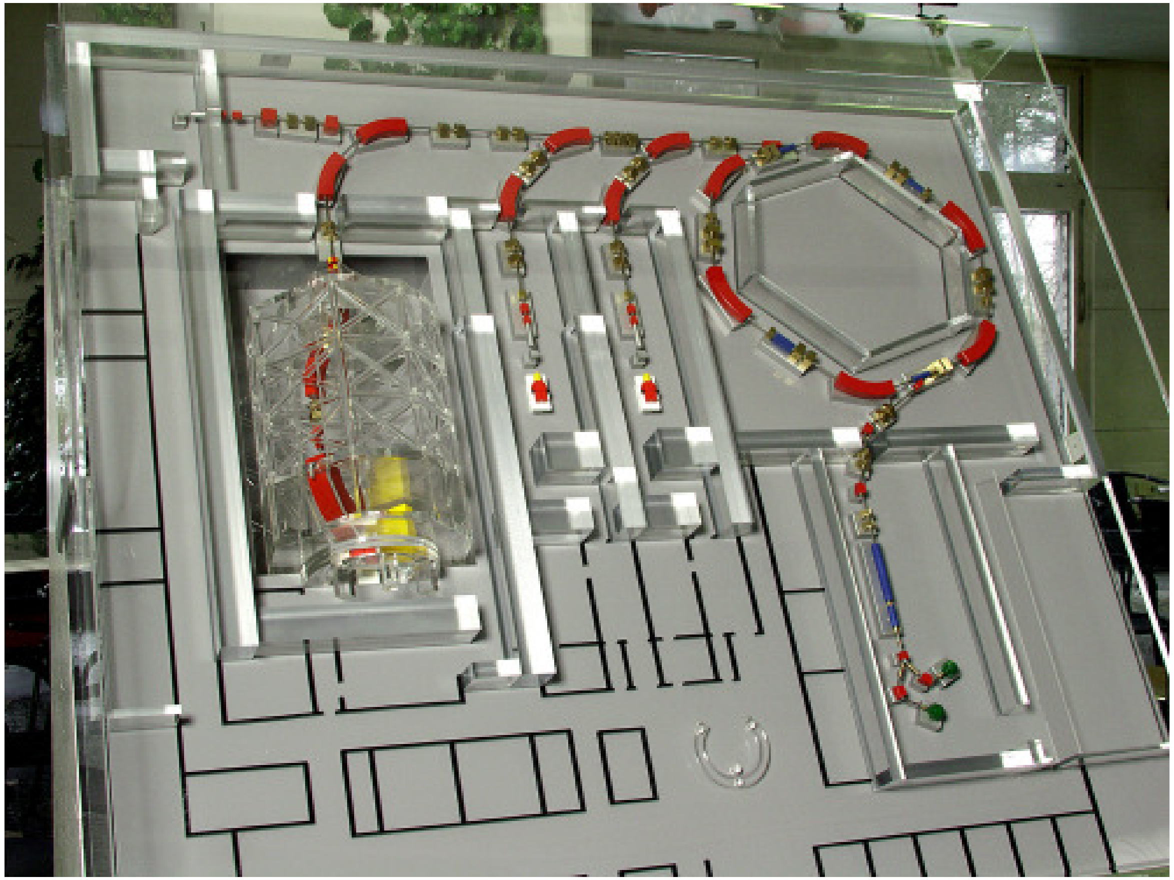
Time table for clinical studies at GSI



The Heidelberg project HIT



1 Isocentric Gantry (360 deg.) and 2 horizontal treatment stations



Heavy-ion Gantry

Weight: 600 t
25 m long
13 m diameter
Deformation < 0.5 mm

Manufacturer: MAN

Design capacity:
1000 patients/year

Time table HIT project

05/ 2004	Laying the foundation-stone
05/ 2005	Ion sources and LINAC commiss.
06/ 2005	Start Gantry installation
11/ 2005	Synchrotron comiss.
04/ 2006	Gantry comiss.
11/ 2006	Clinical operation of 2 horizontal stations
End 2007	Clinical operation total facility

The Heidelberg project HIT

The Heidelberg project

Groundwork May 2004

The Heidelberg project HIT

Summary

– Heavy-ion beams offer favorable conditions for the treatment of deep-seated local tumors
  → *Depth-dose profile and enhanced RBE in the target volume* **ion**

– Highly tumor-conform treatment p, **ion**
  → *Beam scanning + active energy variation*

– In-vivo irradiation monitoring p, **ion**, **RIB**
  → online PET-system

– Encouraging clinical results

– **Construction of clinical ion-facilities in progress**
  → HIT (Heidelberg), TERA (Milano), MedAustron (Vienna)