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Gantry Workshop 2007

„Concept and Performance of the RPTC Gantry Systems“

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Concept and Performance of the RPTC Gantry Systems

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Typical Spatial Precision Requirements

- Beam position: 1-mm-radius sphere around isocenter

Contributions:

- Gantry deflections
- Beam optics (particularly for scanning systems)

► Pencil Beam Scanning aims at sub-millimeter precision ◀

- Patient position: 1-mm-radius sphere around isocenter

Contributions:

- Treatment table precision
- (X-ray) position verification precision (position of tubes and receptors, image quality, geometry calibration, image matching algorithm, users judgment)
- Patient immobilization
- Precision of planning CT and treatment planning

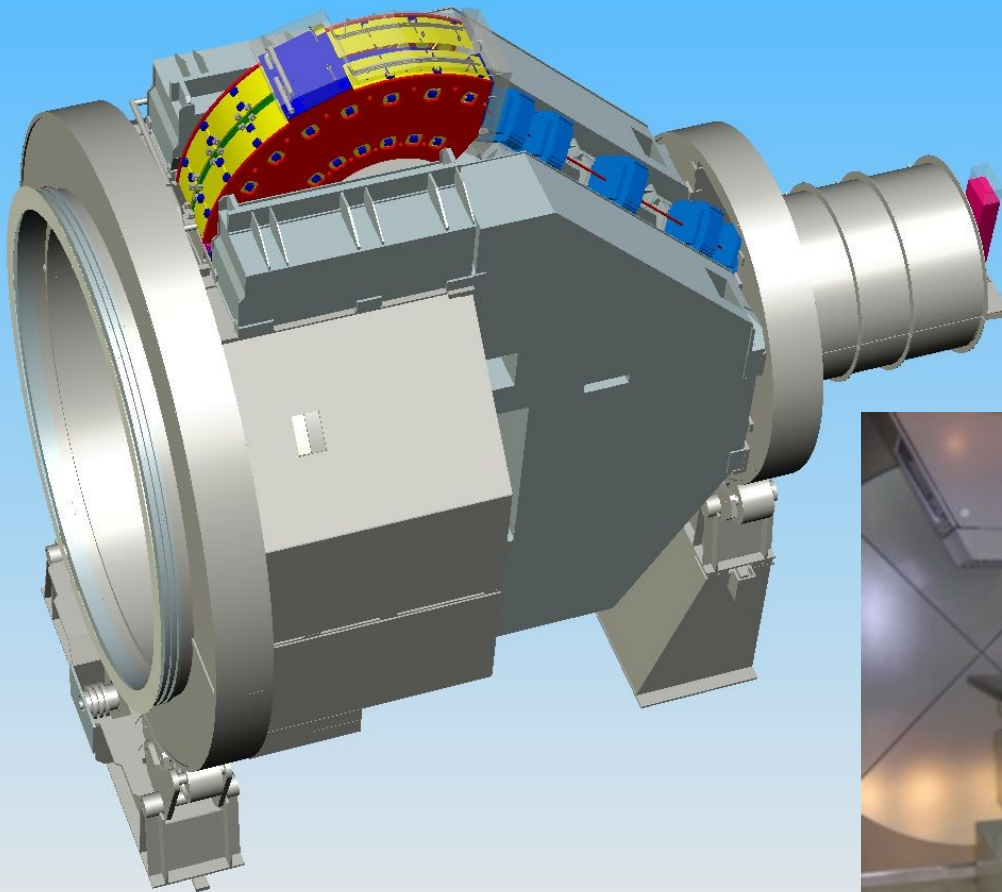
► Sub-millimeter precision should be achievable within this **whole** framework ◀

Patient Throughput

Patient throughput is a major requirement for all clinical facilities!

- Reduce all (positioning) procedure-durations to minimum possible
- Keep maximum possible (positioning) precision

The RPTC Gantry



Constructed by Schär Engineering

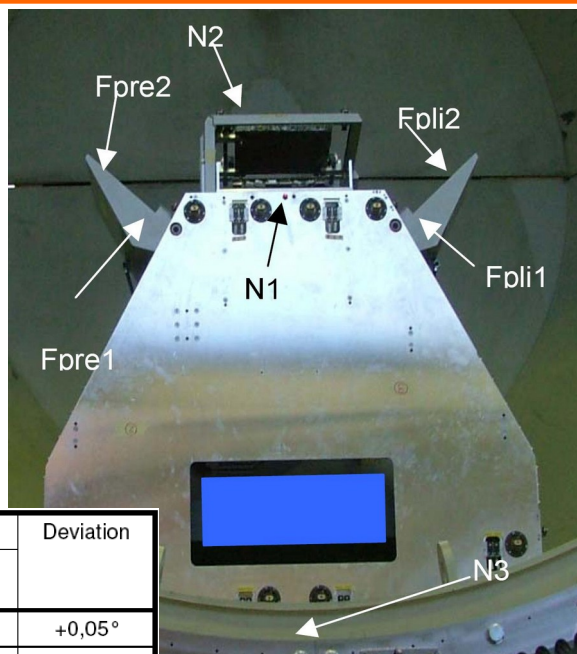
Gantry / Table Key Specifications

- Gantry dynamics:
 - Angle range: $\pm 190^\circ$
 - Rotation velocity: $6^\circ/\text{s}$
 - Acceleration: $2^\circ/\text{s}^2$
 - Emergency braking path: $< 3^\circ$ (1° at low speed)
- Treatment-table movement range:

■ Longitudinal:	central axis treatment range	130 cm
	total movement range	545 cm
■ Lateral (usable treatment area):		± 245 cm
■ Vertical range:	73 cm	
■ Couch rotation:	$\pm 95^\circ$	
■ Couch orientation:	head forward or feet forward	
■ Pitch & roll:	$\pm 3^\circ$	

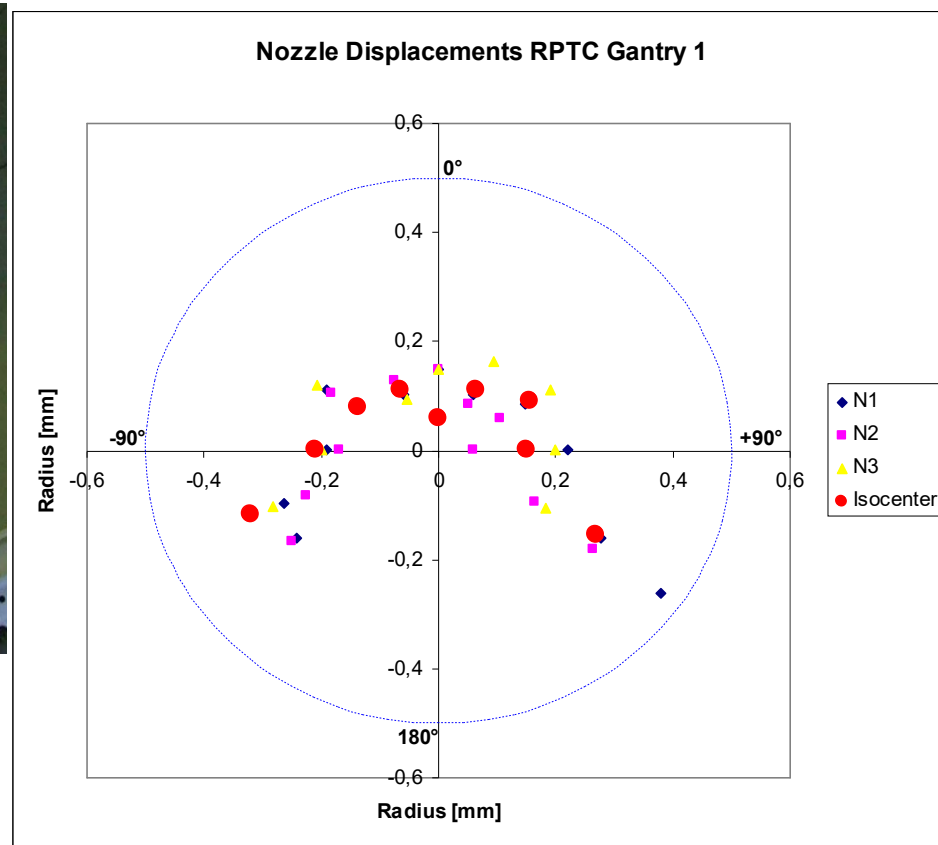
➔ **Flexibility comparable to robotic arm system**
- Positioning precision:
 - Gantry angle / beam direction: $\pm 0.1^\circ$
 - Beam position: Within 0.5-mm-radius sphere around isocenter
 - Couch positioning: Within 0.5-mm-radius sphere around commanded position for any patient weight < 150 kg (relative precision: ± 0.2 mm)
- Safety:
 - Collision avoidance via laser scanner system and via software anti-collision system
 - Collision detection via sensor panels
 - Mechanical patient rescuing system

RPTC Gantry-1 Measurements



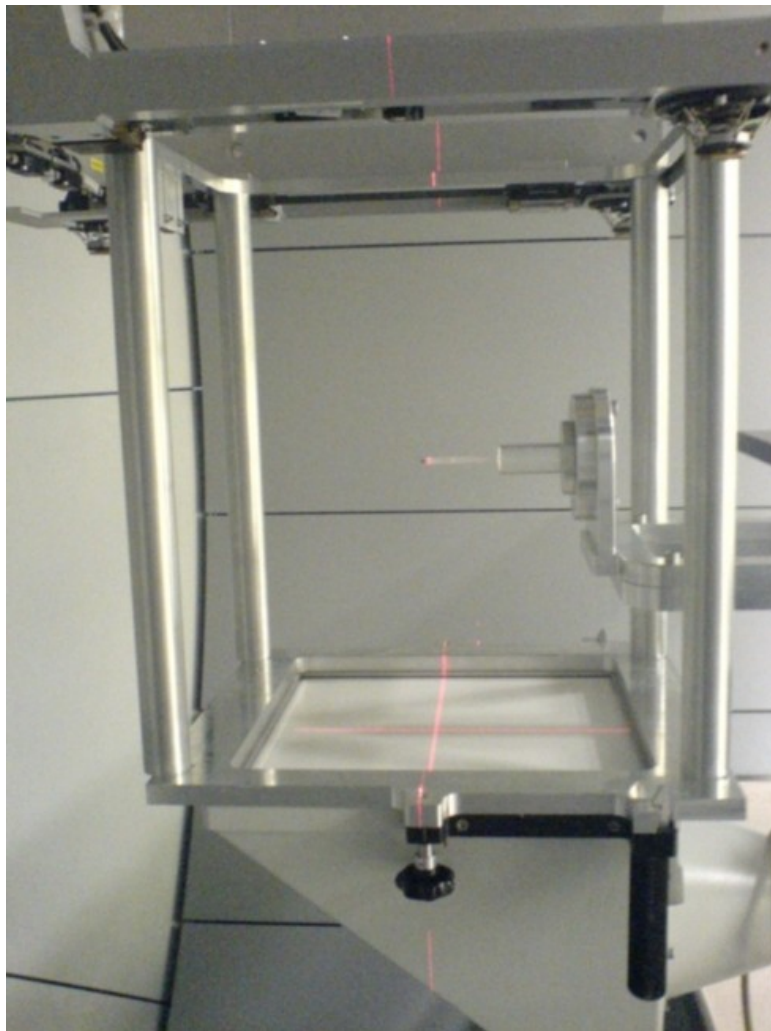
Preset Gantry Angle		Deviation
Control Panel Display	Mechanical Display	
90,00°	90,05°	+0,05°
90,10°	90,15°	+0,05°
0,00°	0,00°	0,00°
266,40°	266,35°	-0,05°
211,83°	211,80°	-0,03°
117,18°	117,28°	+0,10°
170,91°	171,00°	+0,09°
184,84°	184,90°	+0,06°
116,24°	116,30°	+0,06°
119,25°	119,30°	+0,05°
117,18°	117,28°	+0,10°

Angle Precision

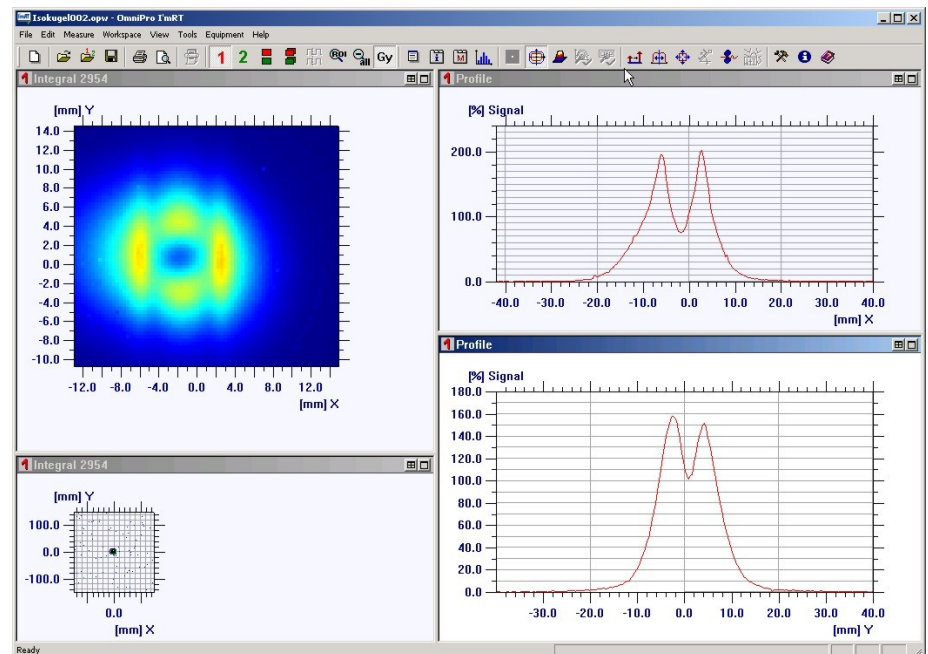


Gantry Isocenter Precision
measured with laser tracker

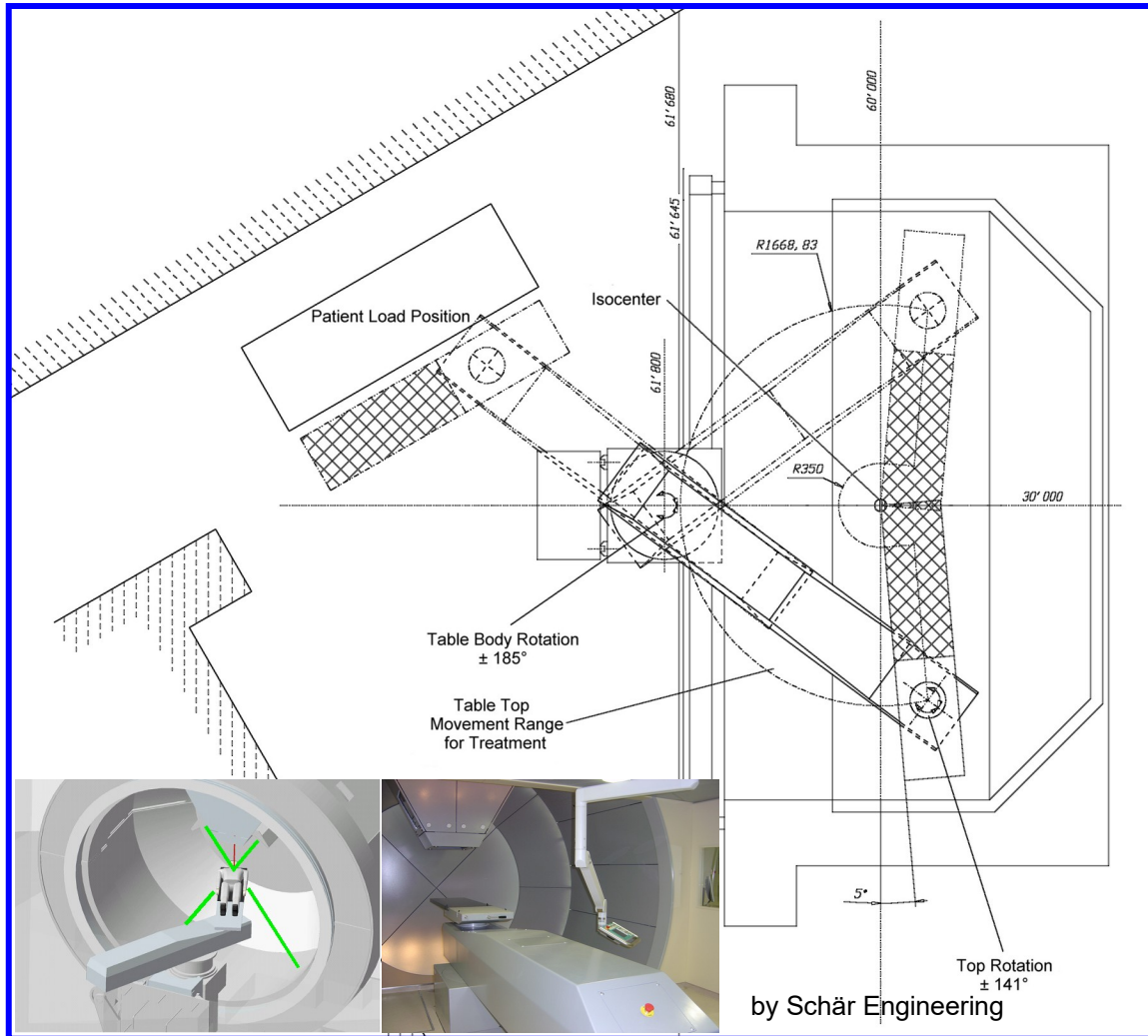
Setup of Isocenter Measurement with Beam



Verify beam at isocenter and
X-ray alignment



Treatment Table

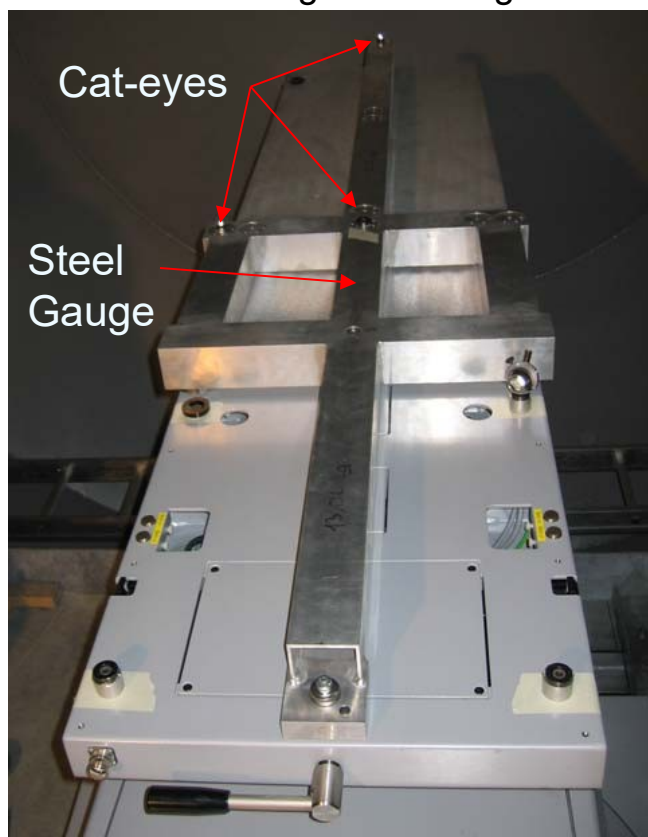


Features

- Two rotation axes, two linear axes, pitch, roll
- Patient load position outside Gantry
- Automated movement to treatment position
- Automatic deflection correction
- Collision avoidance via laser scanner system
- Integral control system

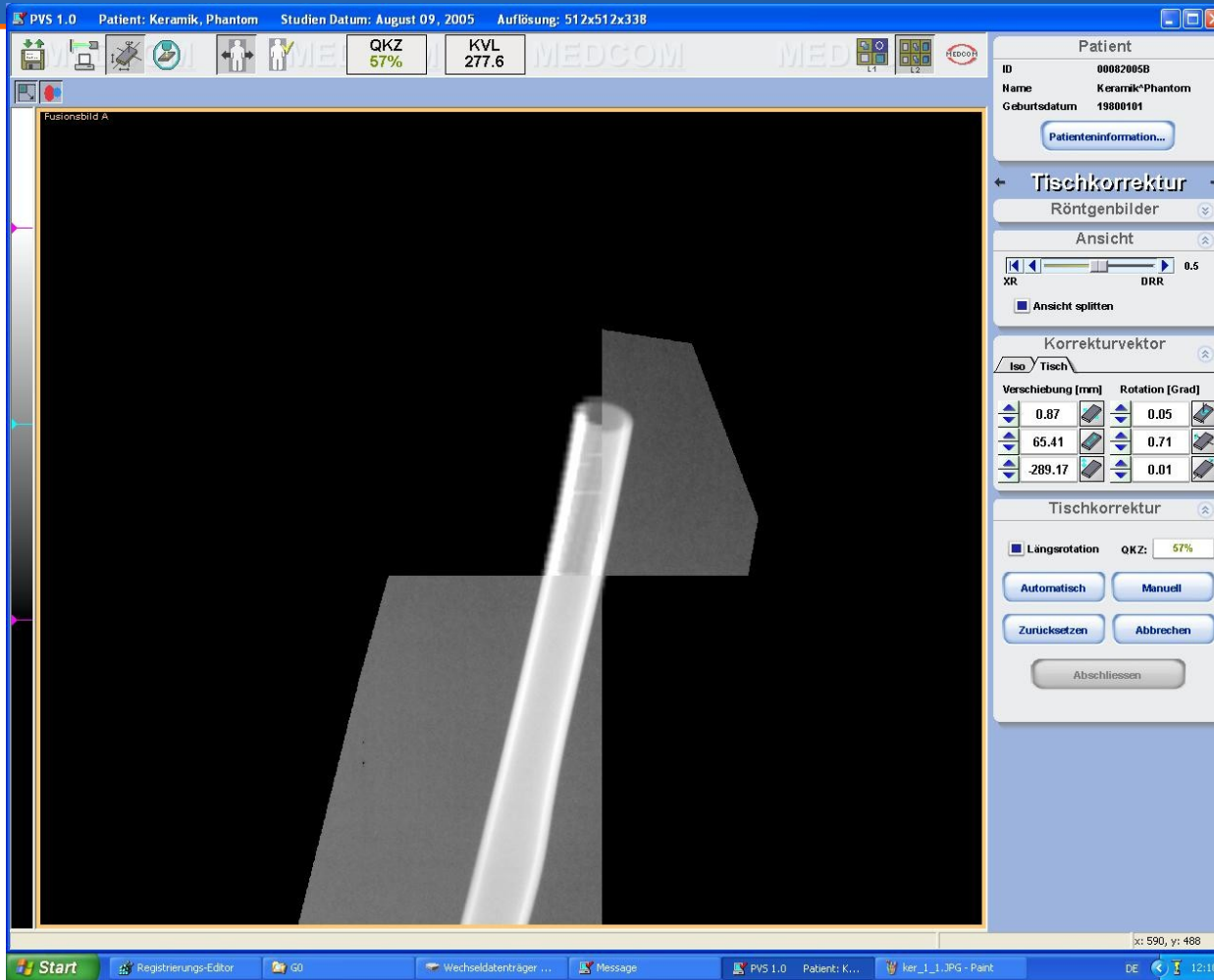
Treatment Table Precision

Positioning precision measurement at RPTC Gantry 1 with laser tracker system and 3 cat-eyes on table, loaded with weight of 120 kg



Deviation Of Cateye Position from Preset Value									Deviation Radius		
Cateye 1			Cateye 6			Cateye 3					
X [mm]	Y [mm]	Z [mm]	X [mm]	Y [mm]	Z [mm]	X [mm]	Y [mm]	Z [mm]	Cat 1	Cat 2	Cat 3
									[mm]	[mm]	[mm]
-0.11	0.02	0.15	-0.14	-0.01	0.01	-0.16	-0.02	0.08	0.19	0.14	0.18
-0.10	0.09	0.15	-0.14	-0.02	0.05	-0.17	-0.02	0.17	0.20	0.15	0.24
-0.04	-0.06	0.17	-0.11	-0.06	0.09	-0.12	-0.06	0.19	0.18	0.15	0.23
-0.16	0.19	0.21	-0.12	0.00	0.03	-0.15	-0.01	0.13	0.32	0.13	0.20
-0.10	-0.07	0.09	-0.13	-0.11	0.02	-0.17	-0.11	0.13	0.15	0.17	0.24
-0.18	-0.01	-0.08	-0.11	-0.12	0.03	-0.10	-0.14	0.11	0.20	0.17	0.20
0.07	-0.14	0.13	0.02	-0.16	0.06	0.03	-0.15	0.13	0.20	0.17	0.20
-0.24	0.11	-0.01	-0.08	0.01	-0.02	-0.13	-0.01	0.09	0.26	0.09	0.16
-0.11	-0.05	-0.27	-0.05	-0.10	-0.02	-0.07	-0.12	0.06	0.30	0.11	0.15
0.08	-0.08	-0.03	0.09	-0.12	0.00	0.10	-0.11	0.10	0.12	0.15	0.18
0.06	-0.03	-0.11	0.19	-0.05	0.01	0.16	-0.06	0.13	0.13	0.20	0.21
0.15	-0.01	-0.04	0.20	-0.03	0.03	0.20	-0.04	0.15	0.16	0.21	0.25
0.22	-0.08	0.01	0.24	-0.12	0.07	0.23	-0.11	0.16	0.23	0.28	0.30
0.00	0.00	0.02	0.13	0.03	0.04	0.15	0.01	0.11	0.02	0.14	0.19
-0.12	-0.05	0.27	0.06	0.03	0.12	0.03	0.02	0.18	0.30	0.14	0.18
-0.22	-0.13	-0.02	0.04	0.08	0.09	0.08	0.06	0.07	0.26	0.13	0.13
-0.19	-0.10	-0.06	0.04	0.21	0.05	0.08	0.20	-0.07	0.22	0.22	0.22
0.03	-0.06	0.04	0.10	0.03	0.10	0.13	0.02	0.08	0.08	0.14	0.16
0.06	-0.02	0.00	0.13	0.07	0.03	0.17	0.06	0.06	0.06	0.15	0.19
-0.05	0.09	-0.07	0.03	0.12	0.06	0.01	0.11	0.12	0.13	0.14	0.17

X-Ray Position Verification



Features

- Field-of-view $20 \times 28 \text{ cm}^2$
- $30 \times 40 \text{ cm}^2$ amorphous silicon panels
- Semi-automated image matching and position correction procedure
- Position Verification in any table position → Only 2 X-ray axes needed
- Alternative geometries:
 - Beams eye view (standard for double scattering)
 - Cone Beam CT geometry
 - 3rd axis

developed with Brandis / MedCom

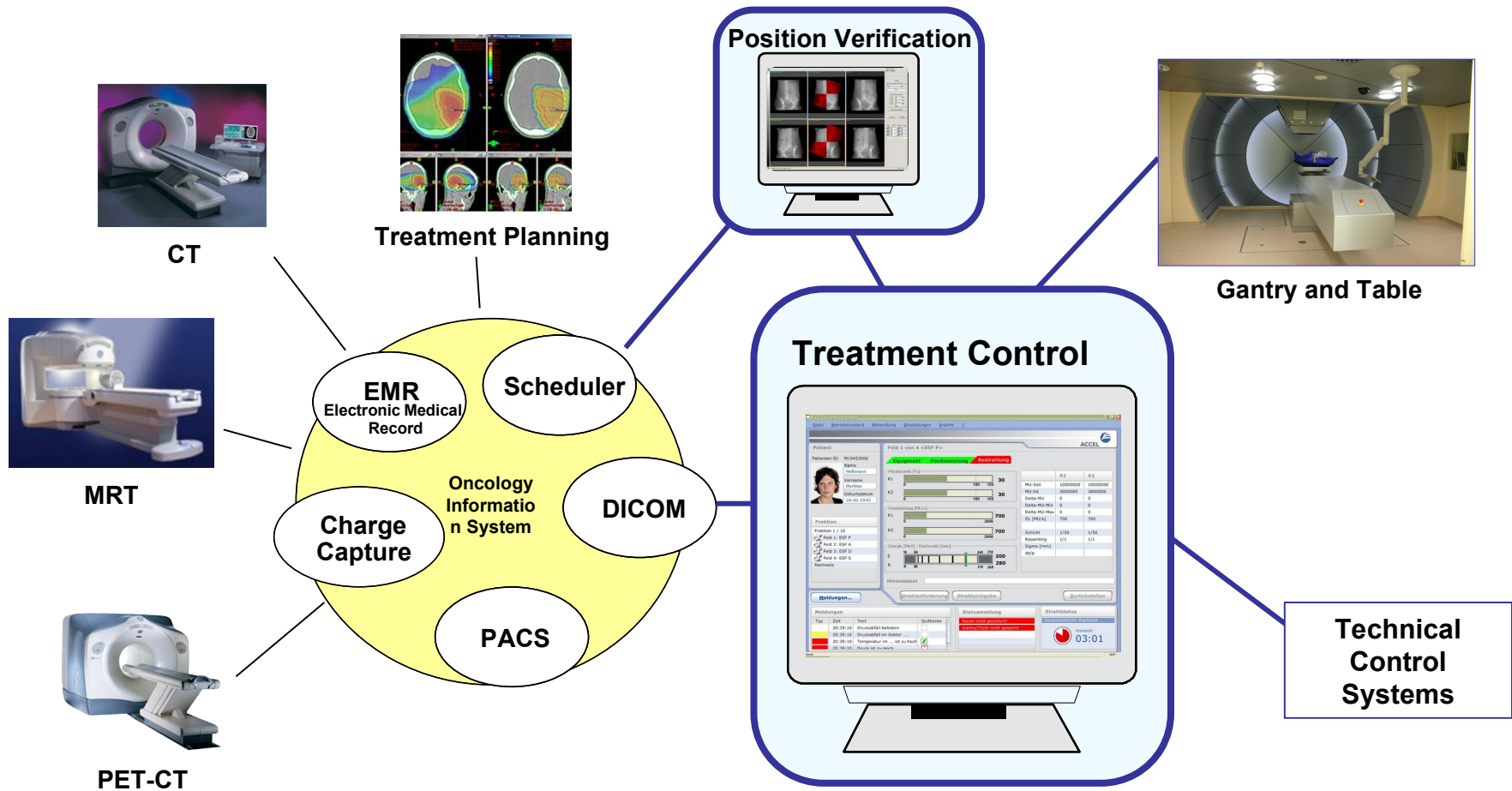
Total positioning precision (table plus X-rays): < 1 mm radius

Patient Immobilization



- BodyFix® and HeadFix® Systems by Medical Intelligence
- Body contours are formed with re-usable vacuum cushion
- Patient immobilization with thin foil and second vacuum
- Head/Neck: Vacuum bite block
- Very good repositioning accuracy

The ACCEL „Absolute Positioning“ Concept



Task: Integrate all systems into one common positioning framework!

„Absolute Positioning“ Key Features

- Link between
 - Planning CT
 - Treatment Planning System
 - X-ray Position Verification System
 - Treatment Table and Gantry

⇒ No pre-positioning with lasers, no stereotactic frames
- Very high **absolute** positioning precision of treatment table (not depending on patient weight, movement start point)
 - ⇒ Only one X-ray verification needed even with multiple fields
- “One button” automated table motion to treatment position

Positioning Sequence (RPTC)

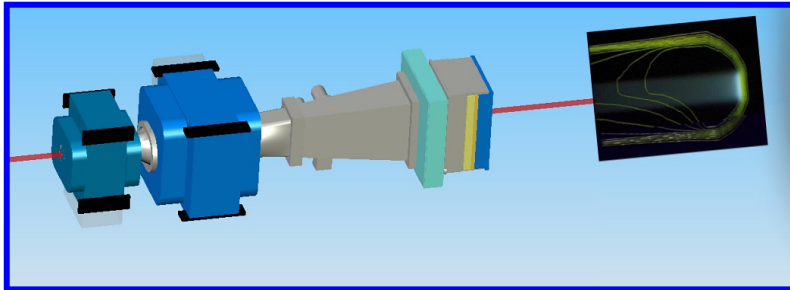
■ Preparation

1. Preparation of molding and patient immobilization
2. CT scan for treatment planning
3. Tumor contouring
4. Treatment planning: Determination of isocenter position and beam direction

■ Treatment

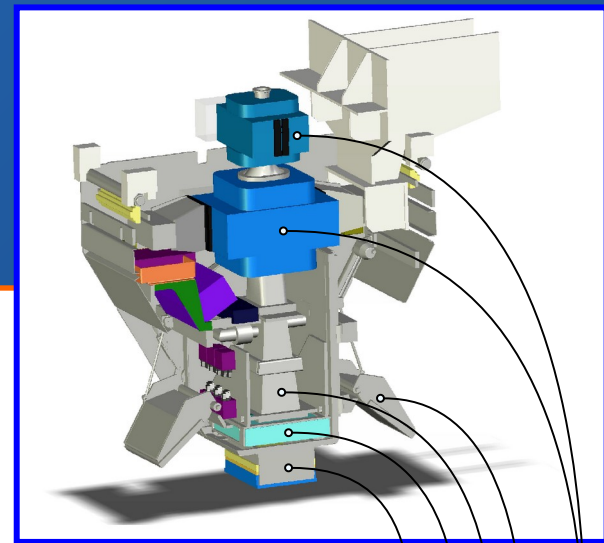
1. Patient immobilization (outside treatment room)
2. Transfer of patient to treatment couch
3. **One-button direct move** to treatment position (possible due to **linked coordinate systems**)
 - ⇒ **Immediate positioning precision better than 5 mm**
 - ⇒ **No Pre-positioning with laser-system**
 - ⇒ **No additional cameras, body markers, ...**
4. X-ray position verification and correction (**one step**, correction vector is stored)
 - ⇒ **Positioning precision better than 1 mm**
5. Irradiation of first field
6. **One-button move to next field**
 - ⇒ **Immediate positioning precision better than 1 mm**
 - ⇒ **Repetition of position verification not necessary!**

Scanning Nozzle

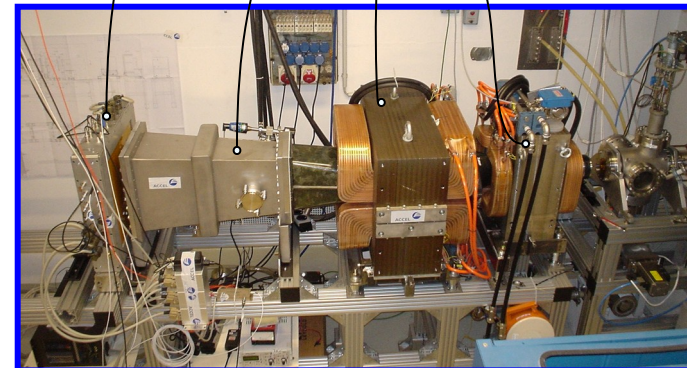


Irradiation of 1-I-Tumor

- Spot scanning with continuous transition in row
- Beam diameter (FWHM): 10 mm
- Spot spacing: 5 mm (20 × 20 × 20 spots)
- ~5 ms per spot (max. ca. 20 ms, min. ca. 2 ms)
- Beam switching on/off: 50 μ s
- 1-10 s irradiation period per layer
- Layer switching time: 1 s
- **Total irradiation time**
 - 2 Gy: < 60 s
 - 1 Gy: < 50 s
 - 0.5 Gy: < 45 s



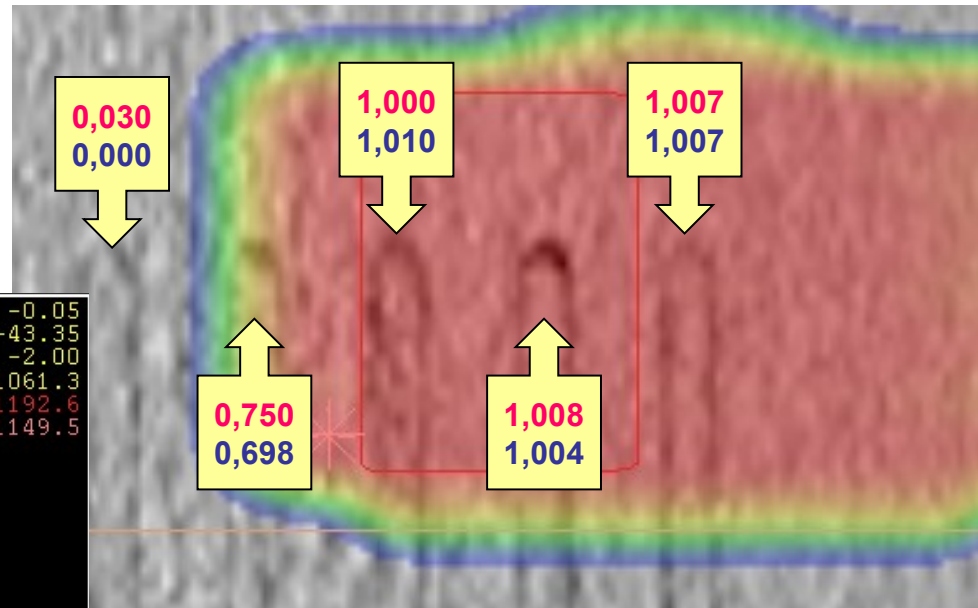
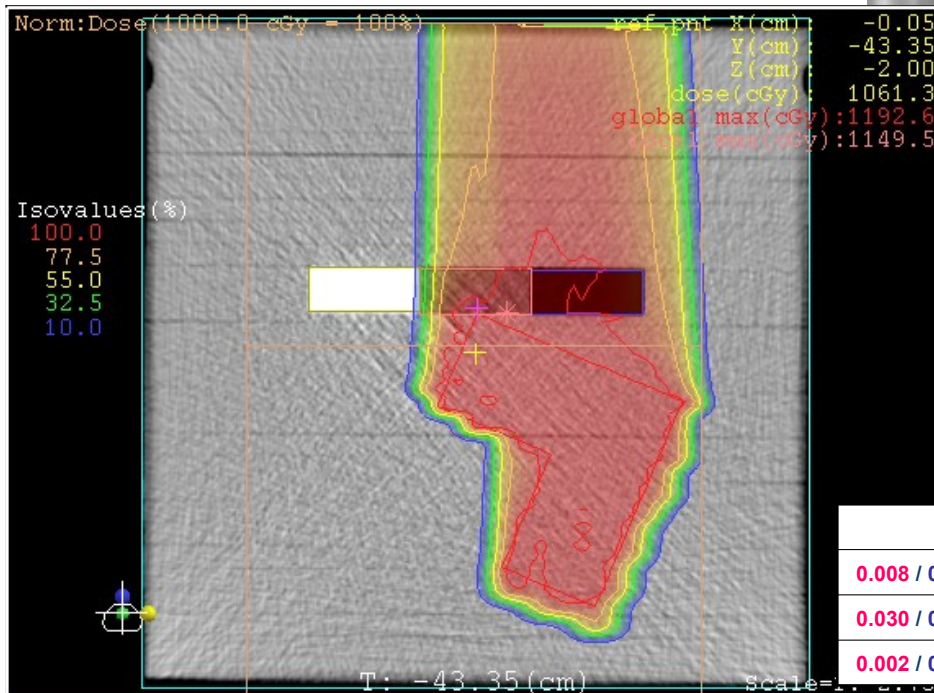
Nozzle 3D-View



Test of Scanning System at HMI, Berlin

Scanning Key Specifications / Measurements

- Range: Up to 37.6 g/cm²
- Field size: Up to 30 × 40 cm²
- Dose Compliance: better than ± 2.5%
- Beam spot size (FWHM): Down to 7 mm
- Repainting



System Performance Tests May 2006

Measured vs. calculated doses [Gy]					depth
0.008 / 0	0.379 / 0.376	0.779 / 0.748	0.882 / 0.919	0.952 / 0.927	6 cm
0.030 / 0	0.750 / 0.698	1.035 / 1.033	1.025 / 1.024	1.007 / 1.007	14.5 cm
0.002 / 0	0.007 / 0.002	0.046 / 0.040	0.845 / 0.881	1.008 / 1.010	19.5 cm

“Hidden” Problems from Standard Components

- Imprecise CT table movements → unpredictable image distortion → improper image matching during position verification
- Duration of CT scan → Potential image distortion due to organ / body movements
- Patient weight loss → matching of differing images → imprecise results
- No fixed CT coordinate system → no direct coordinate transfer to treatment system → longer patient set-up times
- Multiple CTs used with different properties → potential effects on positioning precision and coordinate linking

More Positioning Concepts

- Cone beam CT
 - Proton/particle Gantry as cone beam CT
 - External in-room cone beam CT (table shared with gantry, requires high absolute precision)
- On-line X-ray verification
 - Compensation of organ movement using pencil beam
 - High X-ray dose needed (if fluoroscopic mode)
 - Amorphous silicon panels may be sensitive to neutrons (?)
- Robotic treatment tables and imaging devices
 - Very good experiences at various sites
 - Relatively cheap
- Positioning based on MRT images
- ...

Final Question

What is the precision we need for patient and beam positioning?

Acknowledgements

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