Commissioning a Scanning System

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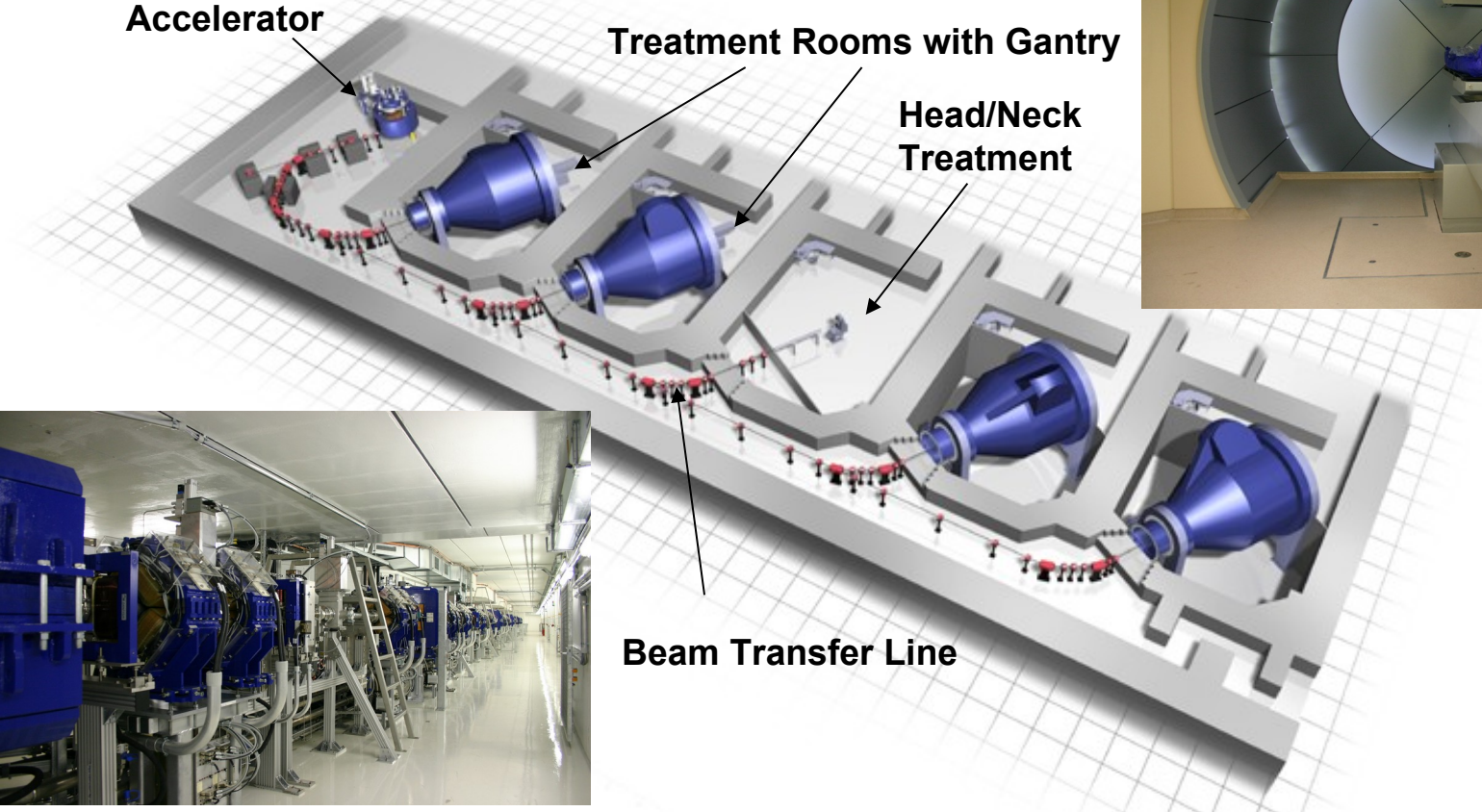
for the Varian/ACCEL Particle Therapy Team

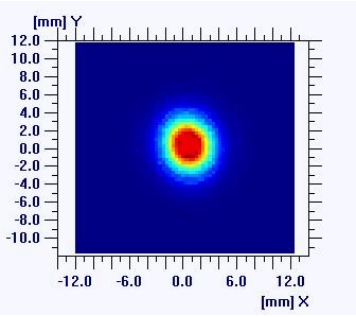
PTCOG 46 Wanjie, Educational Workshop, 19-May-2007

Outline

- Properties of Scanning System installed at RPTC, Munich
- Overview over scanning commissioning tasks
- Examples for commissioning procedures

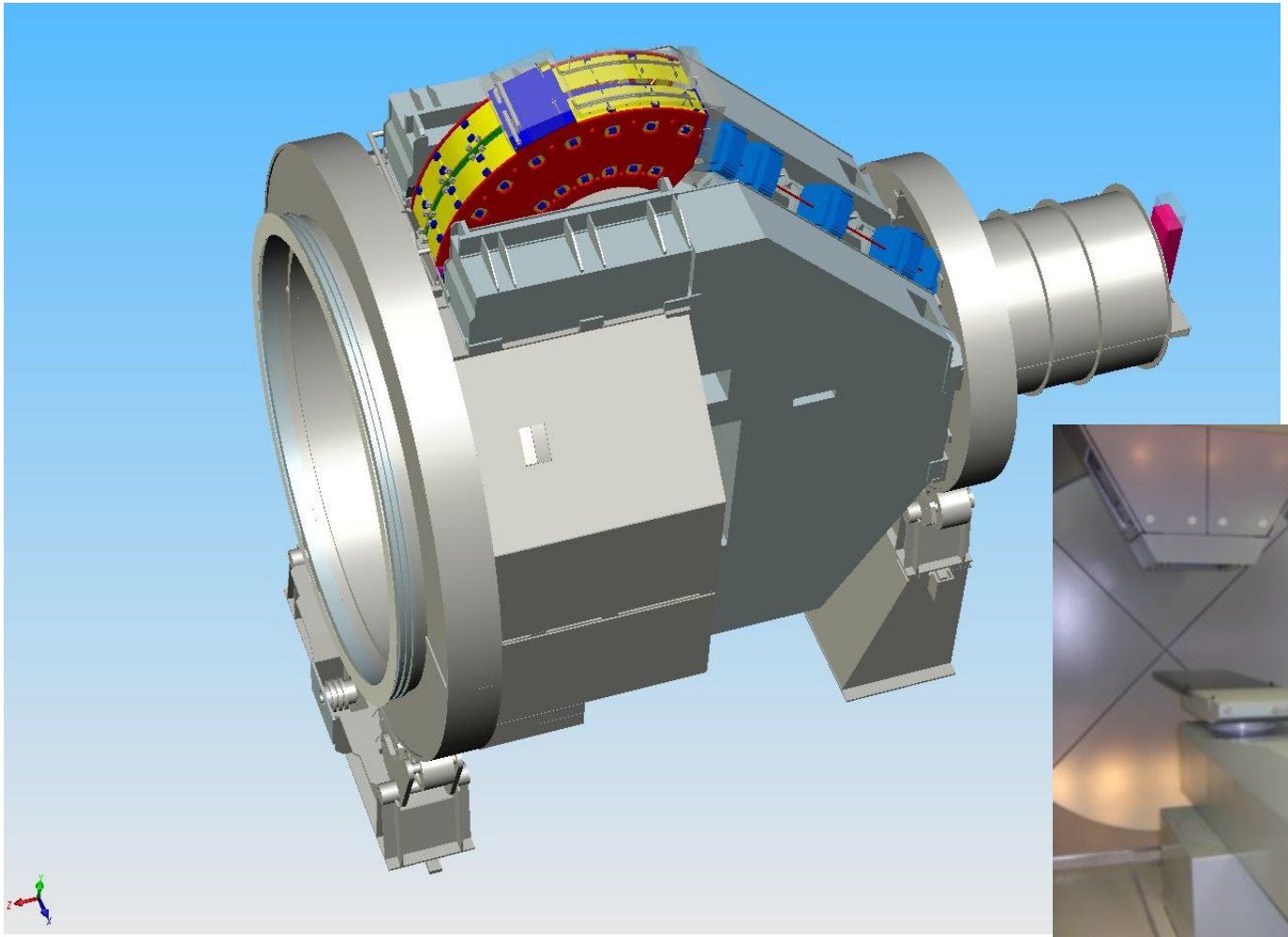
RPTC Munich





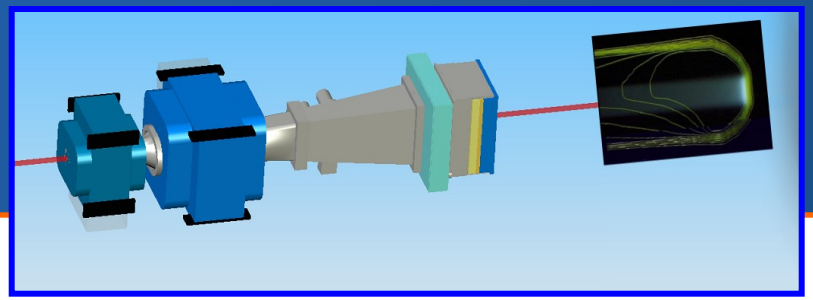
First European Commercial Clinical PT Center

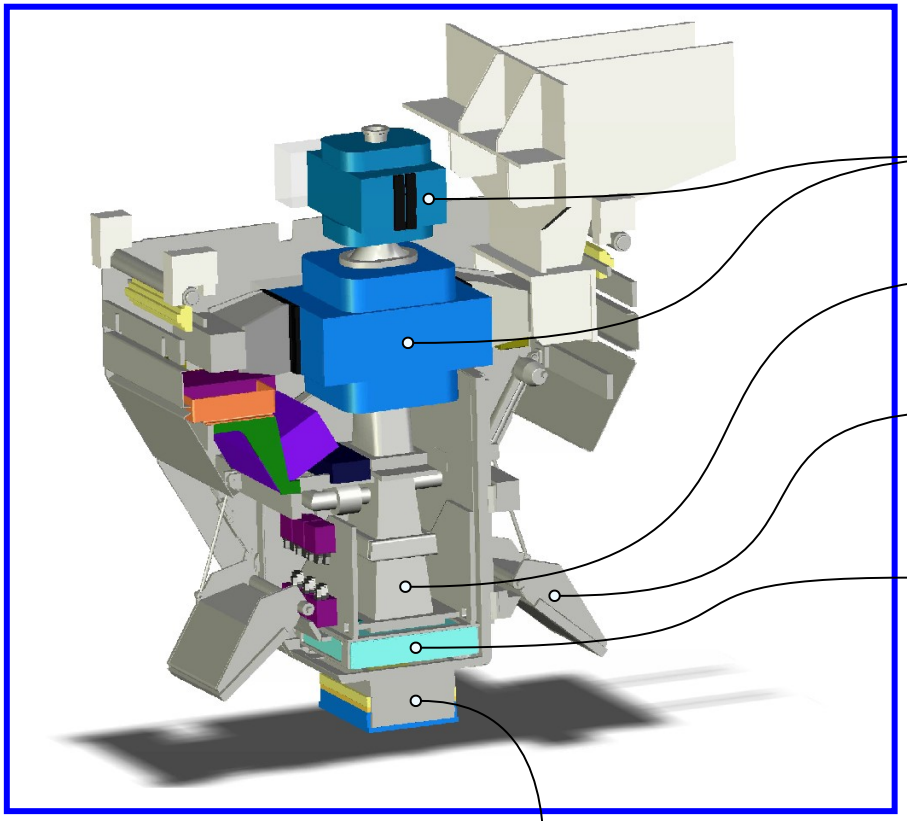
The RPTC Gantries



Constructed by Schär Engineering

Scanning Nozzle





Nozzle 3D-View

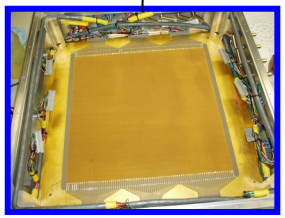
Scanning Magnets

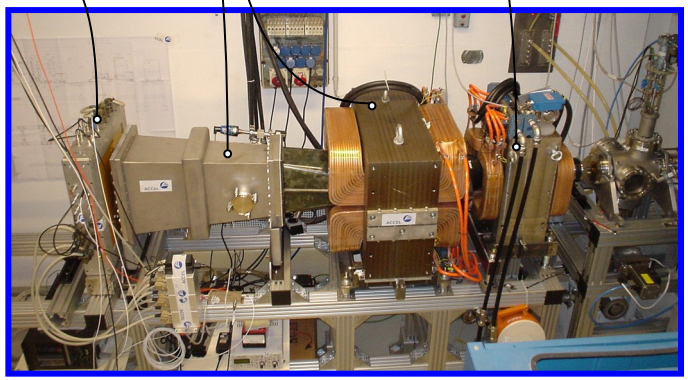
Vacuum Chamber

Diagnostic Flat Panels
(Position Verification)

Dose and Position
Monitors

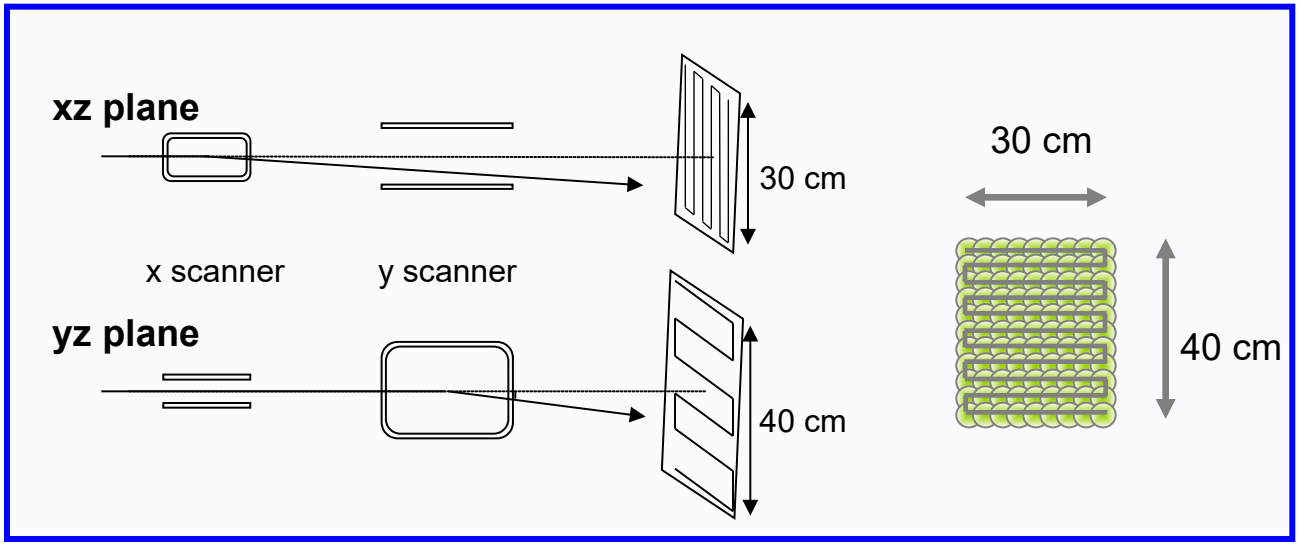
Patient Specific Devices
(Range Shifter, Ripple
Filter, Collimator, etc.)





Test of Scanning System at HMI, Berlin

Scanning Method



General Performance

- Proton energy 250 MeV – 70 MeV ⟹ range of 38,0 cm - 4,0 cm in water
- Variable beam diameter
- Spot / raster scanning (beam off/on in between spots)
- Spot sequence:
  - Treatment plan contains spot list
  - Treatment control system determines sequence
  - Actually in use: Meander shape (may be varied)
- Repainting
- Timings: 2 ~ 20 ms per spot (1-I tumor), beam on/off → 50 µs, layer switching → ~ 1 s

Irradiation of 1-I-Tumor

- Beam diameter (FWHM): 10 mm
- Spot spacing: 5 mm (20 × 20 × 20 spots)
- 1-10 s irradiation period per layer
- Total irradiation time
  - 2 Gy: < 60 s
  - 1 Gy: < 50 s
  - 0.5 Gy: < 45 s

Components Commissioning (without Beam)

- Ion Chambers: Electrical contacts, resistance, leakage current
- IC read-out electronics: Offset, linearity
- Scanning Magnets: Electrical and mechanical testing, verification of magnetic field properties
- Scanning Magnet power supplies: Precision, timing, electrical tests
- Scanning Control System: Algorithms, timing, safety features
- Vacuum components: Leak testing, vacuum window (235 cm × 330 cm)

On-Site Commissioning Tasks

1. Beam optics: Range / energy calibration, adjust central beam position and profile, transmission optimization
2. Scanning Magnets: Calibration of spot position versus magnet current, determination of effective source
3. Multi-strip ionization chambers: Readout calibration (beam position, beam profile)
4. Dose monitors: MU calibration, dose rate, PT correction
5. Safety interlocks
6. Interfaces (layer switching, beam on/off)
7. System performance

Dependencies: Energy, Gantry-angle, dose rate
→ Multiplication factor

Dosimetry Components for Scanning

Calibrated ion chambers

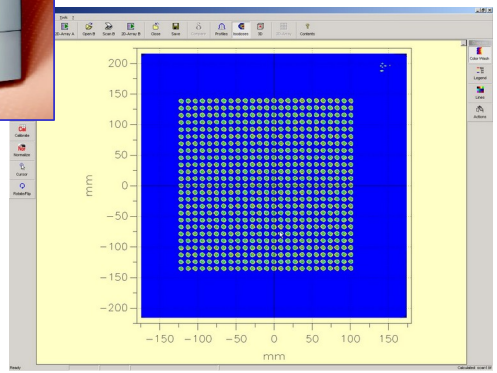
→ Dose measurements

Parallel plate ion chambers

→ Bragg curve measurements

High resolution films

→ Large field geometric measurements

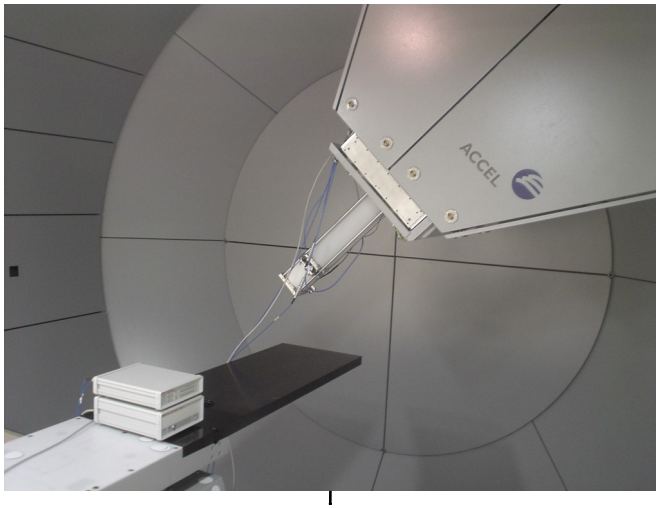


Ion chamber array

→ 2D dose information

Scintillator screen with CCD readout

→ Online field profile information

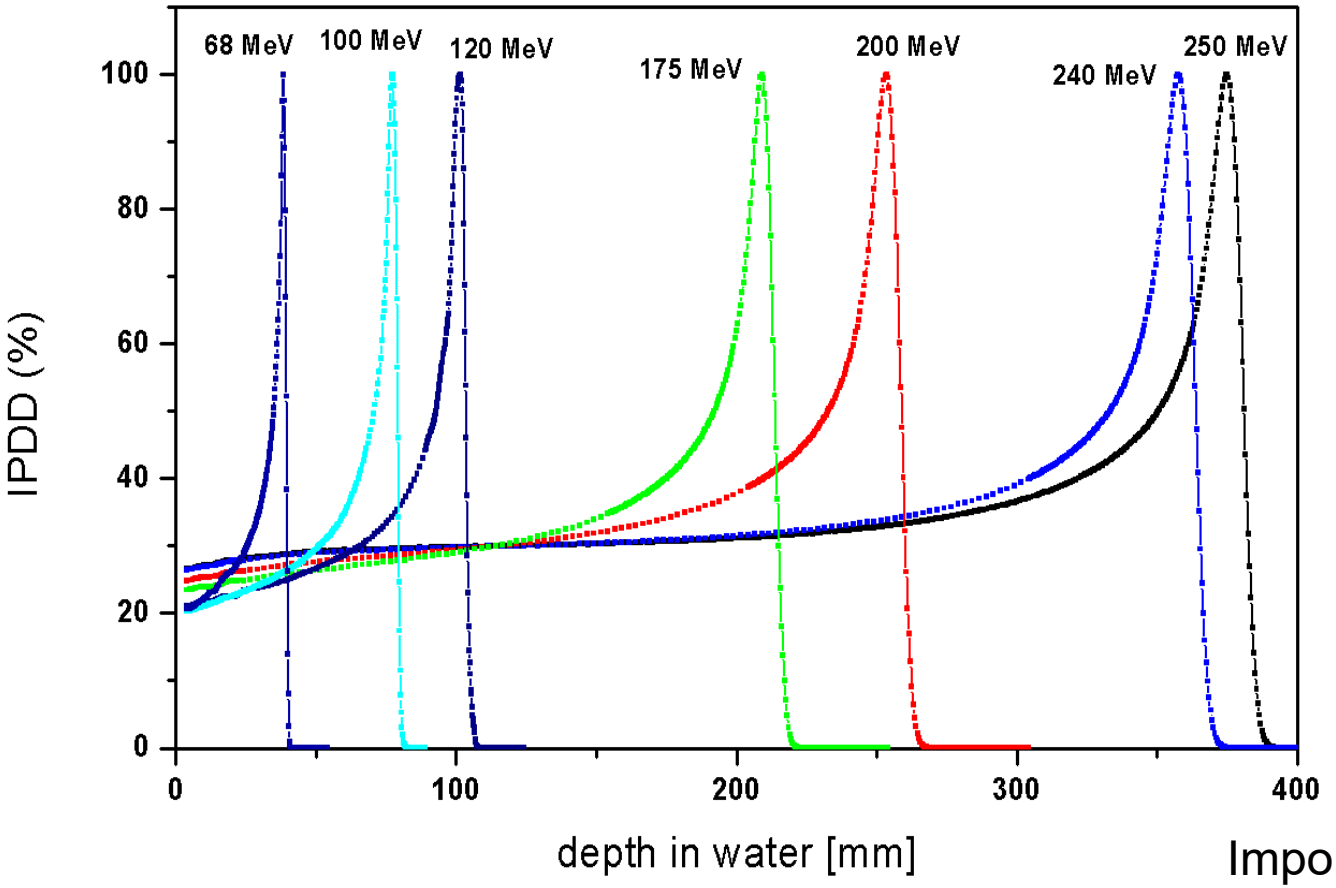


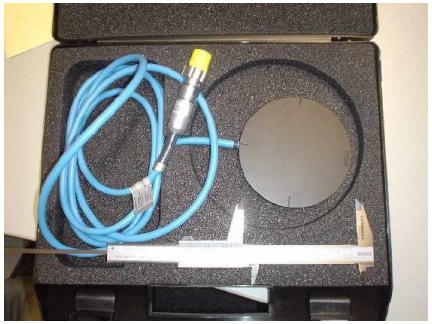
Variable water column

→ Depth dose measurements under varying Gantry angles

Water phantom (not shown)

Beam properties:
Energy / Range Calibration





Important data for
Treatment Planning System!

Beam Optics Adjustment:

Main features to be commissioned:

- Central beam position and axis
- Beam profile (size, symmetry, variation along beam axis)

Method:

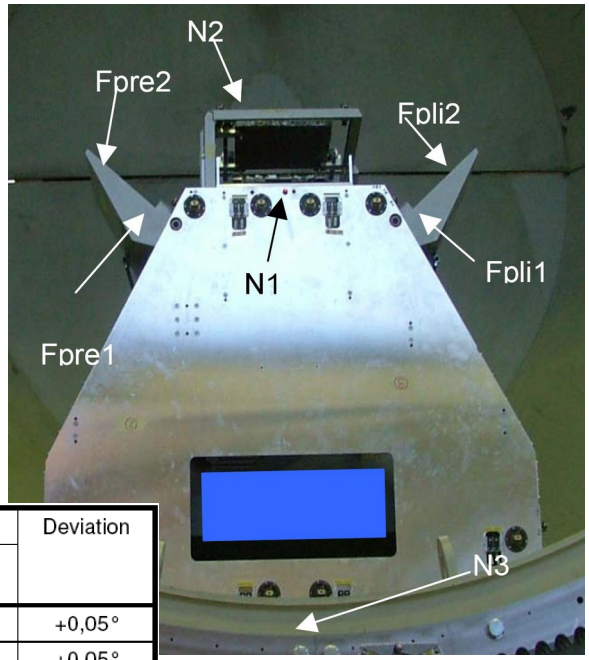
- Adjust at sample points and interpolate

Sample-Point Multipliers:

- Energies: 10 (from 70 MeV to 250 MeV)
- Gantry angles: 24
- Spot sizes: 4

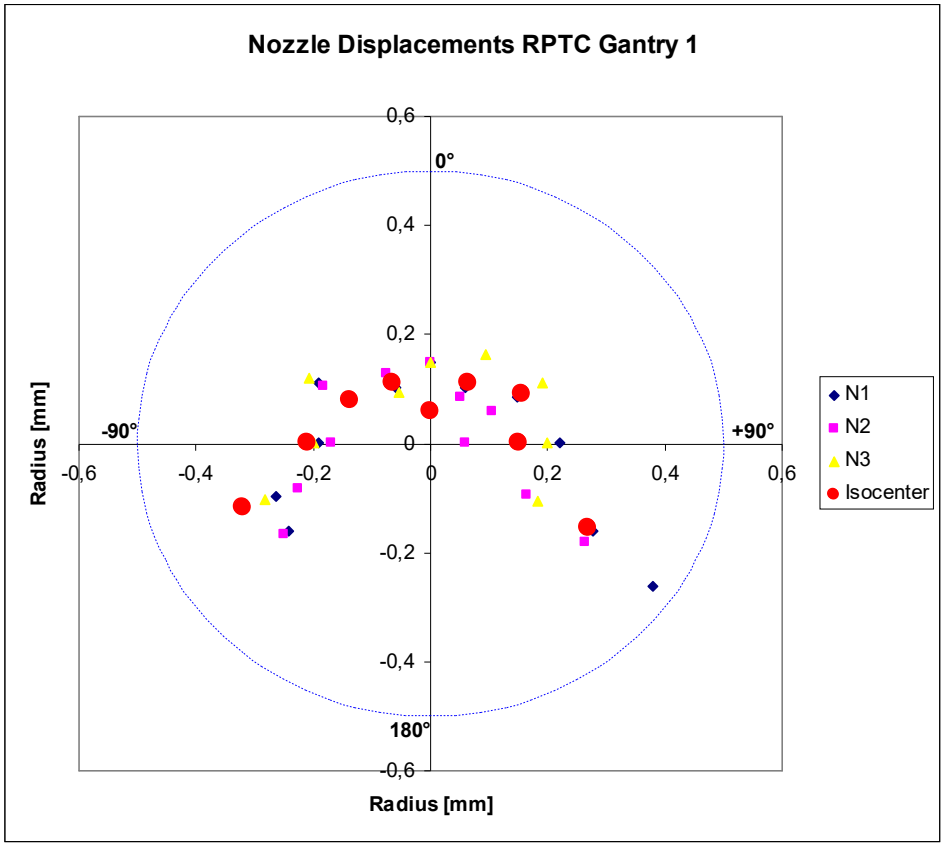
Total: ~ 1000

Beam optics: Geometrical Precision



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°

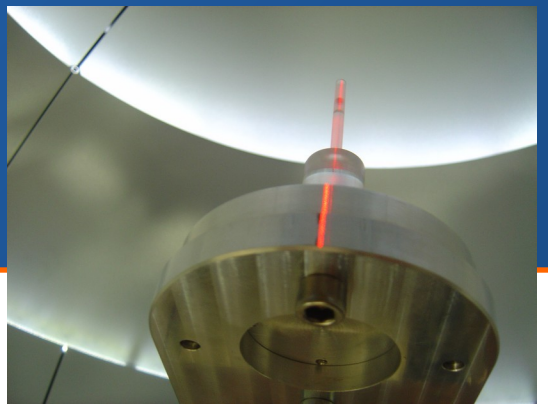
Angle Precision

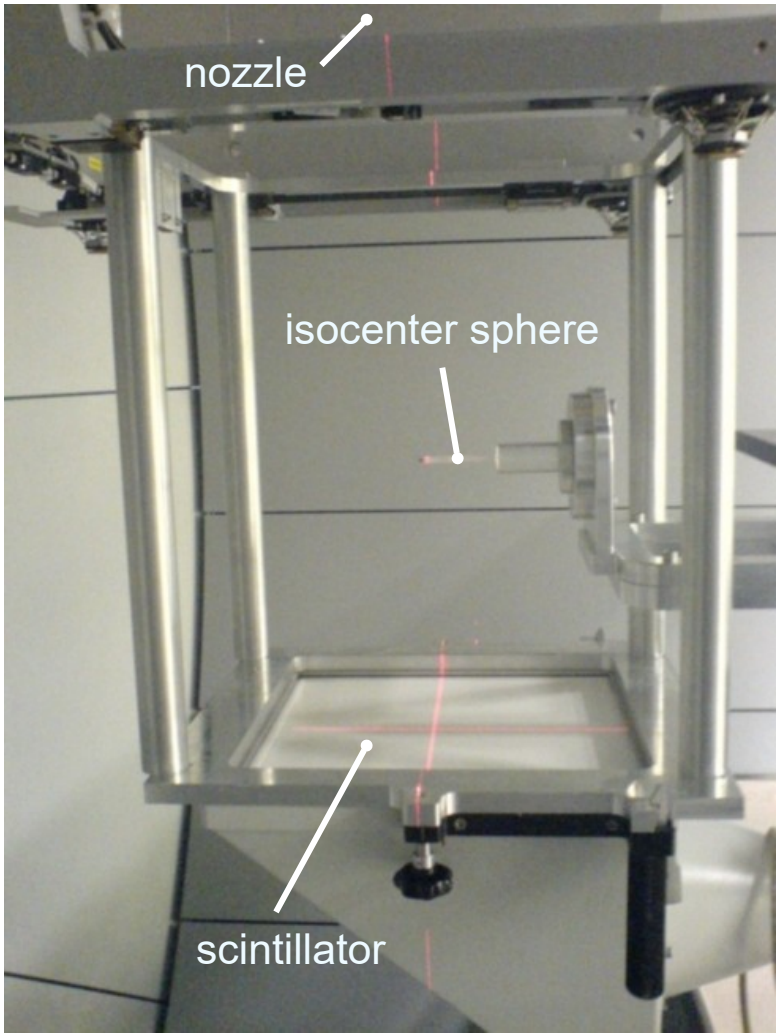


Gantry Isocenter Precision

measured with laser tracker

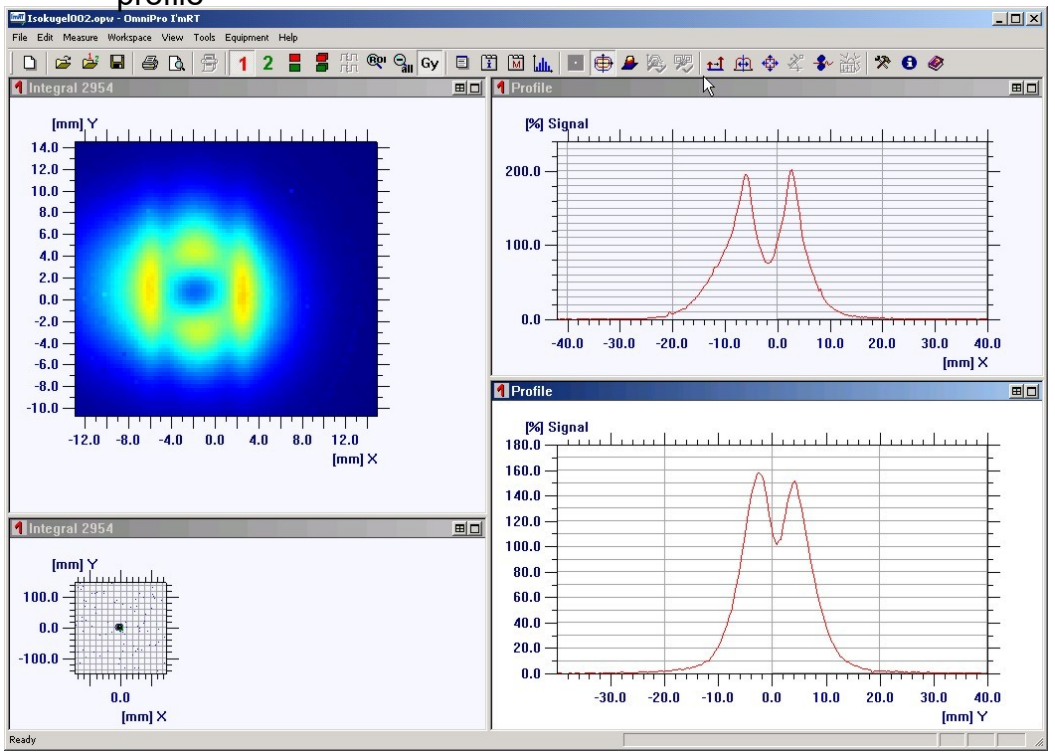
Beam Optics: Isocenter Adjustment





Isocenter sphere:

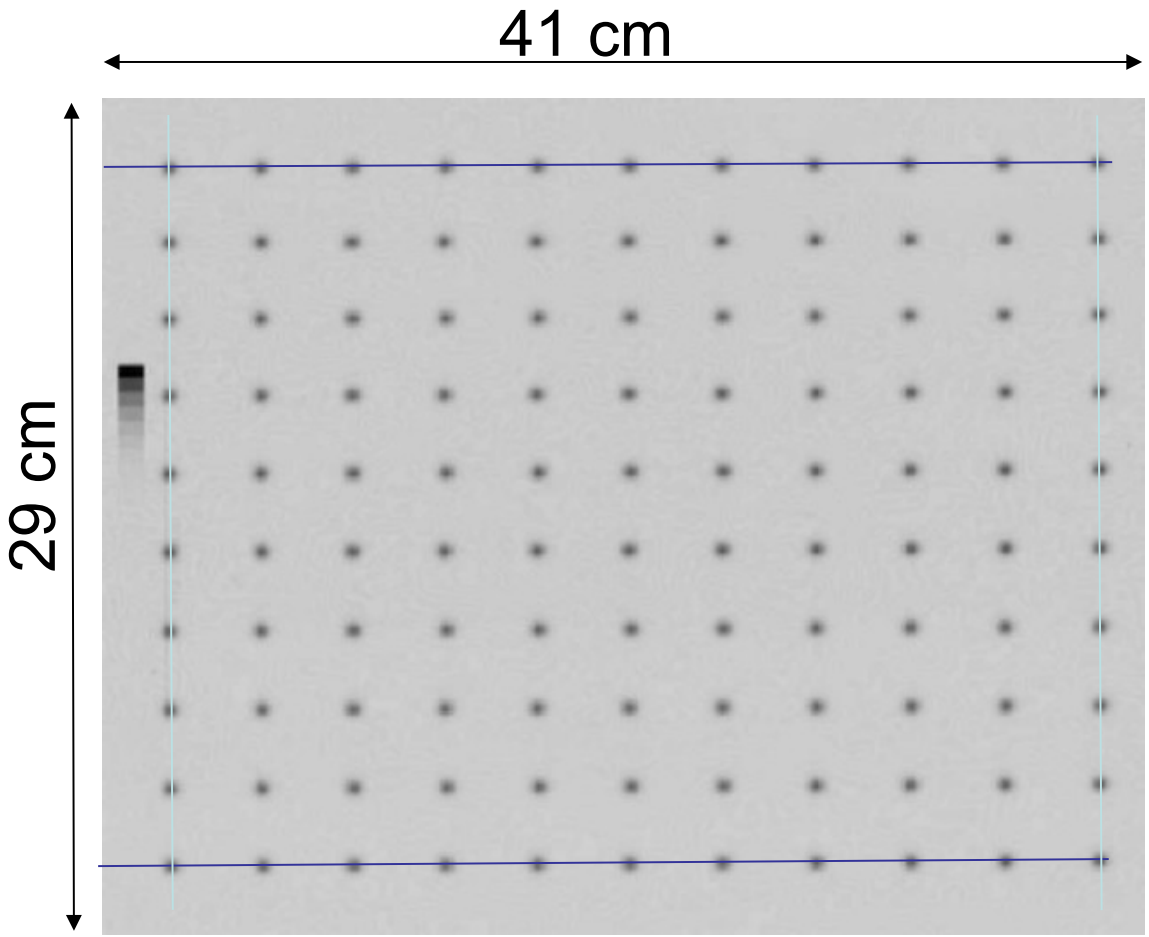
- Steel sphere (Ø 4 mm)
- Bring sphere to geometrical isocenter
- Observe “shadow” of sphere in beam profile



Scanning Magnets: Calibration of Spot Position versus Current

- Measurement set-up:
  - Film at isocenter
- Procedure:
  - Generate spot matrix with separated spots distributed over max. irradiation area
  - Irradiate film at varying energies
- Data to analyze:
  - Spot position on film
  - Magnet current feedback (scanning control system log data)

Scanning:
Calibration of Scanning Magnets



- 10 x 11 spots
- 250-MeV proton beam
- radiographic film

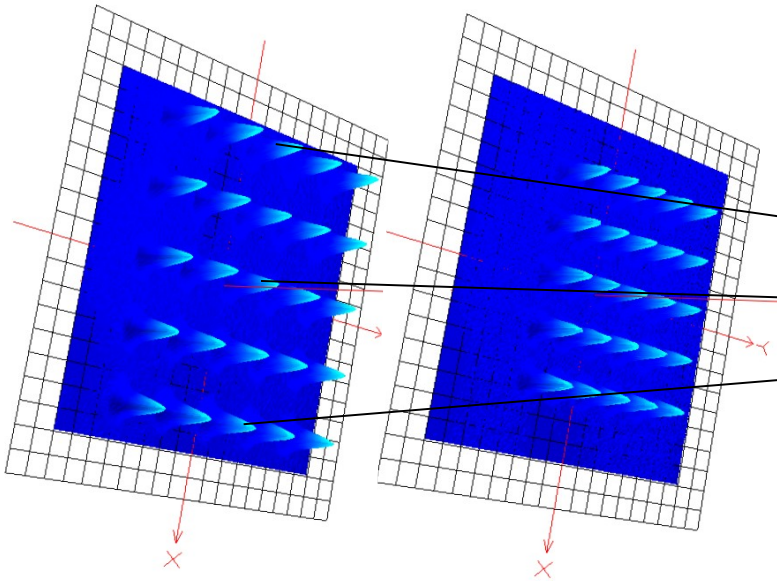
→ Linearity, scan axis direction

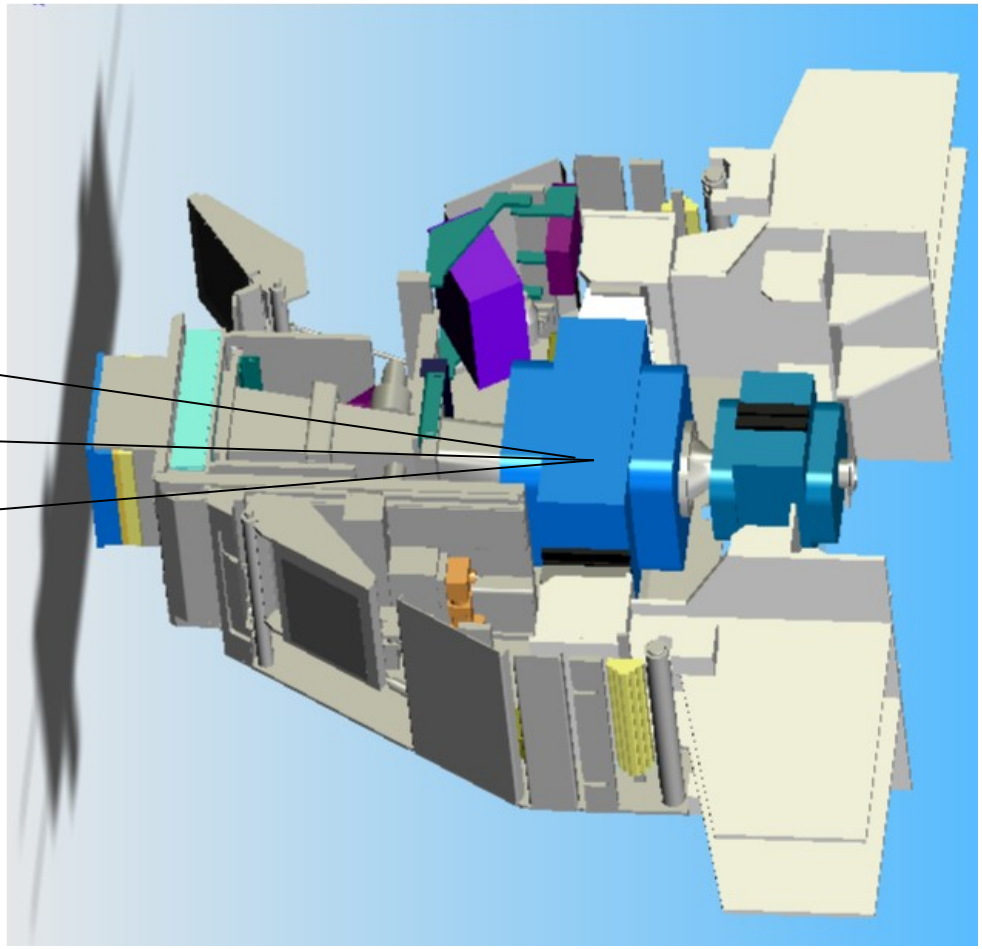
→ Spot position precision

Effective Proton Source

20 cm behind isocenter

50 cm before isocenter

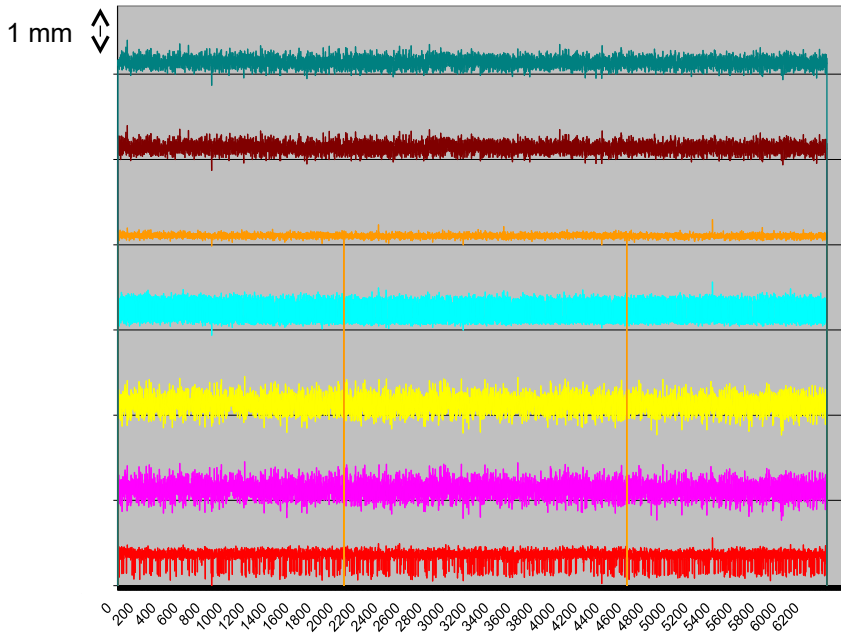




X: 195 cm (mech. 200 cm)
Y: 252 cm (mech. 256 cm)

Multi-Strip Ion Chamber Calibration

- MSIC layout:
  - 4-mm strips (x and y)
  - Readout via I/U converter and ADCs
  - Readout/analysis cycle: 500 µs
- Commissioning:
  - Pre-calibration with calibrated current source
  - Find best algorithms to determine beam position / profile
  - Calibration MSIC position / isocenter beam position



Beam position read-outs

Results for different calculation algorithms (thresholds, number of channels, beam center calculation)

Dose Calculation: Basic Formulas for Scanning

- Dose in water in maximum of gaussian pencil beam:

$$D_c[\mathrm{Gy}] = 1{,}602 \times 10^{-10} \cdot \left.\frac{dE}{dx}\right|_{\mathrm{water}} \left[\frac{\mathrm{MeV}}{\mathrm{g/cm^2}}\right] \cdot \frac{N}{2\pi\sigma^2\,[\mathrm{cm^2}]} \cdot BPR\left(E, \frac{\Delta E}{E}\right)$$

- Dose rate in water:

$$\dot{D}_c\left[\frac{\mathrm{Gy}}{\mathrm{s}}\right] = \left.\frac{dE}{dx}\right|_{\mathrm{water}} \left[\frac{\mathrm{MeV}}{\mathrm{g/cm^2}}\right] \cdot \frac{I_p\,[\mathrm{nA}]}{2\pi\sigma^2\,[\mathrm{cm^2}]} \cdot BPR\left(E, \frac{\Delta E}{E}\right)$$

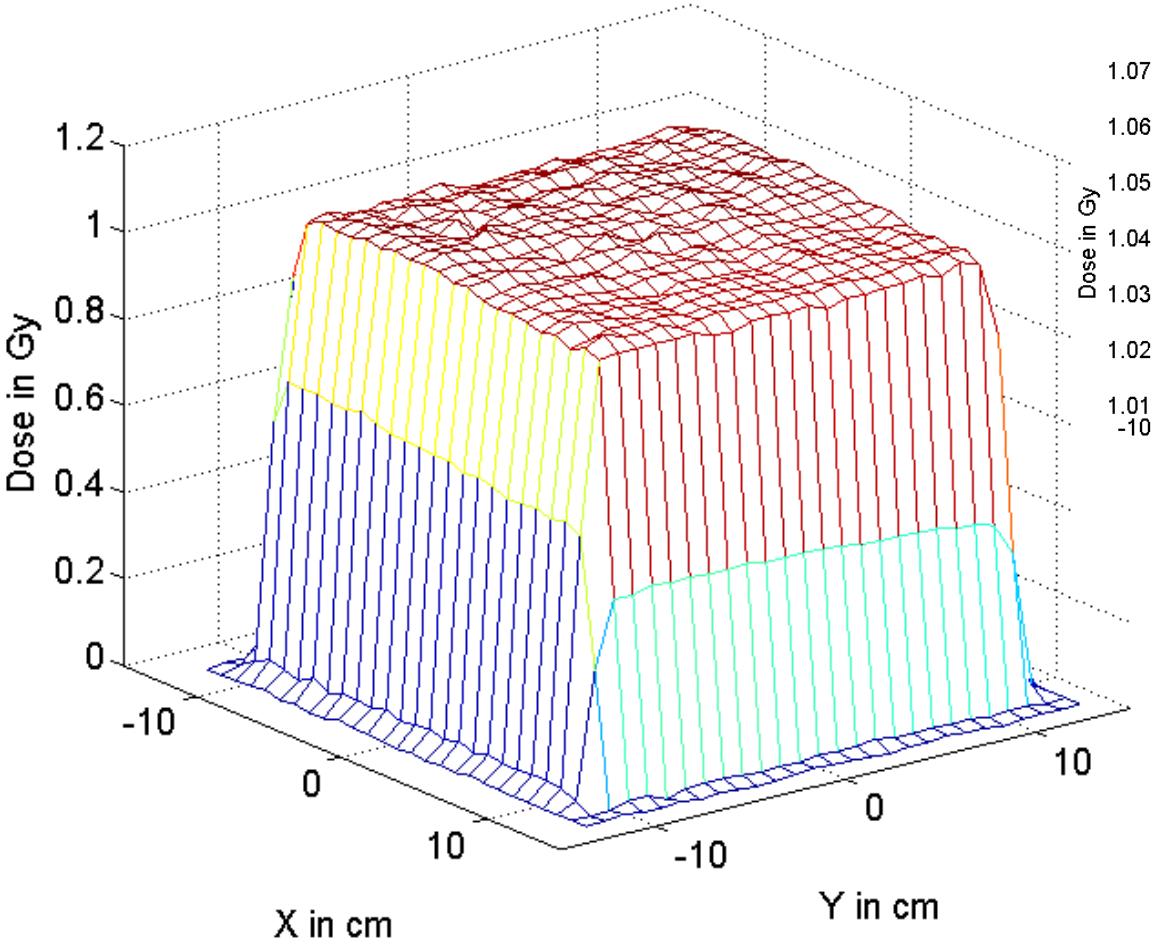
- Plateau dose for homogeneously irradiated layer:

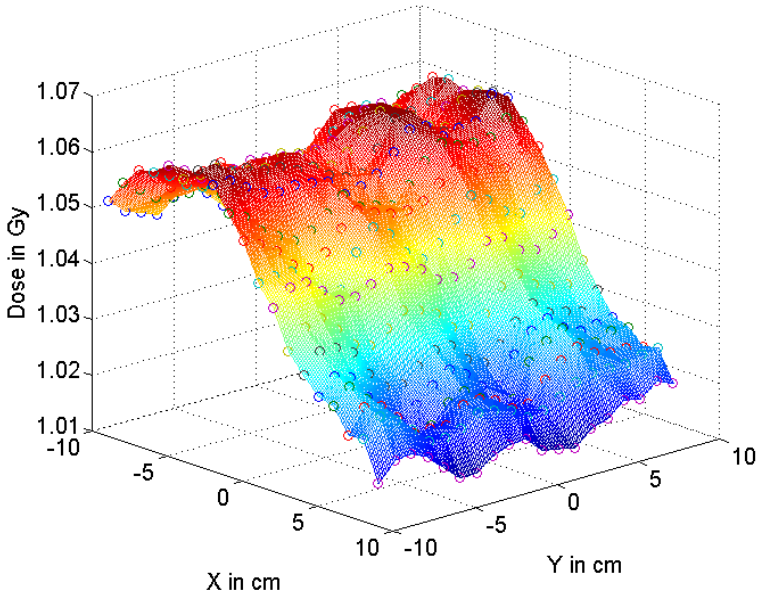
$$D[\mathrm{Gy}] = 1{,}602 \times 10^{-10} \cdot \left.\frac{dE}{dx}\right|_{\mathrm{water}} \left[\frac{\mathrm{MeV}}{\mathrm{g/cm^2}}\right] \cdot N \cdot \rho_{spot}\left[\frac{\mathrm{Spots}}{\mathrm{cm^2}}\right] \cdot BPR\left(E, \frac{\Delta E}{E}\right)$$

Dose (MU) Calibration: Procedure

- Create Spot Matrix for homogeneous irradiation in water
- Measurement set-up:
  - Measure dose with thimble chamber at isocenter
  - Check homogeneity with film at isocenter
- Irradiate at varying energies
- Data to analyze:
  - MUs from dose monitors
  - Dose measured with thimble chamber (surface dose, depth dose distribution obtained separately)
  - Spot density ρ_{spot} (from calibrated MSIC read-out / from field size measured on film)

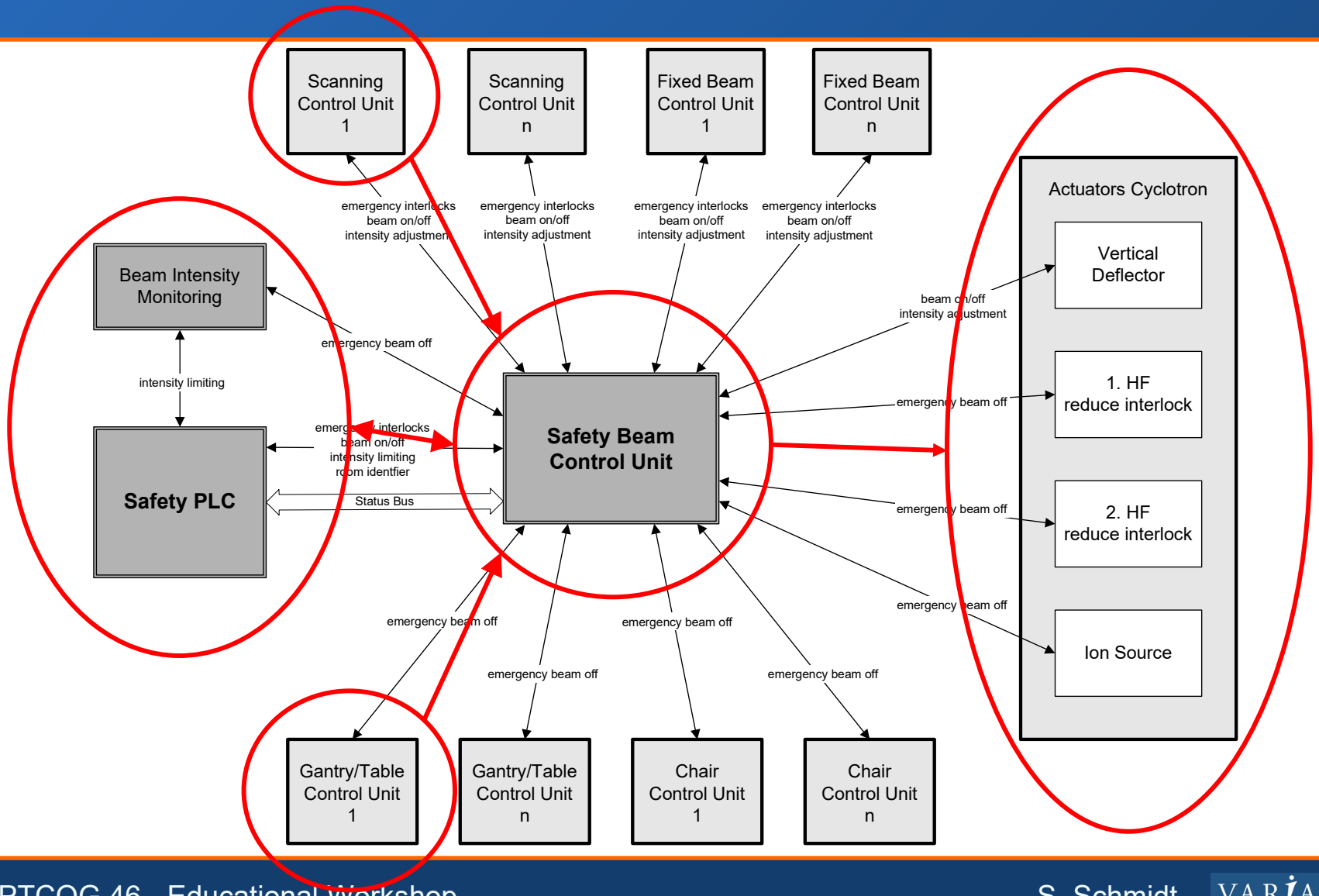
Dose Monitor: Spot position dependency





measured with 2D ion chamber array

Interfaces: Safety



Safety Interlocks from Scanning System

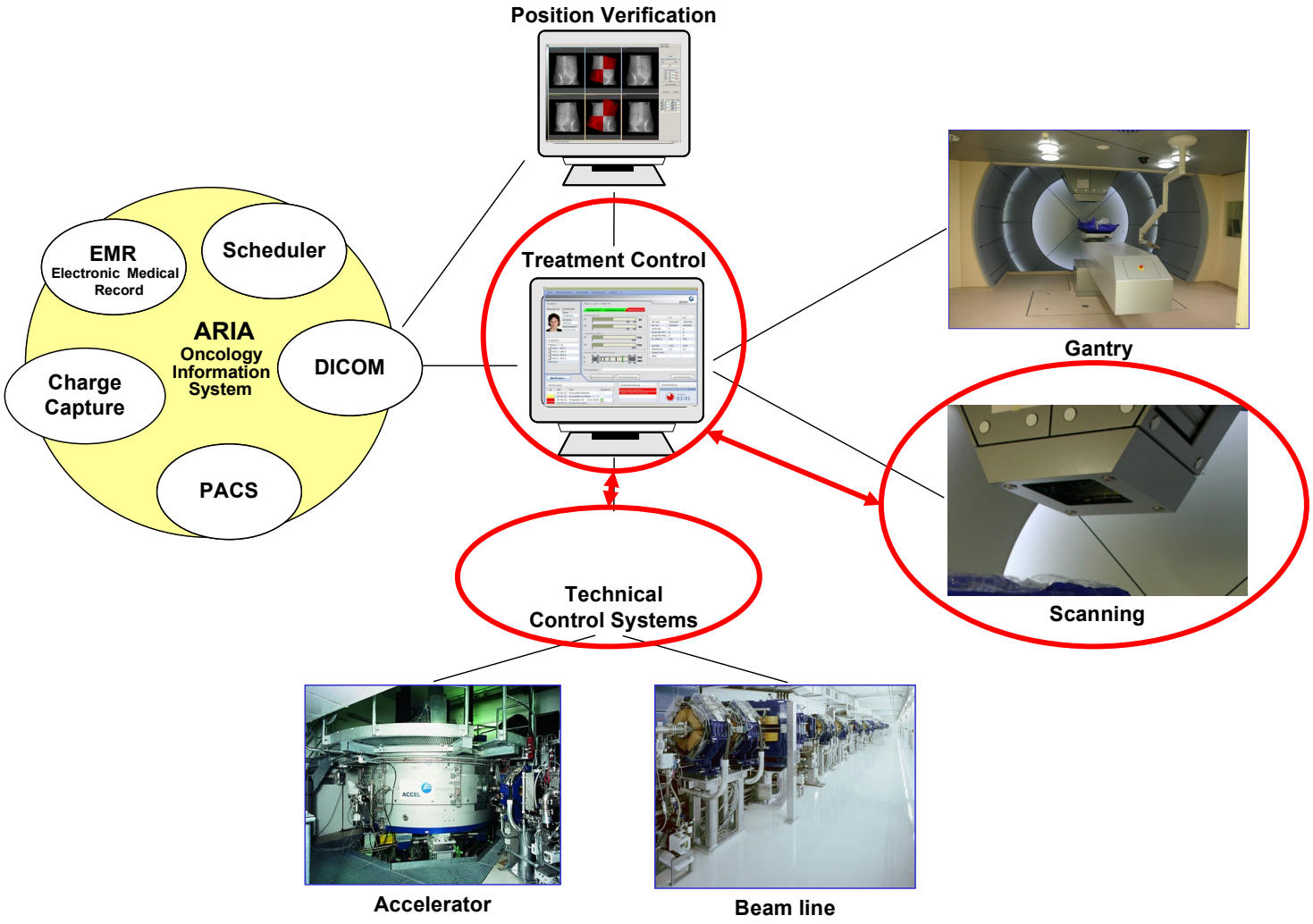
Interlocks

- Spot dose
- Spot duration
- Dose rate
- Synchronism dose monitors 1 and 2
- Spot position (MSIC data)
- Spot profile (MSIC data)
- Magnet current
- HV power
- CPU status (2nd CPU, watchdog)

Commissioning Tasks

- Find correct thresholds
- Test under varying conditions
- Test timings
- End-to-end test of full interlock system

Interfaces to Control System (Layout)

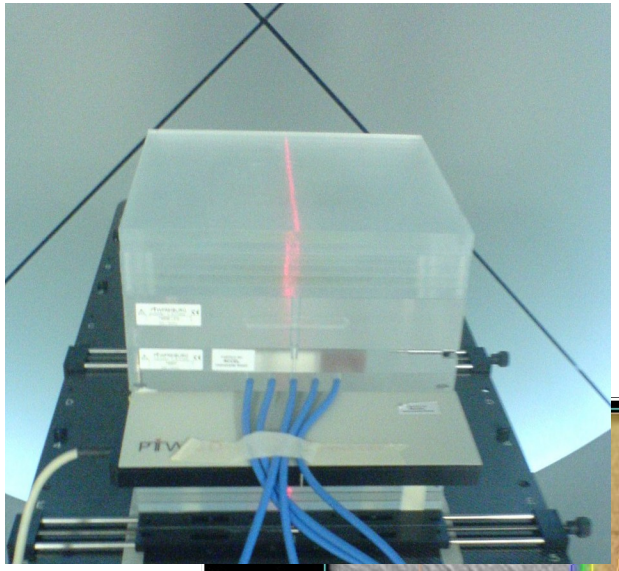


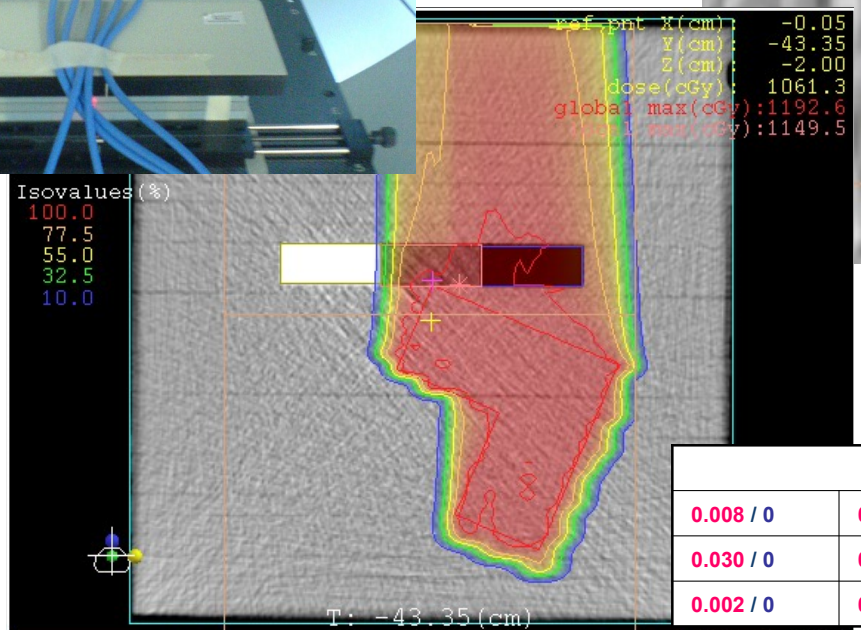
Interface to Control System (Data)

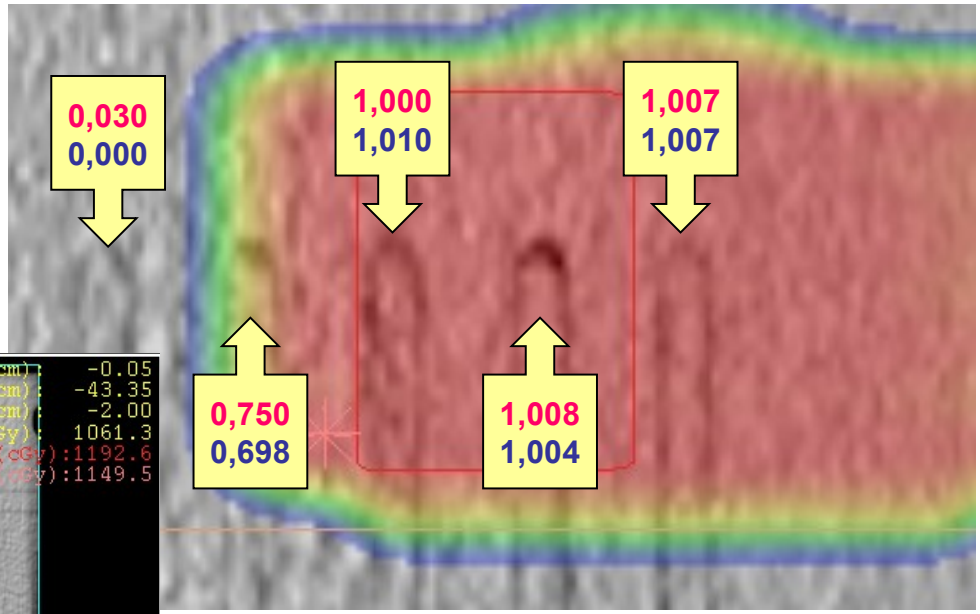
- To Scanning:
  - Engineering data for each spot per layer calculated by Therapy Control System: Magnet currents, MSIC thresholds, monitor units, expected dose rate, …
  - Status information: Mode (treatment, maintenance, stand by), irradiation enable (final enabling through Safety System)

- From Scanning:
  - Measured data: Spot position, spot size, delivered monitor units, dose rate, spot duration)
  - Status information: Layer finished → new layer request (new beamline settings through beamline control system), messages, …

System Performance Test







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

Beam Commissioning and Data by…

- A. Bolzmann, H. Göbel, O. Kotsyuba (scanning)
- J. Heese, L. Przybysz (dosimetry)
- M. Benna, F. Kubo, S. Schwenke (beamline)

... based on the work of the whole commissioning team

Thank You!