

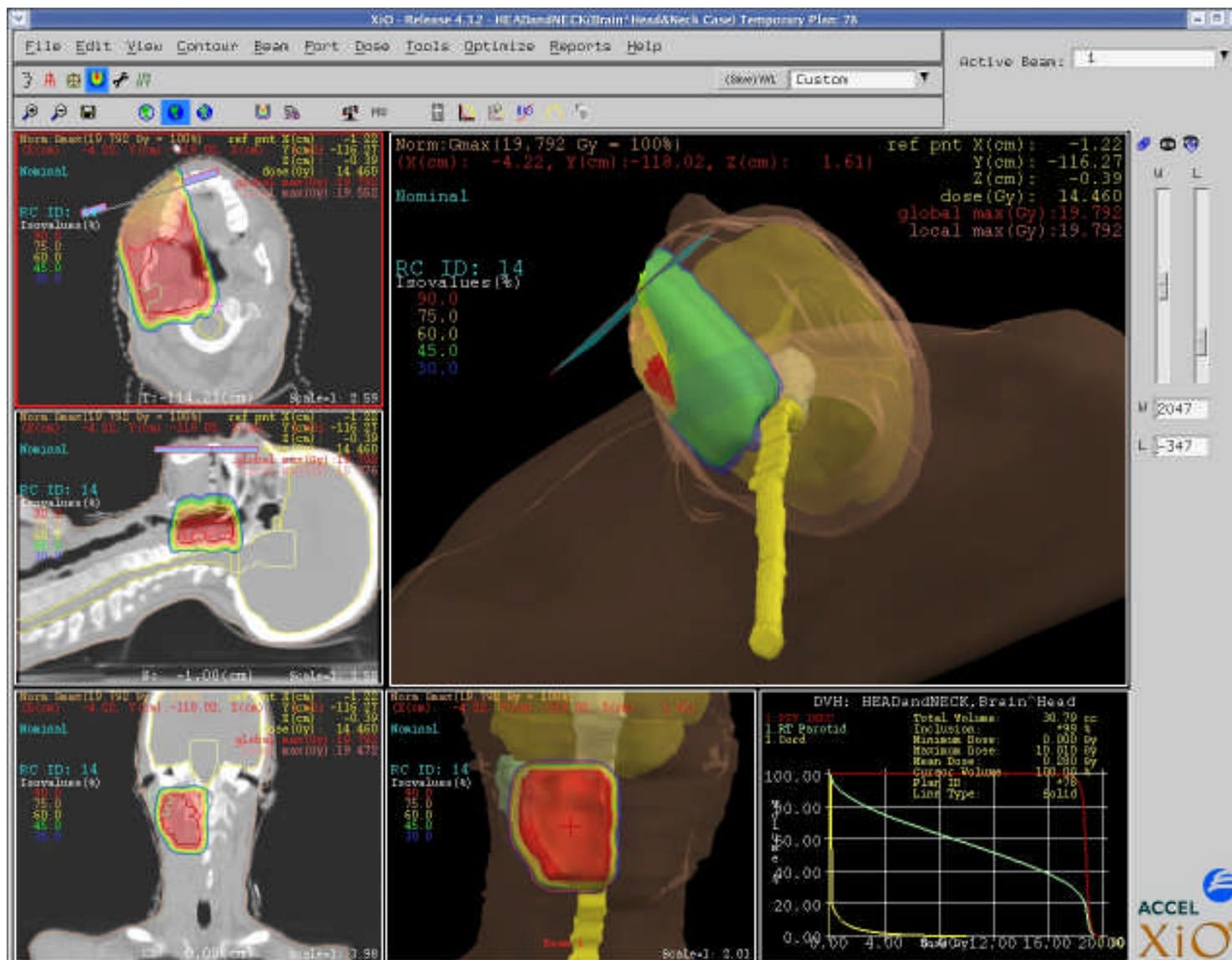
Intensitätsmodulierte Protonentherapieplanung mit CMS

Dr. Gustav Meedt

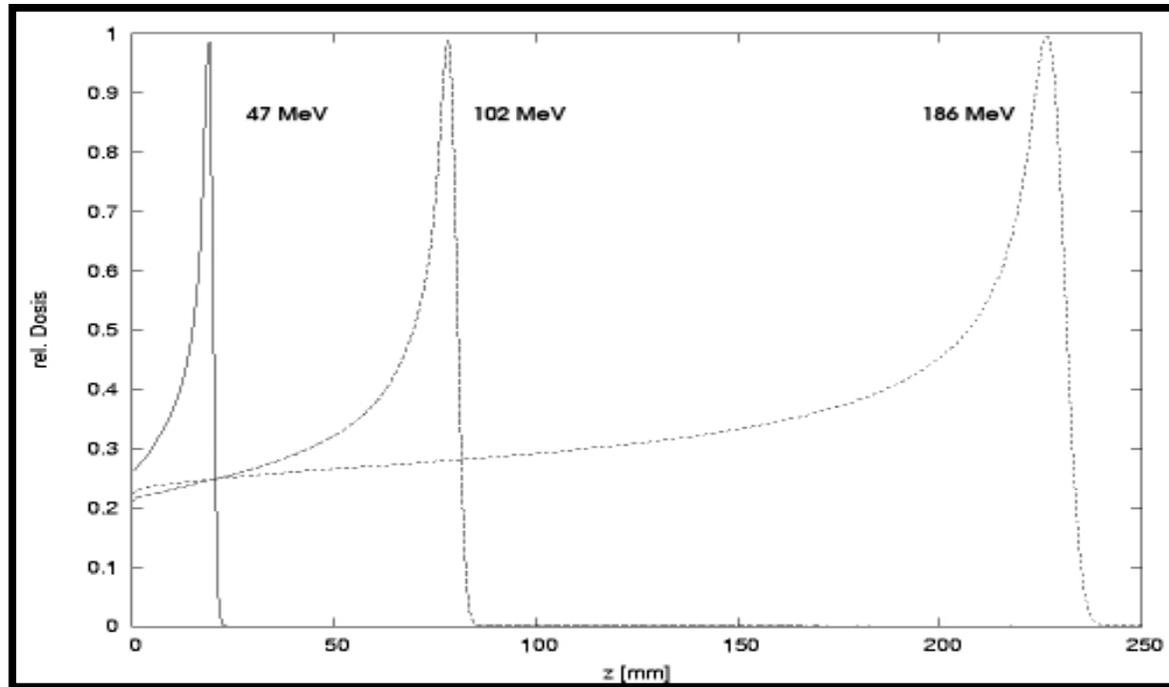
AK IMRT, Heidelberg, 30. März 2007



Protontherapie: Vorteile

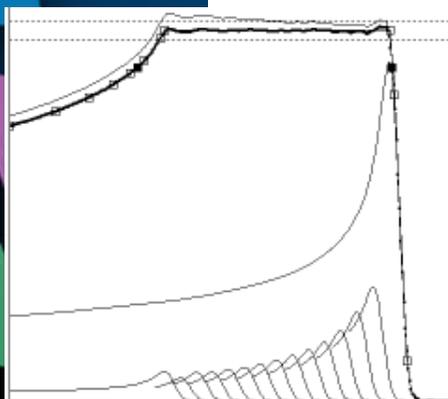


Protonentherapie - Prinzipien

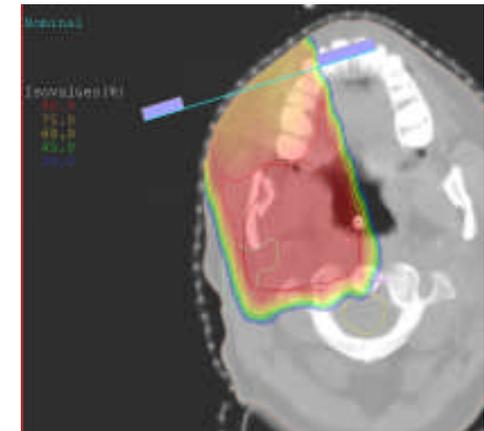
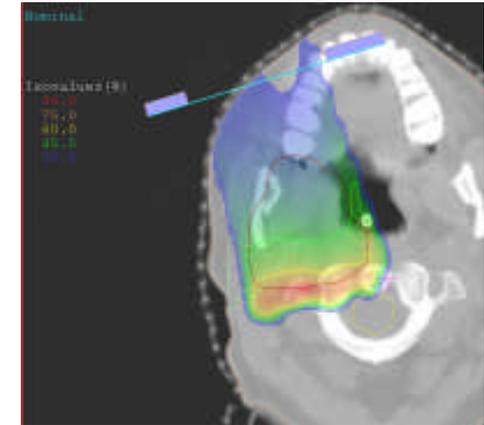


- Charakteristische Tiefendosiskurve
- „Bragg“ - Maximum ist energieabhängig

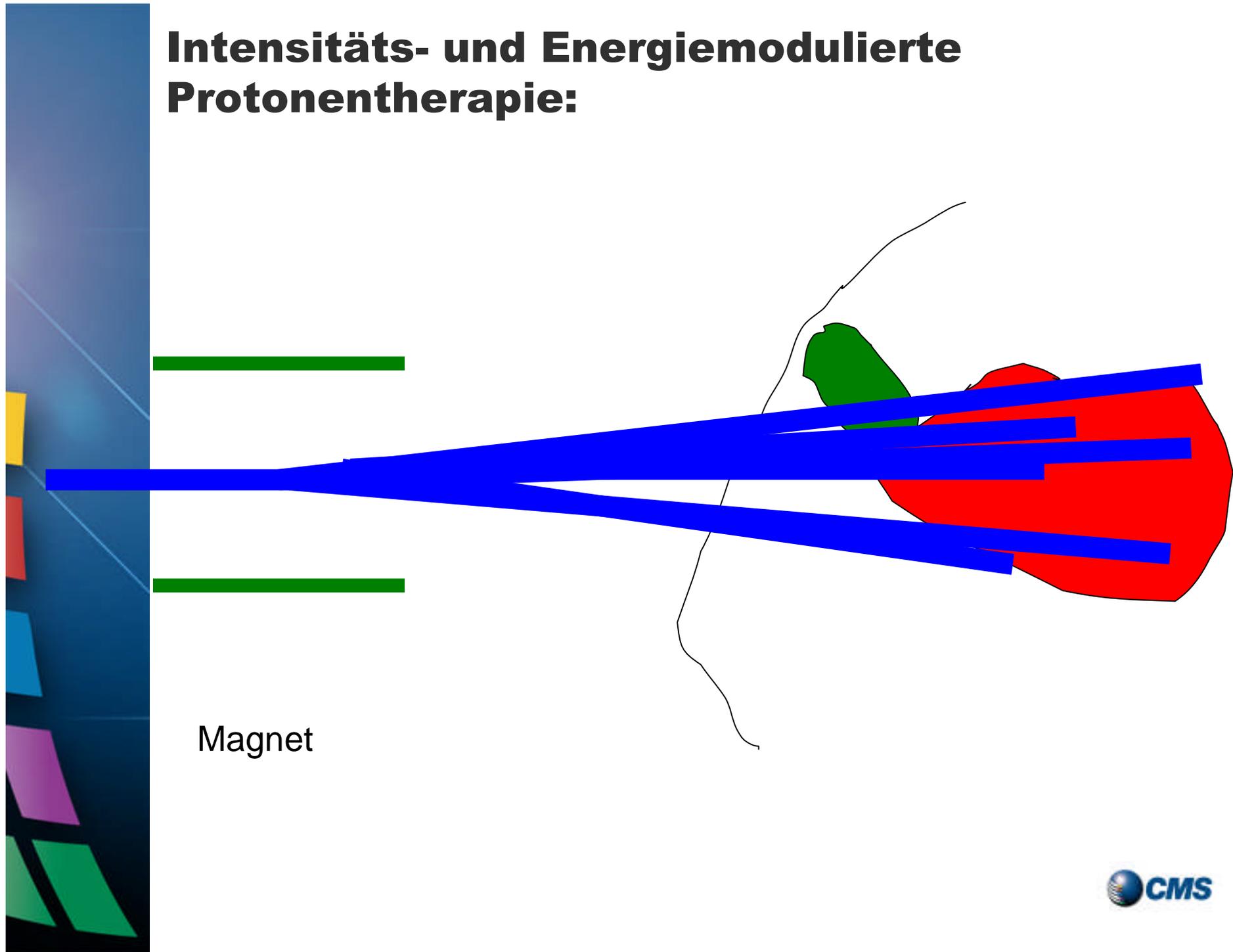
Passive Scattering



- **Blende** mit projizierten Zielvolumen
- **Kompensator** (Patientenkontur bzw. Dichterverteilung)
- **Energiemodulation** (z.B. Modulation-wheel -> Spread Out Bragg Peak)
- Keine Berücksichtigung von Risikoorganen!



Intensitäts- und Energiemodulierte Protonentherapie:



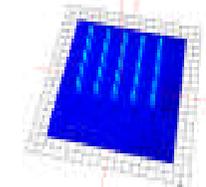
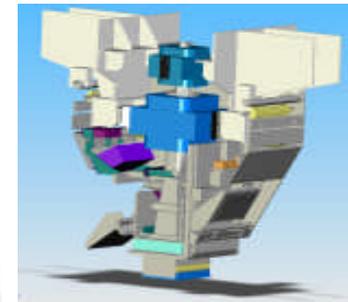
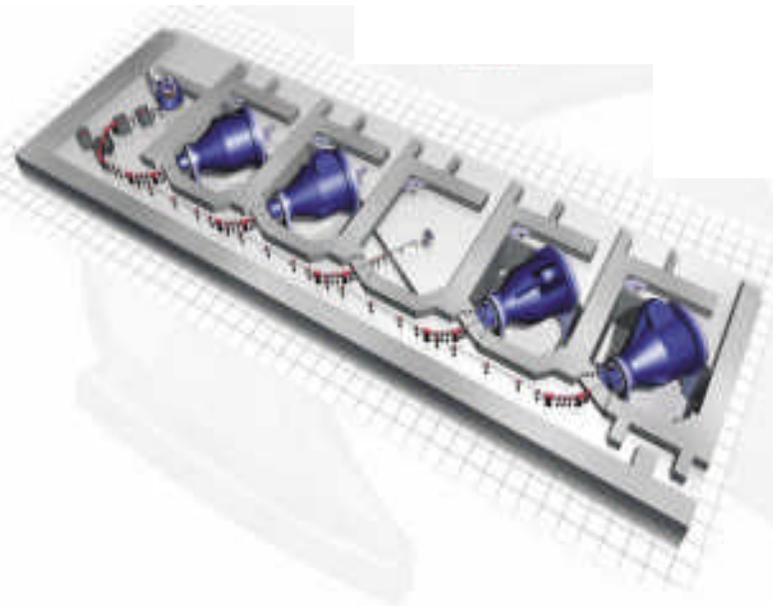
Das RPTC in München



Rinecker Proton Therapy Center

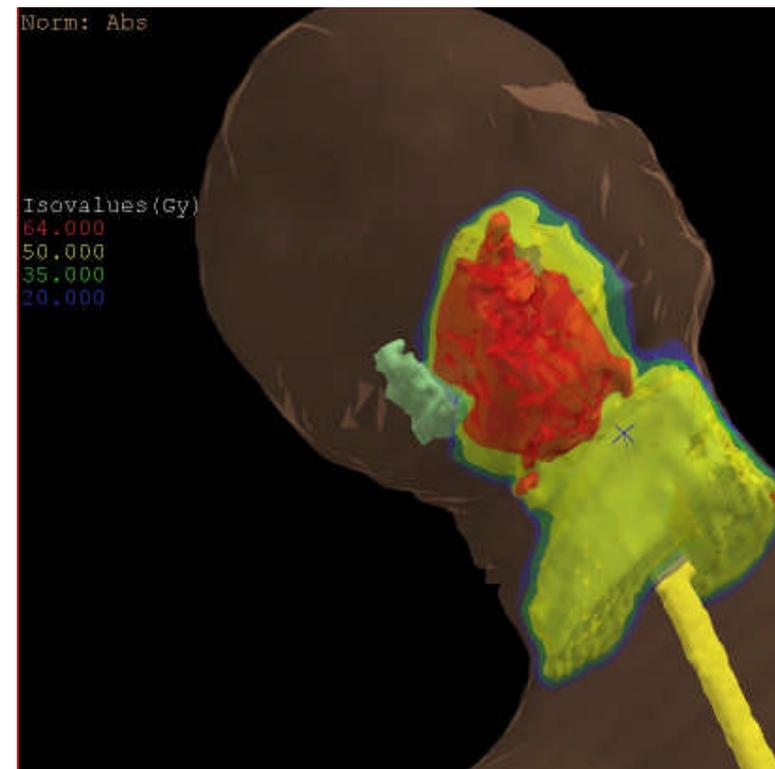
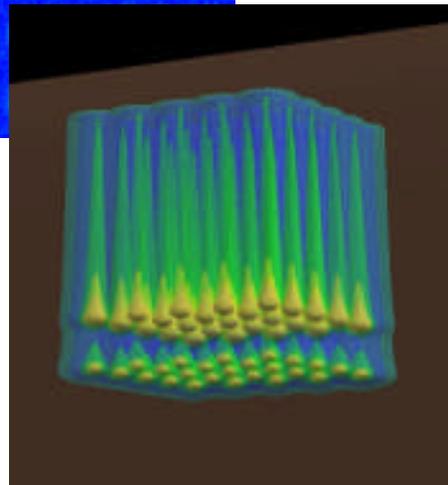
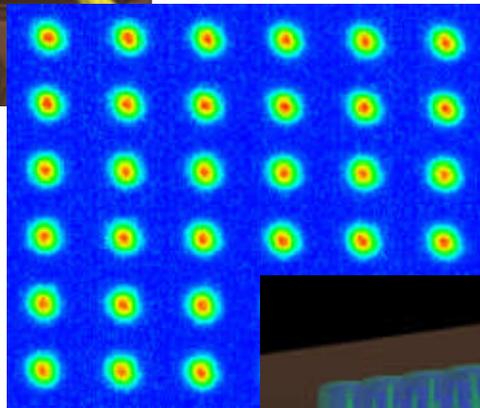
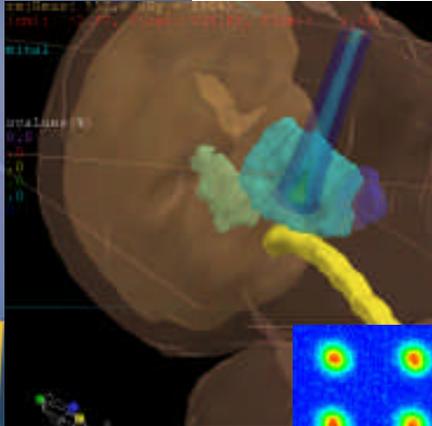
- CMS entwickelte Therapiplanungssoftware.
- 4 Gantries, ein Fixedbeam - Raum.
- Augen – und H&N Planung – Passive Scattering.
- Gantries: IMPT Therapieplanung.

- Kommissionierung der 1. Gantry: (02 – 05 2006).
- CE – zertifizierte Software installiert.

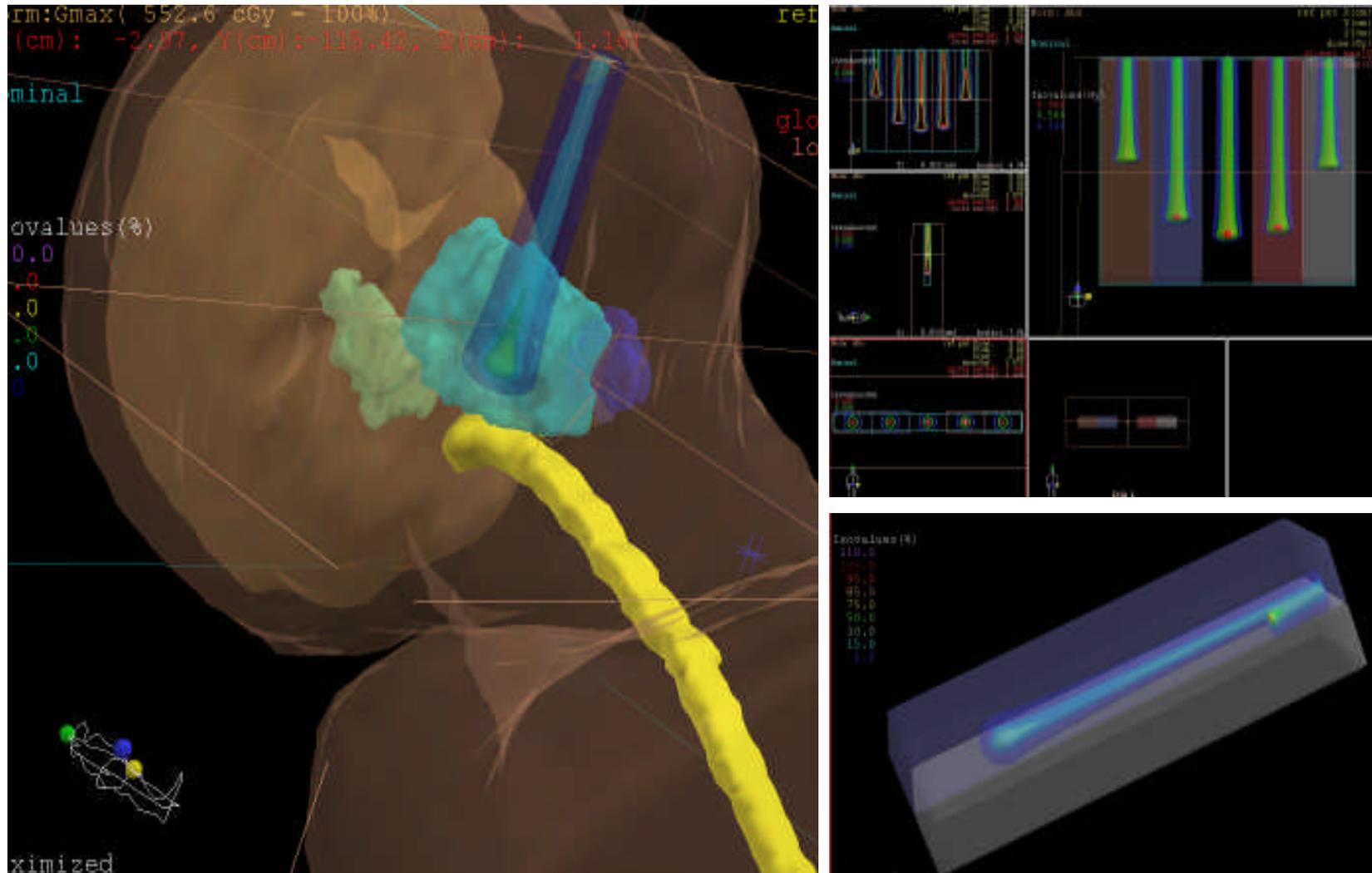


IMPT

- Definition von **Energieschichten** (Reichweiten)
- Für jede Reichweite, definiere rechteckiges Feld
- Optimiere jeden einzelnen Nadelstrahl



Spot Scanning Planung: Dosis-Berechnung mit erweiterten Nadelstrahl



Dosisberechnungsalgorithmus: Spot-scanning

Nadelstrahl-Verfahren Soukup et al.

Prinzipiell ähnlich zu Hogstroms Nadelstrahlverfahren:

$$T(x, y, z) = f(E, \rho) \cdot T(z_{\text{eff}}) \cdot L(x, y; z_{\text{eff}})$$

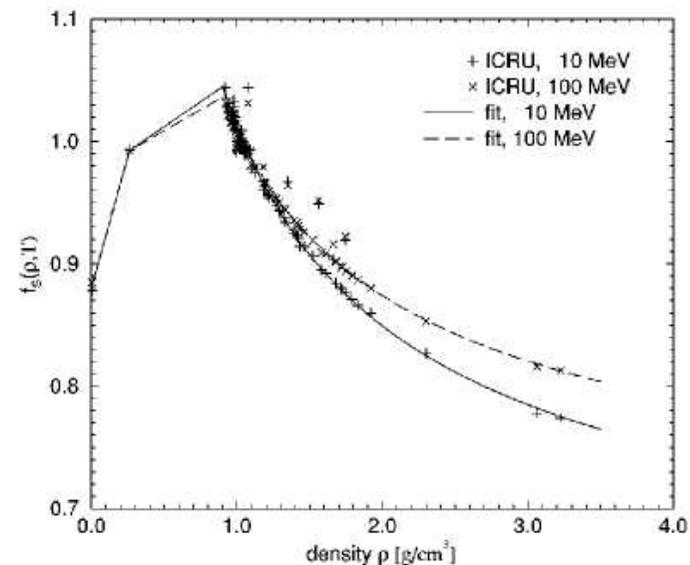
- $f(E, \rho)$ – Stoppingpower-ratio
- $T(z)$ – Integral Depthdose measured in water.
- $L(x, y; z)$ – Lateral distribution (2 D Gaussian with $\sigma_x(z)$, $\sigma_y(z)$)

"Multiple Coulomb scattering of 160 MeV protons" by B. Gottschalk, A. M. Kohler, R. J. Schneider, J.M. Sisterson, and M.S Wagner, *Nuclear Instruments and Methods in Physics Research B74* (1993), p. 467-490.

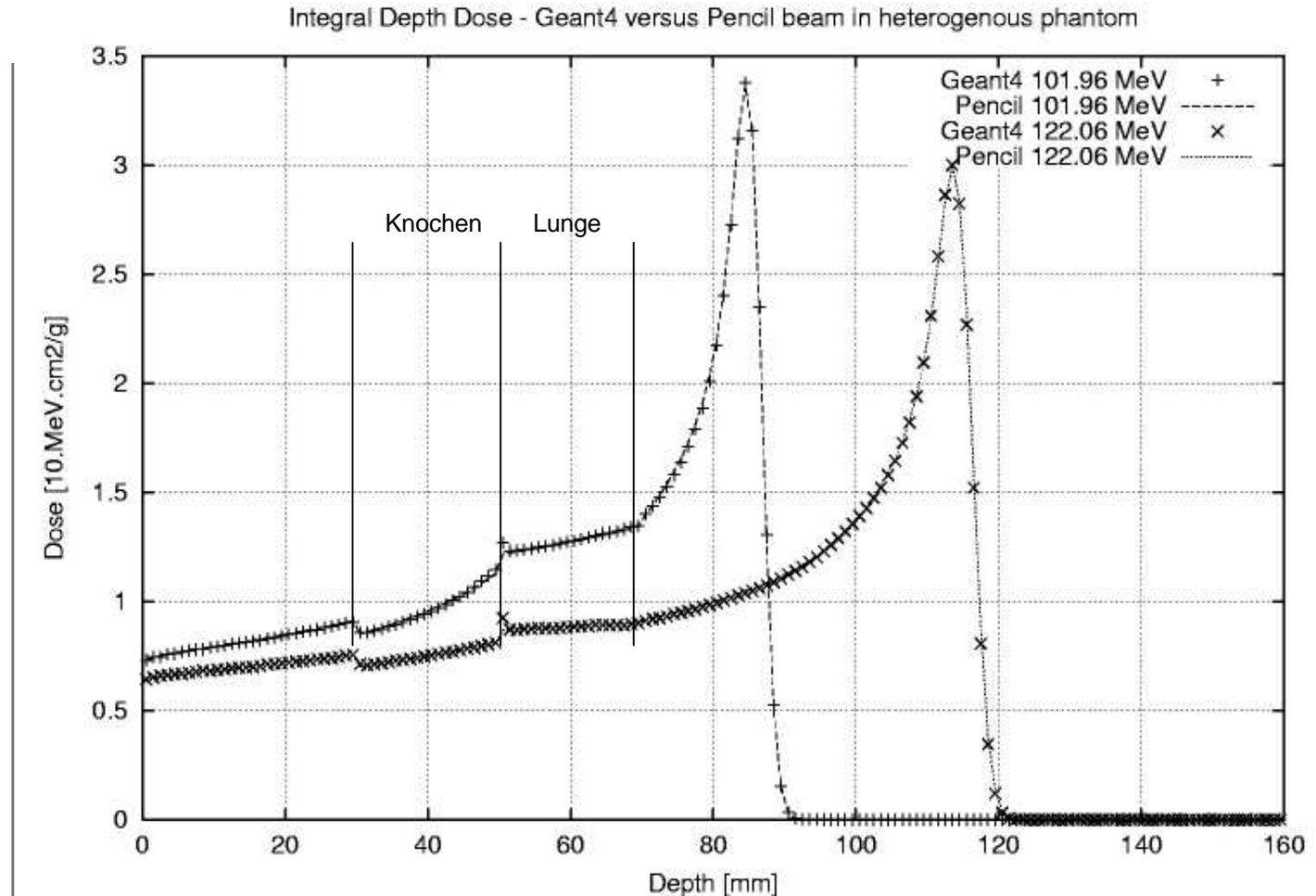
„Cosmic-Ray Theory„ Rossi et al., *Reviews of Modern Physics*, 13/1941

- Z_{eff} – Effective (radiologische äquivalente) Tiefe im Patient.

(*) M. Fippel, M. Soukup (2004): "A Monte Carlo dose calculation algorithm for proton therapy", *Med. Phys* 31(8) 2263-73



Dosisberechnungsalgorithmus: Spot-scanning



ICRU 44 phantom

$$\rho_{\text{bone}} = 1.46 \text{g/cm}^2$$

$$\rho_{\text{lunge}} = 0.26 \text{g/cm}^2$$

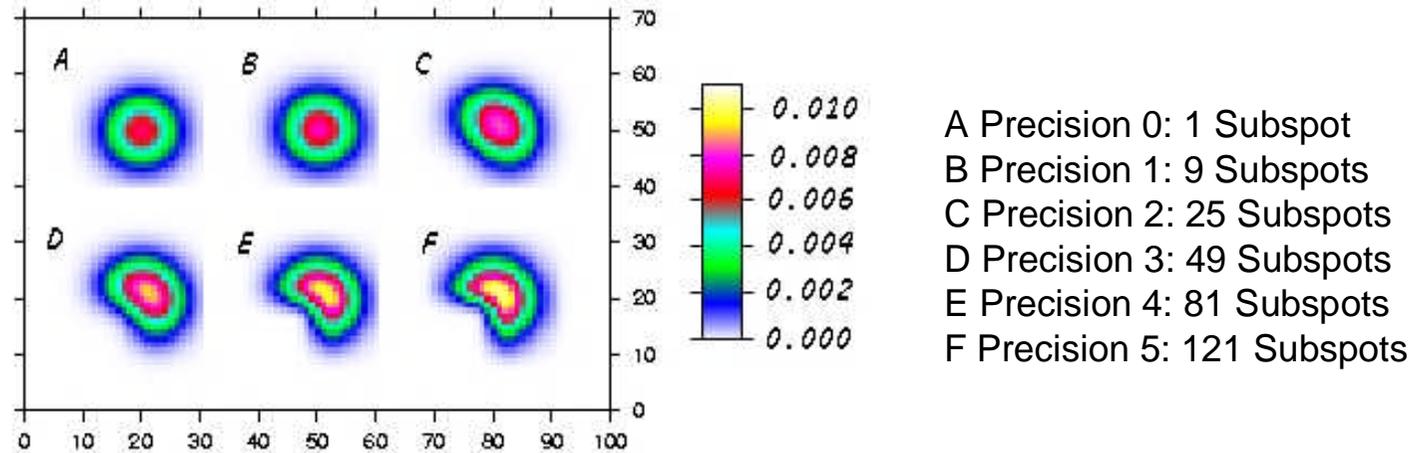
$$\rho_{\text{st}} = 1.03 \text{g/cm}^2$$

Martin Soukup, Universitätsklinikum
Tübingen 2004

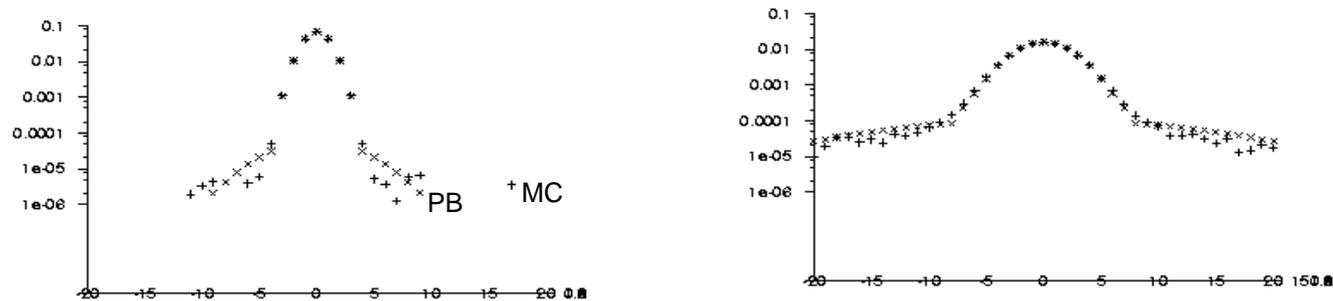


Dosisberechnungsalgorithmus: Spot-scanning

Laterale Inhomogenitäten: Zerlegung der Nadelstrahlen in Subspots

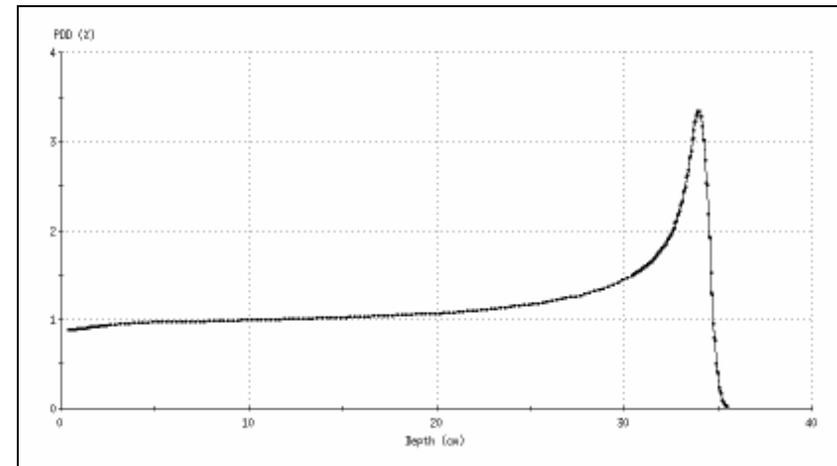


Beitrag der nuklearen Wechselwirkungen an lateraler Streuung

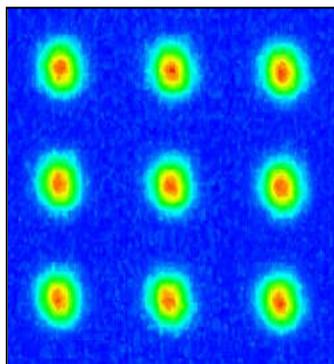


Basisdaten

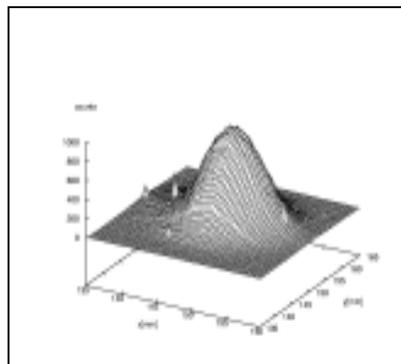
- Integrale Tiefendosiskurve für ausreichend viele Energien



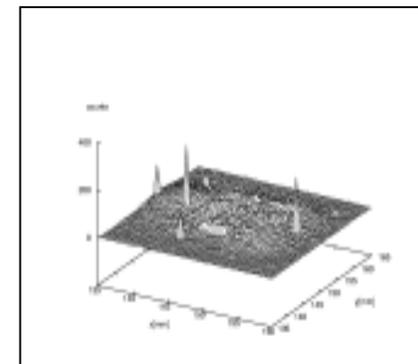
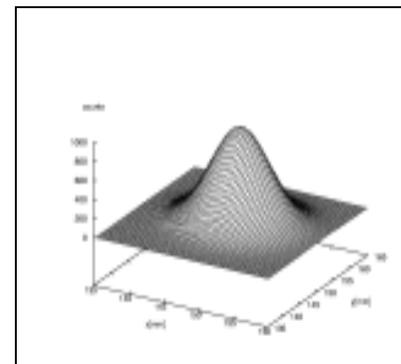
- Spot-Profile im Zentralstrahl:
Gauss'sche Sigma für x, y und alle Energien



Gemessenes Profil



2D Gauss- Fit

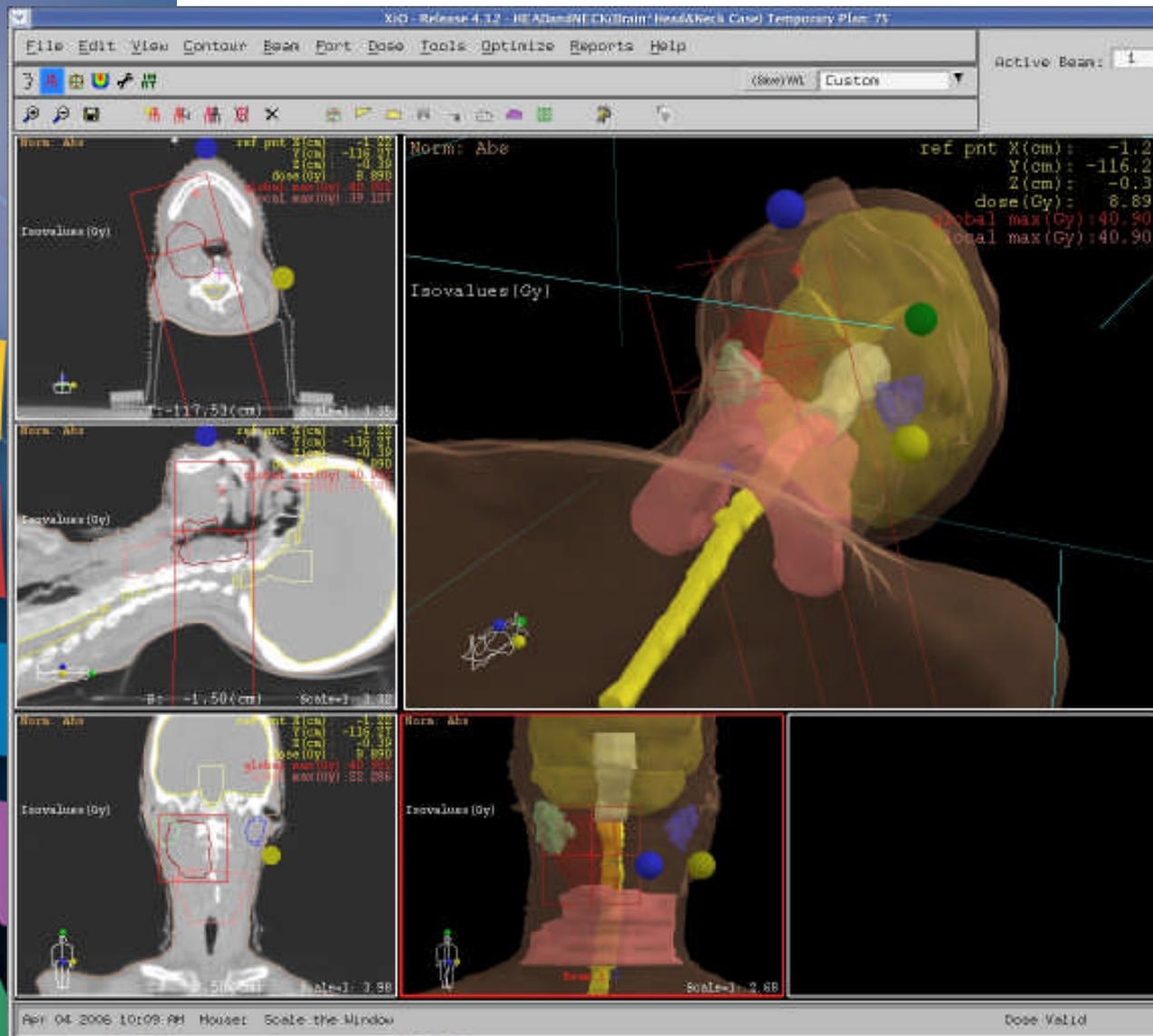


Differenz-Plot

Basisdaten

- Abhängigkeit der Spotgröße von Ablenkung
- MU-Kalibrierung für jede Energie
- Maschinendefinition (Magnetposition)
- Integrale Tiefendosiskurve für Modifiers
(Rangeshifter, Ripplefilters)
- Spot – Divergenz in Luft
- CT-Kalibrierung auf Massendichte

Therapieplanung in XiO: Beamsetup



Therapieplanung in XiO: Beamsetup

The screenshot shows the XiO software interface for beam setup. The main window displays four views of a head and neck case: Axial, Sagittal, Coronal, and a 3D Normo view. A 'Beam Volume Parameters' dialog box is open, showing a table of 13 beam layers. The table includes columns for Layer, Desired Range (g/cm²), Prescribed Range (g/cm²), Auto All, Spot Size (cm), Spot Spacing (cm), Number of Points, Status, and Intensity Map. The 6th layer is highlighted in yellow.

Layer	Desired Range (g/cm ²)	Prescribed Range (g/cm ²)	Auto All	Spot Size (cm)	Spot Spacing (cm)	Number of Points	Status	Intensity Map
1	10.90	10.90	Auto	0.30	0.50	1	On	Edit
2	10.10	10.10	Auto	0.30	0.50	1	On	Edit
3	9.30	9.30	Auto	0.30	0.50	1	On	Edit
4	8.50	8.50	Auto	0.30	0.50	1	On	Edit
5	7.70	7.70	Auto	0.30	0.50	1	On	Edit
6	6.90	6.90	Auto	0.30	0.50	1	On	Edit
7	6.10	6.10	Auto	0.30	0.50	1	On	Edit
8	5.30	5.30	Auto	0.30	0.50	1	On	Edit
9	4.50	4.50	Auto	0.30	0.50	1	On	Edit
10	3.70	3.70	Auto	0.30	0.50	1	On	Edit
11	2.90	2.90	Auto	0.30	0.50	1	On	Edit
12	2.10	2.10	Auto	0.30	0.50	1	On	Edit
13	1.30		Auto	0.30	0.50	1	Off	Edit

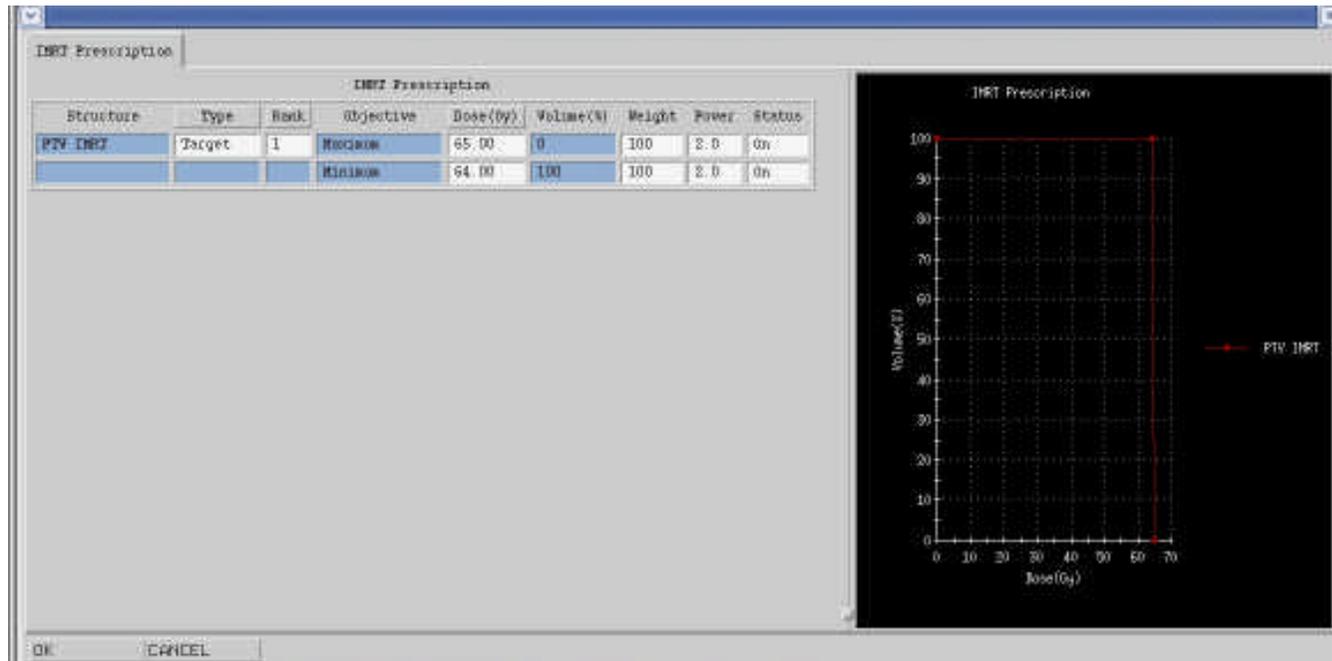
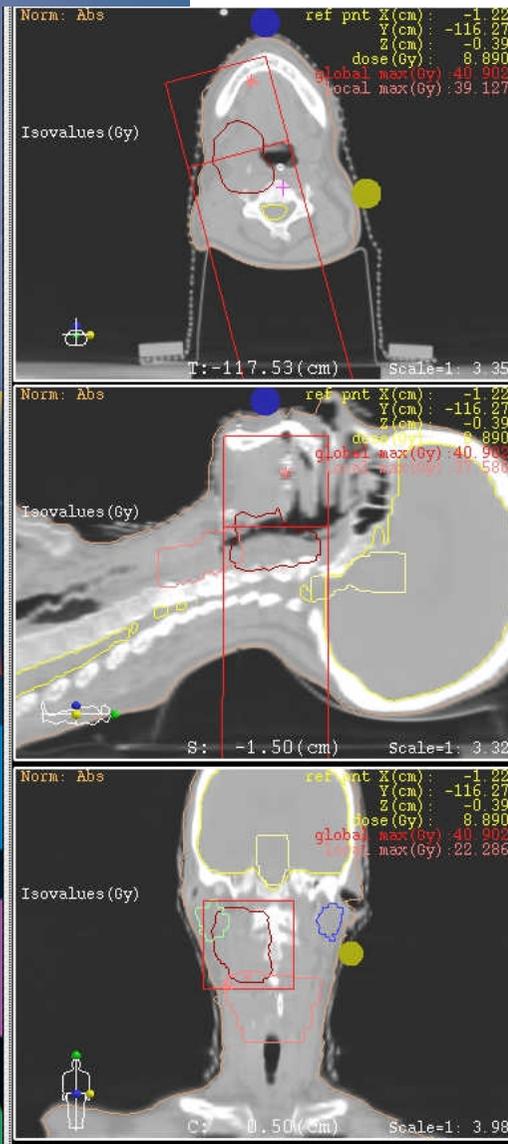
Beam Volume Parameters:

Range Shift: Distal Extent of Target (g/cm²): 10.90
 Ripple Filter (g/cm²): Proximal Extent of Target (g/cm²): 0.40
 Alignment Shift (cm): 0.00 Peak Width Multiplier: 4.00

Scan Layer Table

Apr 04 2006 10:09:PM Mouse: Scale the Window Dose Valid

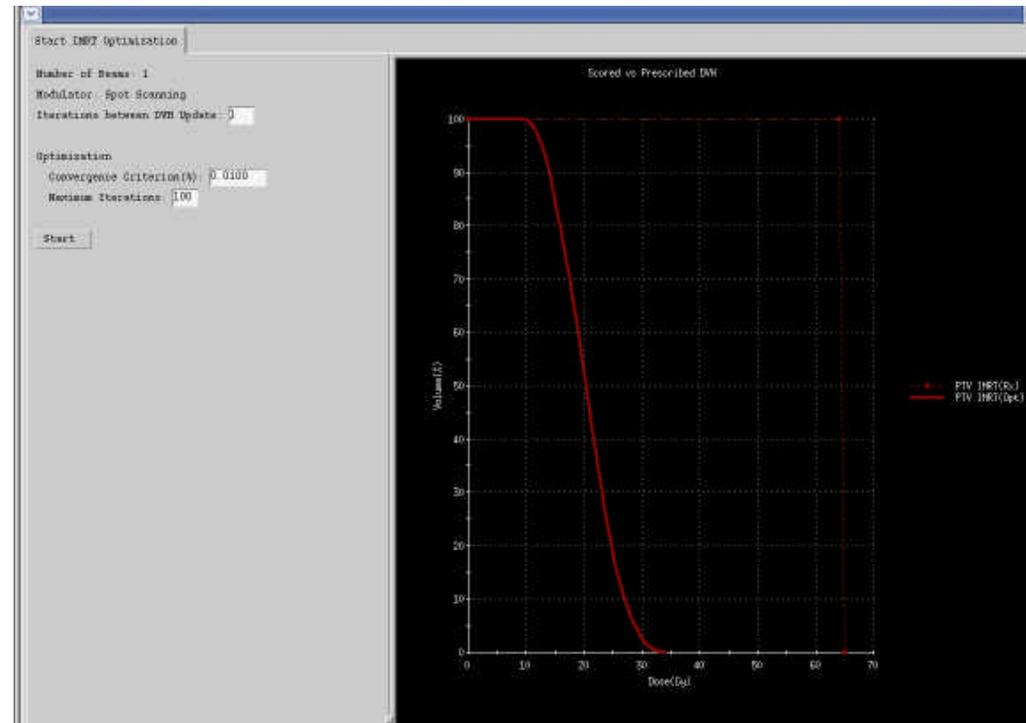
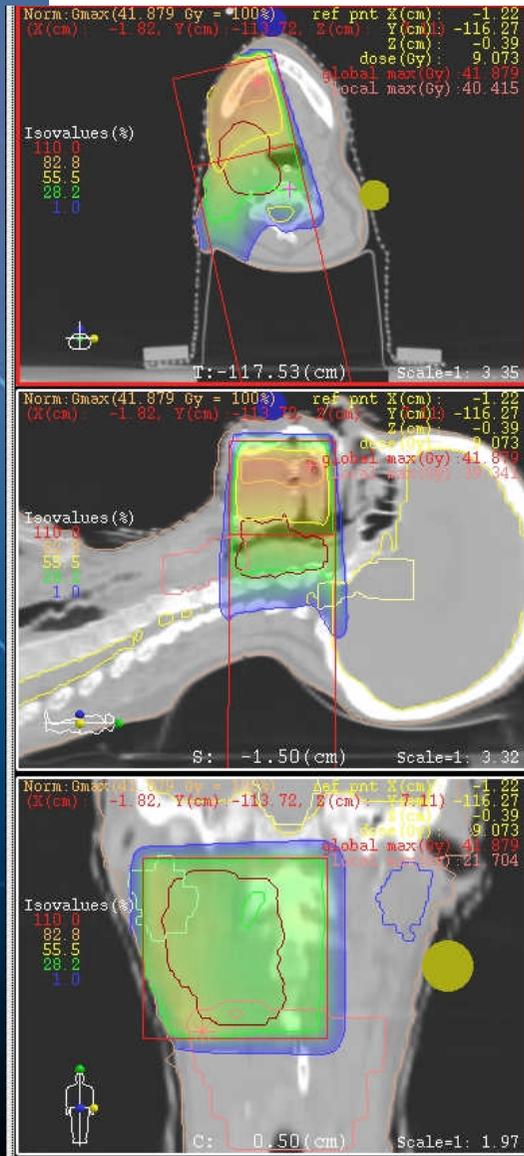
Therapieplanung in XiO: Verschreibung



1. Beispiel: Nur primäres Zielvolumen

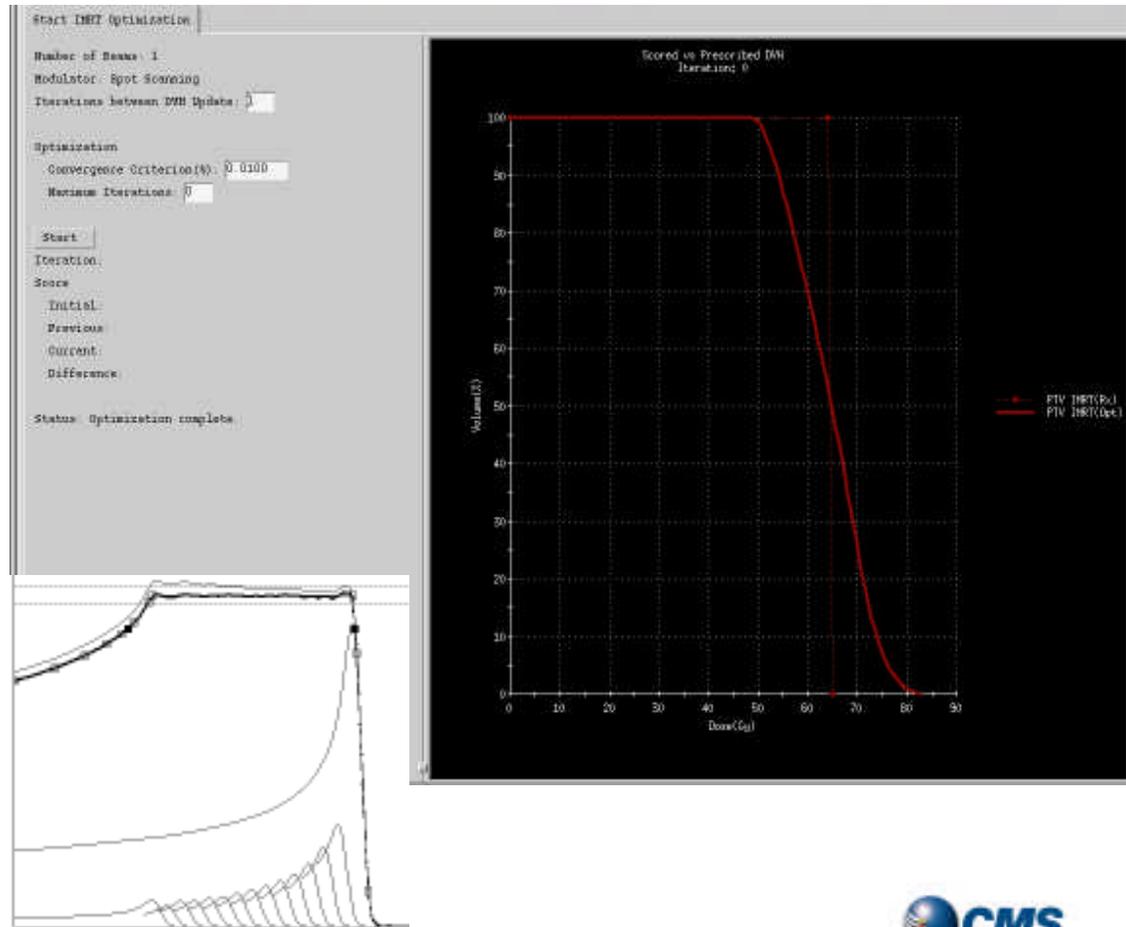
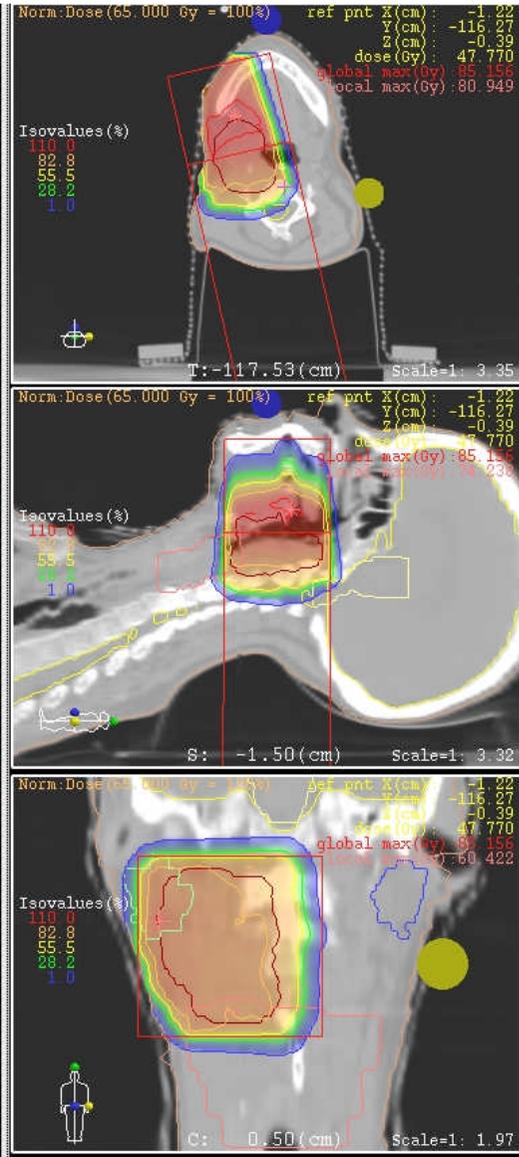
Therapieplanung in XiO: Optimierung

- Anfangsfluenz aller Spots: 100 MU



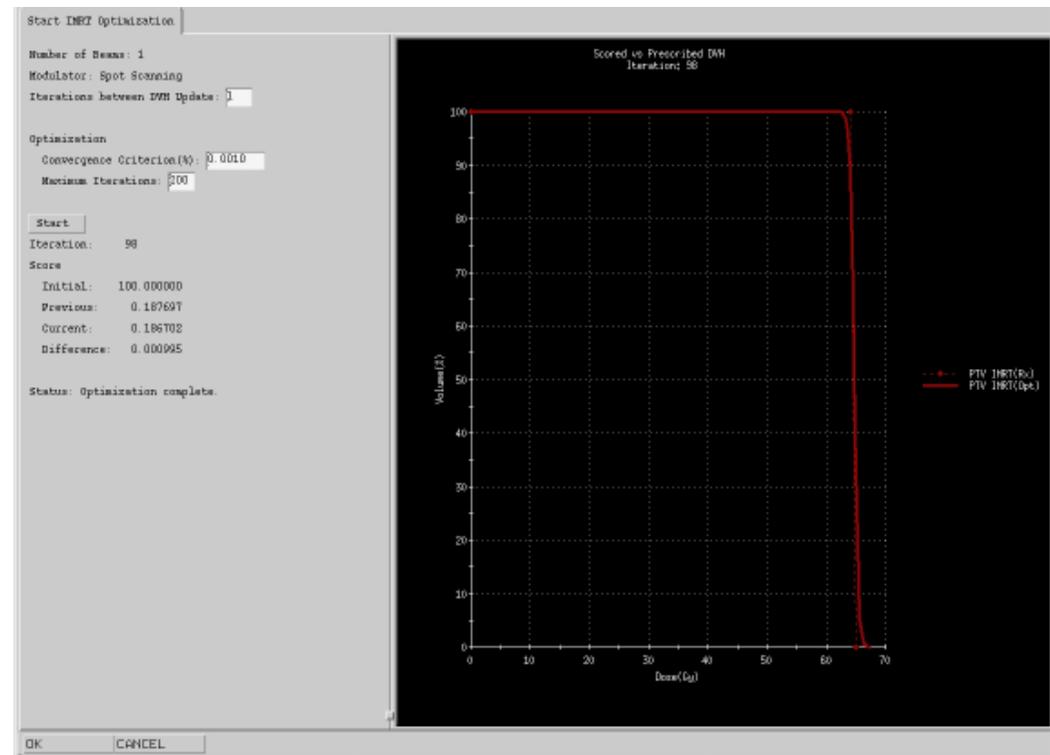
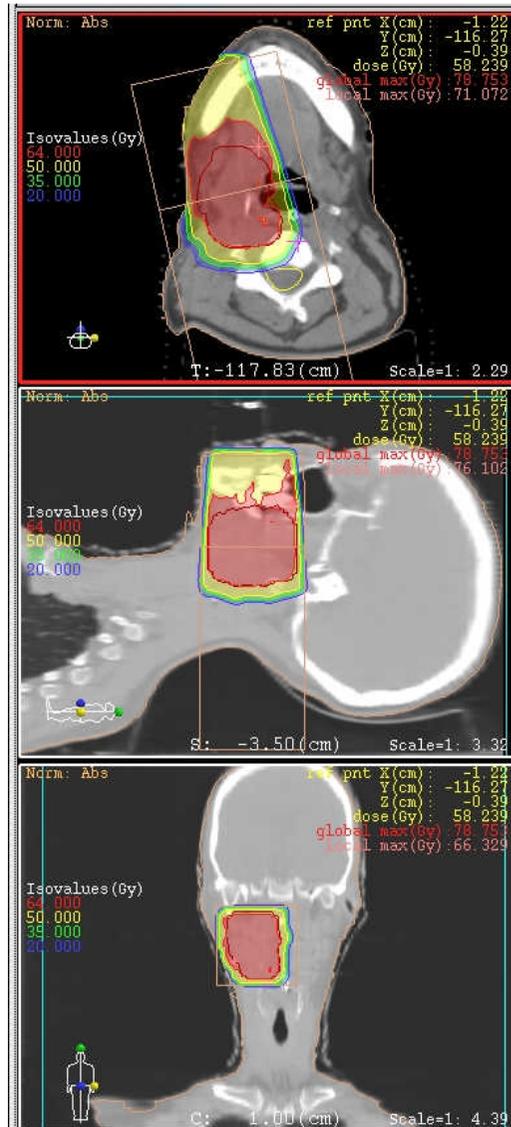
Therapieplanung in XiO: Optimierung

- Vorgewichtung der Spotfluenzen
- Hier: Keine Optimierung

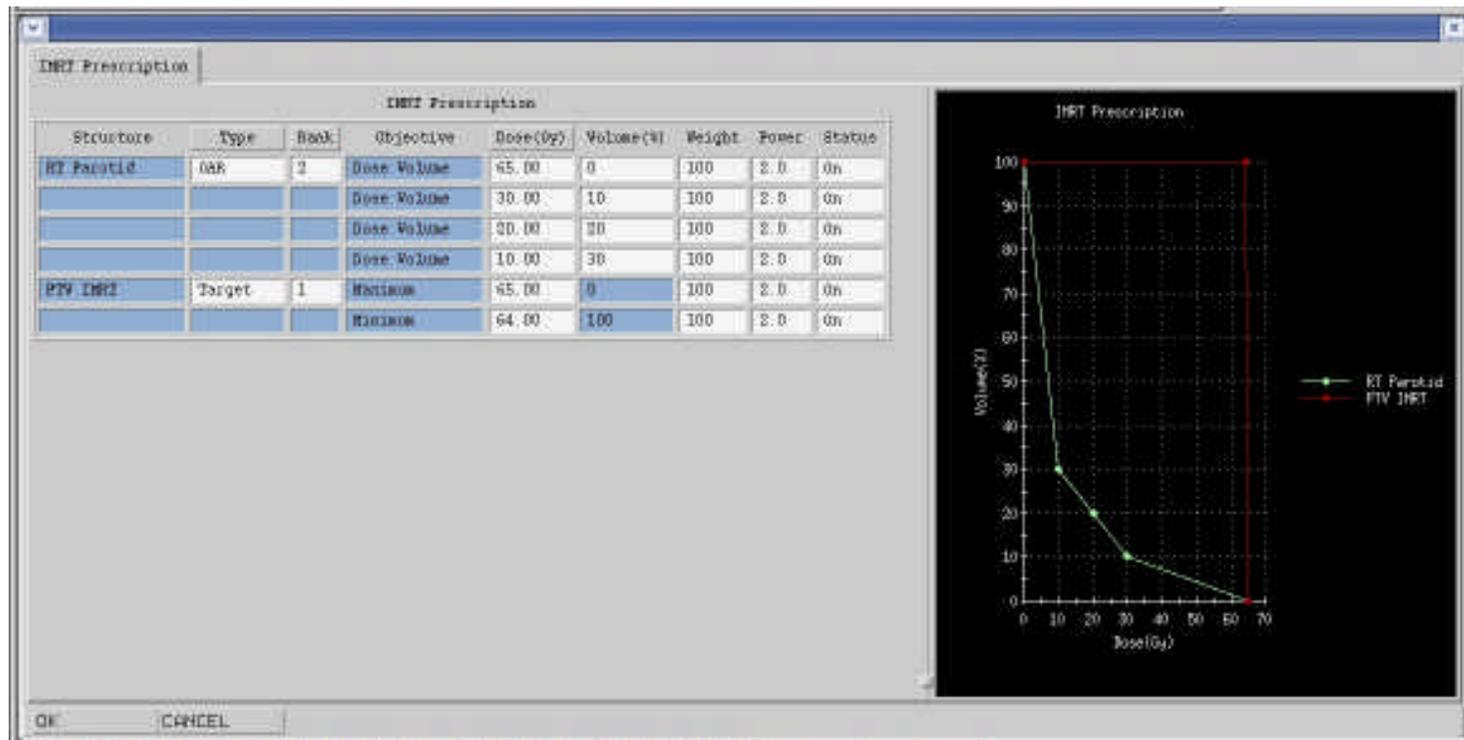


Therapieplanung in XiO: Optimierung

- Optimierung aller Spot-Fluenzen
- Conjugate gradient



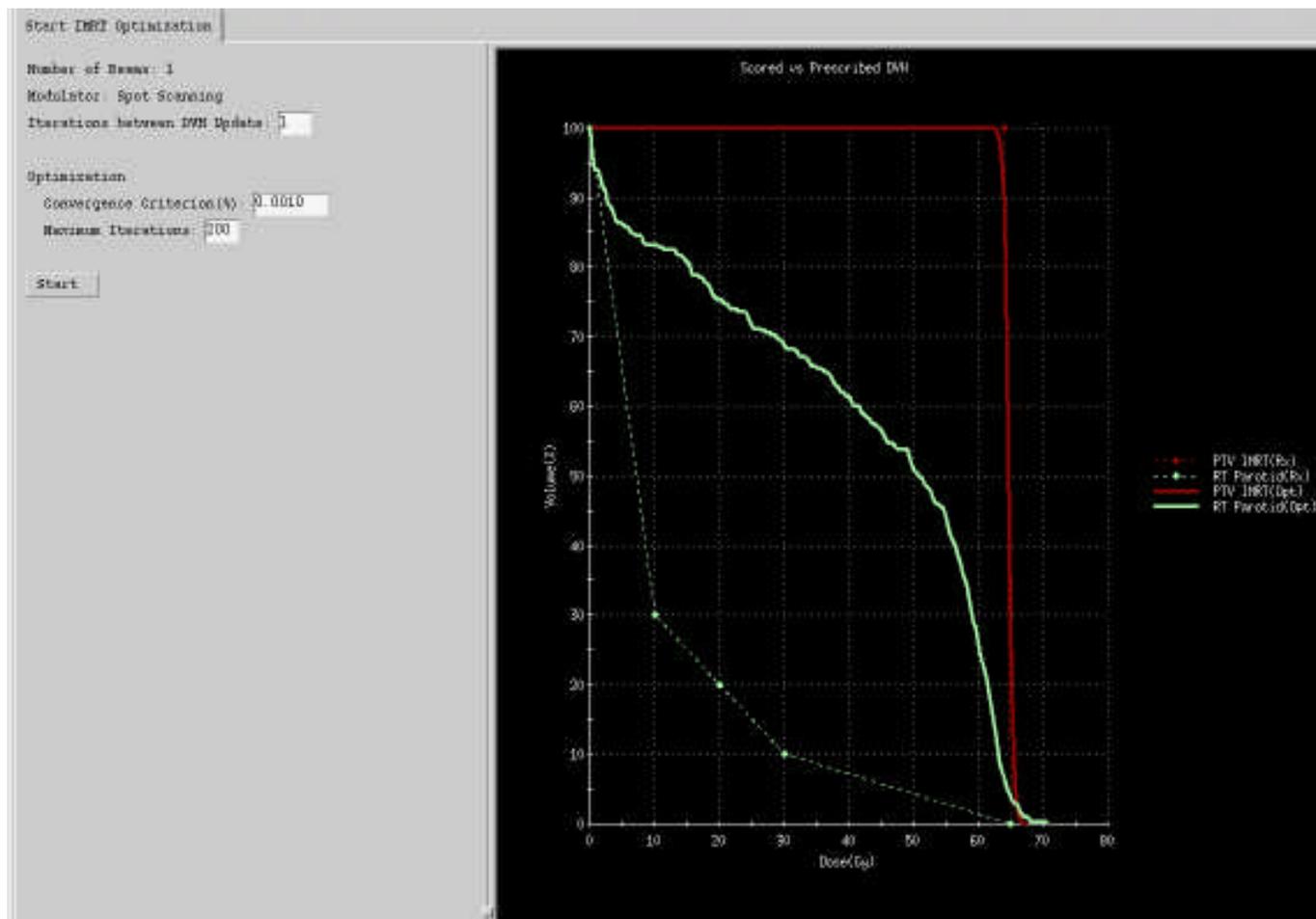
Therapieplanung in XiO: Verschreibung



- Berücksichtigung der rechten Parotide
- Bis zu 5 DVH Punkte verschreibbar

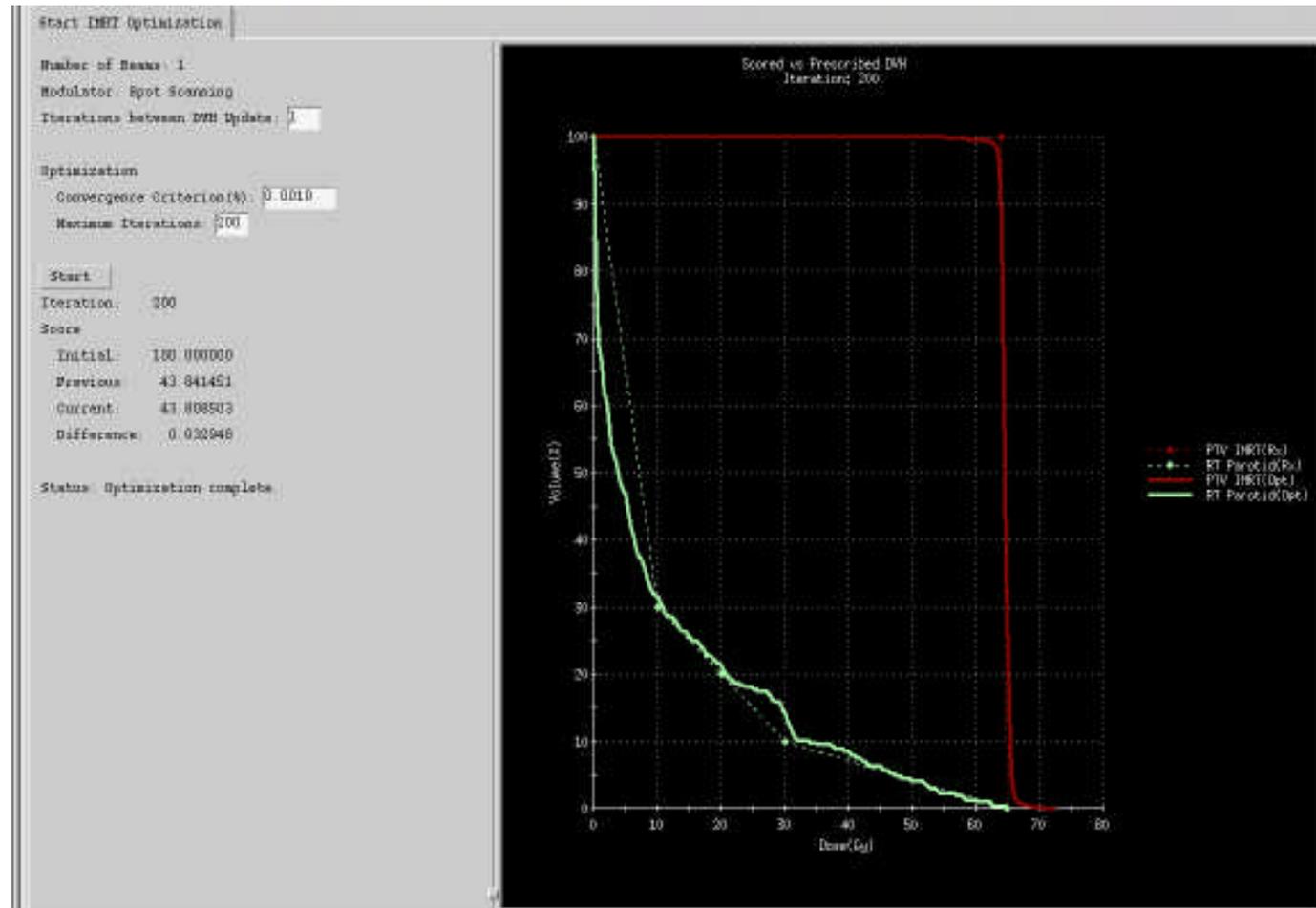


Therapieplanung in XiO: Optimierung



Fluenzprofil der vorherigen Optimierung

Therapieplanung in XiO: Optimierung



Therapieplanung in XiO: Optimierung



Planung in XiO: Spotpositionen

XiO - Release 4.12 -

File Edit View Contour Beam Port Dose Tools Opt

Norm:Dose(65.000 Gy - 100%)

Isovalues (%)

- 110.0
- 82.8
- 55.5
- 28.2
- 1.0

Maximized T: -115.13 (cm) Scale=1: 1.10

Spot Volume Parameters

Range Filter: [] Distal Extent of Target (g/cm²): 11.74

Ripple Filter (g/cm²): [] Proximal Extent of Target (g/cm²): 0.53

Alignment Shift (cm): 0.00 Peak Width Multiplier: 1.00

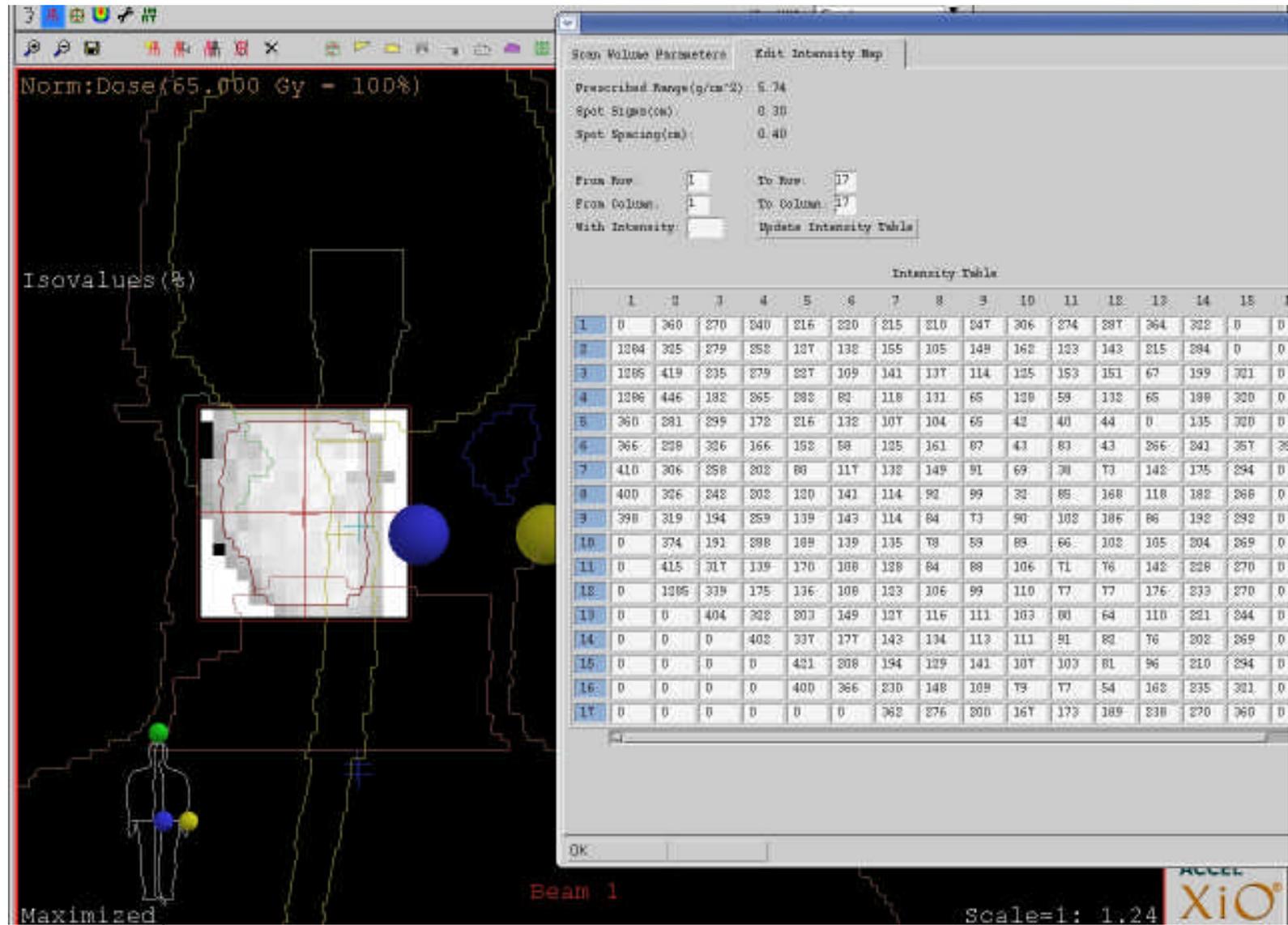
Scan Layer Table

Layer	Desired Range (g/cm ²)	Prescribed Range (g/cm ²)	Auto All	Spot Size (cm)	Spot Spacing (cm)	Number of Points	Status	Intensity Map
5	9.64	9.34	Auto	0.30	0.40	1	On	Edit
6	8.04	8.74	Auto	0.30	0.40	1	On	Edit
7	8.44	8.14	Auto	0.30	0.40	1	On	Edit
8	7.84	7.54	Auto	0.30	0.40	1	On	Edit
9	7.24	6.94	Auto	0.30	0.40	1	On	Edit
10	6.64	6.34	Auto	0.30	0.40	1	On	Edit
11	6.04	5.74	Auto	0.30	0.40	1	On	Edit
12	5.44	5.14	Auto	0.30	0.40	1	On	Edit
13	4.84	4.54	Auto	0.30	0.40	1	On	Edit
14	4.24	3.94	Auto	0.30	0.40	1	On	Edit
15	3.64	3.34	Auto	0.30	0.40	1	On	Edit
16	3.04	2.74	Auto	0.30	0.40	1	On	Edit
17	2.44	2.14	Auto	0.30	0.40	1	On	Edit
18	1.84	1.54	Auto	0.30	0.40	1	Off	Edit

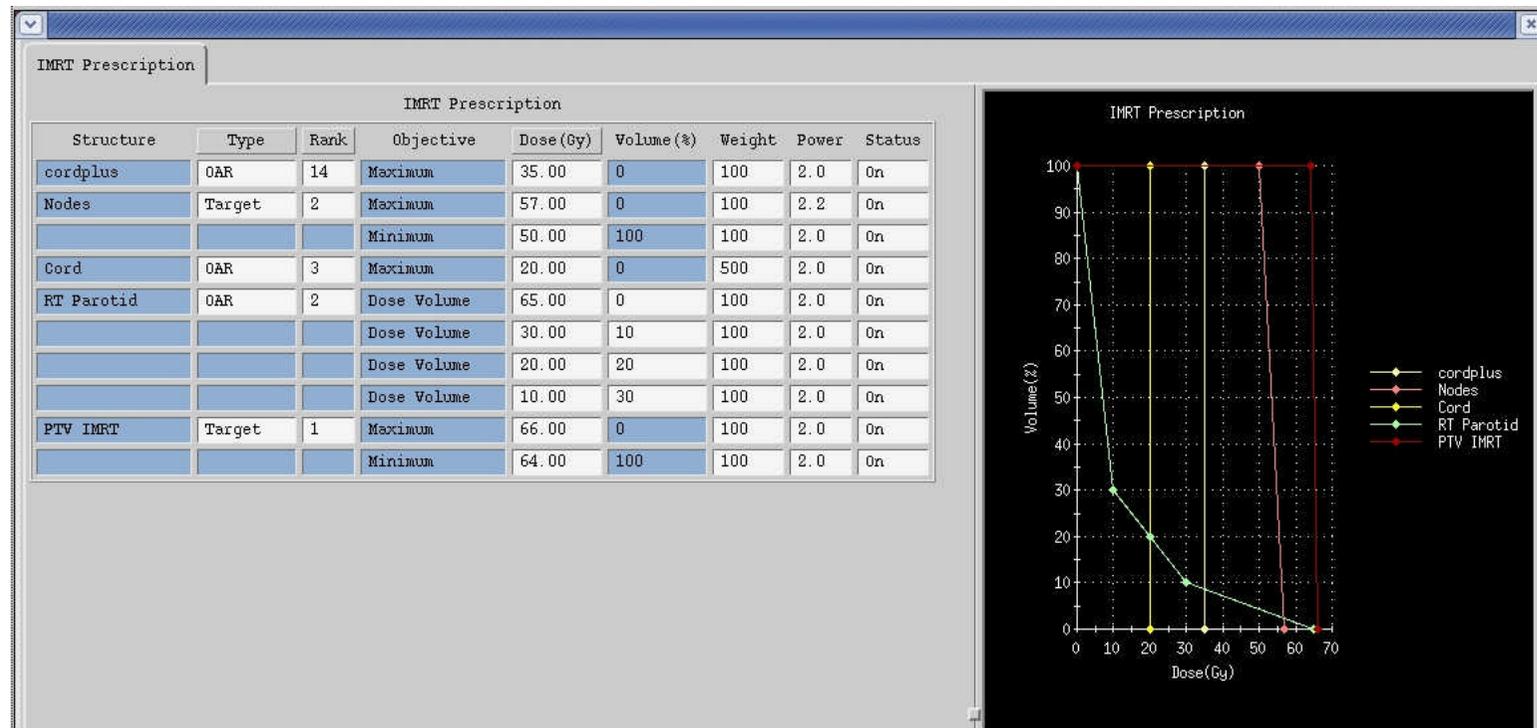
ACCEL XiO

CMS

Planung in XiO: Intensitäten



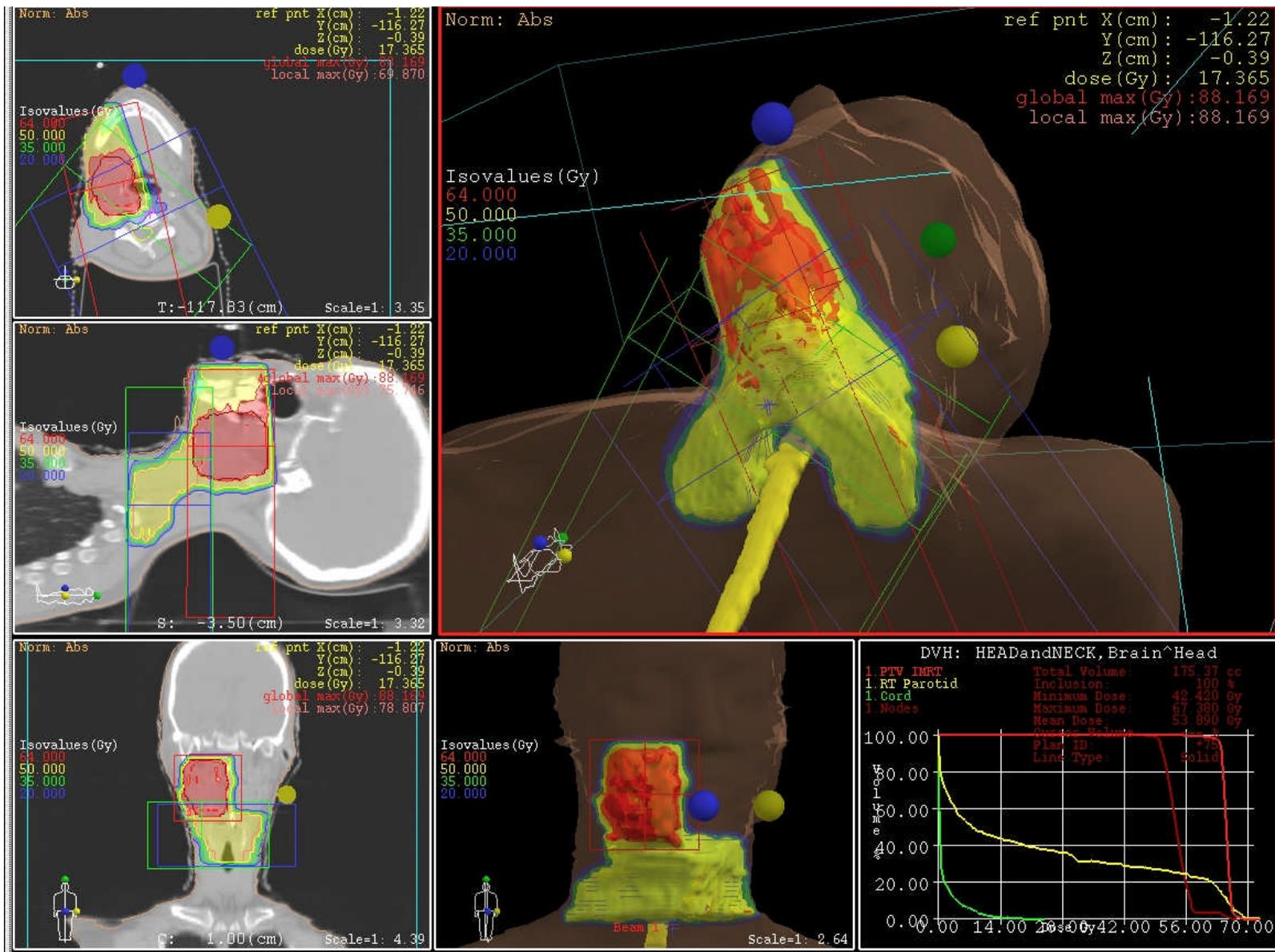
Planning in XiO: Komplexere Verschreibung



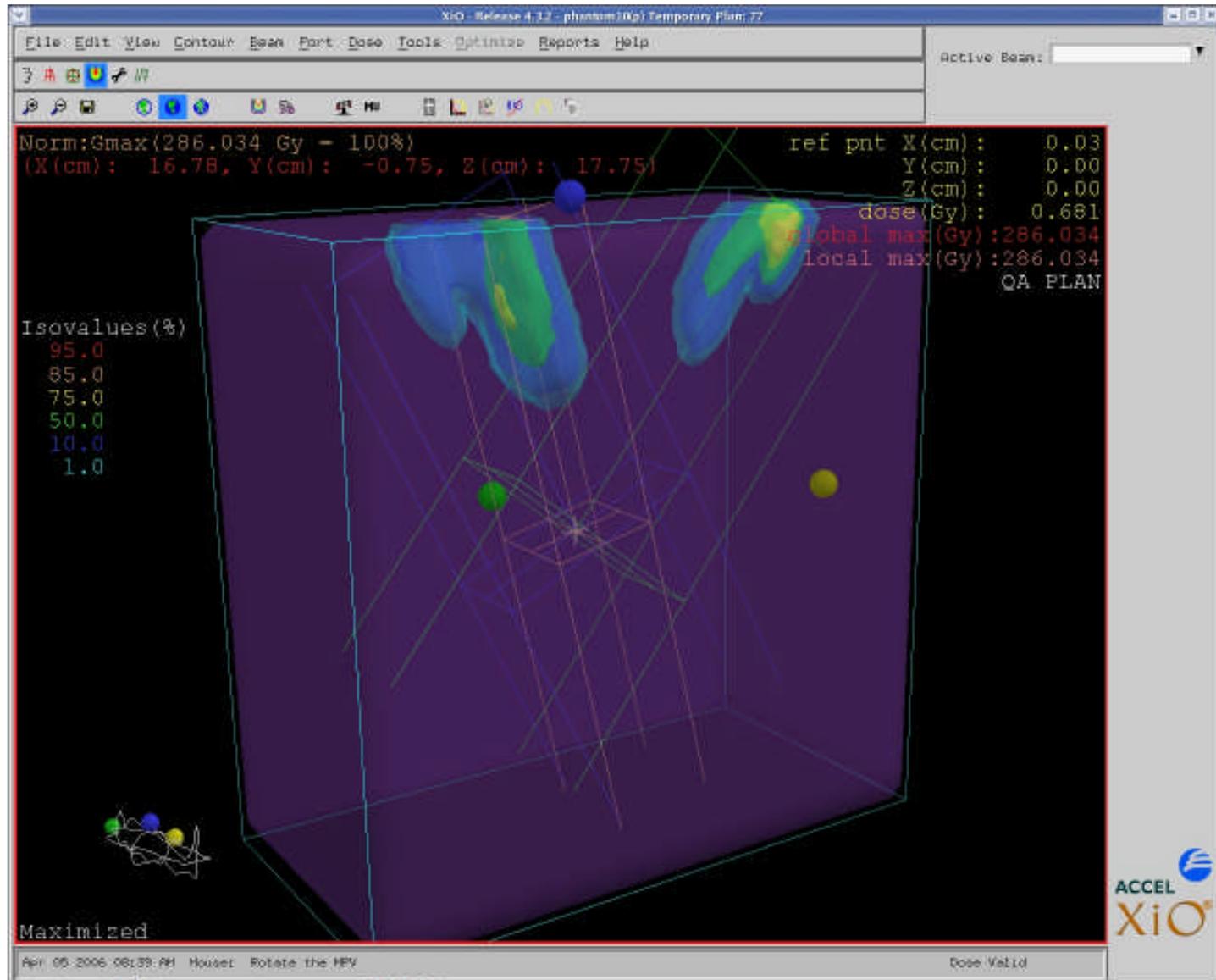
- Alle Risikoorgane in Strahlrichtung müssen berücksichtigt werden.
- Optimierung aller Einstrahlrichtungen:
 - Einzeln (Einfrieren aller anderen)
 - Simultan



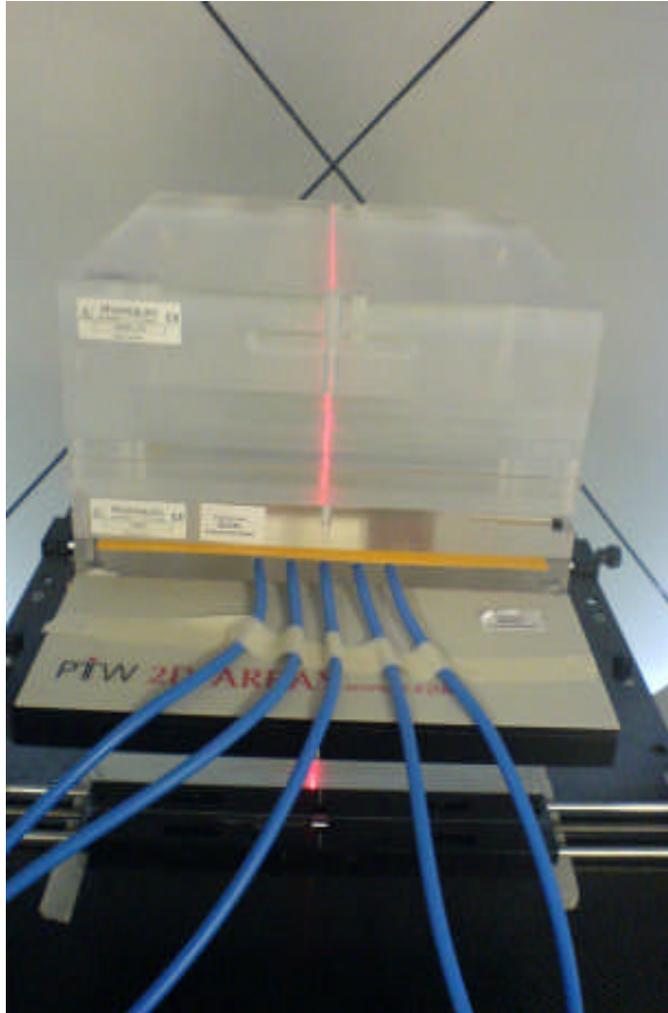
Planung in XiO: Komplette Optimierung



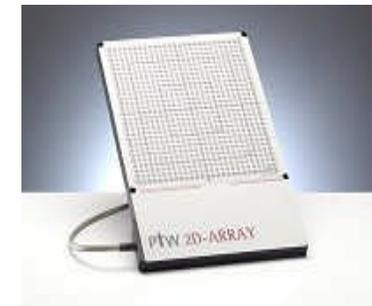
Planung in XiO: QA des Gesamtplanes



Erste Ergebnisse – Tests an gantry 1



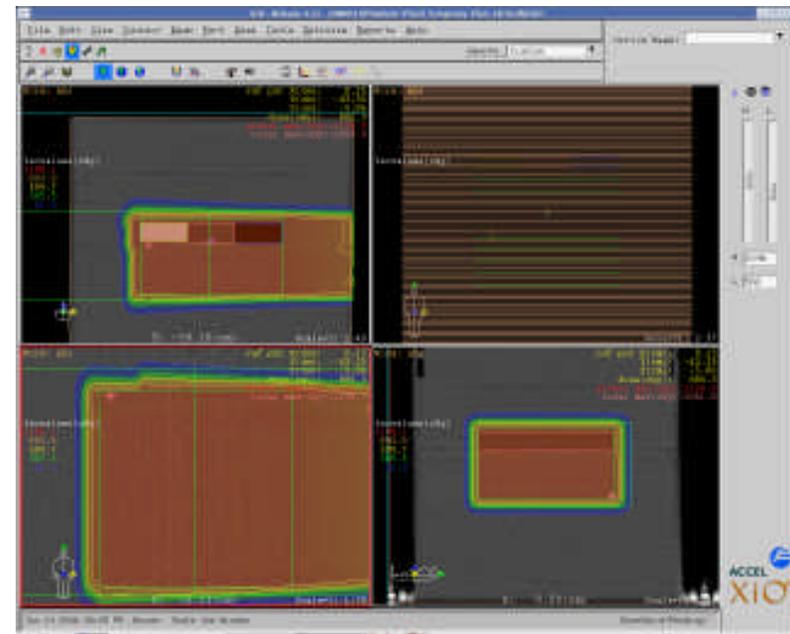
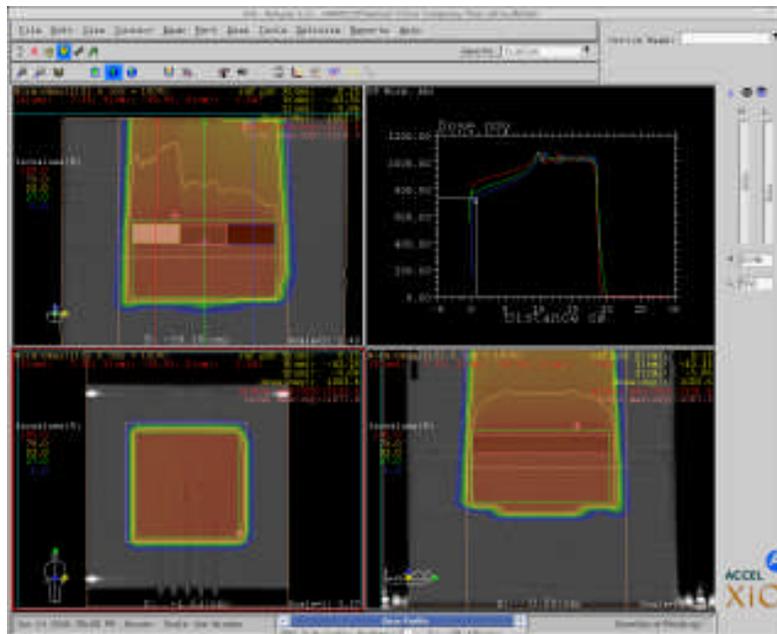
- **Film**
- **Ionisationskammern (Dosismessungen)**
- **Ionisationskammer-Array (2-D Dosisinformation)**



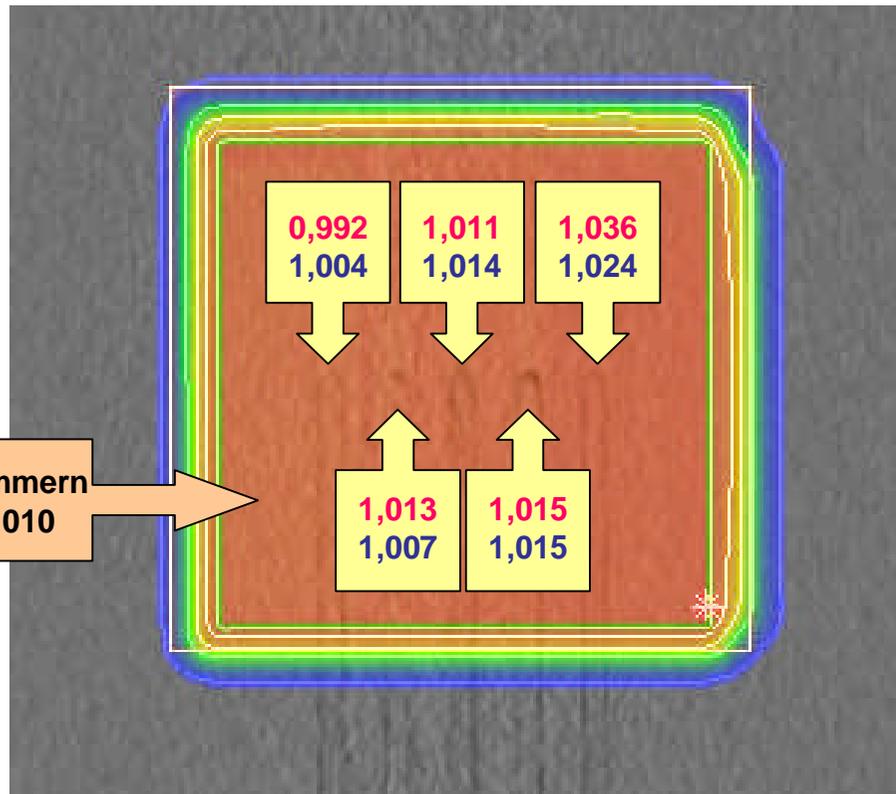
Messungen in unterschiedlichen PMMA Tiefen mit Inhomogenitätsphantom

Erste Ergebnisse – Tests an gantry 1

- Zielvolumen: 1.8 l (15 x 15 x 8 cm³)
- PMMA phantom mit Inhomogenitätsphantom (Knochen, W.t.g, Lunge)
- 13 Energieschichten
- Gesamtdosis 10Gy/ 10 fx
- 2 Einstrahlrichtungen, 0° and 90°, 1 Gy pro Feld



Erste Ergebnisse – Tests an gantry 1



Dosis [Gy]

- gemessen

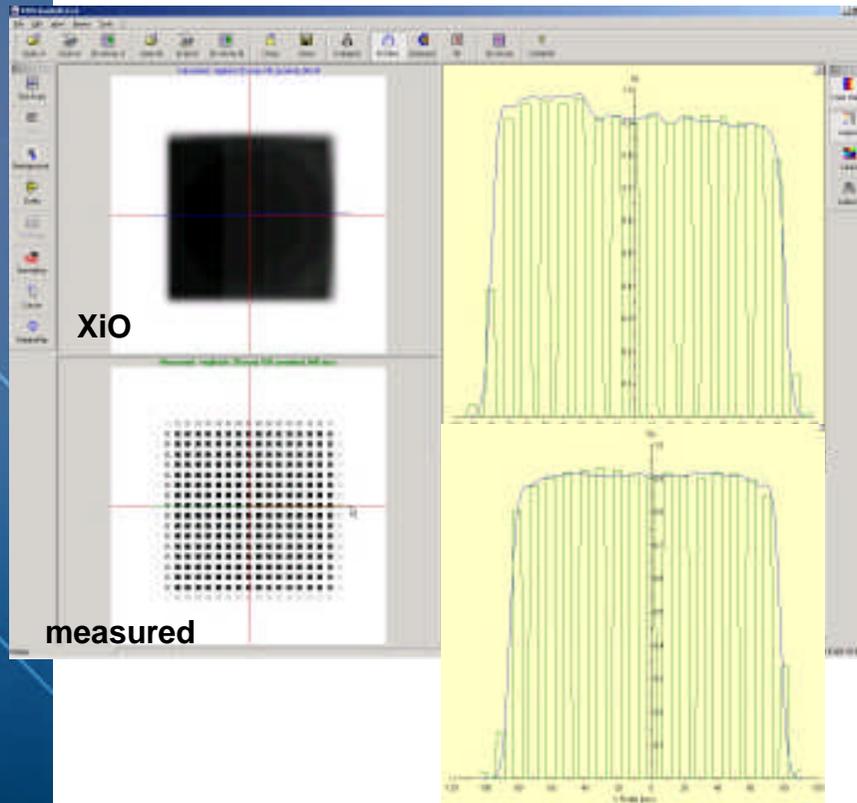
- berechnet

(in Isozentrumsebene)

max. Abweichung: 1.2%

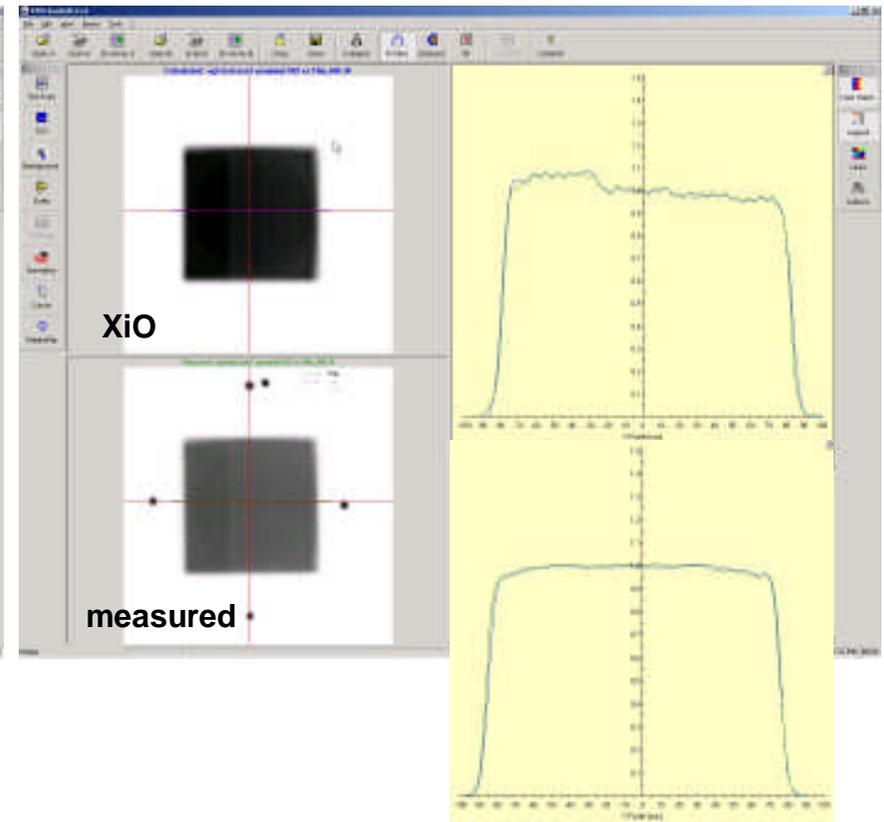
Gemessen vs. Berechnete Dosis [Gy]					
0.947 / 0.951	0.885 / 0.886	0.875 / 0.881	0.868 / 0.866	0.869 / 0.867	Beam 1, 6 cm
0.992 / 1,004	1.013 / 1.007	1.011 / 1.014	1.015 / 1.015	1.036 / 1.024	Beam 1, 14.5cm
0.944 / 1.020	1.031 / 1.020	1.035 / 1.033	1.025 / 1.024	1.025 / 1.023	Beam 2 90°

Erste Ergebnisse – Tests an Gantry 1



XiO vs. 2D array

Messung in 6 cm PMMA Tiefe

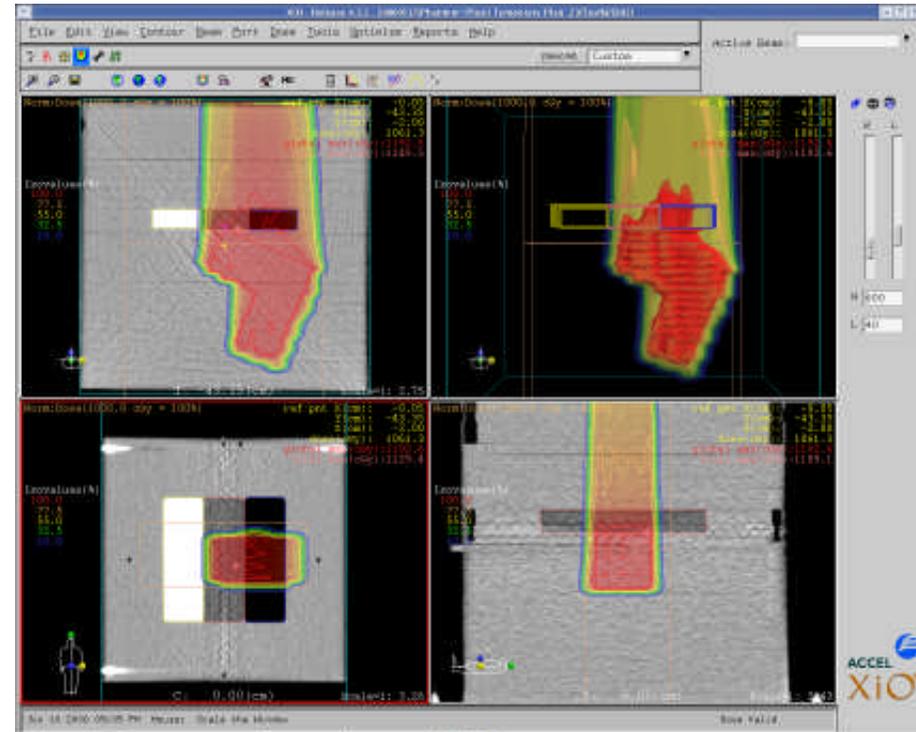


XiO vs. Film

Erste Ergebnisse – Tests an Gantry 1

Plan:

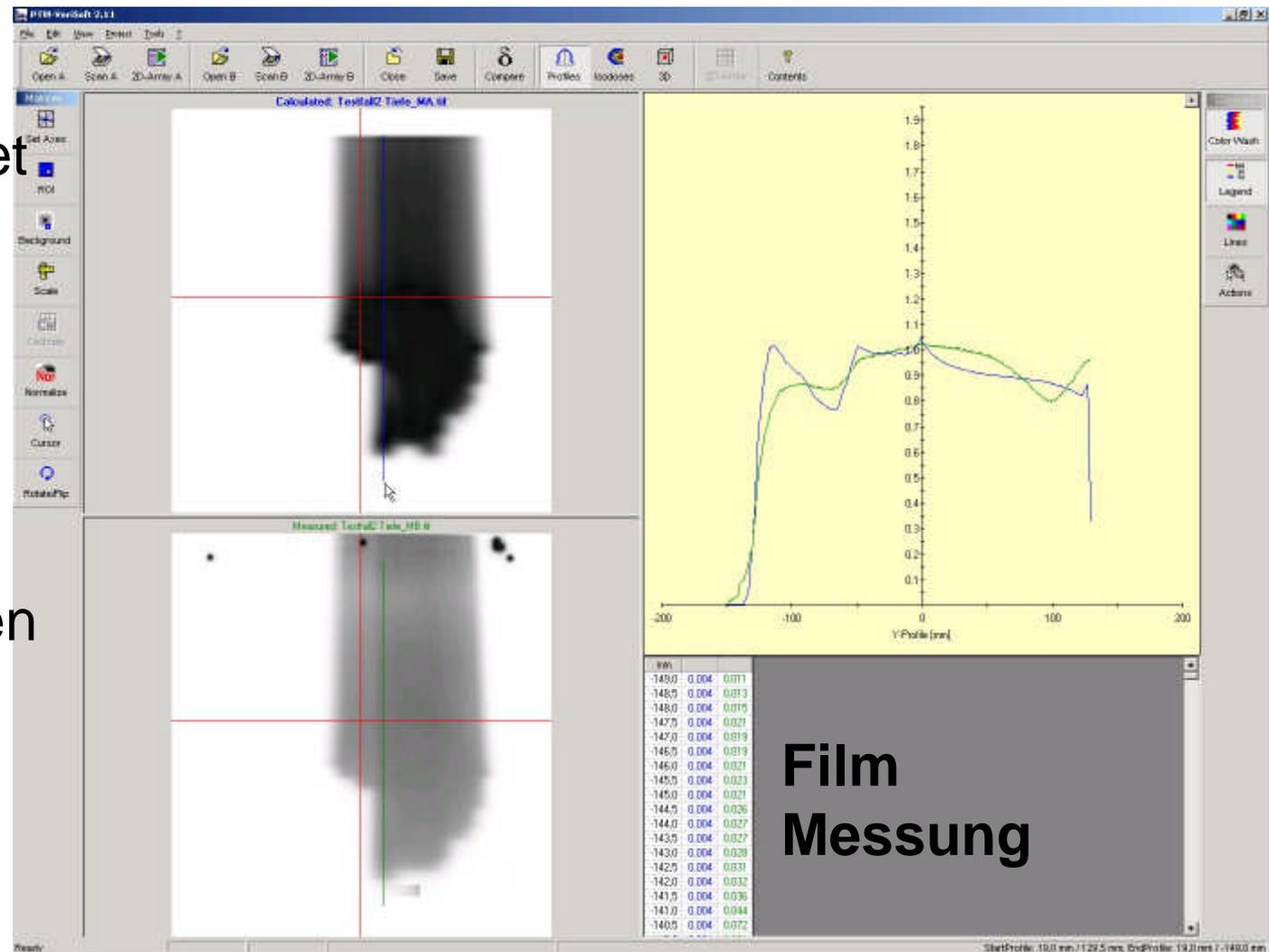
- „L“ förmiges Zielvolumen, 0.36 l
- PMMA Phantom, Inhomogenitätsphantom
- 18 Energieschichten
- ≈ 2000 Spots
- 10 Gy/10 fx



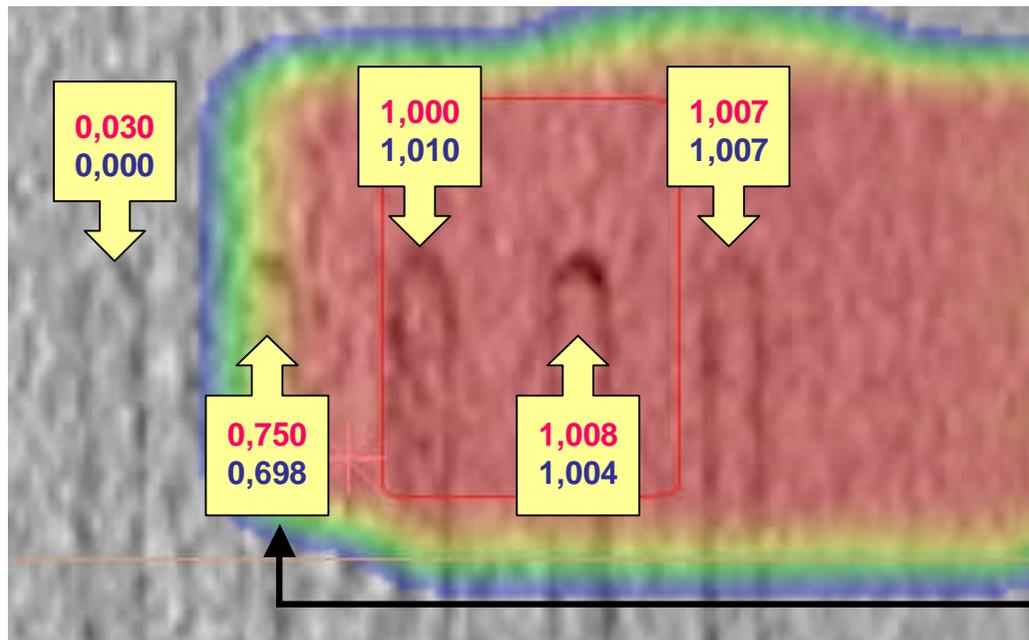
Erste Ergebnisse – Tests an Gantry 1

berechnet

gemessen



Erste Ergebnisse – Tests an Gantry 1



Dosis [Gy]

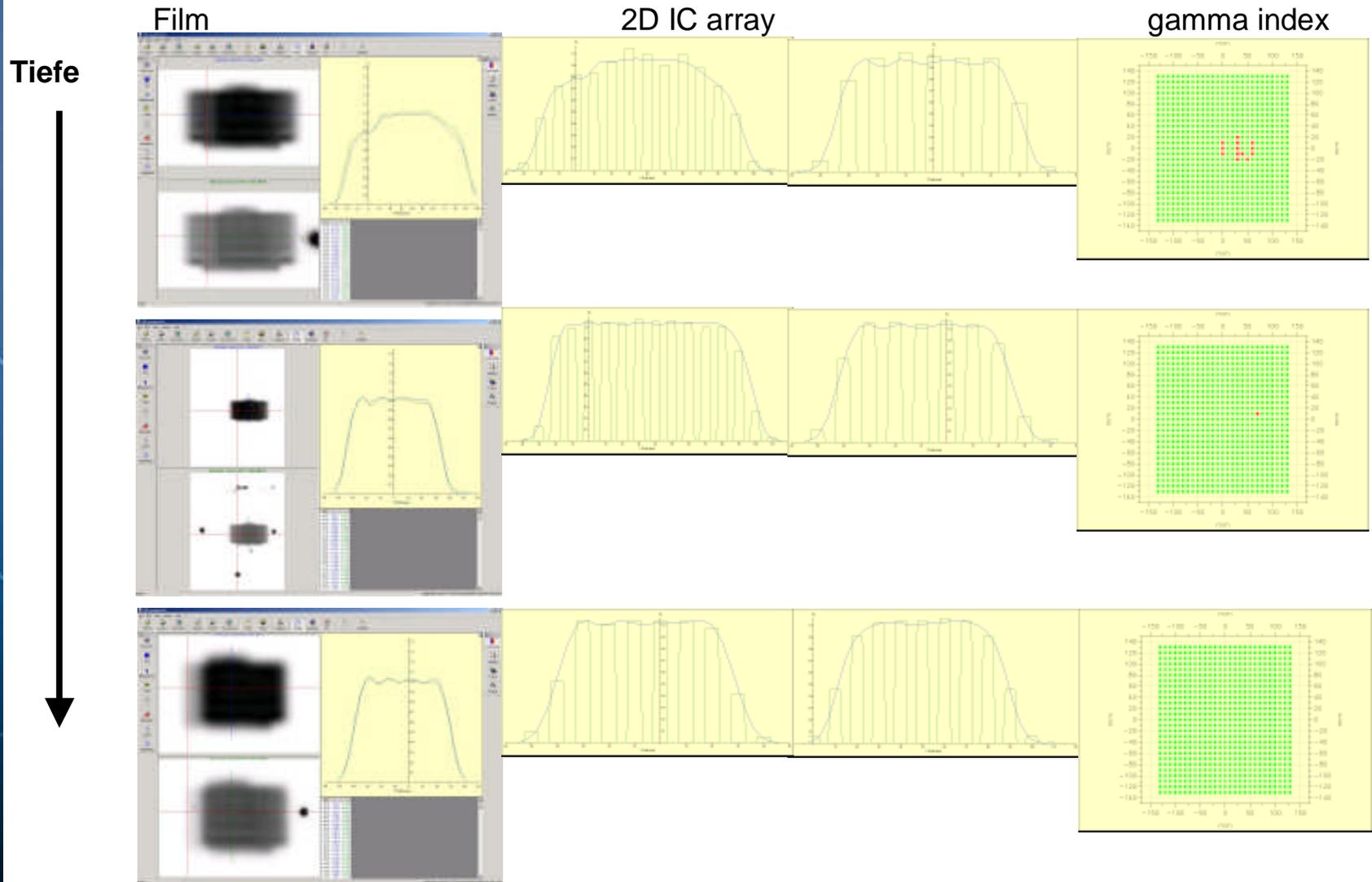
- gemessen

- berechnet

max. Abweichung: 7.4%
(Dosisgradienten!)

Gemessen vs. Berechnete Dosis [Gy]					Tiefe
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

Erste Ergebnisse – Tests an Gantry 1



Zusammenfassung – IMPT

- Aus den Erfahrungen des Passive Scattering Verfahrens und der Photonen IMRT:
Großes Potential der IMPT, hochkonformale Radiotherapie
- CMS erweiterte XiO-IMRT mit der Option für **Intensitätsmodulierte Protonentherapie (IMPT)**
- **IMPT** Planung **analog zur IMRT** Planung
- IMPT ähnlich wie IMRT verlangt nach **IGRT oder ART**
- **Klinische XiO Version** (4.3.2) für Spot Scanning wurde am RPTC/München installiert
- Erste Ergebnisse zeigen **gute Übereinstimmung** zwischen XiO und Messungen.

Danksagung

- Dr. Jürgen Heese
- Accel Team in München
- RPTC-Physikern
- Dr. Martin Soukup, Universität Tübingen