

The background of the slide is a vibrant blue with a radial pattern of light rays emanating from the center, creating a starburst or sunburst effect. The rays are of varying lengths and thicknesses, giving it a dynamic, energetic appearance.

# Theorie zur IMRT:

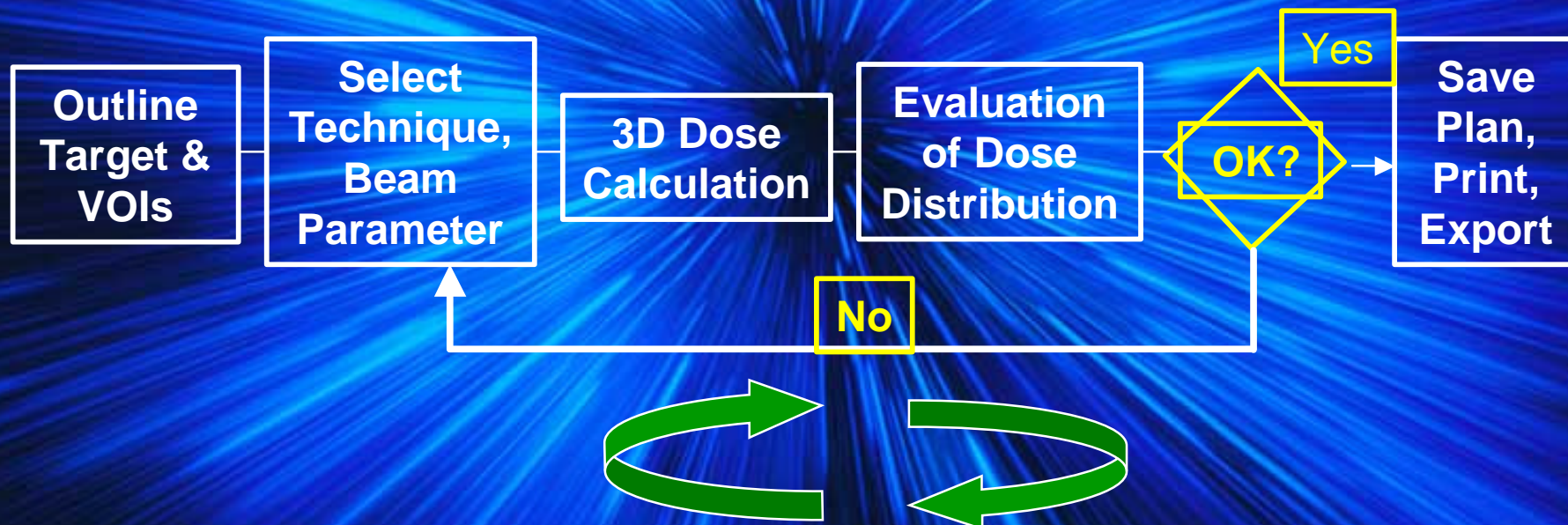
- Inverse Planung
- Parameter zur Dosisoptimierung
- Step and Shoot am Linac

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Institut für Strahlentherapie/Radioonkologie  
Klinikum Darmstadt



# Inverse Planung

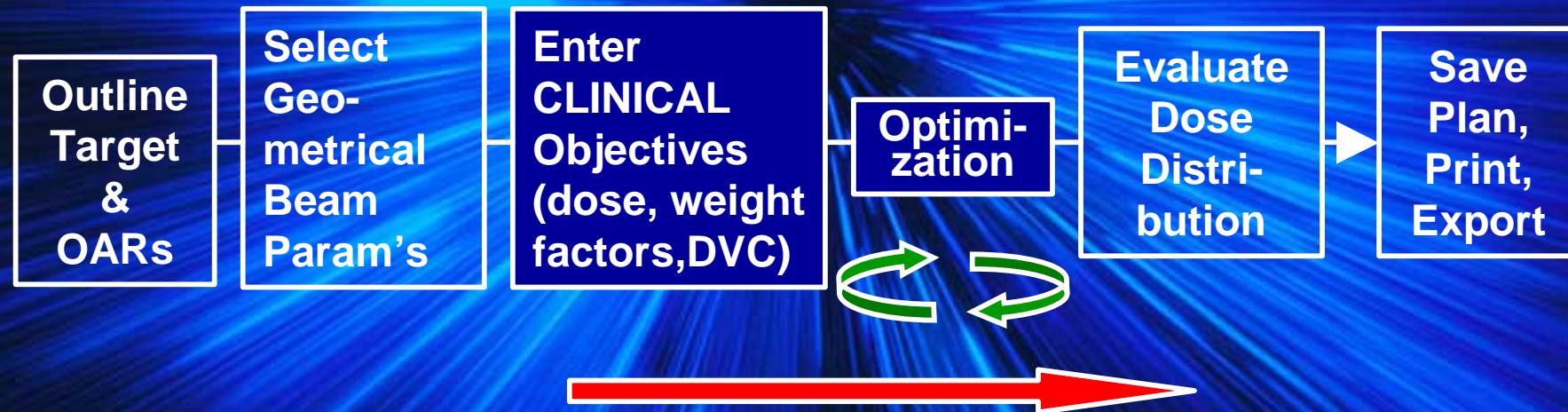
## Conventional Approach:





# Inverse Planung

## Inverse Planning:





# Inverse Planung

## Optimierungsparameter

Optimierung der physikalischen Dosisverteilung:

- Homogenität und Konformität
- Toleranzdosen
- Minimal/Maximaldosen
- Dosis-Volumen Beziehungen
- Einstrahlrichtungen
- Vermeidung von Dosisartefakten

Optimierung von biologischen Wirkungsparametern:

- TCP/NTCP
- RBE



# Inverse Planung

Zielfunktion (Objective Function)

$$F(\mathbf{x}) = \sum_i (d_i - p_i)^2$$

$$d_i = f(x_1, \dots, x_n)$$

$p_i$

Aktuelle Dosis  
Solldosis

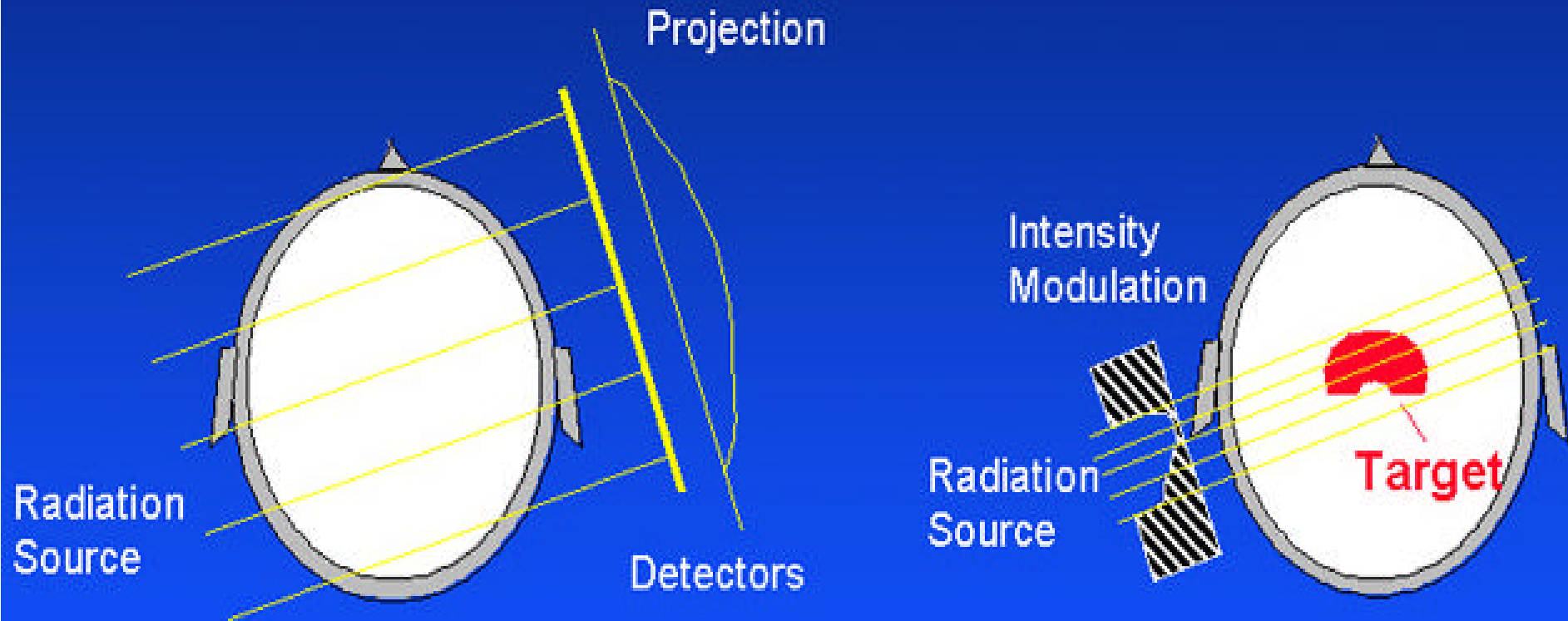
Randbedingungen:  $d_i < d_{\text{tol}}$   
 $x_i > 0$

DVH-Einschränkungen

# Inverse Planung

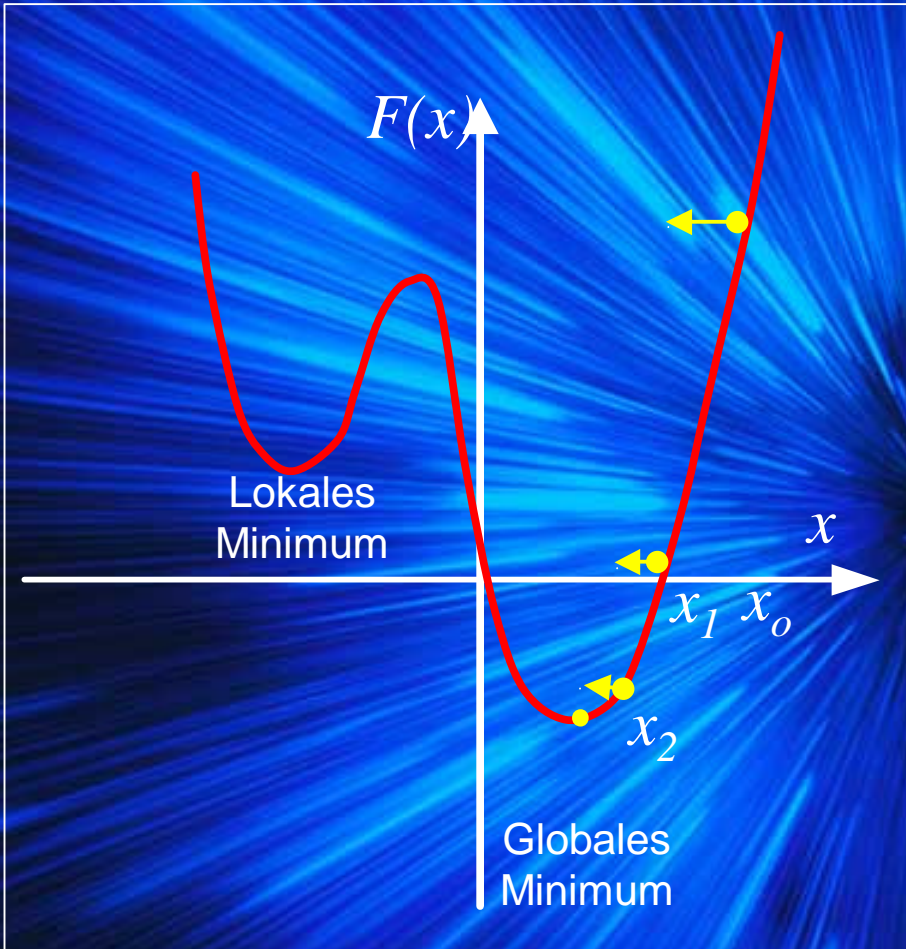
## Computer Tomography

## Conformal Radiotherapy

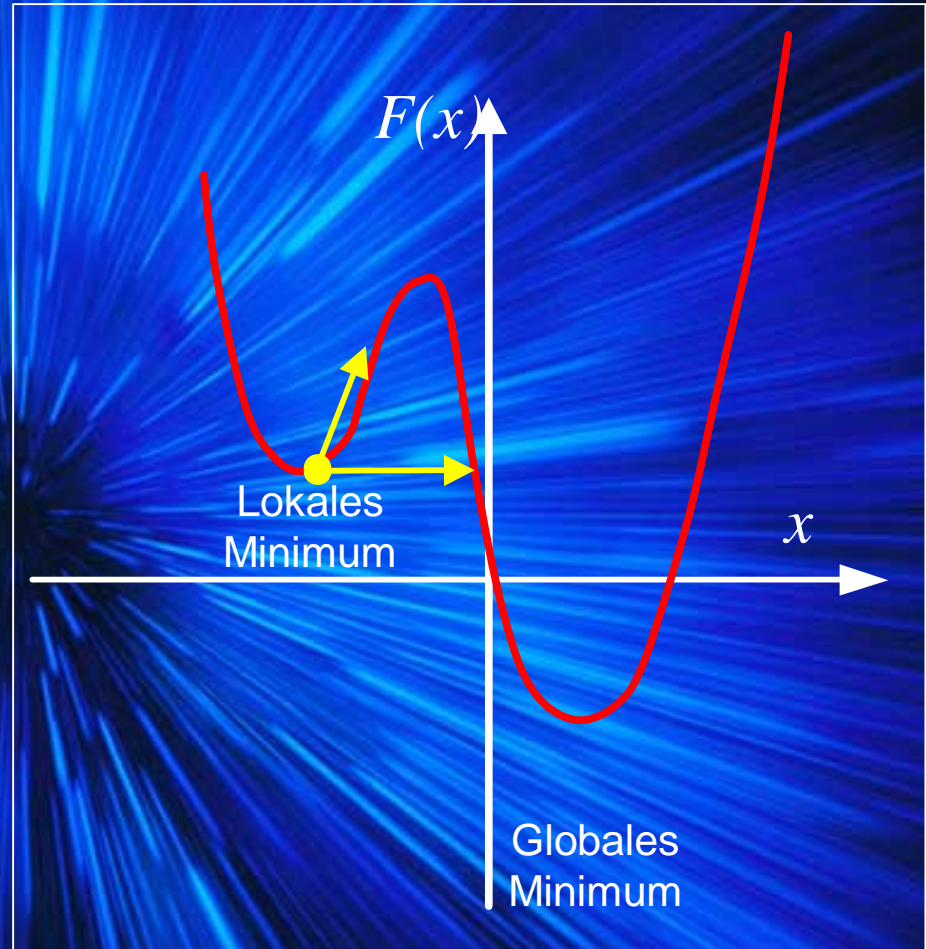




# Inverse Planung



$$\vec{x}_{l+1} = \vec{x}_l - \mathbf{k} \cdot \vec{\nabla}(F(\vec{x}))|_{\vec{x}_l}$$



tunneling

hill climbing



# Inverse Planung

Patient Display Image Plan D Beam Help

Transverse Sagittal Coronal

# 12 Z: 15.00 [mm] # 202 X: 197.00 [mm] # 138 Y: 135.00 [mm]

PLAN: 1 LABEL: PLATORTS v2.1.35 TEST\_on\_07/06/1999 09:35 NORMALIZE: Unnormalized PRESCRIBE: 0.000000 to 0 in 0 DATE: 07-JUN-1999 09:35:56 Beams: 4

Dose-Volume-Histogram

Volume [%] #Levels: 5 #Segm.: 27

Dose [Gy]

Organ Parameters

VOI	On/off	Priority	Body	Organ Type	Max Dose	Penalty	Min Dose	Penalty	DYH Points
PTV	<input checked="" type="checkbox"/>	1	<input type="checkbox"/>	1 2 3	70.0	100.0	68.0	300.0	
[2] Organs at risk									
brain	<input type="checkbox"/>	2	<input type="checkbox"/>	1 2 3	30.0	1.0	0.0	0.0	
left lung	<input type="checkbox"/>	7	<input type="checkbox"/>	1 2 3	30.0	1.0	0.0	0.0	
right lung	<input type="checkbox"/>	8	<input type="checkbox"/>	1 2 3	30.0	1.0	0.0	0.0	
spine	<input type="checkbox"/>	3	<input type="checkbox"/>	1 2 3	25.0	5.0	0.0	0.0	
trachea	<input type="checkbox"/>	4	<input type="checkbox"/>	1 2 3	35.0	1.0	0.0	0.0	
vertebra	<input type="checkbox"/>	5	<input type="checkbox"/>	1 2 3	40.0	1.0	0.0	0.0	

Image

Status

Diff. [%] 0.1162

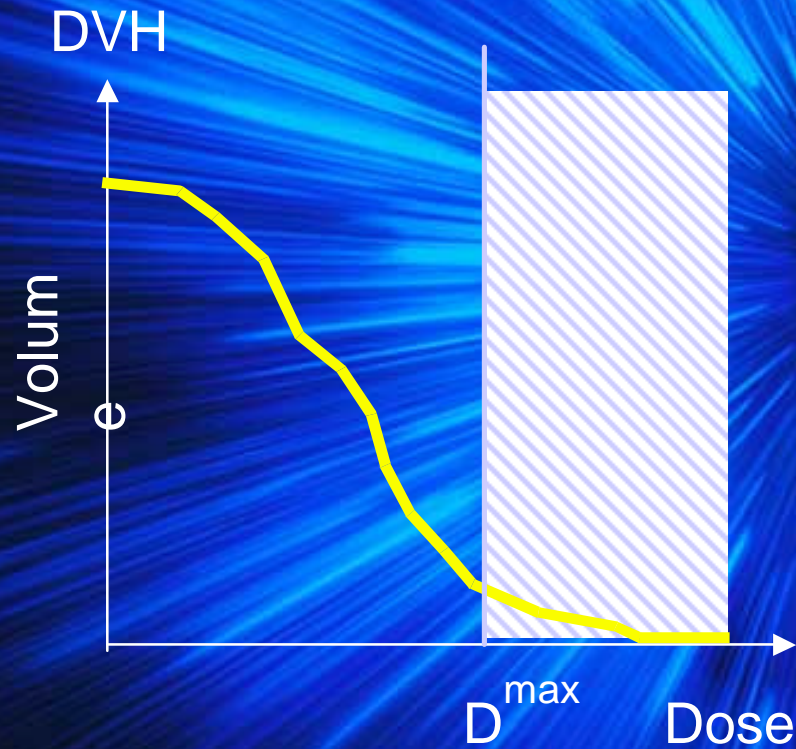
Optimization

Status

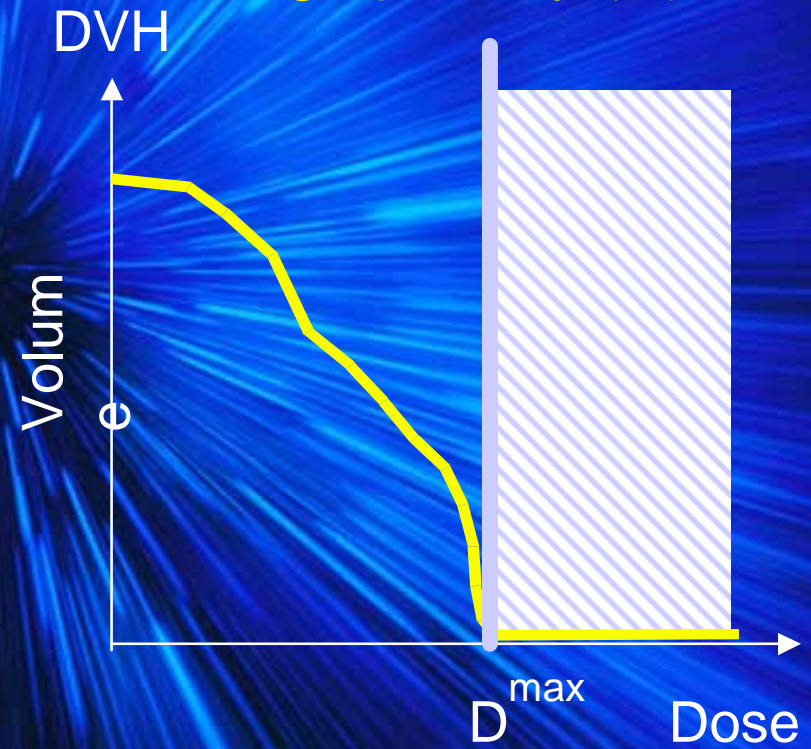


# Inverse Planung

Small penalty ( $w$ )



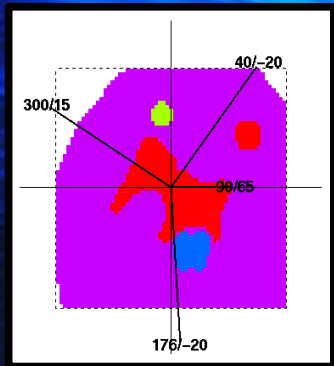
Large penalty ( $w$ )



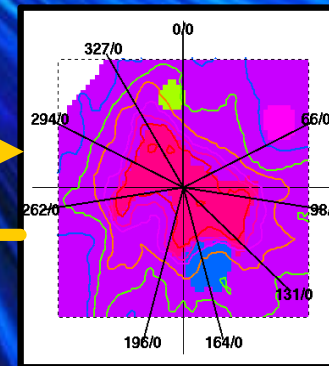
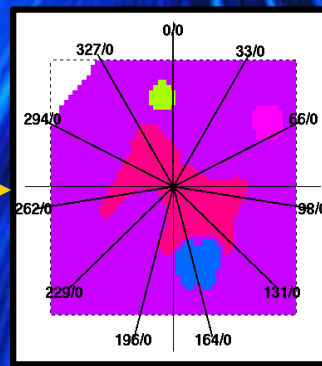
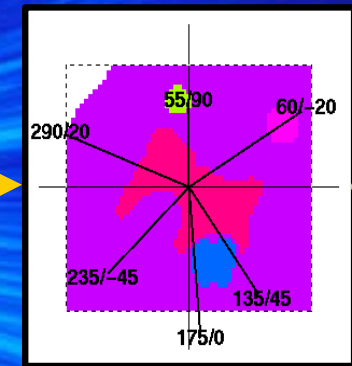
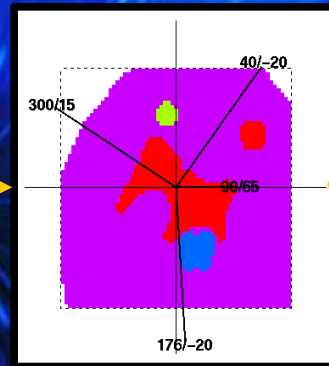
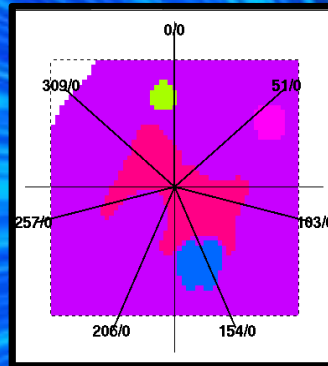


# Inverse Planung

Konventionelle  
r Plan



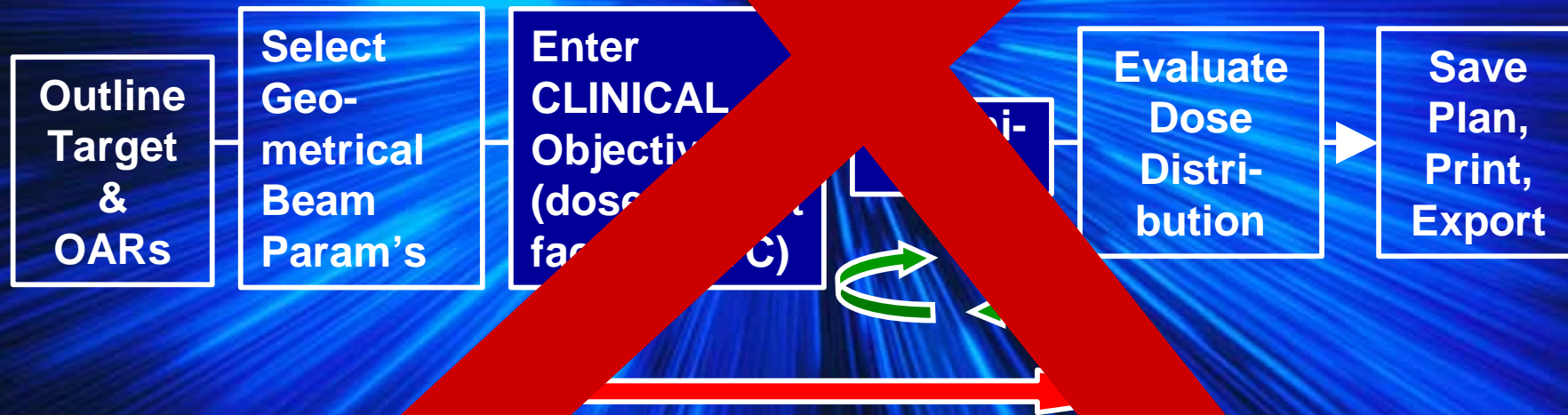
Getestete Beam-Konfigurationen im Rahmen  
der inversen Planung



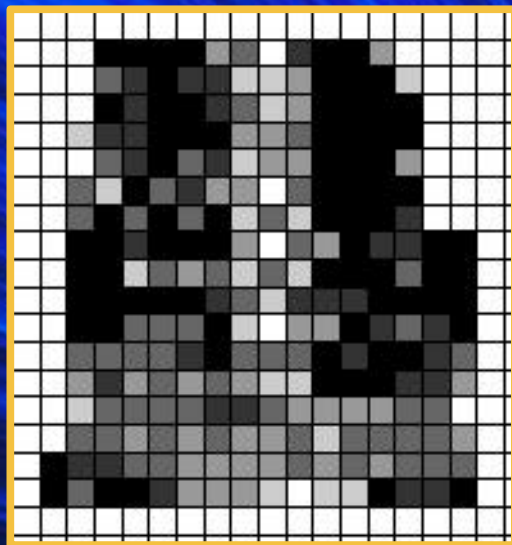


# Inverse Planung

Inverse Planung:







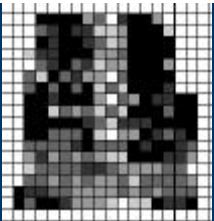
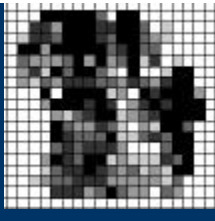
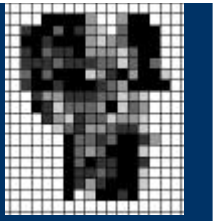
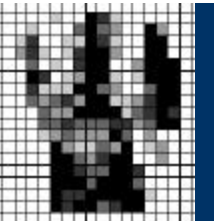
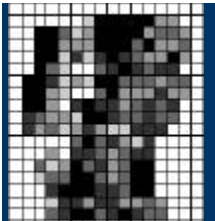
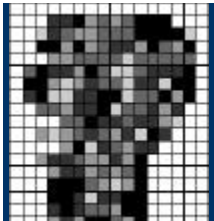
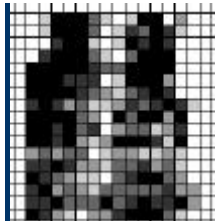




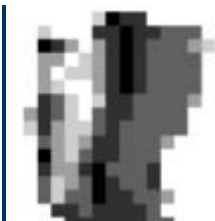
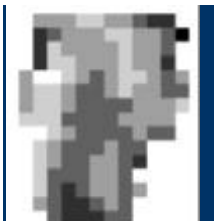
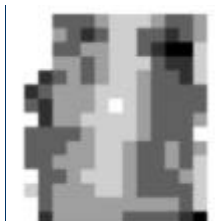
**KonRad**

Gradienten-  
verfahren

**Corvus**

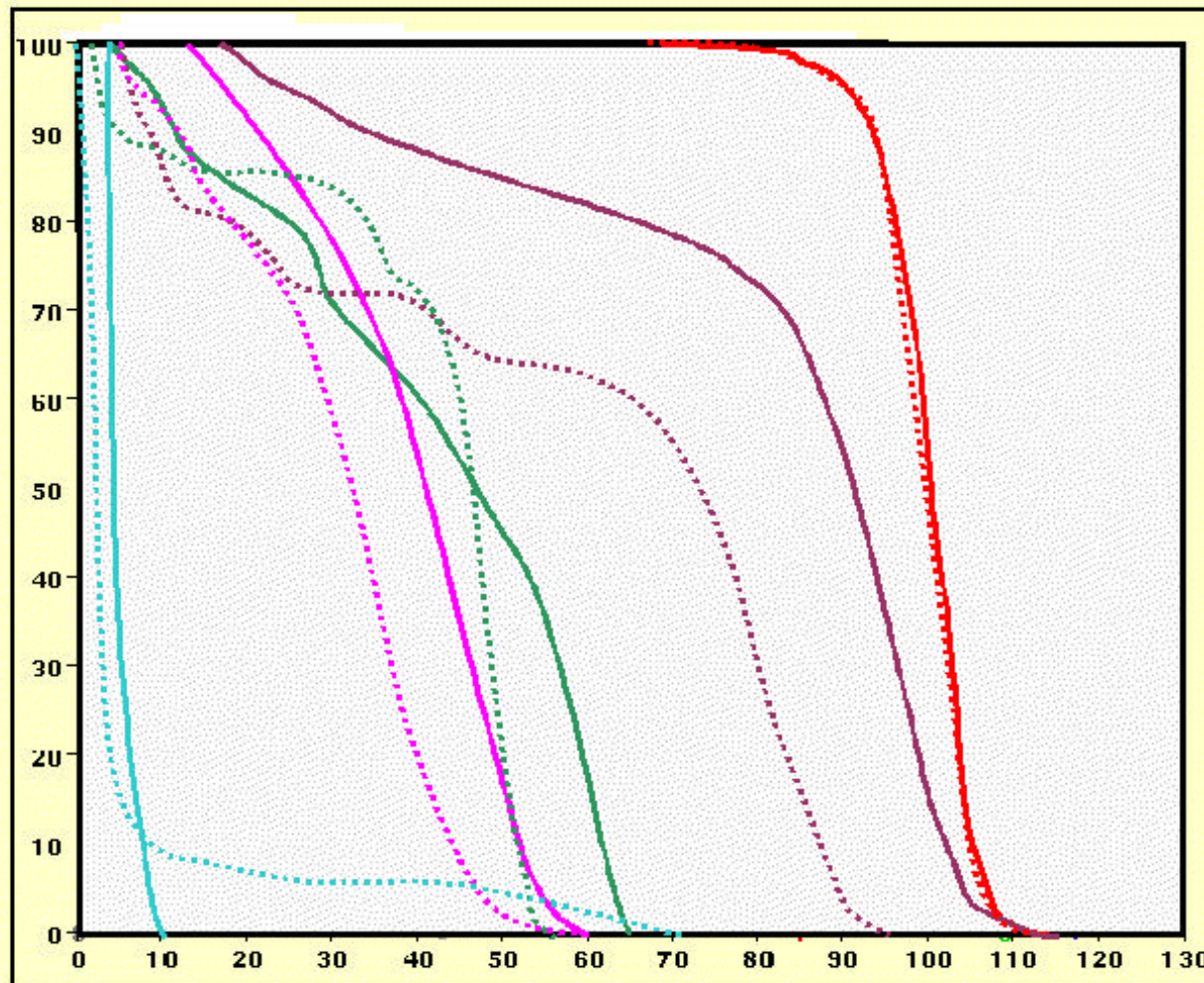
Simulated  
Annealing



CORVUS							
Gantry- winkel	0	40	80	115	245	280	320
KonRaD							



# Inverse Planung



— Planning target volume  
— Right parotid gland  
— Spinal cord  
— Left parotid gland  
— Brain stem

— CORVUS System  
..... KonRad System

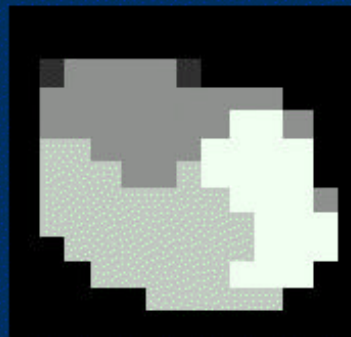


# Inverse Planung

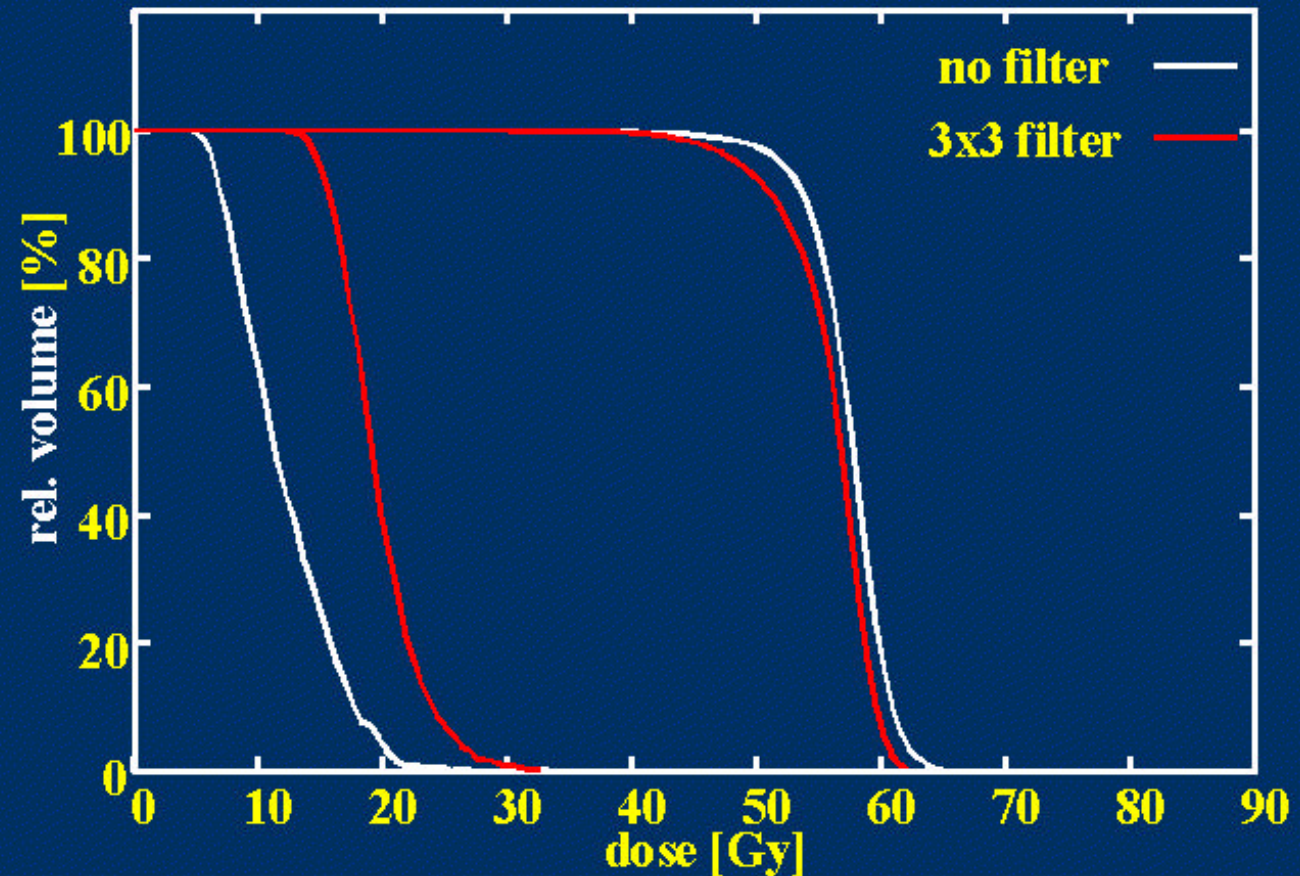
## Anwendung eines 3x3 Median Filters



Ohne Filter

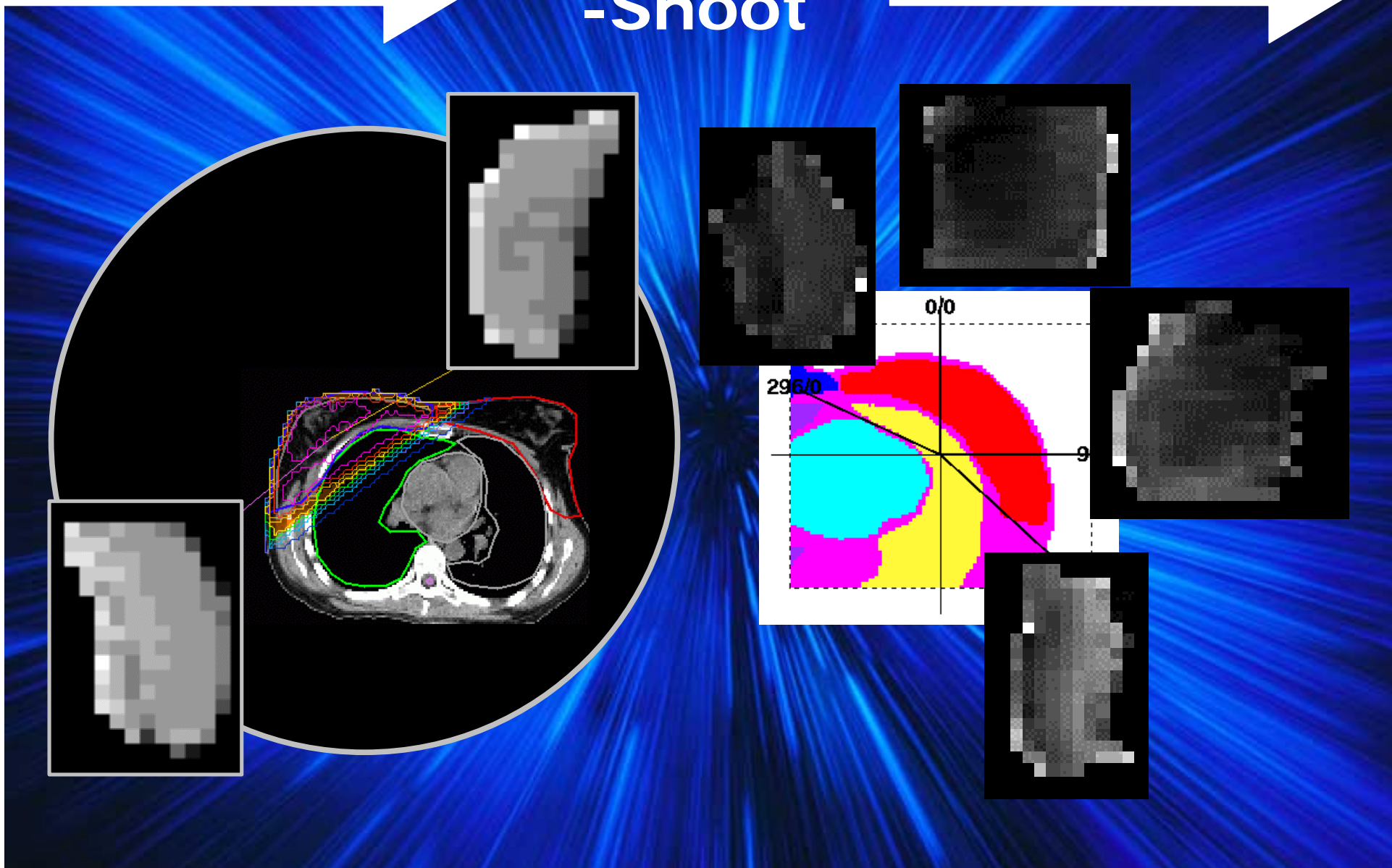


Mit Filter





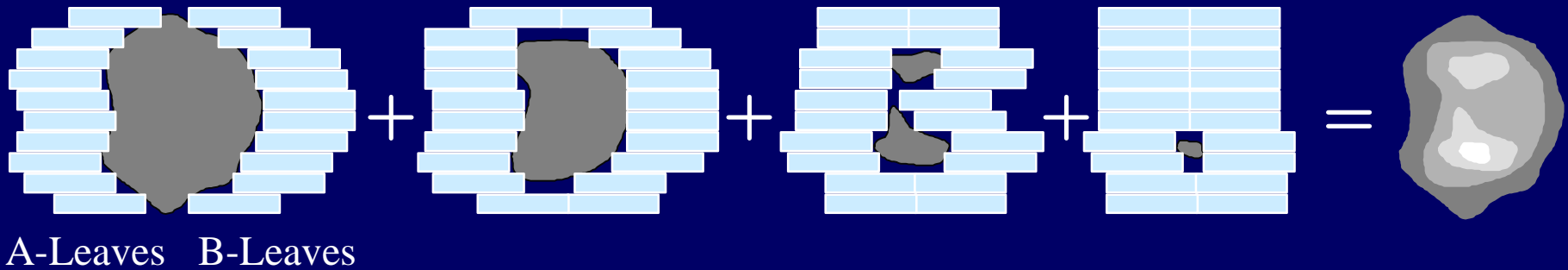
# Step-and-Shoot



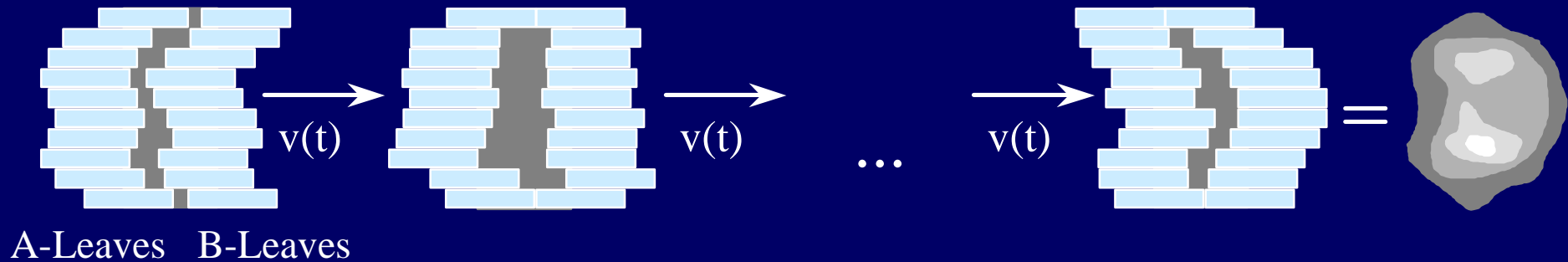


# Step-and-Shoot

## “Step-and-shoot” Technik



## Dynamische (analoge) Technik





# Step-and- -Shoot

## Dynamische Technik:

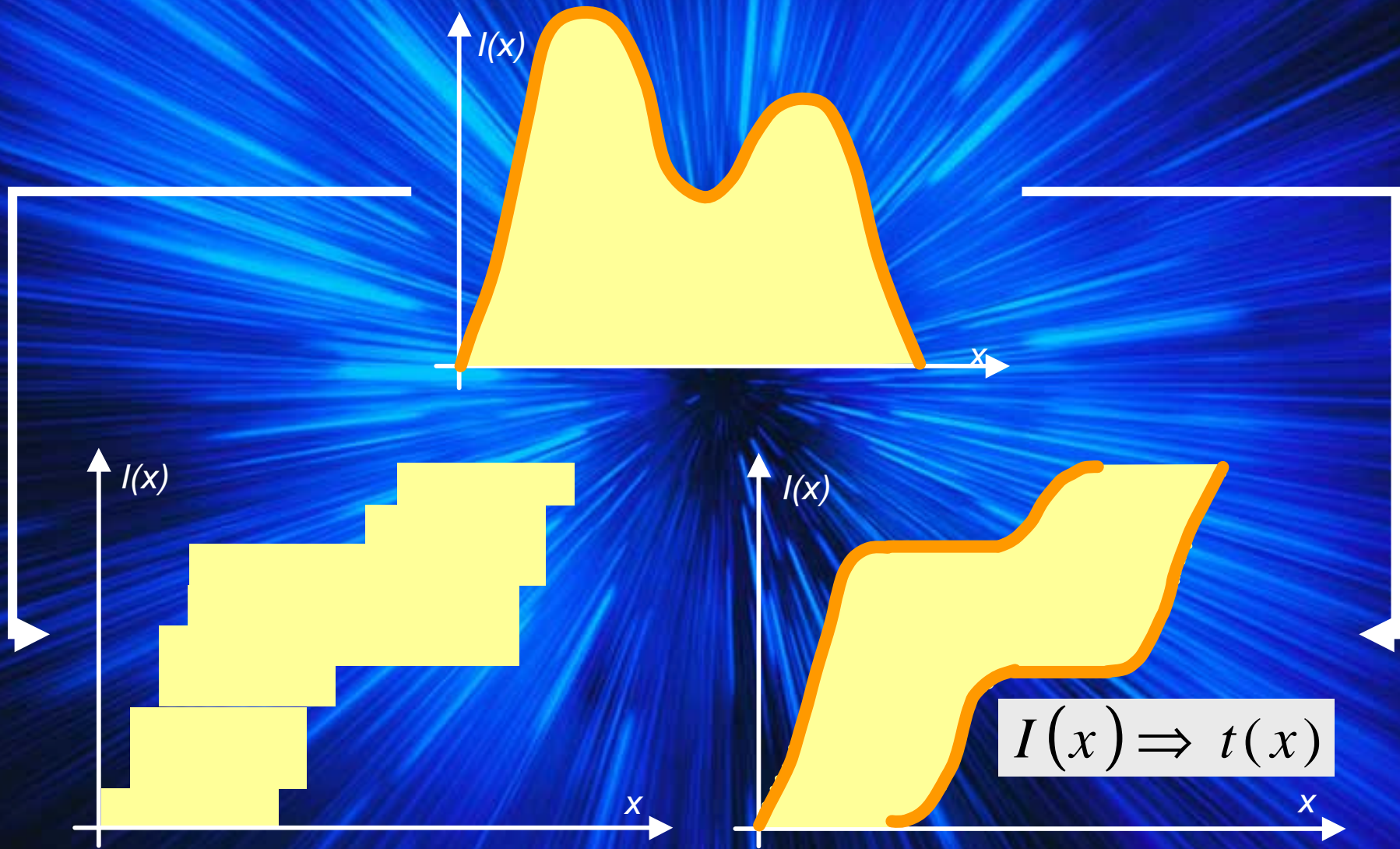
- Schneller
- Komplexe Profile können besser approximiert werden
- Niedrig dosierte Felder tauchen nicht auf
- Komplexer

## Step-and-Shoot

- Einfache Erweiterung konventioneller Techniken
- Einfacher zu verifizieren
- Mehr Variationsmöglichkeiten

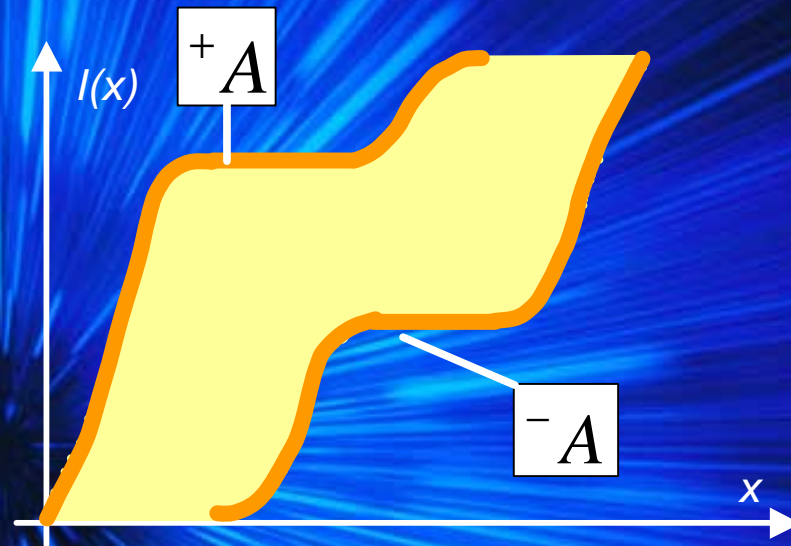
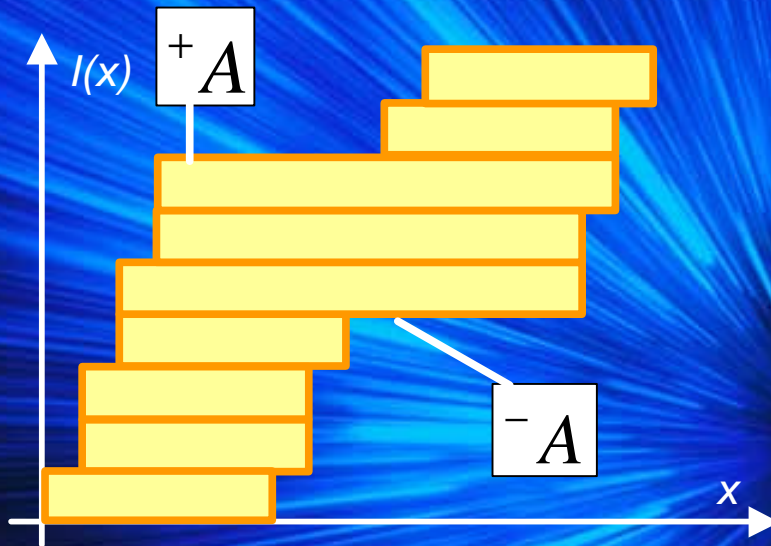


# Step-and-Shoot





# Step-and-Shoot



$${}^+A = S^{-1}(P_+(S \cdot A))$$

$${}^-A = S^{-1}(P_-(S \cdot A))$$

$${}^+A(x_0) = - \int_{x_a}^{x_b} P_+ \left( \frac{d}{dx} A \right) \cdot h(x - x_0) dx$$

$${}^-A(x_0) = - \int_{x_a}^{x_b} P_- \left( \frac{d}{dx} A \right) \cdot h(x - x_0) dx$$



# Step-and- -Shoot

Durch was wird die Anzahl der Subfelder bestimmt, die für die Bestrahlung eines intensitätsmodulierten Feldes benötigt werden?

- Anzahl der Intensity-Levels
- Rastergröße des Gitters
- Größe des Zielvolumens
- Komplexität des Zielvolumens
- Zerlegungsalgorithmus
- MLC-Design
- Optimierungsverfahren

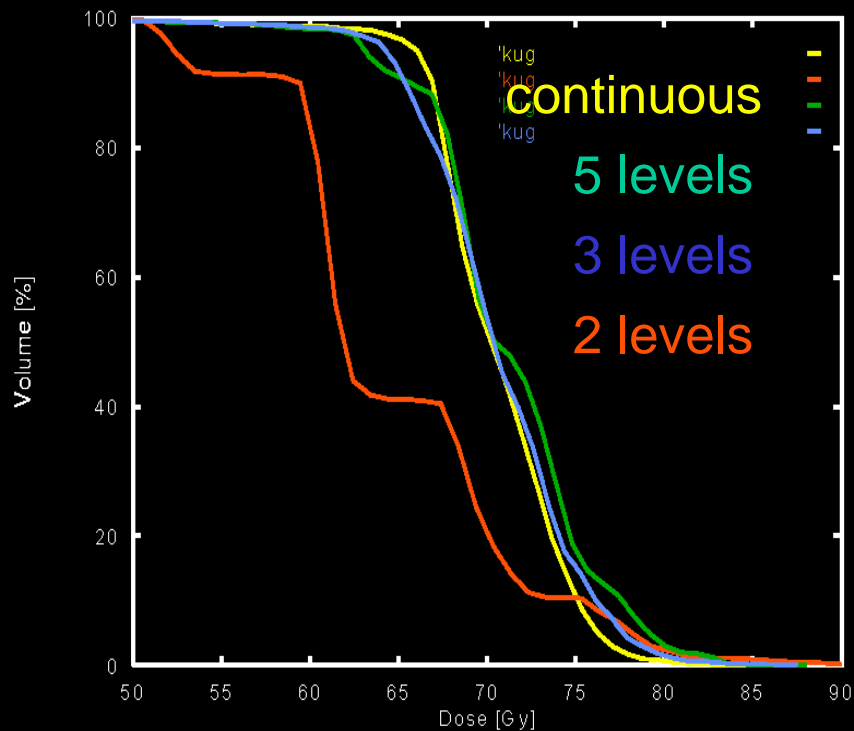
Faustformel:

$$N_s = Level \times \Psi$$

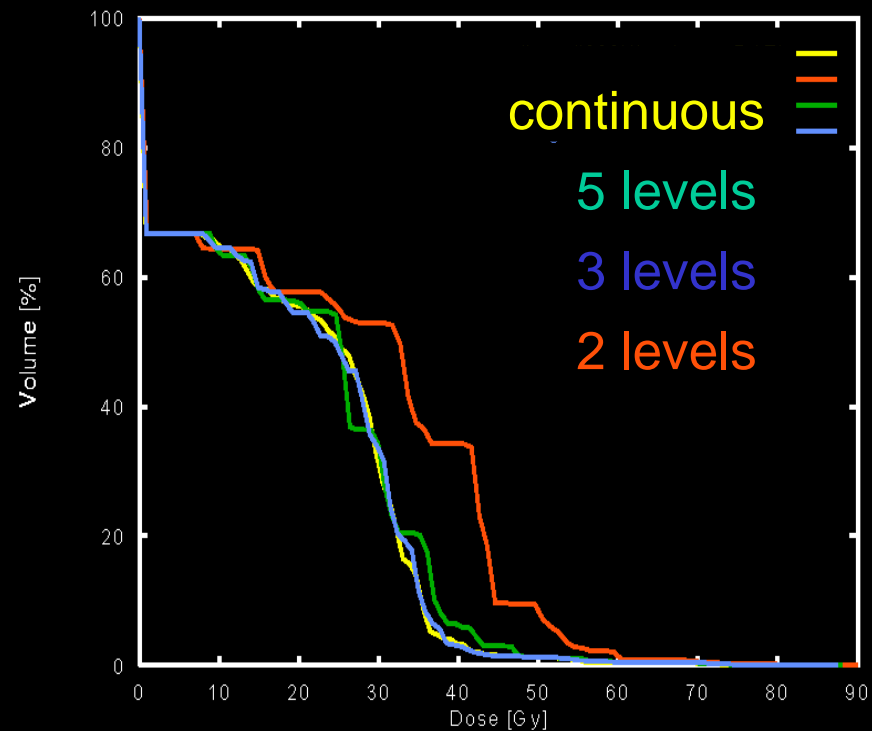
$$\Psi \approx 1 - 2.5$$

# Step-and- -Shoot

## 7 Beams, Target



## 7 Beams, Brainstem





# Step-and-Shoot

**Minimierung der Anzahl der Subfelder:  
Beispiel: Klinische Intensity Map optimiert mit dem inversen  
Planungsprogramm KonRad**

$$A = \begin{pmatrix} 0 & 2 & 2 & 2 & 2 & 3 & 2 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3 & 3 & 3 & 3 & 4 & 4 & 4 & 4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 3 & 3 & 3 & 3 & 3 & 4 & 4 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3 & 3 & 3 & 3 & 3 & 3 & 4 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 3 & 3 & 3 & 3 & 3 & 4 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 4 & 4 & 3 & 3 & 4 & 4 & 4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 3 & 3 & 3 & 3 & 3 & 4 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 3 & 4 & 4 & 4 & 4 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 2 & 4 & 4 & 4 & 4 & 2 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 1 & 3 & 4 & 4 & 4 & 4 & 1 & 2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 1 & 2 & 4 & 4 & 4 & 3 & 2 & 2 & 3 & 3 & 0 & 0 \\ 0 & 0 & 0 & 2 & 2 & 3 & 4 & 4 & 4 & 2 & 2 & 2 & 3 & 0 & 0 \\ 0 & 0 & 0 & 2 & 1 & 4 & 4 & 4 & 4 & 3 & 1 & 2 & 3 & 3 & 0 \\ 0 & 0 & 0 & 0 & 1 & 2 & 4 & 4 & 4 & 3 & 1 & 2 & 3 & 3 & 5 \\ 0 & 0 & 0 & 0 & 0 & 1 & 4 & 4 & 3 & 4 & 3 & 2 & 2 & 3 & 5 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 3 & 3 & 2 & 1 & 2 & 5 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 3 & 4 & 2 & 2 & 4 & 0 \end{pmatrix}$$

17x15 Matrix – 5 Level:

Es existieren genau drei verschiedene minimale Lösungen, die sich in mindestens einem Feldgewicht unterscheiden.

$$\vec{S}_1 = (1,1,1,1,2,2)$$

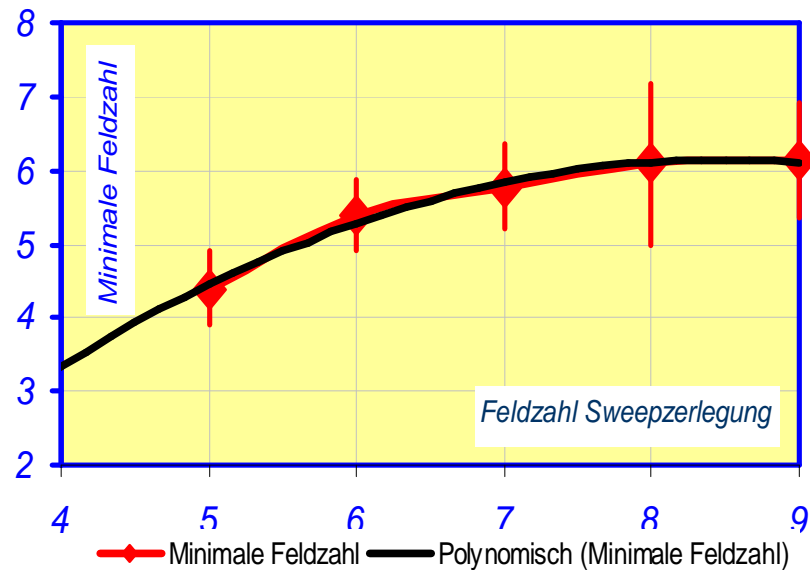
$$\vec{S}_2 = (1,1,1,1,2,3)$$

$$\vec{S}_3 = (1,1,1,2,2,3)$$

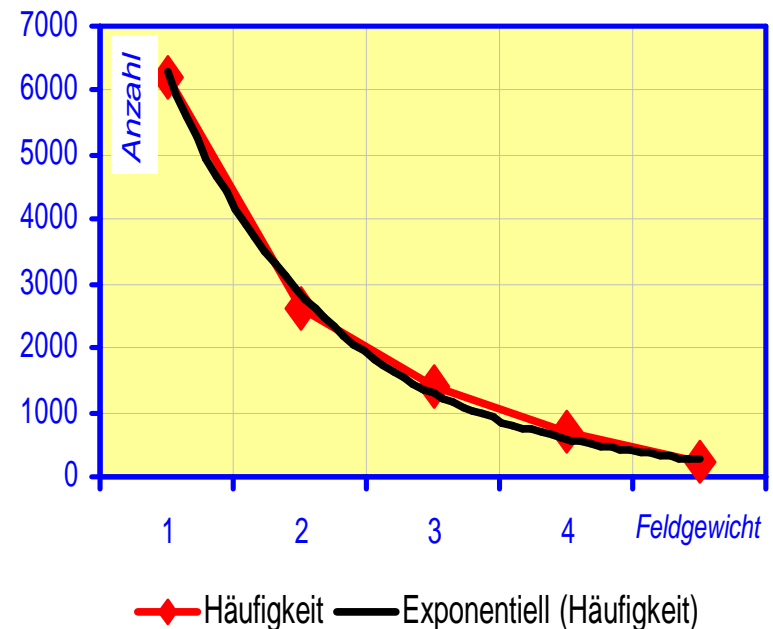
# Step-and-Shoot

## Eigenschaften minimaler Zerlegungen

Minimale Feldzahl als Funktion der Feldzahl der Sweepzerlegung



Häufigkeit der Feldgewichte minimaler Lösungen

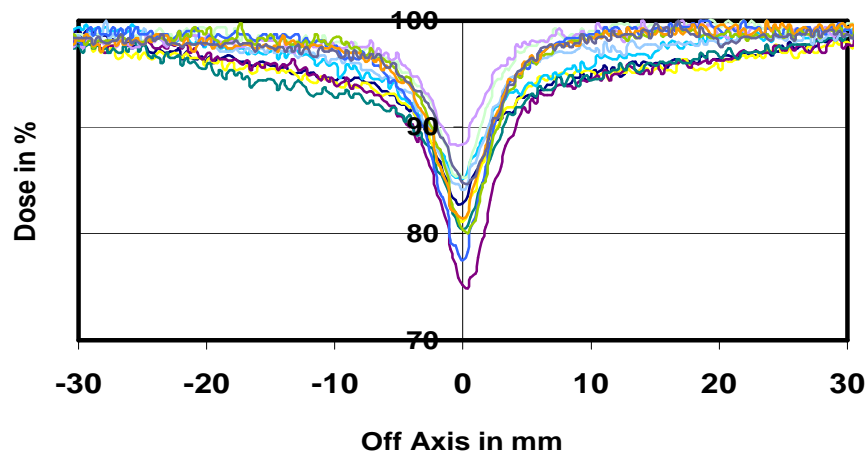




# Step-and-Shoot

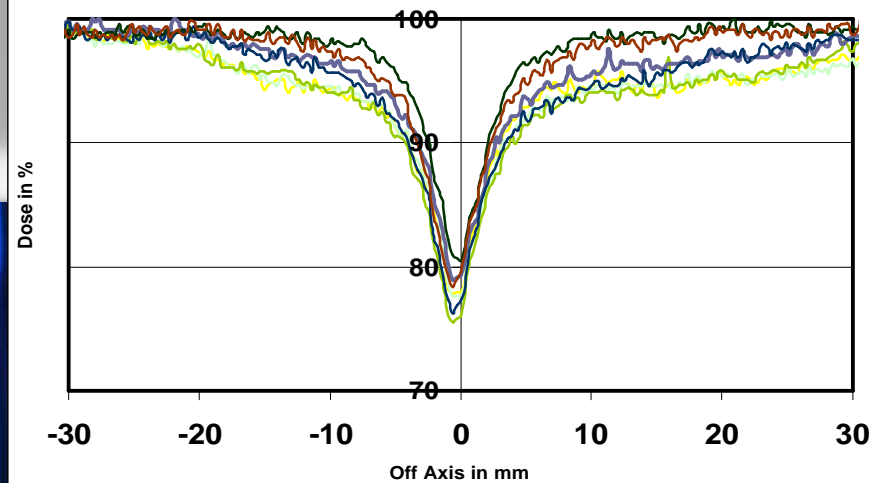
## *Transversale Matchlines*

**Matchline Under-Dose**

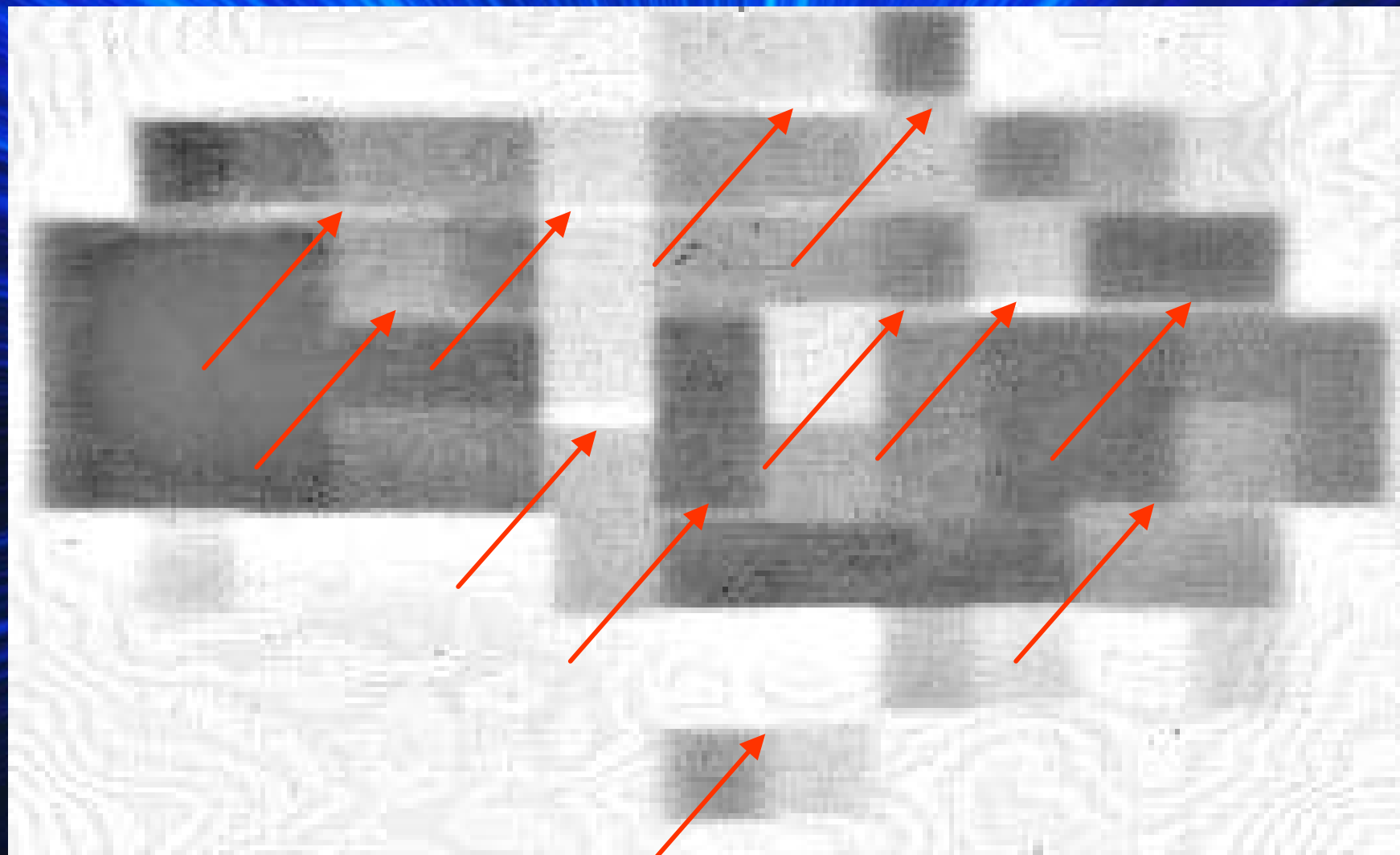


## *Tongue and Groove Effect*

**Tongue and Groove Under-Dose**



# Step-and-Shoot





# Fazit

