

Einführung in die Biophysik

**Vorlesung 4 – Hochauflösende Bildgebung Teil 2 +
Strahlentherapie**

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School of Natural Sciences

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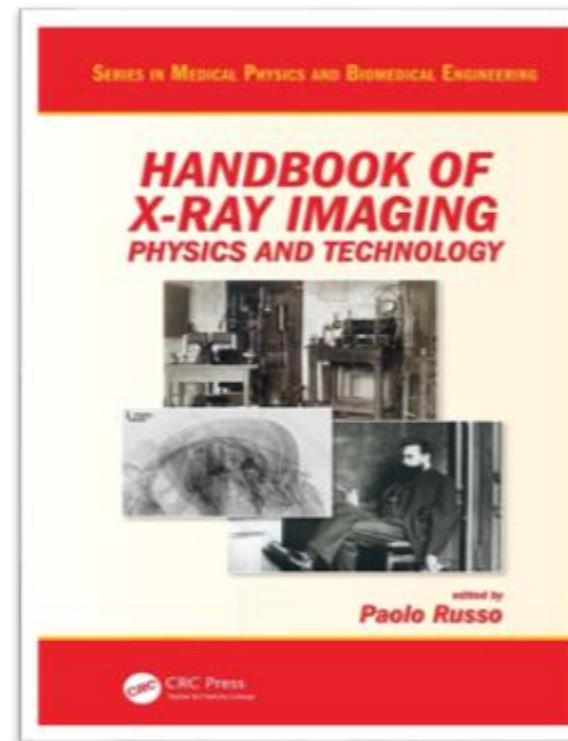
Inhalt - hochauflösende Bildgebung

Teil I: Röntgenquellen

- Synchrotronquellen
- Sonstige Röntgenquellen
- Kohärenz

Teil II: Phasenkontrast Bildgebung

- Grundlagen
- Verschiedene Methoden
- Anwendungen



no access over TUM -
upload to Moodle



Thema Phasenkontrast Bildgebung

Fragen, die Sie am Ende jeder behandelten Methode beantworten können sollten:

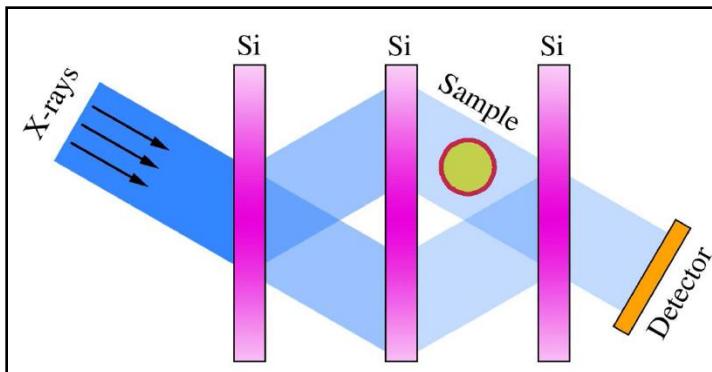
- Was erzeugt den Kontrast?
- Welche Anforderungen an die Röntgenquelle gelten für die verschiedenen Methoden?

ausführlichere Behandlung in folgenden Vorlesungen im Master:

- Biomedical Physics I+II (Prof. Pfeiffer/Prof. Wilkens)
- Modern X-ray Physics (Dr. Achterhold/Dr. Dierolf)
- Image Processing in Physics (Prof. Herzen/Dr. Achterhold)

Φ

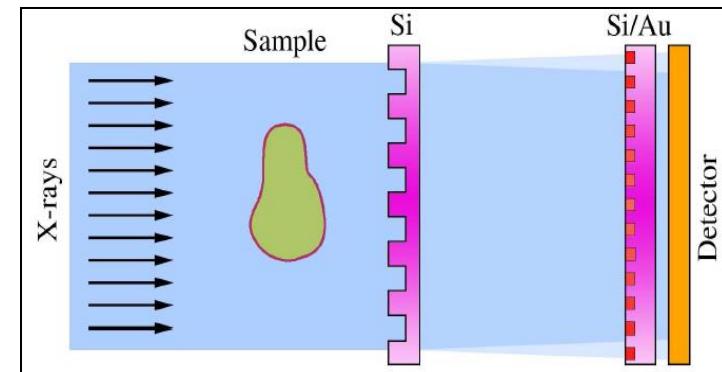
Kristall Interferometer



Bonse & Hart 1965

$d\Phi/dx$

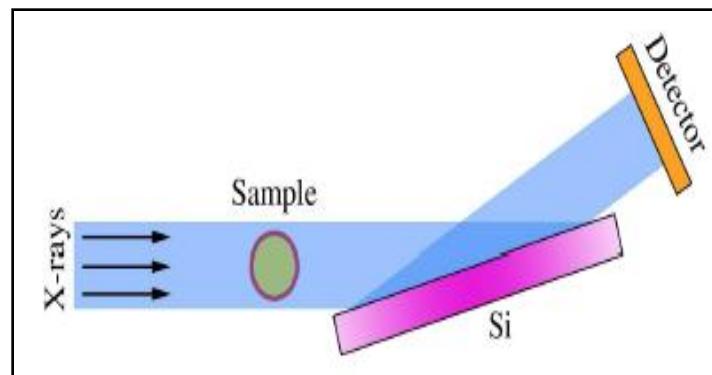
Gitterinterferometer



Momose 2003 & David 2002

$d\Phi/dx$

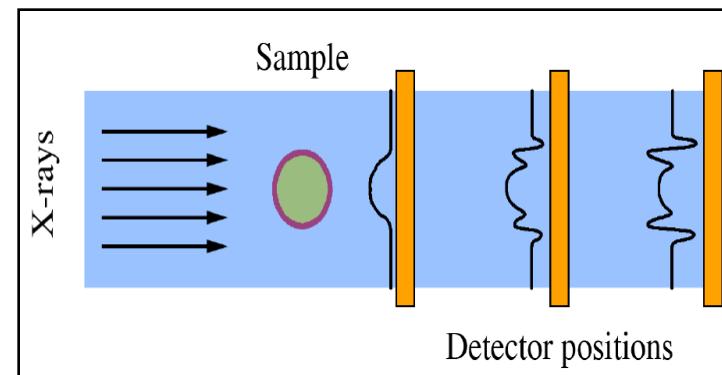
Kristall Analysator



Förster 1980 & Davis 1995

$\Delta\Phi$

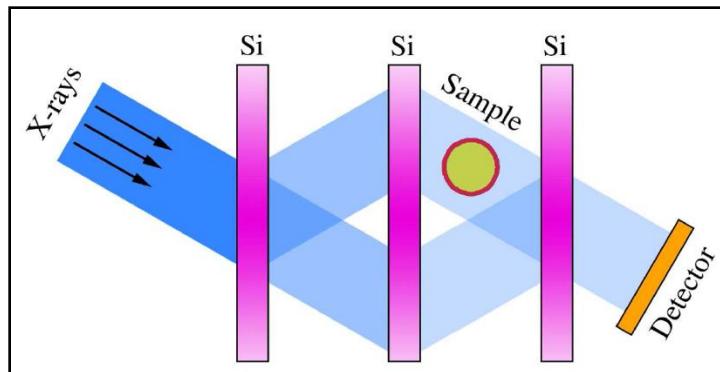
Propagationsbasiert



Snigirev 1995, Cloetens & Wilkens 1996

Φ

Kristall Interferometer

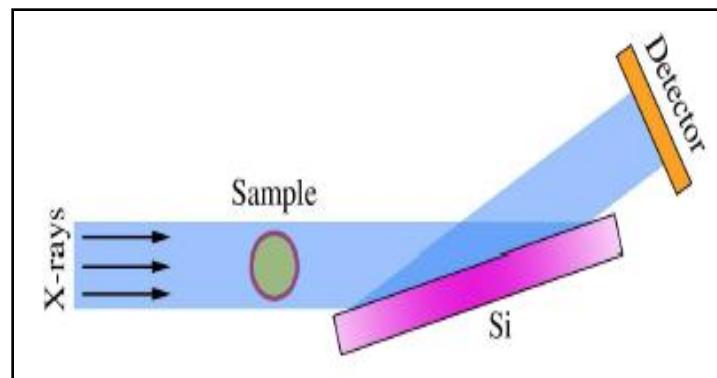


Bonse & Hart 1965

- ++ sehr hohe Sensitivität
- Anforderungen an Ausleuchtung
sehr hoch
- sehr kleine Objekte, instabil

$d\Phi/dx$

Kristall Analysator



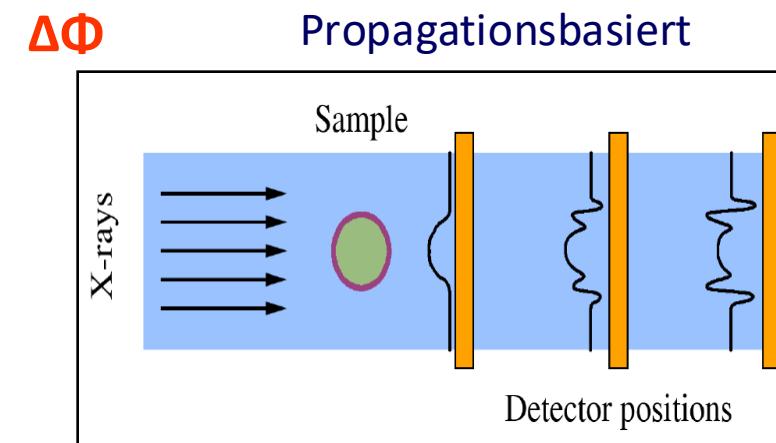
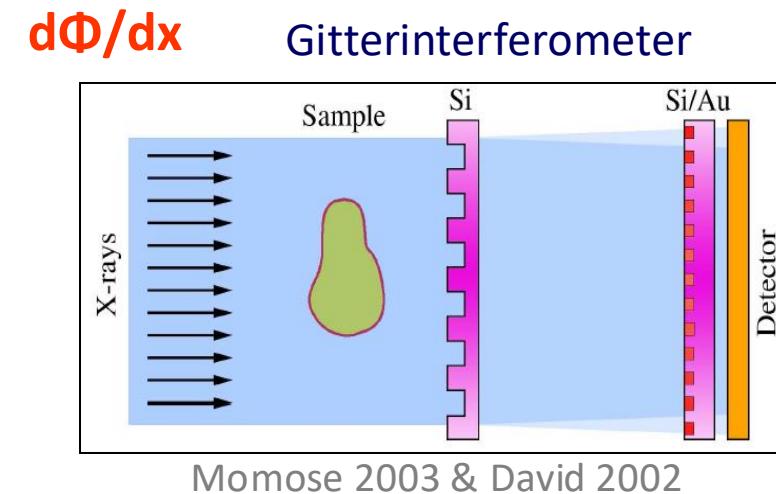
Förster 1980 & Davis 1995

- ++ sehr hohe Sensitivität
- hohe Anforderung an Ausleuchtung
- schwierig quantitative Werte
zu bekommen → Mix von Signalen β/δ

Phasenkontrastmethoden

- ++ hohe Sensitivität, robust
- + + polychromatisch, nicht kohärent, divergent
- + + quantitativ, drei Signale
- Ortsauflösung geringer

- ++ sehr simpel
- ++ sehr hohe Auflösung
- hohe Kohärenz
- nicht quantitativ
- niedrige Sensitivität



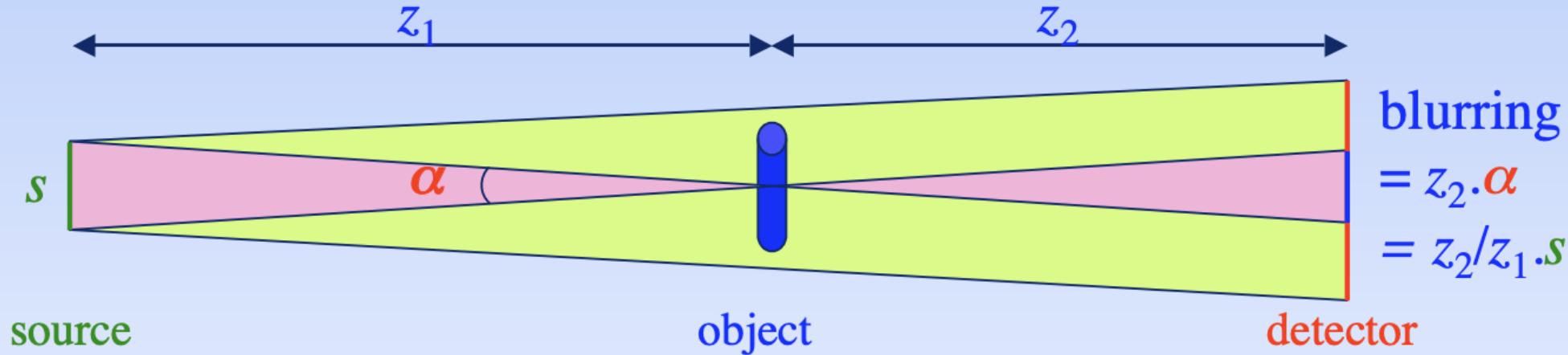
Snigirev 1995, Cloetens & Wilkens 1996

Propagation-Based Imaging (PBI)

Was sind die Anforderungen an die Kohärenz der Quelle?

Transversale Kohärenz für PBI

- Wave is partially coherent when the source is small and far



- Transverse coherence length

$$l_{coh} = \frac{\lambda}{2\alpha} = \frac{\lambda \cdot z_1}{2s}$$

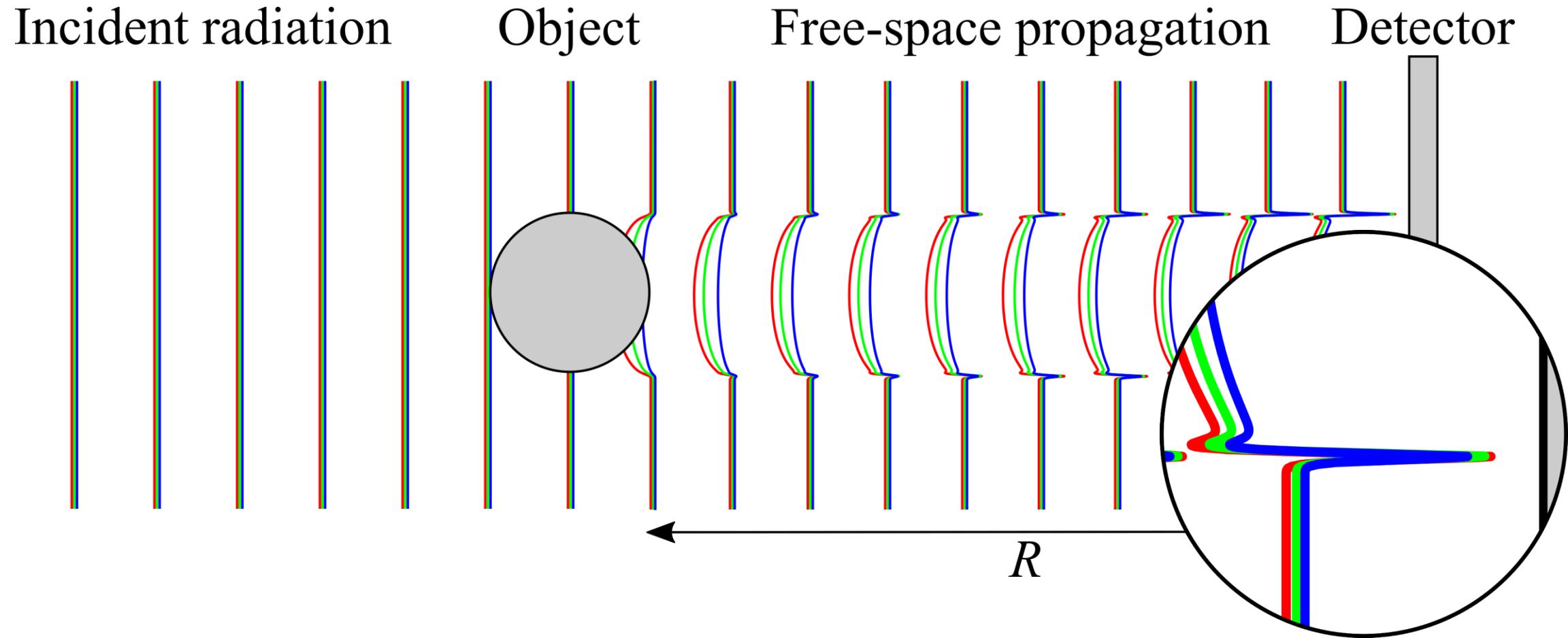
Laboratory: $l_{coh} < 1 \text{ } \mu\text{m}$

ESRF, ID19: $s = 25 \text{ } \mu\text{m}, z_1 = 145 \text{ m}$

$\alpha < 0.2 \text{ } \mu\text{rad}$

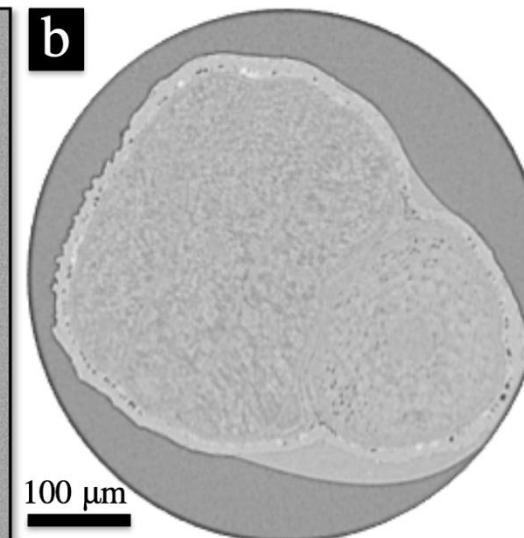
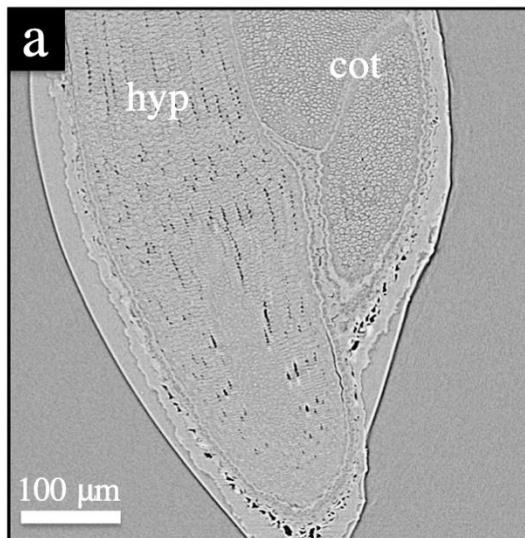
$l_{coh} \sim 250 \text{ } \mu\text{m}$

Zeitliche/longitudinale Kohärenz für PBI

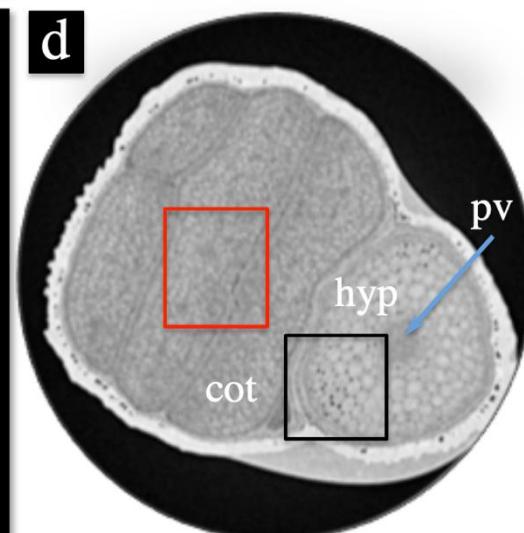
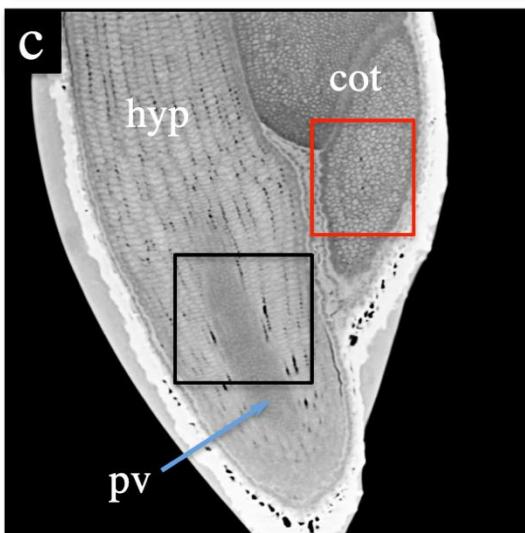


Beispiel – PBI mit Labor-MicroCT

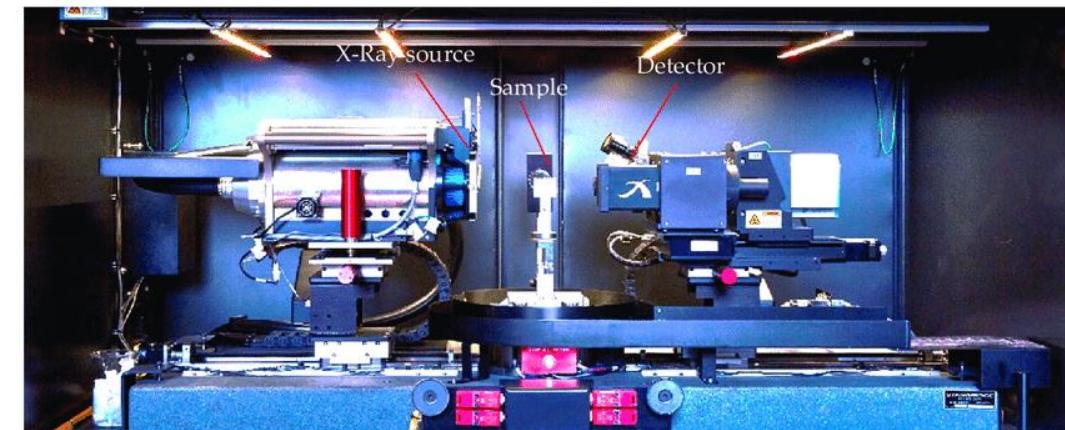
TRANSMISSION



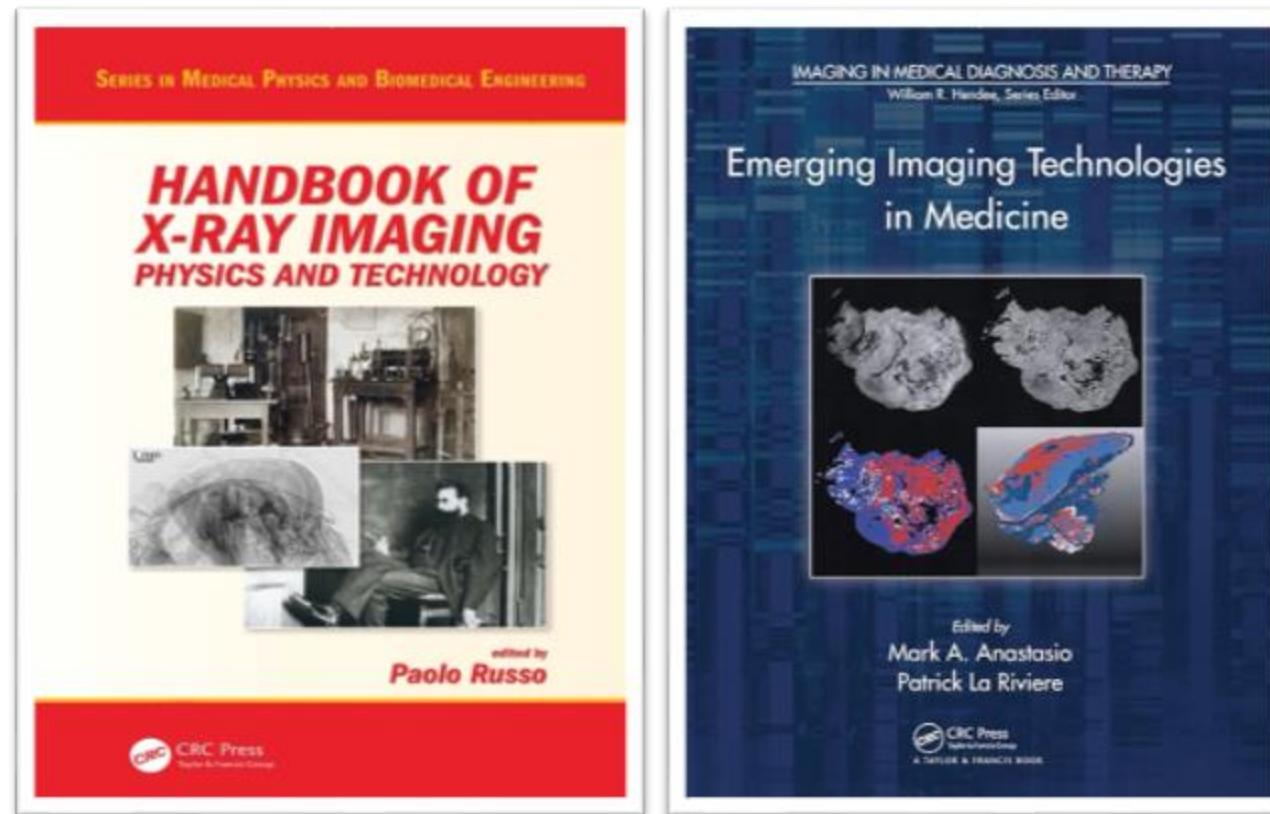
PHASE



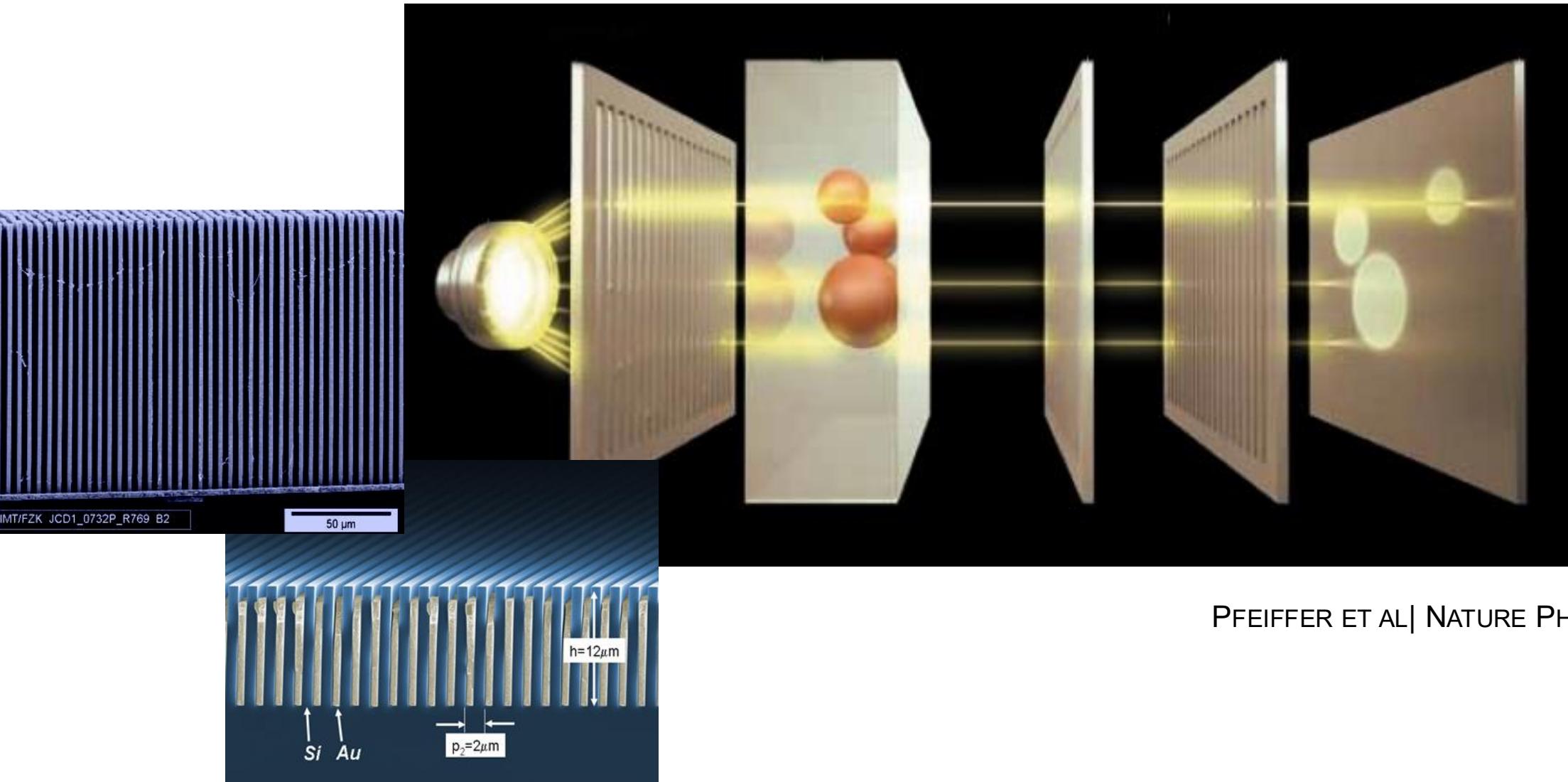
Kressesamen im μCT



Grating-Based Imaging (GBI)

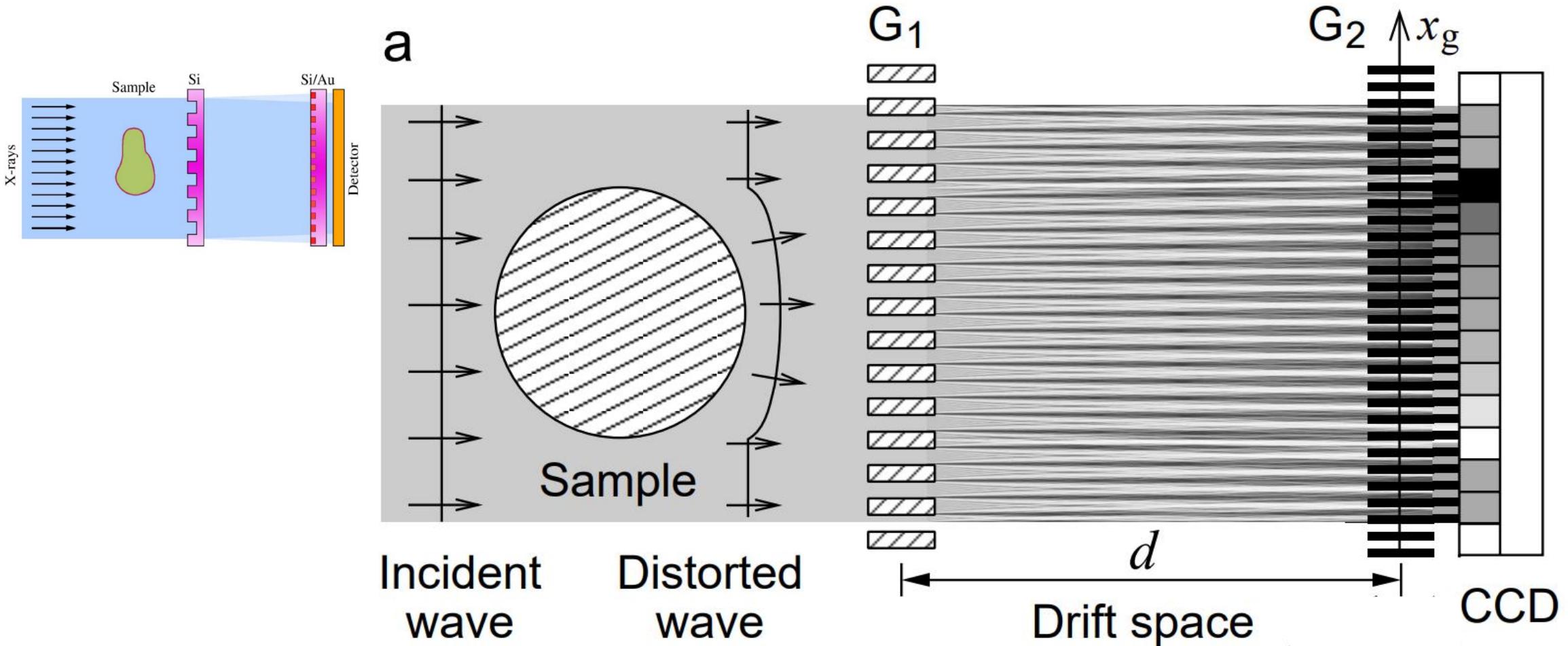


Röntgen Phasenkontrast mit Gittern



PFEIFFER ET AL | NATURE PHYSICS | 2006

Grating-Based Imaging - Basic Idea



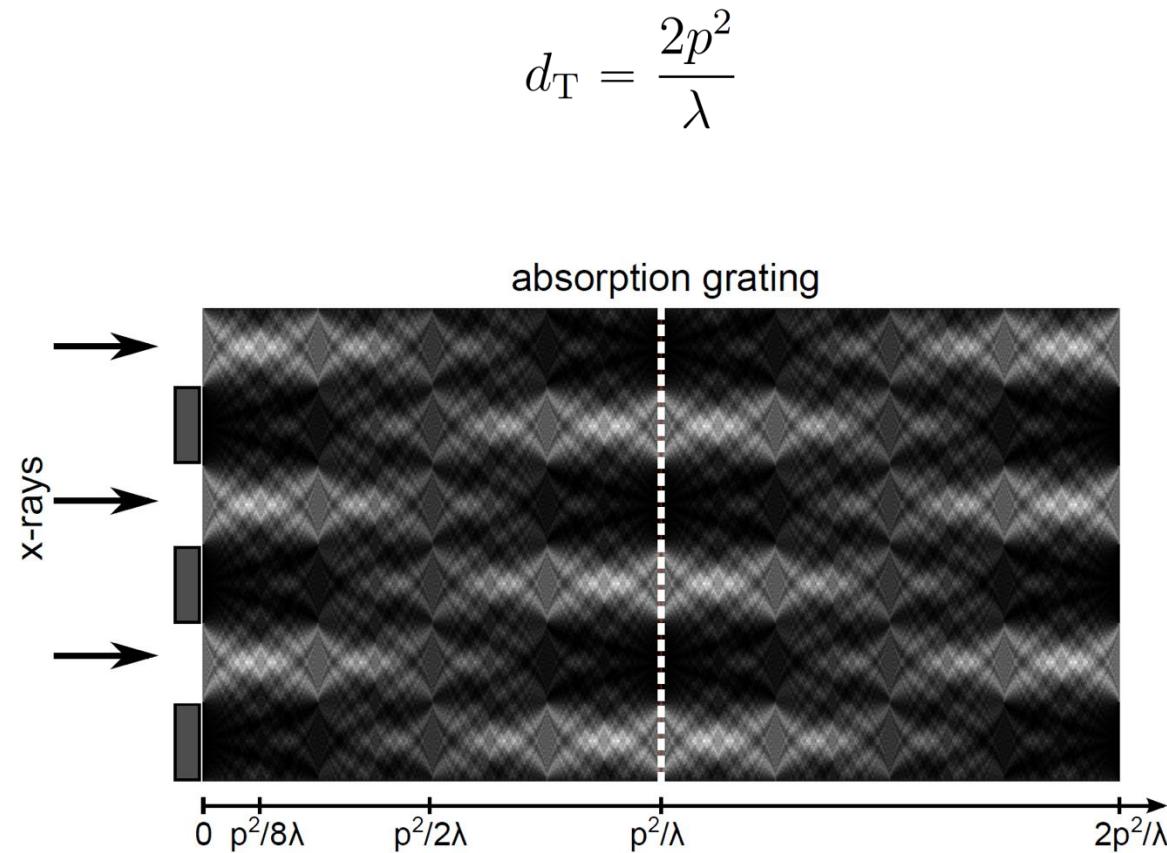
Weitkamp et al | Optics Express | 2005
Pfeiffer et al | Nature Physics | 2006
Pfeiffer et al | Nature Materials | 2008

Talbot Effekt

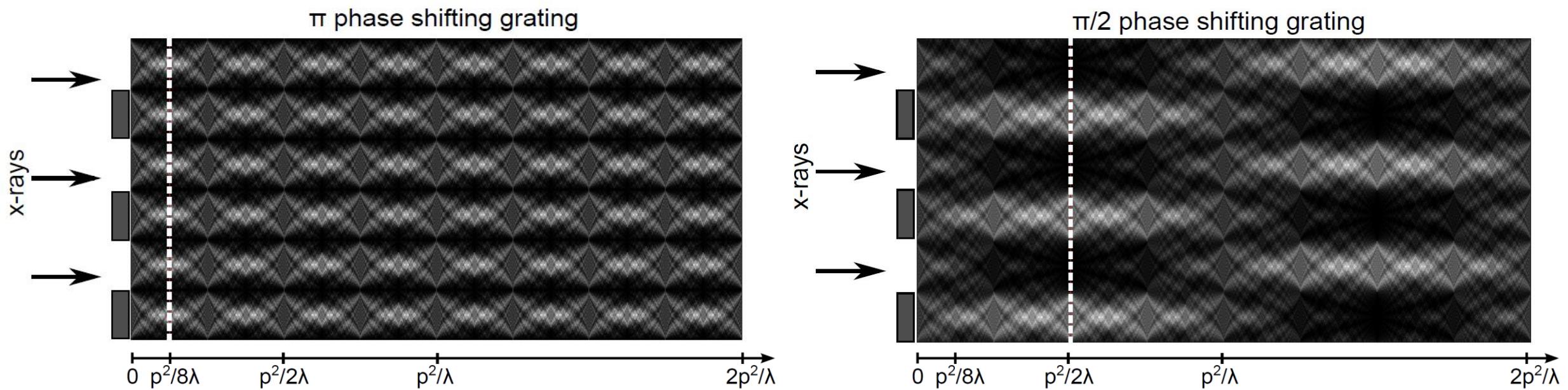
“a periodic wave front will repeat itself at certain distances”



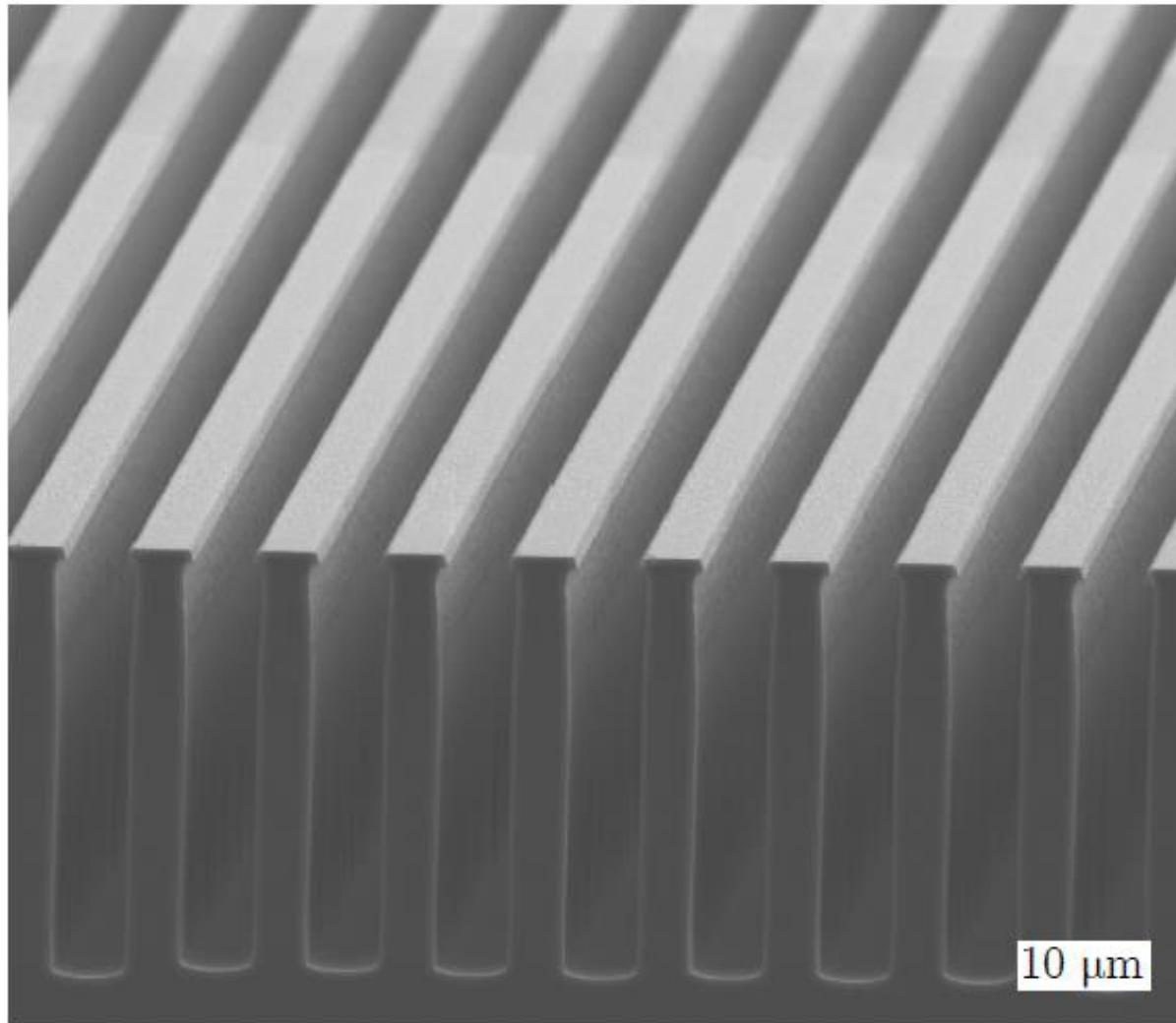
William Henry Fox Talbot 1844 (Inline media)



Fractional Talbot Effect

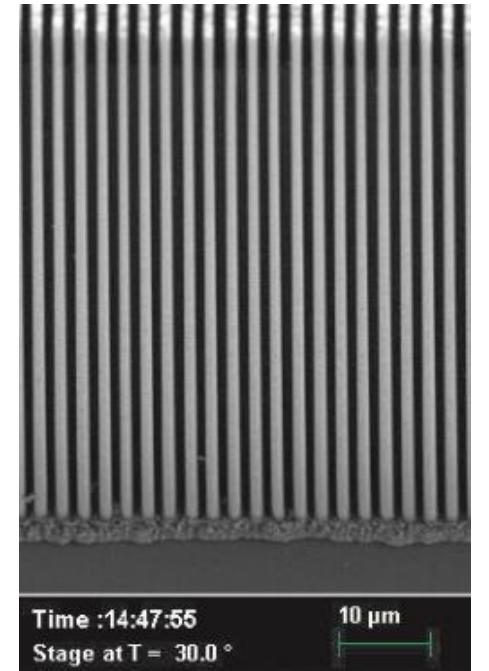
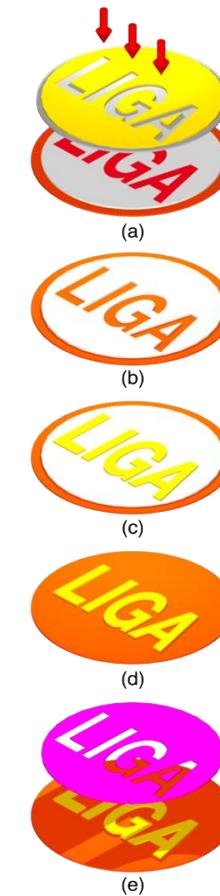
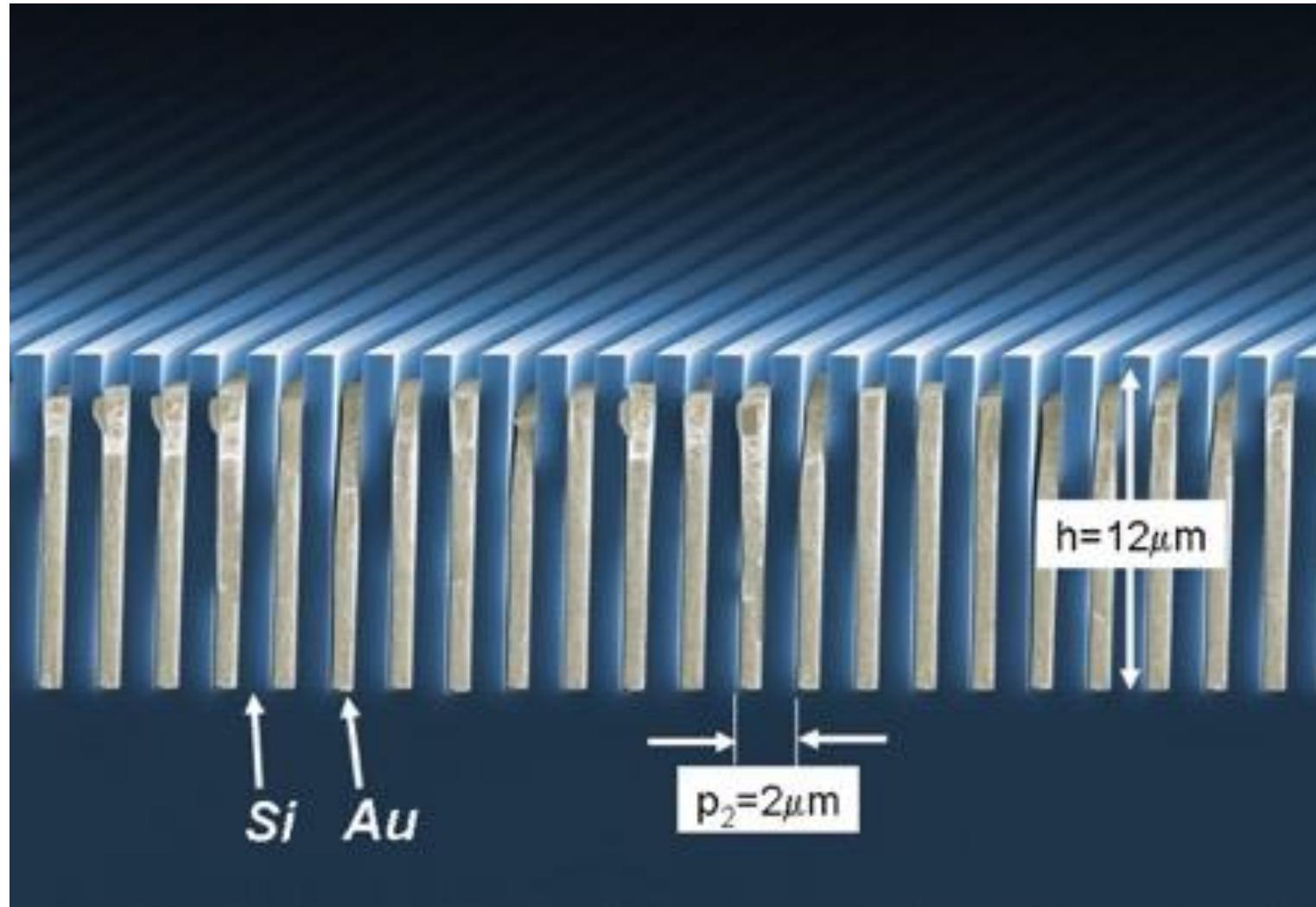


Phasengitter G1



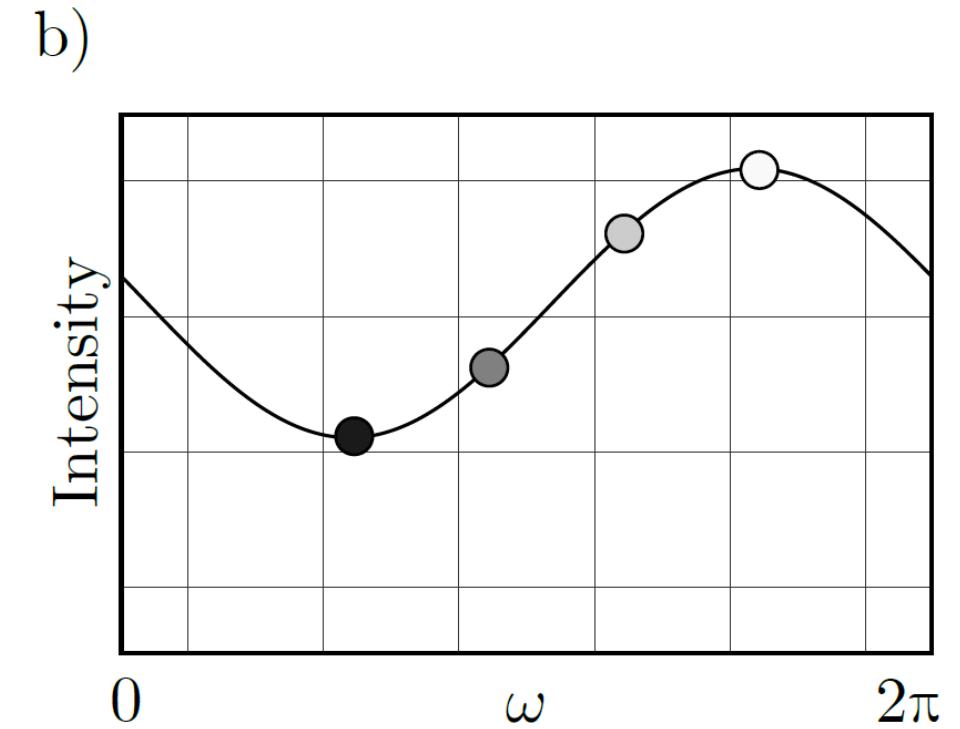
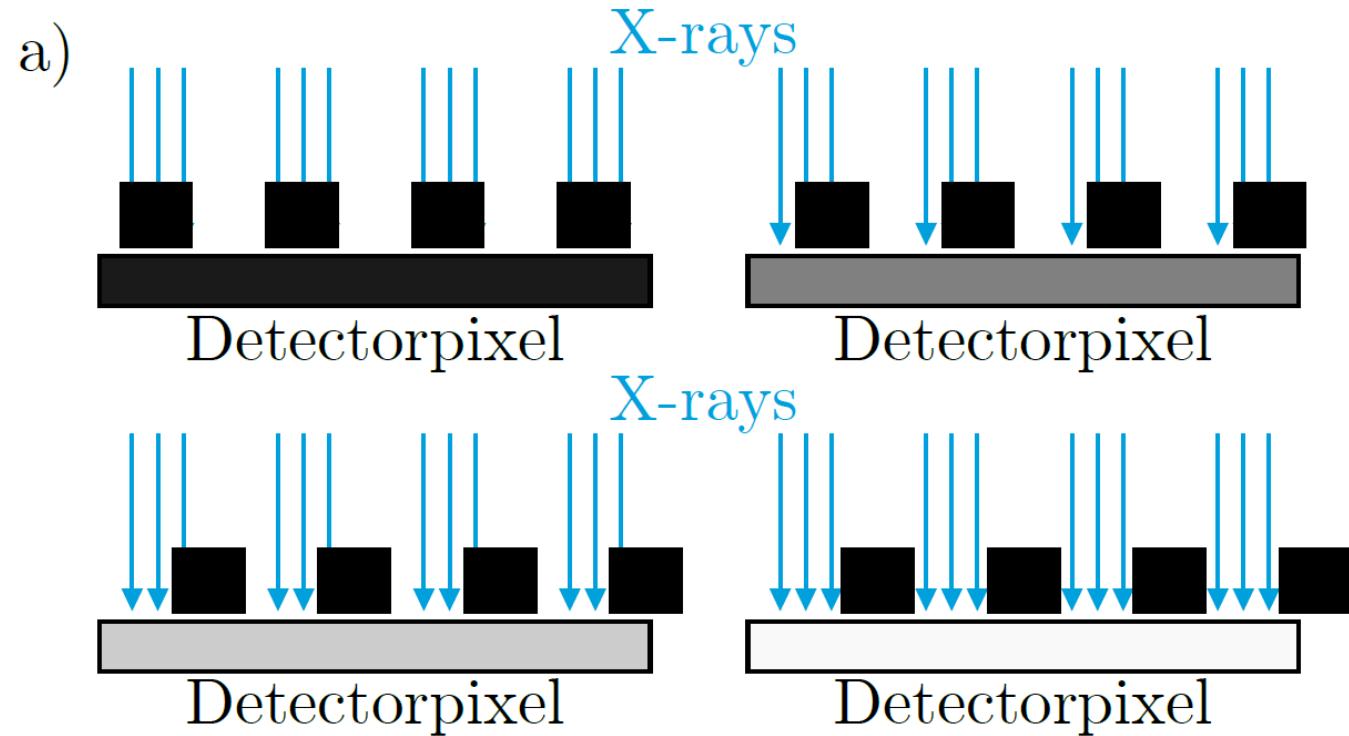
- Intensitätsmuster mit kleiner μm Periode
- Detektorpixel > 100 μm

Analysatorgitter G2



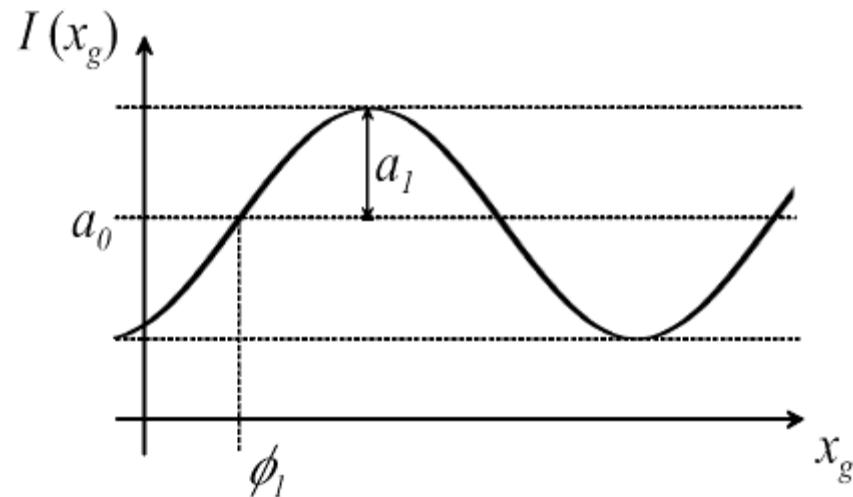
Schröter et al. | RSI | 2017

Phasenstepping



Signal Extraktion

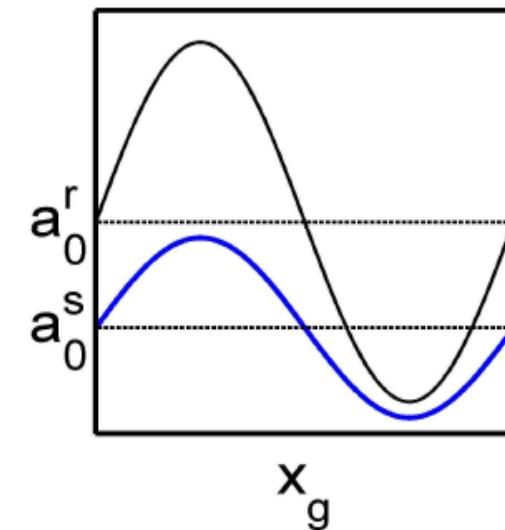
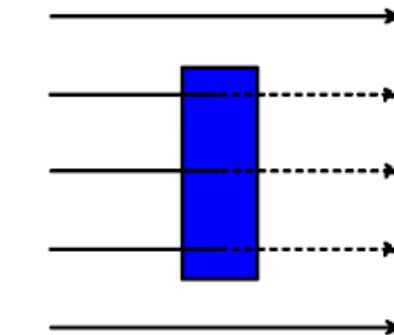
mit 'fringe scanning' oder 'phase stepping'



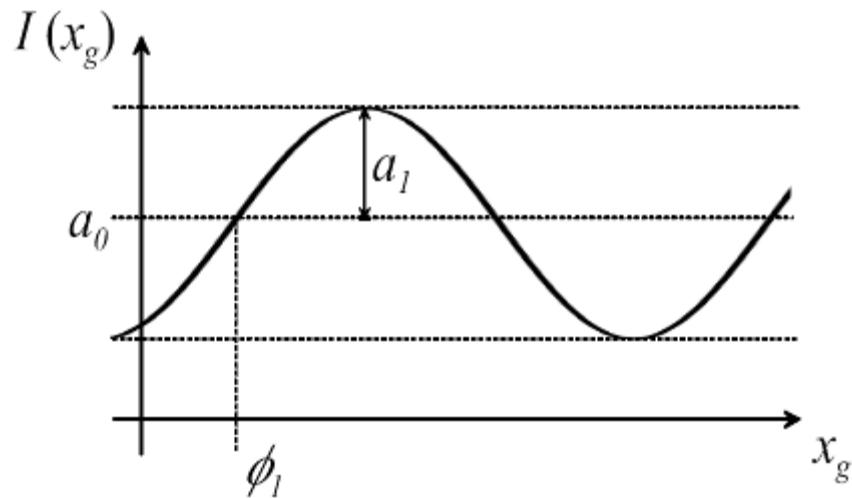
$$I(m, n, x_g) = \sum a_i(m, n) \cos(ikx_g + \phi_i(m, n))$$

$$\approx a_0(m, n) + a_1(m, n) \cos(kx_g + \phi_1(m, n))$$

transmission



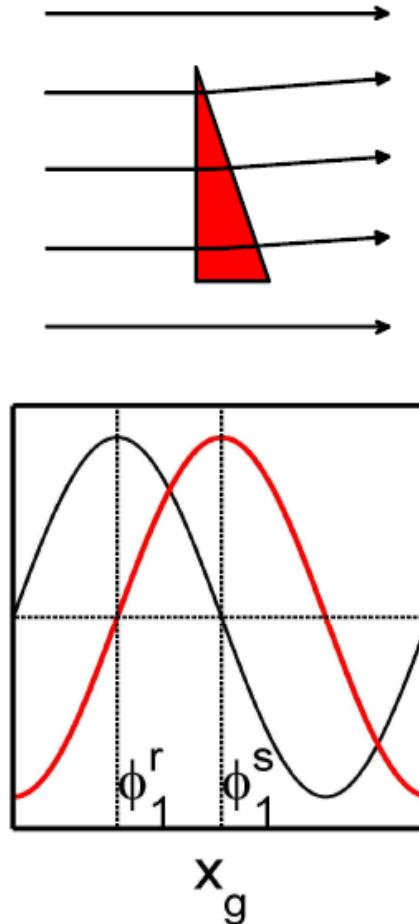
Signal Extraction



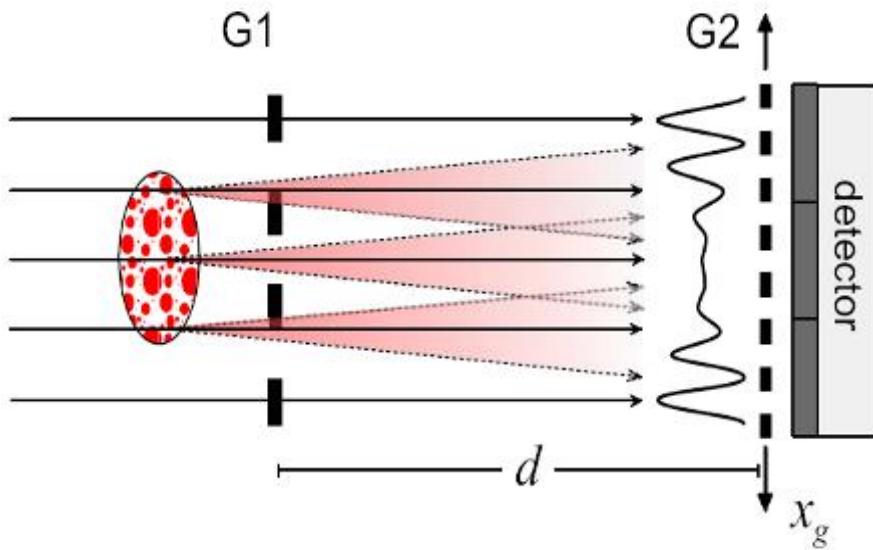
$$I(m, n, x_g) = \sum a_i(m, n) \cos(ikx_g + \phi_i(m, n))$$

$$\approx a_0(m, n) + a_1(m, n) \cos(kx_g + \phi_1(m, n))$$

phase gradient



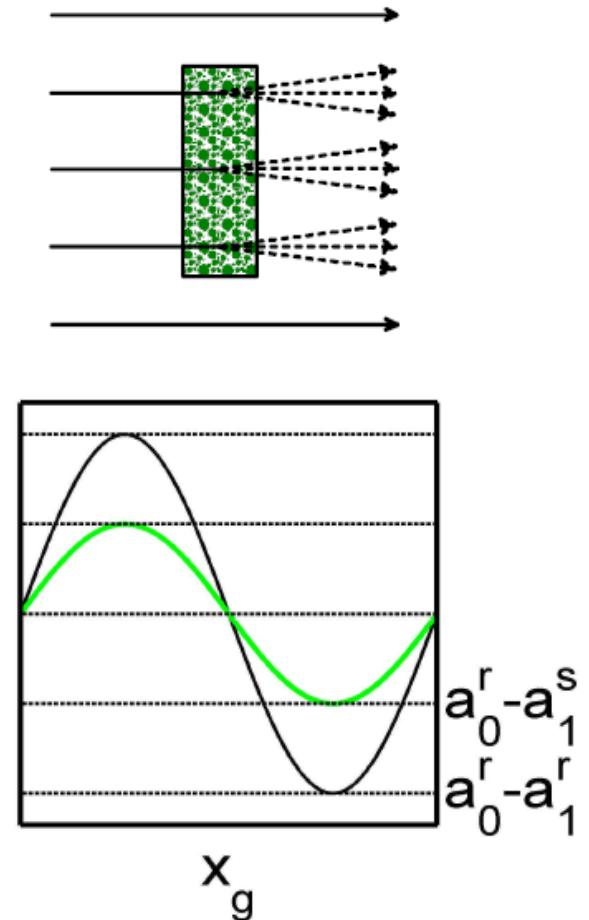
Signal Extraction



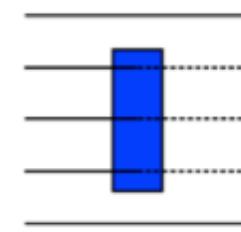
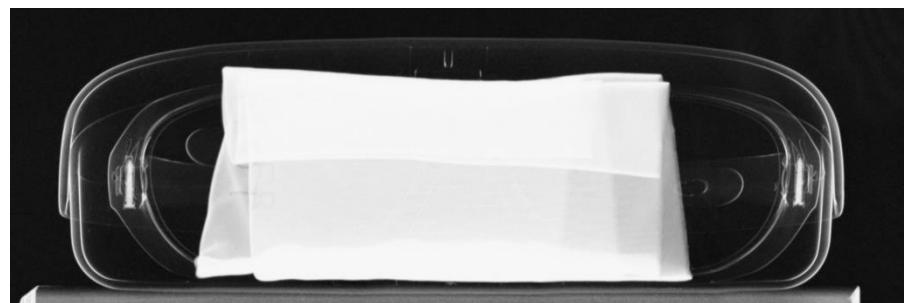
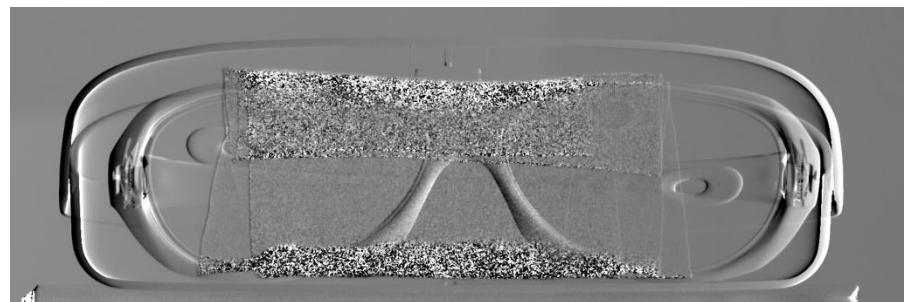
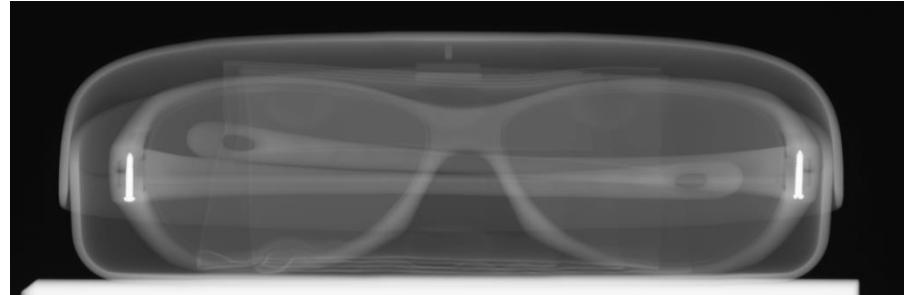
$$I(m, n, x_g) = \sum a_i(m, n) \cos(ikx_g + \phi_i(m, n))$$

$$\approx a_0(m, n) + a_1(m, n) \cos(kx_g + \phi_1(m, n))$$

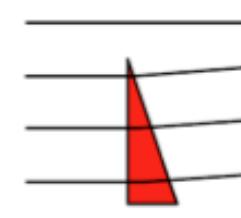
scattering/
dark-field



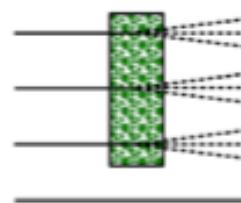
Multimodale Information



ATTENUATION



PHASE

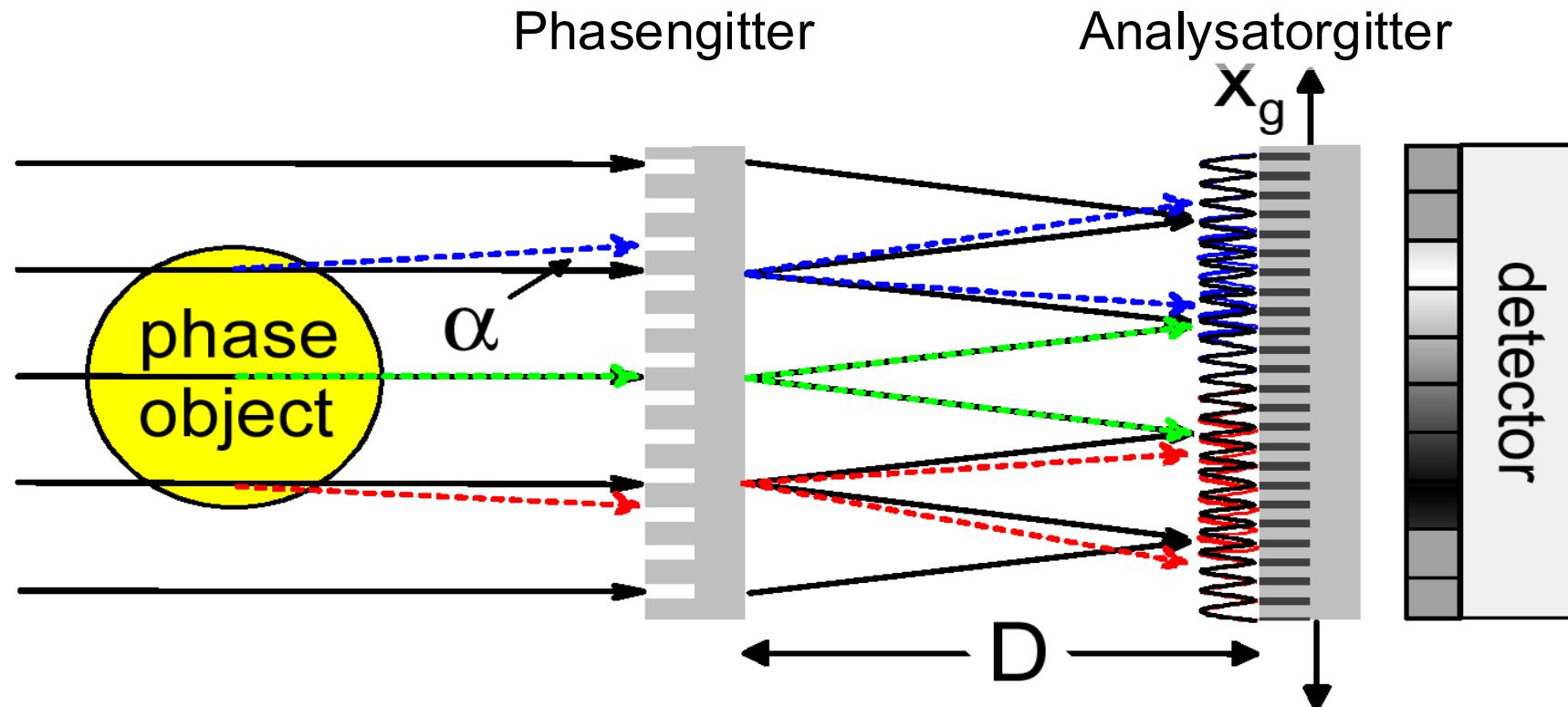


DARKFIELD

Grating-Based Imaging (GBI)

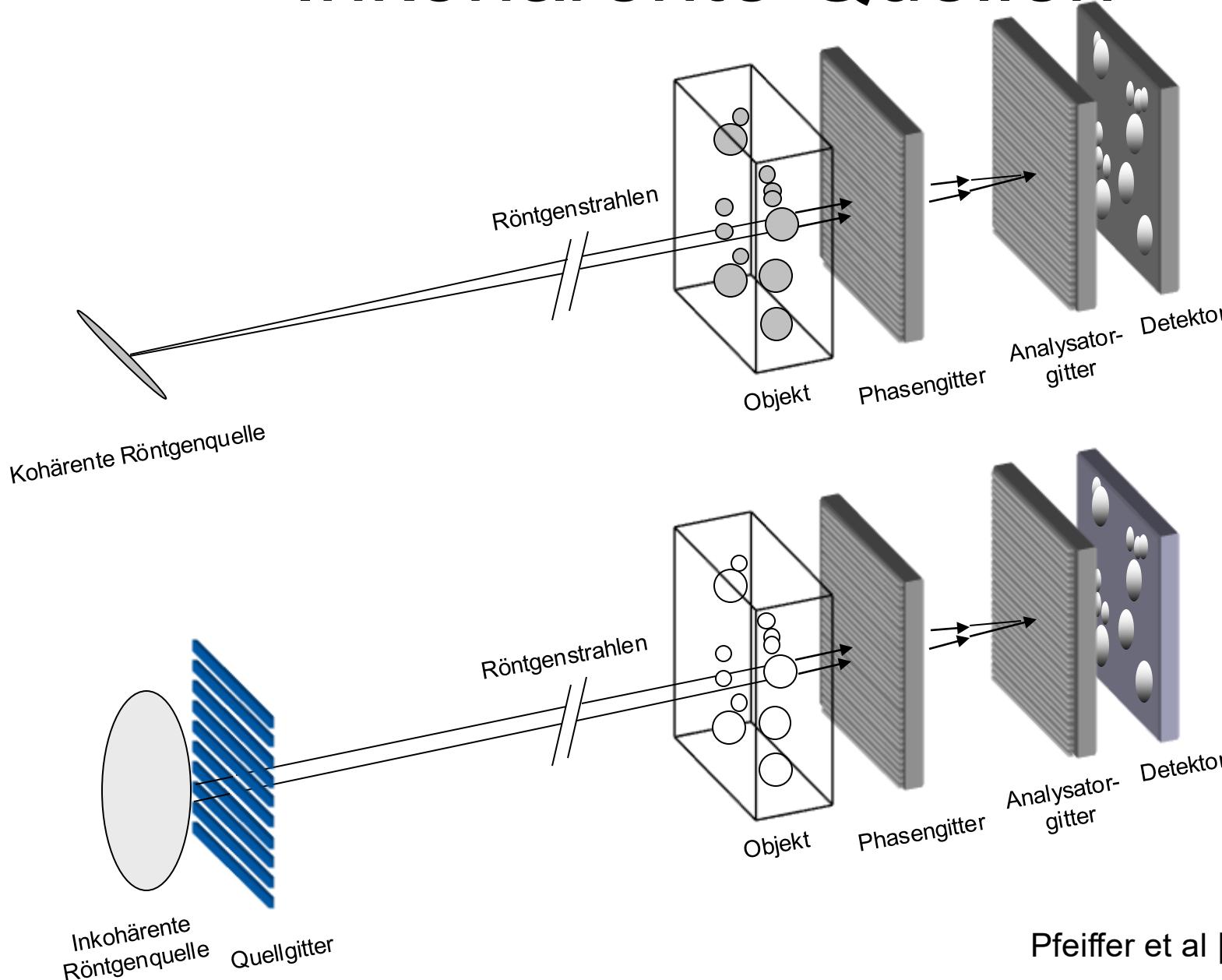
Was sind die Anforderungen an die Kohärenz der Quelle?

Polychromatische Quelle

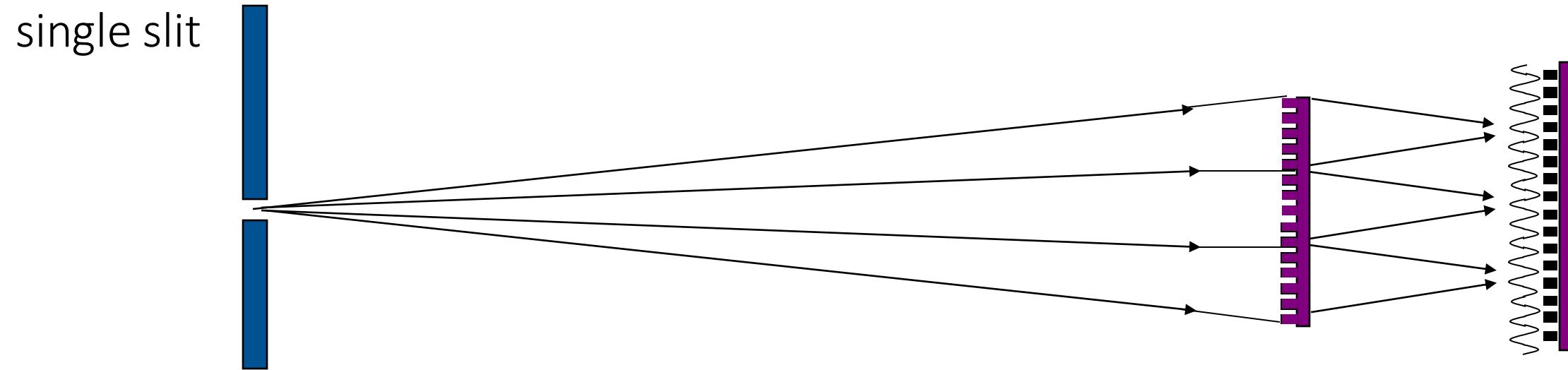


Pfeiffer et al | Nature Physics | 2006
Pfeiffer et al | Nature Materials | 2008

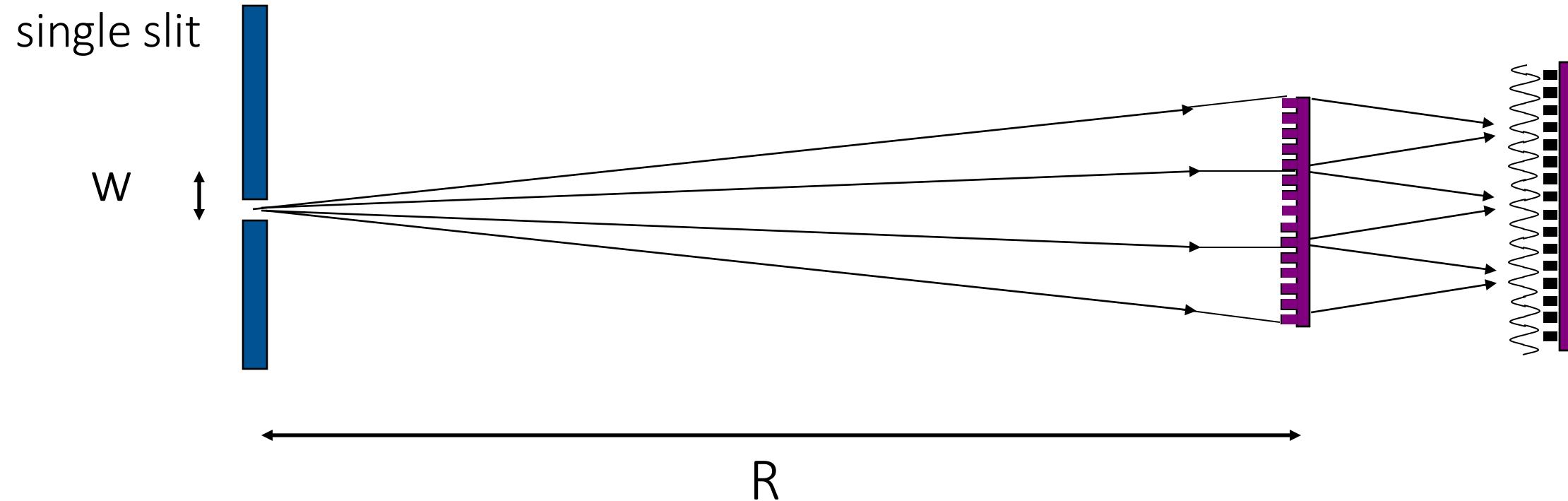
Inkohärente Quellen



Talbot-Lau Grating-based Imaging

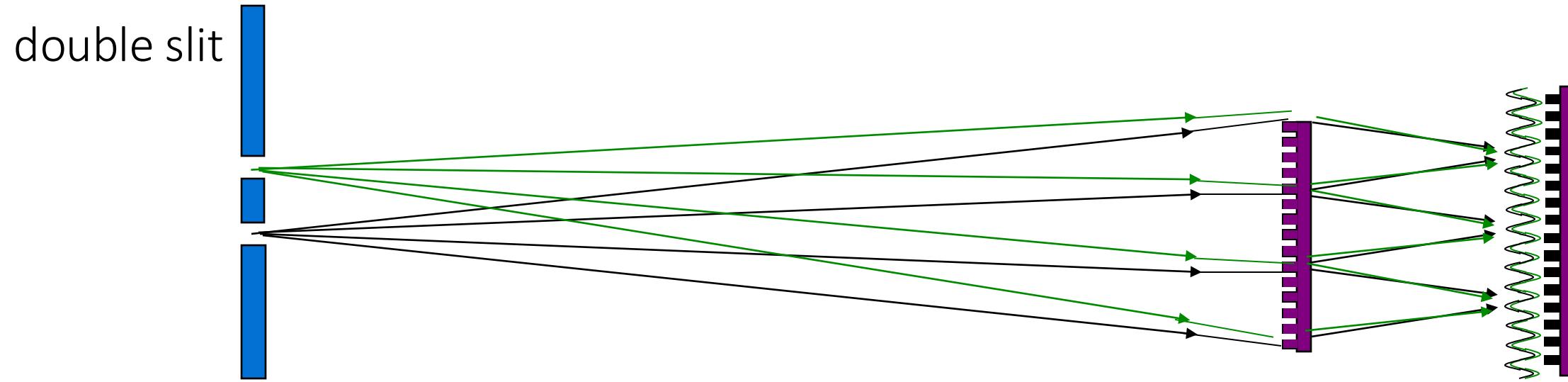


Talbot-Lau Grating-based Imaging

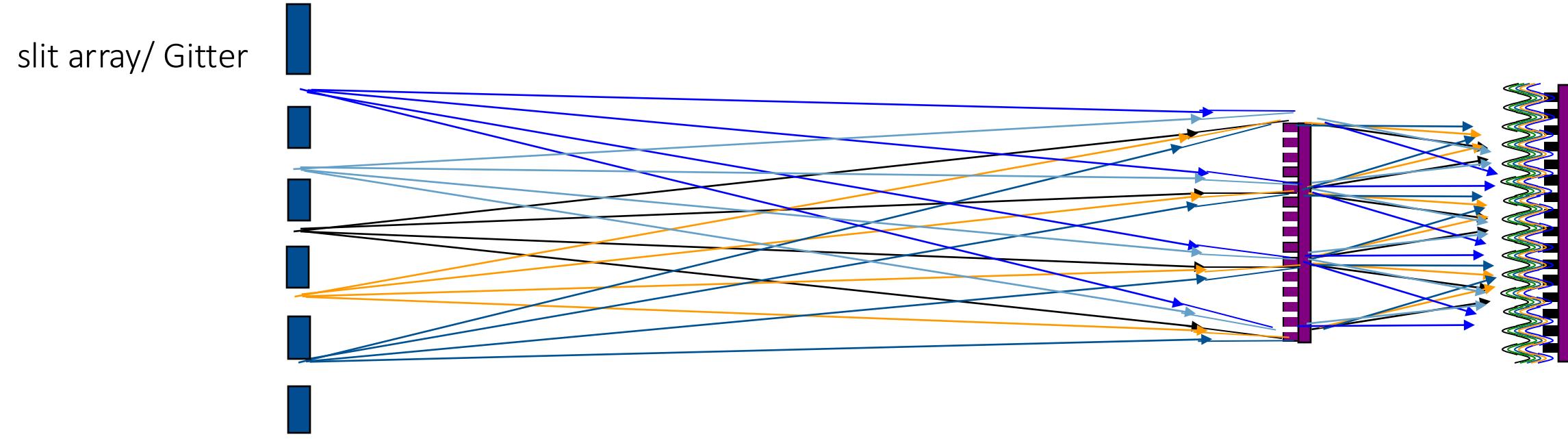


benötigte Kohärenzlänge
 $\xi = \lambda R / w > p$

Talbot-Lau Grating-based Imaging



Talbot-Lau Grating-based Imaging



Decouples coherence from spatial resolution !

Grating-Based Imaging mit Lab-Quelle

PHASENKONTRAST MICRO CT

SYNCHROTRON



2015



X-RAY TUBES

2019



AUFLÖSUNG: 20 µM

100 µM

40 µM

SCAN ZEIT: 10 MIN

2 TAGE

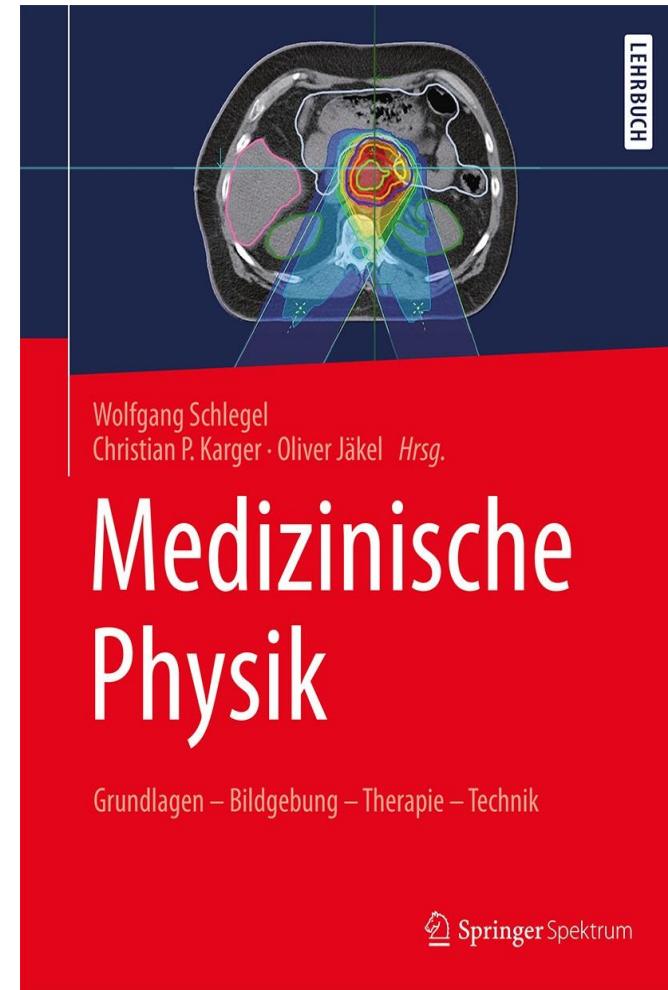
1 TAG

Inhalt - Strahlentherapie

Linearbeschleuniger

- Elektronen & Photonen

Protonen & Ionen Therapie



<https://link.springer.com/book/10.1007/978-3-662-54801-1>

Thema Klinische Strahlentherapie

ausführlichere Behandlung in folgenden Vorlesungen im Master:

- Biomedical Physics I+II (Prof. Pfeiffer/Prof. Wilkens)
- Radiation Physics and Dosimetry (Prof. Wilkens, Dr. Bartzsch)
- Klinische und experimentelle Radioonkologie (Prof. Dr. med. Combs)

Behandlung von Krebs

Chirurgie

Strahlentherapie

Chemotherapie



**überwiegend mit
ultraharter
Röntgenstrahlung**

Mit unsichtbaren Strahlen
auf ein unsichtbares Ziel!

Grundlagen der Strahlentherapie

Ziel:

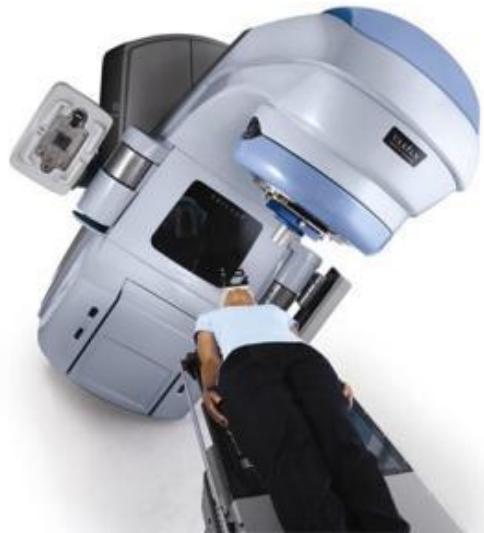
- Ausschalten aller Tumorzellen mit ionisierender Strahlung
- bei möglichst kleinen Nebenwirkungen im gesunden Gewebe

Tumorzellen sind oft sehr strahlenempfindlich
Normalgewebe kann sich besser reparieren

→ fraktionierte Therapie

Tumorkonforme Bestrahlung:

$$\text{Dosis}_{\text{Tumor}} > \text{Dosis}_{\text{Normalgewebe}}$$

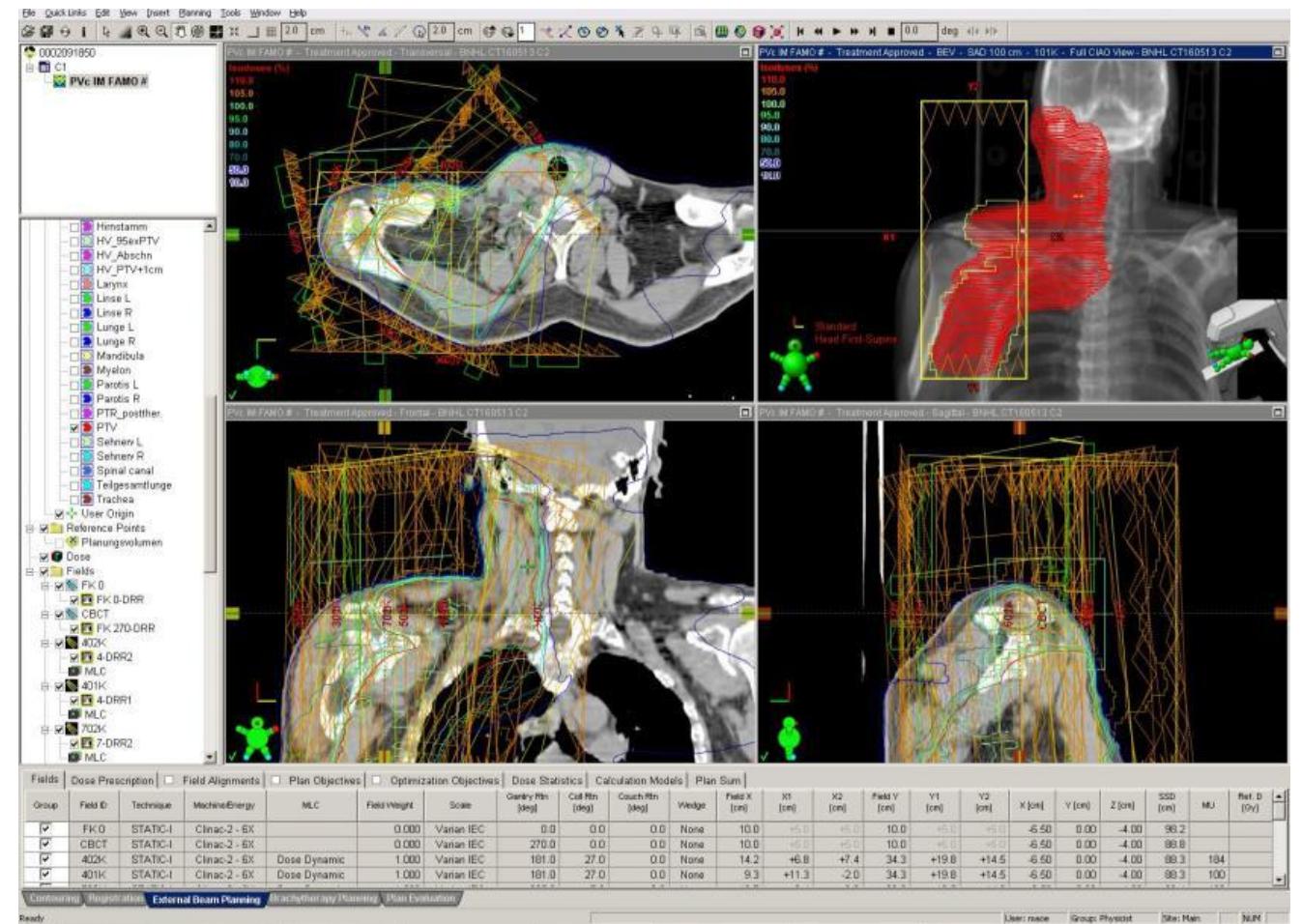


www.varian.com



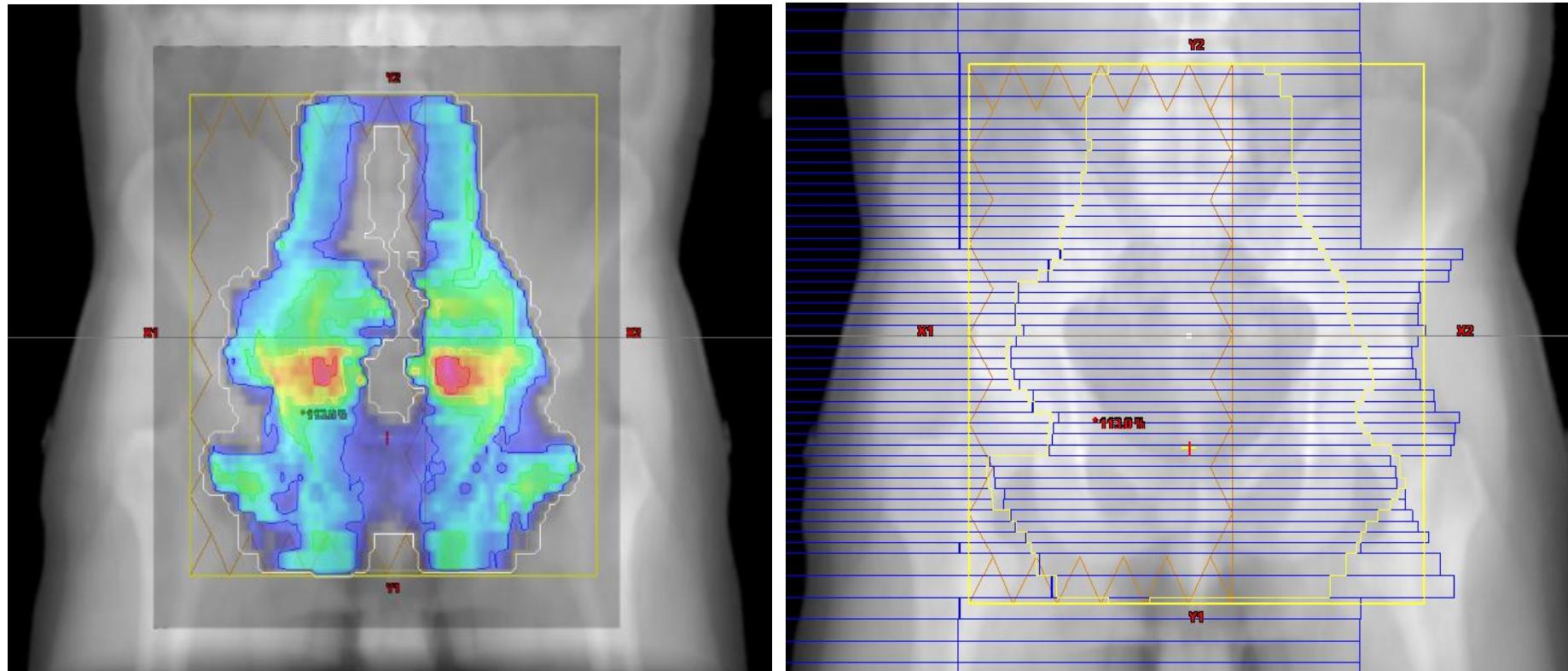
Multileafcollimator (Clinac DHX, Varian)

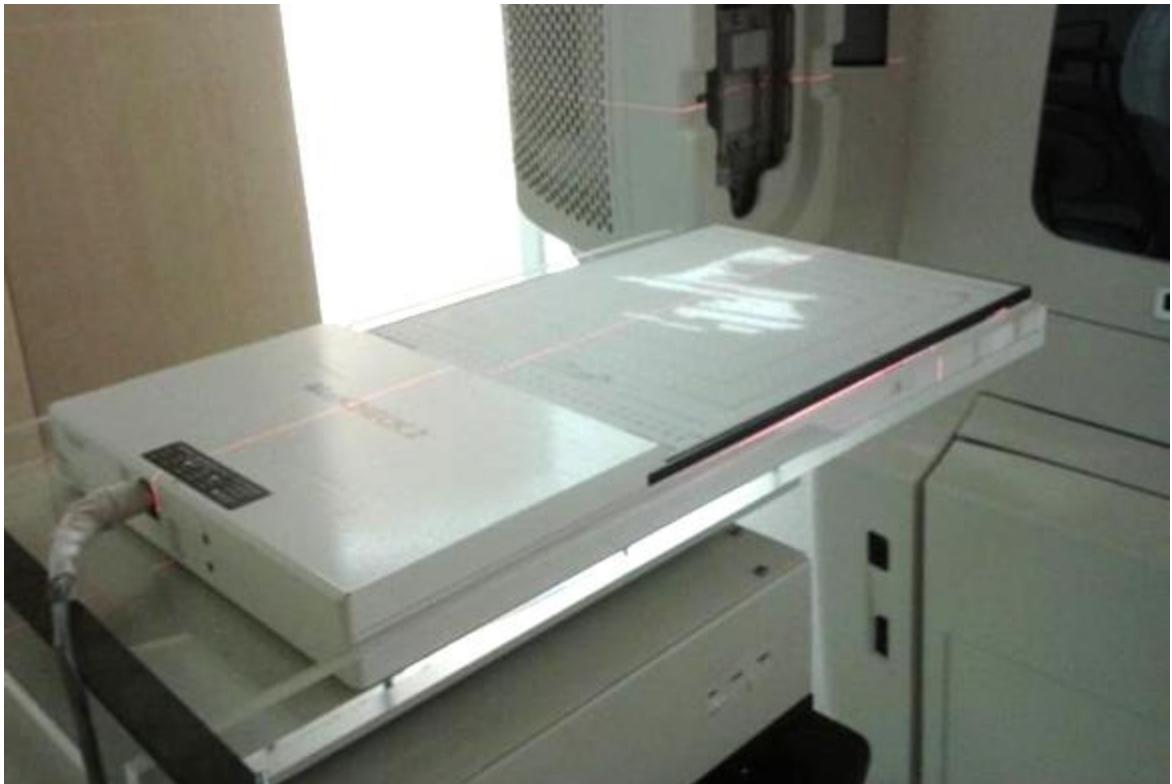
Bilder: M. Oechsner (MRI)



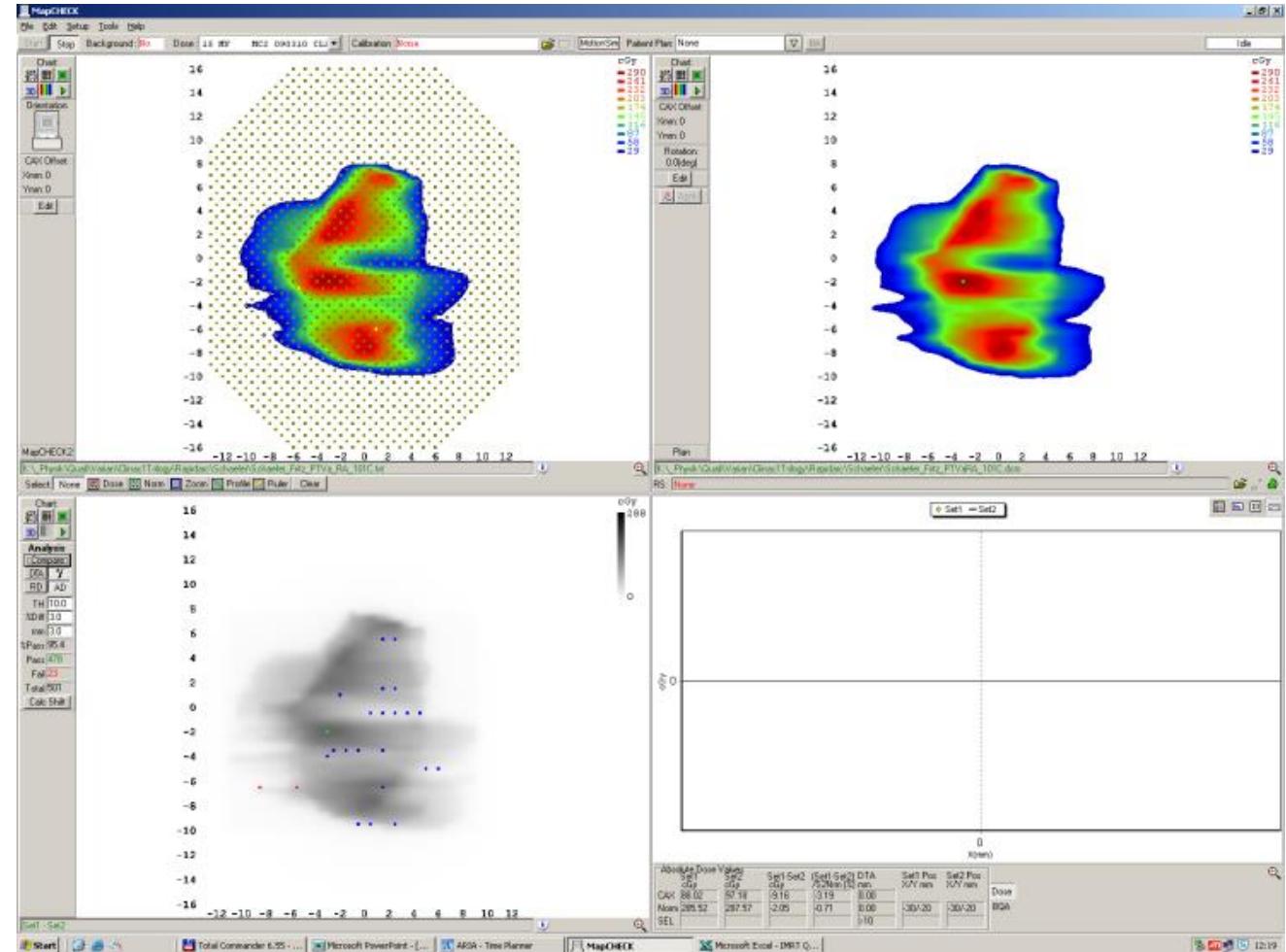
Bestrahlungsplanungssystem (Eclipse, Varian)

Dosismodulation aus einer Einstrahlrichtung wird durch dynamische Leafbewegung erzielt





2D Array



Auswertung

kV Kegelstrahl-CT (CBCT) am Linac

MV-Therapie-
Strahl



Trilogy (Varian)

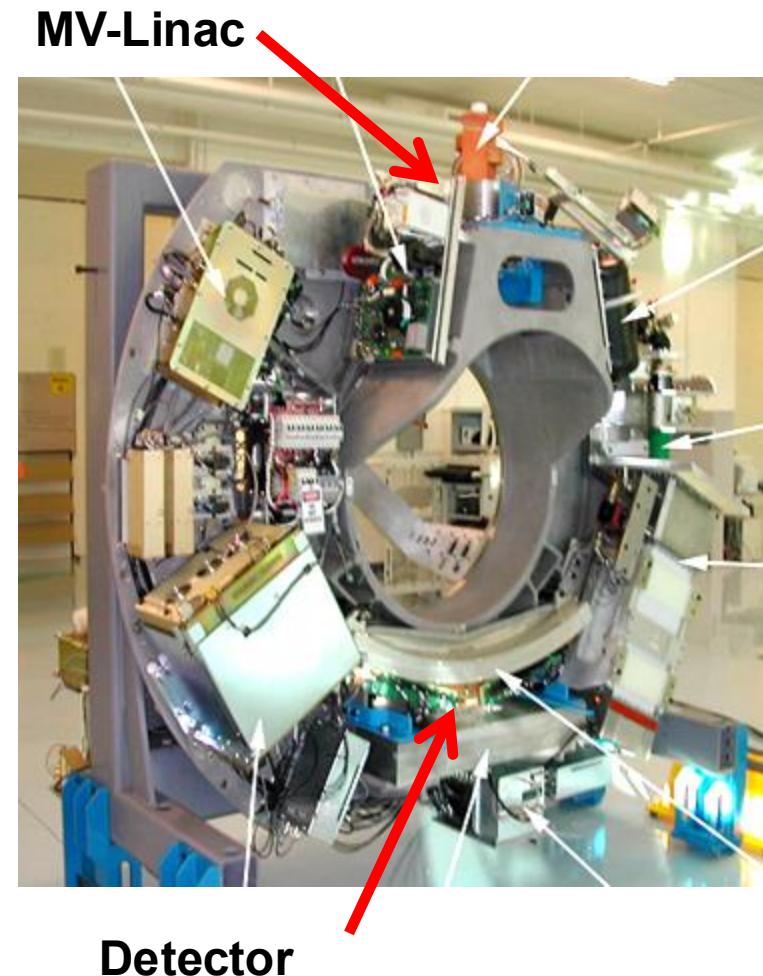
kV-Strahl zur
Bildgebung



MV-Fächerstrahl-CT (Tomotherapy)



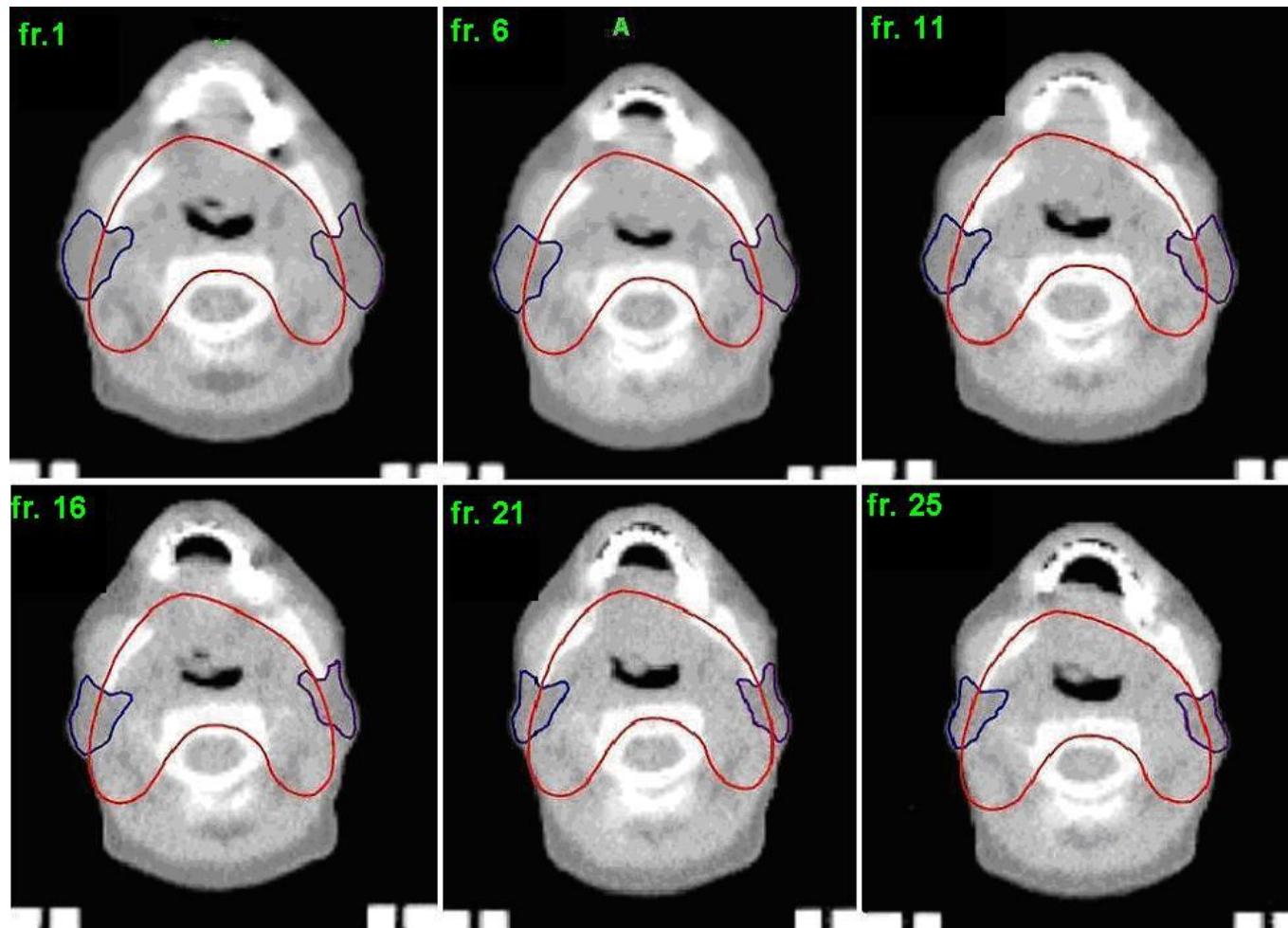
TomoTherapy



MV-Linac
Detector

Adaptive Strahlentherapie

(Online?-)Neuplanung bei geänderter Anatomie



Duma et al. 2010
IJROBP 77 1266-73

Intrafraktionelle Organbewegungen

Dosisapplikation mit Gating
Beam on-off gesteuert über Atemkurve

Synchronisation mit der Organ-Bewegung:
Tracking
Nachführen des Strahls (Cyberknife, Vero)
Nachführen der MLC-Lamellen (Varian)

4D-Bildgebung
(CT, MRI, ...)



www.accuray.com

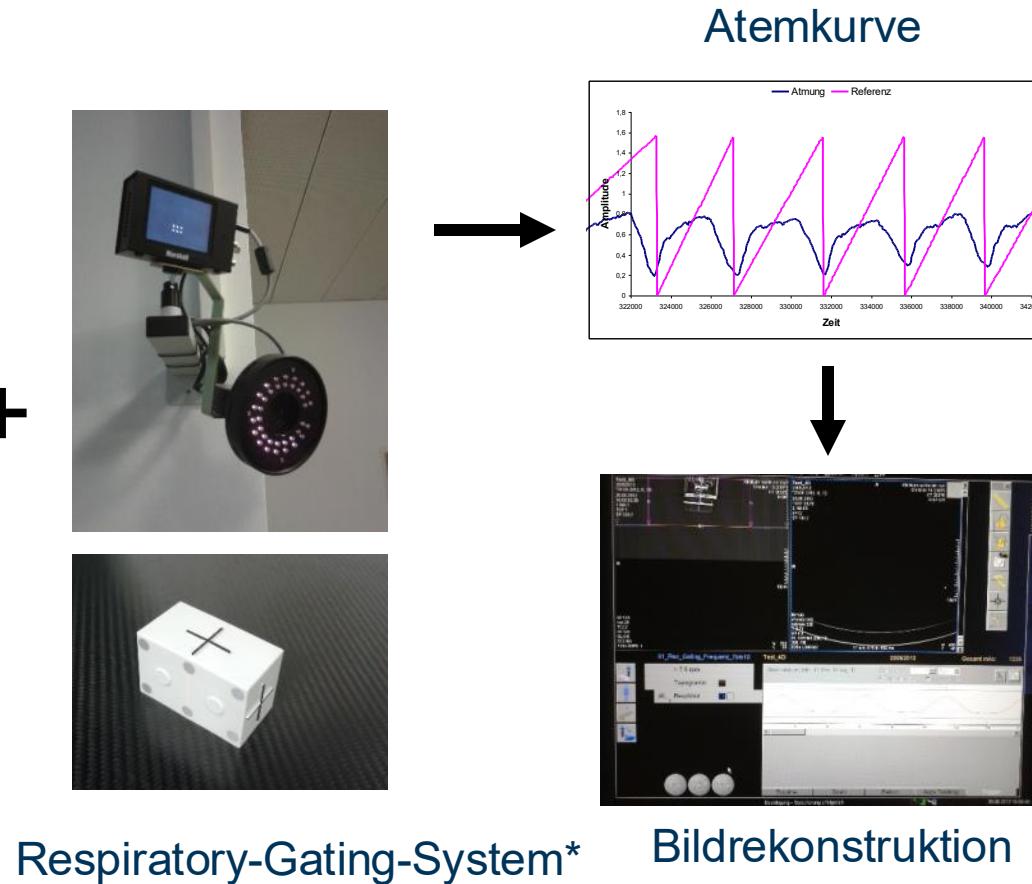
4D-CT



+



Computertomograph (CT), 4D-fähig

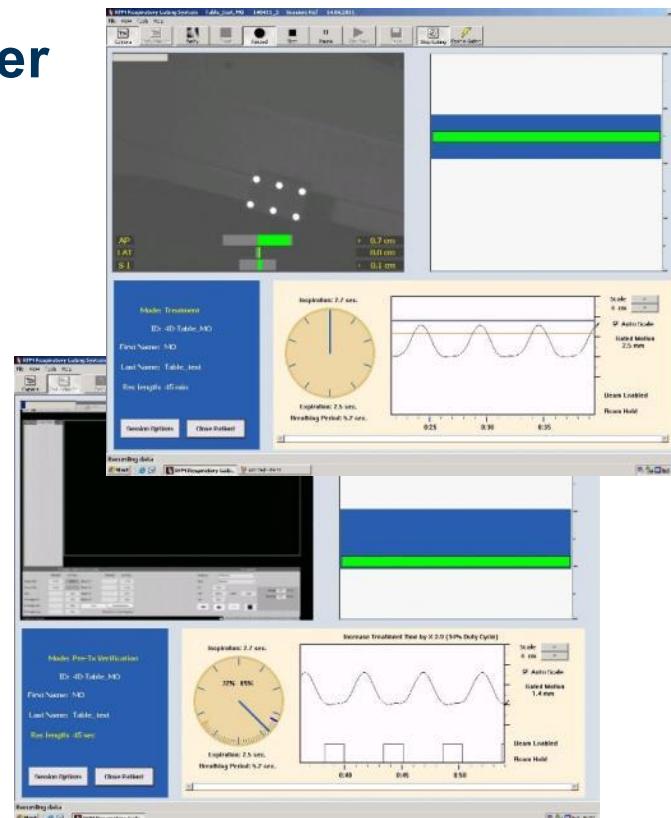


Gating - Behandlung

Am Linearbeschleuniger



Gating-System



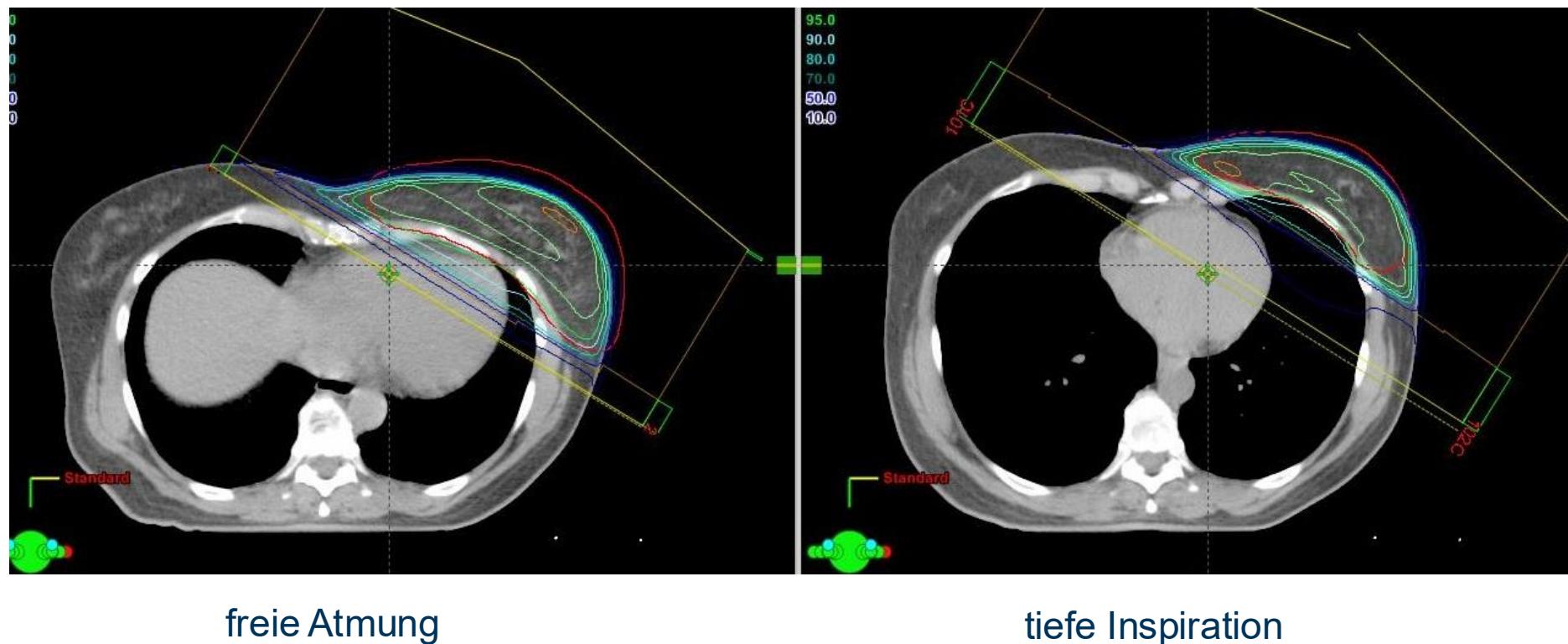
Respiratory-Gating-Software

Beam on

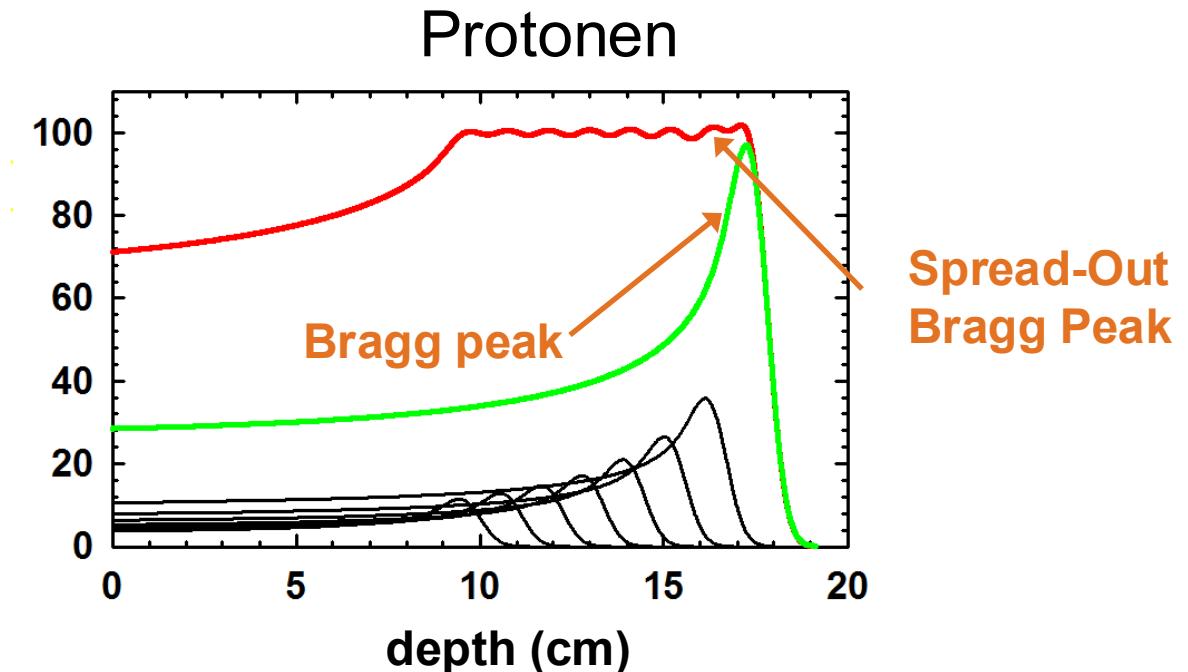
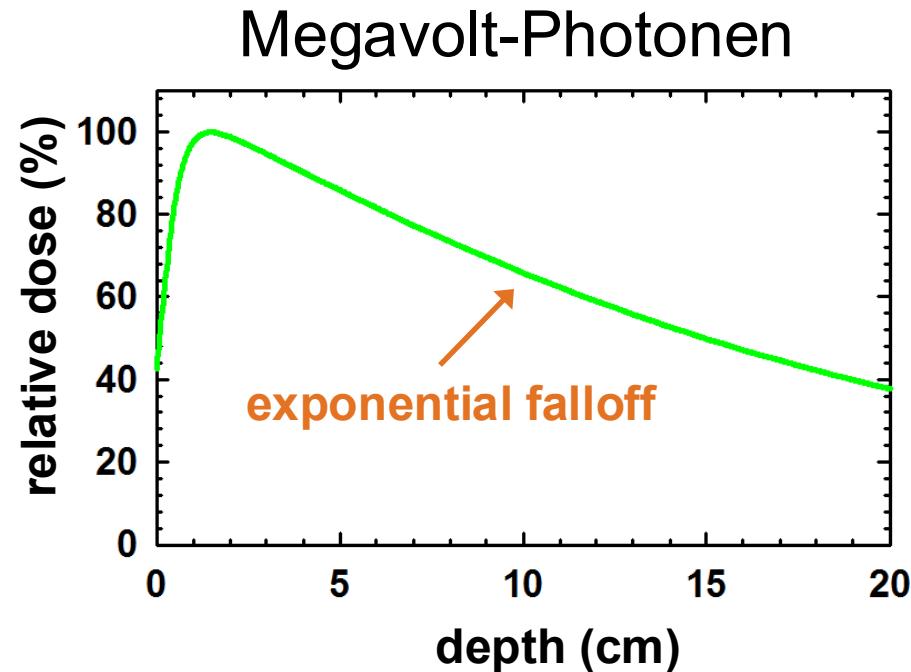


Beispiel: linke Brust

Tiefer Inspirations-Atemstopp => Herzschonung



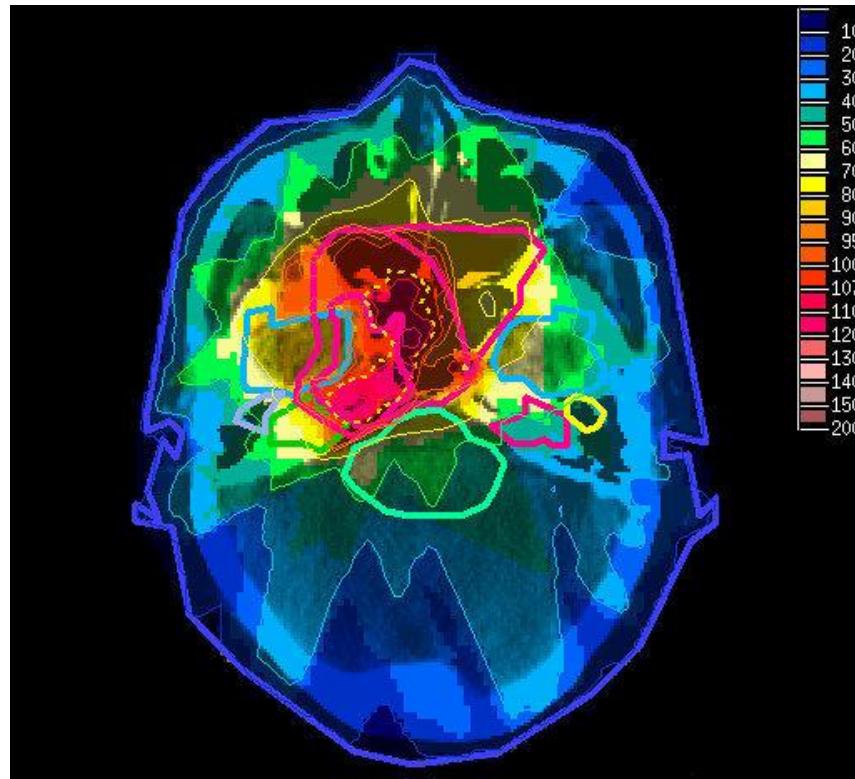
Motivation: Tiefendosiskurven



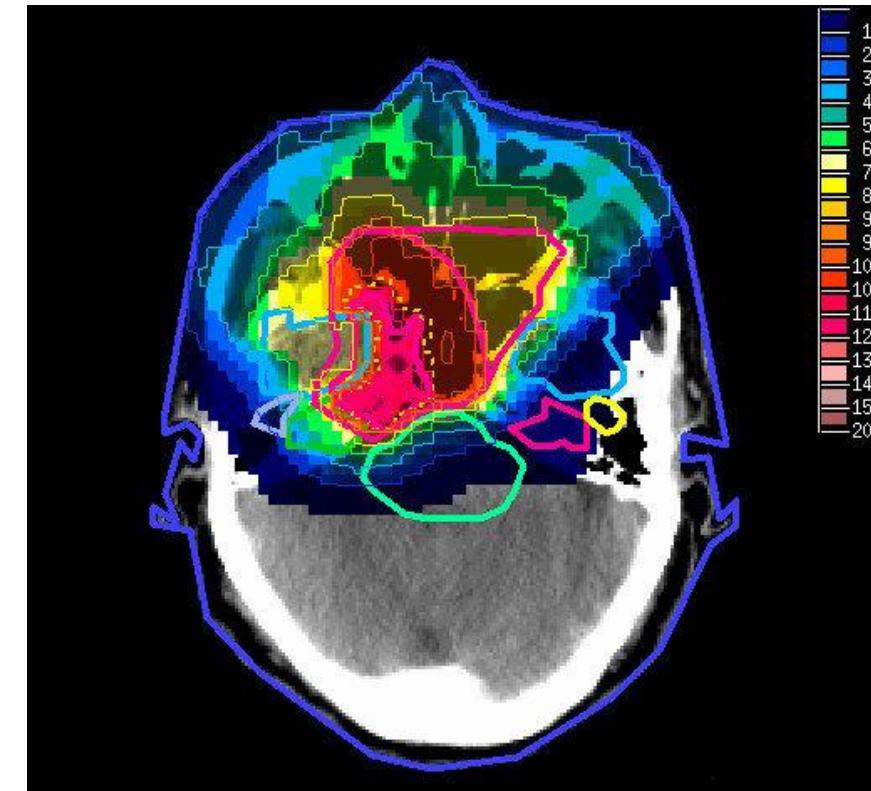
Spread-Out
Bragg Peak

Vergleich Photonen - Protonen

Photonen IMRT



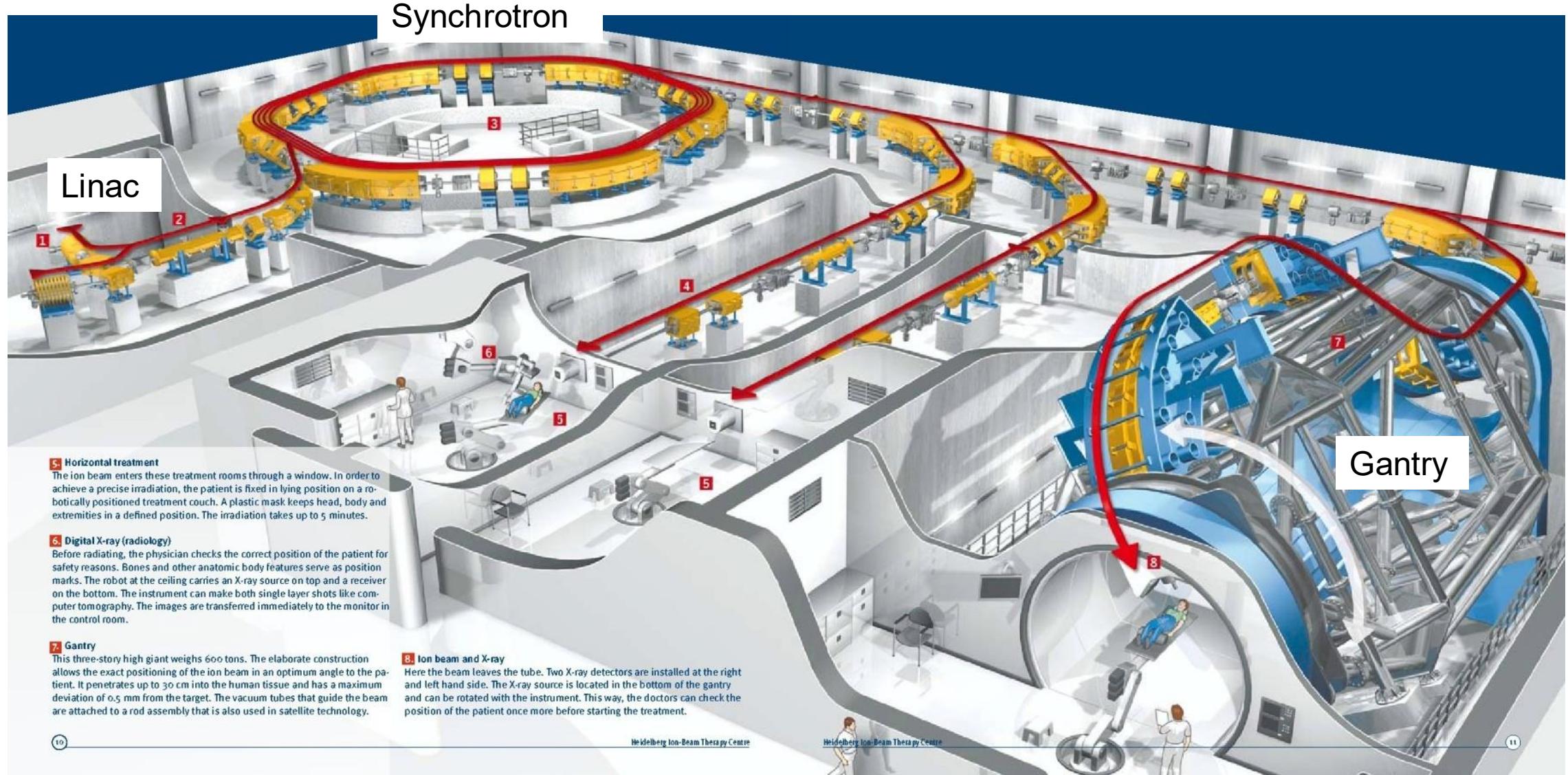
Protonen IMPT



nasopharyngeal carcinoma



Aktuelle Beschleuniger für die Therapie

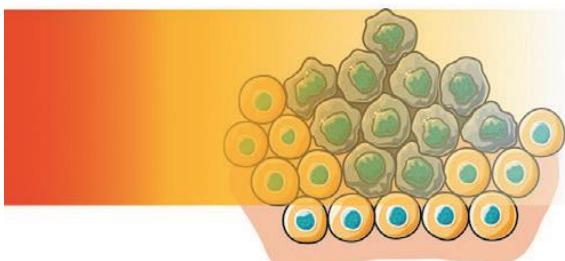


Neueste Entwicklung in der Strahlentherapie – FLASH RT und SFRT



FLASH-RT

Time modulation of the dose



< 200 ms

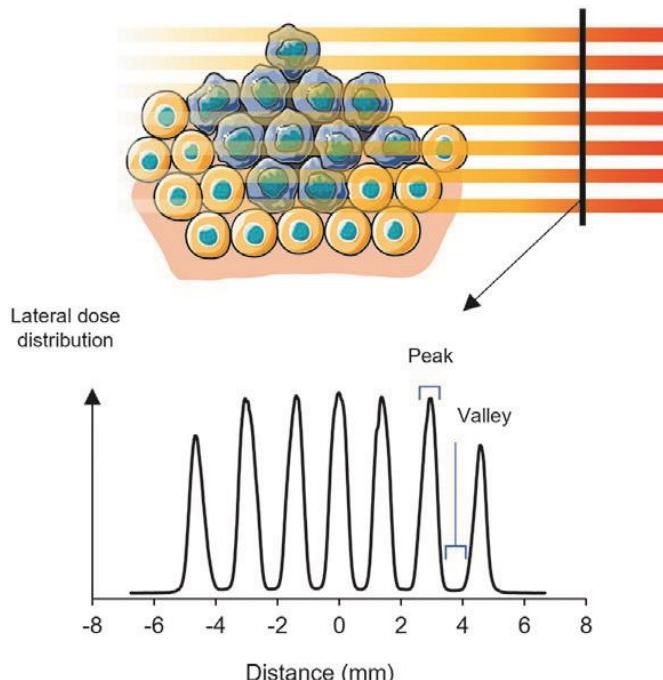
$D \geq 40 \text{ Gy/s}$ (Ultra-High Dose Rate)

Homogeneous dose distribution

Healthy tissues sparing
Equivalent or superior tumor control

SFRT

Spatial modulation of the dose



ARTICLE IN PRESS

Radiation-induced immune response in novel radiotherapy approaches FLASH and spatially fractionated radiotherapies

Annaig Bertho^{a,b}, Lorea Iturri^{a,b}, and Yolanda Prezado^{a,b,*}

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Abstract

The last several years have revealed increasing evidence of the immunomodulatory role of radiation therapy. Radiotherapy reshapes the tumoral microenvironment can shift the balance toward a more immunostimulatory or immunosuppressive microenvironment. The immune response to radiation therapy appears to depend on the irradiation configuration (dose, particle, fractionation) and delivery modes (dose rate, spatial distributions). Although an optimal irradiation configuration (dose, temporal fractionation, spatial dose distribution, etc.) has not yet been determined, temporal schemes

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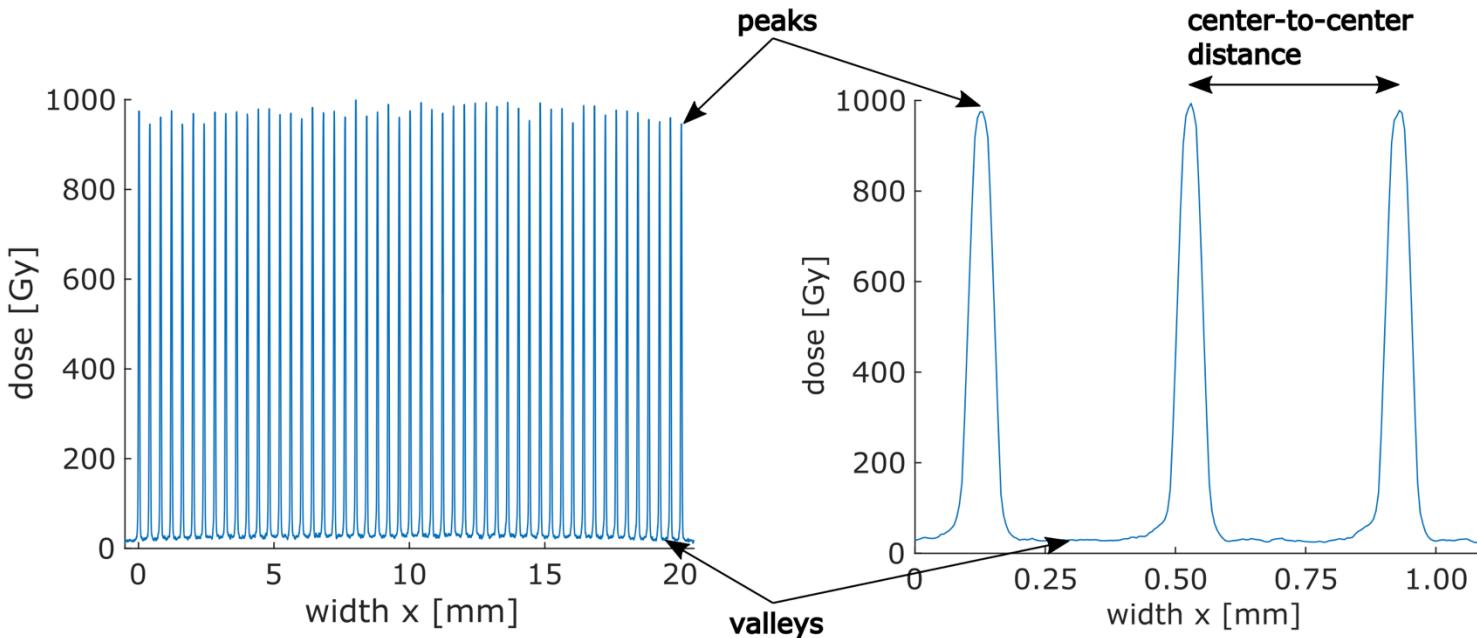


Figure 1.1.: Microbeam dose profile of high-dose peaks and low-dose valleys with a center-to-center distance of 400 μm . The profile is extended into the image plane to form a linear array perpendicular to the beam direction.



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**Microbeam radiotherapy on the path
to clinical application:
A powerful compact x-ray source and
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Johanna Winter

Vollständiger Abdruck der von der TUM School of Natural Sciences der Technischen Universität München zur Erlangung des akademischen Grades einer
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genehmigten Dissertation.

Vorsitz: Prof. Dr. Martin Zacharias
Prüfer der Dissertation: 1. Prof. Dr. Jan J. Wilkens
2. Prof. Dr. Franz Pfeiffer

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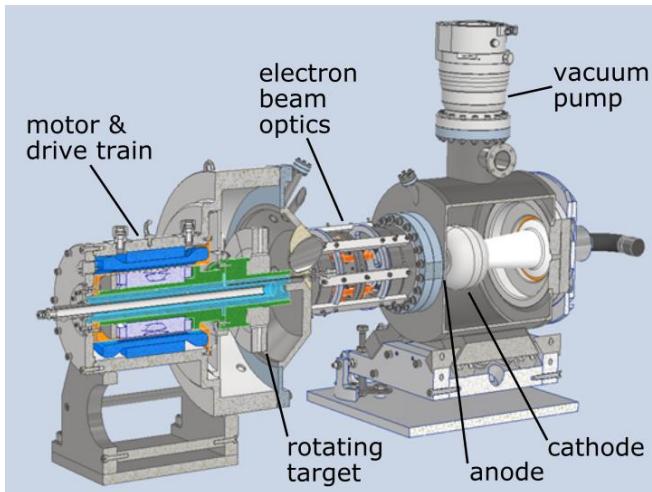


Figure 3.1.: Construction model of the line-focus x-ray tube.

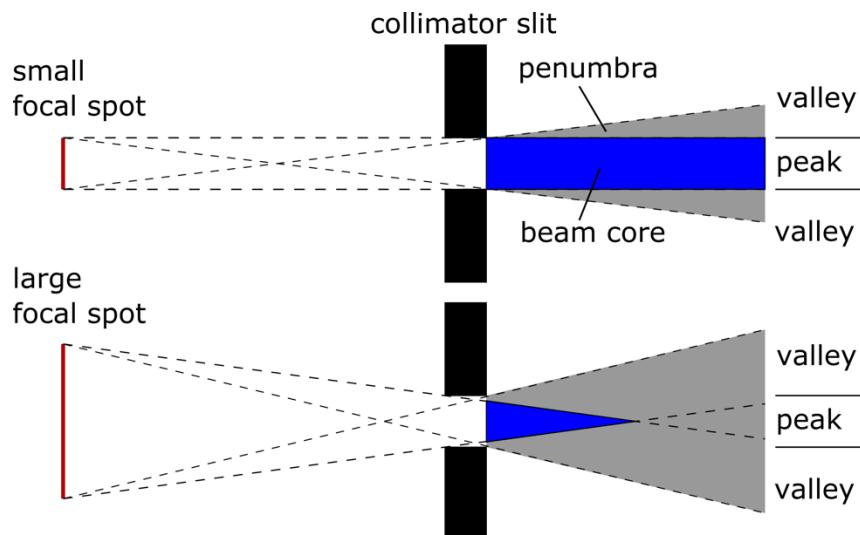


Figure 4.6.: A focal spot width larger than the collimator slits shrinks the beam core and increases the penumbra region.



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Hausaufgaben

Drei Aufgaben auf Moodle

- Aufgabe 1: zur Compact Light Source
- Aufgabe 2: zur Strahlentherapie

**Vielen Dank für ihre
Aufmerksamkeit!**