Medical imaging research & spectroscopy at the MuCLS

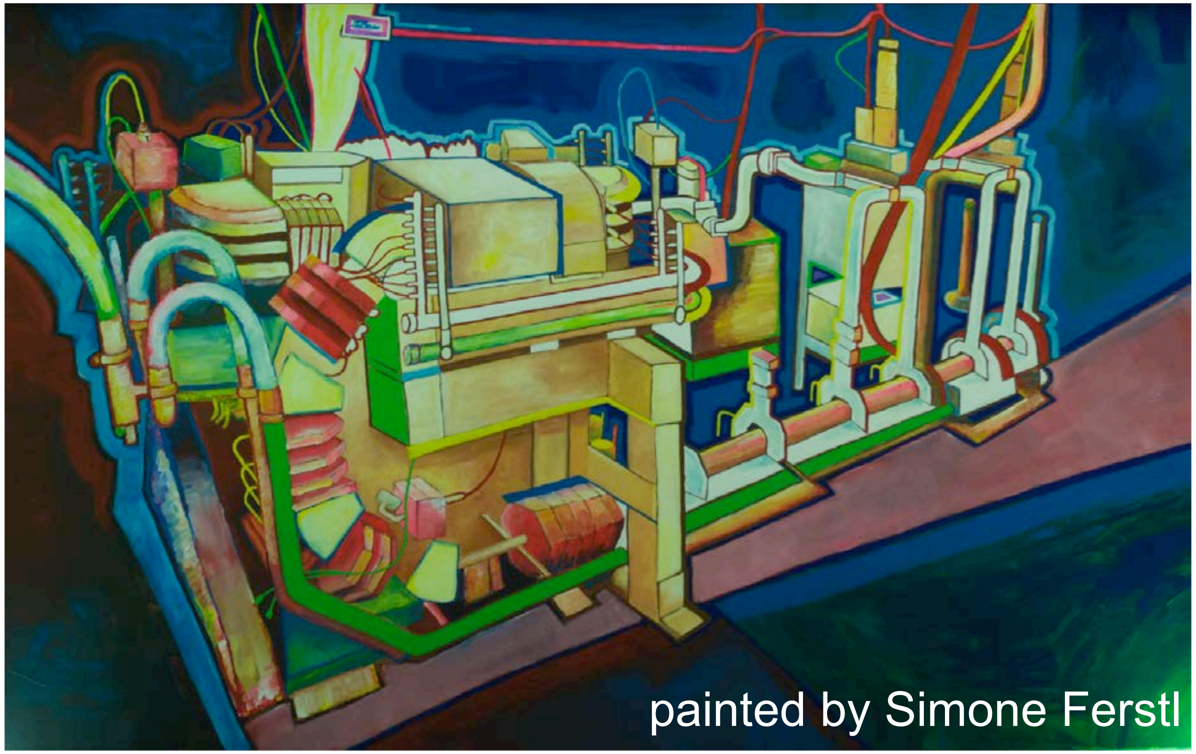
Benedikt Günther

Technical University of Munich

Department of Physics

Chair of Biomedical Physics

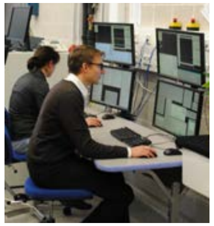
Bologna, November 22nd, 2019



painted by Simone Ferstl

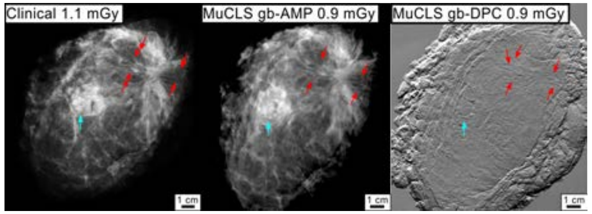
Outline

Brief review of the inverse Compton source at the MuCLS



The beamline at the MuCLS

Medical imaging research & spectroscopy



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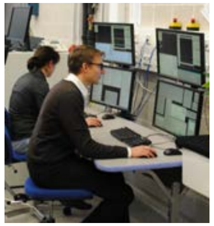

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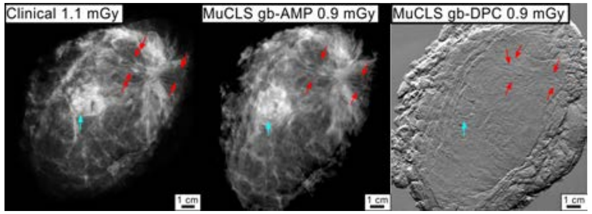
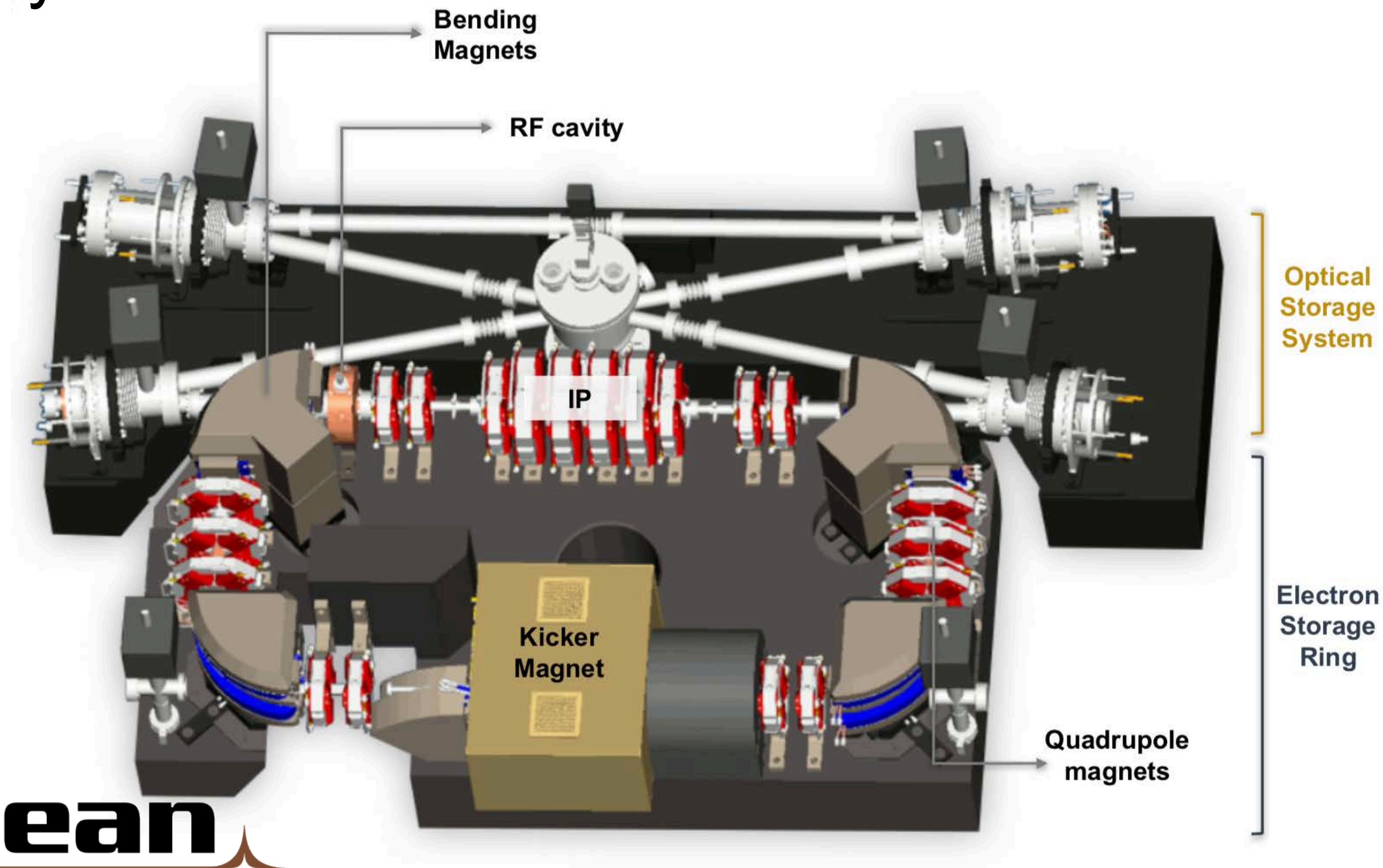
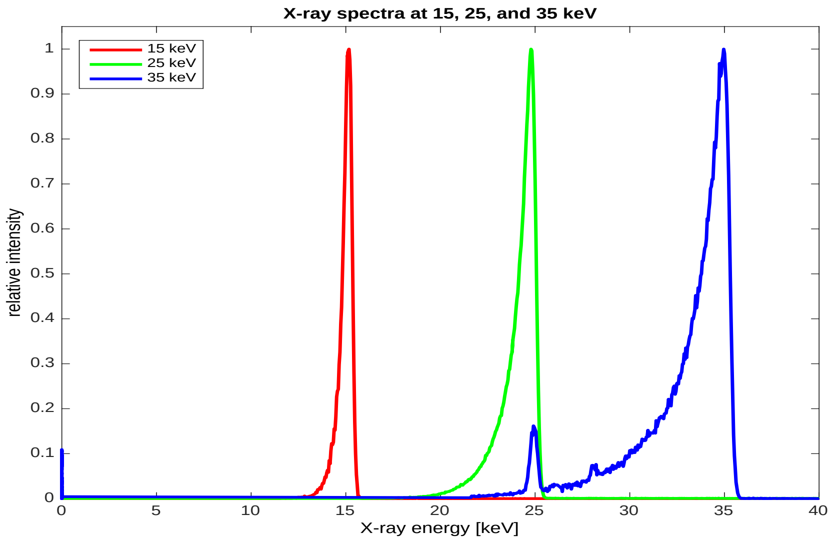


The X-ray source of the MuCLS



X-ray source parameters

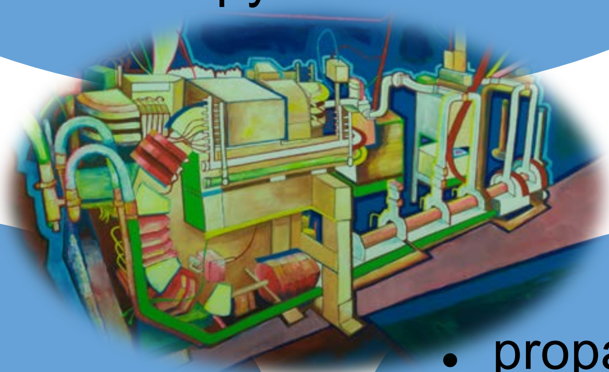
Parameters after upgrade of laser amplifier system			
X-ray energy	15 keV	25 keV	35 keV
Flux	0.8 x 10^{10} ph/s	2.1 x 10^{10} ph/s	3.3 x 10^{10} ph/s
source sizes (h x v, rms)	51 x 46 µm^2	48 x 46 µm^2	43 x 40 µm^2



E. Eggl et al., J. Synch. Rad. 23(5) (2016)

Applications exploiting the source properties of MuCLS

narrow tunable spectrum
- CT without beam hardening
- K-edge (subtraction) imaging
- spectroscopy



high flux density
- radiation therapy studies
- fast (dynamical) imaging
- high-resolution imaging

partial coherence
- propagation-based phase contrast
- grating-based phase contrast (2 gratings only)

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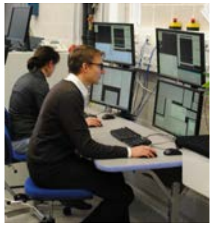

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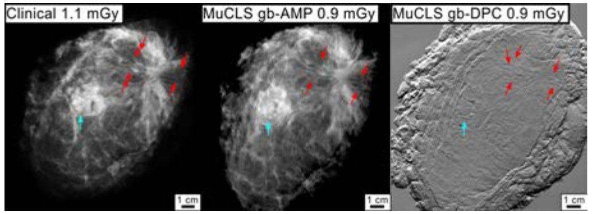
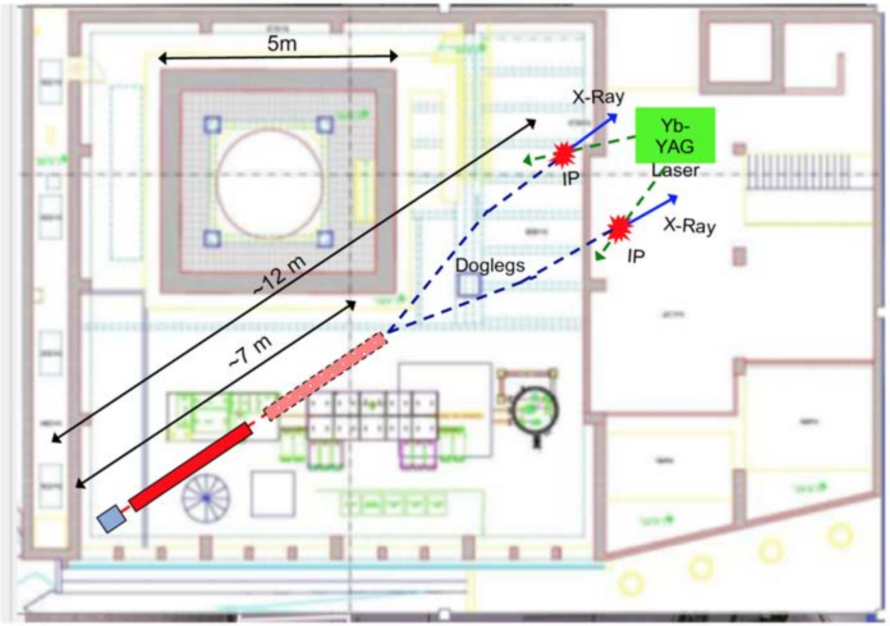


The MuCLS beamline

Comparison to BoCXS layout

→X-ray sources at BoCXS & MuCLS are very similar

Boscherini, BoCXS Whitepaper (2019)

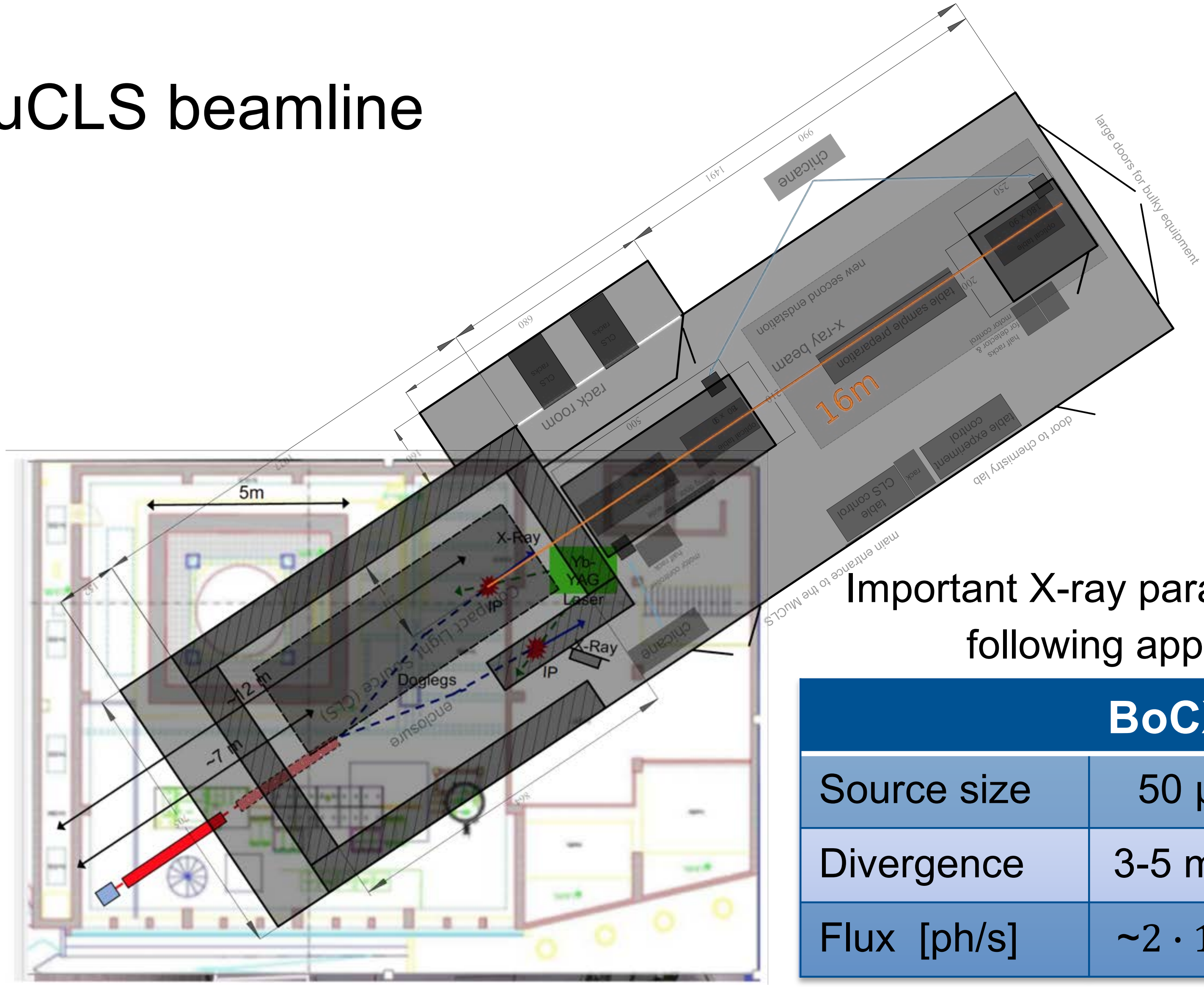


Important X-ray parameters for the following applications

	BoCXS
Source size	50 µm
Divergence	3-5 mrad
Flux [ph/s]	$\sim 2 \cdot 10^{10}$

The MuCLS beamline

Boscherini, BoCXS Whitepaper (2019)



Important X-ray parameters for the following applications

	BoCXS	MuCLS
Source size	50 µm	50 µm
Divergence	3-5 mrad	2 mrad
Flux [ph/s]	$\sim 2 \cdot 10^{10}$	$3.5 \cdot 10^{10}$

The MuCLS beamline

The MuCLS beamline

<u>Front end:</u>

- X-ray beam stabilisation
- X-ray beam refocussing (for MRT)
- X-ray safety measures

Günther et al., in preparation

The MuCLS beamline

Hutch 1:

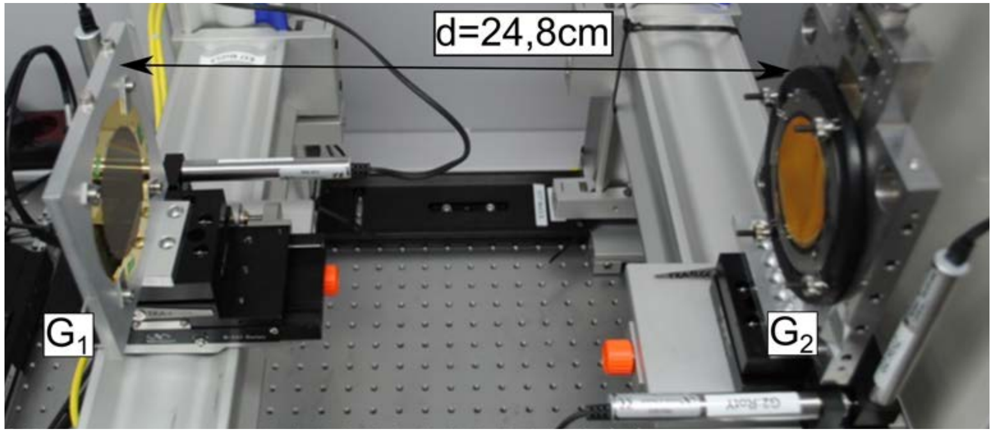
- ~4m to ~7.5m source-sample distance
- 16-28 mm beam diameter

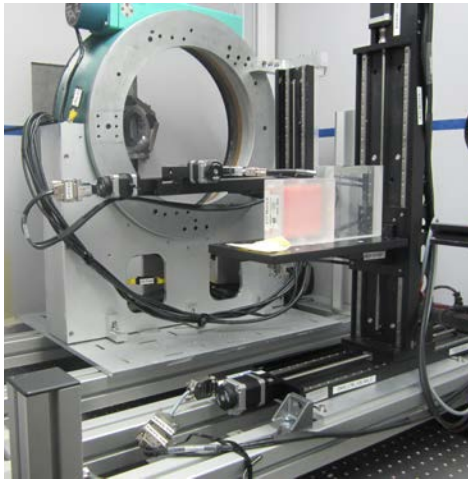
Hutch 2:

- 8-15µm detector resolution
- adjustable sample-detector distance
- optional overhead sample mounting or environment construction

Günther et al., in preparation

The MuCLS beamline





Hutch 2:

- ~14.5m to ~15.5m source-sample distance
- ~60 mm beam diameter
- 75-175 µm detector resolution
- optional grating interferometer
- two complementary sample stages

Günther et al., in preparation

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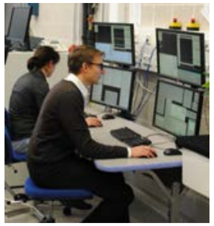
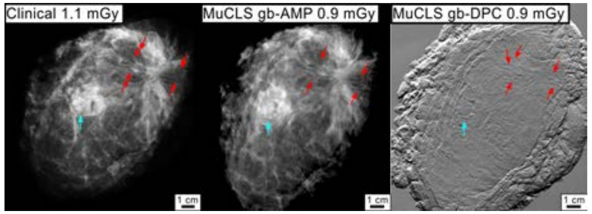


The beamline at the MuCLS

Medical imaging research & spectroscopy



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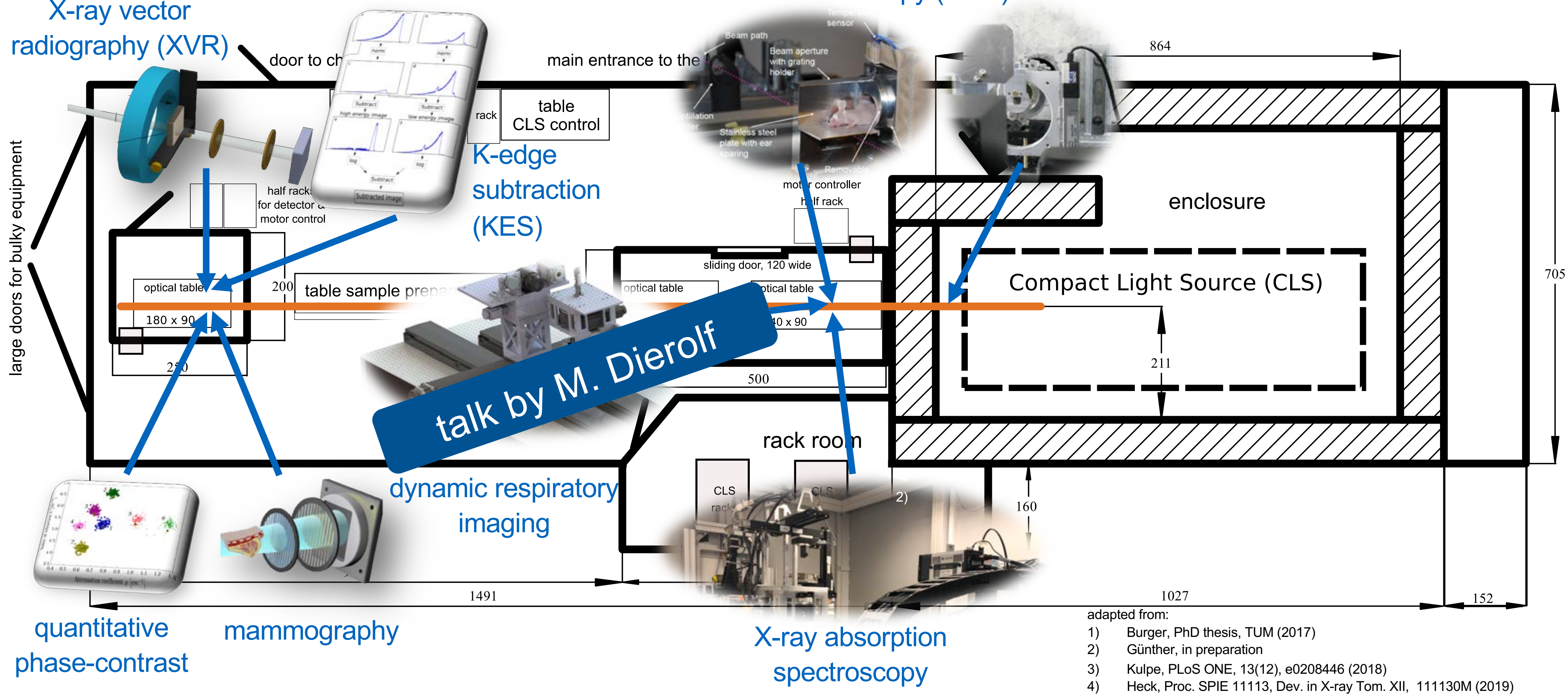

adapted from:
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4) Heck, Proc. SPIE 11113, Dev. in X-ray Tom. XII, 111130M (2019)
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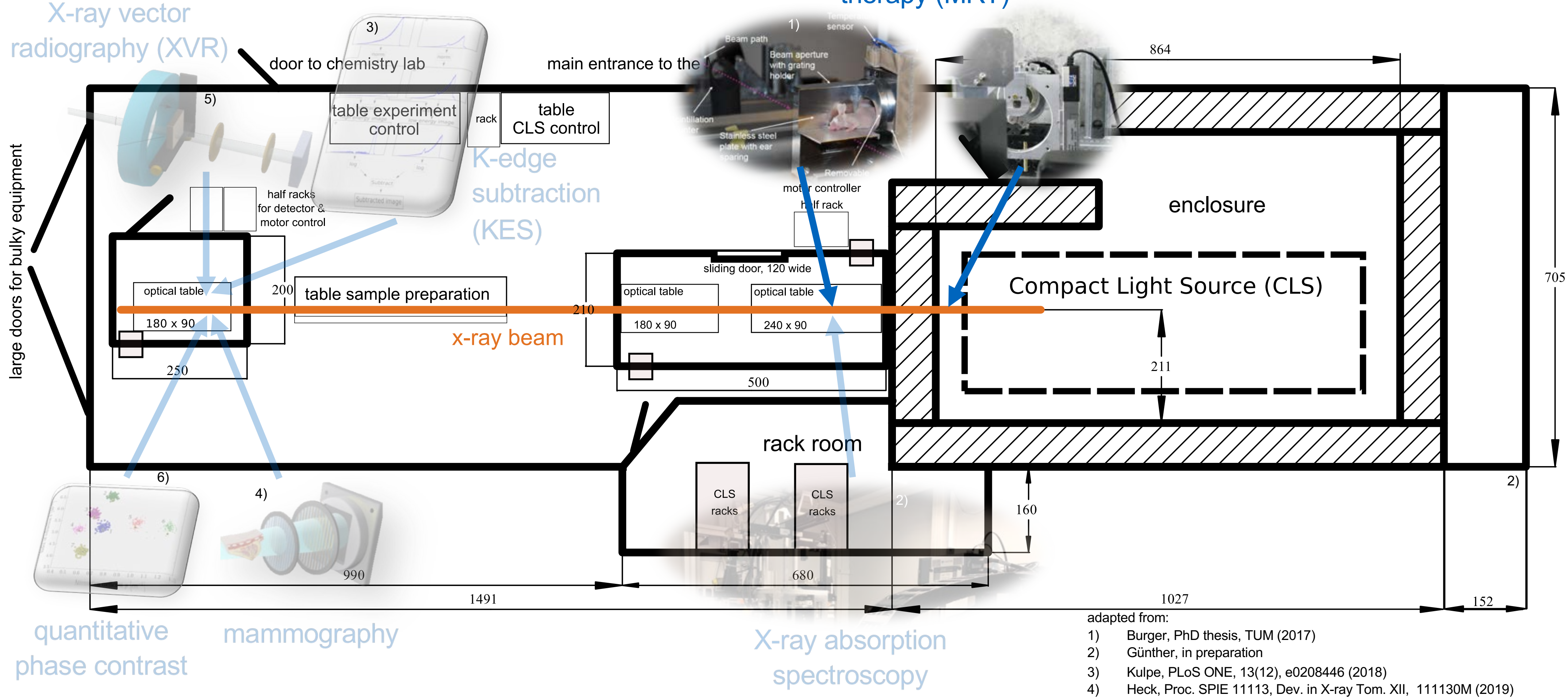

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- CT without beam hardening
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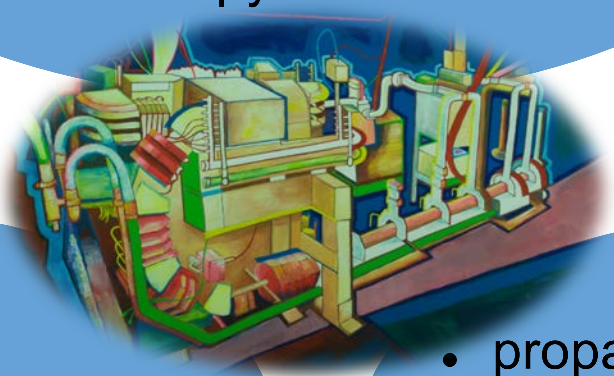

high flux density
- radiation therapy studies
- fast (dynamical) imaging
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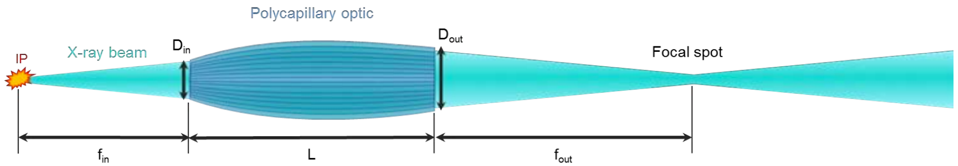
Microbeam radiation therapy at the MuCLS

new set up in enstation 1



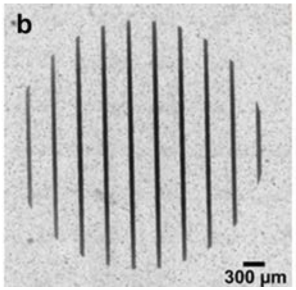
Implementation of a polycapillary optic

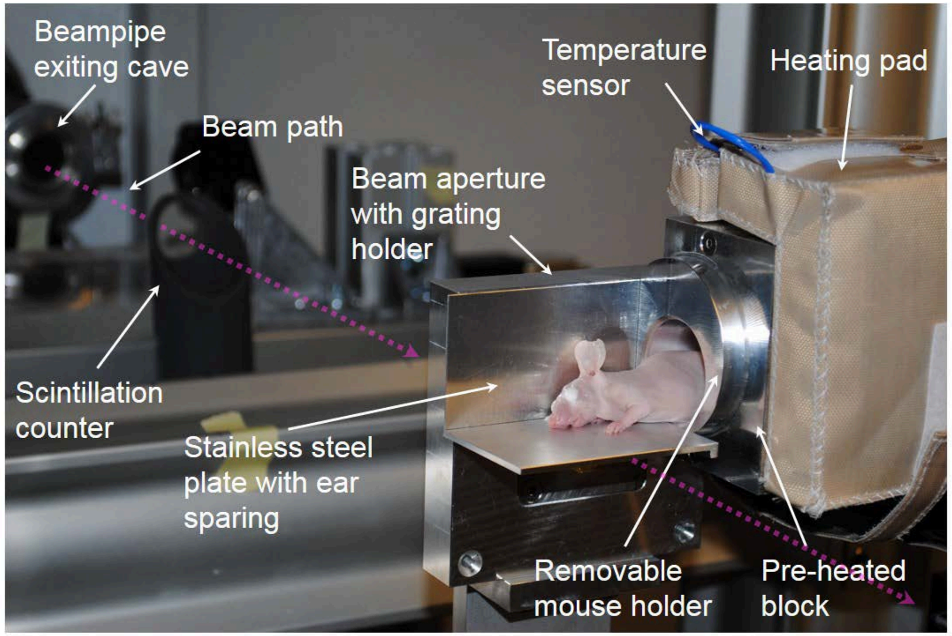
→ focus at a source to sample distance of 3m

→ MRT possible in first endstation

→ less invasive, low radiation background

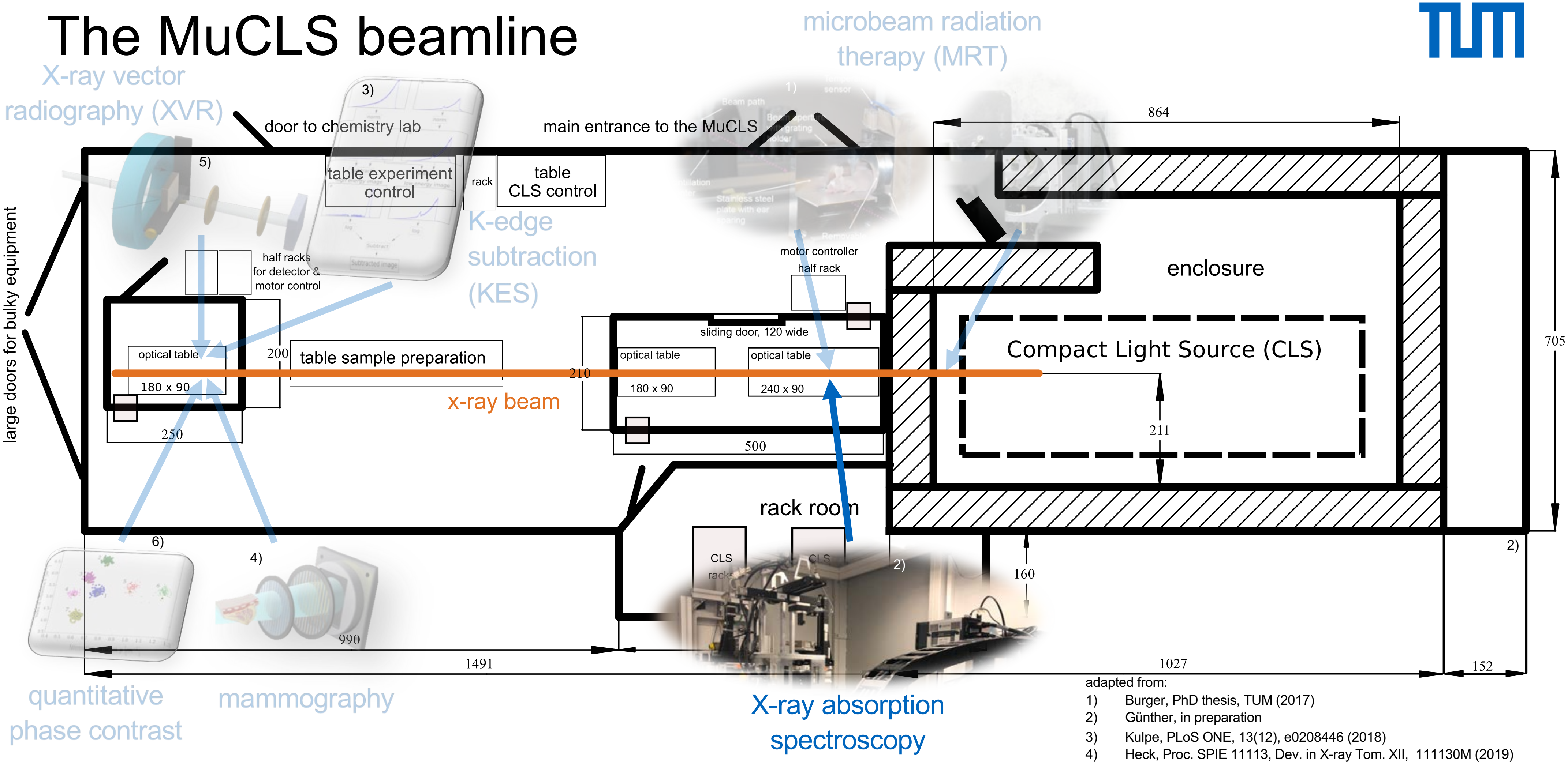
→ *in vivo* studies





Burger, PhD thesis, TUM (2017)
Dombrowsky, Radiation and Environmantal Biophysics, doi.org/10.1007/s00411-019-00816-y (2019)

The MuCLS beamline



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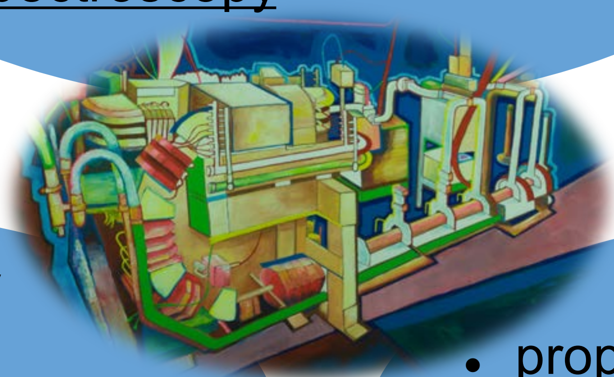

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X-ray absorption spectroscopy (XAS)

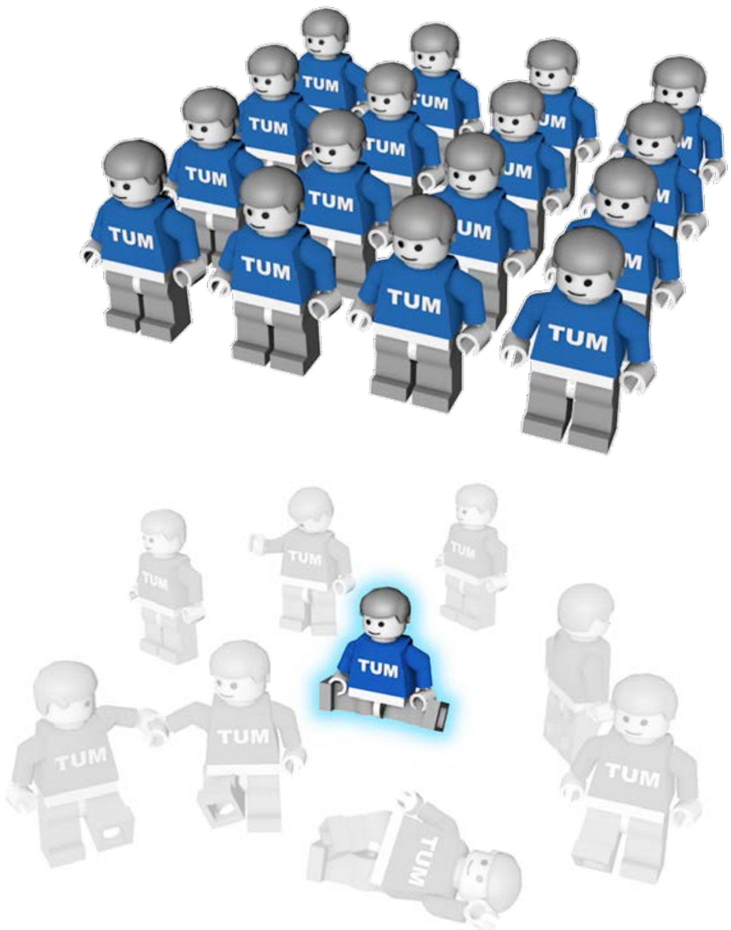
- **Chemical sensitivity**
  - **Fingerprint information**
  - **Oxidation states**
  - **Local geometry**
  - **Coordination numbers**
  - **Bond length**
  - **Spin states**

  And so on..

- **No need of crystalline sample**

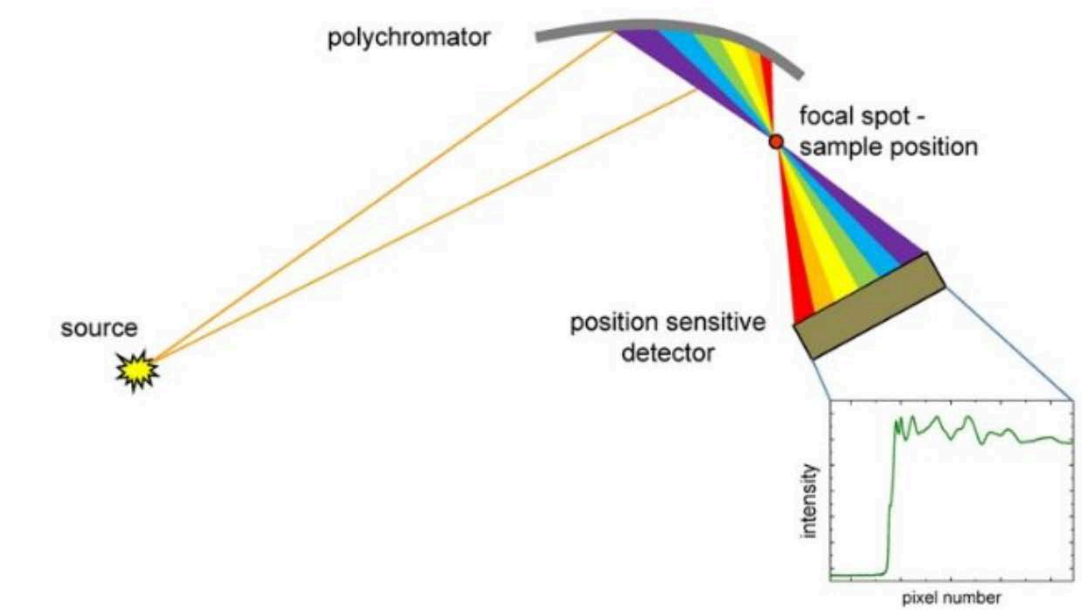
- **Element selective**

  → Interesting for organic molecules which are difficult to crystalise



X-ray absorption spectroscopy (XAS)

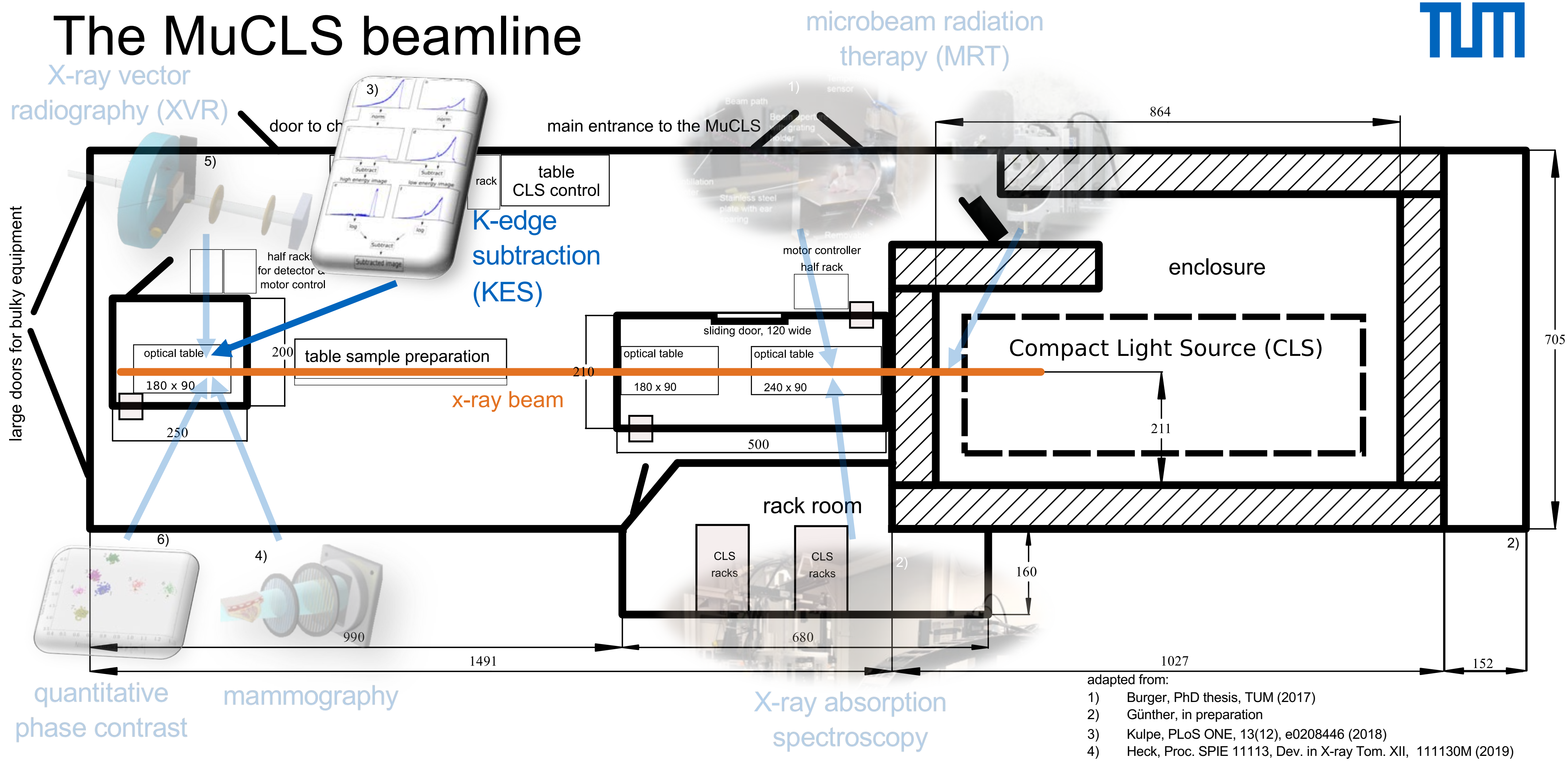
Energy range (at the M
→ wide range of eleme



https://www.diamond.ac.uk/Instruments/Techniques/Spectroscopy/EDE.html

%
etry most efficient

The MuCLS beamline



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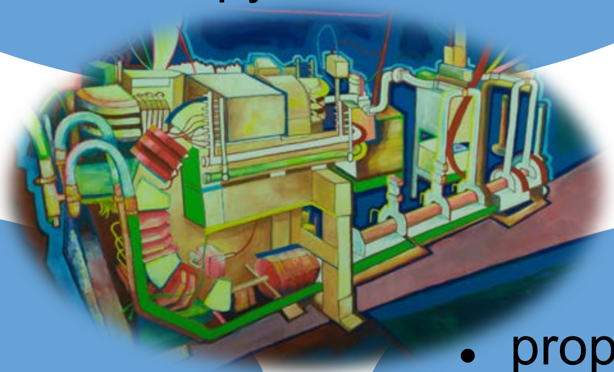

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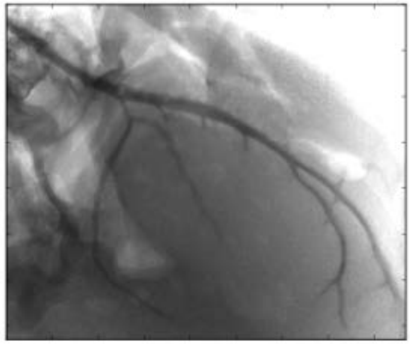
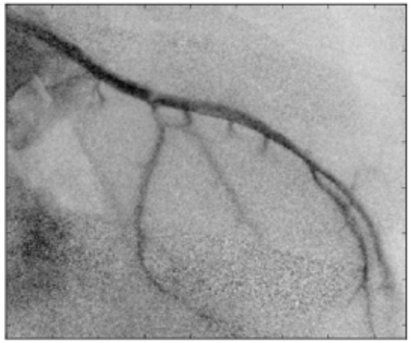
K-edge subtraction imaging – Why should we do it?

Angiography

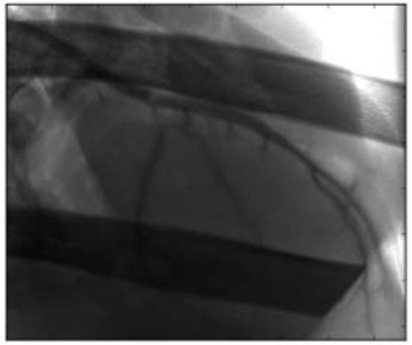
Kulpe et al., PLoS ONE, 13(12), e0208446 (2018)



Angiographic image of an isolated pig heart
→ small vessels are visible



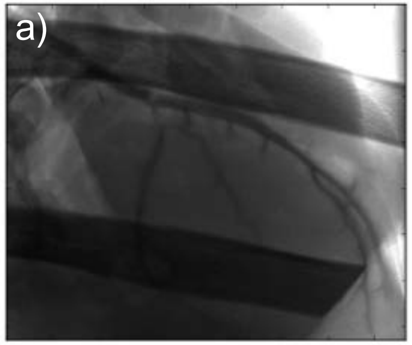
KES image of a pig heart with ribs in front
→ small vessels become visible again



Angiographic image of a pig heart with ribs in front
→ small vessels are invisible

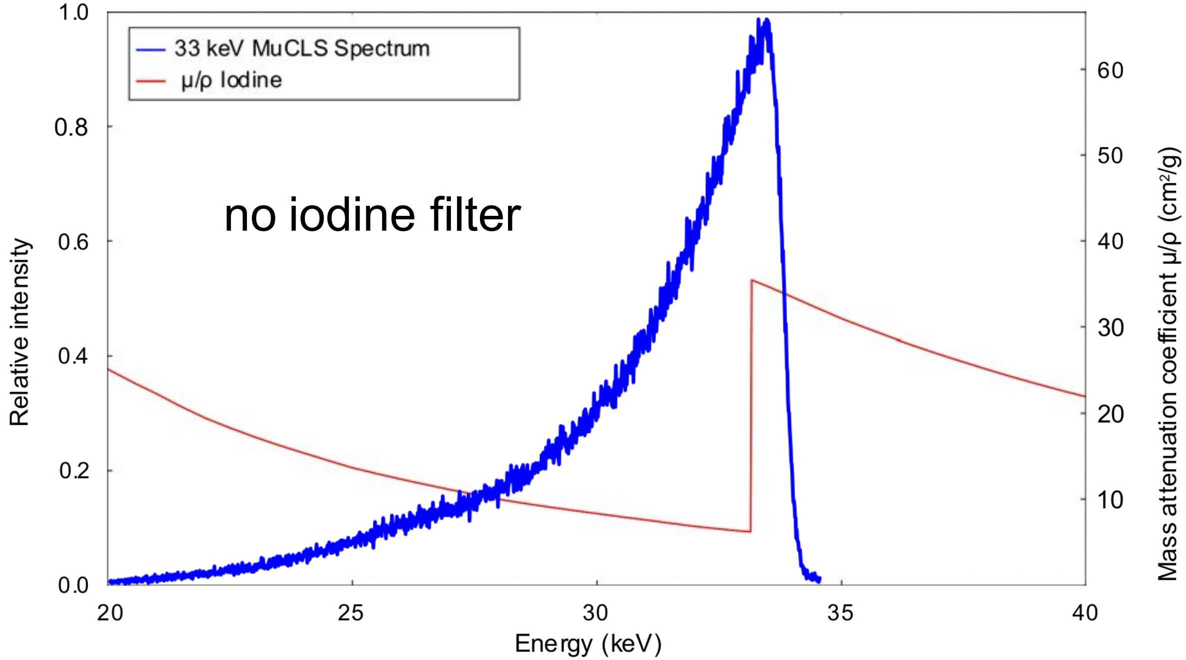
K-edge subtraction imaging

- increase contrast of weakly absorbing structures (e.g. vessels)
- discrimination of similarly absorbing structures (e.g. Ca vs. I)



How does it work?

Kulpe et al., PLoS ONE, 13(12), e0208446 (2018)



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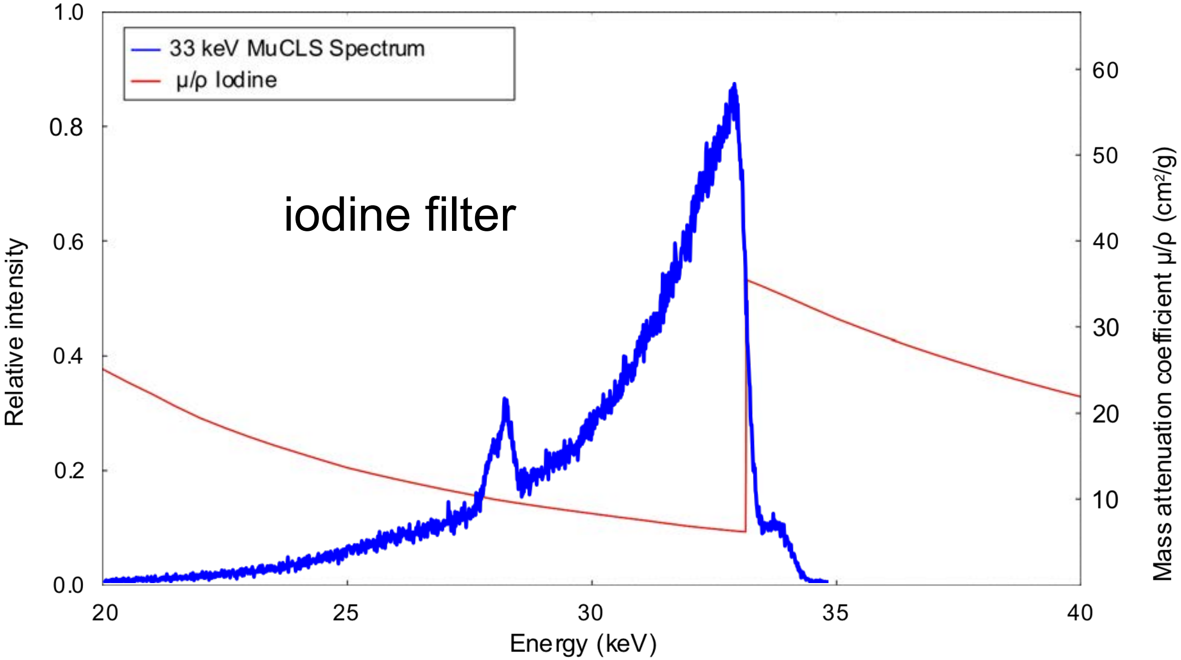

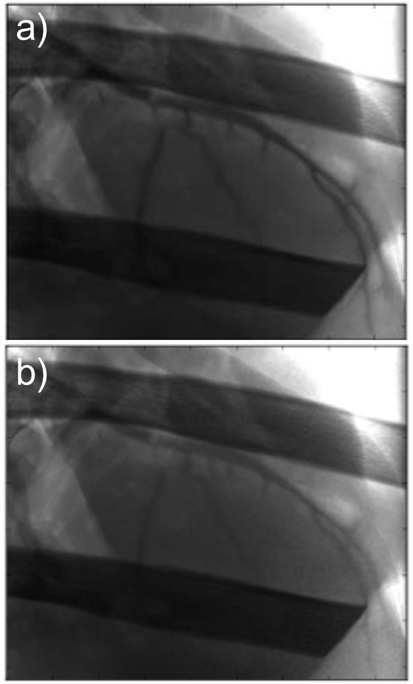

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How does it work?

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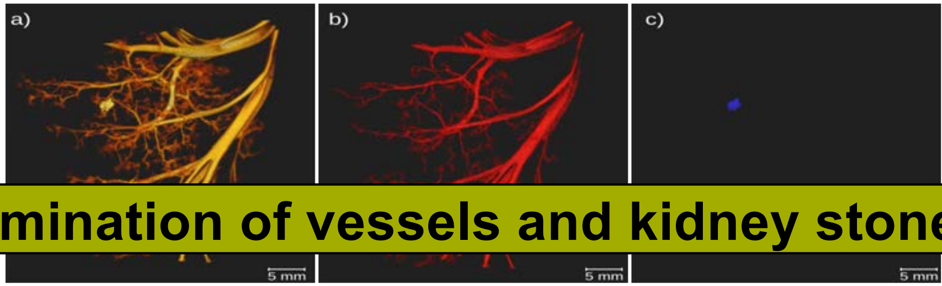
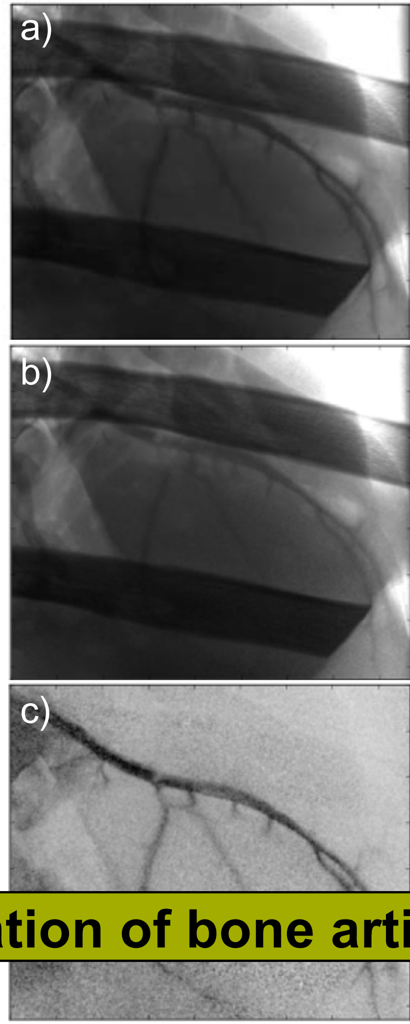
subtract both images with an energy correction factor:

a) − b) = c)

Kulpe et al., Sci. Rep. 9, 13332 (2019)

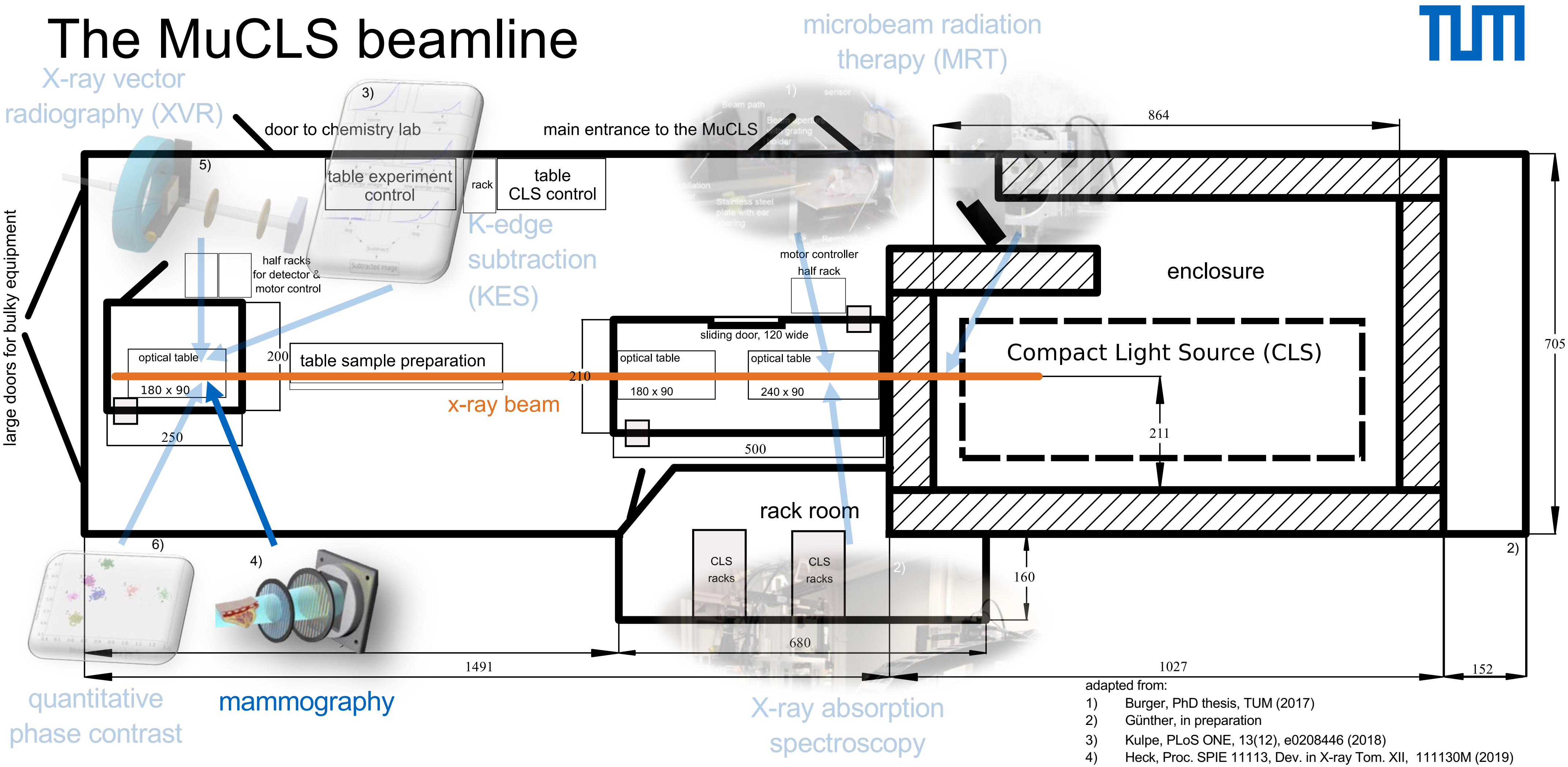


Discrimination of vessels and kidney stones



Elimination of bone artifacts

The MuCLS beamline



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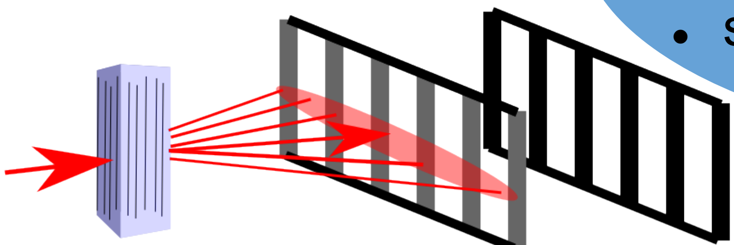

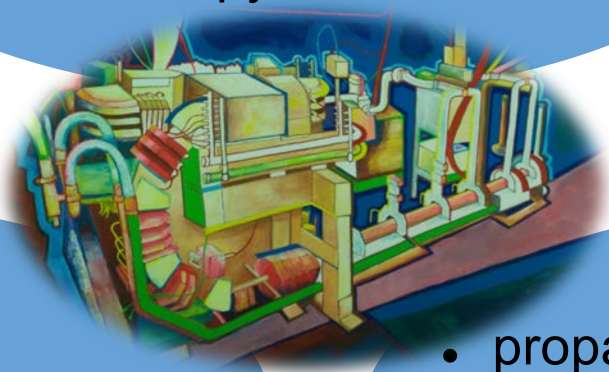

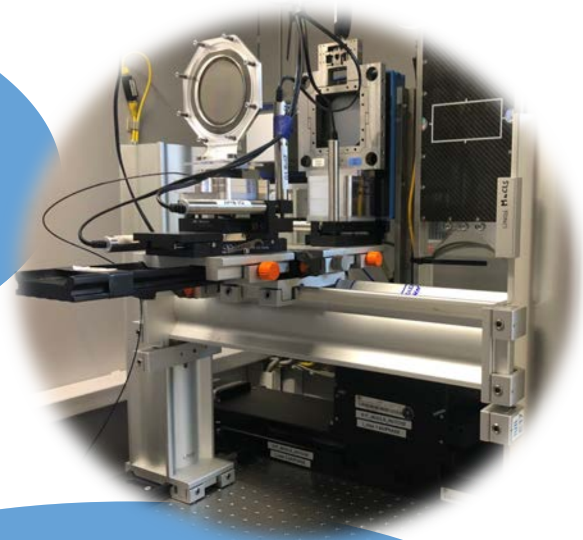

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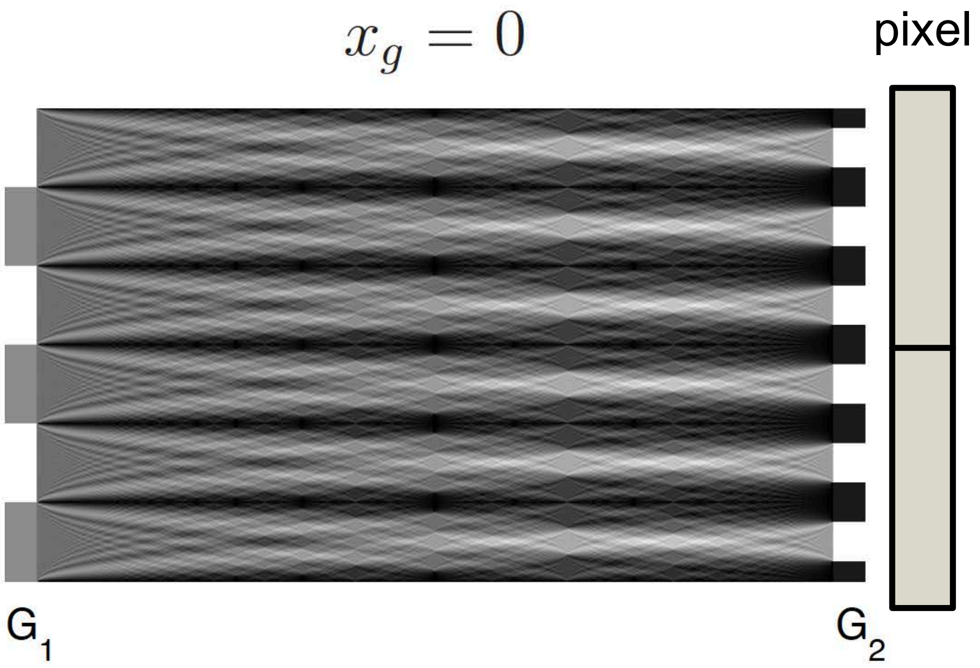
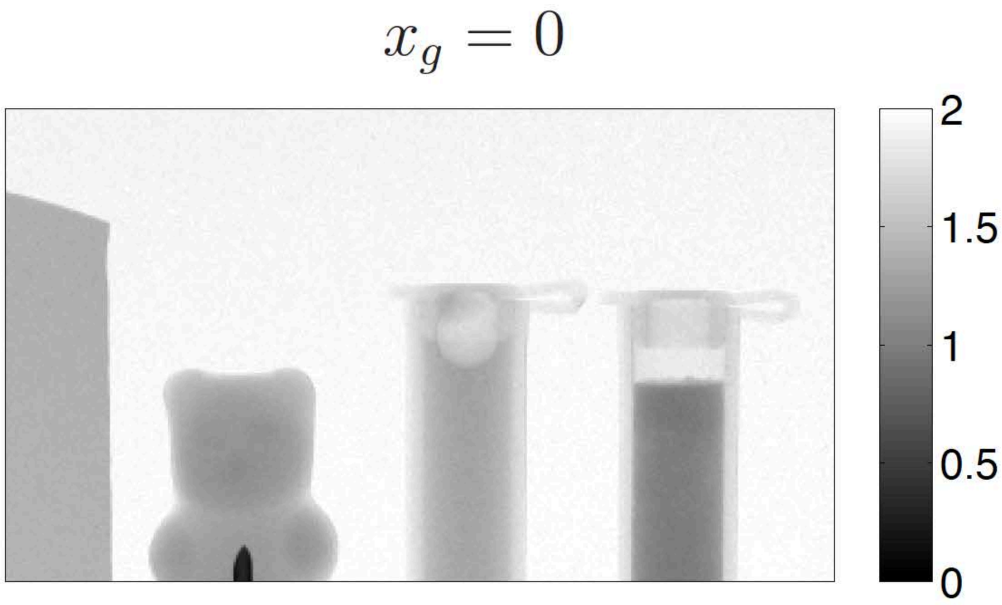
Grating-based phase contrast

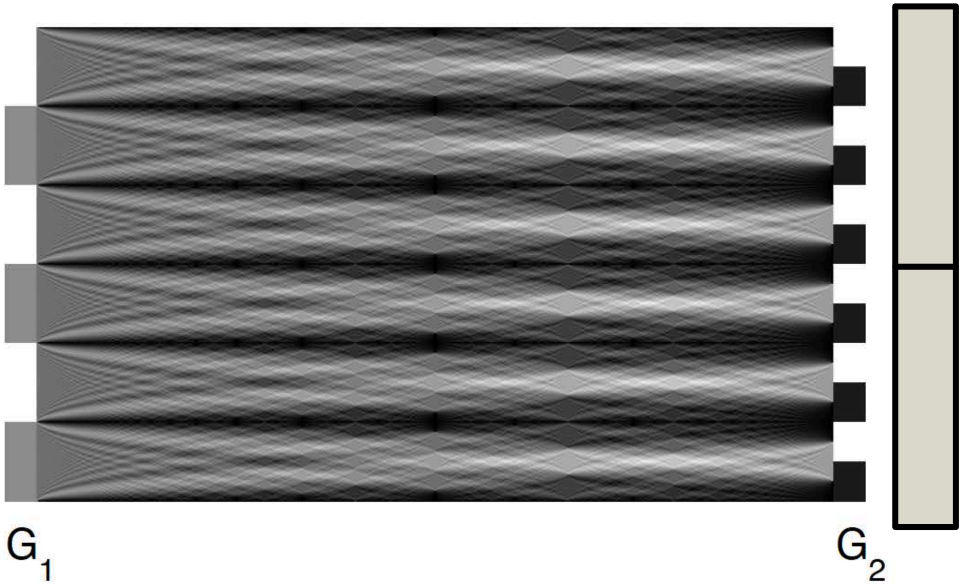




M Bech, PhD thesis, University of Copenhagen, 2009

Grating-based phase contrast

$x_g = g_2/4$



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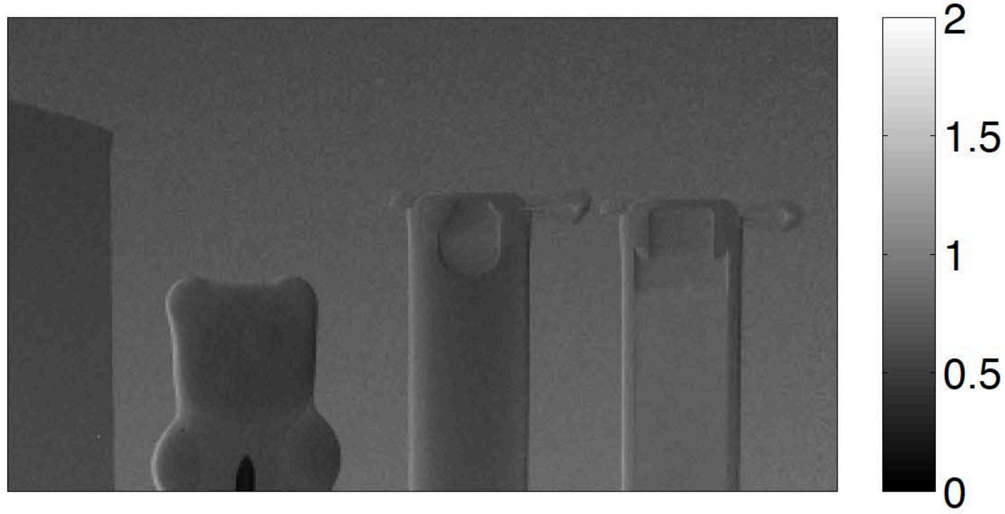

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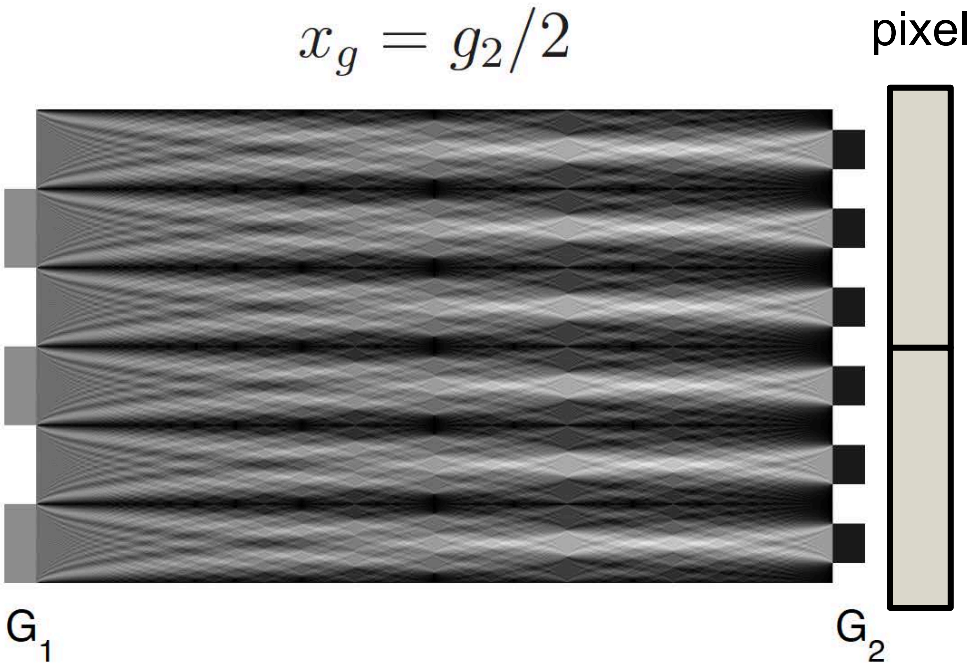

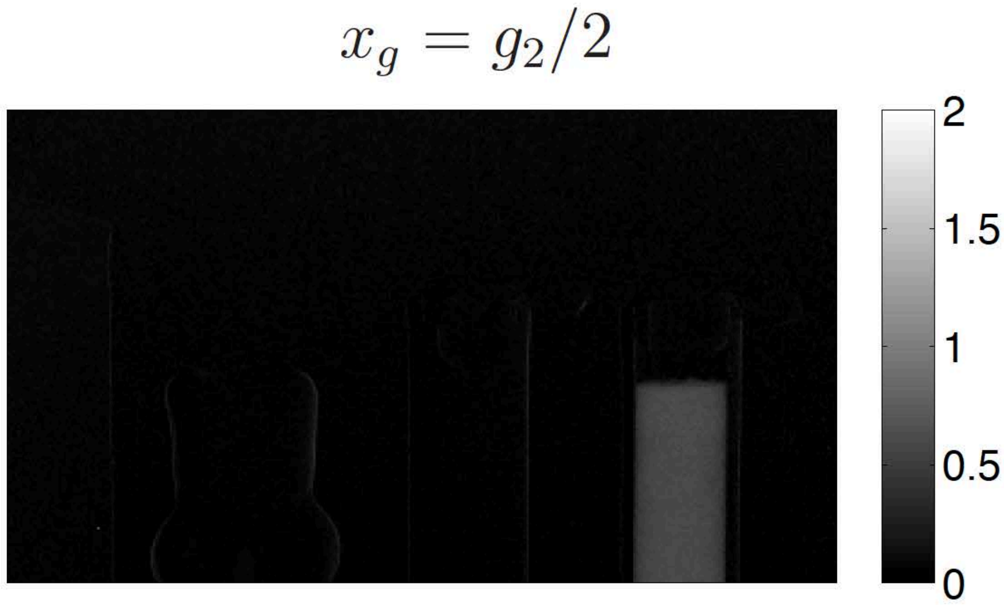

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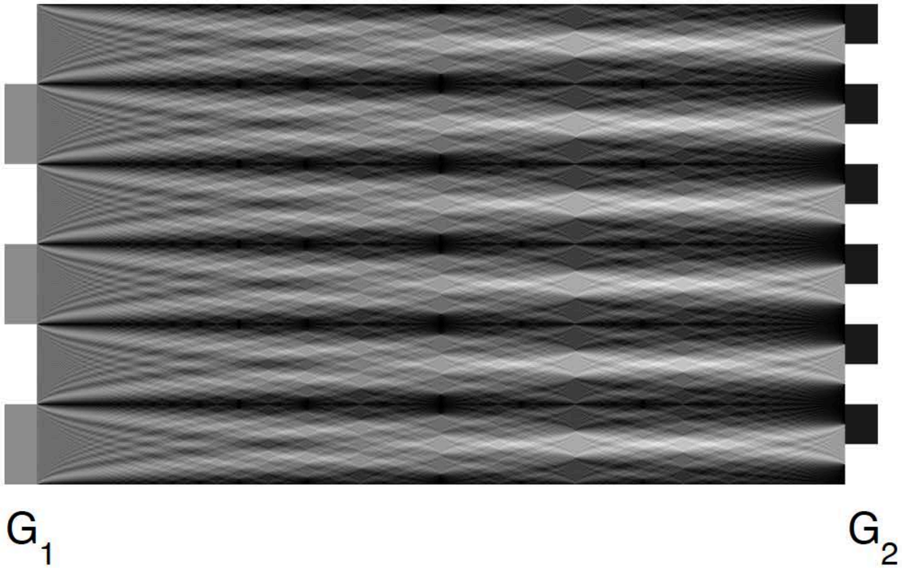

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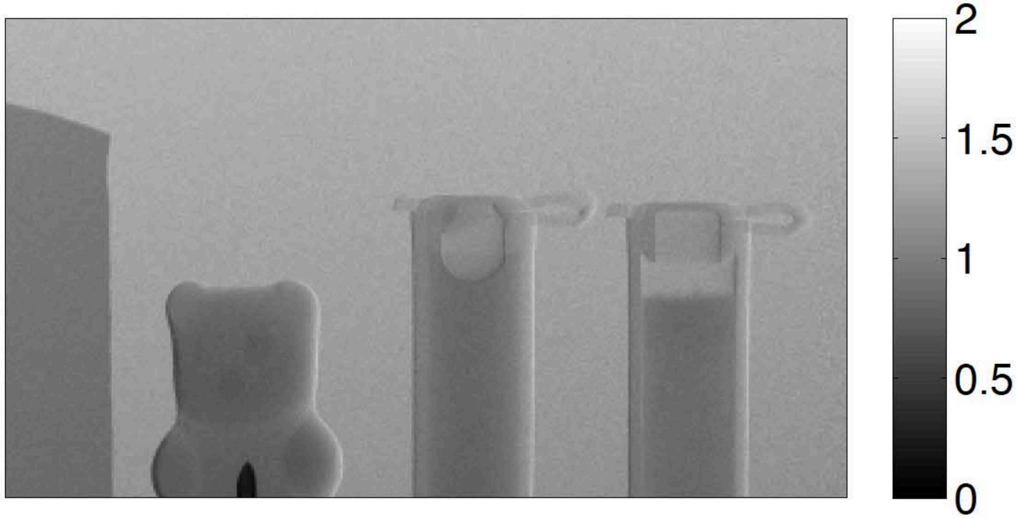

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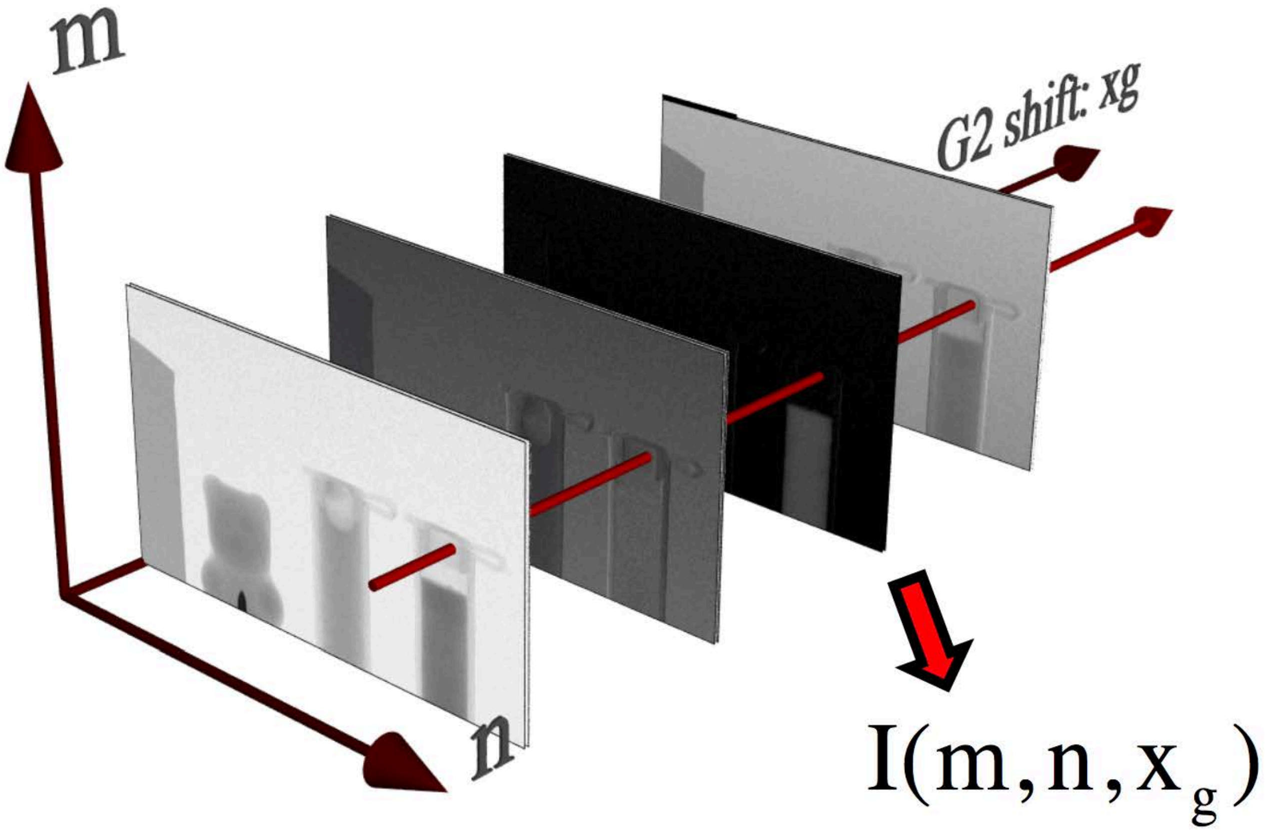

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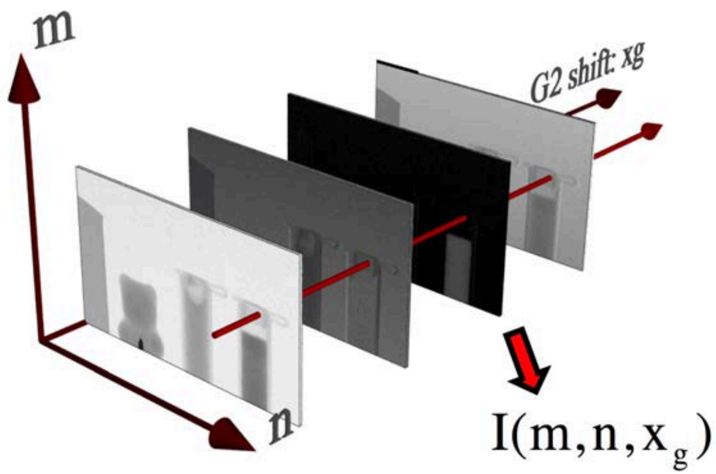

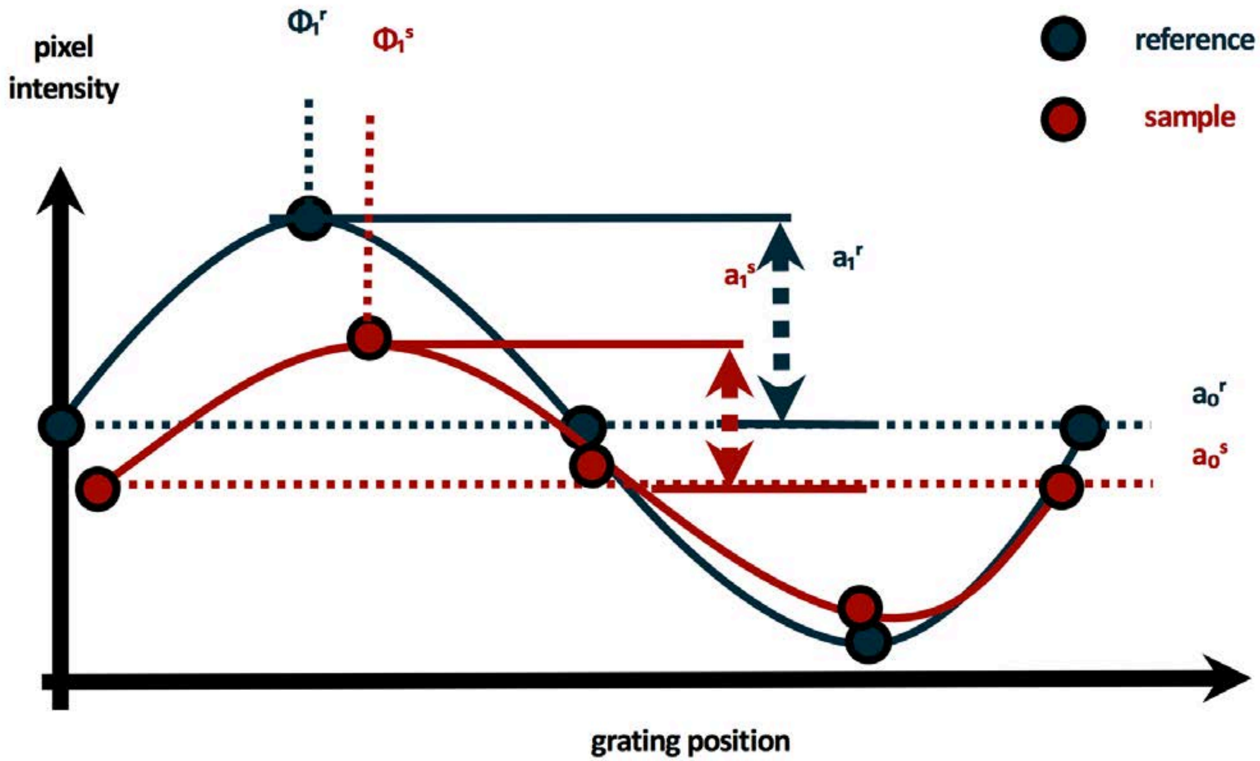

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Grating-based phase contrast

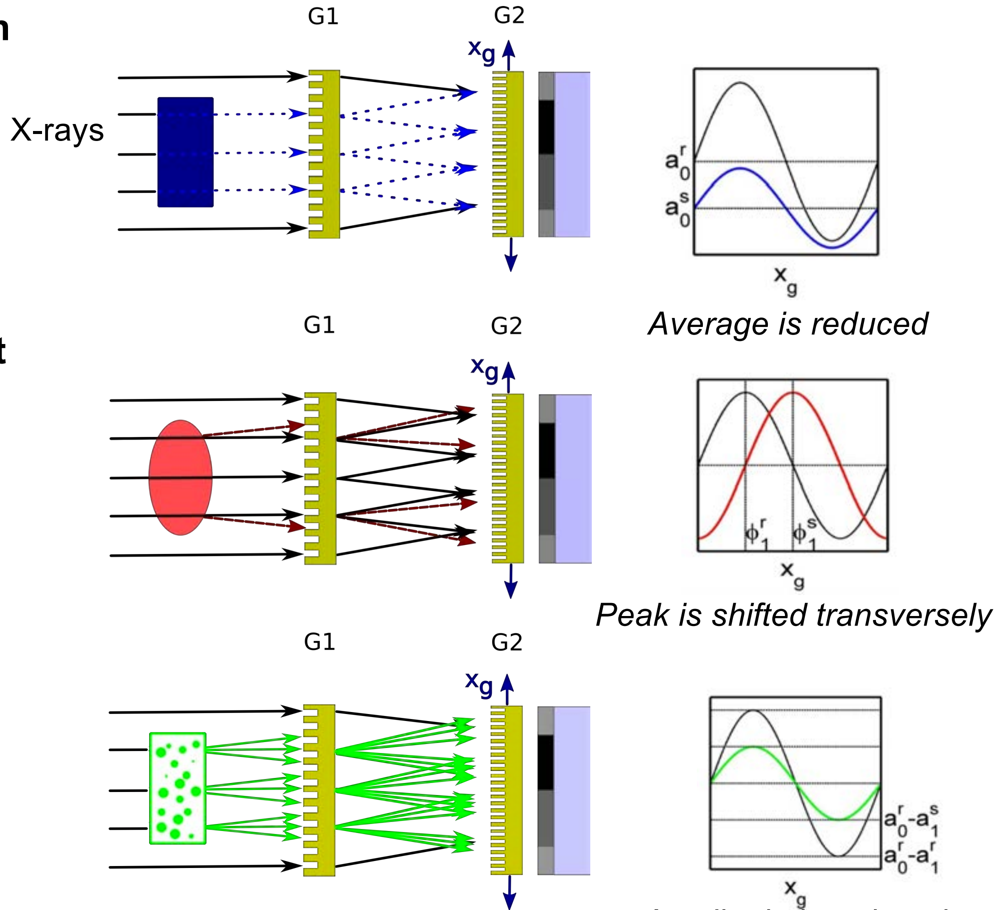
Sample produces:

Attenuation

Phase shift

Dark field

pattern is:



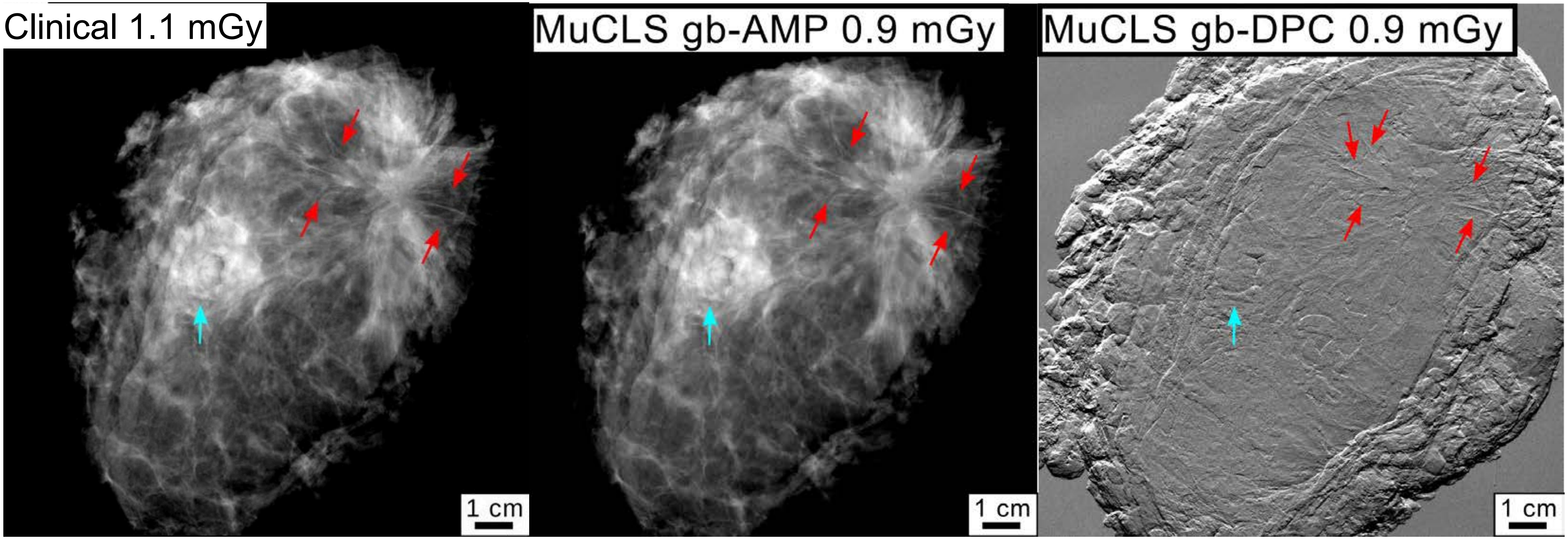
Average is reduced

Peak is shifted transversely

Amplitude is reduced

Resulting images:

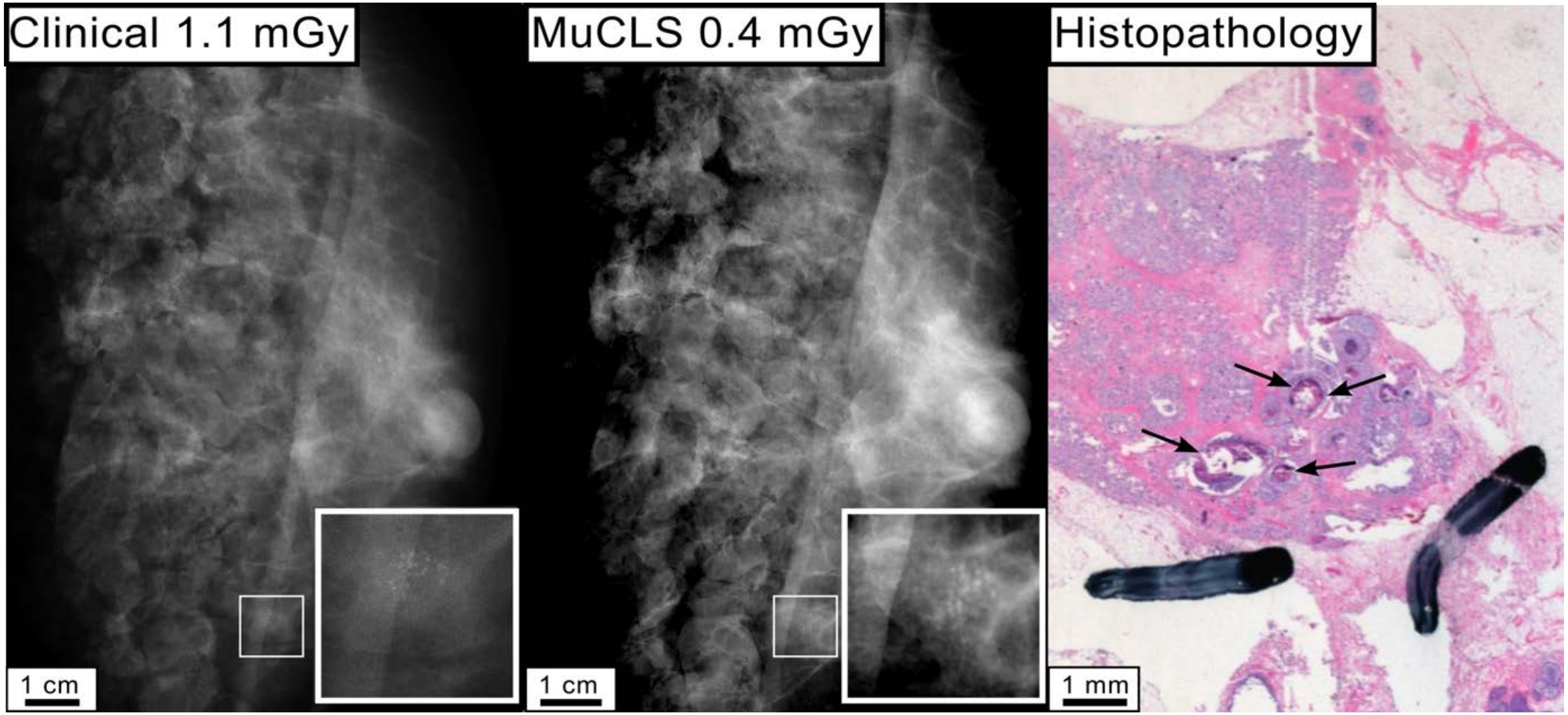
Dose competible phase-contrast mammography



Improved delineation of tumorous lesions in DPC image

Eggl et al., Scientific Reports 8, 15700 (2018)

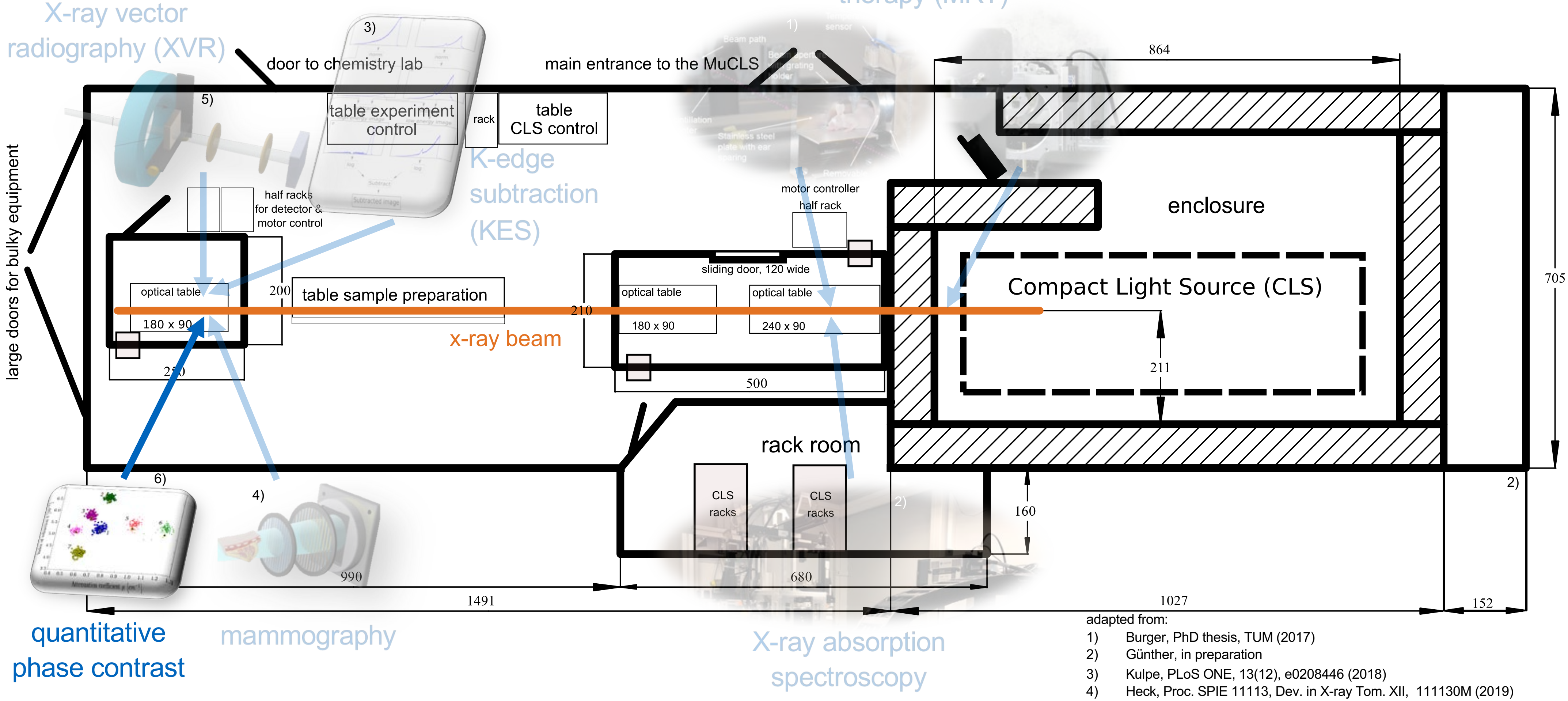
Dose compatible phase-contrast mammography



Equal detection of microcalcifications at reduced dose

Eggl et al., Scientific Reports 8, 15700 (2018)

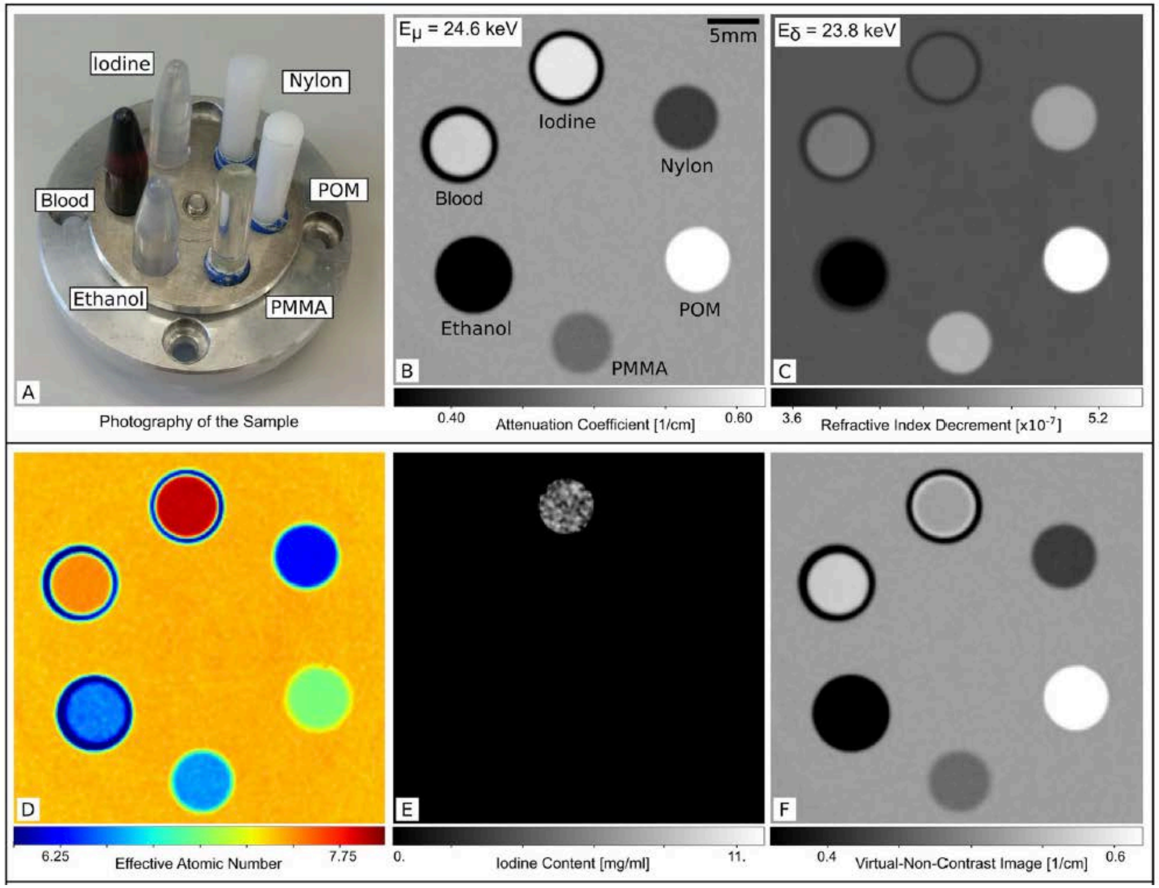
The MuCLS beamline



adapted from:

1) Burger, PhD thesis, TUM (2017)
2) Günther, in preparation
3) Kulpe, PLoS ONE, 13(12), e0208446 (2018)
4) Heck, Proc. SPIE 11113, Dev. in X-ray Tom. XII, 111130M (2019)
5) Jud, Scientific Reports 7, 6788 (2017)
6) Eggl. PNAS 112 (18), p. 5567-5572 (2015)

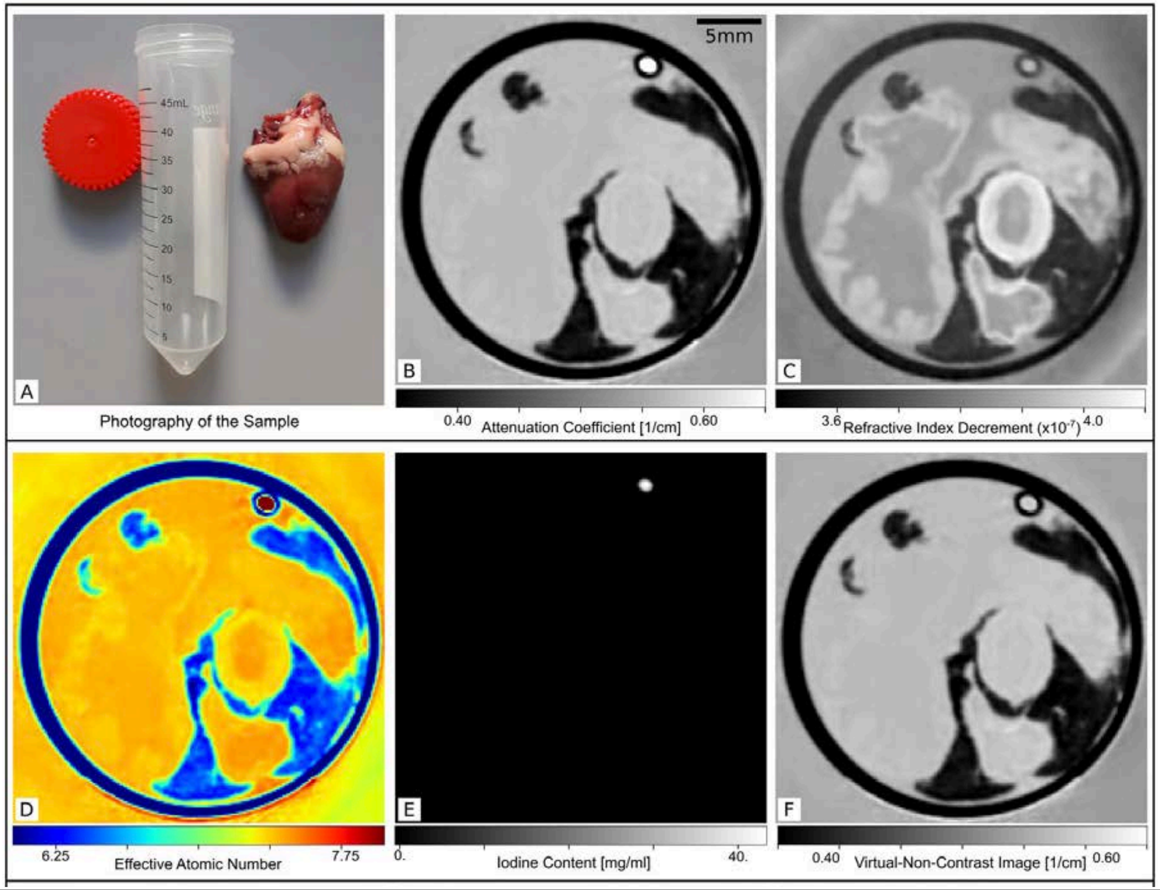
Direct quantitative material decomposition



Braig et al., Scientific Reports 8, 16394 (2018)

Quantitative determination of iodine (contrast agent) content

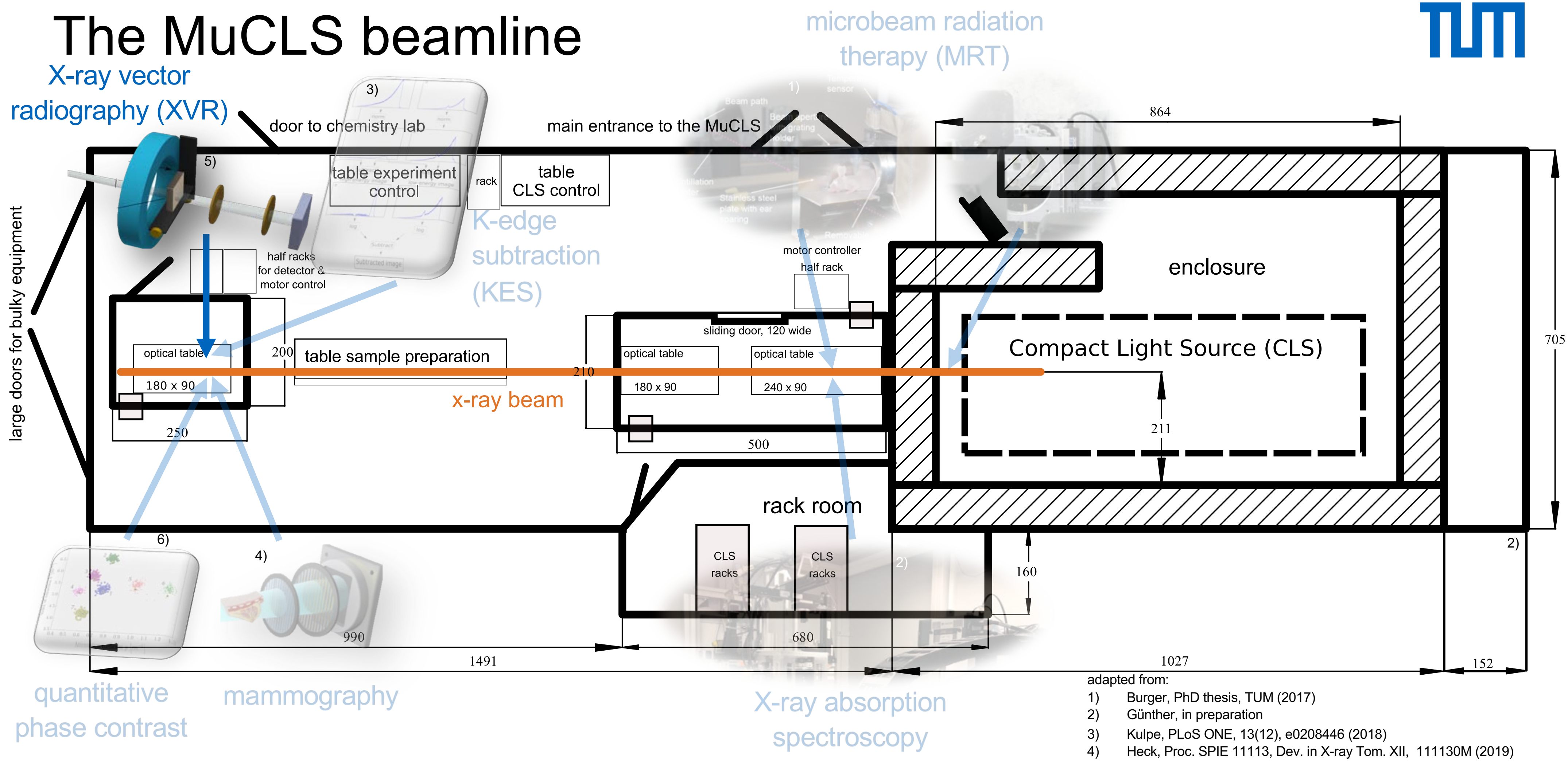
Direct quantitative material decomposition



Braig et al., Scientific Reports 8, 16394 (2018)

Quantitative determination of iodine (contrast agent) content

The MuCLS beamline



adapted from:
1) Burger, PhD thesis, TUM (2017)
2) Günther, in preparation
3) Kulpe, PLoS ONE, 13(12), e0208446 (2018)
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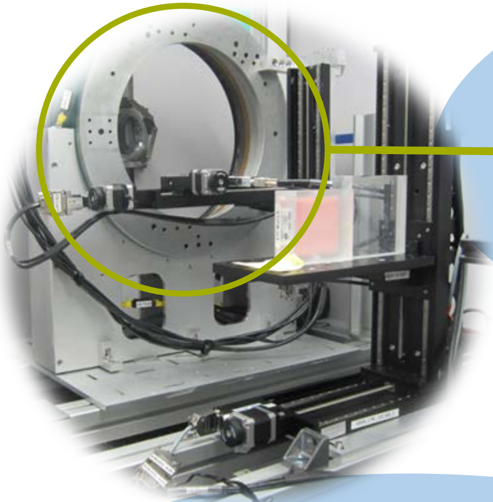
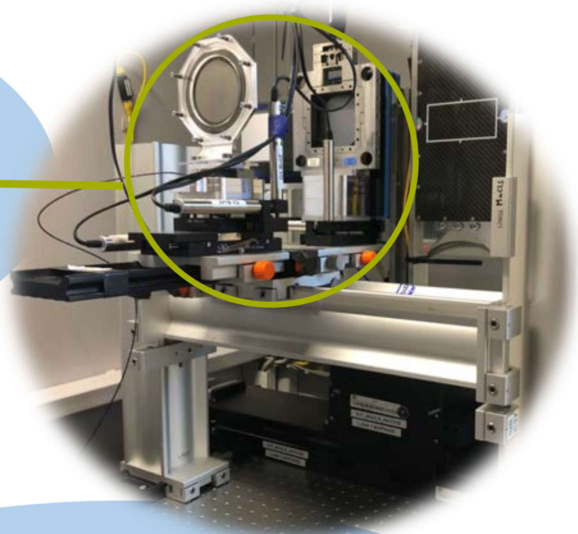
5) Jud, Scientific Reports 7, 6788 (2017)
6) Eggl. PNAS 112 (18), p. 5567-5572 (2015)

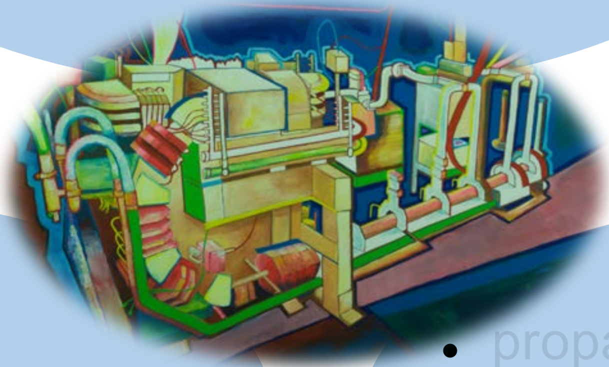
Applications exploiting the source properties of MuCLS





narrow tunable spectrum

- CT without hardening
- K-edge (su on) imaging
- spectroscopy



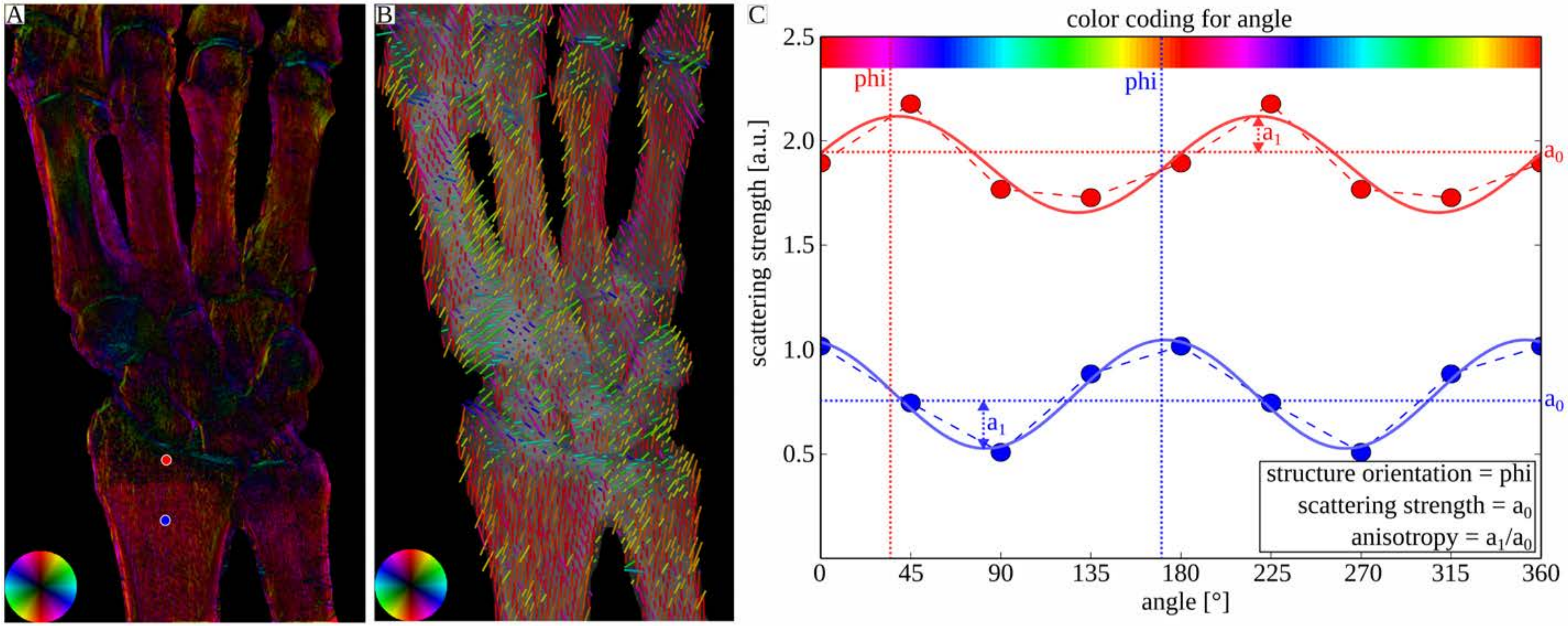
high flux density

- radiation therapy studies
- fast (dynamical) imaging
- high-resolution imaging

partial coherence

- propagation-based phase contrast
- <u>grating-based phase contrast (2 gratings only)</u>

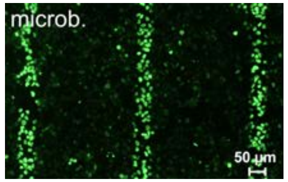
Directional dark-field imaging – bone micro-fractures



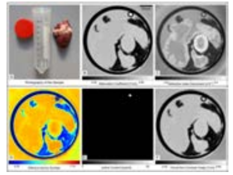
Jud et al., Scientific Reports 7, 6788 (2017)

Detection of micro-fractures

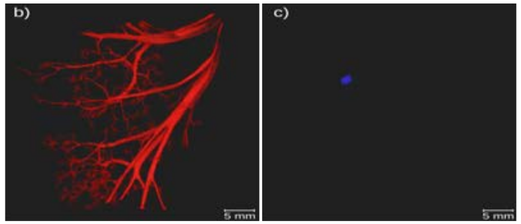
ICS enable the transfer of a variety of synchrotron techniques into the laboratory

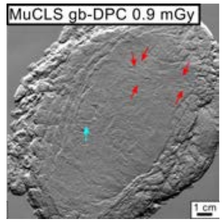


Quantitative multimodal imaging in the laboratory



ICS –in principle– are beneficial for various biomedical applications





ICS still need to improve in order to achieve clinical requirements (stability, measurement time, energy range,…)

Acknowledgements

MuCLS team @ TUM Chair of Biomedical Physics:

Martin Dierolf, Klaus Achterhold, Regine Gradl, Juanjuan Huang, Stephanie Kulpe, Johannes Brantl, Johannes Melcher, Eva Braig, Lisa Heck, Daniela Pfeiffer (Radiology), Julia Herzen, Kaye Morgan, Franz Pfeiffer

+ many more people at the Chair of Biomedical Physics

www.e17.ph.tum.de

www.lynceantech.com

Rod Loewen, Martin Gifford, Chris Juan, Terri Lahey, Bryan Woo, Matt Mezzetta, Michael Feser, Ron Ruth, ...

Munich School of BioEngineering

www.bioengineering.tum.de

Axel Haase, Bernhard Gleich

Martin Groß, Michael Bäuerle

www.munich-photonics.de

DFG Cluster of Excellence Munich-Center for Advanced Photonics (DFG EXC-158)