Prospects of neutron imaging at ESS

EUROPEAN SPALLATION SOURCE

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Instrumentation Division - Imaging

Instrumentation Division@ ESS

NIUS ESS-Science Symposium April 2012

ESS

Baseline parameters:

14 Hz

2.86 ms

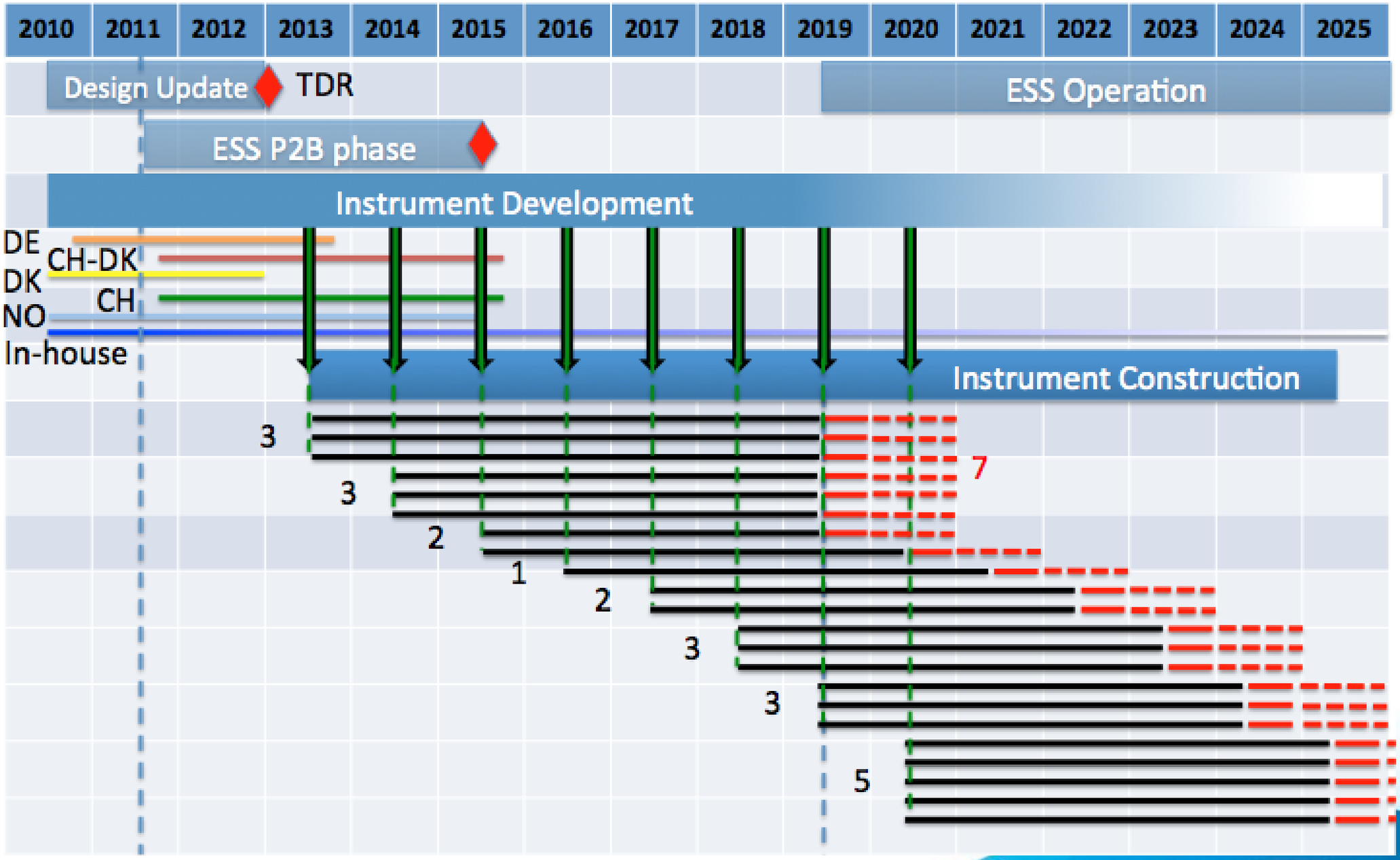
Time average flux of ILL

7 day one instruments 2019

22 instruments 2025

1.5 Billion Euro

Timeplan


2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Design Update
TDR
ESS Operation
ESS P2B phase
Instrument Development
DE
CH-DK
DK
CH
NO
In-house
Instrument Construction
3
3
2
1
2
3
3
5
7

What are the

-Science symposia to provide ESS with user input from community

-Should result in a report defining science drivers and community wishes

-Might strengthen the case for an instrument

-Contribute to science startegy (also at S&S meeting, 19., 20.4., Berlin)

“Strawman” instrument suite

High Performance	High Potential
Cold chopper spectrometer	1 μeV backscattering
Thermal chopper spectrometer	10 μeV backscattering
Small-sample SANS instrument	Extreme-conditions spectrometer
Conventional SANS	Extreme-conditions diffractometer
Grazing-incidence SANS	Narrow-bandwidth powder diffractometer
Horizontal-sample reflectometer	General-purpose powder diffractometer
Vertical-sample reflectometer	Hybrid diffractometer
Macromolecular diffractometer	Engineering diffractometer
Magnetism diffractometer	Fundamental physics
High-resolution spin-echo	Test beamline
Wide-angle spin-echo	
Cold crystal-analyser spectrometer	
Multi-purpose imaging	

Corresponding WUs

Table 4: Work Package breakdown structure for Instrument Concepts

Manag. IC1	SANS IC2	Reflectometry IC3	Macromol. Diffraction IC4	Single Crystal Diffraction IC5	Powder Diffraction IC6	Materials Engin. Diffraction IC7	Imaging IC8	Direct Geom. Spectroscopy IC9	Indirect Geom Spectroscopy IC10	Spin-Echo IC11	Others IC12
	Conventional SANS Full DU for fast conv. ext. q-range SANS, 29 PM, SD004DE/a	Horizontal Reflectometer Full DU for wide q and add-ons, 23 PM, SD003DE/a	Macromol. Diff. Full DU, potent. farm SD036ESS	Magn. Single Crystal Diffractom. Full DU SD060ESS	Wide Band Powder Diffraction Full DU, wfm, gen. purp., 23 PM, SD005DE/a	Engineering Diffraction SPEED full DU plus prototyping tests, 57 PM, SD005DE/b	Multi Purp. HR Imaging Full DU in close collab. with CH, dark-field, Bragg edge, polarized 68 PM, SD006DE	Cold Chopper Spectrometer Full DU, high res., RRM and pol. cap., 26.5 PM, SD001DE/a	Phase Space Transformers Full DU, incl. feasibility studies, focussing, 48 PM, SD007DE/a	High Resolution NSE Full DU, small sample, 24 PM, SD002DE/a	Fund. Physics Full DU Not covered
	GISANS Full DU, potent. SESANS, 5 PM, SD004DE/b	Vertical Magnetism Reflectometer Full DU, focus. pol., 9 PM , SD003DE/b			Multi Purp. Extreme Environ.Diffr. Full DU, tests, 14 PM, SD008DE	CEED Full DU, tests, PM, SD033CZ	Larmor Label. Full DU, TOF DF imaging SD056NL	Bispectral Chopper Spectrometer Full DU, RRM pol., 18.5 PM, SD001DE/b	Multi Crystal Analyser Full DU plus tests and prototyping, 132 PM, SD016DC	Wide Angle NSE Full DU, 6 PM, SD002DE/b	Test Beamline Full DU Not covered
	Small-sample SANS Full DU SANS, 28 PM, SD004DE/c	High Div. Refl. Full DU, SELENE ,plus prototype tests, design full instrument, 108 PM, SD017DC			Hybrid Diffractometer potent. including SANS and imaging Full DU, 78 PM, SD019DC	Hi Flex. Mat. & Engin. Diff. Full DU, WFM, flex .res., SPEED, Fourier, POLDI SD059ESS	Multi Purp. HR Imaging Full DU in close collab. GER, phase, fast, high res., 48 PM, SD029CH	Thermal Chopper Spectrometer Full DU, RRM and pol. cap. SD038ESS	Backscatt. Spectr. Full DU, variable 1 to 20 micro eV resolution SD039ESS	Alternative NSE & Add-ons Resonant NSE, 23 PM, SD007DE/b	UCN full DU Not covered
	Pol. SANS Full DU, incl. SE devices SD054NL	Multi Beam Refl. Full DU, broad simultaneous q-range SD034ESS			Narrow Bandwidth Powder Diffr. Full DU, variable to high res. SD035ESS		Multi Purp. HR Imaging TOF conceptual design SD040ESS	Crystal Monochr. Spectrometer Full DU Not covered			
	Compact SANS Full DU, incl. Monochr. mode, 66 PM, SD018DC				Hybrid Diff. with Multi Monochr. multi monochromators or chop.; concept. design SD037ESS						
Simulation software development, general simulations, supporting GER simulations, VITESS SD015DE, 42 PM											
General simulations, in-house supporting simulations, interface moderator-beam extraction, McStas SD022DK, 51 + 162 PM											

Corresponding WUs

Table 4: Work Package breakdown structure for Instrument Concepts

ol. ion	Single Crystal Diffraction IC5	Powder Diffraction IC6	Materials Engin. Diffraction IC7	Imaging IC8	Direct Geom. Spectroscopy IC9	Indirect Geom Spectroscopy IC10	Spin-Echo IC11	Othe IC1
ol. . farm S	Magn. Single Crystal Diffractom. Full DU SD060ESS	Wide Band Powder Diffraction Full DU, wfm, gen. purp., 23 PM, SD005DE/a	Engineering Diffraction SPEED full DU plus prototyping tests, 57 PM, SD005DE/b	Multi Purp. HR Imaging Full DU in close collab. with CH, dark-field, Bragg edge, polarized 68 PM, SD006DE	Cold Chopper Spectrometer Full DU, high res., RRM and pol. cap., 26.5 PM, SD001DE/a	Phase Space Transformers Full DU, incl. feasibility studies, focussing, 48 PM, SD007DE/a	High Resolution NSE Full DU, small sample, 24 PM, SD002DE/a	Fun Phys Full Not cov
		Multi Purp. Extreme Environ.Diffr. Full DU, tests, 14 PM, SD008DE	CEED Full DU, tests, PM, SD033CZ	Larmor Label. Full DU, TOF DF imaging SD056NL	Bispectral Chopper Spectrometer Full DU, RRM pol., 18.5 PM, SD001DE/b	Multi Crystal Analyser Full DU plus tests and prototyping, 132 PM, SD016DC	Wide Angle NSE Full DU, 6 PM, SD002DE/b	Tes Beam Full Not cov
		Hybrid Diffractometer potent. including SANS and imaging Full DU, 78 PM, SD019DC	Hi Flex. Mat. & Engin. Diff. Full DU, WFM, flex .res., SPEED, Fourier, POLDI SD059ESS	Multi Purp. HR Imaging Full DU in close collab. GER, phase, fast, high res., 48 PM, SD029CH	Thermal Chopper Spectrometer Full DU, RRM and pol. cap. SD038ESS	Backscatt. Spectr. Full DU, variable 1 to 20 micro eV resolution SD039ESS	Alternative NSE & Add-ons Resonant NSE, 23 PM, SD007DE/b	UC full Not cov
		Narrow Bandwidth Powder Diffr. Full DU, variable to high res. SD035ESS		Multi Purp. HR Imaging TOF conceptual design SD040ESS	Crystal Monochr. Spectrometer Full DU Not covered			
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Simulation software development, general simulations, supporting GER simulations, VITESS SD015DE, 42 PM

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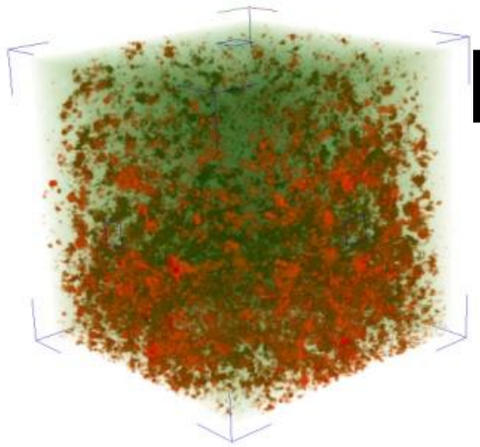
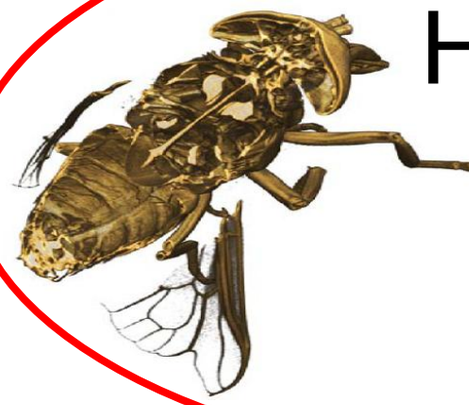
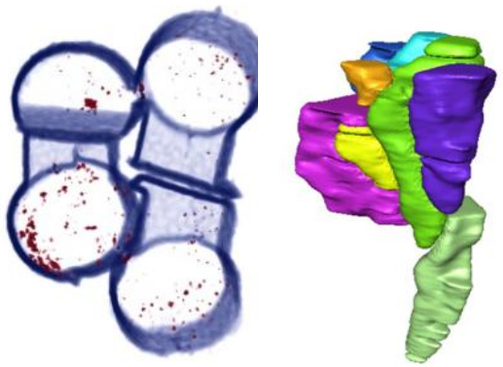
Multi Purpose Imaging



Bragg edge diffraction imaging

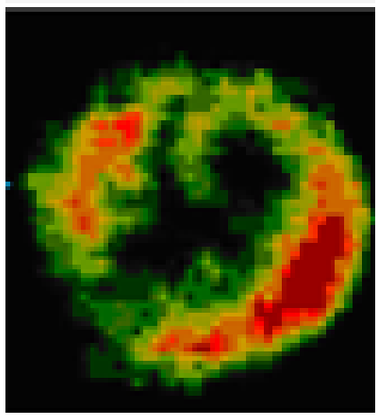


High resolution conventional imaging



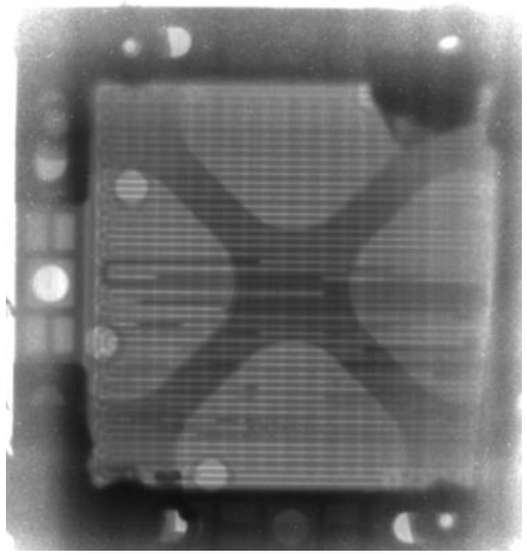
Structural and magnetic dark-field imaging

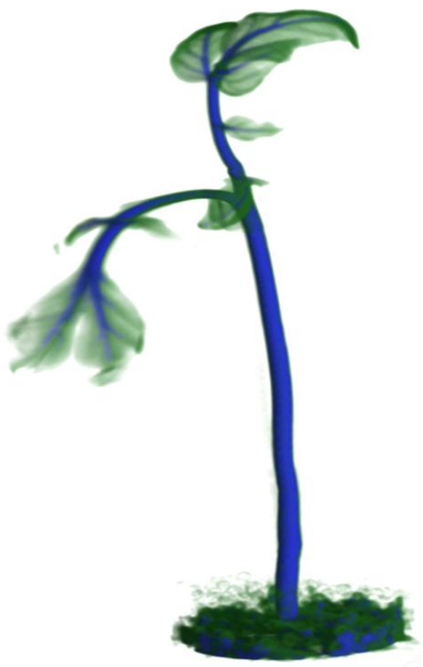
Others: phase contrast, complementary x-ray, fast neutron,..

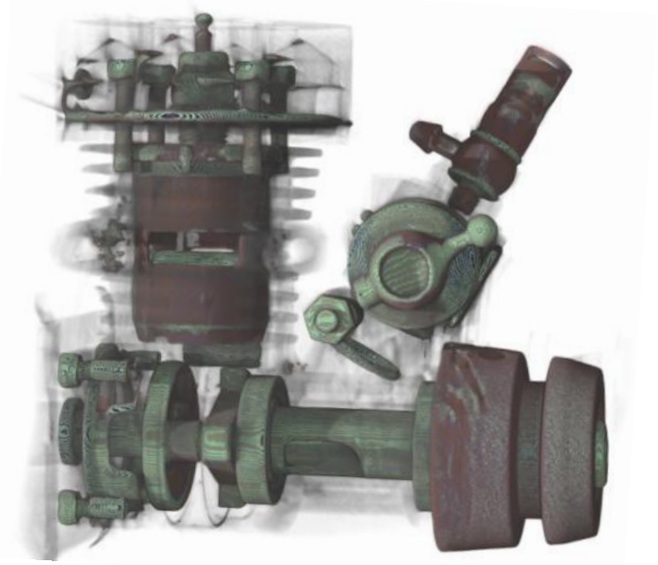


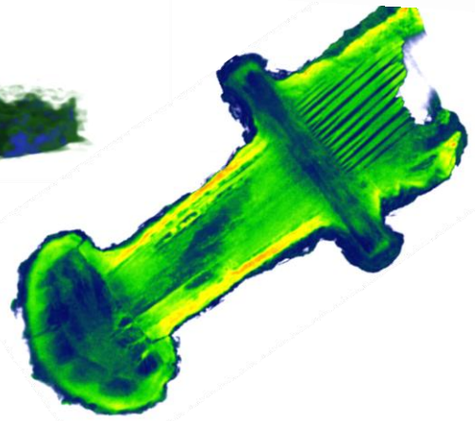
Polarized neutron imaging

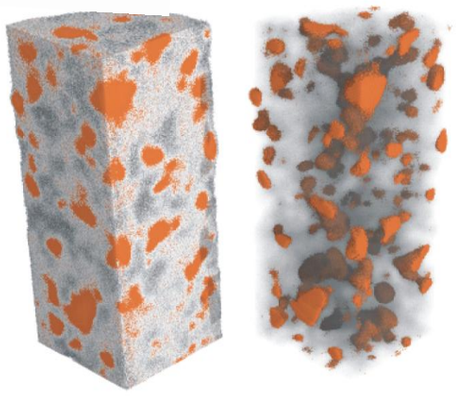
Neutron imaging











n Imaging Applications

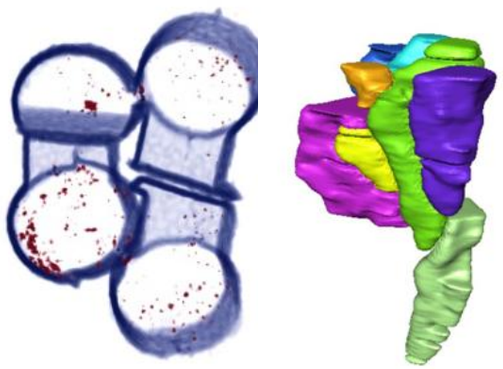
R&D
Biology
& Agriculture
Geology
Archeology
Paleontology
Art History
Material science
& Engineering
Industry
etc.

Multi Purpose Imaging

$$\sigma_{coh}^{el}(\lambda) = \frac{\lambda^2}{2V_0} \sum_{d_{hkl}=0}^{2d_{hkl}<\lambda} |F_{hkl}|^2 d_{hkl}$$

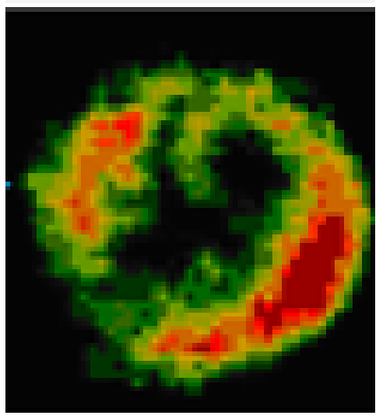
$\lambda_B = 2d_{hkl}$

High resolution conventional imaging



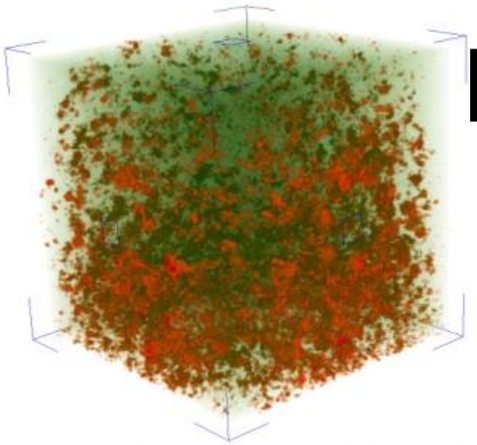
Structural and magnetic dark-field imaging

Others: phase contrast, complementary x-ray, fast neutron,..



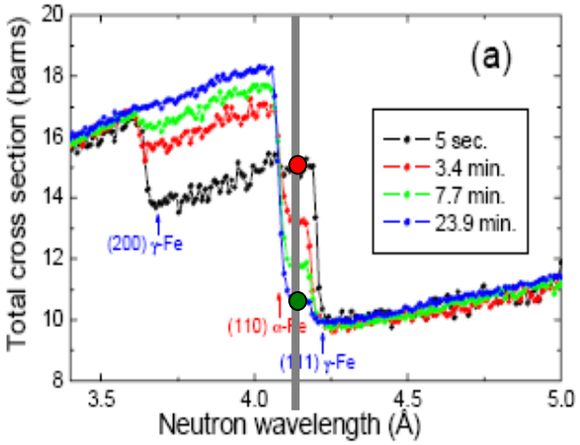
Polarized neutron imaging

Bragg edge imaging



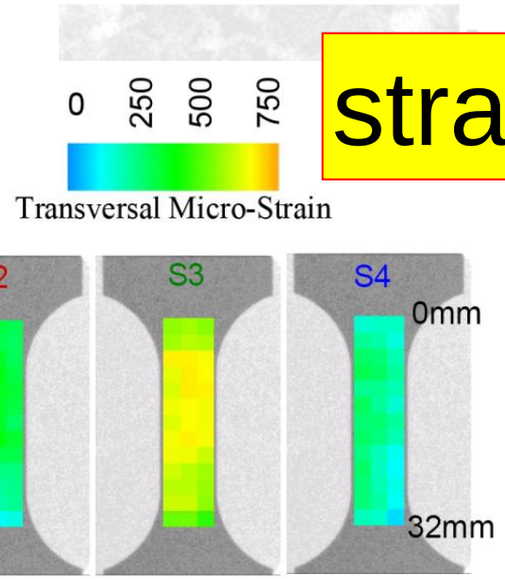
I. Manke, M. Strobl et al.

Bragg edge diffraction imaging



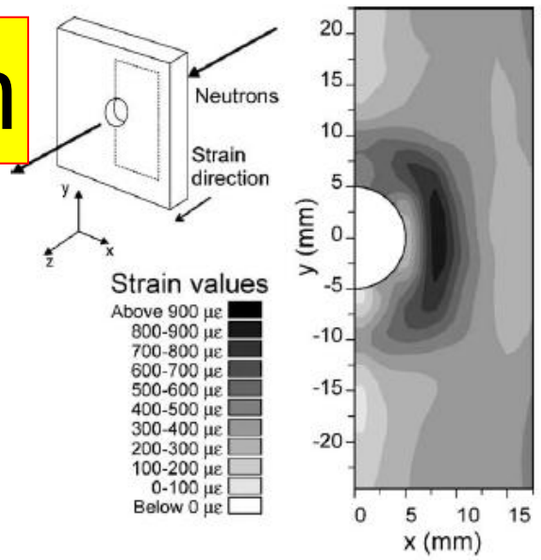
L. Edwards, A. Steuwer et al. ISIS (2002)

phase



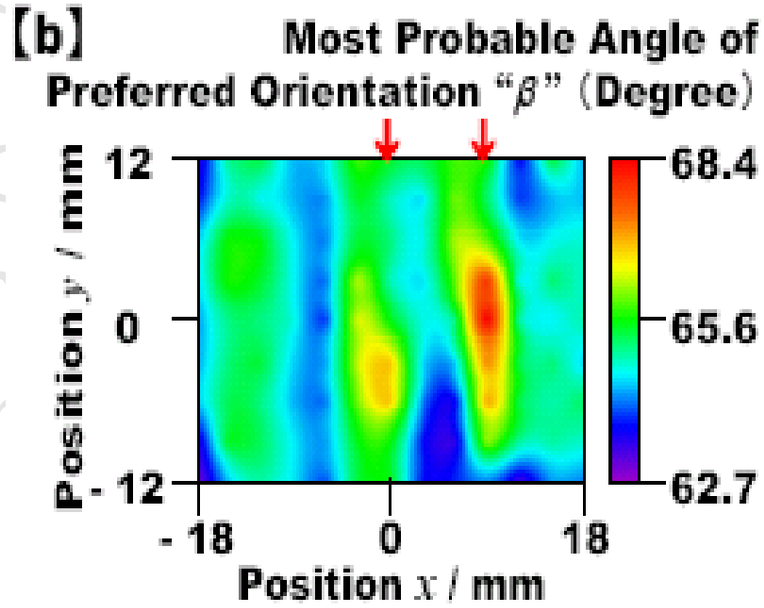
R. Woracek, M. Strobl et al. JAP 2011

strain

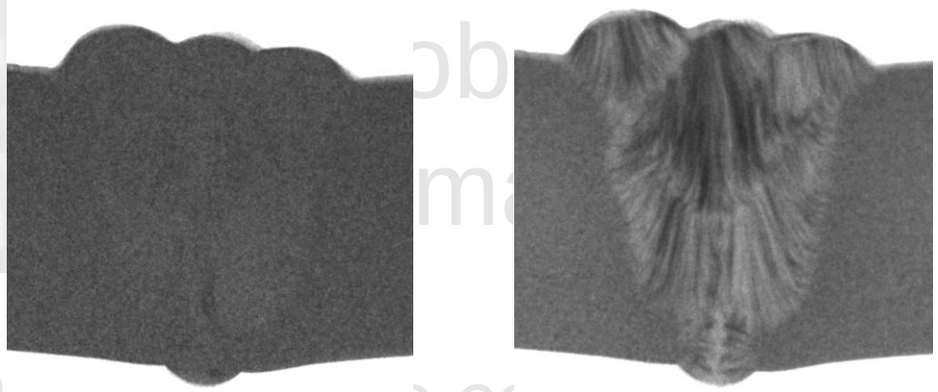


J.R. Santistepan NIMA (2002)

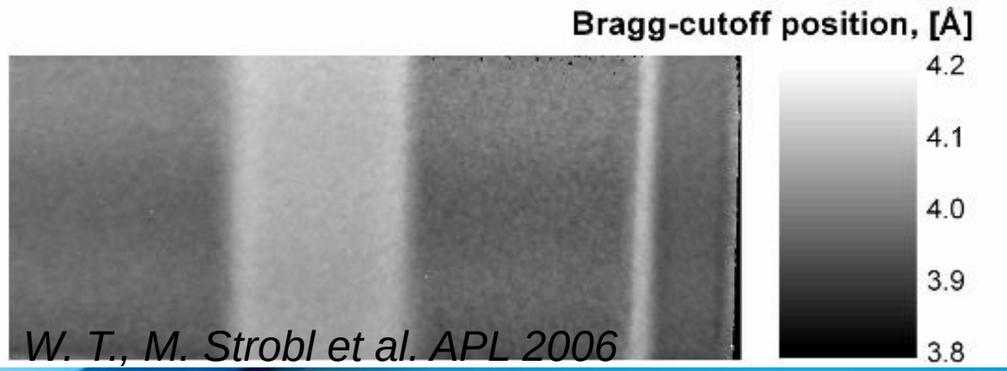
microstructure & texture related



H. Sato et al. J. Phys 2010

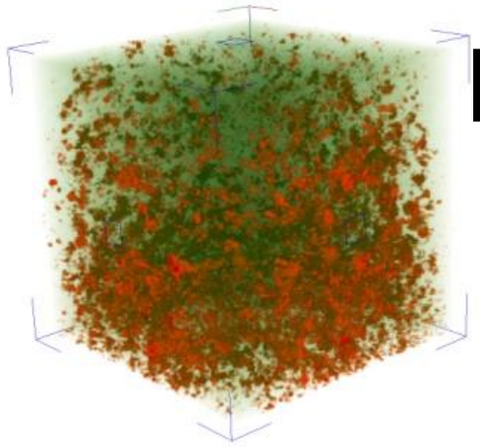


E. Lehmann, N. Kardjilov et al. NIMA 2009

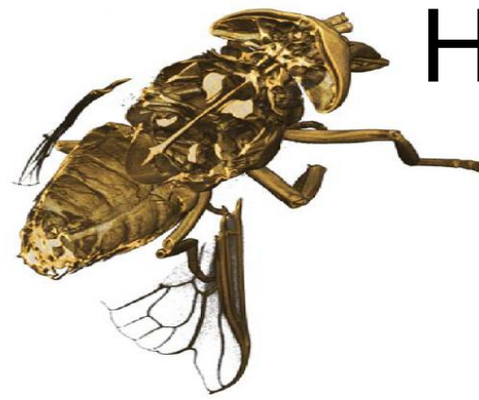


W. T., M. Strobl et al. APL 2006

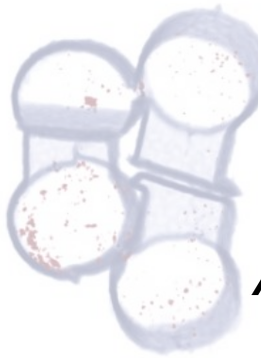
Multi Purpose Imaging



Bragg edge diffraction imaging



High resolution conventional imaging

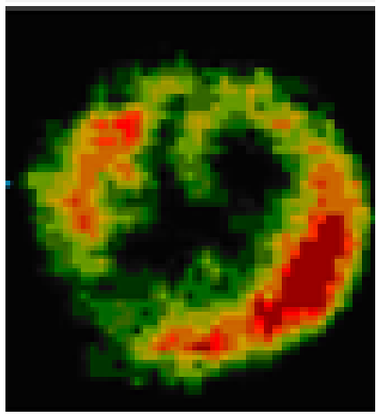


Structural and magnetic dark-field imaging

$Q=2\pi/\lambda \sin\theta$

$A(\lambda)/A_0(\lambda)=exp(\sigma t(G(\lambda)-1))$

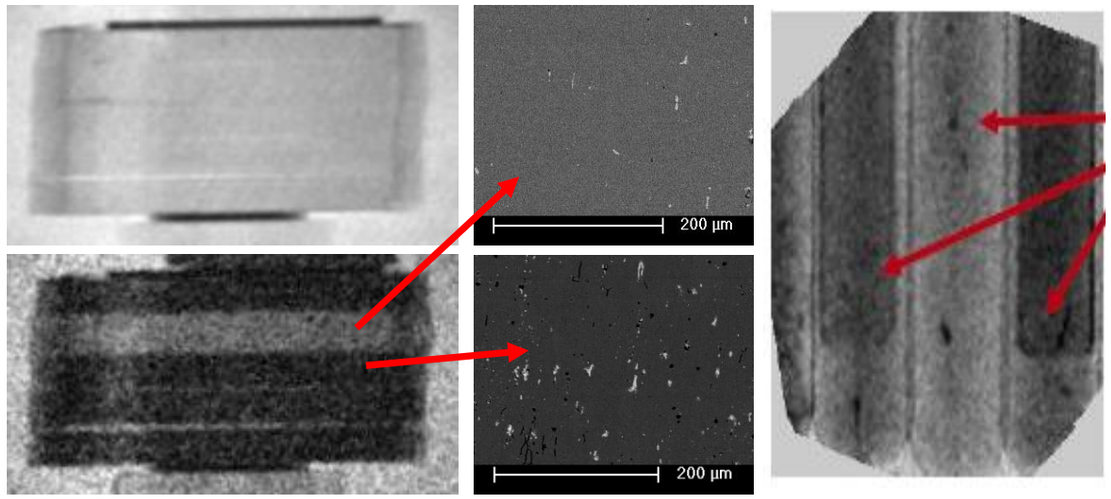
A…amplitude
σ…scatt. cross section
t….thickness, G…correlation function



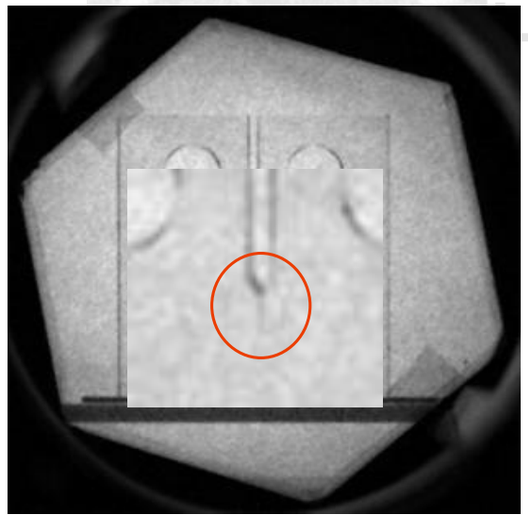
Polarized neutron imaging

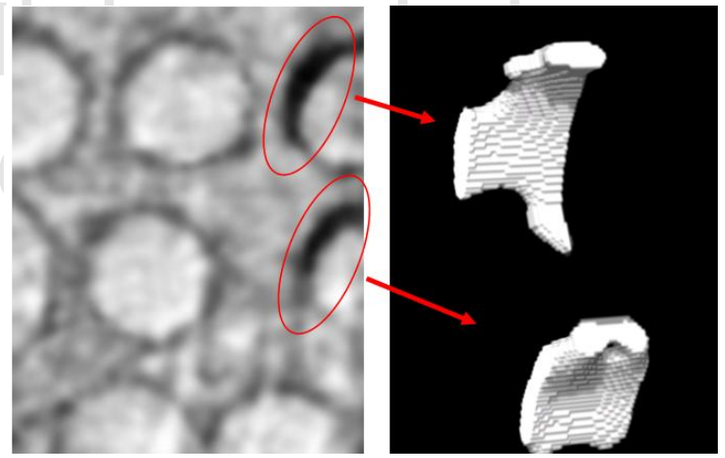
Others: phase contrast, complementary x-ray, fast neutron,..

Dark-field/SANS imaging

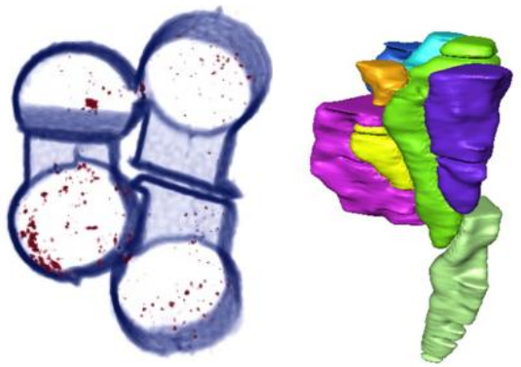


A.Hilger, M. Strobl et al JAP (2010)

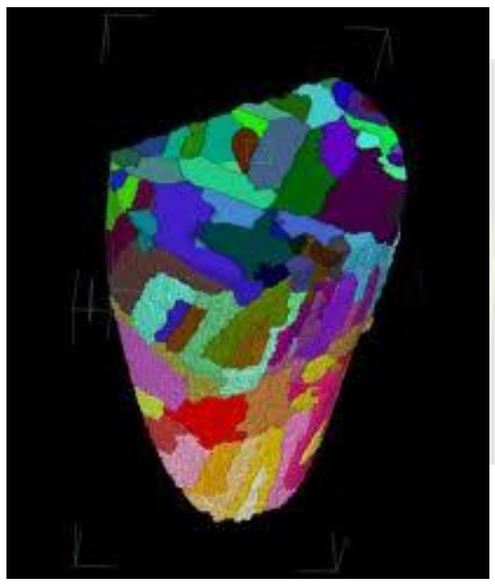


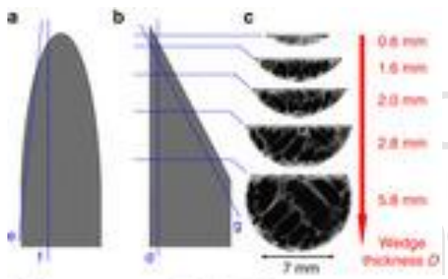


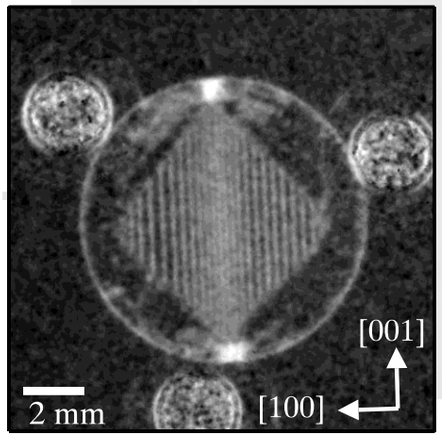
M. Strobl et al. PRL (2008)

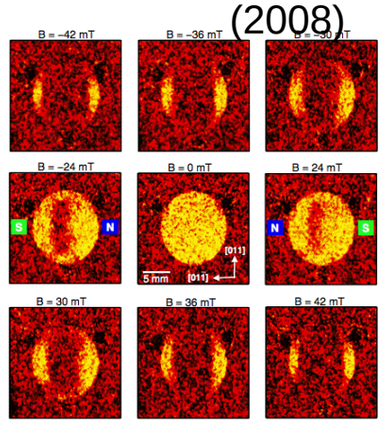


Structural and magnetic dark field imaging

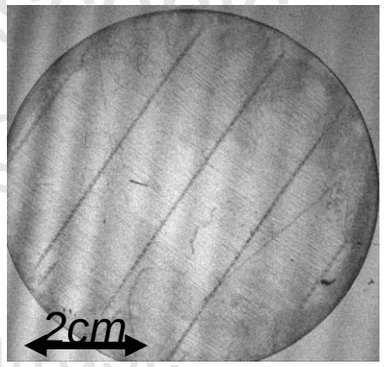




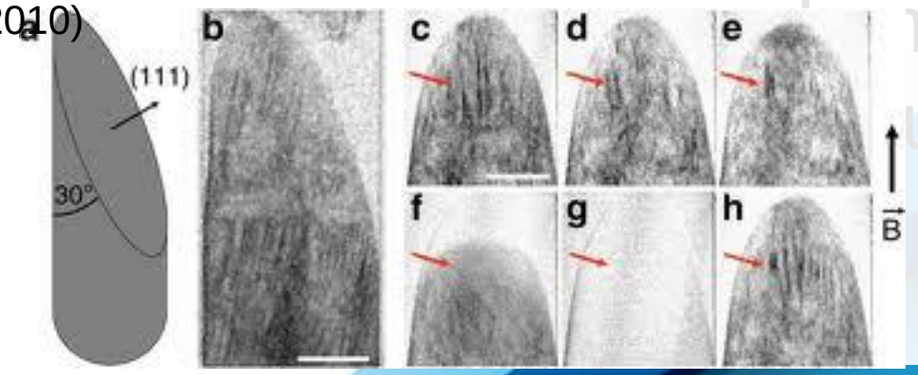


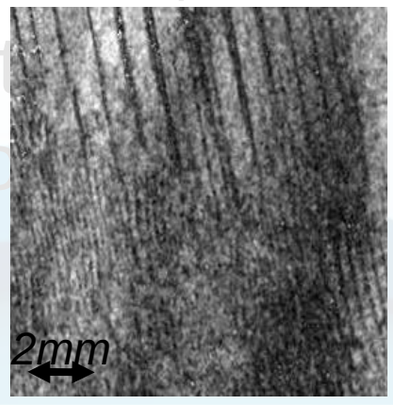


Ch. Gruenzweig et al. APL (2008) & PRL (2008)

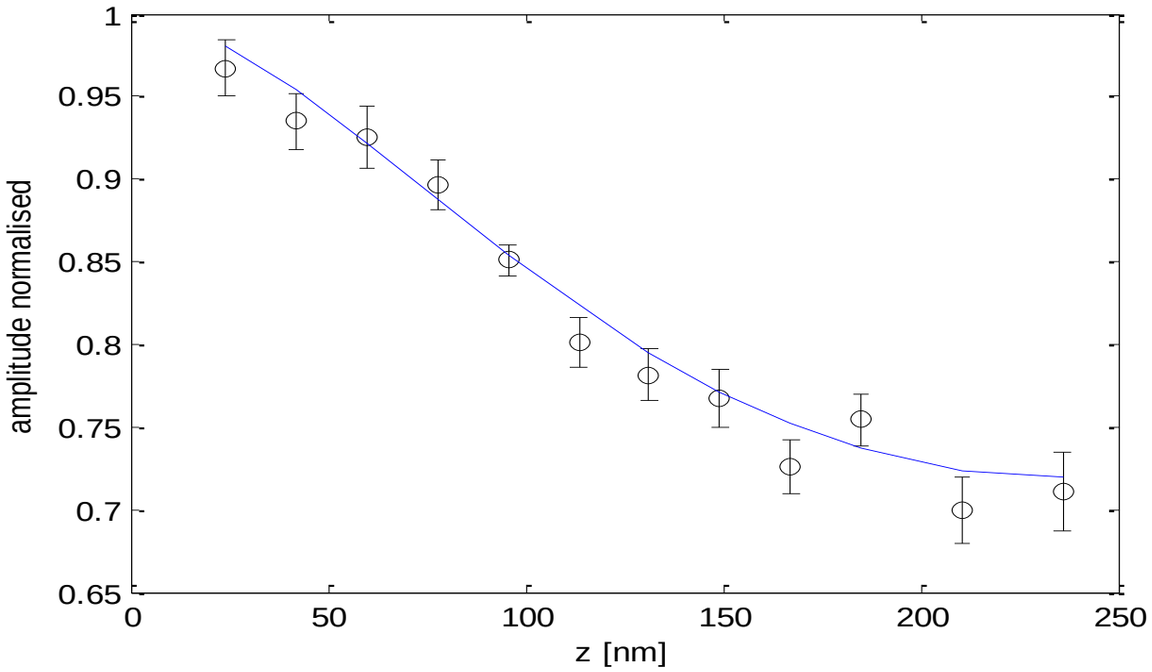


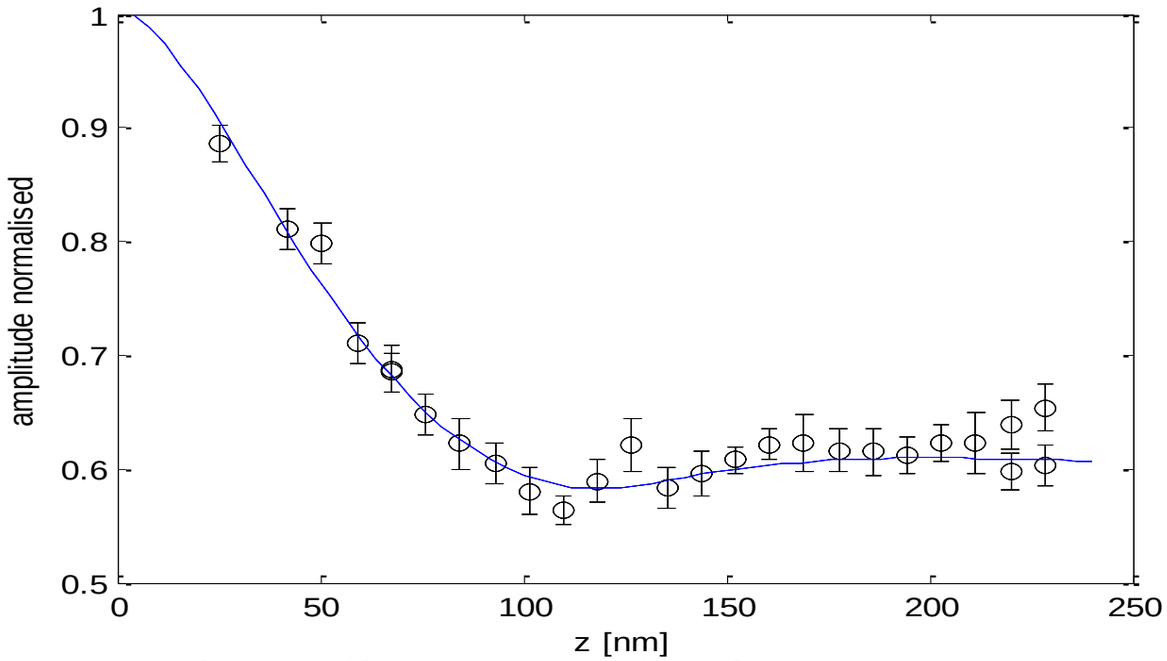
I. Manke, N. Kardjilov,..M. Strobl et al. Nature Com (2010)





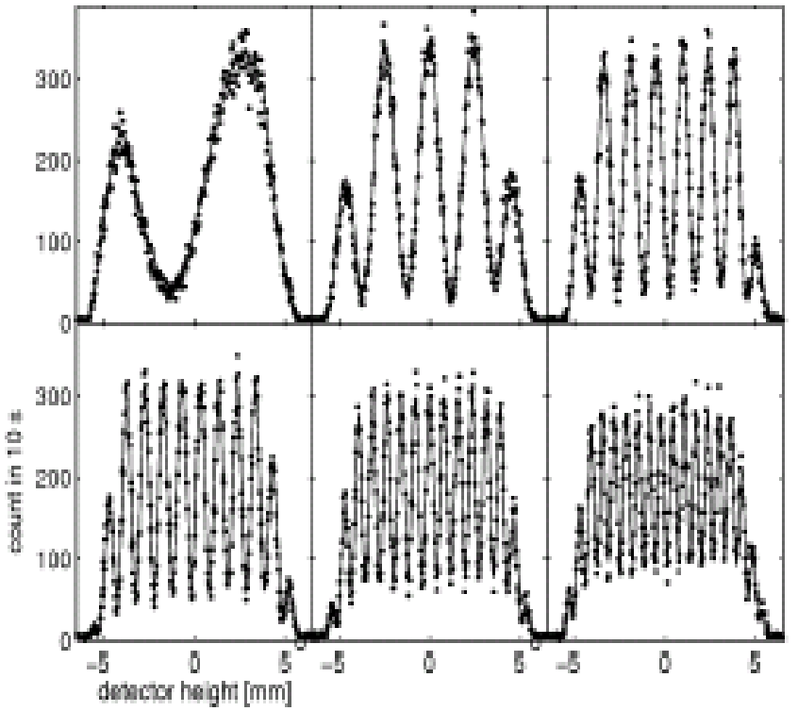
Spatial modulation through SE





$A(\lambda)/A_0(\lambda)=exp(\sigma t(G(\lambda)-1))$

A…amplitude
σ…scatt. cross section
t….thickness, G…correlation function



$A(\delta^{SE}) / A_0 = P(\delta^{SE}) \sim g(r)$

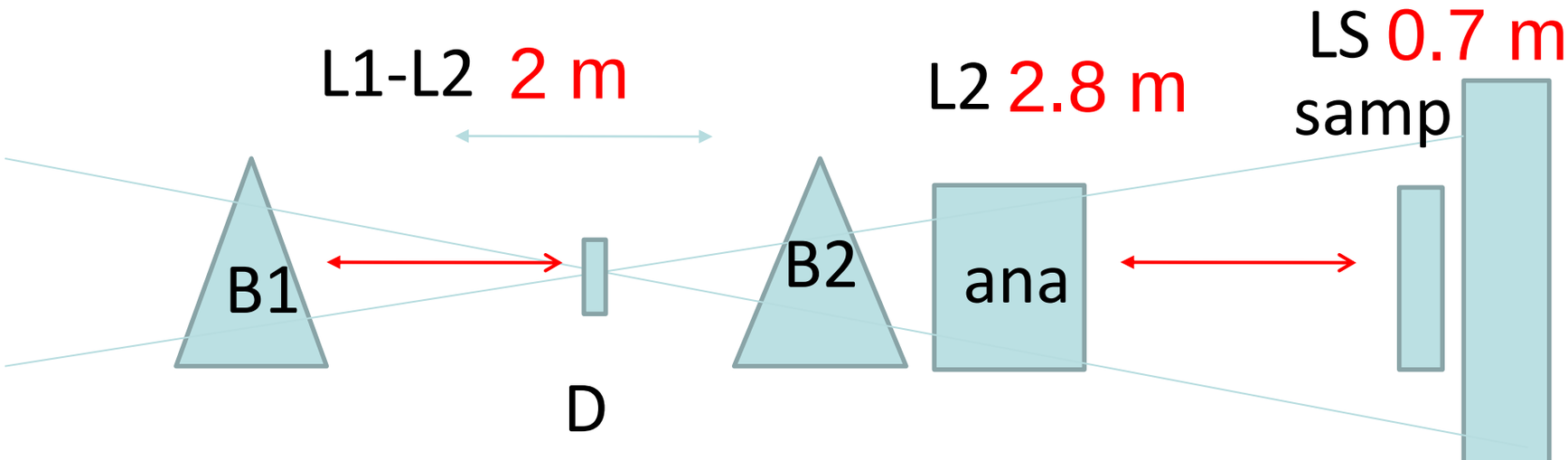
$\zeta = \pi \tan\theta_0/(c\lambda(B2-B1))$ period

$\delta^{SE} = \lambda L_s/\zeta$ SE-length

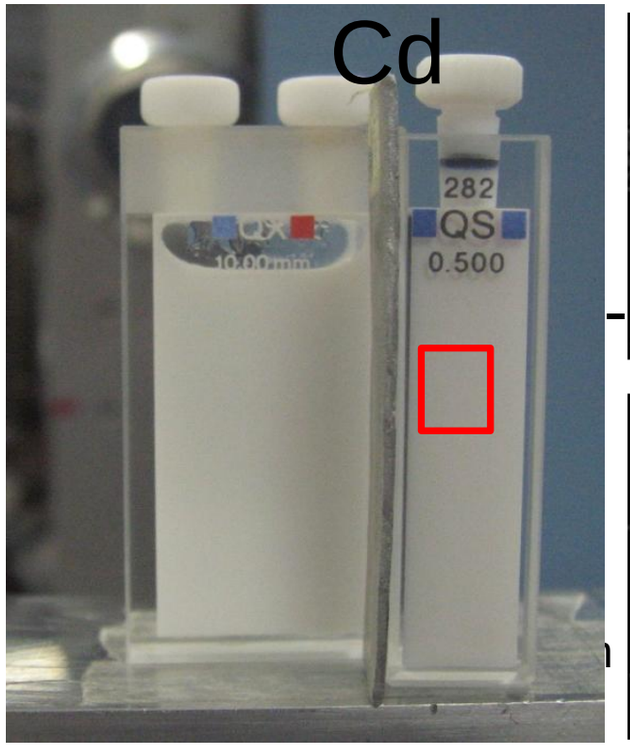
M. Strobl, J. Plomp, W.G. Bouwman et al. submitted to JAP

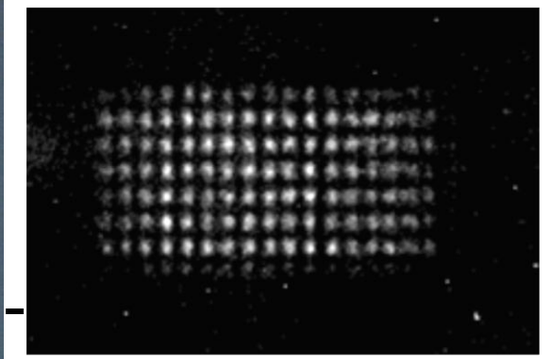
Dark-field/SANS imaging -> 2D spatial resolved SANS

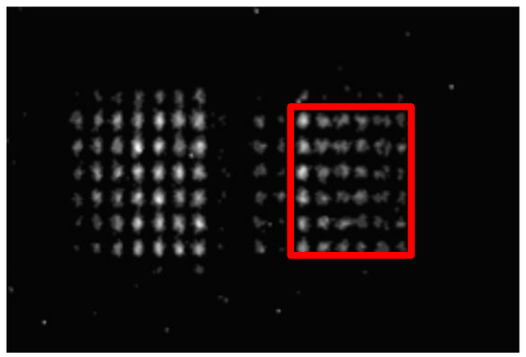
Dark field contrast – SEMSANS (M.Strobl, W. Boumann et al.)

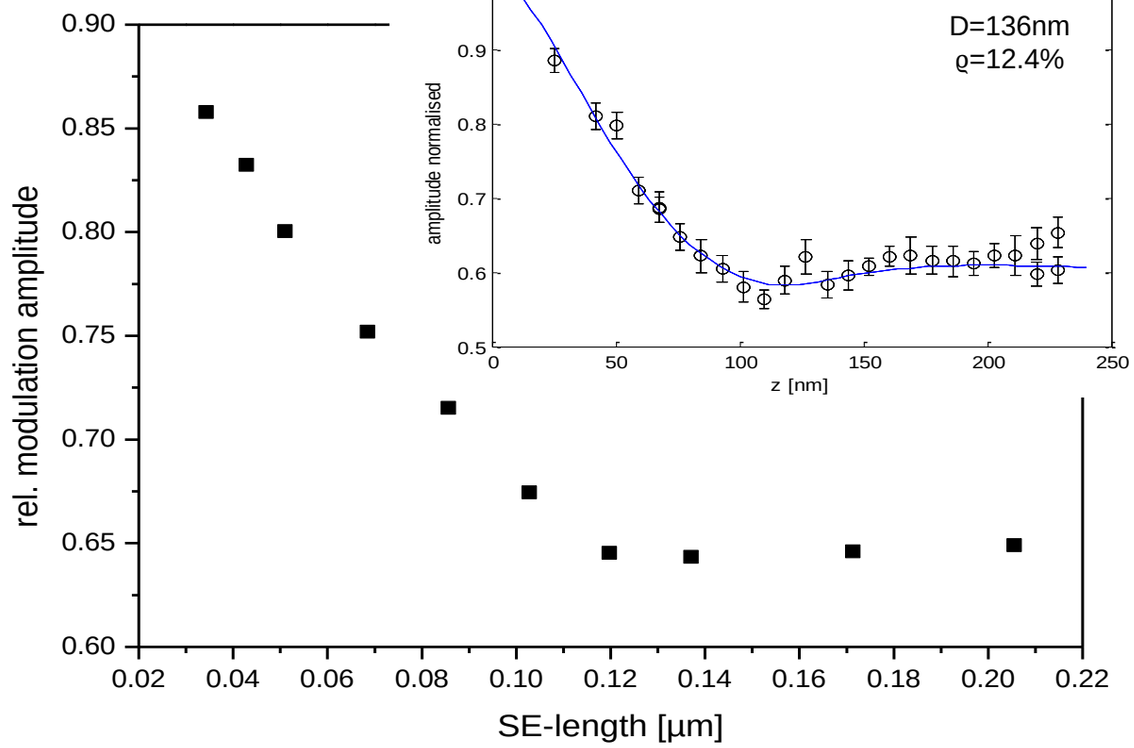


2.1A
theoret.
spatial resolution
app. 1mm

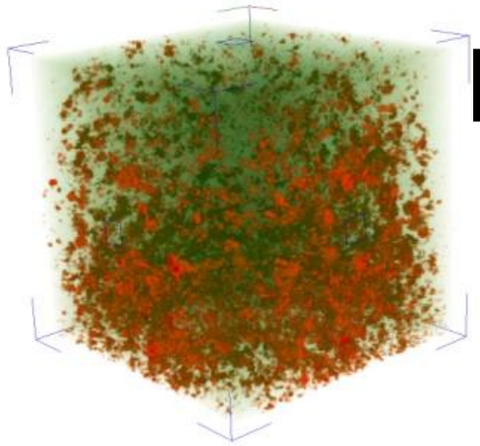






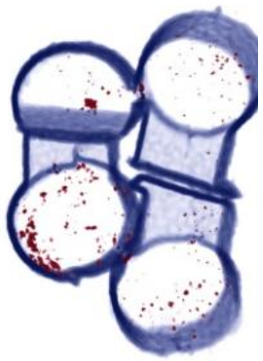


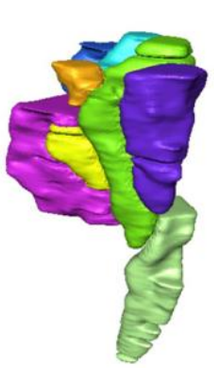
Multi Purpose Imaging



Bragg edge diffraction imaging

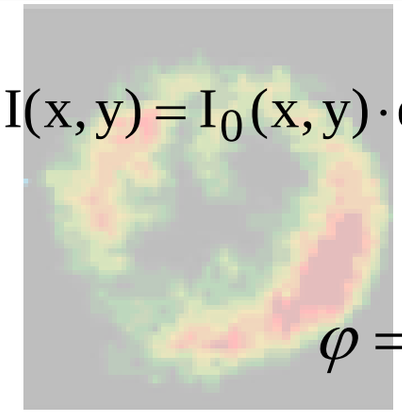
High resolution conventional imaging





Structural and magnetic dark-field imaging

Others: phase contrast, complementary x-ray, fast neutron,..

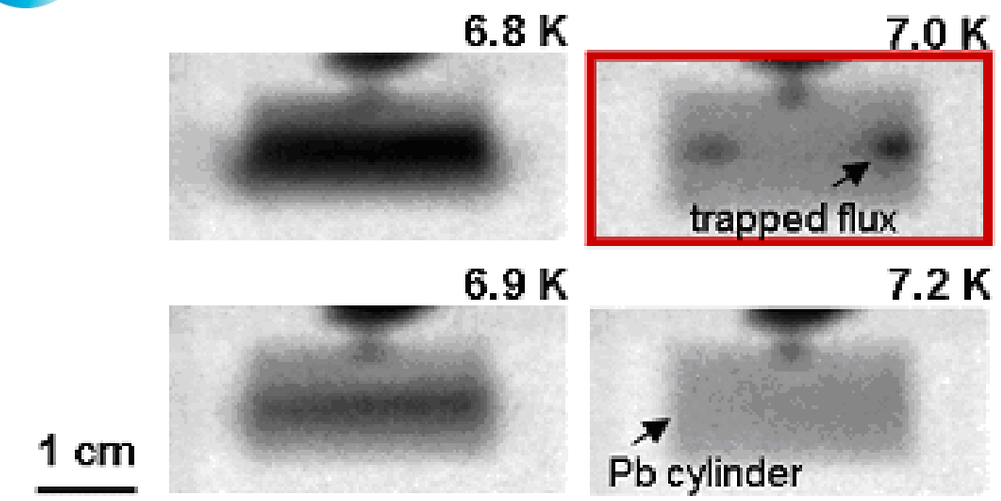


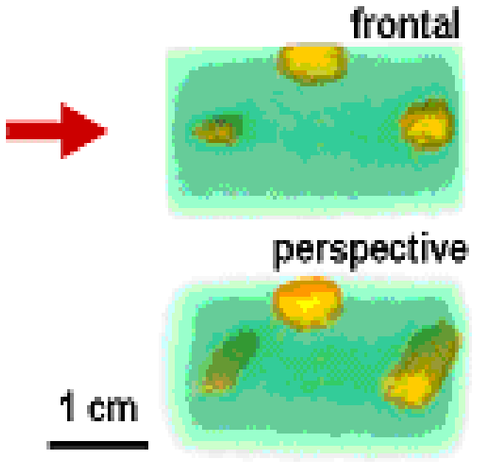
$$I(x,y) = I_0(x,y) \cdot \exp\left(-\int_{path} \sigma \cdot ds\right) \cdot \frac{1}{2}\left(1+\cos\varphi(x,y)\right)$$

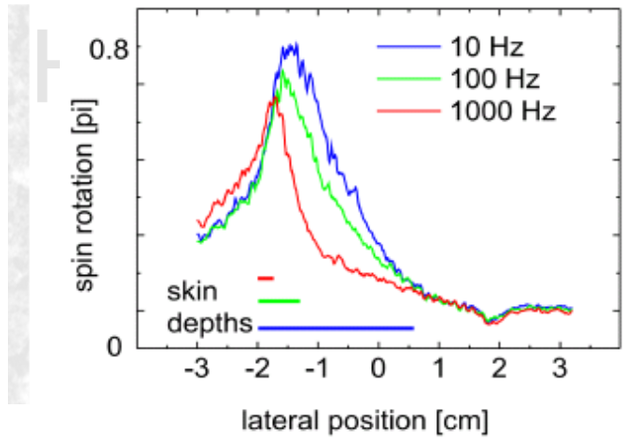
$$\varphi = \int_{path} \frac{\lambda m_n \gamma_n B}{h} ds$$

Polarized neutron imaging

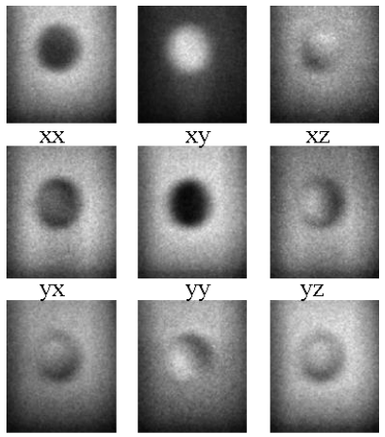
Polarized neutron imaging

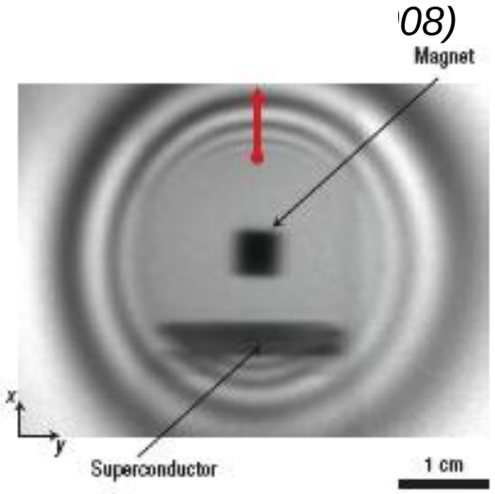


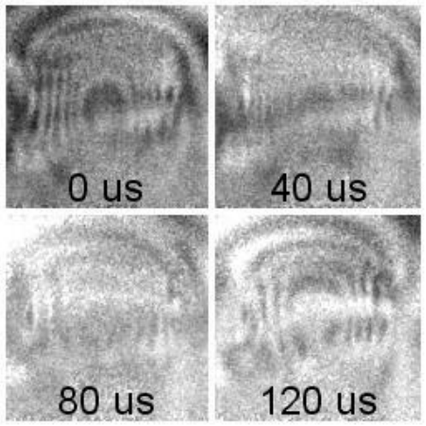


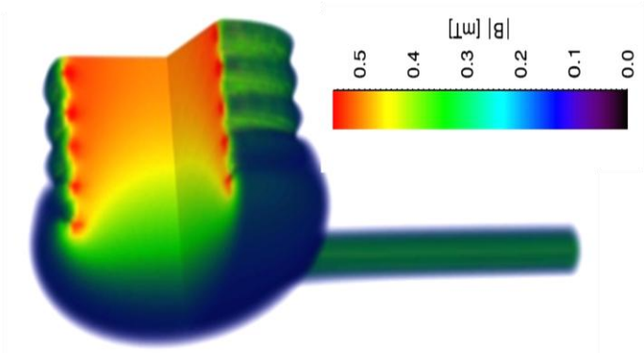


I. Manke et al. JAP (2009)

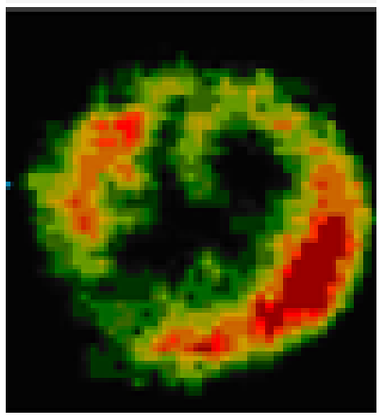




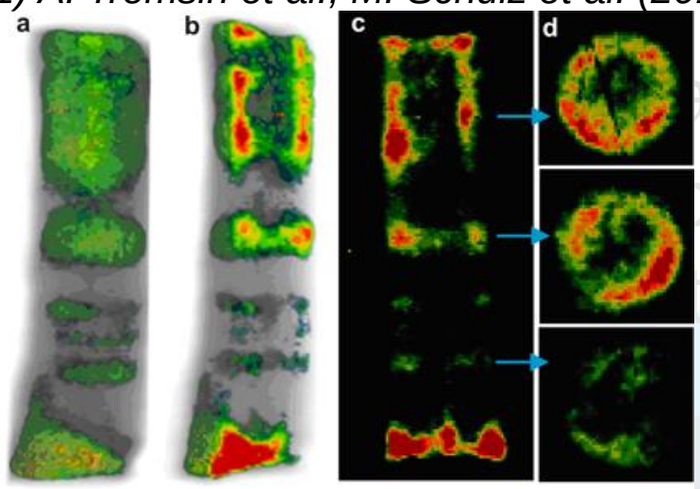


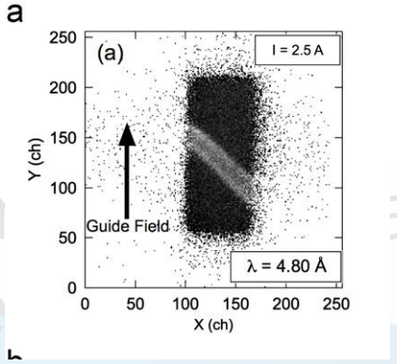


M. Strobl et al Phys B (2009) N.Kardjilov Mat Eng. (2011) A. Tremsin et al., M. Schulz et al. (2010)



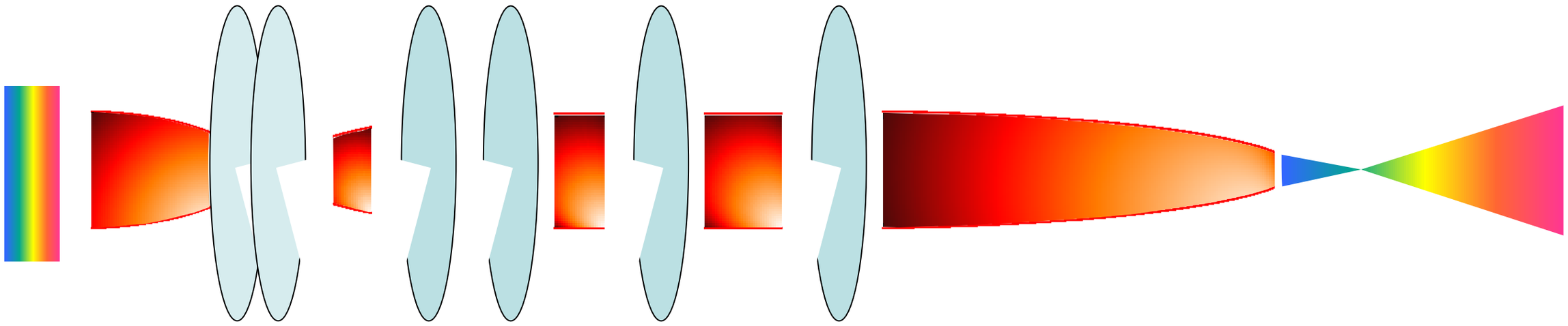
Polarized neutron imaging





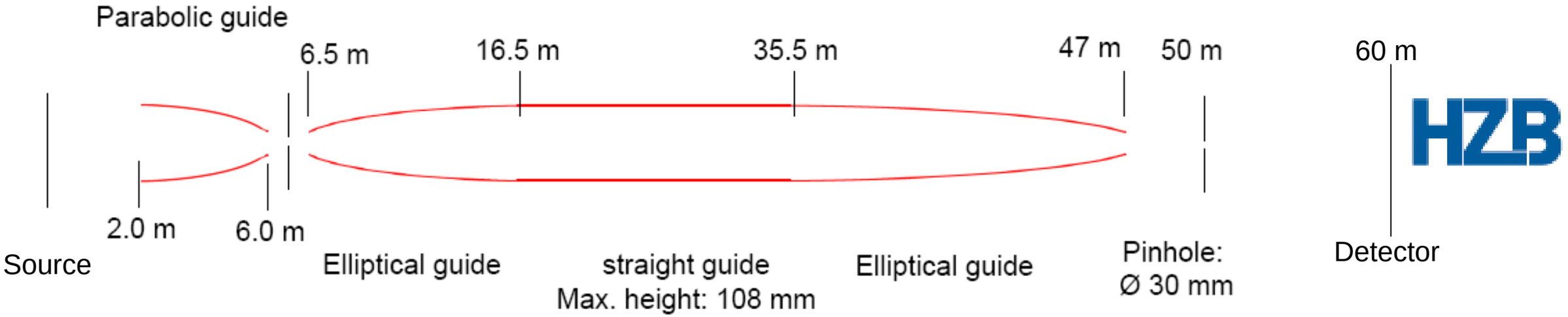
T. Shinohara et al.(2011)

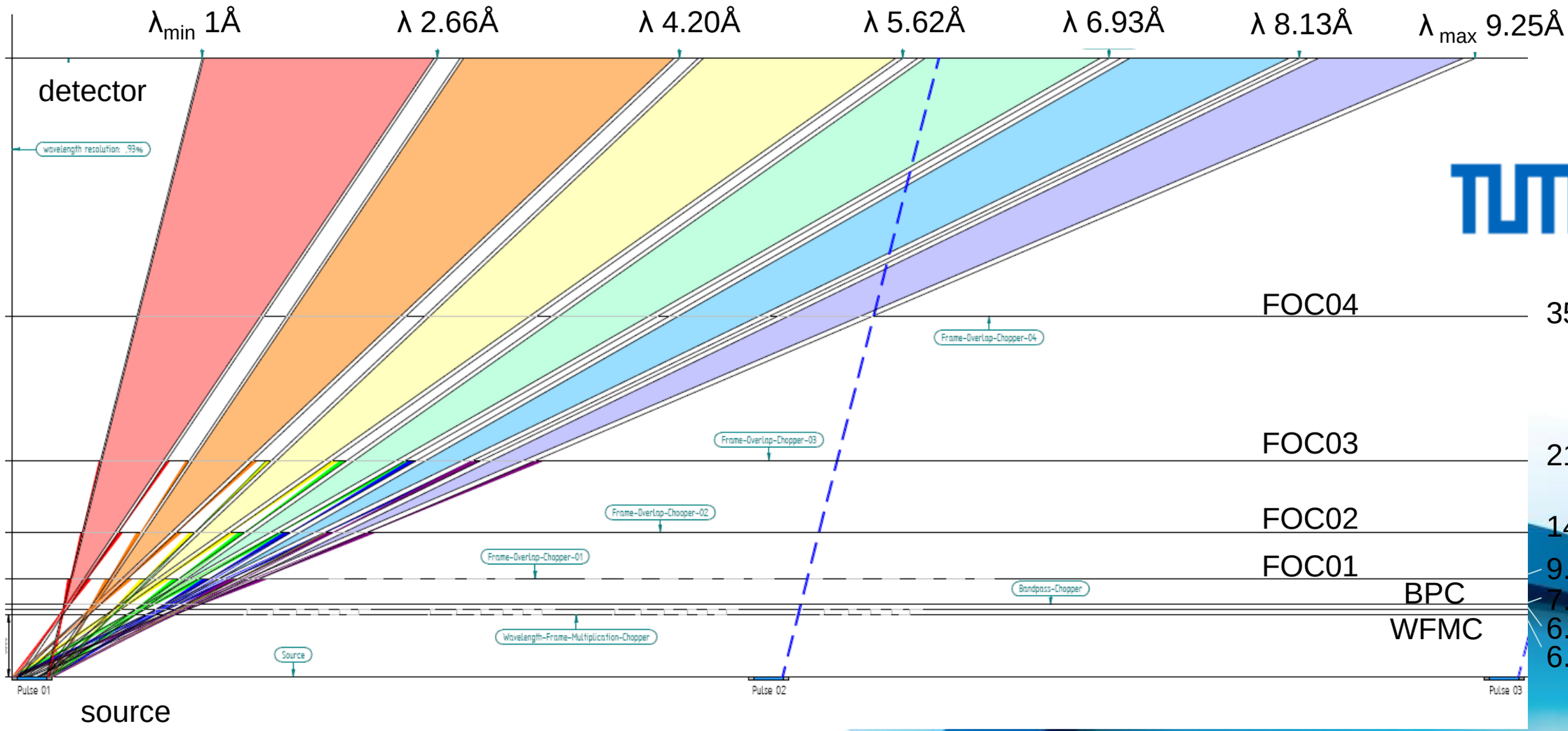
ESS Imaging Instrument Concept



Method	*wlb*	*res.*	*FOV*
Conventional			*25x25cm²*
Strain	*1– 5A*	*0.5%*	*10x10cm²*
Microstr	*2-6A*	*10%*	*10x10cm²*
Texture	*1-5A*	*1%*	*10x10cm²*
Polarized	*1-10/20A*	*1%*	*5x5(10x10)cm²*
DF/SANS	*1-10/20A*	*10%*	*15x15cm²*

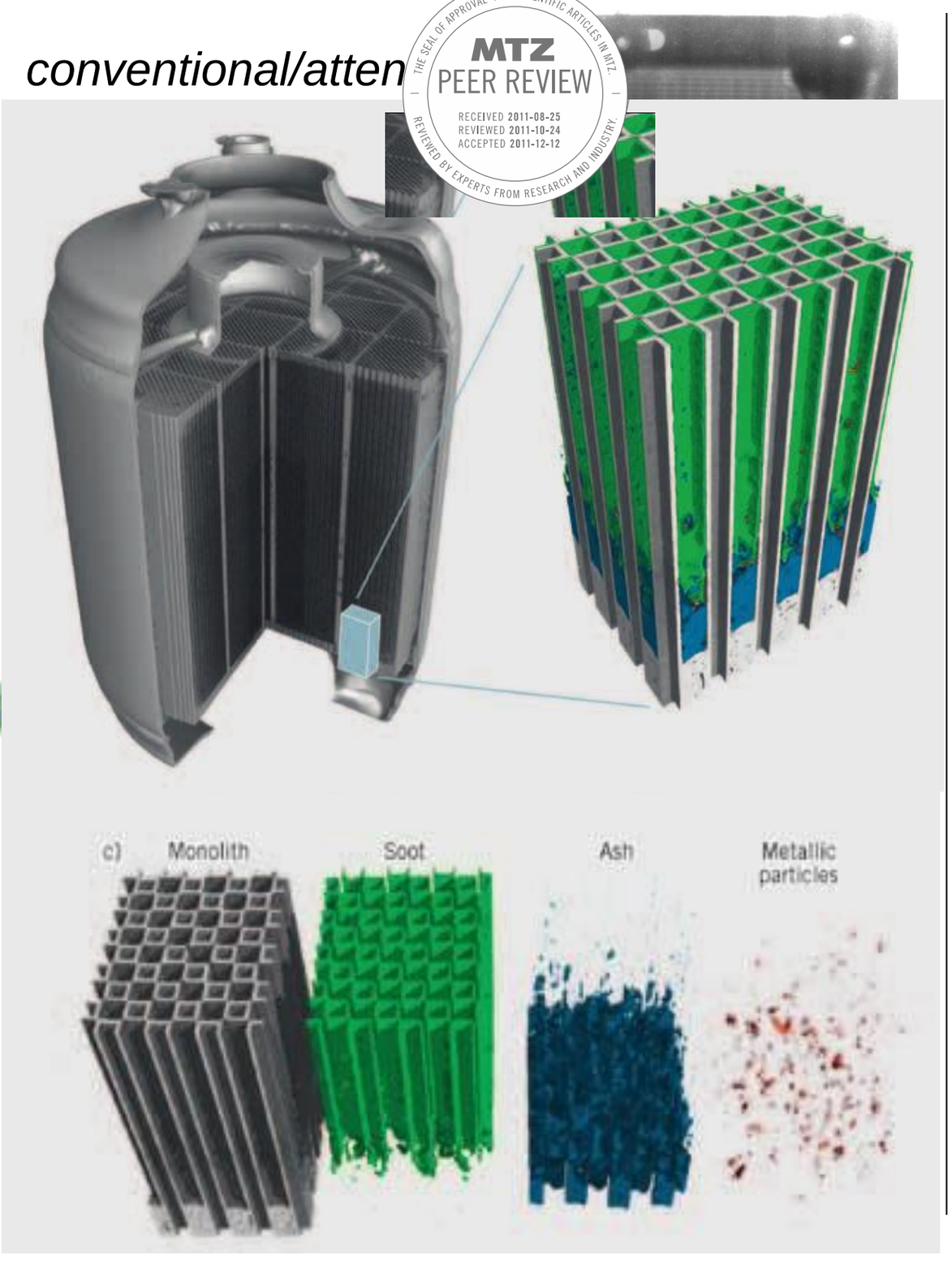
Guide & Choppers



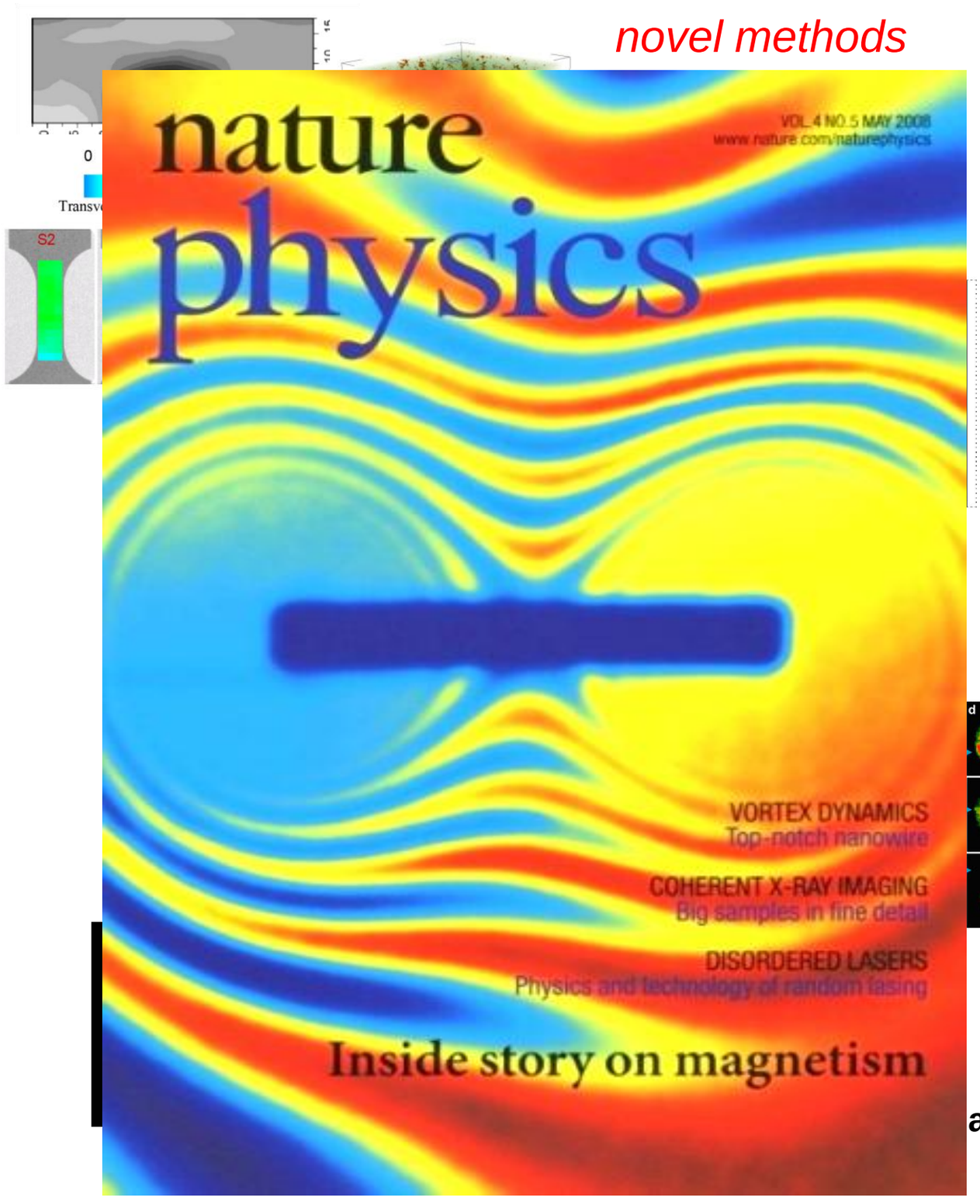


great future prospects

conventional/atten



novel methods



aging

Nature Physics **4** (2008)

Our vision for 2019!

Complementary world-class science facilities!

For Imaging!

Thank you !

EUROPEAN SPALLATION SOURCE

Markus Strobl

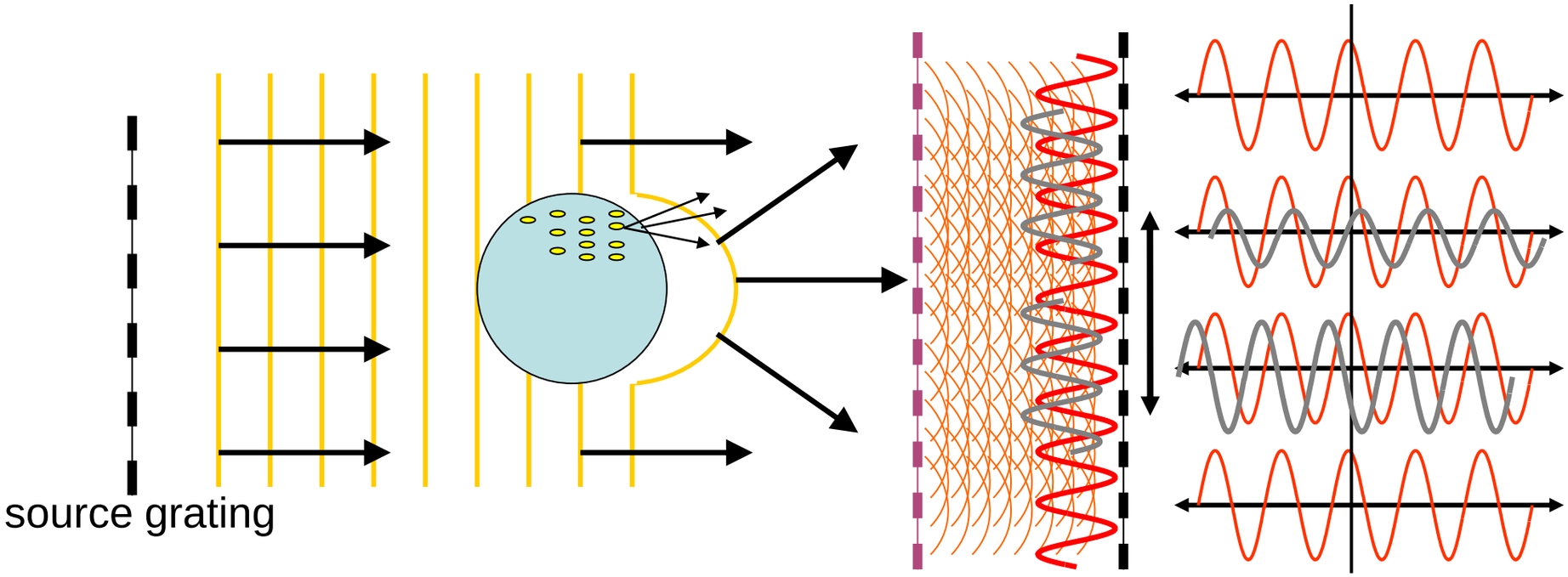
Instrumentation Division - Imaging

Instrumentation Division@ ESS

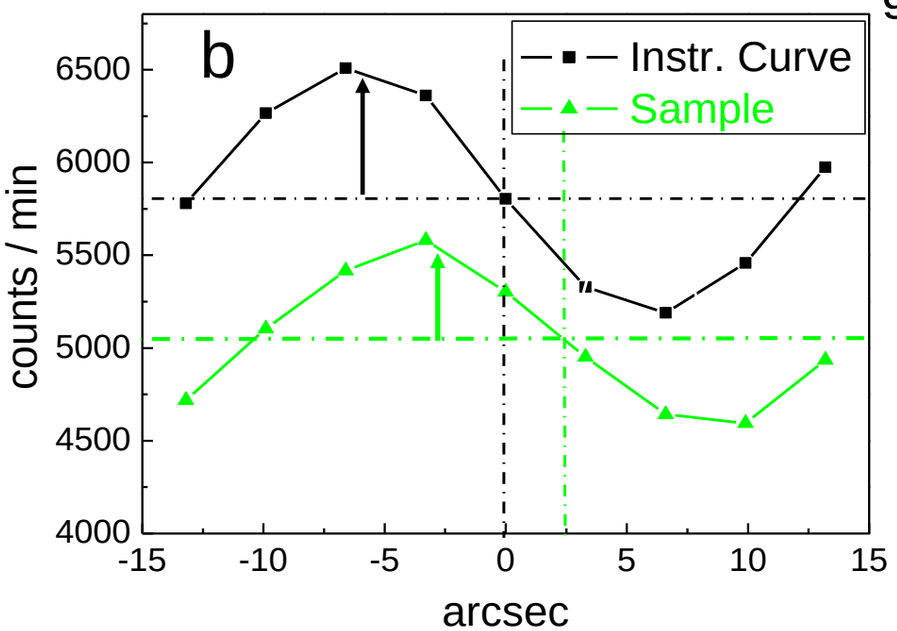
NIUS ESS-Science Symposium April 2012

Imaging methods for ESS

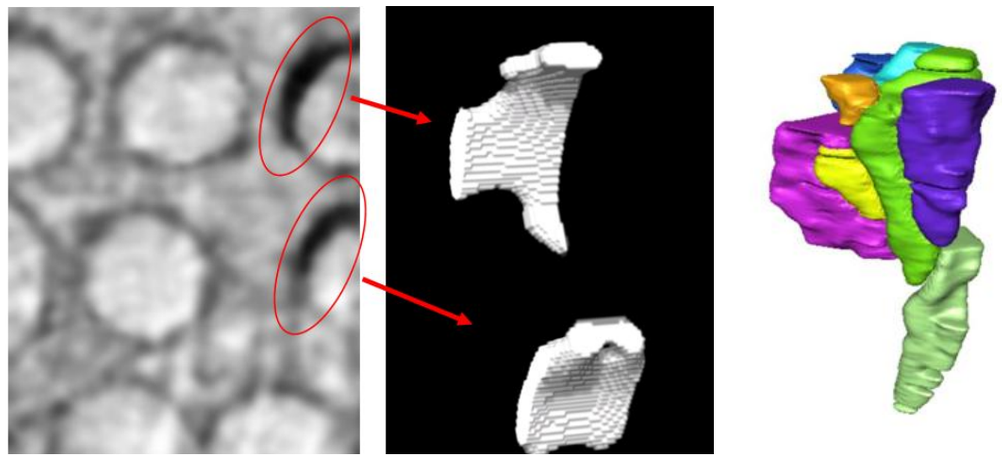
Dark field contrast



grating interferometer (F.Pfeiffer et al PRL2006)



I. Manke et al. Nat. Com. 2010

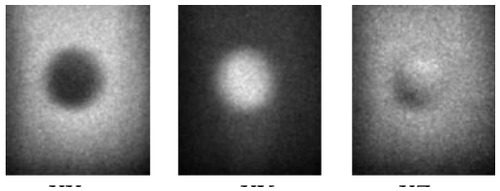


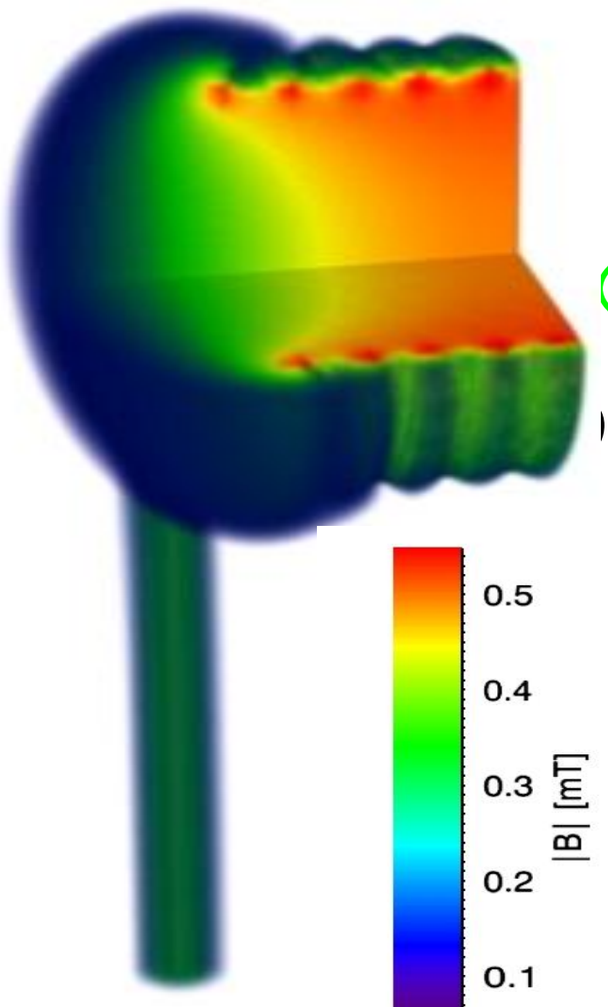
M. Strobl et al., APL (2004)

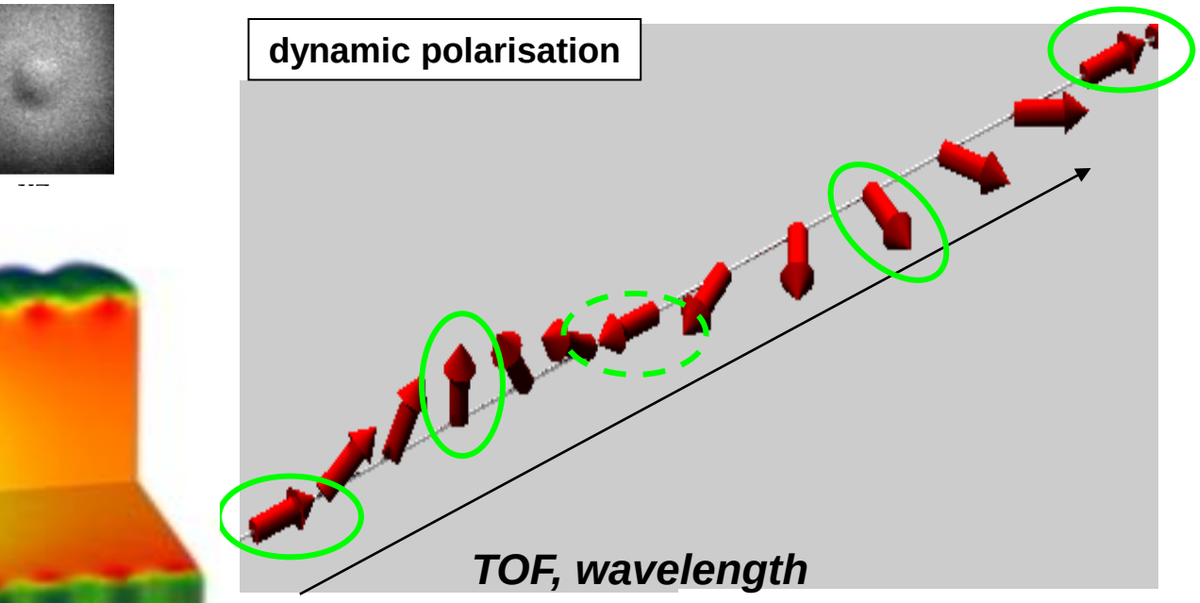
M. Strobl et al. PRL (2008)

Imaging methods for ESS

3D vector quantification through multiple wavelengths

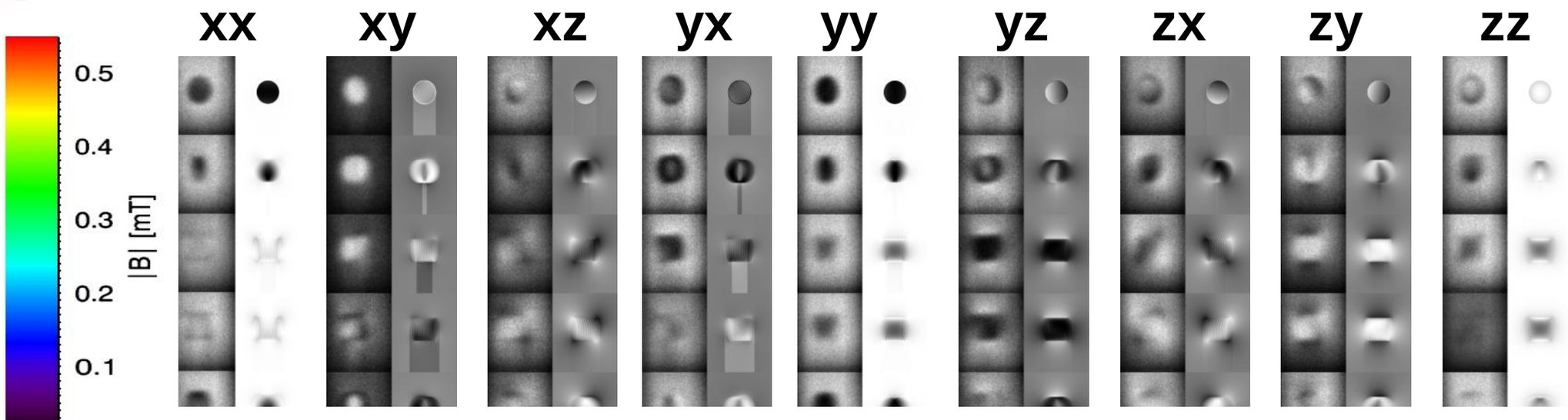




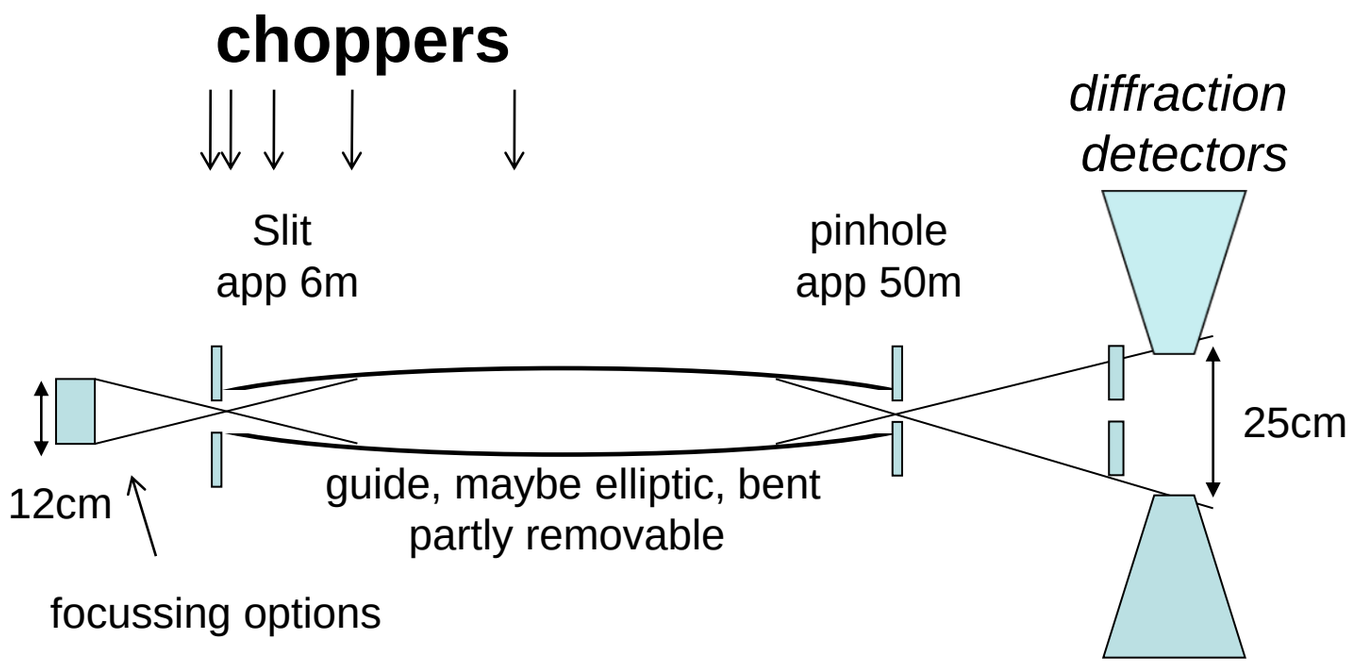


pulsed TOF multi-wavelength measurements for quantification, vector field reconst.

M. Strobl NIMA 2009



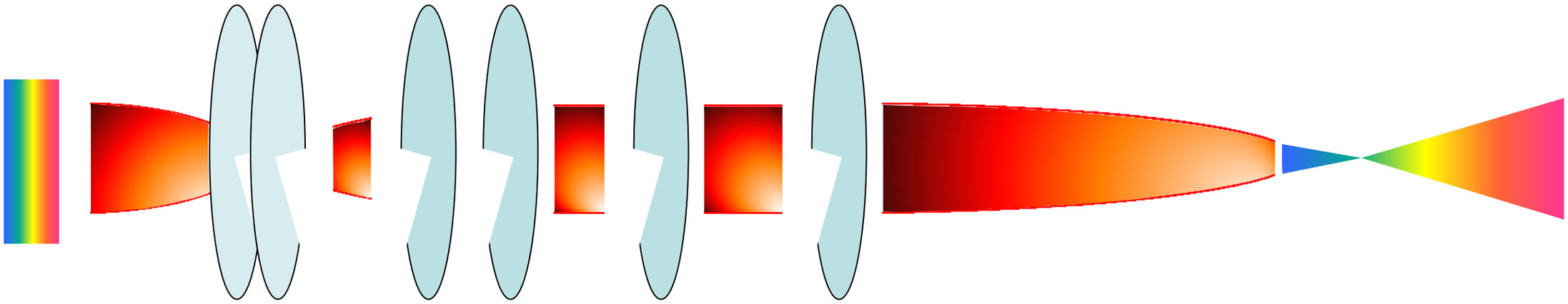
Imaging at ESS

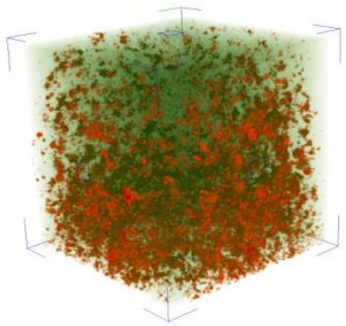


length app. 60 m
3 - 6 frames

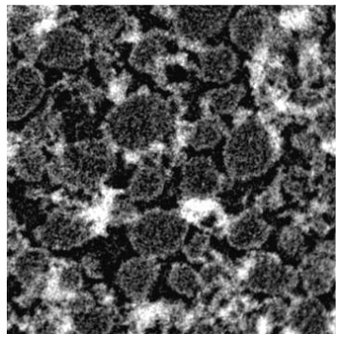
Conventional			*25x25cm²*
strain	*0.5/1.5 – 5A*	*0.5%*	*10x10cm²*
microstr	*2-6A*	*10%*	*10x10cm²*
Texture	*0.5/1.5-5A*	*1%*	*10x10cm²*
polarized	*1.5-10/20A*	*1%*	*5x5(10x10)cm²*
DF	*1.5-10/20A*	*10%*	*15x15cm²*

Imaging at ESS

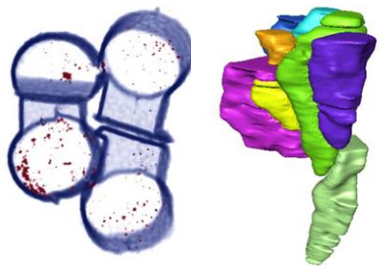




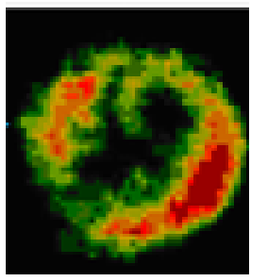
Bragg edge diffraction imaging



High resolution conventional imaging



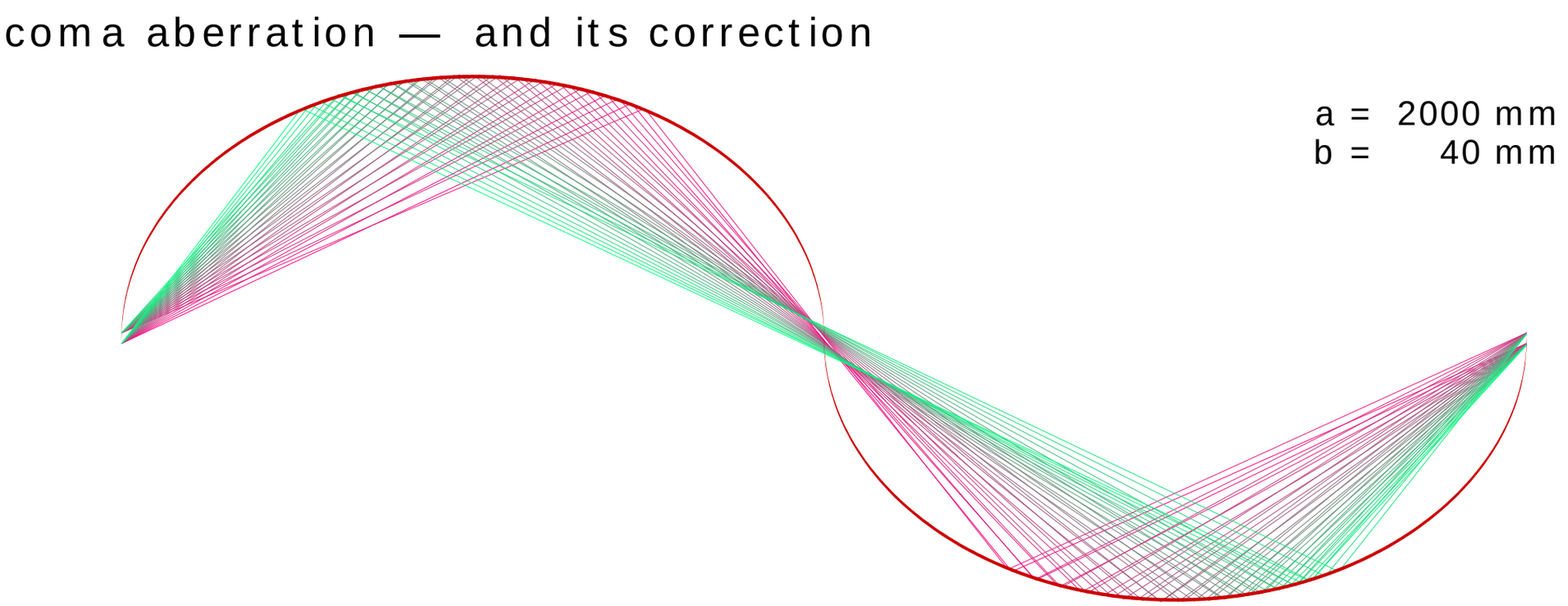
Structural and magnetic dark-field imaging
Spatial resolved SANS

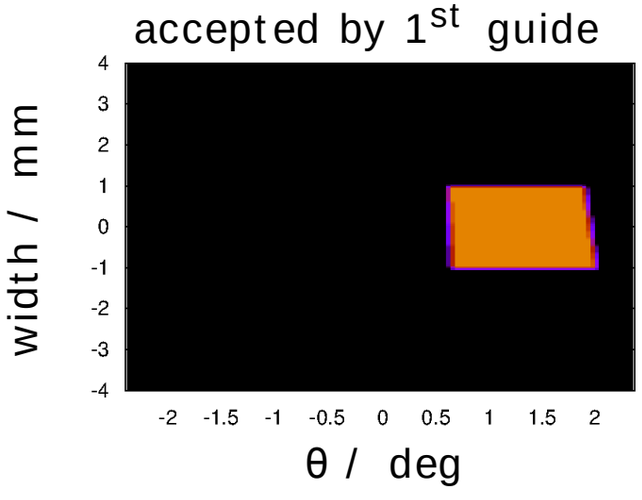


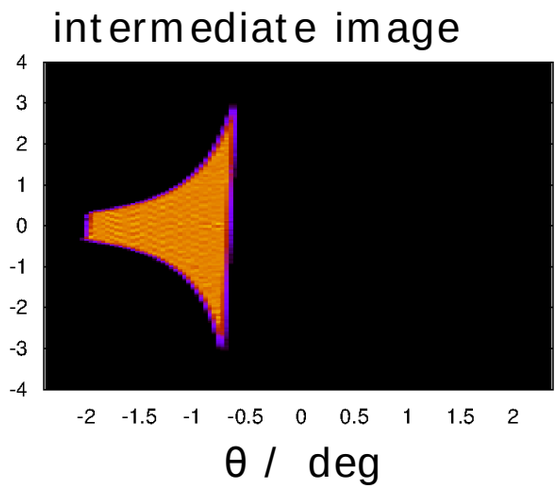
Polarized neutron imaging

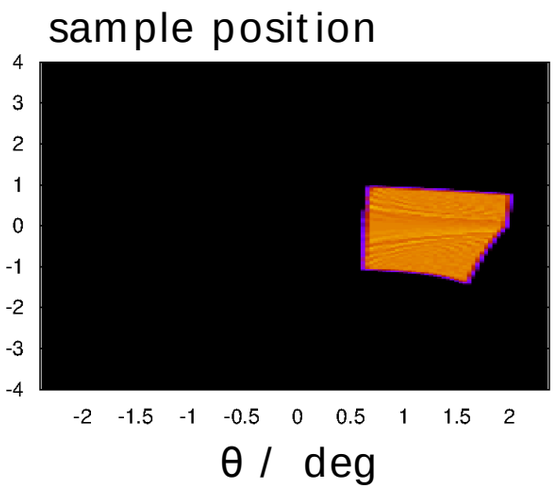
In-kind contributions from HZB, PSI, TUM, RID with ESS to TOF method development
Synergy with JRA!

SELENE for imaging at ESS
topic for Swiss WP



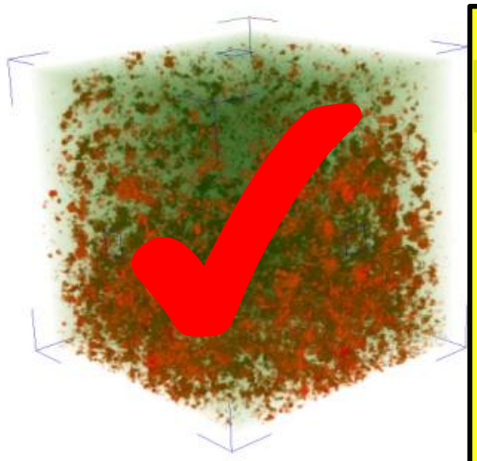




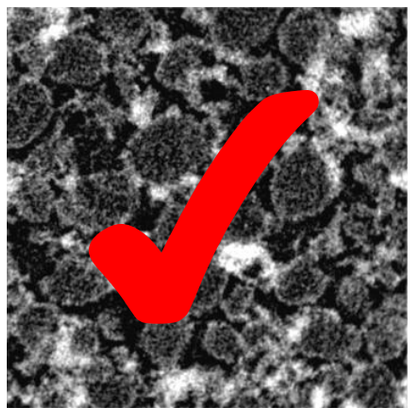


however, they require…

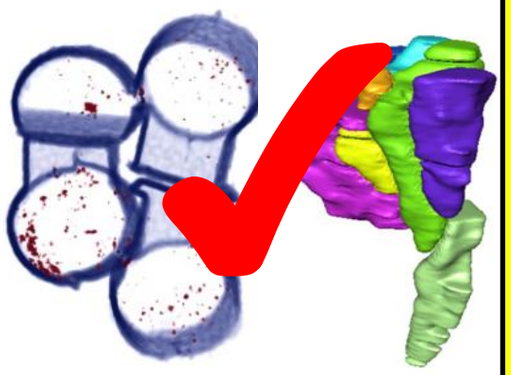
band resol. size



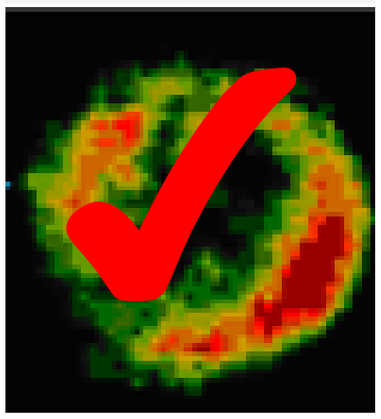
strain
0.5/1.5 – 5A 0.5% 10x10cm²
texture/phase
0.5/1.5-5A 1% 10x10cm²
microstructure
2-6A 10% 10x10cm²



conventional
white beam/10%monochrom.25x25cm²



nuclear and magn. DF
1.5-10/20A 10% 10x10cm²



quantitative polarized
1.5-10/20A 1% 5x5(10x10)cm²

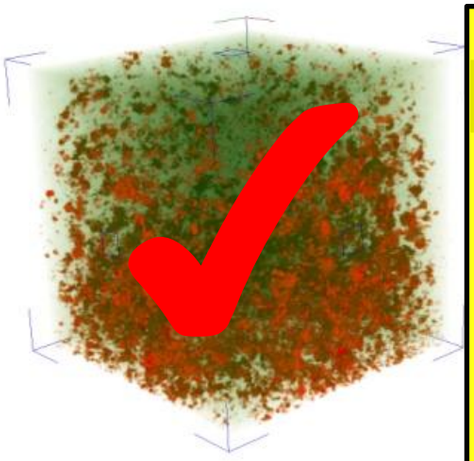
depolarisation
white beam 10x10cm²

excessive resolution & band is highly inefficient!!

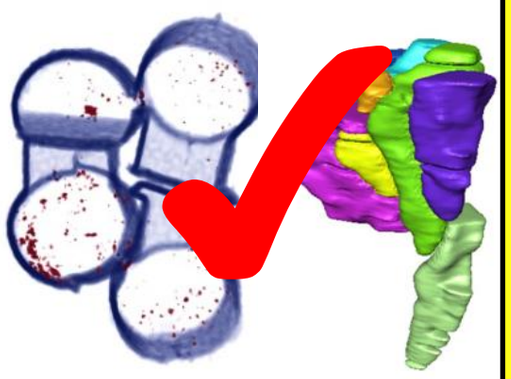
ESS long puls time structure provides opportunity to tailore resolution to requirements!!

..for efficient instrumental realization

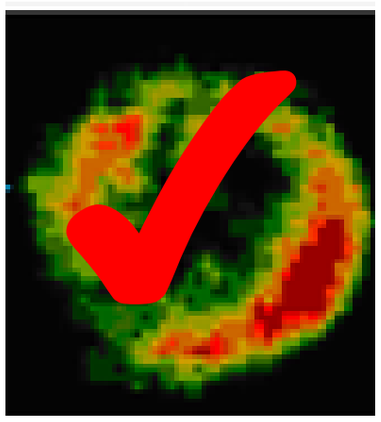
band resol. size



strain
0.5/1.5 – 5A 0.5% 10x10cm²
texture/phase
0.5/1.5-5A 1% 10x10cm²
microstructure
2-6A 10% 10x10cm²



nuclear and magn. DF
1.5-10/20A 10% 10x10cm²



quantitative polarized
1.5-10/20A 1% 5x5(10x10)cm²

depolarisation
white beam 10x10cm²

total length matches loosest resolution (10%) for shortest wavelength

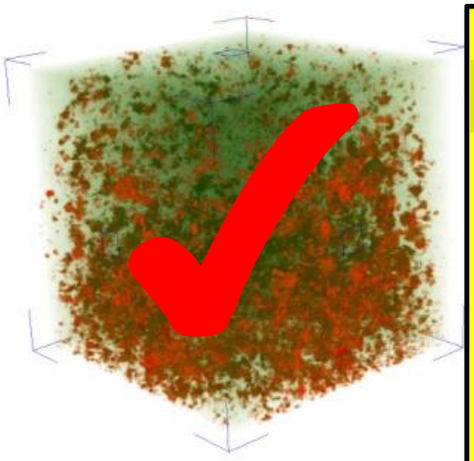
→ app. 60m

→ band 4.5A

with pulse supression option: 9A, 13.5A...

..for efficient instrumental realization

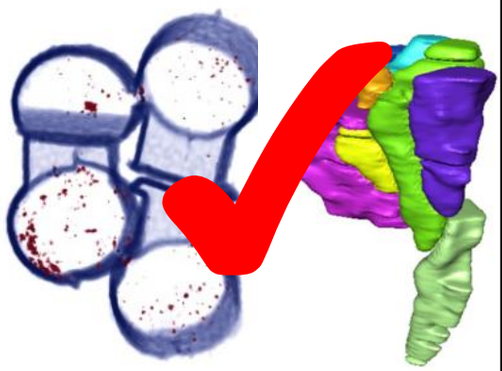
band resol. size



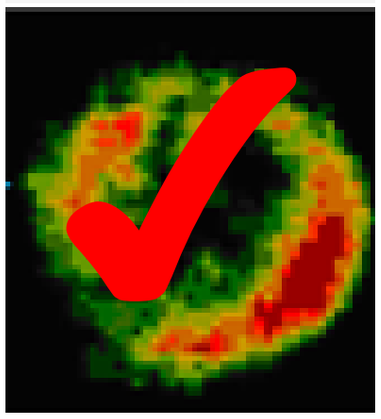
strain
0.5/1.5 – 5A 0.5% 10x10cm² ✓

texture/phase
0.5/1.5-5A 1% 10x10cm² ✓

microstructure
2-6A 10% 10x10cm² ✓



nuclear and magn. DF
1.5-10/20A 10% 10x10cm² ✓



quantitative polarized
1.5-10/20A 1% 5x5(10x10)cm² ✓

depolarisation
white beam 10x10cm²

→ *app. 60m*

→ *band 4.5A (e.g. 2-6.5A)*

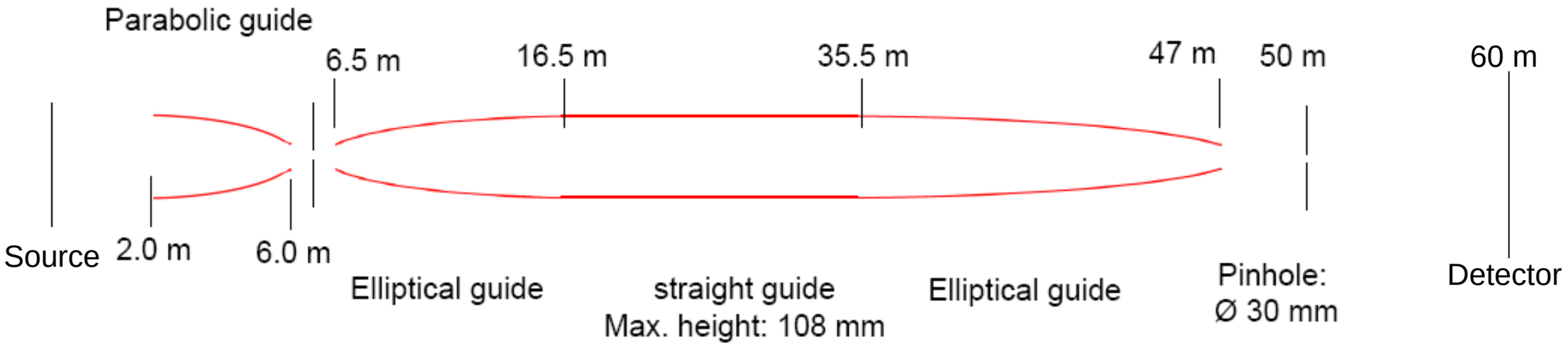
with pulse supression option: 9A, 13.5A...

*Opt. blind double chopper for tuning resolution down to **1%** and **0.5%** in WFM mode incl. pulse suppression mode*

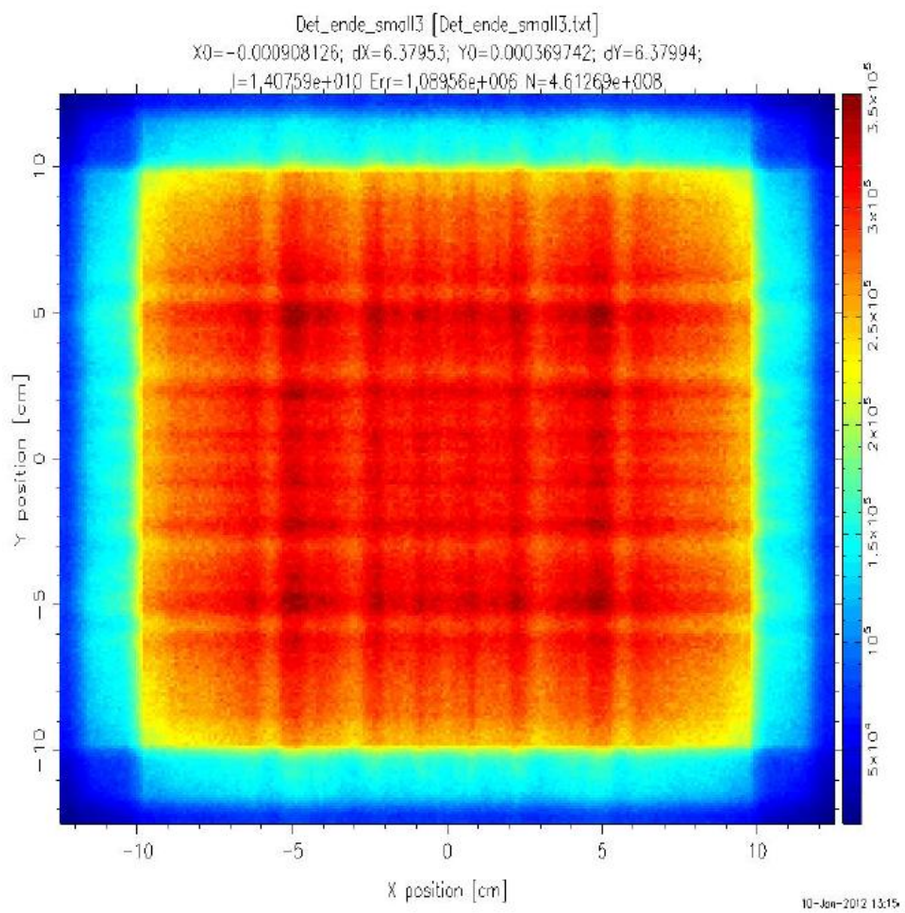
(Developed at ESS-Testbeamline at HZB)

M. Strobl et al.

Guide simulations and Benchmark German WP (HZB)



Neutron flux distribution at the sample position



- The guide system transports 80 % of the initial neutron flux (realted to Benchmark)
- Homogenous flux distribution at the sample position.

EUROPEAN SPALLATION SOURCE

great future prospects

Nuclear Instruments and Methods in Physics Research A 604 (2009) 646–652

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Future prospects of imaging at spallation neutron sources

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Advanced neutron imaging methods with a potential to benefit from pulsed sources

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forward in efficient neutron
ower time-averaged neutron
hniques can be derived from
d into energy, respectively,
lies on an intense continuous
Nevertheless, some recently
nergy resolution. The impact
been investigated, ways to
ng instruments and possible
utlined.

great future prospects

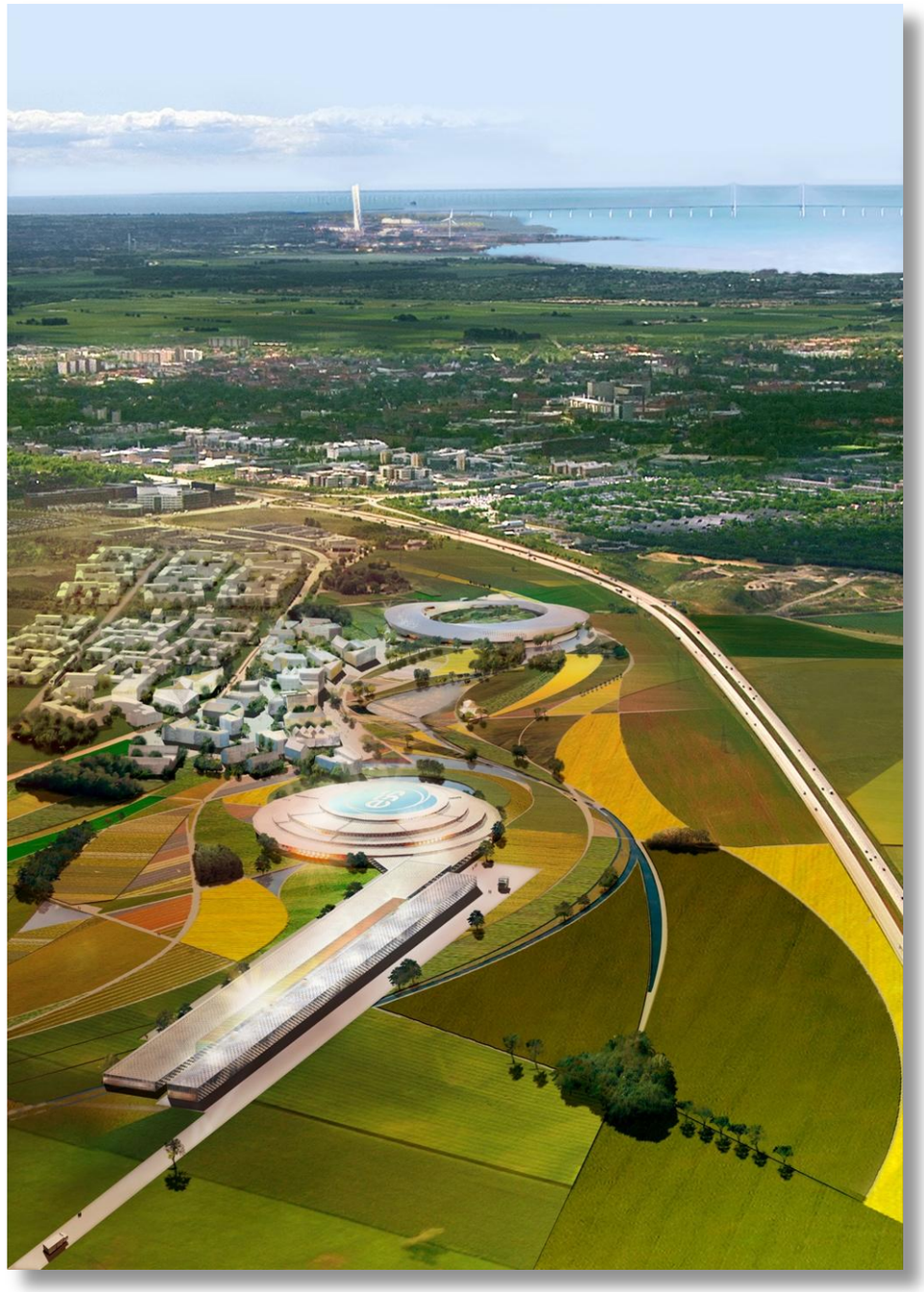
Timeline

- TDR due fall 2012
- 3 instruments selected to start construction 20
selection process repeated every year
- 7 instruments selected between 2012 and 14 a
- “day-one instruments” – start operation 2019
- 15 more accomplished in 2025

The ESS in a Nutshell

- Accelerator 4-500 m long proton linear accelerator at 1.0 GeV
- 2.86 ms pulses, 14 Hz, 5 MW
- rotating tungsten target, He cooled
- 22 neutron dedicated instruments – upgradeable to 33+ instruments

- Supports a 5000-strong user community
- 2000-3000 user visits p.a.
- 450 staff



- Capital Cost : 1,5 B€ + 100 M€ site-specific costs
- Operating Cost 110 M€ p.a.
- Decommissioning Cost 344 M€
- First neutrons 2019