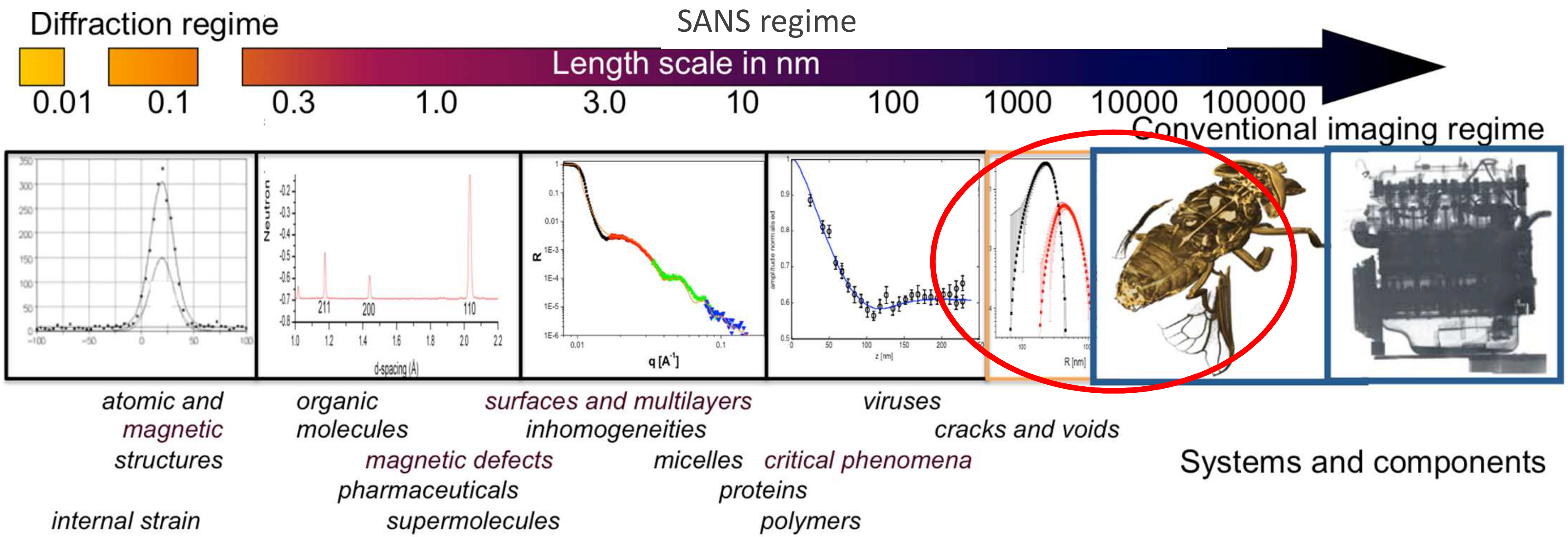
Beamline Design for Imaging

M. Strobl
Deputy Head of Instrument Division
Prof. X-ray and Neutron Imaging Techniques (NBI, KU)
www.europeanspallationsource.se

AUNIRA Sept. 2015

Neutron Imaging



content

BASIC

- Imaging Geometry
- Basic Imaging Requirements
- Beam Conditioning: Source to Detector
- Standard Imaging Instrumentation (continuous source)

ADVANCED

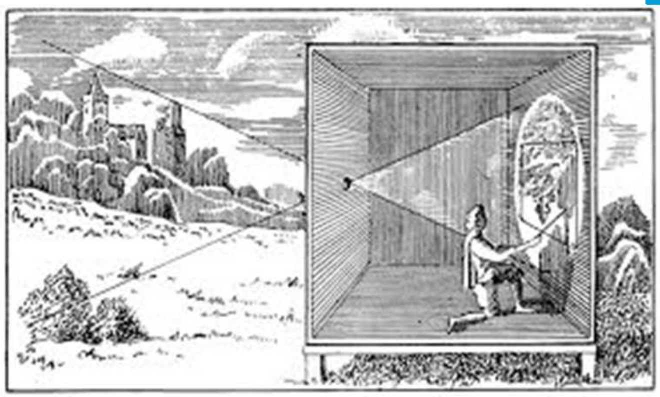
+ Scattering, Diffraction and Polarized Neutrons
+ Additions to Basic Instrumentation: Wavelength Resolution
+ Instrumentation for a Time-of-flight Approach
+ Imaging Instrumentation at Pulsed Sources

Basics

EUROPEAN SPALLATION SOURCE

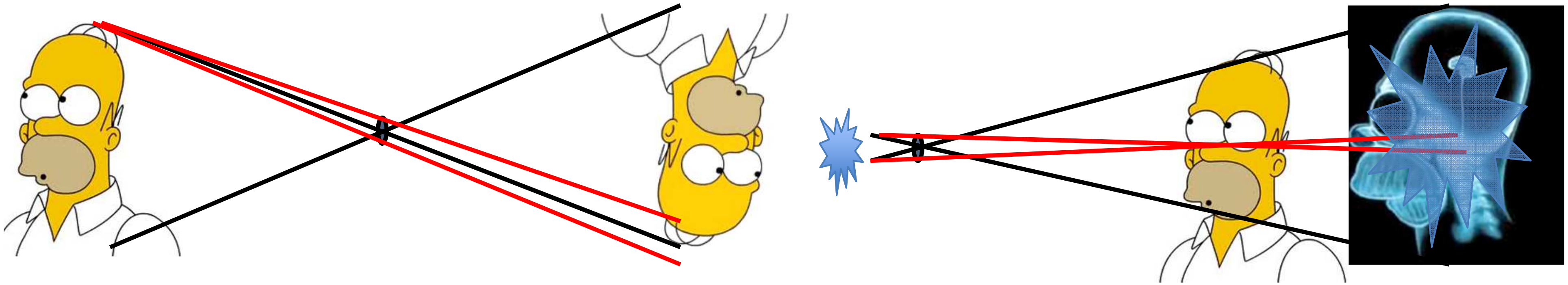
No optics

Basics – Imaging Geometry



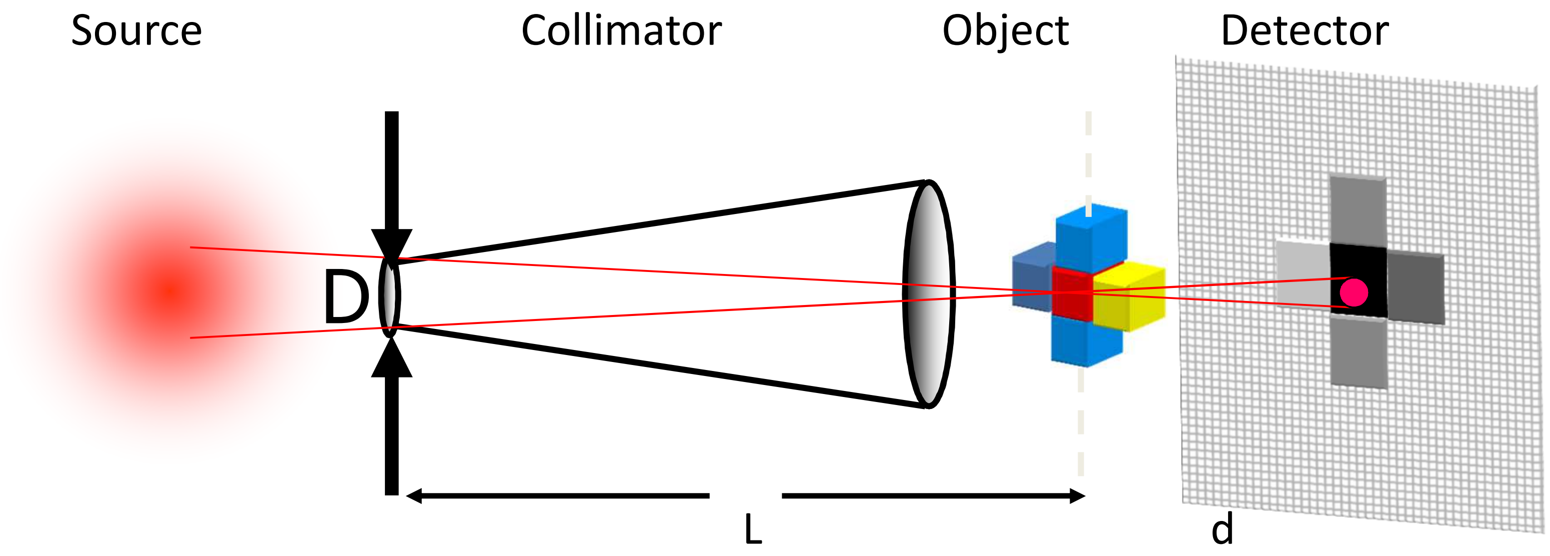
Camera obscura

No optics



But spatial resolution!
Clearly a condition for imaging!

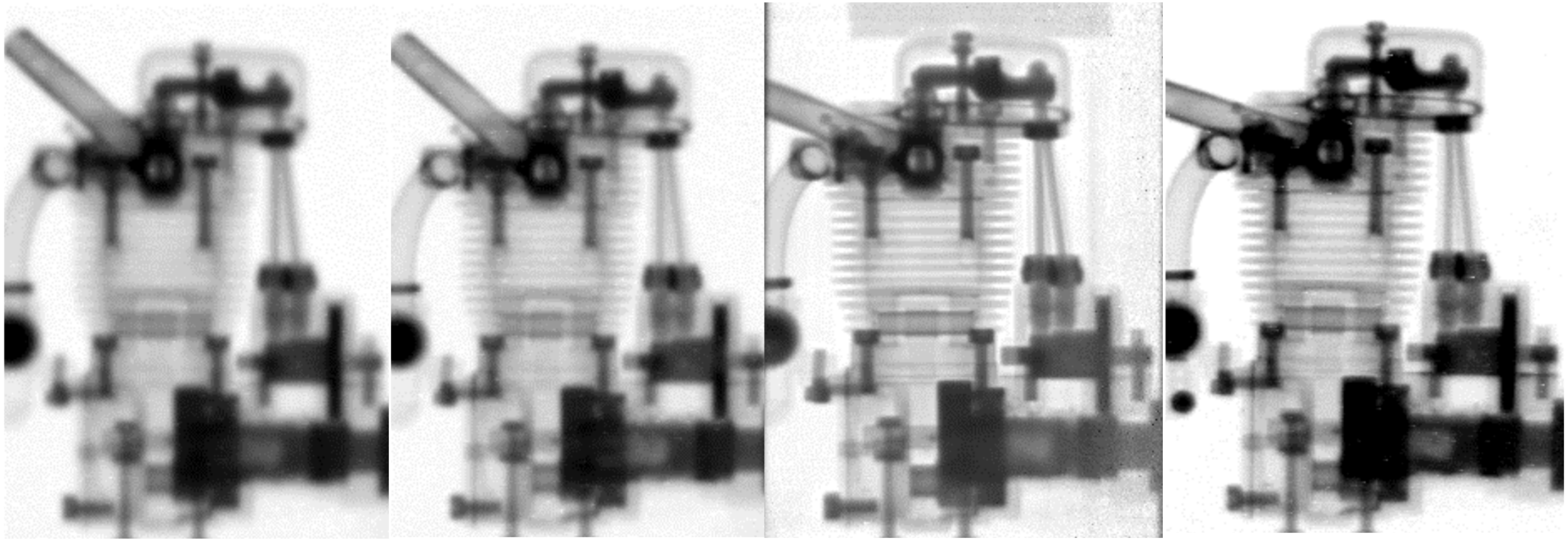
Basics – Imaging Geometry



blur

collimation ratio $b = \dfrac{d}{L/D}$ typical: several 100

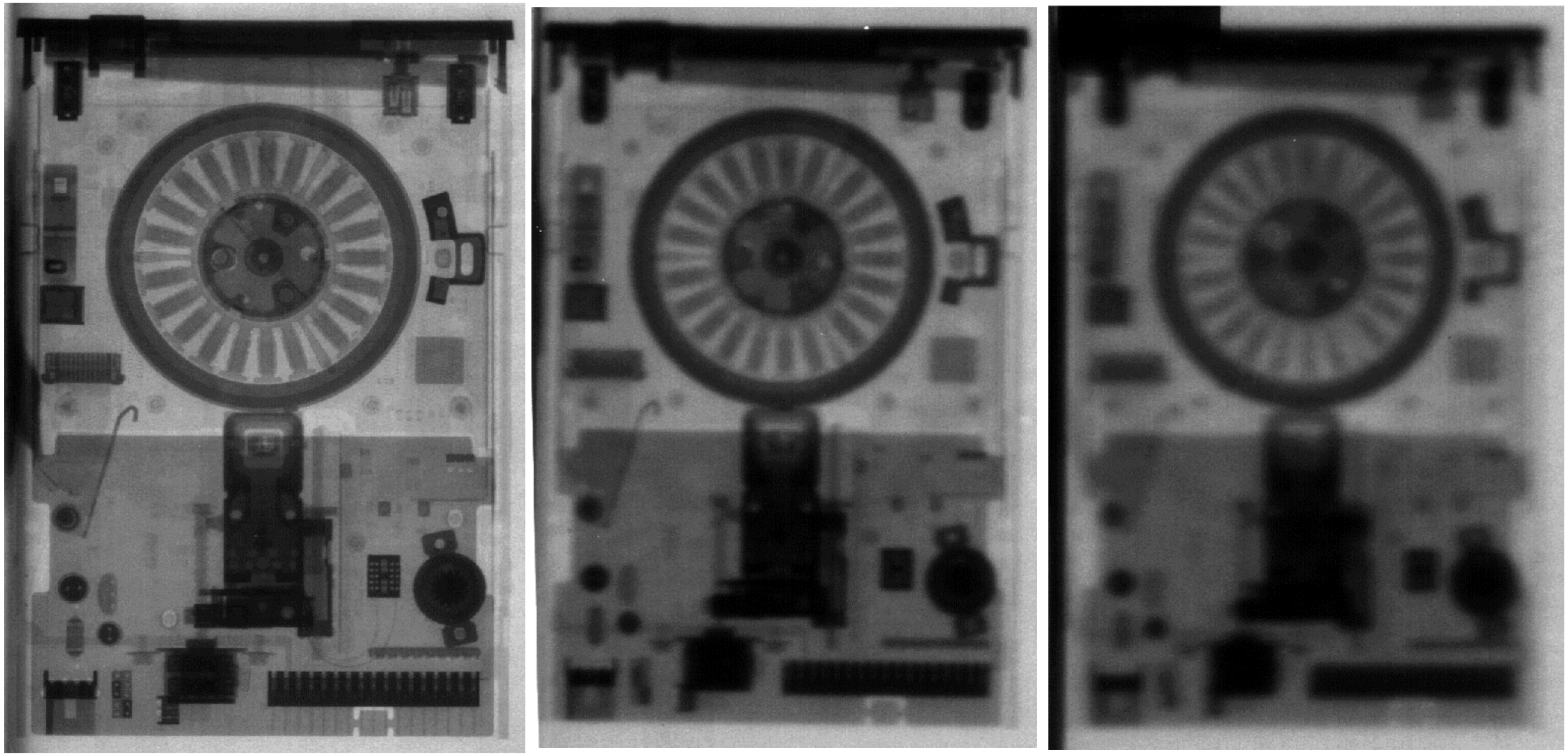
Basics – Imaging Geometry



L/D=71 L/D=115 L/D=320 L/D>500.

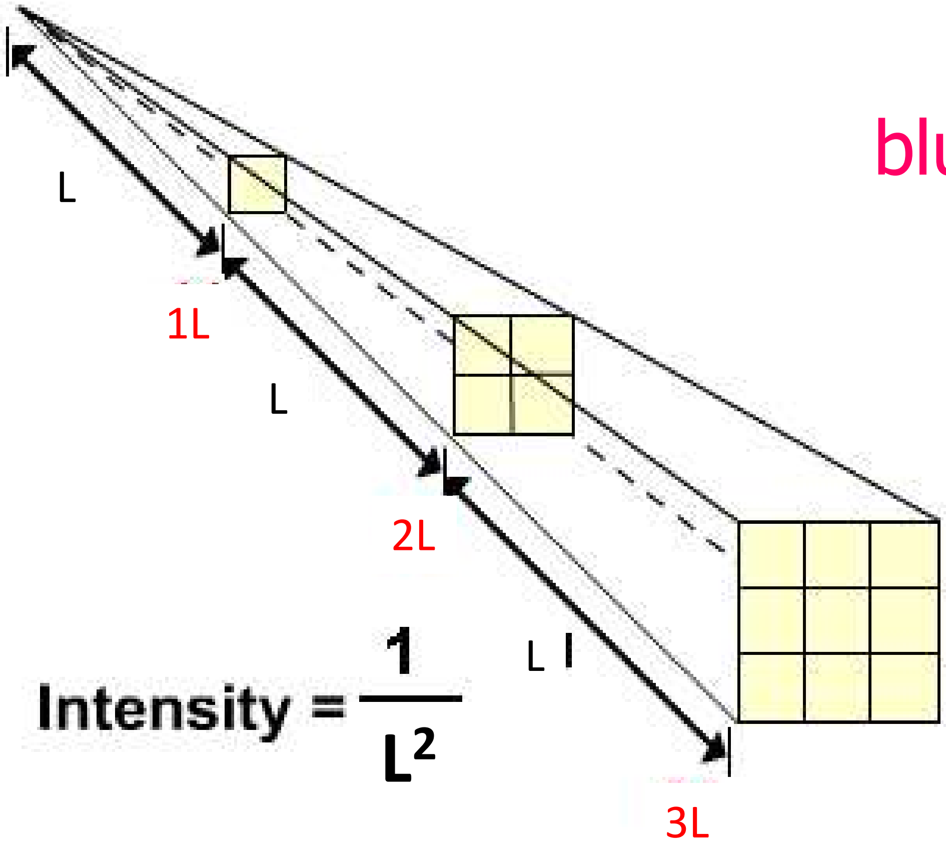
Radiographs of a small motor taken at different beam positions with different L/D ratios.

Basics – Imaging Geometry



Radiographs of a 3,5'' floppy drive in 0 cm, 10 cm and 20 cm distance from a film + Gd sandwich taken at a cold neutron guide with *L/D*=71.

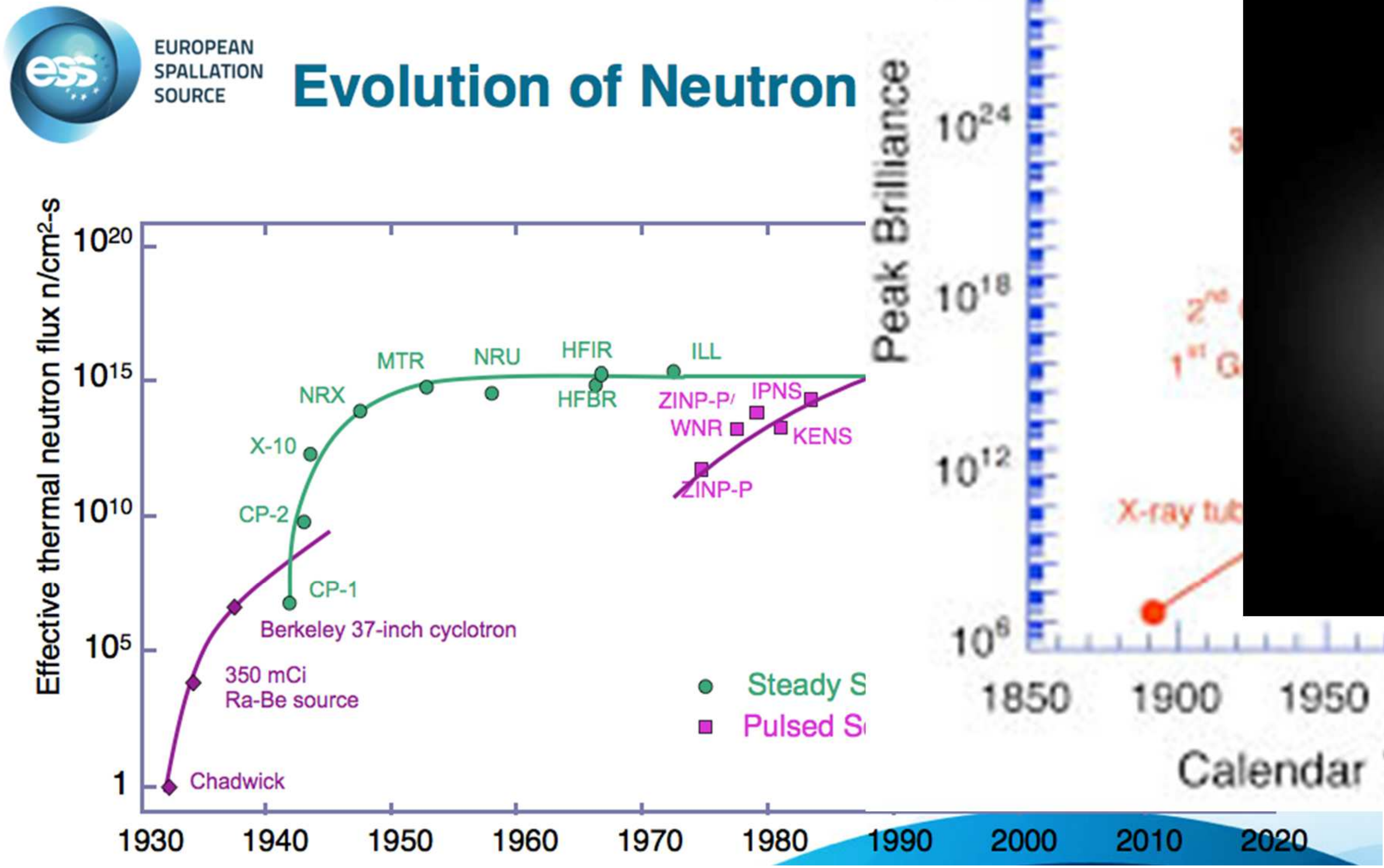
Basics – Imaging Geometry



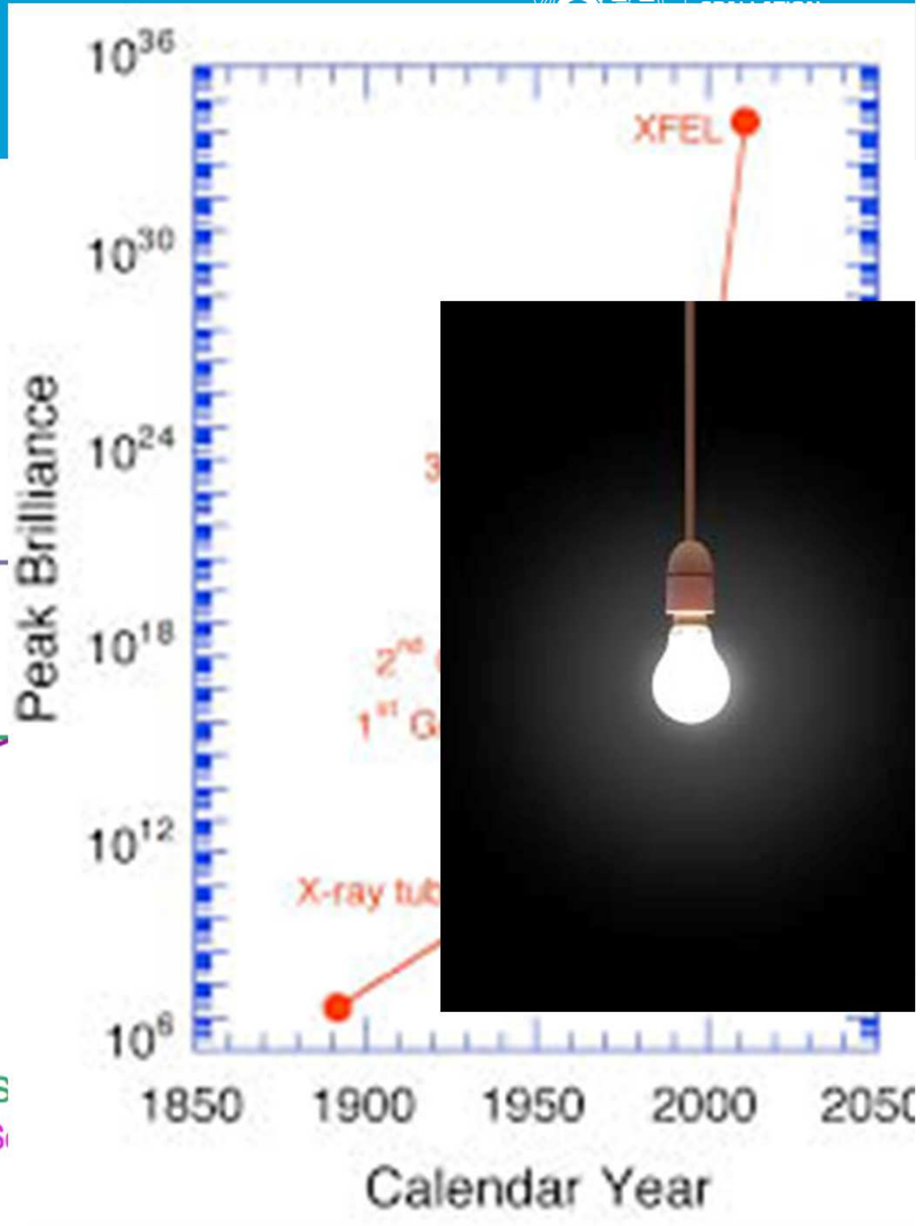
blur

$$b = \frac{d}{L/D}$$

Basics



EUROPEAN
SPALLATION
SOURCE
Evolution of Neutron
Effective thermal neutron flux n/cm2-s
10^20
10^15
10^10
10^5
1
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Chadwick
350 mCi
Ra-Be source
Berkeley 37-inch cyclotron
CP-1
CP-2
X-10
NRX
MTR
NRU
HFIR
HFBR
ILL
ZINP-P/
WNR
IPNS
KENS
ZINP-P
Steady S
Pulsed S



Peak Brilliance
10^36
10^30
10^24
10^18
10^12
10^6
XFEL
X-ray tub
1850
1900
1950
2000
2050
Calendar Year

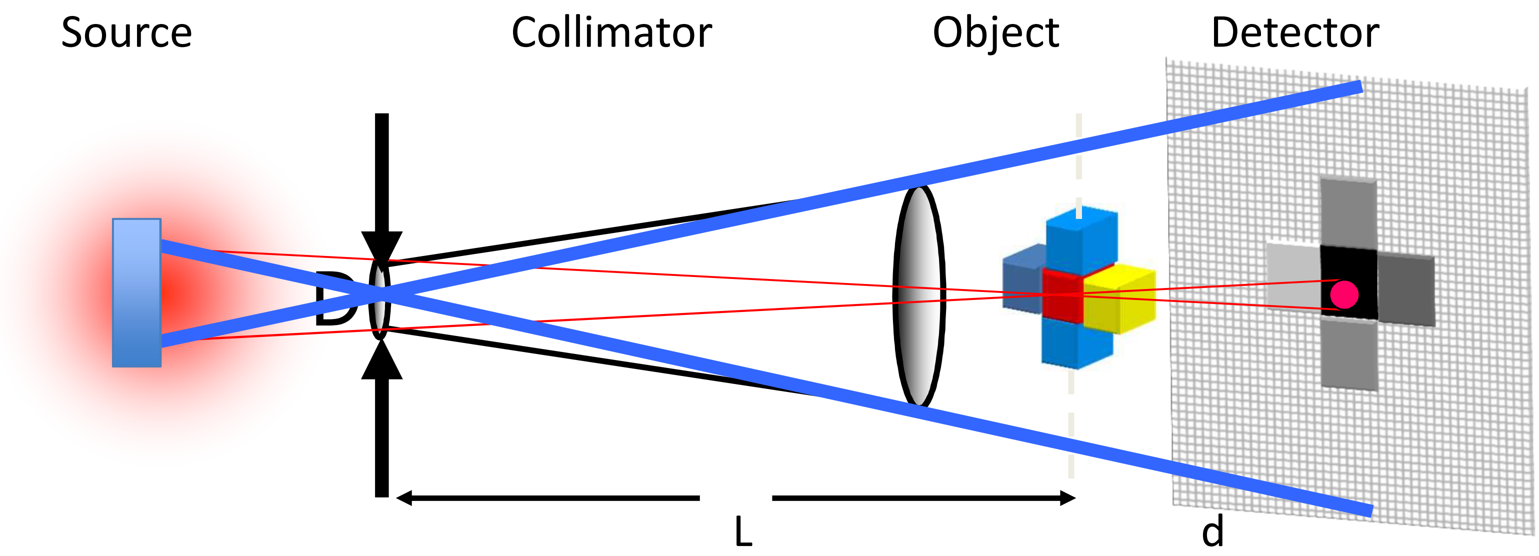
Lens – dan hussey

Basic Requirements

Requirements: - high flux
- large well defined FOV
- spatial homogeneity
- spectral homogeneity
- large detector
- fast detector
- high resolution detector
- save shielding

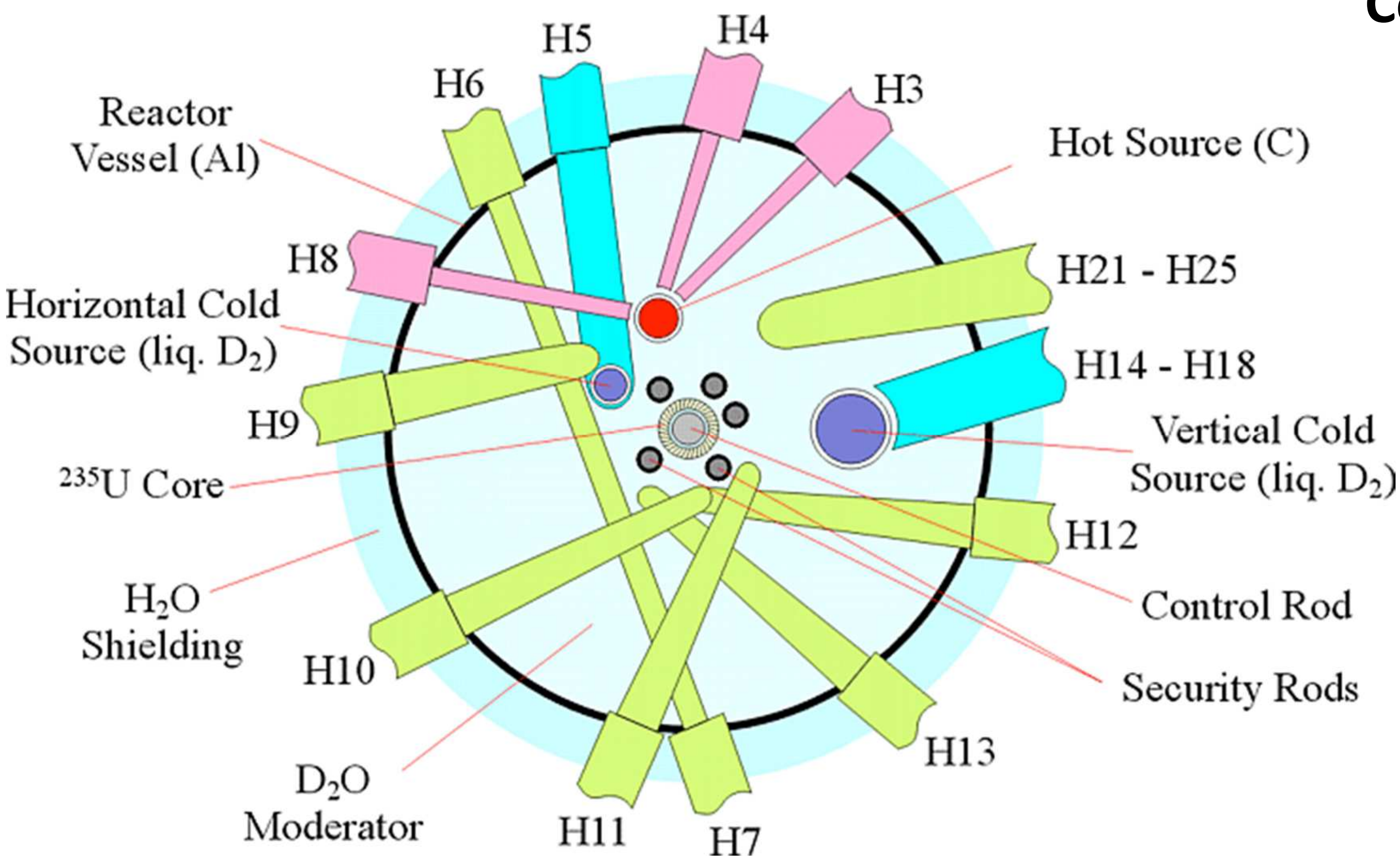
Beam Conditioning: Source to Detector

Requirements: - high flux
- large well defined FOV
- spatial homogeneity
- spectral homogeneity
- large detector
- fast detector
- high resolution detector
- save shielding

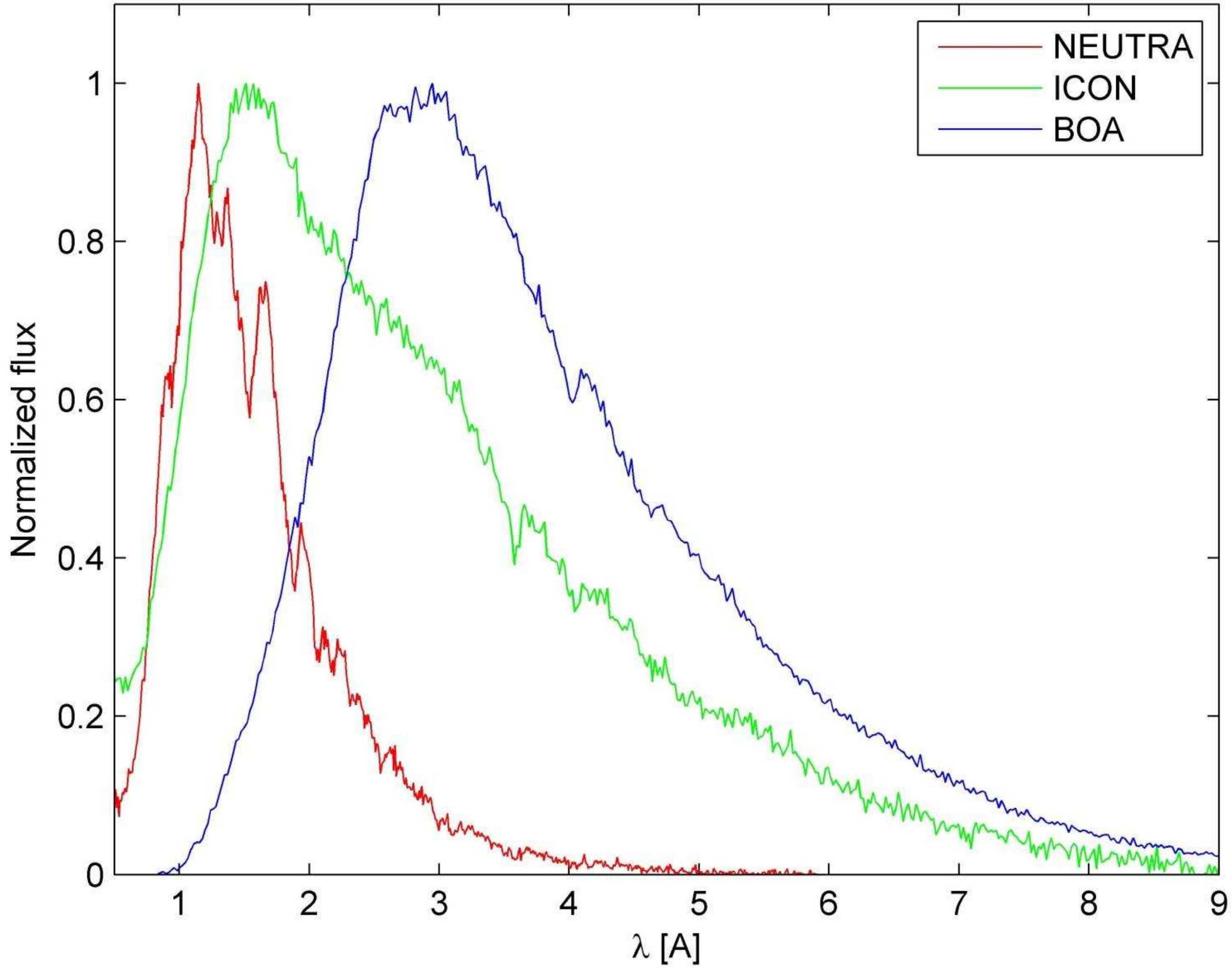


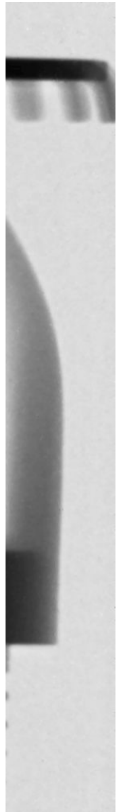
Beam Conditioning: Source to Detector

Direct
Tangential
Cold Moderator
Large
Small

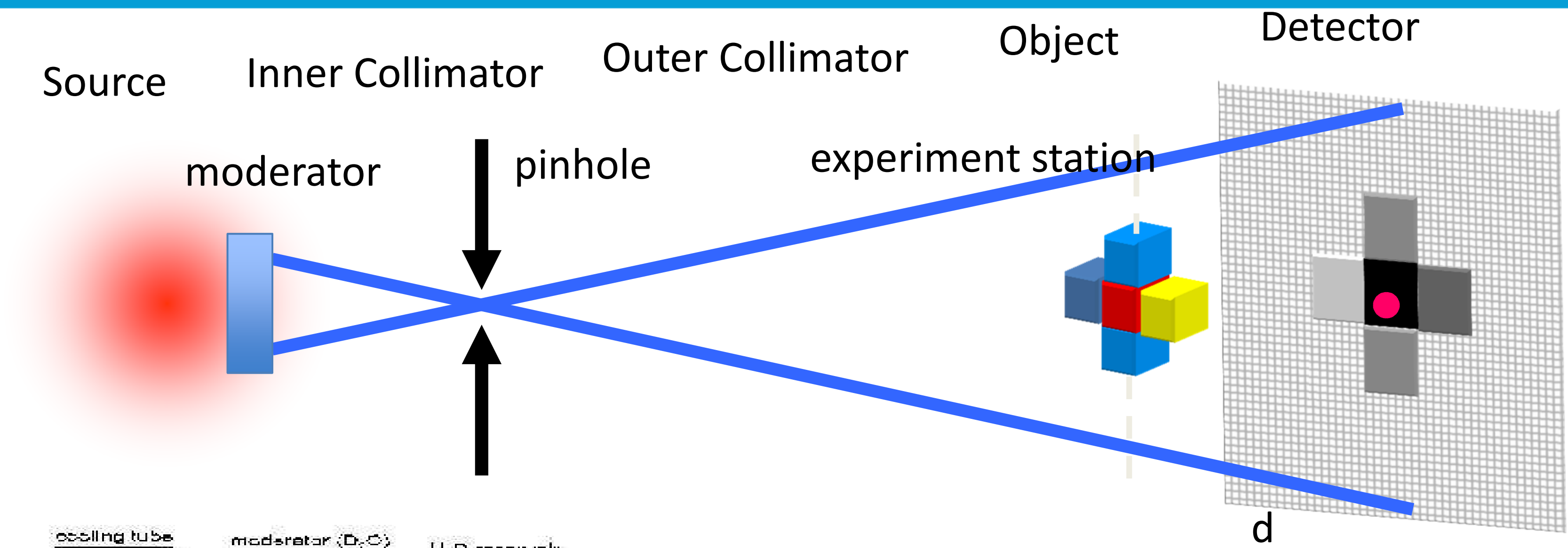


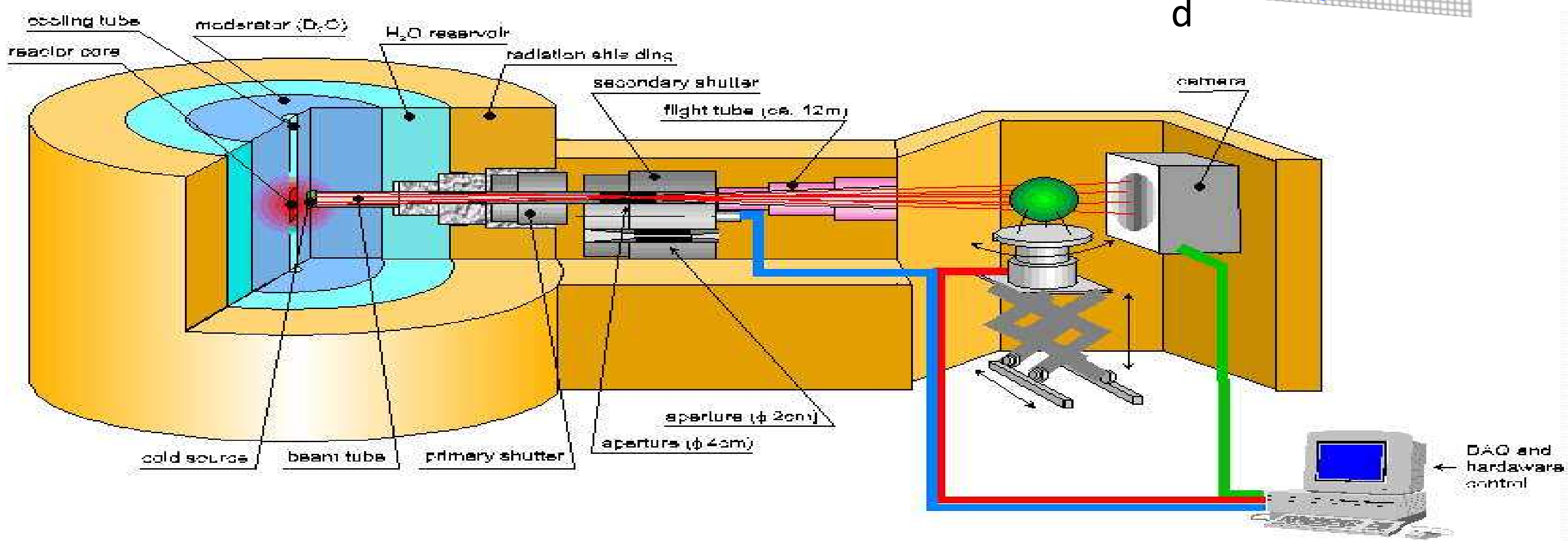
Beam Conditioning: Source to Detector



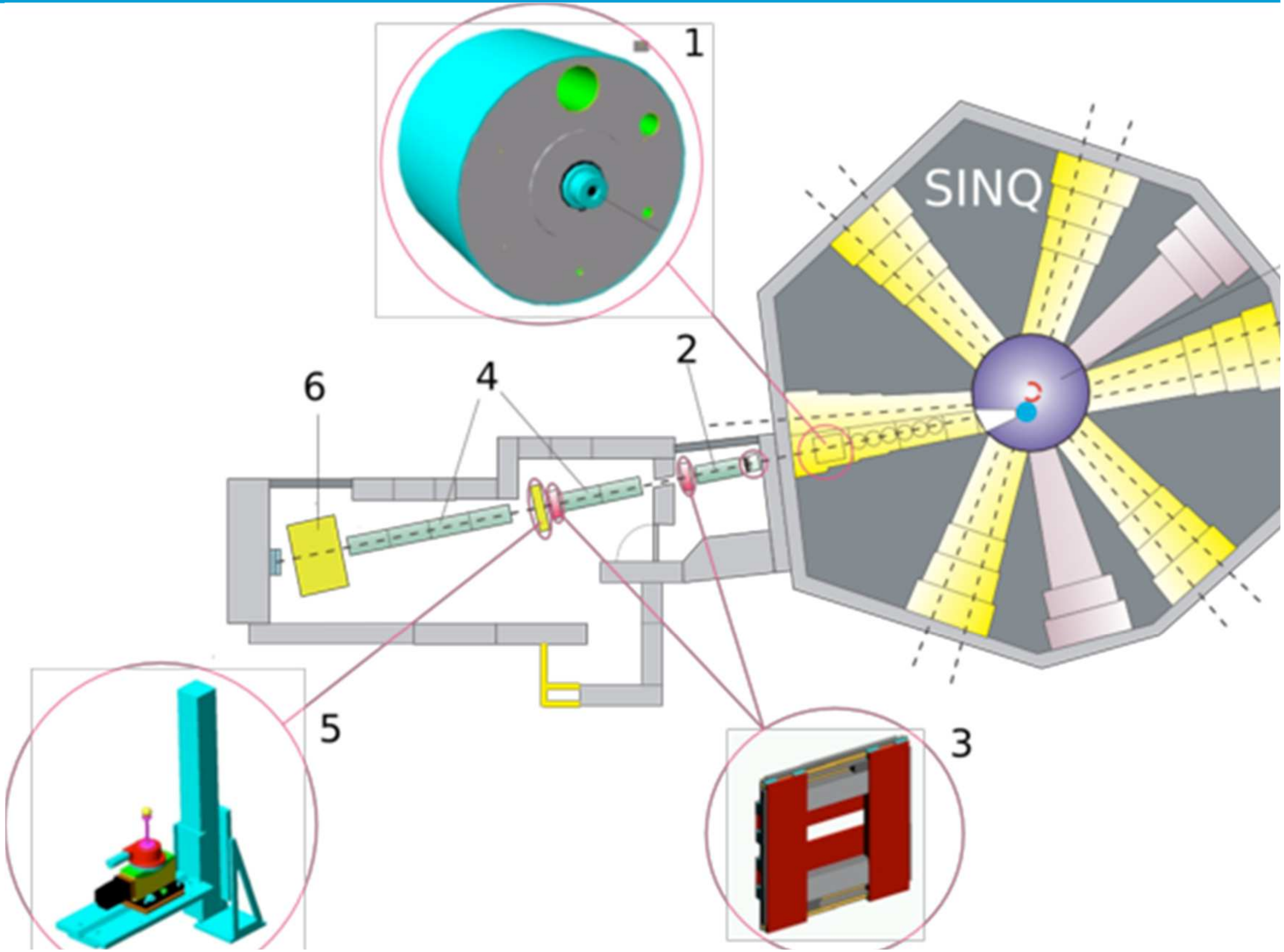


Beam Conditioning: Source to Detector

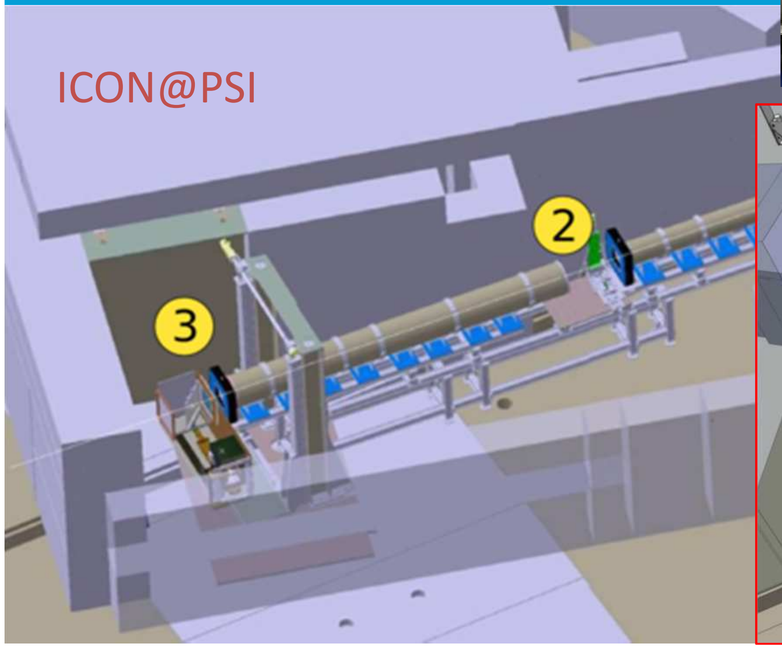


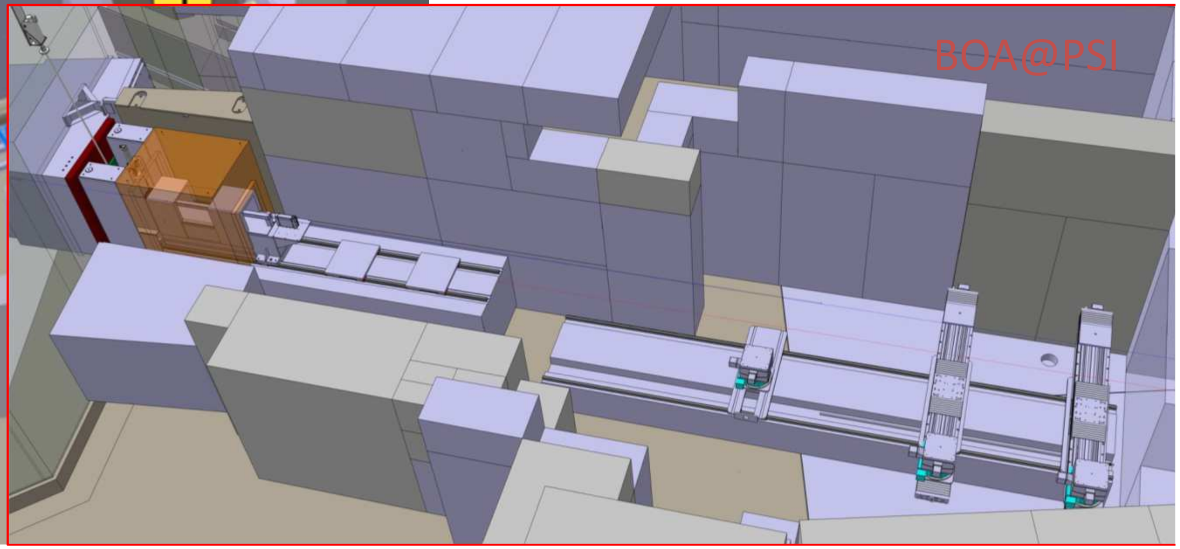


Beam Conditioning: Source to Detector

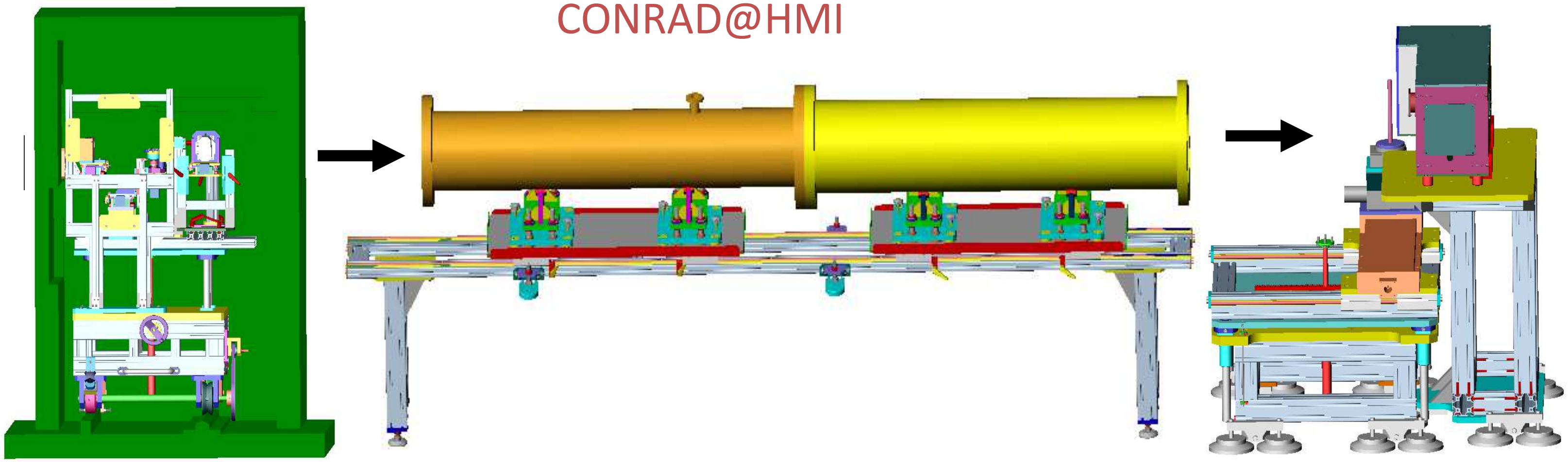


Standard Imaging Inst



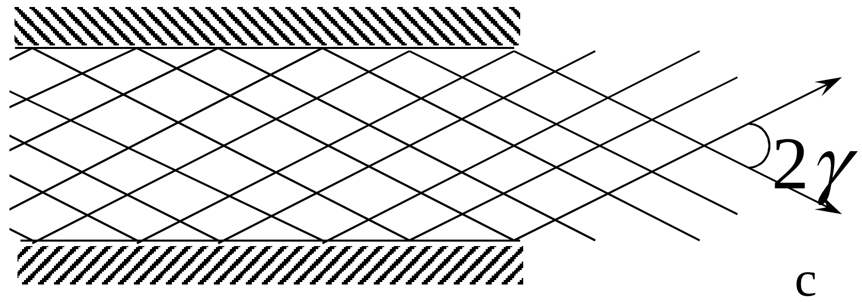


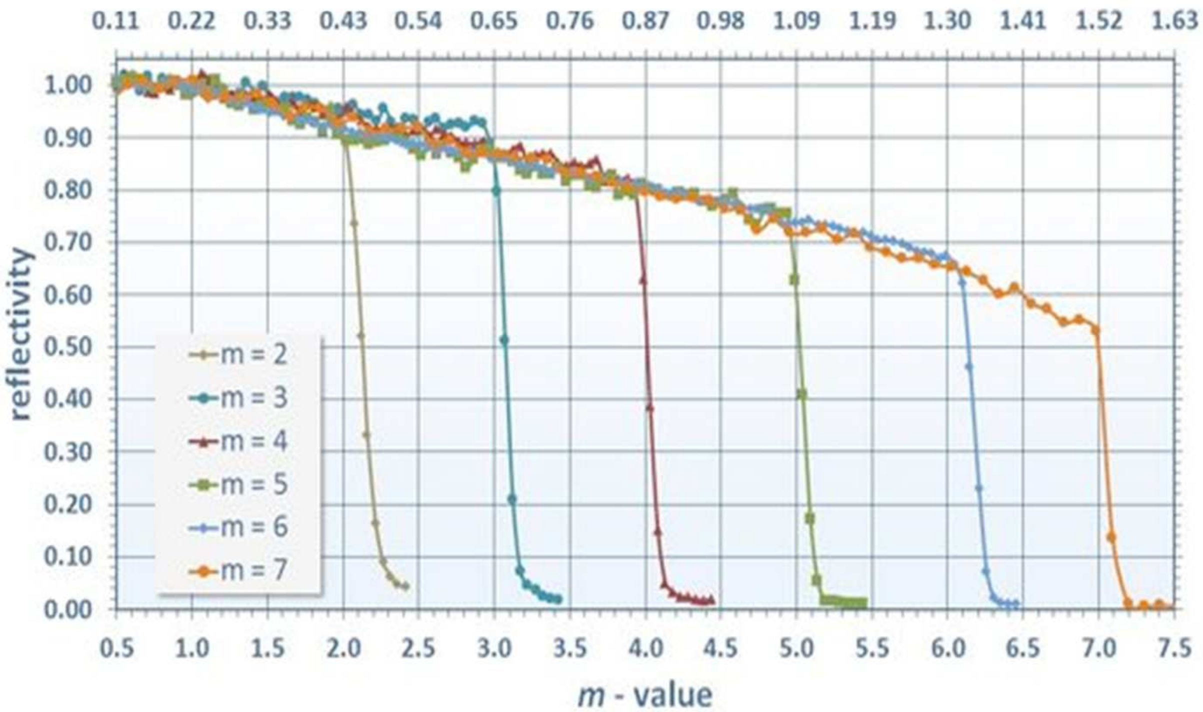
CONRAD@HMI



Standard Imaging Instrumentation

EUROPEAN SPALLATION SOURCE



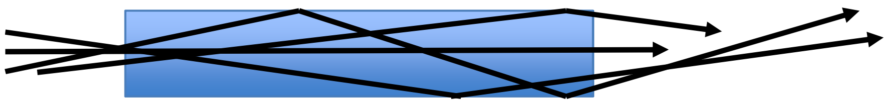


Lower limit L/D

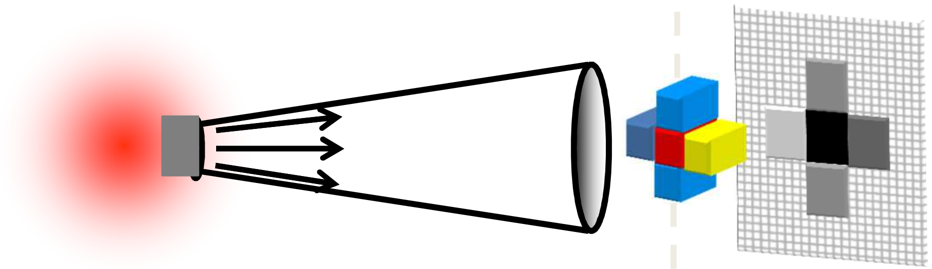
$$L/D = 1/\tan(2\gamma_c(\lambda)).$$

Standard Imaging Instrumentation

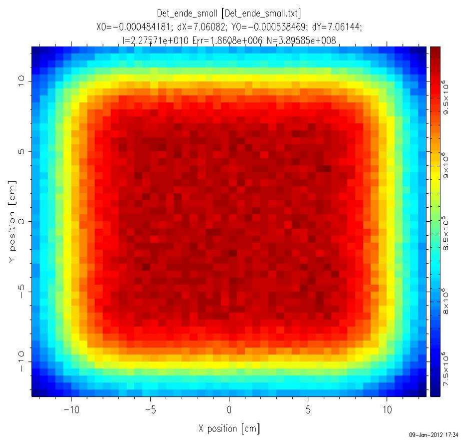
Guide

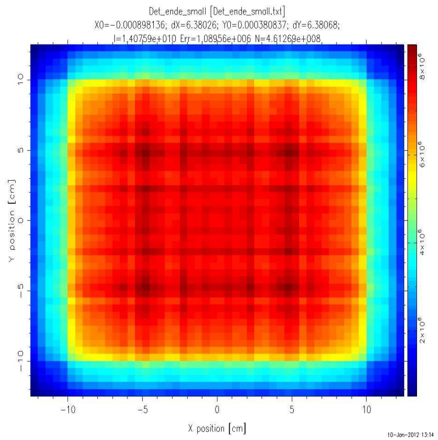


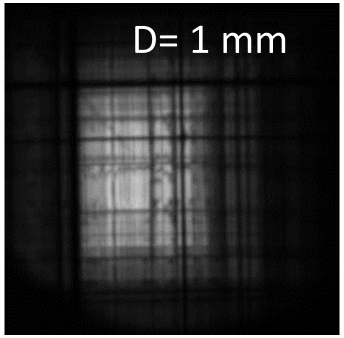
Source Collimator Object Detector

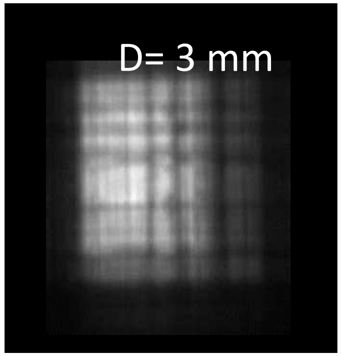


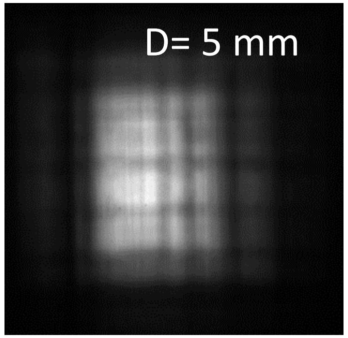
Help: **DIFFUSER**

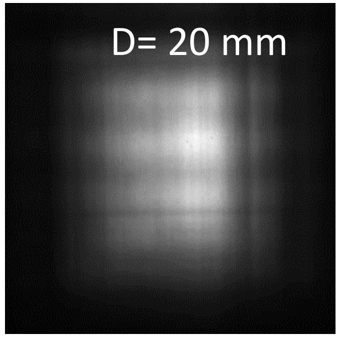






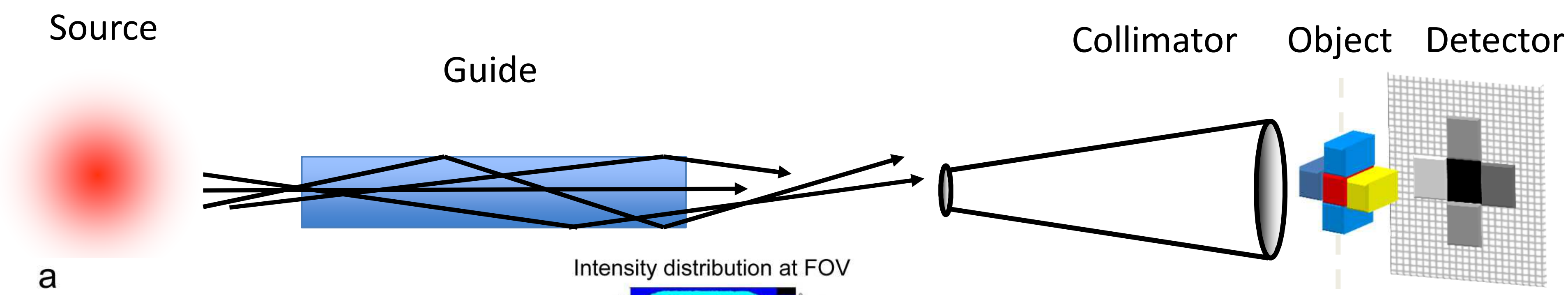


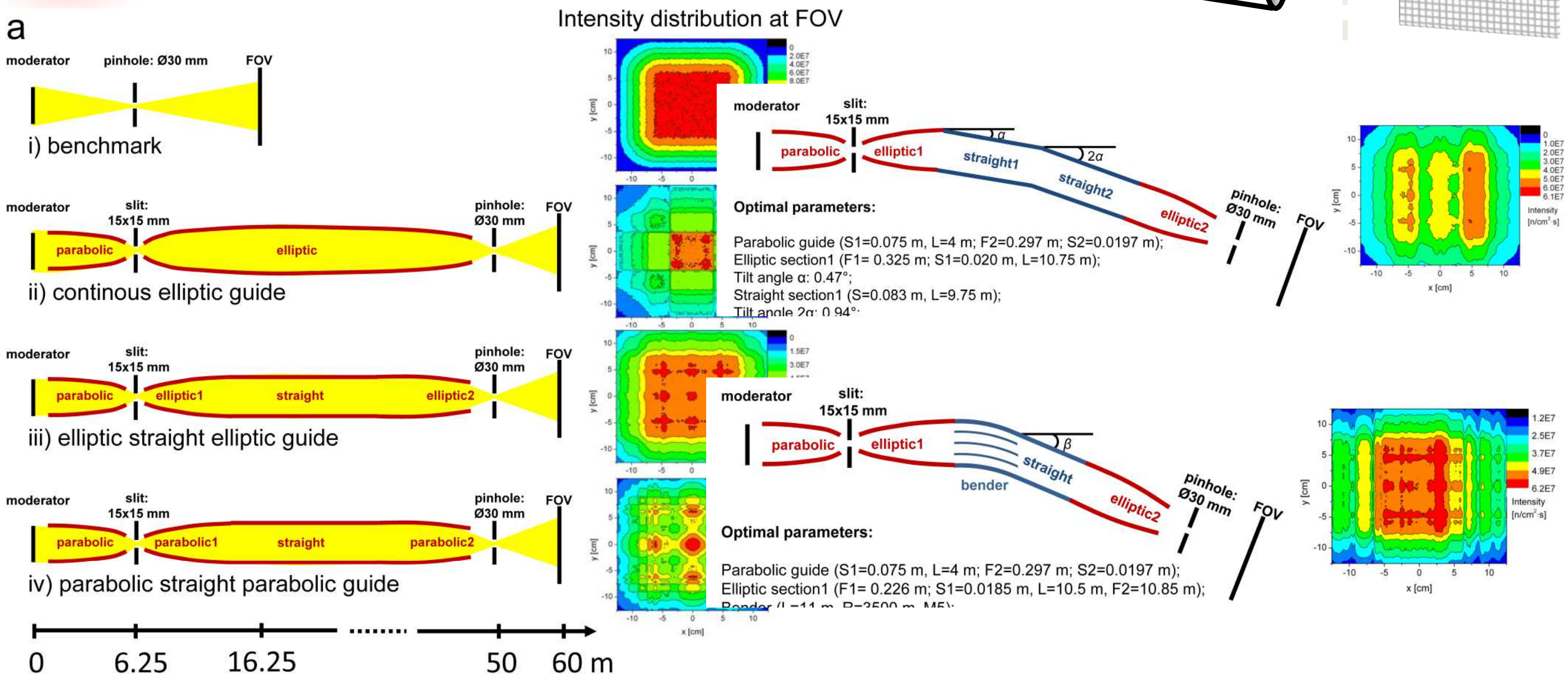




Standard Imaging Instrumentation

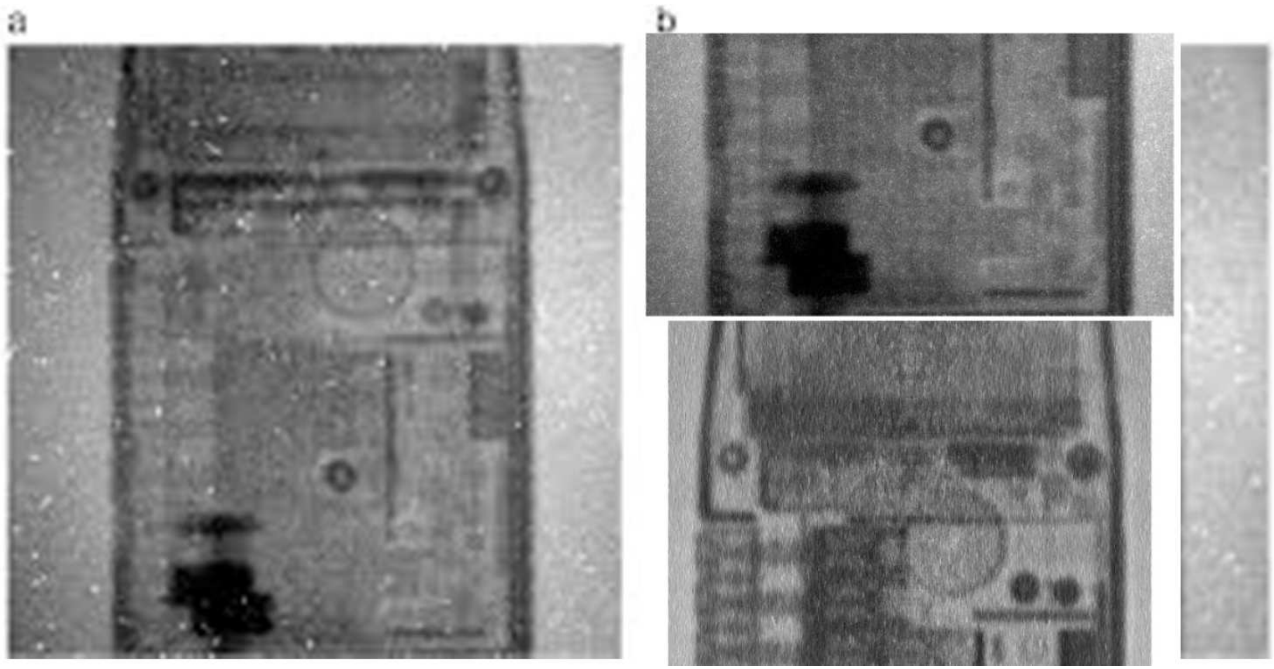
EUROPEAN SPALLATION SOURCE



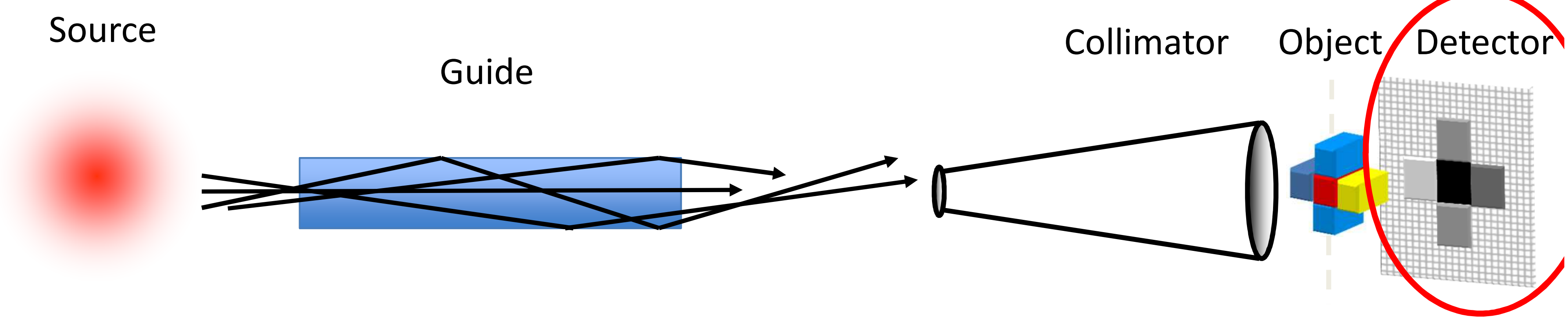


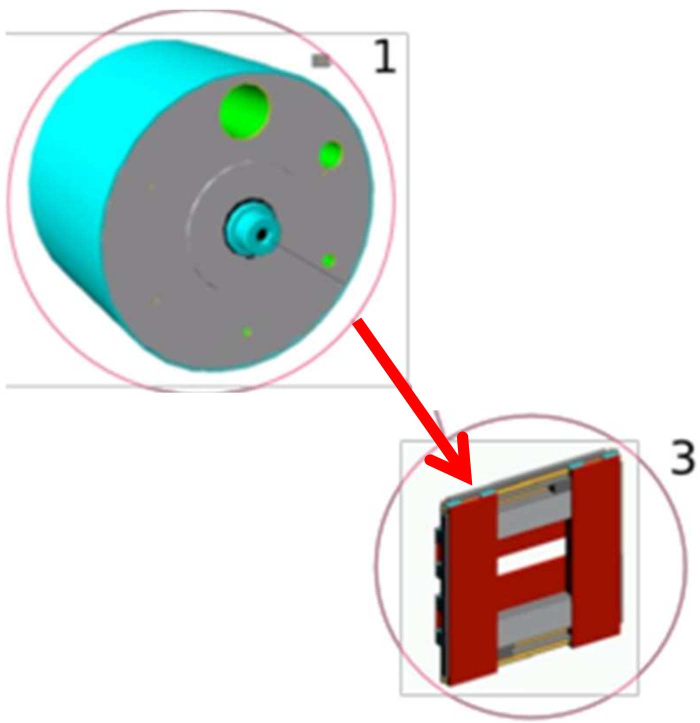
Standard Imaging Instrumentation

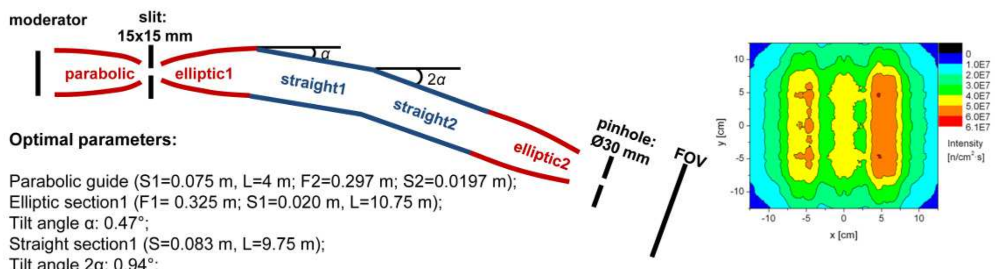
White spots

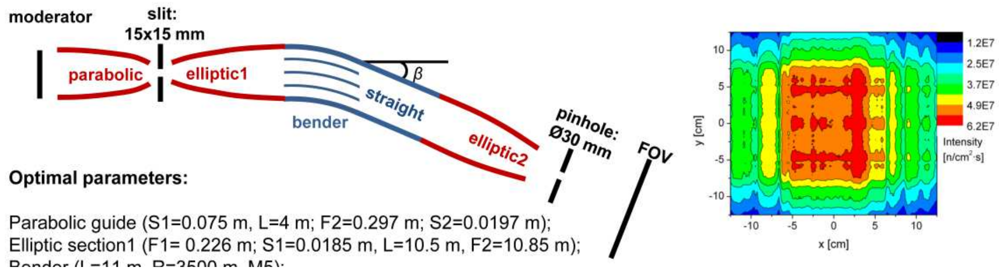


Standard Imaging Instrumentation

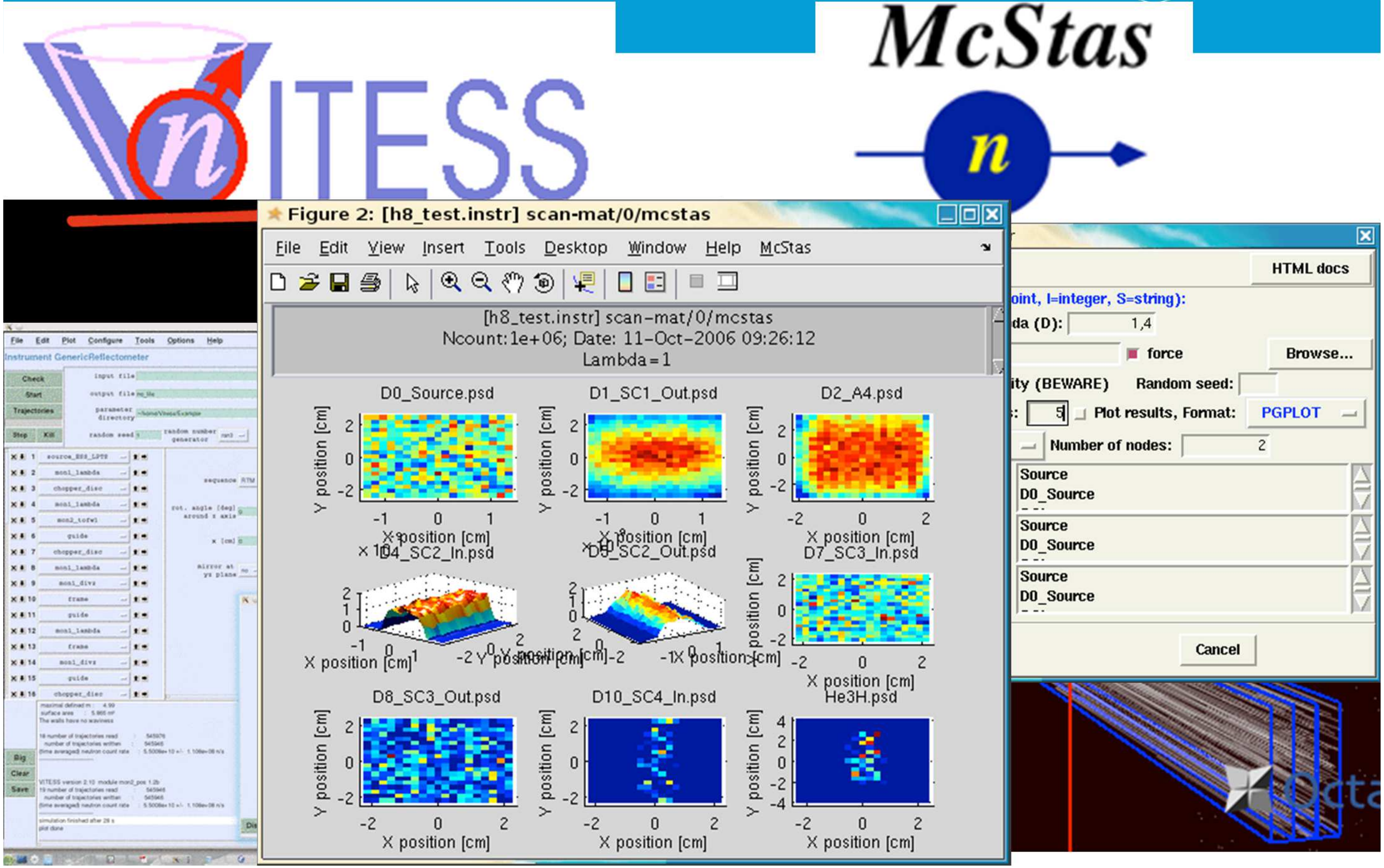




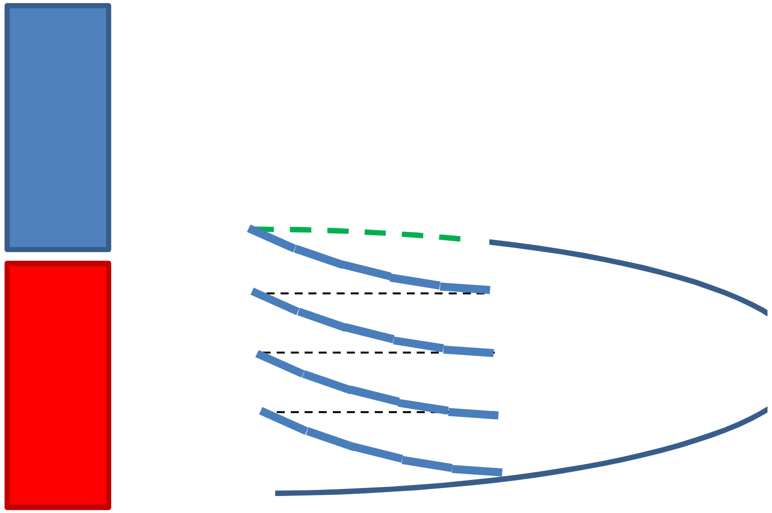


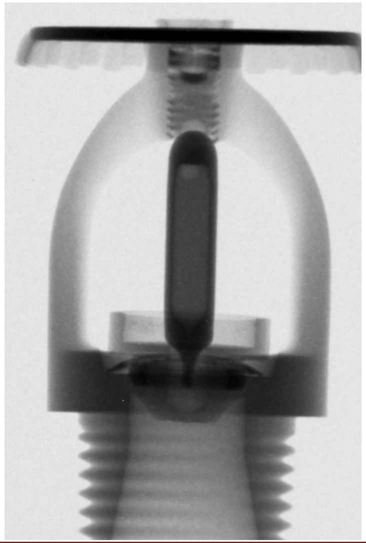


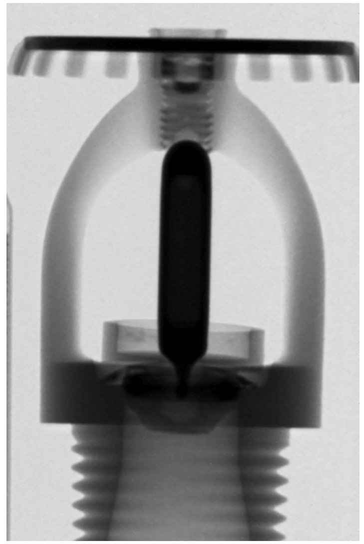
Standard Imaging Instrumentation

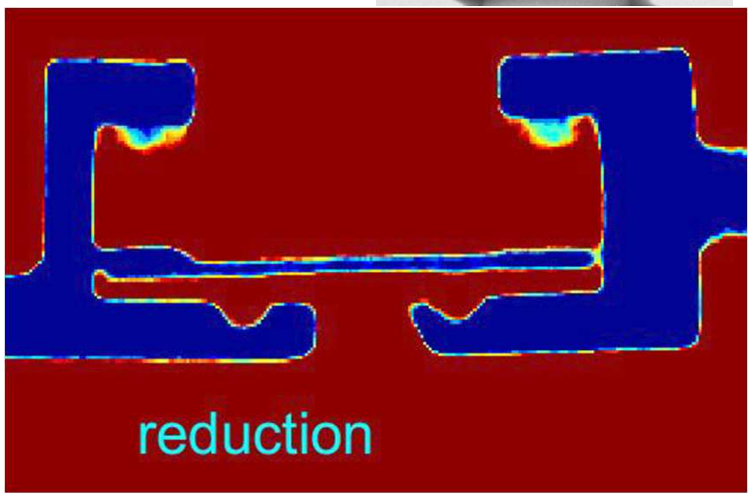


Complex solutions – based on simulations

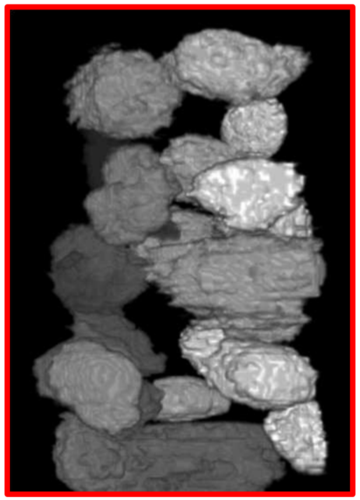






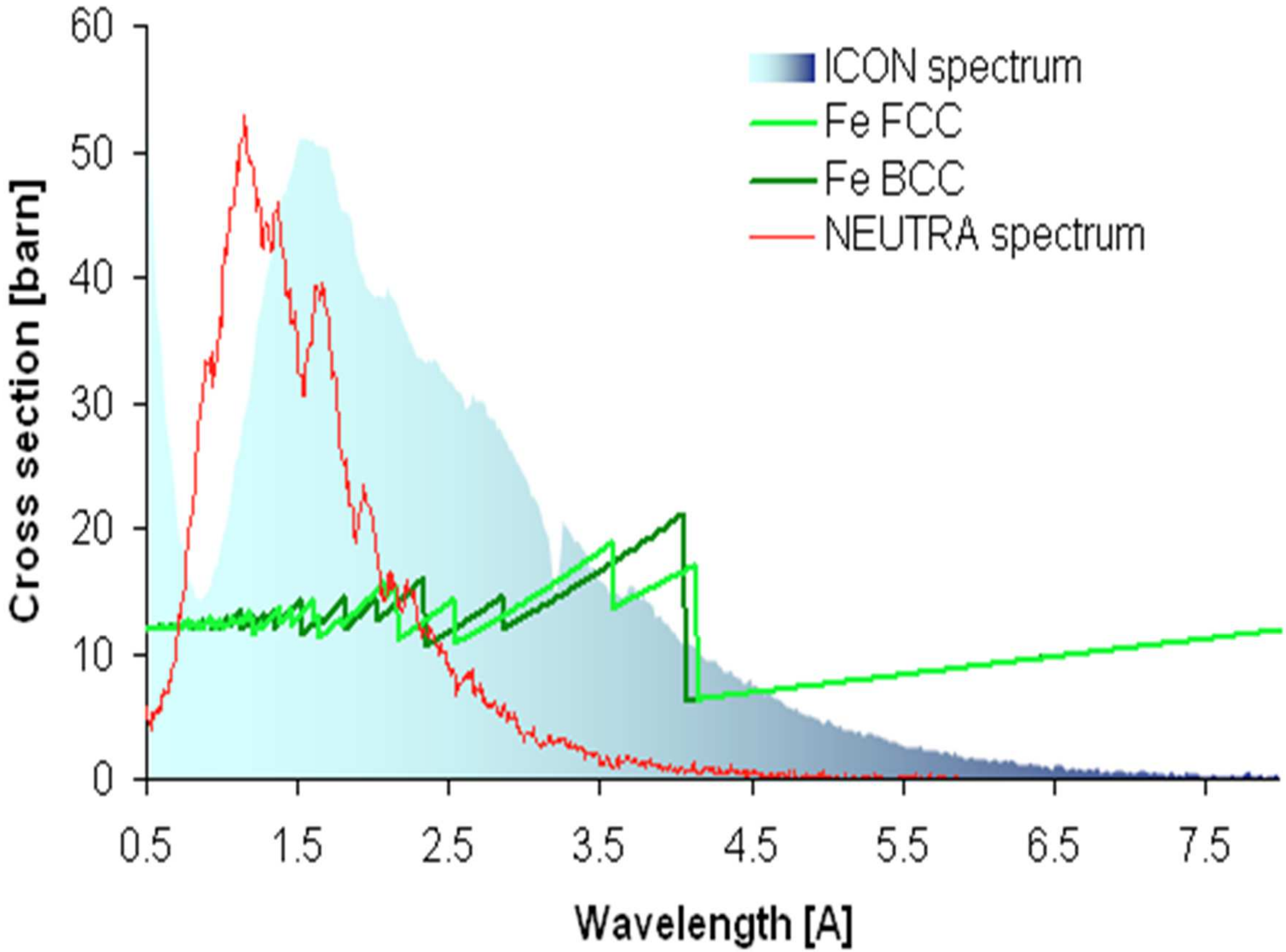


In-situ phase change

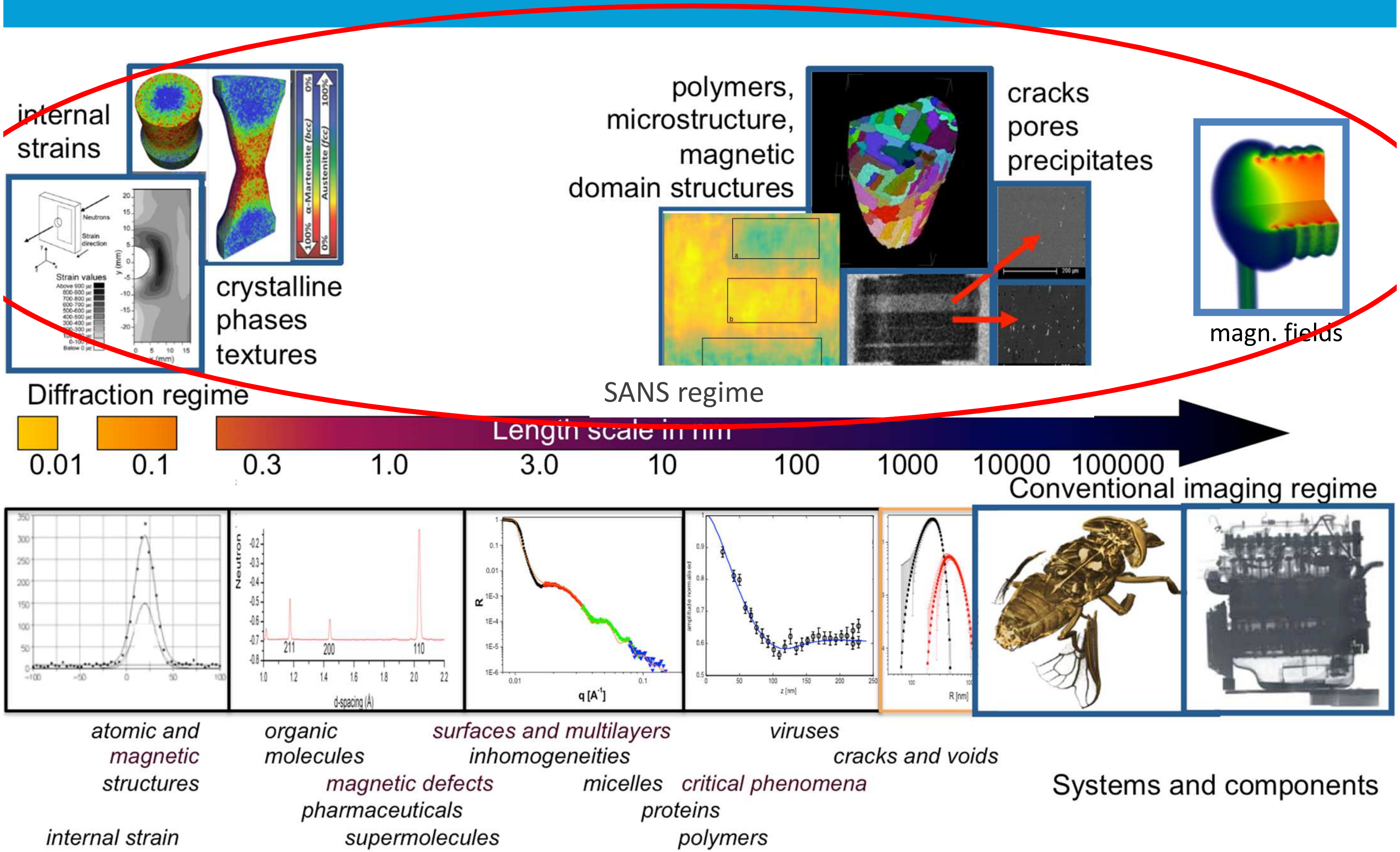


individual crystal grains

Complex solutions – based on simulations



Advanced Neutron Imaging



content

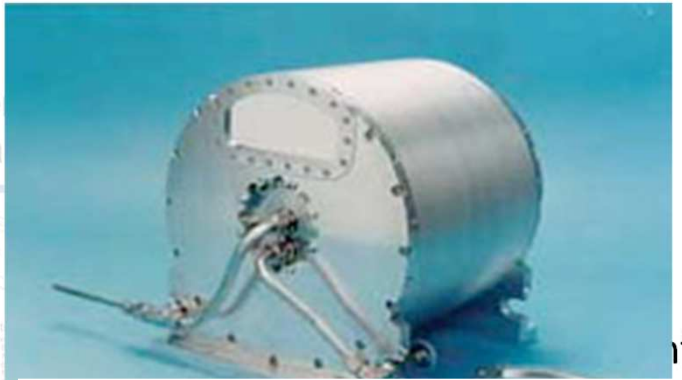
BASIC

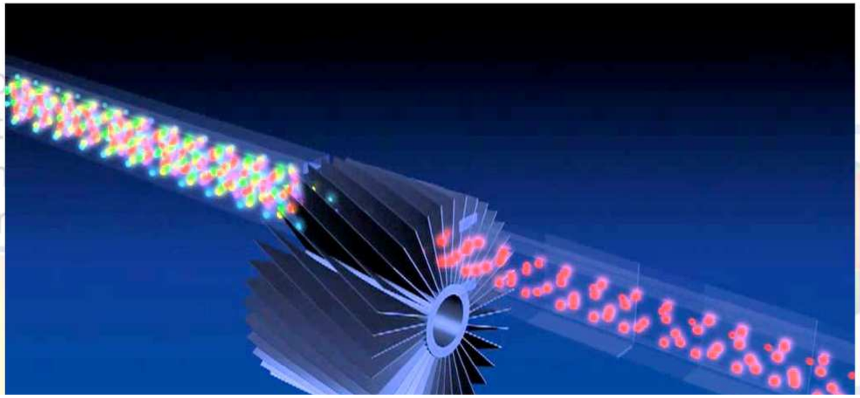
- Imaging Geometry
- Basic Imaging Requirements
- Beam Conditioning: Source to Detector
- Standard Imaging Instrumentation (continuous source)

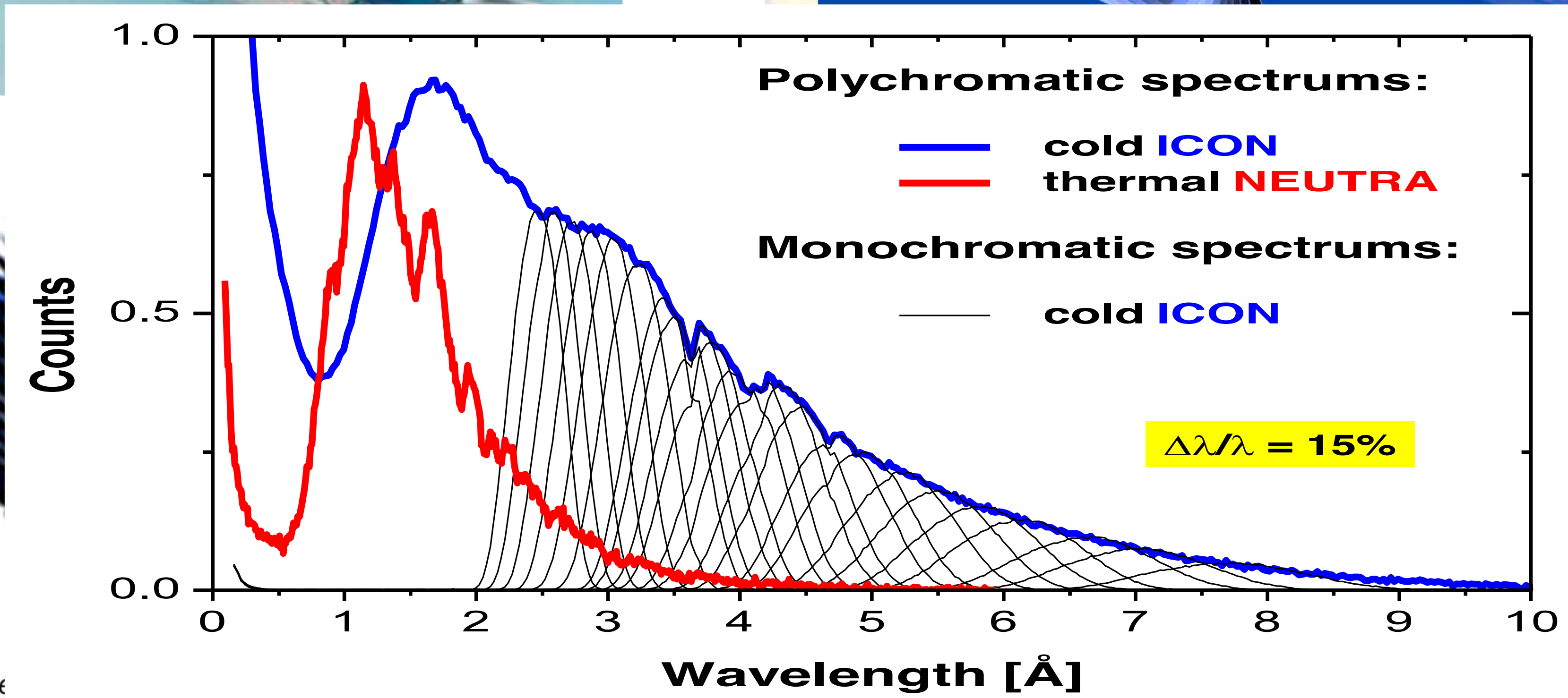
ADVANCED

+ Scattering, Diffraction and Polarized Neutrons
+ Additions to Basic Instrumentation: Wavelength Resolution
+ Instrumentation for a Time-of-flight Approach
+ Imaging Instrumentation at Pulsed Sources

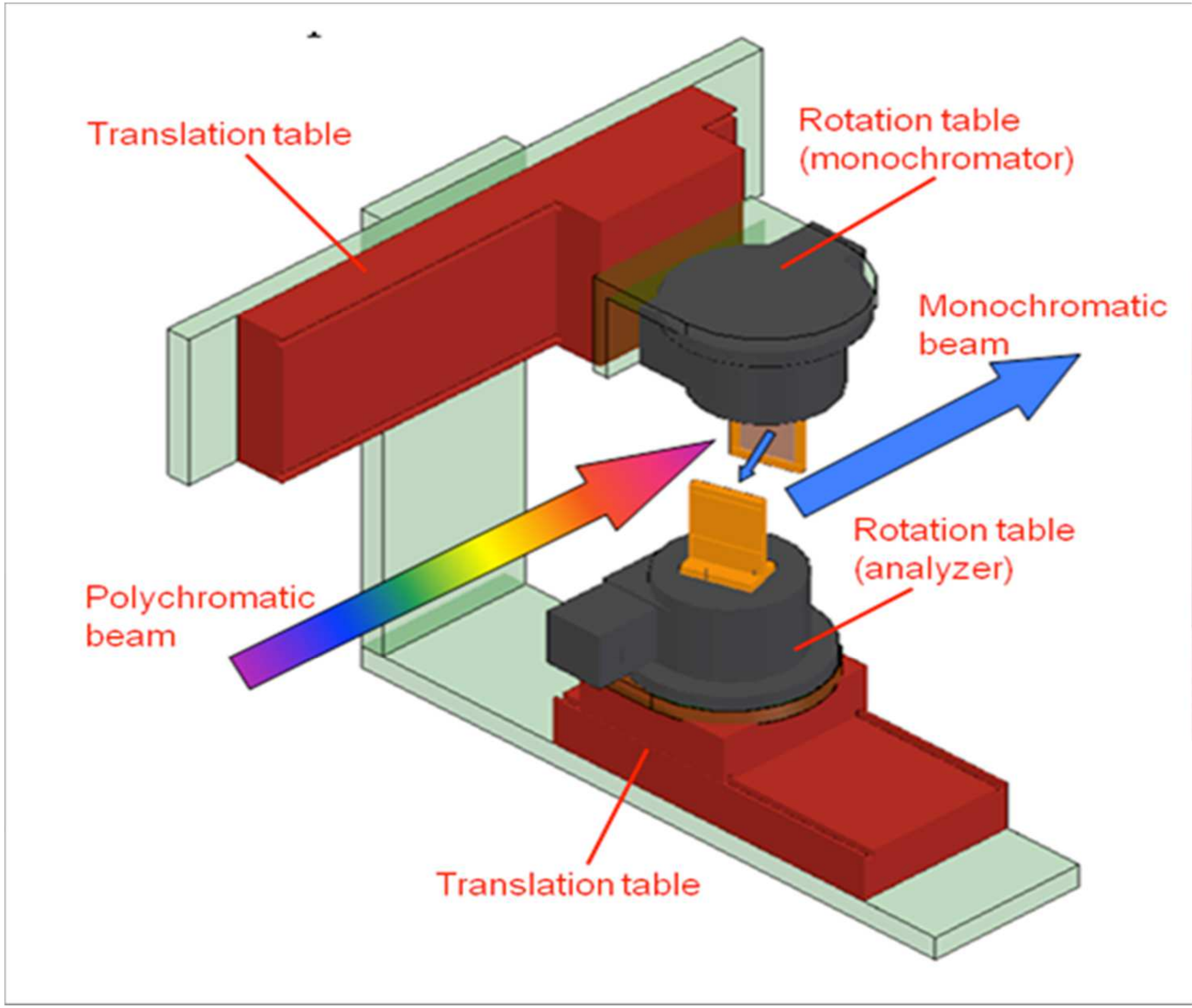
Advanced – Wavelength Resolution



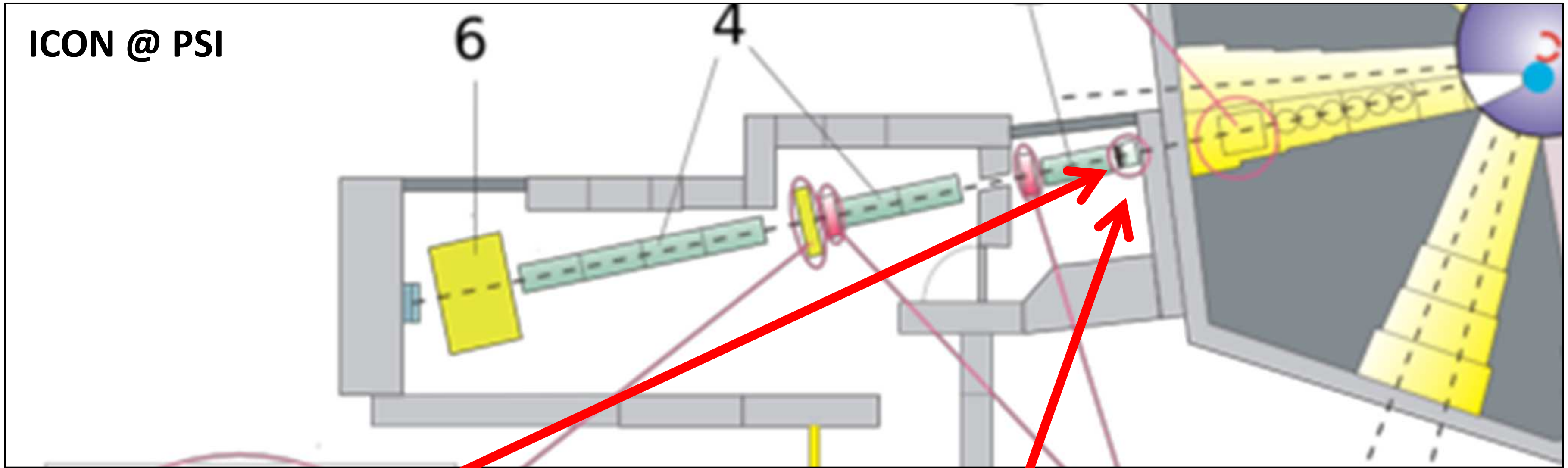


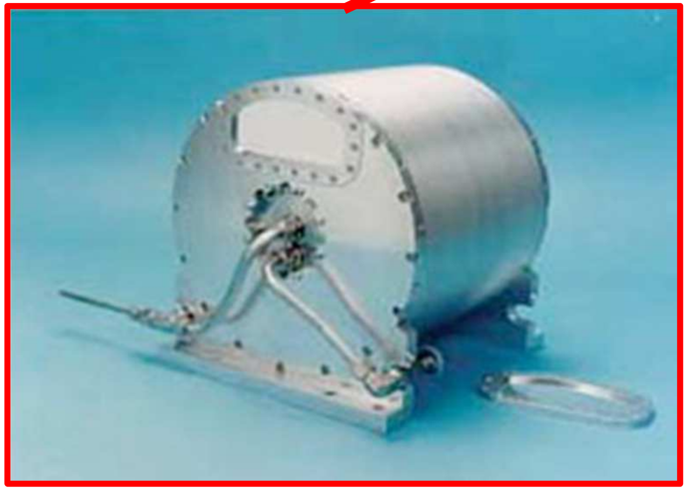


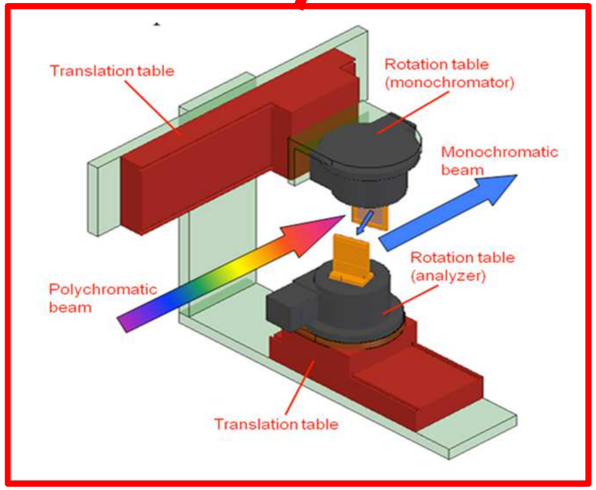
Advanced – Wavelength Resolution



Advanced Neutron Imaging – monochromators





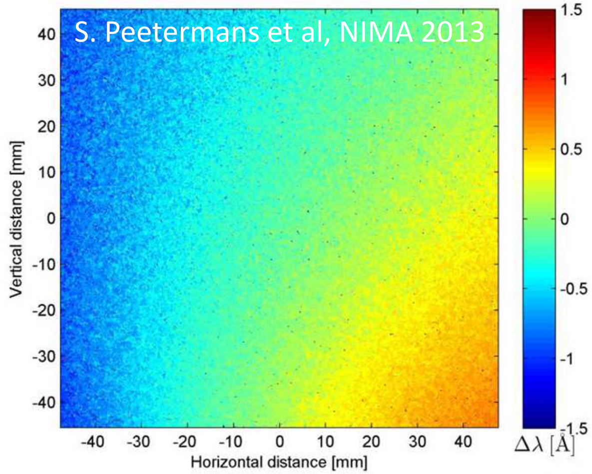


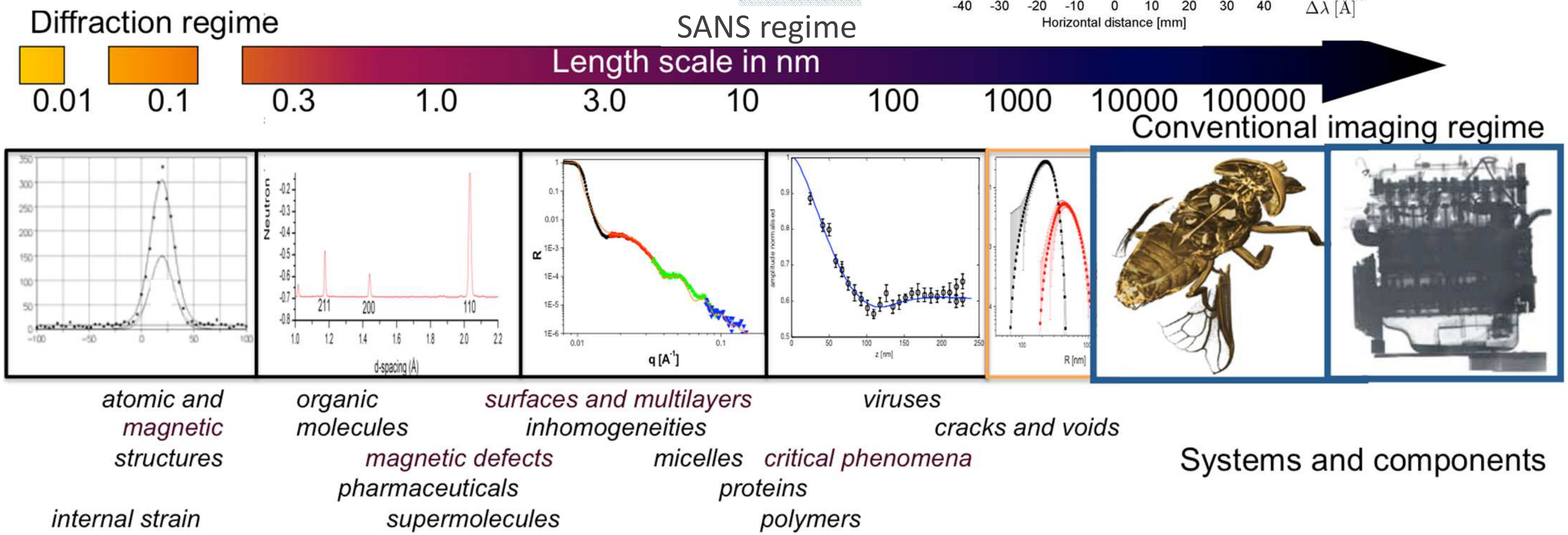
Advanced – Wavelength Resolution

EUROPEAN SPALLATION SOURCE

Monochromators for Imaging:
- crystal monochromators
- velocity selectors
- choppers

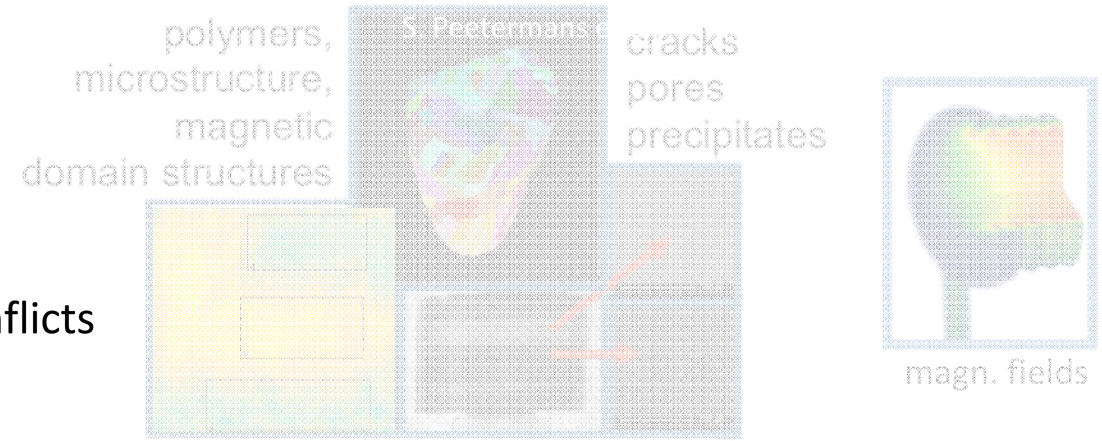
-> homogeneity requirement conflicts

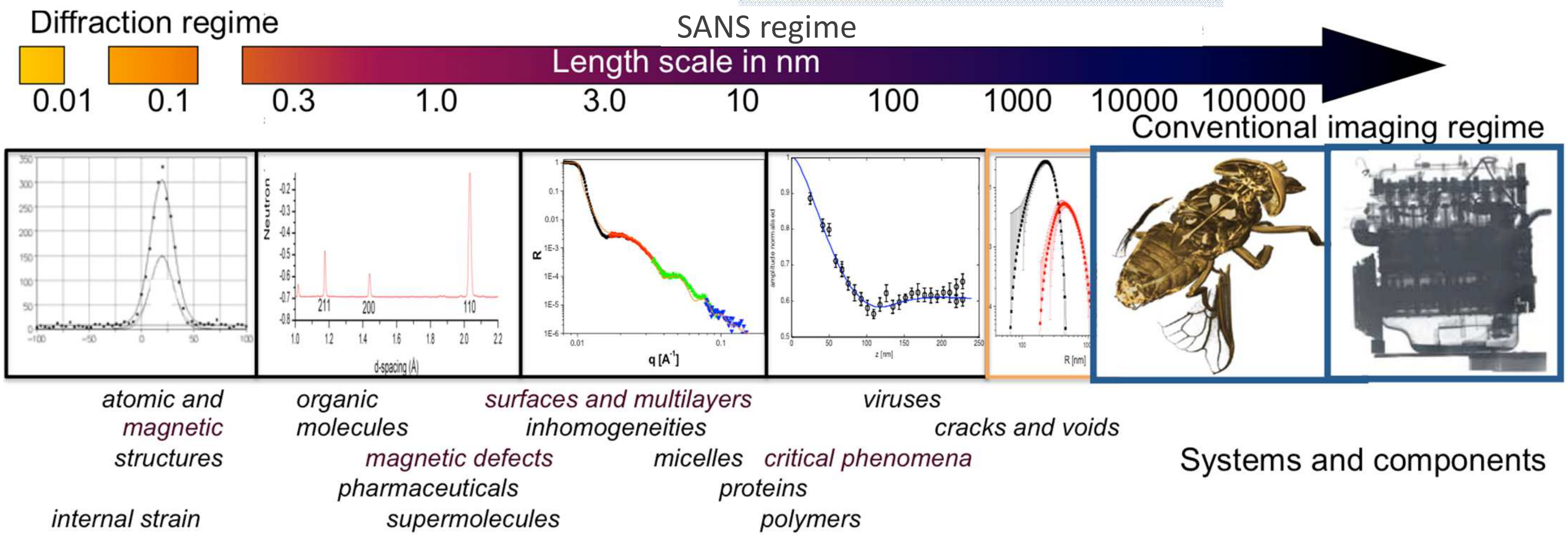




Advanced – Wavelength Resolution

Monochromators for Imaging:
- crystal monochromators
- velocity selectors
- **choppers**
-> homogeneity requirement conflicts



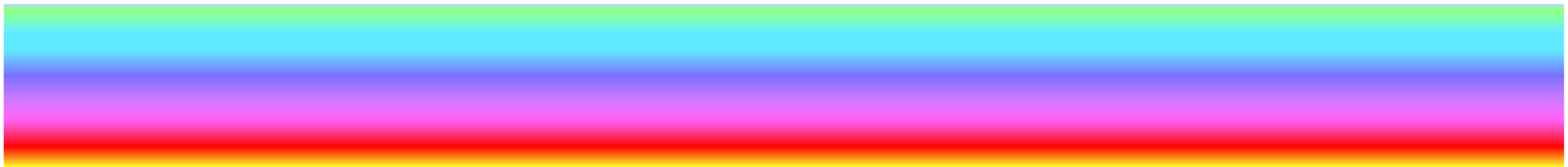


Advanced – Wavelength Resolution
ToF vs Monochromatic

Monochromator

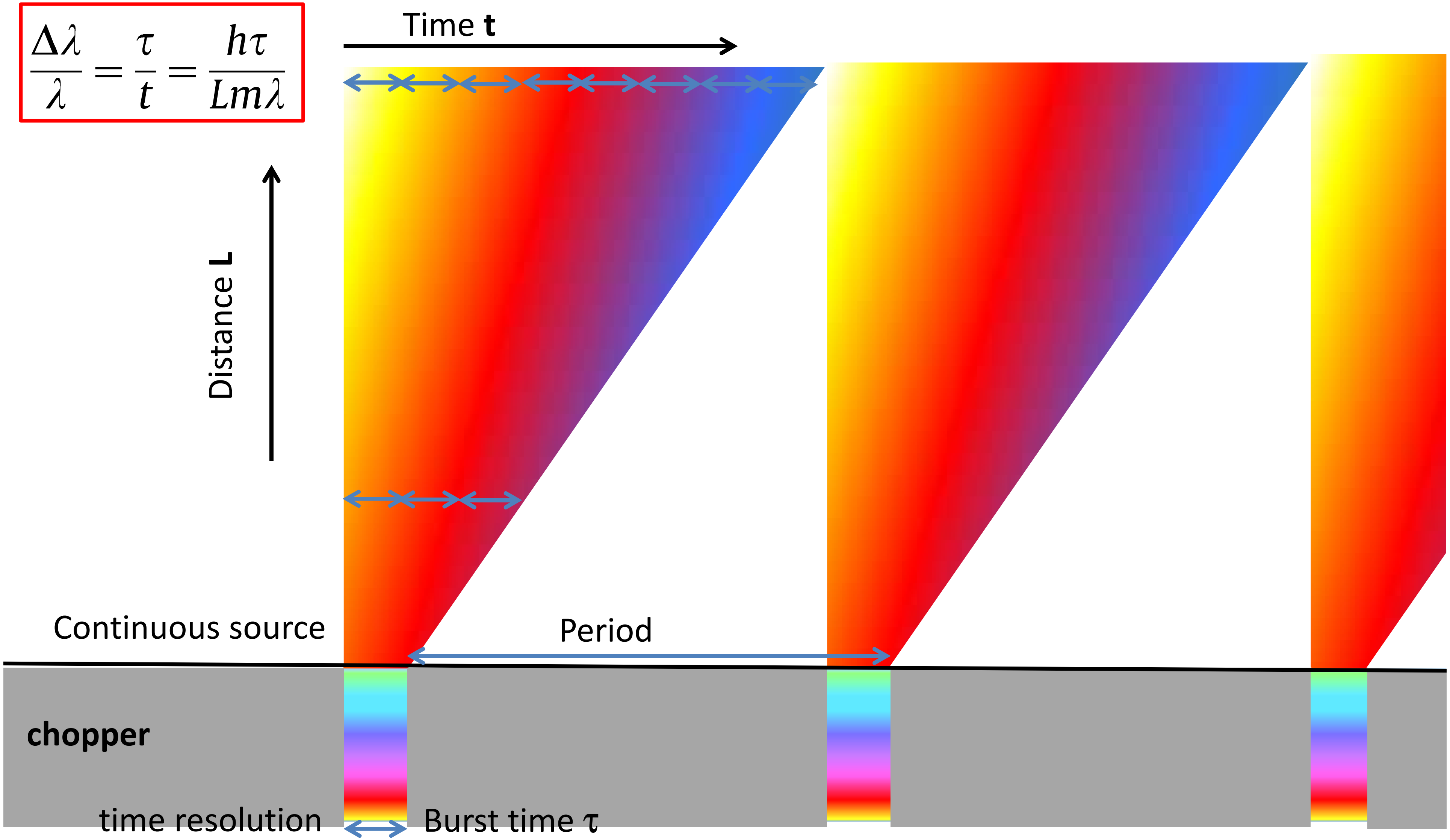
Velocity selector

Continuous source

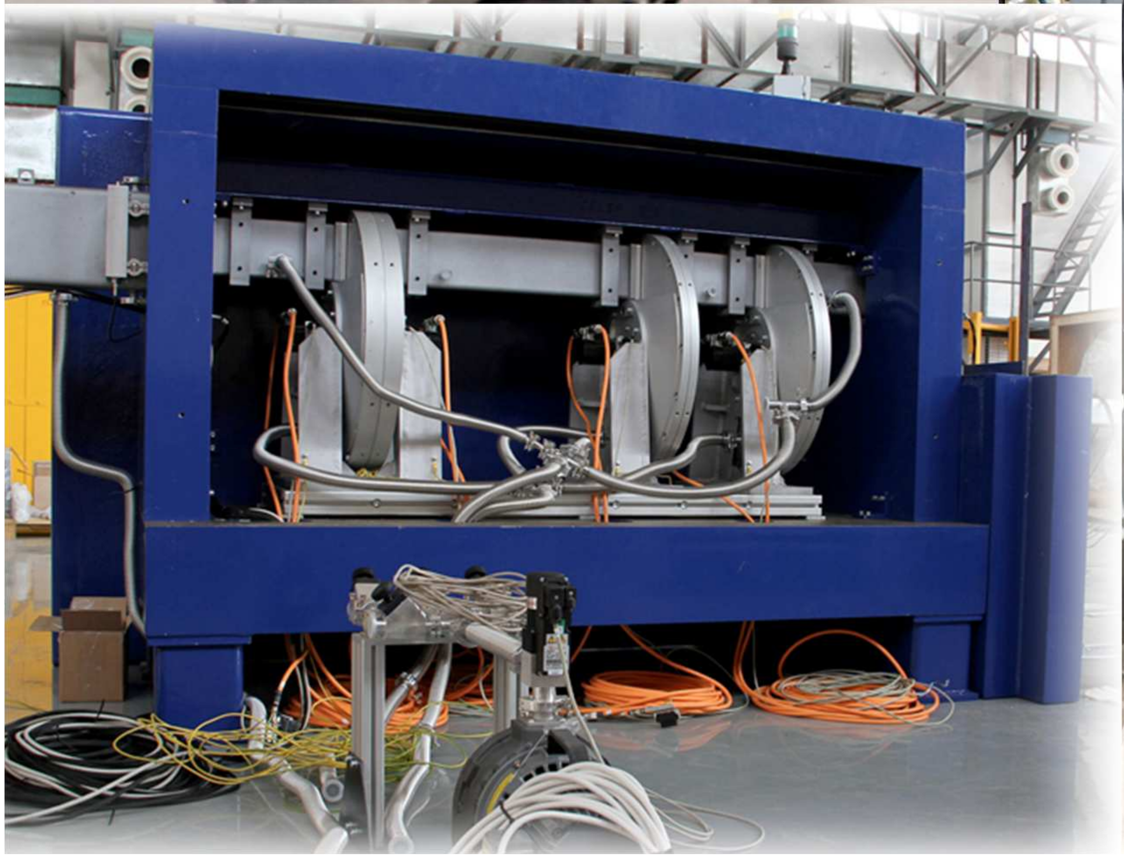


Advanced – Wavelength Resolution
ToF vs Monochromatic

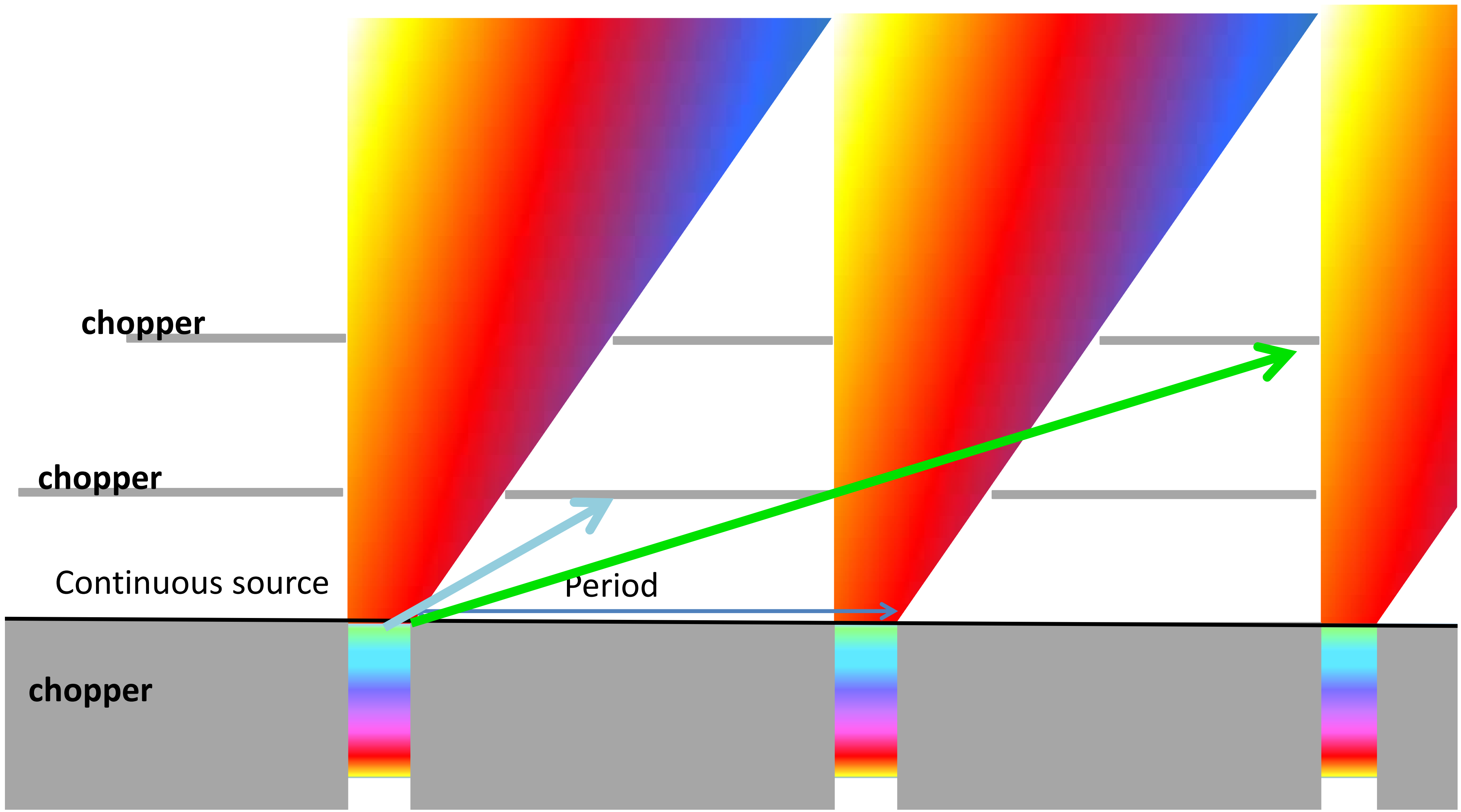
$$\frac{\Delta\lambda}{\lambda} = \frac{\tau}{t} = \frac{h\tau}{Lm\lambda}$$



Advanced – Wavelength Resolution
ToF vs Monochromatic



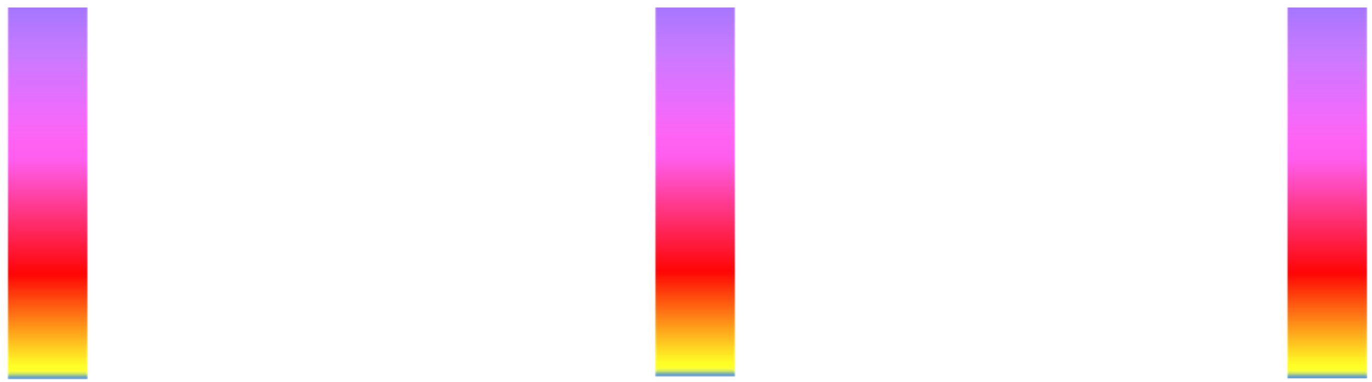
Advanced – Wavelength Resolution
ToF vs Monochromatic



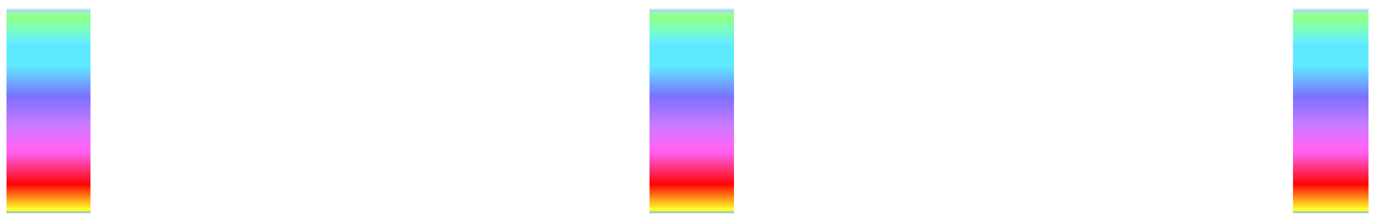
Advanced – Wavelength Resolution
ToF vs Monochromatic

Monochromator

Pulsed source

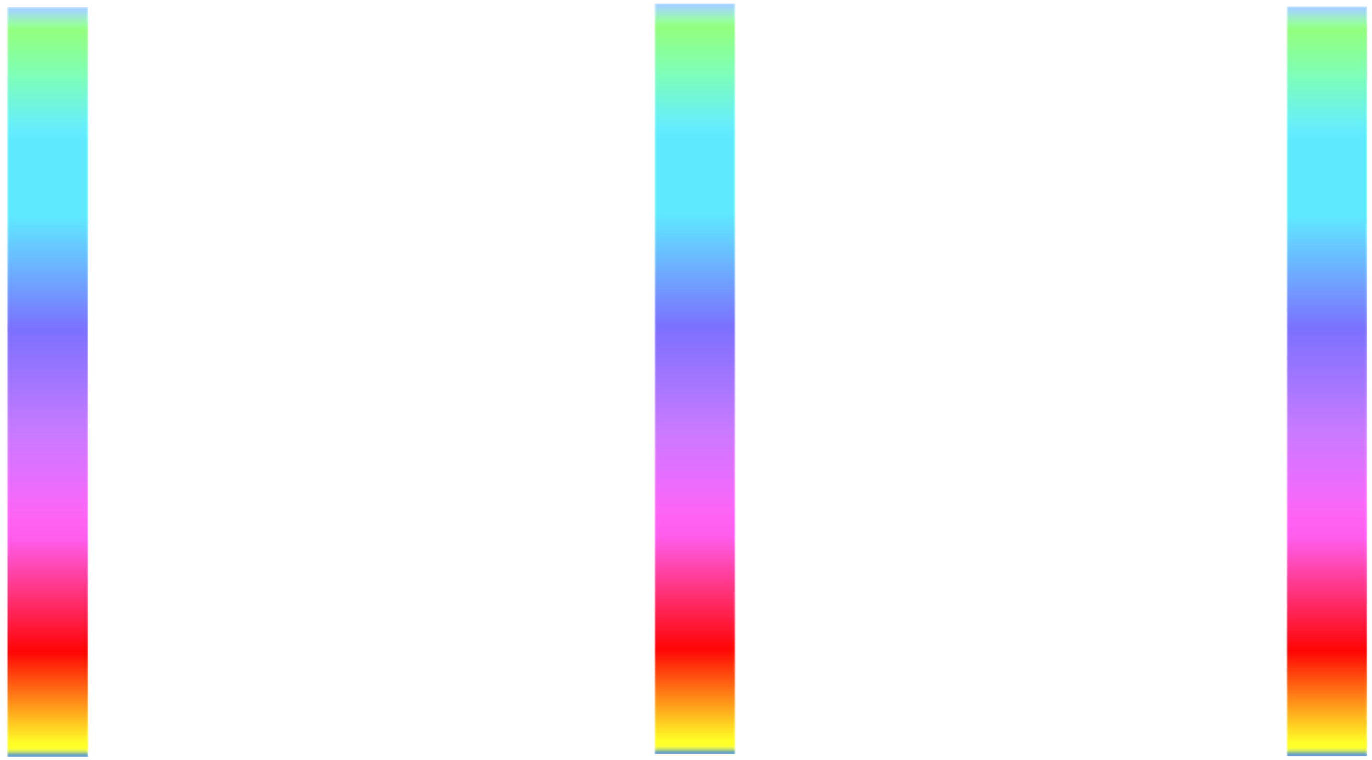


Continuous source   with chopper

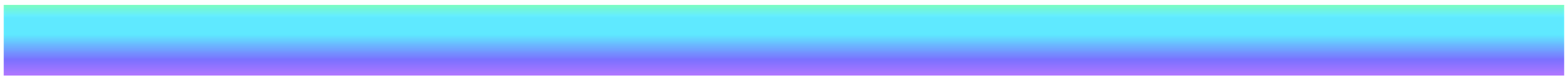


Advanced – Wavelength Resolution
ToF vs Monochromatic

Pulsed source

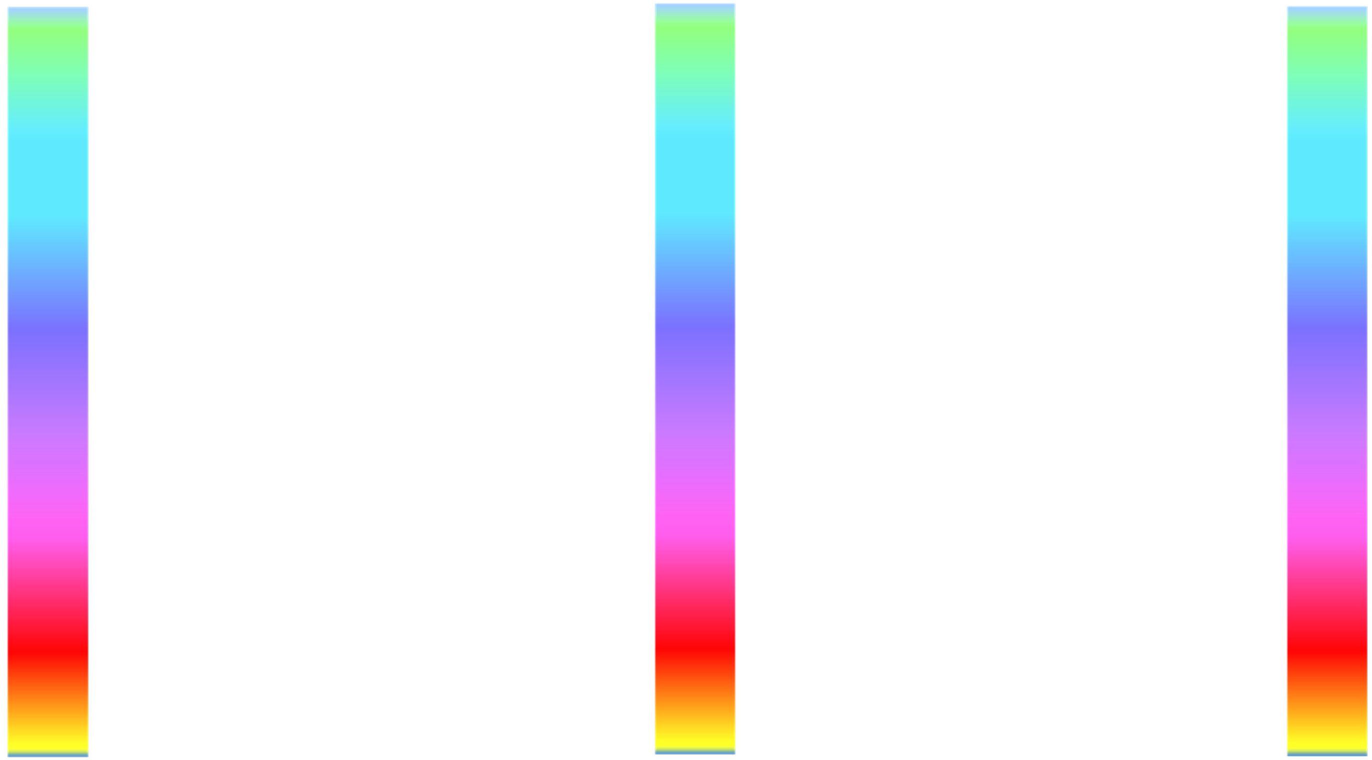


Continuous source with velocity selector

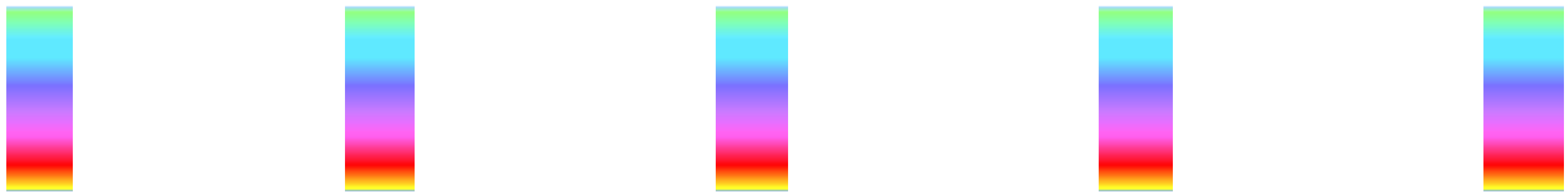


Advanced – Wavelength Resolution
ToF vs Monochromatic

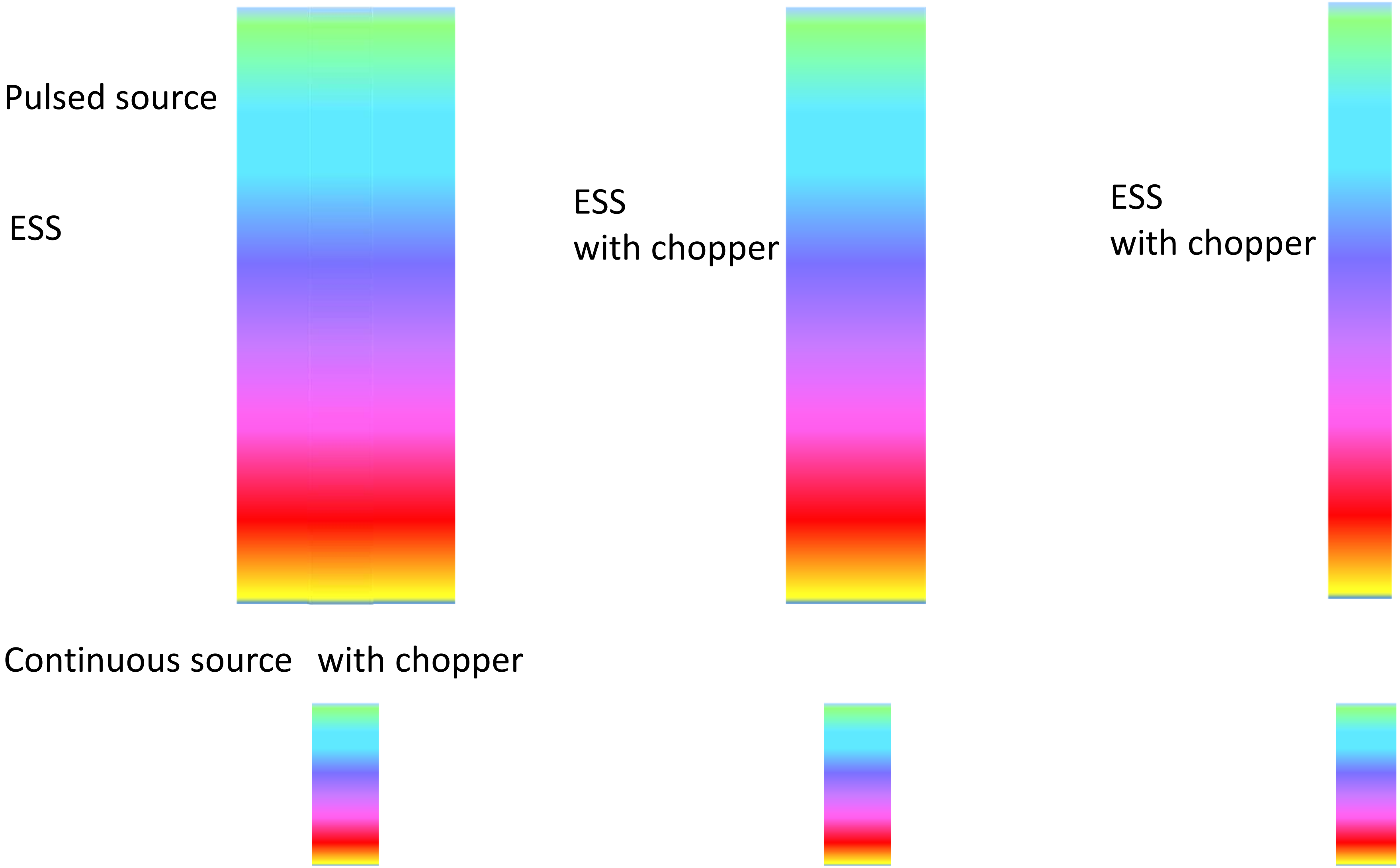
Pulsed source



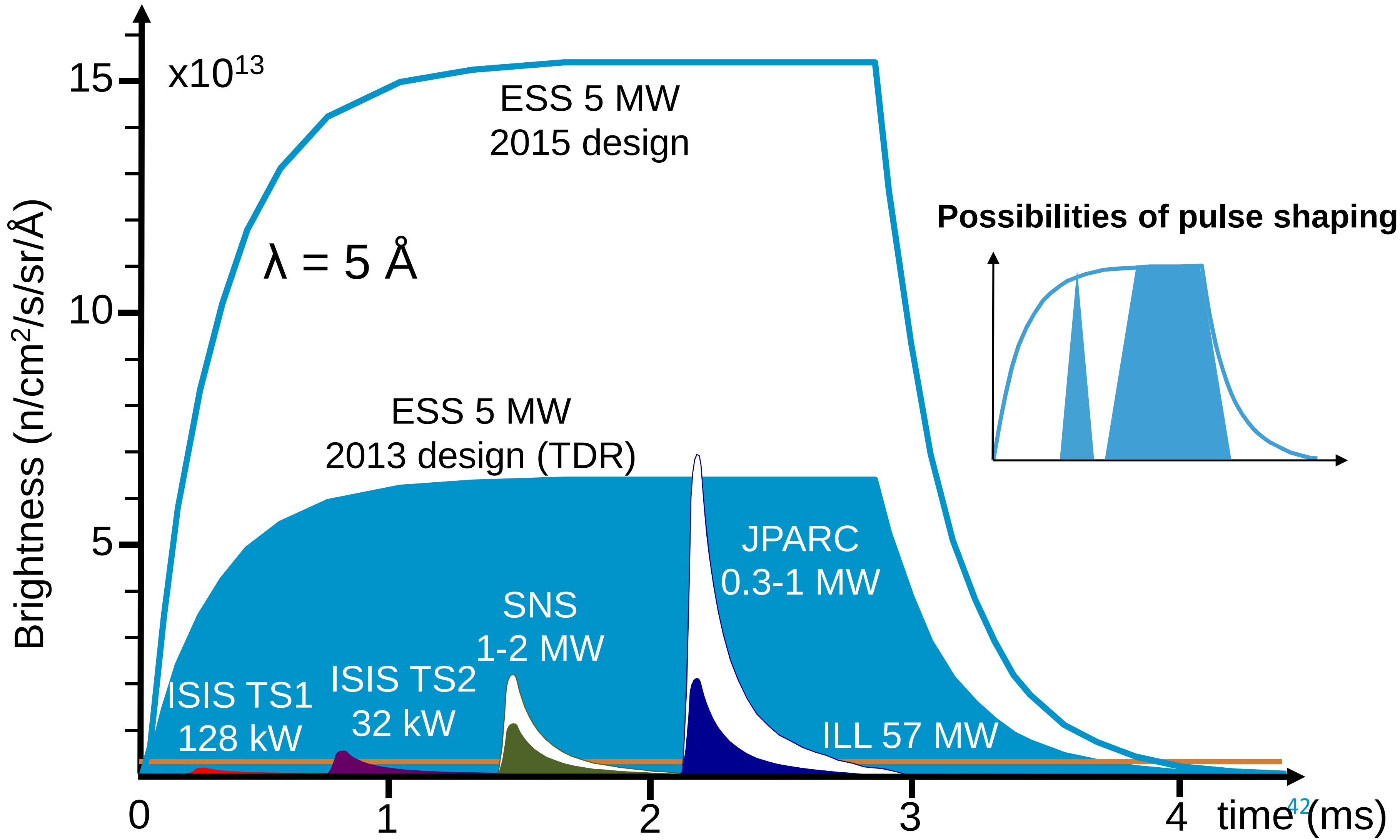
Continuous source   with chopper



Advanced – Wavelength Resolution
ToF vs Monochromatic



Advanced – Wavelength Resolution
ToF vs Monochromatic



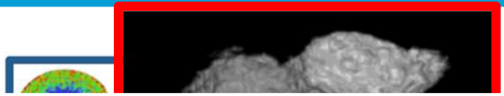
Advanced – Wavelength Resolution
Pulsed - only efficient when wavelength range probed
ToF vs Monochromatic

Monochromator

ToF monochromatic

Advanced – Wavelength Resolution
ToF vs Monochromatic

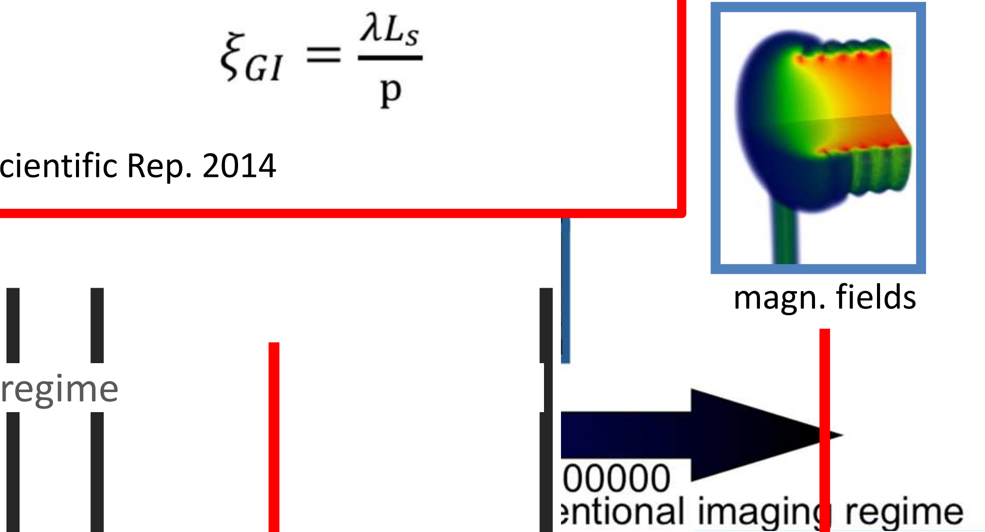
Pulsed - only efficient when wavelength range probed

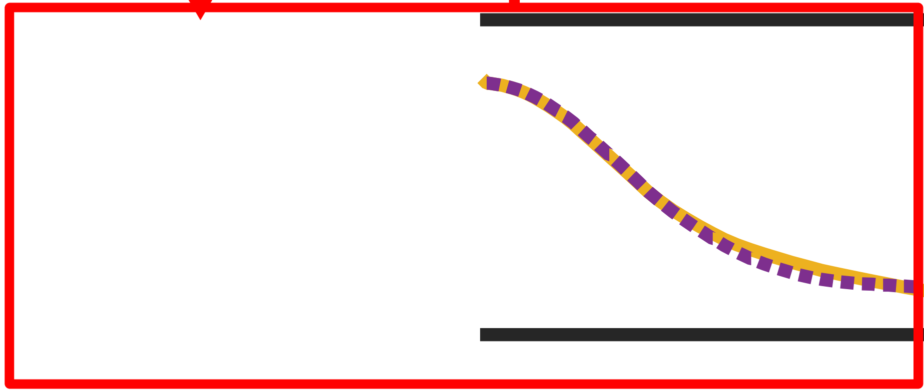


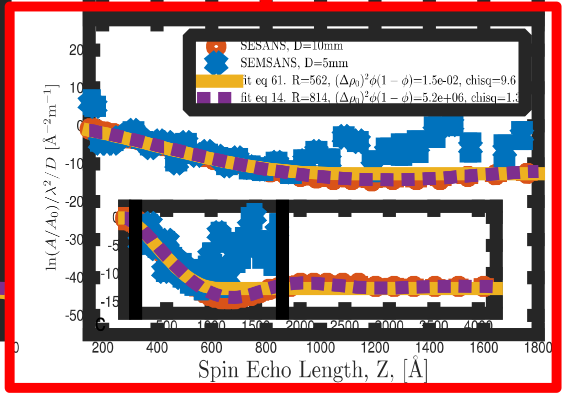
$$V_s(\xi_{GI}) / V_0(\xi_{GI}) = \int_{-\infty}^{\infty} dq\, S(q) \cos(\xi_{GI} q) = G(\xi_{GI})$$

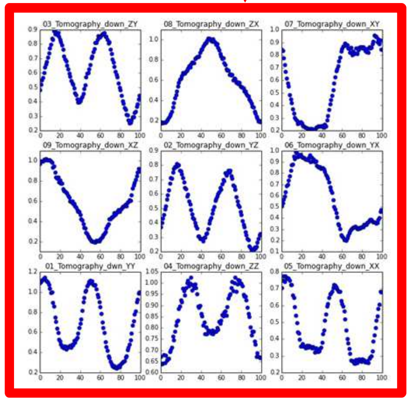
$$\xi_{GI} = \frac{\lambda L_s}{\mathrm{p}}$$

M. Strobl, Scientific Rep. 2014

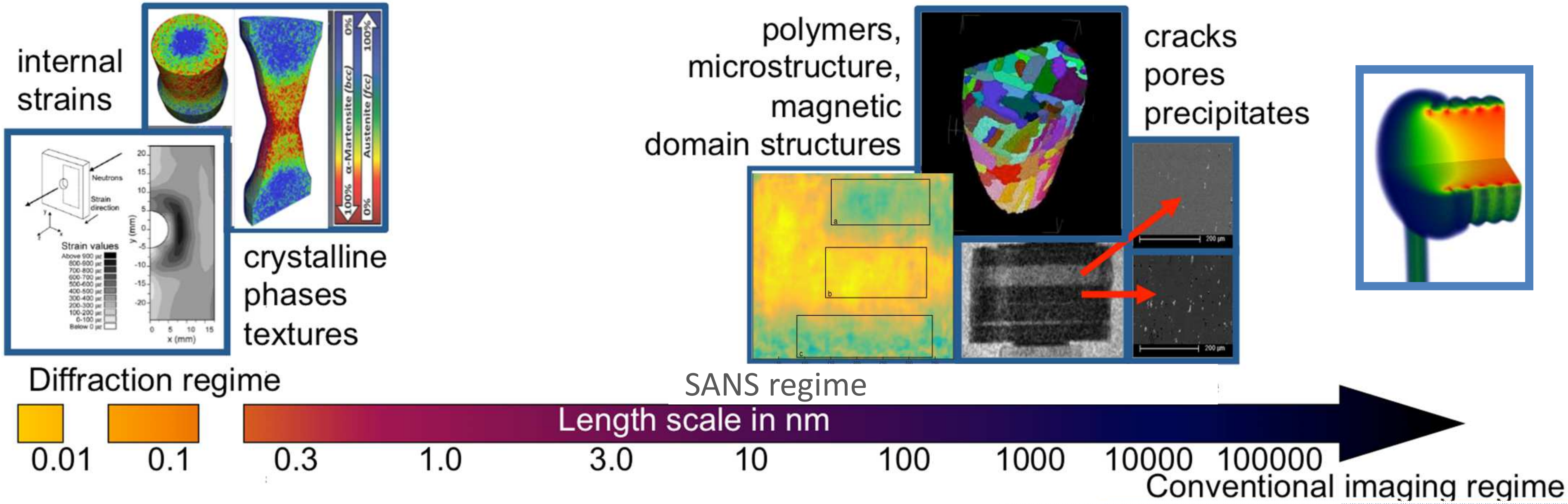


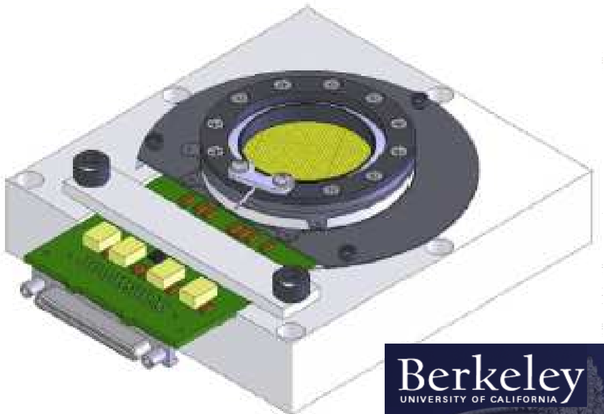






Advanced – Wavelength Resolution
ToF vs Monochromatic





A. Tremsin et al.

pulsed neutron imaging

- High flux
- Large size
- High spatial resolution
- High time resolution

–> detector requirement conflicts

Advanced Neutron Imaging Instrumentation

Pulsed - only efficient when wavelength range probed

polymers

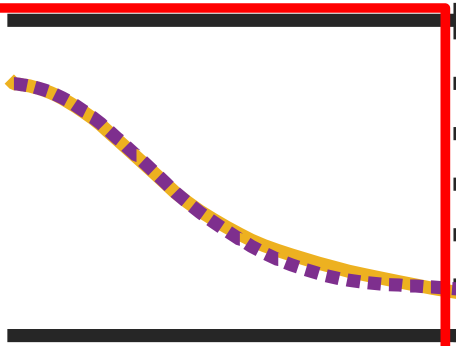
itates

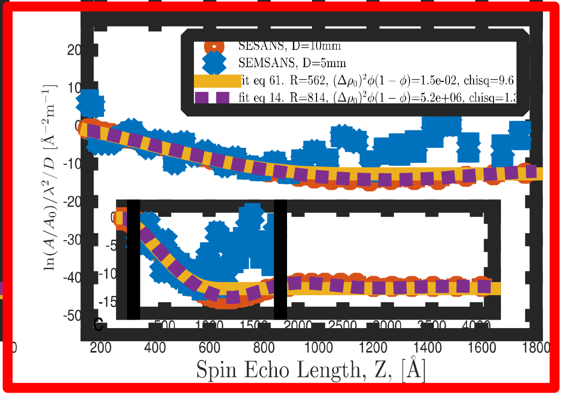
0,3% **1%** **10%**

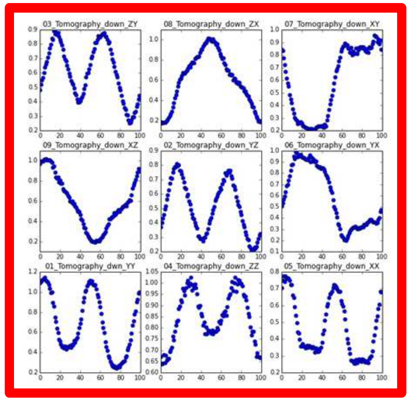
wavelength resolution

00000

ntional imaging regime







M. Strobl & F. Grazzi Neutron News 2013

Advanced Neutron Imaging Instrumentation

Pulsed - only efficient when wavelength range probed

0,3% **1%** **10%**

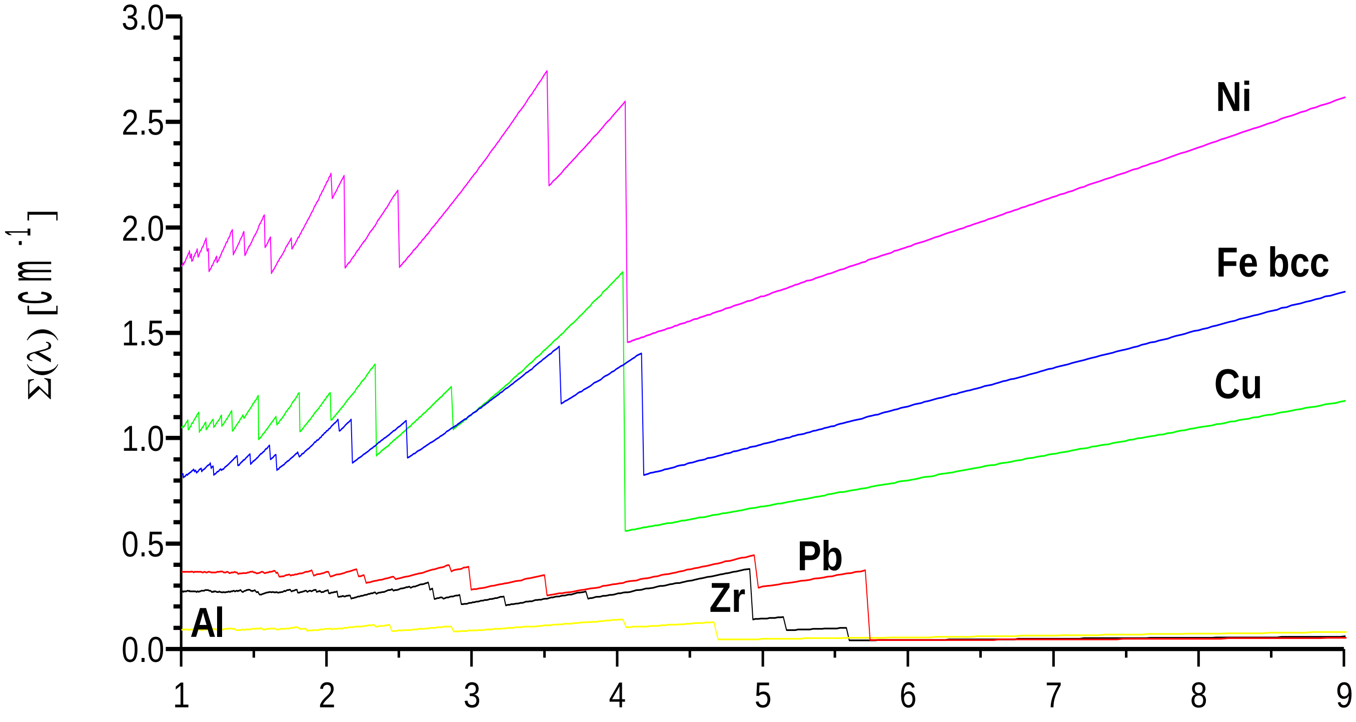
wavelength resolution

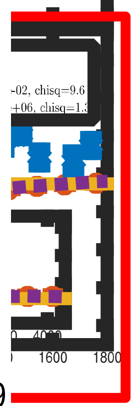
wavelength bandwidth

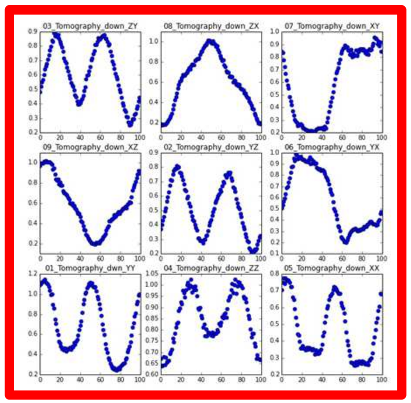
itates

00000

entional imaging regime

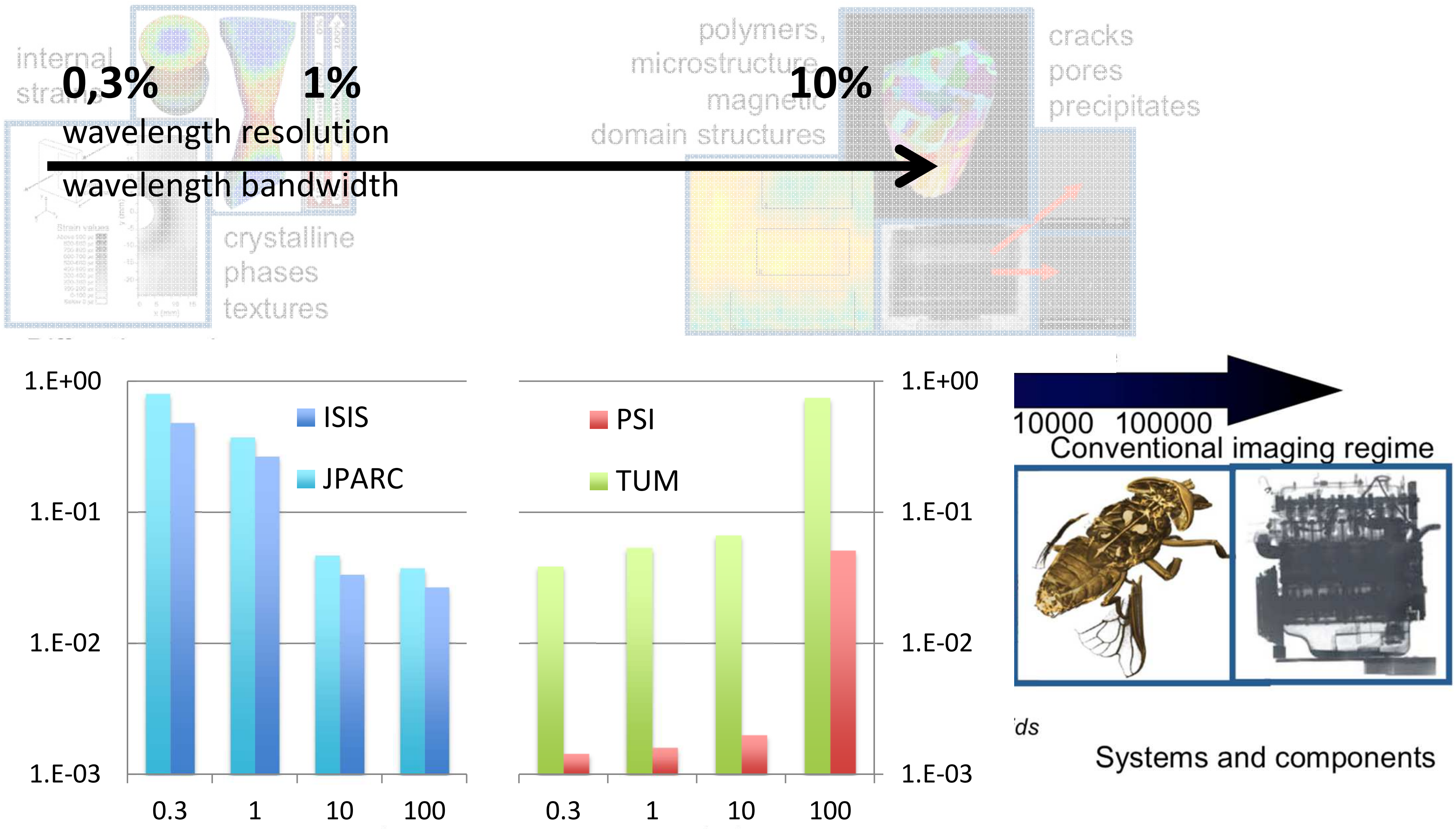




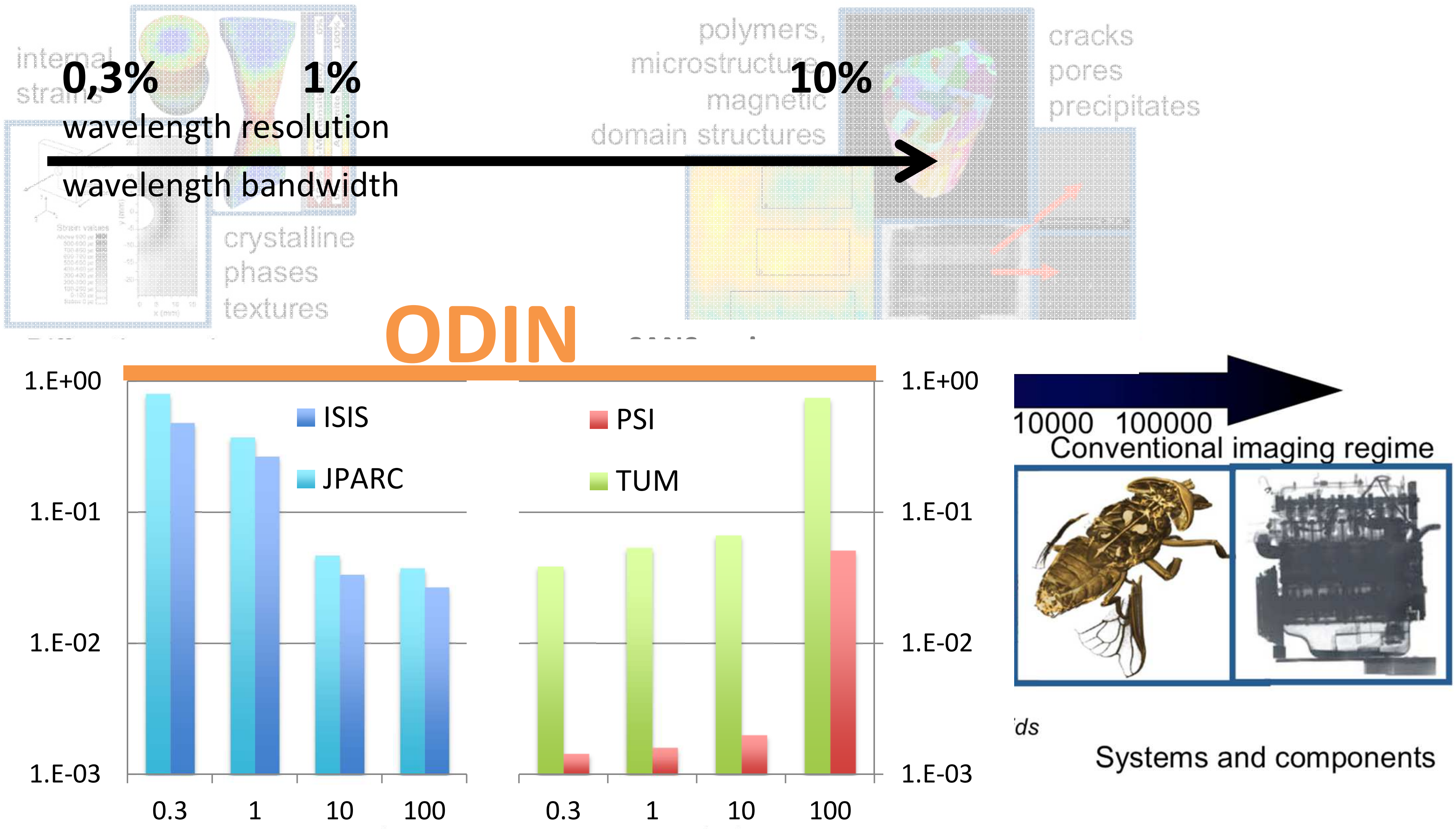


Advanced Neutron Imaging Instrumentation

EUROPEAN
SPALLATION
SOURCE

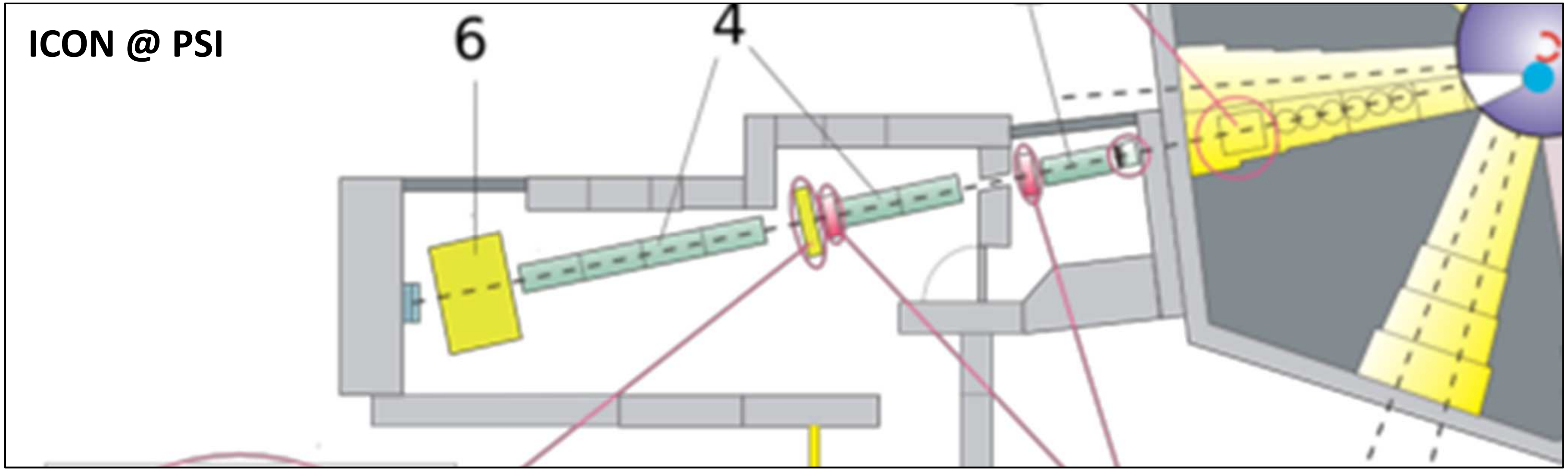


Advanced Neutron Imaging – ODIN @ ESS

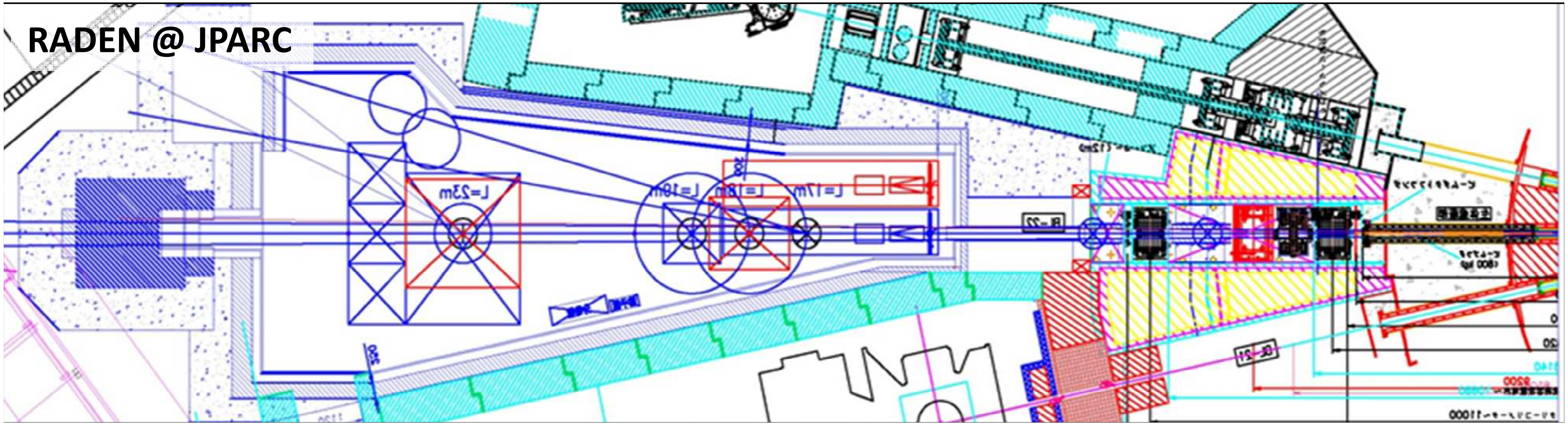


Advanced Neutron Imaging – SP sources

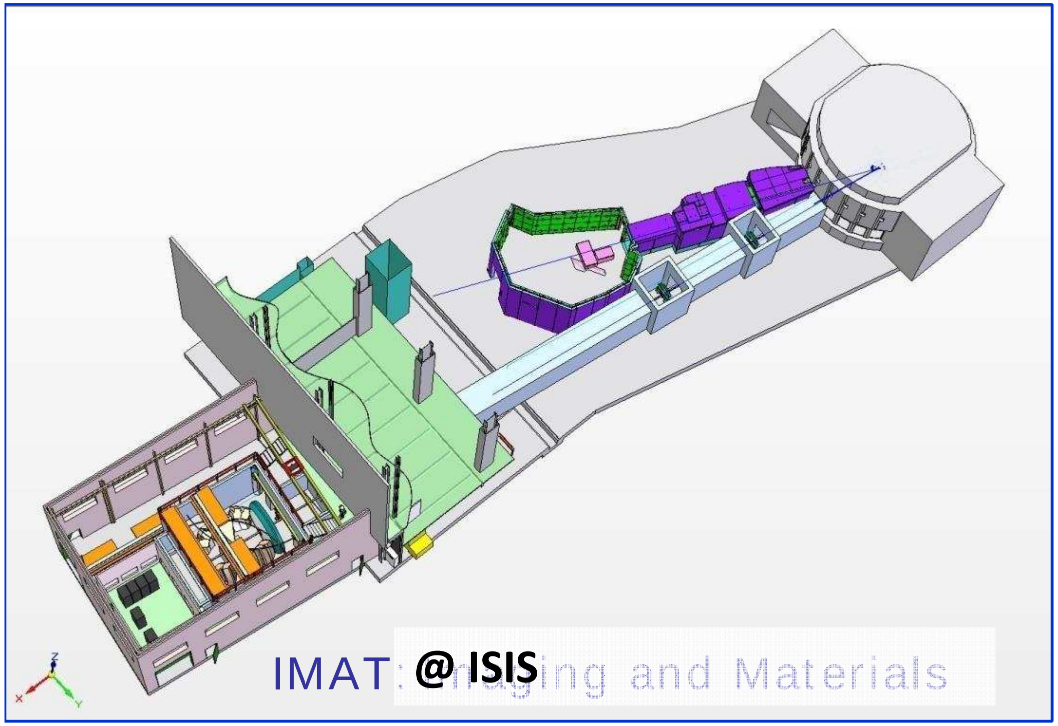
ICON @ PSI

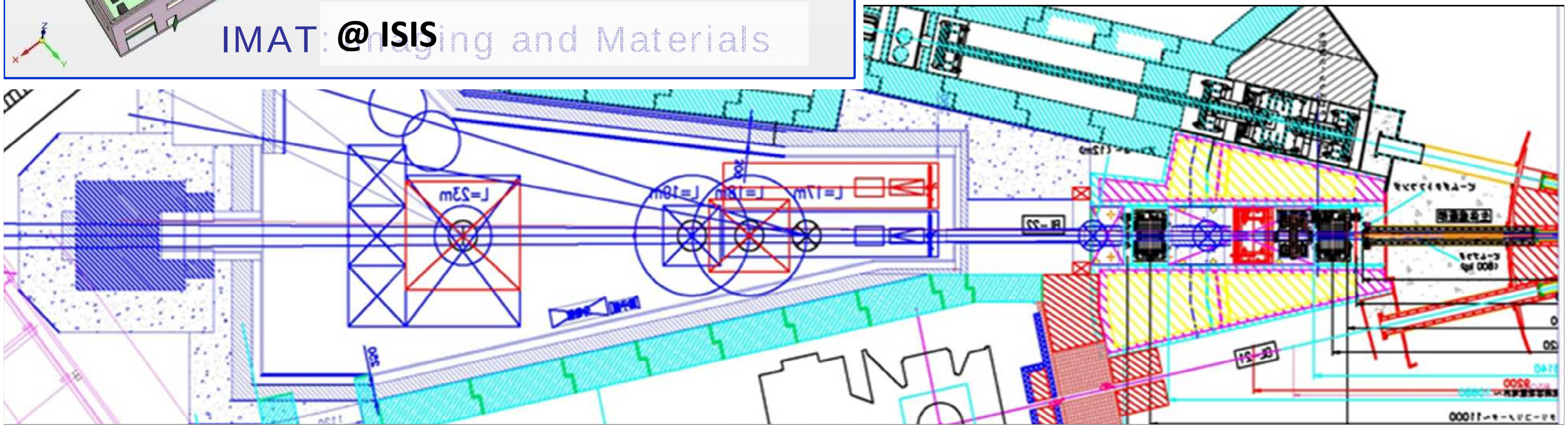


RADEN @ JPARC

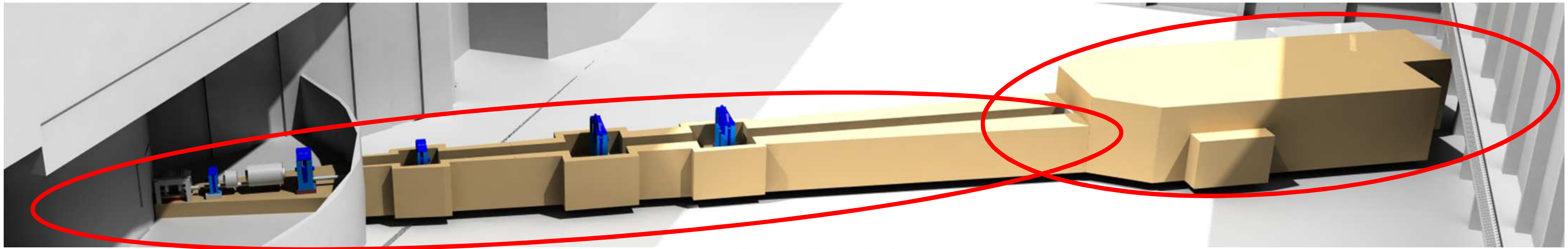


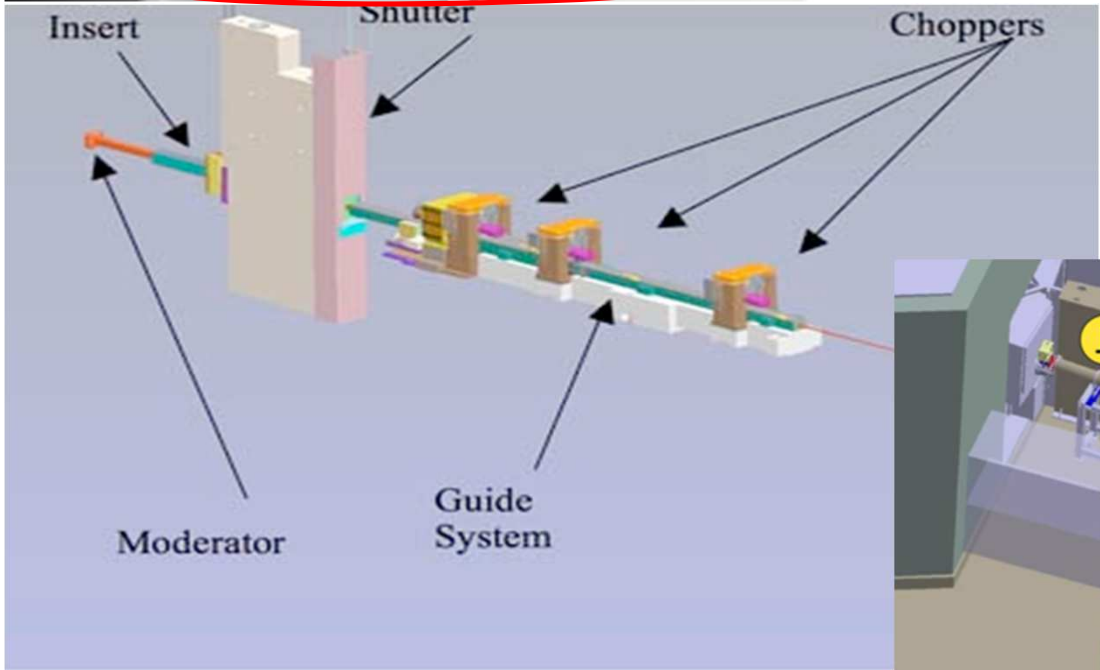
Advanced Neutron Imaging – SP sources

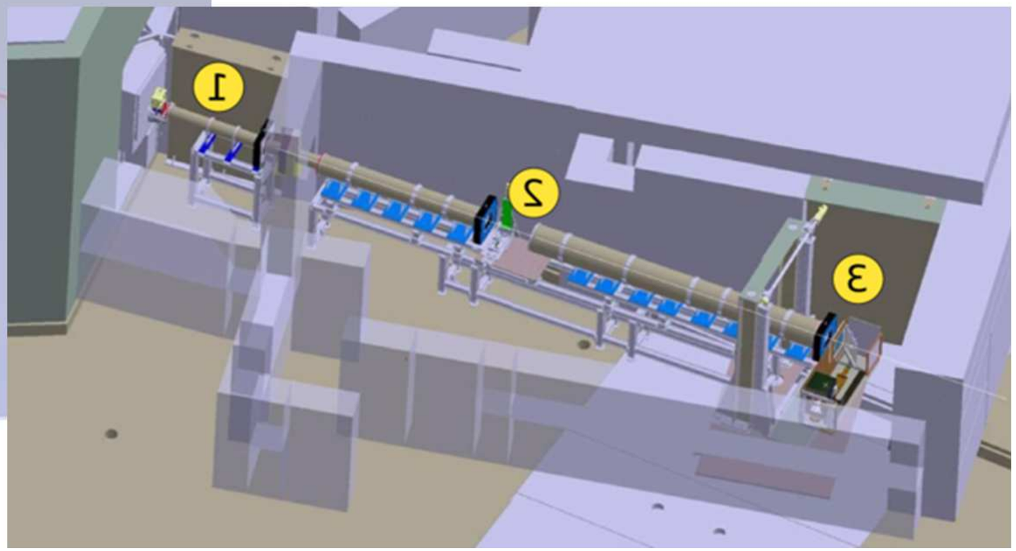




Advanced Neutron Imaging – ODIN @ ESS

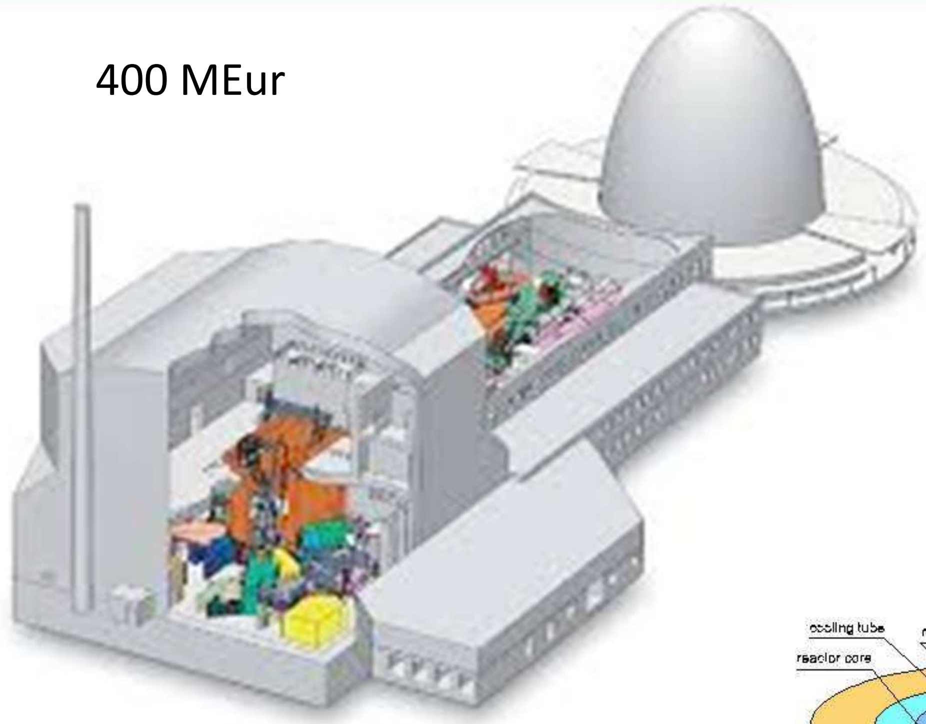




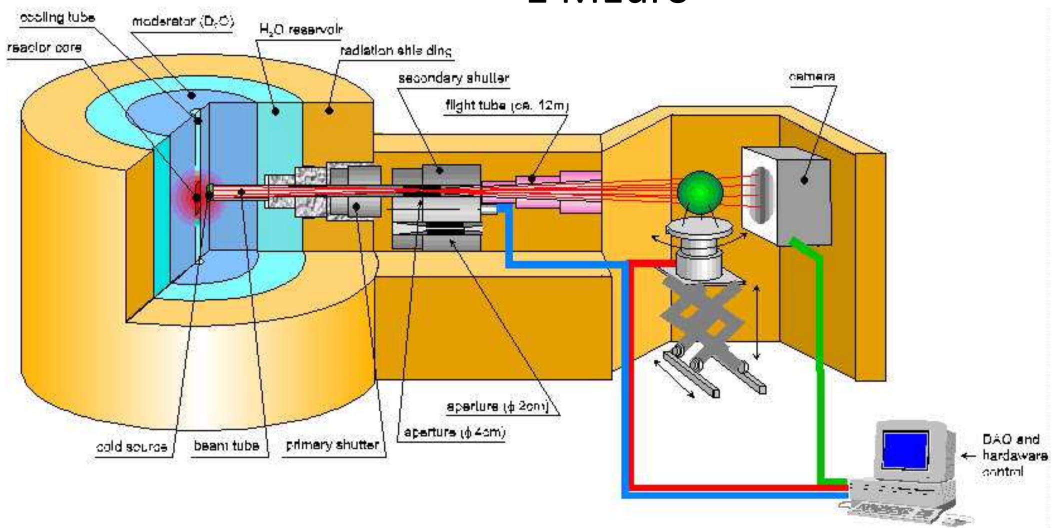


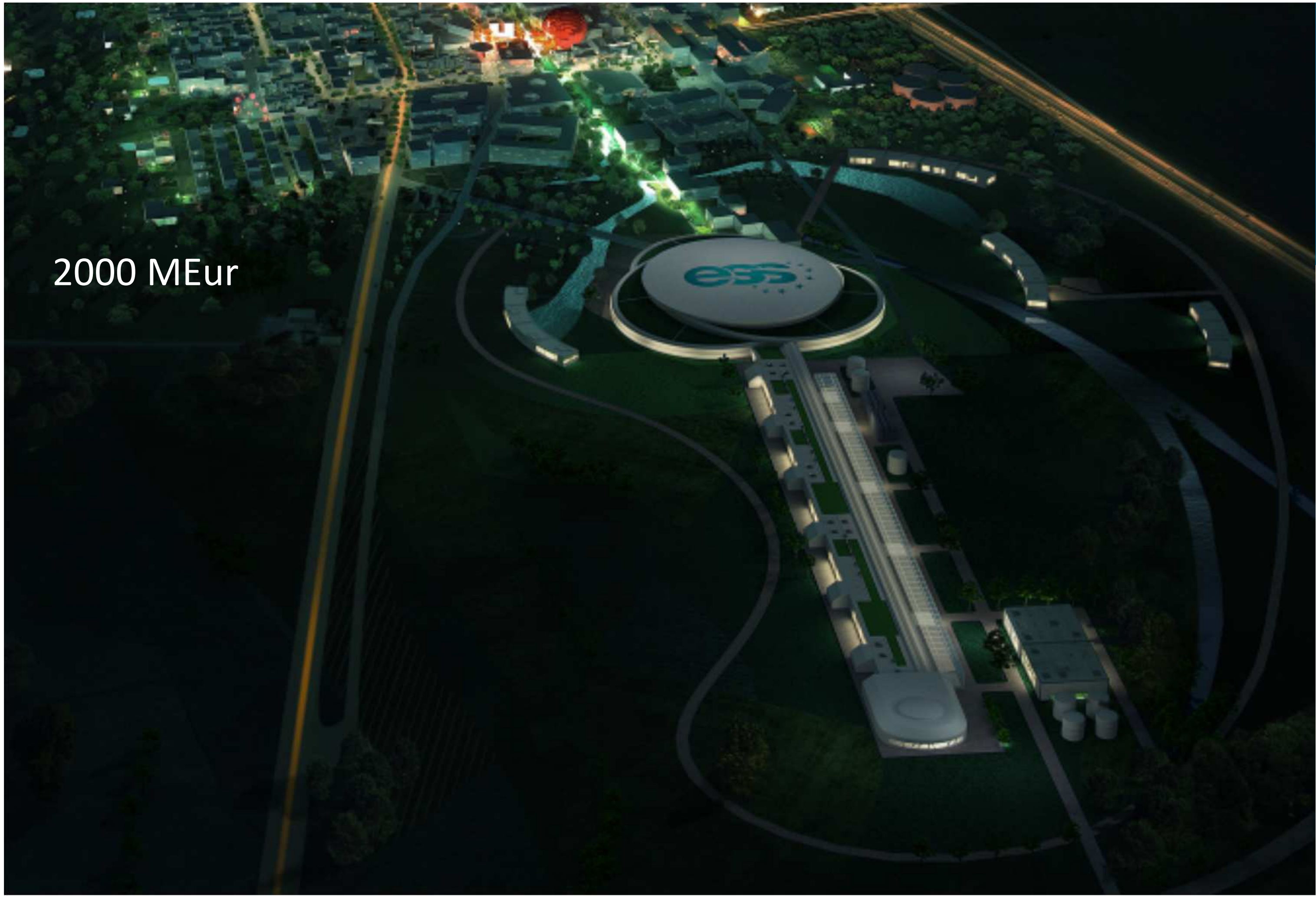
Neutron Imaging Instrumentation – cost

400 MEur

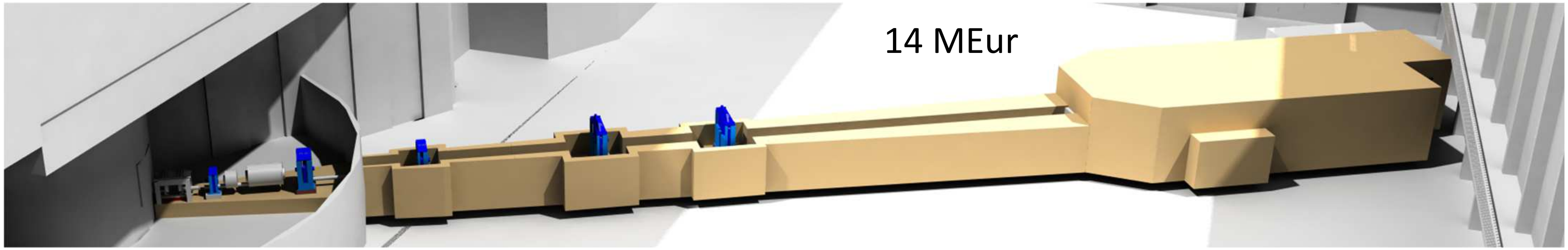


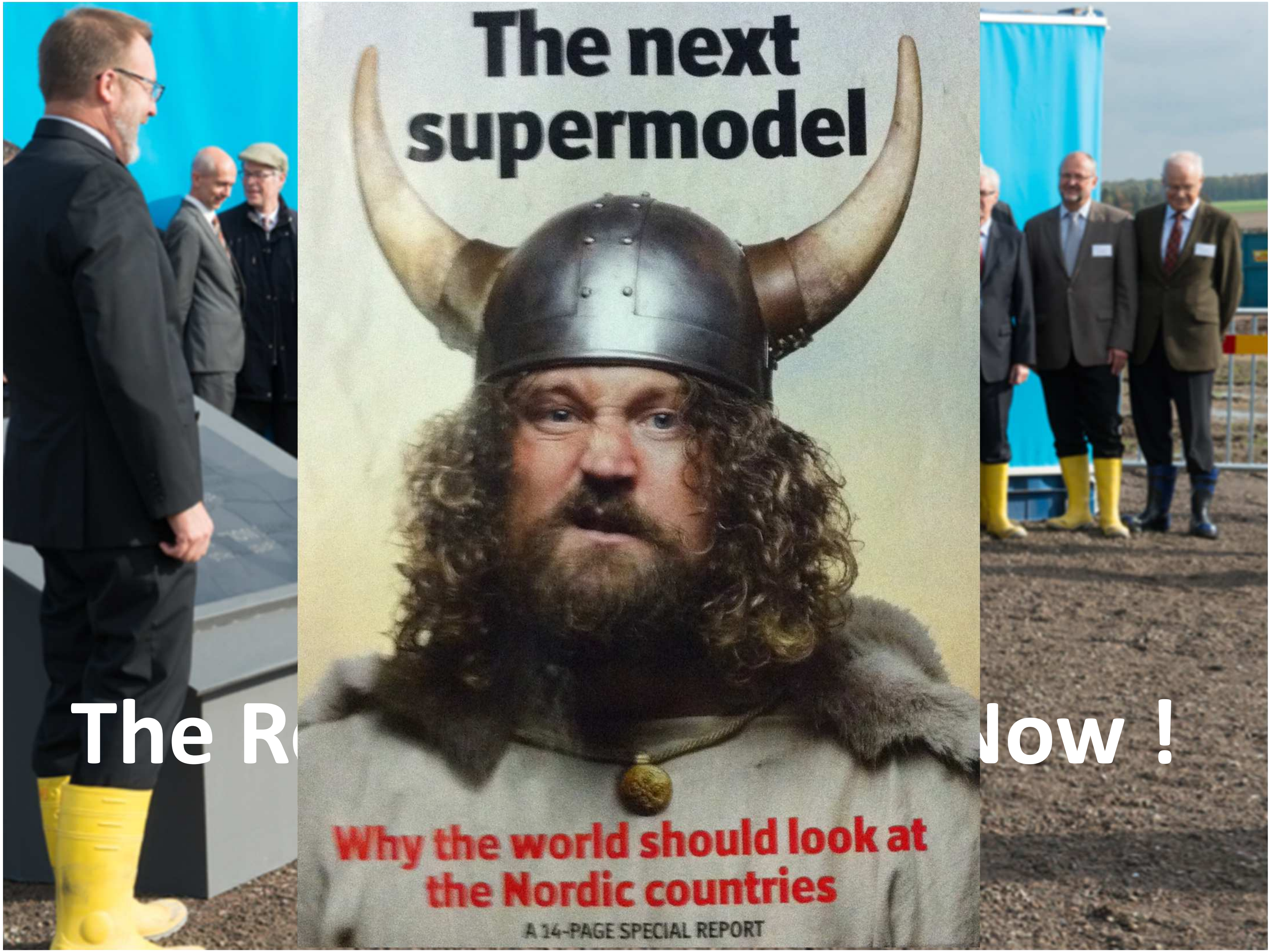
1 MEuro





EUROPEAN SPALLATION SOURCE




The next
supermodel
Why the world should look at
the Nordic countries
A 14-PAGE SPECIAL REPORT
The R
ow !

M. Strobl

Deputy Head of Instrument Division

Prof. X-ray and Neutron Imaging Techniques (NBI, KU)

www.europeanspallationsource.se

Instrument Suite and IK Partners

EUROPEAN SPALLATION SOURCE