

# Neutron Imaging at Spallation Neutron Sources

E.H. LEHMANN, A. KAESTNER

Paul Scherrer Institut, Deptm. Spallation Neutron Source, Switzerland

# OUTLINE

1. Introduction: Motivation for Neutron Imaging
2. Facilities for Neutron Imaging at PSI
3. New neutron sources: accelerator driven → pulsed
4. Challenges for Neutron Imaging at pulsed spallation sources
5. Status world-wide
6. Conclusions

# 1. Introduction: Motivation for Neutron Imaging

- Alternative in non-destructive testing, comparable and complementary to X-rays
- Different contrast mechanism, different transmission → different sample size
- All modern imaging methods available also with neutrons (digital imaging, tomography, phase-contrast methods, time-dependent studies, ...)
- HOWEVER: compared to synchrotron sources – limitation in neutron beam intensity
- Still a lack of suitable Neutron Imaging facilities world-wide (only about 15)

# 1. Introduction: Motivation for Neutron Imaging

- **Many unique applications**

fuel cell research – *electro chemistry*

nuclear fuel inspection – *nuclear technology*

studies for cultural heritage objects – *history, culture*

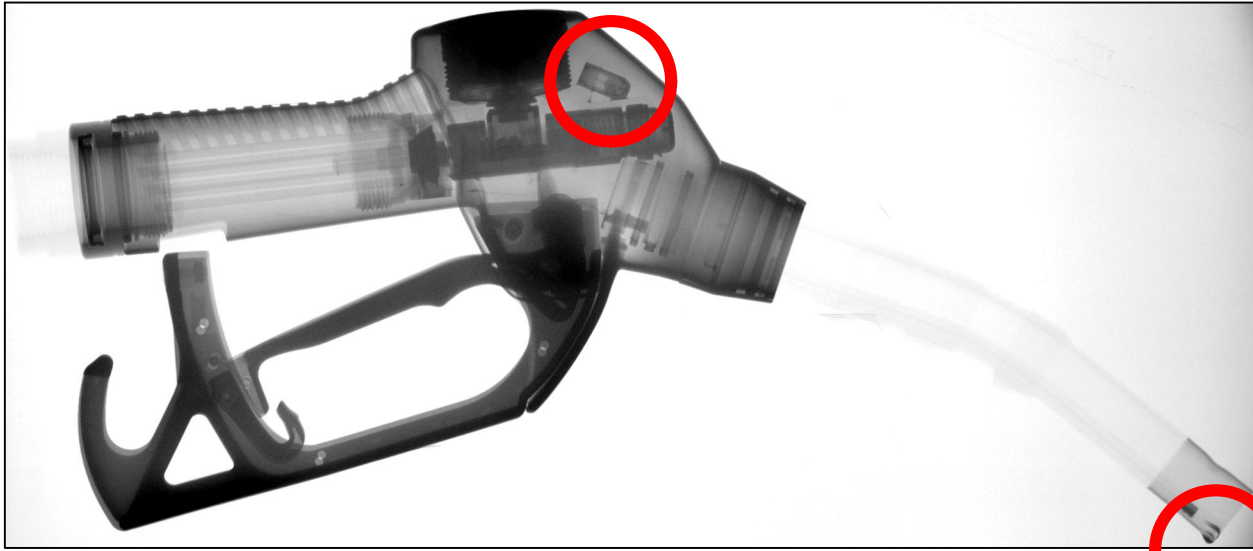
moisture distribution in various structures – *civil engineering*

Root growing behaviour – *biology, environmental research*

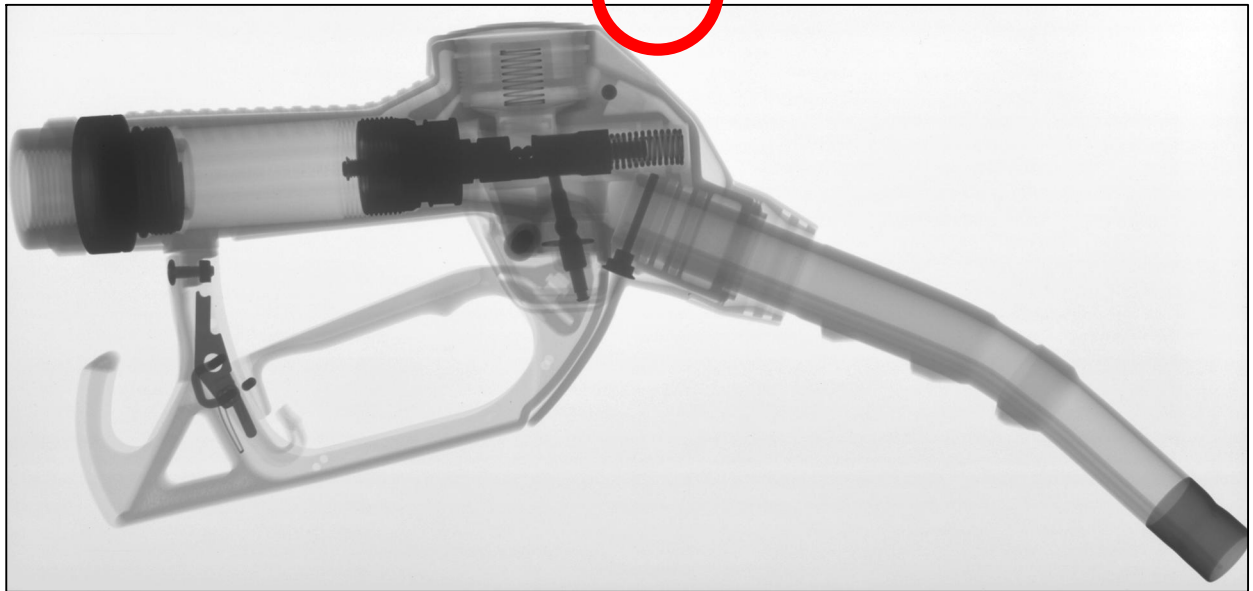
Geological objects + liquid distribution (water, oil, salt, ...) – *geology*

...

# X-ray vs. Neutron Imaging (example dispenser)



neutrons



X-ray

## X-ray

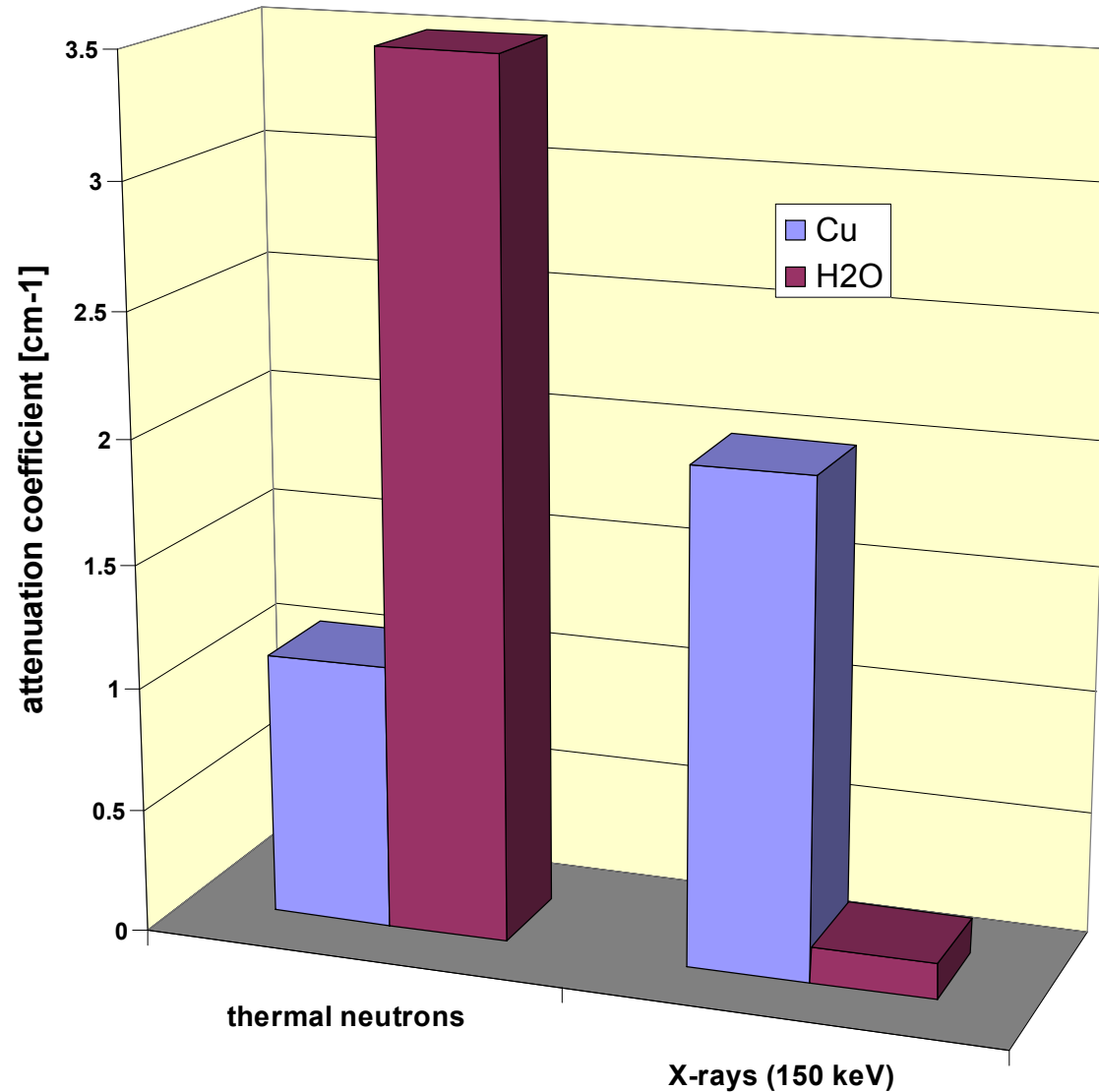
vs.

## Neutron Imaging

- X-rays interact with the electrons in the atomic shell
- Light elements (organic material) have low contrast only
- Heavy elements (e.g. metals) are difficult to transmit
  
- **Method available in many labs**

- (thermal) neutrons interact with the atomic nuclei
- Hydrogenous materials deliver high contrast
- Many metals can easily be transmitted
  
- **Method available in only few dedicated labs**

# Comparison of thermal neutrons $\leftrightarrow$ X-rays



### 3. Facilities at PSI for neutron imaging

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***Competitive Neutron Imaging can be done at spallation sources!***

- Two facilities available: **NEUTRA** (thermal neutrons), **ICON** (cold neutrons)
- In addition: X-ray tube with up to 320 kV high voltage for direct referencing
- Beam diameter up to 40 cm, samples up to 500 kg, spatial resolution up to 10 micro-meters

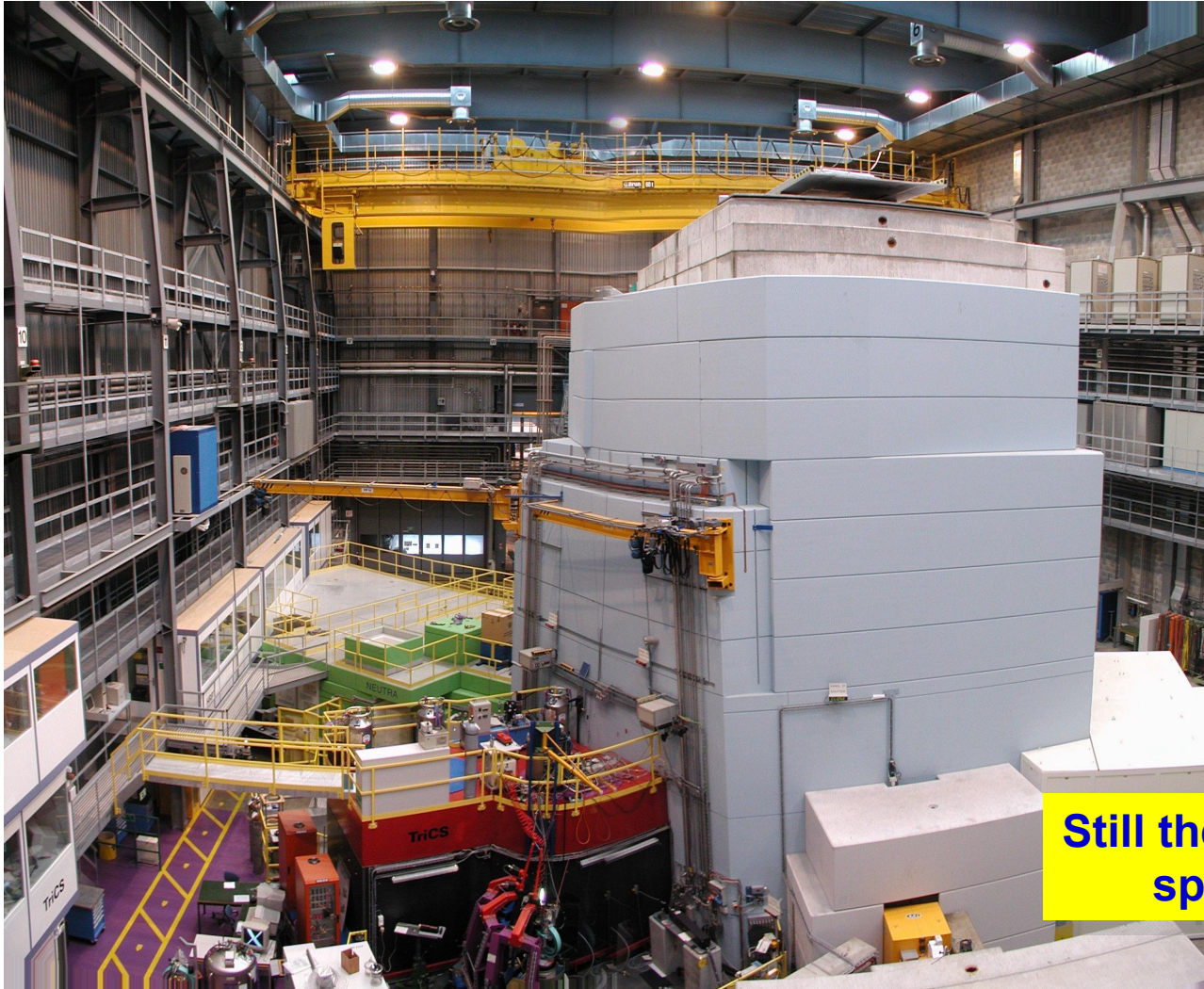
**→ Beam time can be booked via a proposal system (see below)**



# Large scale facilities at Paul Scherrer Institut, CH



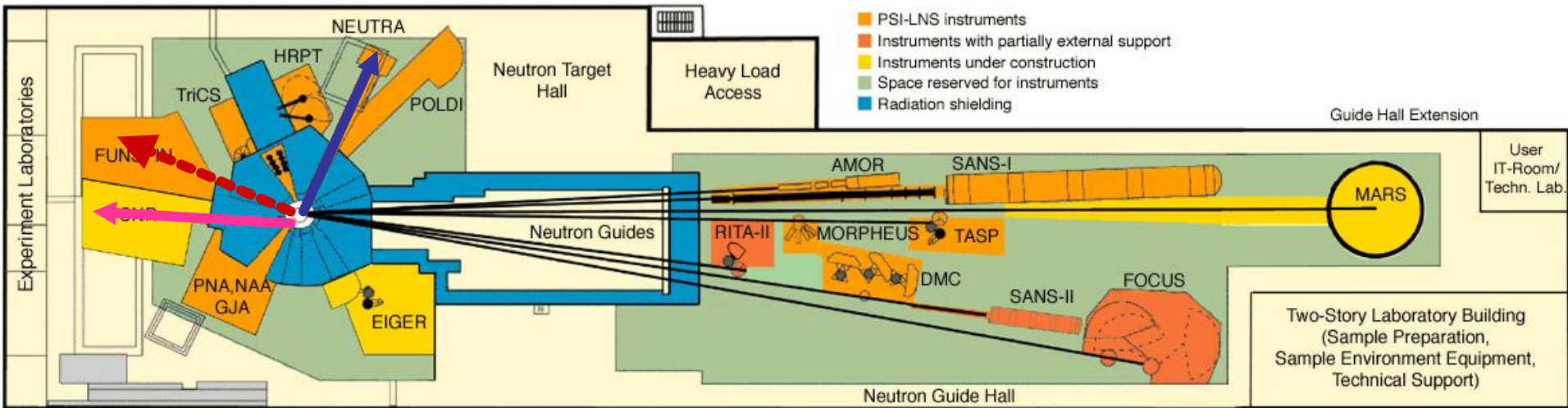
# Spallation neutron source SINQ @ PSI



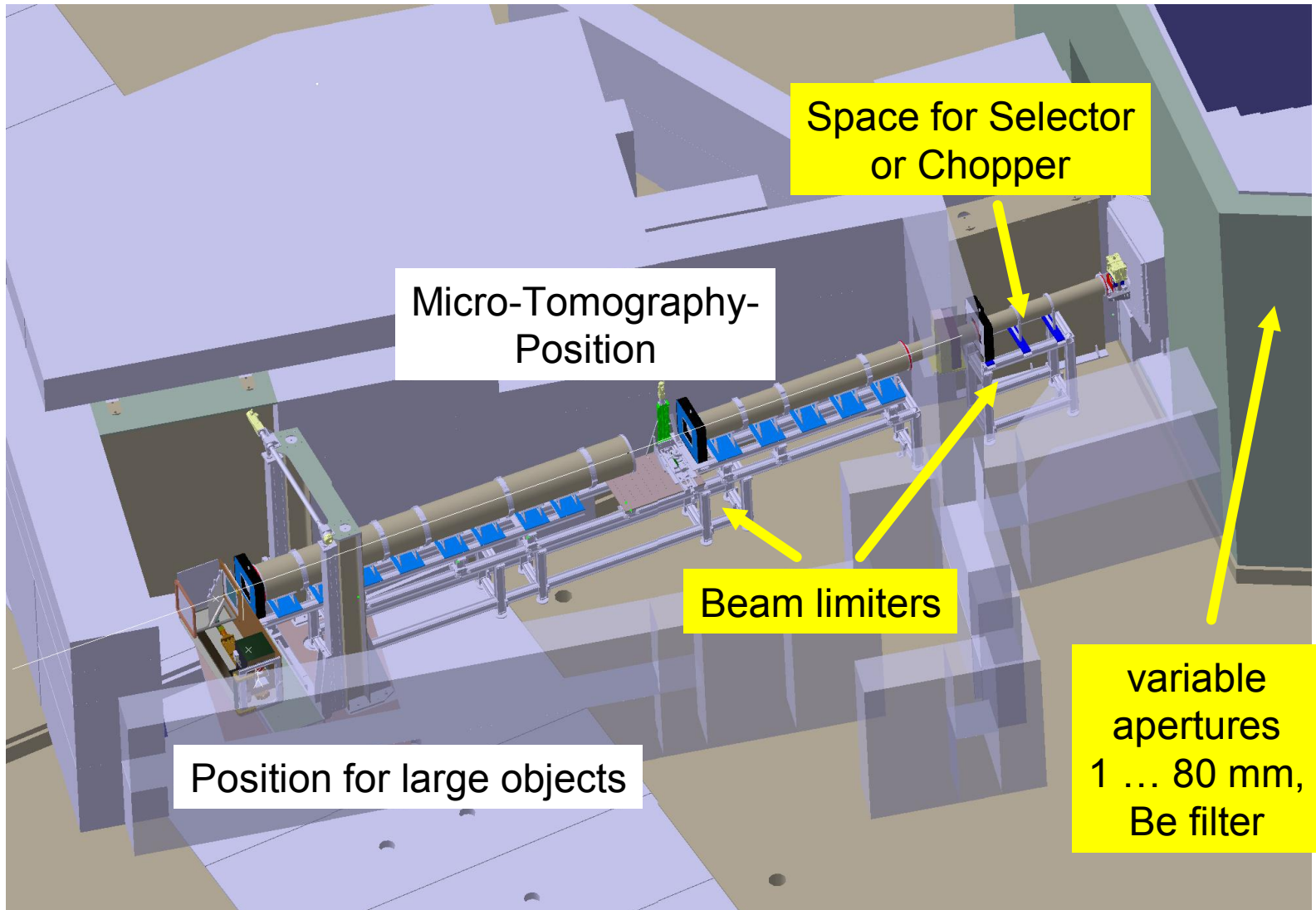
- In operation since 1997
- Driven by 590 MeV protons on a Pb target
- Intensity about 1.2 mA, corresponding to 1MW thermal power
- Installations for research with thermal and cold neutrons

**Still the world's strongest spallation source**

# SINQ-Layout (Status 2009)



# ICON-beam line @ SINQ



### 3. New spallation sources → pulsed

SNS (Oak Ridge, USA)

in operation since 2007

*Neutron Imaging*

**VENUS**

J-PARC (Tokai, Japan)

in test operation since 2008

**considered**

ISIS-TS2 (Rutherford Lab, UK)

under construction

**IMAT**

ESS (Europe)

under consideration

**probable**

**No real installation for NI available for test purposes yet**



**discussed later**

# Imaging at pulsed spallation sources ?

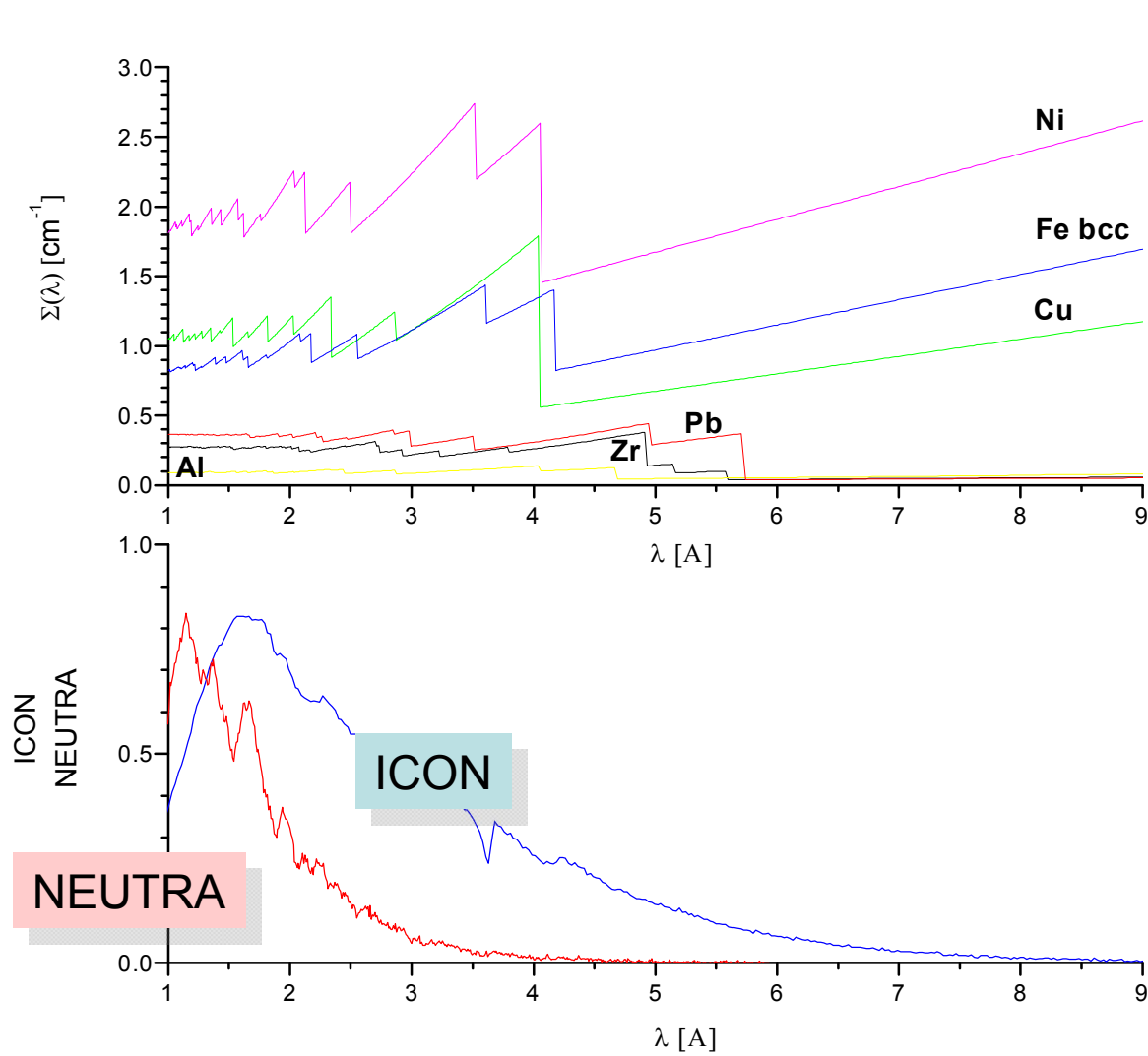
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- **The *energy selection option* has much more potential than simple tests can demonstrate for the moment**
- **The *combination of transmission and diffraction* is very promising for material research and other studies**
- **A dedicated and well designed beam line is needed for this approach**
- **A *stroboscopic option* is important to study time-dependent and repetitive processes**
- **All „standard“ applications will be possible as well in the „integration mode“**

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## Imaging at pulsed spallation sources !

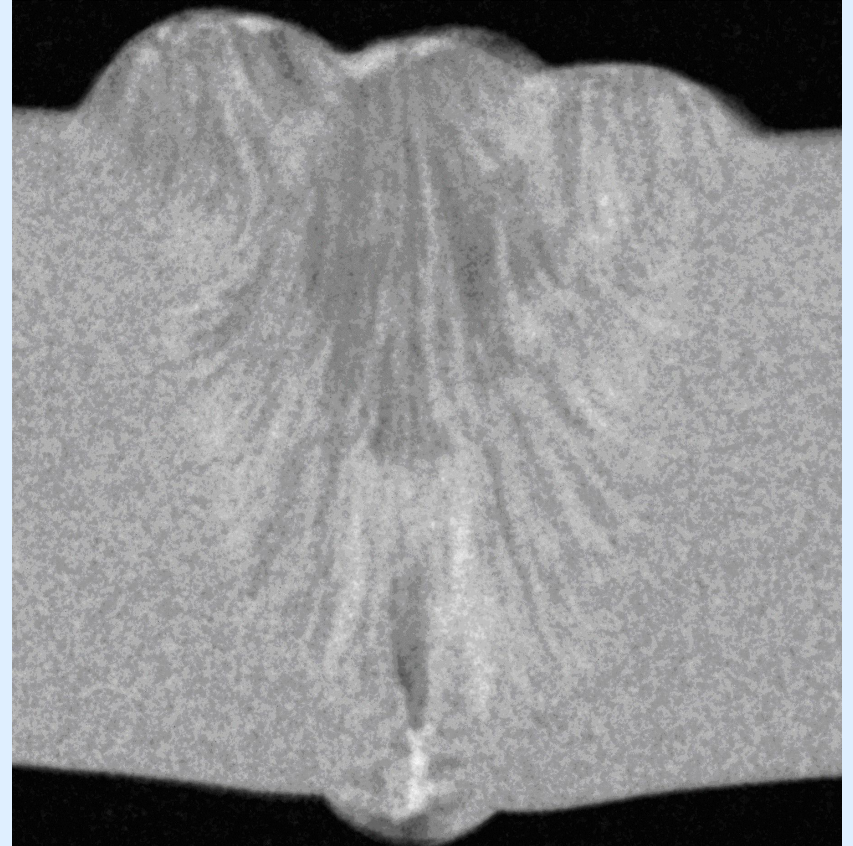
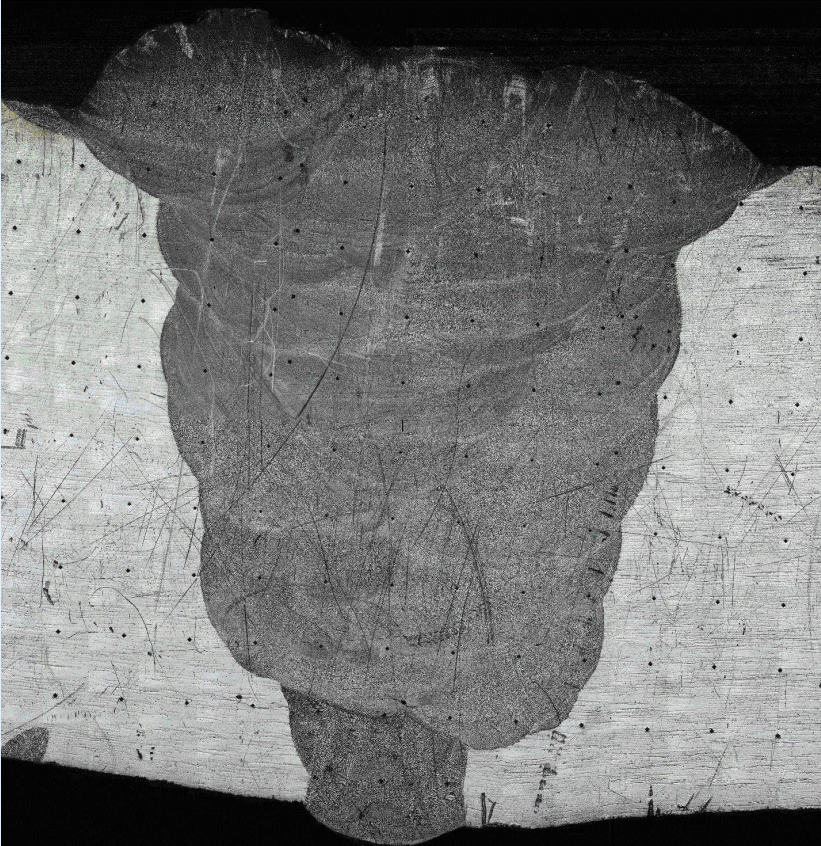
# Experiments at the Bragg edges of the materials

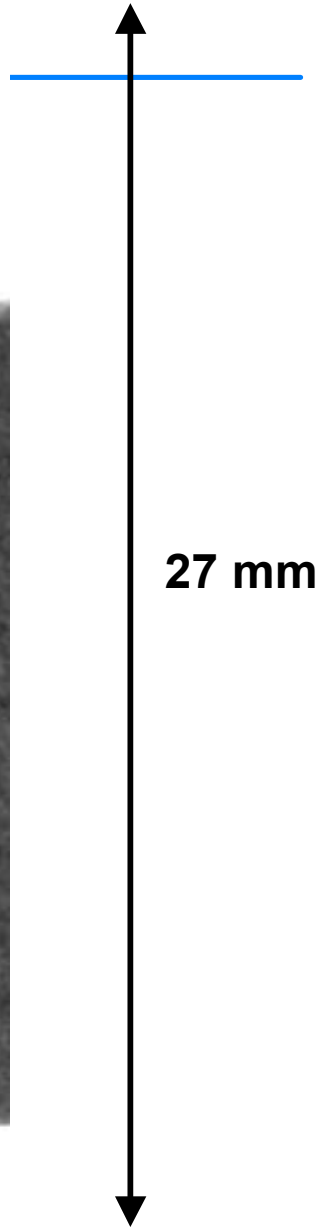
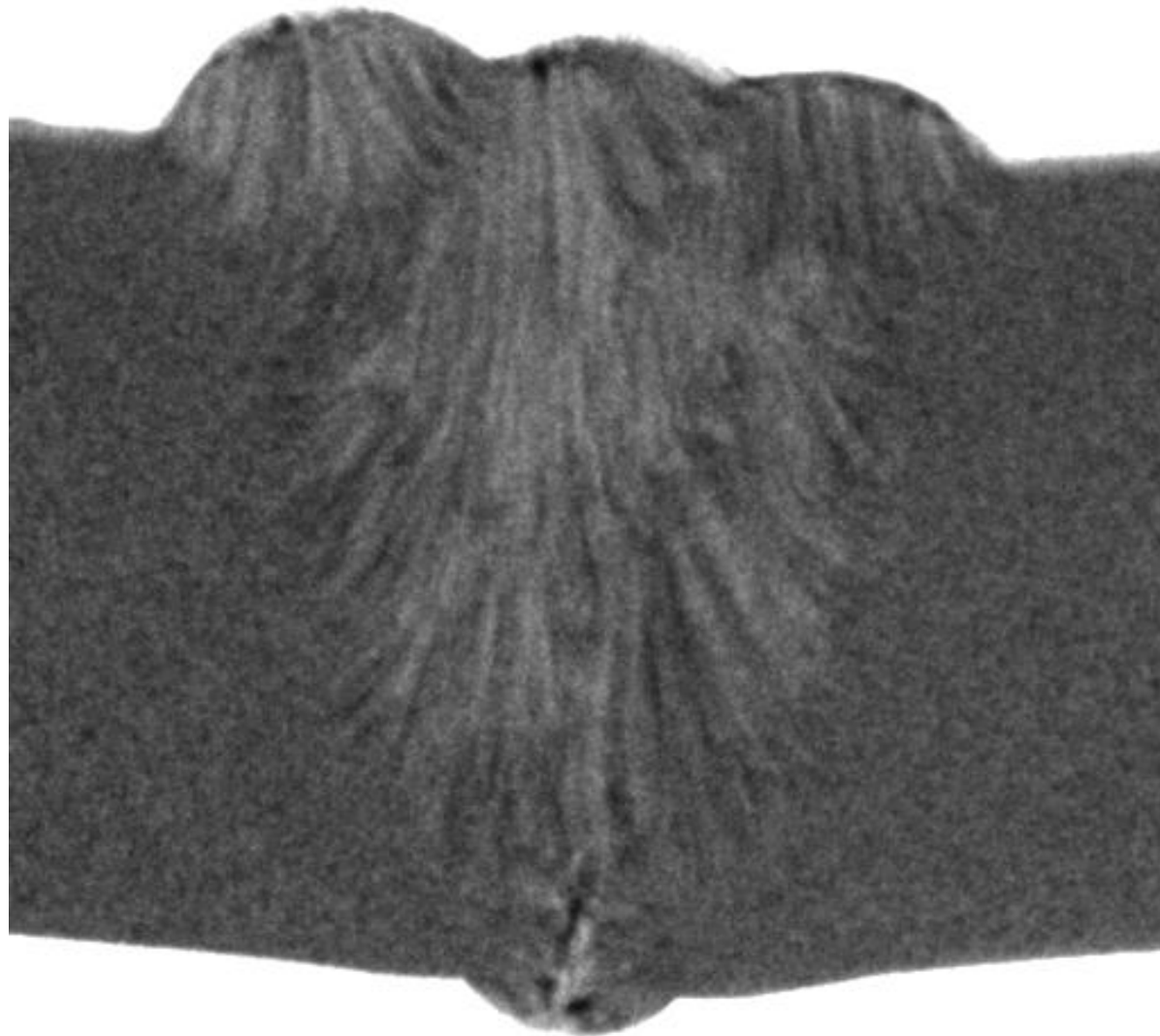


- ***Material research near Bragg edges of poly-crystalline materials***
- ***Structural (phases, textures) behavior under various and changing conditions visible***
- ***Information on the macroscopic scale for large samples (higher transmission)***
- ***Better quantification possible (beam hardening, scattering artifacts are less important)***
- ***Link to the scattering methods, in particular stress analysis***



# Example for energy selective imaging (steel weld)





27 mm

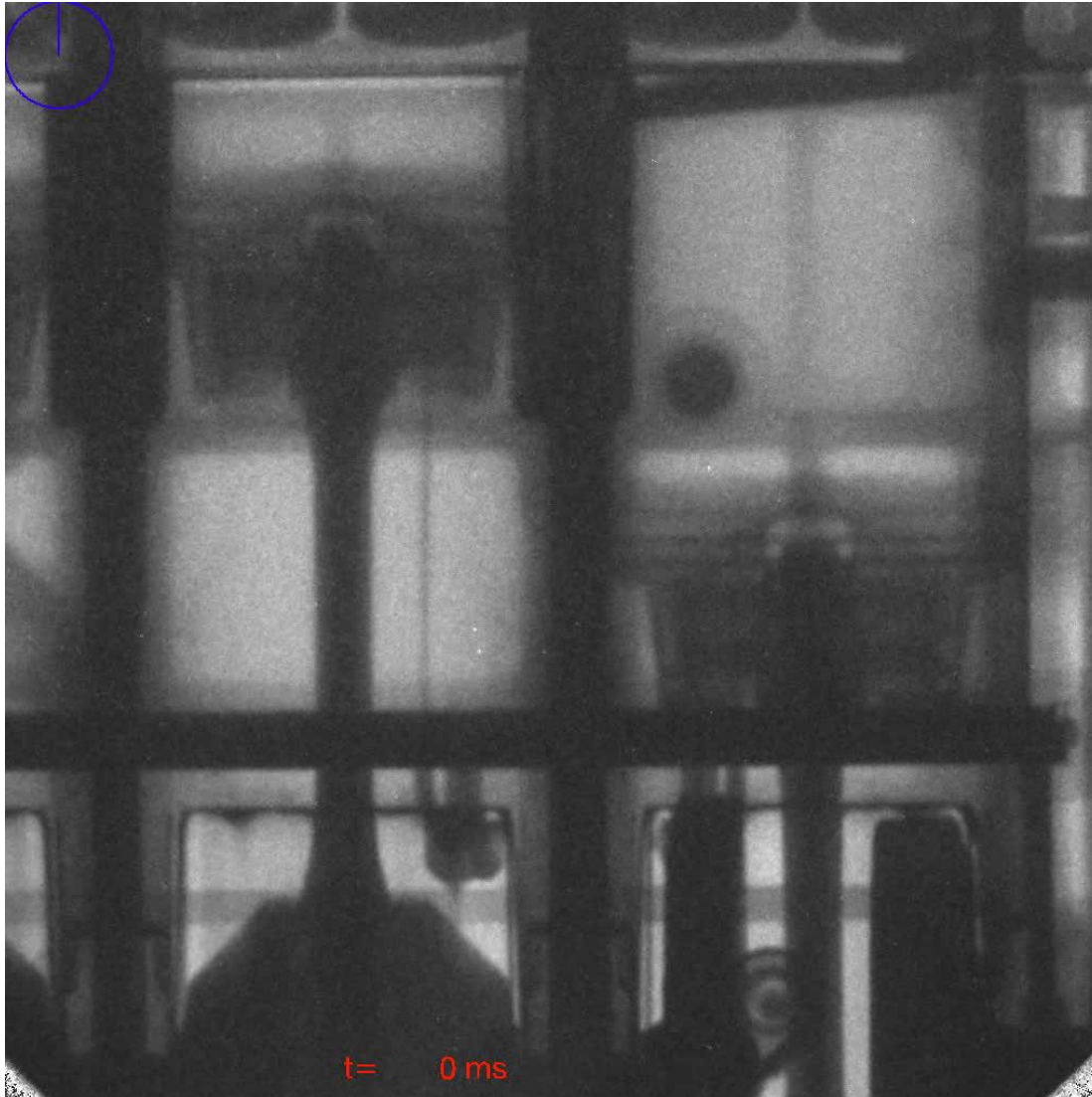
Range: 3.5Å ... 4.5 Å,  $\Delta\lambda=0.29$  Å

Double crystal mono-chromator CONRAD

## Information derived and available from Bragg edges in transmission mode

- **Phase identification and analysis**
- **Phase transition kinetics**
- **Stress and strain**
- **Crystal orientation**
- **Texture**
- **?... because no experimental option, yet**

# Time dependent studies – stroboscopic option



Data obtained at  
ANTARES, FRM-2  
TU Munich

# CONCLUSIONS

- Similar to the stress scanning devices (initiated 10 years ago), E-selective imaging will be a powerful tool for material research in the future
- With the high spatial resolution, neutron imaging methods can deliver a more direct attribute to local material changes
- These findings can directly be compared to destructive material testing methods
- As a non-destructive method this approach will be unique
- Comparison to diffraction experiments will help to improve the interpretation work to do

# Projects @ spallation sources

- Best suitable beam port needed (intensity, spectrum, collimation, ...)
- Layout of the neutron imaging facility different from scattering devices (FOV, flight path length, background requirements, ...)
- Detector development needed to use the neutrons most efficiently
- New research area!

## *Neutron Imaging*

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in operation since 2007

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in test operation since 2008

**considered**

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under construction

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**probable**

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## ***SNS Oak Ridge, USA***

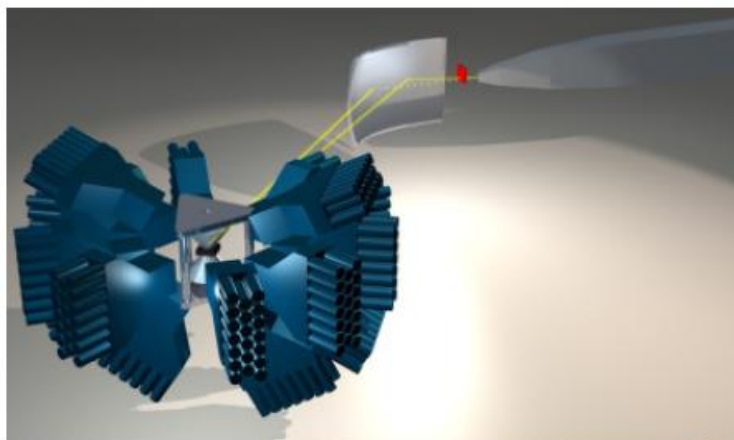
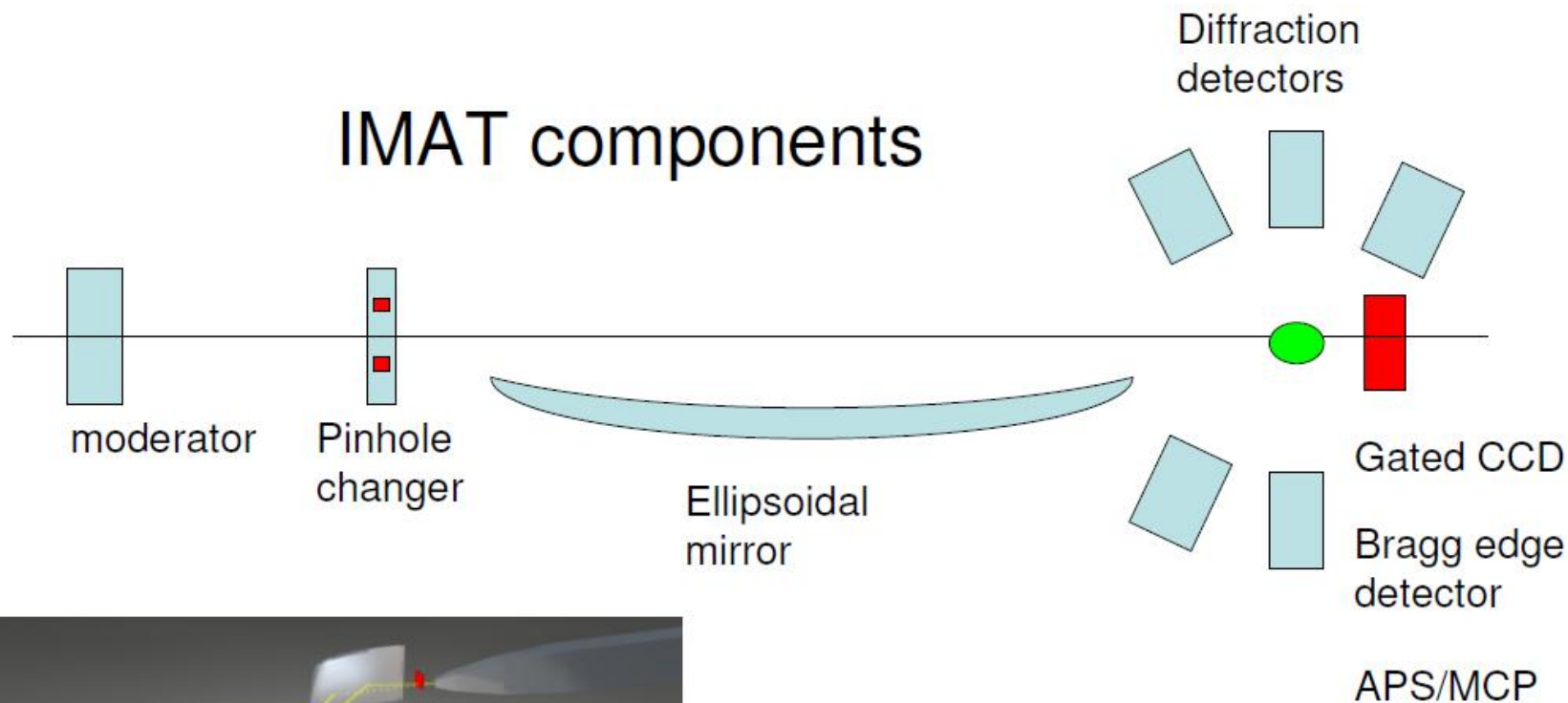
**V**ERSATILE **N**EUTRON IMAGING  
**I**NSTRUMENT  
AT THE **S**PALLATION NEUTRON  
**S**OURCE



# *SNS Oak Ridge, USA*

# ISIS, TS-2, Rutherford Lab, UK

## IMAT components





# ***J-PARC, JSNS, test beam line NOBORU***

# SUMMARY

- Neutron imaging with spallation neutrons will deliver new approaches for material research and many other applications
- Further improvement of the set-up and more experience will help to push the development of suitable installations at the new sources forward
- Pulsed neutron sources will be an important research tool for this investigations and other new options (polarized neutrons, time frames, phase effects, ...)

# CONTACT

For the method:

<http://neutra.web.psi.ch>

For beam time allocation:

<https://duo.psi.ch/duo/>

Generally: [eberhard.lehmann@psi.ch](mailto:eberhard.lehmann@psi.ch)