Experimental facilities

Heinz Maier-Leibnitz Zentrum

Experimental facilities
Heinz Maier-Leibnitz Zentrum (MLZ)

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User Office


PGAA

Dear user of the Heinz Maier-Leibnitz Zentrum (MLZ),

The development of our instrument suite at the neutron source Heinz Maier-Leibnitz (FRM II) progresses continuously. This motivates us to revise this brochure on a regular basis in addition to our up to date information at our new internet pages www.mlz-garching.de. We hope you will find this printed collection of information useful for the application of beam time at our facility.

The major part of the available beam time at the instruments is distributed via an open access policy to the scientific community, where the necessary selection process relies solely on the scientific merit of the proposed experiment. To ensure a high quality of our service to you as our user, significant financial resources had to be put together. Whereas the source itself is funded by the Bavarian State Ministry of Sciences, Research and the Arts via the Technische Universität München (TUM), the budget for the scientific usage is based on the collaboration of different partners. A list of all institutions is given at the end of this brochure.

Since 2011 a cooperation of the TUM with neutron centres from the Helmholtz Association in Jülich, Geesthacht and Berlin is in place to exploit the scientific usage of the FRM II, supported by funds from the Federal Ministry of Education and Research. To present this cooperation as a joint endeavour, the Heinz Maier-Leibnitz Zentrum (MLZ) was inaugurated in Garching on February 21st, 2013. The MLZ is supposed to be the gathering point not only for the cooperation partners, but also for the Institutes of the Max-Planck-Gesellschaft and the numerous university institutes bringing their knowledge and substantial resources to the benefit of the German and international neutron community.

Last but not least, all our instruments as well as the increasing important infrastructure from sample environment to specialized laboratories on site are in constant development. Please get in contact with the staff in Garching to be involved in this development in order to improve our service for your fascinating experiments.

Yours

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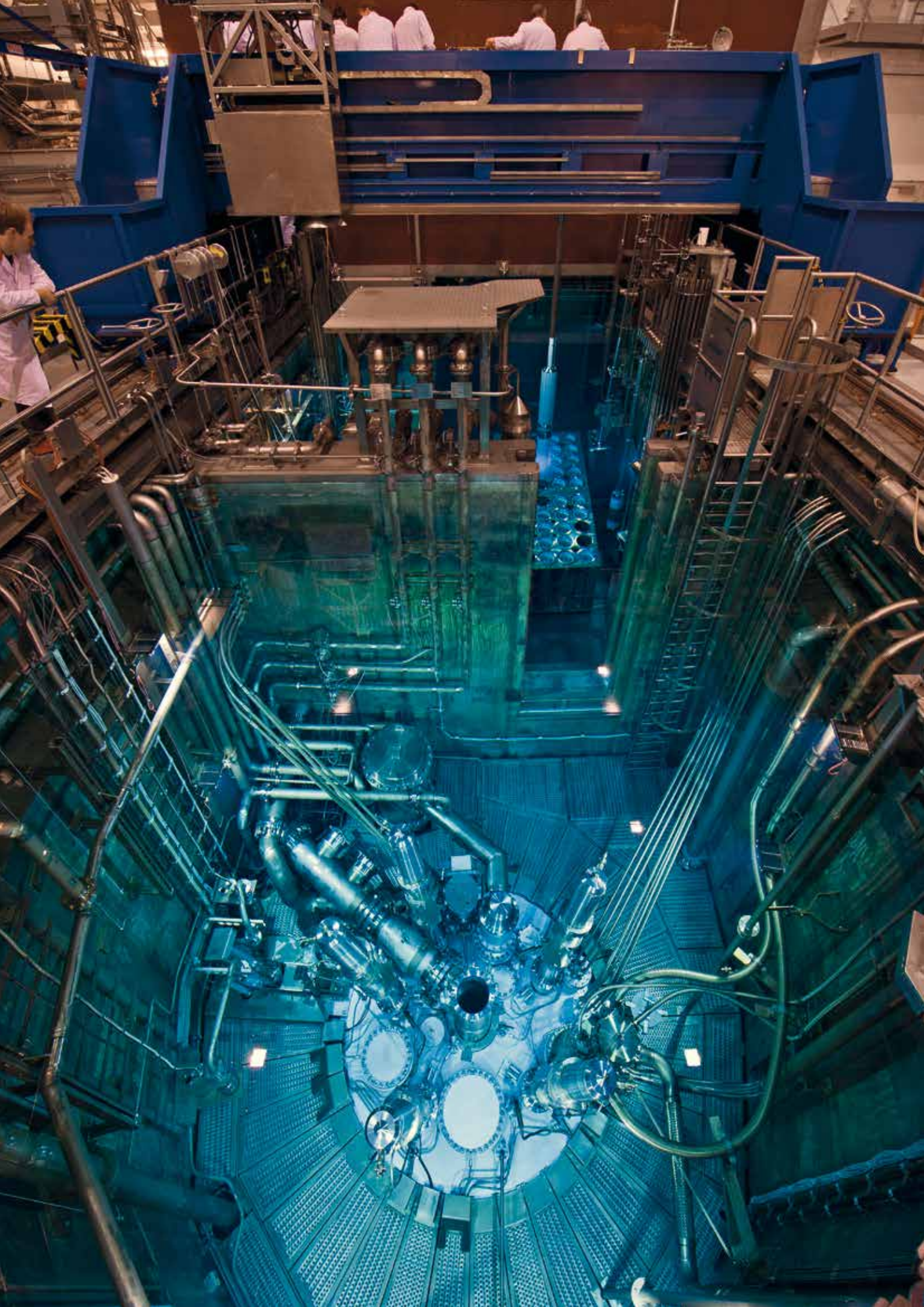

Neutron Source

The neutron source FRM II

Powerful neutron source

The neutron source Heinz Maier-Leibnitz (FRM II) is a multipurpose research reactor with a particular focus on beam tube experiments. It has been designed for providing neutrons to scientific users from all over the world as well as for medical and industrial applications. The FRM II is operated as a central scientific institution by the Technische Universität München (TUM) in Garching near Munich, Germany. Its first criticality was achieved in March 2004.

The FRM II is the most powerful neutron source in Germany and reaches the highest neutron flux density ($8 \cdot 10^{14}$ neutrons $cm^{-2}s^{-1}$, max. undisturbed flux density) relative to its thermal power (20 MW) throughout the world. More than 30 experimental facilities are operated by scientific teams from German universities, research institutes of the Helmholtz Association and the Max-Planck-Society at the neutron source. Today, 23 beam tube facilities are operational. Further 7 irradiation facilities mainly for medical and industrial application are in service, an irradiation facility for the production of the medical isotop ^{99}Mo is under construction. The FRM II is equipped with cold, thermal, hot and fast neutron sources and thus covers a broad range of applications, including a device for the continuous production of an intense positron beam.

Fuel element

The FRM II has been designed for an exclusive purpose: the production of neutrons for basic research and applied physics. Its high performance is based on the concept of a compact core: a single, cylindrical fuel element with a diameter of just 24 centimetres is sufficient for 60 days of reactor operation. The fuel zone measures 70 centimetres in height and contains about 8 kilograms of uranium in the form of U_3Si_2. Like other high-performance neutron sources around the world, the FRM II uses highly enriched uranium.

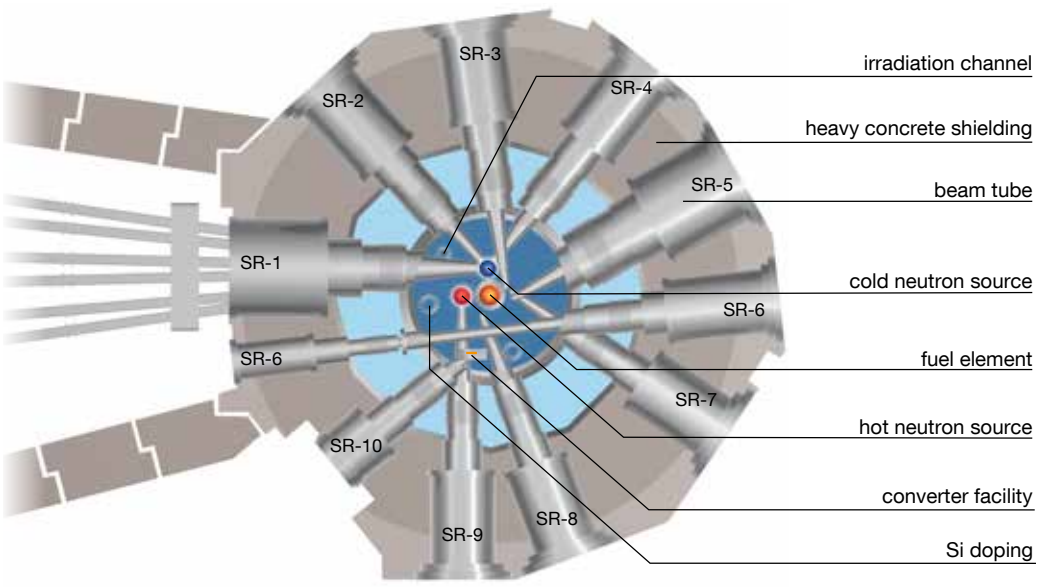

Figure 1: Horizontal section of the reactor pool showing the beam tubes, fuel element, as well as cold and hot neutron source. Beam tube 1, 2 and 4 are fed by the cold source, number 9 by the hot source. The through-going beam tube no. 6 will be used by the ultra cold neutron source. The converter plate for fast neutrons supplies beam tube no. 10 with the tumour treatment facility. The remaining beam tubes are placed into the highest neutron flux taking up the thermal neutrons.

The fuel element is located in the centre of a moderator tank filled with heavy water (D_2O). The tips of the beam tubes are placed in the region of the maximum thermal neutron flux density. Various vertical irradiation channels are arranged in the moderator tank. The beam tubes guide the neutrons to the experiments in the experimental hall and neutron guide hall.
The experimental hall contains scientific instruments exhibiting high neutron flux densities and gives access to the positron beam lines, whereas the neutron guide hall west is connected via six neutron guides to the cold neutron source. A second guide hall will be connected to the reactor building soon in order to extend the number of available instruments.

Safety first

The highest priority is always given to safety at the FRM II. The inherent safety stems from its principle design, with a compact fuel element built into the centre of the moderator tank filled with heavy water. Fuel element, moderator tank and beam tubes are located in the reactor pool filled with 700 cubic metres of highly purified water. While passing the fuel element, the temperature of the cooling water only increases from 36 to a maximum of about 51 degrees Celsius. Neither steam nor high pressures are produced. Three subsequent cooling circuits guarantee the safe dissipation of the 20 MW via the air path.
Redundant safety installations (i.e. multiple, independently constructed units) are a key feature of the safety concept of the FRM II. The single central control rod inside the fuel element is sufficient to regulate and shut down the reactor. Additionally, a redundant set of five shut-down rods is available. Each of these systems is constructed such that the reactor can be shut down in a fast and durable manner, completely independently.
The 1.8 metre thick outer concrete wall of the reactor building protects the reactor against all impacts from outside. It has been designed to resist the crash of a fast military jet as well as the crash of a passenger aircraft. This feature has been approved by independent experts. Furthermore, the building can withstand earthquakes up to level VI ½ (MSK), which is beyond the strength of possible earthquakes in the region, or a high floodwater from the nearby river Isar with a height, that might occur once every 10,000 years.

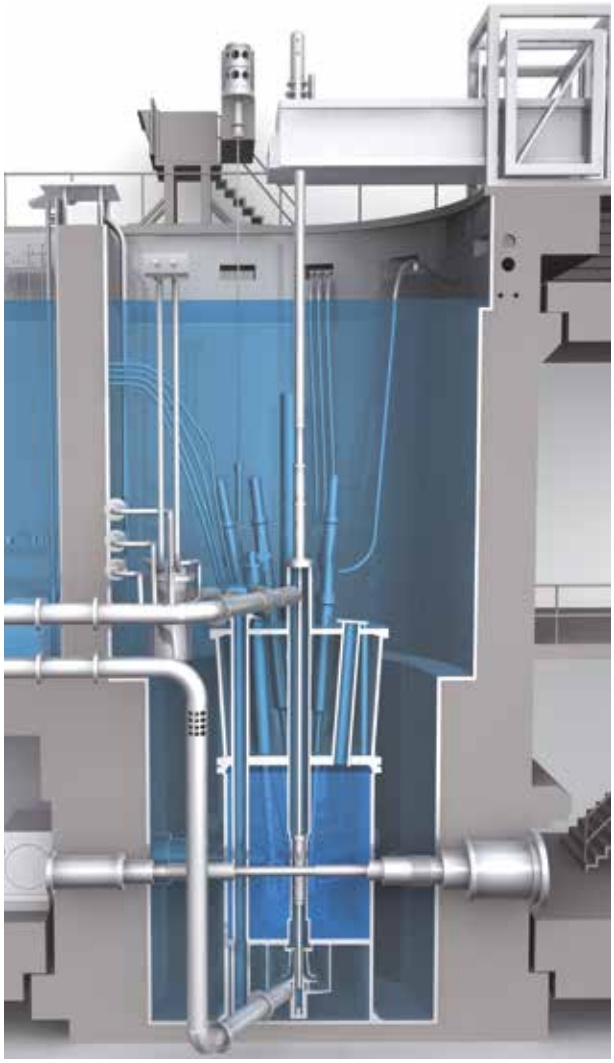

Figure 2: Vertical section of the reactor pool of the FRM II filled with water. The moderator tank, cooling circuit, safety facilities as well as the secondary sources are depicted.

Technical Data

Reactor main parameters

- 20 Megawatt thermal power
- $8 \cdot 10^{14}$ thermal neutrons $cm^{-2}s^{-1}$ max. undisturbed flux density
- 10 horizontal; 2 tilted beam tubes
- D_2O moderator
- H_2O cooling water

Staff and money

- 435 million € construction costs
- ~ 300 employees on site

Instruments

- 26 instruments in routine operation (2013)
- 5 instruments under construction

Fuel element

- Dimensions:
  133 cm height; 24 cm outer diameter,
  70 cm active zone
- 8 kg HEU in U_3Si_2 alloy in 113 fuel plates
- enrichment 92.5% in ^{235}U
- 60 days in a row / fuel element - typical
  240 days of operation per year

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Secondary neutron sources

The different instruments at the neutron source FRM II are supplied by various secondary sources slowing down or speeding up the neutrons after thermalization in the moderator tank. This allows a large variety of applications. Furthermore beam tube SR11 hosts the positron source NEPOMUC, which is described in the chapter Positrons.

The cold source

At FRM II a major part of the experiments is carried out using low energy ("cold") neutrons. For this purpose the beam tubes no 1, 2 and 4 are fed from a special secondary source, the so called cold neutron source, which is located within the moderator tank close to the maximum of the thermal neutron flux density.

The major component of the cold neutron source is the moderator chamber containing about 12 l of liquid deuterium (D_2) at a temperature of approximately 25 K. Neutrons interacting with the liquid D_2 in the moderator chamber are rethermalized at this low ambient. Consequently their energy spectrum is shifted considerably into the low energy range (see fig. 2).

Within the moderator tank the deuterium is available in a closed circuit driven by natural convection. The liquefaction of the deuterium is achieved by means of a He refrigerator acting as the heat sink of a heat exchanger which is installed above the moderator chamber. The liquefied D_2 rinses into the moderator chamber where it is evaporated again due to neutron moderation and gamma heating.

Figure 1: The cold source vessel surrounded by the beam tubes SR 1, 2, 4. View into the moderator tank of the FRM II before operation.

The moderator chamber and the heat exchanger form the inpile section of the cold neutron source. Important components outside the moderator tank are the refrigerator, a buffer tank and a metal hydride storage unit used to keep the deuterium during periods when the cold neutron source is out of operation and warmed to room temperature e.g. during maintenance periods of the reactor. The subsequent preparation of the cold source for low temperature operation, however, takes approximately 1 week.

The energy distribution of the neutrons moderated by the cold neutron source is shown in figure 2. It has its maximum at 40 meV corresponding to a wavelength of 1.4 Å. From the figure it is clearly visible that the corresponding intensity of neutrons exhibiting very long wavelengths is considerably increased as compared to the thermal spectrum generated in the moderator tank at an ambient temperature of about 70 °C.

The hot source

Neutrons of short wavelengths in the range of 0.1 eV to 1 eV are used to investigate the structure of condensed matter. As only a small fraction of this spectral range is present in the thermal neutron distribution, the neutrons are moderated upwards from about 300 K to 2200 K. This spectrum shift is performed by the hot neutron source.

The hot moderator consists of a graphite block thermally insulated and positioned in the moderator tank next to the maximum thermal neutron flux density. The graphite cylinder is heated by gamma radiation from the reactor. A double-wall zircaloy container with interposed insulating graphite felt insulates the graphite block, ensuring a secure containment of the hot graphite. At a reactor power of 20 MW the temperature inside the container rises to about 2000 °C. The hot source provides neutrons to beam tube no. 9, which supplies the single crystal diffractometers HEiDi and POLI.

Converter facility for fast neutrons

In order to obtain a high-intensity neutron beam with an unmoderated fission spectrum, an arrangement of uranium plates is inserted as a secondary aource (so called converter) in front of the tip of beam tube no. 10. It supplies the tumour treatment

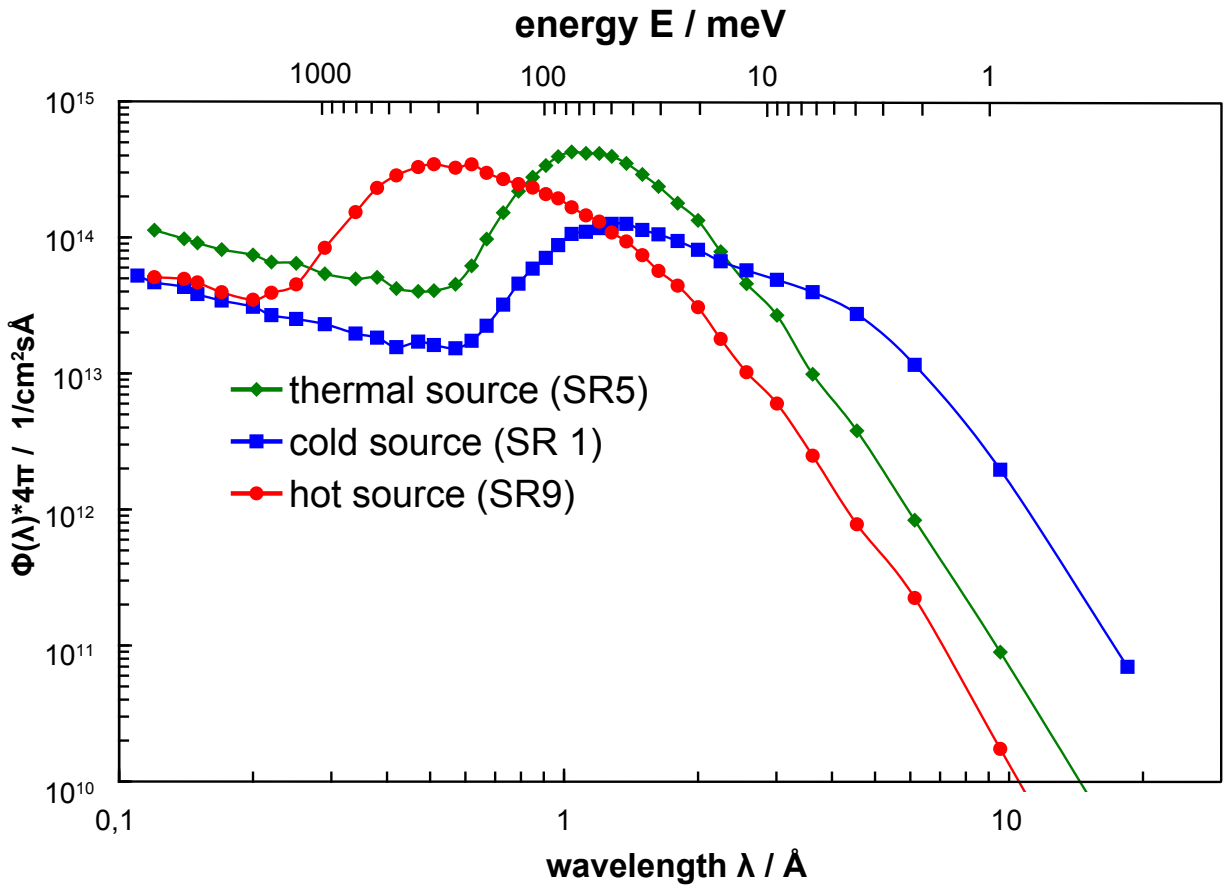

Figure 2: Neutron spectra at the entrance of the beam tubes at 20 MW reactor power.

Figure 3: The moderator of the hot source in the reactor pool of the FRM II during installation.

facility MEDAPP and the radiography and tomography station NECTAR with fast neutrons. Slow neutrons induce nuclear fission in the uranium plates causing the emission of neutrons with an average energy of 1.9 MeV. The fast neutrons are led without moderation through a horizontal beam tube to the experiments. The two converter plates deliver a thermal power of about 80 kW.

Technical Data

Cold source

- T = 25 K
- Volume of moderator chamber: 25 l
- Volume of liquid D_2: 12 l
- Mass of D_2 in cold source: 2.4 kg
- Cold moderator pressure: 1.5 bar
- 18 instruments fed by cold source

Hot source

- Mass of graphite in hot source: 14 kg
- Temperature at 20 MW reactor power: ~ 2000 °C

Converter facility

- Mass of uranium in converter plates: 540 g
- Thermal power 80 kW
- Degree of enrichment: 92.5 % in ^{235}U

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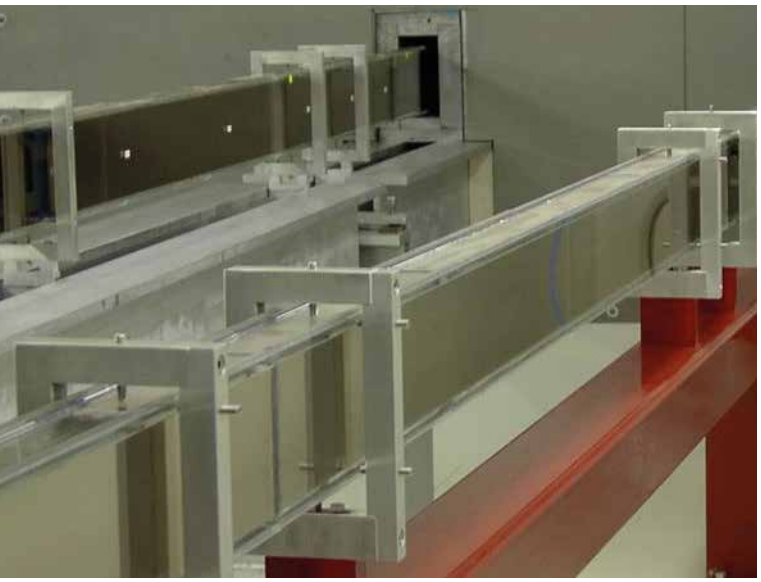
Neutron guides



The MLZ makes extensive use of modern neutron guides to transport and distribute the neutrons over large distances in the Experimental Hall (SR 2, 5, 8) as well as in the Neutron Guide Halls. Adapted to the needs of the instruments with respect to wavelength distribution and angular dispersion the guide elements are coated by ^{58}Ni or supermirror coatings with m values up to 3.0; on focussing sections up to m = 3.6.

Cold neutron guides

Beam tube SR1 facing the cold neutron source delivers the neutron beams for the entire Neutron Guide Hall West. The In-pile unit of SR1 consists of a mirror box with m = 2.2 supermirror coating on Al-plates and a dividing section of 2.1 m length, where the beam is divided into the 6 principal neutron guides. Figure 1 shows schematically how the neutron guides are further split in order to serve a maximum number of instruments, especially with end standing positions.
Besides SR1 the cold neutron three axes spectrometer PANDA on beam tube SR2 also has supermirror inserts in the in-pile section of the primary beam. In the near future SR4b will be equipped with a neutron guide for the nuclear and particle physics beam line MEPHISTO in the Guide Hall East. Right now almost 500 m of cold neutron guides are already installed.

Thermal neutron guides

Beam tubes SR8a and SR8b are equipped with supermirror guides with coatings up to m = 3. At SR5b a polarizing supermirror bender provides the instrument TRISP with polarized neutrons. In total roughly 50 m of thermal guides are installed. In the near future elliptical focussing thermal guides will provide neutron beams for the instruments in the Guide Hall East.

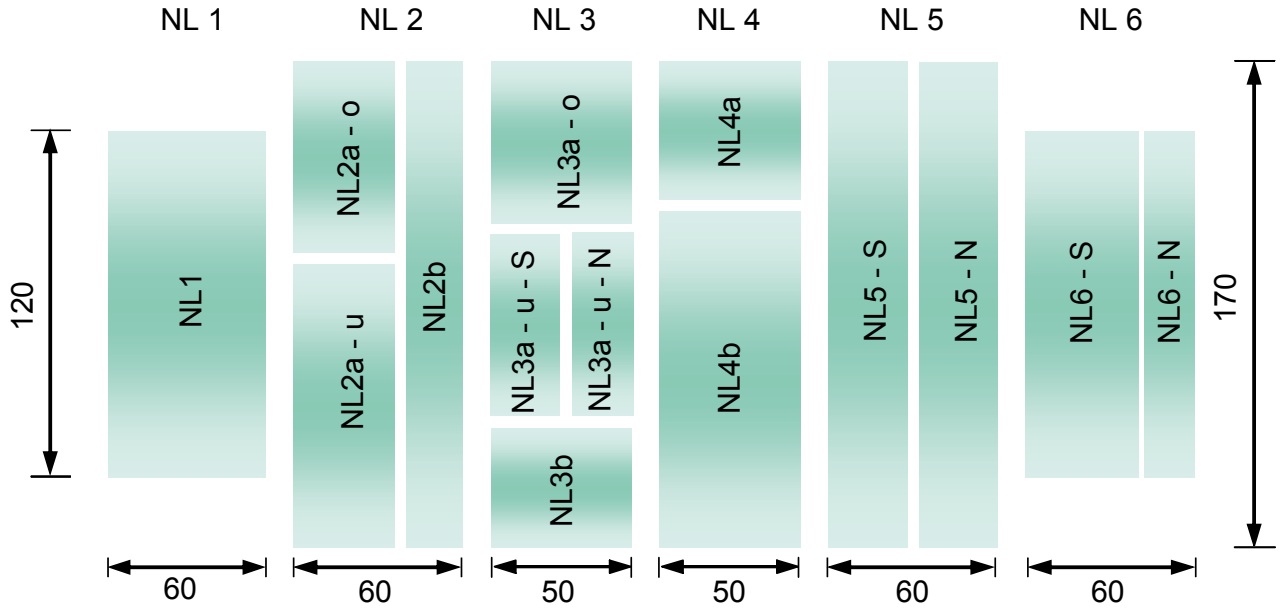


Figure 1: The sectioning of the 6 principal neutron guides of SR1. The subsections are referred to by the letters a, b, u, o, S, N.

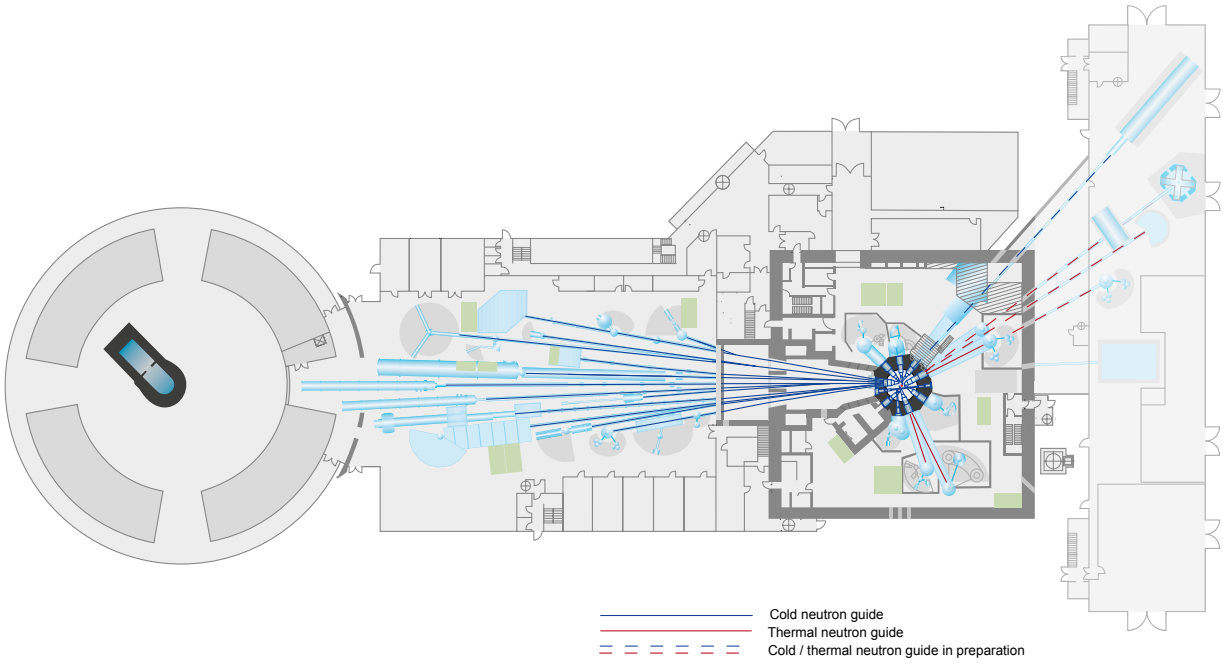


Figure 2: Floorplan of the FRM II with the neutron guide system.

Technical Data

Guide	NL1	NL2a-o	NL2a-u	NL2b
Length (m)	40	48	60	57
Section (mm²)	60 × 120	44 × 60	44 × 100	12 × 170
Coating up to	m = 2.5	m = 3.0	m = 2.0	m = 2.0
Radius (m)	1000	2000	160	400
Instruments	BIODIFF NREX	J-NSE	TOFTOF	REF-SANS

Guide	NL3a-o	NL3a-uS	NL3a-uN	NL3b
Length (m)	46	30	29	51
Section (mm²)	50 × 50	10 × 56	38 × 56	50 × 45
Coating up to	m = 3.0	m = 3.0	m = 3.0	m = 2.0
Radius (m)	460	30	460	1500
Instruments	KWS-2	KWS-3	unused	KWS-1

Guide	NL4a	NL4b	NL5-S
Length (m)	34	52	70
Section (mm²)	50 × 50	50 × 110	29 × 170
Coating up to	m = 2.0	m = 3.0	m = 2.0
Radius (m)	2100	390	1640
Instruments	SANS-1	PGAA	RESEDA TREFF

Figure 3: Neutron guides inside the neutron guide tunnel.

Guide	NL5-N	NL6-S	NL6-N
Length (m)	35	54	35
Section (mm²)	29 × 170	60 × 120	10 × 120
Coating up to	m = 2.0	m = 2.2	m = 2.0
Radius (m)	400	1000	84
Instruments	MARIA	MIRA-2 DNS SPHERES	MIRA

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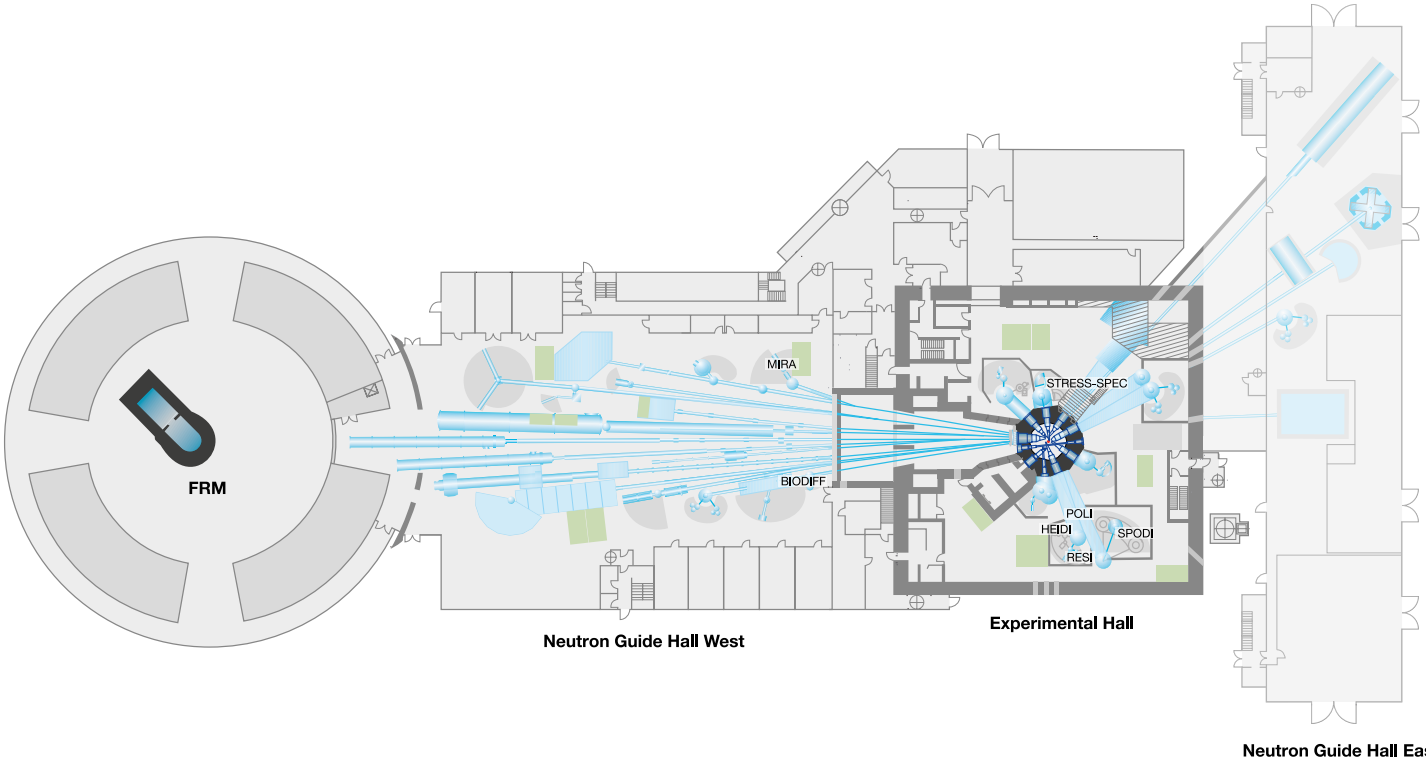


RESI
single-crystal diffractometer
on thermal beam

STRESS-SPEC
materials science
diffractometer

HEIDI
single-crystal diffractometer
with hot neutrons

BIODIFF
diffractometer
for large unit-cells

POLI
polarized neutron
diffractometer

MIRA
cold neutron
mulitpurpose instrument

SPODI
neutron powder diffractometer

Diffraction

RESI

thermal neutron single crystal diffractometer

Description

The diffractometer RESI is designed for using a maximum of thermal neutron intensity at the FRM II, allowing optimum measurement of weak diffraction phenomena in a large portion of the reciprocal space on single crystalline samples.

Typical Applications

Structure analysis with thermal neutrons (λ = 0.8 Å to 2 Å) is complementary to structure analysis with X-rays. The measurement possibilities provided by this instrument are crucial for many scientific questions:

- **Structure analysis, bonding theory, electron densities:** Due to the interaction with atomic cores and the diffraction angle independence of the atomic form factor, it is possible to measure Bragg scattering up to high diffraction angles.
- **Real crystals** and compounds of interest for material science are often not perfectly ordered. The elucidation of these real structures requires the analysis of the corresponding diffuse scattering. The diffuse scattering - off the Bragg reflections - is normally differentially weak and distributed continually (anisotropic) in the reciprocal space.
- **Partially crystalline** compounds, like **fibre structures**, show a specific scattering, which is highly anisotropic and continously distributed in the reciprocal space. Therefore, diffractometers with area detectors like RESI are best suited for this kind of problems.
- A new class of **aperiodic crystals** (“quasi crystals”) show dense, but discrete reflex patterns, where more than 90 % of the reflexes are very weak. Additionally, due to the fact that quasi crystals often contain two or more transition metals (which are almost isoelectronic), neutrons offer much higher contrast than X-ray methods.
- **Structural phase transitions** can be accompanied by continuous reflection shifting.
- **Modulated structures** show satellite reflections at “incommensurable” positions. Both areas require analysis of large portions of the reciprocal space.
- **Twinned crystals** and **multi-domain/multi-phase crystals** are often difficult to measure on single-counter instruments. The area detector at RESI allows for easy detection and in many cases separation of reflections in such systems.

The advantages of the high-resolution area detector can be utilized best, if the reciprocal space is not too empty. That means, that RESI is optimal for cells of ca. 1000 Å^3 to ca. 20000 Å^3. Typical crystal sizes range from 5 mm^3 to 25 mm^3.

Sample Environment

Dedicated sample environment of RESI:

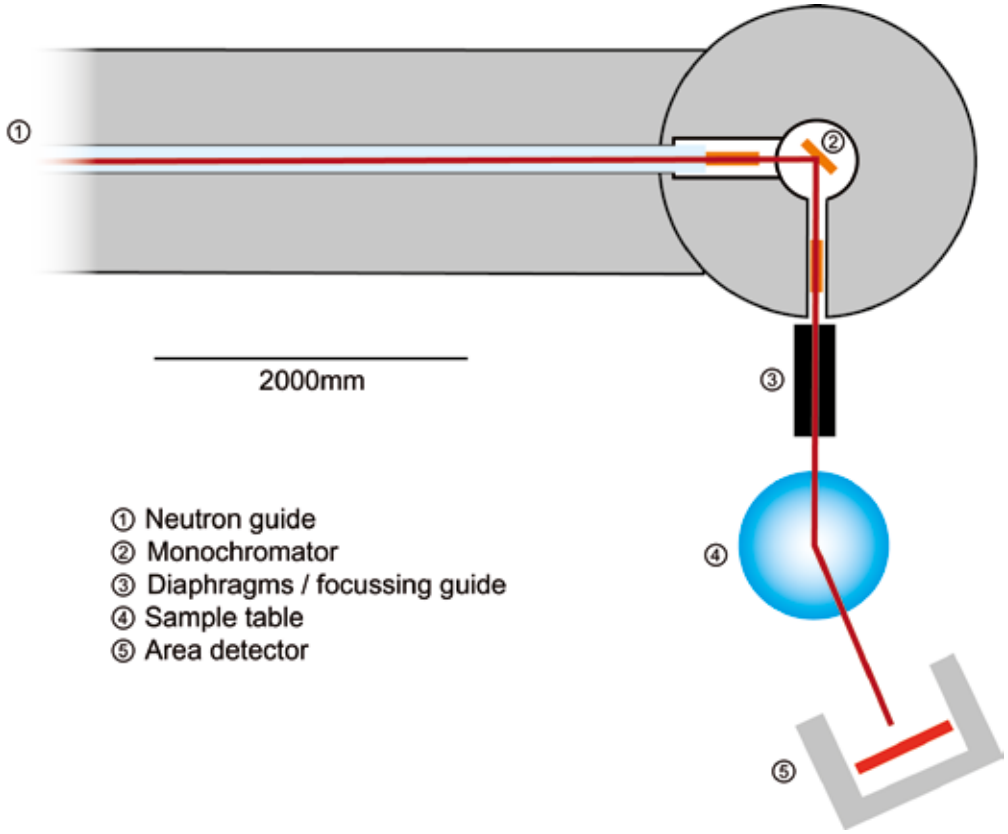
- Oxford Cryosystems Cryostream 700
  temperature range 100 K - 400 K
  consumption ~ 20 l L-N_2/d

- Oxford Instruments Helijet
  temperature range 15 K - 100 K
  consumption ~ 2 l L-He / h
  sample size 1 × 1 × 1 mm^3 max.

MLZ standard sample environment usable with RESI

- Closed-cycle cryostat CC, 2.5 K – 300 K
- Closed-cycle cryostat CCR, 3 K – 100 K
  using ^{3}He insert, 500 mK – 4 K
  using ^{3}He/^{4}He dilution, 50 mK – 1 K
- Vacuum furnace, 340 K – 2100 K
- Mirror furnace, RT – 1250 K

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN



Technical Data

Primary beam

- Beam tube SR8b
- Neutron guide
  Length: 12 m, focussing vertical / horizontal section: 70 × 40 mm → 60 × 30 mm
- Coatings: m = 3 top/bottom; m = 1 side

Monochromators

Vertically focussing lamella type, fixed take-off 90°

- Cu-422, 20' mosaic, 1 Å : $2 \cdot 10^6$ n $cm^{-2}s^{-1}$
- Ge-511, 25' mosaic (deformed wafer stack)
  1.5 Å : $6 \cdot 10^6$ n $cm^{-2}s^{-1}$

Secondary neutron guide

Vertically focussing ellipitical guide-in-guide

- Length: 1 m
- Focus 400 mm after guide exit
- Coating: m = 5

Available goniometers

- Kappa-Goniometer
  Bruker-Nonius Mach3
  carrying capacity: max 100 g
- Eulerian cradle Huber 420
  higher carrying capacity, e.g. for closed-cycle cryostat
- Huber 2-circle goniometer with tilting head
  highest carrying capacity, e.g. for CCR with ^{3}He insert

Available detectors

- MAR345 image plate detector
  345 mm diameter, N-sensitive image plate
- Single counter ^{3}He with optional analyzer
  for pure elastic scattering

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HEIDI

single crystal diffractometer on hot source

Description

The single crystal diffractometer HEiDi is designed for detailed studies on structural and magnetic properties of single crystals using unpolarized neutrons and Bragg's Law:
$2\ d_{hkl} \sin(\Theta) = \lambda$
Because of the large variety of short wavelengths and resolutions (fig. 1) HEiDi is suitable for studies on a lot of crystalline compounds – many of them of potential interest for energy or data storage technologies – like:

- HT superconductors (e.g. cuprates, FeAs-pnictides)
- Multiferroics (e.g. manganates) and other complex ferro- and antiferromagnetic compounds (e.g. Co-olivines)
- Ionic conductors (e.g. nickelates)
- Ferrolelectrica (e.g. KDP family)
- Mixed crystals (e.g. AsSe compounds)
- Highly absorbing compounds (e.g. with Gd, Sm, Eu)

Applications (in general)

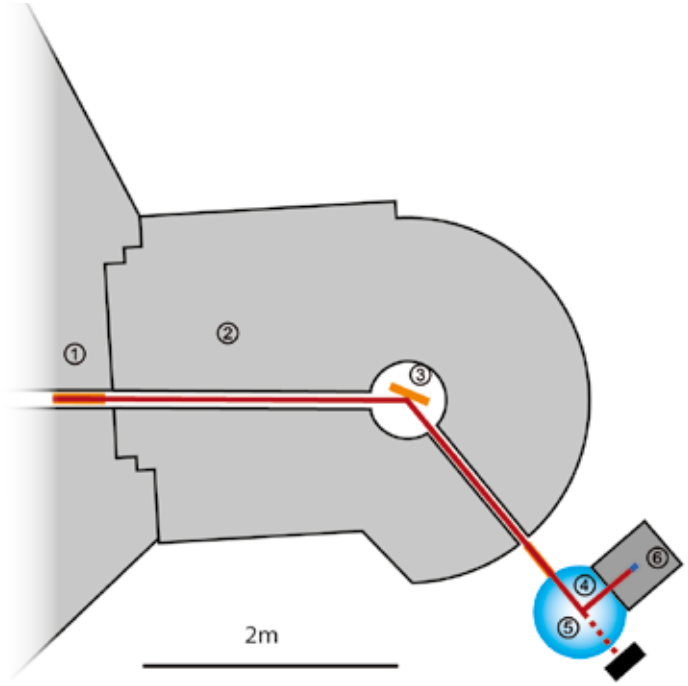
- Structure analysis
- Hydrogen bonds
- Static and dynamic disorder
- Harmonic and anharmonic mean square displacements
- Twinning
- Magnetic structure and order
- Spin densities
- Structural and magnetic phase transitions
- Incommensurate structures

Applications (in detail)

- Studies of atomic positions and bond distances in compounds with heavy and light elements or elements of similar electron shells
- Temperature dependent studies for determination of phase transitions
- Studies of order-disorder phase transitions, e.g. H bonds by determination of anisotropic mean square displacements using large Q range up to $\sin(\Theta)/\lambda > 1$
- Structure determination of compounds with hiqhly absorbing elements (Gd, Sm, Cd) with short wavelengths
- Studies on magetic phase transitions and T dependencies (ferri, ferro and antiferro magnets, multiferroics)
- Studies on HT superconductors (e.g. cuprates, FeAs pnictides)
- Sample characterization by profile analysis
- Determination of sample orientation, e.g. for preparation of experiments on triple axes instruments
- Presentation of fundamentals of crystallography and structure analysis for education

Sample Environment

- Closed cycle cryostat (2 K – RT)
- Mirror furnace (RT – 2000 K)
- Micro furnace (RT – 500 K)
- Uniaxial pressure cell (from PUMA)



Technical Data

Beam-tube

- SR9B (hot source)
- Flux at sample 1.4 · 10^7 $cm^{-2}s^{-1}$ (λ ≈ 1.17 Å)
- Gain by hot source × 10 (λ ≈ 0.6 Å)

Wavelength

$2\Theta_M$	Ge(311)	Cu(220)	Ge(422)	Cu(420)
20°	0.503	0.443	0.408	0.280
40°	1.168	0.870	0.793	0.552
50°	1.443	1.079	0.993	0.680

Q-range

$2\Theta_M$	Ge(311)	Cu(220)	Ge(422)	Cu(420)
20°	1.46	1.95	2.12	3.09
40°	0.74	0.99	1.09	1.57
50°	0.60	0.80	0.87	1.27

Optical components

- Single detector optimized for small wavelengths (sensitivity > 90 % at 0.3 Å)
- Analyzer PG(002); optional for studies of purely elastic scattering and background supression
- Neutron filters for suppression of λ/2- or λ/3-contamination of the monochromatized beam

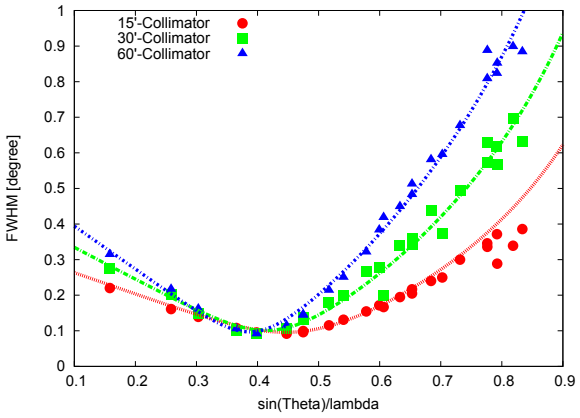


Figure 1: FWHM of reflections from a Si sample measured with a wavelength of 0.87 Å using the Cu (220) monochromator.

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POLI

polarized hot neutron diffractometer

Description

The diffractometer POLI is dedicated to the investigation of single cristalline samples with complex magnetic structures using neutron spin polarization. Neutron beam polarization P can be treated as a classical vector. Zero-field spherical neutron polarimetry (SNP) allows to measure all components of the scattered polarization vector. Determining the relationship between the directions of incident and scattered polarizations gives access to the 16 independent correlation functions involved in the most general nuclear and magnetic scattering process. Generally this leads to the determination of the direction of the magnetic interaction vectors of magnetic structures. For those structures, in which nuclear and magnetic reflections coincide in reciprocal space, SNP leads to the determination of the amplitude of the magnetic interaction vectors, and hence to the magnetisation distribution. Currently the instrument uses the focused monochromatic beam from the monochromator of the single crystal diffractometer HEiDi at the beam channel 9b. The construction of the separate dedicated for POLI monochromator at the beam channel 9a is on the way and will be finalized in 2013.
The separation between monochromator and polarizer allows the use of the polarized neutrons with different wavelengths and high resolution. This feature of POLI is rather unique especially for hot neutrons.

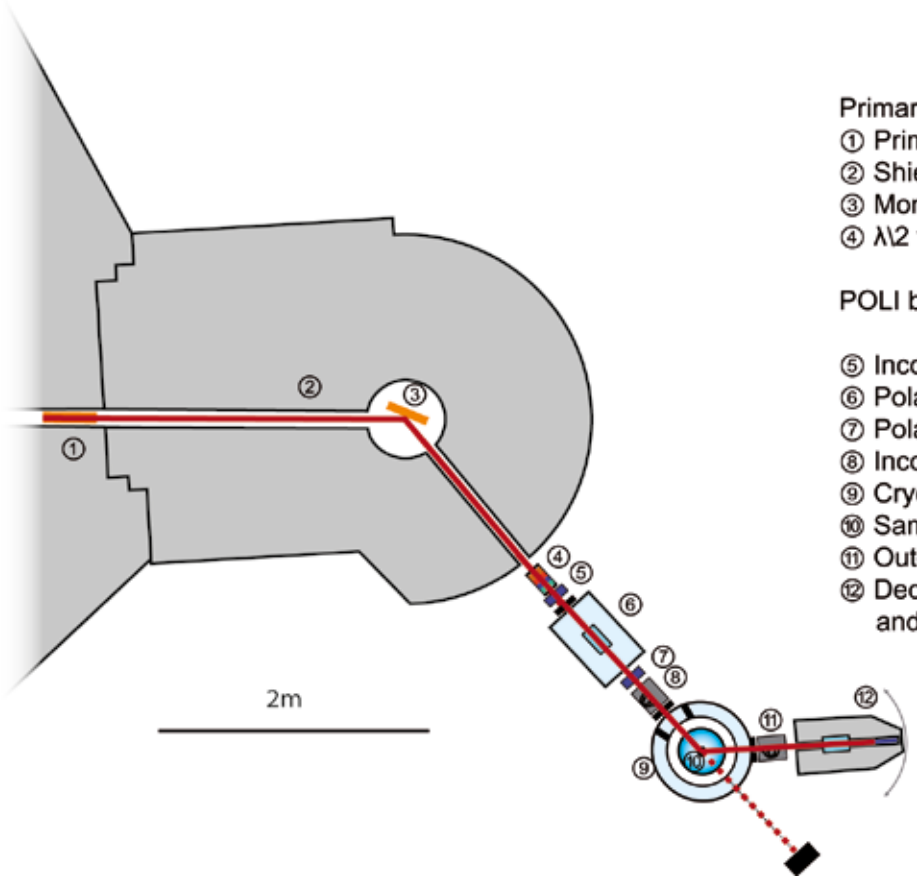
The incoming beam is polarized along the beam axis by mean of ^{3}He spin filter cell (SFC) placed in the polarizer magnetostatic cavity. The polarization of the incoming beam is determined by the transmission measurement of the SFC using two beam monitors. SNP is implemented on POLI using the zero-field polarimeter Cryopad of the third generation. Nutator and incoming precession coil of the Cryopad precisely turn the polarization vector of the incoming beam along any required direction. The outgoing precession coil and second nutator turn the required component of the polarization along the quantization axis of the analyser (SFC in Decpol). X, Y, Z components of the scattered polarization are measured for each orientation of the incoming polarization and hence a polarization matrix of 9 elements for an individual Bragg reflection is determined. The count rates for the two spin states are corrected for background.
To achieve the best available accuracy optimum strategy is applied for each reflection. The in-situ measurements of the incoming polarization permit easy correction of the measured data regarding the time dependence of the SFCs. Dedicated software for SNP instrument control and data analysis developed at ILL is used. The collected data sets can easily be exported, processed and automatically plotted. Further development of the data refinement software is on the way.

Typical Applications

- Complex commensurate and incommensurate magnetic structures studied in ground state (zero-field), this could be very useful especially for superconductors
- Temperature dependence of the magnetic structure
- Studies of magnetic or magneto-electric domains using zero-field SNP on the samples cooled in zero-field as well as in high external magnetic field (up to 7.5 T). The combination of magnetic and electric fields applied on the sample could be important for the studies on multiferroic materials.
- Determination of anti-ferromagnetic form factors

Sample Environment

- Standard MLZ closed-cycle cryostat (4 K – 300 K)
- Low temperature inserts or cryofurnace option on request



Primary beam from HEiDI
① Primary Beam Collimator
② Shielding
③ Monochromator
④ λ\2 filters

POLI backend

⑤ Incoming beam monitor
⑥ Polarizer (with ^{3}He spin filter)
⑦ Polarized beam monitor
⑧ Incoming nutator
⑨ Cryopad
⑩ Sample table
⑪ Outgoing nutator
⑫ Decpol (^{3}He polarization analyzer and detector)

Technical Data

Primary beam (HEiDi)

Beam tube SR9 on hot source

Focussing monochromators

crystal	wavelength λ [Å] at $2\theta_M$			flux at $2\theta_M = 40°$
	20°	40°	50°	
Ge (311)	0.593	1.116	1.443	$9 \cdot 10^6$ n cm^{-2}s^{-1}
Cu (220)	0.443	0.870	1.079	$4.3 \cdot 10^6$ n cm^{-2}s^{-1}
Cu (420)	0.280	0.552	0.680	$2.0 \cdot 10^6$ n cm^{-2}s^{-1}

Diffractometer angles

with Cryopad	without Cryopad
$-10° < 2\theta < 120°$	$-130° < 2\theta < 130°$
$-180° < \omega < 180°$	$-180° < \omega < 180°$
$-4° < \chi_1 < 4°$	$-5° < \chi_1 < 5°$
$-4° < \chi_2 < 4°$	$-5° < \chi_2 < 5°$

Neutron polarization

^{3}He spin filter cell	65 % < P_{3He} (0) < 75 %	
	100 h < T_1 < 200 h	
Neutron beam polarization with cell P_{3He} (0) = 70 % and T1 = 100 h	initial	after 24 h
	> 0.92	> 0.80
Cell replacement	daily	
Time for cell replacement	< 2 min.	

Cryopad (zero-field polarimeter)

- LHe refill (manual): weekly
- LN_2 refill (automatic): daily
- Sample space for closed cycle cryostat or orange type cryostat
- Max. sample size: 25 mm

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SPODI

high resolution powder diffractometer

Description

The high resolution powder diffractometer SPODI is designed for structure solution and Rietveld refinement of structural parameters on crystalline powders. The instrument is characterized by a very high monochromator take-off angle of 155° (standard configuration). Optionally, a take-off angle of 135° is available.

The detector array consists of 80 ^{3}He position sensitive detector tubes (300 mm active height) with fixed Soller collimators of 10‘ horizontal divergence. The multidetector of SPODI spans an angular range of 2θ = 160°. Each detector covers 2° corresponding to 160° / 80 detectors. Therefore the data collection is performed via stepwise positioning of the detector array to obtain a diffraction pattern of the desired step width (typically 2° / 40 steps resulting in Δ(2θ) = 0.05°).

The two-dimensional raw data are evaluated to provide diffraction patterns corresponding to different detector heights ranging from 10 mm to 300 mm and variable detector height, accounting for vertical beam divergence effects (see figure 1). Thus, asymmetric broadenings at quite low and high scattering angles are overcome, while the full detector height in the medium 2θ regime can be used. [1]

Various sample environmental devices enable the characterization of materials under special conditions: A rotatable tensile rig allows in-situ studies under tensile stress, compression stress or torsion while the load axis can be oriented with respect to the scattering plane. A potentiostat for charging/discharging of Lithium ion batteries is available as well as a device to apply high electric fields on ferroelectrics.

[1] M. Hoelzel, A. Senyshyn, N. Juenke, H. Boysen, W. Schmahl, H. Fuess, Nucl. Instr. A 667, 32-37 (2012).

Typical Applications

- Determination of complex crystal and magnetic structures
- Structural evolutions and phase transformations under various environmental conditions.
- Static and thermal disorder phenomena

Research Areas

- Ionic conductors
- Materials for lithium ion batteries
- Oxygen conductors
- Ferroelectrics
- Hydrogen storage materials
- Shape memory alloys
- Superalloys
- Multiferroics, magnetic shape memory alloys
- Correlated electron systems
- Superconductors
- Minerals

Sample Environment

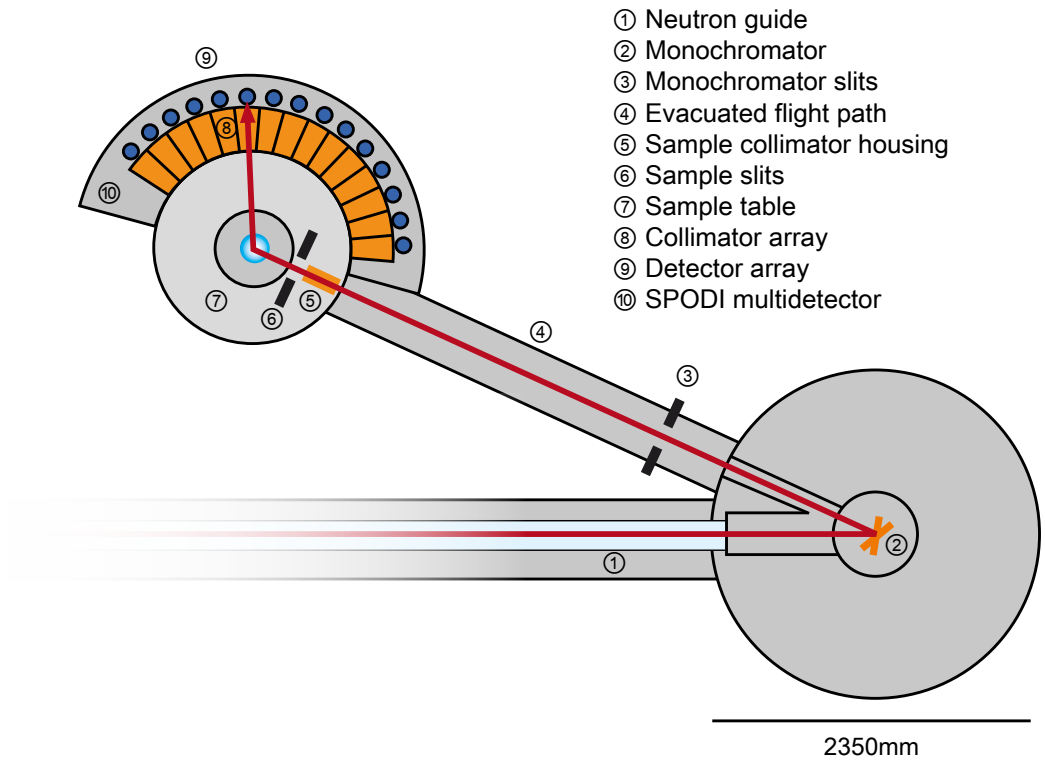
Standard sample environment of FRM II

- Closed cycle cryostat 3 – 550 K
  (with ^{3}He insert: T_{min} = 500 mK)
- Vacuum high temperature furnace
  T_{max} = 1900 °C
- Cryomagnet
  B_{max} at SPODI: 5 T

Special sample environment

- Rotatable tensile rig
  F_{max} = 50 kN, M_{max} = 100 Nm
- Device for electric fields
  V_{max} = 35 kV
- Potentiostat for electrochemical treatment of materials VMP3 and SP240

Karlsruher Institut für Technologie



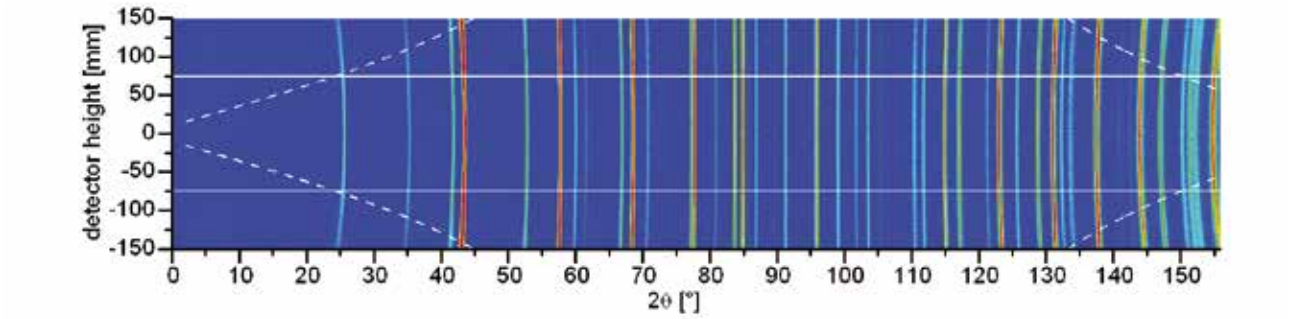


Figure 1: Two-dimensional data set of a corundum reference sample. The straight white lines bound a detector height of 150 mm and the detector height 0 denotes the central line of the detector. The dotted white lines encompass the data used in the “300 mm - variable height” data set.

Technical Data

Monochromator

Ge(551) wafer stack crystals
standard configuration: take-off angle 155°
- Ge(551): 1.548 Å
- Ge(331): 2.436 Å
- Ge(711): 1.111 Å

Collimation

- α1 ≈ 20’ (neutron guide)
- α2 = 5’,10’, 20’, 25’ nat. (for 155°)
  α2 = 10’, 20’, 40’ nat. (for 135°)
- α3 = 10’

Detector array

- 80 position-sensitive ^{3}He tubes,
- angular range 2θ = 160°,
- effective height: 300 mm

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STRESS-SPEC

materials science diffractometer

Description

In response to the development of new materials and the application of materials and components in new technologies the direct measurement, calculation and evaluation of textures and residual stresses has gained worldwide significance in recent years.
The materials science diffractometer STRESS-SPEC is located at the thermal beam port SR3 of the FRM II and can easily be configured either for texture or stress analysis.
The setup utilizes three different monochromators: Ge (511), bent silicon Si (400) and pyrolitic graphite PG(002). This selection of monochromators and the possibility to vary automatically the take-off angles from $2\theta_M$ = 35° to 110° allows to find a good compromise between resolution and intensity for each measuring problem.

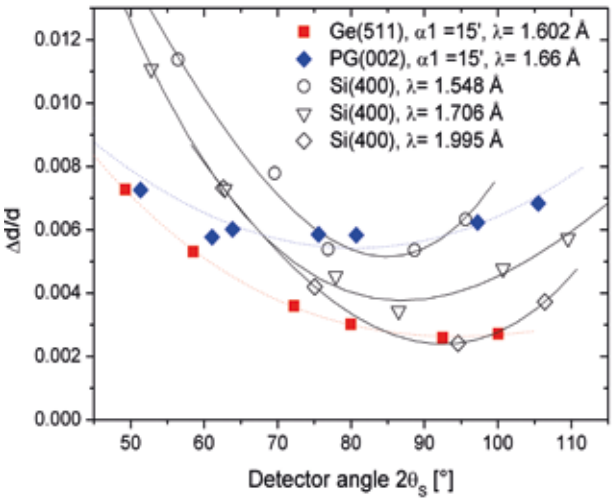


Figure 1: Resolution function for different monochromator options.

The gauge volume defining optical system of primary and secondary slits is designed with regard to reproducibility of geometrical alignment and sturdiness. Both slit systems are linked to the sample table and the detector in such a way that the center of the beam remains the same under all conditions. Samples can be aligned using theodolites and a camera system. In addition the possibility to scan surfaces of components offline using a CMM laser scanner is available at STRESS-SPEC.

Typical Applications

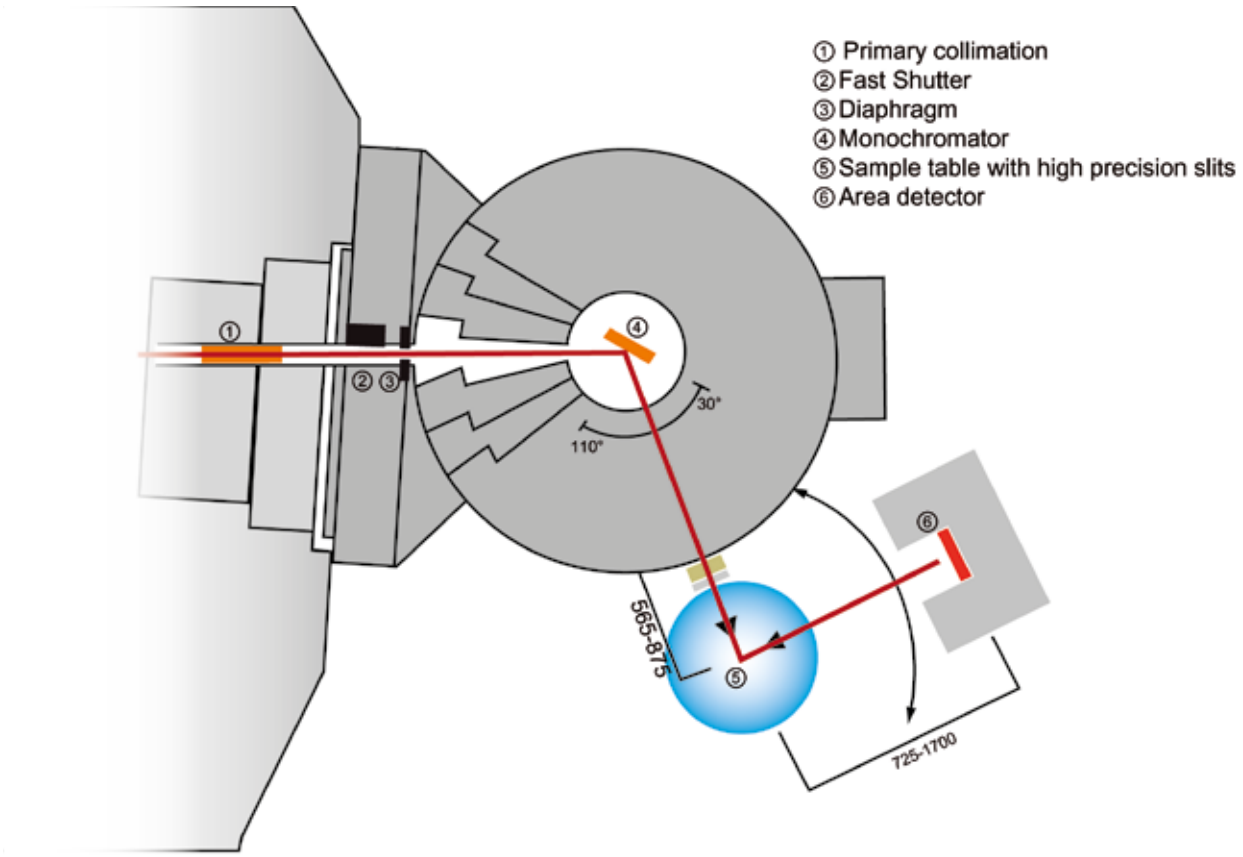
Residual stress analysis
- Industrial components
- Welds
- Superalloys
- Strain mapping

Texture determination
- Global textures
- Local textures
- Strain pole figures
- FHWM pole figures

Sample Environment

- XYZ-table
  capacity 300 kg, Travel xy = ±120 mm,
  z = 300 mm, accuracy ~ 10 µm
- Load frame
  +/- 50 kN, heatable to 1000 °C
- Full circle Eulerian cradle (max. load 5 kg)
- ¼ circle Eulerian cradle for heavy samples
- Standard sample environment MLZ
  (e.g. furnace)

A positioning system consisting of a Stäubli-6-axis robotic arm for texture and strain measurements (payload up to 30 kg) can be mounted instead of the standard sample table. It offers more flexibility than an Eulerian cradle and can be also used as automatic sample changer for texture measurements.



Technical Data

Neutron beam

- SR3 thermal neutrons
- Collimators ('in-pile') 15', 25', open

Monochromators

- Ge(511), Si(400), PG(002)
- $2\theta_M$ 35° – 110° continuous
- wavelength 1 Å – 2.4 Å ; (2.5 $Å^{-1}$ < Q < 10.5 $Å^{-1}$)

Possible slit size - Residual Stress

- Primary slit: 1 x 1 mm^2 up to 5 x 20 mm^2 (W x H)
- Secondary slit: continuously variable up to 15 mm
- Radial collimators (FWHM = 1 mm, 2 mm, 5 mm)

Possible slit size – Textures

- Primary slit: max. 30 x 40 mm^2 (W x H)
- Secondary slit: continuously variable up to 15 mm or open

Detector

^{3}He-PSD, 30 x 30 cm^2; 256 × 256 pixel

Figure 2: Slit-system for residual stress analysis.

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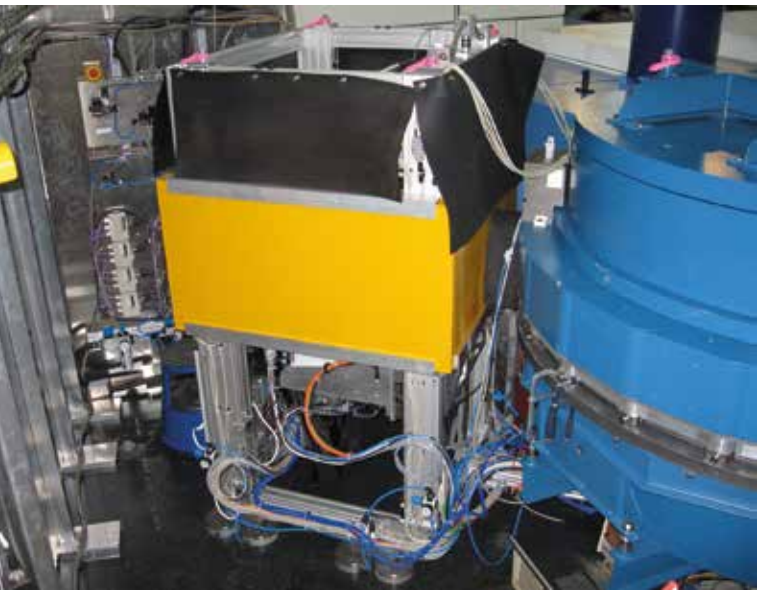
BIODIFF

diffractometer for large unit cells



Description

The monochromatic single crystal diffractometer BIODIFF is a joint project of the FRM II, TUM and JCNS, Forschungszentrum Jülich.

BIODIFF is designed to handle crystals with large unit cells and is dedicated to the structure determination of biological macromolecules. In biological macromolecules, like proteins and nucleic acids, hydrogen atoms play an important role. Hydrogen atoms take part in the substrate binding process and are essential for proton transfer reactions during the catalysis in many enzymes. Therefore the knowledge about the protonation states of amino acid residues in the active centre of proteins is often crucial for the understanding of their reaction mechanisms. However, hydrogen atoms, especially rather flexible ones, are barely detectable in X-ray structure determinations of proteins. On the other hand, hydrogen atoms are clearly visible in neutron crystallography experiments even at moderate resolutions ($d_{min} < 2.0$ Å).

BIODIFF is the first instrument along the cold neutron guide NL-1 and is positioned in a distance of about 32.5 m to the cold source. Using a pyrolytic graphite monochromator PG(002) the diffractometer covers a wavelength range of 2.4 Å to about 5.6 Å. Higher order wavelength contaminations are removed by a neutron velocity selector. The main detector of the diffractometer consists of a neutron imaging plate system in a cylindrical geometry to cover a large solid angle. A fast LiF/ZnS scintillator CCD camera is foreseen for additional detection abilities. The main advantage of this instrument is the possibility to adapt the wavelength to the size of the unit cell of the sample crystal while operating with a clean monochromatic beam that keeps the background level low.

Typical Applications

The main field of application is the neutron structure analysis of proteins, especially the determination of hydrogen atom positions. Typical questions in this field of interest are:

- Enzymatic mechanism (protonation states of amino acids)
- Ligand binding mediated by hydrogen bonds
- Investigation of the hydration shell of proteins
- H/D-exchange pattern as a monitor of structural stability/flexibility

Sample Environment

Besides FRM II standard sample environment BIODIFF provides:

- Oxford Cryosystems Cryostream 700 plus with a temperature range of 90 K to 500 K

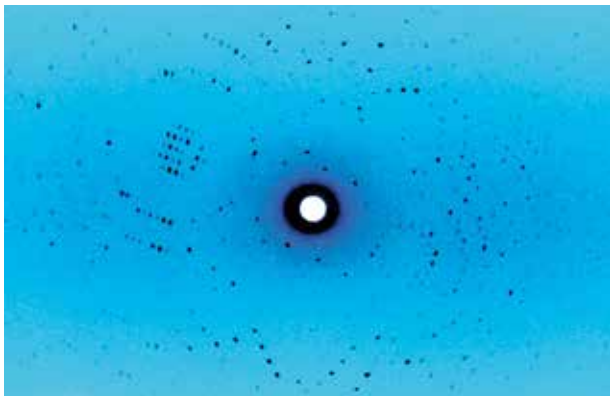
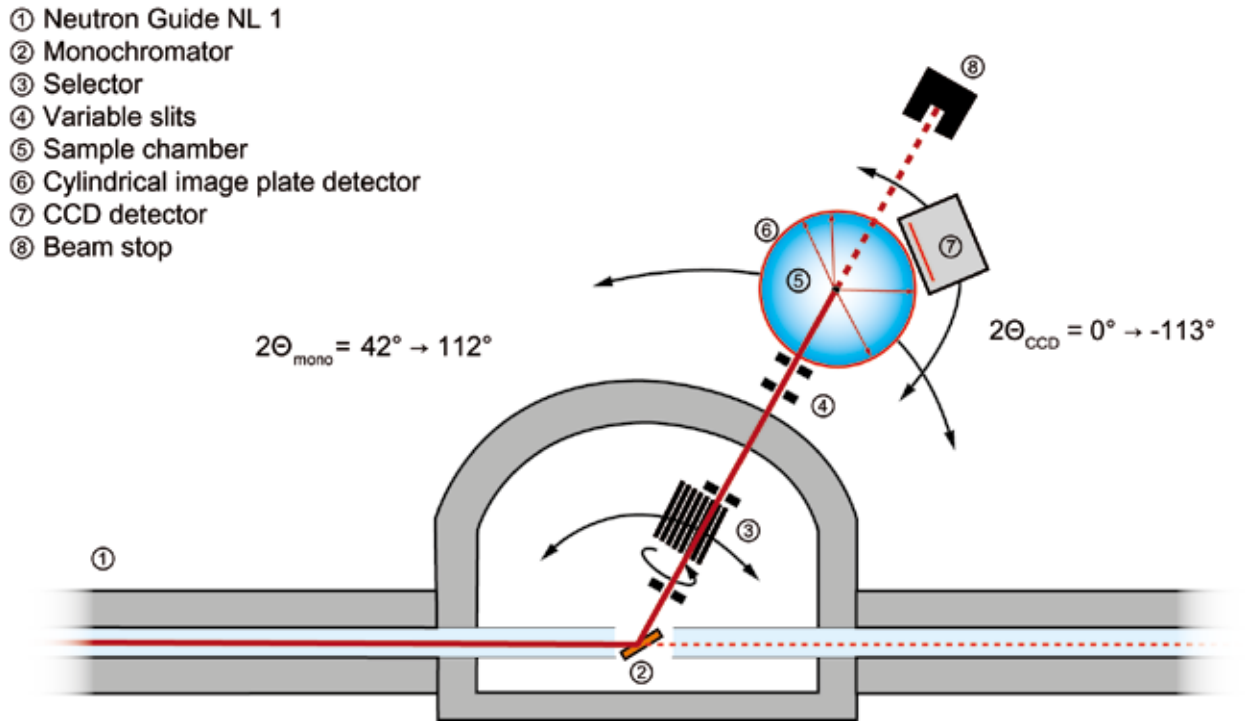


Figure 1: Neutron diffraction pattern of a ß-lactamase protein crystal.



Technical Data

Primary beam

- Neutron guide NL-1; supermirror m = 2
- Monochromator:
  PG(002) mosaicity: 0.4 – 0.5°
- Higher order filter:
  Astrium type velocity selector
  transmission 87 % for 2.4 Å
- Wavelength range:
  2.4 - 5.6 Å with selector
  2.4 - 6.1 Å without selector
- Collimation by adjustable slits down to
  Ø = 1 mm

Beam properties at the sample position

- Wavelength resolution at sample position:
  $\Delta\lambda/\lambda$ = 2.9 % at 2.4 Å
- Beam divergence (no slits)
  0.8° FWHM horizontal
  0.7° FWHM vertical

Main detector

Neutron image plate (cylindrical)

- $BaFBr:Eu^{2+}$ mixed with Gd_2O_3
- Dimensions:

radius	200 mm
angular range	±152° horizontal
	±48° vertical

- Pixel size (quadratic) 125, 250, 500 µm
- Readout time (with erasing):
  4 min (for 500 µm pixel size)

Auxiliary detector

CCD camera with scintillator

- ZnS mixed with ^6LiF
- Dimensions:

Active scintillator area (flat)	200 x 200 mm²
Distance to sample	100 mm

- 2Θ-angle around sample position 0° - 113°
- CCD chip with 2048 x 2048 pixels
- Pixel size: 13.5 x 13.5 µm²
- Overall spatial resolution ≈ 300 x 300 µm² (limited by scintillator thickness)
- Minimum readout time
  ≈ 1 sec (full resolution); < 1 sec (binning mode)

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MIRA

multipurpose instrument

As most experiments are done in modest magnetic fields MIRA has a water-cooled electromagnet, which can be rotated independently from the sample and delivers fields from -0.3 T to 0.3 T. The 7.5 T cryo-magnet of the FRM II standard sample environment can also be used.

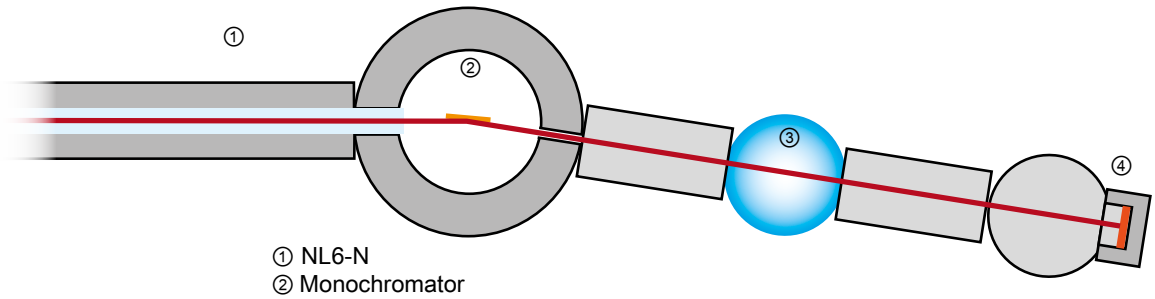
Typical Applications

- Determination of magnetic structures, especially large scale structures, i.e. helical spin density waves or magnetic lattices
- Quasi-elastic measurements in magnetic fields with high resolution
- Determination of structures and dynamics in extreme environments, like pressure
- Determination of layer thickness of films, for instance in polymer physics
- Reflectometry from magnetic multilayers
- Polarization analysis

Description

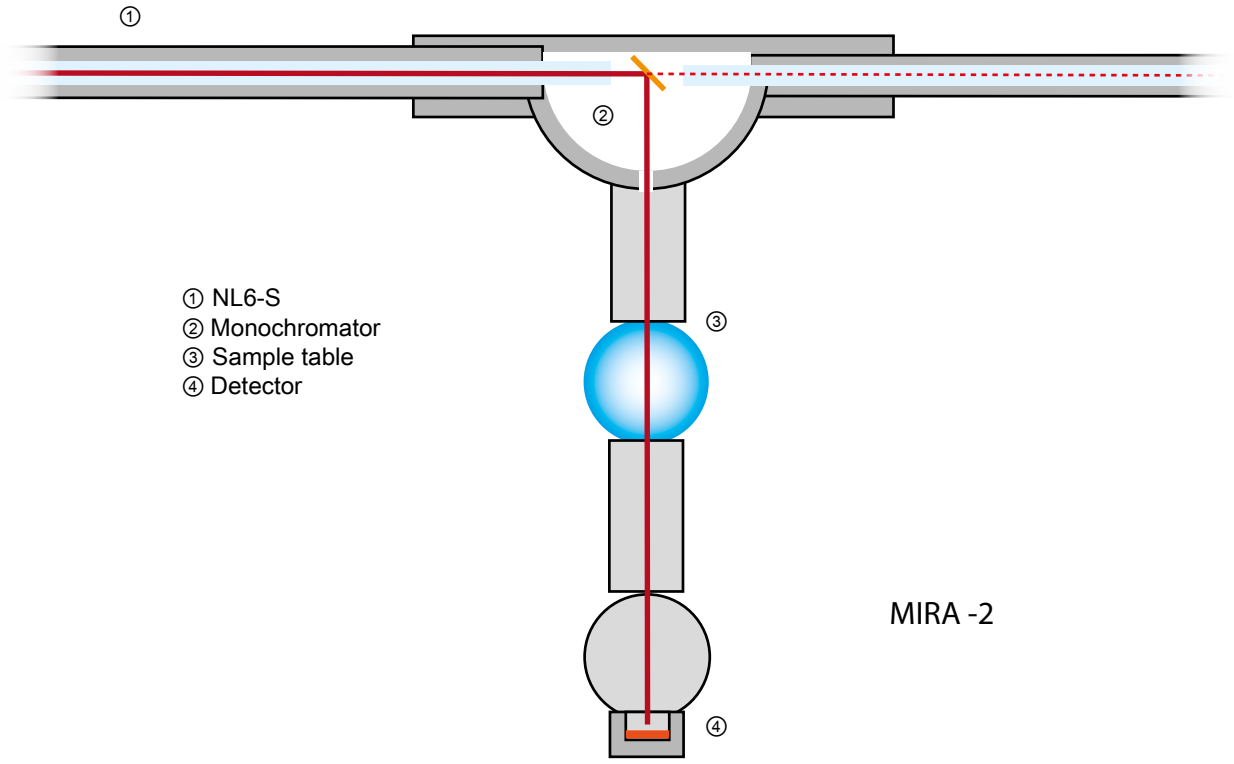
MIRA is a multipurpose instrument at the MLZ. With its two beam ports, namely MIRA-1 (top) and MIRA-2 (right), it provides neutrons over a wide range of wavelengths 3.5 Å < λ < 20 Å. The instrument can easily be moved from one port to the other without changing the sample environment. The large variety of different options offered can also be combined in most cases. This allows for a fast realisation of experiments in a very flexible way using a number of available options:

- Small angle neutron scattering (SANS)
- MIEZE (a type of neutron spin echo method working in magnetic fields)
- Reflectometry
- 3D-Polarimetry
- Cold diffraction
- Cold three axes spectroscopy for extreme environments



① NL6-N
② Monochromator
③ Sample table
④ Detector

MIRA -1



Technical Data

MIRA-1

Primary beam

- Neutron guide: NL6-N
- Dimensions: 10 x 120 mm² (width x height)
- Curvature: 84 m
- Coating: sides m = 1.2, top/bottom m = 2

Monochromator

- Multilayer $\Delta\lambda/\lambda \approx 3$ % (5 % polarized)
- 8 Å < λ < 20 Å

max. differential flux at sample

- $5 \cdot 10^5$ neutrons s^{-1} cm^{-2} at 10 Å
- $2 \cdot 10^5$ neutrons s^{-1} cm^{-2} polarized

Analyzer

- 2 Bender
- ^{3}He-Spin filter

Detector

- 20 x 20 cm² 2-D PSD with 1 x 2 mm² resolution
- 1 inch ^{3}He finger detector
- 20 x 20 cm² 2-D PSD, time resolution < 1 ps

MIRA-2

Primary beam

- Neutron guide: NL6-S
- Dimensions: 60 x 120 mm² (width x height)
- Coating: sides m = 2.0, top/bottom m = 2

Monochromator

- Horizontal focussing HOPG $\Delta\lambda/\lambda \approx 2$ %
- 3.5 Å < λ < 6 Å

max. differential flux at sample

- $1 \cdot 10^7$ neutrons s^{-1} cm^{-2} at 4.7 Å (02/2013)
- $1 \cdot 10^6$ neutrons s^{-1} cm^{-2} polarized

Analyzer

- S-Bender, transmission polarizer
- ^{3}He-Spin filter

Detector

- 20 x 20 cm² 2-D PSD with 1 x 2 mm² resolution
- 1 inch ^{3}He finger detector
- 20 x 20 cm² 2-D PSD, time resolution < 1 ps

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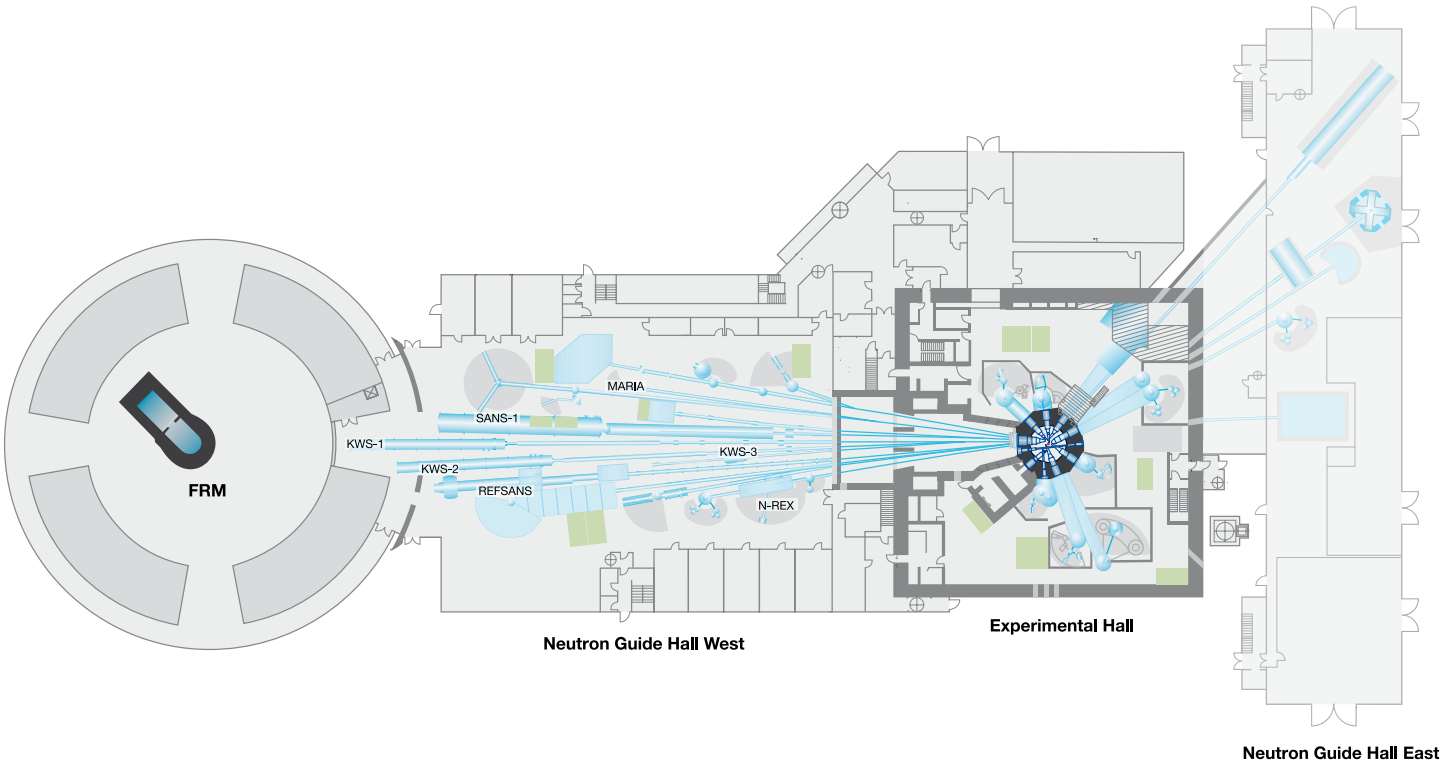


KWS-1
small angle scattering
diffractometer

KWS-2
small angle scattering
diffractometer

KWS-3
very small angle scattering
diffractometer

SANS-1
small angle scattering
diffractometer

REFSANS
reflectometer and evanescent
wave small angle diffractometer

NREX
reflectometer
with X-ray option

MARIA
reflectometer

SANS & Reflectometry

KWS-1

small angle scattering diffractometer

Description

The KWS-1 is dedicated to high resolution measurements due to its 10 % wavelength selector. This property is interesting for highly ordered or highly monodisperse samples. With the foreseen chopper the wavelength uncertainty can be reduced further to ca. 1 %. The scientific background of KWS-1 is placed in magnetic thin films. Magnetic samples will be studied with the full polarization analysis including incident beam polarization and polarization analysis of the scattered neutrons. In front of the collimation, a 3-cavity polarizer with V-shaped mirrors is placed. The full bandwidth of 4.5 to 20 Å will be covered with min. 90 % (95 % typical) polarization. A radio frequency spin flipper allows for changing the polarization. The polarization analysis will be realized with ^{3}He-cells which will be optimized for the used wavelength and scattering angle. Vertical magnets will be provided to render the magnetic field at the sample position. Thin films can be well studied in the grazing incidence geometry – the method is called grazing incidence small angle neutron scattering (GISANS). A newly installed hexapod will allow for positioning the sample with 0.01 mm and 0.01° precision.

Classical soft-matter systems will be investigated on KWS-1 if the resolution is needed. Biological samples can be handled due to the detector distance of ca. 1 m, which will allow for maximal scattering angles of Q = 0.5 Å^{-1}.

The MgF_2 lenses are used for the high flux mode with large sample areas, while the resolution stays in the classical SANS range. These enhanced intensities allow for real time measurements in the 1/10 second region (typical 1 s).

The chopper in parallel allows for studying faster dynamics in the ms range. The so-called TISANE mode interlocks the chopper frequency with the excitation field frequency and with the detection binning. The precise consideration of the flight times allows for higher precision compared to classical stroboscopic illuminations.

Typical Applications

- Grain boundaries
- Alloys
- Magnetic structures
- Flow lines
- Soft matter and biology (as for KWS-2)
- Complex fluids near surfaces
- Polymer films
- Magnetic films
- Nanostructured films

One example of a complex fluid near planar surfaces is discussed in context of figure 1. For enhanced oil recovery often aqueous surfactant systems are used, which, in contact with oil, form microemulsions. The current study focuses on bicontinuous microemulsions adjacent to a planar hydrophilic wall. The surface near structure is lamellar and decays to the bulk structure. Interestingly, this decay is realized by perforated lamellae. Currently, flow experiments are performed.

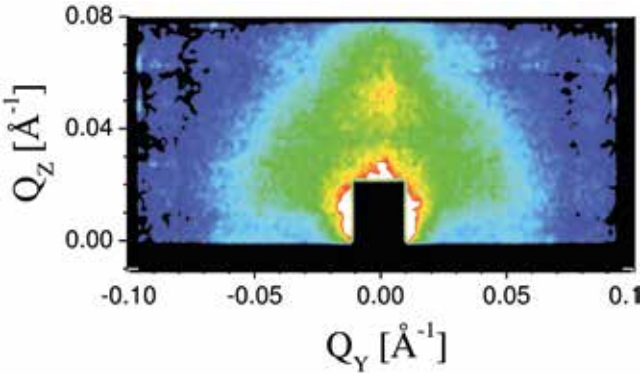
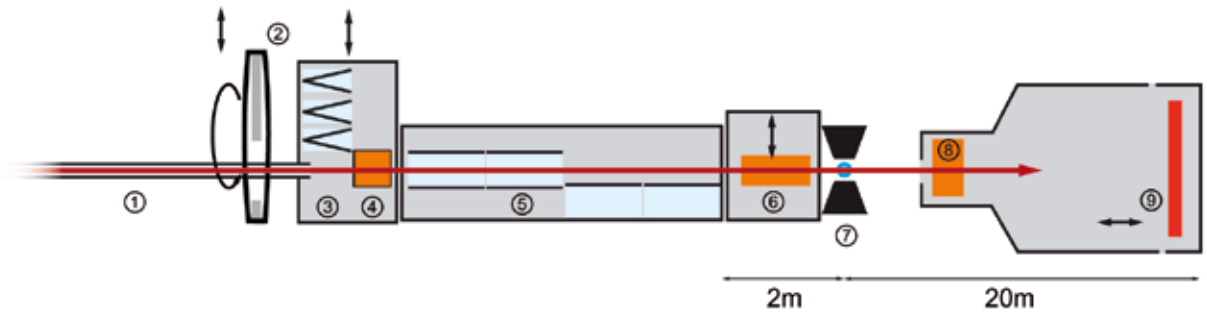


Figure 1: GISANS pattern of a microemulsion adjacent to a planar wall. The Bragg peak indicates the lamellar order induced by the wall. A weak Debye-Scherrer ring arises from the bicontinuous bulk structure.



① Neutron guide NL3
② High-speed chopper
$\Delta\lambda/\lambda$=1%
③ Changeable polarizers
④ Spin flipper
⑤ Neutron guide sections 18 x 1m
⑥ MgF_2 focusing lenses
⑦ Sample position with magnet
⑧ ^{3}He spin filter
with reversable polarization (in vacuum)
⑨ Anger-type scintillation detector

Sample Environment

- Rheometer shear sandwich
- Rheowis-fluid rheometer (max. shear rate 10000 s^{-1})
- Anton-Paar fluid rheometer
- Stopped flow cell
- Sample holders: 9 horizontal x 3 vertical (temperature controlled) for standard Hellma cells 404.000-QX and 110-QX
- Oil & water thermostats (typical 10 °C – 100 °C) electric thermostat (RT – 200 °C)
- 8-positions thermostated (Peltier) sample holder (-40 °C – 150 °C)
- Magnet (horizontal, vertical)
- Cryostat with sapphire windows
- High temperature furnace
- Pressure cells (500 bar, 2000 bar, 5000 bar)

Technical Data

Overall performance

- Q = 0.0007 – 0.5 $Å^{-1}$
- Maximal flux: 1.5 · 10^8 n cm^{-2} s^{-1}
- Typical flux: 8 · 10^6 n cm^{-2} s^{-1} (collimation 8 m, aperture 30 x 30 mm^2, λ = 7 Å)

Velocity selector

Dornier, FWHM 10 %, λ = 4.5 Å – 12 Å, 20 Å

Chopper

for TOF-wavelength analysis, FWHM 1 %

Polarizer

- Cavity with V-shaped supermirror, all wavelengths
- Polarization better 90 %, typical 95 %

Spin-flipper

Radio-Frequency

Active apertures

2 m, 4 m, 8 m, 14 m, 20 m

Aperture sizes

rectangular 1 x 1 mm^2 – 50 x 50 mm^2

Sample aperture

rectangular 1 x 1 mm^2 – 50 x 50 mm^2

Neutron lenses

- MgF_2, diameter 50 mm, curvature 20 mm
- packs with 4, 6, 16 lenses

Sample stage

Hexapod, resolution better than 0.01°, 0.01 mm

Detector 1

- Detection range: continuous 1 m – 20 m
- ^{6}Li-Scintillator 1 mm thickness + photomultiplier
- Efficiency better than 95 %
- Spatial resolution 5.3 x 5.3 mm^2, 128 x 128 channels
- Max. countrate 0.6 MHz (τ_{dead} = 0.64 µs)

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KWS-2

small angle scattering diffractometer

Description

KWS-2 [1] represents a classical pinhole SANS instrument where, combining the pinhole mode using different neutron wavelengths and detection distances with the focusing mode using MgF2 lenses, a wide Q-range, between 1 x 10^{-4} and 0.5 $Å^{-1}$, can be explored (fig. 1). It is dedicated to high intensity / wide-Q investigation of mesoscopic structures and structural changes due to rapid kinetic processes in soft condensed matter, chemistry and biology. The high neutron flux, comparable with that of the world leading SANS instruments, which is supplied by the neutron delivery system (cold source, selector, guides) [2, 3] and the possibility to use large sample area using focusing lenses, enable high intensity and time-resolved studies. On demand, the instrument resolution can be tuned using the double-disc chopper with adjustable opening slit, which allows the variation of the wavelength spread between 2 and 20 % (fig. 2). This offers a high flexibility in optimizing the instrument performance towards improved characterization of structural details and accurate beam characteristics (avoid the gravity and chromatic effects while using the lenses).

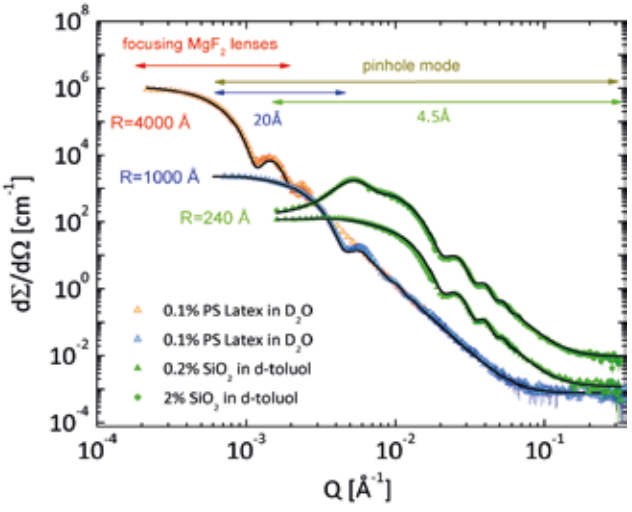


Figure 1: Scattering patterns from silica and polystyrene particles in solution measured in the pinhole and high-resolution (focusing lenses) modes (fits include the form factor and the structure factor of the particles and the instrumental resolution).

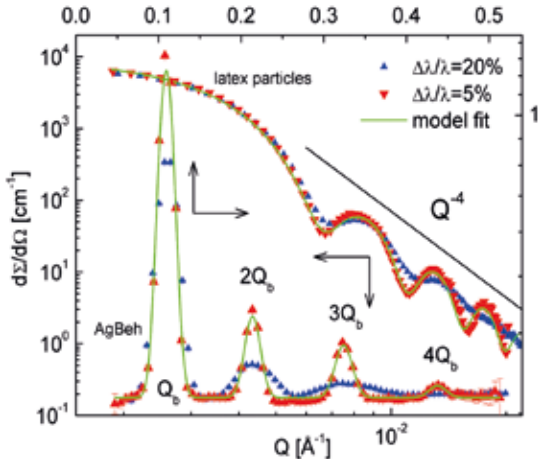
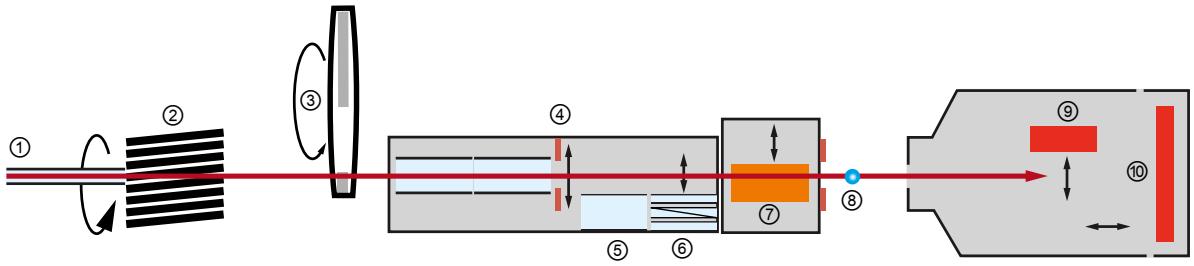


Figure 2: Measurements at KWS-2 with variable resolution on polystyrene latex particles (samples – courtesy of M. Hellsing and A. Rennie, Uppsala University) and silver behenate; the green lines indicate the fit (including instrumental resolution).

Typical Applications

- Colloids, Nanocomposites
- Polymer blends, diblock copolymers
- Microemulsions, complex fluids, micelles
- Membranes, films; in-situ adsorption–desorption / humidifying – drying phenomena
- Kinetics of demixing, formation, aggregation
- Shear induced micelle deformation, rubber network deformation, nanocomposite ordering
- Protein structure and folding/unfolding
- Pressure dependence of phase diagrams, fluctuations, molecular interactions
- In-situ crystallization Semi-crystalline polymer

Typical application relate to fast structural changes of micellar systems (formation, transformation or chain exchange at equilibrium) or polymer crystallization which are investigated by time-resolved SANS in the second or sub-second (up to 50ms) regimes. For example, the fast structure evolution in polymer clathrates with small guest molecules and the diffusion of guests in the crystalline region can



① Neutron guide
② Velocity selector Δλ/λ=20%
③ High-speed chopper Δλ/λ=1%
④ Entrance aperture
⑤ 18 pieces 1m NG
⑥ Transmission polarizer
⑦ MgF_2 focusing lenses
⑧ Sample aperture
⑨ High resolution position-sensitive detector
⑩ Anger-type scintillation detector

be understood by monitoring the time evolution of the reflection due to crystalline lamellae (fig. 3).

[1] A. Radulescu, et al., J. Phys. Conf. Series 351, 012026 (2012)
[2] A. Radulescu and A. Ioffe, Nucl. Inst. Meth. A, 586 , 55 (2008)
[3] A. Radulescu, et al., Nucl. Inst. Meth. A 689, 1 (2012)

Sample Environment

- Anton-Paar fluid rheometer
- Stopped flow cell
- Sample holders: 9 horizontal x 3 vertical (temperature controlled) for standard Hellma cells
- Oil & water thermostats (typical 10..100 °C)
- 8-positions thermostated (Peltier) sample holder (-40 °C..150 °C)
- Magnet (1.5T, vertical)
- Cryostat with sapphire windows
- Pressure cells (500 bar, 2000 bar, 5000 bar)
- Humidity chamber, 5%…95% for 10°C … 60°C

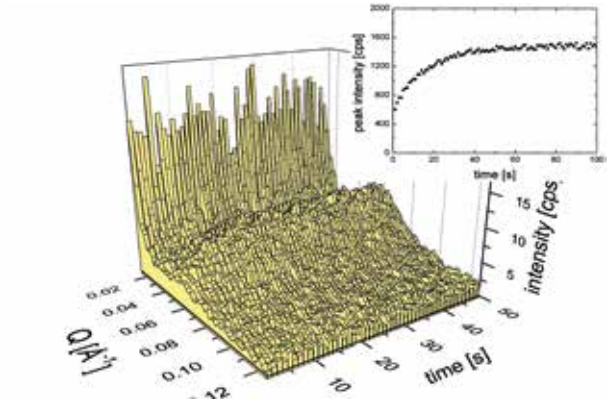


Figure 3: Time evolution of SANS intensity profile and integral intensity of crystalline reflection caused by change in contrast due to exchange from d-benzol to h-benzol in syndiotactic-polystyrene / benzol clathrates (F. Kaneko, Osaka University and A. Radulescu, JCNS)

Technical Data

Overall performance

Q = 0.0001… 0.5 $Å^{-1}$ (0.9 $Å^{-1}$, mid 2013)
Maximal flux: 2 x 10^8 n cm^{-2} s^{-1}
Typical flux: 1.3 x 10^7 n cm^{-2} s^{-1}
(collimation 8 m, 30 x 30 mm^2, λ = 7 Å)

Velocity selector

Astrium, Δλ/λ = 20 %, λ = 4.5… 20 Å; 3 Å (2014)

Chopper

tunable Δλ/λ: 20 %... 2 % (TOF analysis)

Active apertures

2 m, 4 m, 8 m, 14 m, 20 m, sample position

Aperture sizes

rectangular 1 x 1 mm^2 – 50 x 50 mm^2

Neutron lenses

MgF_2, diameter 50 mm, curvature 20 mm
Packs with 4, 6,16 lenses

Polarizer

transmission, P > 95% for λ > 4.5Å

Sample stage

XYZθ translational-rotational stage + craddle
Accuracy better than 0.01°, 0.01 mm

Detector 1

Detection range: continuous 1 m – 20 m
^{6}Li-Scintillator 1 mm thickness + photomultiplier, efficiency better than 95 %, active area
60 cm x 60 cm, Spatial resolution 5.25 x 5.25 mm^2,
Max. countrate 0.6 MHz (τ_{dead} = 0.64 µs)

Detector 2 (high res.)

Spatial resolution 0.45 x 0.45 mm^2
Active area: Ø = 8.7 cm
^{6}Li-Scintillator 1 mm thickness
Fixed position: 17 m after sample position

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KWS-3

very small angle scattering diffractometer

Description

KWS-3 is a very small angle neutron scattering (VSANS) instrument running on the focusing mirror principle at the Research Neutron Source Heinz-Maier Leibnitz (FRM II) in Garching. Standard configuration of the instrument with 9.5 m sample-to-detector distances allows performing scattering experiments with a wave vector transfer resolution between 10^{-4} and $3 \cdot 10^{-3}$ Å^{-1}, bridging a gap between Bonse-Hart and pinhole cameras. Second sample position at 1.3 m distances has extended Q-range of the instrument to $2 \cdot 10^{-2}$ Å^{-1} and reached more than one-decade overlapping with the classical pinehole SANS instruments. The principle of this instrument is a one-to-one image of an entrance aperture onto a 2D position sensitive detector by neutron reflection from a double-focusing toroidal mirror.

Small-angle scattering is used for the analysis of structures with sizes just above the atomic scale, between 1 and about 100 nm, which cannot be assessed or sufficiently characterized by microscopic techniques. KWS-3 is an important instrument, which extends the accessible range of scattering angles to very small angles with a superior neutron flux when compared with a conventional instrumental setup with pinhole geometry. Thus the length scale that can be analyzed is extended beyond 10 µm for numerous materials from physics,

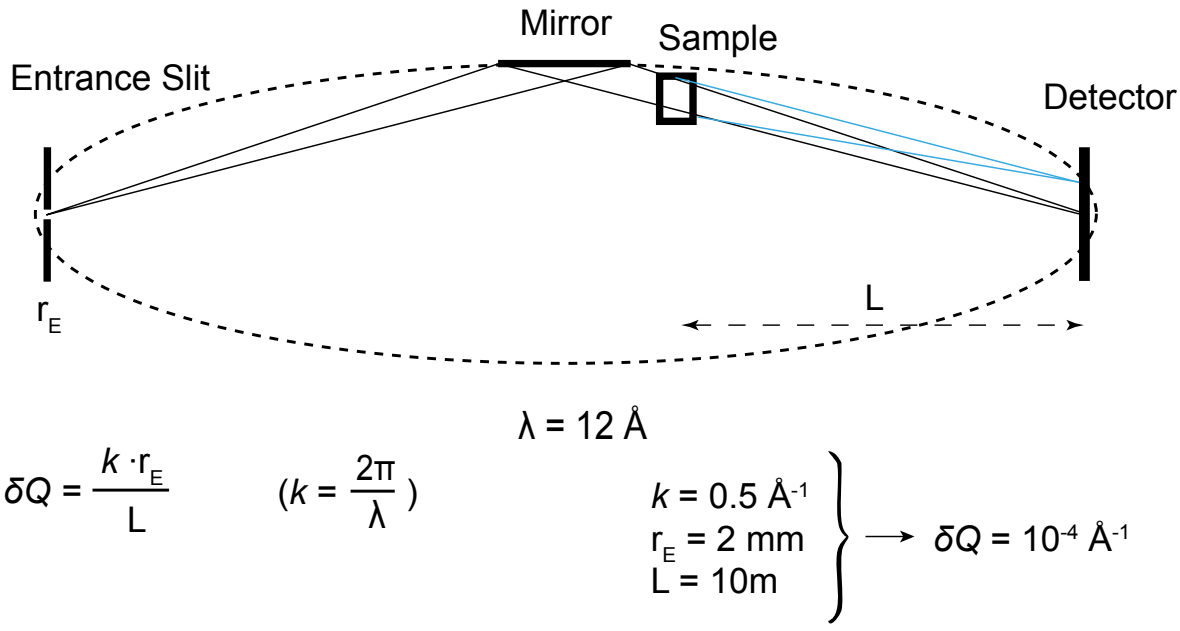
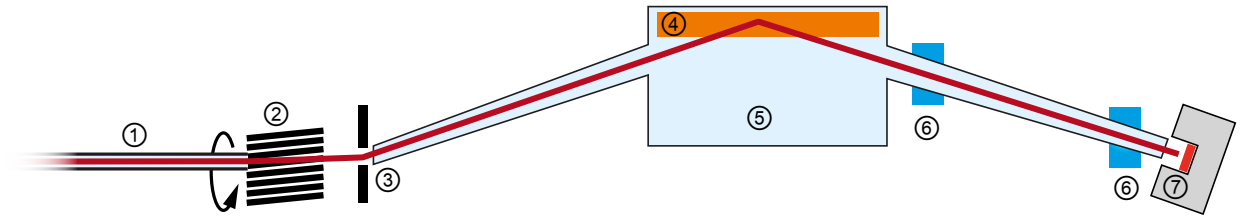


Figure 1: The principle of KWS-3 instrument is a one-to-one image of an entrance aperture onto a 2D position sensitive detector by neutron reflection from a double-focusing toroidal mirror; (right) photo of the mirror installed in vacuum its chamber. Length scales up to 10 µm are accessible.



① Neutron guide NL3a
② Velocity selector
③ Entrance aperture
④ Toroidal mirror
⑤ Mirror chamber
⑥ Sample positions
⑦ Detector

chemistry, materials science and life science, such as alloys, diluted chemical solutions and membrane systems.

Typical Applications:

- High-flux bridge between Bonse-Hart and conventional SANS diffractometers
- Colloid science: mixtures of particles, particles of micron size, silicon macropore arrays, ...
- Materials science: filled polymers, cements, microporous media, …
- Polymer science: constrained systems, emulsion polymerization, …
- Bio science: aggregations of bio-molecules, protein complexes, crystallization of proteins, …
- Hierarchical structures
- Multilamellar vesicles
- ...

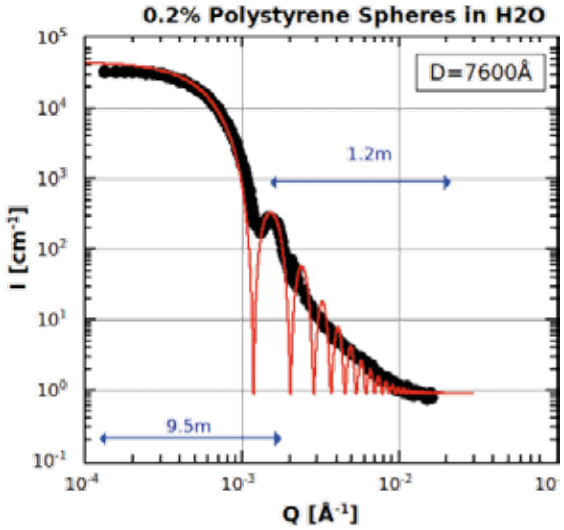


Figure 2: Polystyrene spheres of 7600 Å diameter measured at 9.5 and 1.2 m at KWS-3 (black symbols: concentration of spheres in water 0.2 wt%). The red curve is the theoretical scattering curve (form factor of 7600 Å spheres). The instrumental resolution and sample polydispersity were not taken into account. Mismatching of the measured curve and model at low Q is due to the presence of the structure factor.

The instrument covers the Q range of small angle light scattering instruments. Especially when samples are turbid due to multiple light scattering, V-SANS gives access to the structural investigation. Thus, the samples do not need to be diluted. The contrast variation method allows for highlighting of particular components. In figure 2 the VSANS measurement of water solution of polystyrene (PS) particles with a diameter of 760 nm is depicted. The spherically shaped polymer particles with a diameter of about were measured at both sample positions covering standard Q-range.

Technical Data

Overall performance

- Resolution:
  $\delta Q = 10^{-4}$ Å^{-1} (extension to $4 \cdot 10^{-5}$ Å^{-1} possible)
- Q-range:
  $1.0 \cdot 10^{-4} – 3 \cdot 10^{-3}$ Å^{-1} at 9.5 m distance
  $1.5 \cdot 10^{-3} – 2 \cdot 10^{-2}$ Å^{-1} at 1.3 m distance
- Neutron flux:
  high-resolution mode: > 10000 n s^{-1}
  high-intensity mode: > 60000 n s^{-1}

Monochromator

- MgLi velocity selector
- Wavelength spread $\Delta\lambda/\lambda = 0.2$
- Wavelength range λ = 10 - 30 Å (maximal flux at 12.8 Å)

Aperture size (focus)

1 × 1 mm² – 5 × 5 mm²

Beam size at 9.5 m

0 × 0 mm² – 100 × 25 mm²

Beam size at 1.3 m:

0 × 0 mm² – 15 × 10 mm²

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SANS-1

small angle neutron scattering

Description

The new small angle scattering instrument SANS-1 [1], a project of the Technische Universität München (TUM) and the Helmholtz-Zentrum Geesthacht (HZG), is set up and commissioned in the Neutron Guide Hall West at the MLZ.

To optimise the SANS-1 instrument claiming to be at the “state of the art”, many calculations and variations of instrument parameters were performed by Monte Carlo simulations in advance. Results of these simulations [2] are a vertical S-shaped neutron guide with extreme suppression of fast background neutrons optimised for complementary wavelength packages, a tower with two eligible selectors, one for medium resolution at high intensity and one for high resolution (optional), two optimised Fe/Si transmission polarizers and two area detectors.

After passing the selector tower, a collimation system with four parallel horizontal tracks is installed. One track is occupied with a neutron guide, another one with apertures for improving resolution, one position is for a laser system to support alignment and the last one is equipped with background apertures and could be used for lenses. The detector tube of around 2.4 m inner diameter allows to use an area detector of 1 × 1 m^2 with lateral movement of more than 0.5 m. The detector is equipped with 128 position sensitive detectors to provide 8 mm × 8 mm pixel resolution. The second detector of 0.5 × 0.5 m^2 is for longer distances and achieves a resolution of 3 mm.

As a first stage of the time-of-flight option a chopper system for TISANE will be installed. This setup allows time resolved stroboscopic neutron scattering up to the µ-sec range. In the second stage a complete time-of-flight option will expand the dynamical Q-range.

Typical Applications

The instrument SANS-1 is dedicated to study the structure of material on length scale of 10 to 3000 Å. In particular, SANS is used to study the shapes and sizes of the particles dispersed in homogeneous medium. It involves scattering of a monochromatic beam of neutrons from the sample and measuring the scattered neutron intensity as a function of the scattering angle.

The technique provides valuable information over a wide variety of scientific and technological applications including

- Precipitates in alloys
- Chemical aggregation
- Defects in materials, surfactants, colloids
- Ferromagnetic correlations in magnetism
- Alloy segregation
- Polymers, proteins, biological membranes, viruses, ribosomes and macromolecules

[1] R. Gilles et al., Physica B, 385 386, 1174-1176 (2006).
[2] R. Gilles et al., J. Appl. Cryst., 40, s428-s432 (2007).

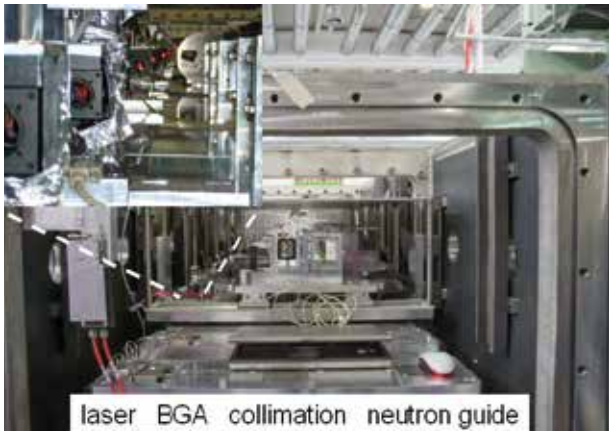
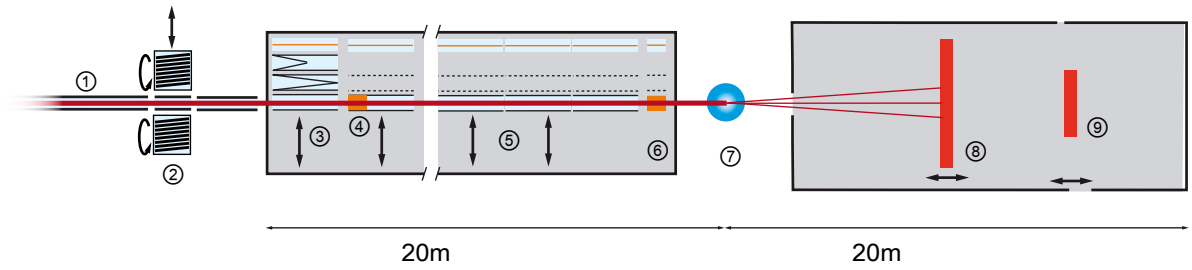


Figure 1: View into the collimation chamber of the SANS-1.



① Neutron guide NL4a
② Velocity selector 1+2
③ Changeable polarizers
④ Spin flipper
⑤ 4 collimation sections 19 m
(neutron guide, collimation slits, laser beam)
⑥ Focusing lenses
⑦ Sample position
⑧ Position sensitive area detector (1 x 1 m²)
⑨ High resolution position-sensitive area detector (0.5 x0.5 m²)

Sample Environment

- High temperature furnace
- Deformation-rig with heating
- Magnet (horizontal and vertical)
- Sample changer with thermostat
- Cryostat

Laser System

A redundant laser alignment system to position in the neutron guide, the collimation slits, the background apertures (BGA) or the laser in the neutron beam is installed. In addition the laser is used to support the positioning of the sample (including the sample environment) or the beam stop in a proper way.

Technical Data

Primary beam

- S-shaped neutron guide (NL 4a), 50 mm × 50 mm
- Mechanical velocity selectors with variable speed
  1) $\Delta\lambda/\lambda$ = 10 % medium resolution
  2) $\Delta\lambda/\lambda$ = 6 % high resolution
- Planned in future: chopper system with $\Delta\lambda/\lambda$ = 1 %
- Wavelength range: 3.5 Å – 30 Å
- Wavelength resolution: 1 % - 25 % (FWHM)

Polarization

- Two V-shaped polarizers

Source-to-sample distance

- 1 m, 2 m, 4 m, 8 m, 12 m, 16 m to 20 m in steps via insertion of neutron guide sections except 1 m

Sample size

- 0 to 50 mm diameter

Q-range

- Theoretical 0.0001 $Å^{-1} < Q < 2 Å^{-1}$

Detectors

- 128 ^{3}He position-sensitive proportional counter with 1000 mm × 1020 mm² total area and 8 mm resolution and lateral detector movement up to 0.5 m, counting rate up 1 MHz
- Detector with better resolution of 3 mm and 0.5 m × 0.5 m total area at long distances

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REFSANS

reflectometer and evanescent wave small angle neutron spectrometer

Description

The horizontal reflectometer REFSANS has been designed to enable specular reflectometry as well as Grazing Incidence Neutron Scattering studies of both solid samples and liquid-air interfaces.
By using a polychromatic incident neutron beam and time of flight (TOF) wavelength resolution, REFSANS gives simple access to a large Q range. Typical reflectometry curves are recorded using three incident angles to cover the 0 – 2 nm^{-1} Q_z domain. In the case of GISANS, the TOF mode provides direct information about the full penetration curve from a single incident angle.
The instrument versatility relies on one hand on the fact that the wavelength resolution can be tuned between 0.2 % and 10 %, on the other hand on the possibility to independently control the horizontal and vertical divergence by means of a complex optics. These two characteristics make it possible to optimally perform reflectometry and GISANS. One can easily switch between these two configurations for a given sample and thereby fully investigate its structure without having to alter externally applied fields or constraints (temperature, chemical environment).
For reflectometry, an horizontally smeared out beam of up to 80 mm width is used in order to maximize intensity. For GISANS, up to 13 point beams are impinging on the sample and point focused on the 2D position sensitive detector placed at a distance of 9 m (see collimation scheme in fig. 1). This setup allows to resolve lateral structures with dimensions up to several micrometer. In all other cases the detector can be placed at any distance between 1.5 m and 12 m from the sample, thereby making it easy to control the explored angular range and optimize the resolution-background intensity trade-off.

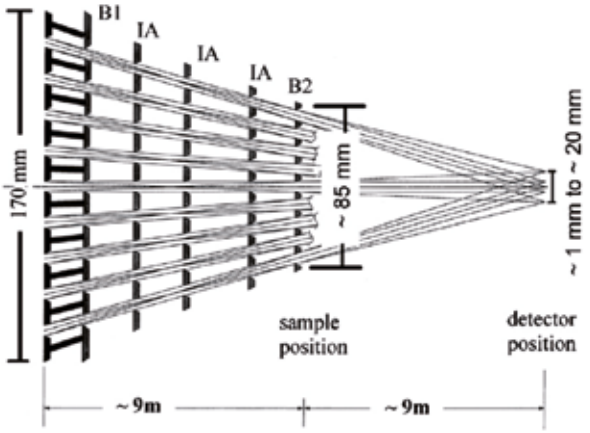


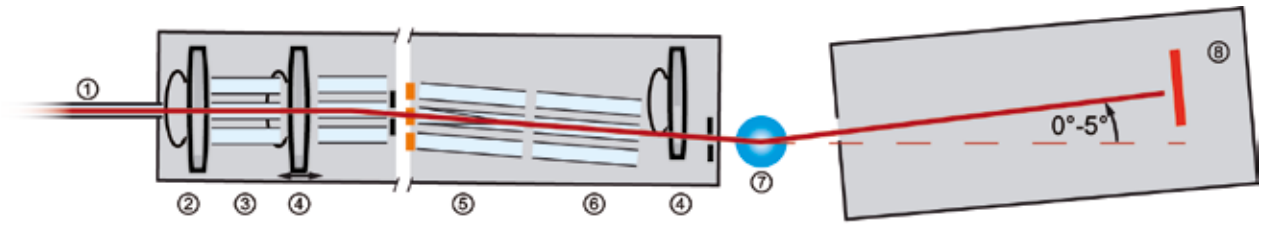
Figure 1: The GISANS focusing channels (used in NGE3 and 4).

Typical Applications

The TOF reflectometry and GISANS techniques can be used to characterize thin films in general. Reflectometry provides information about the structure along the sample's normal, while GISANS gathers information about the in-plane correlations. Typical reflectometry experiments include:

- Characterization of polymer thin film structure and their swelling behavior in presence of various vapors.
- Biological systems such as solid or liquid supported membranes (e.g determination of the morphology and localization of proteins at interfaces) - see figure 2
- Metallic multilayers (e.g magnetically active films)
- Coatings

GISANS complements these measurements and has been successfully applied to polymer thin films (lateral correlations e.g in dewetted systems, detection and identification of polymer lamellae in immiscible blends or semicristalline systems), composites, nanopatterned metallic surfaces for which Bragg truncation rods have been reconstructed (see fig. 3).



① Neutron guide NL 2b
② Master chopper
③ Neutron guide elements
④ Slave chopper 1+2
⑤ Changeable polarizer
⑥ Neutron guide elements
⑦ Sample position
⑧ Detector

Sample Environment

The optimal sample size is 70 × 70 mm². Various environments are available:

- Simple sample changer for three substrates
- Vibration controlled Langmuir trough for liquid-air interfaces studies
- Magnetic fields up to 7 Tesla
- Cryostats

A heavy load Huber goniometer (max load 200 kg) is normally used to carry the experimental setup, but it can easily be removed and replaced by custom equipments.

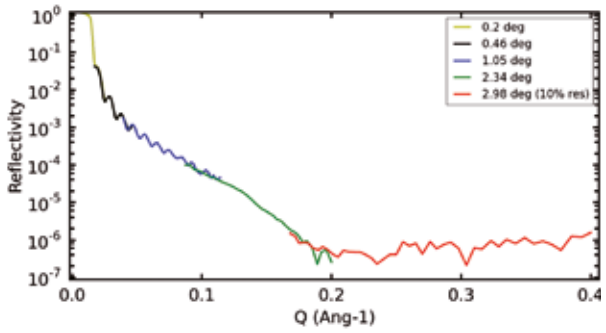


Figure 2: Typical reflectivity curve. Obtained for a biological sample (POPC/POPS Phospholipid bilayer supported on Si).

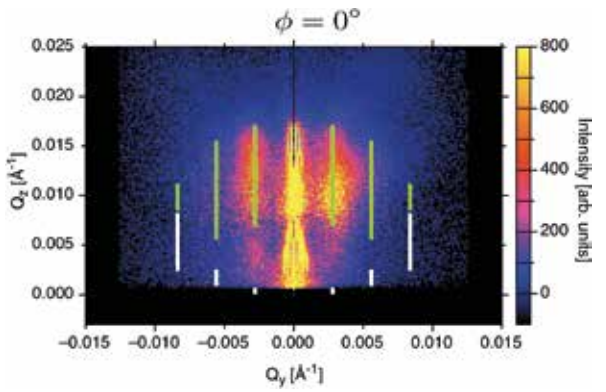


Figure 3: Bragg rods reconstructed from the GISANS pattern of a nanostructured Gd samples (horizontal wires with spacing 250 nm). The annotation marks the expected peak positions.

Technical Data

Primary beam

- Neutron guide NL 2b
- Astrium choppers with wavelength resolution to be chosen in the range 0.2 % – 10 % for wavelengths in the range 2 Å – 20 Å. Rotation speed up to 6000 rpm.
- Collimation: 2 vertical adjustable slits (0 – 12 mm) separated by 8.68 m
- For reflectometry, the horizontal divergence is maximized by use of supermirrors (m = 2 – 3)

Flux at sample

Typical values (ΔQ / Q = 3 %):

- 1 ·10⁴ n s⁻¹ (incident angle 0.2°)
- 3 ·10⁶ n s⁻¹ (at 2.5°)

in the wavelength range 2 to 6 Å for a 60 × 60 mm² sample.

Accessible Q-range

- Reflectometry:
  Q_z up to .0.3 Å^{-1} for reflectivities down to the 10^{-7} range.
- GISANS:
  Q_y = 9.5 ·10^{-5} Å^{-1} to 0.18 Å^{-1} (corresponding to distances from 6 µm down to 3.5 nm)

Detector

High performance 2D 500 × 500 mm² multiwire ^{3}He detector (pixel size 2.7mm, efficiency 80 % at 7 Å, gamma sensitivity < 10^{-6}) positioned between 1.5 m and 12 m from the sample. The detector is installed in a liftable vacuum tube in order to reach exit angles up to 6 degrees at the maximum distance.

TOF analysis

The data are acquired in list mode, each neutron arrival time and impact position being stored for later analysis. This makes it possible to perform various rebinnings in order to tune the resolution/ intensity tradeoff.

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NREX

neutron reflectometer with X-ray option

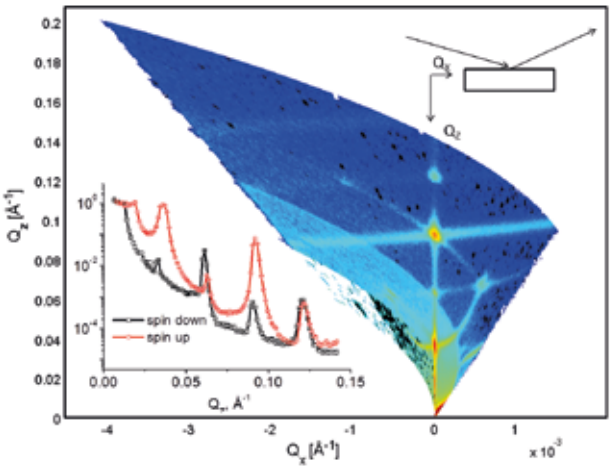


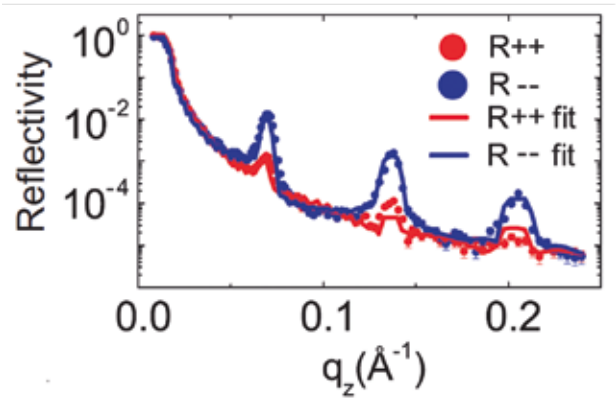
Figure 2: Scattering-map of spin-up neutrons from the [Fe(10 nm)/Si(10 nm)]x50-multilayer measured in magnetic field H = 1 kGs applied in-plane of the structure (scheme of the experiment on the up-right inset). Left-bottom insert: specular reflectivities for different spin channels.

Description

The neutron/ X-ray contrast reflectometer NREX, operated by the Max Planck Institute for Solid State Research, is designed for the determination of structural and magnetic properties of surfaces, interfaces and thin film systems. The instrument is an angle-dispersive fixed-wavelength machine with a default wavelength of 4.3 Å. A horizontal focusing monochromator give the possibility to switch between modes “high intensity/relaxed resolution” and “high resolution/reduced intensity” and provides a beam especially for small samples (down to 5 x 5 mm²). A Beryllium filter (Be) attenuates higher order reflections. Transmittance supermirrors m = 3.5 with a polarizing efficiency of P = 99 % and high efficiency gradient RF field spin flippers are used for a full 4 spin channel polarization analysis. The sample is aligned horizontally. By tilting the sample the incident angle is varied. The detector arm can move for GISANS horizontally as well as vertically for specular and diffuse scattering measurements. Neutrons are detected with a 20 x 20 cm² position sensitive or a pencil detector. An X-ray reflectometer can be mounted on the sample table orthogonal to the neutron beam. It allows for the in-situ characterization of sensitive soft matter samples and neutron/ X-ray contrast variation experiments.

Typical Applications

The instrument provides specular and off-specular reflectometry as well as grazing incidence small angle diffraction both in polarized and non-polarized modes. While the specular reflectivity allows



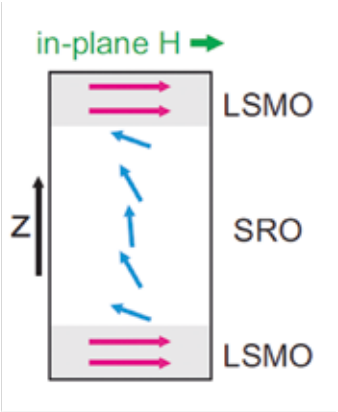
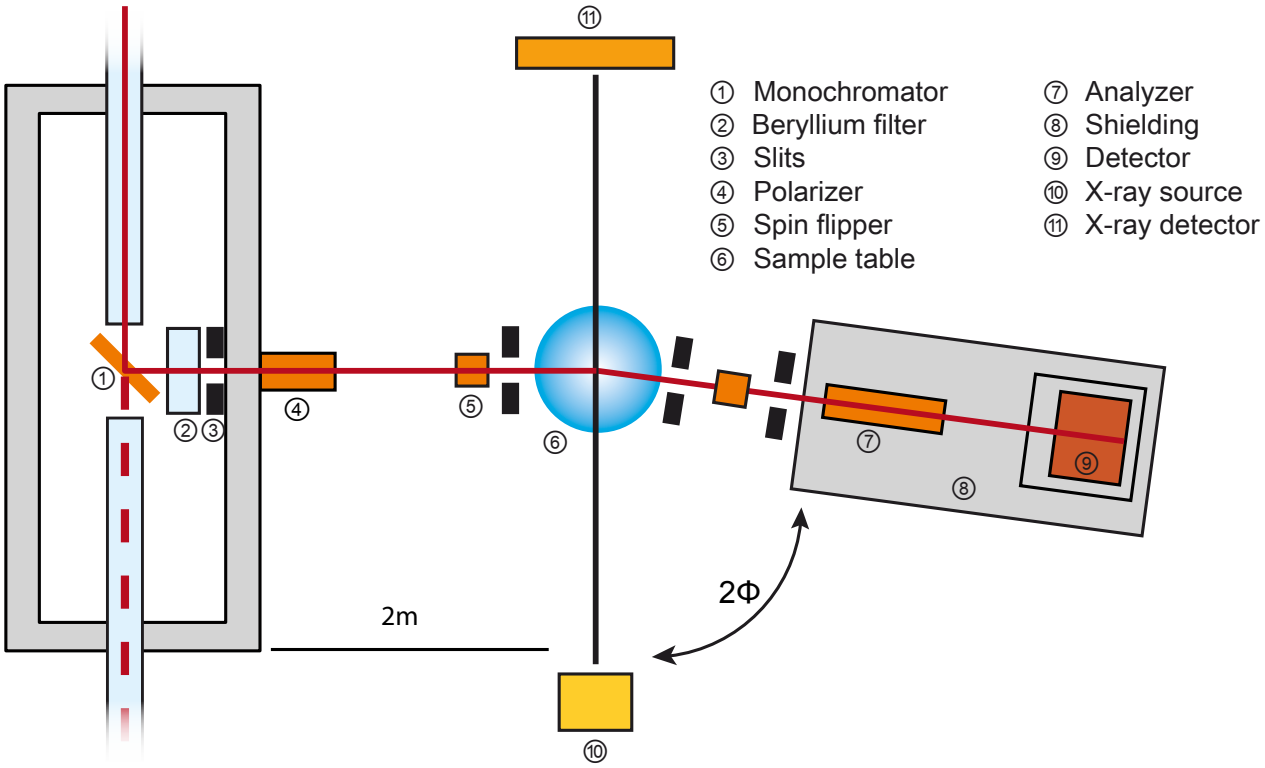


Figure 1: Left: Reflectivity curves from the periodic heterostructure [$La_{0.7}Sr_{0.3}MnO_3$(2 nm)/$SrRuO_3$ (8 nm)]x15 measured at T = 3 K (sample surface area 5 x 10 mm²). Right: Model of the spin configuration explaining experimental data. Taken from J.-H. Kim et al. Phys. Rev. B 86, 180402(R) (2012).



determining the scattering length density profiles (20 – 1500 Å) with nm precession along the surface normal, the off specular reflectivity is sensitive to in-plane-inhomogeneity like roughness, (magnetic) domains, vortices in superconductors, clusters and so on. To probe lateral (in-plane) structures in the order of atom distance (down to few Å) at the surface, grazing incidence diffraction is provided.

Sample Environment

A closed cycle cryostat (down to 3.5 K), an electromagnet (up to 2.5 T), a cell for solid/ liquid interfaces and a gastight chamber are provided. Also the standard FRM II sample environment (magnets up to 7.5 T and ^{3}He inserts for the cryostat down to 50 mK) are available.

Technical Data

Monochromator

- Type: 7 × 5 HOPG Crystals, Horizontal focussing
- Wavelength: 4.3 Å
- Wavelength resolution: 1…2 %
- Distance to sample: 2500 mm
- Higher order filter: cooled Be

Collimation

- Vertical
  - Slit sizes: 0.2 – 6 mm
  - Divergence: 0.05 – 1.4 mrad
- Horizontal
  - Slit: 0.2 – 100 mm

Polarization

- Beam polarization: > 99 %
- Flipper efficiency: > 99 %

Detector

- 2 pencil detectors: ^{3}He
- 2D area detector: ^{3}He wire chamber
- Active area: 200 × 200 mm^2
- Lateral resolution: 3 mm
- Distance to sample: 2465 mm

Dynamical- and Q-Range:

- Specular reflectivity: 1 : 1 x 10^{-6} (@ 5 × 5 mm^2 sample and full polarization)
- Q_z: 0.005 - 0. 5 Å^{-1}
- δQ_z ($0 < Q_z < 0.2$ Å^{-1}) < 0.002 Å^{-1}

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MARIA

magnetic reflectometer with high incident angle

Description

The neutron reflectometer MARIA with polarization analysis has been designed for the investigation of thin magnetic layered structures down to the monolayer scale and lateral structures. The reflection of polarised neutrons allows to determine individually the density and the modulus and the direction of the magnetisation vector of buried layers.

MARIA is optimised for layer thicknesses between 3 – 300 Å and lateral structure sizes from nm to µm sizes. Consequently the instrument is designed for small focused beam and sample sizes of 1 cm^2 at $\lambda = 4.5$ Å (available: 4.5 Å < λ < 40 Å) in a vertical orientation with a maximum incident angle of 180° and outgoing angle ranging from -14° to 100°. Maria provides polarisation analysis in standard operation, where the beam is polarised by a polarising guide (z-geometry; 4.5 Å < λ < 10 Å) and analysed by a wide angle ^{3}He-cell.
Beside the above described reflectometer mode with good resolution in the horizontal scattering plane, MARIA can be used in the GISANS mode with additional resolution in the vertical direction. The latter mode allows one to measure lateral structures down to the nm scale.

At the sample position a Hexapod with an additional turntable (360°) is installed, which can take a load up to 500 kg. In the standard configuration magnetic fields are provided up to 1.3 T (Bruker electromagnet) and cryogenic temperatures down to 4 K (He closed cycle cryostat). Beside this standard setup the complete sample environment of the JCNS can be adopted to MARIA so that magnetic fields up to 5 T and temperatures from 50 mK to 500 K are available.

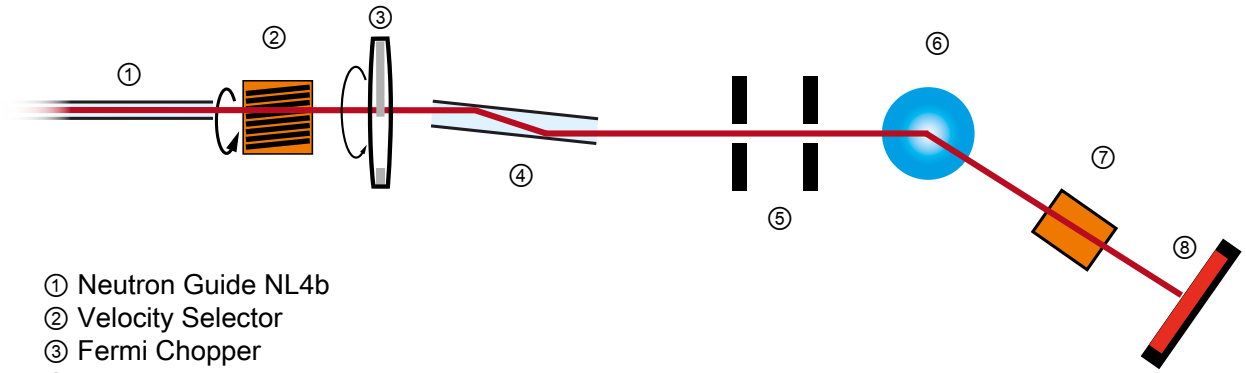
All parts of MARIA are controlled by a computer system according to the “Jülich-Munich” standard based on a Linux workstation. This allows a flexible remote control with automatic scan programs, including the control of sample environment as cryostat and electromagnet.

Typical Applications

With scattering under grazing incidence we investigate depth-resolved the laterally-averaged magnetizations and the correlations between their lateral fluctuations. With an additionally polarized neutron beam we derive a vector information on the laterally-averaged magnetization (reflectivity) and on the correlations between their lateral fluctuations (off-specular scattering - µm length scale, GISANS – nm length scale).

In general MARIA can be used for measurements of magnetic roughness, the formation of magnetic domains in thin layered structures, lateral structures, etc. (polarized mode) and density profiles, structures of solid polymer layers, etc. (unpolarized mode with higher intensity).
Furthermore possible without the need for multilayers investigation of:

- Diluted semi conducters
- Influence of the substrate
- Interfaces between oxide materials



① Neutron Guide NL4b
② Velocity Selector
③ Fermi Chopper
④ Polariser
⑤ Slit pair
⑥ Hexapod sample table
⑦ Polarization Analyzer (^{3}He)
⑧ Detector

Sample Environment

The optimal sample size for MARIA is 10 × 10 mm^2 with the following parameters:

- Thin magnetic layers down to sub mono layers
- Polarization analysis as standard
- Layer thickness of 1 – 300 Å optimized, but – 1000 Å (multi layers) should be feasible
- Lateral structures of nm to µm

Besides the described cryogenic temperatures and magnetic fields MARIA can provide a fully equipped Oxid-MBE (Molecular Beam Epitaxy) to the user. The typical sample sizes are 10 × 10 mm^2 and as targets we can provide Al, Cr, Pr, Fe, La, Nb, Ag, Nd, Tb, Sr, Mn, Ti and Co.

Technical Data

Primary beam

- Neutron guide NL5-N vertically focussing elliptic guide
- Monochromator: Velocity selector
- Wavelength:
  4.5 Å – 10 Å (polarized)
  4.5 Å – 40 Å (unpolarized)
- Resolution:
  10 % velocity selector
  1 %, 3 % Fermi chopper
- Double reflection polarizer
- Horizontal scattering plane

Flux at sample

- Expected pol. flux 5 · 10^7 n cm^{-2} s^{-1} for 3 mrad collimation

Distances and angles

- 4100 mm distance S1 – S2 (collimation)
- 400 mm distance S2 – sample
- 50 mm × 40 mm (w × h) max. opening S2
- 1910 mm distance sample – detector
- 120° maximum detector angle
- GISANS option: 4 m collimation length

Accessible Q-range

- Reflectometry:
  Q_z- range 0.002 Å^{-1} – 3.2 Å^{-1}
  Q_x- range 6 · 10^{-5} Å^{-1} – 0.001 Å^{-1}
  α_f -14° – 100°
- GISANS option:
  Q_y- range 0.002 Å^{-1} – 0.2 Å^{-1}

Polarization analysis

- ^{3}He cell

Detector

- 2D PSD detector
  size 400 × 400 mm^2
  resolution 2 × 3 mm (h × v)

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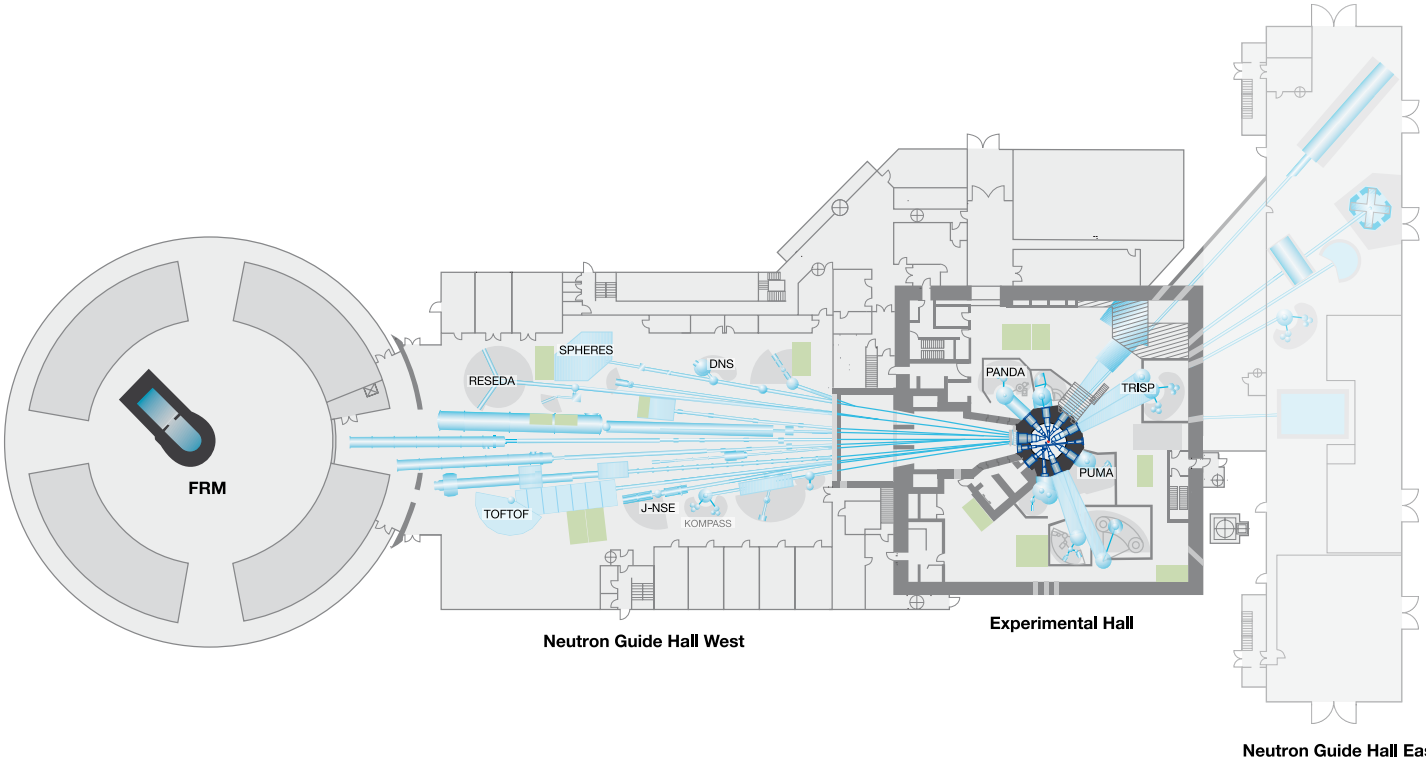


PUMA
thermal three axes
spectrometer

PANDA
cold three axes
spectrometer

TRISP
three axes spin echo
spectrometer

TOFTOF
cold neutron time of flight
spektrometer

SPHERES
backscattering
spectrometer

RESEDA
resonance spin echo
spectrometer

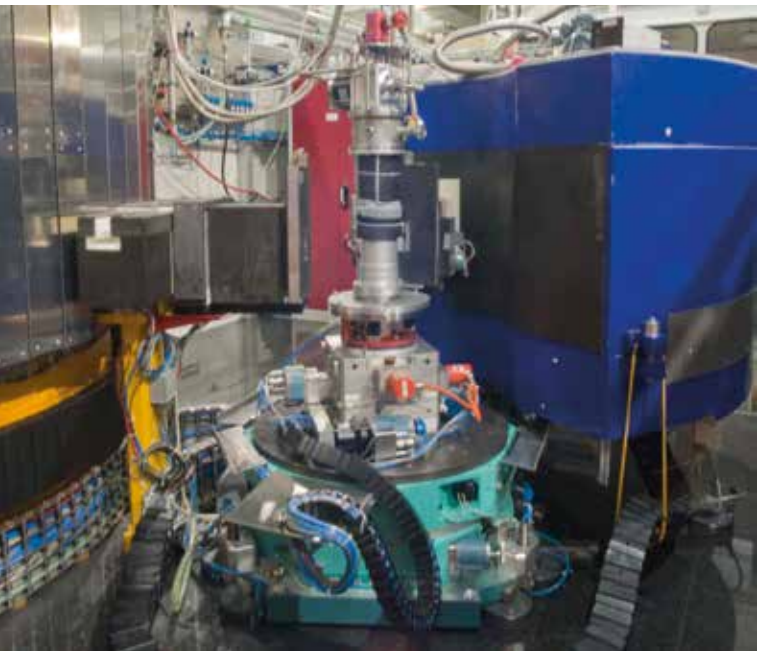
J-NSE
spin echo
spectrometer

DNS
diffuse scattering
time of flight spectrometer

Spectroscopy

PUMA

thermal three axes spectrometer



Description

Three axes spectrometers allow the direct measurement of the scattering function S(Q, ω) in single crystals at well defined points of the reciprocal lattice vector Q and frequency, ω and thus represent the most general instrument type.
PUMA is characterized by a very high neutron flux, as a result of the efficient use of focussing techniques. Three different vertical openings and a horizontal slit, with a maximum opening of 40 mm, define the virtual source, which is two meters before the monochromator. To reduce the contamination of the primary beam by epithermal neutrons, a sapphire filter can be placed in front of the monochromator. PUMA has a remote controlled monochromator changing unit, which allows to place one out of four different monochromators inside the drum. At present two different monochromators (PG(002) and Cu(220)) are available, covering an energy transfer up to 100 meV — Cu(111) and Ge(311) are in preparation. All monochromators are equipped with doubly focussing devices that allow for optimum focussing conditions over a wide range of incident wavevectors k_i. The horizontal divergency of the beam can be defined using a series of four Soller collimators. The two inside the monochromator drum, before and after the monochromator, can be remotely changed, whereas the two in the analyzer housing can be changed manually.
An Eularian cradle can optionally be used to access the four dimensional Q-ω-space. An innovative option of the spectrometer is the multianalyzer / detector system. It allows a unique and flexible type of multiplexing. Using this option a scattering angle range of 16° can be measured simultaneously and flexible Q-ω paths can be realized without the need to reposition the instrument. Mapping of excitations is equally well possible as kinetic single shot experiments on time scales that have not been accessible so far.
A unique feature of the instrument is the possibility to perform stroboscopic, time resolved measurements of both elastic and inelastic signals on time scales down to the microsecond regime. Using this technique, the sample is periodically perturbed by an external variable such as temperature, electric field, etc. The signal is then recorded not only as a function of momentum and energy transfer, but also given a time stamp, relative to the periodic perturbation.

Typical Applications

Phonons
- Electron / phonon interaction
- Phonon anharmocities
- Soft mode phase transitions

Magnons
- Spin waves in antiferromagnets
- Kinematic / dynamic interaction
- Electron-magnon interaction
- Unconventional superconductors
- Crystal fields

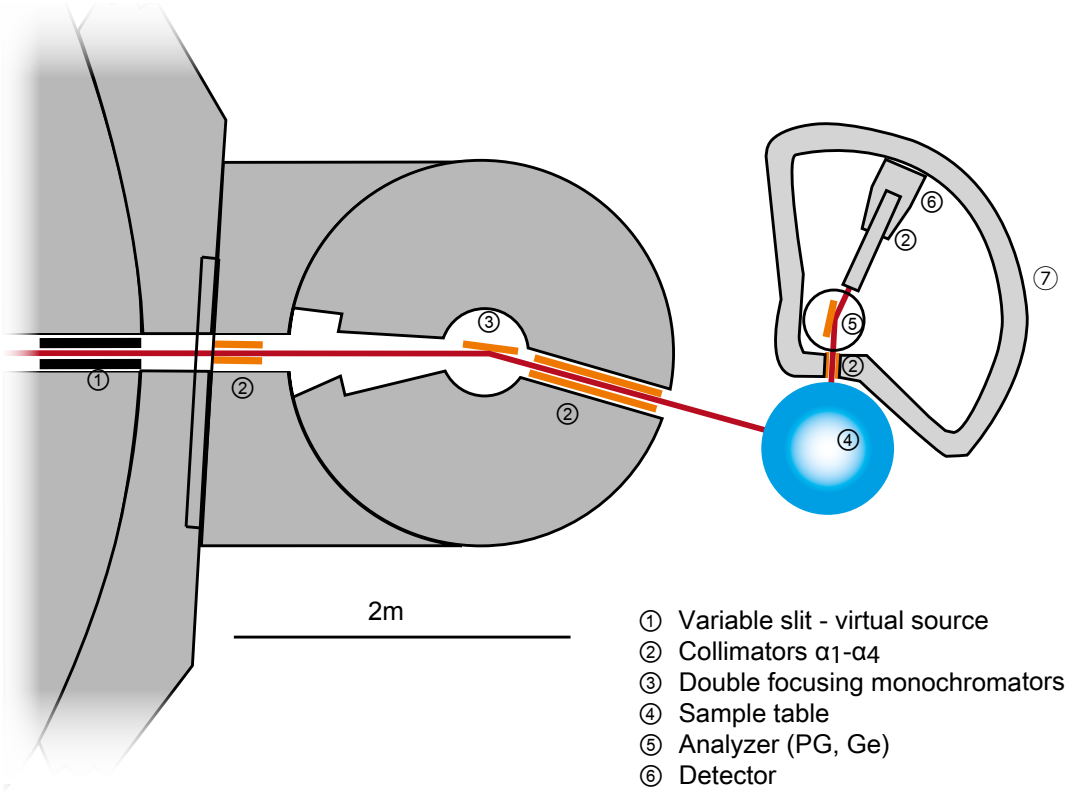
Time resolved / stroboscopic measurements
- Temperature cycling (excitations during demixing processes)
- Electrical field cycling (polarization processes in ferroelectrics)
- Temperature / pressure cycling

Diffraction; purely elastic signals
- Superstructures / satellites
- Diffuse scattering

Sample Environment

Aside from the MLZ standard sample environment the following dedicated devices are provided:
- Closed-cycle cryostates 3.5 – 300 K;
  - 650 K with adaptable heating device
- Cryofurnace 5 K – 750 K
- Paris-Edinbourgh type pressure cell p < 10 GPa

Along with the detector electronics required for time resolved measurements, special sample environment for the rapid cycling is available:
- Furnace for fast temperature jumps (~ 5 K/s cooling rate; < 620 K; ambient atmosphere)
- Switchable HV power supply (< 500 Hz; +/- 10 KV)



① Variable slit - virtual source
② Collimators α1-α4
③ Double focusing monochromators (PG, Cu)
④ Sample table
⑤ Analyzer (PG, Ge)
⑥ Detector
⑦ Common analyzer and detector shielding

Technical Data

Primary beam

- Beam tube SR 7 (thermal)
- Beam tube entrance 140 × 90 mm²
- Virtual source dimensions:
  horizontal: 0 – 40 mm
  vertical: (90, 110, 130 mm)

Distances

- Beam tube entrance - monochromator: 5.5 m
- Virtual source – monochromator: 2.0 m
- Monochromator – sample: 2.0 (± 0.1) m
- Sample – analyzer: 1.0 (± 0.1) m
- Analyzer – detector: 0.9 m

Collimation

Remote controlled:
- α1: 20', 40', 60'
- α2: 14', 20', 24', 30', 45', 60'

Manually changeable:
- α3: 10', 20', 30', 45', 60'
- α4: 10', 30', 45', 60'

Monochromators

Crystals: PG(002), Cu(220), Cu(111);
size: 260 × 162 mm²;
Focus vertically and horizontally adaptable to incident energy

Analyzer

Crystals : PG(002), Ge(311); 210 × 150 mm²; vertical fixed focus; horizontally adaptable to incident energy

Sample table

- Diameter 800 mm
- Max. load 900 kg
- Amagnetic goniometer (± 15°)
- Z translation (± 20 mm)
- Optional Eularian cradle

Main parameters

- Monochromator take off angle
  $-15° < 2\Theta < -115°$
- Scattering angle sample
  $-70° < 2\Theta < 120°$
  (dependent on monochromator take off angle)
- Analyzer scattering angle
  $-120° < 2\Theta < 120°$
- Incident energy range 5 meV – 160 meV
- Momentum transfer range < 12 Å^{-1}
- Energy transfer < 100 meV

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PANDA

cold three axes spectrometer

Description

The cold three axes spectrometer PANDA offers high neutron flux over a large dynamic range keeping the the intrumental background comparably low. PANDA is situated on the cold neutron beam-tube SR2 in the experimental hall. The high flux is achieved by neutron guide elements in the beam tube, a short source to monochromator distance and the double-focussing monochromator and analyzer crystals. Options for high energy and high q-resolution are available. With dedicated sample environments for very strong magnetic fields and very low temperatures, PANDA is ideally suited for the studies of magnetism and superconductivity on single crystals. Lattice dynamics and magnetic structures are investigated successfully, too.
A polarized neutron setup using both Heusler monochromator and analyzer as well as a sample-space Helmholtz-coil set for longitudinal polarization analysis is available.

Typical Applications

Magnetic properties
- Spin-waves
- Crystal field excitations
- Excitations in low dimensional systems
- Magnetic vs nuclear scattering

Lattice dynamics
- Phonon dispersion
- Anharmonic effects
- Polarisations vectors

General
- Critical scattering at phase transitions
- Magnon - phonon interaction
- Soft mode
- Central peak
- Diffraction:
  - without analyser: integral E method
  - with analyser:
    dE close to 0, high E & Q resolution

Sample Environment

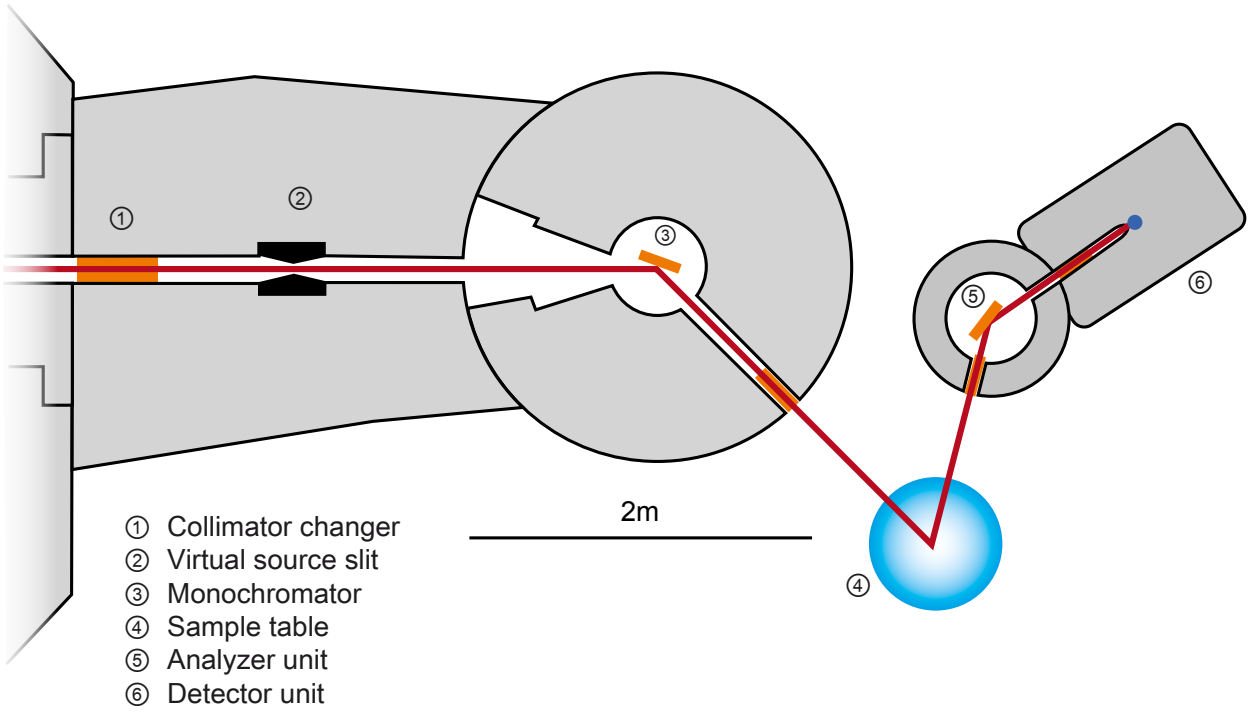
The sample table of PANDA allows for a variety of sample environment and may easily be adapted to user specific devices. Among other PANDA disposes routinely operated sample environment for:

Low temperature
- Closed cycle cryostat (3 K < T < 300 K)
- Variox cryostat (1.5 K < T < 100 K)
- Dilution insert (50 mK < T < 6 K)

typical dimensions for sample space
Ø 50 mm, h = 70 mm

Vertical magnetic field:
- Cryomagnet V15T with optional ^{3}He-^{4}He-dilution insert; H_{max} = 13.5 T
  (50 mK) 1.5 K < T < 100 K
  max. sample diameter: (12 mm) 19 mm
  split of coils 20 mm
- Closed-cycle magnet V7.5T
  H_{max} = 7.5 T
  Closed-cycle cryostat and high temperature furnace inserts available

High temperature
- High temperature furnace
  300 K < T < 2100 K
  sample space: Ø 50 mm, h = 50 mm



Technical Data

Monochromators

- PG(002) (d = 3.355 Å)
  $20° < 2\Theta_M < 132°$
  $1.05\ Å^{-1} < k_i < 4.0\ Å^{-1}$
  variable horizontal and vertical focussing
- Heusler (d = 3.35 Å, polarised neutrons)
  $20° < 2\Theta_M < 120°$
  $1.1\ Å^{-1} < k_i < 4.0\ Å^{-1}$
  variable vertical focussing
- Si(111) (d = 3.135 Å)
  $20° < 2\Theta_M < 132°$
  variable horizontal and fixed vertical focussing
  $1.15\ Å^{-1} < k_i < 4.0\ Å^{-1}$

Analysers

- PG(002)
  $-130° < 2\Theta_A < 100°$
  $1.05\ Å^{-1} < k_f$
  variable horizontal focussing
- Heusler (polarized neutrons)
  $-130° < 2\Theta_A < 100°$
  $1.05\ Å^{-1} < k_f$
  variable horizontal focussing

Detectors

- 1” ^{3}He tube (focussing mode)
- 2” ^{3}He tube (collimated mode))

Flux at sample

Monochromator vertically focused, horizontal flat, no collimation:

- $1.9 \cdot 10^7$ n cm^{-2} s^{-1} for $k_i = 1.55\ Å^{-1}$ Be Filter
- $5.5 \cdot 10^7$ n cm^{-2} s^{-1} for $k_i = 2.662\ Å^{-1}$ PG Filter

Main parameters

- Scattering angle at the sample:
  $5° < 2\Theta_S < 125°$ (moveable beam-stop)
- Energy transfer
  up to 20 meV
- Momentum transfers
  up to $Q = 6\ Å^{-1}$ (depending on k_i)

Filters for higher order suppression:

- PG (l = 60 mm); $k_f = 2.57\ Å^{-1}$ or $2.662\ Å^{-1}$
- Be (closed-cycle cryostat, T ≤ 25 K);
  $k_f = 1.55\ Å^{-1}$
- BeO (liq.-N_2 cooled); $k_f = 1.33\ Å^{-1}$

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TRISP

three axes spin echo spectrometer

Description

TRISP is a high-resolution neutron spectrometer combining the three axes and neutron resonance spin echo (NRSE) techniques. The design of TRISP is optimized for the study of intrinsic linewidths of elementary excitations (phonons, magnons) with an energy resolution in the μeV region over a broad range of momentum and energy transfers. Compared to conventional three axes spectrometers (TAS), this corresponds to an improvement of the energy resolution of one to two orders of magnitude.

TRISP also incorporates the Larmor diffraction (LD) technique, which allows to measure lattice spacings with a relative resolution $\Delta d/d = 1.5 \cdot 10^{-6}$, i.e. one to two orders of magnitude better than conventional neutron or X-ray diffraction. Absolute d-values can be determined by calibrating the instrument against an Si standard. The main applications of LD include thermal expansion under pressure and low or high temperature, and distributions of lattice constants (second order stresses). LD thus is unique in a parameter region, where standard methods such as dilatometry fail.

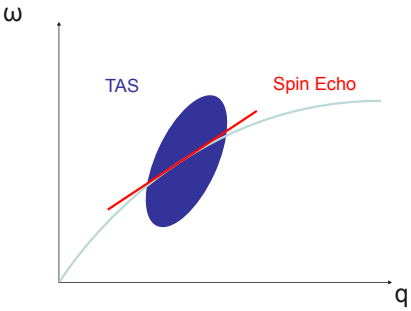


Figure 1: Measurement of the linewidth of a dispersive excitation at TRISP: The TAS background spectrometer defines a resolution ellipsoid in the (q, ω)-space (blue ellipse), the spin-echo enhances the energy resolution within the resolution ellipsoid. Tuning of the spin-echo resolution (red line) to the group velocity of excitations is achieved by rotating the RF spin flip coils. A detailed analysis of the resolution properties is given by K. Habicht et al., J. Appl. Cryst. 36, 1307 (2003).

Typical Applications

- Measurement of the intrinsic linewidths of phonons (fig. 2)
- Measurement of the instrinsic linewidths spin excitations (fig. 3).
- Larmor diffraction is used to determine thermal expansion and second order stresses under pressure and at low or high temperature (fig. 4).

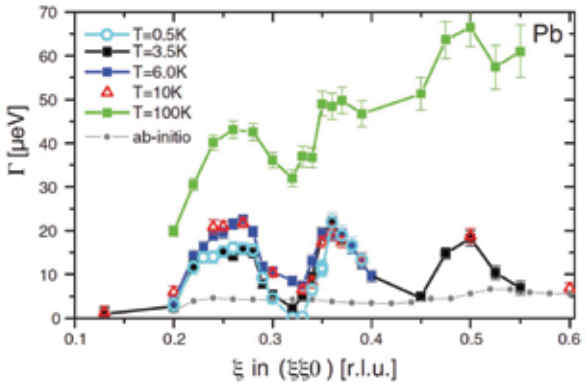


Figure 2: Linewidths of transverse acoustic phonons along q = (ξ, ξ , 0) in Pb at selected temperatures. Several anomalies are visible, which are not predicted by state-of-the-art ab initio calculations (gray symbols). (P. Aynajian et al., Science 319, 1510 (2008)).

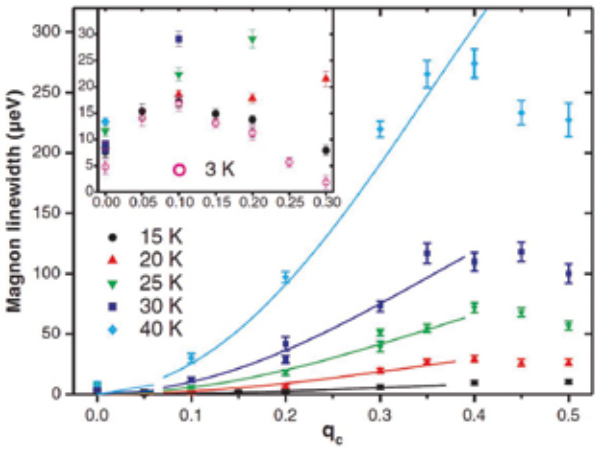
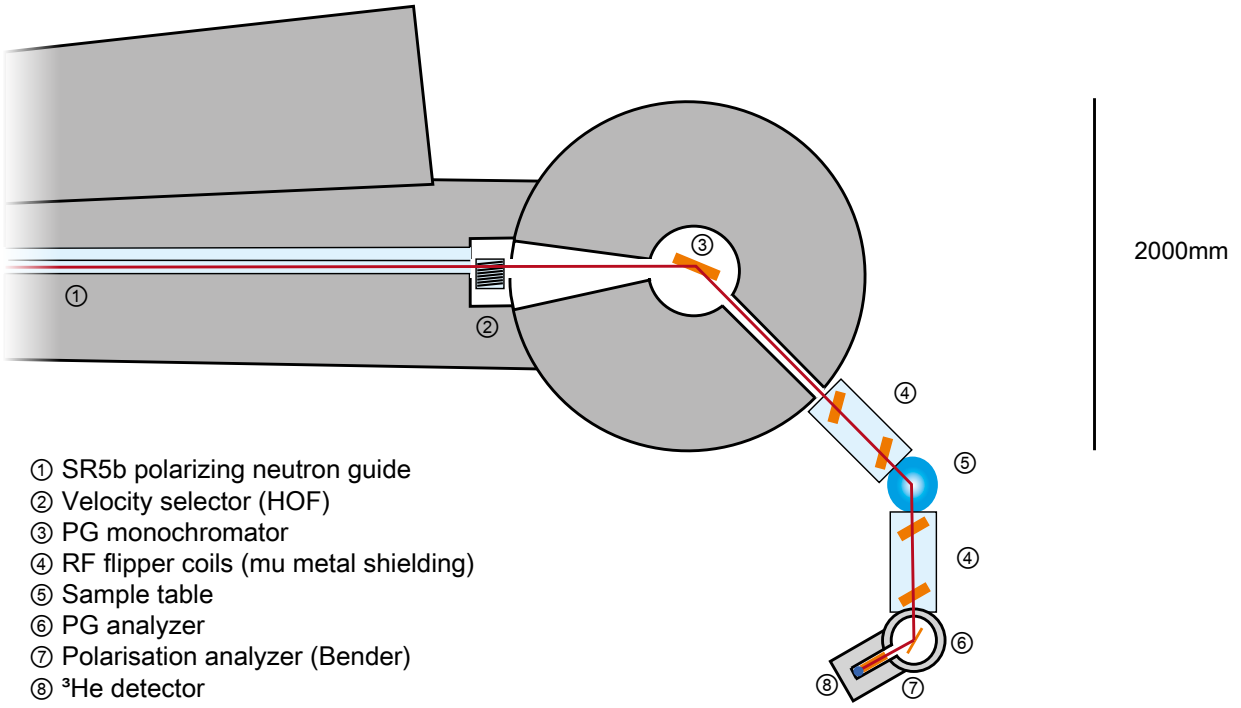


Figure 3: Intrinsic magnon linewidth Γ in antiferromagnetic MnF_2 at temperatures ranging from 15 to 40 K, as a function of q. We have plotted [Γ (T, q) - Γ (3 K, q)], where Γ (3 K, q) is given in the inset. (S. Bayrakci et al., Science 312, 1927 (2006))



Sample Environment

Besides the standard MLZ sample environment a dedicated dilution cryostat with a base temperature of 6 mK is available.

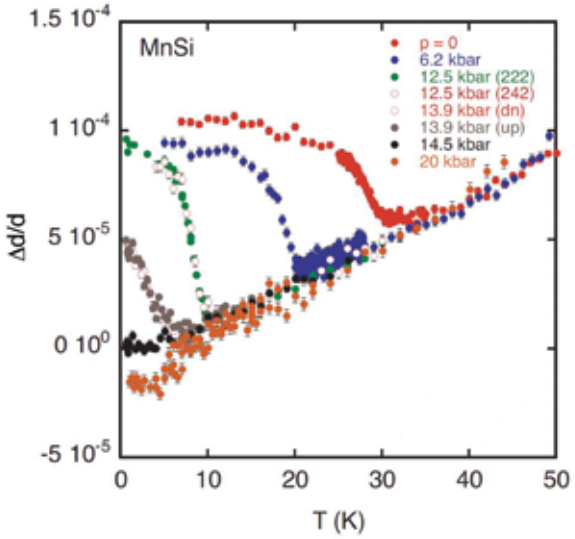


Figure 4: Temperature dependence of magnetic and electronic contributions, a2, of the lattice constant of MnSi at various pressures measured by Larmor-diffraction. The inset displays changes of the lattice constant at ambient pressure versus T_2 as normalized to a_0 = 4.58 Å. The relative resolution is $\Delta d/d = 1.5 \times 10^{-6}$ (C. Pfleiderer et al, Science 316, 1510, (2008)).

Technical Data

Primary beam

- thermal beam tube SR5
  polarizing supermirror bender
  1.3 Å^{-1} < k_i < 7.0 Å^{-1}
- Velocity selector
  Astrium type, as higher order wavelengths filter

Monochromator

- PG(002) or (004)
  variable focussing horizontal and vertical

Analyzer

- PG(002)
  variable horizontal focussing
- Heusler (111) (polarized neutrons)
  variable horizontal focussing

Spin echo

- Resonance spin echo, enclosed by mu-metal magnetic screen.

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TOFTOF

cold neutron time-of-flight spectrometer

Description

TOFTOF is a direct geometry multi-chopper time-of-flight spectrometer operated with incident neutrons from the undermoderated cold source of the reactor.
The 60 m long s-shaped curved primary neutron guide acts as a wavelength filter for the incident neutrons with a cutting edge at λ_i= 1.38 Å leading to a continuously high neutron flux over a wide wavelength range. Selecting an adequate incident wavelength and adjusting the chopper rotational frequency the resolution can be adapted to the needs of the experiment between 2 µeV and 3 meV. The scattered neutrons are detected by 1000 ^{3}He counting tubes mounted around the sample at distance of 4 m. The time-of-flight for each detected neutron is measured by the detector electronics with an accuracy up to 50 ns.
The prototype of a focusing neutron guide, parabolically shaped, has been recently installed, as alternative option to the final stage of the existing neutron guide. Its design combines the advantages of a supermirror coating with the leading-edge Adaptive Optics technology.

Typical Applications

TOFTOF represents a versatile instrument combining high energy resolution, high neutron flux (also at short wavelengths) and an excellent signal-to-background ratio. It is perfectly suited for both inelastic and quasielastic neutron scattering and a variety of scientific topics like:

- Molecular magnetism, quantum criticality in heavy fermion compounds, low energy excitations in multiferroic materials and novel magnetic phases (crystal field levels, phonons, magnons, polarons)
- Diffusion in liquid metals and alloys, simple liquids, colloids, disordered systems
- Aging effects in disordered media and low frequency dynamics in glasses
- Hydrogen storage materials
- Confined dynamics in nanostructures
- Energy-resolved QENS on proteins, vescicles and biological materials
- Biological activity and functionality of proteins and cells under pressure

Sample Environment

MLZ standard sample environment:

- CCR Cryostat (4 - 600 K)
- ^{3}He insertion device (down to 0.5 K)
- Circulation thermostat furnace (255 - 450 K)
- High temperature furnace (300 – 2100 K)

Sample environment provided by collaborators:

- Electromagnetic levitator
- Electrostatic levitator
- Hydraulic pressure cells (up to 3.5 kbar)
- Clamp pressure cells (few GPa)

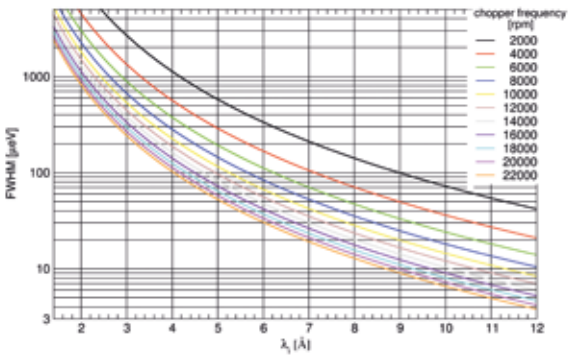
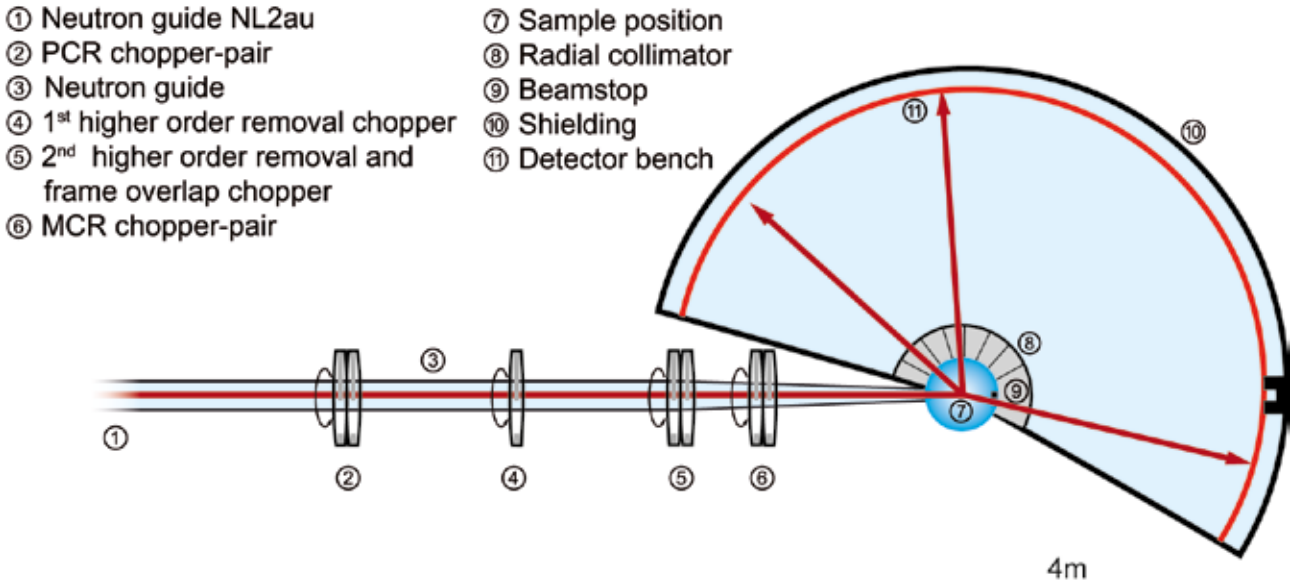


Figure 1: Elastic resolution as a function of the incident neutron wavelength for selected chopper rotational frequencies.



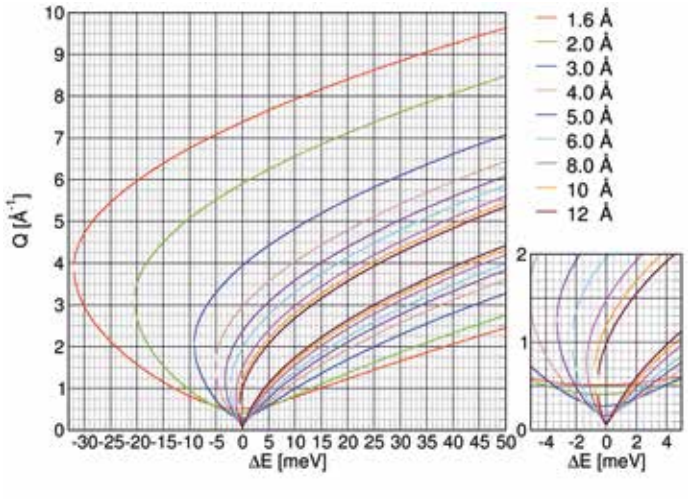


Figure 2: Dynamic range of the TOFTOF spectrometer for different incident wavelengths.

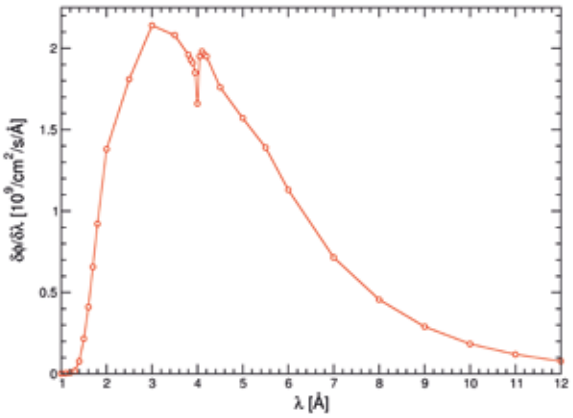


Figure 3: Incident differential white neutron flux at the sample position as measured by a calibrated beam monitor.

Technical Data

Primary Beam	
• Neutron guide	NL2au
• Number of chopper discs	7
• Chopper frequency range	400 min^{-1} – 22000 min^{-1}
• Diameter of chopper disc	600 mm
• Cross section of neutron guide at the entrance	44 × 100 mm^2
• Cross section of neutron guide 20 cm in front of sample position	23 × 47 mm^2
Main Parameters	
• Adjustable range of incident neutrons	1.4 – 16 Å
• Elastic energy resolution	2 µeV – 3 meV
• Range of energy transfers	-30 meV – 50 meV
• Integral neutron flux of the white beam at sample position	10^{10} n cm^{-2} s^{-1}
• Angular range of the detector bank	-15° to -7° and 7° to 140°

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SPHERES

backscattering spectrometer

Description

SPHERES (SPectrometer for High Energy RESolution) is a third-generation backscattering instrument with focussing optics and a phase-space-transform chopper. It is a versatile spectrometer for investigating atomic and molecular dynamics on a GHz scale.

The necessary filtering of neutron energies is achieved by Bragg reflection from perfect monochromator and analyzer crystals under angles close to 180°. The backscattering geometry makes it unavoidable to use a primary beam deflector and a duty-cycle chopper. In SPHERES, these two functions are realized jointly by a chopper that bears deflector crystals on its circumference. This leads to a particularly compact spectrometer layout so that full use can be made of the focussing neutron guide. As an additional advantage, the fast motion of the deflector crystals achieves a phase-space transform of the primary spectrum, thereby enhancing the flux at the sample.

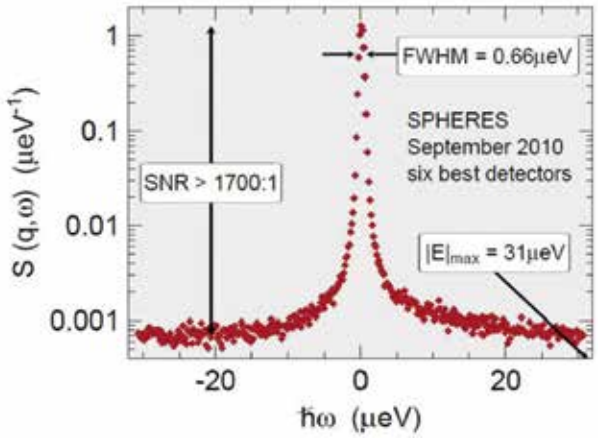


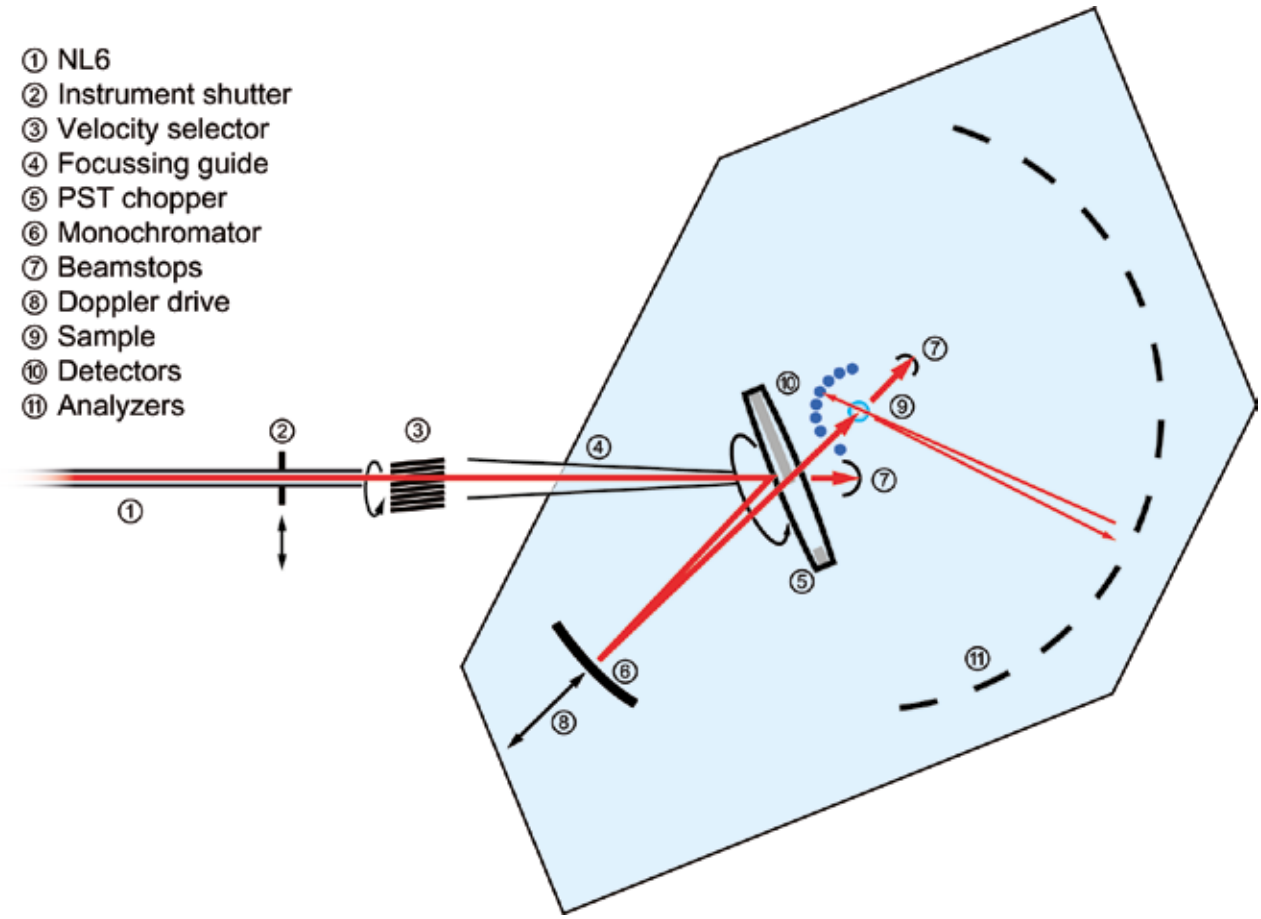
Figure 1: A resolution of 0.65 μeV, a dynamic range of ± 31 μeV, and a signal-to-noise ratio of 1000 : 1 or better are routinely achieved in user experiments [5].

The principal figures of merit (spectral flux, resolution, dynamic range, signal-to-noise ratio Fig. 1) qualify SPHERES as one of the best of its class [1]. Count rates and signal-to-noise ratio have been improved by filling the entire instrument with argon, thereby avoiding air scattering in the secondary spectrometer. Another gain in flux will be achieved by a more efficient phase-space transform chopper, which is currently under development.

As a multi-detector instrument with relaxed angular resolution, SPHERES is particularly suited for studying tagged-particle motion by incoherent scattering. A hot topic is the dynamics of water in confined geometry. The unprecedented sensitivity of SPHERES helps us to detect the onset of quasi-elastic scattering deep in the supercooled state [2]. Other important applications are hyperfine splitting in magnetic materials [3] and rotational tunneling [4]. The high count rates allow inelastic temperature scans (Fig. 2) and real-time kinetic experiments [6].

Raw histograms are accumulated on an equidistant ω grid. A script driven program, SLAW [7], is provided to normalize the raw counts, to perform optional binning, and to deliver S(q,ω) in a variety of output formats so that users are not bound to any specific data analysis programm. In data fitting, it is critcially important to convolute theoretical models with the measured resolution function in an efficient and numerically stable way. We strive to support best practice through our FRIDA package [8].

[1] J. Wuttke et al., Rev. Sci. Instrum. 83, 075109 (2012).
[2] W. Doster et al., Phys. Rev. Lett. 104, 098101 (2010).
[3] T. Chatterji, G. J. Schneider, and R. M. Galera, Phys. Rev. B 78, 012411 (2008).
[4] M. Prager, A. Pawlukojc, A. Wischnewski, J. Wuttke, J. Chem. Phys. 127, 214509 (2007).
[5] W. Häußler et al., Neutron News 22, 24 (2011).
[6] A. Leon, J. Wuttke, J. Phys.: Condens Matter 23, 254214 (2011).
[7] J. Wuttke: SLAW - a neutron histogram to scattering law converter, http://apps.jcns.fz-juelich.de/slaw
[8] J. Wuttke: FRIDA - fast reliable interactive data analysis, http://apps.jcns.fz-juelich.de/doku/frida/start



Typical Applications

- Hyperfine splitting
- Molecular reorientations and rotational tunneling
- Dynamic signature of phase transitions
- Hydrogen diffusion
- Liquid dynamics
- Polymer relaxation
- Protein aggregation

Sample Environment

- Cryofurnace 2..700 K
- Dilution inset 20 mK
- Furnace

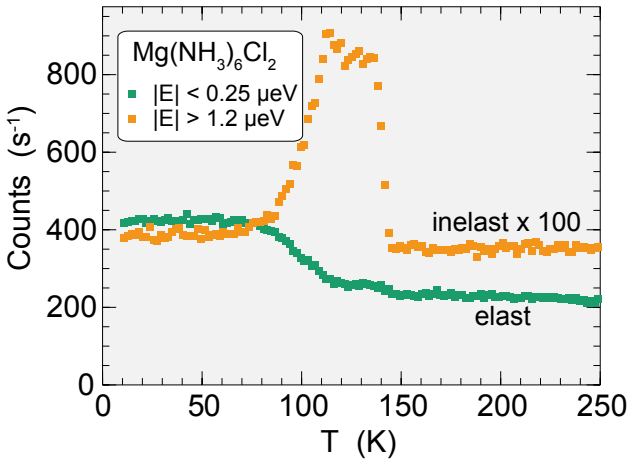


Figure 2: This inelastic temperature scan, measured during 23 h, revealed a hitherto unknown phase transition in $Mg(NH_3)_6Cl_2$ [5].

Technical Data

Primary beam	
Neutron guide	NL6-S
Neutron wavelength	6.27 Å
Neutron energy	2.08 meV

Main parameters	
Resolution FWHM	0.62 – 0.65 μeV
Dynamic range	± 31 μeV
Q range	0.2 – 1.8 $Å^{-1}$
Flux after selector	10^{10} s^{-1}
Flux at sample	$8 \cdot 10^5$ s^{-1}
Illuminated area	30 × 30 mm^2

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RESEDA

resonance spin echo spectrometer

Description

RESEDA is a high-resolution spectrometer installed at the cold neutron guide NL5-S in the Neutron Guide Hall of FRM II. The instrument gives access to a large time and scattering vector range for quasi-elastic measurements. RESEDA supports both “classical” Neutron Spin Echo (NSE, for short time scales in the range 1-500 ps) and Neutron Resonance Spin Echo (NRSE, for higher times, typically ranging from 0.5 to 5 ns). The final polarization value of the neutron spin echo renders the (normalized) Intermediate Scattering Function S(Q,τ), being the real part of the Fourier transform of the scattering function S(Q,τ). The analysis of S(Q,τ) provides characteristic parameters, e.g. relaxation time and amplitude of the dynamic processes in the sample investigated. The determination of S(Q,τ) is feasible for different Q-values and/or different temperatures, pressures, etc. RESEDA allows the measurement of two different Q-values simultaneously due to the presence of two independently operated secondary spectrometer arms. Modulation of Intensity Emerging with Zero-Effort (MIEZE) experiments, in which the spin manipulation is realized well before the sample, are also possible. The latter enables high-resolution study of depolarizing samples, under magnetic field and/or within depolarizing sample environments.

The neutron flight path is surrounded by a double μ-metal shielding, which minimizes magnetic stray fields in the spectrometer arms and at the sample position. Besides being a prerequisite for NRSE, this also provides the possibility to perform spherical polarimetry (SNP). Due to the length of the sample-detector distance and a low background level achieved by evacuated flight tubes, RESEDA is in addition naturally suited to (polarized) Small Angle Neutron Scattering (SANS) applications.

Typical Applications

Standard measurements at RESEDA include, e.g., the dynamics of water in porous media, polymer melts and diffusion processes in ionic liquids. As an example, figure 1 displays the result of a measurement of the microscopic dynamics on a solution of the hydrophobic polymer tetrabutylammonium bromide (TBABr) in D_2O. In the low Q region measured by NSE and NRSE, due to the form factor of the cations, the coherent intensity is measured. At this Q, the system is seen in a coarse-grained manner and the atomic details are irrelevant. Therefore the internal modes of the cation do not contribute to the dynamic signal. The associated relaxation corresponds to the dynamics of the cation center-of-mass and the NSE-NRSE signal was modelled as an exponential decay in the time-domain [1].

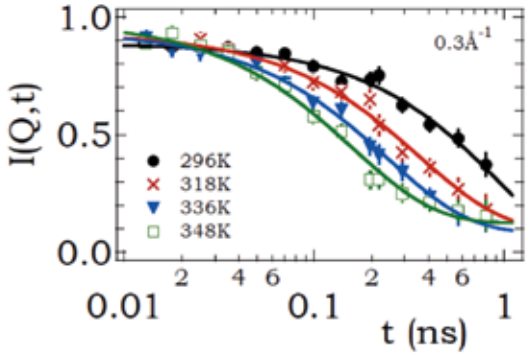


Figure 1: Dynamics of TBABr solution in heavy water (courtesy of D. Bhowmik et al.).

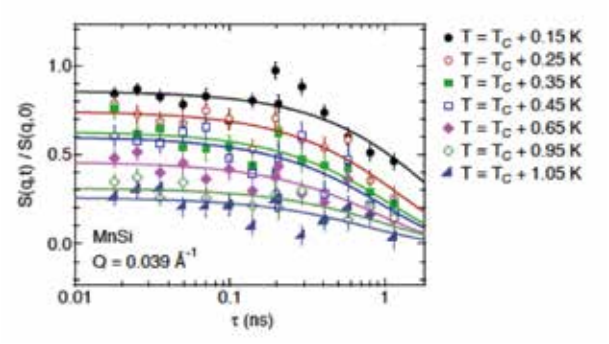
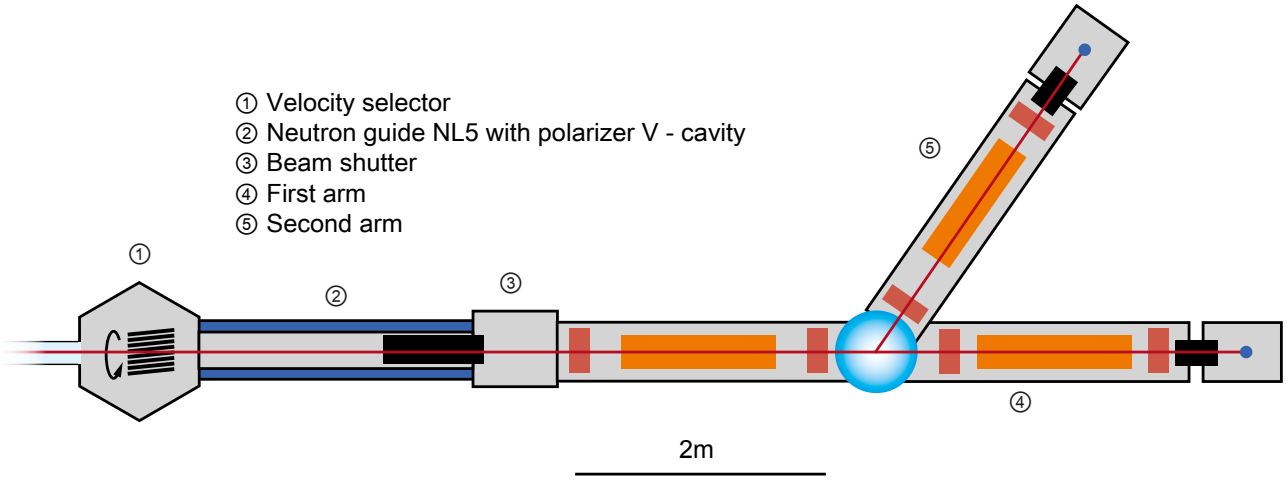


Figure 2: Temperature dependence of the spin dynamics in MnSi above T_C as seen by NRSE.



RESEDA is also intensively employed for studying magnetic dynamics in materials with various magnetic correlations. For instance, manganese silicide (MnSi) is a 3d intermetallic compound that crystallizes in a cubic structure and exhibits a single-handed helical magnet order with a period of approximately 180 Å due to the interplay between ferromagnetic exchange and the Dzyaloshinskii-Moriya interaction. In the vicinity of the critical temperature T_c = 28.85 K, the time scale of the magnetic fluctuations matches well the spin-echo times available at RESEDA. Above T_C, long-range magnetic order is lost. However, chiral fluctuations still persist. The high flux of RESEDA near the wavelength of 5.5 Å allows a clear identification of the magnetic fluctuations. Appropriate collimation of the neutron beam in front of the sample position enables measurements down to small Q-values. The results of typical NSE-NRSE scans on MnSi, corrected for instrumental resolution, are shown in figure 2. Around the ordering vector at Q = 0.039 $Å^{-1}$, the fluctuations are very slowly decaying within about 1.5 ns. With increasing temperature, the fluctuation rate increases as revealed by a faster damping of S(Q,τ). When standing at higher Q, the relaxation rate of the fluctuations also increases quickly.

Sample Environment

The standard closed-cycle cryostats (CCR) available at the FRM II fit within the double µ-metal shielding at the sample position. Thanks to its compactness, the CCR can be tilted in any directions within the double µ-metal shielding up to angles of ± 4.5°. The standard temperature range is 3.5 - 300 K. Moreover, it can be equipped with a ^{3}He or dilution insert thus extending the available temperatures into the mK regime. For reaching higher temperatures, an oven, developed at the MLZ and based on the principle of coaxial, current fed Nb cylinders can be used. Besides its standard ^{3}He finger counters, RESEDA can be equipped with a fast dynamic position sensitive CASCADE Detector, characterized by a spatial resolution of 2.6 mm^2 and a time dynamics of the order of a few MHz [2, 3].

[1] Bhowmik, D. et al., Eur. Phys. J. – Special Topics 213, 303-312 (2012).
[2] Schmidt, C.J. et al., Journal of Physics: Conference Series 251, 012067 (2010).
[3] Häußler, W. et al., Rev. Sci. Instr. 82, 045101 (2011).

Technical Data

Primary beam

- Neutron guide: NL5-S
- Guide cross section: 29 x 34 mm^2
- Wavelength selection: Velocity selector (max. 28000 rpm)
- Wavelength range: λ = 3 - 10 Å
- Wavelength bandwidth at sample position: Δλ/λ = 11...15 %
- Polarizer: V-cavity (length: 2 m, coating: m = 3)

Spectrometer

- Optional Polarizer before sample: V-cavity (length: 30 cm, coating: m = 4)
- Length of the spectrometer arms: 2.6 m
- Number of secondary spectrometer arms: 2
- Magnetic shielding: µ-metal, zero-magnetic-field sample region
- Polarization analysis: Bender
- Detectors: ^{3}He counters, optional 2D detector

Characteristic parameters

- Flux at sample position: $\phi \geq 10^7$ n cm^{-2} s^{-1} (at λ = 4.5 Å)
- Frequency range of RF coils: 35 kHz... 800 kHz
- Spin echo time range: τ = 0.001 - 5 ns
- Energy resolution: 0.1 - 600 µeV
- Maximum scattering angle: 2θ = 93°
- Maximum scattering vector: Q = 2.5 $Å^{-1}$ (at λ = 3 Å)

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J-NSE

neutron spin-echo spectrometer

Description

The neutron spin echo technique uses the neutron spin as an indicator of the individual velocity change the neutron suffered when scattered by the sample. Due to this trick the instrument accepts a broad wavelength band and at the same time is sensitive to velocity changes down to 10^{-5}. However the information carried by the spins can only be retrieved as the modulo of any integer number of spin precessions as intensity modulation proportional to the cosine of a precession angle difference. The measured signal is the cosine transform S(Q, τ) of the scattering function S(Q, ω). All spin manipulations only serve to establish this special type of velocity analysis. For details see "Neutron Spin Echo", ed. F. Mezei, Lecture Notes in Physics, Vol. 128, Springer Verlag, Heidelberg, 1980.

Due to the intrinsic Fourier transform property of the NSE instrument it is especially suited for the investigation of relaxation-type motions that contribute at least several percent to the entire scattering intensity at the momentum transfer of interest. In those cases the Fourier transform property yields the desired relaxation function directly without numerical transformation and tedious resolution deconvolution. The resolution of the NSE may be corrected by a simple division.

For a given wavelength the Fourier time range is limited to short times (about 2 ps for the FRM II-setup) by spin depolarization due to vanishing guide field and to long times by the maximum achievable field integral J. The time is proportional to $J \times \lambda^3$. The J-NSE may achieve a J = 0.5 Tm corresponding to τ = 48 ns at λ = 8 Å.

The instrument itself consists mainly of two large water-cooled copper solenoids that generate the precession field. The precession tracks are limited by the π/2-flippers and the π-flipper near the sample position. The embedding fields for the flippers are generated by Helmholtz-type coil pairs around the flipper locations. After leaving the last flipper the neutrons enter an analyzer containing 60 (30 × 30 cm^2) CoTi supermirrors located in a solenoid set. These mirrors reflect only neutrons of one spin direction into the multidetector. By the addition of compensating loops the main coils and the analyzer coil are designed such that the mutual influence of the different spectrometer components is minimized.

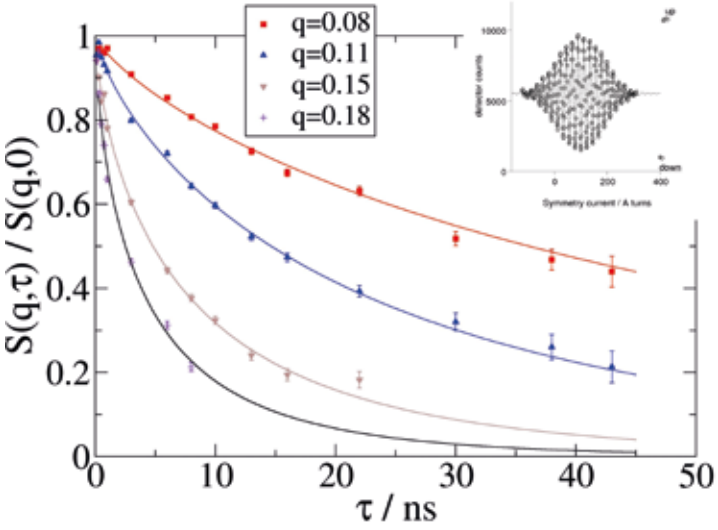
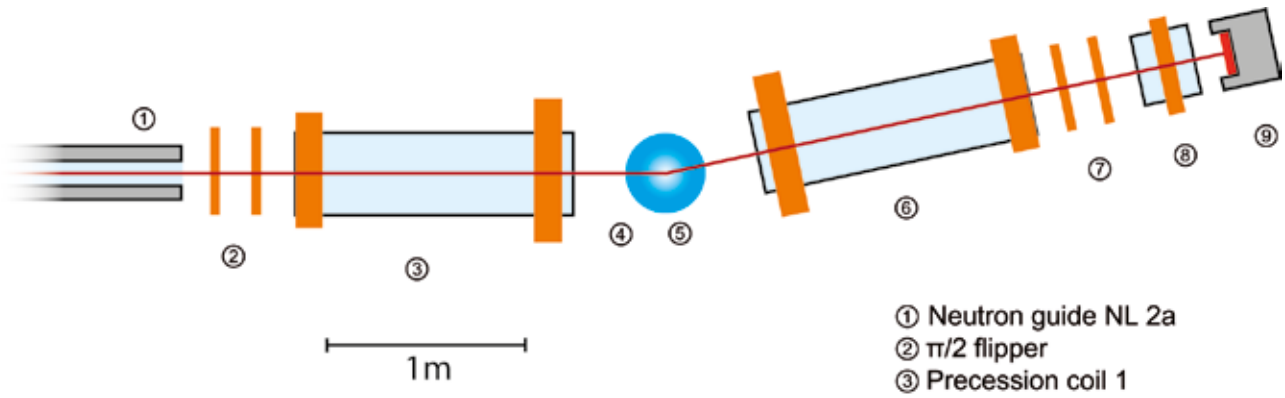


Figure 1: S(q, τ) of a bicontinuous microemulsion at different q values. The inset shows a spin echo group, the amplitude as a measure of the polarization left contains the desired information.



① Neutron guide NL 2a
② π/2 flipper
③ Precession coil 1
④ π flipper
⑤ Sample space
⑥ Precession coil 2
⑦ π/2 flipper
⑧ Analyzer
⑨ Detector

Typical Applications

The spin echo spectrometer NSE is especially suited for the investigation of slow (~ 1-100 ns) relaxation processes. Typical problems from the fields of "soft matter" and glass transition are:

- Thermal fluctuations of surfactant membranes in microemulsions
- Polymer chain dynamics in melts
- Thermally activated domain motion in proteins, which is an important key for understanding the protein function.

Example Experiment

The intermediate scattering function S(q,τ) of a bicontinuous microemulsion is shown in figure 1, where one probes the thermal fluctuations of the surfactant membrane at different q values. The inset shows an echo group obtained in the direct beam at λ = 5 Å and a Fourier time of τ = 0.24 ns. The maximum amplitude of the oscillation compared to the average contains the desired information on the time dependence of S(Q, τ). The residual intensity at the minimum is caused by the imperfection of the polarizes, general background and - rather for higher τ's - by magnetic path integral in homogeneities.

Technical Data

Main parameters

- Polarized neutron flux at sample position
  7 Å: $1 \cdot 10^7$ n cm^{-2} s^{-1}
  12 Å: $6.8 \cdot 10^5$ n cm^{-2} s^{-1}
- Momentum transfer range:
  0.02 – 1.5 $Å^{-1}$
- Fourier time range:
  2 ps (4.5 Å) < τ < 350 ns (16 Å)
- Max. field integral: 0.5 Tm

Primary beam

- Neutron guide NL2a
- Polarisation:
  Short wavelength by bent section with FeSi m = 3 remanent supermirror coating
  Long wavelength by FeSi polariser at entrance of the spectrometer
- Cross section of guide: 6 cm × 6 cm
- Max. sample size: 3 cm × 3 cm
- Collimation:
  By source and sample size or wire collimators 0.5° × 0.5°

Analyzer

30 cm × 30 cm CoTi supermirror venetian blind

Detector

32 × 32 1 cm^2 cells ^{3}He multidetector

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DNS

Diffuse scattering neutron time of flight spectrometer

Description

DNS is a versatile diffuse scattering cold neutron time-of-flight spectrometer with polarization analysis. It allows the unambiguous separation of nuclear coherent, spin incoherent and magnetic scattering contributions simultaneously over a large range of scattering vector Q and energy transfer E. With its compact size DNS is optimized as a high intensity instrument with medium Q- and E- resolution.
New chopper and position sensitive detector systems are to be installed at DNS. This is expected to largely improve possibilities for single-crystal time-of-flight spectroscopy with efficient measurements in all 4 dimensions of S(Q,E). With its unique combination of single-crystal time-of-flight spectroscopy and polarization analysis, DNS is also complimentary to many modern polarized cold neutron triple-axis spectrometers.

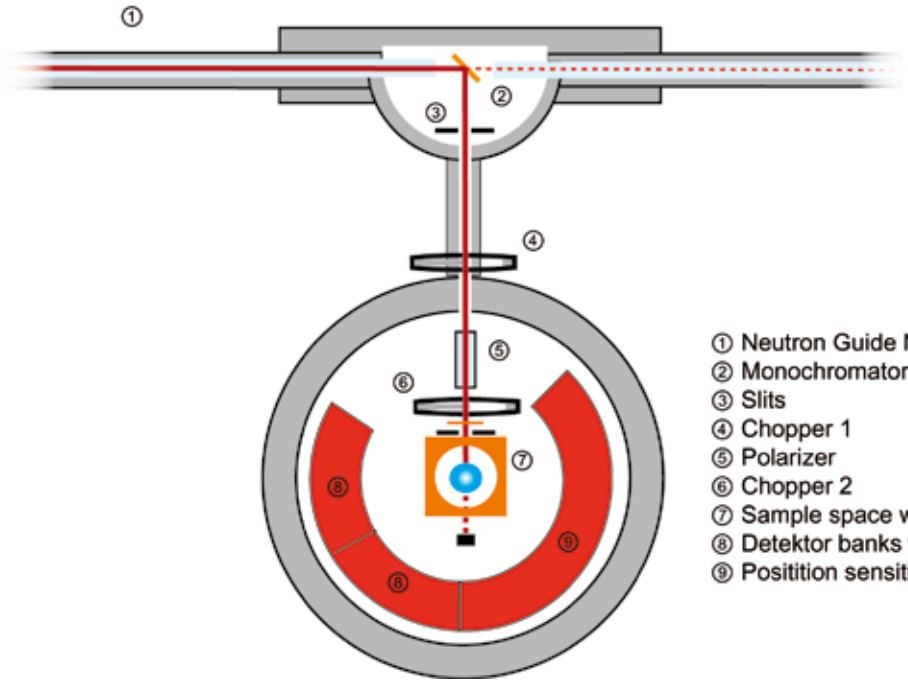
Typical Applications

With the increased flux and efficiency at FRM II, DNS becomes ideal for the studies of complex spin correlations, such as in highly frustrated magnets and strongly correlated electrons, as well of the structures of soft condensed matter systems, such as the nanoscale confined polymers and proteins, via polarization analysis. The exploration of unusual magnetic properties can also be efficiently undertaken on single-crystal samples by reciprocal space mapping. In addition to the separation of magnetic cross section from nuclear and spin-incoherent ones, polarization analysis also allows to distinguish in detail the anisotropy of spin correlations. It has also been well demonstrated that polarized powder diffraction on DNS is complementary to standard neutron powder diffraction and may be extremely useful for magnetic structure refinements, particularly in case of small moments by improving the signal to background ratio. DNS also represents a powerful instrument for the soft condensed matter community for the separation of nuclear coherent scattering from often dominating spin incoherent scattering background. The main applications can be summarized as the follows,

- Application of polarization analysis: uniaxial-, longitudinal- and vector-PA
- Magnetic, lattice and polaronic correlations: geometrically frustrated magnets, strongly correlated electrons, emergent materials
- Single-crystal and powder time-of-flight spectroscopy: single-particle excitations, magnons and phonons
- Soft condensed matters: separation of coherent scattering from hydrogenous materials, polymer, liquids and glasses

Sample Environment

- Top-loading CCR
- Closed-cycle cold head
- Orange-type cryostat
- Cryo-furnace
- Dilution $^{3}He/^{4}He$ cryostat insert (~20mK)
- Cryomagnet (self-shielding, vertical field up to 5T)



Technical Data

Monochromator

- Neutron guide NL6-S
- Horizontal- and vertically adjustable double-focusing
- PG(002), d = 3.355 Å
- Crystal dimensions: 2.5 × 2.5 cm^2 (5 × 7 crystals)
- Wavelengths range: 2.4 Å < λ < 6 Å

Double chopper system

- Chopper frequency ≤ 300 Hz
- Repetition rate ≤ 900 Hz
- Chopper disks: Titanium, 3 slits, Ø = 420 mm

Flux at sample

- Non-polarized ~ 10^8 n cm^{-2} s^{-1}
- Polarized ~ $5 \cdot 10^6 – 10^7$ n cm^{-2} s^{-1} (polarizer: m = 3 supermirror benders)

Detector banks for non-polarized neutrons

- 128 position sensitive ^{3}He tubes Ø = 1.27 cm, height ~100 cm
- Total solid angle covered: 1.9 sr
- Covered scattering angles in the horizontal plane: $0° < 2\theta \leq 135°$

Detector banks for polarized neutrons

- 24 detection units: Polarization analysis by m = 3 supermirror benders ^{3}He detector tubes, Ø = 2.54 cm, height 15 cm
- Covered scattering angle in the horizontal plane: $0° < 2\theta \leq 150°$
- Q_{max}
  λ_i = 2.4 Å (E_i = 14.2 meV): 4.84 $Å^{-1}$
  λ_i = 6 Å (E_i = 2.28 meV) 1.93 $Å^{-1}$

Energy resolution

- λ_i = 2.4 Å (E_i = 14.2 meV): 1 meV
- λ_i = 6 Å (E_i = 2.28 meV): 0.1 meV

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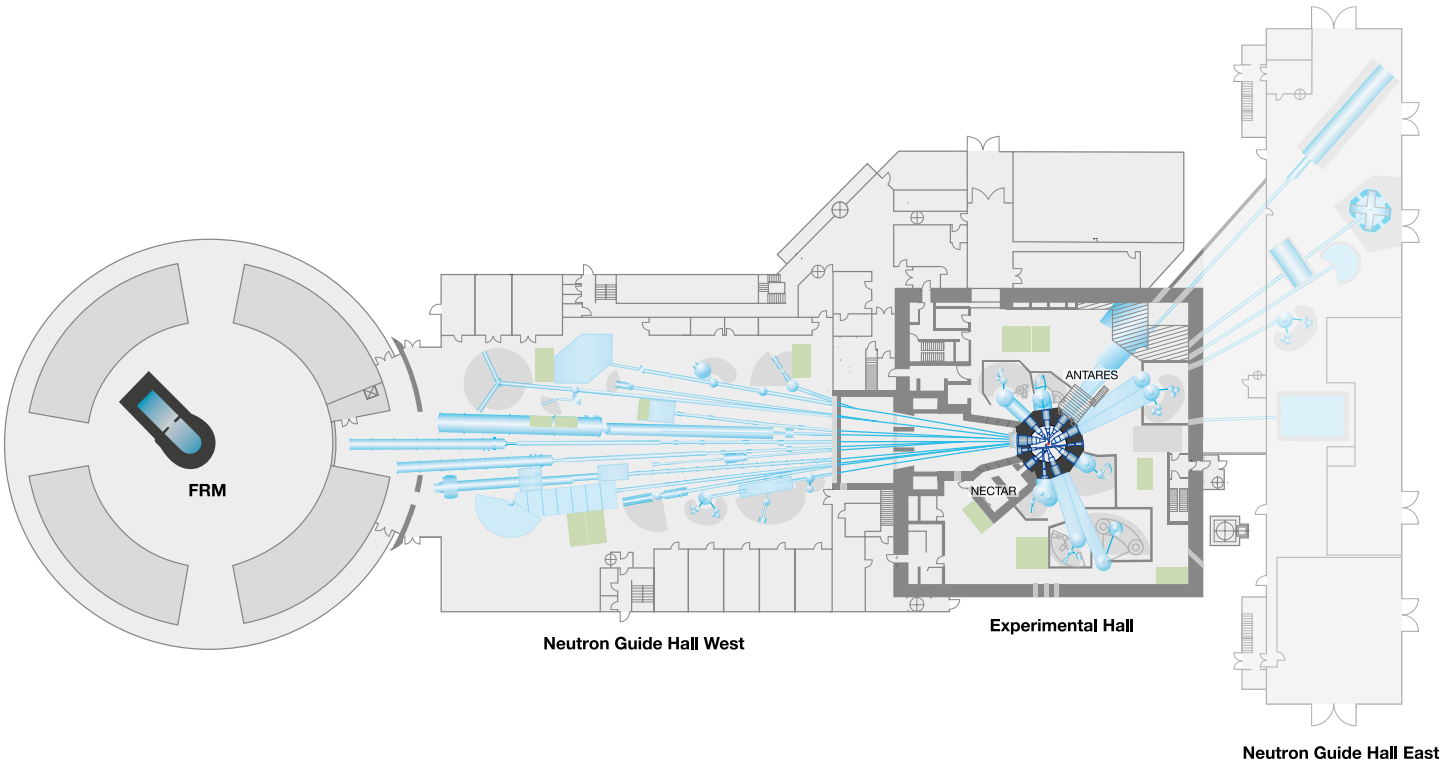


ANTARES
cold neutron radiography and tomography station

NECTAR
radiography and tomography using fission neutrons

Imaging

ANTARES

cold neutron radiography and tomography station

Description

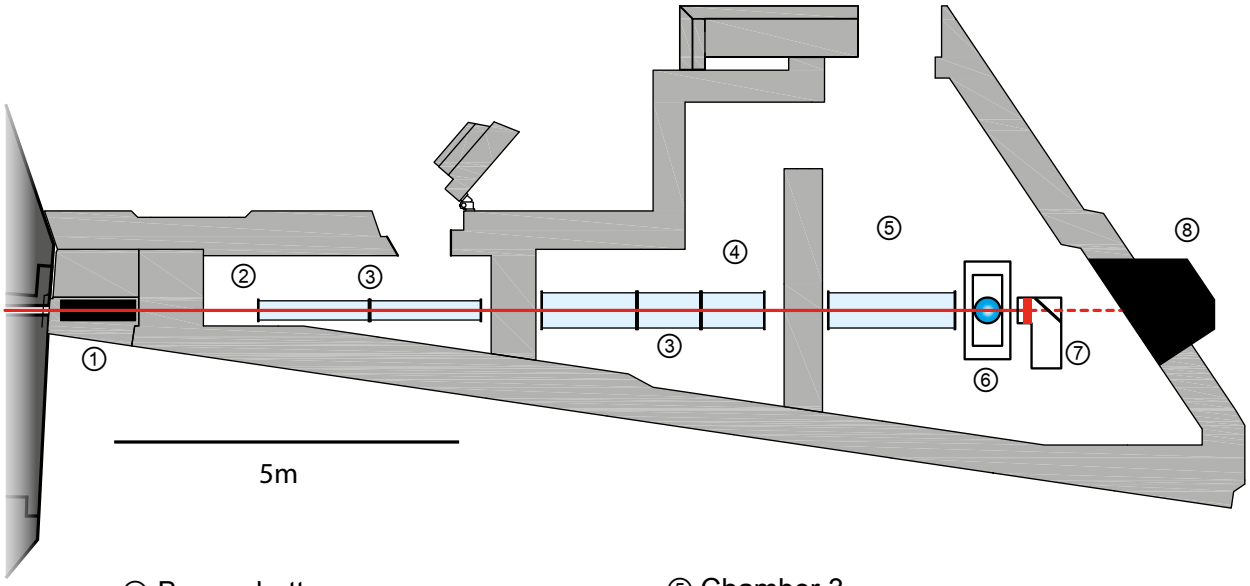
The neutron imaging facility ANTARES is located at the cold neutron beam port SR4b of the FRM II. Based on a pinhole camera principle with a variable collimator located close to the beam port, the facility provides the possibility for a flexible use in high resolution and high flux imaging. ANTARES offers two different detector positions in chamber 2 and 3, which may be chosen according to the requirements for beam size, neutron flux and spatial resolution. Both chambers offer abundant space for user-provided experimental systems or sample environment.
Chamber 1 is separately accessible for the optional installation of beam and spectrum shaping devices provided by the user. At this position ANTARES also offers built-in options such as a velocity selector, double crystal monochromator, interference gratings, and a Be-filter which are readily available for standard user operation.

Typical Applications

The ANTARES Neutron Imaging facility is designed to deliver radiographs and computed tomography of samples, similar to an X-ray machine. The resulting information is often complementary to X-ray measurements, with its most important features the high penetration of metals (Fe ~ 4 – 5 cm, Al ~20 – 30 cm, Pb ~10 – 20 cm) and the high sensitivity for hydrogen. These allow to visualize metal machine parts as well as liquids, sealants and plastics inside of metal parts. Liquid contrast agents can be employed for crack and void detection. Examples of different techniques and their typical applications:

- **Standard neutron radiography**: Moisture in sandstone, o-rings in machine parts, aerospace pyrotechnical components, fuel cells
- **Computed tomography**: Geological samples, mineral phases, voids in carbon fiber structures (with contrast agents), machine parts, biological samples as lung tissue
- **Continuous radioscopy**: Video speed radiography of dynamic processes like boiling in refrigerators or water boilers
- **Stroboscopic imaging**: Visualization of repetitive processes with high time resolution: Oil distribution in running combustion engines
- **Phase contrast**: Edge enhancement, aluminium foams, interface of similar alloys
- **Energy / wavelength scan**: Scanning for Bragg edges, phase or material identification, examination of welds.
- **Magnetic imaging**: Visualization of magnetic fields, fundamental research on ferromagnetic materials
- **Dark field imaging or small-angle scatter measurement**: Scatter gratings used to suppress the direct beam, measuring the spatially resolved SANS or USANS signal of samples

Figure 1: Radiography of a motorcycle engine.



① Beam shutter
② Chamber 1
③ Flight tubes
④ Chamber 2
⑤ Chamber 3
⑥ Sample space
⑦ Detector
⑧ Beam stop

Sample Environment

Standard MLZ sample environment can be used at ANTARES:

- Closed-cylce cryostats CC, CCR:
  T = 50 mK – 300 K
- Furnaces: T = 300 K – 2100 K
- Cooling water & pressurized air

Technical Data

Collimation and flux at the sample position

- L/D = 200, $4 \cdot 10^8$ n cm^{-2} s^{-1}
- L/D = 400, $1 \cdot 10^8$ n cm^{-2} s^{-1}
- L/D = 800, $2.6 \cdot 10^7$ n cm^{-2} s^{-1}
- L/D = 8000, $2.6 \cdot 10^5$ n cm^{-2} s^{-1}
- Beam size up to 35 × 35 cm^2

Neutron beam optics (optional)

- Double Crystal Monochromator:
  2.7 Å ≤ λ ≤ 6.5 Å (1 % < Δλ/λ <3 %)
- Neutron Velocity Selector:
  3.0 Å ≤ λ ≤ 8 Å (Δλ/λ = 10 %)
- Beam Filters:
  Cd filter for epithermal imaging
  Be filter to suppress wavelengths λ < 4 Å
  Sapphire filter to suppress fast neutrons

Sample table

XY-Phi-table:

- Capacity: 500 kg
- Travel: x = 800 mm, y = 600 mm
- Rotation table: 360° rotation
- additional high precision 5-axis HUBER table for small samples (< 10kg)

Detection systems

- various detection systems with spatial resolutions as good as 30 µm
- Camera box with mirror and scintillation screens of different sizes from 6 x 6 cm^2 to 40 x 40 cm^2, screen thickness from 10 µm to 200 µm, plus X-ray screens
- Standard detector: ANDOR cooled CCD camera, 2048 x 2048 pixels, 16 bit
- Intensified triggerable iStar ANDOR cooled CCD camera, 1024 x 1024 pixels, 16 bit
- Intensified NTSC video camera (30 fps) with analog frame grabber, MPEG-2 and DivX recording
- DürrDental Image Plate scanner for arbitrary imaging plates, focus size 12.5 – 100 µm
- Fuji BAS 2500 Image Plate scanner, focus size 25 – 100 µm
- X-ray and neutron imaging plates
- MAR345 image plate detector, 345 mm diameter, N-sensitive image plate

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NECTAR

radiography and tomography using fission neutrons

Description

NECTAR is a versatile facility for the non-destructive inspection of various objects by means of fission neutron radiography and tomography, respectively. The resulting images often show complementary and / or additional information compared to conventional radiography and tomography using X-rays or gamma-radiation, especially in those cases, where large and / or dense objects have to be investigated, while still requiring sensitivity to hydrogen containing materials.

Examples are trunks, glued timbers, water or oil containing (metallic) objects (e.g. gear boxes), archaeological and art historical objects, turbine blades etc.

In addition to the investigation of static objects, time resolved radiography for slow processes is possible, like water intrusion in trunks. The time resolution is actually about 10 s, but will be further reduced in the near future.

As fission neutrons can easily penetrate dense materials, nearly all sample environments available at MLZ can be attached to the instrument.

The measured radiographs are available as tiff-files and can be processed by conventional image processing software. A pre-processing can take place at the facility using a set of routines specially developed for NECTAR being continuously extended.

Typical Applications

Figure 1 shows a selection of typical objects studied at the NECTAR instrument. These are in particular massive items or those with high hydrogen content, where cold and thermal neutron radiography is not suitable.

Technical Data

Neutron source

- Converter facility at FRM II
- 2 plates of uranium-silicide (93 % ^{235}U, total 540 g), P = 80 kW

Neutron spectrum

Fission spectrum

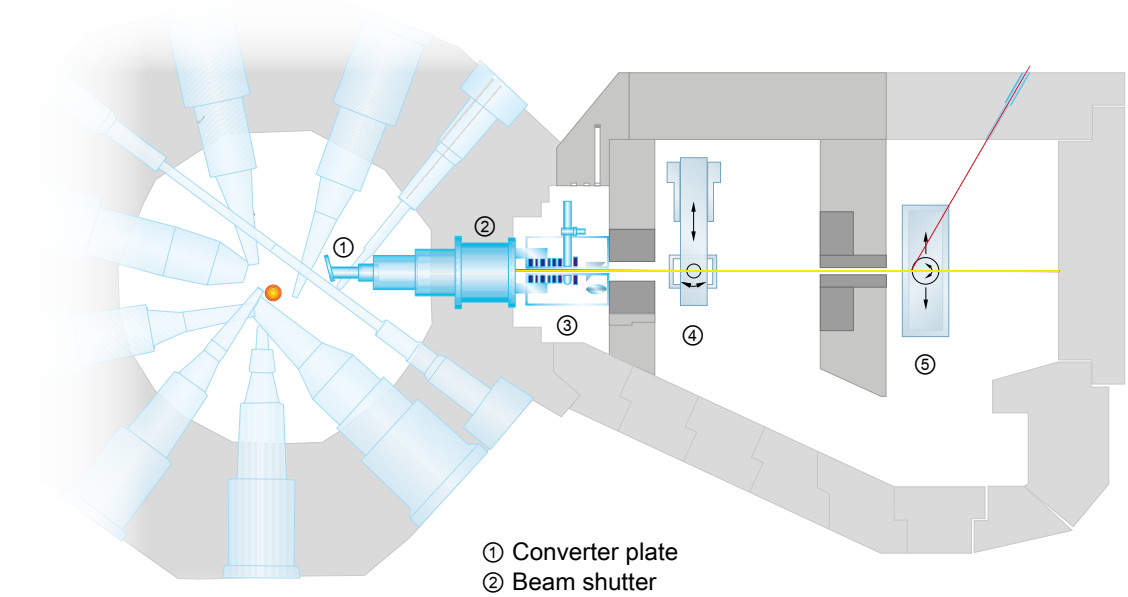
- Mean energy: 1.8 MeV
- Flux: $8.7 \cdot 10^5$ n cm^{-2} s^{-1} – $4.7 \cdot 10^7$ n cm^{-2} s^{-1} (depends on filter used)
- Best L/D: 233 ± 16 (with collimator, measured)

Sample space

Max. 80 cm × 80 cm × 80 cm
Max. 400 kg
Sample environments easily attachable (e.g. pressure cells)

Detection systems

CCD-based (ANDOR DV434-BV, pco. 1600) detection systems with different converters (e.g. pp-converter with 30 % ZnS and 30 cm x 30 cm x 0.24 cm) available



① Converter plate
② Beam shutter
③ Filters
④ Medical treatment station
⑤ Sample table NECTAR

Figure 1: Selected examples of studies performed at NECTAR.

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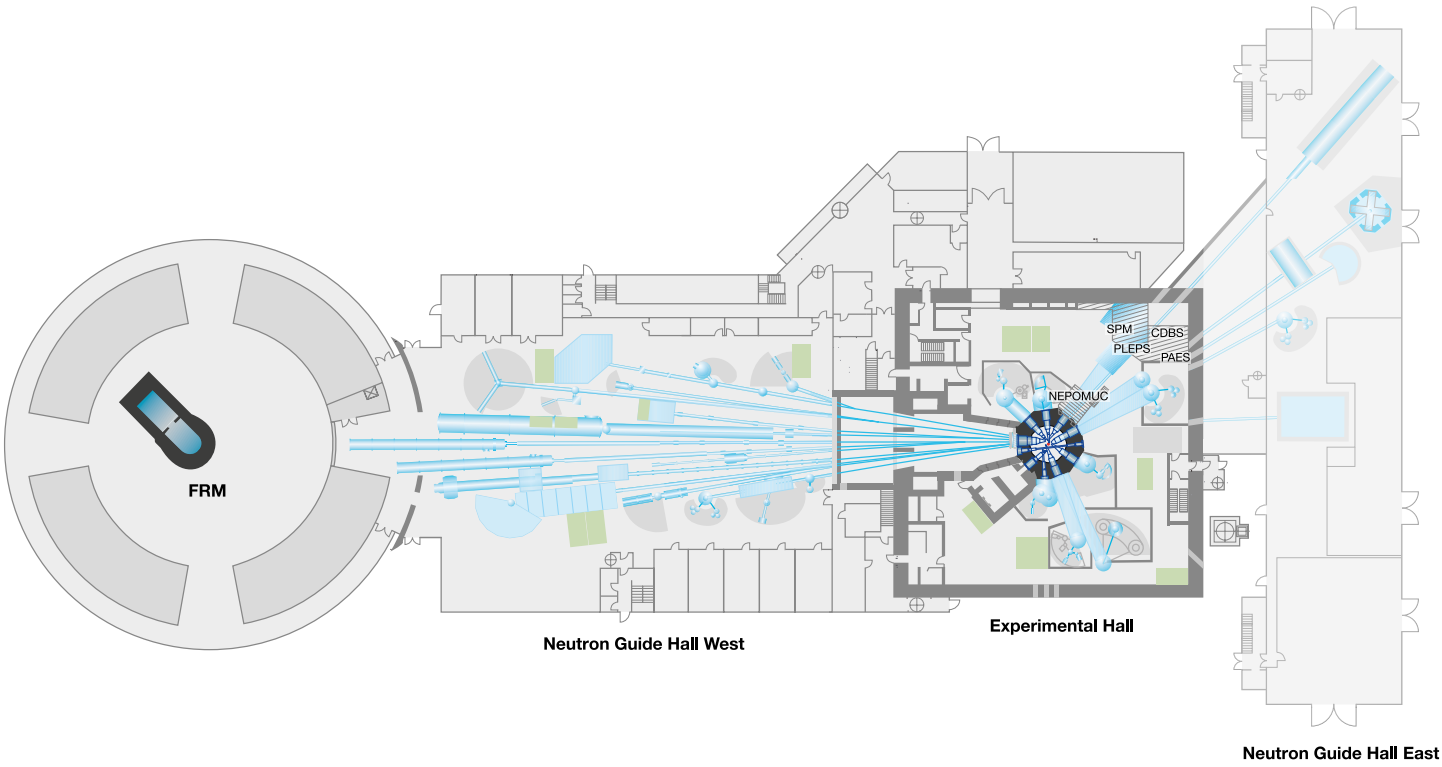
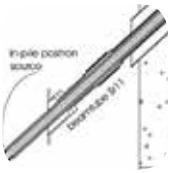
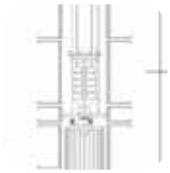
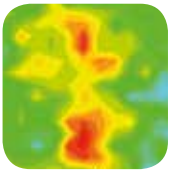




NEPOMUC
neutron induced positron source Munich



PLEPS
pulsed low energy positron system



CDBS
coincident doppler-broadening spectrometer

SPM
scanning positron microscope

PAES
positron annihilation induced auger-electron spectrometer

Positrons

NEPOMUC

neutron induced positron source Munich

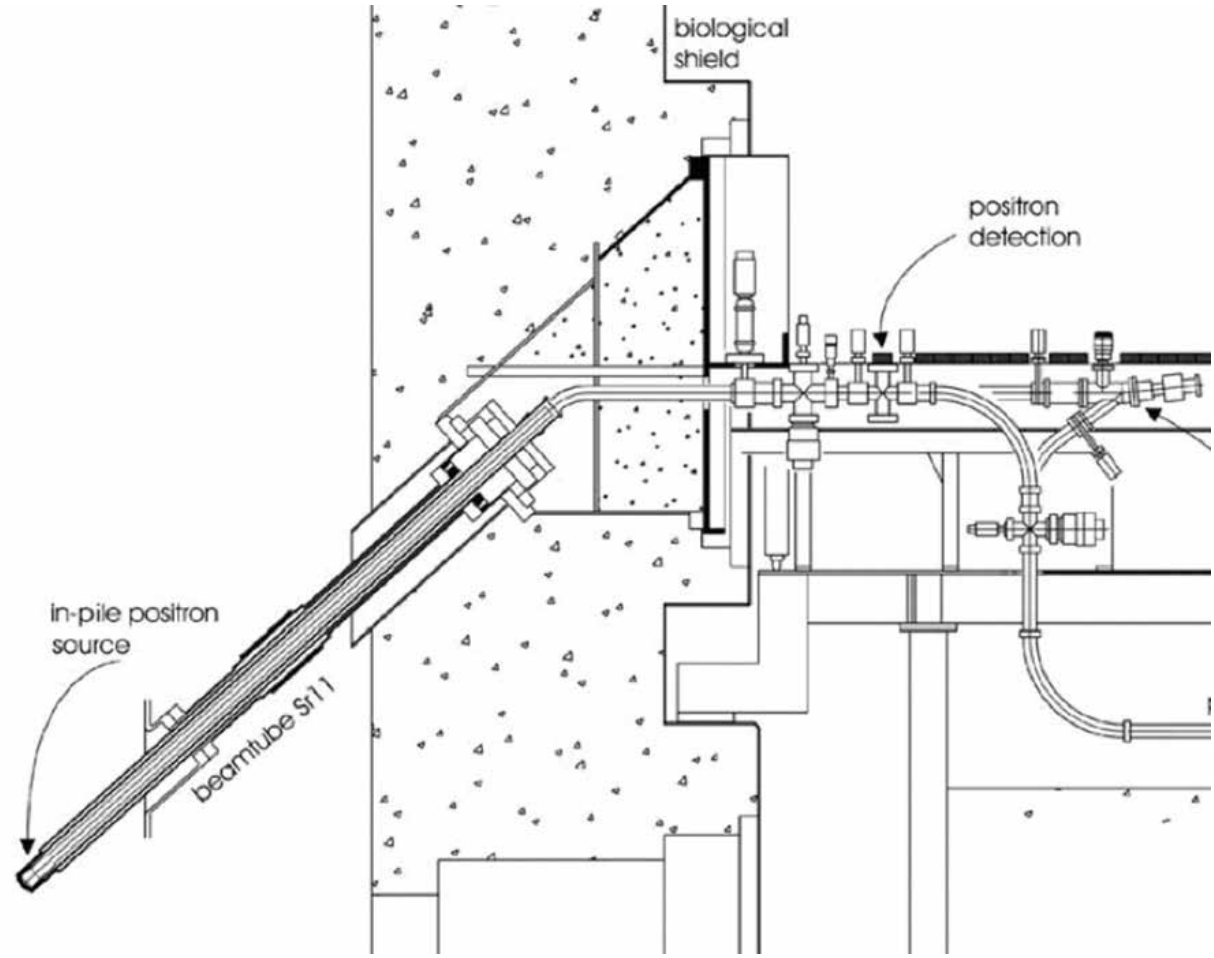


Figure 1: Cross-sectional view of the inclined beam tube SR11: the in-pile positron source is mounted inside the tip. After acceleration, the positron beam is magnetically guided to the remoderation unit outside the biological shield of the reactor.

NEPOMUC – the NEutron induced POsitron source MUniCh

NEPOMUC provides a high-intensity low-energy positron beam for applications in solid state and surface physics as well as for fundamental research in nuclear and atomic physics.
At NEPOMUC, the positrons are generated by pair production from absorption of high-energy prompt gamma-rays after thermal neutron capture in Cd. A cadmium cap is mounted inside the tip of the inclined beamtube SR11 of the research reactor FRM II. The released high-energy gamma-radiation is converted into positron–electron pairs in a structure of platinum foils which is mounted inside the cadmium cap. Positive high voltage is applied in order to extract the moderated positrons. The positron beam is magnetically guided in a solenoid field of typically 7 mT.

Technical Data

Key values of the primary positron beam

- E = 1 keV
- Intensity:
  10^9 moderated positrons per second
- Diameter of beam spot:
  7 mm (FWHM) in 7 mT beam guiding field.

The positron beam facility

The primary positron beam is guided to a positron remoderation unit, which is operated with a tungsten single crystal in back reflection geometry. This device has been implemented in order to improve the beam brightness.
Via a beam switch the positron beam can be guided to 5 different experimental beam ports.
At present, three instruments are in routin operation:

- Pulsed low-energy positron system (PLEPS)
- Coincident Doppler-broadening spectrometer (CDBS)
- Positron annihilation induced Auger-electron spectrometer (PAES)

An interface containing pulsing and remoderation units is currently installed for the:

- Scanning Positron Microscope (SPM)
- Open Port

The multi-purpose open beamport is used for transportable short-term experimental setups. At present, an apparatus for the production of the negatively charged positronium ion is connected to the beamline.

Technical Data

Key values of the remoderated positron beam

- E = 20 eV
- Intensity:
  $5 \cdot 10^7$ remoderated positrons per second
- Diameter of beam spot:
  2-3 mm (FWHM) in 7 mT beam guiding field

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CDBS

coincident Doppler-broadening spectrometer

Description

The Doppler broadening of the 511 keV annihilation line contains information of the electron momentum distribution at the positron annihilation site in the sample. Since the probability of core electron annihilation decreases in open volume defects a narrowing of the annihilation line is observed.
For this reason, DBS with the monoenergetic positron beam allows to determine defect profiles, energy dependent 2D imaging of defects, and defect annealing as a function of temperature. In addition CDBS is applied in order to gain elemental information about the positron annihilation site and hence about the chemical surrounding of defects.

Technical Data

Beam properties

- Positron implantation energy: E = 0.2 – 30 keV
- Mean positron Implantation depth: up to several µm (material dependent)
- Beam size: adjustable between 0.3 – 3 mm Ø

2D x-y-scans

- scan area: 20 × 20 mm²
- step size adjustable between 0.1 and 10 mm

High-purity Ge detectors

- 30 % efficiency
- energy resolution: 1.4 keV at 477.6 keV

Sample

- size up to 20 × 20 × 3 mm³
- optimum 4 samples at one sample holder: < 10 × 10 mm²
- Temperature: 100 K – 900 K

Typical measurement times

- ~ 1 – 2 min / spectrum
- ~ 8 h full 2D overview scan (with Δx = Δy = 1 mm)
- ~1 h depth profile (t = 2 min, 30 energy values)
- ~ 4 – 6 h/spectrum CDBS

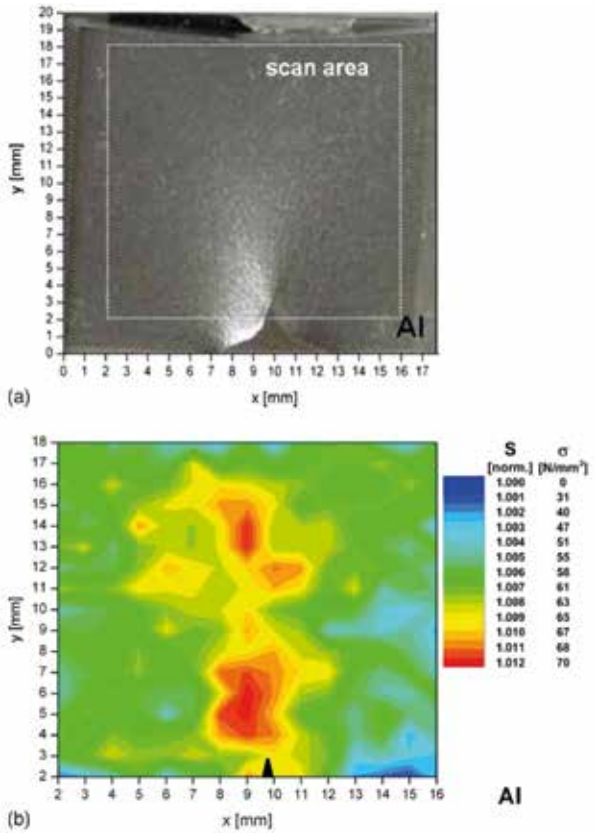

Figure 1: 2D defect map of an plastically deformed Al sample (below) and optical image (above).

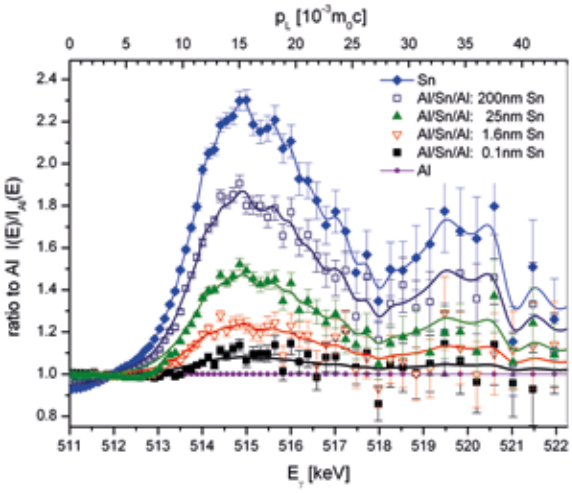

Figure 2: Thin Sn layers of various thickness buried in an Al matrix: Ratio curves recorded with CDBS reveal the elemental signature of layered samples.

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PAES

positron annihilation induced Auger-electron spectrometer

Description

PAES is a newly developed application for surface studies with high elemental selectivity and exceptional surface sensitivity. In PAES the emission of Auger electrons is initiated by positron-electron annihilation that leads to several major advantages, e.g. topmost layer sensitivity, compared with conventional electron induced AES.
Examples are surfaces with sub-monolayers of foreign atoms, high resolution determination of Auger line shapes, element selective surface studies.

Technical Data

Beam properties

- Positron Implantation Energy: 20 eV
- Electron energy resolution: $\Delta E/E < 1$ %

Sample

- Sample size: 20 x 30 mm^2 (minimum size 10 x10 mm^2)
- Sample thickness: max. 3 mm

Typical measurement times

- Measurement time (typically): 10 - 15 min

Complementary techniques

- Conventional Electron induced AES
- XPS/XAES and STM

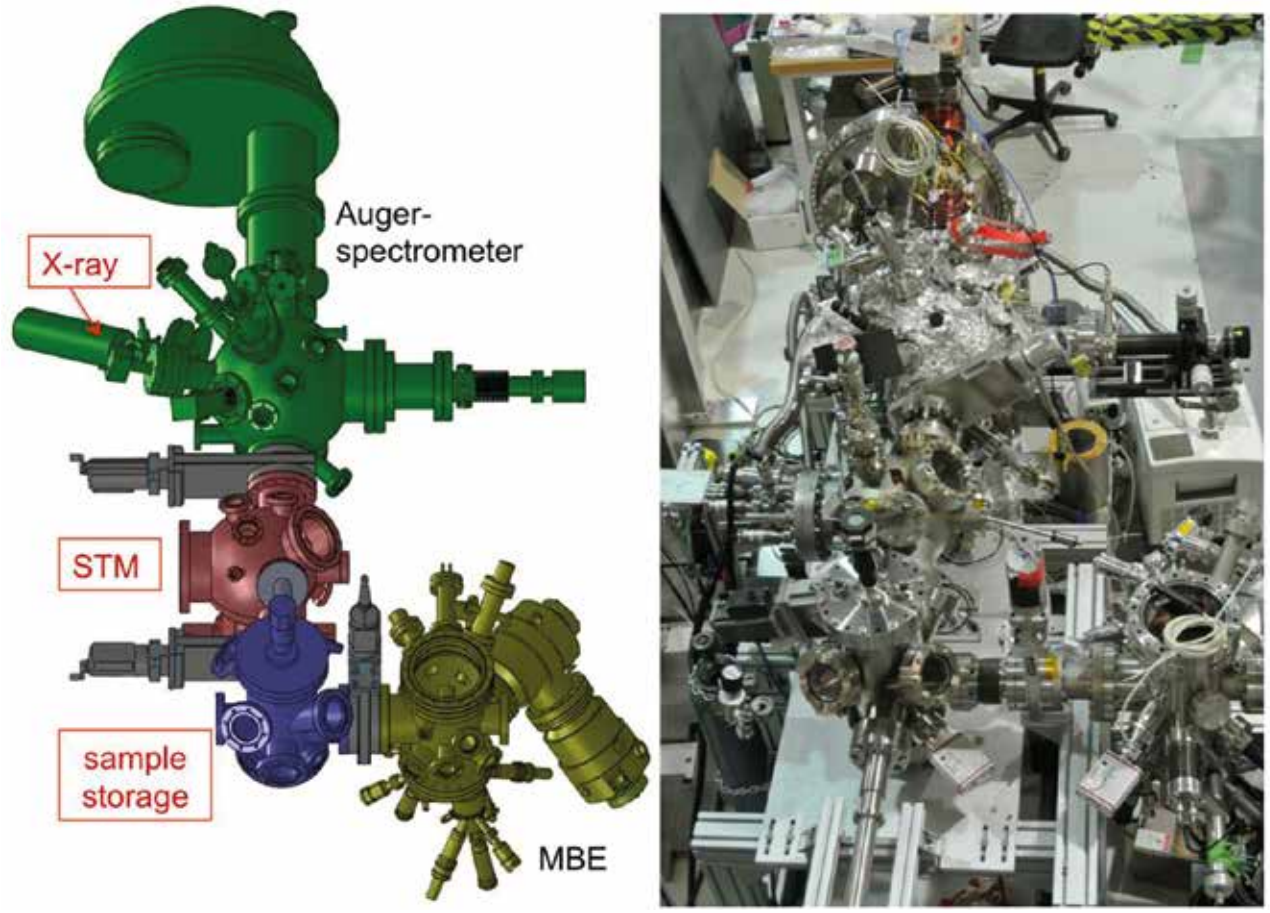

Figure 1: The Auger-spectrometer with STM, sample preparation chamber and lock.

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PLEPS

pulsed low energy positron system

Description

Positron lifetime measurements allow to determine defect size and concentration in metals, insulators and semiconductors as well as the free volume in polymers. Main application of PLEPS at NEPOMUC is the study of defect profiles in thin films and thin polymers.
Recently, first age-momentum correlation measurements (AMoC) were performed.

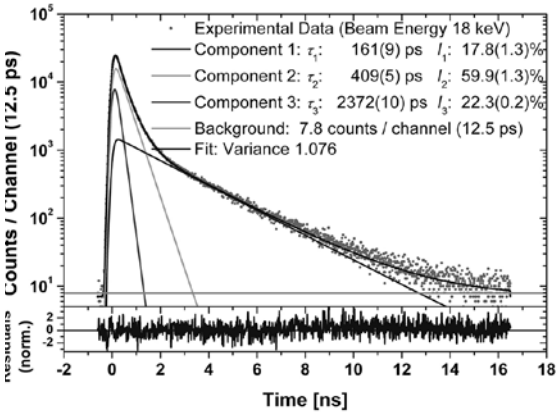

Figure 1: Typical positron lifetime spectrum in an epoxy-based industrial adhesive. The positron implantation energy was 18 keV according to a mean implantation depth of 4 µm. The spectrum can be decomposed into three exponentials with three different lifetimes. From the longest lifetime of 2.3 ns the mean size of free volume cavities in the polymer is estimated to be 0.13 nm³.

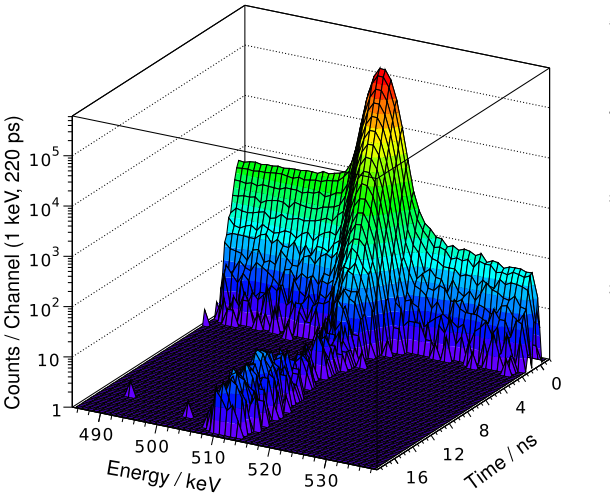

Figure 2: Age-Momentum Correlated (AMoC) spectrum in Kapton measured with a BaF_2 scintillation detector and a HP-Ge detector in coincidence. AMoC measurements contain information about the type of defect and its chemical environment, thus giving a more complete picture of the annihilation site than lifetime measurements and Doppler broadening measurements alone.

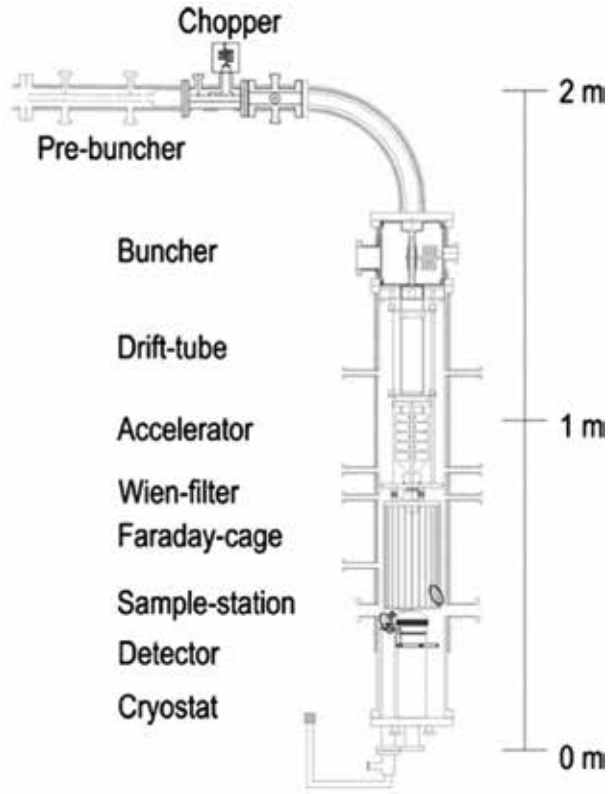

Figure 3: The components of PLEPS.

Technical Data

Beam properties

- Positron implantation energy: 0.5 – 20 keV
- Beam-Spot Ø 2 – 3 mm
- Count rate: ~ 5000 – 10000 cps

Sample

- limited to 7 × 7 mm² – 9 × 9 mm²

Typical measurement times

- < 10 min per spectrum
  (> 3 · 10⁶ counts in the spectrum)
- Depth-profile: 4 – 5 h
  (15 – 20 implantation energies, > 3 · 10⁶ counts in the spectrum)
- Time-window: 20 ns, extension to longer time windows planned
- Time-resolution: 260 – 280 ps
- Peak / Background ~ 10000 : 1

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der Bundeswehr Universität München

SPM

scanning positron microscope

Description

The Munich scanning positron microscope (SPM) is presently operated at the Universität der Bundeswehr München. It permits positron lifetime measurements with a lateral resolution in the µm range and within an energy range of 1-20 keV. Thus, this instrument enables the measurement of high resolved 3D defect maps. One practical limitation of the SPM is set by the long measurement times of several days per 2D-scan due to the low intensity of the positron beam produced by a standard ^{22}Na source. This disadvantage will be overcome by installing the SPM at the high intensity positron beam at NEPOMUC.
Therefore, an interface was designed and tested successfully (see figures). This device converts the continuous beam of NEPOMUC to a high-brightness, pulsed positron beam, which matches the demands of the SPM. Recently, a triply moderated positron beam was generated. Currently, a beam "elevator" unit is under construction in order to connect the optical column of the SPM with the interface.

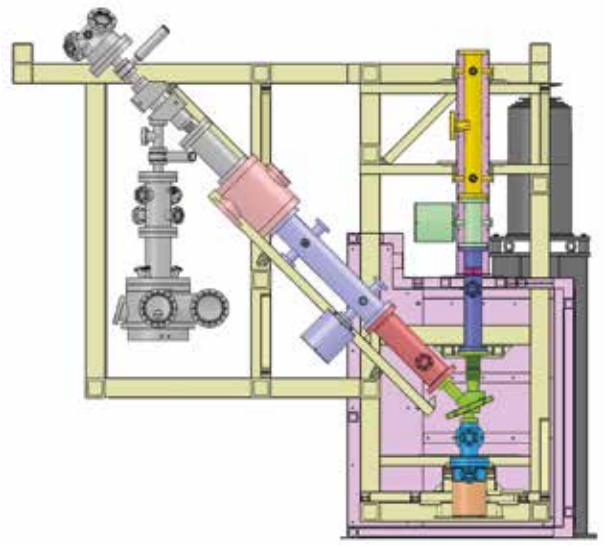

Figure 2: The optical column of the SPM (light gray) connected to the SPM interface. Both is borne by a special frame construction (light yellow), which ensures the vibration decoupling via heavy damper (dark gray, only one shown).

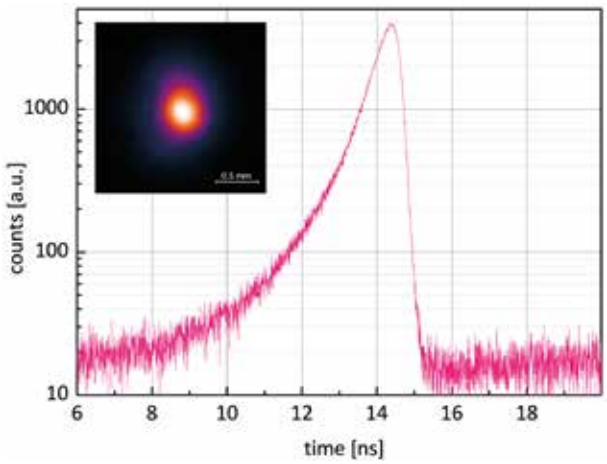

Figure 1: Time spectrum of the threefold bunched and triply moderated positron beam.
Insert: intensity distribution of the beam focused by a long focal electric lens.

Technical Data

Beam properties

- Positron implantation energy: < 20 keV
- Beam-Spot < 1 µm
- Count rate: > 2000 cps
- Time-Window: 20 ns
- Time-Resolution: < 250 ps
- Peak / Background > 5000 : 1

Typical measurement times

- ~ 1 day for one 2D-Scan (12 x 12 µm^2)

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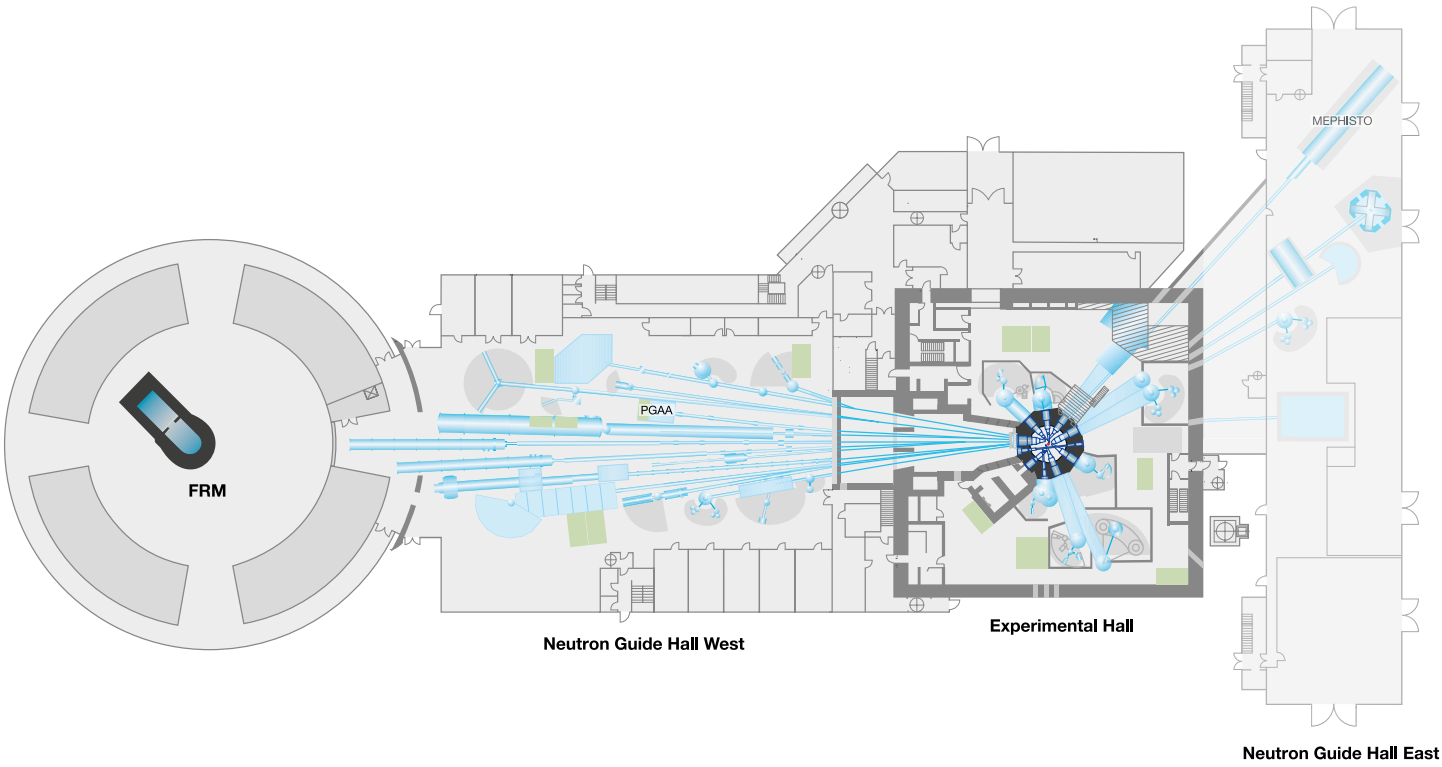


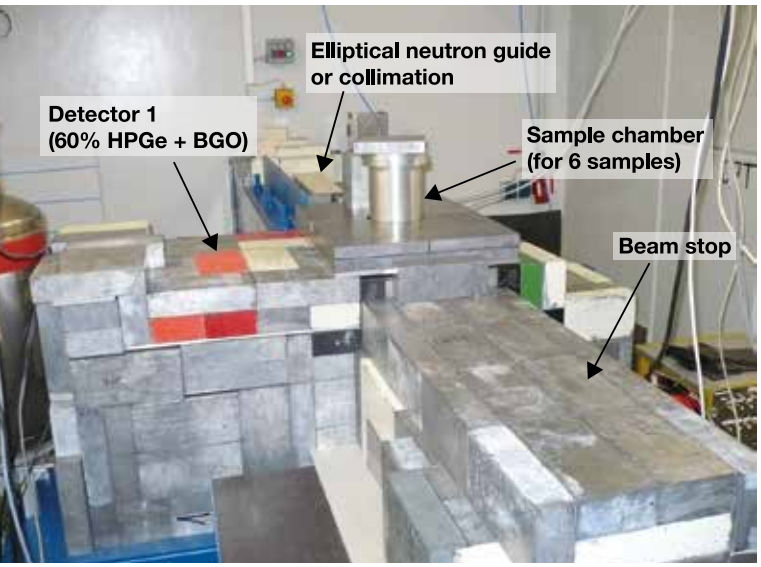
PGAA
prompt gamma activation analysis

MEPHISTO
facility for particle physics with cold neutrons

Nuclear and Particle Physics

PGAA

prompt gamma activation analysis



Description

Prompt Gamma-Ray Activation Analysis (PGAA) is typically used for the determination of elemental composition and concentration of solid samples (ca. down to ppm range). Liquids and gaseous samples can be also measured.

The PGAA method is based on the neutron capture in nuclei of the sample material and the subsequent detection of prompt gamma-rays emitted during deexcitation of the compound nuclei: $^{A}Z(n, \gamma)^{A+1}Z$.

With practically the same PGAA set-up (after minor or major changes in electronics or/and shielding and sample chamber), we can make coincidence measurements and position sensitive measurements (currently 1D or 2D scan). The 3D scanning, so called NT-PGAI (Neutron Tomography driven Prompt Gamma Activation Imaging) is currently under construction.

Typical Applications

- Archaeology and cultural heritage objects (ceramics, coins, metals, conditionally bronze objects)
- Cosmochemistry (meteorites)
- Geology, petrology (macerals, sediments)
- Enviromental research (air pollution, river pollution)
- Medicine (B, Li, Cd in tissues, nano-particles for cancer therapy, radiation damage of DNA)
- Semiconductor or superconductor research and industry
- Analysis of new chemical materials (catalysts, clathrates, crystals)
- Reactor physics (shielding material, new fuel element), radiation hardness testing with cold neutrons (chips, scintillators)
- Fundamental research (nuclear data, low-spin excited states in nuclei, partial and total neutron capture cross-section measurements)
- conditionally NAA after the PGAA irradiation

Figure 1: Six pieces of Greco Roman bronze coins and objects (1st century AC) sealed into FEP foils and mounted at the FEP ladder for the automated PGAA measurement (one FEP frame is 5 cm × 5 cm large).

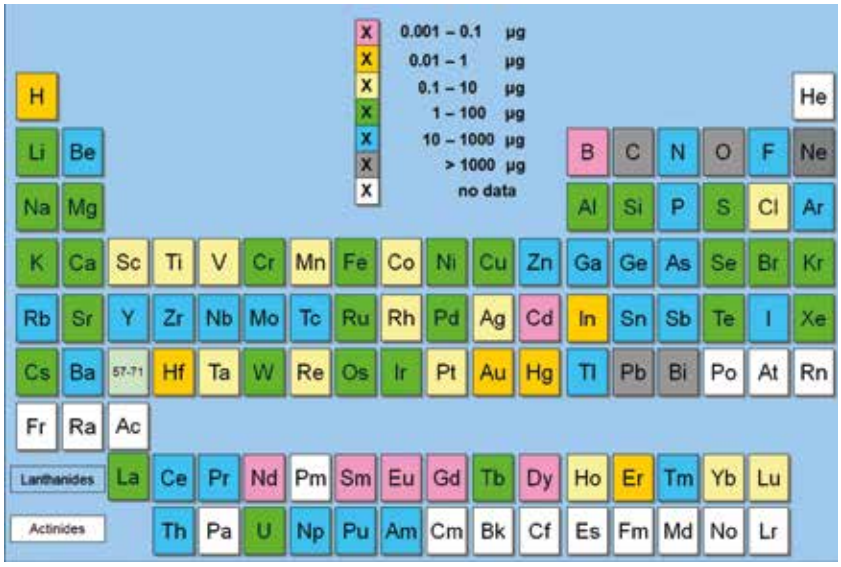
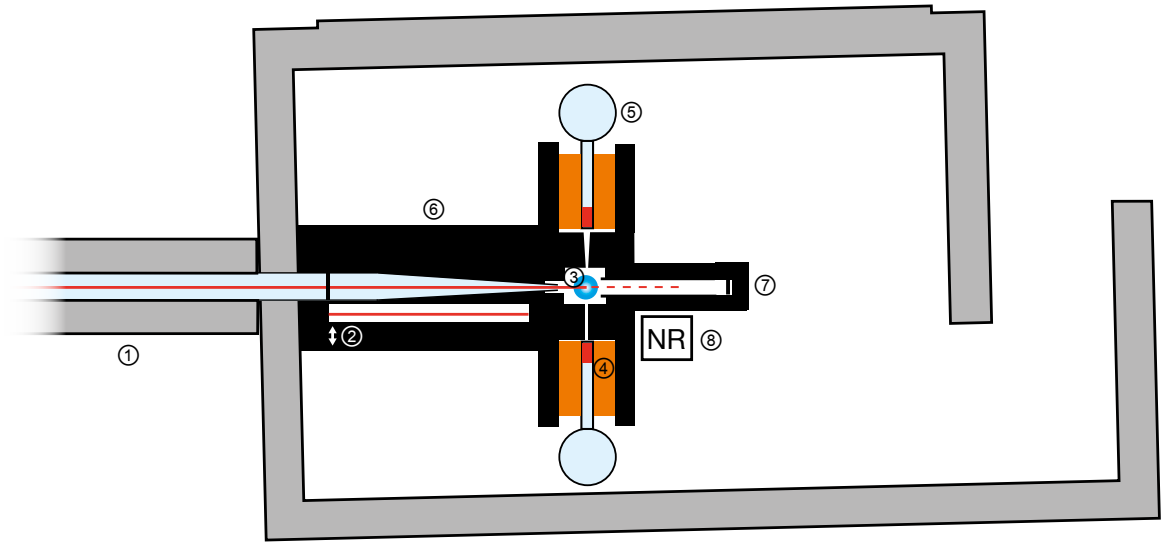


Table 1: This table gives the first estimate for the detection limits of the PGAA technique. The detection limits are mostly located in the µg/g region and they are strongly dependent on the matrix of the sample material (detection limits with dynamic range).

Universität zu Köln

PAUL SCHERRER INSTITUT PSI



① Neutron guide NL4b
② Optional elliptical focussing guide or beam collimation
③ Sample space
④ Detector D1 (HPGe 60%)
⑤ Detector D2 optional (HPGe 30%) for PGAI
⑥ Pb shielding
⑦ Beam stop
⑧ Neutron Radiography (optional)

Technical Data

Neutron beam

Cold neutron spectrum from NL4b (last section of 5.8 m elliptical focussing) with an average energy of 1.83 meV (6.7 Å).
Two measuring conditions:

- for large samples with collimation:
  Beam size: 20 x 30 mm^2
  Neutron flux max.: $2 \cdot 10^9$ n cm^{-2} s^{-1} thermal n. eq.
- for small samples with 1.1 m elliptical guide:
  Beam size: 11 x 16 mm^2
  Neutron flux max.: $5 \cdot 10^{10}$ n cm^{-2} s^{-1} thermal n. eq.

Detection system

For the standard PGAA, one Compton-suppressed spectrometer is used (60 % HPGe detector surrounded with a BGO scintillator and connected in anticoincidence mode). The signal is processed through an analogue electronics (NIM modules) followed by a multichannel analyzer with integrated ADC. A new digital system DPEC-50 is being prepared for operation and will be used routinely soon.
The position 5 on the drawing is an experimenting area for exchangeable set-ups, e.g. for the PGAI detection system (30 % HPGe Detector with BGO scintillator in anticoincidence mode, DSPEC-50 data acquisition).
Detection range is typically of 80 keV – 11 000 keV and can be adjusted
for special purposes.

Measuring conditions

- Low vacuum (0.3 mbar) possible
- Sample weight: units of mg – g
- Max. sample dimensions:
  ca. 40 × 40 x 40 mm^3
- Automated measurement for max. 6 samples in a batch (vertical sample holder with 6 positions)
  Solid samples are usually sealed into thin FEP bags or other suitable material.

Data acquisition and analysis

- Linux based self developed software for the automated measurement of up to 6 samples in a batch run.
- Evaluation of the spectra and the calibration of the spectrometer (efficiency curve and non-linearity) using the software Hypermet PC developed in Budapest.
- Determination of the elemental composition of samples using the Excel macro and Excel sheet package ProSpeRo.
- Automated data acquisition using DSPEC-50 is currently under development.

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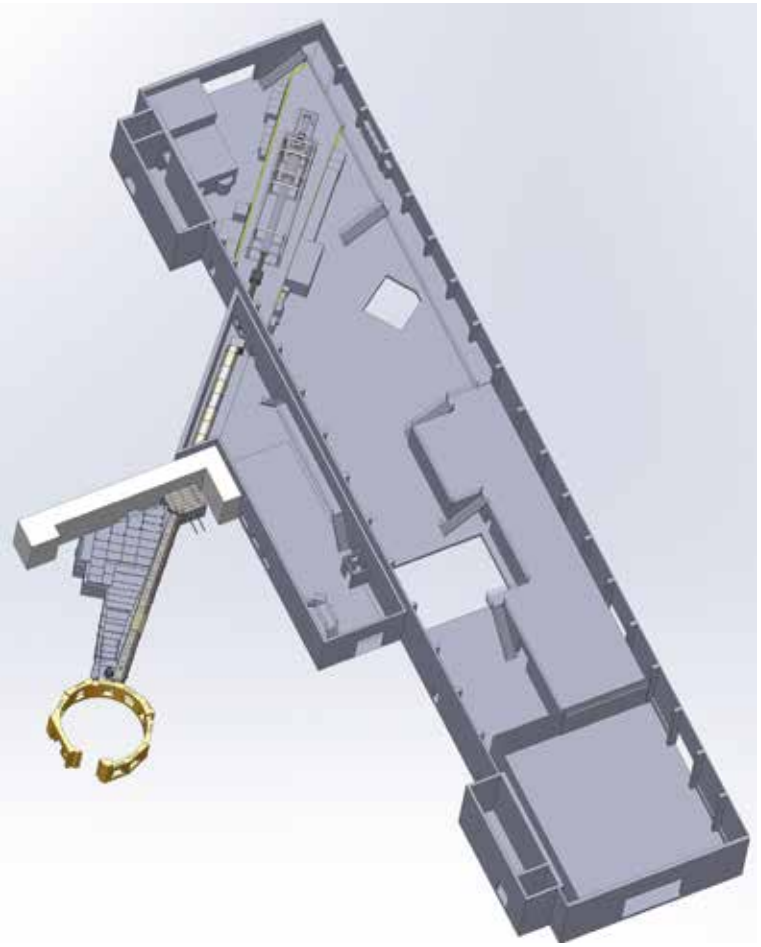
MEPHISTO

facility for particle physics with cold neutrons



Since the start of reactor the FRM II provides a cold white neutron beam for long term user dedicated experimental setups.

Such an experiment is normally planned and built up by an external group. The FRM II offers additional help during the commissioning of the experiment at the reactor. This work must be organised in close contact with the local instrument scientist. The desired precision is reached inter alia by good statistics which means long term experiments about several reactor periods.

The experimental area MEPHISTO, the measurement facility for particle physics with cold neutrons, is dedicated to these experiments in the field of nuclear and particle physics. Currently the experimental area moves from the Neutron Guide Hall West to the Neutron Guide Hall East. The solely used neutron guide SR4b will deliver a white cold spectrum for experiments. A removeable 11 % velocity selector at the end of the guide completes the beam line. The MC-simulation for this beam with a dimension of 60 x 106 mm^2 propose a mean wavelength 4.5 Å and a gold capture flux of $2 \cdot 10^{10}$ n $cm^{-1}s^{-1}$. The experimental area is 5 x 25 m^2, diagonal in the east neutron guide.

It is planned to install the instrument PERC [1] at the MEPHISTO beam line during the first years of operation. This instrument is a precise, bright and intense source of protons and electrons from the neutron decay. The instrument PERC itself is open for external user groups with spectrometers to measure the protons and electrons.

[1] D. Dubbers et al., Nucl.Instr.Meth. A, 596, 238-247, (2008).

Typical Applications

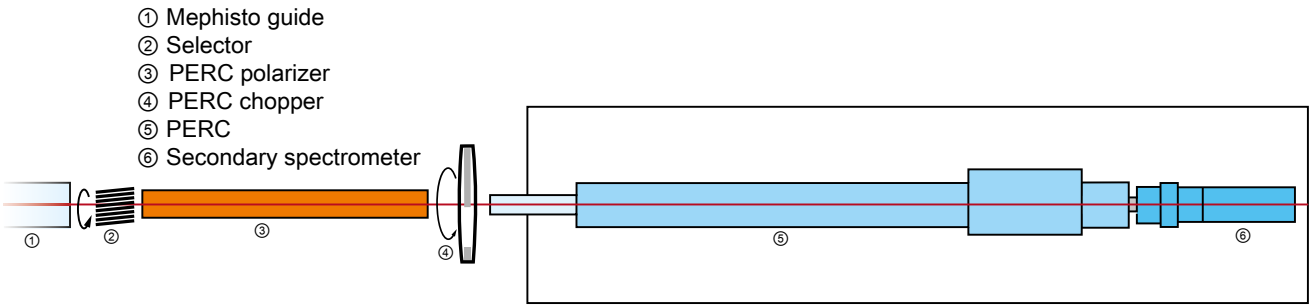
The experiments at MEPHISTO concentrate on induced nuclear reactions of the neutron with atoms or on the free neutron decay with its products.

Some of the experiment types performed at MEPHISTO:

- Free neutron decay and spectroscopy of the decay products
- Spectroscopy of neutron induced fission
- Production of ultra cold neutrons with liquid helium
- Production of ultra cold neutrons with solid gases

Infrastructure

A removeable neutron velocity selector is placed at the end of the neutron guide. The minimal wavelength is 4.5 Å. The resolution of the passing wavelength is 11 %. The selector can be rotated to tune the resolution.
A data system based on VME (ADC, peak ADC, QDC, TDC) is available. For signal forming purpose several NIM inserts exist, a list can be requested from the local instrument scientist. Also available are spectroscopic amplifiers and high voltage sources for detectors.



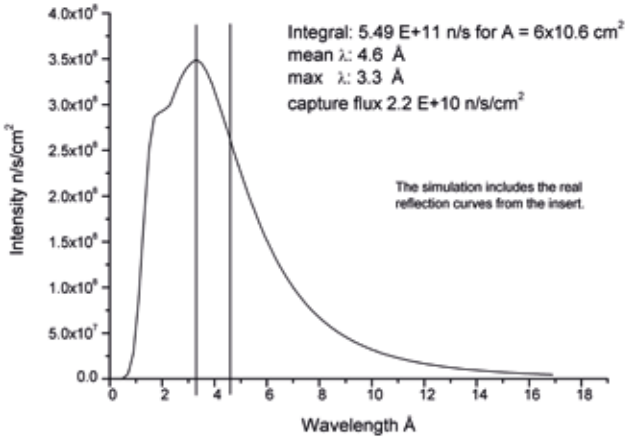


Figure 1: Simulated cold neutron spectrum of the SR4b at the MEPHISTO facility in Neutron Guide Hall East.

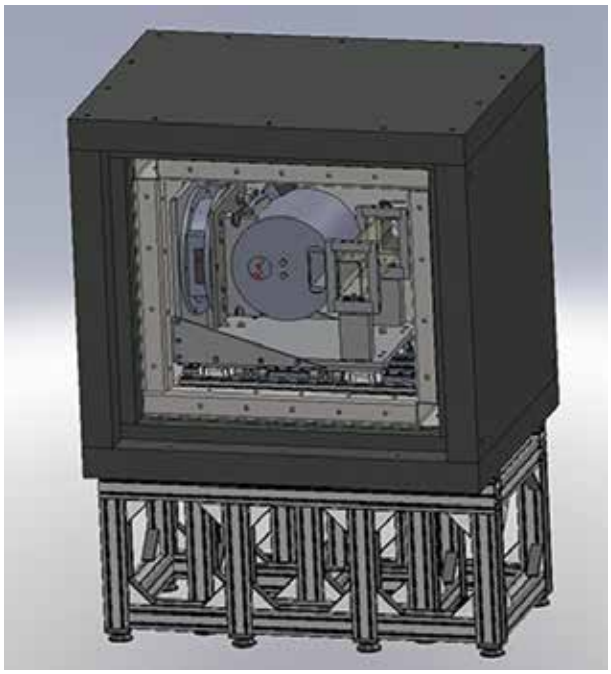


Figure 2: Cutaway view of the removable neutron velocity selector at the end of the MEPHISTO guide.

Technical Data

Neutron beam

- End of the cold neutron guide SR4b (m = 2.5)
- Cross section of the guide: 60 x 106 mm²
- Thermal capture flux (simulated): $2 \cdot 10^{10}$ n $cm^{-1}s^{-1}$
- Mean wavelength (simulated): 4.5 Å
- Beam height from floor: ~ 1300 mm
- Experimental area: 5 x 25 m²

Beam attenuators

By geometrical attenuation, the beam intensity can by reduced to 20 %, 4 % and 2 %.

Polarization

A bender (vertical direction) is available to polarize the complete cross section of the beam.

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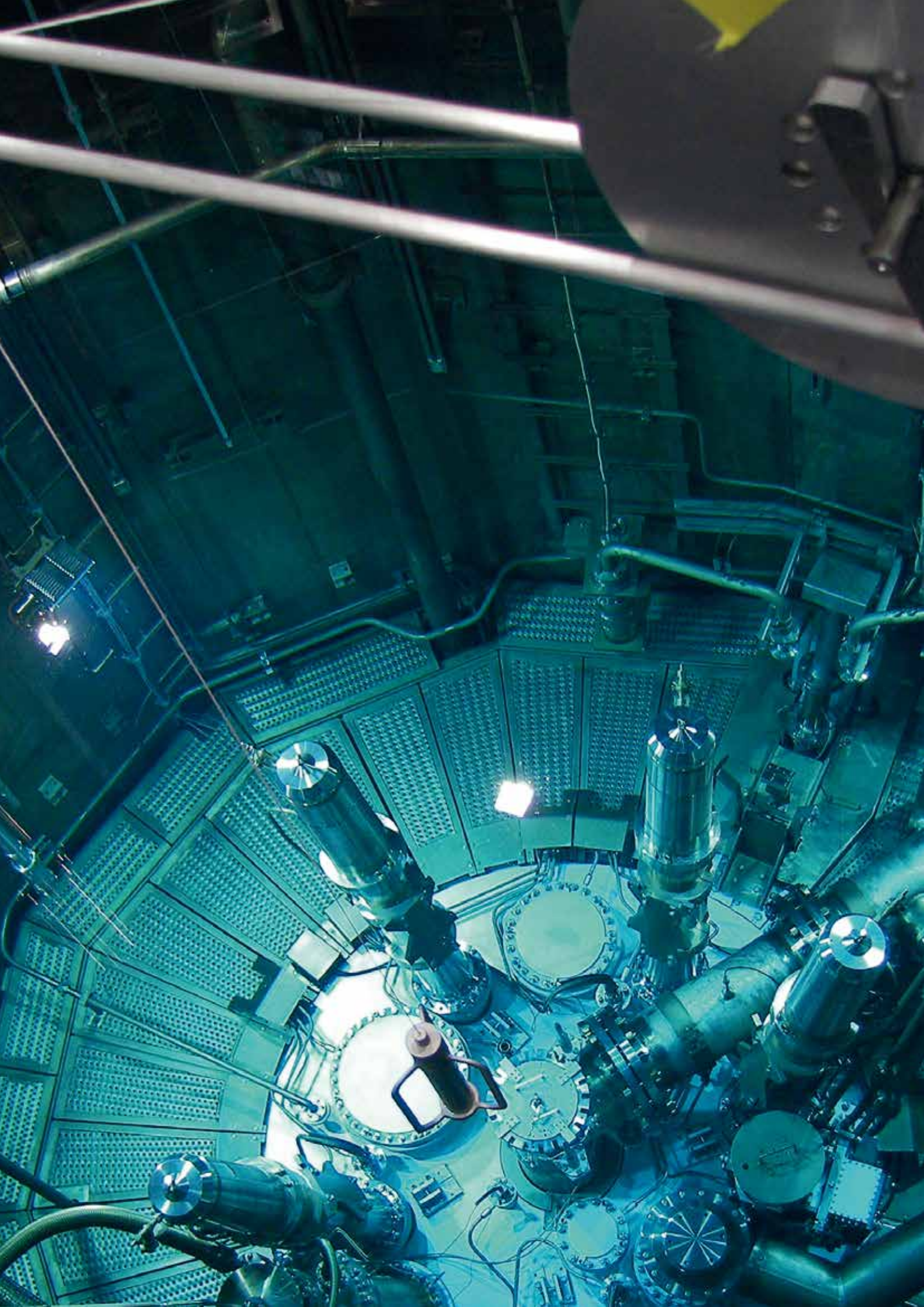

Irradiation facilities

Irradiation facilities

The irradiation of materials serves many purposes including the doping of silicon and the production of radioisotopes for industry and medicine, as well as the examination of samples with neutron activation analysis.

The neutron source FRM II is equipped with a number of irradiation facilities, which cover a wide range of applications both with regard to the available sample volumes and the achievable neutron fluences.

For proposals and experiments dealing with the irradiation facilities please contact directly the responible of the irradiation services Dr. Heiko Gerstenberg.

Standard rabbit irradiation system (RPA)

Six independent irradiation channels are available within the standard rabbit irradiation system. The positions are vertically staggered in the moderator tank, allowing for the selection of a thermal neutron flux density adapted to the sample. The neutron flux densities range from $5 \cdot 10^{12}$ to $7 \cdot 10^{13}$ $cm^{-2}s^{-1}$. Sample sizes should be less than 8 cm^3. The samples are packed in polyethylene capsules and conveyed pneumatically by CO_2 into the irradiation position. The available thermal neutron fluence varies between $2 \cdot 10^{14}$ cm^{-2} and $3 \cdot 10^{17}$ cm^{-2}. For the various irradiation channels the ratio of thermal/fast neutron flux density is as high as 15000 – 60000.

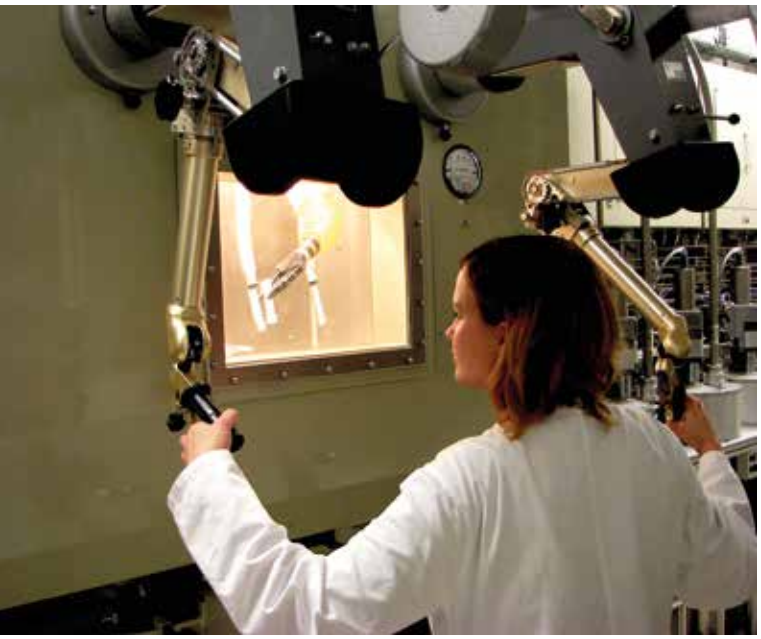

Figure 1: After irradiation in the rabbit system, the samples are prepared via manipulators to be sent to the customers.

Capsule irradiation facility (KBA)

High dose irradiation spanning periods from several hours to weeks, is carried out in the capsule irradiation facility. It is a pool water-operated hydraulic rabbit system with two mainly identical irradiation channels exhibiting thermal neutron flux densities of up to 1.3 · 1014 cm-2s-1. The samples are packed in aluminium capsules with a volume of up to 20 cm3. If required, the samples are additionally packed water tight in an inner capsule from high purity aluminium or quartz. Max. three capsules may be irradiated simultaneously in each channel. The ratio of thermal/fast neutron flux density ranges between 330 and 770.

Mechanical irradiation system

Samples sized up to 120 cm^3 can be irradiated in a facility in the moderator tank. In spite of the available sample size of 2.5 l the facility is typically used for short term irradiations of smaller samples. The thermal neutron flux density is $1.1 \cdot 10^{13}$ cm^{-2} s^{-1}. The maximum licensed irradiation time is 2 h corresponding to a thermal neutron fluence of $8 \cdot 10^{16}$ cm^{-2}.

Irradiation position in control rod

The highest possible fluence of $1.1 \cdot 10^{21}$ cm^{-2} can be reached at the irradiation position within the control rod. It is only possible, however, to load and unload it when the reactor is shut down, after the completion of its 60-day cycle.

Gamma-ray irradiation facility

In order to use the very strong gamma radiation within the spent fuel elements, a gamma-ray irradiation facility has been built. Its installation was supported by the German Research Association (Deutsche Forschungsgemeinschaft: DFG). It is located in the storage rack of spent fuel elements. The typical gamma dose rate ranges from 1 kGy/h up to 100 kGy/h. The sample container has a diameter of 76 mm and a height of approximately 1 metre. Additionally, the sample position can be heated up to 140 °C, if required. The irradiation time can vary between several minutes to several weeks.

Figure 2: The standard rabbit irradiation system has six independent irradiation channels and is operated by carbon-dioxide.

Irradiation possibilities at beam tube SR10

The beam tube SR10 can deliver very different beam qualities: A pair of uranium converter plates generates an unmoderated fission spectrum with mean energy of 1.9 MeV and accompanying prompt and delayed photons. The main applications are medical applications (MEDAPP), i. e. fast reactor neutron therapy and a further one is radiography and tomography (NECTAR). When the converter plates are withdrawn from the beam tube, SR10 provides a beam of thermal neutrons.

- Fast reactor neutrons (uranium converter): A horizontal beam of fission radiation with an area up to 40 x 30 cm^2 can be used to test the radiation hardness of technical objects, and for biological research with hadrons. The ratio of neutron to gamma dose can be varied within a wide range by filters of lead and PE. The fast neutron flux of the unfiltered beam is about $7 \cdot 10^8$ $s^{-1}cm^{-2}$.
- Thermal neutrons (without converter): Objects can be irradiated at the lid of beam tube SR10 with a thermal beam of high purity and an area of 23 x 18 cm^2. The flux is about $3.9 \cdot 10^9$ $s^{-1}cm^{-2}$. This irradiation site is useful if the flux of the near-core irradiation sites is too high or if larger objects have to be irradiated, like etch track foils or objects up to 2 l volume.
- 140-keV neutron beam: A beam with main energy of 140 keV can be generated by help of a very thick silicon filter.

Technical Data

Standard rabbit irradiation system

- $5 \cdot 10^{12}$ to $7 \cdot 10^{13}$ thermal neutrons $cm^{-2}s^{-1}$
- ϕ_{th} / ϕ_f: 15000 – 60000

Capsule irradiation facility

- up to $1.3 \cdot 10^{14}$ thermal neutrons $cm^{-2}s^{-1}$
- ϕ_{th} / ϕ_f: 330 – 770

Mechanical irradiation system

- $1.1 \cdot 10^{13}$ thermal neutrons $cm^{-2}s^{-1}$
- ϕ_{th} / ϕ_f: ~770

Gamma ray irradiation facility

1 kGy/h up to 100 kGy/h

Irradiation position in the control rod

- $2 \cdot 10^{14}$ thermal neutrons $cm^{-2}s^{-1}$
- $2 \cdot 10^{14}$ fast neutrons $cm^{-2}s^{-1}$

Irradiation with fast neutrons at SR10

up to $7 \cdot 10^8$ fast neutrons $cm^{-2}s^{-1}$

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Irradiation facilities

Figure 1: A silicon crystal after the doping at the FRM II neutron source.

Silicon doping facility

Pure silicon is a poor conductor of electricity. In order to gain the properties which make it interesting for components in the electro-technique, it needs to be doped with small amounts of host atoms e.g. phosphorous or boron. For high-performance electronic components as thyristors or IGBTs the Si needs to have a defined content of phosphorous atoms distributed extremely homogeneously within the Si matrix. At the FRM II silicon ingots (see figure 1) up to a diameter of 200 mm and a height up to 500 mm are irradiated in a position within the moderator tank. The doping is achieved by neutron capture and the resulting conversion of individual ^{30}Si atoms into ^{31}P. Due to the neutron moderation by heavy water the facility is particularly useful for the production of high resistivity (up to 1000 Ωcm) neutron transmutation doped (NTD) Si. The semi-automatic silicon doping facility is operated in two working shifts. The typical yearly output sums up to about 15 tons. The customers of the doped ingots are semiconductor producers from Europe and Asia.

Neutron activation analysis

Neutron activation analysis (NAA) is used for determining the concentration of particular elements in matrix materials (see fig. 2). Up to 30 or 40 trace elements can be determined simultaneously down to the ppt and sub-ppt range.

Industrial applications:

- Trace elements in pure material (silicon, graphite, water etc.)
- Determination of impurities in products of the metal or chemistry industry

Figure 2: The NAA analysis includes the treatment of the materials after irradiation.

Applications in archeology, geology, biology and medicine:

- Fingerprint of materials gives clues about the origin of the findings
- Determination of trace elements in geological and biological samples
- Determination of trace elements in protein, blood, urine etc.

Radioisotopes for medical and technical applications

Production of radioisotopes in the different facilities (e.g. KBA, RPA, fig. 3)

- ^{177}Lu, which is used for the therapy of neuroendocrine tumours (see fig. 4)
- ^{188}Re preventing local occlusions of blood vessels
- ^{60}Co for industrial purposes

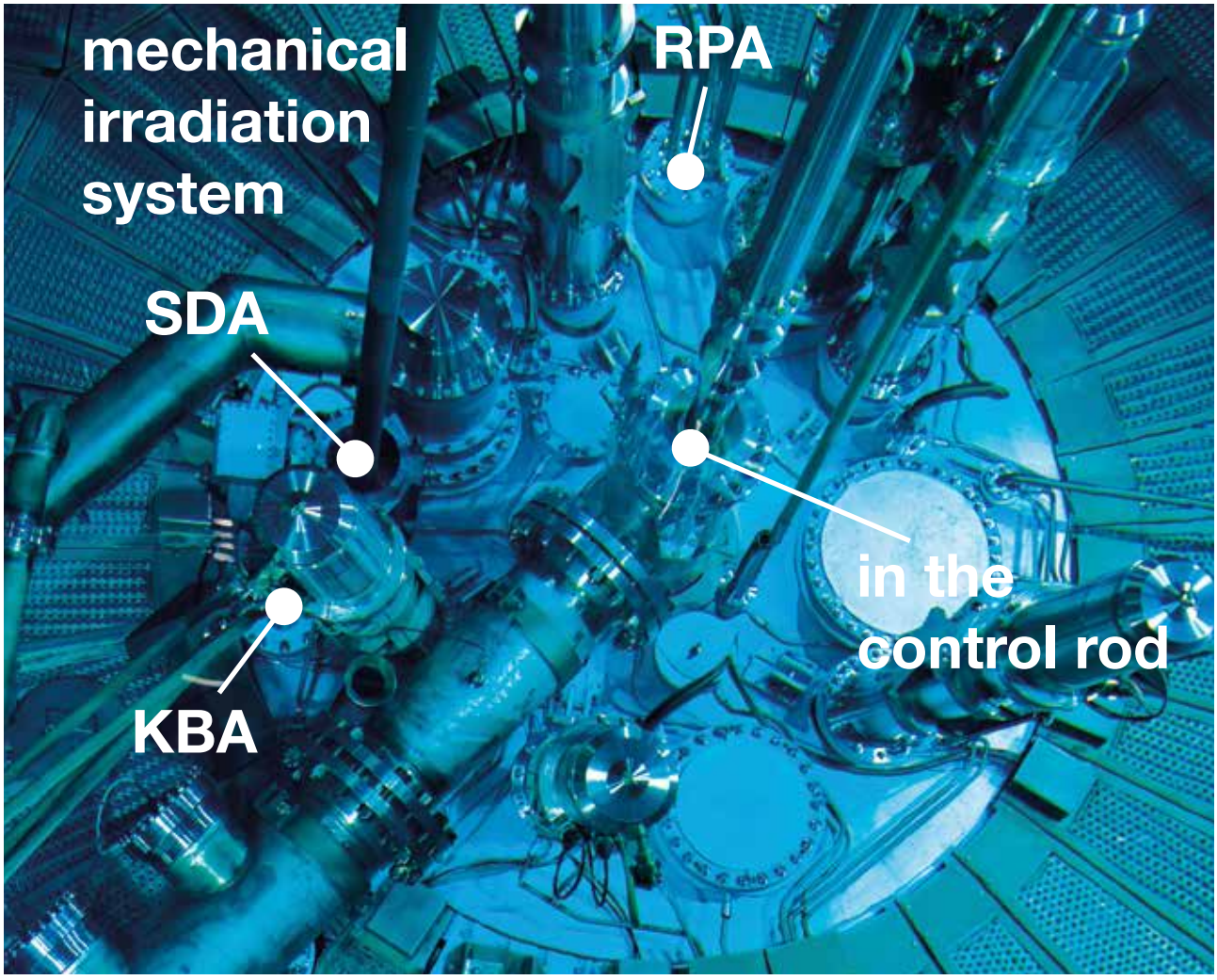

Figure 3: Positions of the different irradiation facilities within the reactor pool: RPA = rabbit irradiation system, KBA = capsule irradiation facility, SDA = silicon doping facility.

- The production of ^{99}Mo at the FRM II is planned to start in 2015. Its daughter isotope ^{99m}Tc is used in more than 90 percent of all nuclear medical diagnoses.

Figure 4: ^{177}Lu produced by the company ITG at the FRM II at the capsule irradiation facility. The radioisotope is filled in little vials with a volume of 2 ml and then packed in cans with a diameter of 45 mm and a height of 70 mm.

Technical Data

Silicon doping facility

- $1.7 \cdot 10^{13}$ thermal neutrons cm^{-2} s^{-1}
- Si dimensions: height ≦ 500 mm, ∅ = 200, 150, 125 mm
- ρ_{target}: 25 Ω cm - 1100 Ω cm

Neutron activation analysis

- Irradiation time: seconds - hours
- Sample weight: mg - g
- relative detector efficiency at 1.3 MeV: > 40%
- energy resolution of the detector: < 0.9 keV at 122 keV, < 1.8 keV at 1.3 MeV
- detection limit: ppm ~ sub ppt

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SE
magnetific field

SE
high pressure

SE
specialized equipment

SE
low temperatures

SE
high temperatures

LAB
Bio Laboratory

LAB
Chemistry Laboratory

LAB
Materials Science Lab

LAB
Sample Preparation Lab

LAB
TEM: JEOL 200 kV JEM-FS2200

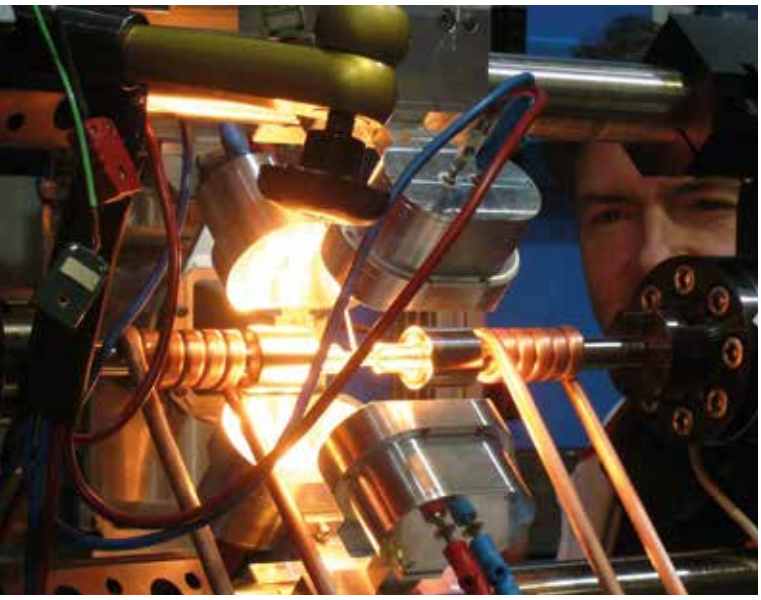
LAB
Thin Film Lab: MBE

LAB
X-ray Tomography: v|tome|x

Sample environment, Laboratories and User facilities

SE

magnetic field



Sample environment

The Heinz Maier-Leibnitz Zentrum (MLZ) offers users a variety of sample environment equipment for neutron scattering experiments, such as magnets and environments to apply high pressure on the sample as well as low and high temperatures. Additional specialized equipment, e.g. for SANS experiments, is also provided.

A major part of the equipment is designed and fabricated or assembled in-house by the sample environment group, offering the ability to adapt environments for special requirements.

A detailed description of the available equipment is shown on the following pages. Furthermore, specialized environments are available at the different instruments, please see the respective sections. If a scientific project has special requirements, please do not hesitate to contact the sample environment group or your local contact for assistance.

For more detailed information, please, visit our webpages **www.mlz-garching.de/se**.

CCM-5.0T-SANS

Specifications

- Maximum magnetic field:
  ± 5.0 T (symm.), ± 2.5 T (asymm.)
- Homogenity of the magnetic field (25 mm x 25 mm cylinder): 2.0 %
- Three room-temperature bores: Ø 80 mm
- Beam window dimensions:
  horizontal and vertical angle: 30°
- Cooling system: dry
- Cool down: 10 days
- Additional sample environment available (CCR)

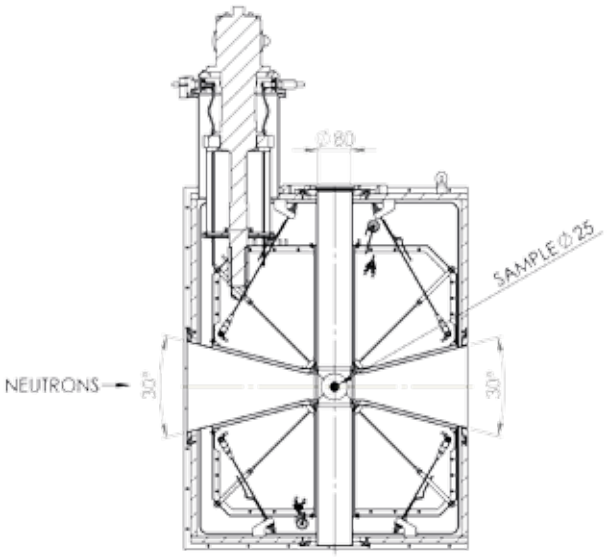


Figure 1: Cut through CCM-5.0T-SANS.

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CCM-7.5T

Specifications

- Maximum magnetic field: ± 7.5 T
- Homogenity of the magnetic field (Ø 15 mm sphere): 0.2 %
- Room-temperature bore: Ø 100 mm
- Beam window dimensions:
  vertical gap: 30 mm
  vertical open angle: 3°
  in plane open angle: 320°
- Cooling system: dry
- Cool down: 3 days
- Total thickness of Al in the beam: 30 mm
- Additional sample environment available (CC, CCR, HTF)

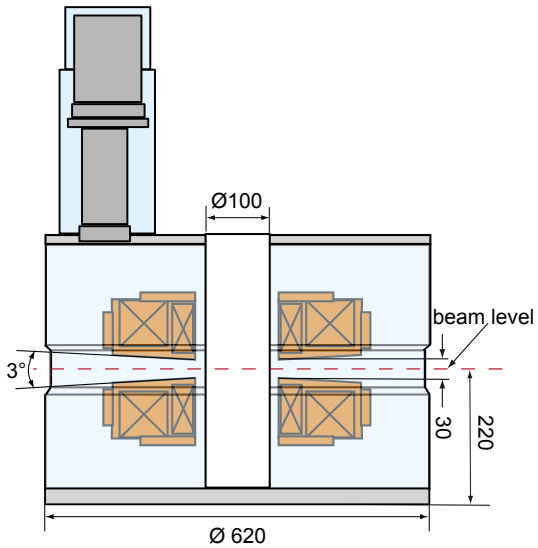
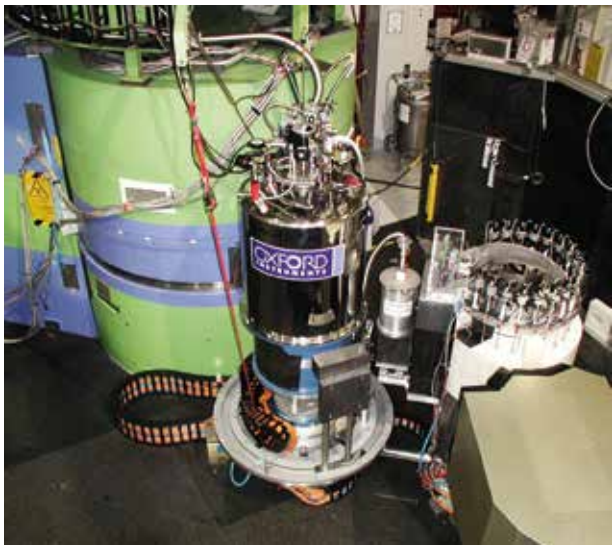


Figure 2: Cut through CCM-7.5T.

MAG-V-15T



Specifications

- Maximum magnetic field: ± 13.2 (14.5) T
- Homogenity of the magnetic field (20 mm x 12 mm cylinder): 0.85 %
- Low-temperature bore: Ø 20 mm
- Beam window dimensions: 20 x 20 mm²
- Scattering angle: 320° horizontal
- Cooling system: LHE
- Additional sample environment available: dilution insert
- MAG-V-15T is available at instrument PANDA; for the use at other instruments ask the local contact.

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Electromagnet with CCR

Specifications

- Two pieces available
- Maximum magnetic field: up to 1.4 T
- Temperature: 3 - 320 K
- used for small angle scattering and reflectometry

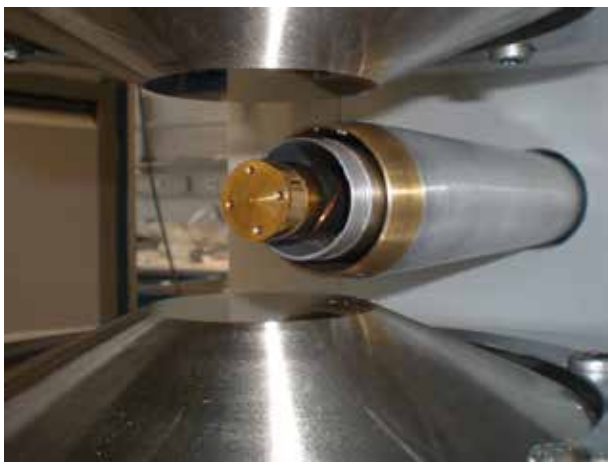

Figure 1: Cryostat with samplemount.

JVM1-5.0T active shielded

Specifications

- Maximum vertical magnetic field: ± 5.0 T (asymm.)
- Homogenity of the magnetic field (Ø 15 mm, 30 mm in height, cylinder): 1.8 %
- Beam window dimensions: horizontal and vertical angle: 30°
- Sample space: Ø 30 mm, height 50 mm
- Split: 30 mm
- Access angle: ± 5° vertical
- Scattering angle: 330° horizontal
- VTI: 1.8 - 300 K
- Strayfield < 1 G at 1 m
- Cooling system: LHE
- Cool down: 4 hours
- Additional sample environment available: Kelvinox insert, base temperature 25 mK

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HP 400 kN press

Specifications

HP 400 kN press:
- compressive force: 450 kN
- repulsive force: 220 kN
- dynamic pressure up to 10 Hz possible

Closed cycle cryostat CC-11-P adapted to be used with the HP 400 kN press.
- Temperature range: 20 K – 600 K
- Cooling power 2. stage: 1.5 W
- number of radiation shields: 1
- Heater cartridge 25 Ω / 100W
- Cool-down time RT – 20 K: 4 h
- Sample space: max Ø 16 mm, height 10 mm
- Pressure range: 200 MPa for Ø 16 mm anvil

A special challenge is to go to low temperatures at high pressures. The newly constructed high-pressure cryostat allows one to apply and vary the force in situ, even at low temperature. The sample cell is operated externally by the hydraulic HP 400 kN press. It can be mounted in a dewar and cooled down to below 10 K within four hours. With a piston-in-cylinder cell and a piston diameter of 16 mm a maximum pressure of 2.0 GPa (20 kbar) can be achieved at a sample size up to 30 mm length and 16 mm diameter. Reducing the piston diameter and the sample volume the pressure can be increased up to 100 kbar. Using anvil cells the pressure range extends to 30 GPa (300 kbar) and above. In addition, a dynamic pressure can be superimposed on the static pressure with a frequency of up to 10 Hz.

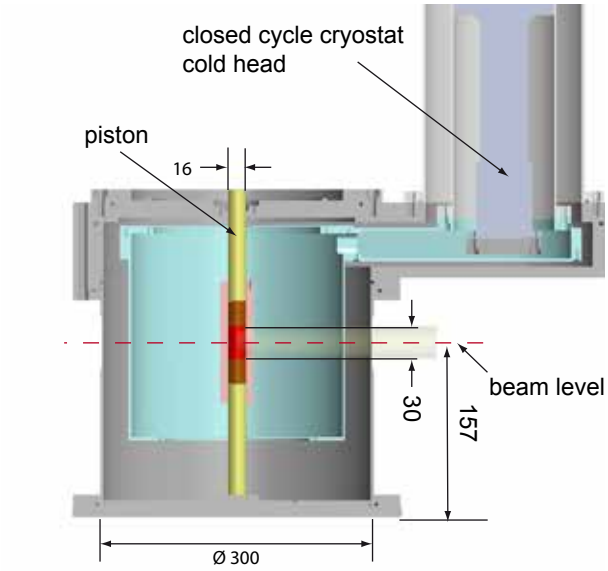

Figure 1: Cut through CC-11-P.

HPG - 10 kbar

To load gas pressure cells the MLZ provides a gas compression unit for inert gas pressure up to 10 kbar. The unit can be oprerated either manually or remote controlled. The remote controlled operation allows for individually programmable pressure time profiles. The measurement system includes a high-precision manometer and a pressure transmitter that cover the range up to 10 kbar.

Specifications

- Pressure range 10^5 Pa ≤ p ≤ 10^9 Pa

Pressure measurement:
- 10^5 Pa ≤ p ≤ $7 \cdot 10^8$ Pa Heise high-precision manometer; resolution 0.1 % ME
- $7 \cdot 10^8$ Pa ≤ p ≤ 10^9 Pa transmitter; resolution $9 \cdot 10^6$ Pa

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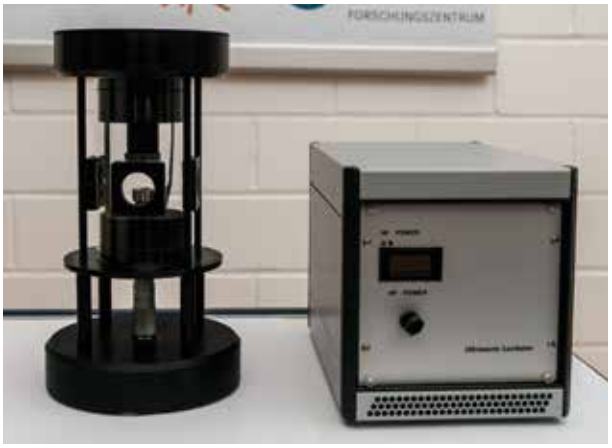
SE

specialized equipment

Ultrasonic levitator (tec5 AG)



Specifications

- Frequency: 58 Hz
- Wavelength: 5.9 mm
- Optimal diameter (without drop deformation): 2.5 mm

Multiposition sample holders

Specifications

- 8 - 32 positions
- Thermalizing devices: Temperature -10 °C - 120 °C (220 °C with silicon oil)

Peltier furnace

Specifications

- 8 positions
- Temperature -20 °C - 120 °C

GISANS liquid flow cell

Specifications

- 15 x 5 x 2 cm^3 silicon block
- liquid volume of 7 ml
- heatable by circulation bath

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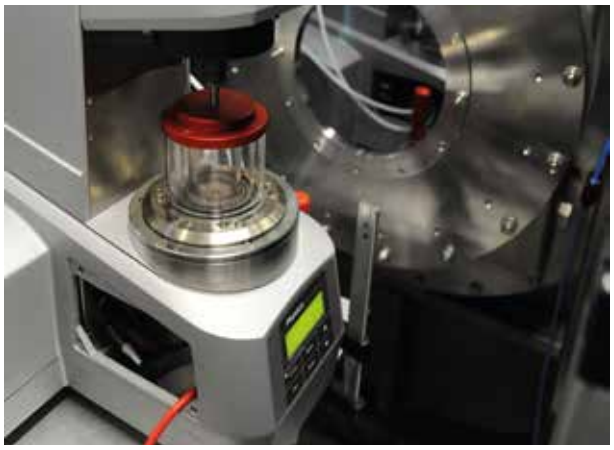
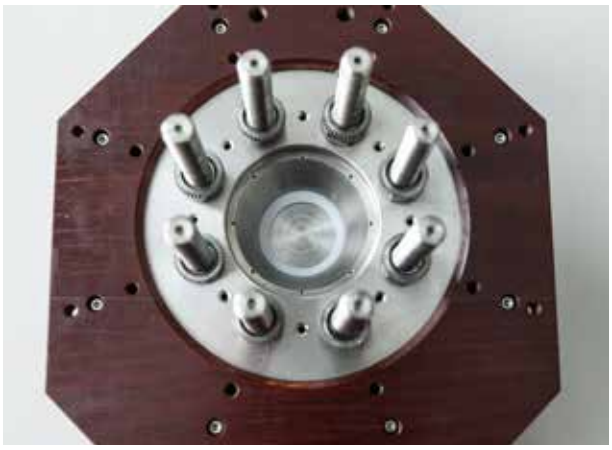
Rheometer RSA II



Specifications

- Couette geometry for liquids
- Shear rate: 0.001 to 5000 s^{-1}
- Temperature: 20 to 200 °C

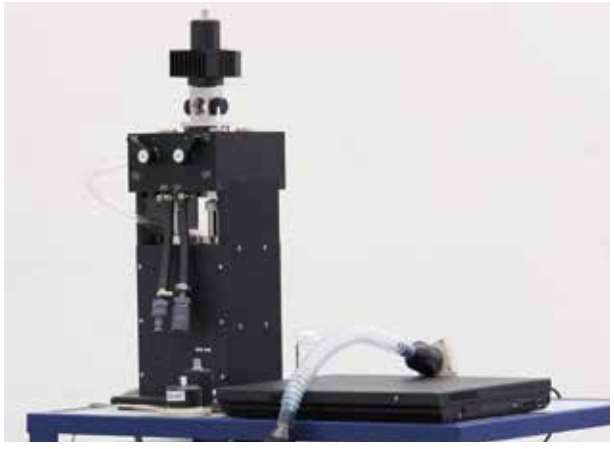
Pressure cell



Specifications

- Temperature: -40 °C - 80 °C
- Pressure: 5000 bar

Stopped-flow (Bio-Logic(R) SFM-300)



Specifications

- 3 independently controlled syringes and two mixers
- Mixing ration from 1 : 1 to 1 : 100
- Exact control of flow rate
- Dead-time of mixing: < 20 msec
- Neutron-cell volume: 0.4 ml
- Recommended mixing volume: 1 ml

Humidity cell

Specifications

- Temperature: 10 °C - 90 °C
- Humidity range: 5 % - 95 %
- Sample size: Ø 8 mm, thickness: 1 mm

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The MLZ sample environment groups supply a variety of liquid refigerant free cryostats adapted for the different needs on the instruments. Besides standard closed cycle cryostats, either of toploading type or sample directly mounted to coldhead, adapted versions for the use inside the vertical field 7.5 T magnet system, the 40 kN press or equiped with a thermoswitch for temperatures above RT are available. For special requirements please contact the sample environment group or your local contact to discuss details.

CCR - closed-cycle cryostat with sample tube

The liquid refrigerant free closed cycle cryostats of the CCR-type are designed for a fast change of samples. They are based on pulse-tube technique refrigerators with a 6 kW water cooled compressor unit. The sample tube is connected to the pulse tube cold plate with a copper heat exchanger.

The sample tube is filled with exchange-gas. Temperature regulation is achieved by a sensor and a heater attached to the sample tube. The sample-holder is in general mounted to a sample stick (see fig. 2). Temperatures ranging from 3.5 K to RT can be regulated. To reach for temperatures above RT to 700 K the sample space has to be evacuated and a special high-temperature sample-stick has to be used. For this case temperature control is provided by a heater and sensor mounted on the sample stick.

Common features

- Based on pulse-tube refrigerator
  cooling power 2nd stage:
  1000 mW
- 1 radiation shield connected to 1st stage
- Temperature sensor Cernox® 1.4 K – 325 K
- Heater 25 Ω / 100 W
- Temperature range:
  with exchange gas in sample space
  2,8 K – 300 K
- Extended temperature range:
  evacuated sample space and HT sample stick
  T < 700 K
- Typical cool down times of the cryostat
  RT to base temperature
  min. 2,5 h
- Cool down time for sample change with cryostat at base temperature < 1.5 h

Dimensions

- Diameter sample space:
  < 50 mm and < 80 mm
- height of sample space (beam window):
  approx. 75 mm

Available sample sticks

- Standard stick (T < 300 K)
- High temperature stick (T < 700 K)
- Rotation sample stick to provide sample rotation with fixed cryostat position (for example in the CCM vertical field magnet)
- Gas adsorption stick

The sample position in the beam can be adjusted by a simple height adjustement at the bottom part of the sample stick

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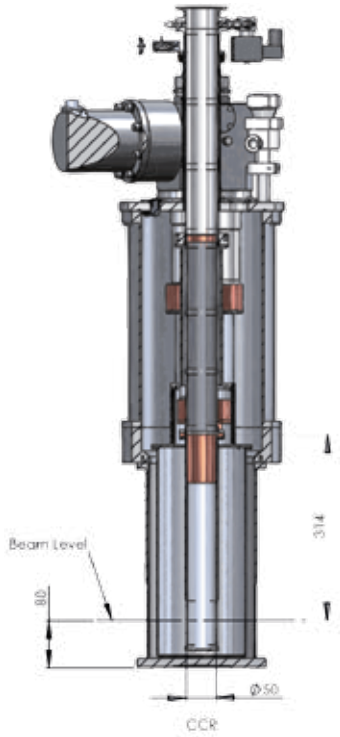

Figure 1: Cut through CCR cryostat.

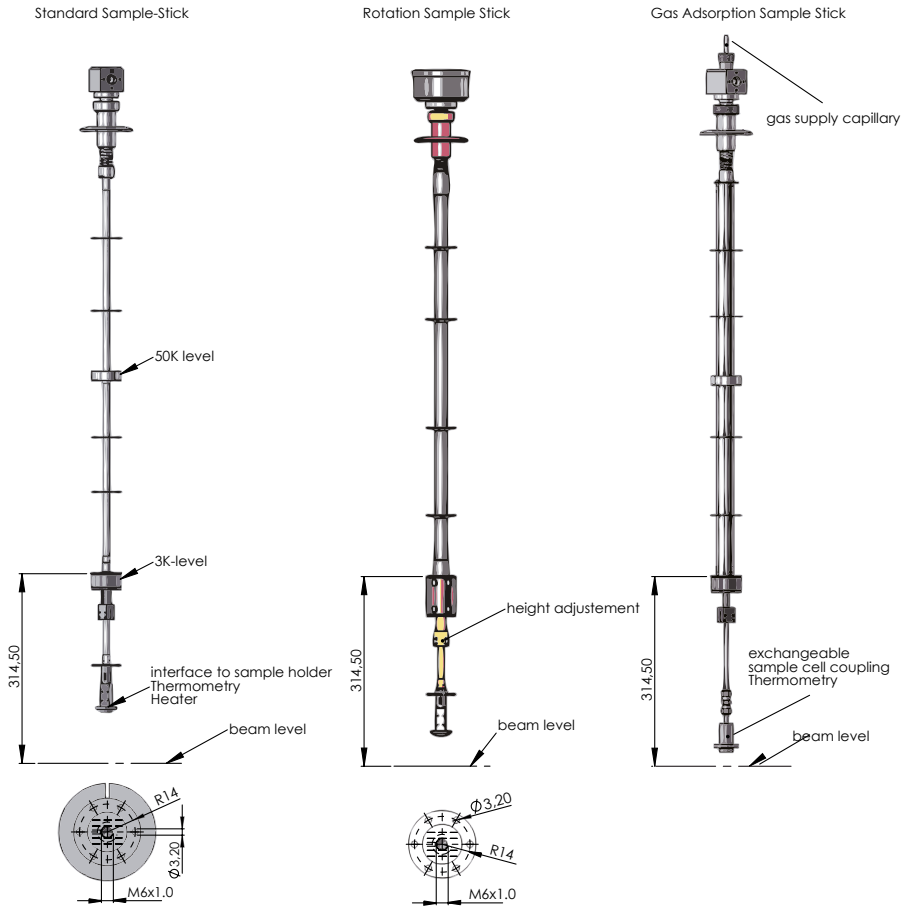

Figure 2: Sample sticks provided for CCR cryostats.

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CCI - low temperature inserts

To reach temperatures below 3 K ^{3}He and ^{3}He / ^{4}He insert cryostats for the CCR systems are available. Please note an additional preparative time of up to 4h is needed before first cool-down.

CCI specifications

	CCI - ^{3}He	CCI ^{3}He/^{4}He
Temp. range	450 mK – 10 K	50 mK – 1 K
Cooling power	1 mW (500 mK)	15 µW (100 mK)
Heater	10 Ω	10 Ω
Cool-down time	5 h	7 h
Sample Ø	30 mm	30 mm
Sample space-height	145 mm	70 mm
Distance cold plate to beam level	106.5 mm	27 mm

CC- closed-cycle cryostats

The closed cycle cryostats of the CC-type are based on SHI-RDK-2025D and SHI-RDK-101D cold-heads mounted with differing isolation vaccum tails. The sample space of these liquid-cryogen free closed-cycle cryostats is inside the isolation vaccum. The thermalisation of the sample is achieved by the thermal conductivity of the sample holder and the cold-plate. The temperature sensor for temperature control is mounted on the cold-plate. To avoid temperature gradients a sample mounting with adequat thermal conductivity is needed. In case of sample with poor thermal conductivity, the usage of an exchange-gas (He) containing sample can or the use of a CCR-type cryostat should be considered.

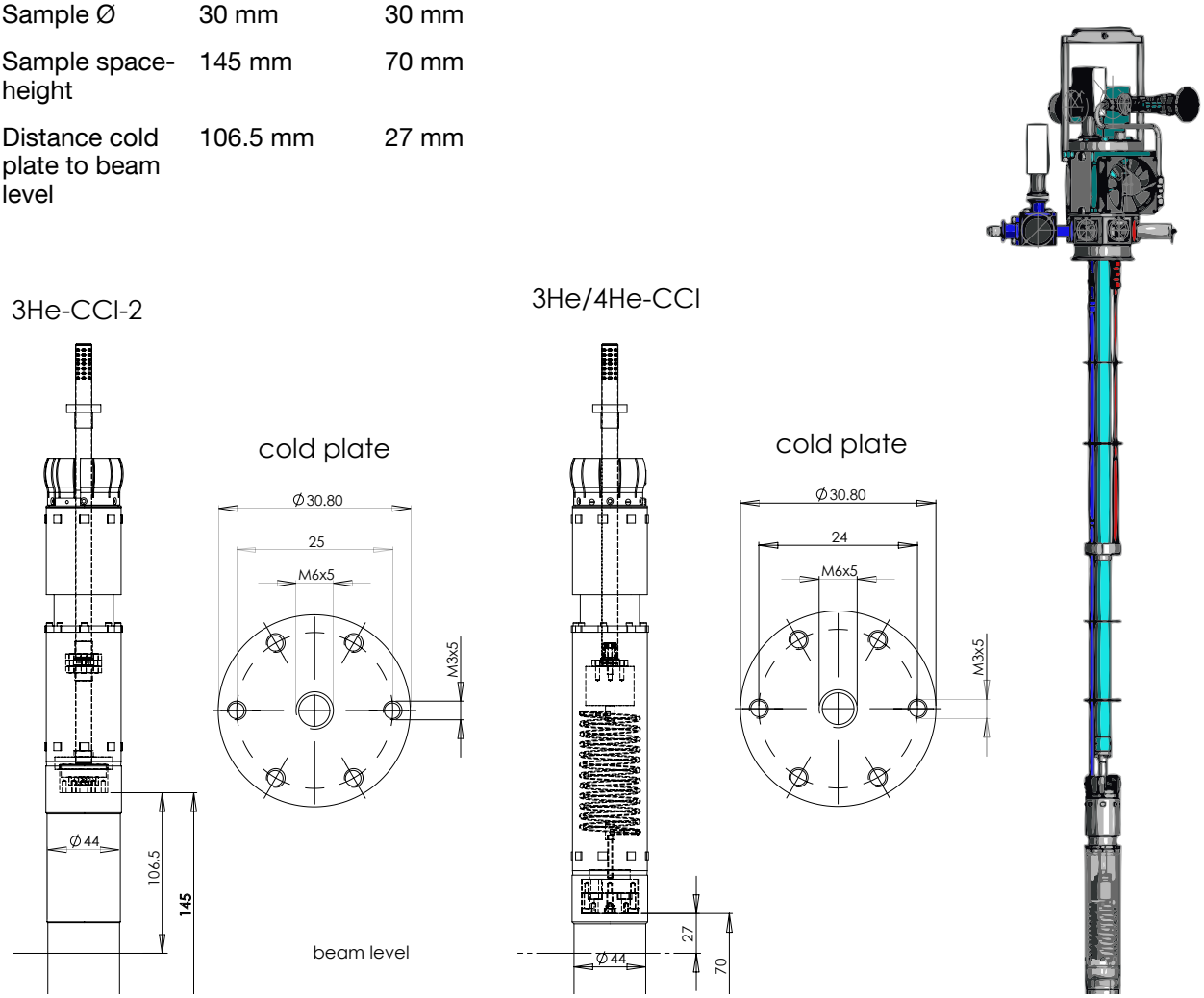

Figure 1: Cut through the CCI inserts.

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CC-1*, CC-2-PUMA, CC-3, CC-4-PANDA

- Temperature range: 2.8 K – 300 K
- Cooling power 2. stage: 250 mW
- radiation shields attached to 1st stage: 1
- Thermometry: Si-diode; Cernox® 1.4 K – 325 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2.8 K: 2.5 h
- total height of sample space: 110 mm
- diameter of sample space: 60 mm

* CC-1 prepared for the condensation of non-corrosive gases up to P = 100 bar

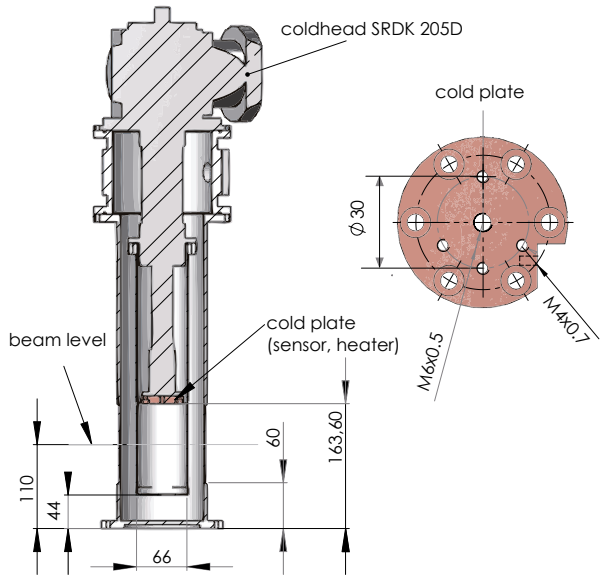

Figure 2: Cut through CC-3.

CC-5, CC-6

- Temperature range: 2.2 K – 300 K
- Cooling power 2. stage: 110 mW
- radiation shields attached to 1st stage: 1
- Thermometry: Si-diode; Cernox® 1.4 K – 325 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2.8 K: 2 h
- sample space: Ø 10 mm, height 10 mm

CC-7-CCM

- Temperature range: 2.2 K – 300 K
- Cooling power 2. stage: 110 mW
- radiation shields attached to 1st stage: 1
- Thermometry: Si-diode; Cernox® 1.4 K – 325 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2.8 K: 4 h
- sample space: Ø 55 mm, height 85 mm

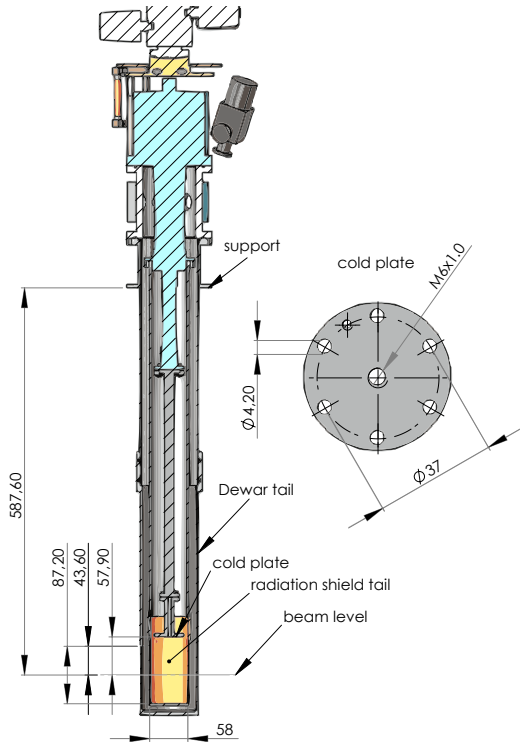

Figure 3: Cut through CC-5 / CC-6.

CC-8, CC-9-RESEDA,CC-10-PUMA

- Temperature range: 2.8 K – 600 K
- Cooling power 2. stage: 110 mW
- radiation shields attached to 1st stage: 1
- Thermometry: Pt1000 IST 10 K – 600 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2.8 K: 3 h
- Cool-down time 600 K – 2.8 K: 5 h
- total height of sample space: < 136 mm (< 85 mm CC-9 / CC-10)
- diameter of sample space: < 138 mm (< 55 mm CC-9 / CC-10)

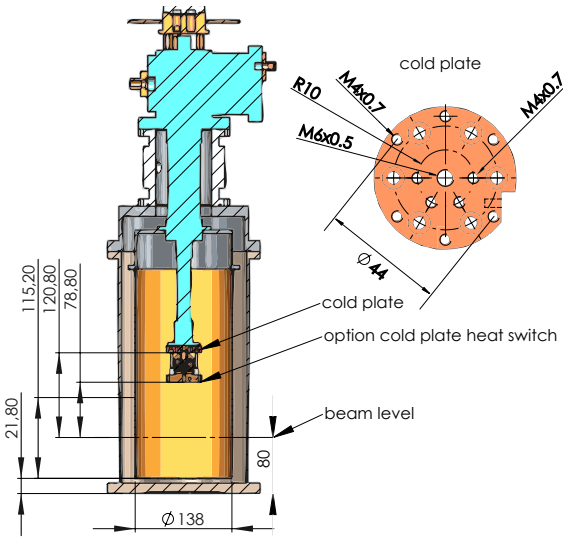

Figure 4: Cut through CC-8.

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JTC 1-4

Common features

- Heater 25 Ω / 100 W
- Temperature range:
  with exchange gas in sample space
  3 K – 300 K
- Extended temperature range:
  evacuated sample space and HT sample stick
  T < 700 K
- Typical cool down times of the cryostat
  RT to base temperature
  min. 2.5 h
- Cool down time for sample change with cryostat at base temperature < 1.5 h

Dimensions

- Diameter sample space:
  < 60 mm
- height of sample space (beam window):
  approx. 100 mm

Figure 1: Standard cryostat.

Available sample sticks

- Standard stick (T 3 - 700 K)

The sample position and orientation in the beam can be adjusted by a simple height adjustement and rotation at the top part of the sample stick during the experiment.

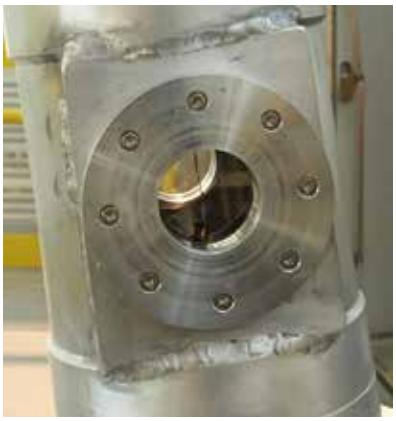

Figure 2: Cryostat with sapphire window (in detail on the left).

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HTF - high temperature furnace

The heater of the HTF consist of a resistive Nb double cylinder element. Radiation shields made of Nb reduce the thermal loss. The sample is mounted on a sample rod top down, using a M8 screw. Maximum reachable temperature is 1900 °C. For temperatures up to 300 °C the furnace can be filled with Ar or He exchange gas to improve regulation stability. Temperature sensors are type C thermocouples.
Further a special version of the furnace with a reduced diameter for usage inside the CCM-7.5T vertical magnet is available.

Specifications

Designation: HTF 1, 2, 3, 4 - SPODI
- Temperature range (vacuum): RT – 1900 °C
- Temperature range (exchange gas): RT – 900 °C
- Thermometry: type C thermocouple
- Total height of sample space: 100 mm
- Diameter of sample space: 45 mm
- Sample rod tail: M8 (male)

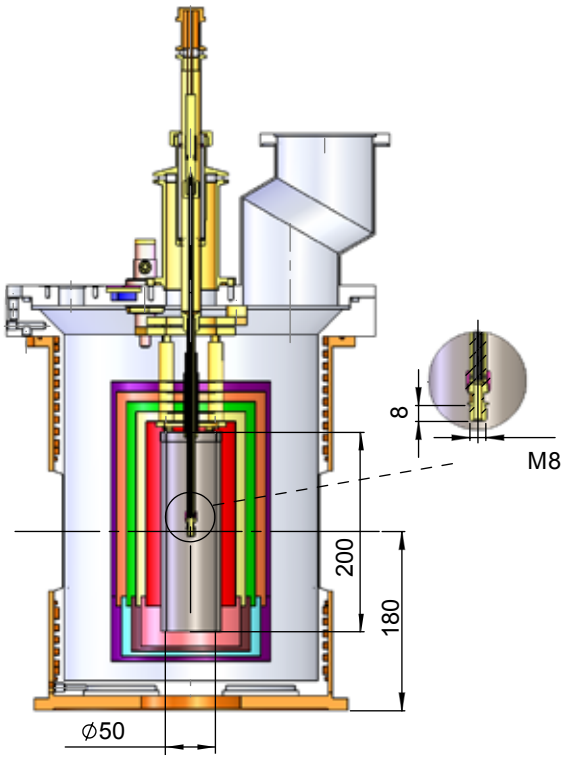

Figure 3: Cut through a standard HTF.

IRF - Infrared light furnace

Compact dimensions are the key feature of the light furnace. The sample is placed at the focus of four halide lamps, therefore restricting the sample volume to a few mm³. The sample can be heated in vacuum or any convenient atmosphere up to ambient pressure respectively. Of course the maximum temperature depends on pressure.
A dedicated version of this furnace for use together with a load frame is availbale. Twelve halogen bulb lamps heat the sample up to 900 °C with an almost homogeneous temperature distribution. The sample volume has 6-8 mm diameter and 30 mm length. By means of an additional heat shield temperatures beyond 950 °C are expected.

Specifications

Designation: IRF 1, 2
- Temperature range (vacuum): RT – 1200 °C
- Temperature range (Ar 100mbar): RT – 300 °C
- Thermometry: type K, R, S thermocouple
- Height of sample space: 15 mm
- Diameter of sample space: 10 mm
- Sample rod tail: M4 (male)

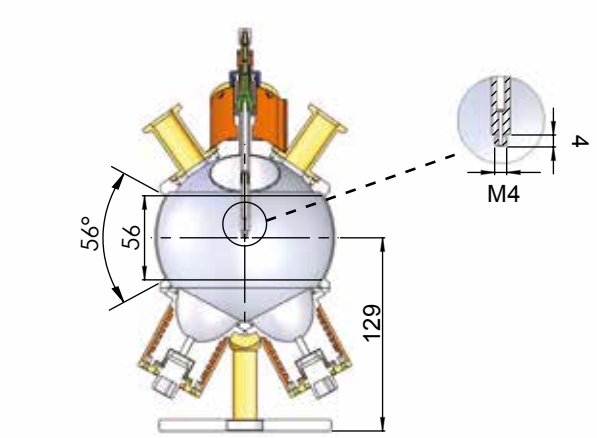

Figure 4: Cut through IRF light furnace.

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PF - Polarised neutron furnace

For experiments using a polarized neutron beam a furnace with special bifilar heater cartridges is availble for the temperature range up to 700 °C.

Specifications

Designation: PF 1

- Temperature range (vacuum): RT – 700 °C
- Thermometry: Pt100
- Height of sample space: 80 mm
- Diameter of sample space: 45 mm
- Sample rod tail: M6 (male)

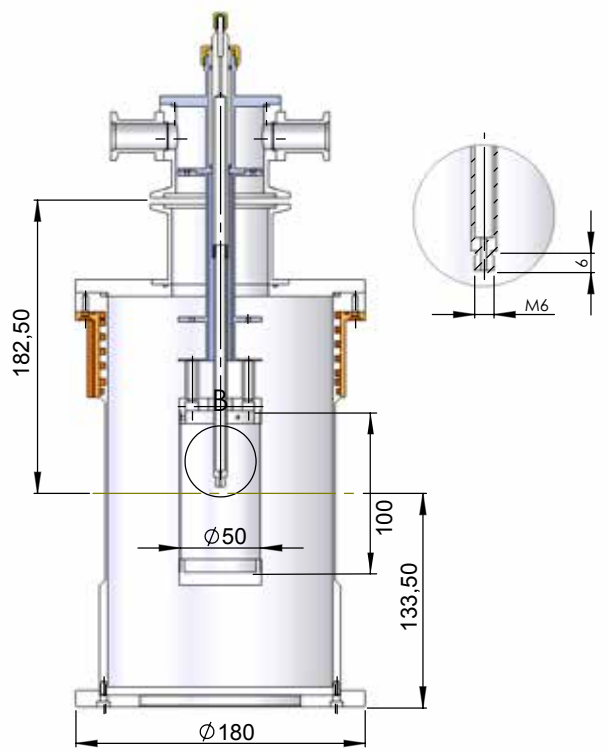

Figure 1: Cut through PF 1 furnace for polarized neutron experiments.

CTF1- Circulation thermostat furnace

For the temperature range -20 °C to 200 °C a furnace using a thermalized cirulating medium allows for a precise regulation of the particularly homogenous sample temperature.

Specifications

Designation: CTF 1

- Temperature range (vacuum): -30 °C – 200 °C
- Thermometry: Pt100
- Height of sample space: 80 mm
- Diameter of sample space: 48 mm
- Sample rod tail: M8 (male)

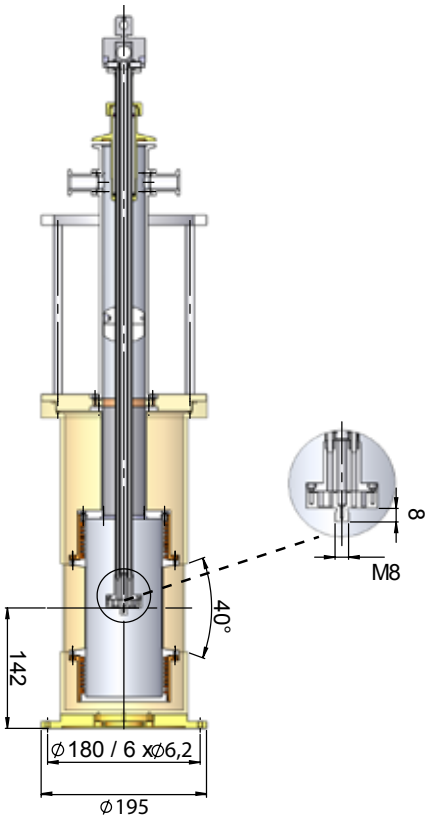

Figure 2: Cut through the CTF Circulation thermostat furnace.

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Special application furnace: battery furnace

For research, e.g. on rechargeable energy storage systems such as lithium-ion batteries, dedicated heater elements are available (fig. 3, 4). Depending on battery size and temperature specification the furnaces have to be designed and manufactured (for details, please get in contact with the sample environment group). Heating is accomplished by an appropriate set of high performance cartridge heaters allowing for temperatures up to 700 °C. A remote controlled power supply provides the heater current. Optional temperatures below room temperature (RT) are possible.

Specifications

- Temperature : RT – 700 °C (optional < RT)
- Thermometry : PT 1000
- Dimension: adapted to battery size

Figure 3: Battery furnace setup.

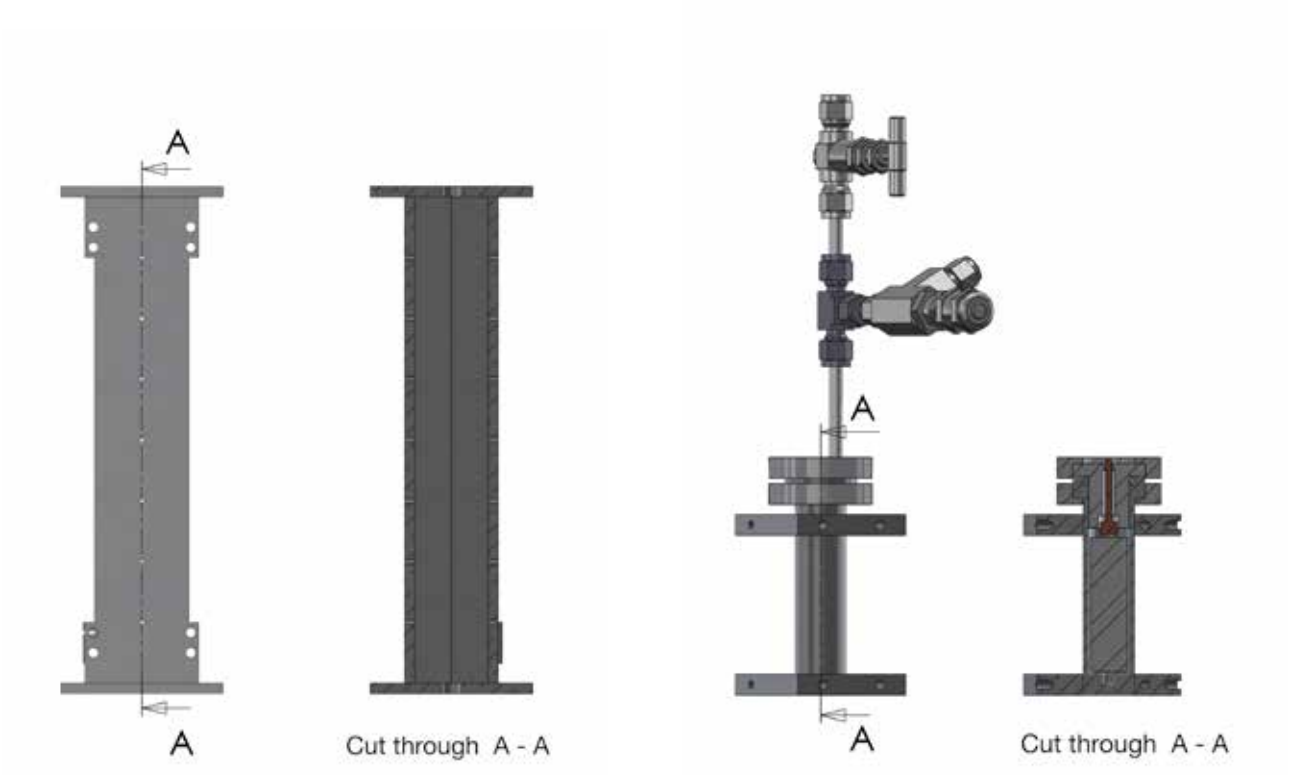

Figure 4: Examples for battery furnaces available at MLZ.

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LAB

laboratories and user facilities

Laboratories and user facilities

The Heinz Maier-Leibnitz Zentrum (MLZ) offers users a variety of laboratories for the preparation or post-treatment of samples such as:

- Bio Laboratory
- Chemistry Laboratory
- Materials Science Lab
- Sample Preparation Lab

These laboratories are well equipped with general equipment as well as more specialized instruments for sample analysis. Please contact the responsible scientists if you need access to the laboratories during your experiment.

The use of highly specialized tools like the X-ray tomography v|tome|x, the transmission electron microscope (TEM), or the molecular beam epitaxy (MBE) thin film deposition system need special appointment with the local scientist prior to the visit at the MLZ. In addition, the thin film lab hosts an atomic force microscope (AFM) and a magneto-optical Kerr effect (MOKE) measurement setup. TEM and MBE may be used in conjunction with proposals to neutron scattering instruments at the MLZ. If you are interested approach the responsible scientists prior to proposal submission.

For more detailed information, please, visit our webpages **www.mlz-garching.de/user-labs**.

Bio Laboratory

The biology laboratory is a 40 m² facility which serves to prepare biological, biophysical and related soft matter samples for measurements at the neutron scattering instruments. It is equipped to handle samples in inert gas atmosphere within a glovebox and pre-characterize samples by UV-VIS spectroscopy. A low-temperature freezer can be used to store samples at temperatures down to -80 °C.

Equipment

- Fine balance
  max. weight 405 g, resolution 1 mg
- Elga Labpure pure water system (18 MOhm)
- Glovebox
- Freezer -80 °C
- Refrigerator +4 °C and freezer -18 °C
- UV-VIS spectrometer
- Optical microscope
- Thermostated Centrifuge up to 60 000 G
- Rheometer
- ÄKTA FPLC for protein purification

Location

UYM-S 0332

Dr. Marie-Sousai Appavou

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LAB

laboratories and user facilities

Chemistry Laboratory

The chemistry and sample preparation laboratory is a 45 m^2 facility equipped with double hood to prepare samples for subsequent measurements on the neutron scattering instruments. It offers a basic tool set to handle samples from users, prepare solutions or even perform chemical reactions resulting in specific modifications. Samples can be handled under inert gas atmosphere like N_2 or Ar.

Equipment

- Fine balance
  max. weight 405 g, resolution 1 mg
- Balance
  max. weight 4.2 kg, resolution 0.1 g
- Refrigerator with freeze box -18 °C
- Vacuum heating cabinet
  max. temperature 300 °C, min. pressure 25 mbar, inertgas: N_2, Ar
- Thermostatic bath, 20 – 80 °C
- Ultra-sonic bath
- Rotary evaporator
- Rheometer Rheometrics Solid Analyzer RSA II, temperature from liquid N_2 to 500 °C

Location

UYM-N 0374

Materials Science Lab

In collaboration with Helmholtz Zentrum Geesthacht and TUM the Materials Science Lab serves as laboratory to prepare samples for subsequent neutron scattering measurements. It provides several instruments e.g. SAXS, DSC, LD, to perform complementary analytics to characterize samples.

Equipment

Analytic instruments:

- Hecus S3 MicroPix – Small Angle X-ray Scattering
- Differential Scanning Calorimetry
- BioLogic – Bi-Potentiostat
- Leica DM 6000 – Digital Microscope

Preparation instruments:

- GERO – Programmable High Temperature Tube furnace
- ATM BRILLANT 200 – corundum wheel saw
- ATM OPAL 410 – resin sample hot embedding
- ATM SAPHIR 520 – polishing machine
- Binder – vacuum heating cabinet (200 °C)

Location

UXB-2.5.04 (IAZ building)

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LAB

laboratories and user facilities

Sample Preparation Lab

For the preparation or post-treatment of samples, the MLZ offers a sample preparation laboratory in the Neutron Guide Hall West for users. In addition to the equipment listed below, the sample preparation lab provides a supply of argon, helium, compressed air and ultrapure water. Usually small amounts of commonly used solvents and laboratory dishes are available. Additionally you can use the official proposal form to point out your special requirements, so that your local contact and the sample environmental group can prepare appropriate conditions for your experiment in time.

Mobile glove boxes are installed in both, Neutron Guide- and Experimental Hall to be used close to the instruments.

Equipment

- Fume hood
- Glove box
- Refrigerator
- Freezer
- Scales
- Stirrers
- Heating oven
- Ultrasonic bath

Location

UYH02-43 (Neutron Guide Hall West)

TEM: JEOL 200 kV JEM-FS2200

Transmission electron microscopy is a complementary technique with neutron scattering in the frame of soft matter studies. With the TEM, real space investigations are performed to access information about shape, size and size distribution of particles, self-assembly and aggregation. Users will be supported by JCNS staff (M. S. Appavou) to conduct the suitable preparation and TEM investigation.

Specifications

- JEOL 200 kV JEM-FS2200 with a field emission gun (FEG) and energy filter.
- Magnification from 50x to 1 000 000x
- image resolution of 0.2 nm in point and 0.1 nm in lattice.
- Tietz CCD camera with 2048 × 2048 pixels.
- Grid preparation by carbon sputtering on bare grids.
- Glow discharge process to make the coated grids hydrophilic.
- Plunge freezer to prepare cryo-specimen for direct imaging (Cryo-DI), for freeze fracture and direct imaging (FFDI) or freeze fracture before shadowing with Pt/C or Ta/W, so-called freeze fracture and electron microscopy (FFEM).
- Cryo-specimen investigation at low temperatu- rearound -180 °C under vacuum.
- Ultramicrotome for room temperature and cryo sectioning

Location

UYM-N 0374

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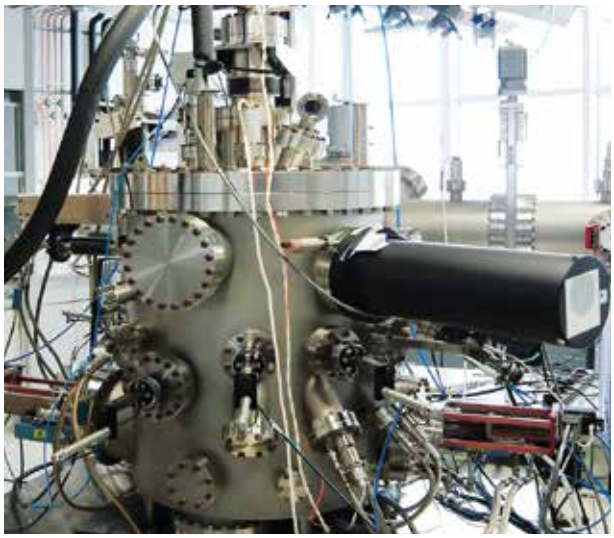
LAB

laboratories and user facilities

Thin Film Lab: MBE



The Jülich Centre for Neutron Science (JCNS) operates a state-of-the-art oxide Molecular Beam Epitaxy (MBE) system (DCA Instruments Oy, Finland) to prepare tailored samples for the investigation with the neutron reflectometer MARIA, other neutron scattering instruments or methods.

The system is equipped with six effusion cells and two e-guns (each with four crucibles) for co-deposition. An RF plasma atom source enables atomic oxygen introduction into the chamber to grow oxides. Thin Film growth analysis is performed by Reflection High Energy Electron Diffraction (RHEED). Additionally Low Energy Electron Diffraction (LEED) and Auger Electron Spectroscopy (AES) are offered for thin film characterization.

Sample growth will be performed in strong collaboration with the instrument scientist (S. Pütter).

Equipment and services

- Thin film growth using MBE technique
  - Typically available elements include Ag, Al, Au, Co, Cr, Cu, Fe, La, Mn, Nb, Sr, Ti.
  - More elements are available on request.
- Atomic Force Microscopy (AFM).
- Magneto-Optical Kerr Effect (MOKE) setup, magnetic field up to 0.7 T, temperature range 4.5 - 420 K.

Location

UYM-3.33

X-ray Tomography: v|tome|x

In order to offer an X-ray facility complementary to the neutron tomography station ANTARES, the FRM II and the Chair of Biomedical Physics at the Technische Universität München have started to operate a high resolution computer tomography facility. The “micro CT VtomeX” is also available to users of the MLZ. Samples, that can be examined, include geo and composite materials, semiconductors and biomedical specimens.
The X-ray tomography station is featured by its high flexibility: Due to two different exchangeable X-ray tubes, both, pictures with high resolution and pictures with lower resolution but higher contrast, can be taken. The detector allows for fast and highly contrasted pictures. The reconstruction of the data is accomplished within a few minutes due to a cluster of four computers using graphic cards to calculate the images.

Possible scanning parameters

- Max. sample diameter 230 mm
- Max. sample height 420 mm
- Min. resolution < 1 micron (isotropic)
- Max. voxel size of reconstruction 2048^3
- Max. X-ray energy 240 keV
- Max. sample weight 10 kg
- Typical scanning time 1-120 min

Location

Institute for Medical Engineering (IMETUM), Boltzmannstr. 11, 85748 Garching

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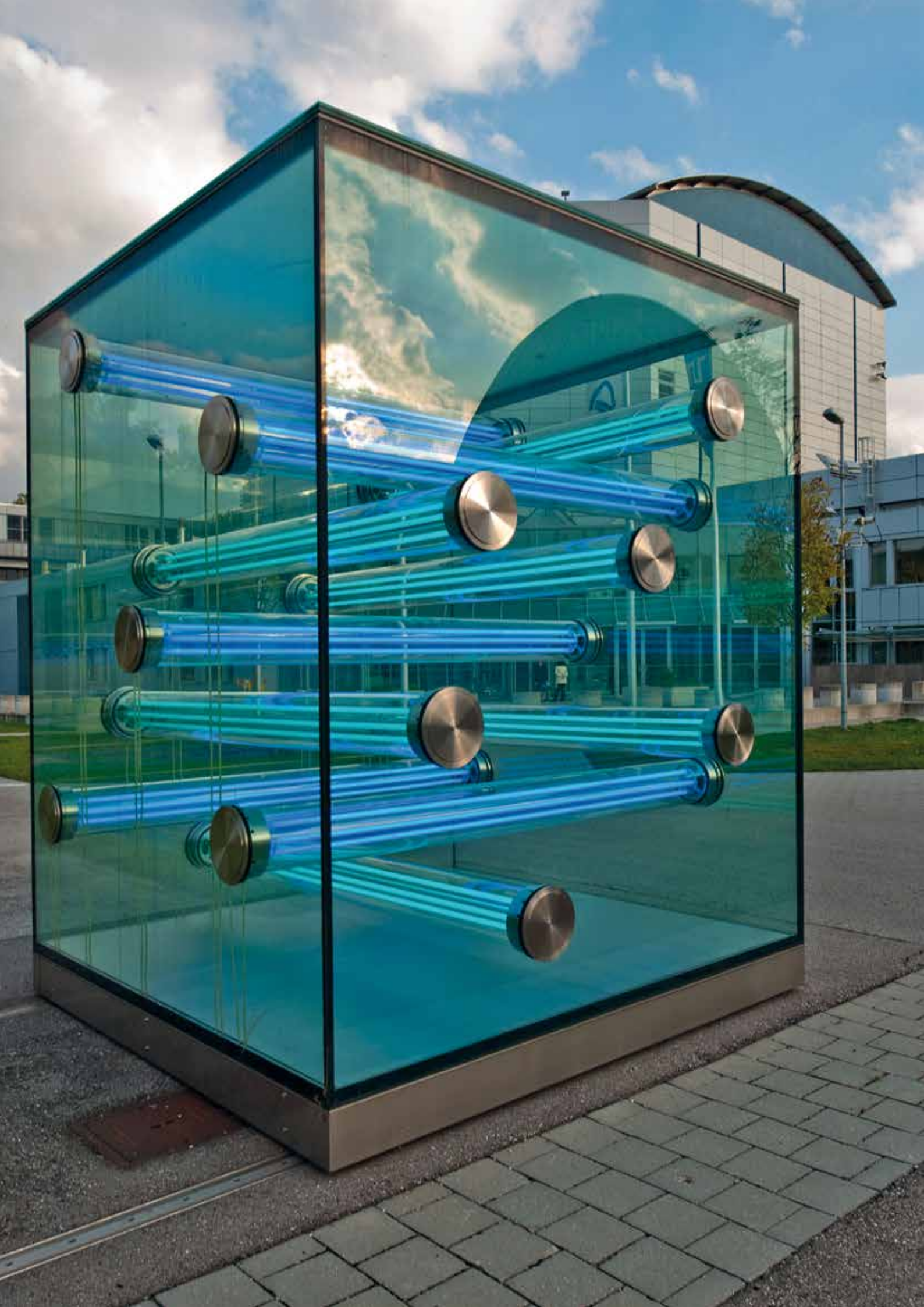
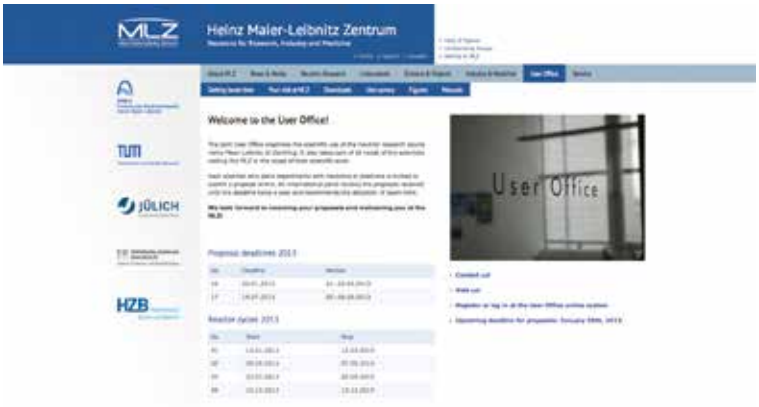


User office

General information for users

The User Office organizes the scientific experiments at the MLZ, handles the proposal rounds and takes care of everything scientists visiting the neutron source in the scope of their work have to deal with.
You can call us, drop in when visiting the MLZ, or find all available information at

www.mlz-garching.de/user-office



There you learn about

- our Terms of References, for example regarding publications,
- reactor cycles and upcoming proposal deadlines,
- the online User Office System,
- workflows,
- requirements for the access to the site,
- radiation protection regulations,
- accommodations at Garching,
- possibilities regarding financial support,
- forms and templates for proposals and reports ready for download,
- and much more...

User Office online

The essential communication tool for all issues of a scientific application is the online User Office, which can be found at:

user.frm2.tum.de

or similar for JCNS at:

fzj.frm2.tum.de

In order to apply for beam time at one of the MLZ instruments, first of all the user has to create an account at the online User Office. Those sites have a common user database, i.e. one account serves for both entries. By means of their account the users have access to appropriate web tools for the submission of proposals for beam time and of experimental reports and EU-reports.

How to get beam time for scientific experiments

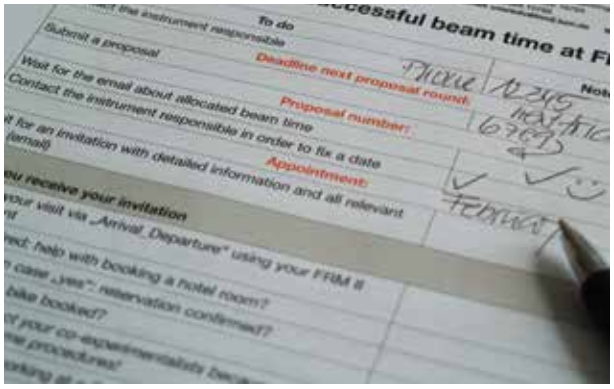
Prior to writing the proposal we strongly recommend to contact one of the instrument scientists to discuss the feasibility of the project. Proposals may be submitted any time – twice a year the User Office organizes a call with deadline for the review process.

Our Terms of Reference mean that beam time and usage of the MLZ instruments are free of charge for nonproprietary scientific research. This is valid under the obligation that the results are published in scientific journals or presented at conferences. Currently around 300 applications are submitted on each call for proposals from Germany, Europe, and abroad.

The submitted proposals are checked under several criteria. Both the radiation protection and general safety aspects are approved by the respective departments at the FRM II. In addition the instrument scientist has to confirm the technical feasibility of the experiment at the chosen instrument.

After this procedure the remaining proposals are reviewed by an international scientific panel within two months of each proposal round's deadline. The panel currently consists of six sub-committees, whose members are from universities and research institutions from all over Europe. The individual subcommittees cover the different scientific fields as magnetism and spectroscopy, structure research, soft matter, biology, imaging analysis and nuclear and partical physics as well as materials research.

During a meeting at the FRM II these committees rank the proposals according to their scientific merit and suggest the distribution of the available beam time to the directorate of the MLZ. On average, two-thirds of the submitted applications receive beam time, i.e. about 50 % of the requested beam days can be accepted.



Shortly after the committee meeting the user gets notified, if his proposal was accepted or not. If the application was approved, the next step is to contact the instrument scientist in order to schedule the experiment.

When the date for the experiment is set, the User Office sends out a detailed invitation letter to the main proposer by email. This letter also informs about who will support the experiment as local contact. As soon as possible each scientist who wants to participate in the experiment has to announce his visit online to the User Office. An early announcement enables the smooth access to the site of the FRM II. Within this procedure it is also possible to ask for assistance reserving a hotel room. Unfortunately, the User Office can not give any help regarding flights or train tickets.

Publications and experimental reports

After performing the experiment at an MLZ instrument we kindly request the submission of an experimental report within two months. Failure to do so may lead to rejection of subsequent proposals. All experimental reports are archived and accessible via the web within the personal user account. Please note: This is only possible after twelve months after the end of the experiment.

Every year the reports of the year before last are published as a pdf document on the web pages of the MLZ.

Our Terms of Reference say that the local contact in charge of the experiment is inluded as coauthor in publications mainly dealing with the results of the measurements. Furthermore users are obliged to notify their local contacts about any publication of the results achieved at the MLZ. Please keep in mind, that without his help during the measurement and providing the instrument the experiments would not be possible. In addition a note indicating the support received from the MLZ or other institutions should appear in the acknowledgement of any publication. For details please refer to our web pages.

Financial support

MLZ is a member of the European Consortium of Infrastructures for Neutron Scattering and Muon Spectroscopy, NMI3.

The EU funds grant free access to our facility and provide support for travel and subsistence expenses for up to two scientists per experiment. A proposal is eligible if the main proposer and the majority of the coproposers work at institutions or universities in a European state or an associated country other than Germany. In case there are more than two participants in the experiment at the MLZ, the group can make the decision whom of them will be supported. The persons have to fulfil the conditions mentioned above.

If a proposal is financially supported by the EU via NMI3, the user has to send the claim for travel expenses with all necessary receipts as well as the user data form to the User Office and submit the EU-report online in addition to the obligatory experimental report. Please take care that you do not wait too long: The claiming process is only possible within six months after the experiment.

Furthermore there is a possibility to ask for financial support for users working at German universities. This support is granted by the MLZ and covers travel and accommodation costs for up to two persons who carry out an approved external experiment at the MLZ. Those persons have to work at a German university and the proposal must not be eligible for any other financial support like NMI3.

The reimbursement process is similar to that of NMI3.

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www.mlz-garching.de/user-office

Access to the MLZ

Certain points need particular attention when visiting the MLZ For access, a valid passport or ID-card is required. Driving licenses or other personal documents are not sufficient!

Security regulations

For users working at German institutes a nuclear reliability check will be performed in order to facilitate the access to the experimental halls. The declaration form has to be completed and signed and the original send by post to the MLZ. The check will be organized by our security department. Please note that this will take up to three months! Independent of the status of the nuclear reliability check the access to the experiment will be possible at any time. Without a valid security clearance, however, the user has to be checked by the security each time he enters the Experimental Hall.

The declaration form can be obtained from the download area of the User Office web page. If a nuclear reliability check exists due to previous visits at other nuclear facilities in Germany, this has to be indicated in the declaration form.

Arriving at the MLZ

The reception at the entrance gate will be the first place to go. Here the users will get their process slips and additional useful information. Also the personal badge valid for this stay will be issued. This badge and the completed process slip have to be returned upon departure. The local contact will be informed about the arrival. Before starting the measurements, everybody has to enrol at the radiation protection office. There, one has to prove that the safety training was undergone. If this is the first visit at the MLZ or it is more than one year since the last safety training one has to complete it first before starting to work.

Please keep always in mind, that those regulations are subject to change without prior notice. The web pages of the User Office provide all users always with the latest information.

Radiation protection

In order to comply with the official regulations of radiation protection, each user must follow strictly the rules. Details are given in the safety training and all information regarding the preparations can be found at the User Office web pages.

There are different regulations for users working at German institutions and scientists from abroad. The latter are additionally subdivided into those who are radiological workers and those who have never worked in a controlled area before. For both categories there are forms available at the User Office download area. The completed and signed documents have to be presented to the radiation protection department at the MLZ prior to start an experiment.

Important for German users: They need a “Strahlenpass” (radiation passport) with dose records not older than three months. They have to carry their own dosimeter (capable of detecting neutrons and gamma radiation). In addition their home institution needs a valid license according to §15 StrlSchV as well as an ‘Abgrenzungsvertrag’ (contract with

TUM defining responsibilities of radiation protection departments).

To learn more about the current regulations, please look at our web pages, section radiation protection.

Sample handling

Any sample or material brought into the experimental hall and the neutron guide hall must be checked by the radiation safety department for clearance before removal from the areas. Special attention must be paid, if an already activated sample is brought along. Please inform the radiation protection service well in advance. Your local contact will assist you in this matter.

Terminal room

A terminal room is available on site allowing users to have access to the internet as well as the possibility to control experiments remotely and access data. Details on the access to the terminal room are provided by the local contact.

Conferences and meetings

In regular intervals, the MLZ invites all users to a User Meeting held in Garching. The meeting is organized in order to discuss recent scientific results presented by the user community. Moreover the MLZ provides updated information concerning the instruments and experimental possibilities.

Workshops on different topics related to the use of neutrons are organized regularly, too. Announcements will be published on the web pages and in the biannual newsletter.

The MLZ participates in national and international conferences on neutron scattering. Besides contributions about recent scientific achievements, updated information on the instruments and available infrastructure are presented. Furthermore you can meet instrument scientists and the User Office staff at a booth, get your questions answered and receive some brochures and further information material.

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Partner institutions

Bayerisches Geoinstitut
Universität Bayreuth
www.bgi.uni-bayreuth.de

Georg-August-Universität Göttingen

- Institut für Physikalische Chemie
  www.uni-pc.gwdg.de/eckold
- Geowissenschaftliches Zentrum
  www.gzg.uni-goettingen.de

German Engineering Materials Science Centre GEMS
Helmholtz-Zentrum Geesthacht GmbH
www.hzg.de

Helmholtz-Zentrum Berlin
für Materialien und Energie GmbH
www.helmholtz-berlin.de

Jülich Centre for Neutron Science JCNS
Forschungszentrum Jülich GmbH
www.jcns.info

Karlsruher Institut für Technologie

- Institut für Angewandte Materialien –
  Energiespeichersysteme (IAM-ESS)
  www.iam.kit.edu

Ludwig-Maximilians-Universität München

- Sektion Kristallographie
  www.lmu.de/kristallographie
- Sektion Physik
  www.softmatter.physik.uni-muenchen.de

Max-Planck-Institut für Festkörperforschung, Stuttgart
www.fkf.mpg.de

Paul Scherrer Institut

- Labor für Radio- und Umweltchemie
  www.psi.ch/lch

RWTH Aachen

- Institut für Kristallographie
  www.xtal.rwth-aachen.de
- Institut für Anorganische Chemie
  www.ac.rwth-aachen.de

Technische Universität Clausthal

- Institut für Werkstoffkunde und Werkstofftechnik
  www.iww.tu-clausthal.de

Technische Universität Dresden

- Institut für Festkörperphysik
  www.physik.tu-dresden.de/ifp

Technische Universität München

- E13 – Lehrstuhl für Funktionelle Materialien
  www.e13.physik.tu-muenchen.de
- E18 – Lehrstuhl für Experimentalphysik I
  www.e18.ph.tum.de
- E21 – Lehrstuhl für Neutronenstreuung
  www.e21.ph.tum.de
- Exzellenzcluster „Origin and Structure of the Universe“
  www.universe-cluster.de
- Klinikum Rechts der Isar
  www.med.tum.de
- RCM - Radiochemie München
  www.rcm.tum.de

Universität der Bundeswehr München

- Institut für Angewandte Physik und Messtechnik
  www.unibw.de/lrt2

Universität zu Köln

- Institut für Kernphysik
  www.ikp.uni-koeln.de
- II. Physikalisches Institut
  www.ph2.uni-koeln.de

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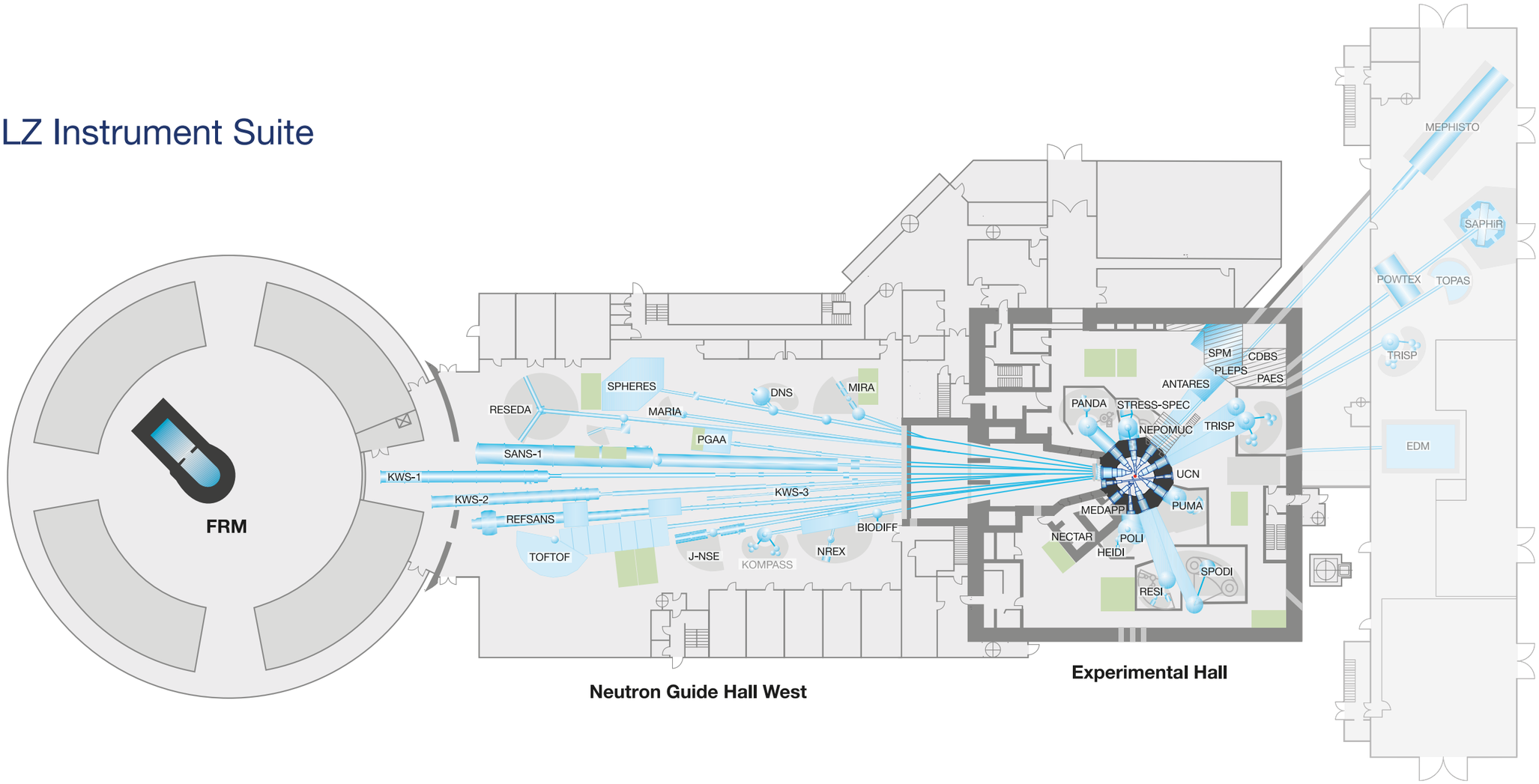
MLZ Instrument Suite



Instrument	Description	Neutrons	Status	Operated by	Funding
ANTARES	Radiography and tomography	cold	operation	TUM	TUM
BIODIFF	Diffractometer for large unit cells	cold	operation	TUM, JCNS	TUM, FZJ
DNS	Diffuse scattering spectrometer	cold	operation	JCNS	FZJ
HEIDI	Single crystal diffractometer	hot	operation	RWTH Aachen	FZJ
J-NSE	Spin-echo spectrometer	cold	operation	JCNS	FZJ
KOMPASS	Three axes spectrometer	cold	construction	Uni Köln, TUM	BMBF
KWS-1	Small angle scattering	cold	operation	JCNS	FZJ
KWS-2	Small angle scattering	cold	operation	JCNS	FZJ
KWS-3	Very small angle scattering	cold	operation	JCNS	FZJ
MARIA	Magnetic reflectometer	cold	operation	JCNS	FZJ
MEPHISTO	Facility for particle physics, PERC	cold	reconstruction	TUM	TUM, DFG
MIRA	Multipurpose instrument	cold	operation	TUM	TUM
MEDAPP	Medical irradiation treatment	fast	operation	TUM	TUM
NECTAR	Radiography and tomography	fast	operation	TUM	TUM
NEPOMUC	Positron source, CDBS, PAES, PLEPS, SPM	-	operation	TUM, UniBw München	TUM, BMBF
NREX	Reflectometer with X-ray option	cold	operation	MPI Stuttgart	MPG
PANDA	Three axes spectrometer	cold	operation	TU Dresden, JCNS	FZJ

Instrument	Description	Neutrons	Status	Operated by	Funding
PGAA	Prompt gamma activation analysis	cold	operation	Uni Köln, PSI	TUM
PUMA	Three axes spectrometer	thermal	operation	Uni Göttingen, TUM	TUM
POLI	Single-crystal diffractometer polarized neutrons	hot	operation	RWTH Aachen	BMBF, FZJ
POWTEX	Time-of-flight diffractometer	thermal	construction	RWTH Aachen, Uni Göttingen, JCNS	BMBF, FZJ
REFSANS	Reflectometer	cold	operation	GEMS	HZG
RESEDA	Resonance spin-echo spectrometer	cold	operation	TUM	TUM
RESI	Single crystal diffractometer	thermal	operation	LMU	TUM
SANS-1	Small angle scattering	cold	operation	TUM, GEMS	TUM, HZG
SAPHIR	Six anvil press for radiography and diffraction	thermal	construction	BGI	BMBF
SPHERES	Backscattering spectrometer	cold	operation	JCNS	FZJ
SPODI	Powder diffractometer	thermal	operation	KIT	TUM
STRESS-SPEC	Materials science diffractometer	thermal	operation	TUM, TU Clausthal, GEMS	TUM, HZG
TOFTOF	Time-of-flight spectrometer	cold	operation	TUM	TUM
TOPAS	Time-of-flight spectrometer	thermal	construction	JCNS	FZJ
TRISP	Three axes spin-echo spectrometer	thermal	operation	MPI Stuttgart	MPG
UCN	Ultra cold neutron source, EDM	ultra-cold	construction	TUM	TUM, DFG

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