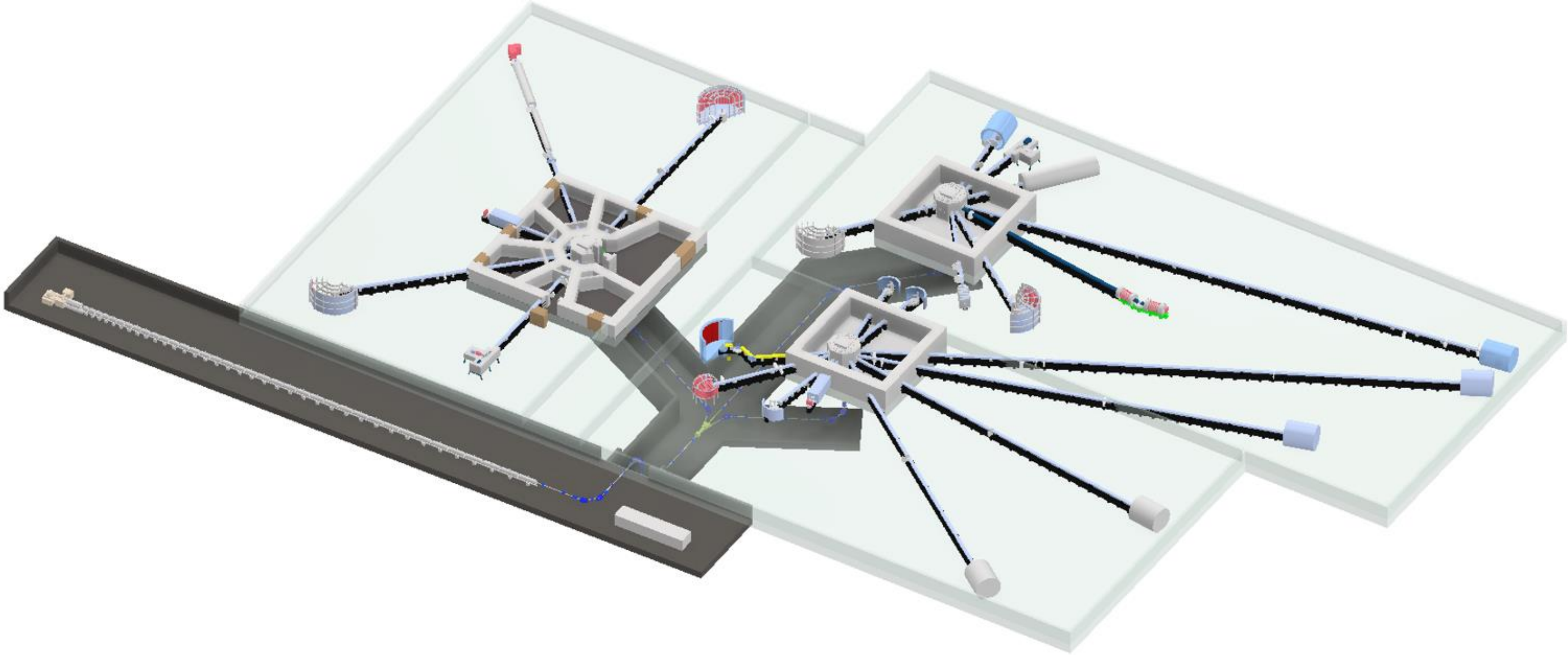


Conceptual Design of Neutron Imaging Instruments for the HBS

13.12.2022 | Norberto Schmidt, M. Strobl, N. Kardkilov, J. Dawidowski, E. Mauerhofer, T. Gutberlet, T. Brückel

Jülich Centre for Neutron Science (JCNS-2/PGI-4) - Instituto Balseiro (IB)

JÜLICH Forschungszentrum

Jülich Centre for Neutron Science

Instituto Balseiro

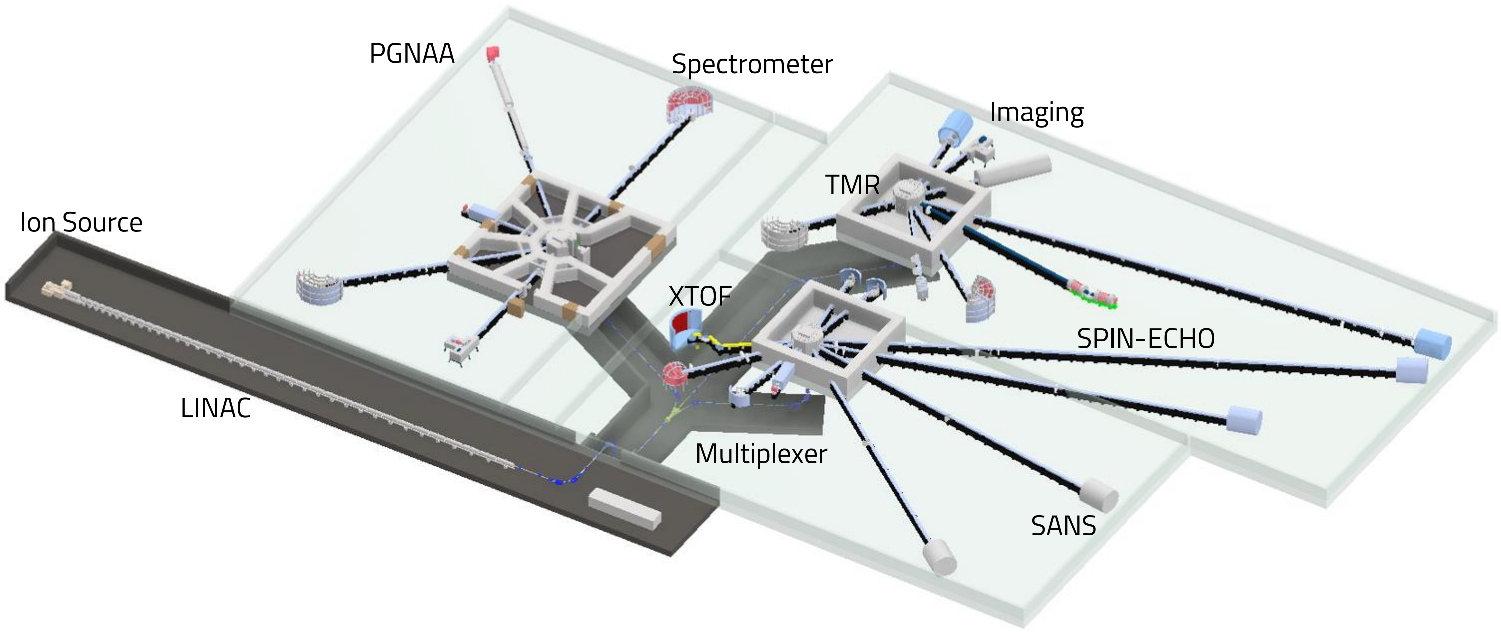
Summary

1. High Brilliance Neutron Source
2. Neutron Imaging Instruments
3. PhD Objectives and Work Schedule
4. Conceptual Design of the Neutron Imaging Instruments
5. Preliminary Results
6. Future Work

High Brilliance Neutron Source

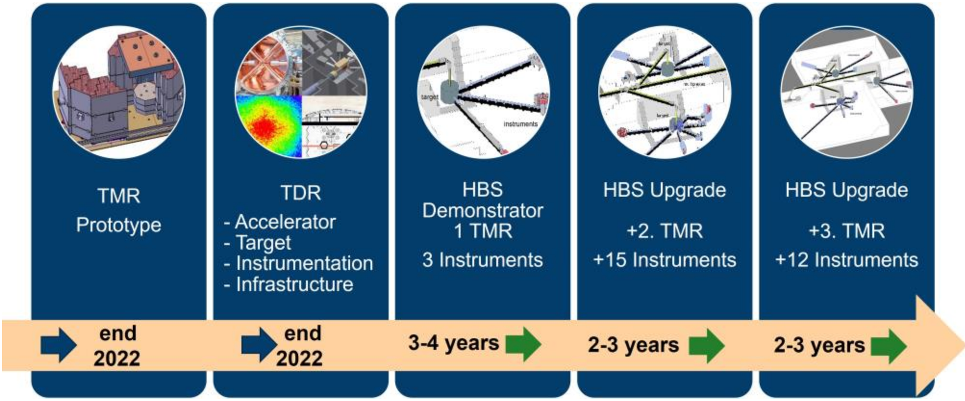
Accelerator:

- Average Power: 100 kW
- Proton Energy: 70 MeV
- Duty Cycle: 1.6 %
- Proton Current: 89.3 mA
- Neutron target: Tantalum



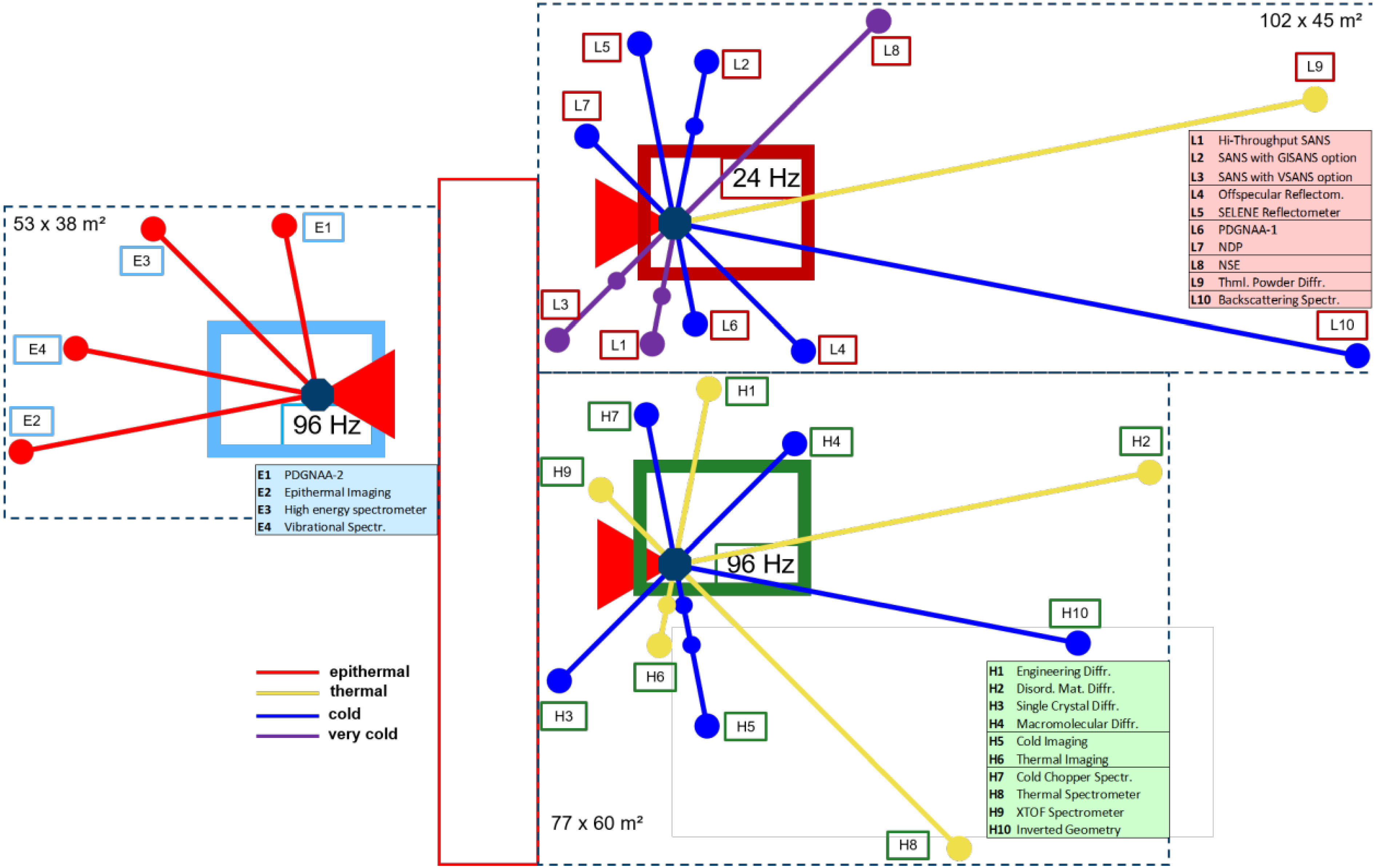
3 Target-Moderator-Reflector (TMR) Stations:

Frequency [Hz]	Period [ms]	Duty cycle [%]	Pulse width [μs]	Purpose
24	41.7	1.60	667	Long pulse, cold neutrons
96	10.4	1.60	167	Medium pulse, thermal neutrons
96	10.4	1.60	167 (down to 10)	Short pulse, epithermal neutrons



Instruments investigated for the Technical Design Report (TDR)

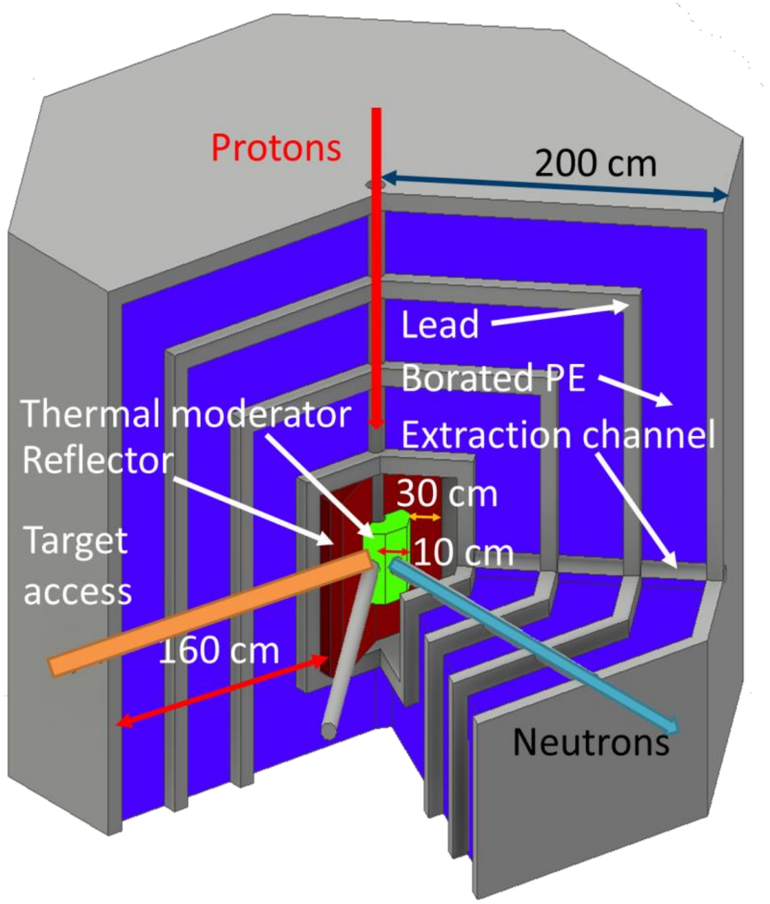
- 3 Analytics Instruments
- 5 Diffractometers
- 5 Large Scale Structure Instruments
- 7 Spectrometers
- **5 Imaging Instruments**



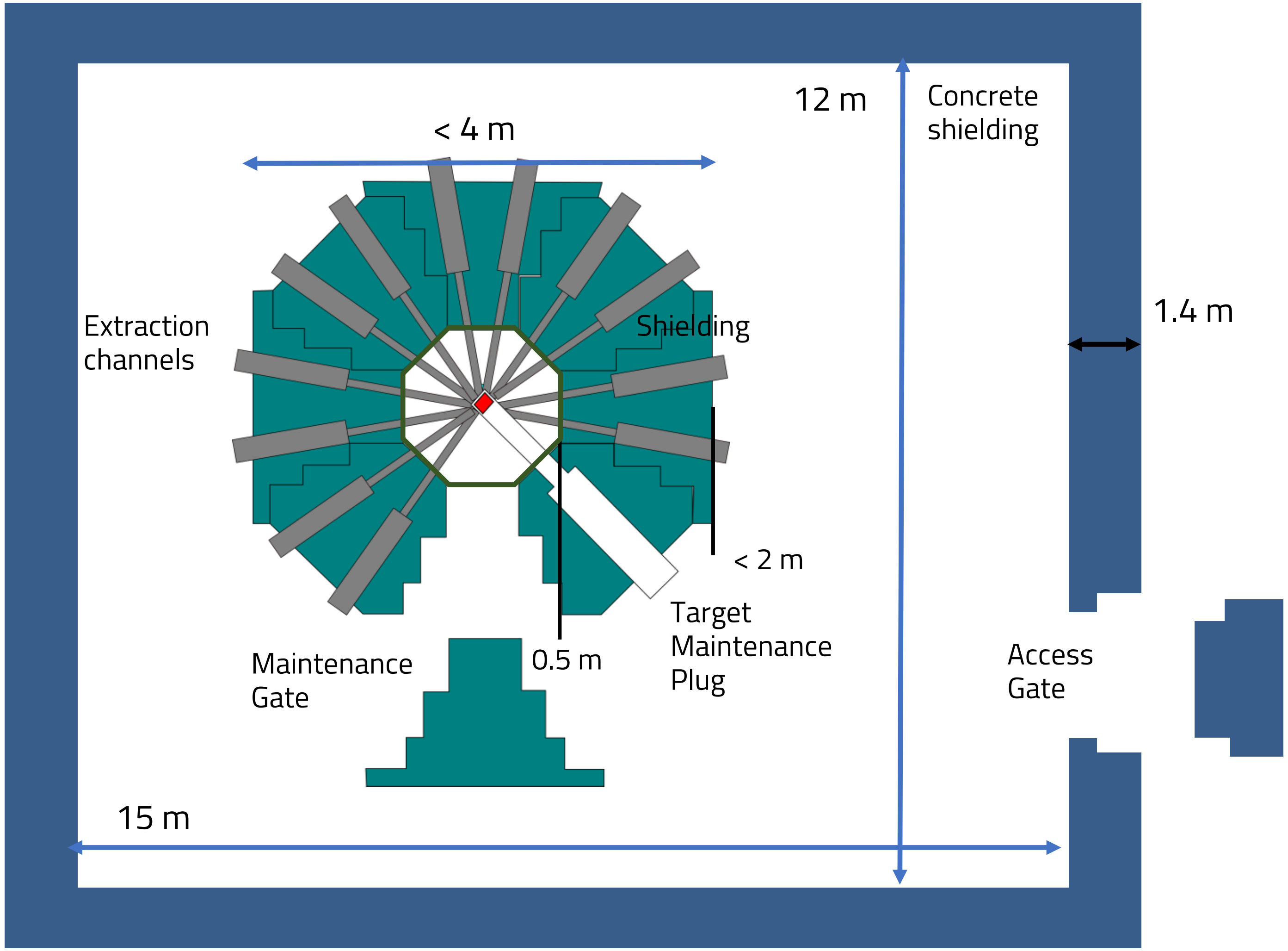
High Brilliance Neutron Source

TMR Station

(old model, now the proton beam comes from the bottom)



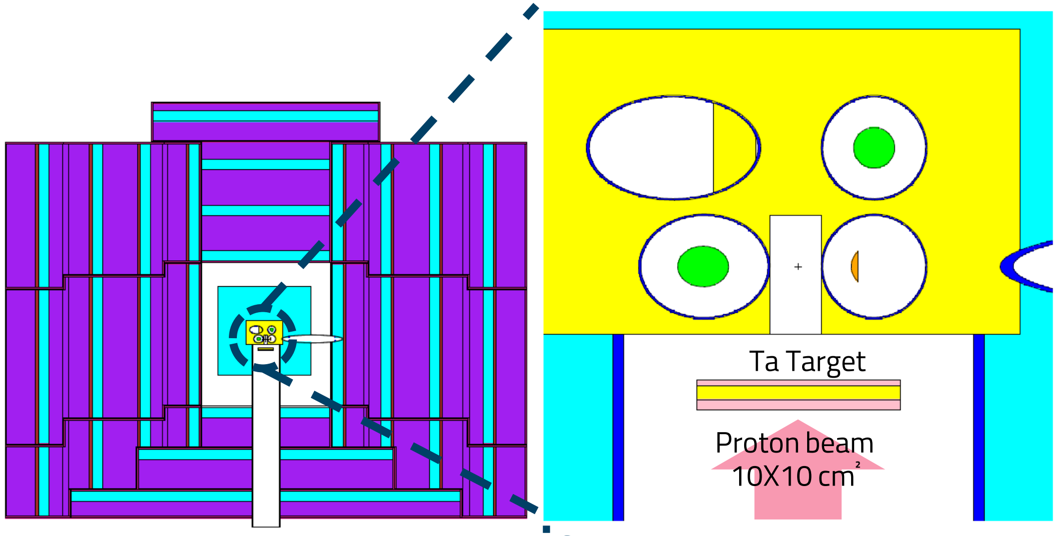
Shielding around the TMR



High Brilliance Neutron Source

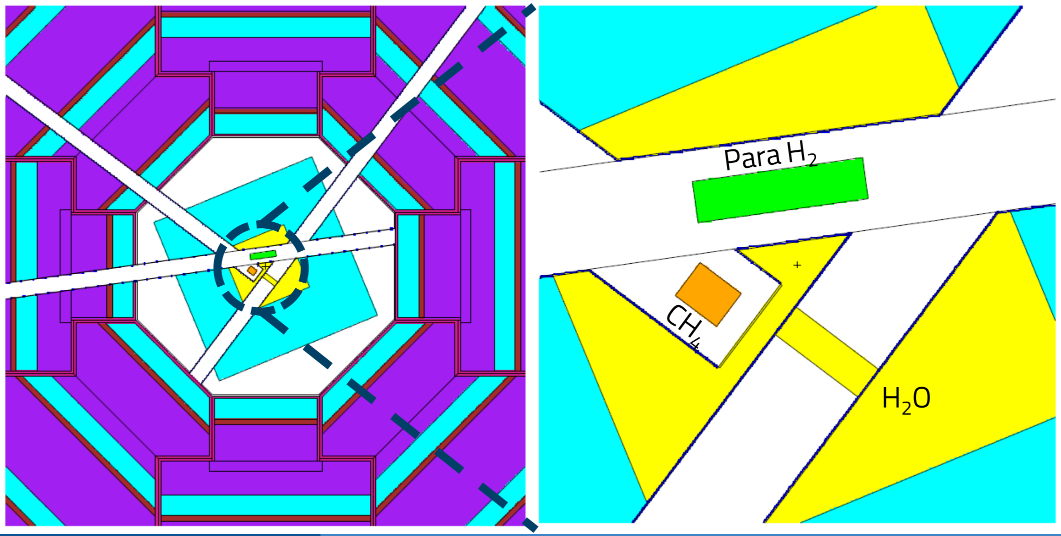
Target-Moderator-Reflector Station:

- Cold moderator diameter: 2.4 cm
- Thermal moderator size: 25 X 20 cm
- Reflector size: 70 x 70 cm



xz view

xy view

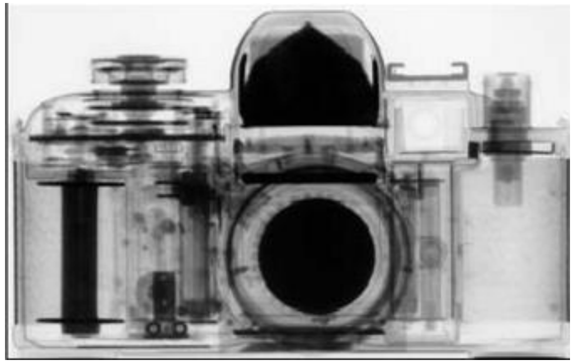


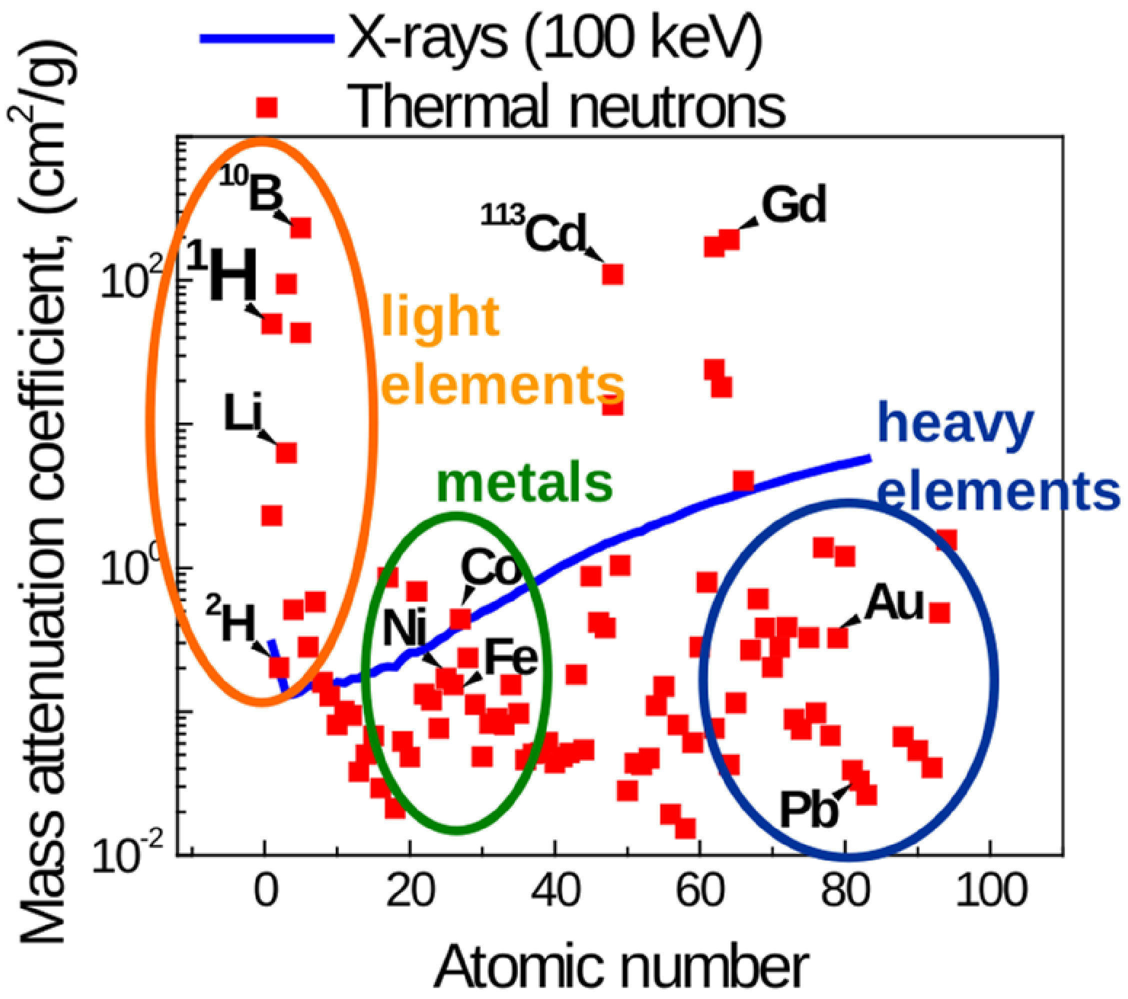
Moderators:

Moderator	State	Temperature [K]	Energy range
Methane (CH_4)	Solid	22	Cold
Para-hydrogen (H_2)	Liquid	20	Cold
Water (H_2O)	Liquid	293.6	Thermal
Heavy water (D_2O)	Liquid	293.6	Epithermal
Lithium fluoride (^7LiF)	Solid	293.6	Epithermal

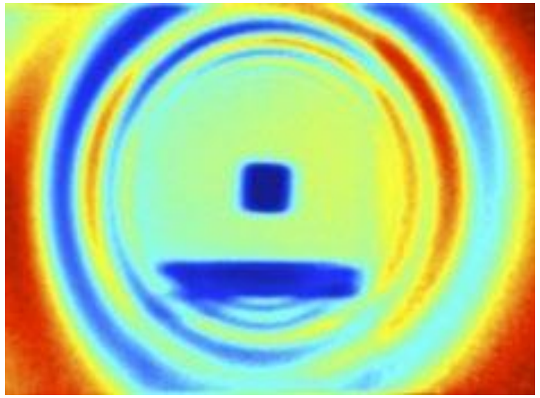
Neutron Imaging Instruments


Radiography example [1]


Neutrography example [1]



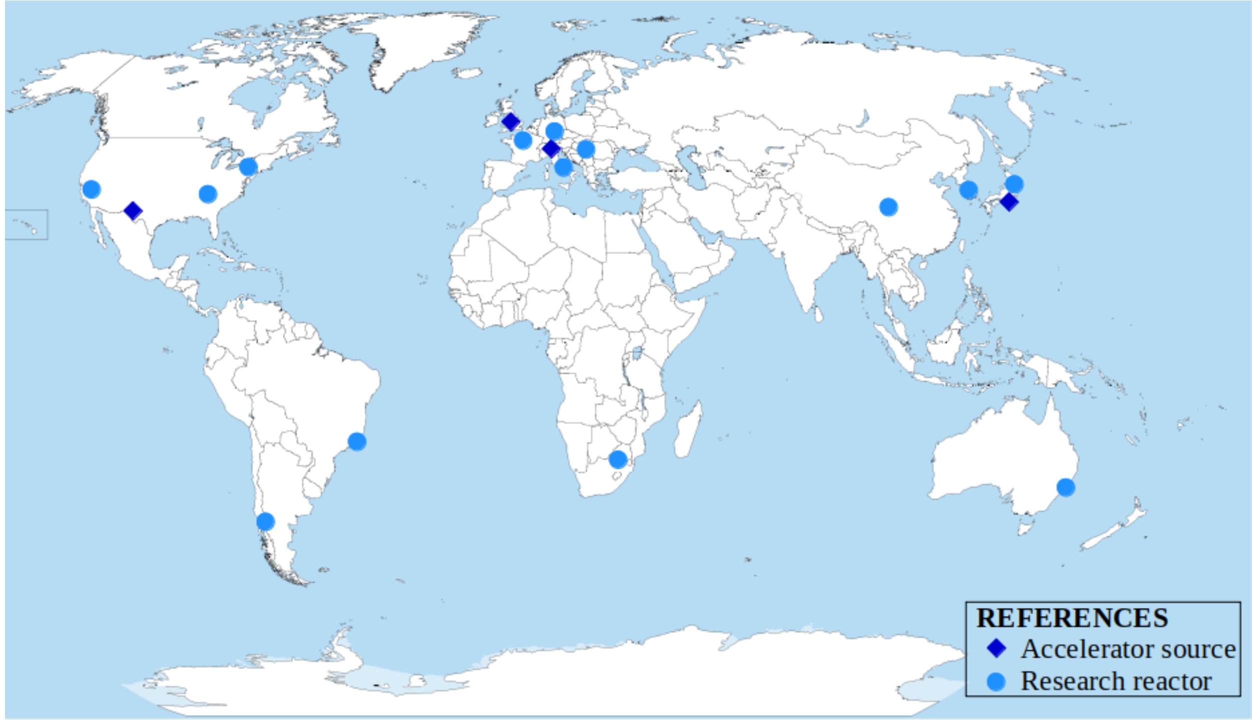
Mass attenuation coefficient, for X-rays and thermal neutrons, as function of the atomic number [1]


Distribution of magnetic fields [3]

Water uptake in plant's root [2]

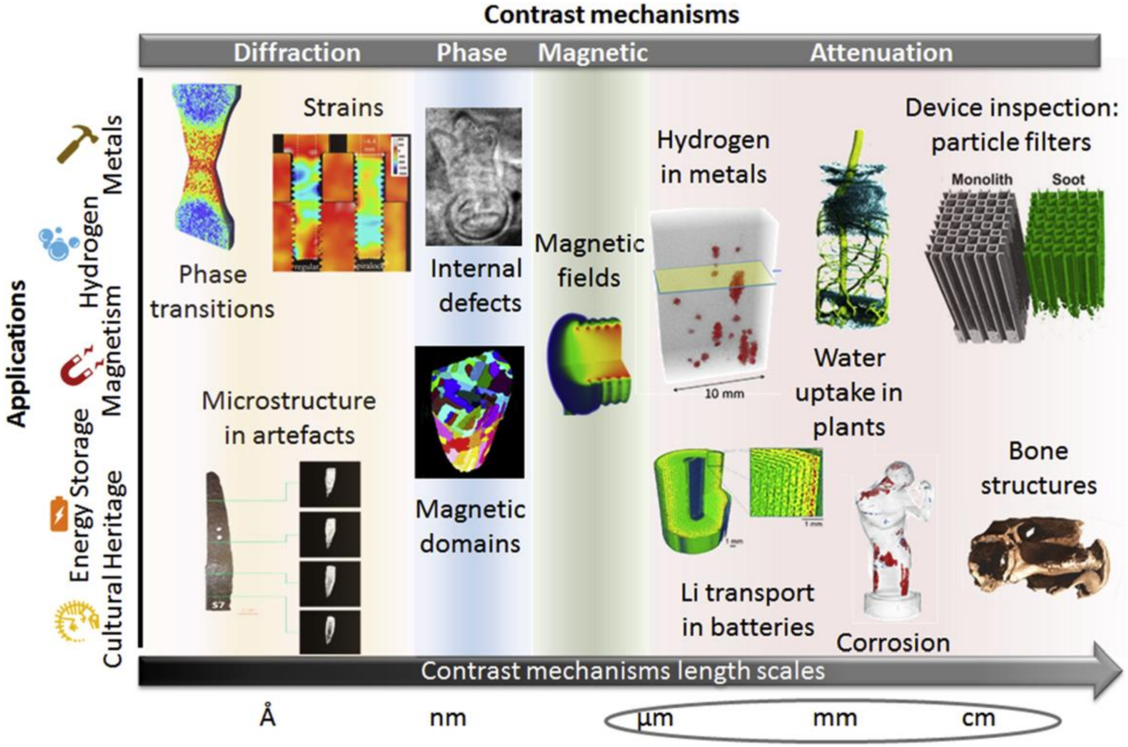

Tomography of a bronze sculpture [3]

Neutron Imaging Instruments



Most important neutron imaging facilities under operation around the world by source type, according to [4], [5]

Total: ~50 facilities worldwide



Contrast mechanisms and application fields [2]

PhD Objectives and Work Schedule

General objective: Design and optimize instruments for time-of-flight cold, thermal and epithermal neutron imaging, within the framework of the High Brilliance Neutron Source (HBS) project at the Jülich Centre for Neutron Science (JCNS)

1) Baseline study	2) Source simulations	3) Instrument design	4) Prototype development	5) Prototype testing
NI instruments to be considered: - MLZ (Germany) - BER-II (Germany) - PSI (Switzerland) - ISIS (UK) - J-PARC (Japan) - LANL (USA) - RA-6 (Argentina)	- HBS model simulations with Monte Carlo codes - Cold and thermal neutron spectra analysis - Epithermal and fast spectra development	- Instruments simulations with VITESS and McStas - Neutron optics - Cold and thermal instruments - Epithermal instrument - Fast instrument	- Collimator development - TMR for epithermal and fast neutrons - Detectors development	- Test of optical components and ToF settings at Big Karl

Conceptual Design of the Neutron Imaging Instruments

Neutrons attenuation law:

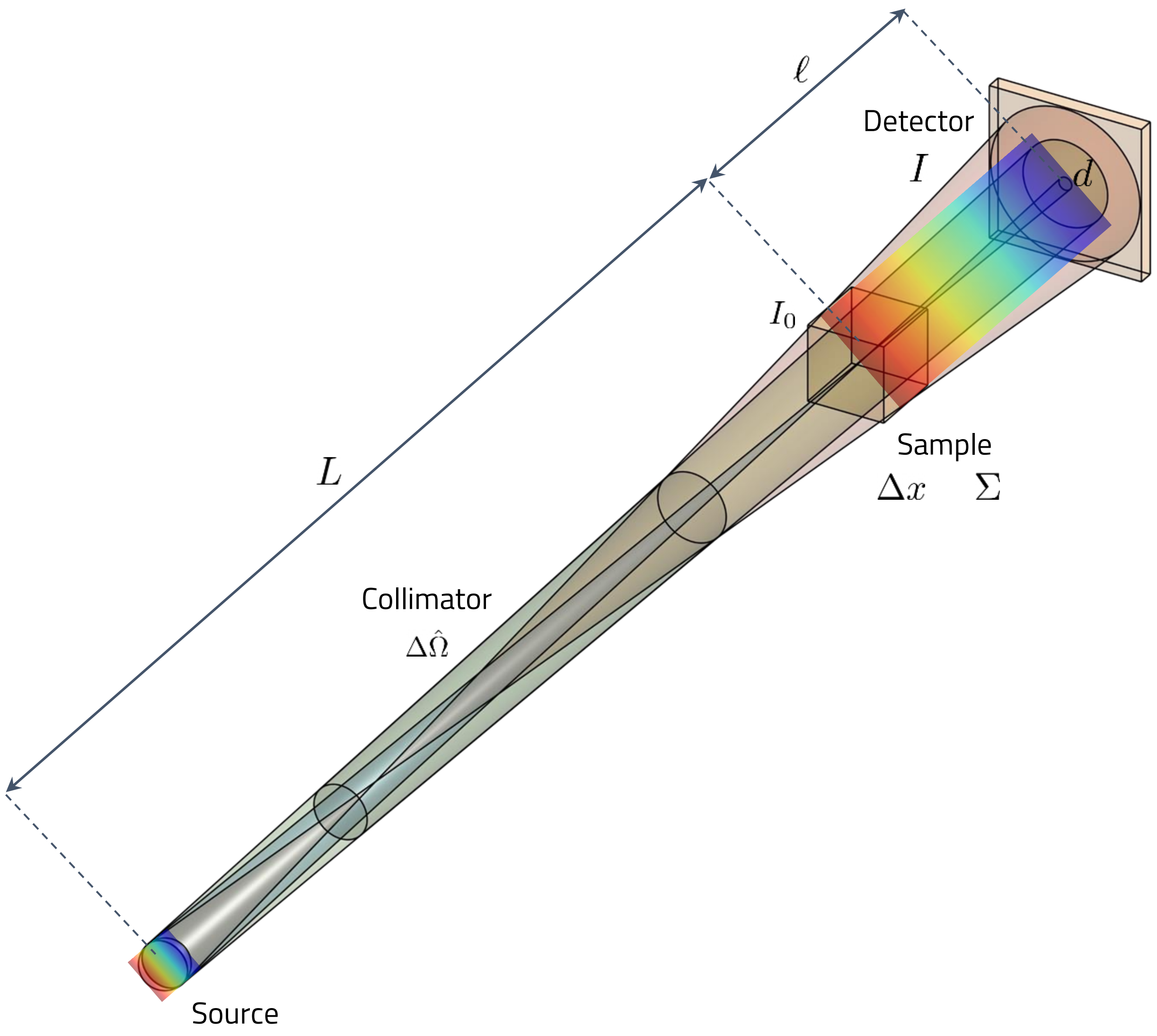
$$I(E) = I_0(E) \cdot e^{-\Sigma(E)\cdot\Delta x}$$

Spatial resolution equation:

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

Intensity at the sample:

$$I(E) \propto \phi(E) \cdot \frac{\Delta\Omega}{4\pi} \approx \frac{\phi(E)}{16\,(L/D)^2}$$



Time-of-flight correlations:

$$\frac{t_f\ [\mu s]}{L\ [m]} = \frac{72.3}{\sqrt{E\ [eV]}} = 252.8\,\lambda\,[\text{Å}]$$

$$\frac{\delta E}{E} = 2\frac{\delta\lambda}{\lambda} \approx 2\frac{\delta t_f}{t_f}$$

Bandwidth (frame overlap):

$$\Delta\lambda[\text{Å}] \leq \frac{\tau_p\ [\mu s]}{252.8\,L\ [m]}$$

Conceptual Design of the Neutron Imaging Instruments

TMR Source Simulations → **Virtual Sources Generation** → **Instruments Simulations**

PHITS
Particle and Heavy Ion Transport code System

- Cold
- Thermal
- Epithermal
- Fast

KDSource

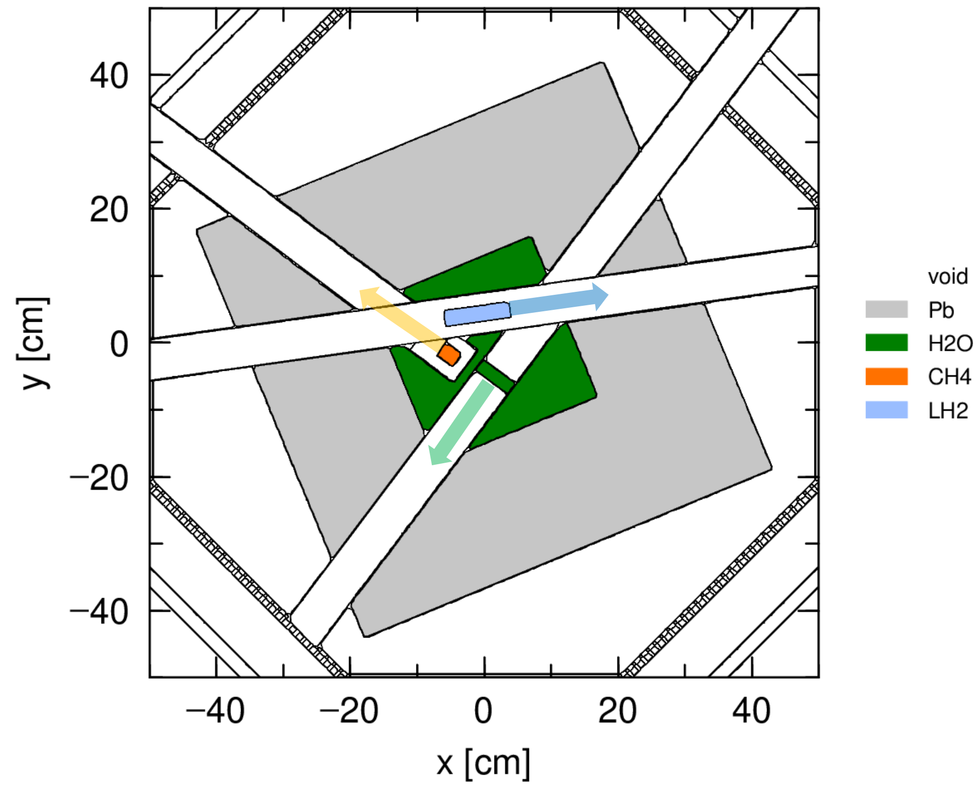
- Machine learning algorithms
- Resampling from the original sources

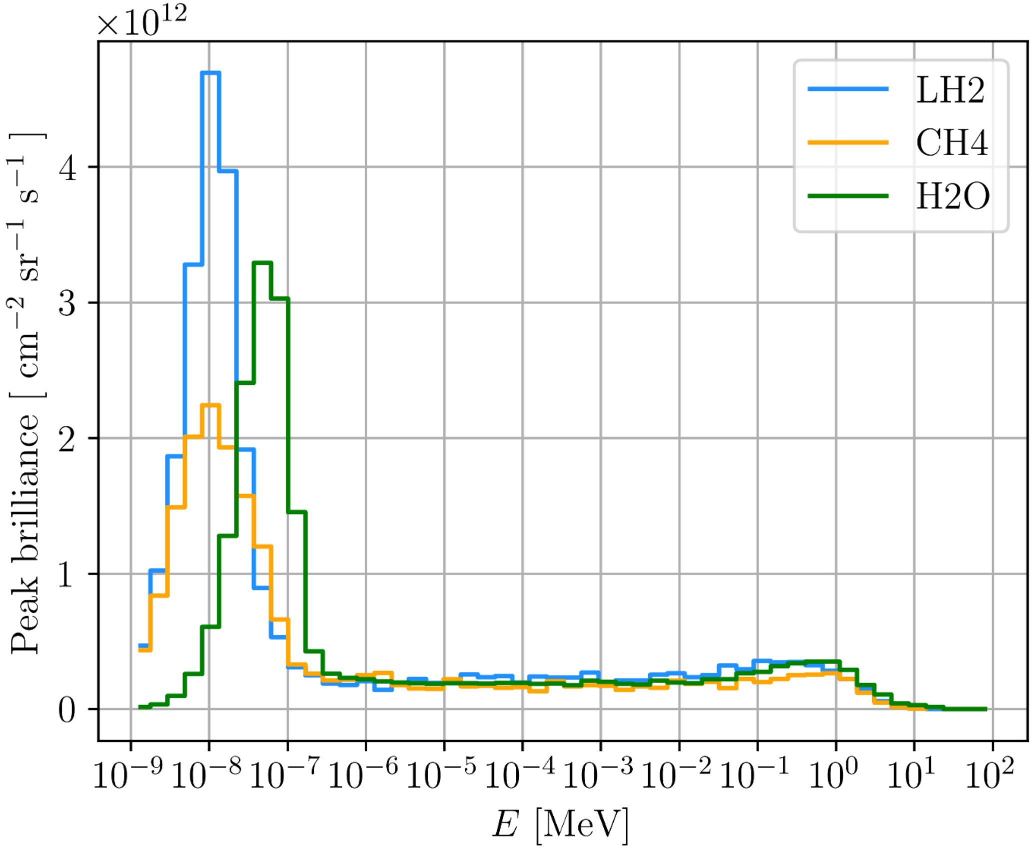
VITESS McStas

- Flux at the sample
- Field of view (FOV)
- Collimation (L/D)
- Spatial distribution
- TOF distribution
- Frame overlap

Preliminary Results

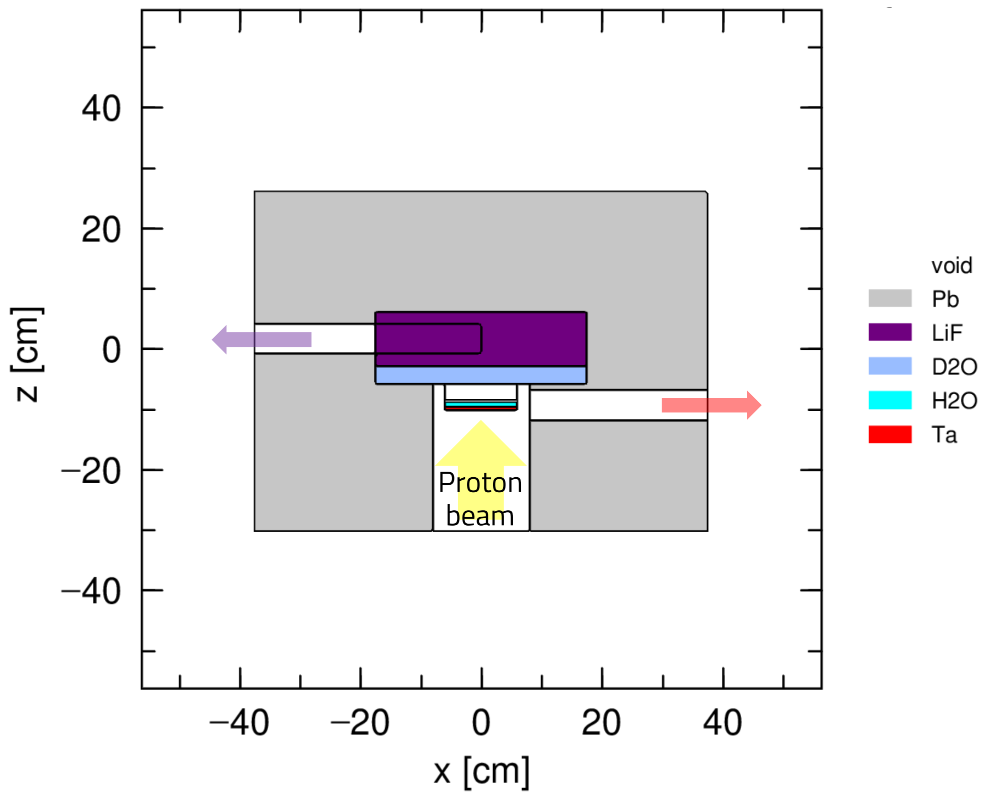
Thermal and Cold Moderators Simulations – Energy distribution

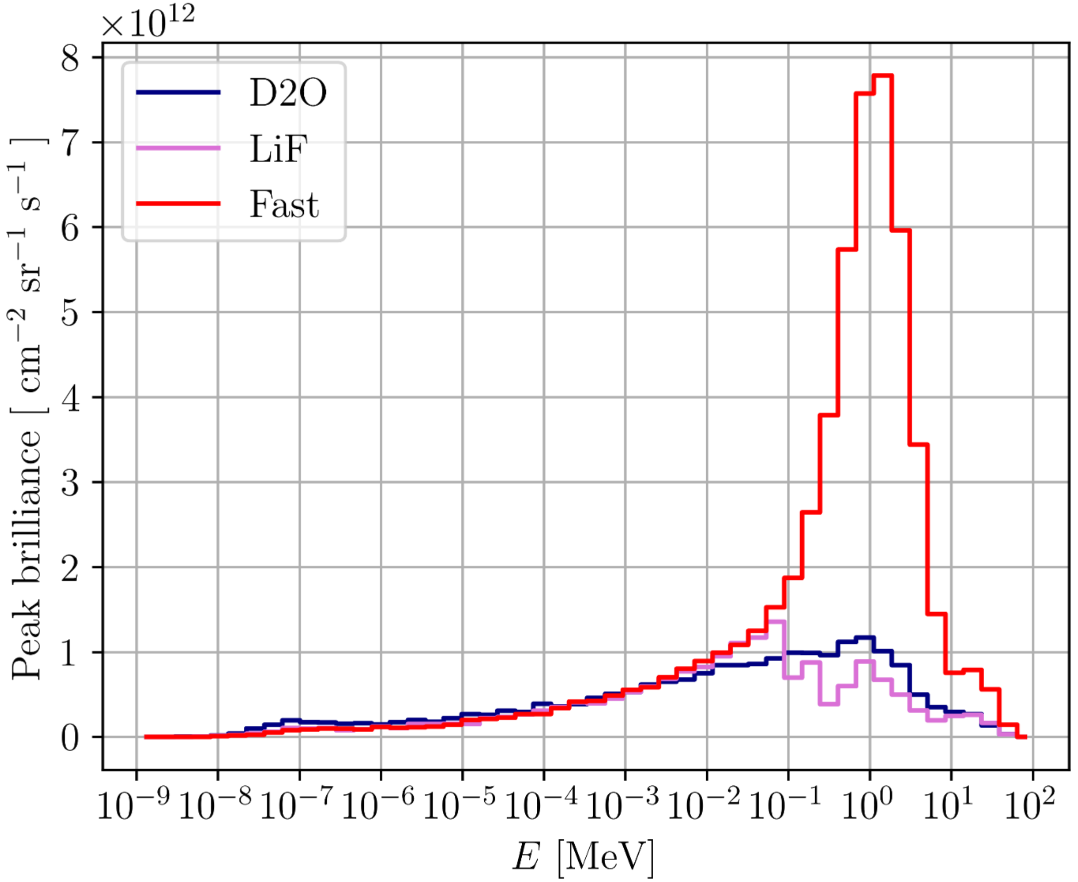




Preliminary Results

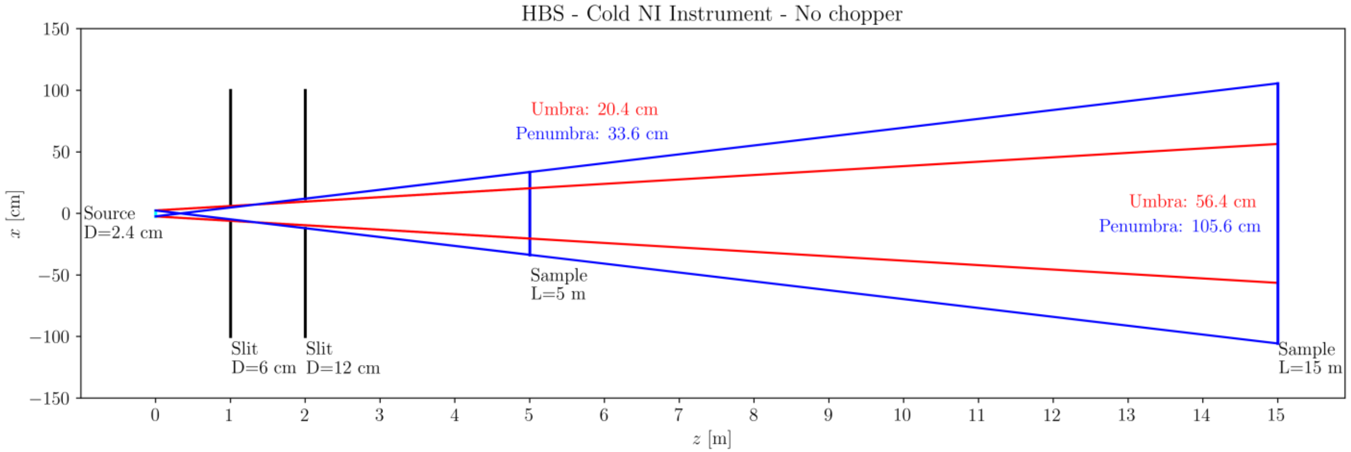
Epithermal Moderators Simulations – Energy distribution

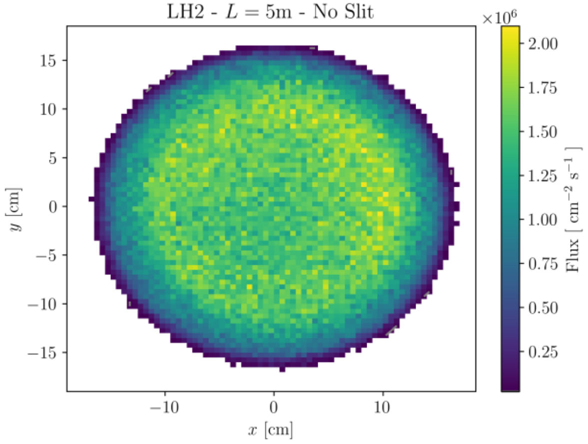


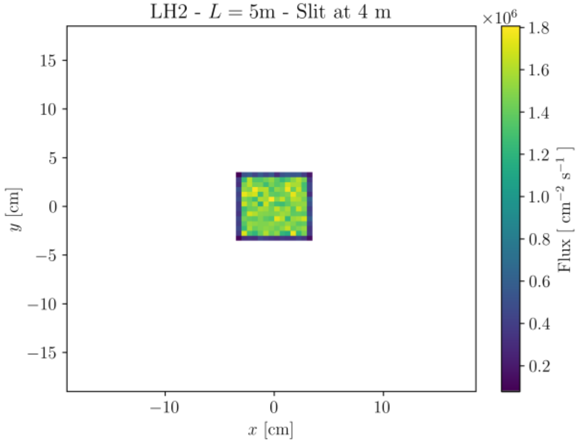


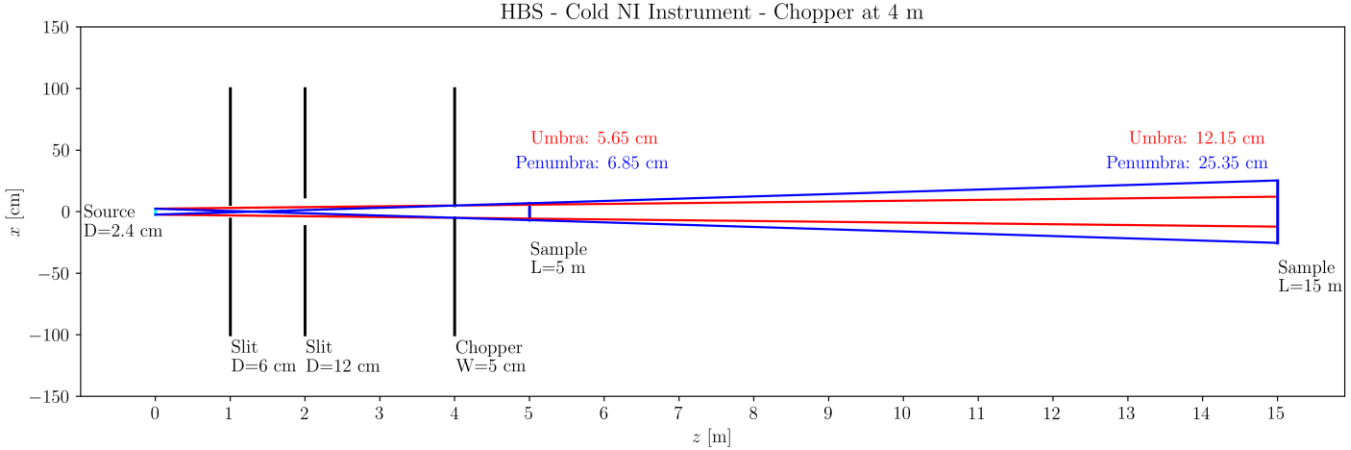
Preliminary Results

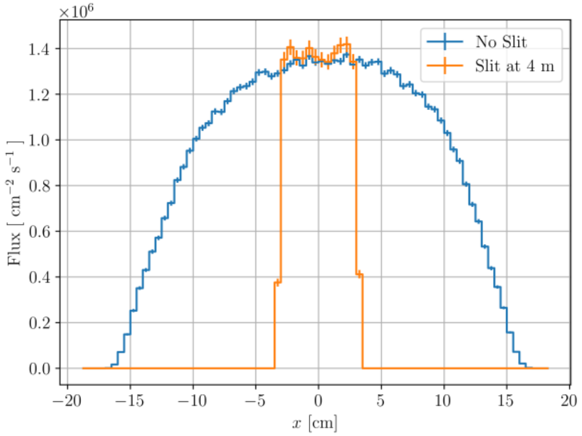
Neutron Imaging Cold Instrument Simulations – Spatial distribution

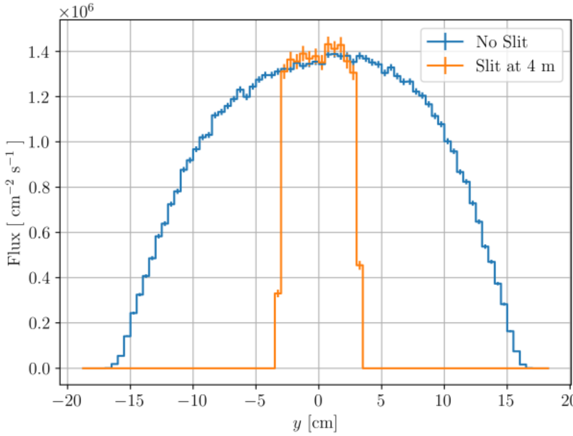








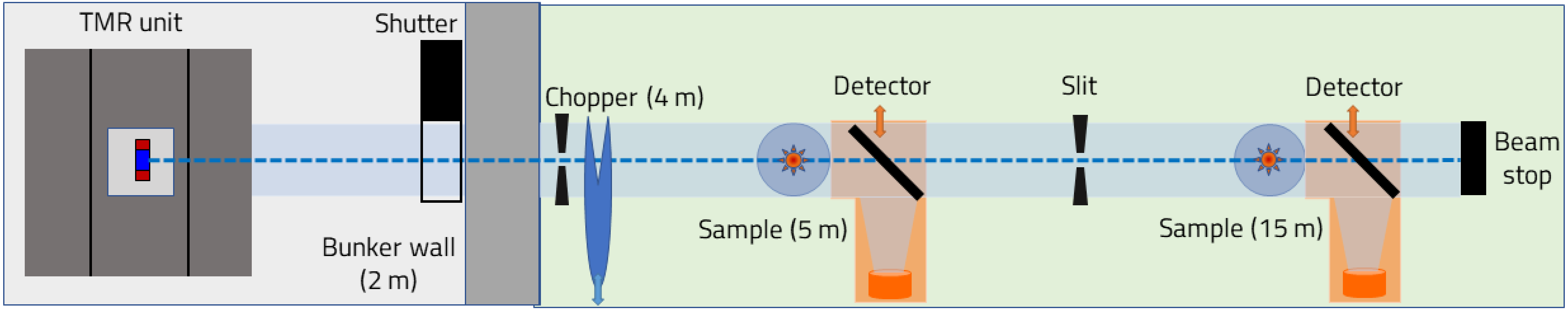




Preliminary Results

Main Parameters for the Neutron Imaging Instruments

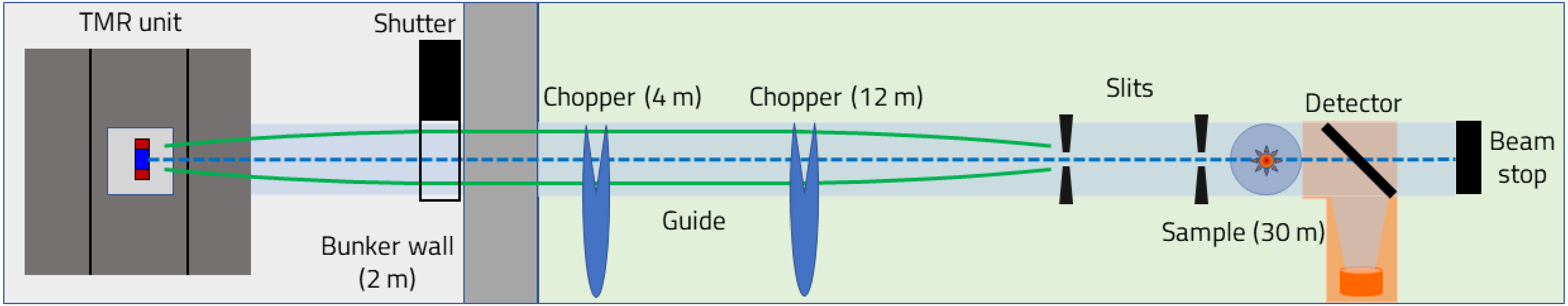
Instrument	Energy range	Wavelength range	Chopper	Guide	Sample positions [m]	Flux at sample [n/(cm² s)]	FOV [cm²]	Collimation L/D	Spatial resolution	Energy/wavelength resolution
Cold (96 Hz)	0-10 meV	>2.9 Å	Yes	No	5 15	3×10^6 3×10^5	5 x 5 15 x 15	200 625	High	1 - 15 Å / 8 Å, 5% 1 - 15 Å / 3 Å, 1%



Preliminary Results

Main Parameters for the Neutron Imaging Instruments

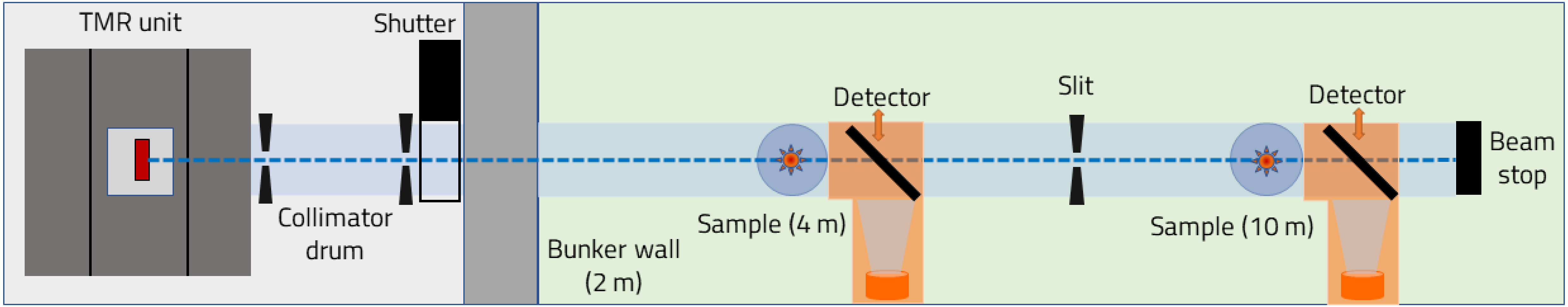
Instrument	Energy range	Wavelength range	Chopper	Guide	Sample positions [m]	Flux at sample [n/(cm² s)]	FOV [cm²]	Collimation L/D	Spatial resolution	Energy/wavelength resolution
Diffractive (96 Hz)	0-10 meV	>2.9 Å	Yes	Yes	30	$5x10^6$	10 x 10	500	High	1 - 15 Å / 1.5 Å, 0.5%



Preliminary Results

Main Parameters for the Neutron Imaging Instruments

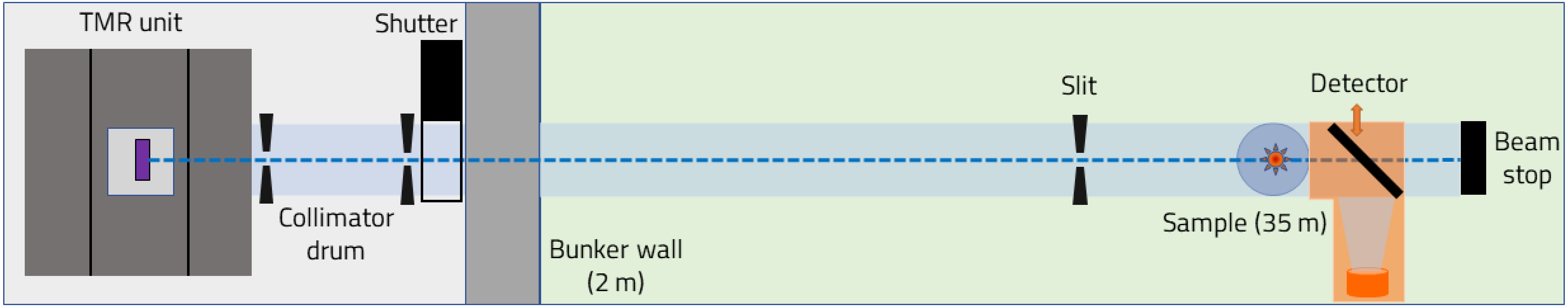
Instrument	Energy range	Wavelength range	Chopper	Guide	Sample positions [m]	Flux at sample [n/(cm² s)]	FOV [cm²]	Collimation L/D	Spatial resolution	Energy/wavelength resolution
Thermal (96 Hz)	10 meV – 0.5 eV	0.4 – 2.9 Å	No	No	4 10	3×10^7 Up to 3×10^6	15 x 15 35 x 35	65 165 (up to 500)	High	No



Preliminary Results

Main Parameters for the Neutron Imaging Instruments

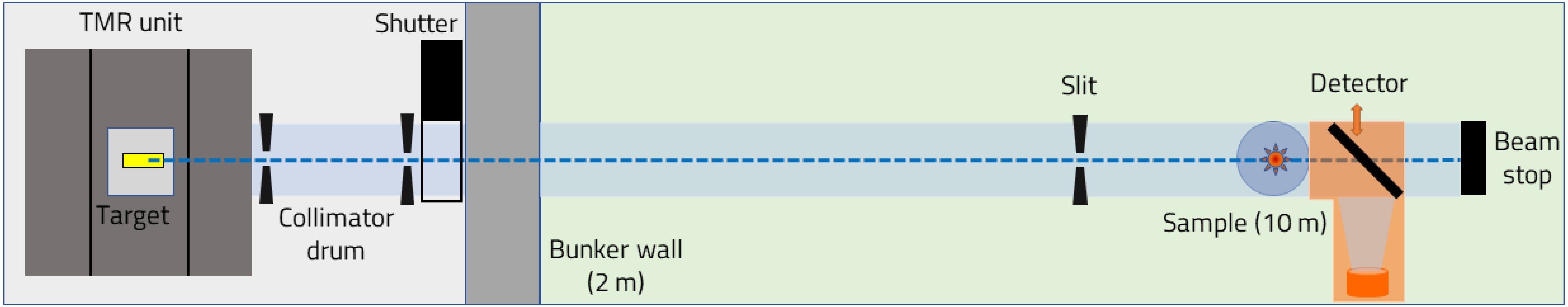
Instrument	Energy range	Wavelength range	Chopper	Guide	Sample positions [m]	Flux at sample [n/(cm² s)]	FOV [cm²]	Collimation L/D	Spatial resolution	Energy/wavelength resolution
Epithermal	0.5 eV – 10 keV	3 mÅ – 0.4 Å	No	No	35	2×10^5	50 x 50	600	Low	1 keV, 5%



Preliminary Results

Main Parameters for the Neutron Imaging Instruments

Instrument	Energy range	Wavelength range	Chopper	Guide	Sample positions [m]	Flux at sample [n/(cm² s)]	FOV [cm²]	Collimation L/D	Spatial resolution	Energy/wavelength resolution
Fast	1 keV – 70 MeV	< 3 mÅ	No	No	10	Up to $8x10^7$	20 x 20	100 (up to 500)	Low	No



Future Work

1) Optimization of the TMR design for epithermal neutrons

2) Simulation of the cold lines with a neutron guide inside the TMR channel

3) Design of the Neutron Imaging instruments with KDSource, McStas and VITESS

PHITS Particle and Heavy Ion Transport code System KDSource McStas VITESS

   a) Variables to optimize: L/D, homogeneity, flux, frame overlap

   b) Instruments to simulate: choppers, neutron guides, pinholes

4) Test of optical components and time-of-flight settings at Big Karl

References

- [1] Kardjilov, N. (2019). Neutron imaging. Oxford School on Neutron Scattering.
- [2] Kardjilov, N., Manke, I., Woracek, R., Hilger, A., & Banhart, J. (2018). Advances in neutron imaging. Materials Today, 21(6), 652-672.
- [3] PSI (2011). Neutron Imaging at the spallation source SINQ: information for potential users and customers. Technical report.
- [4] International Society for Neutron Radiography (2019). Neutron Imaging Facilities Survey. Technical report.
- [5] Lehmann, E. H., Vontobel, P., Frei, G., Kuehne, G., & Kaestner, A. (2011). How to organize a neutron imaging user lab? 13 years of experience at PSI, CH. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 651(1), 1-5.

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GSI Helmholtzzentrum für Schwerionenforschung GmbH

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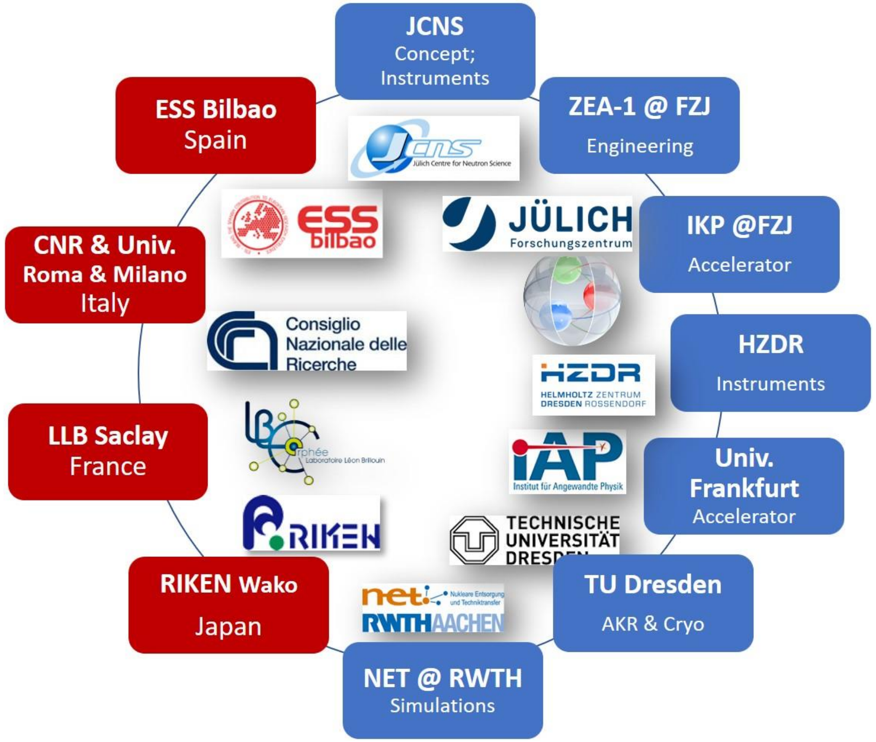
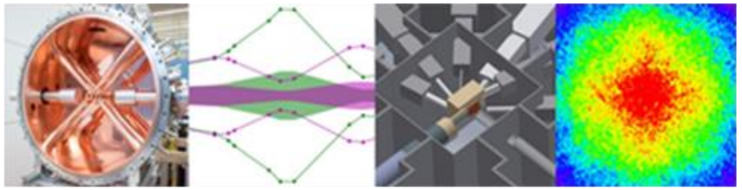
- Accelerator



HBS Innovationpool Project



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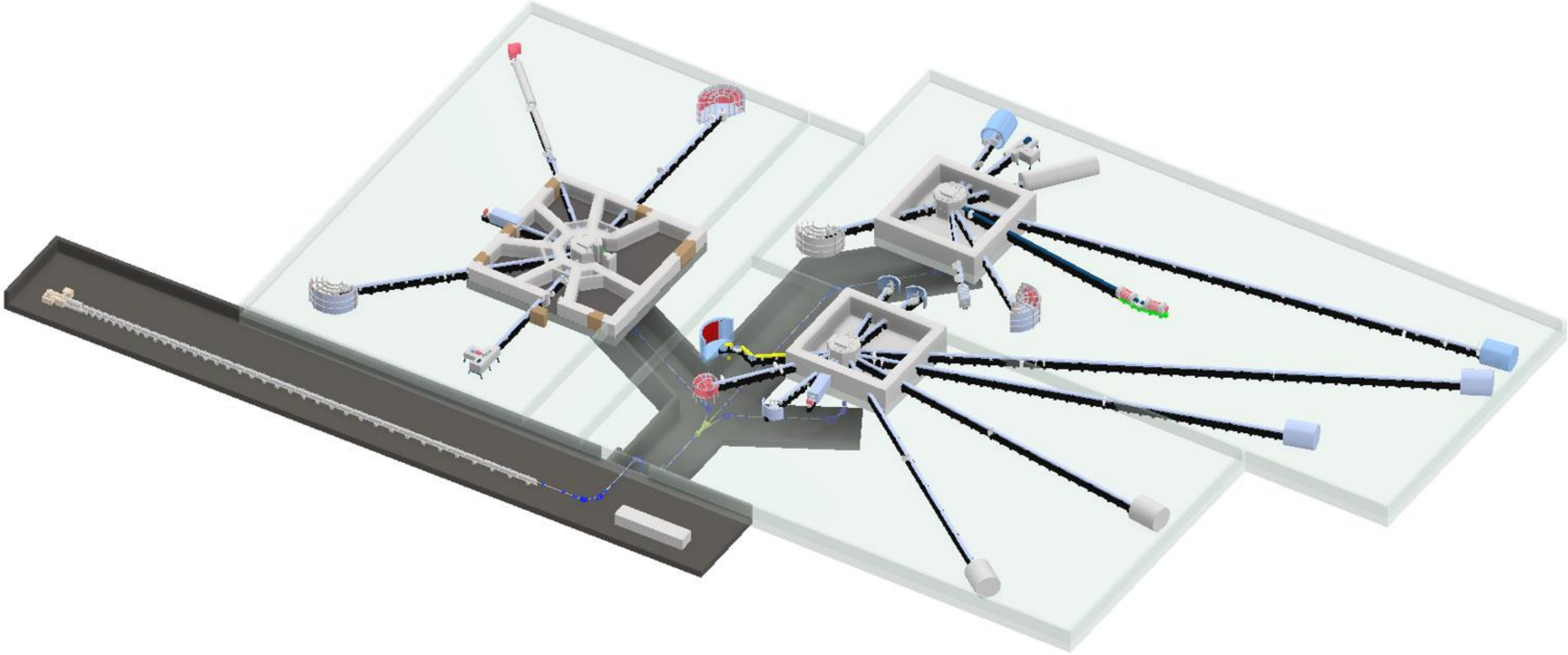

Thanks all for your attention!

Questions?

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