

# The JULIC Neutron Platform, a testbed for HBS

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**Abstract.** The JULIC Neutron Platform was set up at the COSY facility in Jülich as a testbed for the HBS project. Its center is a target station prototype using a tantalum target and a 45 MeV proton beam with a maximum beam power of a few watts. Eight extraction ducts allow the extraction of neutron beams in the fast, epithermal, thermal and cold energy range from the moderator-reflector assembly. Reflectometry and diffractometry measurements, fast and thermal neutron imaging, detector tests and moderator/reflector tests were performed at the JULIC Neutron Platform to show technological feasibility of HBS components and concepts.

## 1 Introduction

The High Brilliance neutron Source (HBS) project aims to develop a High-Current Accelerator-driven Neutron Source (HiCANS) as a potential national user facility [1, 2]. The basic concept of HBS follows existing Compact Accelerator-driven Neutron Sources (CANS) [3] like RIKEN in Japan [4] or LENS in the USA [5]. These sources produce neutrons via nuclear reactions at low proton energies in the range of a few MeV. Typical targets are lithium or beryllium operated at just a few kW beam power due to average currents below 1 mA. HBS tries pushing the performance towards the technological limits in terms of beam current and beam power to achieve a neutron yield above  $10^{15}$  n/s allowing instrument performances similar to medium flux neutron sources [2]. It requires therefore validation of Monte Carlo simulations as well as testing of critical components like the target, moderators-reflector assemblies and tentative instruments.

The HBS target station as described in the Technical Design Report Vol. 2 [6] has the aim to deliver tailored neutron beams to up to 12 instruments with appropriate energy spectrum and time structure. A compact shielding for the target station can be realised due to the low proton energy with a target station diameter of only 4 m. Depending on the instrument suits, different target-moderator-reflector (TMR) assemblies as well as instrument specific moderator plugs will be required.

A slightly modified target station was built at the COSY facility at Forschungszentrum Jülich which has been extended to an experimental platform, the JULIC Neutron Platform, allowing to validate simulations, test critical components and to estimate instrument performances at low power levels.

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Table 1. Parameters of HBS and JULIC Neutron Platform

|               | HBS                      | JNP                        |
|---------------|--------------------------|----------------------------|
| particle      | proton                   | proton                     |
| energy        | 70 MeV                   | 45 MeV                     |
| peak current  | 100 mA                   | 10 $\mu$ A                 |
| frequency     | 24 Hz, 96 Hz             | variable                   |
| beam power    | 100 kW                   | < 10 W                     |
| neutron yield | $10^{15} \text{ s}^{-1}$ | < $10^{10} \text{ s}^{-1}$ |

2 JULIC Neutron Platform

2.1 COSY Facility

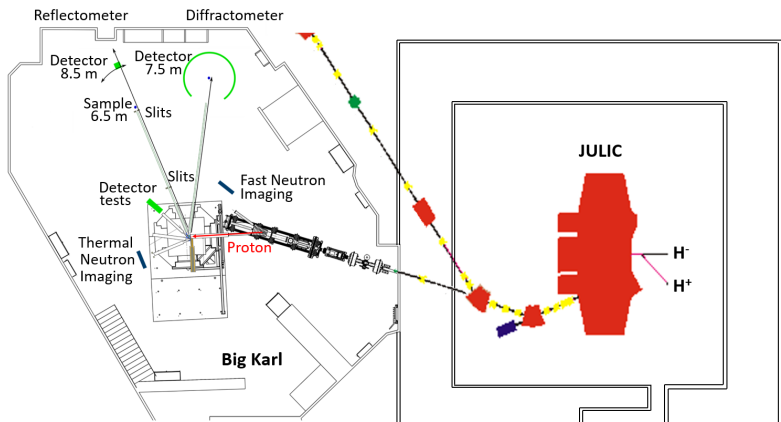
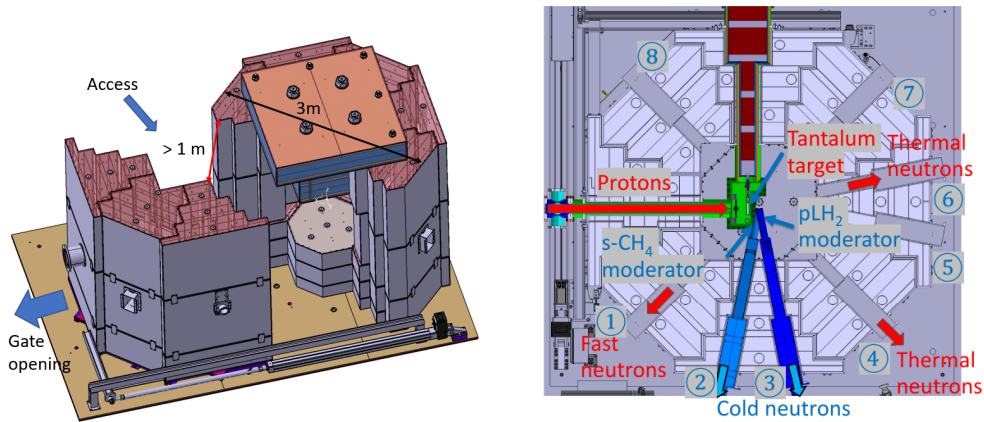


Figure 1. JULIC Neutron Platform

The JULIC Neutron Platform has been implemented in the experimental area of COSY close to the JULIC cyclotron as shown in Figure 1. The COSY facility located at the Forschungszentrum Jülich consists of the Cooler SYnchrotron (COSY) and the Jülich LIght Cyclotron (JULIC) [7]. JULIC provides a proton beam with an energy of 45 MeV with a peak beam current of 10  $\mu$ A and thus is perfectly suited to perform experiments for the HBS project. A maximum duty cycle of 2% can be used due to radio protection requirements resulting in an average beam power at the target of a few watts (see Table 1). The JULIC cyclotron has therefore a beam power of 4 - 5 orders smaller than the design parameters of HBS and thus much lower neutron yield in the range of  $10^{10} \text{ s}^{-1}$ . Nonetheless, it is possible to perform basic scattering experiments, moderator validations and detector tests especially as the pulsing scheme is flexible regarding pulse lengths between 100  $\mu$ s to 2 ms and freely chose-able frequencies.

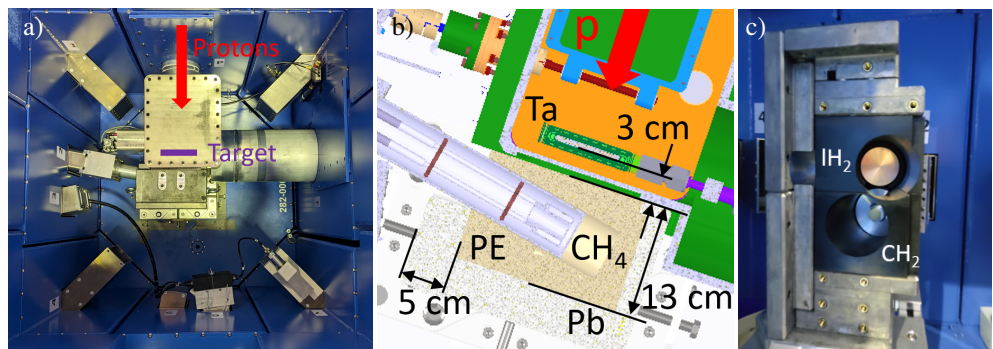
2.2 Target station prototype

The target station prototype shown in Figure 2 (left) was constructed to test all critical components like target, moderators, neutron extraction, shielding and instrumentation. It has a spacious inner core of 1 m<sup>3</sup> in which different target-moderator-reflector (TMR) assemblies can be placed and tested as shown in Figure 2 (right) and Figure 3. An easy access to the



**Figure 2.** Target station prototype

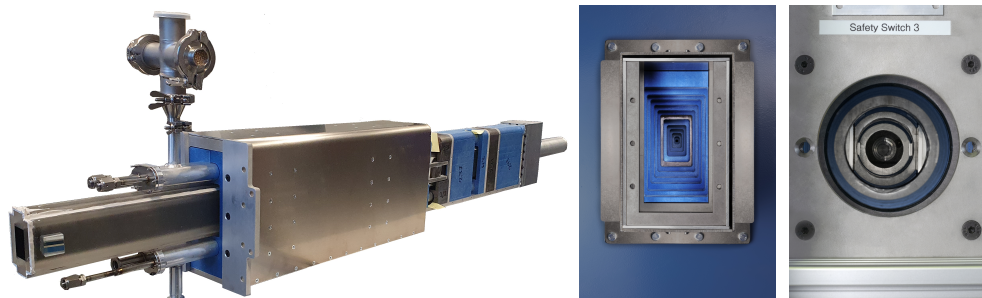
TMR unit was realized by a mechanism opening one segment of the whole target station allowing a spacious access to the inner core as shown in Figure 2 (left). As the power of the JULIC cyclotron is more than five orders lower than for HBS, the shielding requirements are not as severe as for HBS. The target station dimensions could be reduced to 3 m removing an alternating layer of borated polyethylene and lead.



**Figure 3.** a) Inner core of target station prototype with inserted target-moderator-reflector assembly. b) Horizontal cut trough CAD model at beamline 2 height. c) Moderator-reflector looking along beamline 2 & 3 onto the cryogenic moderators.

A tantalum target is mounted at the end of the target plug which is placed slightly of centered inside an aluminium structure in the TMR station in vacuum. The moderator-reflector structure as shown in Figure 3 can be placed directly behind the target in a distance of 2 cm allowing an efficient neutron emission, moderation and extraction. A polyethylene (PE) moderator is used with a thickness of 10 cm. A lead reflector with a thickness of 5 cm is surrounding the PE moderator.

Two extraction channels inclined by  $\pm 11^\circ$  crossing in front of the target and separated by 7 cm in height allow the insertion of thermal or cryogenic moderators trough the extraction ducts 2 & 3 (see Figure 2 right). In the lower extraction channel a small volume moderator optimized for methane was inserted and in the higher extraction channel a one-dimensional



**Figure 4.** Left: Moderator plug with cryogenic source attached and inserted neutron guide; middle: Pin hole plug with 6 mm diameter; right: conical extraction channel with inner diameter of 5 cm and outer diameter of 10 cm

moderator optimized for para-hydrogen was inserted. Further extraction channels through the lead reflector were realised for the extraction ducts 4 & 6 (see Figure 2 right) allowing to extract thermal neutrons from the PE moderator.

Additionally to the flexibility the easy accessible TMR assembly offers, all extraction ducts have the same dimensions allowing an easy switching of different plugs. For the JNP, two plugs with attached cryogenic moderators and inserted neutron guide have been realised as shown in Figure 4. The feeding lines into the moderator vessel attached at the front are going through the plug itself. Two additional plugs (Figure 4 middle and right) offer a pin hole with a diameter of 6 mm used for detector tests and a conical opening with an inner diameter of 5 cm and an outer diameter of 10 cm used for thermal and fast neutron imaging.

### 2.3 Experiments & tests

After the first beam on target in the end of 2022 [8], the JULIC Neutron Platform has been used in 2023 for a number of experiments and tests. Experiments were performed from the HBS team and by external groups from ESS, Hereon, TUM and CEA. In the following a comprehensive overview of work done will be presented. A more detailed description will be given in separate publications by the corresponding experimentalists.

**Fast neutron imaging.** Fast neutrons can be extracted and used for fast neutron imaging of large objects from extraction duct 1 which is looking directly at the target. Using a modified X-ray detector with a  $40 \times 40 \text{ cm}^2$  plastic scintillator with an area of  $20 \times 20 \text{ cm}^2$  filled with scintillator fibers and placed at a distance of 2.75 m from the target allows a L/D ratio of 50. A lead brick sample with different hole sizes was imaged showed the feasibility of fast neutron imaging at the JULIC Neutron Platform.

**Thermal neutron imaging.** At the extraction duct 6 looking at the PE thermal moderator a time-of-flight thermal neutron imaging experiment was done using a Timpepix3 camera system [9] and a scintillator plate with a field-of-view of  $15 \times 15 \text{ cm}^2$ . The time-of-flight operation allows to improve the signal-to-noise ratio as the high neutron background during the proton pulse can be discriminated from useful neutrons. The feasibility of time-of-flight measurements on the JULIC Neutron Platform could be shown on a Cd sheet and by imaging a cactus plant with enough resolution to resolve its roots in soil as shown in Figure 5.

**Reflectometry.** The HERMES reflectometer originally operated at the ORPHEE reactor in Saclay was installed by CEA at extraction duct 3. The performance of the reflectometer was





**Figure 5.** Picture of cactus measured with Timepix3 camera system within one hour.

improved significantly from the first experiment in the end of 2022 [8] by placing additional shielding, adding a frame-overlap mirror as well as bringing the cryogenic moderator into operation. The experiments proved the feasibility to perform reflectometry experiments even on a low flux source and allowed to estimate the performances. Based on the current experiments it is estimated that a  $1 \text{ cm}^2$  sample could be measured with six orders of magnitude of signal-to-background ratio in reflectivity within one hour on a HiCANS as HBS.

**Detector tests.** The JULIC Neutron Platform provides possibilities to test detector equipment including data acquisition system at an accelerator-driven neutron source with a pulsed proton beam under real conditions. Detectors and monitors developed for the European Spallation Source were tested at the JULIC Neutron Platform on extraction duct 4 equipped with a 6 mm pin hole looking at the PE moderator or on extraction duct 2 equipped with a cold source. The experiments provided valuable feedback for the detector development as signal-to-noise ratios could be estimated and the resolution of the detectors could be investigated.

**Moderator tests.** The experimental conditions for moderator tests are excellent at a pulsed neutron source operated at low proton energy due to the low radiation background. This allows to measure to very high wavelengths and thus to test cryogenic moderators for cold, very cold and ultra cold neutrons. A very compact moderator vessel optimized for methane and ethane moderators has been tested as well as a liquid one-dimensional para-hydrogen moderator.

**Reflector material tests.** Due to the easy access and the low activation levels, it is possible to modify components at the TMR within single beamtimes and measure their performances. Different reflector materials like  $\text{MgH}_2$  and nanodiamonds were investigated using the cold methane source to enhance the extractable cold neutron flux within the framework of the HighNESS project [10]. The used reflector materials showed potential but will require further investigations after the initial experiments.

**Shielding performance validations.** The shielding of the target station optimized with MCNP simulations requiring experimental validations. Neutron and gamma dose rate monitors have been placed at different positions around the target station prototype in various heights. Preliminary results indicate that simulated and measured values match.

### 3 Conclusion

The JULIC Neutron Platform provides the possibilities to test critical components for the development of HiCANS sources like target, moderators, shielding, instrumentation and detectors and the interplay of all components combined. It further allowed to validate Monte Carlo simulations for the shielding layout and target-moderator-reflector performances as well as to estimate the performances of instruments like imaging or reflectometry. The JULIC Neutron Platform shows that such a facility can be used also at low power for this kind of technology development where experiments are not possible or very difficult to perform at other sources. It furthermore showed that the concepts presented in the technical design reports of HBS [2] are feasible and that a HBS could be built with the performance estimated regarding its instrumentation.

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