BrightnESS

Building a research infrastructure and synergies for highest scientific impact on ESS

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Report on the conception design of the ESS and the BRR test beam-line

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	Approved by	BrightnESS Steering Board

3 List of Abbreviations

BNC – Budapest Neutron Centre
BRR – Budapest Research Reactor
CNS – Cold Neutron Source
ESPI – Energy Sensitive Pinhole Imaging
ESS – European Spallation Source
GA – Grant agreement
LDM – Low Dimension Moderator
MCNP – Monte Carlo N-Particle code
LH – Liquid Hydrogen
MC – Monte Carlo
NSD – Neutron Spectroscopy Department
PDR – Preliminary Design Review
SANS – Small Angle Neutron Scattering
TBL – Test Beam-line
TOF – Time of Flight
VVER – Water-Water Power Reactor (type of Russian reactors)

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5 Executive Summary

At the European Spallation Source (ESS), beams of neutrons will be generated by accelerating protons and directing them at a target made of tungsten. The high-energy neutrons resulting from the collisions are slowed down by the moderators, then extracted through the beam lines and guided to the instruments. One of the crucial components and a most innovative development in enhancing the neutron source brightness is the compact cryogenic moderator (CCM; also called: Low Dimension Moderator or LDM). Its principle was recently invented by the ESS target team during the design phase of ESS. This very new idea and its technical solutions need complex simulation and experimental verification at various conditions. The Wigner Research Centre, as a partner in BrightnESS Work Package 4, provides valuable contributions to task 4.5 through the experience gained in the construction and operation of a similarly innovative cold neutron source at the Budapest Neutron Centre (BNC). BNC operates a cold neutron research facility which includes a liquid hydrogen moderator inserted horizontally into the reactor core, a supermirror neutron guide system and a suit of 8 experimental stations placed in a neutron guide hall.

The current Budapest Research Reactor (BRR) cold neutron facility is one of the few neutron sources where access for monitoring the Cold Neutron Source (CNS) features is technically feasible; in this way, it serves in the BrightnESS project as an experimental benchmark facility for testing new features of the LDM concept. A direct experimental method and tool to study the neutron brightness features of a moderator is a technique proposed by BNC called “Energy Sensitive Pinhole Imaging” (ESPI). This allow moderator phase space mapping to be applied for wavelength dependent divergence mapping of the moderator and the beam path. A preliminary setup of the test beamline (TBL) was used in the first phase of the BrightnESS project for intensity mapping of the existing liquid hydrogen moderator at BRR. Although this ESPI technique, based on the “camera obscura” principle, was used by BNC several times in the past, the current experiment has provided new information in two areas:

1. verification of the sensitivity of this technique and the actual setup to obtain the ortho-para behaviour of our working moderator;
2. useful new data for the design of the test beamline equipment to be used at ESS, by measuring and extrapolating for example, neutron transmission or radiation shielding features of components. In the current task the conception design, selection of options, definition of the parameters of the setup as well as the components have been performed.

In the current task the conception design, selection of options, definition of the parameters of the setup as well as the preliminary design of components have been performed. During this conception design work the following major components of TBL have been described, the proper drawings prepared for and summarized in this report: Monolith insert, Girder/optical bench, Mask assembly and Double disk chopper system, Heavy shutter structure, Heavy shutter inserts, Bunker wall aperture, Detector, Instrument cave and beam dump.

6 Report on Implementation Process and Status of Deliverable

6.1 Implementing team

The team of experts for the implementation of the task are from the Neutron Spectroscopy Department of Wigner Research Centre for Physics, which is responsible for the beam extraction systems (guides, neutron guide hall infrastructure) and the operation of most of the experimental stations at the 10 MW BRR. To perform most of the experiments related to BrightnESS task 4.5 the neutron TBL No2. at BRR was chosen. This cold neutron guide channel serves for the "Yellow Submarine" small angle scattering instrument (SANS), thus the implementation team comprised Wigner staff operating this device as well as experts of the ESPI technique and related components. BRR operating staff members (Centre for Energy Research – EK) were also invited to assist in the task for the infrastructure related work (cold moderator, shielding, radioprotection). The MIRROTRON Company was subcontracted (within the frame of the "Subcontracting" budget item – followed by a procedure according to the public procurement rules) to take part in the engineering of TBL.

The team comprised the following staff members:

WIGNER:	László Rosta – team leader
	János Füzi – head of dept. expert in neutron instrumentation (ESPI)
	Ferenc Mezei – professor emeritus
	Balázs Koroknai – project manager
	László Almásy – SANS-team
	Adél Len – SANS-team
	Renáta Ünnep – SANS-team
	Viktor Heirich – control system
	Zoltán László – mechanical engineering
	Márton Markó – expert in neutron optics
	Tibor Zsíros – detector expert
EK:	József Janik – CNS responsible
	Ferenc Gajdos – head, reactor dept.
MIRROTRON:	Gábor Szász – lead engineer
	Gábor Nagy – lead of technology
	Gábor Zsuga – mechanical engineer

TBL team members have regular meetings to discuss technical progress in the task.

From the ESS side, the following experts were involved:

Shane Kennedy
Gábor László
Ken Andersen
Günter Muhrer
Peter Jacobsson
Zvonko Lazic
Bengt Jönsson

6.2 Task sharing and schedule

The TBL tasks were carefully discussed with all participants and the task list and preliminary attribution of personnel efforts and funds were established accordingly. The schedule was assigned as a function of the project milestones and deliverable schedules. The reactor 'operation regime', 'licencing conditions' and 'engineering standards' were taken into account. In 2016 a TBL task and project team was set up at ESS, led by Gábor László, Head of engineering at NSS (Neutron Scattering System) and in fact, at its meeting in February 2017 the ESS Council endorsed the establishment of a test beam-line facility in addition to the 15 neutron scattering instruments to be realised within the ESS construction phase. A day-by-day dialog has been in effect between BNC-Wigner and the ESS TBL staff, Wigner experts have got access to the ESS "Confluence" document server as well as the ESS and Wigner team members have established phone and skype conversation channels, while meetings in person are also in practice.

6.3 Definition of starting conditions and input parameters

The description of the cold neutron facility at BRR and the ESPI technique has been published in 3 subsequent papers[1] published in 2002-2008. In the context of BrightnESS project goals, these papers were used as reference to document the design work on the new cold moderator at BRR and TBL. A preliminary setup of the TBL was used in the first phase of this project for intensity mapping of the existing liquid hydrogen moderator at BRR. Although this ESPI technique based on the "camera obscura" principle was used by us several times in the past – for example to optimize the beam take-off for our latest installed split-guide – the current experiment has provided new information in two areas:

1. we could verify the sensitivity of this technique and the actual setup to obtain the ortho-para behaviour of our working moderator in a perspective view of the new design of the ESS cold moderator;
2. we were able to gather useful new data for the design of the test beamline equipment to be used at ESS, by measuring and extrapolating for example, neutron transmission or radiation shielding features of components.

6.4 Sequence of the conception design work

Prior to the design of a new TBL system, various calculations and experiments have been carried out on an ad-hoc setup for the verification of the ESPI configuration on the beamline N2 of BRR. A series of measurements with the old moderator cell were performed. The series of test studies performed so far have allowed us to design, fabricate and commission a device in all details both for BRR and ESS. The principle of moderator and beam-take-off testing is the imaging of the neutron luminosity of the neutron-emitting surface of the moderator. The images taken one after the other will allow to fully characterize the intensity, homogeneity, energy spectrum and time structure of the neutron emission to the beamlines. The first tests of the TBL components and their assembly will be carried out at BRR, after which

[1] Rosta L; Cold Neutron Research Facility at the Budapest Neutron Centre, *Applied Physics* **A 74**, S52-S54 (2002); Füzi J, Dávid E, Kozlowski T, Lewis P, Messing G, Mezei F, Penttila S, Rosta L, Russina M, Török Gy; Neutron optical imaging study of neutron moderator and beam extraction system, *Physica B* **385-386**, 1315-1317 (2006); Füzi J; Neutron beam phase space mapping, In: Modern Developments in X-Ray and Neutron Optics, Eds: Erko A, Krist Th, Idir M, Michette AG, *Springer*, pp 43-57 (2008).

a proper configuration will be set up at ESS. The main components of the set-up used for the verification experiments are:

- a set of pin-holes for image projection to a position sensitive area detector,
- a chopper defining the neutron energy with the help of the time-of-flight to the neutron detection,
- a neutron beam shutter to offer accessibility for adjustments.

The proper biological shielding needs to be installed as well. The complete test set-up will be operational in 2018.

6.5 Status of deliverable

The test phase for the conception design shown in section 6.3 above, has been implemented and reported in BrightnESS milestone MS21 as the "Verification of the energy sensitive pinhole imaging (ESPI) setup, Neutron beam experiments at Wigner/BNC, Budapest (HU)". The conception design has reached 100% completeness, BNC and ESS experts held a meeting in Lund on May 23, 2017 to conclude this work as a PDR report (see attachment).

7 Technical Content

7.1 Introduction

The principle behind moderator testing is the imaging of the neutron luminosity of the neutron-emitting surface of the moderator. Like in a movie, the images that taken one after the other, will allow to fully characterise the intensity, homogeneity, and energy spectrum and time structure of the neutron emission to a neutron facility beamline.

The main components of the set-up are a set of pin-holes for image projection to a position-sensitive area detector, a chopper defining the neutron energy with the help of the time-of-flight to the neutron detection, and a neutron beam shutter to offer accessibility for adjustments. The testing technique follows the time-honoured *camera obscura* principle and has already been used several times at BNC-Wigner, for example to optimize the beam take-off for the latest installed split-guide. Task 4.5 allows us to develop the test beamline concept, test prototype components and prepare for the installation of the moderator test beamline at ESS. The aims of the tis task in short are as follows:

- provide a setup for energy sensitive imaging of the ESS moderator;
- prior to installation at ESS, perform test experiments at BRR.
- ensure sufficient flexibility for further use beyond moderator commissioning;
- design components that may be applied at further beamlines;
- ensure safe operation and minimum interference with neighbouring beamlines.

7.2 Preliminary tests at the Budapest Research Reactor

In figures 7-2. to 7-4. we illustrate the principle of the ESPI measurements by showing the major components, the experimental realization at the neutron guide system at BRR and the image taken with this setup from the liquid hydrogen moderator operated at 20 K, respectively. The results obtained in this exercise are used to perform the conception and engineering design for the real BrightnESS device to be used for future tests at BRR and ESS.

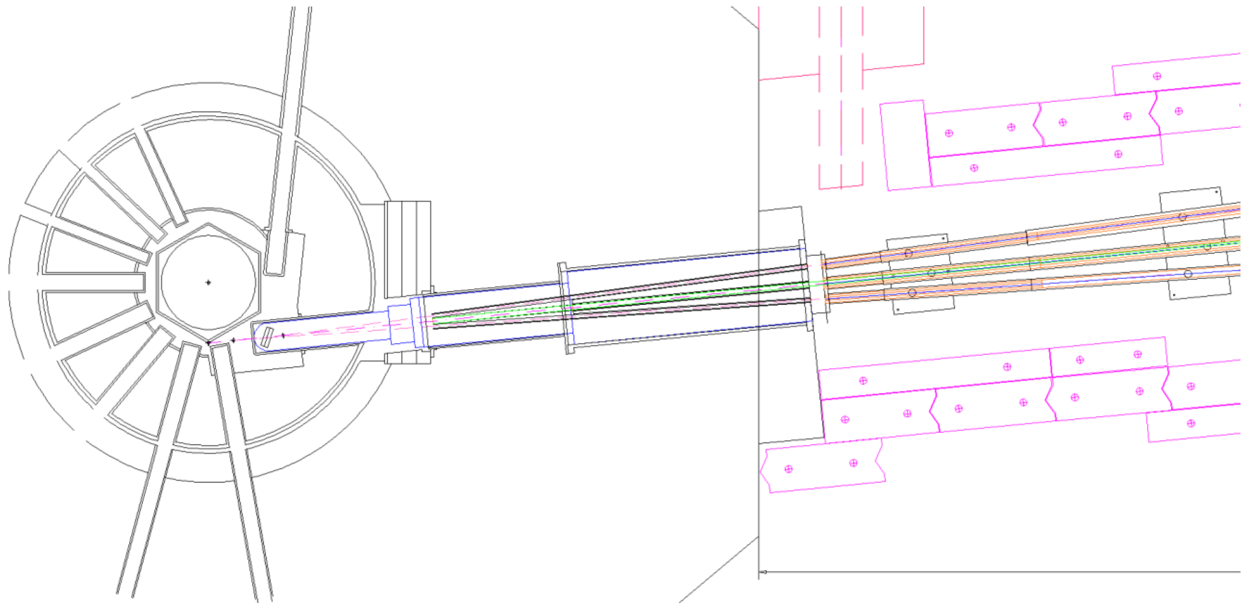

Figure 7-1. Layout of the neutron guide system at the cold neutron source at the BRR.

The middle guide No2 was used to perform the ESPI verification tests.

Figure 7-2. Photo of the ad-hoc setup for the verification of the ESPI configuration on the beamline N2 of BRR.

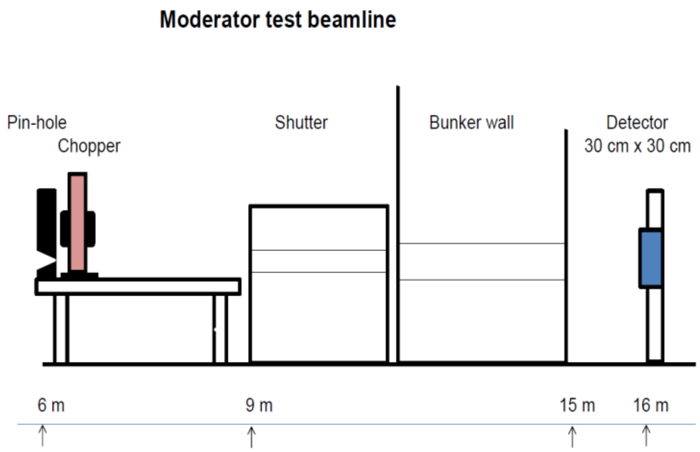

Figure 7-3. Basic components and scheme of the ESPI setup.

In-between the two neighbour guides, the slit1 (top) and the slit2 and the detector can be seen (bottom of the figure).

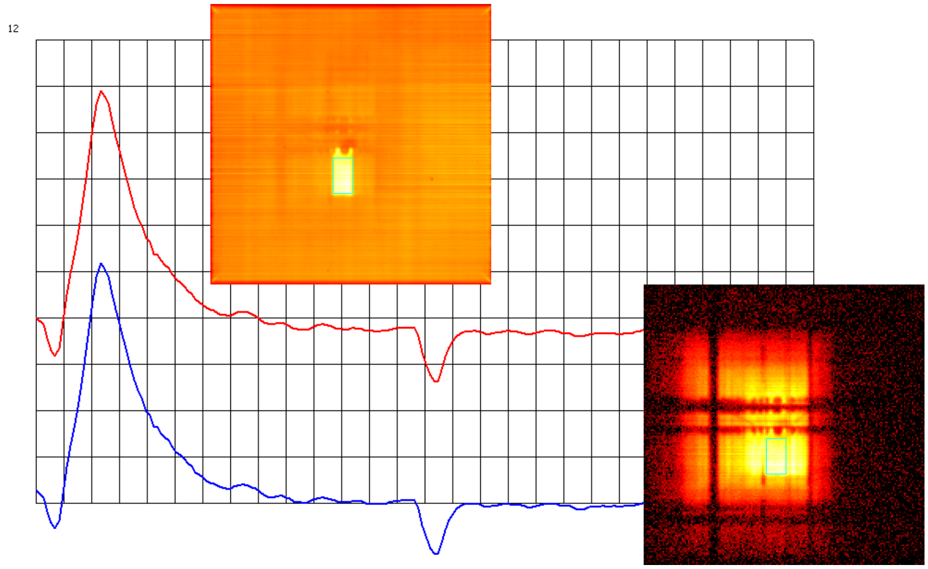

Figure 7-4. Intensity map from the BRR moderator and wavelength distribution.

7.3 Test beamline layout

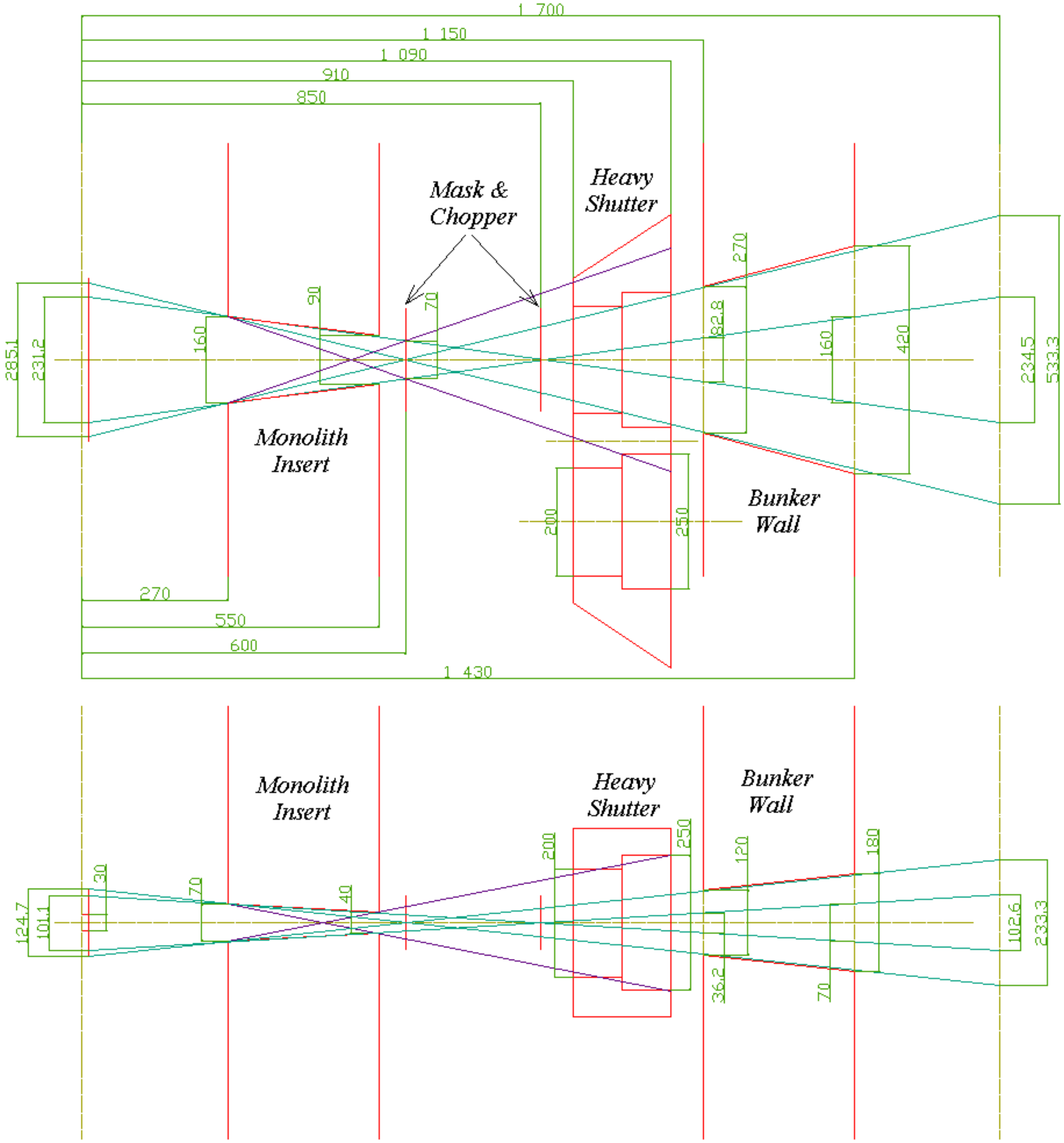

Figure 7-5. Plan view (top) and elevation (bottom) of the proposed ESS test beamline layout.

Vertical: horizontal scale ratio: 10:1. Vertical dimensions in mm, horizontal dimensions in cm.

The following division of scope of work and component specification with respect to the BrightnESS TBL has been adopted:

- the moderator TBL will be designed for viewing the upper moderator of ESS only,
- according to the BrightnESS scope of work, the TBL will first be installed on a beamline at the Budapest Neutron Centre, therefore its parameters will be adapted to this requirement too,
- a set of kinematic spacers of yet unknown dimensions will allow TBL adaptation to a future lower moderator at ESS, when after the initial operation phase a second moderator will eventually be installed.
- in order to allow future use of TBL components in various locations/beam-lines at ESS, a 3.5 m long optical bench is foreseen which will provide flexibility of the beam configuration, as well as minimization of in-bunker activity by performing configuration changes and subsequent pre-alignment outside of the bunker.

The Plan view and elevation of the proposed ESS test beamline layout is shown in figure 7-6 and the different component aspects are described below (including whether the work involved is within BrightnESS task scope or not).

Beam height:

- top position (kinematic spacers in) 1387 mm from bunker floor (137 mm above TCS),
- bottom position (without kinematic spacers) 1000 mm from bunker floor (250 mm below TCS) – this is the beam height at BNC,
- shorter kinematic spacers may allow beam height adjustment to the future lower moderator centre position.

Monolith insert - ESS scope of work (part of the ESS target construction)
The insert limits the beam exit apertures to the size defined by the required field of view. This can best be achieved by means of sub-inserts, viewing the respective moderators. One of these must be closed and only the one viewing the currently investigated moderator fitted with a converging channel. Dimensions are given presuming a width limitation of 200 mm at R = 2700 mm, which limits the field of view at R_0 to 293 mm.

- horizontal:
  - upstream @2700 mm from moderator (R_0): 200 mm;
  - downstream @5500 mm from R_0: 105 mm;
- vertical:
  - upstream @2700 mm from R_0: 70, centred at 137 mm above TCS;
  - downstream @5500 mm from R_0: 40 mm, centred at 137 mm above TCS.

Girder/optical bench - BrightnESS scope of work (Task 4.5)
The girder will be 3 m long and equipped with a 3-point kinematic stand to allow fast and accurate removal and reinstall. It may be put in place and removed by means of a crane from above with all equipment mounted and pre-aligned outside of the bunker. Its main role will be to host the collimators, mask with pinhole, attenuator and diaphragm changer assembly as well as the double disk chopper. Kinematic spacers will allow height adjustment. When the girder is removed from the bunker, sufficient space is created for removal/insertion of the collimating/blocking sub-inserts from/into the monolith insert.

Collimator - ESS scope of work (part of the setup used only at ESS)
There is 2 m space on the optical bench upstream from the pinhole, where the (copper/composite) collimator parts can be mounted. Its role is to limit the divergence of the beam to the useful extent.

Mask assembly and Double disk chopper - BrightnESS scope of work (Task 4.5)
The Mask assembly and Double disk chopper will be mounted on the optical bench at 8.5 m. The mask absorber is 406 mm wide and 216 mm high. The vertical position can be adjusted +/- 30 mm. The horizontal position can also be adjusted: +/- 80 mm. This feature allows further use, when the equipment is removed from the actual beamline. In the current setup, horizontal displacement acts, together with the collimator, as a secondary shutter against thermal and cold neutrons. The chopper disc diameter is 500 mm.

Heavy shutter structure - BrightnESS scope of work (Design - Task 4.5, manufacturing - ESS)
The shutter dimensions are as follows:

- length: 1800 mm,
- insert width and height:
  - upstream: 150 mm;
  - downstream: 250 mm;
- width of moving part: 500 mm,
- height of moving part: 250 mm.

The shutter moving part is centred at 137 mm above TCS with provisions to lower it to 250 mm below TCS (by means of a removable, 387 mm high spacer structure). Should the position of the future lower moderator be defined, a less high spacer structure may be manufactured in order to adjust the shutter height to the lower beam.

Heavy shutter inserts - ESS scope of work (part of the ESS infrastructure)

Bunker wall aperture - ESS scope of work (part of the ESS infrastructure)
The aperture centred at 137 mm above TCS allows the view of the upper moderator through the pinhole. Minimal dimensions to provide access to the full field of view:

- horizontal:
  - upstream @11500 mm from moderator (R_0): 110 mm;
  - downstream @14300 mm from R_0: 210 mm;
- vertical:
  - upstream @11500 mm from R_0: 40 mm;
  - downstream @14300 mm from R_0: 70 mm.

Detector - BrightnESS scope of work
In case a 300mm square detector (see BrightnESS task 4.2) is available in due time, it covers the entire field of view at 18 m from R_0. Should the use of a ^{3}He 200 mm square detector prove to be necessary, a positioning mechanism will allow scanning of the field of view.

Instrument cave and beam dump - ESS scope of work (part of the ESS infrastructure).

7.4 TBL features

The current design envisages the investigation of only the upper moderator. Nevertheless, the main positioning components (girder/optical bench and heavy shutter support) are designed such that they can easily be modified to accommodate the lower moderator height. The mask with pinhole is placed on an optical bench and may be positioned between 6 m and 8.5 m from the target axis. Figure 7.5 shows the beam divergence limits available with the two extreme positions. In case of a downstream end position, a further mask placed in the upstream end is needed to limit the horizontal divergence.

- Monolith insert (provided by ESS) aperture size:
    - horizontal: 160 mm upstream / 90 mm downstream;
    - vertical: 70 mm upstream / 40 mm downstream.
- Bunker wall (provided by ESS) aperture size:
    - horizontal: 270 mm upstream / 420 mm downstream;
    - vertical: 120 mm upstream / 70 mm downstream.
- Bunker wall opening may be restricted when downstream end pinhole position is used to:
    - horizontal: 90 mm upstream / 160 mm downstream;
    - vertical: 40 mm upstream / 180 mm downstream.

The following design options have been considered.

Option A: pinhole at 6 m from target axis.

- Optical magnification with detector at 17 m: 1.87.
- Field of view:
    - horizontal: 285 mm;
    - vertical: 125 mm.

Option B: pinhole at 8.5 m from target axis.

- Optical magnification with detector at 17 m: 1.
- Field of view:
    - horizontal: 231 mm;
    - vertical: 101 mm.

The main components of the system are

The 3D drawing representation of the main components are shown below:

Girder/optical bench

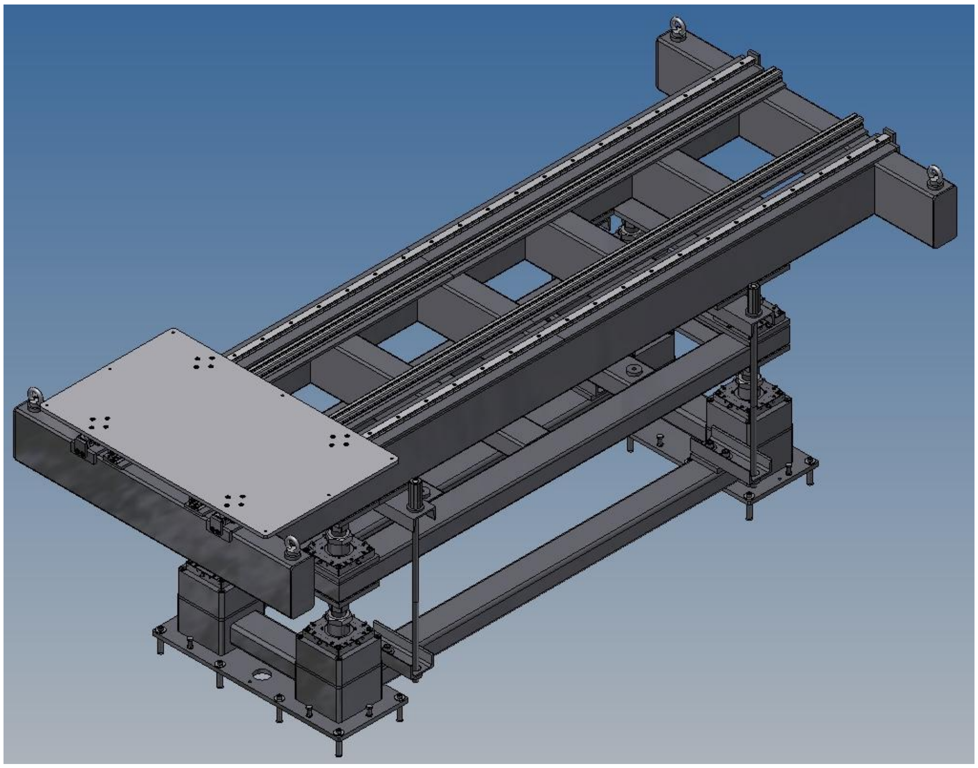

Figure 7-6. Girder / Optical bench.

Double disk chopper

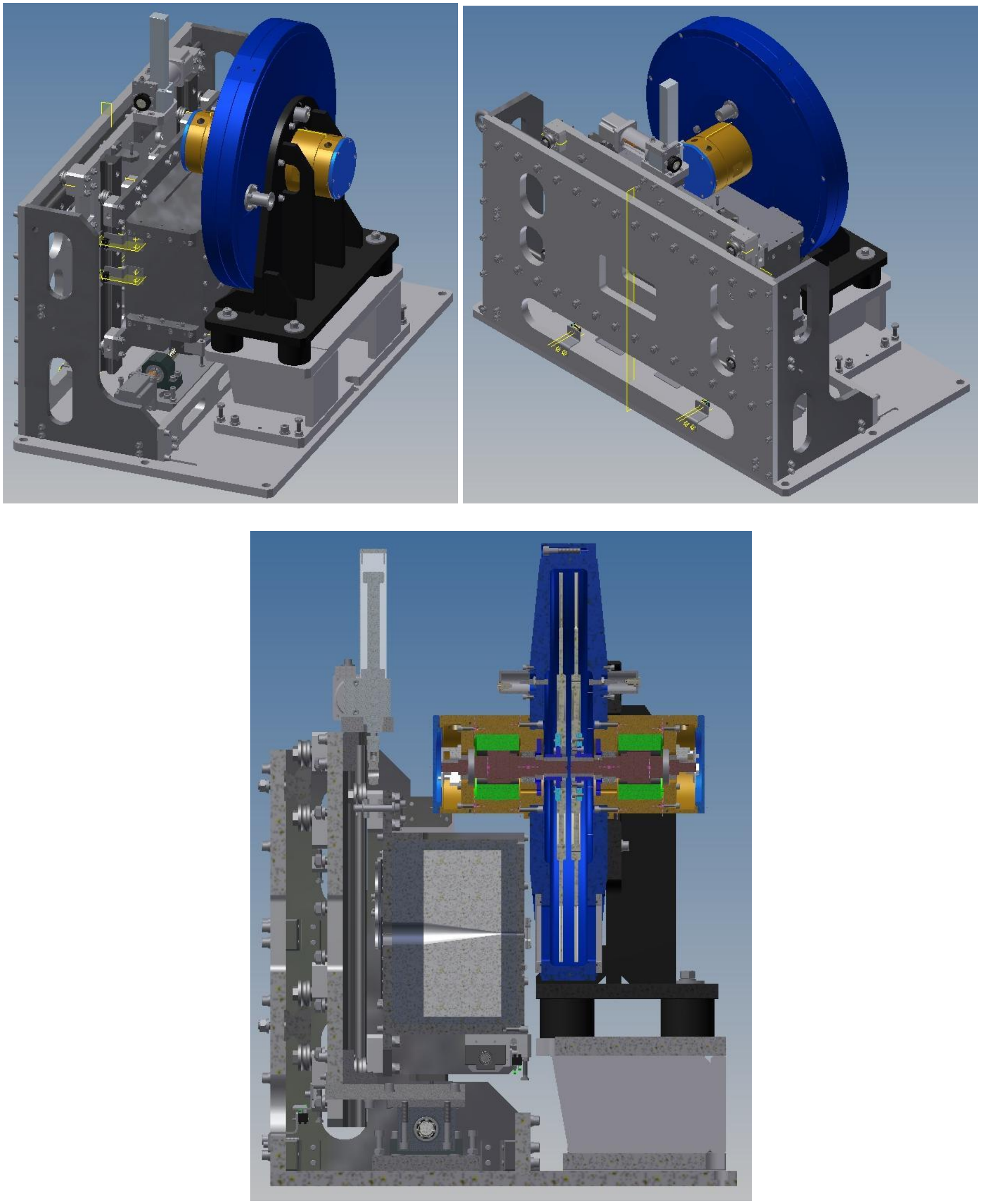

Figure 7-7. Mask with pinhole, attenuator, diaphragm changer and double chopper assembly.

Heavy shutter

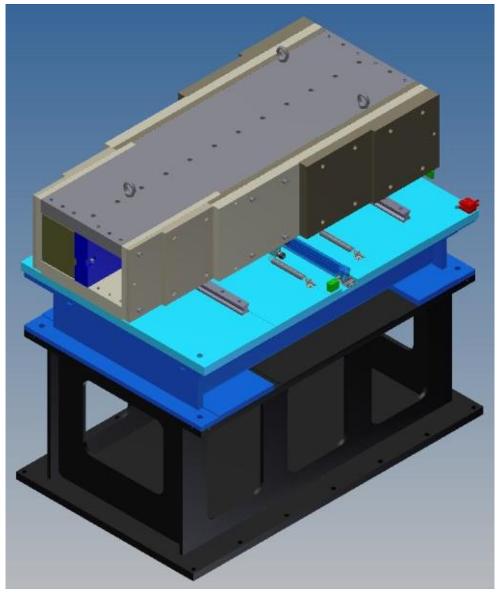

Figure 7-8. Heavy shutter.

8 List of Drawings

The conception design of the ESS and the BRR test beam-line device and its main components are documented in the following AUTOCAD drawings. These documents make part of the TBL package available on the ESS Confluence site (restricted access).

MR304-0000-00-PE	Moderator test beamline (assembly drawing)
MR304-1000-00-PE	Bench assay
MR304-2000-00-PE	Pin Hole Unit
MR304-3000-00-PE	Dual Chopper
MR304-3010-00-PE	Chopper disc 2
MR304-3020-00-PE	Chopper disc 3
MR304-4000-00-PE	Shutter

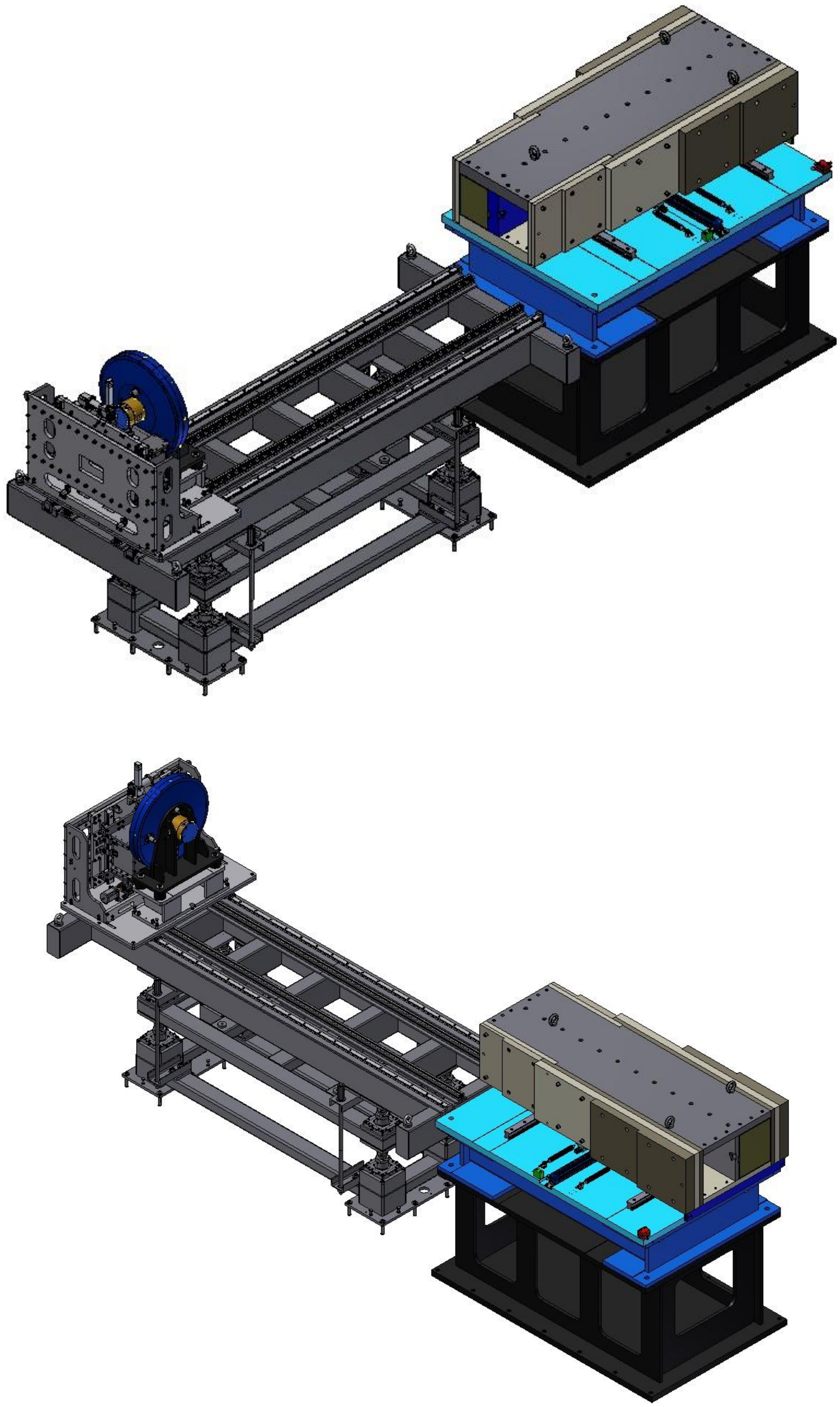

Figure 8-1. Aerial view of test beamline components with heavy shutter in open position.

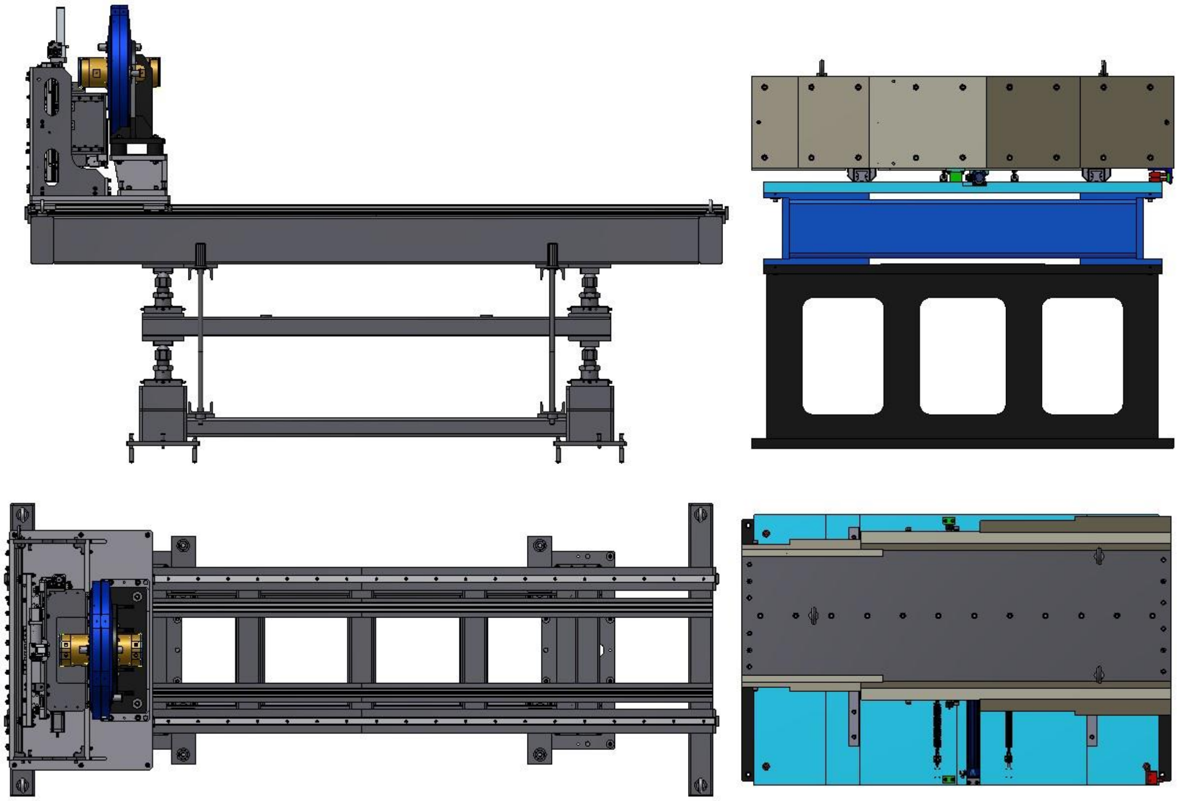

Figure 8-2. Side and top view of test beamline components.

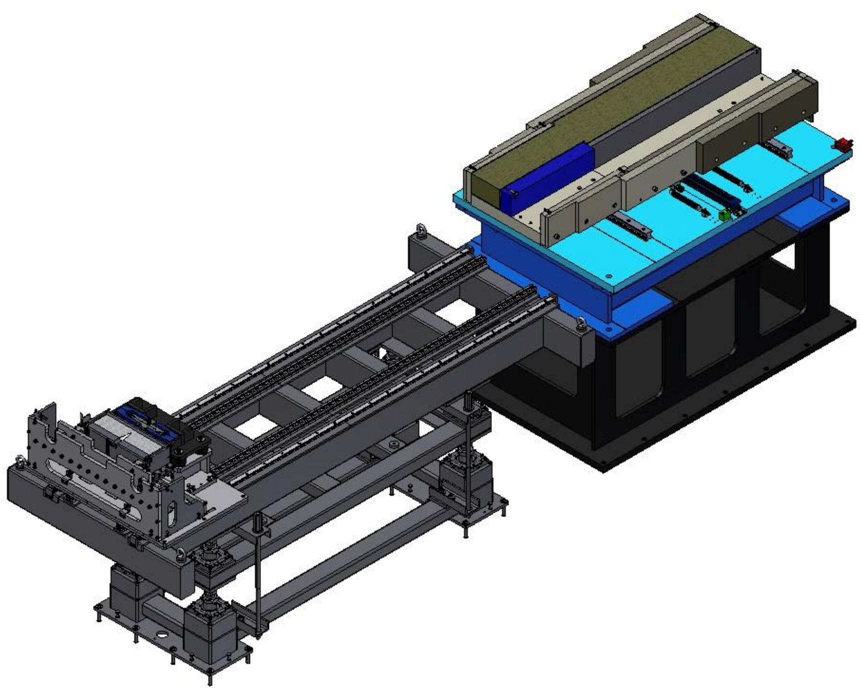

Figure 8-3. Aerial view of test beamline components with horizontal sectioning plane at beam axis height.

9 List of Publications

- János Füzi: Phase space mapping of moderator brilliance and in situ characterization of front end optical components, High Brilliance Source Workshop, 2016 September 29 Unkel, Germany
- Márton Markó: Optimisation of beam components for neutron instruments towards compact sources, HBS Workshop, 2016 September 29 Unkel, Germany
- László ROSTA: Design Efforts for Cost-efficient Cold Moderators, HBS Workshop, 2016 September 29 Unkel, Germany