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Preliminary Systems Design Description for the Bifrost Instrument

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1. INTRODUCTION

1.1 Purpose of the document

The Preliminary System Design Description of the Bifrost instrument describes the system architecture and the physical layout of the instrument. The hardware descriptions result from the design work based on the functional requirements as well as the constraint requirements that have been identified at this point. The purpose of this document, together with the System Requirements and Concept of Operations documents is to:

- Provide a documented description of the design of the instrument that can be reviewed and approved by the stakeholders in the Tollgate-II review,
- Provide a description of the instrument in enough detail that its component parts can be designed in detail (“design-to specification”),
- Provide a description of the hardware and software system components in sufficient detail to assess whether they fulfil the functional requirements
- Discuss the expected scientific performance of the instrument

Please note: **For the Scattering Characterization System (SCS), 6 energy channels are eventually planned for Bifrost. Only 4 energy channels is included in the instrument scope and budget. However, since the design of the SCS for the day 1 instrument needs to take all 6 channels into account – they are all presented here in the drawings. We have re-specified that only 4 channels are in the instrument scope where needed.**

1.2 Definitions, acronyms and abbreviations

ABBREVIATION	EXPLANATION OF ABBREVIATION
PBS	Product Breakdown Structure
NOSG	Neutron Optics and Shielding Group
BTS	Beam Transport and Conditioning System
SES	Sample Exposure System
SCS	Scattering Characterization System
GUI	Graphical user interface
CLI	Command line interface
EPICS	Experimental Physics and Industrial Control System
PSS	Personnel Safety System
PSI	Paul Scherrer Institute
LLB	Laboratorie Leon Brillouin
IFE	Institut for Energiteknik
KU	University of Copenhagen
DTU	Technical University of Denmark

1.3 References

[1] CAMEA - Proposal

[2] Bifrost - Concepts of Operations

[3] Bifrost – System Requirements

[4] F. Groitl, et. Al., “CAMEA—A novel multiplexing analyzer for neutron spectroscopy” Rev. Sci. Instrum. **87**, 035109 (2016)

[5] F. Groitl. Et al., “A combined radial collimator and cooled beryllium filter for neutron scattering”, NIM-A, **819**, 99 (2016)

[6] L.C. Chapon, et. al, Neutron News, 22, 2 (2011)

[7] F. Issa, et. al., "Characterization of Thermal Neutron Beam Monitors", in review

[8] Bifrost, table of motion. Attached to the Indico page.

2. SYSTEM CHARACTERISTICS

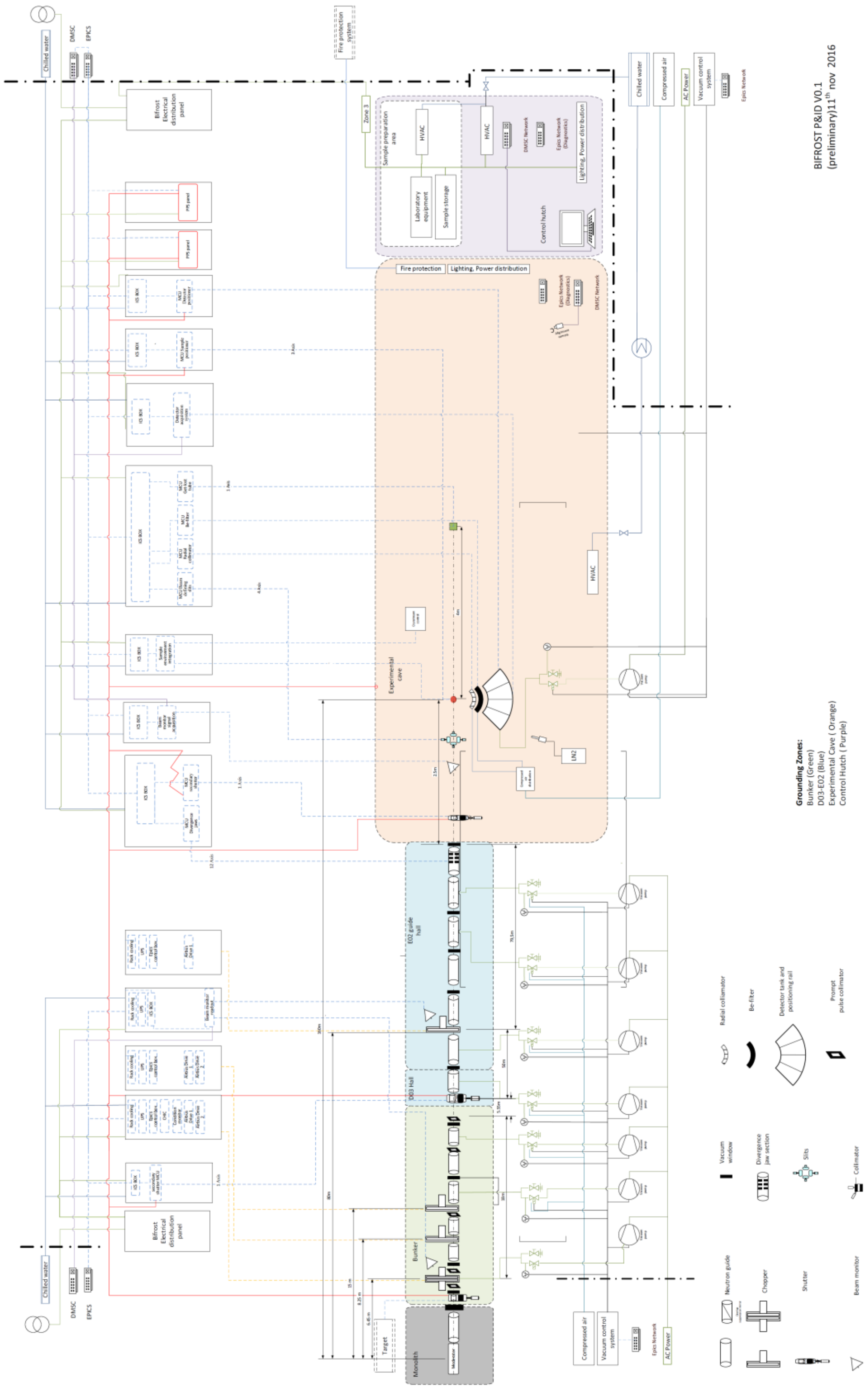
2.1 System purpose

The system allows the measurement of collective dynamics in crystalline systems in the field of materials science, optimized for neutron flux and sample environment performance. The science case for the system is outlined in the instrument proposal [1], the modes of operation in the Concepts of Operations report [2] and the system requirements in the system requirements report [3].

2.2 System overview

The instrument consists of three main technical subsystems: the beam transport and conditioning system (BTS), the sample exposure system (SES) and the scattering characterization system (SCS). In addition, as described in the instrument product breakdown structure (PBS), the instrument includes the structures that house and support these subsystems, the software to control the instrument and the software to process the data. The hardware description in this document does not strictly follow the PBS, but rather a functional breakdown of technical components along the neutron beam path. This makes it easier to map the specifications to the high level scientific requirements. PBS numbers are given for reference where appropriate.

3. P&ID


BIFROST P&ID V0.1
(preliminary)11th nov 2016
Grounding Zones:
Bunker (Green)
D03-E02 (Blue)
Experimental Cave (Orange)
Control Hutch (Purple)
Chilled water
DMSC
EPICS
Compressed air
Vacuum control system
AC Power
Fire protection
Lighting, Power distribution
HVAC
Experimental cave
E02 guide hall
D03 Hall
Bunker
Monolith
Target
Radial collimator
Be-filter
Detector tank and positioning rail
Prompt pulse collimator
Vacuum window
Divergence jaw section
Slits
Collimator
Neutron guide
Chopper
Shutter
Beam monitor

4. OVERVIEW OF THE INSTRUMENT (13.6.14)

Bifrost is located at the W4 beam port in the west sector and will predominantly view the cold moderator. The main geometrical parameters (Table 1) define the layout in the experimental halls (Figure 1) and the instrument envelope. The beam transport and conditioning components of instrument are located in Hall D03, in the guide hall (E02) and the end station is located in the cave hall (E01).

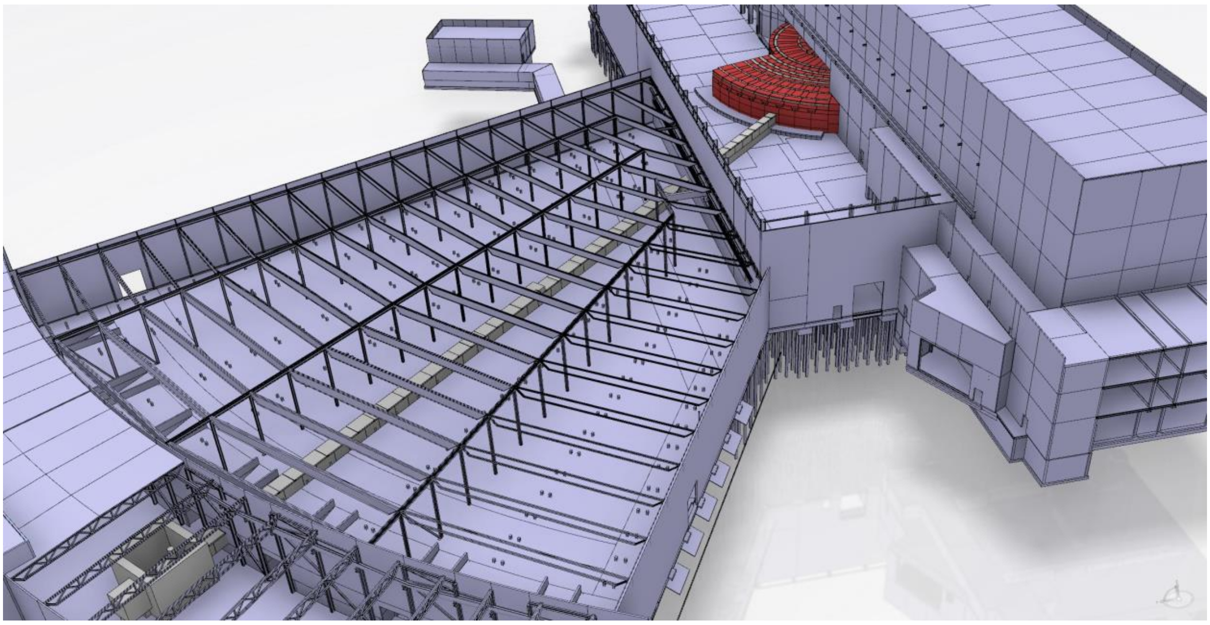


Figure 1: 3D drawing of the planned Bifrost instrument

The guide for Bifrost is 161 m long, and the only moving parts on the guide itself are the four choppers. Three of these choppers are placed inside the bunker and the fourth chopper placed 80 m downstream in the E02 hall.

The geometrical components of Bifrost along the beam path are described in the following Table:

Item	Category	Parameters	Start from origin [mm]	End from origin [mm]
Inner Feeder	Elliptical guide	W = 60 mm, H = 60 mm, m = 3.0-3.5	2000	5327
Heavy collimator (Cu)	Shielding	Insert, L = 3000 mm	2300	5300

Insert flange	Flange including 4 mm vacuum window	L = 170 mm	5330	5500
Gamma Shutter	Shutter with fitted guide	Length = 500 mm	5500	6000
PSC CHIM	Chopper housing containing guide and collimator blocks	Length = 784 mm	6000	6784
Neutron guide	Curved guide R = 2500 m	W = 30 mm H = 50 mm L = 17706 mm	6794	24500
Frame overlap chopper 1	Single disc slow chopper	L = 500 mm	8000	8500
Guide collimator block 1	Copper block	L = 30 mm	11970	12000
Frame overlap chopper 2	Single disc slow chopper	L = 500 mm	14750	15250
Guide collimator block 2	Copper block	L = 30 mm	17970	18000
Guide collimator block 3	Copper block	L = 30 mm	23970	24000
Bunker feedthrough	Bunker feedthrough	W = 30 mm H = 50 mm L = 4000 mm	24500	28500
Neutron guide	Ballistic opening guide section	W = 100 mm (Max) H = 100 mm (Max) L = 25000 mm	24500	49500
Thermal beam shutter	Light shutter for thermal neutrons	W = 150 mm H = 150 mm L = 80 mm	50000	50080
Neutron guide	Straight guide section	W = 100 mm H = 100 mm L = 40000 mm	49500	79740

Bandwidth chopper	Single disc slow chopper	L = 500 mm	79750	80250
Neutron guide	Straight guide section	W = 100 mm H = 100 mm L = 45100 mm	80150	135000
Neutron guide	Ballistic closing guide section	W = 100 mm (Max) H = 100 mm (Max) L = 25000 mm	135000	161000
Divergence jaws (x3)	Slit system near sample	L = 8000 mm	152000	160000
Sample gamma shutter	Lead shutter near the sample	L = 30 mm	161000	161030
Sample position	Sample	W = 20 mm H = 20 mm	161990	162010
Direct beam transport tube	Vacuum tube	W = 30 cm H = 30 cm expanding near sample L =3000+	162600	165600
Beam stop	Heavily shielded beam stop	W = 1000 mm H = 1000 mm	165600	167000

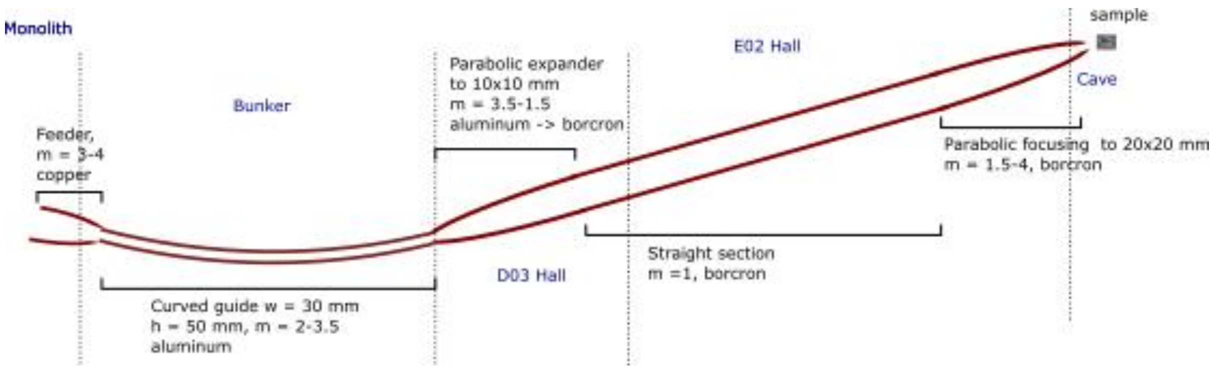


Figure 2: Principle of the guide design for Bifrost

5. BEAM TRANSPORT AND CONDITIONING SYSTEM (BTCS) (13.6.14.1)

To satisfy the high-level system requirements 3-6, the Bifrost beam transport system must be able to transport a large phase space, and transport a useful flux of near-thermal neutrons (1.2 Å). Fulfilling these requirement automatically optimize cold flux on the sample. As a secondary requirement, the Bifrost BTCS should minimize both cost and the impact of the prompt pulse, both scientifically and biologically. Once the large brilliance transfer of a large phase space is ensured, these secondary requirements drive the guide design, and we have settled on the design outlined in figure 2.

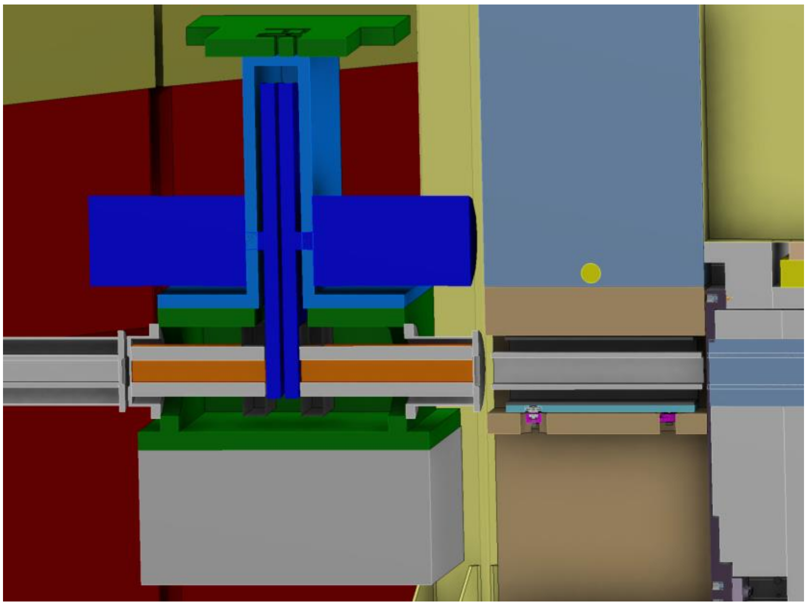


Figure 3: Proposed PSC CHIM design. A shared vacuum spanning between the gamma shutter and the bender, containing guide and tungsten blocks, horizontal split.

5.1 Beam extraction system (13.6.14.1.1)

To transport a large divergence, and achieve high brilliance transfer down to near-thermal wavelengths, a feeder is placed in the monolith insert. A continuation of this feeder is installed in the gamma shutter and in the CHIM of the PSC. The shared vacuum length of the CHIM is 784 mm, but the bulk of the CHIM is only 550 mm. An evacuated tube extends from the bulk of the CHIM to the gamma shutter. The CHIM is a horizontal split, so the choppers can be removed whilst retaining guide alignment. In the CHIM, the guide substrate is 30 mm copper, and close to the discs, we insert an additional tungsten aperture. This becomes heavily activated, but the resulting beta radiation is easily shielded by the CHIM, see figure 3. The feeder serves to create a small virtual source in the horizontal plane but expands in the vertical plane, resulting in a beam dimension at the PSC position of 25x50 mm^2. This reduces the chopper opening time and the accepted prompt pulse spatial angle downstream of the monolith.

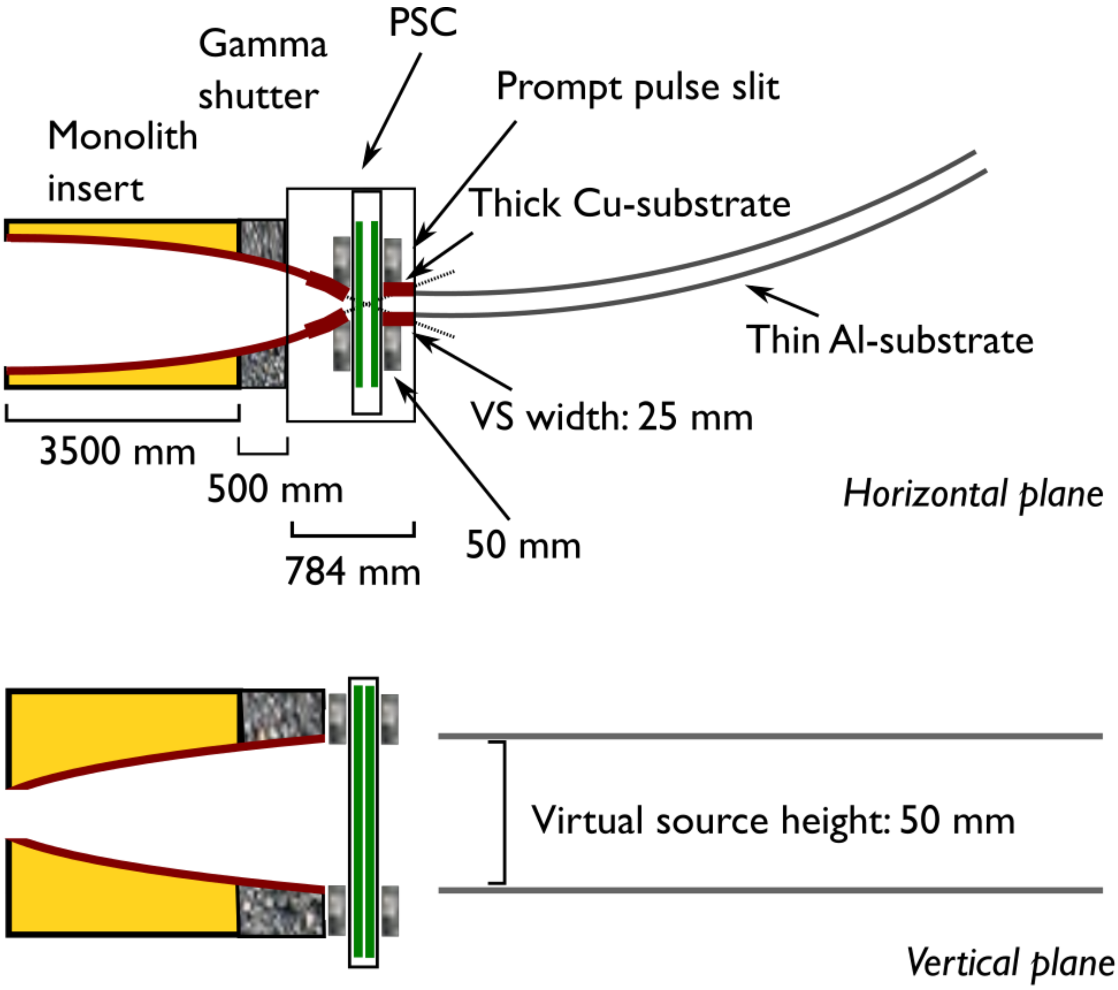


Figure 4: Schematic outline of the feeder geometry and virtual source concept near the monolith

To retain the whole guide within the pillars in the E02 and have only a single curved section, the feeder is rotated within the insert in the horizontal plane to view the cold moderator (see figure 6). The feeder is 45 mm wide so there is ample space. See figure 5 for a sketch of the feeder placement. The feeder centre starts 25 mm from the beam port axis, and has a rotation of 0.6 degrees towards the cold moderator.

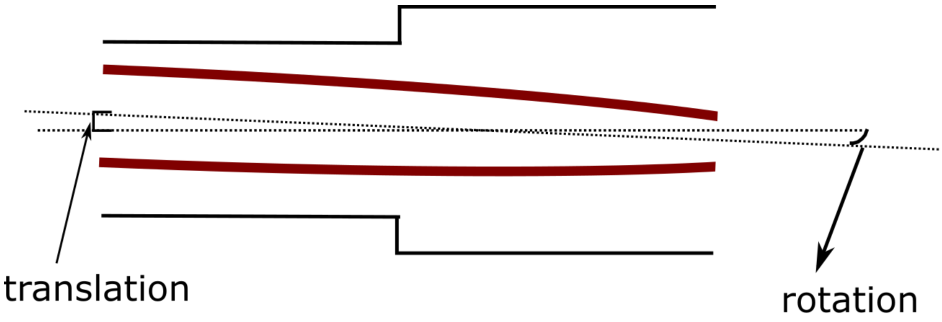


Figure 5: Horizontal plane view of the monolith insert. The feeder is slightly rotated towards the cold moderator but slight translated towards the thermal to retain a respectable flux across the board.

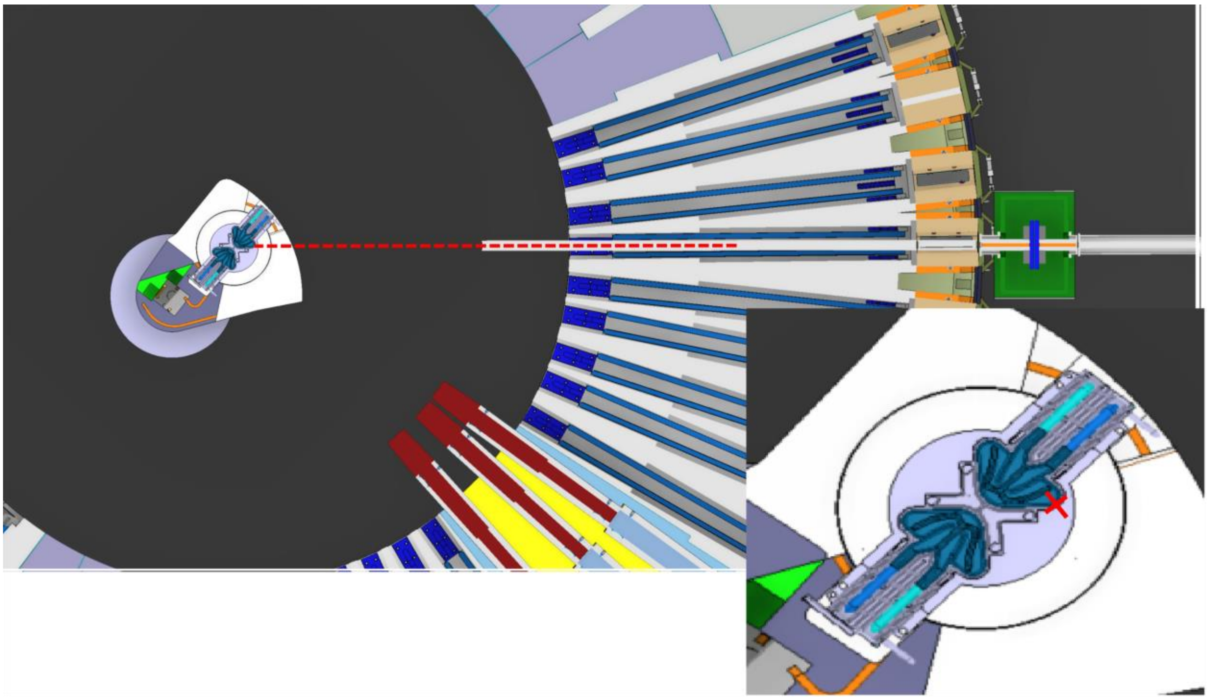


Figure 6: The first 4 metres of beam extraction. (Insert) The viewpoint on the moderator

5.2 Beam delivery system (13.6.14.1.2)

The curved guide in the bunker loses LoS at 24 m, and to reduce the intensity of the prompt pulse at the bunker wall exit, we follow the strategy employed by NMX and simulated by Valentina Santoro, 3-4 copper blocks less than 50 mm in length envelops the guide inside the vacuum housing, acting as scatterers of fast neutrons. This reduces the prompt pulse by orders of magnitude and reduce both the risk and cost of the shielding in the D03 hall. See figure 7.

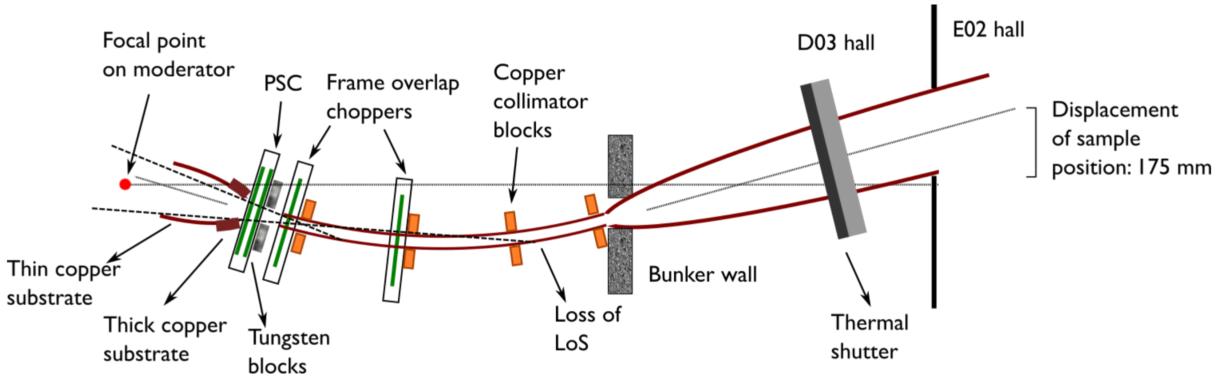


Figure 7: Principle of prompt pulse handling within the bunker.

The curved guide starts as close to the PSC discs as possible and have a radius of curvature of 1400 m. The curved guide width is 30 mm and the height is 50 mm. Upon exiting the bunker wall, the guide parabolically expands to a 100 x 100 mm straight section. Near the sample, there is a parabolic focusing section onto the sample. Both geometry and coating have been optimizing taking both price and performance into account, and the coating values are given in figure 8

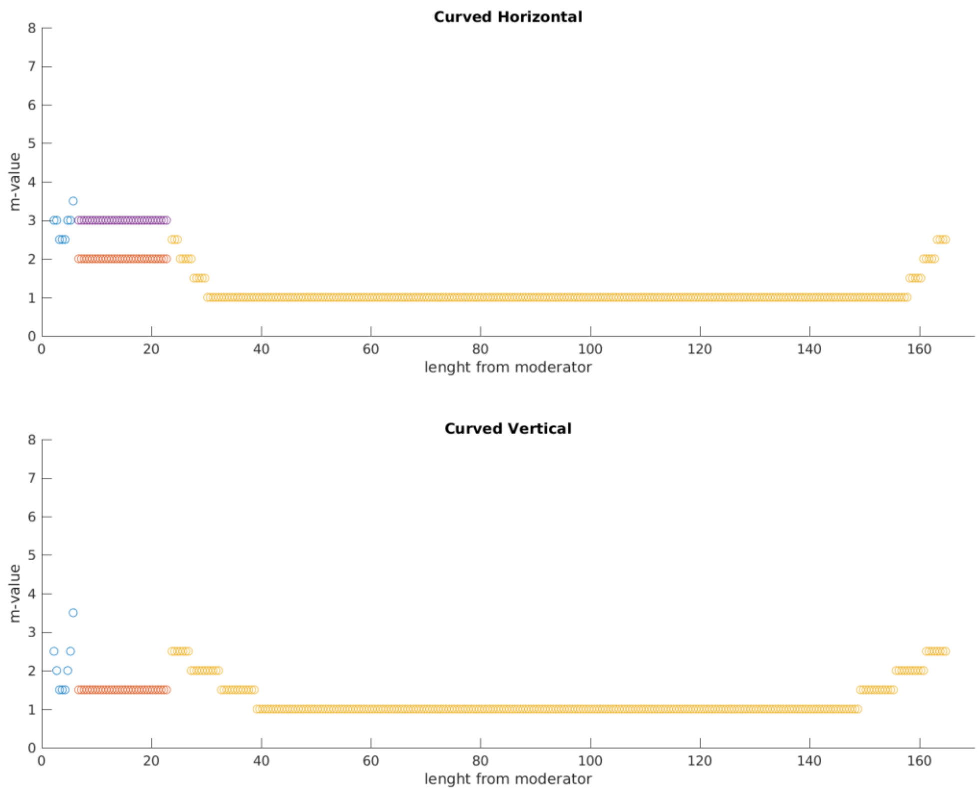


Figure 8: Optimized coating values for the proposed Bifrost guide system. (Top) Horizontal. Purple and orange markers represent the large and small radius part of the curved guide, respectively. (Bottom) Coating values on the vertical part.

The performance of this guide is described in section 13.

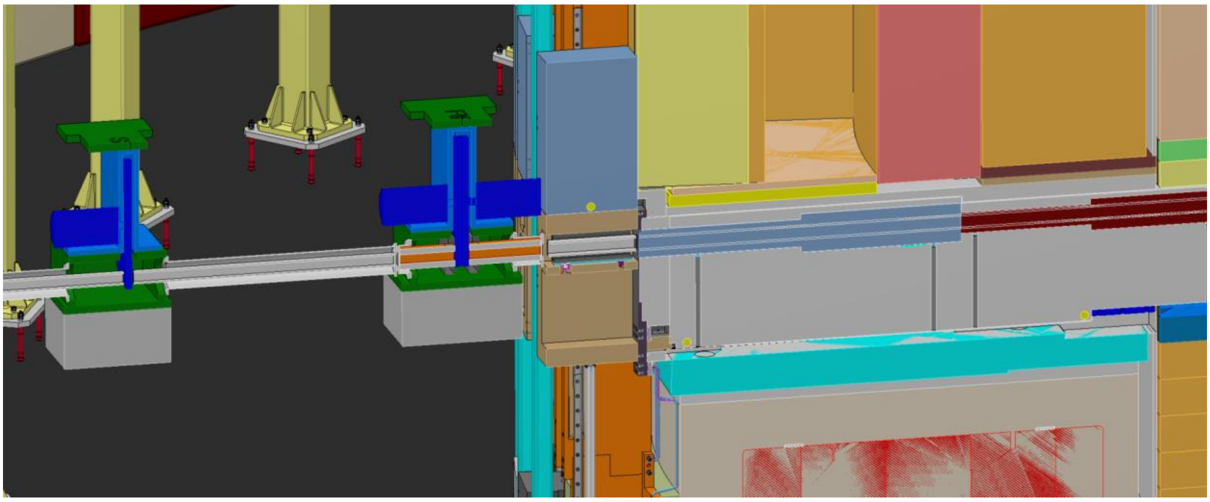


Figure 9: Target-bunker interface. The PSC is placed at 6.45 m and the first FOC at 8 m.

5.3 Chopper system (13.6.14.1.3)

The chopper system on Bifrost is a relatively simple 4-chopper system, with the pulse-shaping chopper (PSC) being the only chopper determining the energy resolution. The other three choppers serve to sort out unwanted frames from the fast PSC chopper and to avoid pulse overlap at the sample position.

The choppers are classified by their function into Pulse Shaping Chopper (PSC), Frame Overlap Choppers (FOCs) and a Bandwidth Chopper (BW). Their respective function is as follows.

5.3.1 Pulse shaping chopper (PSC)

The PSC can allow the full ESS pulse of 3.1 ms to reach the sample or reduce the pulse width by a factor of up to 30 (down to 0.1 ms), to match the best analyser resolution. In order to achieve this, we employ a co-rotating double disc chopper where the relative phase and speed of rotation can be varied, to allow for full flexibility. The PSC consists of two co-rotating 700 mm full aluminium discs coated with Gd. The spindle used should have magnetic bearings. The chopper CHIM to be used is a horizontal split module containing guide and tungsten collimators. This CHIM module is yet to be decided upon, as the design needs to take into account possible removal /realigning during insert replacement, chopper maintenance and the neighbouring beamlines into account. In addition, either lifting guides or a custom lifting frame will be designed to ensure the chopper can be installed/removed without hitting the monolith lip.

Distance from moderator: 6.45 m
Maximum speed: 210 Hz
Opening angle: 170 degrees

5.3.2 Frame overlap choppers (FOCs)

If the PSC spins with a high frequency, there will be a contamination from the slow part of the neutron velocity distribution. To remove this, we place 2 slow boron choppers in the curved guide section rotating at 14 Hz. In unison, these can remove the slow neutron contamination completely. For these slow choppers, we use ball bearings, and the chopper housing should share vacuum with the guide system to optimize guide performance. Therefore we employ a horizontally split CHIM (ESS-0041176), shown in figure 10.

Distance from moderator: 8.25 and 15 m
Maximum speed: 14 Hz
Opening angle: 32.76 and 75.6 degrees

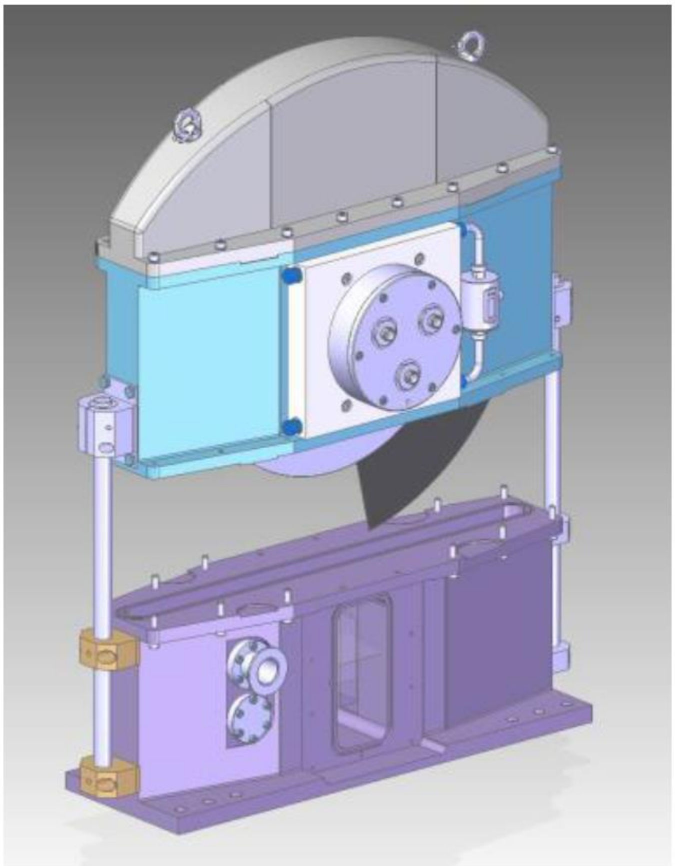


Figure 10: Horizontal split CHIM for all three slow choppers (ESS-0041176).

The placement of the first three choppers are in the bunker and their position relative to the pillars is given in figure 11.

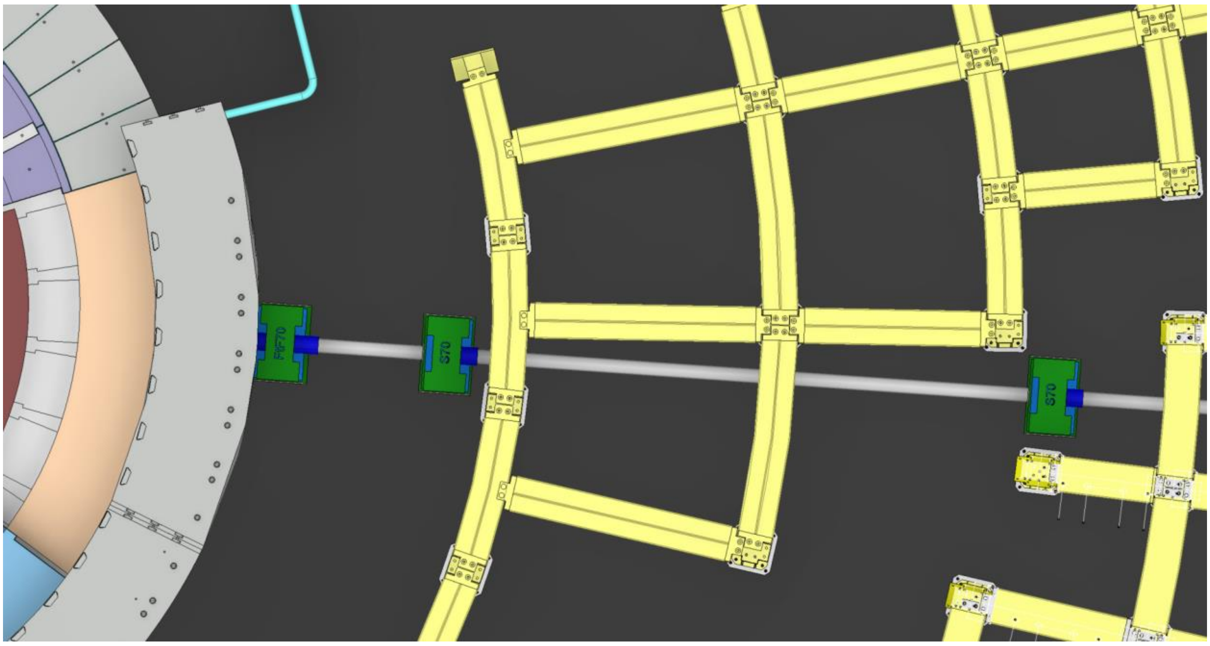


Figure 11: Chopper positions in the bunker with respect to the bunker pillars

5.3.3 Bandwidth chopper (BW)

To ensure non-overlapping frames, a slow boron chopper is placed 100 m downstream from the moderator. The placement is placed this downstream to minimize shadow effects, affecting the resolution at the pulse edges.

Distance from moderator: 80 m
Maximum speed: 14 Hz
Opening angle: 168.84 degree

The resulting effect of the chopper system is shown on a ToF diagram on figure 12.

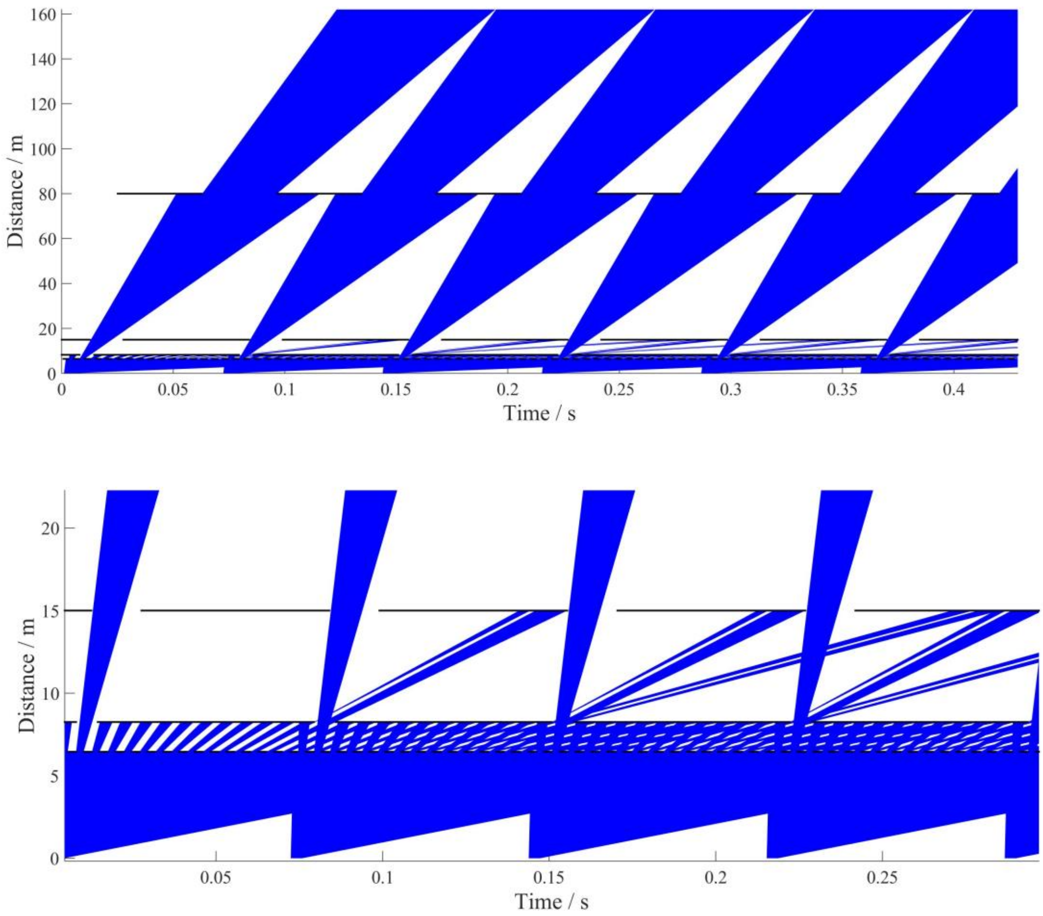


Figure 12: ToF diagram for the chopper system in a worst case setting of maximum speed (210 Hz), maximum opening (2.25 ms). (Top) Full beamline. (Bottom) Bunker and frame overlap

5.4 Beam geometry conditioning (13.6.14.1.4)

The beam geometry conditioning serves to adjust the phase space delivered onto the sample, through the divergence jaws and the sample slit.

5.4.1 Divergence jaws (13.6.14.1.4.1)

The divergence jaws are a set of slits situated in the guide 2-8 metres upstream from the guide endpoint. They serve to limit the divergence in the focusing part of the guide to be able to control the incoming divergence on the sample. The divergence requirements are between 20-120 arcminutes. We envisage using piezoelectric motors in the guide vacuum adjusting B4C slits in the guide system

5.4.2 Sample slit (13.6.14.1.4.2)

The sample slit is a standard component, where 4 thick B4C slits are adjusted into the beam using electric step motors, as close to the sample as possible. This serves to tailor the beam size to the sample size, to minimize background. Due to the varying sample environment dimensions, the slit ensemble has to be manually translatable. The step motors for the individual slits will be very close to the cryomagnet and therefore need to be easily removable. The slit system as a whole should be shielded with lead to minimize gamma background.

5.5 Beam validation (13.6.14.1.5)

For beam validation, we use three monitors. Two low efficiency nitrogen monitors are to be placed right after the PSC and right after the BW chopper. The PSC monitor serves to validate the beam extraction system and the PSC chopper, respectively. The nitrogen monitor after the BW chopper serves to validate the curved/ballistic section of the guide between the PSC and the BW chopper. The validation of the last elliptical section, including divergence jaw and polarizer (not in scope) is done as a secondary function of the sample monitor

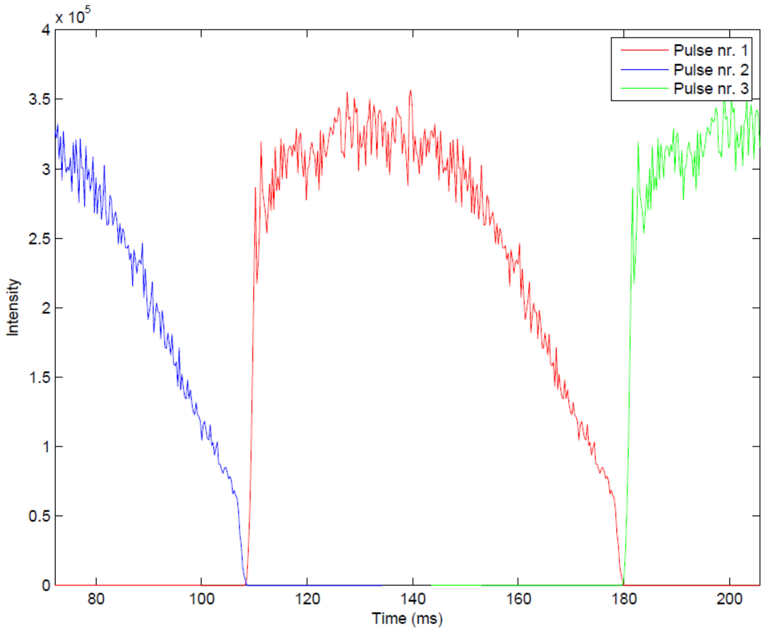


Figure 13: Simulated intensity distribution at 4-5.7 Å in a single frame. No aluminium windows are accounted for

For normalization, we use a sample monitor. The flux on Bifrost will vary between 10^7 n/s/cm^2 (high resolution, short wavelengths) and 10^{10} n/s/cm^2 (low resolution, long wavelengths). Since we employ a white beam on Bifrost, with an uneven intensity profile due to aluminium powder lines, we will need a binned spectrum of the entire frame to normalize the data.

In a maximum resolution mode, there are about 1000 relevant time-bins in a single frame (0.1 ms pulse duration). The flux per time-bin is thus 10^4 n/s/cm^2, and around 10^5 n/s will hit the sample monitor in total. A minimum requirement for intensity normalization is an uncertainty of less than 1 % in a 10-second measurement. Hence, the monitor efficiency should be of the order of 1 % in the thermal range (1 Å) to be able to normalize a high-resolution spectrum properly. However, for such a monitor, the corresponding efficiency at 5 Å would be around 5 %. Hence, we plan on a compromise 0.5 % efficiency or two separate monitors, depending on the price and budget.

The sample monitor(s) need event mode, for flexible binning according to the chose resolution. Examples of monitor solutions are given in [7], and we expect to work closely with the ESS detector group on this issue.

5.6 Beam cut-off (13.6.14.1.6)

5.6.1 Thermal Shutter (13.6.14.1.6.2)

In order to enable access to downstream components and the cave, a thermal shutter will be positioned between the end of the bunker and the bandwidth chopper. The exact position is yet to be confirmed, but the current concept is 50m. At this point, the effect of guide gaps will be reduced, but there will still be steel shielding to suppress gammas from the shutter.

Further analysis is required, but it is believed that a thin neutron-absorbing layer backed with a thicker gamma suppression layer, with a total length of 80mm, will be sufficient at this distance from any required access points. The assembly itself will be of simple design, potentially pneumatic, with vertical motion. This will be linked to the PSS system and fail safe.

Bifrost will look to collaborate with other long instruments considering similar shutters in order to standardise equipment and reduce costs.

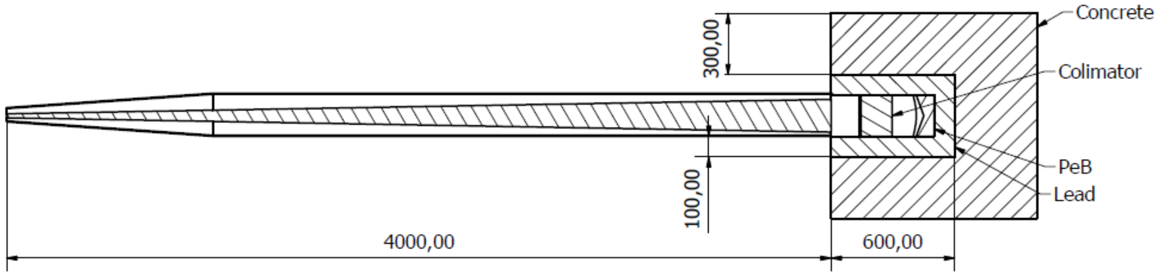
5.6.2 Sample Shutter (13.6.14.1.6.4)

In order to gain access to the cave and sample area, further gamma suppression maybe required from the ballistic guide and vacuum window just before the sample position. This section of beamline will already be surround by a lead shroud and a lead block will be translated into the beam path, once the thermal shutter is down, to fully encapsulate the beamline.

The design for this will be of a similar nature to the thermal shutter and again, it is envisaged that this will be linked to the PSS in order to allow for safe access into the cave. This lead barrier will also ensure that the vacuum window is protected from potential impacts from sample environment and tooling.

5.6.3 Beam Stop (13.6.14.1.6.4)

Due to the unprecedentedly intense primary beam of Bifrost, and the requirement for low background, the dumping of the direct beam needs to be as far as possible away from the detector tank whilst minimizing the number of scattering events along the primary beam path. To this end, our beam stop is placed outside the cave, downstream from the sample. To transport the direct beam to and from the sample, we employ an evacuated tube lined on the inside with borated PE (a get-lost tube). The beam stop itself consists of a block of borated PE, surrounded by a thick lead/concrete casket to shield for the produced low-E gammas (see figure 14)



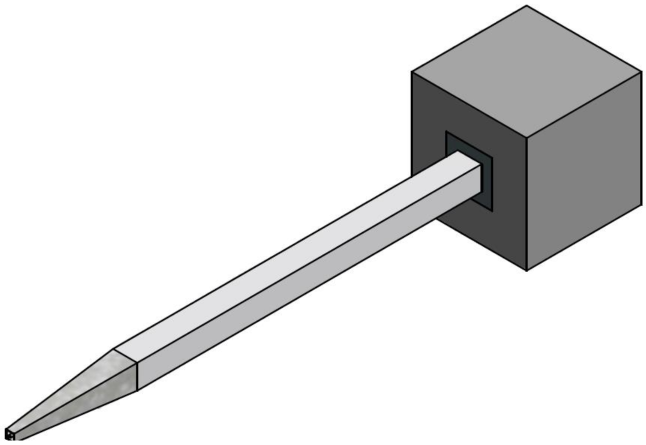


Figure 14: Evacuated get-lost tube and beam stop design

The lead casket is lined on the inside with sheets of BPE. The BPE block itself will backscatter a small fraction of the direct beam – about 4 %. To maximize the angle of deflection from the beam axis of these backscattered neutrons, we construct the BPE beam stop block in a wedge form. To handle the backscattered neutrons, we will construct a 2D radial collimator of either absorbing material (thin borated glass plates) or a strongly incoherent scatterer (like vanadium). The radial collimator will be designed to absorb as little of the incoming beam as possible while maximizing absorption of backscattered neutrons. To this end, the radial collimator will be optimized to the maximum divergence of the beam from the sample position and be placed downstream of the get-lost tube. This should minimize the flux of backscattering neutrons, both onto the sample environment and onto the STT itself. The collimator is shown on figure 15.

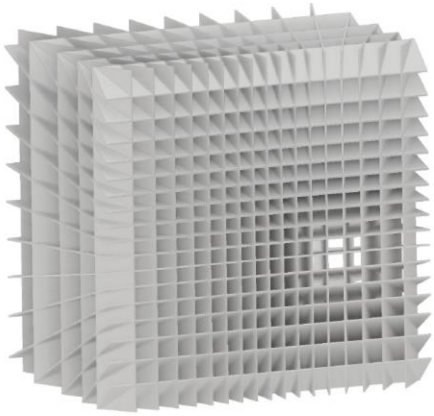


Figure 15: Angular exaggerated drawing of a 2D radially expanding collimator, constructed out of thin plates of absorbing material.

5.7 Vacuum system (13.6.14.1.7)

The vacuum system it outside the scope of the project and will not be considered here.

5.8 Shielding (13.6.14.1.8)

The shielding design from monolith to cave is split into four separate parts, see figure 16:

- Light thermal neutron shielding in the bunker to avoid activation (Blue)
- Fast neutron and gamma shielding in the D03 hall (red)
- Gamma shielding in the E02 (Orange)
- Ballistic guide section guide shielding at the cave (Green)

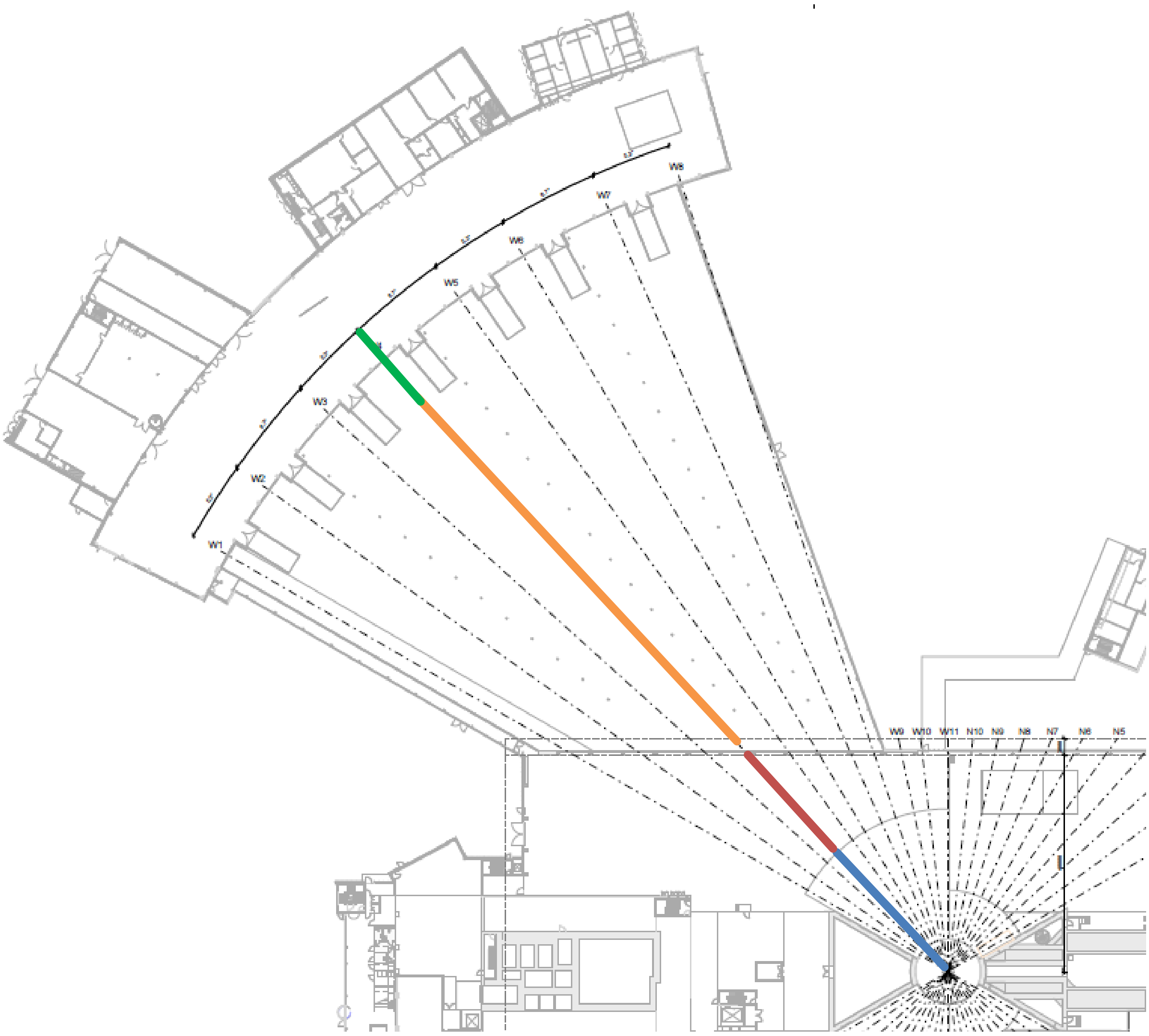


Figure 16: Outline of the west sector beam-lines, outlining the bunker section (blue), the D03 section (red), the E02 section (orange) and the cave section (green).

5.8.1 Shielding in the bunker

The bunker is by itself a shielding construction, so the vacuum housing containing the neutron guides are not shielded directly. However, the bunker wall feedthrough needs to be separately constructed. Here we envisage a replica of the bunker wall material, a layered construction with steel and borated PE concrete. We expect to shield the beamline itself with mirrobor, in order to minimize activation of the bunker components.

5.8.2 Shielding in D03 hall

In the D03 hall, there will be some residual secondary fast neutrons from the curved guide, and in the expanding ballistic guide, there will be a considerable amount of neutron absorption resulting in high-energy gammas. Due to spatial limitations, we employ steel for the inner shielding of the beamline and light concrete for the out shielding. Between guide and steel segment, and steel segments and concrete, we use a 5 cm thick layer of B4C to slow fast neutrons and avoid activation. The guide height is 2 m from the D03 hall floor, and to minimize steel cost we pre-cast a concrete base on which to place the steel and concrete elements (see figure 17).

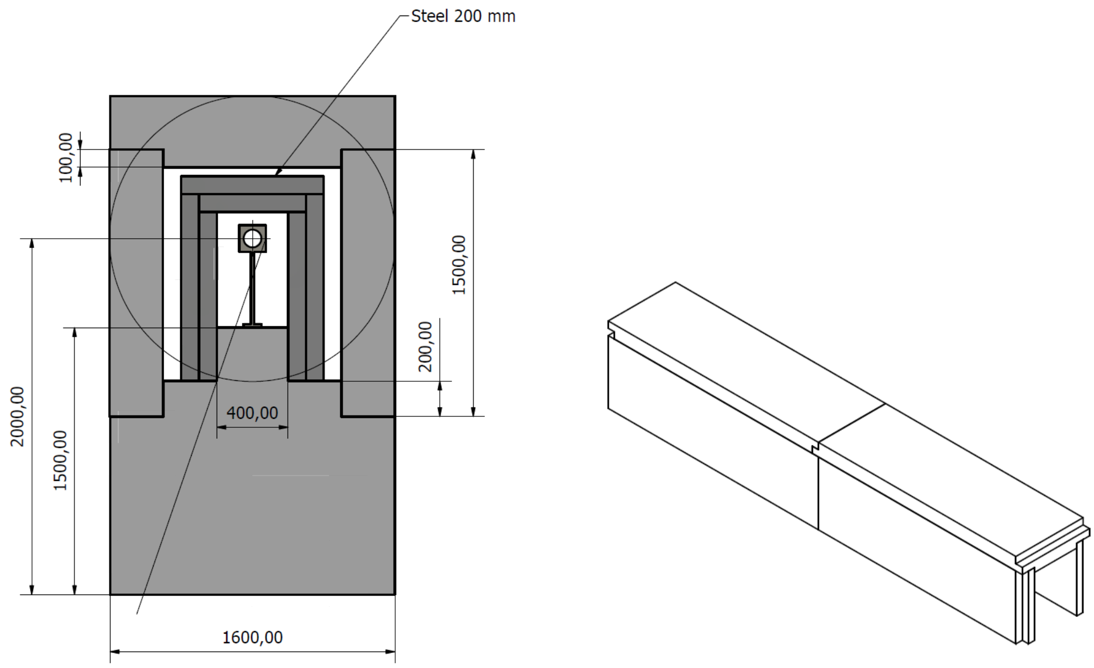


Figure 17: Left: Shielding concept in D03. The base element is casted onsite and the shielding around the beamline is modular. Right: Design of the outer concrete envelope.

This is sufficient to shield for prompt pulse and gammas in the D03 hall, and it does not overload the floor capable of supporting 14 T / m^2.

5.8.3 Shielding in E02 hall

In the E02 hall, only gamma shielding is necessary. Due to the straight section with m = 1, the losses are very low and predominantly from capture in boron. This yields a low flux of predominantly low-energy gammas that can be shielded solely with light concrete. We expect to procure simple and modular concrete elements that can be assembled with a minimum of work force. A simple version is one where a single standard element is used to build shielding wall, and two types of elements comprise a roof. Different elements are necessary to avoid streaming paths for radiation.

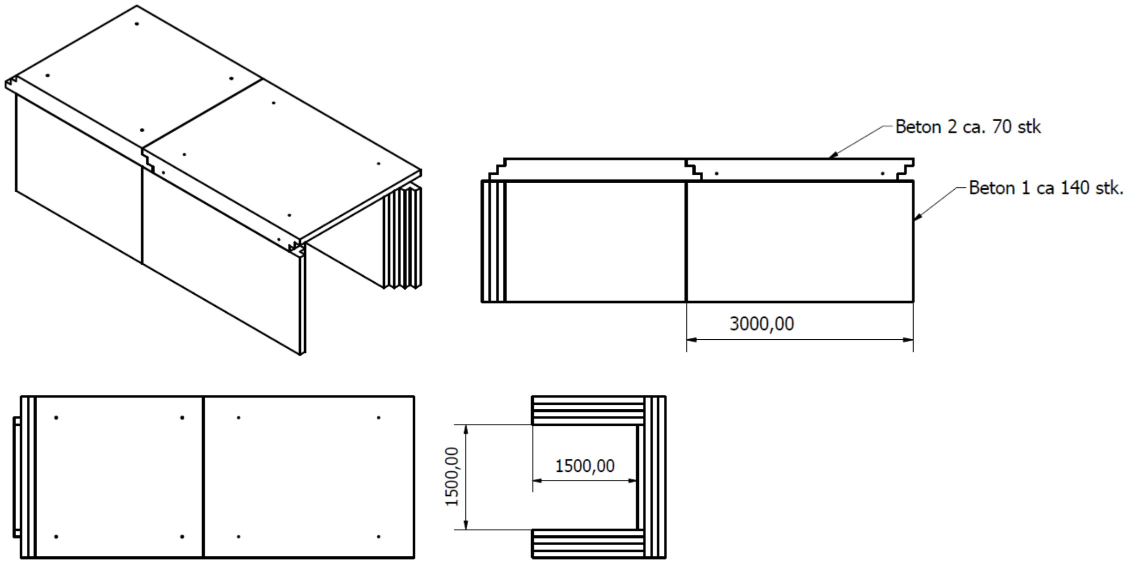


Figure 18: Concrete shielding in the E02 hall. Three elements comprise a streaming-blocked light concrete tunnel

5.8.4 Shielding near the cave

Near the cave, the focusing section in the last 15 meters of guide gives rise to an elevated amount of neutron absorption events in the guide coating. We aim to avoid steel in this part of the guide due to possible magnetization of steel, and thus aim for using lead. We hope to have access to cheap lead blocks of a standard design used for radiation protection throughout the world. For easy removal of such a wall, we aim to construct pre-assembled walls of aluminium containing and fixing such lead blocks, to be placed around the guide. This lead wall is surrounded by a concrete wall, and between guide and lead wall, and lead wall and concrete wall, we place 5 cm of B_4C to avoid activation. The B_4C walls are also necessary for thermalizing and capturing fast neutrons produced in lead via the (gamma, n) cross section.

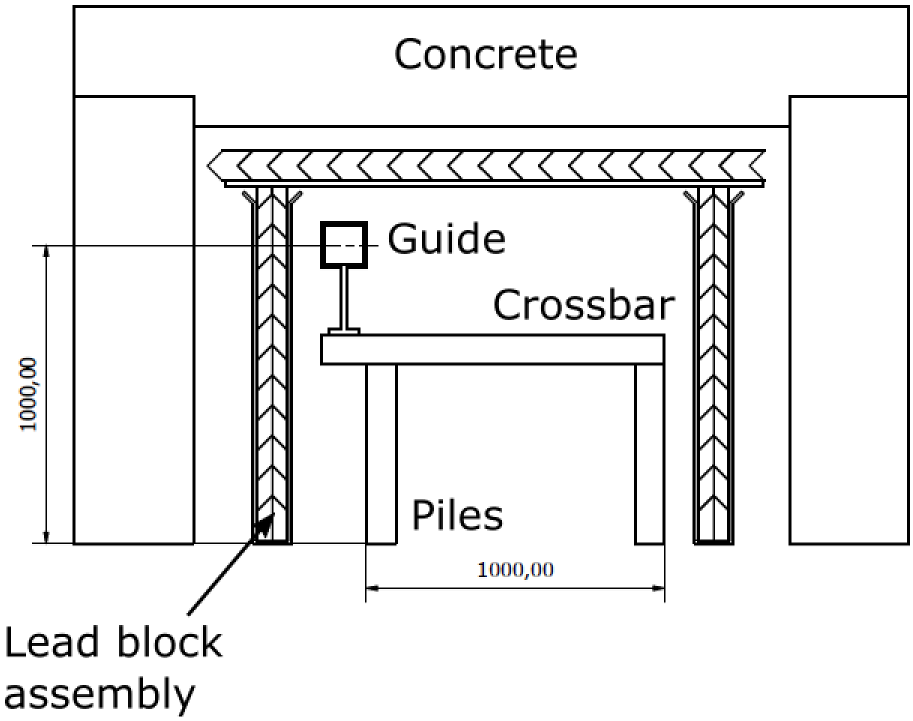


Figure 19: Shielding of the guide near the cave

6. SAMPLE EXPOSURE SYSTEM (13.6.14.2)

The sample position consists of the sample table, the sample environment and the corresponding support structures. Everything in proximity to the sample position has to be constructed out of non-magnetic material.

6.1 Sample table (13.6.14.2.1)

The sample table needs to be constructed out of stainless steel and/or aluminium, and be able to carry up to 5000 kg. The sample table should be statically pre-aligned to the neutron guide, and thus would not have an XYZ translation stage. The sample table should have a rotation stage to align magnets and rotate cryostats with a weight of at least 2000 kg. To align the sample position of the sample environment to the beam position, a range of adapters is to be made. For light sample environment, it will be advantageous to tilt the equipment to which a removable goniometer will be used. High-field magnets will not be tilted.

6.2 Sample environment (13.6.14.2.2)

Most of the experiments at Bifrost will be conducted at cryogenic temperatures. In case no magnetic field is needed, a standard ILL orange cryostat is to be used, which is in the instrument scope (figure 20 right). This allows for a wide VTI with a lot of room for additional equipment (e.g. devices for E-field and pressure). If a magnetic field is needed a cryomagnet is used where the liquid helium reservoir serves to cool down a superconducting magnet (figure 20, left). This is expected to be in the sample environment pool)

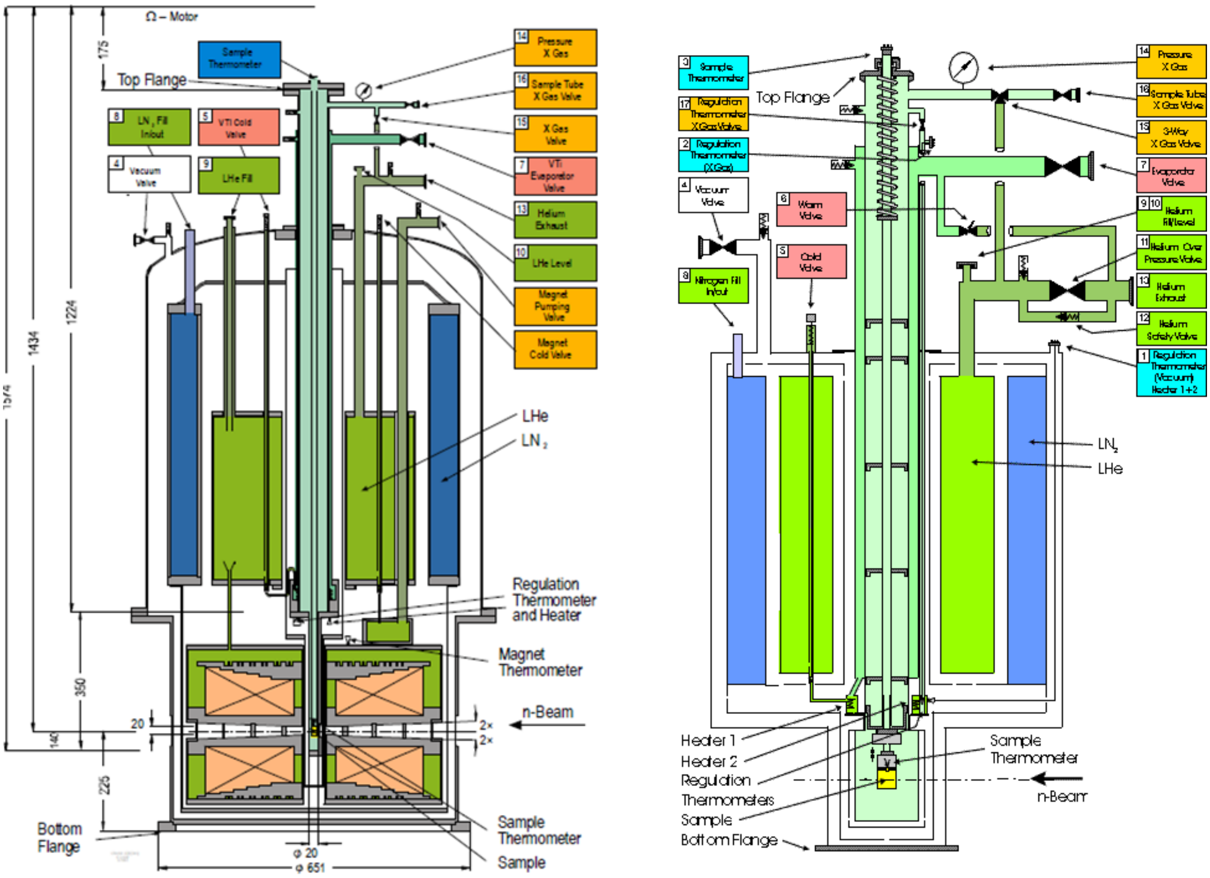


Figure 20: (Left) Outline of a standard Oxford 15 T cryomagnet (VM1B at HZB). (Right) Outline of a standard orange cryostat.

A standard 15 T cryomagnet weighs 900 kg, but Bifrost needs to handle future designs that might well be much heavier. Bifrost also needs to allow space for a larger magnet than the standard Oxford system, to allow for future developments in superconducting magnet technology. A pressure cell can be inserted into both a cryomagnet and a cryostat, but the larger room in the cryostat allows for more flexibility.

7. SCATTERING CHARACTERIZATION SYSTEM (13.6.14.3)

The scattering characterization system consists of the filtering system and the secondary spectrometer tank.

7.1 Filtering system (13.6.14.3.1)

The filtering system is situated between the sample environment cryo-magnet and the spectrometer tank and is crucial for Bifrost fulfilling the high-level background. The spurious scattering of the white beam off the sample environment will be unprecedented.

7.1.1 Beryllium filter (13.6.14.3.1.1)

A beryllium filter is an essential component for background reduction on Bifrost; the cold beryllium has a very low transmission of cold/thermal neutrons with energies above 5 meV and above 90 % transmission of neutrons with an energy below 5 meV. In some operational modes of Bifrost, the incident beam on Bifrost will have an energy range extending below 5 meV. To block elastic scattering from the sample environment from entering the tank in that case, we envisage a Be-filter with a built in radial collimator, as experimentally demonstrated feasible in [5]. This allows for a two-folk background reduction where the filtering is both spatial and energetic.

The solution will follow closely the prototype tested in [5] and outlined on figure 21. Here, Be-wedges are machined to fit inside a longer ensemble of coated lamellas, all mounted on a baseplate in an evacuated vacuum vessel. A pulsed tube cooler allows for cooling the plate and thereby the beryllium.

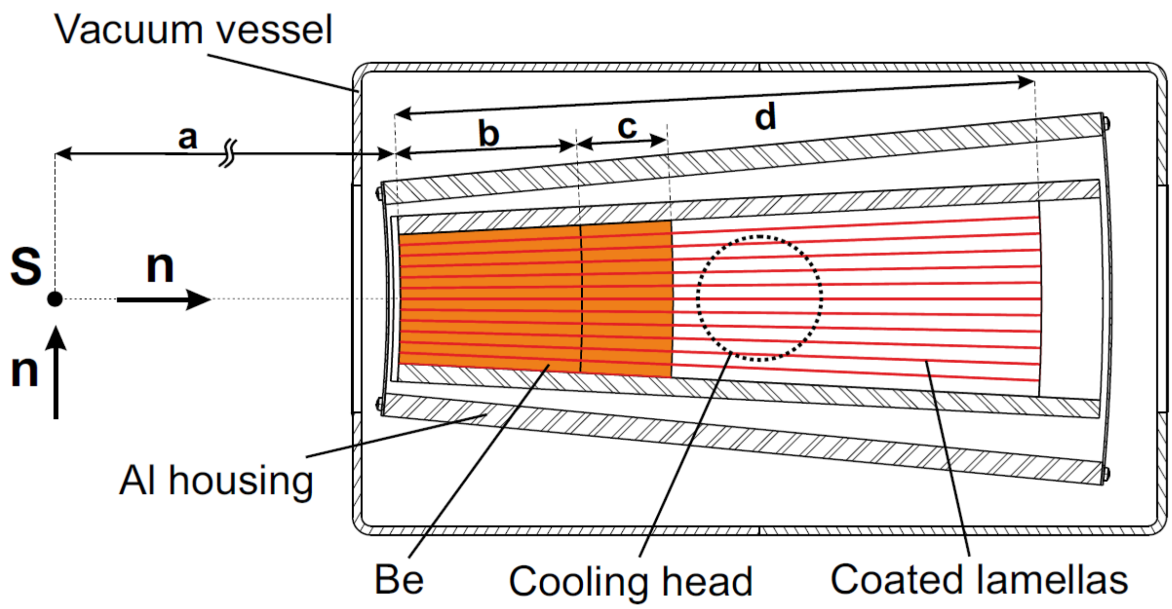


Figure 21: Prototype of a beryllium filter with built in radial collimation

The filter will cover the full 90-degree scattering angle and is cooled by 2-3 pulsed tube coolers. The filter should be translatable out of the beam path, to allow for alignment of certain samples and for indirect use of higher order reflections off the analyser by subtraction.

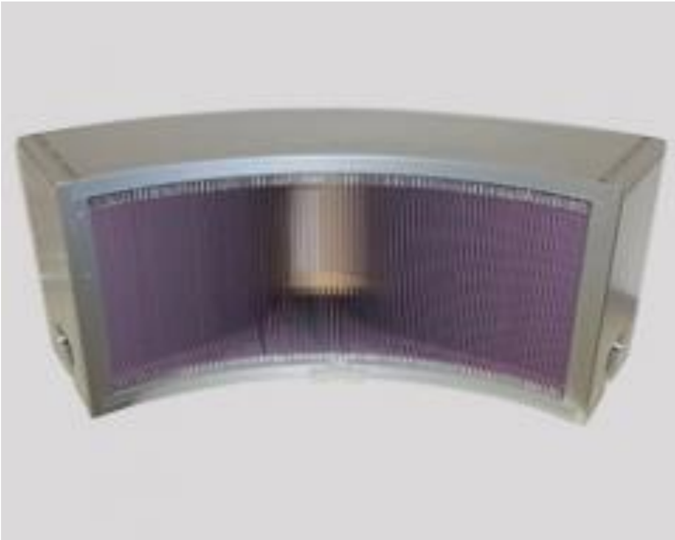


Figure 22: Neutron radial collimator as produced by JJ X-ray

7.1.2 Radial collimator (13.6.14.3.1.2)

For shielding unwanted scattering from very small VTI's a dedicated radial collimator is necessary, due to the very small spacing between lamellas. This radial collimator is to cover all 90 degree scattering angle and accept a horizontal radius of 1 cm from the sample position. This acceptance radius is defined by the lamella spacing and the lamella length, while the lamella thickness and waviness affects overall transmission in a given design. A radial collimator from the company JJ X-ray is shown in figure 22. In order to shield a VTI 2 cm wide, a radial collimator with 0.5 degree spacing between lamellas, with 10 cm long lamellas starting 60 cm from the sample is necessary. When enriched boron is used, the lamella thickness can be greatly reduced, allowing for a compact radial collimator. To minimize systematic effects, the radial collimator should oscillate in the direction of the circle normal to the blades. This is achieved with a rotating motor, sliding the collimator along the arc.

7.2 Secondary spectrometer tank (13.6.14.3.2)

The secondary spectrometer tanks houses the analysers, the detectors and the crosstalk shielding between energy- and Q-channels. The tank itself will be heavily shielded for thermal neutron background.

7.2.1 Vacuum vessel (13.6.14.3.2.1)

The vacuum vessel will be made out of non-magnetic aluminium, since the deformation under evacuation has little impact on the relatively small detector ensembles. However, the deformation of the tank shall be minimized, controlled and reproducible to enable a precise positioning of both the analysers and the detectors. Due to the dead angles of the analyser ensembles, reinforcement can introduced either on the inside or outside of the tank. The vacuum vessel shall be lined with cadmium sheets on both the inside the outside, there shall be infrastructure for mounting B4C shielding components. These components will allow HV coaxial cables to pass from the detectors to the outside of the tank, where the preamplifiers are placed. This cable feedthrough shall minimize the penetration of diffusive neutrons air-scattered from the direct beam filling the vicinity of the sample position.

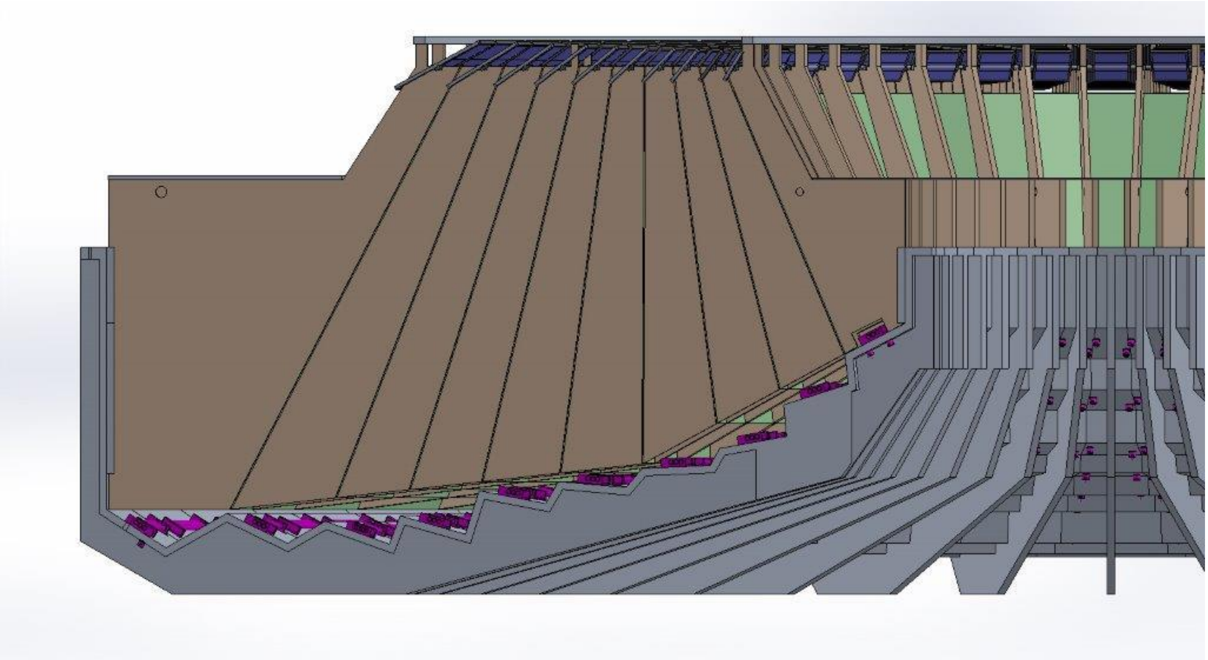


Figure 23: Preliminary design of the vacuum tank (containing 10 analysers - 4 are in scope). A multistep underside allows for correct positioning of the detectors on the tank underbelly.

7.2.2 Analysers (13.6.14.3.2.2) – Note: Only 4 analysers in scope

The PG analysers utilizes Bragg's law to reflect a single wavelength onto the detector, which is placed at the appropriate angle. The take-off angles and therefore the accepted wavelengths of the analysers are fixed. Due to the transparency of PG at long wavelengths, several analysers are placed behind each other, downstream from the sample, each accepting a different wavelength. This fixed multi-analyser approach is stable – with no moving parts.

Each analyser will consist of a number of HOPG blades. These will need to between 80-150 mm in length. This necessitates mounting 2-3 separate blades in extension to achieve the desired length. This can be achieved by ordering the smaller blades with a 45-degree cut, allowing them to be straightforwardly mounted in extension of one another. The analyser blades are mounted on a thin Si-wafer, with excellent neutron transmission properties. The mounting method will be with either a thin layer of shellac, using aluminium clips or directly binding the blade to the wafer with a heat treatment procedure. The wafers themselves will be slightly longer than the HOPG blades to prevent the analyser holders being in the sample-detector path.

The wafers are mounted directly on aluminium holders. These holders shall be machined with high precision to maintain the correct analyser geometry. The holders will be shielded upstream to the sample to avoid exposure to Bragg peaks from the sample, which would generate a Debye-Scherrer cone in the vacuum tank resulting in unwanted background.

The analyser energies chosen, their distances from the sample and their geometrical specifications are given below.

Table 1 Analyser specifications for BIFROST

Analyser energy	Distance from sample [m]	Take-off angle [deg]	2-Theta coverage [deg]	Total area of analyser [mm^2]
2.7 meV	1.05	55.11	4.6	6075
3.0 meV	1.13	51.09	4.85	7360
3.4 meV	1.21	46.97	5.1	8840
3.9 meV	1.32	43.04	5.35	10738
4.4 meV	1.42	39.98	5.6	13230
5.0 meV	1.52	37.07	5.85	15960

The analyser-detector distance needs to be the same as the analyser-sample distance to maintain the optimal Rowland geometry. The analyser blades are placed on the Rowland circle, containing the sample, the analyser centre and the detector centre. The analyser curvature radius is twice that of the Rowland circle and the analyser blades are places accordingly. See figure 24.

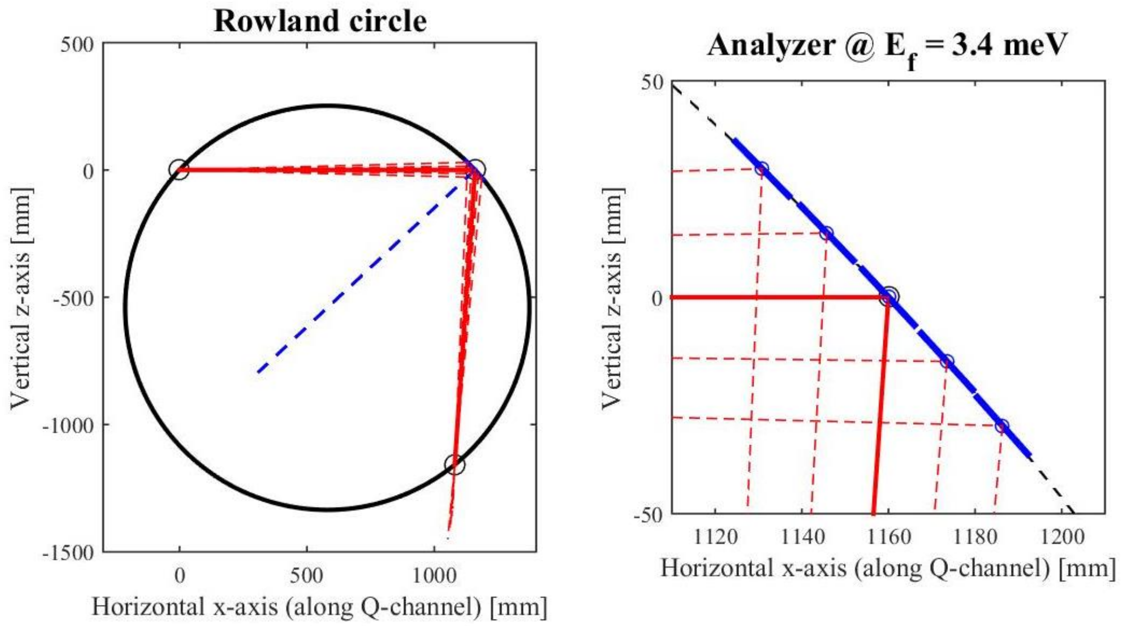


Figure 24: Example of a Bifrost analyser comprised of 5 blades, placed in the symmetric Rowland geometry.

In the vertical plane the analyser with the different final energies placed behind each other, downstream from the sample. Since the take-off angle is decreasing with increasing E_f the analysers have to be placed with increasing final energy as ones goes downstream from the sample position. The first analyser at E_f = 2.7 meV will cover a vertical opening angle of +/- 2 degrees. The analysers further downstream with a larger E_f will result in larger resolution volume and hence father more intense signals from the sample. In order to balance the count rates, we have chosen the vertical coverage of the analyser with E_f > 2.7 meV to have the same vertical elastic Q-resolution as the 2.7 meV analyser. Due to the large E_f's, these analysers will cover a smaller opening angle than at 2.7 meV, see figure 25. This design choice serves to save costs as well.

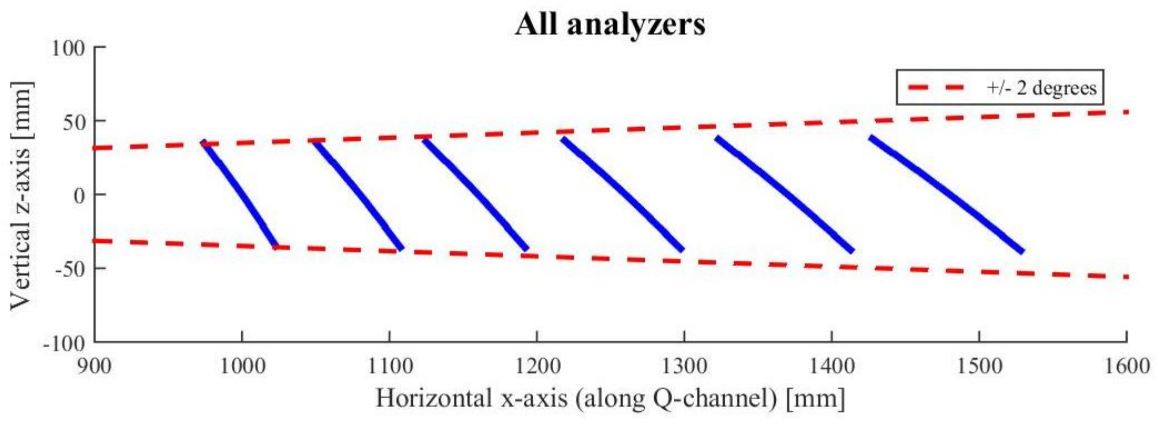


Figure 25: Cross section of the six planned analysers in the vertical plane.

In the horizontal scattering plane, the analysers are arranged in Q-channels. We employ 10 Q channels, with a 9-degree angular separation between Q-channels. Since dead angles are unavoidable in any case, we allow for a considerable dead angle between adjacent Q-channels, with the requirement of having full gapless angular coverage in two tank settings. Hence, the low energy analysers have an angular coverage slightly larger than 4.5 degrees. The angular coverage is gradually increasing with increasing E_f, since spatial limitations are less severe further away from the sample. The angular coverage of adjacent Q-channels in two settings is shown on figure 26.

For the 5 meV analysers, there is a 55 % overlap of the angular coverage in two settings. This is mainly for three reasons:

1) Maximize single setting angular coverage for fast parametric studies
2) Recognition of spurious signals by being able to cover a similar range using different tank settings
3) High probability for sample alignment using a single tank setting.

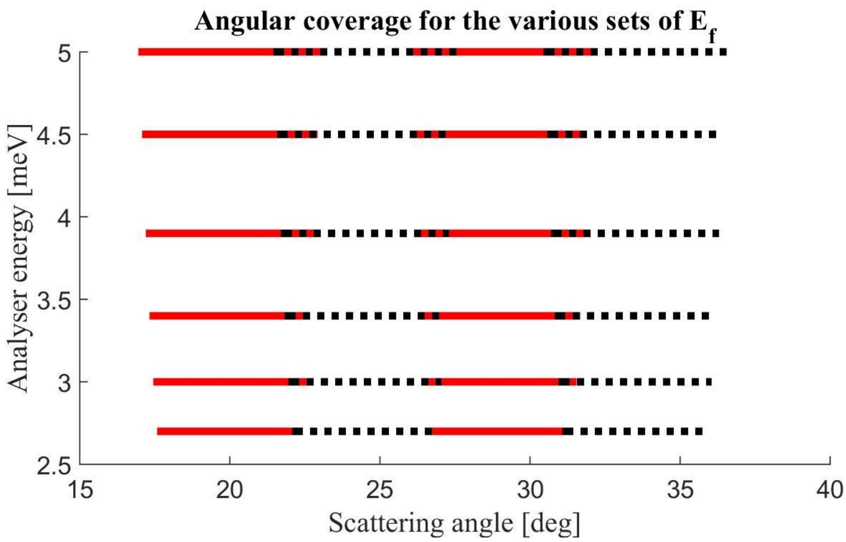


Figure 26: Coverage in scattering angle for the proposed analyser geometries for to adjacent Q-channels in two settings. The full red lines are the first tank setting, the dashed black lines the second. The deliberate overlap of up to 55 % exists at the large energies

This arrangement leaves ample space for crosstalk shielding. To leave space for the detectors of Bifrost, a staggered arrangement of analysers is necessary, see figure 27. Due to this arrangement, adjacent analyser rows will not cover the sample spatial angle, which would need to be taken into account in count normalization. However, these effects are smaller than the variance in HOPG reflectivity.

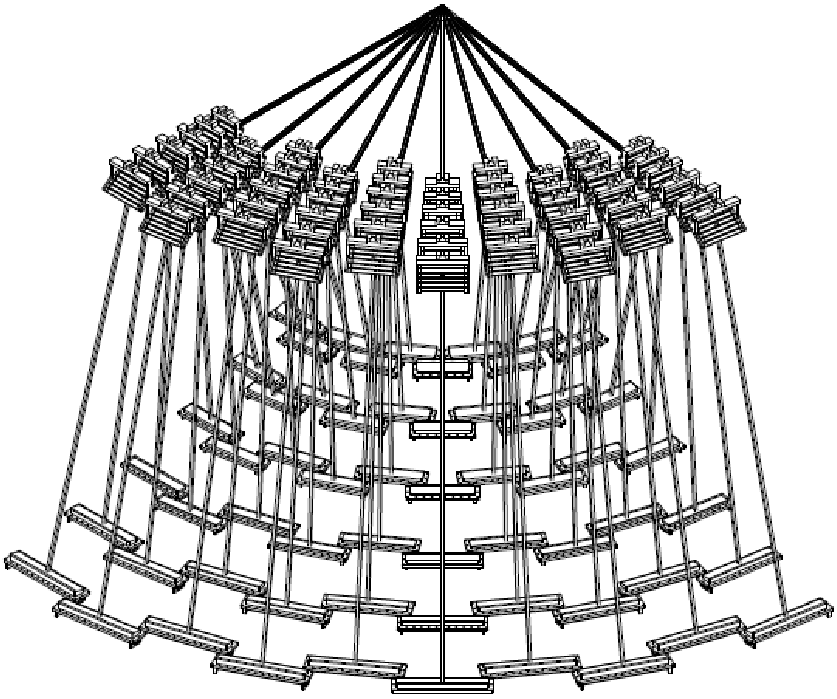


Figure 27: Top view of the proposed analyser arrangement. To leave space for the detectors a staggered arrangement is necessary.

7.2.3 Detectors and electronics (13.6.14.3.2.3)

To detect all neutrons scattered from the analysers, the detectors need to be slightly more than twice the length of the analysers. To utilize the prismatic analyser concept, we employ three 1D detector tubes placed side-by-side. The detectors are placed inside the vacuum tank. To reduce the readout electronics cost, we place the detector tubes in series, with only two connections per detector ensemble. The detectors are welded airtight onto a vacuum flange allowing for high voltage feedthrough in the vacuum vessel.

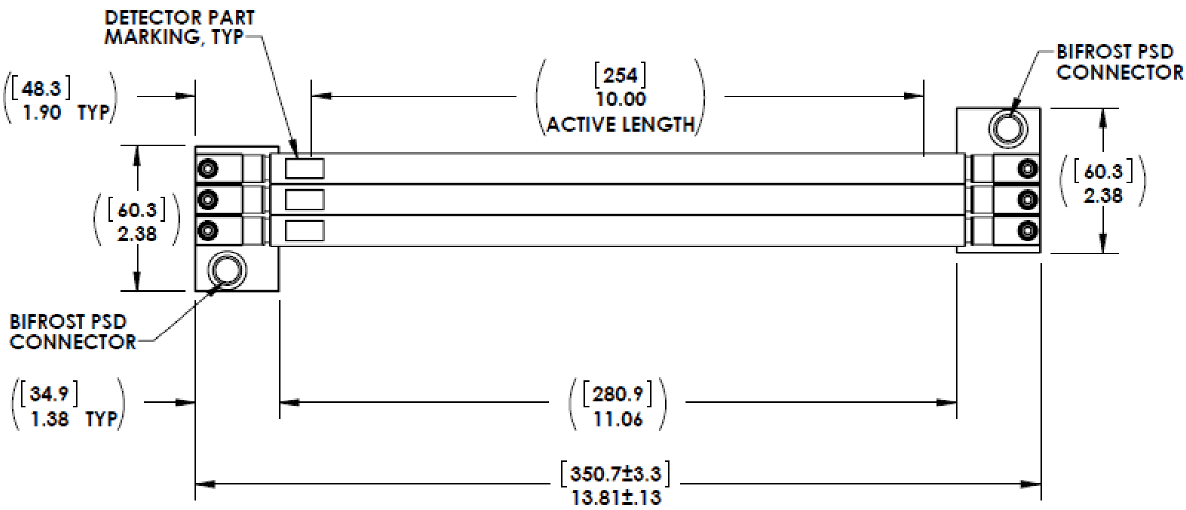


Figure 28: Suggestion for a detector ensemble (Reuther-Stokes quote)

Due to the sample size and the relaxed mosaicity, the natural spot size of a diffracted beam from the analyser is 40 mm. Therefore, a spatial resolution of 50-100 mm would be enough for Bifrost.

Since the detector flanges are vacuum tight, the entire high voltage cable will be in atmospheric pressure. In case of a leak, there will be no significant reduction of pressure around the HV wire inducing sparks. For this reason, the vacuum requirements of the tank are determined by background requirements only.

The preamplifiers are to be placed outside the shielding of the main spectrometer tank, minimizing the length of the HV cable between preamplifier and detector ensemble. The detector readout/backend electronics are to be placed outside the cave, in the instrumental hutch.

Even in a staggered arrangement, the detector ensembles are tightly placed to one another, as evident on figure 29. This puts strict requirements on the cross talk shielding.

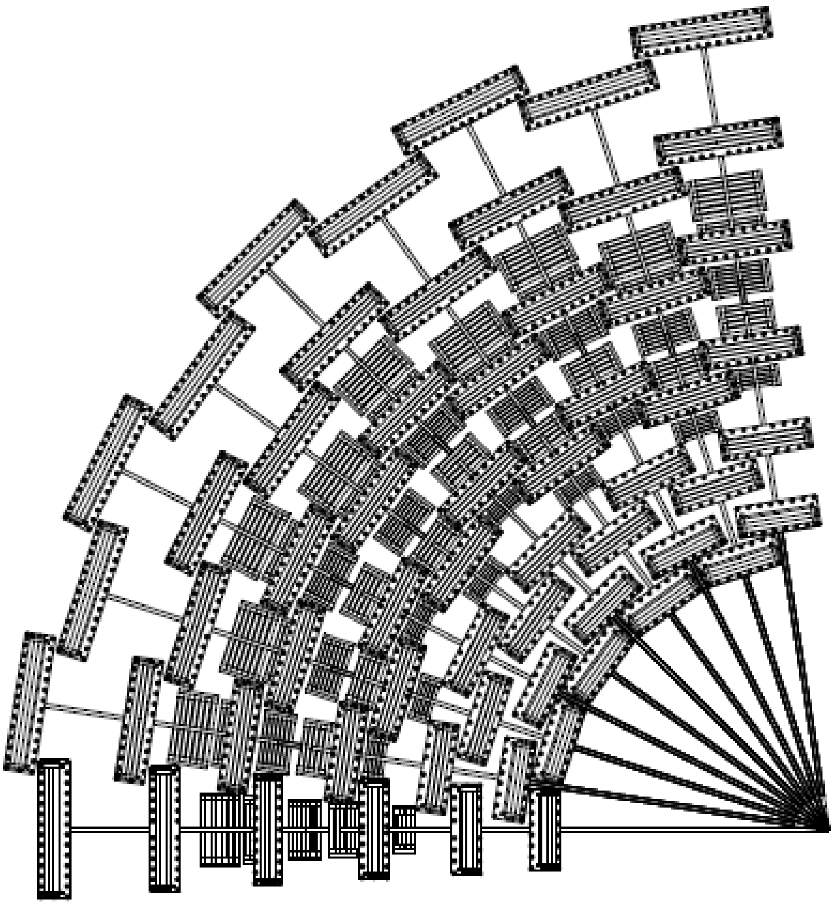


Figure 29: View of the analyser-detector ensemble from the bottom.

7.2.4 Crosstalk shielding (13.6.14.3.2.4)

The crosstalk shielding is the most important shielding component of Bifrost, as it prevents crosstalk between channels. A future operation of Bifrost accepting high energies in the spectrometer tank could produce large amount of spurious scattering from the PG crystal. Therefore, it is paramount that each detector ensemble only sees the analyser designated to it. A proposal for such closed shielding channels are shown in figure 30.

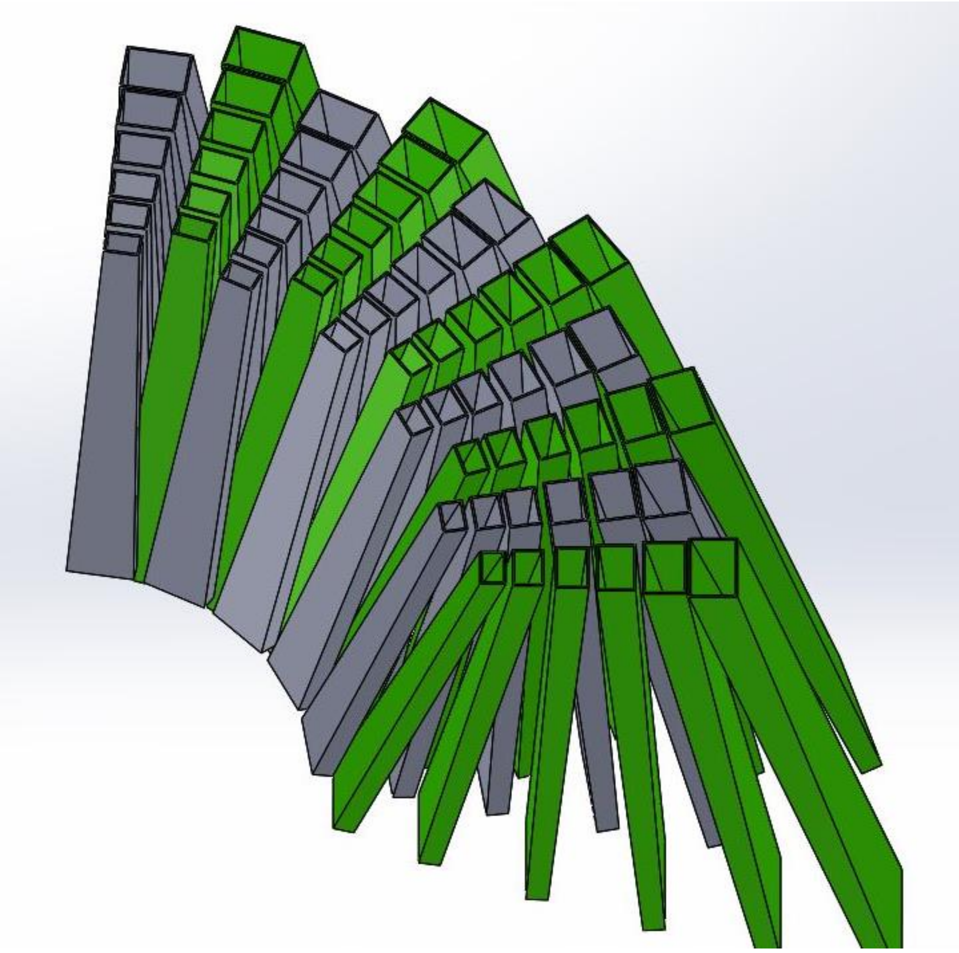


Figure 30: Design of cross talk shielding in the secondary spectrometer tank. The staggered placement of the channels are shown as grey and blue sets of shielding. The material to be used is B4C.

7.2.5 Tank positioning system (13.6.14.3.2.5)

The tank positioning system is merely a set of rails in the cave on which the vacuum vessel is to move. On the tank, we position a set of wheels or air pads, and a large electrical step motor is to facilitate the movement. This motor is to be placed as far away from the sample position as possible.

Since the absolute tank position is the most important parameter on Bifrost, we envisage an external encoder system to monitor the tank position.

Two limit switches will be used for invoking hard limits, independent of any soft zeros. This is to avoid tank damage in case of human error, in either the software or hardware.

8. EXPERIMENTAL CAVE (13.6.14.4)

At the end of the Bifrost guide is the experimental cave, containing the sample exposure system and the scattering characterization system. This area is accessed by users and instrument scientists and is controlled by the PSS, as the main purpose of the cave is to shield the surroundings during operation.

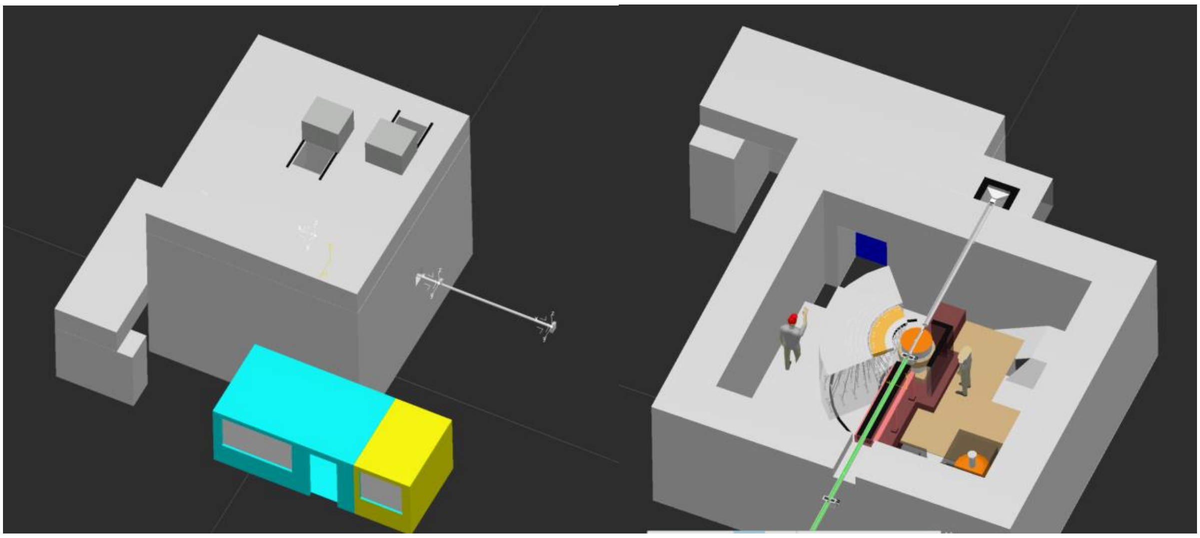


Figure 31: External view of the Bifrost cave

8.1 Support infrastructure (13.6.14.4.1)

The support infrastructure in the cave of Bifrost serves the main purposes of providing access to component and provide safe as well as easy handling of samples and sample environment.

The guide and slits leading up to the sample position will produce a high intensity gamma field during operation, that unshielded would cause a lot of background on the detectors. Therefore, they need to be shielded with lead, with considerable weight associated with it. The sample table needs to hold 5 T of weight as well, and therefore we construct a concrete plinth to support the sample position and everything upstream to it. The get-lost tube downstream the sample position is light and easy to support on a false floor.

For handling the sample environment we build a lead wall on one side around the sample position, able to shield a person standing next to a cryomagnet containing an active sample, see figure 32. In the corner of the cave, a lead enclosure is situated in which a hot magnet can be placed, allowing full cave access.

For accessing the sample position, the tank and the lead enclosure, a false floor is built inside the cave. For accessing the cave itself, we employ a labyrinth. The internal cave door is mainly neutron shielded and the outer door into the labyrinth is a thin gamma shield or even a metal fence if possible.

For heavy lifting, a non-magnetic 2 T crane is to span the roof of the cave, able to lift a 15 T Oxford cryomagnet. Through the cave roof, we have two access points, one at the sample position and one at the lead enclosure at the cave corner. This serves as redundancy, enabling the staff to handle an active magnet even in case of internal crane failure, but also enables heavier magnets to be placed at the sample position.

Removing a hot sample without removing the sample environment will occur in the following way: One stands close to the magnet, protected by the lead screen. A lead glass screen protect the face as the upper part of the magnet is handled – venting the sample space and removing a flange. As one pulls out the sample stick and expose the sample, the body and face remain protected while the hand is exposed for a short while. The sample stick is lowered onto a holder on the inside of the lead screen, protecting users and staff. This procedure will be sufficient for the vast majority of cases to the much larger dose limits to extremities as compared to the body. See section 12, for a preliminary safety analysis.

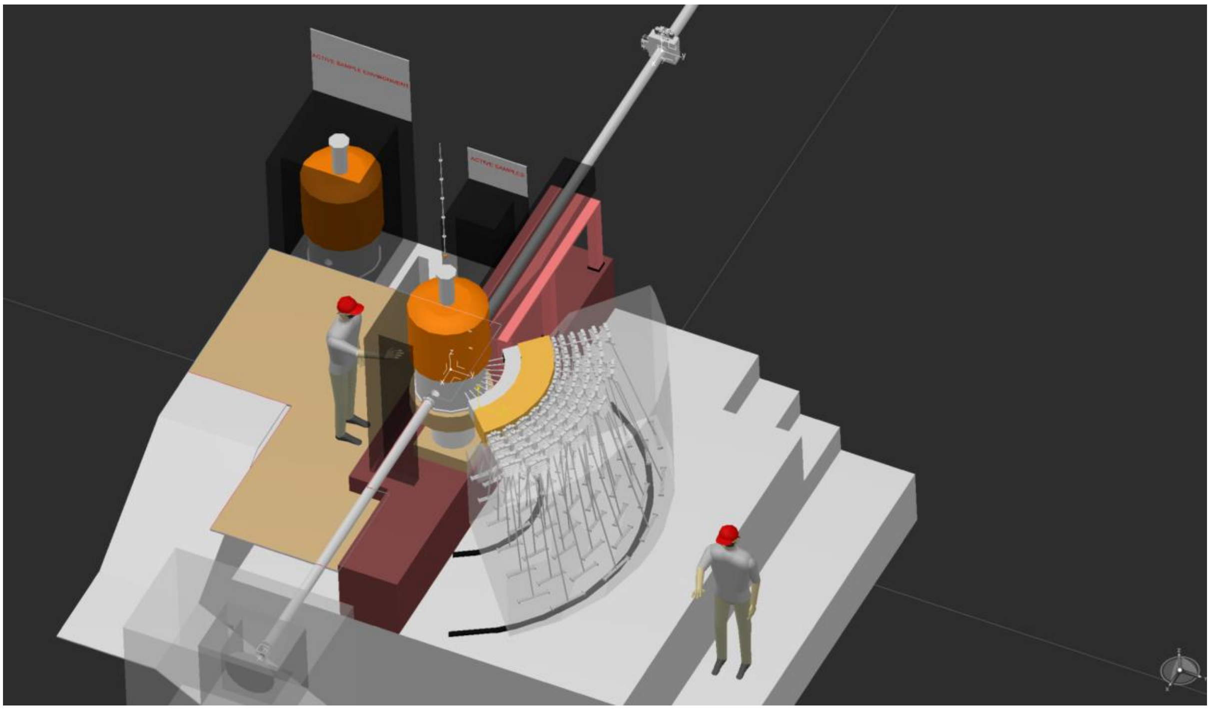


Figure 32: Internal support structures in the cave

8.2 Shielding (13.6.14.4.2)

The shielding of the cave takes into account an H2 event, the full flux Bifrost beam absorbed by a Cd plate at the sample position. This results in 10^{11} 2 MeV gammas scattered in 4 pi. This necessitates 1.1 m of light concrete for shielding. This is the only option on Bifrost, since even stainless steel contain magnetic impurities. 4 pi scattering of all thermal neutrons will be absorbed by a 3 mm sheet of boralcan, lining the inside of the cave.

8.3 SE utilities (13.6.14.4.3)

The SE Utilities board distribute media and signal interfaces to auxiliary sample environments that will be installed in the instrument. The SE utilities control will be installed outside the cave on Bifrost, in order to maintain control of utilities during prolonged periods of limited cave access. The location of the SE utilities is on top of the cave roof, to facilitate easy feedthrough of gas tubes.

8.4 Sample environment control box (13.6.14.4.4)

The sample-environment control box is a small rack where the sample environment control is centralised to communicate with instrument controls. This should be located close to the experimental hutch.

9. CONTROL HUTCH (13.6.14.5)

The control hutch of Bifrost will be a standard one, where a research group controls the experiment, analyse their data on the fly and conduct strategy meetings.

9.1 Support infrastructure (13.6.14.5.1)

The control hutch shall have standard office equipment, and contain all the appropriate manuals. The room shall be a pleasant one, with comfortable chairs and lighting, designed to help users through long hours and stressful time pressure.

9.2 Hutch building (13.6.14.5.2)

The hutch building shall be large enough to accommodate 5 people working uninterrupted by the movements of one another, and to have a small meeting table. The hutch building shall be sound proof and the electronics racks shall not be placed in the control hutch.

9.3 Sample preparation area (13.6.14.5.3)

Outside the user workspace of the hutch, there shall be a dedicate sample mounting space. This will have a mounting table with a generalized sample stick bench, with an adjustable laser spot to measure the sample distance from the stick flange. This area does not need an enclosed building, merely a fence. All necessary tools should be available. It should be possible to work with acetone based glue and Ge-Varnish.

9.4 Control terminals (13.6.14.5.4)

There should be separate control terminals for instrument control, sample environment control and monitoring, and data analysis. In addition, Bifrost should have monitors showing the inside of the cave, the status of the accelerator and the status of sample environment.

10. UTILITIES DISTRIBUTION (13.6.14.6)

10.1 Bunker

In the bunker, we need cooling water for the PSC, 230 and 400 V AC power lines.

10.2 D03 hall (13.6.14.6.1)

The only moveable component in the D03 hall is the thermal shutter. The mechanism of closure shall be pneumatic, and hence air pressure supply is necessary. AC power lines with 230 V, 50 Hz is necessary for the radiation monitors close to the shutter, and a PSS limit switch box. An EPICS network should be available at the thermal shutter as well, for instrumental remote control of the shutter.

10.3 E02 hall (13.6.14.6.2)

The E02 hall has a 14 Hz chopper at 80 m's from the moderator in the first half of the E02 hall, downstream, which would need 230 V AC power lines for the power supply and EPICS network.

In addition, there should be a 230 V AC power supply, 400 V AC power supply, cooling water supply and EPICS network in the last 10 meters of the E02 hall, close to the cave. This is to allow for a future order sorting chopper and guide field. These are not in the current scope however.

10.4 Experimental cave (13.6.14.6.3)

The experimental cave shall have several 230 V AC power supplies, a 400 V AC power supply, cooling water supply, pressurized air, Ethernet cable and EPICS network. There should also be artificial illumination in the experimental cave. A PA system might be installed inside the cave for communication with the control, and a webcam for monitoring with external user access.

11. INTEGRATED CONTROL AND MONITORING (13.6.14.7)

There is a significant software element to the instrument control and monitoring work package on Bifrost. This is outside the scope of the project and is to be developed in close collaboration with the motion control group, the chopper group and the DMSC. Whenever possible, Bifrost will follow the standards suggested by these groups.

11.1 Instrument control and automation (13.6.14.7.1)

Here, the main axes of motion control will be briefly described in downstream order. The requirements are given in detail in the Bifrost table of motion [8]

Shutters (2 axes): The translation stage of the thermal shutter and the cave lead shutter needs to be controlled by the instrument. These are pneumatic translation stages, in air but subjected to high levels of radiation

Divergence jaws (12 axes): The motors for the divergence jaws should be piezoelectric, function in vacuum and high radiation environments

Slit motors (4 axes): The slit motors should be step motors with encoders and able to work in high radiation environments. They do not necessarily need to work in high magnetic fields, but if not, they should be removable or placed far from the magnet.

Sample table rotation stage motor (1 axis): This step motor should come with an encoder and be able to work 1.5-2 meters from a 35 T dipole. The angular precision should be better than 0.05 degrees. It should be able to rotate 5 Tons on air pads.

Sample stick rotation stage motor (1 axis): This step motor should come with an encoder and be able to work 1.5-2 meters from a 35 T dipole. The angular precision should be better than 0.05 degrees.

Translation stages for collimator and filter (2 axes): These should be able to translate up to 150 kg's, work in high radiation environments and in high magnetic fields. Non-magnetic pneumatic stages are to be used.

Vacuum tank motor (1 axis): This step motor should be very powerful, able to move about 5-7 Tons. It should work in applied magnetic fields and in high radiation environments.

11.2 Personal safety system (PSS) (13.6.14.7.2)

The PSS is the system in place to prevent cave access whilst the beam is on. The system is designed and maintained by the ESS.

In addition to providing safe operation and access to the instrument components, the PSS should allow feedback to the main control software to be able to quickly evaluate conditions that prohibit opening the shutters or leading to alarms. The reverse direction is necessary for the instrument controls to be able to open the instrument shutters remotely

The PSS system shall allow for remote control of the shutters, provided the cave is clear and has not been entered in the time interval of remote control.

11.3 DMSC (13.6.14.7.2)

DMSC is outside the scope of this project. The requirements unique to Bifrost are many, both for data reduction and analysis. Close collaboration with DMSC will follow TG2 to ensure a realistic plan for having the necessary software to complete hot commissioning.

12. PRELIMINARY SAFETY ANALYSIS

The one atypical danger on Bifrost that needs to be addressed is the high levels of radiation that will occur after sample irradiation. During days of irradiation with a cold neutron intensity of up to 10^{10} n/s/cm^2, a sample radiation level in the range of 100 uSv/h is to be handled on a regular basis, and the range 1 mSv/h in rare instances. Below follows a range of worst-case scenario elements, where a 500 mg mass has been maximally irradiated on Bifrost for 10 days. The elements are the worst case examples found in three science cases to be investigated on Bifrost: High Tc superconductivity (La, Cu), quantum magnets (Cu, Co), spin liquids in the Iridates (Ir) and multiferroicity in manganites (Mn). 500 mg of material is considered a maximum for this small sample instrument. Bifrost will be used on large single crystal, but only in high-resolution mode since low resolution experiments can be done elsewhere on large crystals. The high-resolution mode of Bifrost has an order of magnitude lower flux as compared to the coarse resolution mode, and thus results in proportionately less severe sample activation.

For handling radiation at Bifrost, some special precautions are taken:

1) **Sample changes only by personnel**
2) **Sample changes occurs with exposure predominantly to extremities (hands)**
3) **Ring dosimeter mandatory**
4) **Radioactive samples and sample environment should be stored *temporarily* in the cave *retaining cave access***
5) **A list of trigger elements shall be prepared. Before putting any of these elements in the beam, a conservative calculation of the activity shall be done by the instrument scientist, following a procedure agreed upon with Radiation Protection.**

For sample changes, three strategies are proposed to minimize loss of beam time

1) **Time the shutter to close 3-6 hours before end-of-experiment**
2) **Schedule the experiment at the end of a cycle**
3) **Establish a planned procedure with radiation protection for extreme cases**

In general, the instrument team should inform users with Cobalt, Iridium and similar compounds that sample activation will be an issue and could rule out further experiments or need special time consuming transport.

Table 2: List of most common problematic isotopes. 500 mg of mass is irradiated at $3*10^{10}$ n/cm^2/s for 10 days. Dose level is given at 30 cm from sample. Ir-dose after 1 year is 0.025 mSv/h

Element	Lanthanum	Copper	Cobalt	Iridium	Manganese
Dose rate after beam off [mSv/h]	*1.6*	*0.14*	*10*	*5*	*2.7*
Dose rate after 1 h [mSv/h]	*1.6*	*0.11*	*0.25*	*2.8*	*2*
Dose rate after 24 h [mSv/h]	*1.12*	*0.036*	*0.063*	*1.16*	*0.004*
Dose rate after 15 days [mSv/h]	*0.003*	*0*	*0.063*	*0.6*	*0*
Close-shutter early strategy?	**No**	**Yes**	**Yes**	**No**	**Yes**
End-of-Cycle strategy?	**Yes**	**Yes**	**Yes**	**Possibly?**	**Yes**
Special procedure for handling?	**No**	**No**	**No**	**Yes**	**No**
Special storage time?	**2 weeks**	**2 days**	**30 years (a career)**	**2 years**	**1 day**

As evident in table 2, it is very unlikely that Bifrost will produce problematic waste and very unlikely that any sample irradiated at Bifrost is unable to be handled by the ESS staff. However, any cobalt sample irradiated on Bifrost will be shipped only to other facilities during the course of a career. This is standard procedure. An Iridium sample would be shippable to universities after maximum 2 years.

For handling of radiation hazards while the beam is on, the general shielding and the PSS system mitigates risk in a standard manner.

The other more standard hazards of Bifrost are handling cryogenic liquids, oxygen deficiency, high magnetic fields, fire and moving equipment. Oxygen detectors and oxygen level alarms will be installed in the experimental cave if necessary. The main risk would be a ruptured cryogenic vessel, releasing liters of liquid cryogens in the cave. An event of this type is exceedingly improbable. The supply vessels for the cryogenic equipment will be situated outside the cave.

Fire detection and automatic fire fighting systems will be installed at the instrument.

An interlock system could be installed to prevent movement of the spectrometer tank during maintenance, alternatively an emergency stop button at the access point.

During applied fields, we will install a 3-step warning lamp system to notify the user of high magnetic fields. Proper working procedures and training would ensure proper handling of cryogen liquids and strong magnetic fields.

13. SCIENTIFIC PERFORMANCE

13.1 Brilliance transfer and flux

The brilliance transfer of the BTCS is shown below. The price estimate for this guide is 2 M€.

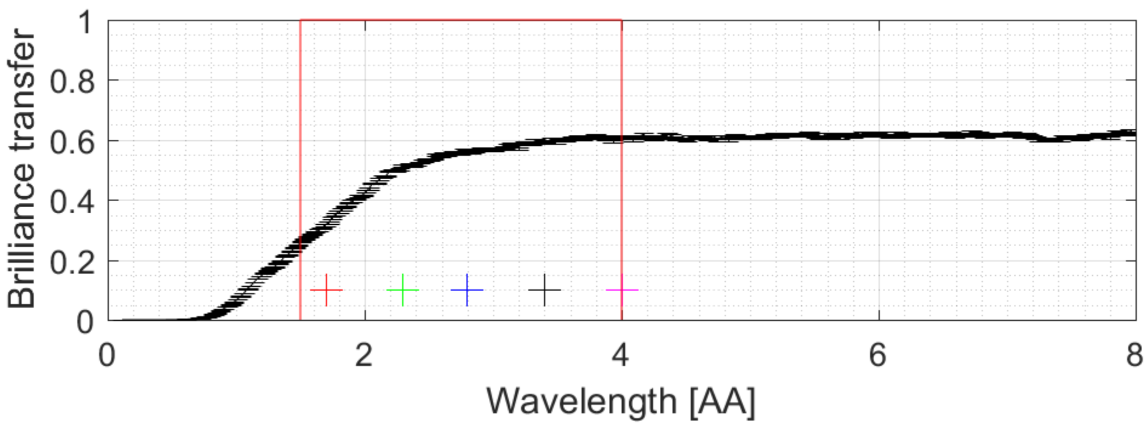


Figure 33: Brilliance transfer of the BTCS. The red lines denote the interval of optimization and the markers denote wavelengths where the beam characterization is shown in the next section

The flux on the sample should be given in 1.7 Å intervals, due to the polychromaticity of the neutron beam. Below, the integrated flux on the sample in a 1.7 Å interval is shown normalized to Å. The values shown is for the centre interval, so the value at 2 Å, is the wavelength interval (1.15-2.85).

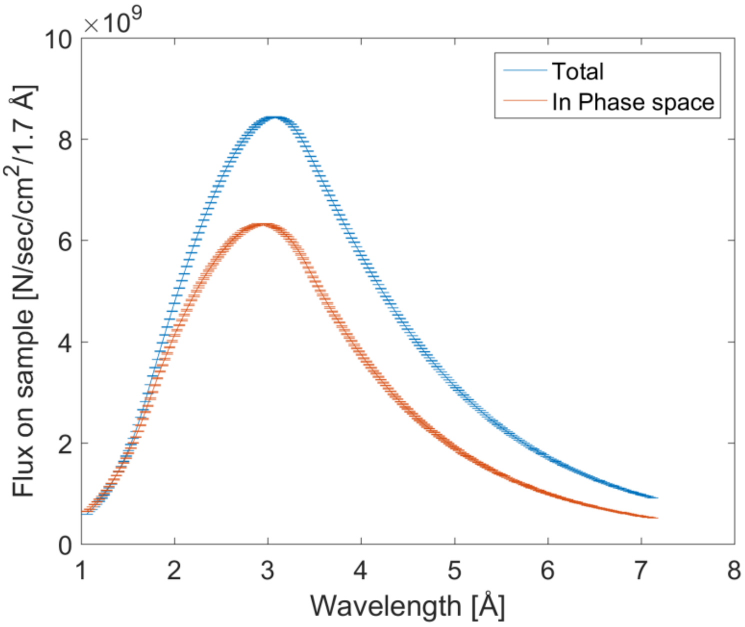


Figure 34: Integrated flux on the sample. Blue: Total flux. Red: Flux in the phase space optimized upon. These curves are obtained using a 3 MW, 3 cm ESS moderator.

It is evident from figure 34, that the flux on the sample position the interval 2.3-4 Å is around $8*10^9$ n/s/cm^2 at 3 MW. In all our simulations, the maximum brilliance transfer was around 62 %, unless a large prompt pulse spatial angle is accepted into the experimental halls (upon which the maximum is 75%), so this is close to the optimal value. It is worth noting, that at 5 MW in the cold range, there will be above 10^{10} n/s/cm^2 in the whole divergence range transported by the guide.

13.2 Beam characteristics

The beam characteristics at the sample at selected wavelengths – figure 35 – is given below.

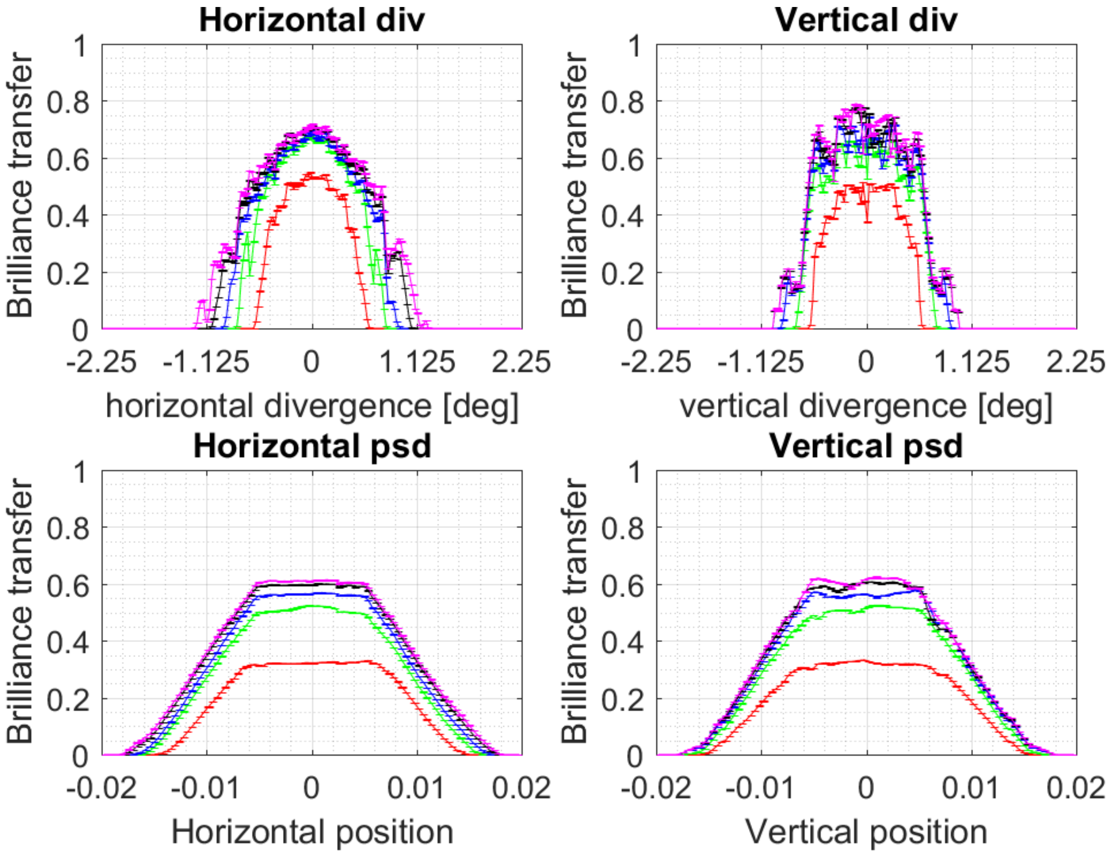


Figure 35: Beam characteristics at the sample position.

As evident, the beam position profiles are very smooth, and the divergence profiles symmetric and relatively uniform. This is to be smoothed out further due to minor imperfections in the guide system.

For an experiment, these minor variations are of little importance since the overall resolution function is a convolution between the primary and secondary resolution functions and the sample mosaicity. This will result in Gaussian peak profiles in any experiment with a symmetric mosaicity profile.

13.3 Chopper system

The energy resolution of the entire primary spectrometer is determined by the PSC, and the simulated energy resolution of the primary spectrometer in the cold energy range is plotted on figure 36, for different PSC opening times.

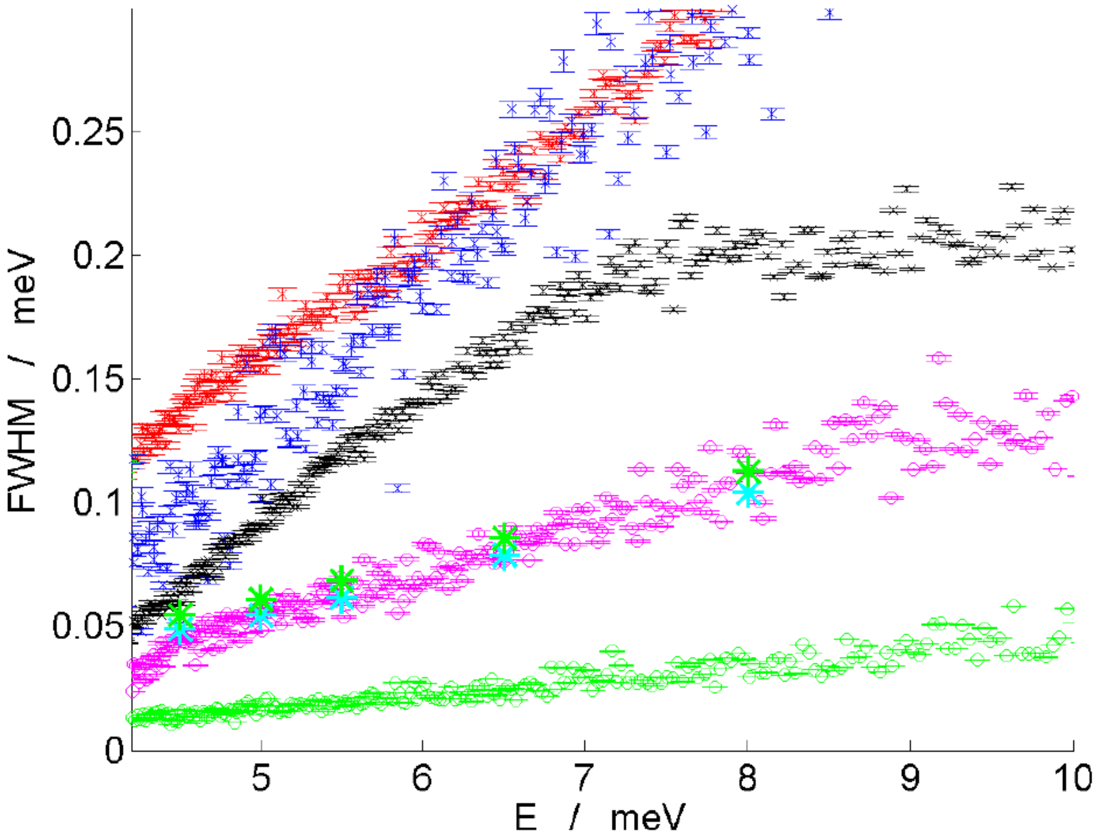


Figure 36: Energy resolution of the chopper system. Red: open. Blue: 5 ms. Black: 2.9 ms. Magenta: 1 ms. Green: 0.1 ms. Asterisks are secondary spectrometer resolution for the given energy.

At 5 meV the primary energy resolution of a fully open PSC actually matches the energy resolution of a 5 meV analyser in standard configuration, which is around 0.16 meV. The finest analyser configuration is the prismatic setting of the 2.7 meV analyser, which is around 0.02 meV. As evident on figure 36, this is more than matched by the primary spectrometer for a 0.1 ms pulse duration. It is worth noting that having much shorter pulse lengths than 0.1 ms, will not improve matters much. Thus, the energy resolution of Bifrost spans an order of magnitude, yielding more flexibility than a standard triple axis spectrometer.

13.4 Secondary spectrometer

The performance of the secondary spectrometer of Bifrost is determined by the analyser/detector geometry. The angular and prismatic energy resolution are plotted below, as simulated in McStas.

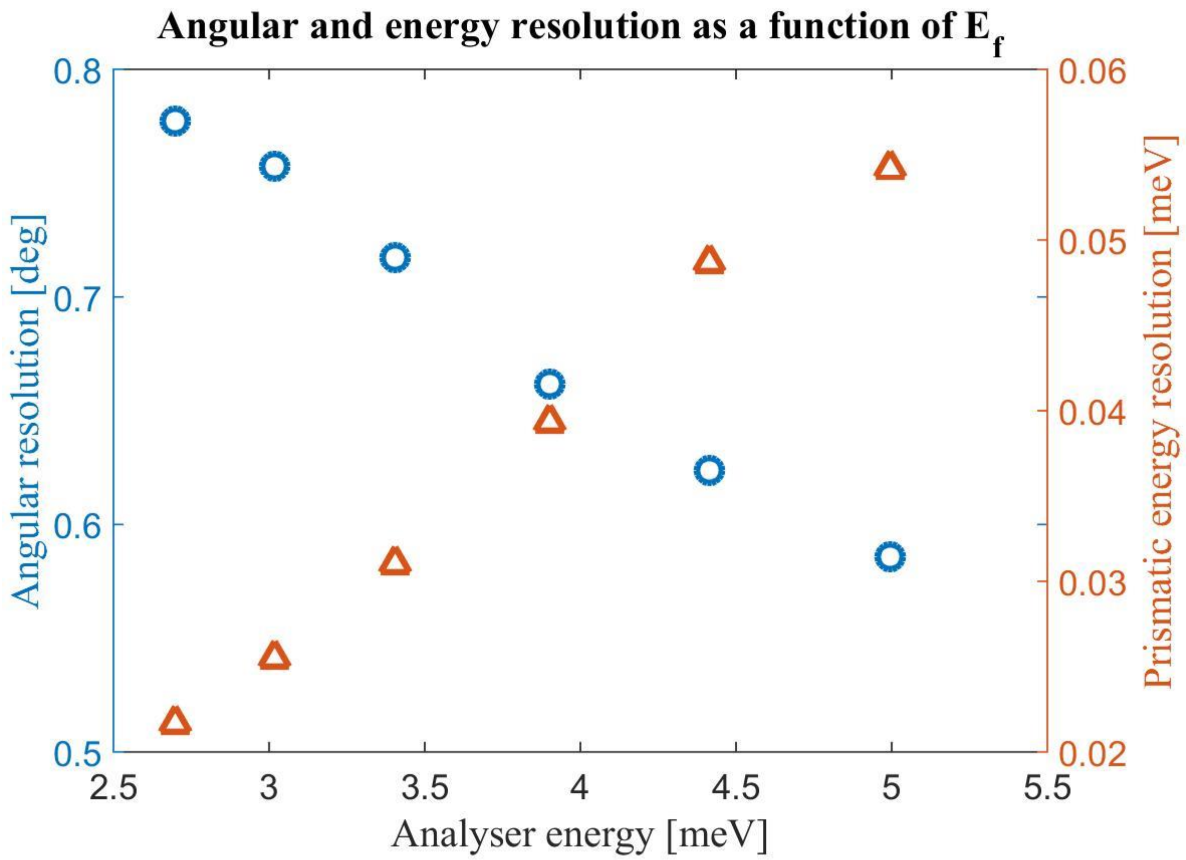


Figure 37: Energy and angular resolution of Bifrost secondary spectrometer.

It is worth noting that the Q-resolution of Bifrost is variable as it depends on the incoming wavelength and the divergence profile at the sample at that wavelength. Since many dispersive features measured in magnets are rather flat, the requirements for Q-resolution are assumed rather loose. The incoming divergence – and hence the Q-resolution – are then tuned by the divergence jaws. The Q-resolution obtainable on Bifrost will be more flexible that on a standard triple axis spectrometer, due to the position sensitive detectors.