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Chopper design for powder diffraction Instrument : HEIMDAL

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SUMMARY

This report describes the chopper system for the thermal powder diffraction part of the instrument HEIMDAL. The instrument should be able to run in four different resolution modes, ranging from high resolution mode ($\Delta d/d$=0.1%) to high flux mode ($\Delta d/d$=0.7%) at 1.5 Å and 90° scattering. The instrument resolution is tuned by the frequency of the pulse shaping double disc choppers placed 6.5 m from the moderator. Frame overlap is avoided by placing a single disc chopper in the middle of the guide hall. A T0 chopper placed in the bunker, will lower the background of fast neutrons at the sample position.

The chopper system for the cold guide (used for SANS) of the instrument is not described in detail in this document, as it is outside the project scope. The full scope instrument, however, includes the cold chopper system and the preparations necessary to insure a successful later installation.

1. INTRODUCTION

This report reflects the current state of the chopper design work of HEIMDAL done by the instrument team. There are still unresolved issues and open questions that we would like to discuss with the ESS chopper group. This document is meant as a starting point of the dialogue between the instrument team and ESS.

1.1. Instrument overview

HEIMDAL has a cold and a thermal guide system in order to accommodate the very different requirements of the powder diffraction and the SANS parts of the instrument. The thermal beam goes straight from the moderator to the sample position. The cold beam moves downwards from the moderator out through the monolith. At 8 m from the moderator the cold beam is 150 mm below the thermal beam, from this position the cold guide is straighten up and continues horizontally until 130 m from the moderator, where it is curved back up to the thermal beam plane. Seen from above the cold beam moves to the right of the thermal beam. At 15 m from the moderator the cold beam is curved back towards the thermal beam and the two beams cross half way down the instrument at 78 m. In figure 1 is a schematic drawing of the two beam paths, positions of the foreseen choppers, and their assigned numbers.

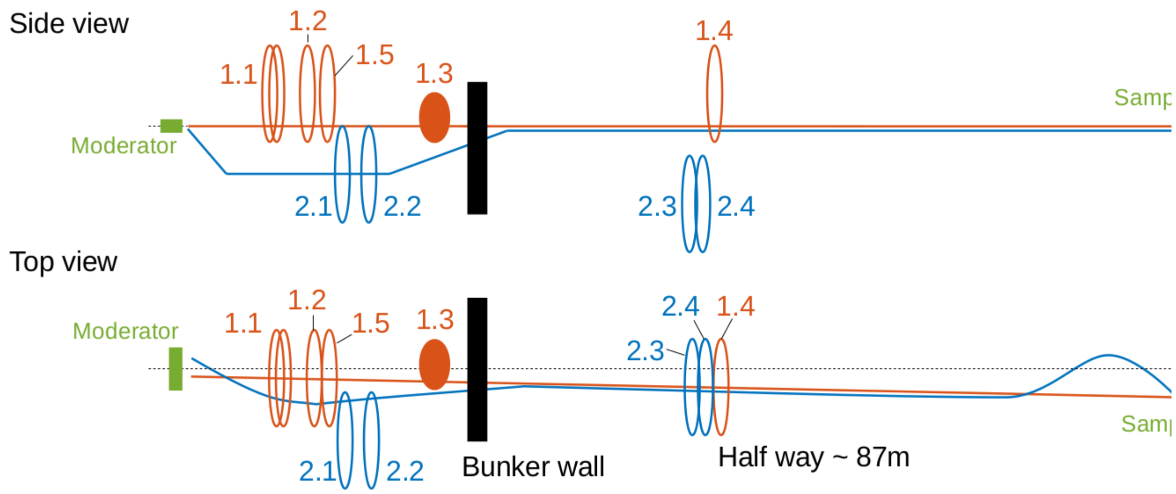

Illustration 1: Overview of the chopper system for the HEIMDAL instrument. The red line represents the thermal beam and the blue line the cold. The numbers corresponds to the last two digits of the numbers given to the choppers also listed in table 1.

In table 1 a list of all the foreseen choppers of the full instrument scope is presented. The five thermal choppers listed in black are the choppers included in the instrument scope.

The thermal choppers are placed above the cold beam and the cold choppers are placed to the right of the guides for upwards extraction inside the bunker. In figure 2 the positions of the choppers inside the bunker can be seen. The positions of the choppers are chosen to avoid the roof pillars of the bunker.

ID 13.6.13 .1.3.x.x	Name	Distance ISCS, x	Type	Diameter	Max speed
1.1	Thermal pulse shaping chopper (TPSC1)	6.47 m 6.53 m	double disc face-to-face	700 mm	168 Hz
1.2	Thermal wavelength sorting chopper (TWSC1)	8 m	single disc	700 mm	14 Hz
1.3	Thermal T-zero chopper (TTZC1)	21.6 m	T0		28 Hz
1.4	Thermal frame overlap chopper (TFOC1)	78 m	single disc	700 mm	14 Hz
1.5	Thermal frame selection chopper (TFSC1)	8 m	single disc	700 mm	14 Hz
2.1	Cold wavelength band chopper (CWBC1)	12.2 m	single disc	700 mm	14 Hz
2.2	Cold wavelength band chopper (CWBC2)	14 m	single disc	700 mm	14 Hz
12.3	Cold frame overlap chopper (CFOC1)	78 m	single disc	700 mm	14 Hz
2.4	Cold frame selection chopper (CFSC1)	78 m	single disc	700 mm	14 Hz

Table 1: A list of all the choppers currently foreseen for HEIMDAL. The thermal choppers are included in the instrument scope and the choppers listen in blue are included in the full scope instrument.

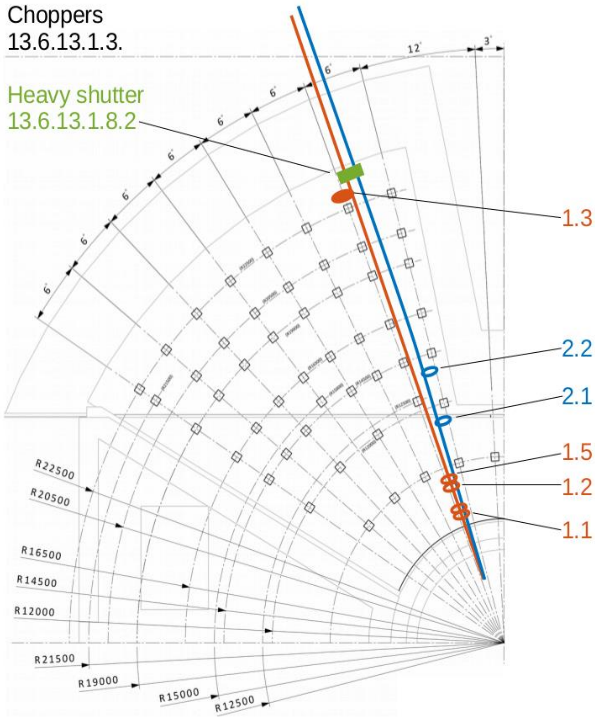

Figure 2: The positions of the choppers for the HEIMDAL instrument inside the bunker. The red line represents the thermal beam and the blue line the cold. The coloured lines and circles are not to scale.

1.2. Scope-setting budget and recommendations

From the scope-setting meeting the following statements about choppers were made:

> "Current neutronics calculations indicate that only a single T0 chopper is needed for the long instruments. The cost for the chopper system was therefore reduced from 1174 k€ to 924 k€ by removing one of the T0 choppers and its control electronics. A cost saving of 250 k€."

The budget for the scoped instrument includes:

- T0 chopper, background suppression, 250 k€
- Double disc chopper, pulse shaping, 230 k€
- Single disc chopper, wavelength sorting, 130 k€
- Single disc chopper, frame overlap, 130 k€
- Shielding, vacuum, cabeling, control racks, manpower, 184 k€

The following recommendations were made at the scope setting meeting:

"The chopper system should be revisited together with the optics concept. If there are cost implications, that will be dealt with at the time."

"Provision should be made in the instrument design to allow the later installation of an additional T0 chopper, if operational experience should show that it is necessary."

2. THERMAL CHOPPER CASCADE FOR DIFFRACTION

In this section different solutions for the thermal chopper systems are described. There are two main issues to consider; obtaining the desired time structure of the beam, and lowering the background at the sample position.

2.1. Time structure, diffraction

HEIMDAL is a narrow wavelength band, thermal diffractometer with a tunable resolution. The band width is given by the placement of the first choppers and the instrument length and it is $\Delta\lambda$=1.7 Å. In order to reach high q-values, needed for PDF analysis, the lower limit of the wavelength band is 0.5 Å. To match the resolution effect of the sample and pixel size smearing, the high resolution opening time of the pulse shaping choppers should be Δt = 123 μs. The opening time will be changed slightly after the detector design has been updated.

Fast spinning counter rotating disc choppers with a hole size comparable to the guide width, ensure a triangular pulse shape. The thermal guide has been optimized with a cross section, at the double disc chopper position, of 30 x 50 mm². The openings in the choppers are therefore ω = 5.72°. This is calculated by

$$\omega=2*\mathrm{atan}(w/(2b)) \quad \text{where} \quad b=\mathrm{sqrt}(R^2+(w/2)^2)-h$$

To find the speed of the chopper, which should be an integer times the source frequency, the following calculation is done:

$$n = (\omega/360°)(1/14/123\ \mu s) = 9.22 \sim 10$$

In figure 3 a summary of the chopper dimensions is given.

h	50	mm
w	30	mm
R	350	mm
b	300.3	mm
ω	5.719	°
n	10	

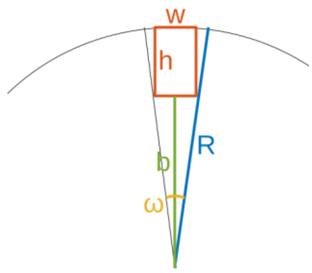

Figure 3: Chopper opening.
h is the height of the guide,
w is the width of the guide,
R is the radius,
b is the inner radius, and
ω is the opening angle.

The diffraction instrument will have four default resolution settings where the chopper resolution and divergence at the sample match. In figure 4 the time-of-flight intensities simulated just after the double discs are shown for the disc run at n=10, 3, 2, and 1.

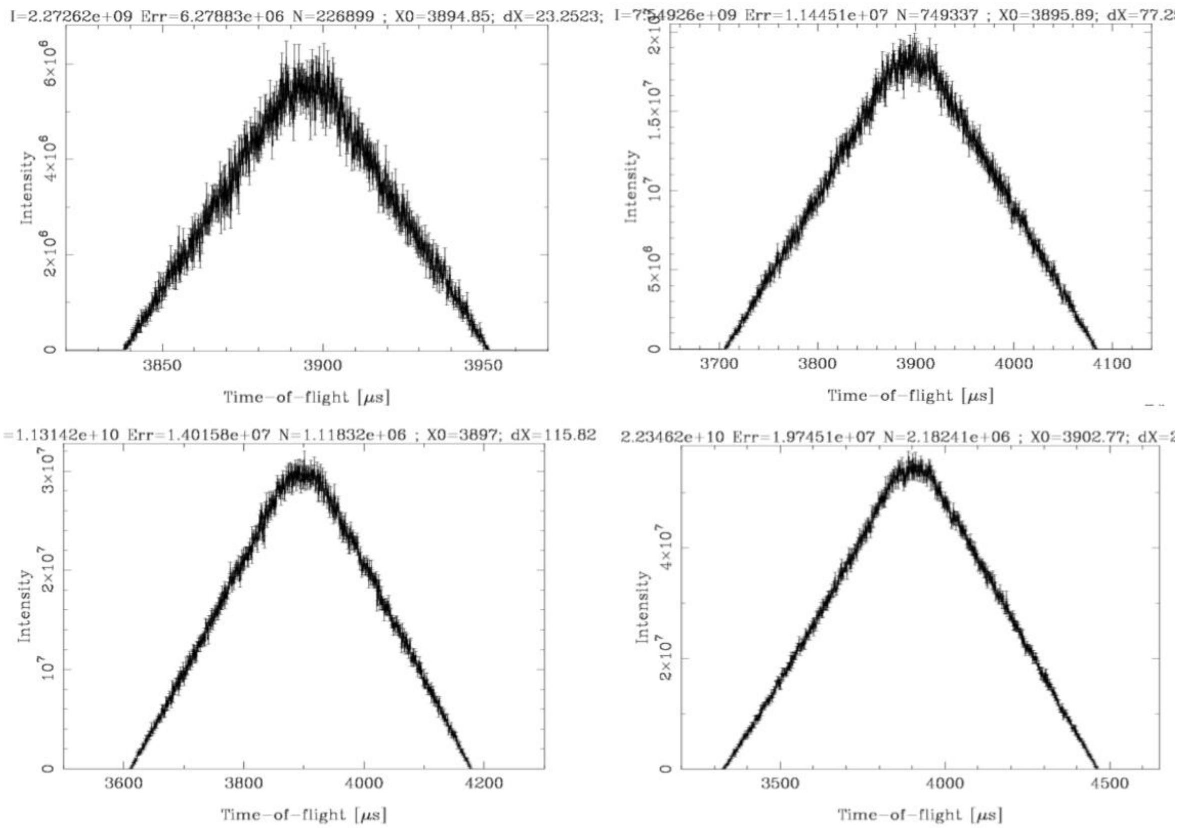

Figure 4: McStas simulations of the pulse after the double discs for the four resolution settings. The header of the four plots include the intensity, I, the uncertainty of the intensity, Err, the number of rays simulated, N, the mean value in micro seconds, X0, and the spread in micro seconds, dX.

A summary of the numbers found in the McStas simulation of the double disc assembly is found in table 2.

Chopper speed [Hz]	Normalized intensity	σt [μs]	Full opening time [μs]
140 (n=10)	1	23.3	113
42 (n=3)	3.33	77.3	378
28 (n=2)	4.98	115.8	567
14 (n=1)	9.84	229.7	1135

Table 2: The key numbers of the time structure obtained by the double discs for the four resolutions modes of the diffraction instrument.

The thermal wavelength sorting chopper (TWSC1) placed 8 m from the source ensures that only the desired wavelength is lead through and the thermal frame overlap chopper (TFOC1) placed half way down stream cut off the neutrons from the pulse tails and prevents frame overlap. In figure 5 the TOF diagrams with the four disc choppers for the high resolution (n=10) case are shown.

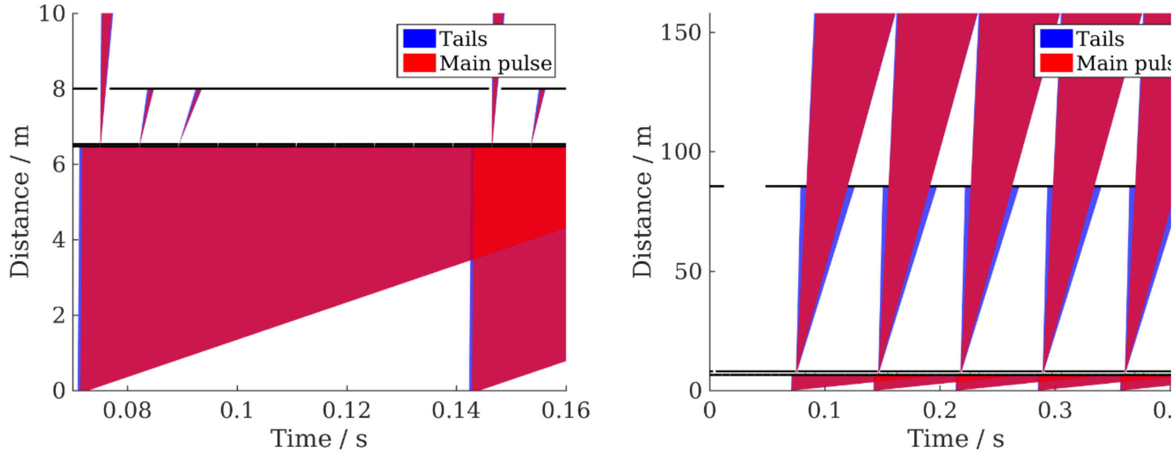

Figure 5: TOF diagrams showing the effect of TWSC1 (8 m) and TFOC1 (78 m). This is the high resolution case with n=10. The red areas are the main pulse and the blue areas are neutrons from the build-up and tail of the main pulse. Wavelengths from 0.2 Å to 80 Å are shown.

2.2. Background consideration, diffraction

It has been chosen to have a guide that does not loose direct-line-of-sight, to obtain high flux numbers for the short wavelengths. It is therefore imperative that the choppers can stop the unwanted high energy neutrons. The prompt pulse is mainly stopped by a T0 chopper. However, the disc choppers should be able to stop the neutrons with energies up to around 11.3 eV (0.085 Å), depending on the final design and position of the T0 chopper.

1.1.1. Prompt pulse suppression chopper or T0 chopper

The thermal guide does not loose direct-line-of-sight, and it is therefore a necessity to have a T0 chopper in order to lower the background. The T0 chopper is in the current design placed 20 m from the moderator inside the bunker. The guide at the T0 chopper position is 60 mm wide and 80 mm tall. Under the assumption that the T0 chopper runs at 28 Hz and has a radius of 300 mm (numbers from DREAM report on T0 chopper), the cut off of the T0 chopper can be calculated. The time it takes the T0 chopper to open is

$$t = 1/28\ (\omega/360°) = 1/28\ (15.42°/360°) = 1.53\ \text{ms}$$

where ω is calculated as in section 2.1. The time t_1 in figure 6 is half the opening time of the double discs choppers in the low resolution mode. The red dashed lines indicate where λ_{min} is sampled from. The time t_{cut} is calculated as

$$t_{cut} = t_{min} - t - t_1 = (\alpha * 20\ \text{m} * 0.5\ \text{Å}) - 1.53\ \text{ms} - 1.135\ \text{ms}/2 = 0.24\ \text{ms}$$

and the fastest wavelength let though the T0 chopper is $\lambda_{cut} = t_{cut}/\alpha/L = 0.085$ Å corresponding to 11.3 eV.

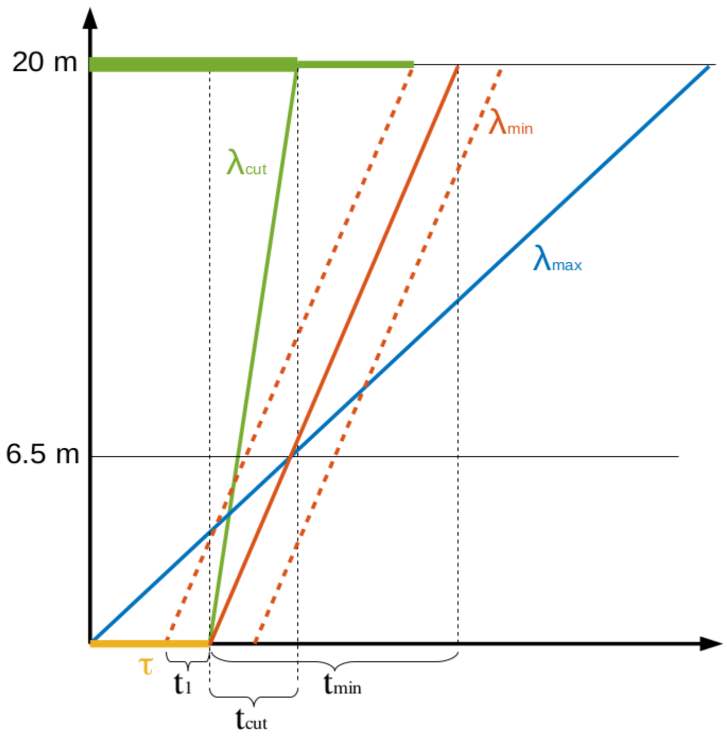

Figure 6: TOF diagram used to calculate the wavelength cut off of the T0 chopper. The yellow line is the source pulse, the thick green line is where the T0 chopper is fully closed and the extension is the time it takes for the T0 chopper to open. The red lines are the speed of the 0.5 Å and the blue line is 2.2 Å. t_1 is half the full opening time of the double disc choppers in low resolution mode. The green speed is the fastest neutrons let though the T0 chopper.

1.1.2. Disc materials

A survey of different chopper disc materials and their absorptions has not been done yet. It is, however, clear that it is extremely important for the performance of the instrument. The TWSC1 (placed at 8 m) and the TFOC1 (placed half way down stream) are both running at 14 Hz and have a radius of 350 mm. As they both are small and slow choppers we do not anticipate any issues regarding material choice. We might, however, run into trouble when designing the double disc choppers, as they have to run at up to 140 Hz.

1.1.3. Counter rotating at different speeds

It is possible to suppress higher order neutrons with the double disc by running them at 10 and 12 times the source frequency respectively. In figure 7 a TOF diagram of this scheme is shown. This scheme makes the TWSC1 chopper unnecessary, but the holes in the choppers will have a slightly different size.

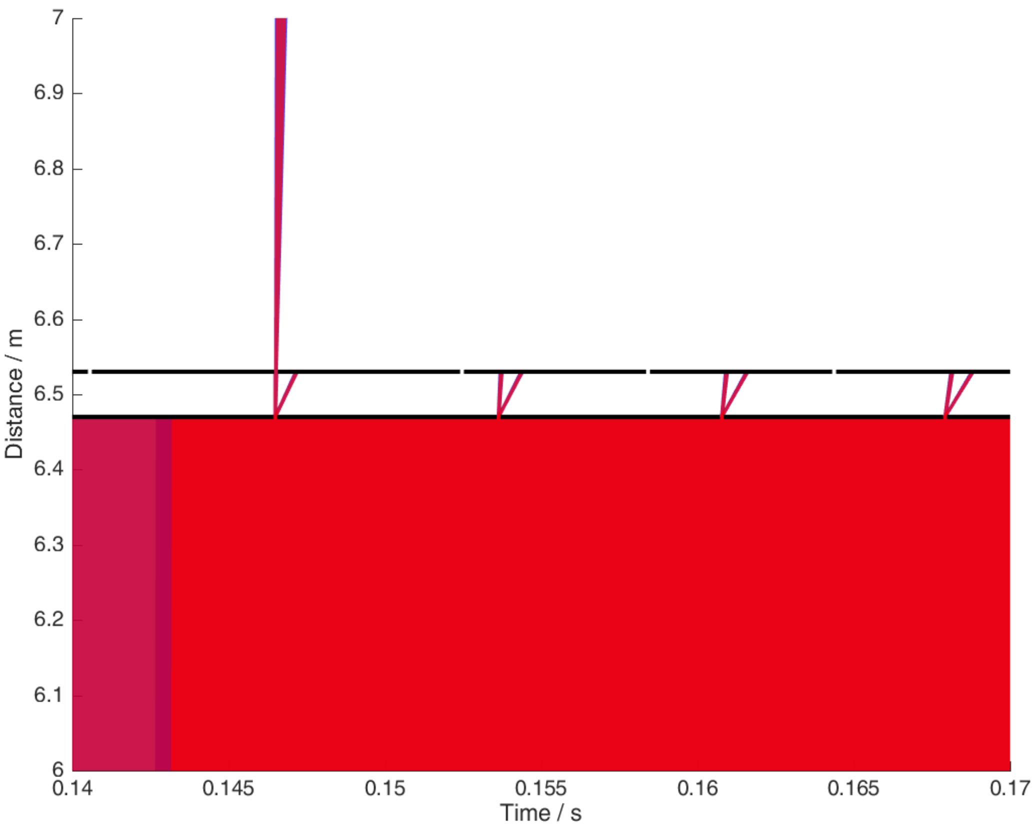

Figure 7: TOF diagram showing the double discs run at 10 and 12 times the source frequency respectively.

The scheme does however not work for n=1 as neutrons from the previous pulse can make it through the two choppers. This is illustrated in figure 8. The TWSC1 chopper is therefore needed in order to run the instrument in the high flux mode. More over the TWSC1 chopper also reduces the background of the instrument, as the disc material can be chosen more freely than for the double disc.

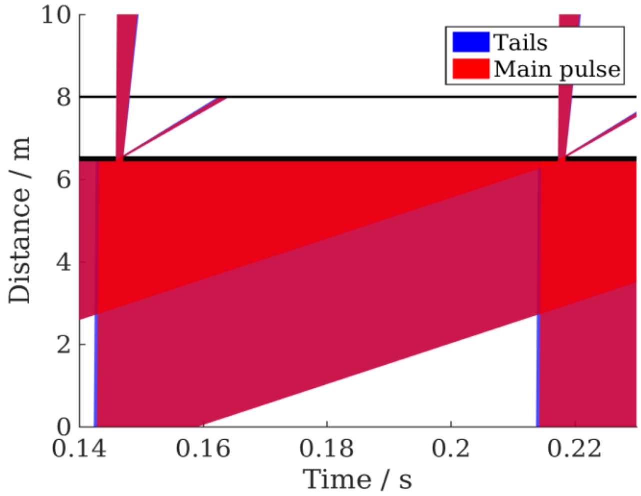

Figure 8: TOF diagram of the low resolution setting with n=1.

2. COLD CHOPPER CASCADE FOR SANS

The SANS part of HEIMDAL is an upgrade of the project scope and is not included in the instrument budget. The design of the cold instrument, however, needs to be mature enough, that sufficient space for choppers, cabling and racks are taken into account in the design of the thermal part of the instrument. The cold guide inside the bunker will be installed as part of the project scoped instrument, as radiation will prevent later installation. The stationary part of the CHIM should also be installed for the cold choppers inside the bunker.

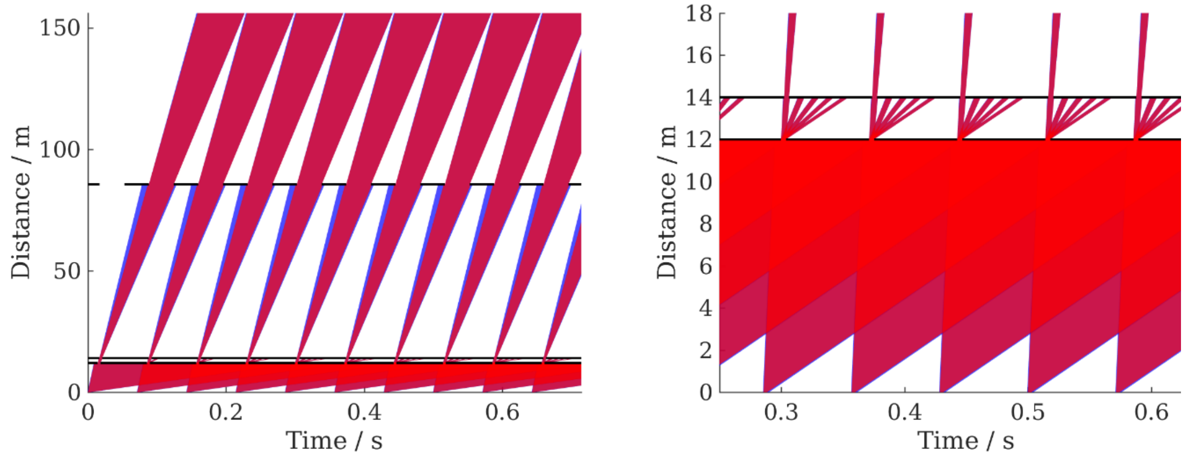

Figure 9: TOF diagrams for the cold beam.

The current design of the cold chopper cascade includes three choppers; two wavelength band choppers inside the bunker at 12 m and 14 m and a frame overlap chopper half way down stream. The full pulse width of the source will be used and the wavelength band will be tuned by changing the phase of the choppers. All three choppers will spin at 14 Hz and have a radius of 350 mm. The TOF diagram of the cold instrument can be seen in figure 9.

2.1. Frame selection choppers

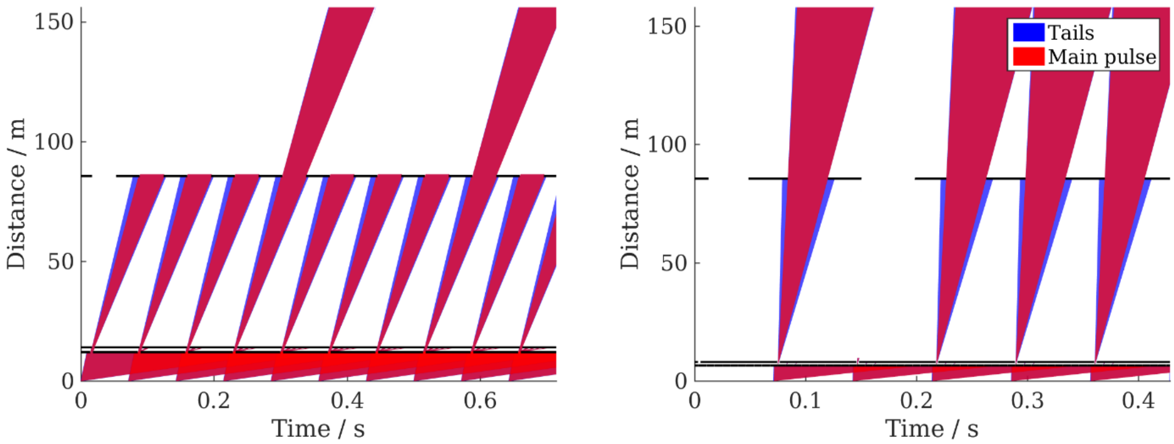

Figure 10: TOF diagrams of the cold (left) and thermal (right) with the frame selection running at 1 to 4 between the cold and thermal beams.

The cold and thermal frame selection choppers placed half way down stream will be installed along with the SANS upgrade. The purpose of these choppers is to ensure that only one of the wavelength bands is hitting the sample in a given time frame. An example of the frame selection is found in figure 10.