HighNess

UCN and VCN source studies in the HighNESS project

Luca Zanini

on behalf of the HighNESS Consortium

9 April 2024, Workshop on UCN and VCN Source at the Institute of Nuclear Physics, Kazakhstan

HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

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ESS Journey

HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

Outline

1. The ESS current moderator
2. Overview of the HighNESS project
3. Development of a Very Cold Neutron Source
4. Development of an Ultra Cold Neutron Source

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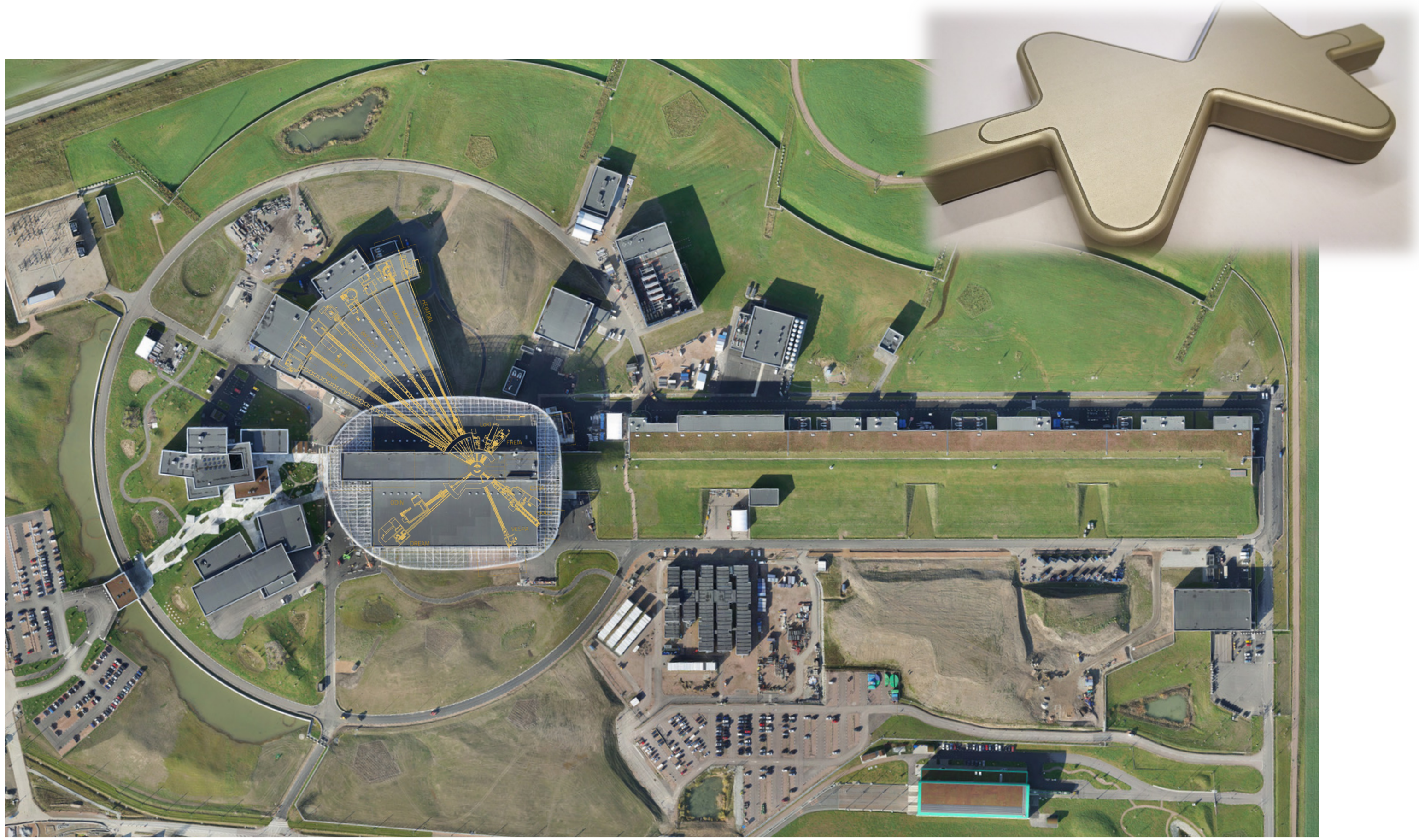
Upgradeability of ESS



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Upgradeability of ESS

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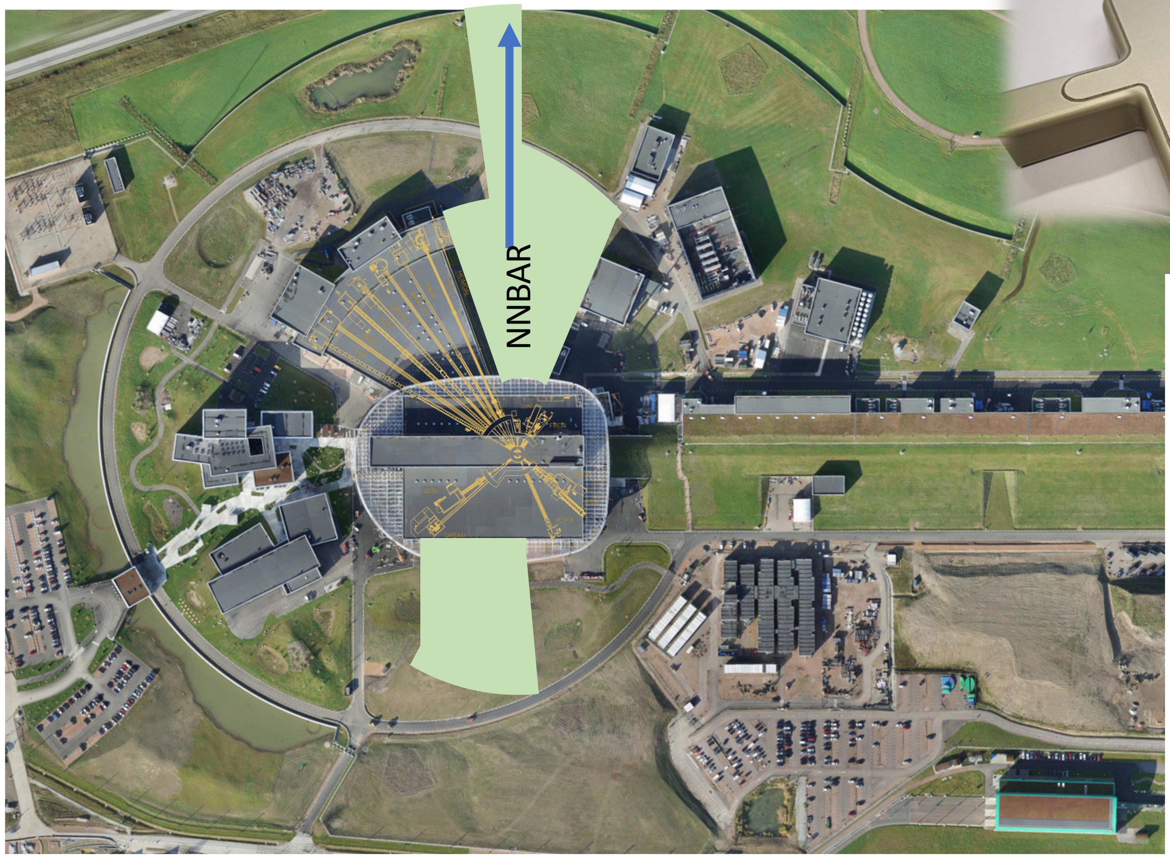

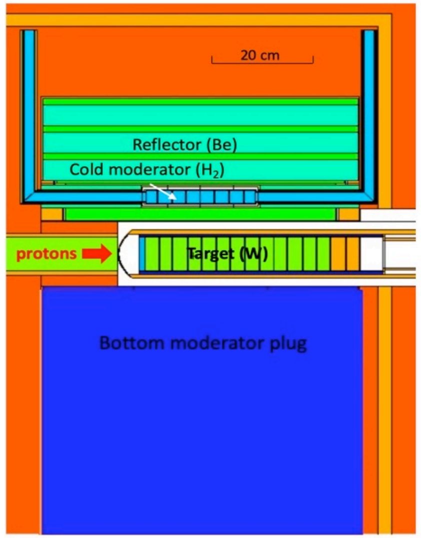

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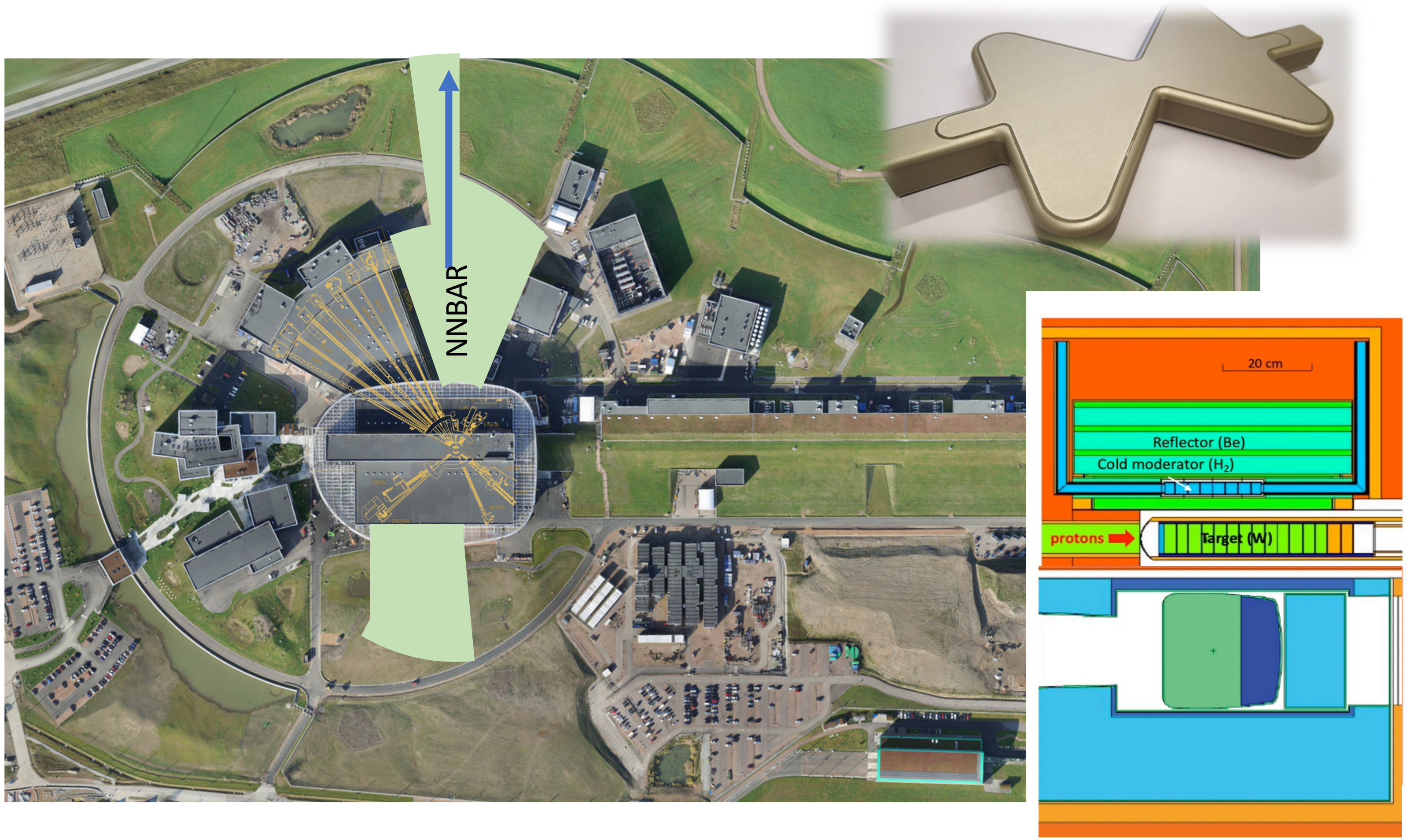

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The HighNESS Project

Development of **High** Intensity **N**eutron Source at the **E**uropean **S**pallation **S**ource

- The HighNESS project (3 MEURO funded by the European Commission) has as purpose the development of the new source that will be installed at ESS >2030

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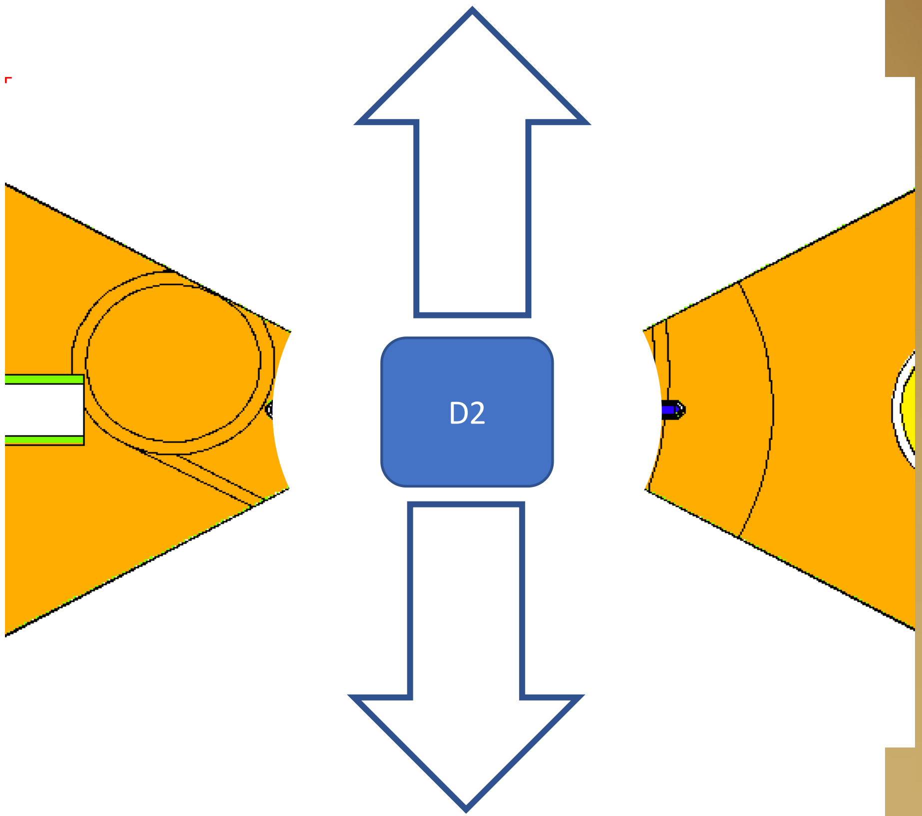

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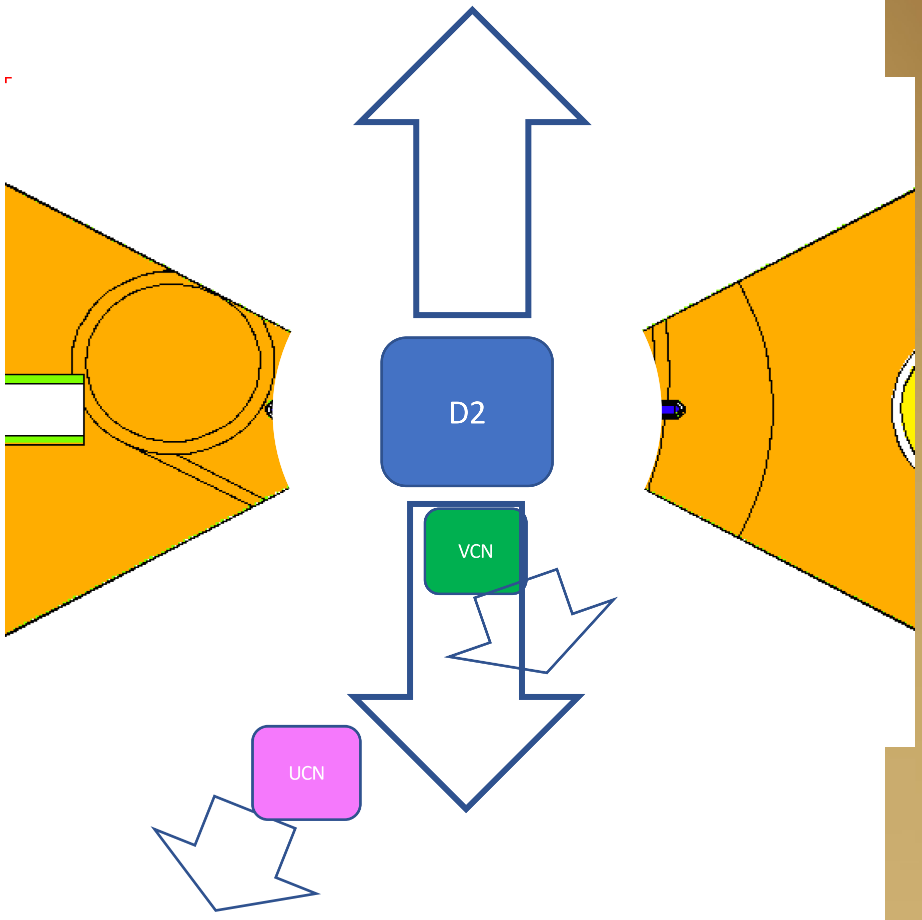

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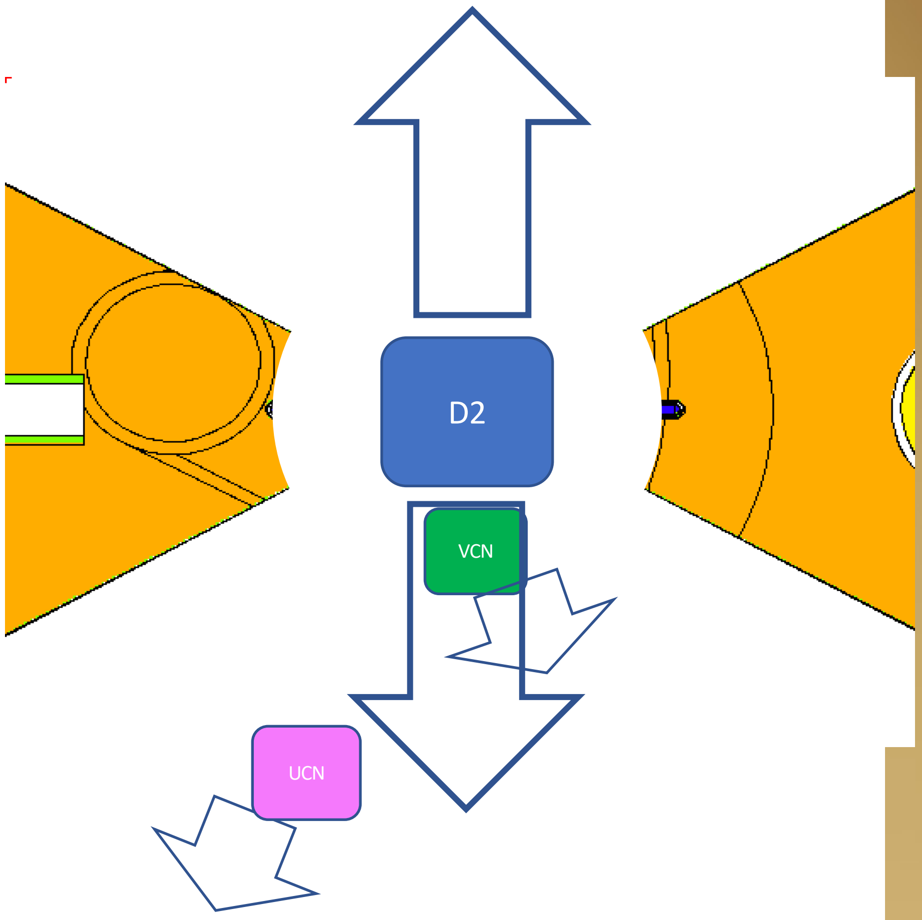
- **Conceptual Design Report of the ESS upgrade was written at the end of 2023**



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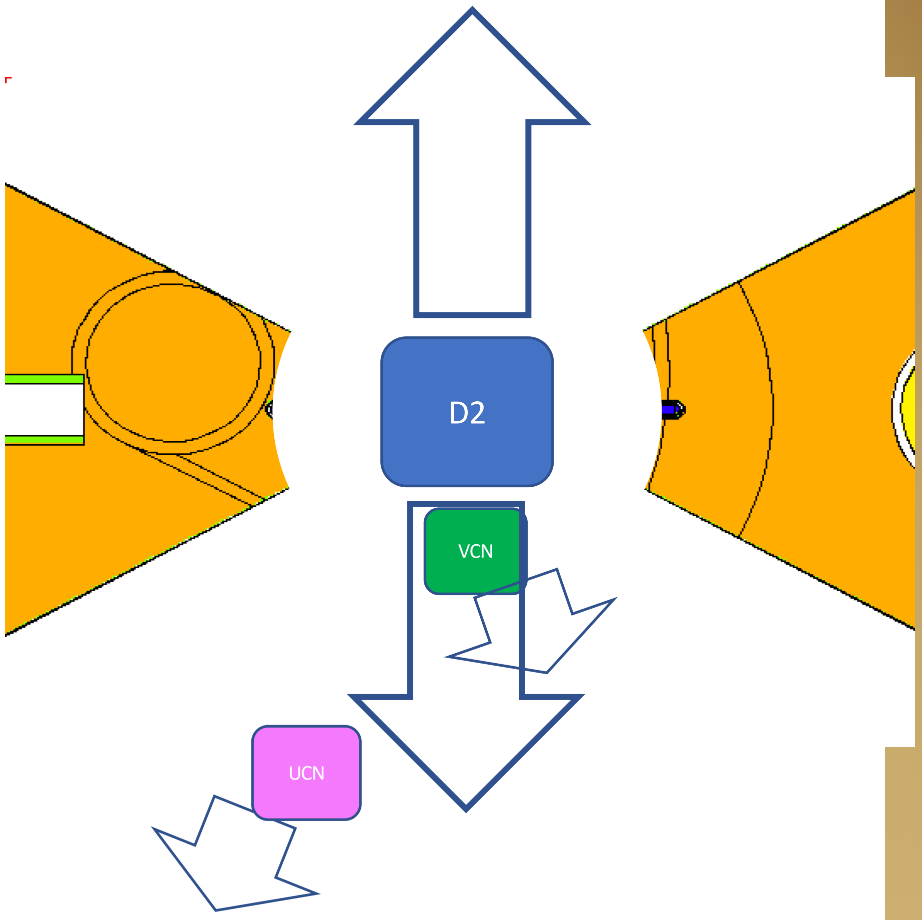

Complementarity with what is currently available at ESS

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Offering both unprecedented brilliance, flux, and spectral range in a single facility, this upgrade will make ESS the most versatile neutron source in the world and will further strengthen the leadership of Europe in neutron science

From the HighNESS evaluation letter from the European Commission

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The HighNESS Consortium

Participant No.	Participant organisation name	Short name	Country
1 (coord.)	European Spallation Source ERIC	ESS	SE
2	Institut Max von Laue – Paul Langevin	ILL	FR
3	Forschungszentrum Julich Gmbh	FZJ	DE
4	Universita' Degli Studi Di Milano-Bicocca	UNIMIB	IT
5	Danmarks Tekniske Universitet	DTU	DK
6	Paul Scherrer Institut	PSI	CH
7	Mirrotron Multilayer Laboratory Ltd	Mirrotron Ltd	HU
8	Stockholms Universitet	SU	SE

8 EU Institutes,
7 countries,
>40 people involved

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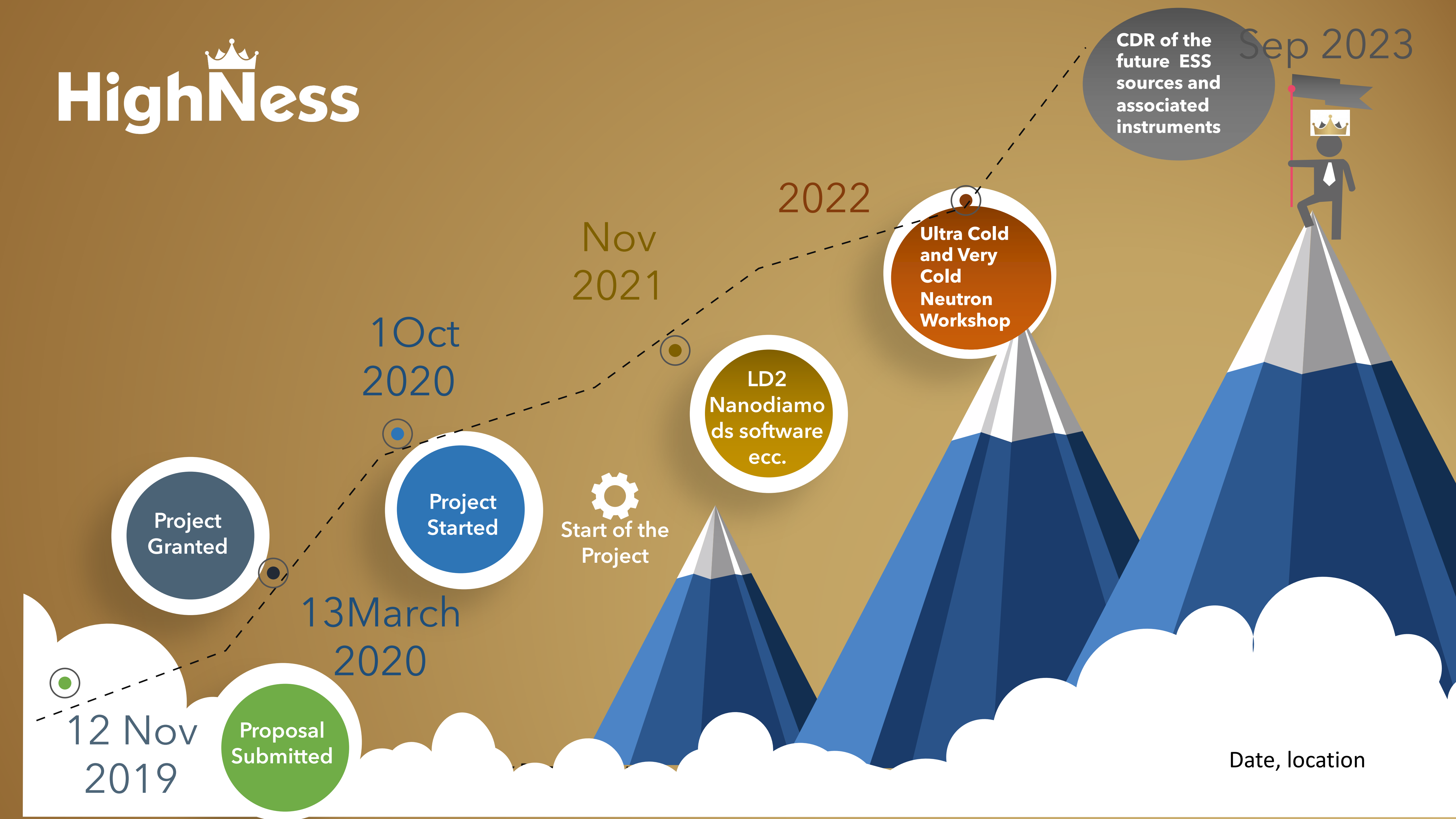

HighNess
12 Nov 2019
Proposal Submitted
Project Granted
13March 2020
1Oct 2020
Project Started
Start of the Project
Nov 2021
LD2 Nanodiamods software ecc.
2022
Ultra Cold and Very Cold Neutron Workshop
Sep 2023
CDR of the future ESS sources and associated instruments
Date, location

HighNess

HighNESS aims at complementing the ESS current moderator in **two** different aspects

High Intensity

larger emission surface and bigger moderator

Longer wavelengths

Cold, Very Cold and Ultra Cold neutrons

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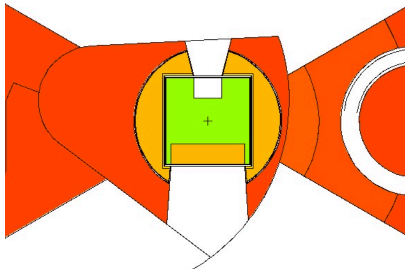
HighNESS Moderators design

cold	2-20 Å
very cold	10–120 Å
ultracold	> 500 Å

Goal of the project is to design three sources

1 COLD - CN

High intensity liquid D2 at about 20 K



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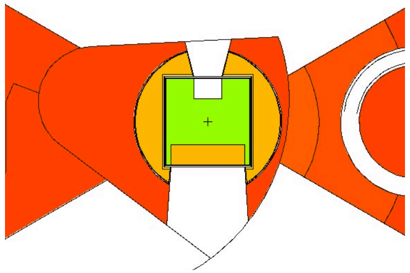
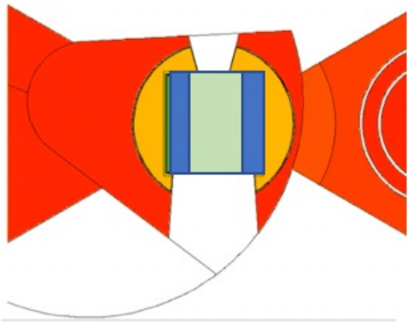


VERY COLD - VCN

VCN extraction from main source using advanced reflectors

Dedicated VCN converter



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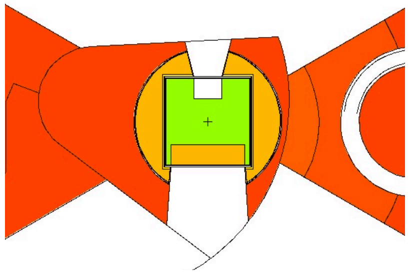

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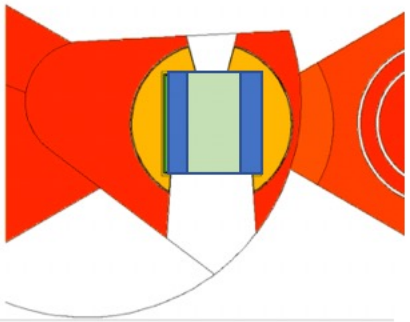
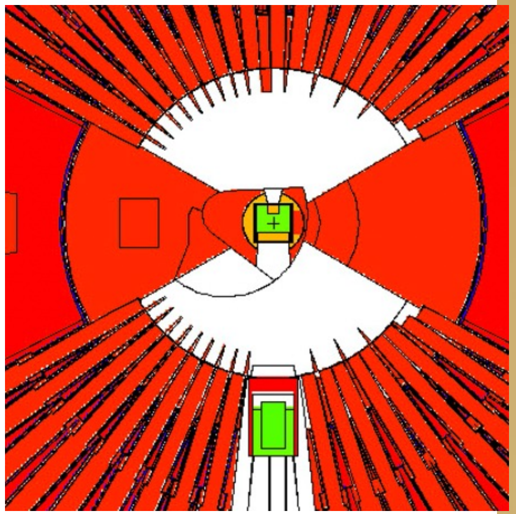


ULTRA COLD - UCN → **In beam UCN** | **In pile UCN**



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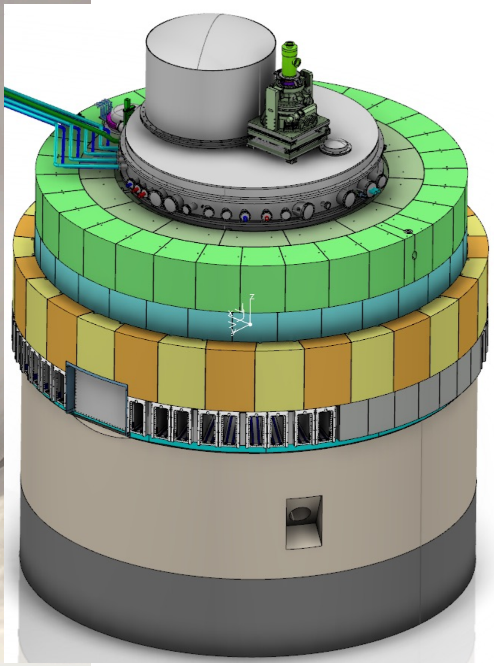
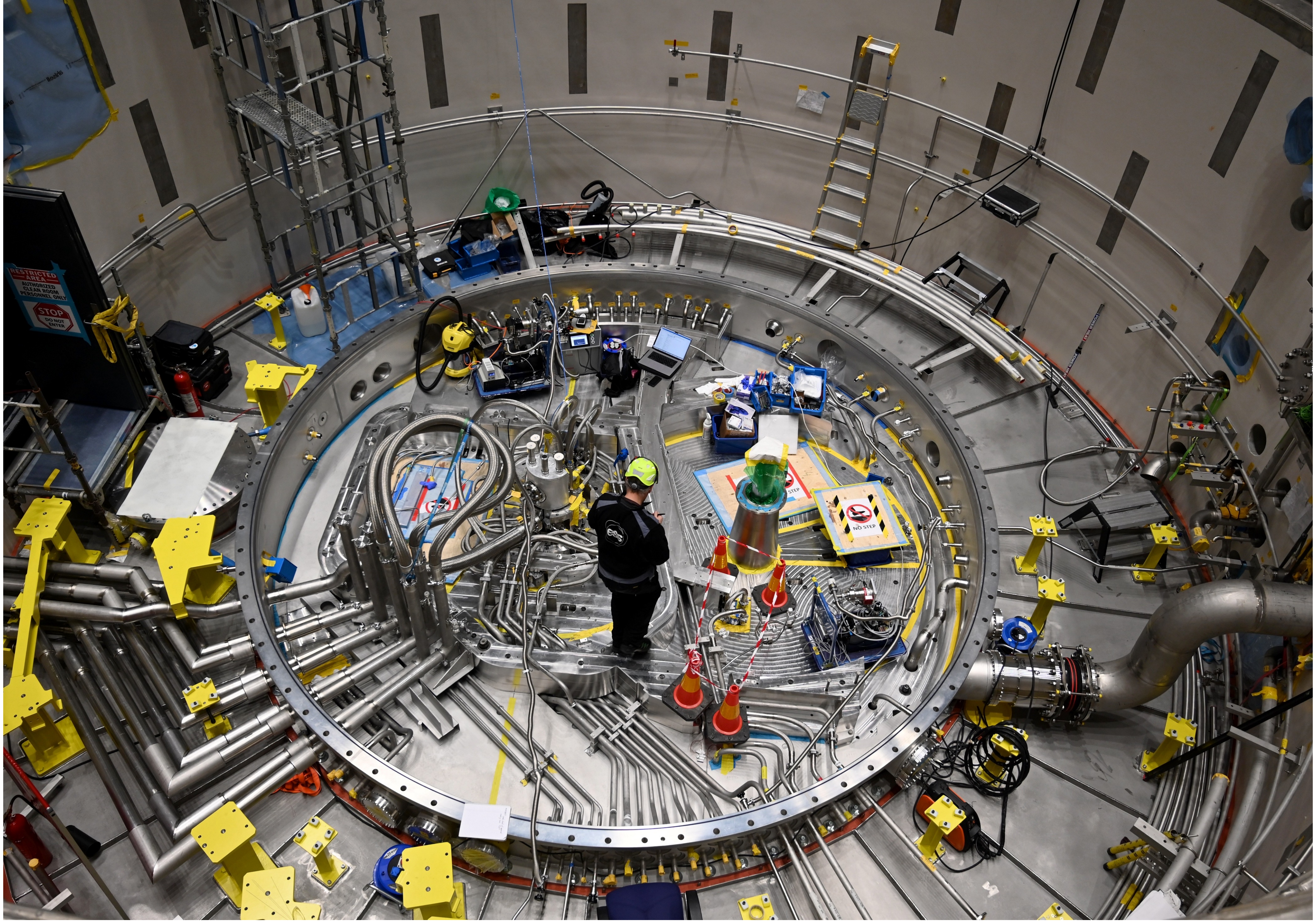
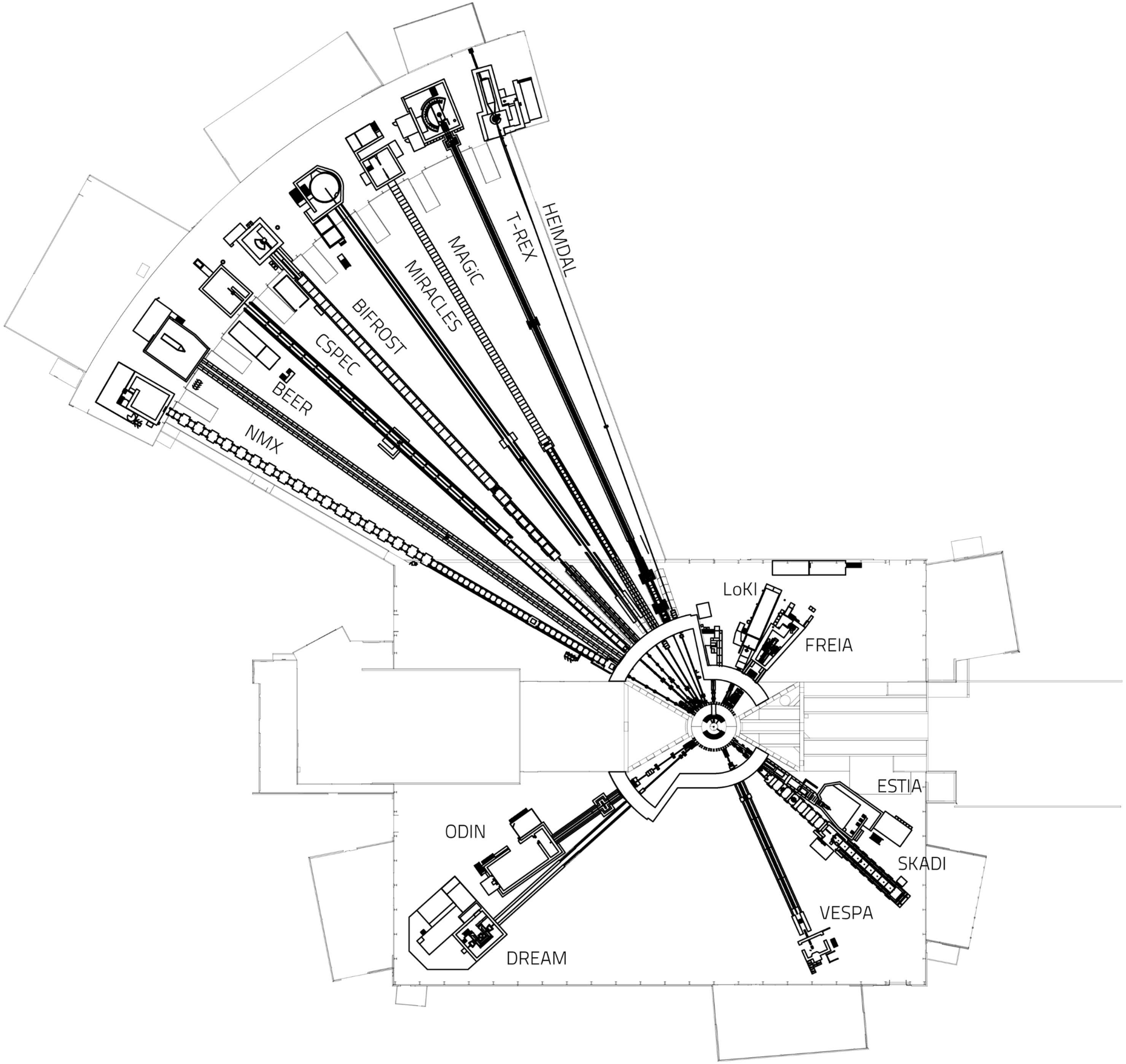
However, the new sources must fit into an existing facility

(courtesy U. Odén)


LARGE BEAMPORT



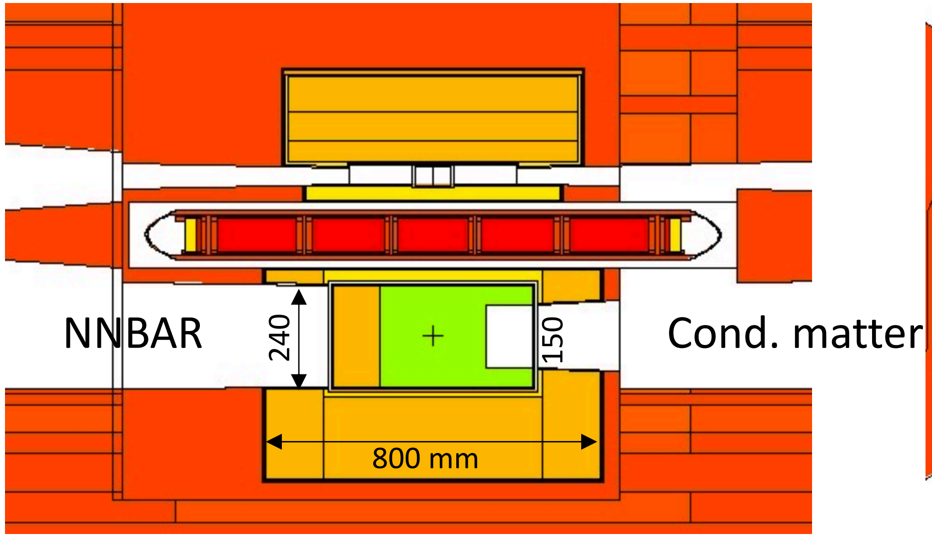

RESTRICTED AREA
STOP
NO STEP

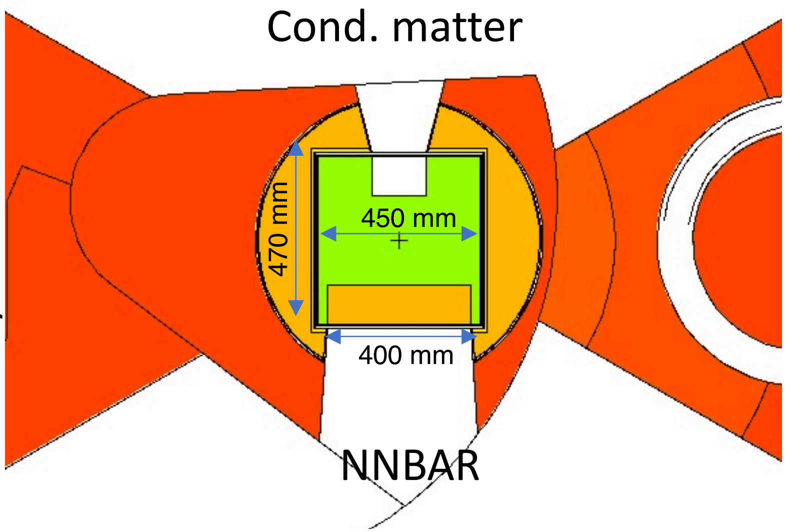

HEIMDAL
T-REX
MAGiC
MIRACLES
BIFROST
CSPEC
BEER
NMX
LoKI
FREIA
ESTIA
SKADI
VESPA
ODIN
DREAM

HighNess

Design of the Cold Source

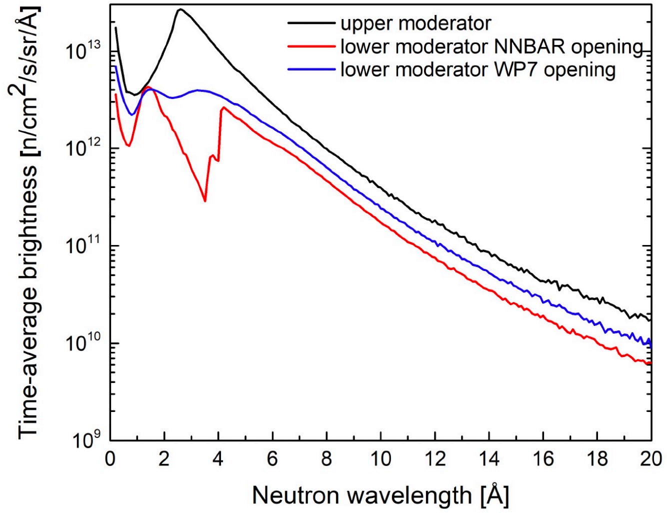
cold	2-20 Å
very cold	10–120 Å
ultracold	> 500 Å



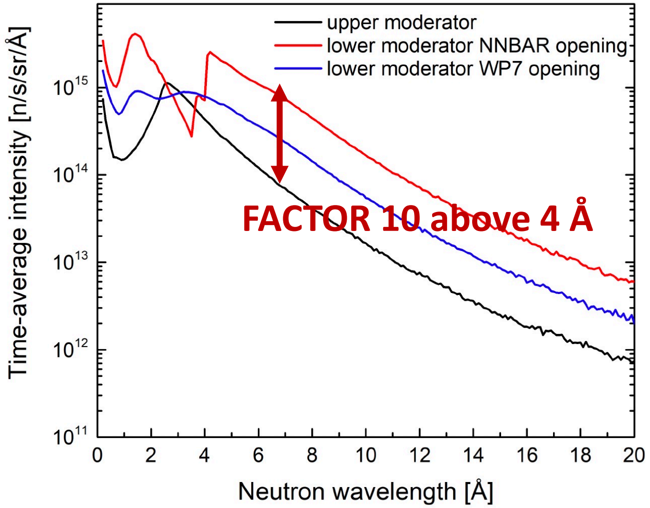


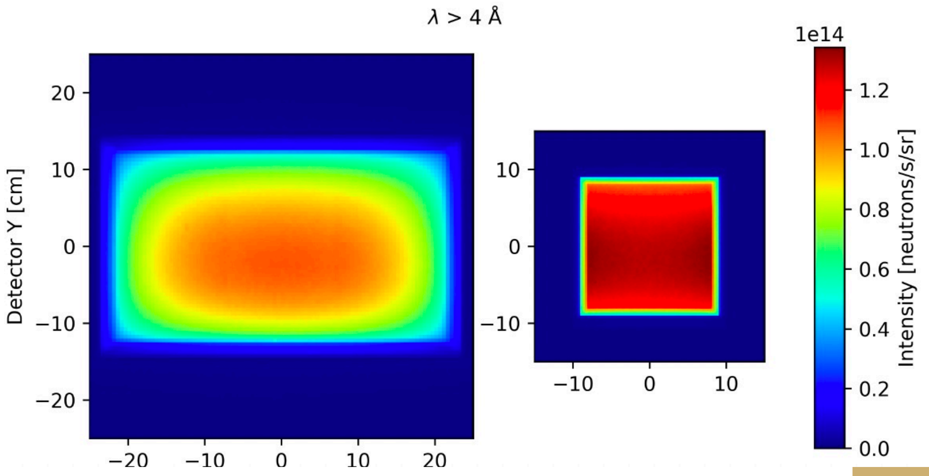
The high-intensity liquid deuterium moderator has been designed with two openings, for NNBAR and neutron scattering instruments

Brightness



Intensity





Research and Innovation Horizon 2020, under grant ag

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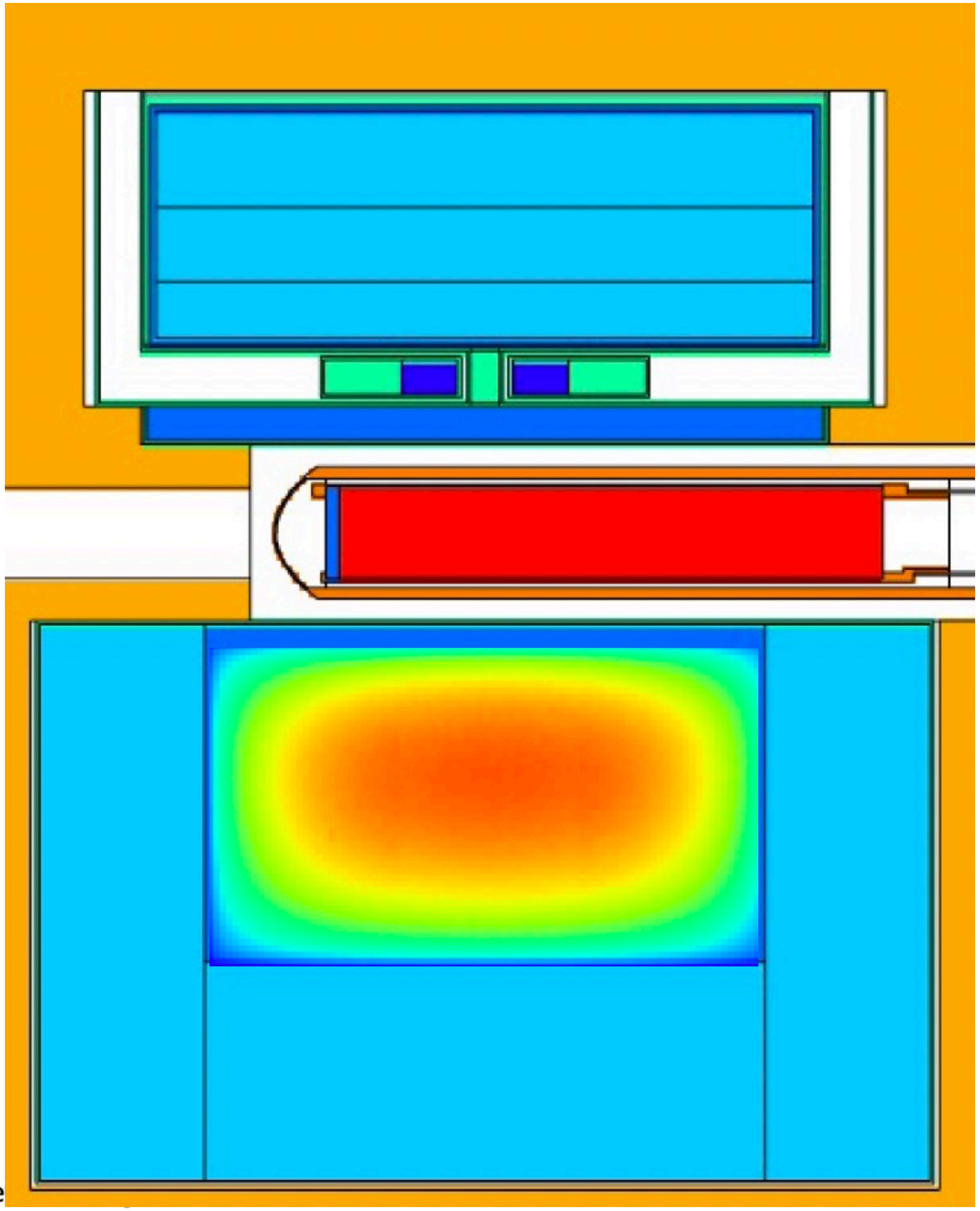

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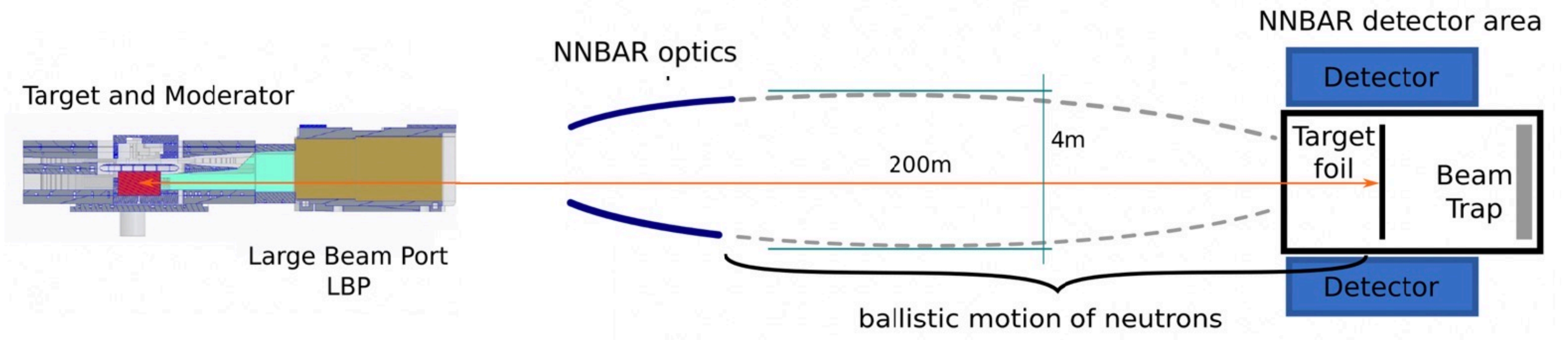
Sensitivity increase of factor 1000 in search for neutron-antineutron oscillation compared to previous experiment (M. Baldo-Ceolin et al, 1994).



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The HighNESS/LENS workshops on VCN and UCN sources at ESS

First workshop https://indico.esss.lu.se/event/2810/

- On February 2-4 2022, more than 100 scientists and experts from 23 nationalities took part in the workshop

- Workshop proceedings to published in a special issue of the Journal of Neutron Research in 2022
https://content.iospress.com/journals/journal-of-neutron-research/24/2

- Follow up workshop 8-9 May 2023

2^{nd} workshop https://indico.esss.lu.se/event/3195/

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Reflectometry (Ott) https://indico.esss.lu.se/event/2810/

SUMMARY

The time structure of ESS is ideally suited for reflectometry experiments → hard to compete

Assuming a temperature shift from 20K to 5K,

- The wavelength spectrum would be shifted by a factor 2

Technique	Gain	20K → 5K
Specular reflectivity	$\propto \lambda^2$	4
Off-specular reflectivity	$\propto \lambda^2$	4
GISANS	$\propto \lambda$	2

- Assuming that the integrated VCN flux is identical to the CN flux (brightness value)
- Assuming the time structure is not too dilated (pulse < 10ms)
- VCN neutrons could be practically useful up to a shift of a factor 3 in the wavelength spectrum.
- Beware that neutrons are falling in the gravity field → challenge to achieve clean horizontal instrument measurements

HighNESS is funded by Research and Innovatic

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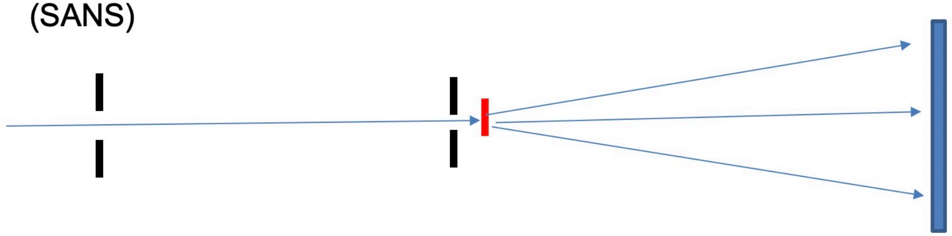
SANS (Mezei) https://indico.esss.lu.se/event/2810/

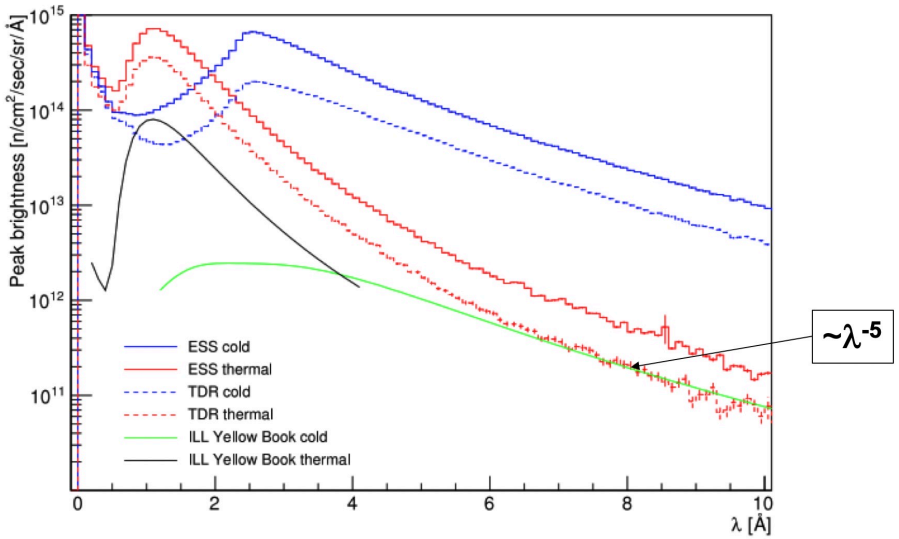
Small angle neutron scattering: small **q** → large scale structures
(SANS)



Through put of incoming beam shaping @ equal resolution: $\propto \lambda^{5}$

Long wavelength tail of Maxwellian particle spectrum: $\propto \lambda^{-5}$

→ all wavelengths about equivalent for a Maxwellian spectrum



L. Zanini et. al. 2019

Cold moderators are less Maxwellian and a VCN source could offer unprecedented intensity in SANS studies

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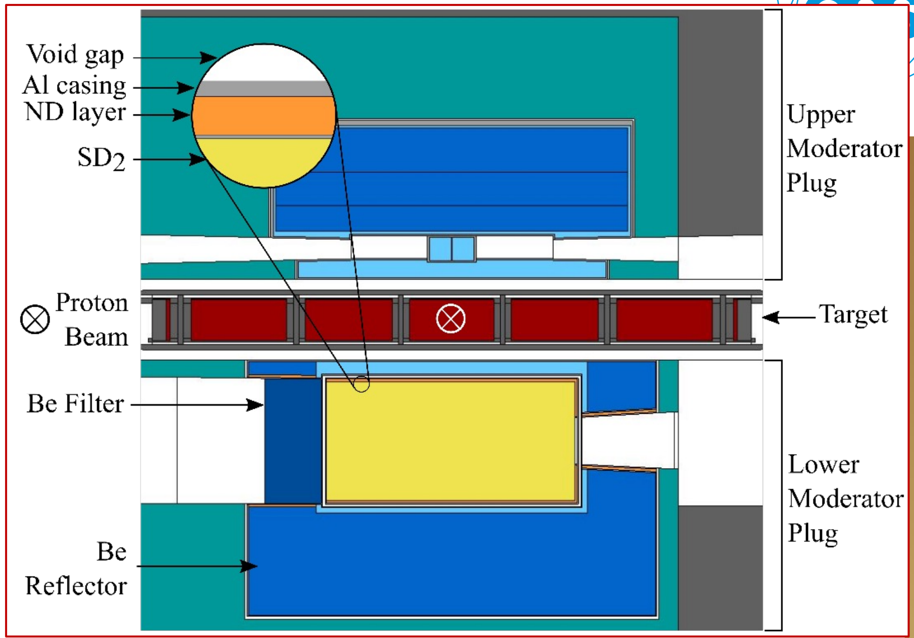
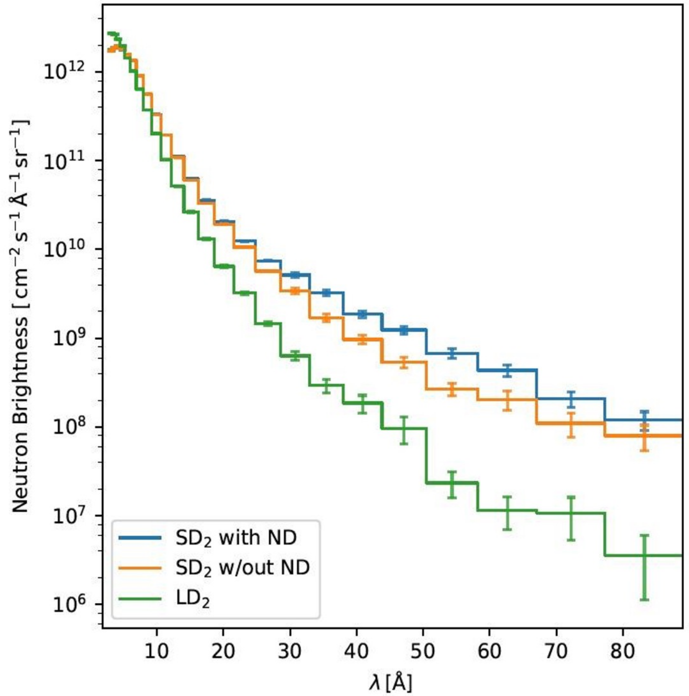
Dedicated VCN moderator

Ferenc Mezei   Journal of Neutron Research 24 (2022) 205–210

in order to be advantageous in SANS type of experiments, must therefore provide high intensity at wavelengths $\lambda > 10$ Å, that is above the presumed λ^{-5} dependence of the spectra of current cold moderators (which happens to be only well established in practice for neutron wavelengths below 10–20 Å).

Different, innovative, more sophisticated moderator designs might eventually even offer larger favorable deviation from the λ^{-5} dependence.





~ $\lambda^{-3.5}$

λ^{-5}

For SD2: see talk by N. Rizzi

For deuterated clathrate hydrates: see talk by V. Czamler

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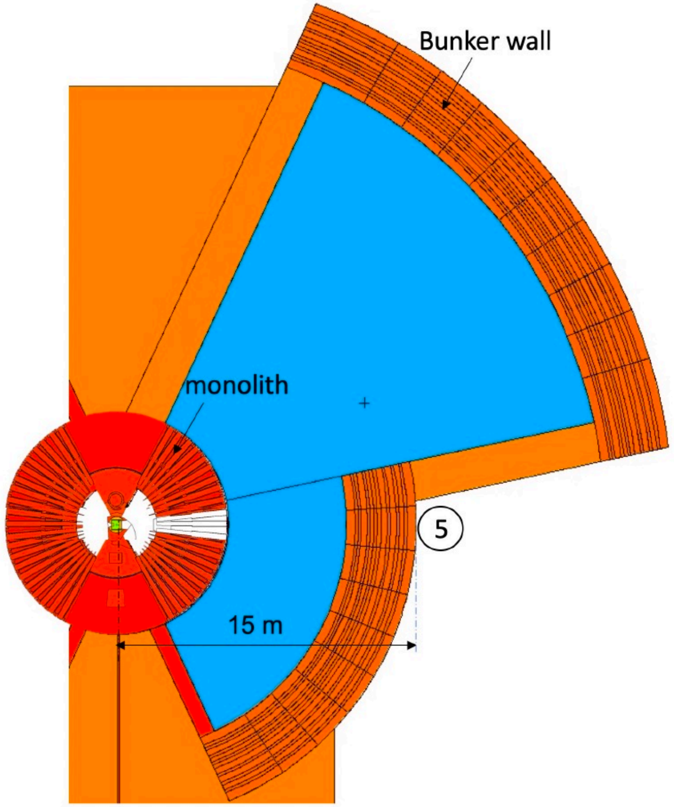
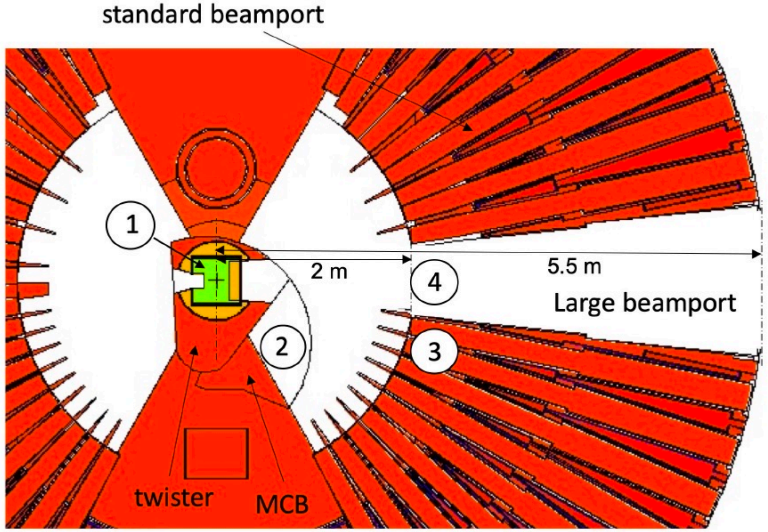
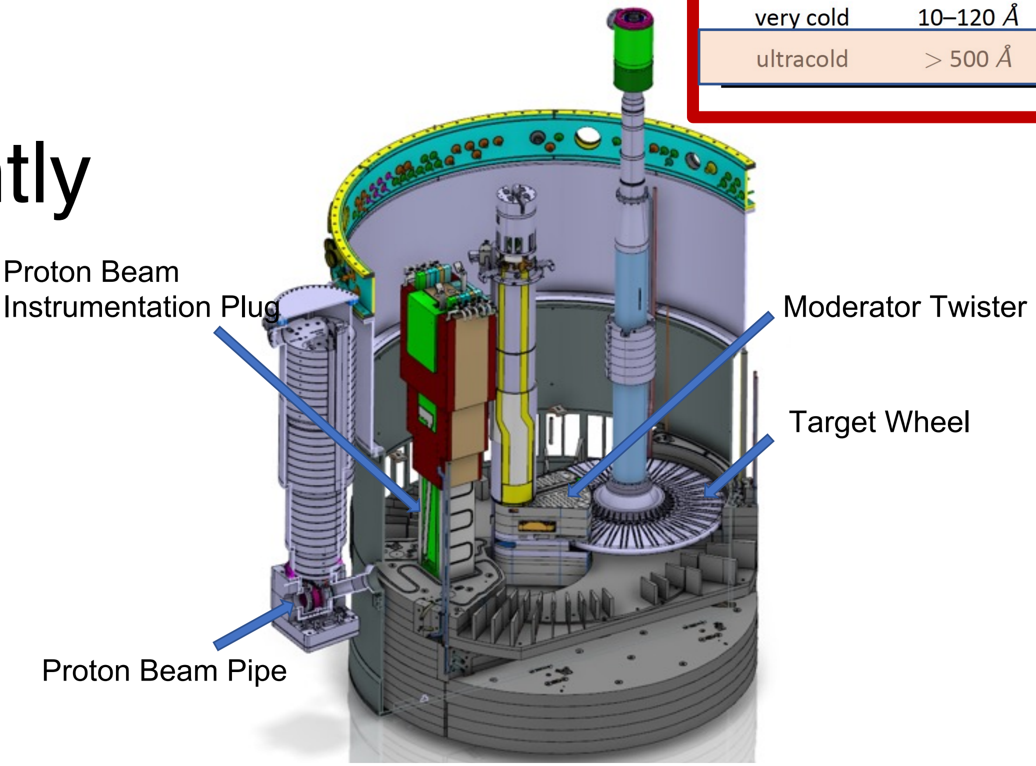
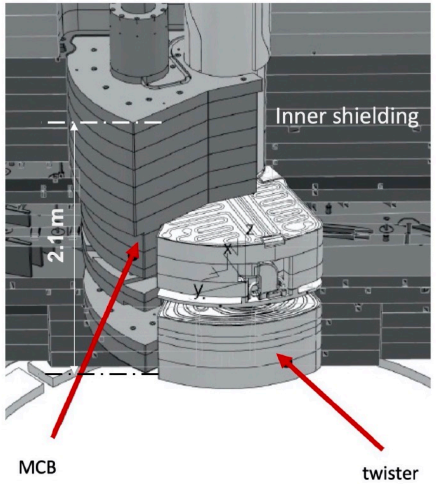
UCN sources: possible locations identified at the workshop are currently under study









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Production rate densities for He-II and SD2 as a function of distance

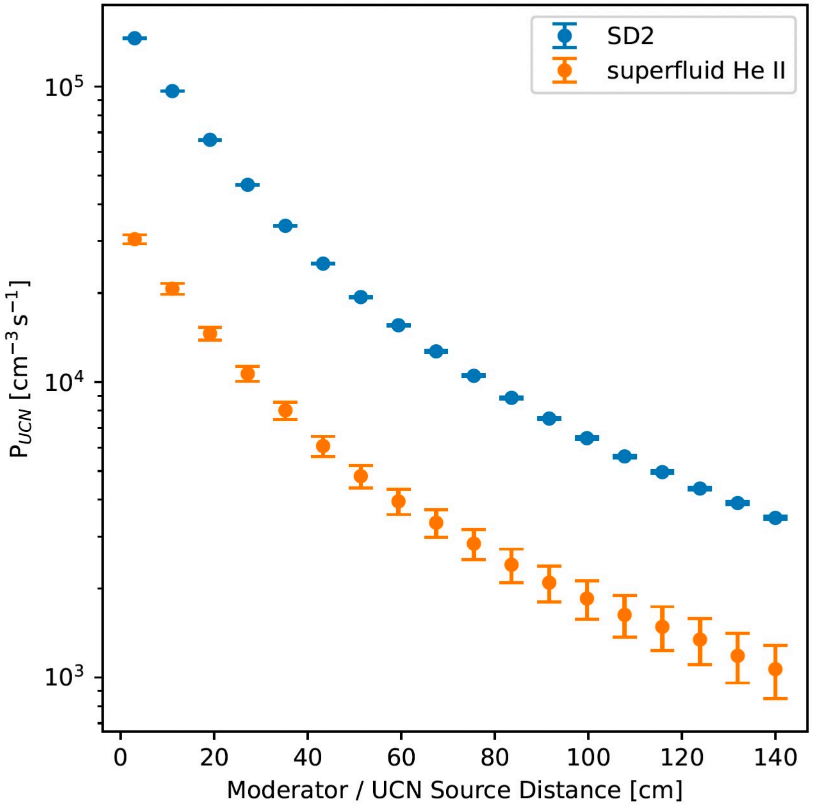

Fig. 12. Calculated production rate densities for He-II [39] and SD_2 [40, 41, 42] as a function of the distance from the LD_2 moderator.

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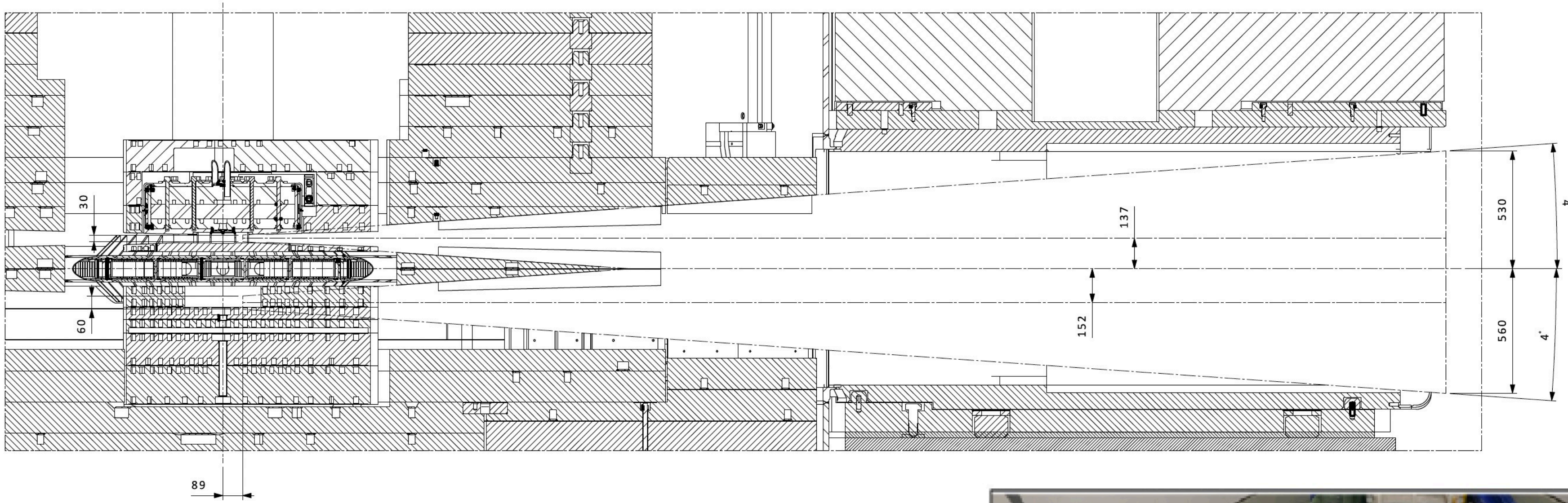
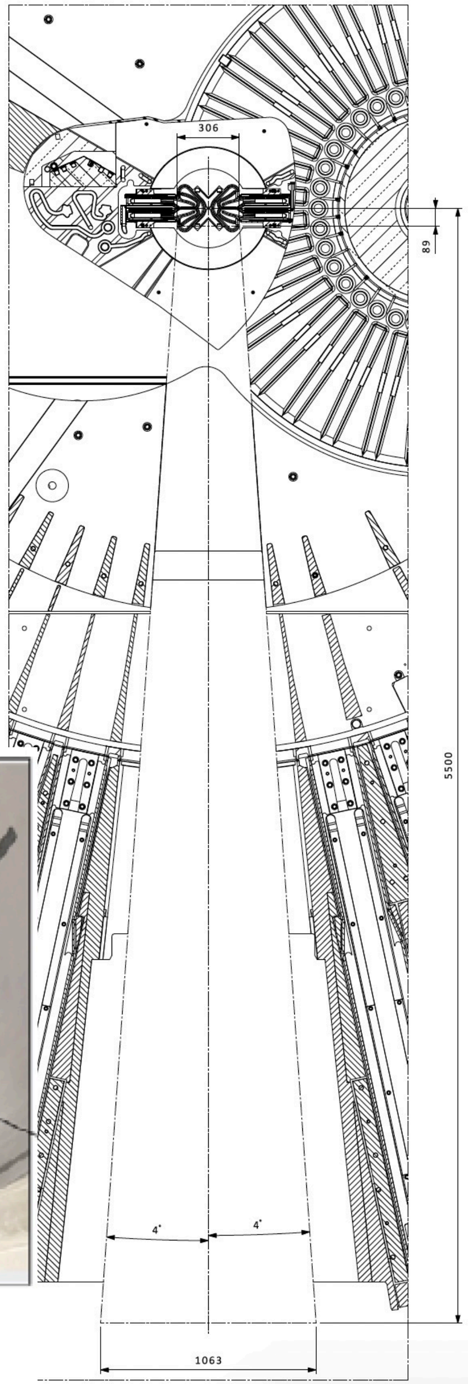
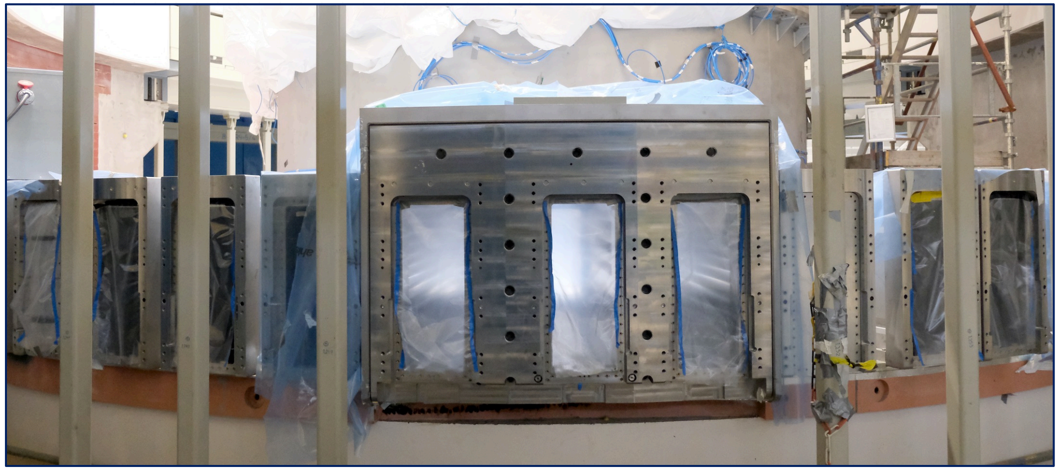
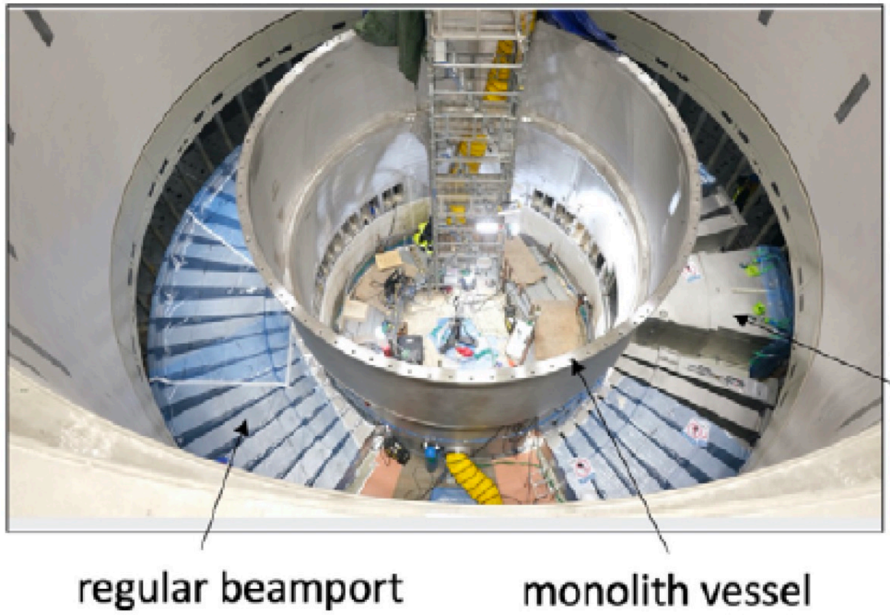
The Large Beam Port for NNBAR could accommodate a UCN source (location 4,5)









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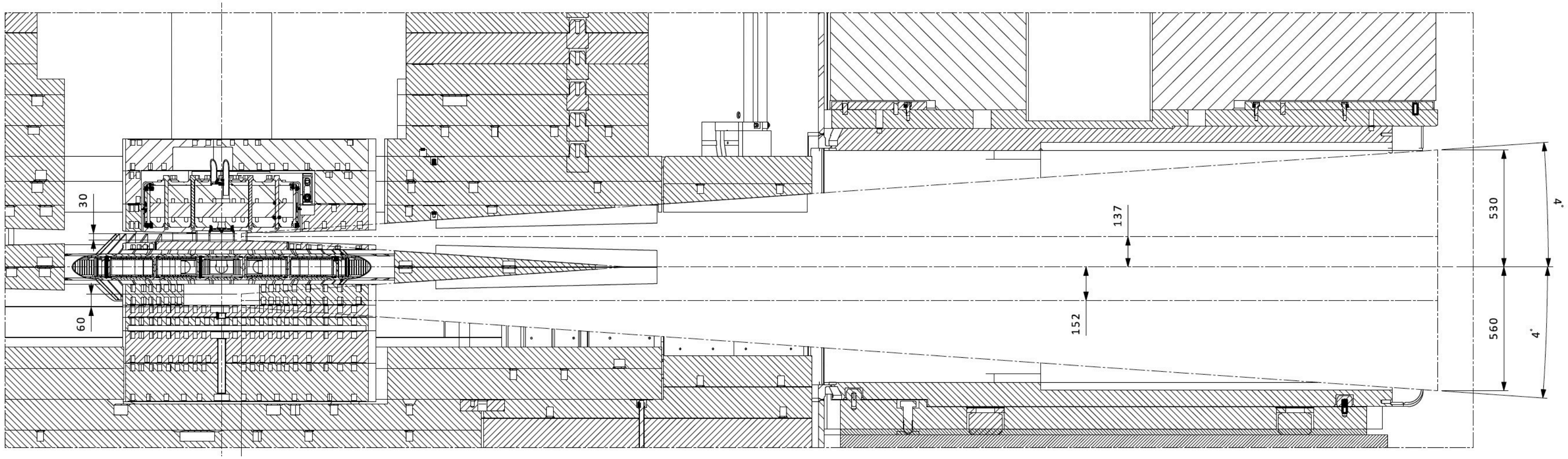

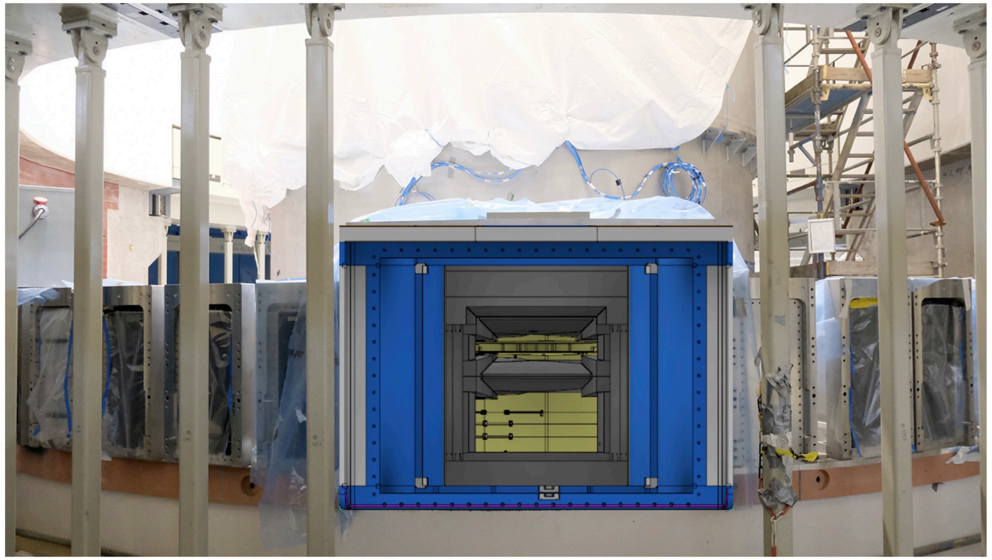

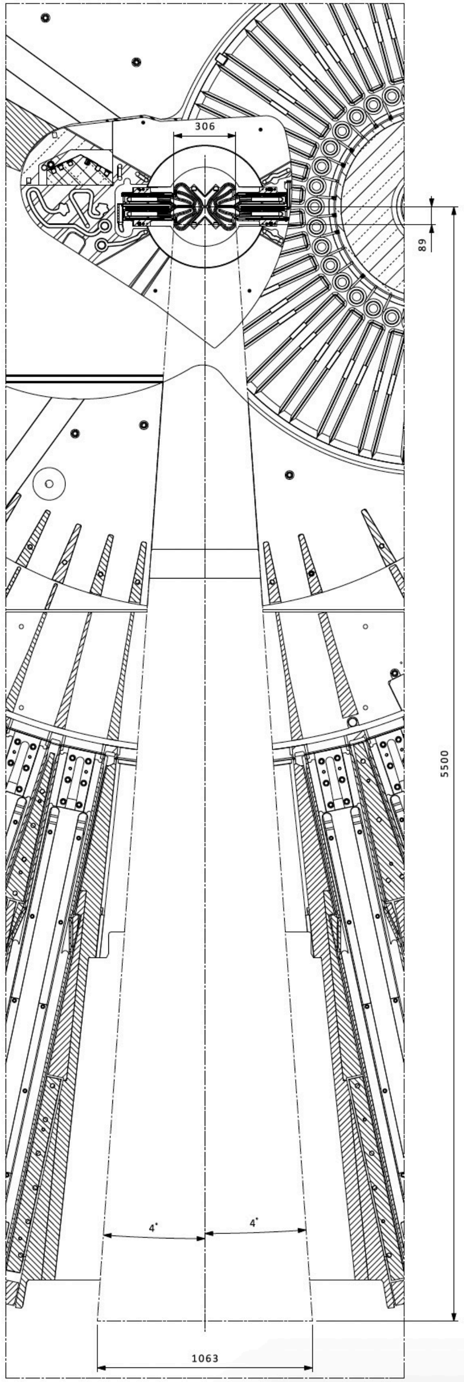

Large Beam Port has the size of 1mx1m

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UCN source in large beamport (location 5)

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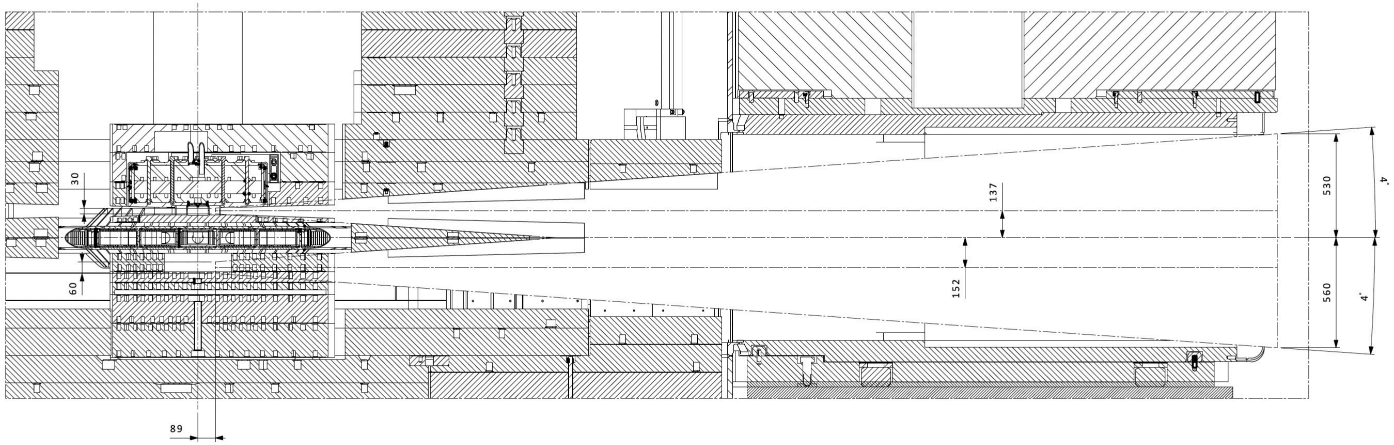
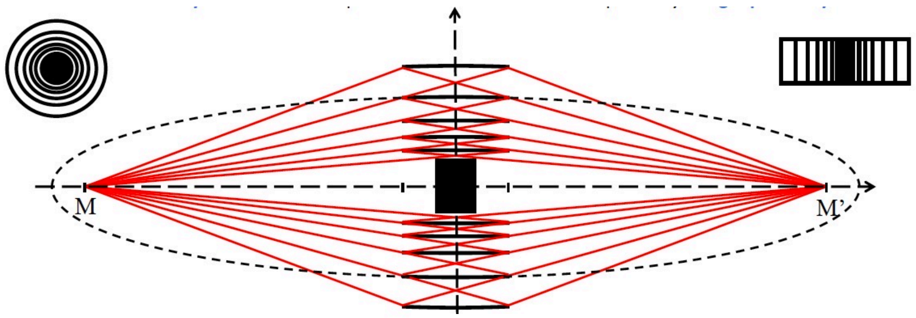
ultracold	> 500 Å

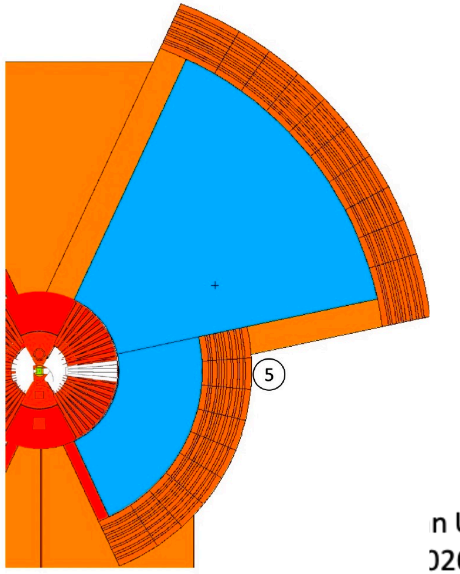
The large beamport for NNBAR could be used for a world-class UCN source



In-beam solution with superfluid He converter and advanced optics system outside the large beamport (concept O. Zimmer)



Neutronic study in progress



- Need a neutron delivery system with high brilliance transfer from moderator to UCN source, with largest technically possible solid angle
- Neutron imaging from the moderator to the UCN source via the arrangement of nested mirrors has been identified as possible solution

Potential production rate in 120 liter source volume of superfluid He: 2.5×10^7 n/s

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HighNess

Potential world-leading UCN densities compared to other facilities under design or construction

Results from position 5 (in beam with use of nested mirror optics) are very promising.
Higher production in closer locations, however with bigger challenges

	ρ [cm^{-3} s^{-1}]	ρ V[s^{-1}]	ρ [cm^{-3}]
Gatchina, Russia	$3\ 10^3$	$1\ 10^8$	$6.\ 10^4$
SUPERSUN (ILL)	14	$1.6\ 10^5$	$1.7\ 10^3$
SHIN (compact source)[a]	80	$5\ 10^6$	$4\ 10^3$
LEUNG[b] (inverted geometry)	$5\ 10^4$	$5\ 10^8$	$1\ 10^4$
ESS (NMO) Position 5	**209**	**$2.5\ 10^7$**	**$6.3\ 10^4$**

Source: O. Zimmer, UCN/VCN workshop 2022

[a]arXiv:1810.08722v3 (October 2018)
[b]arXiv:1905.09459 (October 2019)

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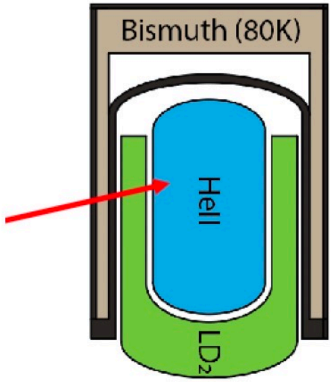
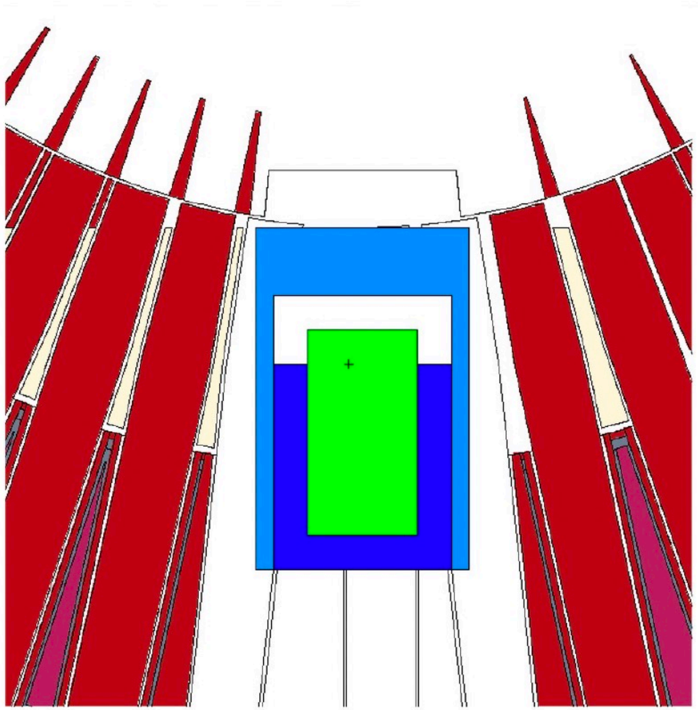
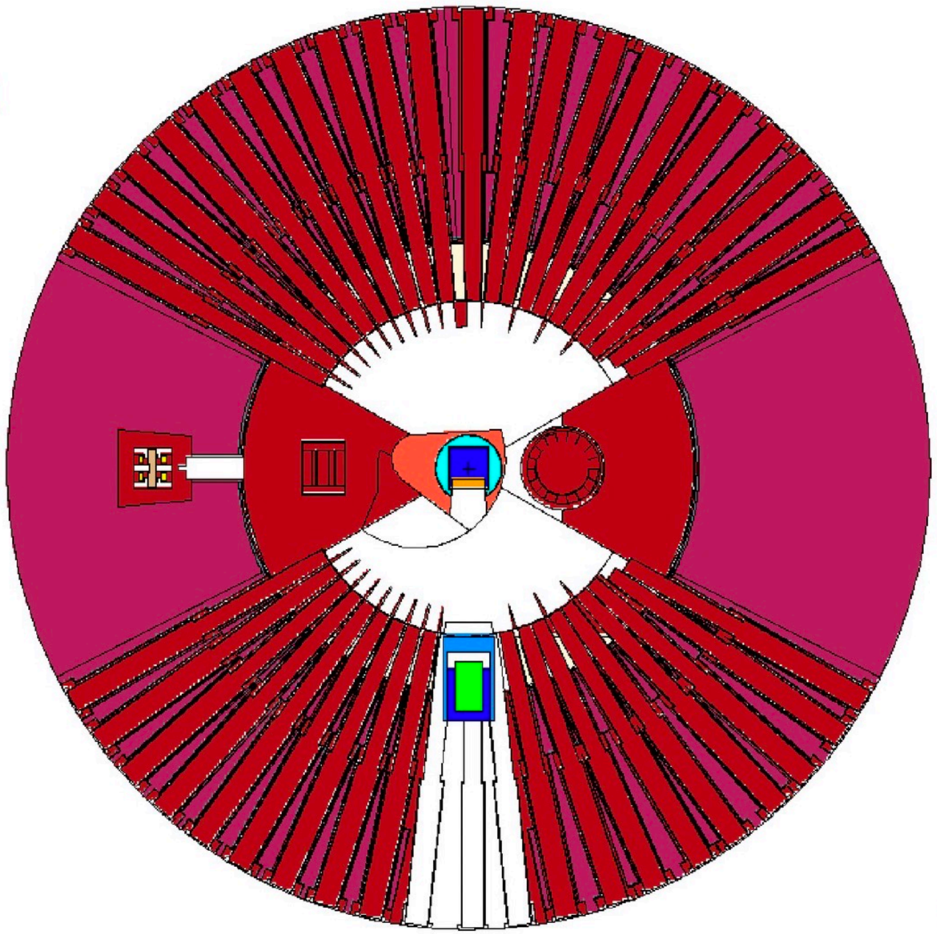
UCN source in large beamport (location 4)

concept by Serebrov-Lyamkin

He4 Box: 60 cm x 30 cm x 32 cm







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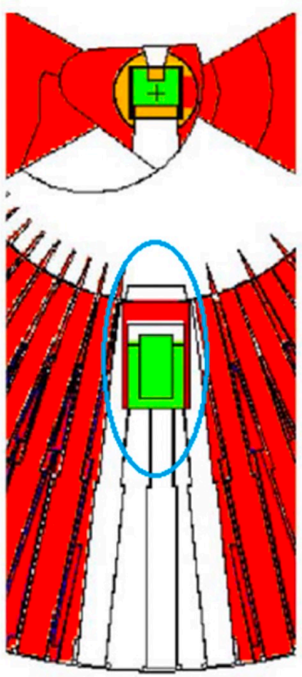


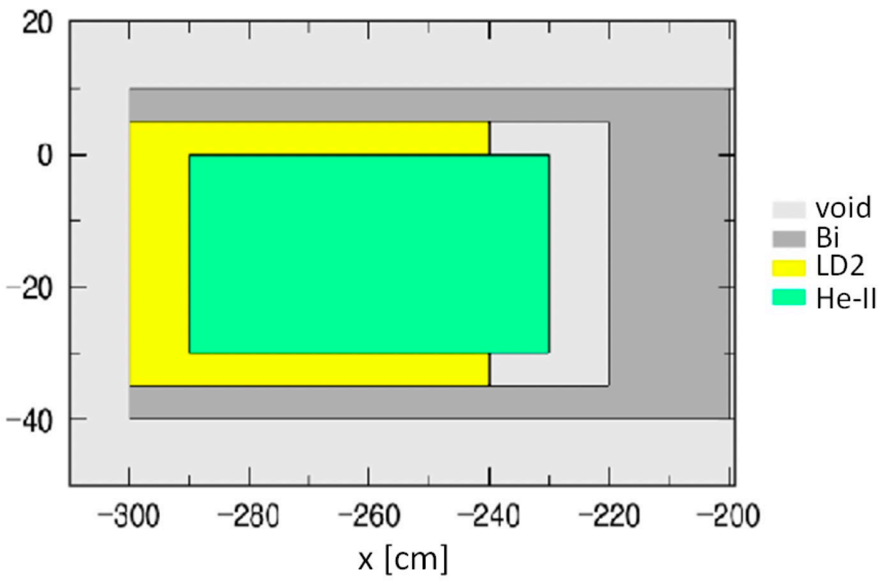


Figure 5.8: *Left*: Geometry showing the He-II source backed by a LD_2 reflector in the large beamport, concept of Serebrov and Lyamkin [43]. *Right*: The geometry and the materials used in the UCN source located at LBP. The direction of the incoming neutron beam is towards the left [130].

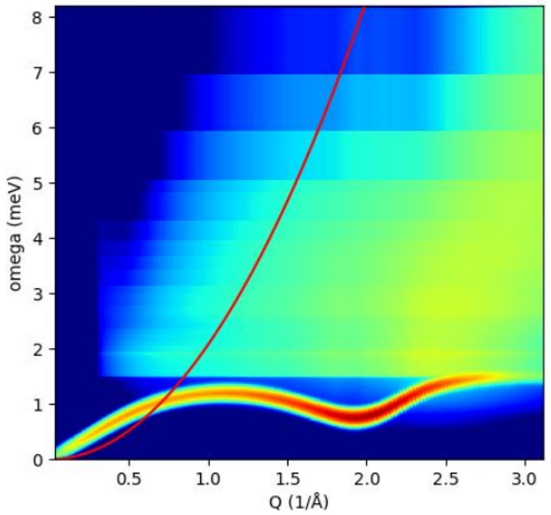
Table 5.7: Performance of optimized geometry of He-II UCN source in the LBP.

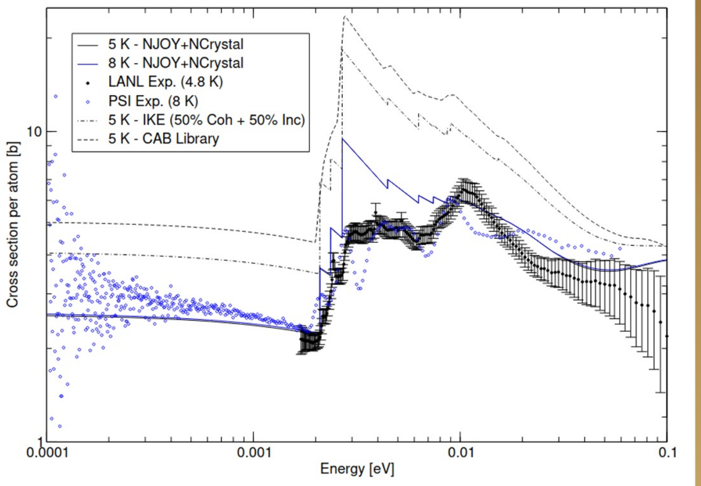
	He – II Volume [Liters]	P_{UCN} [n/s/cm^3]	$\dot{N}_{UCN}$ [n/s]	Heat-load [W]
He-II in LBP (Final design)	57.6	590	3.4×10^7	32.2

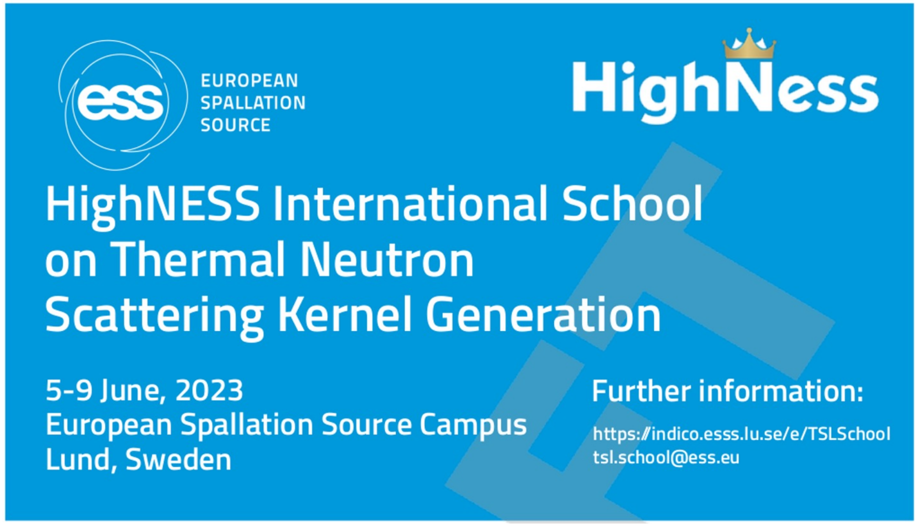
(PhD thesis M. Akhyani)

UCN and VCN materials scattering kernels

- Development of new scattering kernels for materials of interest, i.e. solid deuterium, superfluid helium, nanodiamond particles and clathrate hydrates
- Improved sampling and biasing methods in NCrystal for UCN and VCN applications
- School on scattering kernel development was held at ESS in 2023
- Contact: Jose Ignacio Marquez Damian, Douglas Di Julio and Thomas Kittelmann







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Conclusions

- The HighNESS project started in October 2020 and ended in September 2023
- The scope is the development of the ESS upgrade
- For the cold source, neutronic and engineering design has been completed, with expected intensity 10 times higher than upper moderator.
- For the VCN source, we have an outstanding design with SD2 + nanodiamonds
- For the UCN source simulations several options have been investigated. We think a world-leading UCN source can be built.
- The HighNESS CDR is under publication as a special issue of JNR, divided in 2 parts: General Results, and NNBAR.
- A follow-up grant proposal has been submitted to EC

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Thanks to everybody