HighNess

Neutrons for Europe
USER MEETING
2022

Development of an Ultra Cold and Very Cold Neutron Source at the European Spallation Source

Valentina Santoro ESS

on behalf of the HighNESS Consortium

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

ESS Journey

2022

2027

2070

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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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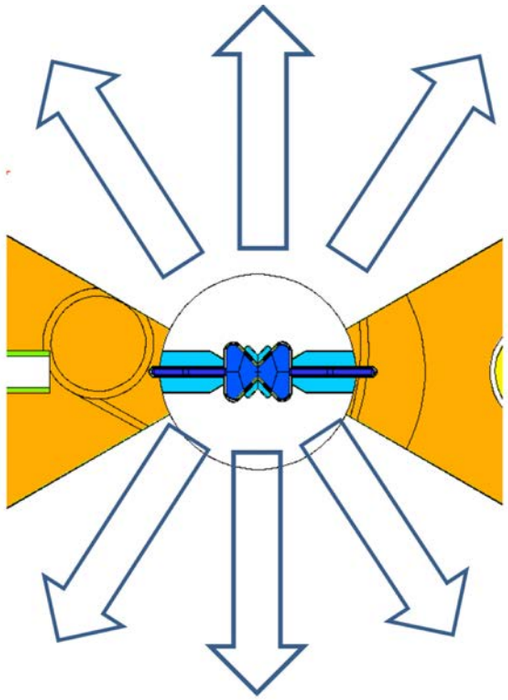
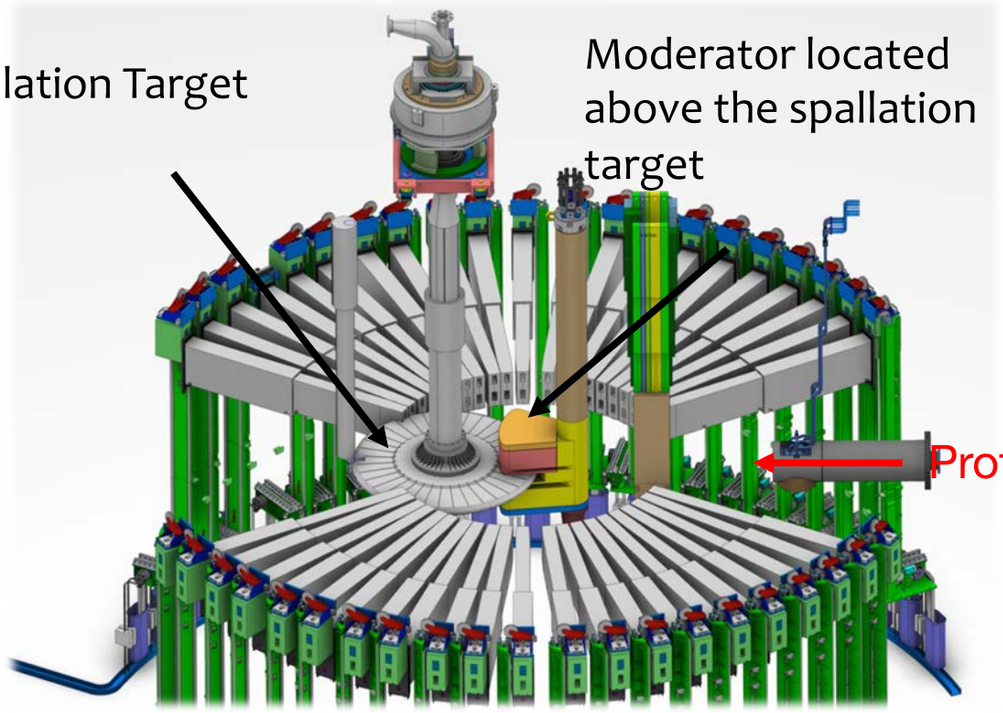
The ESS current moderator

- The design of the ESS moderator is based on the novel concept of low-dimensional moderators
- It is a single **high-brightness** moderator system placed on top of the spallation target

ESS current moderator unprecedent brightness to all the available beamport





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- The space below the target is available for future upgrade →HighNESS project

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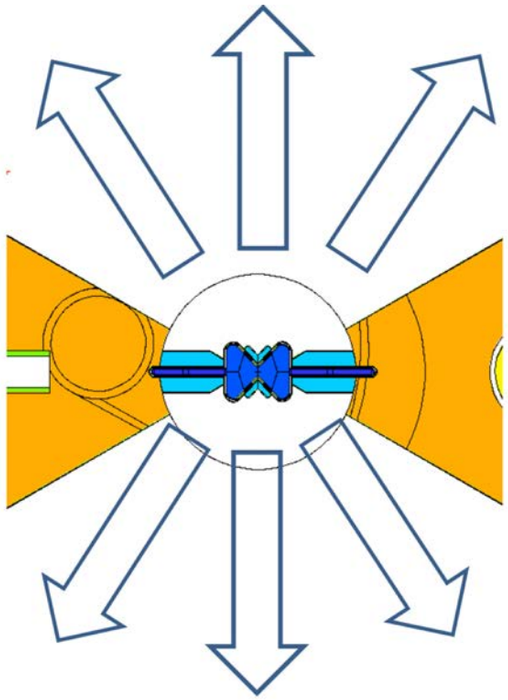

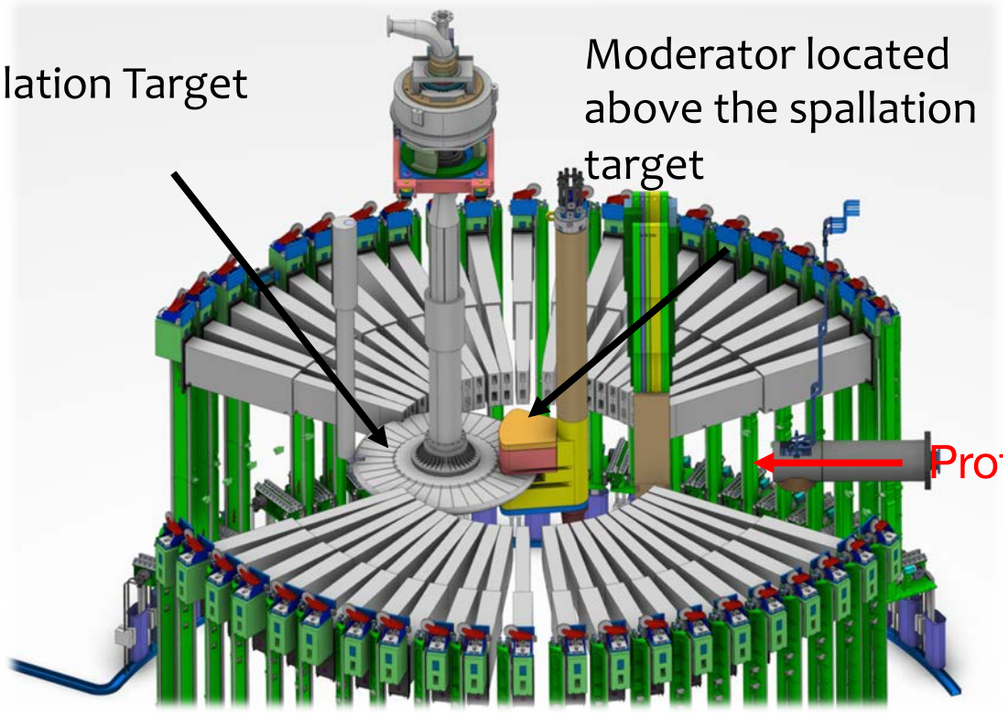

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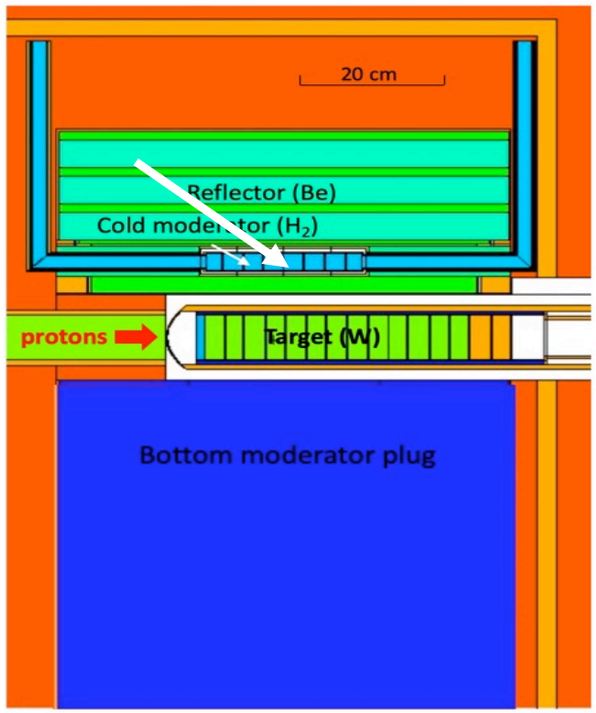
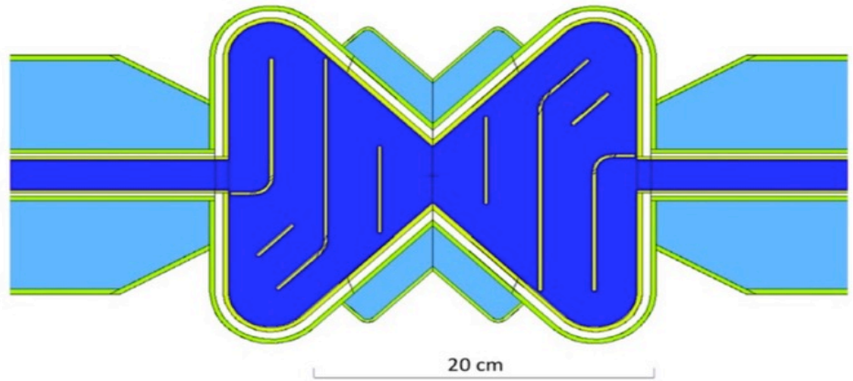


ESS current moderator
Located above the spallation target



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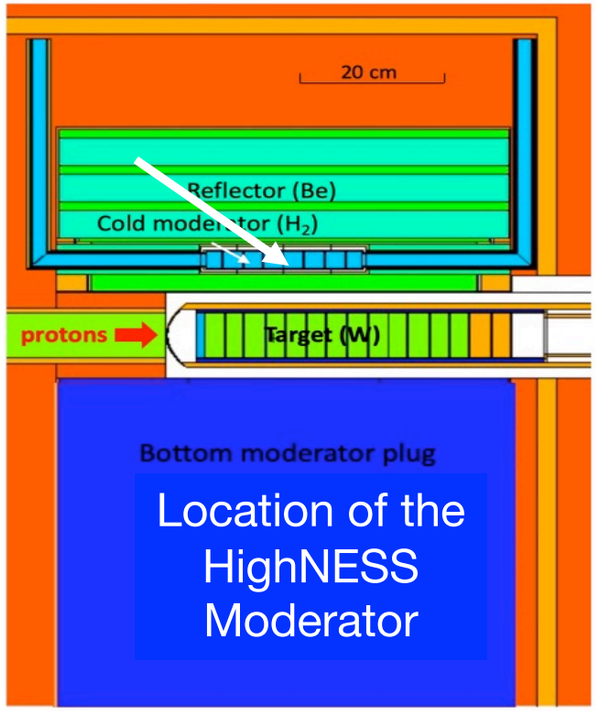

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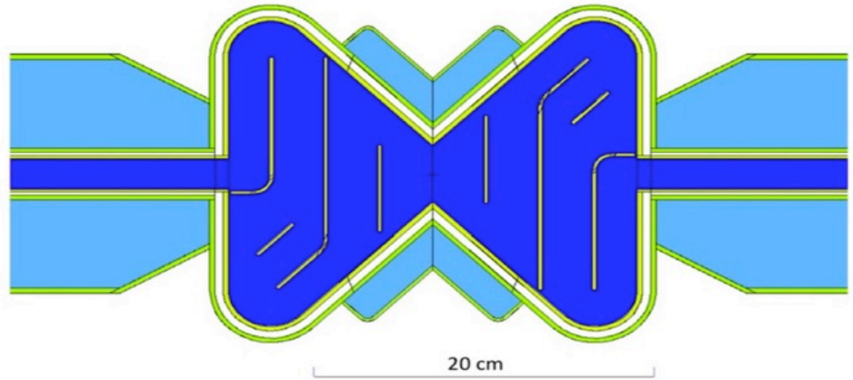

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The path to the ESS upgrade

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Design of the cold and thermal neutron moderators for the European Spallation Source

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[a] European Spallation Source ESS ERIC, PO Box 176, 22100 Lund, Sweden
[b] DTU Nutech, Technical University of Denmark, DTU Risø Campus, Frederiksborgvej 399, DK-4000, Roskilde, Denmark

ARTICLE INFO

Keywords:
Low-dimensional moderators
Source brightness
Parahydrogen
Water
Neutron beam extraction
Long pulse sources

ABSTRACT

At the European Spallation Source (ESS), neutrons will be generated by spallation induced by a 2-GeV proton beam on a tungsten target. ESS will have a grid of 42 beamports available for a variety of neutron scattering experiments. Neutron moderators will provide thermal and cold neutrons to the instruments, allowing bispectral beam extraction wherever needed.

The moderators were designed by adopting a holistic design approach that has considered brightness, brightness transfer and beam extraction constraints, resulting in a system with the following main features: low-dimensional moderators for enhanced brightness and maximum flux to the sample; a single moderator system placed above the spallation target; lateral shape of the moderators optimized for bispectral extraction. A moderator with a vertical extraction surface of 3 cm was chosen as result of the optimization process.

With all initial instruments pointing to the top moderator, and a beamport system that allows the possibility to extract neutrons from above and below the target, the adopted configuration opens the possibility to have different types of moderators below the target, so that other neutron beams of different intensity, or spectral shape, with respect to the ones delivered by the top moderator, could be envisaged, adding additional scientific opportunities to the facility without having the need to build a second target station.

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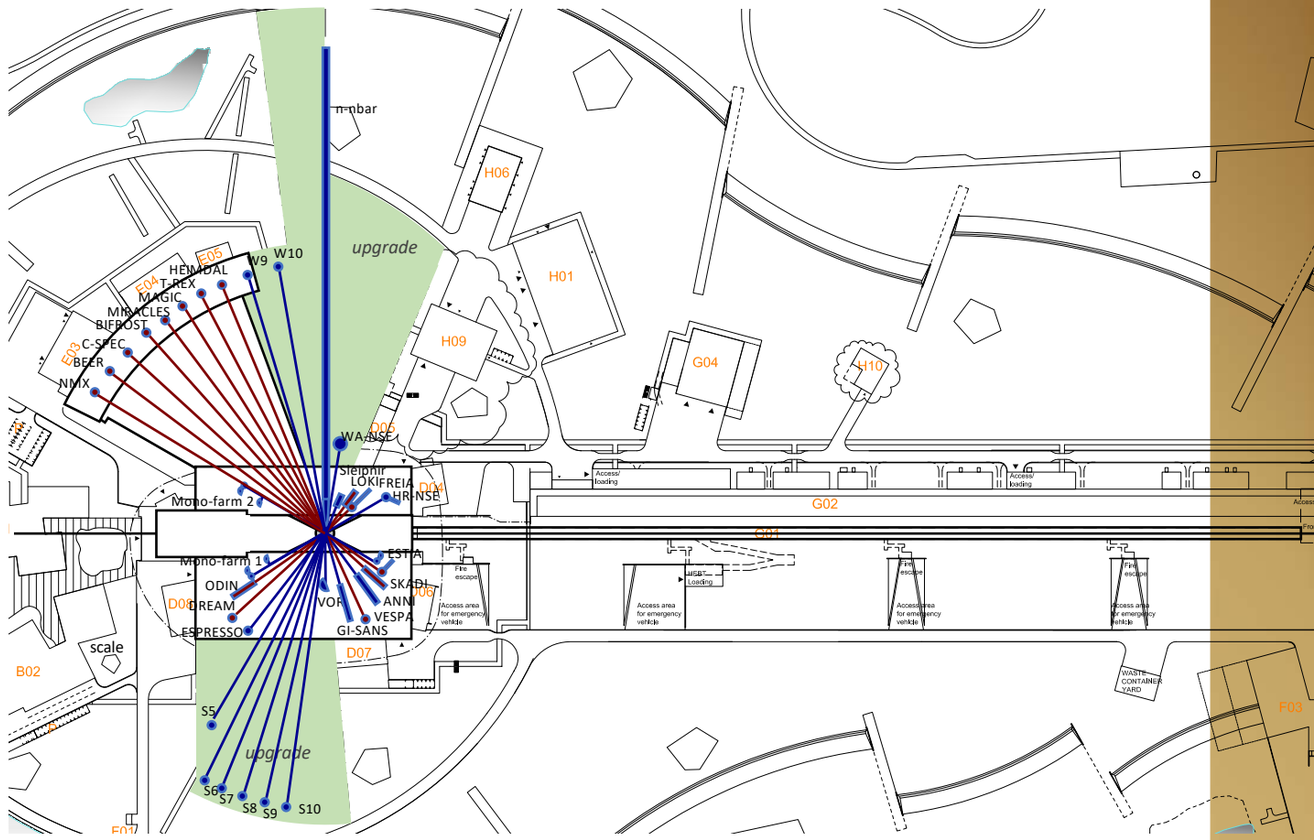
Upgradeability of ESS

- Primary upgrade path: more instruments
- 42 beamports with ~6° separation
- Upgrade areas ~ 35 instruments possible
- **Lower moderator**
  - **all beamports can view both moderators**



The green part show the upgrade area

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

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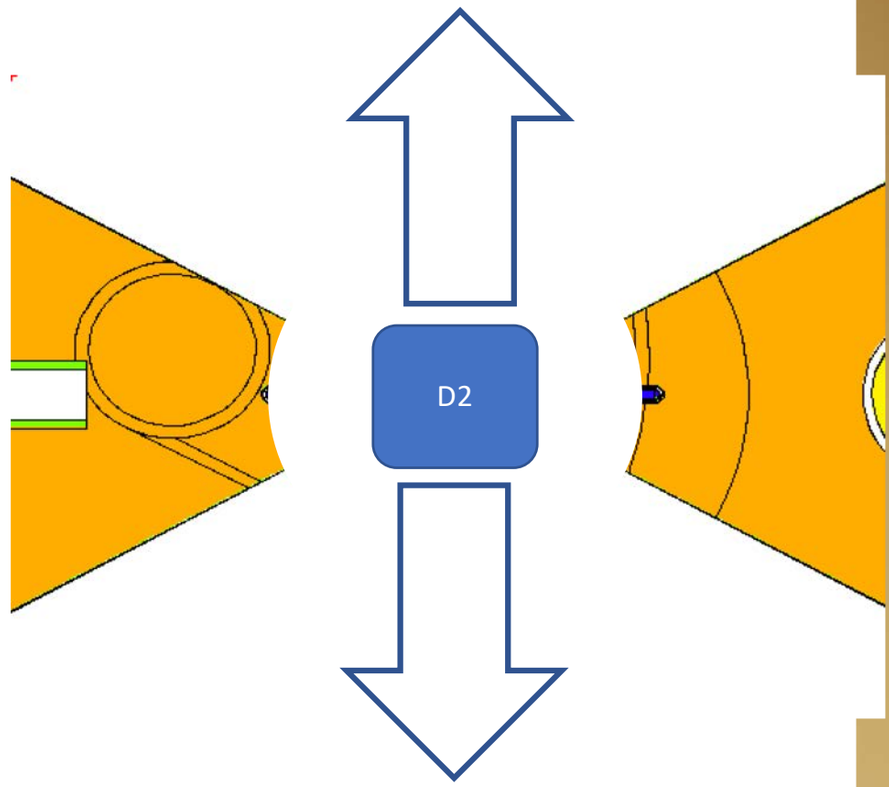

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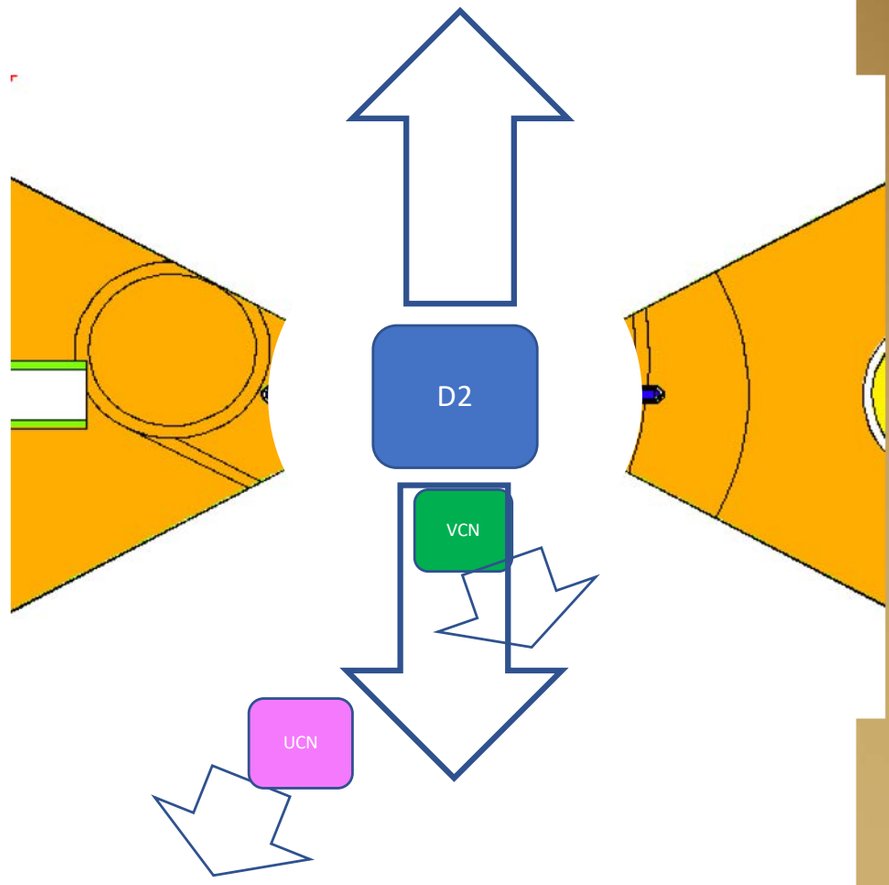

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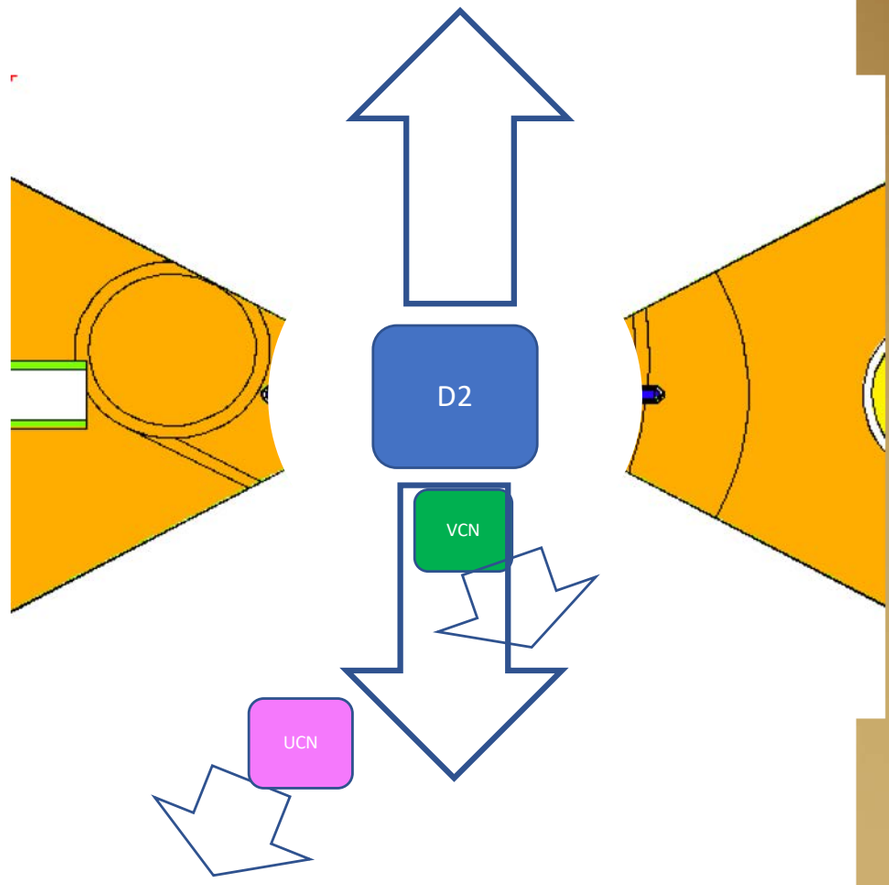
- **Conceptual Design Report of the ESS upgrade is expected by the end of 2023**



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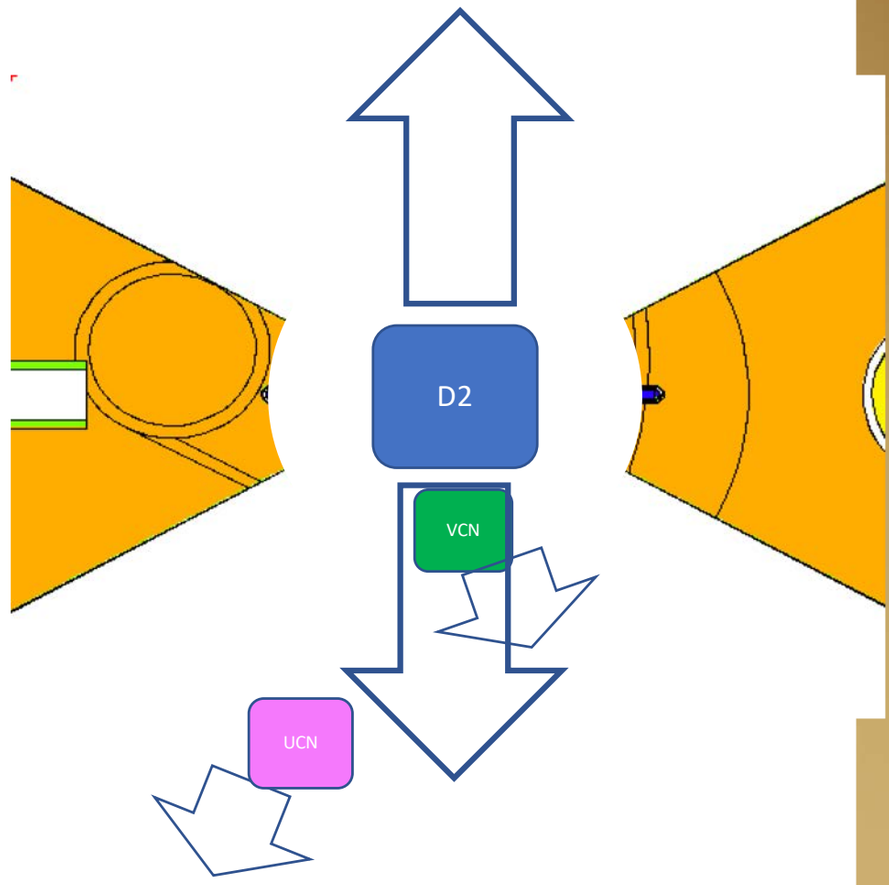

Complementarity with what is currently available at ESS

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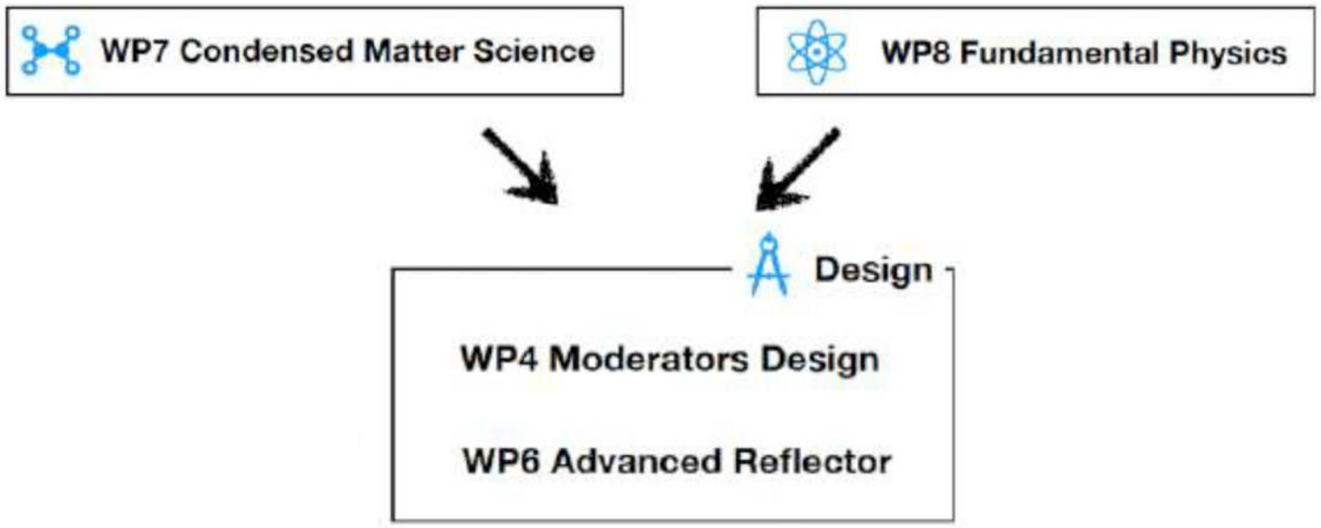

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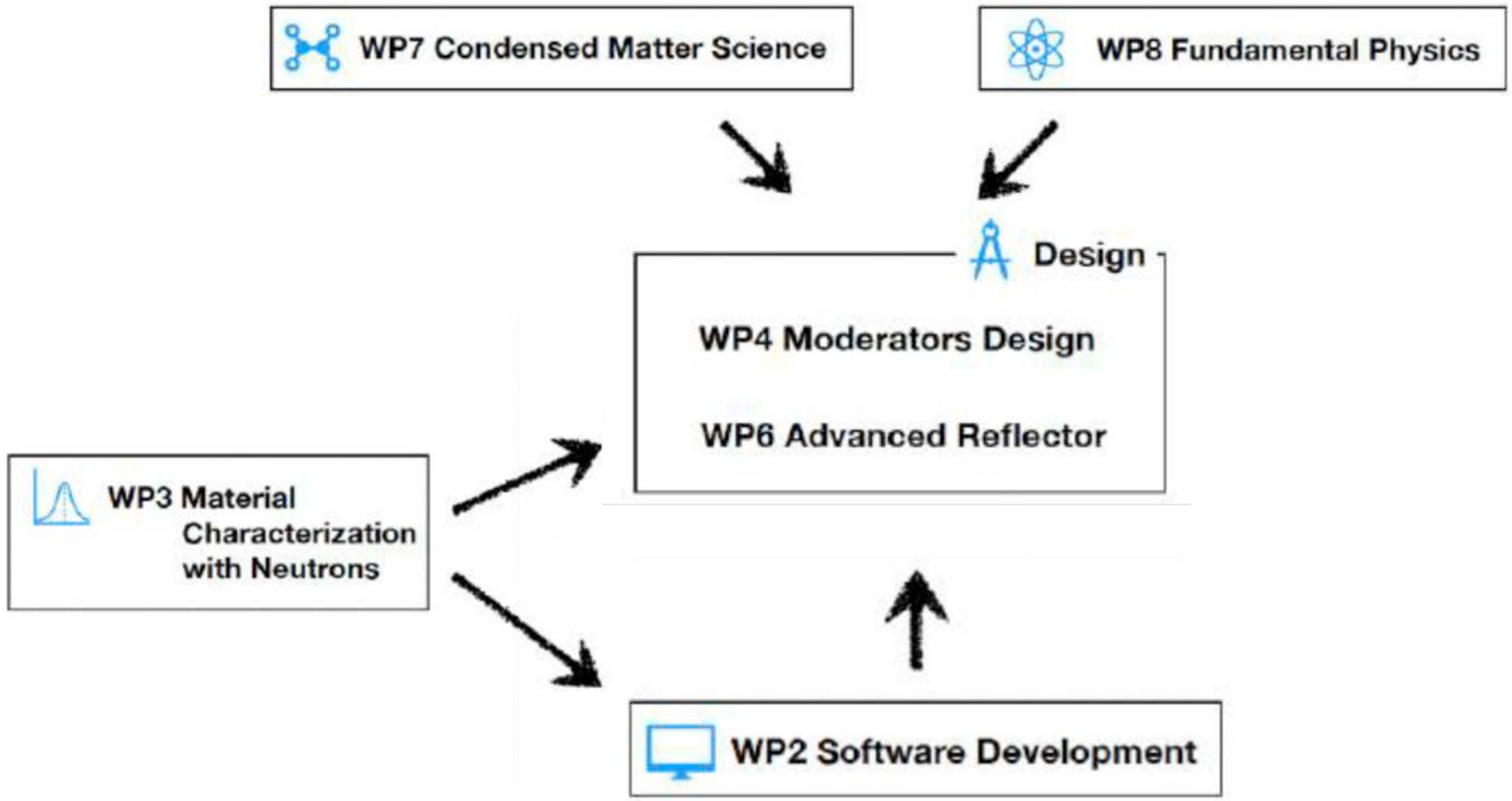

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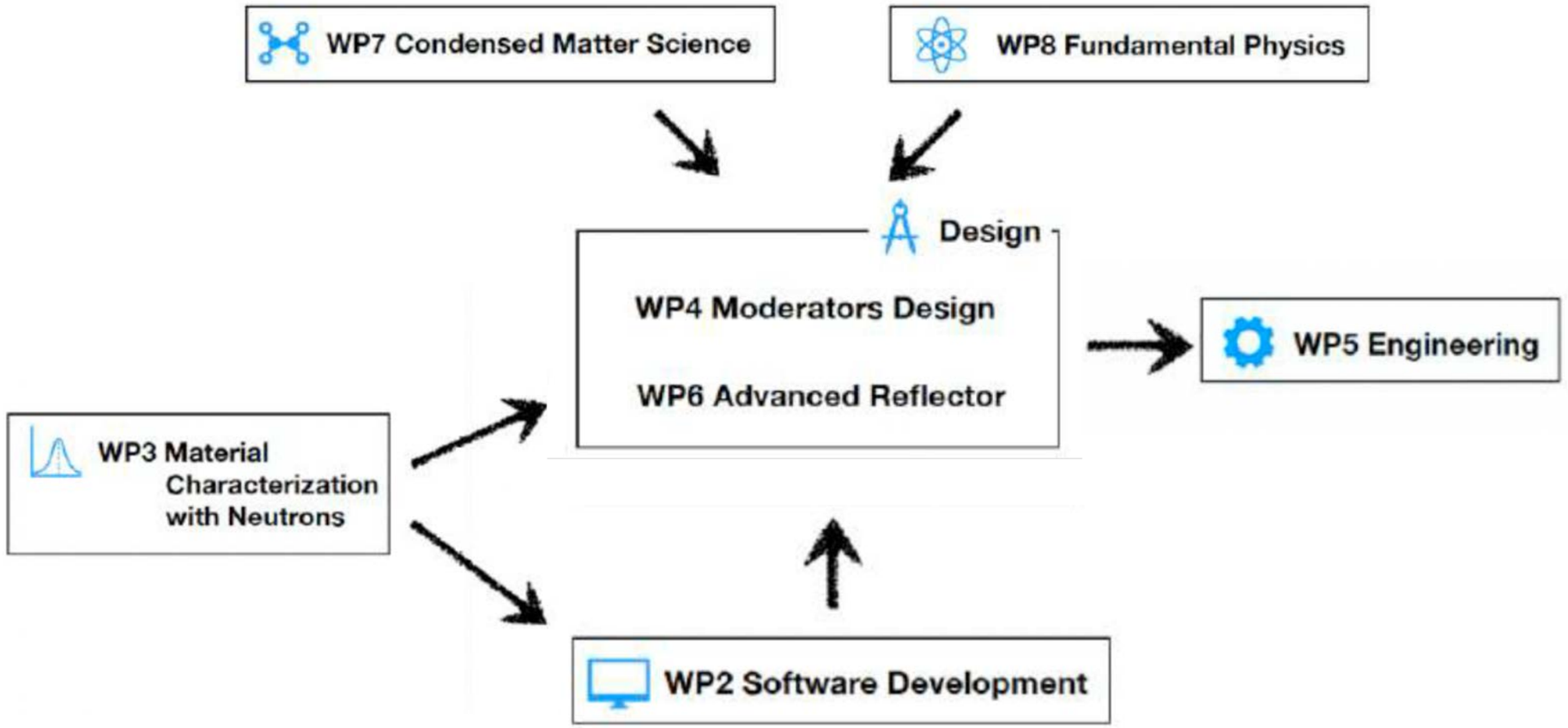

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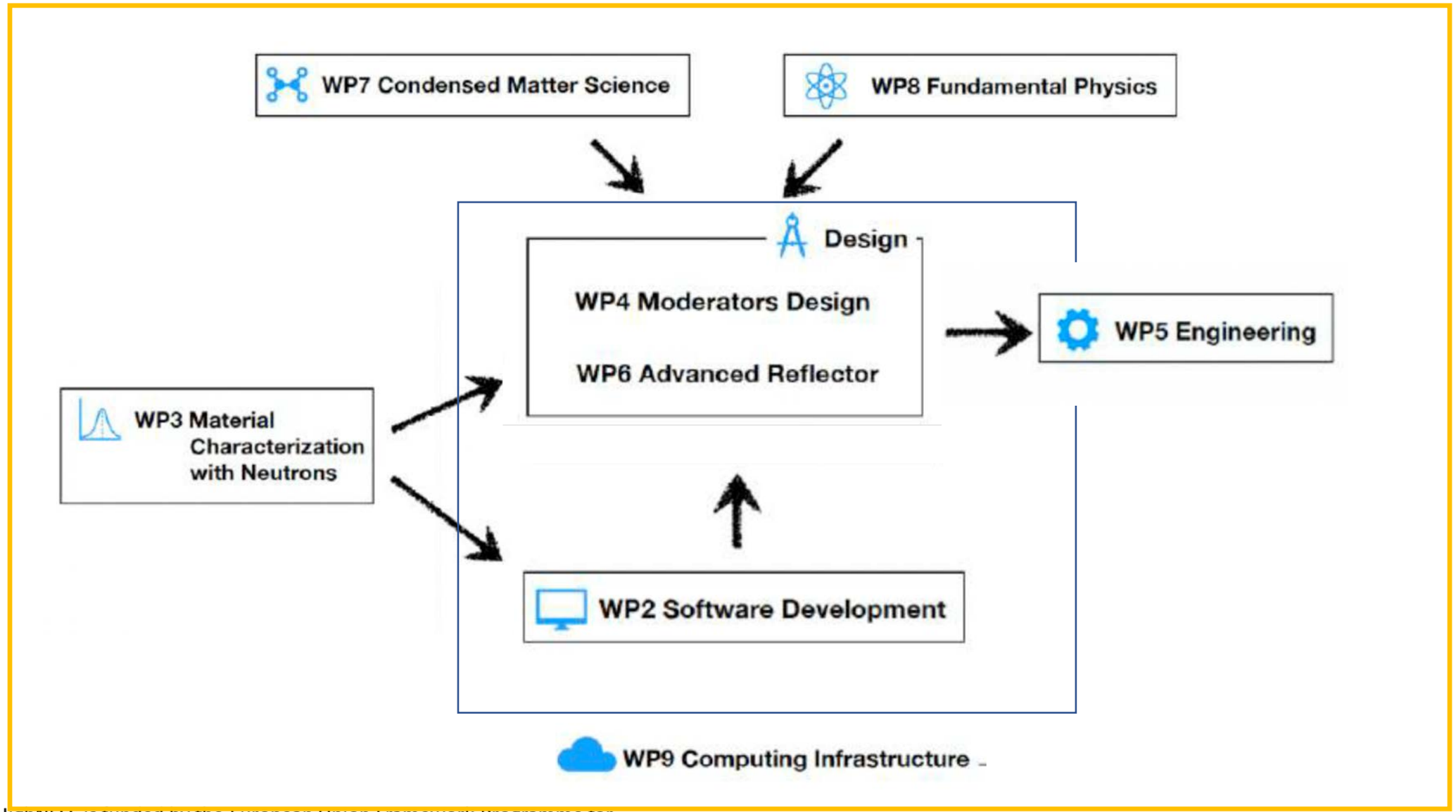

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The HighNESS Consortium

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,
42 people presently involved

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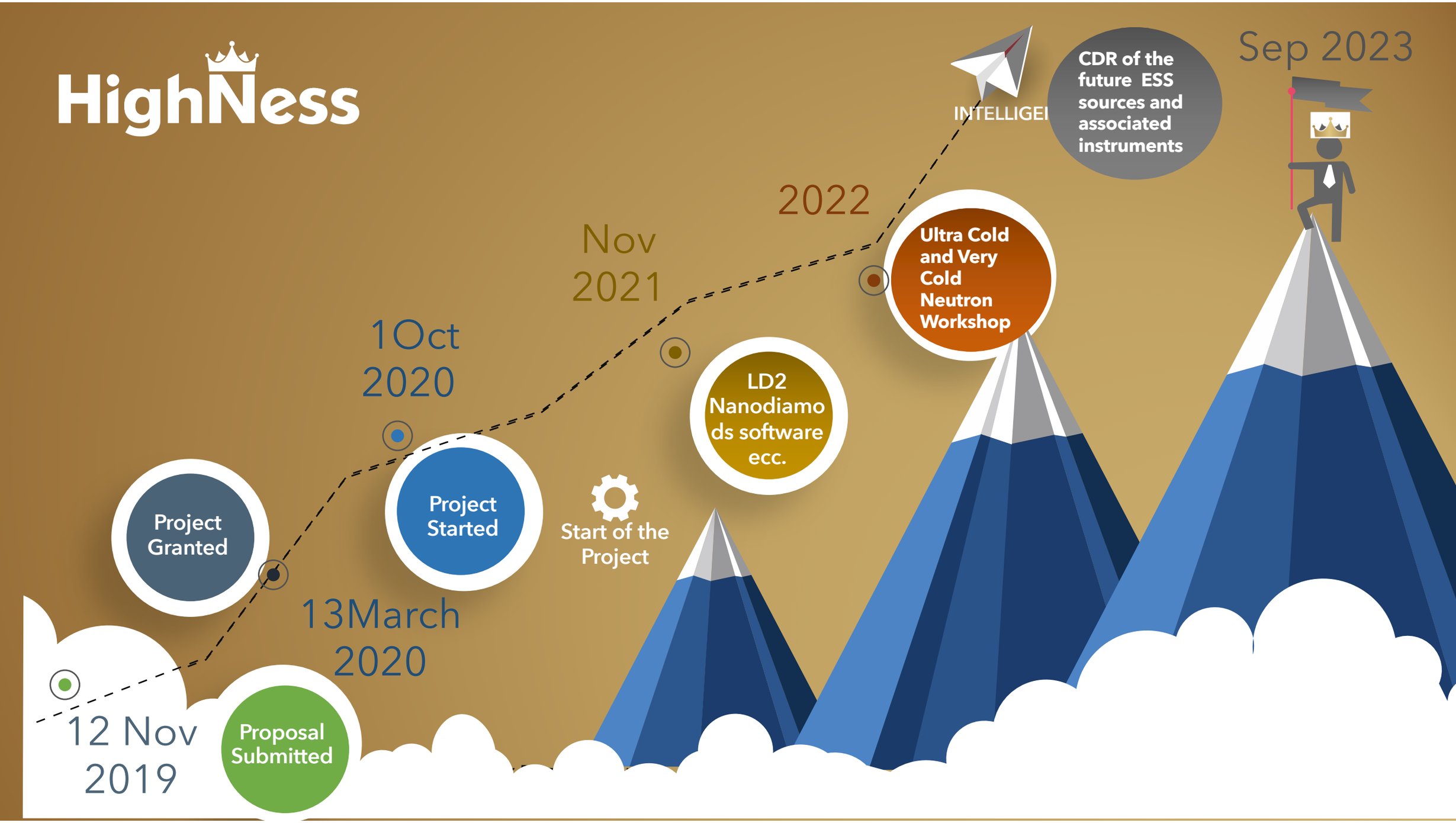
HighNess
12 Nov 2019
Proposal Submitted
13March 2020
Project Granted
1Oct 2020
Project Started
Start of the Project
Nov 2021
LD2 Nanodiamonds software ecc.
2022
Ultra Cold and Very Cold Neutron Workshop
INTELLIGEI
CDR of the future ESS sources and associated instruments
Sep 2023

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

High Intensity

- We look at applications where total delivery of neutrons is of higher value than the high brightness
- Higher intensity means larger emission surface and bigger moderator

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Shift the spectrum of delivered neutrons to longer wavelengths

- The upper moderator is a bispectral thermal-cold source -> thermal neutrons are not considered in HighNESS.
- In HighNESS, besides cold neutrons, we are looking at Very Cold and Ultra Cold neutrons
- The main cold source in HighNESS is intended to serve instruments, and secondary VCN and UCN sources
- **The number and configuration of sources to deliver VCN and UCN is the focus of today's presentation**

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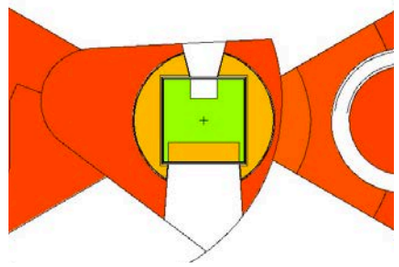
HighNESS Moderators design

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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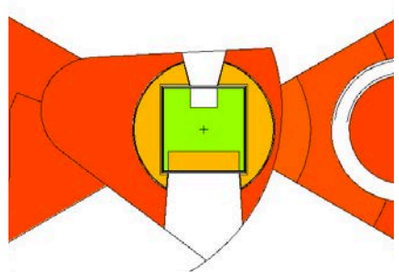
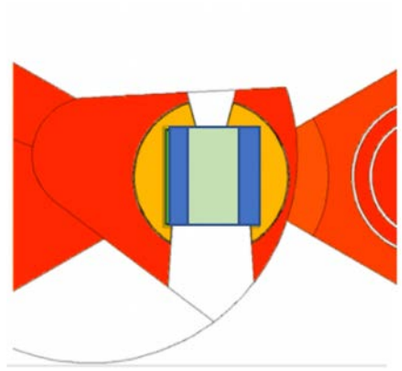


VERY COLD - VCN → **VCN extraction from main source using advanced reflectors**

Dedicated VCN converter



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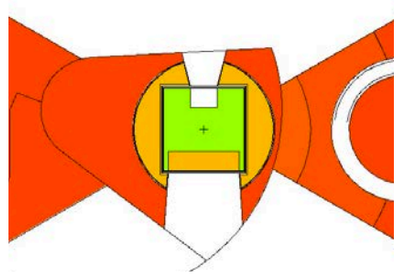

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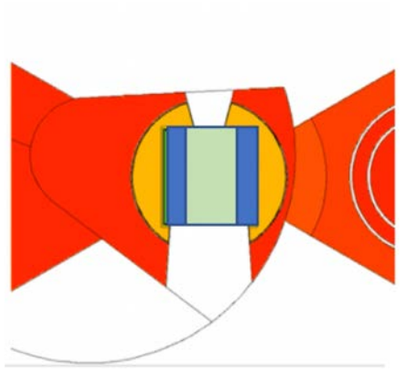
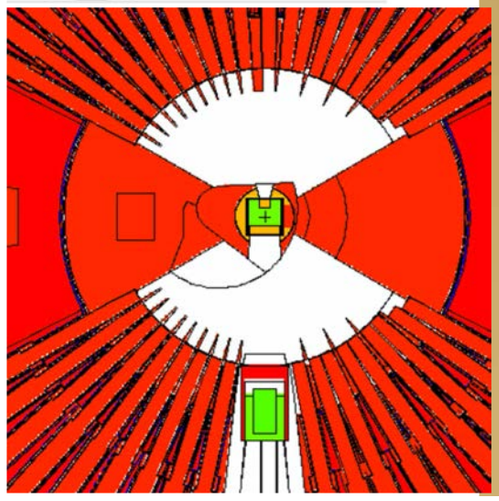


ULTRA COLD - UCN → In beam UCN

In pile UCN



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Design of the Cold Source

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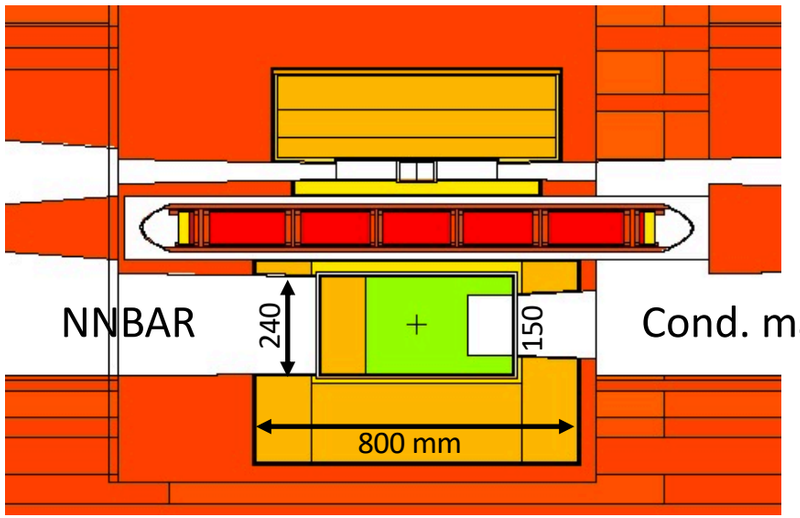
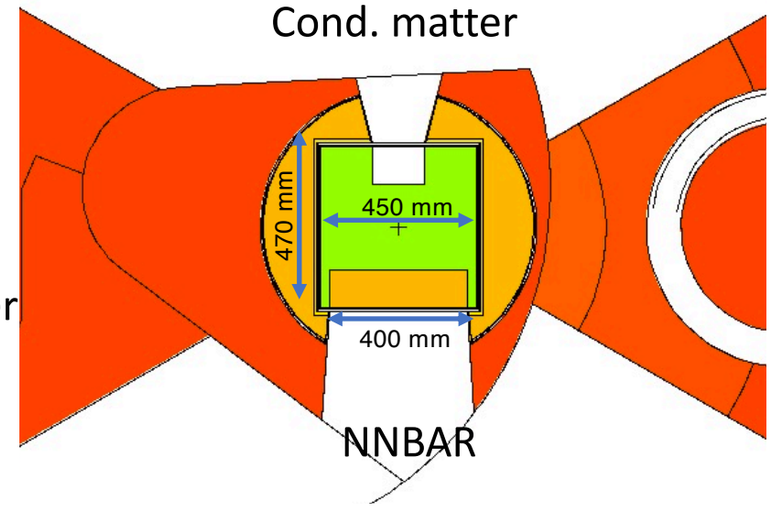
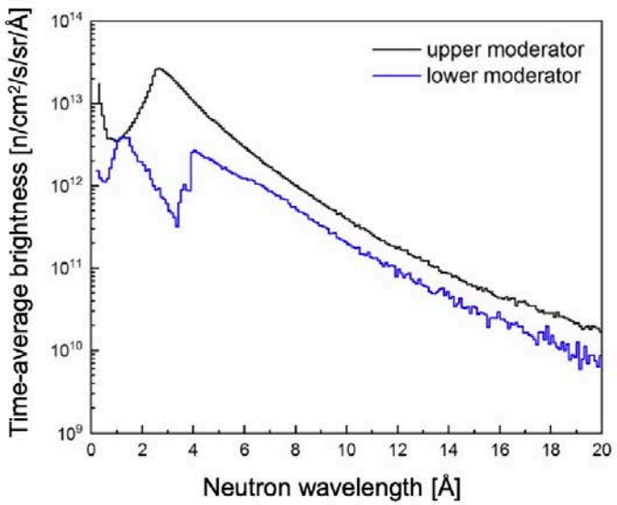


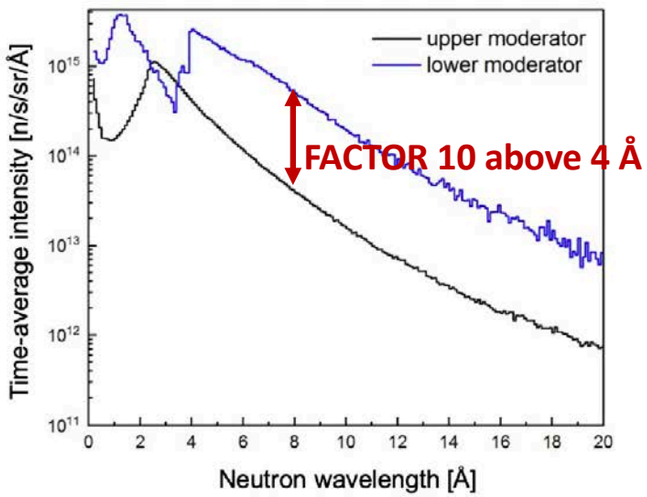


The high-intensity liquid deuterium moderator has been designed with two openings, for NNBAR and neutron scattering instruments

Brightness



Intensity



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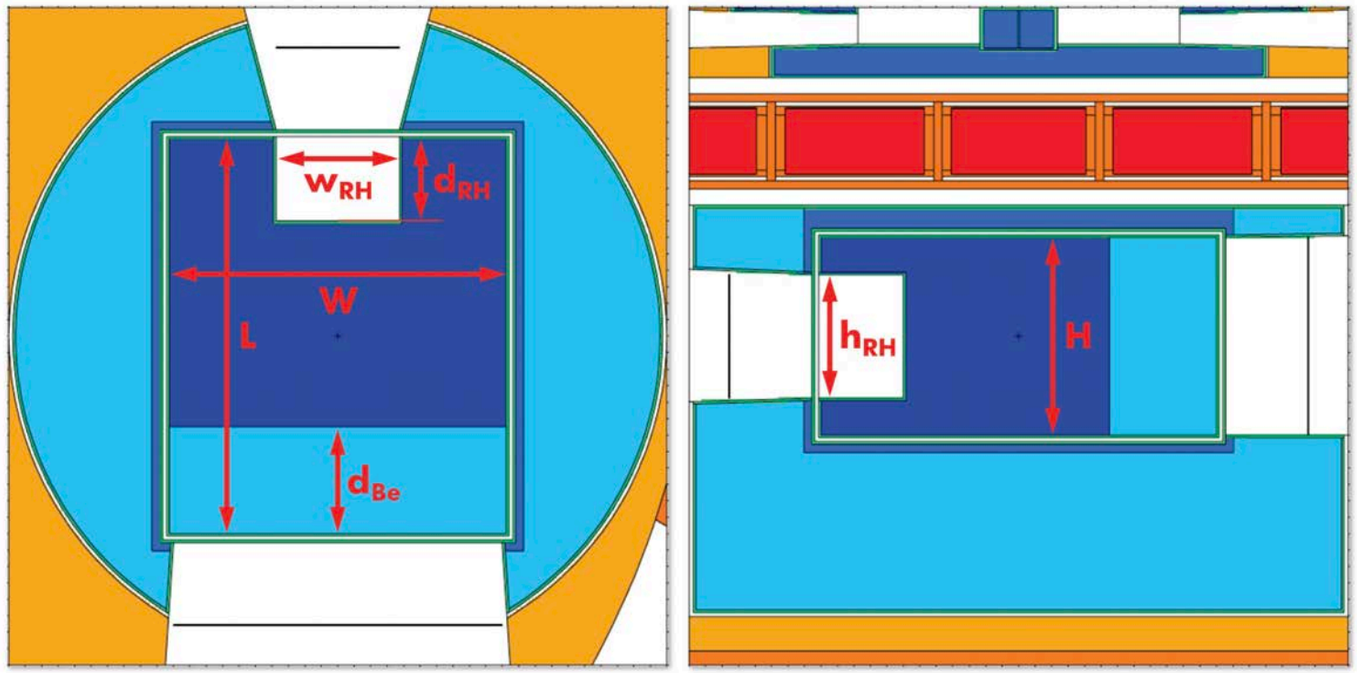
”Final”neutronic design LD2 moderator currently under engineering design (September 2022)



- 410 mm width in the beam direction (W),
- 480 mm width in the direction transverse to the beam direction (L),
- 240 mm in the vertical direction (H).

Optimization with Dakota

Effect of Be filter on NNBAR:s 20%

Effect of RH on n.s. side: 30%

Heat loads at 5 MW

- LD2 (+ 4% Al): 29.8 kW,
- Al walls: 7.4 kW,
- Be: 19.6 kW,
- Total: 56.7 kW.

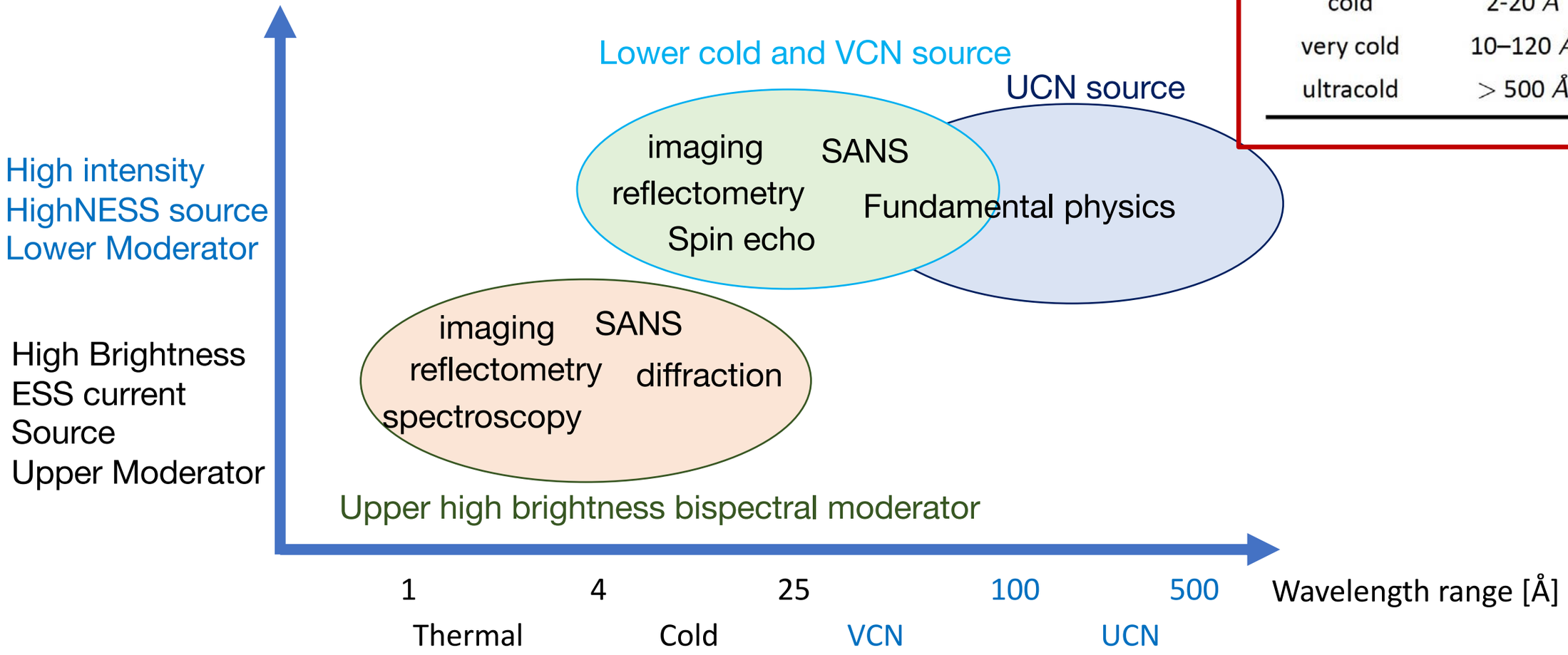
HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

Why UCN and VCN?

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

A broader wavelength range and source intensity for more applications

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



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

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

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

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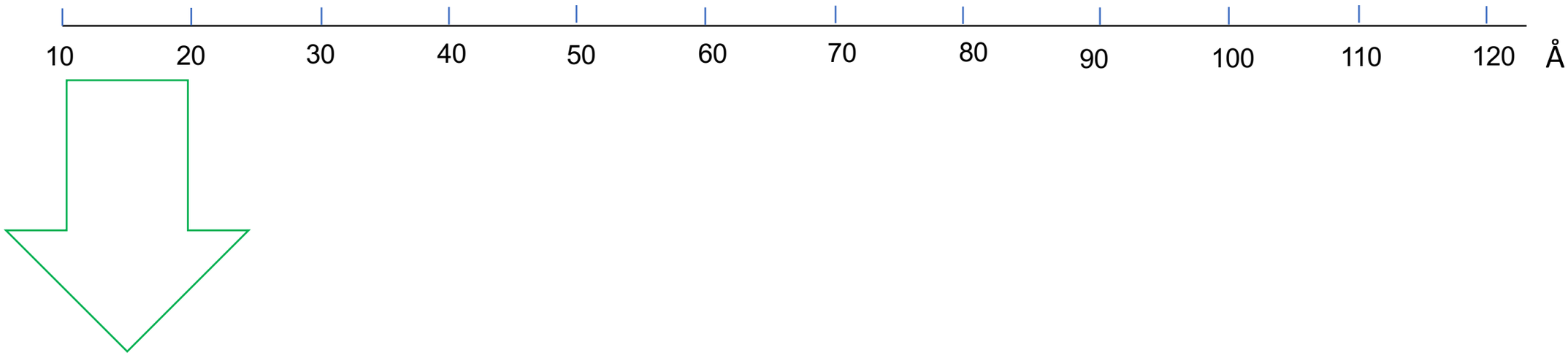
VCN: a broad λ range with different applications



- Increase the longer wavelength part **(10-20 Å)** of the cold spectrum by using colder moderators such as solid deuterium or deuterated clathrates hydrates and/or advanced reflectors.
- Colder spectrum + larger emission surface, very interesting for neutron scattering applications for longer wavelengths: spin-echo, SANS, reflectometry, imaging see ESS UCN/VCN workshop presentations by Falus, Ott, Strobl, Mezei **https://indico.esss.lu.se/event/2810/**

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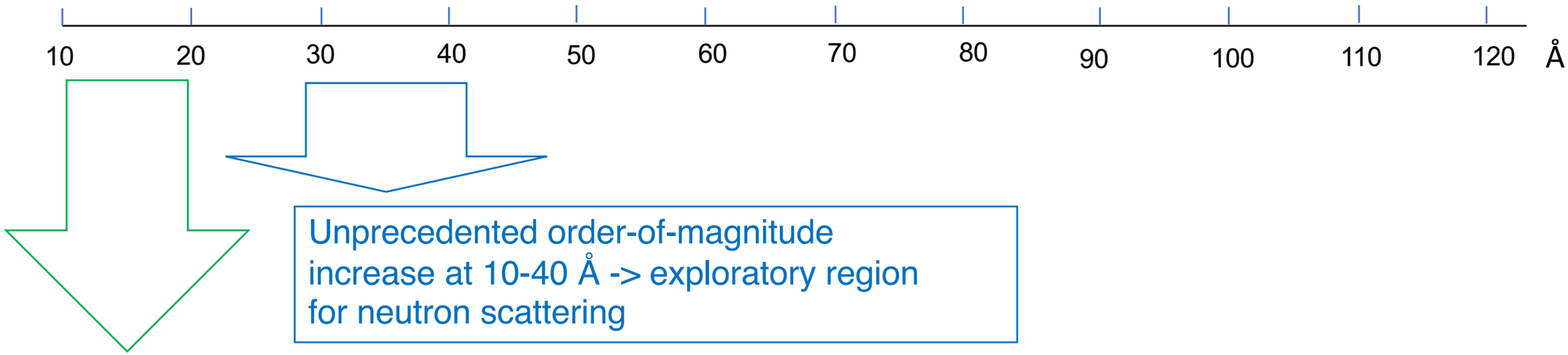

Unprecedented order-of-magnitude increase at 10-40 Å -> exploratory region for neutron scattering

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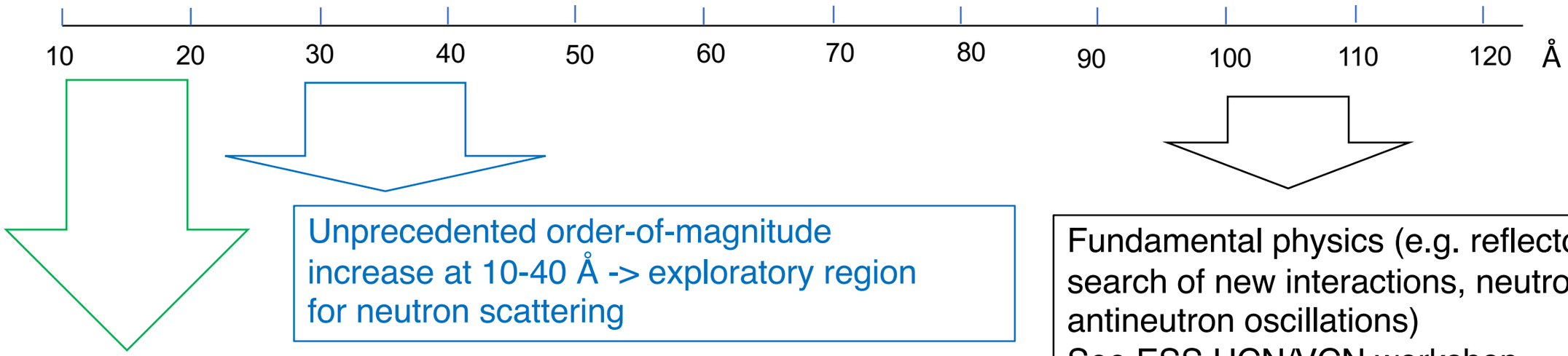

Unprecedented order-of-magnitude increase at 10-40 Å -> exploratory region for neutron scattering

Fundamental physics (e.g. reflectometry, search of new interactions, neutron-antineutron oscillations)
See ESS UCN/VCN workshop presentations by Shimizu, Nesvizhensky
https://indico.esss.lu.se/event/2810/)

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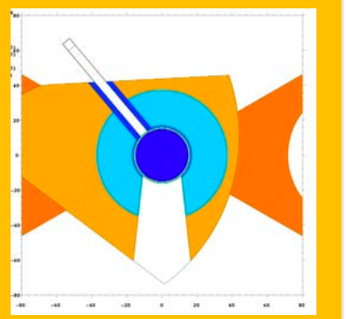
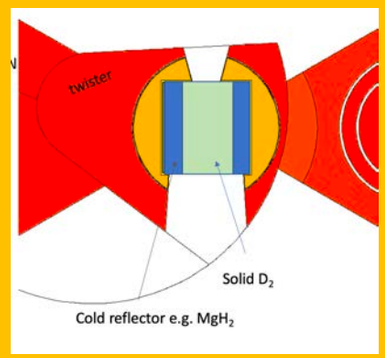
Three possibilities for a VCN source at the ESS

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

Use of advanced reflectors to increase transport of VCNs from the main cold source



Use of dedicated VCN converter



In the original HighNESS proposal

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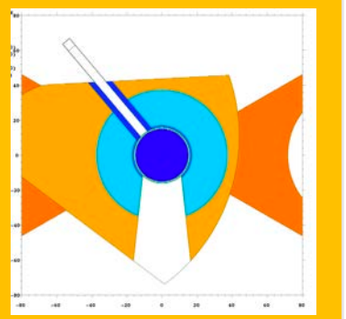

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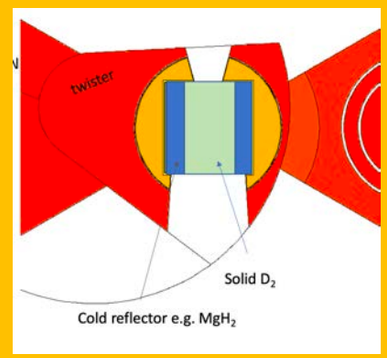
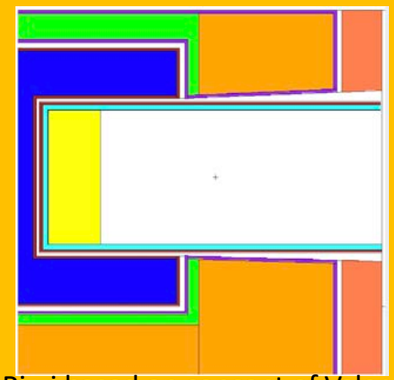


Combined use of LD2, SD2 and nanodiamonds



MCNP model of N. Rizzi based on concept of Valery

In the original HighNESS proposal

Recent concept by V. Neshvizevsky et al

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HighNess

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

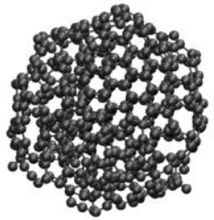
There are 4 classes of novel reflector materials under study in HighNESS, with possible application to CN and VCN sources

Nanodiamonds

CN and VCN reflector

Thermal scattering library determination

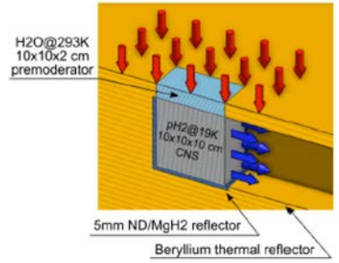
within HighNESS



MgH2

CN reflector

Thermal scattering library available

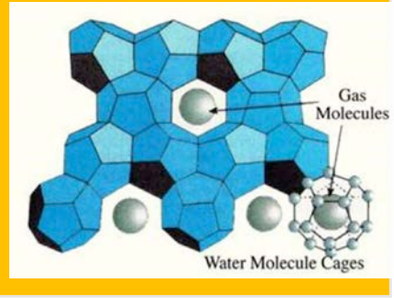


Clathrates hydrates

Possible VCN converter or VCN reflector

Cross section measurements and thermal scattering

library determination within HighNESS



GIC

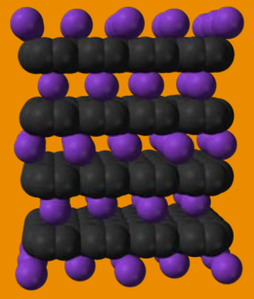
Bragg edge at longer wavelengths > 10 Å

Might be good for VCN

Cross section measurements and thermal scattering

library determination

within HighNESS



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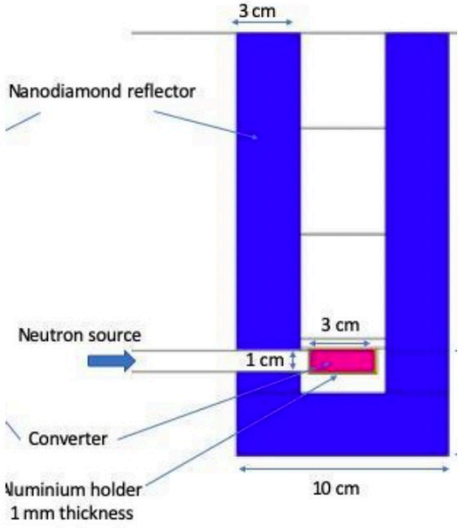
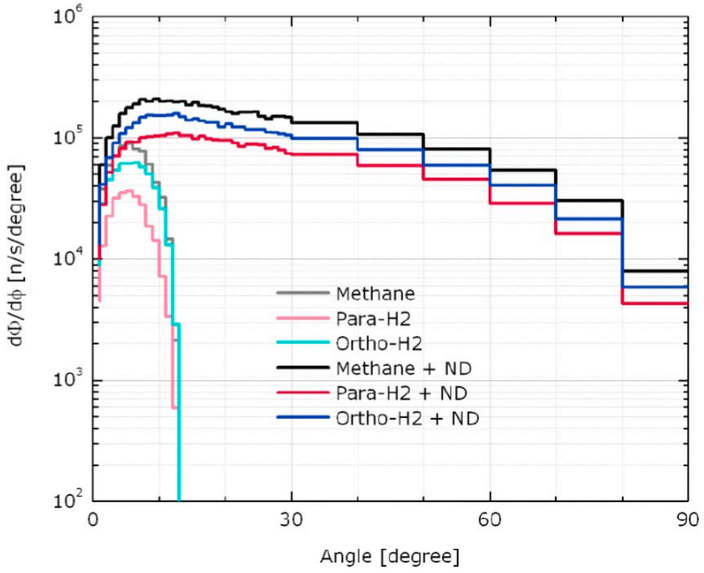
First VCN option: use of nanodiamonds reflectors

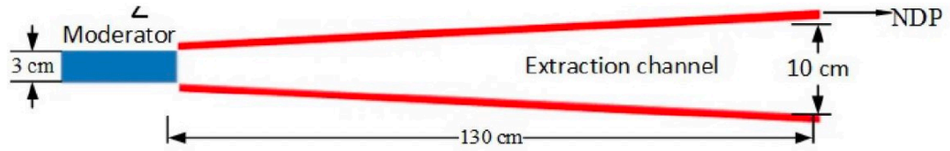
cold	2-20 Å
very cold	10–120 Å
ultracold	> 500 Å

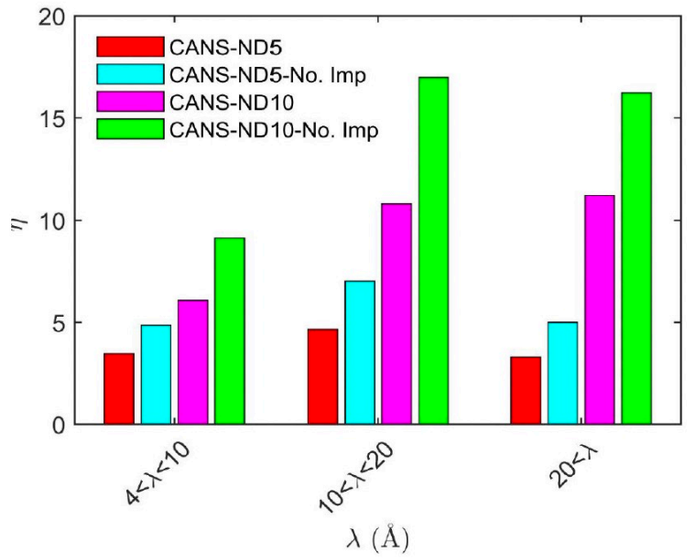
Existing calculations on ND layers around CN or VCN source





Courtesy of Zsofia Kokai, CREMLIN+





M. Jamalipour et al, Improved beam extraction at compact neutron sources using diamonds nanoparticles and supermirrors, Nuclear Inst. and Methods in Physics Research, A 1033 (2022) 166719

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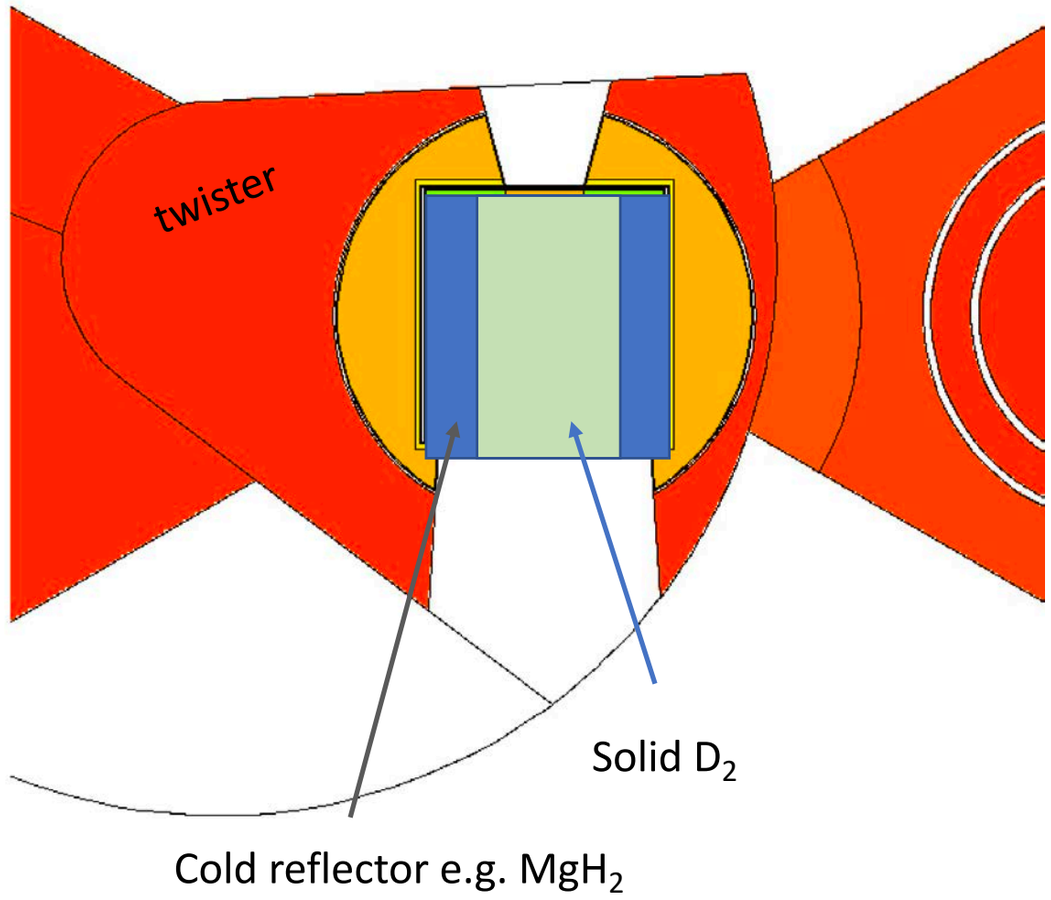
Second VCN option: dedicated source

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

Two materials considered for VCN converter

- solid D2 at 5 K (new library available from R. Granada)
- Deuterated clathrate hydrates at around 2 K (currently under study)



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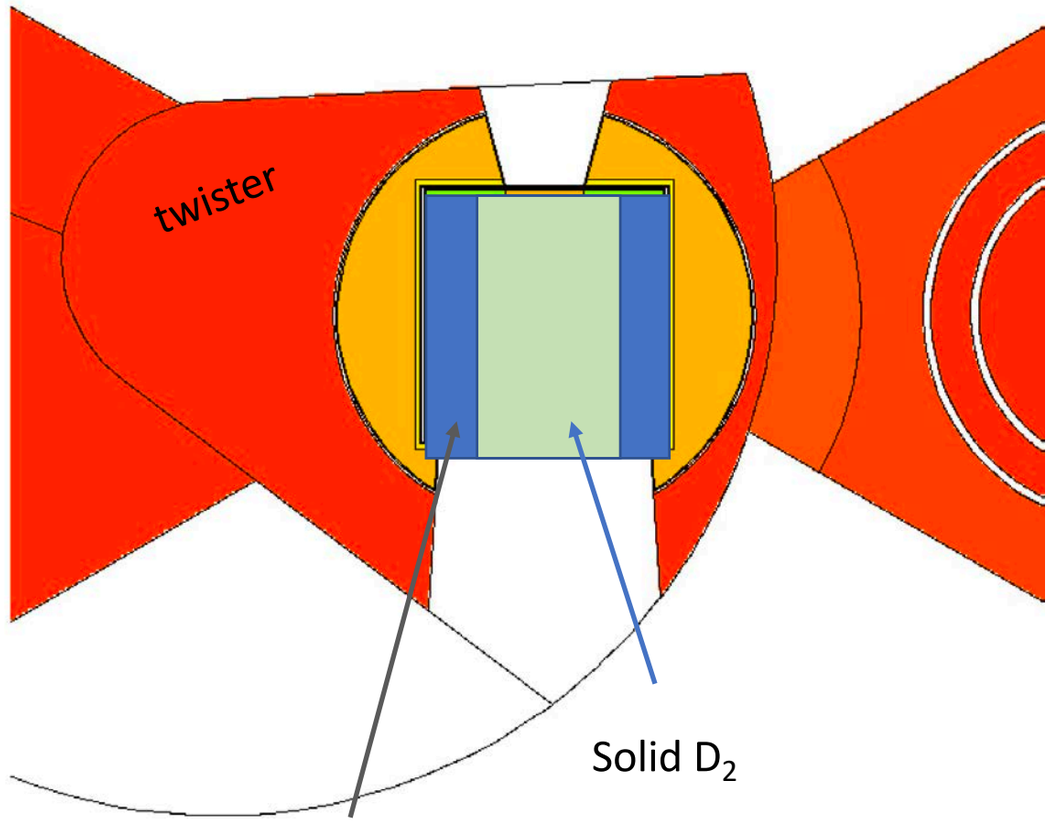

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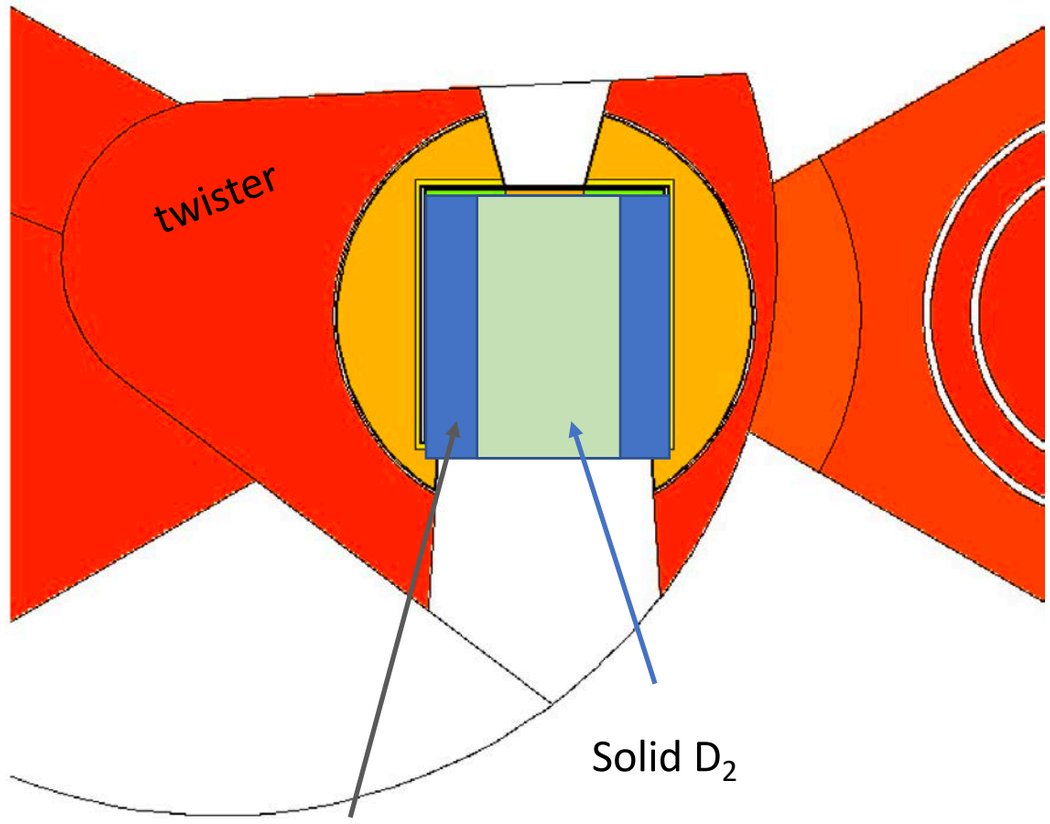
  - Might use also reflectors such as nanodiamonds or MgH2 e.g. to increase performance
  - Various tests are in progress
  - Best location for flux is below the spallation target but cooling is challenging



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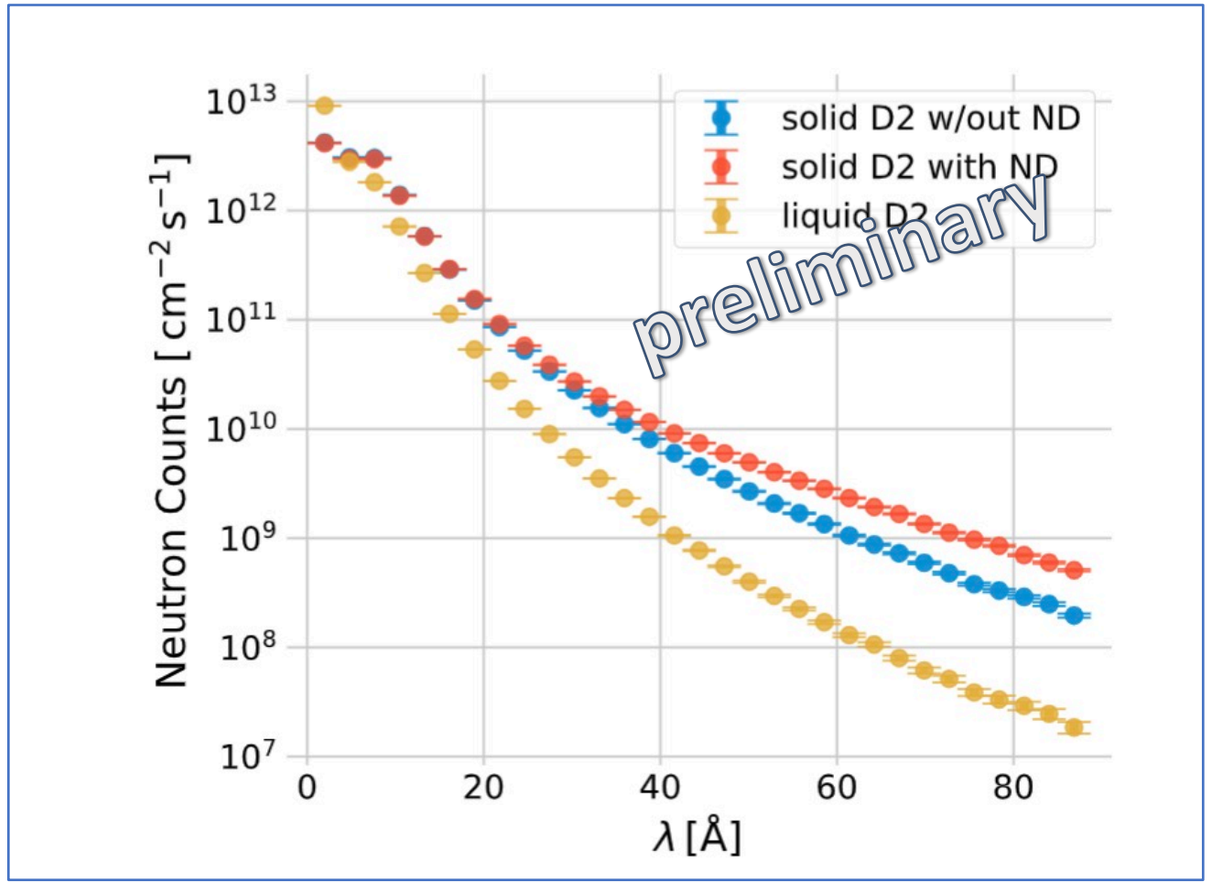
Second VCN option: dedicated source: **results**

- Replacement of the LD_2 moderator with SD_2 could be a future upgrade
- Additional gain by using advanced reflectors: nanodiamonds (for VCN reflector) and MgH_2 (for cold reflection)



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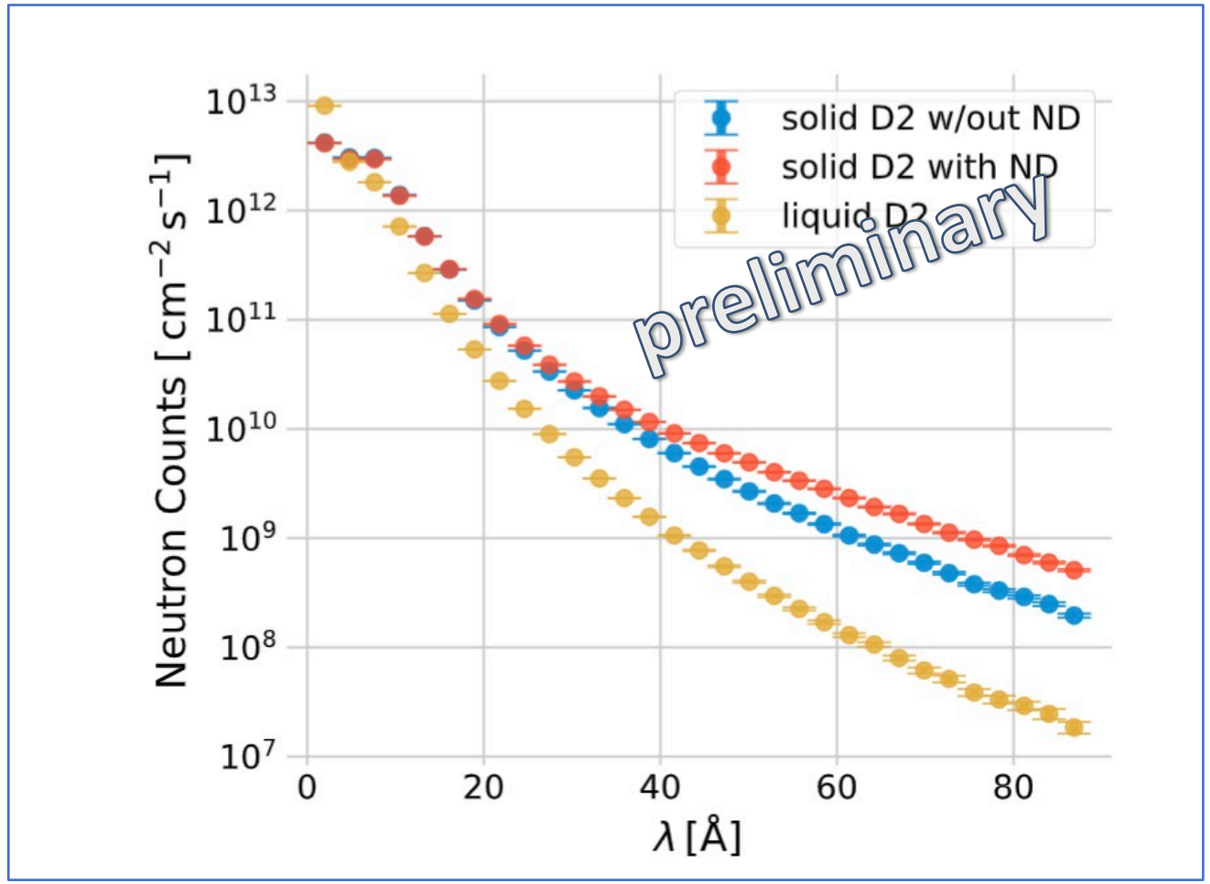
Second VCN option: dedicated source: **results**

- Replacement of the LD_2 moderator with SD_2 could be a future upgrade
- Additional gain by using advanced reflectors: nanodiamonds (for VCN reflector) and MgH_2 (for cold reflection)
- Significant gains above 10 Å, order of magnitude increase above 40 Å
- Unprecedented VCN flux maintaining a high cold flux.
- Using Al or Be foams inside the SD2 vessel could allow for cooling even at ESS power level.
- Manuscript in preparation for publication



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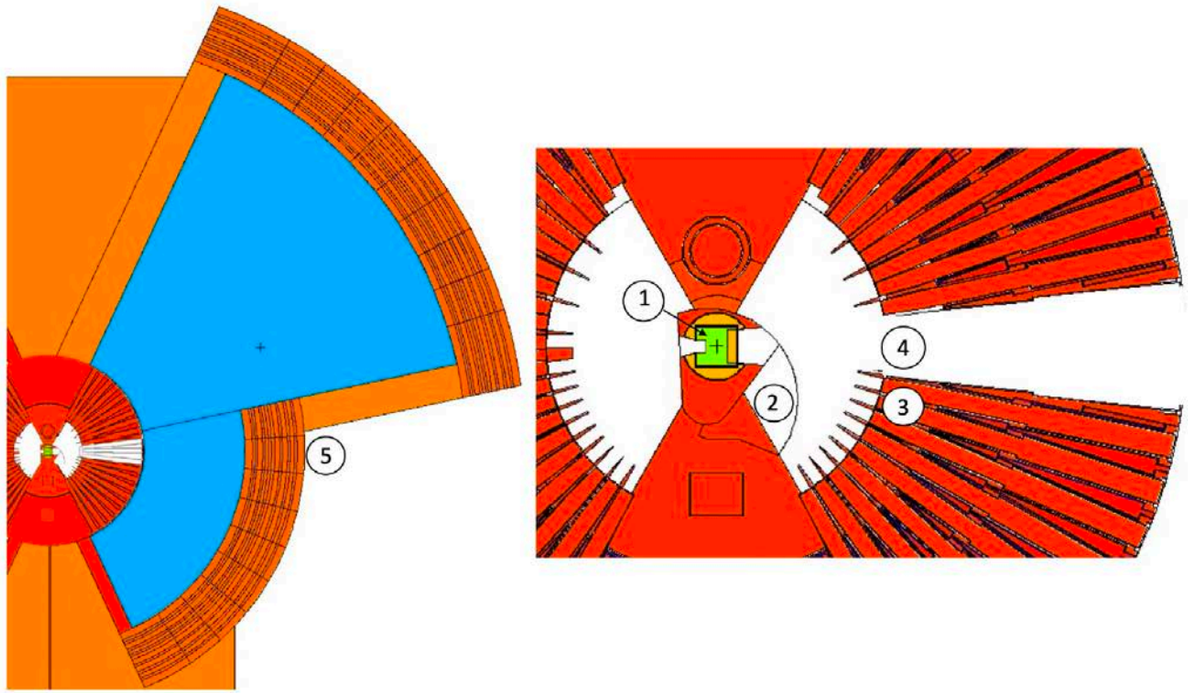
UCN sources: possible locations identified at the workshop are currently under study



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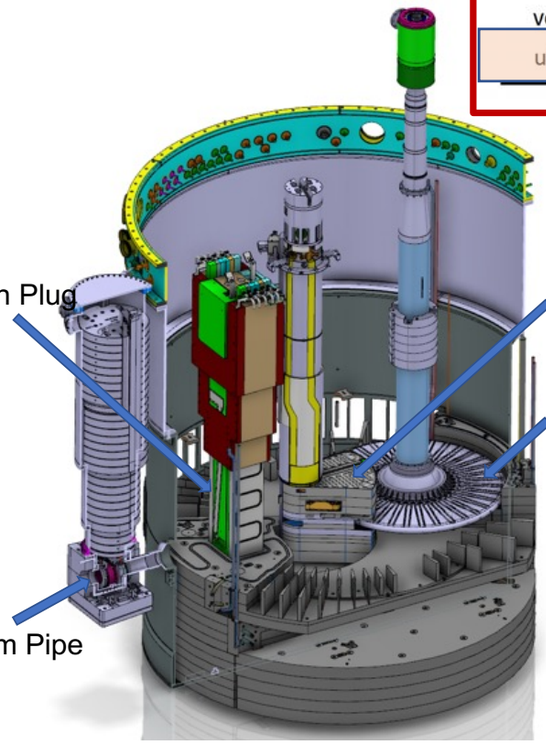

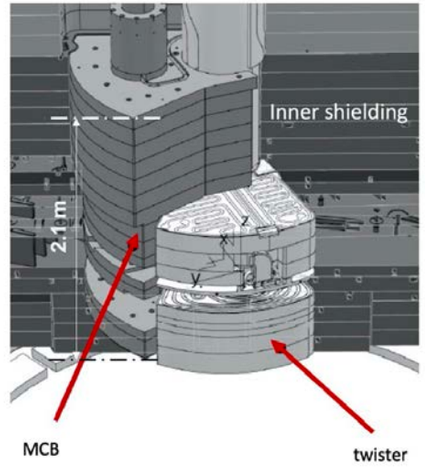

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Moderator cooling block location number 2

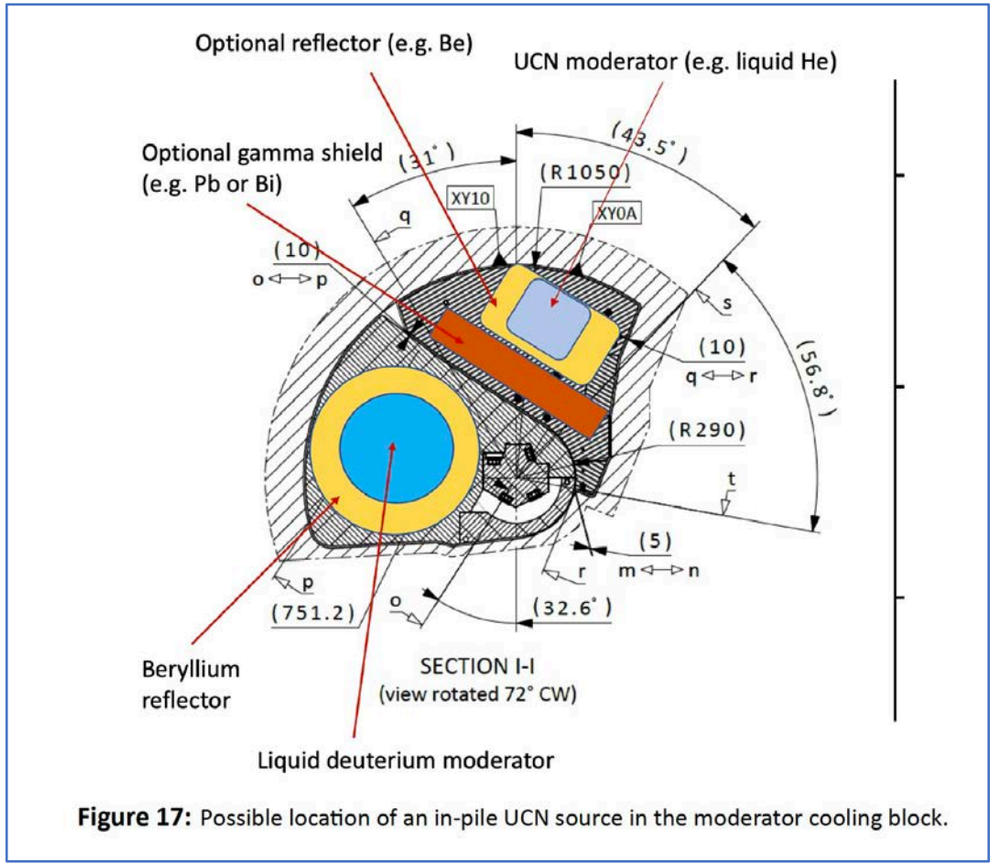
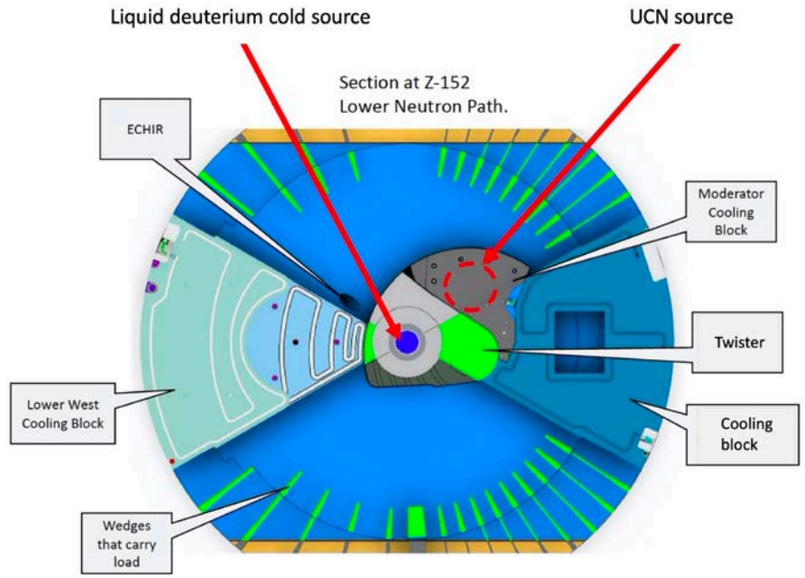
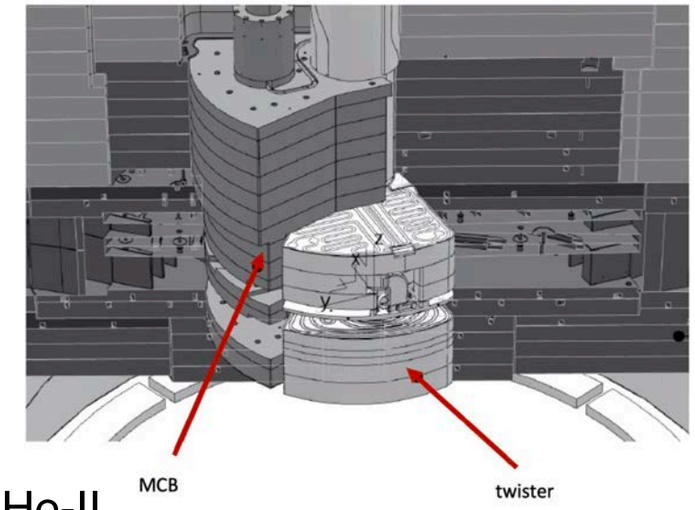


Figure 17: Possible location of an in-pile UCN source in the moderator cooling block.





MCNP model under development -> could be challenging for cooling of He-II

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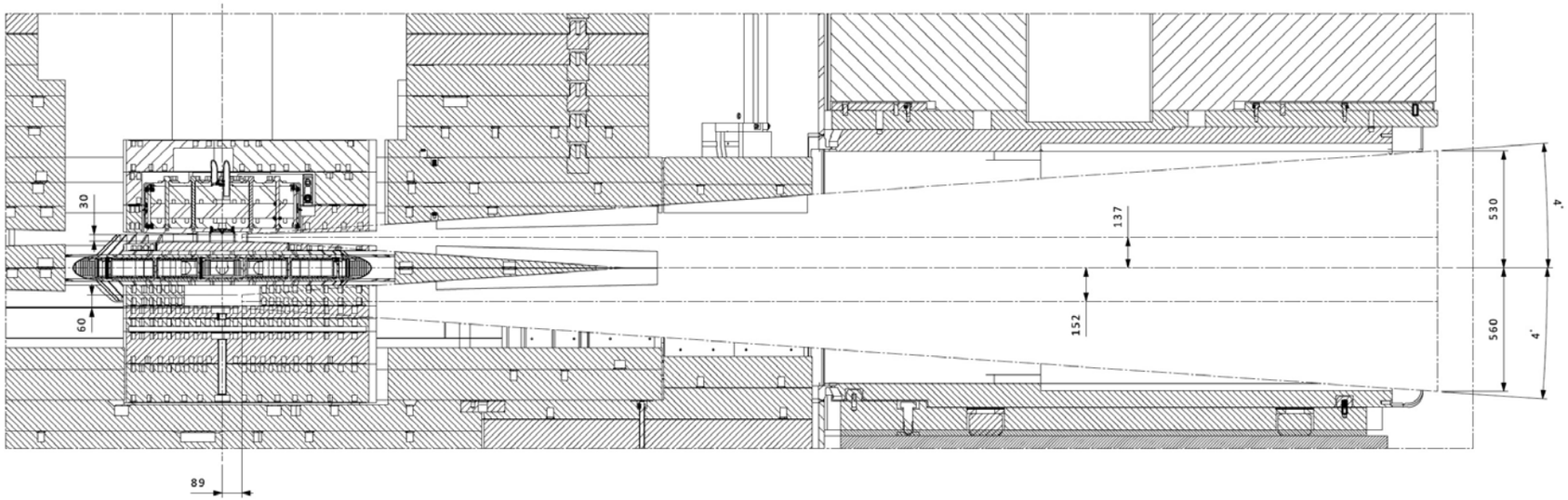
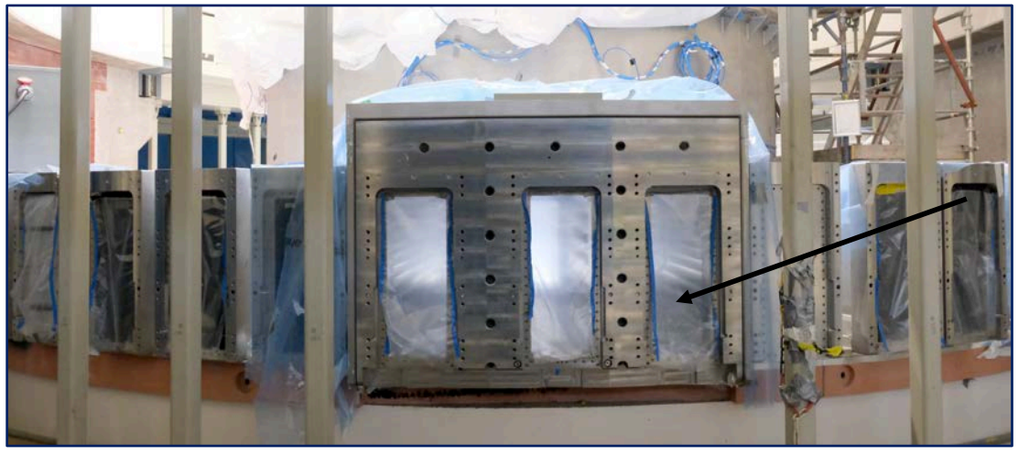
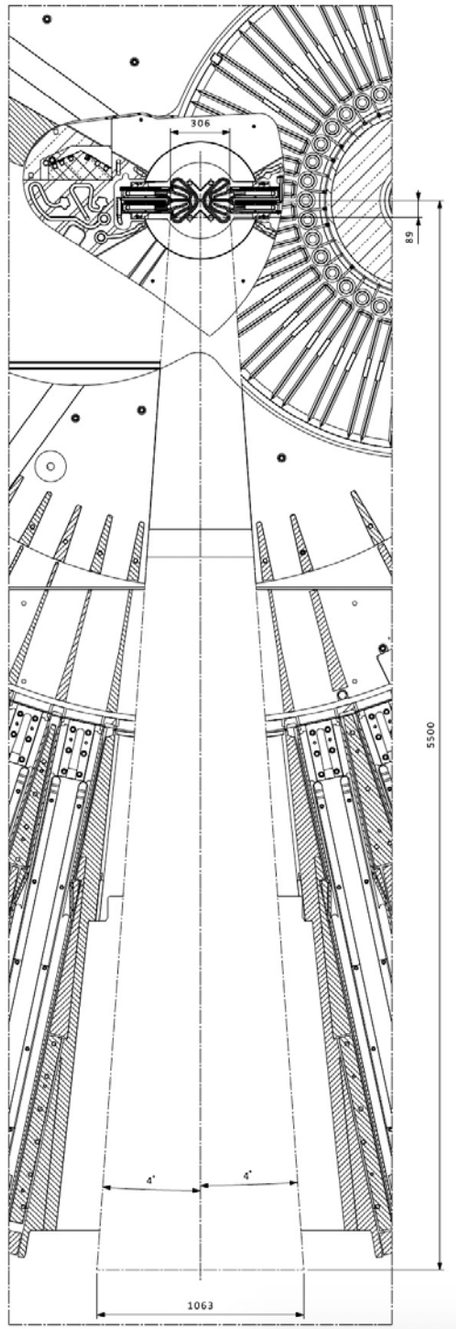
The Large Beam Port for NNBAR could accommodate a UCN source (location 4,5)





Standard ESS Beam port



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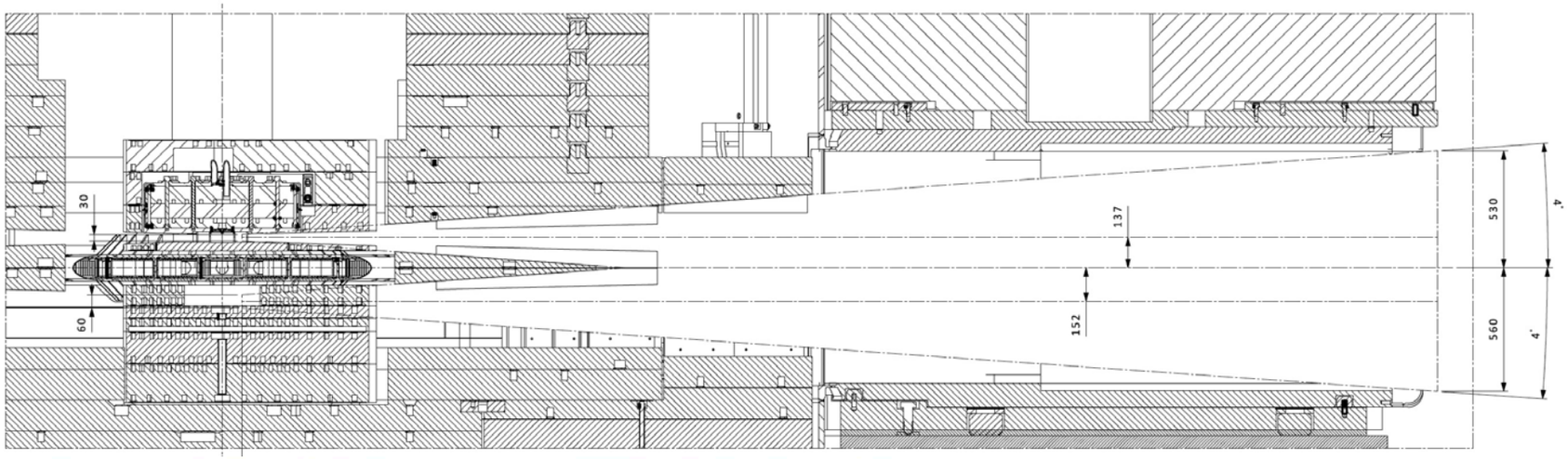
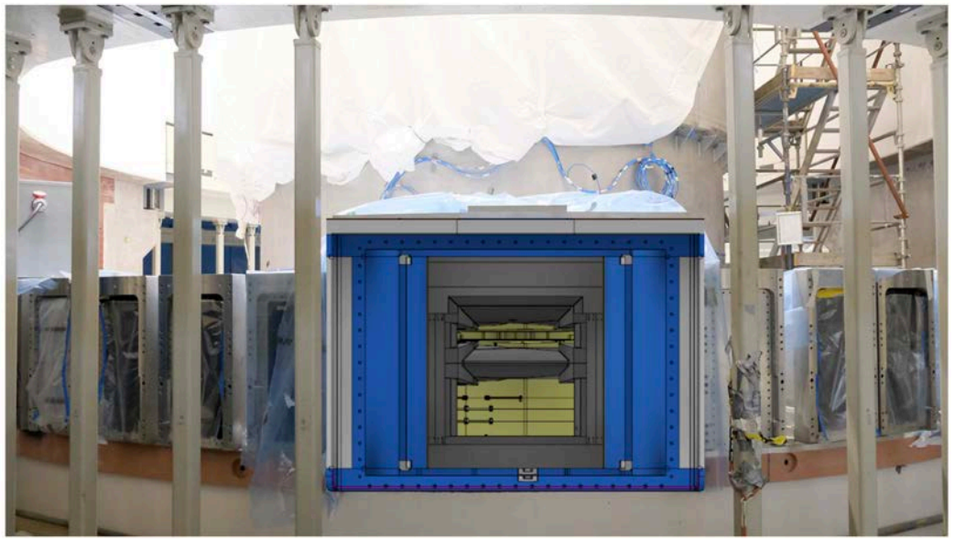
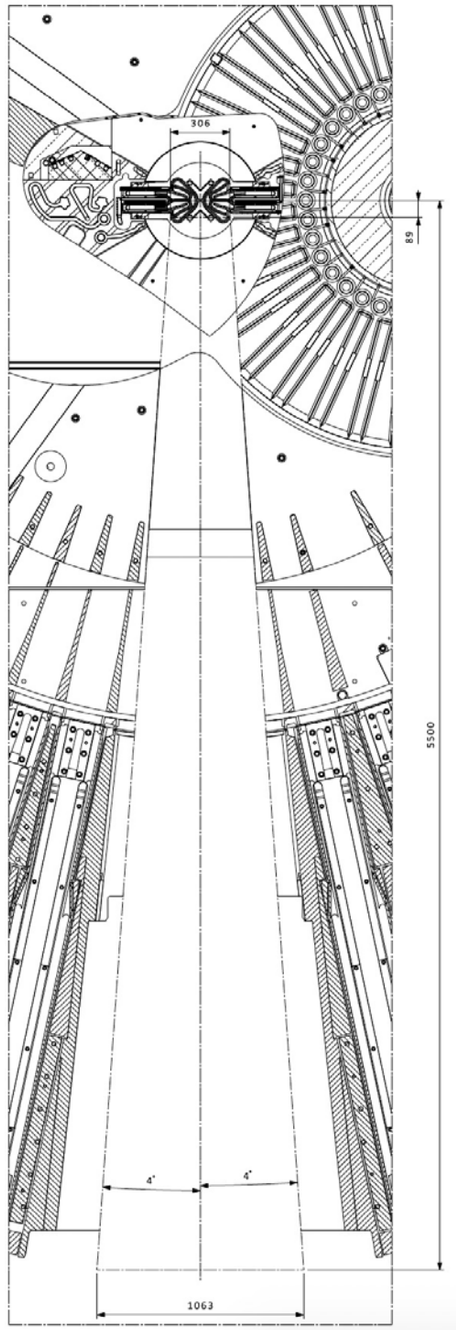




Large Beam Port has the size of 1mx1m



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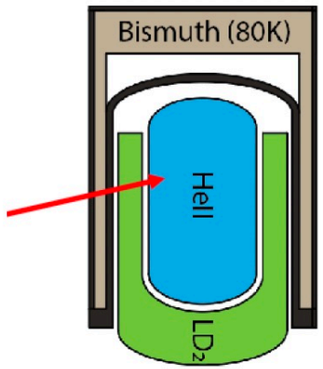
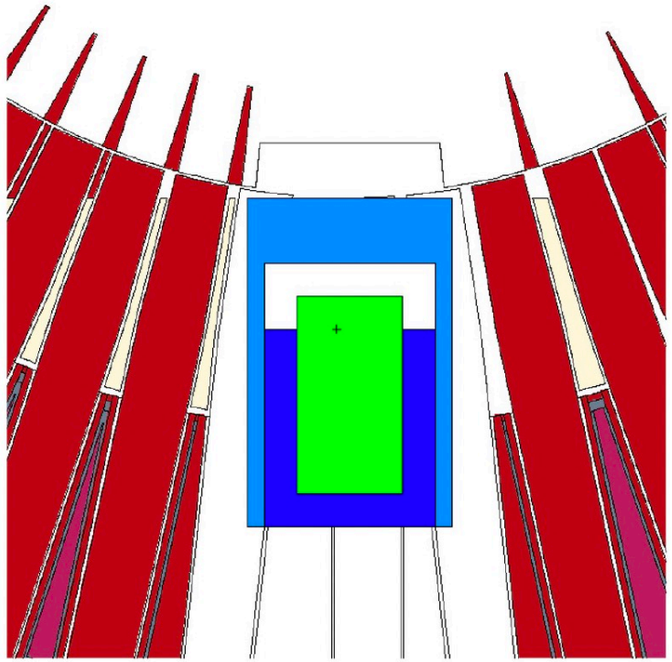
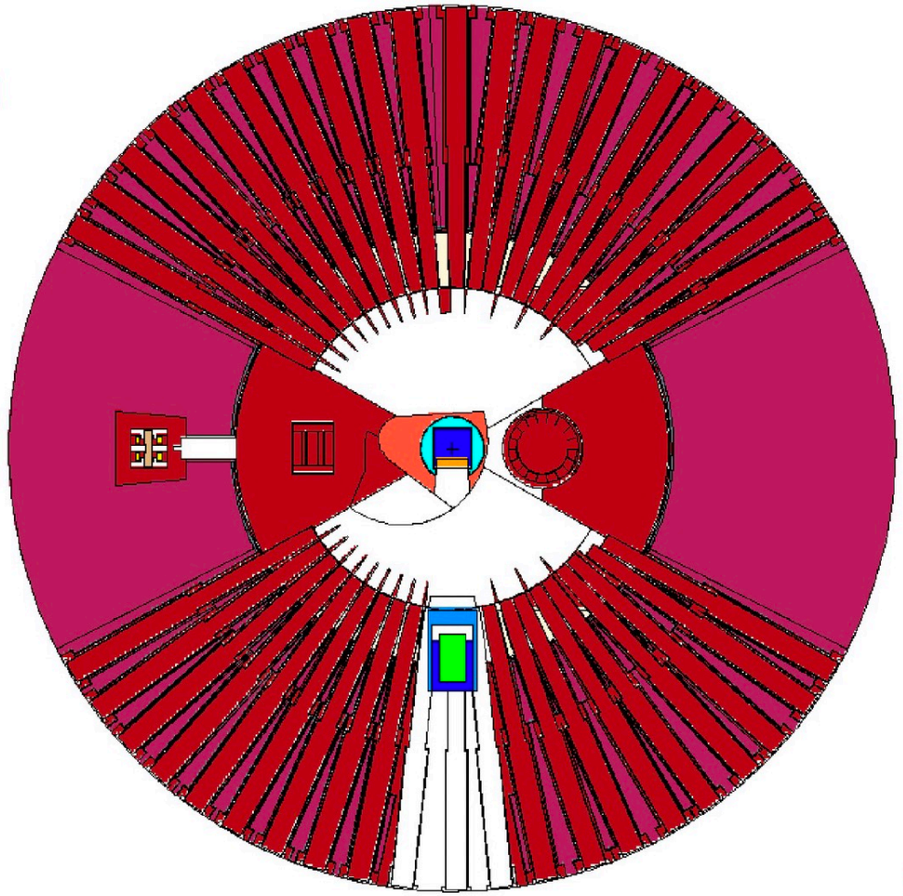
UCN source in large beamport (location 4)

concept by A. Serebrov

He4 Box: 60 cm x 30 cm x 32 cm







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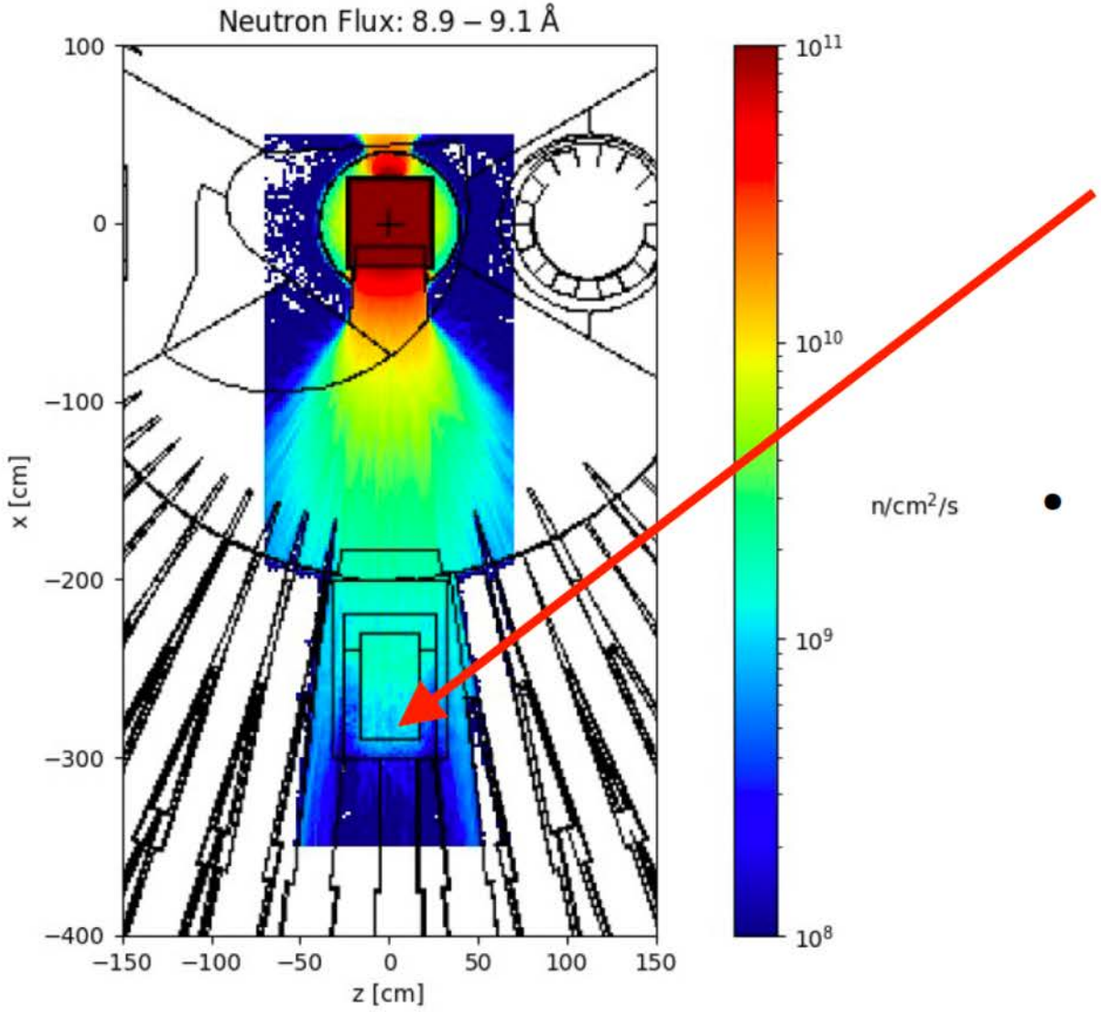
UCN source in large beamport (location 4): **results**



Effect of LD2 reflector on flux inside source volume

- TBD: study variants of reflector material
  - ➔ MgH
  - ➔ Intercalated Graphite

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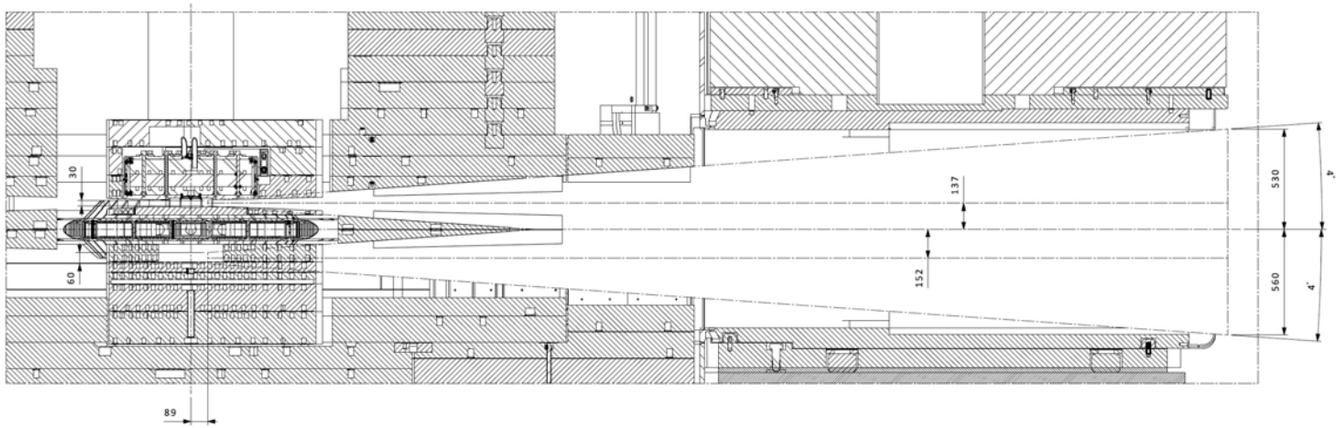
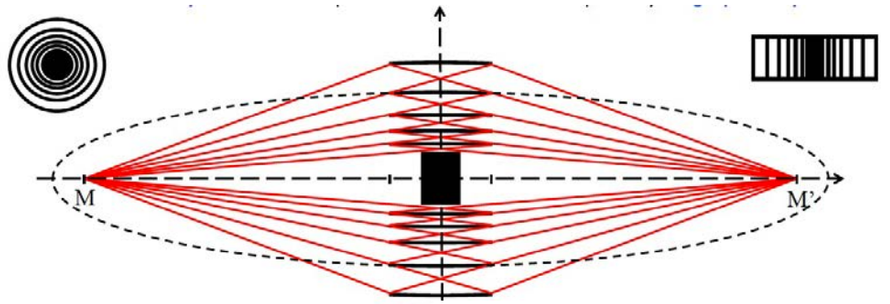
UCN source in large beamport (location 5)

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

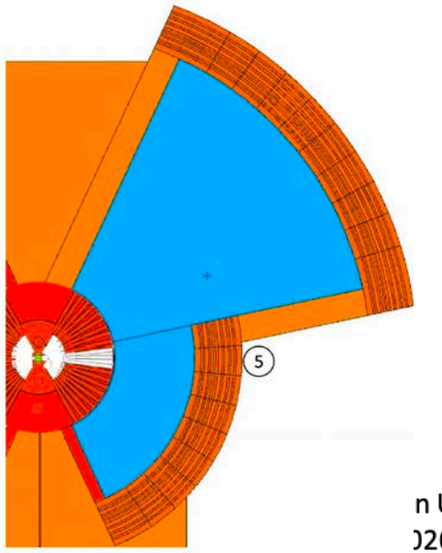
The large beamport for NNBAR could be used for a world-class UCN source



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 x 10^7 n/s

n Union Framework Programme for
020, under grant agreement 951782

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

	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 production rate density**	**$2.5\ 10^7$**	**$6.3\ 10^4$**

First results from position 5 (in beam with use of nested mirror optics) are very promising.
Potential higher production in other locations, currently under investigation.

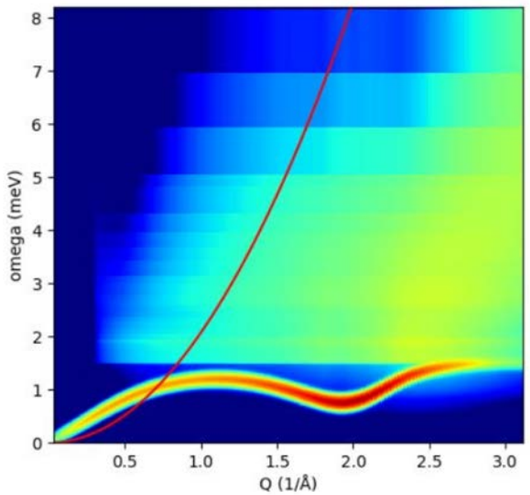
Source: O. Zimmer, UCN/VCN workshop 2022

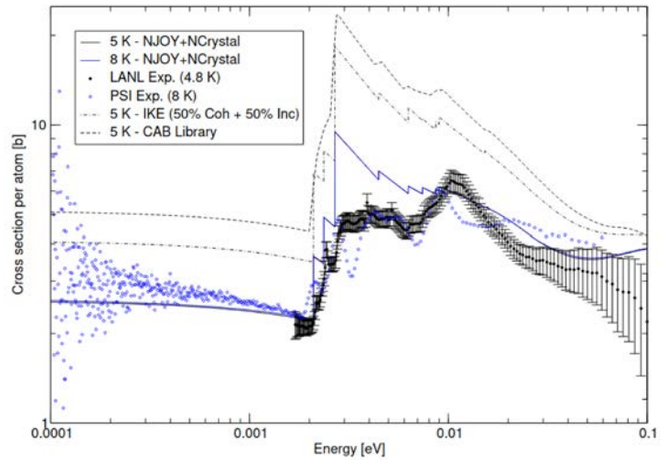
[a]arXiv:1810.08722v3 (October 2018)
[b]arXiv:1905.09459 (October 2019)

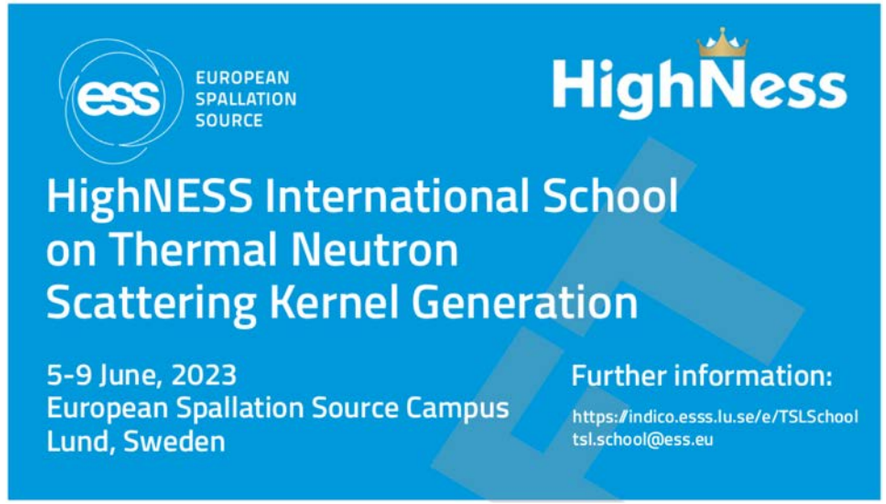
HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

UCN and VCN 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 to be held at ESS in 2023
- Contact: Jose Ignacio Marquez Damian, Douglas Di Julio and Thomas Kittelmann







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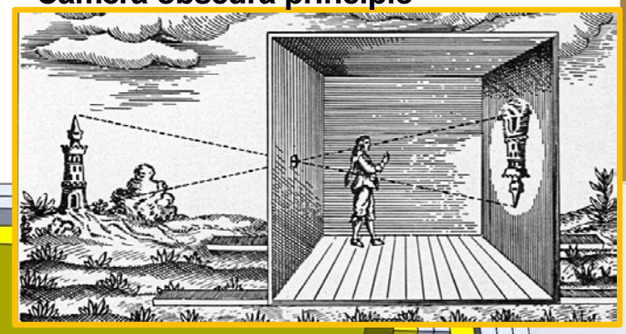
Measurements at the moderator test facility at the Budapest Neutron Center

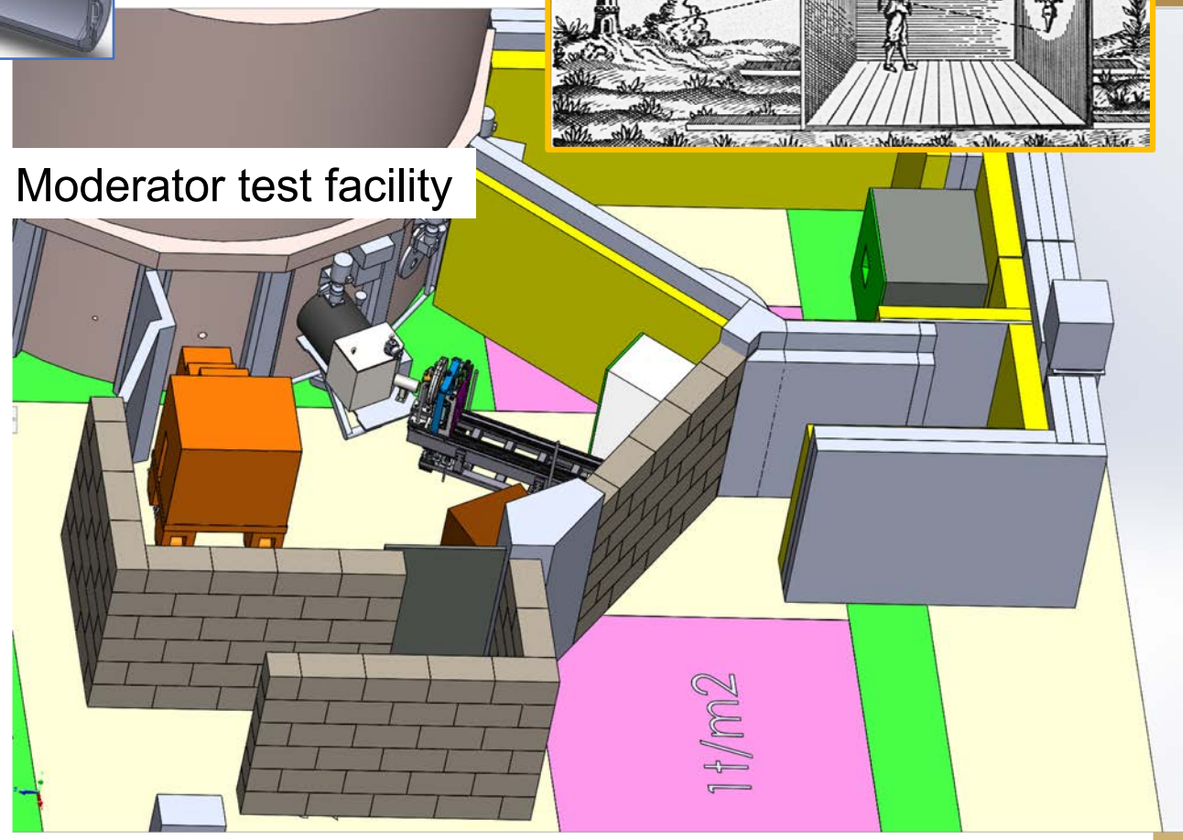
Centre for Energy Research

- Test facility under construction with dedicated beamline and camera obscura system
- Channel 4 selected with fast neutron spectrum

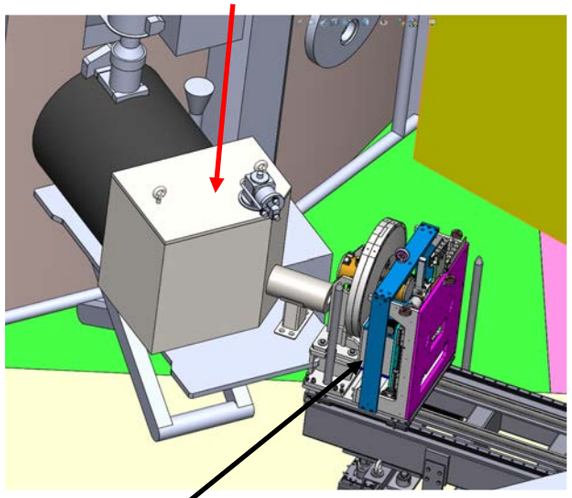
Camera obscura principle



Moderator test facility



Target box with Be disk, Pb reflector and cold moderator



Camera obscura pinhole with chopper

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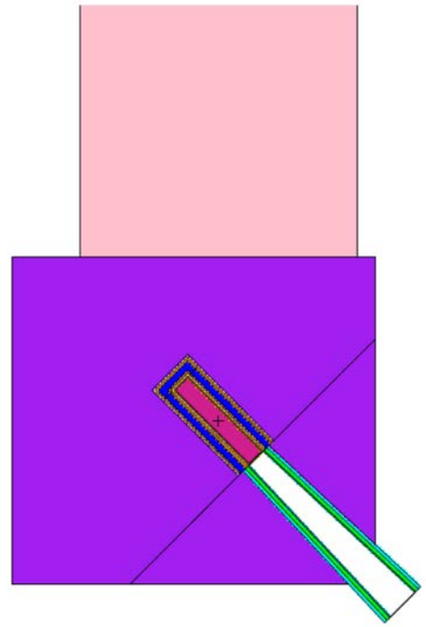
HighNESS-BNC collaboration on moderator tests

- BNC currently building Test Beam line at the Budapest reactor, first measurement will be on a tube moderator
- HighNESS is supporting the design of first experiment with neutronic calculations and support on cryogenic system and ortho-parahydrogen conversion
- HighNESS prototype experiment with advanced reflectors in 2023



Prelminary MCNP model of Budapest moderator test facility by N. Rizzi

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

Conclusions

- The HighNESS project started in October 2020
- The scope is the development of the ESS upgrade

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→ 10 times higher cold neutron intensity than ESS upper moderator

Engineering design in progress

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Conclusions

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Engineering design in progress

- For the VCN source we have an outstanding design with SD2→order of magnitudes flux increase above 40 Å
- For the UCN source simulations are still in progress → world leading performances expected

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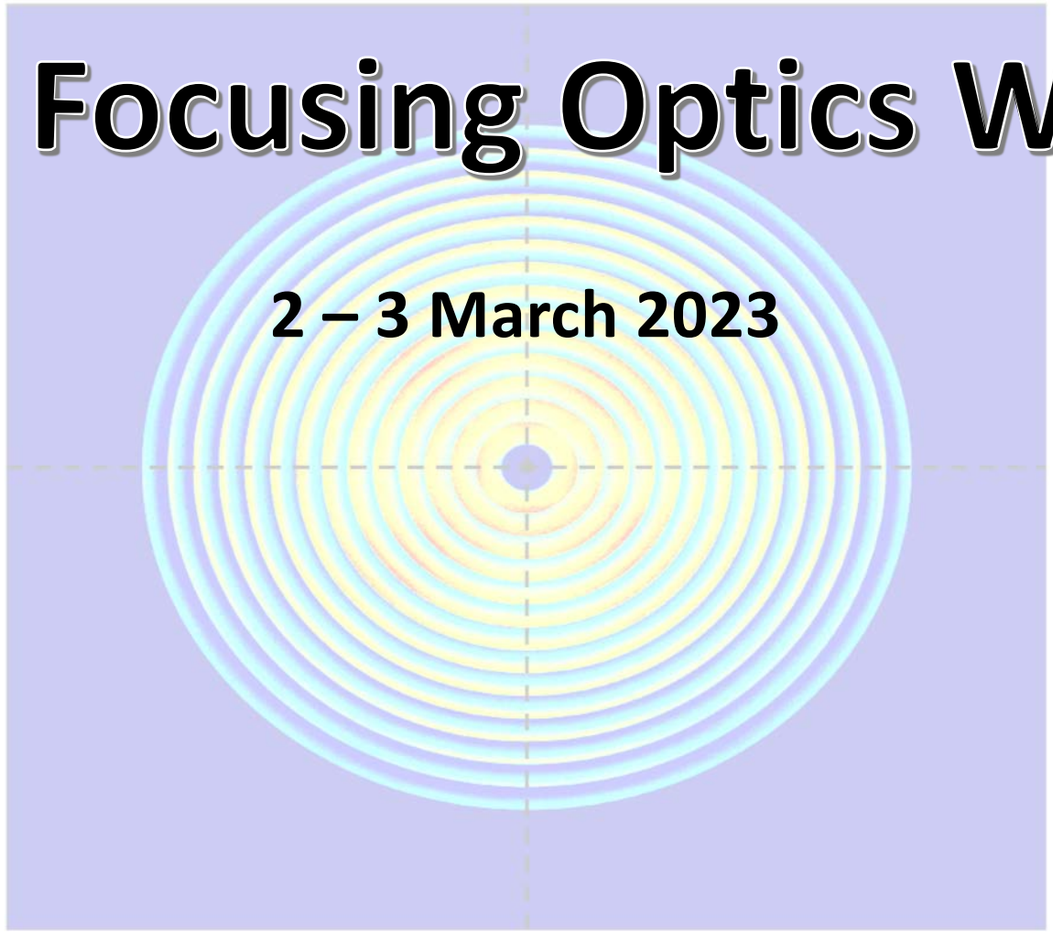
PAUL SCHERRER INSTITUT

PSI

Neutron Focusing Optics Workshop



2 – 3 March 2023

HighNess


Thanks to everybody

Back Up Slides

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

WP7: Condensed Matter Science (I)

- A key objective of this WP is to design the instruments that will make use of the new sources
- Development of Instrument Concepts using the HighNESS Cold Moderator

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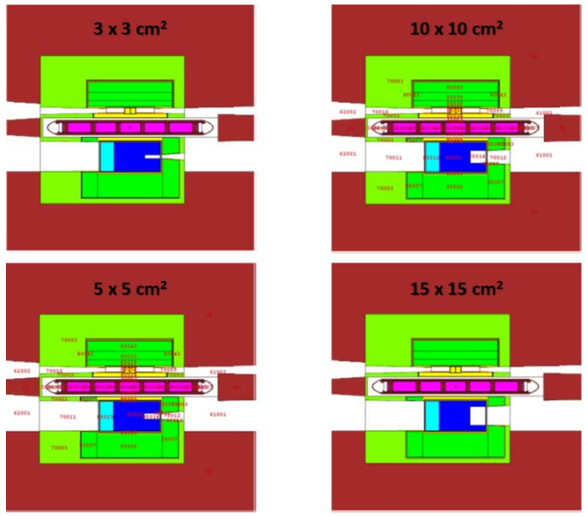
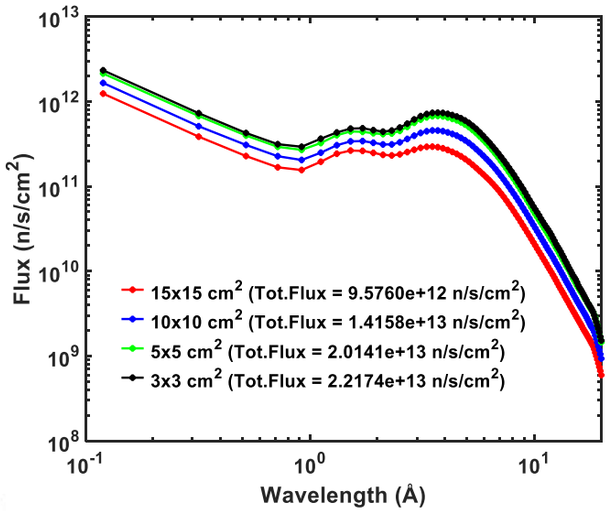
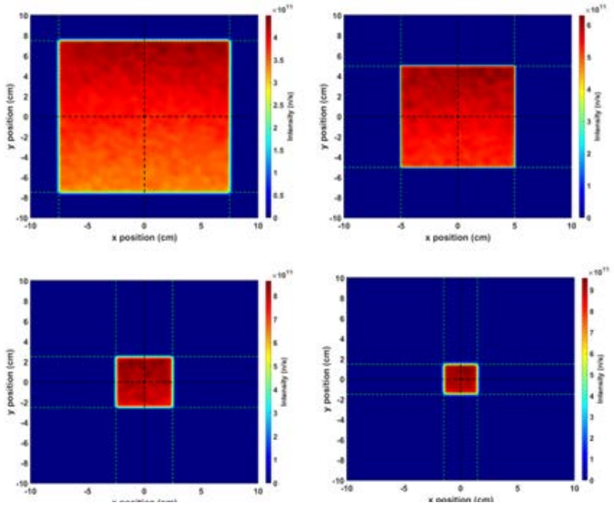
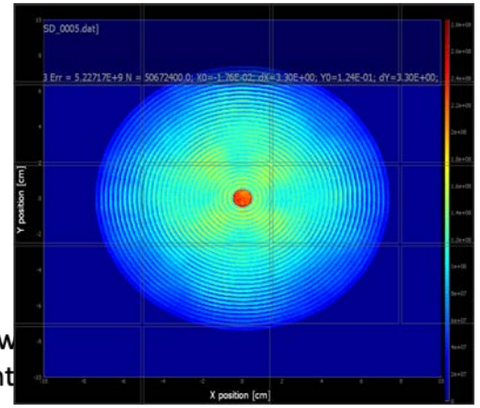


MCPL Testing





PH – Type I Wolter Optics



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grant

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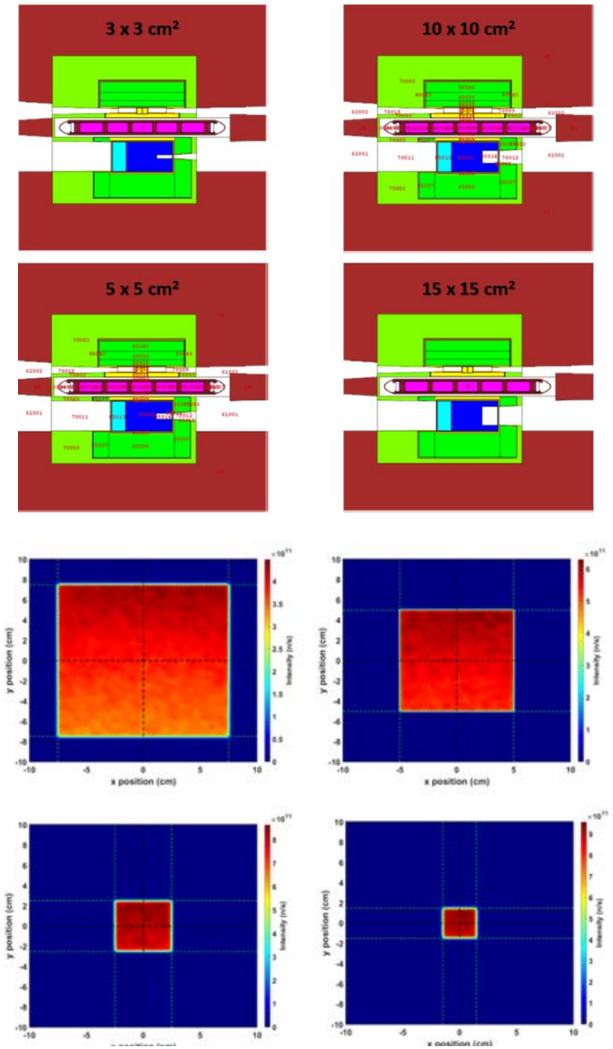

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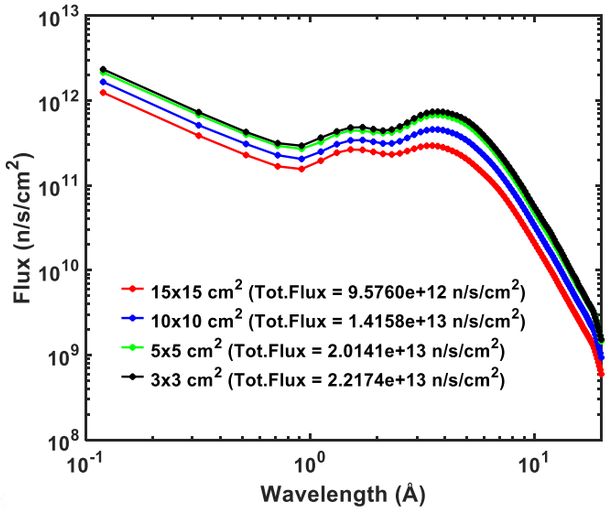

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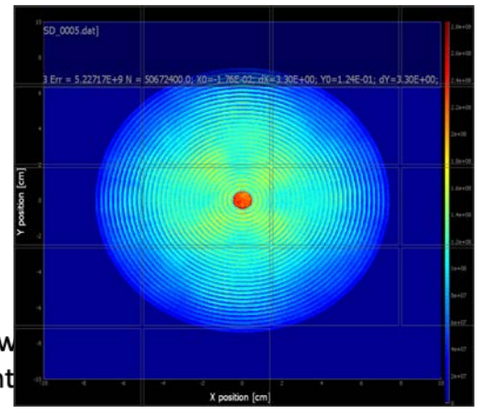
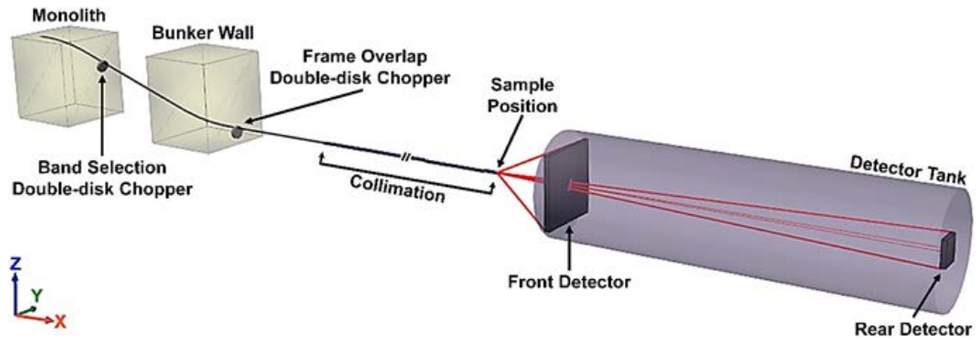
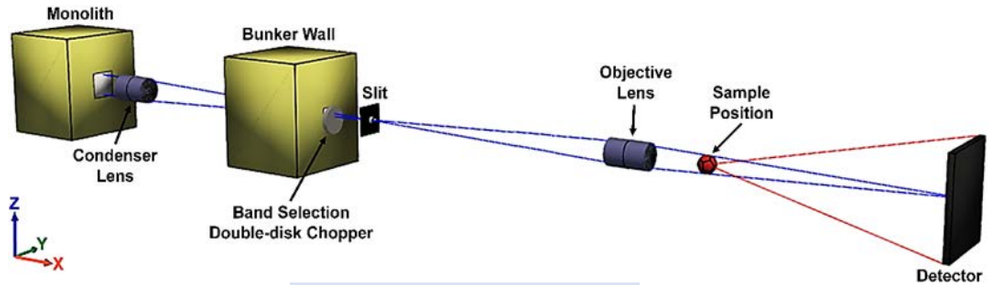


ConvSANS



WOF-SANS



Markus Strobl
Mads Bertelsen
Stavros
Samothrakitis

WP7: Condensed Matter Science (II)

guide_bot

- Original MATLAB version in 2013
- Rewritten in python for HighNESS

- Full neutron guide optimization workflow
- Python module, easy install through pip
- Scalable and expandable

guide_bot workflow

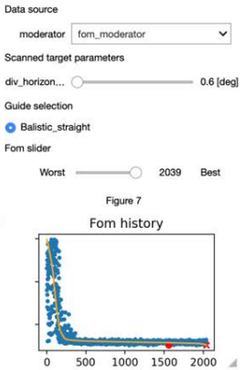
Explore data

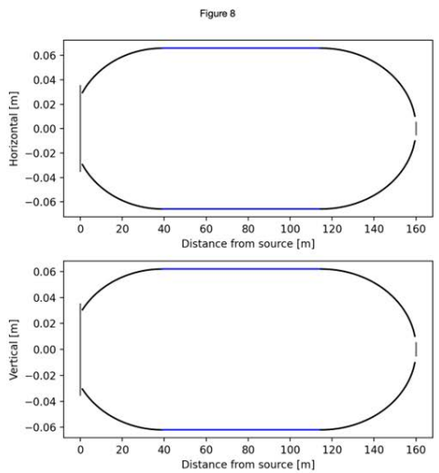
demo

Widgets

- Use interactive widgets to explore data
- Visualize guide at each step of the optimization

Visualize optimized guides





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- Use interactive widgets to explore data
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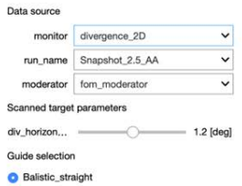
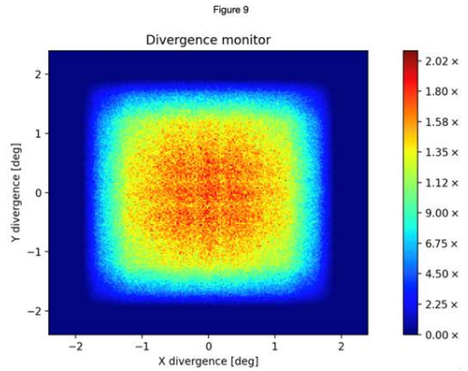
- View results from any monitor

Visualize any monitor





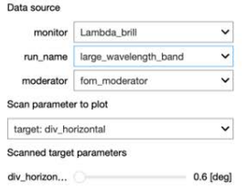
Explore data

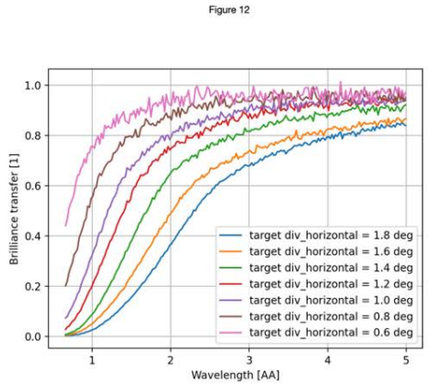
demo

Widgets

- Use interactive widgets to explore data
- Visualize guide at each step of the optimization
- View results from any monitor
- Compare results from guides / scans

Compare 1D results across scans





WP2: Software Development (II)

- Making use of NJOY+NCrystal we have generated 200+ evaluations for 100+ new and updated materials
- **This is the largest contribution ever made to thermal scattering libraries (by an order of magnitude!),** and it is 100% reproducible, documented and open source
- All developments are freely available online: https://github.com/highness-eu/

Douglas Di Julio
Jose Ignacio Marquez Damian
Giuseppe Gorini
Marco Bernasconi
Davide Campi
Sara Isaline Laporte
Shuqui Xu
Nicola Rizzi
Thomas Kittelmann

NJOY+NCrystal: an open-source tool for creating thermal neutron scattering libraries
https://doi.org/10.1016/j.nima.2021.166227

See Douglas Di Julio, Sara Isaline Laporte and Shuqi Xu talks

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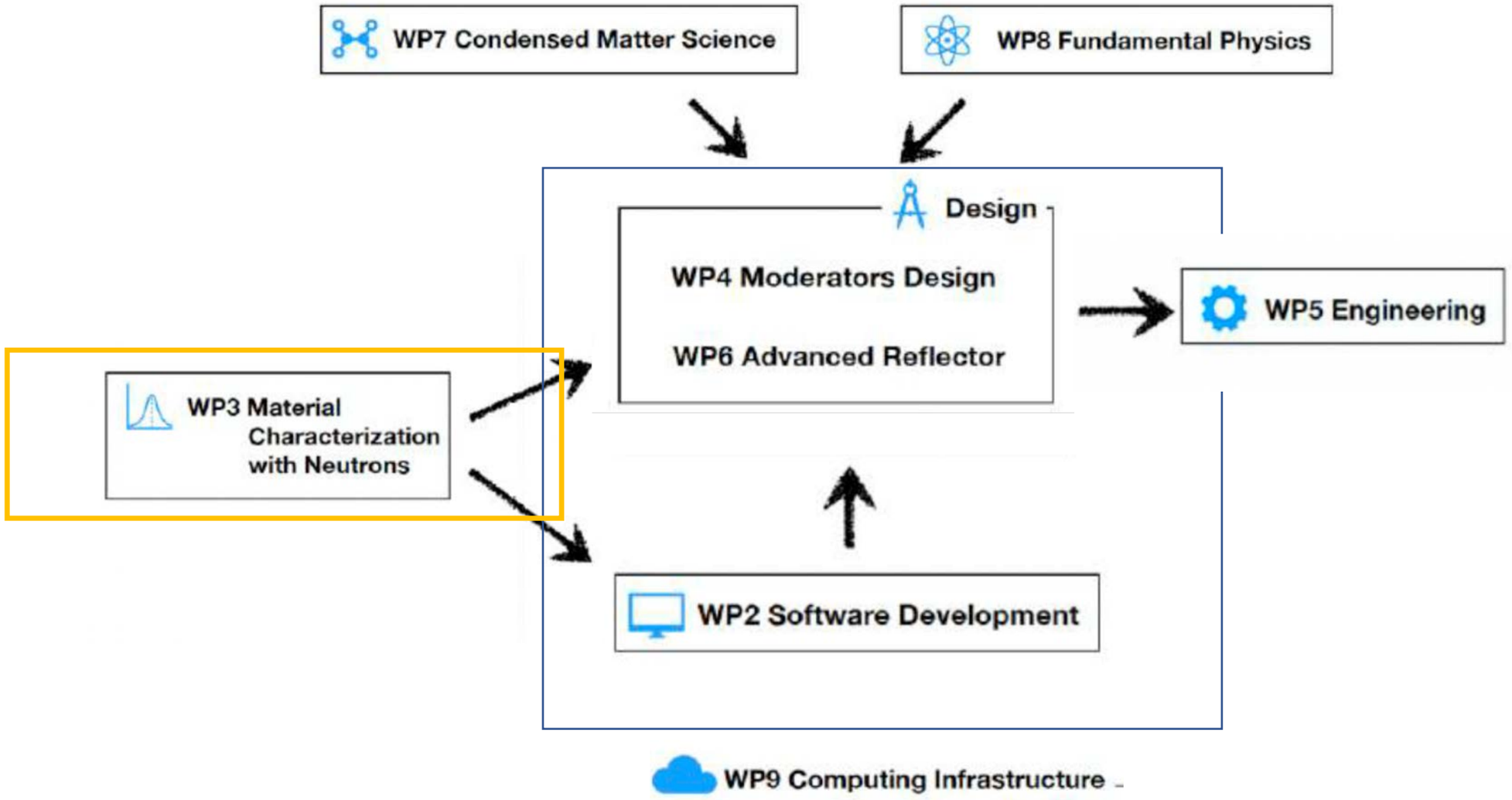
The HighNESS Project



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WP3: Material Characterization with neutrons

- For some of the materials of interest of the HighNESS project crucial neutron scattering parameters are not available

- WP3 has as key objective to measure the properties of these materials at ILL

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- Experimental campaign on-going using different ILL beam line and different samples (17D2O:TDF, 17H2O:TDF, 17D2O:THF, 17H2O:THF)
- Measurement of Cold Neutron and Very Cold Neutron transmission through these materials

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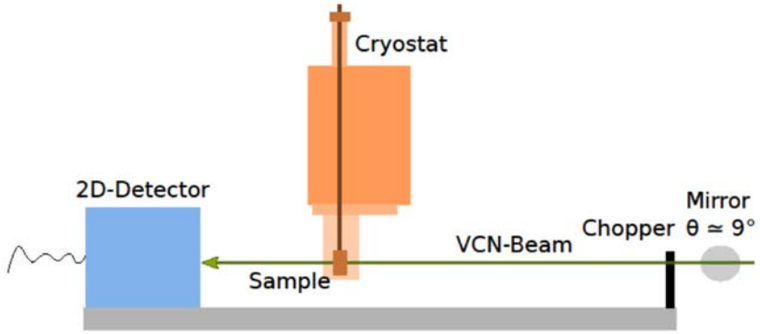
VCN trasmission experiments at the PF2 beamline at ILL: data analysis on-going

Oliver Zimmer
Richard Wagner
Valentin Czamler



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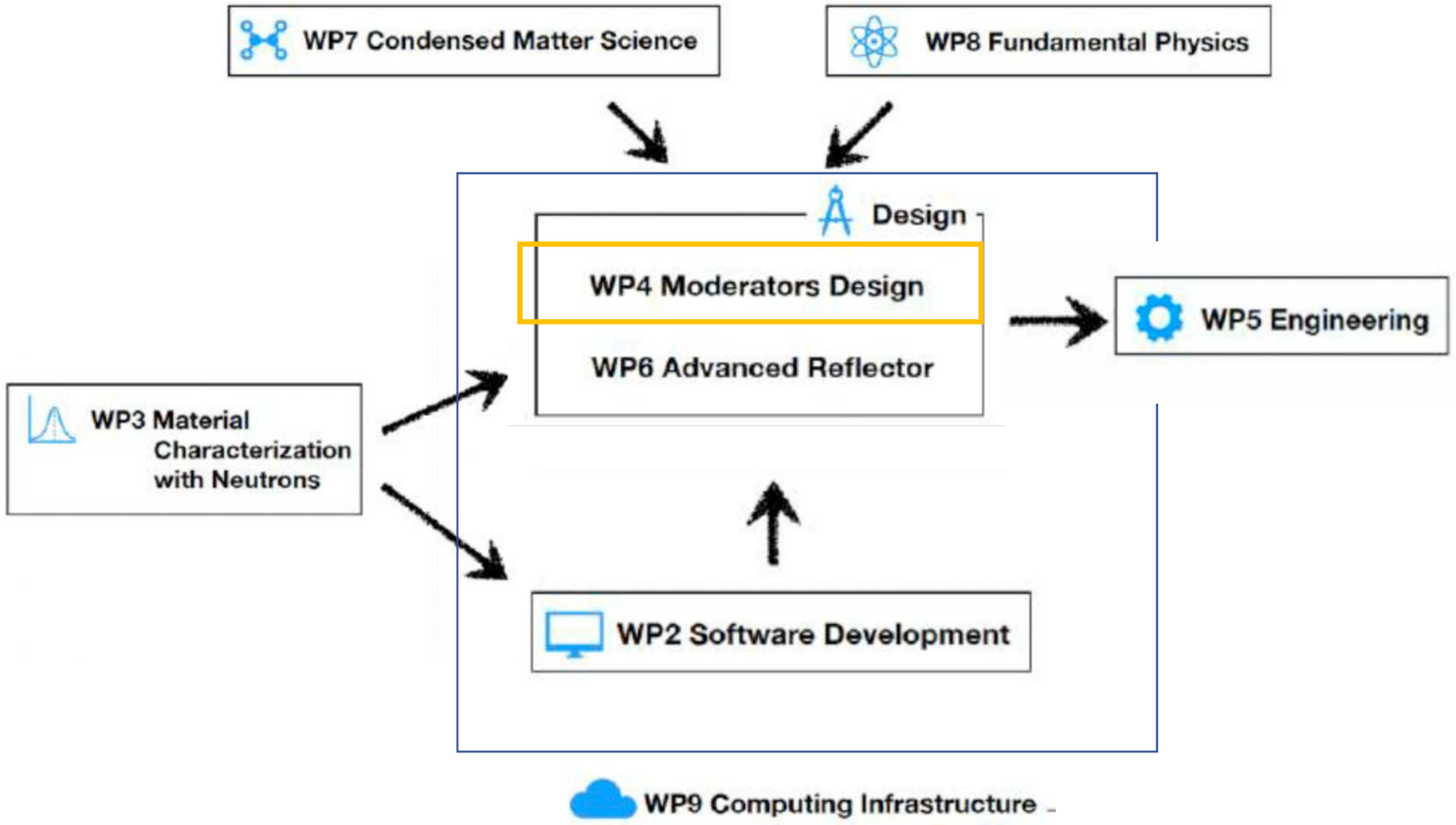
The HighNESS Project



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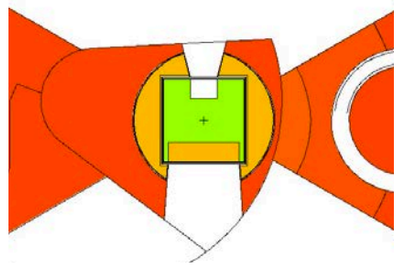
WP4: Moderators design

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

Goal of the WP is to design three sources

1 COLD - CN

High intensity liquid D2 at about 20 K



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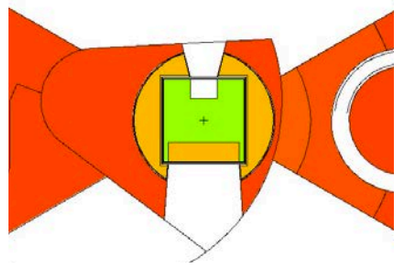
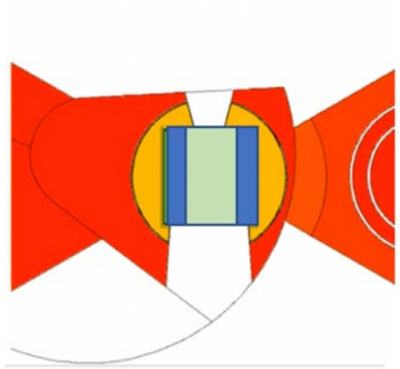


VERY COLD - VCN

VCN extraction from main source using advanced reflectors

Dedicated VCN converter



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1 2 3

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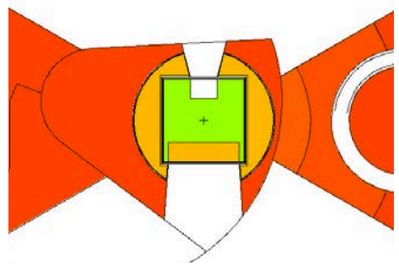

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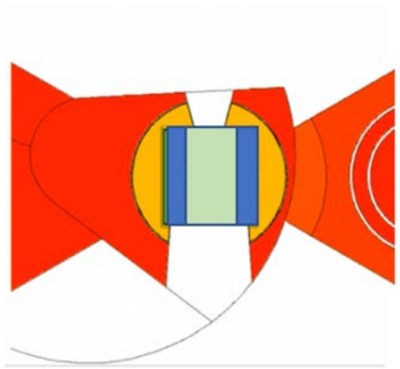
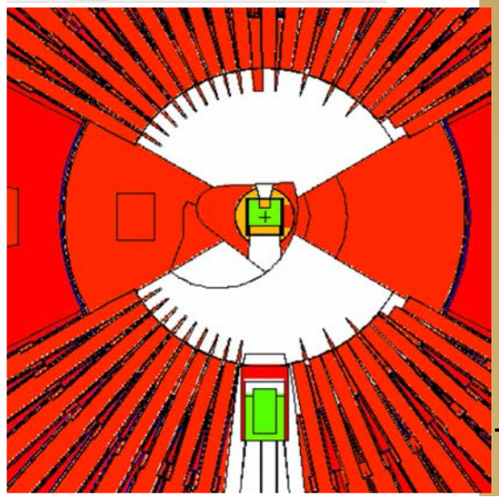


ULTRA COLD - UCN → In beam UCN

In pile UCN



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Design of the Cold Source

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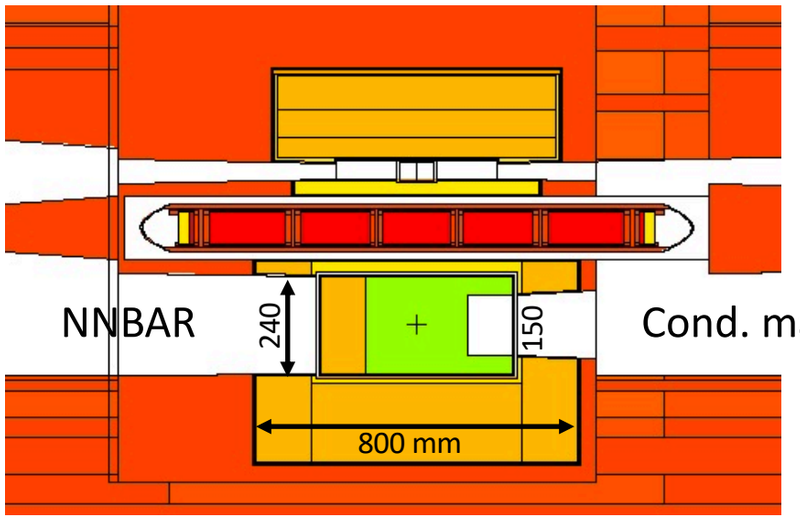

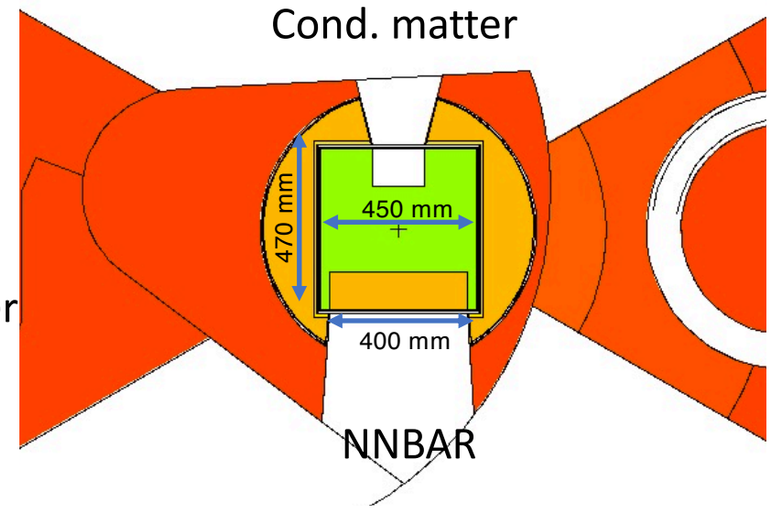

The high-intensity liquid deuterium moderator has been designed with two openings, for NNBAR and neutron scattering instruments

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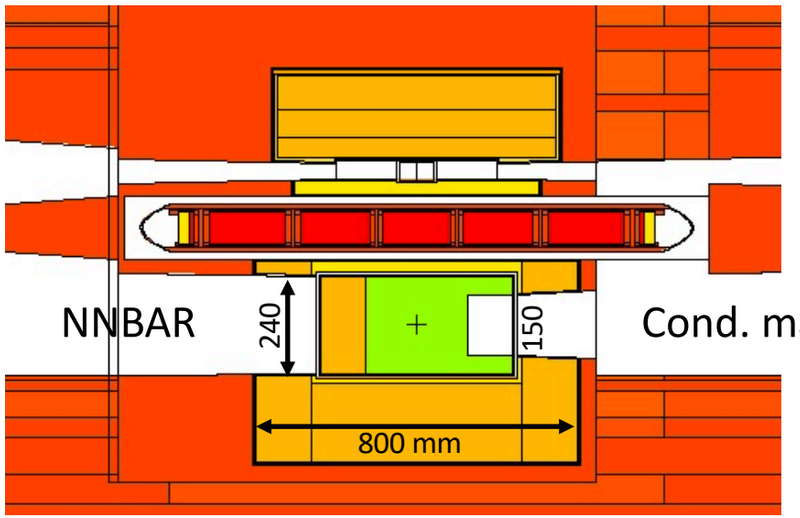

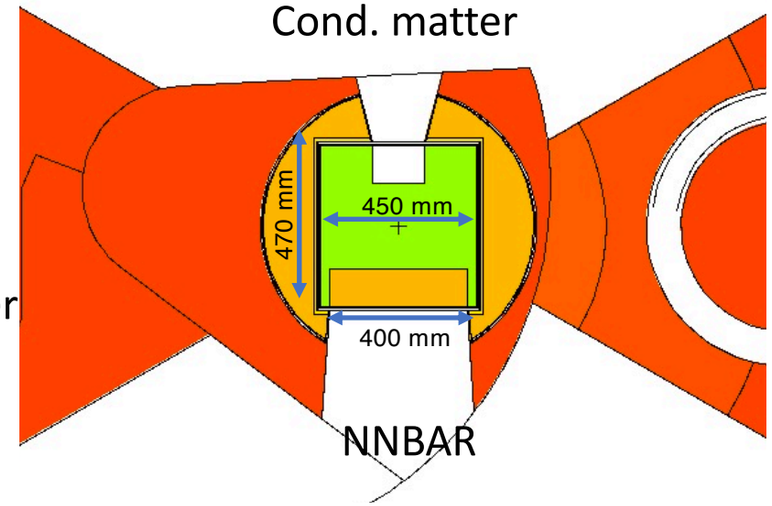

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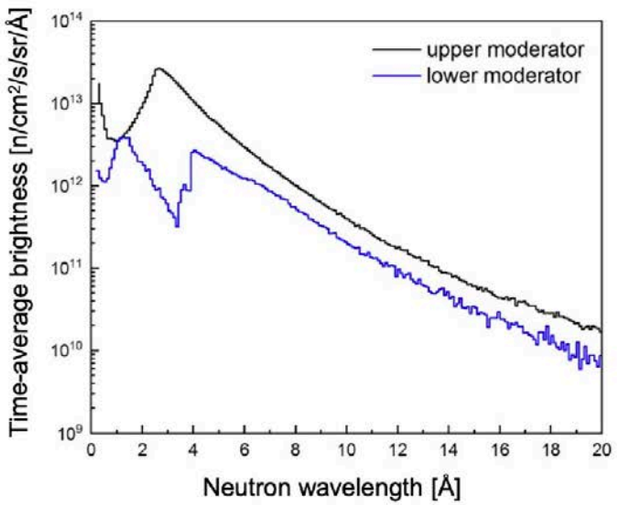
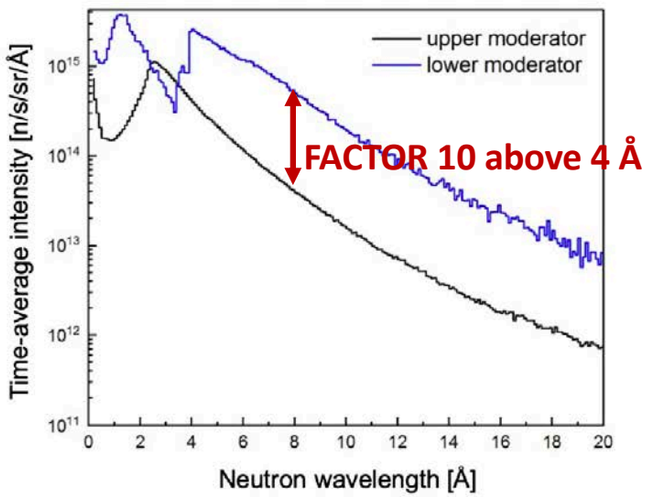
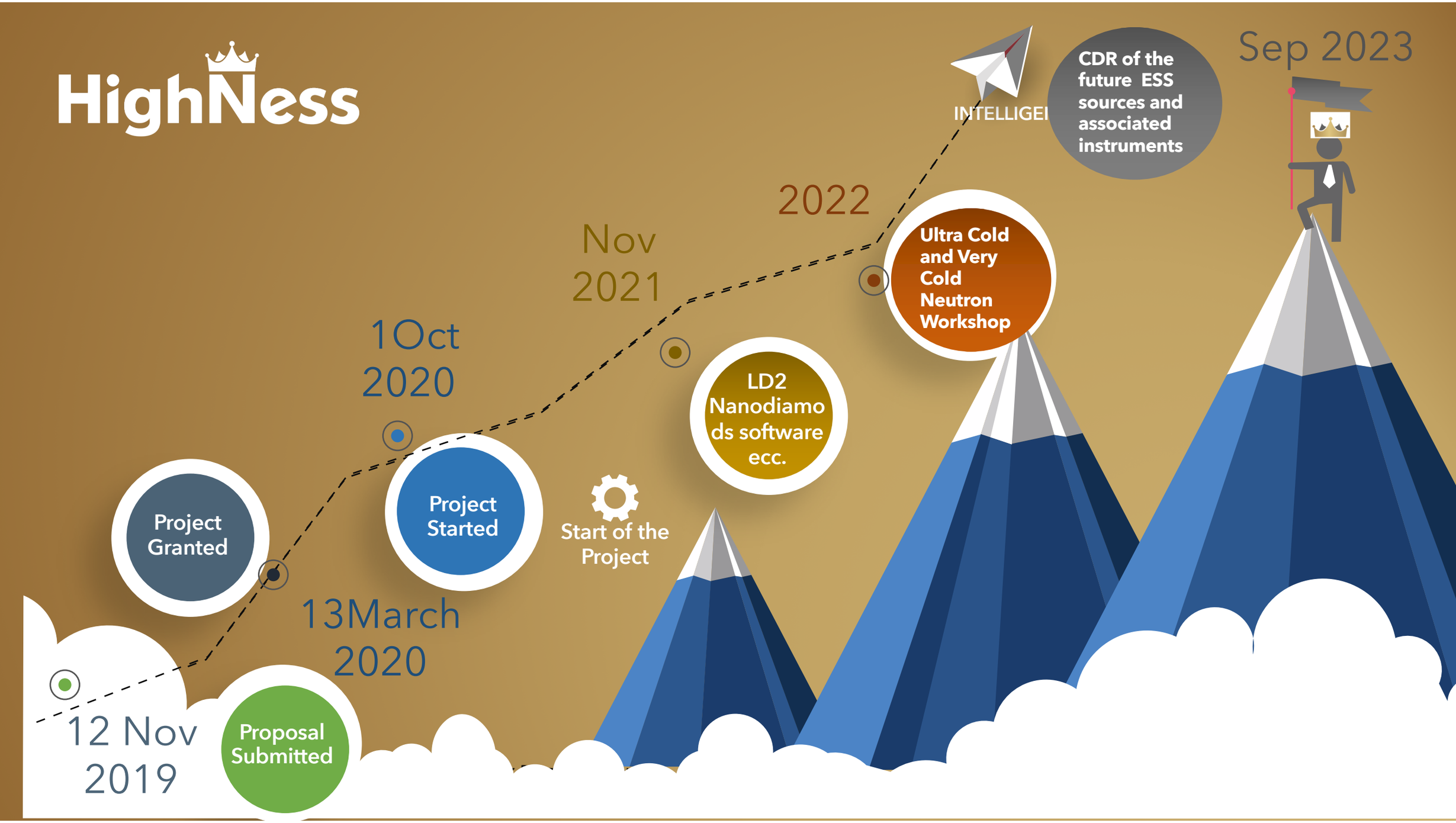
Brightness



Intensity




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

1. The ESS current moderator
2. Overview of the HighNESS project
3. On-going developments in the HighNESS project
4. Some info about today's meeting

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