S2387: Commissioning the UCN source with beam

Ruediger Picker

for the TUCAN collaboration

01-May-2024

Close-up view of UCN source

TUCAN
TRIUMF Ultra Cold Advanced Neutron source

Contents:

- Intro
- Status
- Plans

Discovery, accelerated

Intro

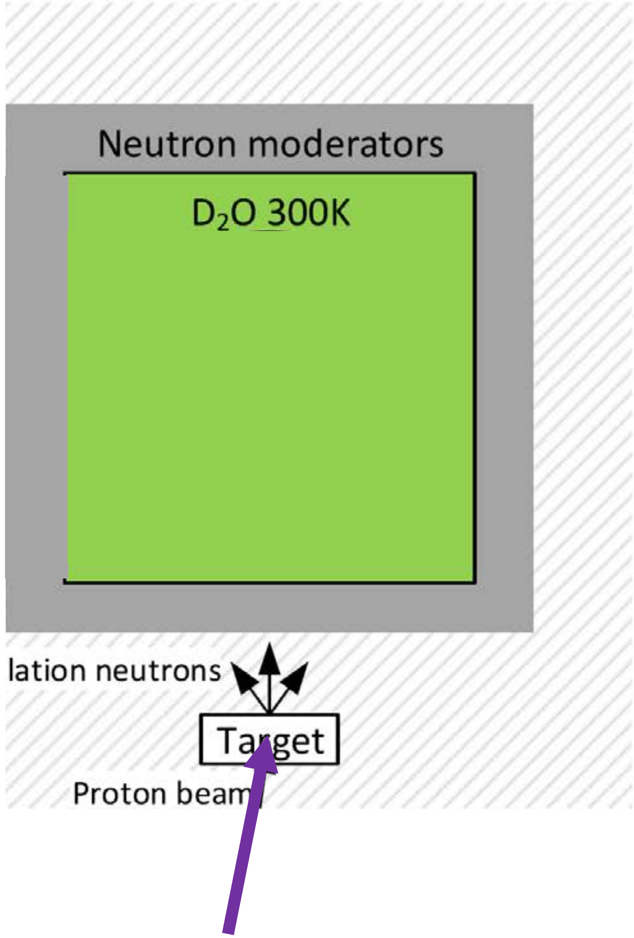
- The TRIUMF UltraCold Advanced Neutron (TUCAN) source is a spallation-driven superfluid-helium, superthermal source.
- Its goals are
  1. To provide record amounts of ultracold neutrons to the TUCAN EDM experiment
  2. To establish a UCN user facility at its second port.
- Installation and cryogenic commissioning has started.
- We are working very hard to make UCN production in 2024 possible.

C. Bidinosti[2], M. Bradley[16], A. Brossard[3], C. Davis[3], D. Fujimoto[3], M. Gericke[4], P. Giampa[3], R. Golub[5], S. Hansen-Romu[4], K. Hatanaka[6], T. Hayamizu[7], T. Higuchi[8], G. Ichikawa[9], S. Imajo[10], A. Jaison[11], B. Jamieson[2], S. Kawasaki[9], M. Kitaguchi[12], W. Klassen[13], A. Konaka[3], E. Korkmaz[14], E. Korobkina[5], M. Lavvaf[4], L. Lee[3], T. Lindner[3], K. Madison13, Y. Makida 9, R. Mammei2, J. Mammei4, J. Martin2, R. Matsumiya[3], M. McCrea[2], E. Miller[13], K. Mishima[15], T. Momose[13], T. Okamura[9], H. Ong[10], R. Picker[3], D. Ramsay[3], W. Schreyer[3], H. Shimizu[12], S. Sidhu[3], S. Stargardter[4], I. Tanihata[6], S. Vanbergen[13], W. vanOers[3], Y. Watanabe[9], A. Zahra[11]

1 - Nagoya University, 2 - UW, Winnipeg, Canada, 3 - TRIUMF, Vancouver, Canada, 4 - UofM, Winnipeg, Canada, 5 - NCSU, Raleigh, NC, USA, 6 - RCNP, Osaka, Japan, 7 - RIKEN, 8 - KURNS, Kyoto University, Kyoto, Japan, 9 - KEK, Tsukuba, Japan, 10 - RCNP, Osaka University, 11 - University of Manitoba, 12 - Nagoya University, Nagoya, Japan, 13 - UBC, Vancouver, Canada, 14 - UNBC, Prince George, Canada, 15 - KEK, Tokai, Japan, 16 – University of Sasketchewan, Saskatoon, Canada

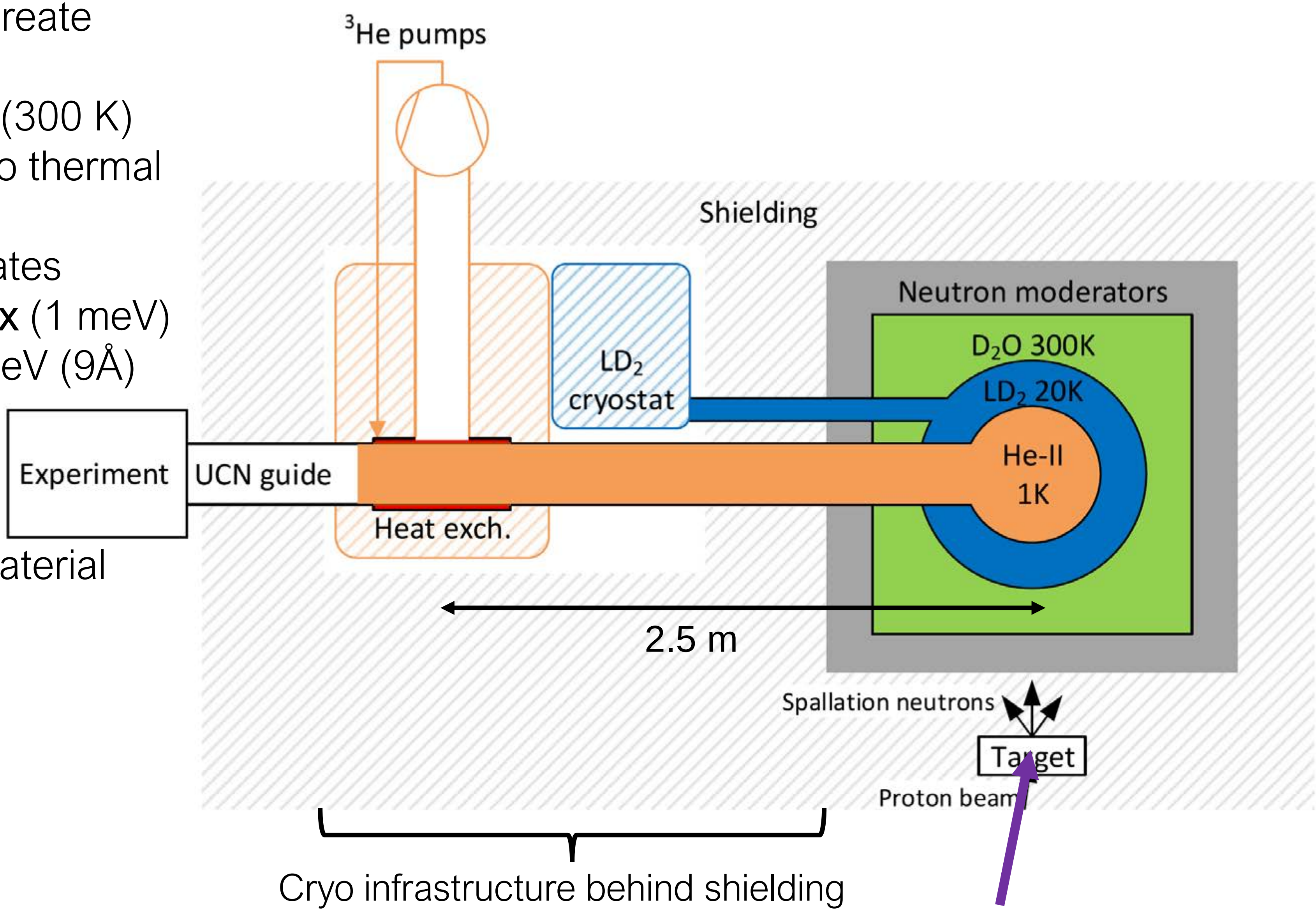
TUCAN source recipe

1. 480 MeV protons on tungsten create **spallation neutrons**
2. lead, graphite and heavy water **moderate** fast neutrons (MeV) to thermal neutrons (25 meV)
3. liquid deuterium at 20 K moderates further to create a **large cold flux** (1 meV)
4. ^{4}He at around 1 K **converts** 1 meV (9Å) neutrons **to UCN** (< 215 neV)

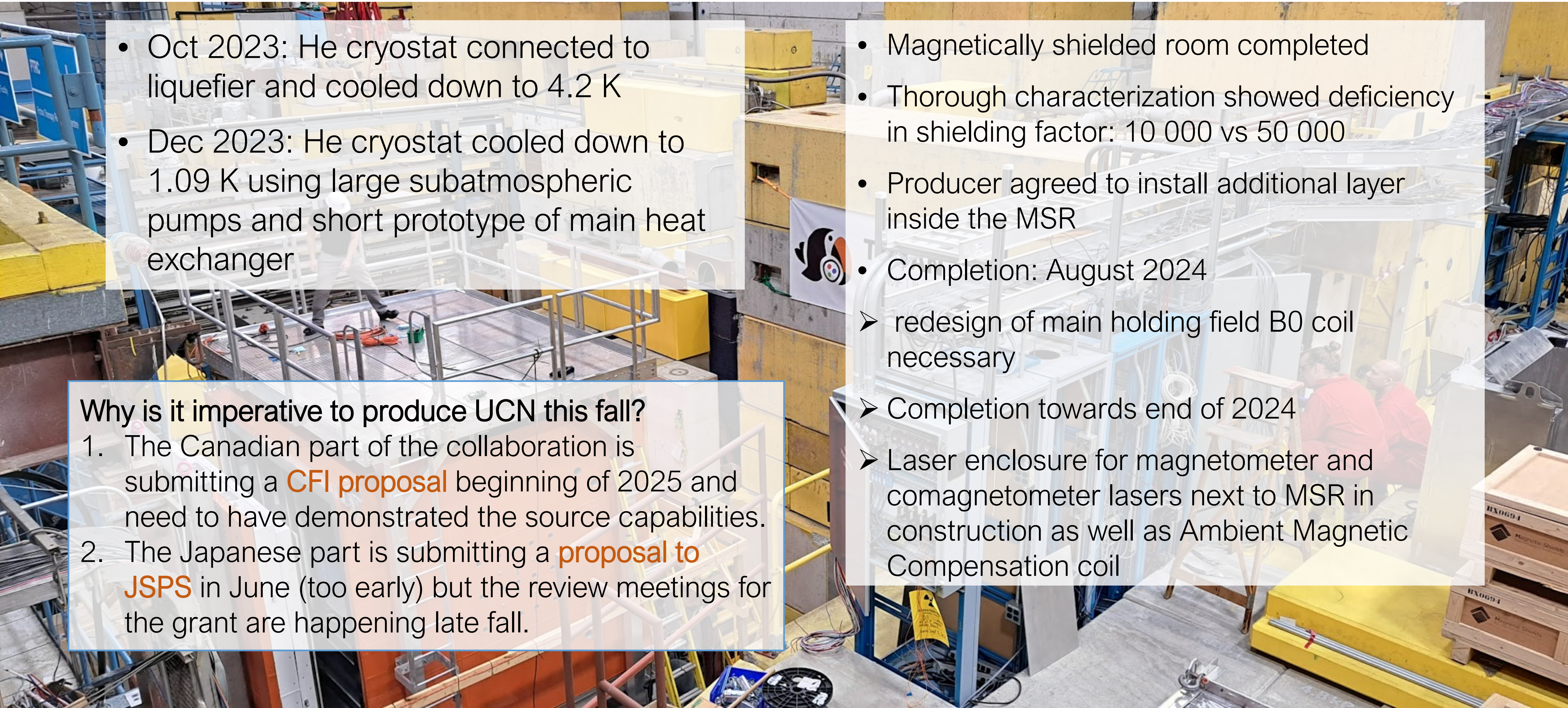


TUCAN source recipe

1. 480 MeV protons on tungsten create **spallation neutrons**
2. lead, graphite and heavy water (300 K) **moderate** fast neutrons (MeV) to thermal neutrons (25 meV)
3. liquid deuterium at 20 K moderates further to create a **large cold flux** (1 meV)
4. ^{4}He at around 1 K **converts** 1 meV (9Å) neutrons **to UCN** (< 215 neV)
5. **Extraction** to experiments via material guides



Progress since last EEC meeting



UCN source cryogenic testing

- Oct 2023: He cryostat connected to liquefier and cooled down to 4.2 K
- Dec 2023: He cryostat cooled down to 1.09 K using large subatmospheric pumps and short prototype of main heat exchanger

Why is it imperative to produce UCN this fall?

1. The Canadian part of the collaboration is submitting a CFI proposal beginning of 2025 and need to have demonstrated the source capabilities.
2. The Japanese part is submitting a proposal to JSPS in June (too early) but the review meetings for the grant are happening late fall.

EDM

- Magnetically shielded room completed
- Thorough characterization showed deficiency in shielding factor: 10 000 vs 50 000
- Producer agreed to install additional layer inside the MSR
- Completion: August 2024

➢ redesign of main holding field B0 coil necessary

➢ Completion towards end of 2024

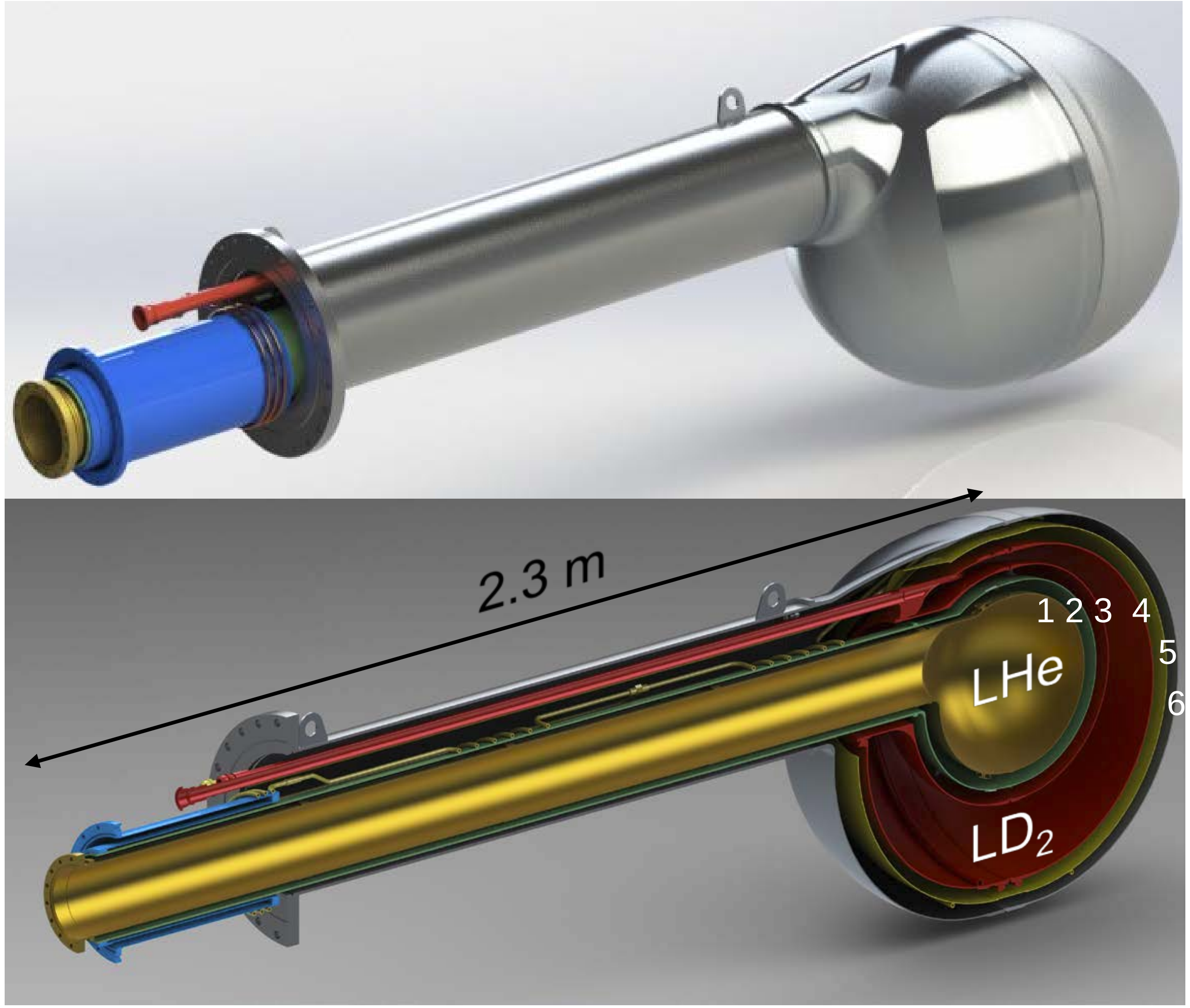
➢ Laser enclosure for magnetometer and comagnetometer lasers next to MSR in construction as well as Ambient Magnetic Compensation coil

TUCAN
TRIUMF Ultra Cold Advanced Neutron source

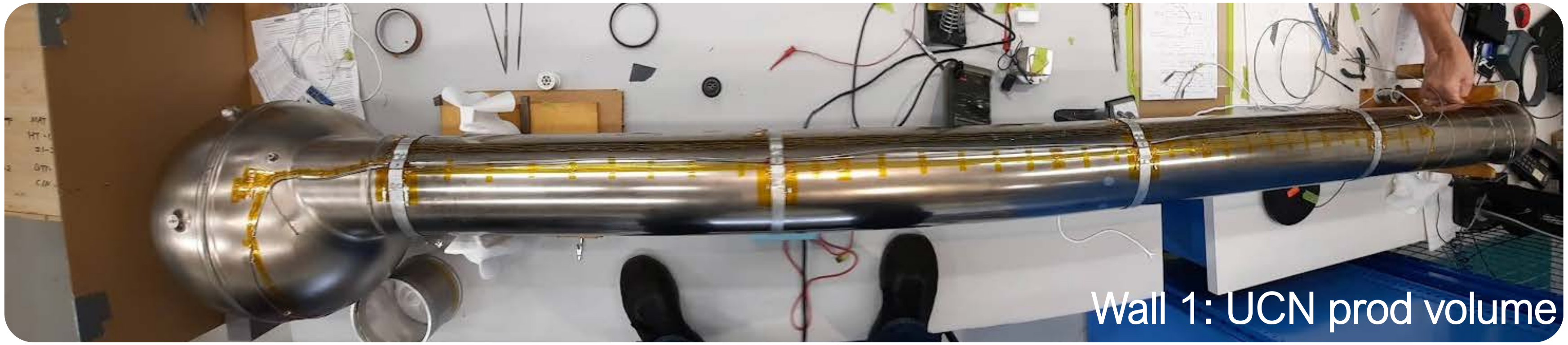
Top view of UCN area
(April 4, 2024)

Tail vessel

- 6 layer vessel
  1. Superfluid vessel, UCN production volume, cryogenic guide
  2. Vacuum separation wall (withstands D_2 explosion, 21 bar)
  3. Inner wall of LD2 vessel
  4. Out wall of LD2 vessel
  5. Thermal radiation shield
  6. Vacuum vessel
- All welded due to lack of space for flanges
- Passive, except temperature sensors and heaters
- We received go-ahead for production Oct 2023
- Installed and connected in April 2024
- Heroic effort by Cam Marshall and machine shop!



Tail section manufacturing


Wall 1: UCN prod volume


Wall 2: vacuum separation


Wall 2


Wall 2


Wall 3:
inside wall of LD_2 vessel


Wall 4:
outside LD_2 wall


Wall 4


Wall 4


Wall 5:
thermal radiation shield

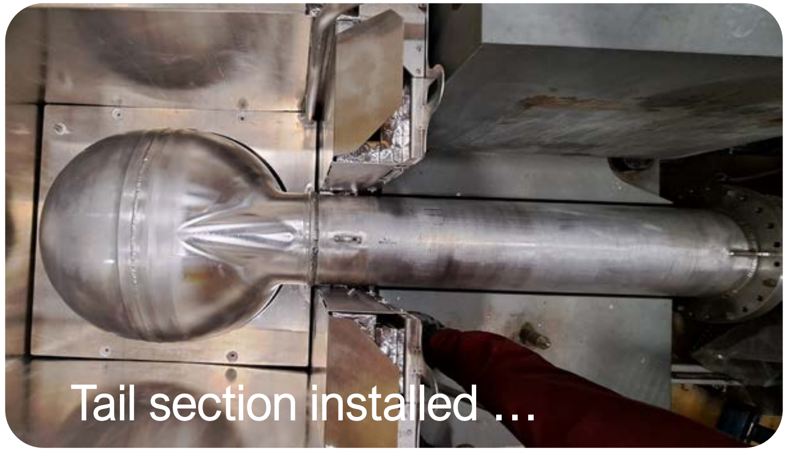

Wall 6: vacuum vessel
plus wall 5 superinsulation

Tail section completion and installation


The machine shop crew with the completed tail section

Tail section installation 1


Tail section installation 2


Tail section installed …


… and connected

TUCAN
TRIUMF Ultra Cold
Advanced Neutron source

Status: installing and cryo commissioning

TRIUMF


Helium transfer line 2022

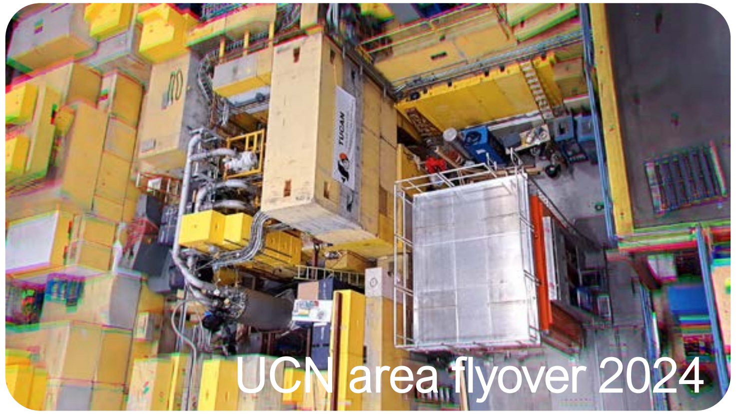

Cryo connection box 2023

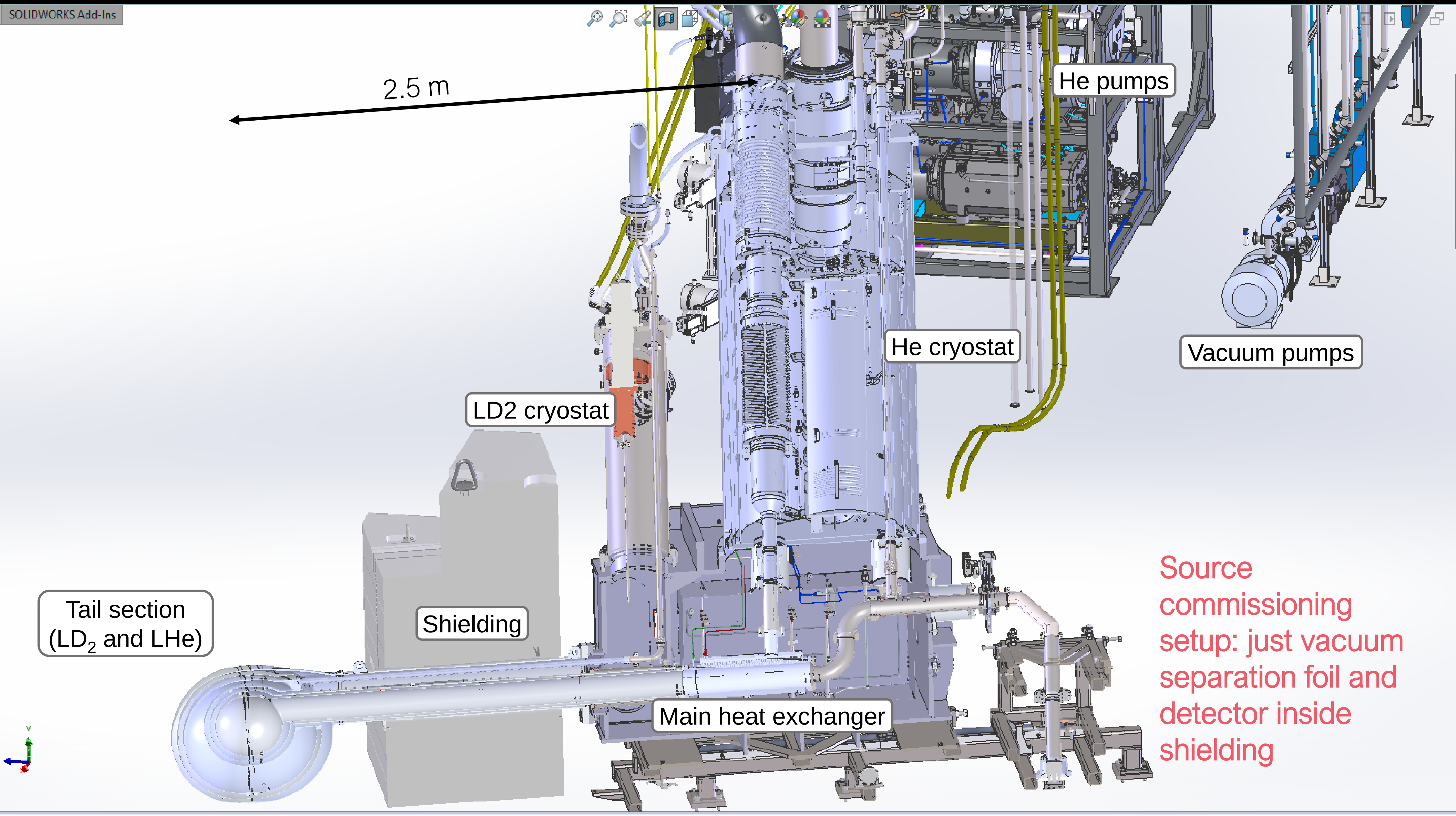

Wrapping graphite 2023


Graphite moderator carrier 2024

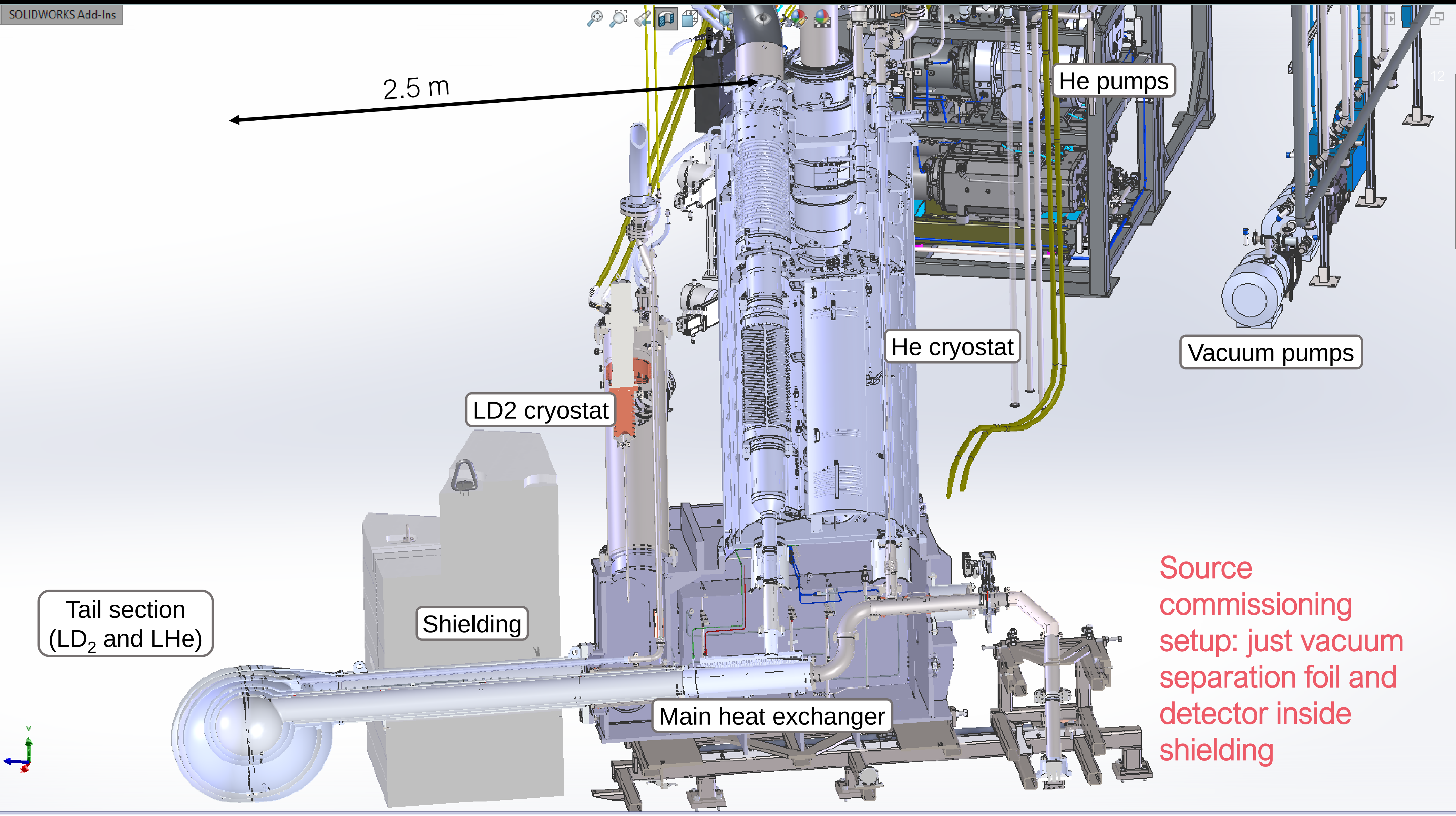

Lower D2O tank 2024


Upper D2O tank 2024


UCN area flyover 2024



Source commissioning setup: just vacuum separation foil and detector inside shielding



Source commissioning setup: just vacuum separation foil and detector inside shielding

Next steps

Source

- Reconnect all He cryostat connections
- Install, pipe and test 3He gas system
- Complete slow control
- Test source with 3He => <1 K ⇒ June
- Install large HEX1 and UCN guide
- Pipe and test isopure helium gas system
- Complete its slow control
- Condense and cool helium inside UCN production volume ⇒ August
- Install UCN guides and detector
- Produce UCN ⇒ September

BL1U

- Reconnect target water cooling system
- Complete shielding and safety systems
- Perform BL1U commissioning to 40 uA
  ⇒ June to September
- Ready for UCN production

Sounds simple, but we identified at least 99 individual tasks to get there!

LD2 moderator deferred to 2025.

Phase 6A: Source commissioning with beam 2024

⇒ scheduled for September 24 to Oct 1, 2024

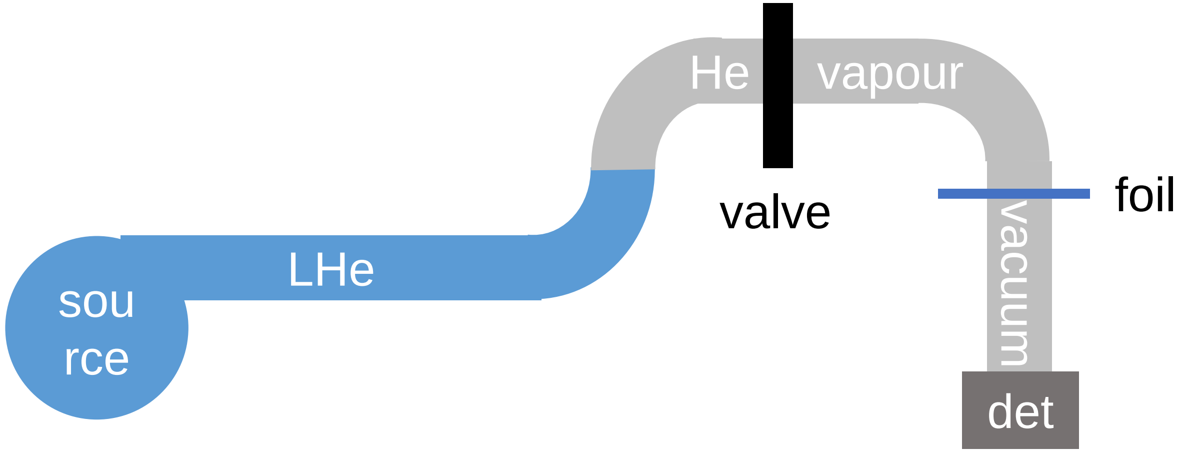
First UCN production and source characterization Sept 24 to Oct 1

Investigation of neutron yield and UCN storage lifetime in the source as a function of

- Proton current (1 – 40 uA)
- Irradiation duration (few s to few min)
- Temperature of superfluid helium (0.8 K to 1.6 K)

Also production during detection.

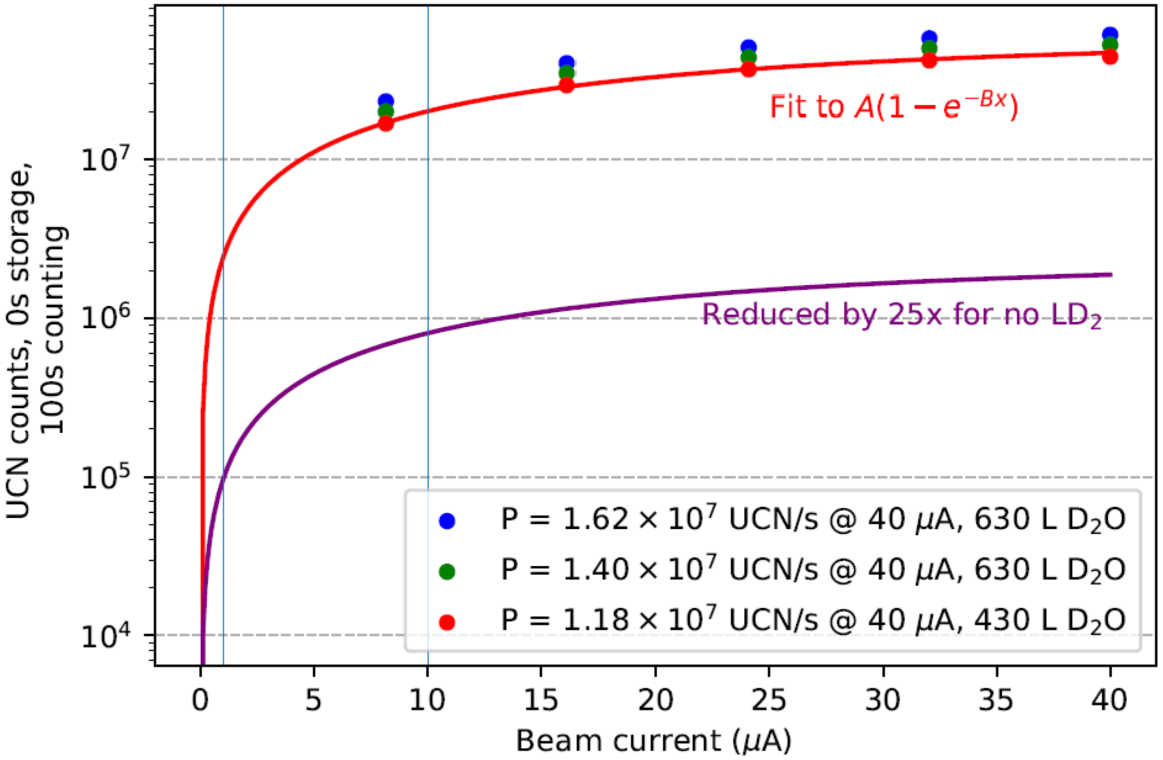
⇒ Compare with predictions from simulations!



Experiment procedure:

1. Produce UCN with valve just outside source closed
2. Stop UCN production, keep valve open
3. Open valve to detect UCN

Vary durations of 1 and 2.



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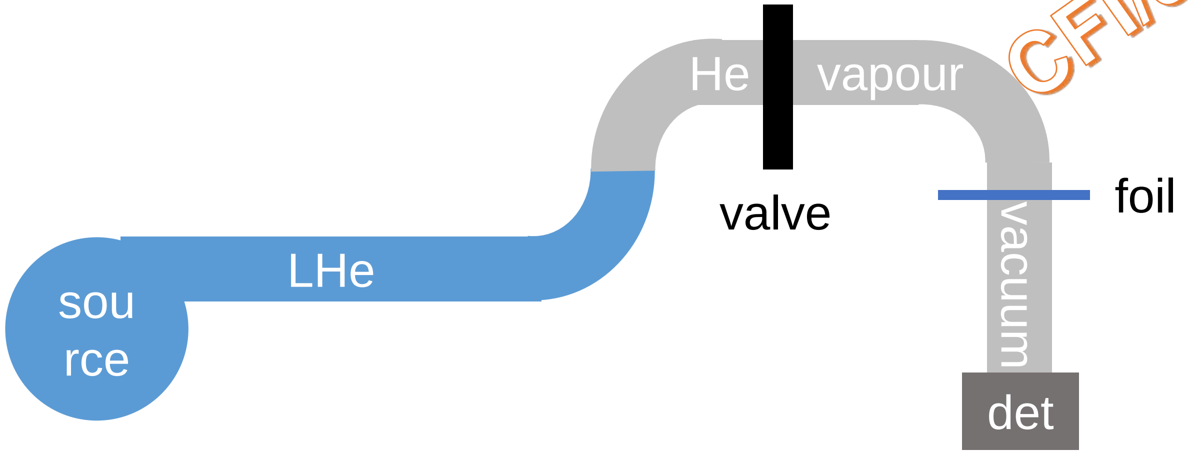
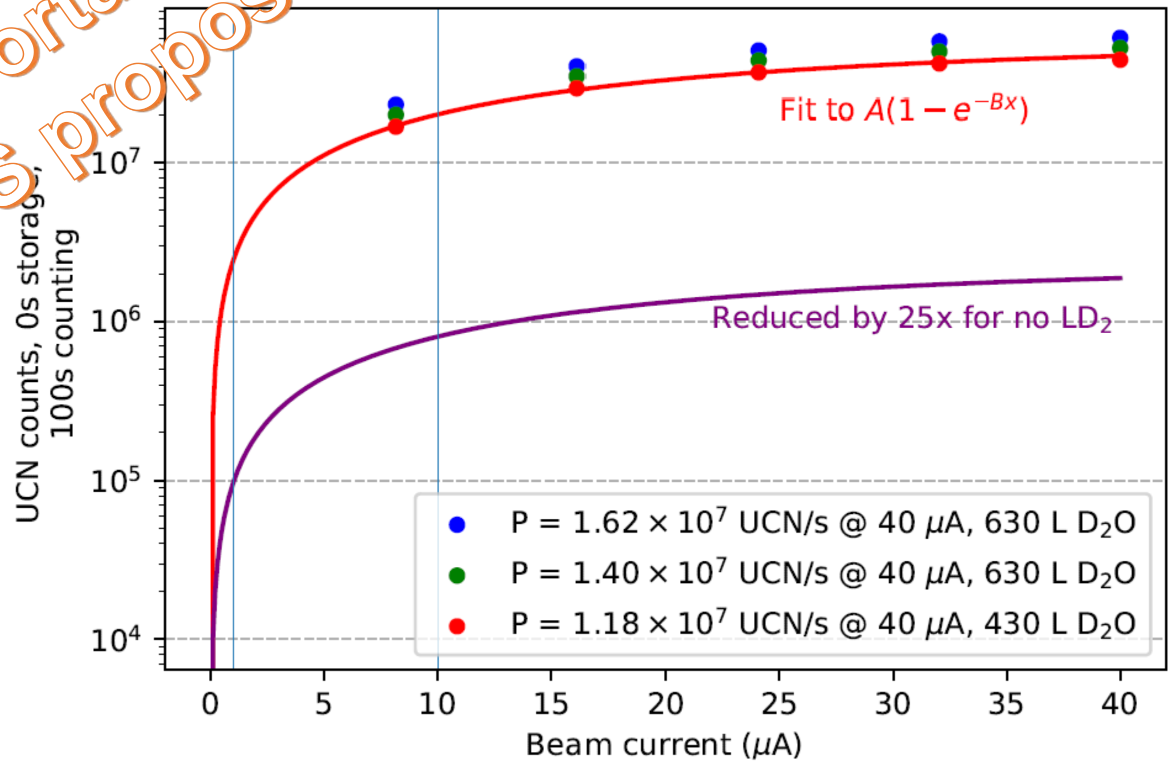
Vary durations of 1 and 2.

very important for CFI/JSPS proposals.

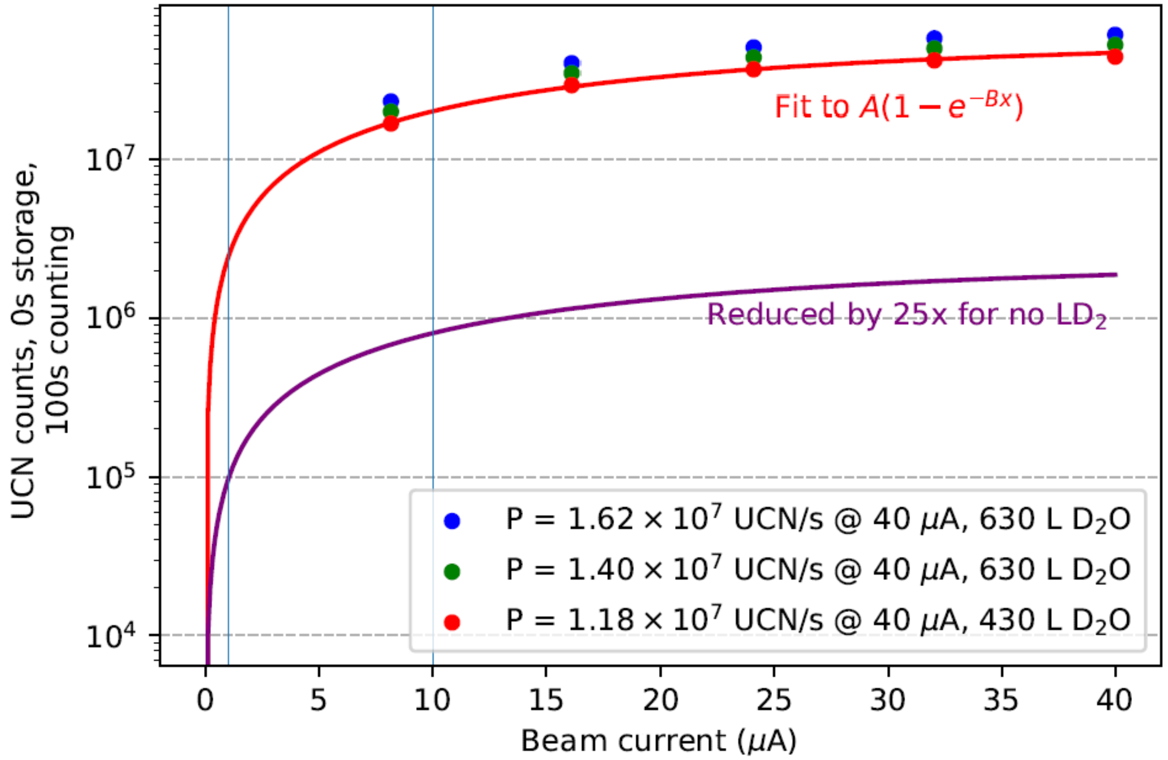




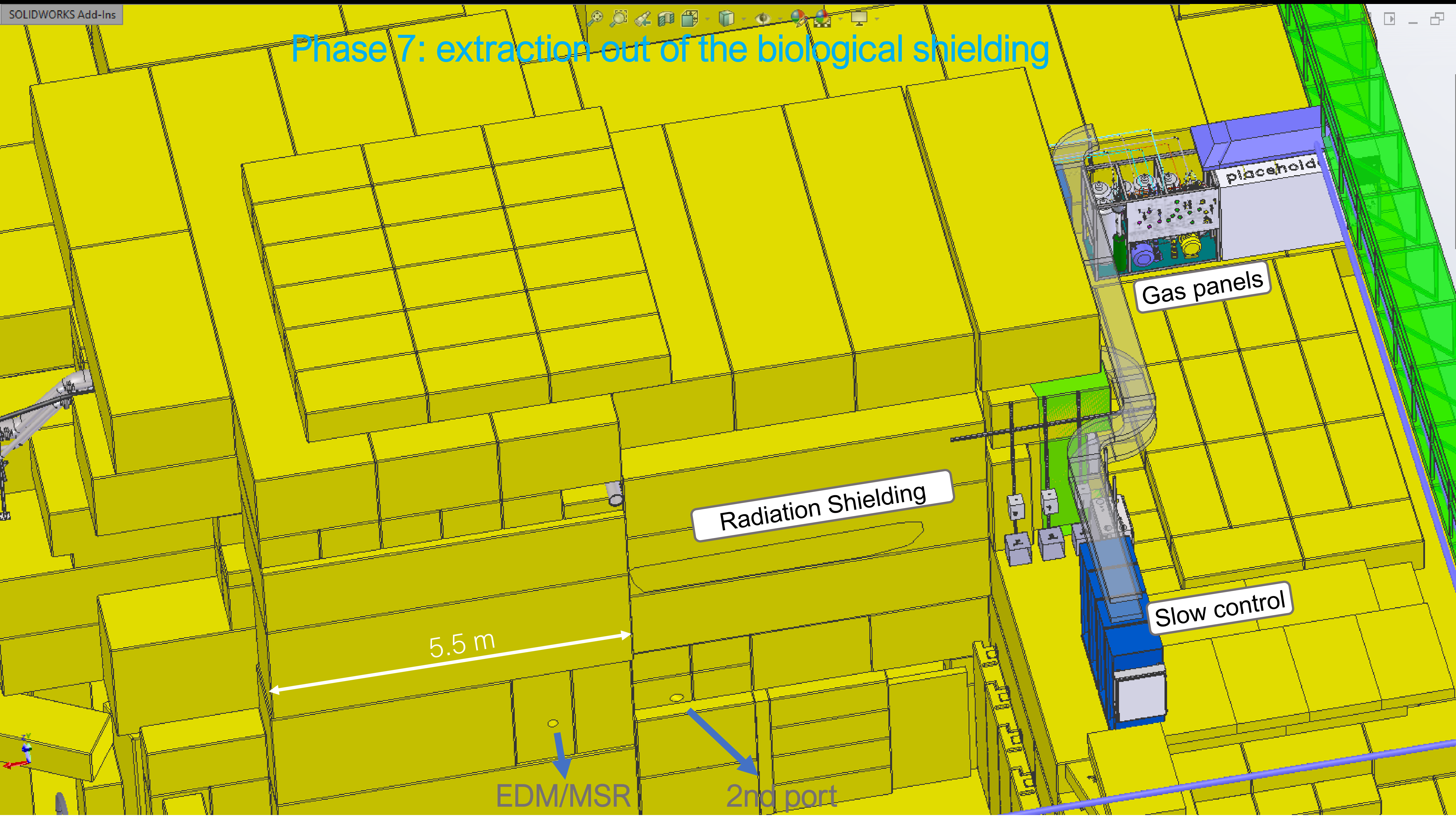
Phase 6B: UCN production with LD2

⇒ **spring 2024**

- Repeat program from before, now with LD2.



Phase 7: extraction out of the biological shielding



Phase 7: Extraction out of the biol. shielding

⇒ summer 2024

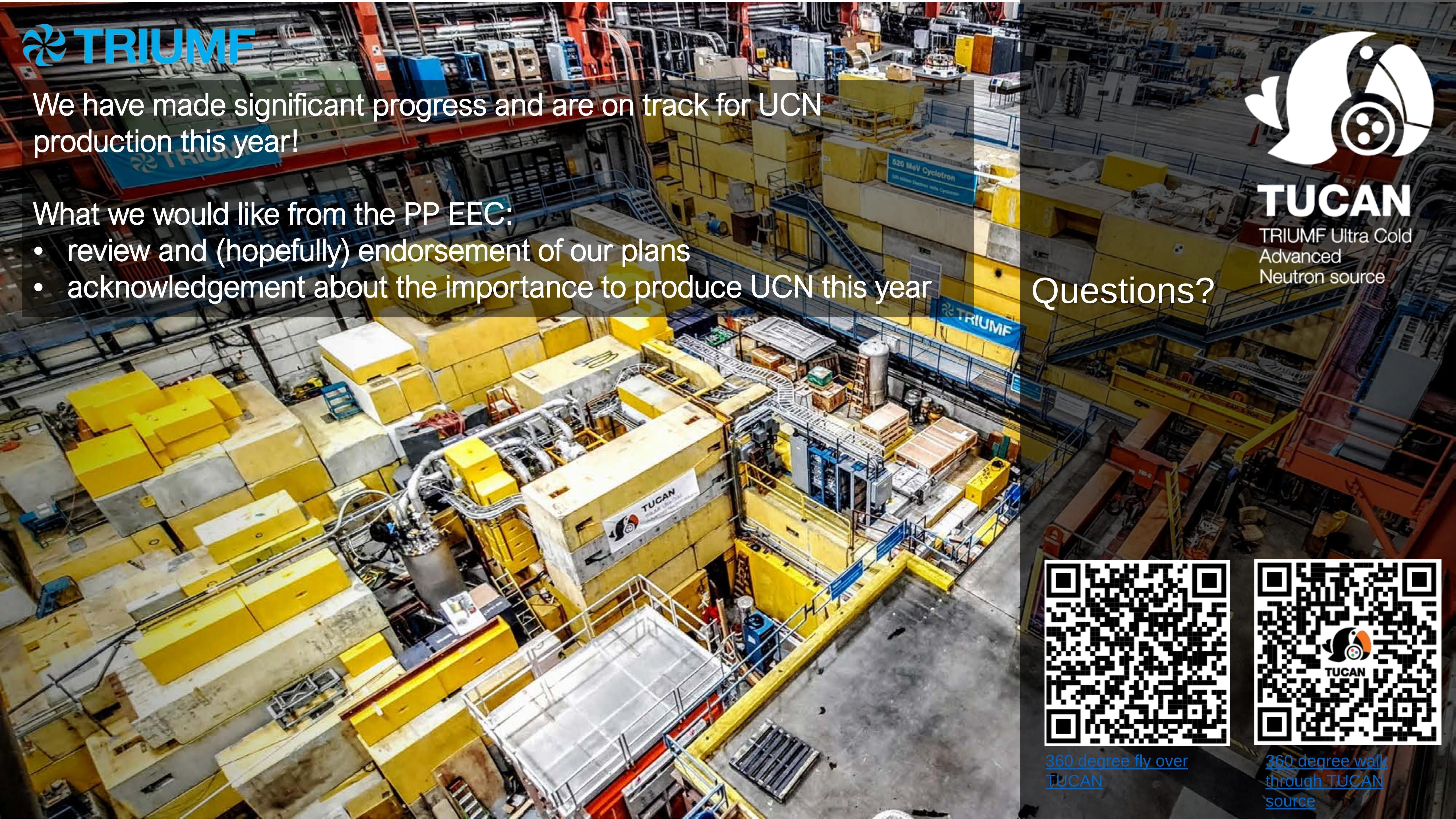
Possible experimental program:

- Transmission and storage lifetime with
  - different vacuum separation foil sizes and thicknesses inside the superconducting polarizer
  - Various neutron handling components
- Polarization transport
- Detector tests

29 days of UCN runs in 2028 – 28 different configurations

For the EDM commissioning, we will submit a new proposal.

TRIUMF



We have made significant progress and are on track for UCN production this year!

What we would like from the PP EEC:

- review and (hopefully) endorsement of our plans
- acknowledgement about the importance to produce UCN this year

Questions?

TUCAN

TRIUMF Ultra Cold Advanced Neutron source

[360 degree fly over TUCAN]

[360 degree walk through TUCAN source]

Important dates

Shutdown and beam related

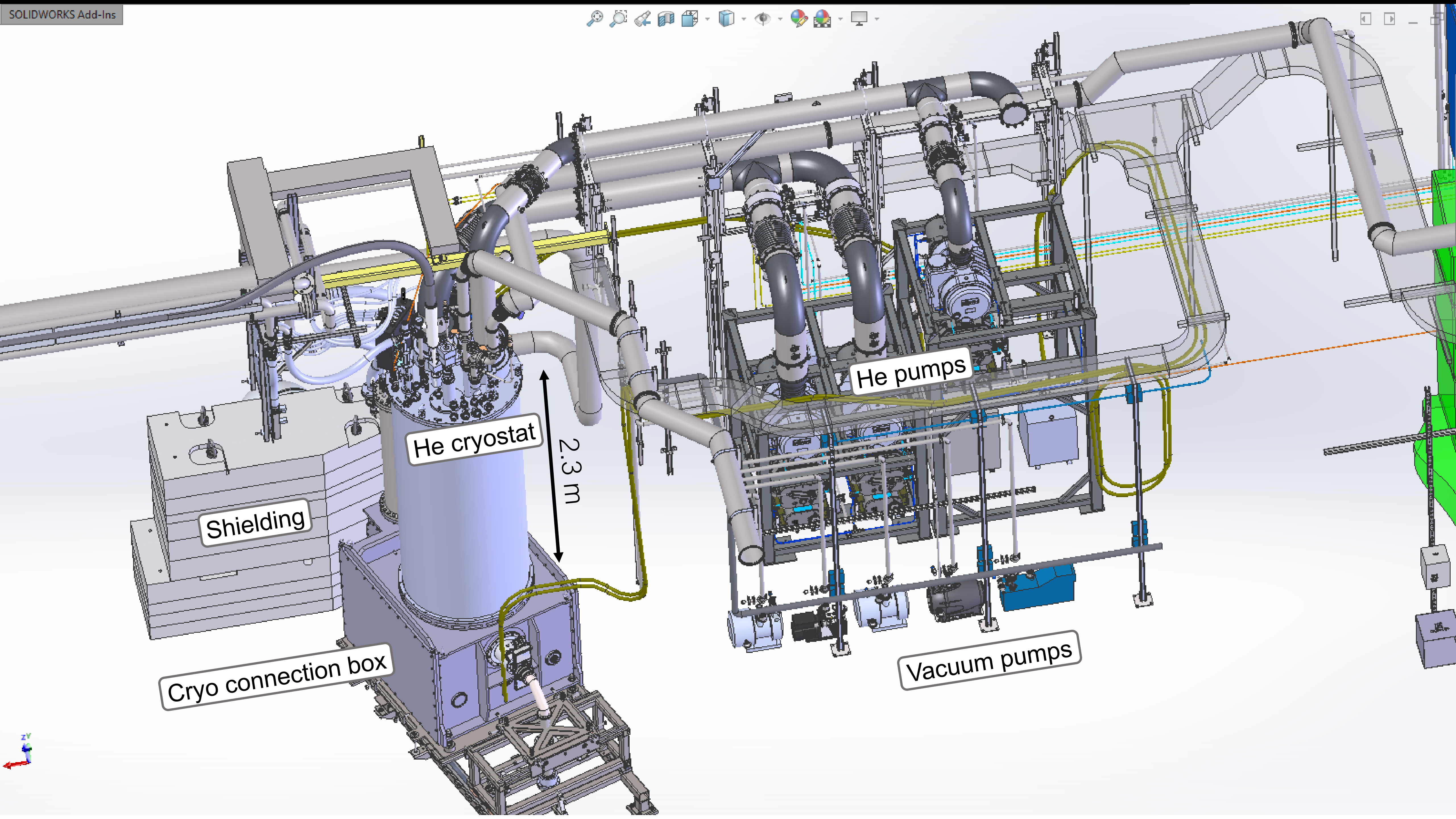
- Block migration into Meson hall: May 15-17 (22-24?)
- Moving UCN blocks inside: right after
- PIF run, limited PIF roof access: May 24 to Jun 2
- BL1A startup: June 4
- First BL1U beam: June 19

Cryogenic and source dates

- 3AS, 3BS cooldowns June 2024
- 3BL July 2024
- 5 August 2024
- UCN production Sept 24 – Oct 1

Beam development shifts:

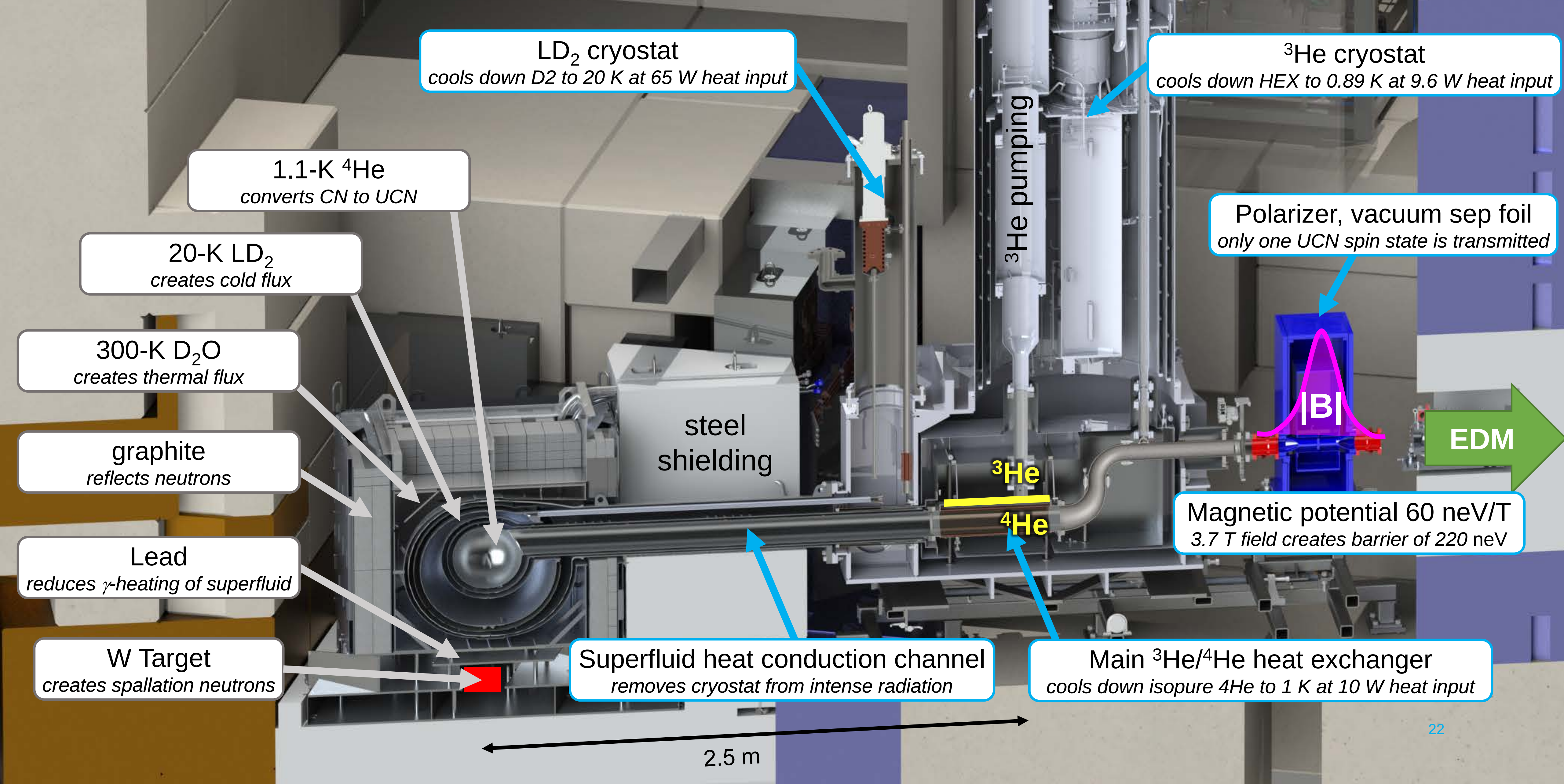
1	Date	Shift(s)	Plan
2	Fri June 14, 2024	DAY, EVE	Commission 1VM5 Beam Halo Monitor, investigate high BSM55 spill levels
3	Wed, June 19 2024	DAY	Re-establish BL1U beam on target (DC, 1 uA), then ramp up current to 5 – 10 uA, commission BPMs, perform RPG surveys at 1, 5 and 10 uA
4	Fri, June 28	DAY	see above
5	Thu, July 4 2024	DAY	Find optimal beam tune for BL1U and BL1A using the UCN kicker, TNIM calibrations kicking and commissioning new kicker sequencing mode
6	Thu, Aug 1 2024	DAY	see above
7	Thu, Aug 8 2024	DAY	see above
8	Thu, Aug 15 2024	DAY	Commission TPM, determine TPM calibration using knife edge method
9	Fri, Aug 23 2024	DAY	see above
10	Thu, Sep 12 2024	DAY	ramp up BL1U current to 40 microA, perform RPG surveys at 10, 20 and 40 uA


SOLIDWORKS Add-Ins
He pumps
He cryostat
2.3 m
Shielding
Cryo connection box
Vacuum pumps

TUCAN
TRIUMF Ultra Cold Advanced Neutron source

TUCAN UCN source components

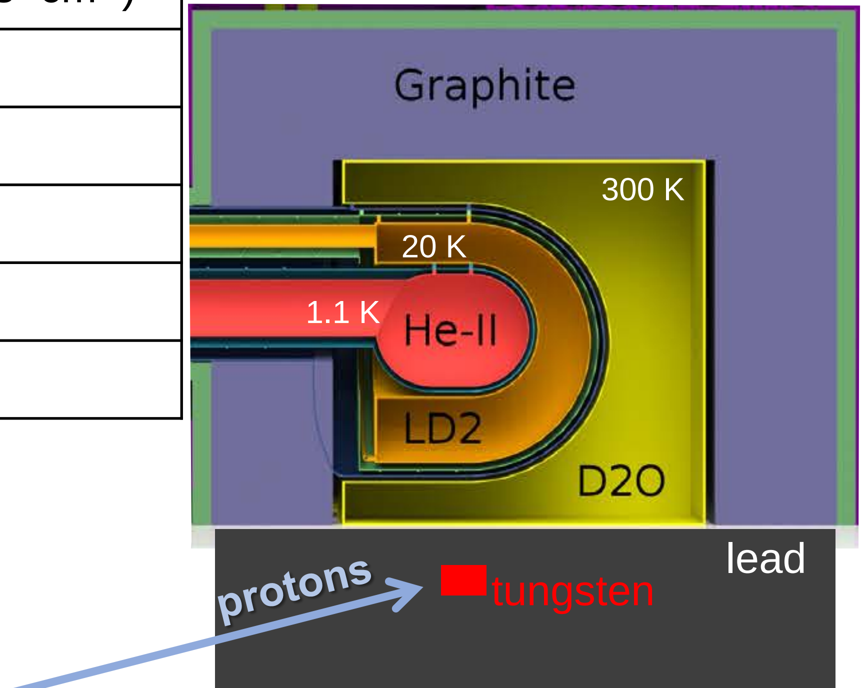
TRIUMF



TUCAN Next generation UCN source strategy

Similar basic layout with major improvements:

Parameter	Prototype source	Next gen source
Beam current	1 μA	40 μA (480 MeV)
Production volume	8 L	27 L
Cold moderator	sD_2O	LD_2
Production rate	$2x10^5$ /s	$1.4\text{-}1.6x10^7$/s (500 $s^{-1}cm^{-3}$)



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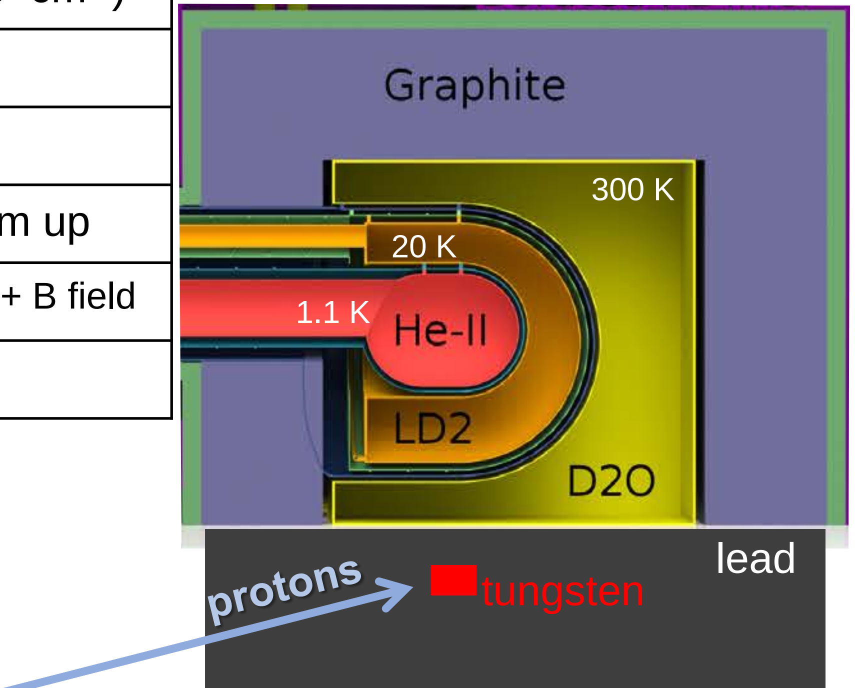
Cooling power	0.3 W	10 W
He-II temperature	0.9 K	1.1 – 1.15 K
Extraction	Vertical by 1.2 m	Near horizontal 0.3 m up
Vacuum separation	No foil	Warm vacuum sep foil + B field
Position of cryostat	On top of source	2.5 m away



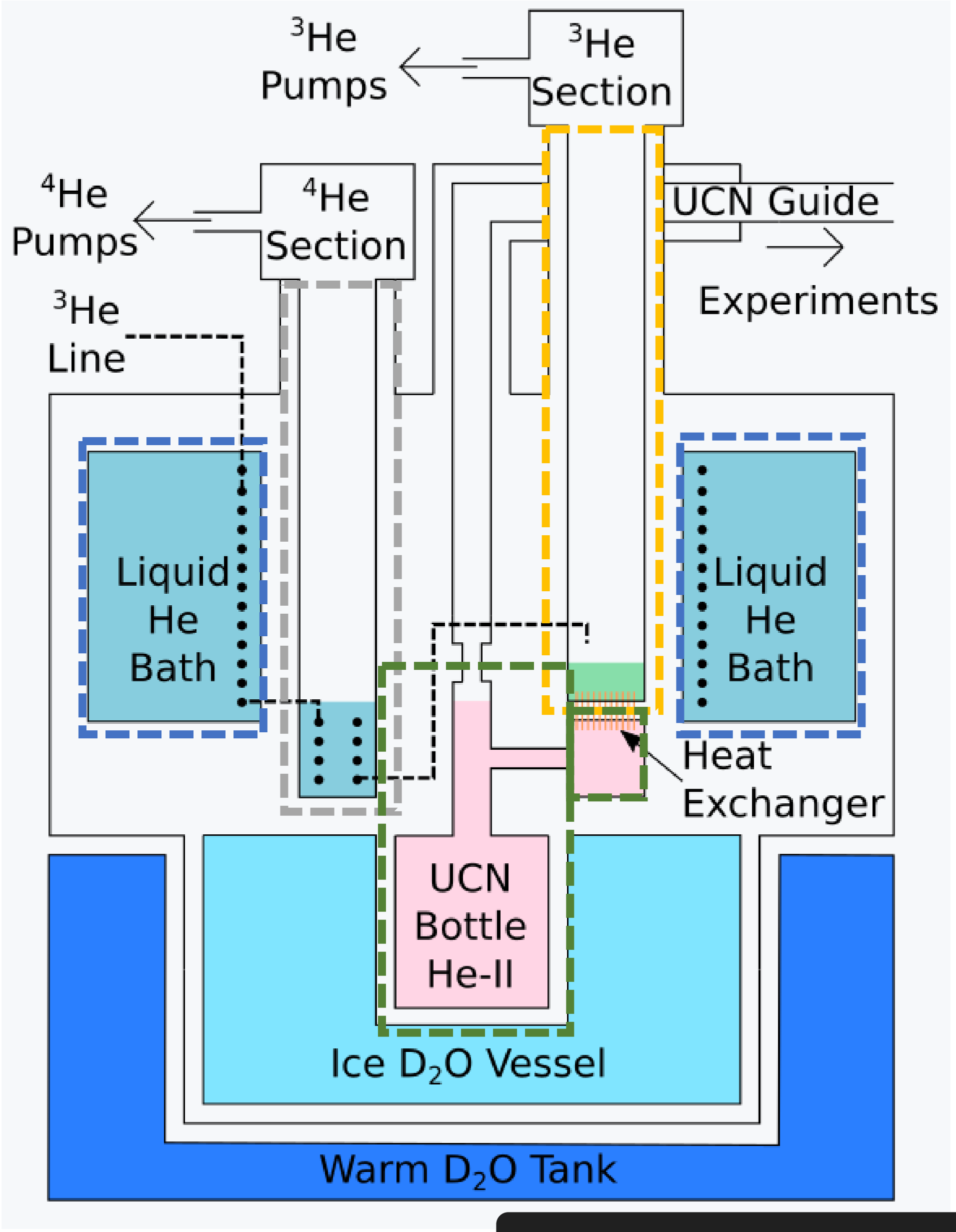
Vertical UCN source cryostat

from KEK/RCNP, Japan

3 cooling stages, heat exchanger to cool isopure ^{4}He UCN converter

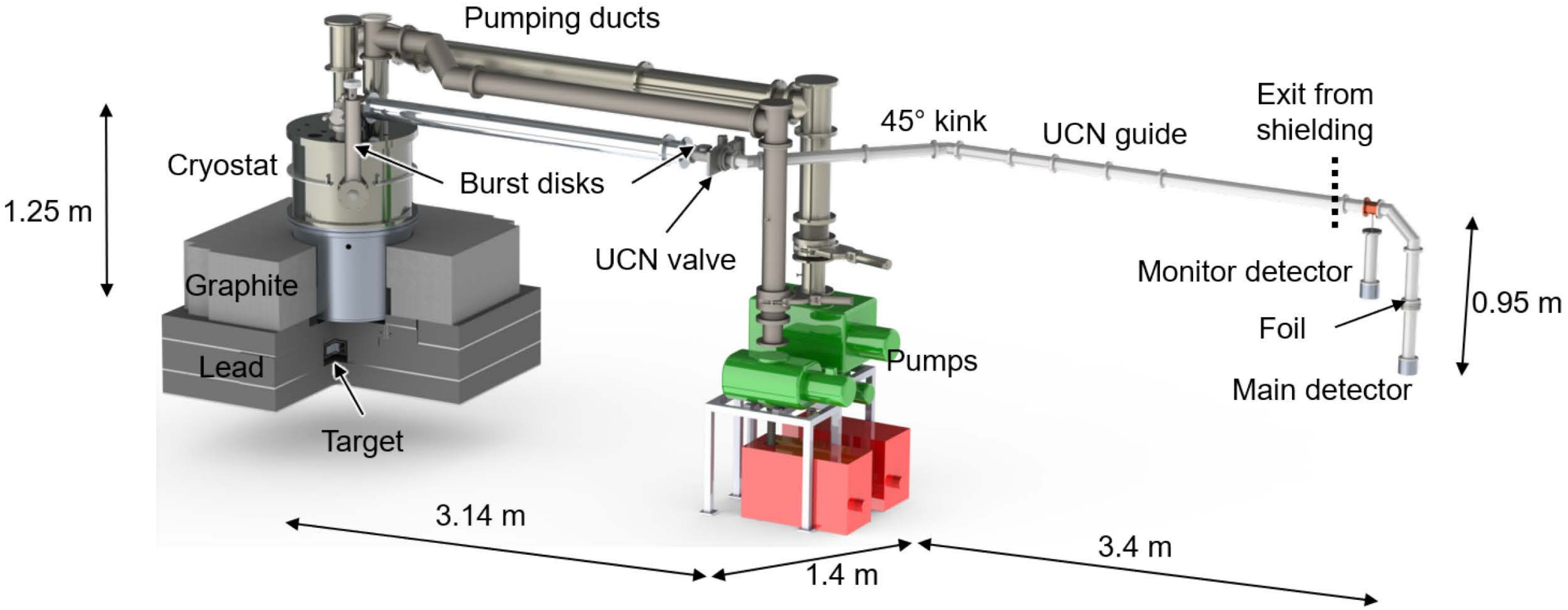
- lHe bath cryostat (4.5 K)
- ^{4}He pumping section (1.4 K)
- ^{3}He pumping section (down to 0.8 K)
- Isopure ^{4}He UCN converter cooled via heat exchanger

⇨ Running nominally at 1 µA beam (as at RCNP).



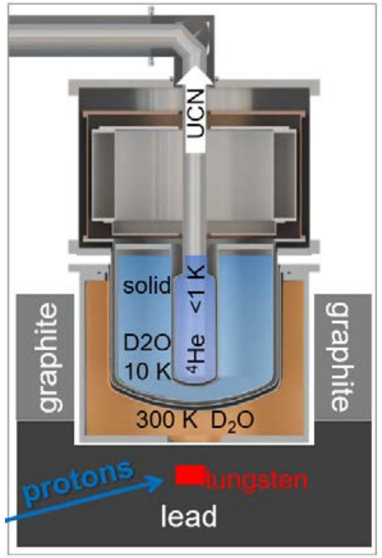
Ryohei Matsumiya, Shinsuke Kawasaki

The vertical source and UCN guides



https://arxiv.org/pdf/1809.04071.pdf

Prototype vs Next gen source



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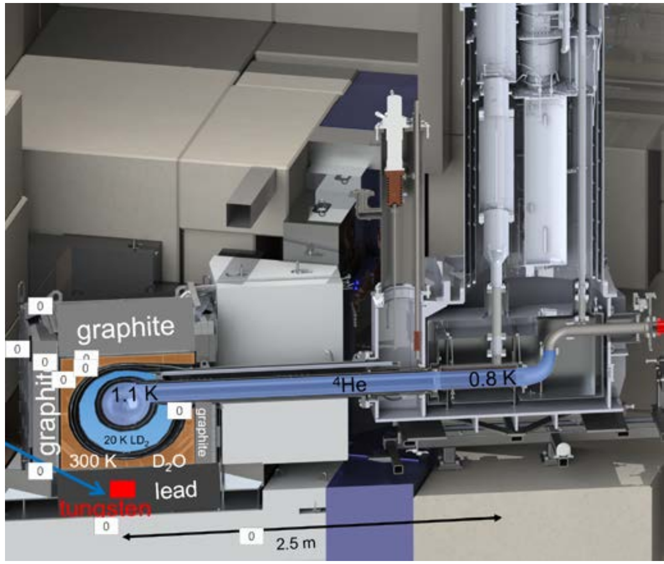


Statistical Comparison

EDM Experiment	published		future					
	ILL-RAL-Sussex	PSI nEDM	PSI n2EDM*	LANL EDM**	panEDM stage I***	panEDM stage II***	TUCAN OC100****	TUCAN 2C200****
UCN detected per cycle	14 000	15 000	121 000	78 000	51800^x	1 380 000^x	846 000	1 420 000
Size	20 l	20 l	116 l	40 l	34 l	34 l	31.5 l	63 l
Density detected (1/cc)	0.7	0.75	1	2	1.5^x	40^x	27	23
Publication	(1)	(2)	(2)	(3)	(4)	(4)		(5)

Bottom cell only

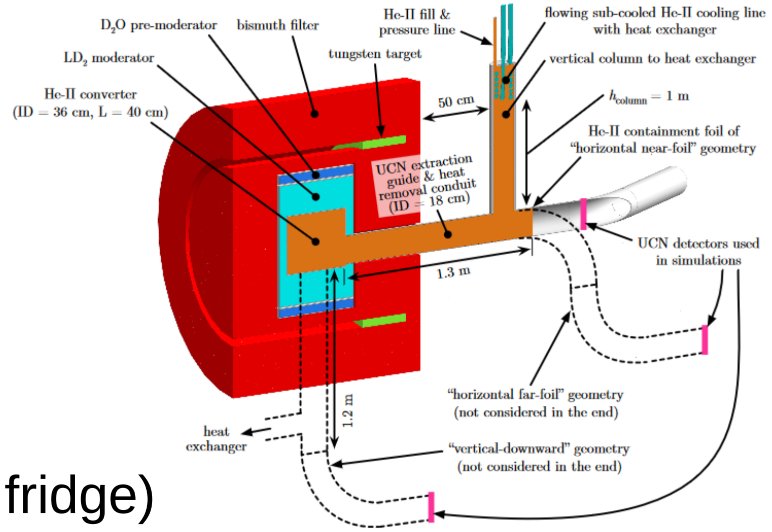
* expected, based on PSI nEDM.
** expected, based on storage expts.
*** estimation based on loss factors
**** expected, extensive MC.
^{x} at end of Ramsey cycle

Steve Sidhu
Source and EDM optimization
Tuesday, 10:50 am

Publications:

(1) C.A. Baker, et al, 2006: http://dx.doi.org/10.1103/PhysRevLett.97.131801
(2) G. Pignol, et al, 2021: https://doi.org/10.21468/SciPostPhysProc.5
(3) T. Ito et al, 2020: http://dx.doi.org/10.1103/PhysRevC.97.012501
(4) D. Wurm, 2021: https://mediatum.ub.tum.de/doc/1631520/1631520.pdf
(5) S. Sidhu et al, 2022: https://doi.org/10.1051/epjconf/202328201015

Some relevant numbers (compared to inverse geometry source)



TUCAN source

(engineering stage)

- Production 1.4-1.6 x 10^7 UCN/s
- Source helium temp 1.03 K to 1.13 K
- Cooling power 10 W (3He fridge)
- Source storage lifetime 28 s
- Figure of merit Pτ = 4.5 x 10^8
- Density in the source 3 x 10^3 UCN/cc
- Total number in the source 3 x 10^8 UCN
- Initial density in 70 l EDM expt 200 UCN/cc
- Counted at the end of cycle 2 x 10^6

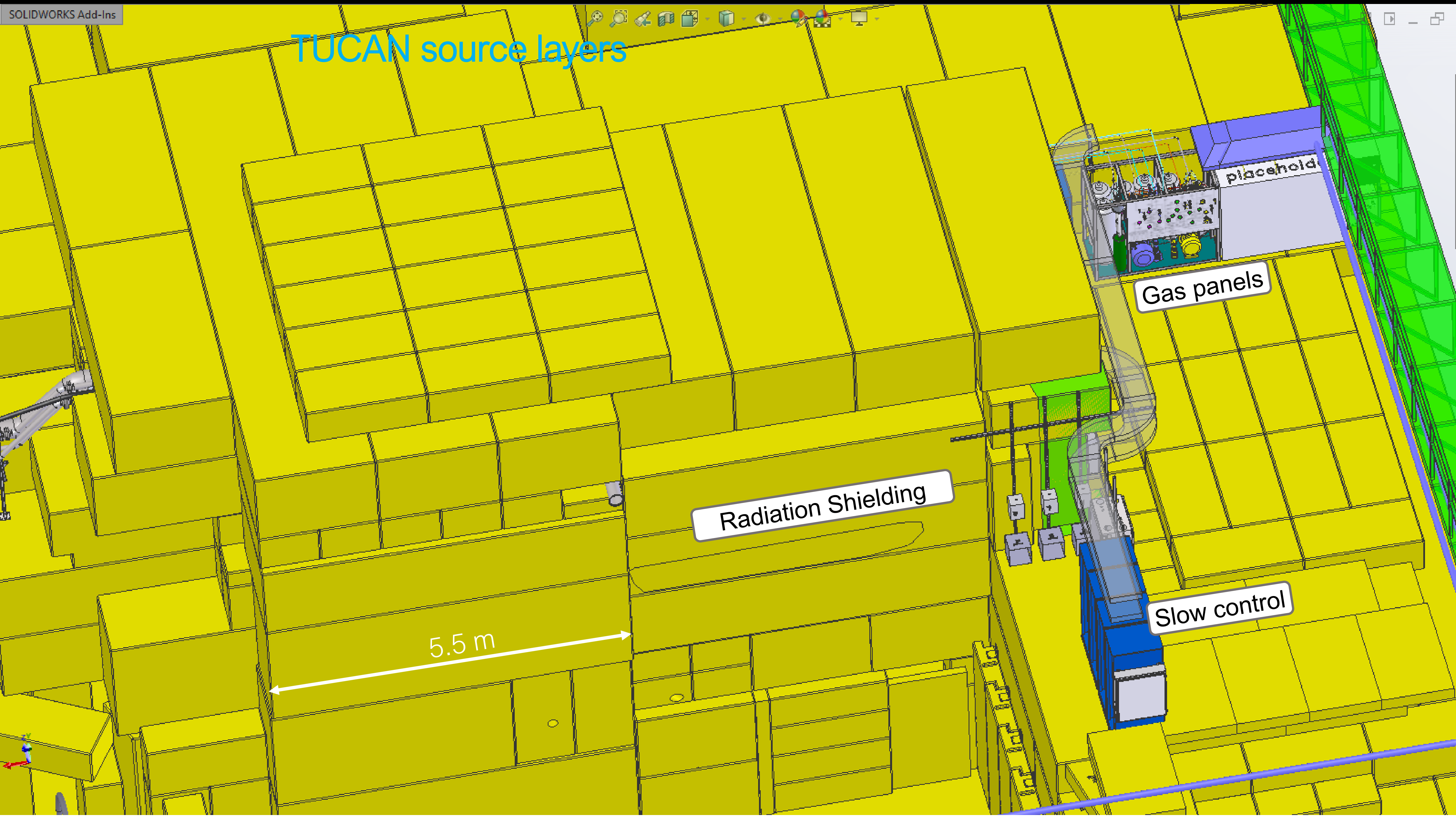
Inverse geometry source

(conceptual stage)

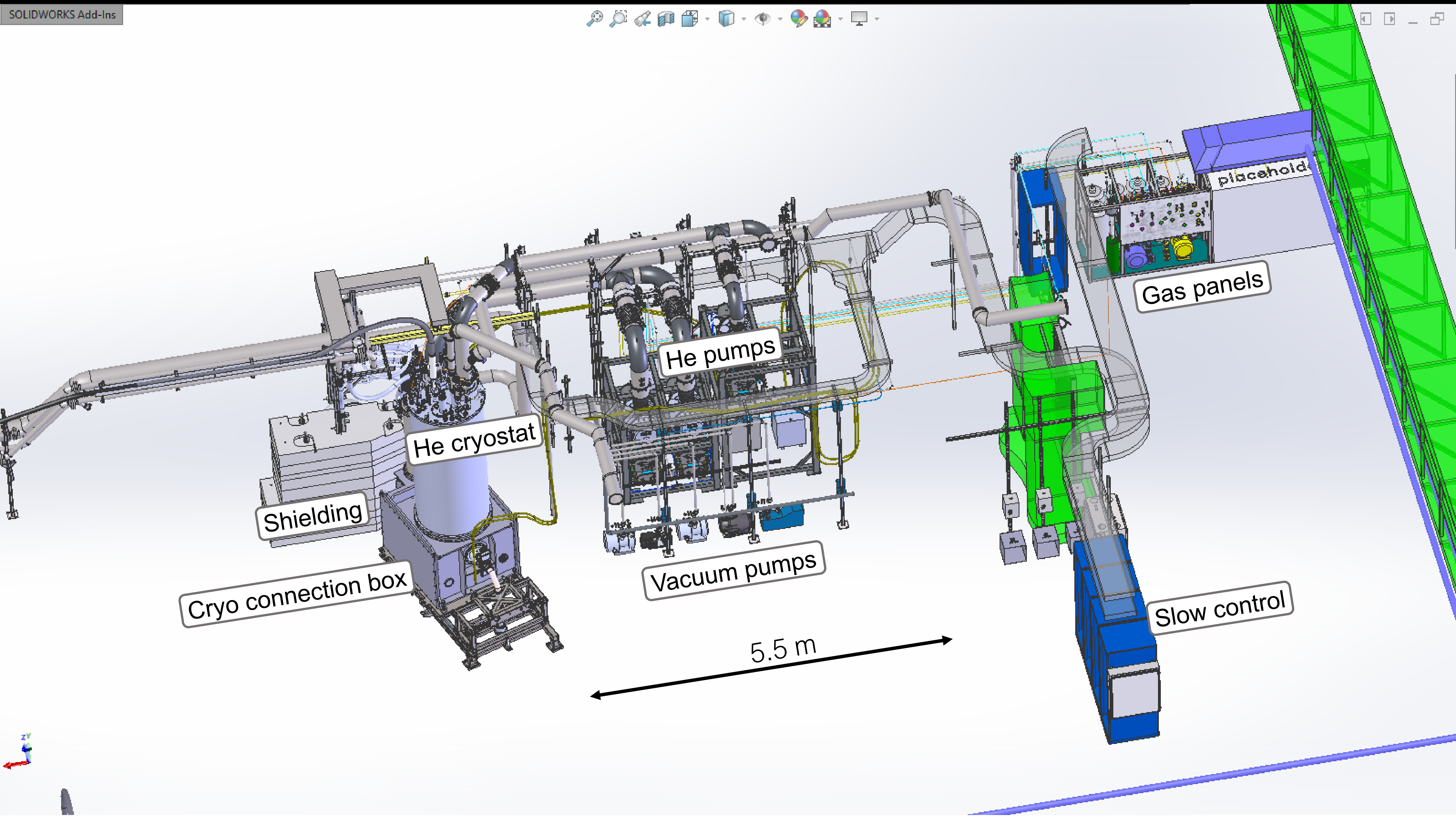
- Production 1.8 x 10^9 UCN/s
- Source helium temp 1.6 K
- Cooling power 100 W (4He fridge)
- Source storage lifetime 2 s
- Figure of merit Pτ = 3.6 x 10^9
- Density in the source 5 x 10^4 UCN/cc
- Total number in the source 6.5 x 10^9 UCN
- Initial density in 100 l perfectly matched expt 10000 UCN/cc

https://arxiv.org/abs/1905.09459

TUCAN source layers




SOLIDWORKS Add-Ins
placehold
Gas panels
He pumps
He cryostat
Radiation Shielding
Slow control
5.5 m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Shielding
Cryo connection box
Vacuum pumps
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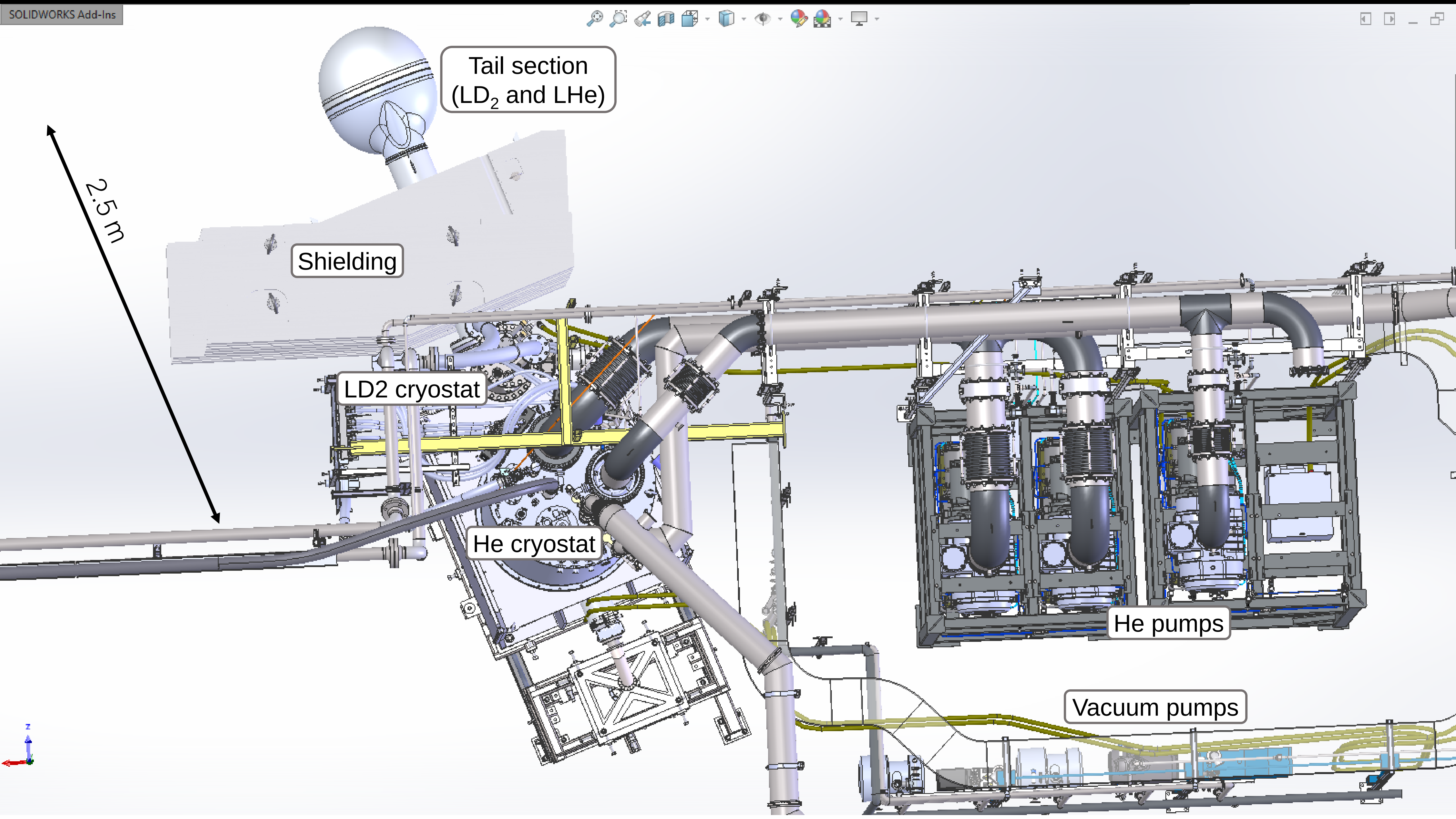
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Tail section
(LD$_2$ and LHe)
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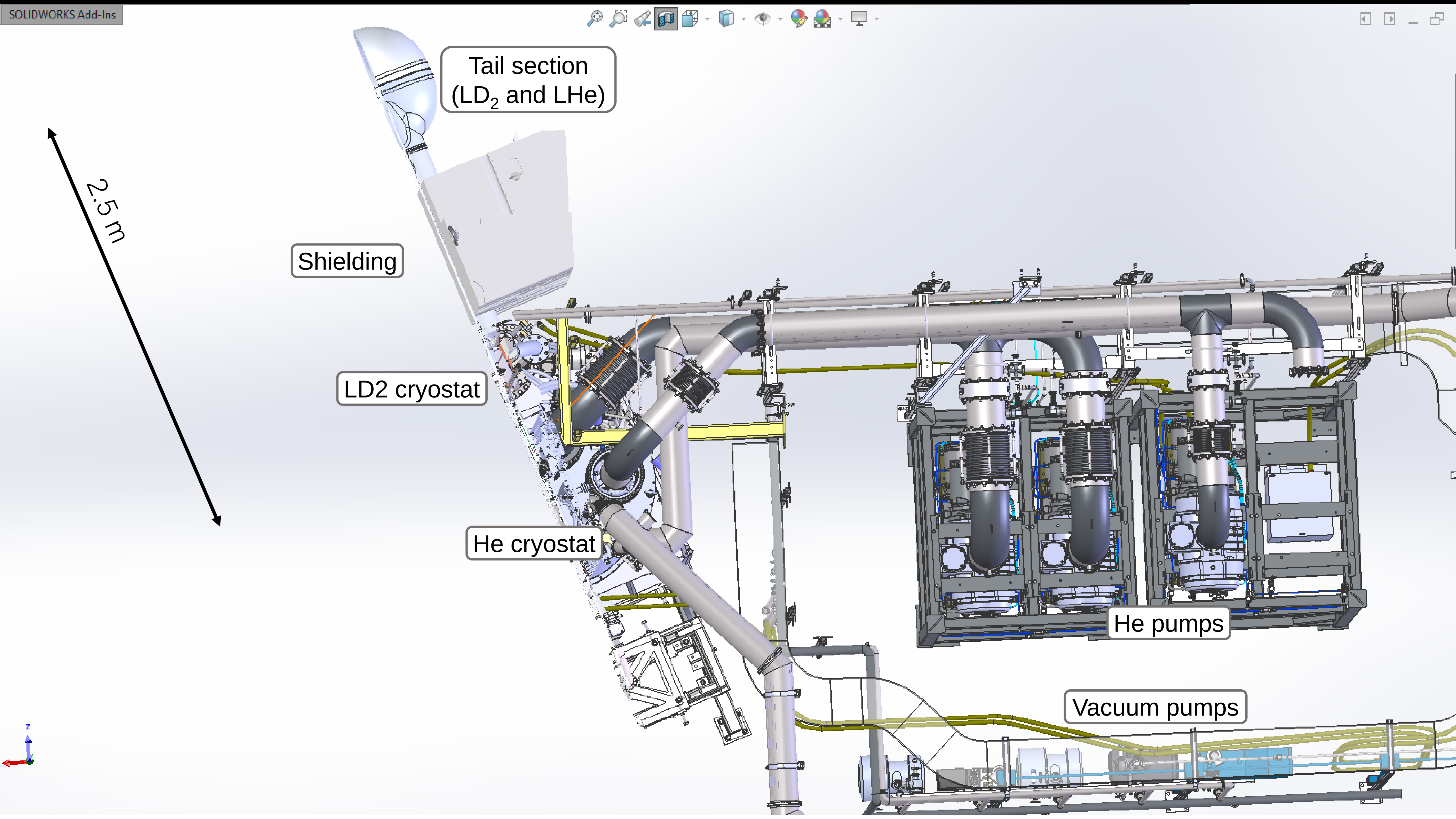
Shielding
LD2 cryostat
He cryostat
He pumps
Vacuum pumps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