TUCAN

TRIUMF Ultra Cold Advanced Neutron source

World’s highest intensity UCN source at TRIUMF

Alexis Brossard
On behalf of the TUCAN collaboration

February 27, 2026
PAINT 2026 - TRIUMF

Ultracold neutrons

Ultra Cold Neutron (UCN)

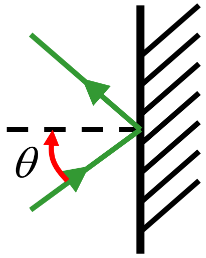
Ultracold neutrons are free neutrons **reflected** from some material surface under **all angles of incidence**.
They can be stored using:

Strong force

$$V_F(\vec{r}) = \frac{4\pi\hbar^2}{2m}\sum_i a_i\,\delta(\vec{r} - \vec{r_i}')$$

Material	V_F (neV)	v (m/s)
Al	54	3.2
^{58}Ni	350	8.2
Graphite	180	5.9
Stainless Steel	188	6
DLC	282	7.3

$E_{kin} < V_F$:



They have very low kinetic energy, about **300 neV** corresponding to ~3.5 mK.

Ultra Cold Neutron (UCN)

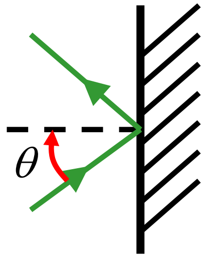
Ultracold neutrons are free neutrons **reflected** from some material surface under **all angles of incidence**.
They can be stored using:

Strong force

$$V_F(\vec{r}) = \frac{4\pi\hbar^2}{2m}\sum_i a_i\,\delta(\vec{r} - \vec{r}_i{}')$$

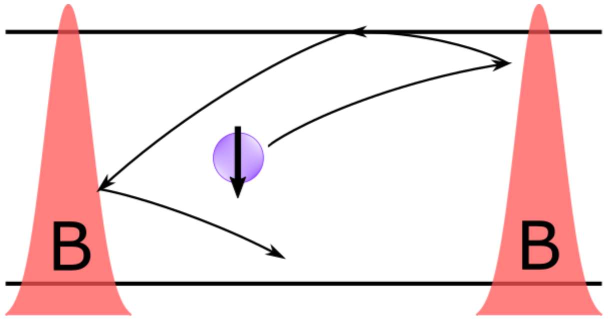
Material	V_F (neV)	v (m/s)
Al	54	3.2
^{58}Ni	350	8.2
Graphite	180	5.9
Stainless Steel	188	6
DLC	282	7.3

$E_{kin} < V_F$:



Magnetic field

$$\mu_N = 60.3\ \frac{\text{neV}}{\text{T}}$$



They have very low kinetic energy, about **300 neV** corresponding to ~3.5 mK.

Ultra Cold Neutron (UCN)

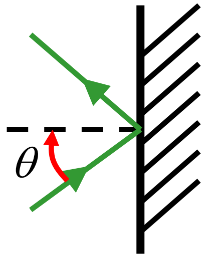
Ultracold neutrons are free neutrons **reflected** from some material surface under **all angles of incidence**.
They can be stored using:

Strong force

$$V_F(\vec{r}) = \frac{4\pi\hbar^2}{2m} \sum_i a_i \, \delta(\vec{r} - \vec{r_i}')$$

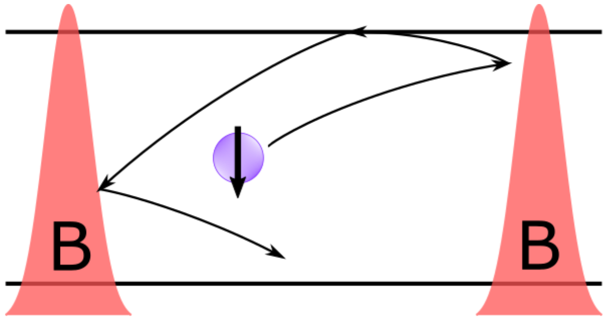
Material	V_F (neV)	v (m/s)
Al	54	3.2
^{58}Ni	350	8.2
Graphite	180	5.9
Stainless Steel	188	6
DLC	282	7.3

$$E_{kin} < V_F :$$



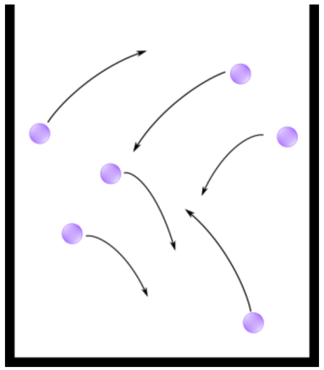
Magnetic field

$$\mu_N = 60.3 \ \frac{\text{neV}}{\text{T}}$$



Gravity

$$V_g = m_n g z = \left(102.5 \ \frac{\text{neV}}{\text{m}}\right) z$$



They have very low kinetic energy, about **300 neV** corresponding to ~3.5 mK.

What to do with UCN?

- Measuring the neutron electric dipole moment. Test of CP violation, baryon asymmetry.
- Measuring the neutron lifetime. Test of CKM unitarity, Big Bang nucleosynthesis, lifetime puzzle.
- Beta decay parameter.
- Studying neutrons and gravity.

The TUCAN source

UCN production

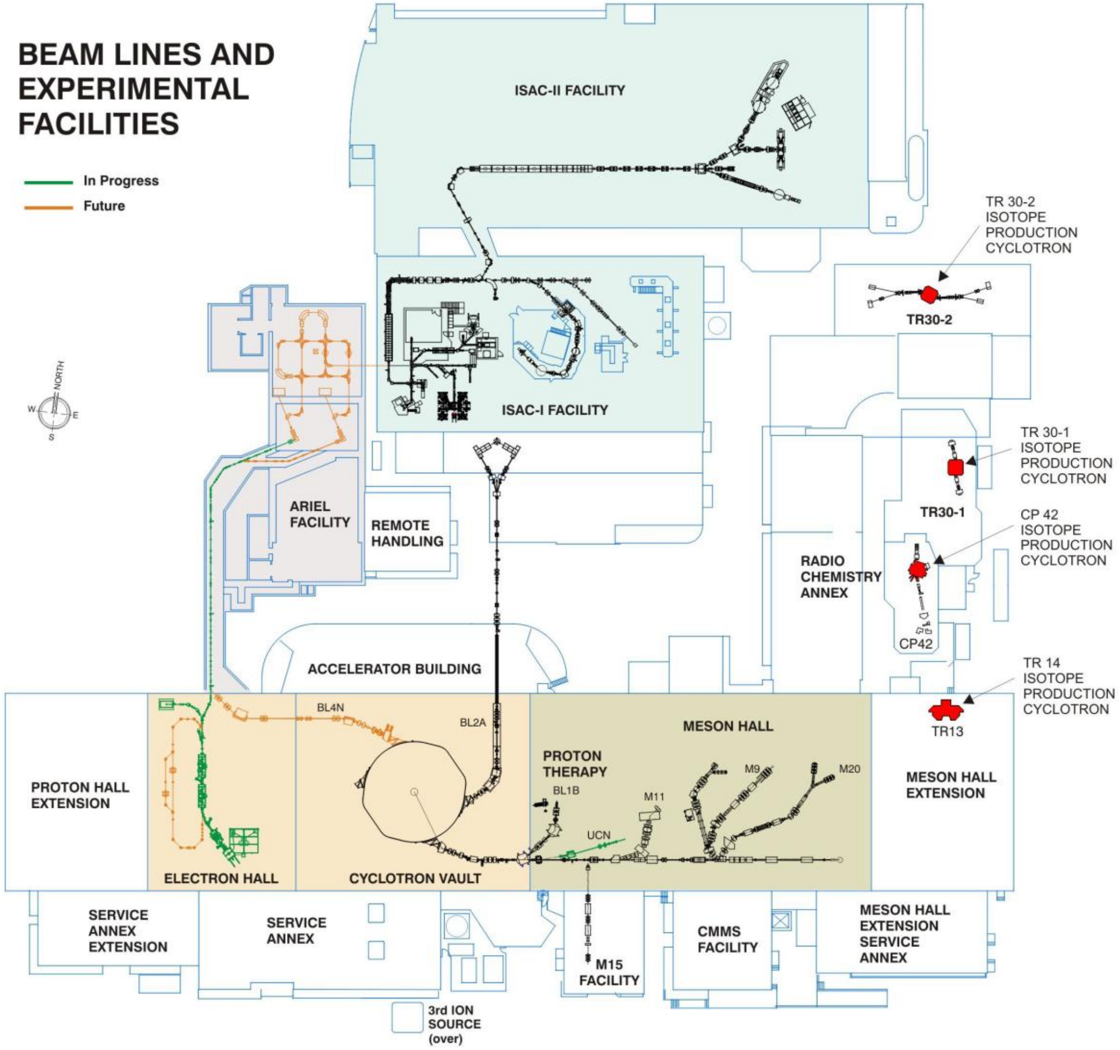
Step 1: High energy protons hit a spallation target.

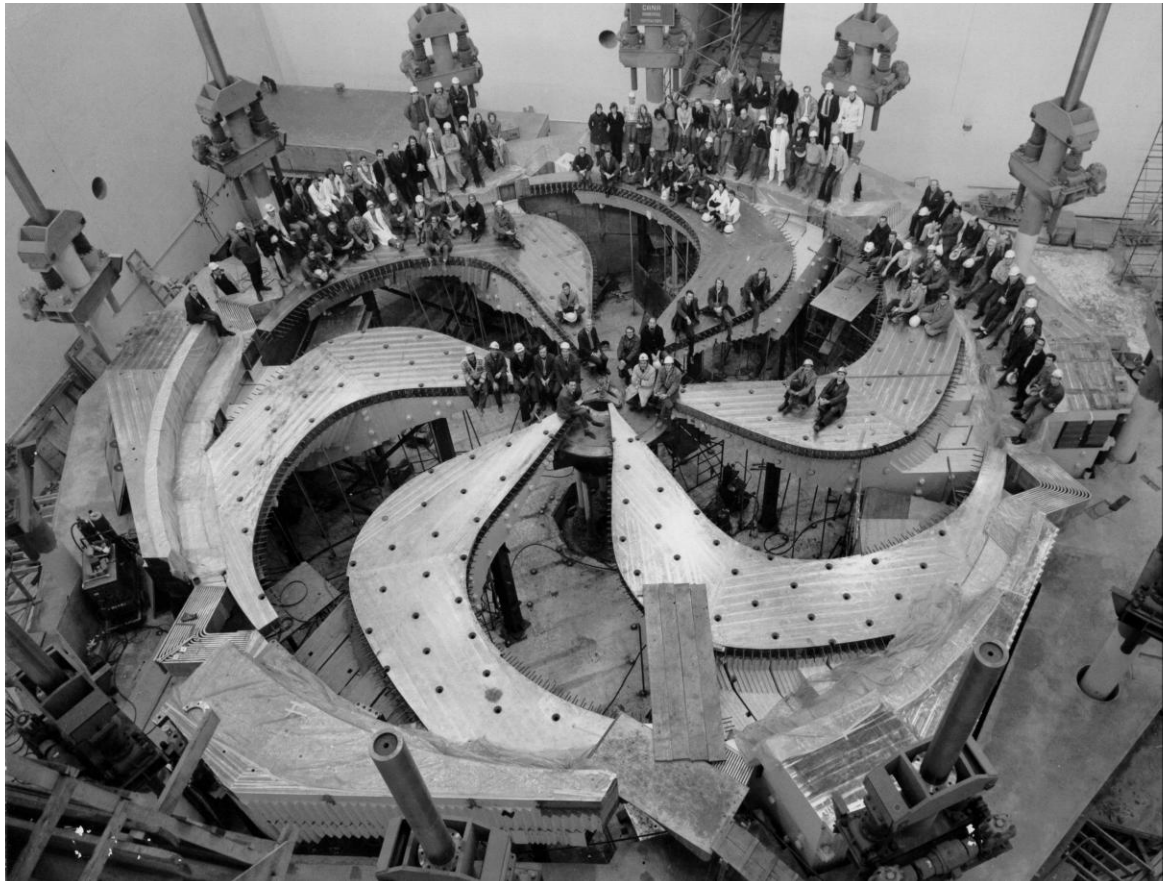
Fire a proton on a high Z target

Excited Nucleus

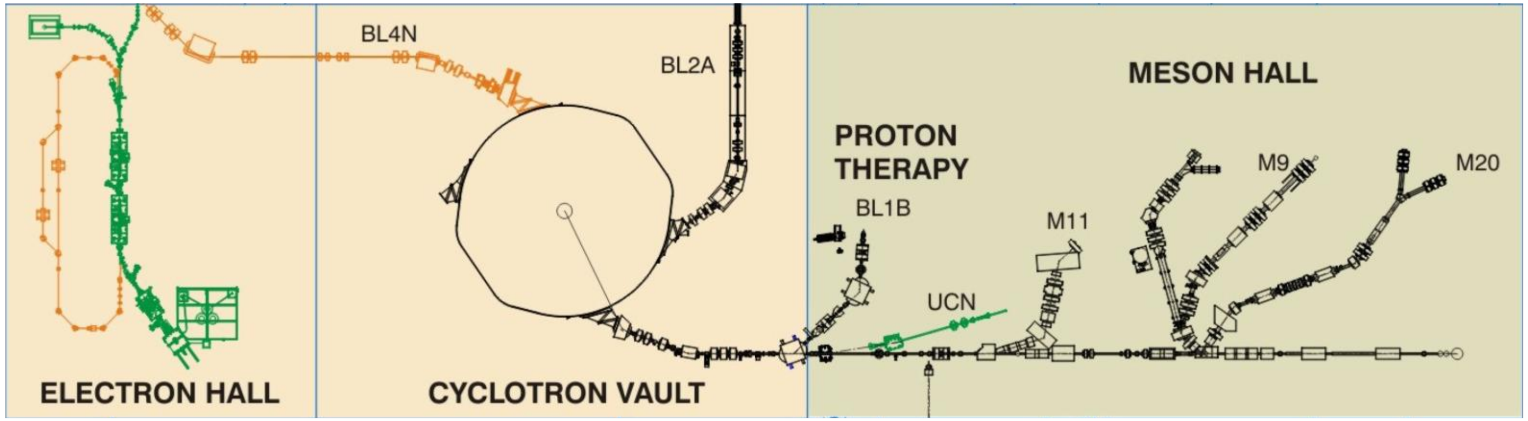
Nucleus de-excites (10^{-12}-10^{-14} s), releasing MeV neutrons

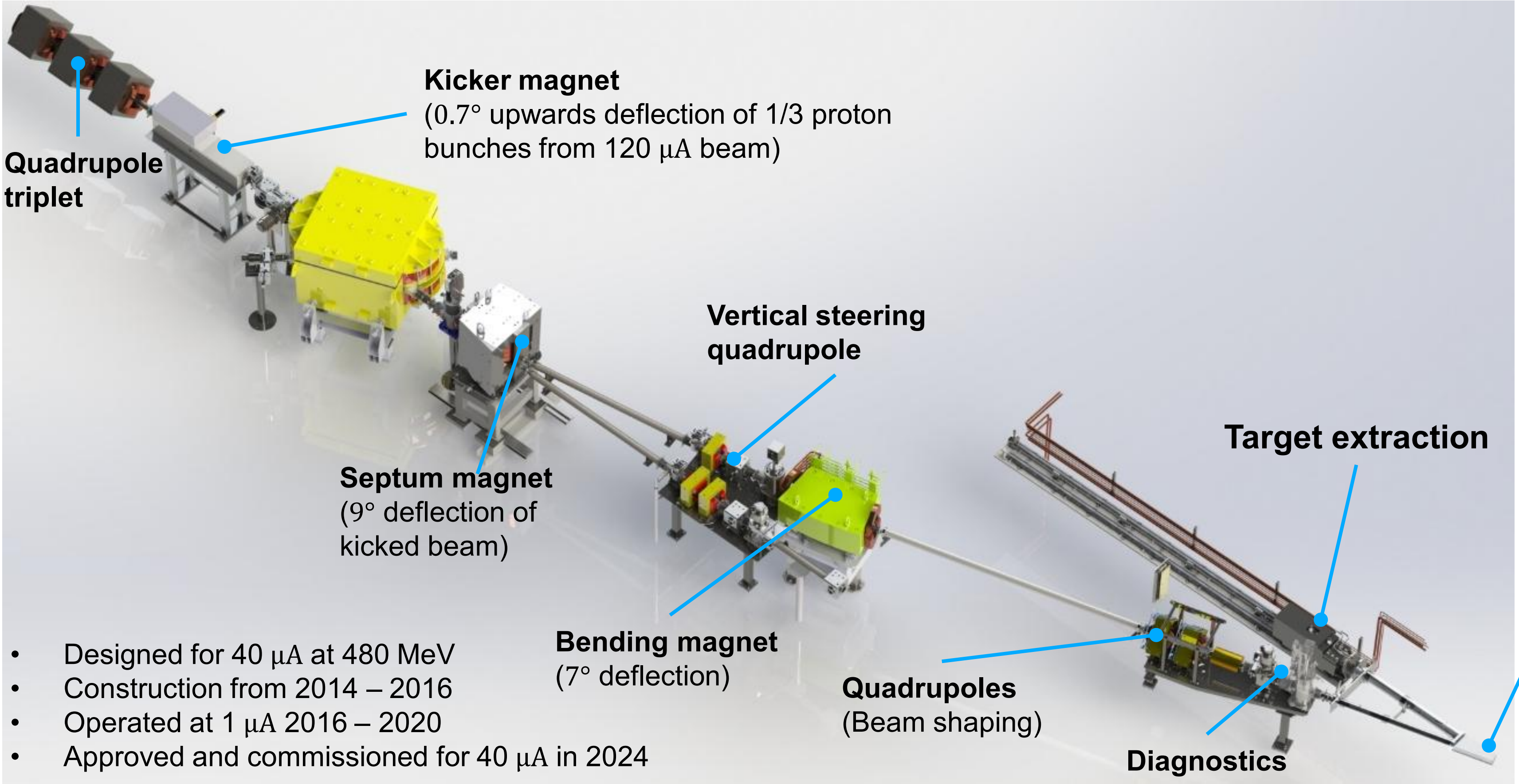
Step 1: High energy protons hit a spallation target.



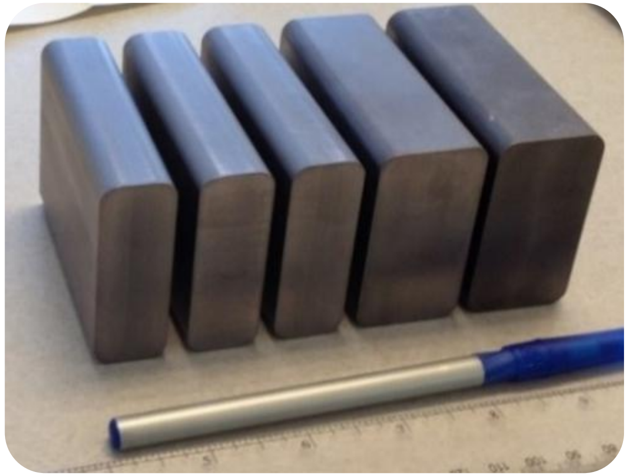


Step 1: Kicking (high energy) neutrons out of nucleus

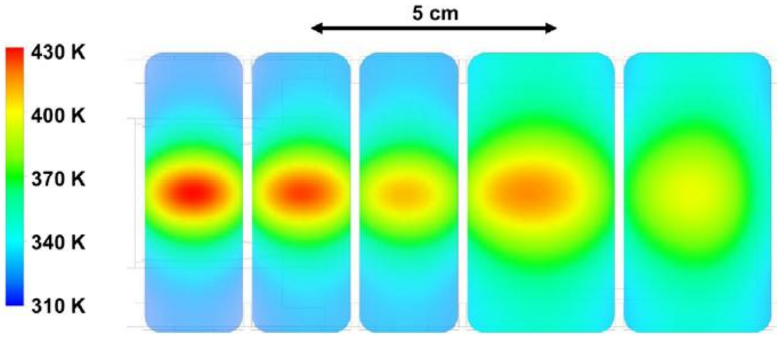




- Designed for 40 μA at 480 MeV
- Construction from 2014 – 2016
- Operated at 1 μA 2016 – 2020
- Approved and commissioned for 40 μA in 2024



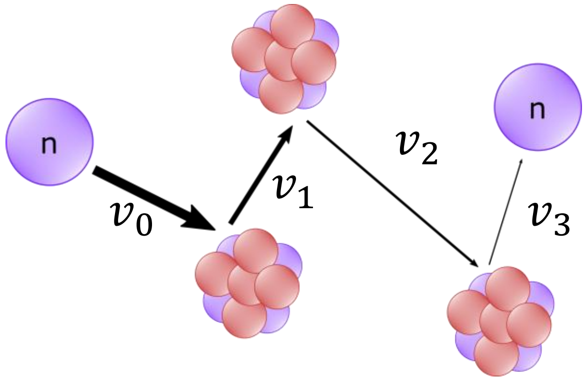
Tantalum-clad tungsten target



Temperature profile at the center of the target.

UCN production

Step 2: Moderation by elastic scattering.

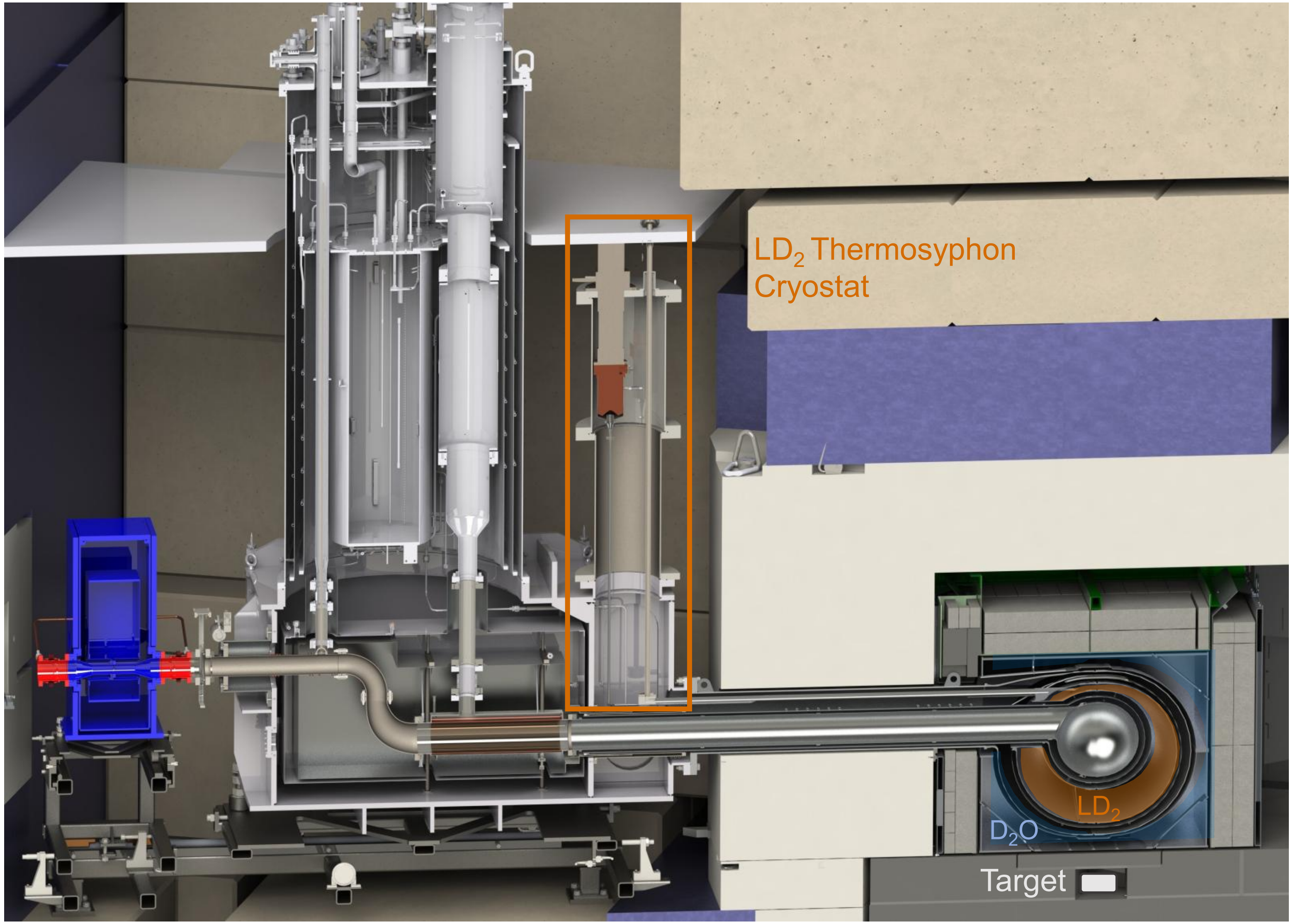


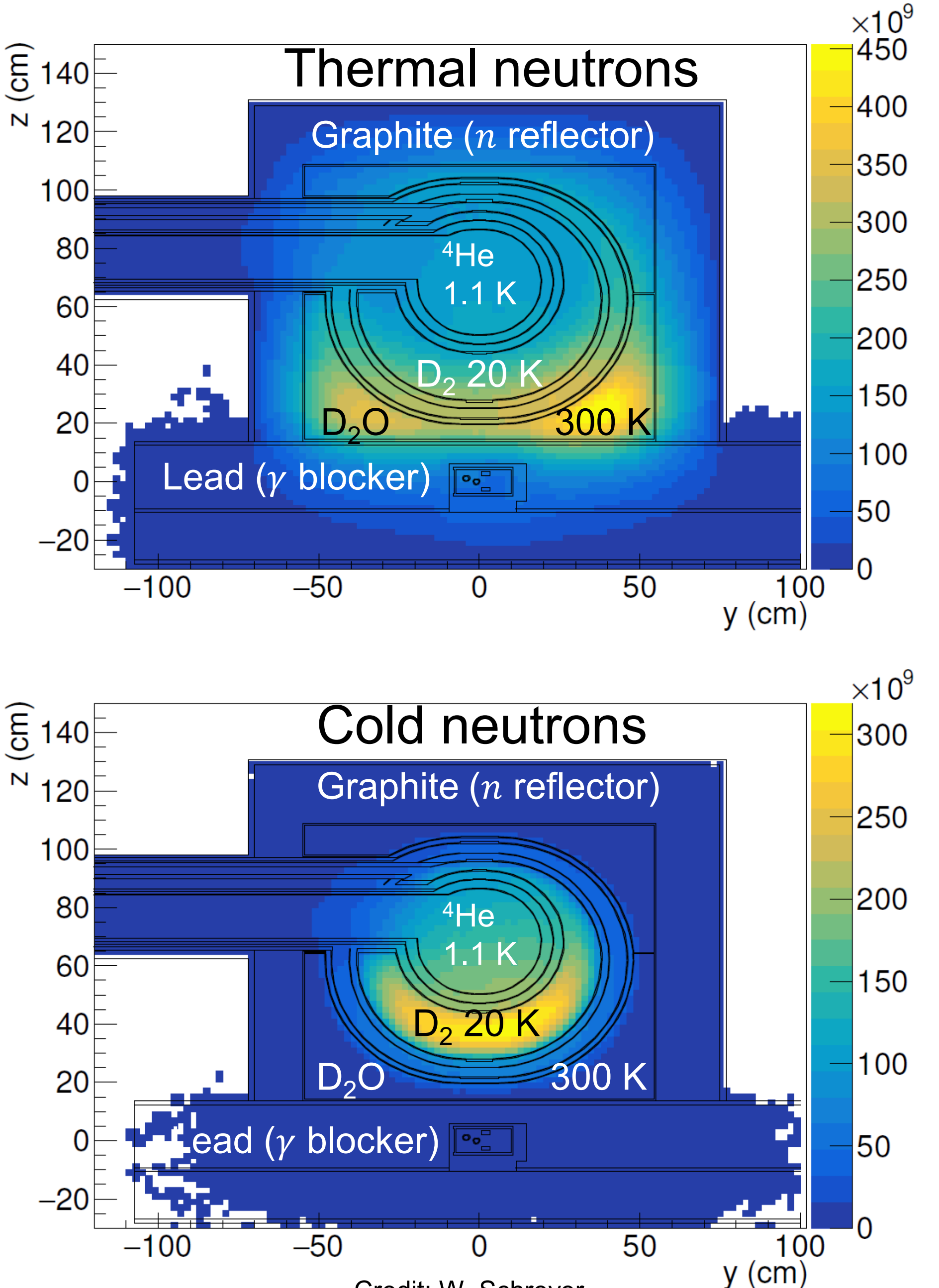
$$v_0 > v_1 > v_2 > v_3$$

Step 2: Moderation by elastic scattering.

The moderation is made in:

- 546 L of room temperature **heavy water**
- 125 L of 20 K **liquid deuterium**



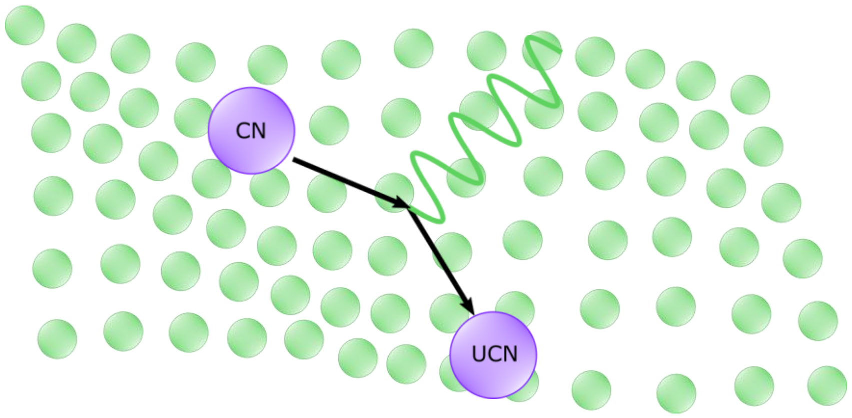


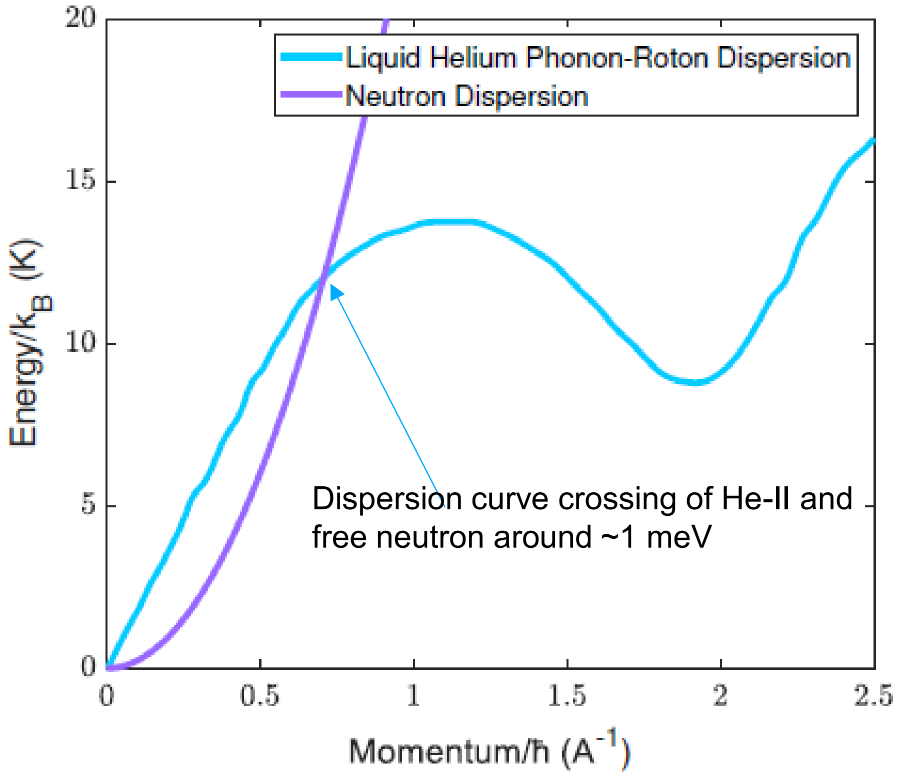
Credit: W. Schreyer

UCN production

Step 3: Superthermal conversion to UCNs

Neutrons with $E \approx 1$ meV can transfer their energy to an excitation of the scattering medium, a phonon.

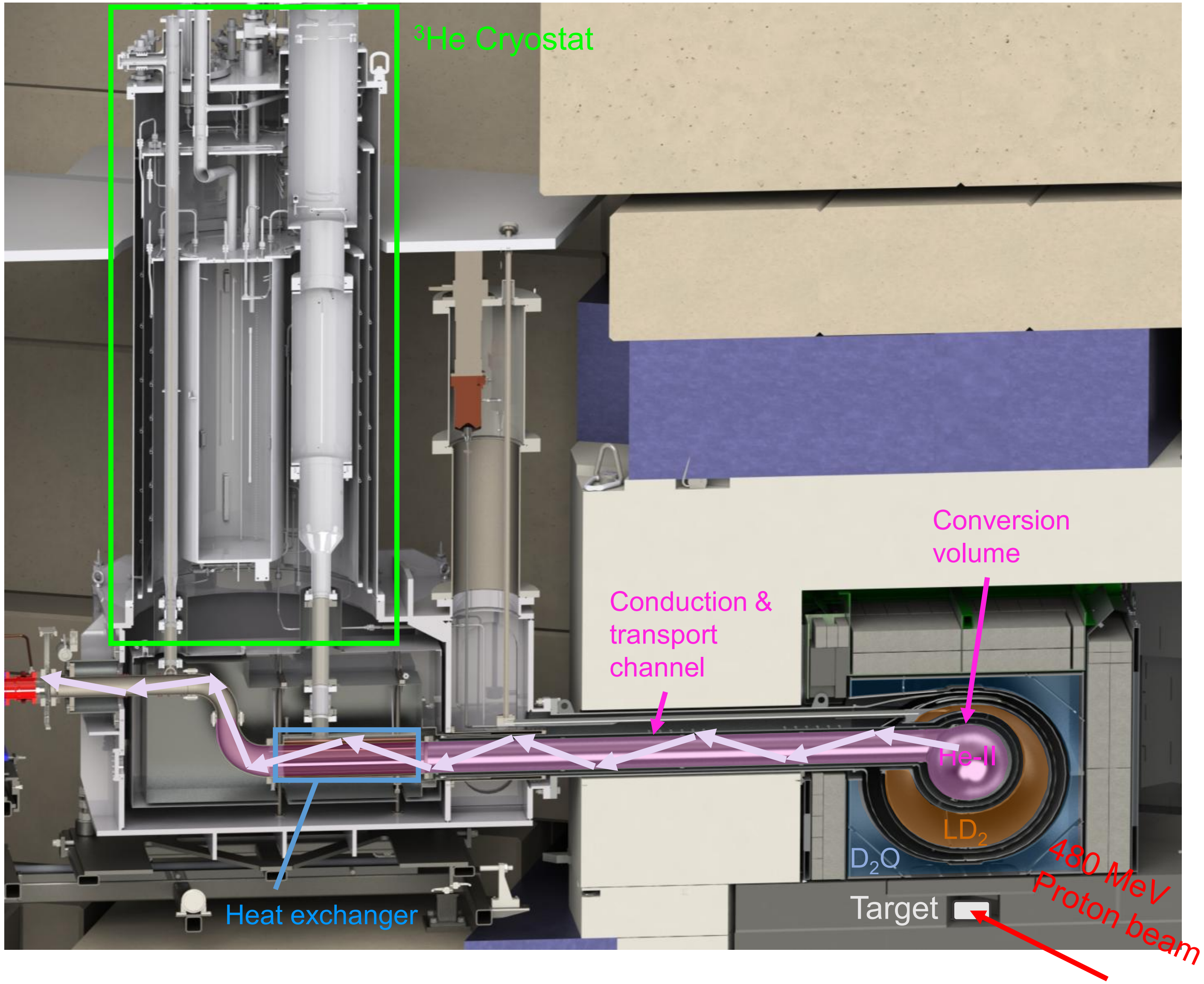




Step 3: Superthermal conversion to UCNs

Cold neutrons are converted to UCN in isopure ^{4}He kept below 1.1 K and diffuse in transport channel towards experimental area. Neutron loss by phonon absorption is proportional to T^7.

The temperature of the isopure ^{4}He, exposed to 10 W of beam heat load is kept by the ^{3}He cryostat connected and the heat exchanger.



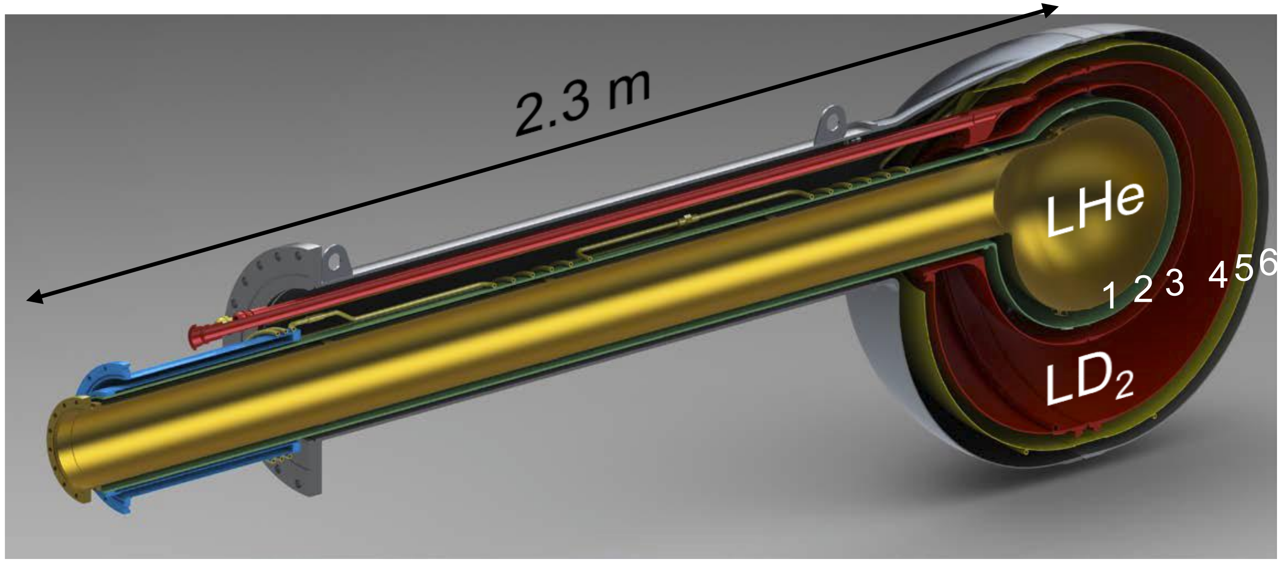
The tail section

- Build at TRIUMF

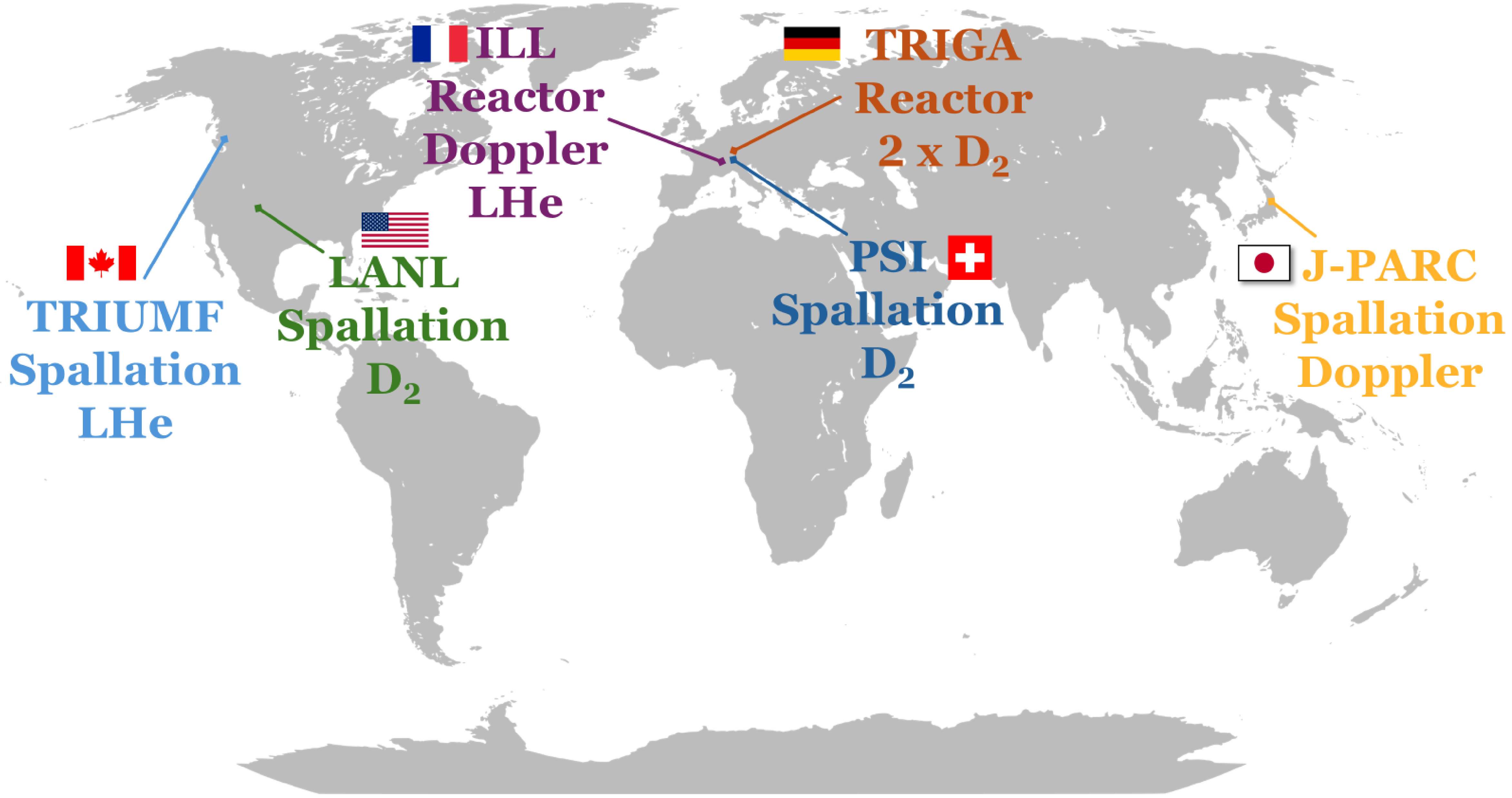
- Six welded aluminium layers
  1. Superfluid He vessel
  2. He/D2 vacuum separation (able to withstand 21 bar D2 explosion pressure) and 20 K thermal shield
  3. Inner LD2 vessel wall
  4. Outer LD2 vessel wall
  5. 100 K thermal shield
  6. Outer vacuum vessel

- Layer 1 completed and UCN storage lifetime validated at LANL in December 2020 (https://doi.org/10.1016/j.nima.2023.168106)

- Layer 6 welding and installation completed April 2024



UCN sources:


ILL
Reactor
Doppler
LHe
TRIGA
Reactor
2 x D_2
TRIUMF
Spallation
LHe
LANL
Spallation
D_2
PSI
Spallation
D_2
J-PARC
Spallation
Doppler

2025 first UCN production

Timeline:

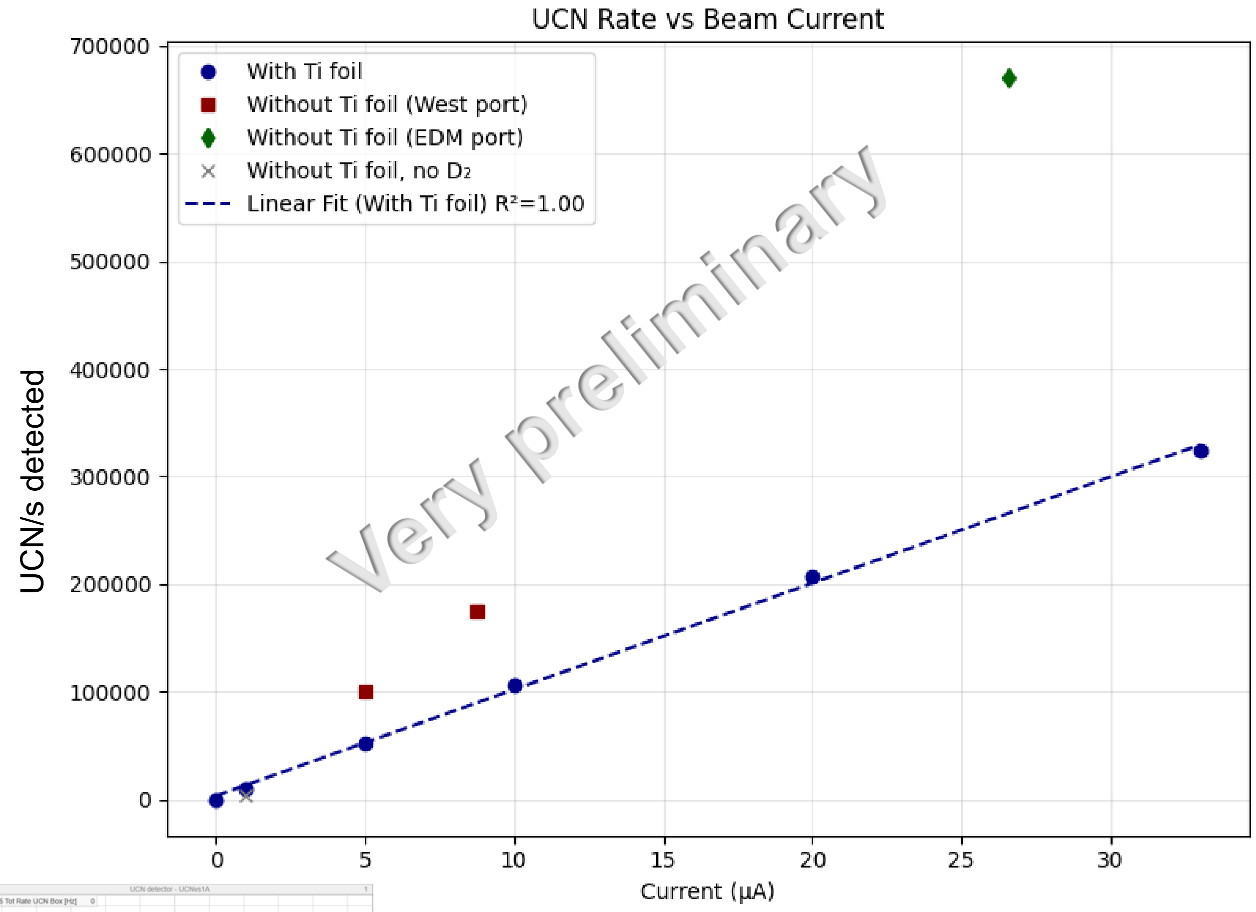
- 2009: project initiation
- 2014-2016: construction of the proton beamline and spallation target.
- 2017-2021: prototype UCN source from RCNP, Osaka, installed. First UCN production at TRIUMF.
- 2020-2025: new TUCAN source construction and installation.
- 2024: First UCN production attempt failed.
- June 2025: First UCN production without LD2 moderator.
- December 2025: UCN production with complete source.
- January 2026: First storage in experimental area.

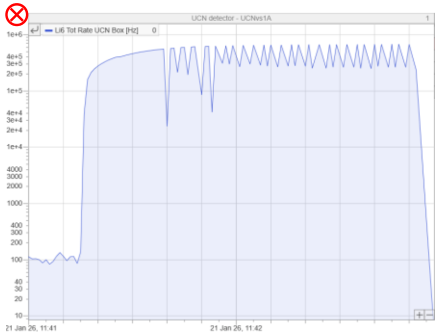
Continuous UCN production:

- UCN valve open during spallation target irradiation
- 3.25 x 10^5 UCN/s detected at 33 μA with 0.15 μm Ti foil
- **6.7 x 10^5 UCN/s** detected at 26.6 μA without foil DAQ saturated⊗

Comparison:
- ILL PF2 source 2.6 x 10^4 UCN/s[a]
- SuperSUN 2.1 x 10^4 UCN/s[b]

[a] PF2 webpage: www.ill.eu/
[b] S. Degenkolb et al, 2025: https://doi.org/10.48550/arXiv.2504.13030

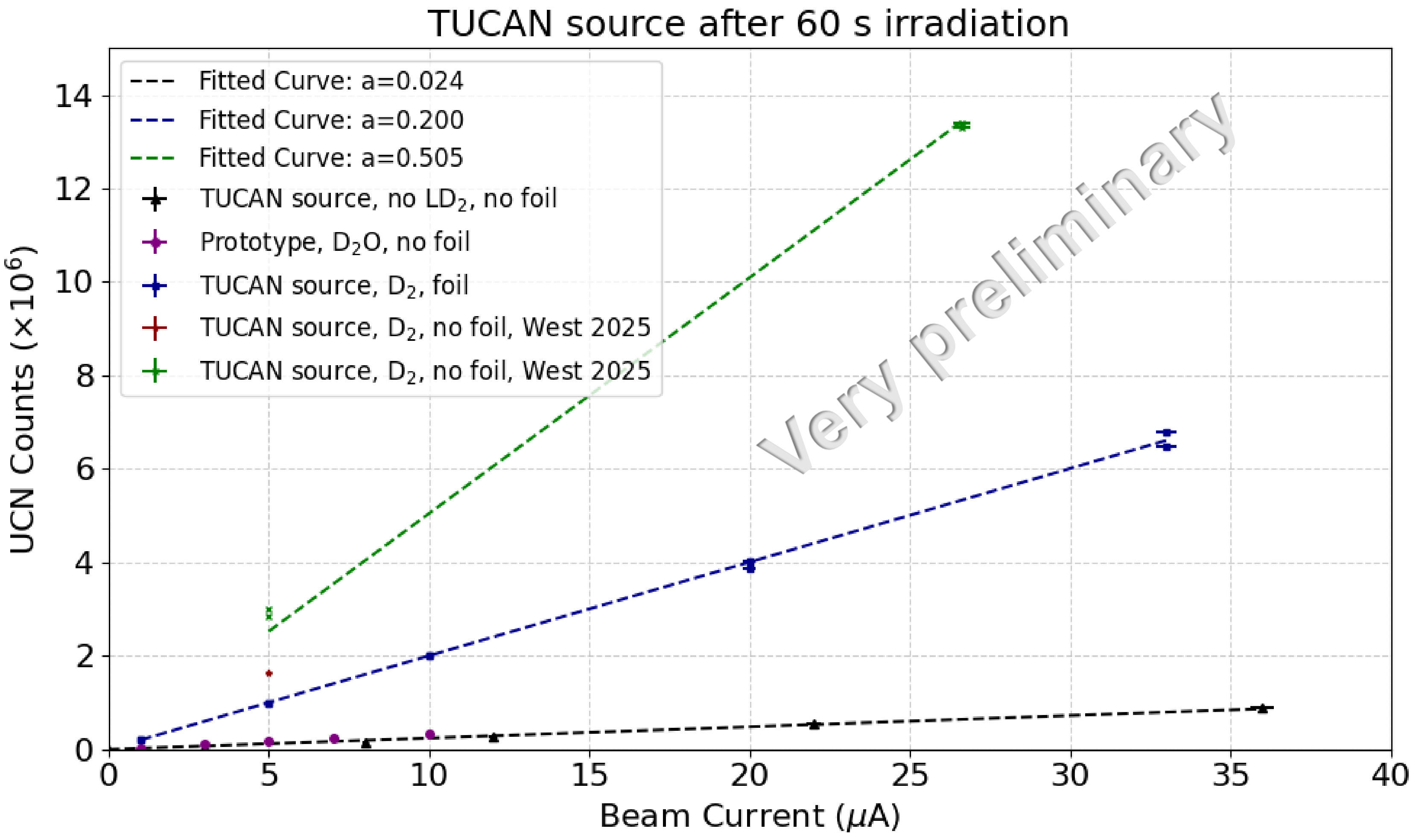


⊗


60 s stored production:

- 1.3 x 10^7 UCN counted after 60s irradiation at 26.6 μA.
- DAQ saturation at higher current.

Comparison per shot:
- PSI 5.5 x 10^7 UCN[a]
- SuperSUN 3.9 x 10^6 UCN[b]
- Mainz 5.4 x 10^5 UCN[c]
- LANCSE 10^7 UCN ??[d]



[a] G. Bison et al, 2020: https://doi.org/10.1140/epja/s10050-020-00027-w
[b] S. Degenkolb et al, 2025: https://doi.org/10.48550/arXiv.2504.13030
[c] J. Karch et al, 2014: https://arxiv.org/abs/1308.4610
[d] T. Ito et al, 2020: http://dx.doi.org/10.1103/PhysRevC.97.012501 ⇒ rough estimate from density in source

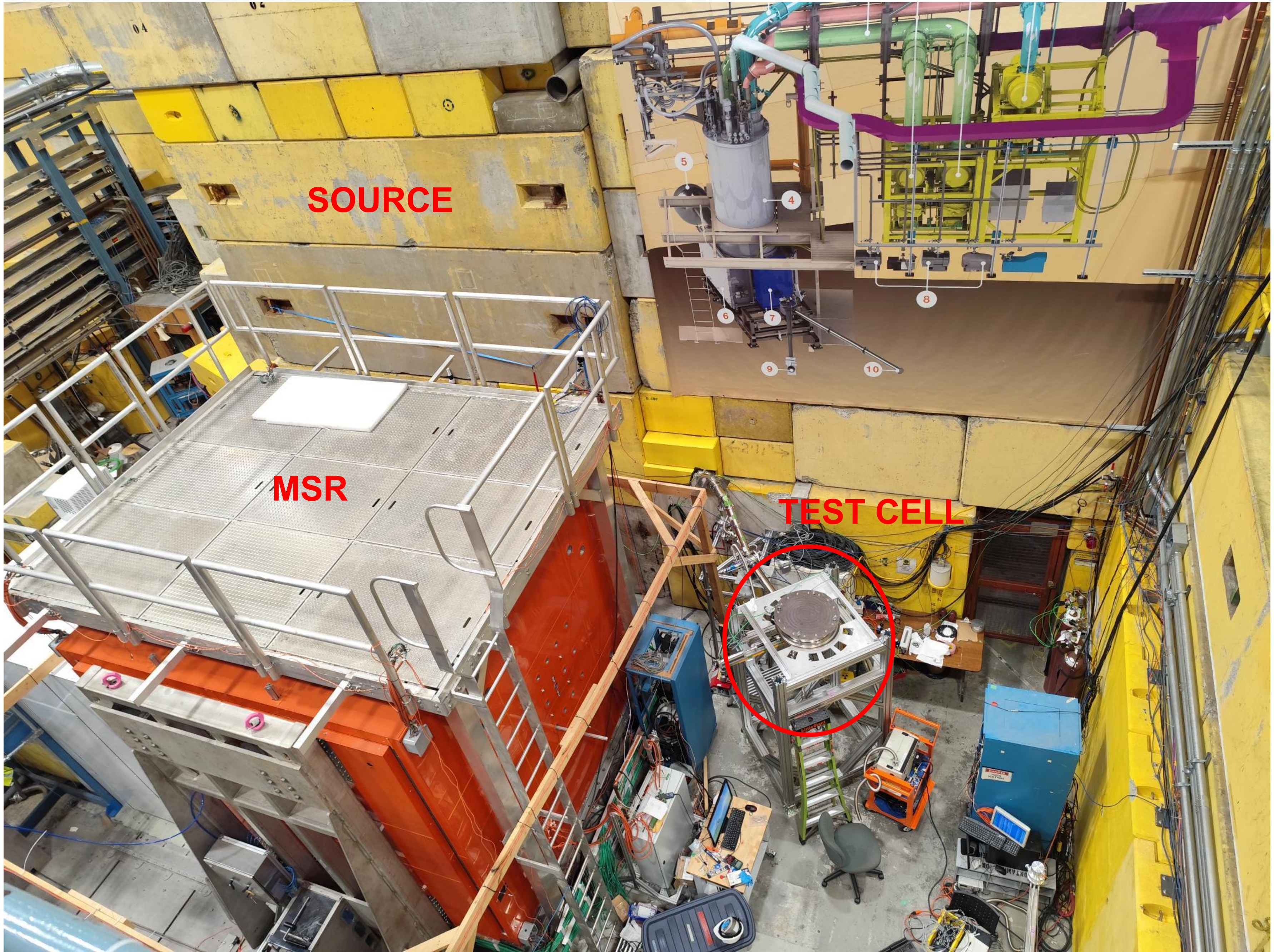
Prototype EDM measurement:

A neutron Electric Dipole Moment measurement will be connected to UCN source and start in 2027
nEDM measurement is based on Ramsey's method of separated oscillatory fields.

$$\sigma_d \propto \frac{1}{T\sqrt{N}}$$

- *N*: Number of neutron detected, needs for high efficiency at few 100 kHz detection rate
- *T:* Free precession time, must be optimized considering neutron decay, absorption, storage lifetime, de-polarization…

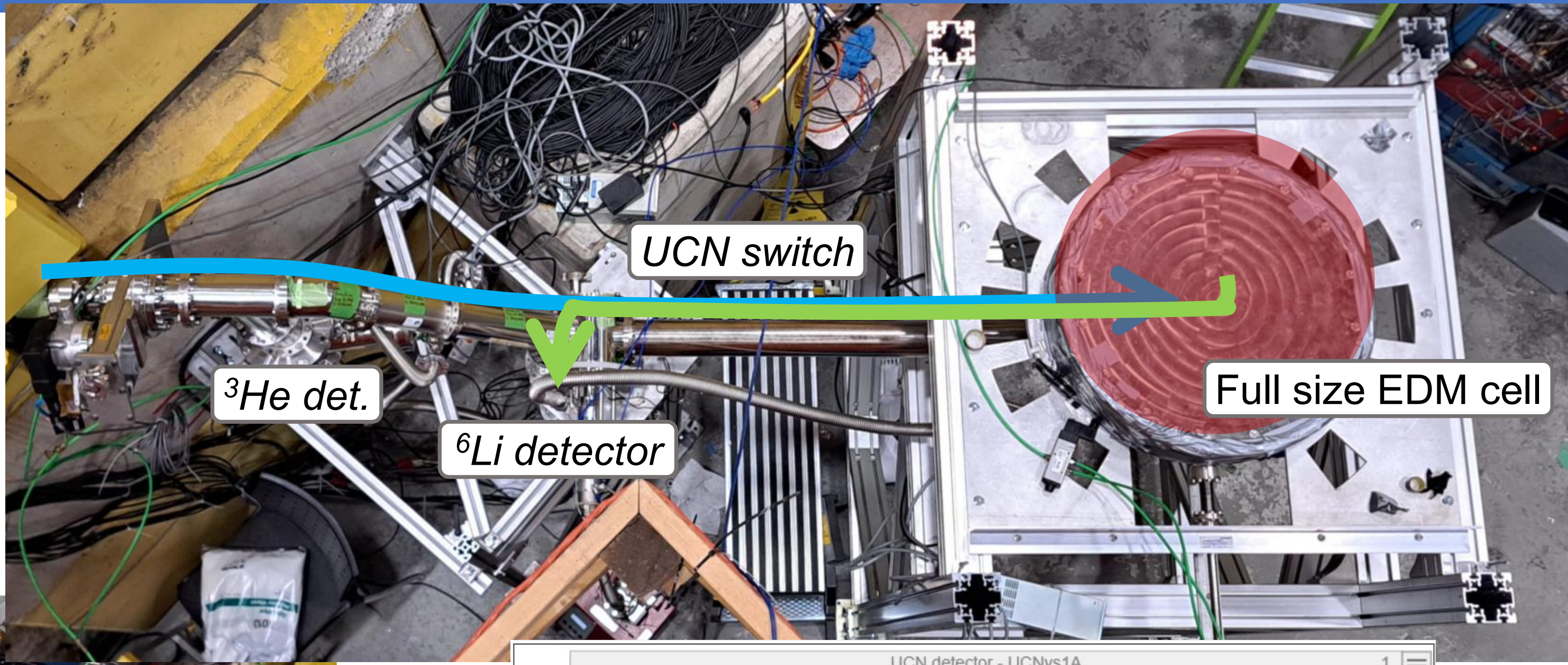
The experiment requires to store a large number of neutrons, for long period of time.

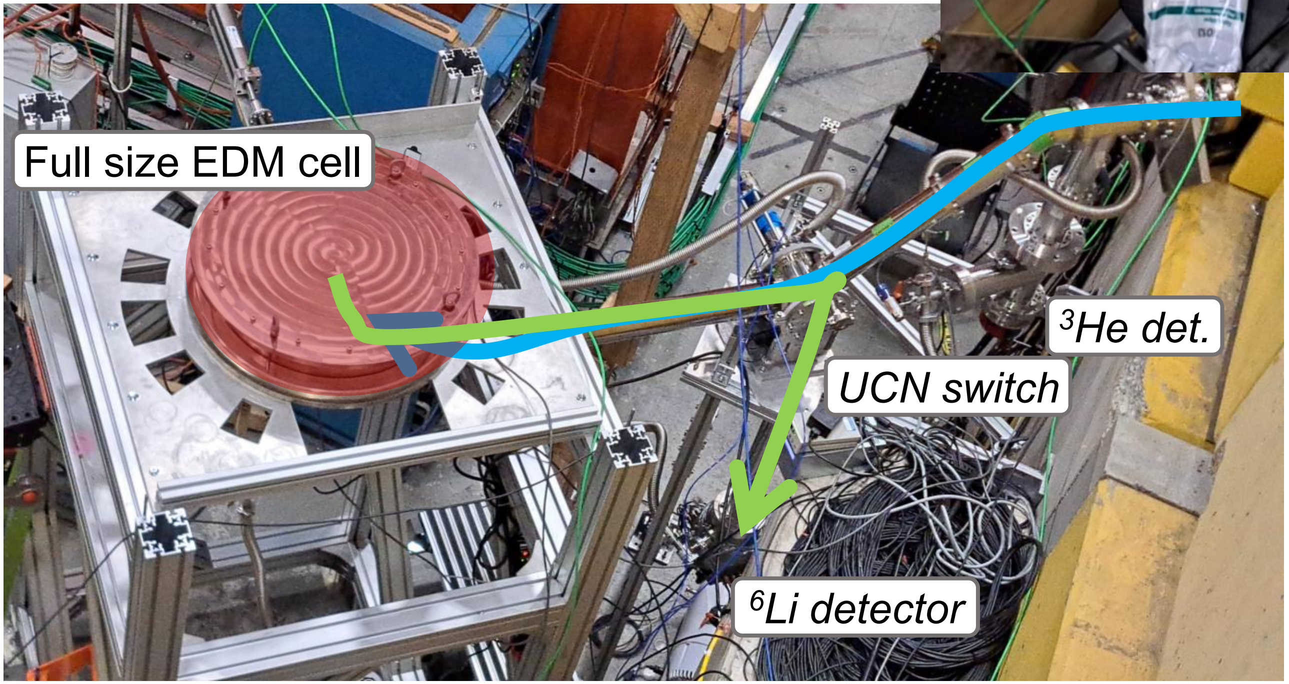

SOURCE
MSR
TEST CELL

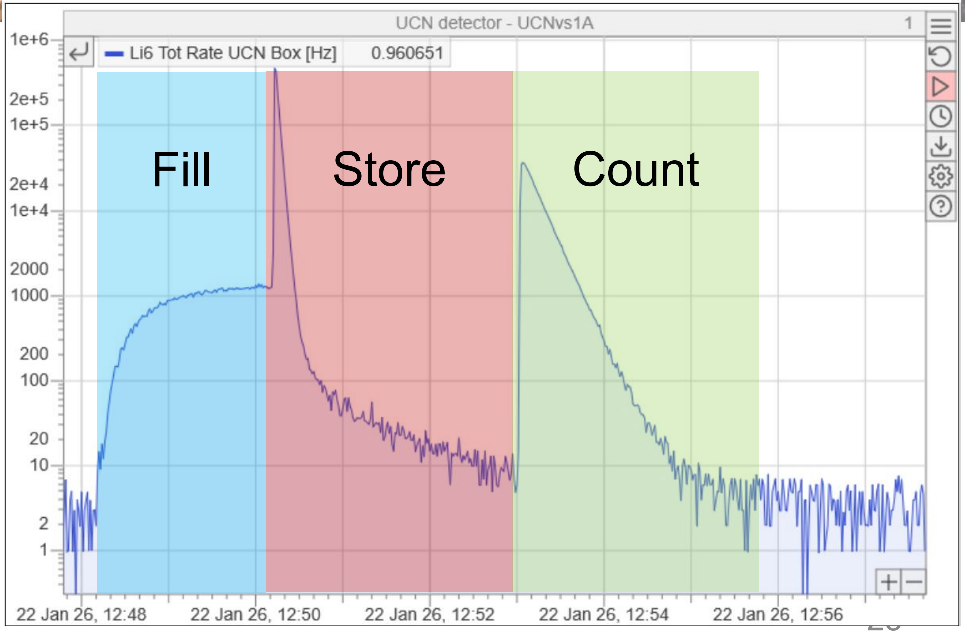
Prototype EDM measurement:

Sequence:

1. Fill UCN into cell 120 s
2. Store in cell 0 - 700 s
3. Count in detector 200 s



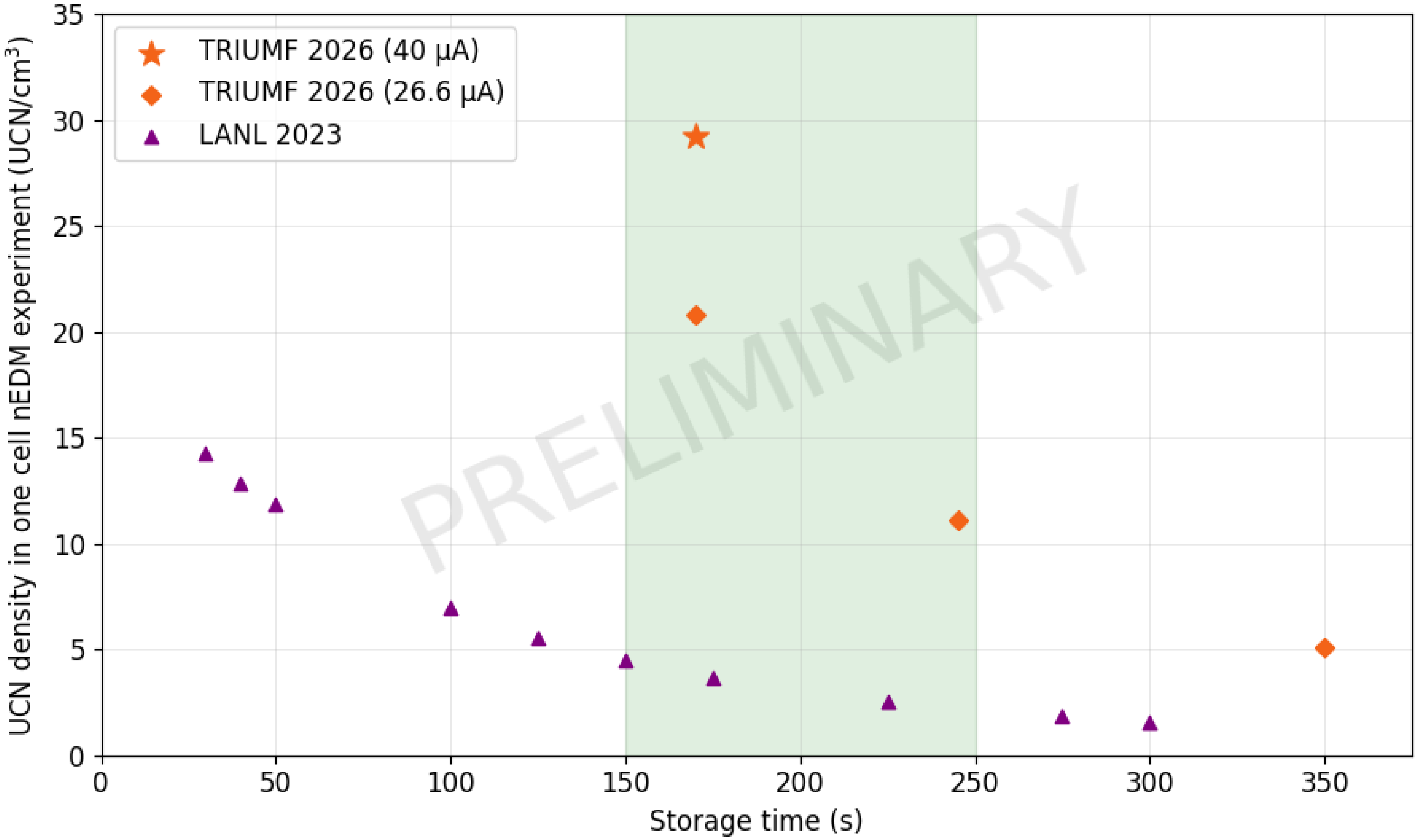




Prototype EDM measurement:

- LANL cell size 19 l
- TUCAN cell size 25.2 l

- Typical density for nEDM experiment < 2 UCN/cm^3



PSI/ILL: https://doi.org/10.1051/epjconf/201921907001
LANL: https://doi.org/10.1016/j.nima.2023.168105

CONCLUSION

- The TUCAN collaboration commissioned the highest yield UCN source.
- Record number of UCN has been stored in a cell.
- Cryogenic study to be done to understand the source and improve further.
- nEDM measurement campaign to start in 2027.

TUCAN

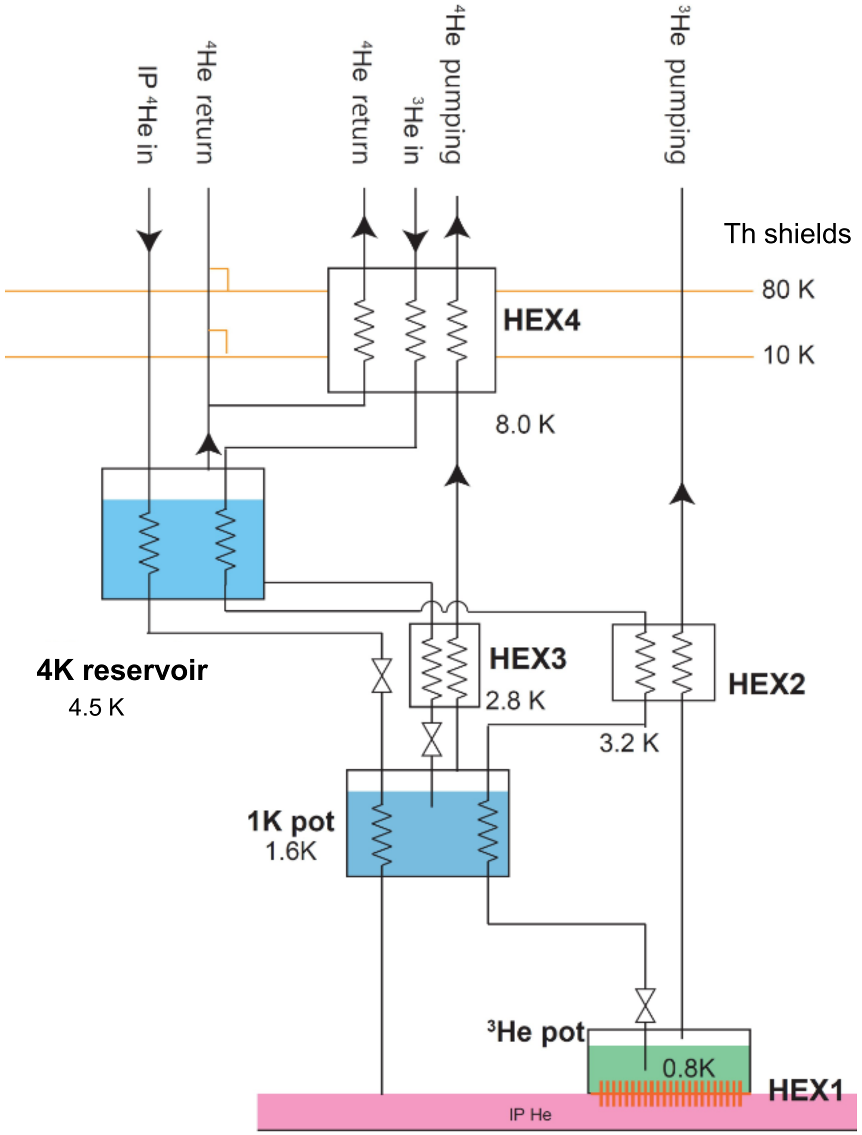
TRIUMF Ultracold Advanced Neutron Collaboration

February 2026 collaboration meeting

TRIUMF
SFU SIMON FRASER UNIVERSITY
UBC THE UNIVERSITY OF BRITISH COLUMBIA
UNBC UNIVERSITY OF NORTHERN BRITISH COLUMBIA
UNIVERSITY OF SASKATCHEWAN
University of Manitoba
THE UNIVERSITY OF WINNIPEG
KEK
J-PARC
RCNP
KYOTO UNIVERSITY
NAGOYA UNIVERSITY
NC STATE UNIVERSITY
KURNS

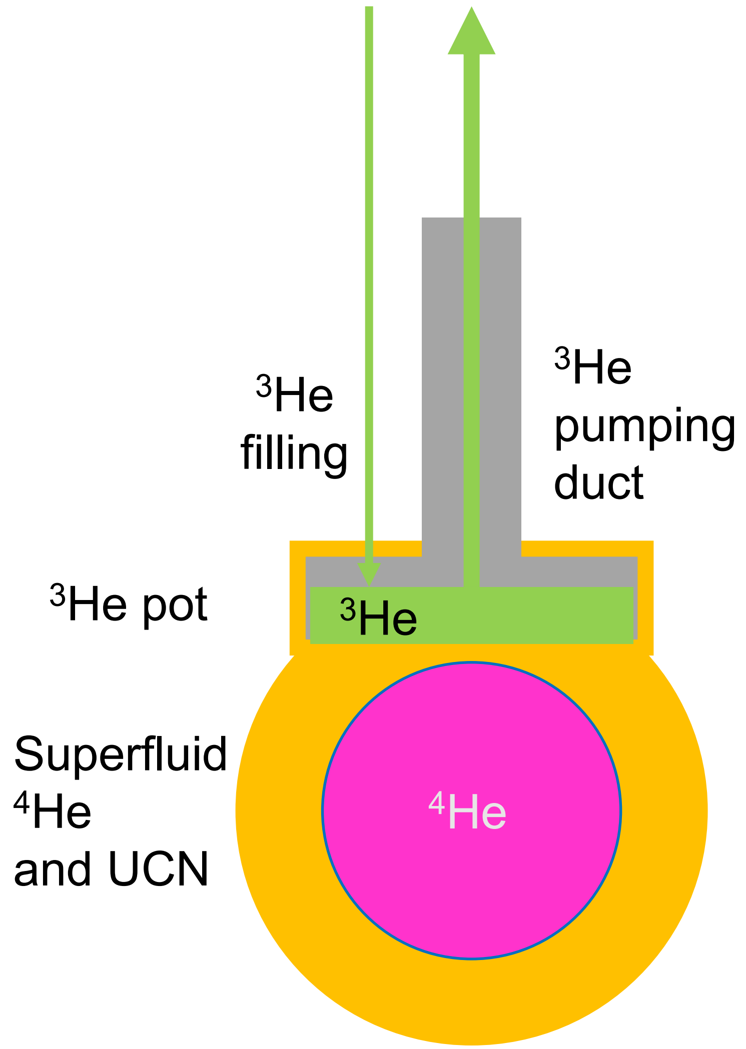
INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION
NSERC CRSNG
JST
JSPS

^{3}He cryostat

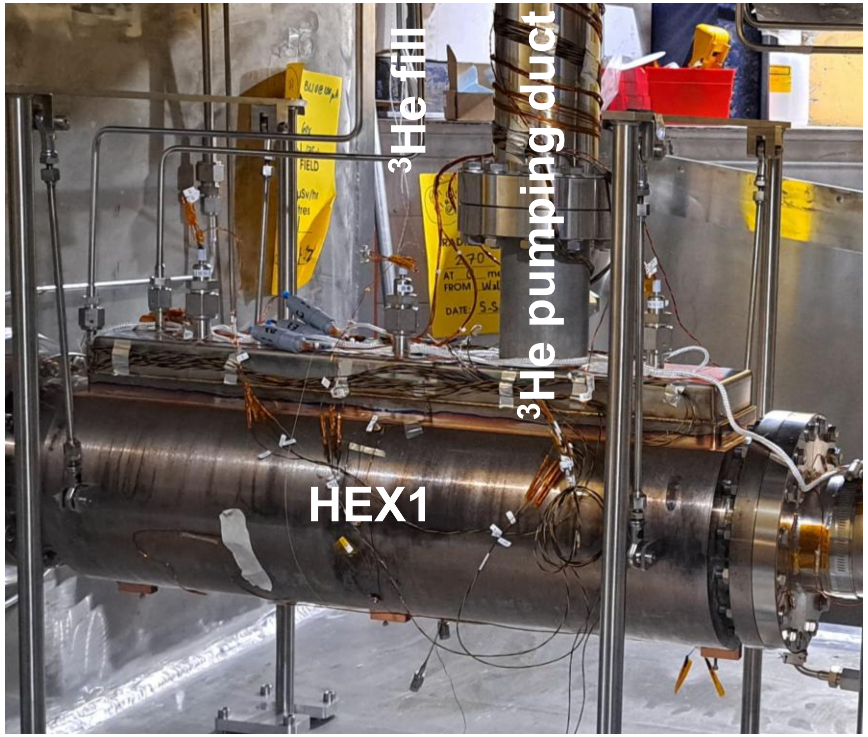


- 4He pumping system to reach 1.6 K
- 3He pumping system to reach 0.8 K
- Designed to cool 3He to ~0.8 K with 10 W heat load
- Performance in 2024: ~0.9 K with 10 W heat load

HEX1 Heat Exchanger



- Cold liquid ^{3}He drops into a pot
- The boiling ^{3}He in the pot removes heat from the superfluid ^{4}He via a copper heat exchanger (HEX1)
- Boiling ^{3}He is pumped away by very big pumps



^{3}He cryostat pumping system:

The 4K pot is filled by the ^{nat}He purifier with a ~40 l/h capability.

The 1K pot and 3He are cooled down by the 3 sets of Busch pumps.

	Mass Flow [g/s]	Flow [m^3/h]	Vacuum [Torr]
^{3}He	0.57	4650	2.5
^{nat}He	0.607	1900	4.83