TUCAN
TRIUMF Ultra Cold
Advanced
Neutron source

The TRIUMF UltraCold Advanced Neutron source and nEDM experiment

Second workshop on UCN and VCN Sources at ESS

Alexis Brossard
May 10th, 2023 ESS, Lund

The TUCAN collaboration aims for measuring the neutron electric dipole moment.
We use the Ramsey's method of separating oscillatory field.

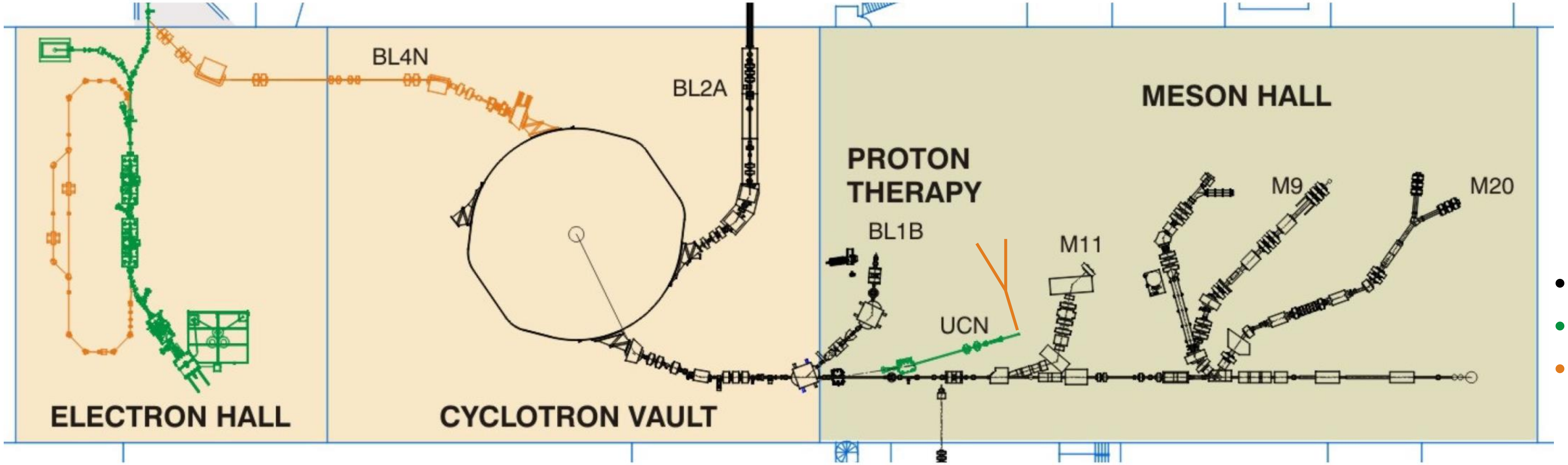
$$\sigma_d = \frac{1}{2\alpha E T \sqrt{N}}$$

- α: Visibility
- *E:* Electric field strength.
- ***N*: Number of neutron detected**
- ***T:* Free precession time**

UCN are ideal for such measurement

Proton beamline and target

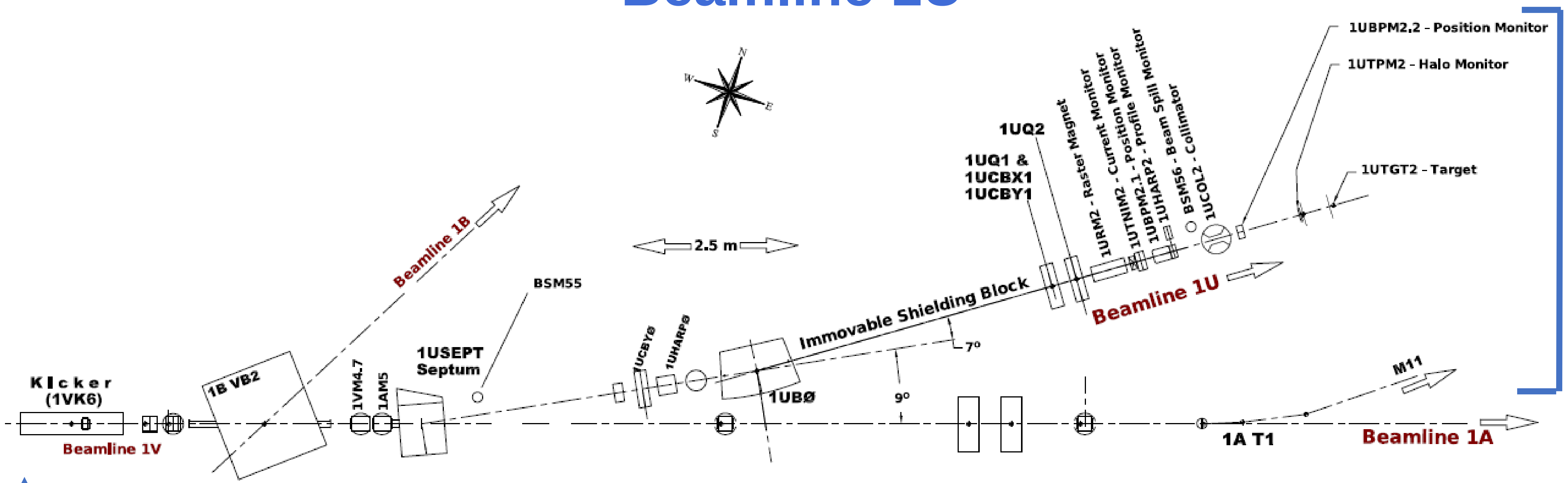
TRIUMF proton beams



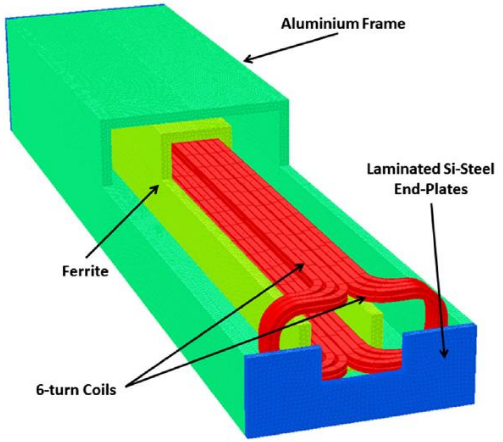
- Existing
- New
- Planned

H^- ions are accelerated by TRIUMF's main cyclotron (up to 520 MeV).
Foils strip electrons and p^+ can be extracted at selectable radii (and energies).
Three beamlines can be fed with up to 120 μ A at a time.

Beamline 1U



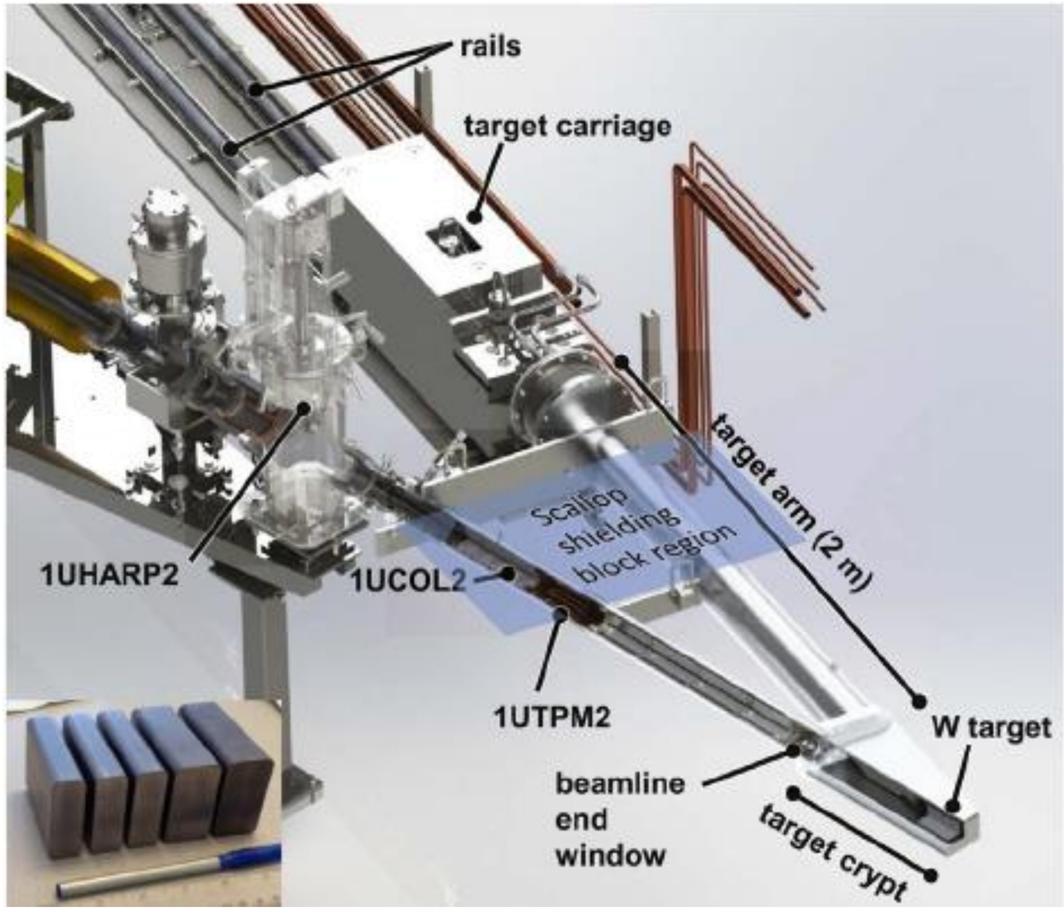
Diagnostic elements
Bending and quadrupole magnet



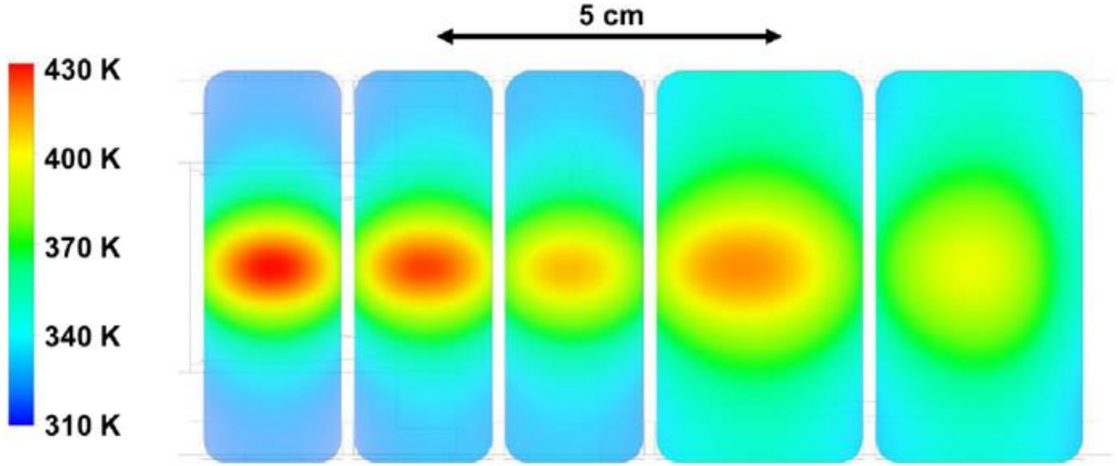
Fast-switching kicker magnet:
Ramped up/down in ~50 μs to a current of 193 A
12 mrad deflection
Held for approximately 1 ms
Repetition rate of approximately 375 Hz
Allows for ~40 μA time average beam on target.

Fast-switching magnet serving a spallation-driven ultracold neutron source. S. Ahmed, et al. DOI: 10.1103/PhysRevAccelBeams.22.102401

Spallation target



The target is made of 5 blocks of tungsten
Clade in tantalum and water cooled down
3 first blocks are 20 mm thick and the two last 30.



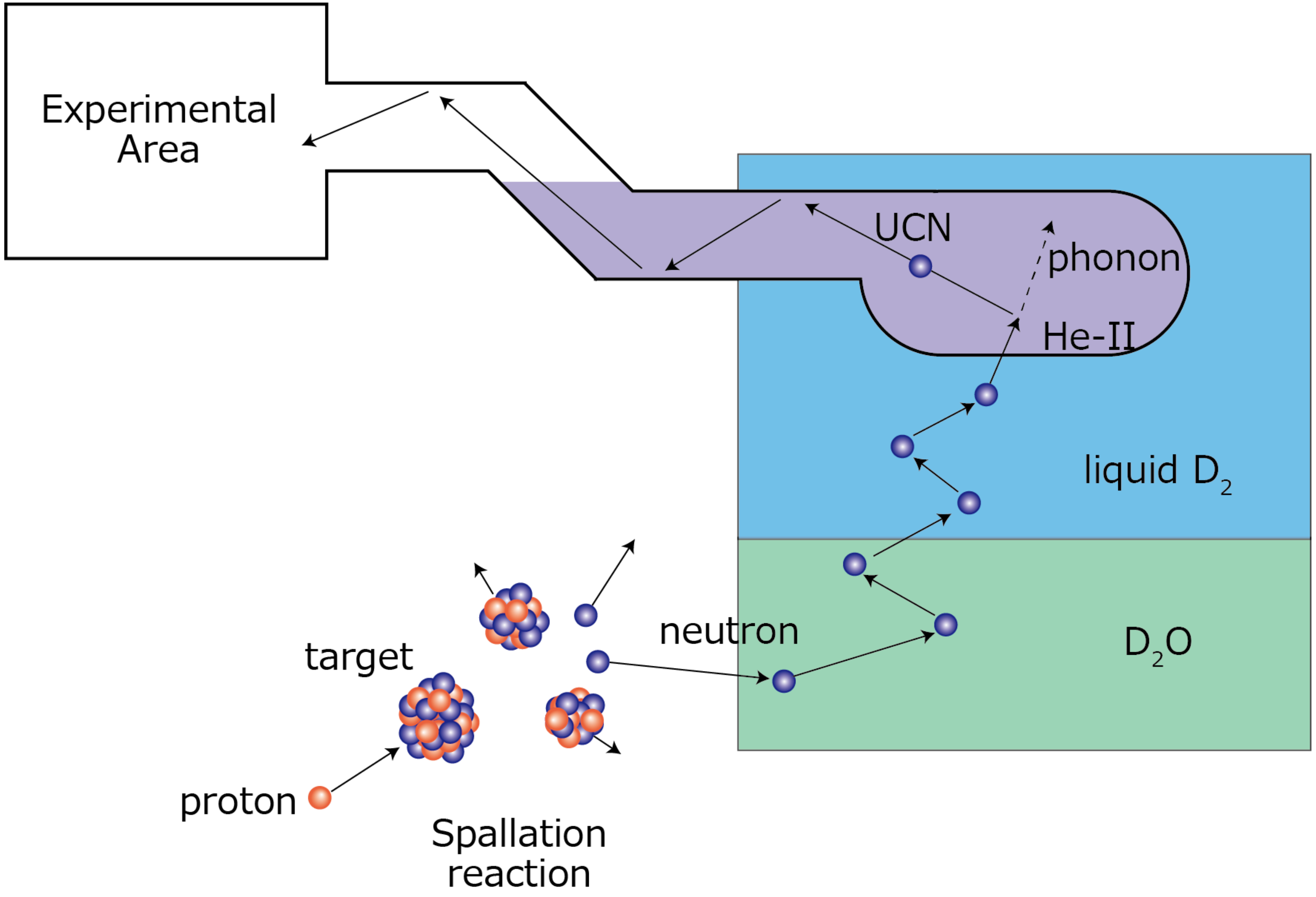
Temperature profile at the center of the target.

The target is attached to an arm and will be remotely placed in a 15 cm thick lead casket at the end of its lifetime

A beamline for fundamental neutron physics at TRIUMF S. Ahmed, et al. DOI: https://doi.org/10.1016/j.nima.2019.01.074

UCN production

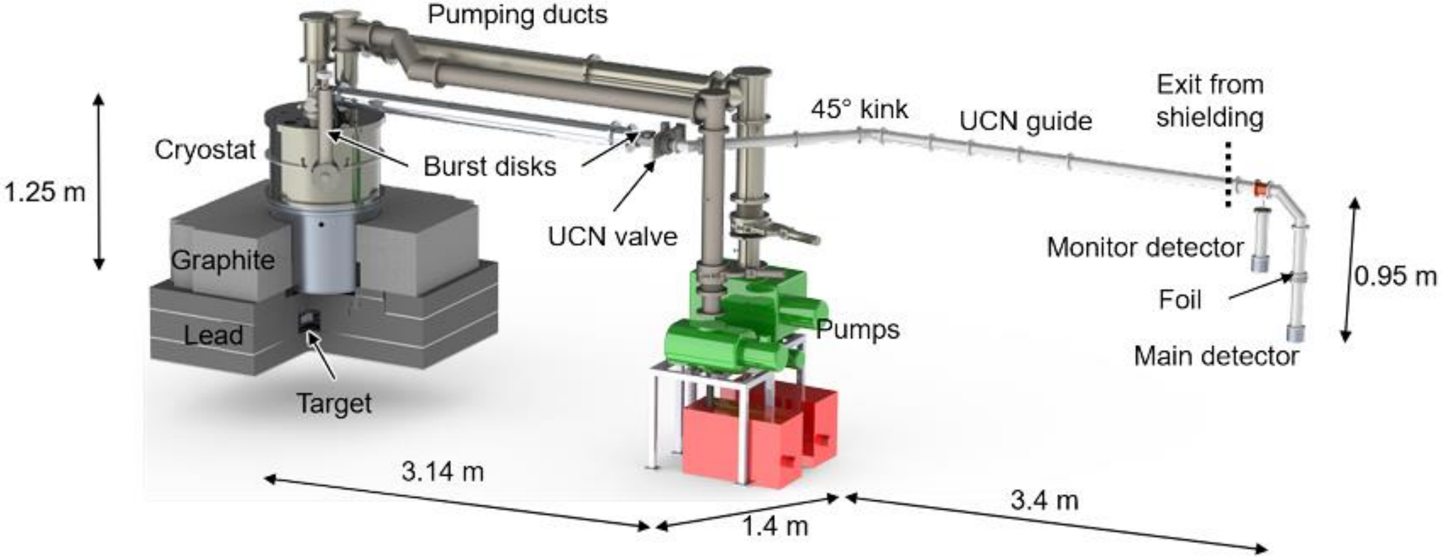
TUCAN method for UCN production



Neutron moderation in room temperature D_20 and 20 K D_2

UCN production by phonon emission in superfluid Isopure ^4He

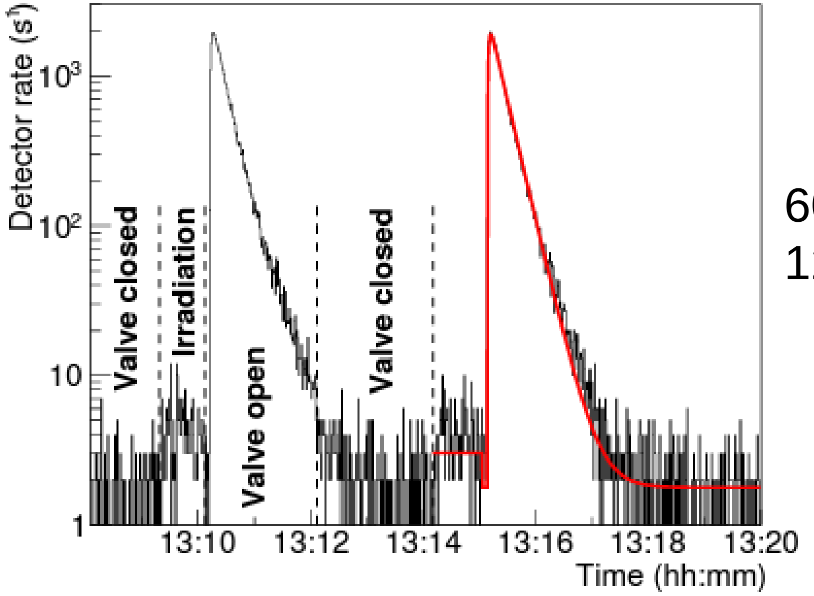
TUCAN first prototype:



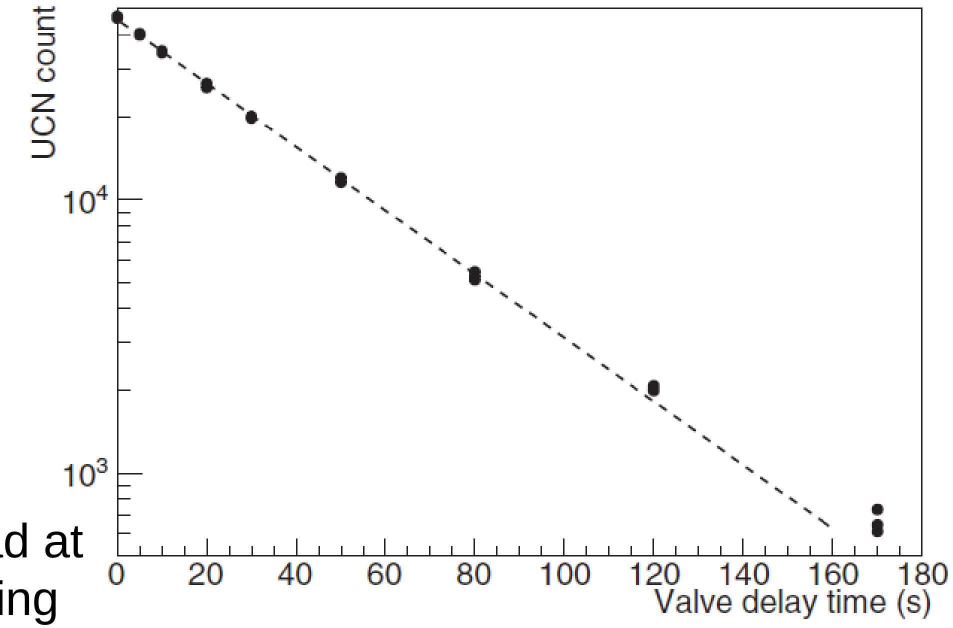
- First UCN on November 13, 2017
- 2 10^4 UCN/s
- Decommissioned in 2019
- Validate components and simulation for the new source
- Gives first operational experience

First ultracold neutrons produced at TRIUMF S. Ahmed *et al* : DOI: 10.1103/PhysRevC.99.025503

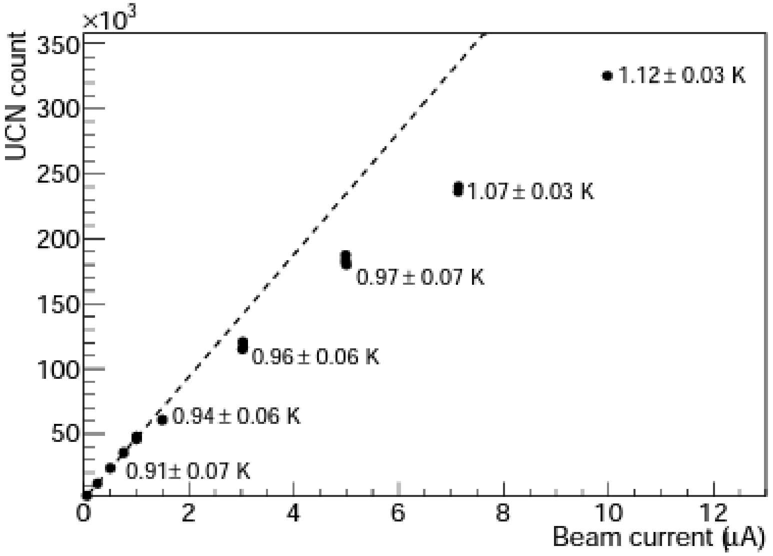
TUCAN first prototype results:



60 s irradiation time
120 s valve open



Storage lifetime measured after 60s irradiation time at 1 μA.



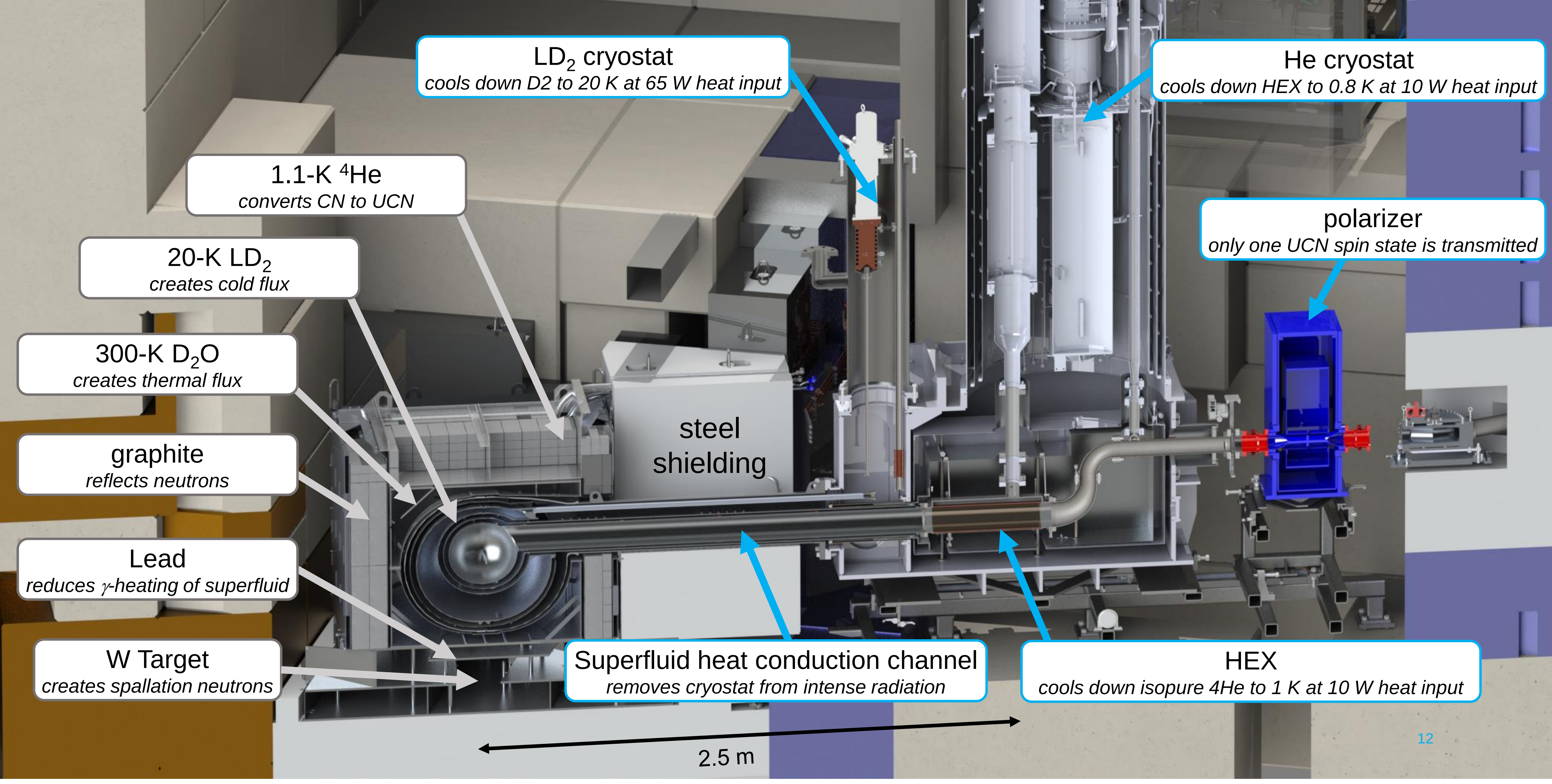
Increased heat load at high current reducing performances

First ultracold neutrons produced at TRIUMF S. Ahmed *et al* : DOI: 10.1103/PhysRevC.99.025503

TUCAN next source:

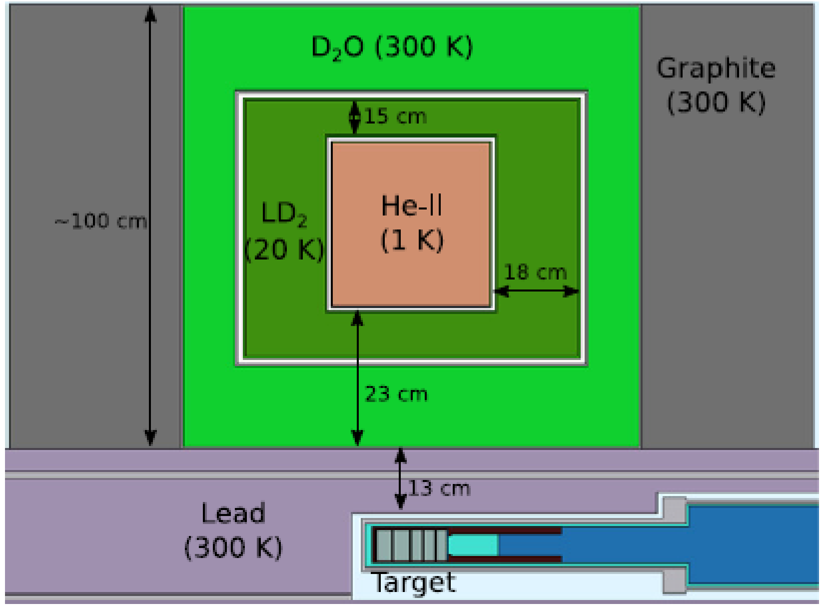
- 40x beam current
- 40x cooling power
- 3.5x production volume
- **800x UCN production**
- 2nd UCN port for user facility

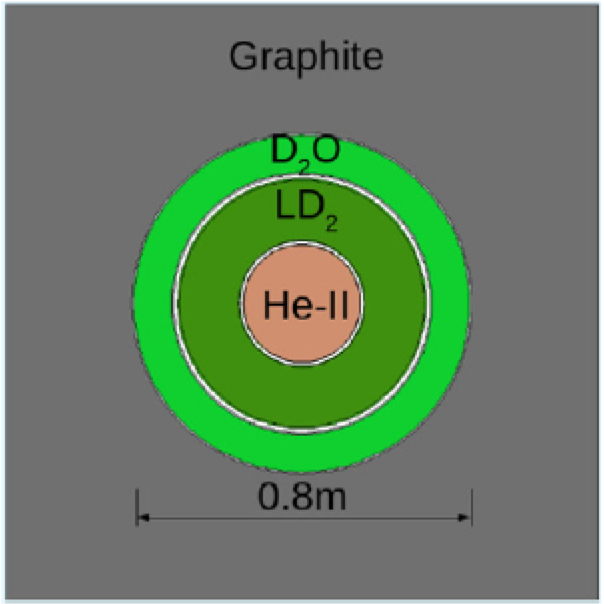
TUCAN UCN source components



Neutron moderator optimization

Optimization took into account a range of engineering and safety requirements to increase the UCN production.



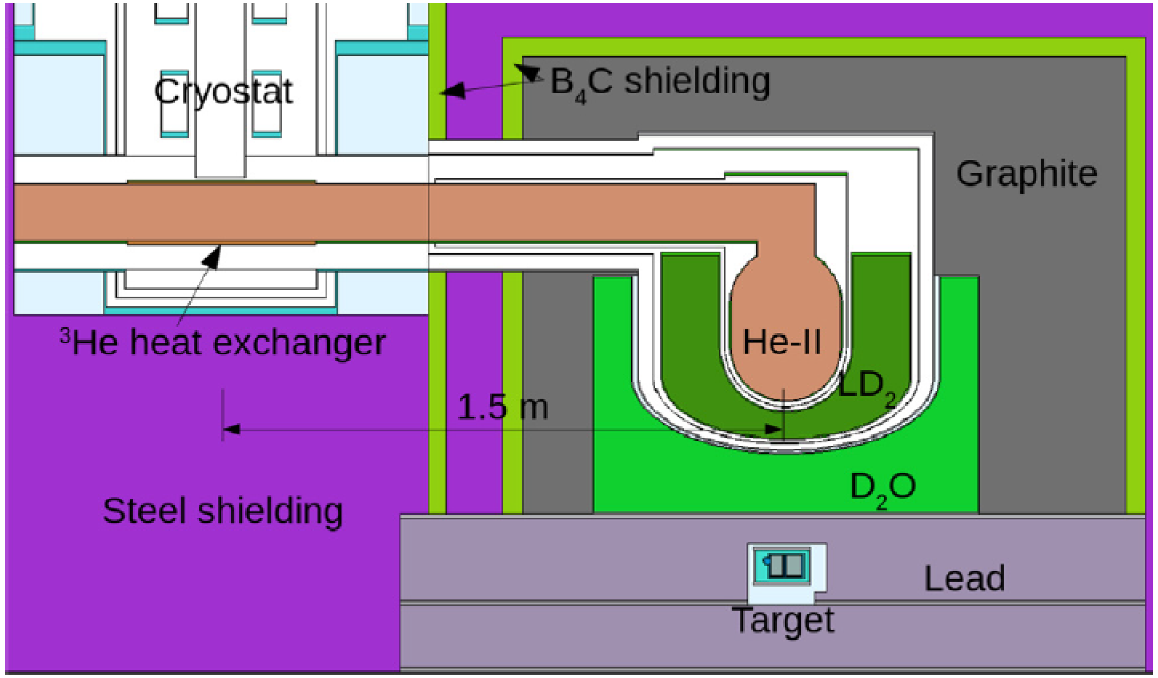


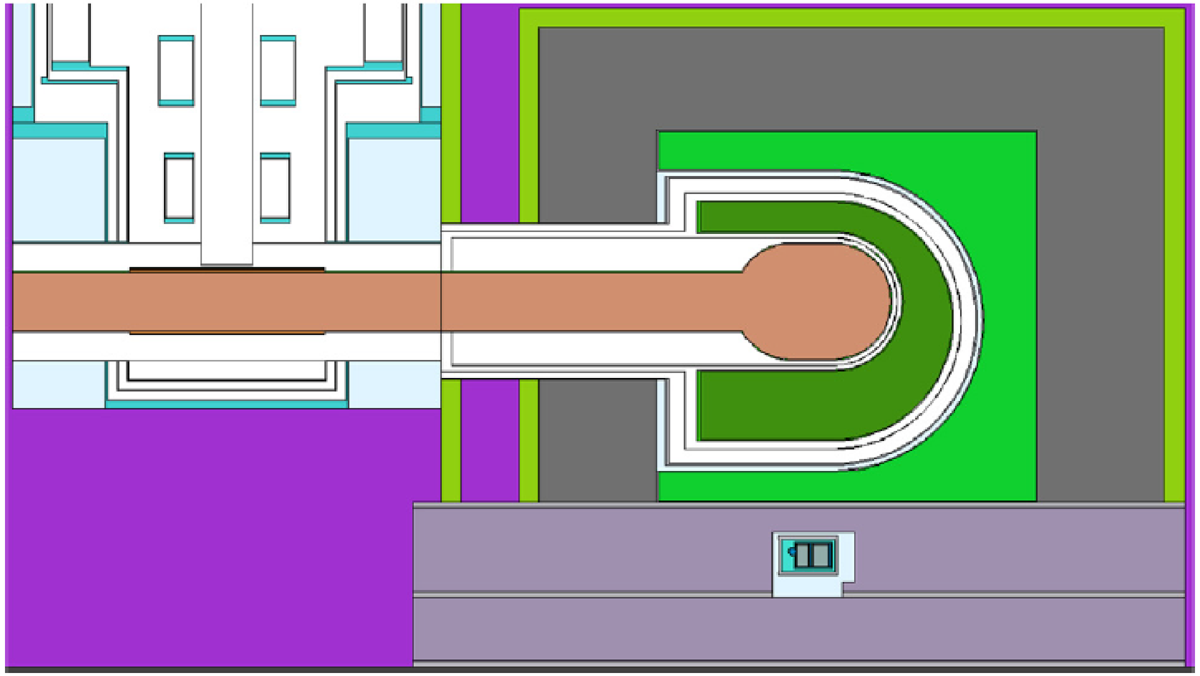
Initial simulation concentric, vertical cylinders, centered above the target.

Show that the liquid D_2 radial thickness is the most important parameter.

Optimizing neutron moderators for a spallation-driven ultracold-neutron source at TRIUMF, W. Schreyer et al: DOI: https://doi.org/10.1016/j.nima.2020.163525

Neutron moderator optimization

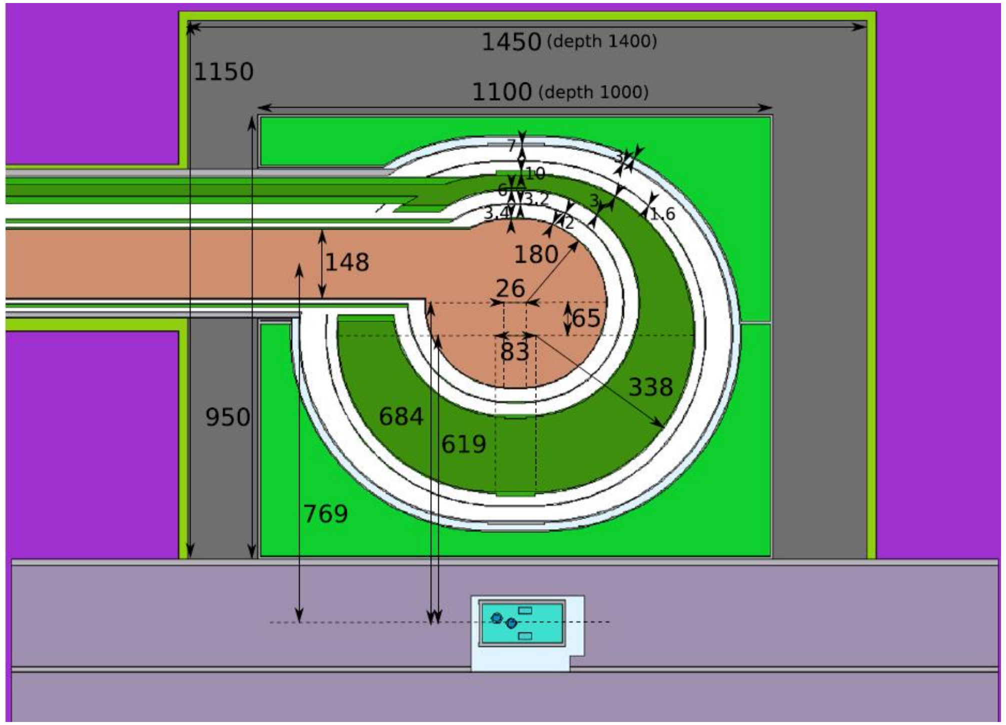




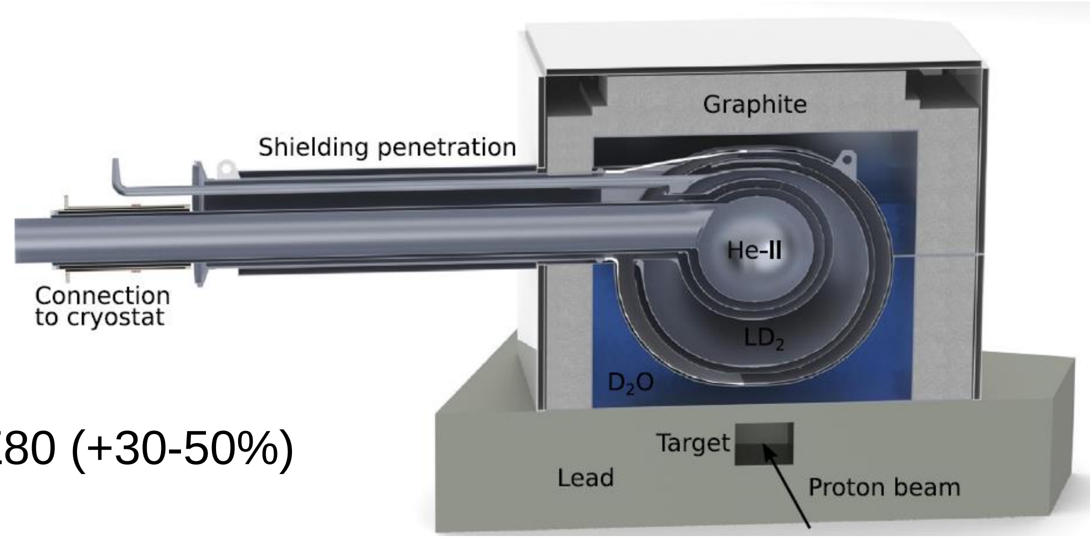
Two different options, vertical and horizontal to extract UCN from the converter through a UCN guide were tested. The two options show similar performances, the horizontal one was chosen as it is more mechanically feasible.

Optimizing neutron moderators for a spallation-driven ultracold-neutron source at TRIUMF, W. Schreyer et al: DOI: https://doi.org/10.1016/j.nima.2020.163525

Neutron moderator optimization



Several geometrical parameters tested and optimized:
-thickness of lead above target,
-thickness of heavy-water layer above target,
-horizontal offset between UCN-converter volume and liquid deuterium vessel -length of the liquid-deuterium vessel,
-horizontal offset between target and UCN-converter vessel,
-radius of the UCN-converter vessel,
-length of the UCN-converter vessel, and
-vertical offset between liquid-deuterium vessel and UCN converter Vessel
….



Converter vessel will be made of Aluminum
Upgrade using Beryllium (+90% UCN density), AlBeMet or AZ80 (+30-50%) is possible.

Optimizing neutron moderators for a spallation-driven ultracold-neutron source at TRIUMF, W. Schreyer et al: DOI: https://doi.org/10.1016/j.nima.2020.163525

Moderator vessel

Machining finished, preparing to start complicated assembly.

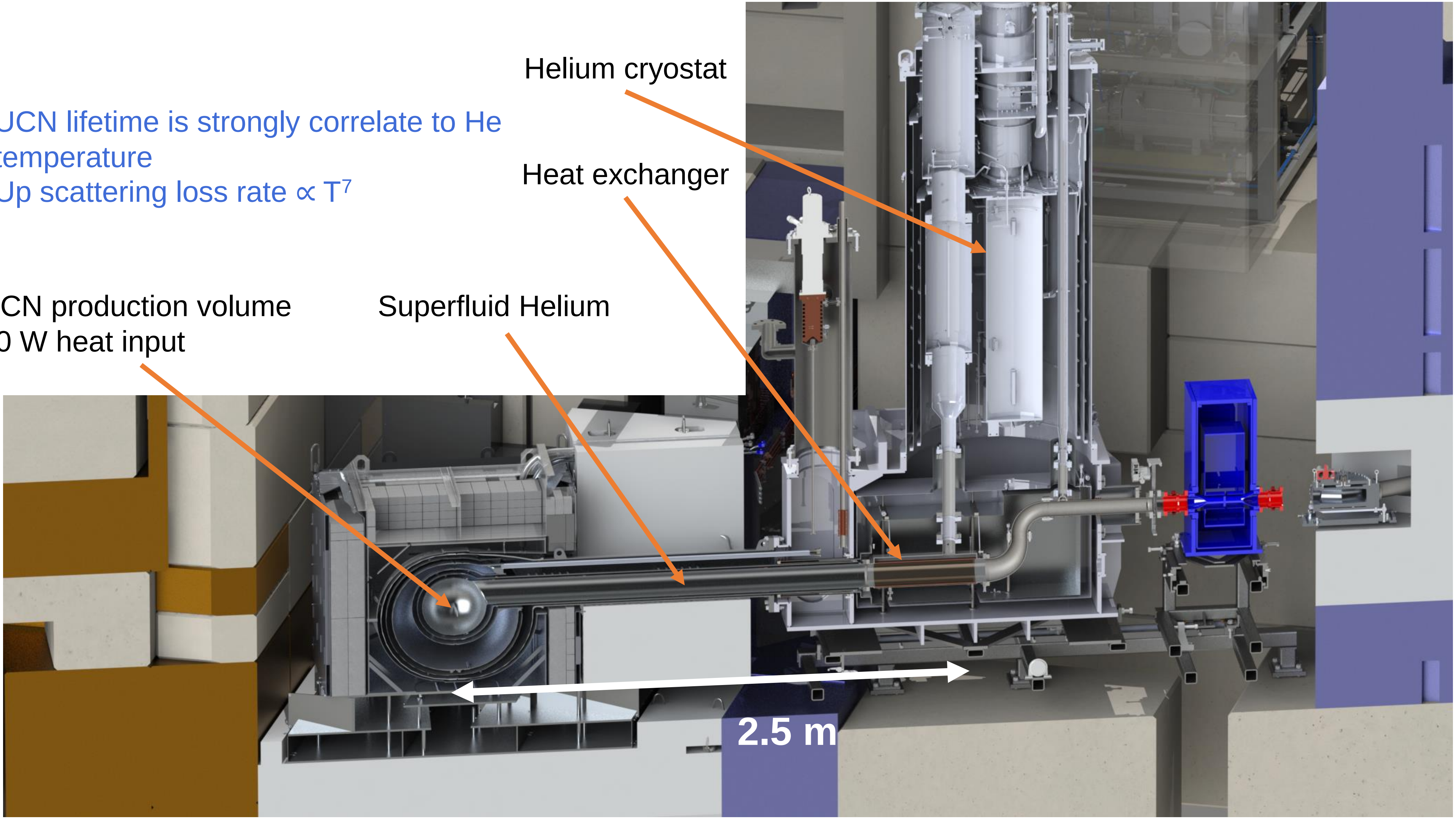
Superfluid-He converter vessel

- Machined, thin-walled Al domes to minimize neutron absorption and heat load
- UCN-reflective NiP coating: Measured UCN storage lifetime at LANL in 2021
  ➔ higher loss rate than expected, but acceptable
- Superfluid-tight: extensive leak checking completed

Superfluid-He cooling

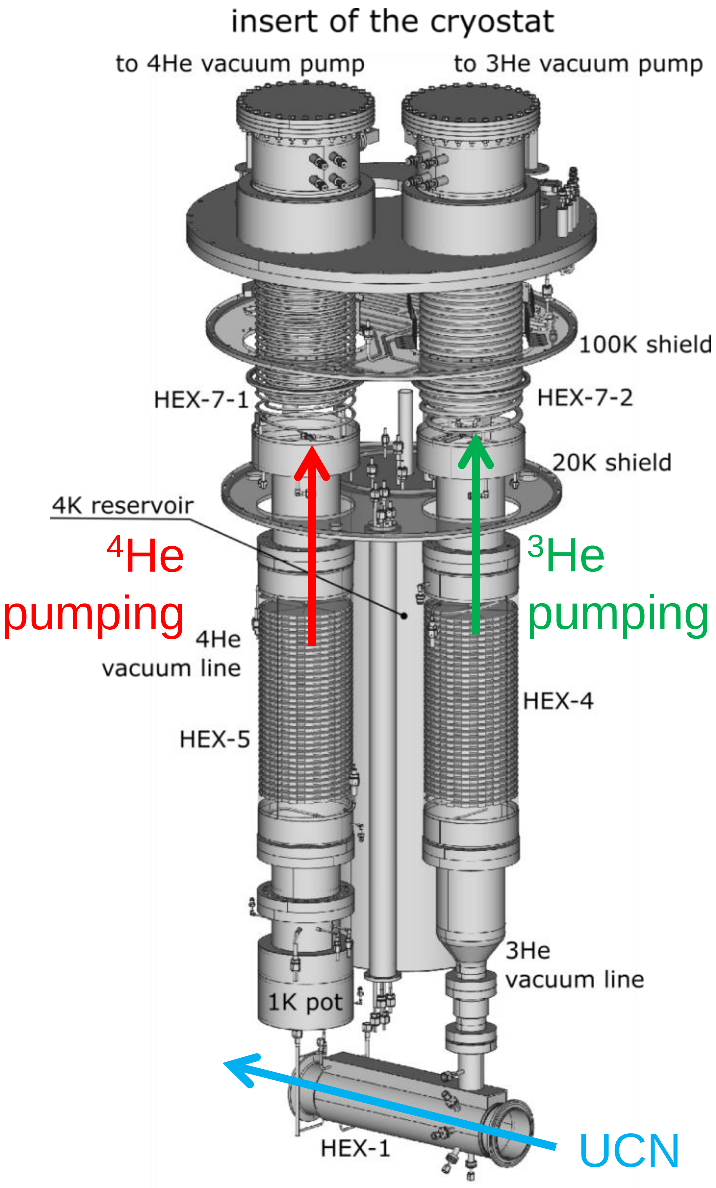
TUCAN
TRIUMF Ultra Cold
Advanced Neutron source

UCN lifetime is strongly correlate to He temperature
Up scattering loss rate ∝ T^7



^{3}He fridge

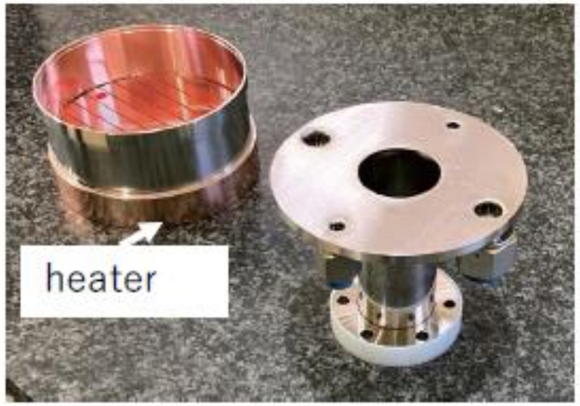
- Cooling power 10 W @ 1.1K
- Built & tested at KEK in Japan, shipped to TRIUMF in 2021
- Pumps arrived 2021 (8000 m^3/h for ^{3}He)
- To be installed and commissioned in the coming weeks.

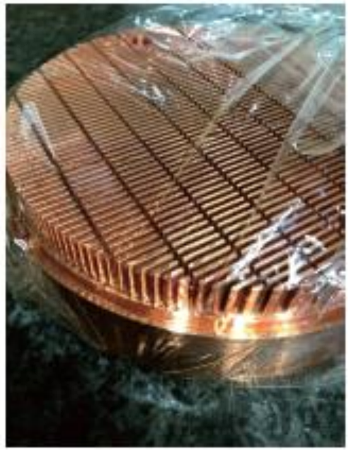


HEX1 Heat exchanger

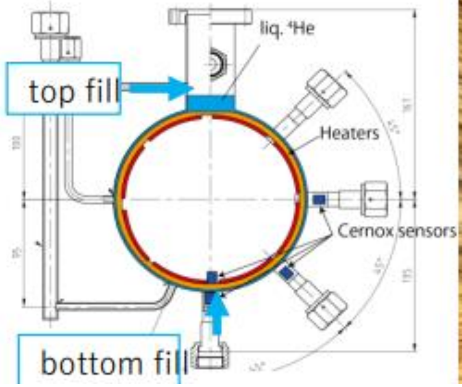
Two ideas were studied and tested:

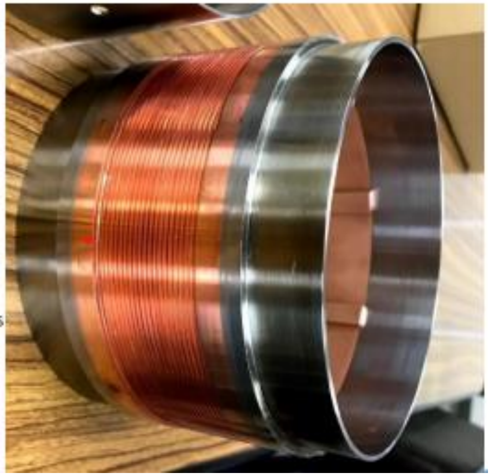
Vertical fin



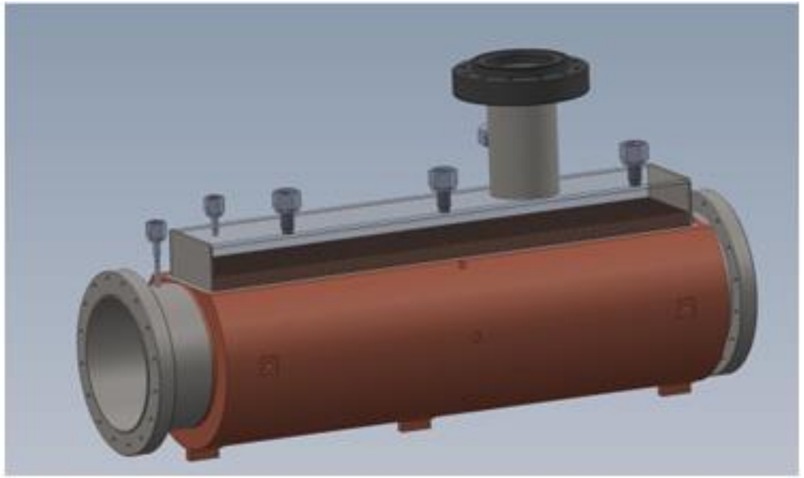


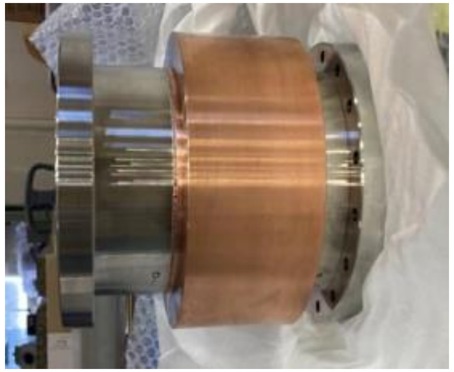
Cylindrical fin





Vertical fin HEX was selected

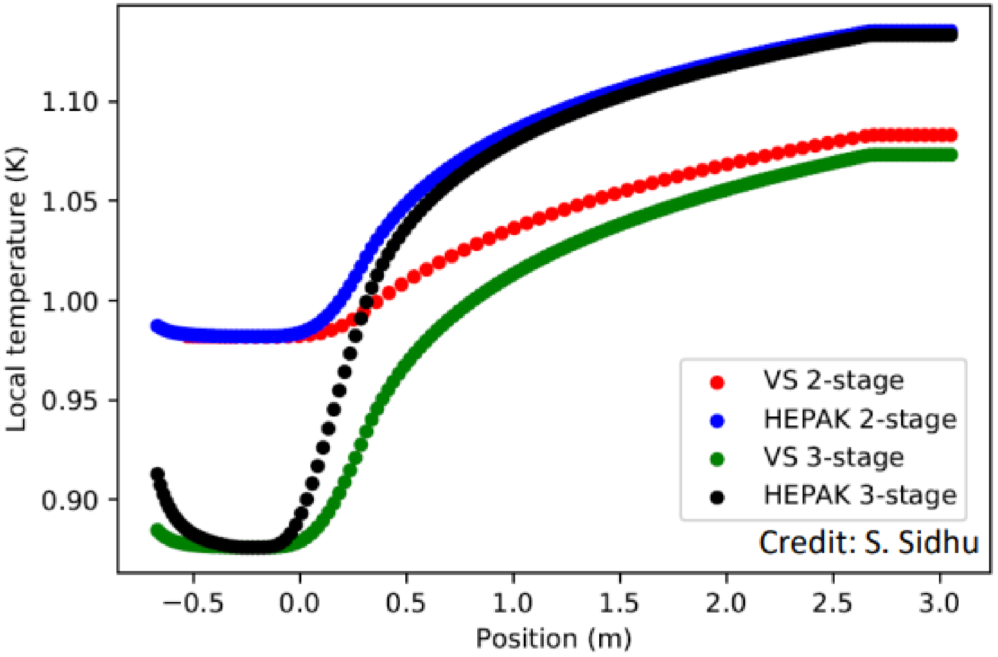




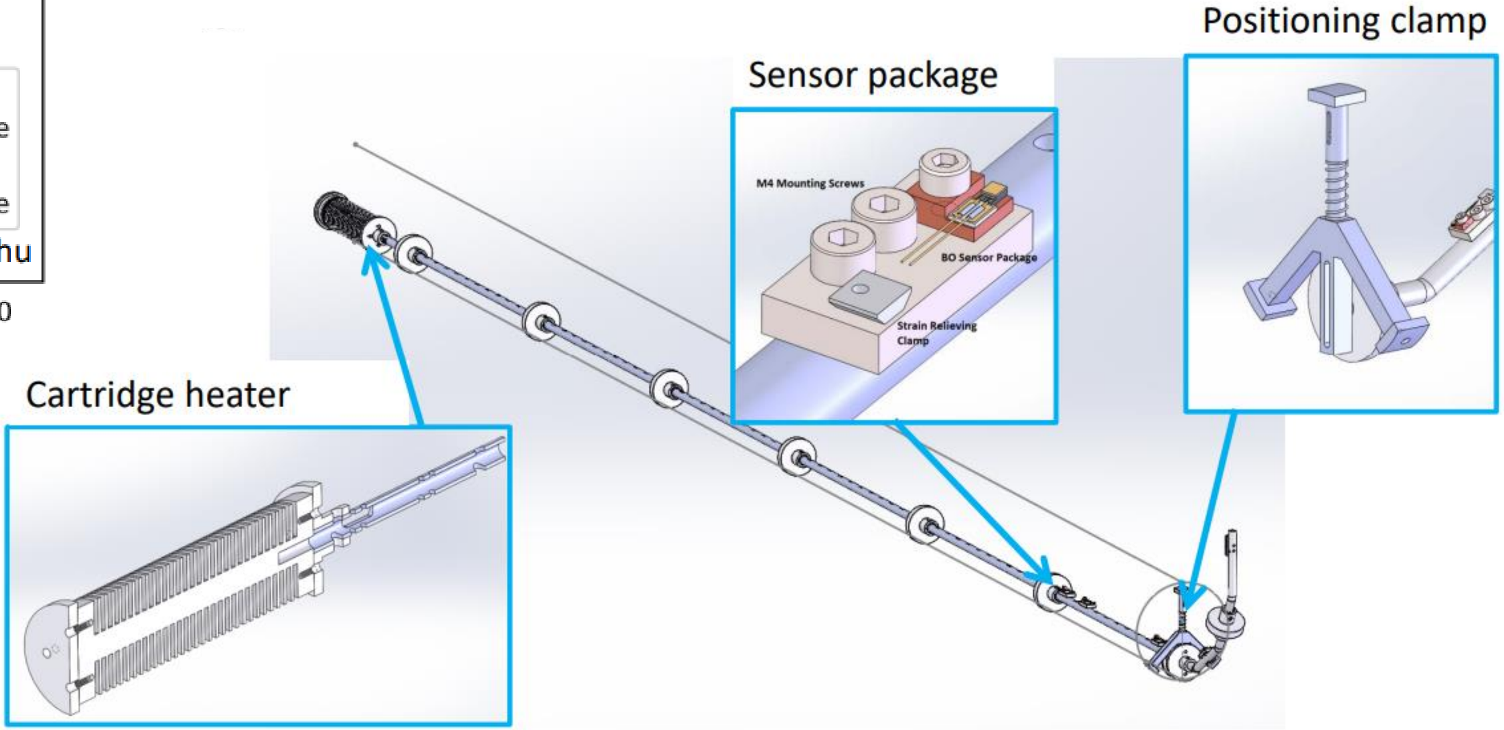
Small prototype ready to be tested

S. Kawasaki

Superfluid ^{4}He thermal conductivity



HEPAK and Van Sciver models of heat conductance have been studied.



Measurement of temperature in superfluid ^{4}He will be performed.

Timeline:

Summer 2023: Helium cryostat commissioning, LD_2 cryostat and gas system fabrication

Fall 2023: LD_2 cryostat commissioning, tail section and moderator vessel fabrication

Winter 2024: Installation of the tail section and moderator

Cyclotron shutdown

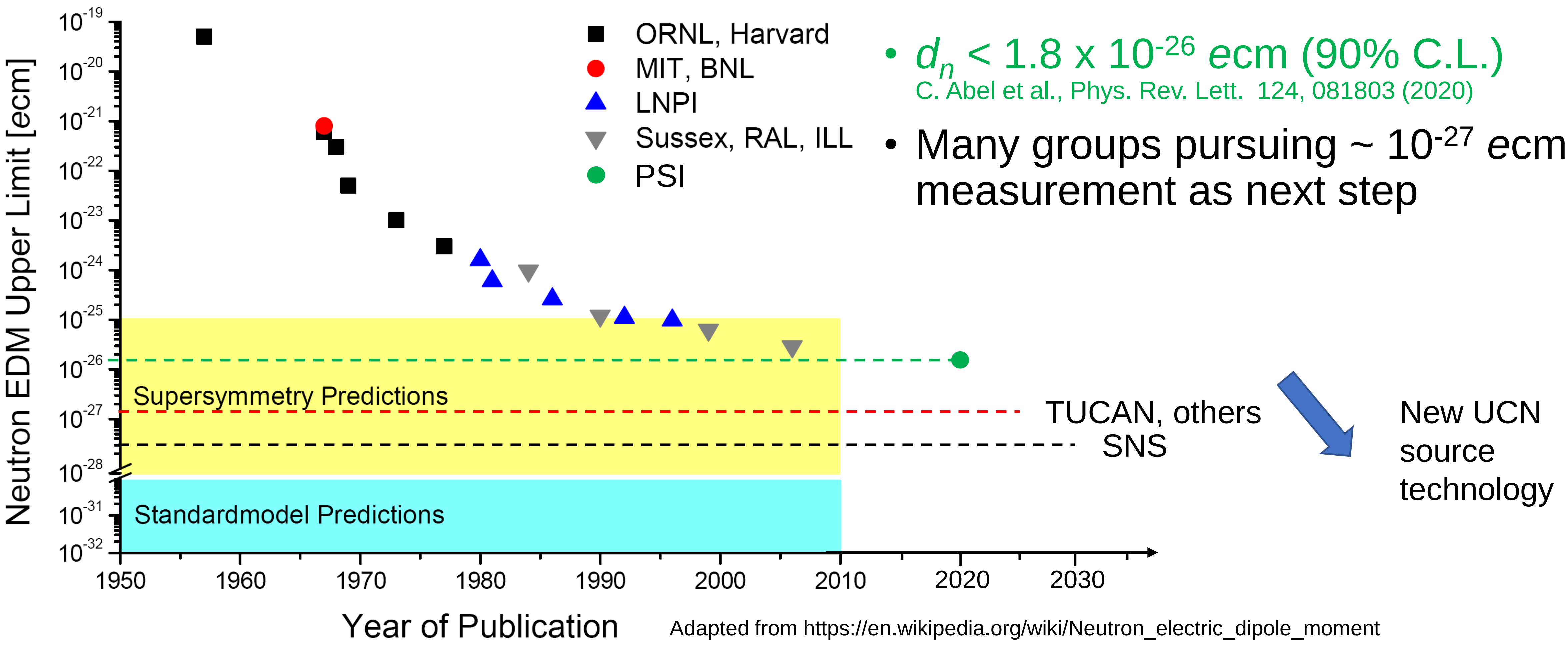
Summer 2024: UCN production

COMPARISON:

Option	Volume [liters]	P_{UCN} [$cm^{-3}\ s^{-1}$]	$\dot{N}_{UCN}$ [s^{-1}]	Heat [Watt]
		SD_2 thin slab in twister - location 1		
Fig. 5	1.81	3.1×10^5	5.6×10^8	760
Fig. 6	1.75	7.7×10^5	1.4×10^9	2910
Fig. 7	0.38	1.3×10^6	5.0×10^8	560
Fig. 9	0.13	1.7×10^6	2.2×10^8	520
		full SD_2 in twister - location 1		
Fig. 10	48.2	6.56×10^5	1.32×10^9	39886
		SD_2 thin slab in MCB - location 2		
Fig. 18a	0.91	3.8×10^4	3.4×10^7	159
		He-II in MCB - location 2		
Fig. 21	24.3	2160	5.23×10^7	328
		He-II in LBP - location 4		
Fig. 24	58	369	2.1×10^7	8
		He-II in beam - location 5		
in-beam (D4.3)	114	234	1.53×10^7	
TUCAN	27		1.6×10^7	10

nEDM experiment

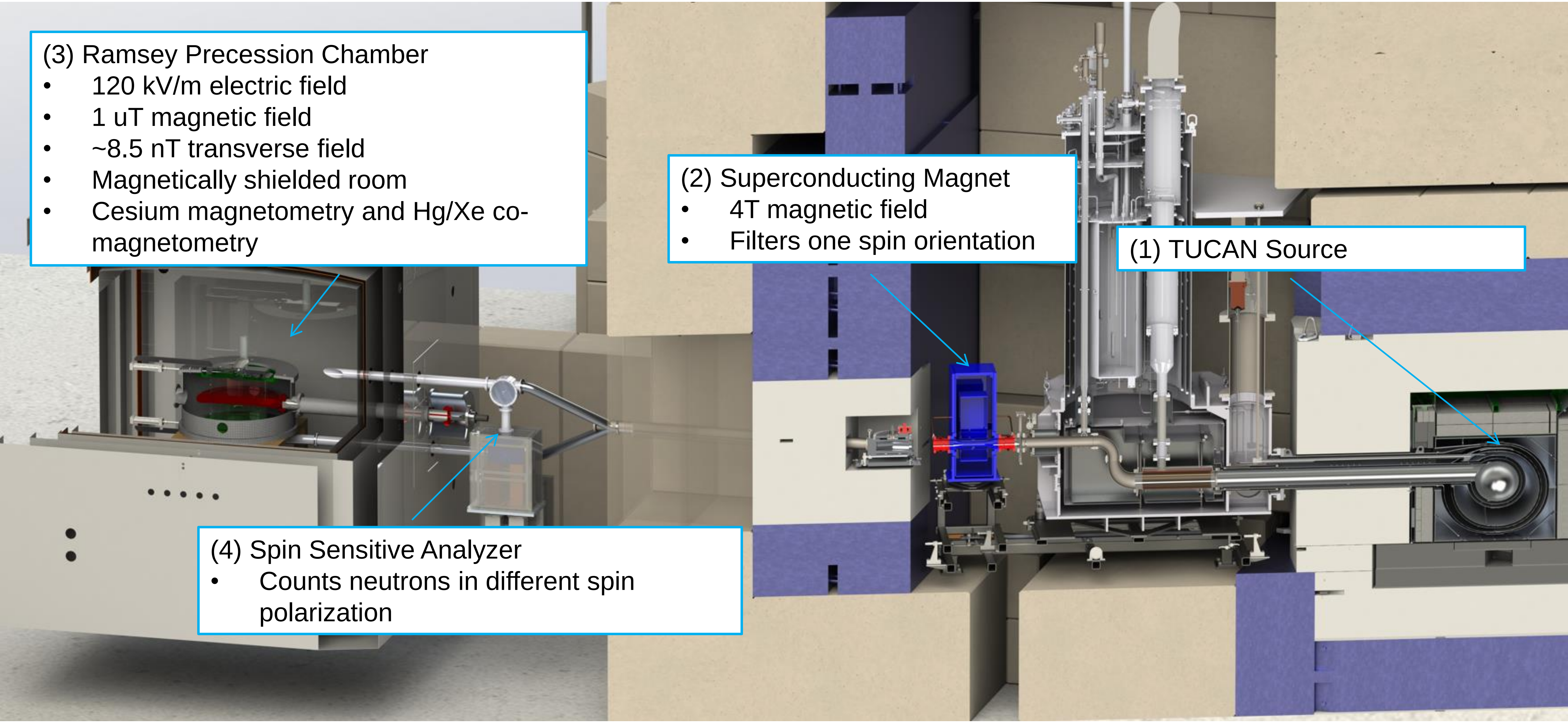
Neutron EDM – experimental status



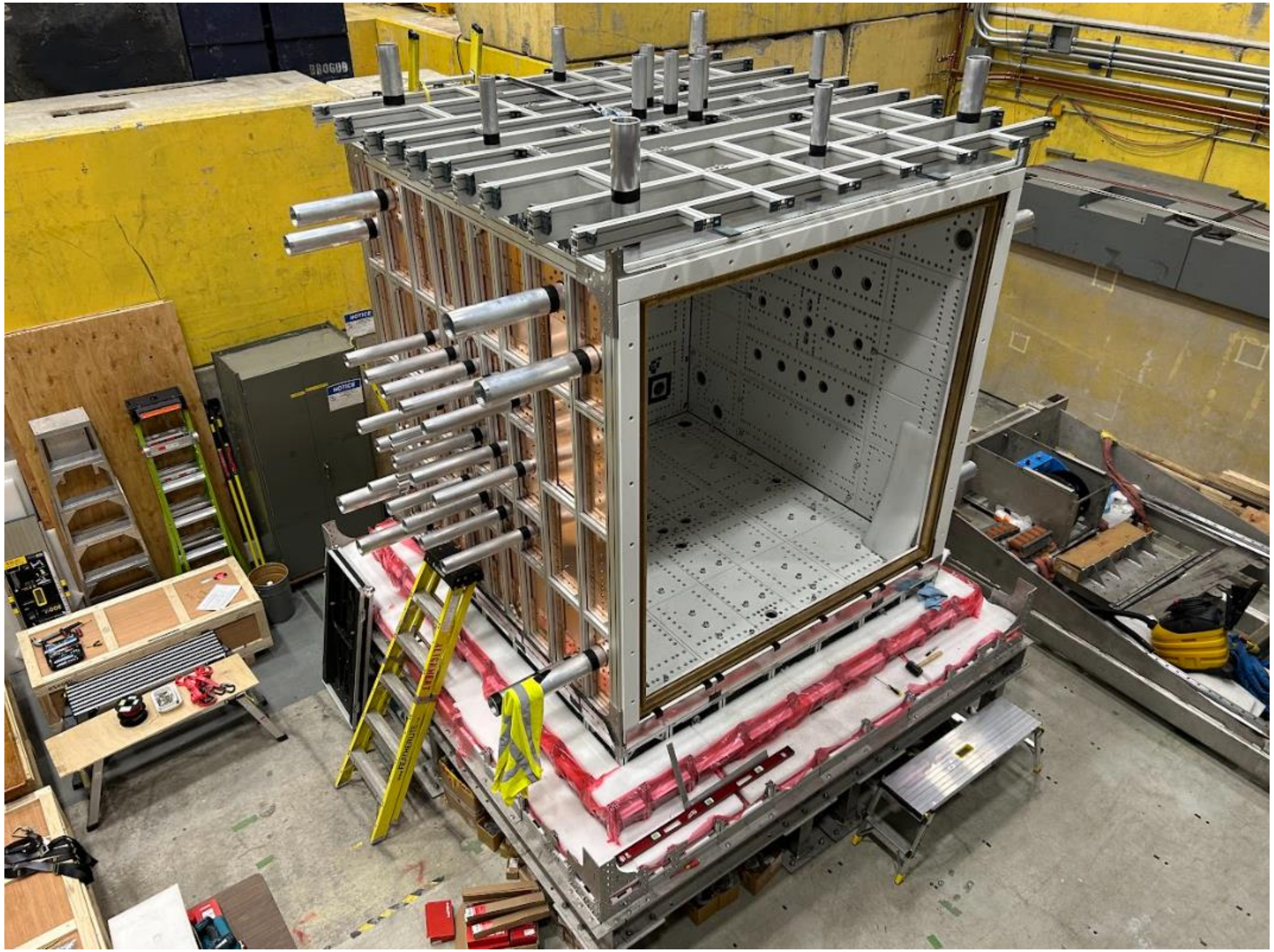
- $d_n < 1.8 \times 10^{-26}$ *e*cm (90% C.L.)
  C. Abel et al., Phys. Rev. Lett. 124, 081803 (2020)
- Many groups pursuing ~ 10^{-27} *e*cm measurement as next step

Adapted from https://en.wikipedia.org/wiki/Neutron_electric_dipole_moment

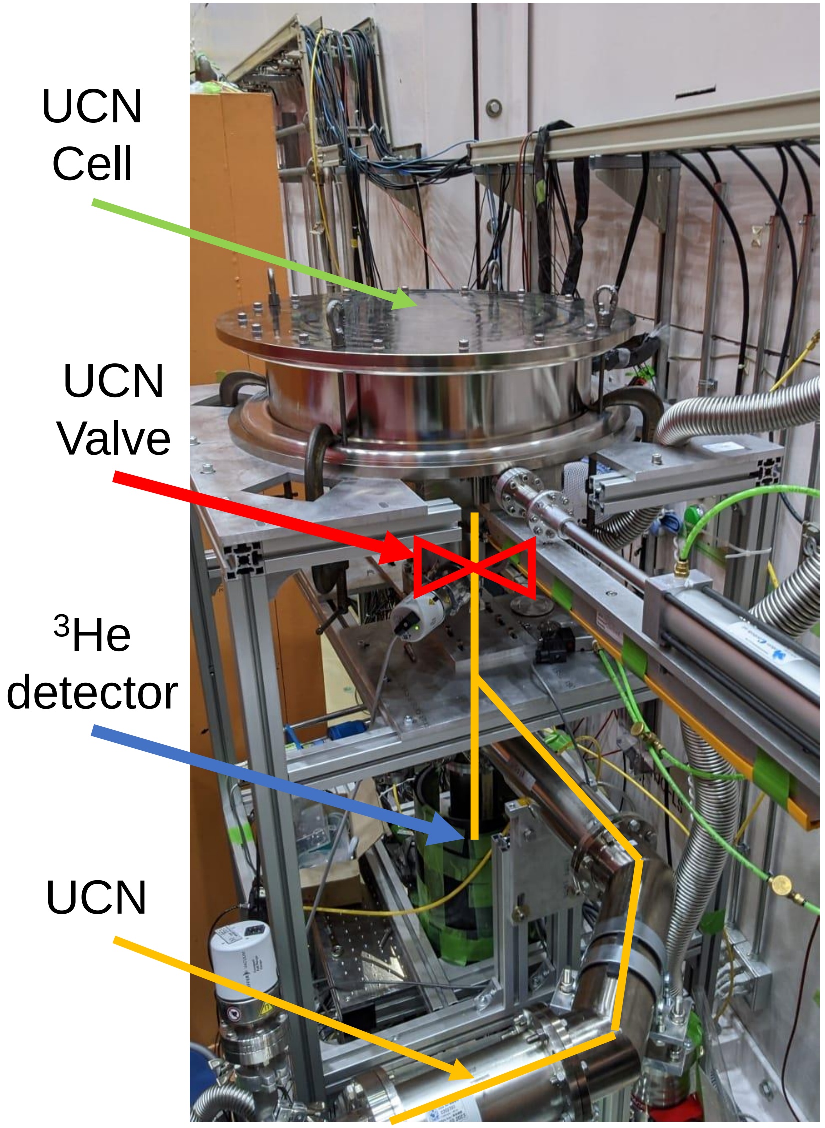
TUCAN METHOD:

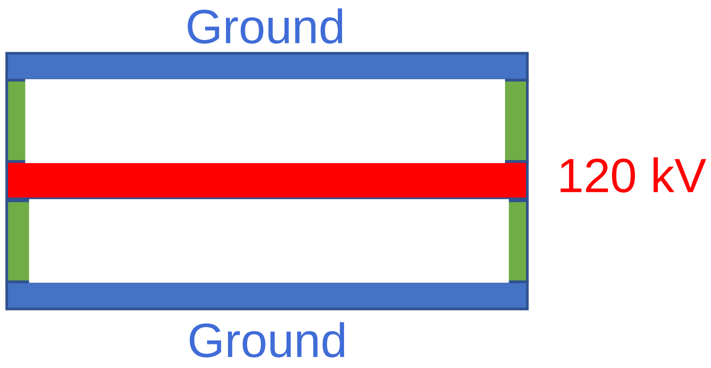


Magnetically shielded room under construction in the meson hall



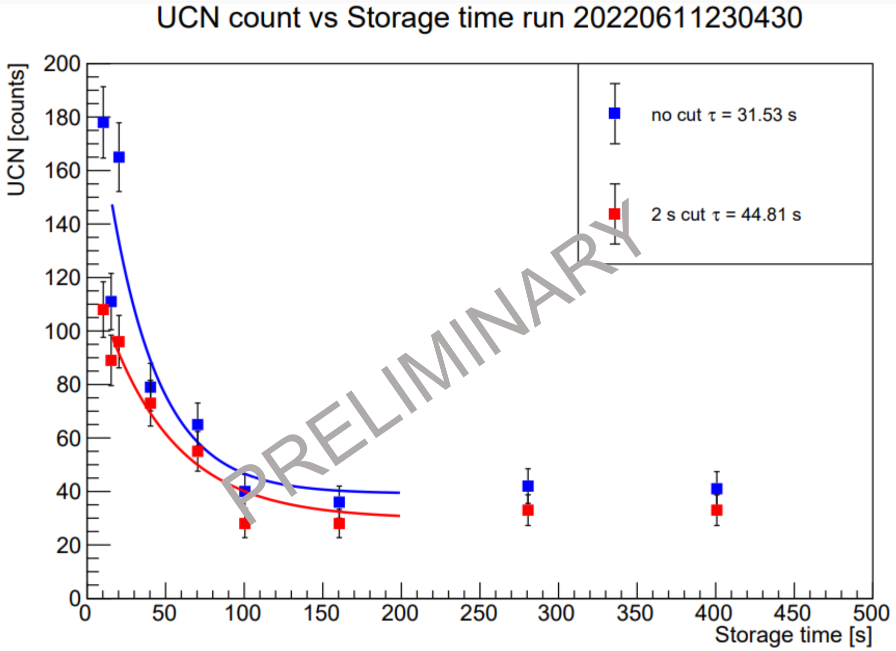
Precession cell: UCN storage test



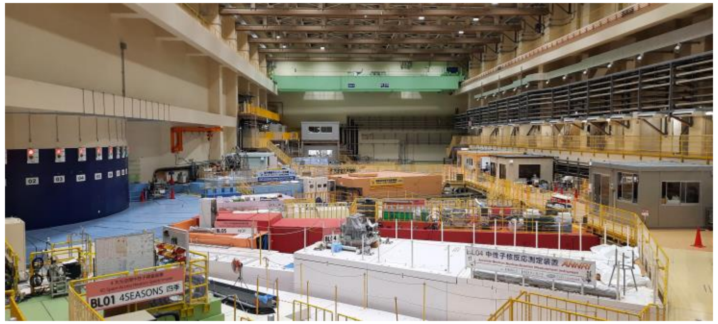


High voltage can't be applied with nickel-phosphorus coated cell.

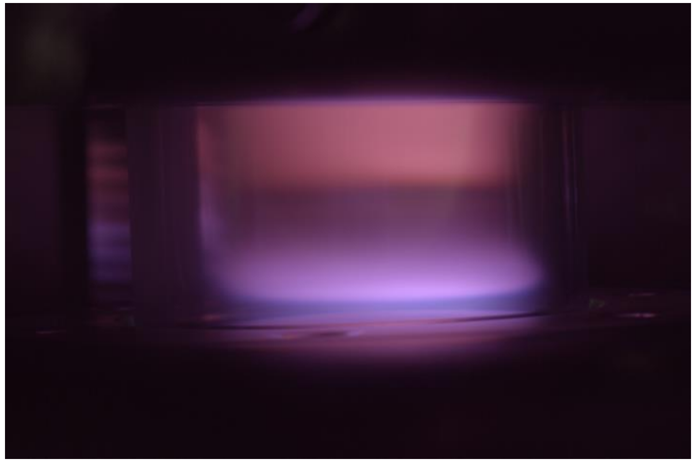
On going test using deuterated polystyrene.

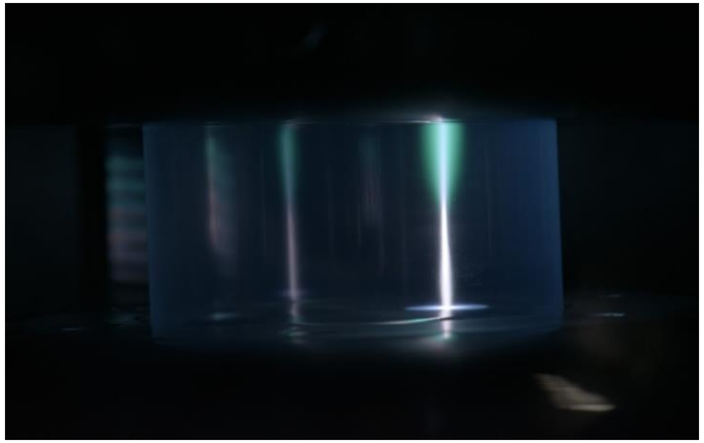


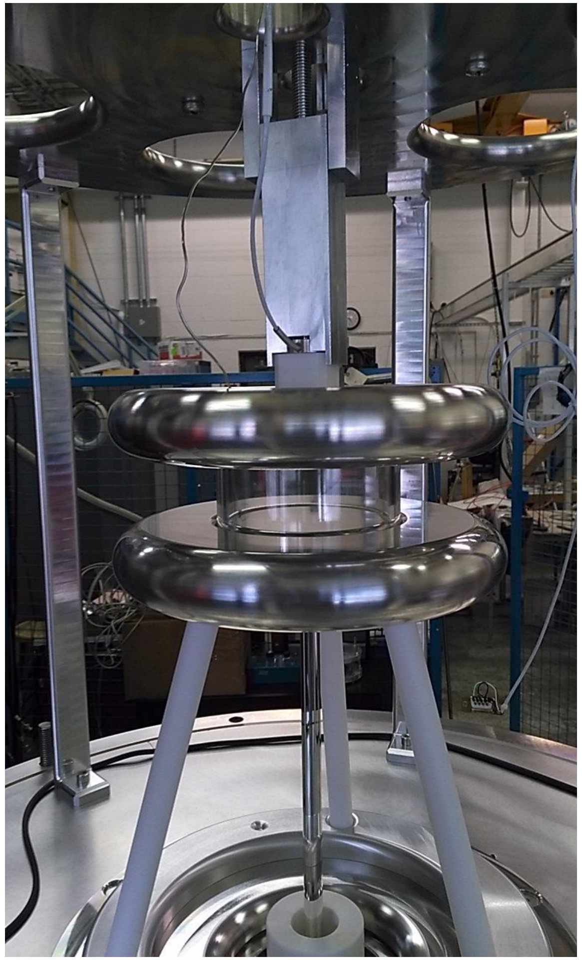
Tested at J-PARC UCN source: Prototype cell & valve, polarizers, detectors

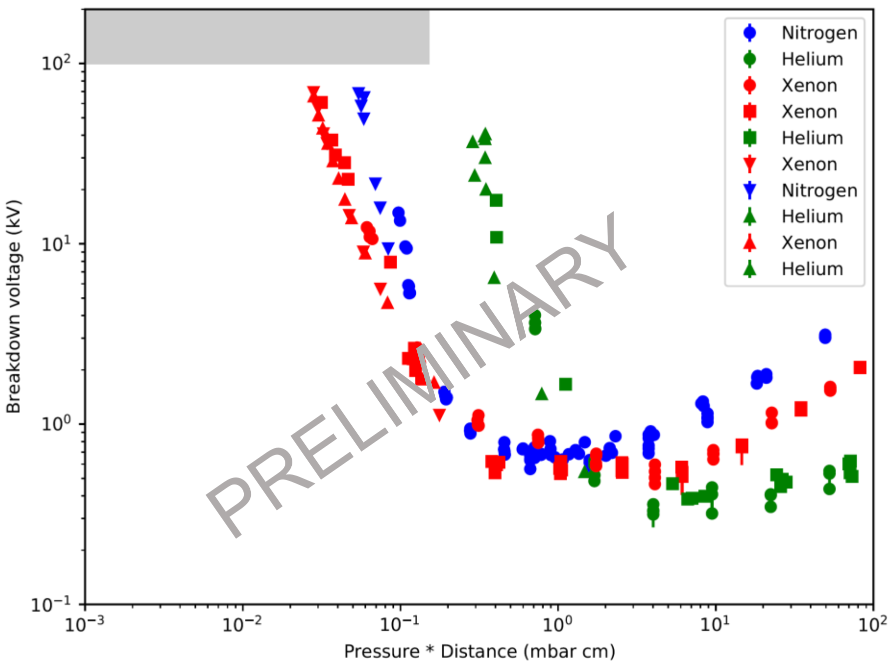


Precession cell: Electrical properties:



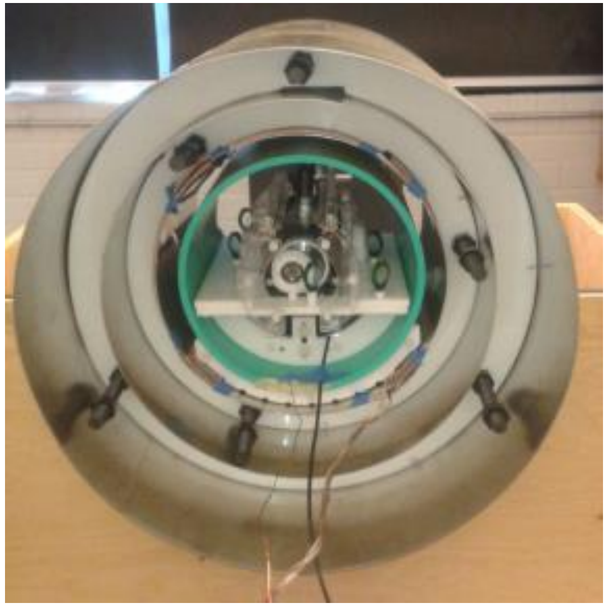


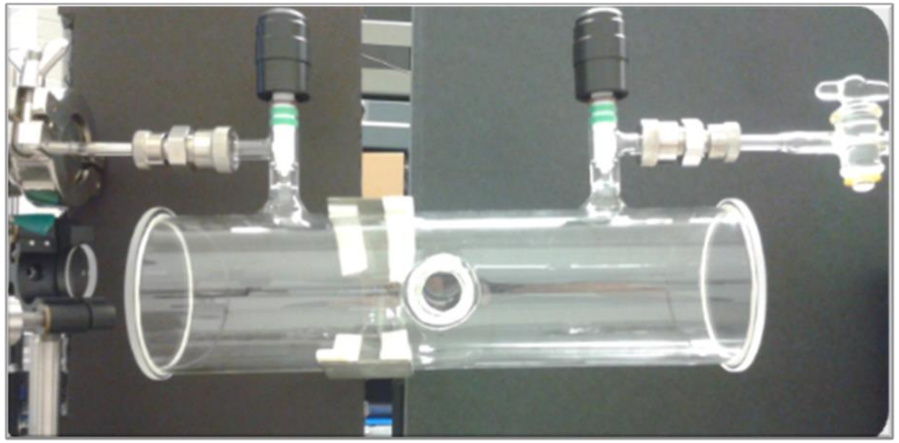




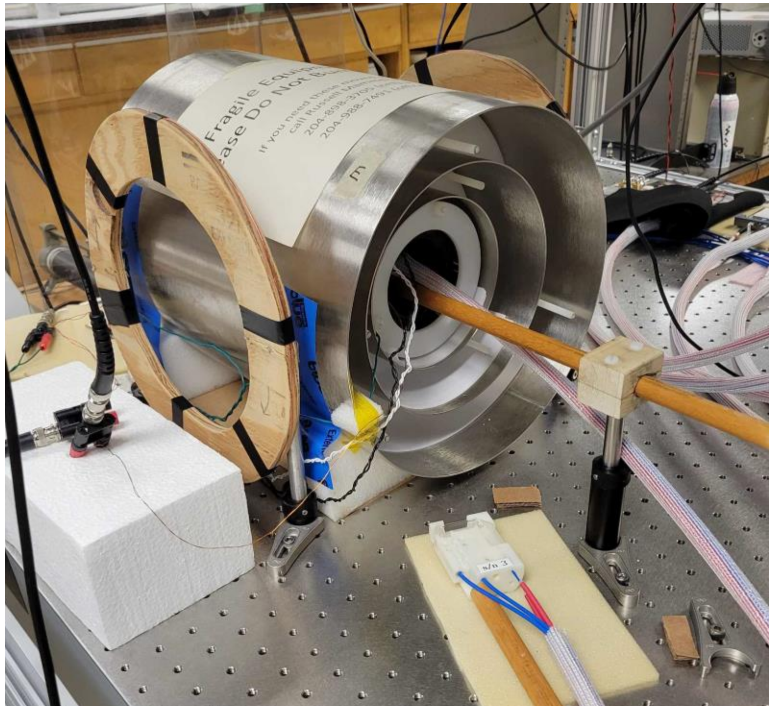
HV discharge testing of electrodes, insulators, coatings, comagnetometer gases.

Magnetometry

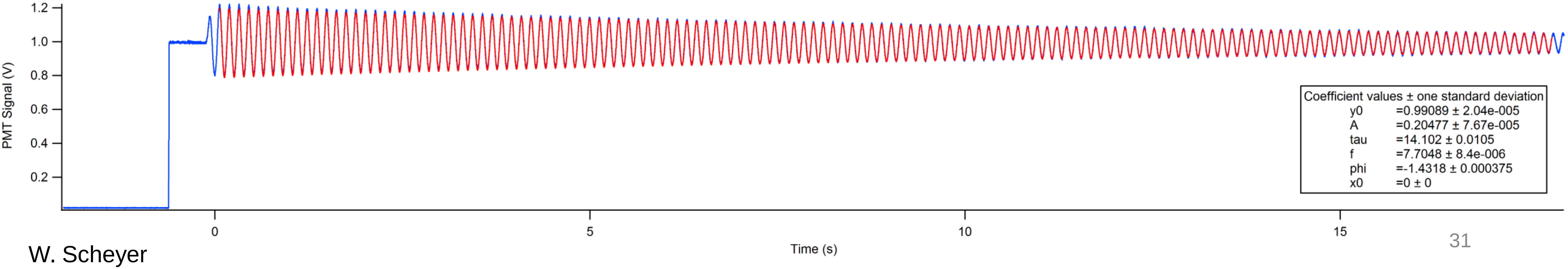




Hg comagnetometer prototype achieved 10s free precession, 1 pT resolution
Goal: 10 fT

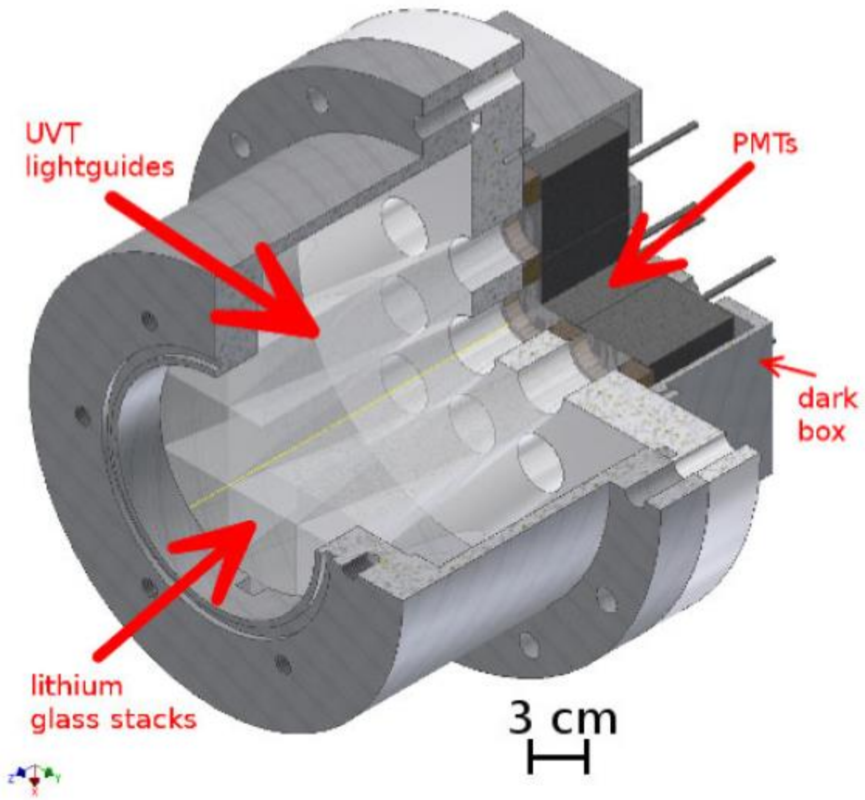


Operating 5 optical Cs magnetometers & 5 more on order



W. Scheyer

UCN detection



Scintillating stacks Lithium detector:

^{6}Li + $n \rightarrow \alpha$(2.05MeV) + t(2.73MeV)

The upper layer is 60 μm thick depleted ^{6}Li glass (0.01 %), and the lower layer is 120 μm thick doped ^{6}Li (95 %) glass. Ensure energy deposition in scintillating glass.

Fast signal 6 ns rise time 55 ns fall time allows for MHz detection. 89.7 % efficiency

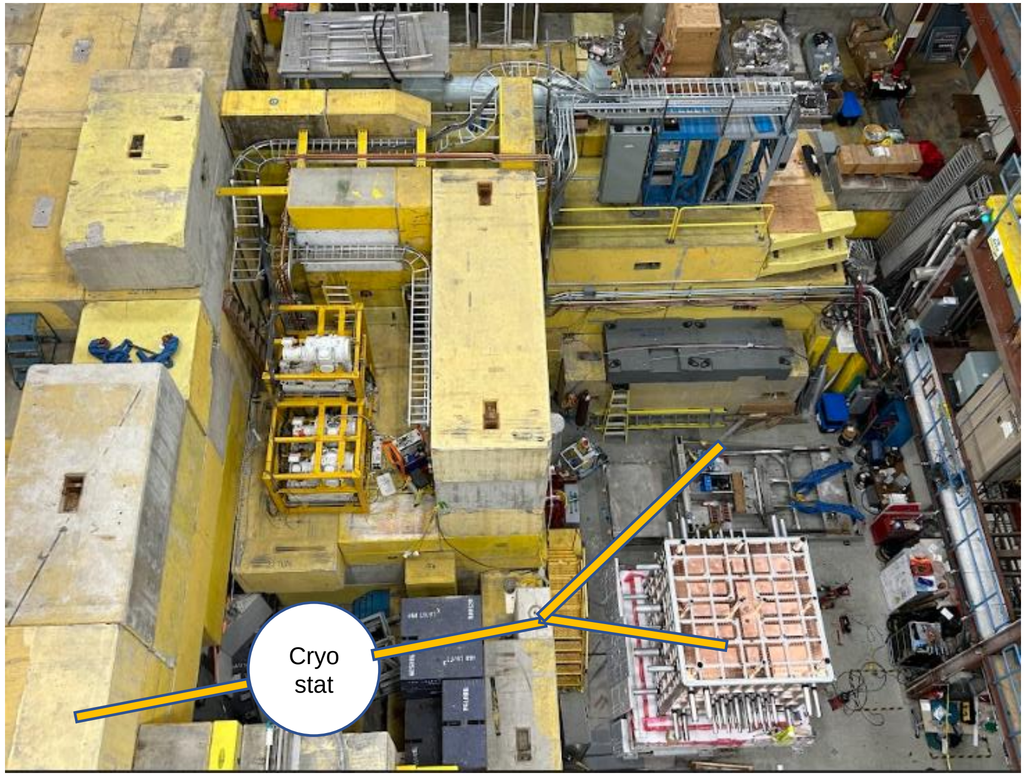
CONCLUSION:

The TUCAN collaboration builds the next ultra cold neutron source with a production rate of 1.6 x 10^{7} $n.s^{-1}$

We aim for a 10^{-27} *e*cm sensitivity for neutron electric dipole moment.

The source will also deliver UCNs to a second port that will be open to proposals from users worldwide.

First UCN production by next summer!



Thank you!

TUCAN

Collaboration meeting January 2023