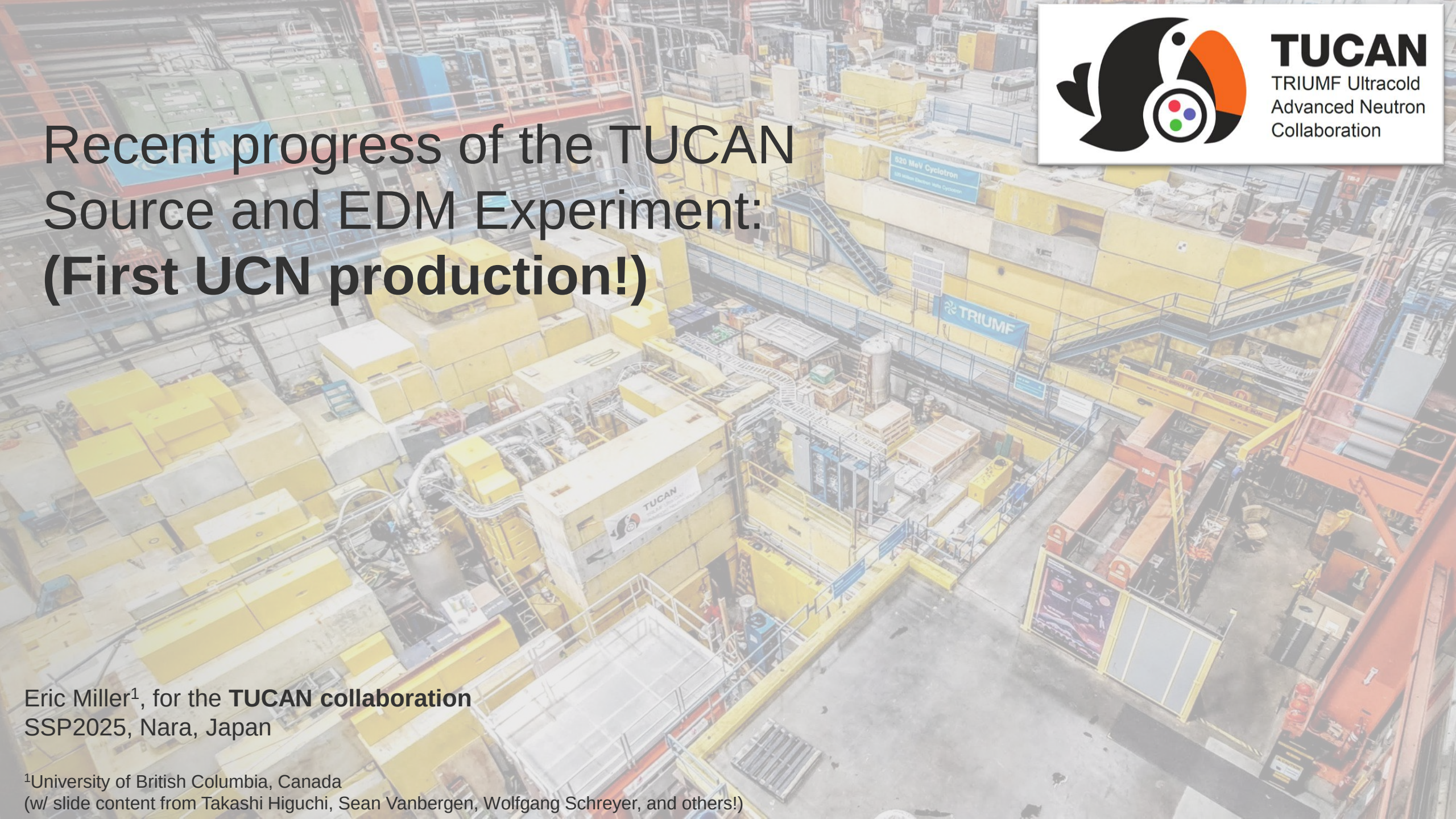


Recent progress of the TUCAN Source and EDM Experiment: **(First UCN production!)**

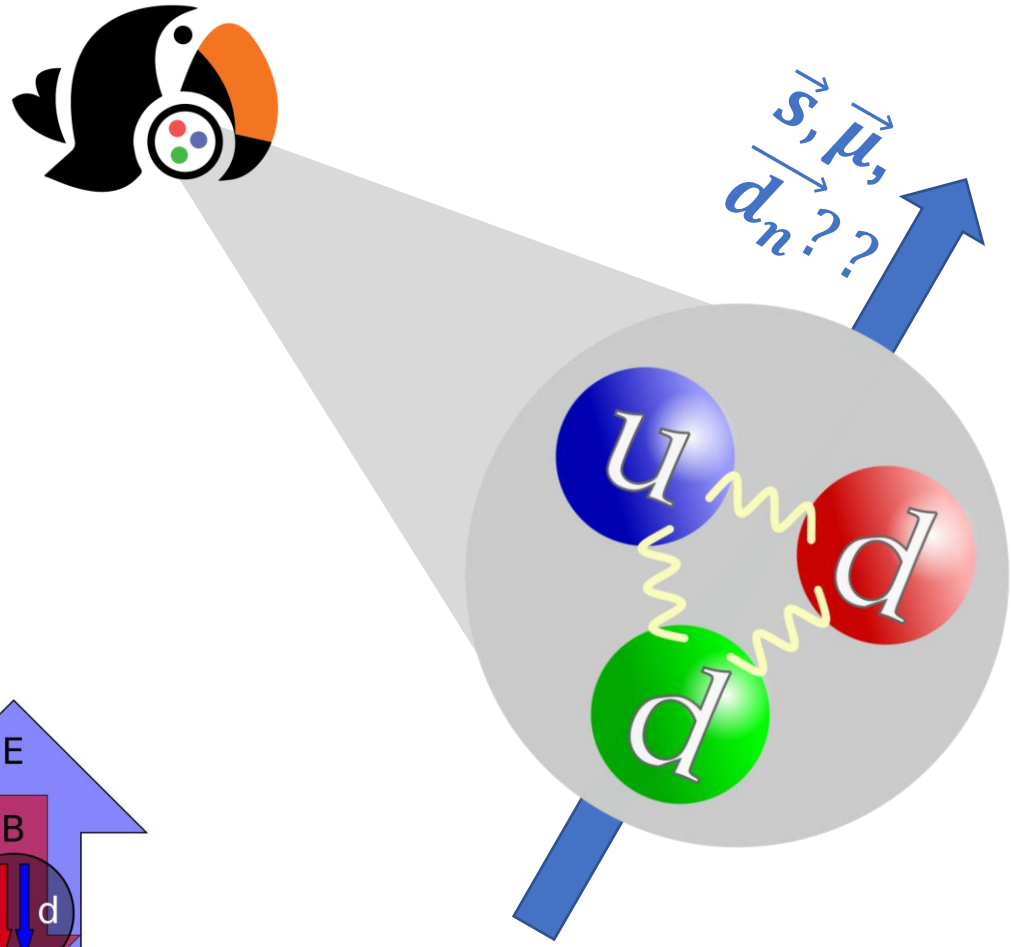
Eric Miller[1], for the **TUCAN collaboration**
SSP2025, Nara, Japan

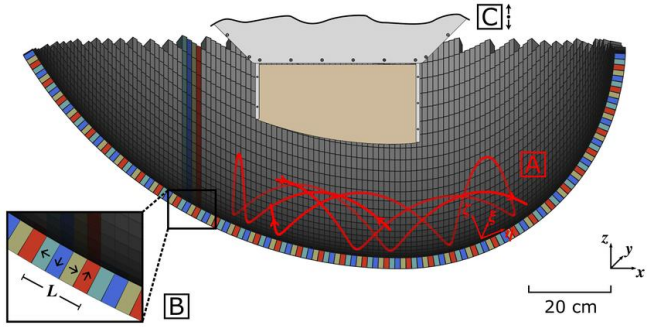
[1]University of British Columbia, Canada
(w/ slide content from Takashi Higuchi, Sean Vanbergen, Wolfgang Schreyer, and others!)

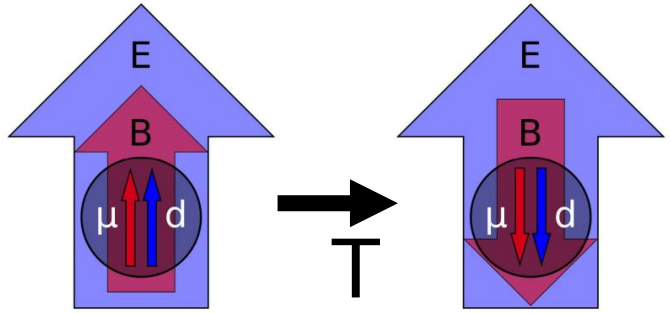
TUCAN is building the world's strongest source of ultracold neutrons:

- Ultracold neutron (UCN): low enough kinetic energy to be ***trapped*** in material bottles.
  - 300neV, long de Broglie wavelength
  - Confined by nuclear strong interaction → Fermi potential

- Other interactions
  - gravitational potential: 102 neV/m → 3m max height!
  - Weak interaction → β decay **878s or 888s???**
  - Magnetic dipole: $\vec{\mu} \cdot \vec{B}$ → **29 MHz/T** (magnetic trapping / magnetic walls also possible)
  - Electric dipole moment → T-reversal (CP violation)!
    - $\vec{d} <$ **1.8 x 10^{-26} ecm (90% C.L.)**







https://doi.org/10.1103/PhysRevC.100.015501

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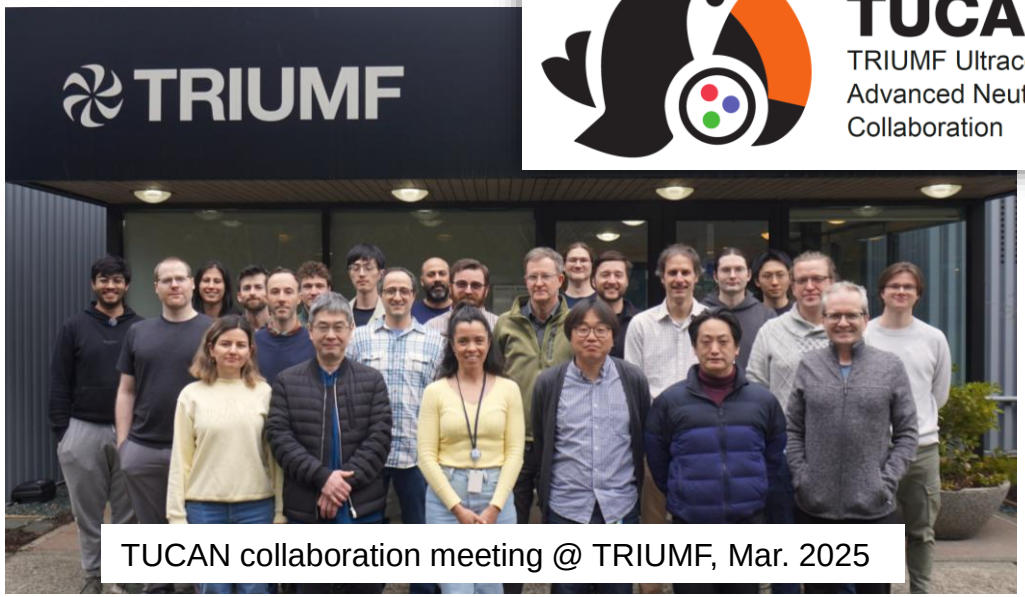


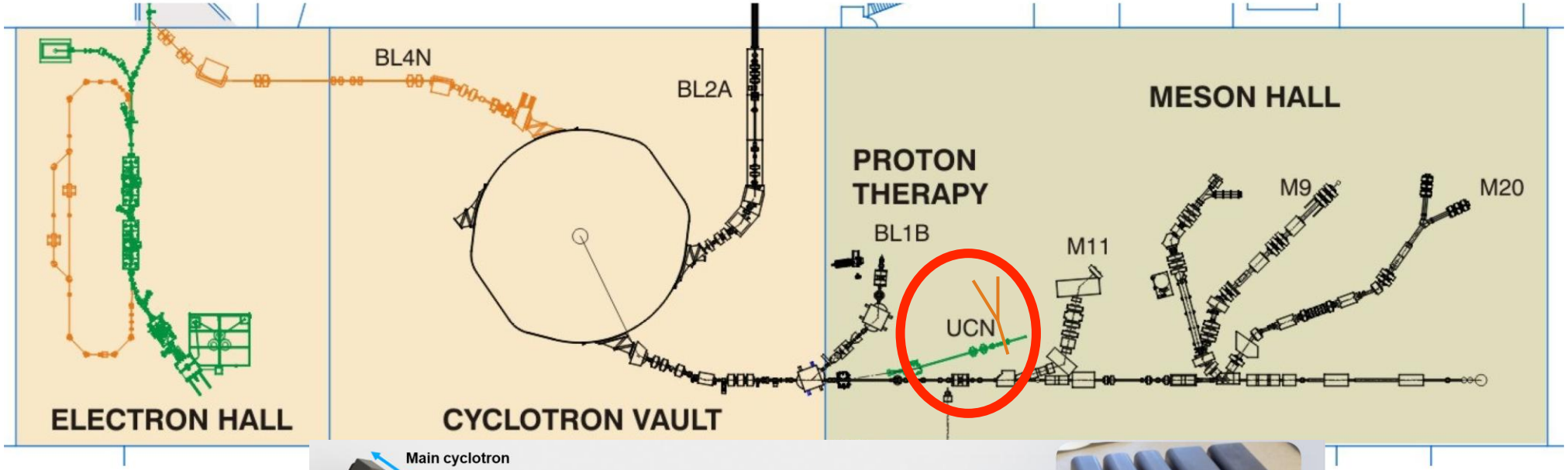
TUCAN collaboration meeting @ TRIUMF, Mar. 2025

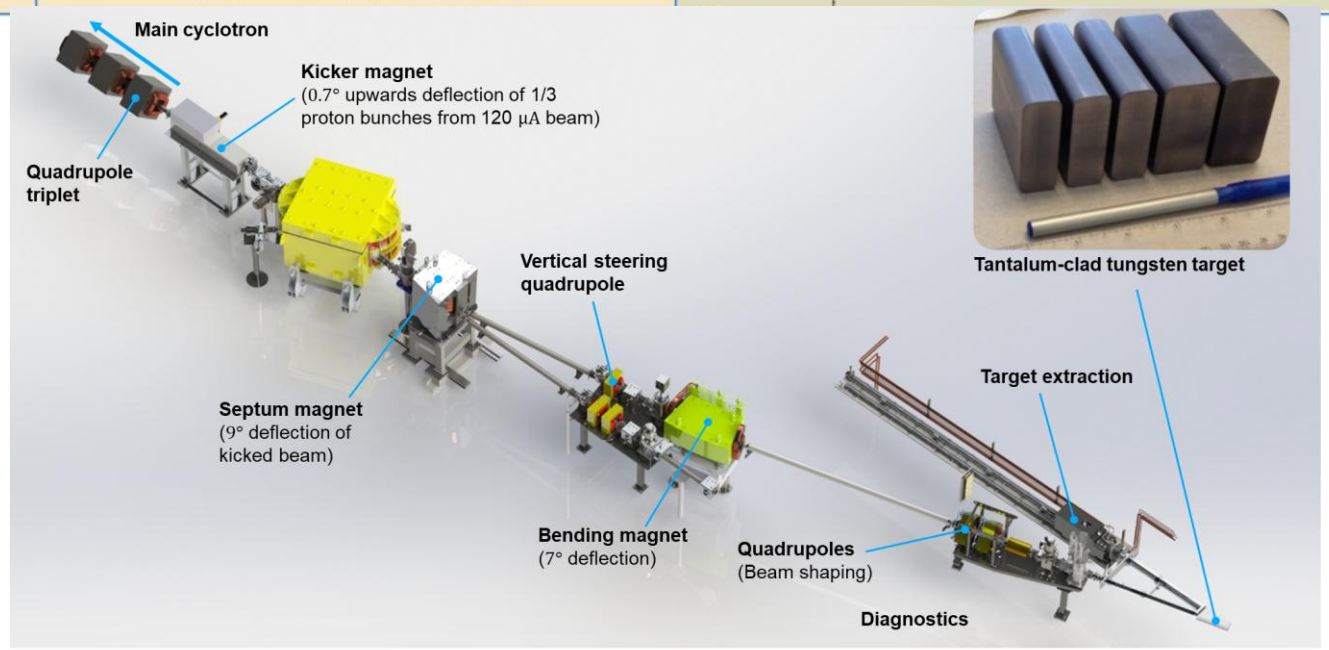
Collaboration goals:

- Build the world's most intense ultracold neutron (UCN) source: 1.4×10^7 UCN/s expected
- Search for the neutron EDM at the 10^{-27} e·cm level in ~ 280 measurement days

TRIUMF
KEK
UBC
THE UNIVERSITY OF WINNIPEG
RCNP
J-PARC
SFU
UNBC
NC STATE UNIVERSITY
KYOTO UNIVERSITY
名古屋大学 NAGOYA UNIVERSITY
OAK RIDGE National Laboratory
University of Manitoba
UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO
UNIVERSITY OF SASKATCHEWAN
KURNS
NSERC CRSNG
JST Japan Science and Technology Agency
JSPS
INNOVATION Canada Foundation for Innovation / Fondation canadienne pour l'innovation

Experiment hosted at TRIUMF proton beamline (Vancouver, Canada):



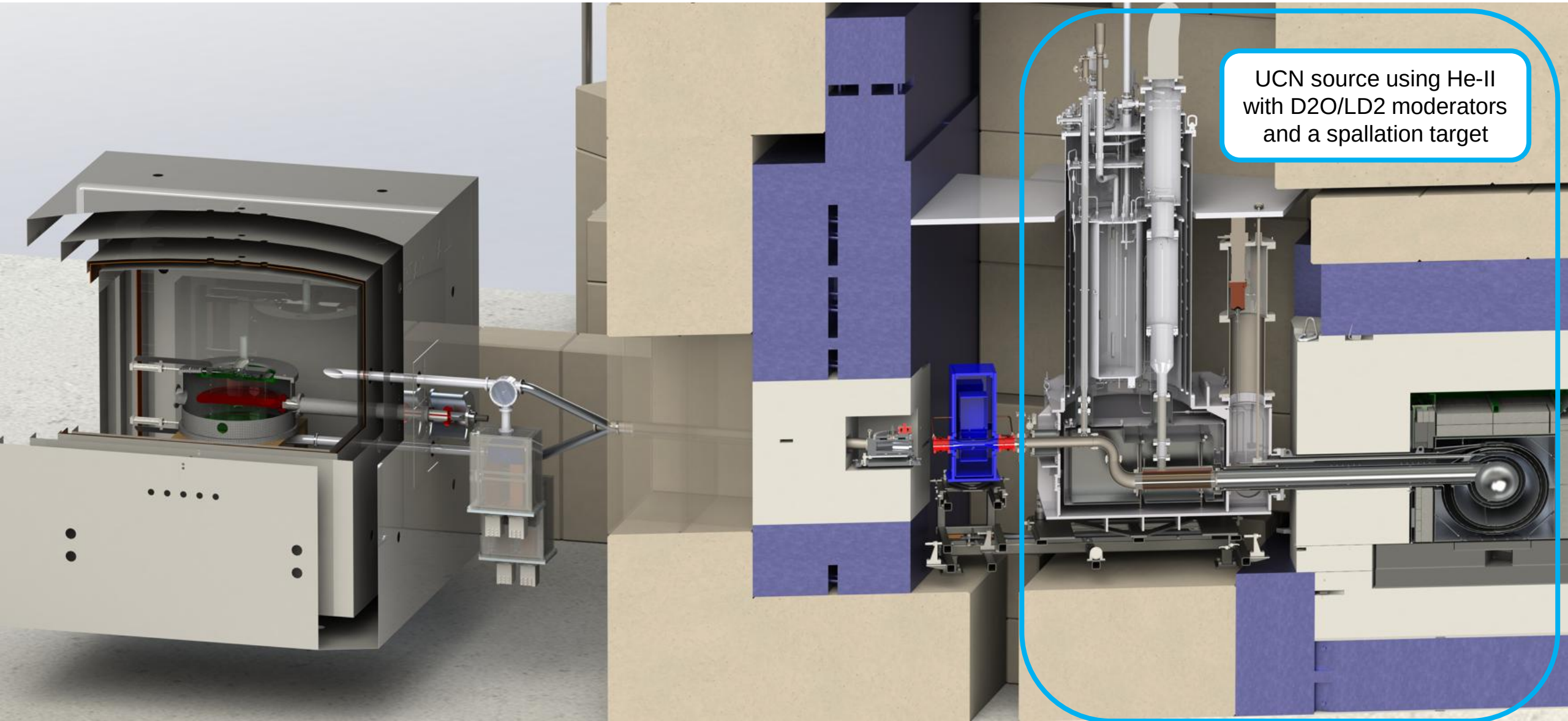


Fast kicker magnet to share proton beam with other users

10.1016/j.nima.2019.01.074
10.1103/PhysRevAccelBeams.22.102401

TUCAN
TRIUMF Ultra Cold
Advanced Neutron source

The TUCAN Source and EDM Experiment



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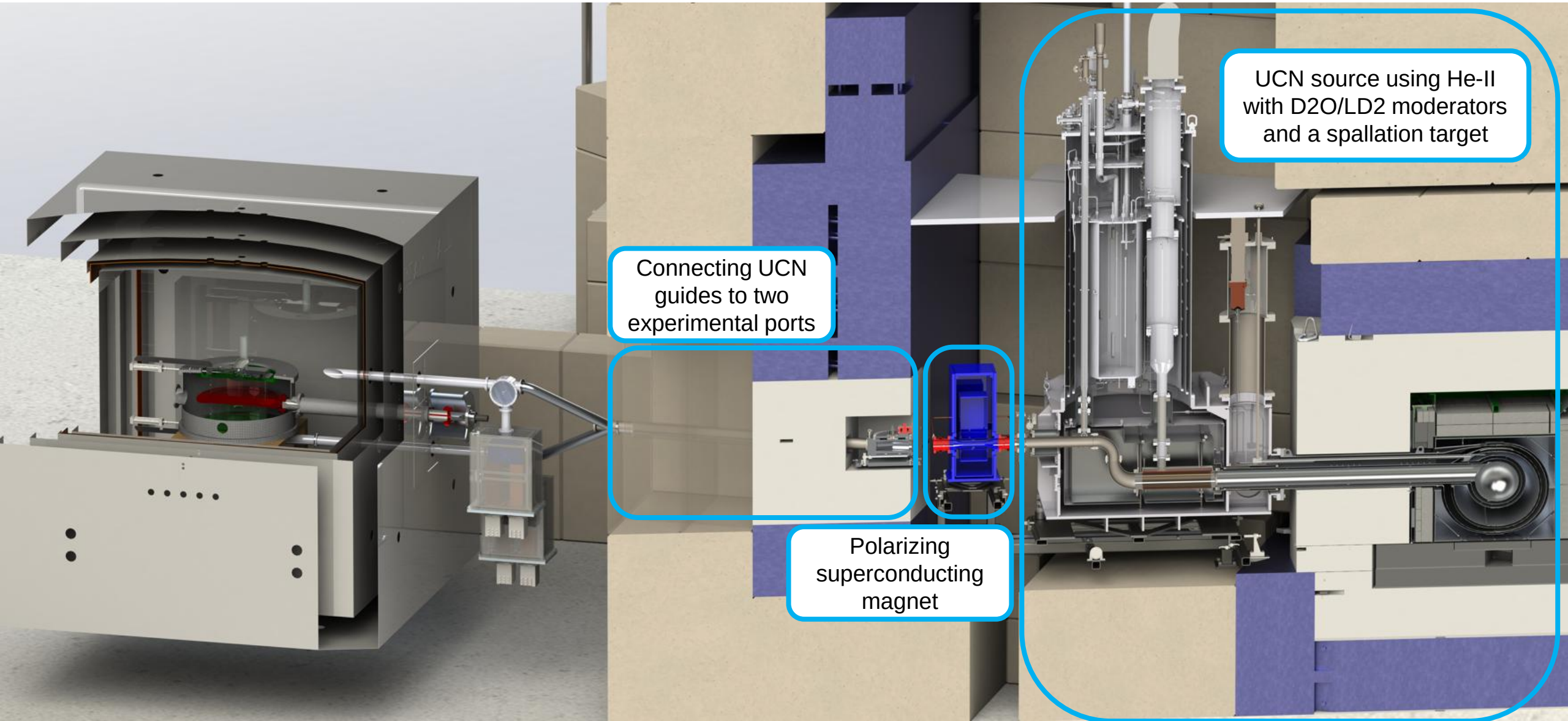

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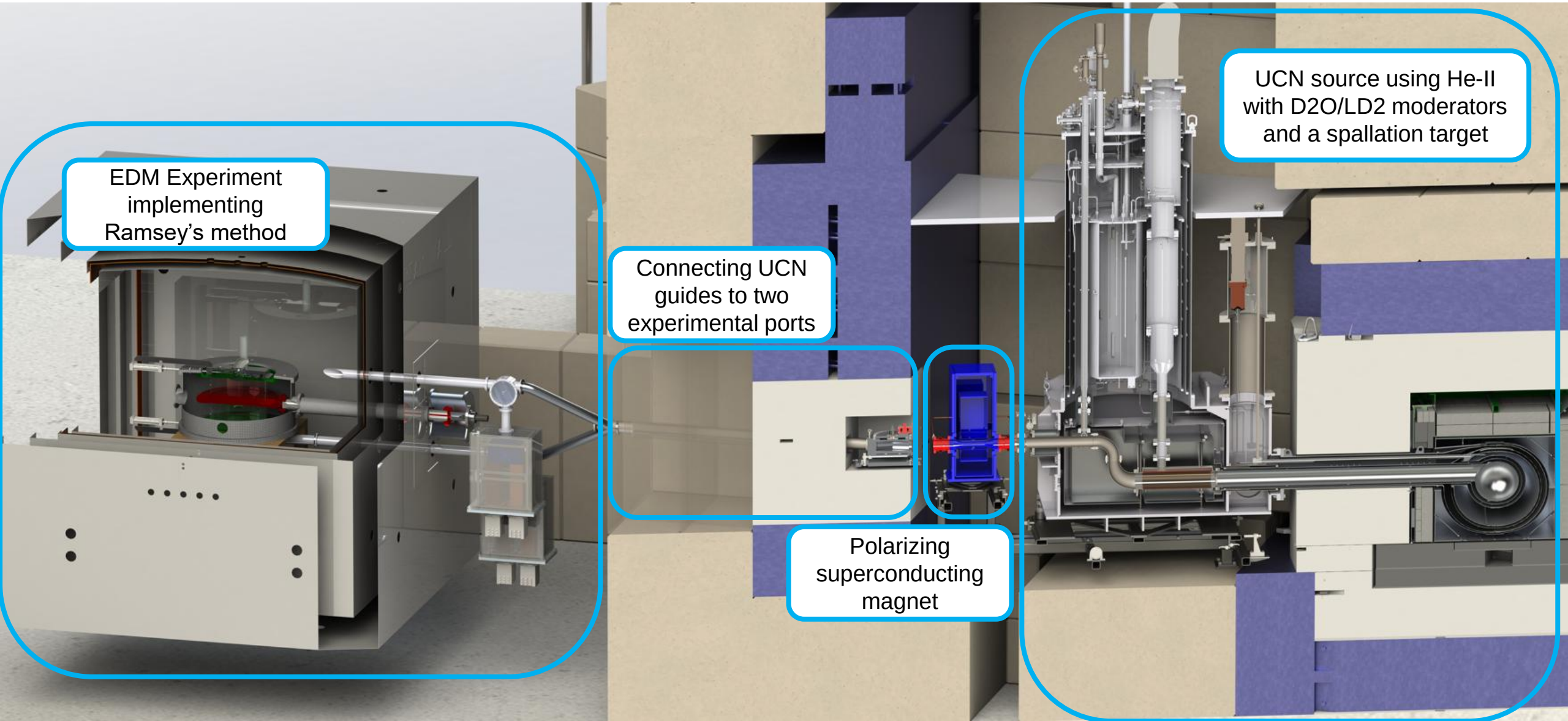
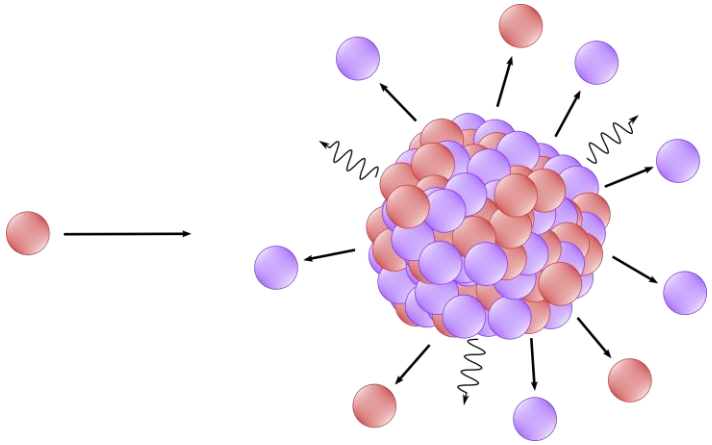
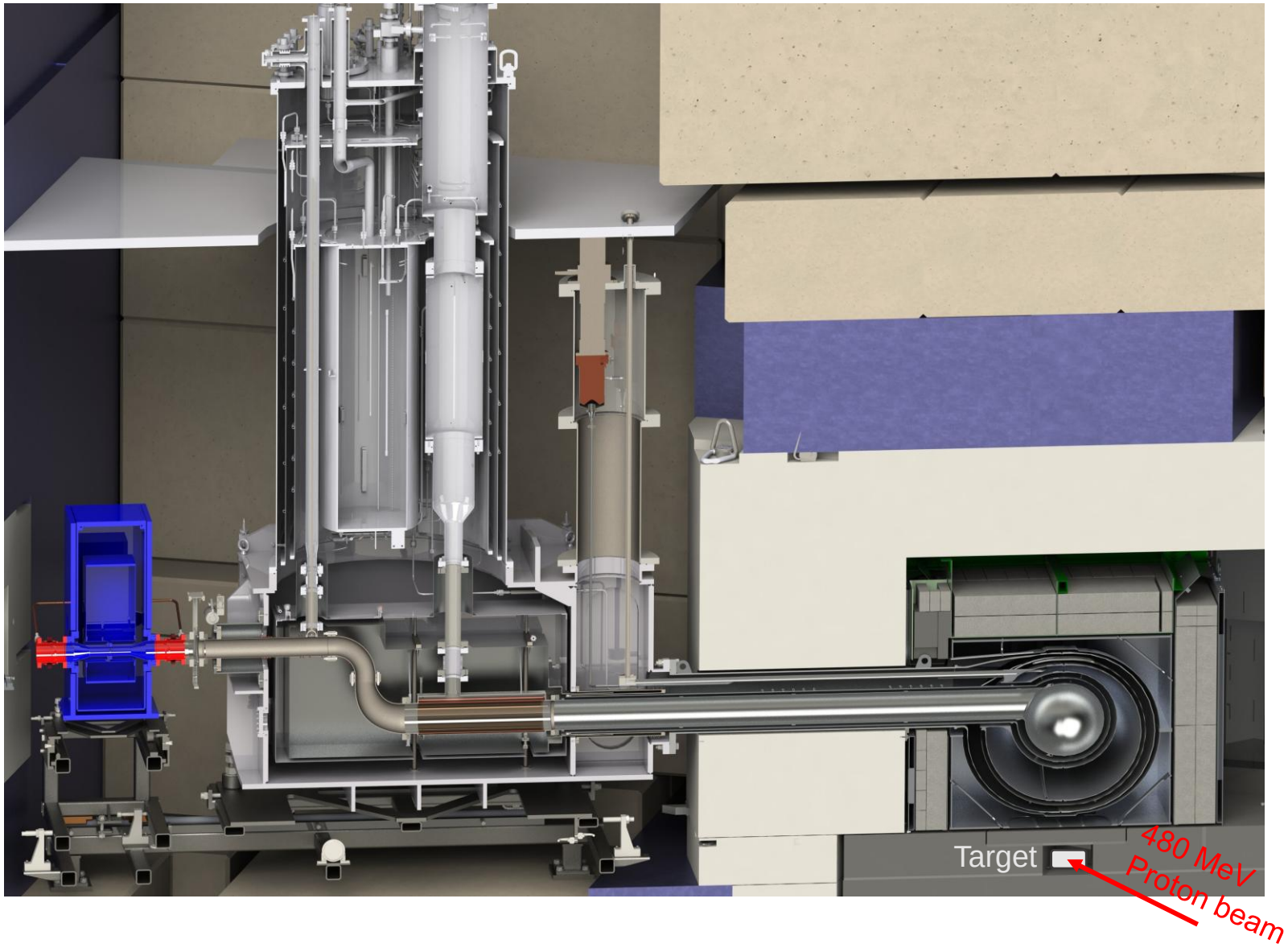


The TUCAN Source

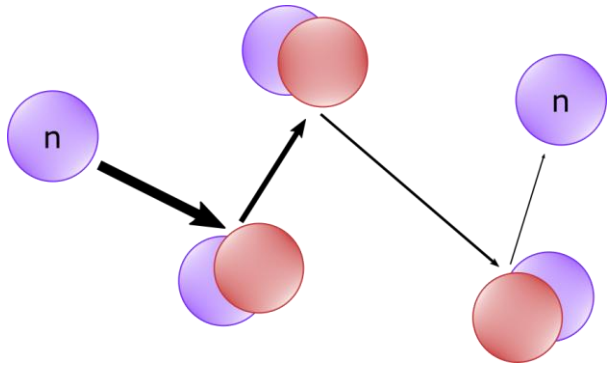
1. Production of high energy neutrons by spallation (MeV)



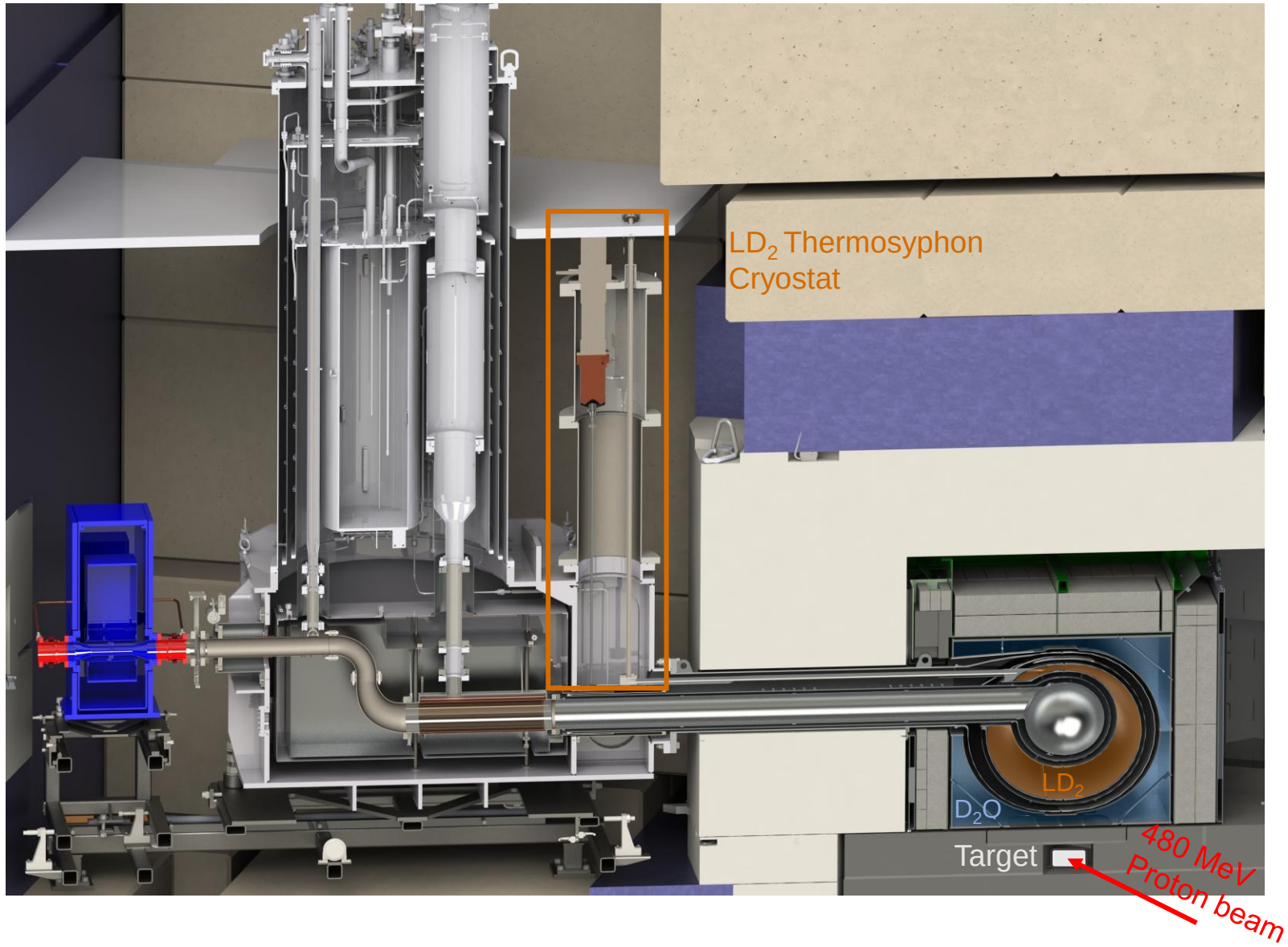


The TUCAN Source

2. Moderation to cold energies (~meV)

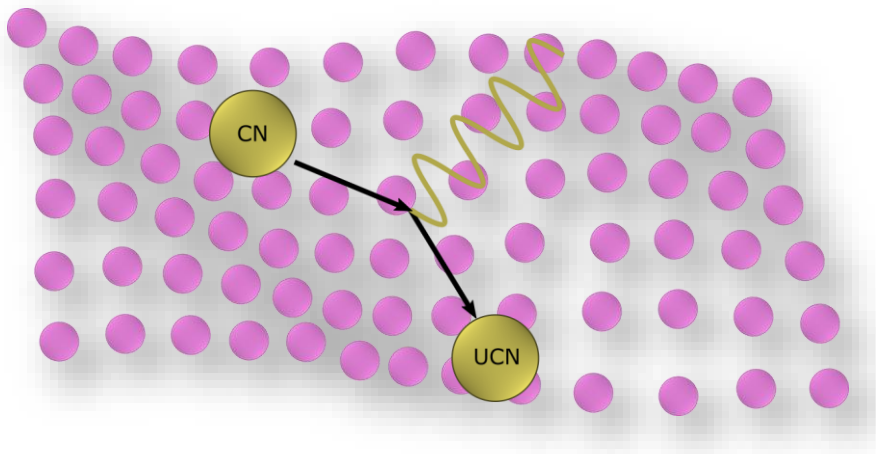


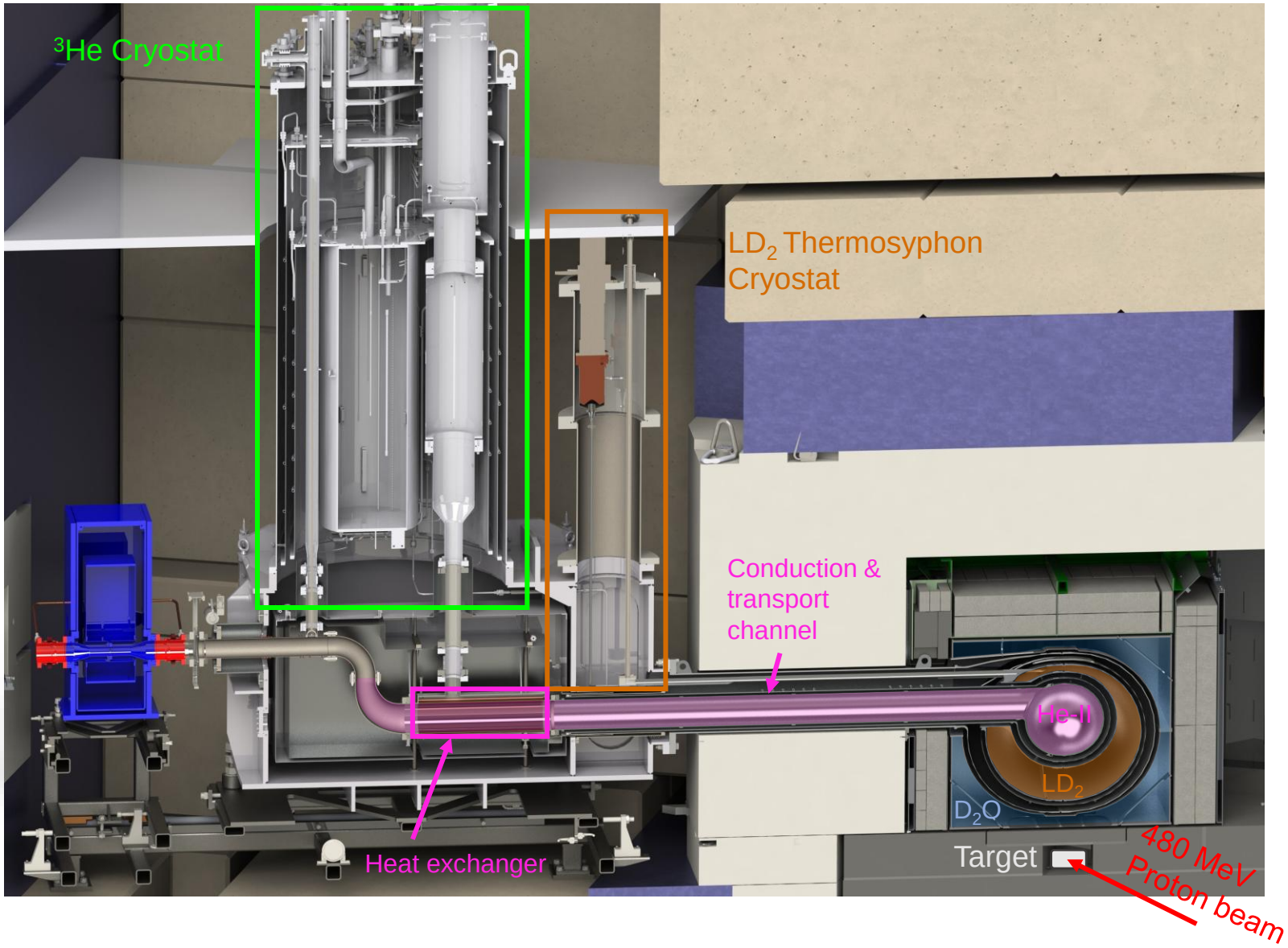
Moderators: D_2O and LD_2



The TUCAN Source

3. Superthermal conversion to UCNs (neV) by phonon emission in superfluid helium (He-II)





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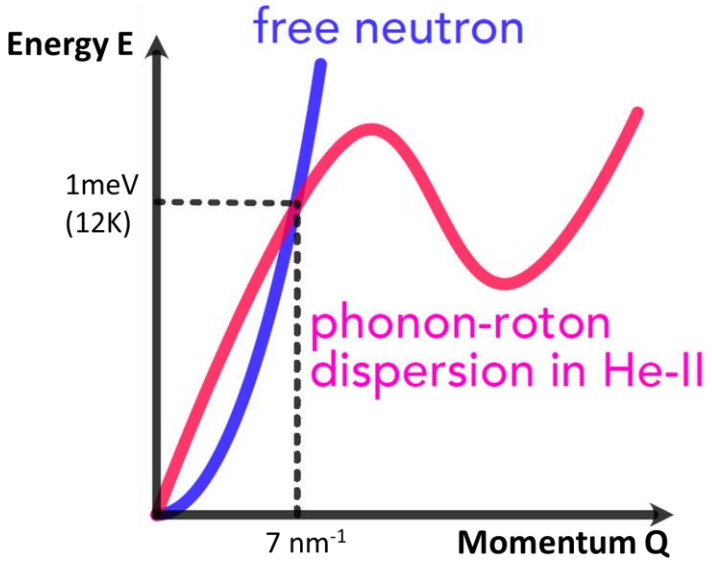

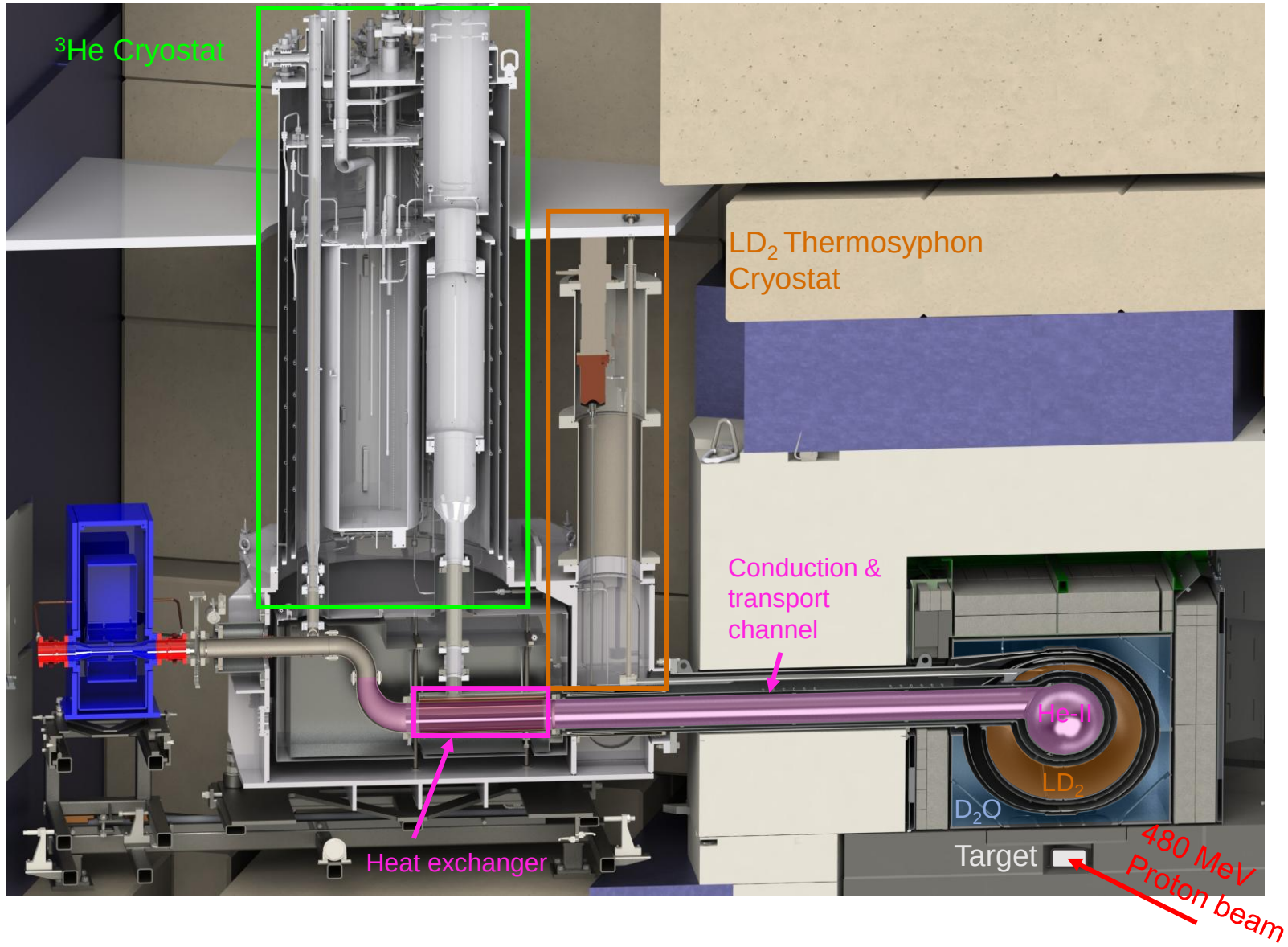

The TUCAN Source

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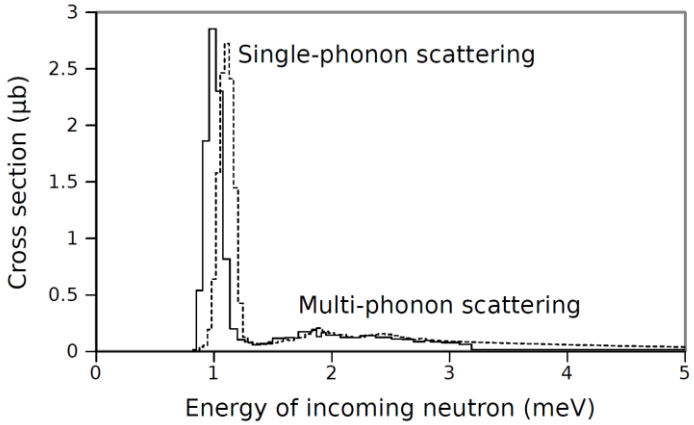
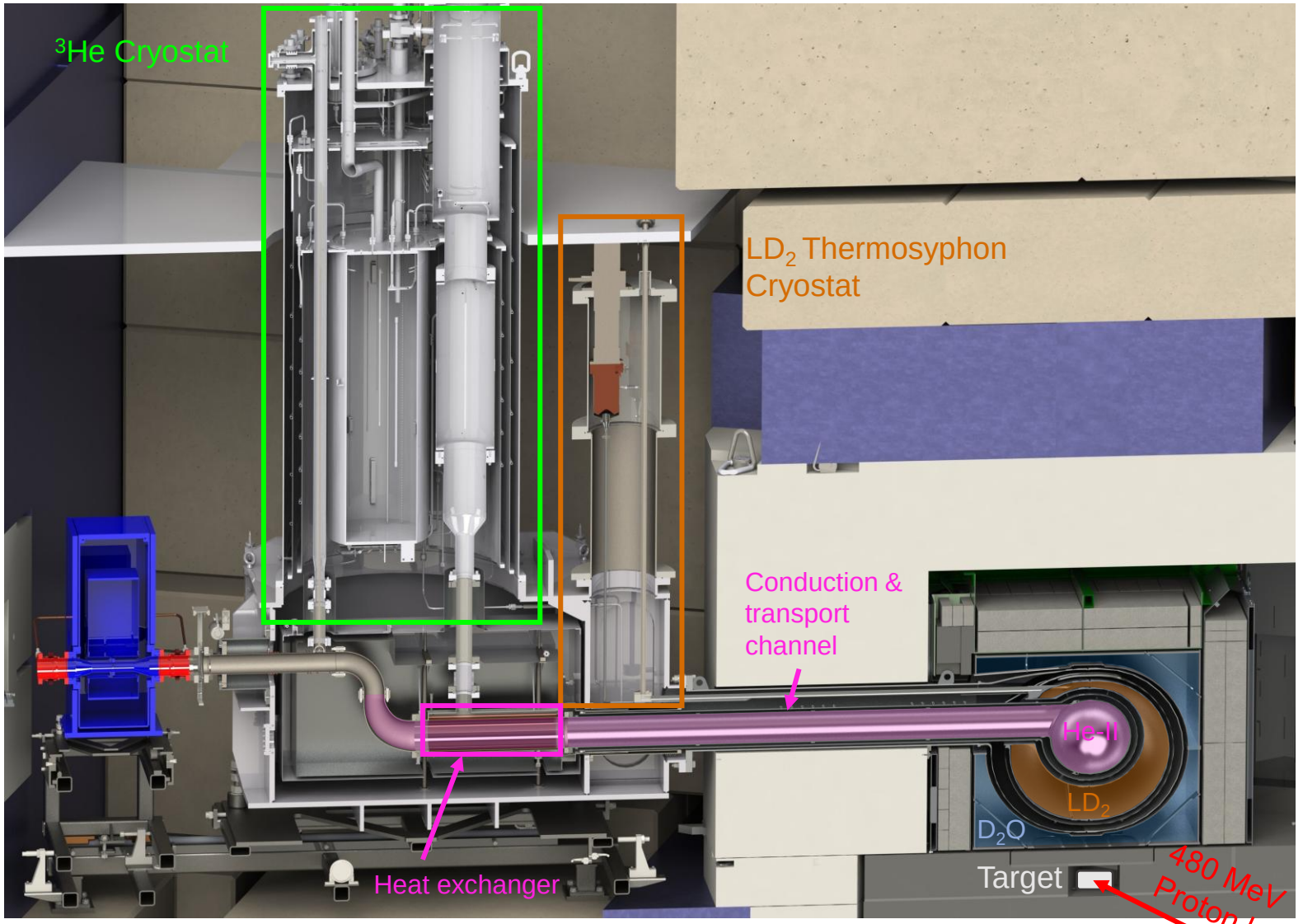
UCN-production cross section in superfluid helium

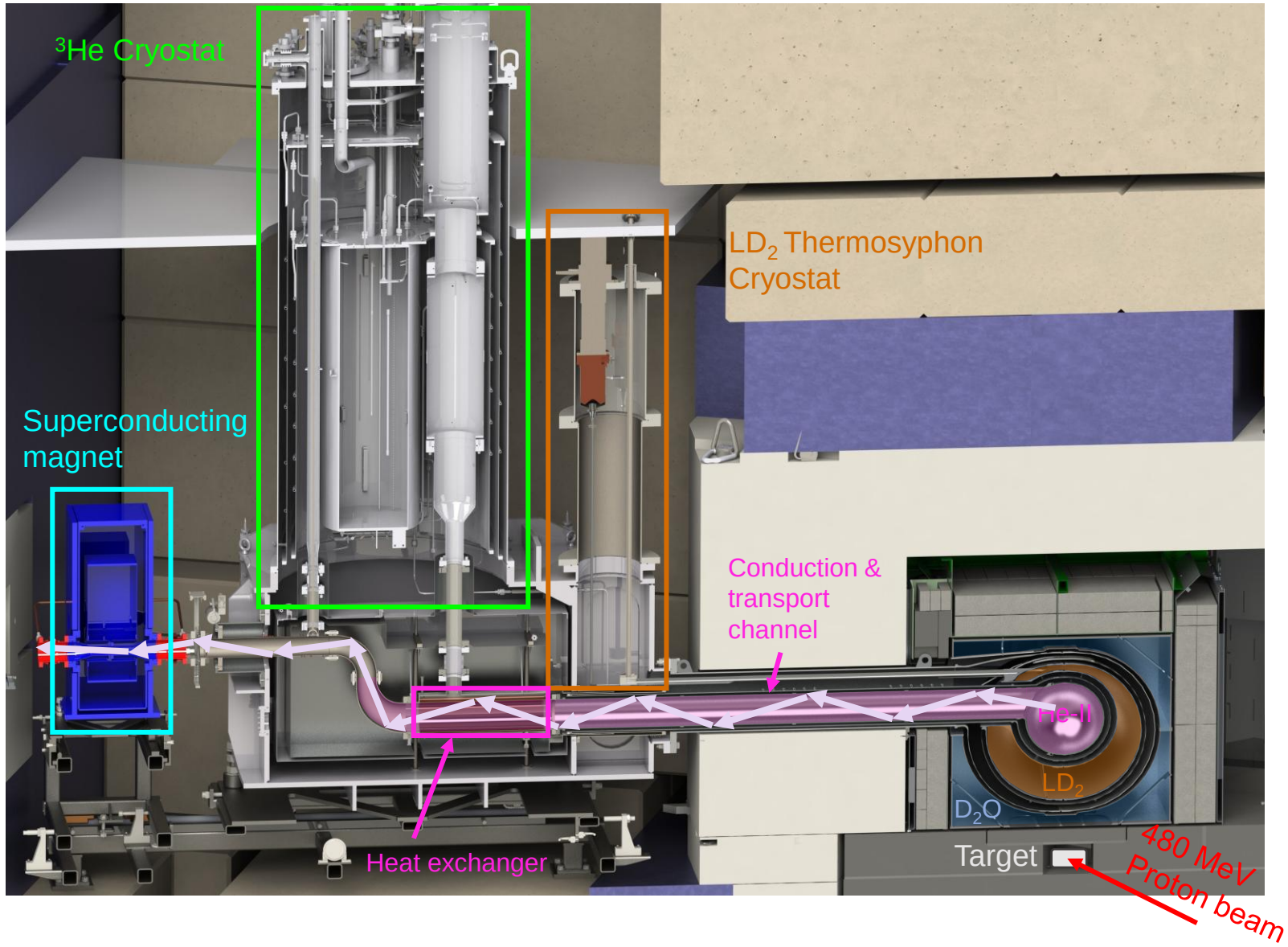




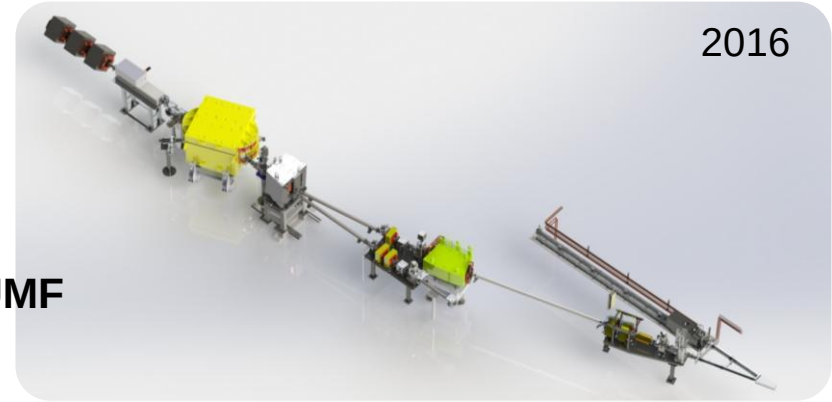
Superfluid He-II cooled by a 10W ^{3}He cryostat

The TUCAN Source

4. Diffusion of UCNs out to experimental area



TUCAN source timeline



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2018 Conceptual Design Report of the TUCAN source

2019 Last beamtime with the prototype source → decommissioned

2021 ^{3}He cryostat shipped KEK → TRIUMF

Superfluid He-II production volume (wall 1) tested at LANL

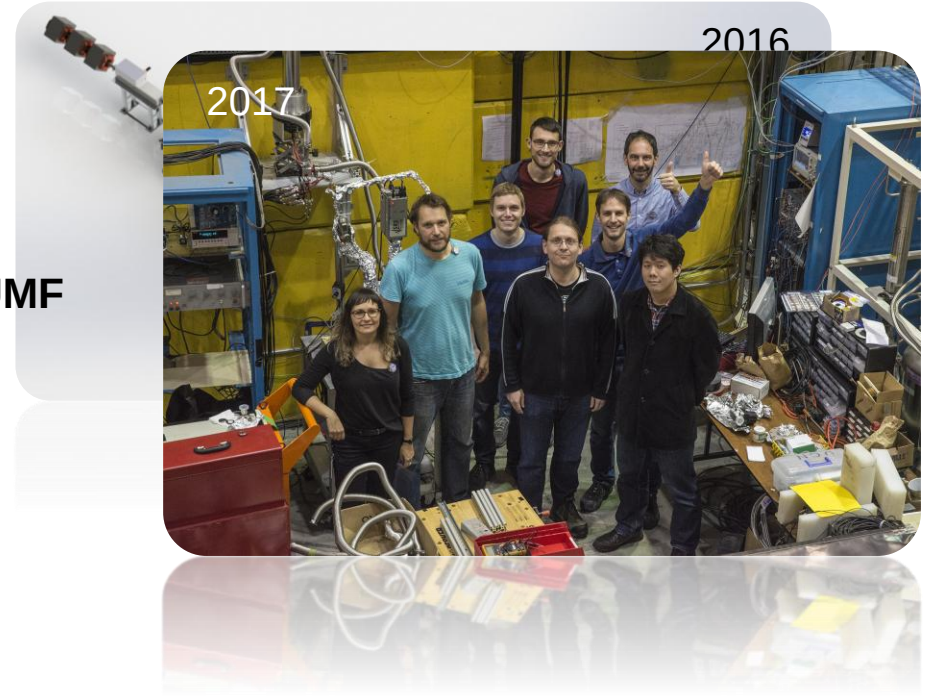
2023 Started manufacturing the rest of the production volume vessels

2024 Major manufacturing completed (apart from the LD_2 cryostat)

First attempt of UCN production with the TUCAN source

2025.06 First UCN production from the TUCAN source

TUCAN source timeline



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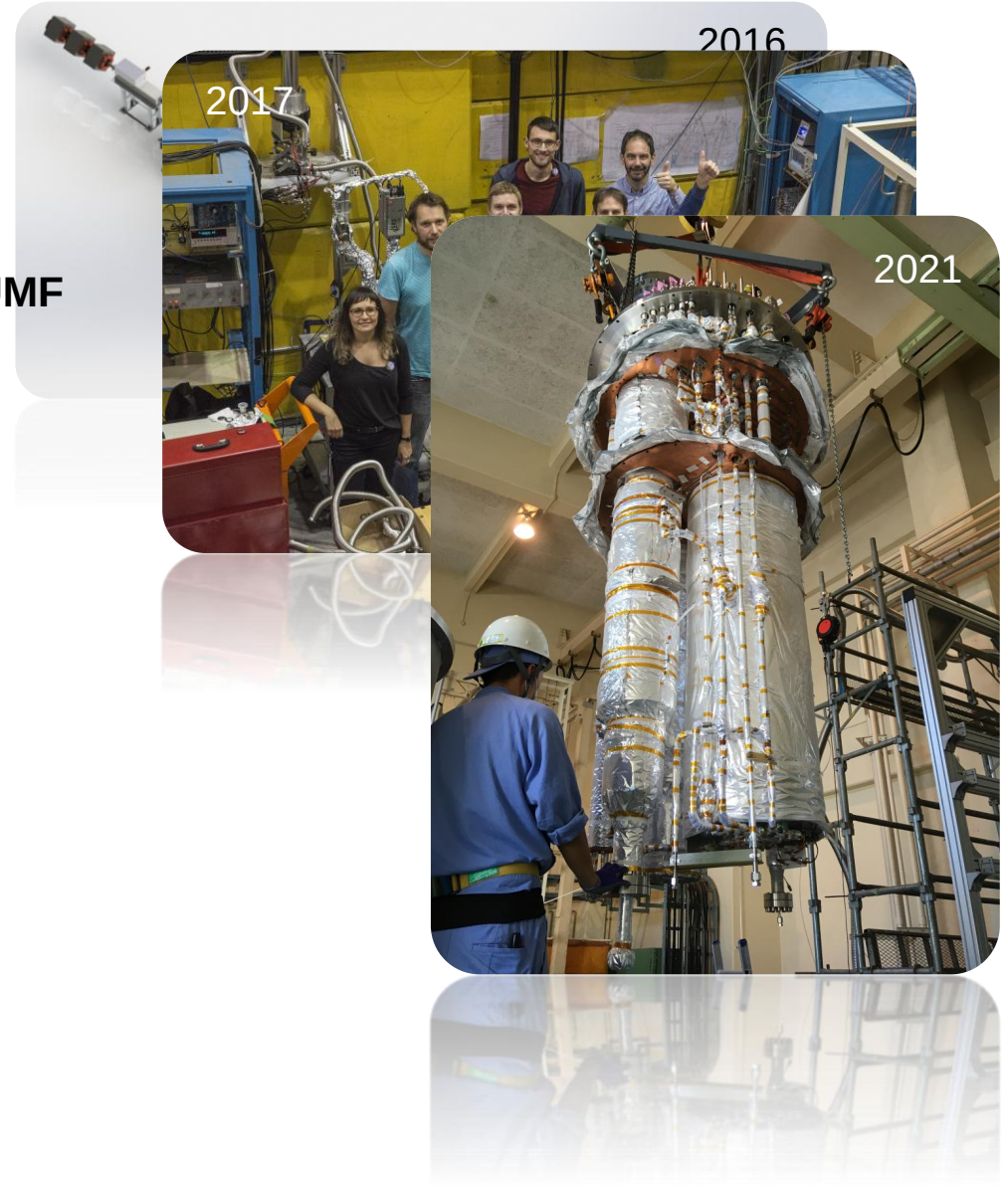

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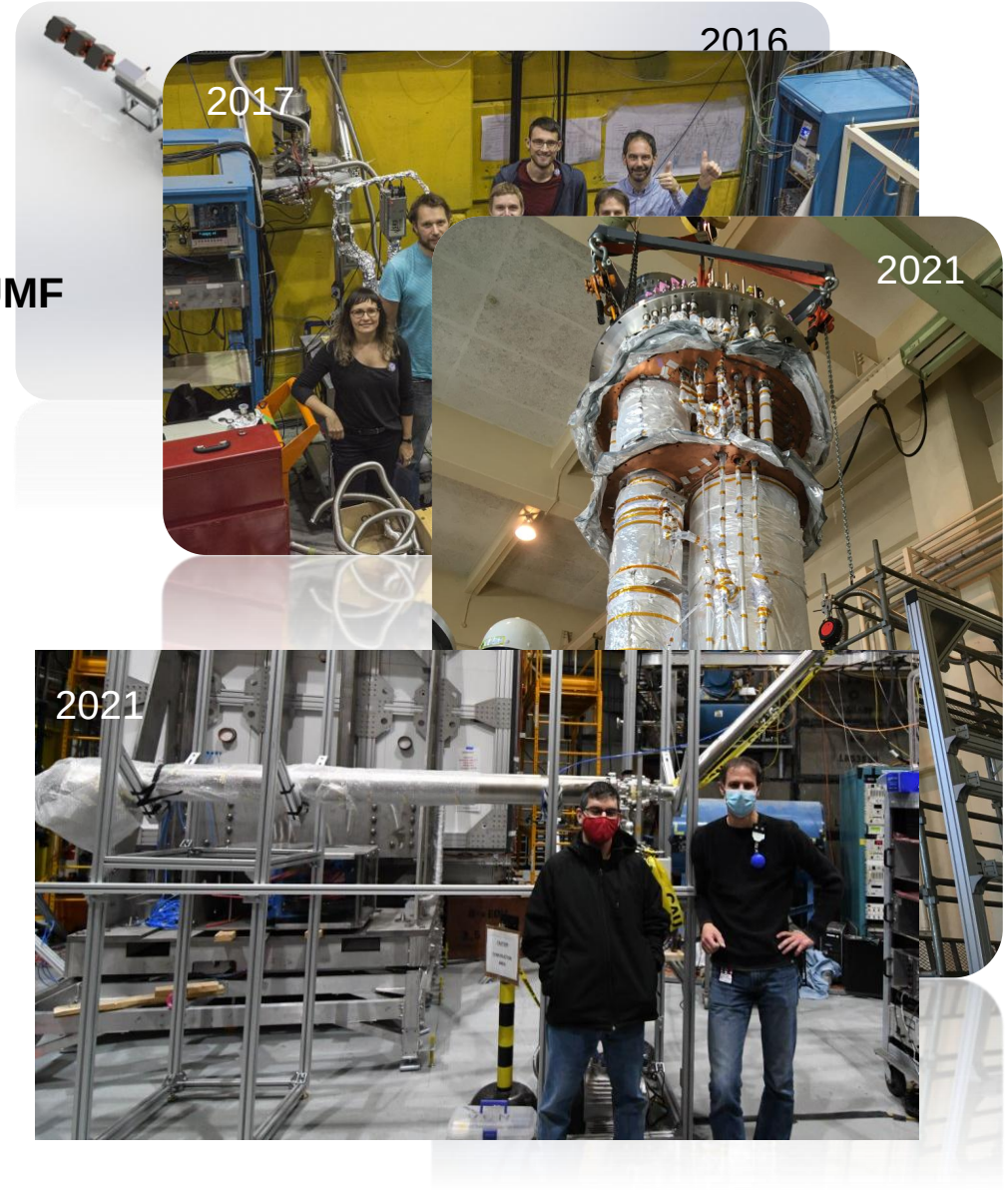

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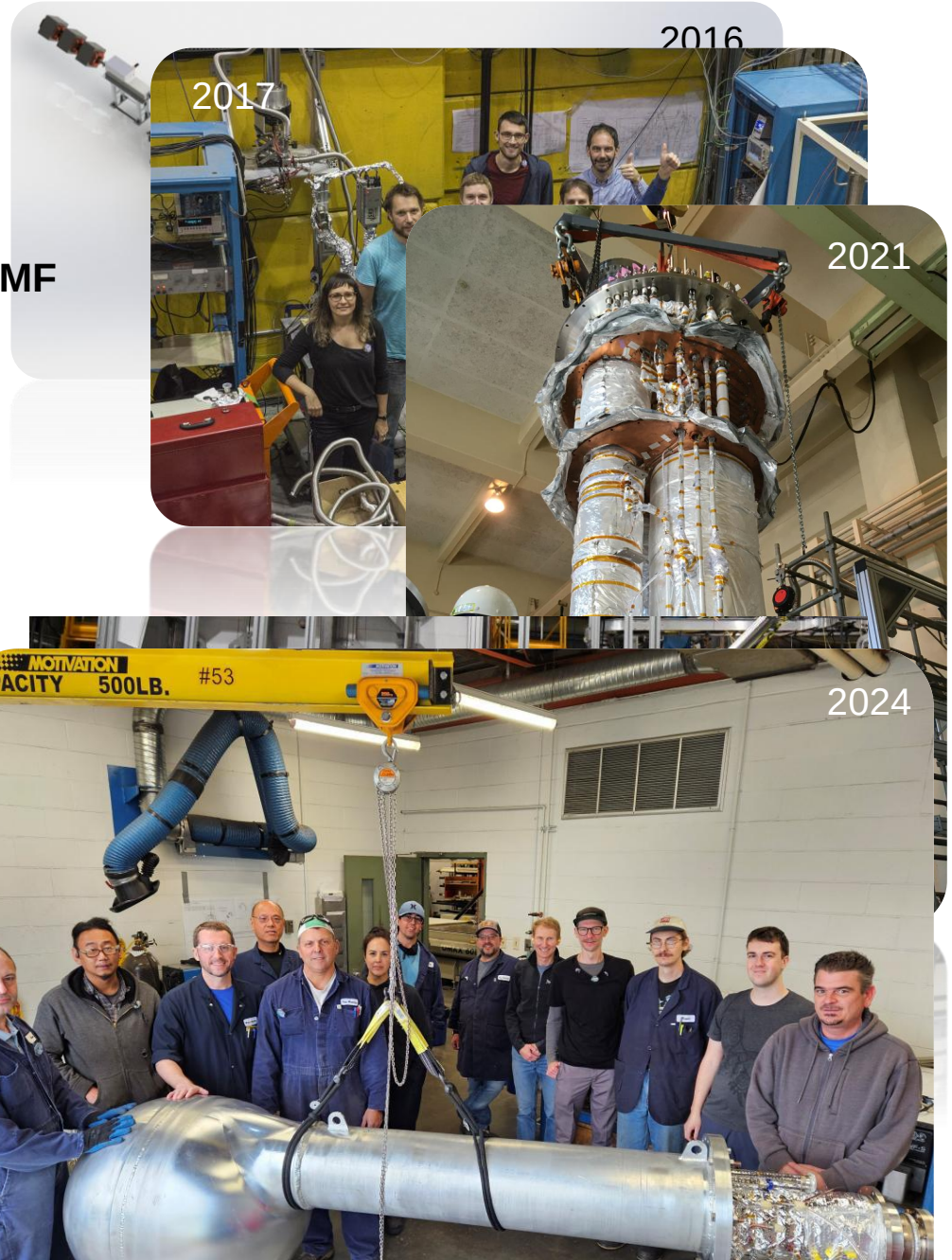

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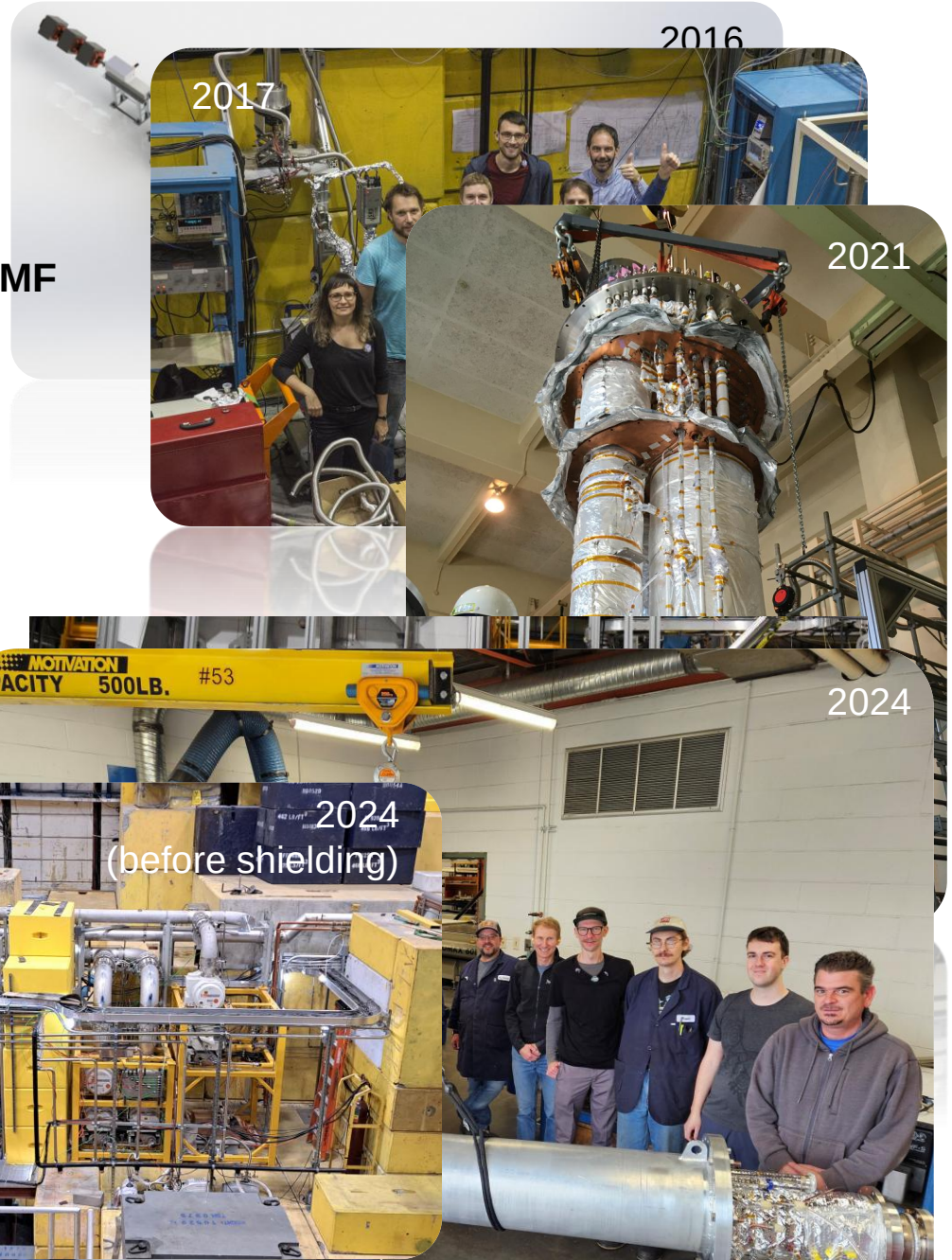
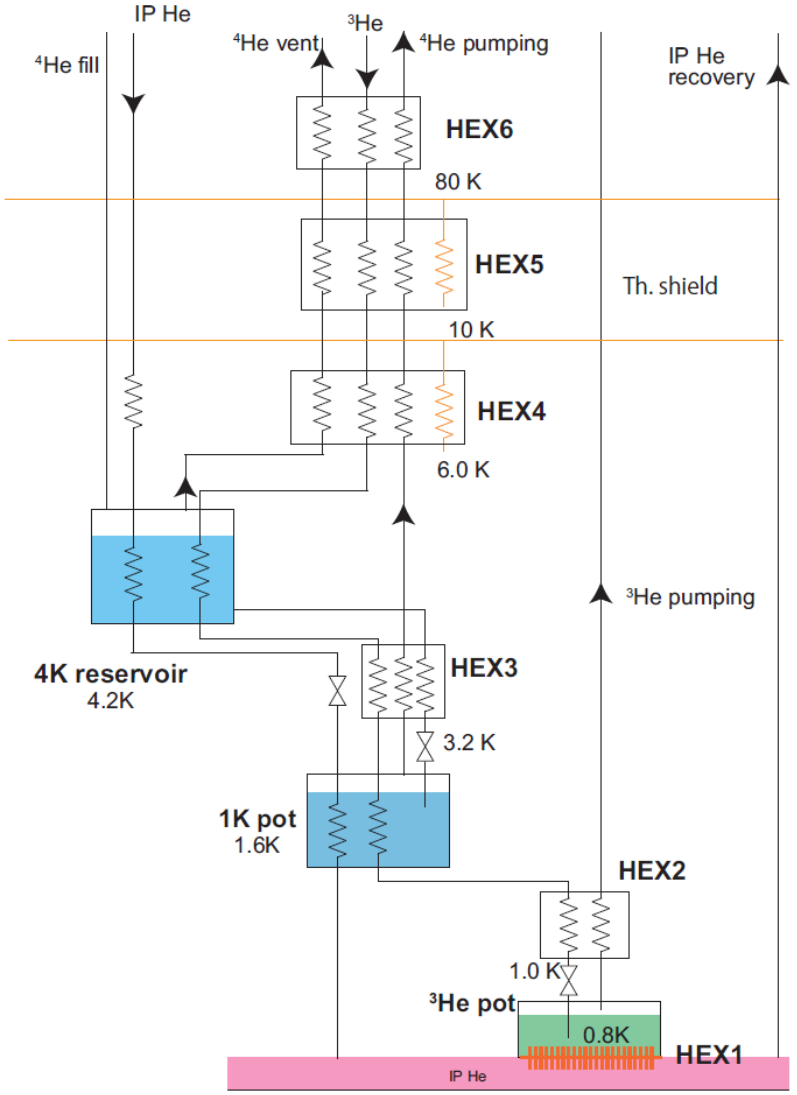


Cryostat

^{3}He cryostat built in Japan/KEK & installed at TRIUMF:

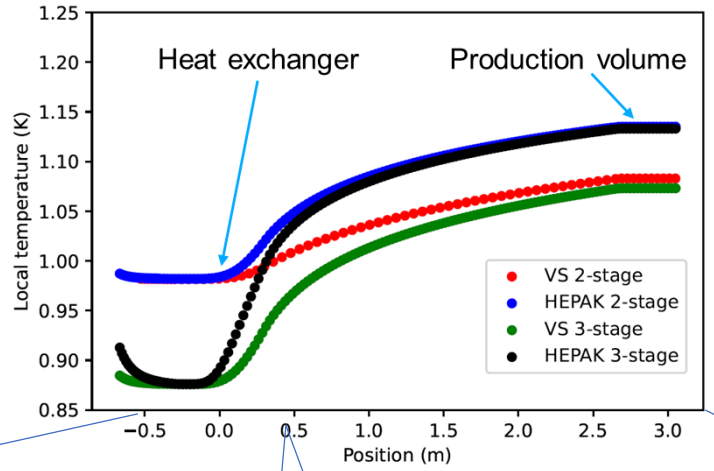


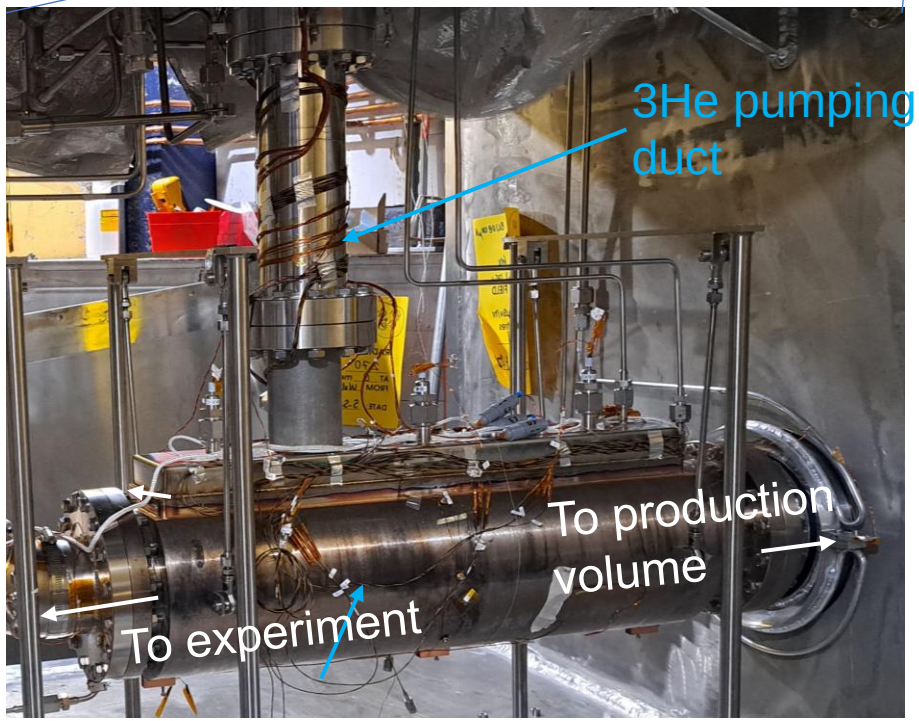
Capable of cooling source to 1.1K under 10W heat load

Development of a Helium-3 Cryostat for a Ultra-Cold Neutron Source - IOPscience

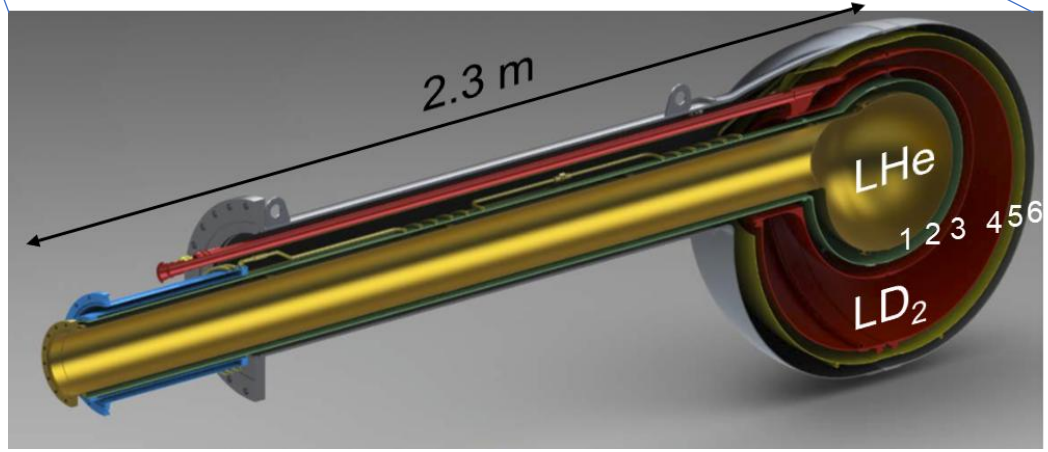
Thermo-fluid analyses for UCN cryogenic system - IOPscience

UCN production volume



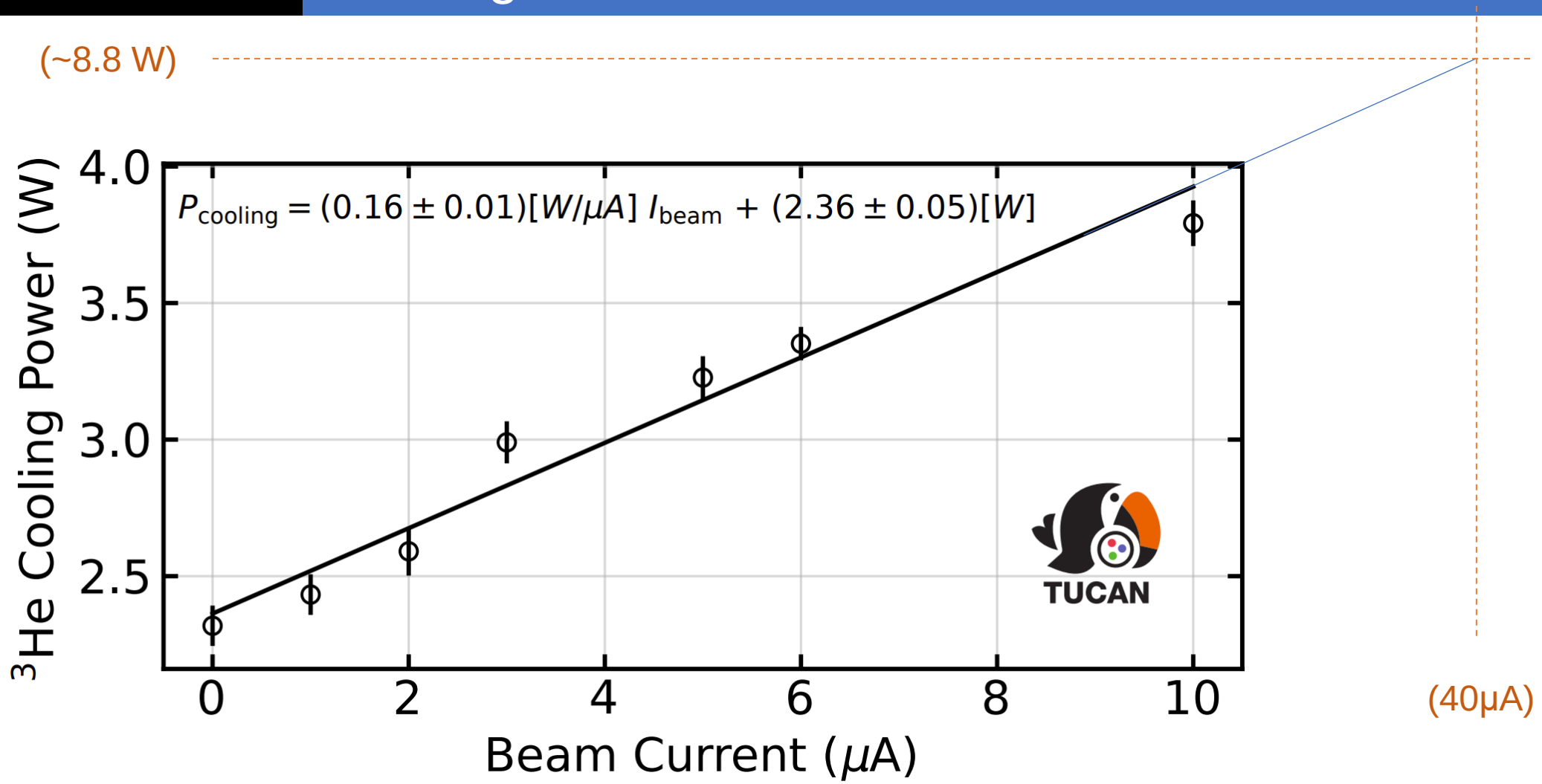


Keep cold to prevent losses!
UCN upscattering loss rate ~ T^7



Cooling tests

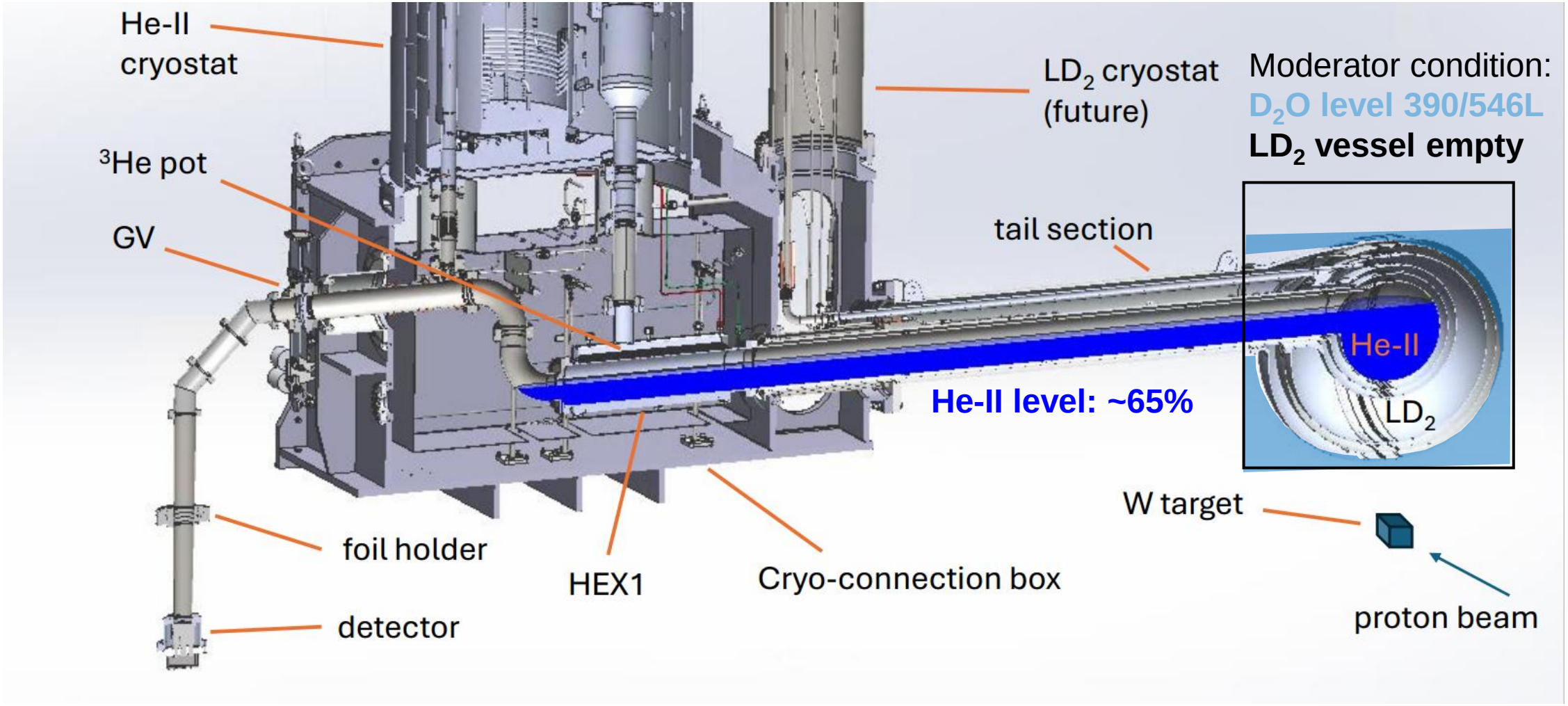
arxiv.org:2509.02916 (subm. Phys Rev Lett)



Operated with beam up to 37uA with sufficient cooling power.
Beam heat load matched MCNP simulations within 10%
Vapour pressure in tail section consistent with superfluid He temp of 0.9-1.1K
No clogs in He-3 or natural He cooling system during >2week operation

Experiment in June 2025

arxiv.org:2509.02916 (subm. Phys Rev Lett)



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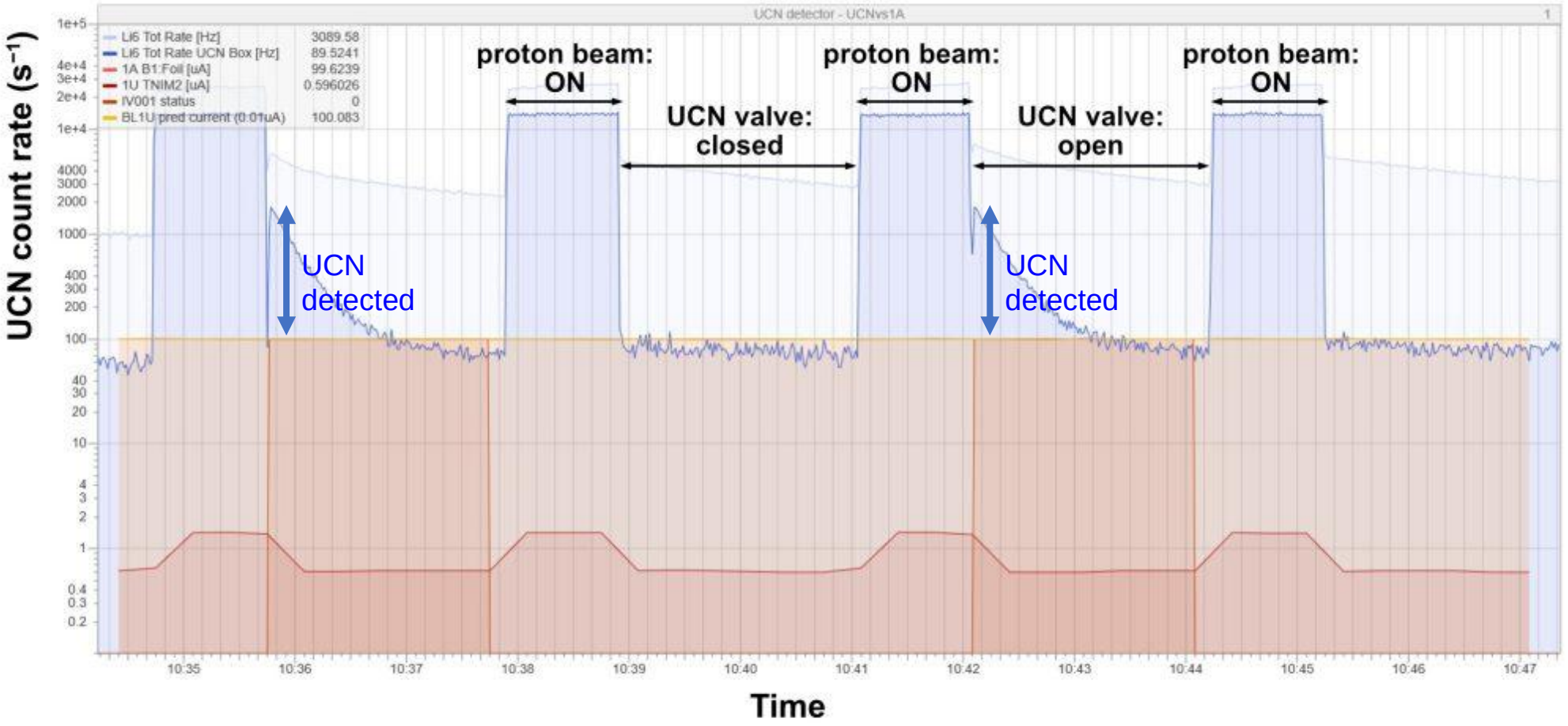
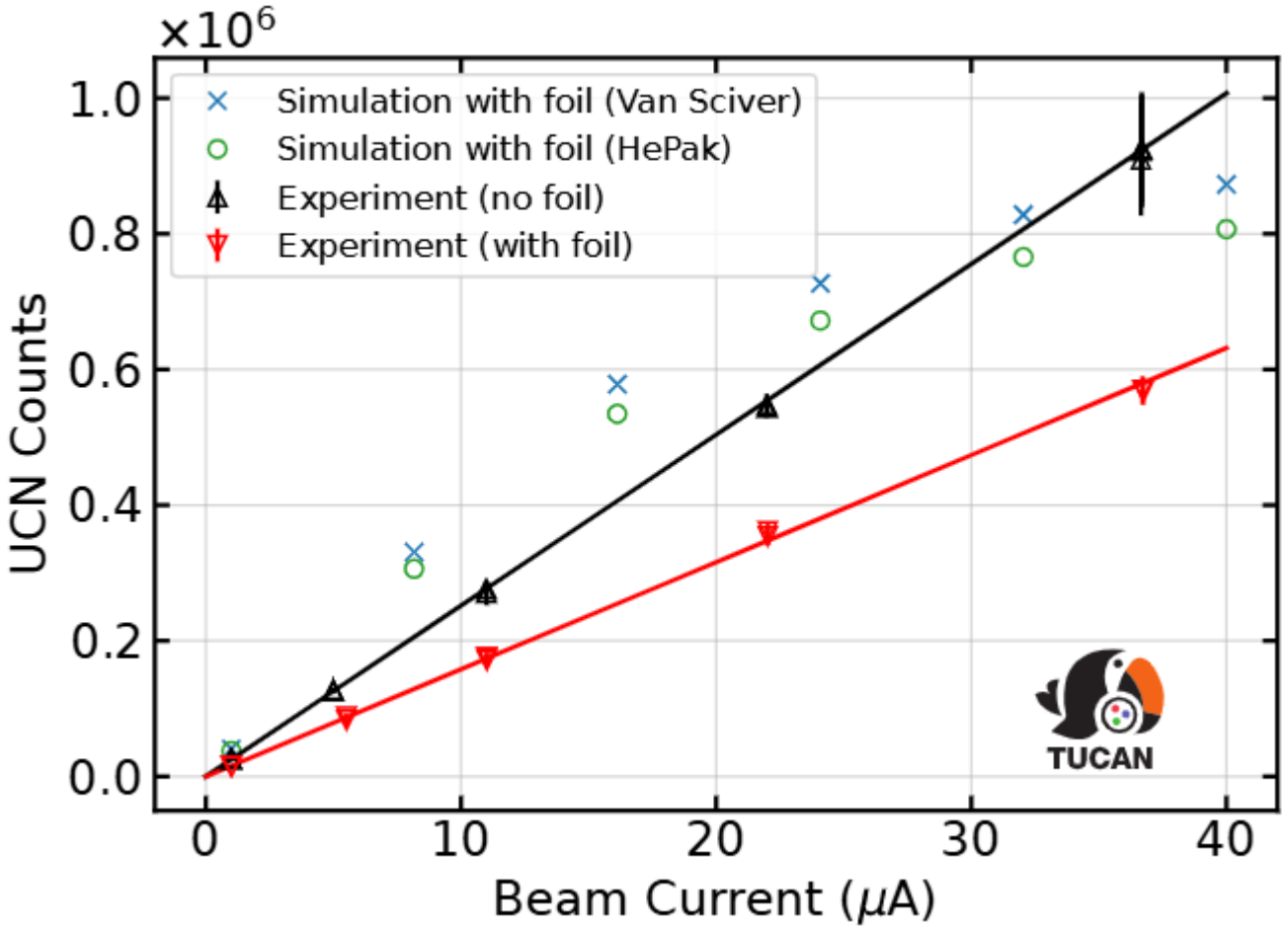


First UCN detection!

60s proton beam irradiation / 120s counting UCN /
alternating detection (open) & background (closed) cycles

Results

arxiv.org:2509.02916 (subm. Phys Rev Lett)



High UCN counting rate:
940,000 UCN counted after 60s irradiation

Reasonable storage lifetime in the production volume:
~25–30 s

Source production did not saturate with beam current, up to 37μA beam current – good news!
Maybe source can support higher neutron flux?

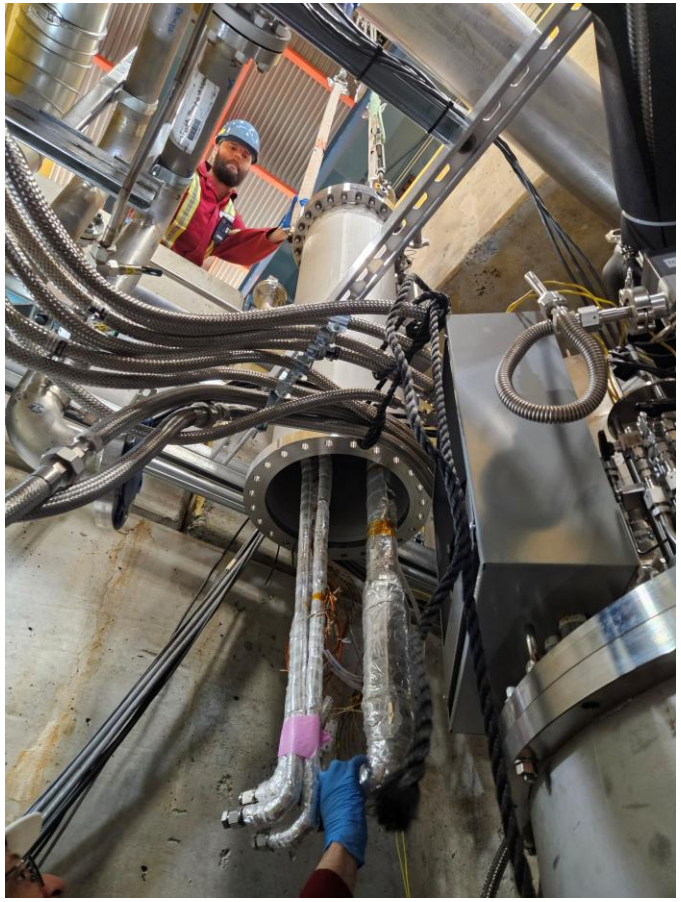
Next Steps

- Transport UCN outside of radiation shielding
  - (lower detector background)

- Finish UCN source:
  - Commission and fill LD_2 moderator vessel
  - Fully fill the superfluid He converter vessel (superleak?)
  - Expect 61x increase

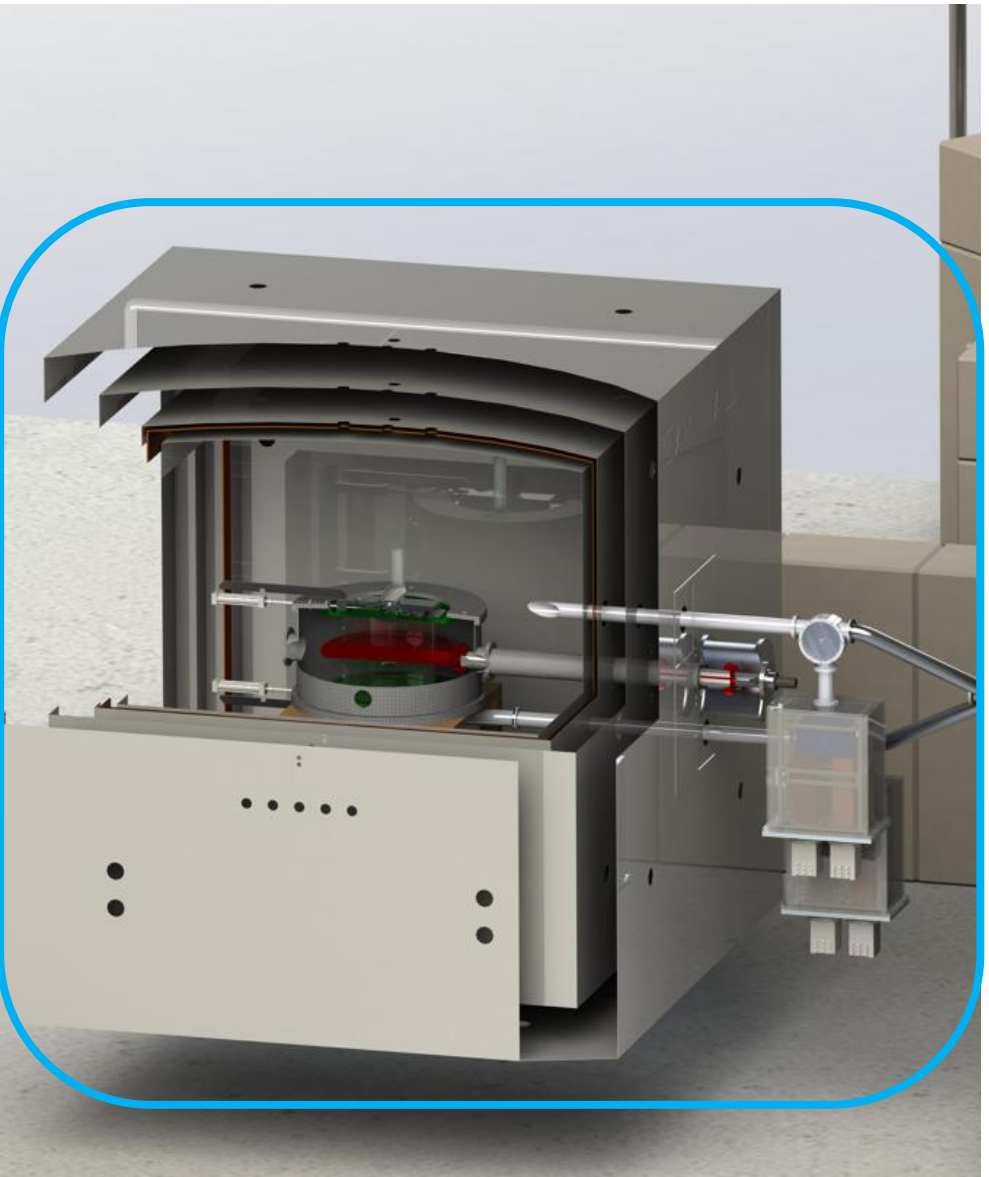
- Upcoming TRIUMF shutdown Jan 2026-April 2027 for ARIEL work.

  → We will focus on nEDM development



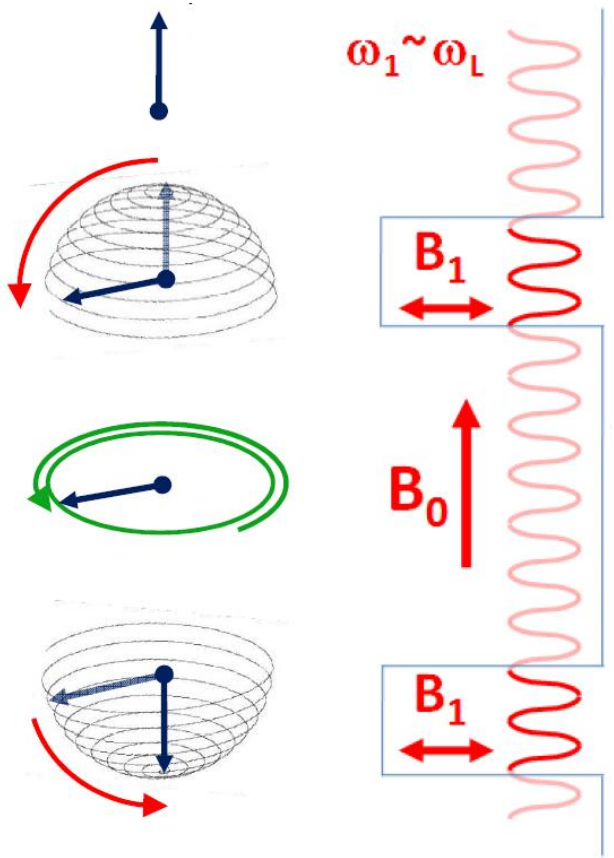
LD_2 cryostat installation in pit (Aug 2025)

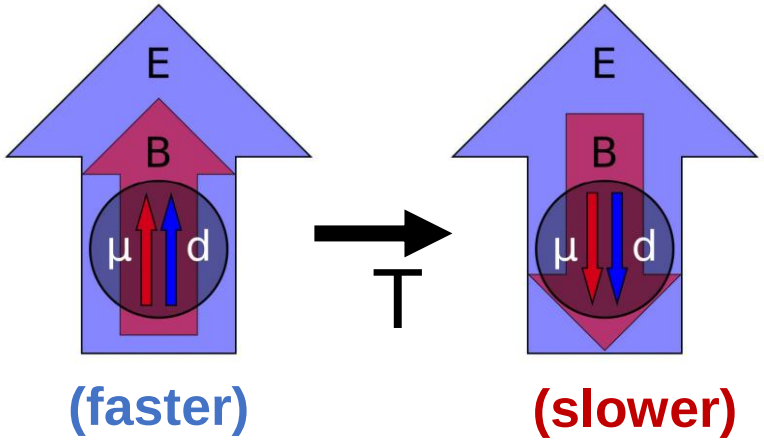
EDM Experiment



Method:

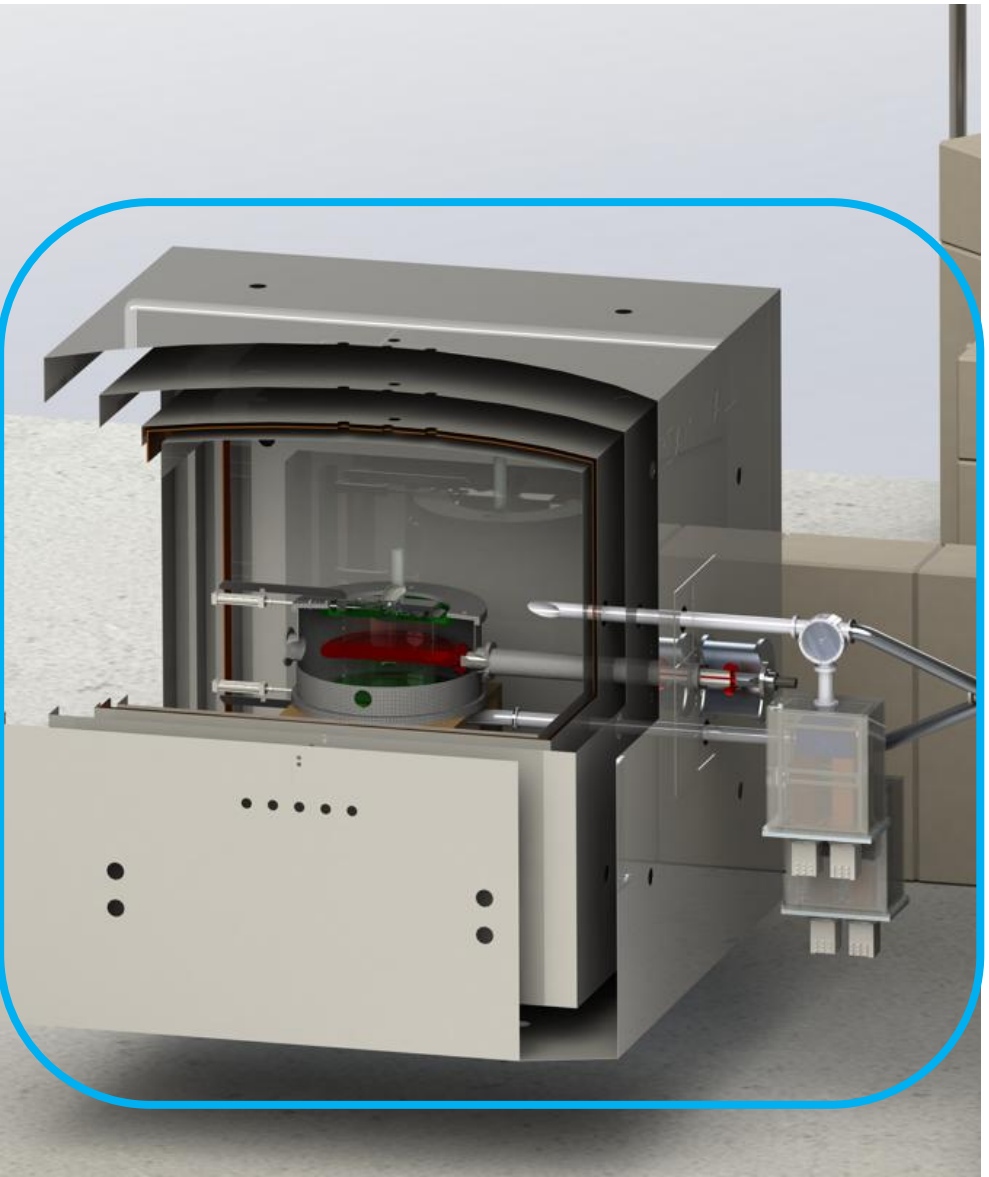
Ramsey resonance with $\vec{E}$ & $\vec{B}$-field reversal





(faster) (slower)

EDM Experiment



Staged development, based on funding:

- 2021 begin to Shift 2017 Large Funding Award from nEDM apparatus to Source
- 2025 Submitted new Large Funding award to realize full nEDM apparatus and source operations

	OC100 (One cell, 100 kV)	2C200 (two cells, 200 kV)
Principle	Development platform	Full experiment
Number of cells	One	Two
HV	100 kV	200 kV
Cell coatings	NiP, dPS	DLC, dPE
Comagnetometry	Hg	Hg, Xe
Statistical reach	$10^{-26}\ e\text{cm}$ in 36 days	$10^{-27}\ e\text{cm}$ in 2-3 years
Systematic effects	“Best effort”	$< 10^{-27}\ e\text{cm}$

Magnetically shielded room: biggest investment completed

- Expected shielding factor: 50,000 – 100,000
- Initial 5-layer shielding ➔ ~10,000
- Retrofit of sixth layer ➔ ~40,000
- Currently improving residual field by optimizing degaussing procedure

Magnetically Shielded Room (MSR)

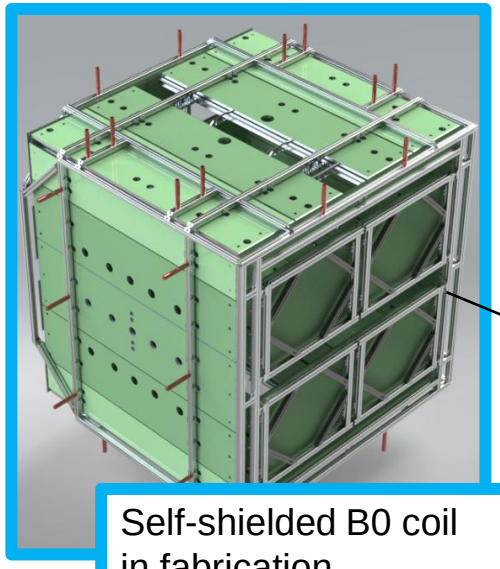
Magnetically shielded room: biggest investment completed

- Expected shielding factor: 50,000 – 100,000
- Initial 5-layer shielding ➔ ~10,000
- Retrofit of sixth layer ➔ ~40,000
- Currently improving residual field by optimizing degaussing procedure

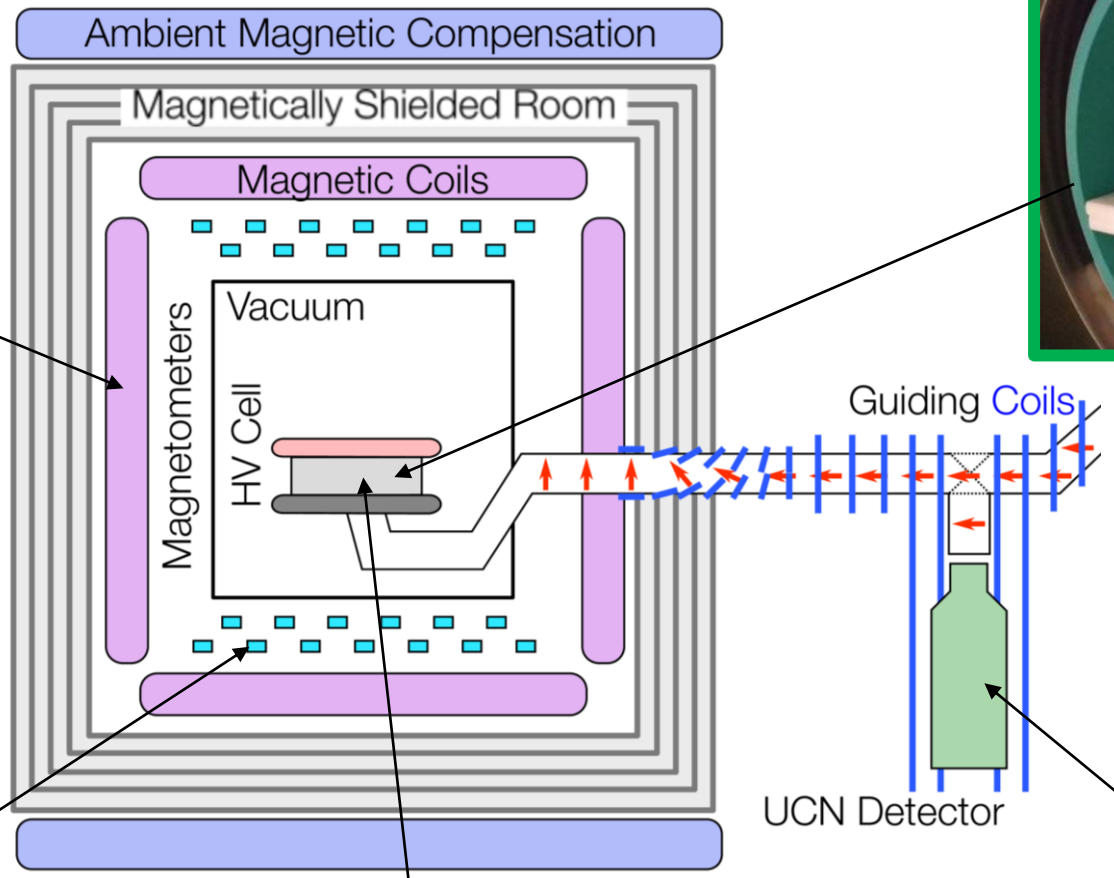
- Added active magnetic compensation of ~400uT cyclotron field

Magnetically Shielded Room (MSR)

nEDM subsystem status

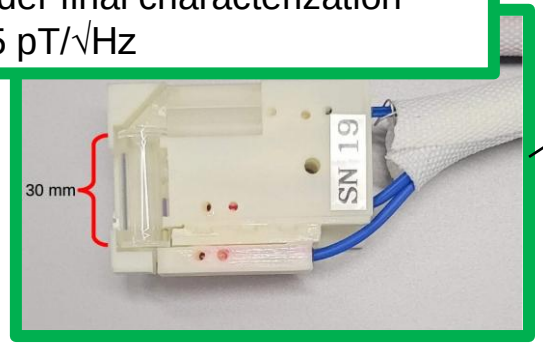


Self-shielded B0 coil in fabrication



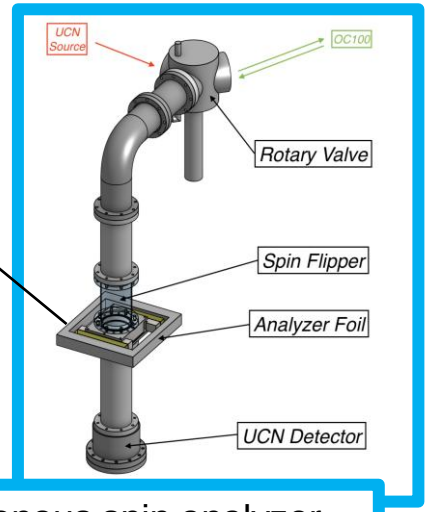
Hg comagnetometer prototype tested; preparing installation in MSR

Array of 20 Cs magnetometers under final characterization
3.5 pT/√Hz



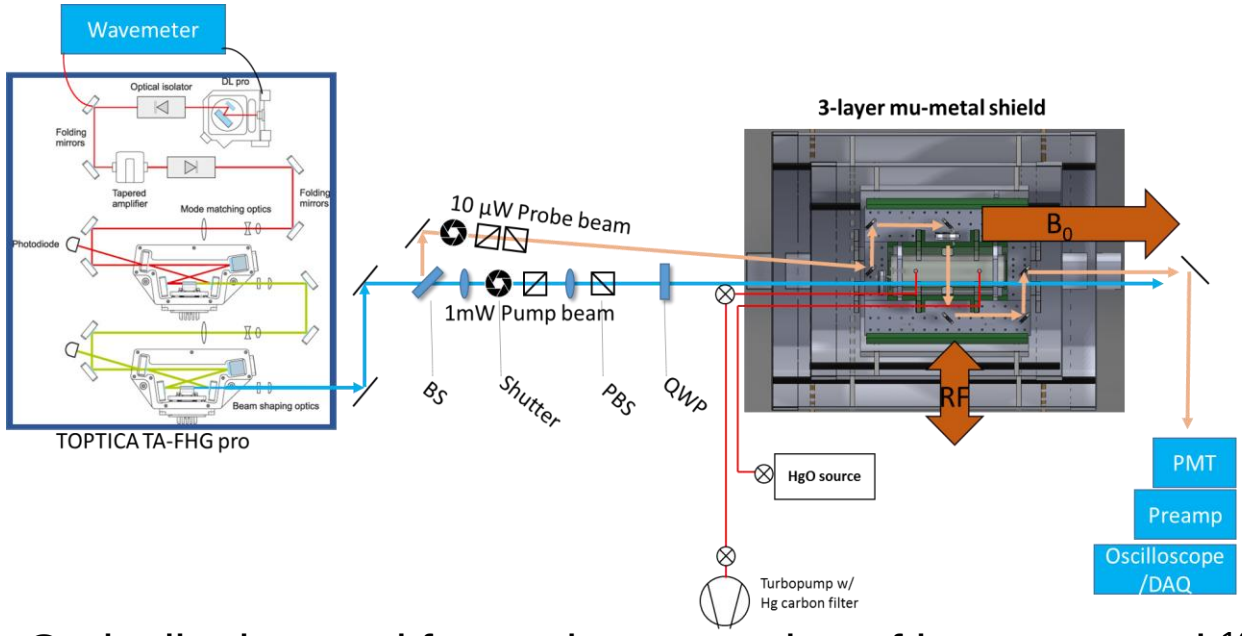
https://doi.org/10.1140/epjc/s10052-024-13544-5

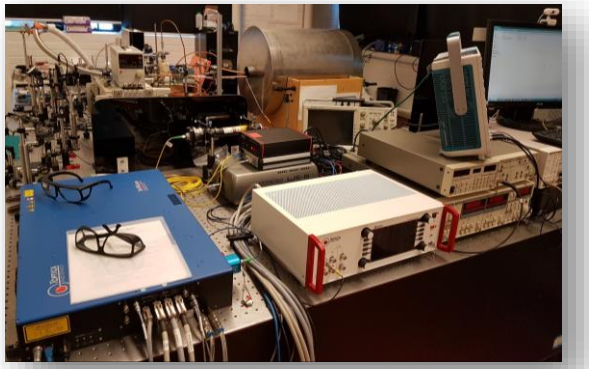
Half-precession cell prototype tested with UCN at J-PARC
Lifetime > 130s

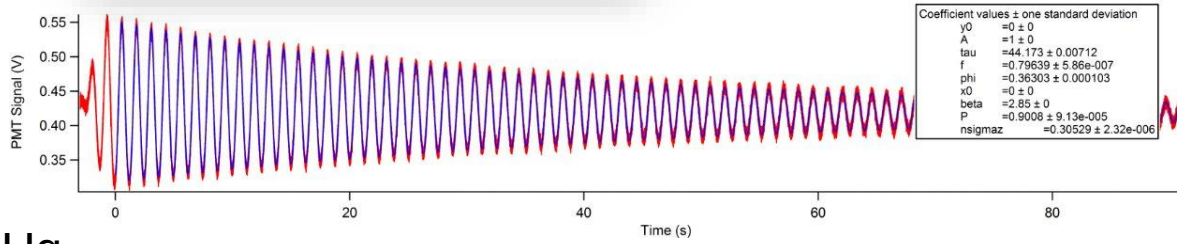


Asynchronous spin analyzer reuses existing UCN detector

Mercury comagnetometer







Optically detected free spin precession of laser pumped ^{199}Hg

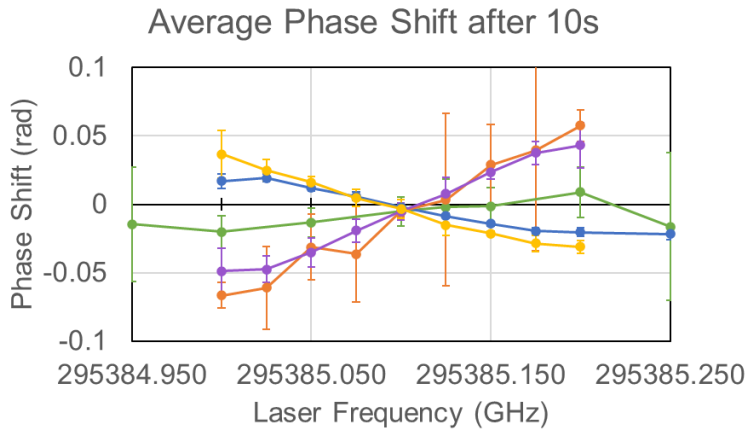
Performance in small-scale model:

$\sigma_B < 1\mathrm{pT}$

$T_2 > 40\mathrm{s}$,

limited by larger gradients and higher wall collision rate

Installing in MSR for expected $\sigma_B < 10\mathrm{fT}$, $T_2 > 120s$



Other development work:

- Systematic studies of Hg light shift (AC Stark)
- detection with shot noise limited SNR

Conclusions

- The successful generation of UCN marks a major milestone
  - No evidence of saturation with proton beam current – opens the door to future more intense UCN sources
- LD_2 commissioning ongoing.
  - When complete, TUCAN source will have the world's highest UCN production rate.
- Enables an nEDM experiment with $d_n \leq 10^{-27}$ e.cm in ~280 measurement days!

https://doi.org/10.48550/arXiv.2509.02916

Ultracold Neutron Successfully Produced at TUCAN Experiment | Institute of Particle and Nuclear Studies
New ultracold neutron source produces record for Canada | TRIUMF