TUCAN

TRIUMF Ultra Cold
Advanced
Neutron source

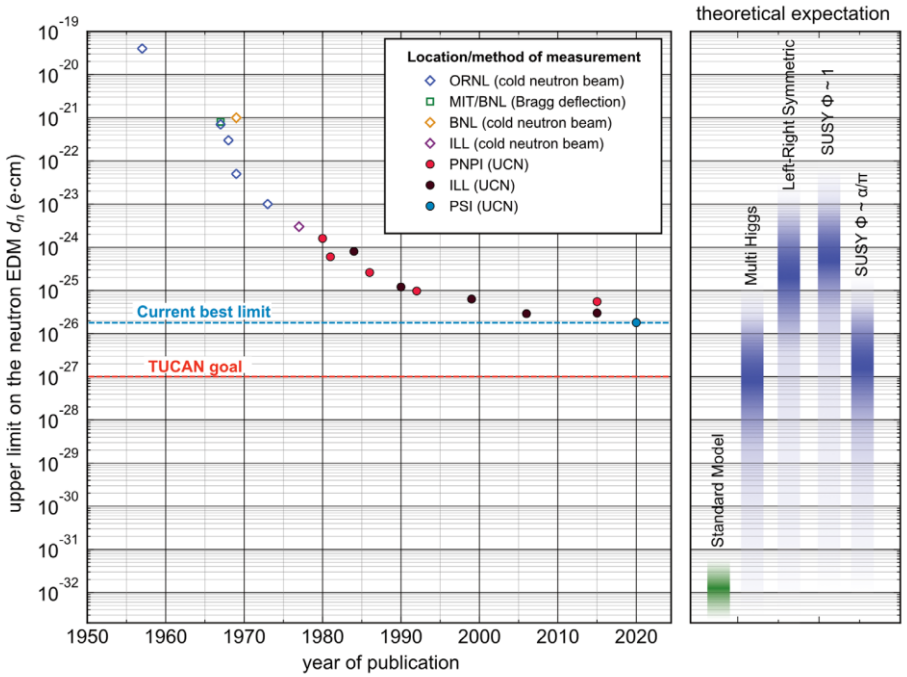
The TUCAN source and UCN experiments

Alexis Brossard
On behalf of the TUCAN collaboration

Science week 2024, TRIUMF

Neutron are tools for probing new physics

Neutron electric dipole moment
Source of CP violation

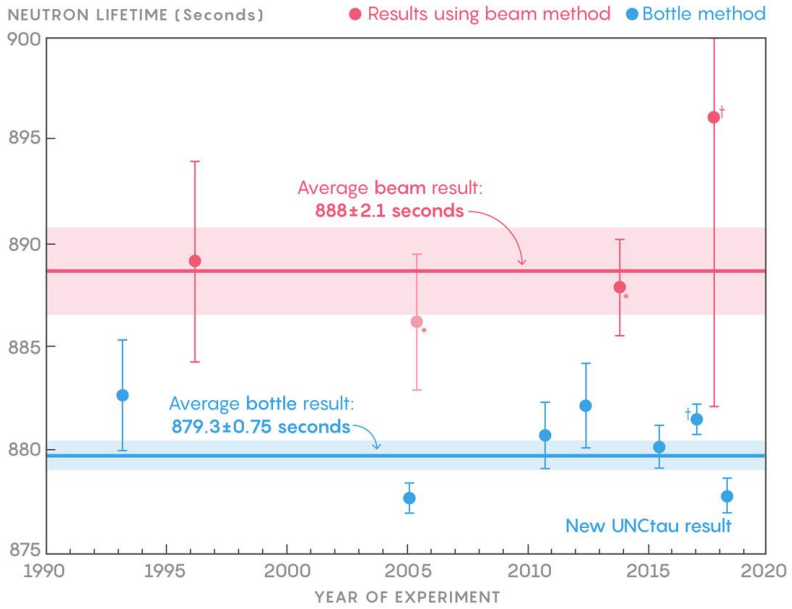


- $d_n < 1.8 \times 10^{-26}$ *ecm* (90% C.L.)

C. Abel et al., Phys. Rev. Lett. 124, 081803 (2020)

- Many groups pursuing ~ 10^{-27} *ecm* measurement as next step

Neutron lifetime
Inconsistency of two methods



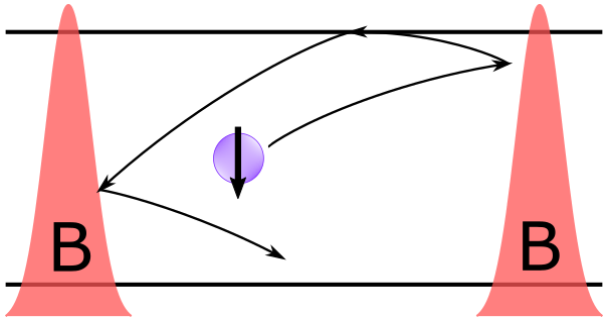
*Nico result (2005) was superseded by an updated and improved result, Yue (2013);
†Preliminary results

- Beam method 888 ± 2.1 s
- Bottle method 879 ± 0.75 s

Ultracold neutron

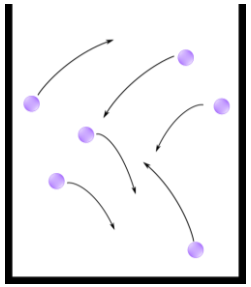
- Magnetic Field:

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



- Gravity:

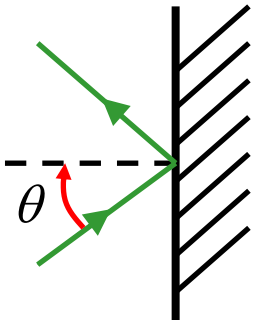
$$V_g = m_n g z = \left(102.5 \frac{\text{neV}}{\text{m}}\right) z$$



- Strong force:

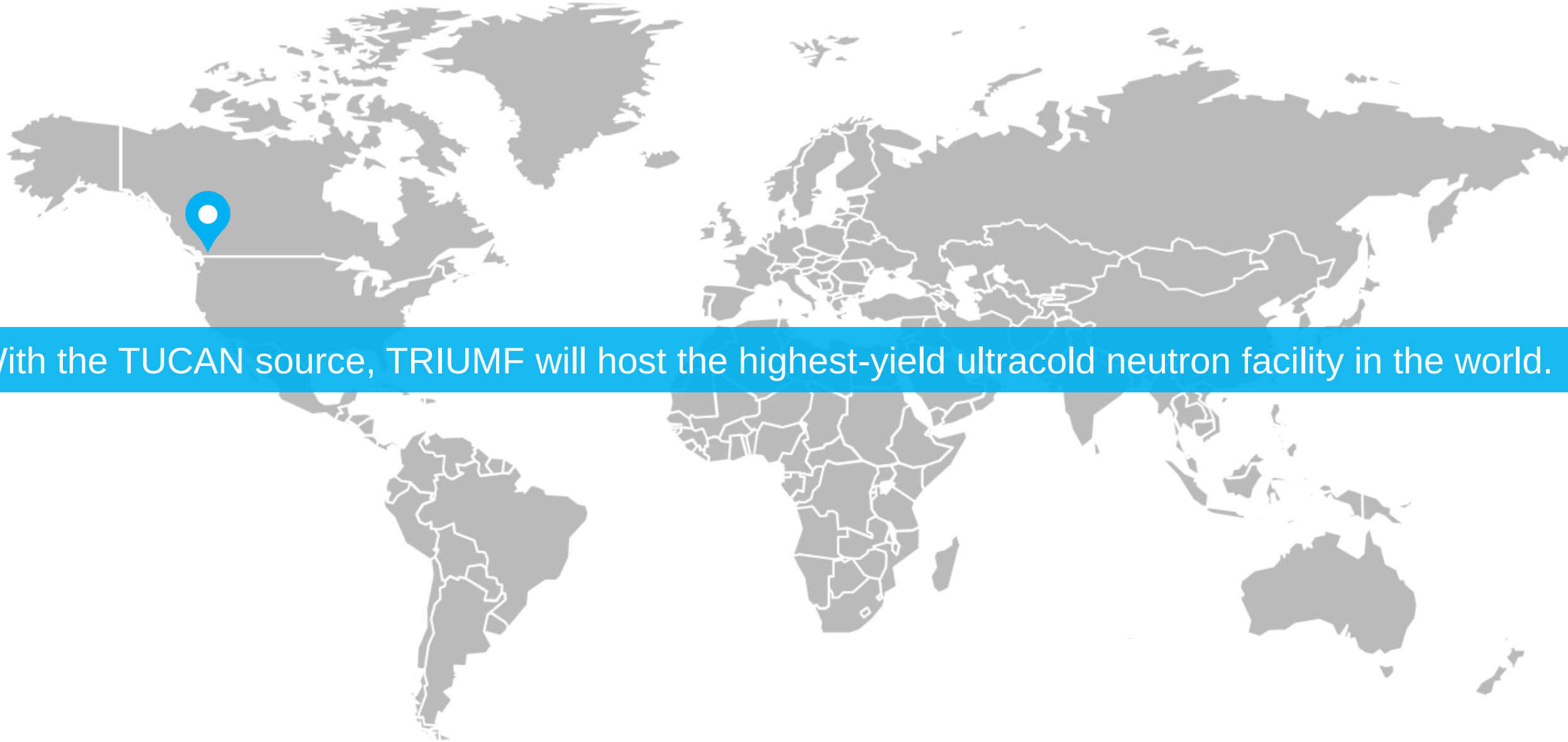
$$V(\vec{r}) = \frac{4\pi\hbar^2}{2m} \sum_i a_i \delta(\vec{r} - \vec{r}_i')$$

$E_{kin} < V_F$:



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

Ultracold neutrons, with kinetic energy below a few hundreds of neV can be stored for a few hundreds of seconds.

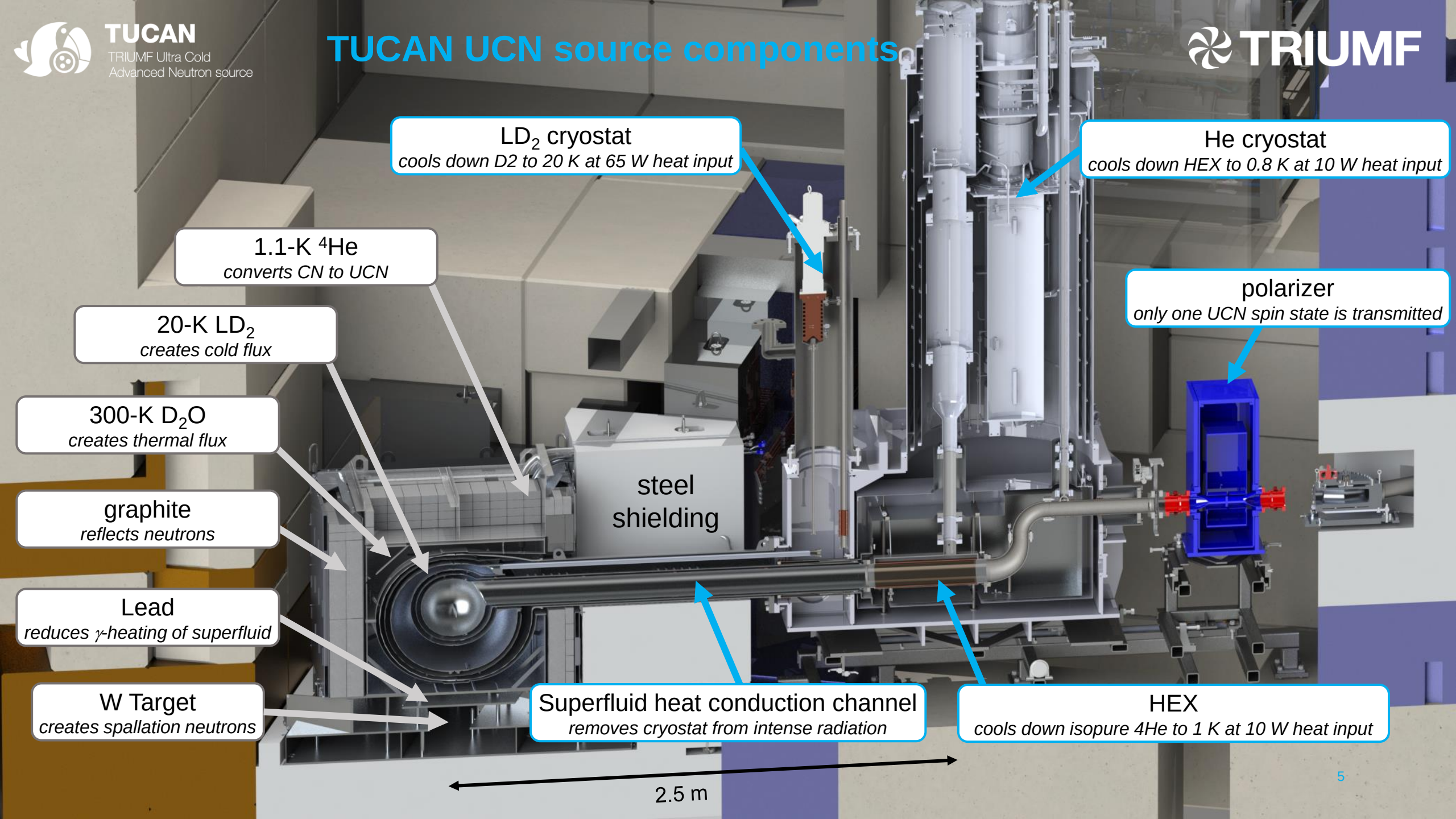


With the TUCAN source, TRIUMF will host the highest-yield ultracold neutron facility in the world.

TUCAN
TRIUMF Ultra Cold Advanced Neutron source

TUCAN UCN source components

TRIUMF



Major milestones:

Helium cryostat installation

Aug 2023

Tail section installation

April 2024

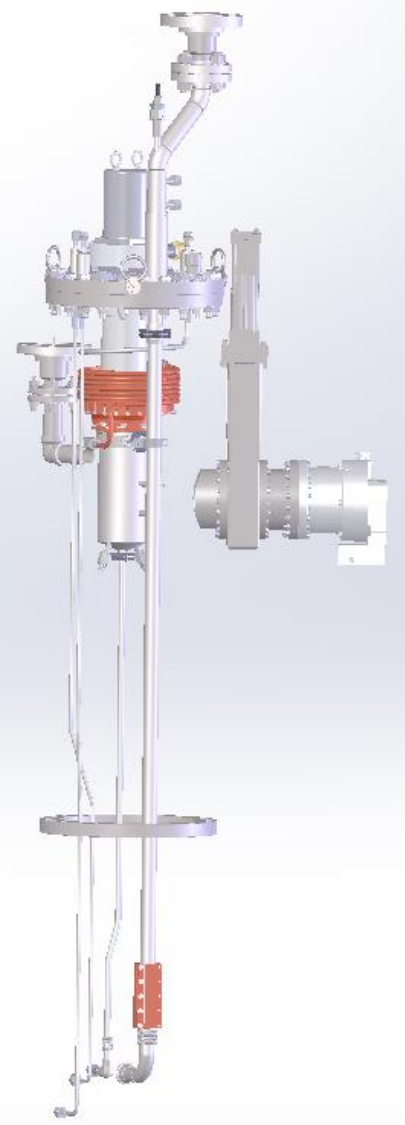
Heat exchanger prototype installation

November 2023

- September 2023: Cryostat filling with liquid natural helium from liquefier.
- December 2023: Commissioning of gas system and heat exchanger prototype characterization with natural helium.
- June 2024: Test with Helium-3.
- July 2024: Beamline 1U recommissioning.

Major coming milestones:

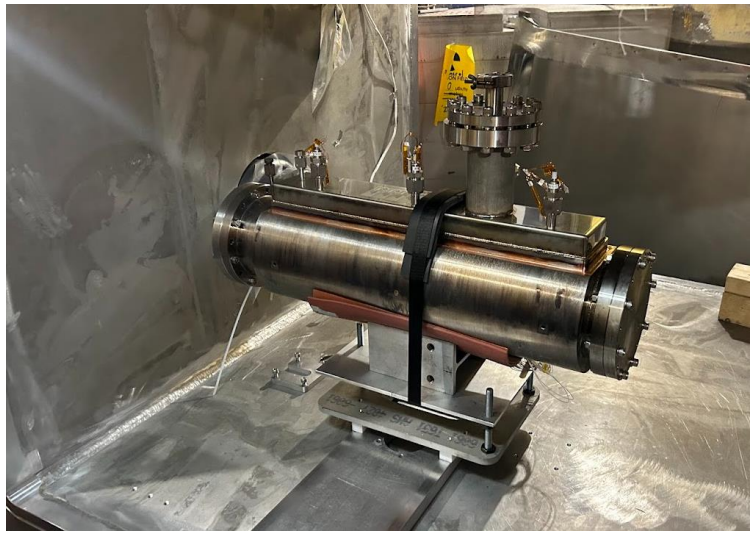
LD2 cryostat



- August 2024: commissioning of heat exchanger and isopure Helium-4 gas system.
- **September 2024: first UCN production.**
- Shutdown 2025: installation of deuterium system.
- **After shutdown 2025: UCN production with complete source.**

LD2 and isopure ^{4}He tank

Heat exchanger



The nEDM experiment

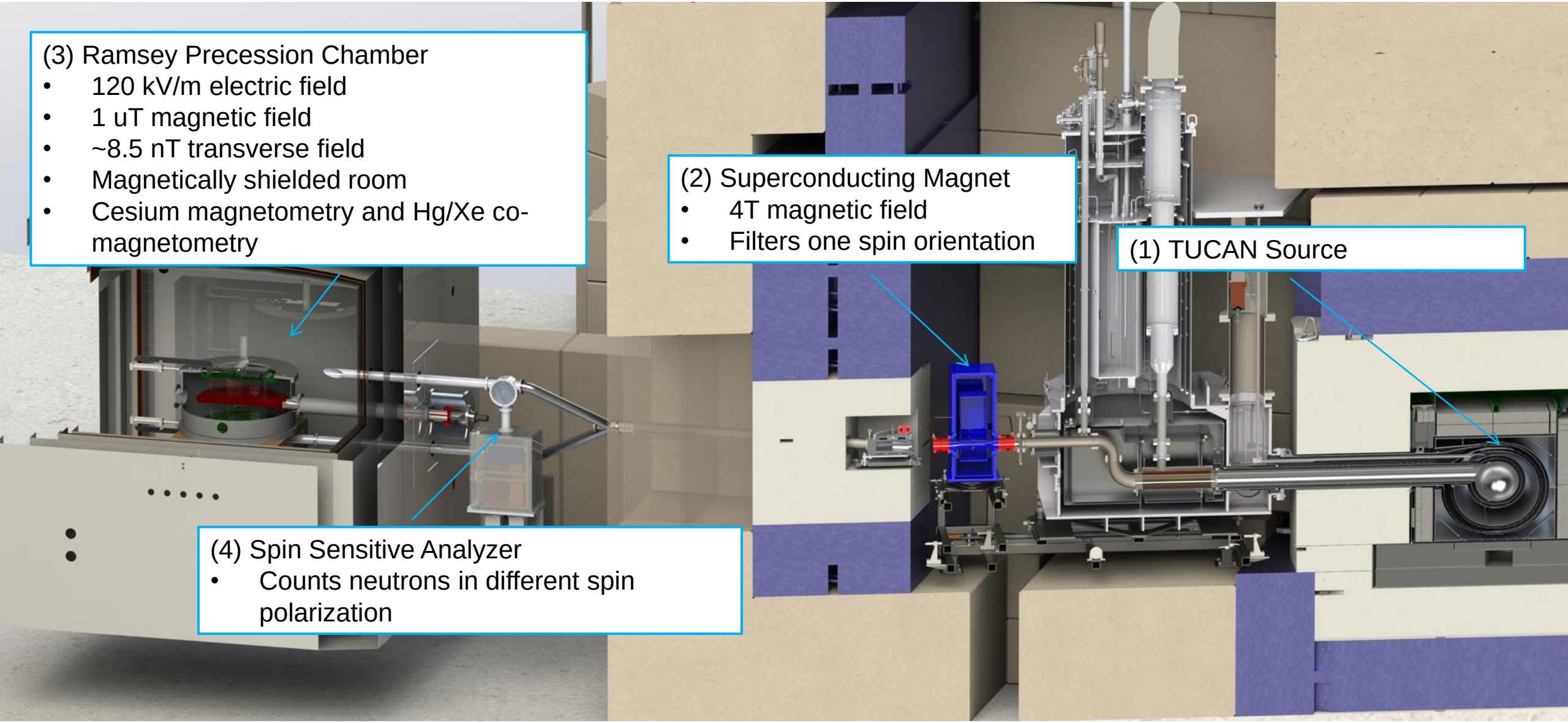
Neutron Electric Dipole Moment with Ramsey's method of separated oscillatory fields

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

- α: Visibility, neutron polarization. Account for polarization at the beginning of the cycle, depolarization during the cycle and efficiency of the spin analyzer.
- *E:* Electric field strength. Limited by the cell breakdown voltage
- *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…

Figures by D. Ries
https://www.youtube.com/watch?v=QBKPQFUdDB0

TUCAN METHOD:



(3) Ramsey Precession Chamber
- 120 kV/m electric field
- 1 uT magnetic field
- ~8.5 nT transverse field
- Magnetically shielded room
- Cesium magnetometry and Hg/Xe co-magnetometry

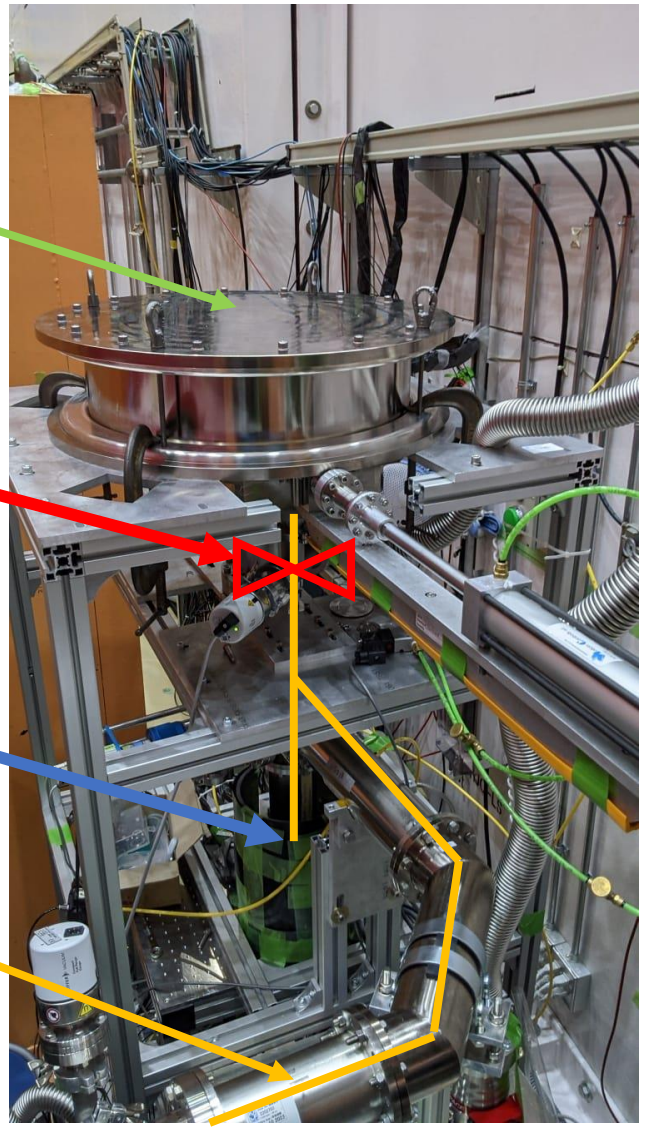
(2) Superconducting Magnet
- 4T magnetic field
- Filters one spin orientation

(1) TUCAN Source

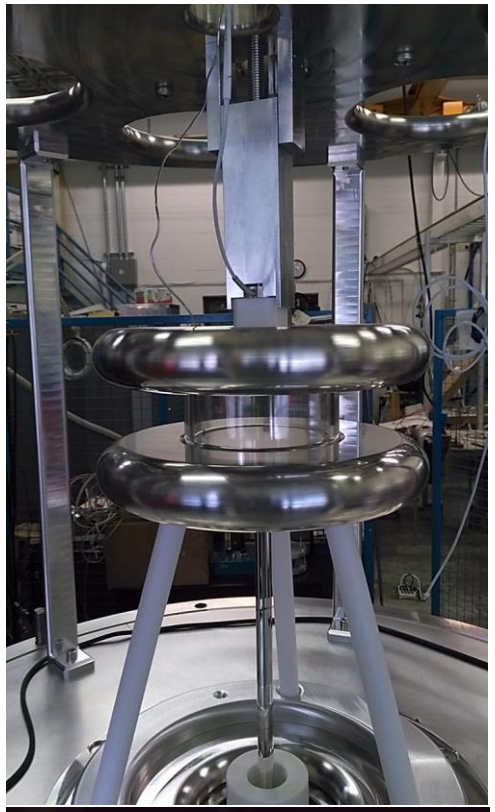
(4) Spin Sensitive Analyzer
- Counts neutrons in different spin polarization

Subsystem development for nEDM experiment

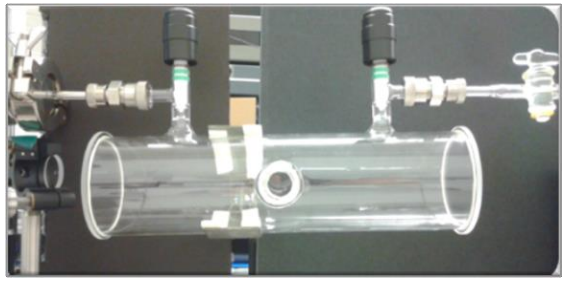
Cell lifetime measurement

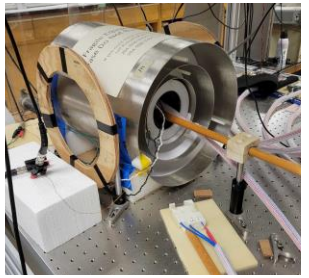


Cell HV test



Magnetometry



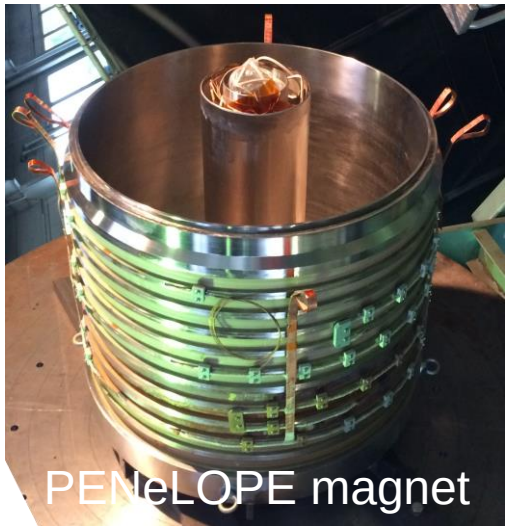


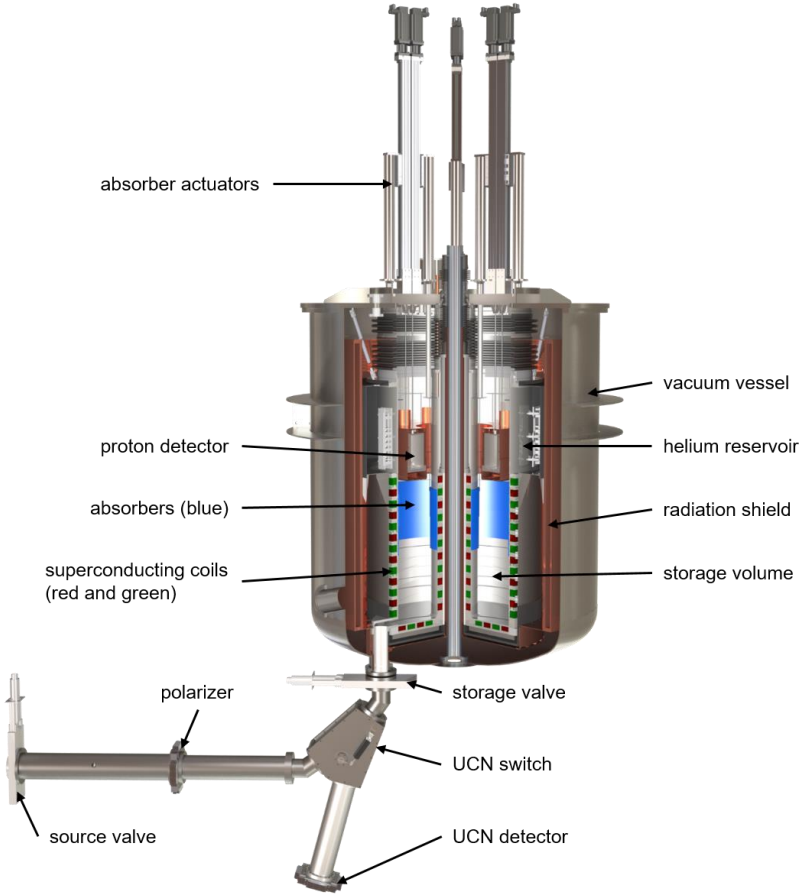
Magnetically shielded room

The neutron lifetime experiment

The PENeLOPE neutron lifetime experiment:

- The experiment arrived at TRIUMF in June 2024. Magnet qualification and quench training starting by the end of the year.
- Neutron lifetime measurement possible next year. The experiment will require TRIUMF support, the second port of the UCN source, liquid nitrogen and helium, etc.



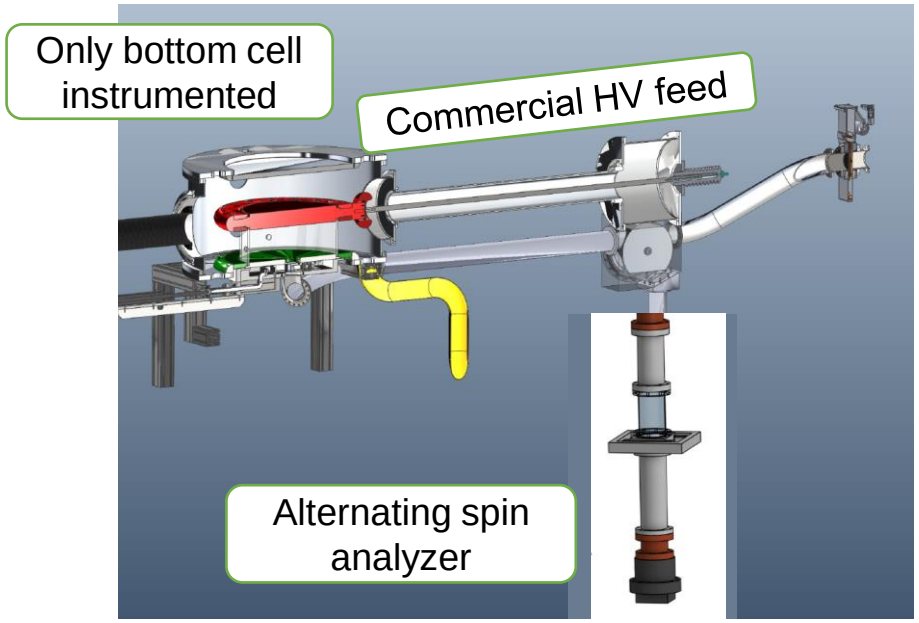


More on Dinel Anthony poster, tomorrow Wednesday July 24th at 4:30 pm.

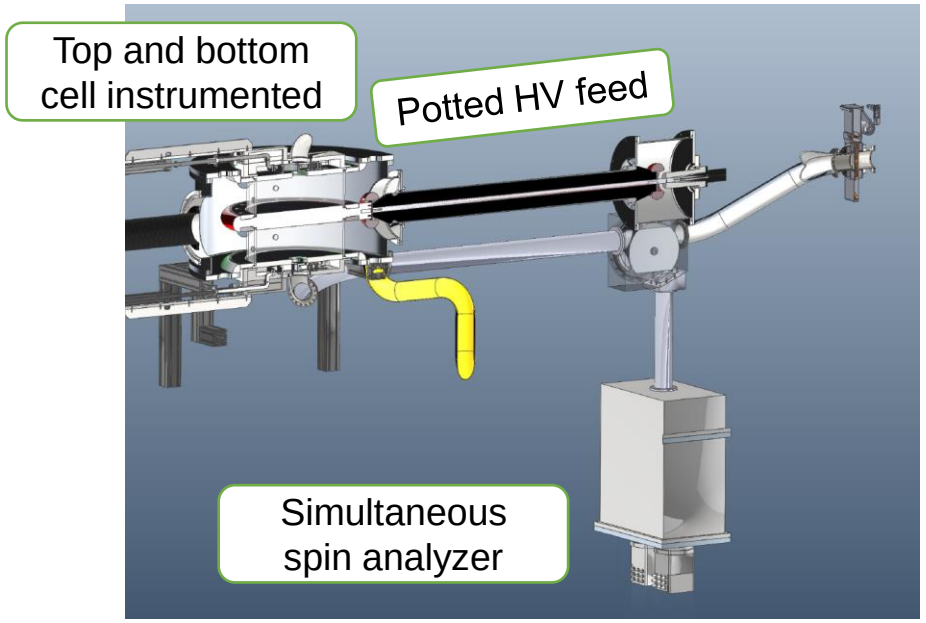
CFI and JSPS proposal:

- Liquefier upgrade currently 55 l/h not enough for required beam duty cycle for nEDM statistics
- Heavy water, we have 460 l out of 620 l
- Healium-3 we might need 100 l to 200 l gas stp
- Helium pump ugrade to double pumping speed
- Additional radiation shielding
- Tail section upgrade
- Second port development and cryogenic infrastructures

- OC100 to 2C200 nEDM experiment upgrade 10^{-26} to 10^{-27} *e*cm



One experimental cell, 100 kV high voltage, Alternating spin analyzer, existing EDM switch



Two experimental cells, 200 kV high voltage, simultaneous spin analyzer, new EDM switch

- Magnetometry upgrade
- Xenon comagnetometer lab upgrade
- External compensation coil
- Magnetic assay and degaussing

CONCLUSION:

- Exciting years are ahead of us!
- The UCN source is being commissioned and will be fully operational after 2025 shutdown.
- nEDM experiment OC100 to start in 2026.
- Full shutdown in 2026-2027 would delay important developments that require UCNs
- PENeLOPE neutron lifetime experiment to be tested and operated in the coming years.
- TRIUMF will be a world leading place for neutron studies.

TRIUMF UBC UNBC SFU University of Manitoba The University of Winnipeg NC State University University of Saskatchewan

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Neutron source

February 2024 Collaboration Meeting, Winnipeg

KEK RCNP Nagoya University Japan Society for the Promotion of Science NSERC CRSNG INNOVATION.CA Canada Foundation for Innovation | Fondation canadienne pour l'innovation

Statistical Comparison

	published		future					
EDM Experiment	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