Recent Progress of TUCAN

Search for the Neutron Electric Dipole Moment Using Ultra-Cold Neutrons

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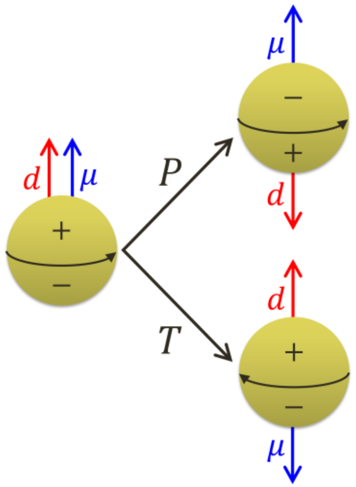
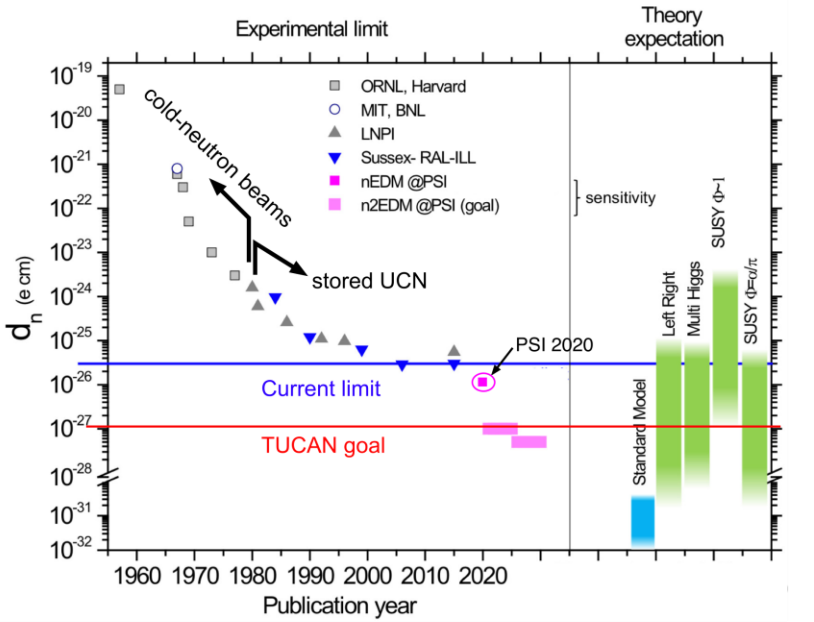
Contents

neutron EDM



- Current upper limit @PSI 2020
  - $d_n = (0.0 \pm 1.1_{\mathrm{stat}} \pm 0.2_{\mathrm{sys}}) \times 10^{-26} \mathrm{e} \cdot \mathrm{cm}$
    $\rightarrow |d_n| < 1.8 \times 10^{-26} \mathrm{e} \cdot \mathrm{cm} (90\% \mathrm{C.L})$
    C. Abel et al, Phys. Rev. Lett. 124, 081803 (2020)



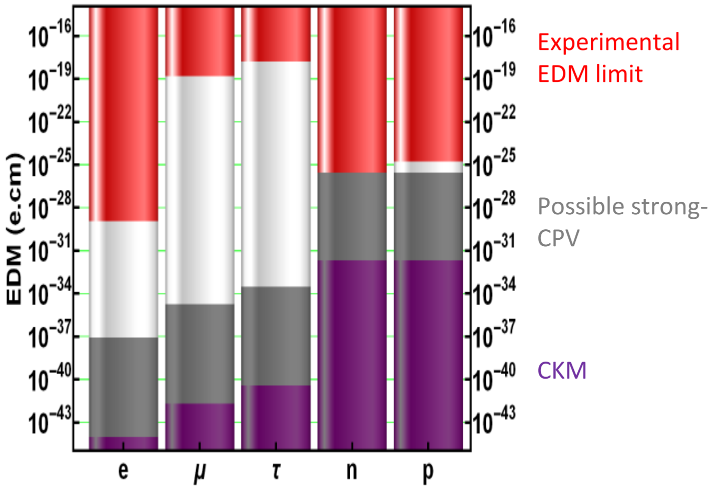
Slide courtesy: B. Lauss, nEDM workshop 2017, based on NIMA 440, 471 (2000), Phys. Rev. D 92, 092003 (2015) AIP Conf. Proc. 1753, 060002 (2016)

- Test of Time reversal symmetry
  - Same as CP symmetry assuming CPT conservation
- Strong-CP problem
  - $d_n = -(1.5 \pm 0.7) \times 10^{-16} \bar{\theta}\ \mathrm{e} \cdot \mathrm{cm}$
    Jordy de Vries et al., Phys. Rev. D **104,** 055039 (2021)
    -> $\theta \lesssim 10^{-10}$
- SUSY mass scale
  - $d_n \sim \left(\frac{300\ \mathrm{GeV}}{M}\right)^2 \frac{\sin\phi}{\tan\beta} \times 10^{-24} e \cdot cm \Rightarrow \sim 2$ TeV (PSI limit)

$$\Rightarrow \sim 10\ \mathrm{TeV}\ (|d_n| \sim 1 \times 10^{-27} \mathrm{e} \cdot \mathrm{cm})$$

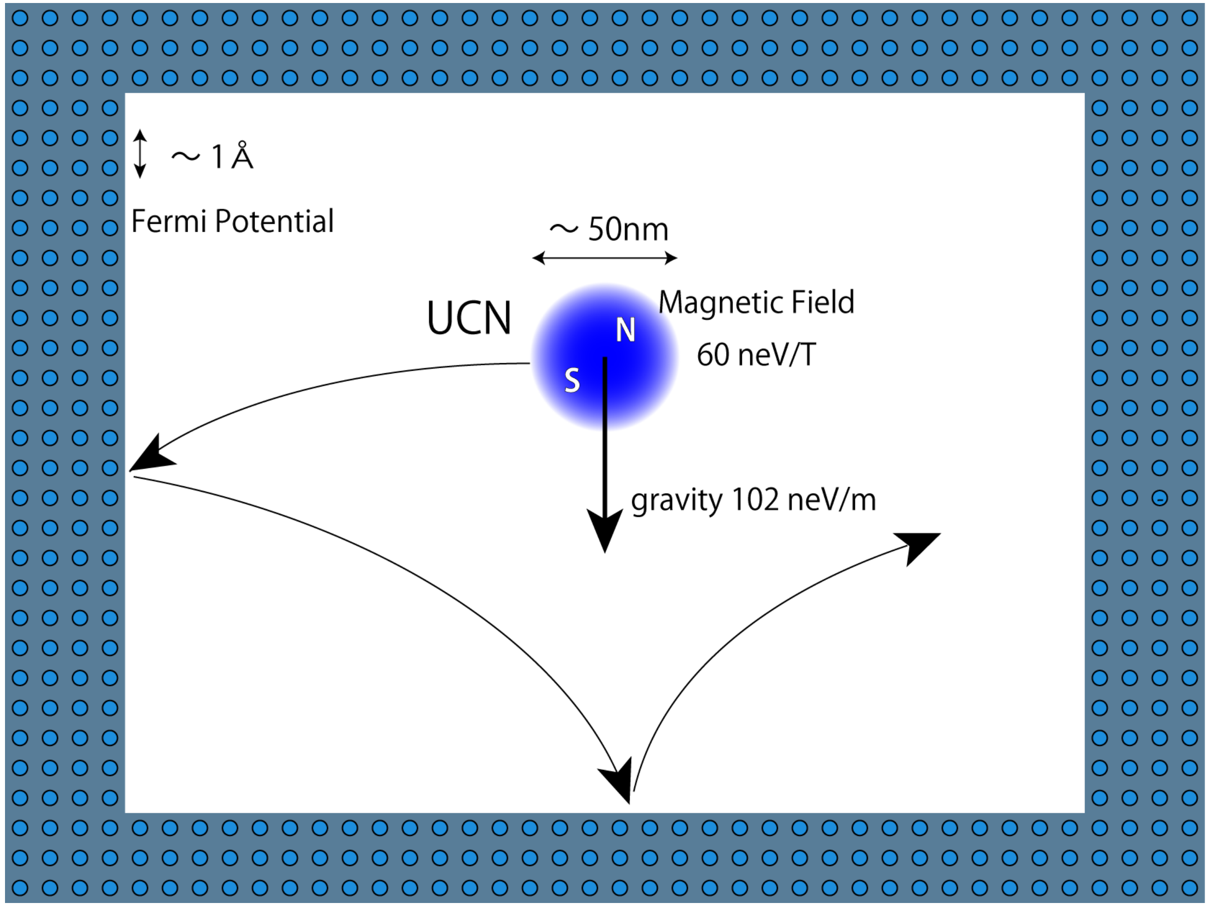
S. A. Abel and O. Lebedev, JHEP01(2006)133

Current EDM limits for Strong CP



K. Kirch and P. Schmidt-Wellenburg, EPJ Web of Conferences **234** (2020) 01007

Ultra Cold Neutron (UCN)



UCN can be confined ～ 100 sec

by material/gravity/magnetic potential

Ultra Cold Neutron

Energy	～ 100 neV
Velocity	～ 5 m/s
Wave length	～ 50 nm

Interaction

Gravity	100 neV/m
Magnetic field	60 neV/T

Weak interaction

β-decay n → p + e

Strong interaction

Fermi potential 252 neV (Ni)

atom distance : ~ Å

UCN feels average nuclear potential

Unique property

UCN can be measured for ～ 100 sec in trap

→ Use various experiments

nEDM, n lifetime, gravity ....

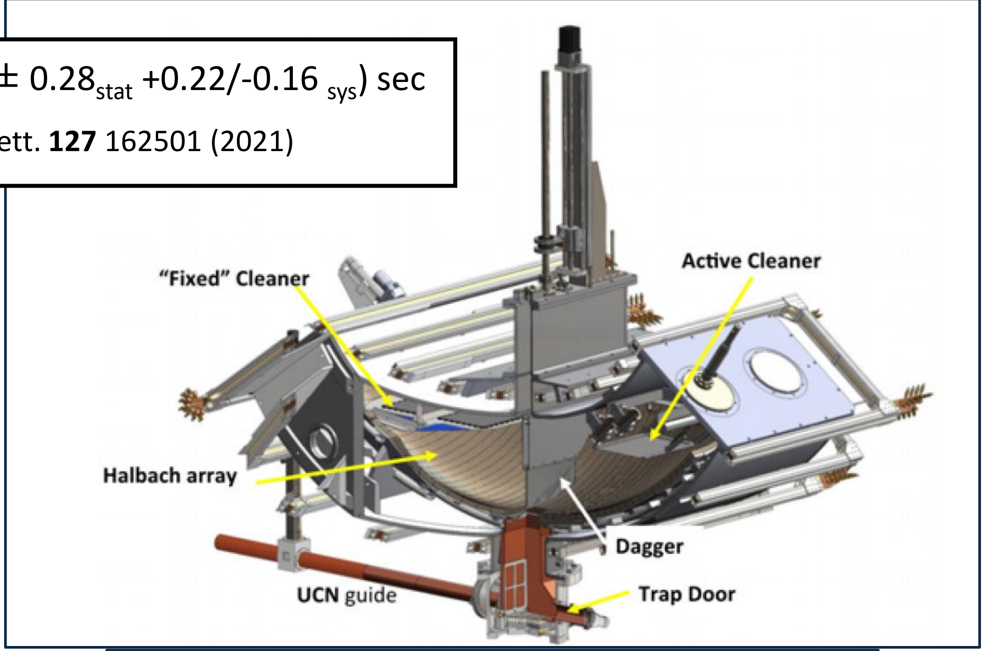
Physics using UCN

- neutron life time measurement
- gravity experiment
- nEDM search
- n-nbar oscillation and so on,

High intensity UCN source is necessar

τ_n = (877.75 ± 0.28_{stat} +0.22/-0.16 $_{sys}$) sec

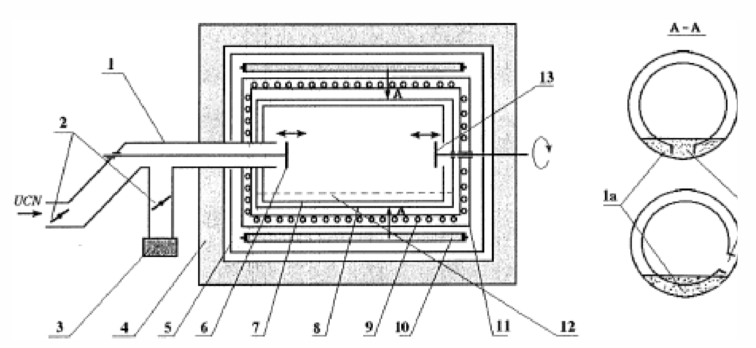
Phys. Rev. Lett. **127** 162501 (2021)



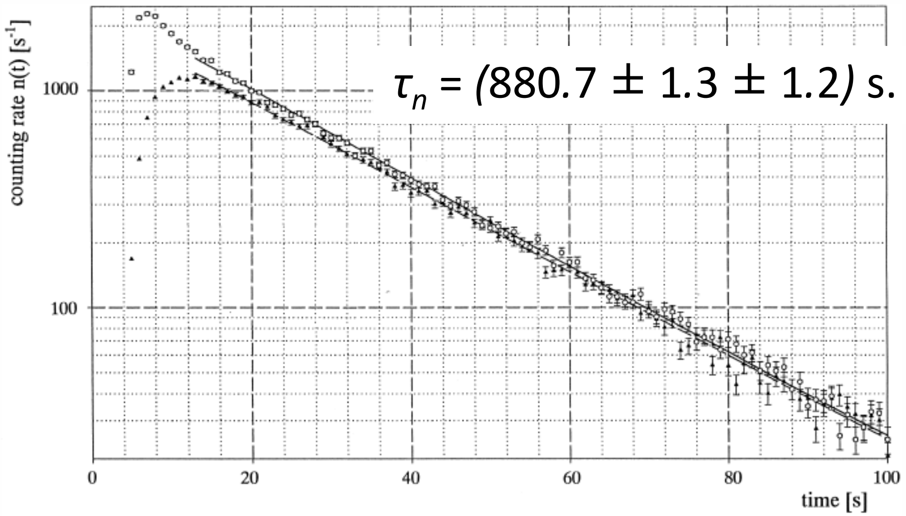
setup of UCNτ experiment (LANL)
magneto-gravity trap
UCNs cannot touch the material wall.

neutron lifetime measurement

MAMBO experiment



S. Arzumanov et al., Phys. Lett B 483, 15 (2000)
A.P. Serebrov et al., Phys. Lett. B 605, 72 (2005)
A. Pichlmaier et al., Phys. Lett. B,693:221-226 (2010)

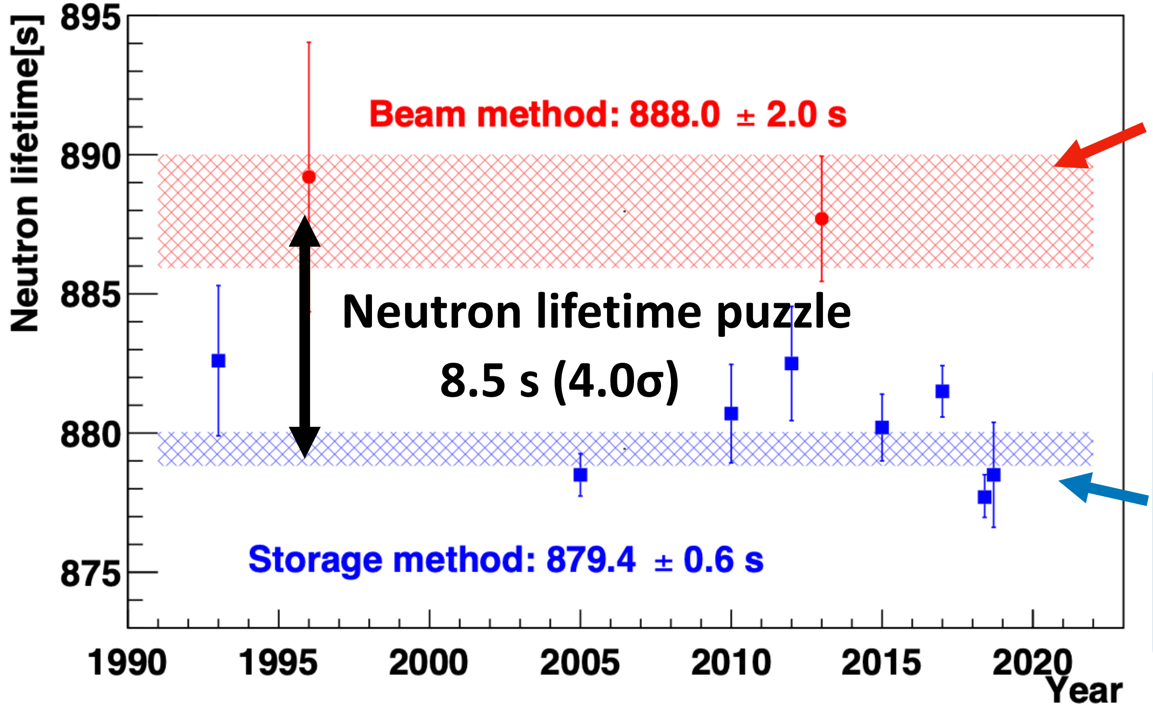


τ_n = (880.7 ± 1.3 ± 1.2) s.

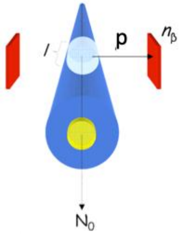
Neutron Lifetime puzzle

Slide from K. Mihsima(RCNP)

Between two methods of measurement, which measured decay and missing, there is 8.5 s (4.0σ) deviation of the value of lifetime.



Beam method: Count the decay



$$-\frac{\mathrm{d}N}{\mathrm{d}t}=\frac{N}{\tau}$$

Storage method : Count the surviving

$$\frac{N_1}{N_2}=\mathrm{e}^{-(t_1-t_2)/\tau}$$

Unknown systemstic?	arXiv:2011.13272 (2020)
New physics (dark decay, ...)?	Mod. Phys. Lett. A 35, 31, 2030019 (2020)
Quantum Zeno effect?	PRD 101, 056003 (2020)
Measurement in space	arXiv:2011.07061 (2020)

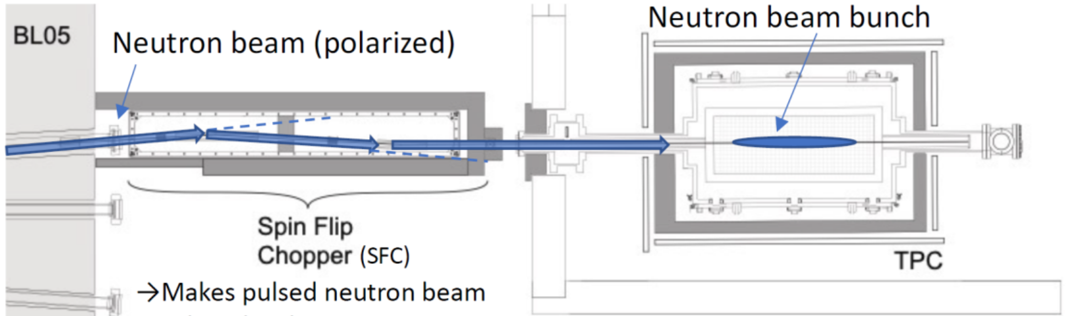
New, and different type of experiment is required.

Principle of J-PARC experiment

Slide from K. Mihsima(RCNP)

Cold neutrons are injected into a TPC.

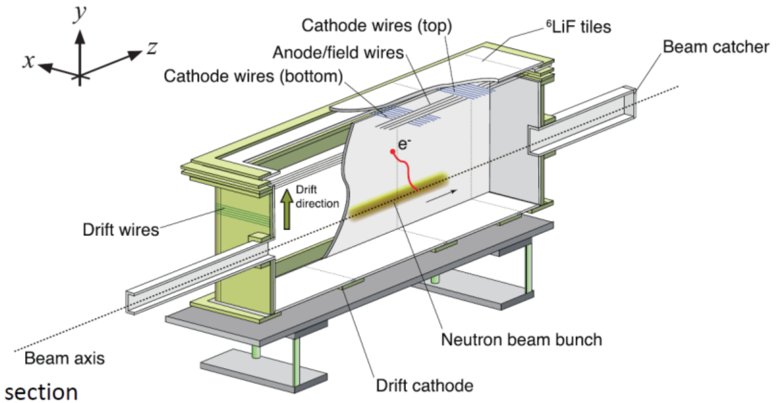
The neutron β-decay and the $^3He(n,p)^3H$ reaction are measured simultaneously.

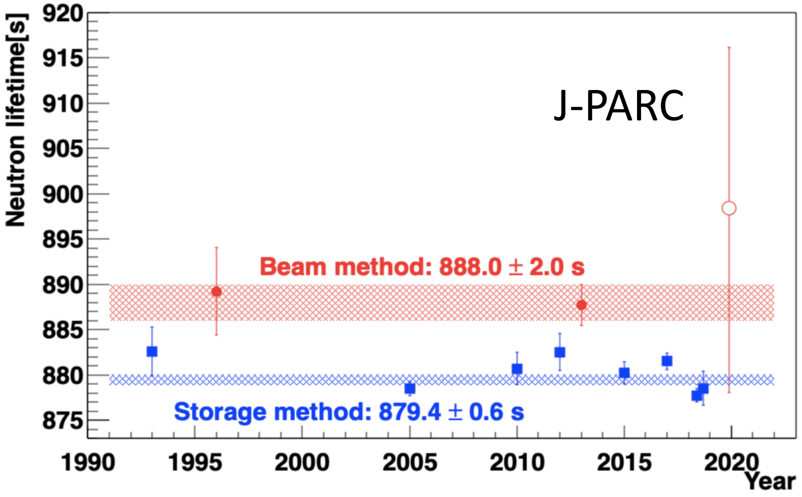


→Makes pulsed neutron beam into bunches by magnetic mirrors and spin flippers

Principle （Kossakowski,1989）

- Detector: Time Projection Chamber (TPC)
  - Gas： ^{4}He, CO_2 , ^{3}He (~85%, ~15%, 0.5 - 2 ppm, respectively) Total pressure: 100 kPa or 50 kPa





$$\tau_n = \frac{1}{\rho\sigma_0 v_0}\frac{(S_{\mathrm{He}}/\varepsilon_{\mathrm{He}})}{(S_\beta/\varepsilon_\beta)}$$

ρ : ^{3}He dencity
σ_0 : ^{3}He neutron absorption cross section
v_0 : Velocity of neutron
S_{He} : Number of ^{3}He neutron absorption event
S_β : Number of neutron β decay
$\varepsilon_{\mathrm{He}}, \varepsilon_\beta$: Efficiency

Hosokawa, RCNP workshop "Fundamental Physics Using Neutrons and Atoms 2022"

This method is free from the uncertainties due to external flux monitor, wall loss, depolarization, etc.

The goal is the experiment is accuracy of 1 sec.

Gravity experiment

- Gravity

potential well

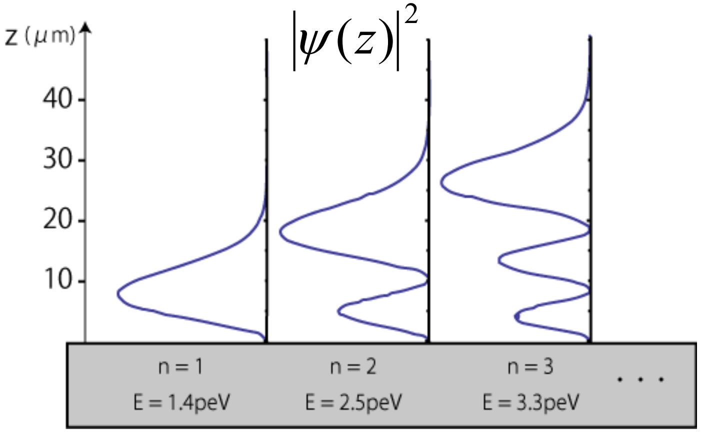
$$V(z) = \begin{cases} mgz & (z \ge 0) \\ \infty & (z < 0) \end{cases}$$

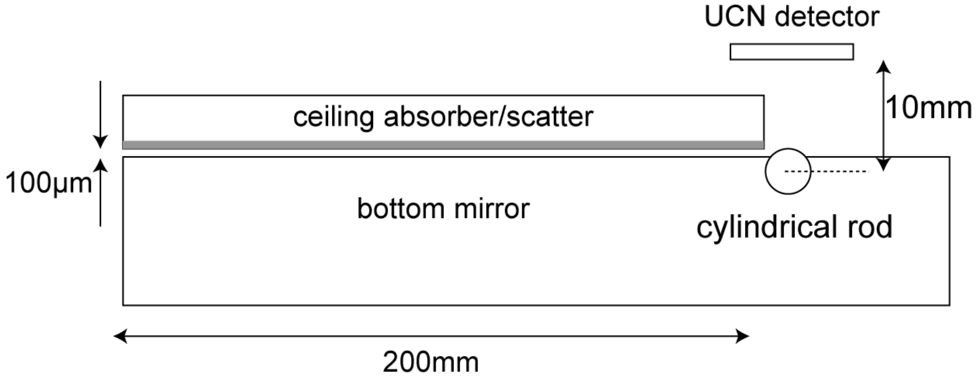
Schrödinger equation

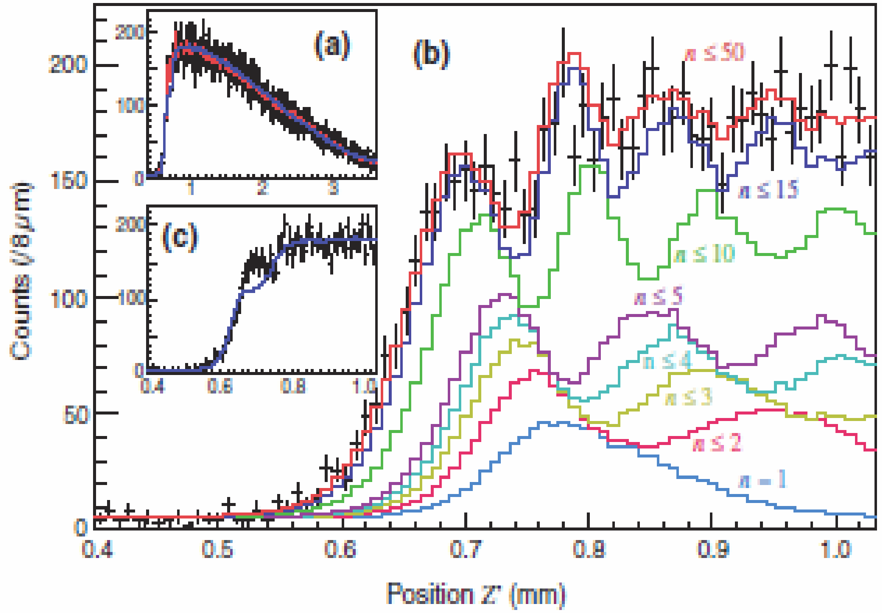
$$\left(-\frac{\hbar^2}{2m}\frac{d^2}{dz^2} + \mathrm{V}(z)\right)\psi(z) = \mathrm{E}\,\psi(z)$$

$$\psi(z) = A\,\varphi(z)$$

$\varphi(z)$: Airy function







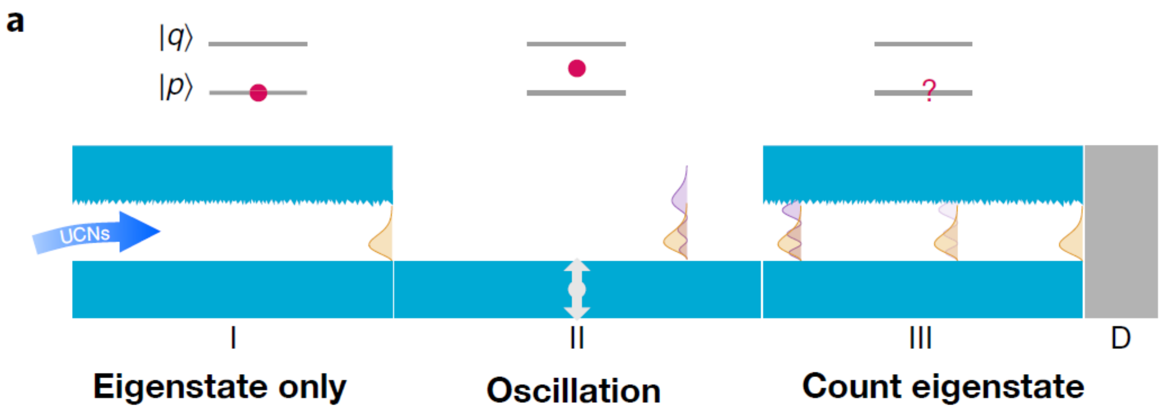
Ichikawa et al., PRL 112, 071101 (2014)

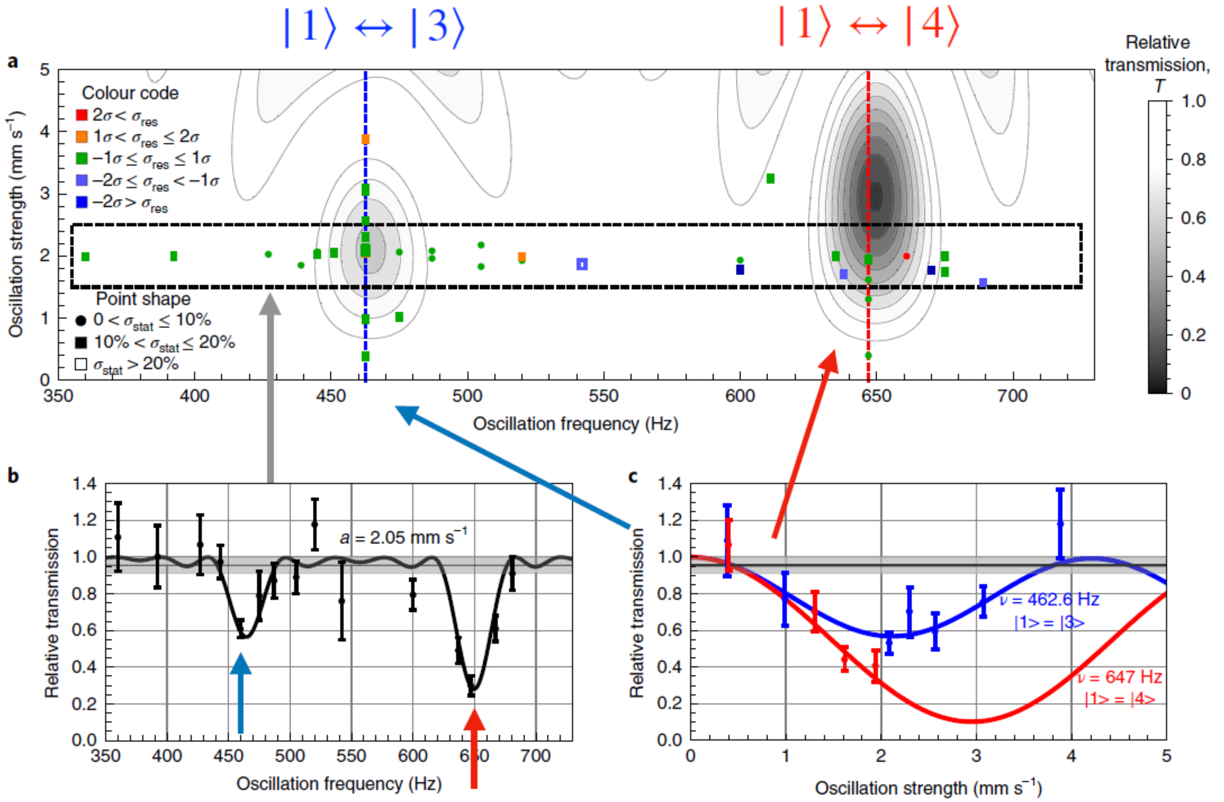
Slide from G. Ichikawa (KEK)

Oscillation (qBOUNCE)

Induce **Rabi's oscillation**s by the vibrating bottom mirror.

T. Jenke, et al., Nature Phys. 7 468-472 (2011).
T. Jenke, et al., Phys. Rev. Lett. 112, 151105 (2014).
G. Cronenberg, et al., Nature Phys. 14 1022-1026 (2018).





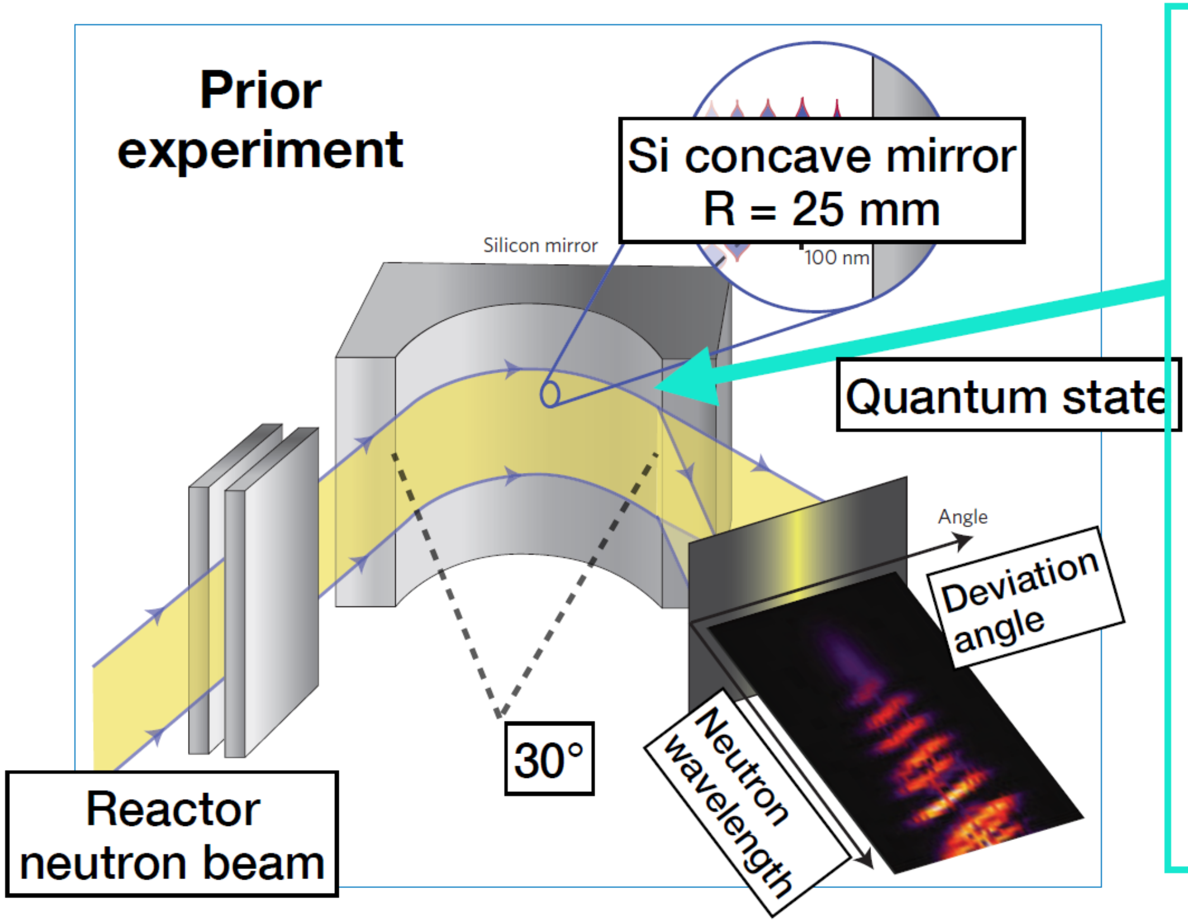
UCNs oscillate between eigenstates at resonant frequency.
Raised neutrons are removed by the ceiling.

The qBOUNCE set up can measure energy levels precisely and excluded some parameter space of new physics.
(Dark matter and Dark energy)
They achieved energy resolution of $\delta(\Delta E)=2\times10^{-15}$ eV (2 feV ~ 3 Hz) in 2018.

Slide from G. Ichikawa (KEK)

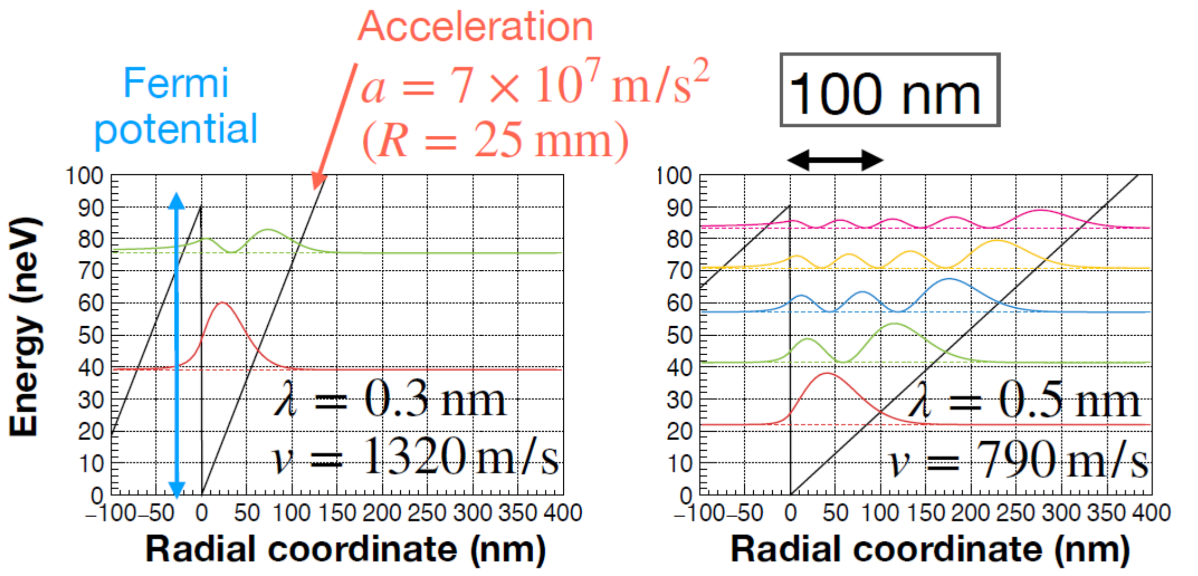
Neutron whispering gallery

V. V. Nesvizhevsky, et al., Nature Phys. 6 (2010) 114-117.



H. Rauch, Nature Phys. 6 (2010) 79.

At ILL reactor PF1B D17 (reflectometer).
peak: λ~5 Å



- Faster neutrons
- Steeper potential
- Fewer states

- Slower neutrons
- Gentle potential
- More states

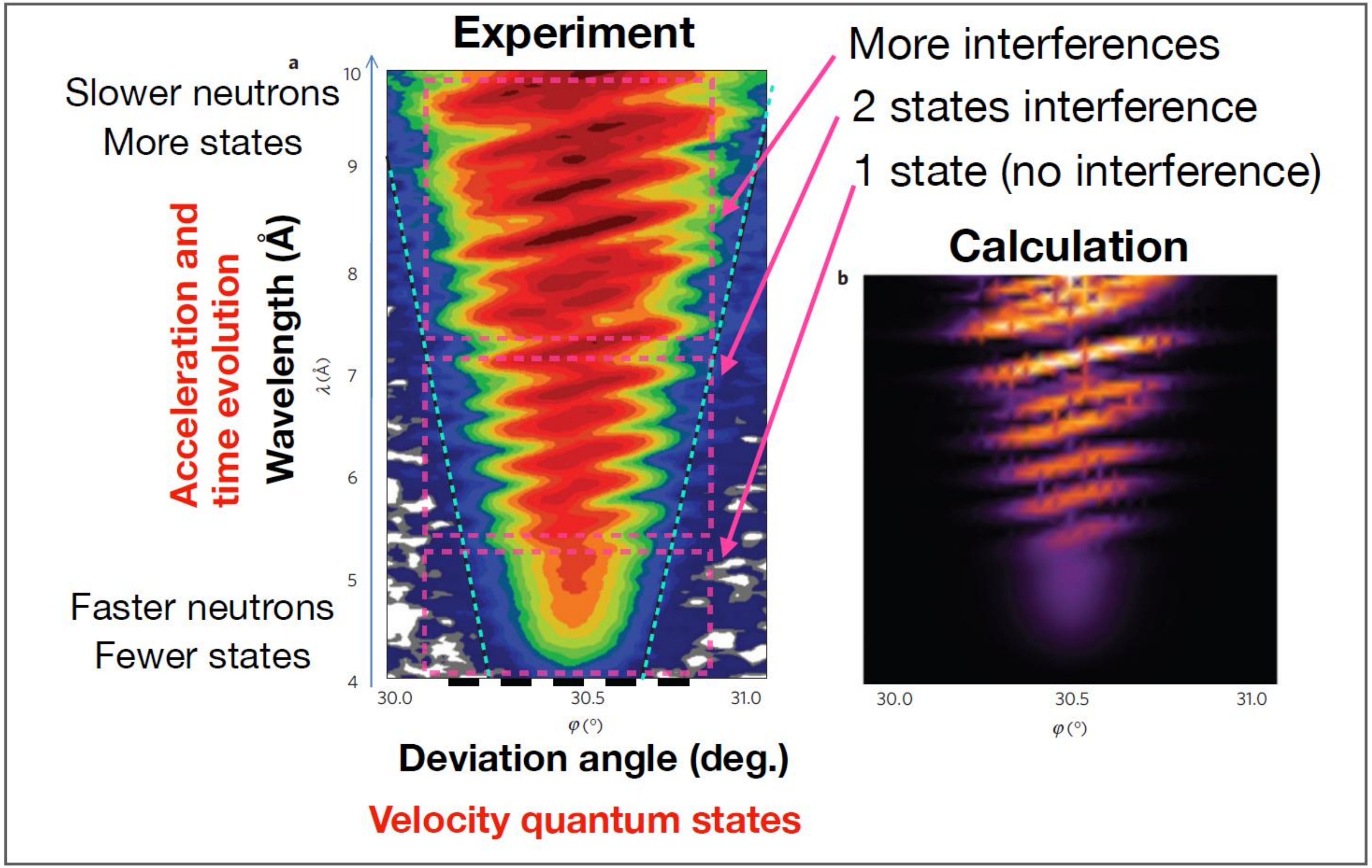
The size of whispering gallery states is ~100 nm。

1

Slide from G. Ichikawa (KEK)

Discovery of neutron whispering gallery

V. V. Nesvizhevsky, et al., Nature Phys. 6 (2010) 114-117.



The position in λ of 2-states interference patterns are proportional to $(E_2 - E_1)t/\hbar$. Energy differences can be determined by the interference.

Quantitative results could not be reliably extracted due to oxidation-related effects.

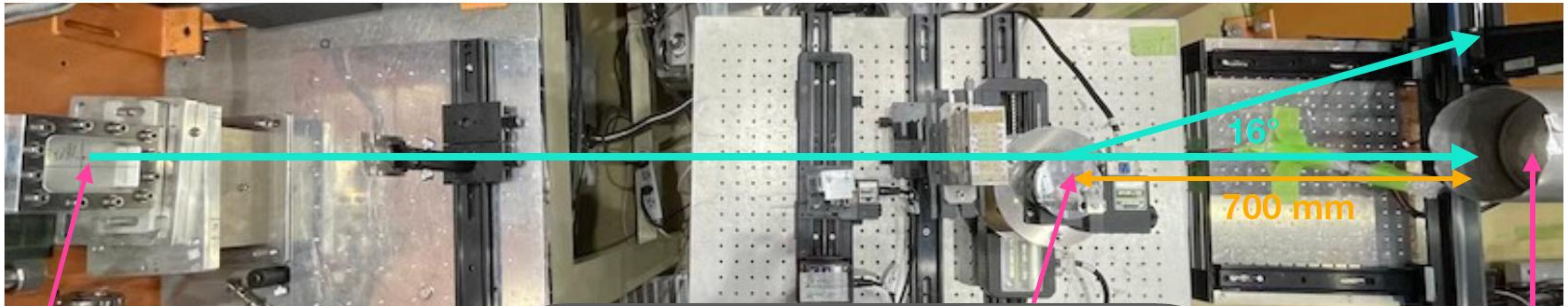
Experiment at J-PARC

- **x40 neutron intensity**
- **Well-polished SiO_2 mirror**

Slide from G. Ichikawa (KEK)

Experiment at J-PARC MLF BL05

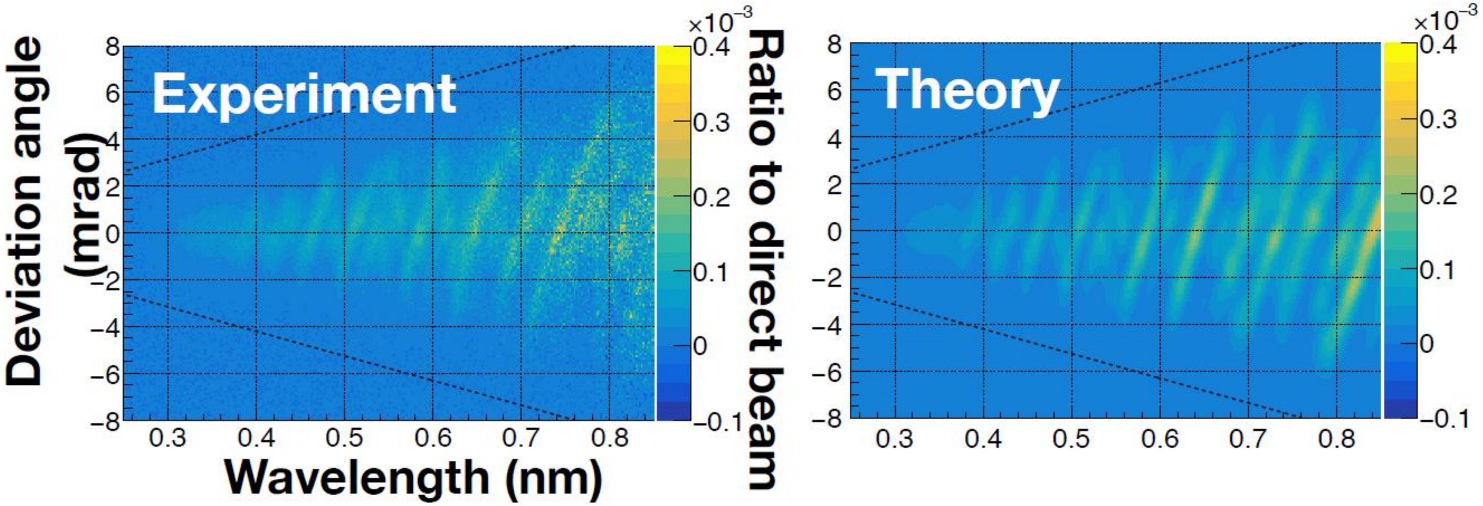
Phys. Rev. D 111, 082008 (2025)



Low divergence branch
MLF cycle: 25 Hz
Horizontal divergence:
σ_H=0.090 mrad.

Concave mirror
15×25×40, R=25, ϕ_0=16°
Roughness RMS=0.58 nm
(0.08×0.08 mm^2)

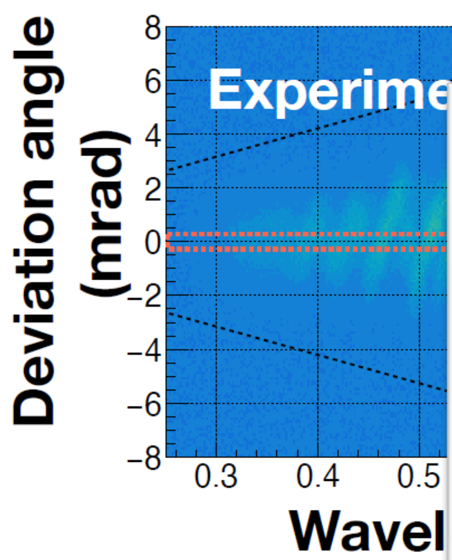
RPMT detector
ZnS(Ag)/^{6}LiF
σ~0.1 mm with time resolution



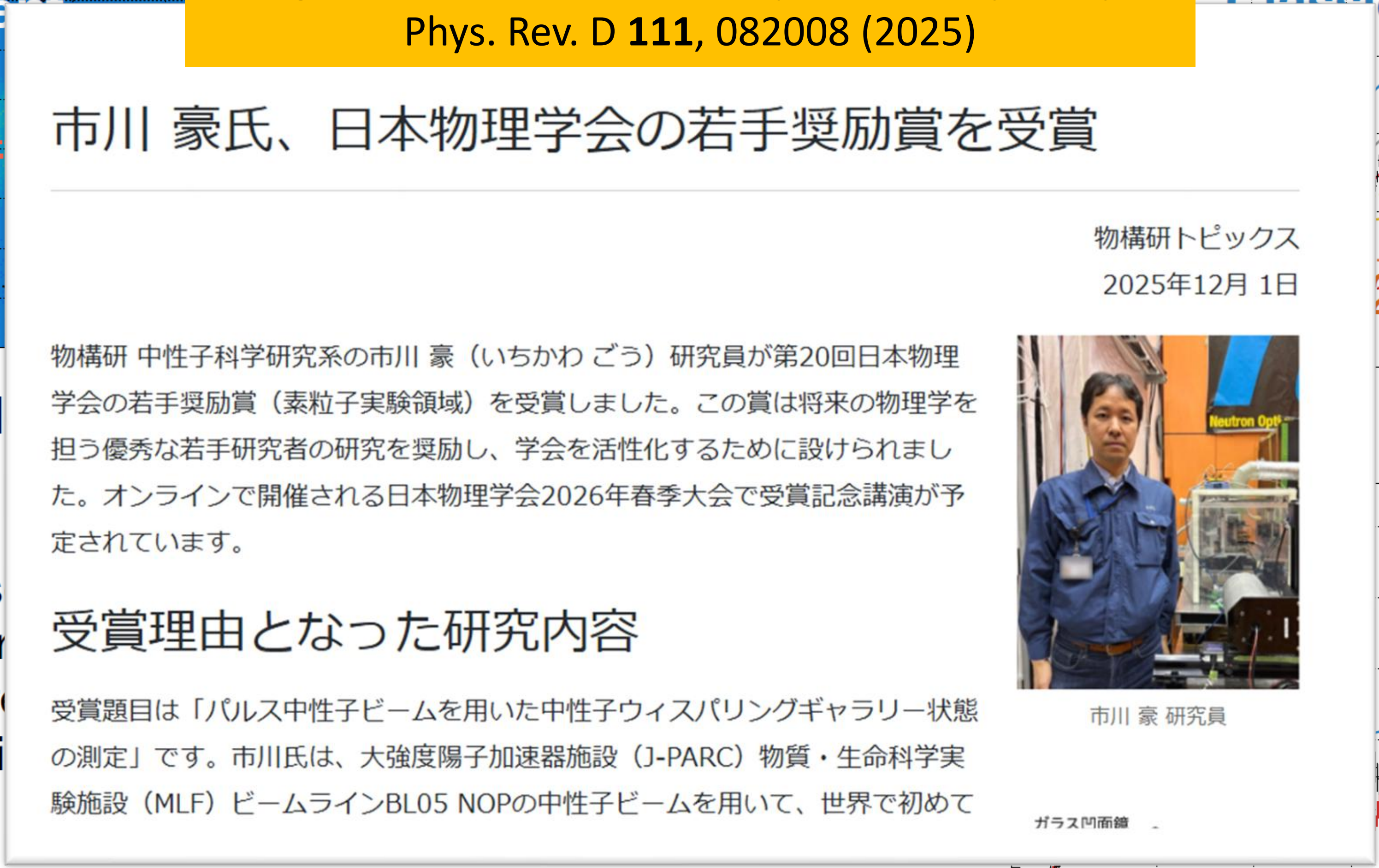
Interference fringes appear in the 2D distribution of neutron wavelength and deviation angle at a scattering angle of 16°.
We aim to quantitatively compare experiment and theory.

Slide from G. Ichikawa (KEK)

Experimental results



Young Scientist Award of the Physical Society of Japan
Phys. Rev. D **111**, 082008 (2025)



市川 豪氏、日本物理学会の若手奨励賞を受賞

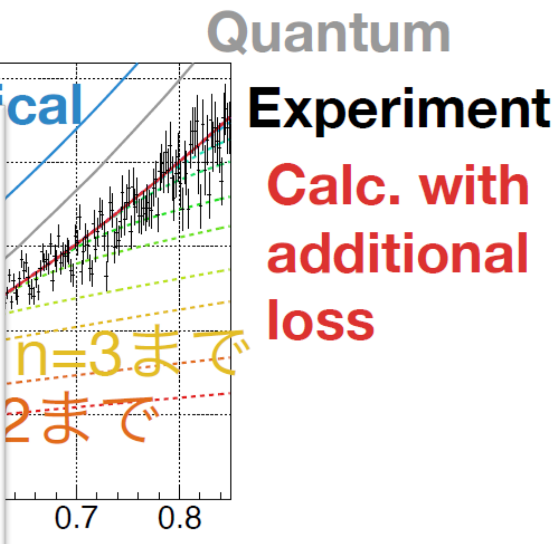
物構研トピックス
2025年12月 1日

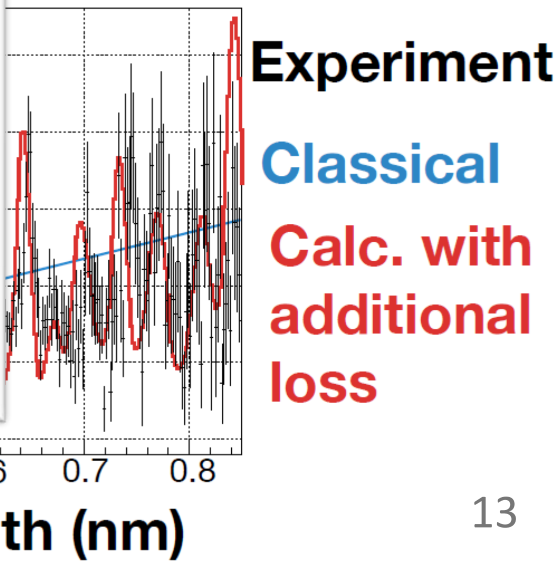
物構研 中性子科学研究系の市川 豪（いちかわ ごう）研究員が第20回日本物理学会の若手奨励賞（素粒子実験領域）を受賞しました。この賞は将来の物理学を担う優秀な若手研究者の研究を奨励し、学会を活性化するために設けられました。オンラインで開催される日本物理学会2026年春季大会で受賞記念講演が予定されています。

市川 豪 研究員

受賞理由となった研究内容

受賞題目は「パルス中性子ビームを用いた中性子ウィスパリングギャラリー状態の測定」です。市川氏は、大強度陽子加速器施設（J-PARC）物質・生命科学実験施設（MLF）ビームラインBL05 NOPの中性子ビームを用いて、世界で初めて





Additional losses aris
Experiment and theor
The fitting precision r
that this level of preci
ideal conditions.

n-nbar oscillation

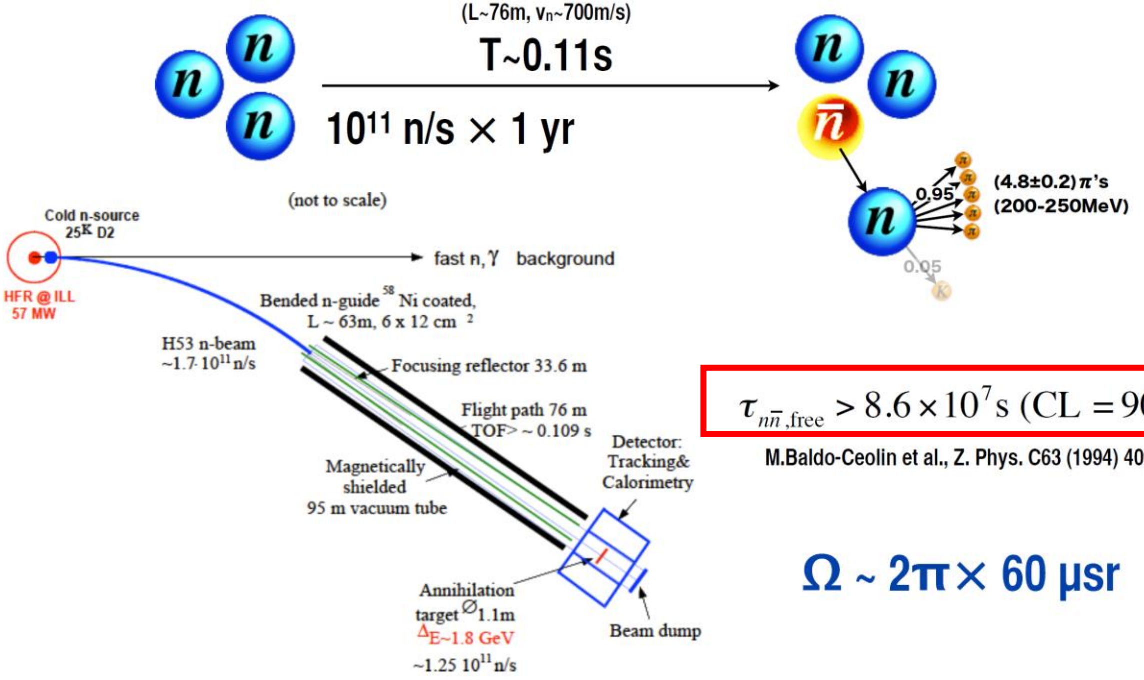
- Baryon number violation

$$n \rightarrow \bar{n} \; : \; \Delta B \; = \; -2$$

- post-sphaleron baryogenesis

$SU(2)_L \times SU(2)_R \times SU(4)_c$ $\qquad \tau_{n\bar{n}} \leq 5 \times 10^{10}$ sec

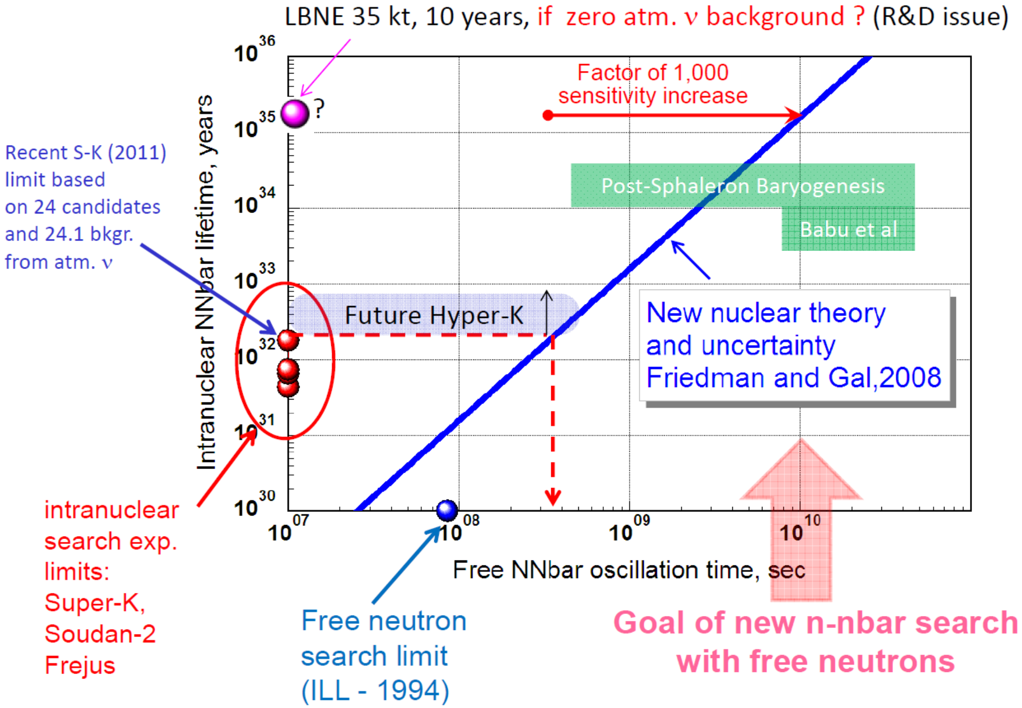
K.S. Babu et al., Phys. Rev. D 87, 115019 (2013)



$$\boxed{\tau_{n\bar{n},free} > 8.6 \times 10^{7}\,\mathrm{s}\ (\mathrm{CL} = 90\%)}$$

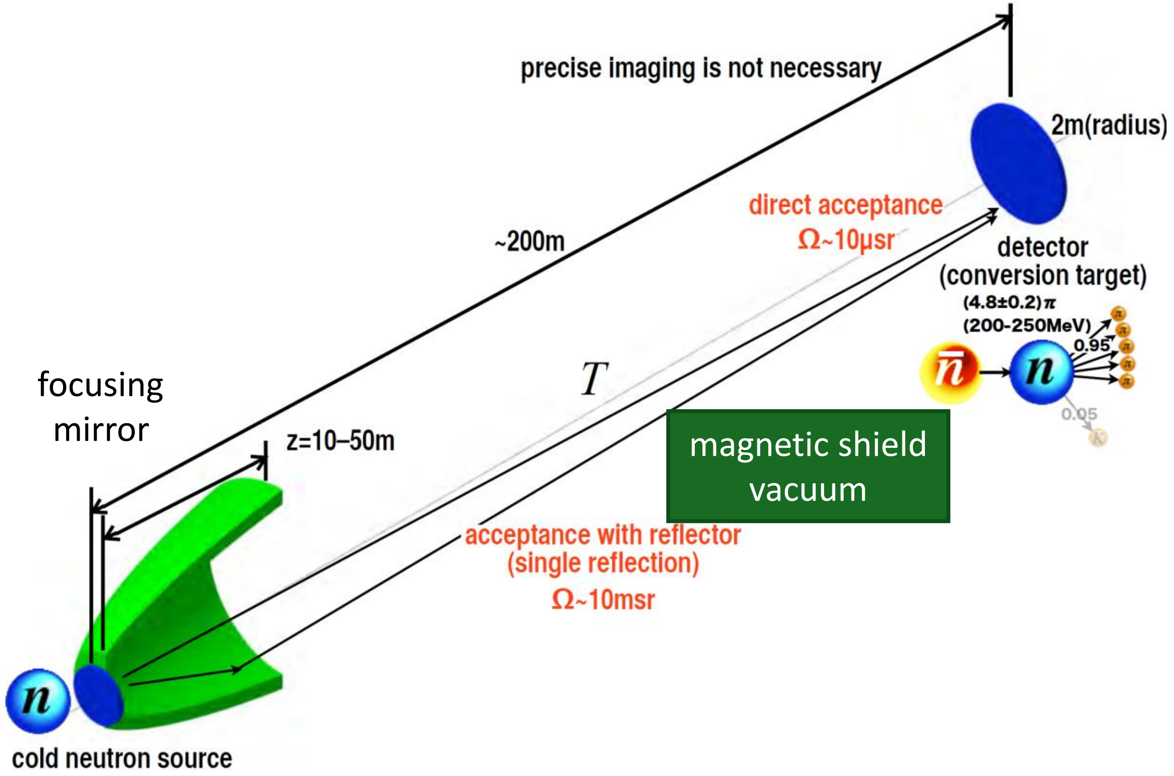
M.Baldo-Ceolin et al., Z. Phys. C63 (1994) 409.

Ω ~ 2π× 60 μsr



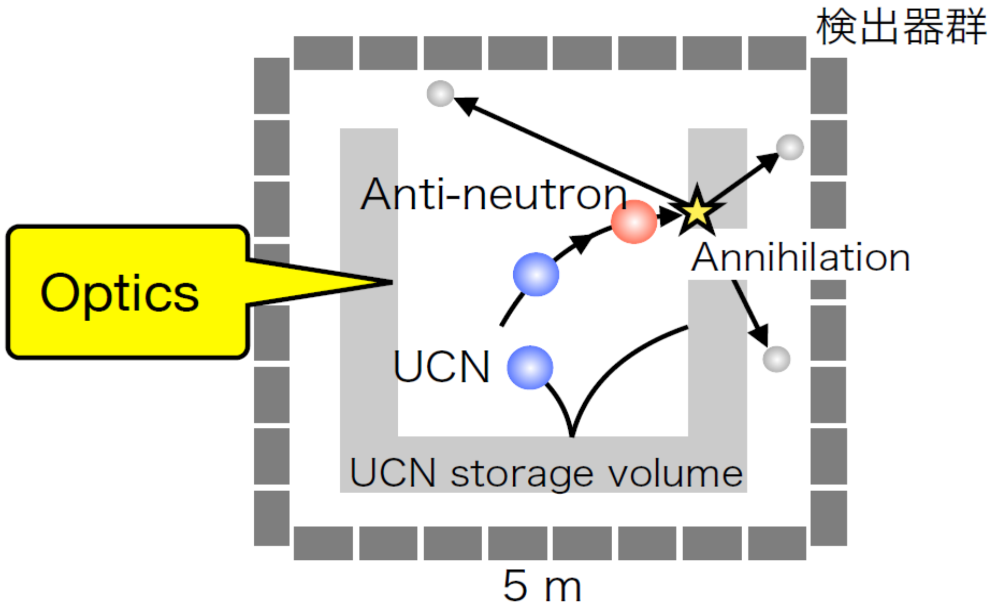
n-nbar oscillation experiments

Proposal @ ESS
free flight cold neutron



- > few 10 times better sensitivity than ILL
- strongly depend on the cold neutron source performance

UCN storage



UCN beam intensity ; $\Phi_n = 10^8$ n/sec

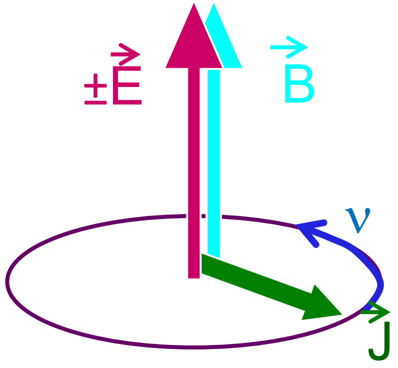
Storage time ; $T_s = 500$ sec Flight time ; $t_{TOF} = 1$ sec

Detector efficiency ; $\varepsilon = 0.5$

Measurement time ; $T_{mes.} = 2 \times 10^7$ sec

➡ **$\tau_{n\text{-}nbar} \sim 7 \times 10^8$ sec**

The nEDM Measurement



presession frequency
in Electro-Magnetic field

$$\boxed{\hbar\omega = 2\mu_n B \pm 2d_n E}$$

±: depends on the direction of E and B

difference when E and B are parallel/anti-parallel

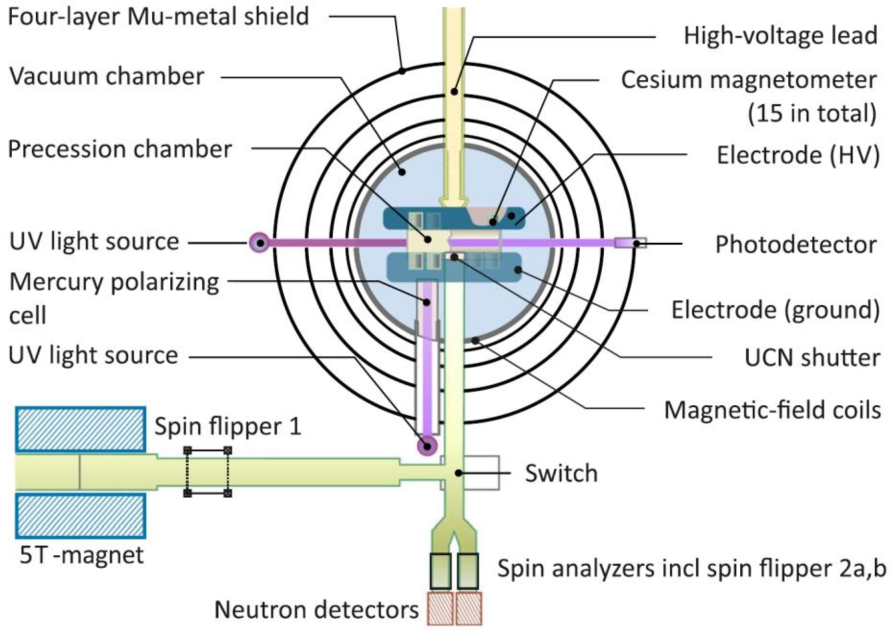
$$\Delta\omega = \omega_{\uparrow\uparrow} - \omega_{\uparrow\downarrow} = \frac{4dE}{\hbar}$$

in case of $d_n = 10^{-27}$ecm, E= 10 kV/cm

$$\Delta\omega = 10^{-8} Hz$$

cf. Larmor frequency of neutron
30Hz @ $B_0 = 1\mu T$

Very precise measurement is required!!



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

Latest Result@ PSI, 2020

$d_n = (0.0 \pm \underline{1.1_{stat}} \pm 0.2_{sys}) \times 10^{-26}$ e.cm

upper limit

1.8×10^{-26} ecm (90% C.L.)

limited by statistics

$$\boxed{\sigma_d = \frac{\hbar}{2\alpha E t_c \sqrt{N}}}$$

α : polarization (visibility)
E : electric field
t_c : precession time
N : number of UCN

TUCAN collaboration

TRIUMF UltraCold Advanced Neutron

KEK

TRIUMF

THE UNIVERSITY OF BRITISH COLUMBIA

UNBC UNIVERSITY OF NORTHERN BRITISH COLUMBIA

NAGOYA UNIVERSITY

KURNS


TUCAN collaboration meeting @UNAM, Mexico, Feb. 2026

THE UNIVERSITY OF WINNIPEG

RCNP

SFU SIMON FRASER UNIVERSITY

NC STATE UNIVERSITY

UNIVERSITY OF MANITOBA

Goal of TUCAN

- **Construct the world's most intense Ultra Cold Neutron source**
- **To search the neutron electric dipole moment down to** $10^{-27} e \cdot cm$

UCN source in the world

	nEDM/n2EDM	TUCAN	LANL	Super-SUN
Laboratory	PSI	TRIUMF	LANL	ILL
Neutron source	Accelerator 1.3 MW 570 MeV× 2.2 mA	Accelerator **20 kW** 480 MeV× 40 μA	Accelerator 1 MW 800 MeV× 12 mA	Reactor 57 MW
UCN converter	SD_2	He-II	SD_2	He-II

Superfluid Helium UCN Converter

- Long UCN storage lifetime (～ 100 sec) enables extended production and accumulation, leading to higher UCN density.
  - cf) SD_2 converter: UCN storage lifetime ～ 10 msec
- A high-performance UCN source can be realized with (relatively) low accelerator power.
- The key is maintaining superfluid helium at low temperatures, specifically around 1.0 K or below.

nEDM search Experiments in the world

	nEDM[1]	n2EDM[2]	TUCAN	nEDM@LANL[3]	panEDM[4]	nEDM@SNS[5]
Laboratory	PSI	PSI	TRIUMF	LANL	ILL	ORNL
Neutron source	Accelerator	Accelerator	Accelerator	Accelerator	Reactor	Accelerator
UCN converter	SD_2	SD_2	He-II	SD_2	He-II	He-II
Cell volume	20 litter (D=47cm, H=12cm)	60 litter (D=80 cm, H=12cm) Double cell	30 litter (D=50 cm, H=16cm) Double cell	20 litter, Double cell	17 litter (D=48 cm, H=9.4 cm) Double cell	
Target sensitivity	1.8×10^{-26} ecm	1×10^{-27} ecm	1×10^{-27} ecm	3×10^{-27} ecm	1×10^{-27} ecm	3×10^{-28} ecm

↔ transport UCNs from production volume

produce UCN in situ

Statistical Error

$$\sigma_d = \frac{\hbar}{2\alpha E t_c \sqrt{N}}$$

α : polarization (visibility)
E : electric field
t_c : precession time
N : number of UCN

1. C. Abel *et al*., Phys. Rev. Lett. **124**(8), 081803 (2020).
2. n2EDM collaboration, Eur. Phys. J. C **81,** 512, (2021)
3. T. M. Ito *et al.* Phys. Rev. C **97**, 012501(R)
4. David Wurm *et al.* EPJ Web of Conferences 219, 02006 (2019)
5. M.W. Ahmed *et al.* JINST, **14**, P11017 (2019)

n2EDM @ PSI

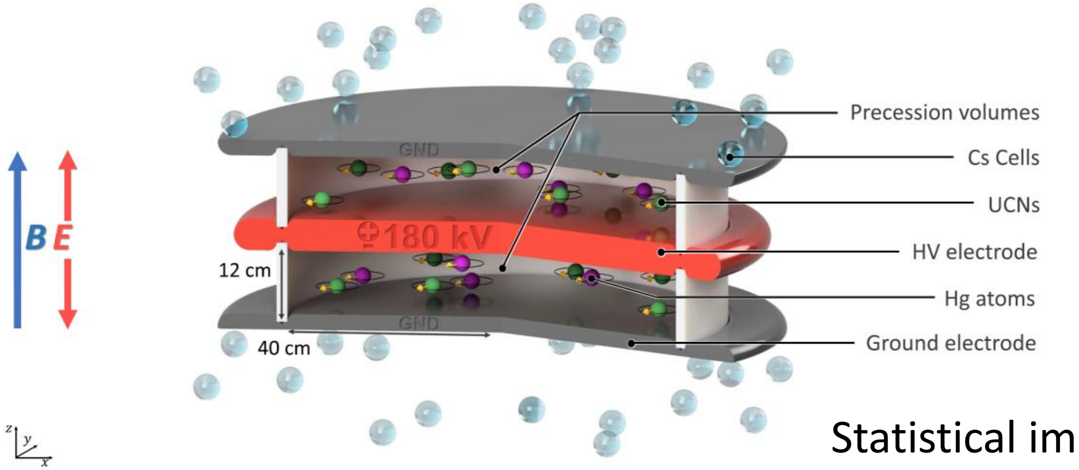
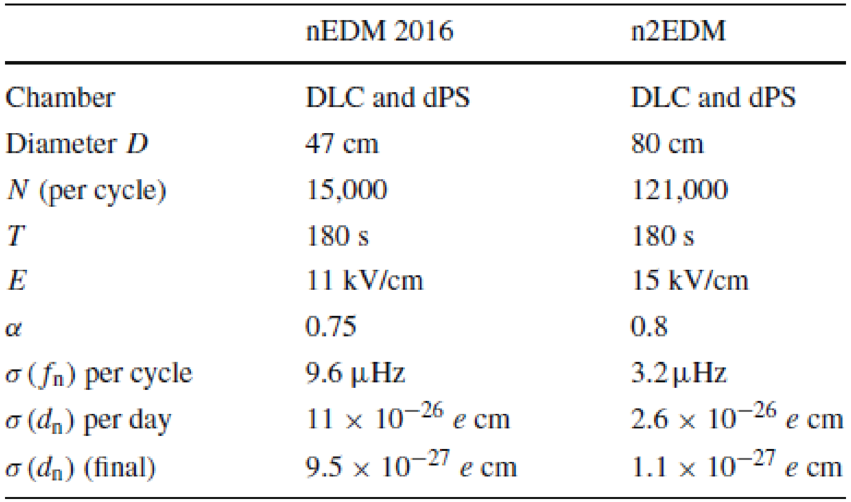


Fig. 1 Cut through the central part of the n2EDM apparatus. Two vertically stacked storage (Ramsey spin-precession) chambers, filled with polarized UCNs and Hg atoms, are embedded in the same vertical magnetic field **B**, but with opposite electric-field directions **E**



	nEDM 2016	n2EDM
Chamber	DLC and dPS	DLC and dPS
Diameter D	47 cm	80 cm
N (per cycle)	15,000	121,000
T	180 s	180 s
E	11 kV/cm	15 kV/cm
α	0.75	0.8
$\sigma(f_n)$ per cycle	9.6 μHz	3.2 μHz
$\sigma(d_n)$ per day	11×10^{-26} e cm	2.6×10^{-26} e cm
$\sigma(d_n)$ (final)	9.5×10^{-27} e cm	1.1×10^{-27} e cm

n2EDM collaboration, Eur. Phys. J. C **81,** 512, (2021)

Statistical improvement

- Larger cell

  D=47 cm → D=80 cm

Systematics improvement

- Double Cell
  - cancel the effects of time-dependent magnetic fields
  - Contribute statistics too
- new Magnetic Shield Room
  - 5.2 m × 5.2 m × 5.2 m (outer)
  - 2.93 m × 2.93 m × 2.93 m (inner)
  - residual magnetic field < 0.5 nT
  - field gradient < 0.3 nT/m

new Magnetic Shield Room

TUCAN Project

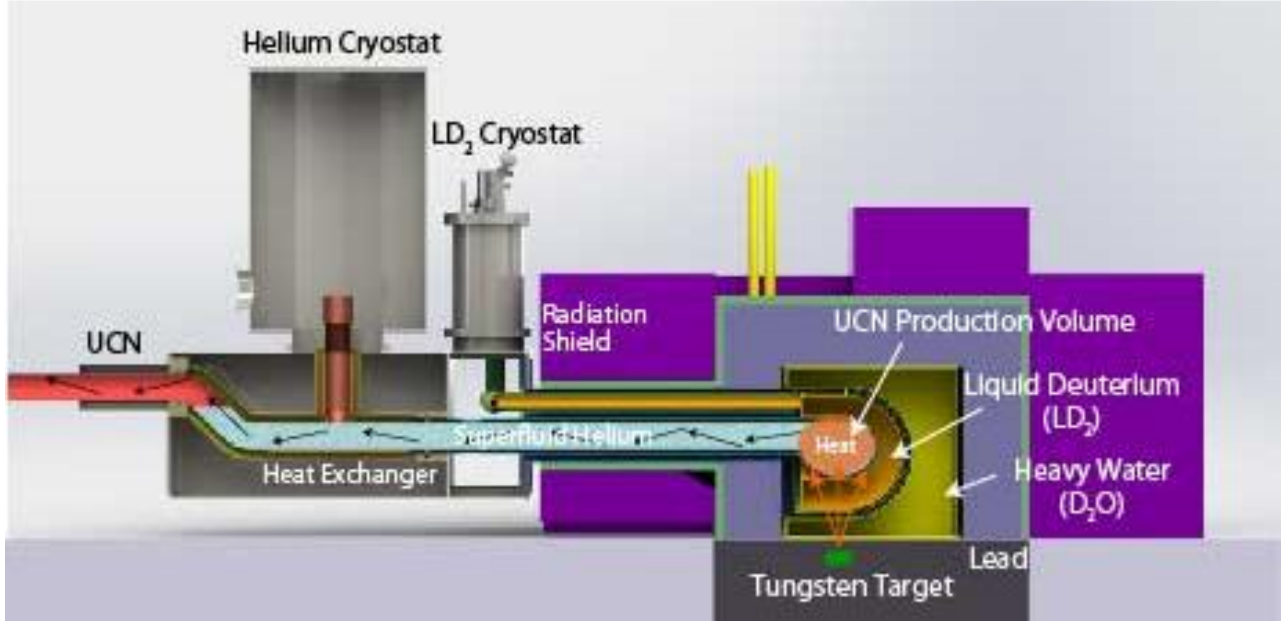
TUCAN

TRIUMF Ultra-Cold Advanced Neutron

- Japan-Canada Collaborative Research
- Including participation from the US and Mexico

Goal of TUCAN

- Construct the world-leading Ultra Cold Neutron source
- To search the neutron EDM with the precision of $10^{-27}\ e{\cdot}cm$



TUCAN Source Overview
Combination of a spallation neutron source
and superfluid helium UCN converter

Expected performance

UCN Source

- Production rate 1.4×10^7 UCN/sec
- Source storage lifetime 28 sec
- UCN density in the source 3×10^3 UCN/cc
- Total number in the source 3×10^8 UCN

EDM measurement

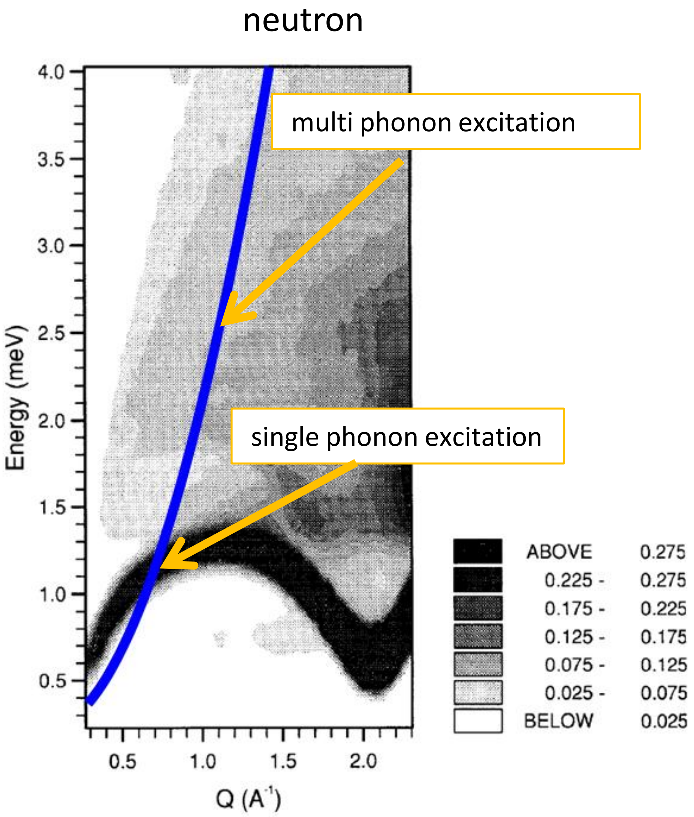
- Initial density in EDM cell 200 Pol. UCN/cc
- To reach statistical sensitivity of $\sigma_d = 10^{-27}$ ecm
  400 MT day

Helium Cryostat System

- Cooling Power 9.6 W
- liquid 3He temperature 0.8 K
- He-II temperature
  - 1.0 K @ HEX
  - 1.1 K @ production volume

UCN production by super-thermal method

- phonon up-scattering of super-fluid He or solid D_2
- use large phase space of phonon
- free from Liouville's theorem



dispersion curve of phonon in He-II

M. R. Gibbs, et al J. Low Temp. Phys. 120 (2000) 55

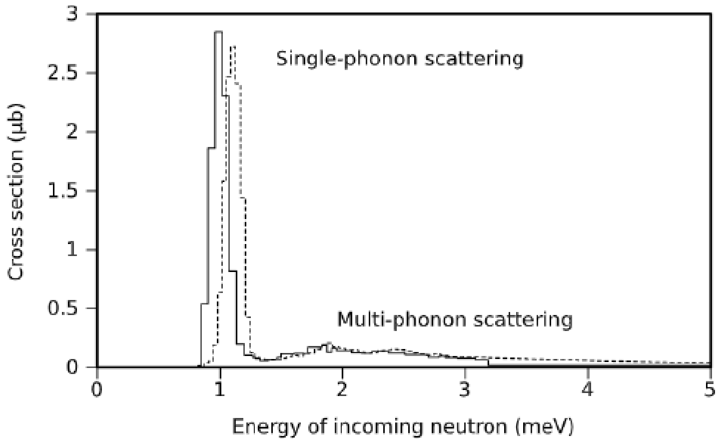


Fig. 1. Cross sections for production of ultracold neutrons with energies up to 233.5 neV in superfluid ^{4}He, calculated from [27] (solid line) and [28] (dashed line).

UCN Productino cross section
～2.8 μb@1meV
mean free path: 17 m

W. Schreyer et al., NIMA 959, 163525 (2020)

UCN production cross section

$$\frac{d\sigma}{dE} = 4\pi b^2 \frac{k_f}{k_i} S(q,\hbar\omega)$$

k_i, k_f : wavenumber

$S(q,\hbar\omega)$: Dynamic structure factor

resonant energy (single phonon excitation)

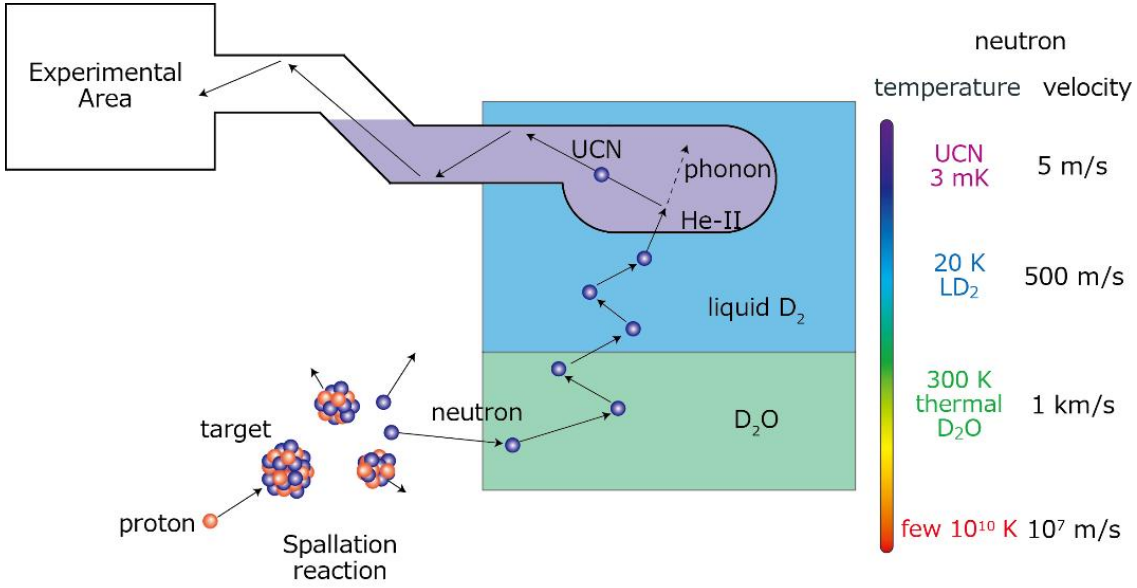
1 meV

UCN Production rate

$$P(E_u)dE_u = \left[\int \frac{d\Phi(E_i)}{dE} N_{\mathrm{He}} \frac{d\sigma}{dE}(E_i \to E_u) dE_i\right] dE_u$$

$$P = \int p(E_u)dE_u = N_{\mathrm{He}} 4\pi b^2 \left(\frac{\hbar}{m_n}\right)^2 \frac{k_c^3}{3}\left[\int \frac{d\Phi(q)}{dE} S\left(q, \hbar\omega = \frac{\hbar^2 q^2}{2m_n}\right) dq\right]$$

TUCAN UCN source



UCN production

spallation neutron MeV

↓ D_2O Moderator (300K, 20K)

cold neutron ～meV

↓ Phonon scattering in He-II

Ultra cold neutron ～100neV

Combination of

- accelerator driven neutron source (spallation neutron)

  High neutron flux

  High heat load

  small distance from target

- Super-thermal UCN production with Super-fluid Helium

  long storage lifetime

  up-scattering by phonon

  $\tau_s \propto 1/T^7$

  τ_s = 36 s at T_{HeII} = 1.2 K

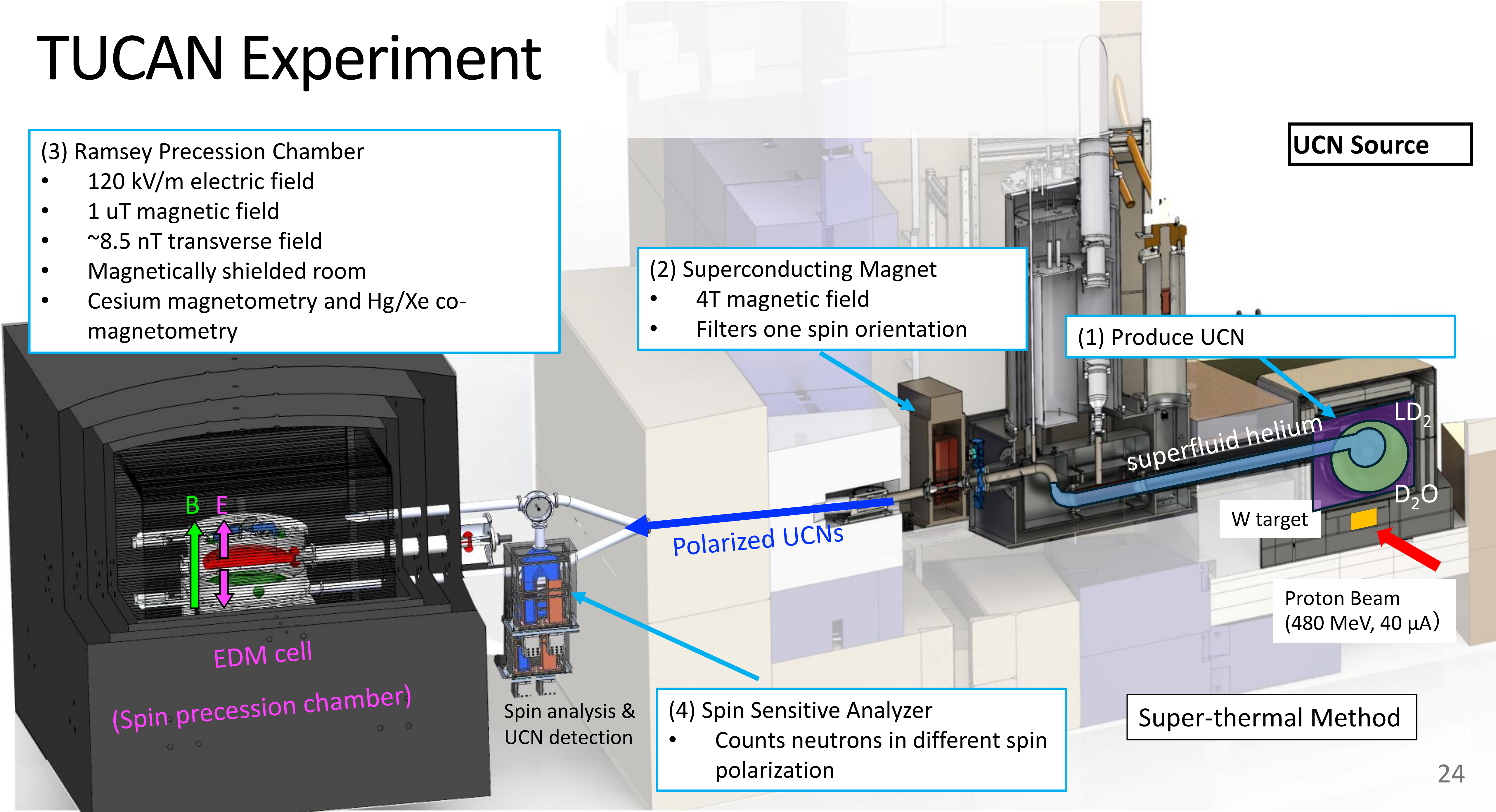
  τ_s = 600 s at T_{HeII} = 0.8 K

  (Cf. SD_2 : T_s = 24ms)

Challenge

to keep T_{HeII} ～ 1.0 K under high heat load

TUCAN Experiment



(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

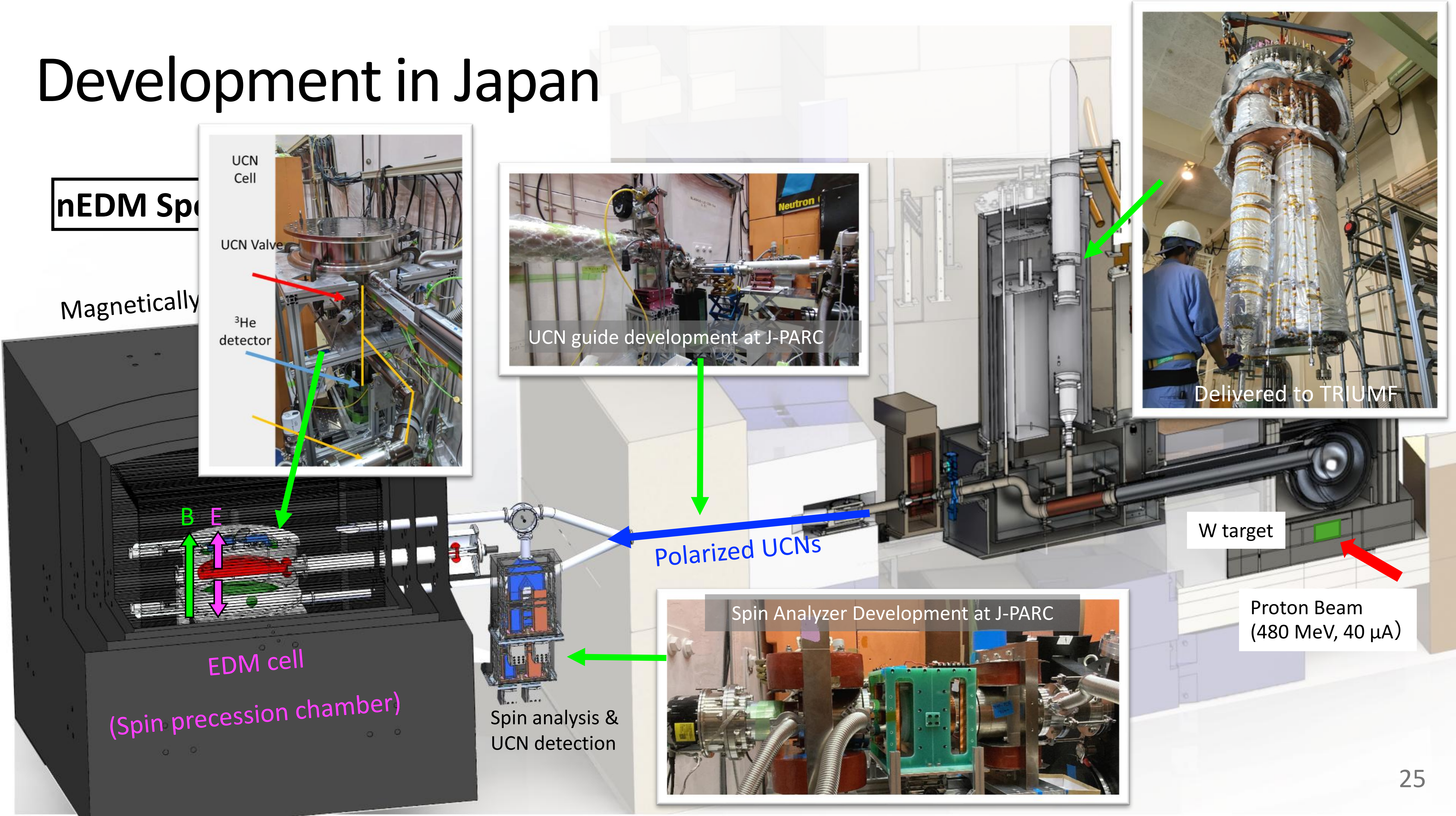
(1) Produce UCN

UCN Source

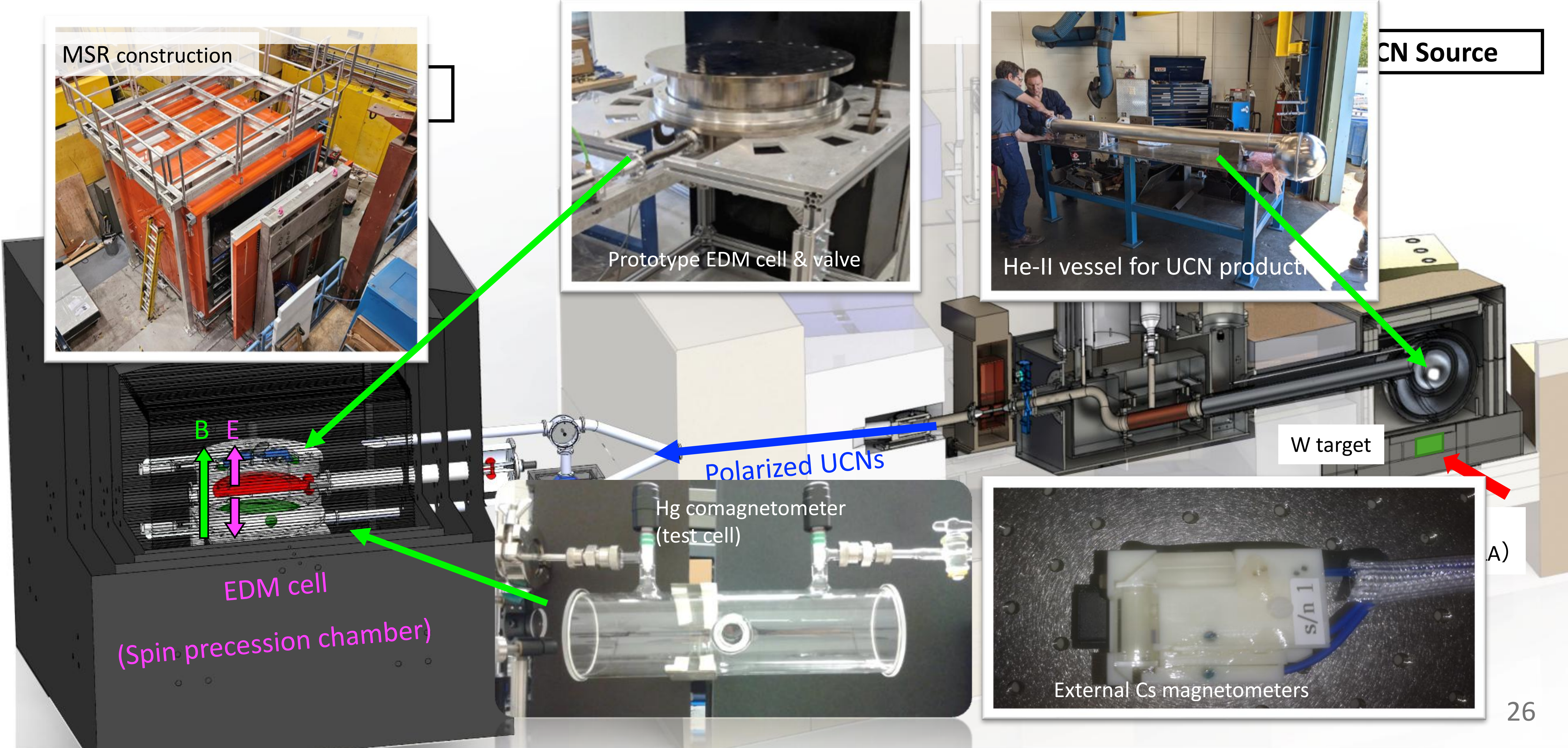
(4) Spin Sensitive Analyzer
- Counts neutrons in different spin polarization

Super-thermal Method

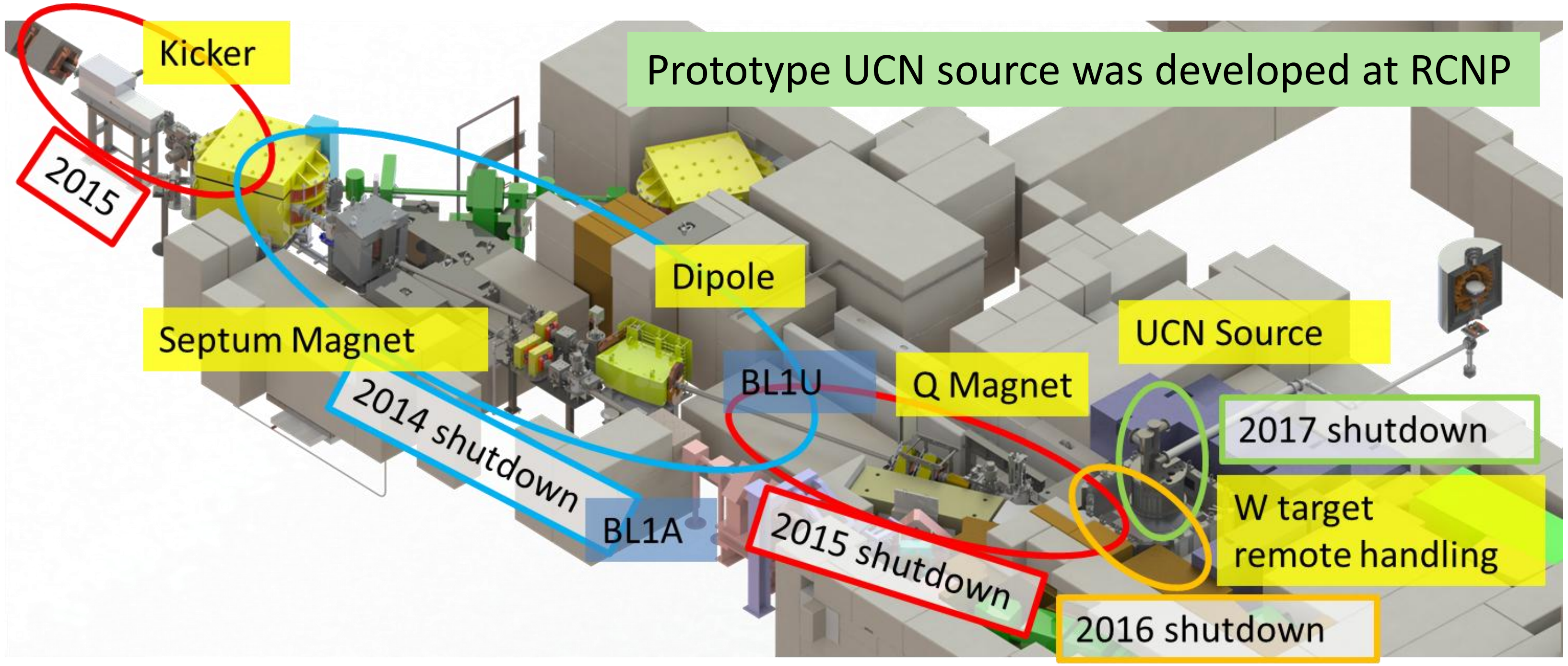
Development in Japan

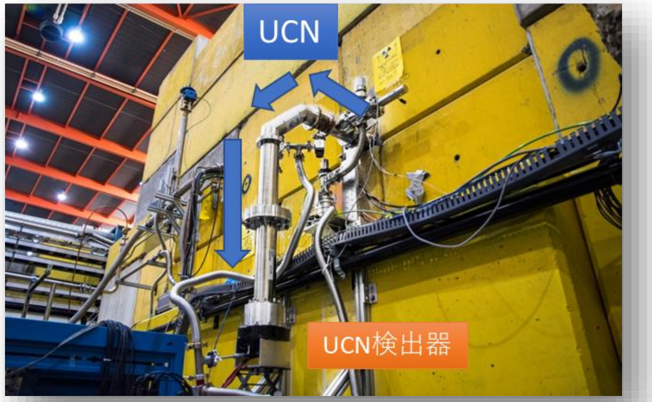


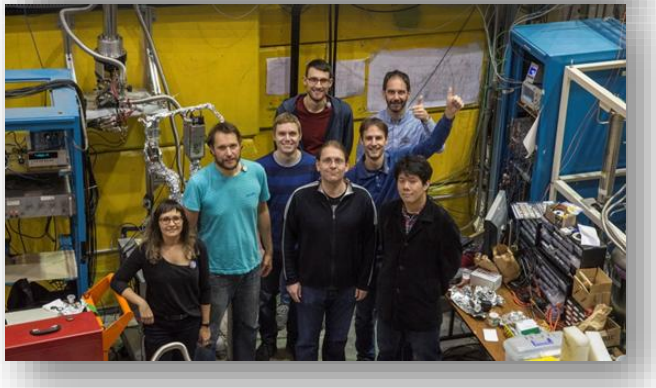
Development in Canada



Prototype UCN Source @ TRIUMF


Prototype UCN source was developed at RCNP





Major Milestone

- 2016 dedicated beam line construction (BL1U 500MeV, 40μA)

Nov 13, 2017 first UCN produced at TRIUMF

2017 - 2019 UCN production

1 month/year

Performance check, components R&D

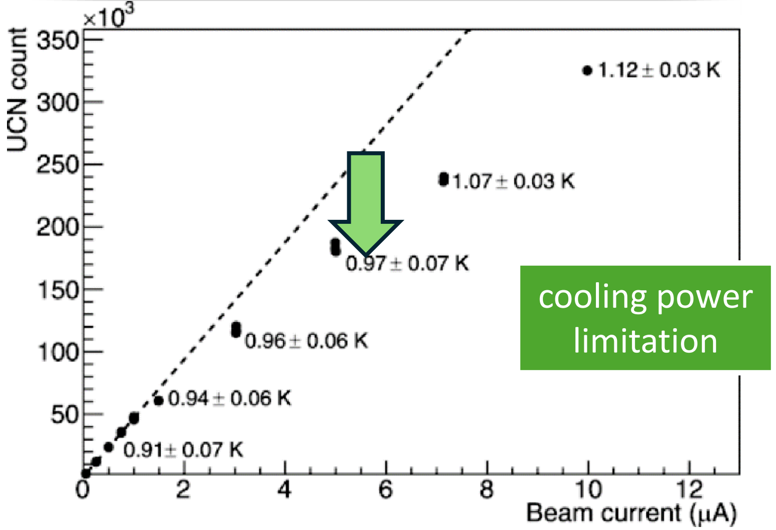
UCN production rate

5×10^4 UCN at 1 μA

$> 3 \times 10^5$ at 10 μA

UCN lifetime : 35 sec

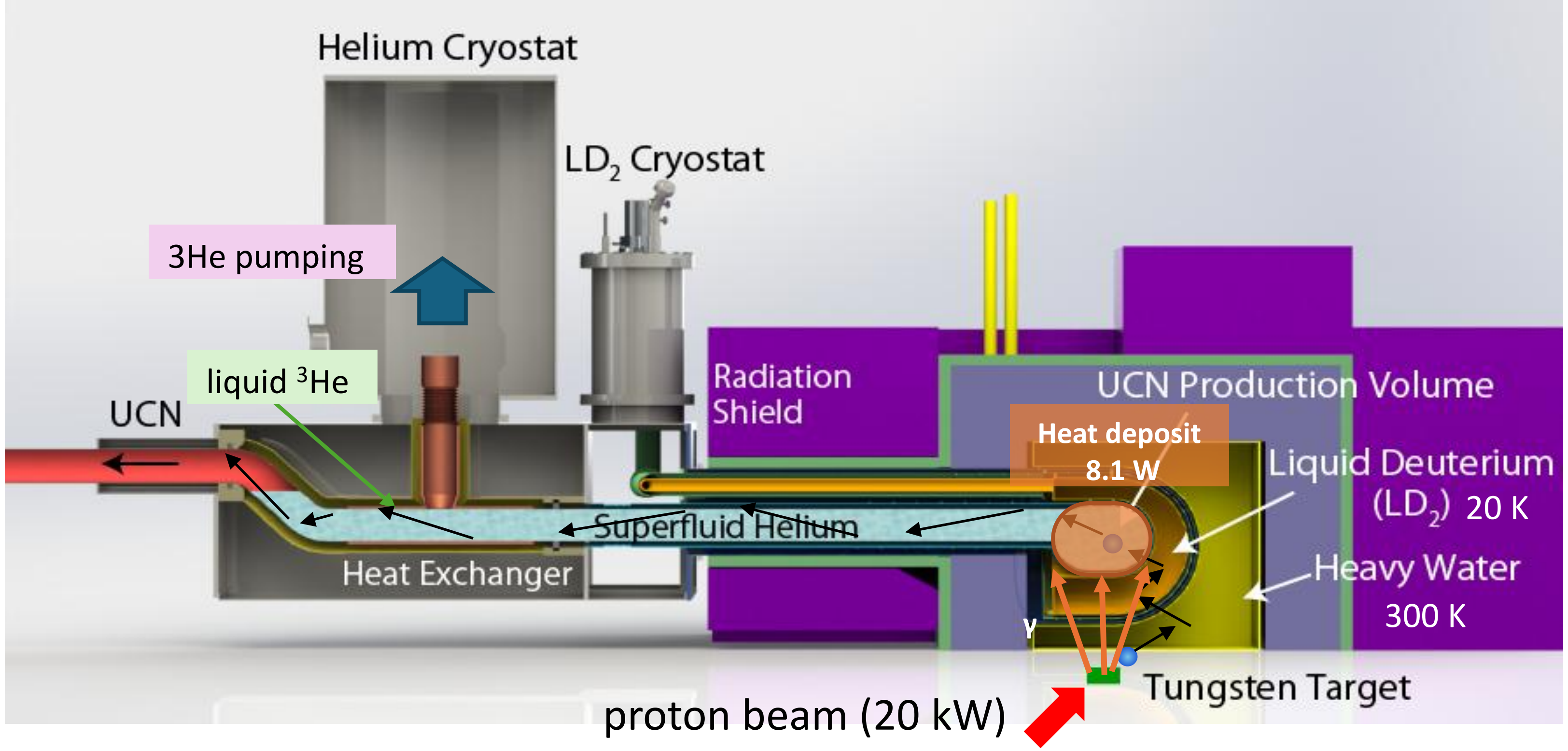
(81 sec at RCNP)



cooling power limitation

UCN yield dependence on proton current

TUCAN Source



- Liquid deuterium (LD$_2$)Moderator
  - To get colder neutron in order to produce UCN effectively
- High power helium cryostat
  - proton beam power → 0.5 kW (prototype) -> 20 kW (final)
  - Remove high radiation heat → Cooling power of 10 W around 1.0 K

Helium Cryostat Development

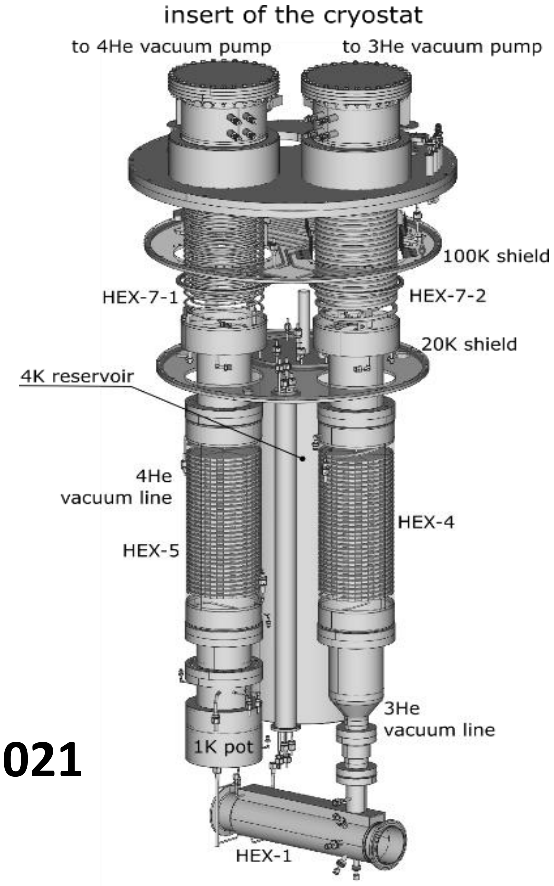
Helium-3 cryostat

- Requirements
  - Cooling power: 10 W @ 0.8 K
    - Heat load: 8.1 W from beam, 1.5 W from static
      - Including safety margin
      - Actual heat deposit: 8.1 W by beam
  - Has to be placed behind radiation shield
    - L = 2.65 m
  - Minimize liquid helium consumption
    - < 40 L/hour
- Designed by KEK
- Fabricated by JECC Torisha, Japan

Fabrication and test completed, shipped to TRIUMF in 2021

Test at KEK

- use helium-4 instead of helium-3
- confirm designed performance
  - minimum temperature 1.25 K (pumping speed: 2,000 m^3/hour)
- no superleak



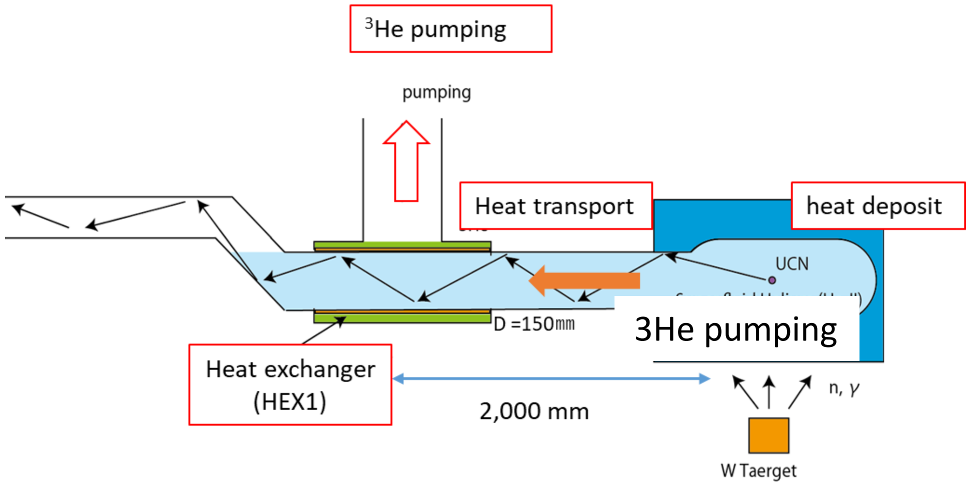
HEX1 development

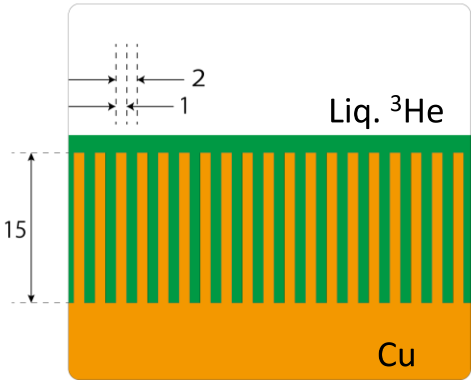
HEX1: Main Heat Exchanhger

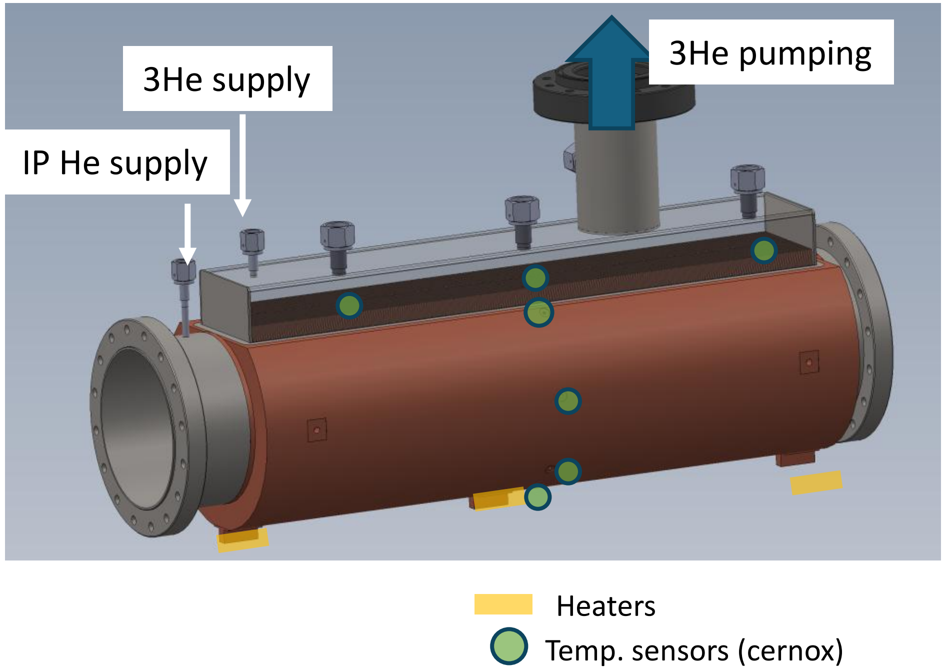
- To cool superfluid helium UCN converter by liquid helium-3
  - $T_{\text{He-II}} \sim 1.0$ K
    - to suppress UCN up-scattering by phonon
  - $T_{3\text{He}} = 0.8$ K
    - maintain by the helium-3 cryostat
  - Heat load: 9.6 W

Design

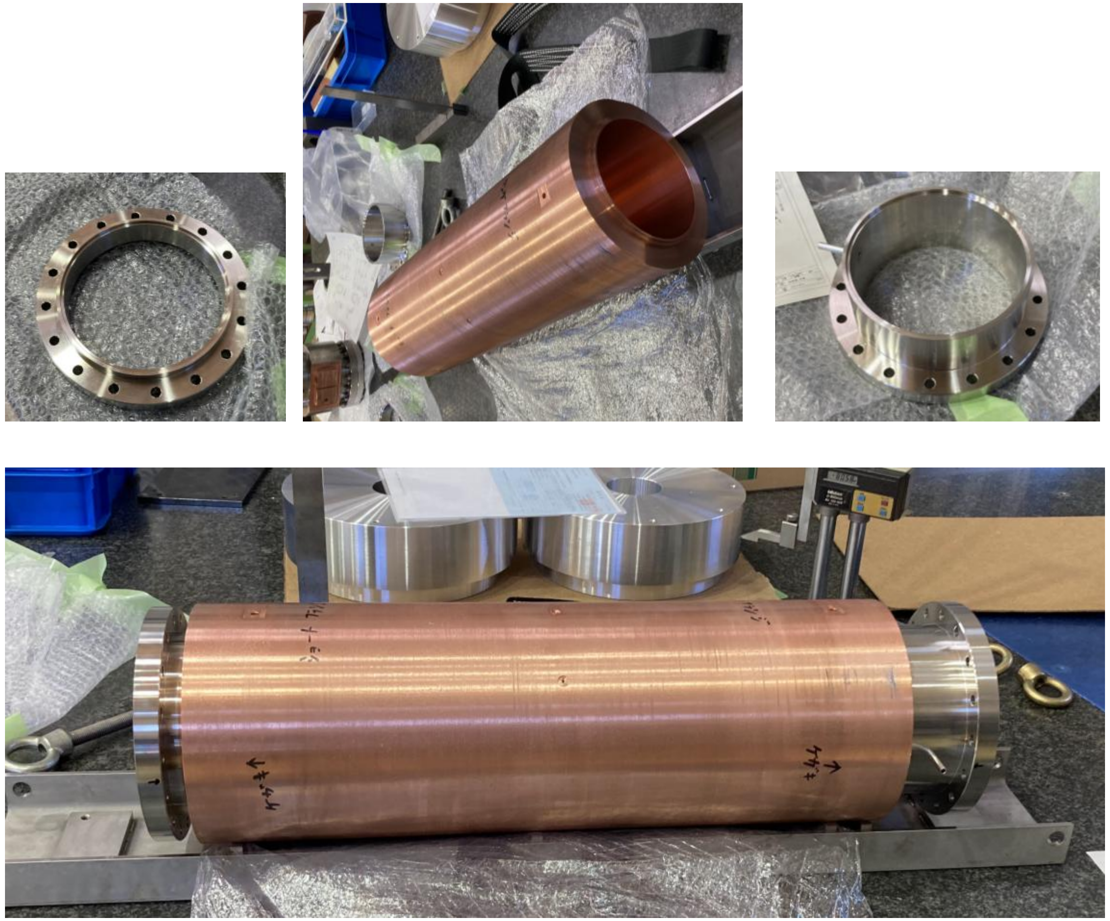
- Main body
  - Oxygen-Free High Conducting Copper (C1011)
    - purity: > 99.99 %
  - Vertical Fins
    - Fin height: h = 15 mm
    - Fin width: w = 1.0 mm
    - Fin pitch: p = 2.0 mm
    - Surface area: S = 0.90 m^2



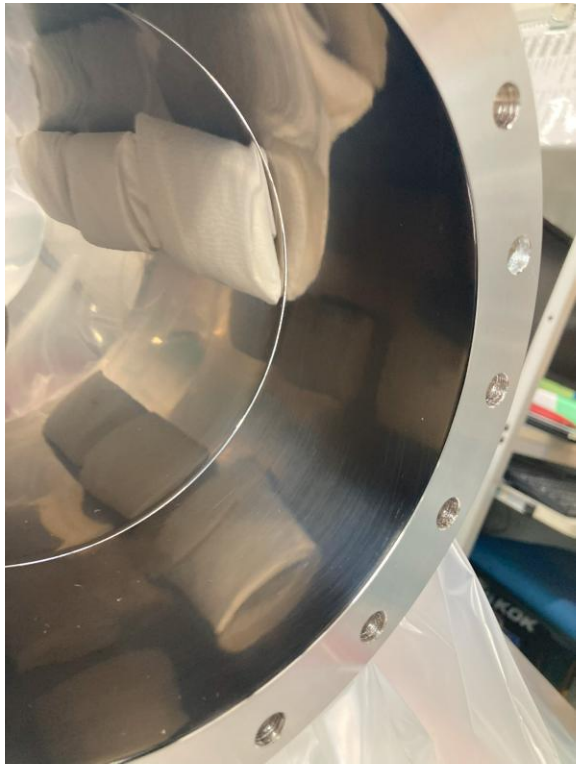




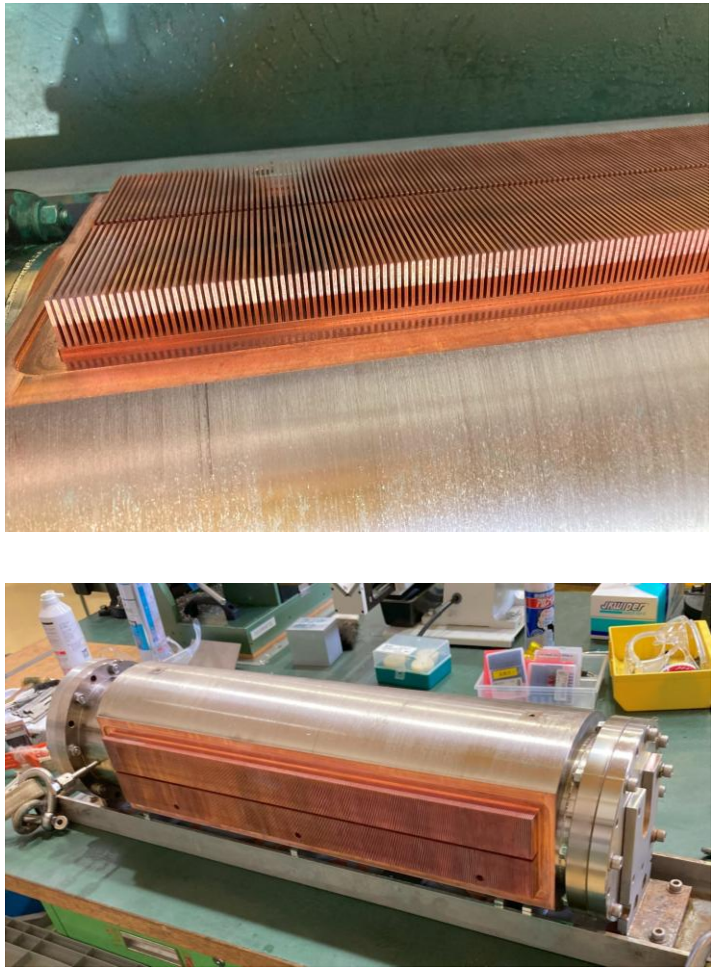
Actual Heat Exchanger Manufacturing



Flange Welding

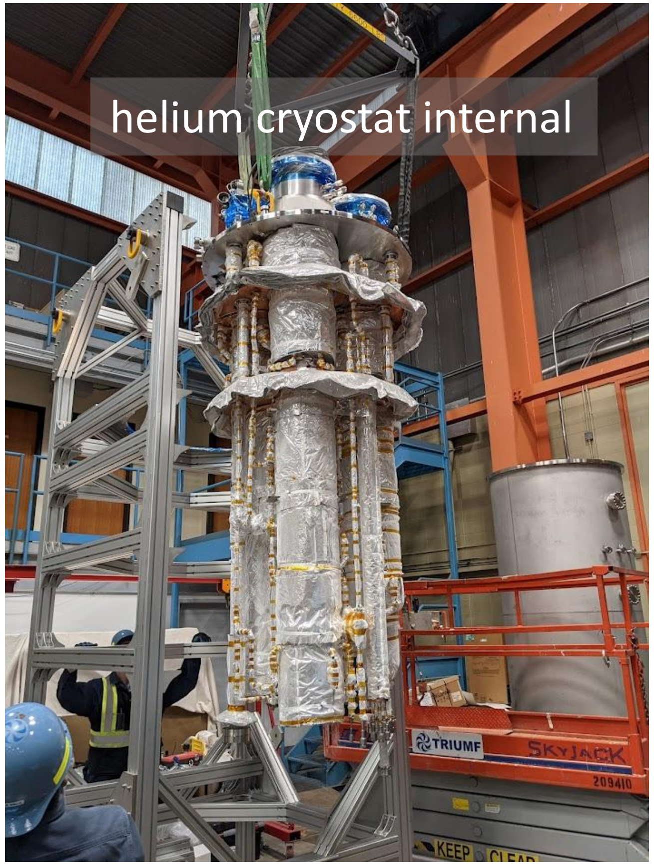


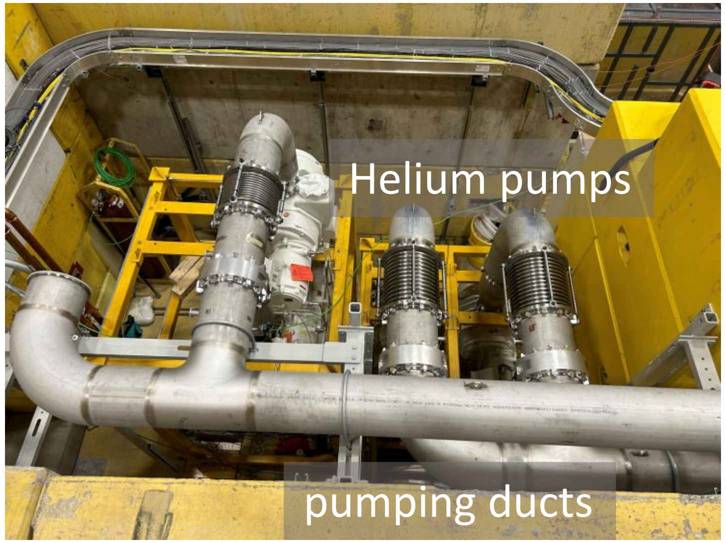
Polishing
&
NiP Plating



Fin machining

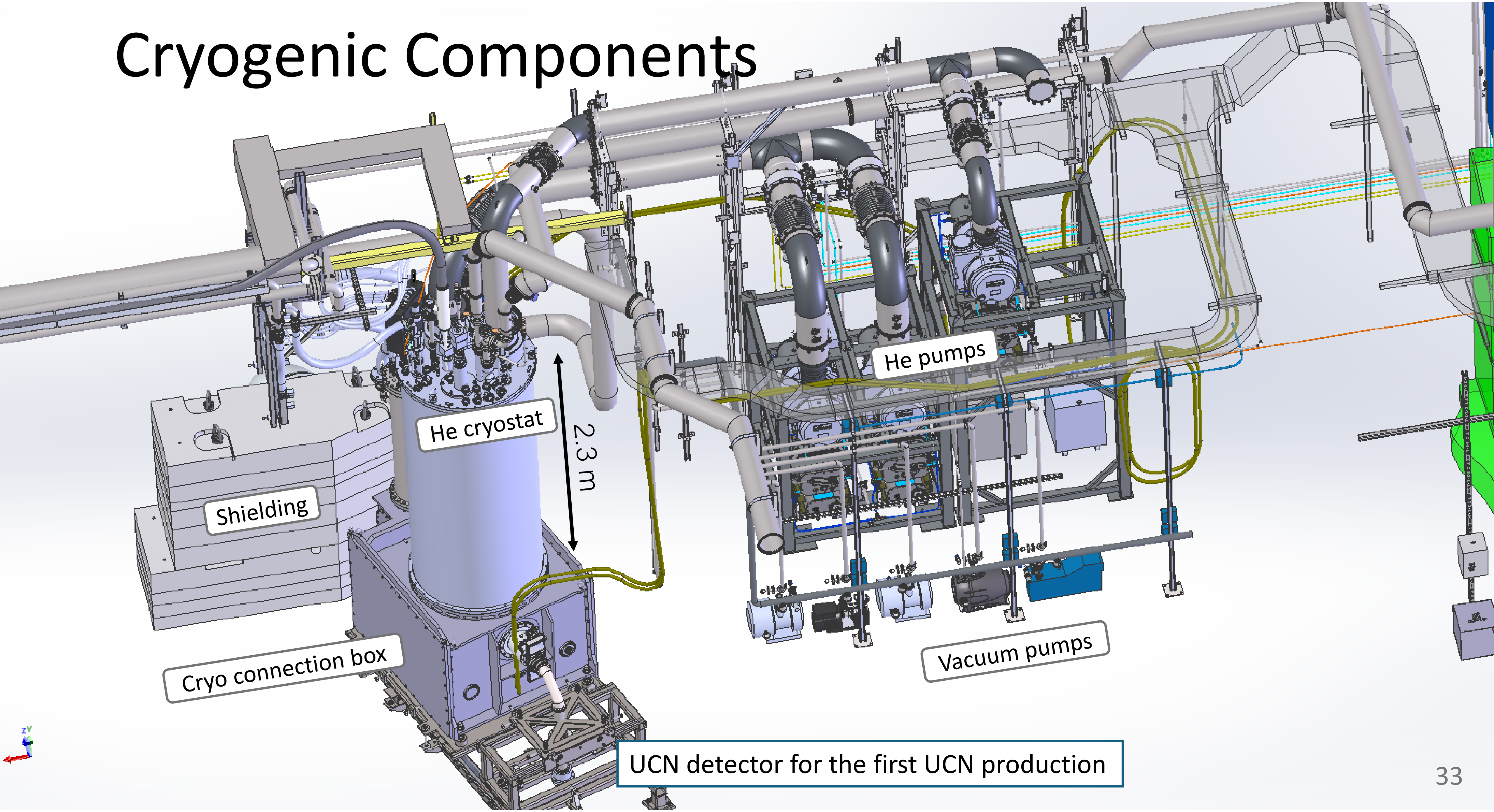
Helium cryostat installation on beamline





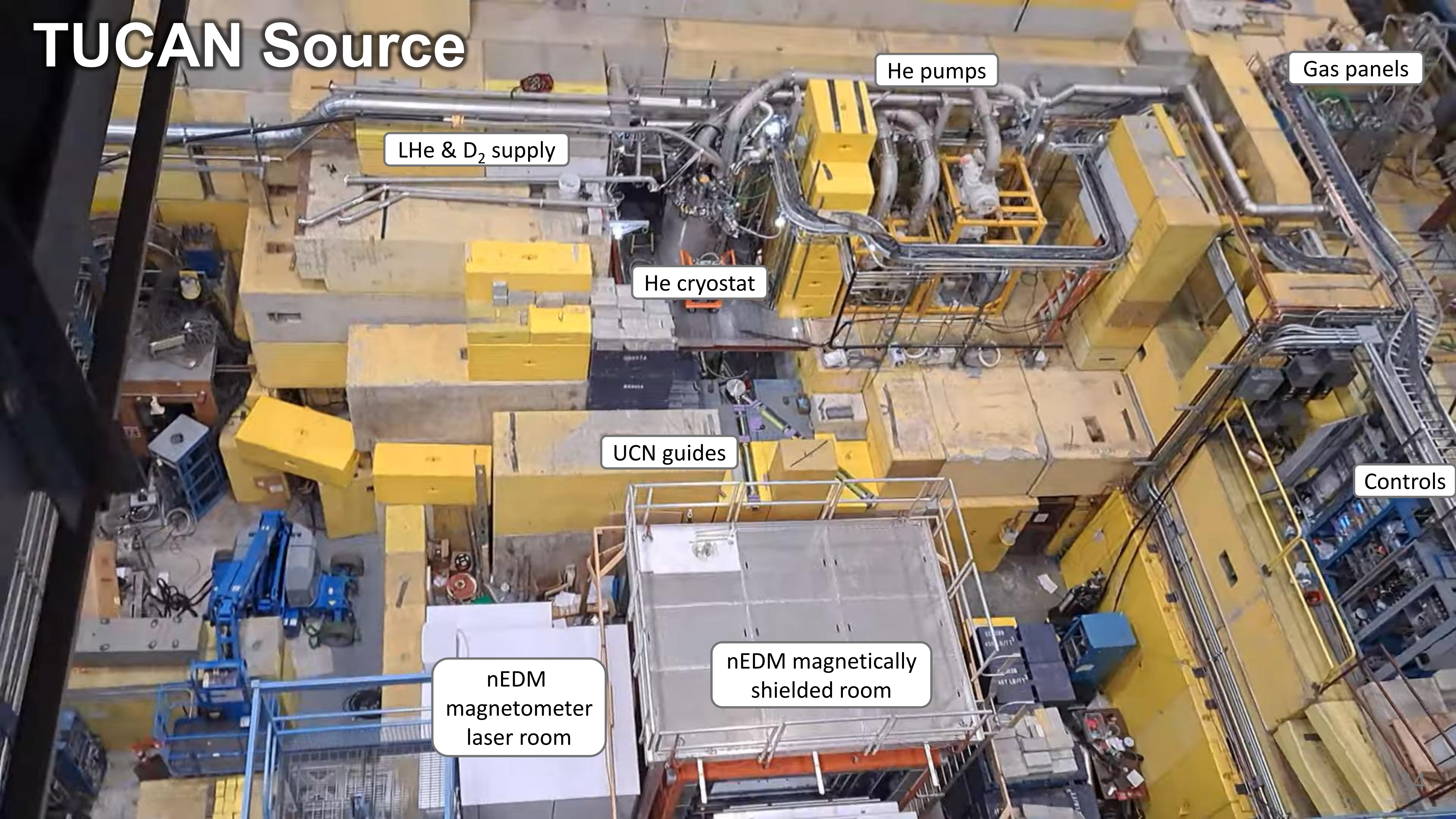
Helium cryostat installed at the beamline. Commissioning started. Cryogenic test with natural ^{4}He instead of ^{3}He was successful. The short HEX1 is used for the test.

Cryogenic Components



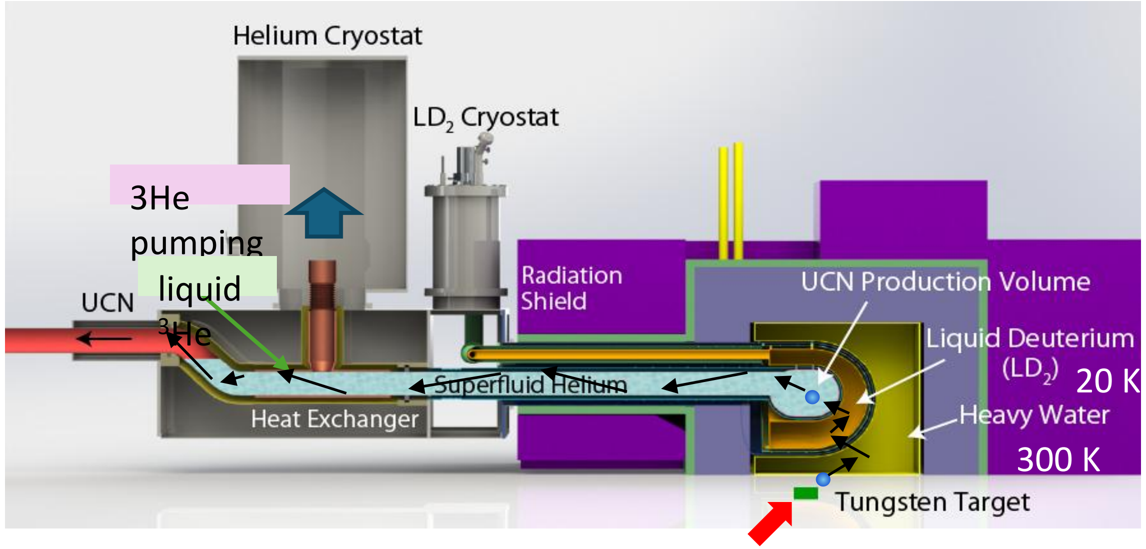
UCN detector for the first UCN production

TUCAN Source



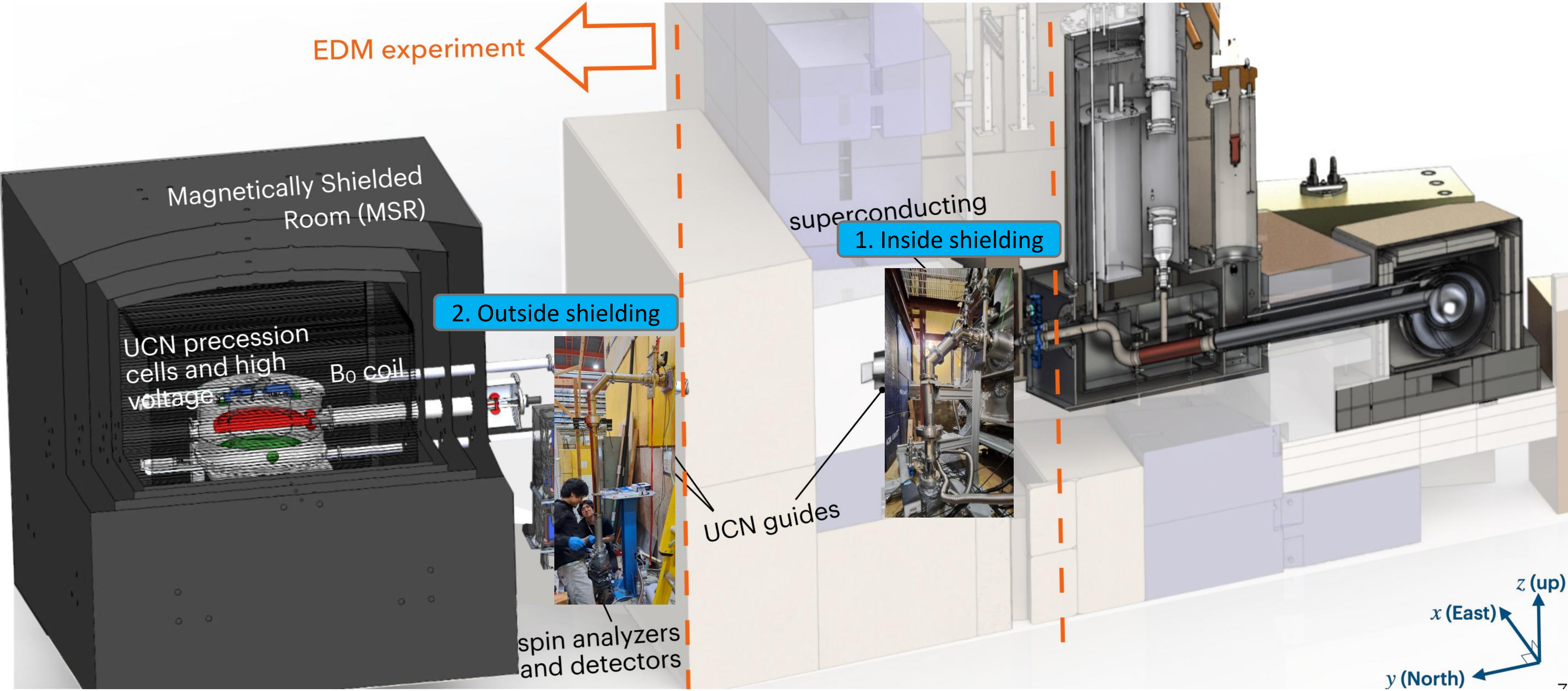
UCN source commissioning campaign

- 2023
  - Helium cryostat installation
  - Cryogenic tests using natural helium
- 2024
  - Cryogenic tests using helium-3
    - UCN converter temperature : 1.14 K
      - without beam
  - Proton beam commissioning up to 40 µA
  - install warm moderator (D_2O)
- 2025
  - June**: successful UCN production without LD_2 moderator**
  - November: **successful UCN production with LD_2 moderator**
- 2026
  - January: UCN storage tests in the EDM cell



proton beam (20 kW)

UCN experiments without LD_2

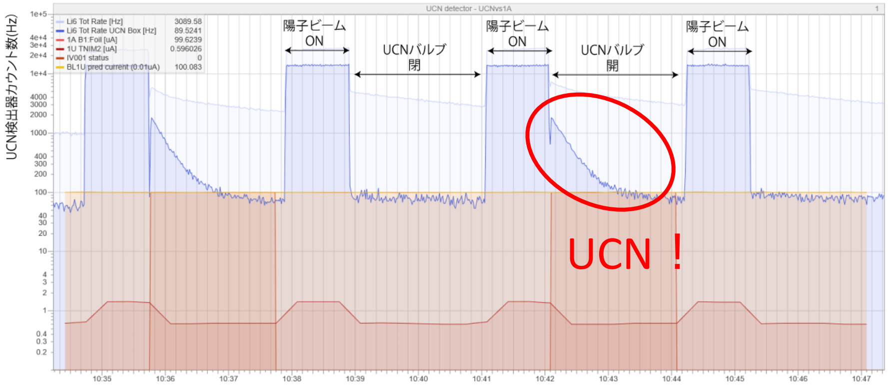


1. Inside shielding

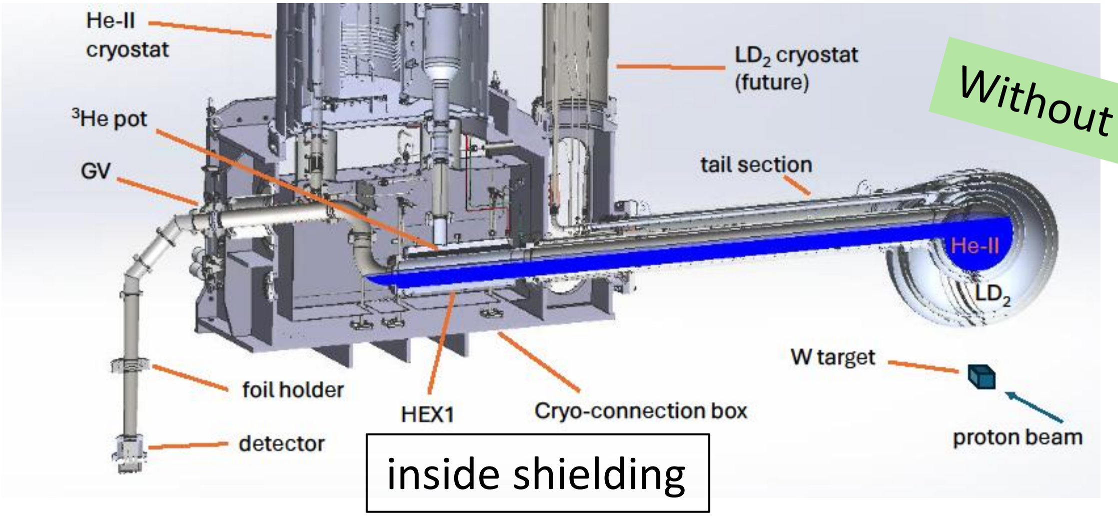
2. Outside shielding

First UCN Production without LD_2 moderator

- On June 13, 2025, the TUCAN collaboration successfully produced the first UCNs at the new UCN source!
  - **940,000 UCN counted** after 60s irradiation
    - Without LD_2 moderator
    - inside biological shielding
  - initial UCN production paper
    - Submitted
    - arXiv:2509.02916
      - Proton current vs. UCN yields
      - UCN lifetime in the source
        - Temperature dependence
      - Heating tests etc.

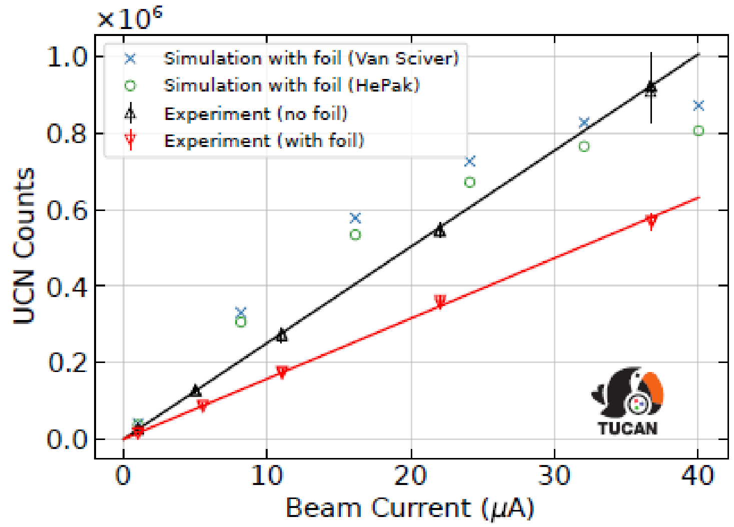


UCN !



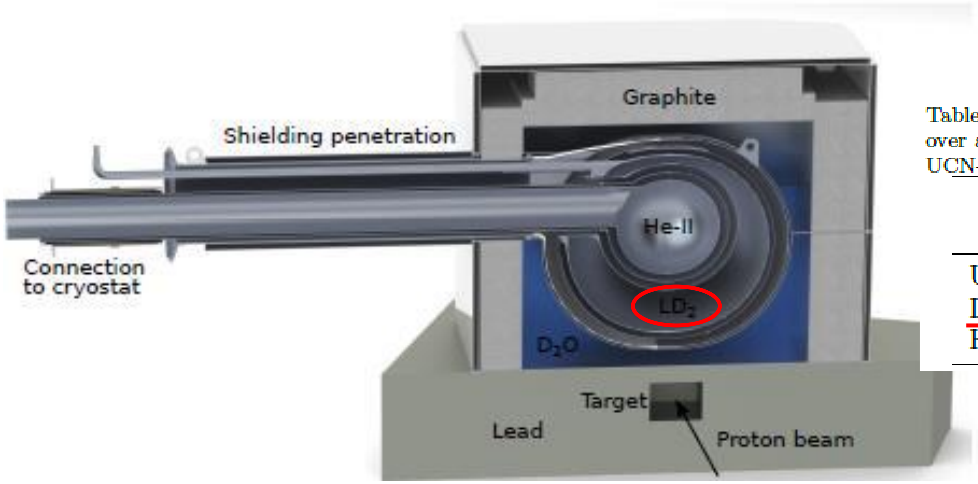
Without LD_2

inside shielding



Liquid Deuterium Moderator

- UCN is produced by down scattering of cold neutron by phonon in He-II
    - Resonant energy : 1 meV
- Cold neutron moderator
    - Cool down neutron by elastic scattering
    - increase ~ 30 times cold neutron flux
- LD_2 moderator is ready now



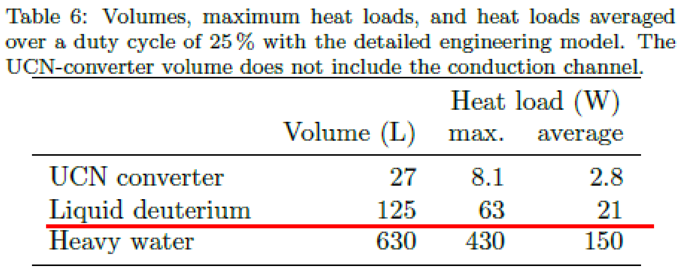
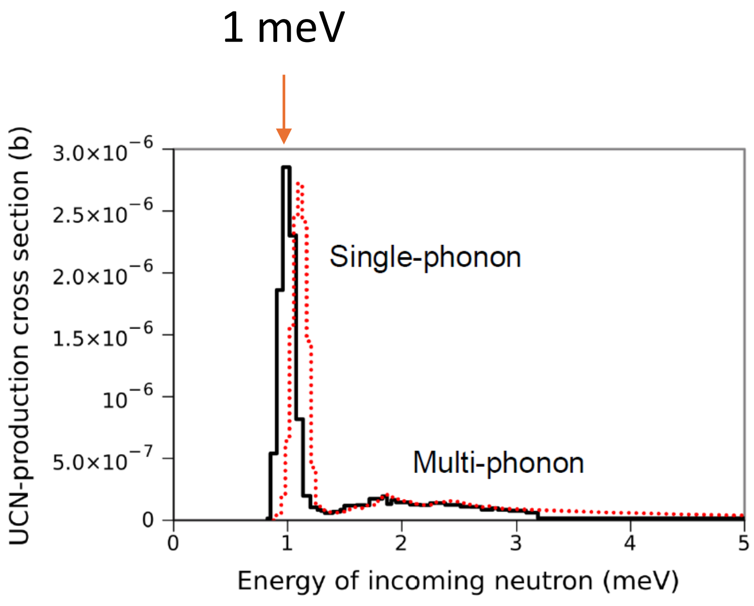


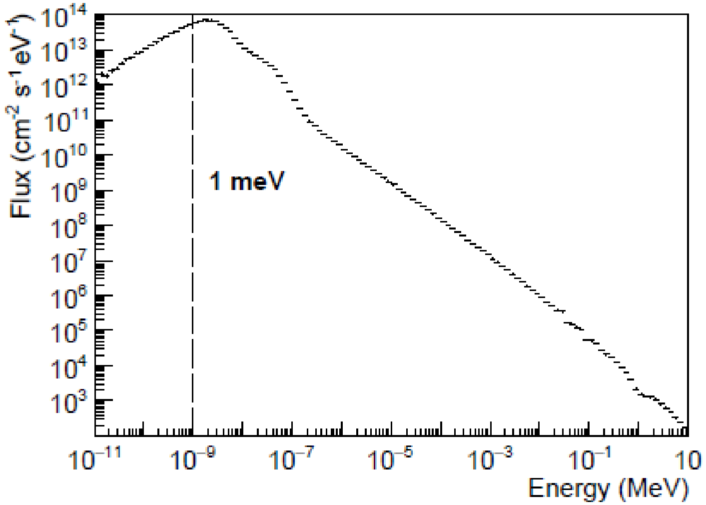
Table 6: Volumes, maximum heat loads, and heat loads averaged over a duty cycle of 25 % with the detailed engineering model. The UCN-converter volume does not include the conduction channel.

	Volume (L)	Heat load (W) max.	Heat load (W) average
UCN converter	27	8.1	2.8
Liquid deuterium	125	63	21
Heavy water	630	430	150



Schmidt-Wellenburg et al, 2009; Korobkina et al, 2002

UCN production cross section

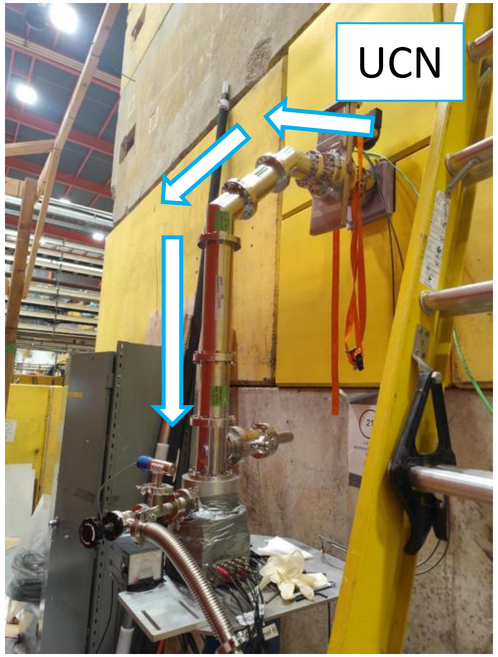


Neutron Spectrum

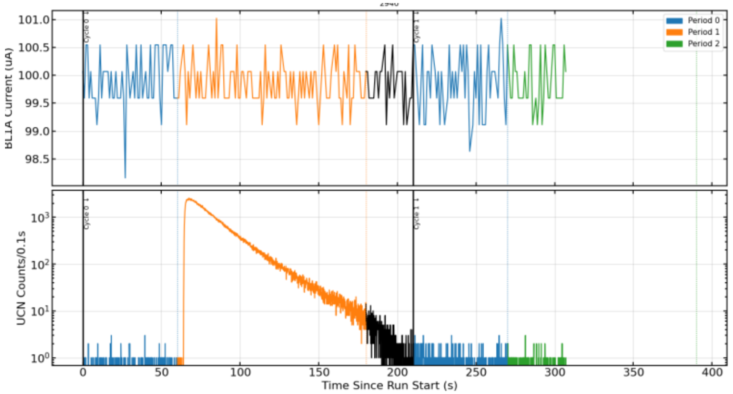
UCN production with the LD_2 moderator

- On December 12, the first UCN was produced with an LD^2 moderator.
- Achieved an improvement of factor ～20 in UCN yield compared to the configuration without LD_2
  - 1.3×10^7 UCN counted after 60s irradiation
    - at 26.6 μA
    - outside biological shielding
  - consistent with MC simulation
    - cold neutron flux gain, extracted loss
- Lots of experimental programs were conducted
  - UCN yield vs. proton current (up to 33 μA) for both batch and continuous mode
  - TOF flight measurement with a chopper to estimate UCN velocity distribution
  - Au foil activation measurement to estimate cold neutron flux
  - $CF_4 + {}^3He$ detector test and so on

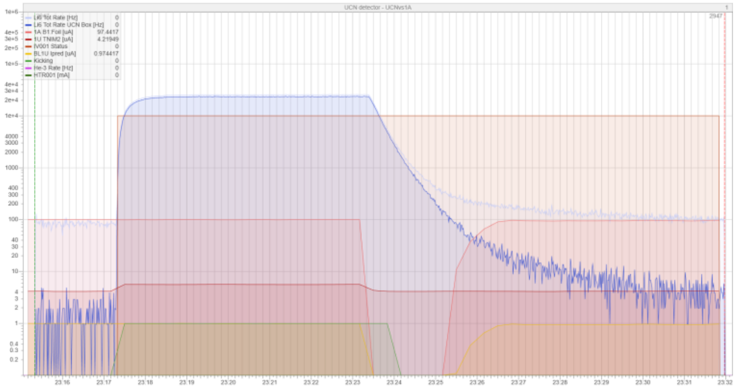
outside shielding



UCN detector outside of the radiation shield



UCN yield for batch mode
500,000 UCN/batch fat 1μA operation

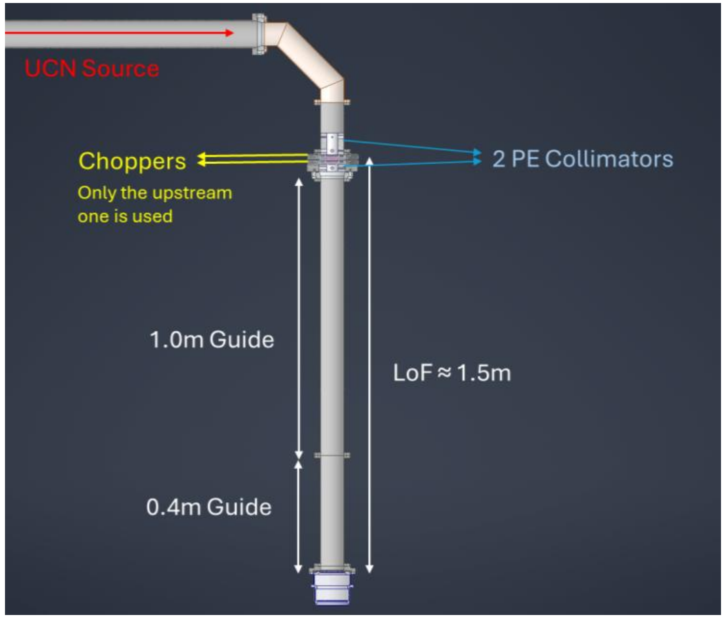


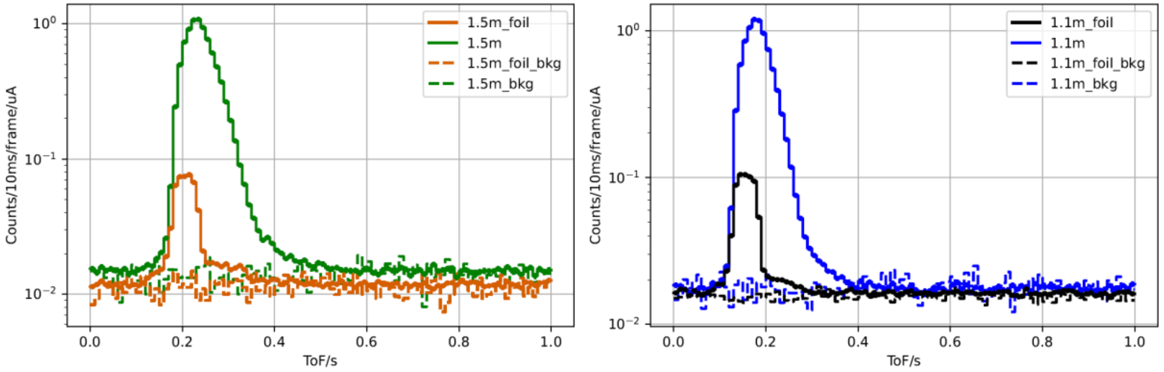
UCN yield for continuous mode
230,000 UCN/s at 1μA operation

UCN time-of flight measurements

Kelin Quao (RCNP)

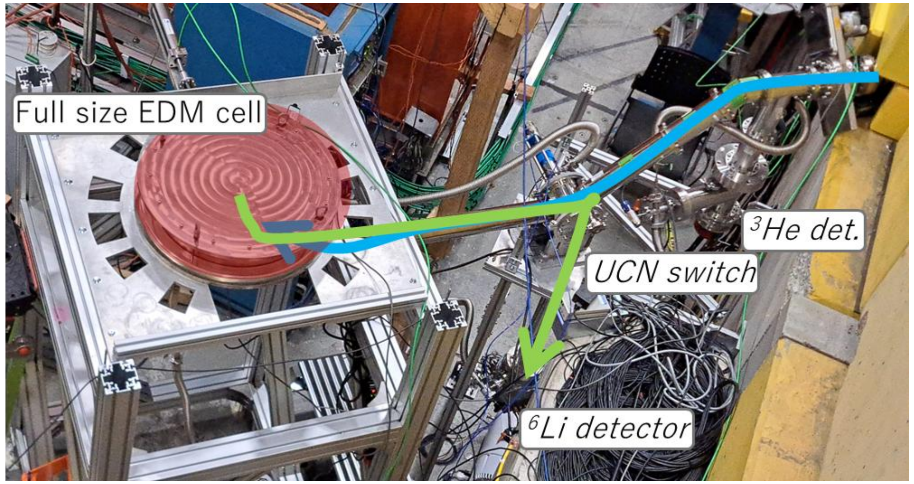
- UCN time of flight (TOF) spectrum was measured in Dec. 2025 and Jan. 2026
- Setup
  - Chopper
  - time of flight length: 1.1 m or 1.5 m
- The setup is stable and yields consistent data.
- Future analysis is ongoing

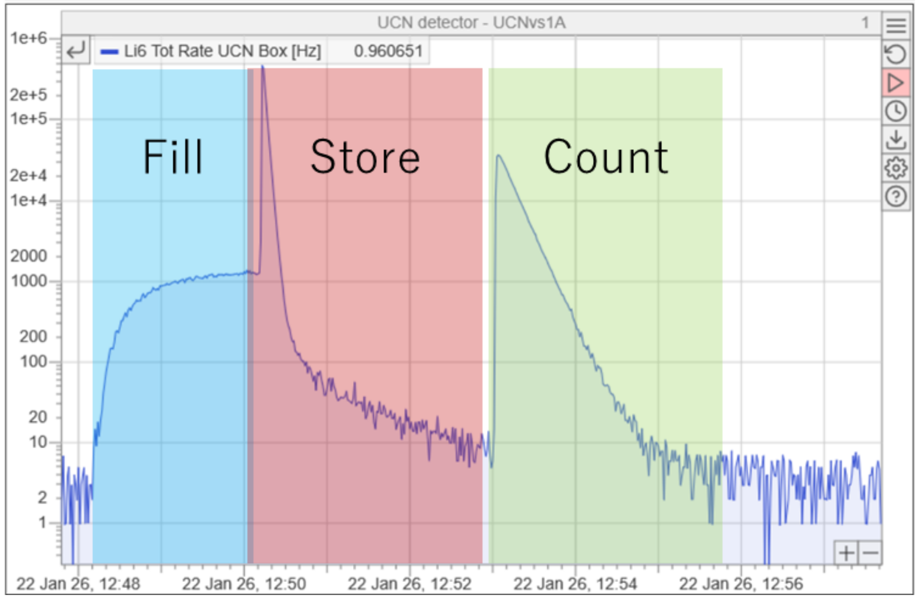




Time of Flight spectrum

UCN storage test





Evaluation of UCN density in a full-scale storage cell

- Experimental Condition:
  - 2nd port of the UCN source
    - 1st port: Magnetic Shile Room located
  - Storage Cell Volume: 25.2 L
  - Unpolarized UCN
  - Storage Time: 170
- Measured UCN Density (Preliminary)
  - Measured UCN density at the cell:
    - **21 UCN/cm^3** @ 26.6 uA (Proton beam current)
    - **29 UCN/cm^3** @ 40.0 uA (Proton beam current)

      Note: These values are preliminary; detailed analysis is currently ongoing.
- Current Setup & Constraints
  - UCN Transport System:
    - Non-final configuration (includes narrower sections)
    - Ongoing development: New DLC-coated UCN guides are being fabricated to optimize transport efficiency.
  - UCN Converter:
    - Current He-II volume is at 85% of full capacity.

Timeline and Expected sensitivity

- Timeline
  - UCN Production in 2025/2026
  - TRIUMF shutdown in 2026
  - nEDM measurement will start in 2027
- Expected sensitivity (statistics only)

UCN production rate	2×10^{7} UCN/sec
UCN density @ production	6,400 UCN/cm^3
UCN density @ nEDM cell	250 Pol. UCN/cm^3

$$\sigma_d = \frac{\hbar}{2\alpha E t_c \sqrt{N}}$$

E = 10kV/cm
t_c = 130s
α = 0.8 (visibility)

N : # ofUCN
cell ϕ 36 cm × H 15 cm (15L)×2 cell
N = 7.8×10^{6} UCN/batch

To reach statistic sensitivity of $\sigma_d = 1\times10^{-27}$ ecm

400 day(MT)

(1 cycle : 8 fill to determine the resonant frequency)
assume stable running of 14 hours/day

Summary

- UCNs are powerful tool for fundamental physics experiments
    - neutron lifetime, gravity, n-nbar oscillation, etc
- nEDM is the a good probe for beyond standard model physics
    - nEDM violates time reversal symmetry (= CP violation)
        - CP violation is the key of current matter dominant universe
- TUCAN
    - Goal
        - Construct the world's most intense Ultra Cold Neutron source
        - To search the neutron electric dipole moment down to 10^{-27} $e{\cdot}cm$
    - UCN production succeeded in 2025/2026
        - Detailed analysis is still underway, but the performance is consistent with our predictions.
    - nEDM experiment will start in 2027