

The TUCAN Source Commissioning and First Results

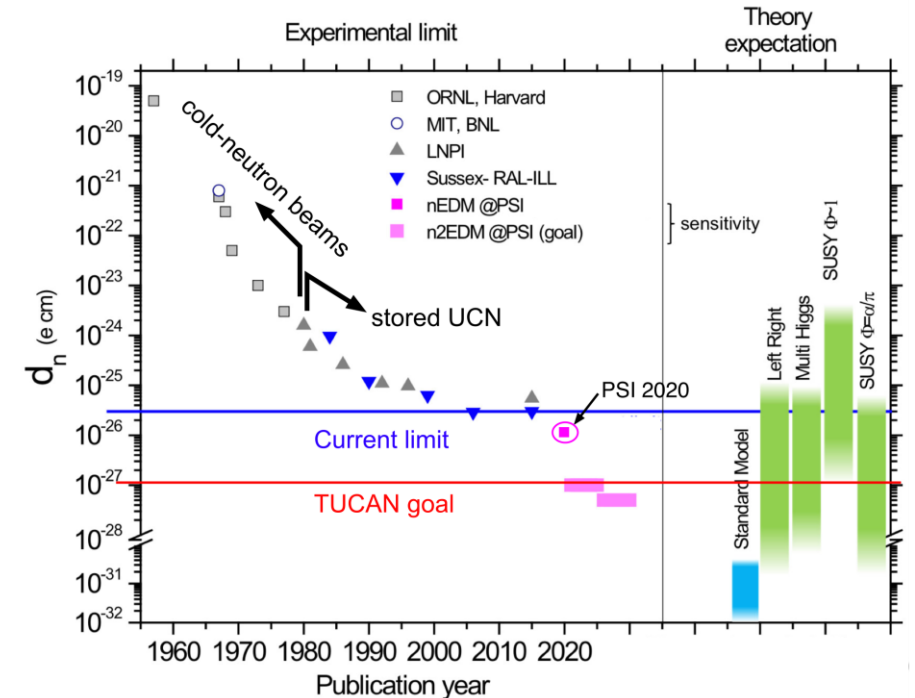
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for the TUCAN Collaboration



Improving nEDM Sensitivity

- Current upper limit (PSI, 2020)
 - $d_n = (0.0 \pm 1.1_{\text{stat}} \pm 0.2_{\text{sys}}) \times 10^{-26} \text{ e} \cdot \text{cm}$
 $\rightarrow |d_n| < 1.8 \times 10^{-26} \text{ e} \cdot \text{cm} (90\% \text{C. L})$

limited by statistical uncertainty



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)

Approaches to Reducing Statistical Uncertainty

1. Increase the size of the measurement cell
 - This is the approach of PSI's next experiment (n2EDM)
 - Cell diameter: **47 cm $\rightarrow$ 80 cm**
 - Challenge: maintaining magnetic field uniformity in a larger cell
2. Increase the UCN density
 - Develop a high-intensity UCN source.
 - UCN density: $\sim 1 \text{ UCN/cm}^3$ (PSI) $\rightarrow$ target of **200 UCN/cm³ (TUCAN)**

TUCAN Source



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 $10^{-27} \text{ e}\cdot\text{cm}$

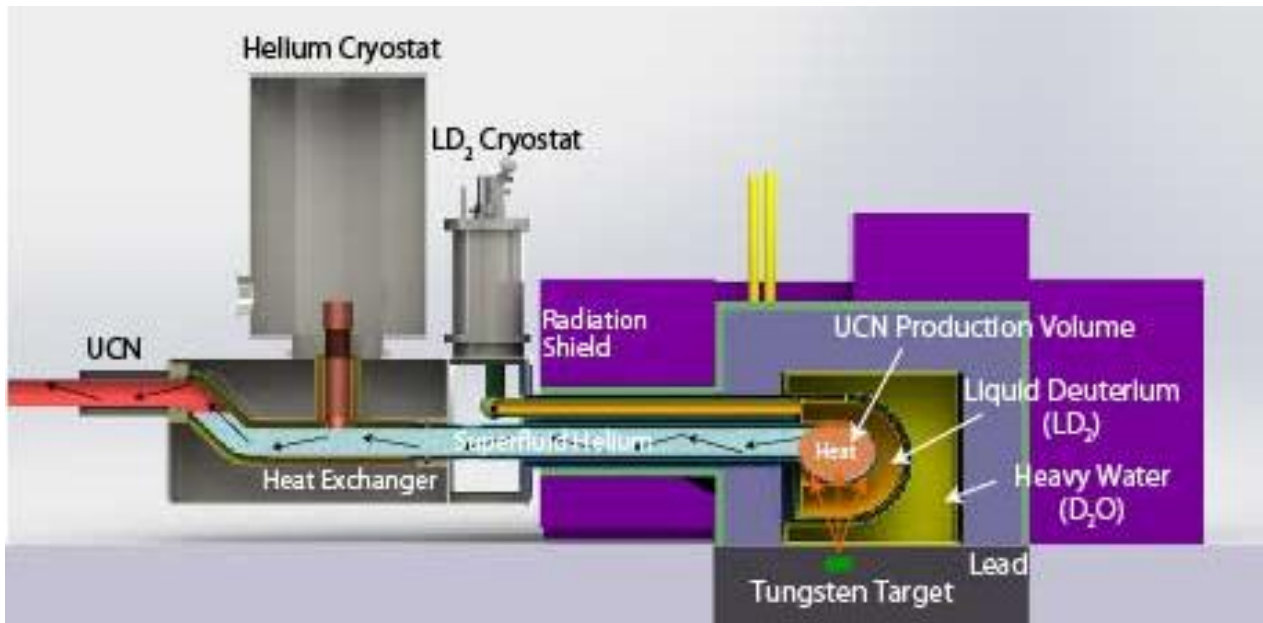
Expected performance

UCN Source

- Production rate $1.4 \times 10^7 \text{ UCN/sec}$
- Source storage lifetime 28 sec
- UCN density in the source $3 \times 10^3 \text{ UCN/cc}$
- Total number in the source $3 \times 10^8 \text{ UCN}$

EDM measurement

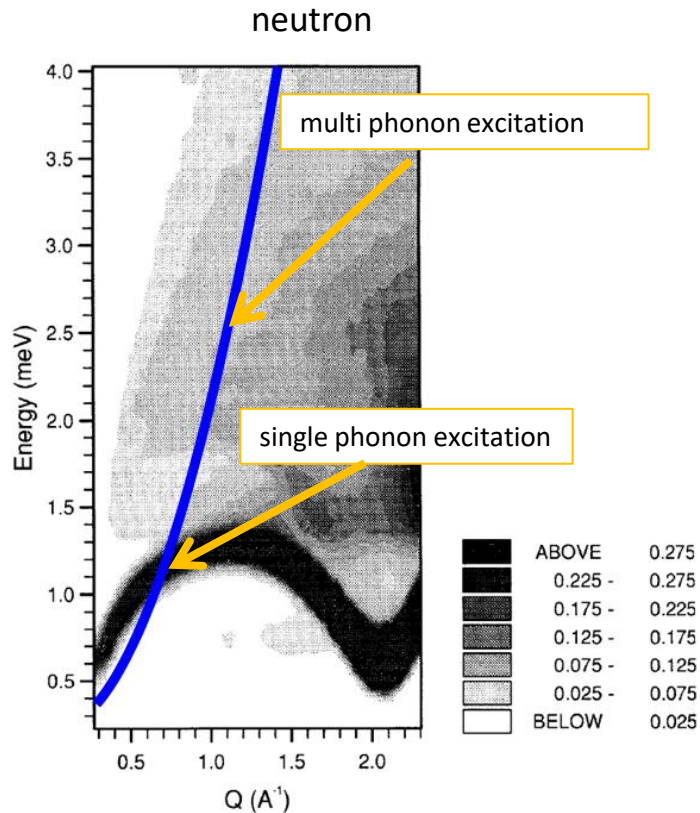
- Initial density in EDM cell 200 Pol. UCN/cc
- To reach statistical sensitivity of $\sigma_d = 10^{-27} \text{ ecm}$
 400 MT day



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

UCN production by super-thermal method

- phonon excitation in super-fluid He (He-II)
- 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

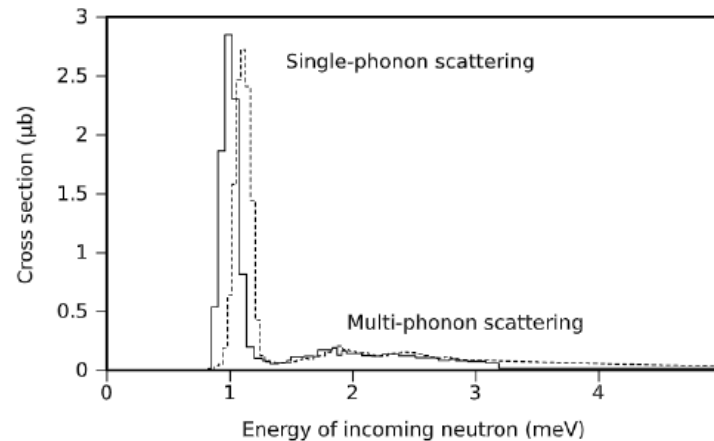


Fig. 1. Cross sections for production of ultracold neutrons with energies up to 233.5 neV in superfluid ⁴He, calculated from [27] (solid line) and [28] (dashed line).

UCN Production cross section
 $\sim 2.8 \mu\text{b}@1\text{meV}$
 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)

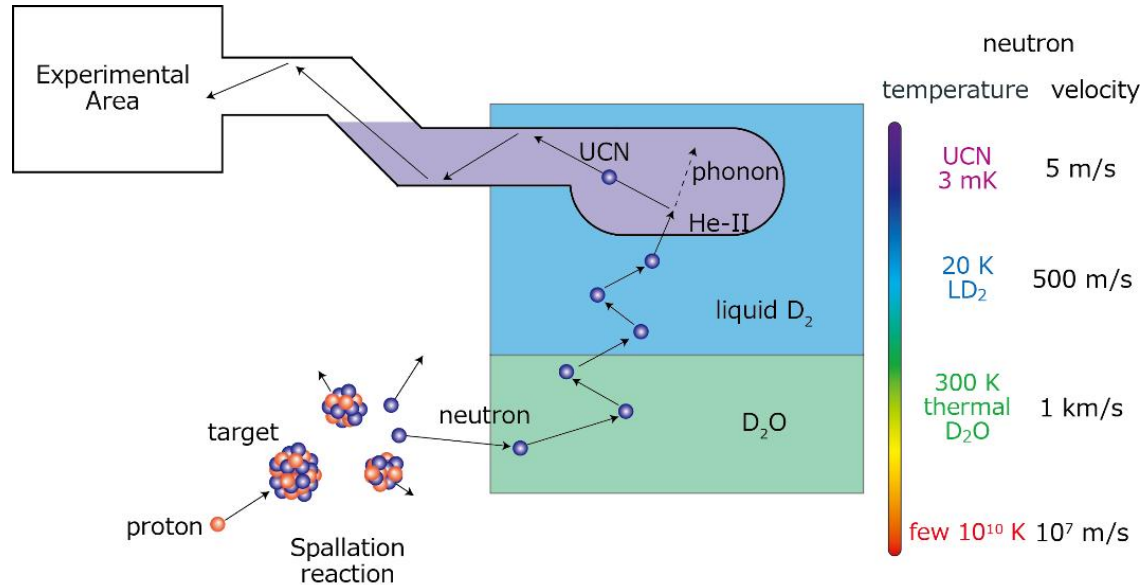
1 meV

UCN Production rate

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

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

TUCAN UCN source



UCN production

spallation neutron MeV
 ↓ D₂O 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 (He-II)

long storage lifetime

up-scattering by phonon

$$\tau_s \propto 1/T^7$$

$$\tau_s = 36 \text{ s at } T_{\text{HeII}} = 1.2 \text{ K}$$

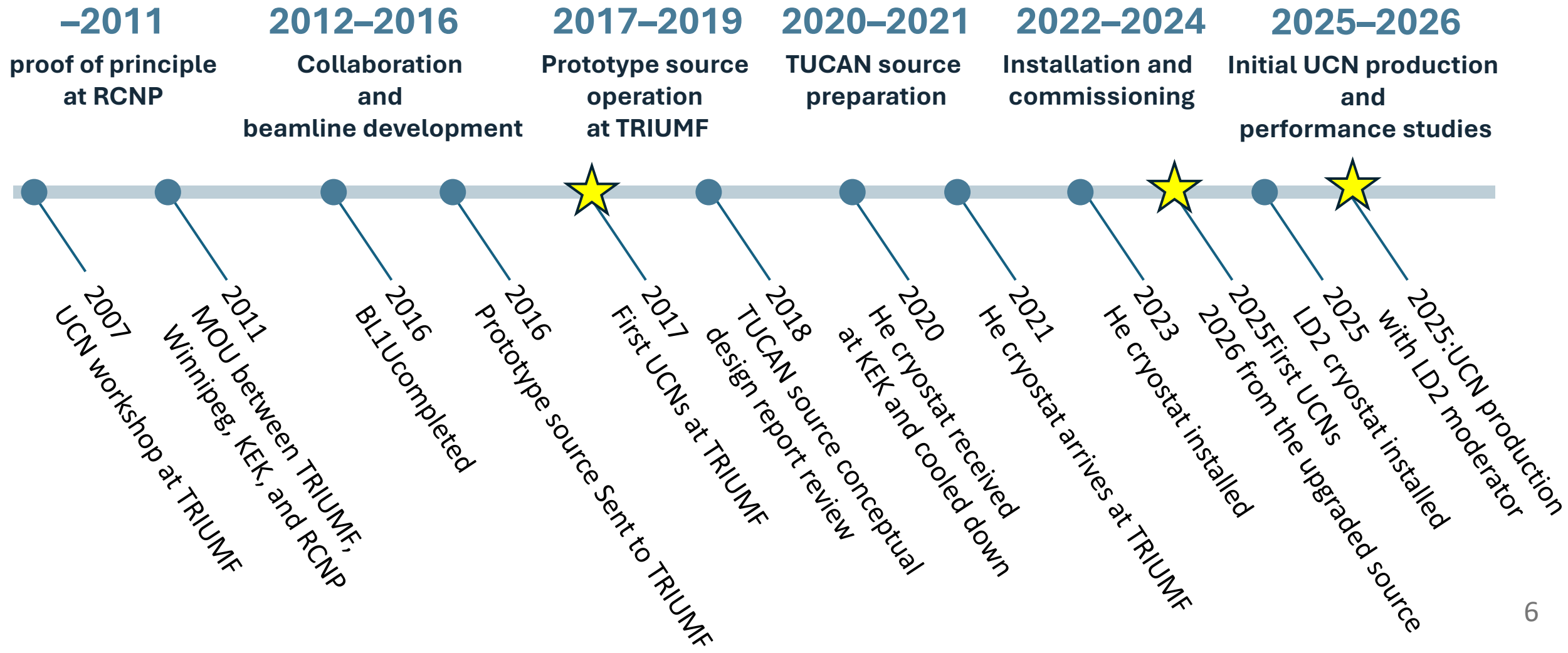
$$\tau_s = 600 \text{ s at } T_{\text{HeII}} = 0.8 \text{ K}$$

(Cf. SD₂ : T_s = 24ms)

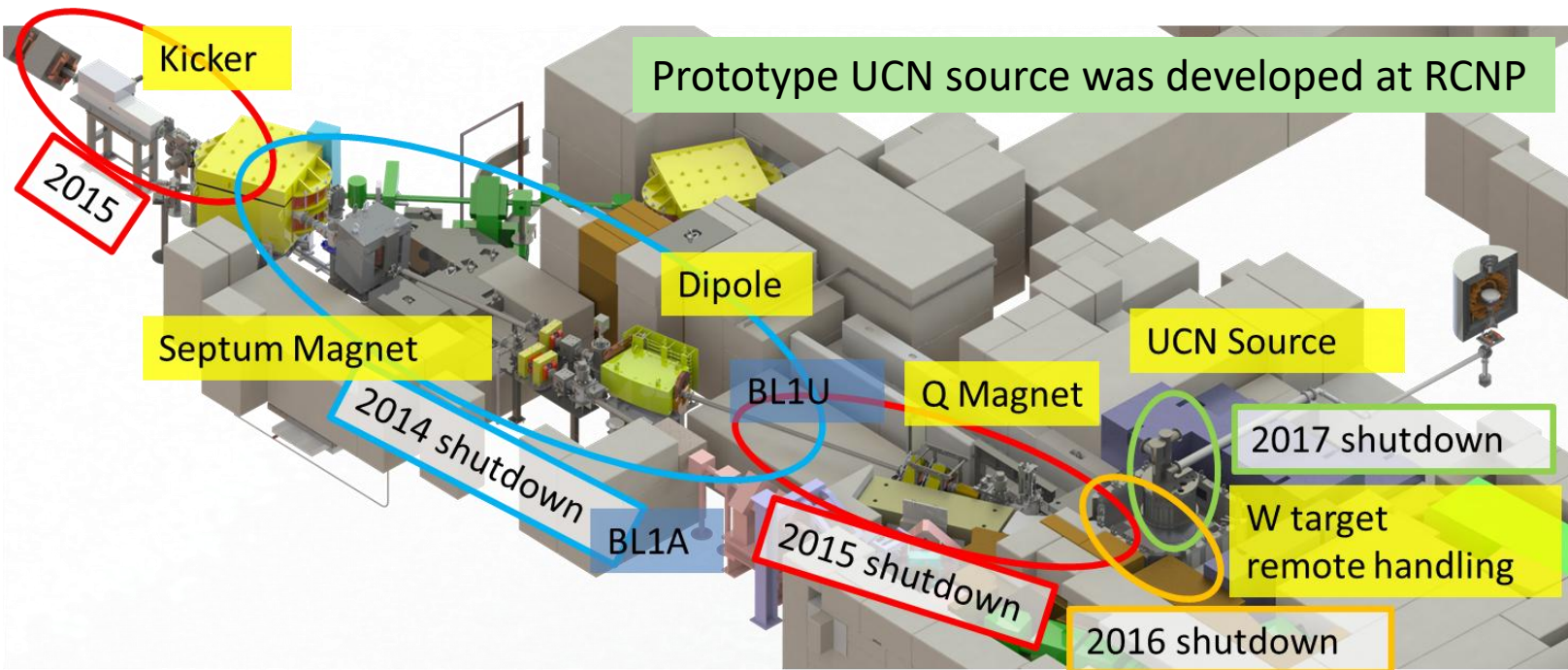
Challenge

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

History of the UCN source development



Prototype UCN Source @ TRIUMF



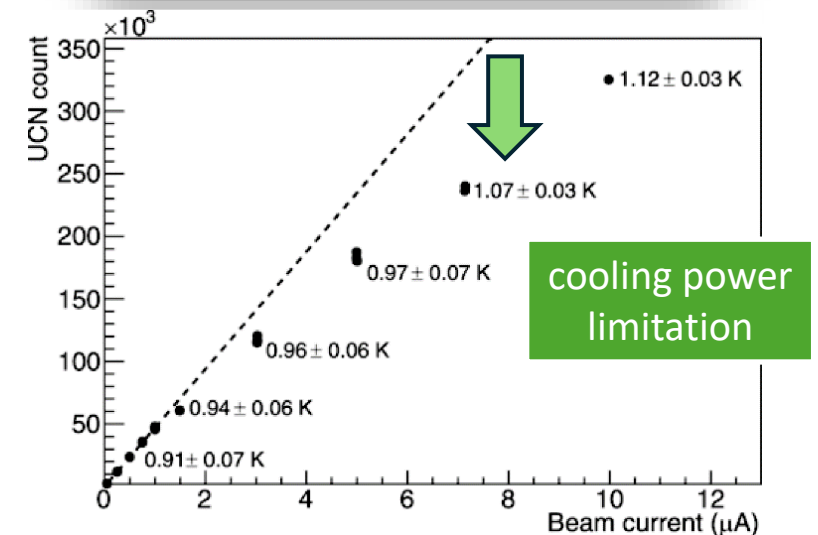
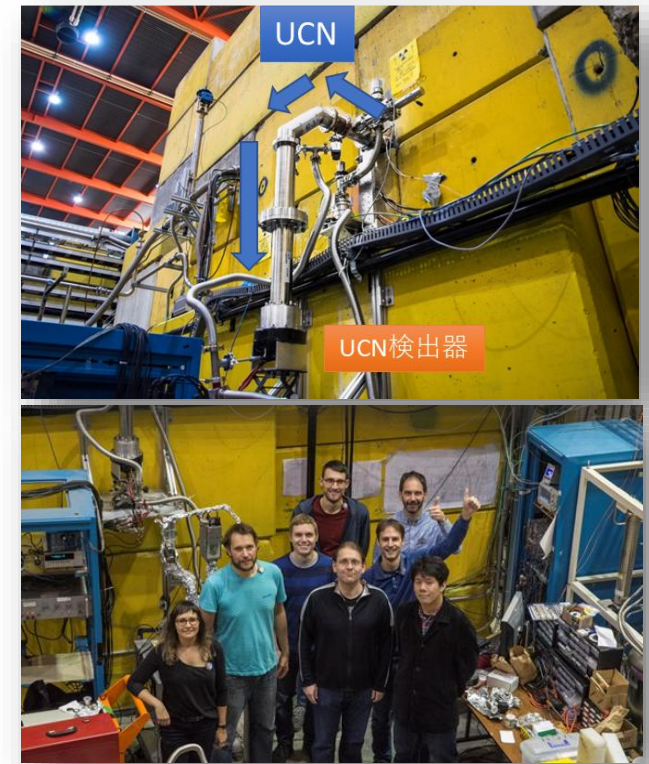
Major Milestone

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

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 μ A
 $> 3 \times 10^5$ at 10 μ A
 UCN lifetime : 35 sec
 (81 sec at RCNP)



UCN yield dependence on proton current 7

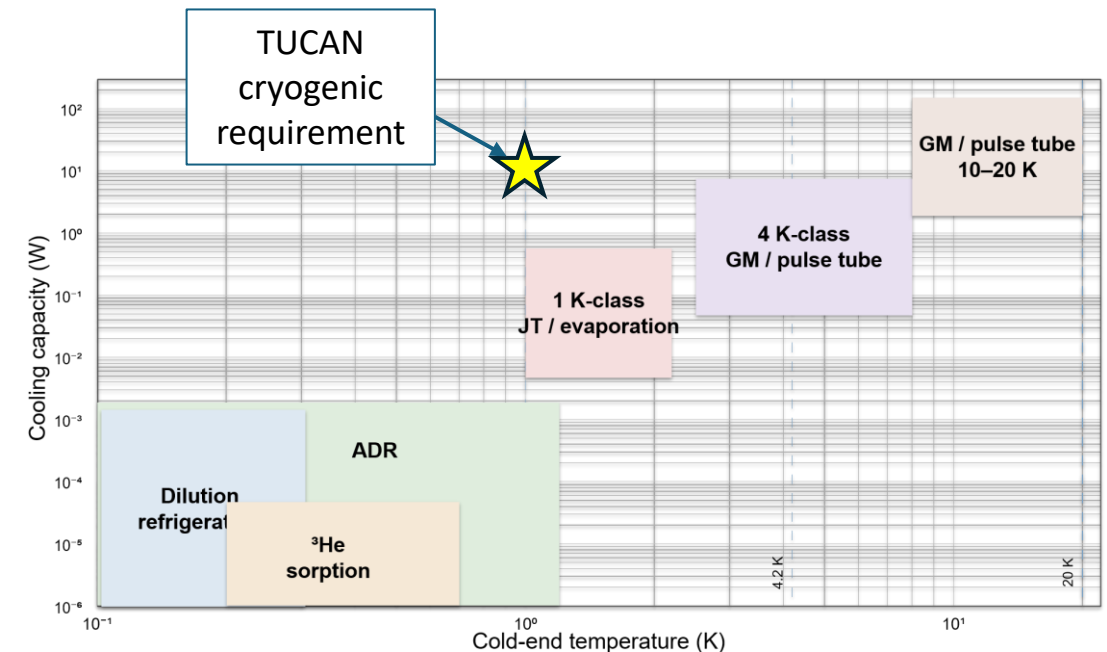
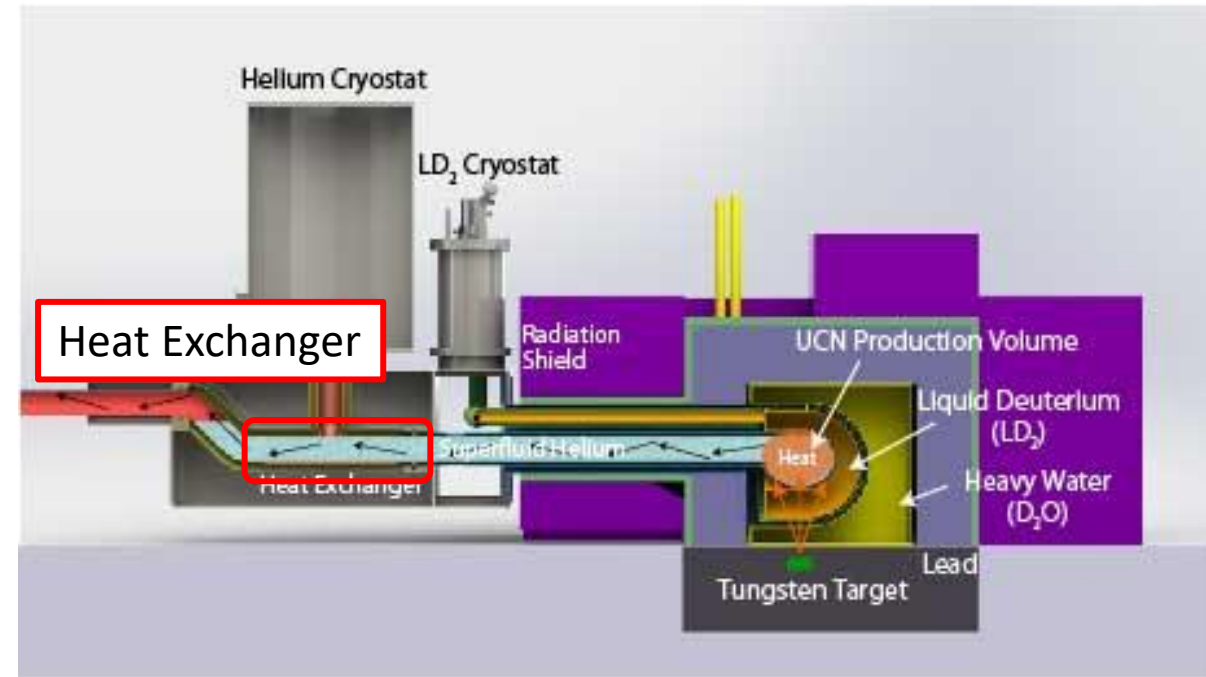
TUCAN source

TUCAN source

- Combination of spallation neutron source and superfluid helium (He-II) UCN converter
- Challenge: maintain superfluid helium at ~ 1.0 K

Cryogenic Requirements

- Handle a heat load of **9.6 W**
 - 8.1 W (beam) + 1.5 W (static)
- Keep the He-II temperature at **~ 1.0 K**
- Heat exchanger
 - Integrated into the UCN guide
 - Should be UCN friendly
- ^3He cryostat temperature at **0.8 K**
- Liquid ^4He consumption < **40 litter/hour**
- Helium cryostat must be located outside of the biological shielding

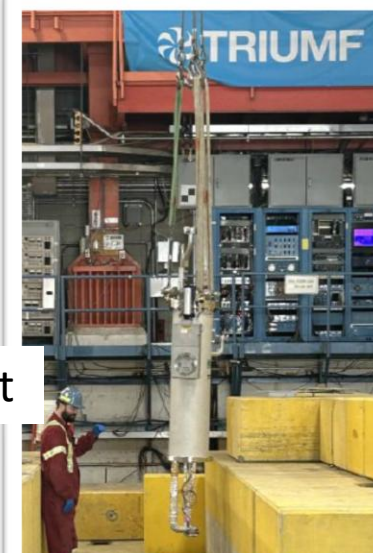
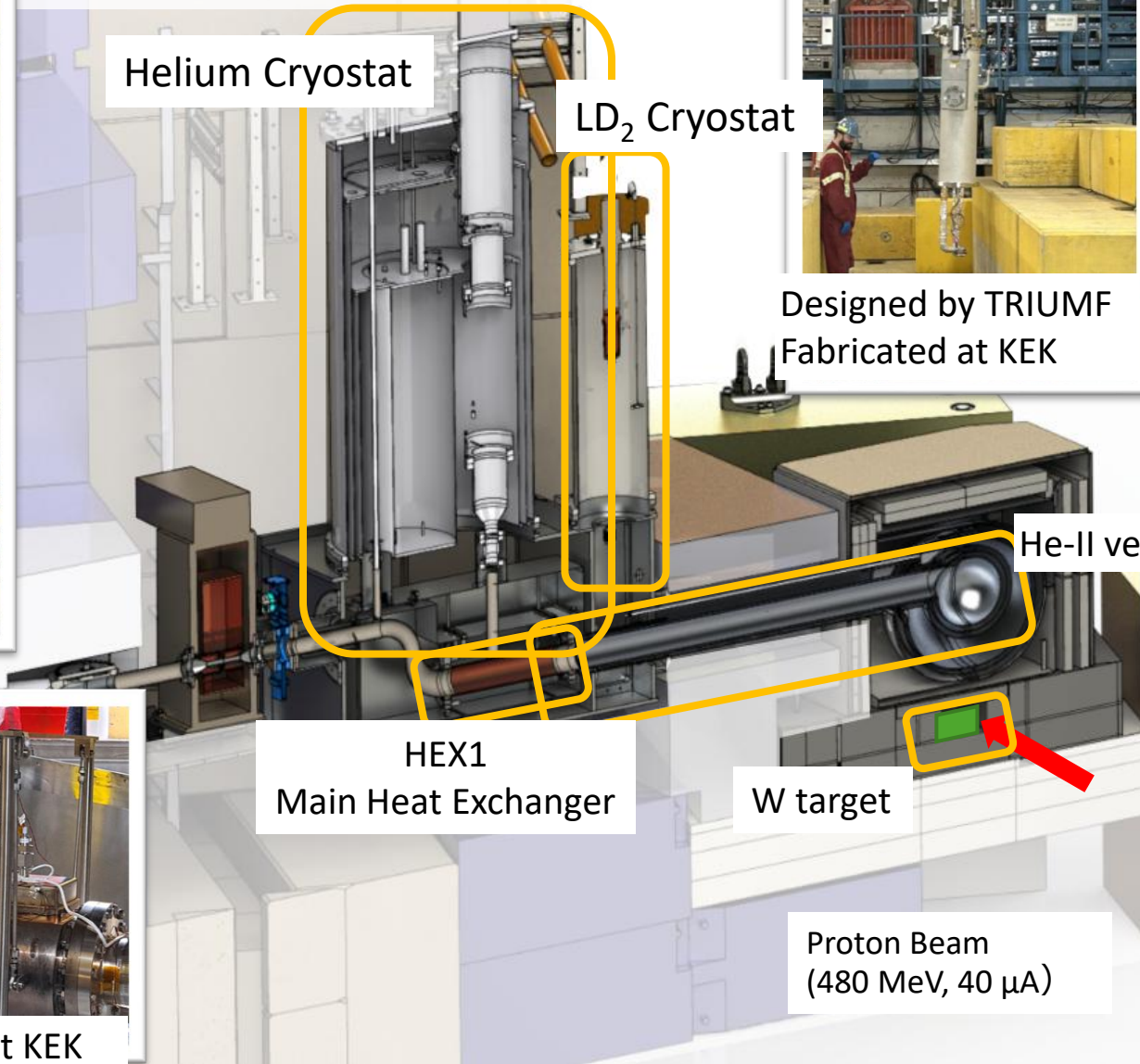


A dedicated high-power cryogenic system is required

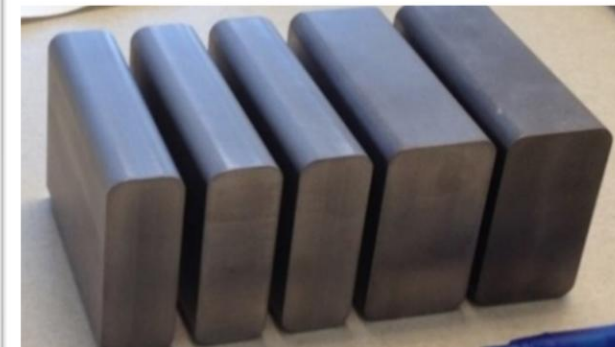
UCN Source Development



Developed at KEK



Designed by TRIUMF
Fabricated at KEK



Tantalum-clad tungsten target
Developed at RCNP



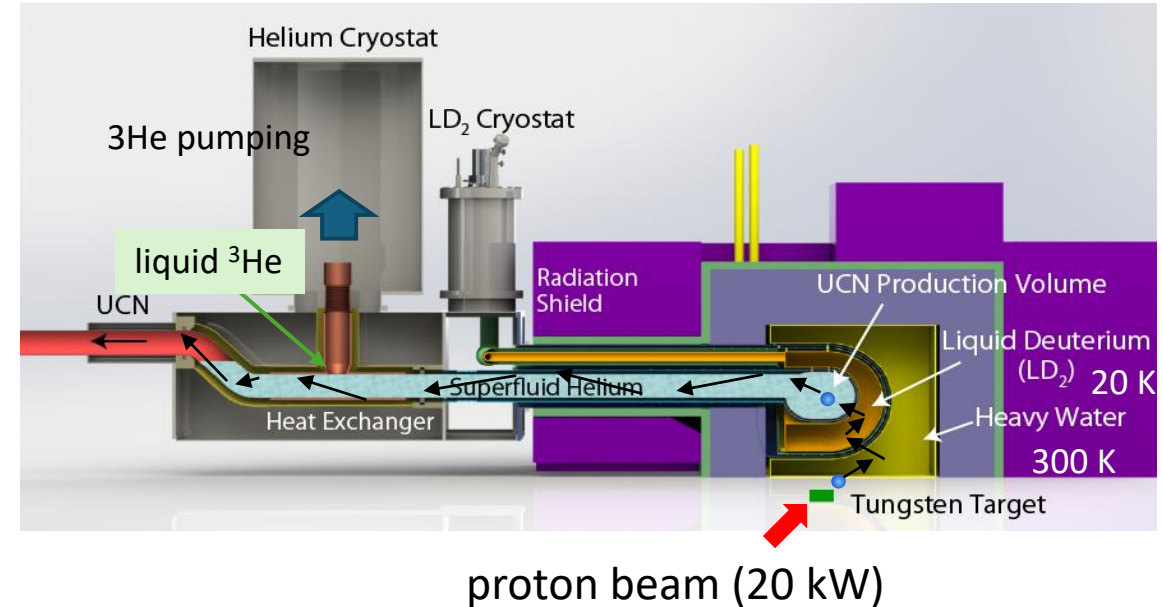
Developed at KEK



Developed at TRIUMF

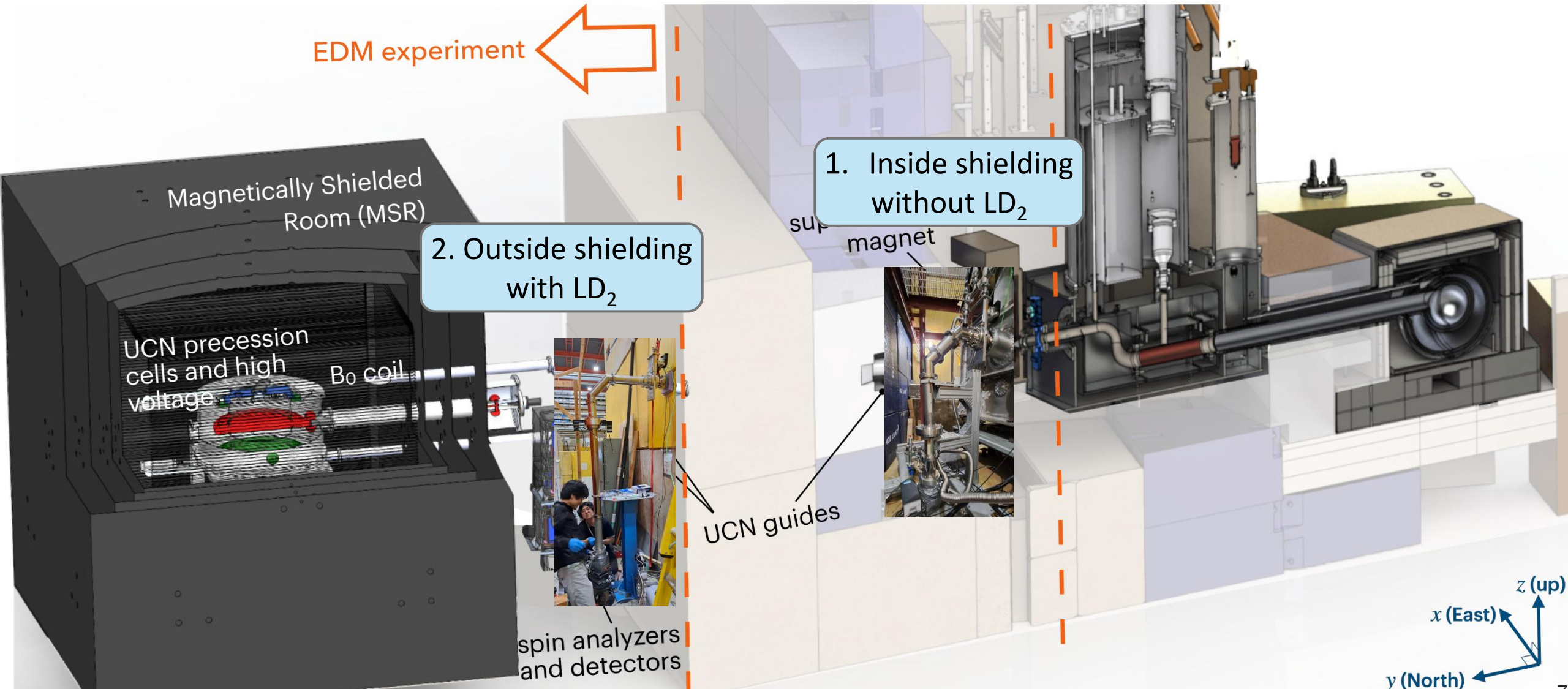
UCN source commissioning campaign

- 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**
 - Install LD_2 cryostat
 - December: **successful UCN production with LD_2 moderator**
- 2026
 - January: UCN storage tests in the EDM cell



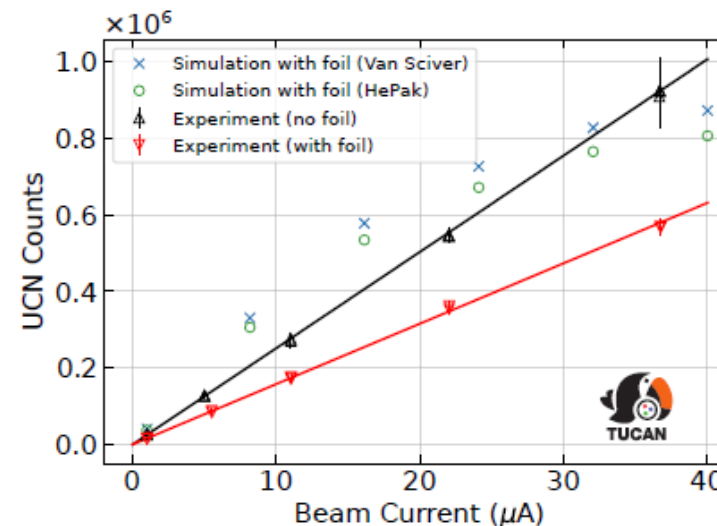
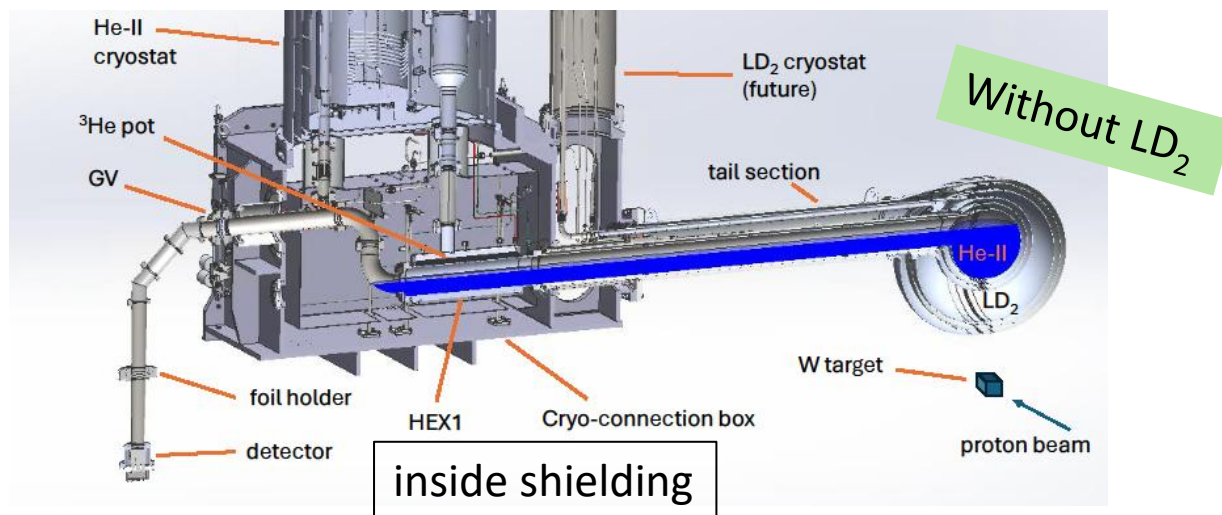
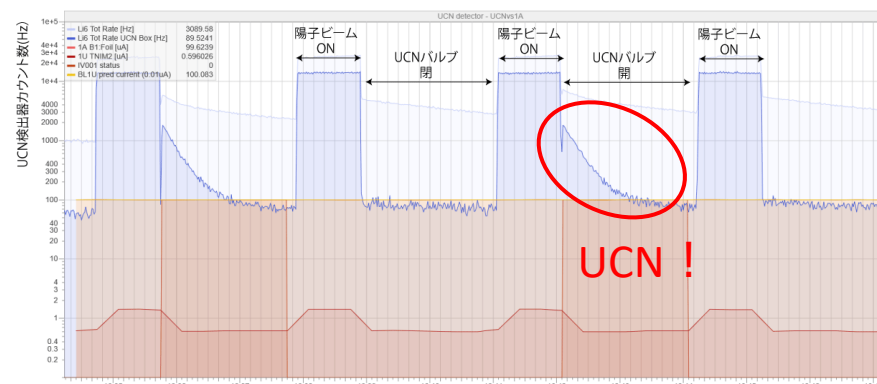
UCN production

EDM experiment



First UCN Production without LD₂ 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 LD₂ moderator
 - inside biological shielding
 - initial UCN production paper
 - [Phys. Rev. C **114**, L012501 \(2026\)](#)
 - Proton current vs. UCN yields
 - UCN lifetime in the source
 - Temperature dependence
 - Heating tests etc.



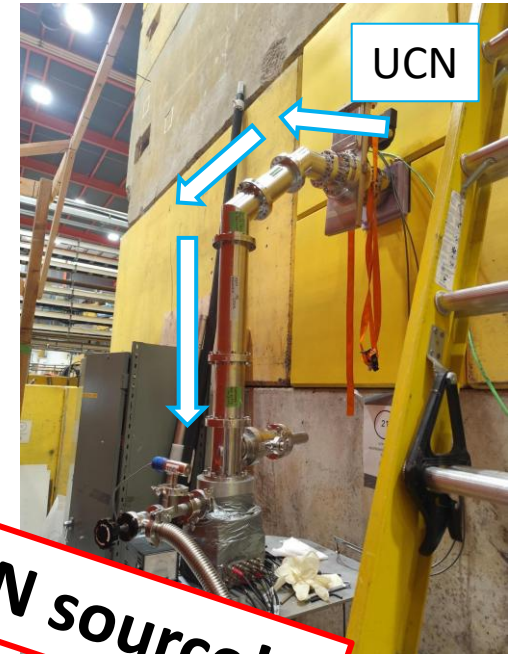
UCN production with the LD₂ moderator

- On December 12, 2025, the first UCN was produced with an LD² moderator.
- Achieved an improvement of factor ~ 20 in UCN yield compared to the configuration without LD₂
 - Batch mode: 7 UCN counted after 60s irradiation
 - Continuous mode: 23,000 UCN/sec
 - at proton current of 20 μ A
 - outside biological shielding
 - consistent with MC simulation
 - cold neutron flux gain, extracted loss

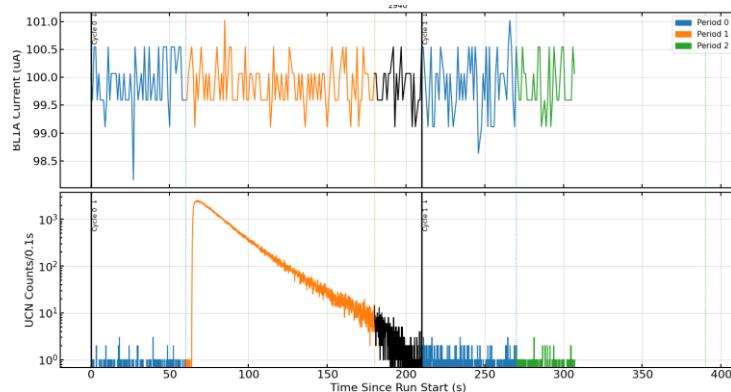
We have obtained the world's highest-Intensity UCN source!

[arxiv: 2512.08417](#)

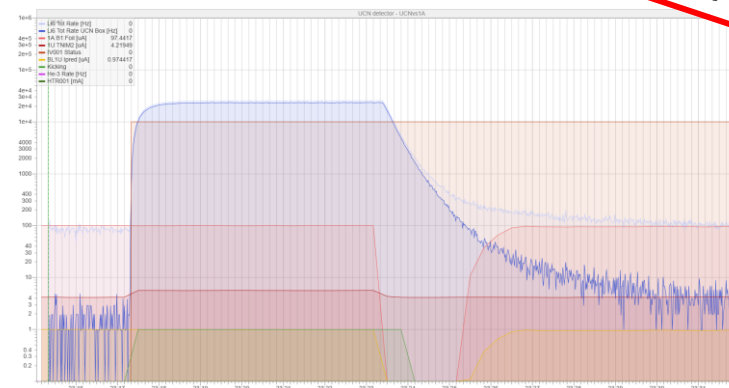
outside shielding



UCN detected outside of the radiation shield

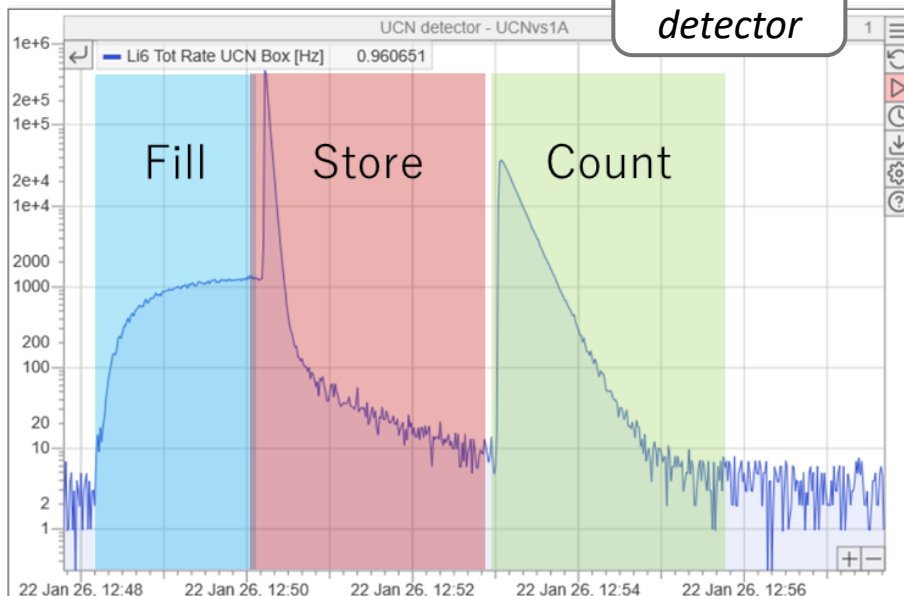
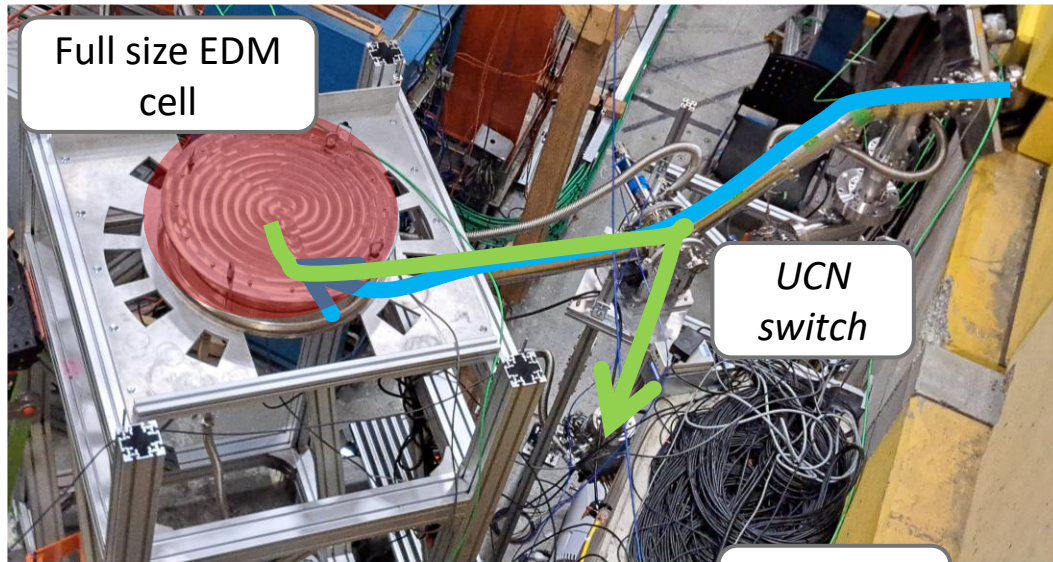


UCN yield for batch mode
 $\sim 500,000$ UCN/batch at 1 μ A operation



UCN yield for continuous mode
 $\sim 23,000$ UCN/s at 1 μ A operation

UCN storage tests



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 sec.
- Measured UCN Density (Preliminary, Un-Polalized)
 - Measured UCN density at the cell:
 - **21 UCN/cm³ @ 26.6 uA** (Proton beam current)
 - **29 UCN/cm³ @ 40.0 uA** (Proton beam current)
 - **one order of magnitude larger than previous experiment!** ($\sim$ few UCN/cm³)
- More improvements
 - 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.

Helium Liquefier upgrade

Current situation

- Consumption of UCN source during last runs was 36 - 38 l/h for a beam duty cycle of 8.3% at 40 μ A
- CMMS uses around 10 – 15 l/h when operational
- Best LHe production run so far: 42 l/h

⇒ UCN and CMMS cannot run concurrently

Liquefier upgrade

1. Add one more compressor to current system
 - Our conservative estimate: 15 – 25 l/h gain
⇒ **57 l/h to 67 l/h**
 - Expected to enable concurrent UCN and CMMS operation
2. New Turbine liquefier with > 70 l per hour
 - for sustained source operation
⇒ CFI proposal



L1610 liquefaction guaranteed performance (liters/hour)

50 Hz	60 Hz	50 Hz	60 Hz	Compressor
Without LN ₂ precooling	Without LN ₂ precooling	With LN ₂ precooling	With LN ₂ precooling	
-	-	-	-	RSS
17	20	40	49	RS
20	21	49	57	RSX
-	-	70	70	2RS



TUCAN

From UCN Production to nEDM Measurement

The UCN source is ready. The measurement is next.

ACHIVED

**The world's highest-intensity
UCN source**

Built and commissioned by the
TUCAN collaboration



NEXT

**The neutron EDM
measurement**

Moving into the experimental phase

*We gratefully acknowledge the support of TRIUMF, KEK, and our
partner institutions, especially their engineers and technical staff.*