Status and Prospects of the TUCAN EDM experiment

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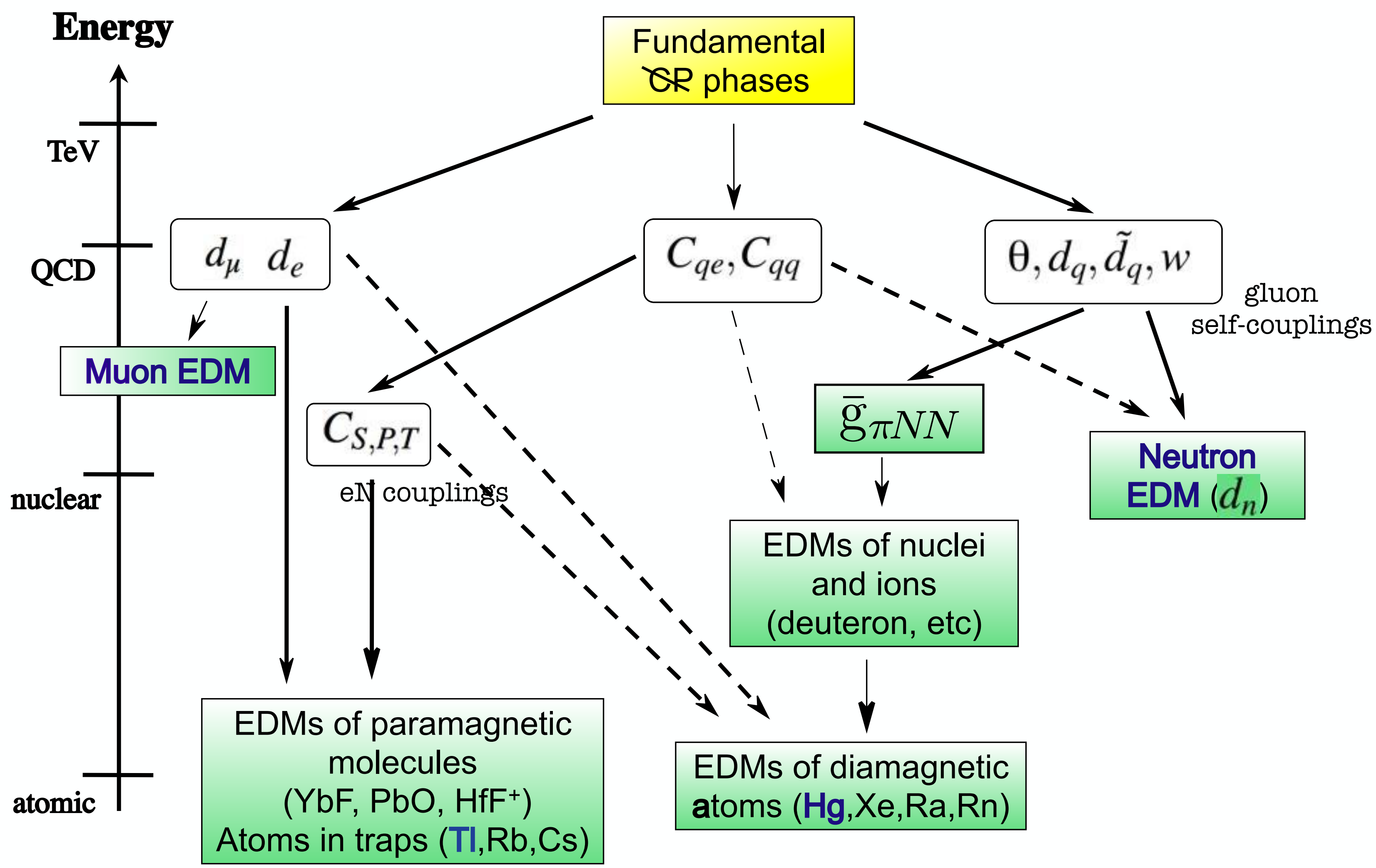
Neutron EDM



Pospelov Ritz, Ann Phys 318 (05) 119

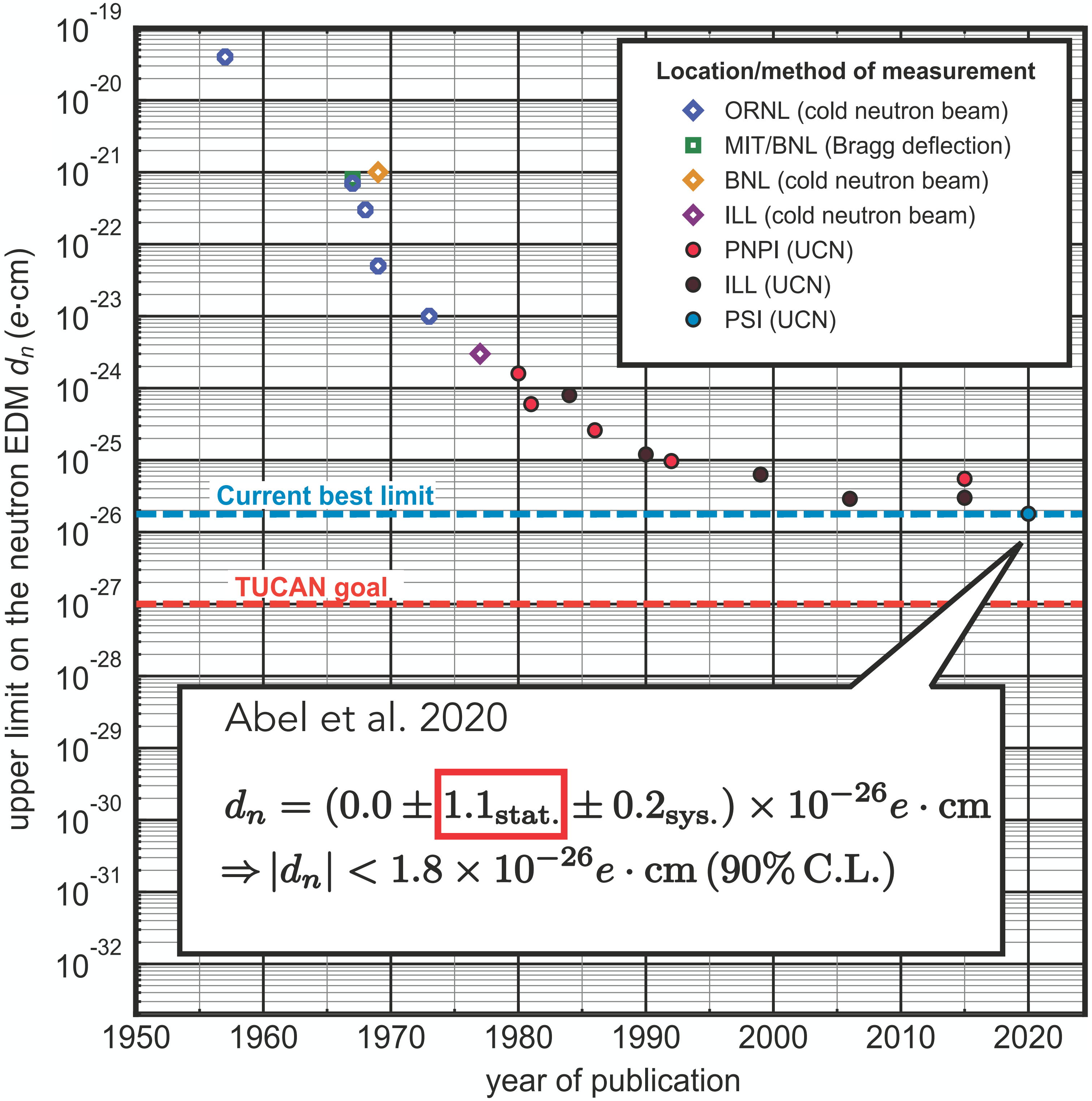
J. Engel et al., Prog. Part. Nucl. Phys. 71 (2013) 21.

$$d_{\mathrm{Hg}} = -\left(0.38^{+2.3}_{-0.19} \times 10^{-17}\right) \bar{g}^{(0)}_{\pi NN} + \left(0^{+1.6}_{-4.6} \times 10^{-17}\right) \bar{g}^{(1)}_{\pi NN} - \left(2.0^{+3.9}_{-0.0} \times 10^{-20}\right) C_{\mathrm{T}}$$

$$d_{\mathrm{Xe}} = -\left(0.29^{+2.3}_{-0.11} \times 10^{-18}\right) \bar{g}^{(0)}_{\pi NN} - \left(0.22^{+1.7}_{-0.11} \times 10^{-18}\right) \bar{g}^{(1)}_{\pi NN} + \left(4^{+2}_{-0} \times 10^{-21}\right) C_{\mathrm{T}}$$

$$d_{\mathrm{n}} = -\left(1.5 \times 10^{-14}\right) \bar{g}^{(0)}_{\pi NN} + \left(1.4 \times 10^{-16}\right) \bar{g}^{(1)}_{\pi NN}$$

Neutron EDM



Abel et al. 2020

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

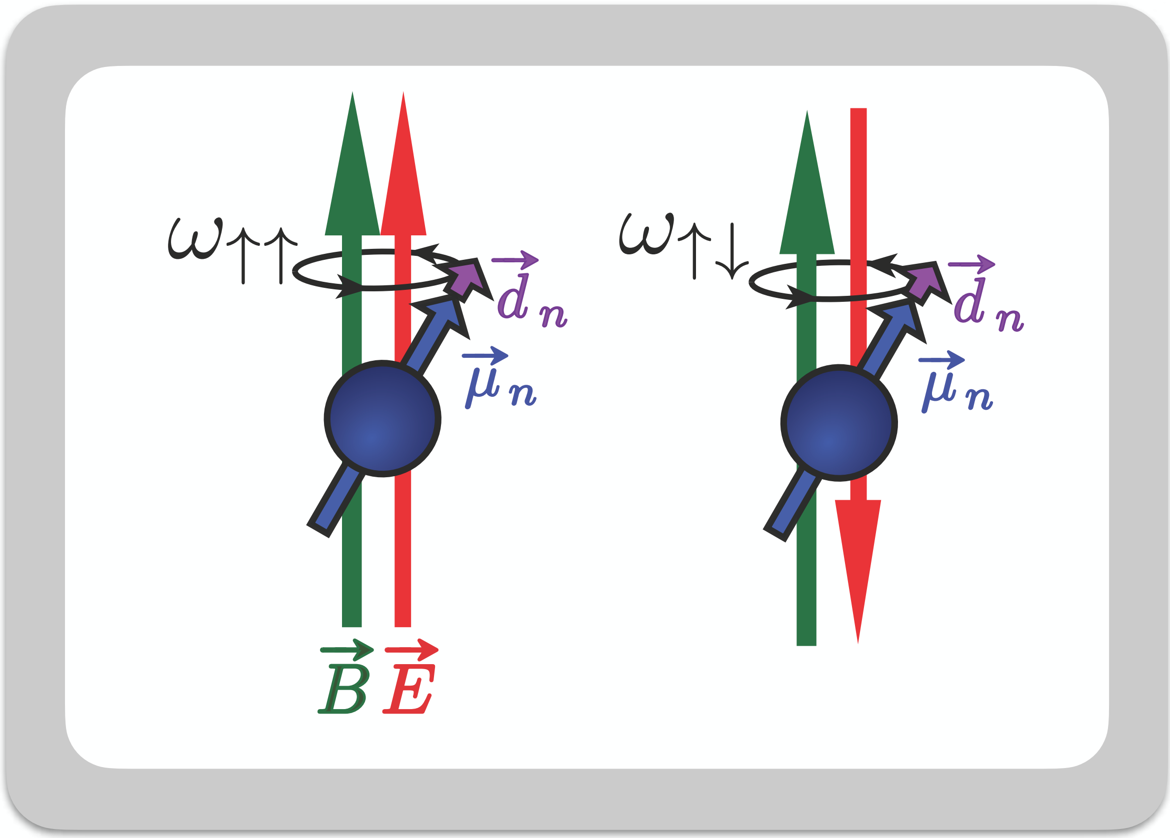
$$\Rightarrow |d_n| < 1.8 \times 10^{-26} e \cdot \mathrm{cm}\ (90\%\ \mathrm{C.L.})$$

Sensitivity was limited by statistical uncertainty.

J.M. Pendlebury & E. Hinds NIM A, 440 (2000), 471.
T. Chupp et al., Rev. Mod. Phys., 91 (2019) 015001.

EDM search with UCNs

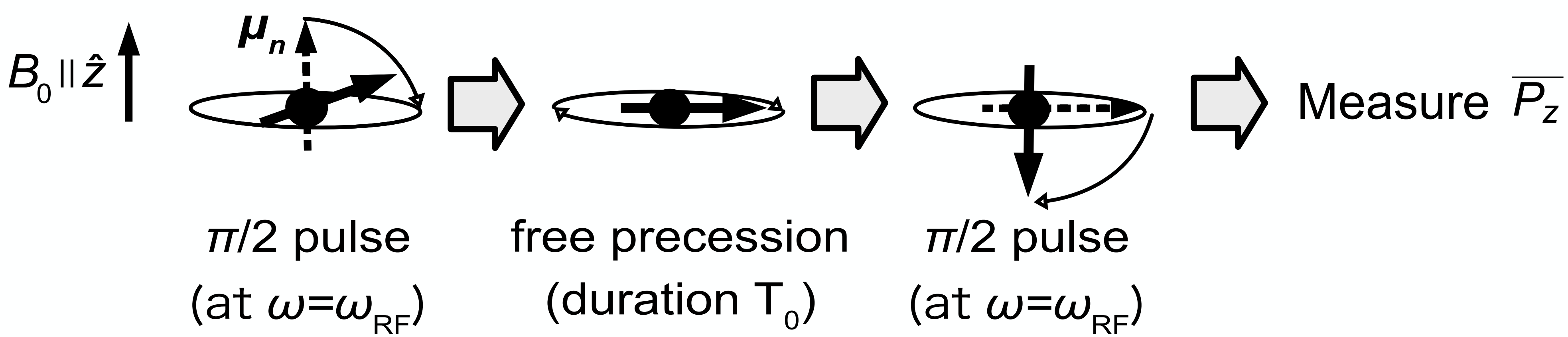
Measure spin-precession frequency in high electric field



B, E parallel (↑↑) $\omega_{\uparrow\uparrow} = \dfrac{2\mu_n|B| + 2d_n|E|}{\hbar}$

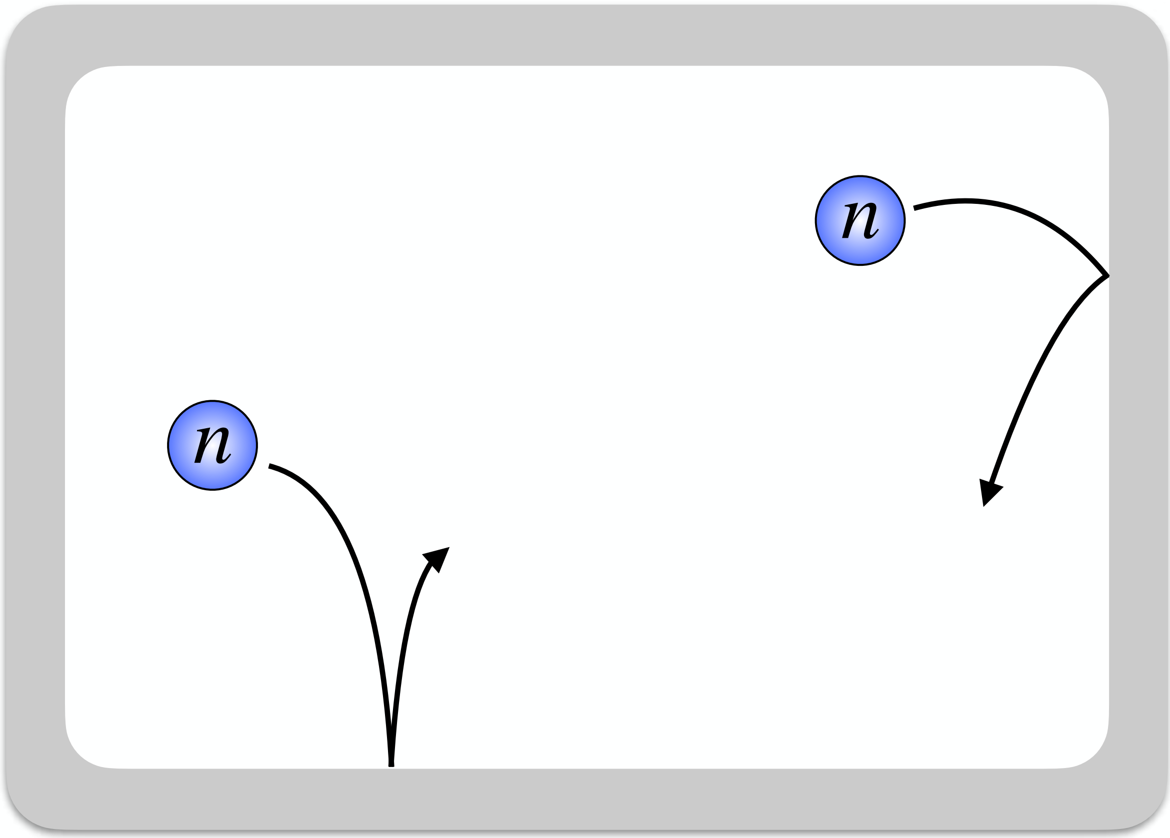
B, E antiparallel (↑↓) $\omega_{\uparrow\downarrow} = \dfrac{2\mu_n|B| - 2d_n|E|}{\hbar}$

$$d_n = \frac{\hbar(\omega_{\uparrow\uparrow} - \omega_{\uparrow\downarrow})}{4|E|}$$



EDM search with UCNs

Extremely-low energy neutrons (UCNs) can be stored in the bottle.



$$\sigma(d_n) = \frac{\hbar}{2\alpha E T \sqrt{N}}$$

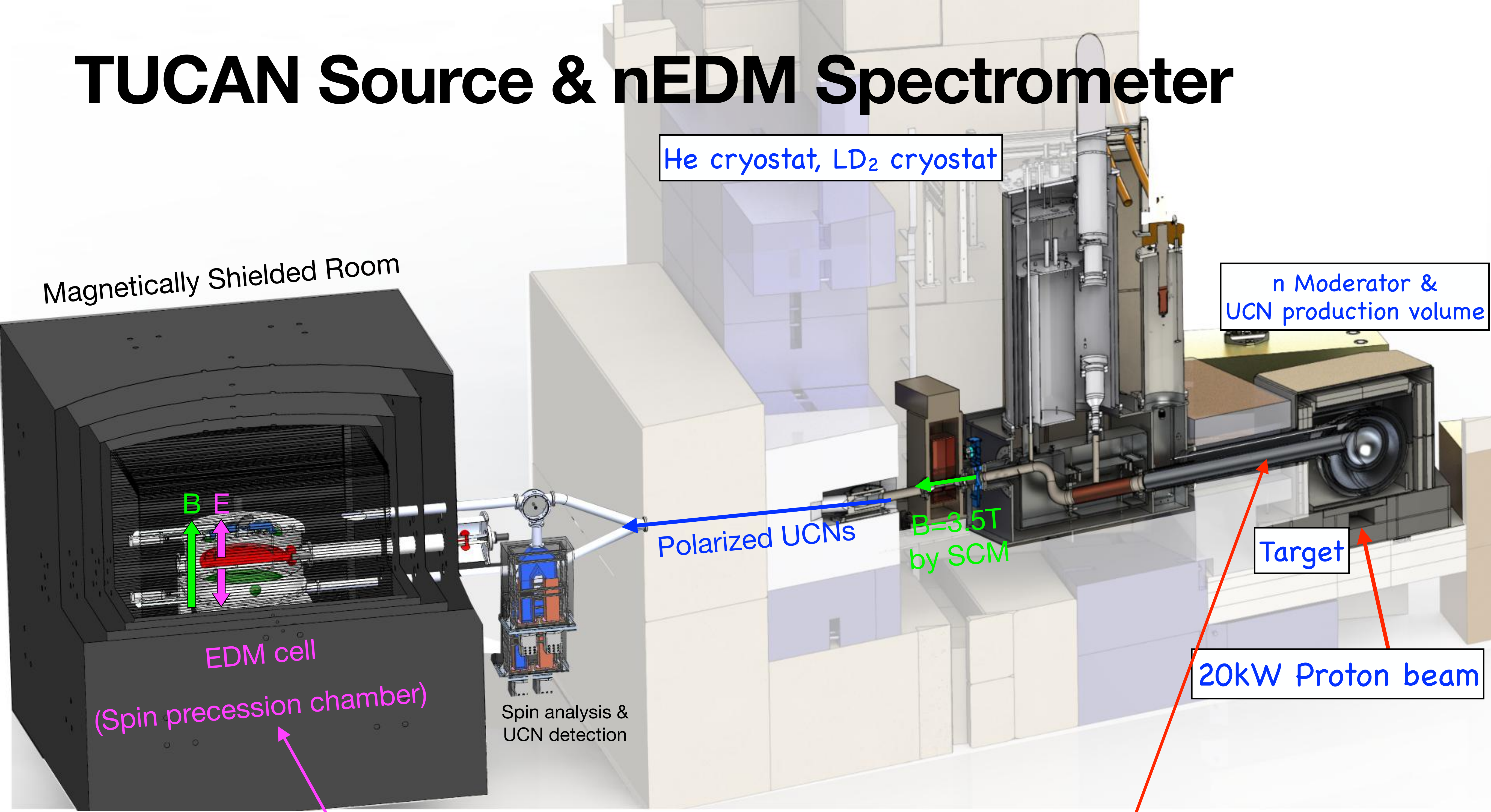
Spin precession is accumulated in long storage time.

Sensitivity was limited by statistical uncertainty.

UCN density can not be increased from that in source. (Liouville's theorem)

High intensity source required

TUCAN Source & nEDM Spectrometer



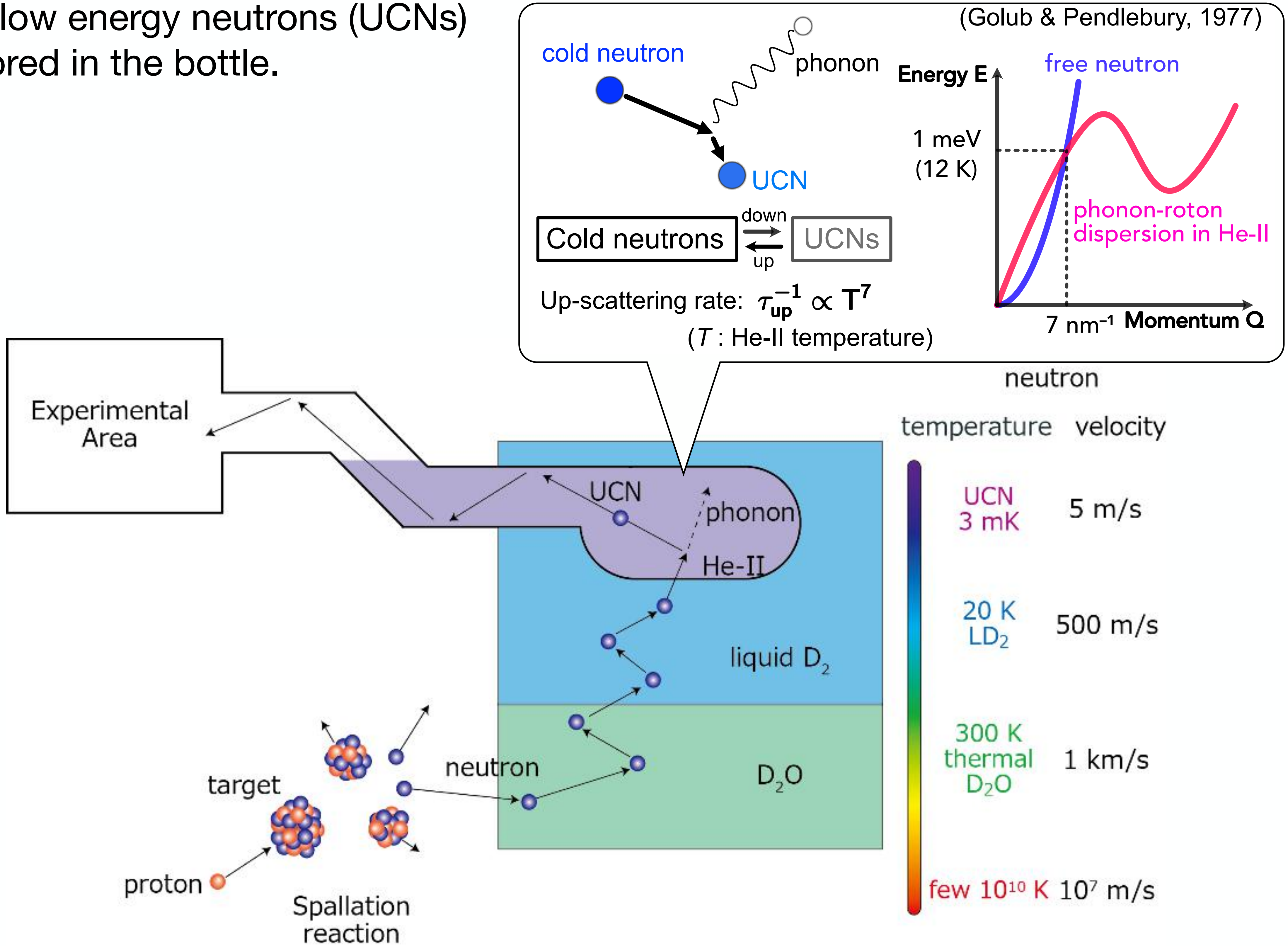
Expected ~200 UCN/cm^3 1.4-1.6×10^7 UCN/s yield

➡ Measure the nEDM with 10^{-27} ecm precision

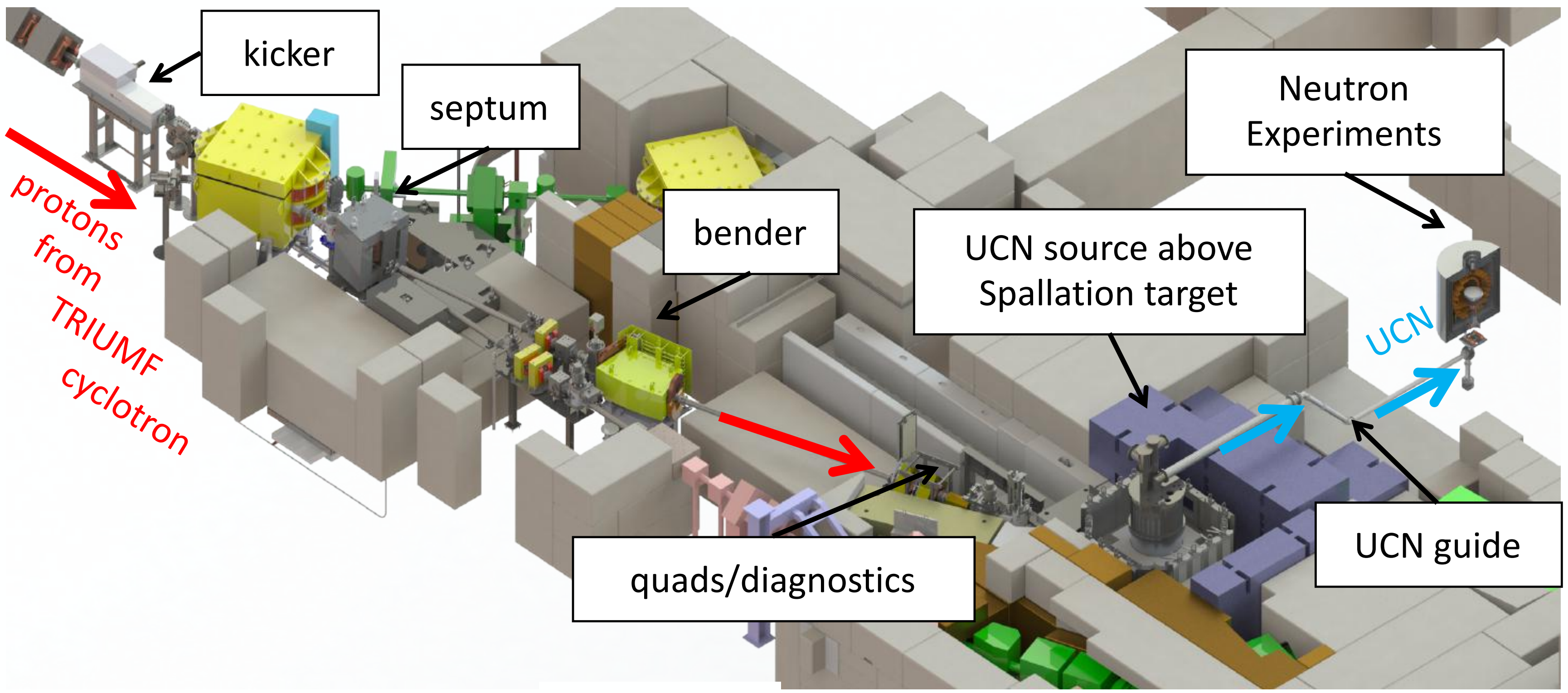
UCN source

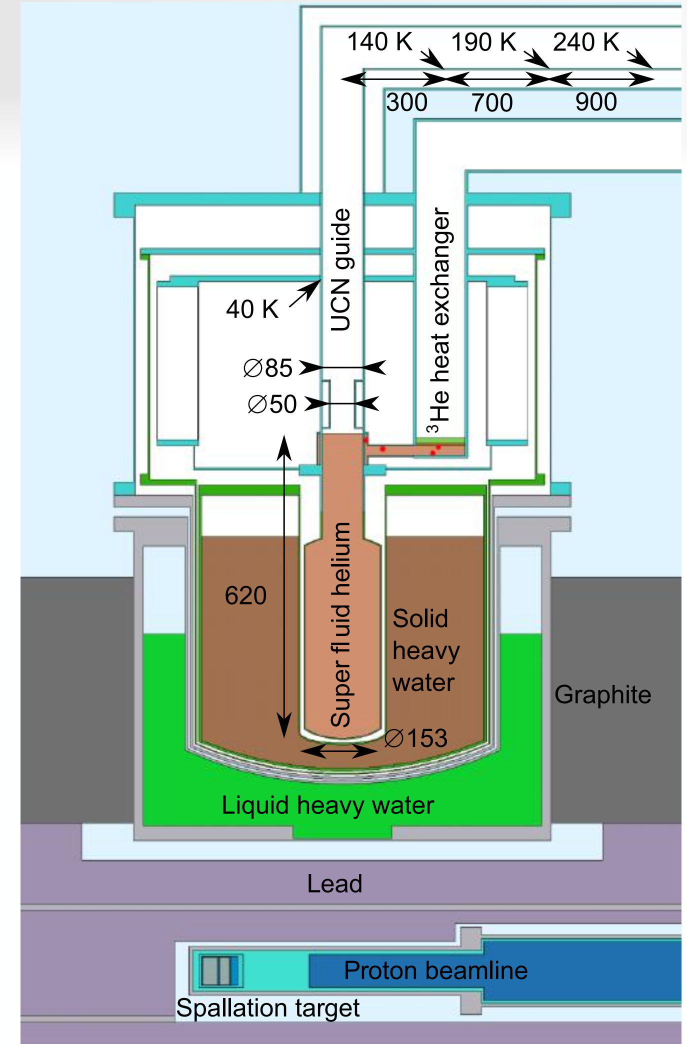
Superthermal method with superfluid He

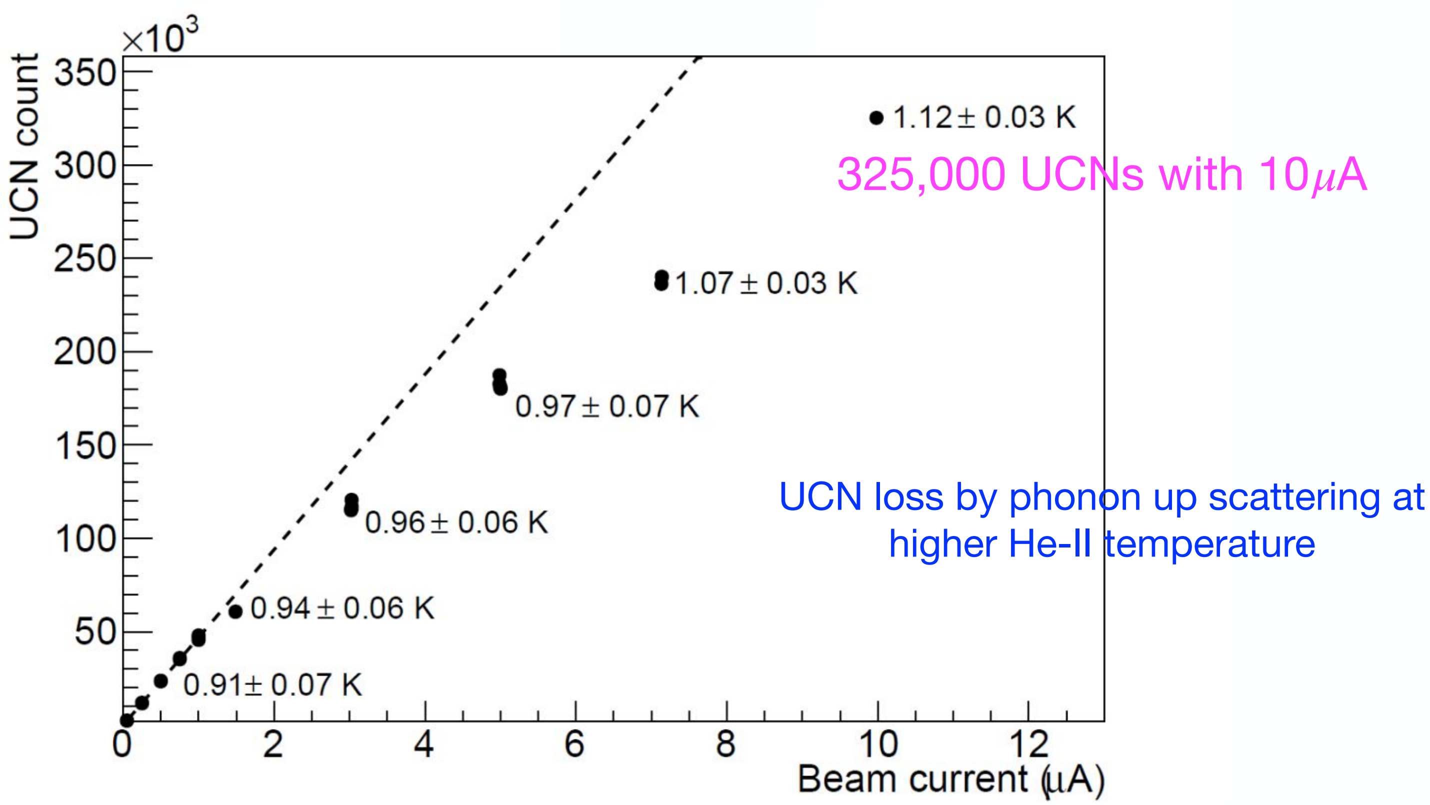
Extremely-low energy neutrons (UCNs) can be stored in the bottle.

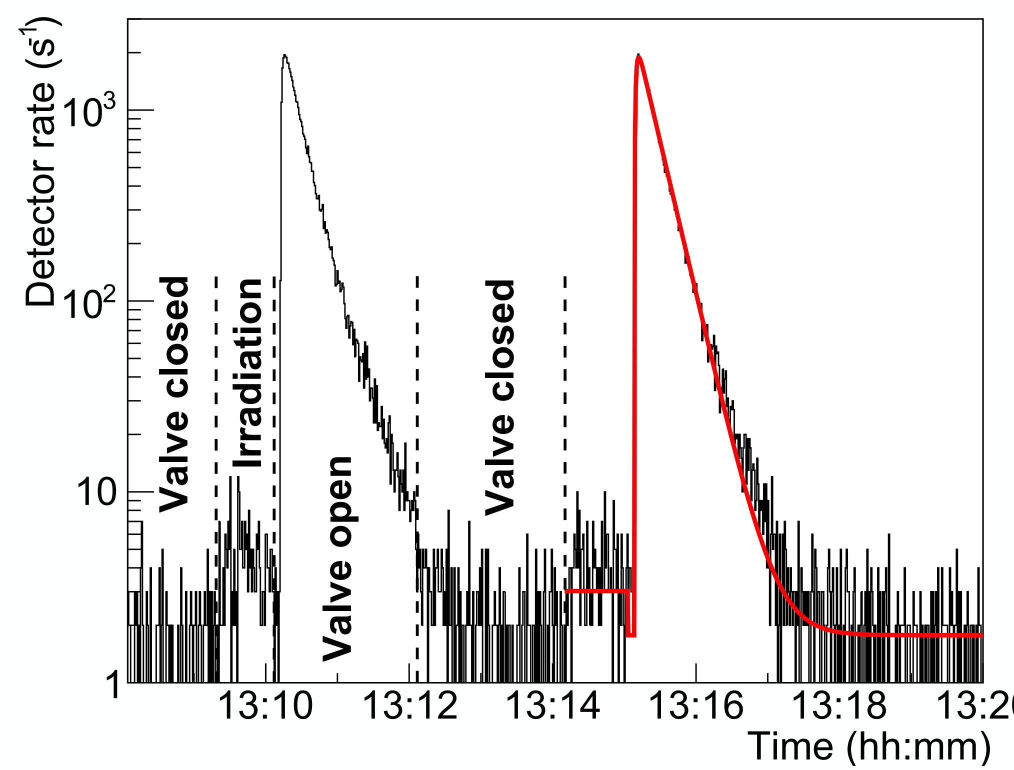


Prototype UCN source at TRIUMF









Prototype UCN source at TRIUMF

First proton beam: 2016

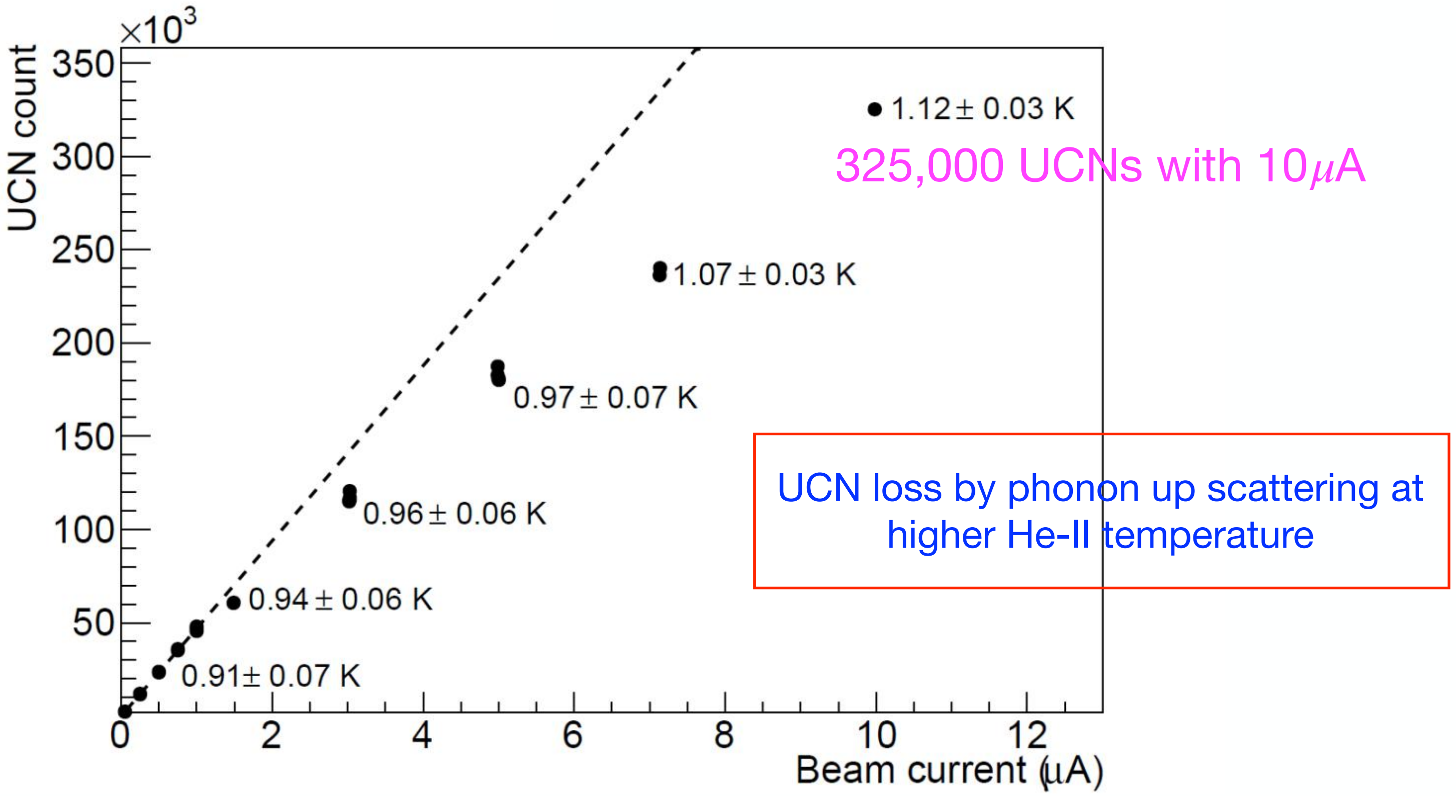
Prototype UCN source installation: 2016~2017

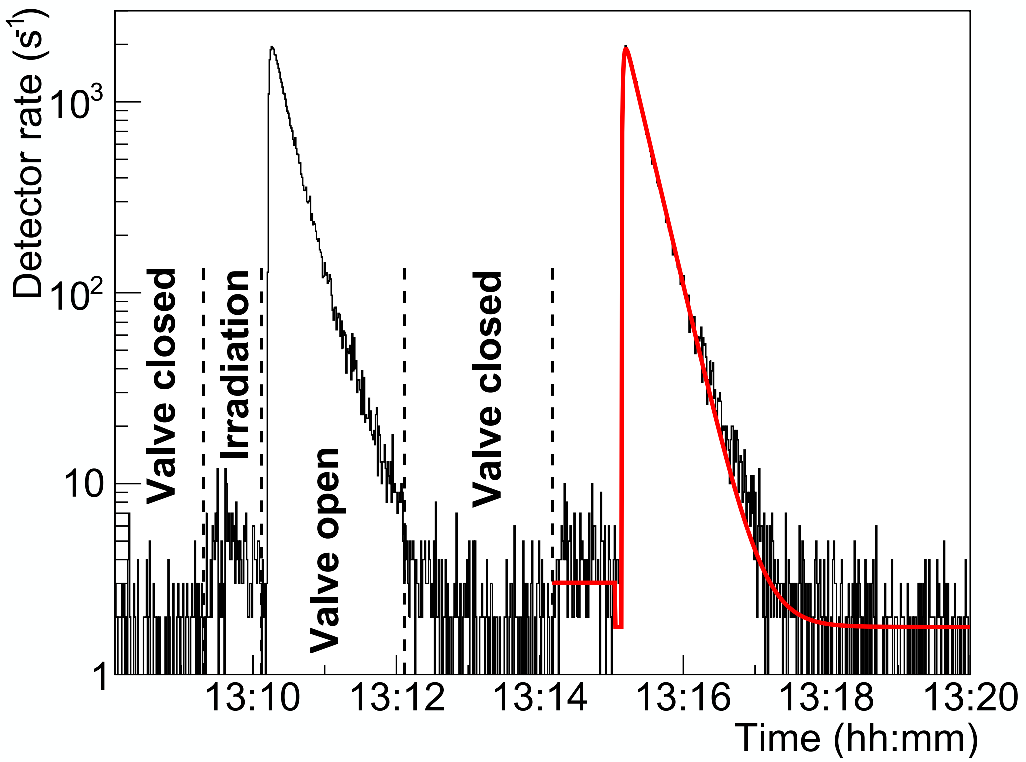
UCN production: 2017

Testing UCN apparatus: 2018~2019

Uninstall: 2021

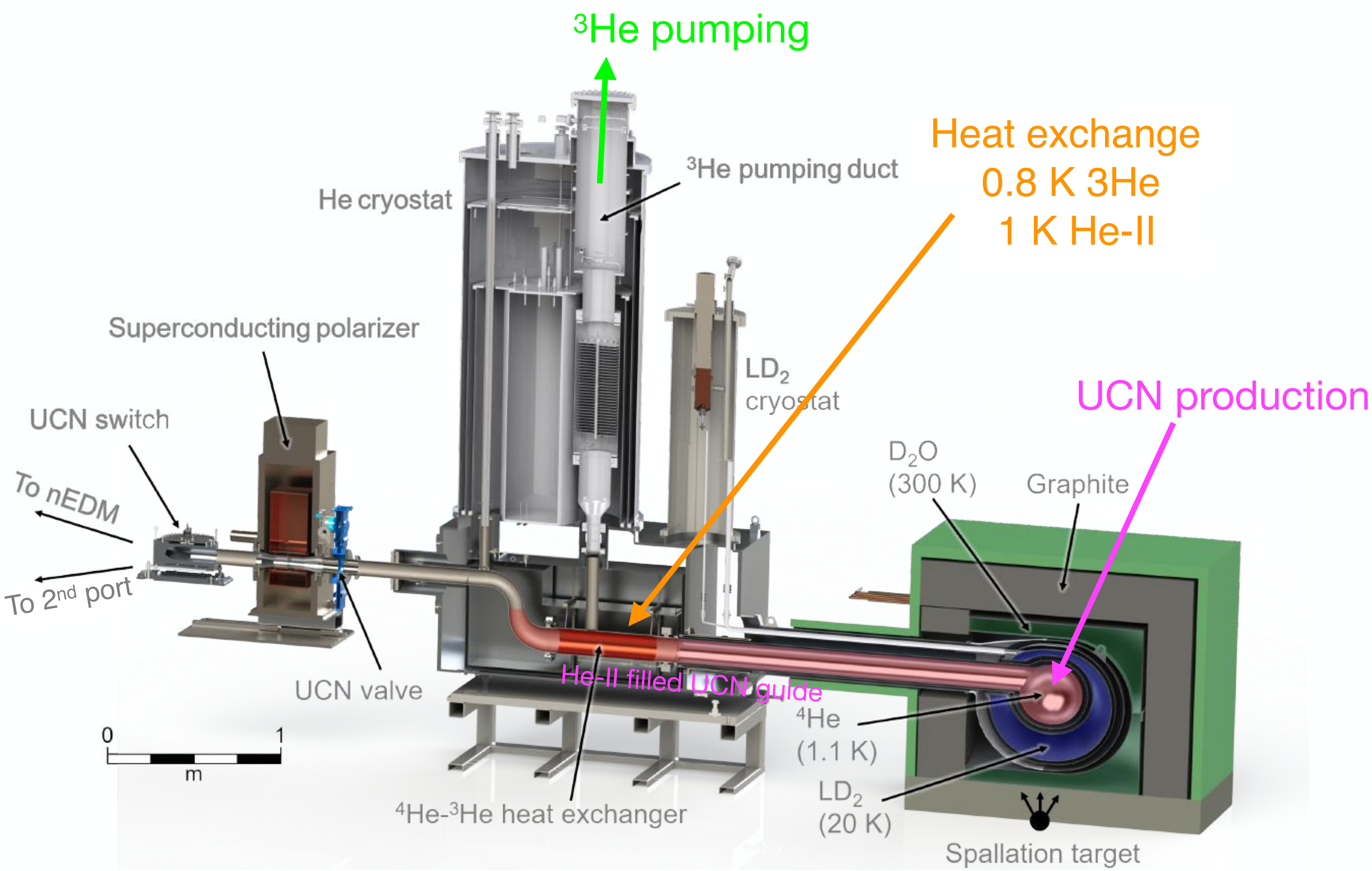
High power cryostat required!





UCN source upgrade

	Prototype	New	Factor
Cooling power of He cryostat	0.4 W	10 W	x 25



	Prototype UCN source (RCNP)	New UCN source (TRIUMF)	Factor
Beam power	400 W (400 MeV x 1uA)	20 kW (500 MeV x 40uA)	x 50
Cold moderator	20 K Solid D_2O	20 K Liquid D_2 (optimized geometry)	x (2-3)
UCN production volume	8 L	27 L	x 3.4
UCN production rate	3.2×10^4 UCN/s	$(1.4\text{-}1.6) \times 10^4$ UCN/s	x (350-500)

Temperature of He-II 0.8 K → 1.1 K decrease lifetime

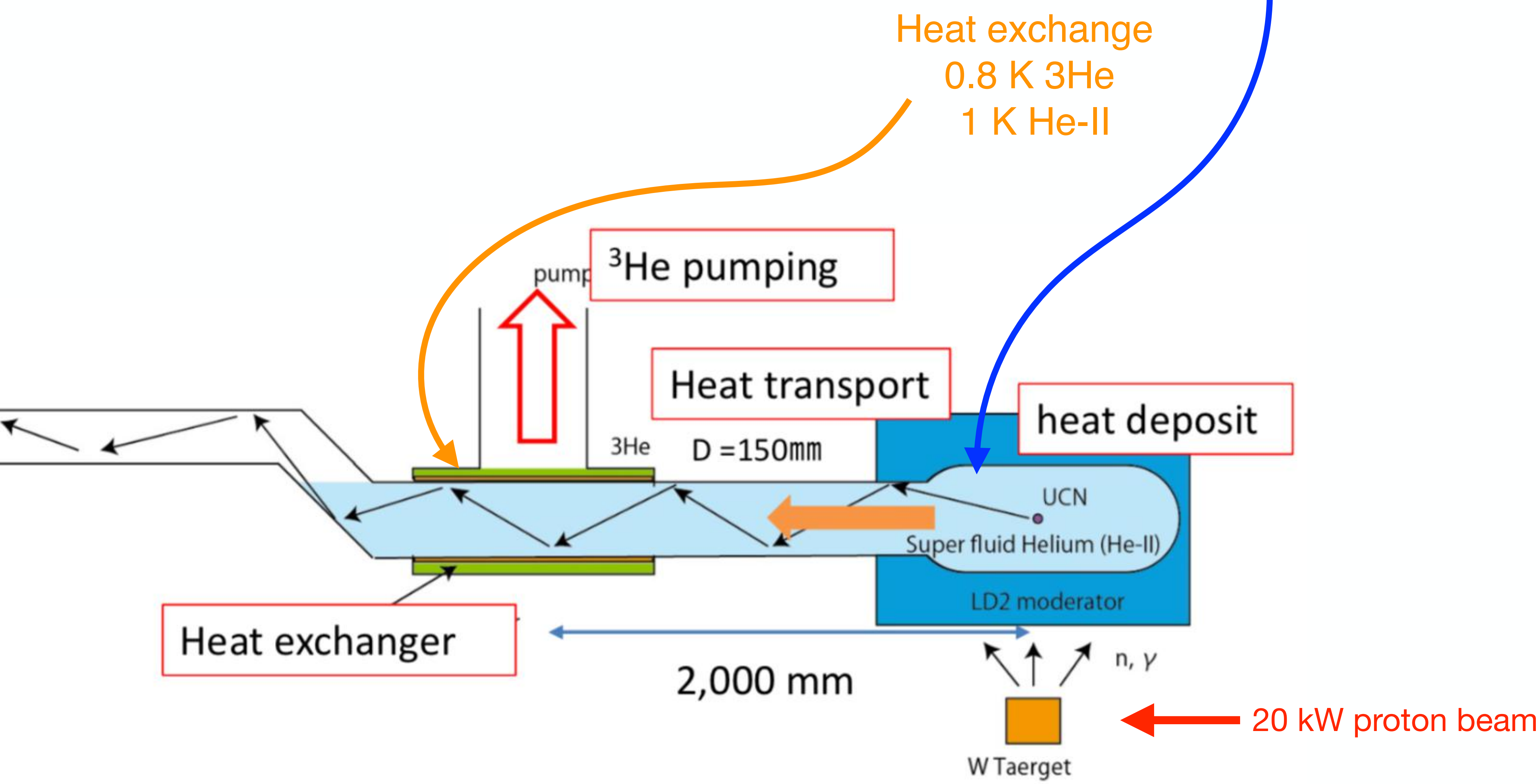
UCN density in source	9 UCN/cm^3 (E < 90 neV)	4.7×10^3 UCN/cm^3 (E < 210 neV)	x 520

UCN source upgrade

Keep the production volume at **~1K** under **10 W** of heat load

by latent heat of boiling **^{3}He**

With ^{3}He pot at **0.8 K**, the UCN production volume is kept ~1K



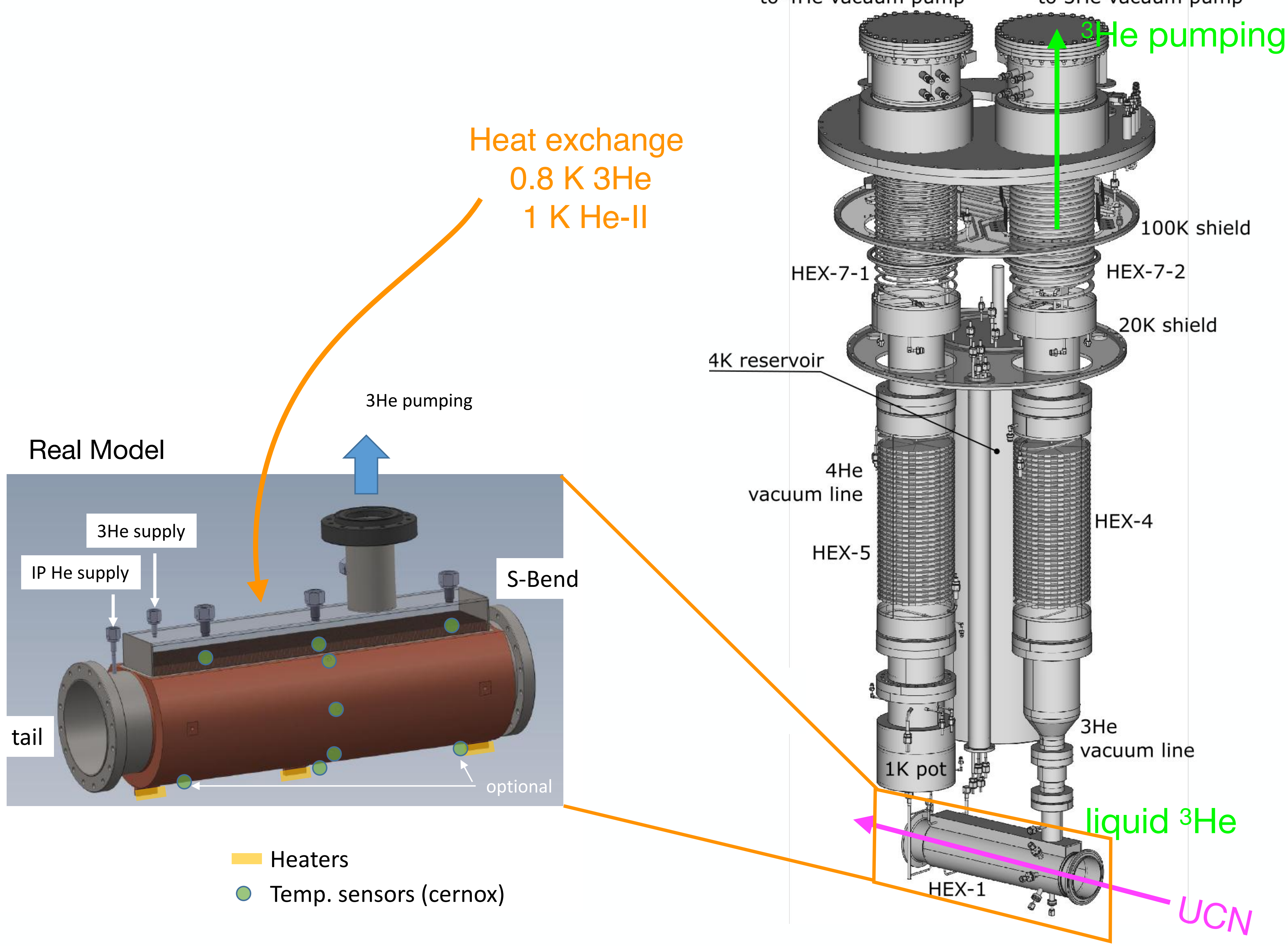
$$T_{3\mathrm{He}} + \Delta T_{3\mathrm{He\text{-}Ni}} + \Delta T_{\mathrm{Ni\text{-}HeII}} + \Delta T_{\mathrm{HeII}} = T_{\mathrm{prod.}}$$

~0.8K (Kapitza conductance) ~1.1K

S. Kawasaki et al.,
IOP Conf. Ser.: MSE.755, 012140 (2020)

Helium cryostat

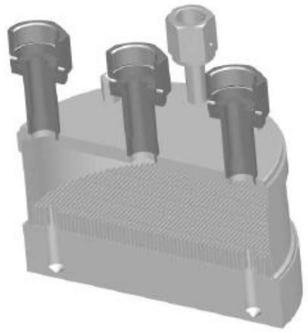
Studies with cryostat, heat exchanges



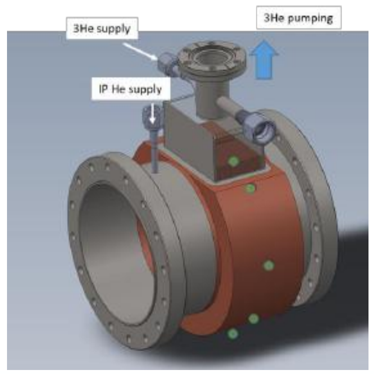
Helium cryostat

Studies with cryostat, heat exchanges

Vertical Fin Prototype



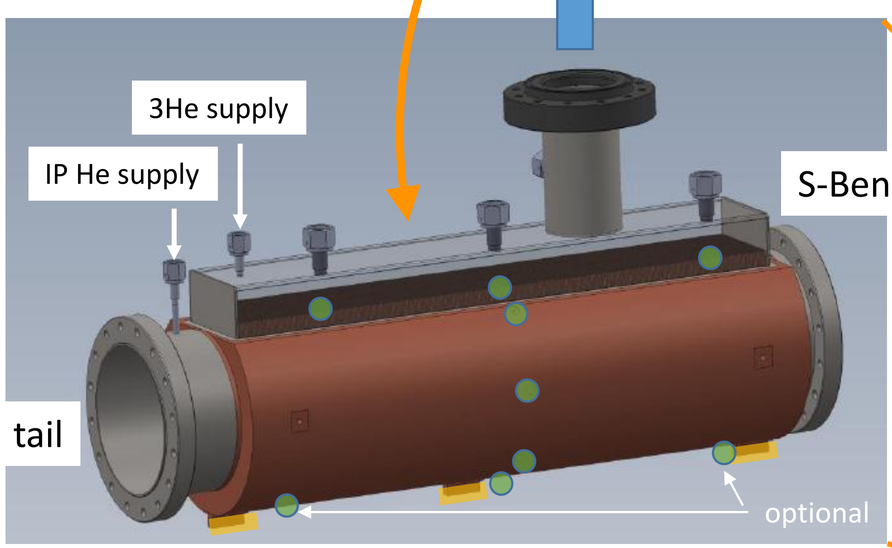
Short Model



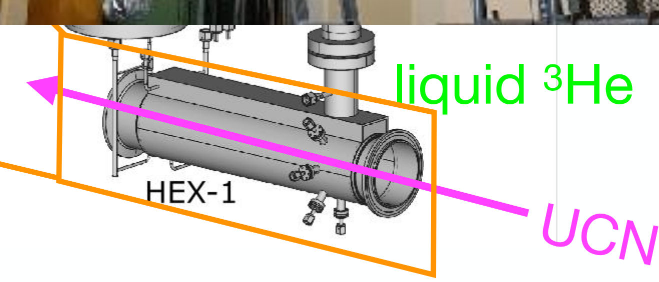
Heat exchange
0.8 K 3He
1 K He-II

Real Model

3He pumping



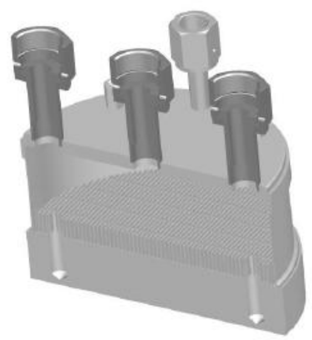
Heaters
Temp. sensors (cernox)



Helium cryostat

Studies with cryostat, heat exchanges

Vertical Fin Prototype



➡ Decided on the HEX1 design

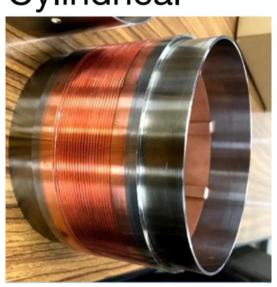
Cryostat tests at KEK with natural helium

1.23 K with ^{4}He
⟷ 0.65 K with ^{3}He

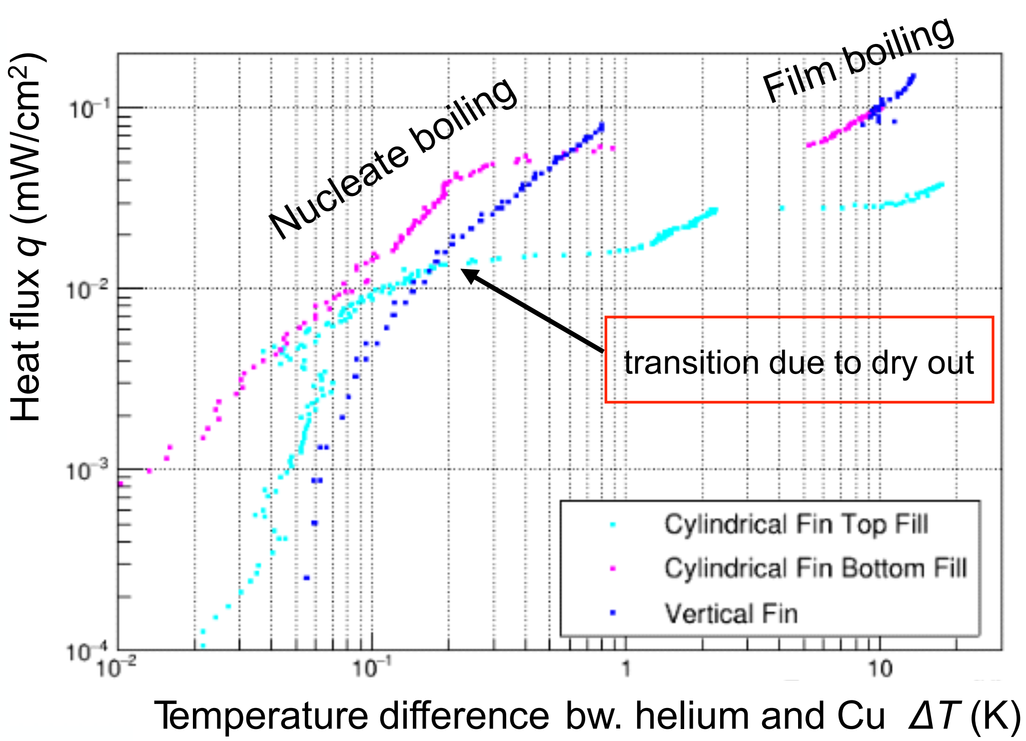
Component tests (2019)

Kapitza conductance of flat-plate samples

Cylindrical



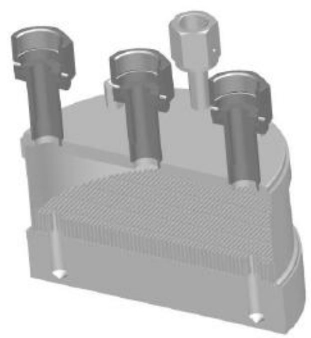
Vertical



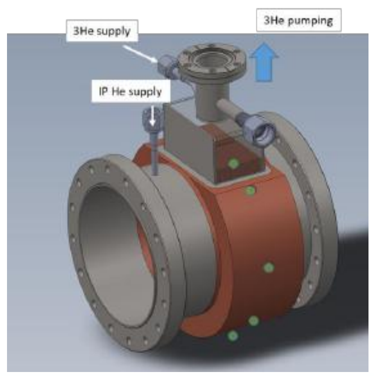
T. Okamura et al.,
IOP Conf. Ser.: MSE. 755, 012141 (2020)

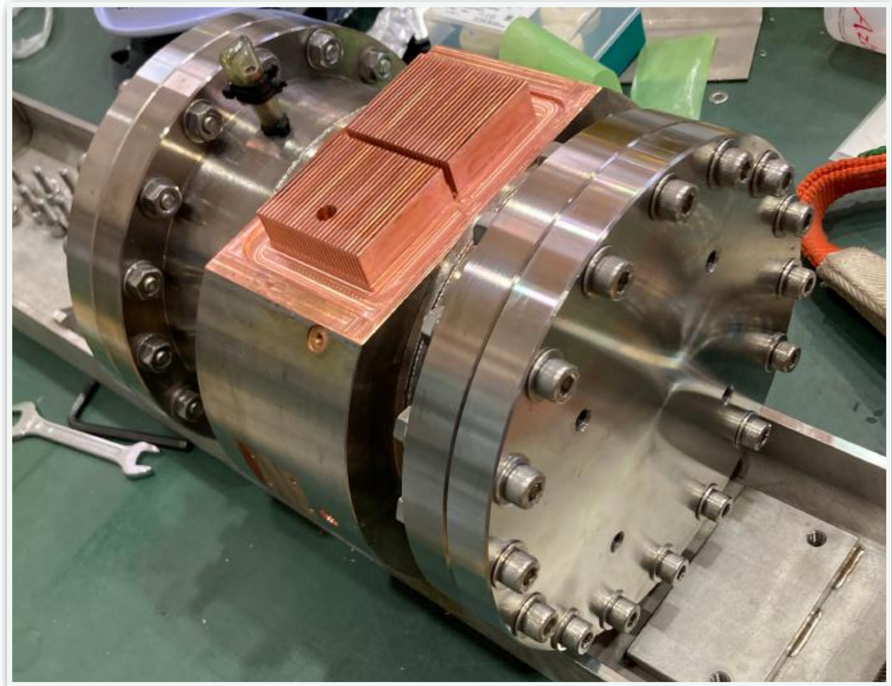
Heat Exchange development

Vertical Fin Prototype

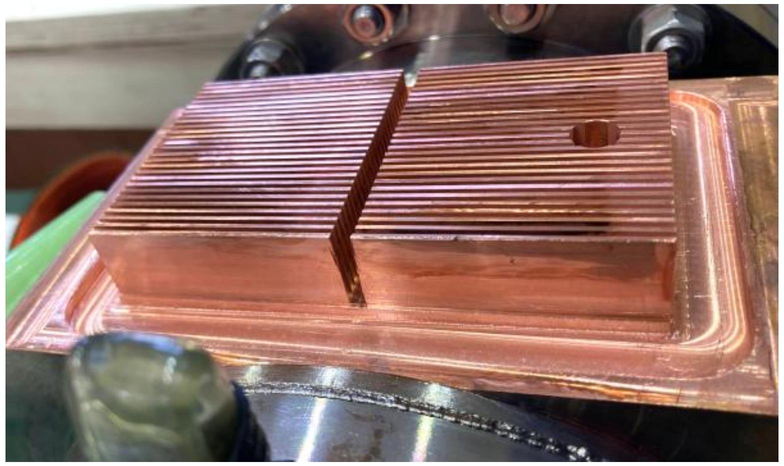


Short Model



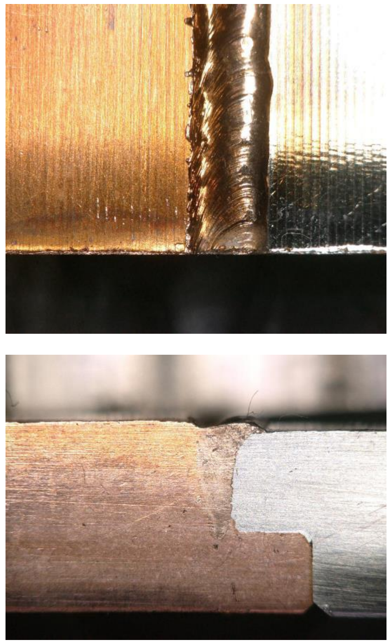


Fin machining

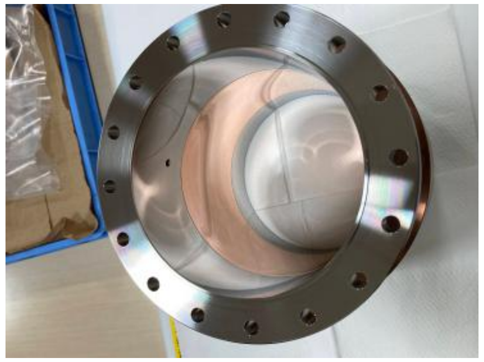


Height 15 mm,
thickness 1 mm,
Gap 1 mm

EB welding test



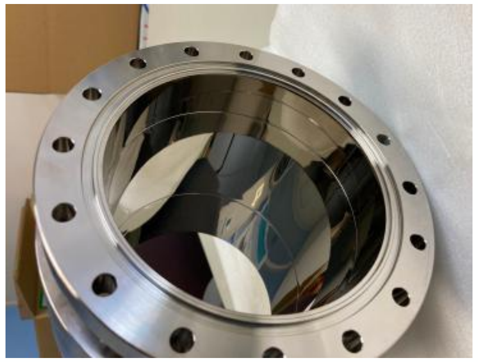
Polishing



@SUS
Ra = 0.019 μm

@Cu
Ra = 0.020 μm

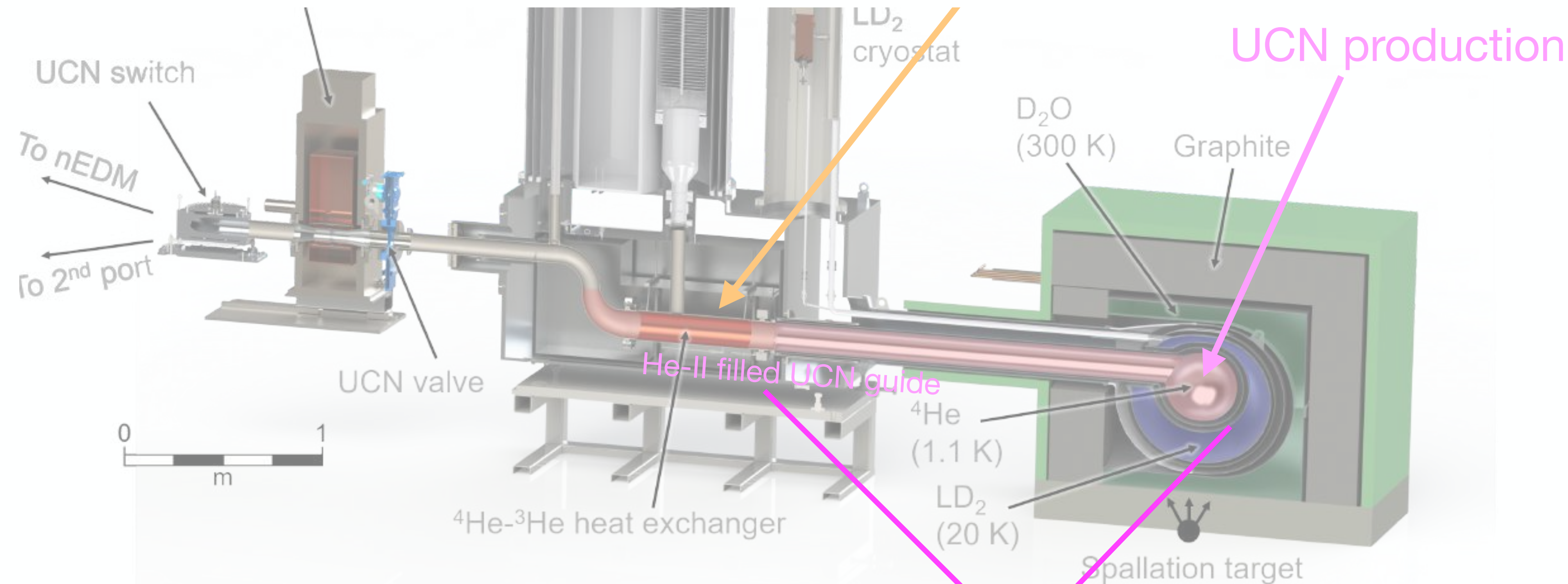
NiP plating



Thickness 5 μm
P fraction 12.36 %
(X-ray fluorescence analysis)

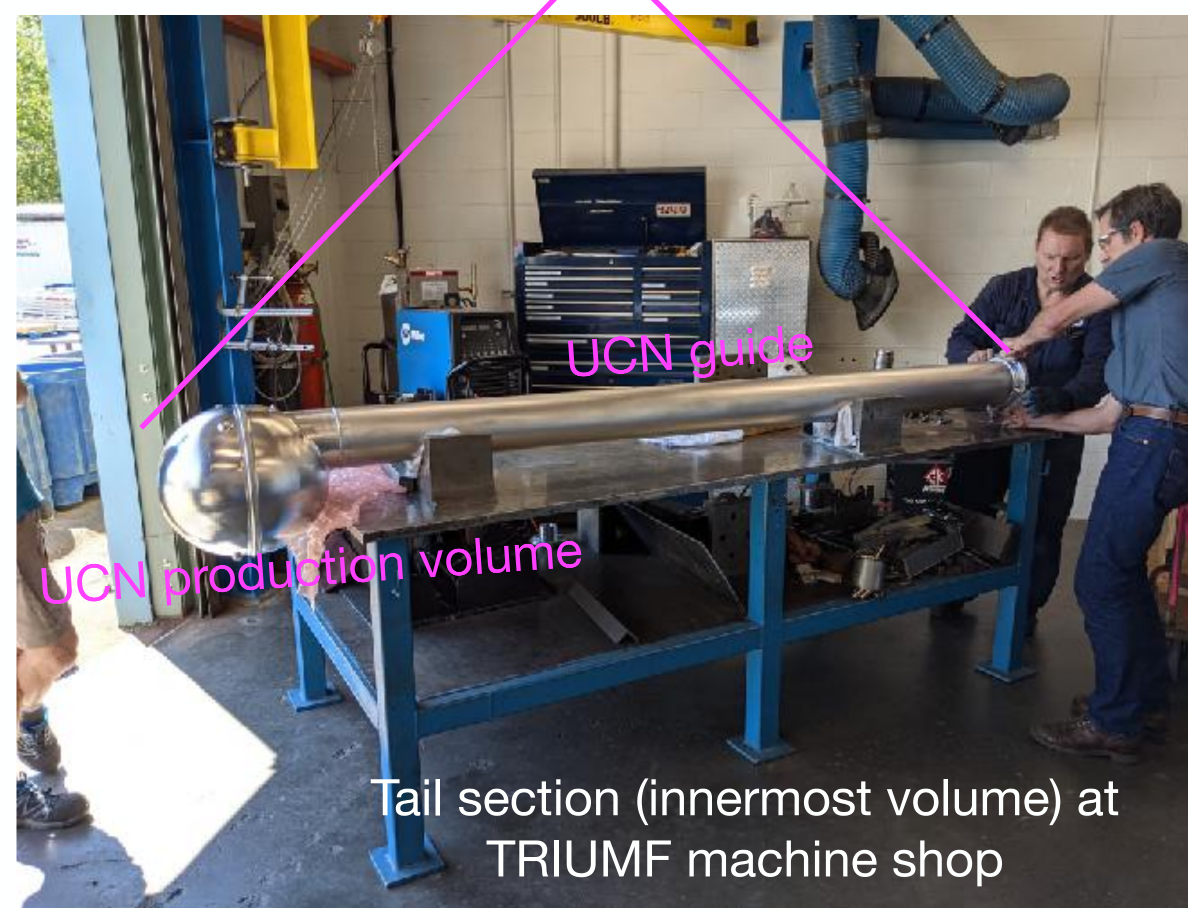
Tail section and UCN guide

UCN production volume and UCN guide has been mede at TRIUMF.



UCN storage test at LANL

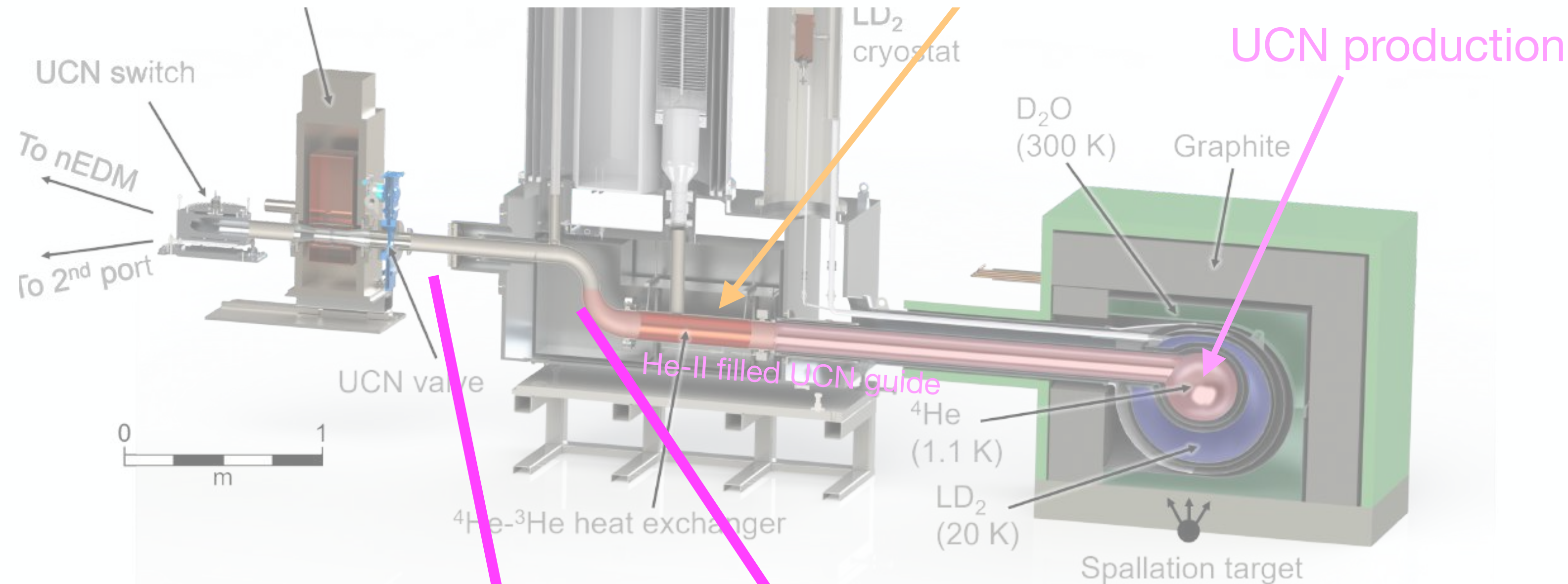
$\tau_{\text{storage}} \approx 96$ s



Tail section (innermost volume) at TRIUMF machine shop

Tail section and UCN guide

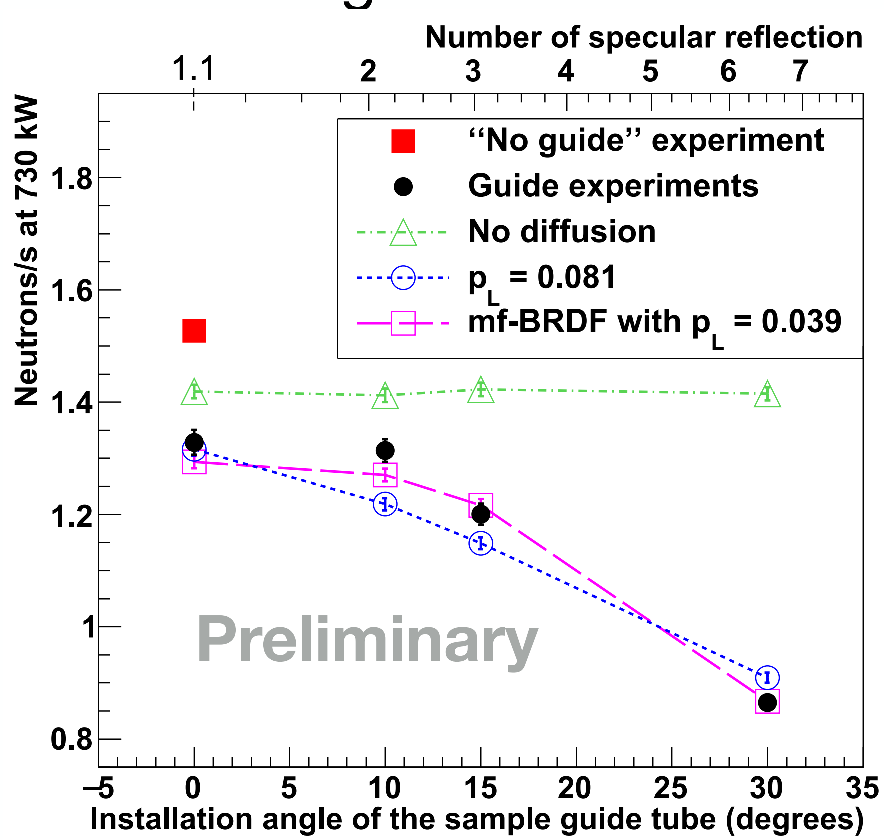
UCN production volume and UCN guide has been mede at TRIUMF.

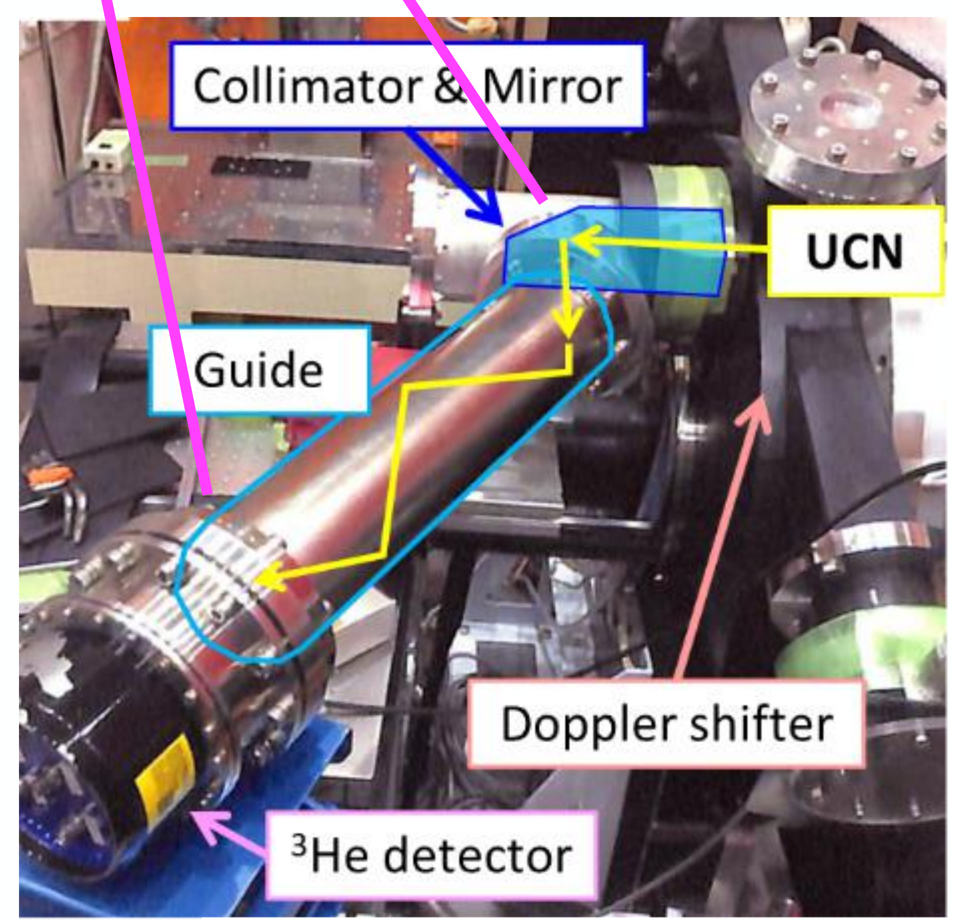


UCN guide test at J-PARC

Precise study of UCN reflection

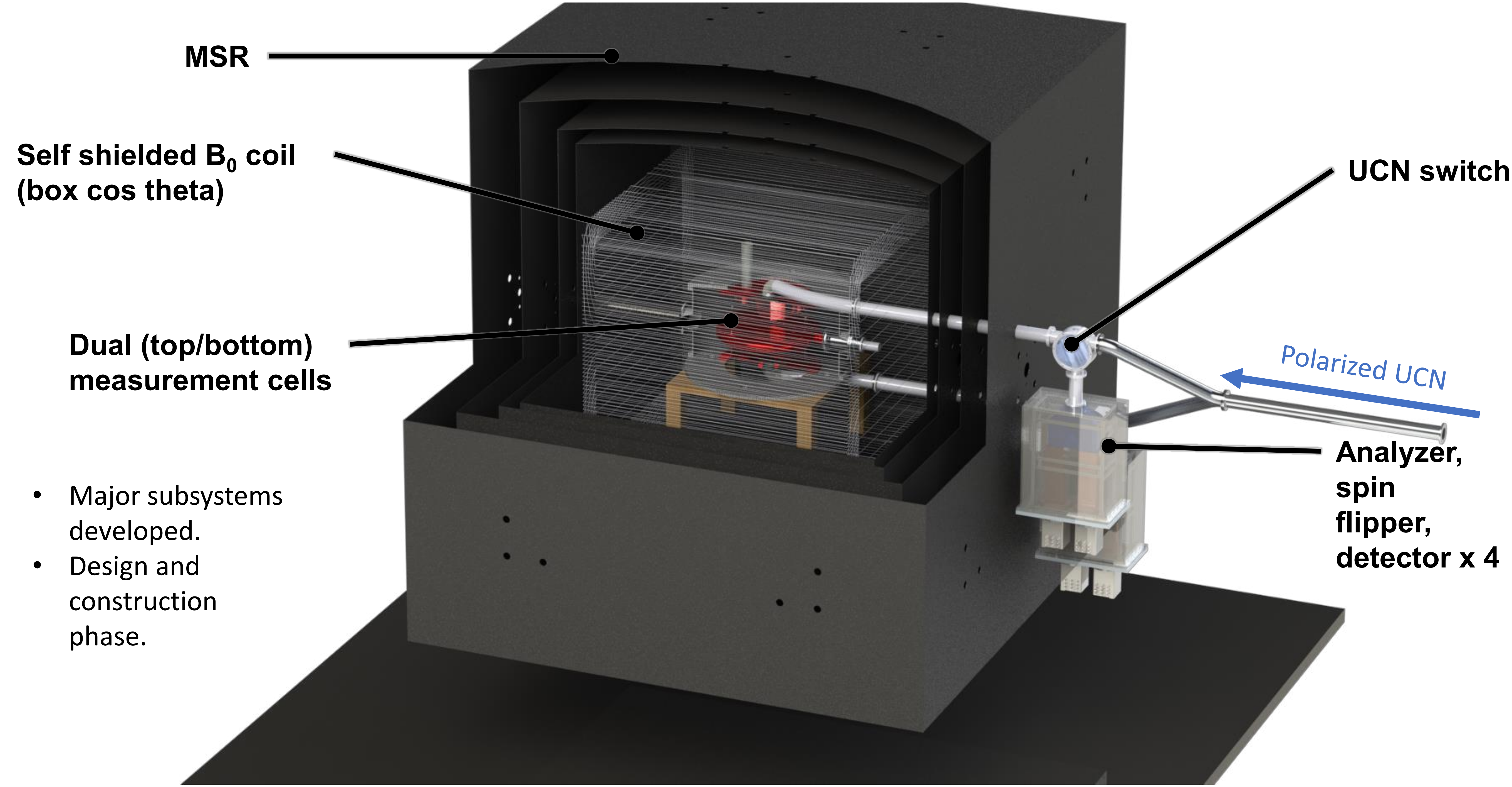
➡ Select NiP coating





nEDM spectrometer

nEDM Spectrometer



- Major subsystems developed.
- Design and construction phase.

Magnetically Shielded Room

Requirements

- Shielding factor ~10^5 (@10 mHz or higher)
- to achieve ~10 pT/cycle stability (1 cycle~100s)
  - Fields < 1nT
  - gradient < 100 pT/m

  in the central $(1\text{m})^3$ volume

cf: N. Ayres et al., Rev. Sci. Inst. 93, 095105 (2022)

Construction started from October 2022.

- 4-layer mumetal shield (+1 layer of Cu layer)
- Design shielding factor of ~10^5

  confirmed by FEA simulations

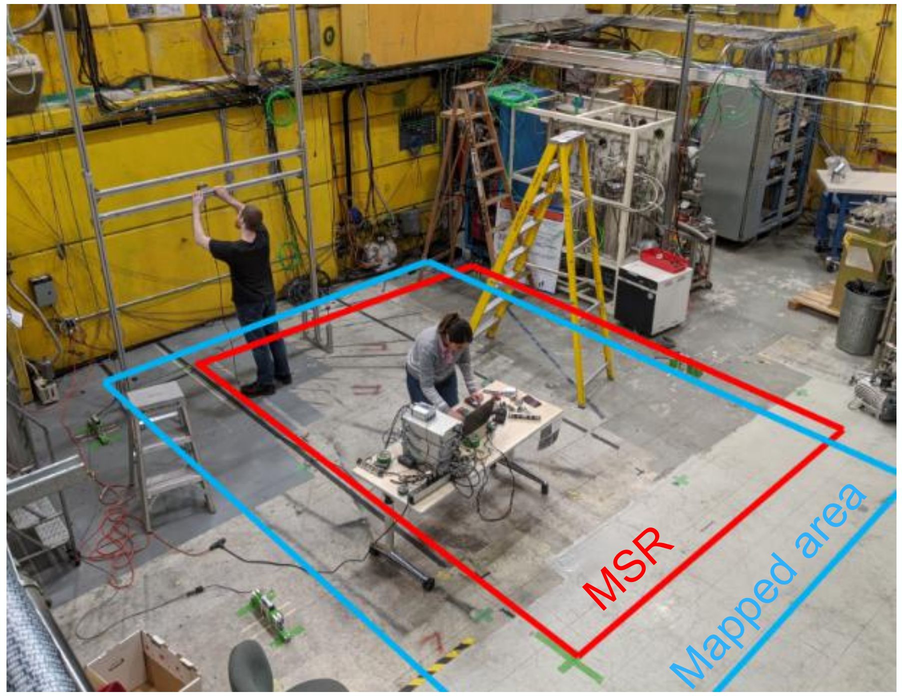
Magnetically Shielded Room

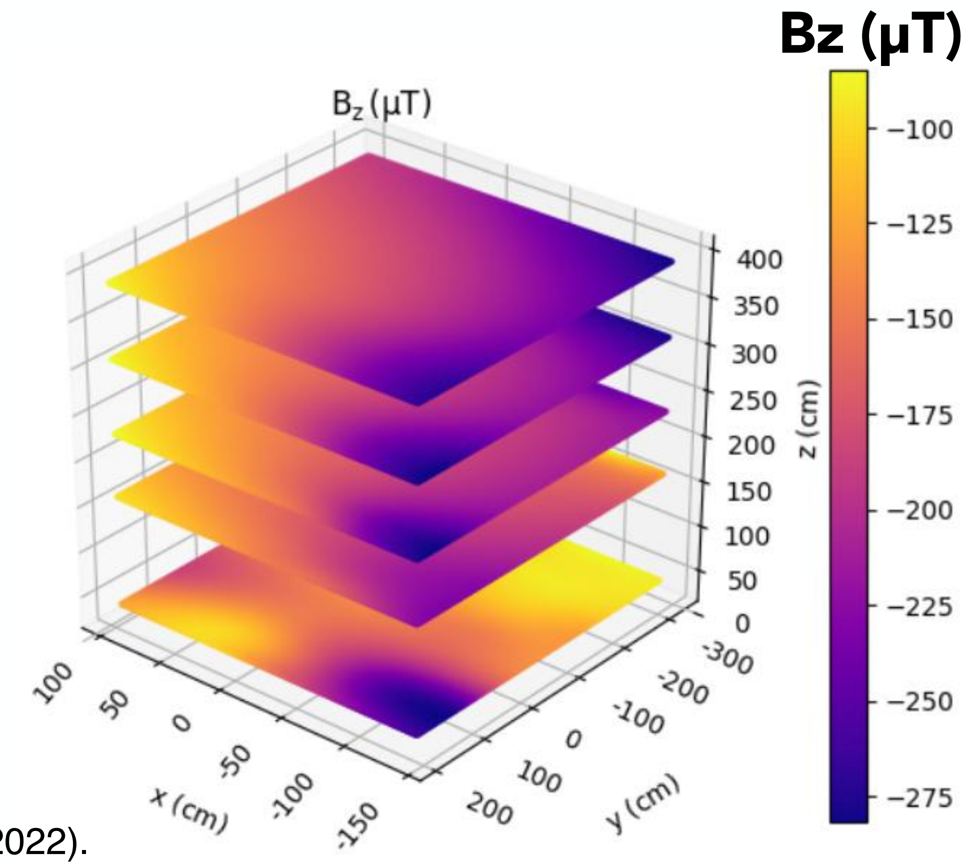
Magnetic field mapping

$|B| \approx 370\ \mu\mathrm{T}$
at maximum

Dipole-like field
from the cyclotron

Fluctuation
$< 150\ \mathrm{nT}$
at 100 s averaging

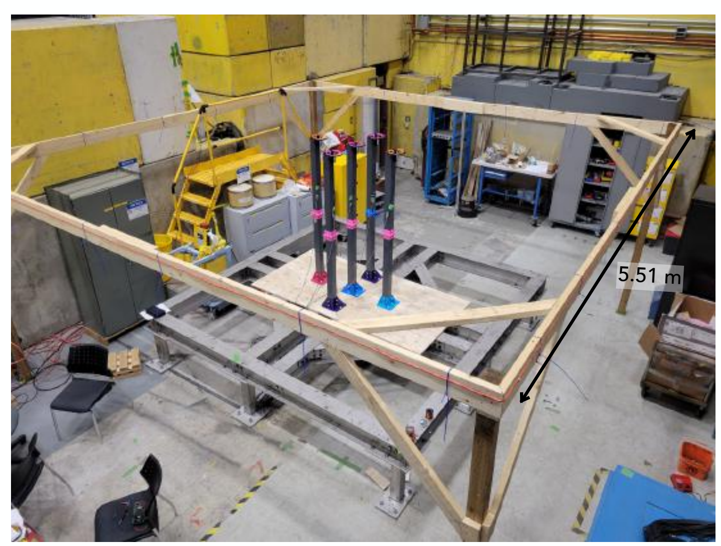




T. Higuchi, EPJ Web. Conf. 262, 01015 (2022).

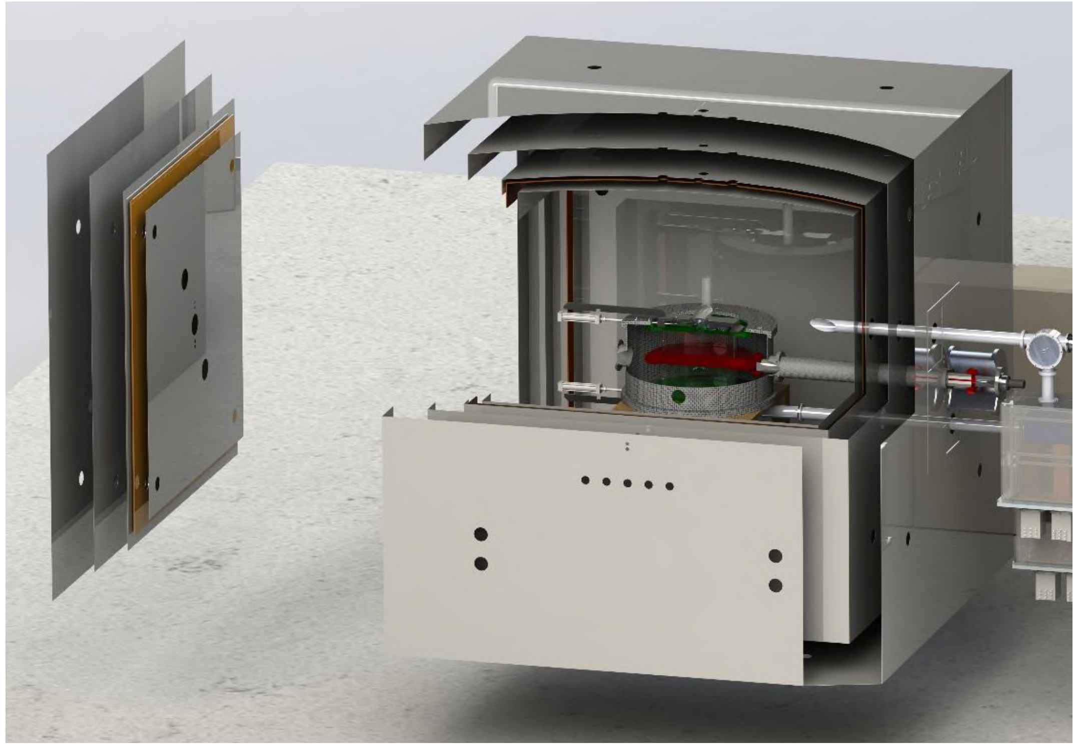
➡ Design compensation coils, to be made by 2023.

Shielding factor measurement



cf: N. Ayres et al., Rev. Sci. Inst. 93, 095105 (2022)

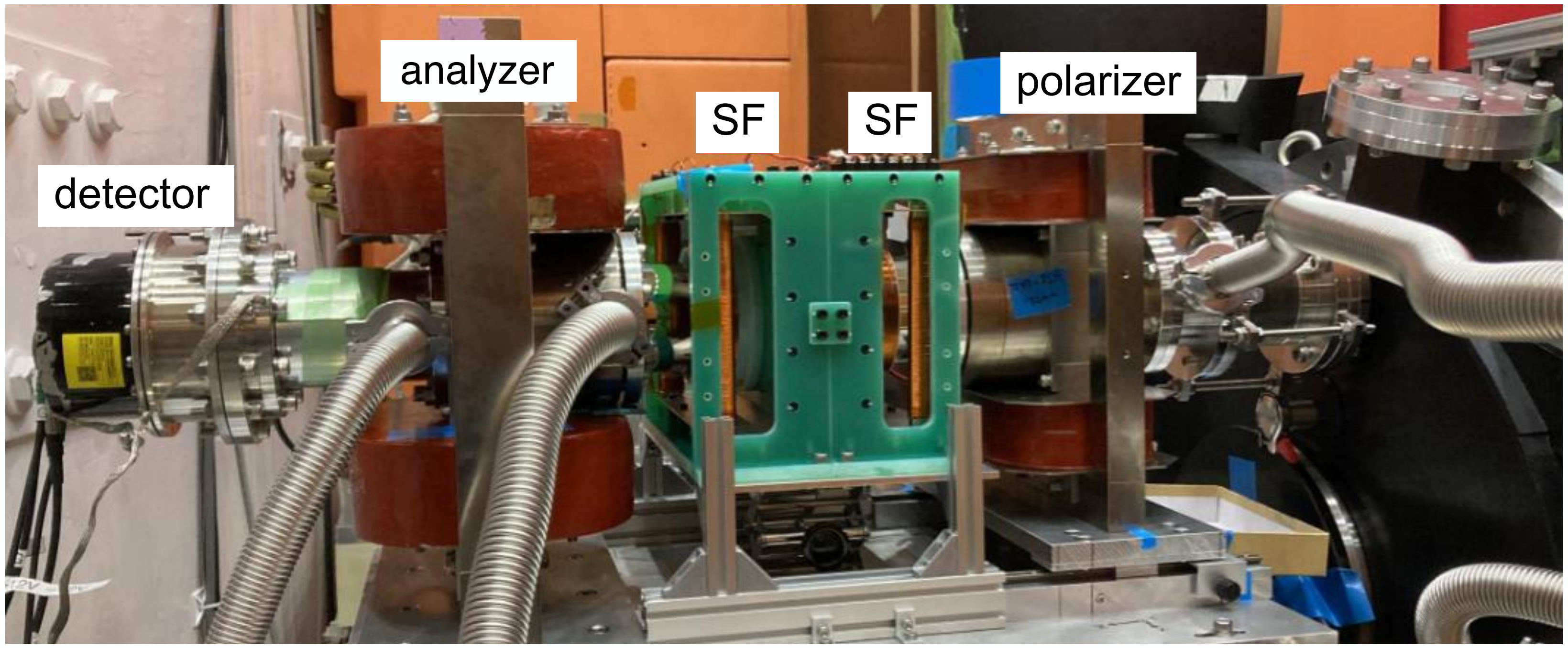
Magnetically Shielded Room

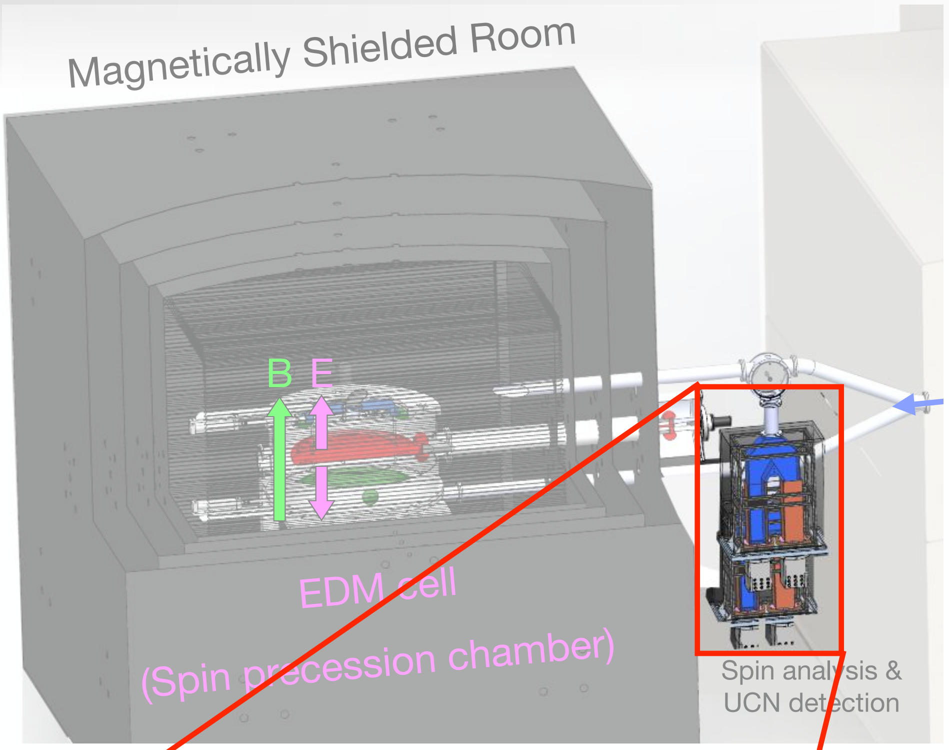


Simultaneous Spin Analyzer (SSA)

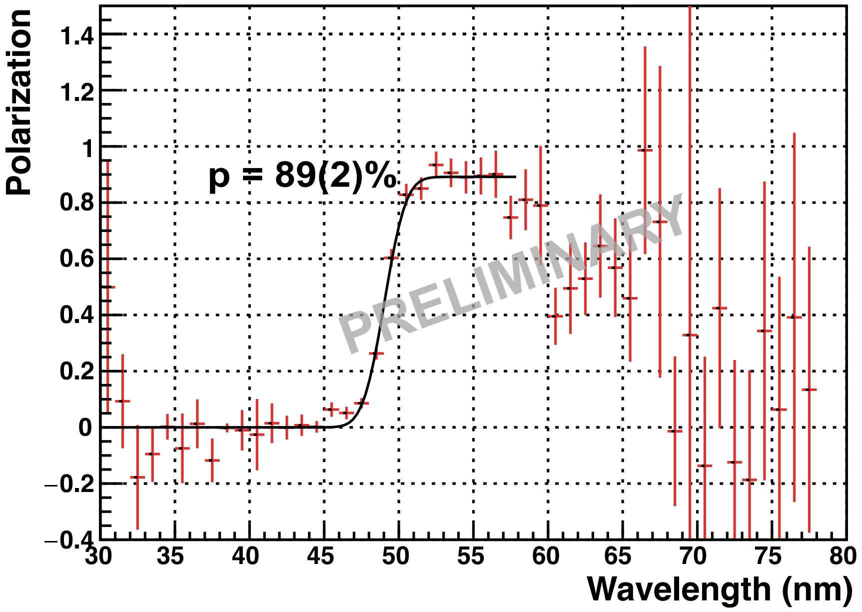
Prototype test at J-PARC

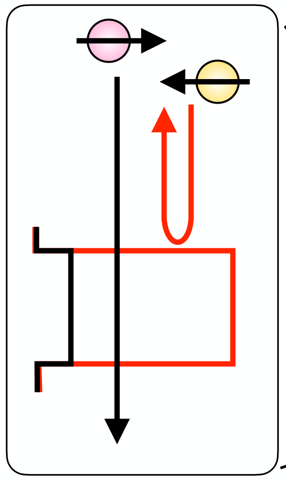
Magnetic thin film functions as an analyzer with low magnetic field.

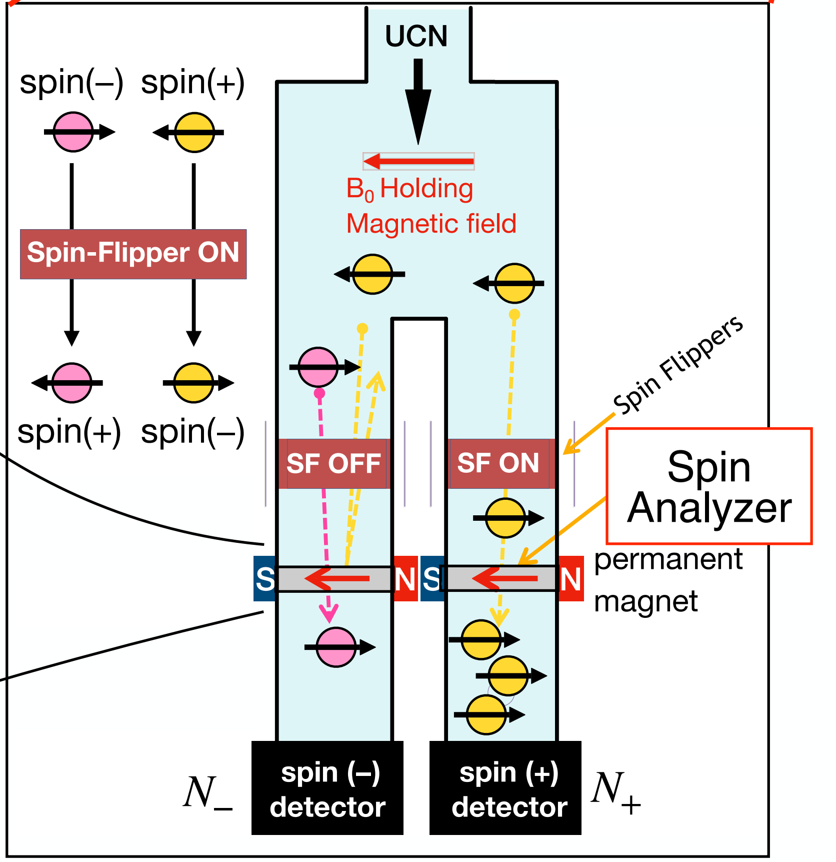




UCN polarization

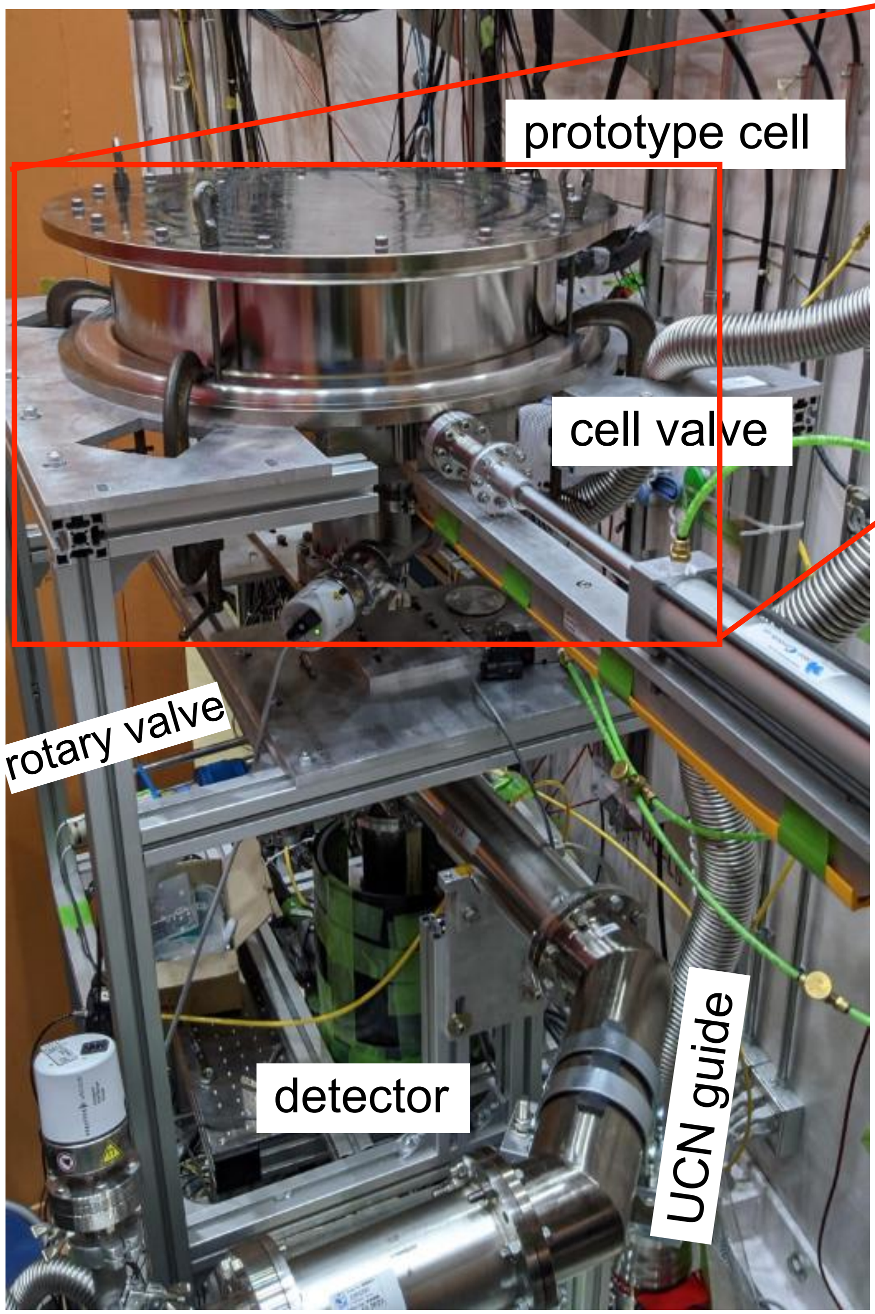


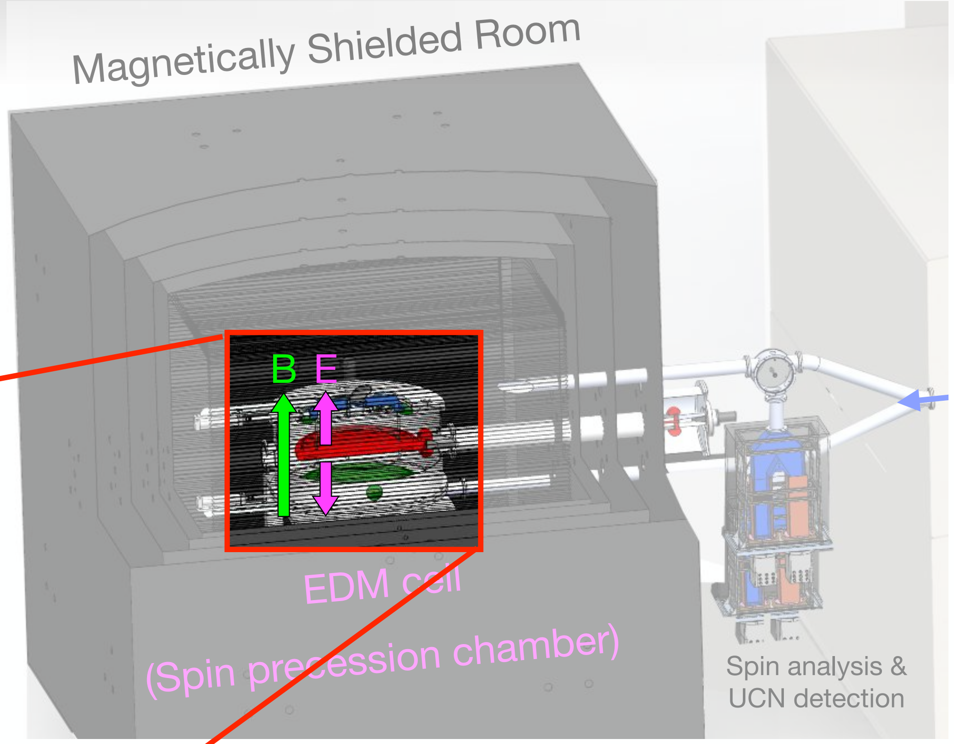




EDM cell and UCN valve

Prototype test at J-PARC

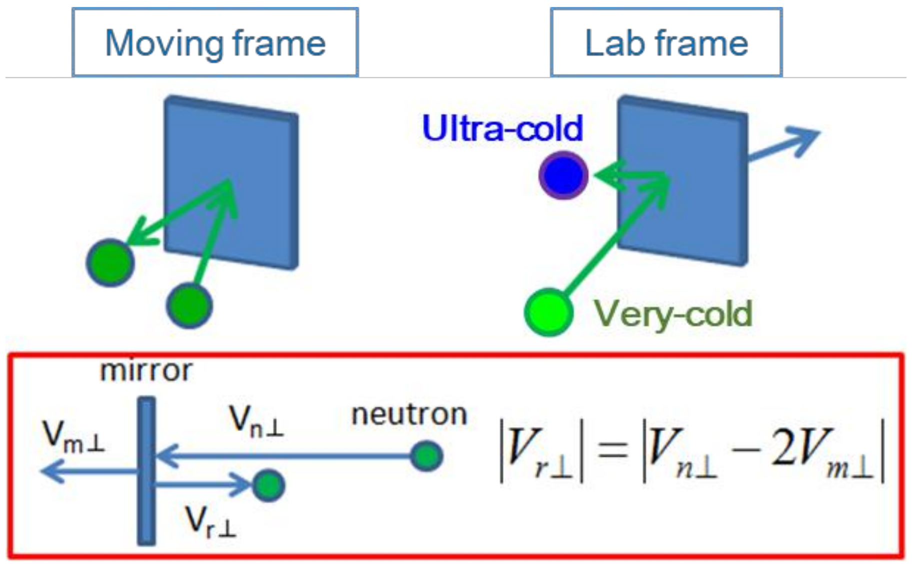


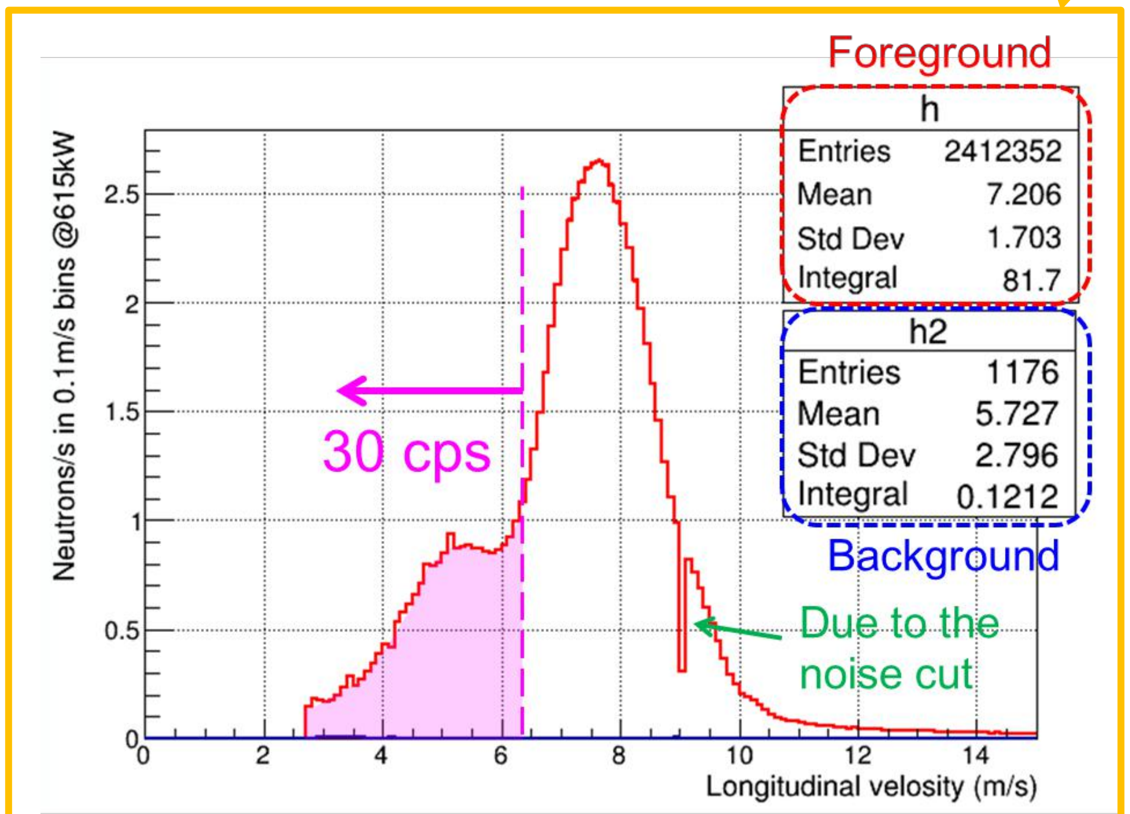


UCN doppler shifter at J-PARC

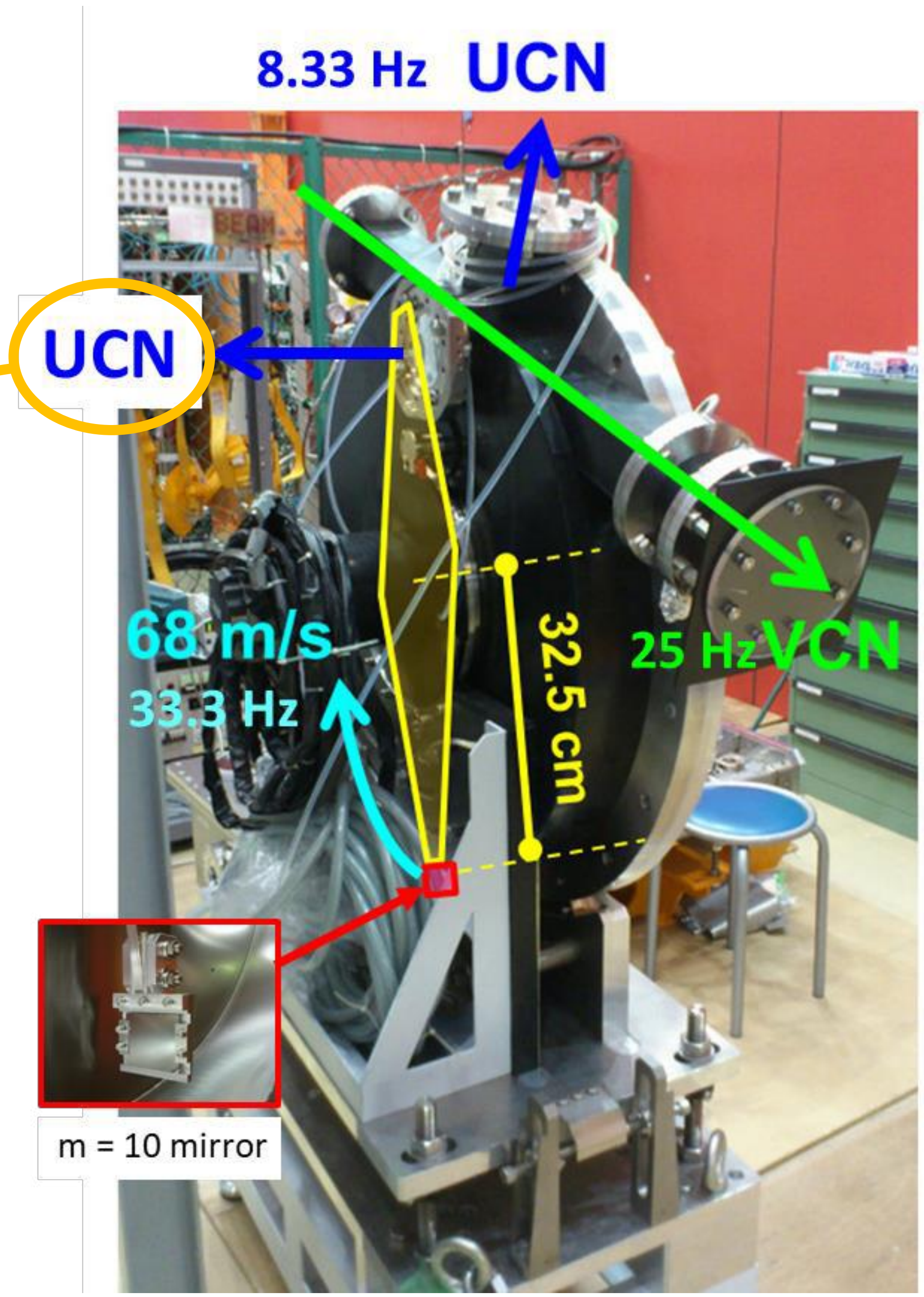
Various tests can be done with 'pulsed' UCNs.

Turn on, Get UCNs.





Velocity distribution



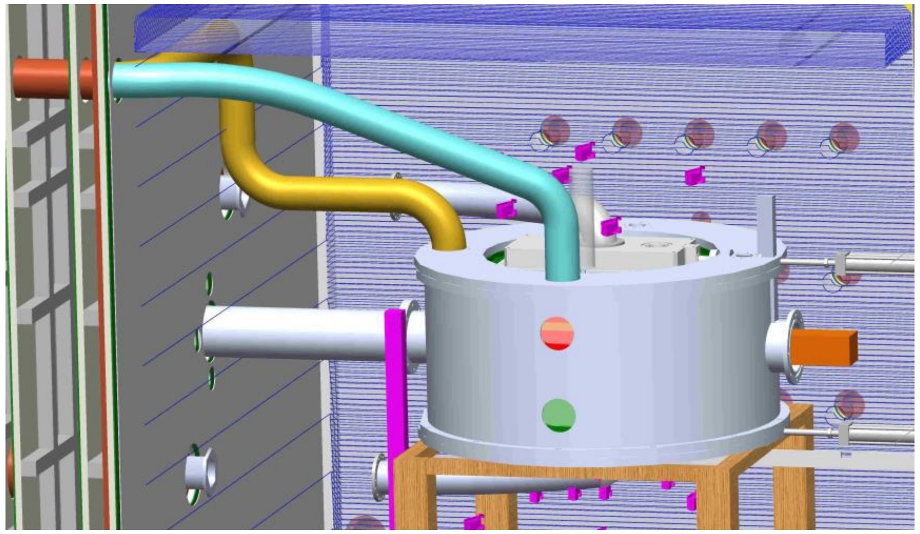
Prog. Theor. Exp. Phys. **2016**, 013C02 (2016)

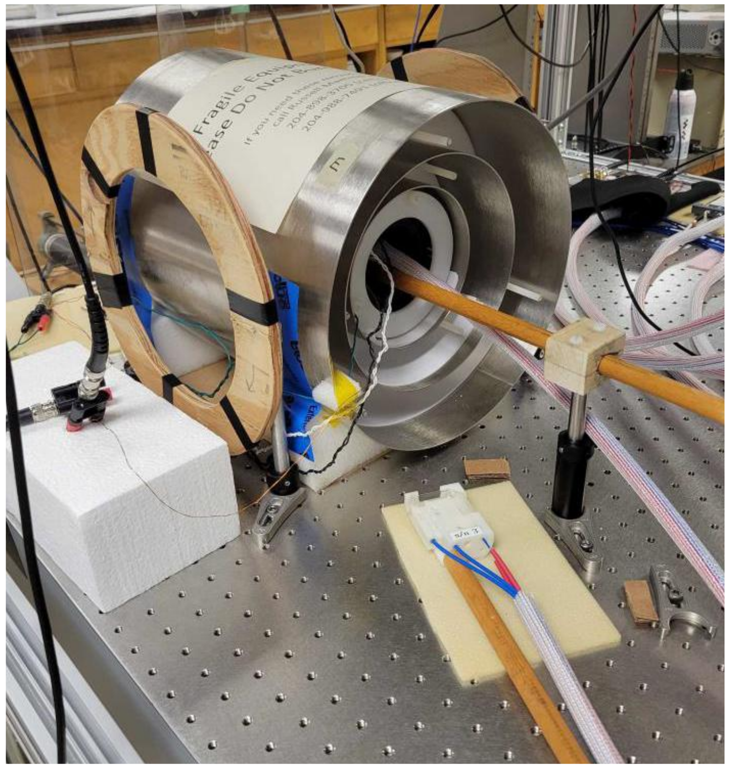
Others

Equipment in the mechanical design/construction phase

External field compensation (RCNP Osaka, TRIUMF)	design phase
UCN detector (Winnipeg)	prototype, test at J-PARC
HV/cell/valves/central region (TRIUMF)	prototype, test at J-PARC
Hg comagnetometer and Xe development lab (UBC)	prototype, prep. design
NMOR-based Cs magnetometers (Winnipeg)	5 completed, 5 on order

Cs magnetometers
Precise to ~ pT/√Hz





Prospects

Prospects

UCN source

2023- Helium cryostat install/tests

➡ installation of other source subsystems

2024- UCN production with the new source

nEDM spectrometer

2023- MSR completion

➡ magnetometers install
inner coils tests

2024- assembly and commissioning of the nEDM spectrometer

➡ 2025- nEDM data taking

UCN production rate

2×10^7 UCN/s

UCN density at production

6400 UCN/cm^3

UCN density at nEDM cell

250 Pol . UCN/cm^3

400 days (MT) ➡ $\sigma(d_n) = 1 \times 10^{-27}$ e cm

stable running of 14 hours/day

$$\sigma(d_n) = \frac{\hbar}{2\alpha E T \sqrt{N}}$$

$E = 10$ kV/cm $\quad \alpha = 0.8$

$t_c = 130$ s $\quad N = 7.8 \times 10^6$ UCN/batch

TUCAN

TRIUMF Ultra Cold Advanced Neutron source

TRIUMF KEK RCNP

THE UNIVERSITY OF BRITISH COLUMBIA · THE UNIVERSITY OF WINNIPEG · UNIVERSITY OF MANITOBA

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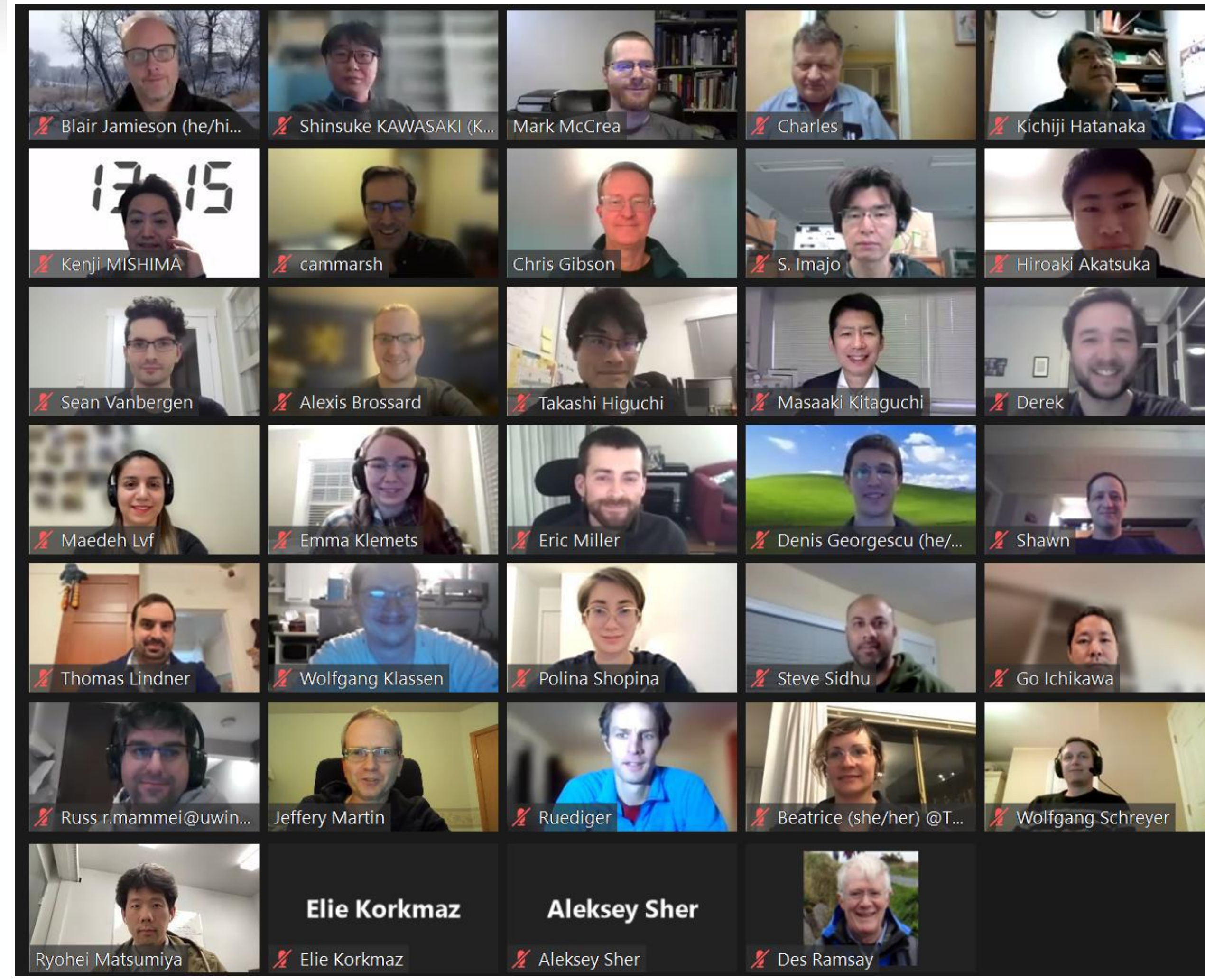

Jan. 2022 virtual collaboration meeting

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*As of 2022-Jan-22