TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Progress of the UCN facility and nEDM experiment at TRIUMF

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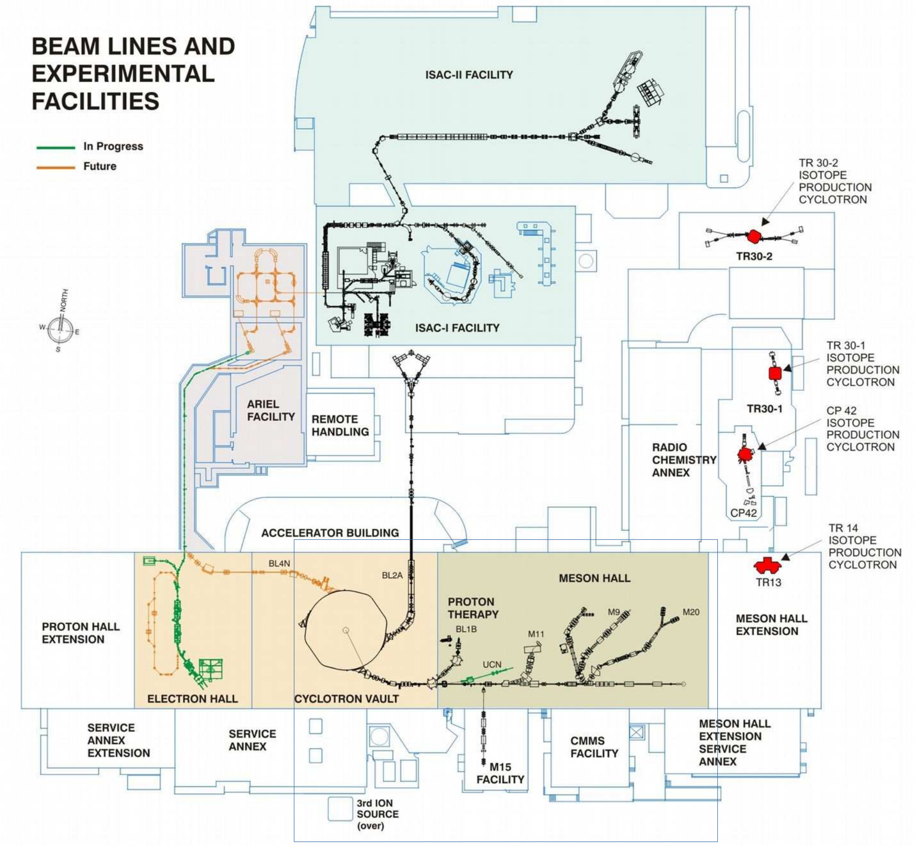
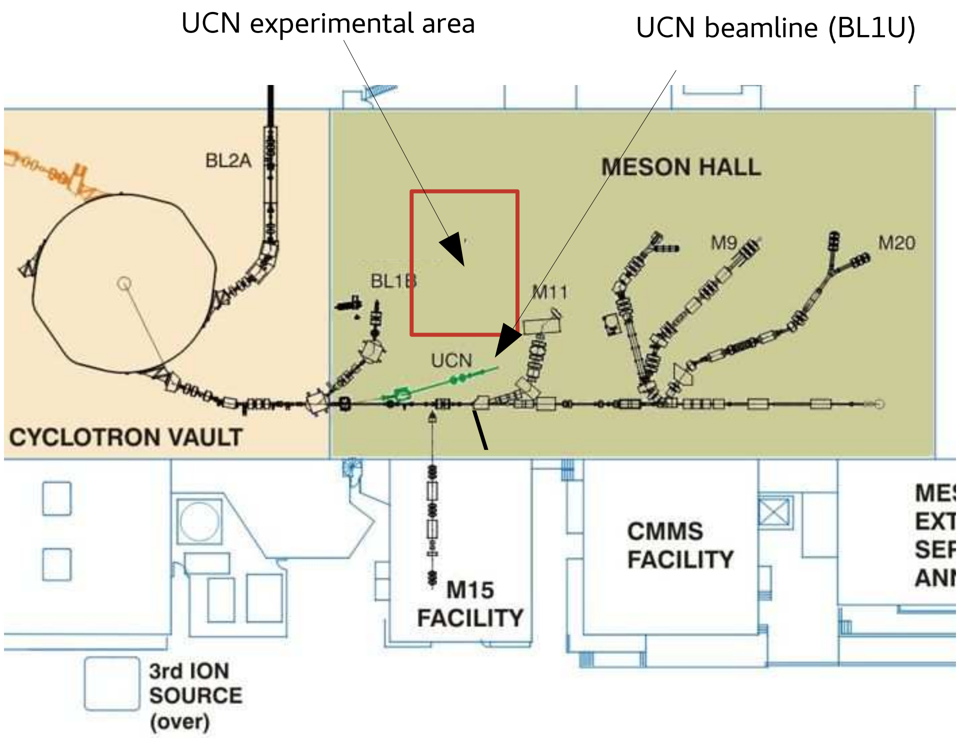
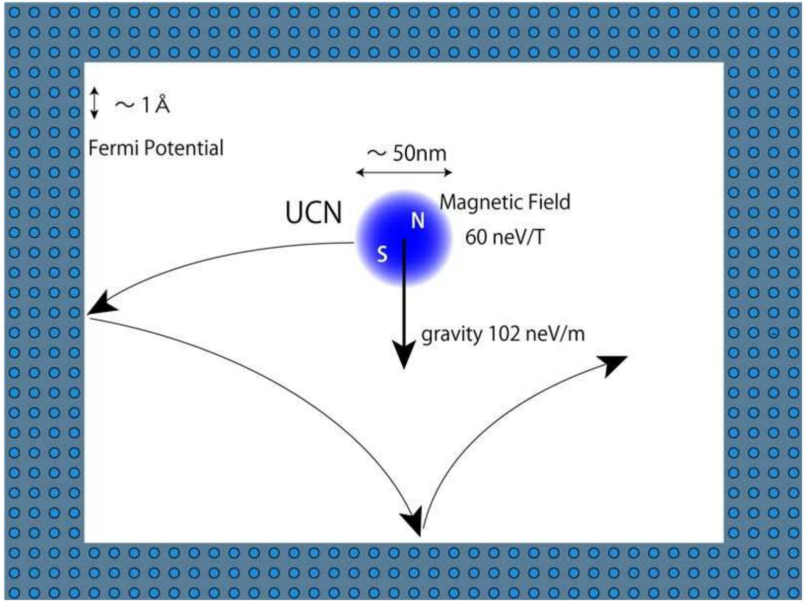

BEAM LINES AND EXPERIMENTAL FACILITIES
In Progress
Future
ISAC-II FACILITY
ISAC-I FACILITY
TR 30-2 ISOTOPE PRODUCTION CYCLOTRON
TR30-2
TR 30-1 ISOTOPE PRODUCTION CYCLOTRON
TR30-1
CP 42 ISOTOPE PRODUCTION CYCLOTRON
CP42
TR 14 ISOTOPE PRODUCTION CYCLOTRON
TR13
ARIEL FACILITY
REMOTE HANDLING
RADIO CHEMISTRY ANNEX
ACCELERATOR BUILDING
BL4N
BL2A
MESON HALL
PROTON THERAPY
BL1B
M11
M9
M20
UCN
PROTON HALL EXTENSION
MESON HALL EXTENSION
ELECTRON HALL
CYCLOTRON VAULT
SERVICE ANNEX EXTENSION
SERVICE ANNEX
M15 FACILITY
CMMS FACILITY
MESON HALL EXTENSION SERVICE ANNEX
3rd ION SOURCE (over)



<u>Goal:</u> Establish UCN user facility with two UCN ports and attract international scientific community.

Energy	~ 100 neV
Velocity	~ 5 m/s
Wavelength	~ 50 nm



<u>Interactions:</u>

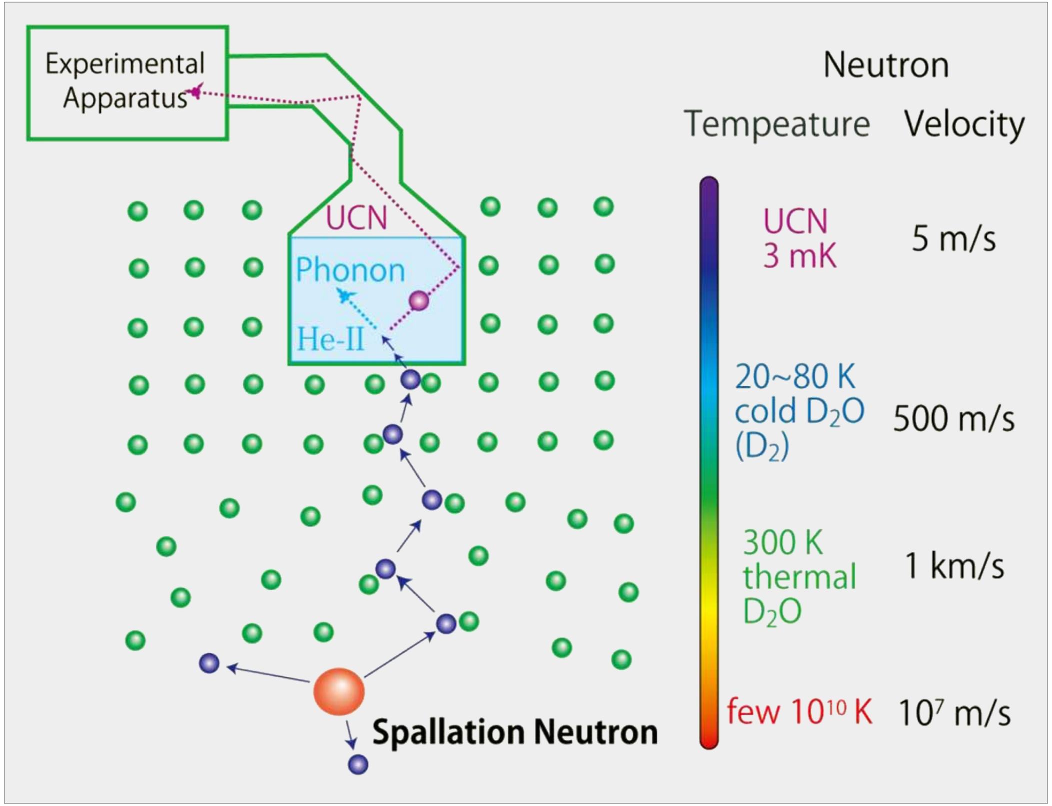
Gravity	100 neV/m
Magnetic field	60 neV/T
Weak interaction	β-decay n → p + e, $T_{1/2}$ ~ 880s
Strong interaction	Fermi potential 335 neV (^{58}Ni) (atom distance : ~ 1 Å)

UCN 'feel' average nuclear potential

UCN can be confined in material bottle

→ long observation times on order of $T_{1/2}$

Combination of spallation neutron source and superfluid helium converter



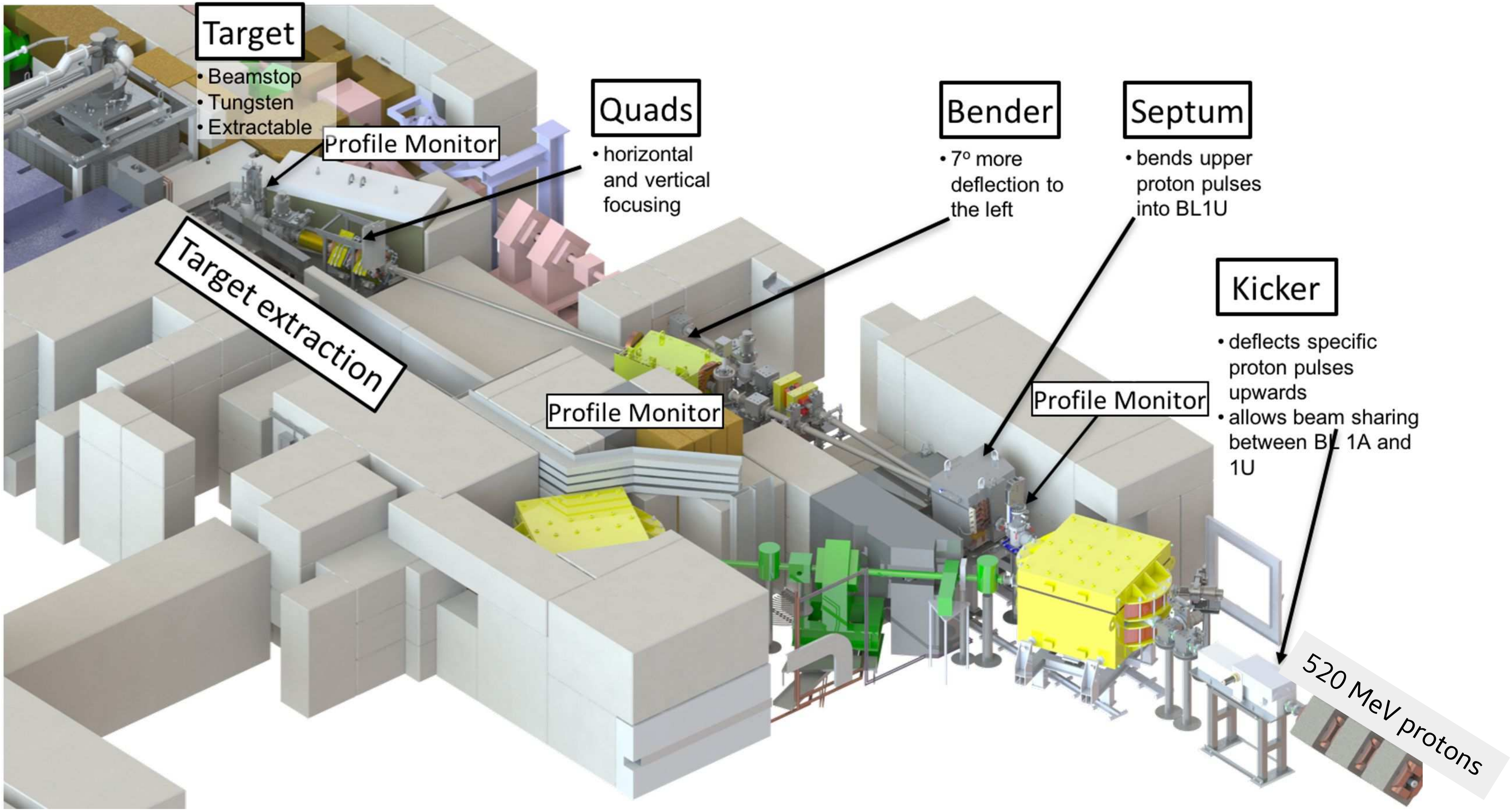
- D_2O, ice D_2O, LD_2 moderator (300K, 20K)
- phonon down-scattering in He-II

Features of the source:

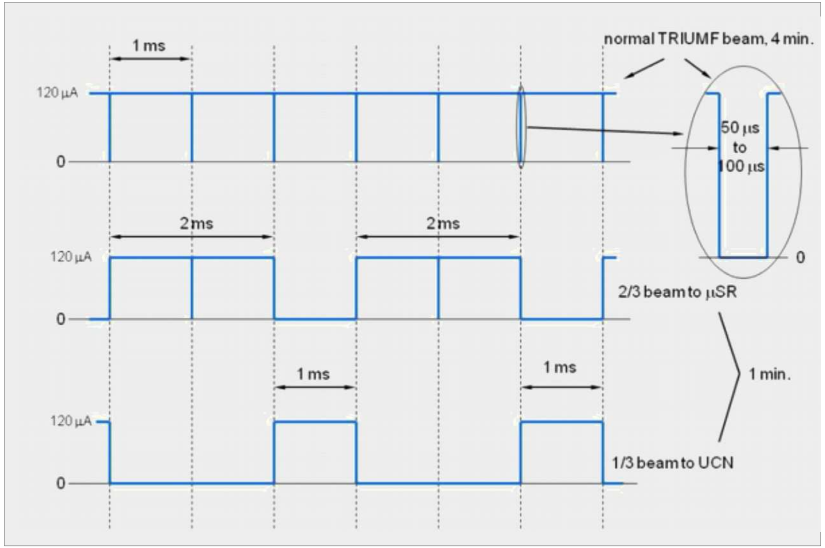
- Small distance between spallation target and UCN production volume
  - heat-load
- Long storage lifetime in superfluid helium:
  - $\tau_s \sim T^{-7}$

Storage time τ_s	He-II temperature
600 s	0.8 K
36 s	1.2 K

UCN beamline: Overview



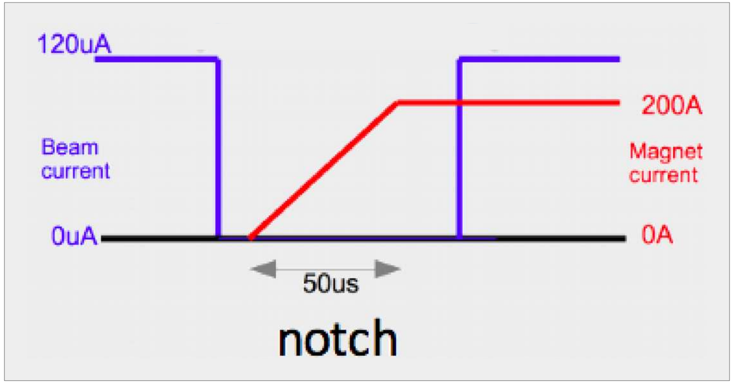
<u>TRIUMF beam structure:</u> 120 μA pulse for 1 ms
no beam for 50-100 μs



Kicker ramps up during beam notch (200 A/50 μs)

- kicks every 3rd pulse to BL1U (UCN)
- average of 40 μA for UCN

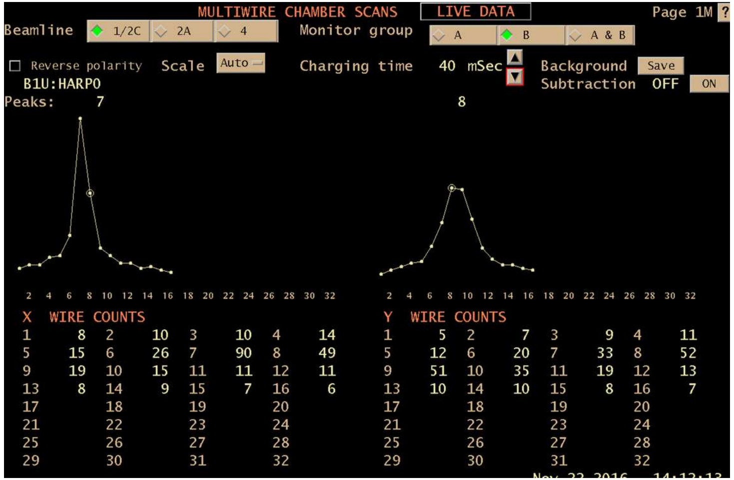
- currently limited to 1 μA (every 120th pulse)



Timing of target irradiations:

- Balance of UCN density accumulation and heat load
- Planning target irradiation time of ~ 60 s

- First beam on target Nov 2016
- New UCN beamline commissioned
- Kicker commissioned
- Operator training and handover



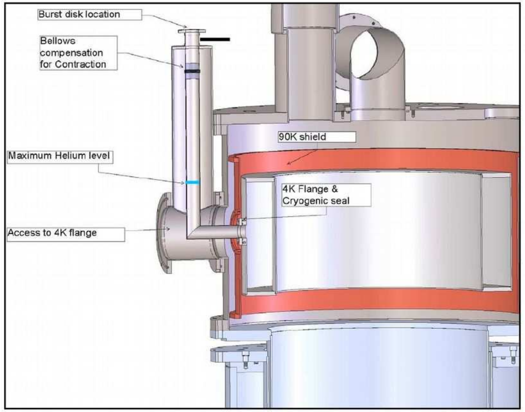
Vertical UCN source developed at RCNP

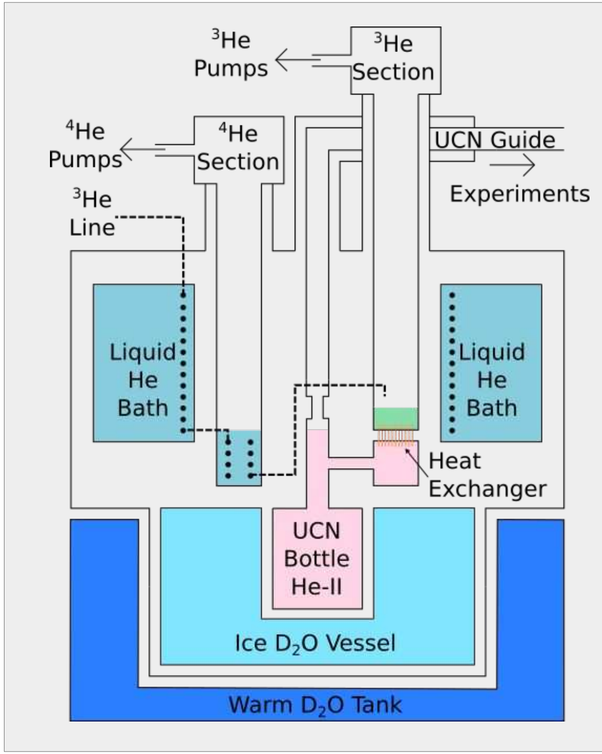
Cooling stages:

- 60L liquid helium bath
- 1 K pot
- ^{3}He pot and heat exchanger

Final $T^{\text{He-II}}$ = 0.8 K
UCN lifetime: 81 sec
UCN density: 9 UCN/cm^3

2016 Oct	Move to TRIUMF
2016 Nov-Jan	Savety modifications
2017 Jan–Apr	Installation





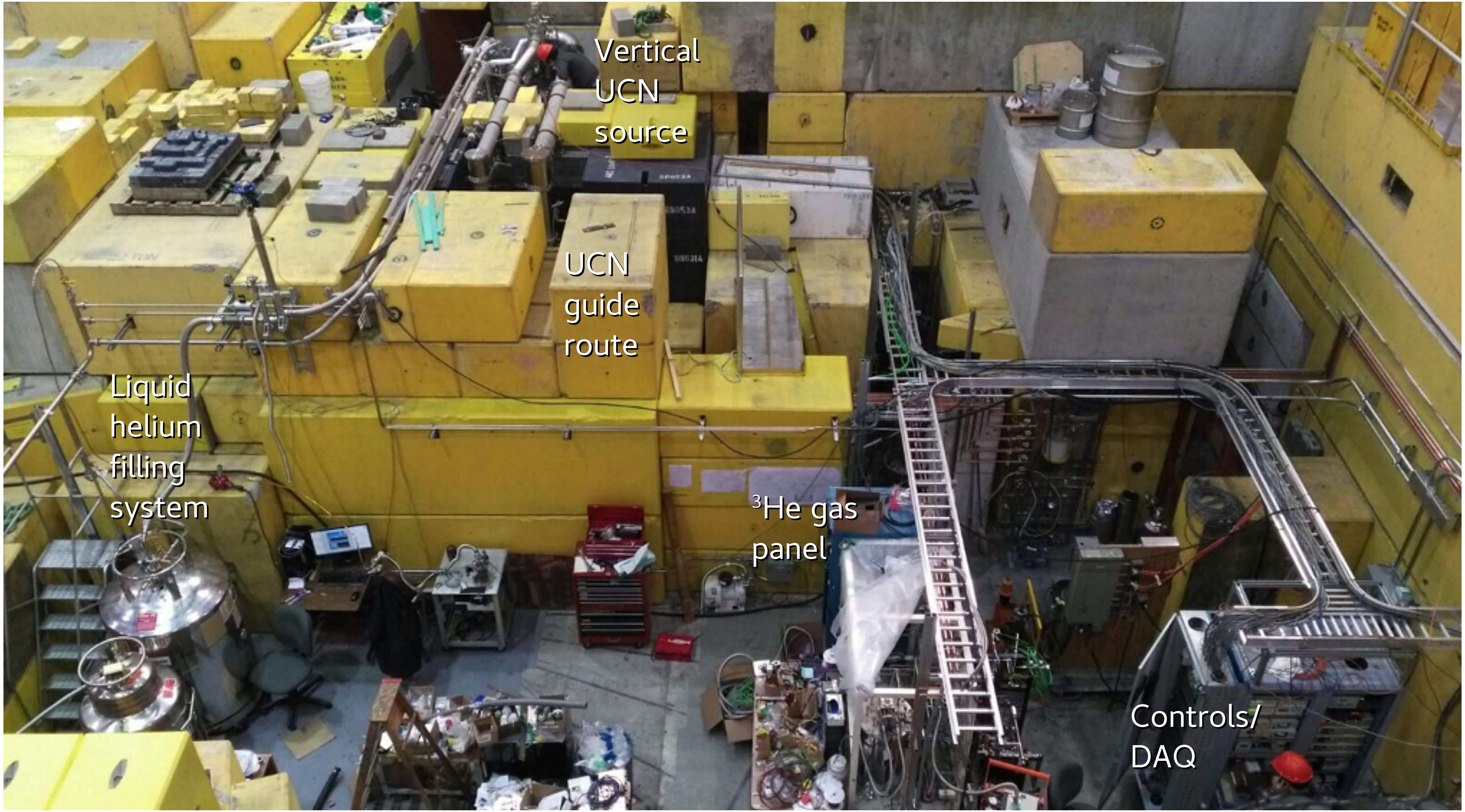
Masuda et. al., Phys. Rev. Lett. **108**, 134801 (2012)

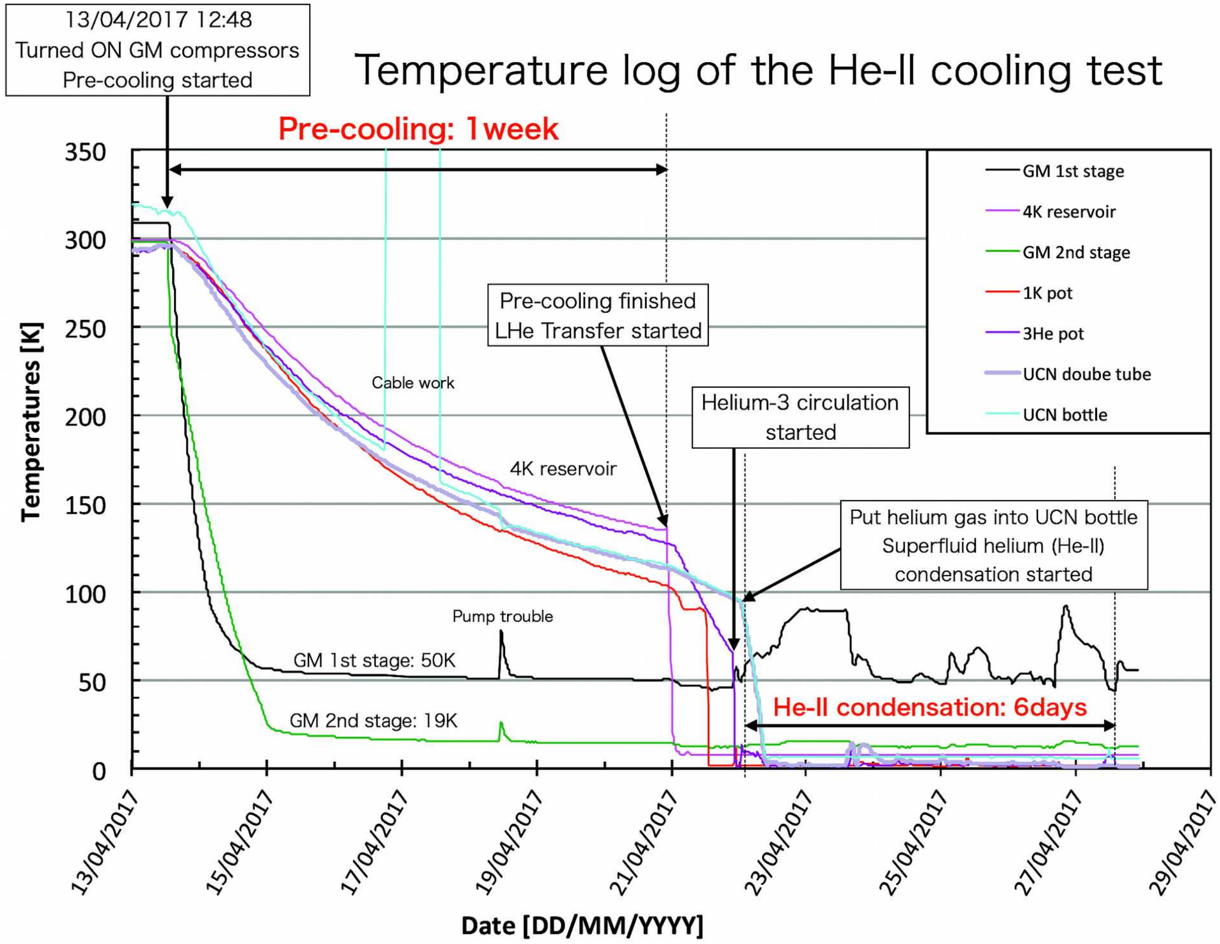
Vertical UCN source installation

Vertical UCN source installation timelapse

Vertical UCN source installation timelapse

Vertical UCN source installation





- Full cooling test in April 2017
- Final temperature 0.92 K
- 8 L of liquid He-II condensated

Shortage of liquid helium delayed condensation:

- TRIUMF helium liquefier plant now upgraded by liquid nitrogen
- Liquid helium supply of 50 L/hr

2016 Oct	Move to TRIUMF
2016 Nov-Jan	Savety modifications
2017 Jan–Apr	Installation
2017 Apr-May	Cooling test ($T^{He\text{-}II}$ = 0.9 K)
2017 Aug	**^{3}He line blockage**
2017 Nov	UCN production

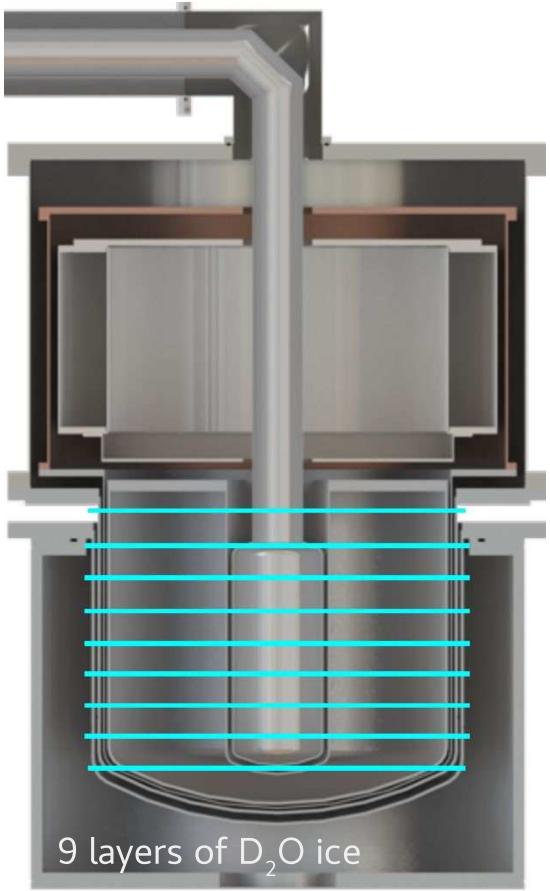
Just restarted cooling process:

- D_2O moderator filling/cooling (1-2 weeks)
- liquid helium filling (1 day)
- ^{3}He circulation (1 day)
- condensation of isopure helium (3 days)

-> possible first UCN production: **Nov 11th**

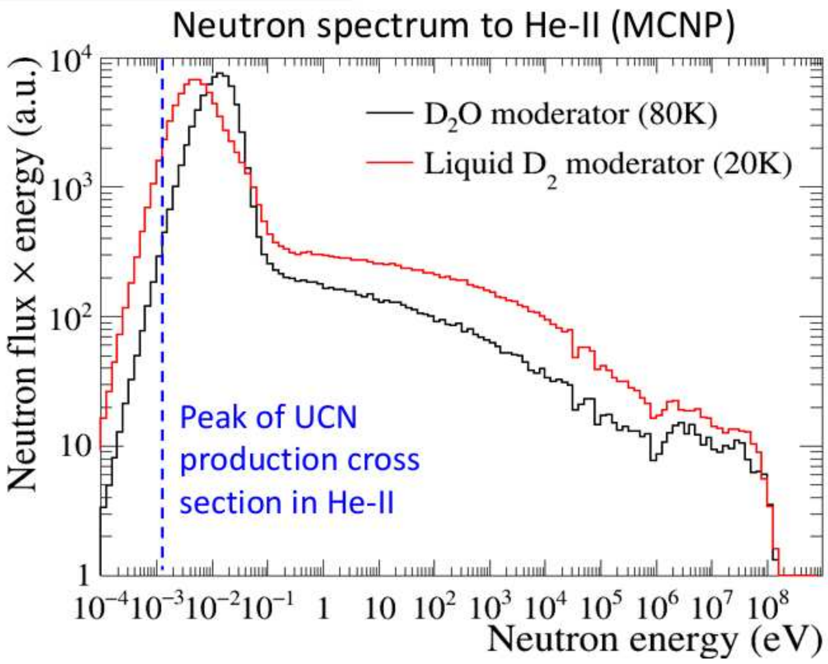
Expectation: 10^5 UCN for 60s irradiation, several UCN/cm^3

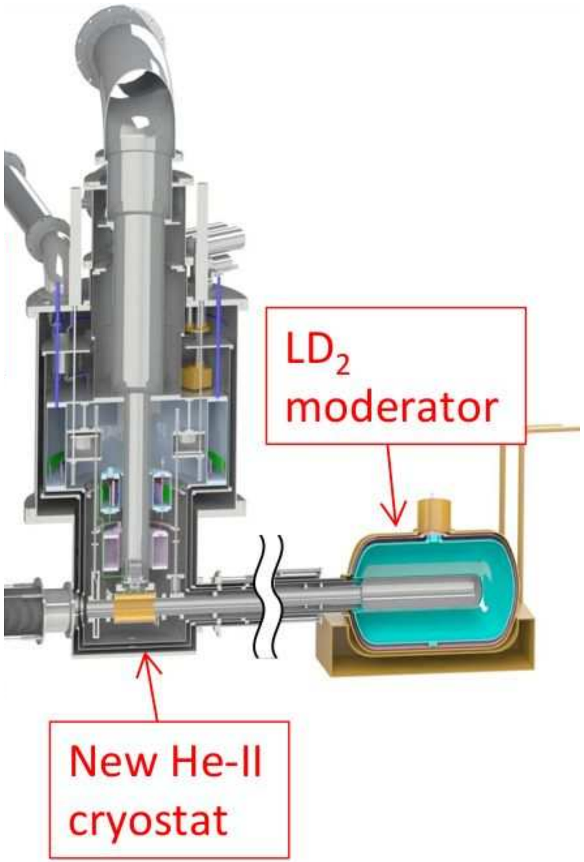
→ Factor 100 with newly developed phase-II source (2-3 years)



Liquid D_2 moderator will increase the cold neutron flux to He-II

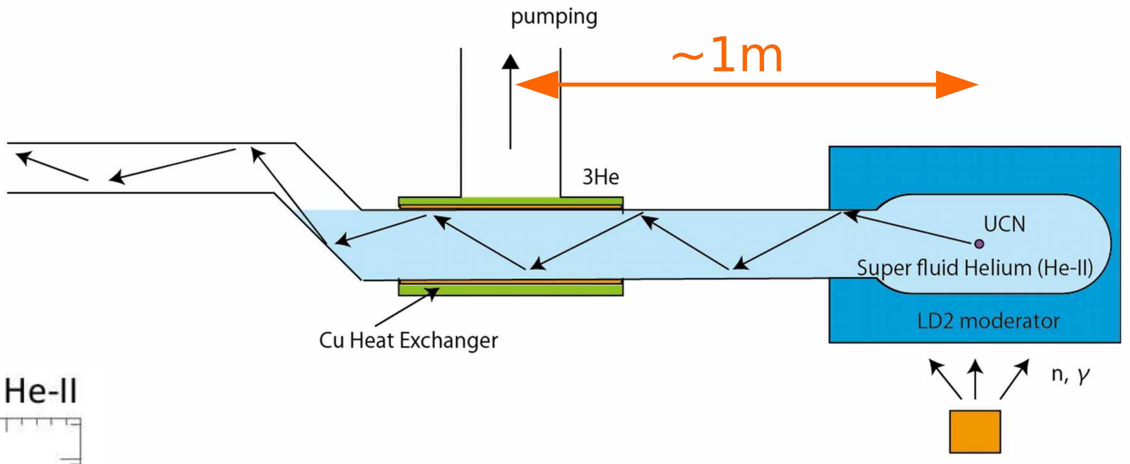
- Safety issue: liquid D_2 volume order of 20 L max
- Optimizing the geometry by MC simulation
- 5–9 times larger cold neutron flux achievable vs. ice D_2O

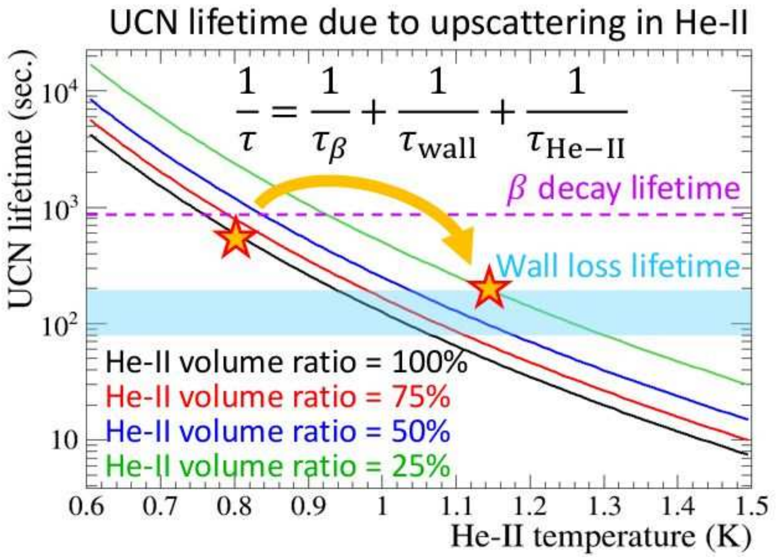




Confine He-II by gravity

- Heat transfer in superfluid helium only sufficient for 1m distance
- Relaxed the target temperature of He-II to 1.0-1.2K



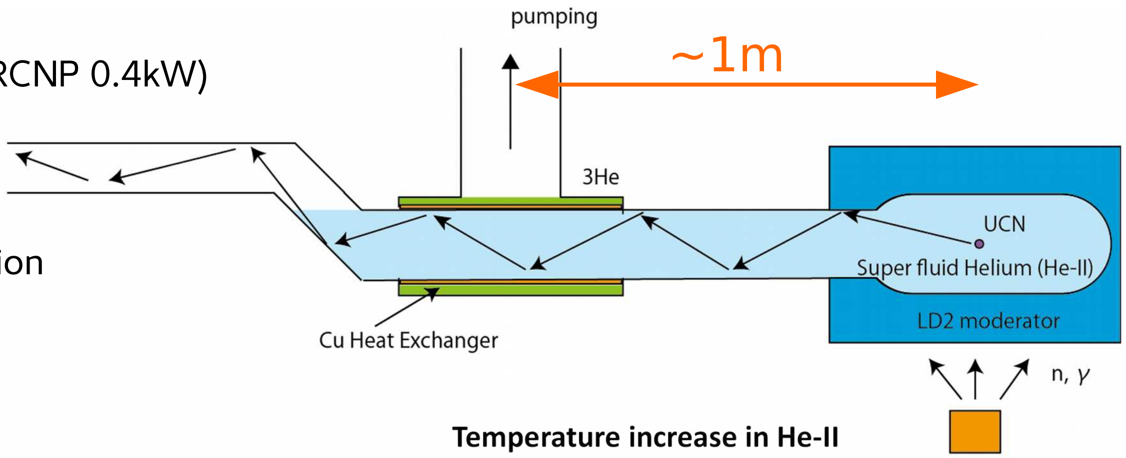


Cooling method options

- Heat exchange with 3 He (primary)
- Direct pumping of He-II (alternative)

Reduce He-II/vacuum volume ratio to ~25%

Proton beam power @ TRIUMF: 20 kW (RCNP 0.4kW)



Expected heat load on superfluid production volume (20 L): up to 10 W (at 1 K)

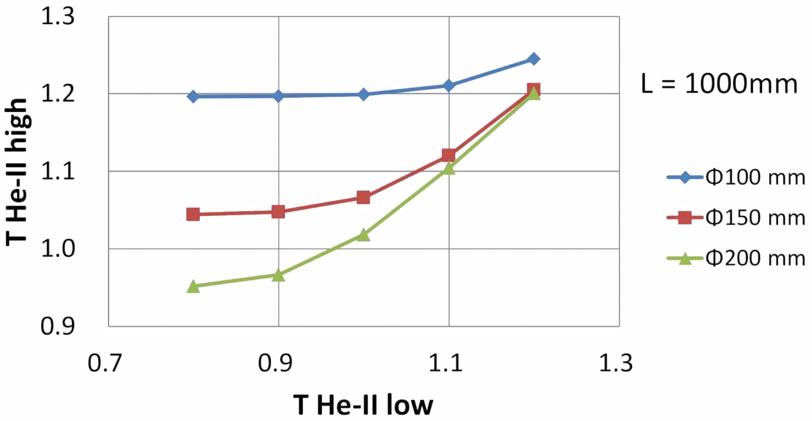
d=150 mm, L=1 m
pumping speed 10,000 m^3/hour

<u>Resulting temperature distribution</u>

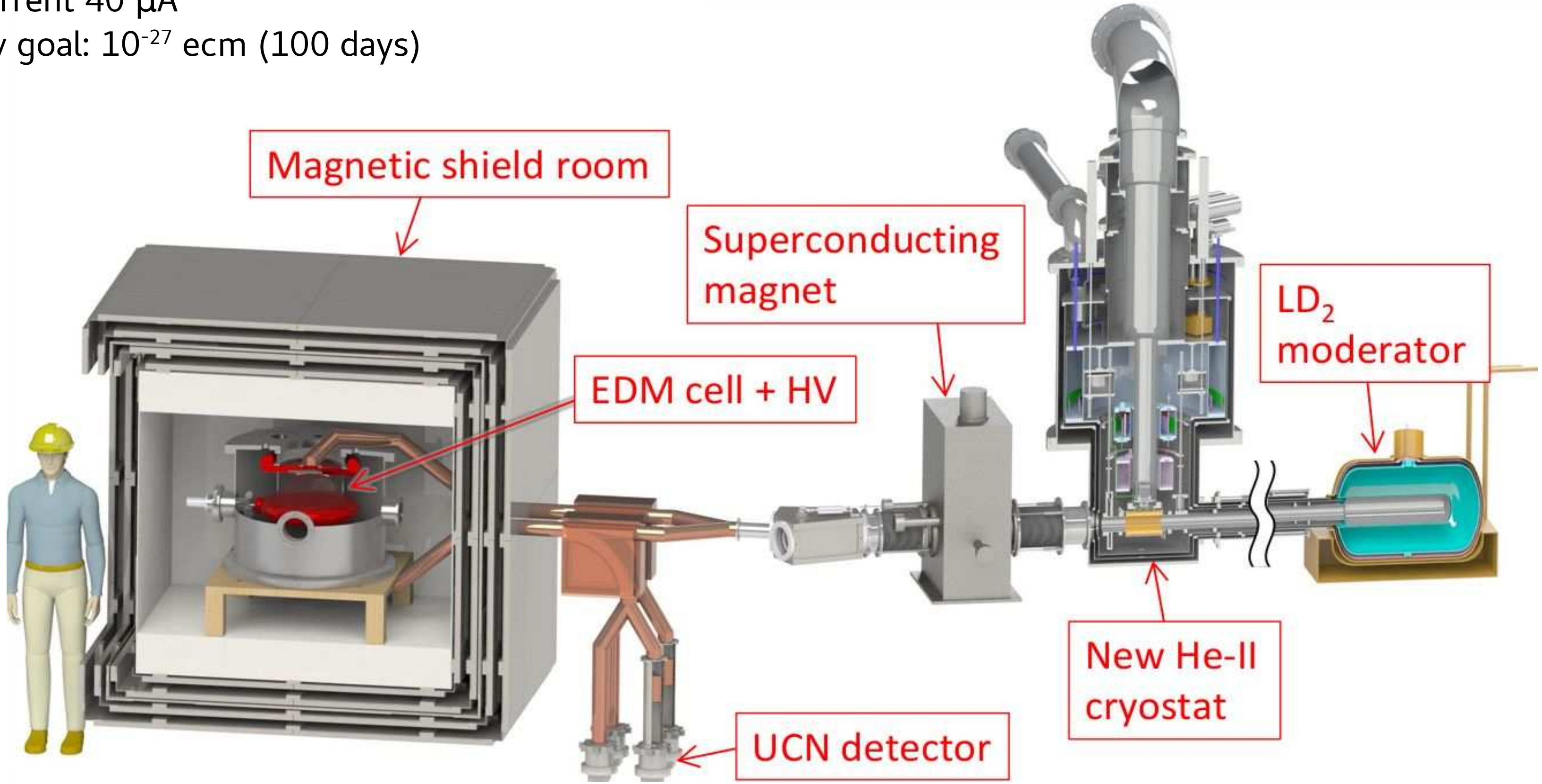
He-II high:	1.06 K ($\tau_{up\text{-}scat}$ = 87 sec)
He-II low:	1.00 K
Cu high:	0.84K
Cu low:	0.83 K
3He:	0.75 K

ΔT = 0.31 K

Temperature increase in He-II
10 W heat load



- Upgrade the UCN source and install EDM apparatus (aiming to be ready in 2020)
- Proton current 40 μA
- Sensitivity goal: 10^{-27} ecm (100 days)



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

α: Visibility (spin polarization)
E: Electric field
T: Spin presession time
N: Number of UCN

Sensitivity reach (based on simulation)

$N_0 = 2 \times 10^7$ UCN
$\alpha_0 = 0.95$
$E = 12$ kV/cm

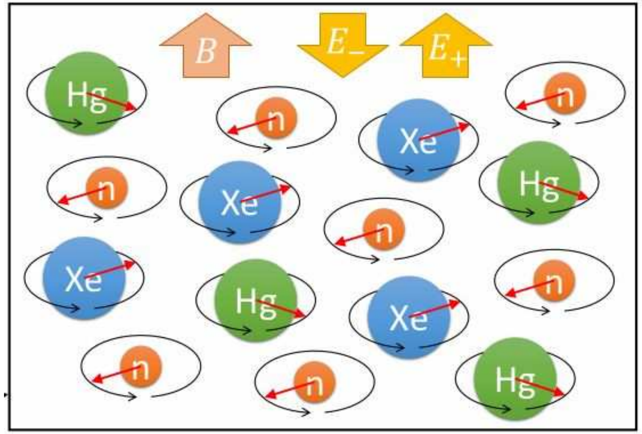
$\tau_{cell} = 100$ sec.
$T_1 = 2000$ sec.
$T_2 = 1000$ sec.
$T = 100$ sec.

$\sigma_{stat} = 5 \times 10^{-26}$ e·cm per cycle
$\sigma_{stat} = 10^{-27}$ e·cm in 100 days

Features/goals:

- UCN densitiy inside EDM cell >100 cm^{-3}
- Dual-comagnetometer inside EDM cell (^{199}Hg/^{129}Xe)
- EDM experiment inside magnetically shielded room
- Simultanous spin detection

Comagnetometry by atoms



- Installation of vertical UCN source cryostat in 2017
- UCN beamline (and kicker) ready!
- First UCN production at TRIUMF hopefully in 2017
- Design of new UCN source ongoing (>10^7 UCN/s)
- Meanwhile also neutron EDM design/R&D
- Received CAD 15.7 million infrastructure funds (CFI)
- Future UCN user facility

TUCAN collaboration

TRIUMF Ultra Cold Advanced Neutron source

KEK	T. Adachi, S. Jeong, S. Kawasaki, Y. Makida, K. Mishima, T. Okamura, Y. Watanabe
U Nagoya	M. Kitaguchi, H. Shimizu
RCNP Osaka	K. Hatanaka, I. Tanihata, R. Matsumiya (also TRIUMF), E. Pierre (also TRIUMF)
UBC	E. Altiere, D. Jones, K. Madison, E. Miller, T. Momose, T. Hayamizu
U Wininipeg	Ch. Bidinosti, B. Jamieson, R. Mammei (also TRIUMF), J. Martin
U Manitoba	T. Andalib, J. Birchall, M. Gericke, M. Lang, J. Mammei, S. Page, L. Rebenitsch, S. Hansen-Romu, S. Ahmed
TRIUMF	Ch. Davis, B. Franke, K. Katsika, T. Kikawa, A. Konaka (also Uvic and Osaka U.), F. Kuchler, L. Lee, R. Picker (also SFU), W. Ramsey, W. Van Oers (aslo U. Manitoba), T. Lindner (also UW)
UNBC	E. Korkmaz
SFU	J.Sonier

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Thank you!
Merci!

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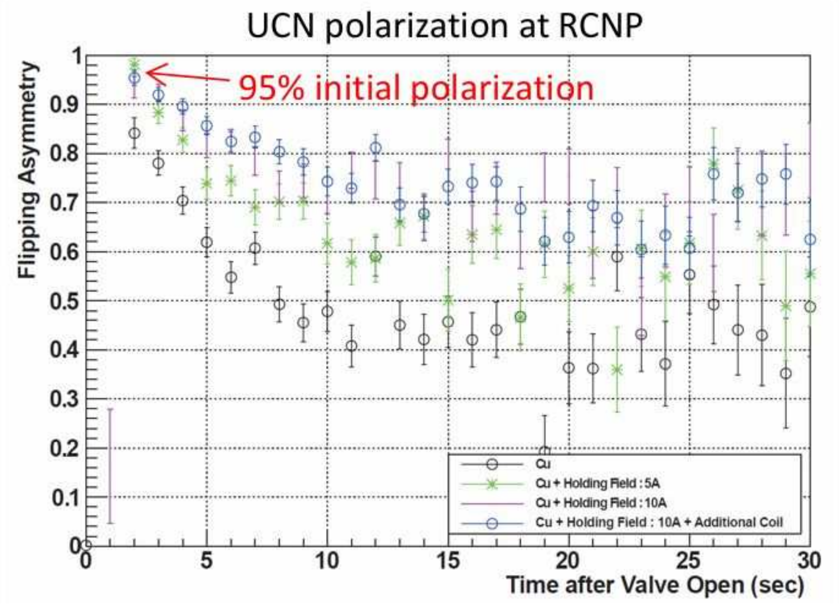
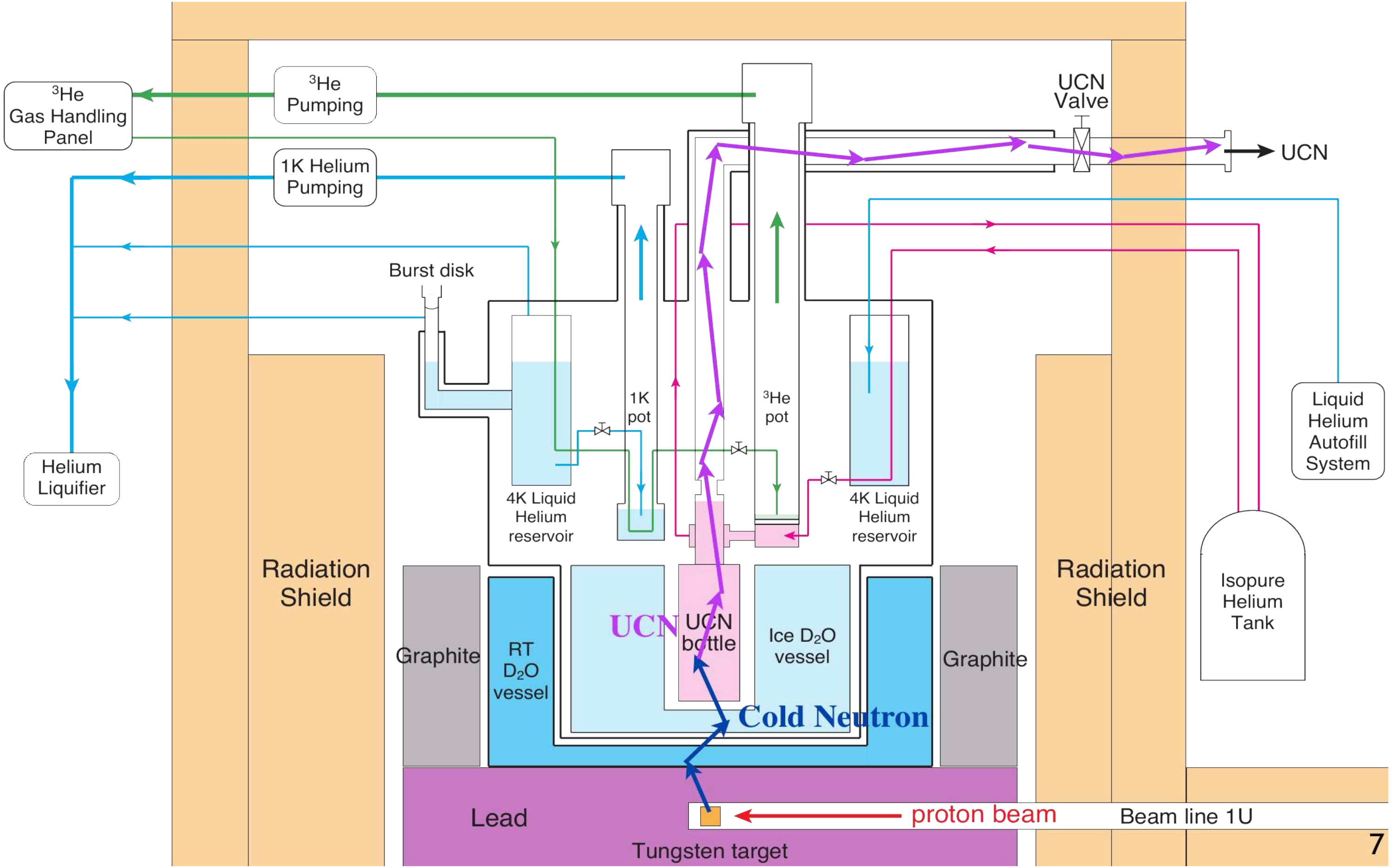
Superconducting polarizer was developed at RCNP and shipped to TRIUMF

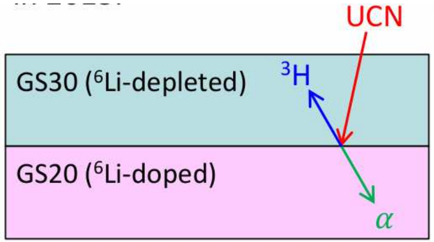
- Produce 3.75T magnetic field at the center.
- 95% UCN polarization was achieved at RCNP



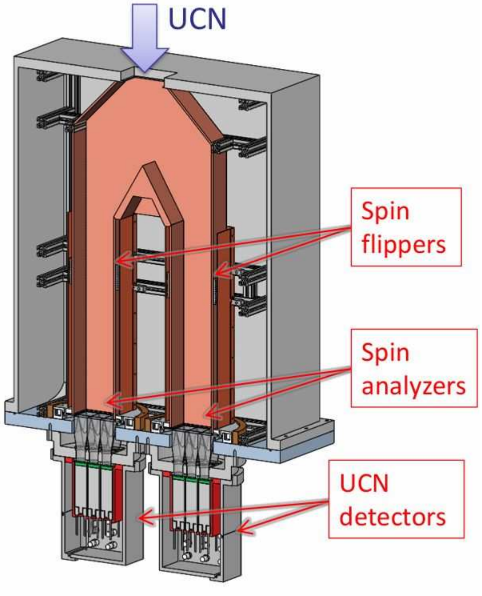

^{3}He Gas Handling Panel
^{3}He Pumping
1K Helium Pumping
Helium Liquifier
Burst disk
UCN Valve
UCN
Liquid Helium Autofill System
Isopure Helium Tank
1K pot
^{3}He pot
4K Liquid Helium reservoir
4K Liquid Helium reservoir
Radiation Shield
Radiation Shield
Graphite
Graphite
RT D$_2$O vessel
UCN
UCN bottle
Ice D$_2$O vessel
Cold Neutron
Lead
proton beam
Beam line 1U
Tungsten target

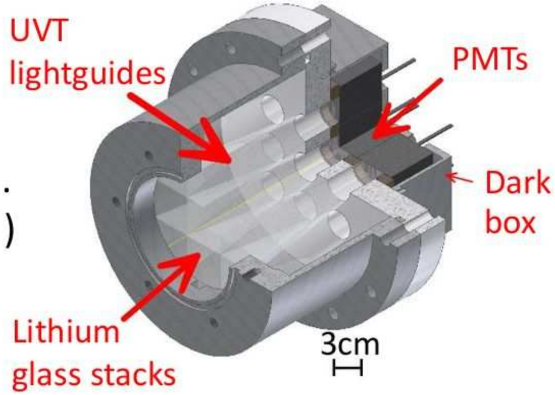
High rate counting (>1.3MHz) and UVT efficiency stability (0.05% / hour) lightguides are required

- Detection via neutron capture in 6 Li: 6 Li + n → 3 H(2.73MeV) + α(2.05MeV)
- Detector was well characterized by beam test at PSI UCN beamline
- Increase the UCN statistics by measuring both spin state simultaneously
- Increase visibility due to less depolarization while storing above analyzer foil

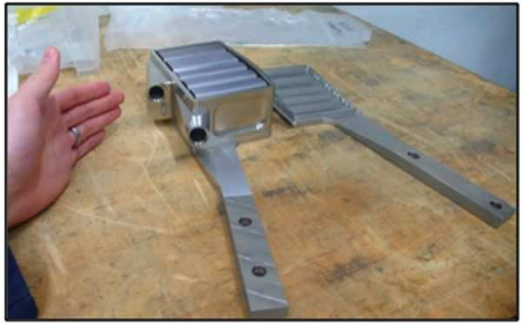


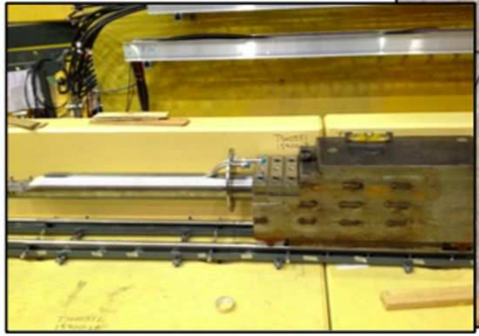
Layout of simultaneous spin analysis

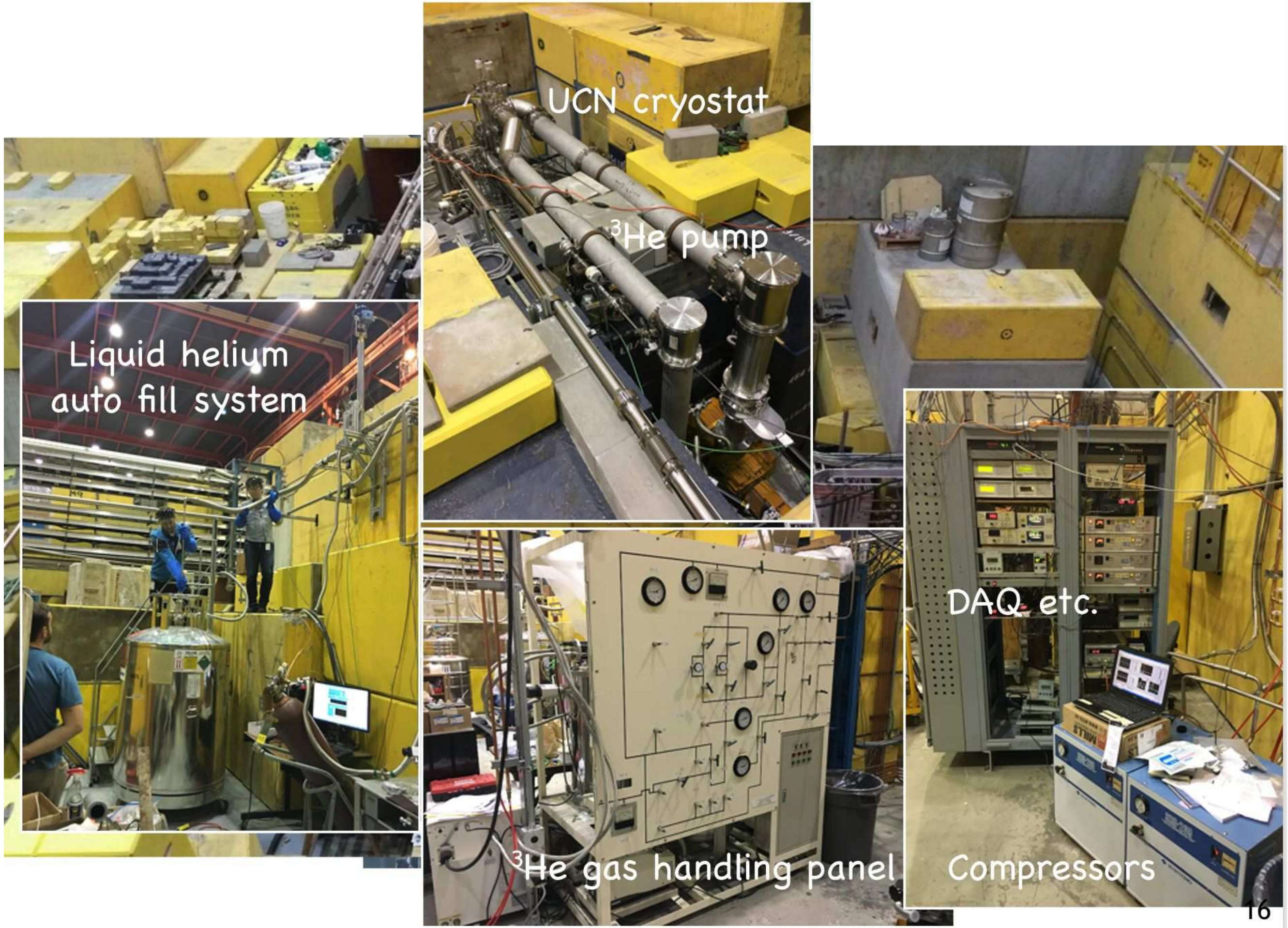




- UCN target: tantalum-clad tungsten.
- Installed during Winter 2016.
- Water cooling; 14kW of heat to remove (at final power)
  - Need to deal with activated water. Finishing commissioning water package now.
- Have system for remotely removing UCN target

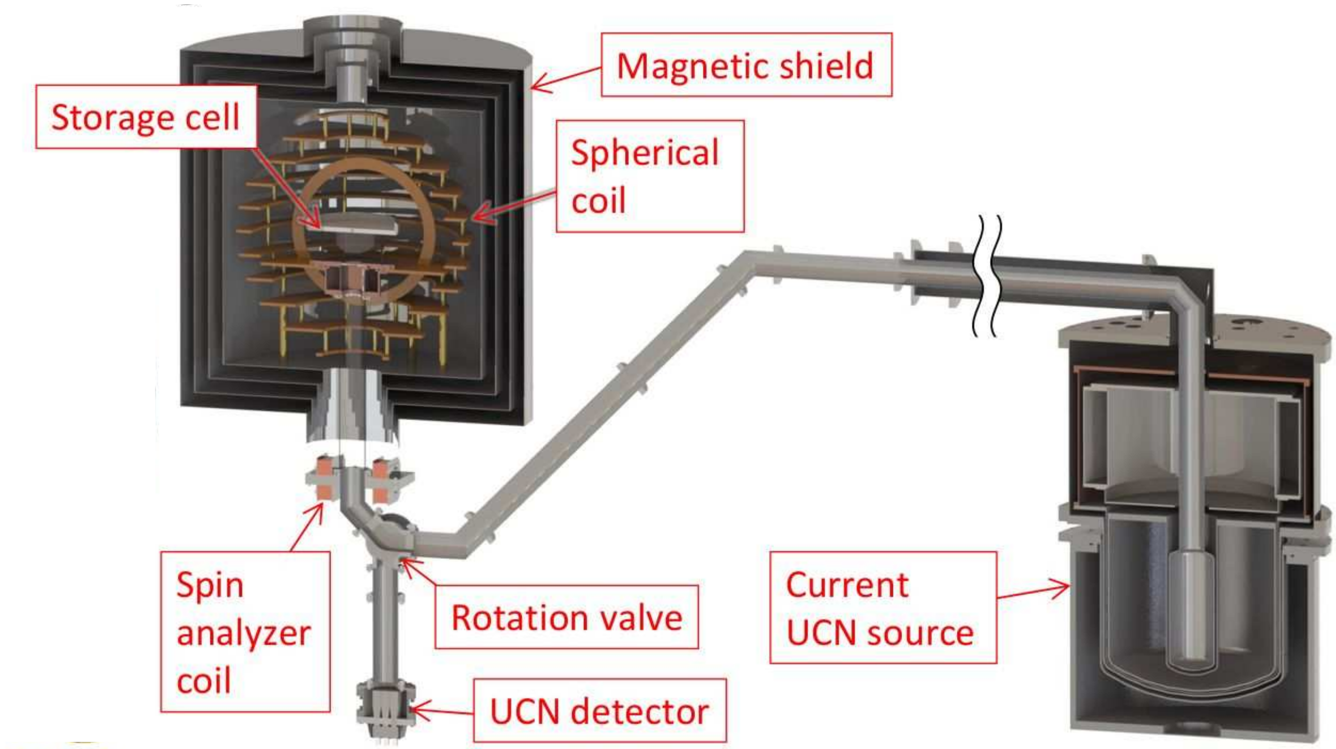





UCN cryostat
^{3}He pump
Liquid helium
auto fill system
DAQ etc.
^{3}He gas handling panel
Compressors

EDM equipment shipped from Japan (magnetic shields, UCN handling,...)

UCN produced at proton beam current of 1 μA (license, heat input)



Requirements to achieve 10^{-27}e·cm sensitivity

System	Requirement	Value
Neutron moderator, UCN source	High UCN production rate	$>2.3\times10^{7}$UCN/sec.
UCN guide	High transportation eff.	>4%
Polarizer	High polarization	>95%
EDM cell and high voltage	High electric field	>12kV/cm
	Low leakage current	<10pA
	Long UCN storage life time	>100sec.
	Large radius	>0.1m
Magnetic field system	Field stability	1-8 pT stability over EDM cycle
	Field homogeneity	<0.1nT/m
Comagnetometer	Precise B_0 measurement	10fT per EDM cycle
UCN detector	High counting rate	>1.3MHz
	Efficiency stability	<0.05% over hour