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

Status of the Vertical UCN Source for the TRIUMF nEDM Experiment

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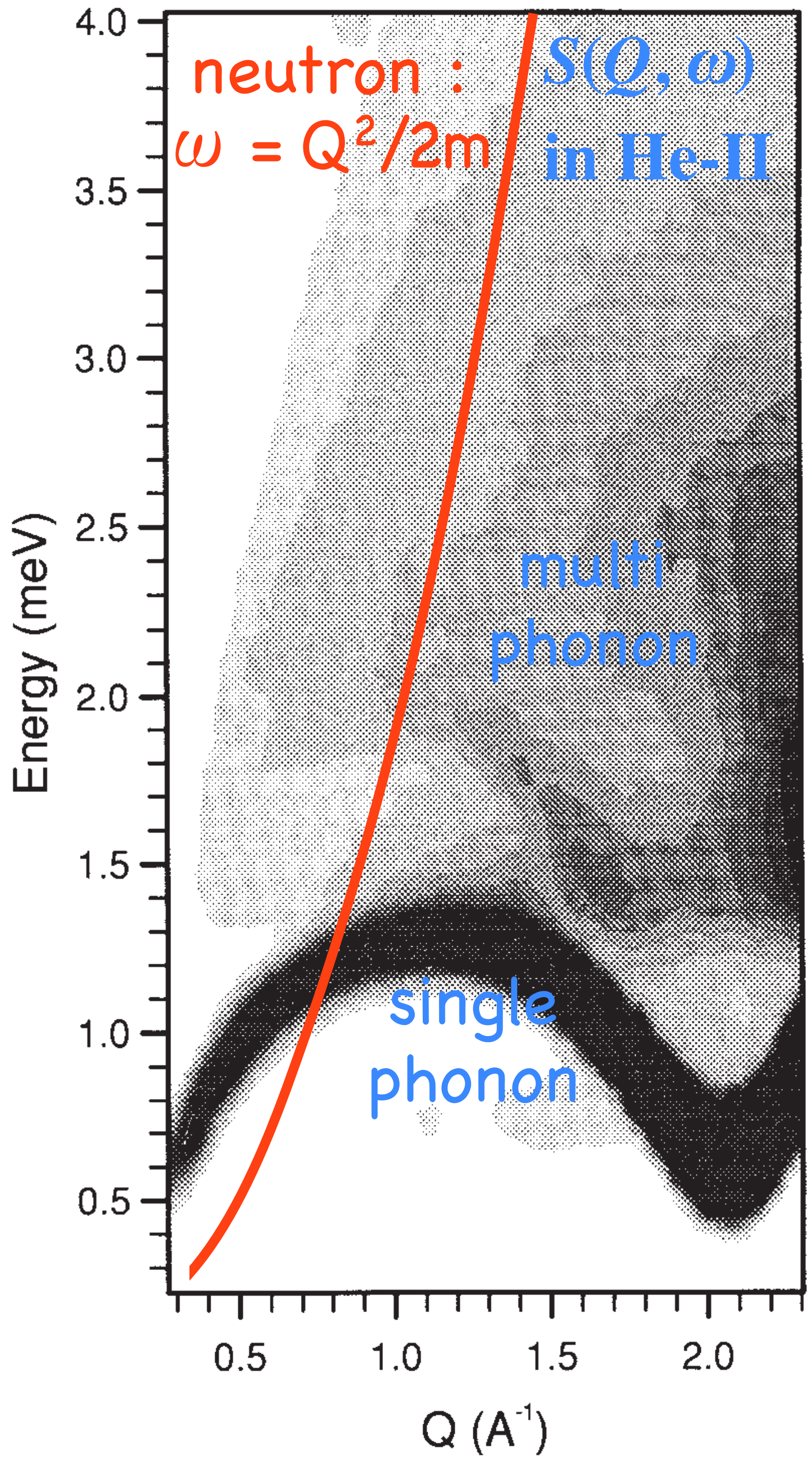
The TRIUMF Japanese-Canadian Collaboration

nEDM2017
October, 17, 2017, Harrison Hot Springs, Vancouver, BC

Outline

- Superthermal UCN production
- The Vertical UCN Source
    - Structure
    - Installation
    - Cooling test
- Schedule for UCN production
- Summary

Superthemal UCN Production



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

UCN Production rate in He-II

$$P = \int dE_{ucn} \int dE_{in} \; N_{4He} \; d\sigma(E_{in} \rightarrow E_{ucn})/d\omega \; d\Phi_n(E_i)/dE$$

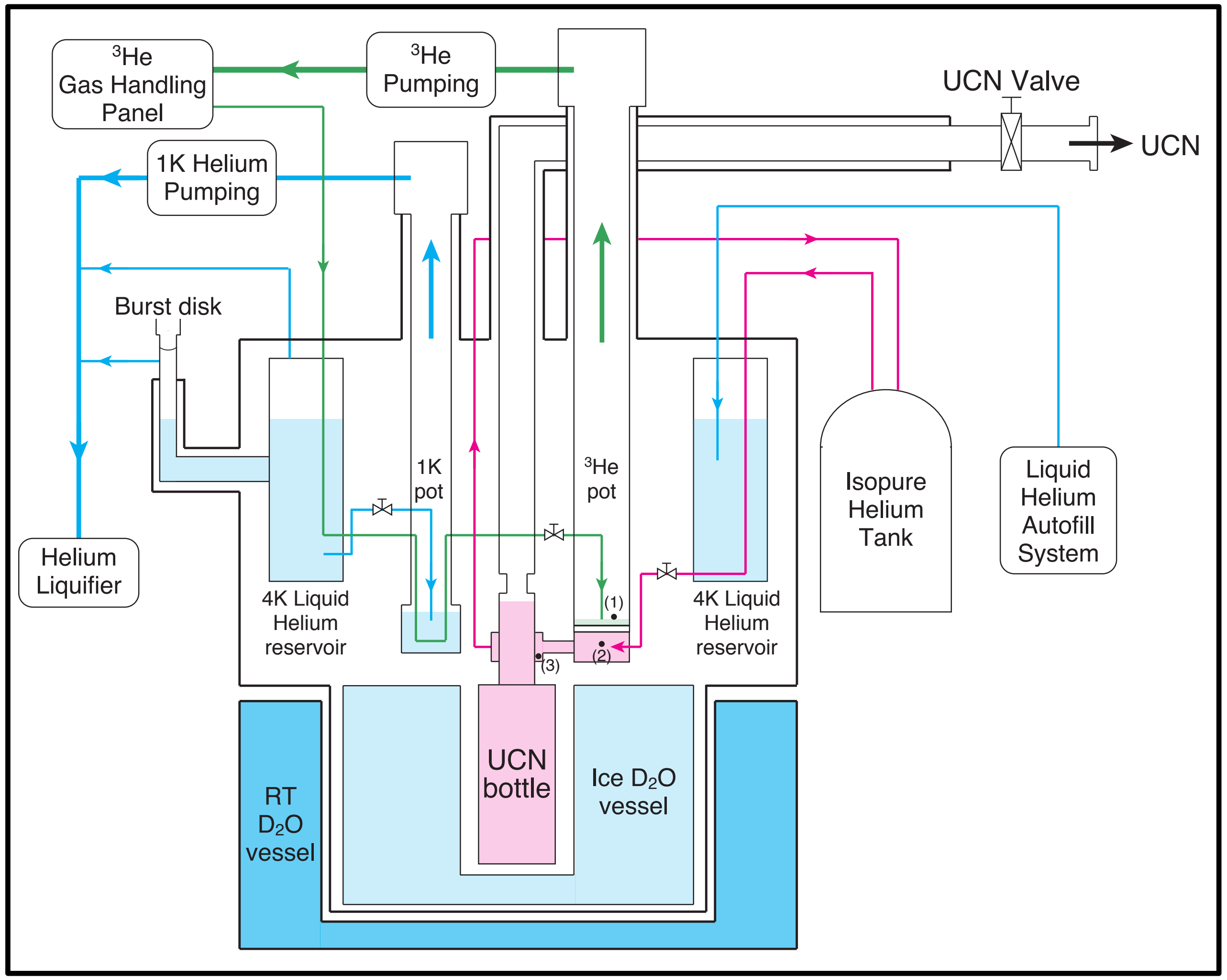
He-II density — cross section — cold n flux

$$\frac{d\sigma}{d\omega} = 4\pi\, b_{coh}^2 \frac{k_f}{k_i} S(Q,\omega)$$

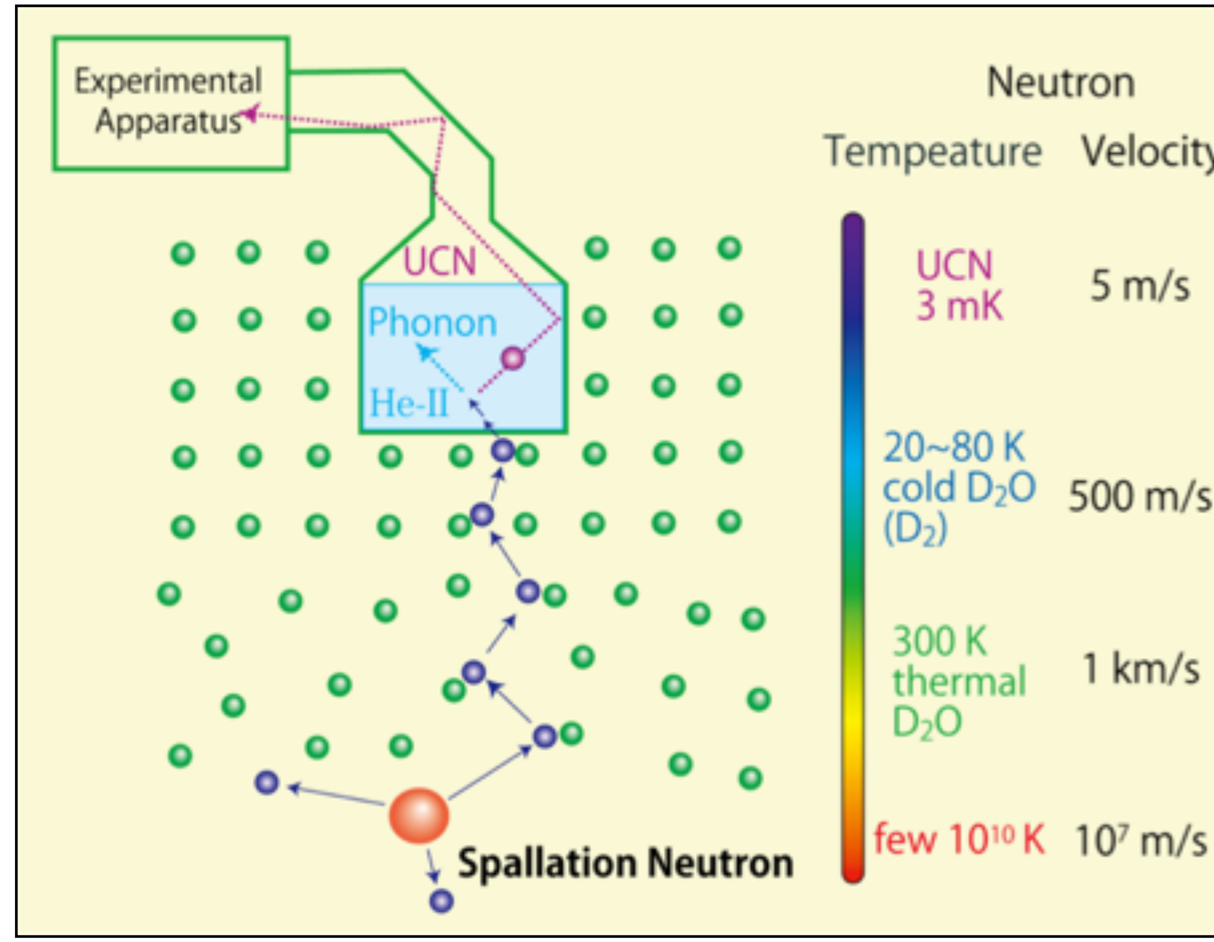
- b_{coh}: scattering length
- k_f: wave number of scattered n
- k_i: wave number of incident n
- $S(Q,\omega)$: Scattering function

Our UCN Source

(1)Vertical UCN Source



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

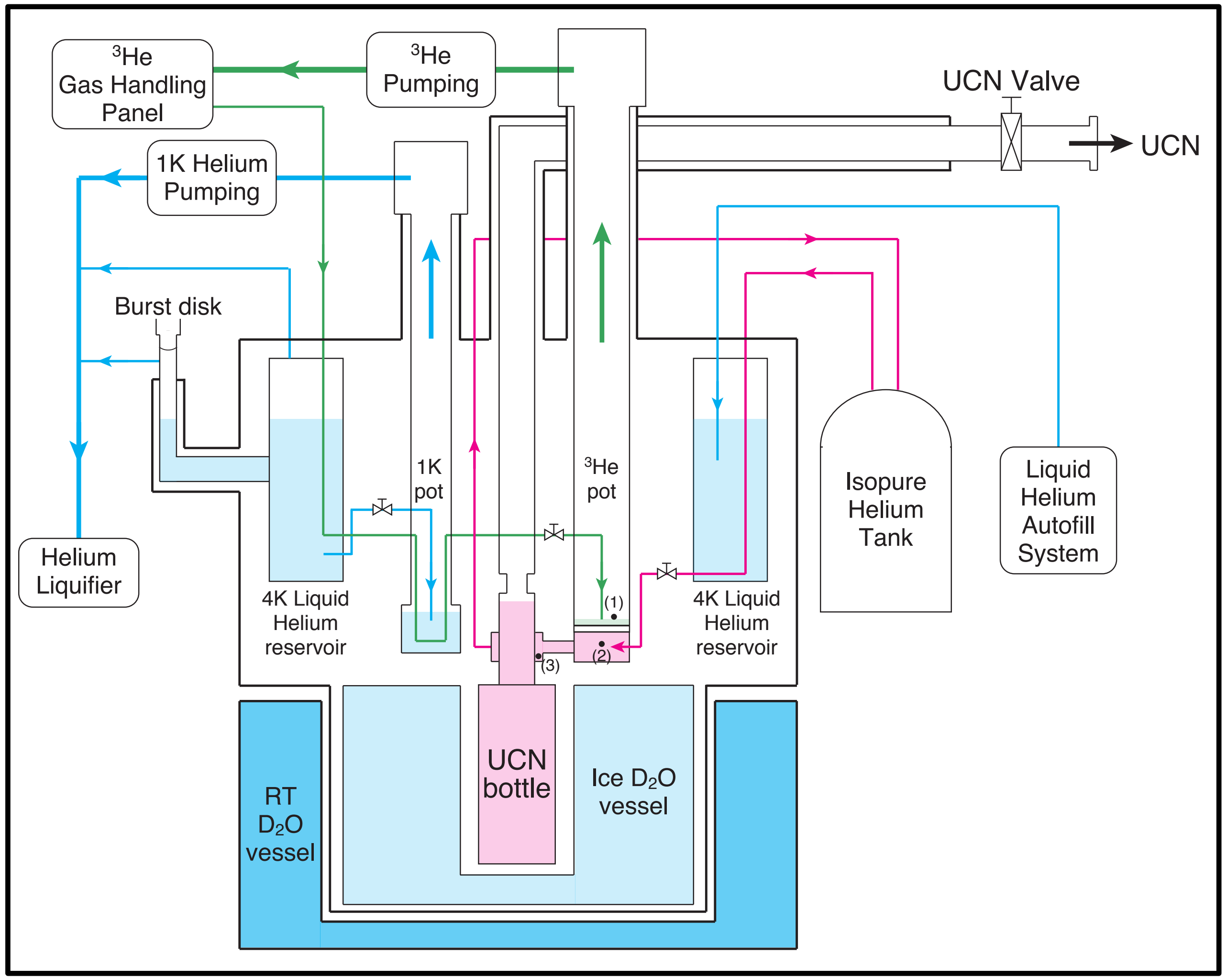


- Developed at RCNP, Japan in 2011
- Shipped to TRIUMF in 2016
- To be driven for a few years at 1μA p-beam current

- Coupled He-II UCN converter with a spallation neutron source
- D$_2$O as a thermal and cold moderator

Our UCN Source

(1)Vertical UCN Source



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

- Developed at RCNP, Japan in 2011
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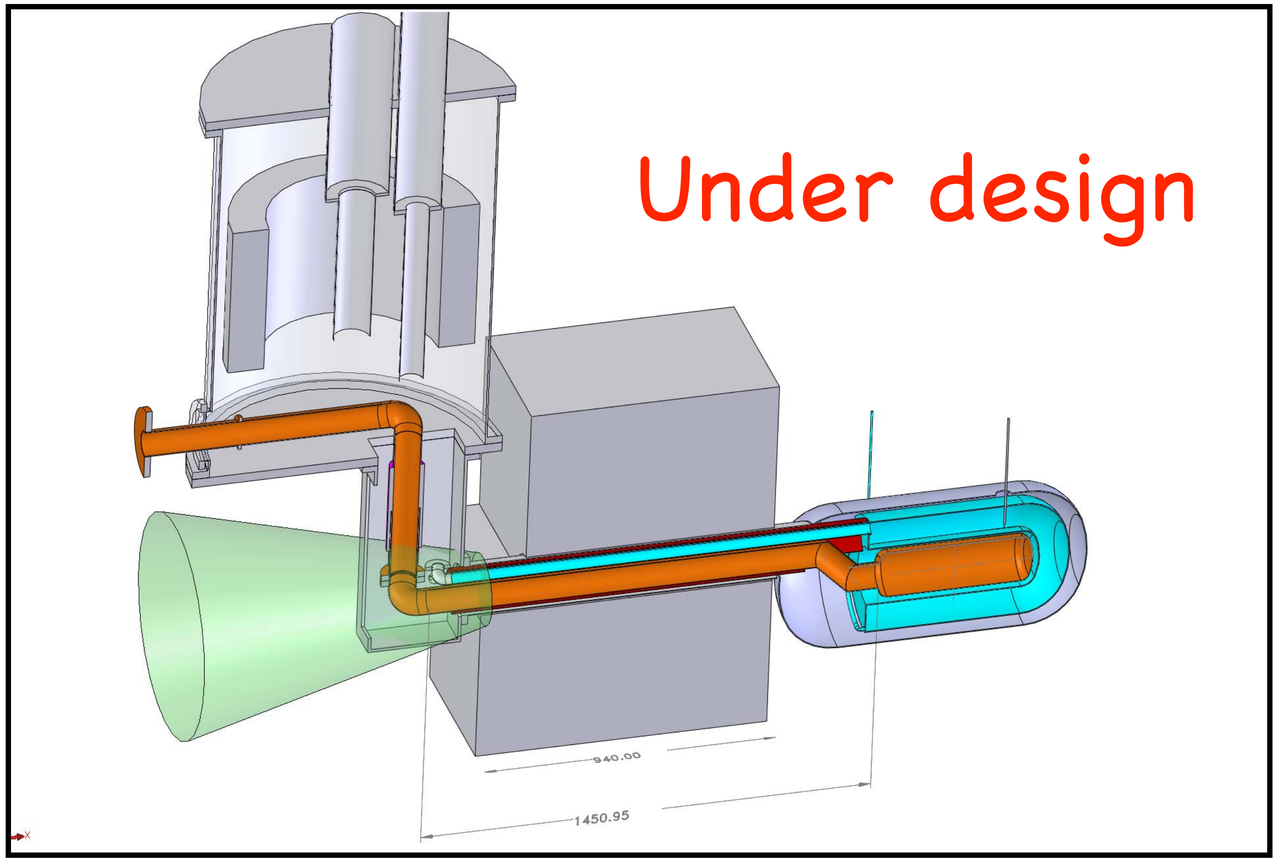
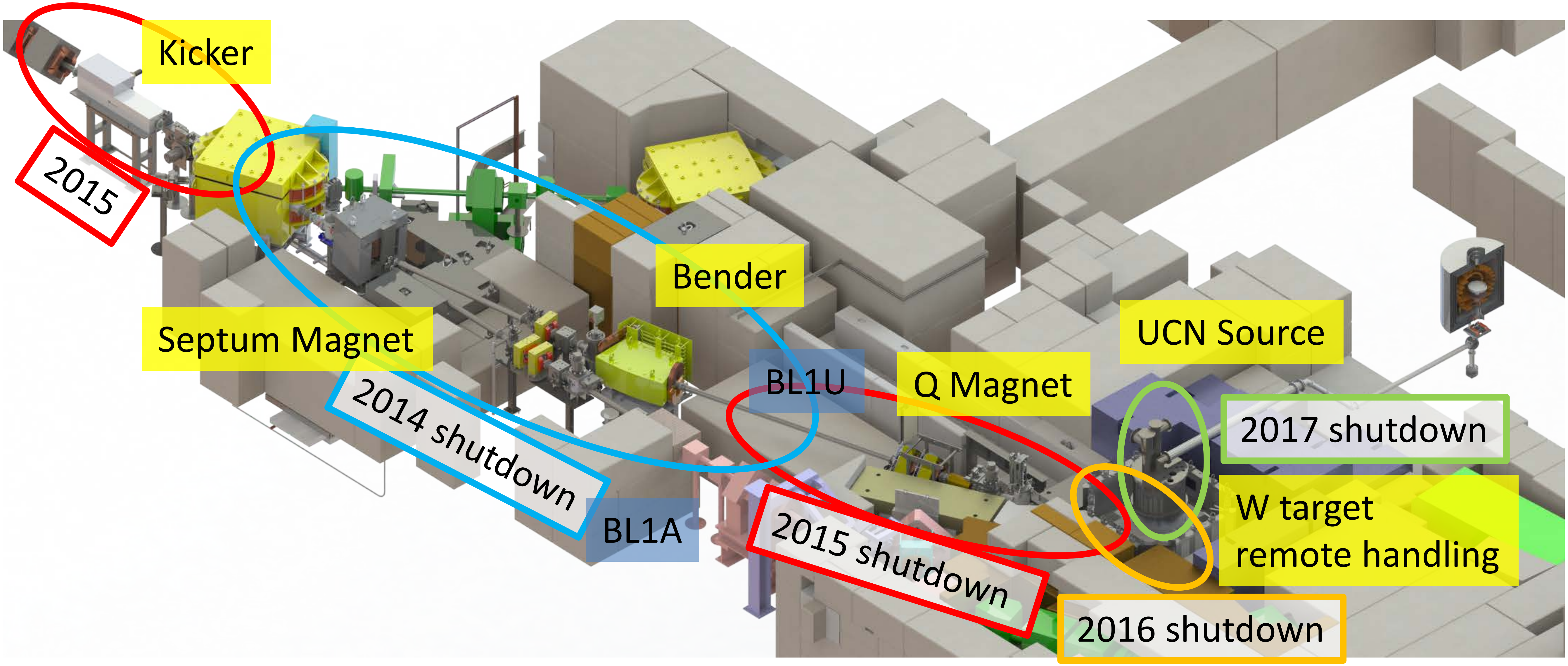
- To be driven for a few years at 1μA p-beam current

(2) Next Generation UCN Source



- Under design
- To be designed for 20kW (520MeV×40μA) p-beam
- To be designed to achieve 600 UCN/cm³ in a EDM vessel

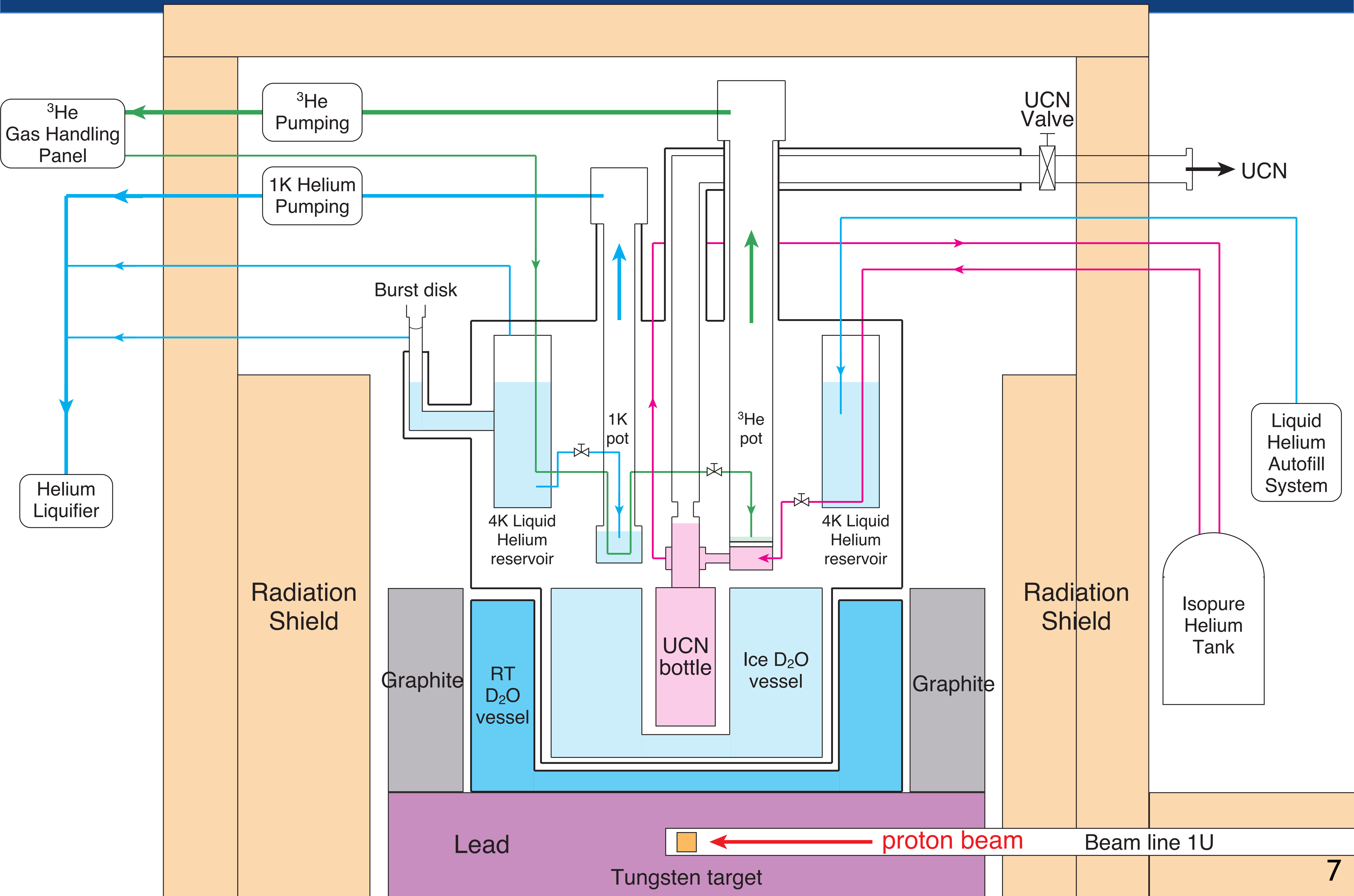
Beam line and UCN source at TRIUMF



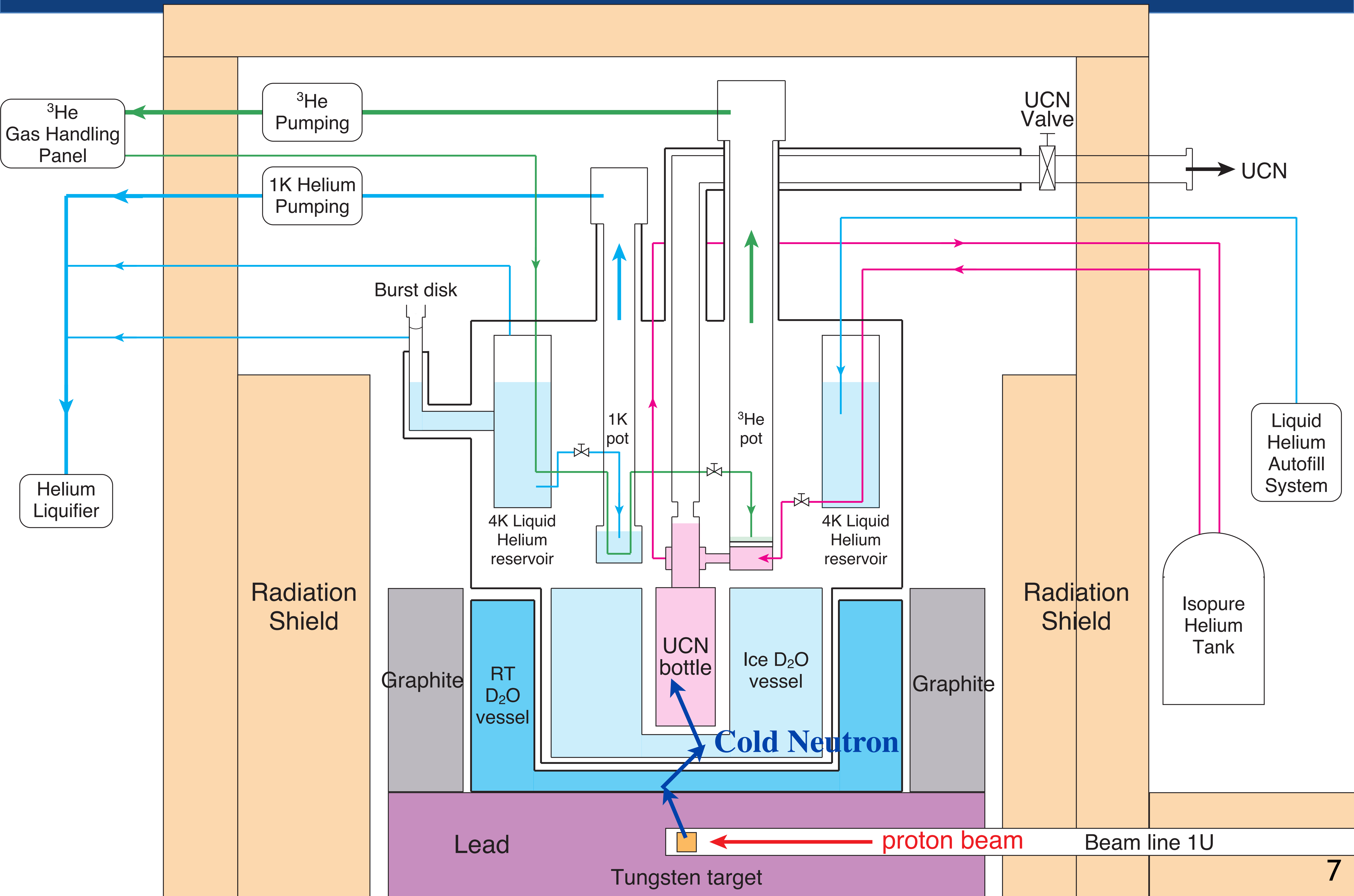
Major milestones

- ⭐ 2014~2016 Construction of Beam line 1U
- ⭐ 2016 Fall Commissioning of the proton beam and CN measurement
- ⭐ 2017 Spring Vertical UCN Source Installation & Cooling test
- 2017 Nov. UCN Production with the Vertical UCN Source
- 2020? Next Generation UCN Source

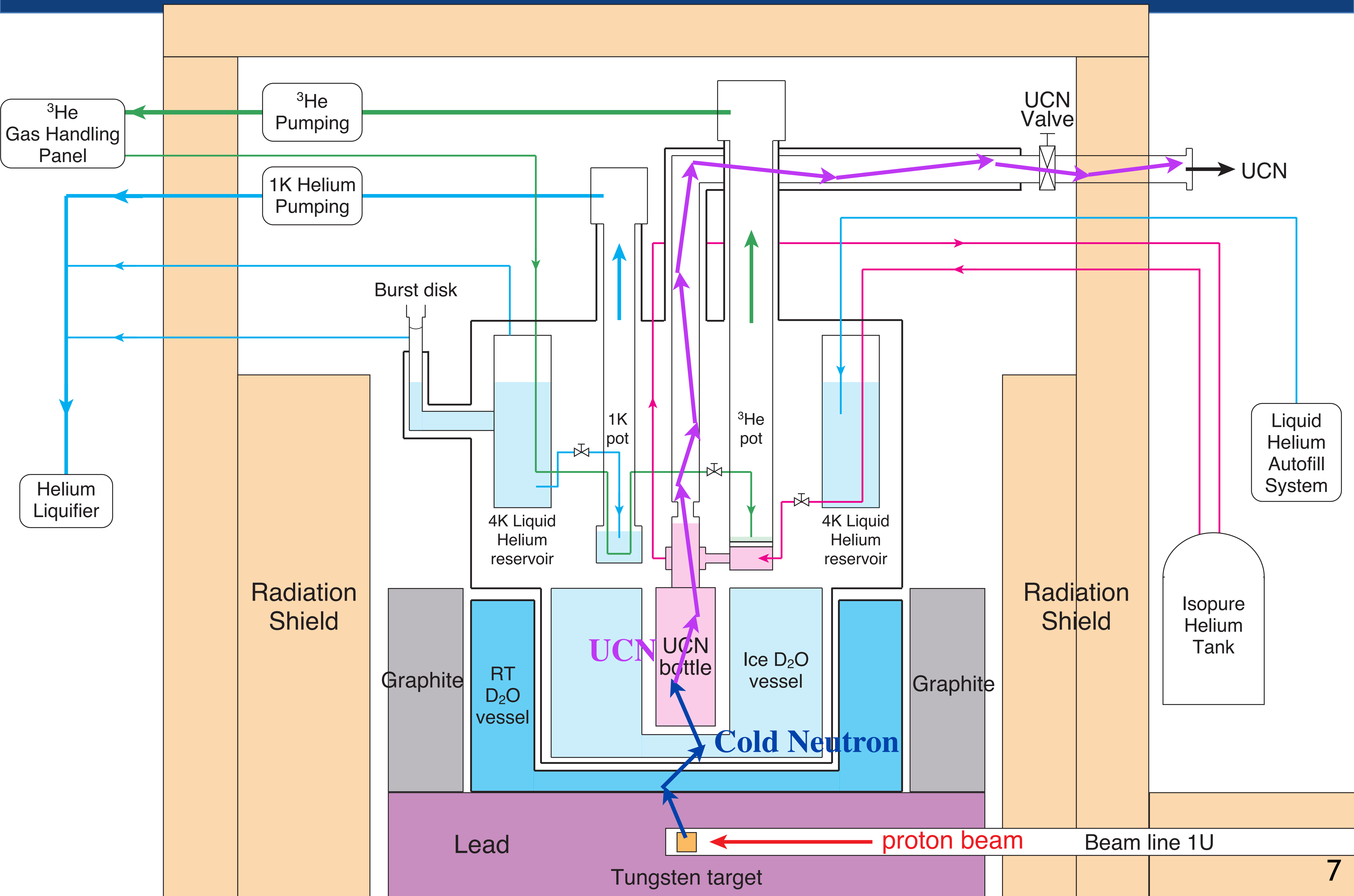
The Vertical UCN Source



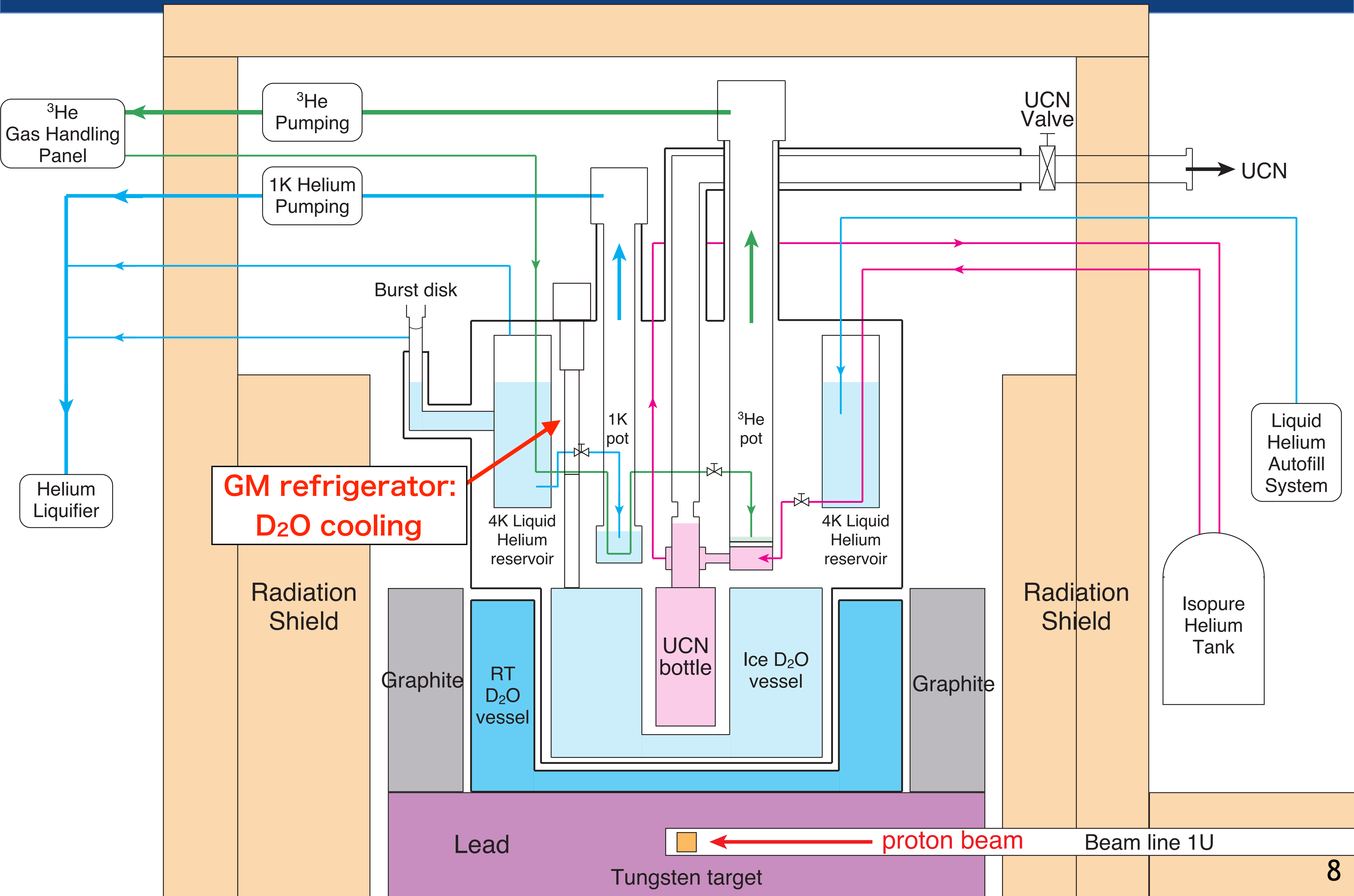
The Vertical UCN Source



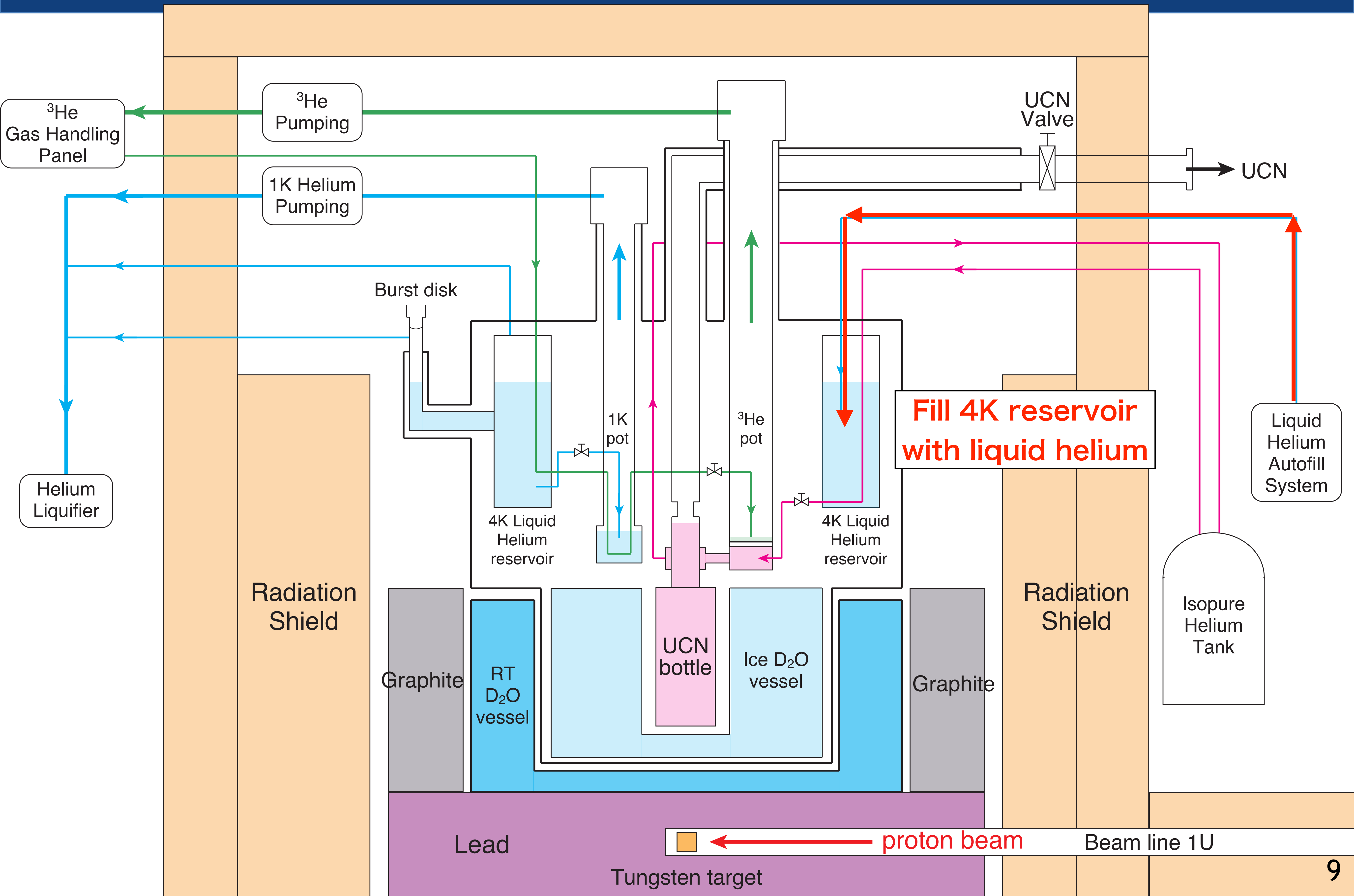
The Vertical UCN Source



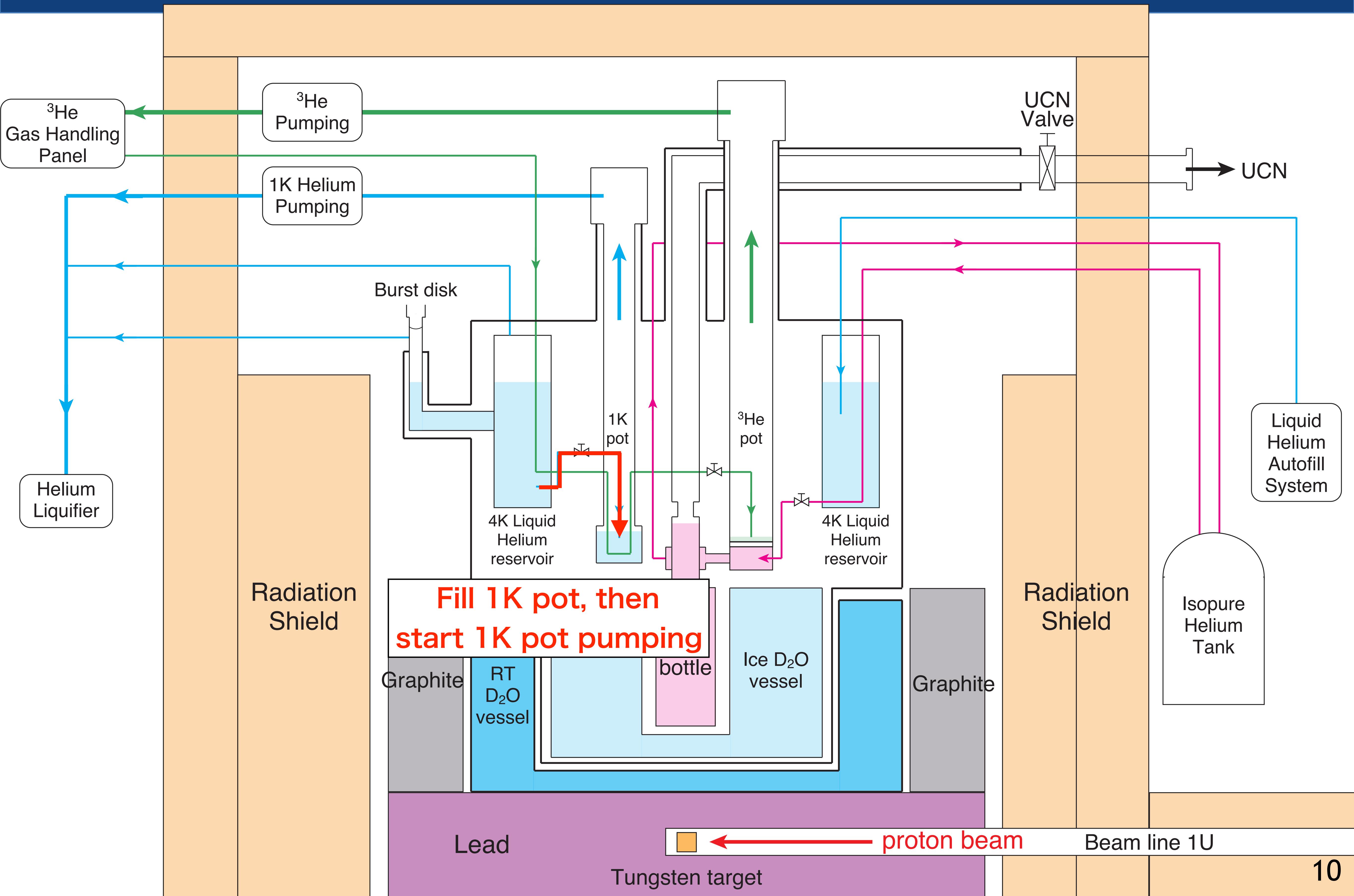
Cooling the UCN cryostat



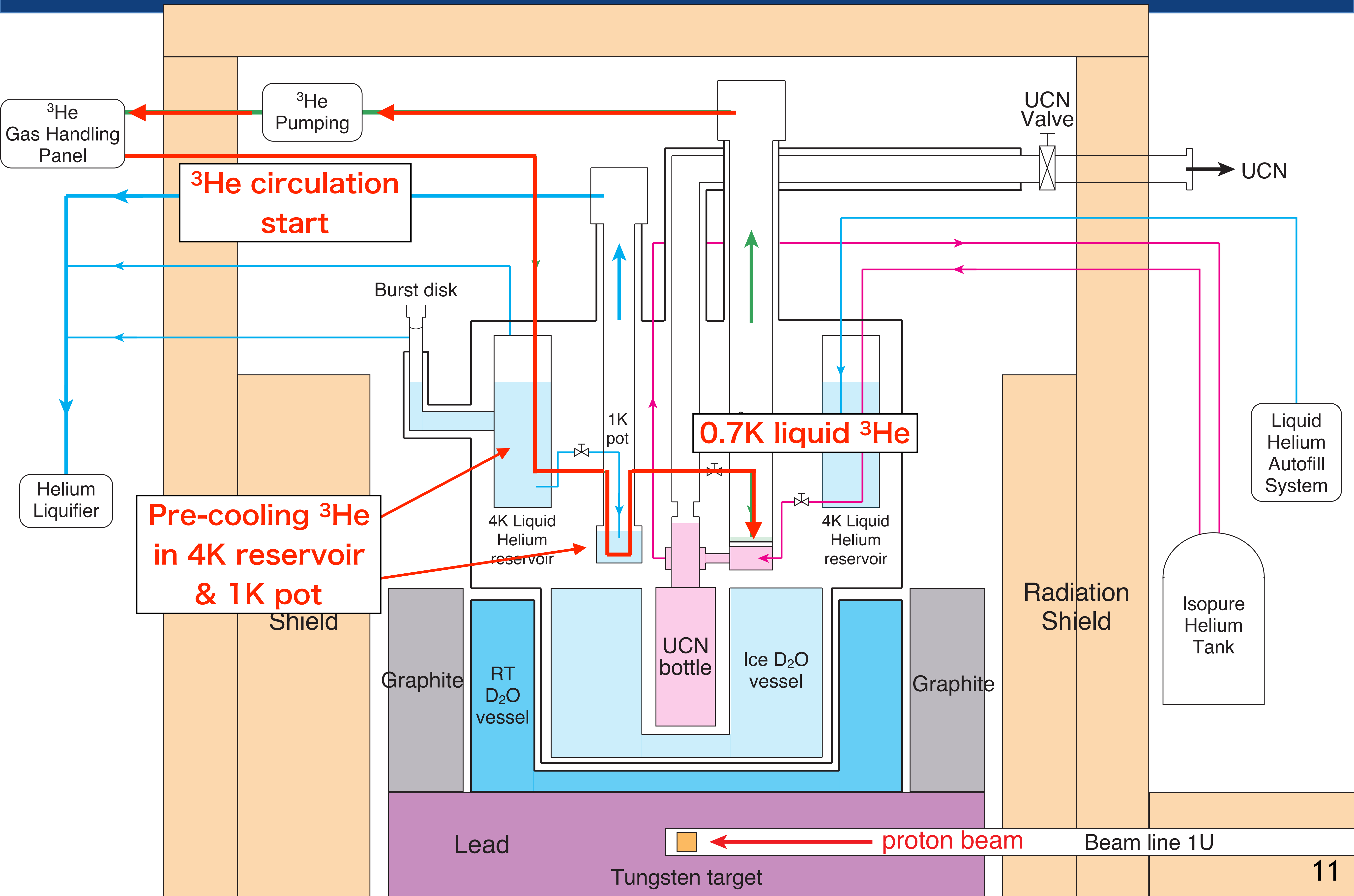
Cooling the UCN cryostat



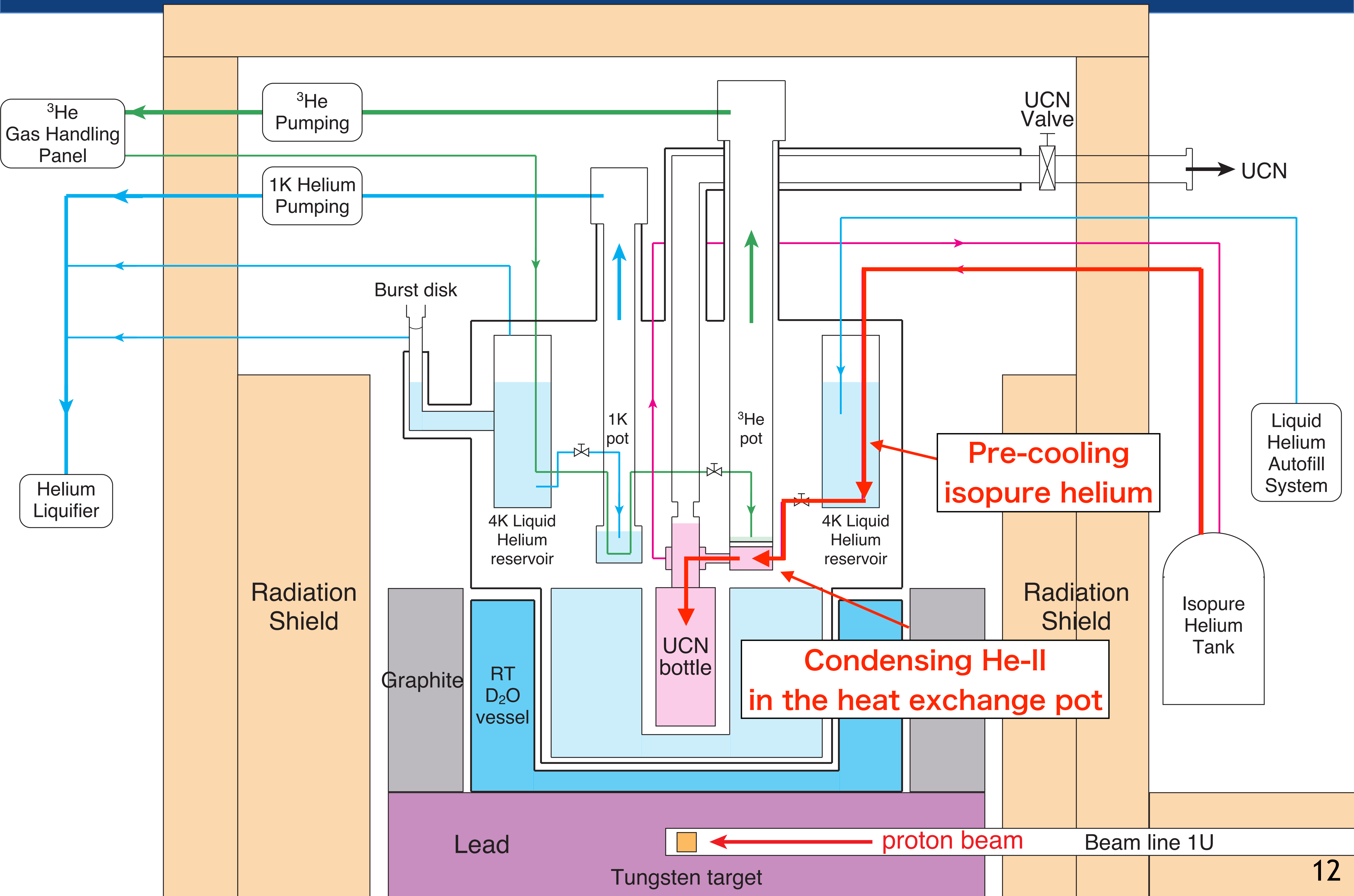
Cooling the UCN cryostat



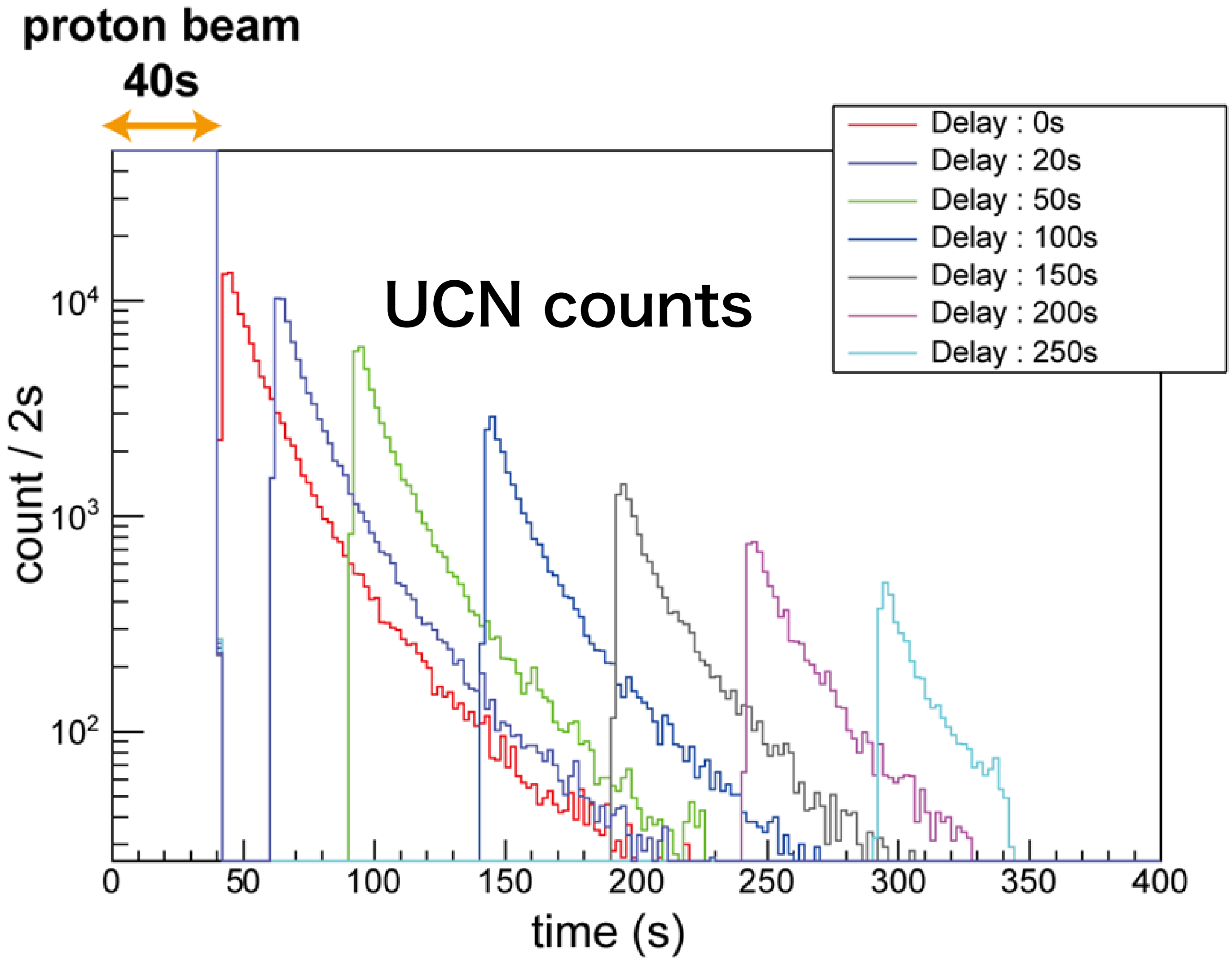
Cooling the UCN cryostat

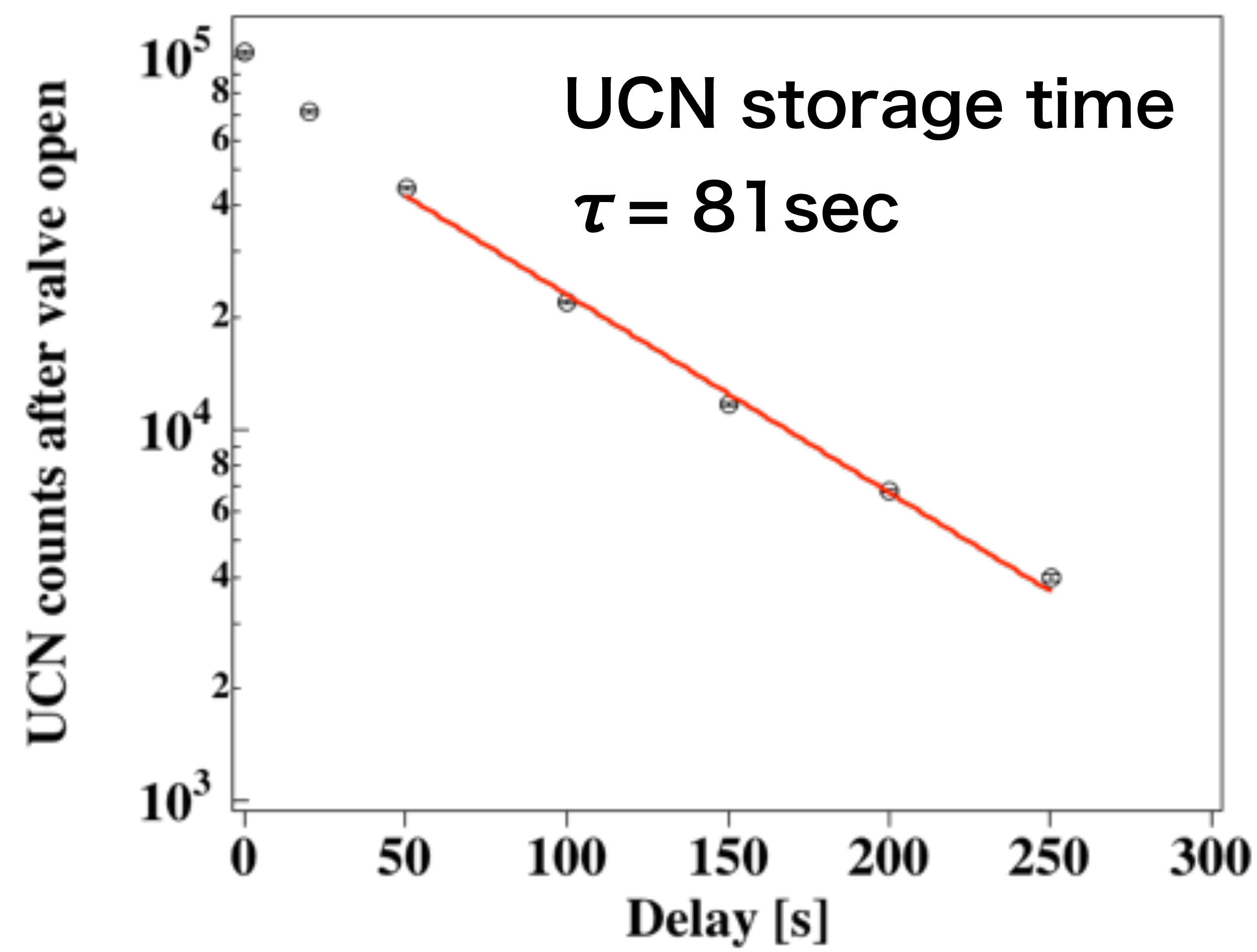


Cooling the UCN cryostat



Development at RCNP, Osaka, Japan





Best record (2011)

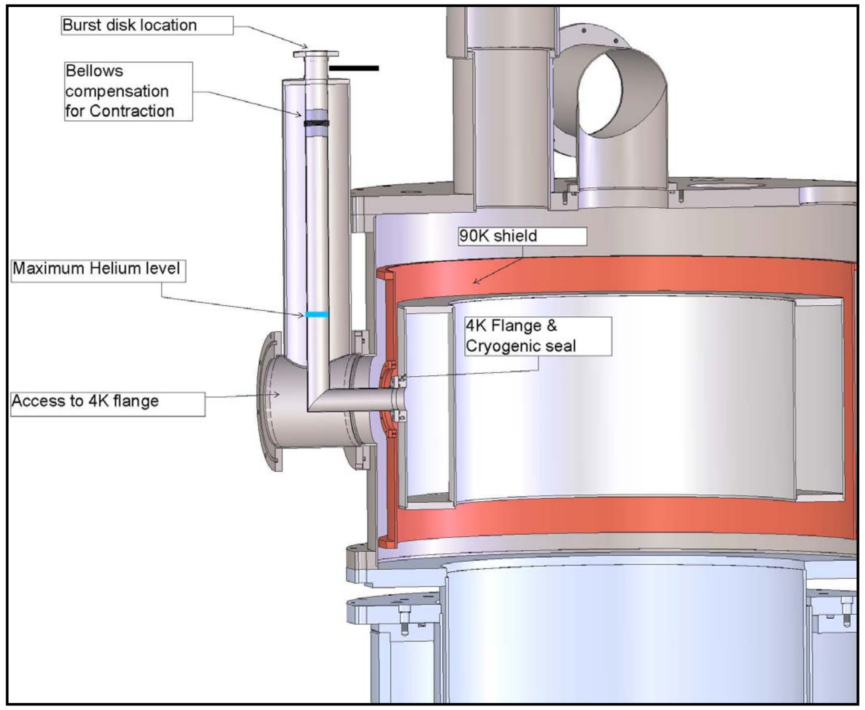
- p-beam: 400W (1μA×400MeV)
- UCN counts: 10^5 UCN for 40s p-beam
- 260,000 UCN expected for 240s p-beam
- Volume of UCN guide and UCN bottle: 30L

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

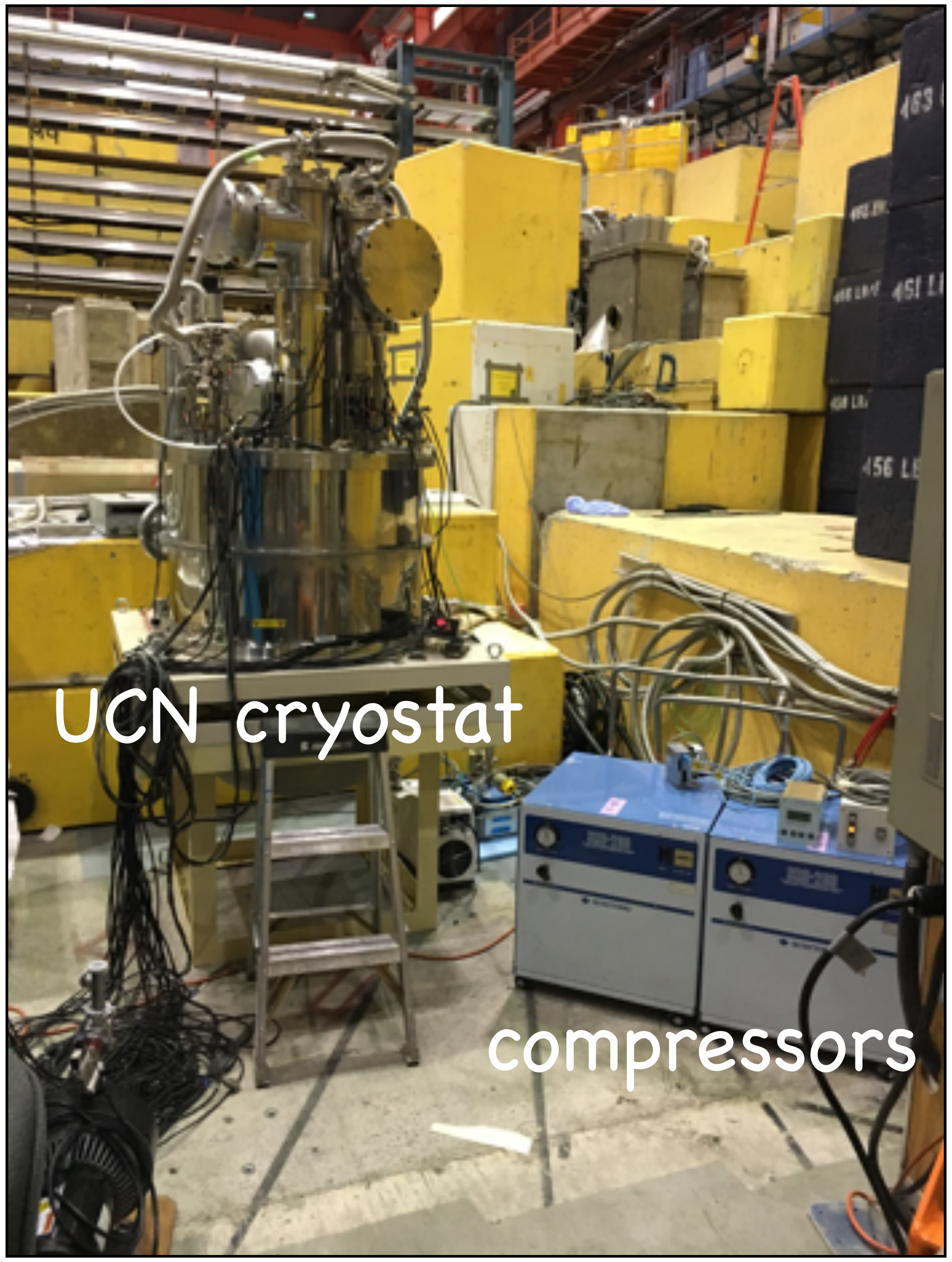
- 2002 First UCN production
- 2011 Development finished
- 2016
  - Shipping from RCNP to TRIUMF
  - Safety upgrade of the cryostat
- 2017
  - Cooling tests
  - Installation on beam line 1U

Cooling test at TRIUMF

- 2017 February - GM cooling test
  - After safety upgrade, cooling the cryostat with only GM refrigerator was performed.
  - The cryostat was successfully cooled down to 12K.
  - No leak at low temperature



Safety upgrade - Burst disk on the 4K reservoir



GM cooling test in Meson hall (not on the beam line)

Installation

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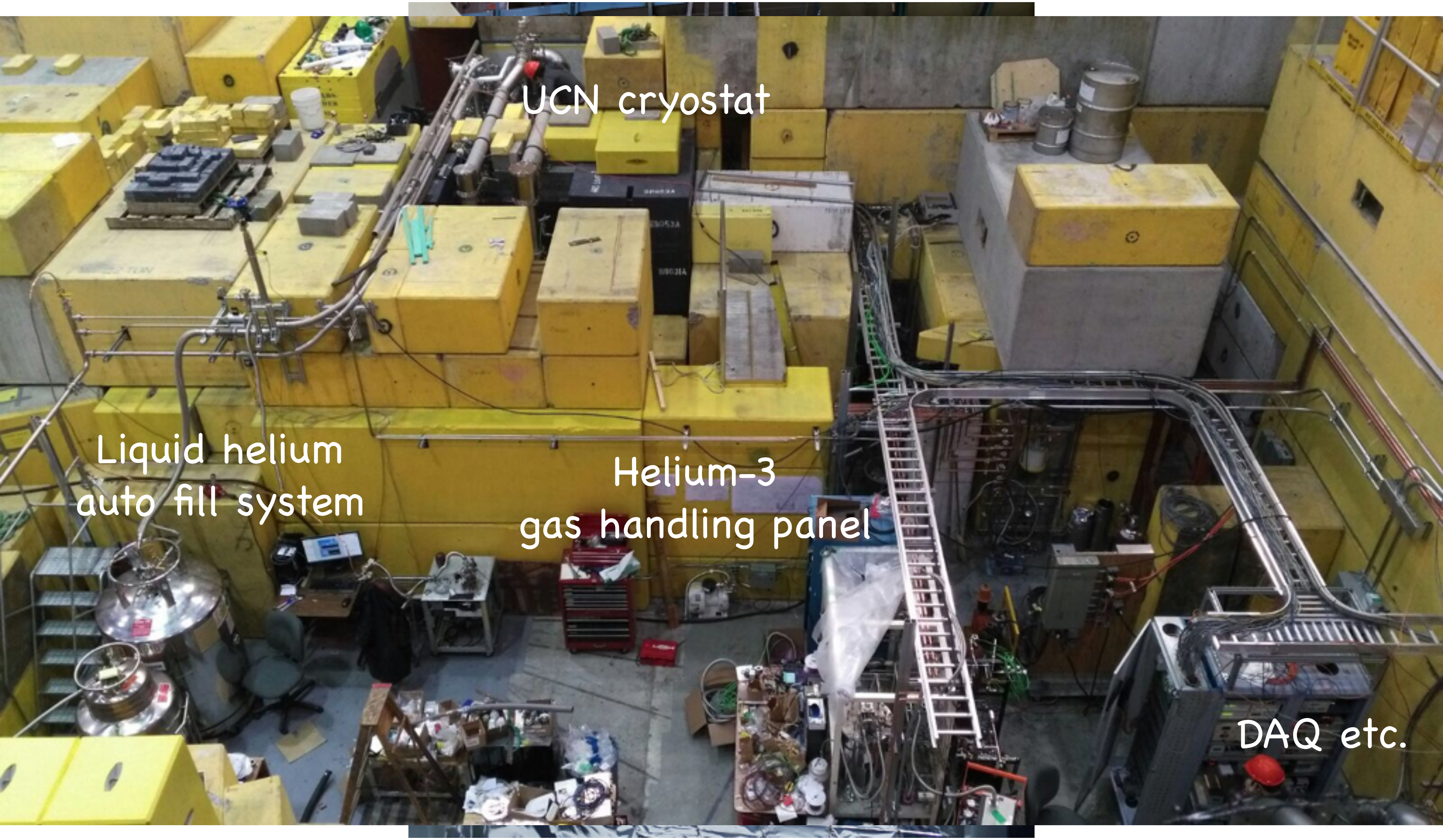
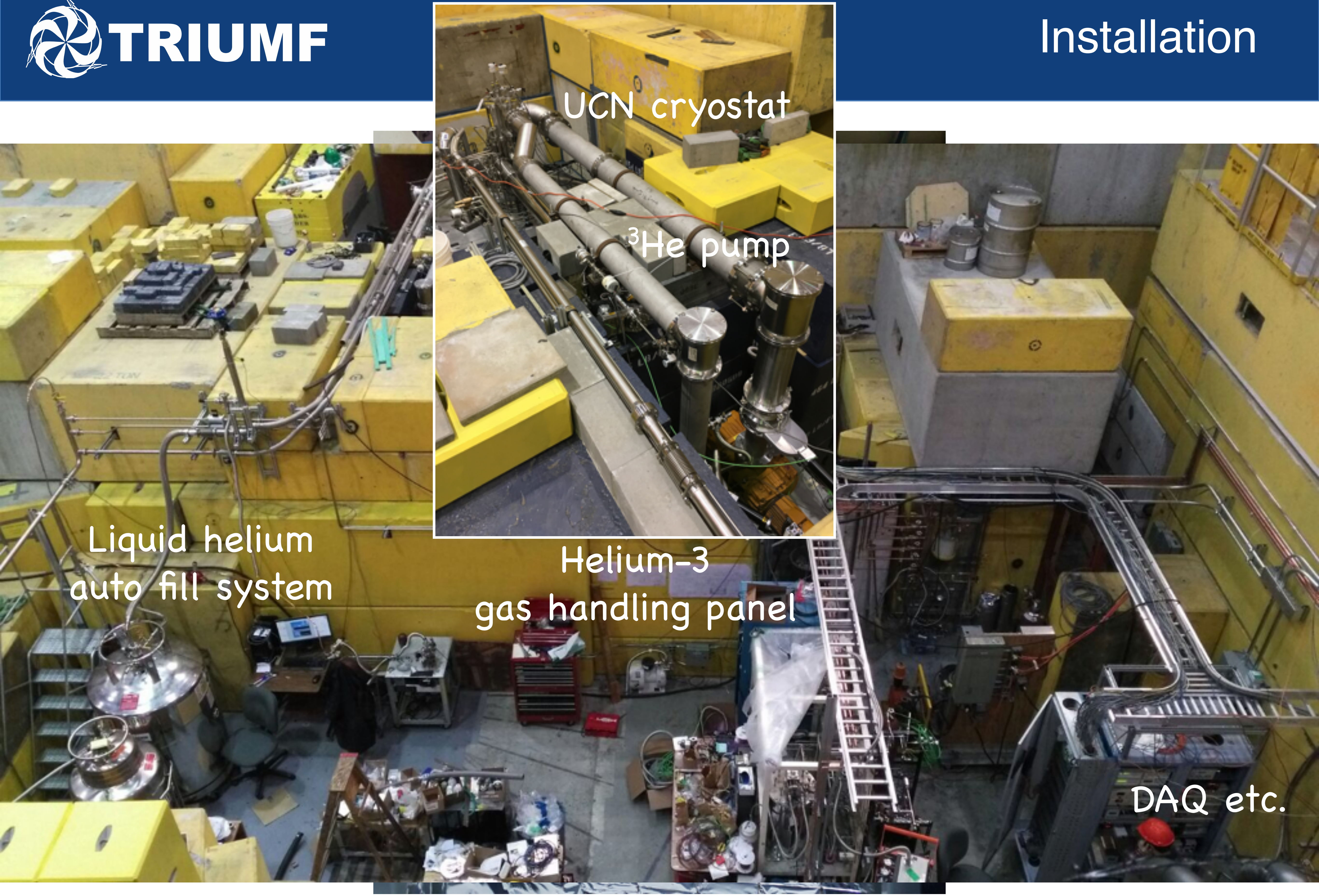
Installation

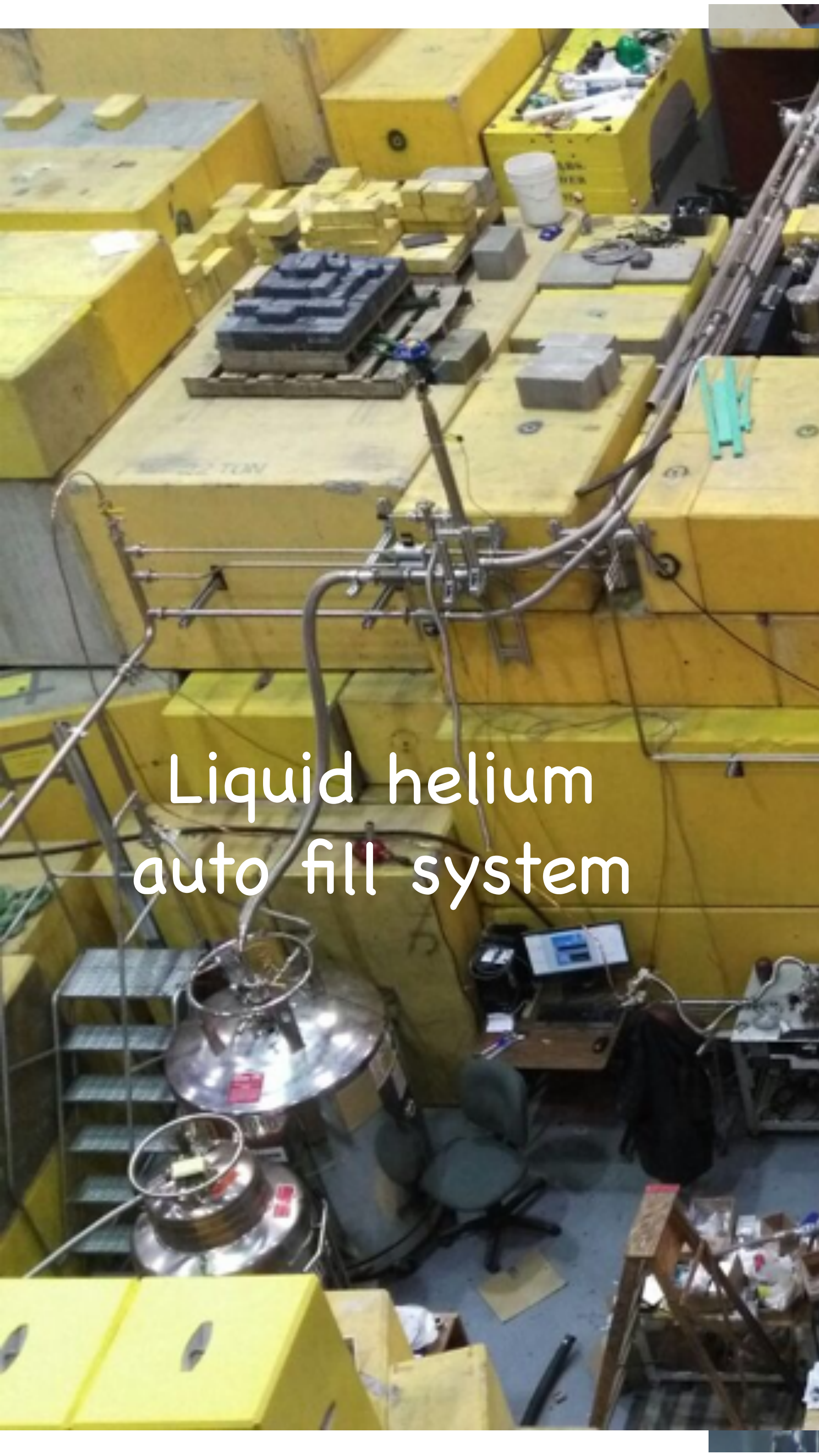
Installation

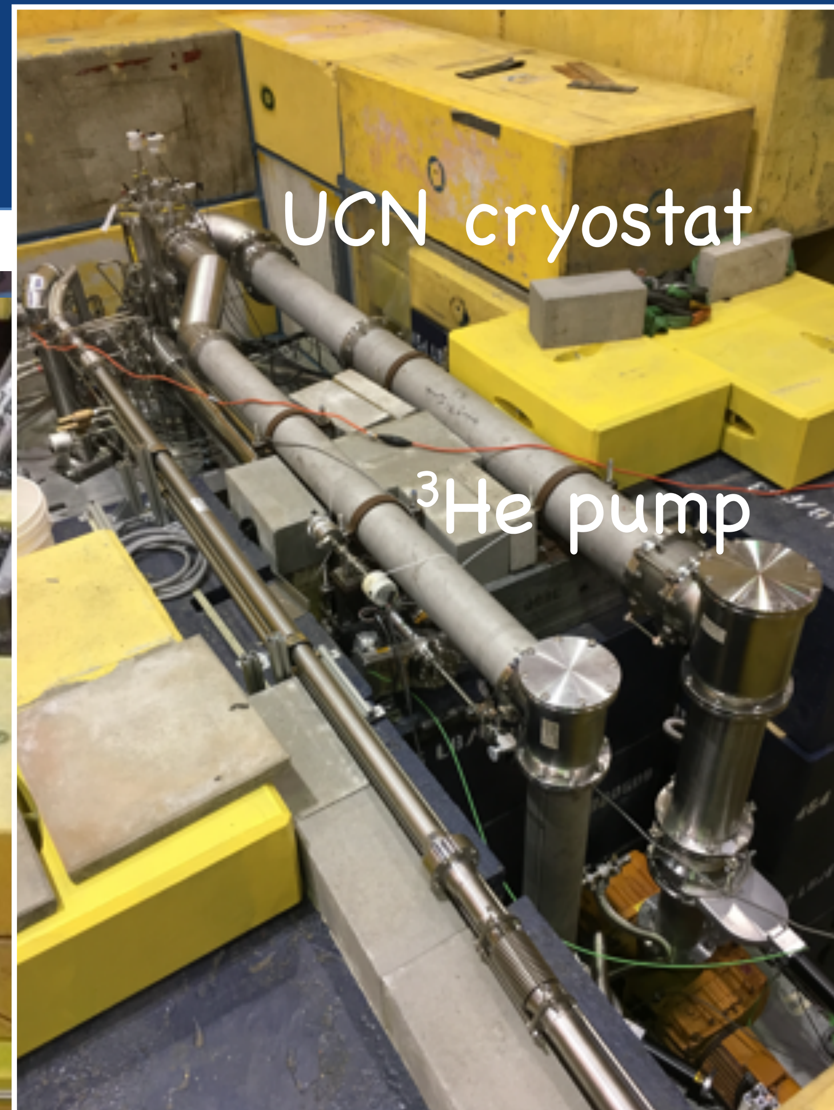


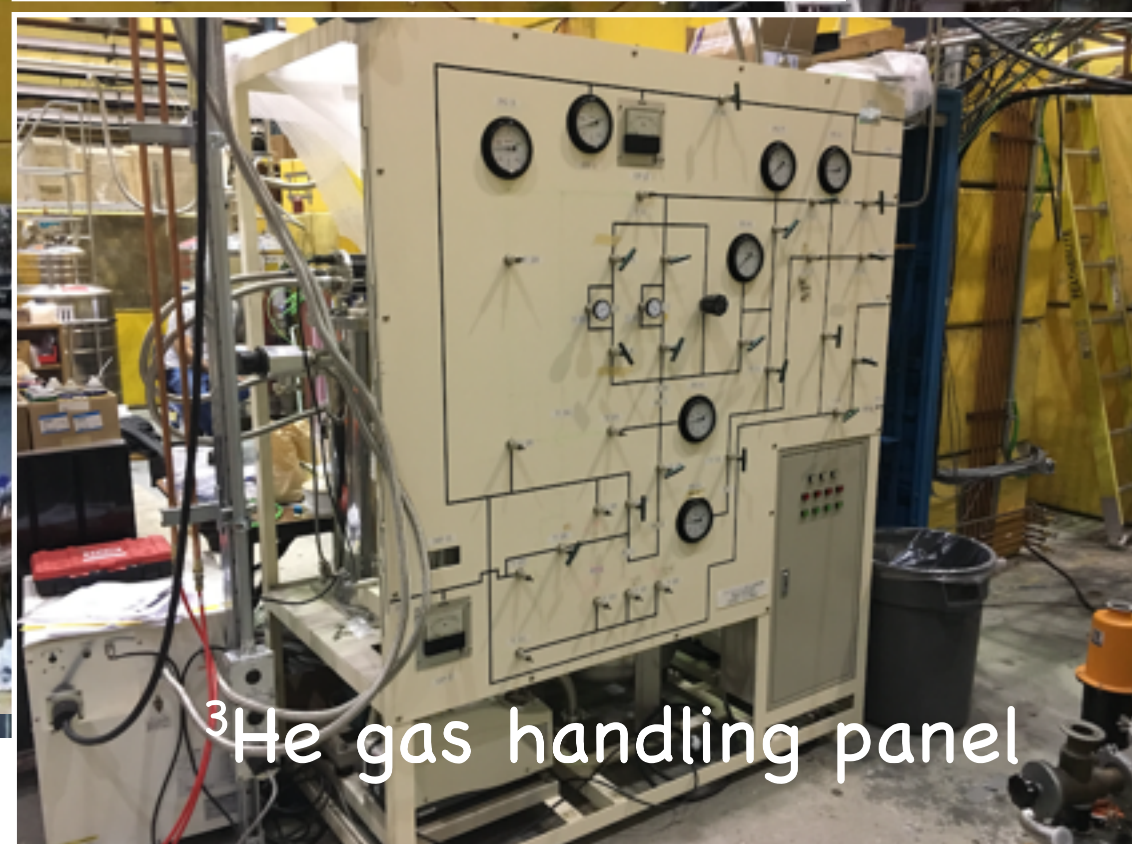
Installation



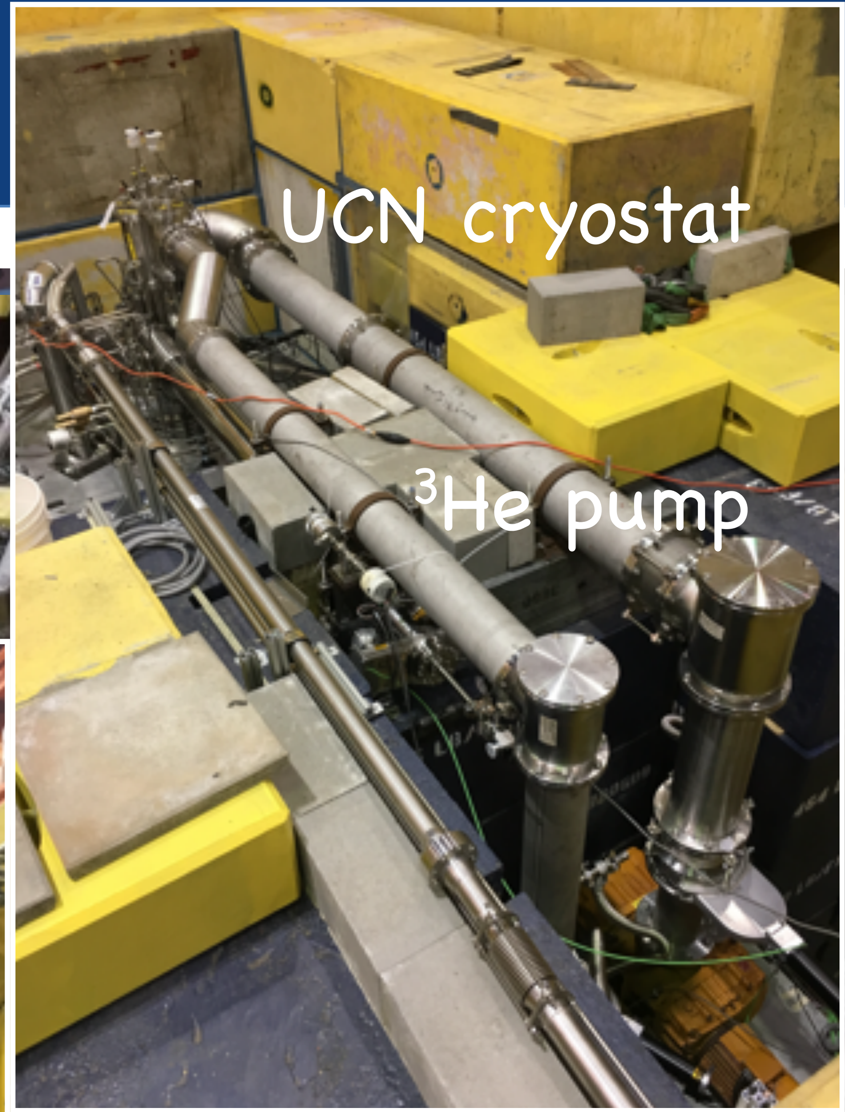
Installation

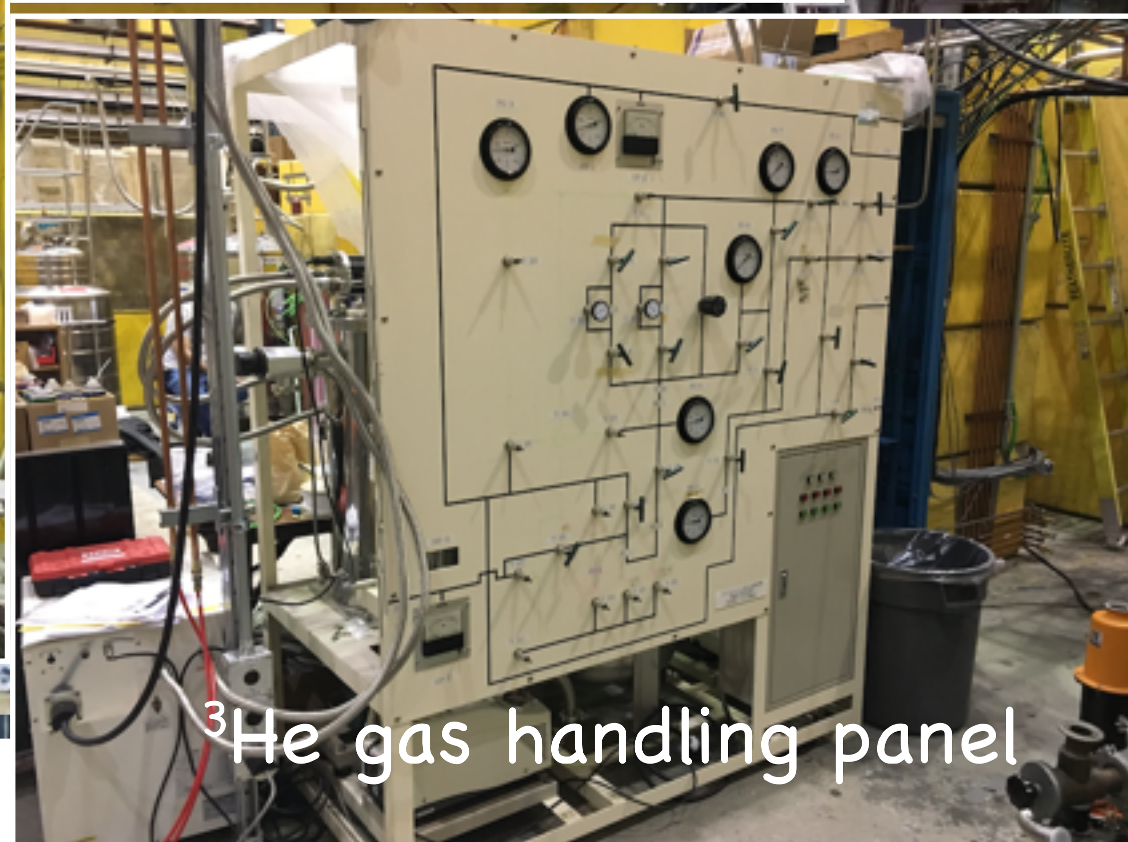




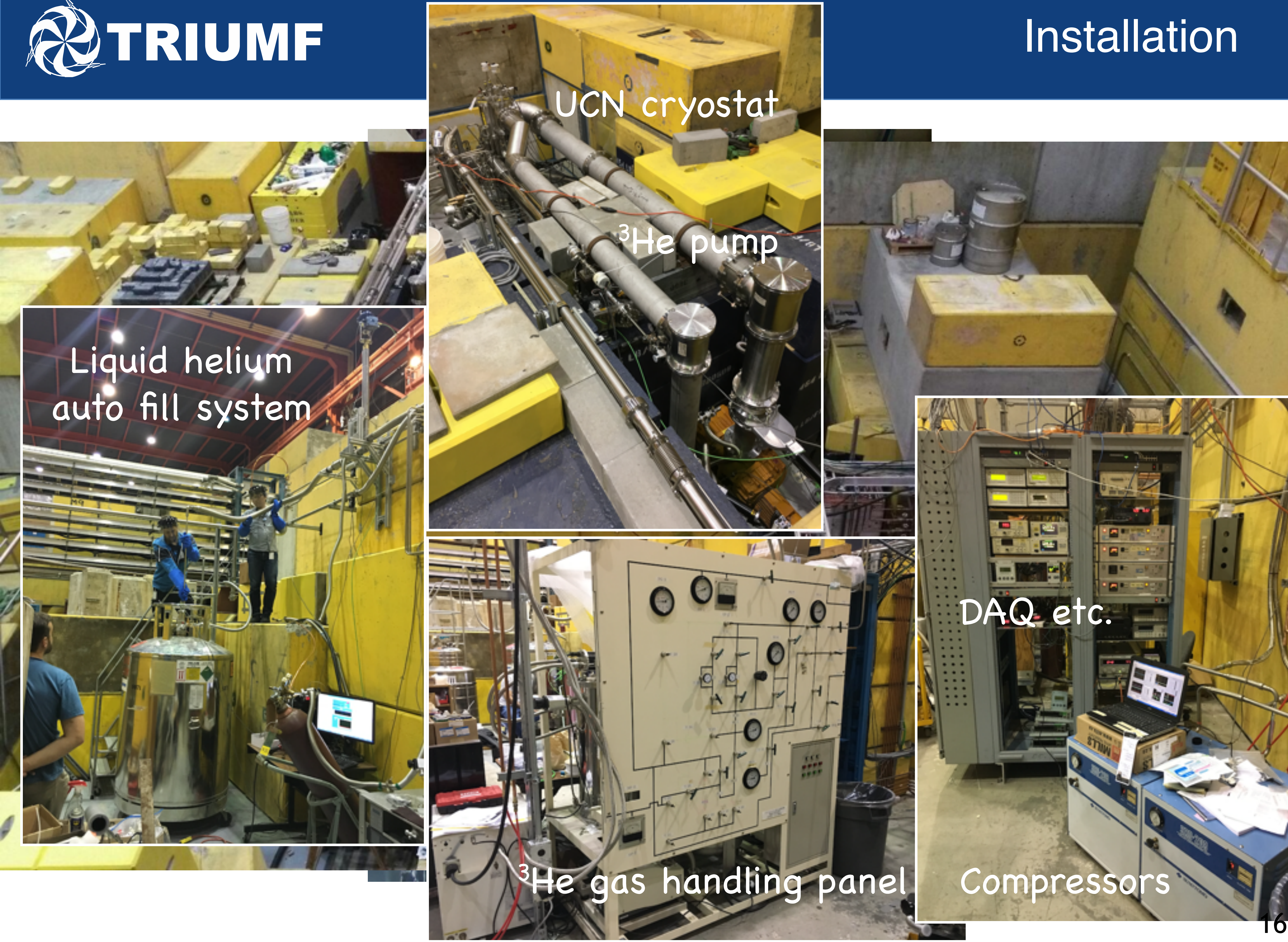


Installation





Installation



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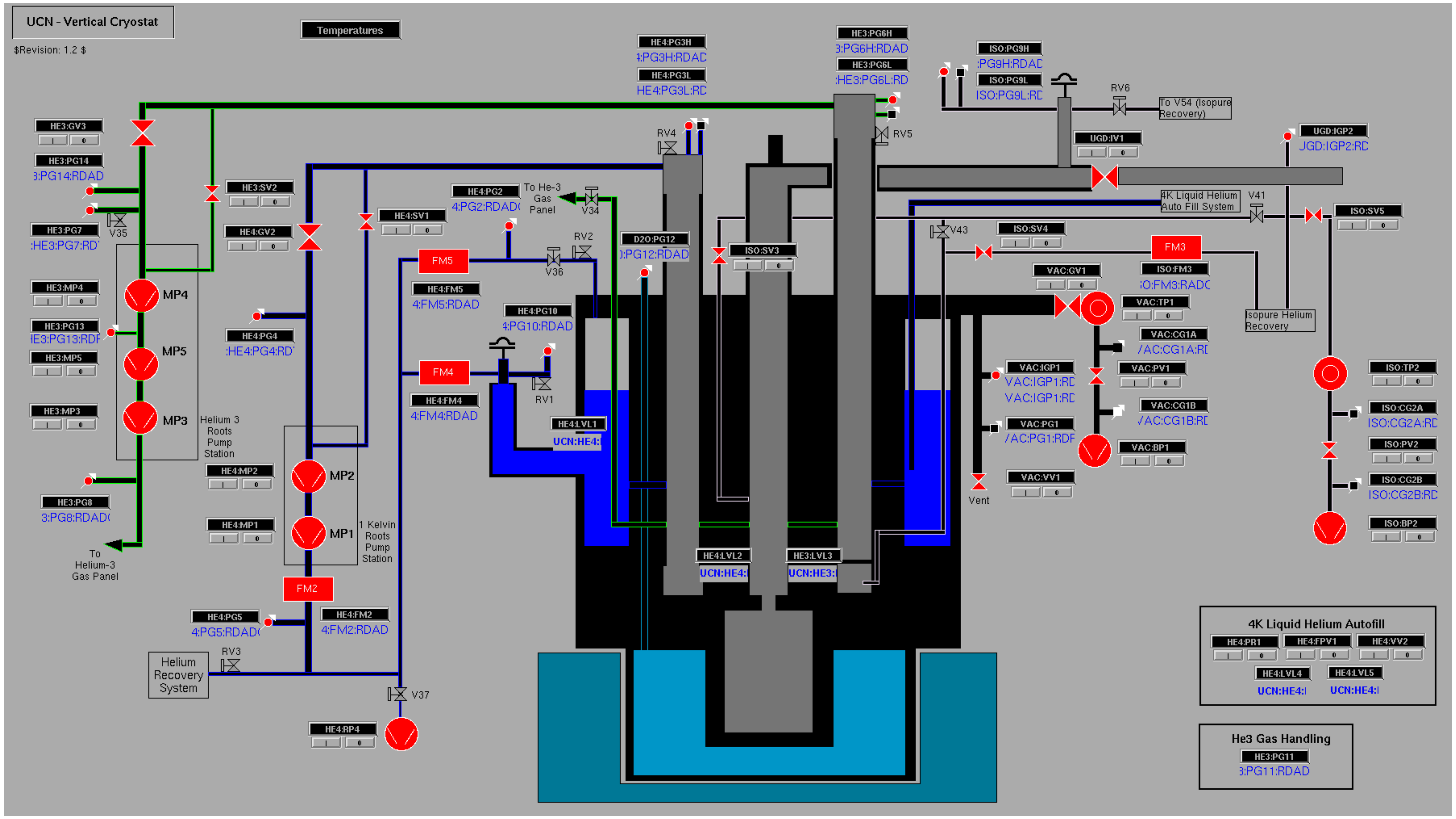
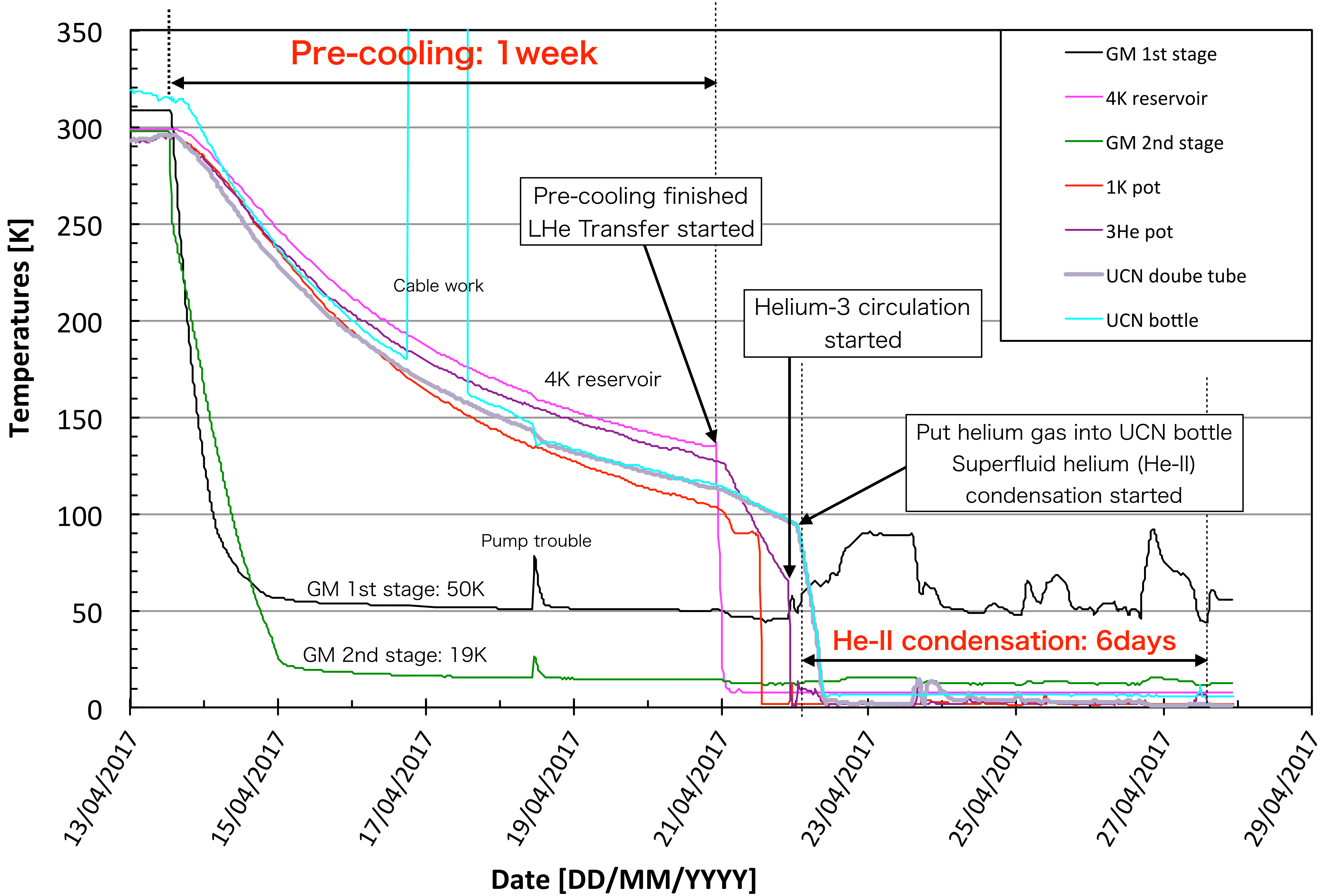
UCN source control and Data taking



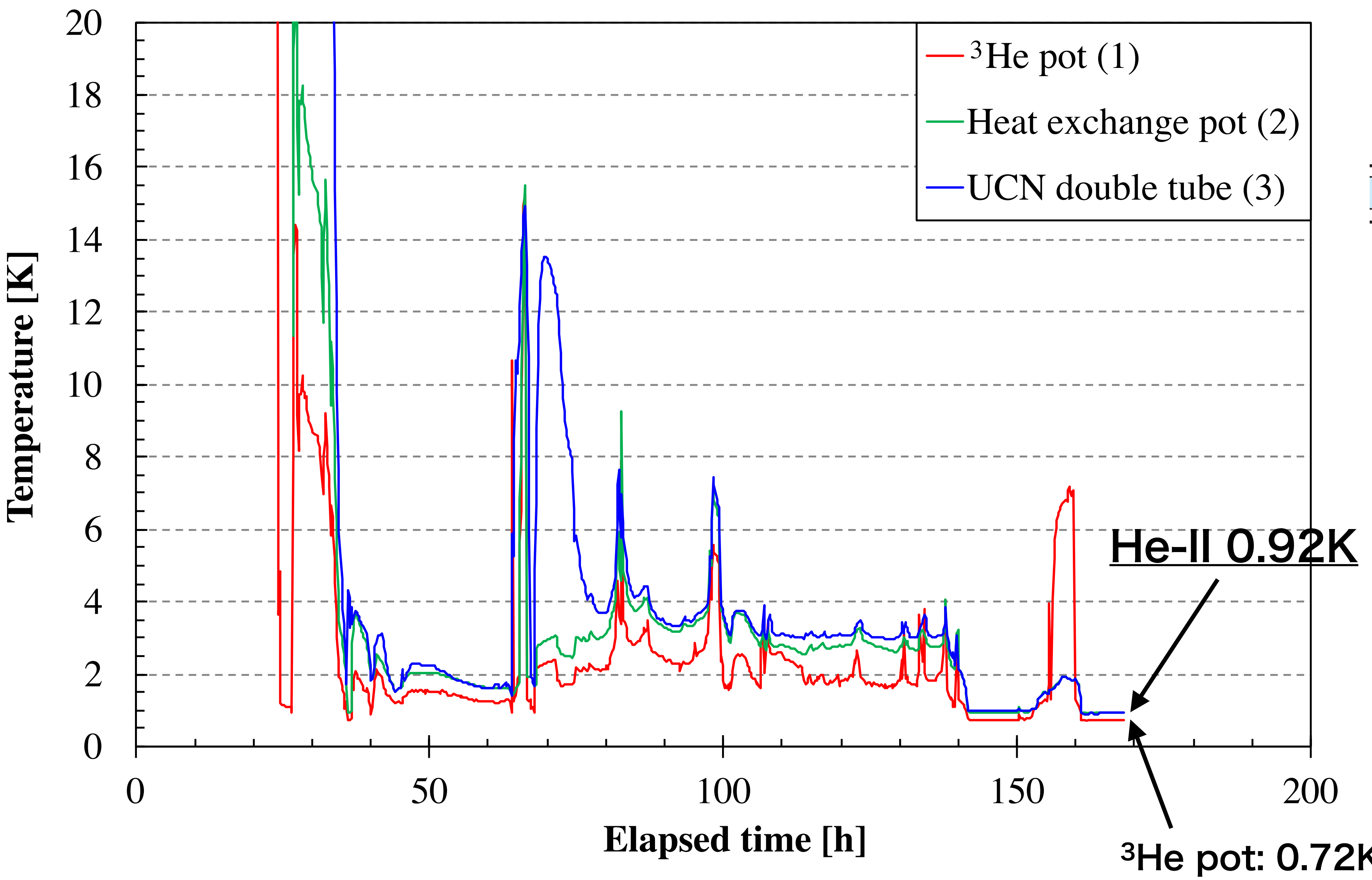
UCN source control panel on EPICS Screen

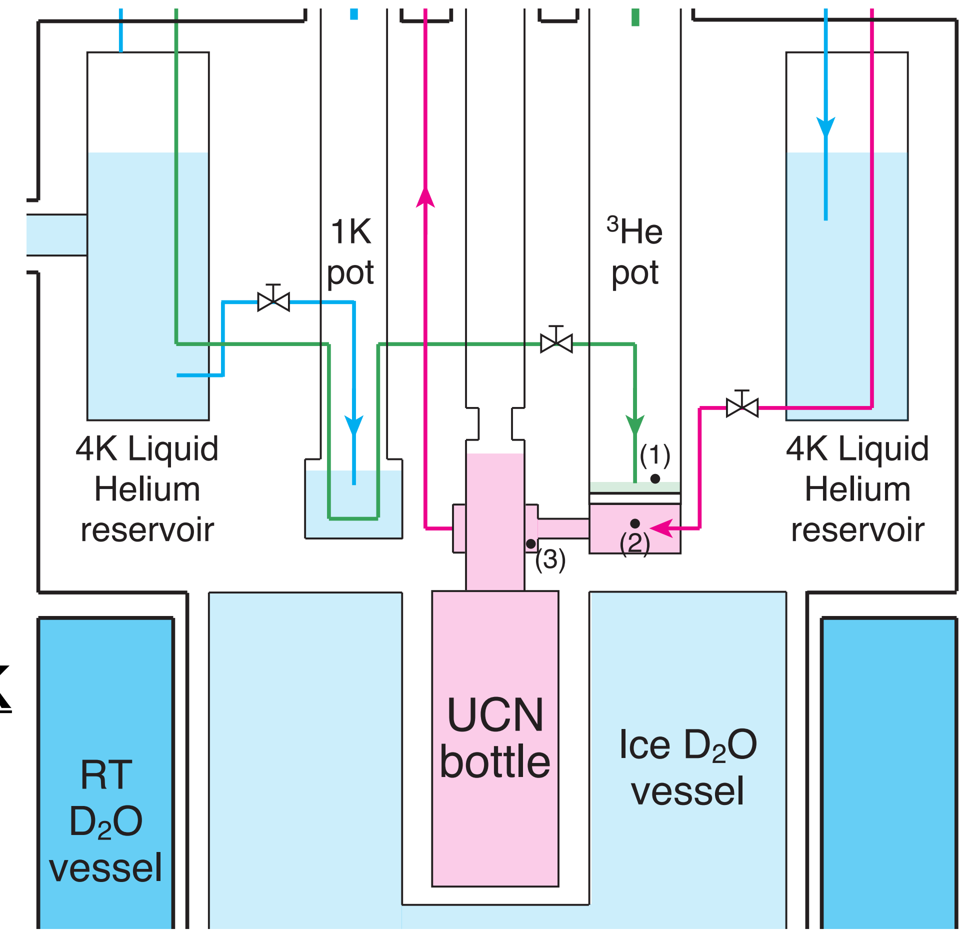
- Most of the devices (valve, pump, pressure gauge, temperature sensor etc) are connected to PLC.
- We can control the devices on EPICS screen.
- Some devices are still controlled manually - needle valve, ^{3}He gas handling
- Data (temperature, pressure, pump status) is recorded on MIDAS.

He-II cooling test in April 2017



He-II cooling test in April 2017





- Succeeded in condensing He-II in the UCN bottle
- Achieved $T_{He\text{-}II}$ = 0.92K
- UCN loss by phonon up-scattering in He-II is suppressed enough below 1K
- We can go to next step - UCN production

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UCN production schedule

- Late 2016 — Shipping the source from Japan
- Early 2017 (Main shutdown of the Cyclotron)
  - First cooling test
  - Installation of the UCN source
- 2017 April — He-II cooling test
- 2017 June — UCN guide baking at 120 degC
- 2017 July — D_2O cooling (next slide)

2017 August — First UCN Production

- Clogging in the ^{3}He circulation line
- Stopped cooling and warmed up the cryostat

D_2O cooling

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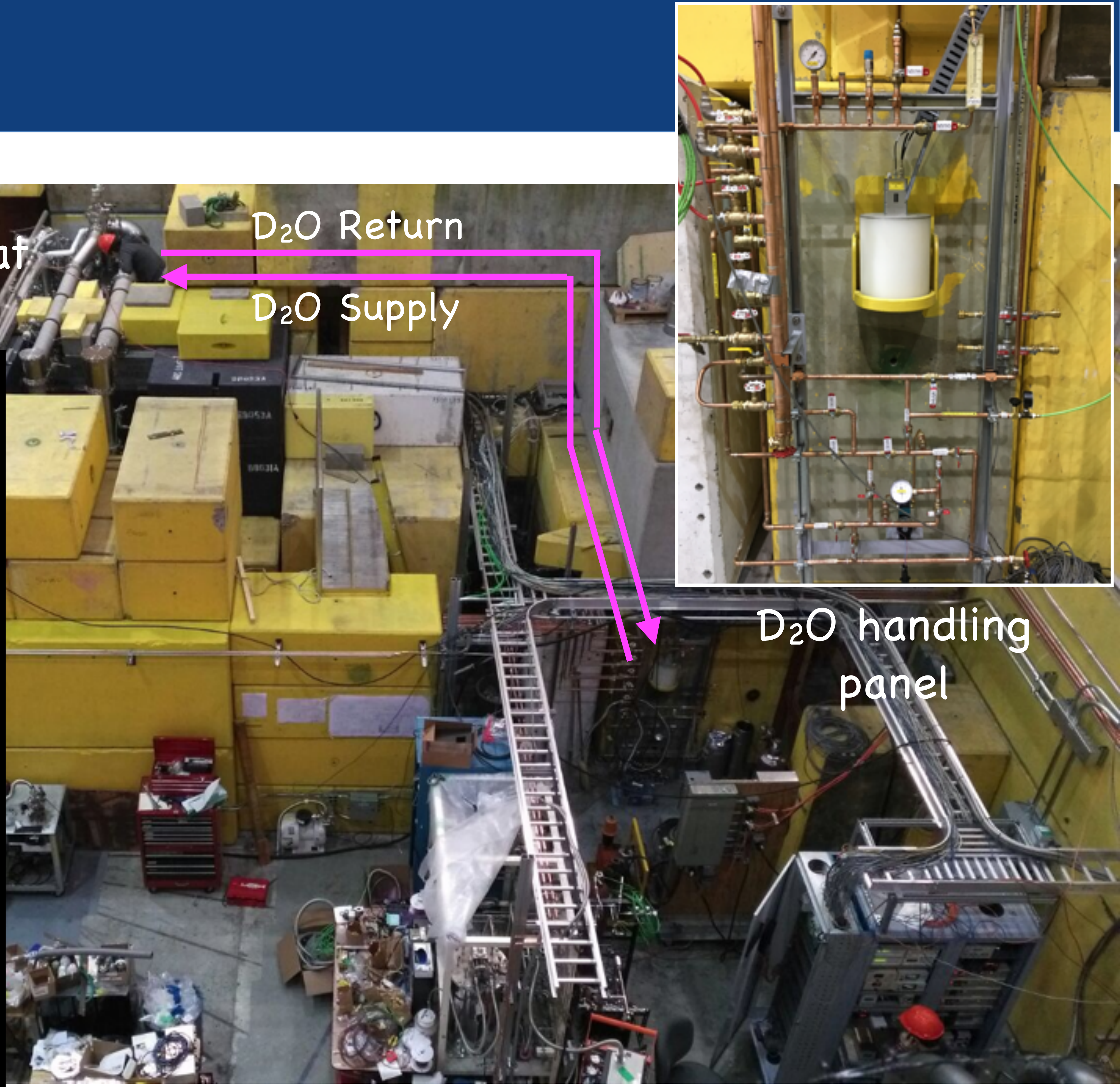
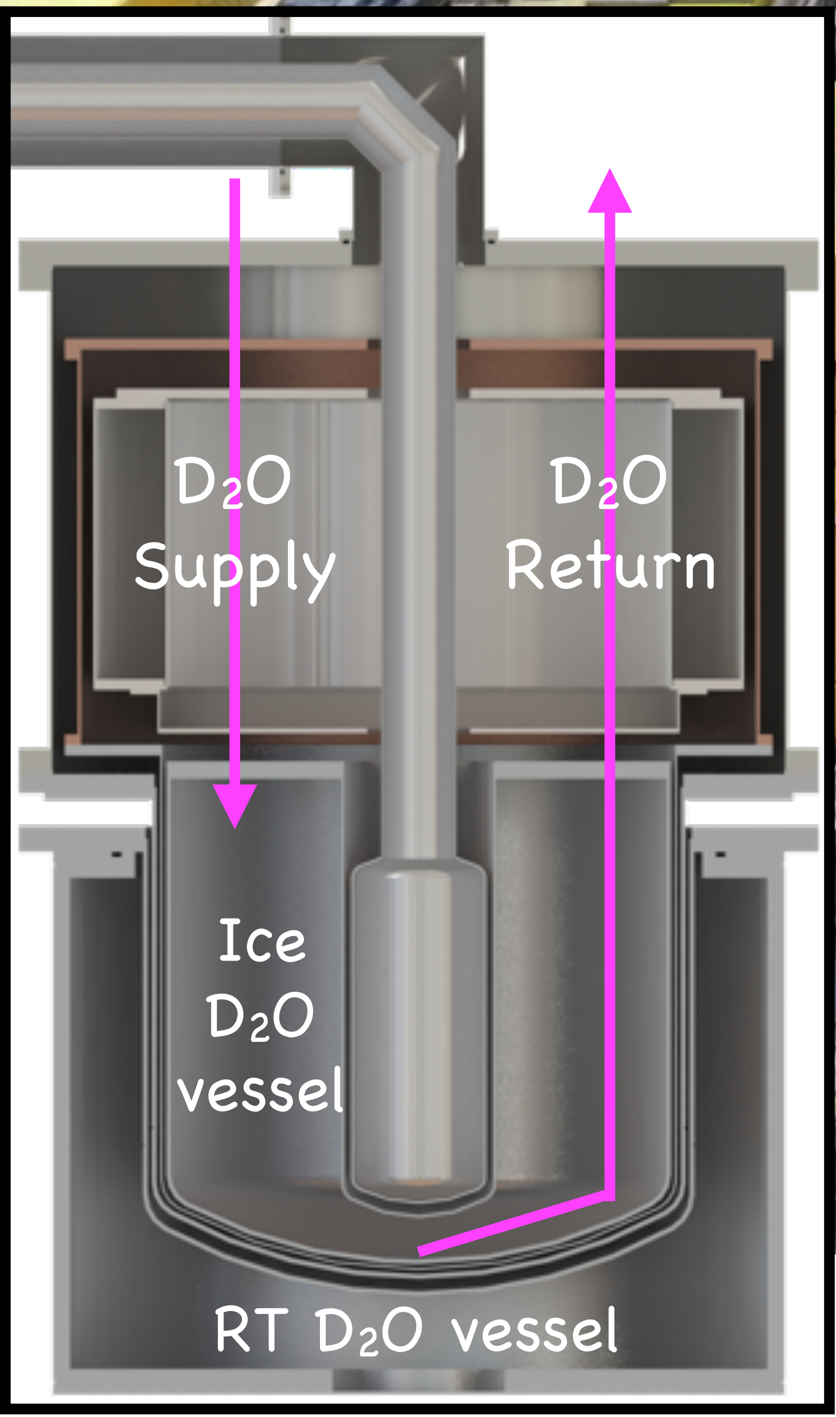
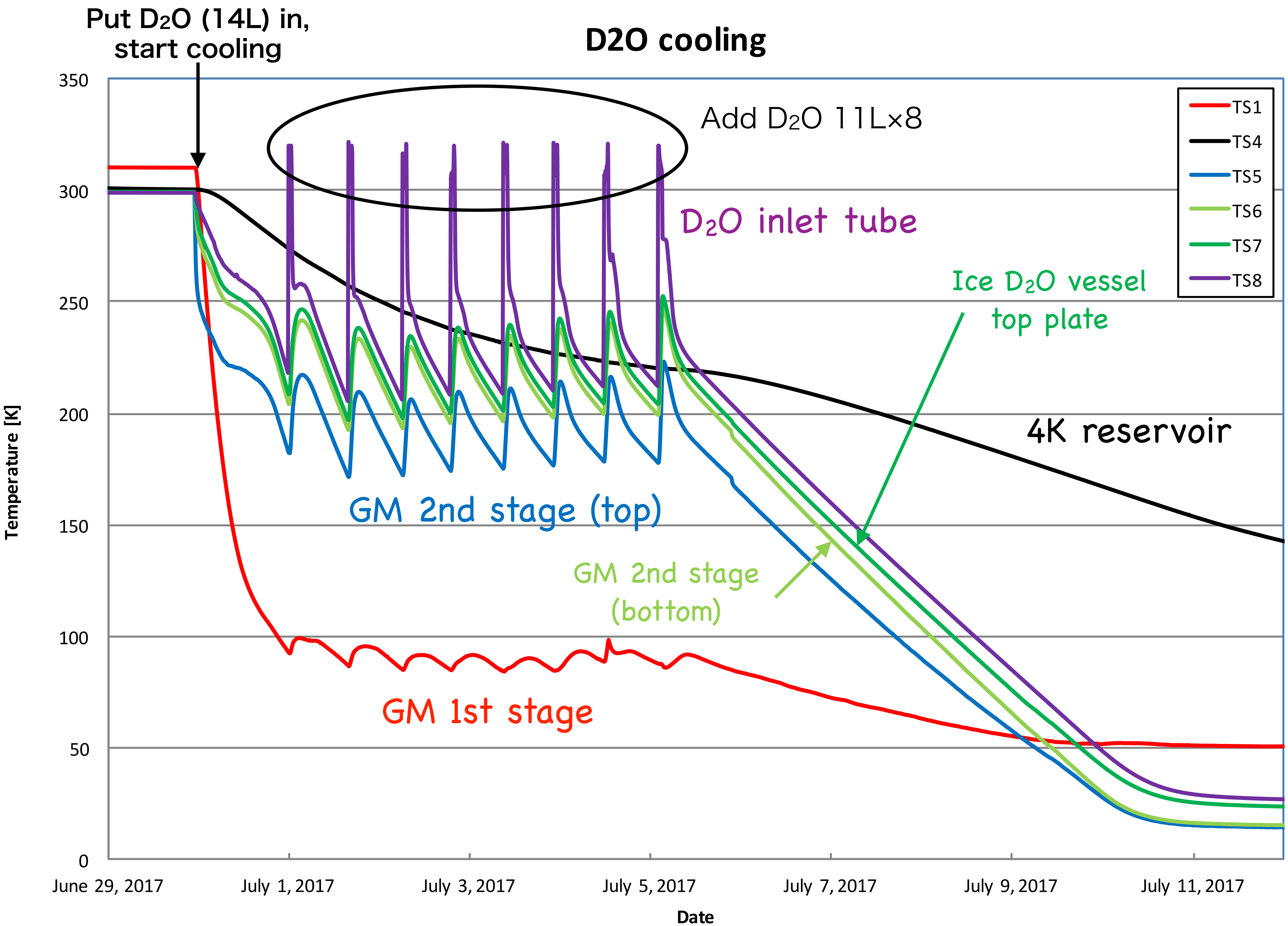
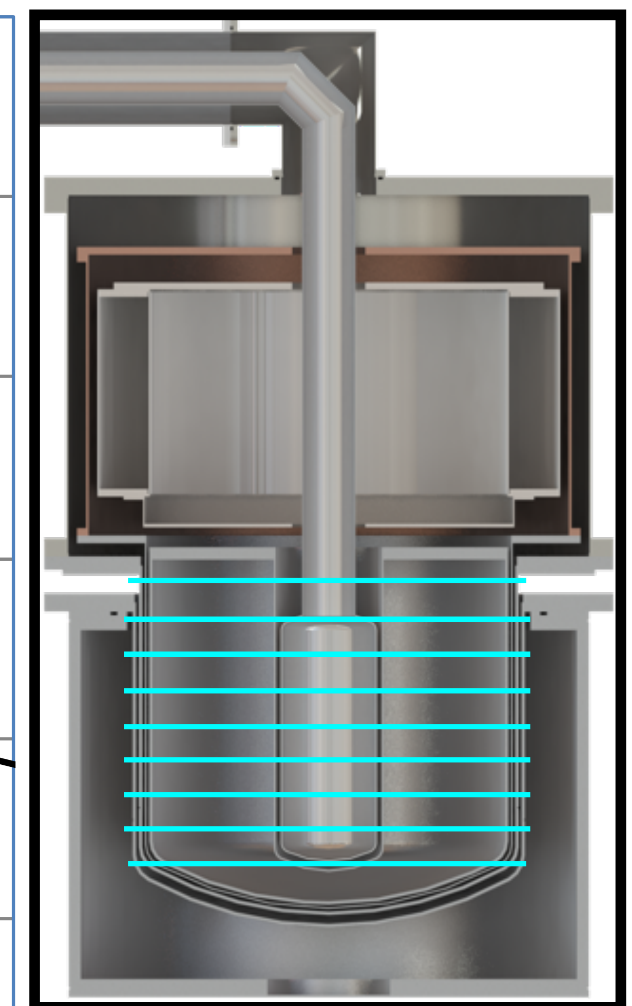

UCN cryostat
D₂O Return
D₂O Supply
D₂O handling panel


D₂O Supply
D₂O Return
Ice D₂O vessel
RT D₂O vessel

D_2O cooling in July 2017





9layers D_2O ice

- Added D_2O every 16 hours. 9 layers of D_2O ice in total to protect the vessel from volume expansion of D_2O
- 100L of D_2O in total became ice in 11 days (300K to 20K).

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UCN production schedule

- Late 2016 — Shipping the source from Japan
- Early 2017 (Main shutdown of the Cyclotron)
  - First cooling test
  - Installation of the UCN source
- 2017 April — He-II cooling test
- 2017 June — UCN guide baking at 120 degC
- 2017 July — D_2O cooling (next slide)

2017 August — First UCN Production

- Clogging in the ^{3}He circulation line
- Stopped cooling and warmed up the cryostat

2017 Sept.-Oct. — Fixing the ^{3}He line problems

2017 October — Start cooling for next UCN production

2017 November — UCN production

Summary

- The vertical UCN source was shipped from Japan, and installed on the beam line 1U at TRIUMF
- The UCN source passed the full cooling test.
- We succeeded in condensing and cooling He-II down to 0.92K.
- We also succeeded in cooling D_2O.
- In August, He-II condensation failed due to clogging in the ^{3}He circulation line.
- We're fixing the problems and will try UCN production in November.

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Thank you!
Merci!

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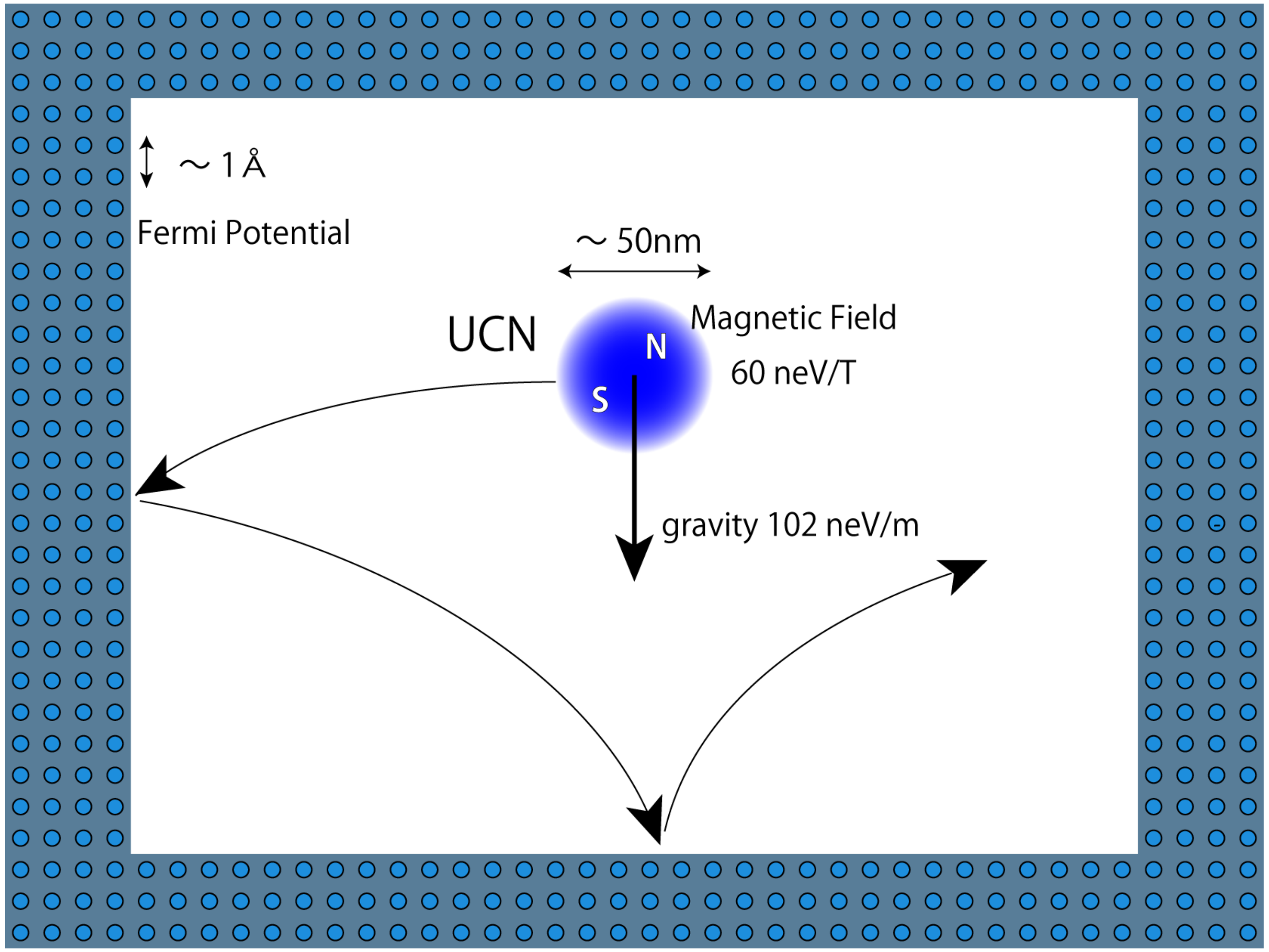
Backup slides

Ultracold Neutron (UCN)



Ultracold Neutron (UCN)

Energy ~ 100neV

Velocity ~ 5 m/s

Wavelength ~ 500 Å (50 nm)

Interaction

Gravity ~ 102 neV/m

Magnetic field ~ 60 neV/T

Weak interaction: $n \rightarrow p + e + \nu$

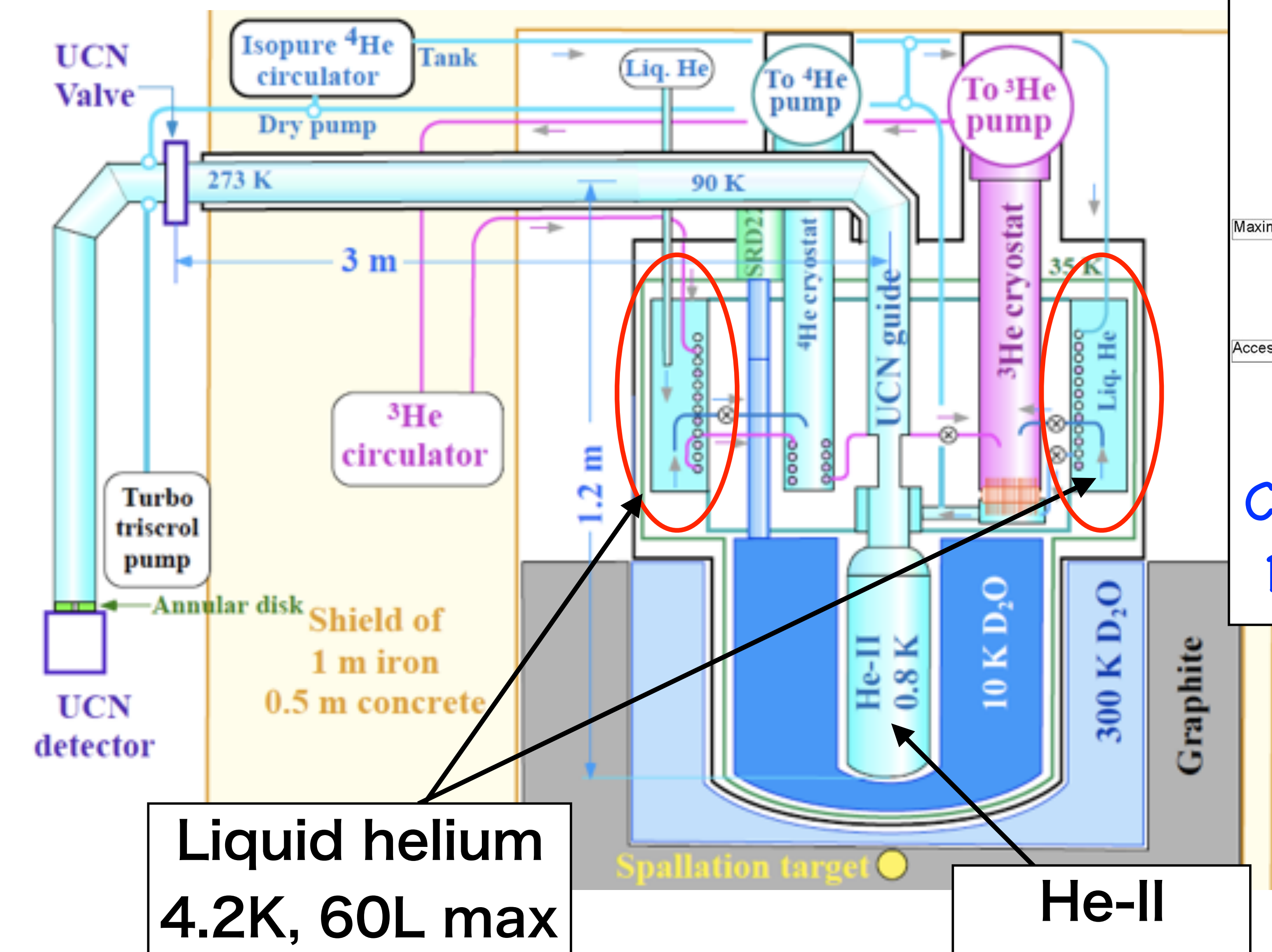
Strong interaction (Fermi potential)

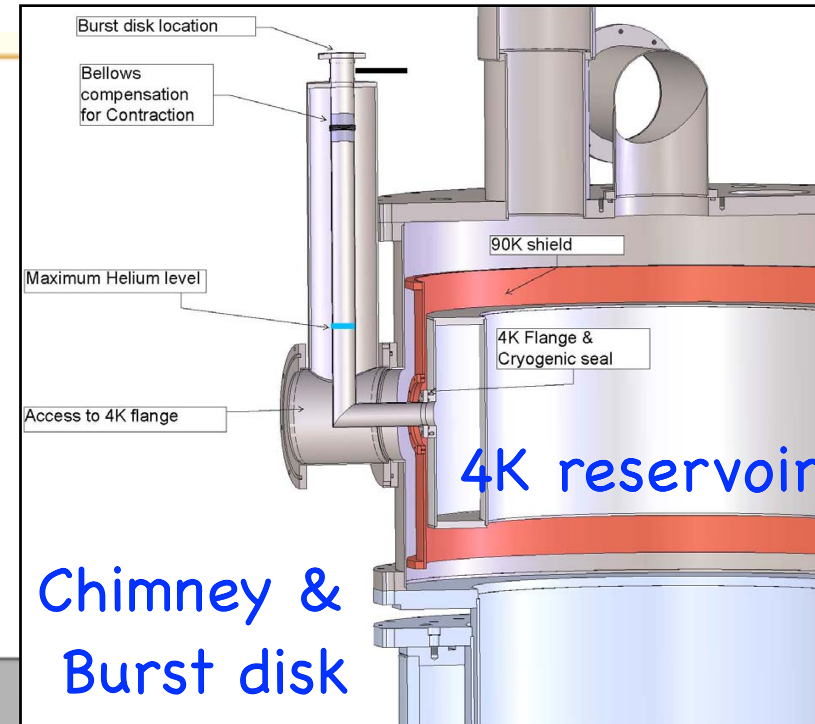
^{58}Ni wall potential: 335 neV

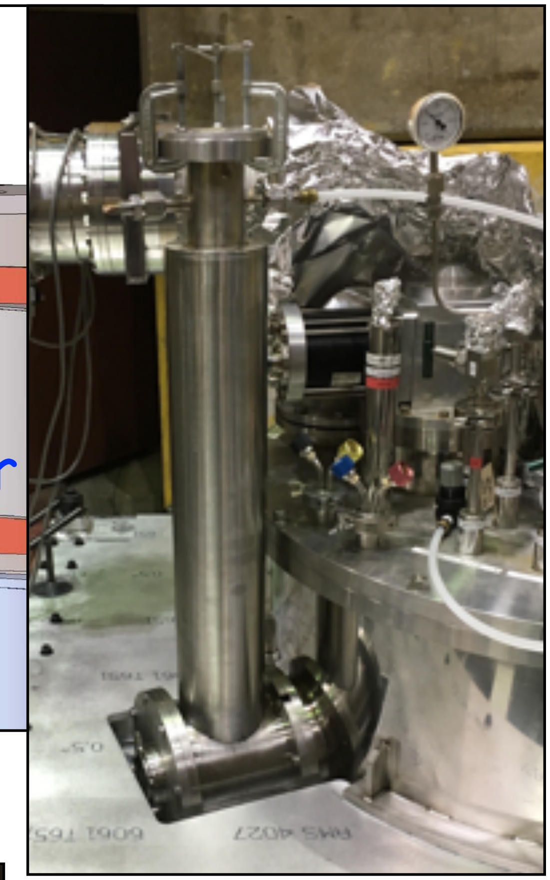
UCN can be confined in a vessel for a long time
→ nEDM, n lifetime, Gravity etc…

- UCN density in a vessel is the most important for precision measurements.
- 0.7 UCN/cm^3 (E_c = 90neV) for nEDM measurement at ILL (Grenoble)
- Much more intense UCN source is necessary to search for nEDM.
- We are developing a high density UCN source with superfluid helium (He-II).

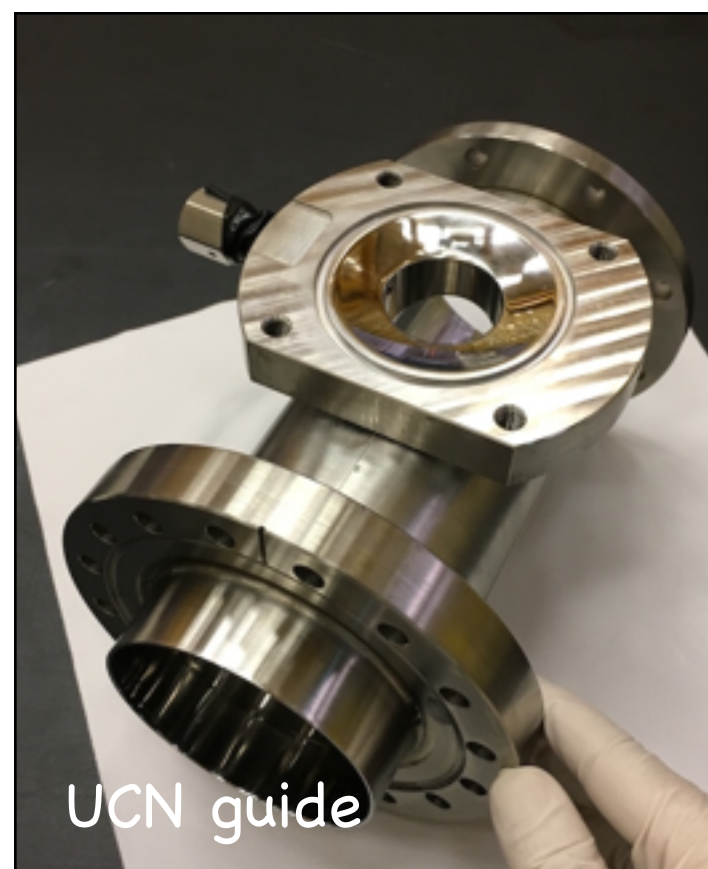
Cryostat Safety Upgrade (4K reservoir & UCN guide)





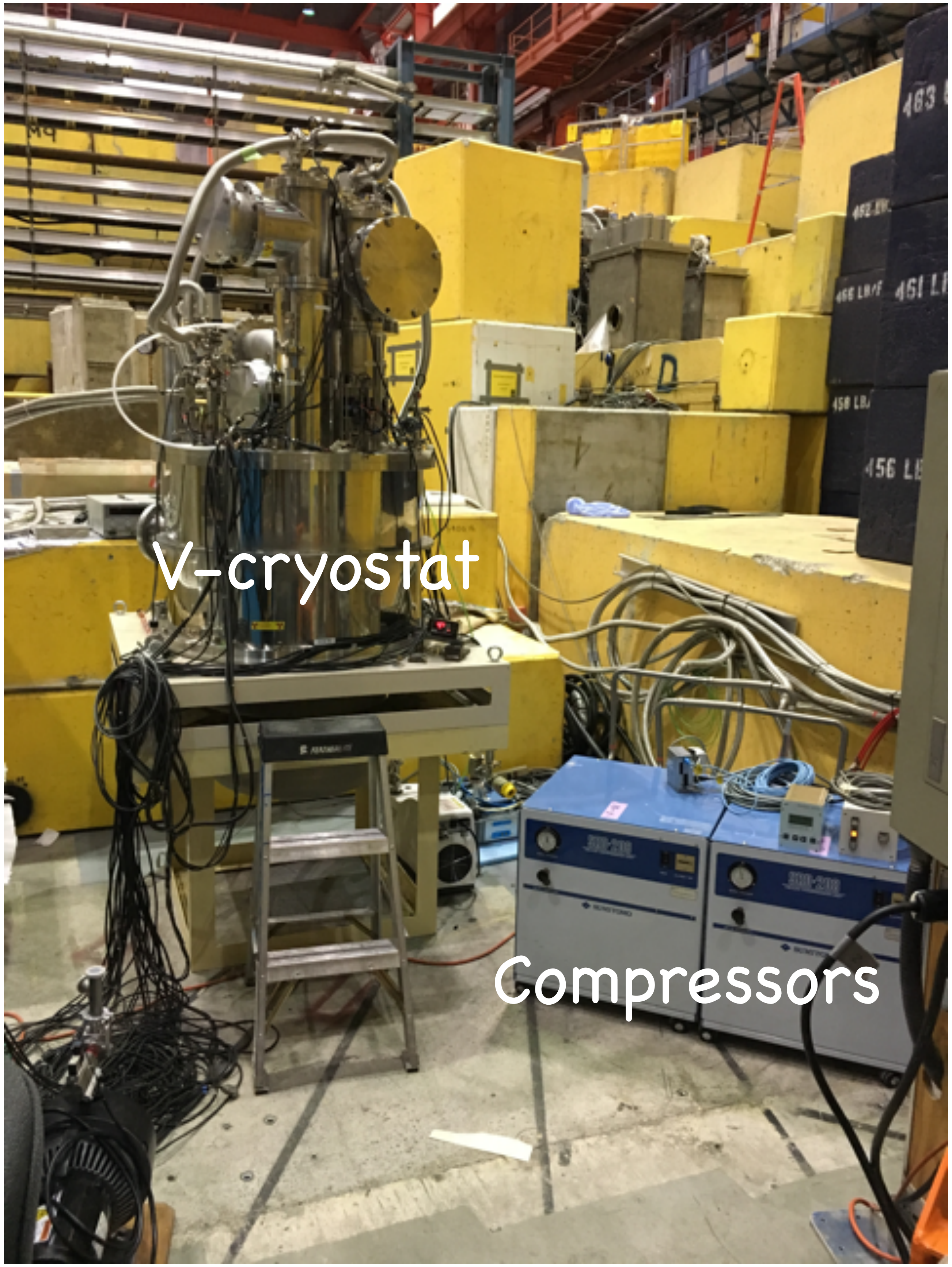


- When the insulating vacuum is broken, heat load on liquid helium becomes ~10kW.
- Liquid helium is boiled off.
- We installed burst disks to save the cryostat.



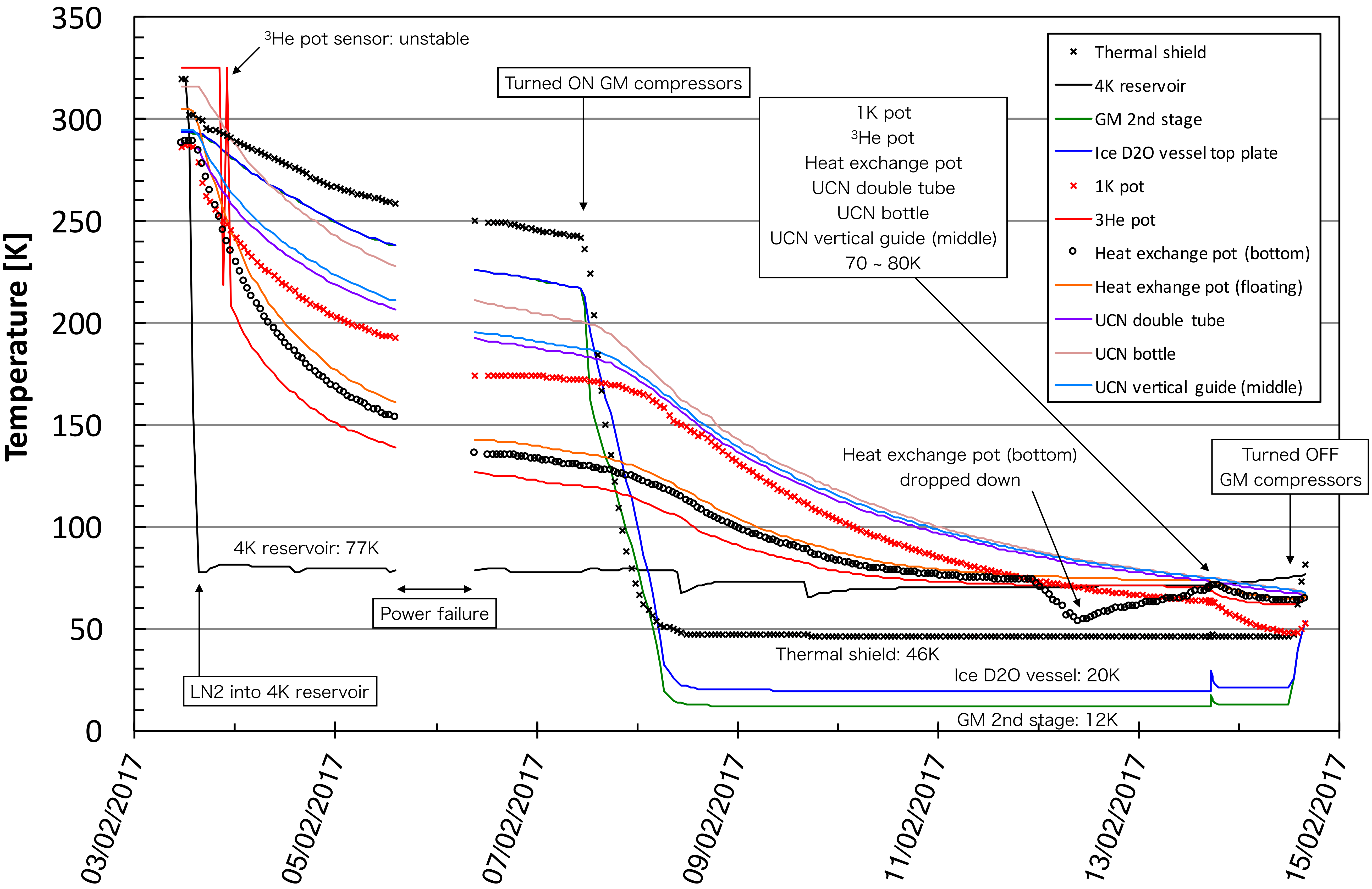
Burst disk at
UCN guide end

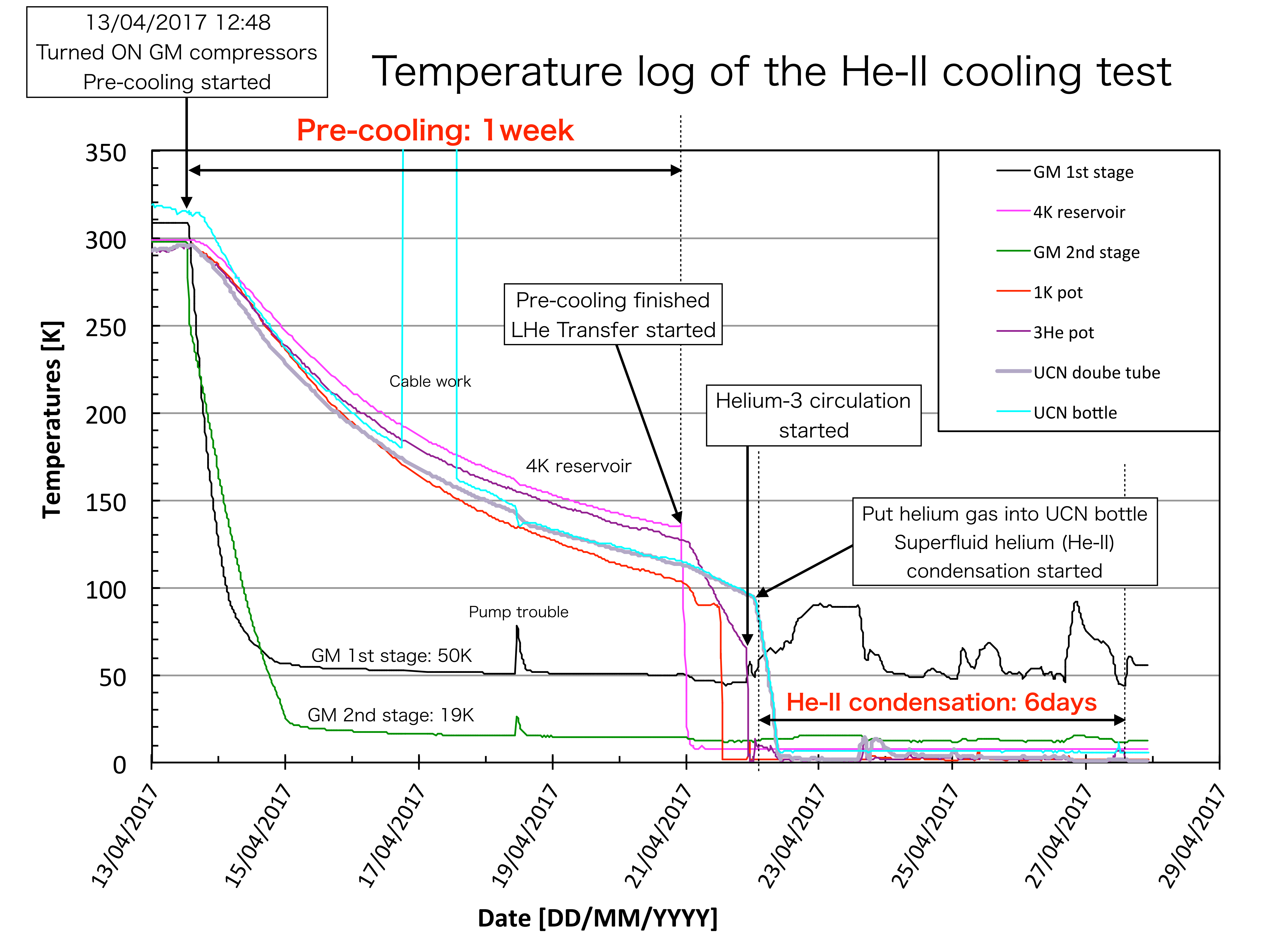
GM cooling test (detail)



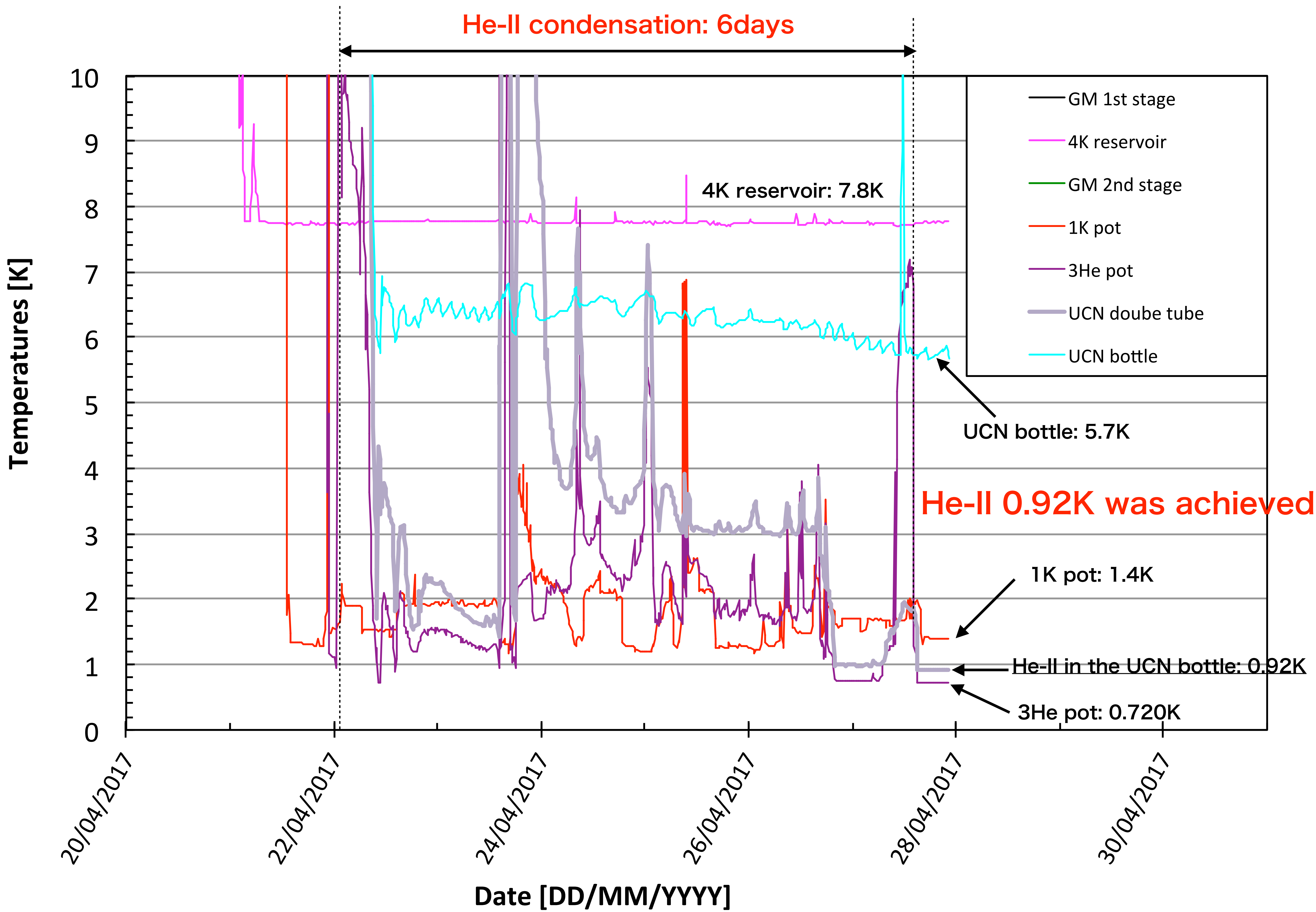
- Moved the cryostat to Meson hall (Feb 2)
- Put LN2 into 4K reservoir (Feb 3)
- Turned on compressors (Feb 6)
- Ice D_2O vessel became ~20K (Feb 8)
- 1K pot, ^{3}He pot, UCN guide became ~ 77K (Feb 13)
- Cold leak test (Feb 14)
- Turned off compressors (Feb 14)

Temperature log of the GM cooling test



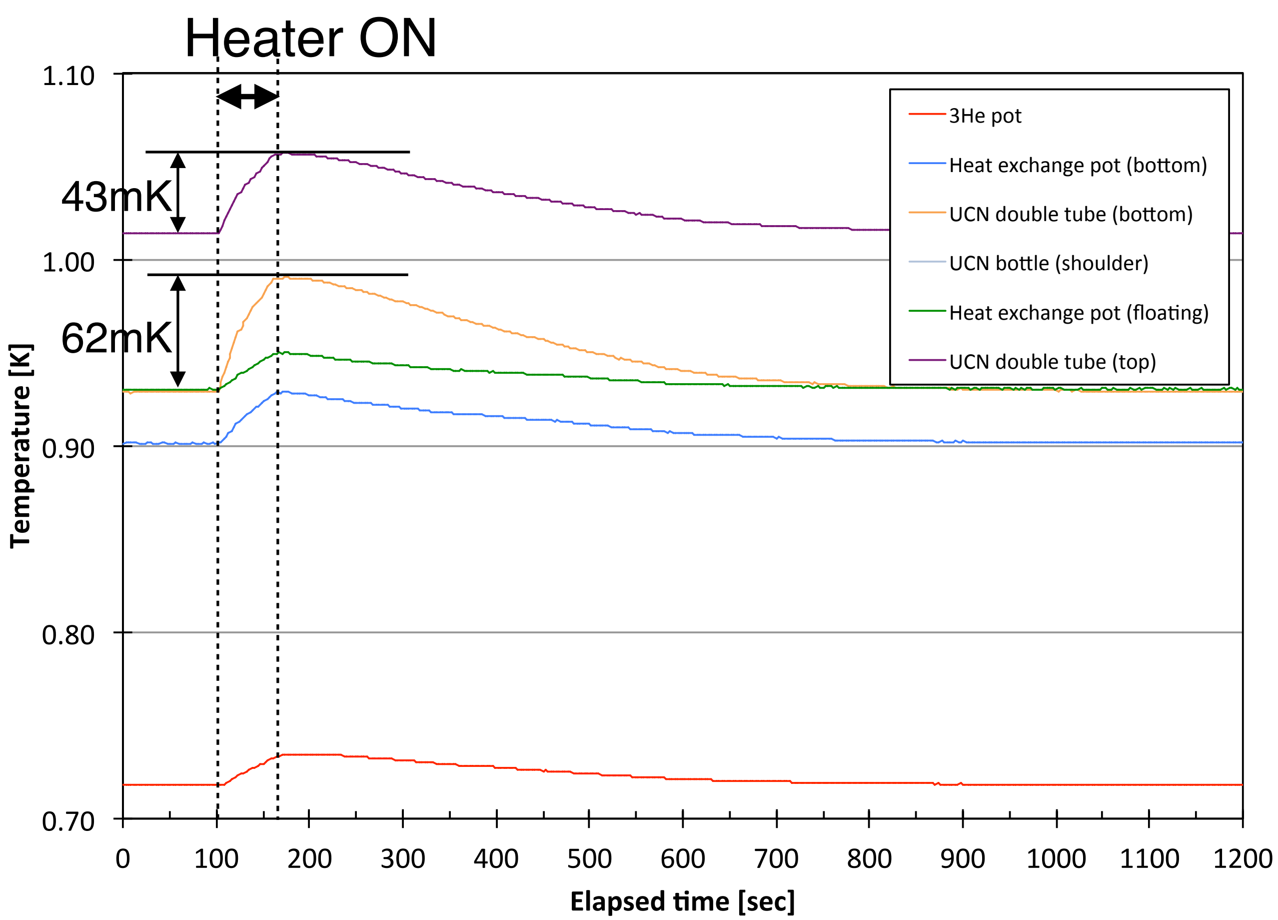


13/04/2017 12:48
Turned ON GM compressors
Pre-cooling started
Temperature log of the He-II cooling test
Pre-cooling: 1week
GM 1st stage
4K reservoir
GM 2nd stage
1K pot
3He pot
UCN doube tube
UCN bottle
Cable work
Pre-cooling finished
LHe Transfer started
4K reservoir
Helium-3 circulation
started
Put helium gas into UCN bottle
Superfluid helium (He-II)
condensation started
Pump trouble
GM 1st stage: 50K
GM 2nd stage: 19K
He-II condensation: 6days
Temperatures [K]
350
300
250
200
150
100
50
0
13/04/2017
15/04/2017
17/04/2017
19/04/2017
21/04/2017
23/04/2017
25/04/2017
27/04/2017
29/04/2017
Date [DD/MM/YYYY]


He-II condensation: 6days
10
9
8
7
6
5
4
3
2
1
0
Temperatures [K]
GM 1st stage
4K reservoir
GM 2nd stage
1K pot
3He pot
UCN doube tube
UCN bottle
4K reservoir: 7.8K
UCN bottle: 5.7K
He-II 0.92K was achieved
1K pot: 1.4K
He-II in the UCN bottle: 0.92K
3He pot: 0.720K
20/04/2017
22/04/2017
24/04/2017
26/04/2017
28/04/2017
30/04/2017
Date [DD/MM/YYYY]

Heat load test

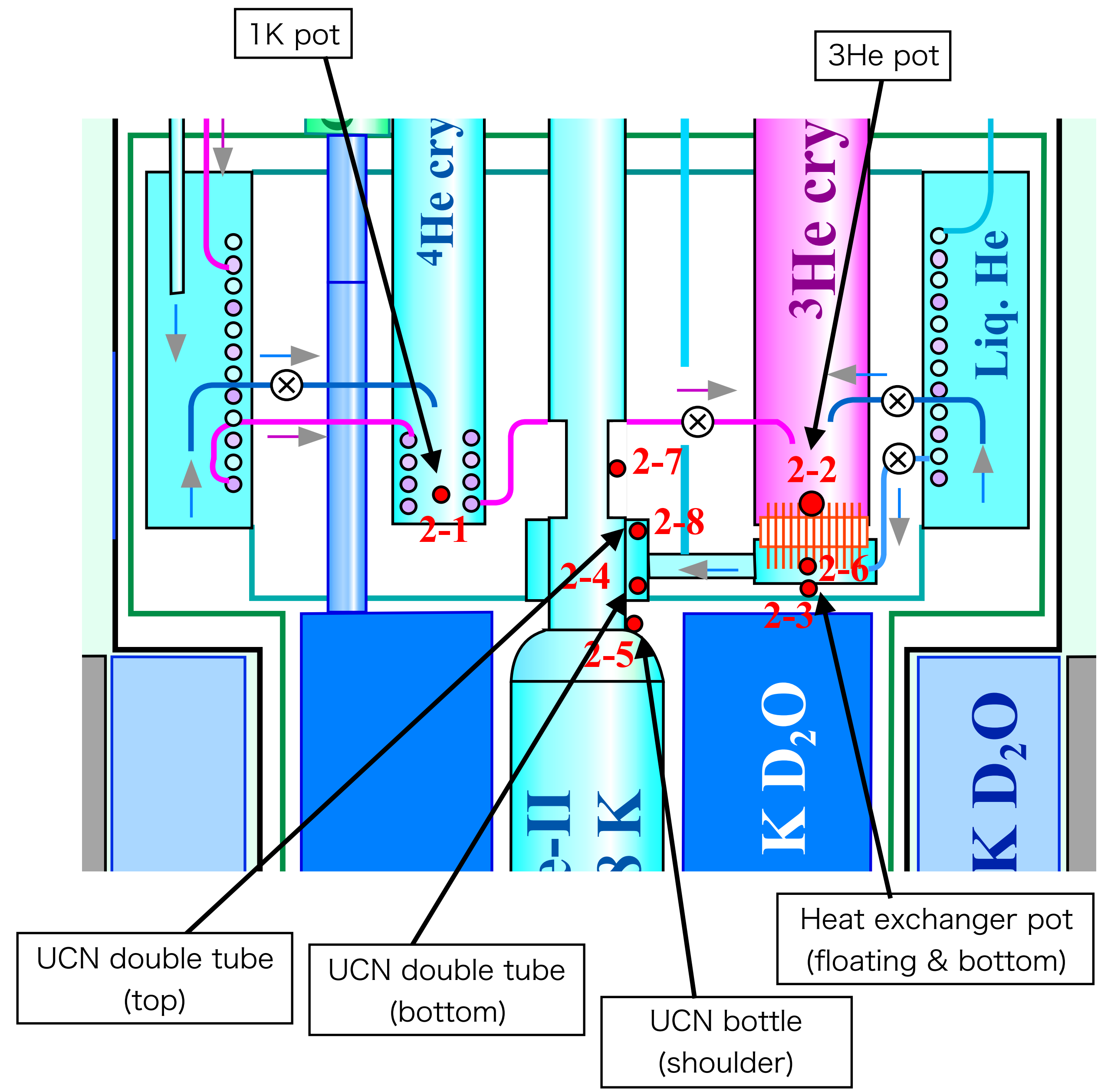
- 1uA p-beam: 100mW heat load by γ/β-heating
- Put heat load into He-II using a heater wound around the UCN bottle.
- Heater power: 2.5mW, 12.5mW, 25mW, 75mW, 250mW, 1000mW, 4000mW
- Heating time: 10sec, 20sec, 60sec, Continuous (5minutes or more)



Heater power 1000mW, 60sec

ΔT (UCN double tube bottom) = 62mK

ΔT (UCN double tube top) = 43mK



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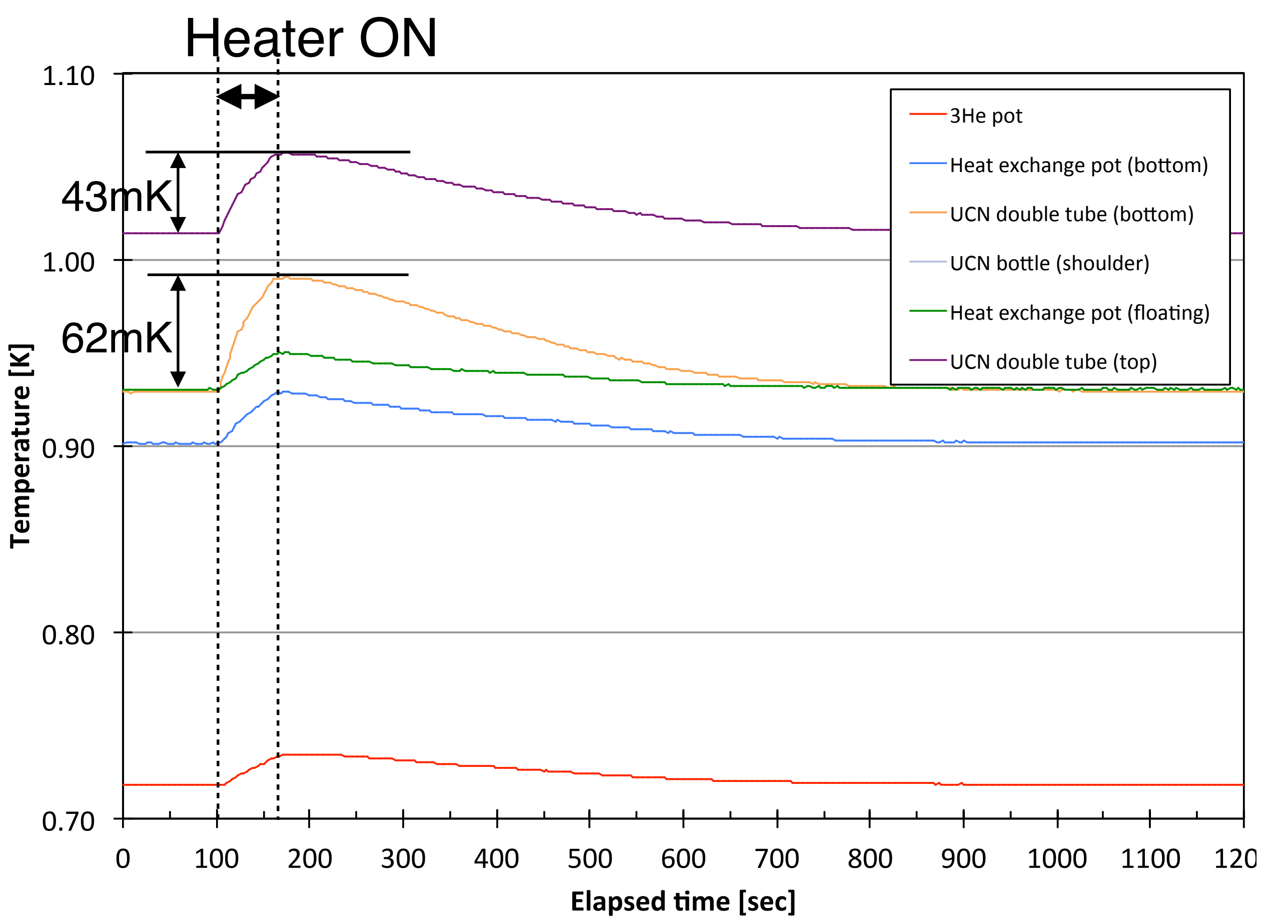

Heater power 1000mW, 60sec

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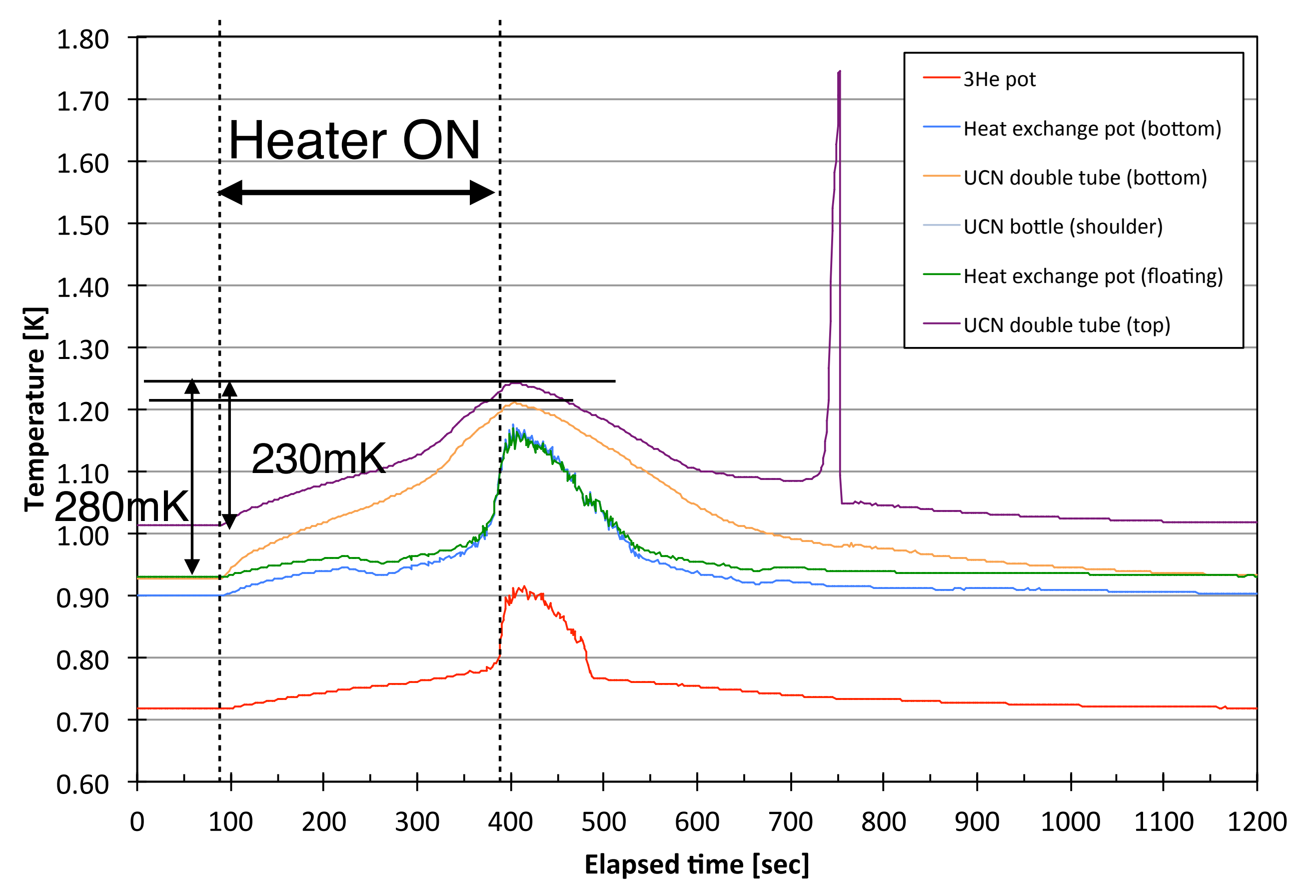
ΔT (UCN double tube top) = 43mK



Heater power 1000mW, Continuous

ΔT (UCN double tube bottom) = 280mK

ΔT (UCN double tube top) = 230mK

(Had to abort test)

Heat load test

Heater power [mW]	Heating time [s]	ΔT (UCN double tube bottom)	ΔT (UCN double tube top)
2. 5 (25nA p-beam)	10	0	0
	20	0	0
	60	0	0
	continuous	1 mK	1 mK
12. 5 (125nA p-beam)	10	1 mK	1 mK
	20	1 mK	1 mK
	60	2 mK	1 mK
	continuous	4 mK	4 mK
25 (250nA p-beam)	10	1 mK	1 mK
	20	–	–
	60	4 mK	3 mK
	continuous	10 mK He-II 0.93K	9 mK
75 (750nA p-beam)	10	3 mK	2 mK
	20	3 mK	3 mK
	60	10 mK	7 mK
	continuous	30 mK He-II 0.95K	20 mK
250 (2.5uA p-beam)	10	6 mK	3 mK
	20	11 mK	7 mK
	60	27 mK	17 mK
	continuous	72 mW He-II 1.0K	53 mK
1000 (10uA p-beam)	10	21 mK	13 mK
	20	32 mK	21 mK
	60	62 mK	43 mK
	continuous	280 mK (test aborted)	230 mK (test aborted)
4000 (40uA p-beam)	10	51 mK	35 mK

UCN storage time

$$\frac{1}{\tau} = \frac{1}{\tau_n} + B \cdot T^7$$

$$\tau_n = 880 \sec$$

T [K]	τ (B=8x10^{-3})
0	880
0.5	834
0.7	557
0.8	355
0.9	202
1.0	109

Liquid helium consumption