Status of the Superfluid Helium UCN source at TRIUMF

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June 1, 2017, Queen's University, Kingston, ON

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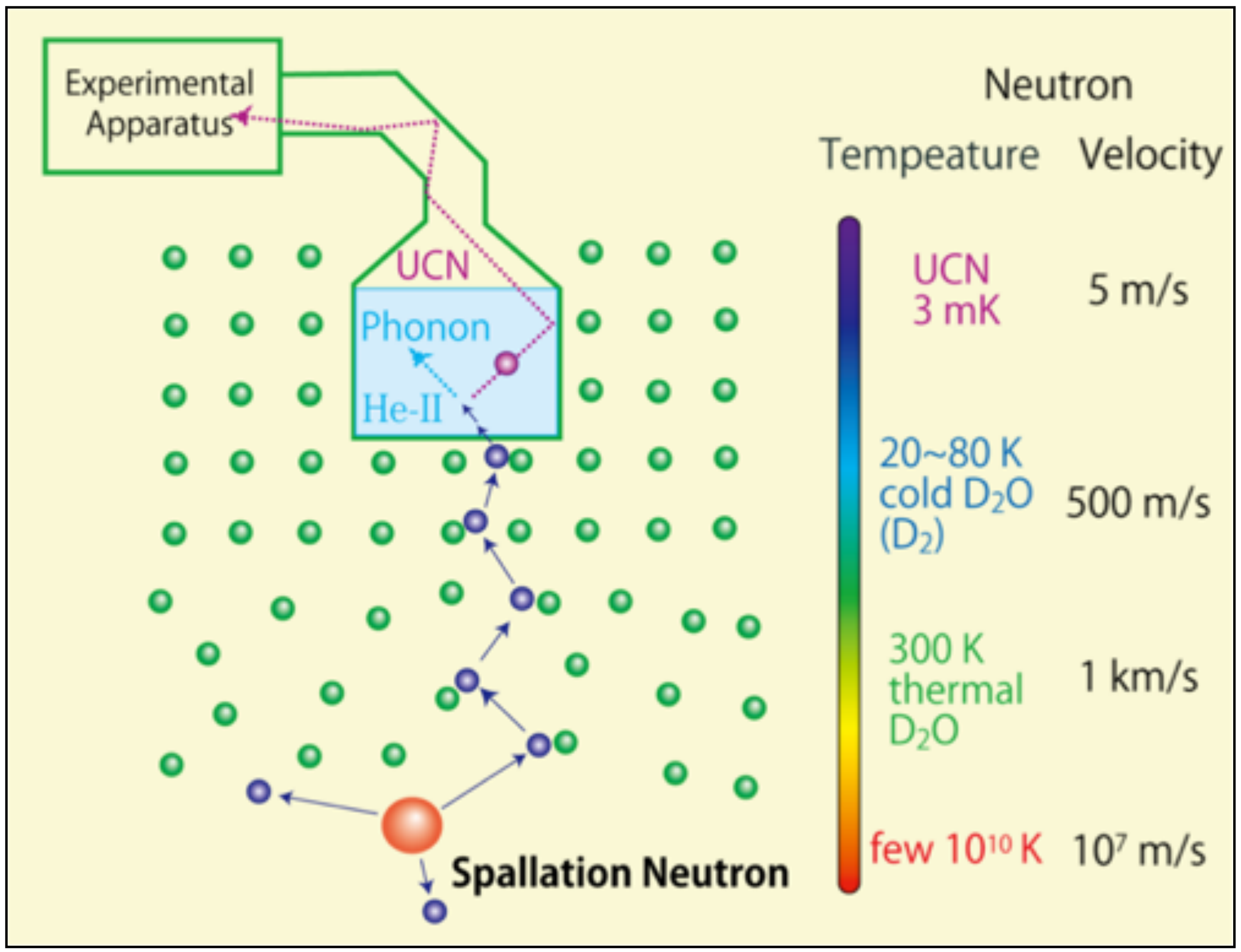
Super-thermal UCN Production



- Produce fast neutrons by proton-induced spallation

  ↓ ~ a few MeV

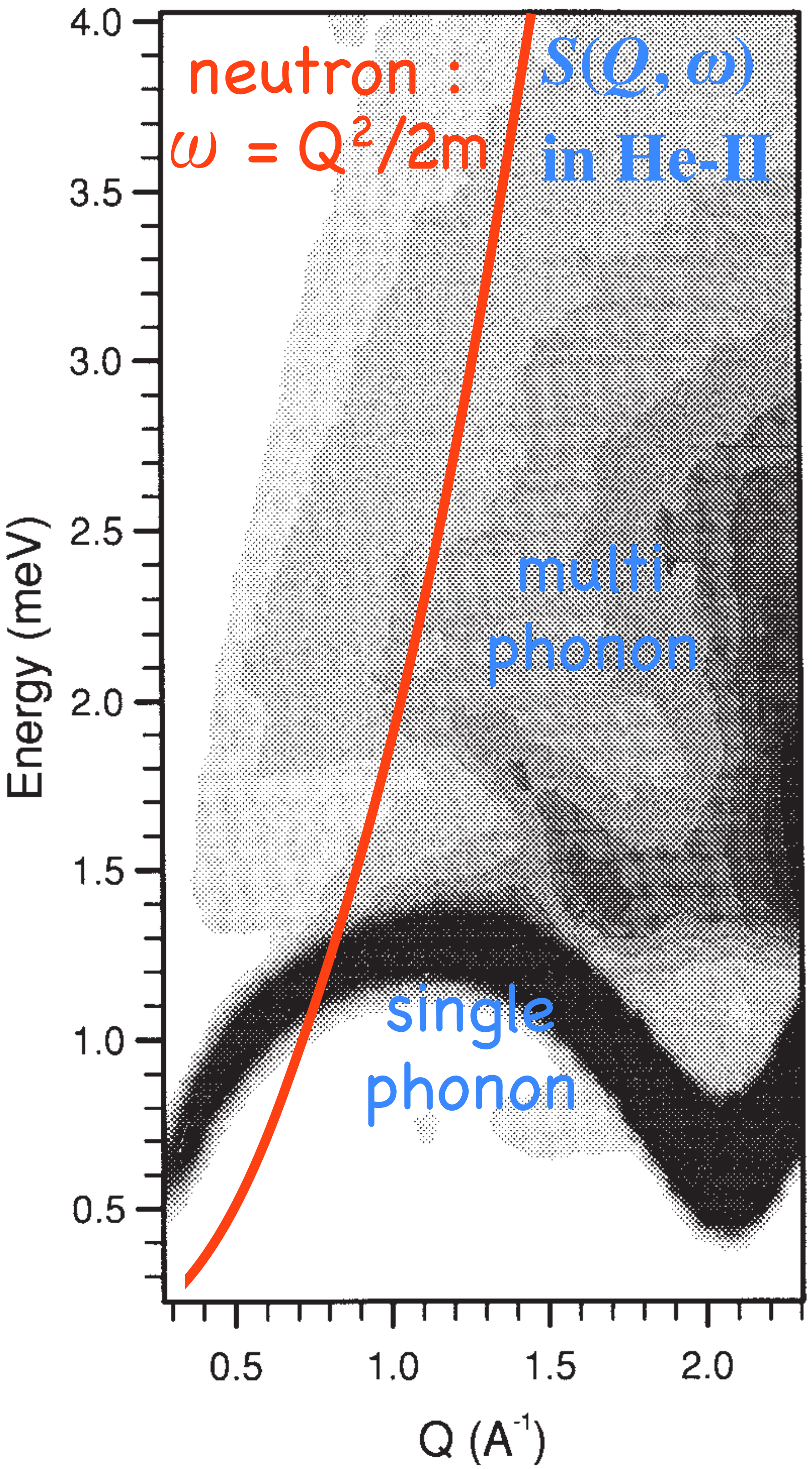
- Moderate (thermalize) neutrons in 300K and 20K D_2O

  ↓ ~ a few meV

- Cold neutrons are down-scattered to near zero energy by phonon scattering in superfluid helium (He-II)

  < 300 neV

Super-thermal UCN Production



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

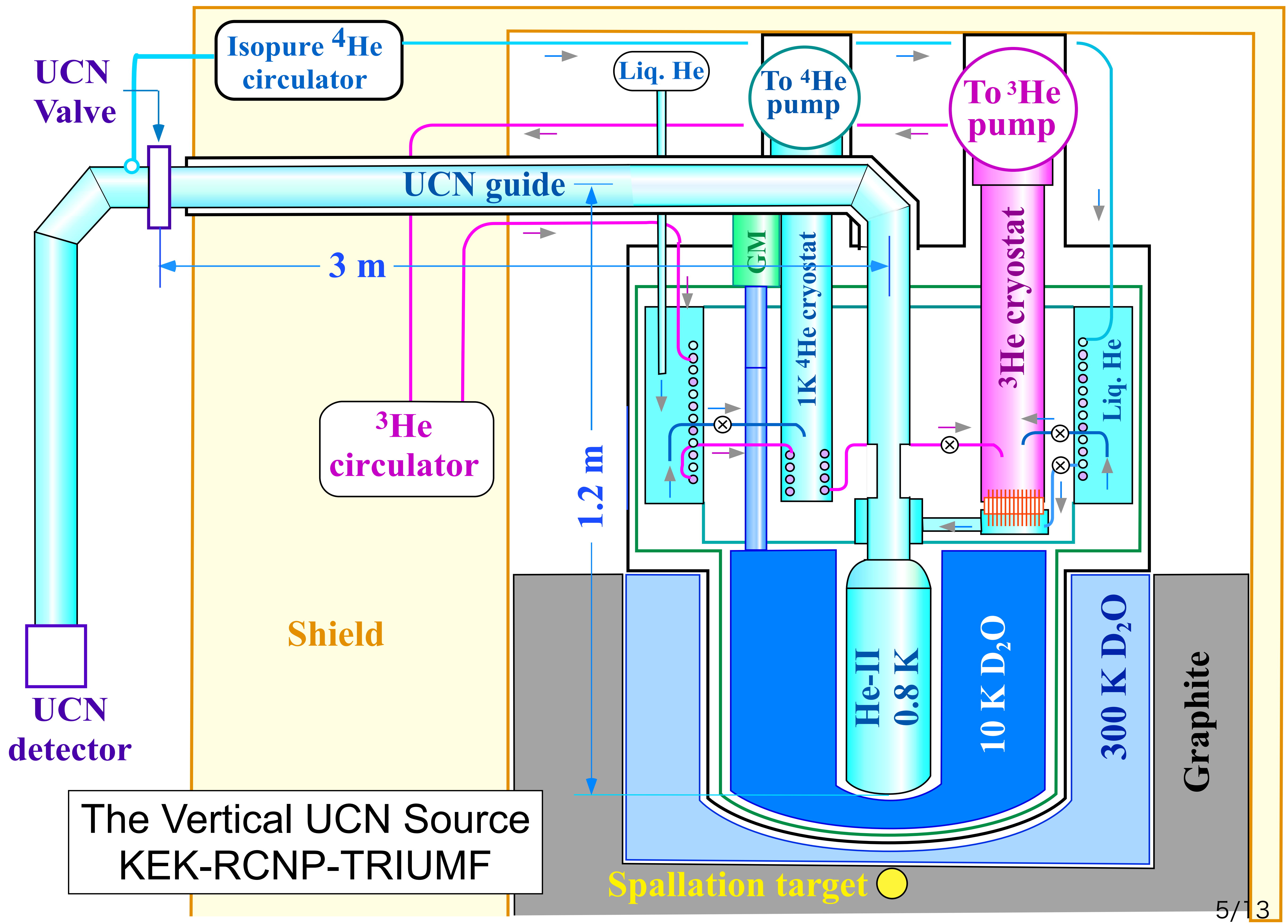
UCN Production rate in He-II

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

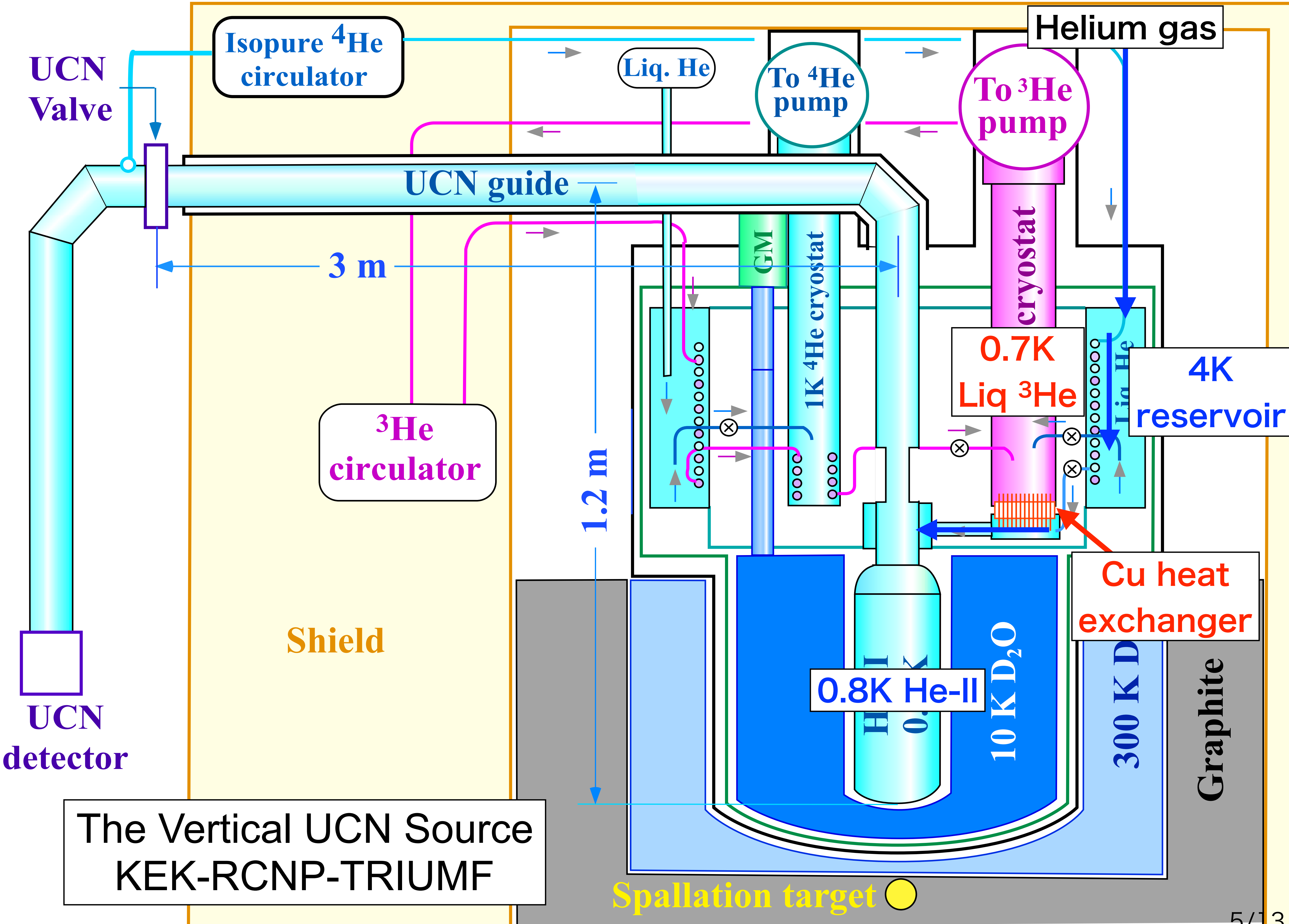
He-II density — cross section — cold n flux

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

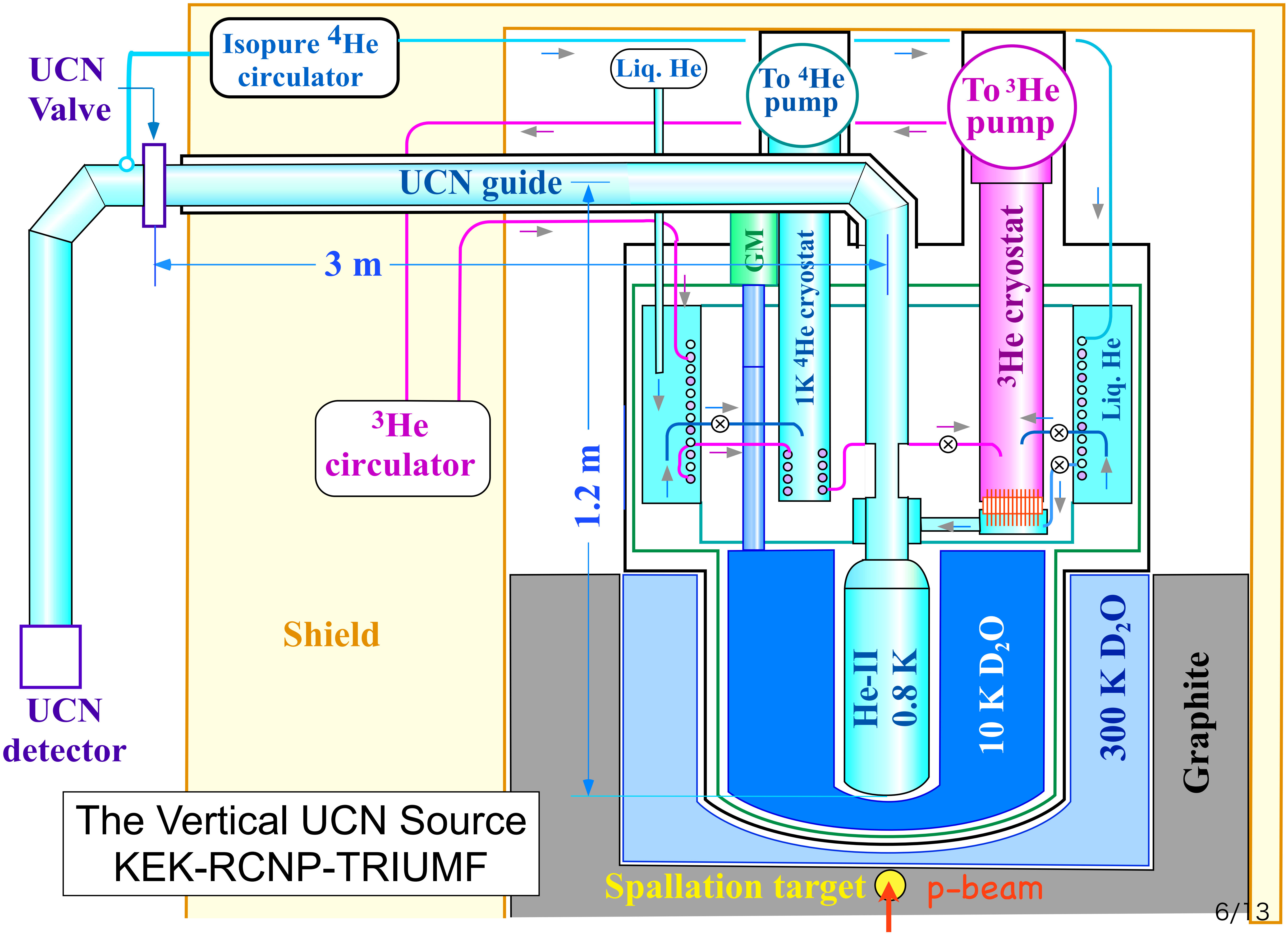
- b_{coh}: scattering length
- k_f: wave number of scattered n
- k_i: wave number of incident n
- $S(Q,\omega)$: Scattering function



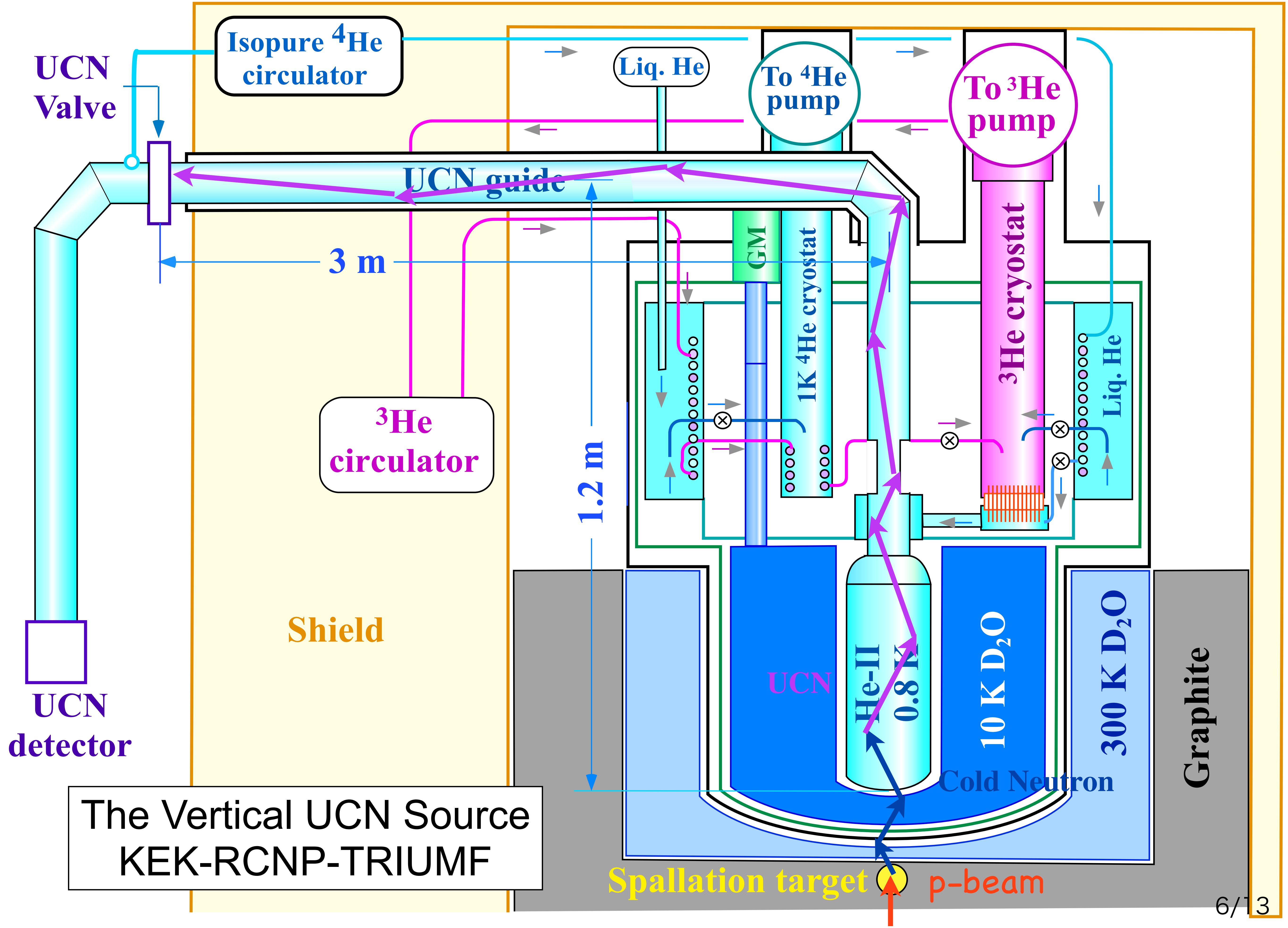
The Vertical UCN Source
KEK-RCNP-TRIUMF



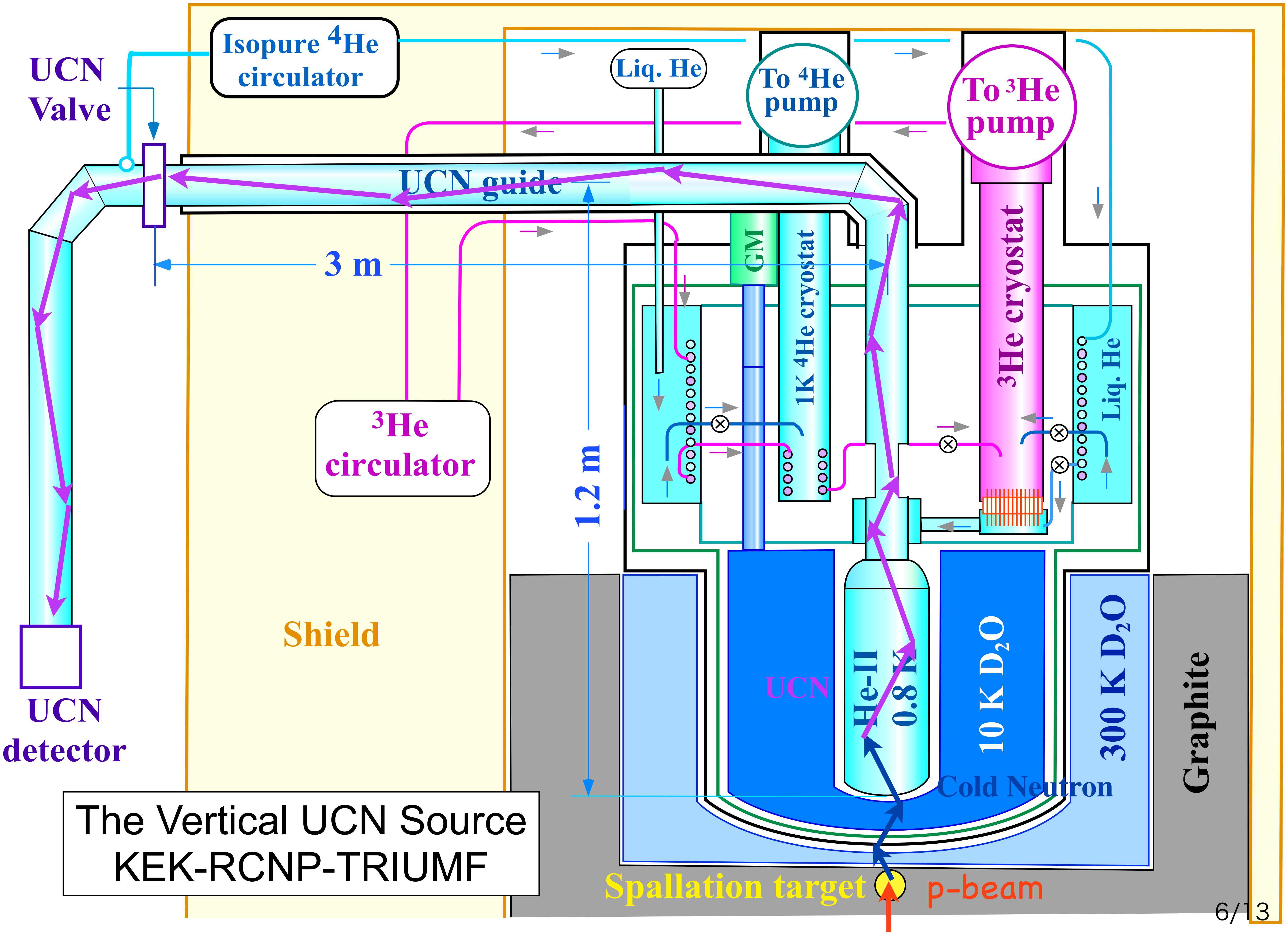
UCN Valve
Isopure 4He circulator
Liq. He
To 4He pump
Helium gas
To 3He pump
UCN guide
3 m
GM
1K 4He cryostat
cryostat
0.7K Liq 3He
4K reservoir
3He circulator
1.2 m
Cu heat exchanger
0.8K He-II
10 K D2O
Graphite
Shield
UCN detector
Spallation target
The Vertical UCN Source
KEK-RCNP-TRIUMF



The Vertical UCN Source
KEK-RCNP-TRIUMF

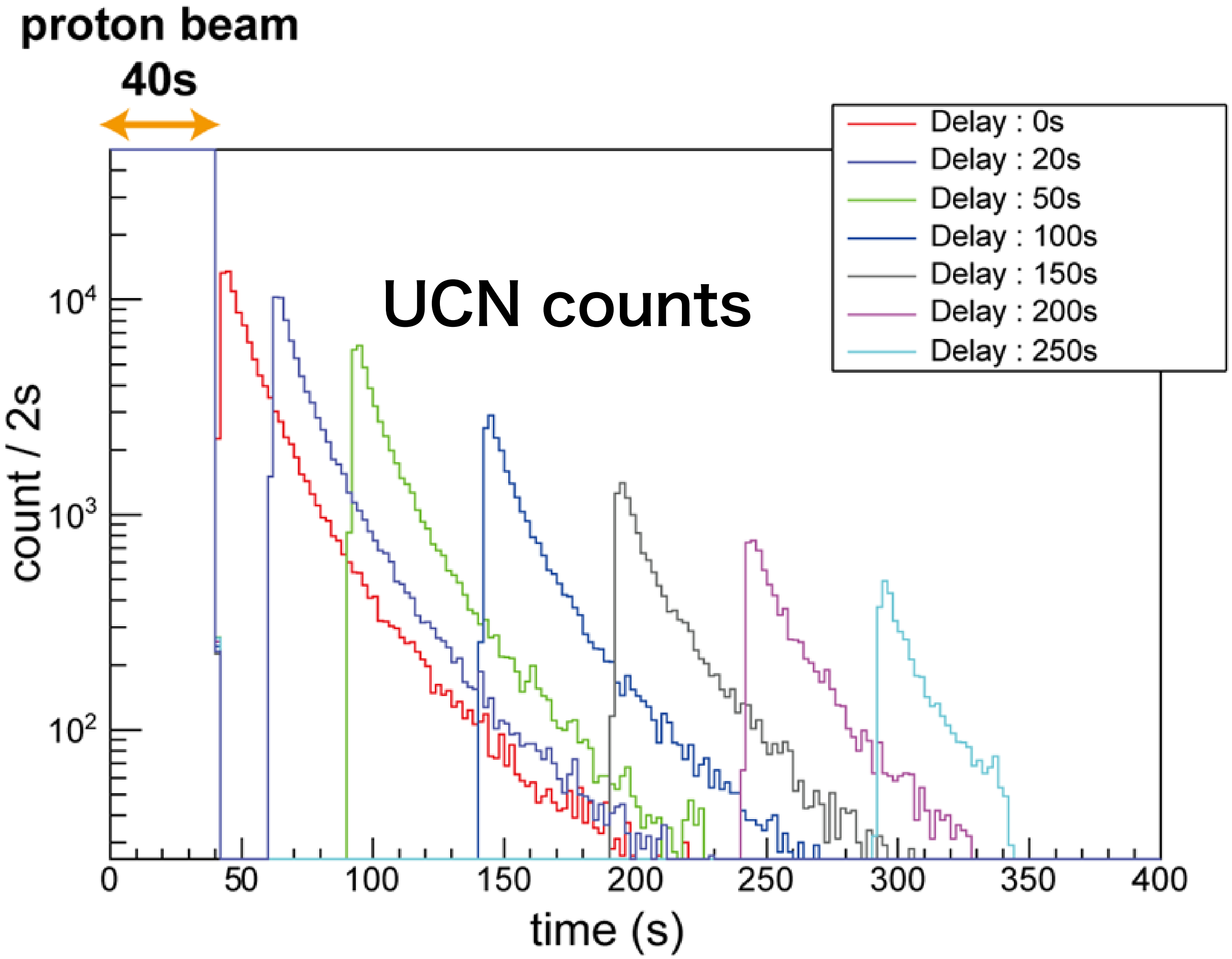


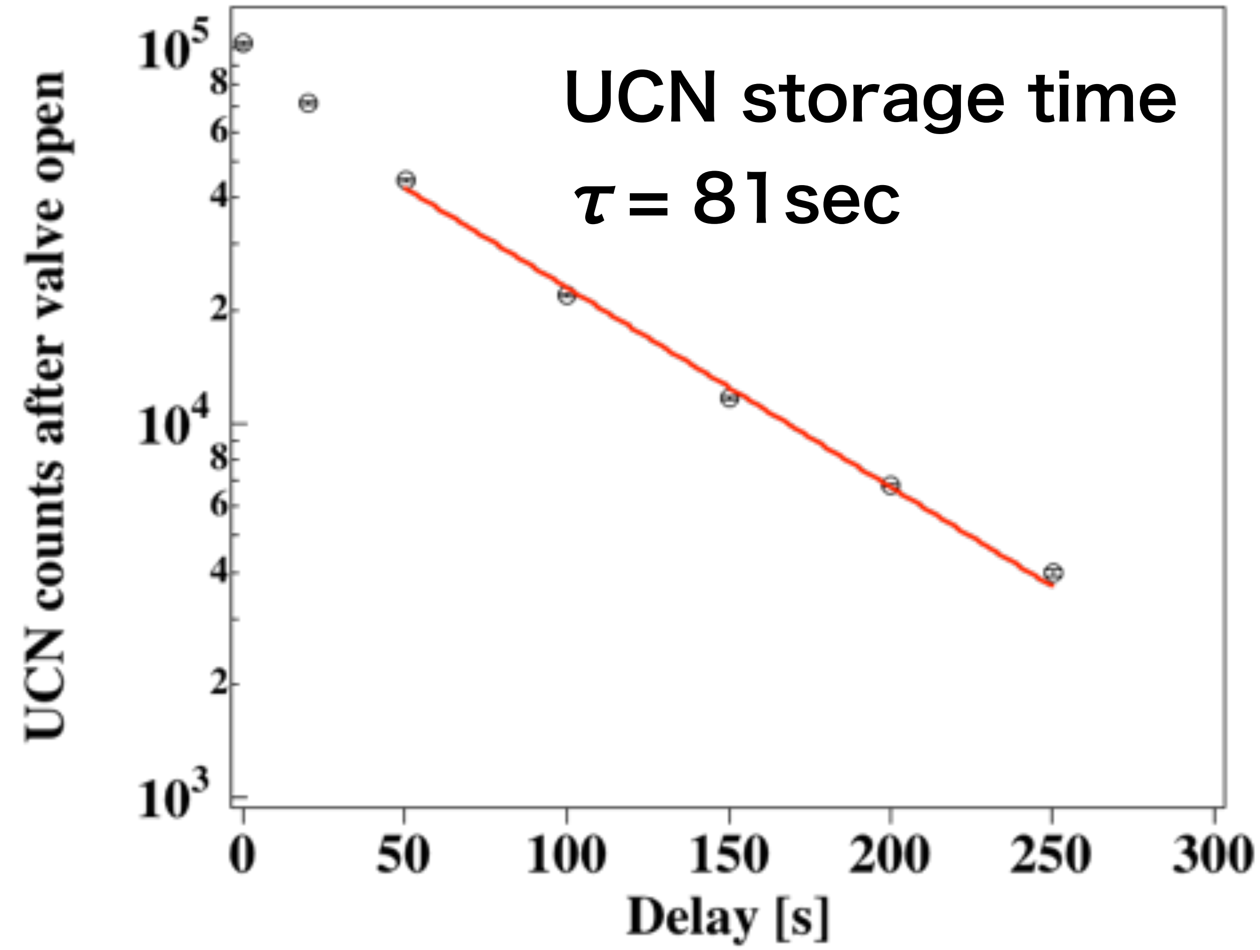
The Vertical UCN Source
KEK-RCNP-TRIUMF



The Vertical UCN Source
KEK-RCNP-TRIUMF

UCN Source Development in RCNP (2002~2011)





Best record (2011)

- p-beam: 400W (1uA×400MeV)
- UCN density: 26 UCN/cm³ (E_c = 90neV)
- UCN storage time: τ = 81sec

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 tests

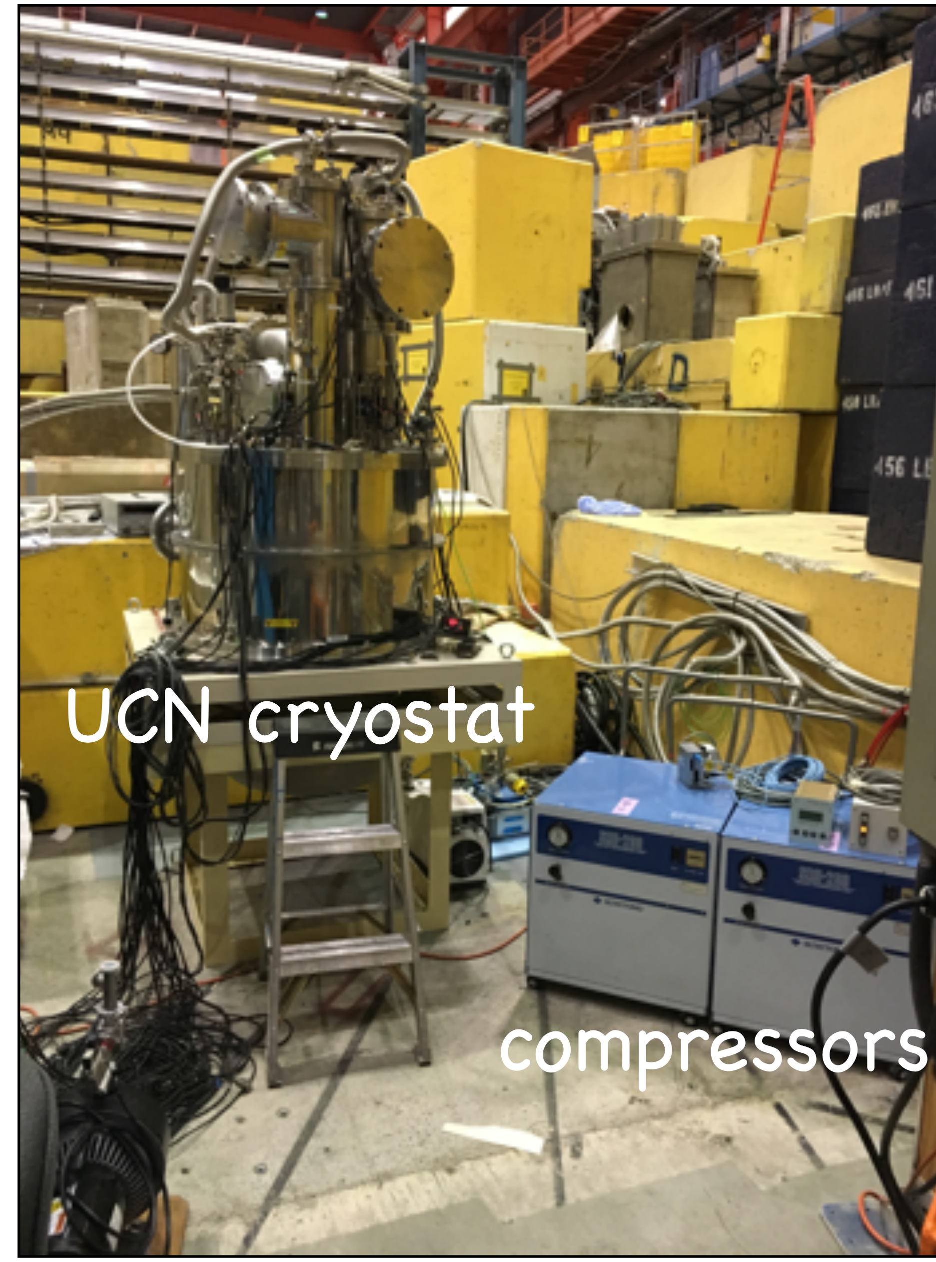
- 2017 February - First cooling test
  - Cooling the cryostat with only GM refrigerator
  - Liquid helium was not used.
  - Confirmed the GM refrigerator worked. The cryostat was cooled down to 12K.
  - Pre-cooling the cryostat had no problem.

↓

UCN cryostat installation on beam line 1U

↓

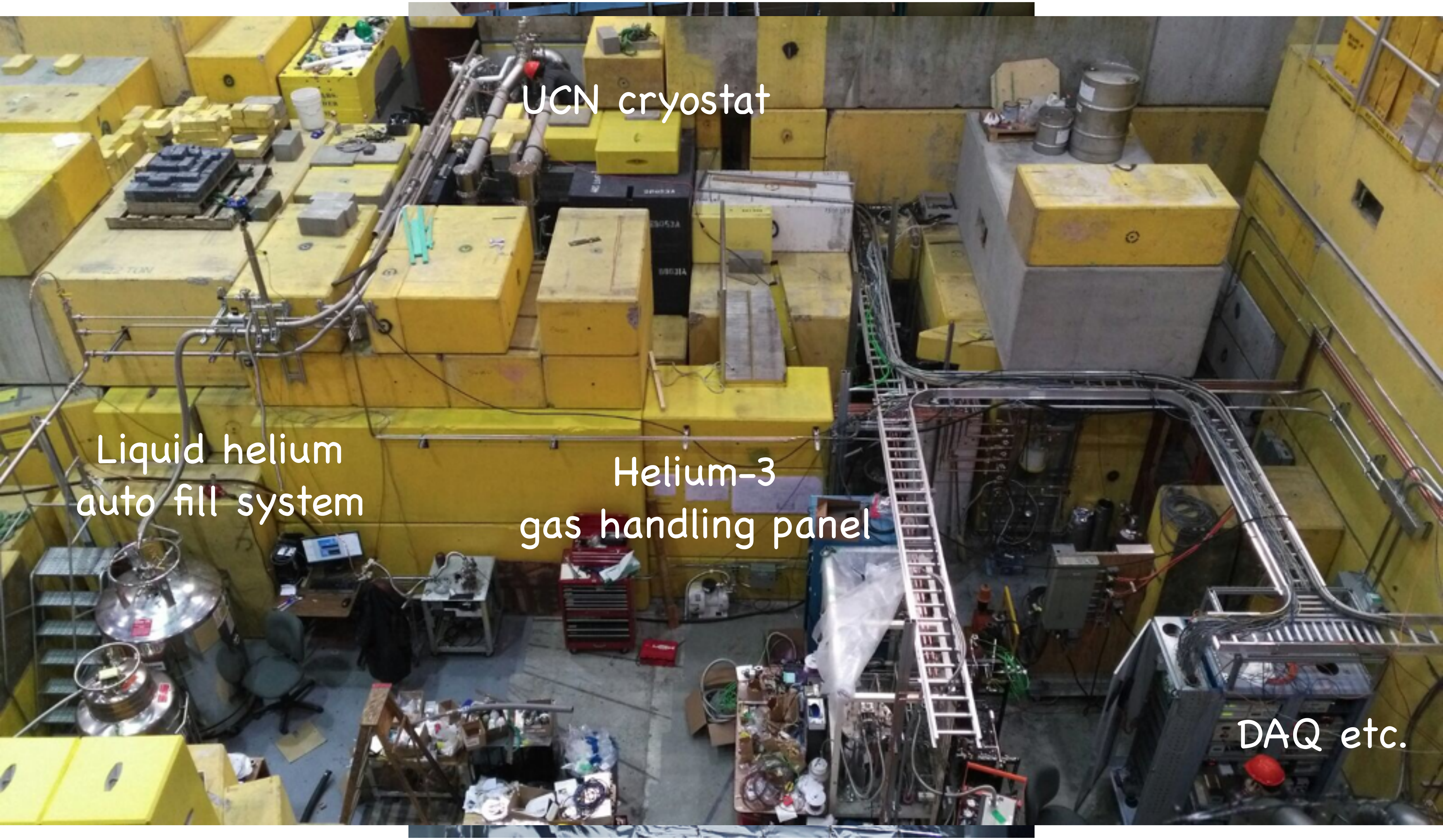
- 2017 April - Full cooling test
  - After pre-cooling by GM refrigerator, we put liquid helium into the cryostat.
  - Succeeded in condensing He-II.
  - The He-II temperature was 0.92K.



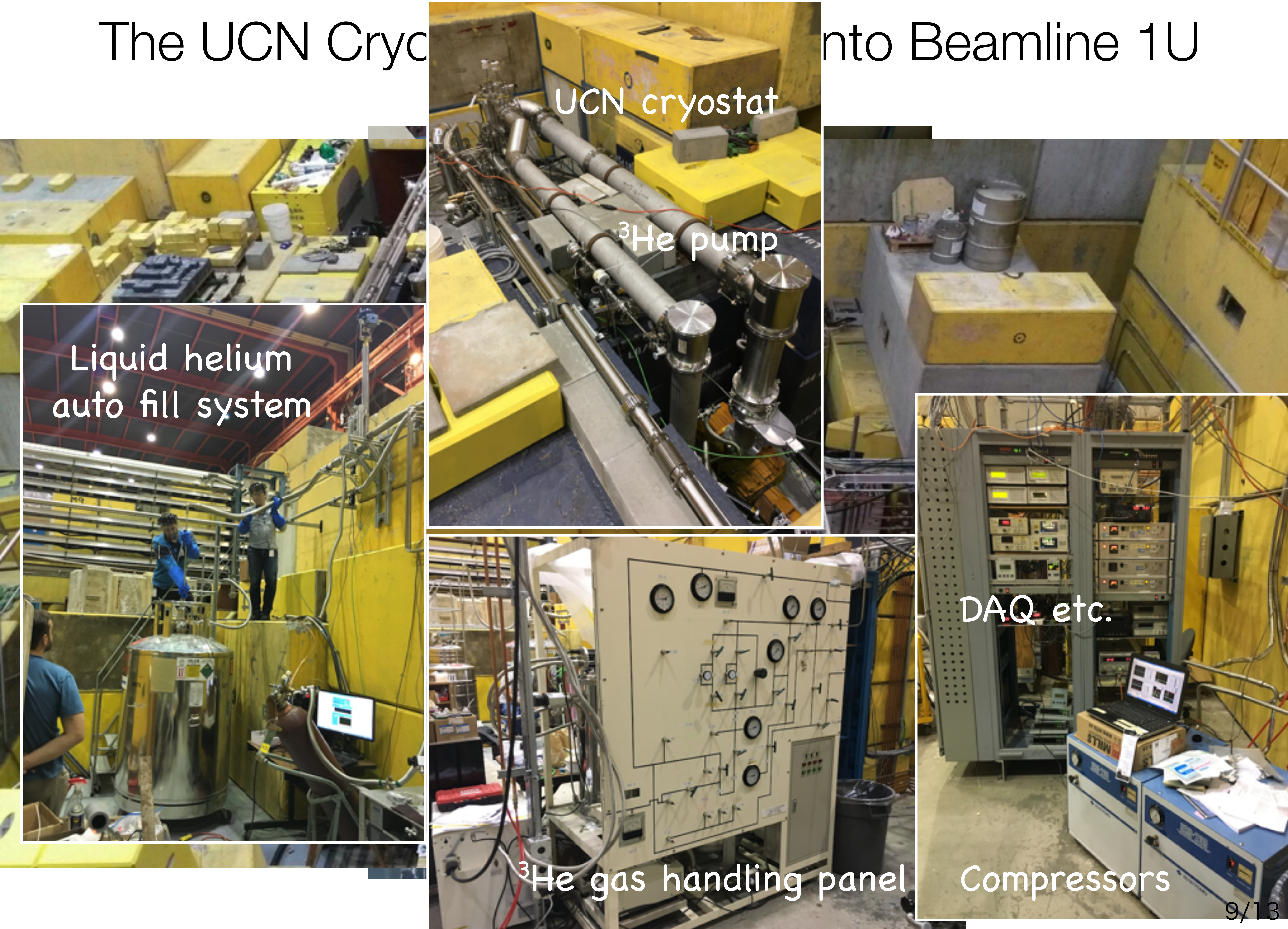
1st cooling test in Meson hall
(not on the beam line)

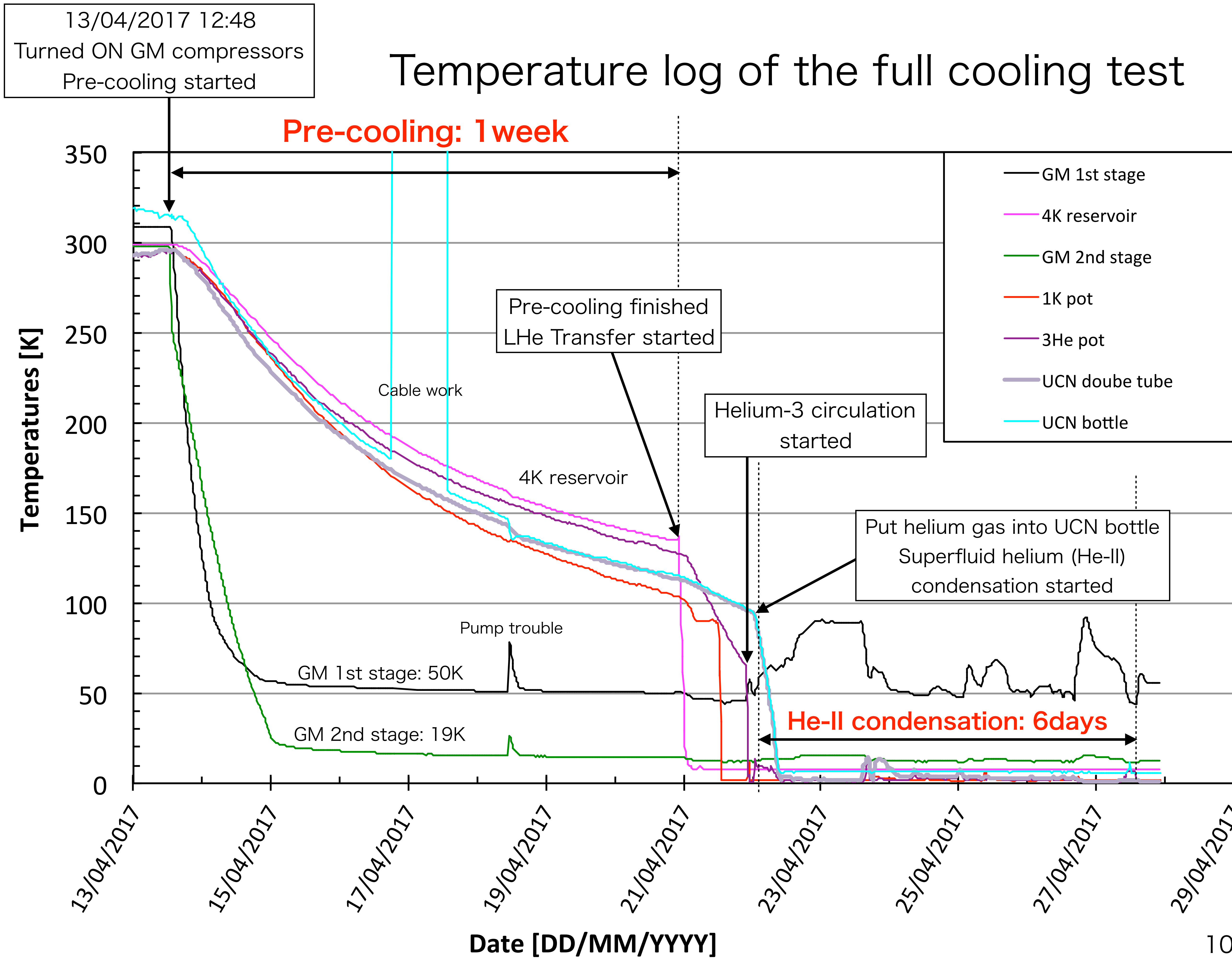
The UCN Cryostat Installation onto Beamline 1U

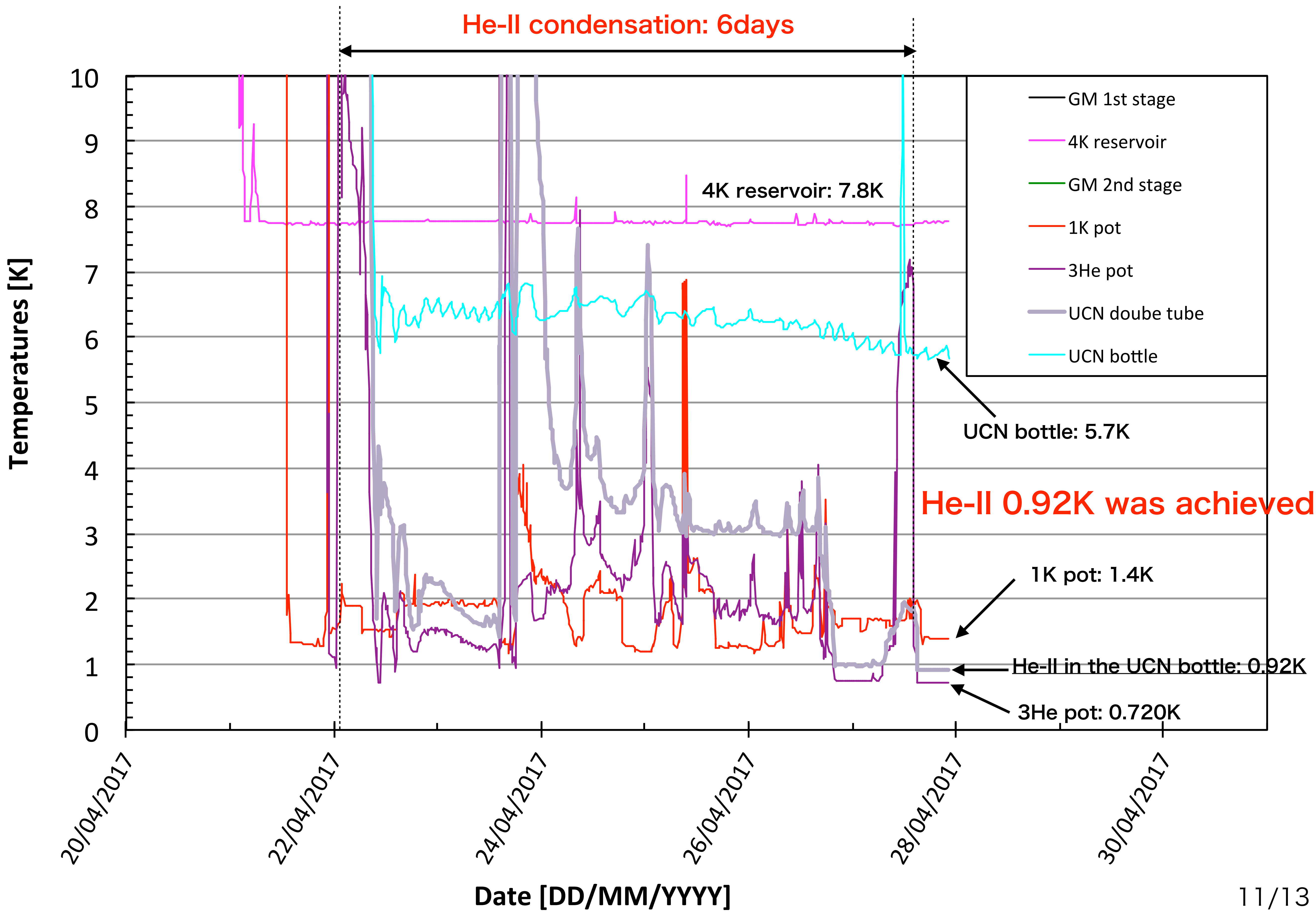
The UCN Cryostat Installation onto Beamline 1U



The UCN Cryc … nto Beamline 1U

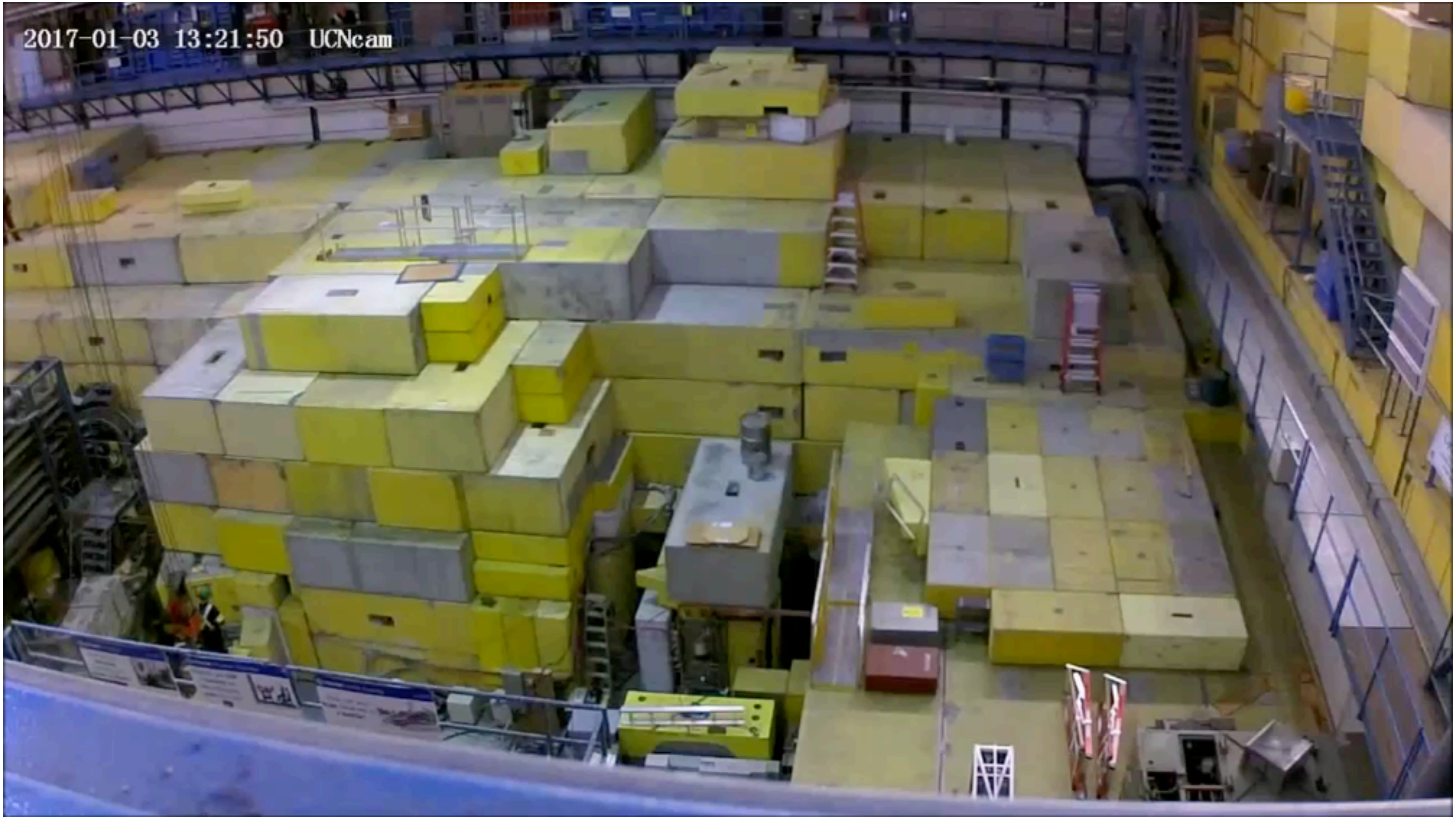



13/04/2017 12:48
Turned ON GM compressors
Pre-cooling started
Temperature log of the full cooling test
Pre-cooling: 1week
Cable work
Pre-cooling finished
LHe Transfer started
4K reservoir
Helium-3 circulation started
Put helium gas into UCN bottle
Superfluid helium (He-II) condensation started
Pump trouble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


He-II condensation: 6days
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
GM 1st stage
4K reservoir
GM 2nd stage
1K pot
3He pot
UCN doube tube
UCN bottle
Temperatures [K]
Date [DD/MM/YYYY]
20/04/2017
22/04/2017
24/04/2017
26/04/2017
28/04/2017
30/04/2017

Movie: Work in Meson hall

Jan 3 ~ May 1, 2017

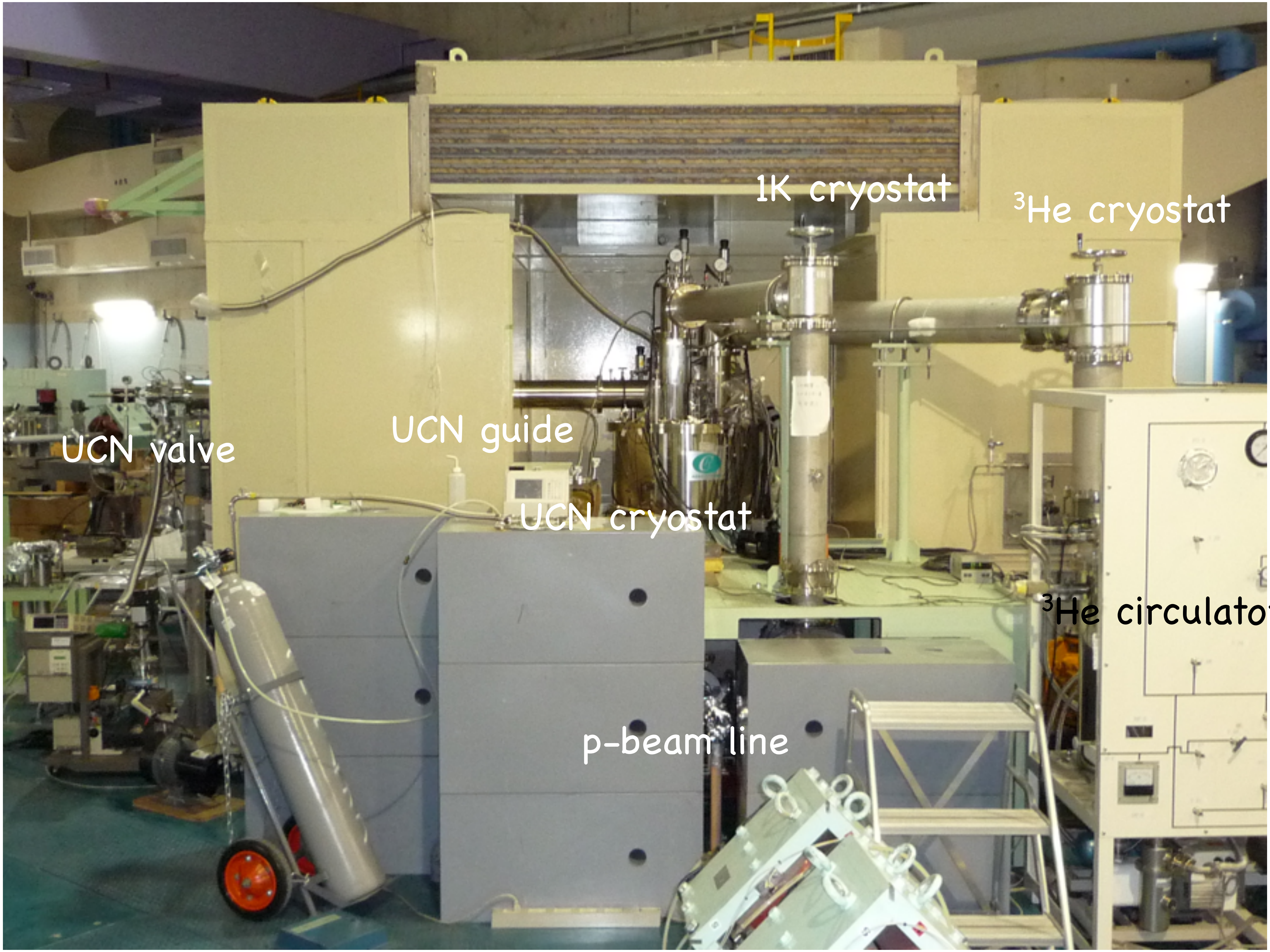


Summary & Schedule for UCN production

- The vertical UCN source was developed in Japan, and achieved a UCN density of 26 UCN/cm^3 (E_C = 90neV). The UCN source was shipped to TRIUMF in 2016.
- The UCN cryostat was installed on the beam line 1U after safety modification.
- We succeeded in condensing He-II and lowering the temperature to 0.92K.
  - He-II temperature was a bit higher than RCNP (0.8K)
  - Acceptably low temperature (<1K) for long UCN storage time
- Schedule for UCN production
  - June 20: Start pre-cooling & D_2O cooling
  - July 21: Start liquid helium transfer, then He-II condensation
  - Aug 1: Ready for UCN production

Backup slides

The vertical UCN source in the east hall of RCNP

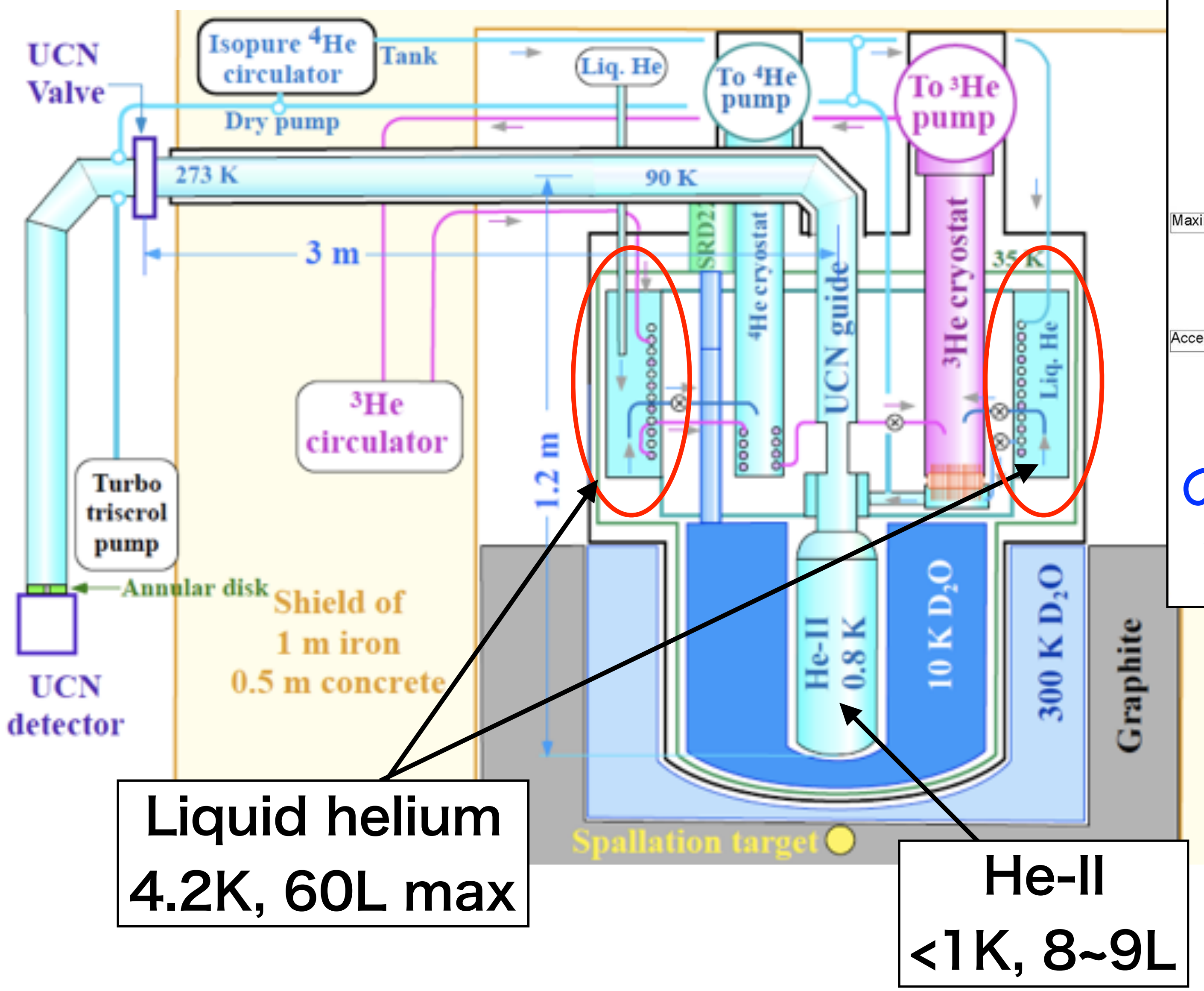


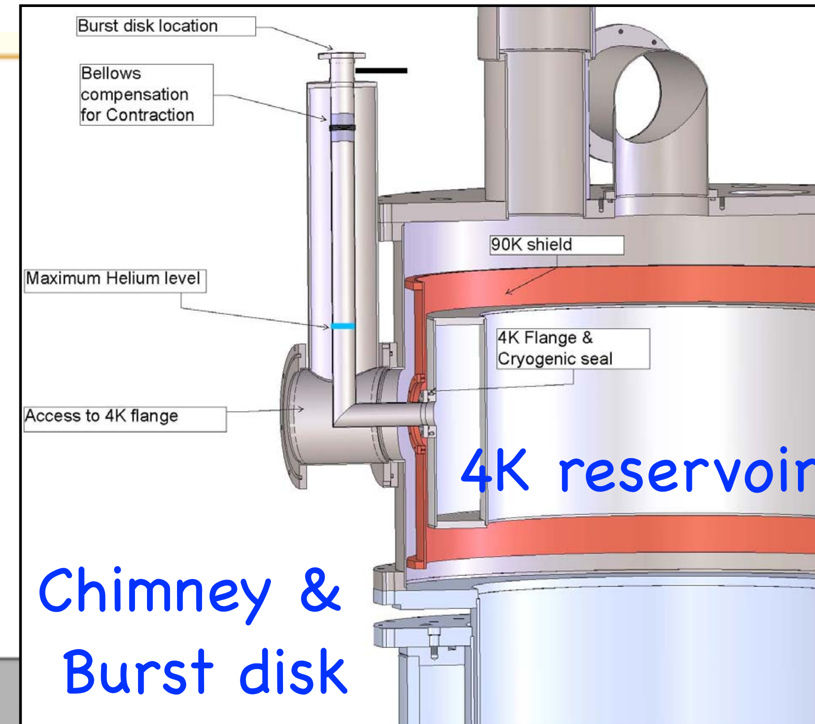
Improvement of the UCN storage time

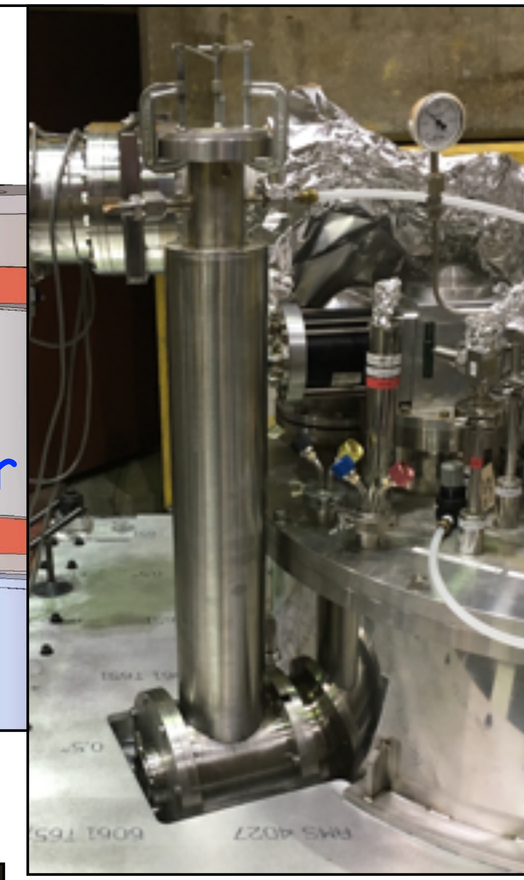
Year	I_P	τ_s	T_{HeII}	Improvement
2002	200nA	14 s	1.2K	
June 2006	1μA	29 s	0.9K	^{3}He cryostat
Nov. 2006	1μA	34 s	0.8K	Reduce HeII film perimeter (8.5 cm → 5 cm)
July 2007	1μA	39 s	0.8K	Remove ^{3}He contamination
April 2008	1μA	47 s	0.8K	Fomblin coating
Dec. 2009	1μA	61s	0.8K	Alkali cleaning
Feb. 2011	1μA	81s	0.8K	High temperature baking (140°C)

- Decreased phonon up-scattering by lowering $T_{He\text{-}II}$
- Removed ^{3}He in superfluid helium by introducing isopure helium (^{3}He/^{4}He < 10^{-11})
- Surface cleaning by alkali degreasing and high temperature baking

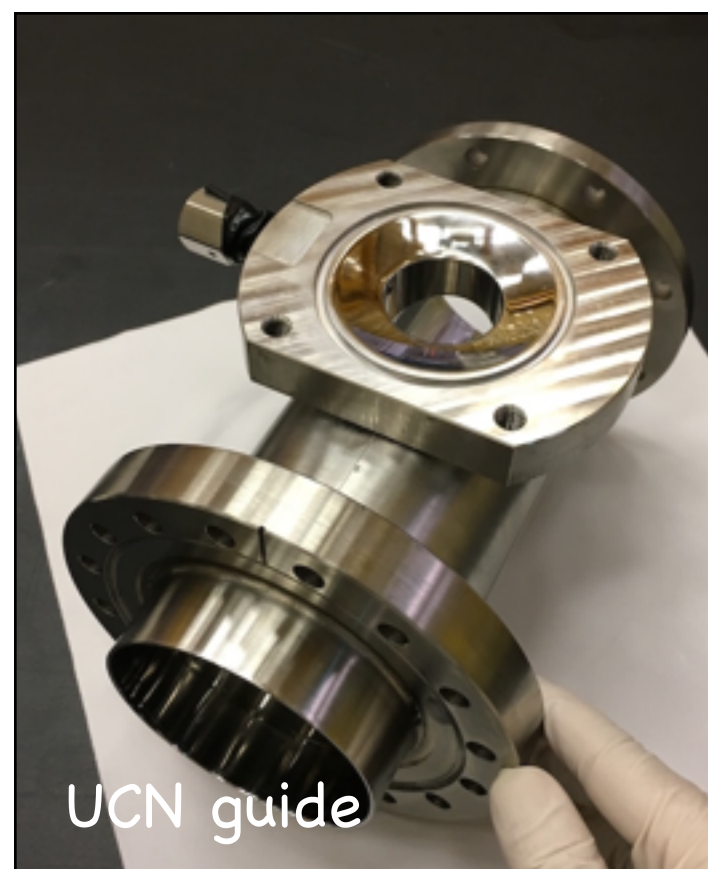
Cryostat Safety Upgrade (4K reservoir & UCN guide)





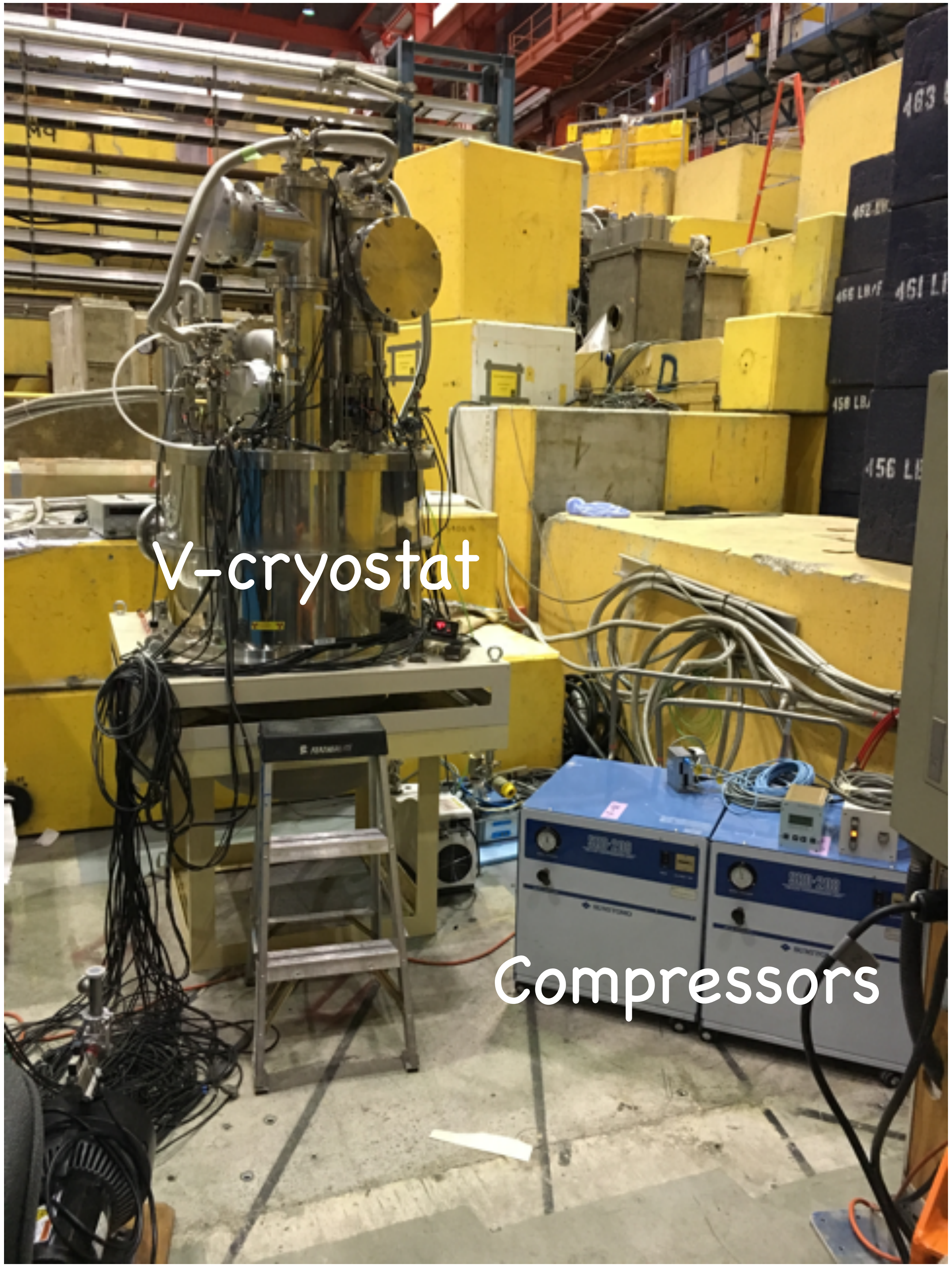


- When the insulating vacuum is broken, heat load on liquid helium becomes ~10kW.
- Liquid helium is boiled off.
- We installed burst disks to save the cryostat.

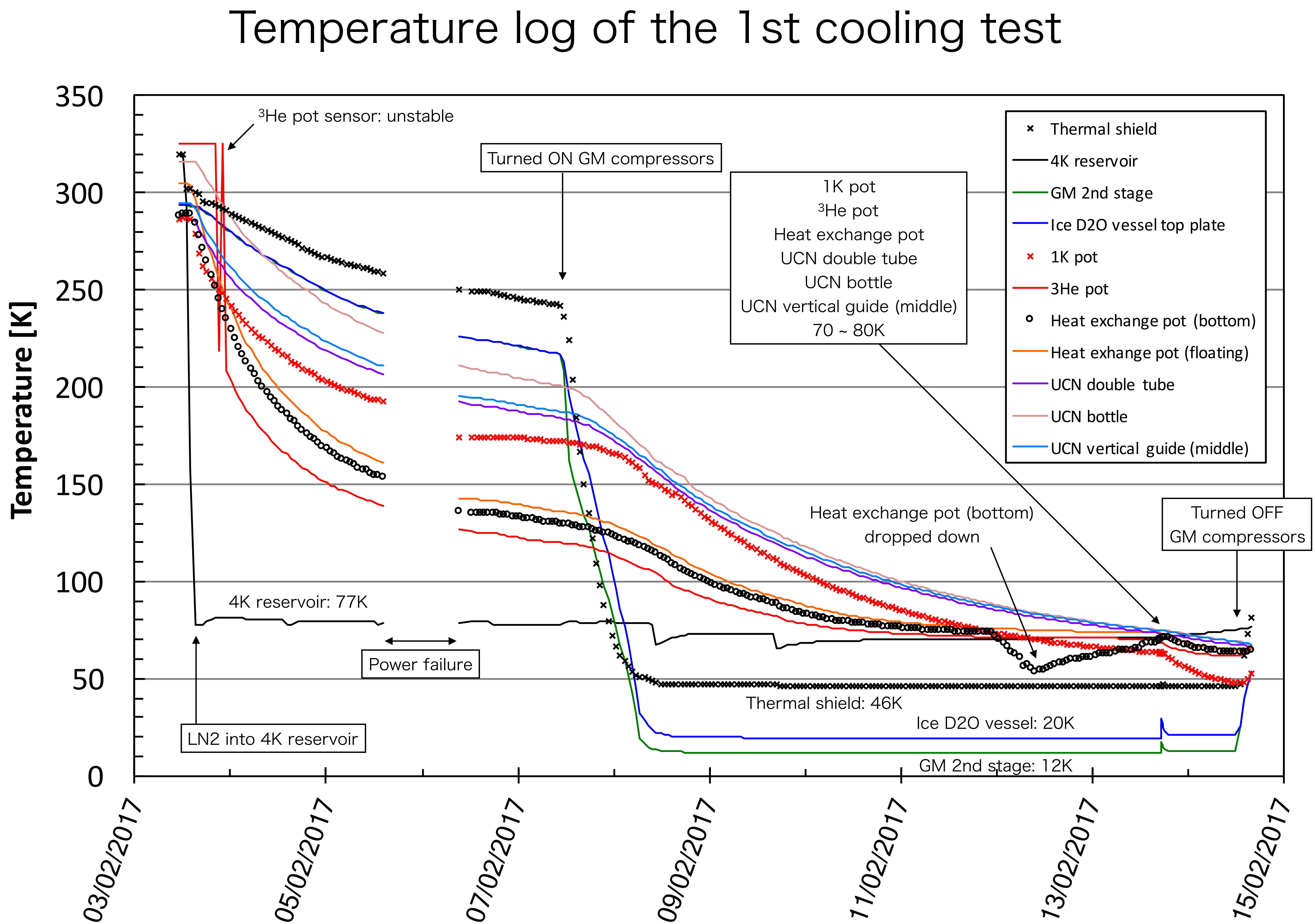


Burst disk at
UCN guide end

1st cooling test (detail)

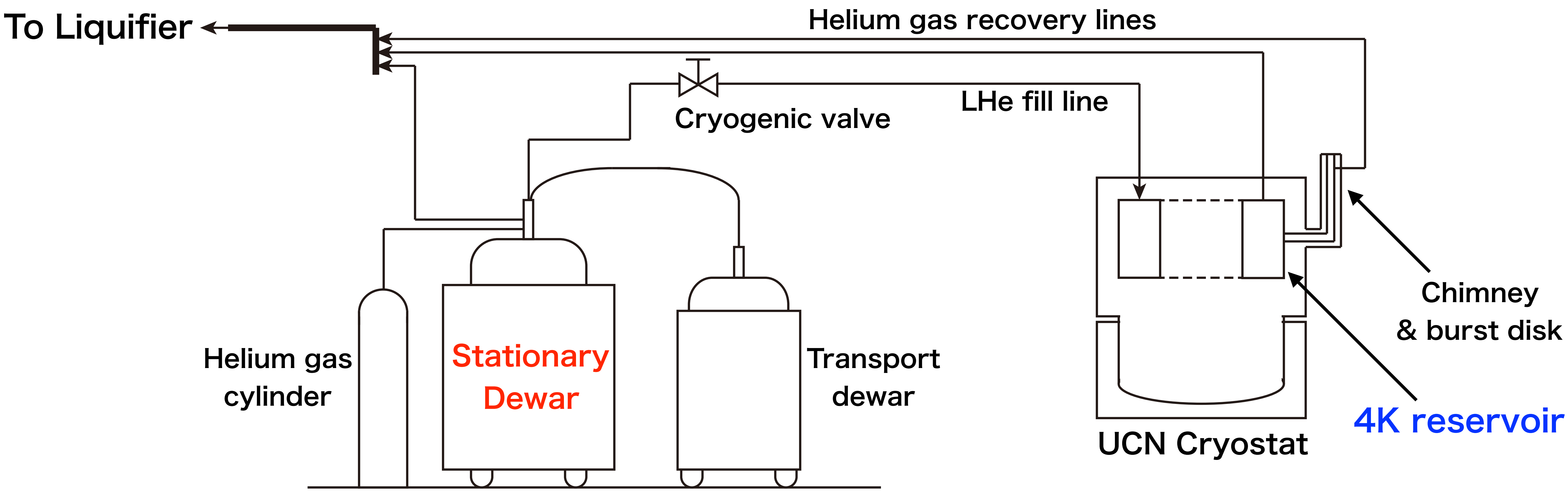


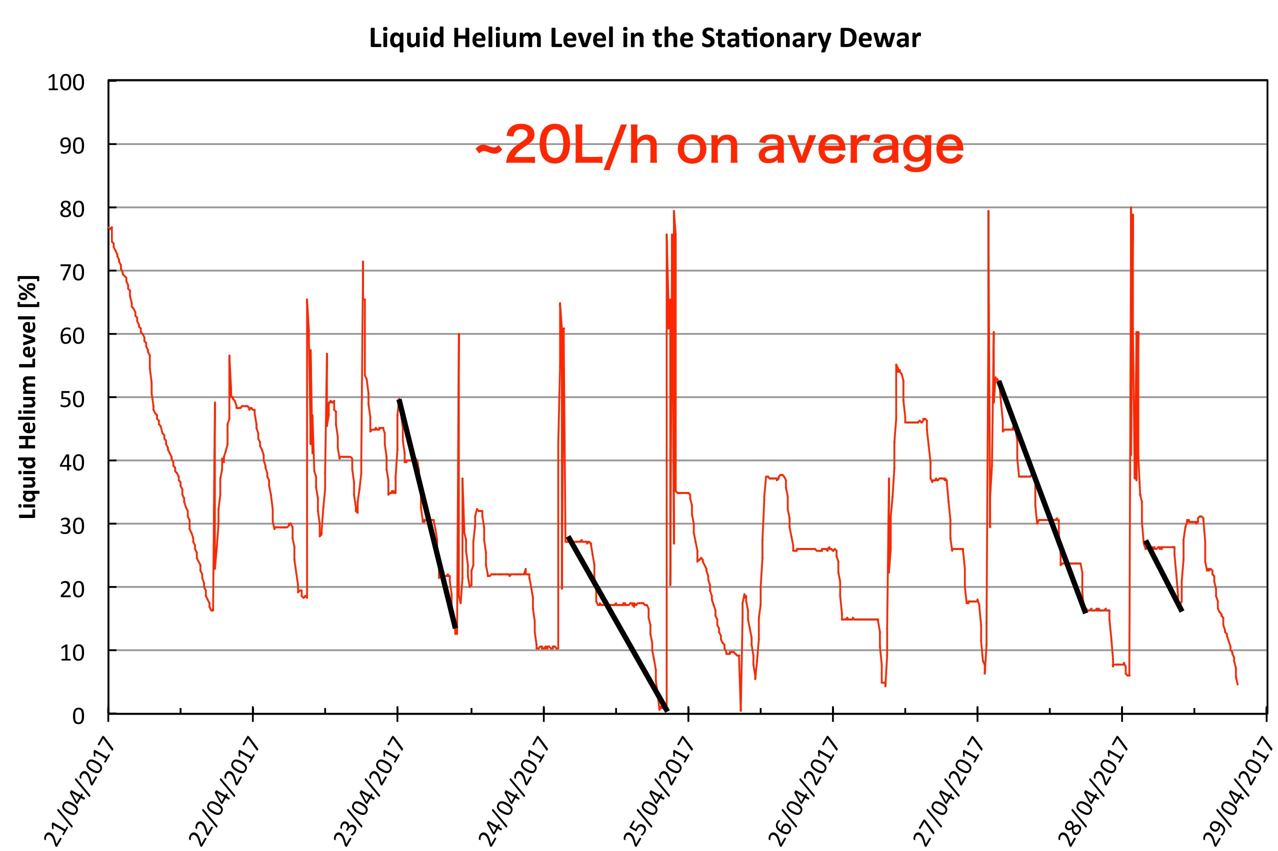
- Moved the cryostat to Meson hall (Feb 2)
- Put LN2 into 4K reservoir (Feb 3)
- Turned on compressors (Feb 6)
- Ice D_2O vessel became ~20K (Feb 8)
- 1K pot, ^{3}He pot, UCN guide became ~ 77K (Feb 13)
- Cold leak test (Feb 14)
- Turned off compressors (Feb 14)



Temperature log of the 1st cooling test
Temperature [K]
350
300
250
200
150
100
50
0
³He pot sensor: unstable
Turned ON GM compressors
1K pot
³He pot
Heat exchange pot
UCN double tube
UCN bottle
UCN vertical guide (middle)
70 ~ 80K
Thermal shield
4K reservoir
GM 2nd stage
Ice D2O vessel top plate
1K pot
3He pot
Heat exchange pot (bottom)
Heat exhange pot (floating)
UCN double tube
UCN bottle
UCN vertical guide (middle)
Heat exchange pot (bottom)
dropped down
Turned OFF
GM compressors
4K reservoir: 77K
Power failure
LN2 into 4K reservoir
Thermal shield: 46K
Ice D2O vessel: 20K
GM 2nd stage: 12K
03/02/2017
05/02/2017
07/02/2017
09/02/2017
11/02/2017
13/02/2017
15/02/2017

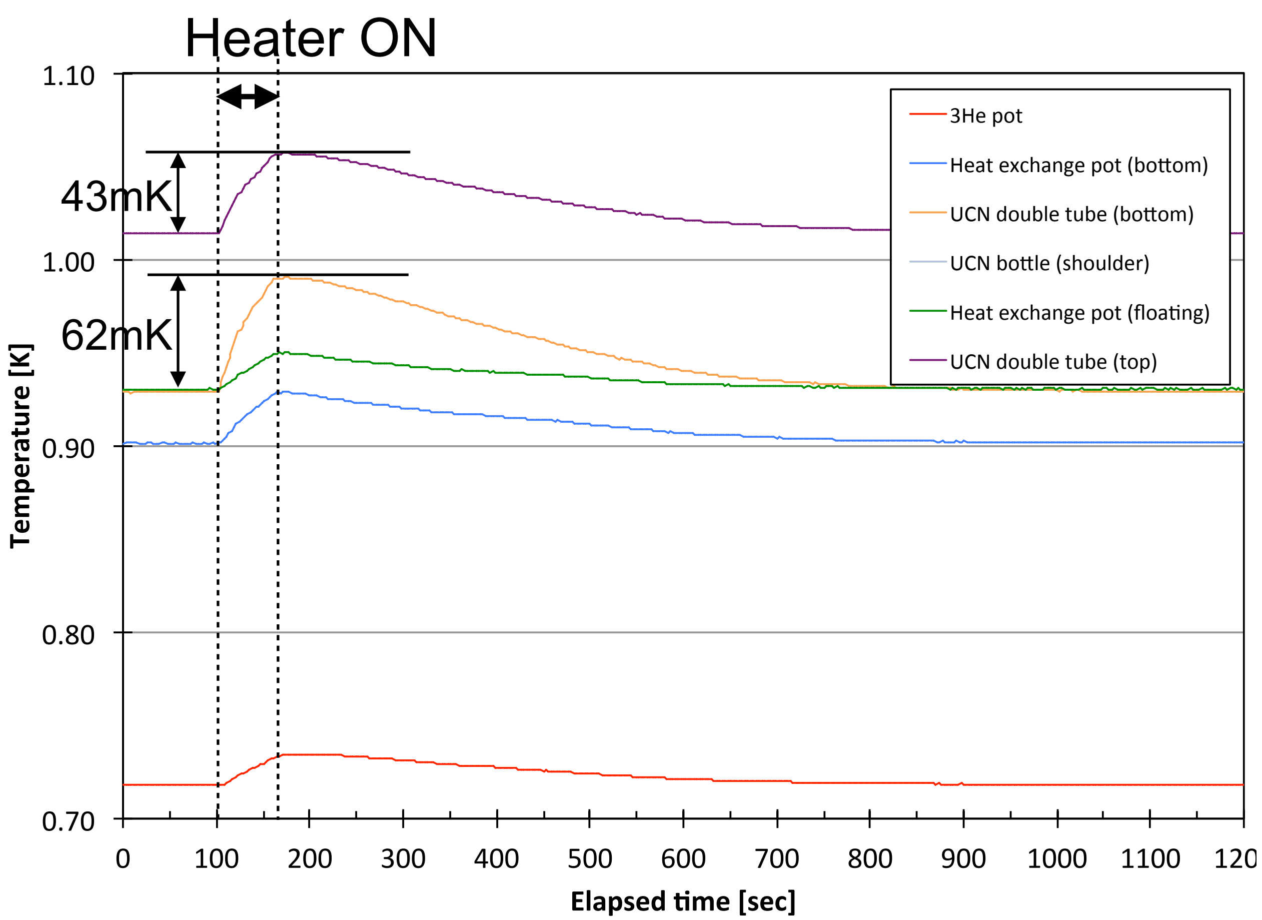
Liquid helium consumption





Heat load test

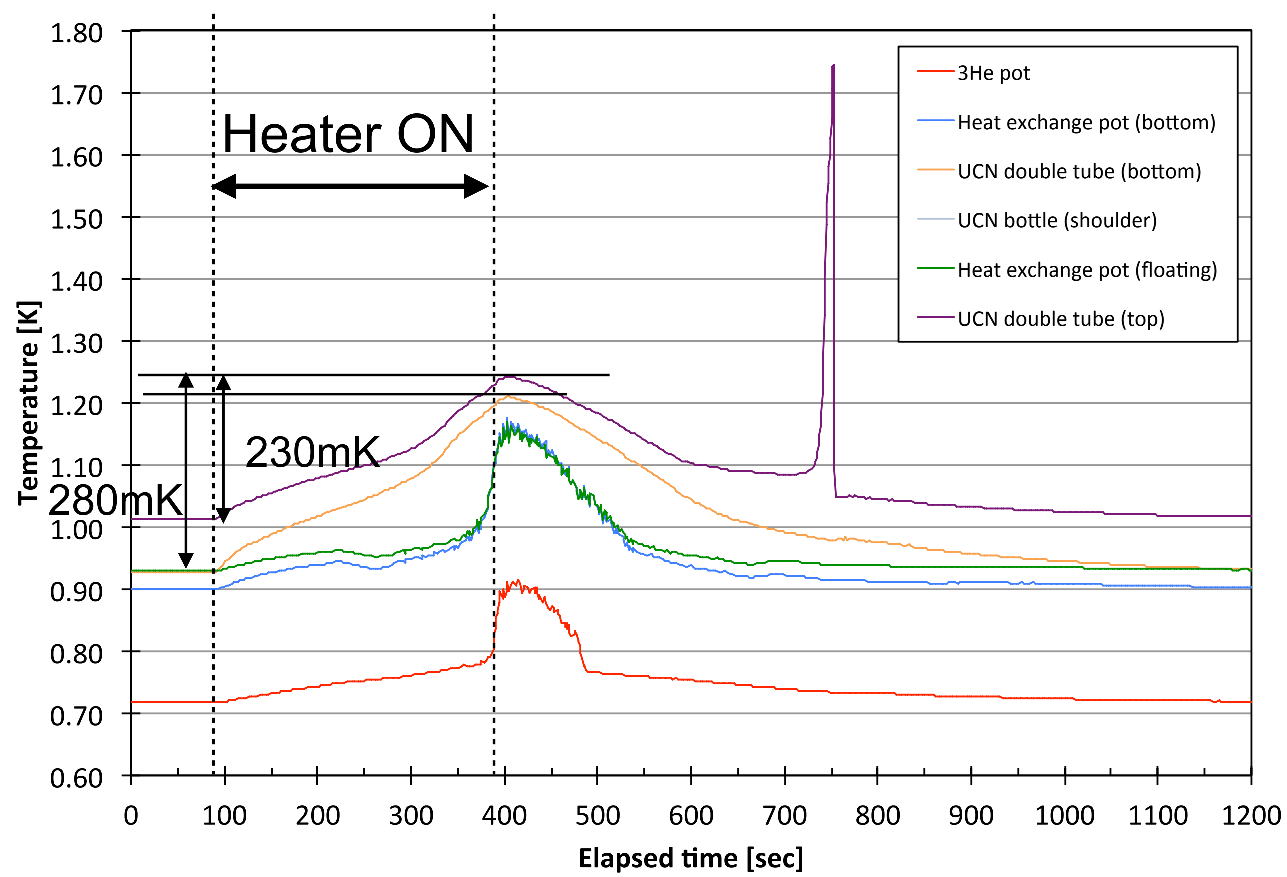
- 1uA p-beam: 25mW heat load by γ/β-heating
- Put heat load on the He-II volume using a heater wound around the UCN bottle.
- Heater power: 2.5mW, 12.5mW, 25mW, 75mW, 250mW, 1000mW, 4000mW
- Heating time: 10sec, 20sec, 60sec, Continuous (5minutes or more)



Heater power 1000mW, 60sec

ΔT (UCN double tube bottom) = 62mK

ΔT (UCN double tube top) = 43mK



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 (0.1uA p-beam)	10	0	0
	20	0	0
	60	0	0
	continuous	1 mK	1 mK
12.5 (0.5uA p-beam)	10	1 mK	1 mK
	20	1 mK	1 mK
	60	2 mK	1 mK
	continuous	4 mK	4 mK
25 (1uA p-beam)	10	1 mK	1 mK
	20	–	–
	60	4 mK	3 mK
	continuous	10 mK He-II 0.93K	9 mK
75 (3uA 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 (10uA 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 (40uA 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 (160uA p-beam)	10	51 mK	35 mK

UCN storage time

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

$$\tau_n = 880\,\mathrm{sec}$$

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