R&D for UCN Source Upgrade

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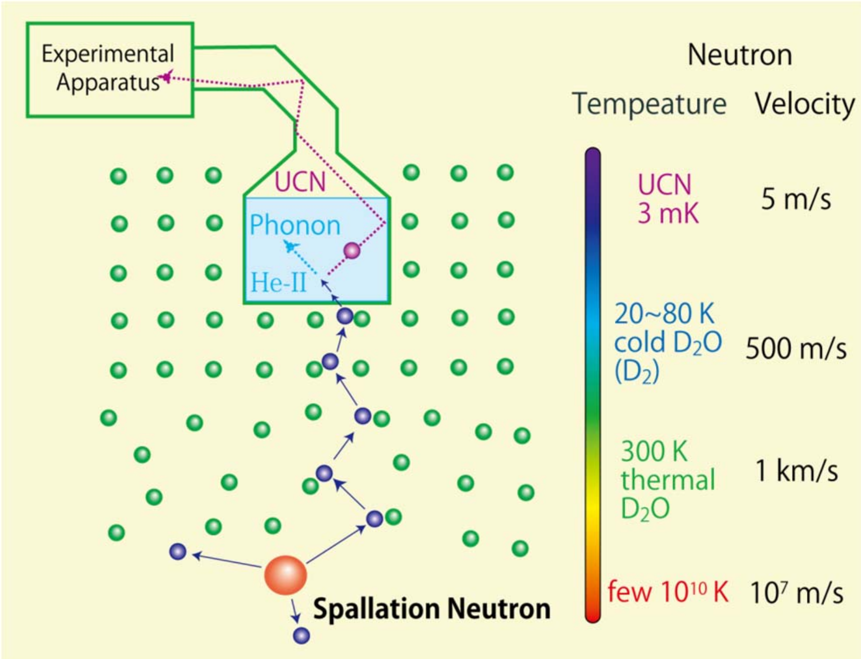
for TUCAN collaboration

outline

- UCN production by super thermal method
- UCN source at TRIUMF
  - Vertical source
  - new UCN source
    - cooling scheme
      - temperature distribution
    - possibility to have very cold neutron beam line
- Other R&D
  - Diamond nano-particle neutron reflector

UCN production by super fluid Helium



UCN production

spallation neutron

↓ D_2O, LD2 Moderator (300K, 20K)

cold neutron ～meV

↓ Phonon scattering in He-II

Ultra cold neutron ～100neV

Feature of our source

・spallation neutron

High neutron flux

small distance between target and UCN production volume

・Super-fluid Helium converter

long storage lifetime

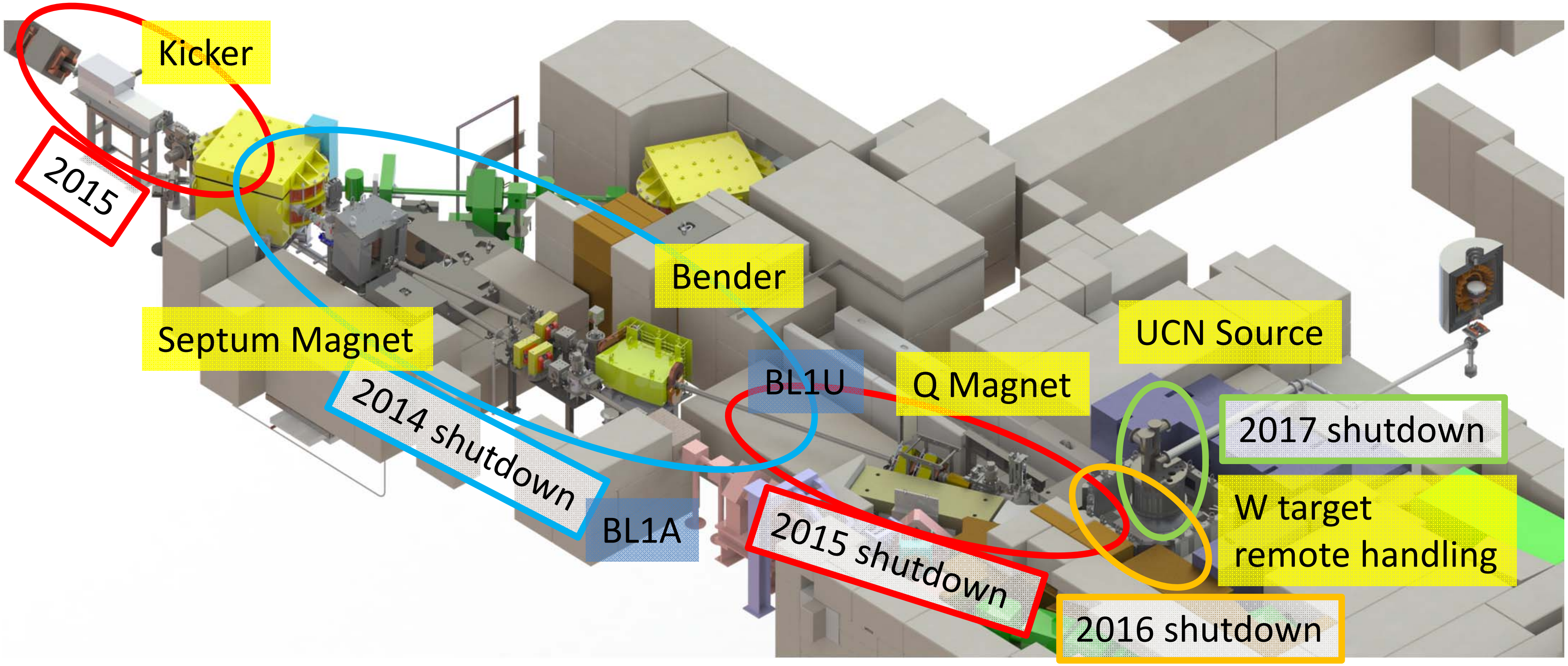
up-scattering by phonon

τ_s = 600 s at T_{HeII} = 0.8 K

τ_s = 36 s at T_{HeII} = 1.2 K

$1/\tau_s \propto T^7$

UCN Source @ TRIUMF



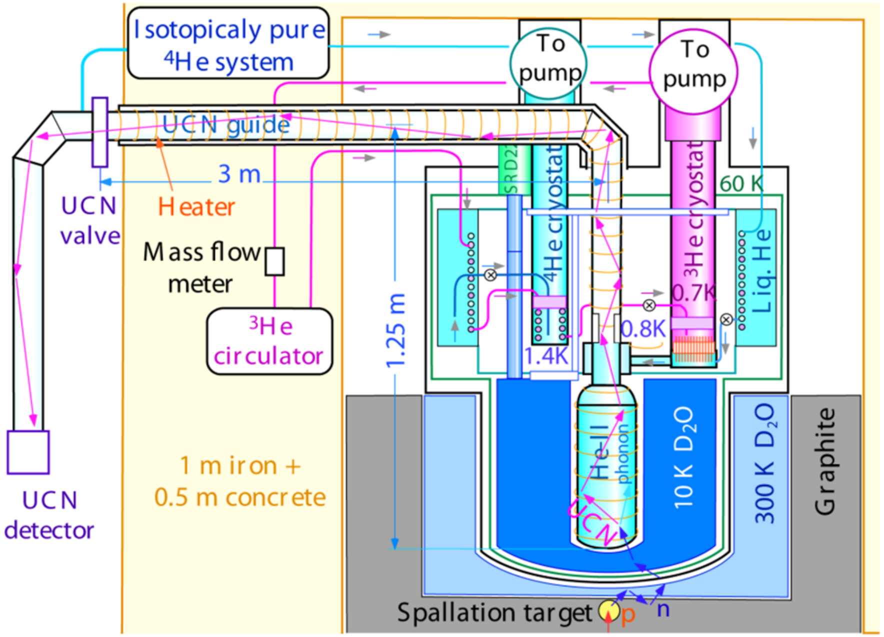
Major Milestone

✓ - 2016	proton beam line for UCN source(BL1U 500MeV, 40µA)
✓ 2016	commissioning proton beam line and cold neutron production
2017	UCN production by Vertical source (~ 1µA)
- 2020	High intensity UCN source (40µA)

Vertical UCN source

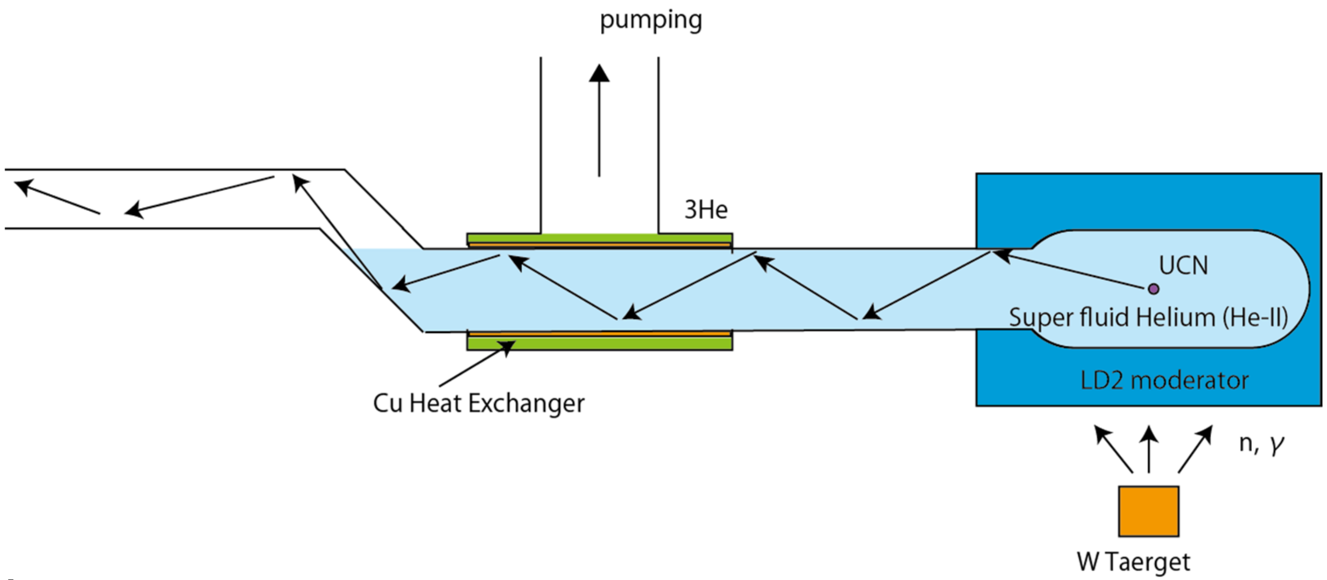
- Vertical UCN source
  - developed at RCNP
    - $T_{He\text{-}II}$: 0.8 K
    - UCN life time: 81 sec
    - UCN density: 9 UCN/cm^3
      - 400 MeV × 1 μA = 0.4 kW

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



  - move to TRIUMF
    - modification for safety requirement
  - 2017 Jan. – Apr. install at Meson hall
  - 2017 Nov. UCN production

new UCN source



proton beam power

0.4 kW at RCNP -> 20 kW at TRIUMF

A new helium cryostat which has high cooling power is necessary

Heat load on He-II depends on geometry

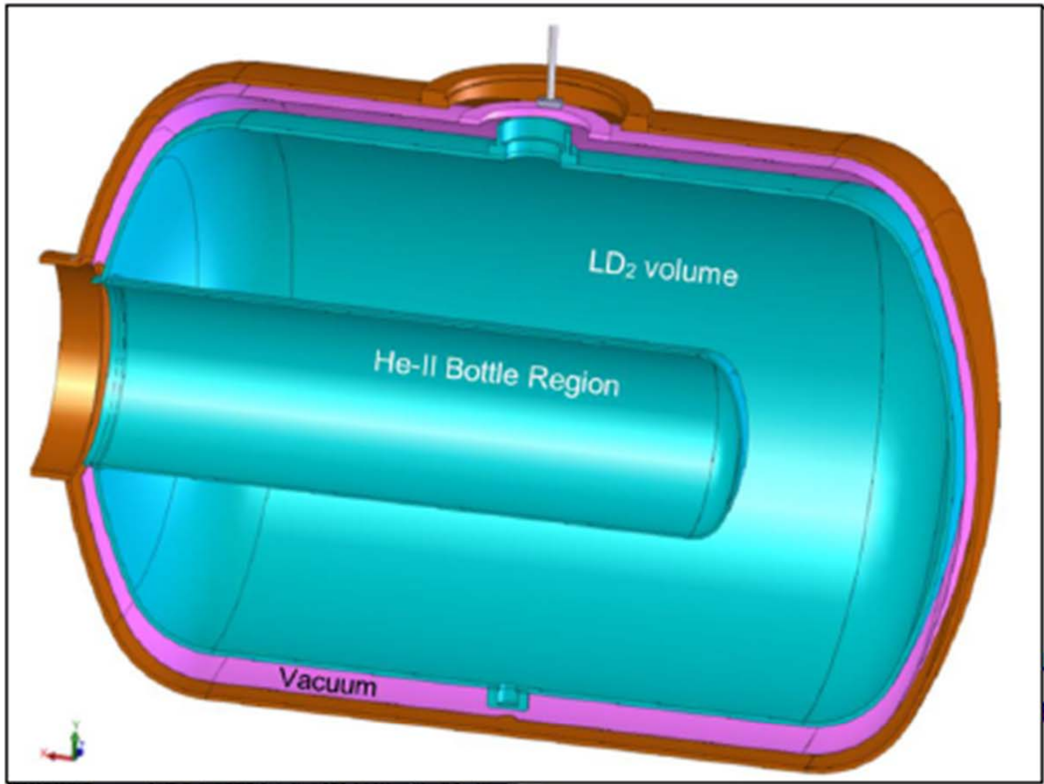
- distance between target and He-II
- cold moderator
- gamma shield

and so on

- higher cold neutron flux cause higher heat load
- ratio of this is constant in some region

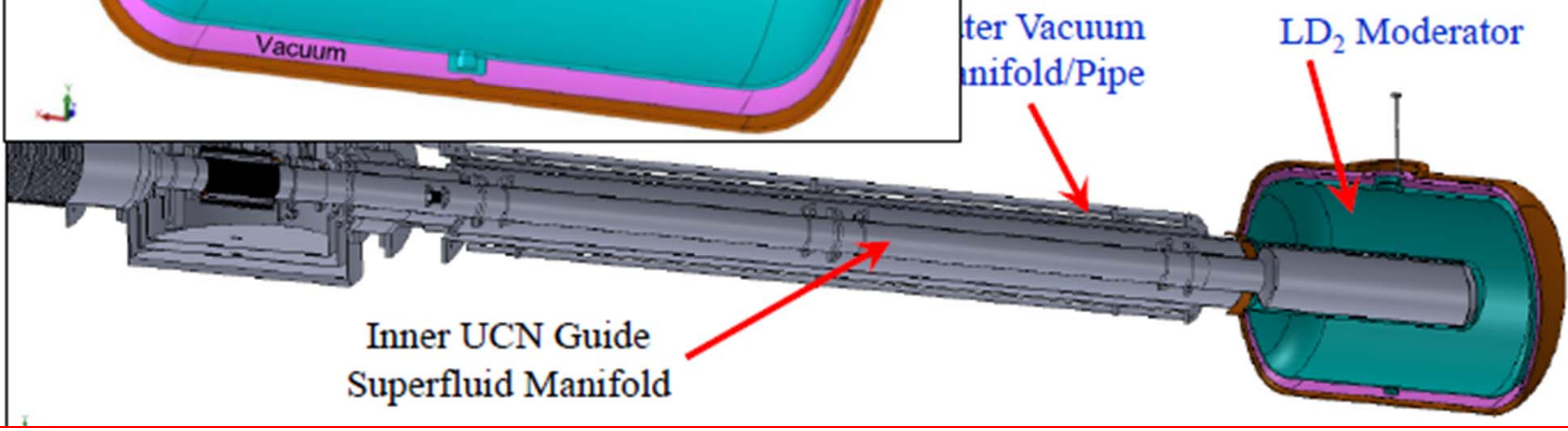
Optimization is necessary

LD_2 Moderator Cryostat



- Aluminum Cryostat
- 125 Liquid Litres of D_2
- 75 W Heat Load
- Circulate LD_2 to remote condenser + cryo-cooler

- $300k for LD2 cryostat system
- $250k for LD2



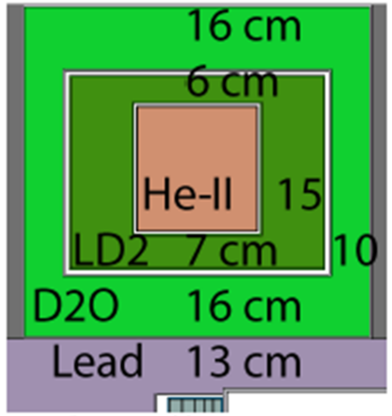
5 – 9 times large cold neutron flux is achivable compared with ice D_2O

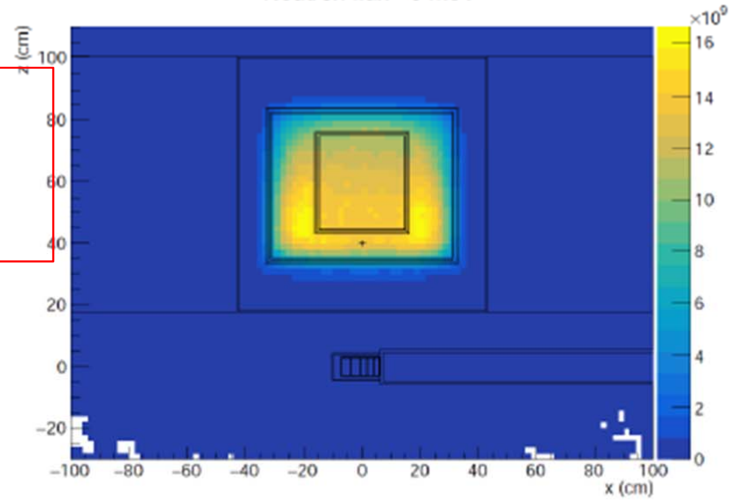
Heat load on UCN production volume

TRIUMF — Preliminary results

- Radial LD_2 layer more important than lower
- Best He-II-bottle height 30-40 cm, radius 15-20 cm (for current cooling scheme)
- Limited by amount of LD_2!
- For He-II height 30 cm, radius 15 cm, 40 μA beam:
  - 20.6 l He-II, 115 l LD_2
  - $3.9 \cdot 10^7$ UCN/s
  - 7.9 W max. heat in He-II
  - 65 W max. heat in LD_2
- Best strategy to reduce LD_2: reduce He-II size and go closer to target

deal with such a huge heat load around 1 K

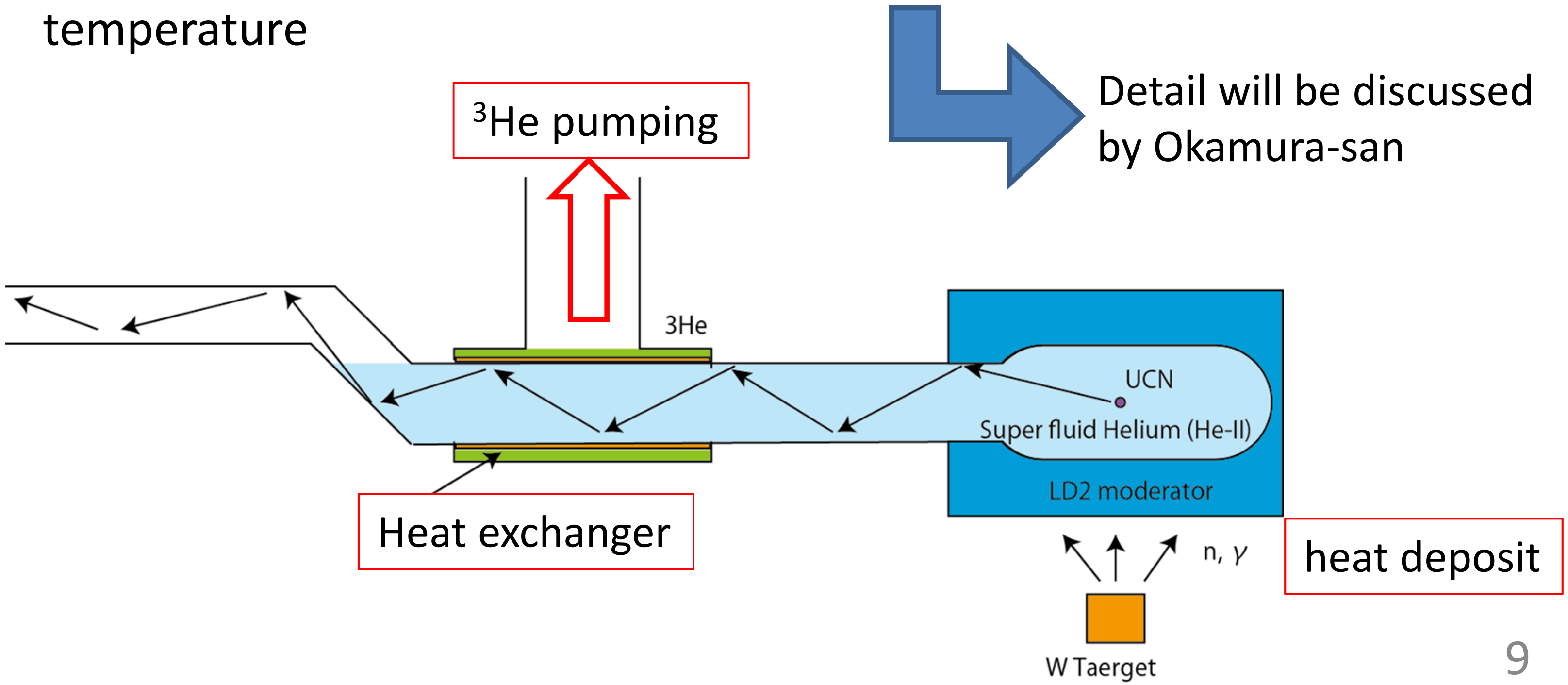




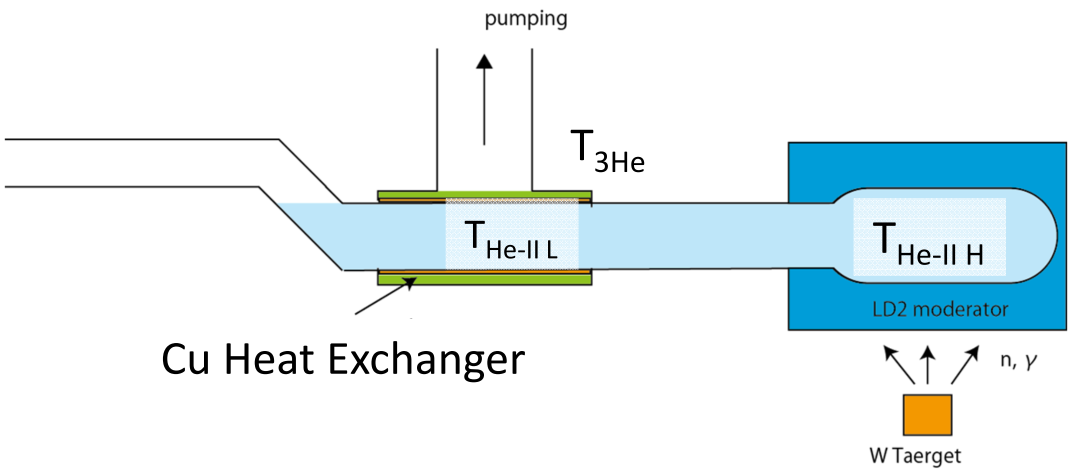
2017-10-18

Heat transfer between heating point and cooling point

- Heat transfer in He-II
  - below 1 K, heat transfer is not good because of low fraction of normal fluid which convey heat (two fluid model)
- Kapitza conductance of heat exchanger
  - Conductance at the surface between liquid and solid is small at low temperature



Equilibrium temperature



Equilibrium temperature can be calculated as a function heat load.

example)

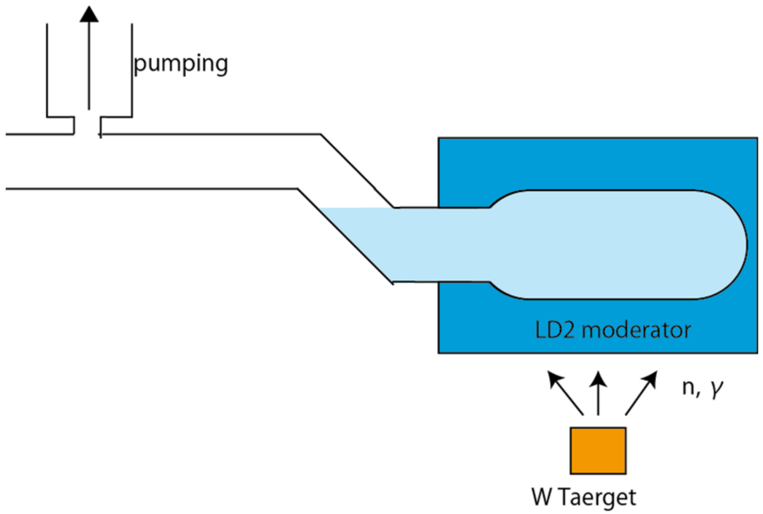
d = 150 mm, L = 1,500 mm
pumping speed 10,000 m^3/hour
Heat load : 10 W case

Temperature distribution

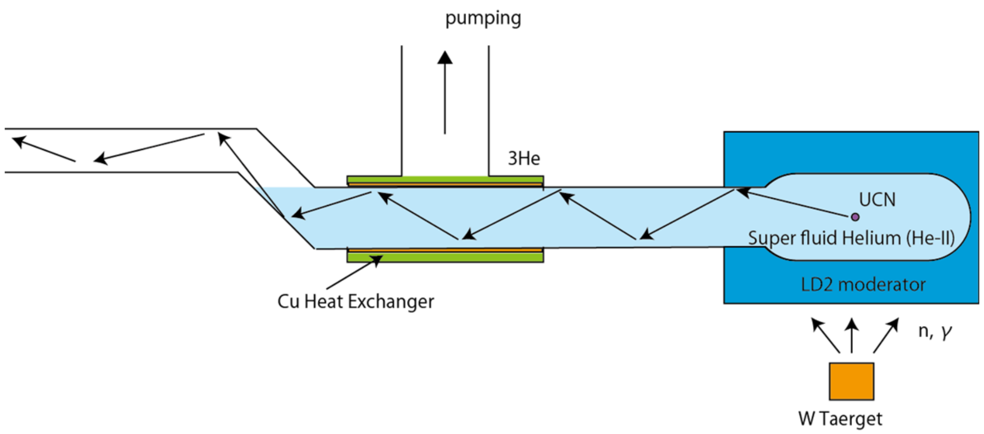
$T_{He\text{-}II\ H}$: 1.15 K ($\tau_{up\text{-}scat}$ = 50 sec)
$T_{He\text{-}II\ L}$: 1.00 K
$T_{Cu\ H}$: 0.84K
$T_{Cu\ L}$: 0.83 K
T_{3He} : 0.75 K
ΔT = 0.40 K

Alternative plan : direct pumping

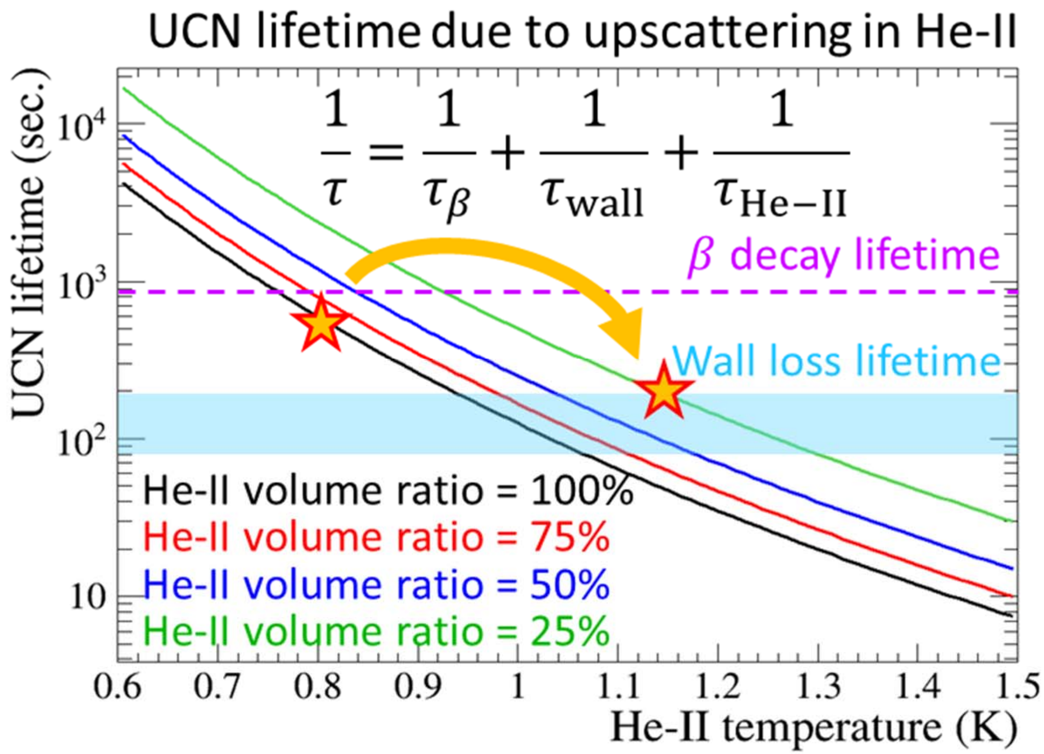
- direct pumping of He-II
  - another way to cooldown He-II
    - There is no effect of Kapitza conductance since they have no heat exchanger
      - if Kapitza conductance is found to be smaller than expected, the direct pumping have large advantage
    - He-II volume can be small
  - Cooling power : 7 W at 1.2 K with 10,000 m^3/hour pumping
    - upscattering life time at 1.2 K : 36 sec



Effect of He-II Volume ratio



- Volume ratio of He-II and Vacuum is also important parameter.
- Total lifetime is increase when volume ratio is small
- UCN scattering with vapor He become serious when He-II temperature above 1.4 K

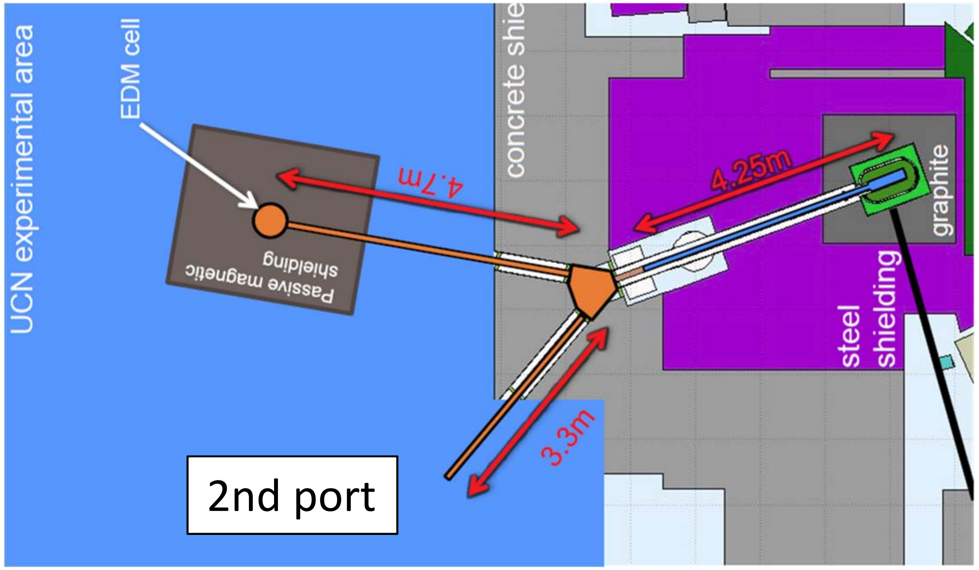


He-II cryostat

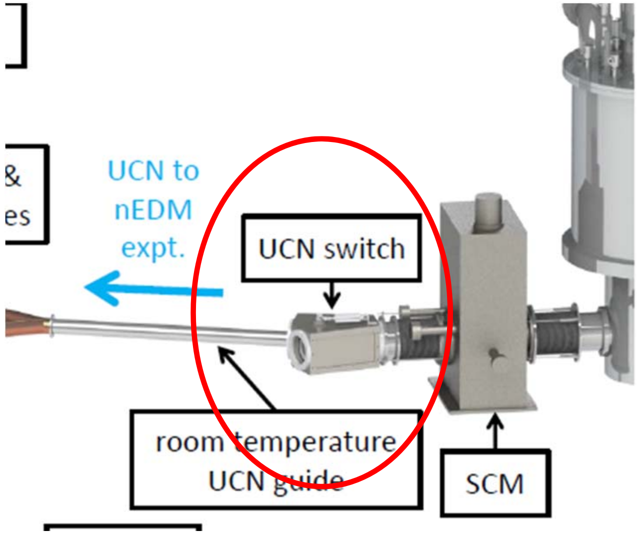
- A new He-II cryostat is been developing
  - TRIUMF proton beam line BL1U

    500 MeV × 40 μA = 20 kW
  - necessary cooling power is around 10 W at 1.0 K
  - Cryostat
    - 3He cryostat
      - Heat transfer in He-II and heat exchanger is important parameter
    - Isopure 4He direct pumping is alternative method

Second UCN port : Y switch



beamline layout

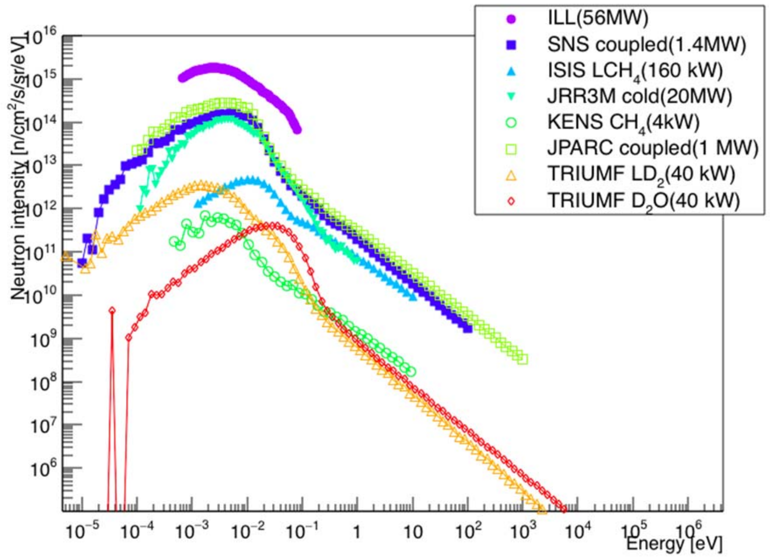


schematic view

- Bend is necessary for radiation protection
  - not to see target area directly
- Y switch can be diverted UCN to another area.
  - R&D for UCN guide, detector and so on
  - open for user facility in future
    - Japanese and Canadian group

Very Cold Neutron

- Very cold neutron (~100m/s) is useful for
  - interferometry
  - neutron imaging
  - condensed matter physics
- VCN beam line constructed using a curved neutron guide viewing the LD_2 cold source
- Estimate flux of VCN is not so strong, however, it is important to have a our own VCN beamline
  - moderator study
  - R&D for new experiment
  - neutron detector test



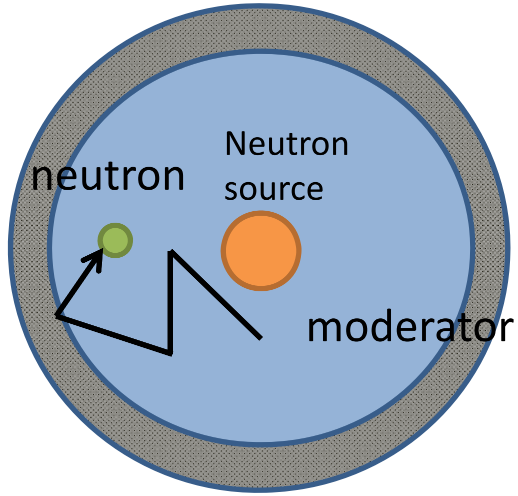
neutron flux of various UCN source and estimated flux at TRIUMF

Other R&D topic

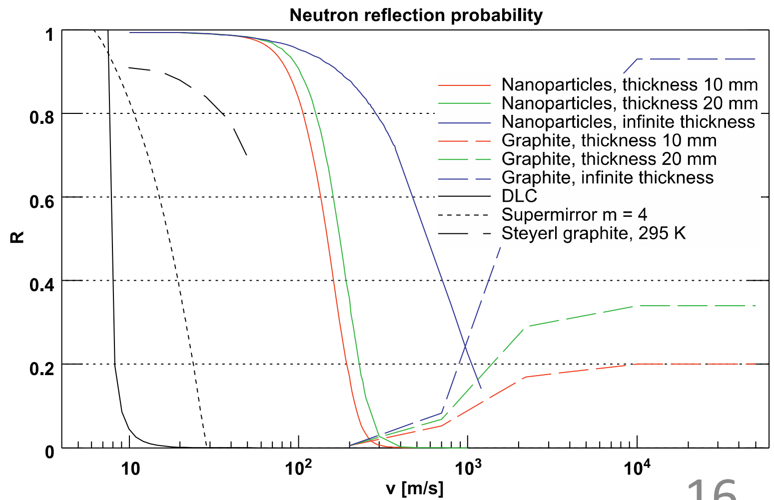
Diamond nano-particle (DNP) neutron reflector

- Coherent scattering by diamond nano-particles is a candidate of the good reflector.
- DNP reflector R&D is ongoing at J-PARC

(by K. Mishima)

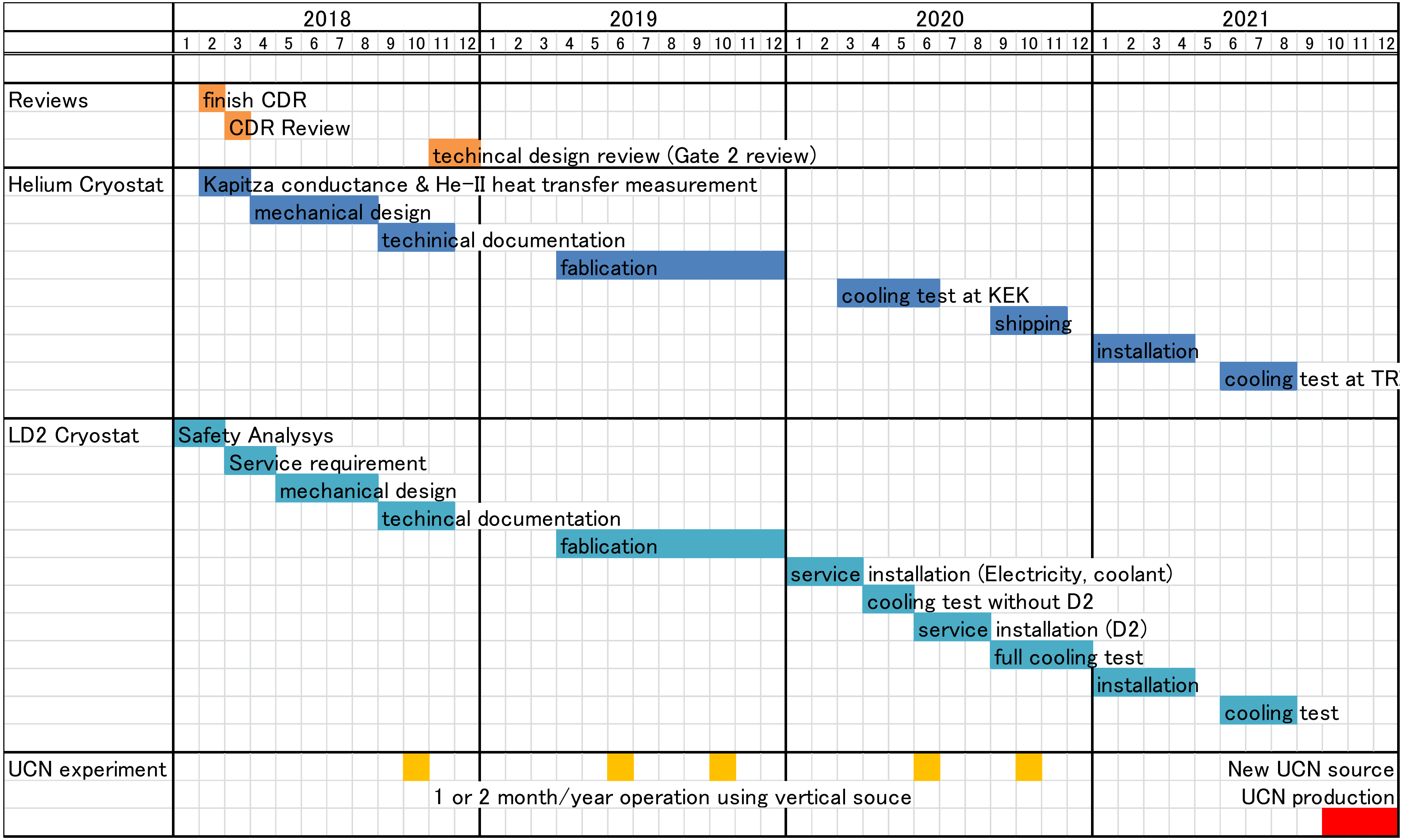


DNP reflector



V.V. Nesvizhevsky et al. / NIM A 595 (2008) 631–636

time line


2018
2019
2020
2021
1 2 3 4 5 6 7 8 9 10 11 12
Reviews
finish CDR
CDR Review
techincal design review (Gate 2 review)
Helium Cryostat
Kapitza conductance & He−II heat transfer measurement
mechanical design
techinical documentation
fablication
cooling test at KEK
shipping
installation
cooling test at TR
LD2 Cryostat
Safety Analysys
Service requirement
mechanical design
techincal documentation
fablication
service installation (Electricity, coolant)
cooling test without D2
service installation (D2)
full cooling test
installation
cooling test
UCN experiment
1 or 2 month/year operation using vertical souce
New UCN source
UCN production

time line in 2018

- Feb. : finish CDR
  - both 3He pumping and direct pumping are discussed
  - feasibility of 100 L LD2
- Mar. - Apr. : review of CDR
  - decide 3He pump / direct pump
  - Result of Kapitza conductance measurement should be available by this time
- Sep. finish mechanical design
  - Helium cryostat : Torisha
  - LD2 cryostat : TRIUMF
  - integration plan
  - list up sensor
- Dec. Technical review
  - Safety analysis
    - cryogenic
    - radiation
  - control
    - interlock

IF we succeed to get JSPS fund in 2018, helium cryostat design precede other components such as LD2 moderator. Then, separate technical review focus on helium cryostat will be arranged.

Summary

- High intensity UCN source is been developed
  - proton beam power : 500 MeV * 40 µA = 20 kW
  - new cryostat with higher cooling power
    - necessary cooling power : ~10 W at 1.0 K
      - 3He pumping, isopure 4He pumping
  - possibility to have VCN beam line has been studyed
  - Final optimization is on going
  - Plan to produce UCN from 2021