CSNS
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CHINESE ACADEMY OF SCIENCES

31^{st} International Seminar on Interaction of Neutrons with Nuclei

Recent Progress of the Physical Design for Ultra-cold Neutron Source at CSNS

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May 29^{th}, 2025

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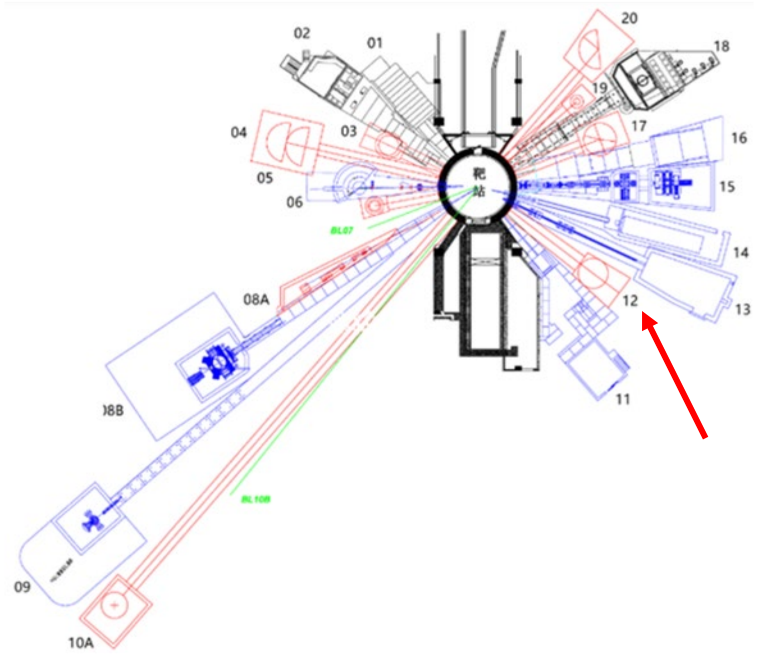
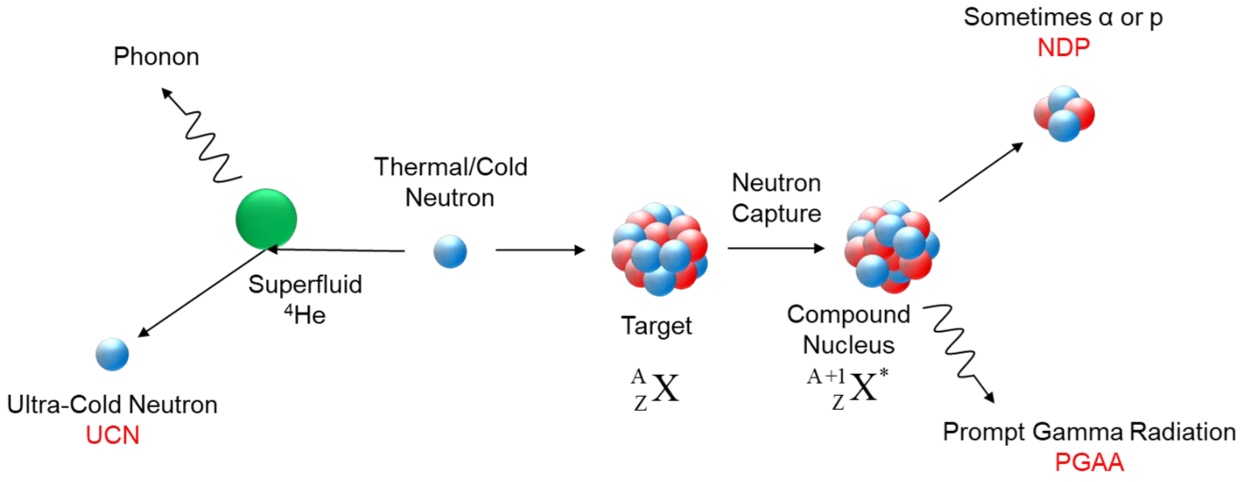
□ Outline

1. Introduction
2. Cold Neutron Beam Line
3. Ultra-Cold Neutron Source
4. Summery
5. Time Table and Team Member

1. Introduction -- Neutron Physics and Application Instrument

- Neutron Physics and Application Instrument (NPAI)
  - One of neutron instruments at the 12th port in CSNS II Project
  - Will split into two different beamlines



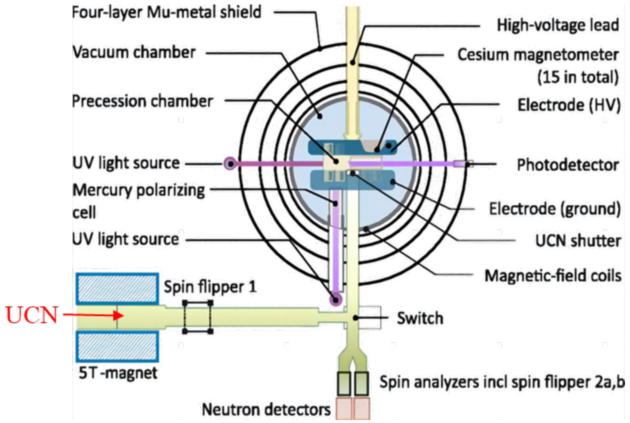


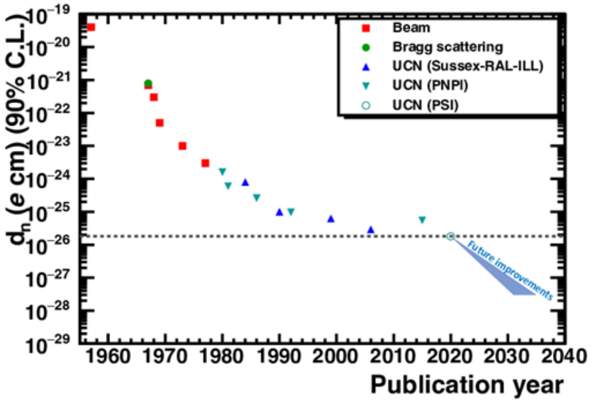
- BL12A for neutron activation technique application, such as prompt gamma activation analysis and neutron depth profiling
- BL12B for fundamental physics research, will build up the first *ultra-cold neutron source* in China

1. Introduction – UCN Source Application

- Fundamental Physics Research
  - Neutron electric dipole moment
  - Neutron lifetime
  - Neutron beta decay
  - Earth's gravity
  - Dark matter
  - Neutron-antineutron oscillations
  - ……

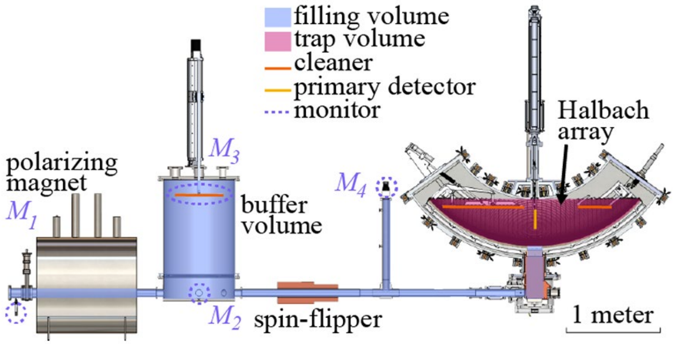
- nEDM measurement

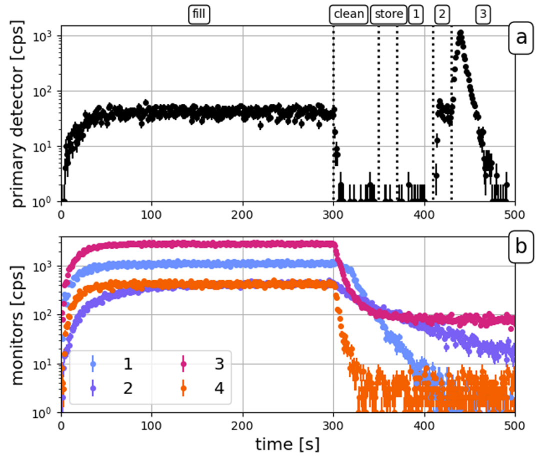




Phys. Rev. Lett. 124, 081803 (2020)

- Neutron Lifetime measurement





Phys. Rev. Lett. 127, 162501 (2021)

1. Introduction － UCN Source

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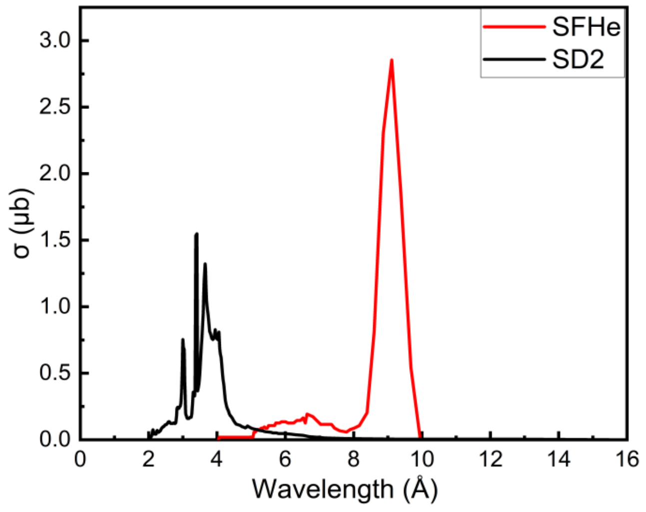
- Two types of ultra-cold neutron conversion materials
  - Solid deuterium: higher production cross-section, higher work temperature
  - Superfluid helium4: no UCN absorption cross-section



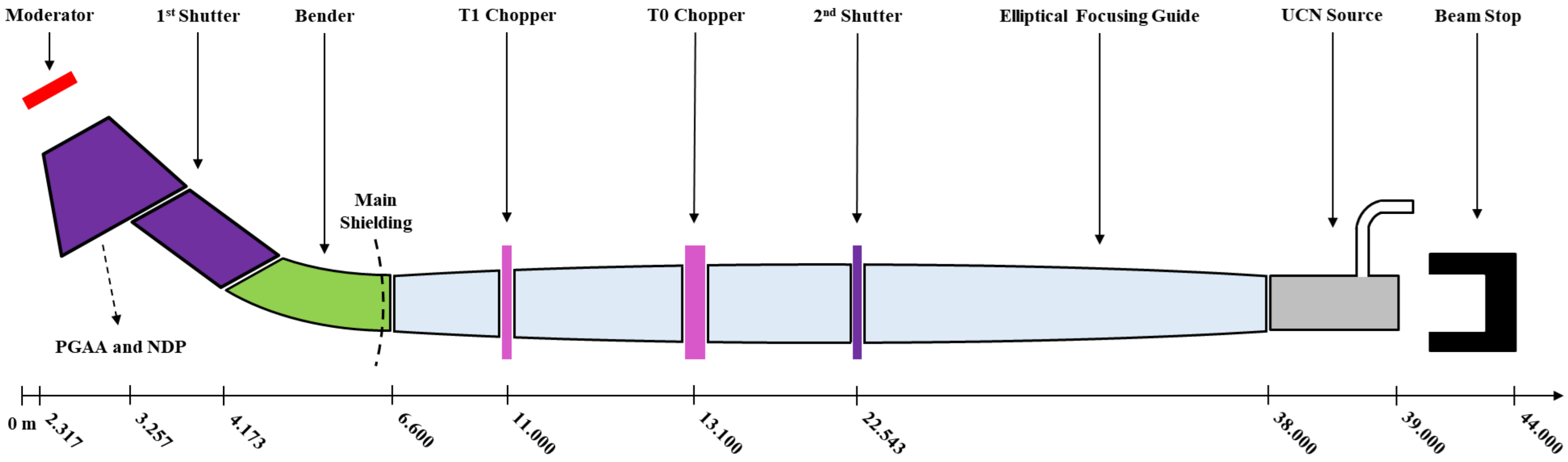
SD_2 and $SFHe_4$ production cross-section

Conversion Material	T (K)	σ_{abs} (barn)	Storage time under ideal condition (s)
^{4}He	< 1.6	0	878
^{2}D	5	0.000519	0.146

Two conversion materials physical parameters

- A compact, SFHe4-based and high storage time UCN source will be constructed at the CSNS.

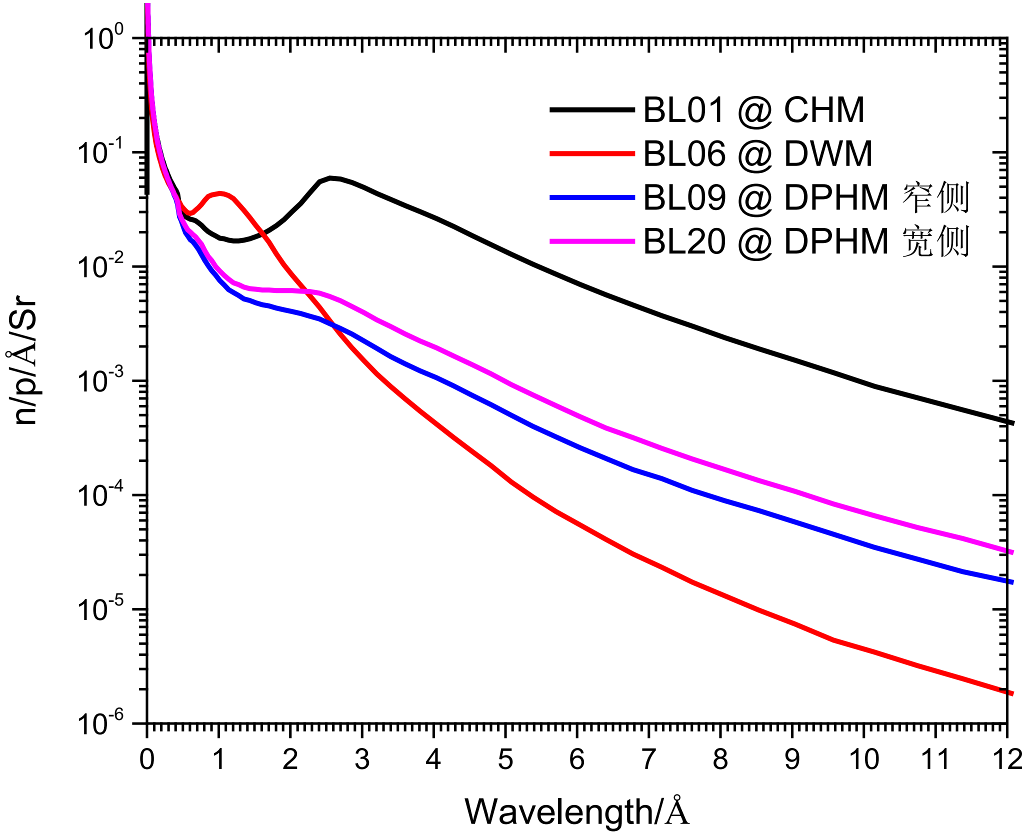
2. Cold Neutron Beam Line

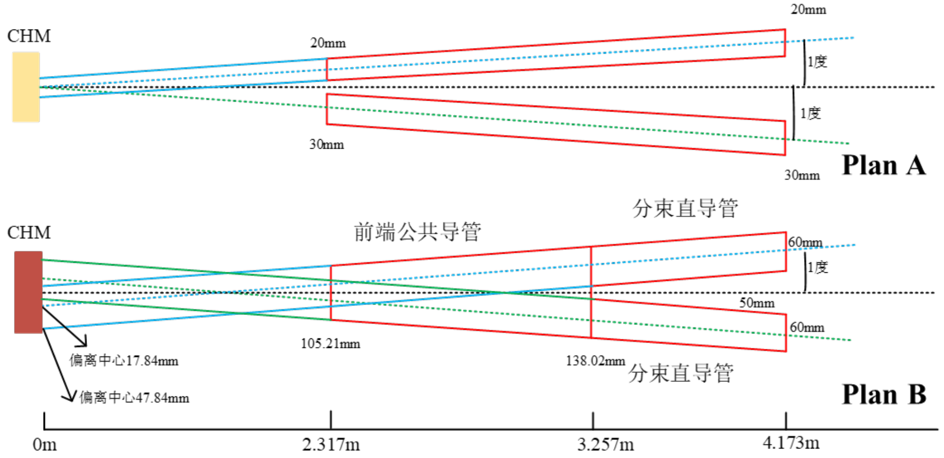


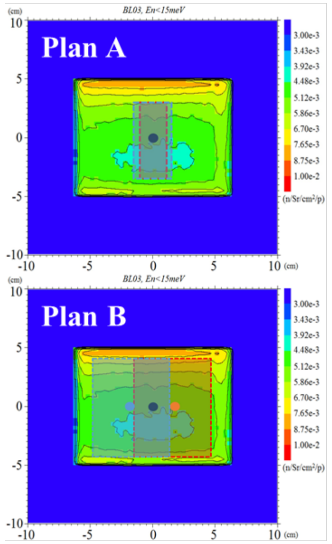
Parameter Name	Design Parameter
Moderator	Coupled Hydrogen Moderator
Neutron Beam Line	The 12th Beam Line, Physics Port
Neutron Guide	Common + Straight + Bender + Elliptical @ 2.317 ~ 38 m
Chopper Location	11 m @ T1 chopper, 13.1 m @ T0 chopper
2nd Shutter Location	22.543 m
Beam Size @ Convertor	7 cm × 7 cm
Convertor Location	38 ~ 39 m @ SF-He4

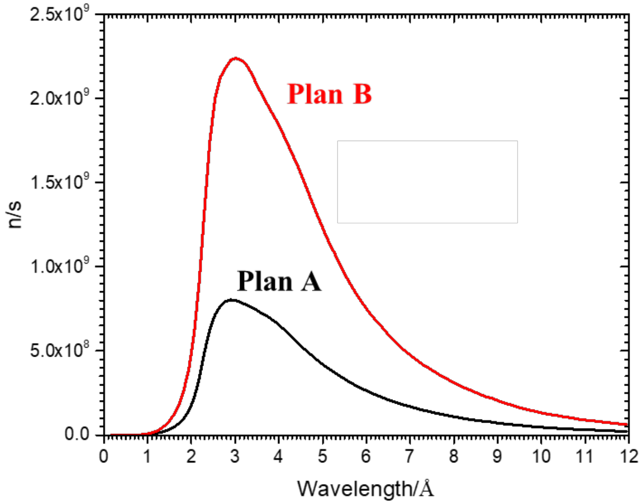
2. Cold Neutron Beam Line － Moderator and Splitting Scheme

- UCN source need a high flux cold neutron beam
- Three moderators of CSNS:
  - Decoupled Water Moderator (DWM)
  - Decoupled Poisoned Hydrogen Moderator (DPHM)
  - Coupled Hydrogen Moderator (CHM)





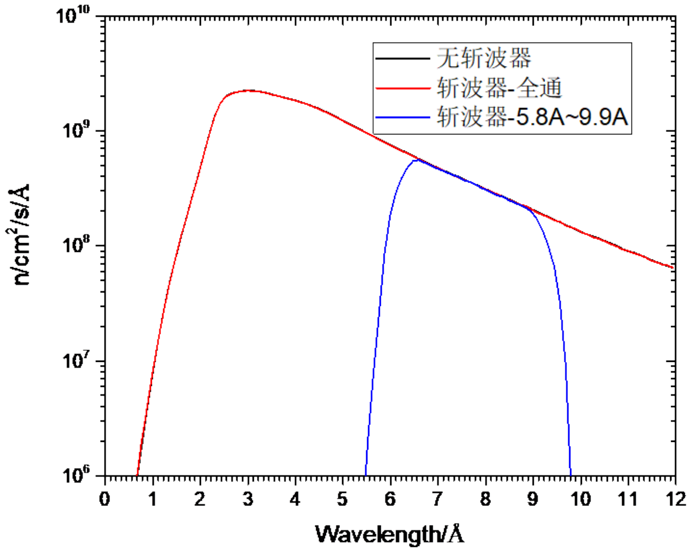




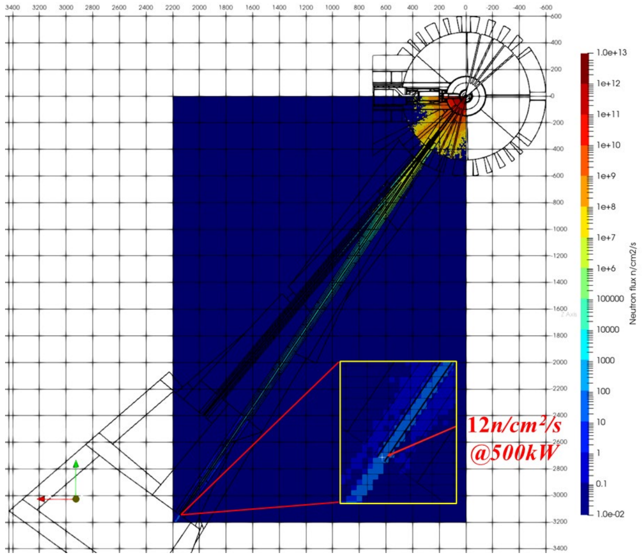
- Plan A: 2.38E+10 n/s (0.16Å~12.00Å) @ 38 m
- Plan B: 6.71E+10 n/s (0.16Å~12.00Å) @ 38 m

2. Cold Neutron Beam Line – Chopper

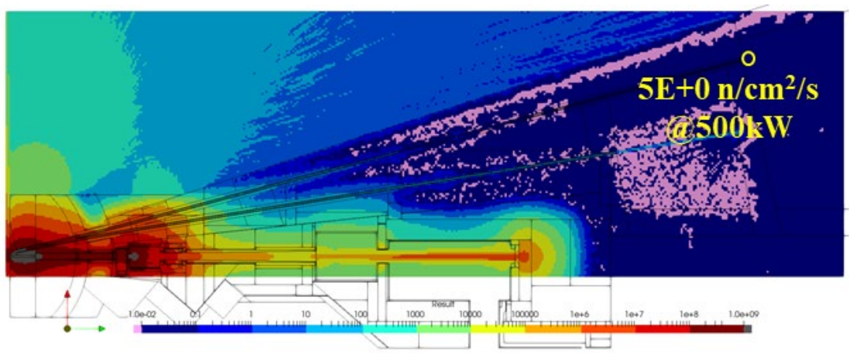
- T1 chopper provides a bandwidth of 4.1 Å
- T0 chopper reduces the fast neutron (>1eV) background from the target station and adjacent beam line



Neutron wavelength spectrum



Fast neutron from target station

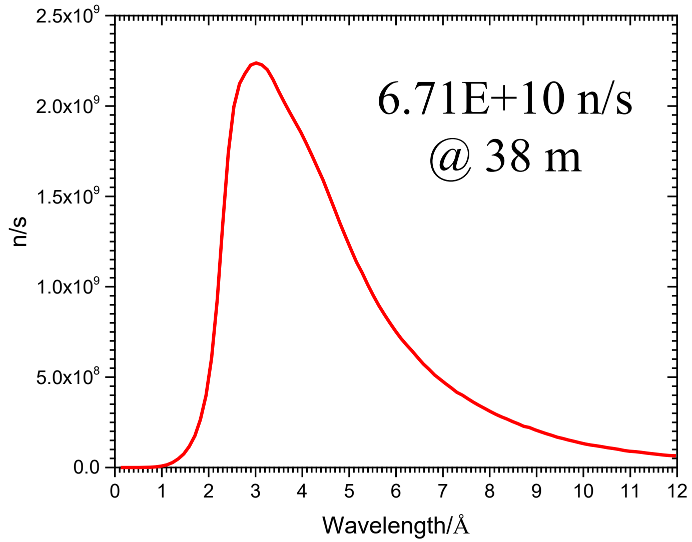


Fast neutron from adjacent beam line

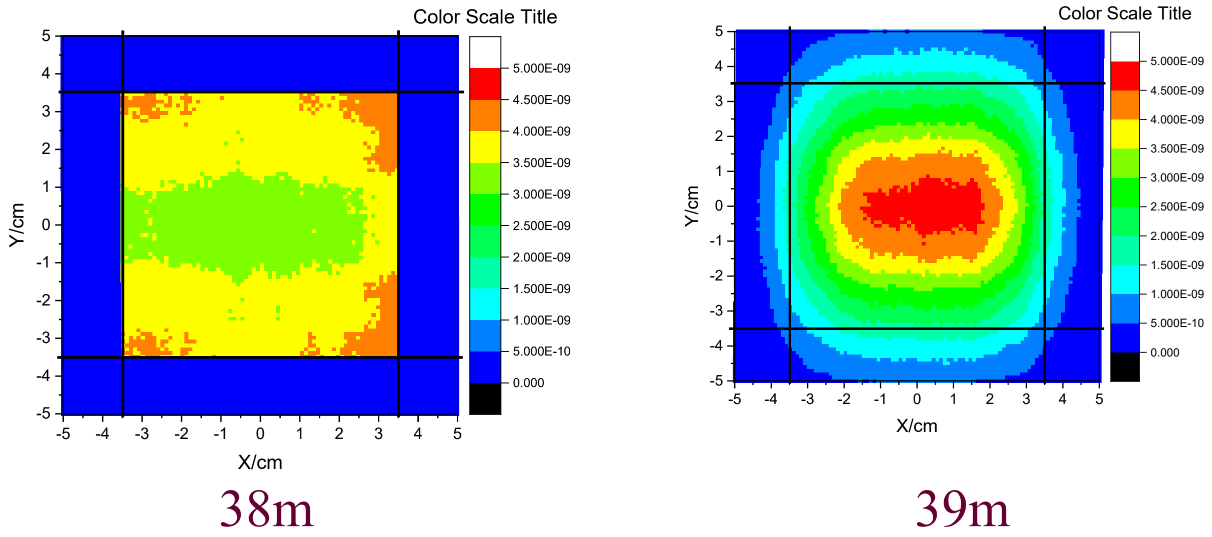
- Without T0 chopper: 5 n/cm^2/s from BL11, 12 n/cm^2/s from target station @ UCN source
- T0 chopper: 1.1E-3 n/cm^2/s from BL11, 0.135 n/cm^2/s from target station @ UCN source

2. Cold Neutron Beam Line － Guide

Guide	Entrance/cm²	Exit/cm²	m Value	Length/m	Location/m	
Common	10.521×9	13.802×9	3	0.94	2.317-3.257	In 1st shutter
Straight	6×9	6×9	3	0.916	3.257-4.173	
Bender	6×9	6×9	4/2.5/2.5	2.427	4.173-6.6	Radius:70 m
Elliptical	6×9	7×7	2.5@6.6-37m 4@37-38m	31.4	6.6-38	Horizontal b: 6cm Vertical b: 8cm



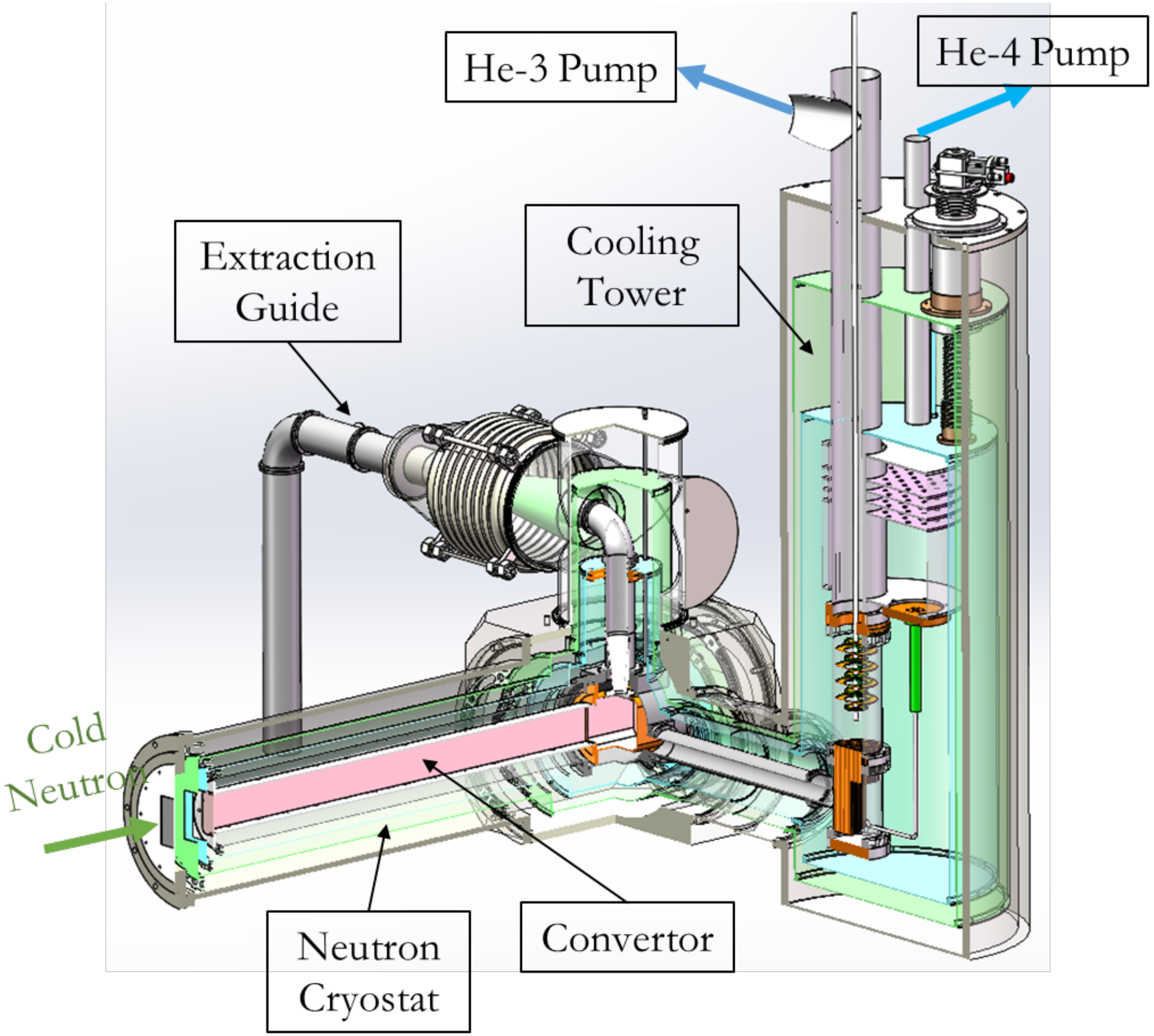
Neutron wavelength spectrum of the guide exit@500kW



Neutron distribution at SF-He4

3. Ultra-Cold Neutron Source

- Ultra-cold neutron source
  - Low temperature system
    - Cooling tower
    - Neutron cryostat
  - SF-He4 convertor (7 cm × 7 cm × 100 cm)
  - Extraction guide
- Physical design based on three processes
  - Production
  - Storage
  - Extraction



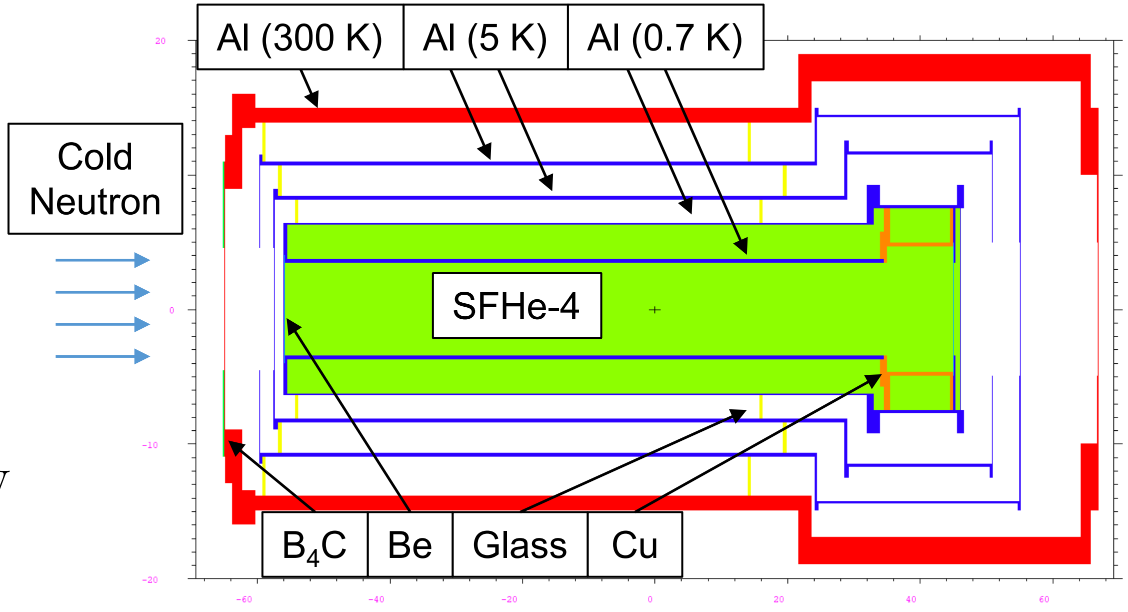
3. Ultra-Cold Neutron Source -- Production

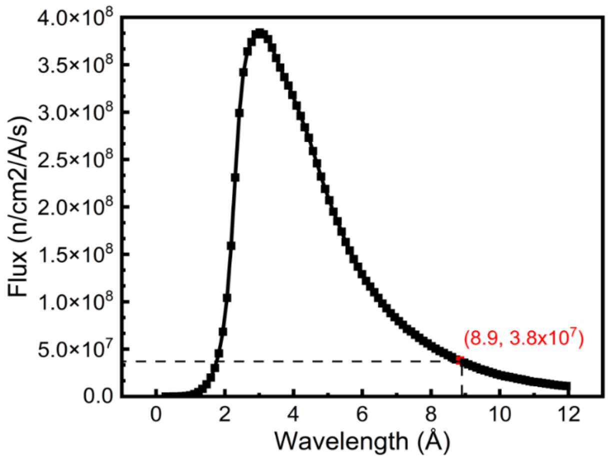
- UCN production rate

$$P = \int \phi(E)\Sigma(E)\,dE$$

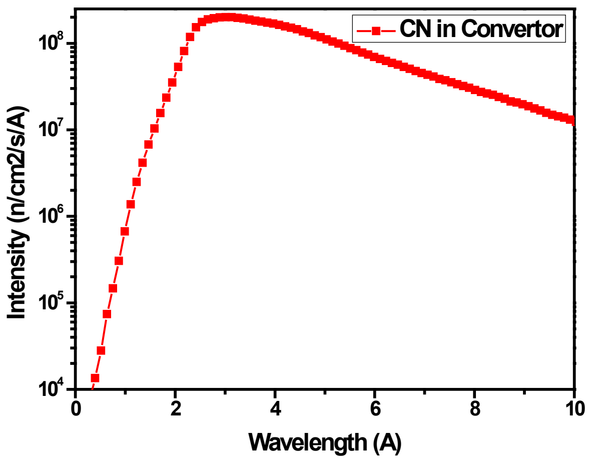
Φ is cold neutron flux in SFHe-4, Σ is cross section in SFHe-4

- UCN production rate: 12055 UCN/s @ 500 kW

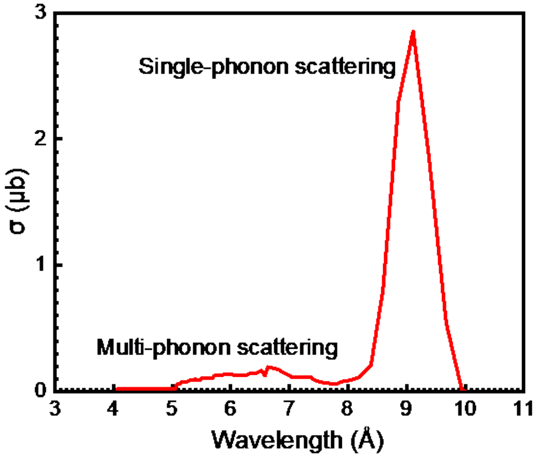




Incident cold neutron spectrum

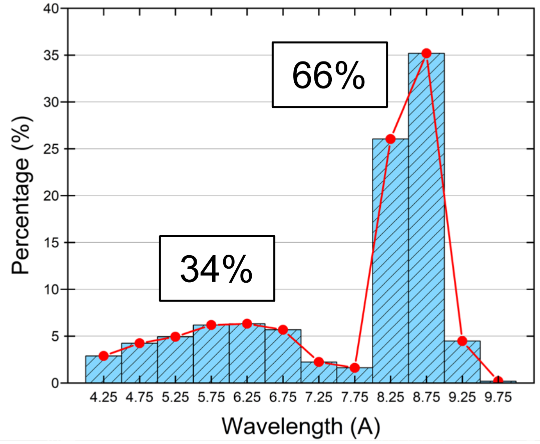


Cold neutron spectrum in SFHe



CN to UCN cross section

Physical Review Letters 131, 191801 (2023)



UCN production rate vs. CN wavelength

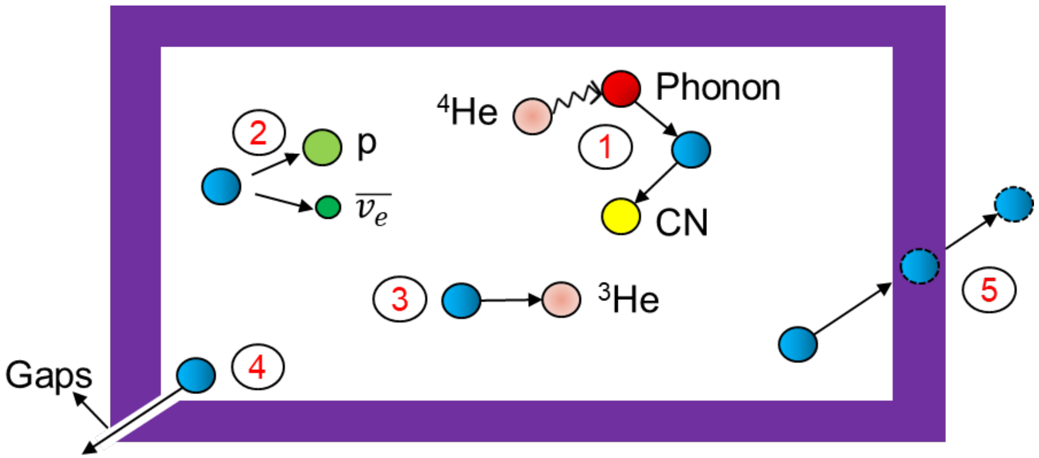
3. Ultra-Cold Neutron Source -- Storage

- Cold neutron will be converted into ultra-cold neutron in SF-He4
- UCN will be accumulated in converter vessel for fill and empty experiment

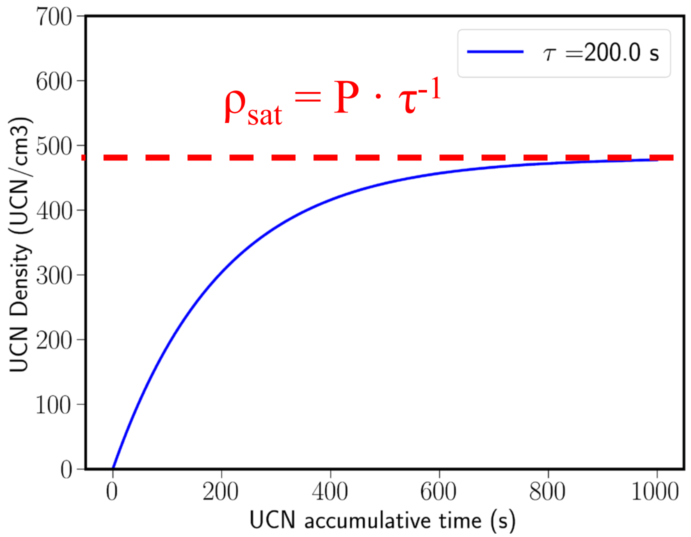
$$\rho_{sat} = P \cdot (\tau_{upscattering}^{-1} + \tau_{\beta decay}^{-1} + \tau_{absorption}^{-1} + \tau_{leakage}^{-1} + \tau_{wall}^{-1})^{-1}$$

$\tau_{upscattering}$	$\tau_{\beta decay}$	$\tau_{absorption}$	$\tau_{leakage}$	τ_{wall}
＞1,000 s	878 s	＞1,000 s	＞1,000 s	＞300 s

~200 s

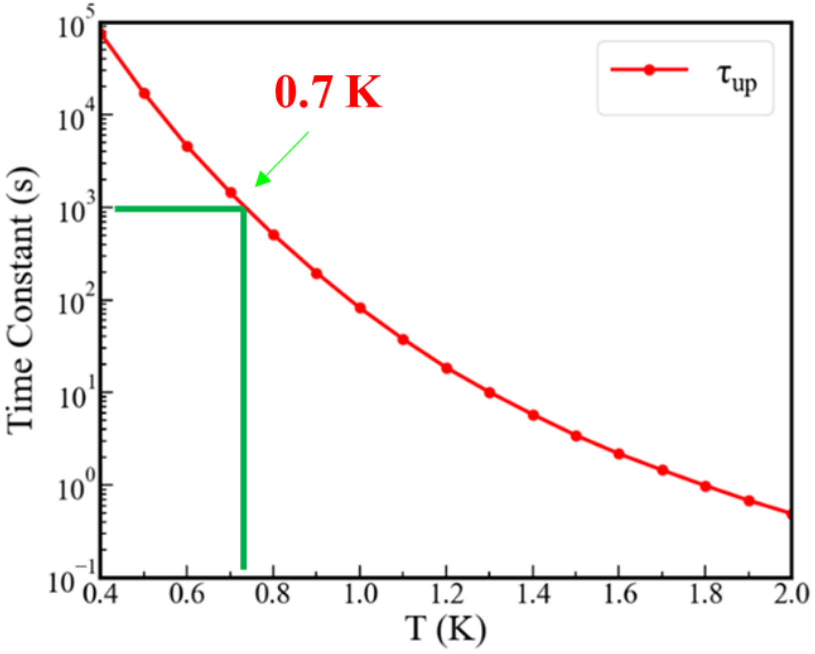


Ultra-cold neutron loss mechanism

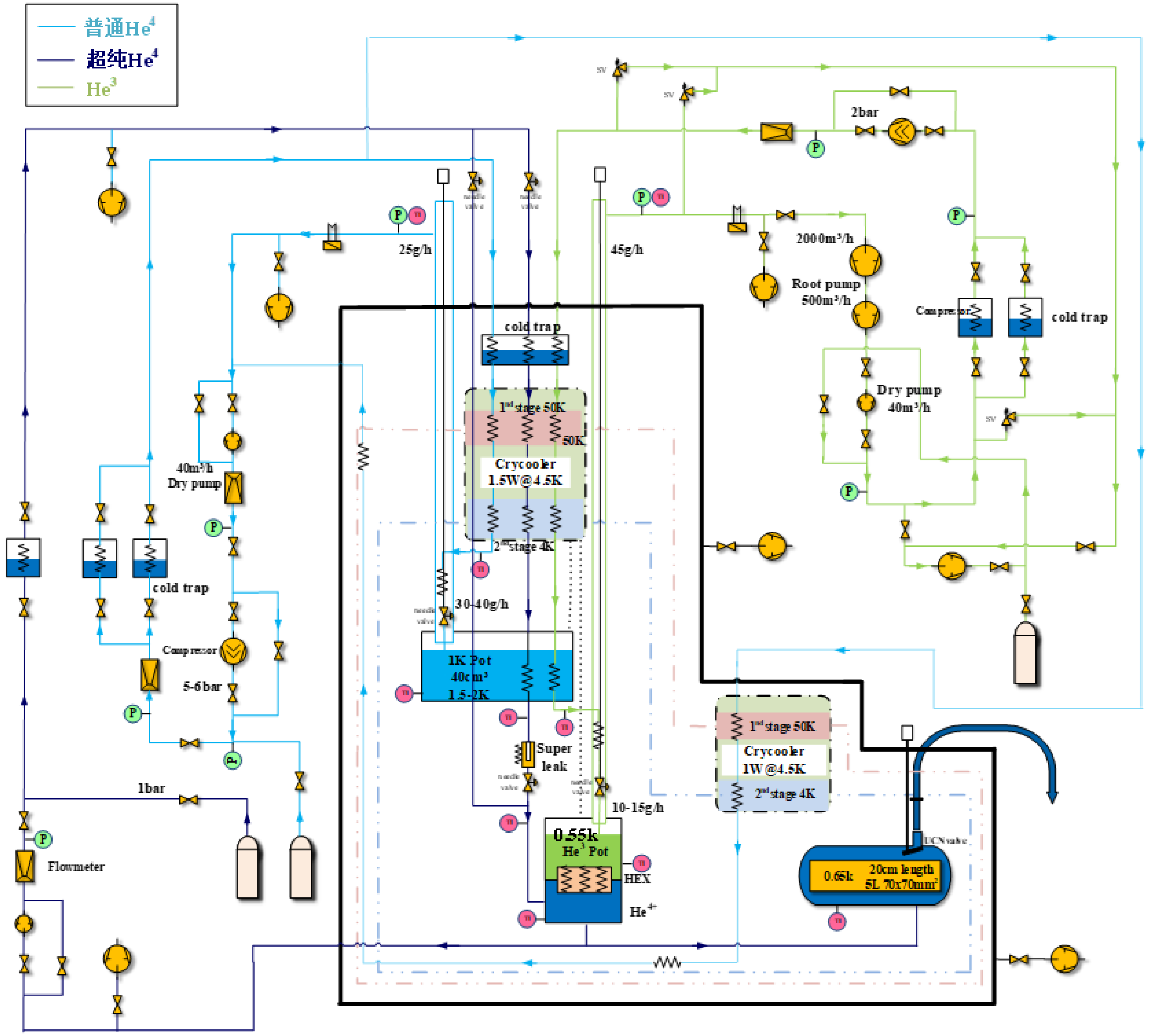


3. Ultra-Cold Neutron Source -- Upscattering storage time

- SF-He4 design temperature is 0.65 K
- Three circuits: 1 for He-3, 2 for He-4
- Two cold screens: 5 K and 50 K
- Cold trap -> Crycooler -> He-4 pot -> He-3 pot



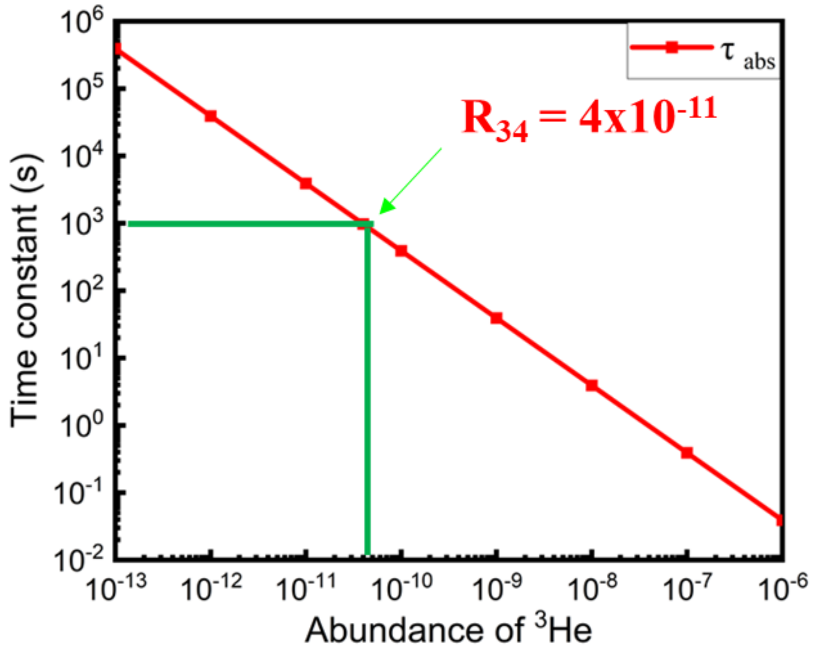
Up-scattering storage time



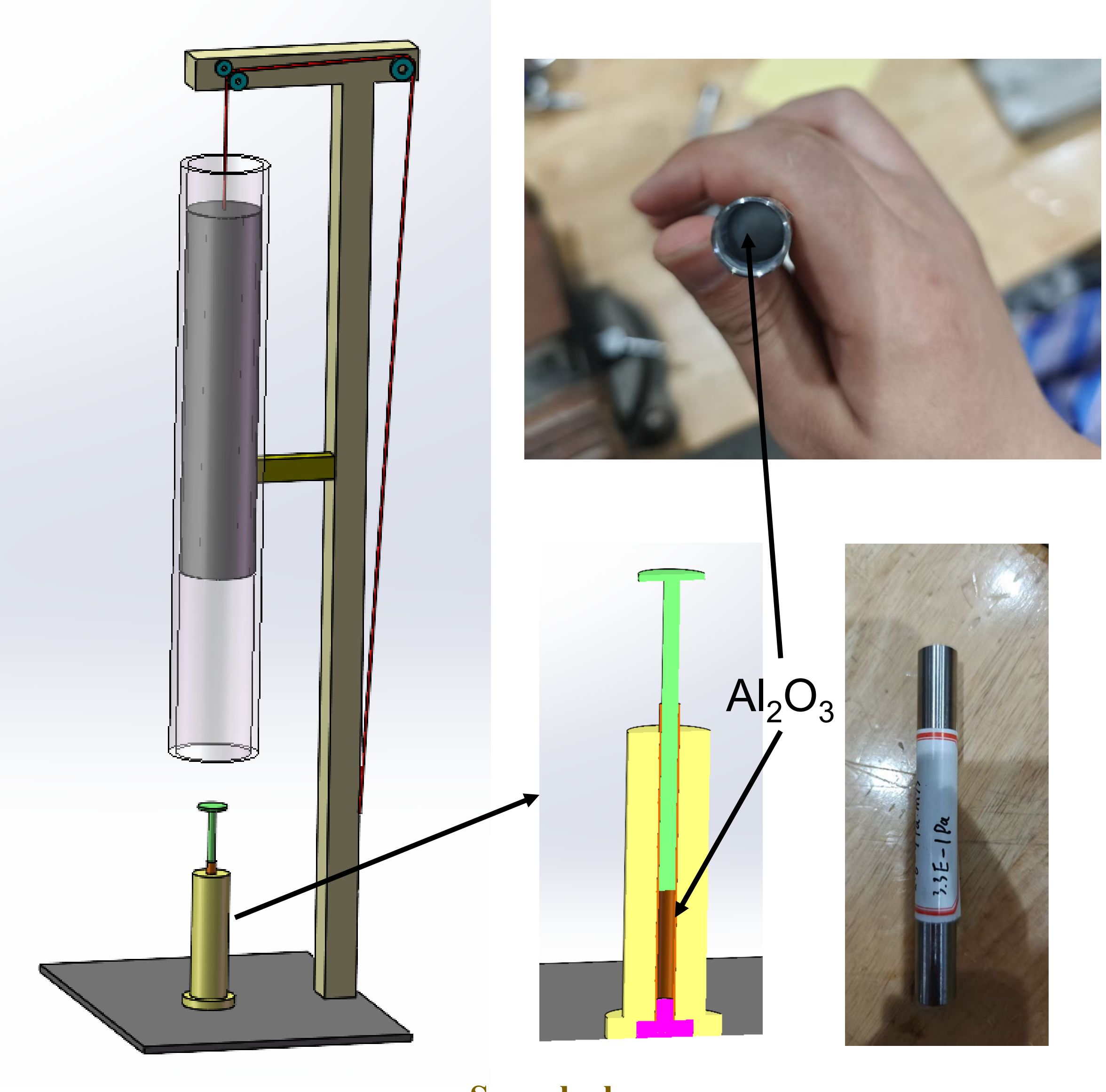
UCN source low temperature system

3. Ultra-Cold Neutron Source -- Absorption storage time

- UCN will be absorbed by He-3
- Need to reduce the ratio of He-3 to He-4 (R_{34})
- Superleak is under development
- The leakage rate of superleak is $10^{-8} \sim 10^{-9}$ Pa·m³/s



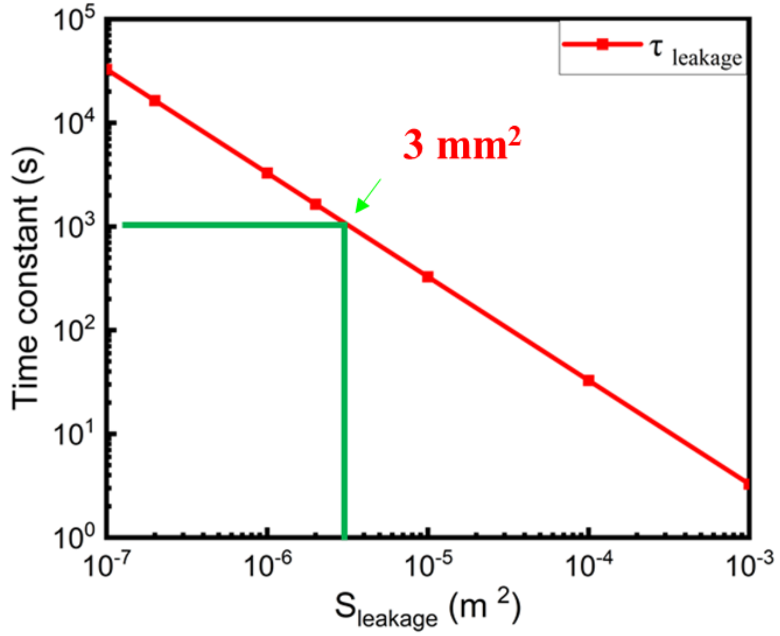
Absorption storage time



Superleak

3. Ultra-Cold Neutron Source – Leakage and wall storage time

- $\tau_{leakage}$ depends on the area of convertor leakage
- τ_{wall} depends on the materials of convertor wall



Leakage storage time

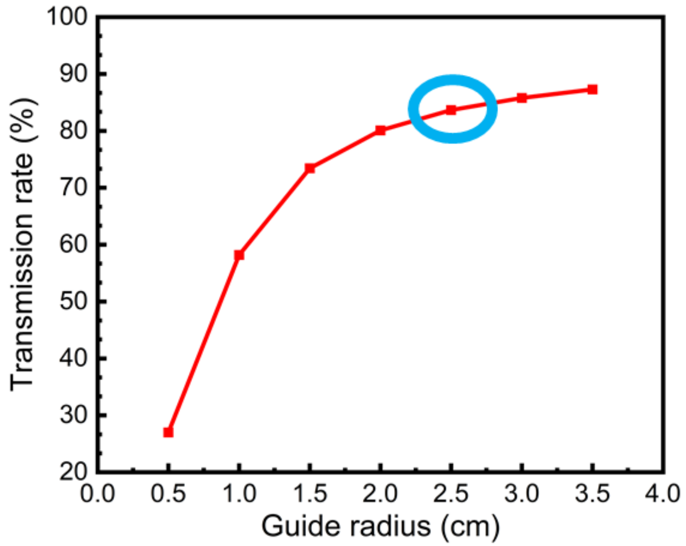
Materials	Fermi Potential (neV)	Loss Factor $[10^{-5}]$	Wall Storage Time (s)
^{58}Ni	335	8.6	93
DLC	220	0.0146	481
BeO	261	1.35	307
Be	252	0.5	382
SS	183	9.3	131
Fomblin	115	1.85	475
CYTOP	115	2.7	419
dPS	161	1.5	406

Convertor wall material parameters

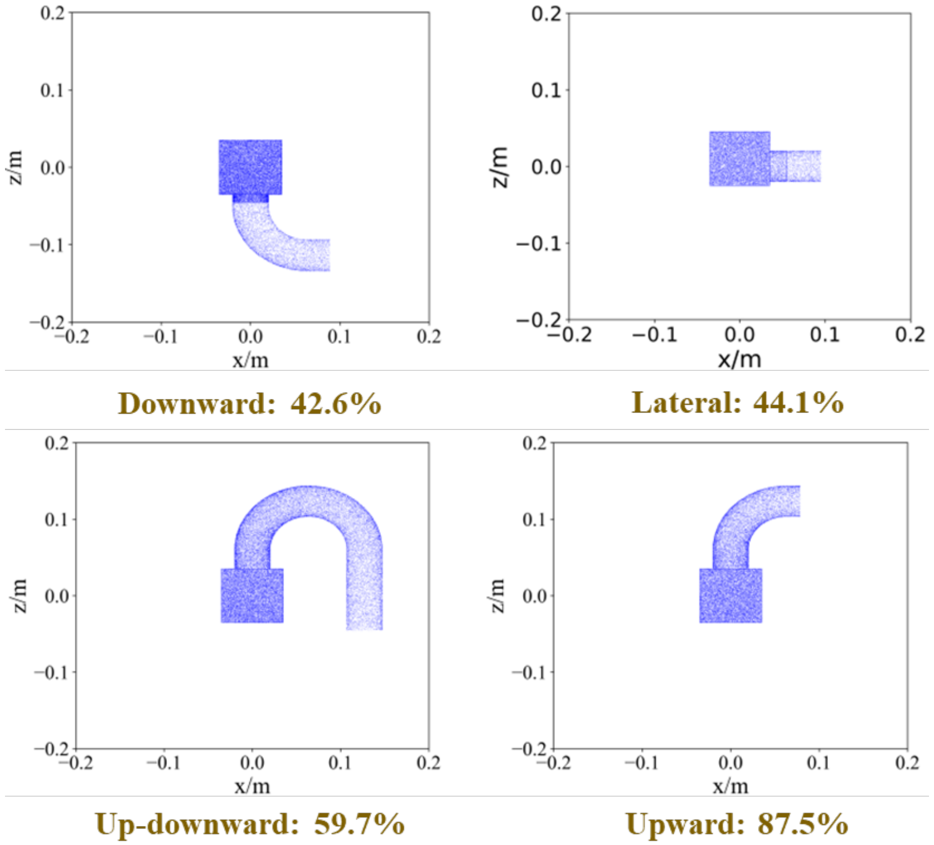
- An attempt is being made to prepare and test the CYTOP film
- BeO ceramics is an alternative solution

3. Ultra-Cold Neutron Source － Extraction

- The larger guide size, the more UCN are extracted
- The guide size is limited by engineering requirement
- The guide radius is 2.5 cm



Guide size vs. transmission rate



Extraction mode and its extraction rate

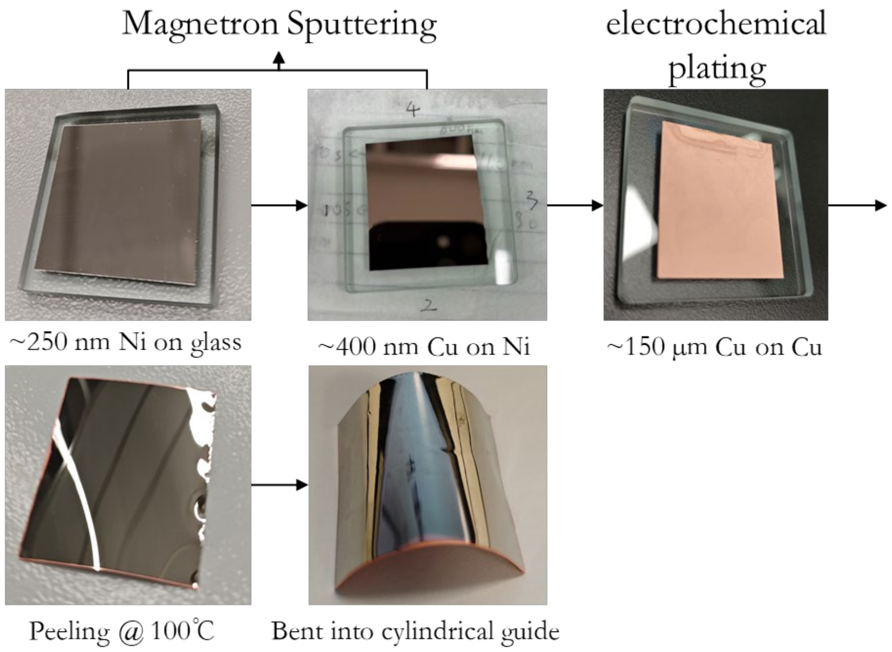
- The extraction mode depends on the application experiment requirement
- Currently, the upward extraction mode with the highest extraction rate is adopted

3. Ultra-Cold Neutron Source − Extraction

- The guide material will affect the extraction of ultra-cold neutrons
- An attempt is being made to prepare the Ni-58 extraction guide
- Stainless steel guide is an alternative solution

Parameters of guide material

Material	Fermi Potential (neV)	Loss Factor [10^{-5}]	Extraction Rate (%)
DLC	220	0.0146	91
Stainless Steel	183	9.3	87
^{58}Ni	335	8.6	92
^{58}NiMo	215	8.95	91
Ni	252	12.1	91
NiMo	220	12.0	90
NiP	213	11.0	90

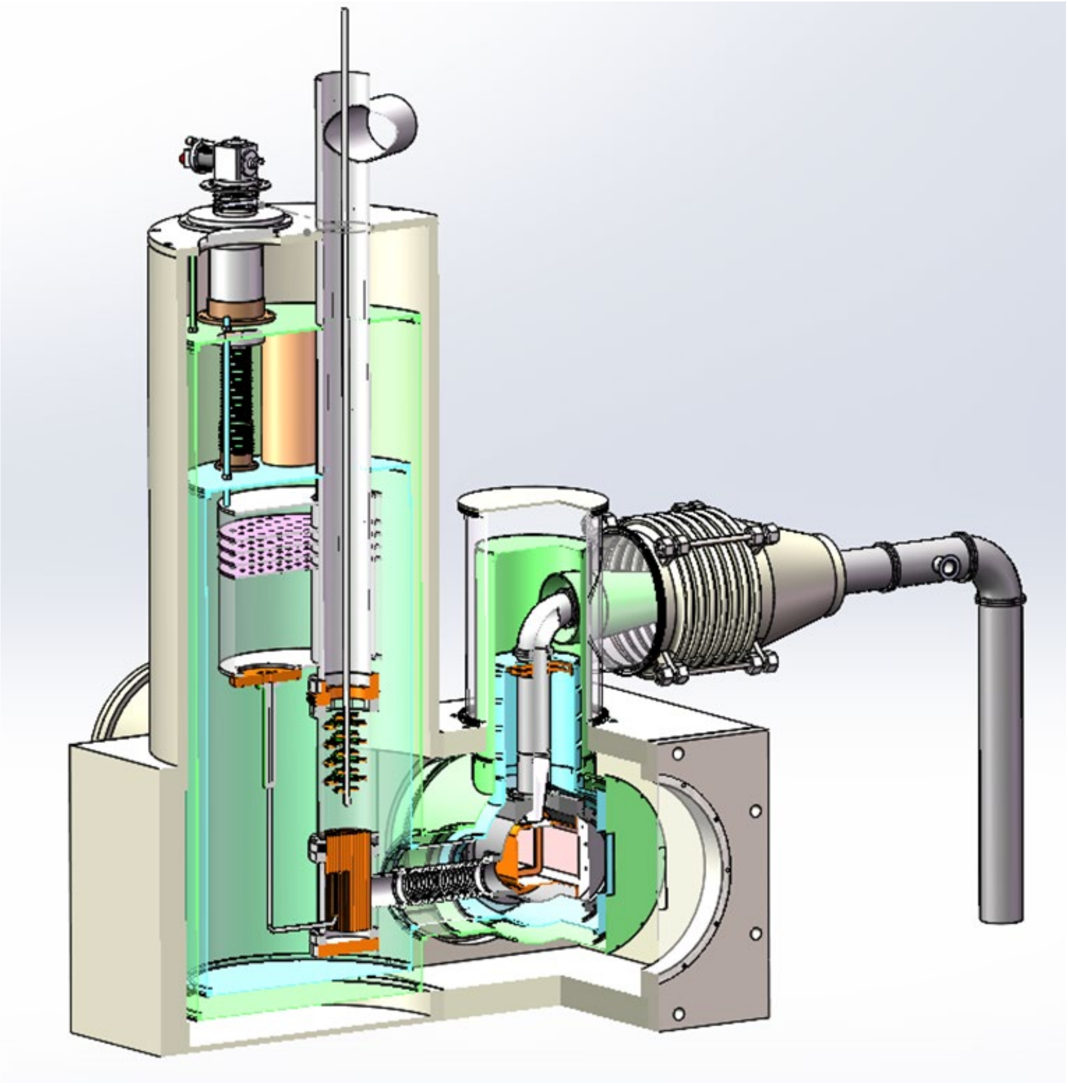


- The small sample of the Ni guide have been prepared on the 4.5 cm × 4.5 cm glass
- The next step will be to prepare larger sample of the Ni guide

4. Summary

- Design Parameter
  - SFHe temperature: 0.65 K
  - Convertor size: 7 * 7 * 100 cm^3
  - Extraction mode: upward extraction
  - Extraction Guide: Ni-58, D = 5 cm
- Expected UCN source performance

Incident cold neutron flux (n/s)	6.71E10
Storage time constant (s)	200
UCN production rate (UCN/s)	12055
Saturation UCN density (UCN/cm^3)	492
UCN extraction rate (%)	87.5



5. Time Table and Team Member

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- Time Table

Time	Content
2025.01	NPAI Physical Design Review
2025.10	UCN Equipment Design Review
2026.11	Cooling Tower Commissioning
2027.06	Neutron Beam Performance Test
2027.08	Neutron Cryostat Commissioning
2028.10	Joint Commissioning
2029.04	UCN Equipment Installation
2029.07	NPAI Acceptance and Operation

- Team Member

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