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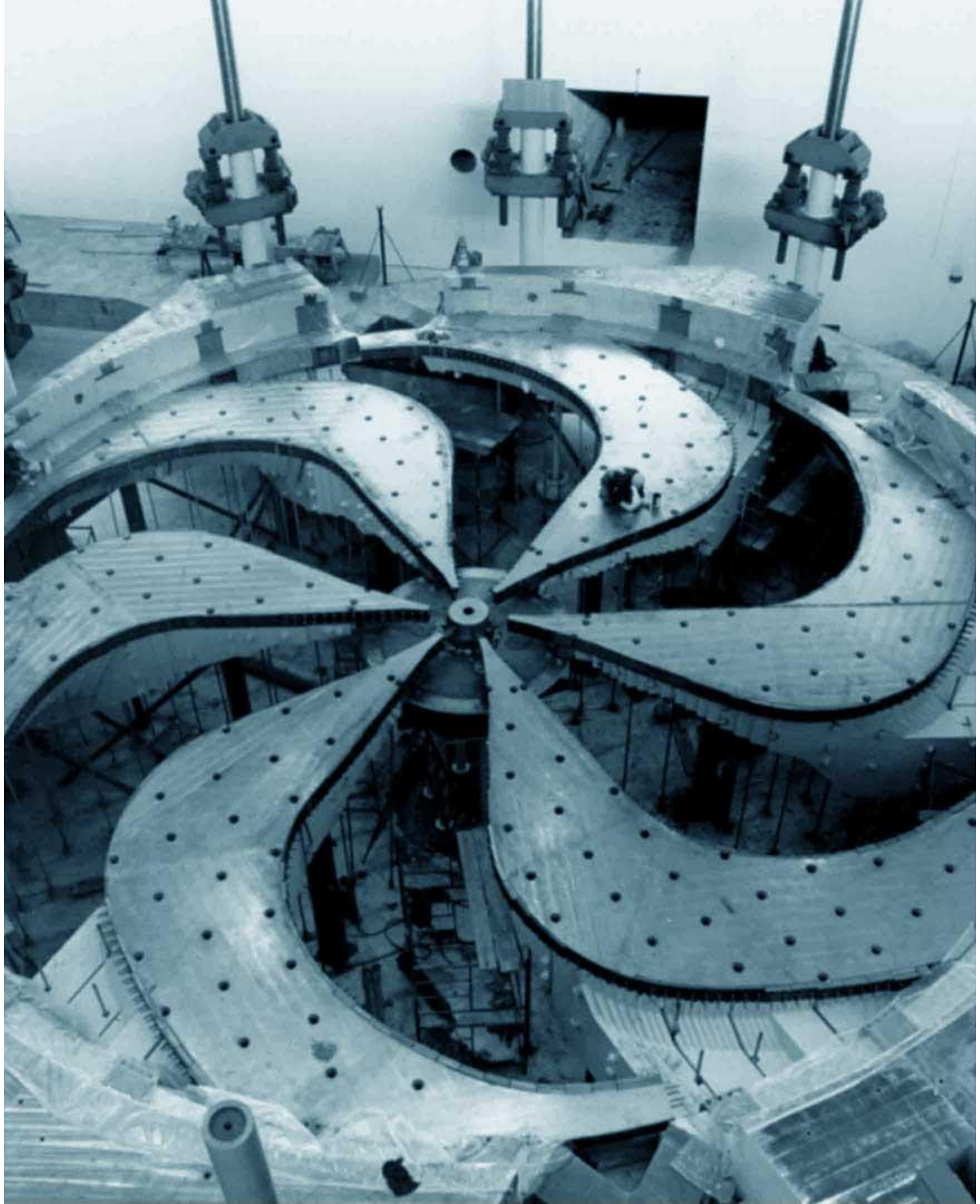
Optimizing the performance of a spallation-driven ultracold-neutron source with deuterium and superfluid-helium moderators

Wolfgang Schreyer

TUCAN collaboration

2021-02-17



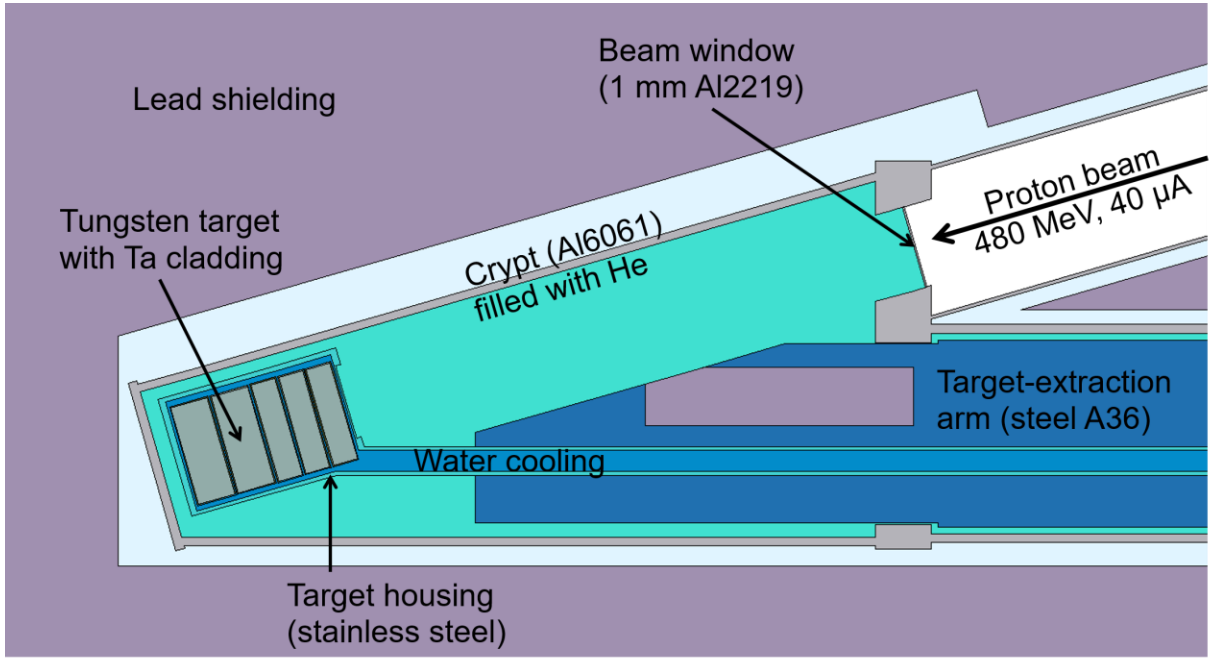
Discovery, accelerated

TUCAN timeline

- 2013 – 2016: Installation of new beamline and neutron spallation target
  S. Ahmed et al, A beamline for fundamental neutron physics at TRIUMF, NIM A 927 (2019), 101-108
  S. Ahmed et al, Fast-switching magnet serving a spallation-driven ultracold neutron source, Phys. Rev. Accel. Beams 22 (2019), 102401
- 2017 – 2019: Operation of prototype UCN source
  S. Ahmed et al, First ultracold neutrons produced at TRIUMF, Phys. Rev. C 99 (2019), 025503
- 2020 – 2022: Installation of upgraded TUCAN source
- 2022: Installation of TUCAN EDM experiment with sensitivity goal 10^{-27} ecm

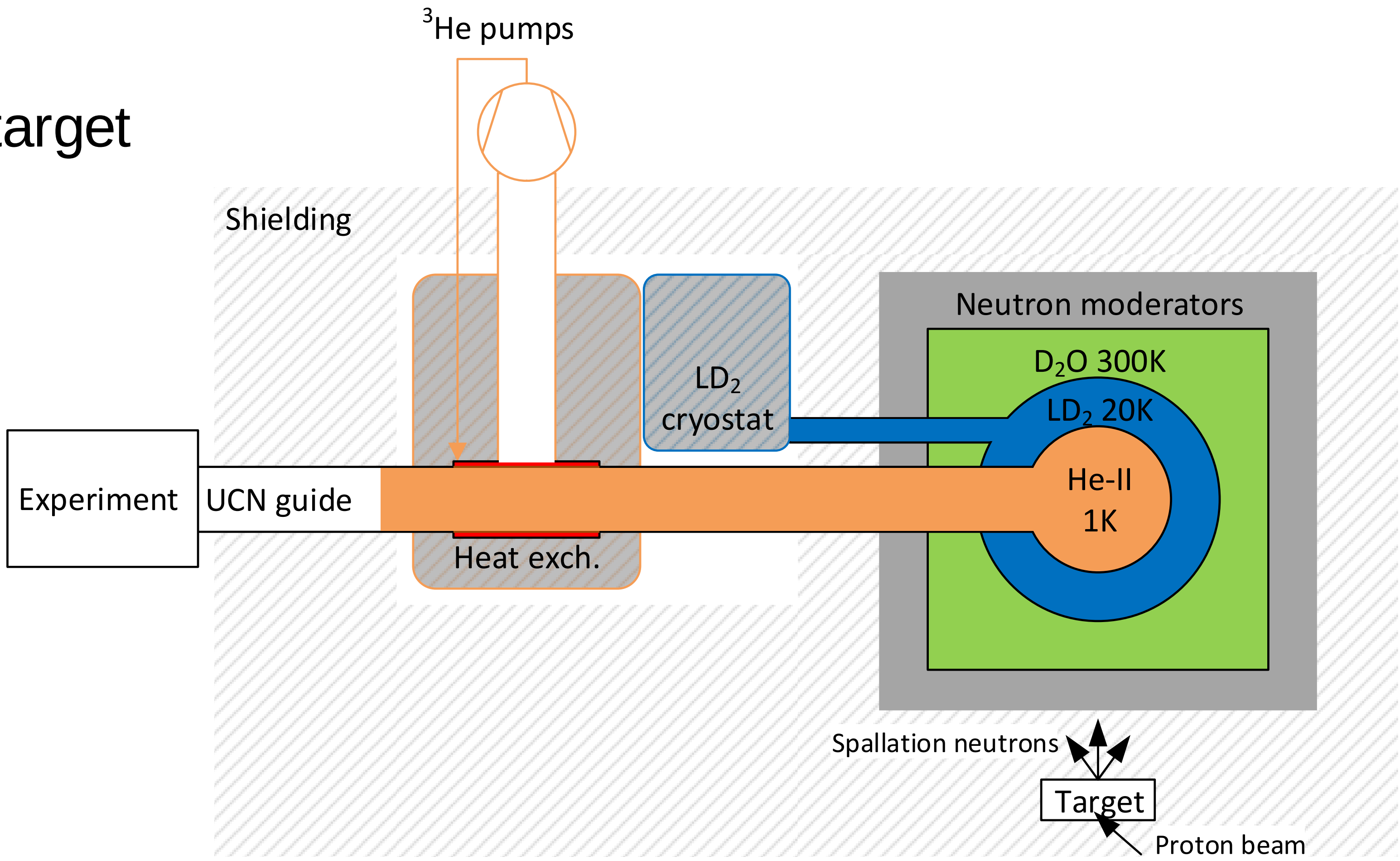
Neutron spallation target

- 19 kW beam power
- Intensity & time structure adjustable with kicker magnet



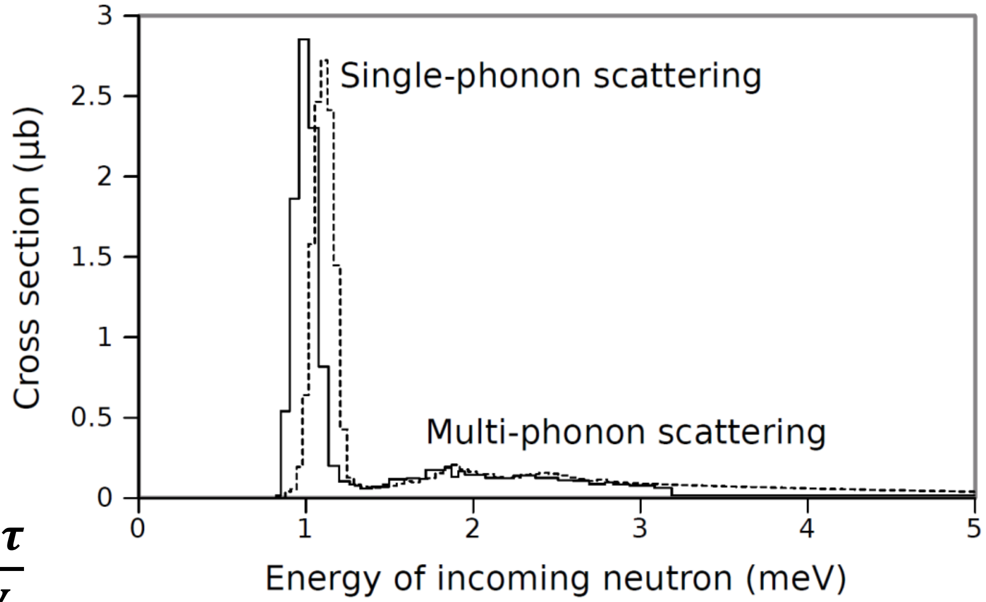
Concept of new TUCAN source

- Nested moderators above target
- Horizontal UCN extraction
- Cryostat accessible

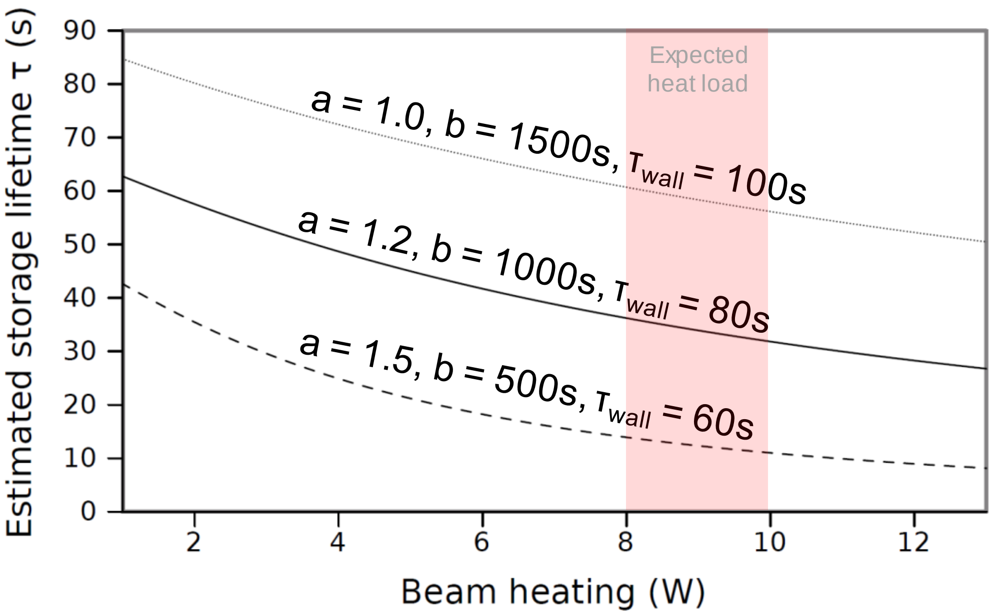


Optimization goal

- **Maximize UCN density in experiment $\rho = \frac{P\tau}{V}$**
- Production rate P and heat load Q from MCNP
  $P = \int \phi_n(E)\sigma(E)dE$
- Volume $V = V_{source} + V_{guides} + V_{exp}$
- Storage lifetime $\tau^{-1} = \tau_{He}^{-1} + \tau_{abs}^{-1} + \tau_{wall}^{-1} + \tau_{\beta}^{-1}$
  - $\tau_{He}^{-1} \approx B\left(\frac{T}{1K}\right)^7 \approx \frac{1}{b}\left(\frac{Q}{1W}\right)^a$

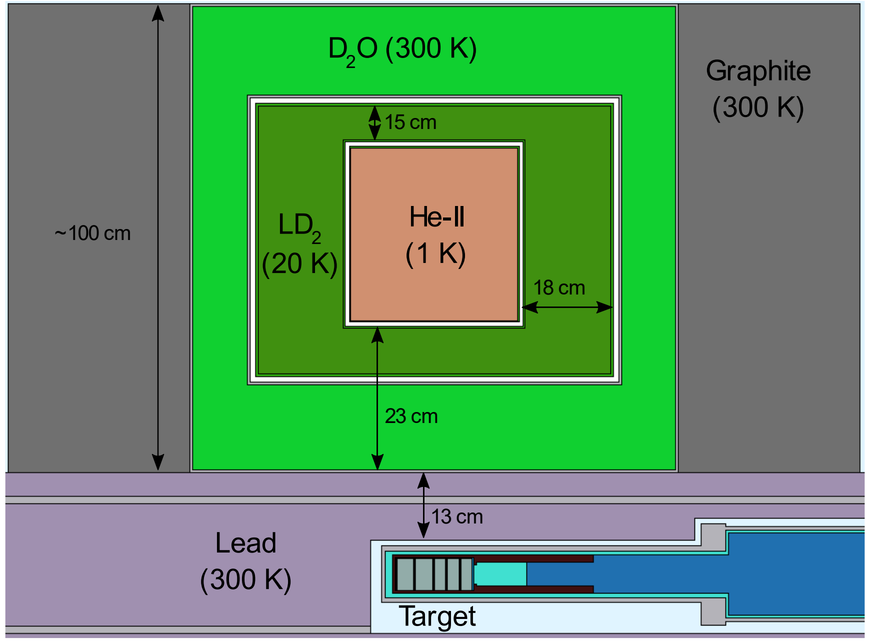


P. Schmidt-Wellenburg et al, Phys. Rev. C 92 (2015), 024004
E. Korobkina et al, Phys. Lett. A 301, 5-6 (2002), 462-469

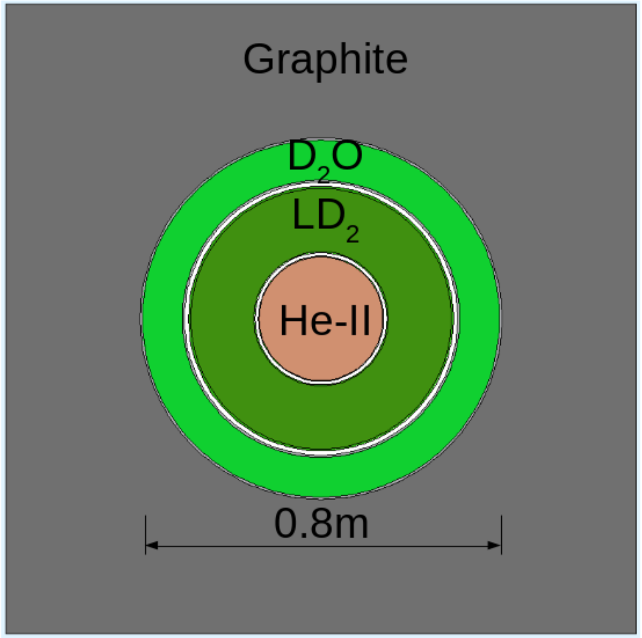


Initial MCNP simulation model

Side view

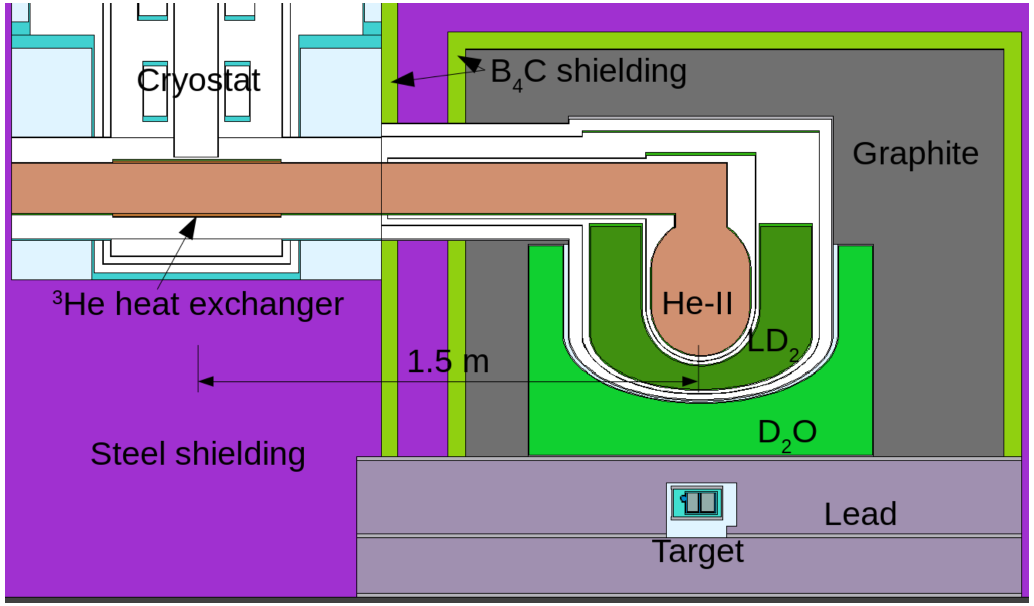


Top view

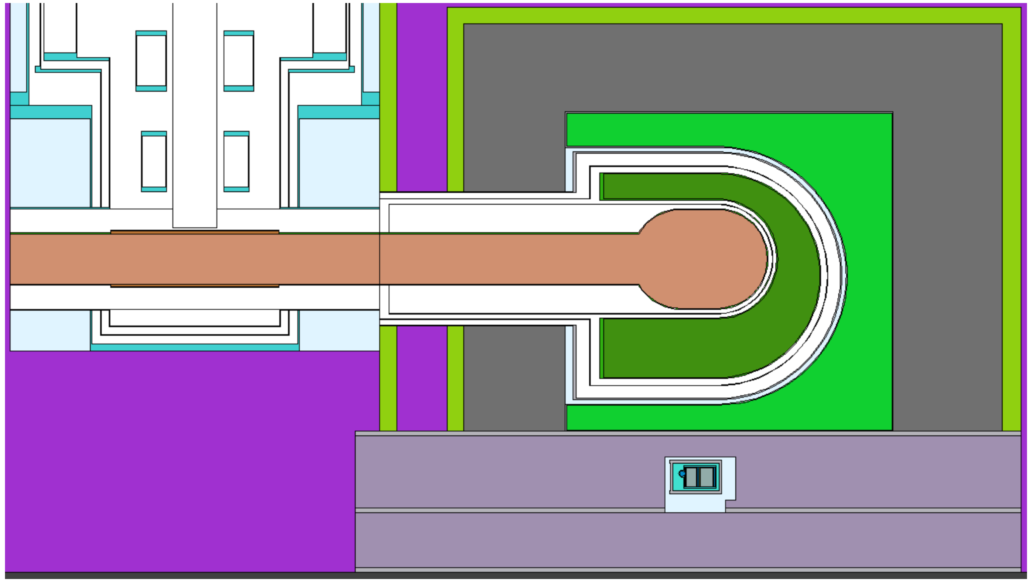


Adding UCN guides

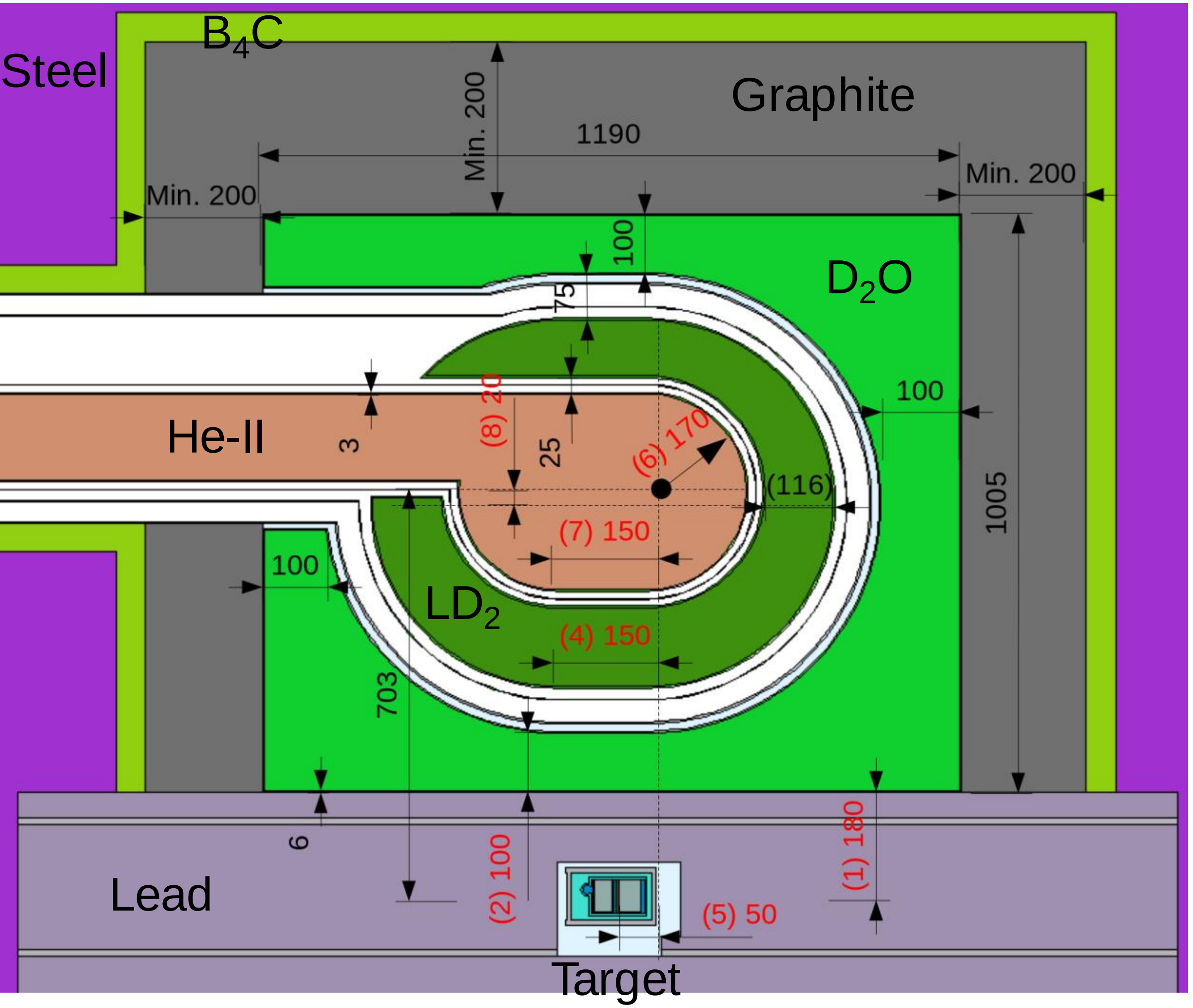
Vertical extraction



Horizontal extraction



Optimization

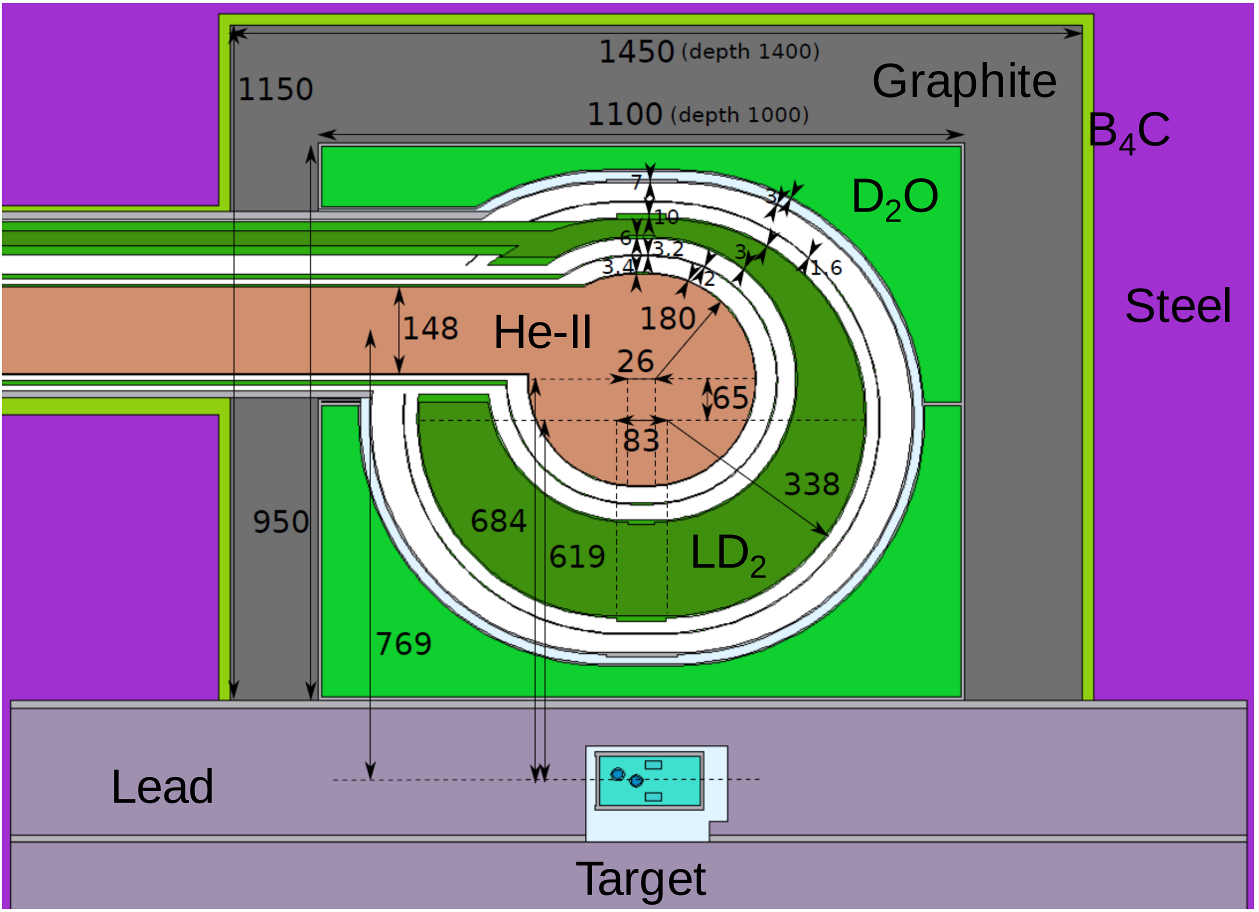


- Multi-dimensional optimization with 8 parameters
- Allows fair comparison of different moderators:

Table 4: Effect of different cold moderators on the production-to-heat ratio in individually optimized geometries.

Moderator	Average layer thickness (cm)	Volume (L)	Effect on P/Q (%)
Ortho-LD_2	12.5	125	+160
Ortho-LD_2	19.4	200	+230
Solid D_2O	11.6	95	(baseline)
Para-LH_2	3.6	33	-15

Engineering challenges



- Minimize wall thicknesses
- Explosive D_2:
  - Limited quantity (<150 L liquid)
  - Explosion-proof pressure vessels (Al2219 alloy with high post-weld strength, domes machined out of large billets)
- Large radiation fields (10 kSv/h), minimize shielding penetration
- Minimize gaps between moderators

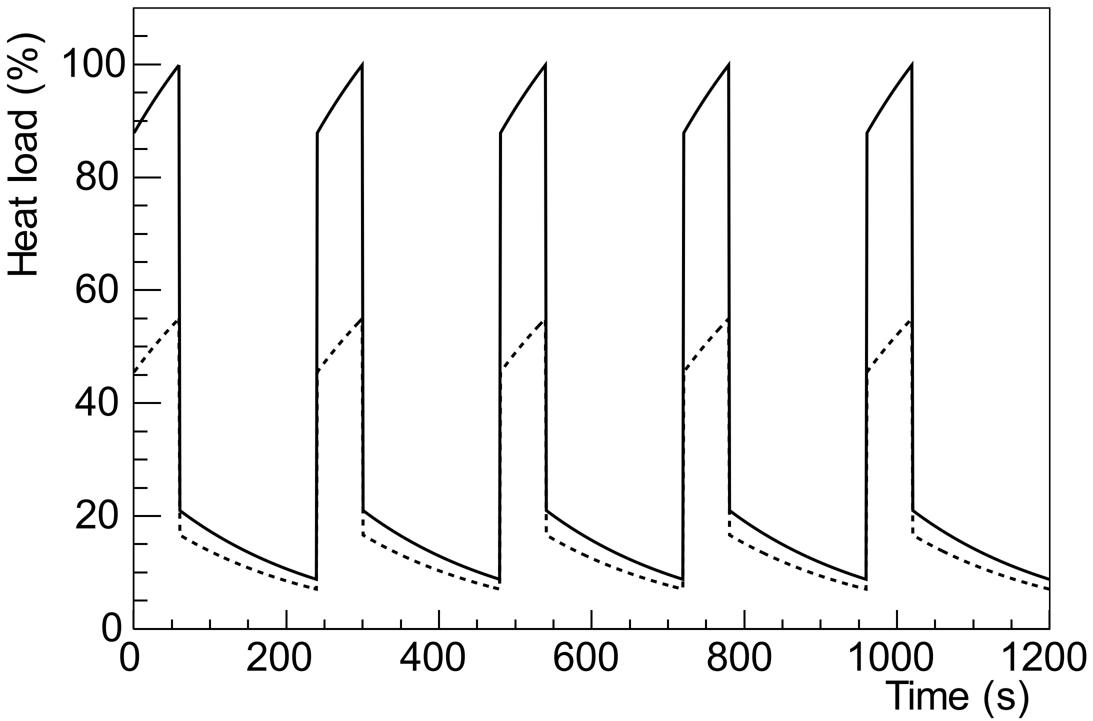
He-II vessel	Thickness (mm)	Effect on P/Q (%)
Aluminium	2	(baseline)
Al6061	2	-5
AlBeCast 910	3	+5
AlBeMet 162	2	+50
AZ80	2.5	+40
BerAlCast 310	1.5	-5
Beryllium	1.5	+90
Magnox AL80	4	+15

Results

- Production rate: 1.4 to 1.6×10^7 UCN/s
- Heat loads:

	Volume (L)	Heat load (W) max.	Heat load (W) average
UCN converter	27	8.1	2.8
Liquid deuterium	125	63	21
Heavy water	630	430	150

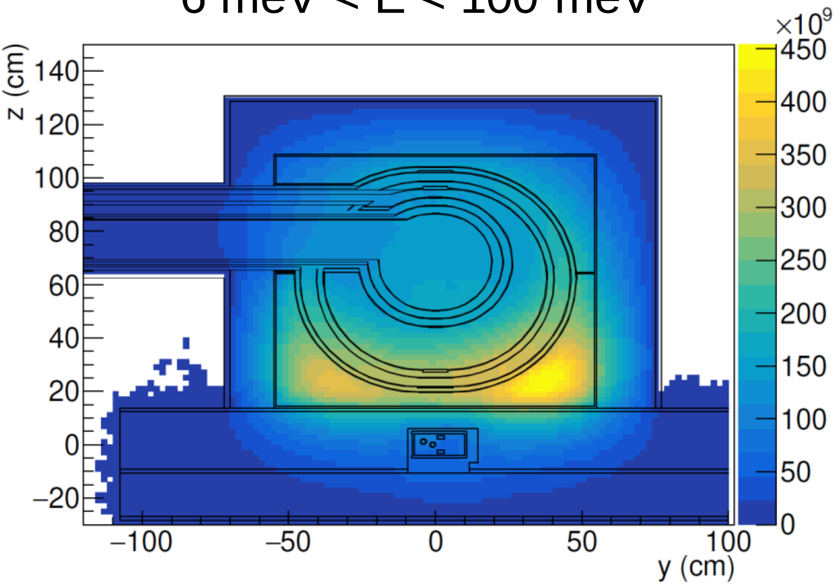
- He-II temperature ~1.1 K
- Storage lifetime ~30 s



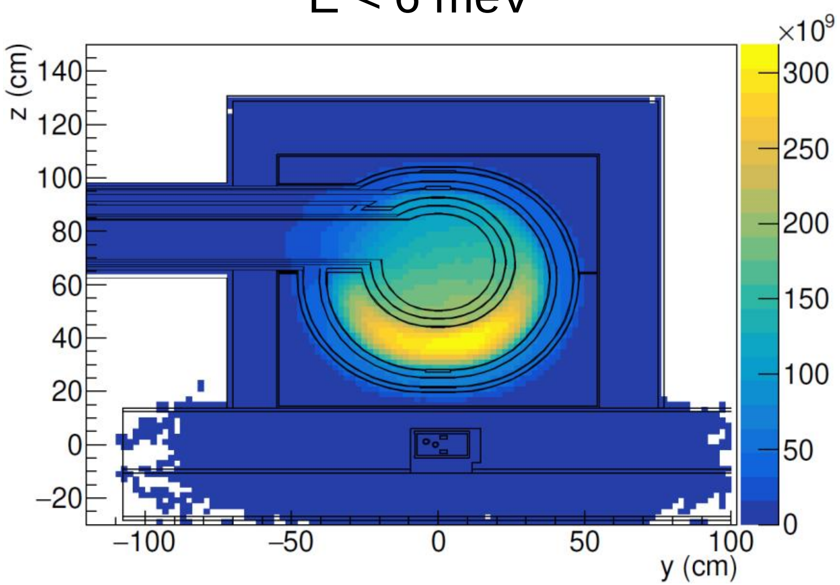
W. Schreyer et al, NIM A 959 (2020), 163525

Neutron flux

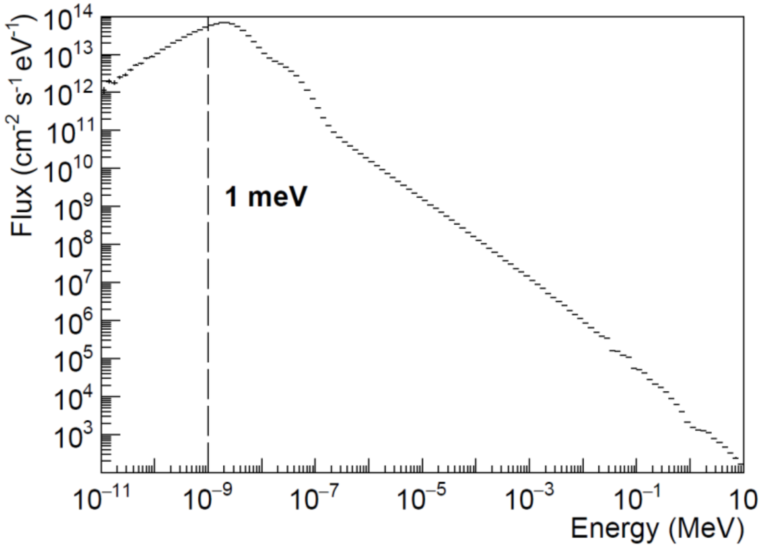
6 meV < E < 100 meV



E < 6 meV



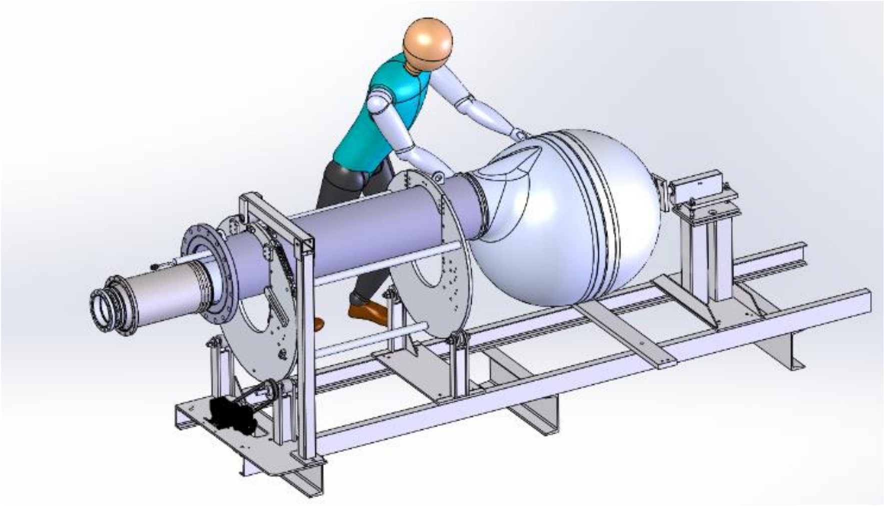
Neutron flux in He-II converter



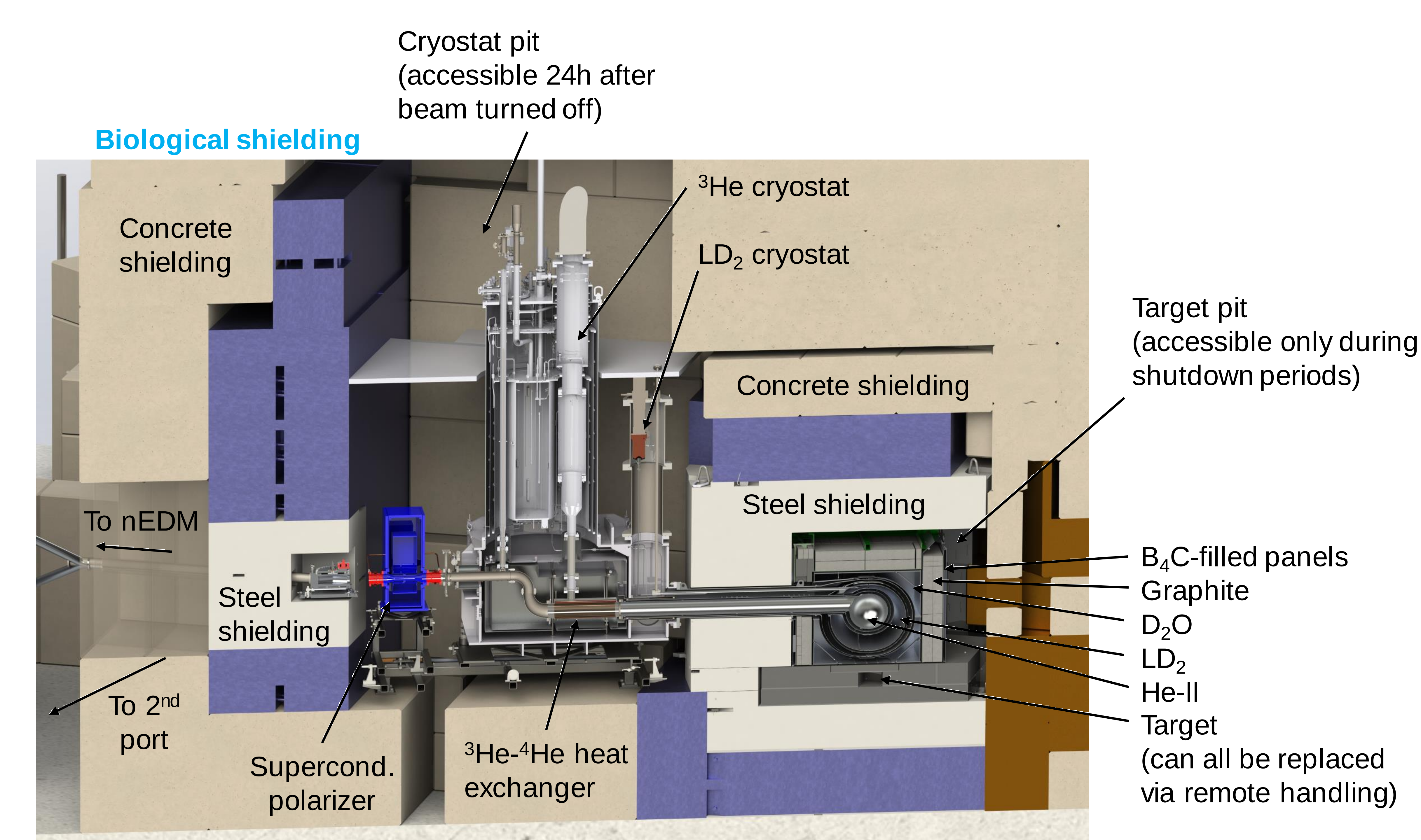
UCN production by
60% single-phonon scattering
40% multi-phonon scattering

Moderator vessel assembly

- He-II domes complete
- Preparing for welding, plating, test with UCN
- Outer vessels to be completed by June



Biological shielding



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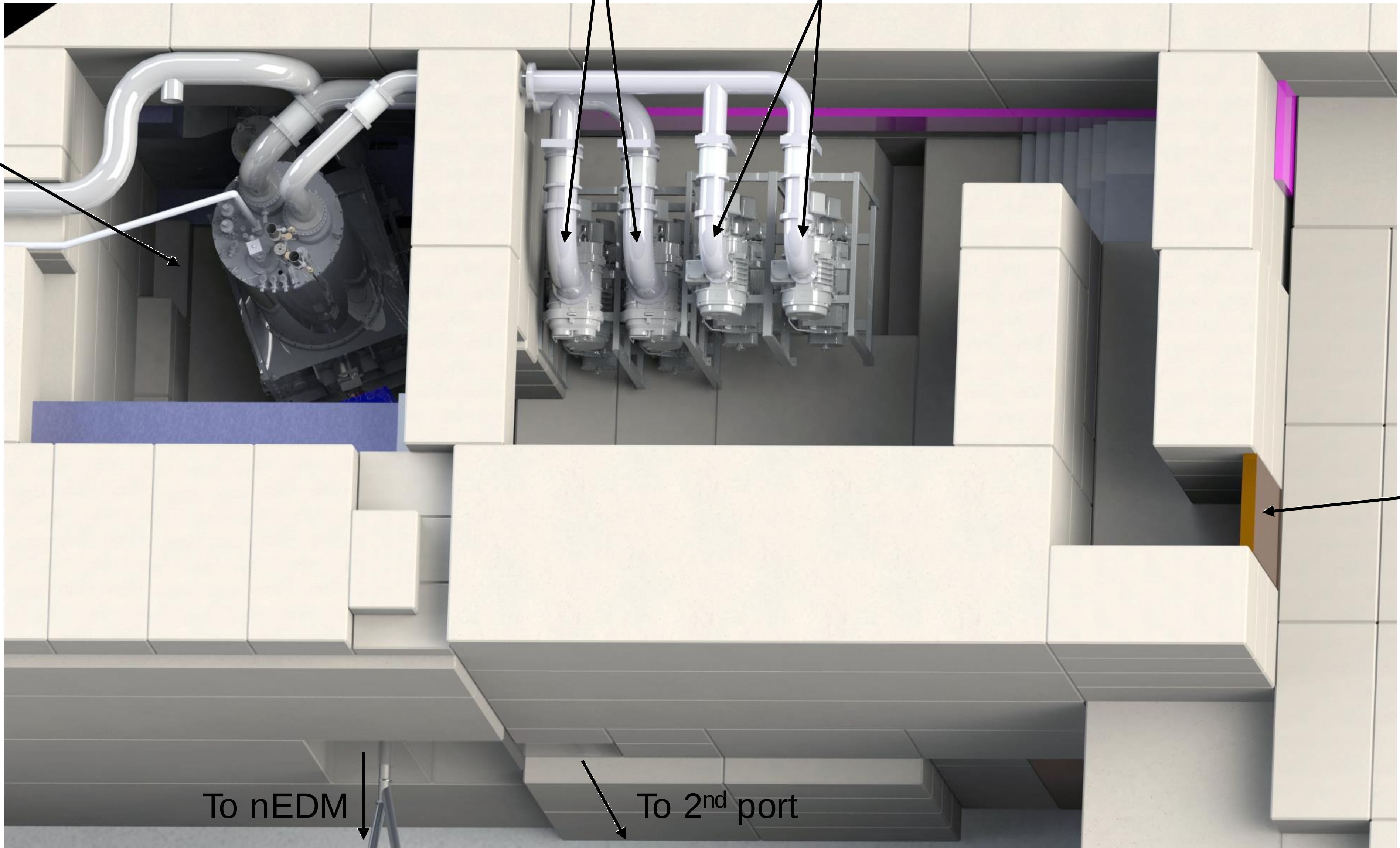

Outlook

- Dec. 2020: He-II vessel machined
- Mar. 2021: D_2O vessel & graphite/B_4C carrier complete
- Apr. 2021 (end of 2021 shutdown): shielding reconfigured
- June 2021: moderator vessels machined
- June 2021: test of He-II vessel with UCN
- July 2021: welding of nested moderator vessels
- Jan. 2022: installation of completed moderator vessels
- Apr. 2022 (end of 2022 shutdown): shielding completed

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Key parameters

- 1.4 – 1.6×10^7 UCN/s
- 8.1 W heat load on He-II
- ~1.1 K He-II temperature
- ~30 s storage lifetime
- Projected UCN density in nEDM:
  - 200 – 400 polarized UCN/cm^3 filled
  - 30 – 60 UCN/cm^3 detected
- First UCN production 2022

Thank you

Discovery, accelerated