

Ultracold neutron (UCN) production and extraction from the solid deuterium (sD₂) converter at the

PAUL SCHERRER INSTITUT



PSI UCN source



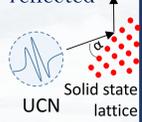
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1. Introduction/Motivation

What are ultracold neutrons?

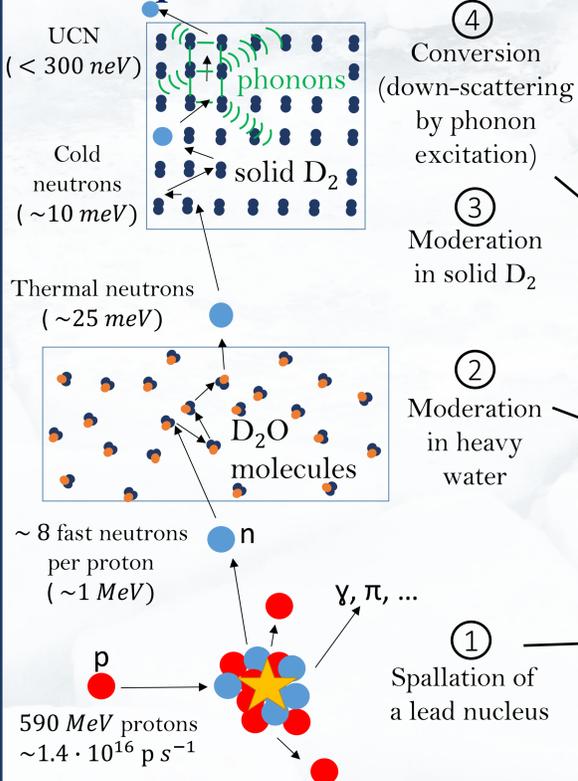
- $E_{kin,UCN} \lesssim 300 \text{ neV} \leftrightarrow \lambda_{de\text{ Broglie}} \gtrsim 500 \text{ \AA}$
- Interactions with nuclei in a solid lead to a material specific effective optical potential V_F (Fermi 1936)
- If $E_{kin,UCN} < V_F$, the UCN will be totally reflected from surfaces for all angles of incidence
- **UCN can be stored in material bottles for hundred of seconds [1]**



What are they used for?

UCN are used in experiments that benefit greatly from long measurement times. The n2EDM experiment [2] at the Paul Scherrer Institut (PSI) will search for a permanent electric dipole moment of the neutron, which could reveal a new source of CP violation and help to answer fundamental questions in baryogenesis. **As experiments using UCNs are limited by statistics, it is an ongoing effort to increase the UCN output of the PSI UCN source.**

2. UCN production at PSI

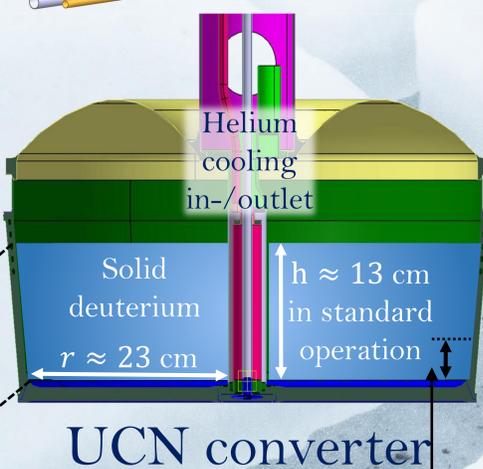
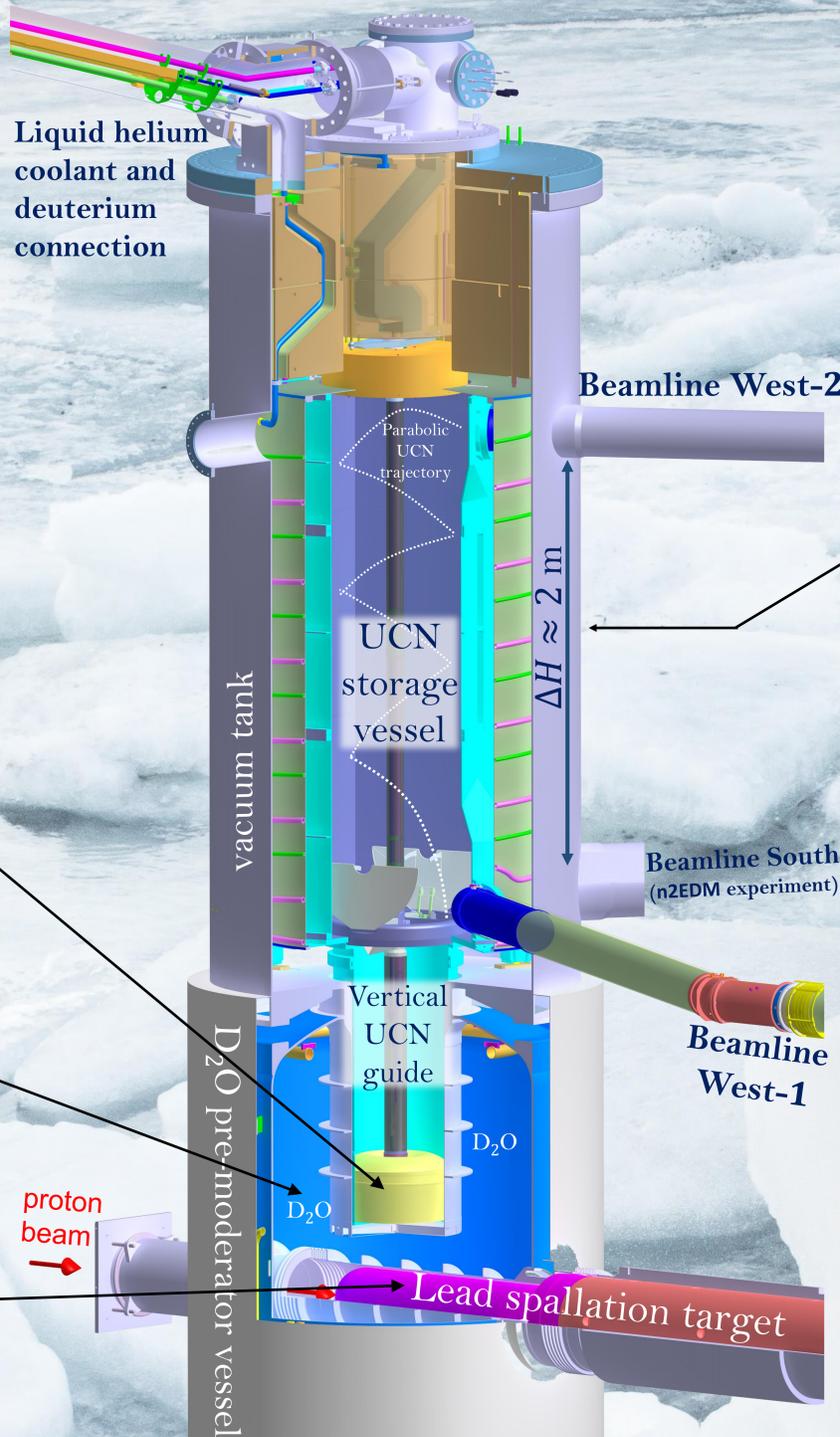
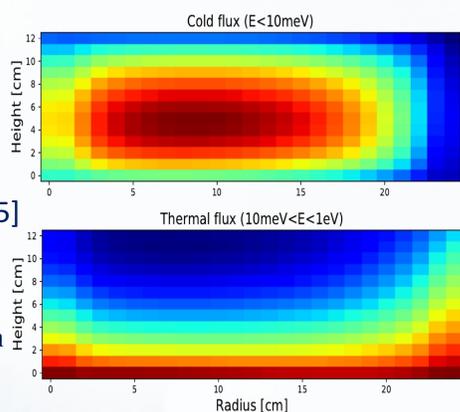


3. The challenge - UCN extraction

- Lifetime in sD₂ limited to $\sim 30 \text{ ms}$ [3]
- Elastic scattering on **structural defects** in the sD₂ (can be caused by thermal stress) can lead to longer extraction times exceeding the lifetime
- We work towards **optimizing the UCN extraction** with in-situ improvements or a potential upgrade of the converter design

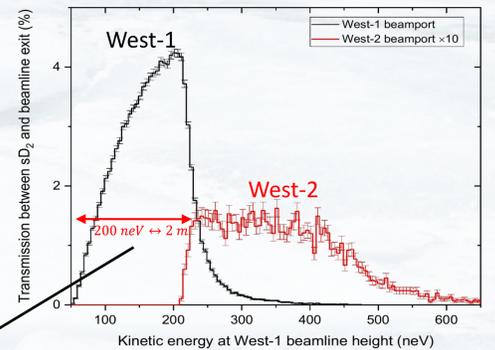
4. Simulation of thermal/cold flux

- MCNP6 [4] was used to simulate the spallation process and moderation [5]
- Cold neutron distribution and spectrum required as input to investigate UCN production and extraction



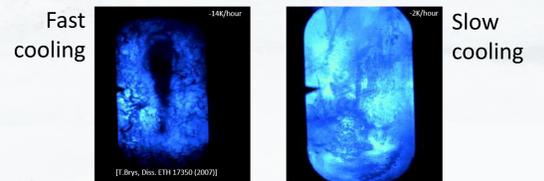
5. UCN transport simulation

- UCN behave like a very dilute gas with mainly elastic & specular wall reflections and are strongly affected by gravity

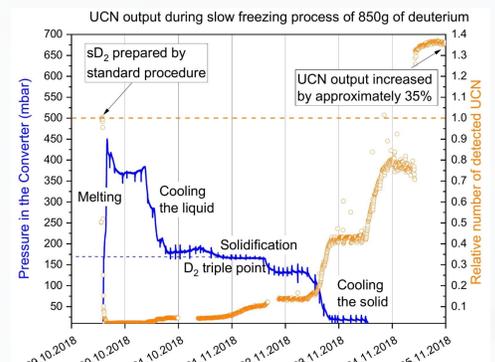


6. Optimization of the D₂ freezing procedure

- Studies of small sD₂ samples revealed more defects when rapidly cooled



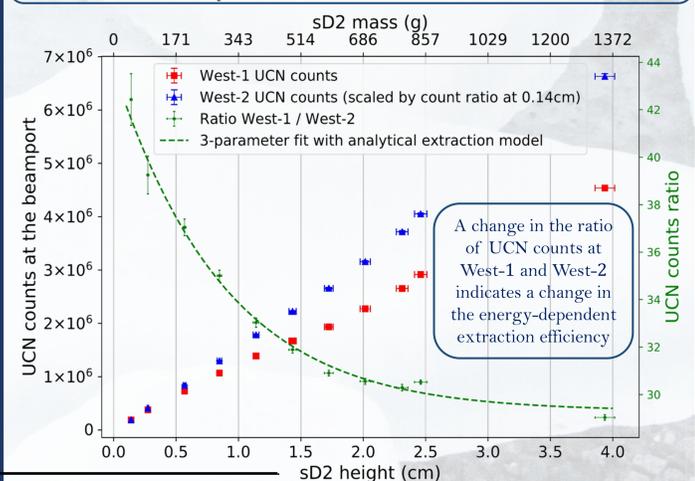
- Controlled slow freezing and cooling of deuterium at the PSI UCN source



7. Measurement of UCN output as a function of deuterium content

- Idea: $\boxed{\text{Low sD}_2 \text{ content}} \xrightarrow{\text{increase}} \boxed{\text{Study extraction efficiency } \epsilon_{ext}}$
- Used data from both beamports with different transmissions ϵ_{trans} to normalize for changing proton beam parameters, neutron flux ϕ and macroscopic UCN production cross section Σ

$$N_{UCN}(V_{sD_2}) = T_{pulse} \int_{V_{sD_2}} d^3r \int dE dE_0 \frac{d\Sigma}{dE} (E_0) \frac{d\phi}{dE_0} (r, V_{sD_2}) \epsilon_{trans}(E) \epsilon_{ext}(r, E)$$



References: [1] R. Golub, D. Richardson and S. Lamoreaux, Adam Hilger (1991)
[2] C. Abel et al., arXiv [1811.02340] (2018)
[3] CL. Morris et al., Physical Review Letters 89(27) (2002)
[4] X-5 Monte Carlo Team, Los Alamos National Laboratory (2003)
[5] H. Becker et. al., NIM Physics Research A 777 (2015)

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