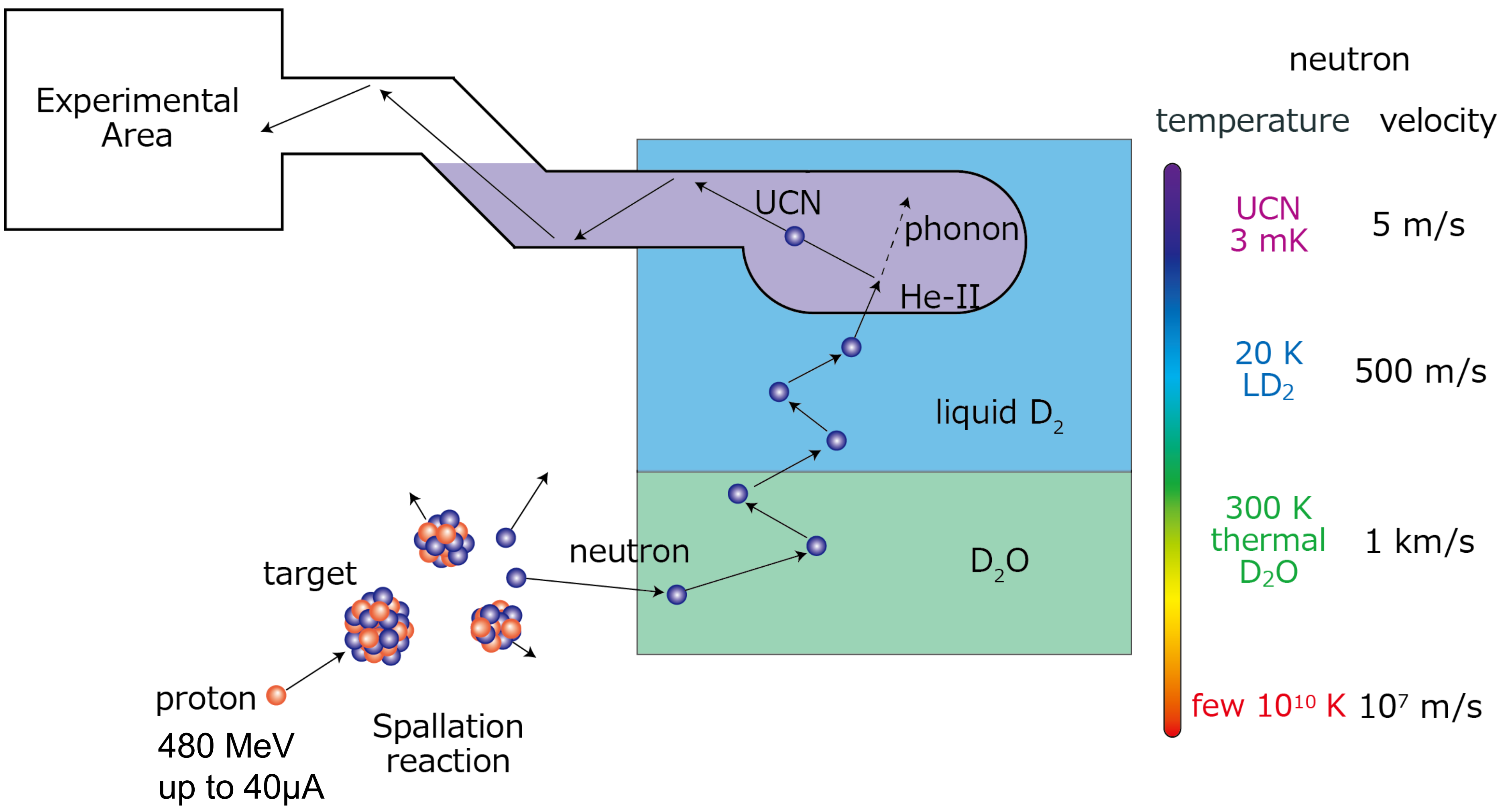
# Producing ultracold neutrons with a spallation source and superfluid helium

Wolfgang Schreyer for the TUCAN collaboration

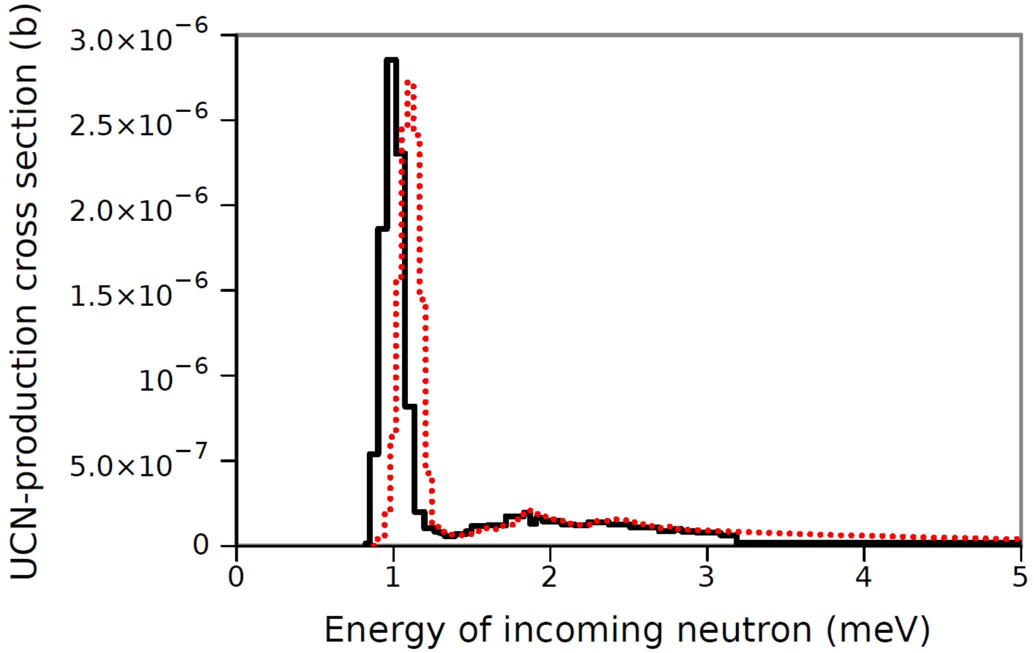
# Goals of the TUCAN collaboration

- Measure neutron electric dipole moment with a sensitivity of $10^{-27}$ ecm
- Need stronger UCN source to reach that in reasonable time
  ➔Build the strongest UCN source in the world
- Provide a second UCN port for a user facility

# A superthermal spallation source for UCN using superfluid helium



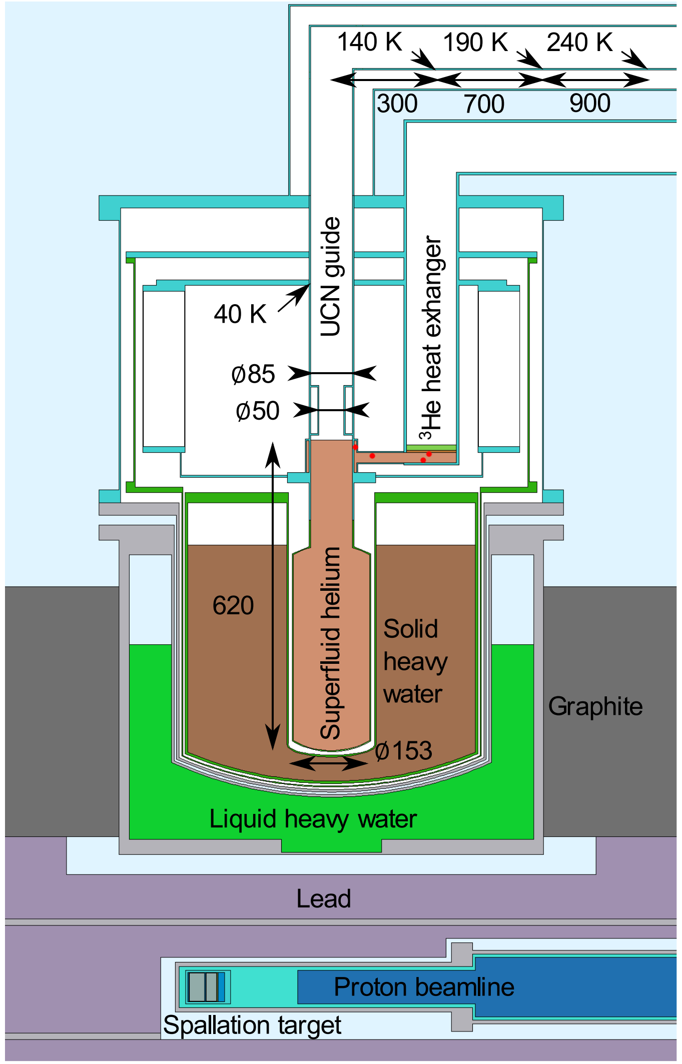
# UCN production and losses in superfluid helium




- Maximize neutron flux @ 1meV
  ➔cold moderators
- Losses proportional to $T^7$
  ➔low temperature: ~1K
  ➔minimize heat load


https://doi.org/10.1016/S0375-9601(02)01052-6
https://doi.org/10.1016/j.nima.2009.07.085

# Modeling the prototype source

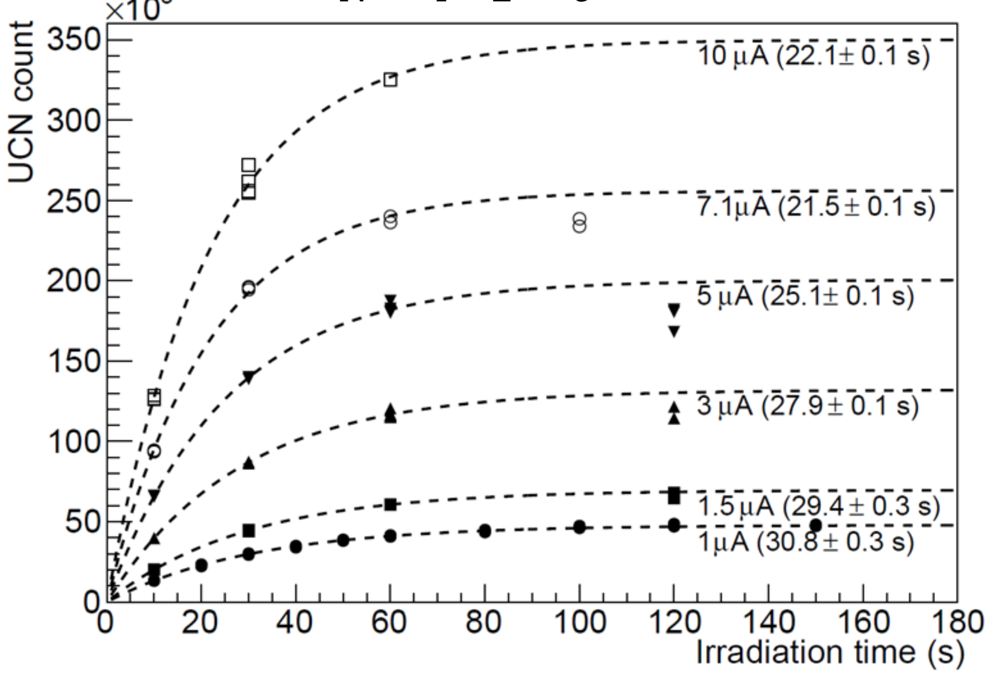


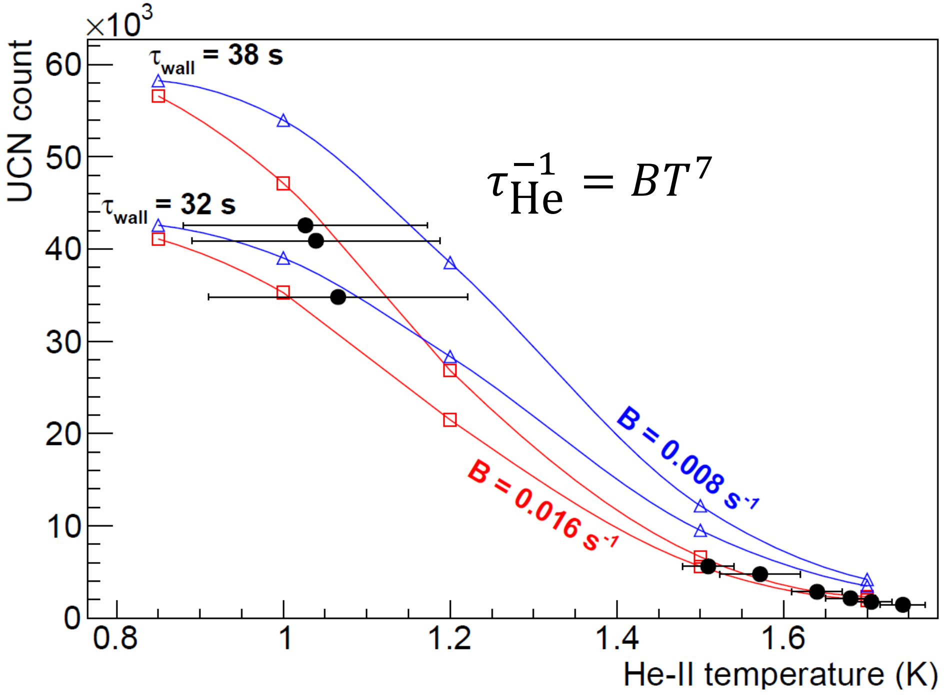

- MCNP simulations: 20600 UCN/s, 80mW heat load @ 1µA beam current
- $N = P\tau\left(1 - e^{-\frac{t}{\tau}}\right) \xrightarrow[t\to\infty]{} P\tau$
- $\tau^{-1} = \tau_{\mathrm{wall}}^{-1} + \tau_{\beta}^{-1} + \tau_{\mathrm{He}}^{-1}$
- $\tau_{\mathrm{He}}^{-1} \approx 0.016\,\mathrm{s}^{-1} \cdot T^7$
- UCN transport simulated with PENTrack

https://doi.org/10.1103/PhysRevLett.108.134801
https://doi.org/10.1103/PhysRevC.99.025503

# Measurements confirm models and simulations

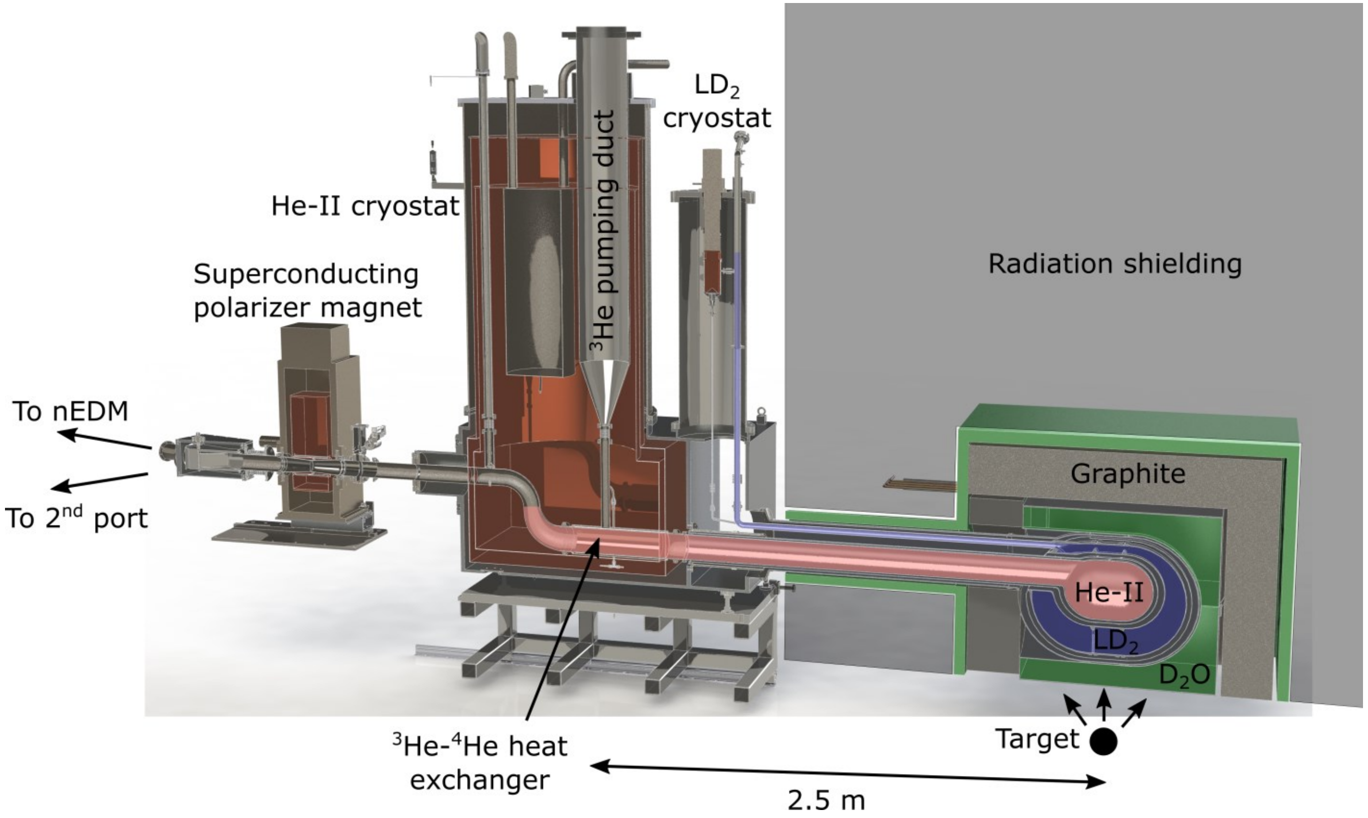
$$N \propto P\left(1 - e^{-\frac{t}{\tau}}\right)$$




https://doi.org/10.1103/PhysRevC.99.025503

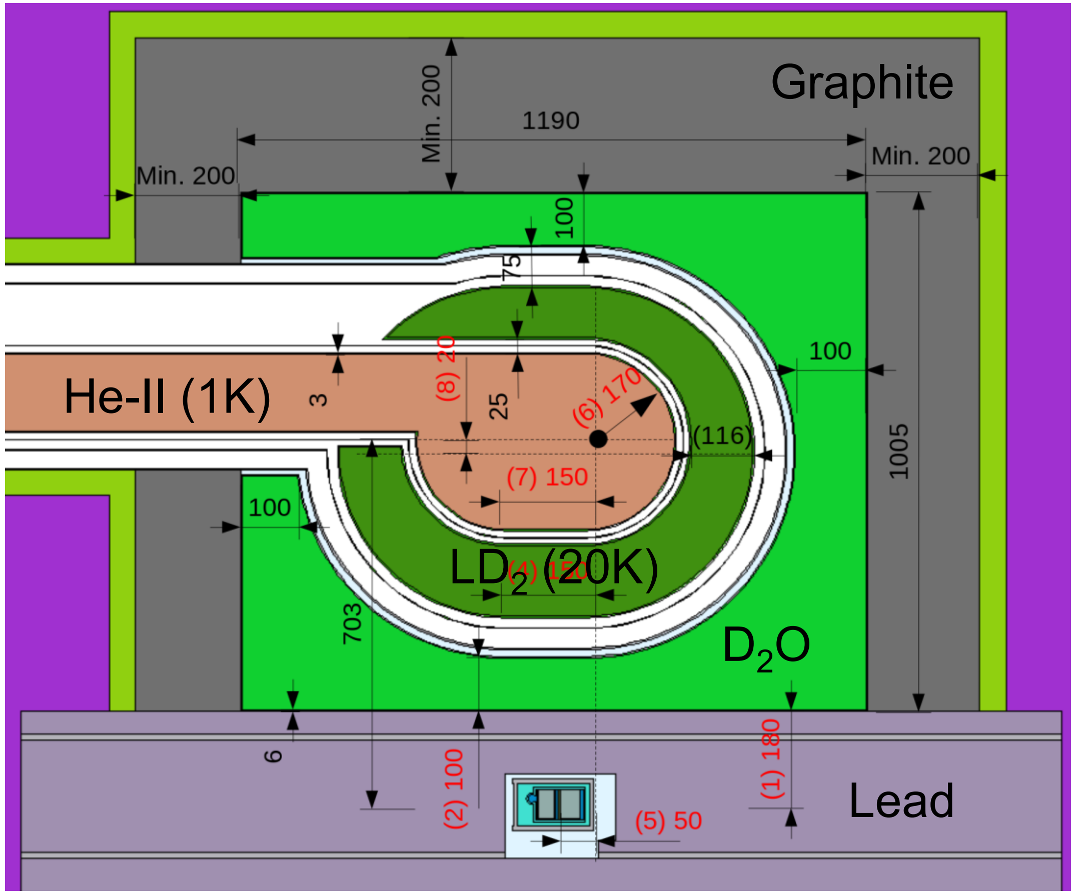
# Design of the new source




## Improvements:

- $^3$He pumping: 2,000m$^3$/h → 10,000m$^3$/h
- Beam current: 1µA → 40µA
- Cold moderator: $D_2O$ → $LD_2$
- Converter volume: 8 L → 28 L
- Larger heat exchanger
- Horizontal UCN extraction
- To go into operation 2021

# Modeling the new source



Target

- Estimate helium temperature, taking into account
  - $^3$He pumping speed + pressure drop
  - Conduction + Kapitza resistance in heat exchanger
  - Gorter-Mellink heat conduction in superfluid helium
  - $\tau_{\mathrm{He}} \approx 500 \sim 1500\mathrm{s} \cdot \frac{Q}{1W}^{-1.5\sim-1.0}$, $\tau_{\mathrm{wall}} = 60\sim100\mathrm{s}$
- Vary moderator dimensions to maximize UCN density $\rho \propto \frac{P\tau}{V}$
  - $V = 28L + V_{guides} + V_{experiment} = 28L + 100\sim200L$
  - $P \approx 1.8\times10^7$ UCN/s
  - $Q \approx 8W$
  - $T \approx 1.1K$

# Studied impact on UCN density for many variations

## Most critical parameters

- Choice of cold moderator
  - +100% to +200% with $LD_2$ compared to $sD_2O$, $LH_2$
  - despite limit of 125L for explosion safety
- Material of superfluid-helium vessel
  - Default choice: aluminium 6061
  - Pure beryllium: +100% (expensive!)
  - Al+Be or Al+Mg alloys: +30% to 50%
- Thickness of superfluid-helium vessel
  - Machining limit 2mm
  - +25% per 1mm reduction

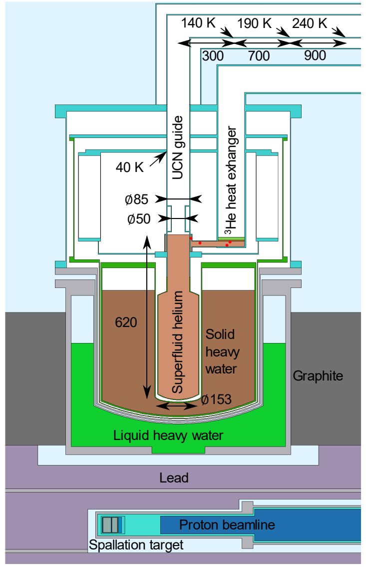
## Other studies

- Para/ortho deuterium ratio
  - -20% for 100% para-$D_2$ (natural content < 30%)
- Isotopic purity of deuterium
  - -4% per 1% H (D enrichment > 99.8%)
- Polycrystalline bismuth “neutron filter”

# Comparison of sources

## Prototype source

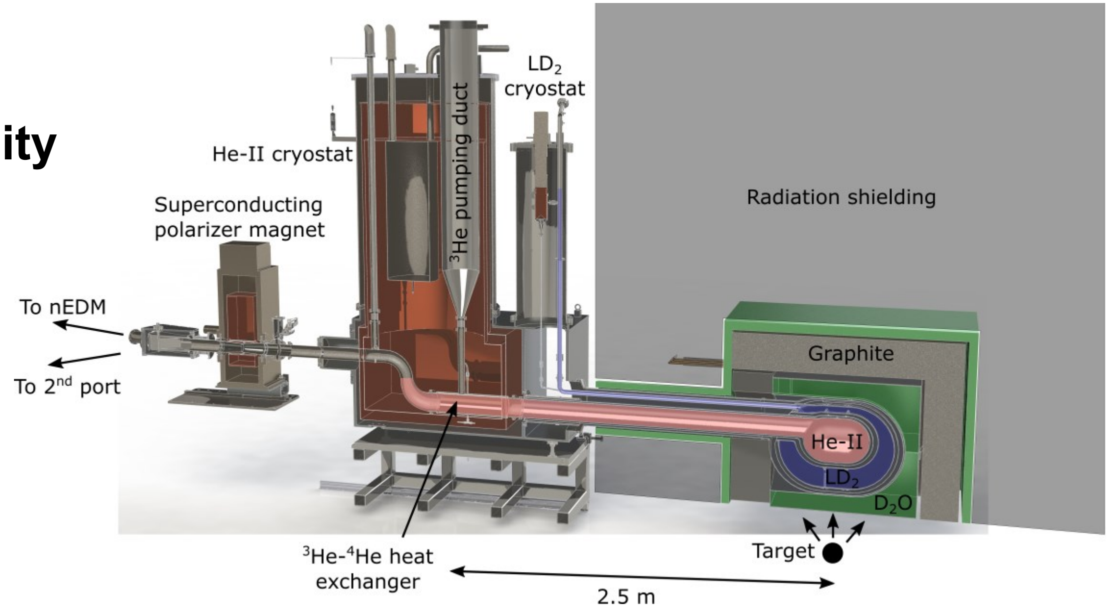
- UCN production: $0.02 \cdot 10^6$/s
- Heat load: 0.08 W
- Helium temperature: ~1.0 K




**~500x UCN density**

## New source

- UCN production: $17 \cdot 10^6$/s
- Heat load 8.3 W
- Helium temperature: ~1.1 K



# Conclusions

- Benchmarked simulation models with prototype UCN source
- New optimized moderator geometry as basis for detailed engineering
- Use simulations to study impact of every design decision
- New source will give us competitive edge over other nEDM experiments

# Thank you for your attention

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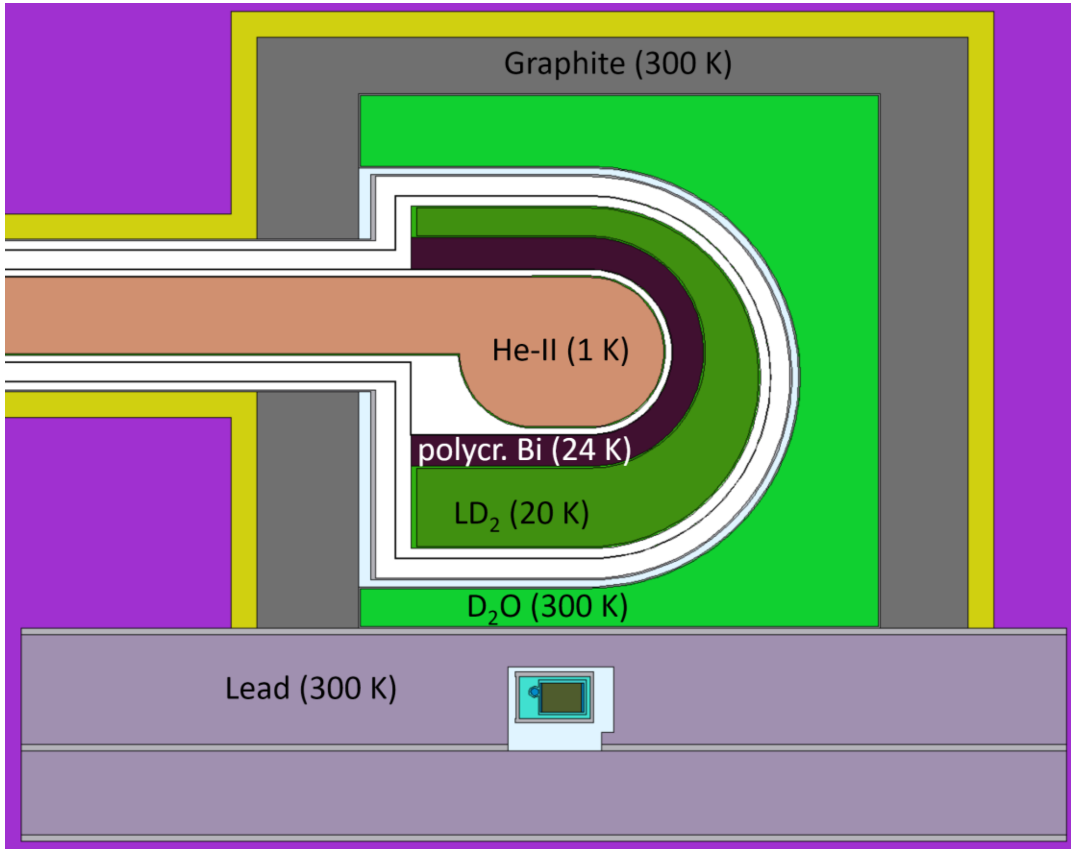
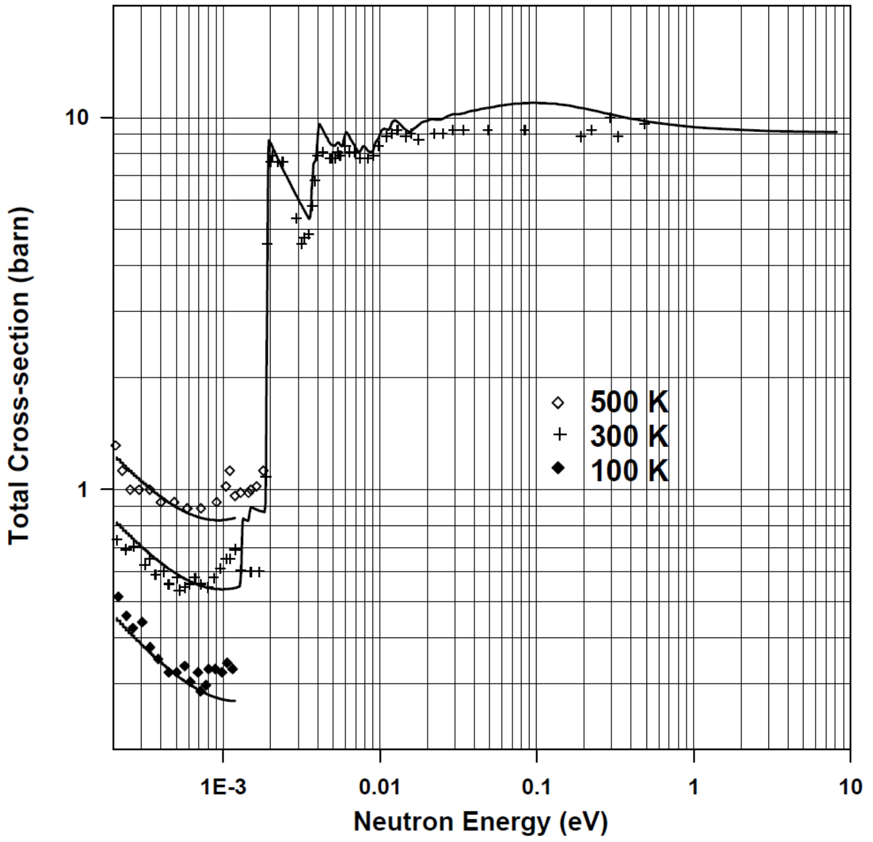
# A polycrystalline bismuth neutron filter





https://doi.org/10.1016/S0969-806X(02)00368-7
https://doi.org/10.1080/00223131.2002.10875069