UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

PHYSIKALISCHES INSTITUT

Approaches to *in-situ* UCN production and detection for high-density storage experiments

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Words to remember:

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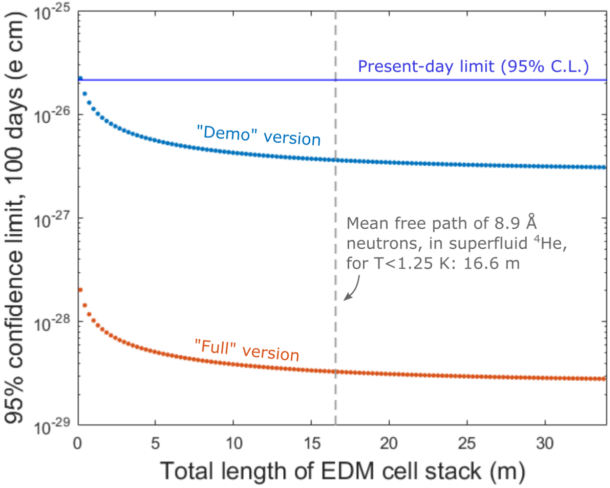
- "Don't worry... it gets worse."

Confronting the impossible: the case of nEDM



- statistics only!
- $d_n^{(\mathrm{SM})} \sim 10^{-32}\ e \cdot \mathrm{cm}$
- uses CN directly

Positions for motivated students and post-docs!

Low-Energy Precision Physics Group (“LEPP”):
degenkolb -at- physi.uni-heidelberg.de

what-if.xkcd.com

Key words: "modular" and "scalable"

Fundamental particle physics* projects are **long-term commitments**, with many/much:

- Sub-projects and connected partner institutions
- Facilities, space, and support needs
- Synergies and intermediate outputs
- Requirements for test R&D and demonstrations

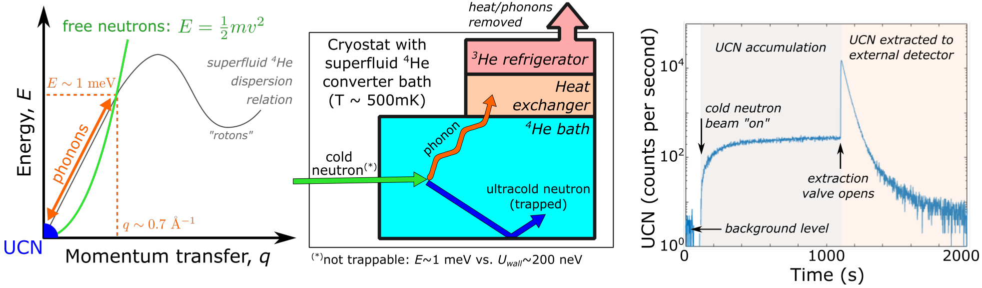
Parameter:	*[Demo version]*	*[Full version]*
Cell volume, V:	*550 cm^3*	*2000 cm^3*
Electric field, E:	*7 MV/m*	*8.5 MV/m*
t=0 UCN density:	*55 cm^{-3}*	*1600 cm^{-3}*
Storage duration:	*250 s*	*350 s*
Contrast, α:	*0.85*	*0.85*
Detector efficiency:	*1%*	*50%*

Note that the most ambitious nEDM precision now being attempted is in the range of 4–8×10^{-28} e cm (95% C.L.), by the American nEDM@SNS project. No European effort to date is competitive with this target.

... i.e., they require a community.

*(fundamental $\not\leftrightarrow$ particle)

Producing Ultracold Neutrons (super-thermally)



- Figure of merit for production: $\tau \cdot \int d^3\boldsymbol{k}\, \left(1 - e^{-n\sigma l(\boldsymbol{k})}\right) \left.\frac{d\Phi}{d\lambda}\right|_{8.9\text{Å}}$
- Note: partial mean free path $\lambda_{\text{“UCN”}} \sim 10$ km, while $\lambda_{\text{tot}} \sim 10$ m
- Loss for a 3m converter: factor 10 (unused CN beam)
- Loss for *ex-situ* storage: factor 100 (UCN extraction/transport/detection)

Don't worry, it gets worse...

Or: handling ideal gases at partial-pressures of 10^{-20} mbar

Extracting a **beam** vs. a stored **density**

- Easy-to-transport UCN are not easy-to-store
- Idem, but vice-versa
- Everything depends on spectrum*
- Multiple vs. single users

So the question is: *how far can we get with the resources that can be reasonably foreseen?*

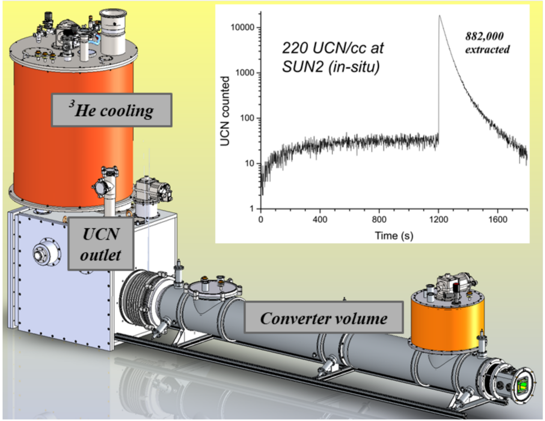
*(3D spectrum, not just energy)

Recall the scaling of statistical sensitivity: $\hbar|\delta\omega|T \sim \hbar/2$

- $\sigma_d \sim \hbar/\left(\alpha E T \sqrt{N}\right)$
- $T \leq \tau_\beta$, so use LHe
- E limited to $\sim 10^7$ V/m
- $\alpha \leq 1$

I.e., mainly N and T can deliver the next orders of magnitude.

Good news: we know source cryogenics

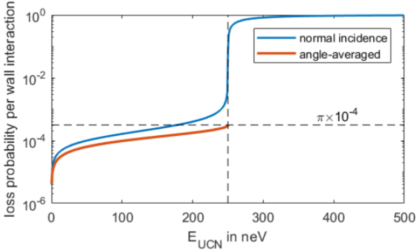


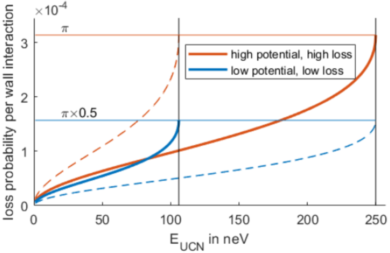
<u>Production rate density, and storage losses</u>

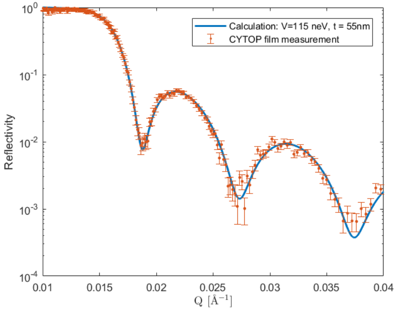
5-15 /(cm^3 s) ← $$R \sim \left(\frac{5\times10^{-8}}{\mathrm{cm}^3\ \mathrm{s}}\right)\times\left.\frac{d\Phi}{d\lambda}\right|_{8.9\text{Å}}\times\left(\frac{V_{\mathrm{trap}}}{233\ \mathrm{neV}}\right)^{\frac{3}{2}}$$

limited by decay, wall interactions ← $$\frac{1}{\tau}=\frac{1}{\tau_\beta}+\frac{1}{\tau_{\mathrm{up}}}+\frac{1}{\tau_{\mathrm{capture}}}+\frac{1}{\tau_{\mathrm{wall}}}+\cdots$$

More good news: coating materials

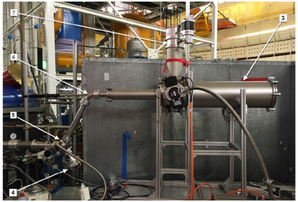




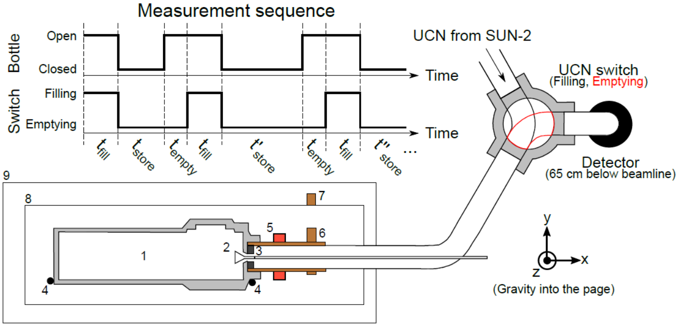


Measured UCN storage (3-4 liters): 310s (room temp.) and 560s (10K). [T. Neulinger, PhD 2021]

Suniño test cryostat: R&D strategy

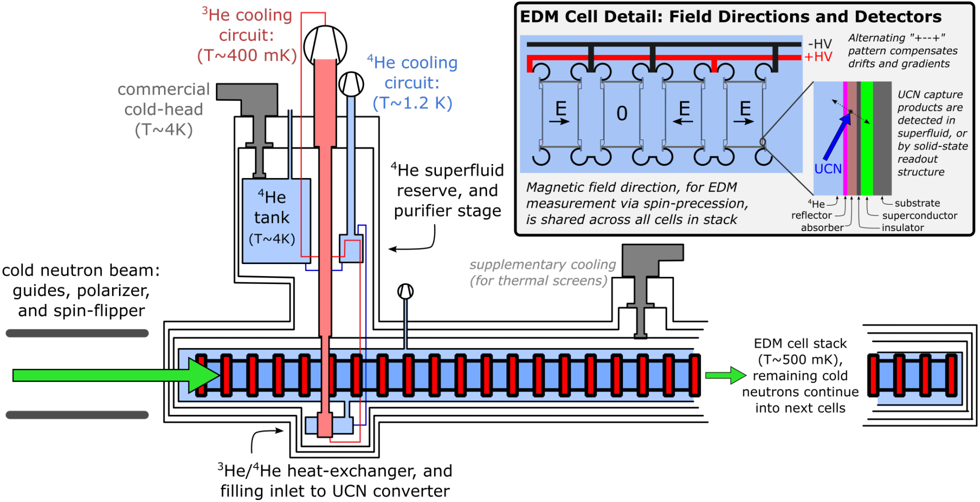


J. Hingerl, MSc 2019



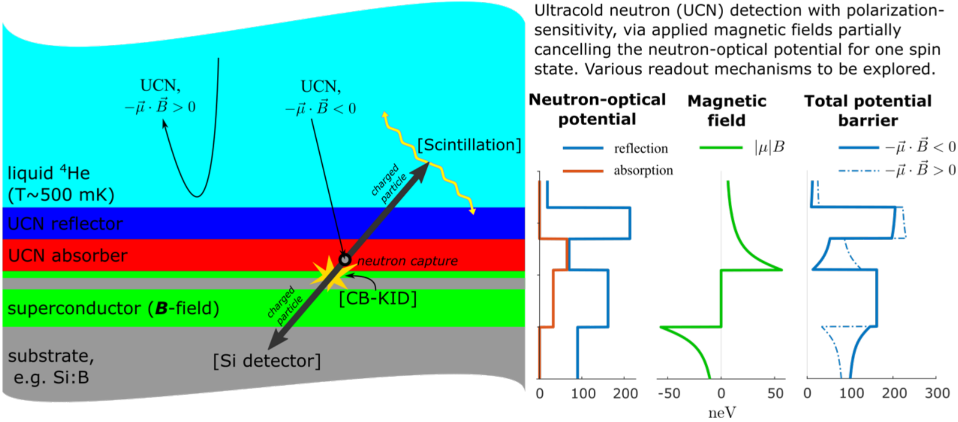
T. Neulinger

EDM^n concept (cartoon-level)

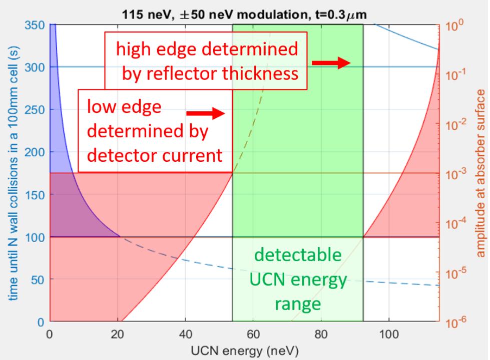


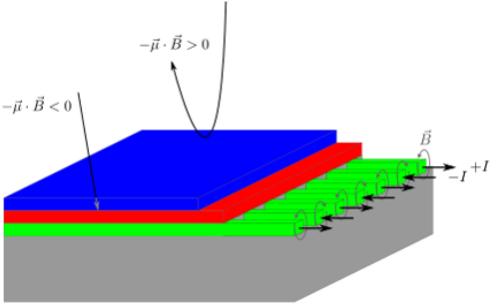
Detector concept: several readout possibilities

Ultracold neutron (UCN) detection with polarization-sensitivity, via applied magnetic fields partially cancelling the neutron-optical potential for one spin state. Various readout mechanisms to be explored.



Detector concept: dynamic range





The magnetic field determines the penetration depth of the evanescent (sub-critical) UCN wavefunction into the absorber layer. Since efficiency is both energy- and spin-dependent, the low edge can be scanned for systematics studies.

Don't worry, it gets worse...

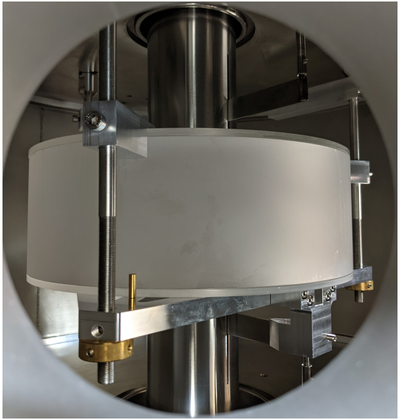
Problems/challenges/opportunities to be addressed (i.e., open projects):

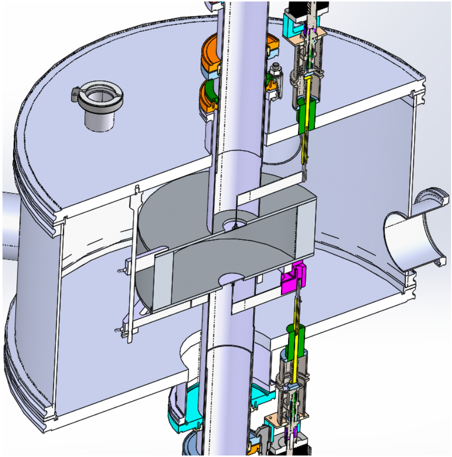
- SANS due to electrodes and cell materials
- CN guiding and/or focusing
- Alternate detector readout
- Beam polarization
- Shielding and magnetometry
- ...

And some reasons to be optimistic:

- R&D at the single-cell level
- Detector concept fully decoupled
- Modest UCN-production needs
- HV and magnetic shields
- Lots to do at UCN sources...
- ...and CN beams, instruments.

A beginning: cell testing at the PF2 turbine



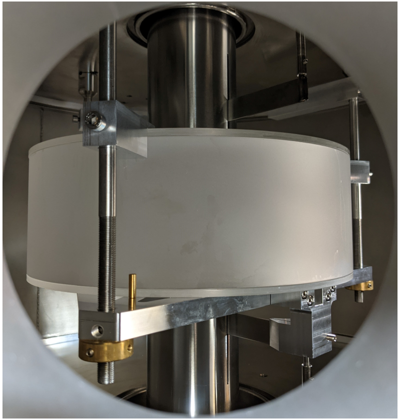


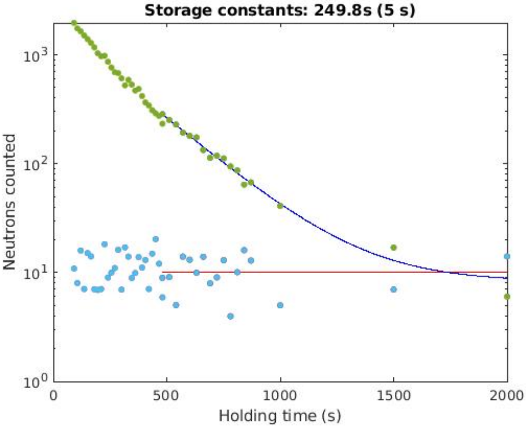
Quartz cells: S-DH, GmbH

Testing storage at the PF2 flux source

Isolating the soft spectral tail

Preliminary: analysis ongoing





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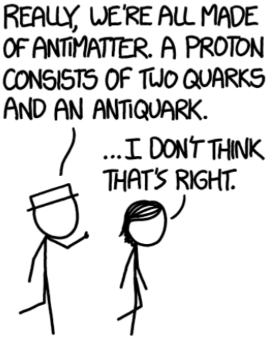
Questions?



xkcd.com

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