Measuring the free neutron lifetime with the τSPECT experiment at PSI

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Neutron Lifetime

Why n-lifetime?

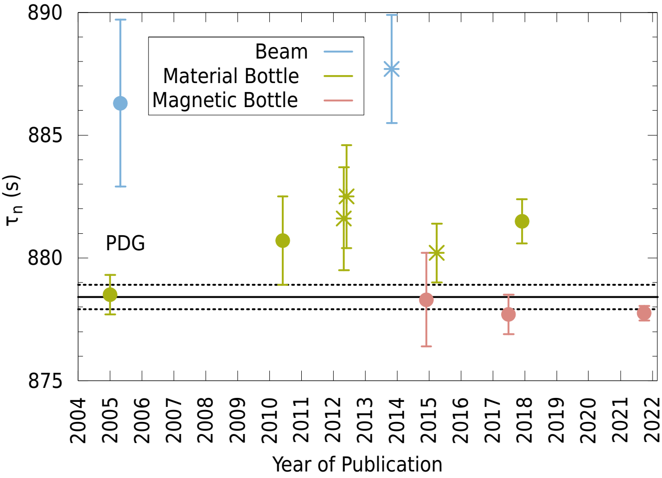
a) Big Bang Nucleosynthesis (He abundance)
[Cyburt et al., doi:10.1103/RevModPhys.88, 2016]

b) CKM Unitarity (V_{ud})
[Marciano and Sirlin, doi:10.1103/PhysRevLett.96.032002, 2006]

c) “It’s 2023. We cannot agree on τ_n to better than 10s?!”

$$\tau_{\text{n,beam}} = 887.7 \pm 1.2 \pm 1.9\text{s}$$
$$\neq$$
$$\tau_{\text{n,stored}} = 877.75 \pm 0.28 \pm 0.22\text{s}$$

The Lifetime Puzzle



τSPECT

Concept:

- 3-D magnetic storage
  - Two solenoids + Octupole

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    - Holding field polarizes neutrons
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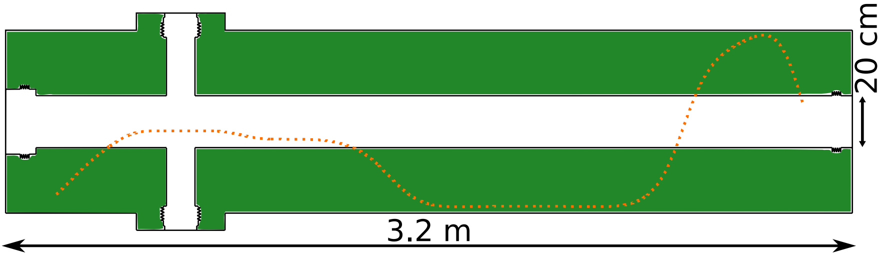
- 3-D magnetic storage
  - Two solenoids + Octupole
- Spinflip-loading
  - Holding field polarizes neutrons
  - Fast adiabatic spinflip as loading mechanism
- In-situ UCN detection
  - Minimizes extraction losses
  - High detector requirements wrt temp. & B-field

τSPECT fields



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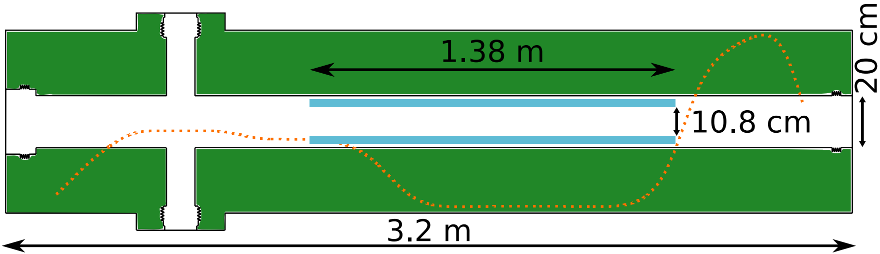

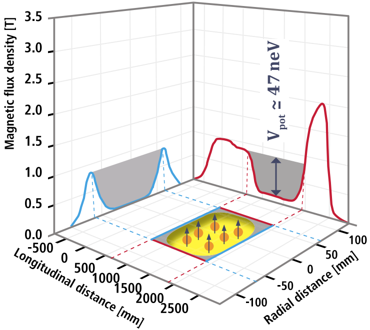

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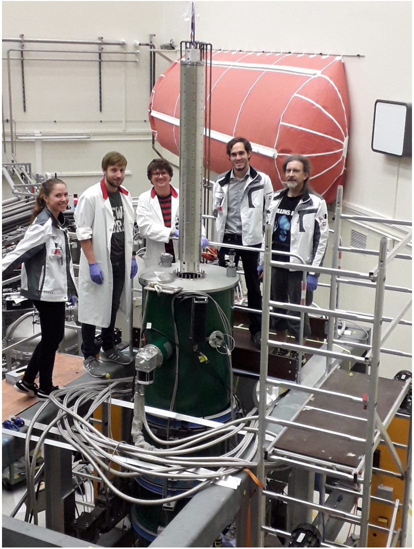

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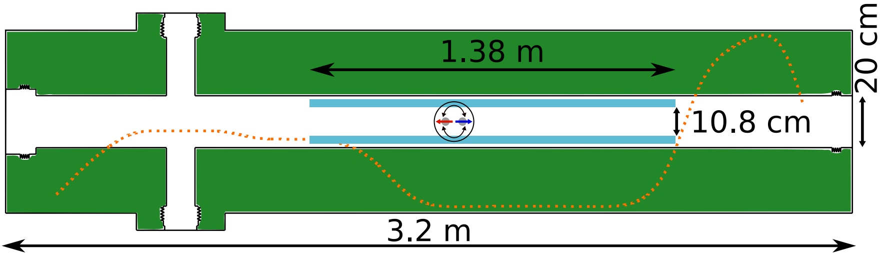

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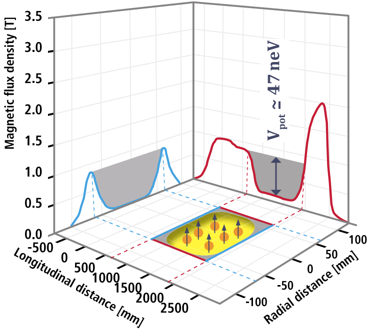
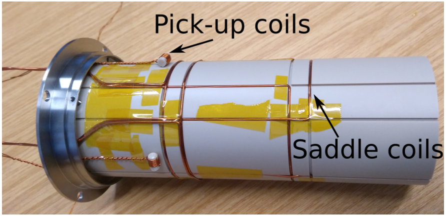
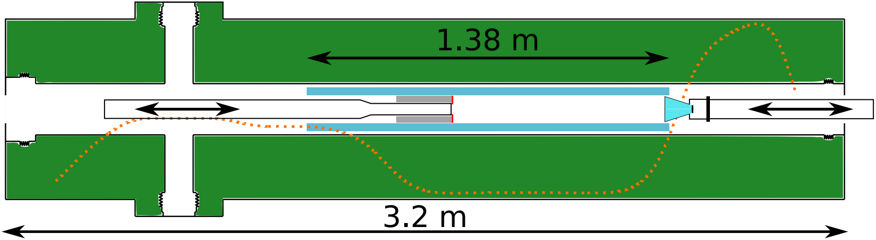




K. U. Ross

Measurement Procedure



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   - Polarization due to high Magnetic Field, SF on
   - Simultaneously: Intensity Monitoring (non-trappable UCN)

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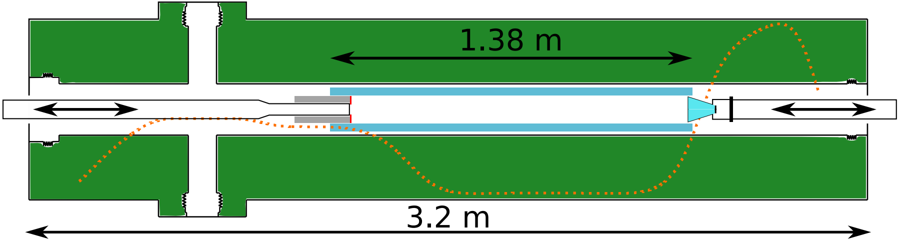

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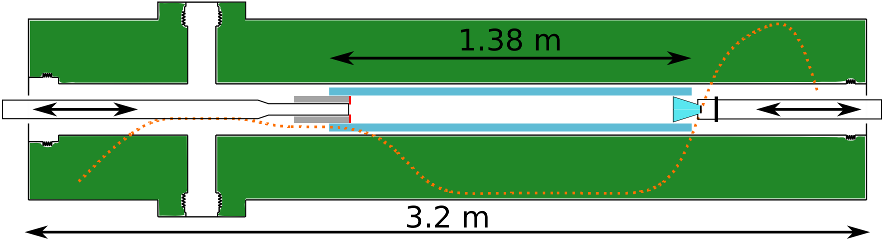

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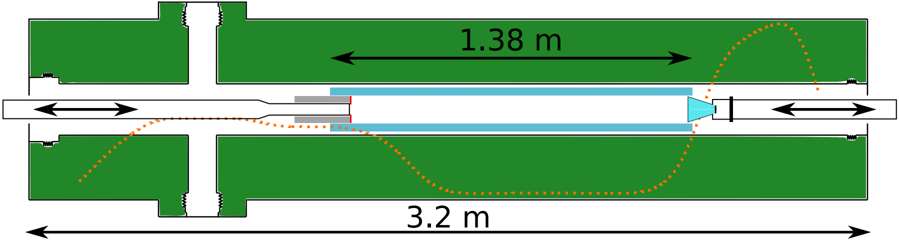

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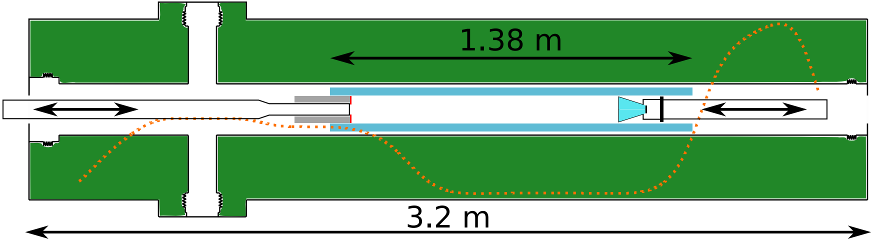

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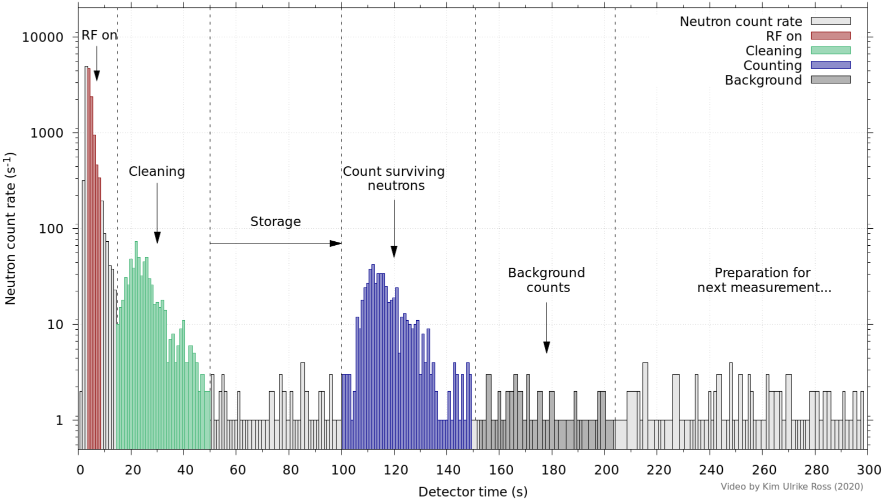
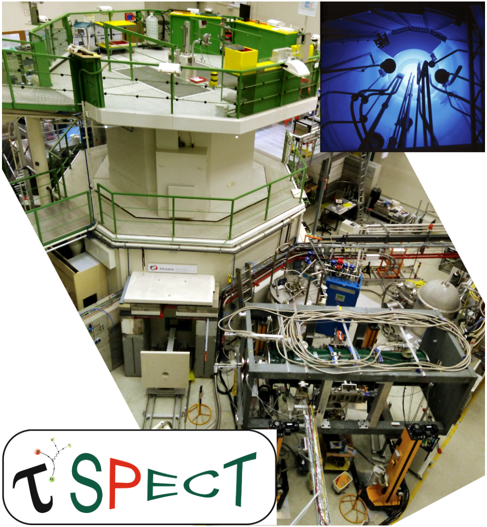
2. Remove SF from storage region
3. Detector to cleaning position and back
4. Wait ...
5. Count UCN

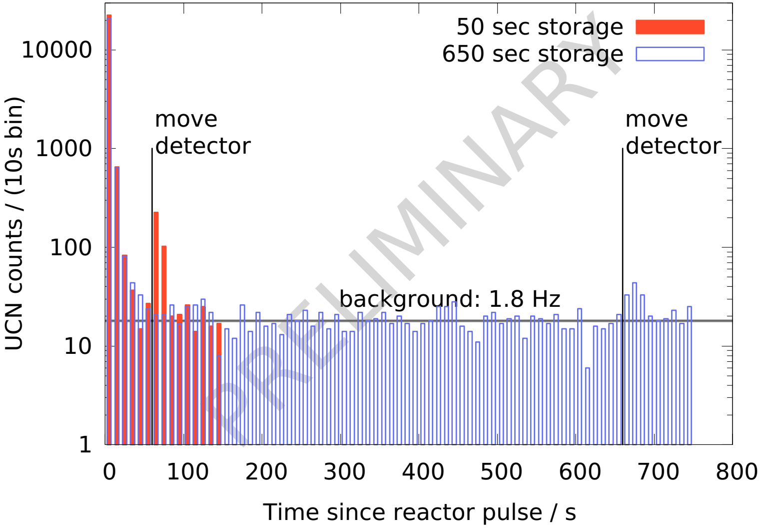
A look at the data



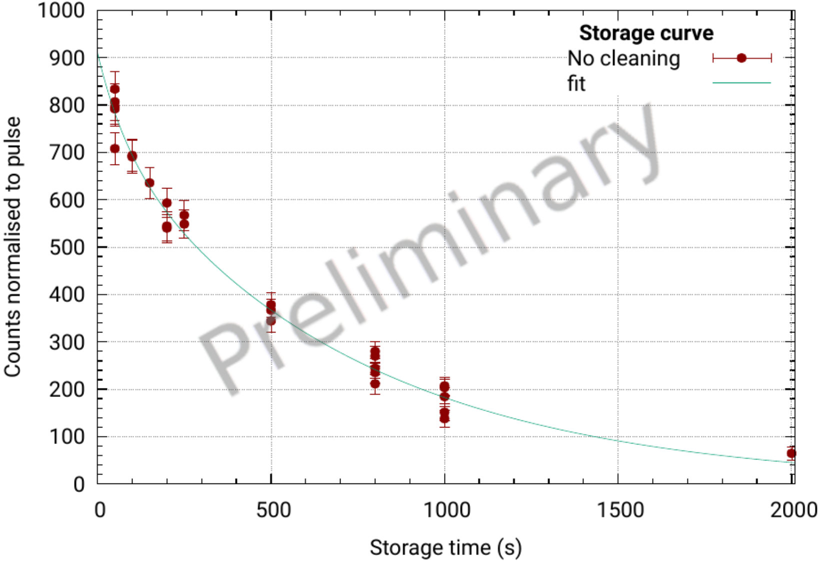
τSPECT@TRIGA Mainz



First neutrons in τSPECT: Sept. 2019



Optimised spin-flip: Feb. 2020



Systematics

- Gaps:
- Wall losses:

Systematics

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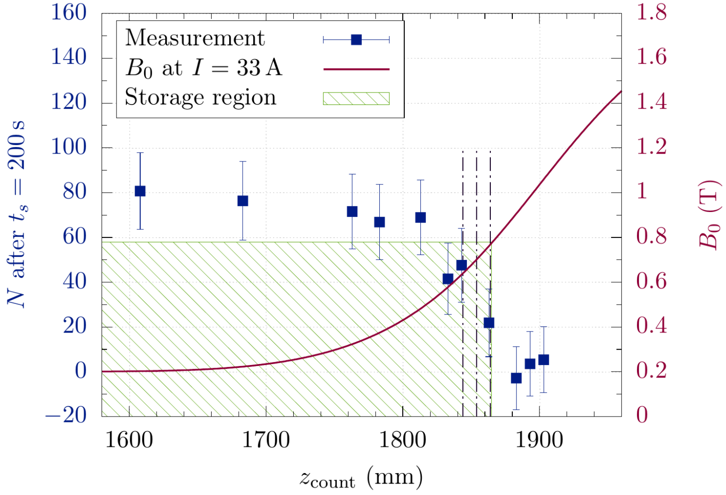
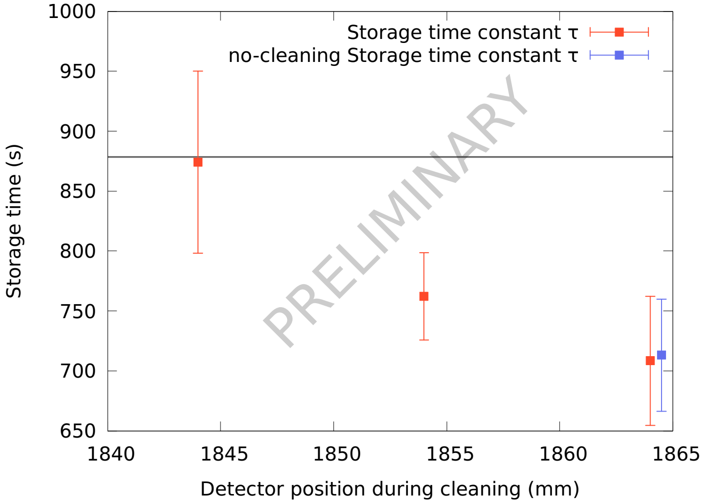
- Gaps: $\rightarrow 0$ ✓
- Wall losses: $\rightarrow 0$ ✓
- Depolarisation: $<< 0.1\,\mathrm{s}$ ✓
- Rest gas interactions: $\lesssim 0.1\,\mathrm{s}$ ✓
- Marginally trapped neutrons: Spectrum cleaning necessary! ✓

Countermeasures



K. Ross

Countermeasures

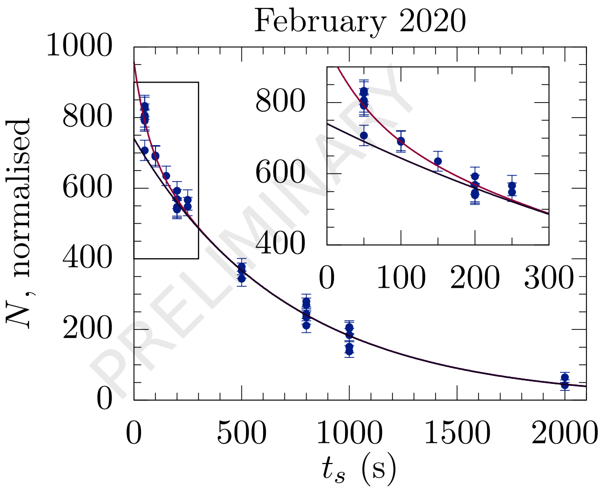


Systematics Control

Marginally trapped neutrons:

- Clean spectrum with active detector before $t = 0$
- Demonstrated to work
- 2 parameters: position and duration
- Too aggressive cleaning → lower statistics
- Introduce asymmetry: τSPECT at a small tilt angle

Without Energy Spectrum Cleaning



Decay times:

Fast:

$\tau = 64.5\,\mathrm{s}$

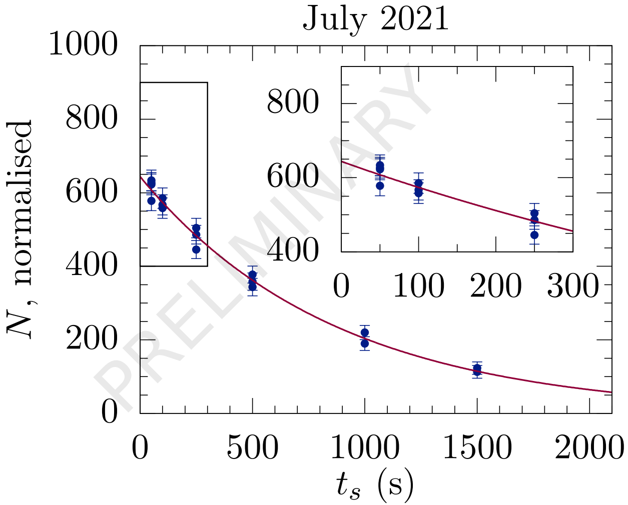
Slow:

$\tau = 740(47)\,\mathrm{s}$

$\chi^2 = 1.6$

K. U. Roß

With Energy Spectrum Cleaning



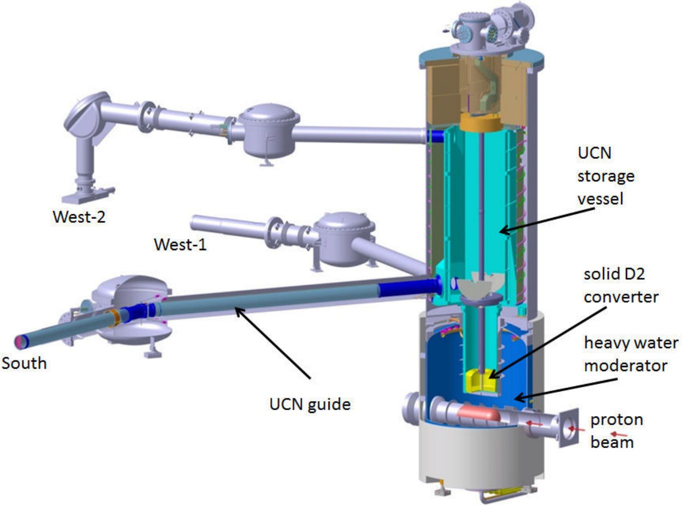
Decay times:

$\tau = 869(29)\,\mathrm{s}$

$\chi^2 = 0.6$

K. U. Roß

PSI UCN area


UCN
storage
vessel
solid D2
converter
heavy water
moderator
proton
beam
West-2
West-1
South
UCN guide

τSPECT at PSI

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Status

- τSPECT has been fully commissioned at TRIGA Mainz
- Move and setup to PSI are being concluded
- First pump-down / cool-down starting this week
- First neutrons in the trap expected in 3 weeks

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Goal: Show statistical reach and systematics control for a physics run aiming for a precision of 0.1 s in the next years.

Team

+ W. Heil & P. Blümler

Team

J. Auler[1], P. Blümler[1], M. Engler[2], M. Fertl[1], K. Franz[2], W. Heil[1], S. Kaufmann[2], N. Pfeifer[1], D. Ries[3], N. Yazdandoost[2]

[1] Institute of Physics, Johannes Gutenberg University Mainz, Germany
[2] Institute of Nuclear Chemistry, Johannes Gutenberg University Mainz, Germany
[3] Paul Scherrer Institute, Villigen, Switzerland

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Thank you for your attention!

Backup

UCN Interactions

- Strong Interaction
  - Neutron Optical Potential (Fermi Potential):
  - $V_F \propto \rho b_{\text{coh}}$
  - ^{58}Ni: ∼335 neV, Stainless steel: ∼190 neV, Al: ∼54 neV
- Gravity
  - $102.5\,\text{neV}\,\text{m}^{-1}$
- Magnetism
  - Spin polarization with strong magnetic fields.
  - $\mu_n = -60.3\,\text{neV}\,\text{T}^{-1}$

UCN Detection

Slow neutrons are fundamentally hard to detect
(= to generate an electric signal)

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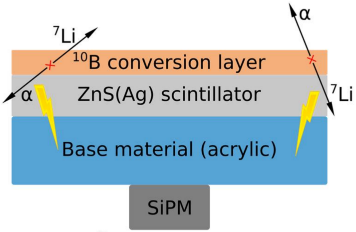

- Neutron capture on ^{10}B
- Subsequent decay into $\alpha + {}^{7}$Li back-to-back
- Charged particle generates light in scintillator
- Detect light in Silicon Photomultiplier (SiPM)

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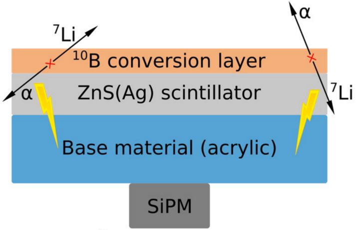
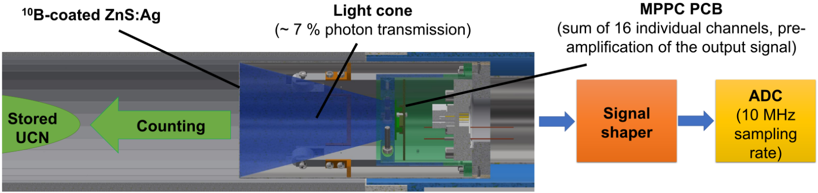
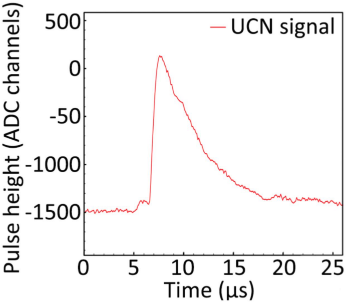


- Neutron capture on ^{10}B O(100 nm)
- Subsequent decay into $\alpha + {}^{7}$Li back-to-back
- Charged particle generates light in scintillator O(10 µm)
- Detect light in Silicon Photomultiplier (SiPM)

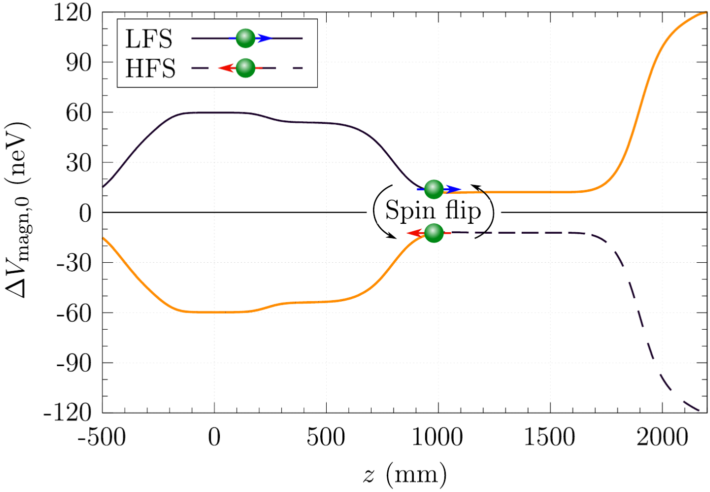
τSPECT Detector





PhD work of J. Kahlenberg

spin-flip loading



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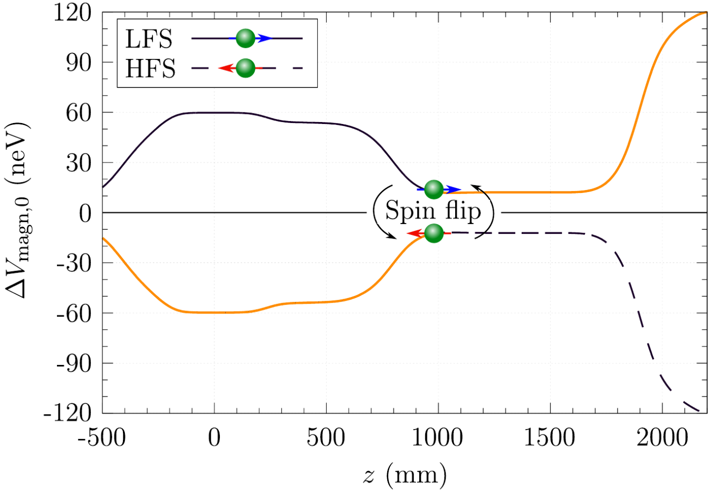
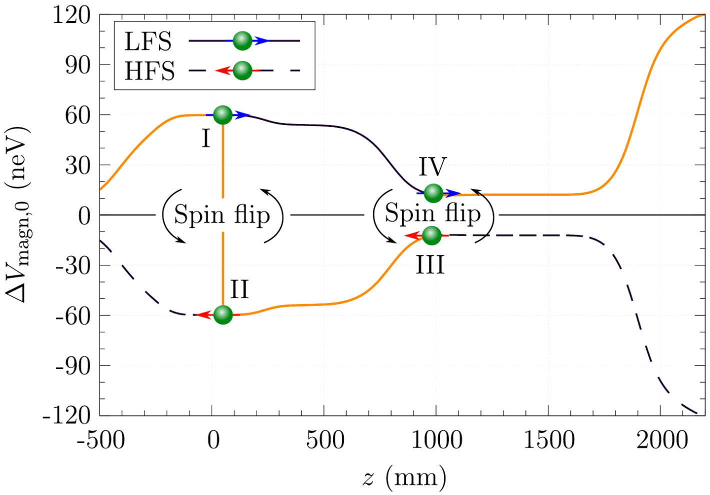
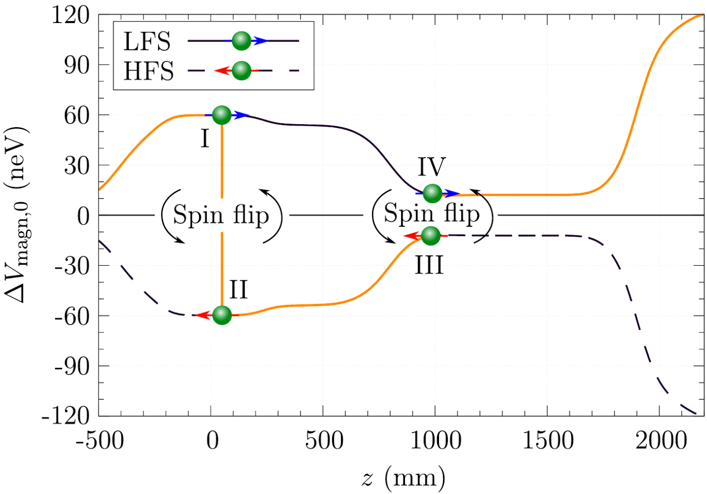


$E_a = 18.9\,\text{neV}$

Double spin-flip loading

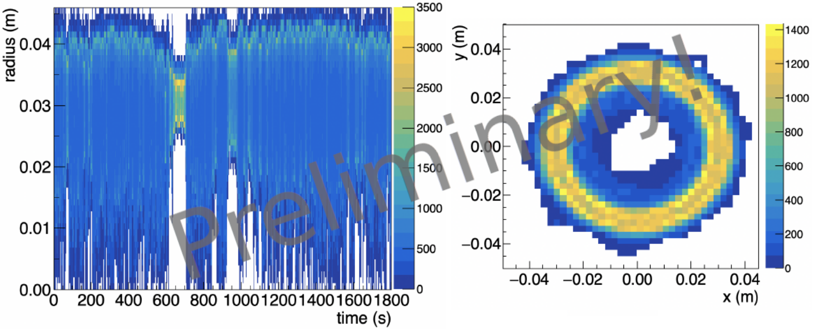


Double spin-flip loading



$E_a = 31.5\,\mathrm{neV}$

Systematics: Marginally Trapped Neutrons



C. Schmidt

Populated closed orbits:

- Counted in short storage time runs
- Lost in long runs

⇒ Systematic shift towards small τ_n!