The Neutron Lifetime Experiment τSPECT

Dieter Ries
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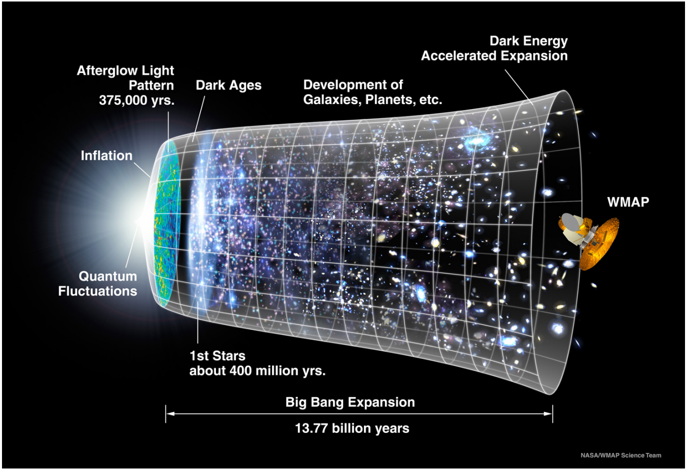
Workshop on UCN and VCN sources at the INP, Kazakhstan

April 8, 2024

Why Neutron Lifetime?

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

Big Bang Nucleosynthesis



@t = 2 min: $n/p \simeq 1/6$ @t = 4 min: $n/p \simeq 1/7$

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})
[Czarnecki, Marciano, Sirlin, doi:10.1103/PhysRevD.100.073008, 2019]

Cabibbo–Kobayashi–Maskawa matrix

$$\begin{bmatrix} |V_{ud}| & |V_{us}| & |V_{ub}| \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}| & |V_{ts}| & |V_{tb}| \end{bmatrix}$$

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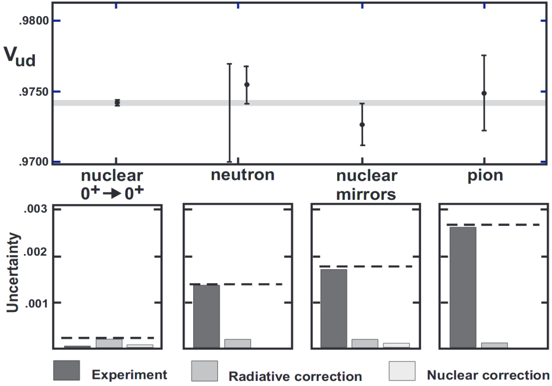
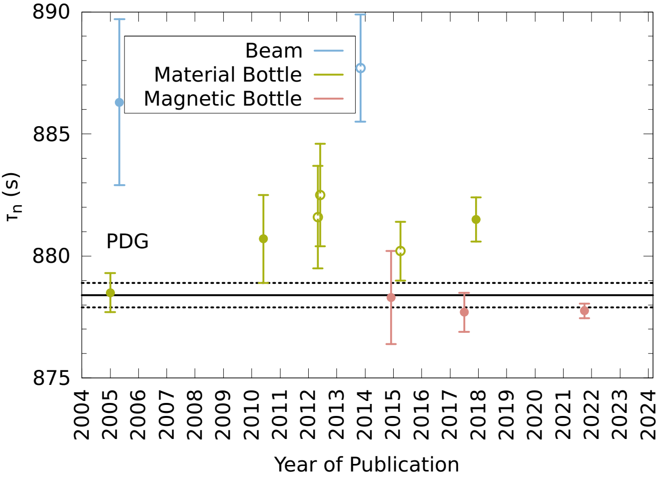


[Hardy and Towner, doi:10.48550/arXiv.1807.01146, 2018]

The Lifetime Puzzle



Neutron Lifetime

Why n-lifetime?

a) Big Bang Nucleosynthesis (He abundance)
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b) CKM Unitarity (V_{ud})
[Marciano and Sirlin, doi:10.1103/PhysRevLett.96.032002, 2006]

c) "It's 2024. We cannot agree on τ_n to better than 10s?!"

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

τSPECT

Concept:

- 3-D magnetic storage
  - Two solenoids + Octupole

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- 3-D magnetic storage
  - Two solenoids + Octupole
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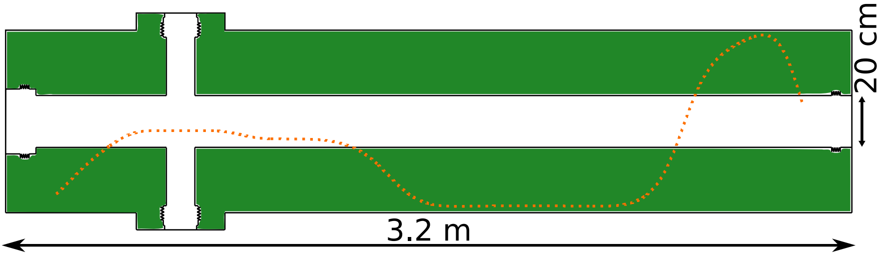
- In-situ UCN detection
  - Minimizes extraction losses
  - High detector requirements wrt temp. & B-field

τSPECT fields



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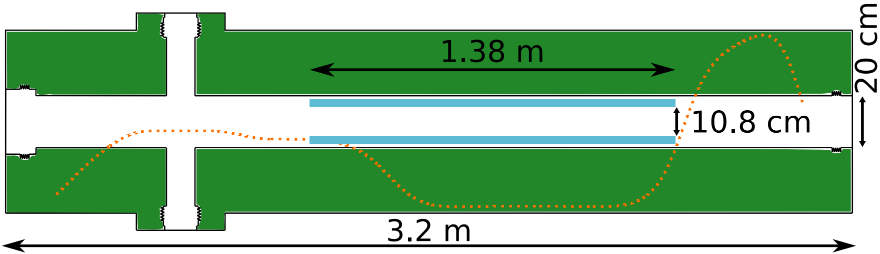

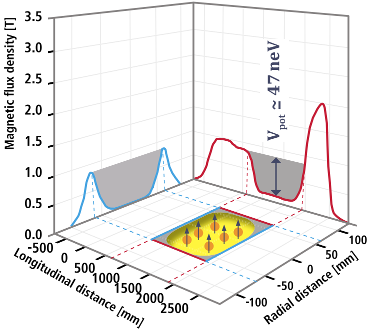

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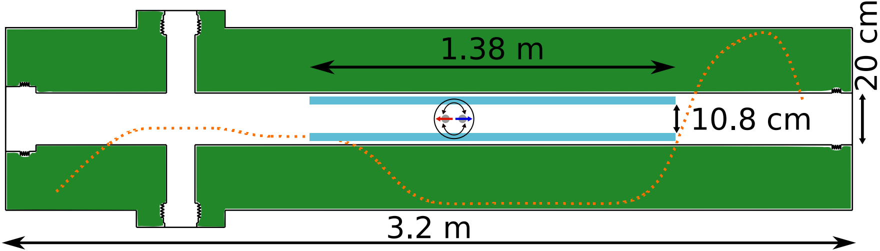
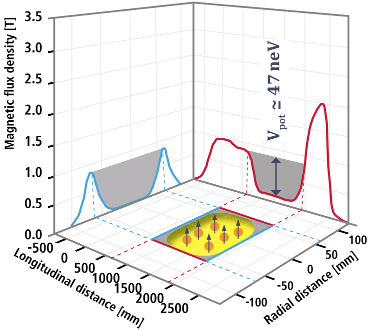
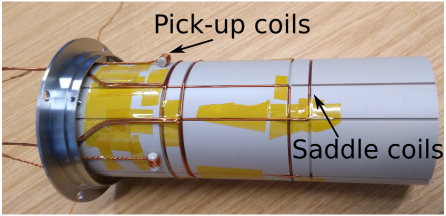
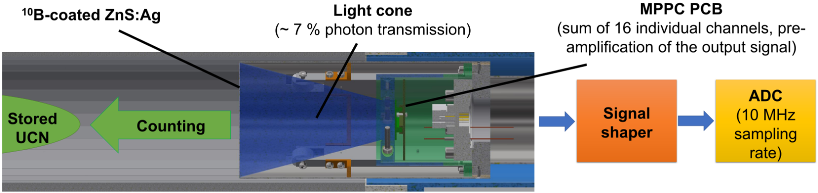


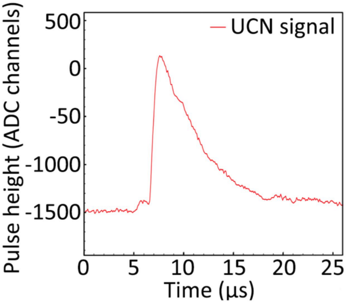




K. U. Ross

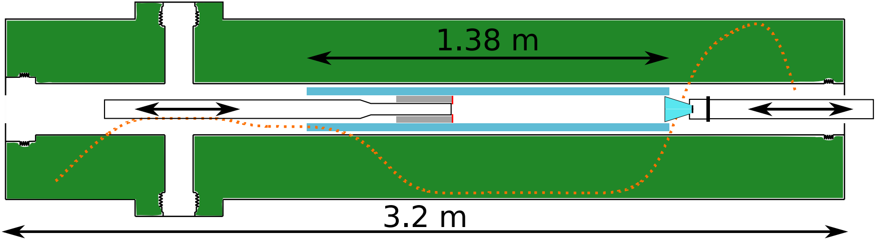
τSPECT Detector





PhD work of J. Kahlenberg

Measurement Procedure



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

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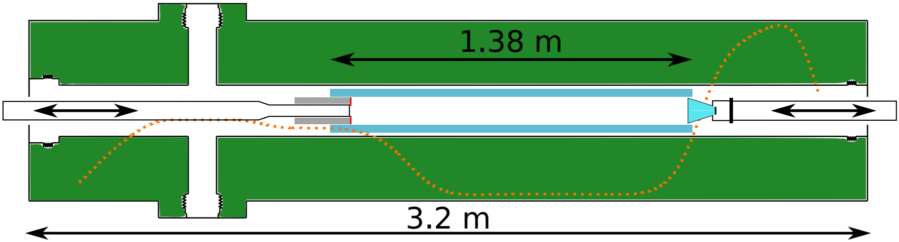

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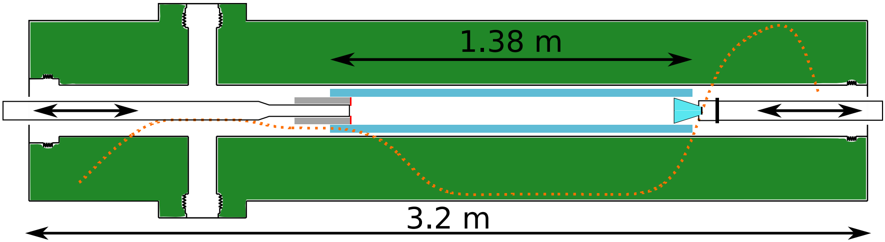

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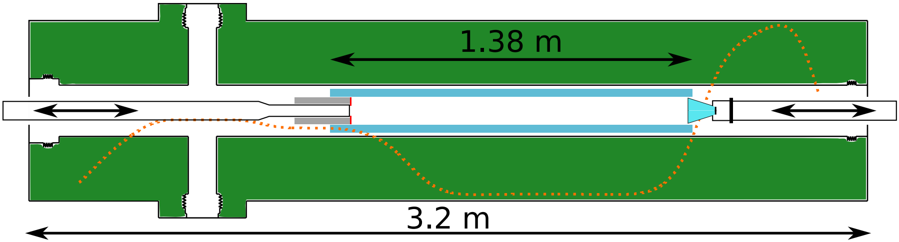

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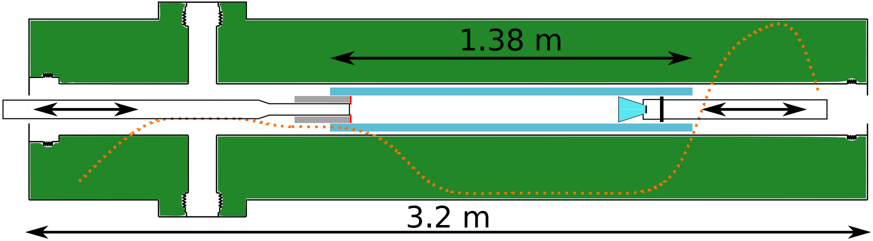

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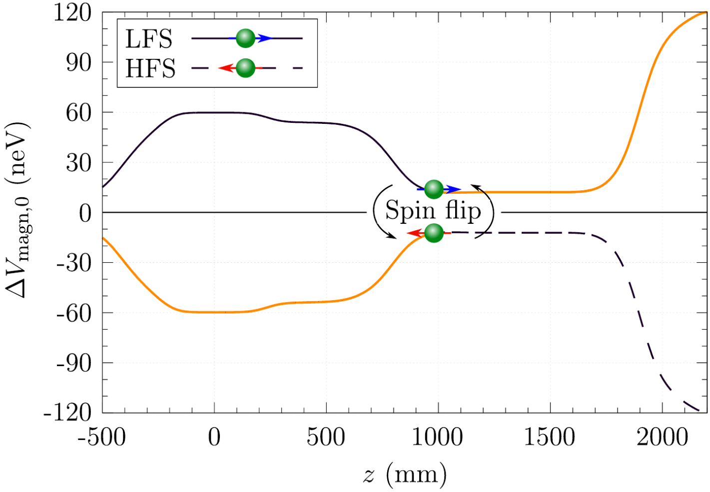
3. Detector to cleaning position and back
4. Wait ...
5. Count UCN

spin-flip loading



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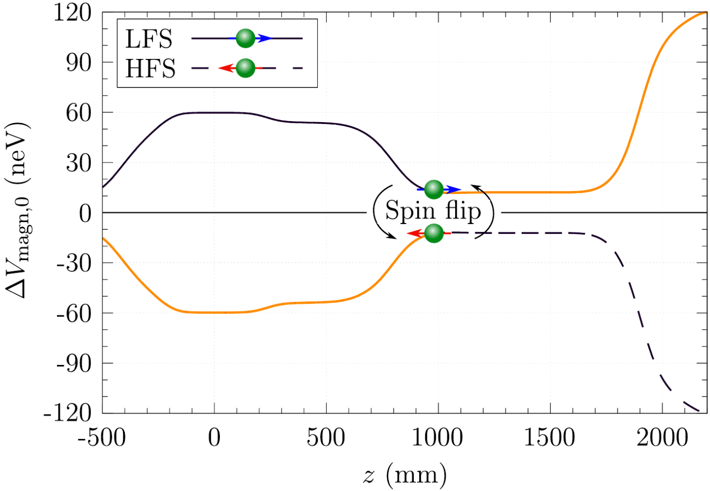
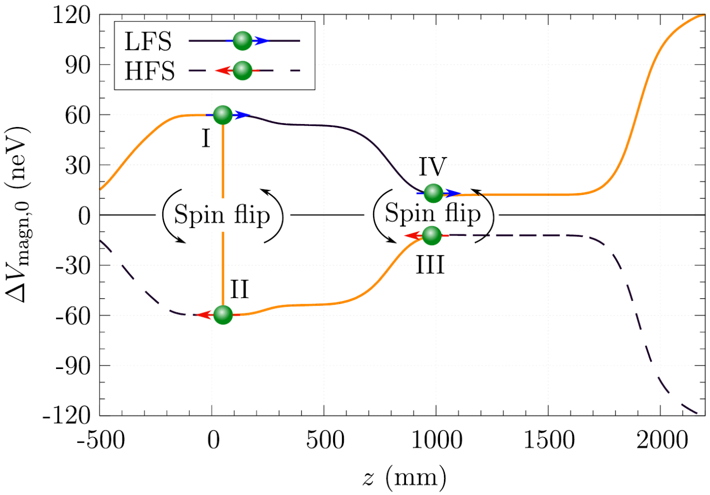


$$E_a = 18.9\,\mathrm{neV}$$

Double spin-flip loading



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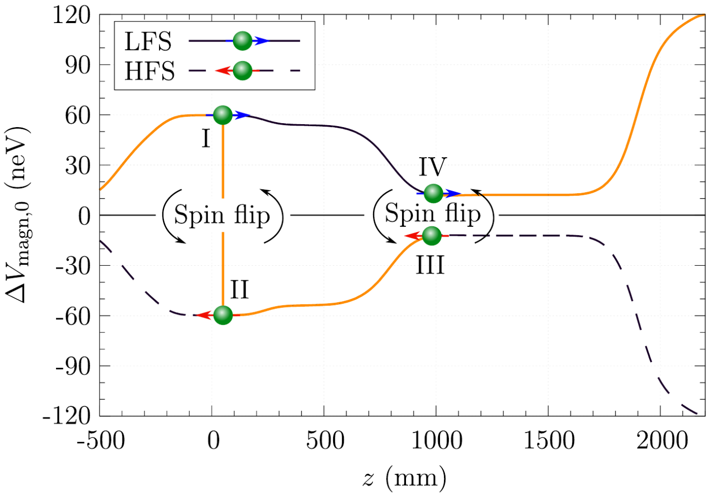

$E_a = 31.5\,\mathrm{neV}$

UCN Intensity Monitor

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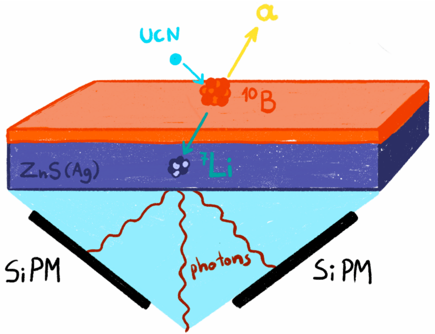

Illustrations: D. Kanta

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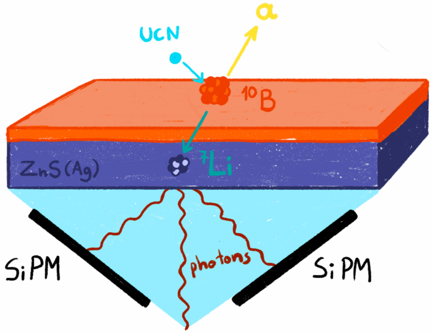

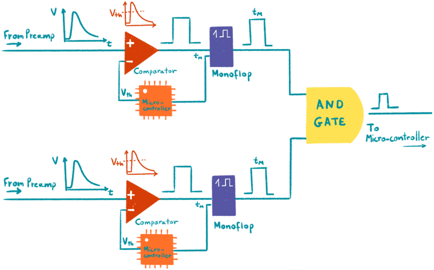

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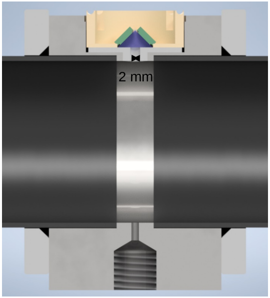

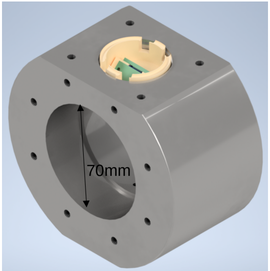

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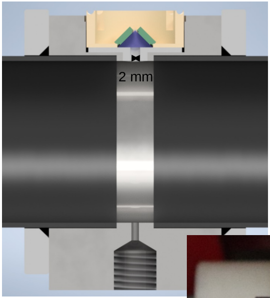

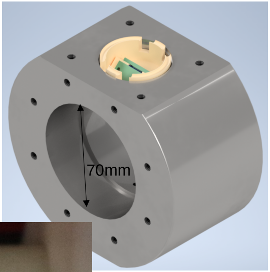

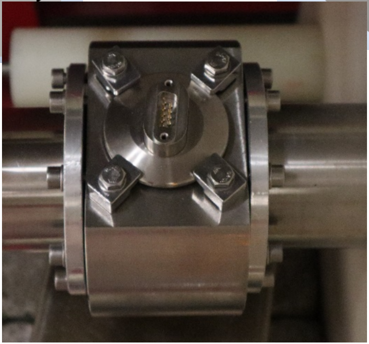

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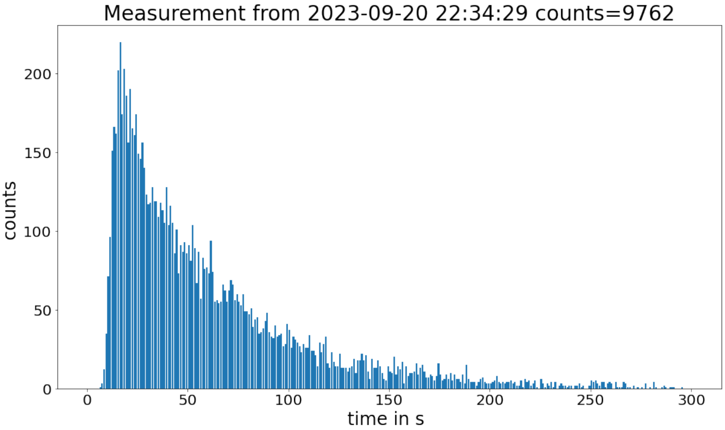

- Detector and readout works!
- Second generation electronics for more robustness and 24/7 operation in development

Systematics

- Gaps:
- Wall losses:

Systematics

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- Depolarisation:

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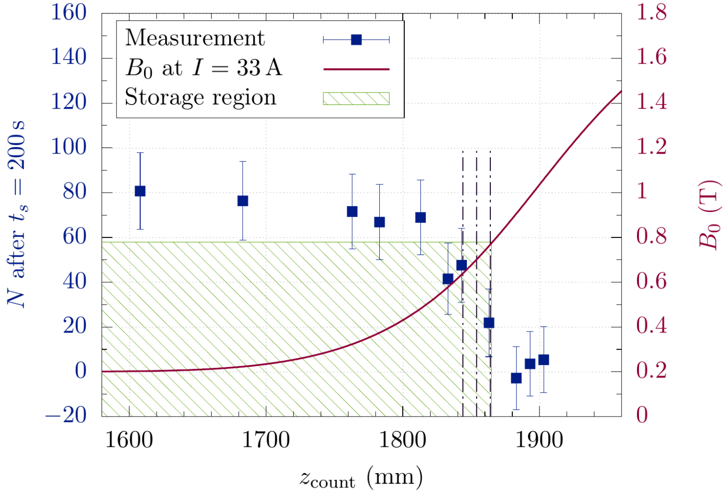
- Microphonic heating:
- Marginally trapped neutrons:

Systematics

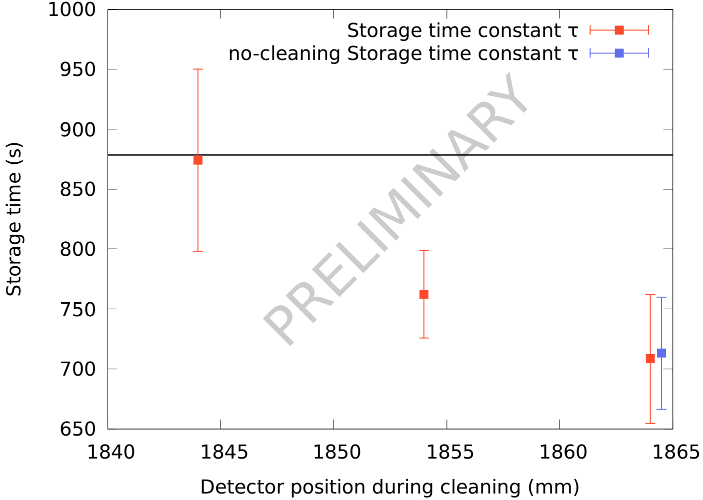
- Gaps: $\rightarrow 0$ ✓
- Wall losses: $\rightarrow 0$ ✓
- Depolarisation: $<< 0.1\,\mathrm{s}$ ✓
- Rest gas interactions: $\lesssim 0.1\,\mathrm{s}$ ✓
- Microphonic heating: Has not been observed, measure. ✓
- Marginally trapped neutrons: Spectrum cleaning necessary! ✓

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

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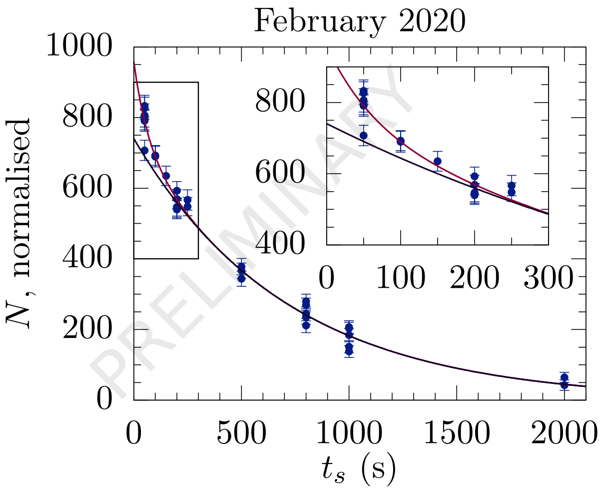
  - Introduce asymmetry: τSPECT at a small tilt angle
- Microphonic heating:
  - Microphonic heating has not been observed
  - Can be measured via change in arrival time
  - Can be measured by "cleaning" again!
  - New τSPECT timing controller can do that.

Without Energy Spectrum Cleaning

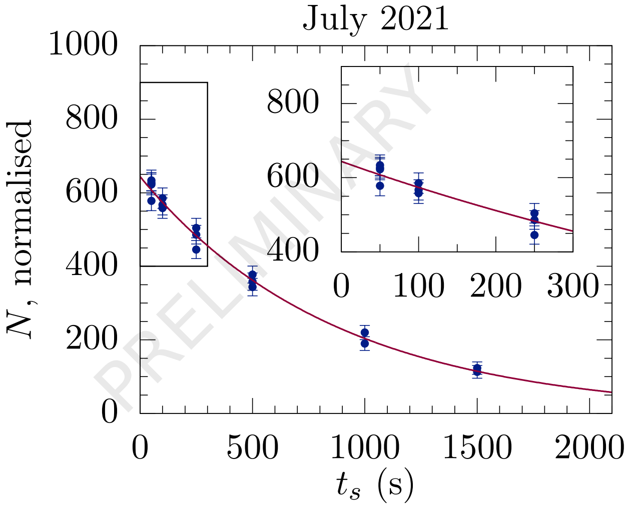


Decay times:
Fast:
$\tau = 64.5\,\mathrm{s}$
Slow:
$\tau = 740(47)\,\mathrm{s}$

$\chi^2 = 1.6$

K. U. Roß

With Energy Spectrum Cleaning



Decay times:

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

$\chi^2 = 0.6$

K. U. Roß

τSPECT at PSI

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Status

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- Move and setup to PSI are being concluded
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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]

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Thank you for your attention!