A Method of UCN Storage

For use in measurement of the unbound neutron lifetime

Storage of ultracold neutrons in the magneto-gravitational trap of the UCNτ experiment, D.J. Salvat, et al. Physical Review C (2014)

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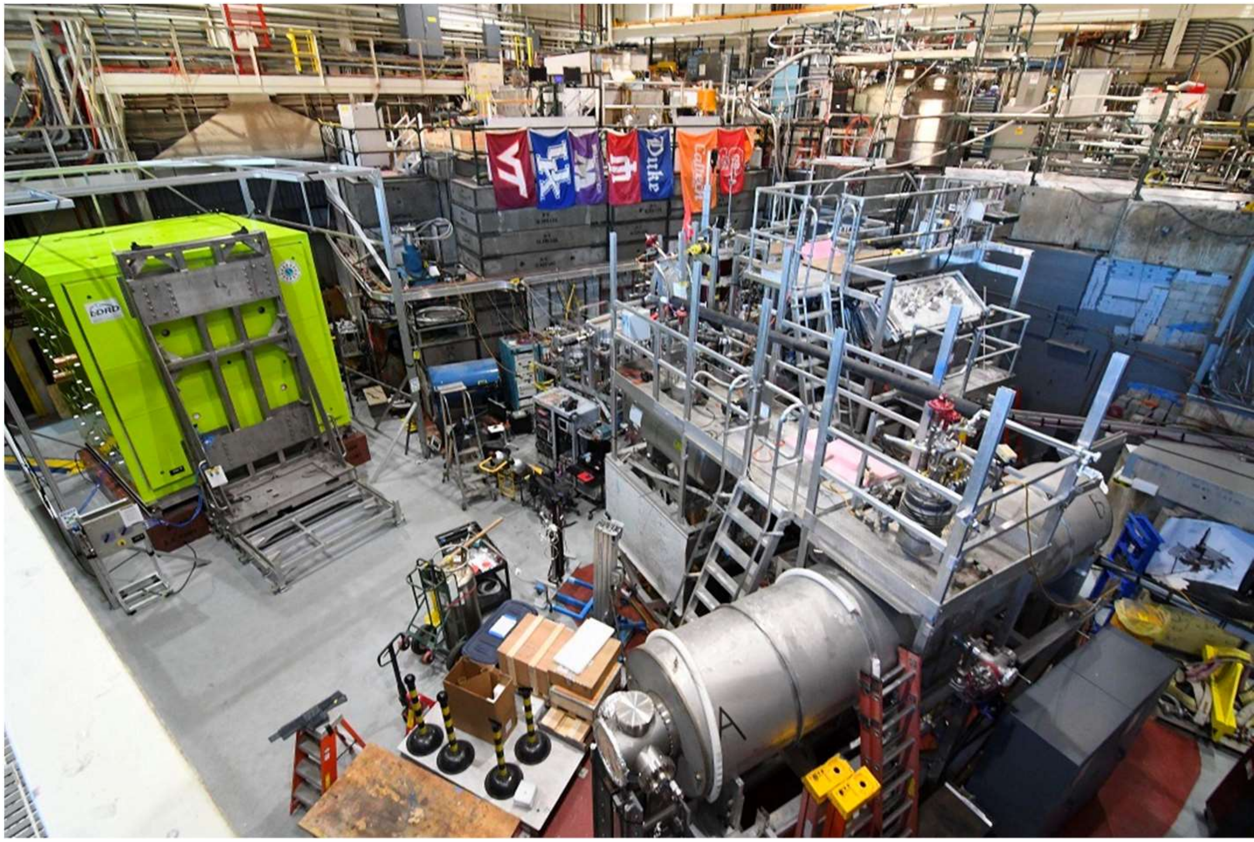
A brief context for neutron lifetime experiments

- Unbound neutrons undergo simple β decay

$$n \rightarrow p + e^{-} + \bar{\nu}_e$$

- The lifetime of the neutron, τ_n, is a parameter needed to understand [5]
  - Cosmic Baryon Density
  - β-decay correlations
    - Parity violation/BSM
- Beam vs Bottle
  - Bottle needs to store n
  - UCN convenient E~100neV

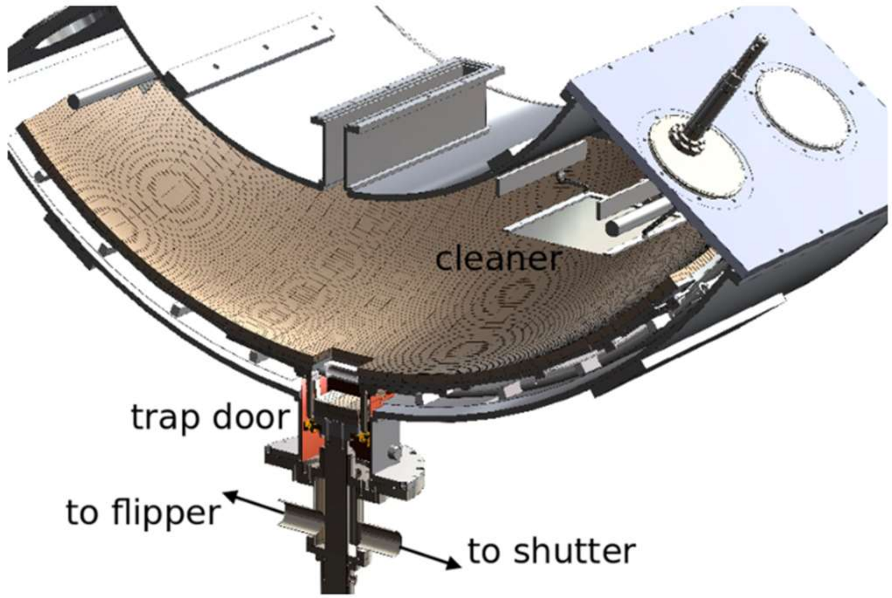


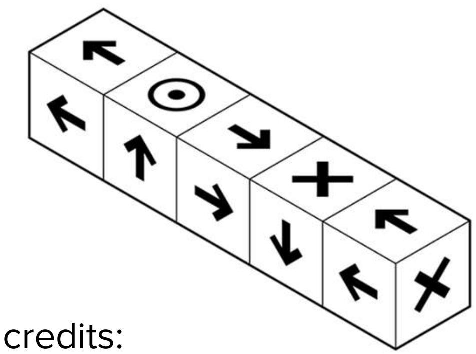
Los Alamos UCN Experimental Area

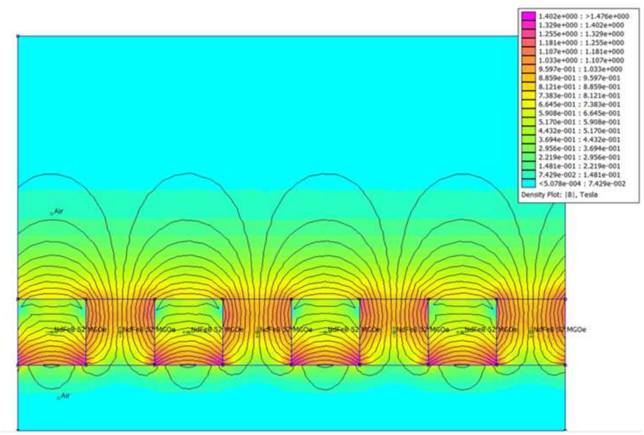
“Storage Method for Measuring
Free Neutron Lifetimes”

Summary of Paper

- Presents an experimental apparatus capable of holding ultracold neutrons (UCN) for various amounts of time
- Demonstrates the use of a magneto-gravitational trap utilizing a Halbach magnet array
- The holding time, τ_{store} can be measured by counting the number of UCN which survive the holding process





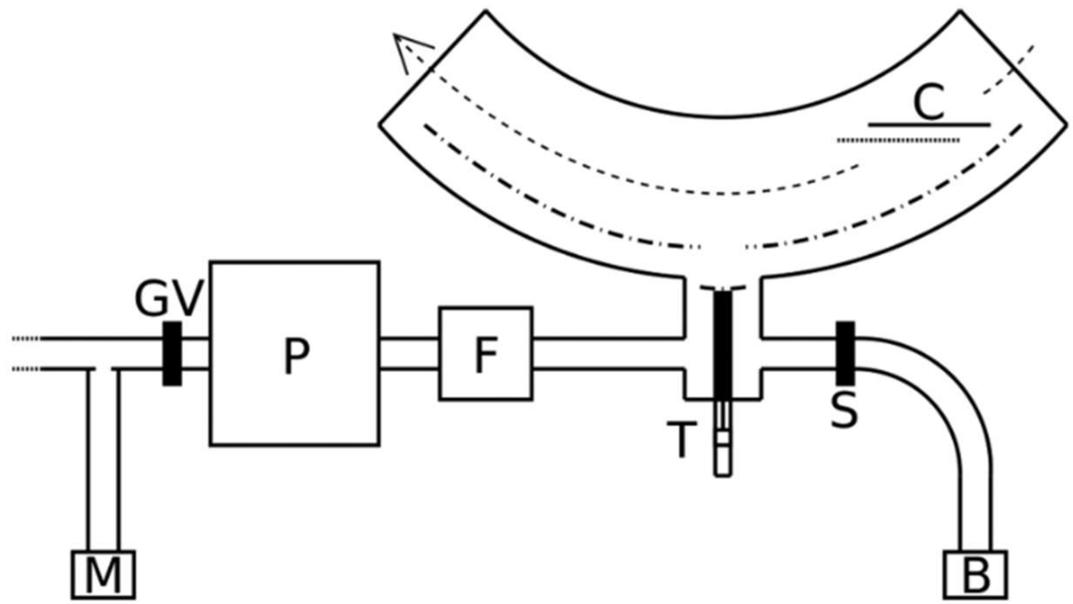


"Storage Method for Measuring Free Neutron Lifetimes"

Image credits:
Top: Salvat et al. Phys Rev. C 89, 052501(R) (2014)
Bottom: https://en.wikipedia.org/wiki/Halbach_array

Experimental Apparatus

- **M**: Proportional counter
  - Counts UCN at the experiment start
  - Filled with He3/CF4 gas mixture for neutron reactions [3]
- **GV**: Gate valve
- **P**: Polarizing magnet
  - Polarizes neutrons to seek high strength magnetic fields
- **F**: Phase flipper
  - Converts neutrons to low field seeking
- **T**: Piston driven trap door
- **C**: Polyethylene cleaner
  - For getting rid of quasibound neutrons
- **S**: Aluminum shutter
- **B**: Boron-10 coated counter



Salvat et al. Phys Rev. C 89, 052501(R) (2014)

Comparison of Results and Conclusions

Novel study for proof of concept for the UCN storage apparatus could measure a valid neutron lifetime

$$\tau_n^{-1} = \tau_{store}^{-1} - \tau_{loss}^{-1}$$

Two methods of comparison:

Show measured τ_{store} is close to previous measurements of τ_n (and how τ_{store} relates to τ_n for future studies)

Show that technique for measuring τ_{store} is different from previous methods for τ_n

Comparison to Previous τ_n Measurements

Serebrov (2010) provides detail of global average for τ_n.

$\tau_n = 879.9 \pm 0.9$ s

Compared to our paper, $\tau_{store} = 860 \pm 19$ s, which falls within 1σ of global average.

UCNτ experiment/instruments capable of measuring τ_n

TABLE I. Experimental results for neutron lifetime.

Author(s), year [ref. no.]	τ_n (s) till 2007
Arzumanov *et al.*, 2009 [3]	
Ezhov *et al.*, 2007 [4]	878.2 ± 1.9
Serebrov *et al.*, 2005 [1]	878.5 ± 0.7 ± 0.3
Dewey *et al.*, 2003 [5]	886.3 ± 1.2 ± 3.2
Arzumanov *et al.*, 2000 [6], Fomin and Serebrov, 2010 [7]	885.4 ± 0.9 ± 0.4
Pichlmaier *et al.*, 2000 [8]	
Byrne *et al.*, 1996 [9]	889.2 ± 3.0 ± 3.8
Mampe *et al.*, 1993 [10]	882.6 ± 2.7
Nesvizhevski *et al.*, 1992 [11]	888.4 ± 3.1 ± 1.1
Byrne *et al.*, 1990 [12]	893.6 ± 3.8 ± 3.7
Mampe *et al.*, 1989 [13], Serebrov and Fomin, 2009 [14]	887.6 ± 3.0
Kharitonov *et al.*, 1989 [15]	872 ± 8
Kossakowski *et al.*, 1989 [16]	878 ± 27 ± 14
Paul *et al.*, 1989 [17]	877 ± 10
Spivac *et al.*, 1988 [18]	891 ± 9
Last *et al.*, 1988 [19]	876 ± 10 ± 19
Arnold *et al.*, 1987 [20]	870 ± 17
Kosvintsev *et al.*, 1986 [21]	903 ± 13
Byrne *et al.*, 1980 [22]	937 ± 18
Bondarenko *et al.*, 1978 [23]	881 ± 8
Christensen *et al.*, 1972 [24]	918 ± 14

Comparison of Experimental Technique to Previous

UCN's place alongside previous approaches to measure τ_n

- Material Bottle Experiments - yielded disagreements with expected results
- Validity tests with neutron beam experiments

Promising developments in trap technology:

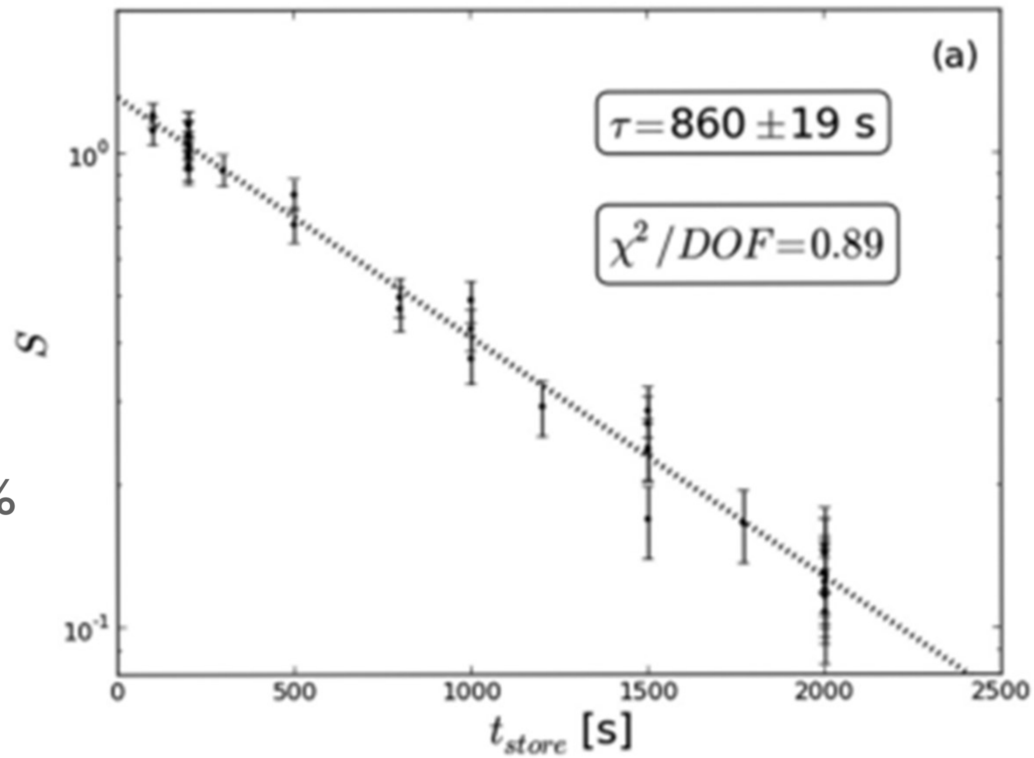
- Preliminary storage time measurement using Ioffe-Pritchard trap (Yang, 2006)
- Storage in a cylindrical permanent magnet trap (Ezhov, 2005)
- Asymmetric magnetic traps to rapidly remove neutrons in quasibound orbits (Bowman 2005)

Analysis of Results

$$\tau_n^{old} \sim 879.9 \pm 0.9s$$

- Well-behaved fit (DOF)
- Statistical sensitivity 2.2%
- Storage time constant 1 std from neutron lifetime

- Claim: **Can improve sensitivity to 0.1%**
- Propose possible changes to achieve goal



Log plot Signal S vs storage time. Gradient relates to storage time constant

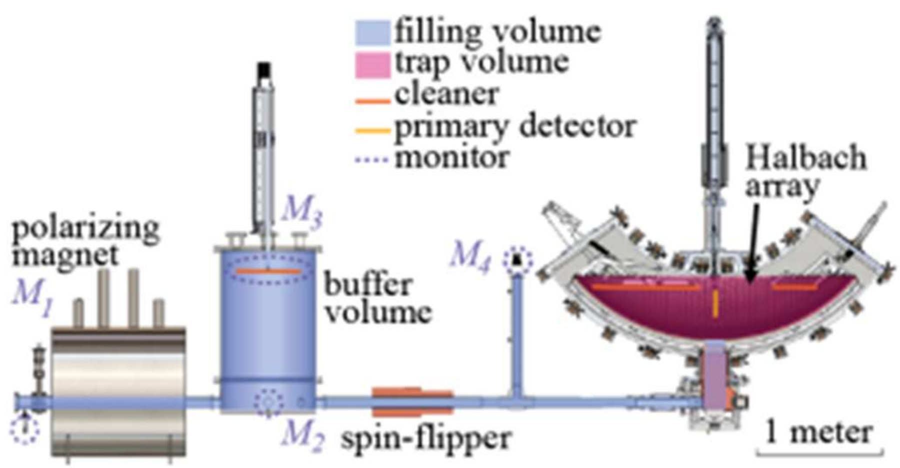
"Storage Method for Measuring Free Neutron Lifetimes"

Were they successful?

- Achieved 0.1% sensitivity?
- Improved measurement of neutron lifetime?

$$\tau_n^{new} = 877.75 \pm 0.34s$$

- Yes! FM Gonzalez et al. PRL 127, 162501 (2021)[9]
- Sensitivity 0.04%
- Below theoretical shift



"Storage Method for Measuring Free Neutron Lifetimes"

Impact on the field

- Cited 45 times (Google Scholar), 27 times (Scopus and APS)

- Scopus “Field-Weighted Citation Impact” of 1.81 > 1
  - Surprisingly high-impact for a rapid communications paper
  - Somewhat niche subfield

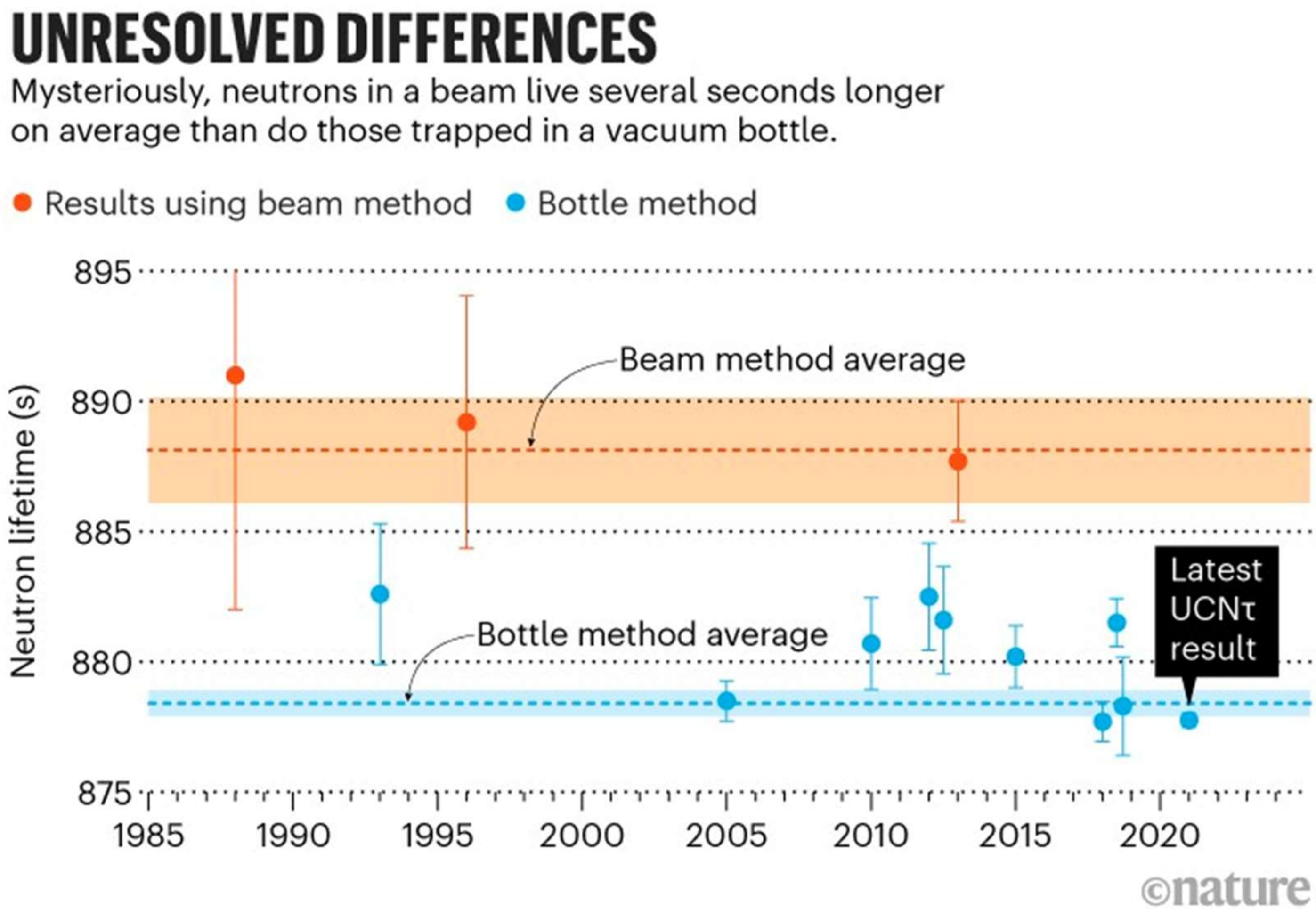
Impact on the field

- Cited by two much more seminal papers
  - 2018 Paper: **Measurement of the neutron lifetime using a magneto-gravitational trap and in situ detection**
    - 178 Citations (GS), 76 Citations (Scopus), FWCI of 3.51
  - 2021 Paper: I**mproved Neutron Lifetime Measurement with UCNtau**
    - 40 (GS), 15 (Scopus), FWCI of 3.08

- Cited by a group that adopted the MGT style of storage 4 years later
  - Measurement of the Neutron Lifetime with Ultracold Neutrons Stored in a Magneto-Gravitational Trap

The field since this paper

- Record sensitivity with reduced uncertainty
  - ➢ The Neutron Lifetime Puzzle



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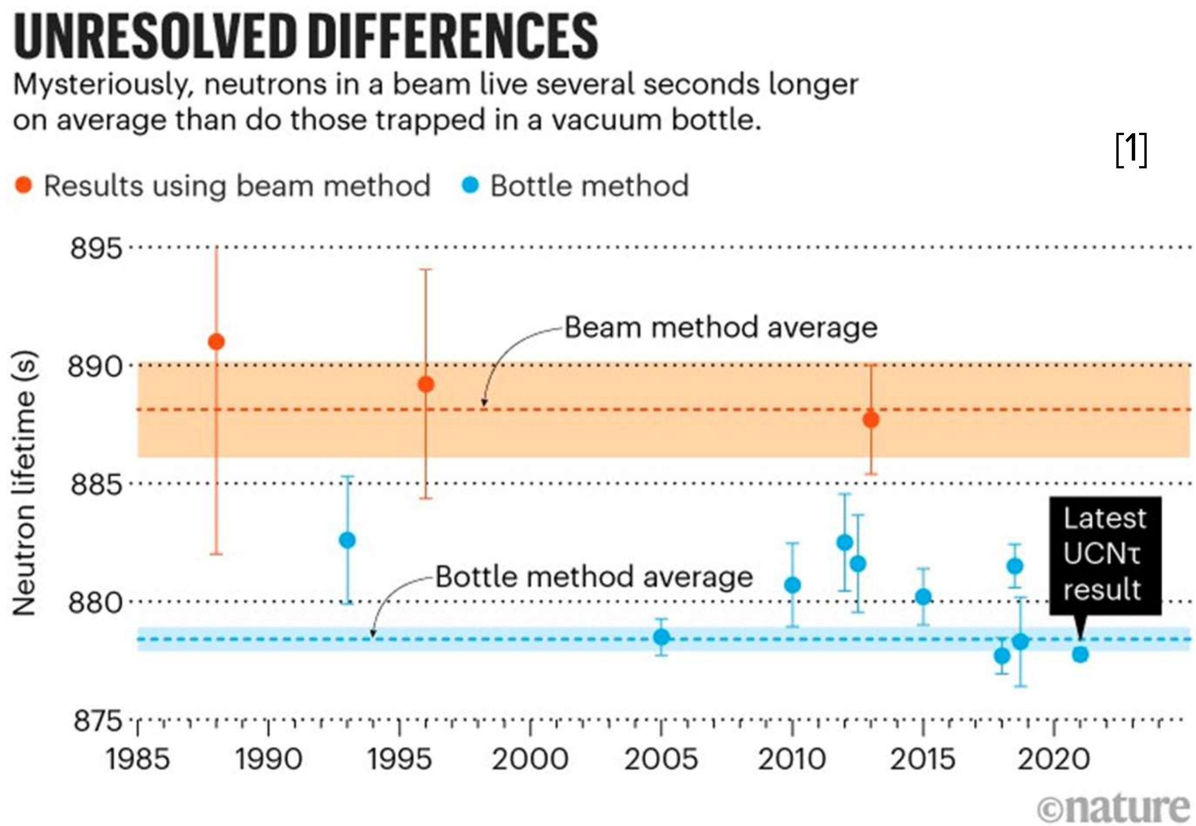
The field since this paper

- UCNtau+
- NIST BL3
- Lunar prospector data



[1]

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Key Takeaways

1. Then new method of storing UCN through magneto-gravitational trap
2. Storage time in trap close to free neutron lifetime
3. Later lead to improved measurement of the free neutron lifetime

$$\tau_n = 877.75 \pm 0.34s$$

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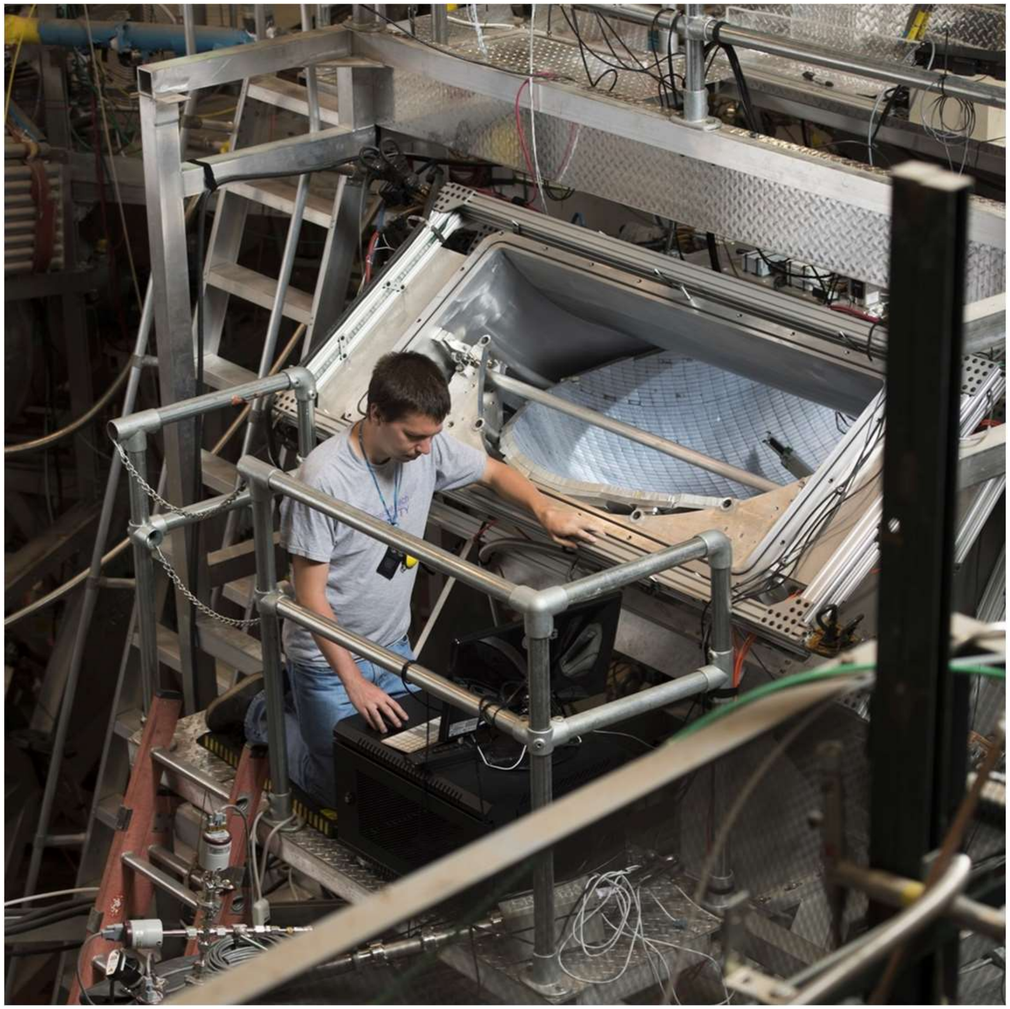

References (Just for record, don’t show)

- [1] “Storage of ultracold neutrons in the magneto-gravitational trap of the UCNτ experiment” by D.J. Salvat, et al. (2014) DOI: 10.1103/PhysRevC.89.052501
- [2] http://aesop.phys.utk.edu/QFT/Hayes/Neutron_Decay.pdf
- [3] “Multi-wire Proportional Chamber for Ultra-Cold Neutron Detection” C. L. Morris et al., Nucl. Instrum. Methods A 599, 248 (2009)
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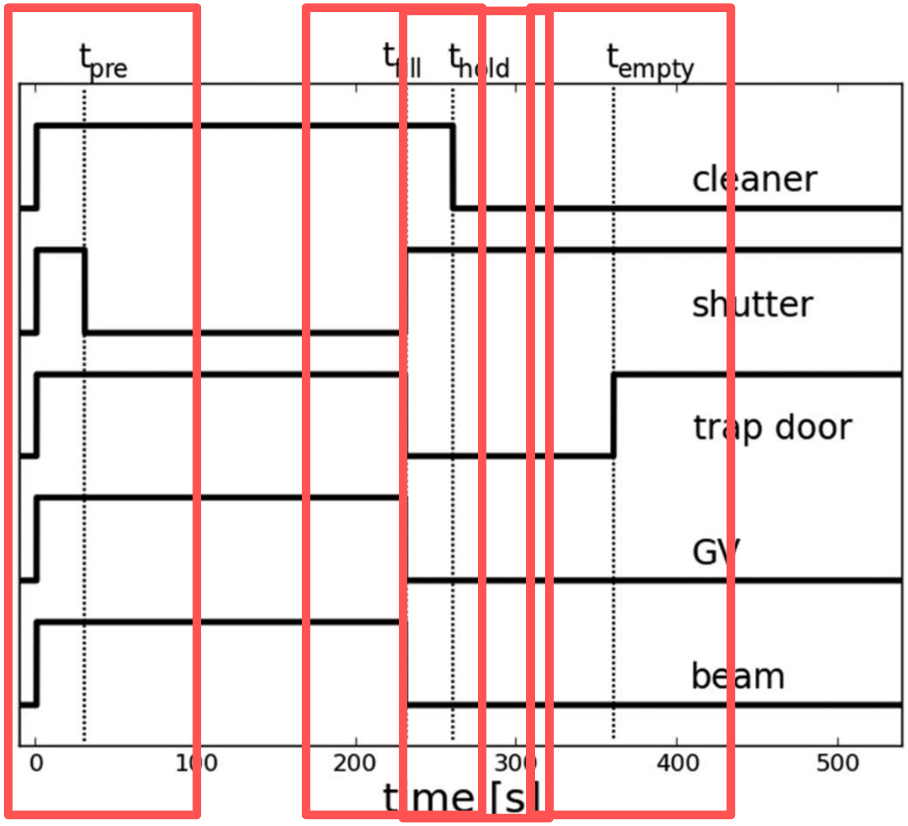
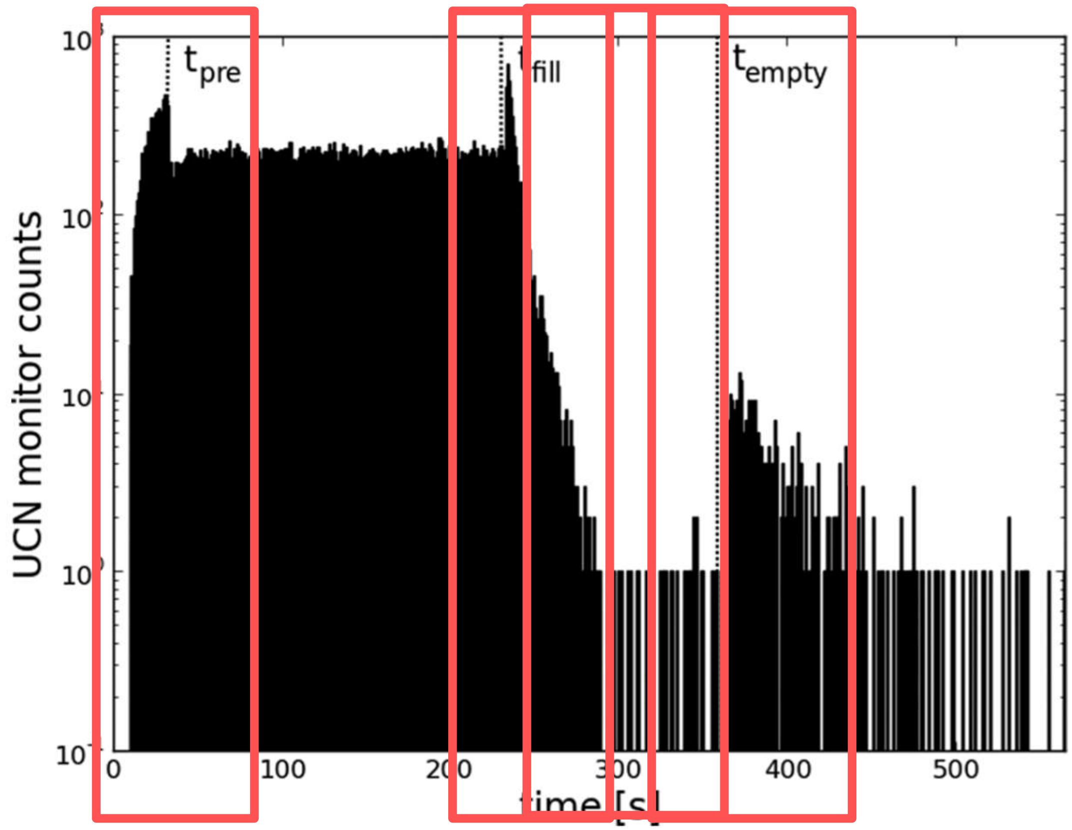
- [9] “Improved Neutron Lifetime Measurement with UCNtau” by Gonzalez F.M., et al. 2021
- [10] V. F. Ezhov et al., J. Res. Natl. Inst. Stand. Technol. 110, 345 (2005).
- [11] https://www.nature.com/articles/d41586-021-02812-z
- [12] https://ultracold.web.illinois.edu/ucntau

Neutron Counts at Various Timesteps (supplementary)





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