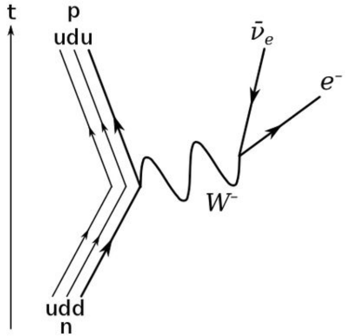
Daniel J Salvat

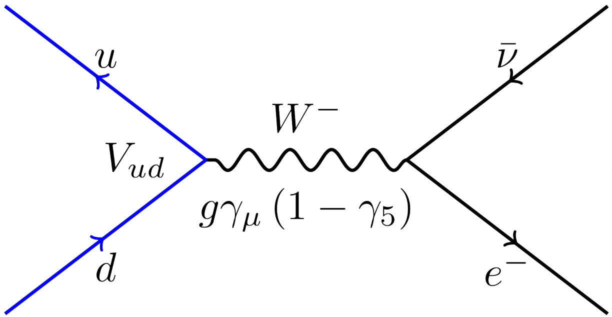
Measuring the neutron lifetime with UCNτ

INDIANA UNIVERSITY BLOOMINGTON

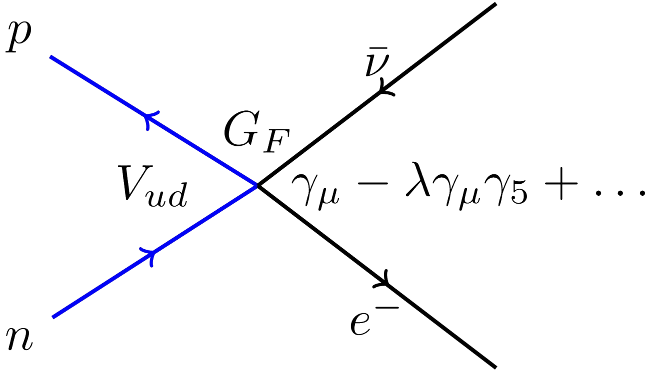
FNAL W&C 6 May 2022

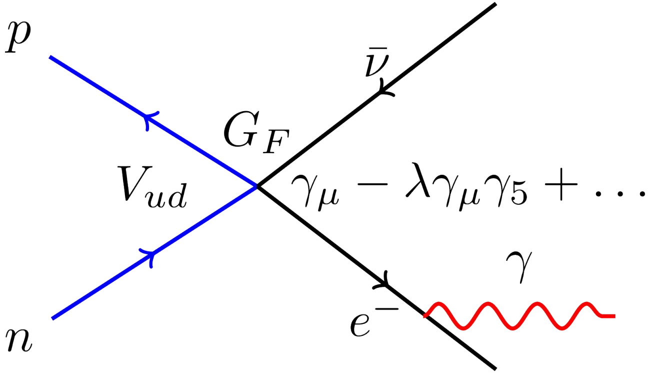
Neutron β-decay



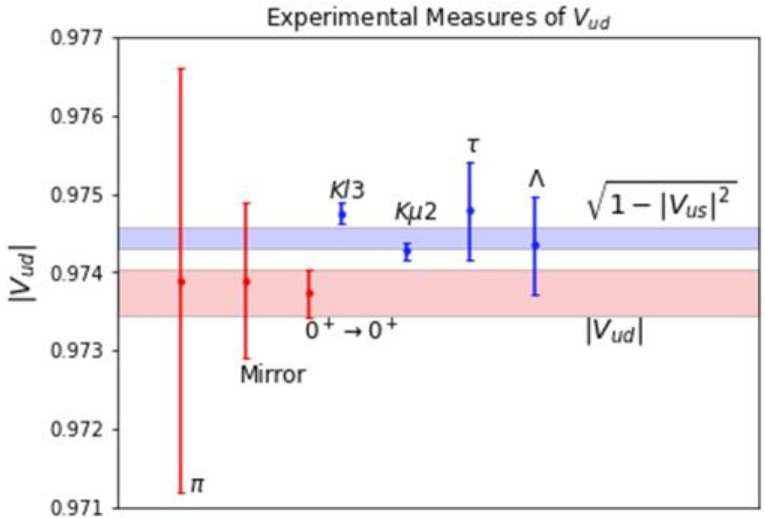


$$J^\mu = \bar{u}_n\left[g_V\gamma^\mu + \frac{g_M}{2M}\sigma^{\mu\nu}q_\nu + g_A\gamma^\mu\gamma_5\right]u_p$$





Cabibbo-Kobayashi-Maskawa Matrix Unitarity



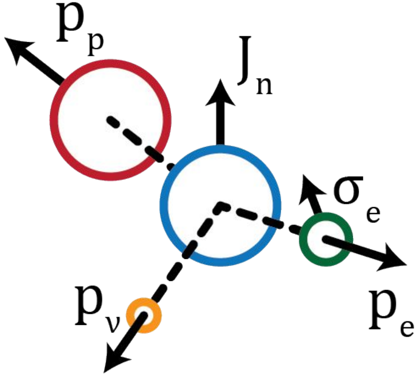
$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

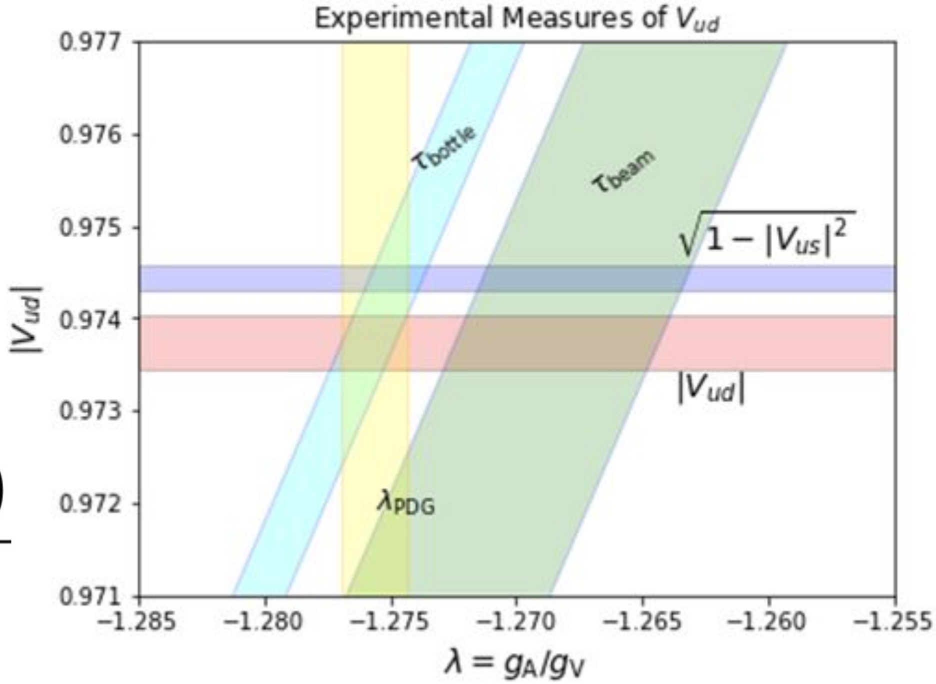
The weak axial current

$$J^\mu = \bar{u}_n \left[g_V \gamma^\mu + \frac{g_M}{2M}\sigma^{\mu\nu} q_\nu + g_A \gamma^\mu \gamma_5 \right] u_p$$

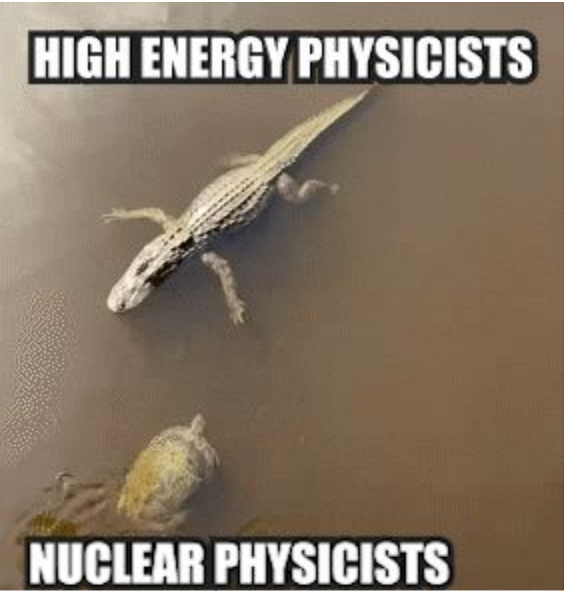
$$\tau_n^{-1} = \frac{|V_{ud}|^2 \left(1 + 3\lambda^2\right)\left(1 + \Delta_R\right)}{5099.3 \text{ s}}$$

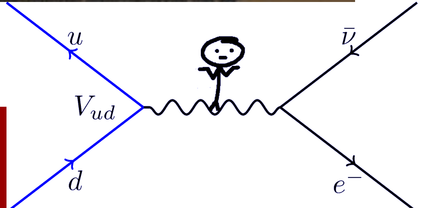


$$A = -2\frac{\lambda(\lambda + 1)}{1 + 3\lambda^2}$$



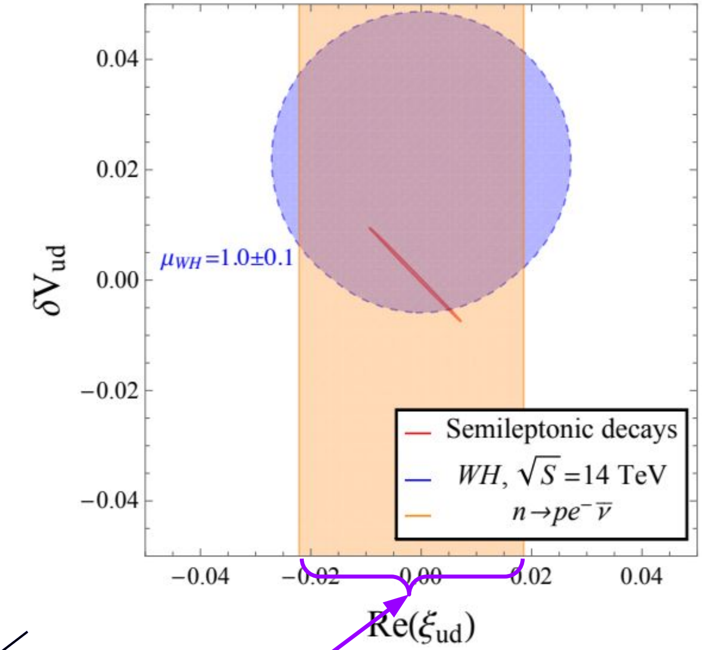
Why bother?





Right-handed charged currents in the era of the Large Hadron Collider

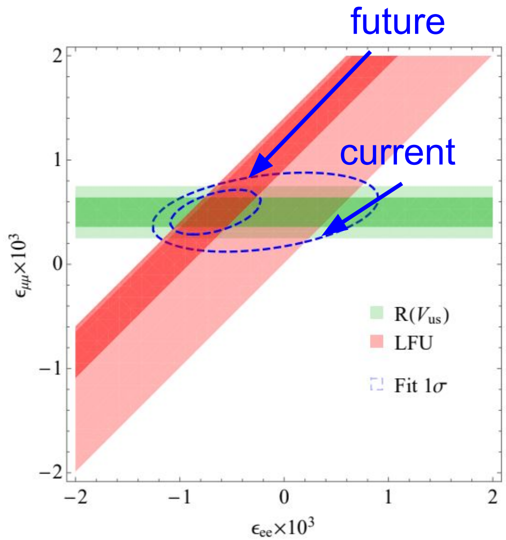
S. Alioli,[a] V. Cirigliano,[b] W. Dekens,[b,c] J. de Vries[d] and E. Mereghetti[b]

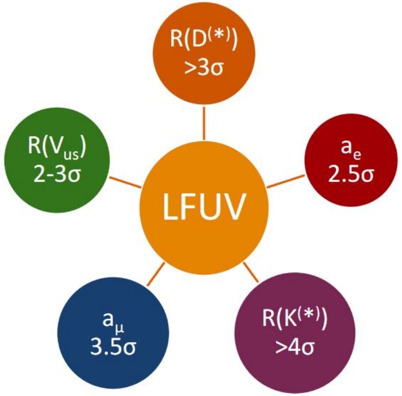


remarkable lQCD progress

Beta decays as sensitive probes of lepton flavor universality

Andreas Crivellin[1,2] and Martin Hoferichter[3,4]



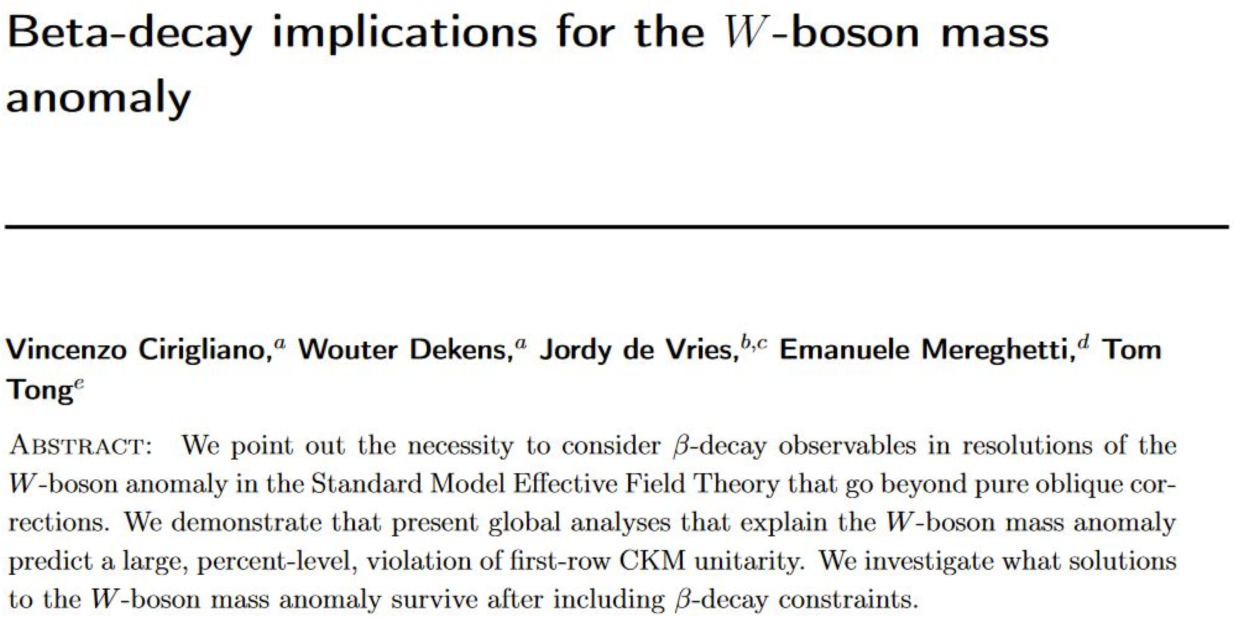


Why bother?

High-precision measurement of the *W* boson mass with the CDF II detector

CDF COLLABORATION†‡, T. AALTONEN, S. AMERIO, D. AMIDEI, A. ANASTASSOV, A. ANNOVI, J. ANTOS, G. APOLLINARI, J. A. APPEL, [...] S. ZUCCHELLI +389 authors

Authors Info & Affiliations

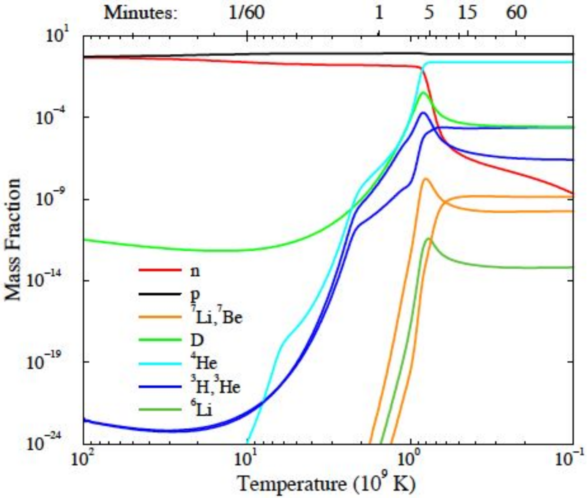


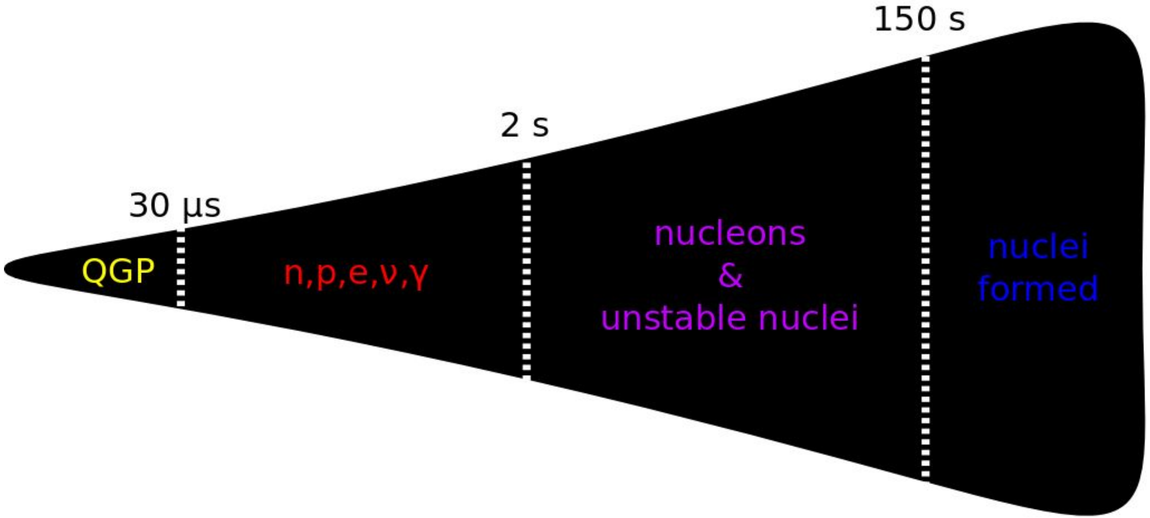
Beta-decay implications for the W-boson mass anomaly

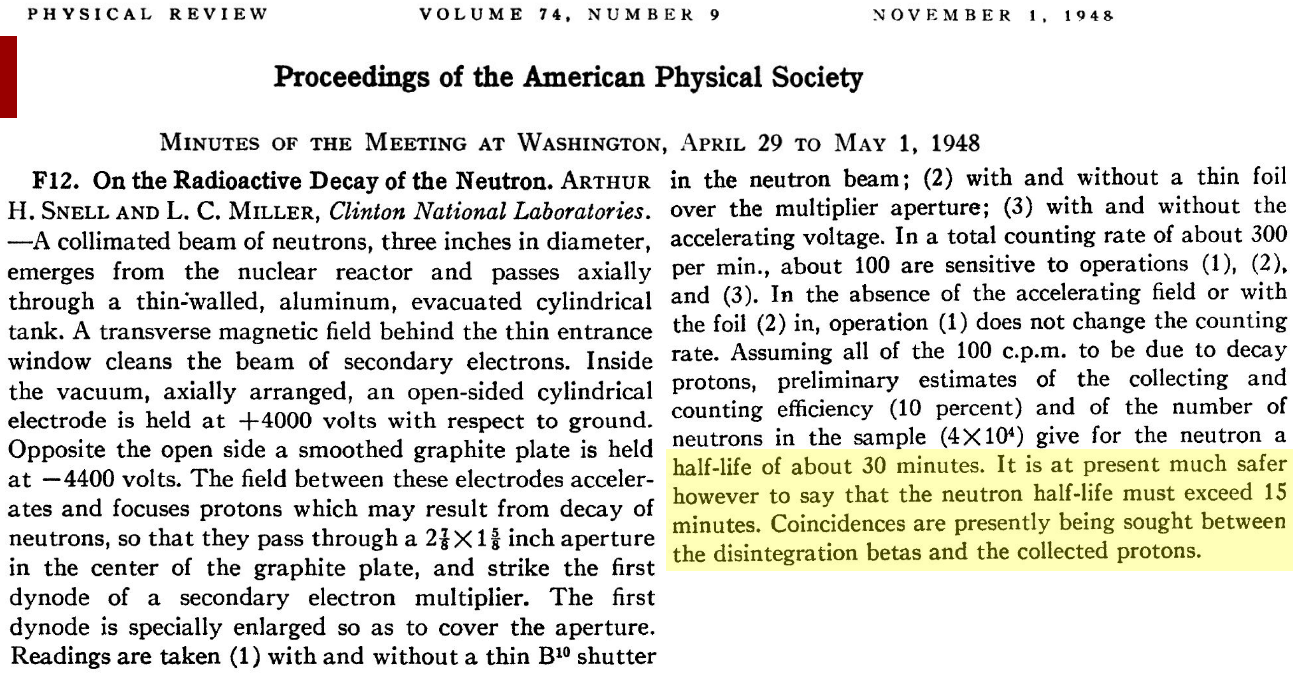
Vincenzo Cirigliano,[a] Wouter Dekens,[a] Jordy de Vries,[b,c] Emanuele Mereghetti,[d] Tom Tong[e]

ABSTRACT: We point out the necessity to consider β-decay observables in resolutions of the W-boson anomaly in the Standard Model Effective Field Theory that go beyond pure oblique corrections. We demonstrate that present global analyses that explain the W-boson mass anomaly predict a large, percent-level, violation of first-row CKM unitarity. We investigate what solutions to the W-boson mass anomaly survive after including β-decay constraints.

Big bang nucleosynthesis







PHYSICAL REVIEW VOLUME 74, NUMBER 9 NOVEMBER 1, 1948

Proceedings of the American Physical Society

MINUTES OF THE MEETING AT WASHINGTON, APRIL 29 TO MAY 1, 1948

F12. On the Radioactive Decay of the Neutron. ARTHUR H. SNELL AND L. C. MILLER, *Clinton National Laboratories.*—A collimated beam of neutrons, three inches in diameter, emerges from the nuclear reactor and passes axially through a thin-walled, aluminum, evacuated cylindrical tank. A transverse magnetic field behind the thin entrance window cleans the beam of secondary electrons. Inside the vacuum, axially arranged, an open-sided cylindrical electrode is held at +4000 volts with respect to ground. Opposite the open side a smoothed graphite plate is held at −4400 volts. The field between these electrodes accelerates and focuses protons which may result from decay of neutrons, so that they pass through a $2\frac{7}{8}\times 1\frac{5}{8}$ inch aperture in the center of the graphite plate, and strike the first dynode of a secondary electron multiplier. The first dynode is specially enlarged so as to cover the aperture. Readings are taken (1) with and without a thin B^{10} shutter in the neutron beam; (2) with and without a thin foil over the multiplier aperture; (3) with and without the accelerating voltage. In a total counting rate of about 300 per min., about 100 are sensitive to operations (1), (2), and (3). In the absence of the accelerating field or with the foil (2) in, operation (1) does not change the counting rate. Assuming all of the 100 c.p.m. to be due to decay protons, preliminary estimates of the collecting and counting efficiency (10 percent) and of the number of neutrons in the sample (4×10^4) give for the neutron a half-life of about 30 minutes. It is at present much safer however to say that the neutron half-life must exceed 15 minutes. Coincidences are presently being sought between the disintegration betas and the collected protons.

(880 s)×ln2 ~ 10.2 minutes

Angular Correlation in the Beta Decay of the Neutron

J. M. ROBSON
Chalk River Laboratory, Atomic Energy of Canada Limited, Chalk River, Ontario, Canada

(Received August 22, 1955)

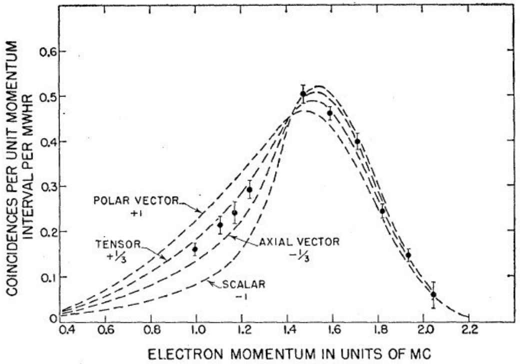
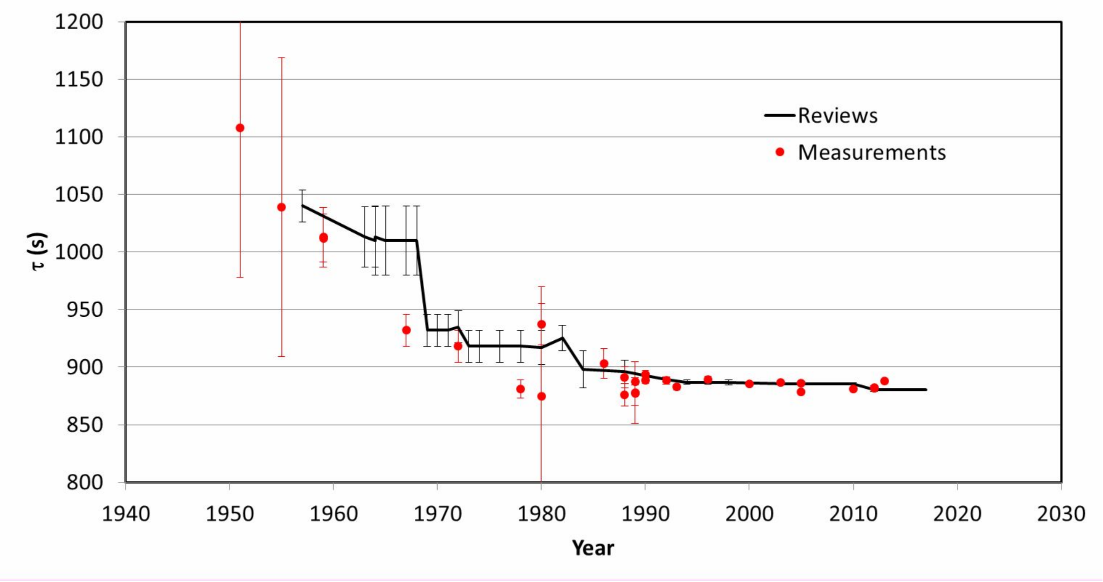
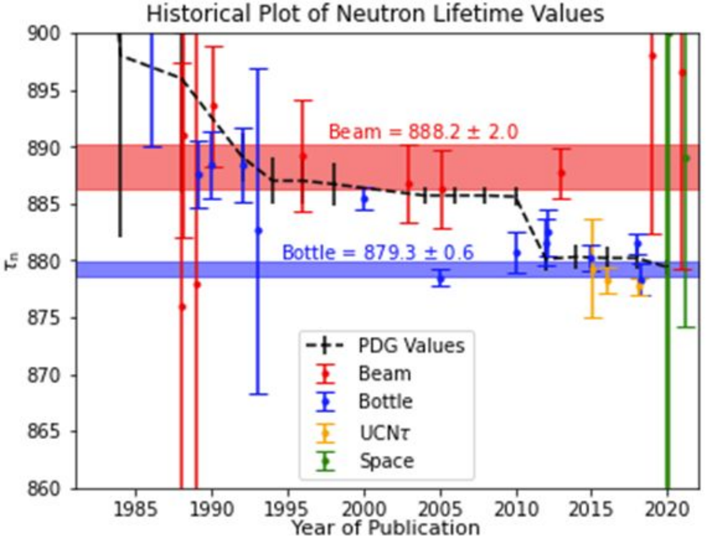


FIG. 3. The momentum spectrum of the electrons. The points represent the experimental data with standard deviations, and the dashed curves are the theoretical spectrum shapes for the pure interactions normalized by least squares.

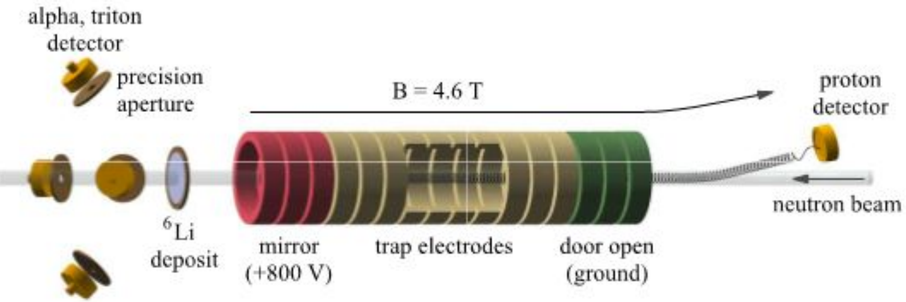
A storied history





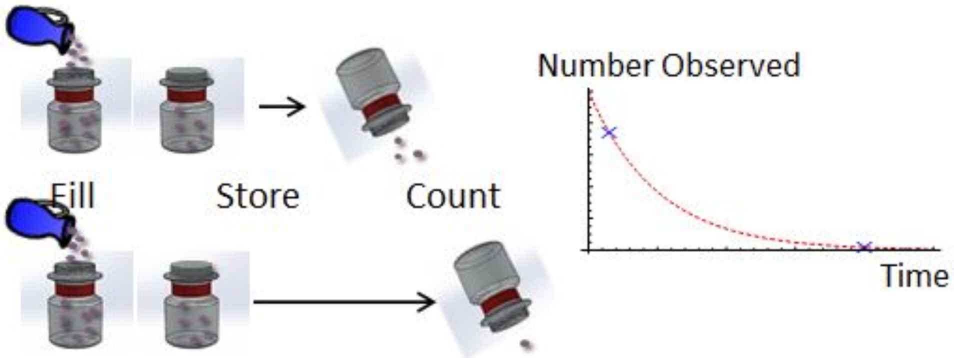
The “beam” and “bottle” techniques

$$\tau_n = \frac{L}{v_n}\frac{\dot{N}_n/\epsilon_n}{\dot{N}_p/\epsilon_p}$$



$$Y(t) = Y_0 e^{-t\,/\,\tau_{meas}}$$

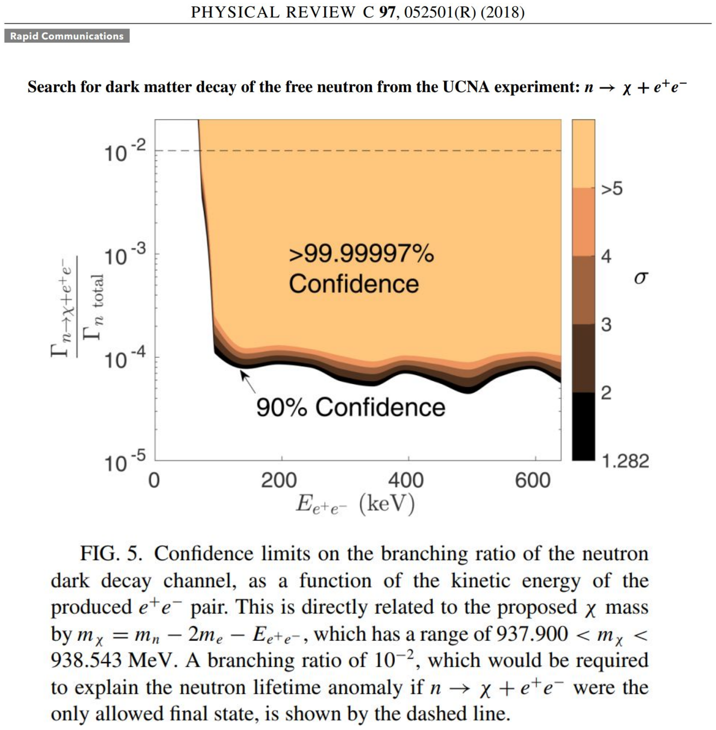
$$\tau_{meas}^{-1} = \tau_n^{-1} + \tau_{loss}^{-1}$$



“It sounds hard, and it is hard”
Geoff Greene

“It sounds easy, and it is hard”
Geoff Greene

Tackling the lifetime problem

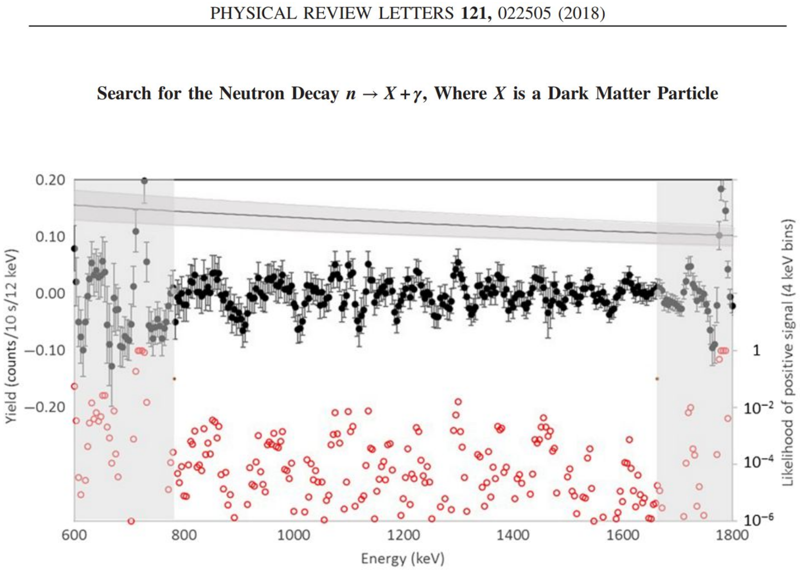


PHYSICAL REVIEW C **97**, 052501(R) (2018)

Rapid Communications

Search for dark matter decay of the free neutron from the UCNA experiment: $n \rightarrow \chi + e^+e^-$

FIG. 5. Confidence limits on the branching ratio of the neutron dark decay channel, as a function of the kinetic energy of the produced e^+e^- pair. This is directly related to the proposed χ mass by $m_\chi = m_n - 2m_e - E_{e^+e^-}$, which has a range of $937.900 < m_\chi < 938.543$ MeV. A branching ratio of 10^{-2}, which would be required to explain the neutron lifetime anomaly if $n \rightarrow \chi + e^+e^-$ were the only allowed final state, is shown by the dashed line.



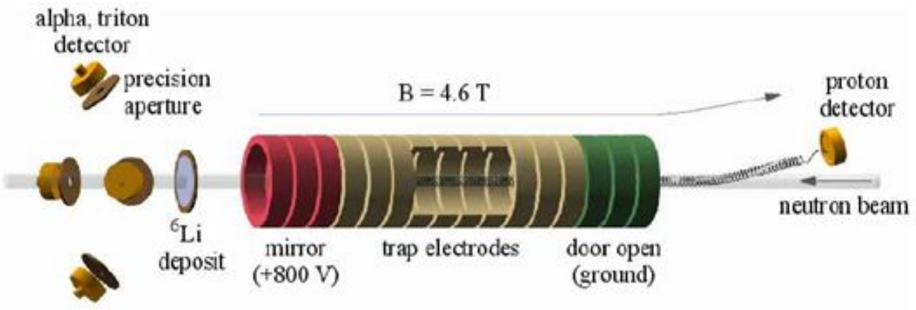
PHYSICAL REVIEW LETTERS **121**, 022505 (2018)

Search for the Neutron Decay $n \rightarrow X + \gamma$, Where X is a Dark Matter Particle

from Nadia Fomin

The BL2 experiment at NIST

- Data taking with Mark II trap complete
  - Mark III trap was installed right before unplanned NCNR outage
- Cold Source Upgrade timeline limits remaining data taking

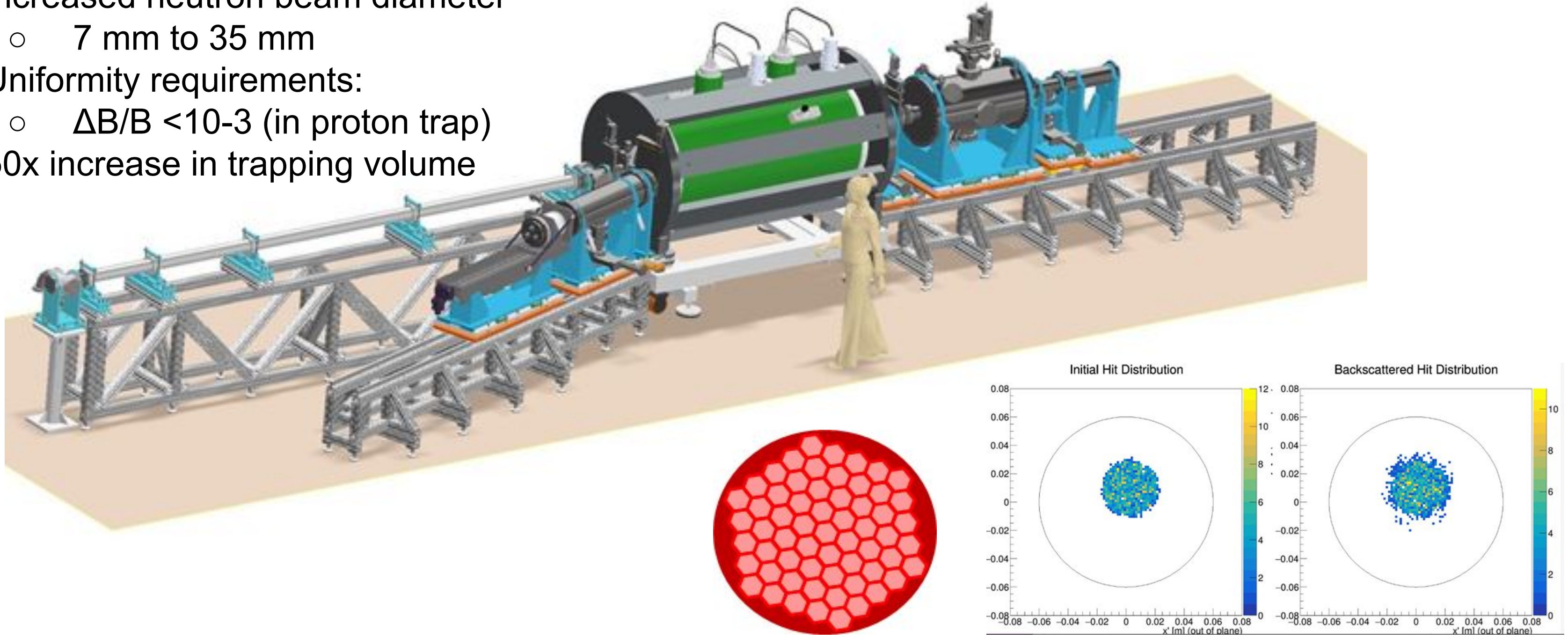


- Neutron flux monitor efficiency – 2.7s
  - Alpha-Gamma technique (0.5s)
- Neutron absorption by 6Li – .8s
  - Measured neutron spectrum, thinner foils (0.6s)
- Neutron beam halo – 1.0s
  - Larger proton detector, simulation, better imaging methods (0.2s)
- Electrode trap nonuniformity – 0.8s
  - Use 9 electrodes, Mark 3 trap (0.2s)
- Proton counting statistics – 1.2s
  - Larger neutron flux, longer run time, more stable detection system (TBD)

from Nadia Fomin

The BL3 experiment

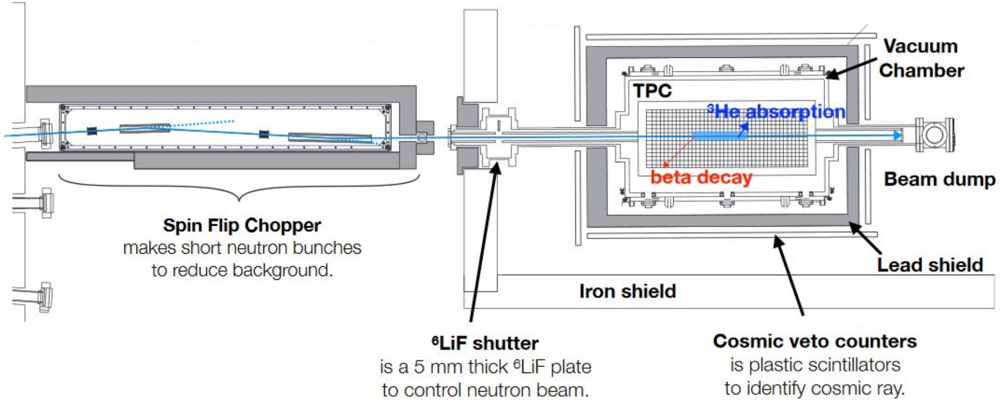
- Increased neutron beam diameter
  - 7 mm to 35 mm
- Uniformity requirements:
  - ΔB/B <10-3 (in proton trap)
- 50x increase in trapping volume



Successful project review at NSF completed – recommended for full funding!

from Naoyuki Sumi

The JPARC TPC



Spin Flip Chopper
makes short neutron bunches
to reduce background.

⁶LiF shutter
is a 5 mm thick ⁶LiF plate
to control neutron beam.

Cosmic veto counters
is plastic scintillators
to identify cosmic ray.

↓ **Data analysis**

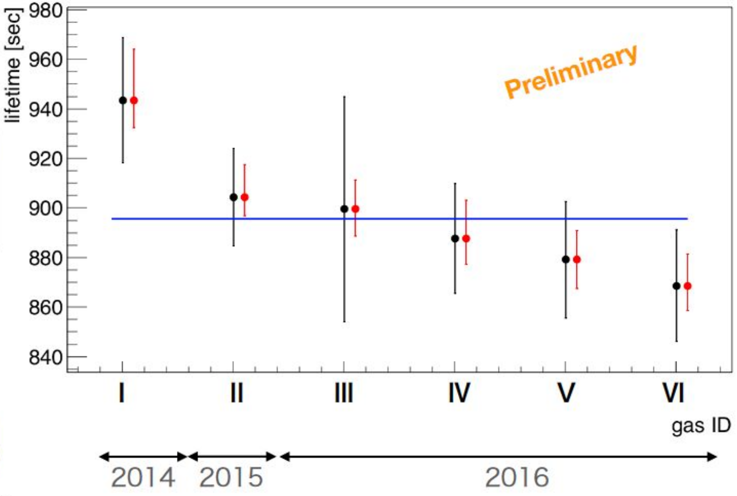
$$\tau_n = \frac{1}{\rho\sigma v}\left(\frac{S_{\mathrm{He}}/\varepsilon_{\mathrm{He}}}{S_\beta/\varepsilon_\beta}\right)$$

Injected ³He ↑

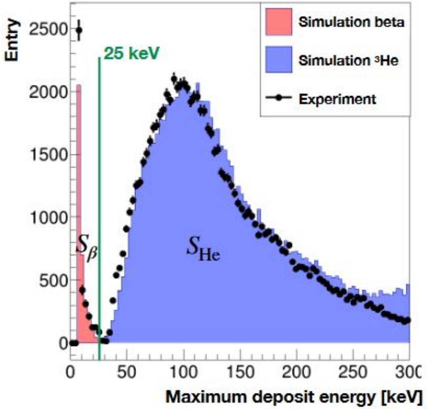
↑ Literature value
5333 ± 7 barn
2200 m/s

↑ Simulation analysis

$$\tau_n = 896 \pm 10\,(\mathrm{stat})\,{}^{+14}_{-10}\,(\mathrm{syst})\ \mathrm{sec}$$



- beam optics upgrade (5x stats)
- low-P operation, improved amps
- solenoid for background suppression



The gravitrap at the ILL

- Only remaining material bottle experiment
- lifetime of $881.5(0.7)_{stat}(0.6)_{syst}$ s (3.2σ higher than 2008)
- Plans to cool to *10* K, repeat measurement

$$\tau_{st}^{-1}(E) = \tau_n^{-1} + \tau_{\text{loss}}^{-1}(E) \qquad \tau_{\text{loss}}^{-1} = \eta(T)\gamma(E)$$

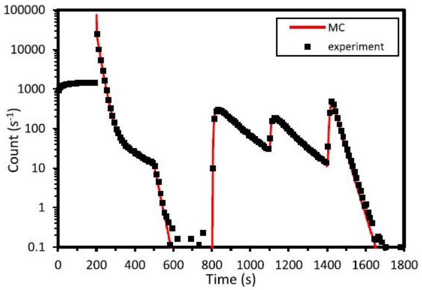
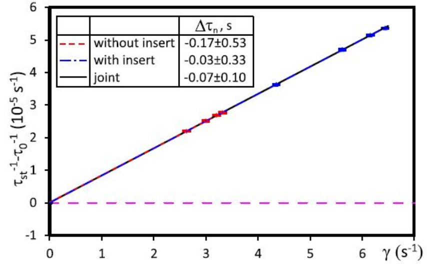


FIG. 5. Simulated and measured UCN registered by the detector.



	$\Delta\tau_n$, s
without insert	-0.17±0.53
with insert	-0.03±0.33
joint	-0.07±0.10

FIG. 7. The results of the MC model self-consistence test.

PHYSICAL REVIEW C **97**, 055503 (2018)

Neutron lifetime measurements with a large gravitational trap for ultracold neutrons

A. P. Serebrov,[1,*] E. A. Kolomensky,[1] A. K. Fomin,[1] I. A. Krasnoshchekova,[1] A. V. Vassiljev,[1] D. M. Prudnikov,[1] I. V. Shoka,[1] A. V. Chechkin,[1] M. E. Chaikovskiy,[1] V. E. Varlamov,[1] S. N. Ivanov,[1] A. N. Pirozhkov,[1] P. Geltenbort,[2] O. Zimmer,[2] T. Jenke,[2] M. Van der Grinten,[3] and M. Tucker[3]

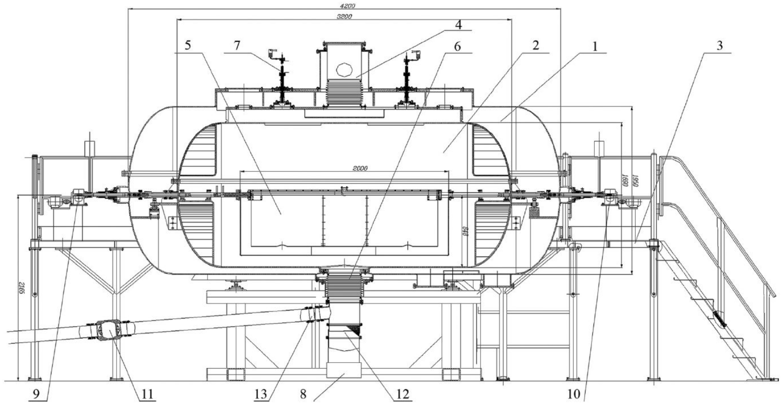


FIG. 2. 1 external vacuum vessel, 2–internal vacuum vessel, 3–platform for service, 4–gear for pumping out internal vessel, 5–trap with insert in low position, 6–neutron guide system, 7–system of coating of trap and insert, 8–detector, 9–mechanism for turning trap, 10–mechanism for turning insert, 11–turbine shutter, 12–detector shutter, 13–neutron guide shutter.

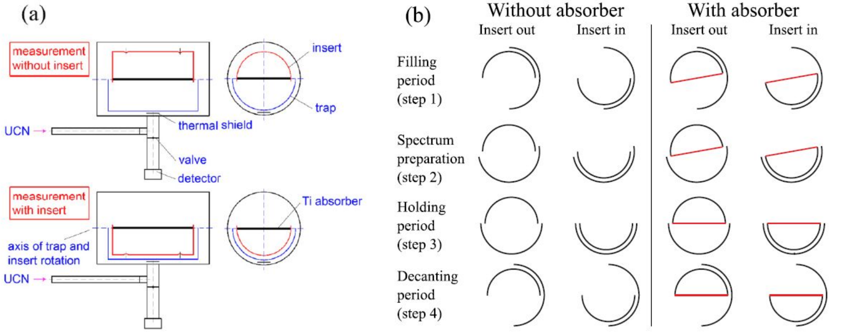
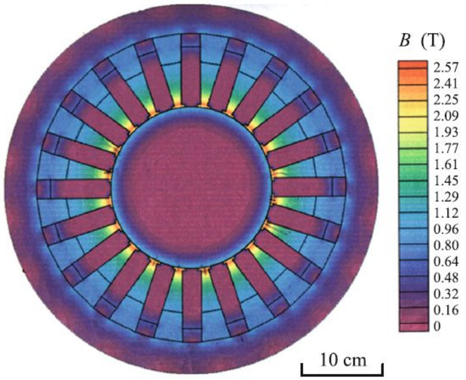
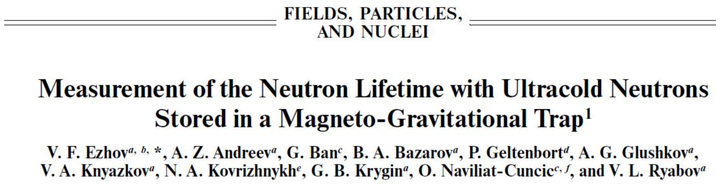


FIG. 1. Basic scheme of inner part of the apparatus (a) with conceptual scheme for the measuring procedures (b)

The ILL magneto-gravitational trap

- Permanent magnet Halbach array, regular conducting coils
- Novel “elevator” loading system
- 3.7 s extrapolation to final result from known UCN losses due to spin flips. Monitored *in situ* with the detector
    - lifetime of *878.3(1.6)(1.0)* s
- A new trap with increased volume has been proposed




FIELDS, PARTICLES, AND NUCLEI

Measurement of the Neutron Lifetime with Ultracold Neutrons Stored in a Magneto-Gravitational Trap[1]

V. F. Ezhov[a, b, *], A. Z. Andreev[a], G. Ban[c], B. A. Bazarov[a], P. Geltenbort[d], A. G. Glushkov[a], V. A. Knyazkov[a], N. A. Kovrizhnykh[e], G. B. Krygin[a], O. Naviliat-Cuncic[c, f], and V. L. Ryabov[a]

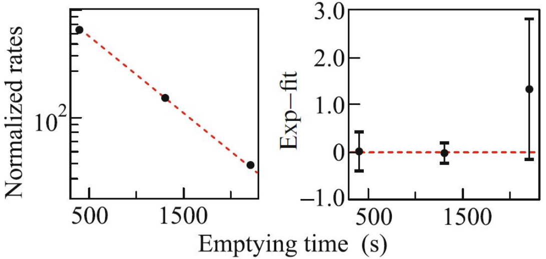
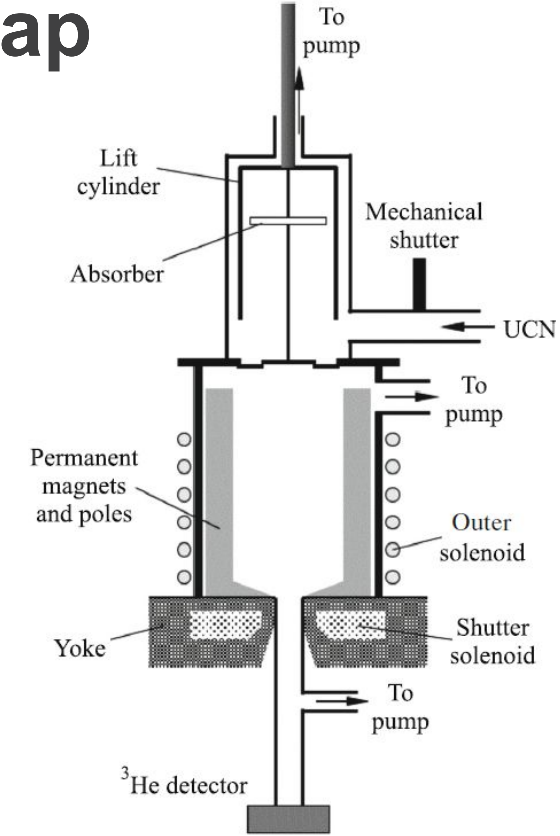
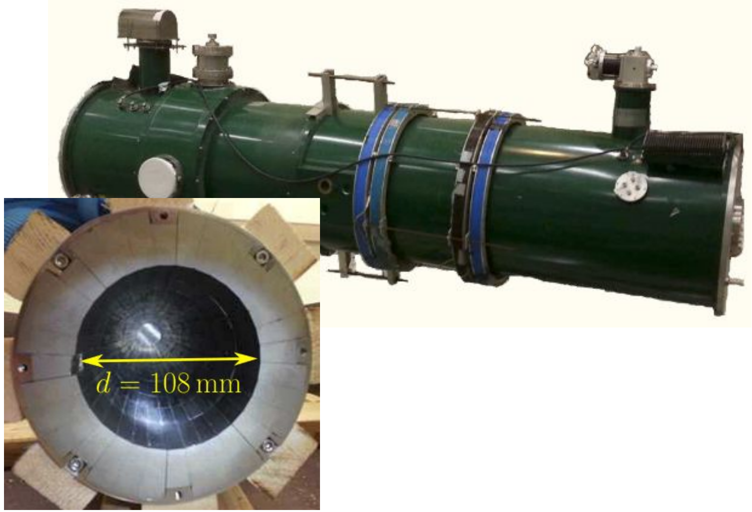


Fig. 3. (Color online) (a) Normalized rates and fit from run A. (b) Differences between experimental data and fit.

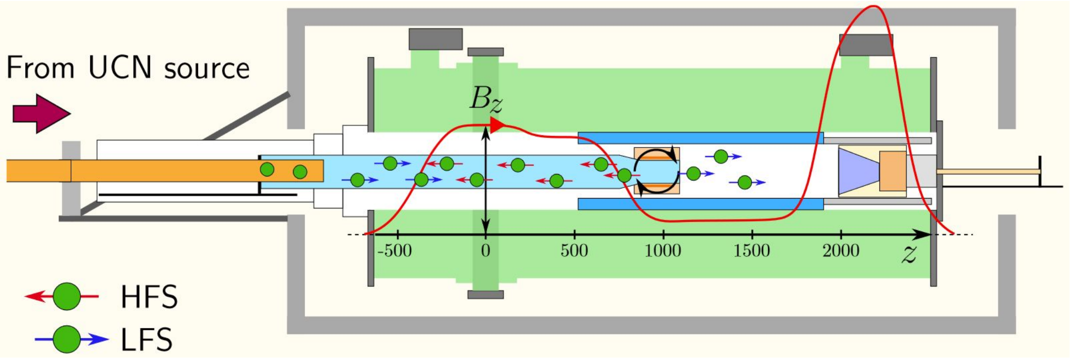


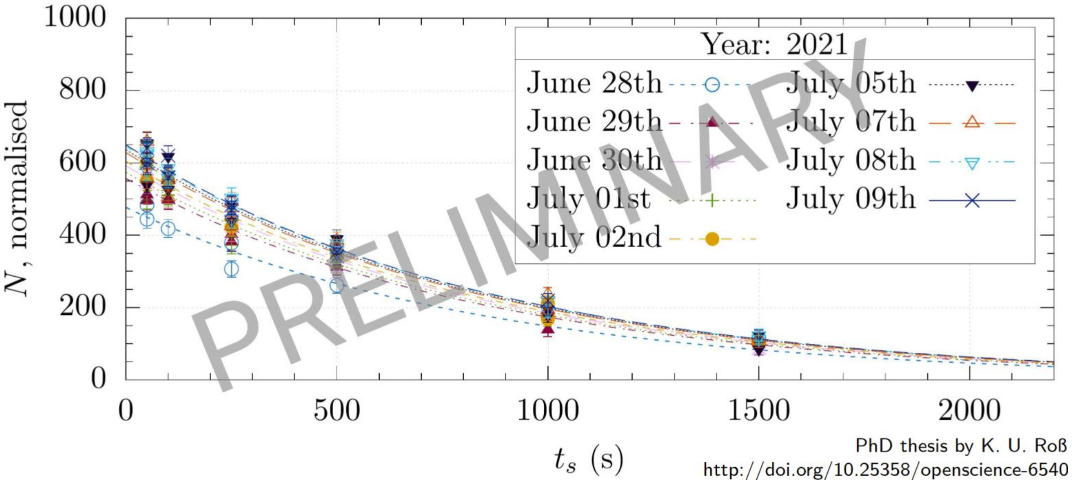
from Kim Ulrike Ross

τSPECT in Mainz



- 10L octupole trap using former aSPECT solenoids
- Novel spin-flip loading scheme
- Moveable *in situ* detector
- First results forthcoming, need to address quasi-stable neutron trajectories





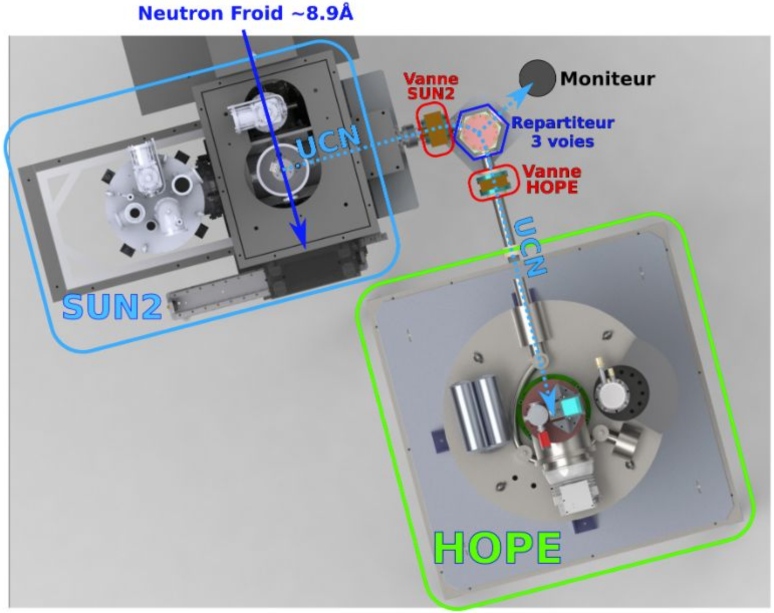
PhD thesis by K. U. Roß
http://doi.org/10.25358/openscience-6540

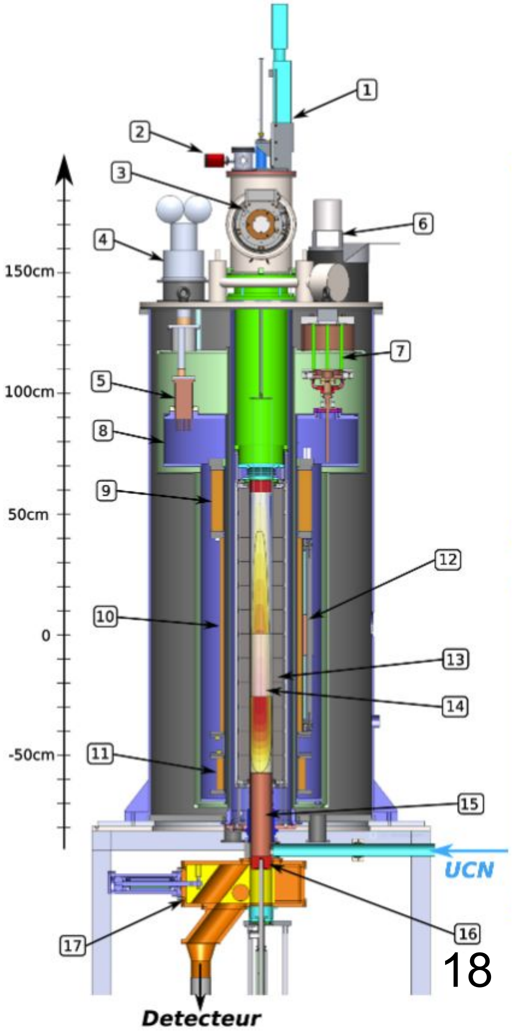
$$\tau = 858.6(15.5)\,\mathrm{s}\ (\chi^2/\mathrm{ndf} = 1.14,\ \mathrm{ndf} = 109)$$

Loris Babin, PhD dissertation (2019)

HOPE at the ILL

- Permanent magnet octupole, superconducting end coils
- Preliminary storage time measurements of 899(19) s and 882(17) s
- Expect sub-second stat error per reactor cycle
- Changing to horizontal configuration with regular conducting coils, larger trap volume and reduced vibration

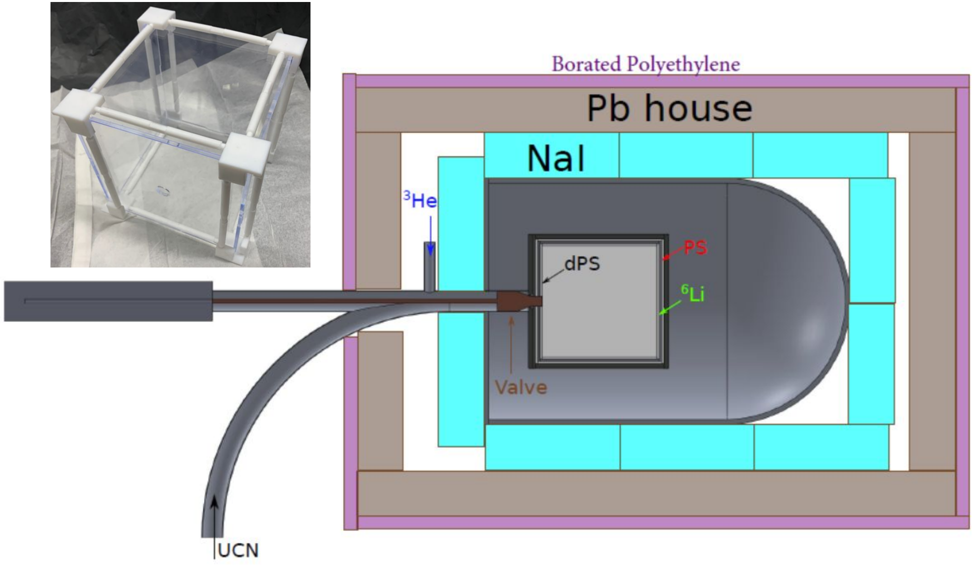


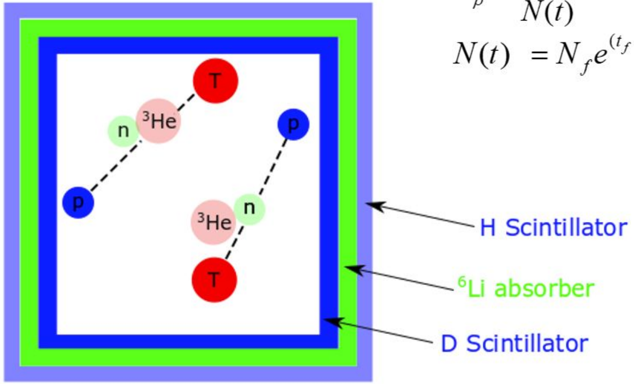


from Zhaowen Tang

UCNProBe at LANL

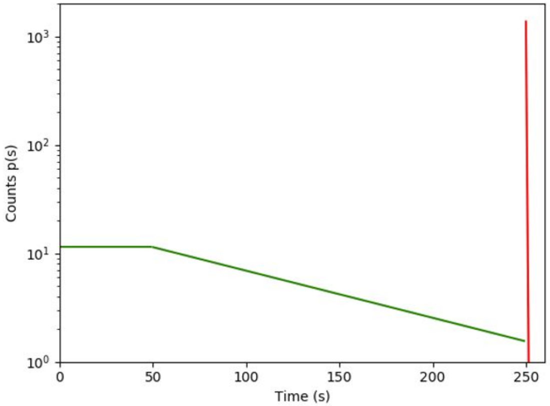
- 4π scintillator UCN volume
- Normalize number of βs to absolute measurement of UCN using ^{3}He gas
- Absolute measurement requires knowledge of scintillator dead layer, other inefficiencies
- Requires considerable background mitigation
- Currently procuring scintillator, electronics for feasibility demonstration with $\alpha/\beta/\gamma$ sources





$$\tau_\beta = \frac{\beta(t)}{N(t)}$$

$$N(t) = N_f e^{(t_f - t)/\tau}$$



from Jack Wilson

Neutrons

- Compare MCNP model of neutron flux from moon’s surface as detected by the Lunar Prospector as a function of altitude
- Treat neutron lifetime as a free parameter in comparing the model
  - $\tau_n = 887 \pm 14_{\text{stat}}\,{}^{+7}_{-3\,\text{syst}}$ s
- Considering venusian or terrestrial orbit experiment, lunar surface experiment

PHYSICAL REVIEW C **104**, 045501 (2021)

Measurement of the free neutron lifetime using the neutron spectrometer on NASA’s Lunar Prospector mission

Jack T. Wilson,* David J. Lawrence, and Patrick N. Peplowski
The Johns Hopkins Applied Physics Laboratory, 11101 Johns Hopkins Road, Laurel, Maryland 20723, USA

Vincent R. Eke and Jacob A. Kegerreis
Institute for Computational Cosmology, Durham University, South Road, Durham DH1 3LE, United Kingdom

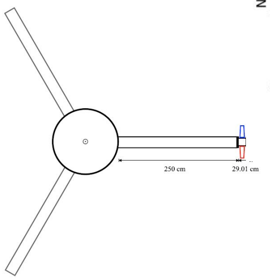
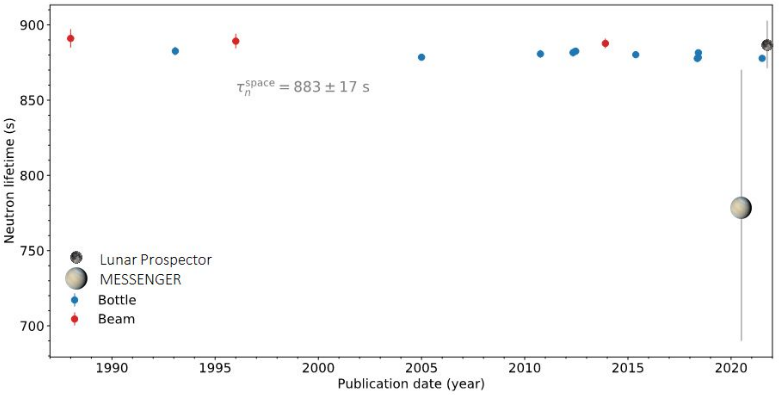
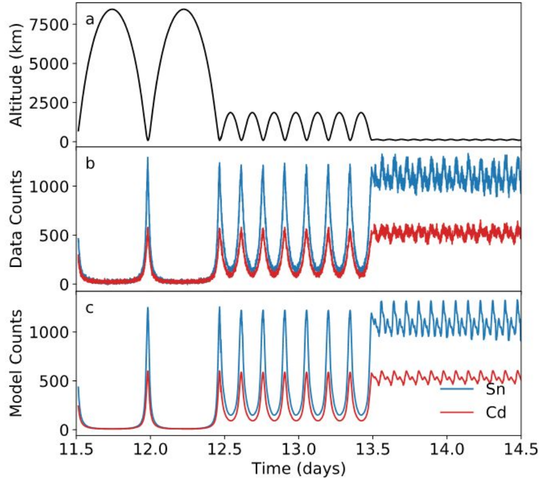


FIG. 5. A cartoon of the LP spacecraft and NS looking along the spacecraft rotation axis. The locations of the Sn-covered and Cd-covered tubes are shown in red and blue, respectively. The axis of rotation, pointing out of the page, is indicated with the circled dot.





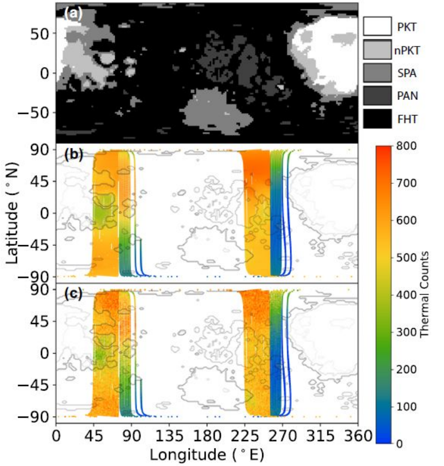
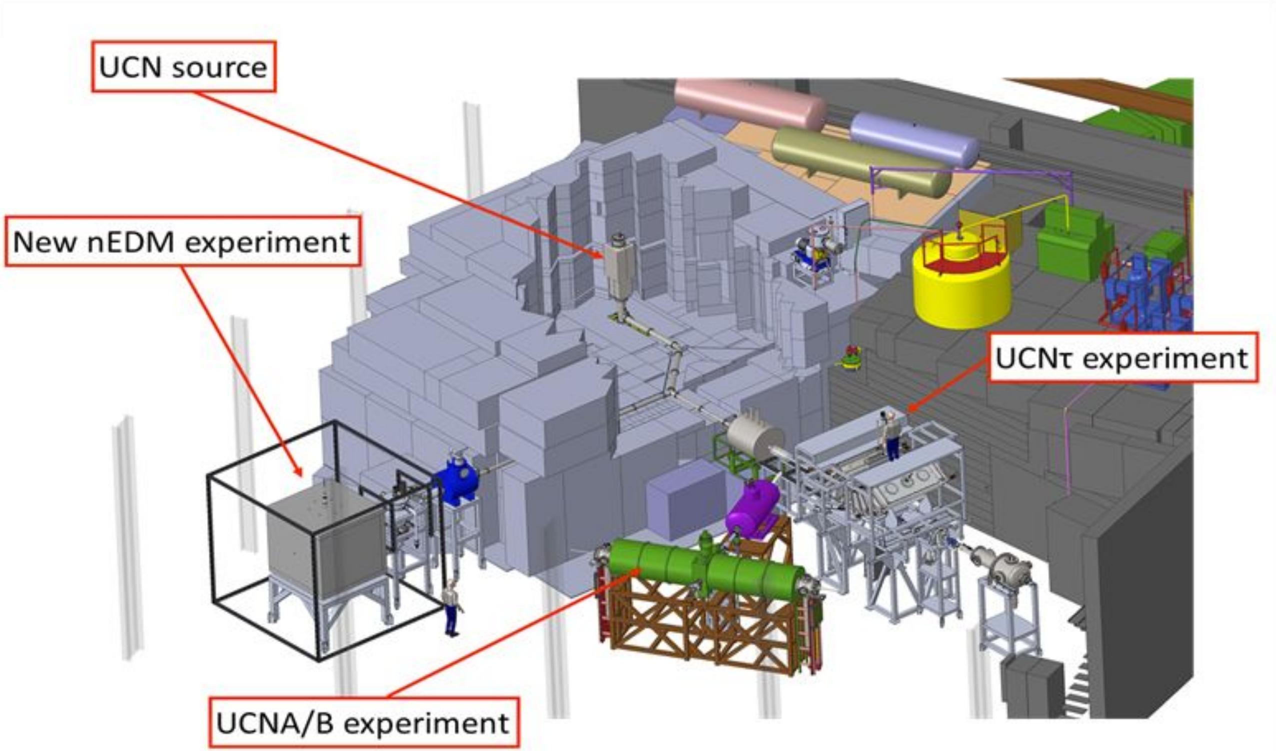


FIG. 3. (a) The five regions with distinct compositions included in the neutron count-rate models: procellarum KREEP terrane (PKT), south pole Aitken terrane (SPAT), Feldspathic highland terrane (FHT), pure anorthosite terrane (PAN), and non-PKT maria (nPKT). (b) The model thermal neutron counts, i.e., the difference between the Sn-covered and Cd-covered detectors. (c) The measured thermal detector counts. The grey contours in (b) and (c) show the regions defined in (a).

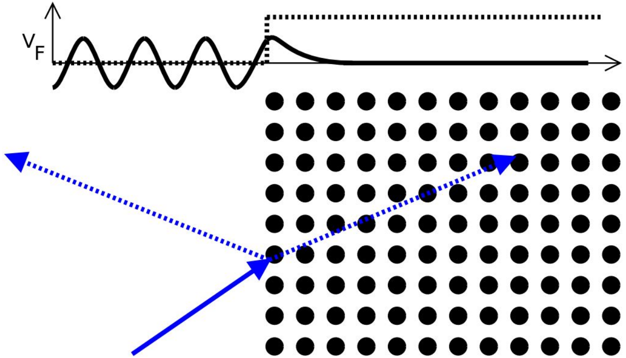
The UCNτ collaboration

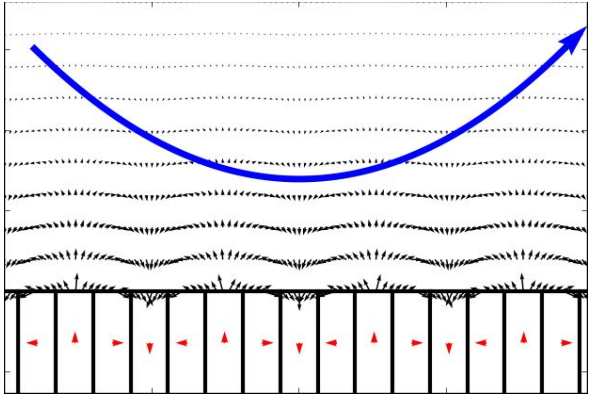
- **Argonne National Laboratory**
    - N Callahan
- **California Institute of Technology**
    - M Blatnik, B Filippone, E M Fries, K P Hickerson, S Slutsky, V Su, X Sun, C Swank, W Wei
- **DePauw University**
    - A Komives
- **East Tennessee State University**
    - R W Pattie, Jr
- **Indiana University and CEEM**
    - M Dawid, W Fox, C-Y Liu, F Gonzalez, D J Salvat, J Vanderwerp, G Visser
- **Institut Laue-Langevin**
    - P Geltenbort
- **Joint Institute for Nuclear Research**
    - E I Sharapov
- **Los Alamos National Laboratory**
    - S M Clayton, S A Curry, M A Hoffbauer, T M Ito, M Makela, C L Morris, C O'Shaughnessy, Z Tang, P L Walstrom, Z Wang
- **North Carolina State University**
    - T Bailey, J Choi, C Cude-Woods, L Hayen, R Musedinovic, A R Young
- **Oak Ridge National Laboratory**
    - L J Broussard, J Ramsey, A Saunders
- **Tennessee Technological University**
    - R Colon, D Dinger, J Ginder, A T Holley, M Kemp, C Swindell

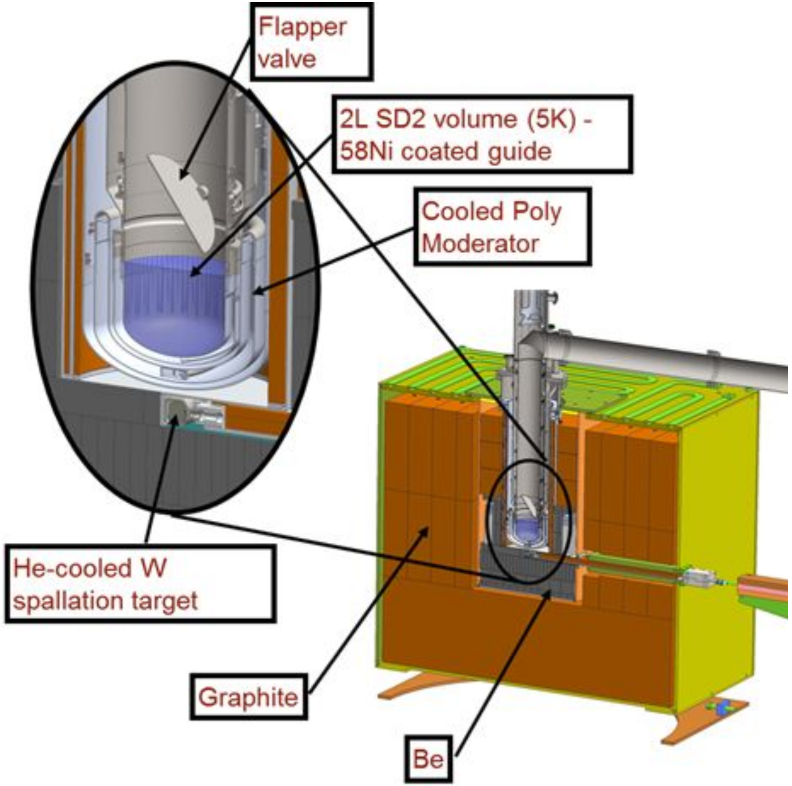
LANSCE Area B



Ultracold neutrons






Flapper valve

2L SD2 volume (5K) - 58Ni coated guide

Cooled Poly Moderator

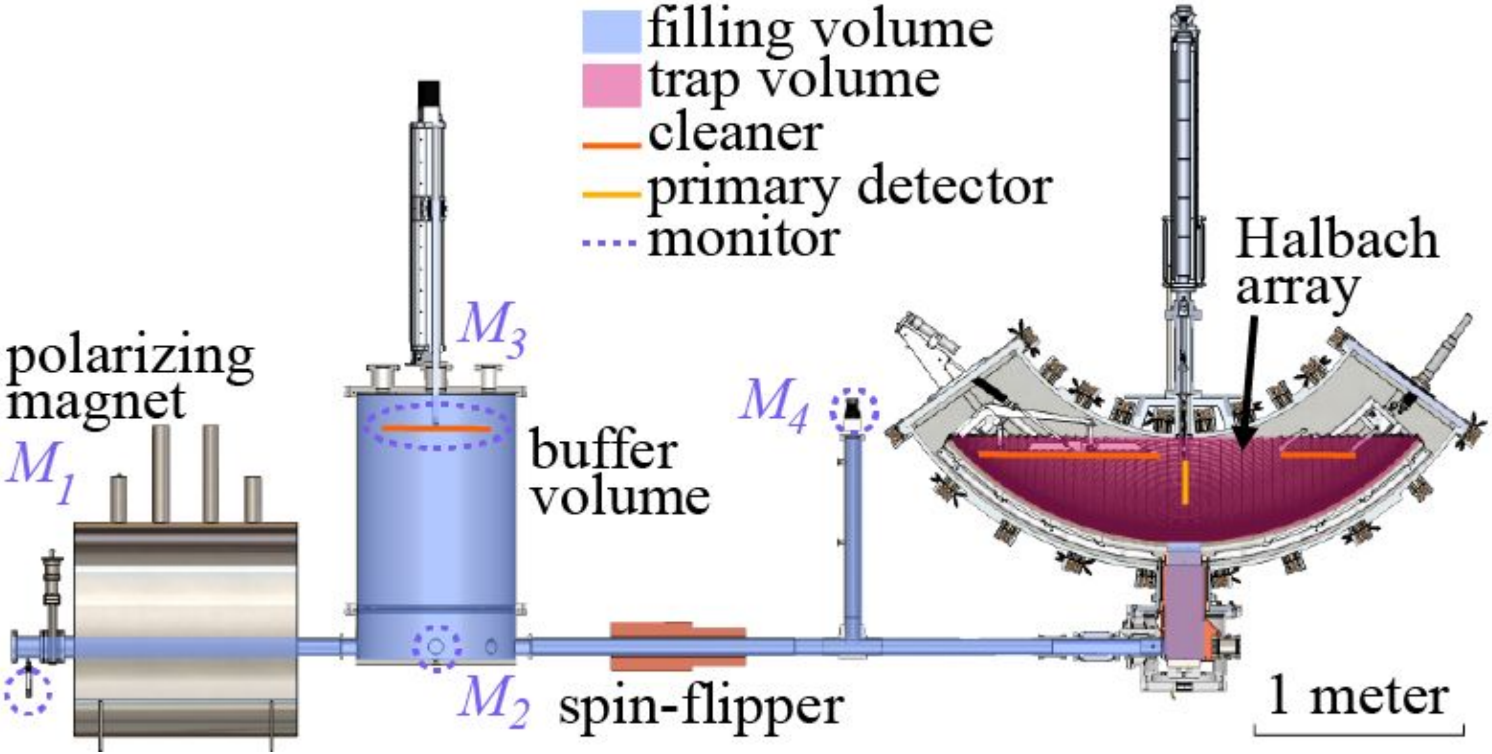
He-cooled W spallation target

Graphite

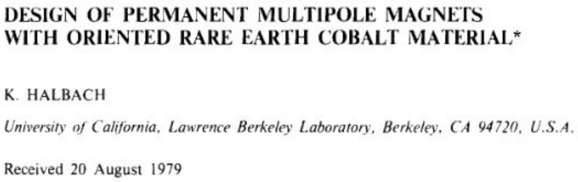
Be

Ultracold neutrons

The UCNτ experiment



The UCNτ “Halbach” array



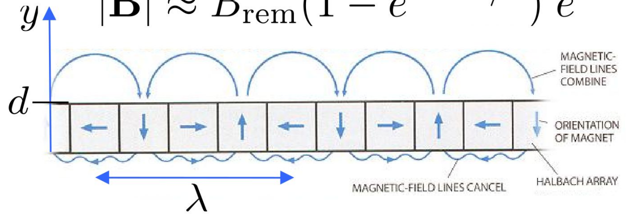
DESIGN OF PERMANENT MULTIPOLE MAGNETS
WITH ORIENTED RARE EARTH COBALT MATERIAL*

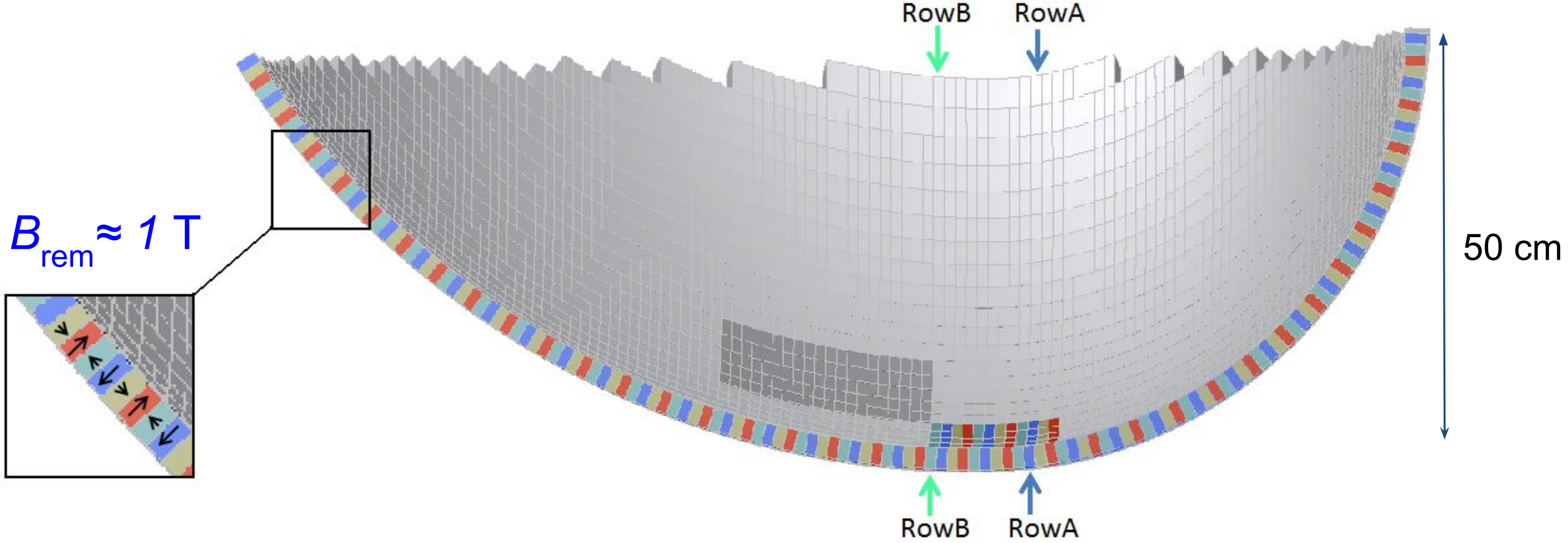
K. HALBACH

University of California, Lawrence Berkeley Laboratory, Berkeley, CA 94720, U.S.A.

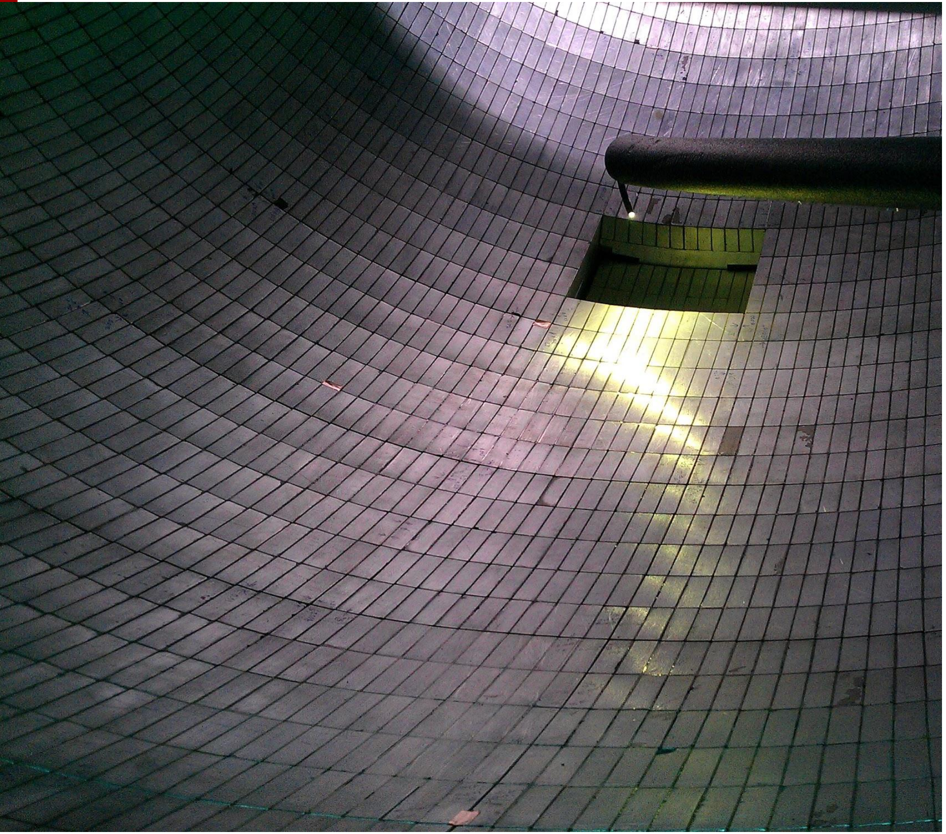
Received 20 August 1979

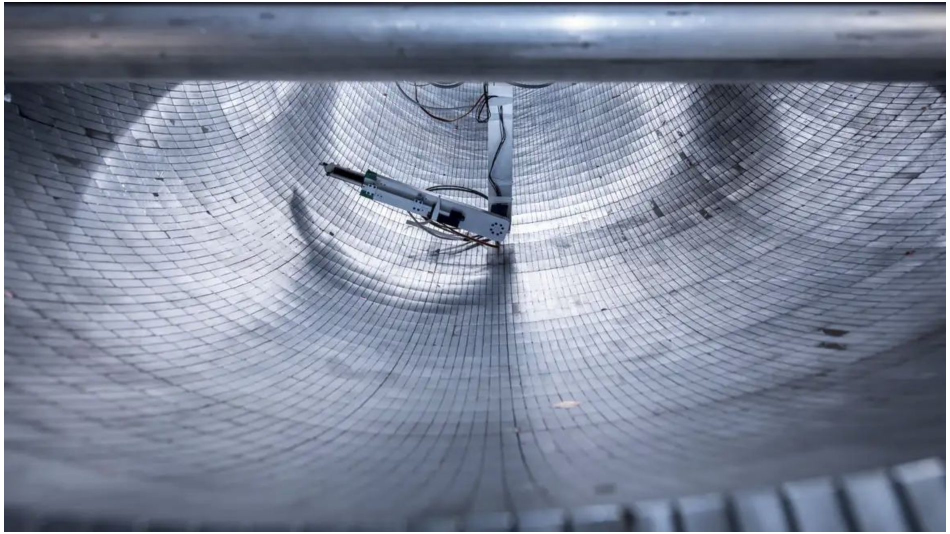
$$|\mathbf{B}| \approx B_{\mathrm{rem}}(1-e^{-2\pi d/\lambda})\, e^{-2\pi y/\lambda}$$

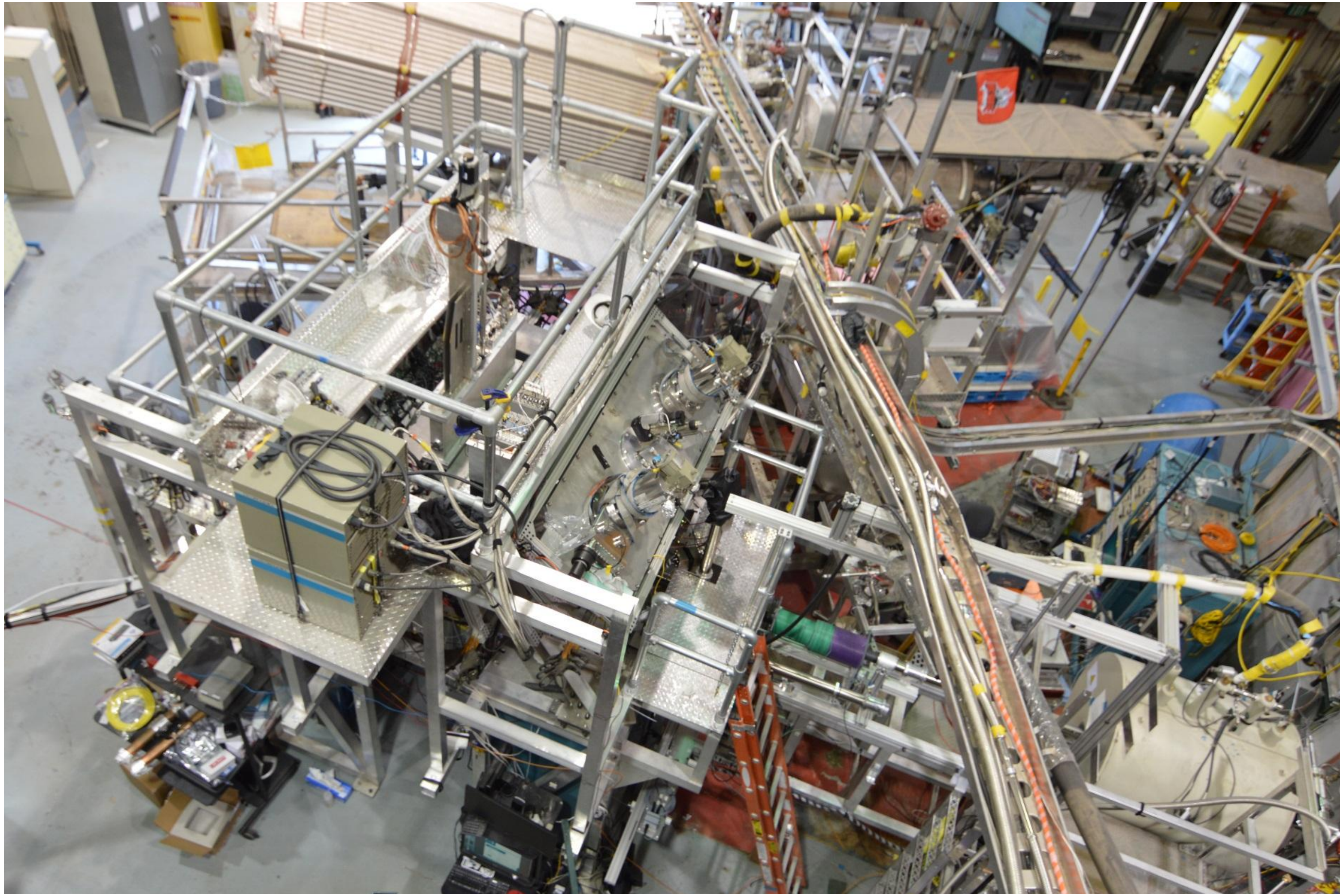




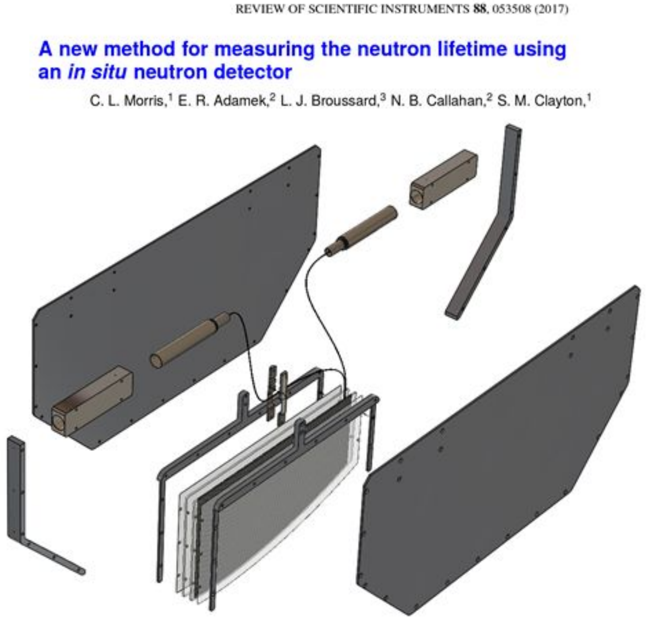
$B_{\mathrm{rem}} \approx 1$ T







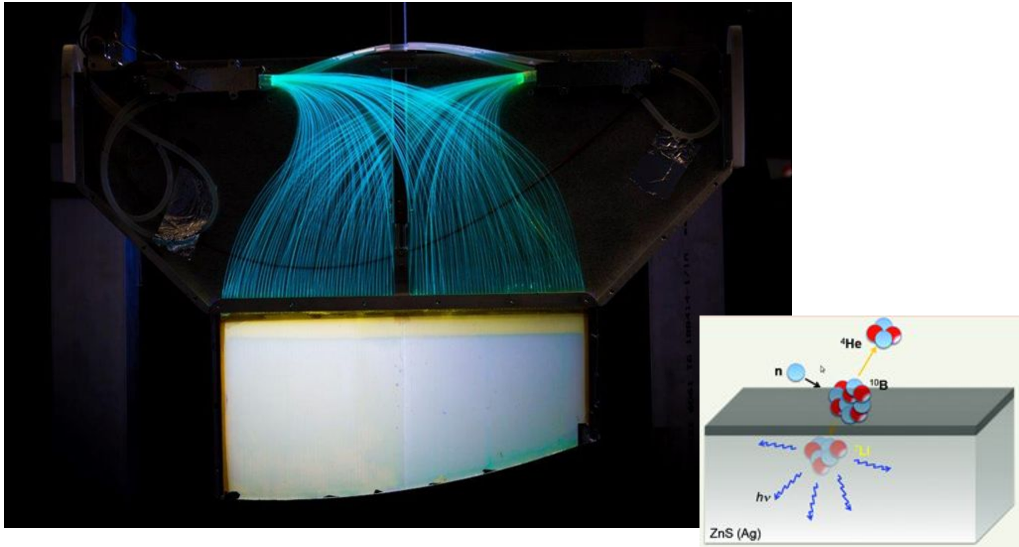
The “dagger” detector



REVIEW OF SCIENTIFIC INSTRUMENTS **88**, 053508 (2017)

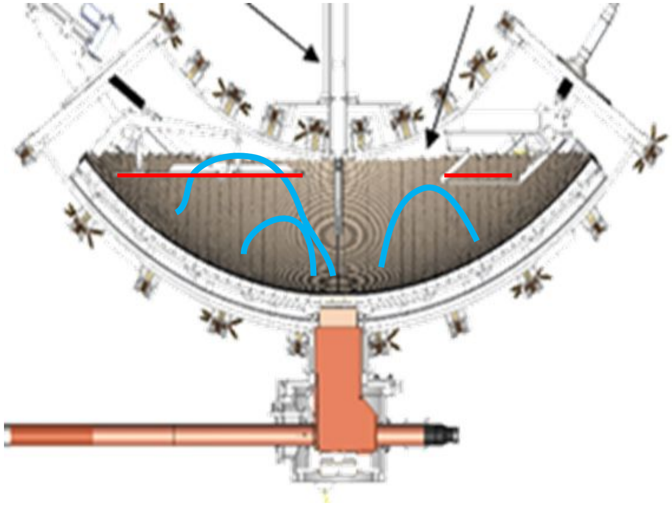
A new method for measuring the neutron lifetime using an *in situ* neutron detector

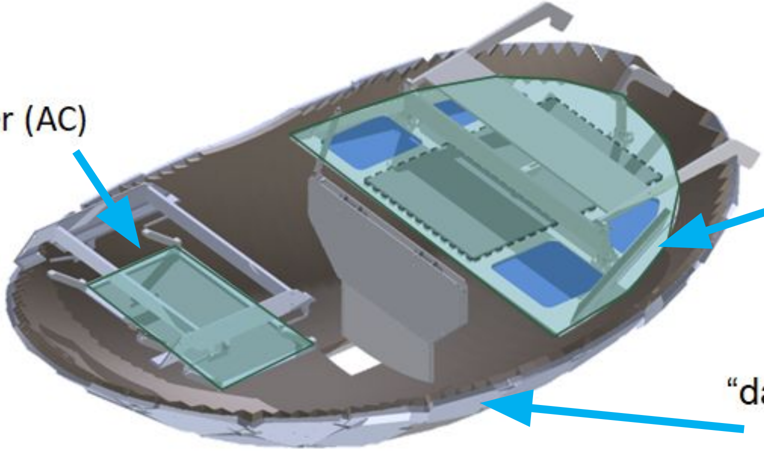
C. L. Morris,[1] E. R. Adamek,[2] L. J. Broussard,[3] N. B. Callahan,[2] S. M. Clayton,[1]



Permits UCN detection ***in the trap!***

How to “clean” UCN



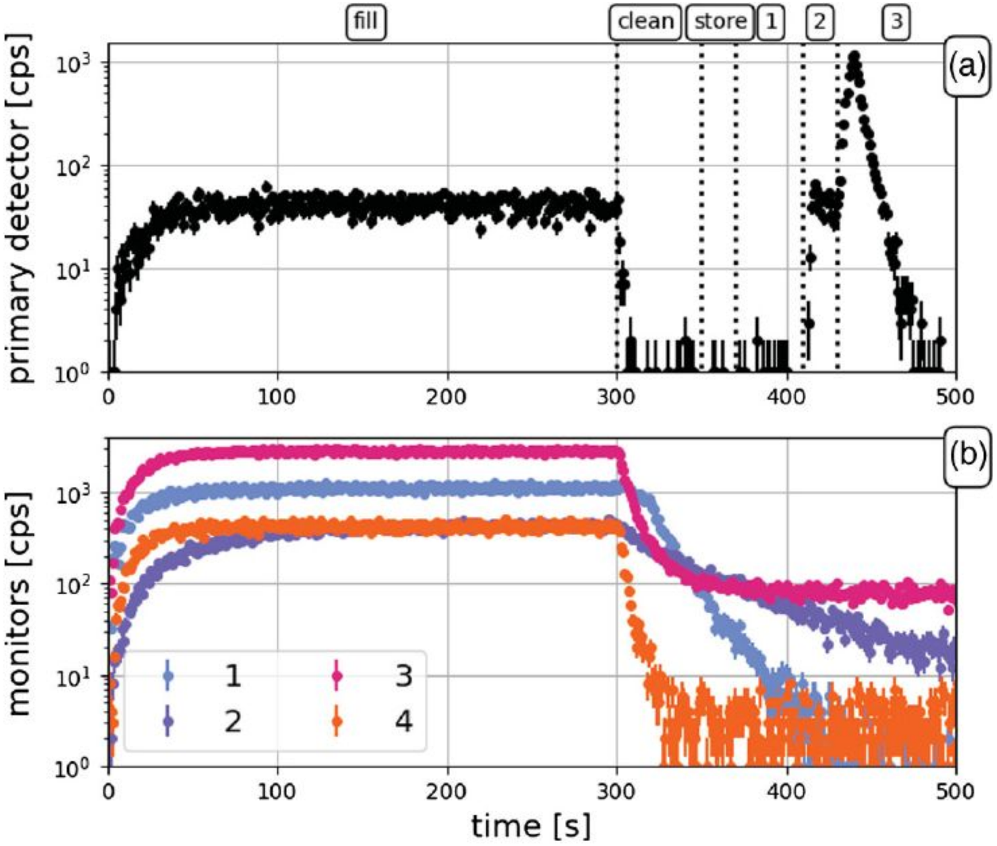


active cleaner (AC)

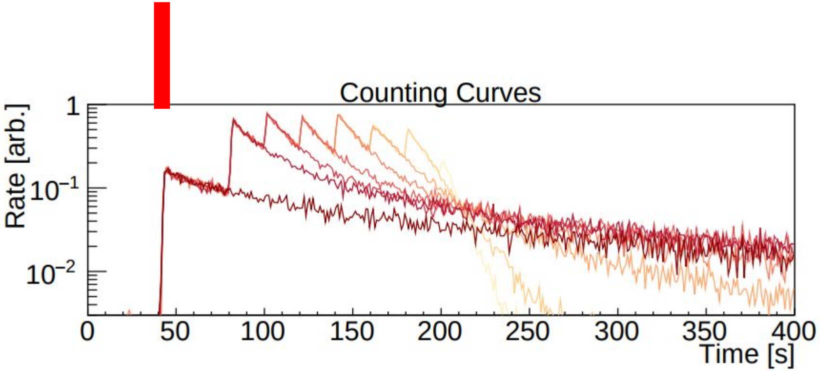
giant cleaner
(GC)

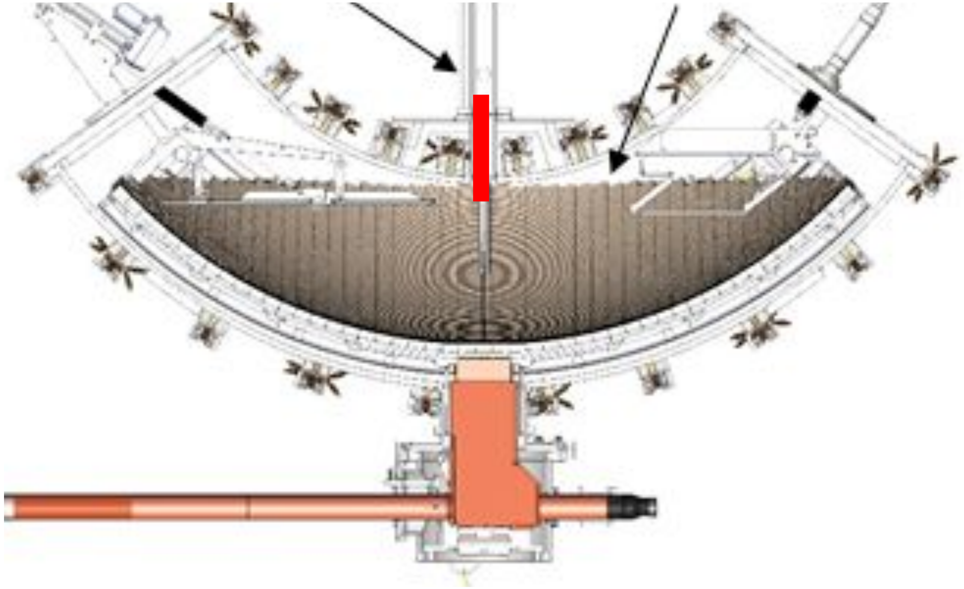
“dagger” detector

What do data look like?

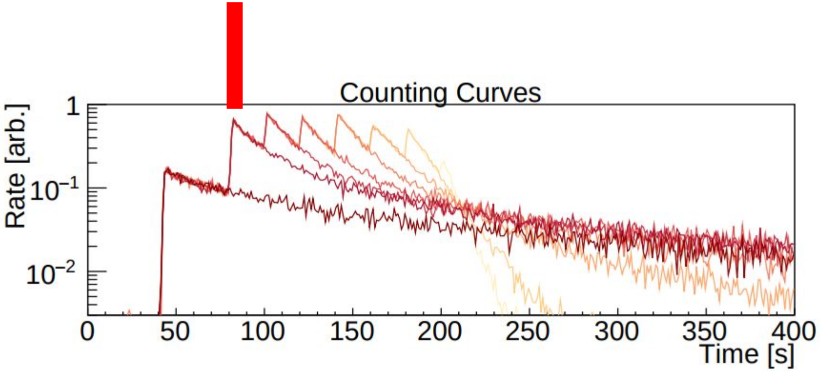


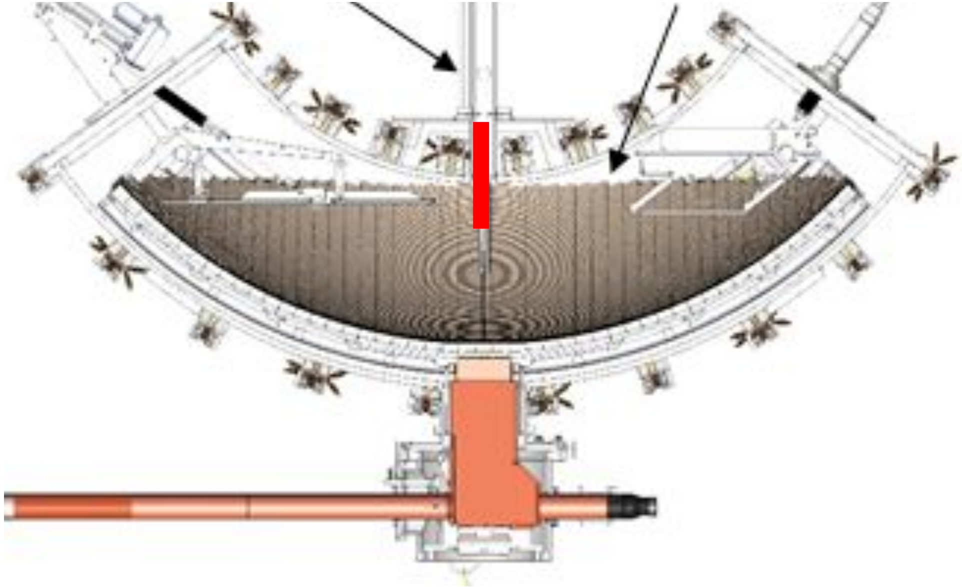
The dagger probes systematic effects



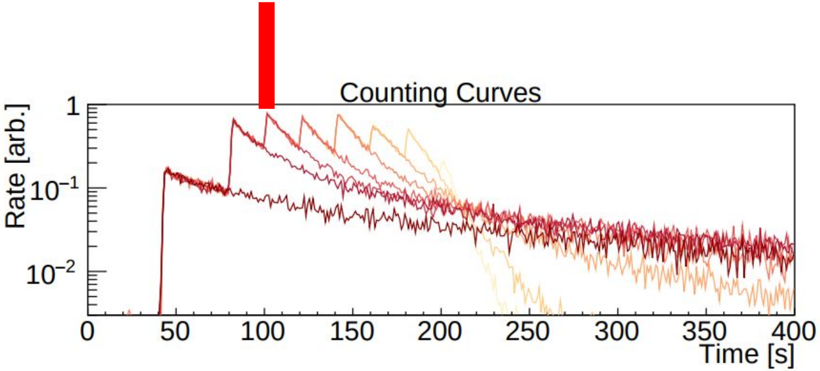


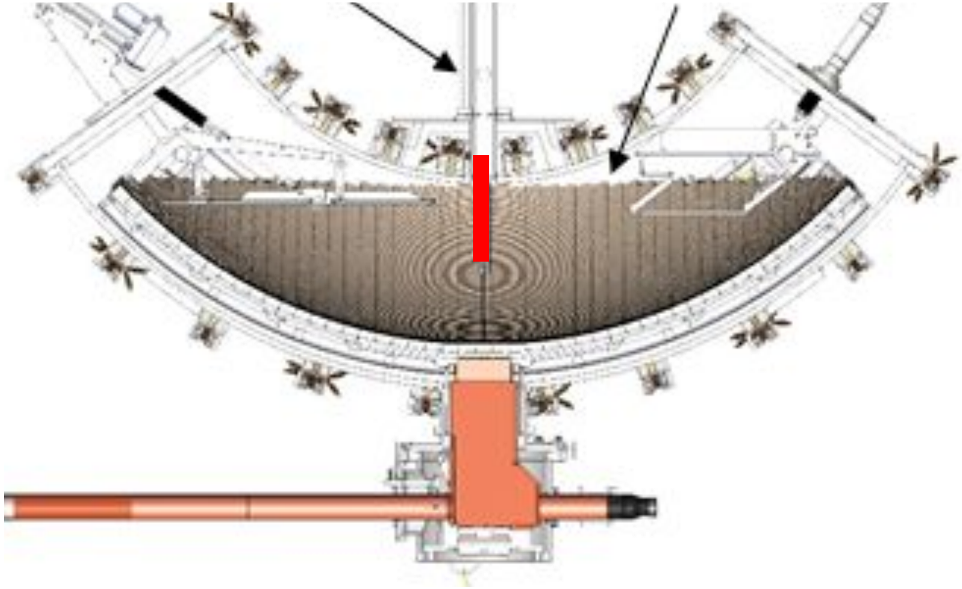
The dagger probes systematic effects





The dagger probes systematic effects

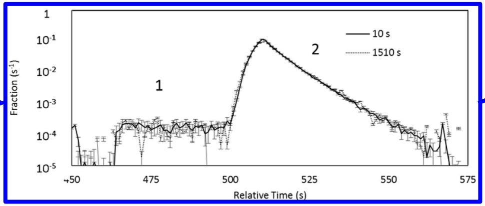




Analyzing data...

Single p.e. dagger counts

UCN events passing cuts

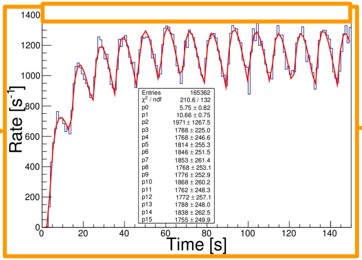


Dagger unload counts

Background measurements

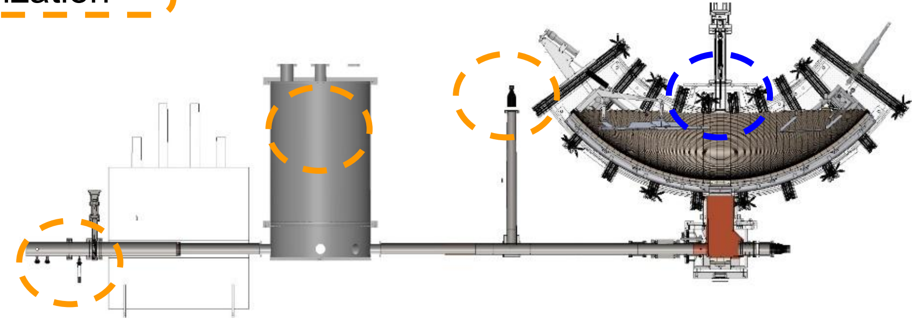
$$Y_t = \frac{D_t - B}{M}$$

“Monitor” detector counts



Entries	165362
χ^2 / ndf	210.6 / 132
p0	5.75 ± 0.82
p1	10.66 ± 0.75
p2	1971 ± 1267.5
p3	1788 ± 225.0
p4	1768 ± 246.6
p5	1814 ± 255.3
p6	1846 ± 251.5
p7	1853 ± 261.4
p8	1768 ± 253.1
p9	1776 ± 252.9
p10	1868 ± 260.2
p11	1762 ± 248.3
p12	1772 ± 257.1
p13	1788 ± 248.0
p14	1838 ± 262.5
p15	1755 ± 249.9

“**M**onitor” normalization



2015-2016 results

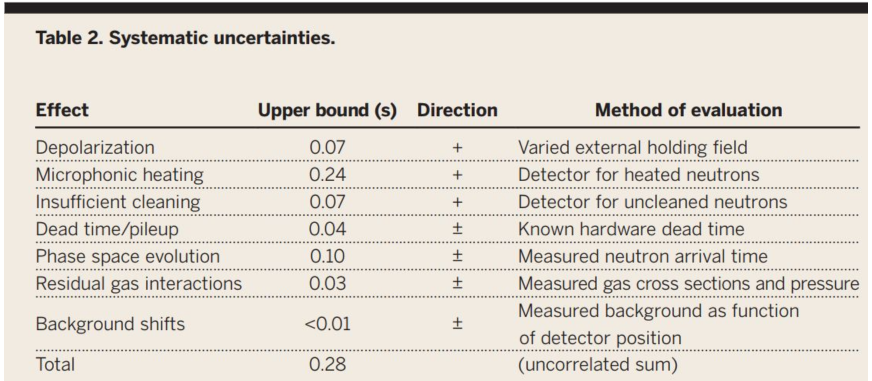
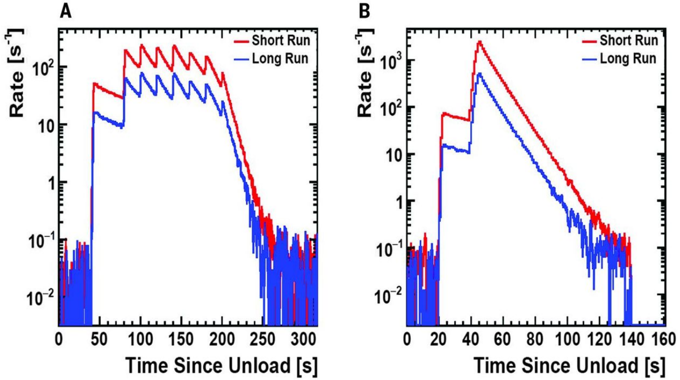
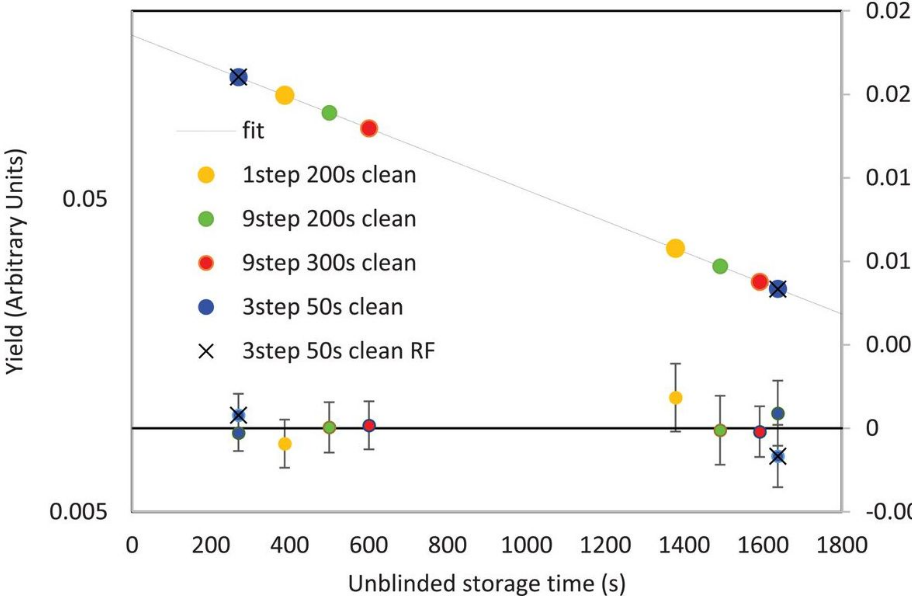


Table 2. Systematic uncertainties.

Effect	**Upper bound (s)**	**Direction**	**Method of evaluation**
Depolarization	0.07	+	Varied external holding field
Microphonic heating	0.24	+	Detector for heated neutrons
Insufficient cleaning	0.07	+	Detector for uncleaned neutrons
Dead time/pileup	0.04	±	Known hardware dead time
Phase space evolution	0.10	±	Measured neutron arrival time
Residual gas interactions	0.03	±	Measured gas cross sections and pressure
Background shifts	<0.01	±	Measured background as function of detector position
Total	0.28		(uncorrelated sum)



$$877.7 \pm 0.7\ (\text{stat})\ +\boxed{0.4/-0.2}\ (\text{sys})\ \text{s}$$



IU PhD Nathan Callahan (2018)

2015-2016 results

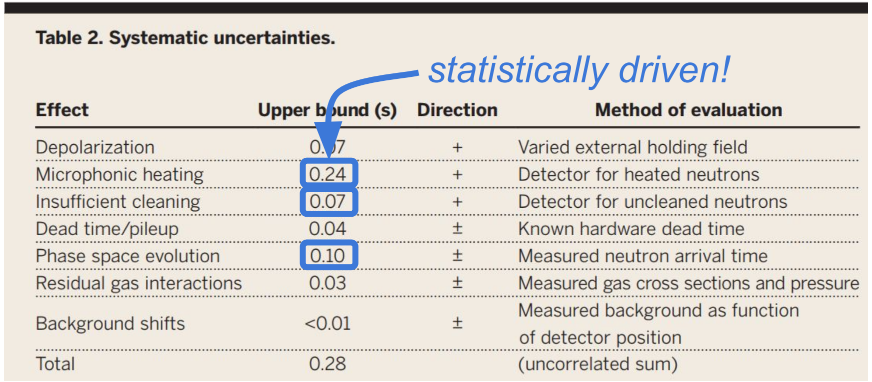


Table 2. Systematic uncertainties.

statistically driven!

Effect	Upper bound (s)	Direction	Method of evaluation
Depolarization	0.07	+	Varied external holding field
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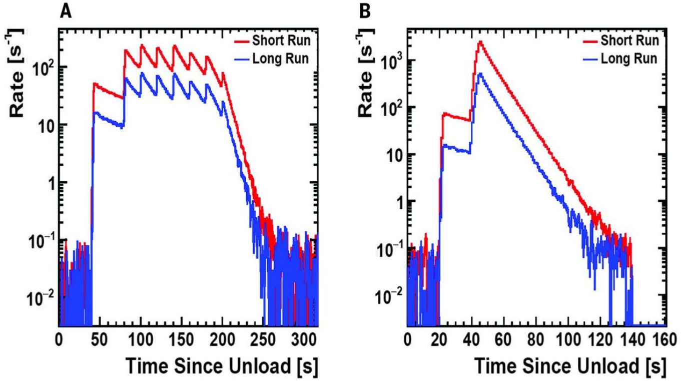
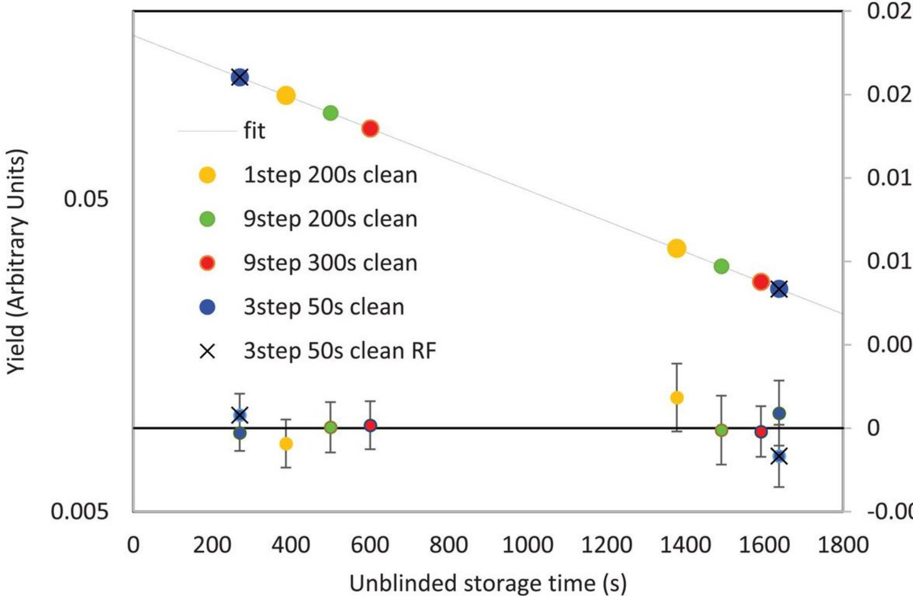


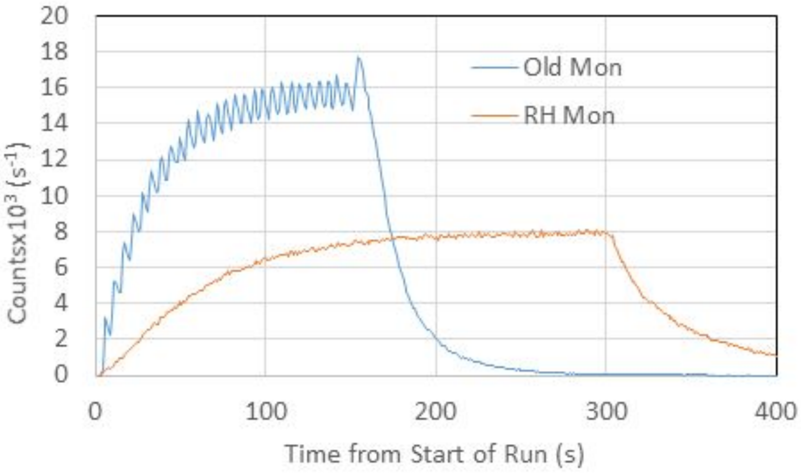
$$877.7 \pm 0.7\,(\text{stat})\ \boxed{+0.4/-0.2}\,(\text{sys})\ \text{s}$$

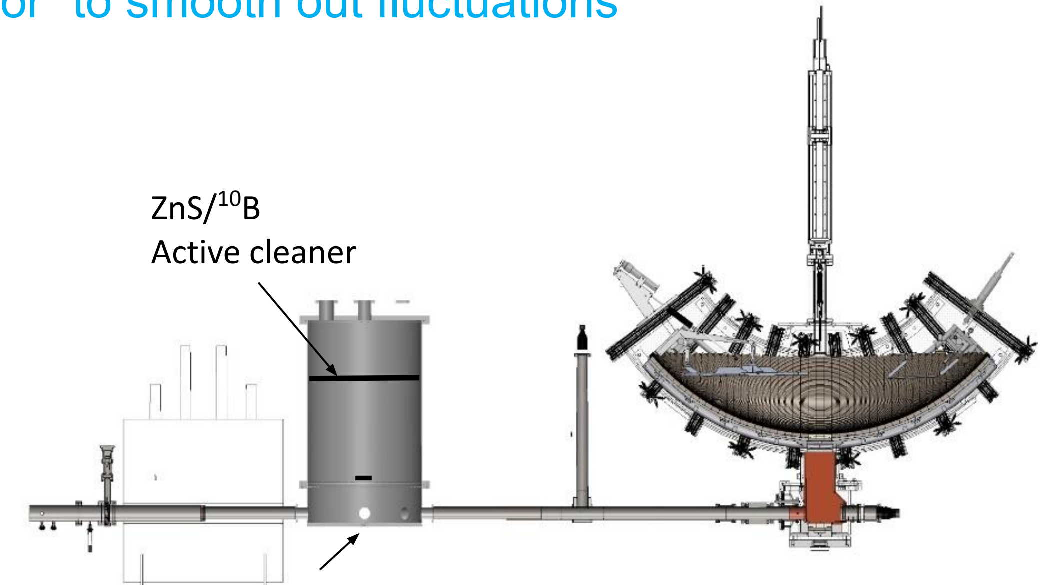


IU PhD Nathan Callahan (2018)

Improved stability

- Buffer volume serves as “capacitor” to smooth out fluctuations
- Pre-cleaner built in





ZnS/^{10}B
Active cleaner

ZnS/^{10}B
Monitor

Making a UCN out of photons

Suppress backgrounds by forming “coincidences”

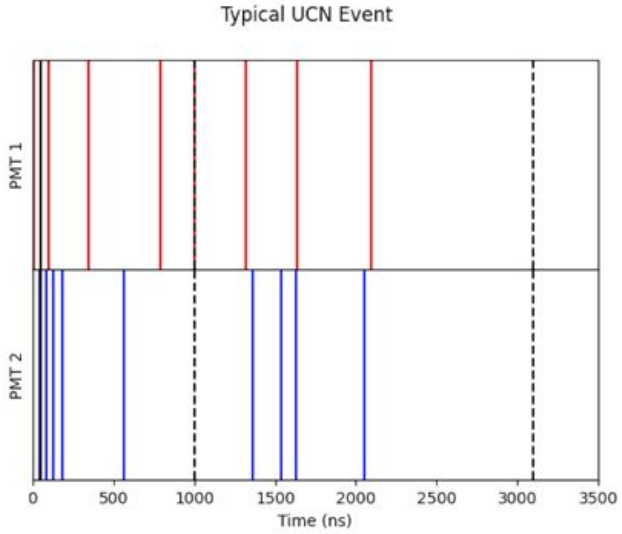
- “Initial Window” 50 ns (must trigger on both PMTs)
- Require ≥ 8 photons in first 1000 ns
- “Telescoping Window” 1000 ns

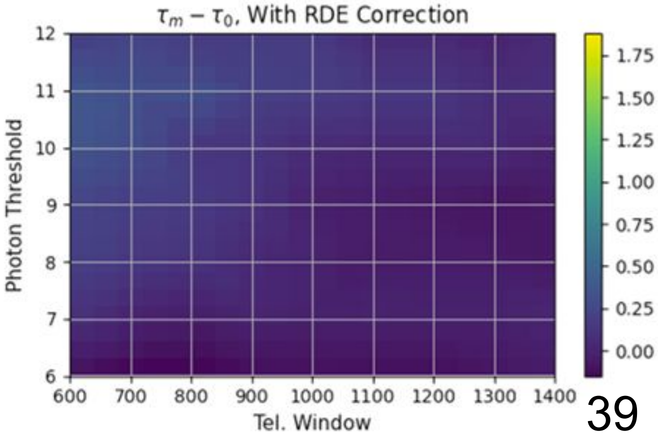
Need constant counting efficiency

- Peak neutron counting rate ~1 kHz
- ZnS:Ag scintillator has ~10^{-5} s “glow”

Correct rate dependent effects on per-event basis

- Monte Carlo studies resampling data
- Contributes to $\Delta\tau_{RDE}$=±0.13 s systematic uncertainty





Normalization

Want to find a lifetime using:

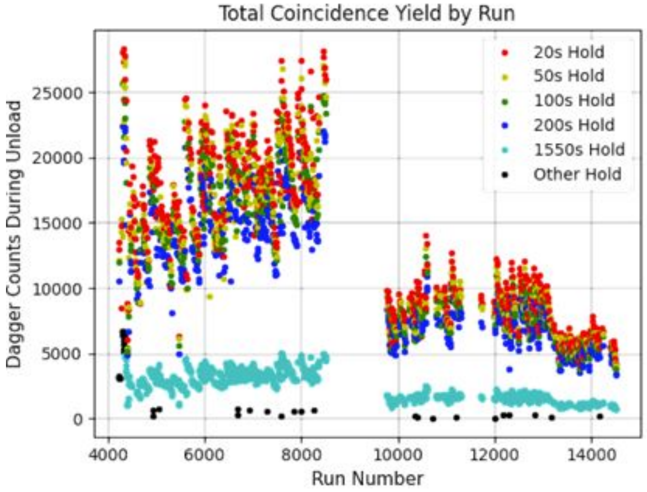
- $Y(t_i) = Y_i \, exp(-t_i / \tau_{meas})$
- Intermediate step: Find Y_i, the initial number of neutrons in the trap

Have ~4000 runs to fit

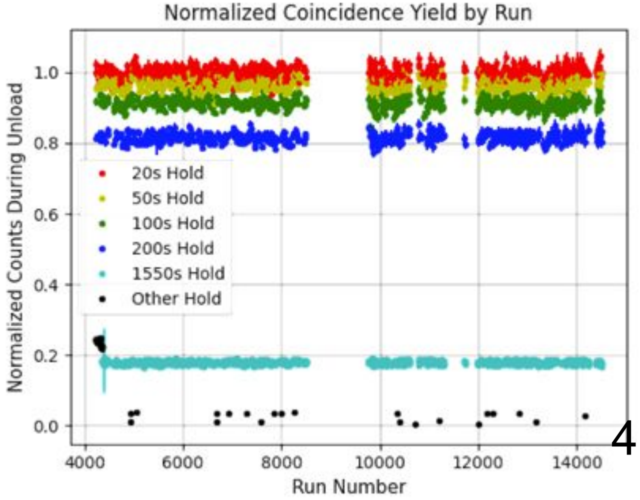
- Reconstructed detector counts D_i
- Measure backgrounds B_i at end of run + dedicated runs

Incorporate normalization monitors with $f(M_i)$

- Exact form of $f(M_i)$ can differ by analyzer
- Example: $f(M_i) = \alpha \, m_{main} + \beta_s \, m_{spec}$
- Need to fit (likelihood or least squares) for α, β_s



Total Coincidence Yield by Run



Normalized Coincidence Yield by Run

“Paired” & “global” analyses

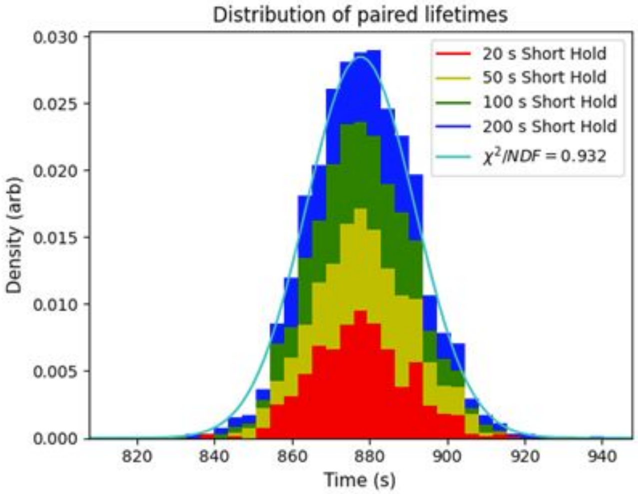
Finally time to solve for τ_{meas}

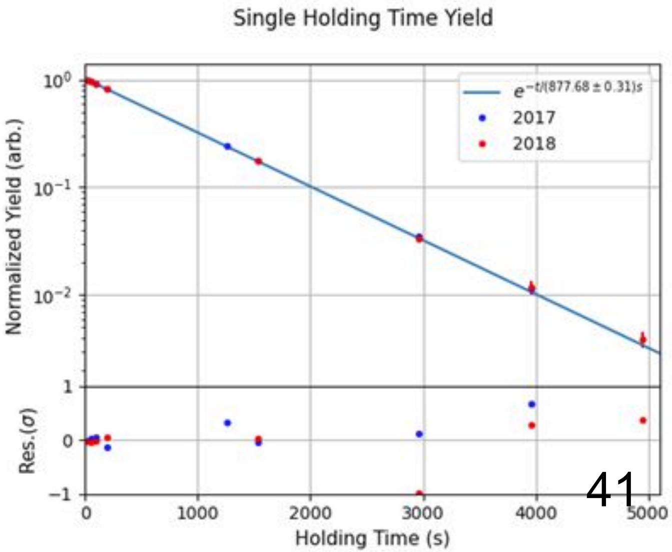
Method 1: pair together short and long holding cycles

- $\tau_{meas}=(t_L-t_S)/\ln(Y_S/Y_L)$

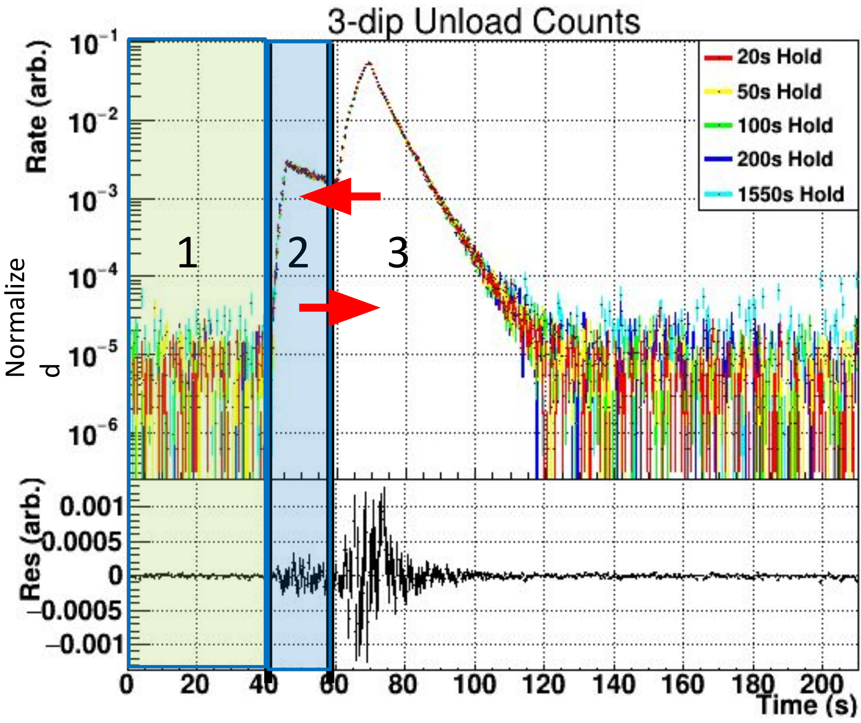
Method 2: Maximum Likelihood analysis to get a “global” lifetime

- Simultaneously fit τ_{meas} and additional parameters from $f(M_i)$





“Heating” and “cleaning” effects



Overthreshold UCN above cleaning height

- “Heated” UCN (long times): $\Delta\tau_{heat}$=0+0.08 s
- “Uncleaned” UCN (short times): $\Delta\tau_{unc}$=0+0.11 s

Overthreshold neutrons <2×10^{-5}!

Require constant detection efficiency

- Phase space couples to counting time
- Use mean arrival time during unload
- $\Delta\tau_{PSE}$=0.02±0.01 s

Three analyses

Frank Gonzalez
(IU)

Eric Fries
(Caltech)

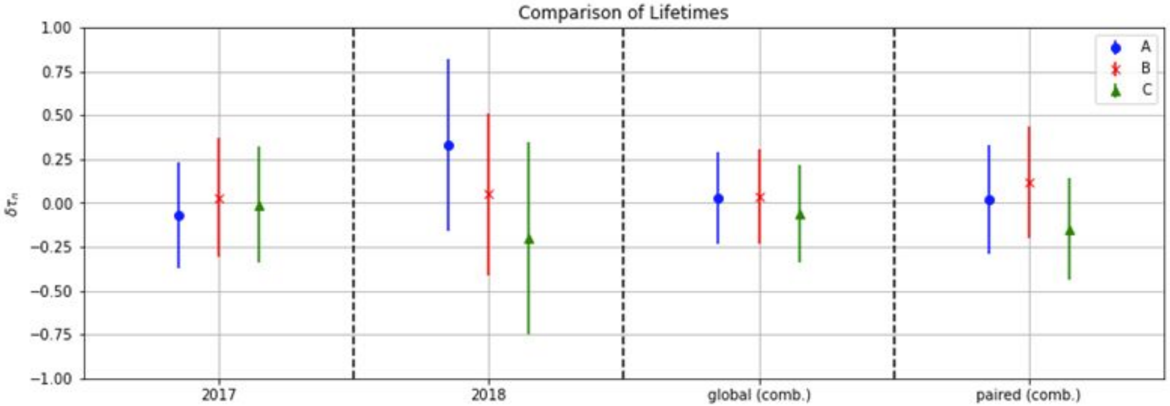
Chris Morris
(LANL)

Blinded data:

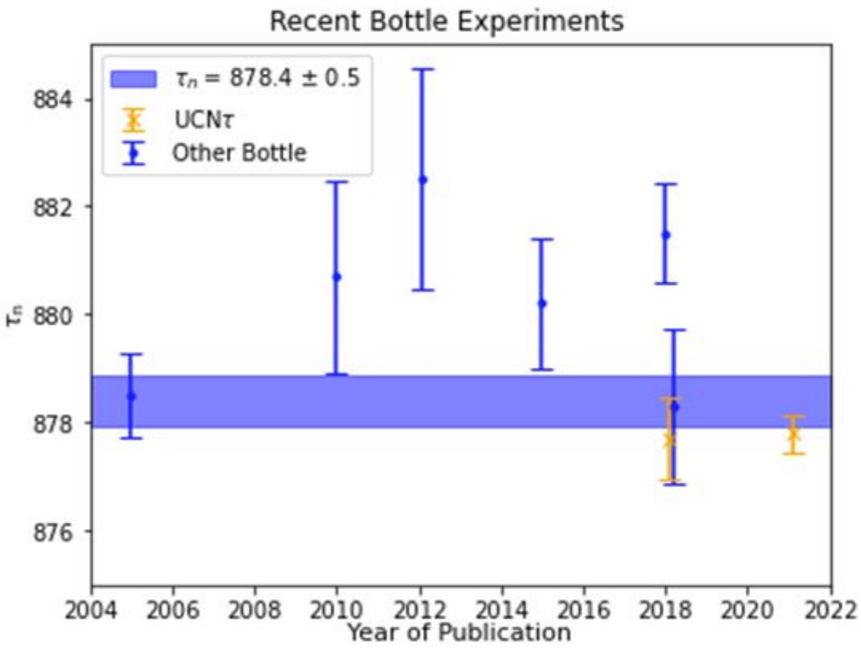
- Holding time is modified
- blinded by up to ±15 s

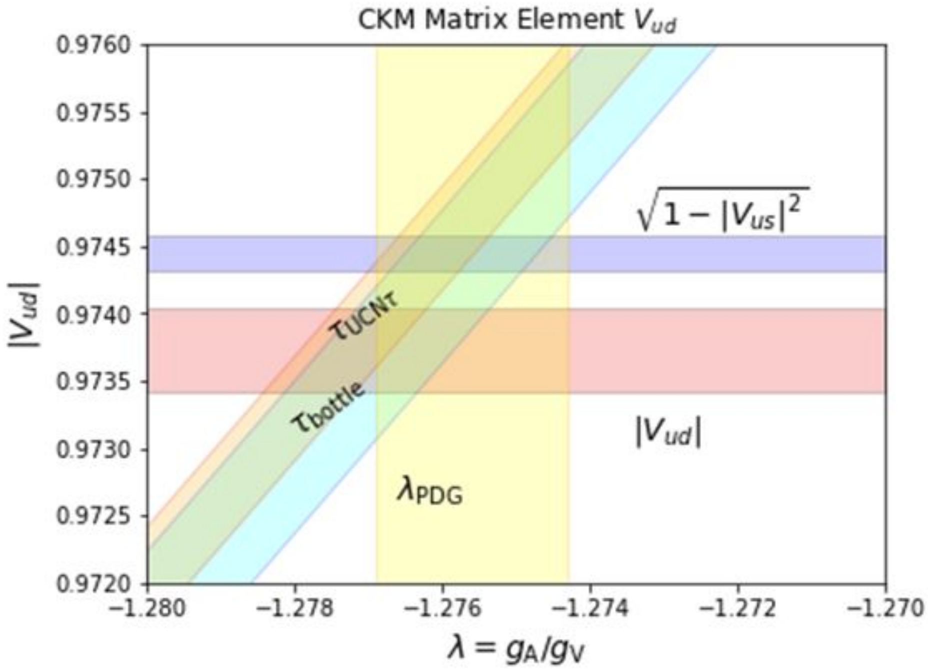
Unblinding Criteria:

- Three complete (statistical and systematic) analyses
- After cross-checking analyses, take unweighted average, use largest uncertainties



877.75 seconds

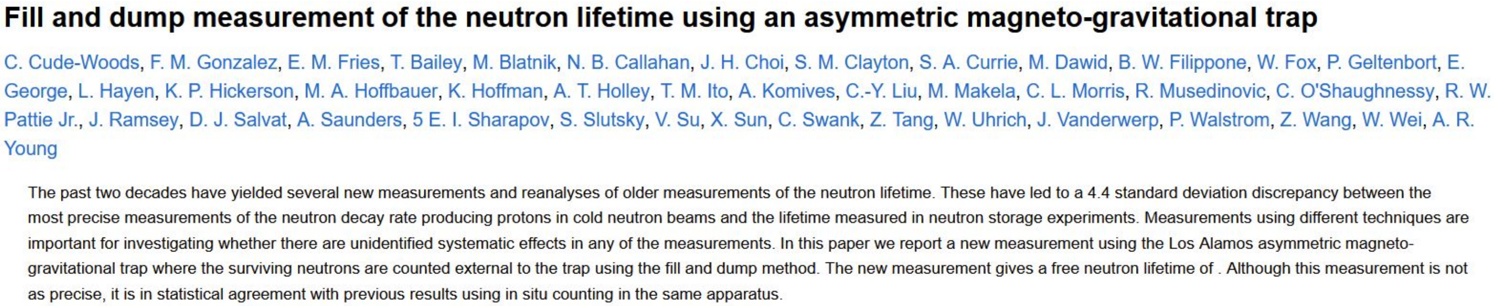




The error budget

Effect	Previous Reported Value (s)	New Reported Value (s)	Notes
τ_{meas}	877.5 ± 0.7	877.58 ± 0.28	Uncorrected Value!
UCN Event Definition	0 ± 0.04	0 ± 0.13	Single photon analysis vs. Coincidence analysis
Normalization Weighting	--	0 ± 0.06	Previously unable to estimate
Depolarization	$0 + 0.07$	$0 + 0.07$	
Uncleaned UCN	$0 + 0.07$	$0 + 0.11$	
Heated UCN	$0 + 0.24$	$0 + 0.08$	
Phase Space Evolution	0 ± 0.10	--	Now included in stat. uncertainty
Al Block	--	0.06 ± 0.05	Accidentally dropped into trap...
Residual Gas Scattering	0.16 ± 0.03	0.11 ± 0.06	
Sys. Total	$\mathbf{0.16^{+0.4}_{-0.2}}$	$\mathbf{0.17^{+0.22}_{-0.16}}$	
TOTAL	$\mathbf{877.7 \pm 0.7^{+0.4}_{-0.2}}$	$\mathbf{877.75 \pm 0.28^{+0.22}_{-0.16}}$	

A cross check



Fill and dump measurement of the neutron lifetime using an asymmetric magneto-gravitational trap

C. Cude-Woods, F. M. Gonzalez, E. M. Fries, T. Bailey, M. Blatnik, N. B. Callahan, J. H. Choi, S. M. Clayton, S. A. Currie, M. Dawid, B. W. Filippone, W. Fox, P. Geltenbort, E. George, L. Hayen, K. P. Hickerson, M. A. Hoffbauer, K. Hoffman, A. T. Holley, T. M. Ito, A. Komives, C.-Y. Liu, M. Makela, C. L. Morris, R. Musedinovic, C. O'Shaughnessy, R. W. Pattie Jr., J. Ramsey, D. J. Salvat, A. Saunders, 5 E. I. Sharapov, S. Slutsky, V. Su, X. Sun, C. Swank, Z. Tang, W. Uhrich, J. Vanderwerp, P. Walstrom, Z. Wang, W. Wei, A. R. Young

The past two decades have yielded several new measurements and reanalyses of older measurements of the neutron lifetime. These have led to a 4.4 standard deviation discrepancy between the most precise measurements of the neutron decay rate producing protons in cold neutron beams and the lifetime measured in neutron storage experiments. Measurements using different techniques are important for investigating whether there are unidentified systematic effects in any of the measurements. In this paper we report a new measurement using the Los Alamos asymmetric magneto-gravitational trap where the surviving neutrons are counted external to the trap using the fill and dump method. The new measurement gives a free neutron lifetime of . Although this measurement is not as precise, it is in statistical agreement with previous results using in situ counting in the same apparatus.

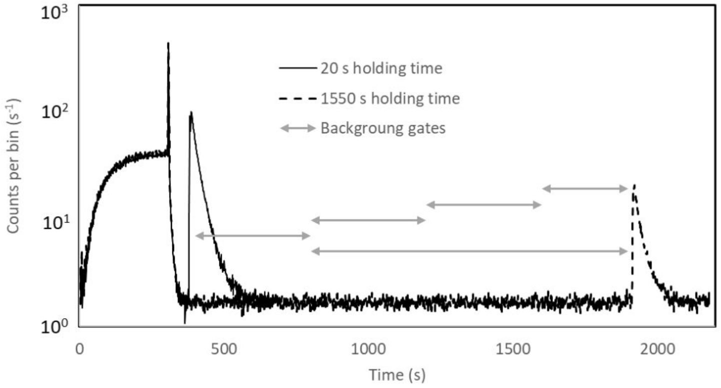


Figure 4. The figure shows a comparison of the average of the short holding time runs with the long holding time runs. The gray double arrows show the background gates that have been used in the analysis.

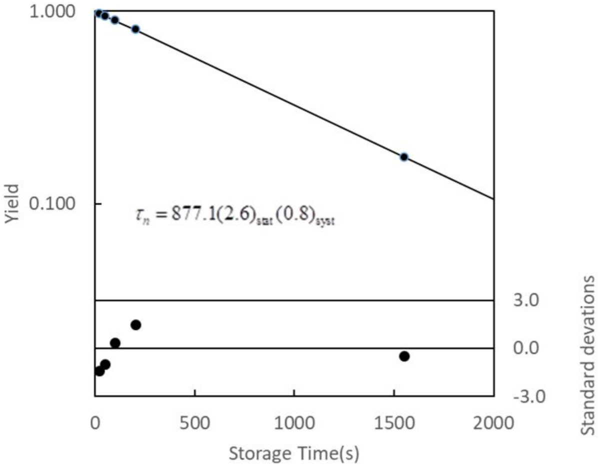
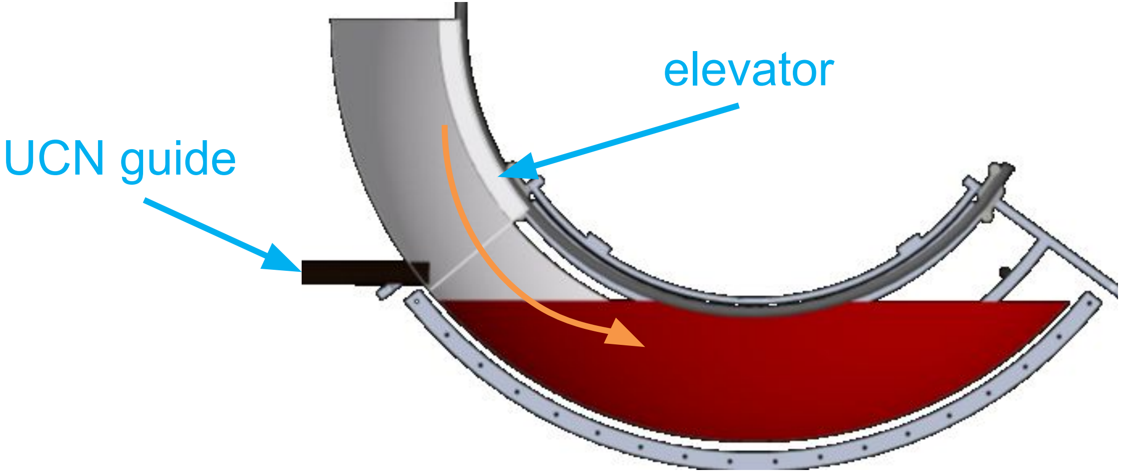


Figure 6. Plot of average yield vs time, lifetime fit, and residuals.

A neutron elevator

New Loading Mechanisms to maximize statistics

- Funded by LANL LDRD
- Anticipate 10× counts



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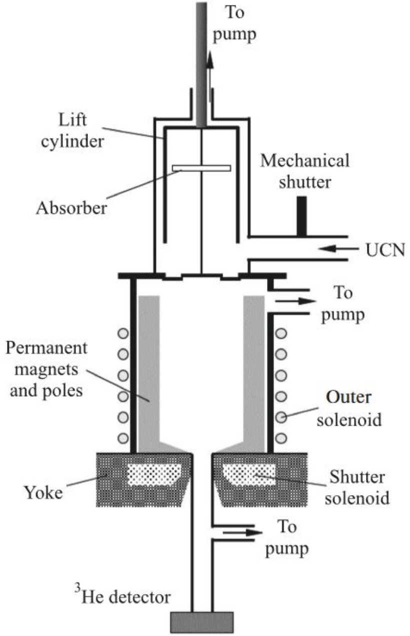
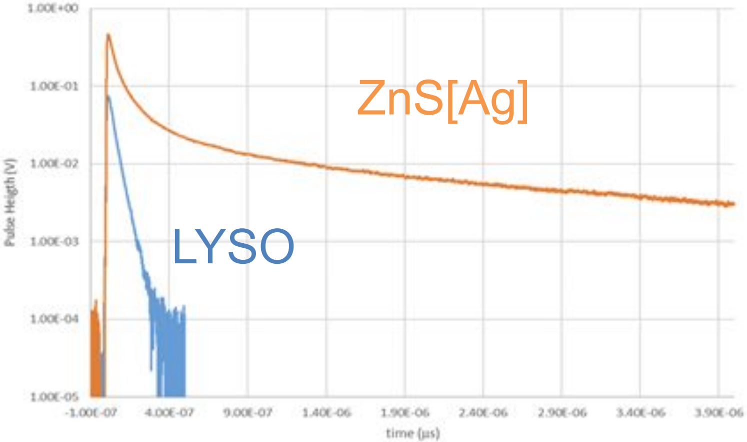


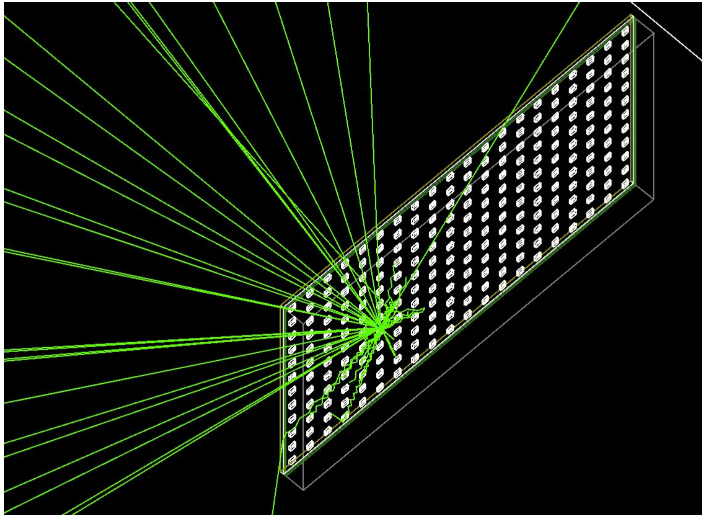
Improved detector

Developing new detectors to count UCN faster and mitigate rate dependent effects

- Faster scintillator (LYSO, plastic)
- Segmented SiPM-based detector

Bring UCNτ+ to a lifetime sensitivity of $\Delta\tau<0.15$s





Conclusions and outlook

- Neutron lifetime measurements promise to test the standard model, due to improved theoretical underpinnings, freedom from nuclear structure effects, and experimental advances
- The neutron lifetime fits within a broader landscape of understanding the weak response of the nucleon and addressing timely investigations of BSM physics such as LFUV
- UCNτ is to date the most precise measurement, and promises to improve by mitigating rate dependent effects and increasing statistical sensitivity
- The “lifetime anomaly” persists, but active efforts with a multitude of techniques can provide a resolution