Precision Measurements of Neutron Beta Decay

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CERN EP Seminar
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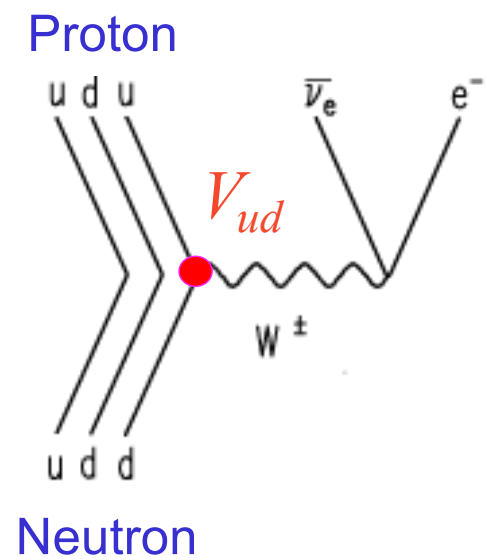

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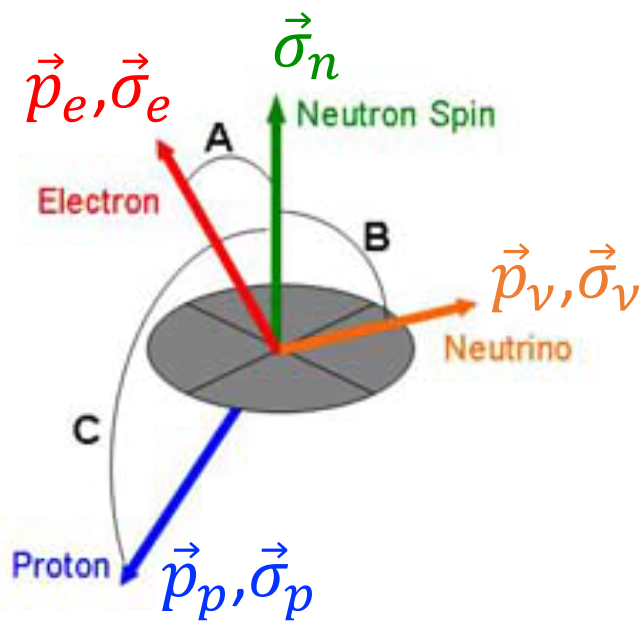
Neutron β decay observables

$n \rightarrow p + e + \bar{\nu}_e$, β endpoint energy 782 keV



Many observables (20+, Dubbers&Schmidt, Rev. Mod. Phys. **83** (2011), p. 1111-):

- Mean lifetime τ_n
- $A\ \vec{\sigma}_n \cdot \vec{p}_e$
- $B\ \vec{\sigma}_n \cdot \vec{p}_\nu$
- C $\vec{\sigma}_n \cdot \vec{p}_p$
- $D\ \vec{\sigma}_n \cdot (\vec{p}_e \times \vec{p}_\nu)$
- $a\ \vec{p}_e \cdot \vec{p}_\nu$
- Twofold correlations involving electron spin
- Threefold correlations (*D*, *L*, *R*, *V*)
- …

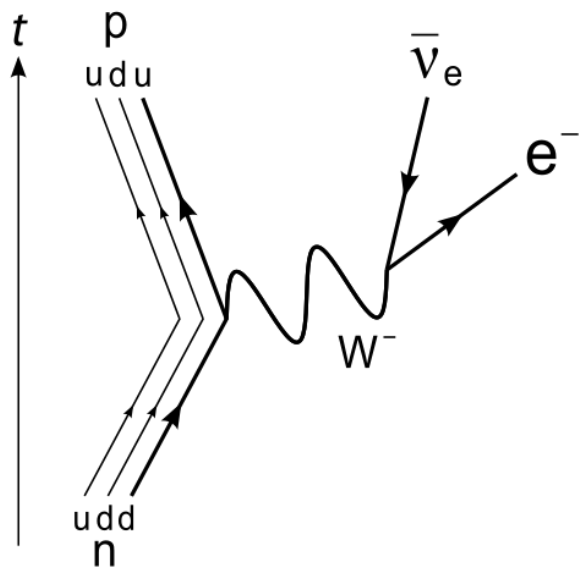
Differential decay rate:

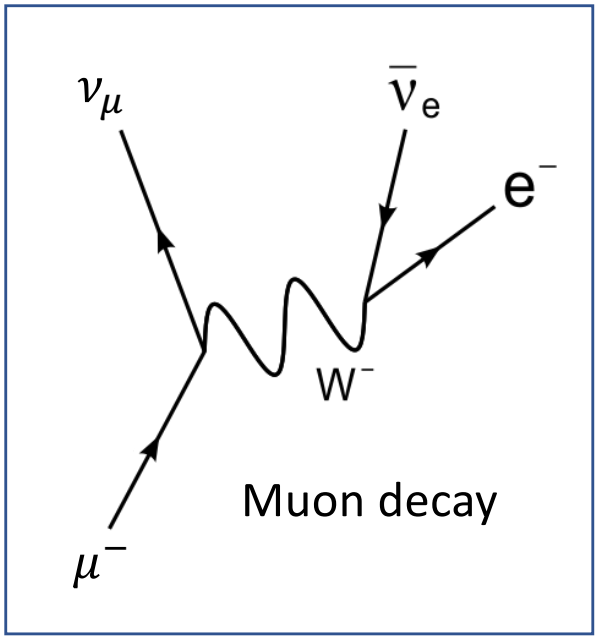
$$\frac{dW}{dE_e d\Omega_e d\Omega_\nu} = G(E_e)\left(1 + a\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + \langle\vec{\sigma}_n\rangle \cdot \left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu}\right)\right)$$

…also $\vec{\sigma}_e$ combinations

Neutron β decay at the quark level

$n \to p + e + \bar{\nu}_e$, β endpoint energy 782 keV





$q^2 \ll m_W$: 4-fermion interaction

$V - A$ interaction

Quark level: $\mathcal{M}_q = \frac{G_F}{\sqrt{2}} V_{ud} \left[u \overbrace{\gamma_\mu (1 - \gamma_5)} d \right] \left[e \gamma^\mu (1 - \gamma_5) \nu_e \right]$

CKM Matrix

Quark level: $\mathcal{M}_q = \frac{G_F}{\sqrt{2}} V_{ud} \left[u\gamma_\mu(1-\gamma_5)d\right]\left[e\gamma^\mu(1-\gamma_5)\nu_e\right]$

$$\begin{pmatrix} d_w \\ s_w \\ b_w \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Weak states	CKM mixing matrix	Mass eigenstates

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

Nucleon level: form factors

=1 by CVC

≈ -1

$$\mathcal{M}_q = \frac{G_F}{\sqrt{2}} V_{ud} \left[p(\gamma_\mu (g_V + g_A \gamma_5) + \frac{\kappa_p - \kappa_n}{2M} \sigma_{\mu\nu} q^\nu) n \right] [e\gamma^\mu (1 - \gamma_5) \nu_e]$$

Weak magnetism: determined from electromagnetic properties (anomalous magnetic moments)

Other terms are forbidden in the SM or can be neglected at low energies.

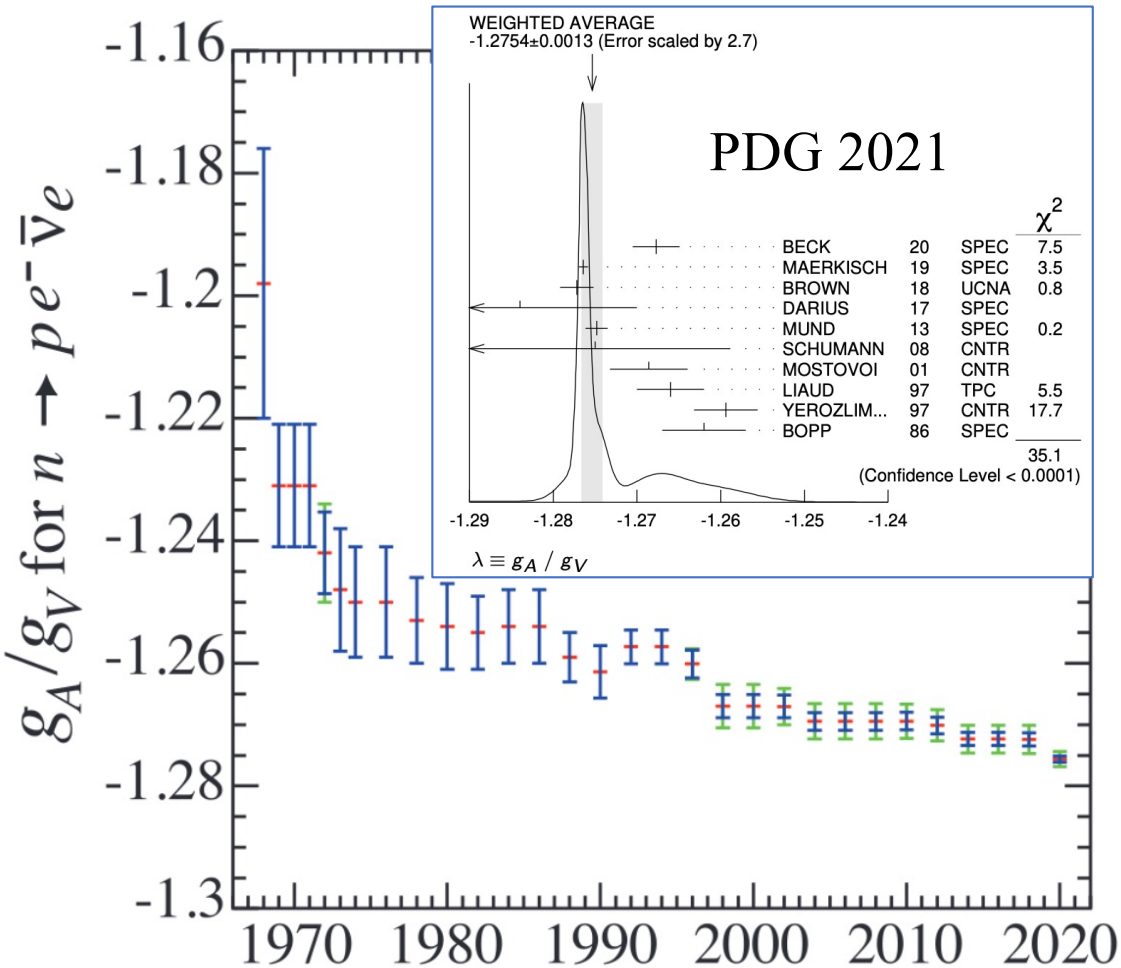
→ Essentially a single parameter, g_A or $\lambda \equiv \frac{g_A}{g_V}$, accounts for nucleon structure.

Neutron decay master formula

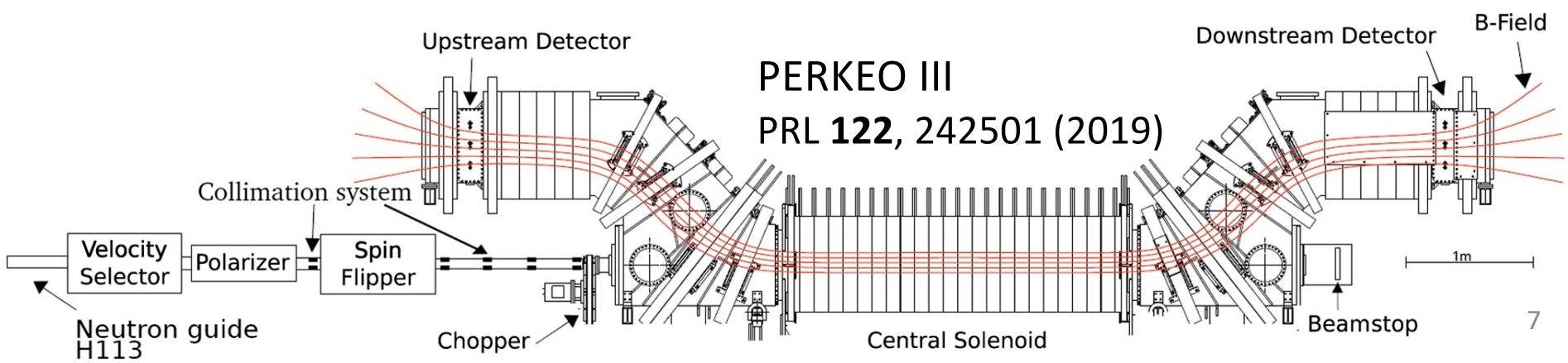
$$|V_{ud}|^2 = \frac{5099.3(4)\mathrm{s}}{\tau_n(1+3g_A^2)(1+RC)}$$

V_{ud}: quark mixing parameter in CKM matrix
τ_n: neutron lifetime
g_A: axial charge of the neutron
RC: radiative corrections

Weak axial charge of the nucleon (g_A) determined by neutron decay



- More recent experiments based on A correlation measurement are coming into agreement.
- Upcoming Nab and UCNA+ experiments are targeting similar precision as PERKEO III.
- Future PERC facility will target the next level of precision.



PERKEO III

PRL **122**, 242501 (2019)

Universal beta decay radiative corrections

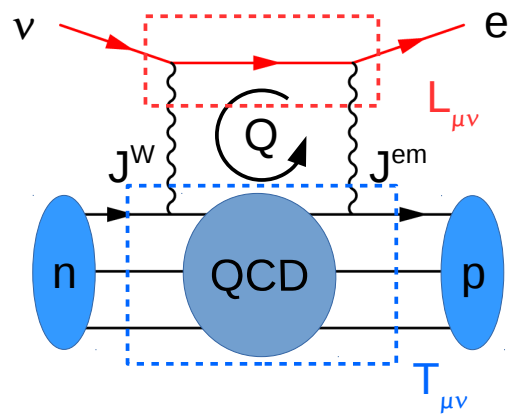
Neutron decay:

$$|V_{ud}|^2 = \frac{5099.3(4)\mathrm{s}}{\tau_n(1+3g_A^2)(1+RC)}$$

Superallowed nuclear decay:

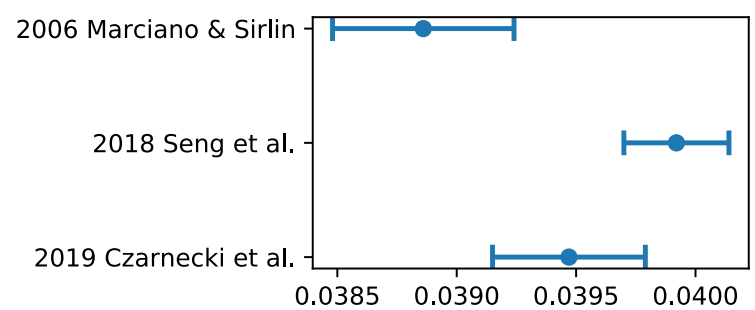
$$|V_{ud}|^2 = \frac{2984.432(3)\ \mathrm{s}}{\mathcal{F}t(1+\Delta_R^V)}$$

- The box diagram Δ_{np} contributes only ~3% but dominates the uncertainty.
- The integral $\int d^4Q$ requires control over low (non-perturbative) and high (perturbative) momenta



- Marciano and Sirlin, PRL **96**, 032002 (2006)
  - RC = 0.03886(38), $\Delta_R^V = 0.02361(38)$
- Seng et al., PRL **121**, 241804 (2018)
  - RC = 0.03992(22), $\Delta_R^V = 0.02467(22)$
- Czarnecki, Marciano, Sirlin, PRD **100**, 073008 (2019)
  - Update/extension of 2006 Marciano and Sirlin
  - RC = 0.03947(32), $\Delta_R^V = 0.02426(32)$
- Work in progress: LQCD

RC for *n* decay



V_{ud} from experiments can test self-consistency of the Standard Model

CKM mixing matrix

$$\begin{pmatrix} d_w \\ s_w \\ b_w \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Weak states

Mass eigenstates

$$\Delta_{CKM} \equiv |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1$$

	$\lvert V_{ud}\rvert$	$\lvert V_{us}\rvert$	$\lvert V_{ub}\rvert$	Δ_{CKM}
PDG 2020	0.97370(14) [from **nuclear decay** measurements]	0.2243(8)	$3.82(24)\times10^{-3}$	$\mathbf{-15.8(4.5)\times10^{-4}}$

- (Using Seng et al. rad. Corrections) V_{ud} from *nuclear* decay shows 3.5-σ tension with the Standard Model!

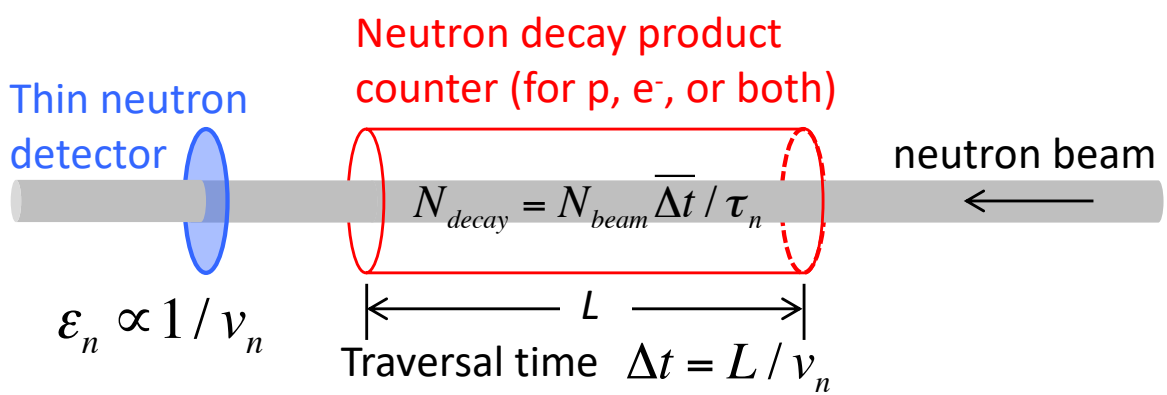
- Neutron decay measurement is *clean* and the systematics are *independent*.

$$|V_{ud}|^2 = \frac{5099.3(4)\text{s}}{\tau_n(1+3g_A^2)(1+RC)}$$

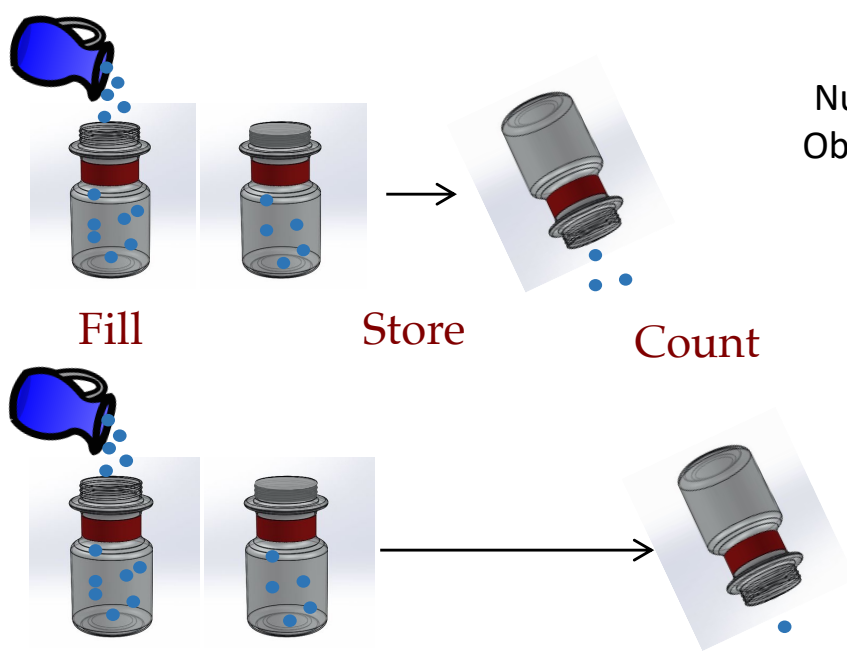
Two* techniques are used to measure τ_n

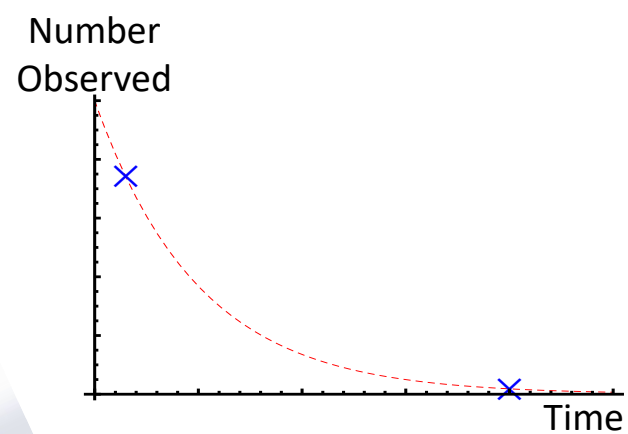
*Plus VCN storage ring by Paul et al.; also, other novel ideas…

Cold Neutron Beam

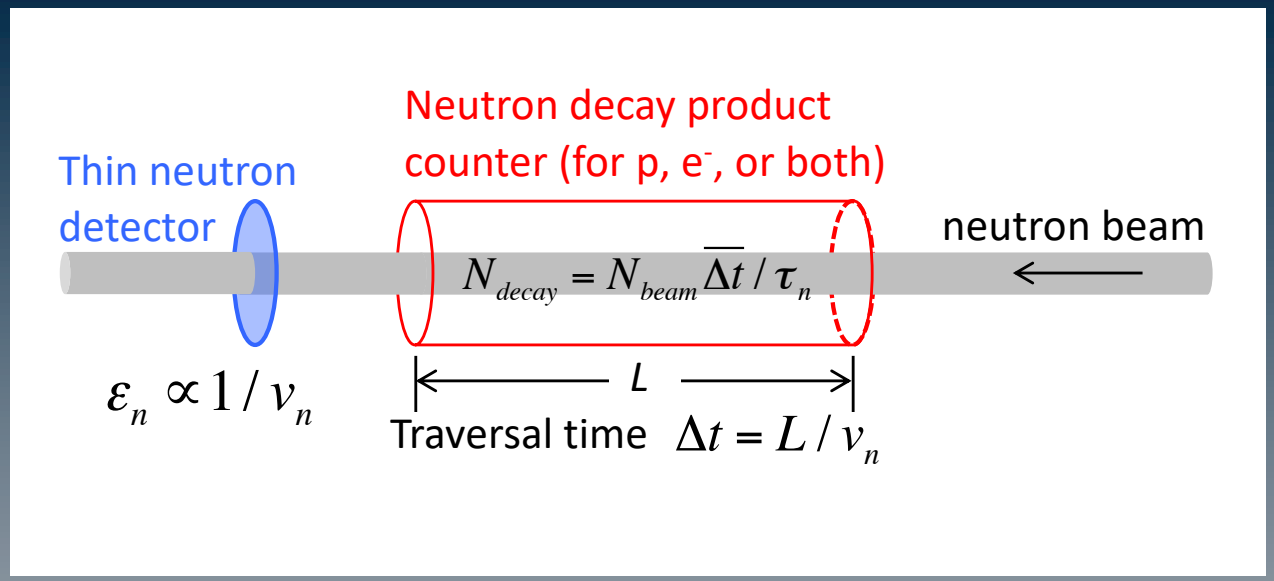


Ultracold Neutron (UCN) Bottle





Could also detect decay products…



Beam Experiments

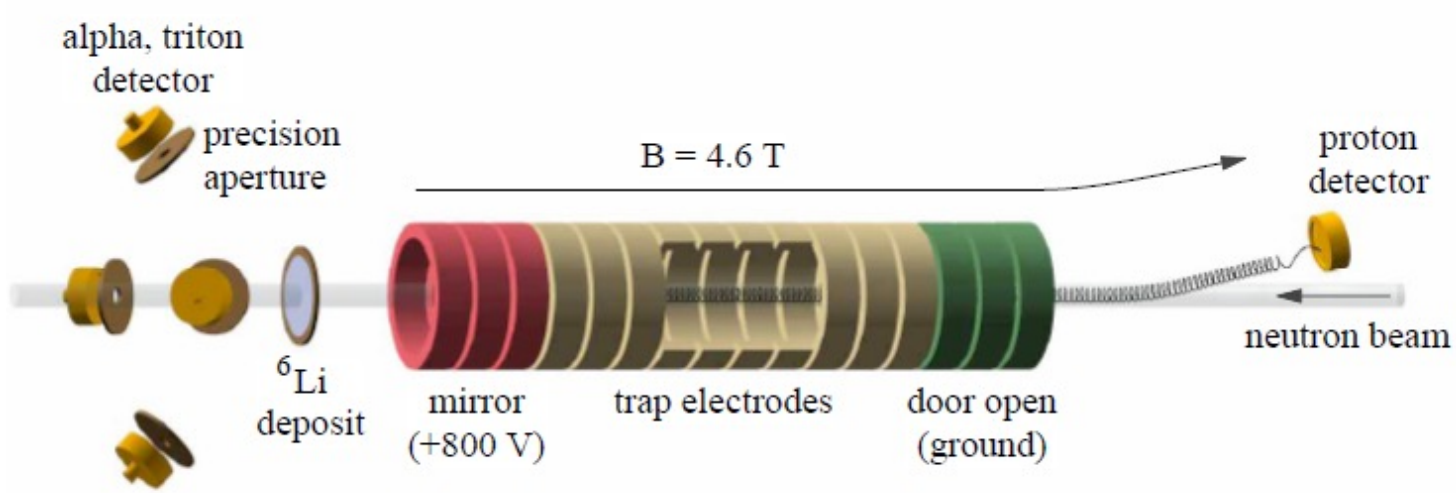
Measure decay products from well-characterized neutron beam

Key features:

- 1/*v* cancels out between neutron detector and time spent in fiducial volume: allows use of broadband beam.
- Need to know absolute detector efficiencies:
  - For neutron detector with known v_n
  - For decay product (*e* or *p*, or both)

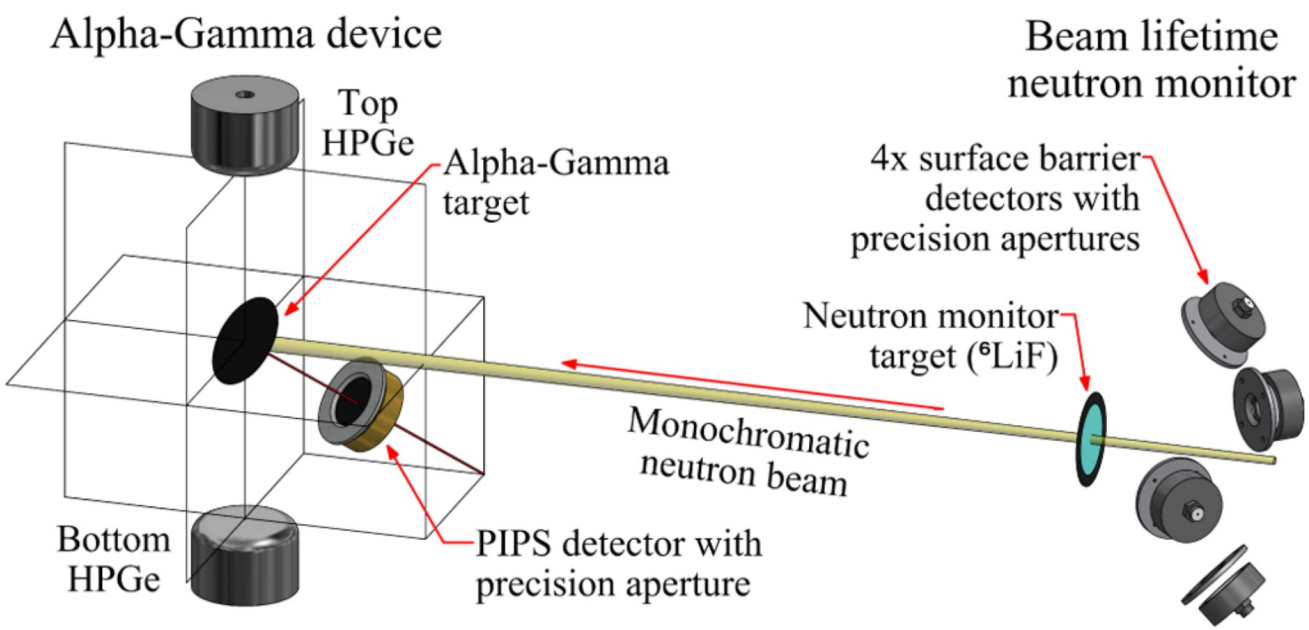
NIST Beam Experiment "BL-1"

Original result (2005): τ_n = (886.3 ± 1.2[stat] ± 3.2[syst]) s
Updated (2013): τ_n = (887.7 ± 1.2[stat] ± 1.9[syst]) s



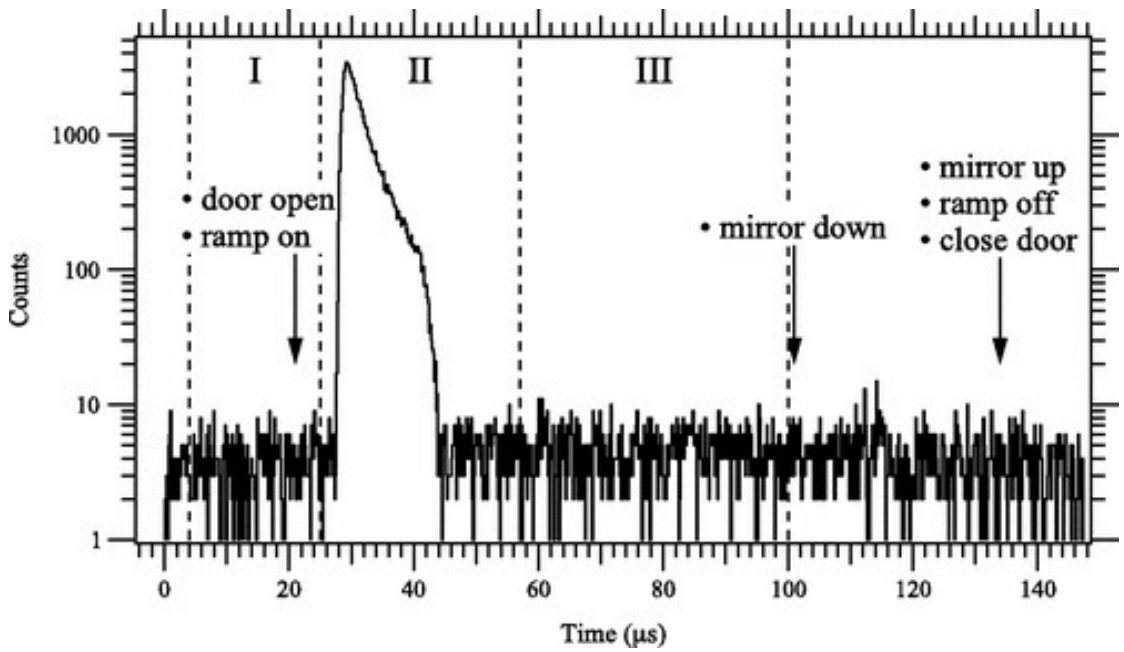
- Counts protons from beta-decays in flight
- Absolute neutron flux must be measured very accurately
- Absolute proton detection efficiency must be known very accurately
- The n counter absolute efficiency calibration was later improved, reducing systematic uncertainty in the original (2005) result.

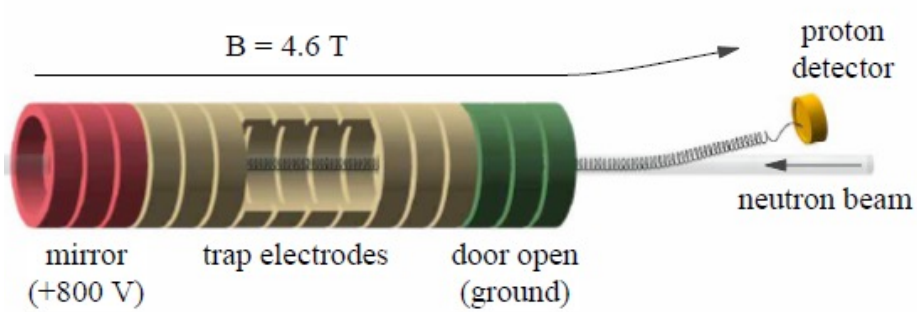
Neutron detector calibration for BL-1



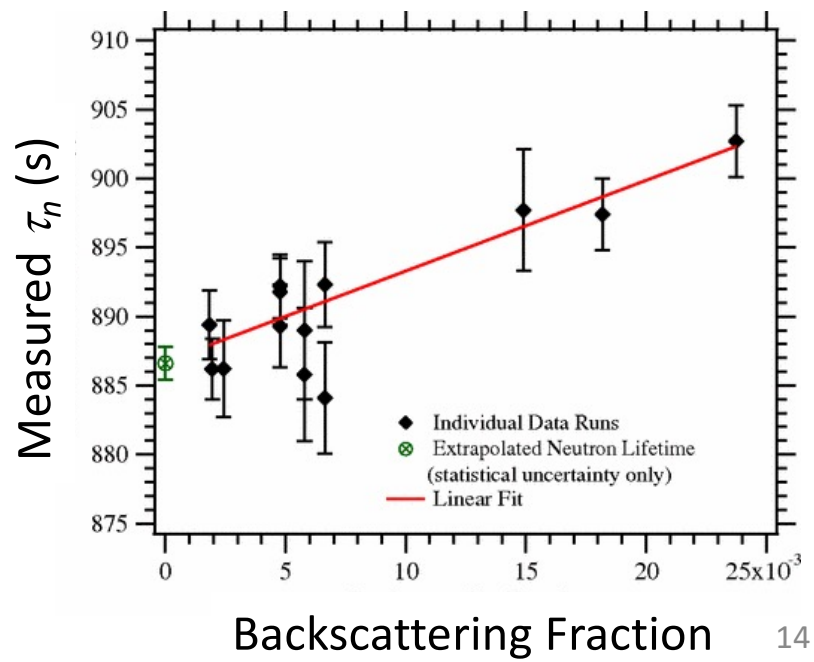
- Original result (2005) relied on knowing precise thickness of ^{6}LiF target and *n* absorption cross section
- New calibration technique measures the efficiency, reducing systematic correction in 2013 result [Yue et al., PRL 111, 222501 (2013)]

Proton detection

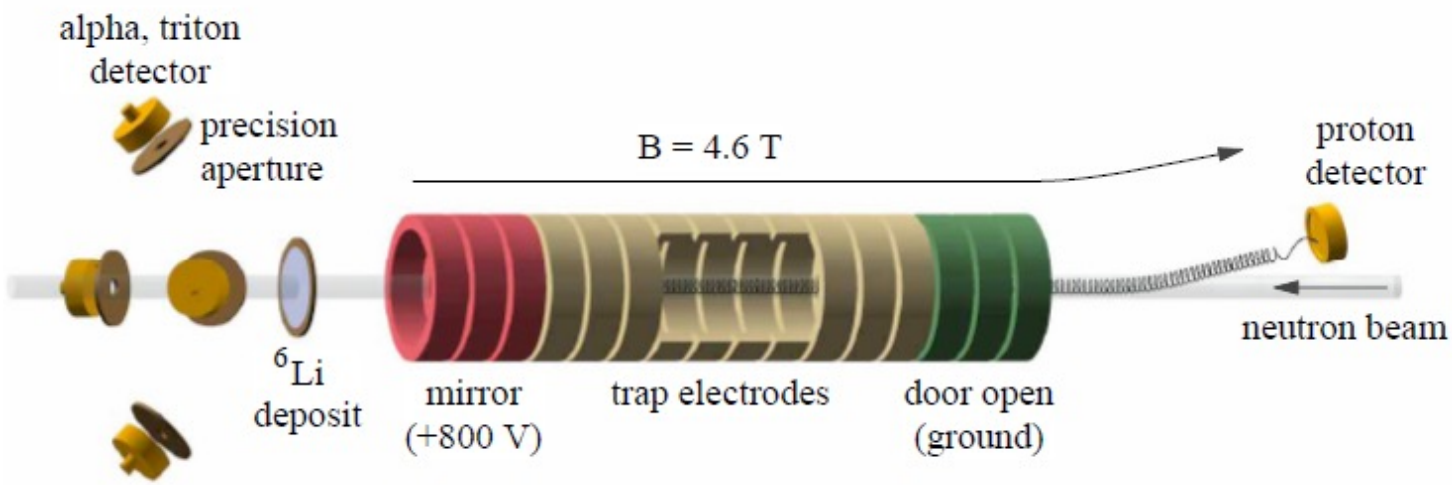




- Protons are accelerated into a ≈99%-efficient detector.
- Corrections must be applied for:
  - Dead layer
  - Backscattering
- Corrections were determined by combination of the following:
  - Dead layer measurement using radioactive sources
  - Taking data with thin coatings added to enhance backscattering
  - Monte Carlo calculations
  - Extrapolation to zero loss

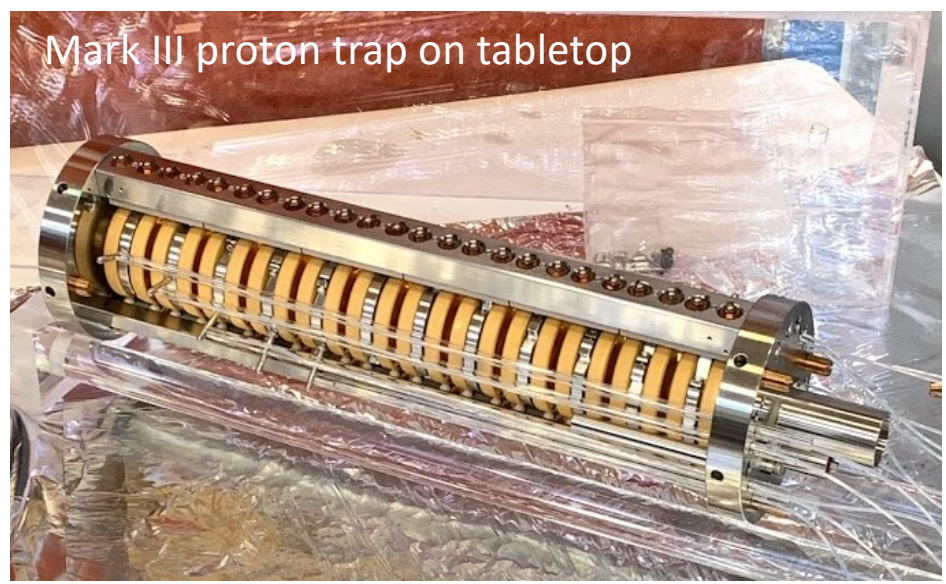


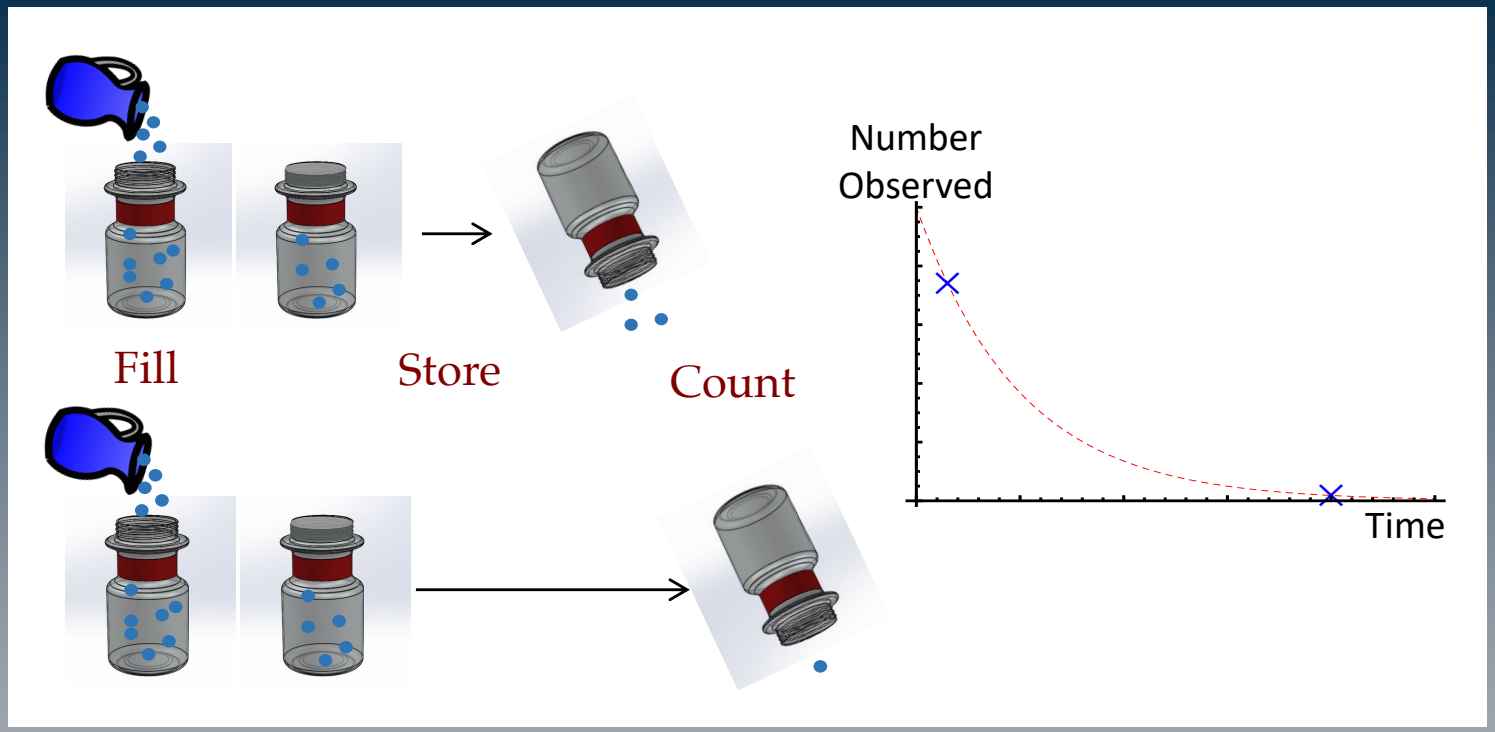
Beam Experiment "BL-2"



- Same experiment as BL-1, but several improvements*:
  - Moved to more intense neutron beamline
  - Improved proton trap electrodes: longer holding times possible
  - Production data were acquired and many systematic studies were performed with previous-style trap (No results released yet).
  - New trap installed with blinded length, gaps for better pumping (lower residual gas). Awaiting beam…

* J. Caylor, *private communication*





Bottle Experiments

Measure total disappearance rate of neutrons

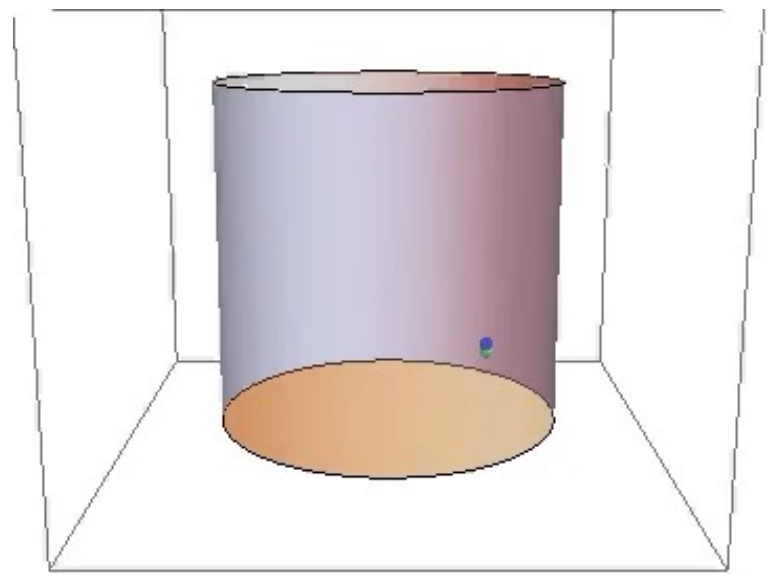
Key features:

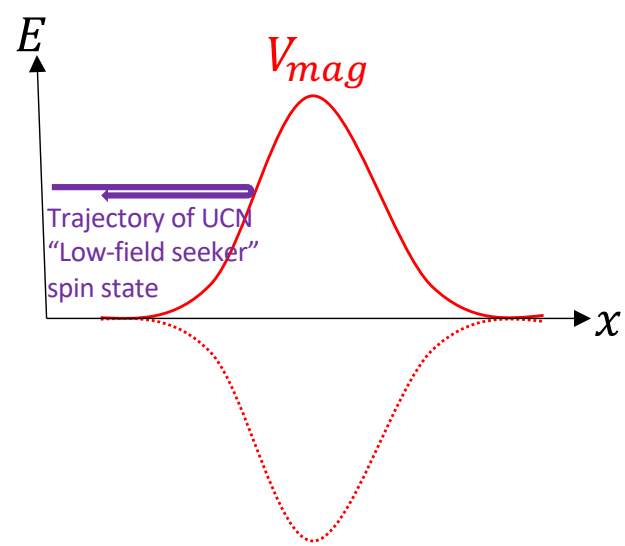
- Ultracold neutron storage
- Can either detect surviving neutrons after different holding periods, or detect the change in rate of decay products as neutrons decay away.

Ultracold neutrons (UCN) are convenient for measurements of neutron properties.

Ultracold neutrons

- Neutrons with kinetic energy < ≈ 350 neV (velocity up to ≈ 5 m/s)
- *Total external reflection* from common materials (e.g., stainless steel V_F ≈180 neV, ^{58}Ni V_F ≈350 neV) – can be stored in a material bottle.
- Gravitational confinement to a few meters height ($V_{grav} = mg \approx 100$ neV/m)
  - Can change KE by guiding to different height
- Magnetic potential similar to KE with a few Tesla field ($V_{mag} = \vec{\mu}_n \cdot \vec{B} \approx 60$ neV/T)
  - Total reflection from laboratory-scale fields
  - 100% spin selection filter
- One inconvenience: hard to get a high density of neutrons into an actual experiment.





All material bottles "leak" UCN to some extent.

Neutrons remaining after time Δt: $N(\Delta t) = N_0 e^{-\Delta t/\tau_s}$

$$\tau_s^{-1} = \tau_\beta^{-1} + \tau_w^{-1} + \tau_O^{-1}$$

Beta decay

Total loss rate due to interactions with the walls

All other mechanisms, e.g. gas upscattering

$$\tau_w^{-1} = \tau_u^{-1} + \tau_c^{-1} + \tau_{qb}^{-1} + \tau_g^{-1}$$

Upscattering

Capture

Escape of quasibound UCN

Gaps, etc.

Wall interaction loss contribution for process i:

$\tau_i^{-1} = \gamma(v)\mu_i(v)$, where $\gamma =$ wall collision rate.

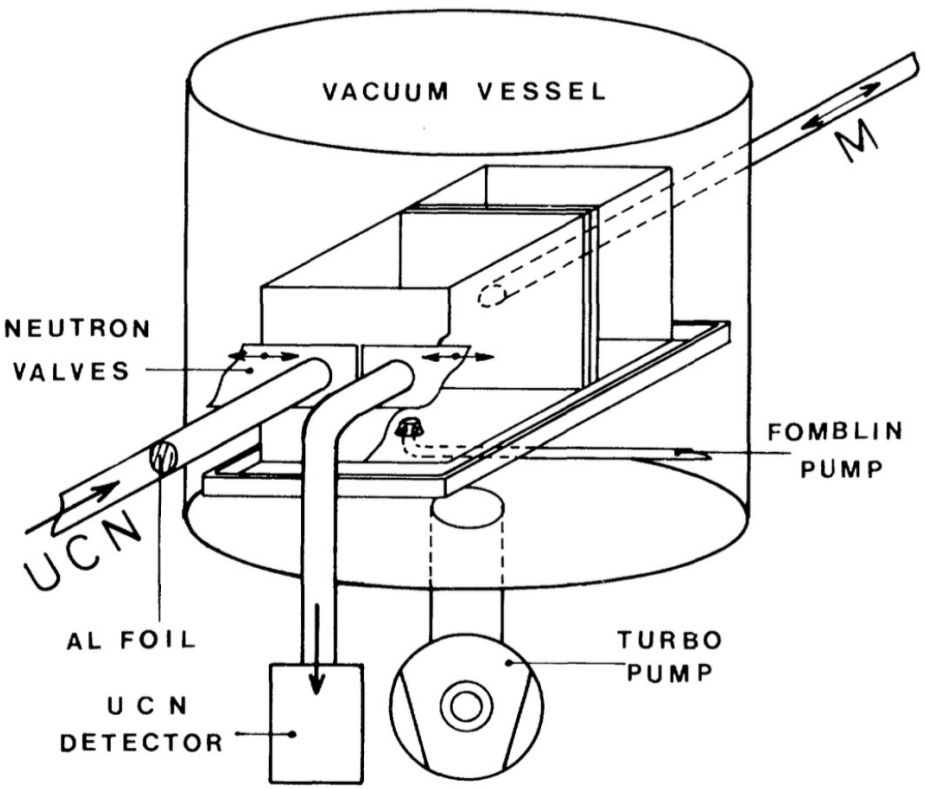
Vary $\gamma(v)$ to enable extrapolation to $\tau_w^{-1} = 0$

$$\tau_s^{-1}(v) = \tau_\beta^{-1} + \tau_w^{-1}(v) = \tau_\beta^{-1} + \mu(v)v/\lambda$$

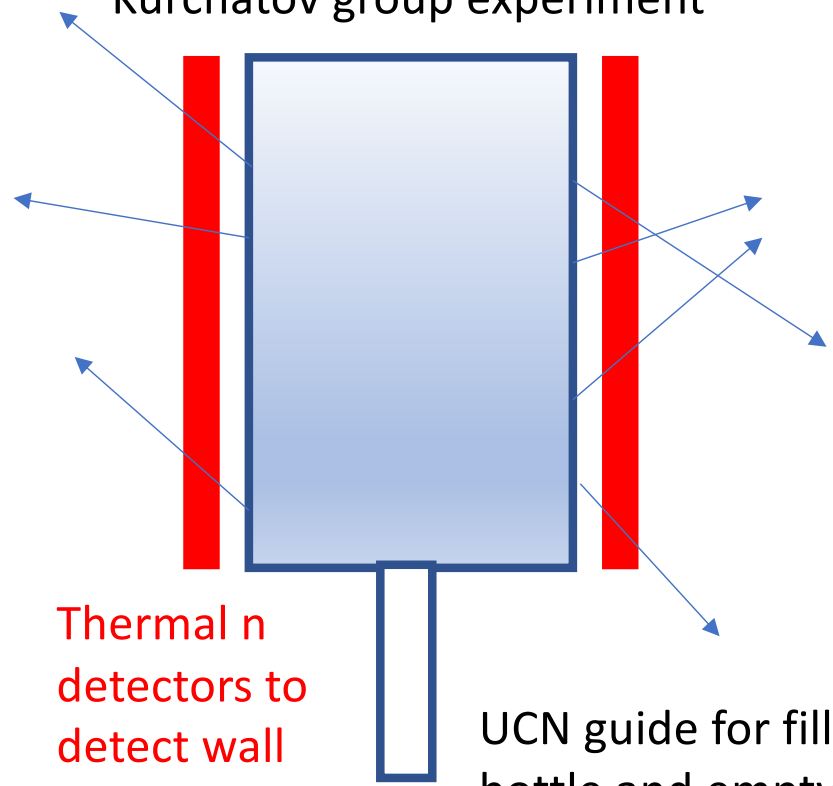
Mean free path between wall collisions

- Energy spectrum evolves over storage time
- Different approaches have been used to vary wall collision rate, typically by changing bottle surface-to-volume ratio

"MAMBO 1"



Kurchatov group experiment

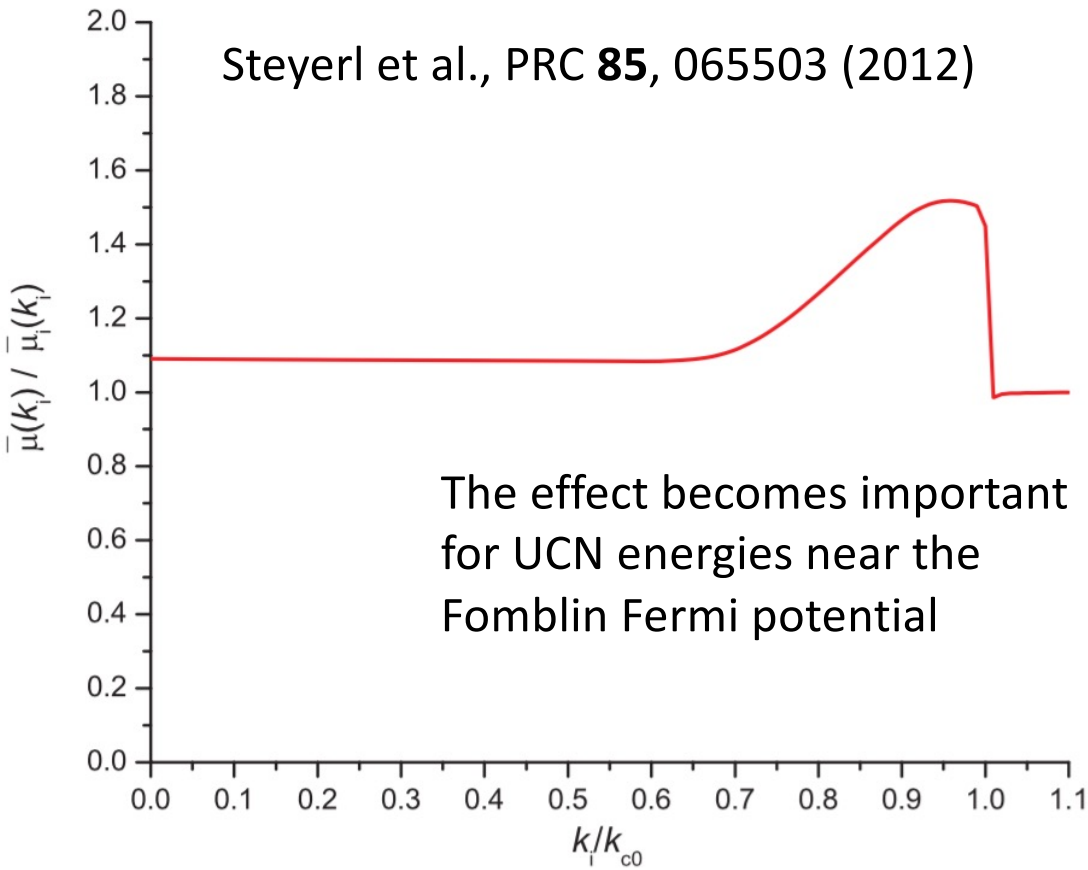


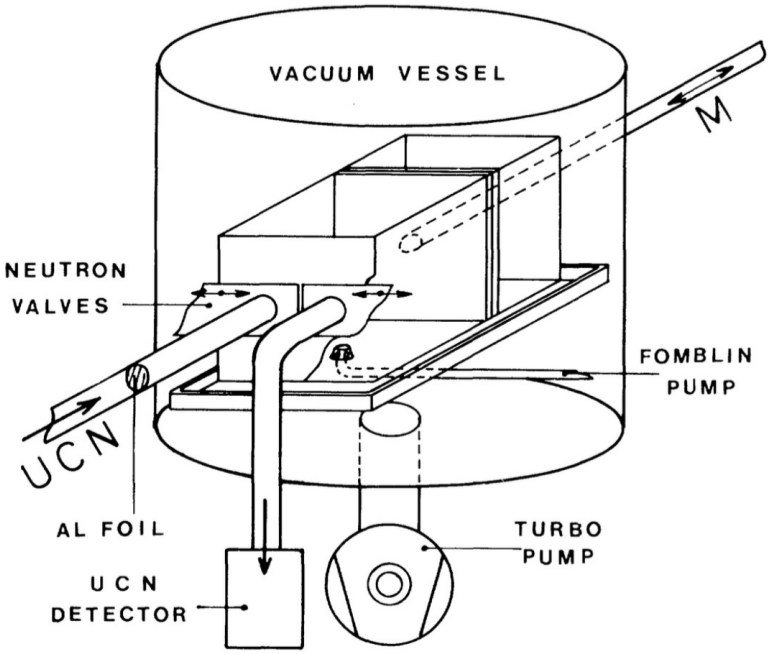
Thermal n detectors to detect wall upscattering

UCN guide for filling bottle and emptying into UCN detector

Mambo I

- Fomblin-coated bottle of variable size
- Corrections applied to original result for energy spectral evolution did not include surface waves in liquid-Fomblin coating
- Steyerl et al. calculated this effect for Mambo 1 (extended previous calculations by others):



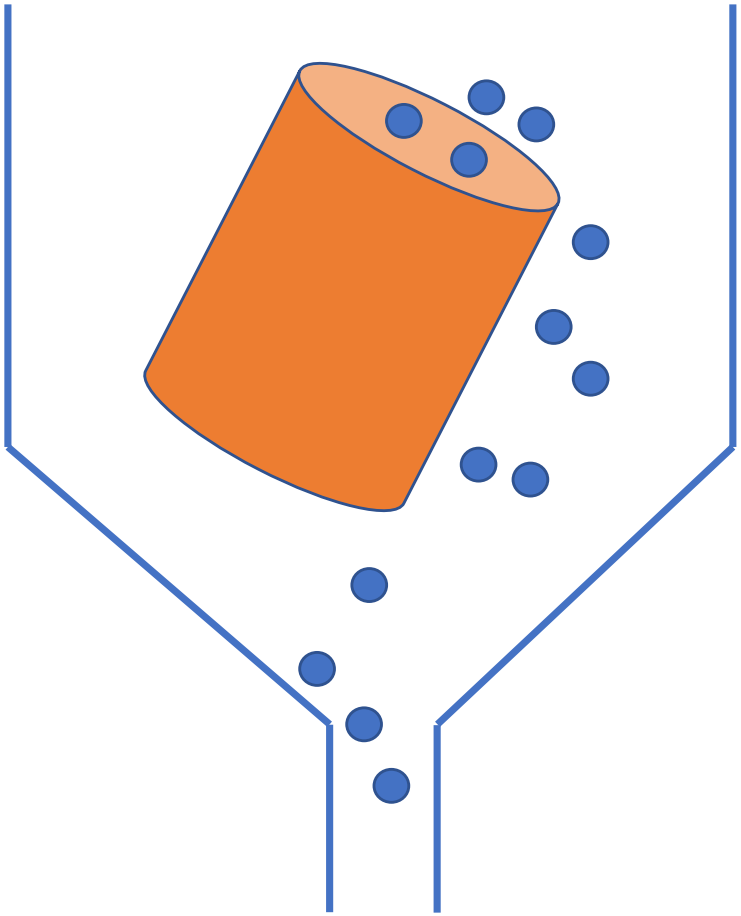


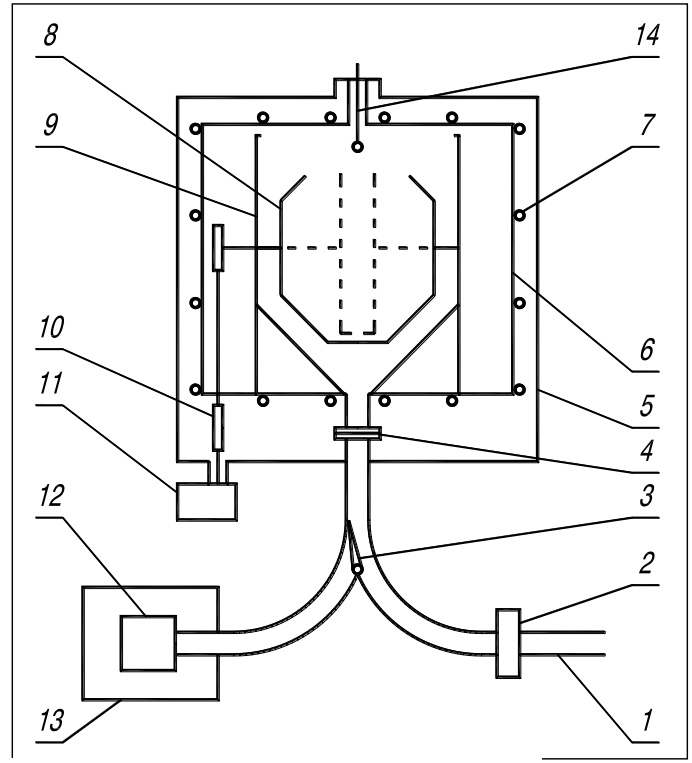
887.6 ± 3 s (1989)

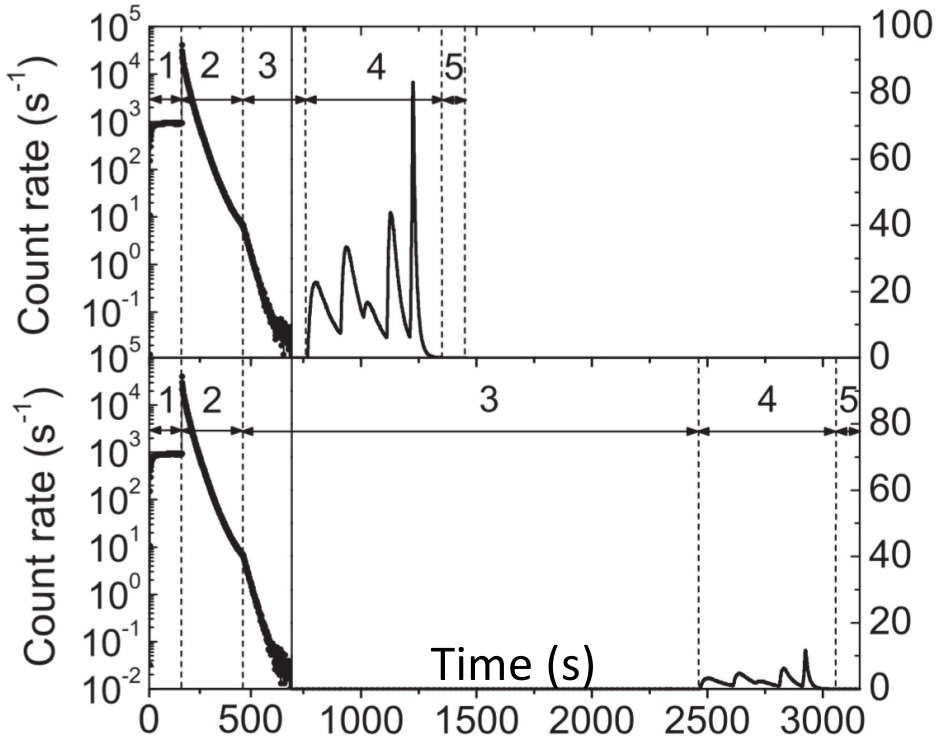
882.5 ± 2.1 s (2012)

Gravitrap I

Serebrov *et al.*, Phys. Lett. **B605**, 72 (2005).
Serebrov *et al.*, PHYSICAL REVIEW C **78**, 035505 (2008)







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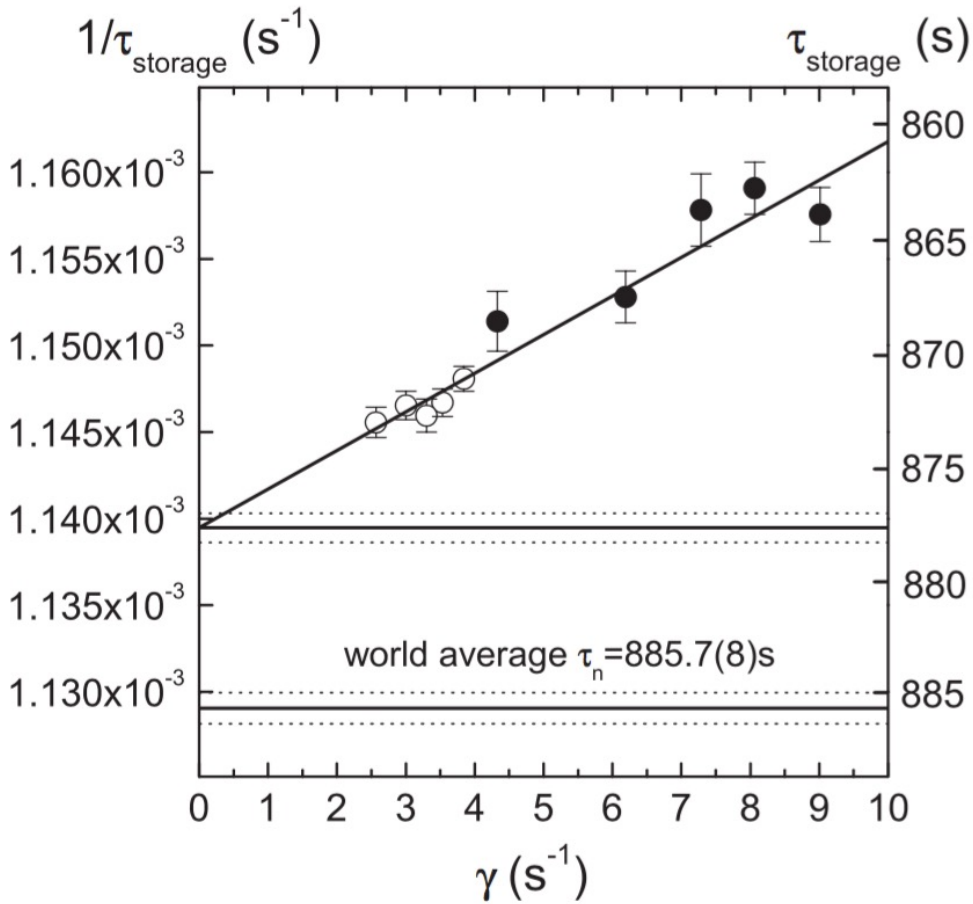
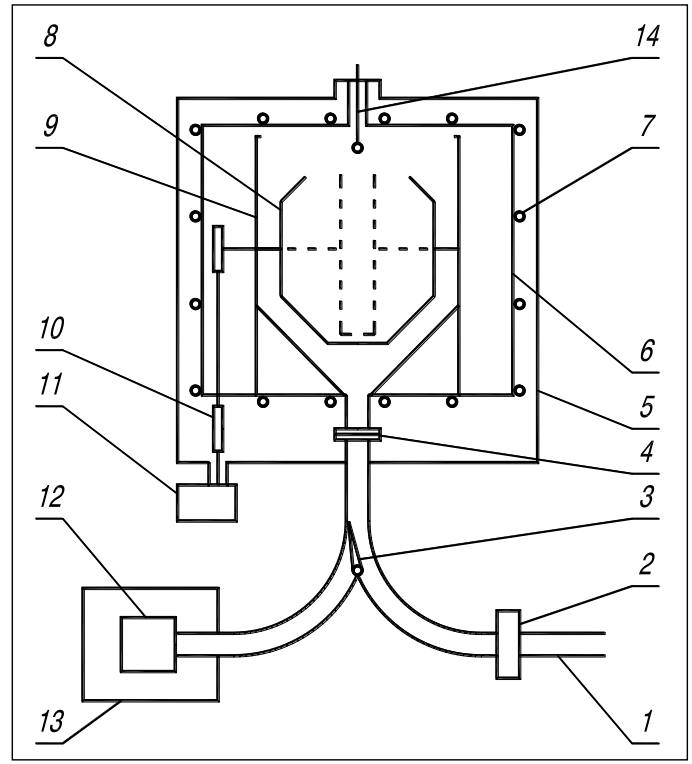


FIG. 12. Result of extrapolation to the neutron lifetime when combined energy and size extrapolations are used. The open circles represent the results of measurements for a quasispherical trap, and the full circles the results of measurements for a cylindrical trap.



Gravitrap II

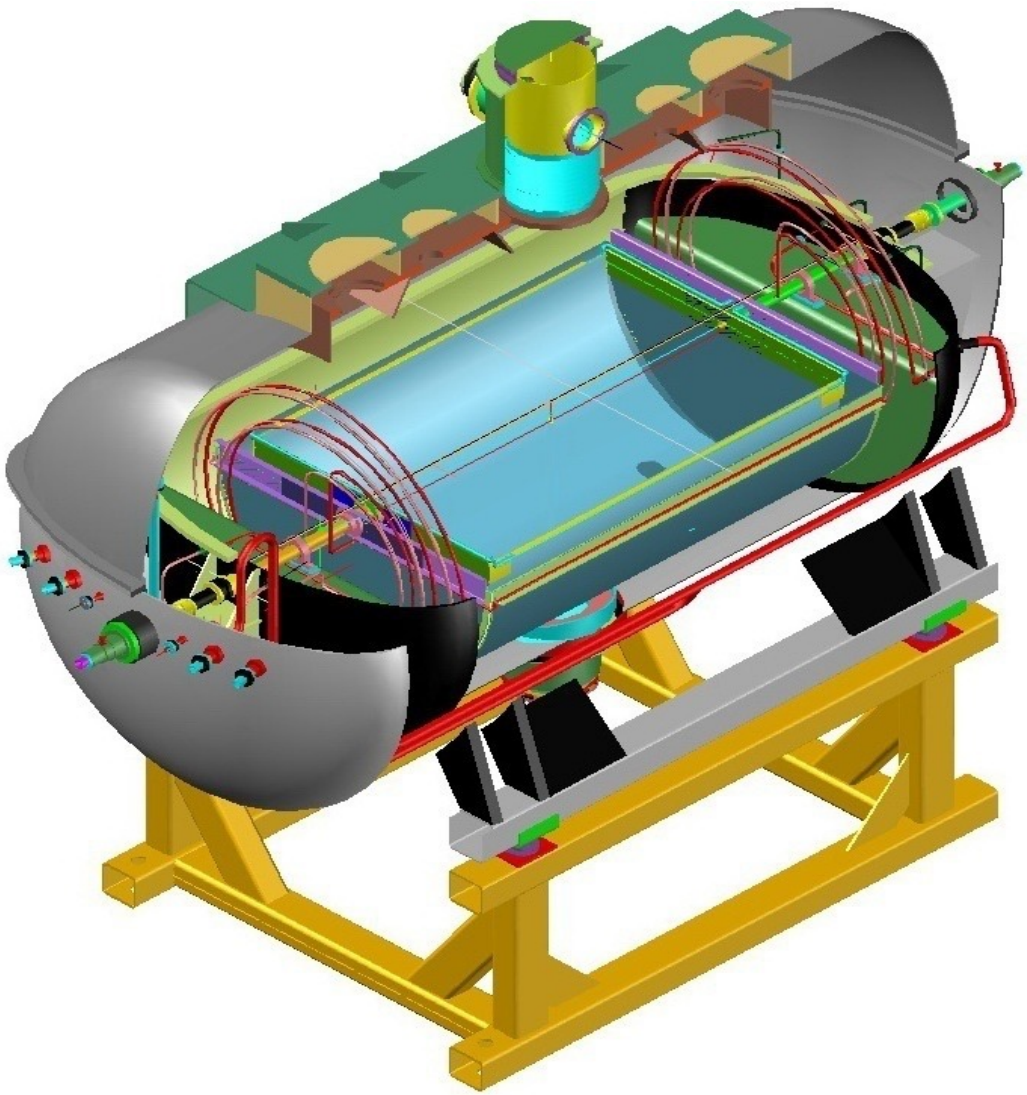
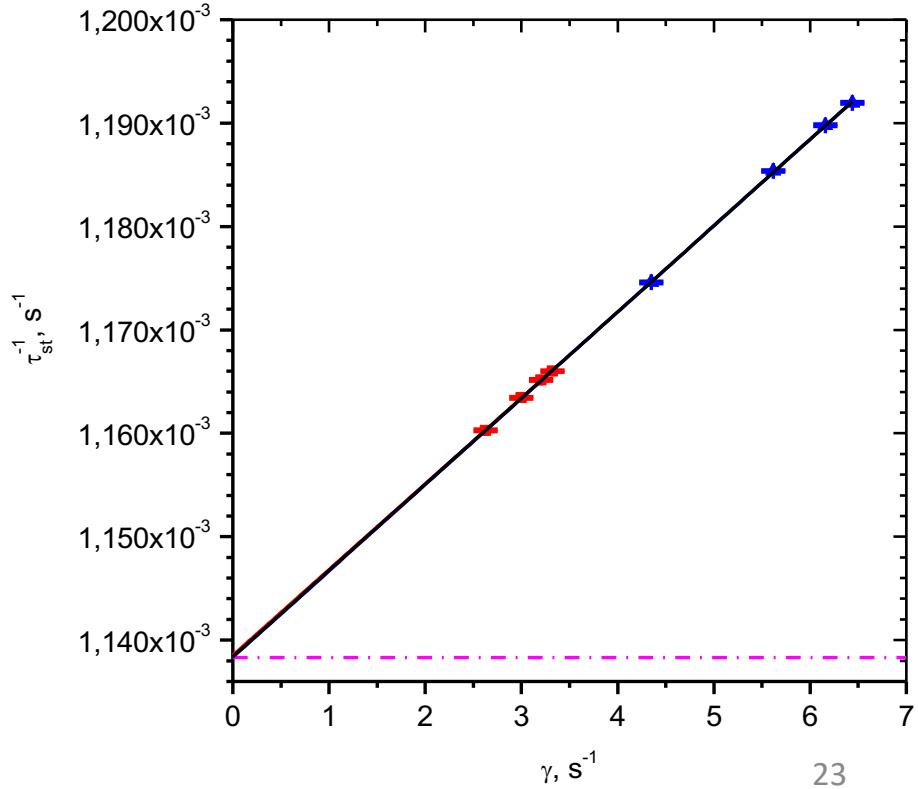
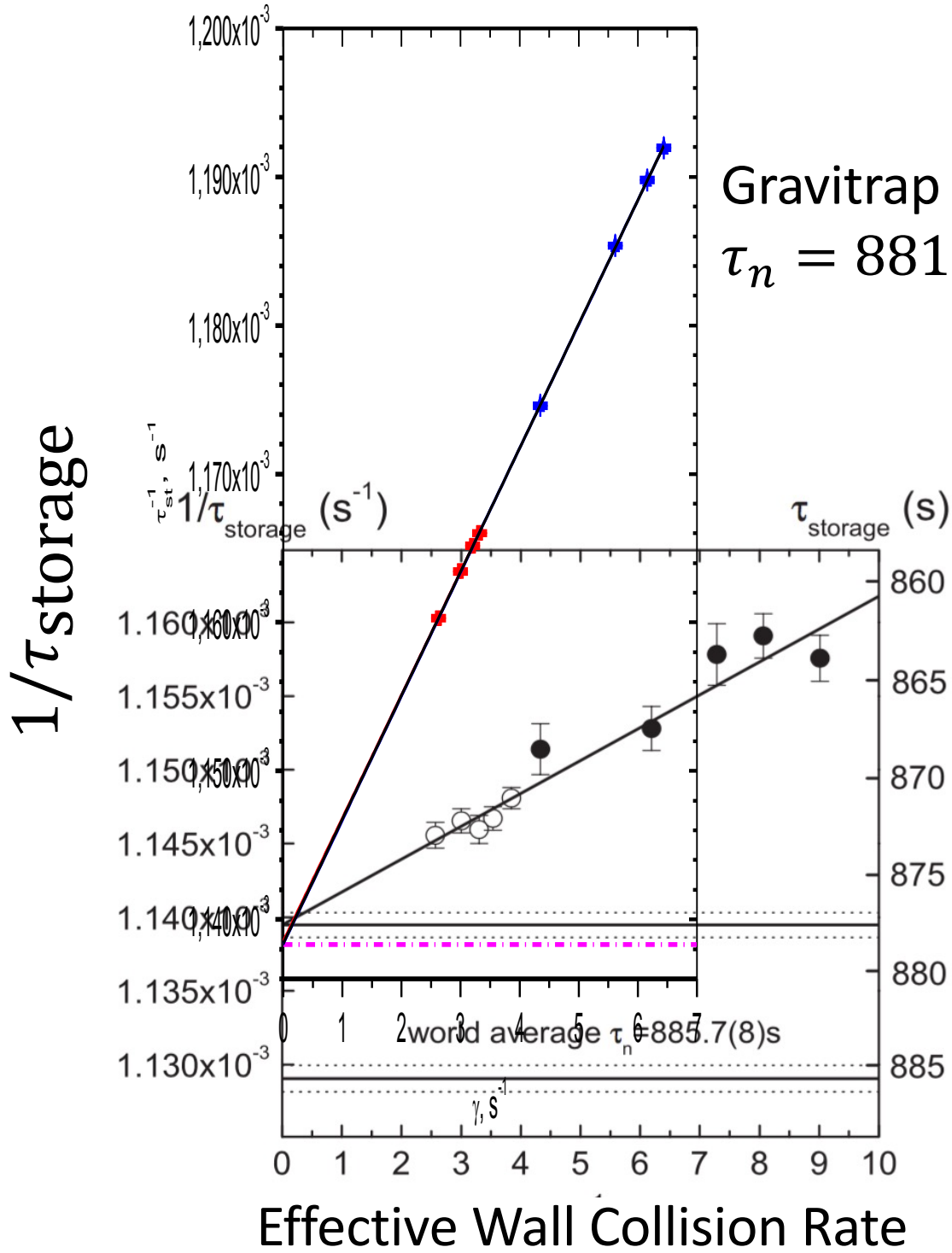


Fig.1. Gravitational spectrometer with service platforms



Content from A. Serebrov, PPNS2018



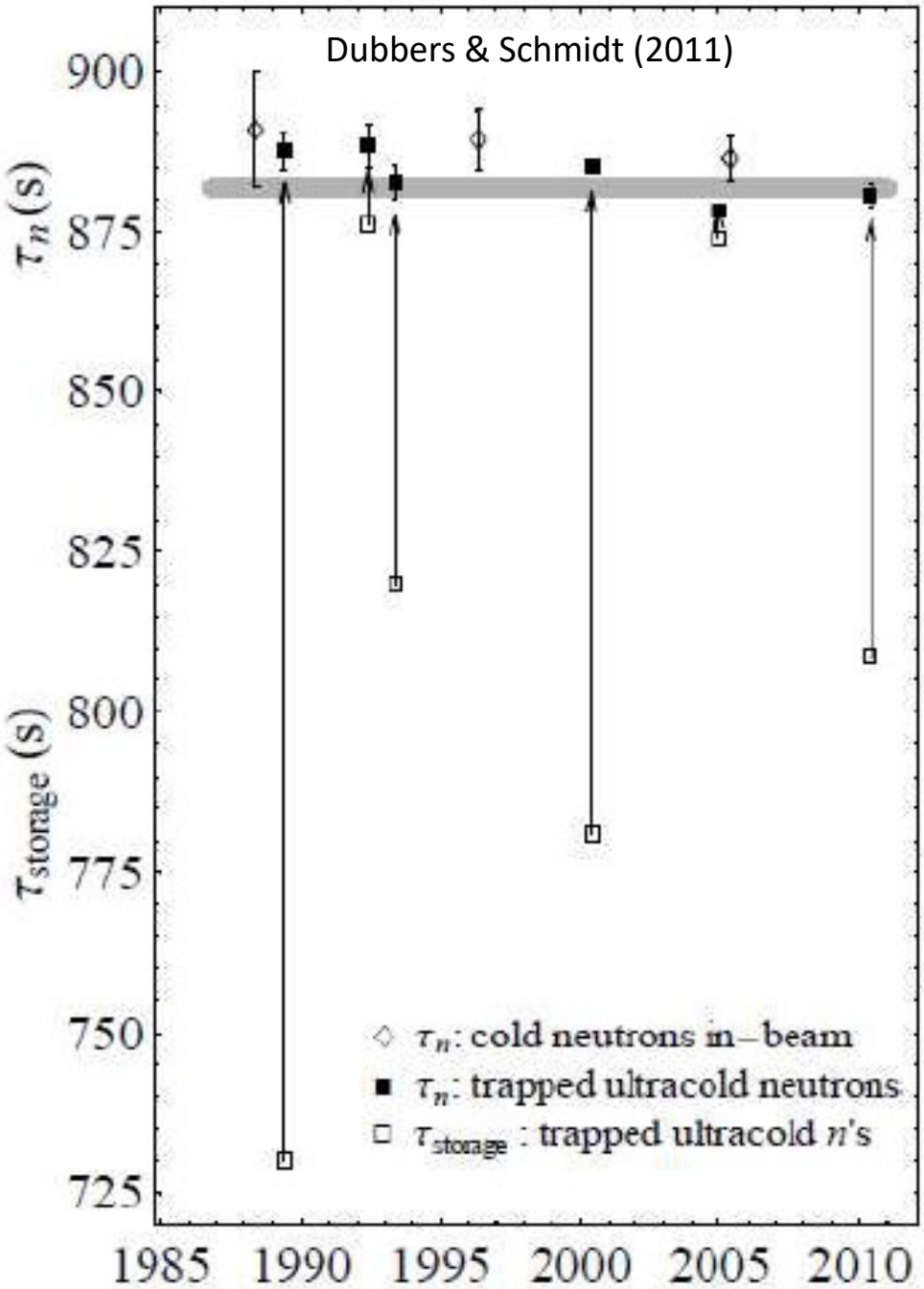
Gravitrap II

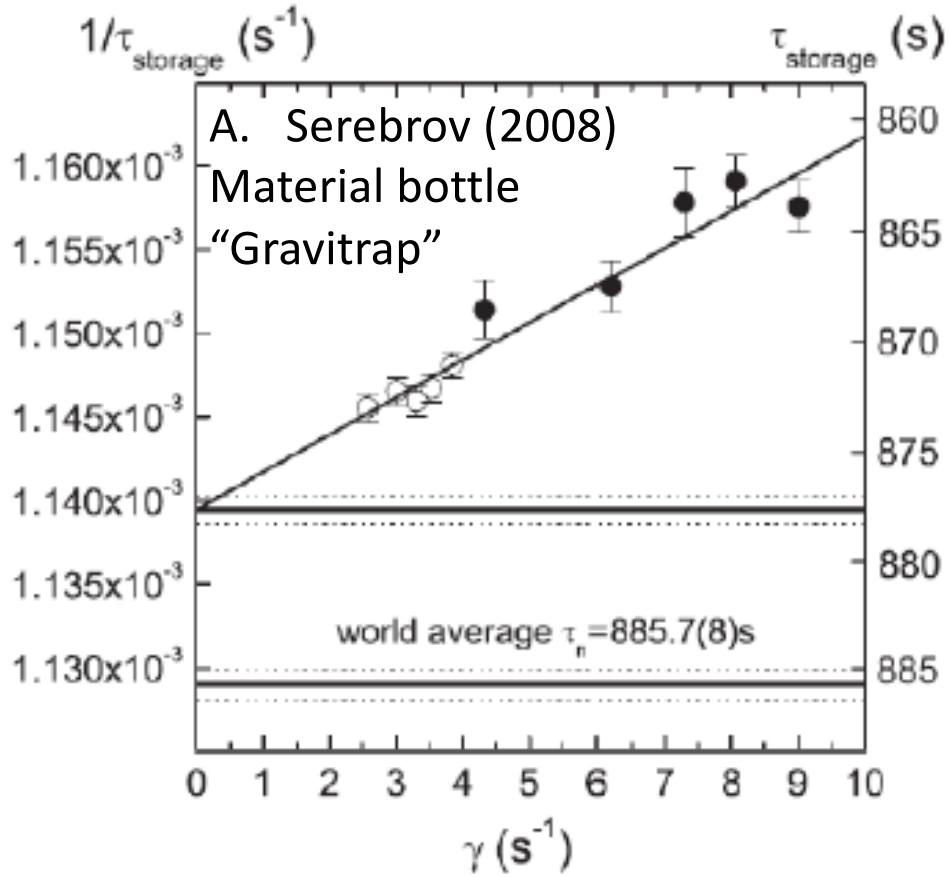
$\tau_n = 881.5 \pm 0.7 \pm 0.6$ s

Gravitrap I

$\tau_n = 878.5 \pm 0.7 \pm 0.3$ s

Size of Systematic Corrections for Losses

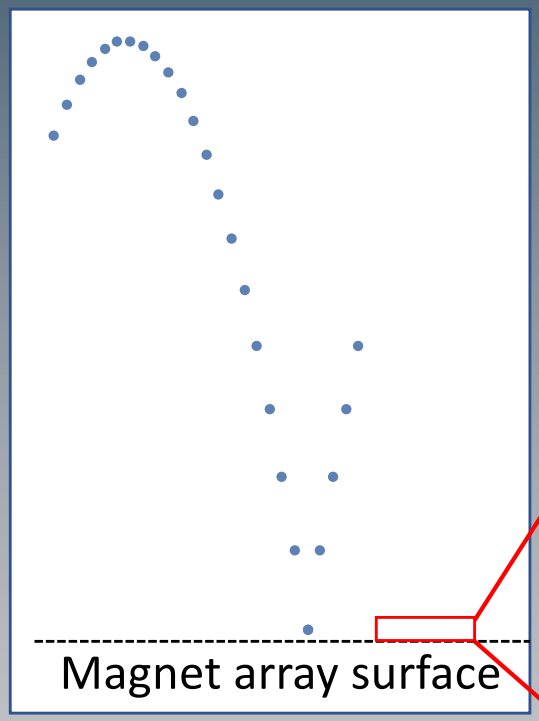




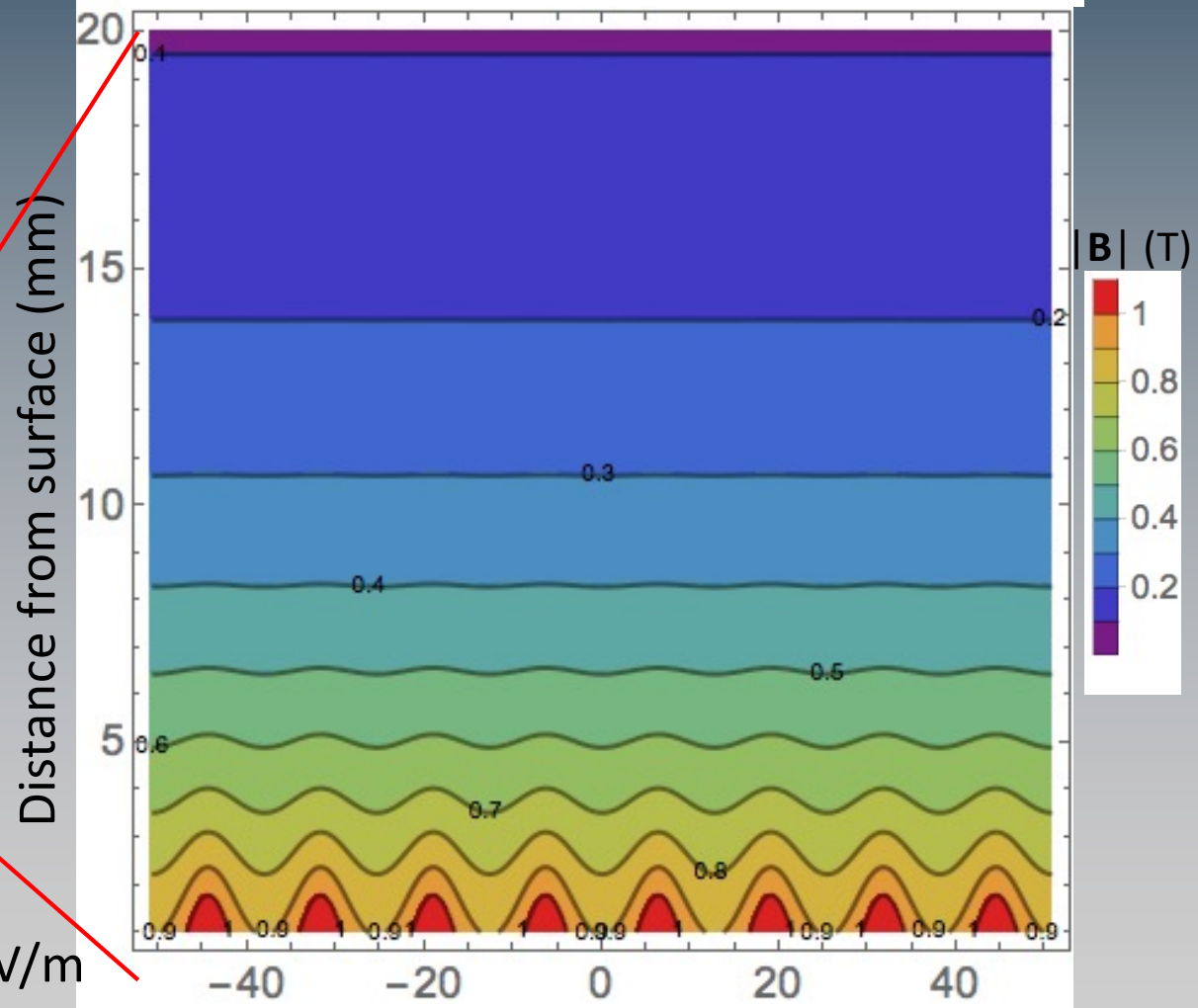
Large systematic corrections must be very well understood!

Magnetic bottles are designed to eliminate wall losses

Gravity confines from above, magnetic fields from below and laterally.



Field from permanent magnet Halbach array



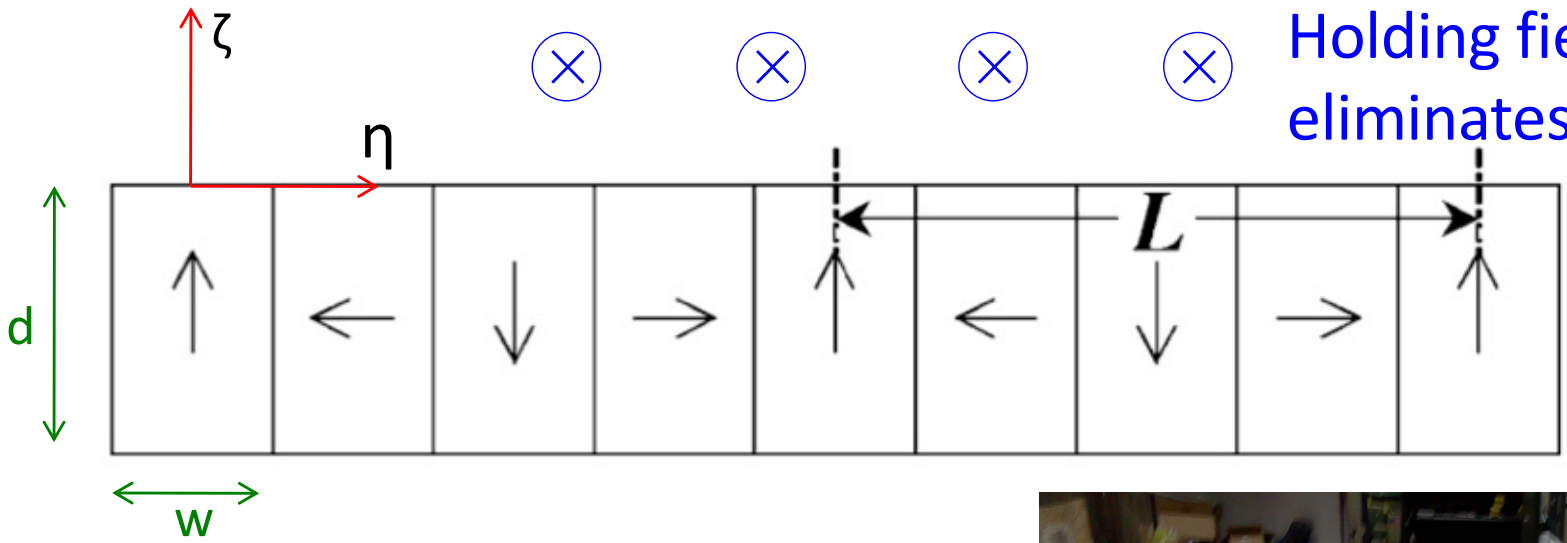
UCN τ Example:

- ***μ•B*** for neutron ≈60 neV/Tesla
- Gravitational potential ≈100 neV/m
- 50 cm drop (from rest) → closest approach to surface about 2 mm

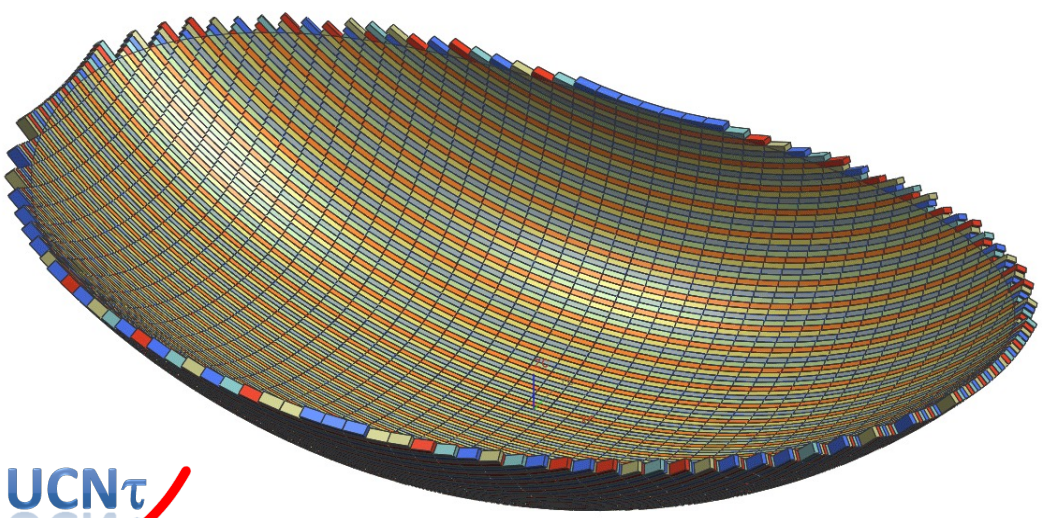
Halbach Array + Holding Field

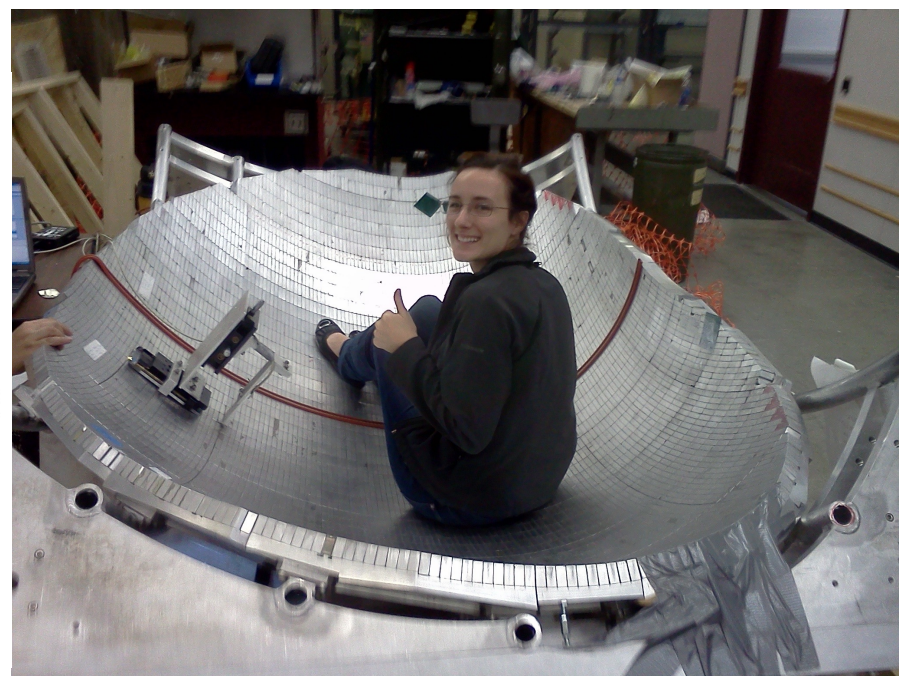
$$|\mathbf{B}| = B_{\mathrm{rem}}(1 - e^{-kd})e^{-k\zeta}$$

(if continuous rotation of M)

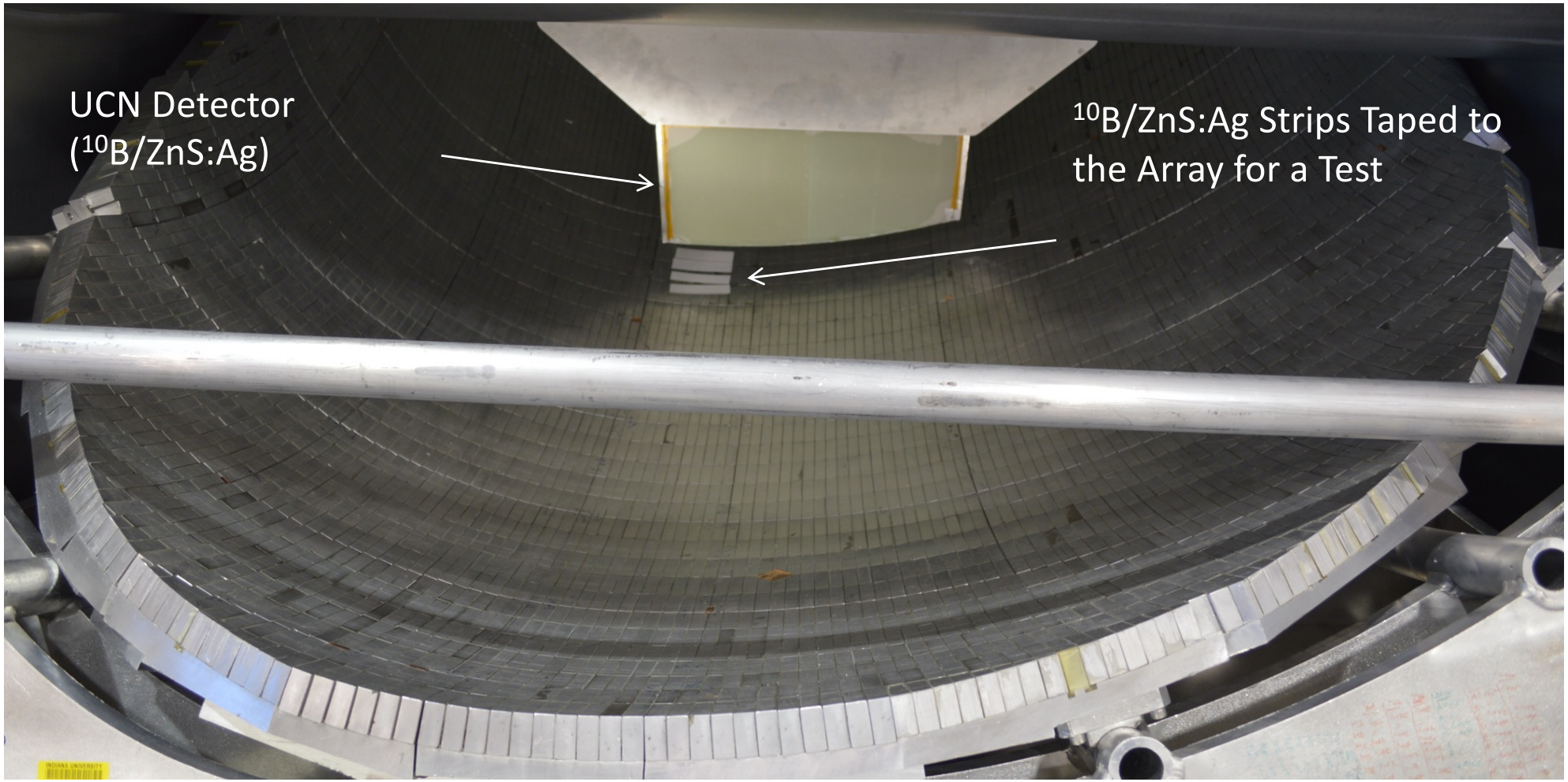


Holding field eliminates field zeros





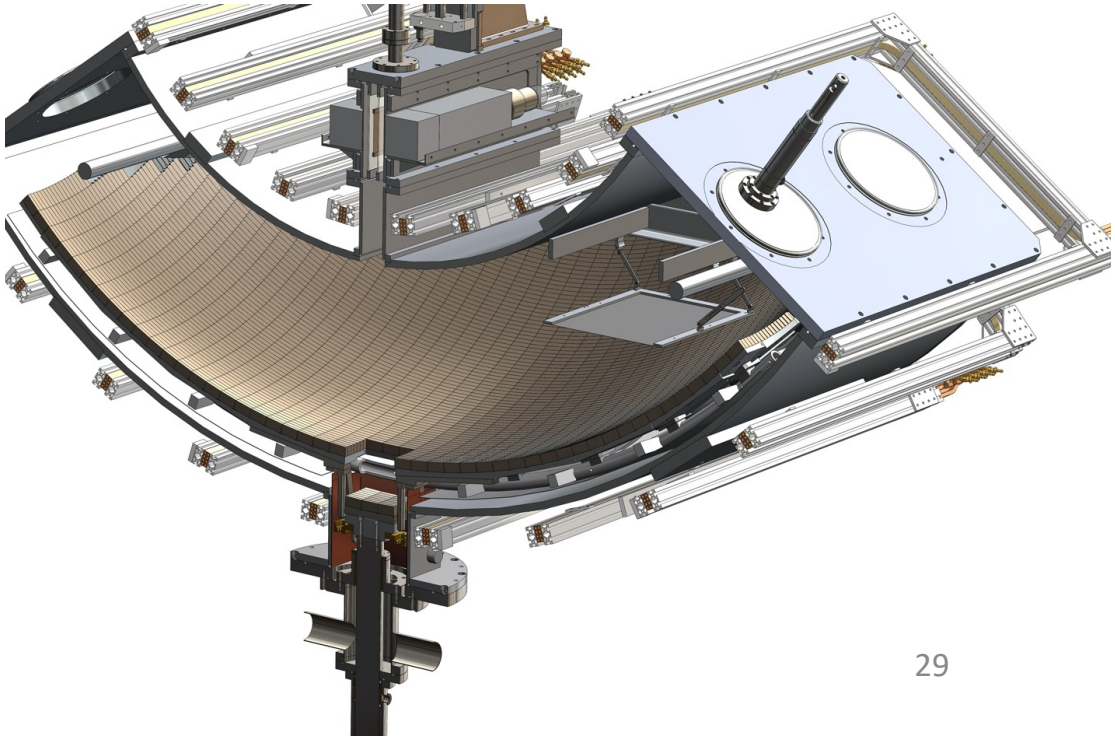
View of the Halbach Array and Lowered UCN Detector



UCNτ Overview

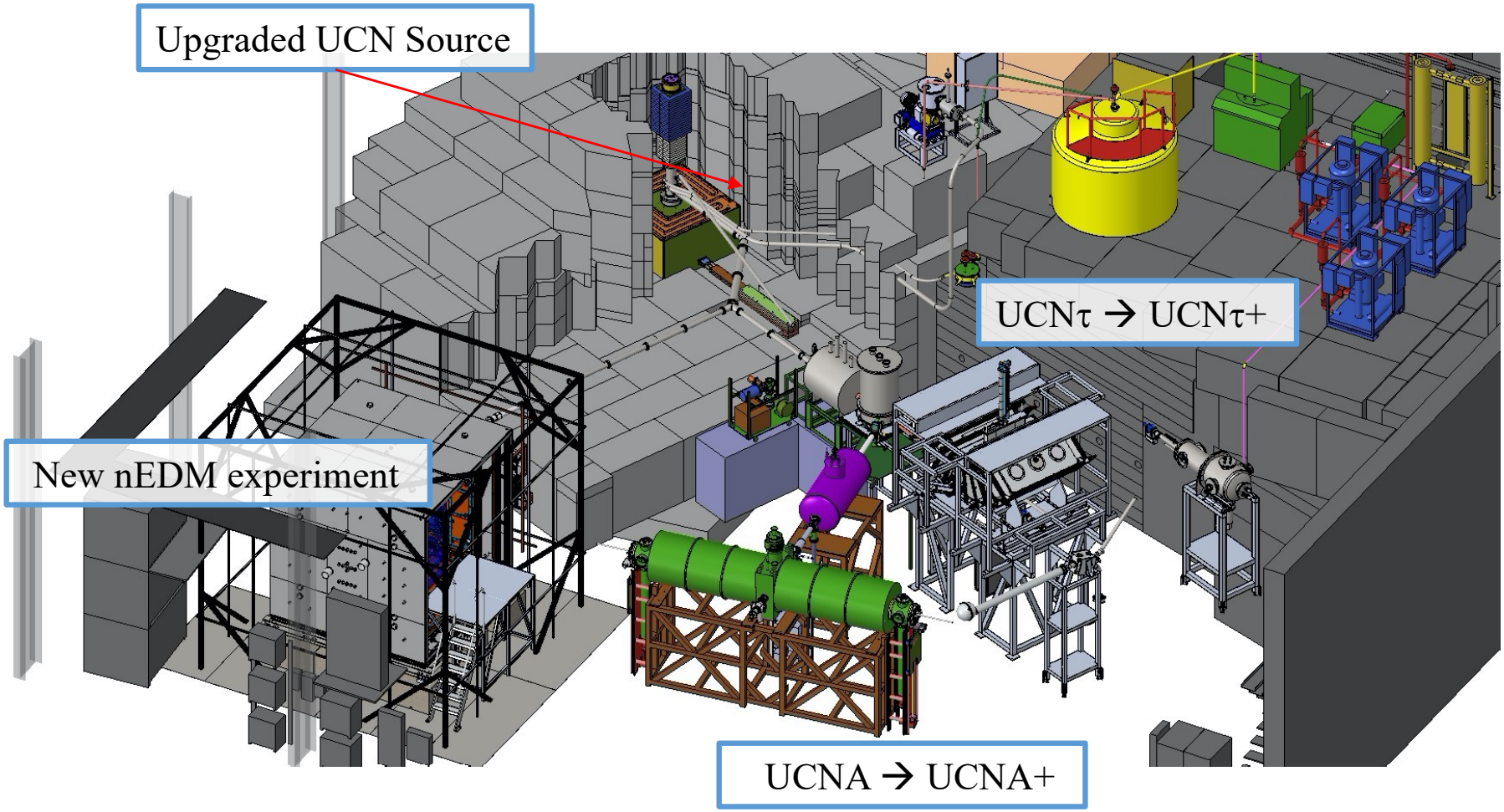
- UCN trap with very low intrinsic losses
  - Magneto-gravitational trap
  - Superposed holding field to eliminate B-field zeros (no depolarization losses)
  - Fast removal of quasi-bound UCNs possible through trap asymmetry and field ripple
- High statistics are achievable
  - Large volume
  - *In situ* UCN detector
    - High overall efficiency
    - Also: Less sensitive to phase-space evolution than draining

Based on original concept: P.L. Walstrom, J.D. Bowman, S.I. Penttila, C. Morris, A. Saunders, NIMA 599 (2009) 82-92

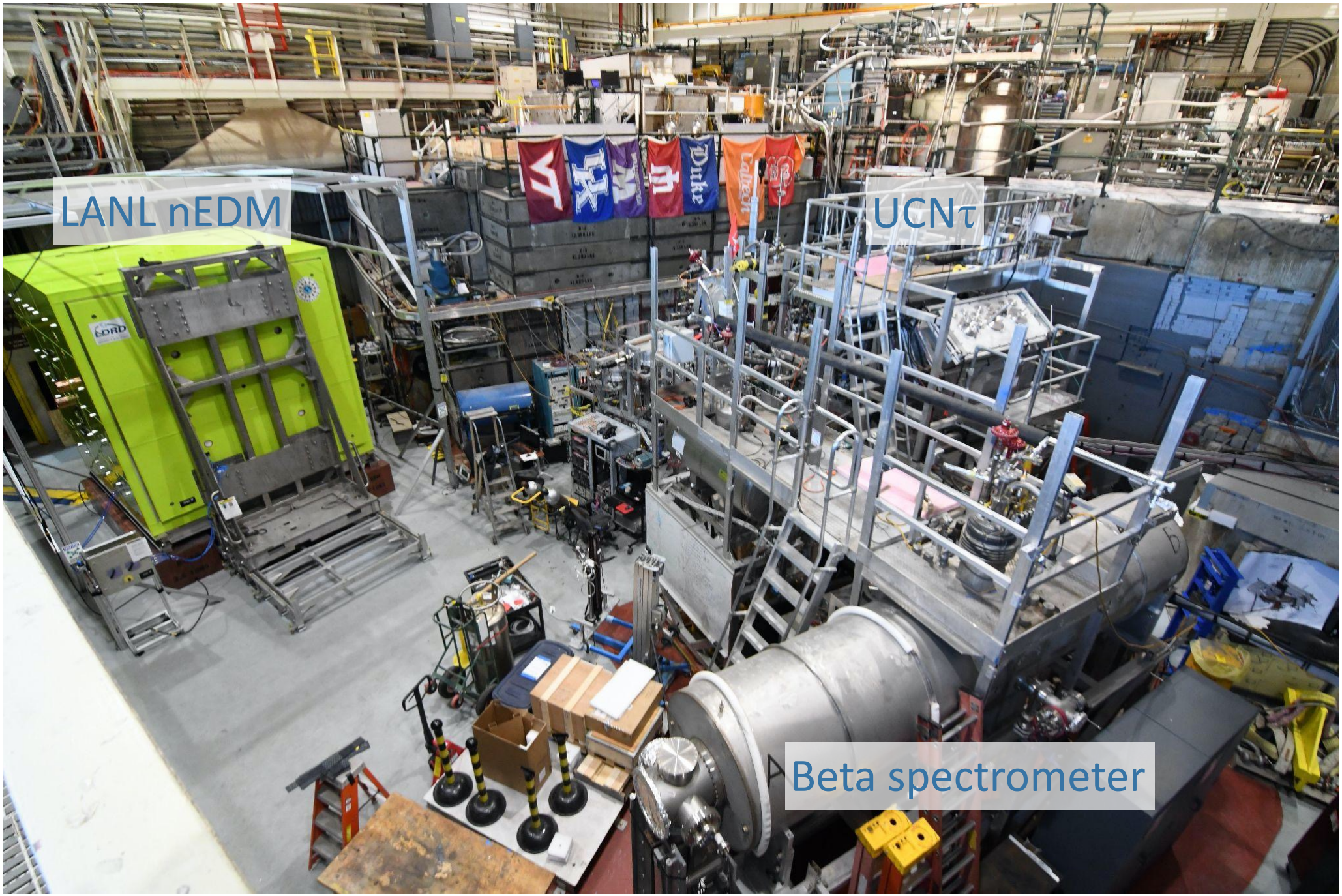


LANL's UCN Source Feeds Multiple Experiments

2016 UCN Source Upgrade: 5x improved output

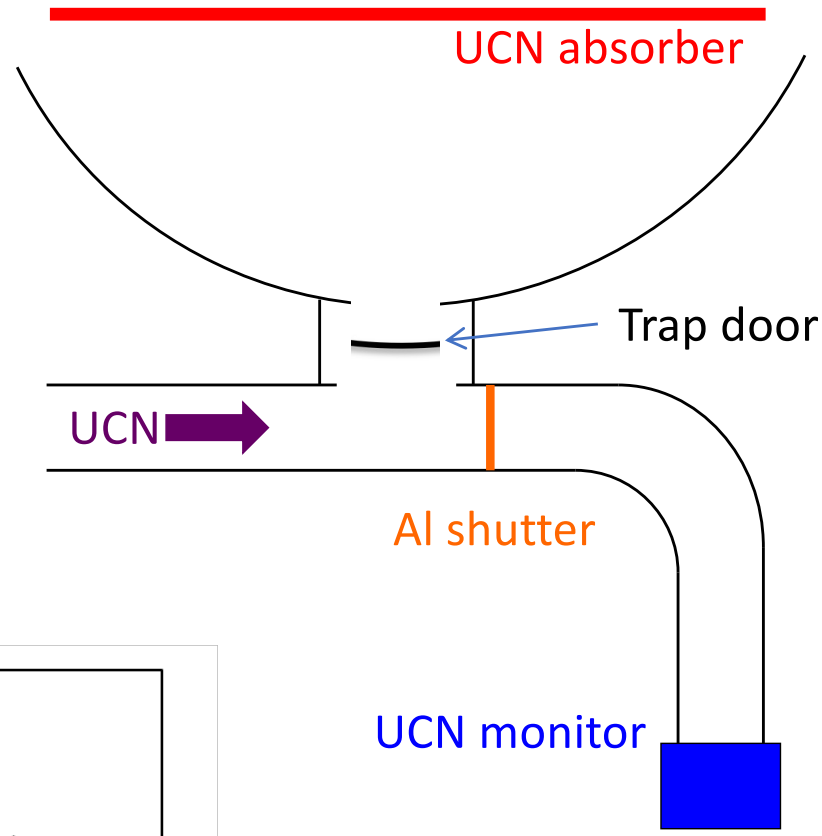


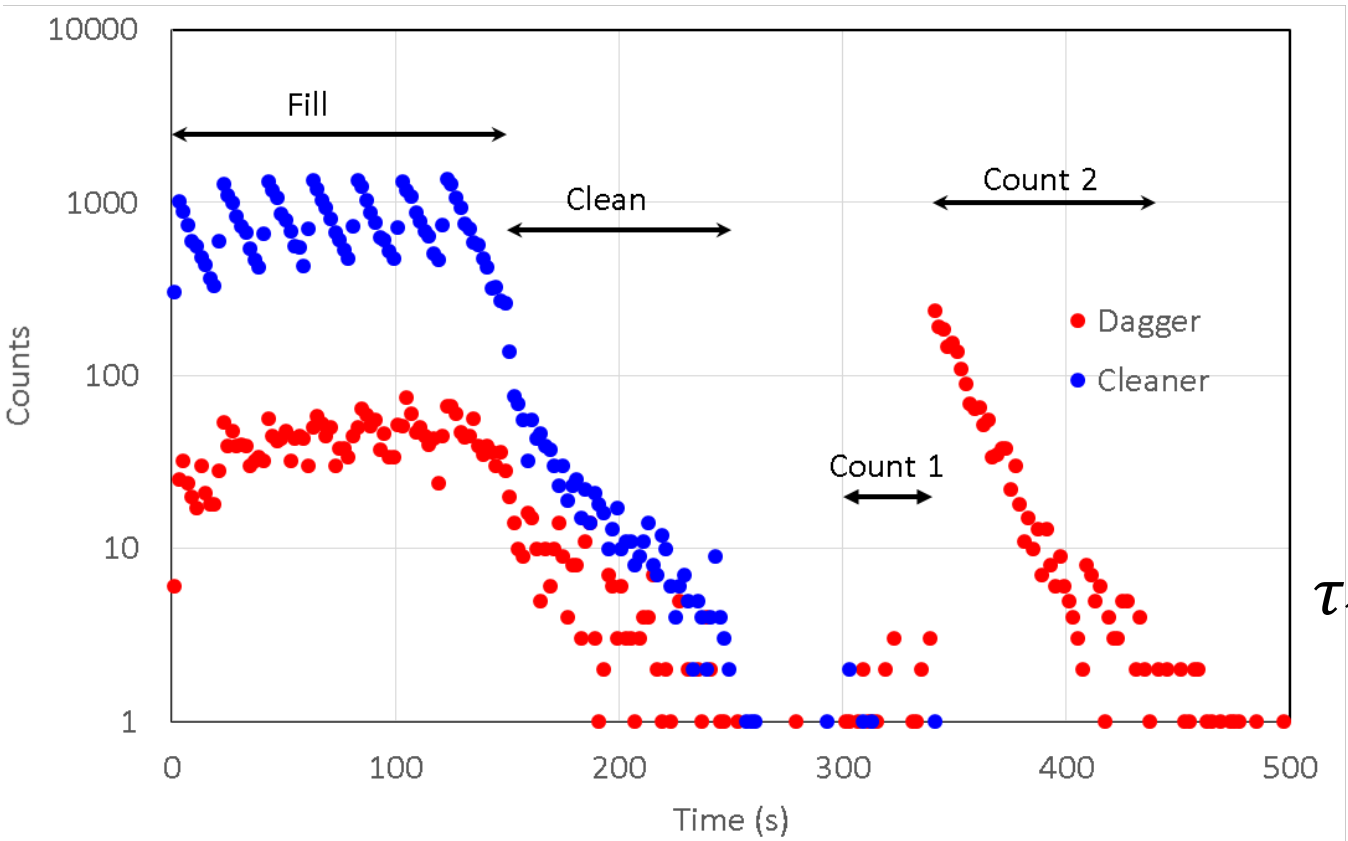
LANL UCN Experimental Hall



Measurement Cycle

1. Load the trap
2. Close the trap door
3. Remove quasi-bound UCNs (lower absorber, wait, raise absorber)
4. Hold UCNs in the trap for time *t*
5. Count the surviving UCN population *N*





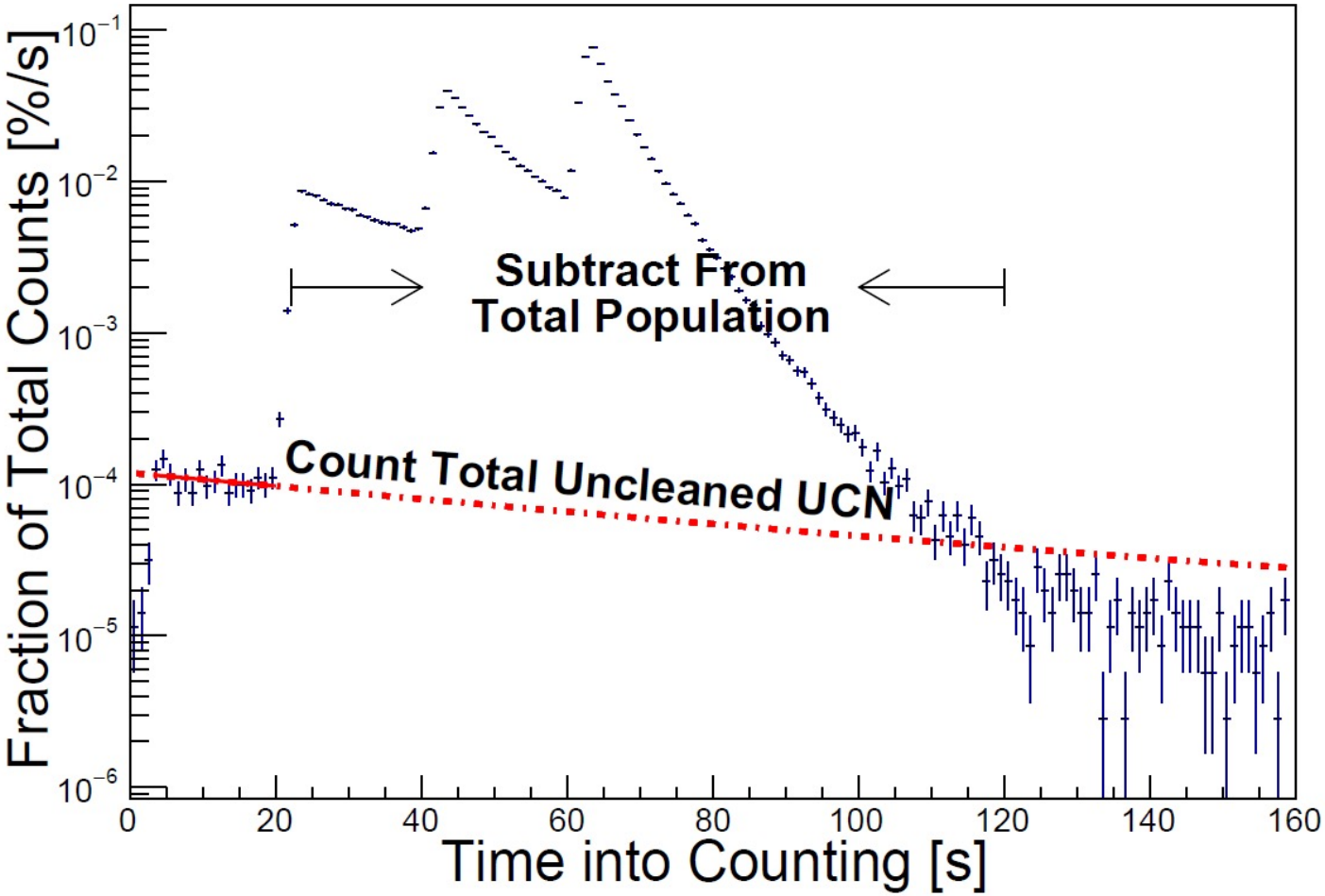
Using two different cycles with holding times t_1 and t_2,

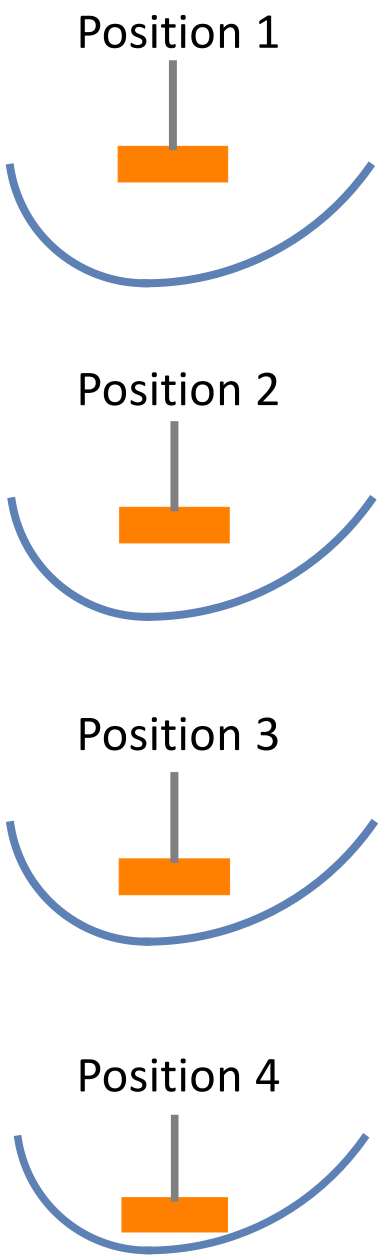
$$\tau_n = -(t_2 - t_1)/\log(\frac{N_2}{N_1})$$

Multi-step UCN detection

Example with an insufficiently-cleaned UCN population

(Before we installed the "Giant Cleaner")



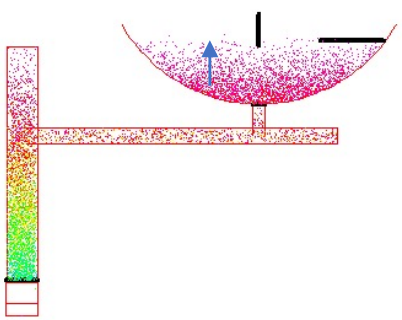


Systematic uncertainties in UCNτ 2018

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 variations	<0.01	±	Measured background as function of detector position
Total	**0.28**		**(uncorrelated sum)**

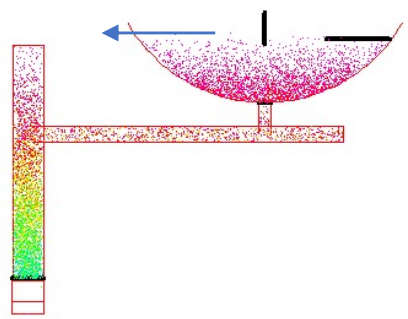
Heating

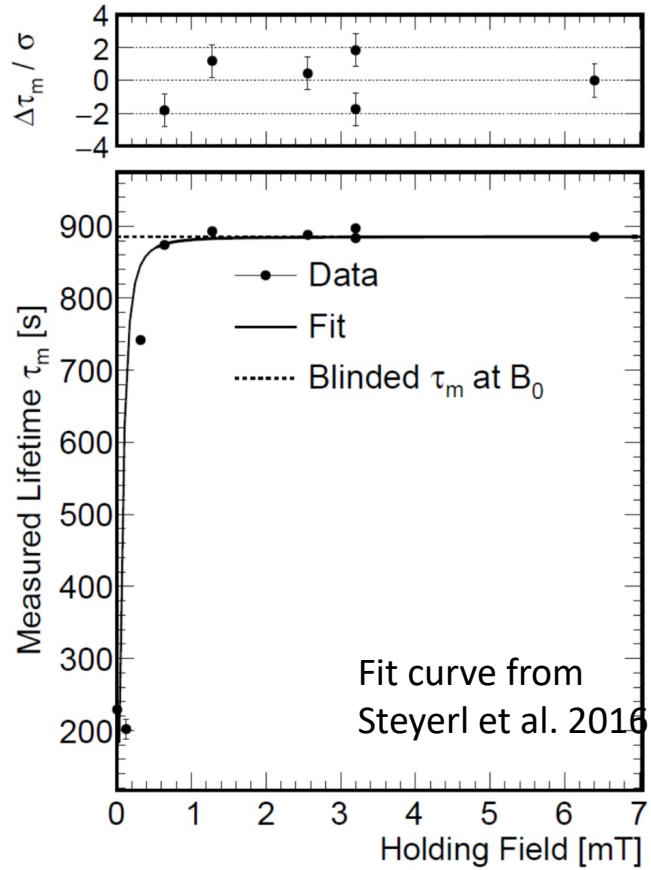
Limit established by long holding time excess



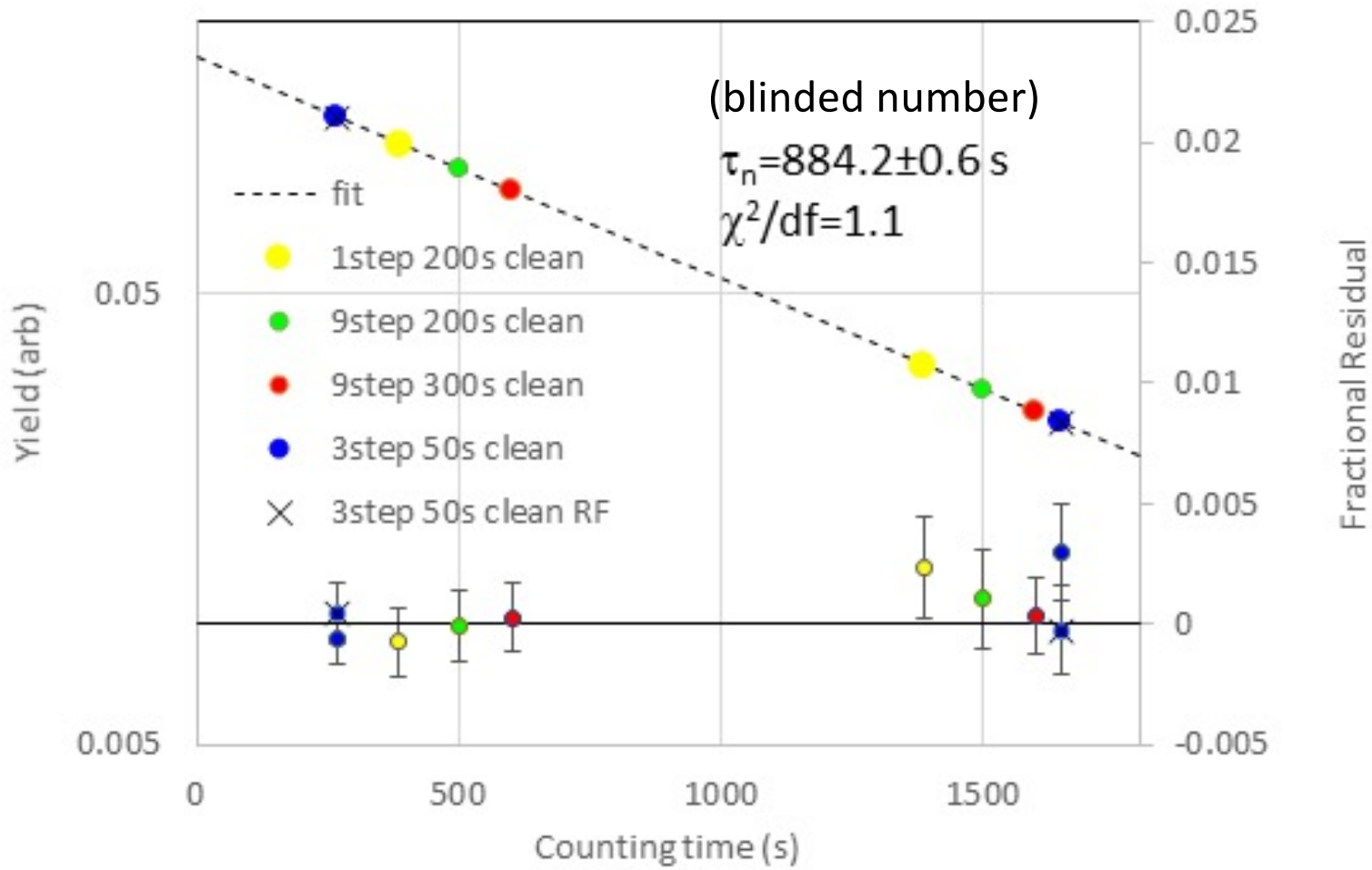
Insufficient Cleaning

Limit established by short holding time excess





UCNτ first physics result was released in 2017



After unblinding: 877.7 ± 0.7 (stat) +0.4/–0.2 (sys) s

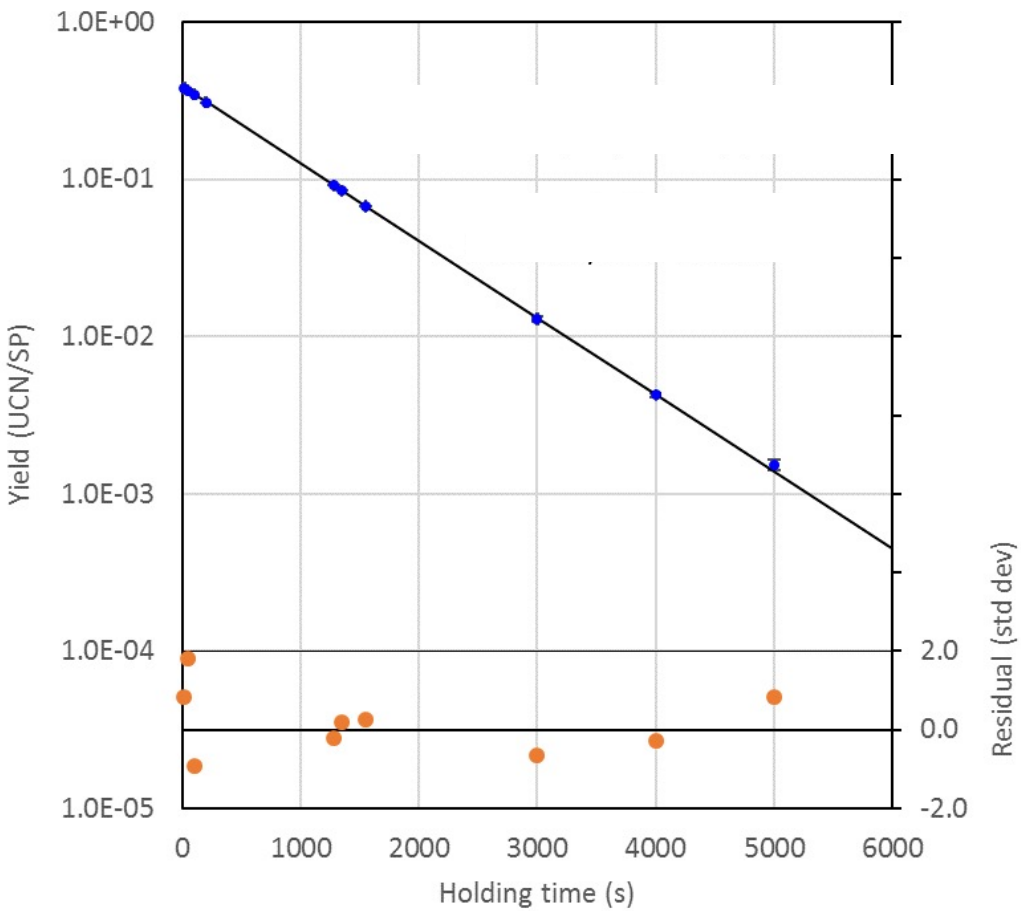
Science 06 May 2018, DOI: 10.1126/science.aan8895

New result from UCNτ

$\tau_n = 877.75 \pm 0.28_{stat} +0.22/-0.16_{syst}$ s

Phys. Rev. Lett. **127**, 162501 (Oct. 13, 2021)

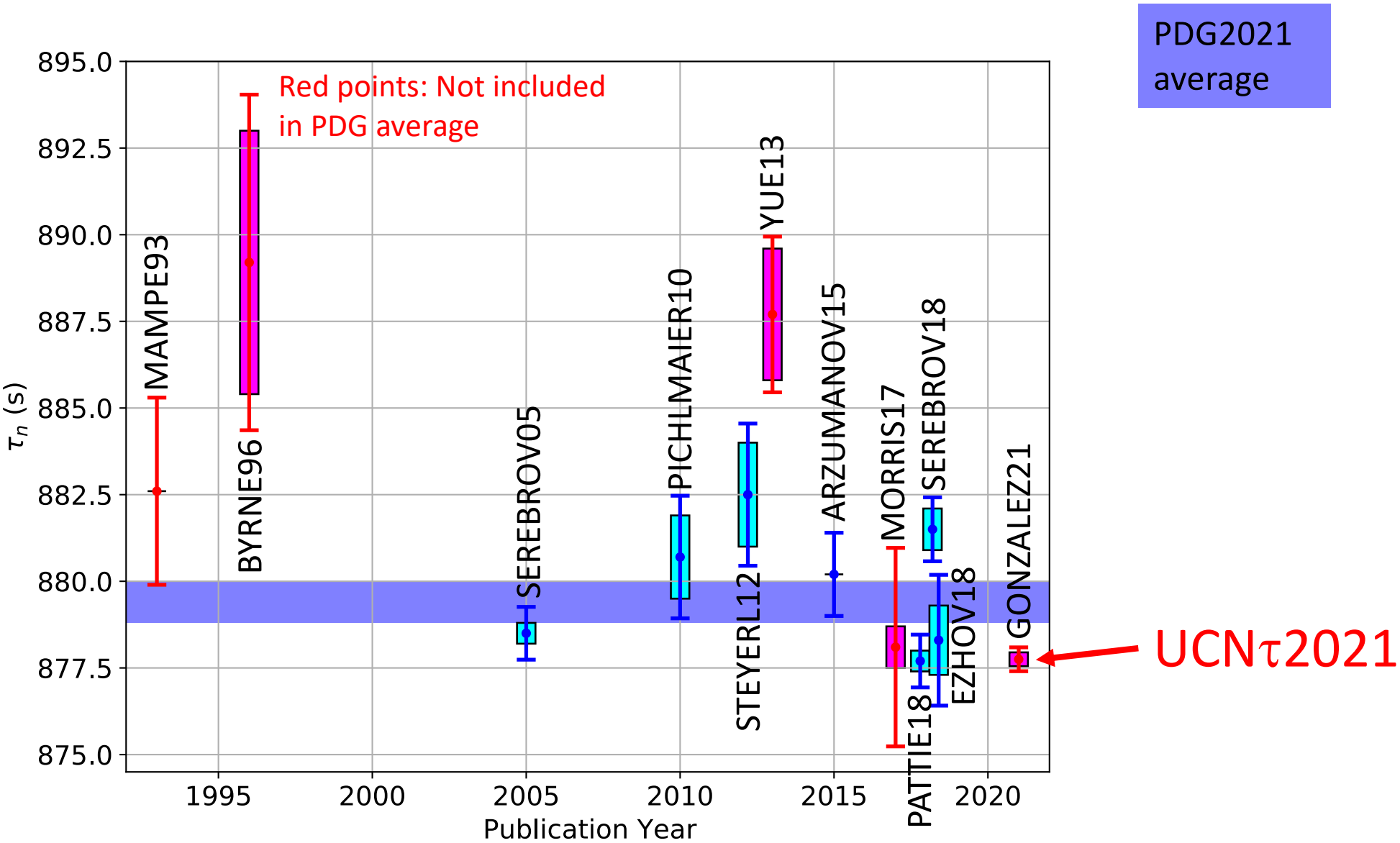
2017-2018 Run Campaigns:



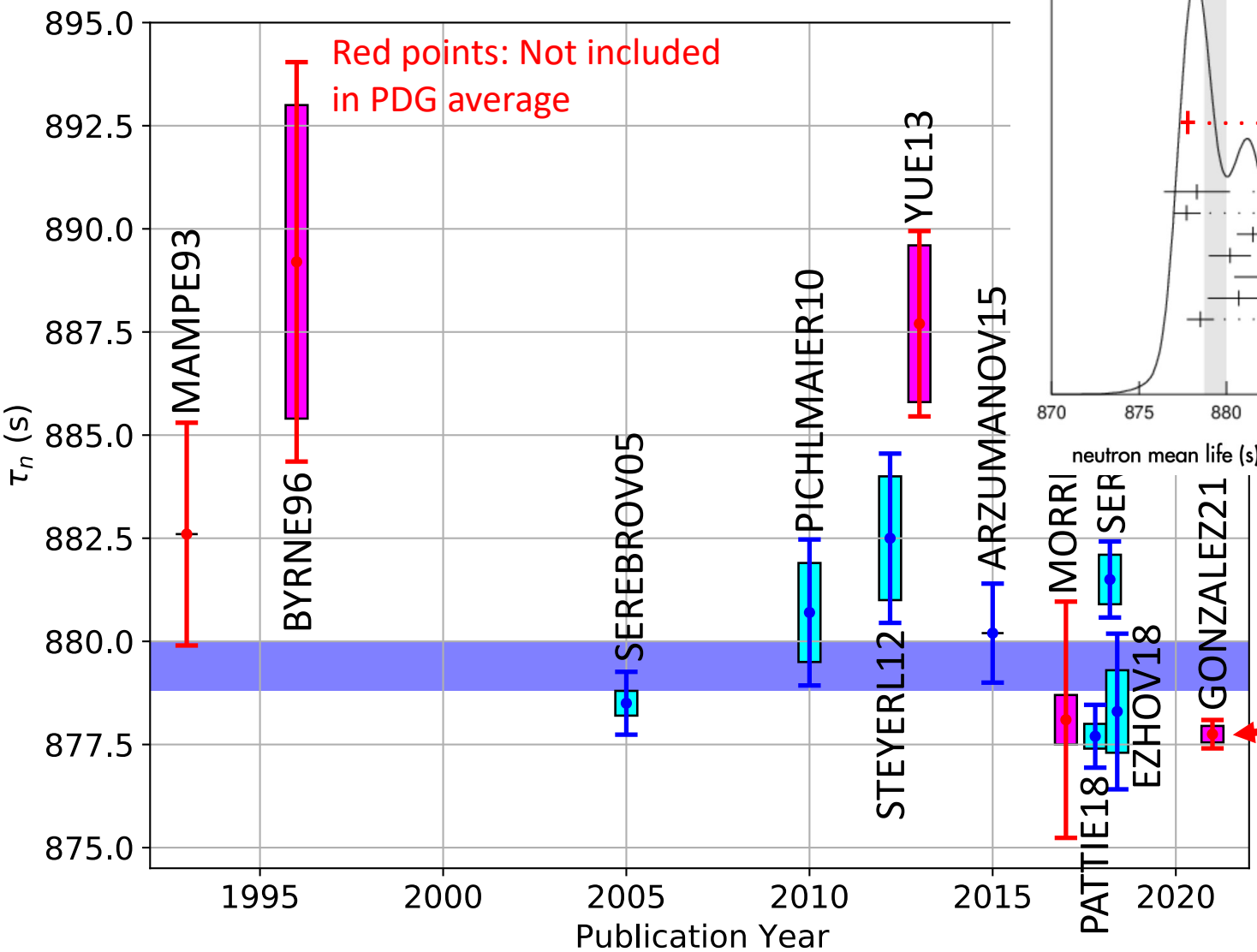
Final systematics table (2017-2018)

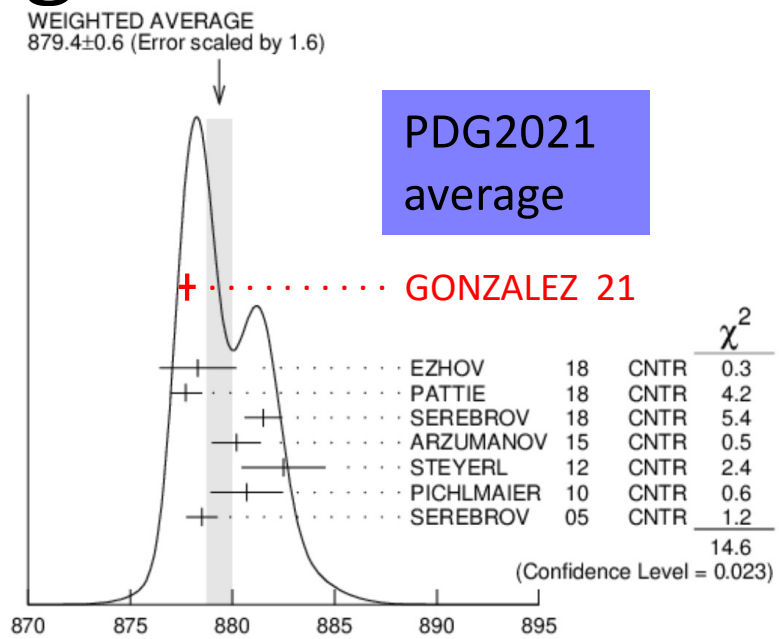
Effect	Correction	Uncertainty
UCN event definition	–	±0.13
Normalization weighting	–	±0.06
Depolarization	–	+0.07
Uncleaned UCN	–	+0.11
Heated UCN	–	+0.08
Al block	+0.06	±0.05
Residual gas scattering	+0.11	±0.06
Uncorrelated sum	$0.17^{+0.22}_{-0.16}$ s	

World data on τ_n including UCNτ2021



World data on τ_n including UCNτ2021

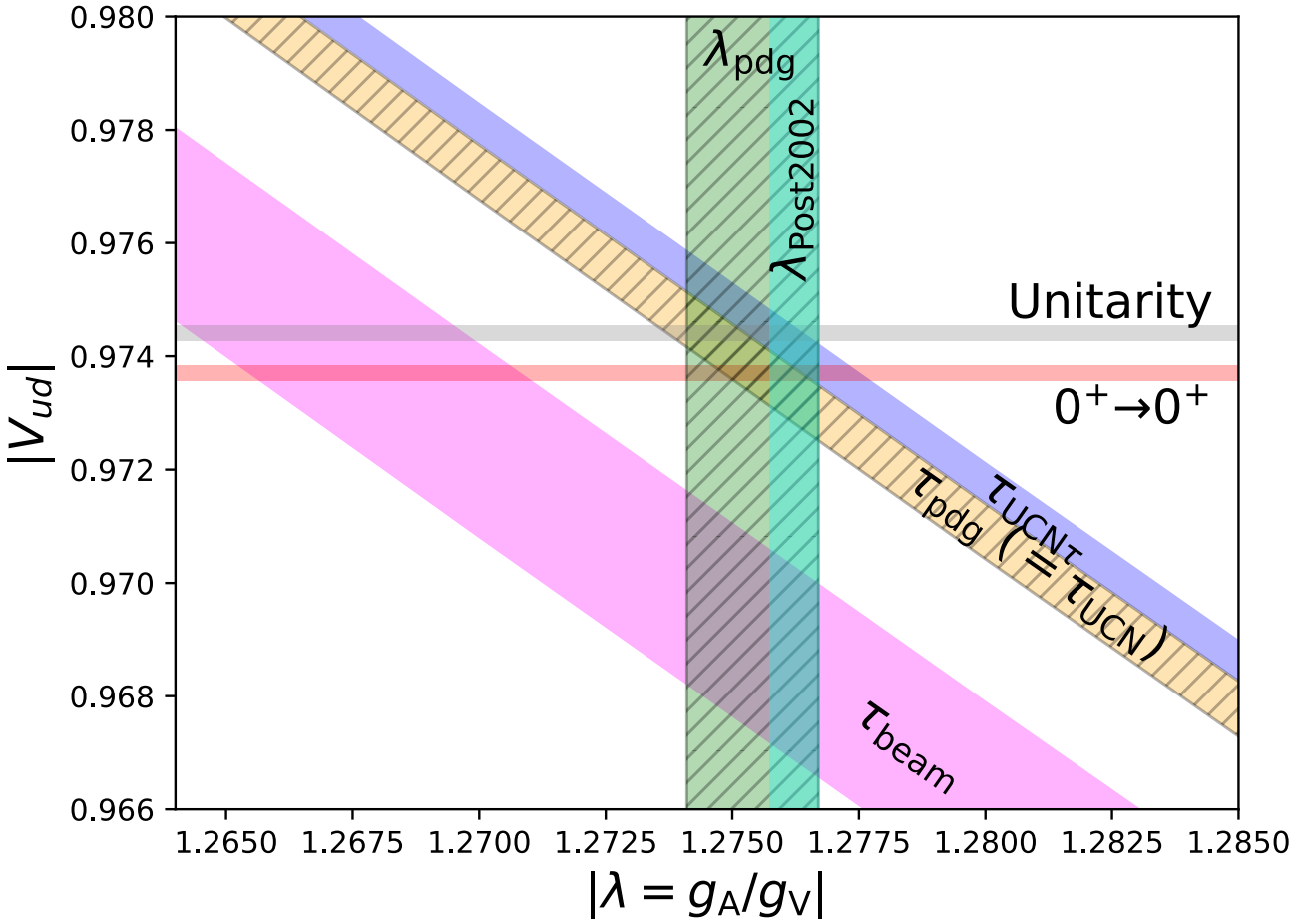




UCNτ2021

Can we test the standard model with neutron decay (yet)?

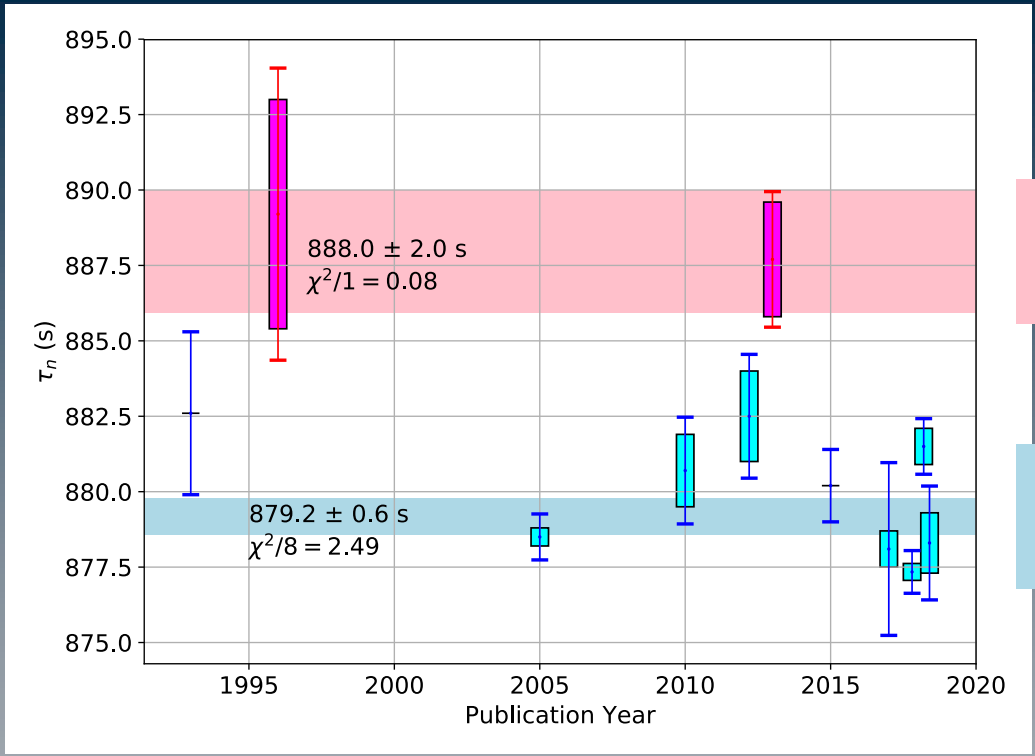
V_{ud} vs. Nucleon Axial Charge



Neutron decay master formula:

$$|V_{ud}|^2 = \frac{5099.3(4)\text{s}}{\tau_n(1+3g_A^2)(1+RC)}$$

Using RC from Seng et al., PRL **121**, 241804 (2018).



Beam average

Bottle average

What about beam vs. bottle?

There were many publications in 2018 following a suggestion of a dark matter explanation for the beam vs. bottle discrepancy.

Could the neutron β-decay branching ratio be <100%?

PHYSICAL REVIEW LETTERS **120,** 191801 (2018)

Editors' Suggestion Featured in Physics

Dark Matter Interpretation of the Neutron Decay Anomaly

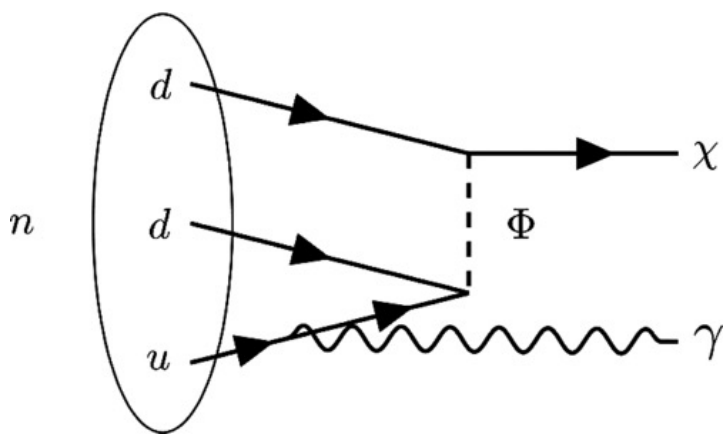
Bartosz Fornal and Benjamín Grinstein

Department of Physics, University of California, San Diego, 9500 Gilman Drive, La Jolla, California 92093, USA

(Received 19 January 2018; revised manuscript received 3 March 2018; published 9 May 2018)

There is a long-standing discrepancy between the neutron lifetime measured in beam and bottle experiments. We propose to explain this anomaly by a dark decay channel for the neutron, involving one or more dark sector particles in the final state. If any of these particles are stable, they can be the dark matter. We construct representative particle physics models consistent with all experimental constraints.

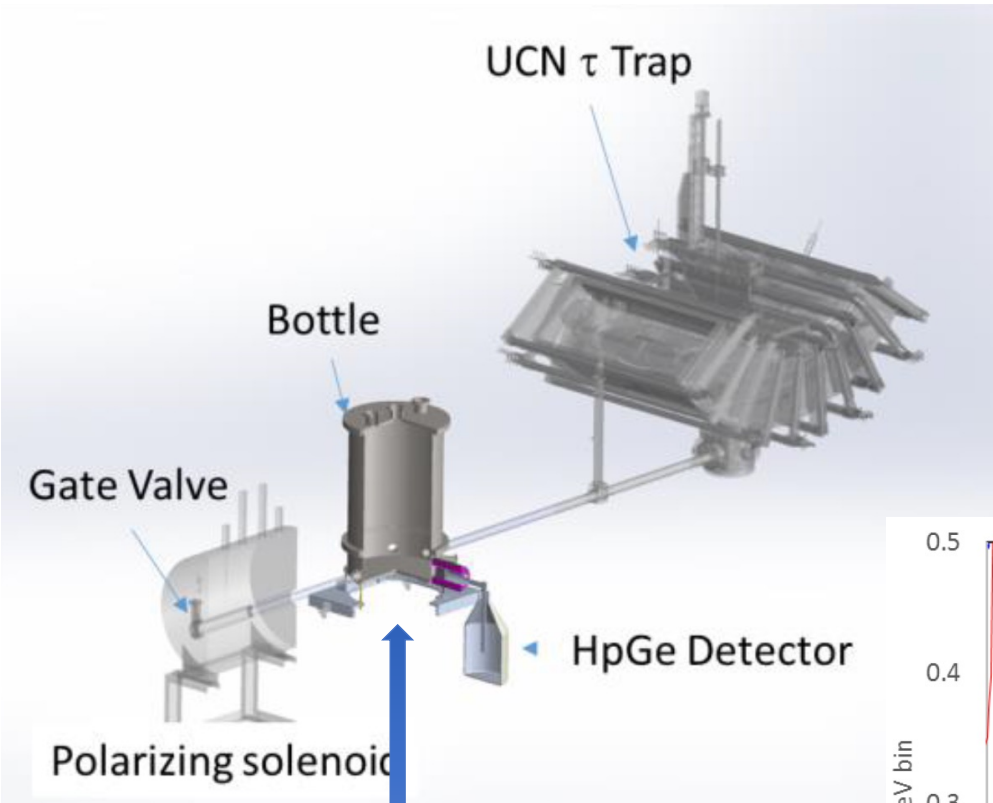
DOI: 10.1103/PhysRevLett.120.191801



Simplest signature: photon with
0.782 MeV < E_γ < 1.664 MeV

Also: e+/e- pair with total
E < 1.665 MeV

We looked for the γ and e^+/e^- signatures…

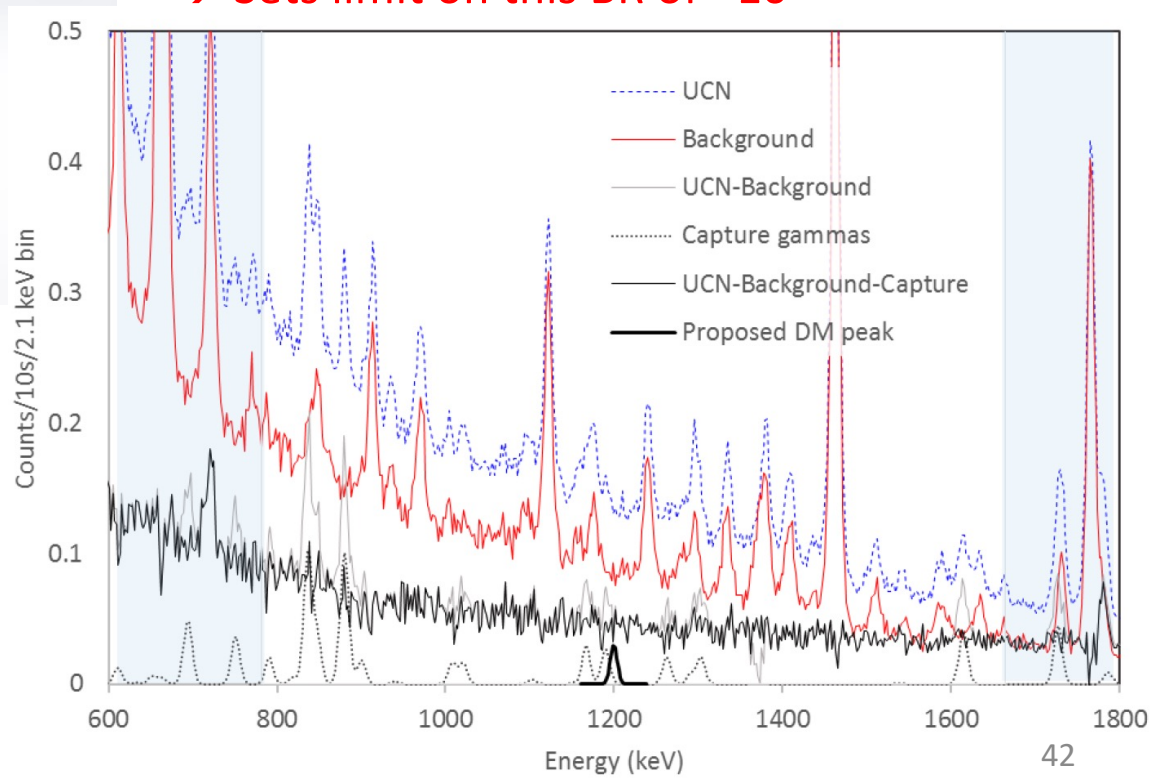


A buffer volume installed (2018) to smooth out the pulse response for more stable normalization.

Sun, X et al., "Search for dark matter decay of the free neutron from the UCNA experiment: $n \rightarrow \chi + e+e-$," PHYSICAL REVIEW C **97**, 052501(R) (2018) .

Tang, ZT et al., "Search for the Neutron Decay n→ X+γ where X is a dark matter particle," PRL **121**, 022505 (2018).

→ Sets limit on this BR of ~10^{-3}



Neutron decay to dark matter is inconsistent with observed heavier neutron star masses.*

PHYSICAL REVIEW LETTERS **121,** 061802 (2018)

Neutron Stars Exclude Light Dark Baryons

David McKeen,[1,2,*] Ann E. Nelson,[3,†] Sanjay Reddy,[4,‡] and Dake Zhou[3,4,§]

[1]*Pittsburgh Particle Physics, Astrophysics, and Cosmology Center, Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA*

[2]*TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia V6T 2A3, Canada*

[3]*Department of Physics, University of Washington, Seattle, Washington 98195, USA*

[4]*Institute for Nuclear Theory, University of Washington, Seattle, Washington 98195, USA*

(Received 26 February 2018; revised manuscript received 1 June 2018; published 6 August 2018)

Exotic particles carrying baryon number and with a mass of the order of the nucleon mass have been proposed for various reasons including baryogenesis, dark matter, mirror worlds, and the neutron lifetime puzzle. We show that the existence of neutron stars with a mass greater than 0.7 $M_\odot$ places severe constraints on such particles, requiring them to be heavier than 1.2 GeV or to have strongly repulsive self-interactions.

DOI: 10.1103/PhysRevLett.121.061802

*Unless the dark matter particle is strongly self-interacting, with specific constraints on this interaction.

Same conclusion by other authors:

PHYSICAL REVIEW LETTERS **121,** 061801 (2018)

Testing Dark Decays of Baryons in Neutron Stars

Gordon Baym,[1] D. H. Beck,[1] Peter Geltenbort,[2] and Jessie Shelton[1]
[1]*Department of Physics, University of Illinois, 1110 West Green Street, Urbana, Illinois 61801, USA*
[2]*Institut Max von Laue Paul Langevin, 71 avenue des Martyrs, F-38042 Grenoble Cedex 9, France*

(Received 23 February 2018; revised manuscript received 27 June 2018; published 6 August 2018)

The observation of neutron stars with masses greater than one solar mass places severe demands on any exotic neutron decay mode that could explain the discrepancy between beam and bottle measurements of the neutron lifetime. If the neutron can decay to a stable, feebly interacting dark fermion, the maximum possible mass of a neutron star is $0.7M_{\odot}$, while all well-measured neutron star masses exceed one $M_{\odot}$. The existence of $2M_{\odot}$ neutron stars further indicates that any explanation beyond the standard model for the neutron lifetime puzzle requires dark matter to be part of a multiparticle dark sector with highly constrained interactions. Beyond the neutron lifetime puzzle, our results indicate that neutron stars provide unique and useful probes of GeV-scale dark sectors coupled to the standard model via baryon-number-violating interactions.

DOI: 10.1103/PhysRevLett.121.061801

However, there may still be scenarios consistent with neutron star observations:

PHYSICAL REVIEW LETTERS **123,** 091601 (2019)

Neutron Star Stability in Light of the Neutron Decay Anomaly

Benjamín Grinstein*
Department of Physics, UC San Diego, La Jolla, California 92093, USA

Chris Kouvaris† and Niklas Grønlund Nielsen‡
CP^3-Origins, University of Southern Denmark, Campusvej 55, DK-5230 Odense, Denmark

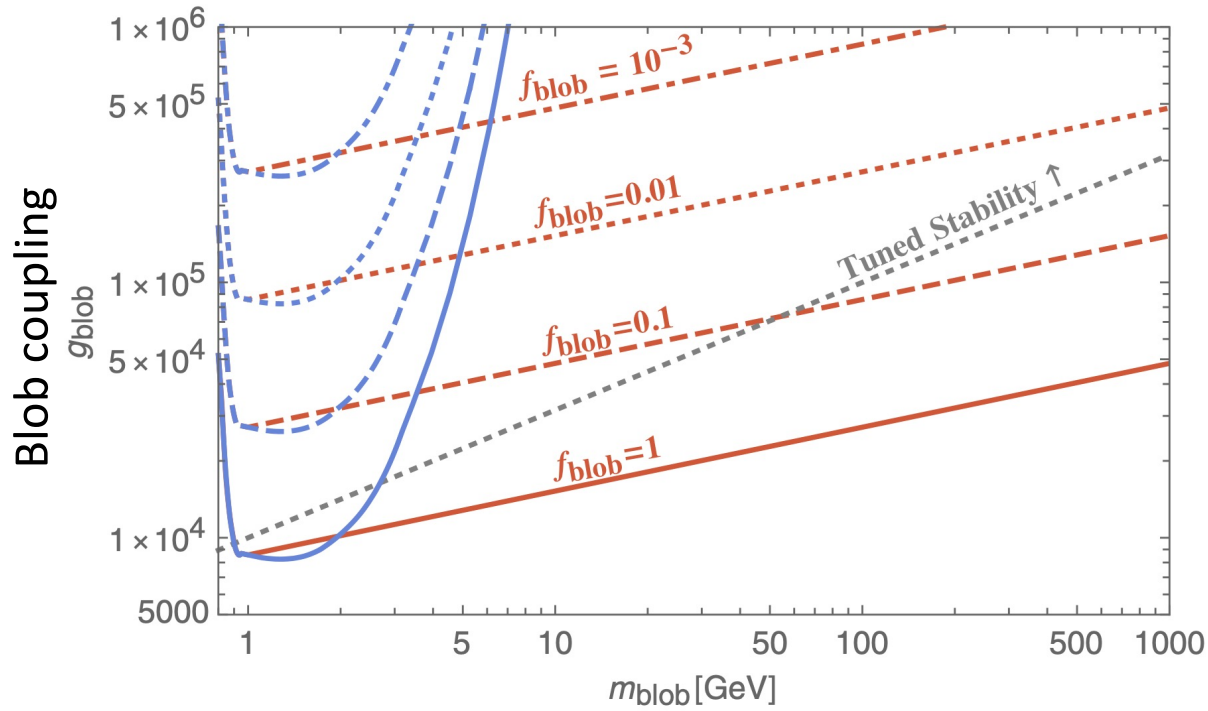
(Received 5 December 2018; published 28 August 2019)

A recent proposal suggests that experimental discrepancies on the lifetime of neutrons can be resolved if neutrons decay to dark matter. At the same time it has been demonstrated that such a decay mode would soften the nuclear equation of the state resulting in neutron stars with a maximum mass much below currently observed ones. In this Letter, we demonstrate that appropriate dark matter-baryon interactions can accommodate neutron stars with mass above two solar masses. We compare this stabilization mechanism to one based on dark matter self-interactions, finding that it is less sensitive to the details of the nuclear equation of state. We present a simple microscopic model realization of this mechanism.

DOI: 10.1103/PhysRevLett.123.091601

Or something completely different: soft scattering of UCN by dark matter "blobs"

Rajendran and Ramani, "Composite solution to the neutron lifetime anomaly," Phys. Rev. D **103**, 035014 (2021)



- f_{blob}: Fraction of dark matter in blobs
- Considering +50 neV kick to a neutron removes it from trap
- Blue/orange: different DM interaction scenarios

Might motivate space-based neutron lifetime measurements, which are total-disappearance-rate measurements not sensitive to this mechanism.

The bottle lifetime result is consistent with beta asymmetry measurements and V_{ud}.

PHYSICAL REVIEW LETTERS **120,** 202002 (2018)

Neutron Lifetime and Axial Coupling Connection

Andrzej Czarnecki
Department of Physics, University of Alberta, Edmonton, Alberta, Canada T6G 2E1

William J. Marciano
Department of Physics, Brookhaven National Laboratory, Upton, New York 11973, USA

Alberto Sirlin
Department of Physics, New York University, 726 Broadway, New York, New York 10003, USA

(Received 22 February 2018; published 16 May 2018)

Experimental studies of neutron decay, $n \to pe\bar{\nu}$, exhibit two anomalies. The first is a 8.6(2.1) s, roughly 4σ difference between the average beam measured neutron lifetime, $\tau_n^{\text{beam}} = 888.0(2.0)$ s, and the more precise average trapped ultracold neutron determination, $\tau_n^{\text{trap}} = 879.4(6)$ s. The second is a 5σ difference between the pre2002 average axial coupling, g_A, as measured in neutron decay asymmetries $g_A^{\text{pre2002}} = 1.2637(21)$, and the more recent, post2002, average $g_A^{\text{post2002}} = 1.2755(11)$, where, following the UCNA Collaboration division, experiments are classified by the date of their most recent result. In this Letter, we correlate those τ_n and g_A values using a (slightly) updated relation $\tau_n(1 + 3g_A^2) = 5172.0(1.1)$ s. Consistency with that relation and better precision suggest $\tau_n^{\text{favored}} = 879.4(6)$ s and $g_A^{\text{favored}} = 1.2755(11)$ as preferred values for those parameters. Comparisons of g_A^{favored} with recent lattice QCD and muonic hydrogen capture results are made. A general constraint on exotic neutron decay branching ratios, $< 0.27\%$, is discussed and applied to a recently proposed solution to the neutron lifetime puzzle.

DOI: 10.1103/PhysRevLett.120.202002

The bottle lifetime result is consistent with other beta decay measurements.

PHYSICAL REVIEW LETTERS **120,** 202002 (2018)

Neutron Lifetime and Axial Coupling Connection

Department of Physics, U

Department of Physics, Bro

Department of Physics, New Y

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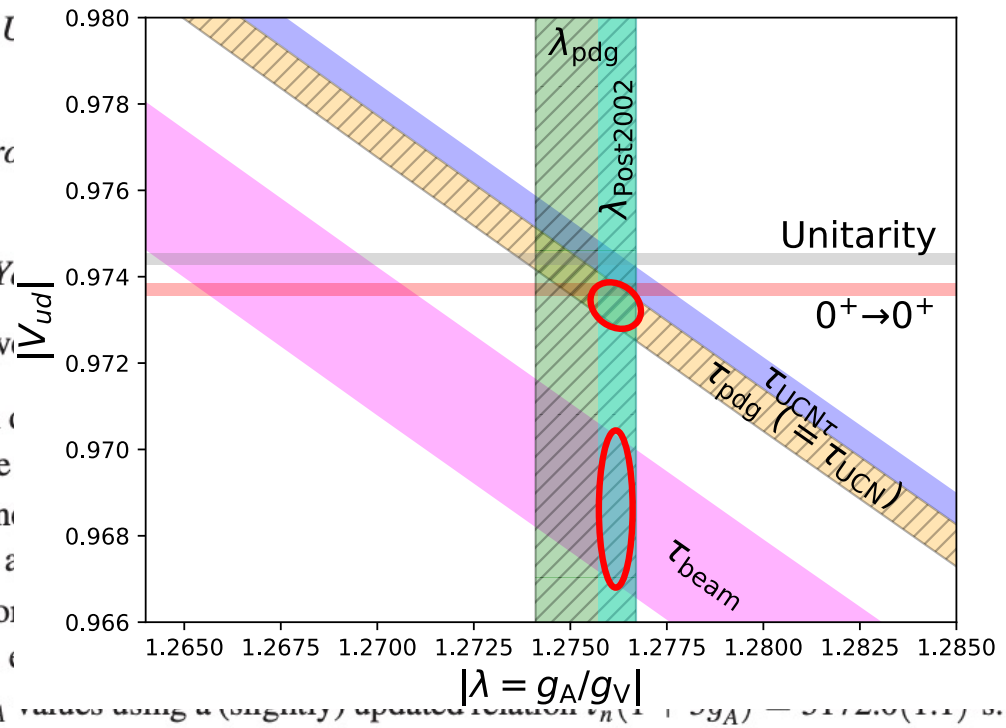


Experimental studies of neutron
4σ difference between the average
precise average trapped ultracold n
between the pre2002 average a
$g_A^{\text{pre2002}} = 1.2637(21)$, and the mo
the UCNA Collaboration division,
Letter, we correlate those τ_n and g_A

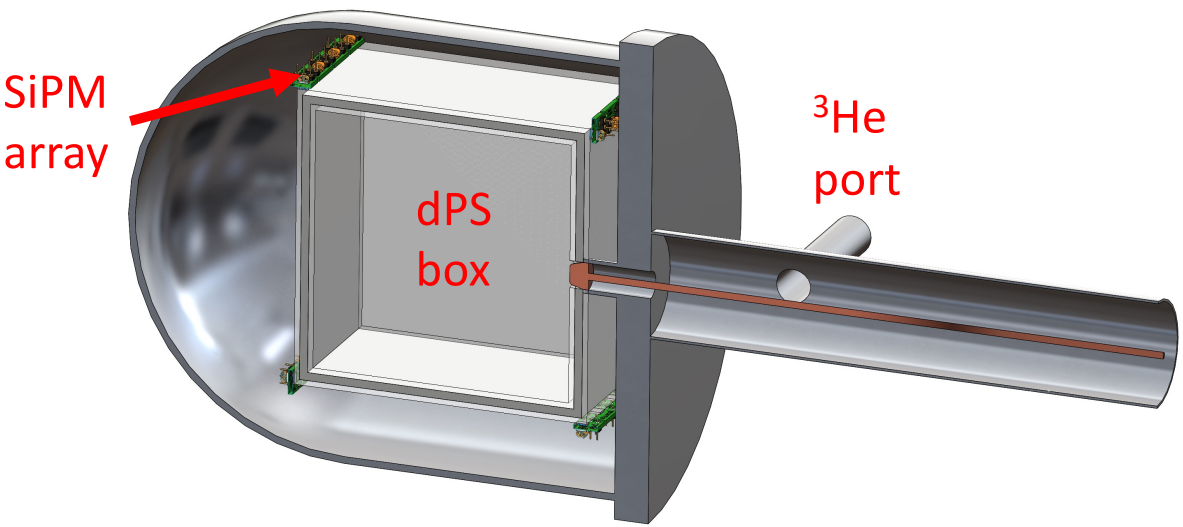
Consistency with that relation and better precision suggest $\tau_n^{\text{favored}} = 879.4(6)$ s and $g_A^{\text{favored}} = 1.2755(11)$ as preferred values for those parameters. Comparisons of g_A^{favored} with recent lattice QCD and muonic hydrogen capture results are made. A general constraint on exotic neutron decay branching ratios, $< 0.27\%$, is discussed and applied to a recently proposed solution to the neutron lifetime puzzle.

DOI: 10.1103/PhysRevLett.120.202002

Ultimately, it's an experimental question

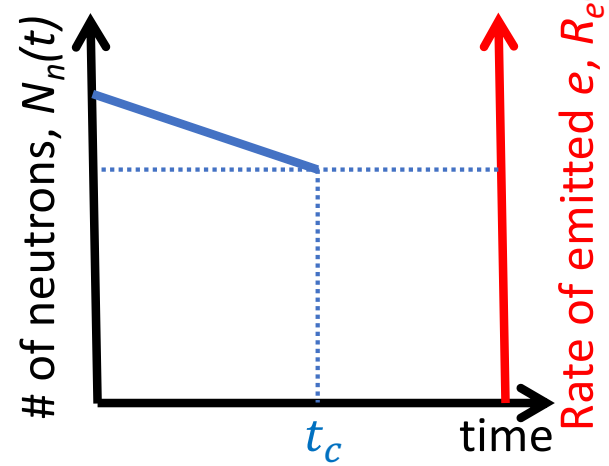
New idea: Ultra-Cold Neutron Experiment for Proton Branching Ratio in Neutron Beta Decay (UCNProBe)

Z. Tang, LANL



Quickly count neutrons at time t_c

$$R_e(t_c) = \tau_n^{-1} N_n(t_c)$$



- Requires *absolute measurements* similar to the beam experiment:
  - Number of neutrons in the trap
  - Number of decay products
  - Needs precision <<1% for each quantity
- Now in R&D stage to determine feasibility

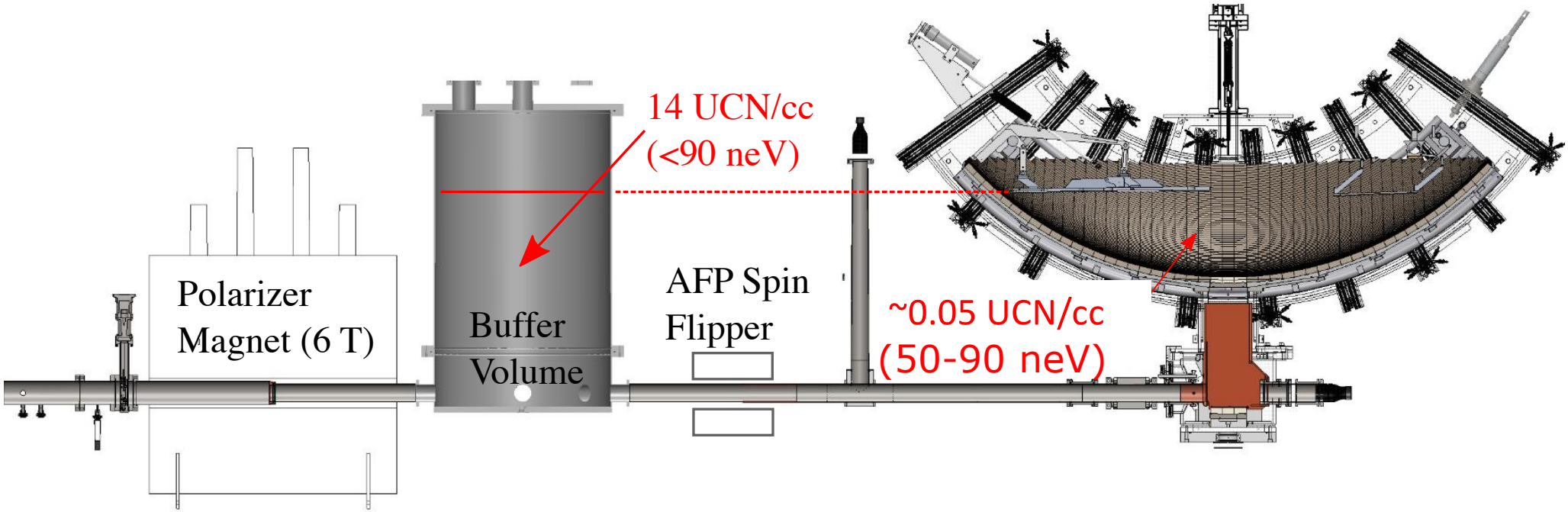
Summary

- Neutron beta decay experiments are approaching a level of precision that tests the standard model of particle physics.
- With upcoming experiments, we can check the tension with first-row CKM unitarity when using V_{ud} from superallowed beta decay.
- There is good agreement among UCN bottle lifetime experiments, each using quite different techniques (material bottles with different extrapolation strategies, magnetic bottles).
- Beam lifetime experimental result still a puzzle; we await BL-2 results, or UCNProBe.

UCNτ → UCNτ+ : Elevator Concept for **10**× loading increase

Limitation of the present apparatus: low loading efficiency.

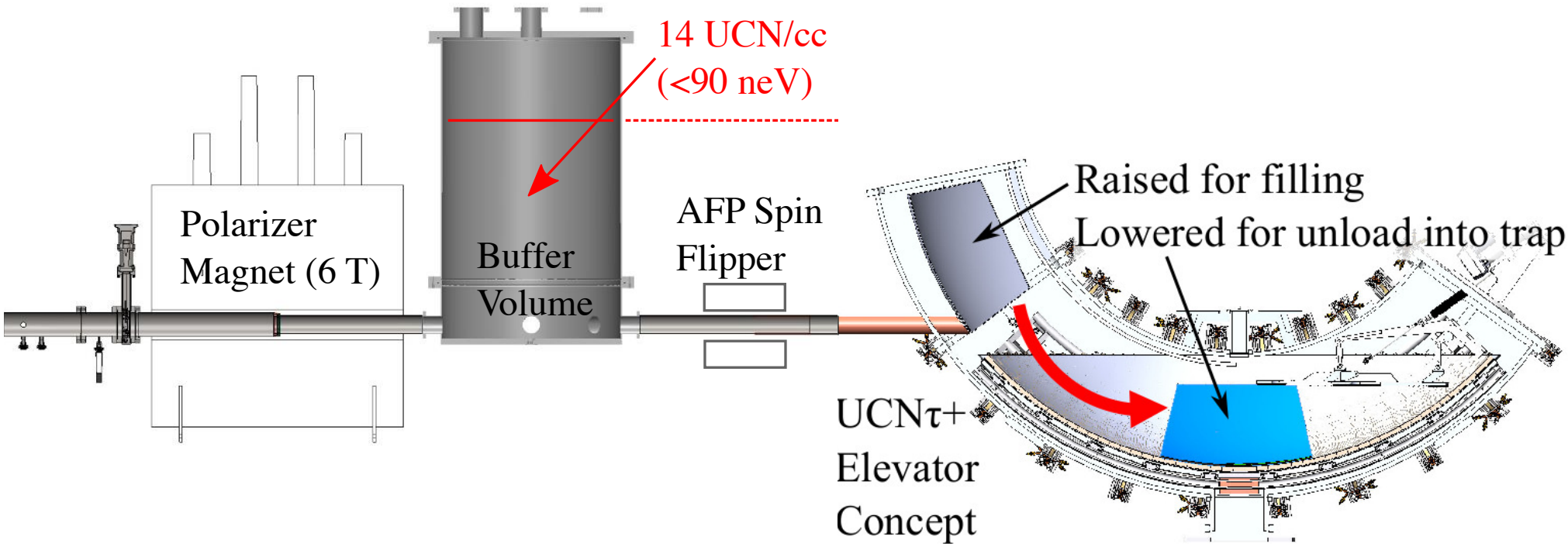
<1% loading efficiency



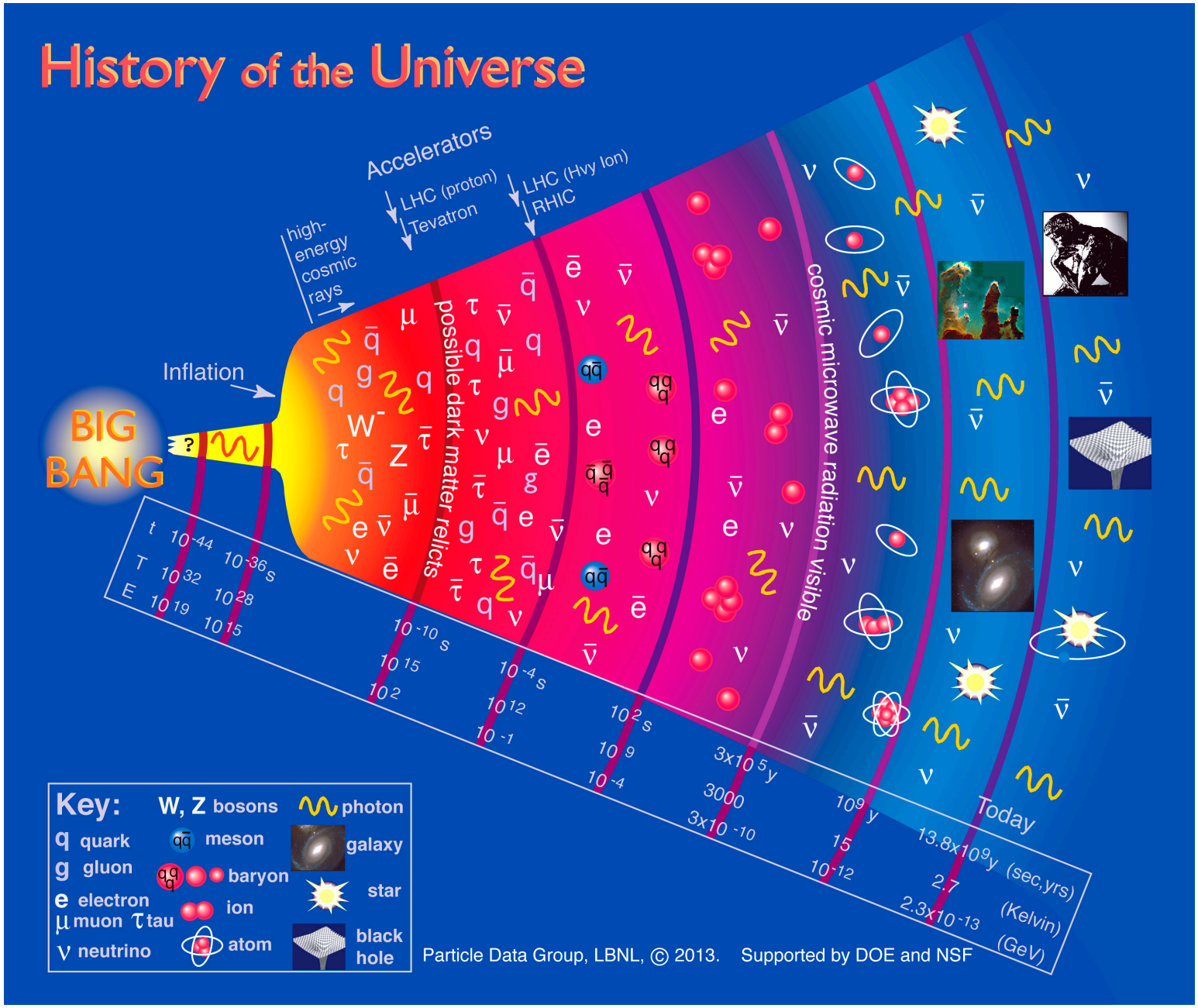
Gaps and magnetic field zeros in trapdoor region limit loading

UCNτ → UCNτ+ : Elevator Concept for **10**× loading increase

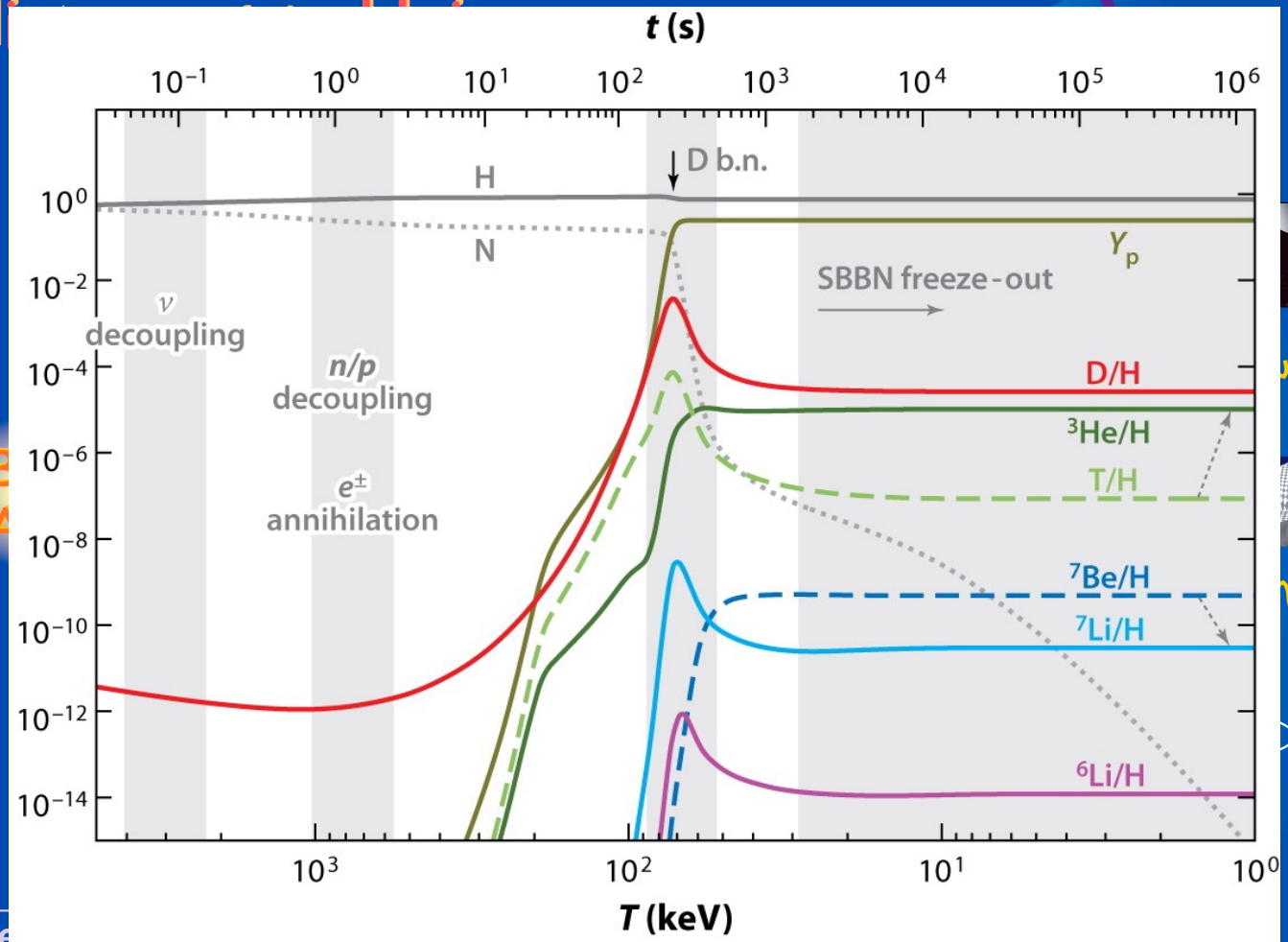
We expect at least 10× more UCN in the trap with this loading method.



Neutron Lifetime and Big Bang Nucleosynthesis

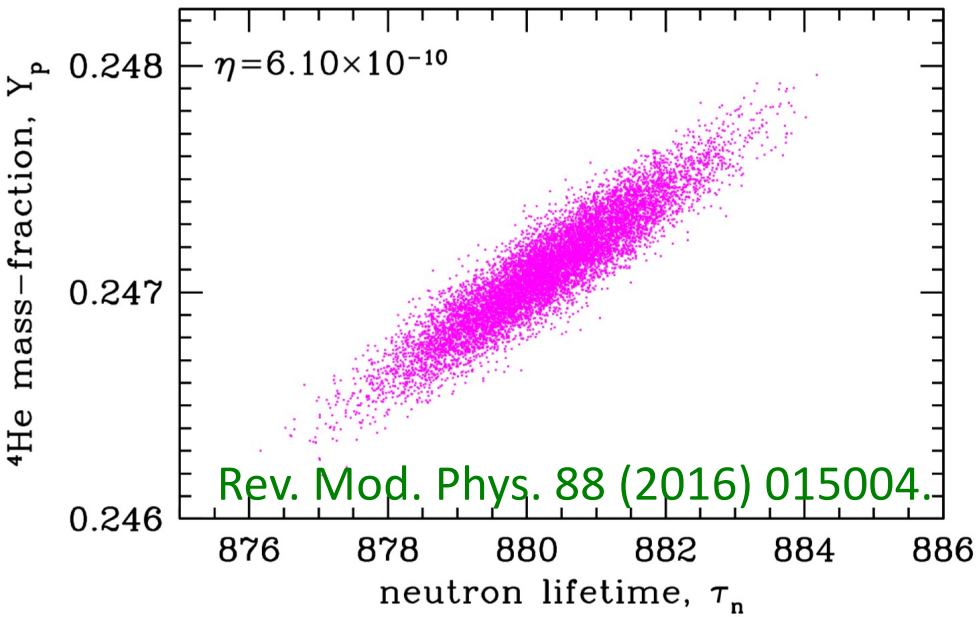


Neutron Lifetime and Big Bang Nucleosynthesis



Pospelov M, Pradler J. 2010.
Annu. Rev. Nucl. Part. Sci. 60:539–68

Neutron Lifetime and Big Bang Nucleosynthesis



- τ_n is an input to models of BBN
  - Determines how many neutrons survive to be bound up in nuclei: ^{4}He abundance prediction
  - Need $\delta\tau_n \approx 1$ s or better.
  - Can compare prediction to observed primordial ^{4}He abundance