Measuring the free neutron lifetime with spin-polarized ultracold neutrons at TRIGA Mainz

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SPIN 2018

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Neutron Lifetime

Why measure the Neutron Lifetime?

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[Cyburt et al., doi:10.1103/RevModPhys.88, 2016]

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[Marciano and Sirlin, doi:10.1103/PhysRevLett.96.032002, 2006]

Neutron Sources

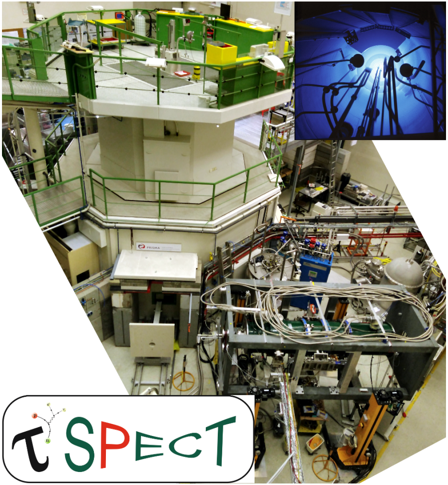
- Reactors: Nuclear Fission
  - FRM II (Munich)
  - ILL (Grenoble, France)
  - TRIGA Mainz
  - ...
- Accelerators: Spallation
  - SINQ (Villigen, Switzerland)
  - SNS (Oak Ridge, USA)
  - ESS (Lund, Sweden)
  - ...

τSPECT@TRIGA Mainz

30 ms Pulse:
250 MW_{th}

10 MW s
10^{15} n/cm^{2}s

5 Pulses / h



Neutron Reflection

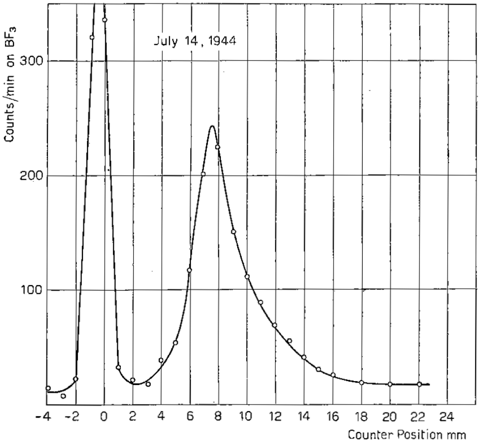


Fig. 1. – Graphite mirror. Glancing angle 3 minutes. Refected beam displaced 0.8 cm.

'Enrico Fermi. Note e Memorie (Collected Papers), vol. II, United States 1939-1954',

Roma 1965, Accademia Nazionale dei Lincei

Fermi Pseudopotential

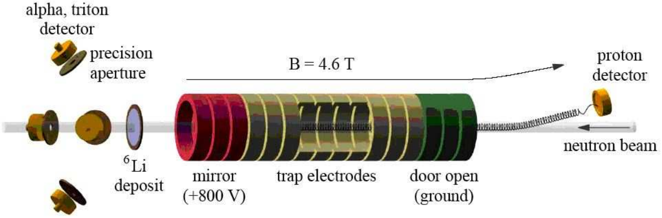
$$V_F = \frac{2\pi\hbar}{m_n}\rho b_{\text{coh}}$$

m_n: Neutron Mass
ρ: Number Density
b_{coh}: Coherent Scattering Length

Typically: $b_{\text{coh}} > 0$

E.g. Nickel: $b_{\text{coh}} \approx 10\,\text{fm} \Rightarrow V_F \approx 250\,\text{neV}$

In-Beam τ_n Measurement

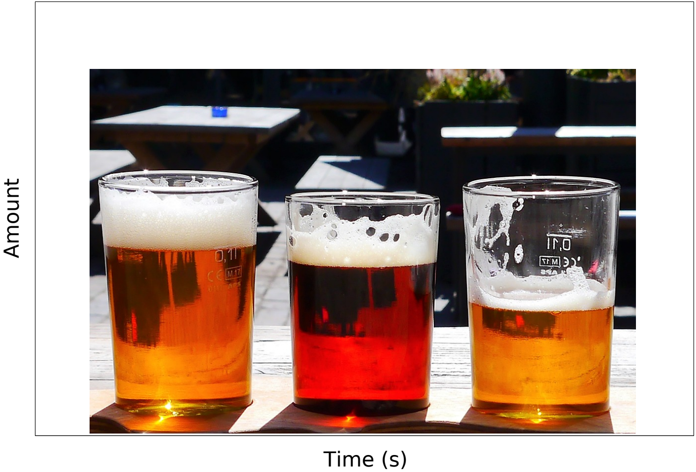


[Nico et al., doi:10.1103/PhysRevC.71.055502, 2005]

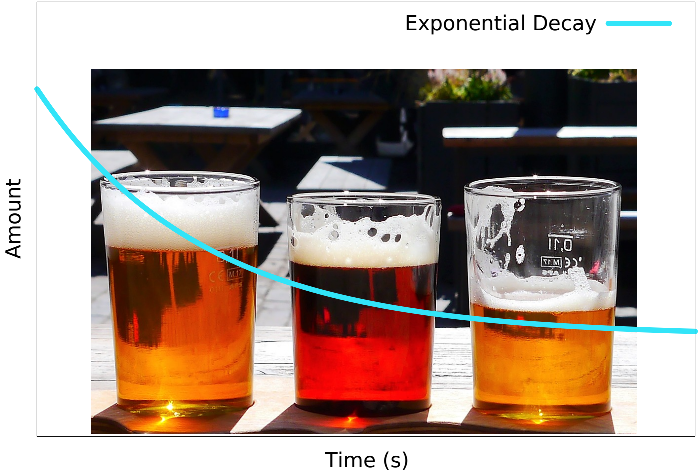
Needs *Absolute*:

- Neutron Detection
- Proton Detection
- Decay Volume Determination

Relative?



Relative?



Ultracold Neutrons - UCN

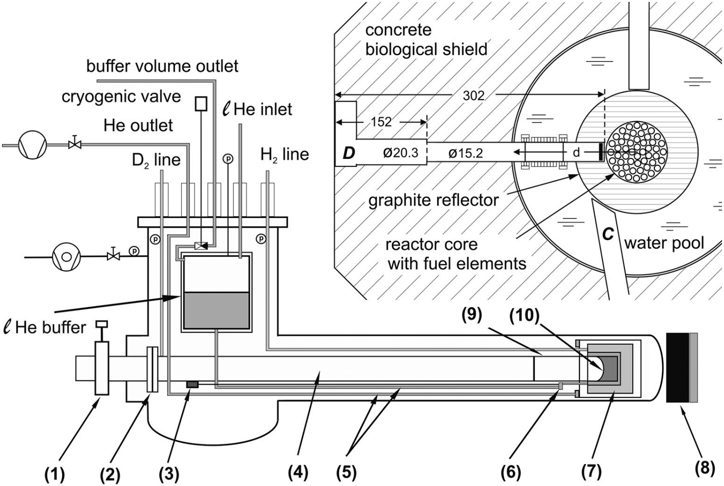
Subatomic Particles at Human Velocities

$$E_{\mathrm{kin}} \lesssim 335\,\mathrm{neV}$$

$$\Leftrightarrow$$

$$v \lesssim 8\,\mathrm{m\,s^{-1}}$$

UCN Production



[Karch et al., doi:10.1140/epja/i2014-14078-9, 2014]

UCN Interactions

- Strong Interaction
  - Neutron Optical Potential (Fermi Potential):
  - $V_F \propto \rho b_{\text{coh}}$
  - ^{58}Ni: ∼335 neV, Stainless Steel: ∼190 neV, Al: ∼54 neV

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- Magnetism
  - Spin polarization with strong magnetic fields
  - $\mu_n = -60.3\,\mathrm{neV\,T^{-1}}$

Stored UCN Lifetime

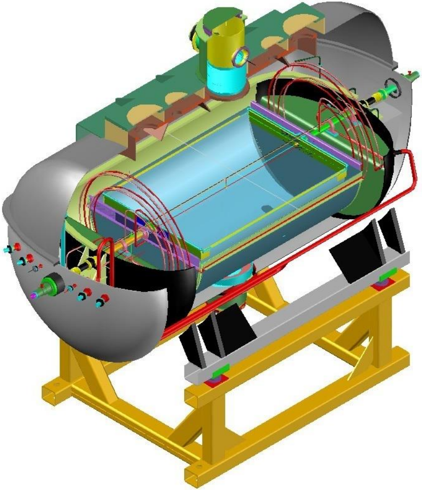
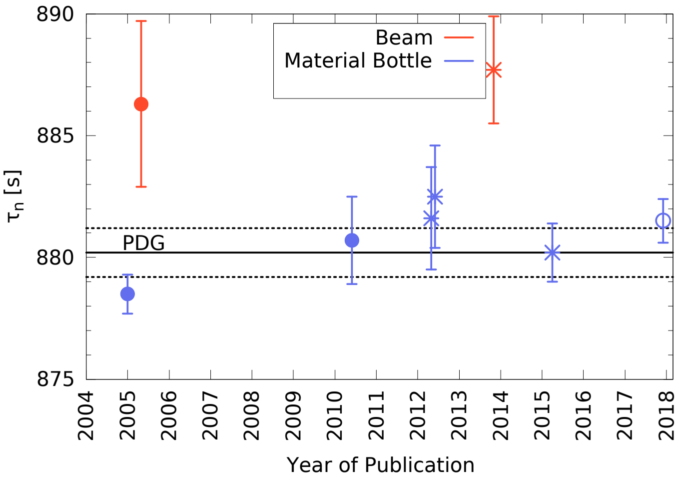


Illustration: A. Serebrov

The Lifetime Puzzle



Neutron Lifetime

Why n-lifetime?

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

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

c) “It’s 2018 and we cannot agree on τ_n to better than 7s?!”

$$\tau_{\text{n,beam}} = 887.7 \pm 1.2 \pm 1.9\text{s}$$
$$\neq$$
$$\tau_{\text{n,stored}} = 878.5 \pm 0.7 \pm 0.3\text{s}$$

UCN Interactions

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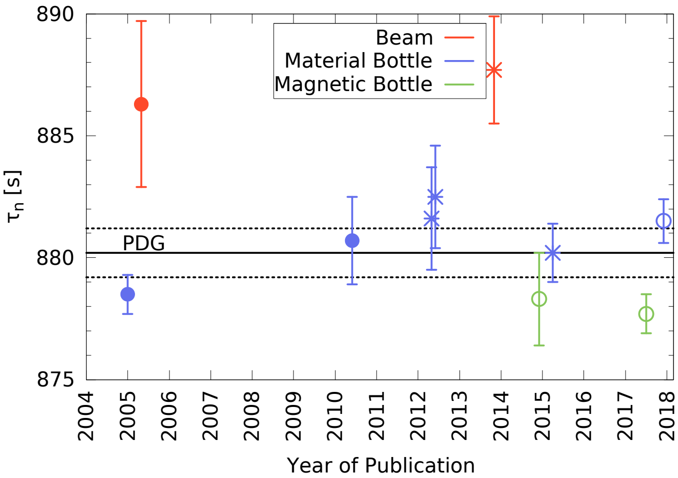
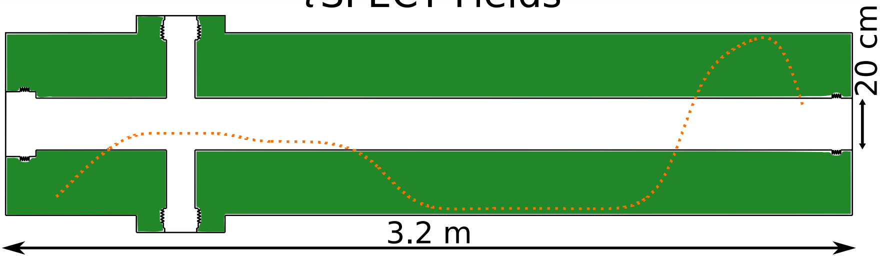


τSPECT

Why τSPECT?

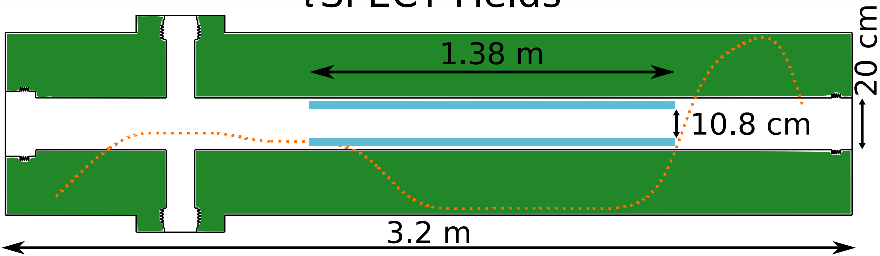
- Wall Losses: Hard to Monitor, Large Extrapolations
  - ⇒ Full Magnetic Storage
  - Depolarization Losses: Possible to Monitor
- *a*SPECT → τSPECT:
  - Axial Confinement: Well-known Magnet
  - Decay Proton Detection Shown by *a*SPECT

τSPECT Fields



based on [Konrad et al., doi:10.1016/j.nima.2014.09.014, 2014]

τSPECT Fields



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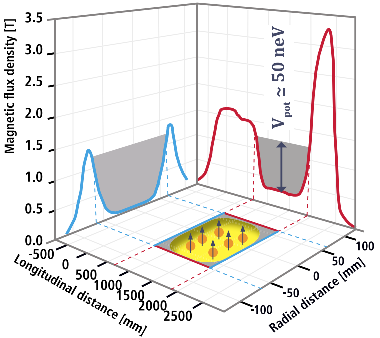

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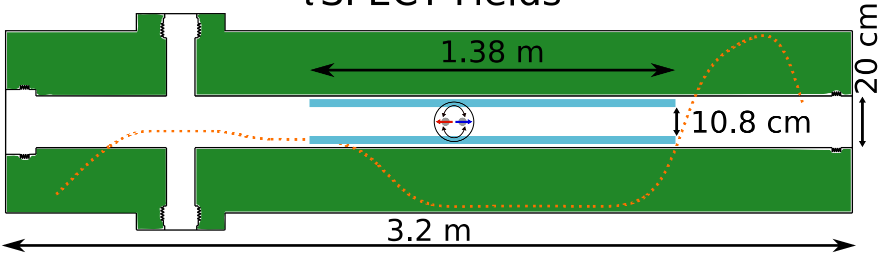

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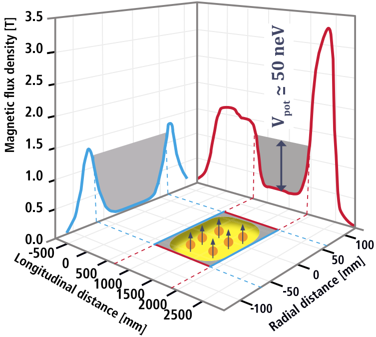
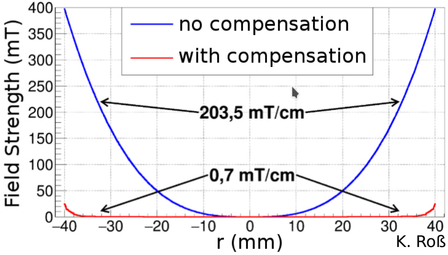
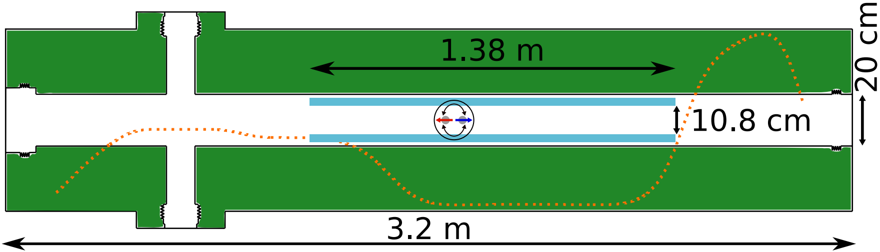


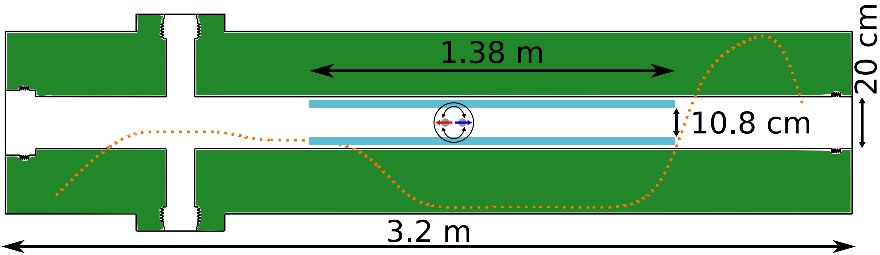


Measurement Procedure



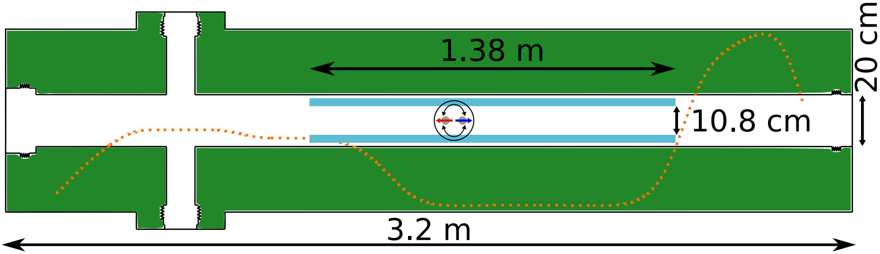
1. UCN production (30 ms reactor pulse)

Measurement Procedure



1. UCN production (30 ms reactor pulse)
2. Fill UCN into τSPECT Magnet from the left
   - Polarization due to high Magnetic Field
   - Simultaneously: Intensity Monitoring (not spin-flipped Neutrons)
   - Short Axial Field Lowering (spectral cleaning)

Measurement Procedure



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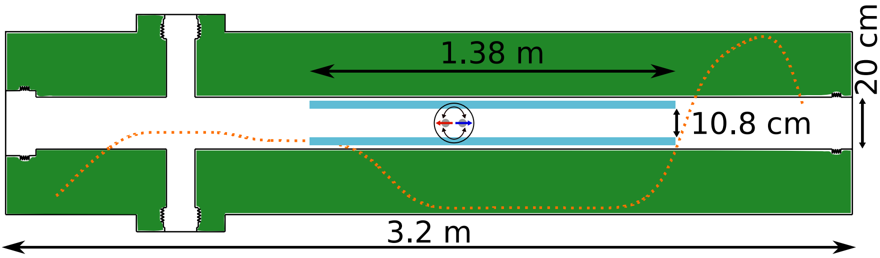

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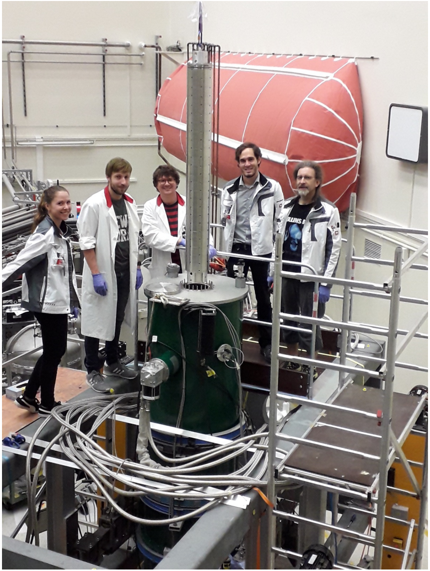
   - Short Axial Field Lowering (spectral cleaning)
3. Wait ...
4. Count remaining UCN

τSPECT Schedule

- Phase I
  - Aim: $\Delta\tau_n \lesssim 1.0\,\mathrm{s}$
  - Commissioning: 2018
  - Data Taking: 2019
  - Neutron Detection only (in-situ)
  - Extensive Systematics Studies
- Phase II
  - Aim: $\Delta\tau_n \lesssim 0.3\,\mathrm{s}$
  - Commissioning: $\sim$2020
  - Neutron and Decay-Proton Detection
  - Depolarization Detection

Progress



July 2018

Summary

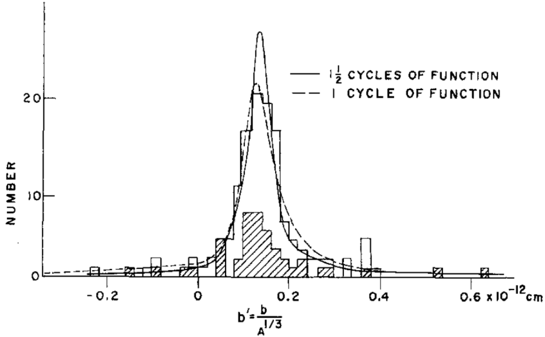
- Free Neutron Lifetime: Puzzle to be Solved!
- UCN: Valuable Tool for Fundamental Neutron Research
- τSPECT at TRIGA Mainz: τ_n Results in Upcoming Years

Institute of Nuclear Chemistry & Institute of Physics
Johannes Gutenberg University Mainz

Thank you for your attention!

Backup

Distribution of Scattering Lengths



[Peshkin and Ringo, doi:10.1119/1.1986132, 1971]

The Fermi (Pseudo-)potential is typically a positive value!

DM Interpretation of the N Decay Anomaly

arXiv.org > hep-ph > arXiv:1801.01124

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High Energy Physics - Phenomenology

Dark Matter Interpretation of the Neutron Decay Anomaly

Bartosz Fornal, Benjamin Grinstein

(Submitted on 3 Jan 2018 (v1), last revised 15 Jan 2018 (this version, v2))

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 a dark sector particle in the final state. If this particle is stable, it can be the dark matter. Its mass is close to the neutron mass, suggesting a connection between dark and baryonic matter. In the most interesting scenario a monochromatic photon with energy in the range 0.782 MeV - 1.664 MeV and branching fraction 1% is expected in the final state. We construct representative particle physics models consistent with all experimental constraints.

Comments:	5 pages, 2 figures; v2: references added, further nuclear physics experimental signatures proposed
Subjects:	**High Energy Physics - Phenomenology (hep-ph)**; Nuclear Experiment (nucl-ex); Nuclear Theory (nucl-th)
Cite as:	**arXiv:1801.01124 [hep-ph]**
	(or **arXiv:1801.01124v2 [hep-ph]** for this version)

DM Interpretation of the N Decay Anomaly

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arXiv.org > hep-ph > arXiv:1802.01804

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High Energy Physics - Phenomenology

The Neutron Lifetime and Axial Coupling Connection

Andrzej Czarnecki, William J. Marciano, Alberto Sirlin

(Submitted on 6 Feb 2018 (v1), last revised 22 Feb 2018 (this version, v2))

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, $\tau_n^{\rm beam} = 888.0(2.0)$s, and the more precise average trapped ultra cold neutron determination, $\tau_n^{\rm trap} = 879.4(6)$s. The second is a 5σ difference between the pre2002 average axial coupling, g_A, as measured in neutron decay asymmetries $g_A^{\rm pre2002} = 1.2637(21)$, and the more recent, post2002, average $g_A^{\rm post2002} = 1.2755(11)$, where, following the UCNA collaboration division, experiments are classified by the date of their most recent result. In this study, 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 $\tau_n^{\rm favored} = 879.4(6)$s and $g_A^{\rm favored} = 1.2755(11)$ as preferred values for those parameters. Comparisons of $g_A^{\rm favored}$ with recent lattice QCD and muonic hydrogen capture results are made. A general constraint on exotic neutron decay branching ratios is discussed and applied to a recently proposed solution to the neutron lifetime puzzle.

DM Interpretation of the N Decay Anomaly

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arXiv.org > nucl-ex > arXiv:1802.01595
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Nuclear Experiment

Search for the Neutron Decay n$\rightarrow$ X+γ where X is a dark matter particle

Z. Tang, M. Blatnik, L. J. Broussard, J. H. Choi, S. M. Clayton, C. Cude-Woods, S. Currie, D. E. Fellers, E. M. Fries, P. Geltenbort, F. Gonzalez, T. M . Ito, C.-Y. Liu, S. W. T. MacDonald, M. Makela, C. L. Morris, C. M. O'Shaughnessy, R. W. Pattie Jr., B. Plaster, D. J. Salvat, A. Saunders, Z. Wang, A. R. Young, B. A. Zeck

(Submitted on 5 Feb 2018)

In a recent paper submitted to Physical Review Letters, Fornal and Grinstein have suggested that the discrepancy between two different methods of neutron lifetime measurements, the beam and bottle methods can be explained by a previously unobserved dark matter decay mode, n$\rightarrow$ X+γ where X is a dark matter particle. We have performed a search for this decay mode over the allowed range of energies of the monoenergetic gamma ray for X to be a dark matter particle. We exclude the possibility of a sufficiently strong branch to explain the lifetime discrepancy with greater than 4 sigma confidence.

Comments: 6 pages 3 figures
Subjects: **Nuclear Experiment (nucl-ex)**
Cite as: arXiv:1802.01595 [nucl-ex]
(or **arXiv:1802.01595v1 [nucl-ex]** for this version)