Neutron Beta-decay Studies at LANL

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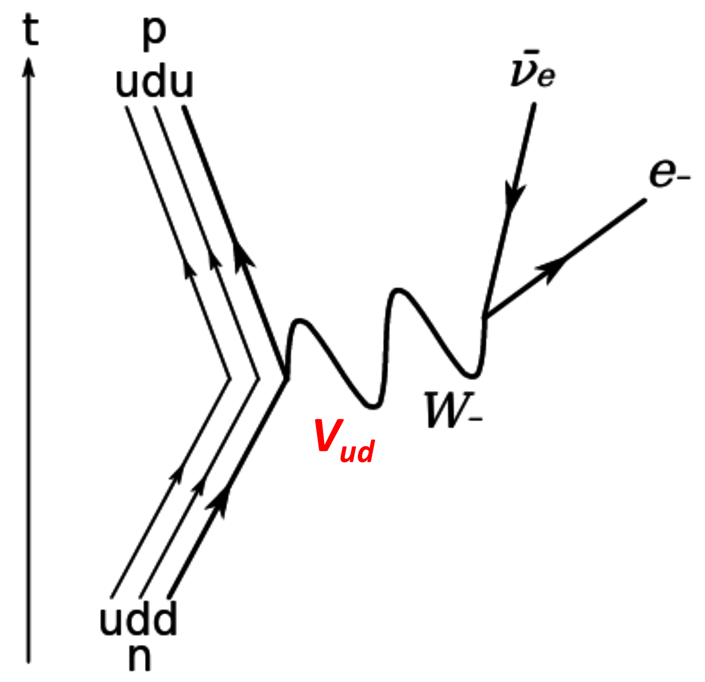
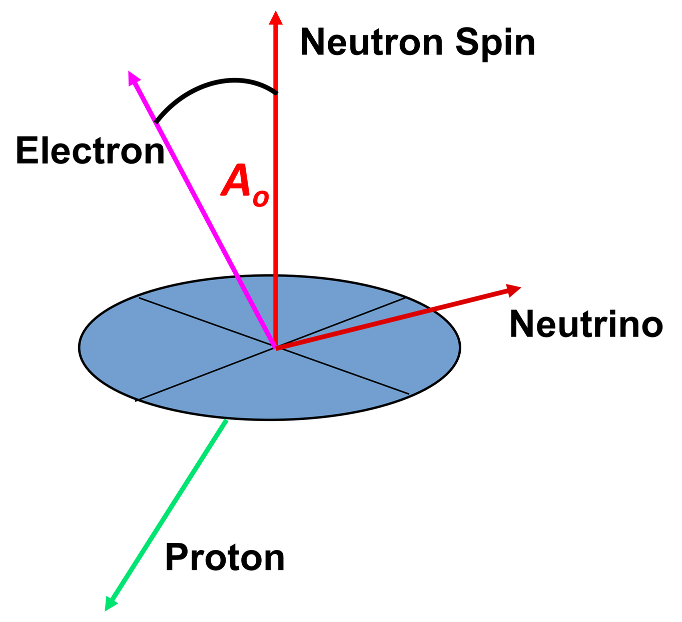
UCNA+ and UCNτ+ Collaboration

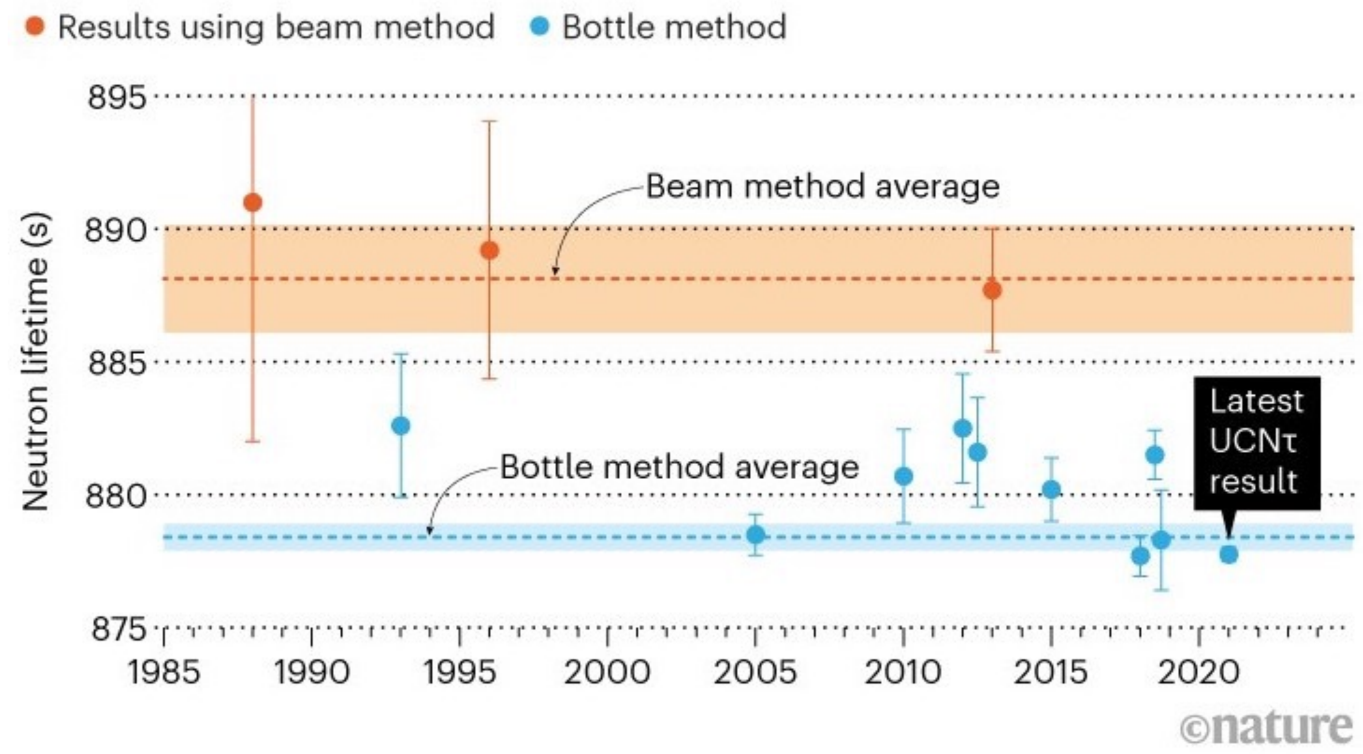
MOTIVATION

FREE NEUTRON DECAY PARAMETERS





- The "semi-leptonic" decay is free of any nuclear structure effects.
- Key observables in the decay: Neutron ***lifetime*** (***τ_n***) and neutron spin ***angular correlation*** (***A_o***) with electron initial momentum.
- τ_n measurement is challenging and different ("bottle" or "beam") techniques have yielded different results.



PHYSICS BEYOND STANDARD MODEL

- Cabibbo–Kobayashi–Maskawa (CKM) matrix representing the flavor change in a weak interaction is primarily lead by $\mathbf{V_{ud}}$ for a free neutron decay, and its determination from the decay is free of uncertainties from the nuclear structure effects.

$$\Delta_{\mathrm{CKM}} = 1 - |V_{ud}|^2 - |V_{us}|^2 - |V_{ub}|^2; \quad \textit{Unitarity check!}$$

$$|V_{ud}|^2 = \frac{5099.3(4)s}{\tau_n(1+3g_A{}^2)(1+RC)}; \quad \textit{Needs precise determination!}$$

- Precision measurement of τ_n and neutron axial charge (g_A) are needed to determine V_{ud}. Radiative corrections (RC) are provided by lattice QCD calculations.

ULTRA COLD NEUTRONS

- Free neutrons with kinetic energy $\lesssim$ 350 neV; can undergo *total external reflection* from many material surfaces. Also: gravitational confinement $\approx$100 neV/m, magnetic interaction $|\boldsymbol{\mu} \cdot \boldsymbol{B}| \approx$ 60 neV/T.

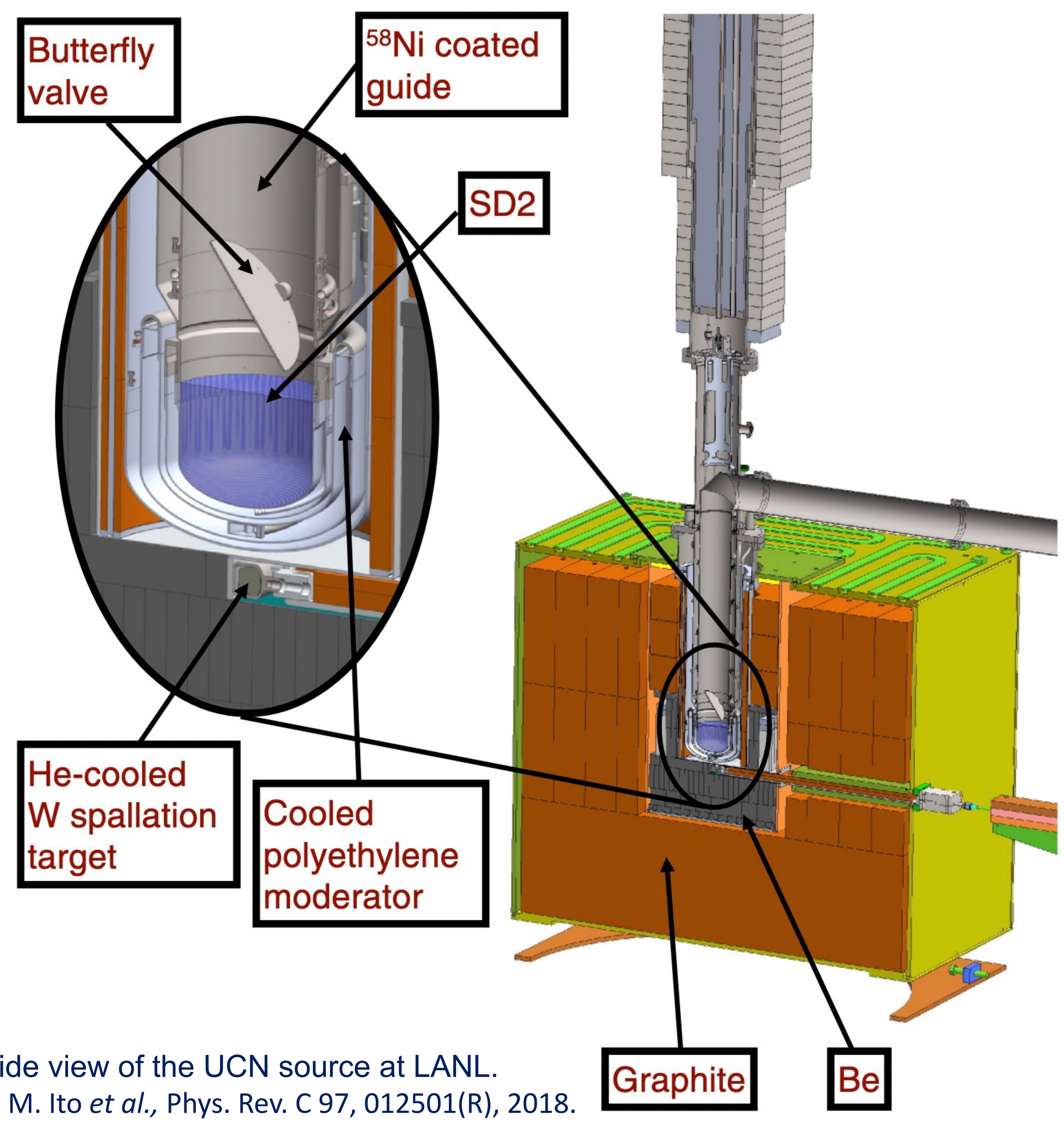


Fig. 1. Side view of the UCN source at LANL.
Source: T. M. Ito *et al.*, Phys. Rev. C 97, 012501(R), 2018.

EXPERIMENTS

NEUTRON LIFETIME (UCNτ)

- Neutron lifetime can be obtained by counting neutrons with two different storage times (T_1 and T_2) as follows:

$$N(t) = N_o e^{-\frac{t}{\tau}} \qquad \tau = \frac{T_1 - T_2}{\ln(\frac{N_2}{N_1})}$$

- The technique doesn't require characterization of neutron counting system efficiency.
- Neutrons are detected using ***^{10}B-coated-ZnS*** scintillation counters via the ***^{10}B+n→^{7}Li+α*** capture reaction.
- The experiment yielded world's most precise neutron lifetime of ***877.7±0.3*** s by Gonzalez *et. al.*, 2021.
- Upgrade of the experiment from **UCNτ to UCNτ+** is in progress with data being taken with new neutron dagger counter.

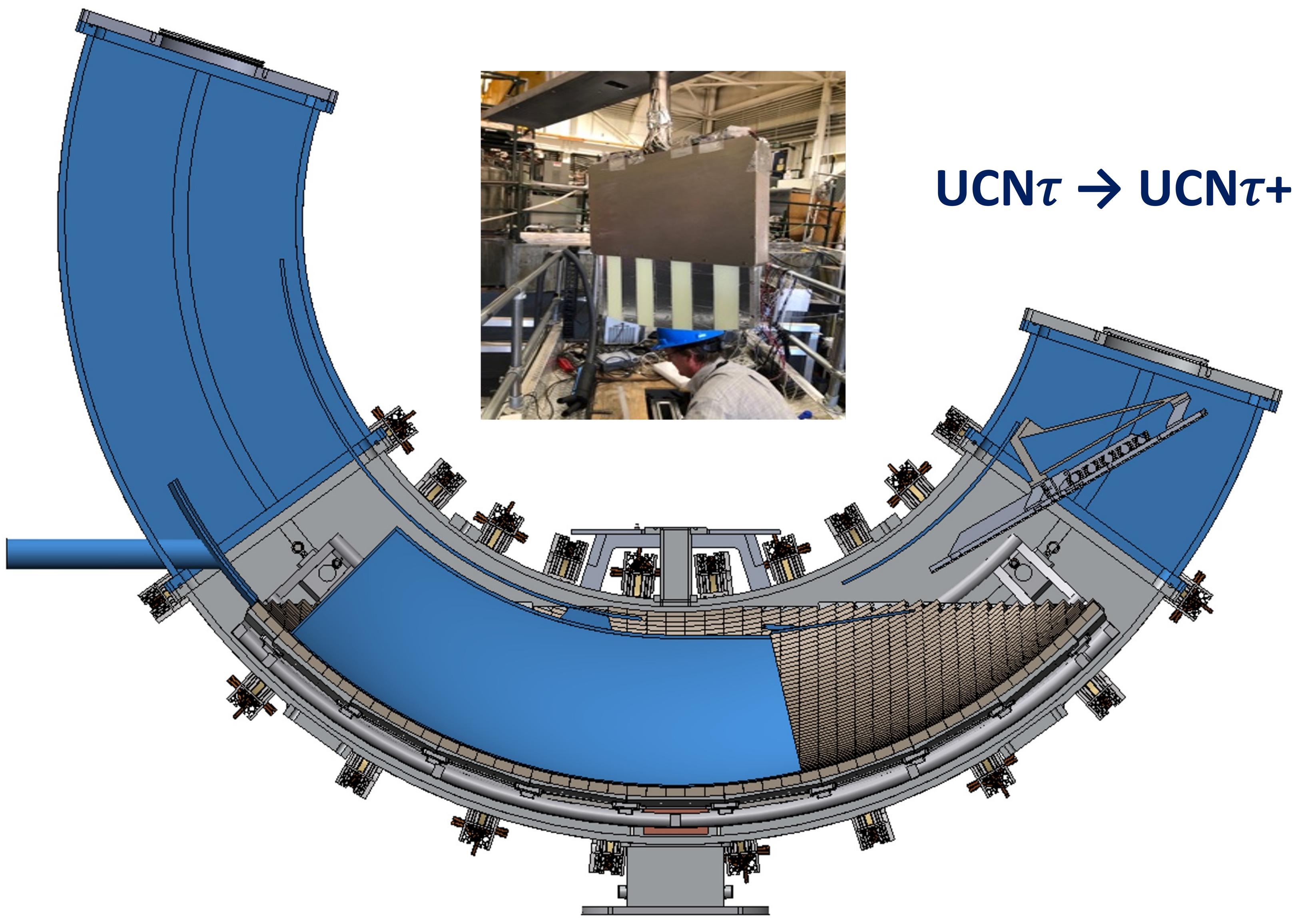
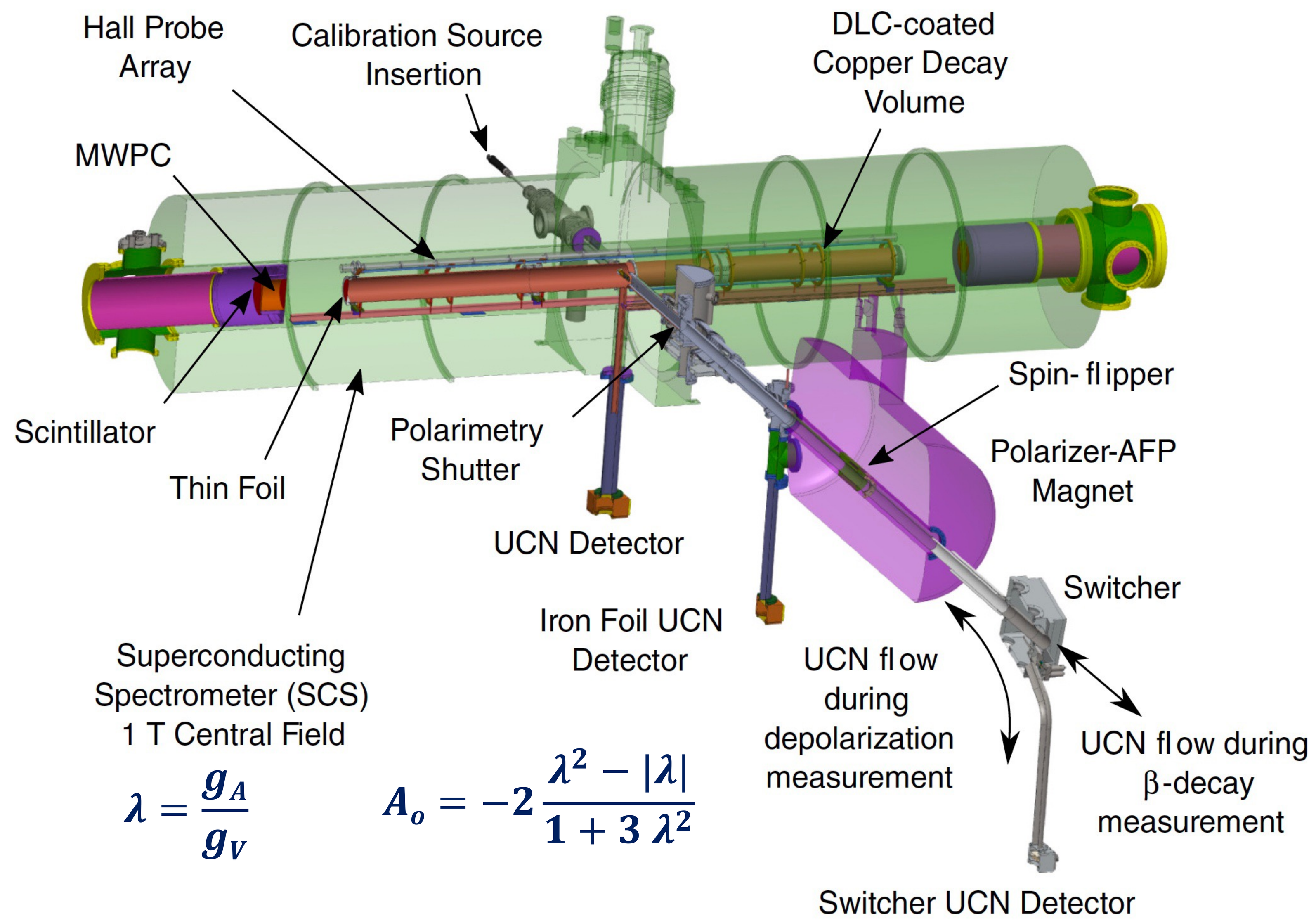


Fig. 2. Layout of the UCNτ+ experiment to measure the neutron lifetime. The experiment will lower the height of the current UCN trap and employ elevator method for filling of the trap, improving trap loading efficiency by ~10x.

BETA-ASYMMETRY PARAMETER (A_o) UCNA



$$\lambda = \frac{g_A}{g_V} \qquad A_o = -2\frac{\lambda^2 - |\lambda|}{1 + 3\,\lambda^2}$$

Fig. 3. Schematic diagram showing the primary components of the UCNA experiment, including the 7 T polarizing magnet, the spin flipper, the electron spectrometer, and the UCN detector at the switcher (used for polarization measurements). Source: M. A.-P. Brown *et al.* (UCNA Collaboration) Phys. Rev. C 97, 035505, 2018.

- UCNA is the world's only UCN-based experiment to measure the asymmetry.
- Measurement based on the difference in the number of electrons detected in two directionally-opposite placed detection systems.

UCNA→UCNA+

- Replaces the MWPC+scintillator/PMTs with scintillator/SiPMs for better light collection and reduced backscattering from dead layers.
- Upgraded UCN source will give higher statistics, the new detectors and calibration system will reduce systematics: targeting $\frac{\delta A}{A}$ ~0.2%.

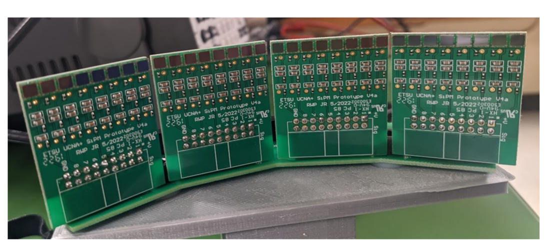


Fig. 4. Design of the electron counting detection system with 128 SiPMs arranged in a circular manner for the UCNA+ experiment.