Measurements of the First Polarized Ultracold Neutrons at TRIUMF

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TUCAN Collaboration

TRIUMF

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Motivation

- Testing components for the future TUCAN Collaboration nEDM Measurement
- Frequency measurement
    - Requires detection of two spin states
- Counts of each state and their ratio is the handle by which we measure the resonant frequency of the UCN

- Super Conducting Magnet (to polarize UCN)
- Spin Analyzer Components (to analyze UCN spin state)

Neutron EDM

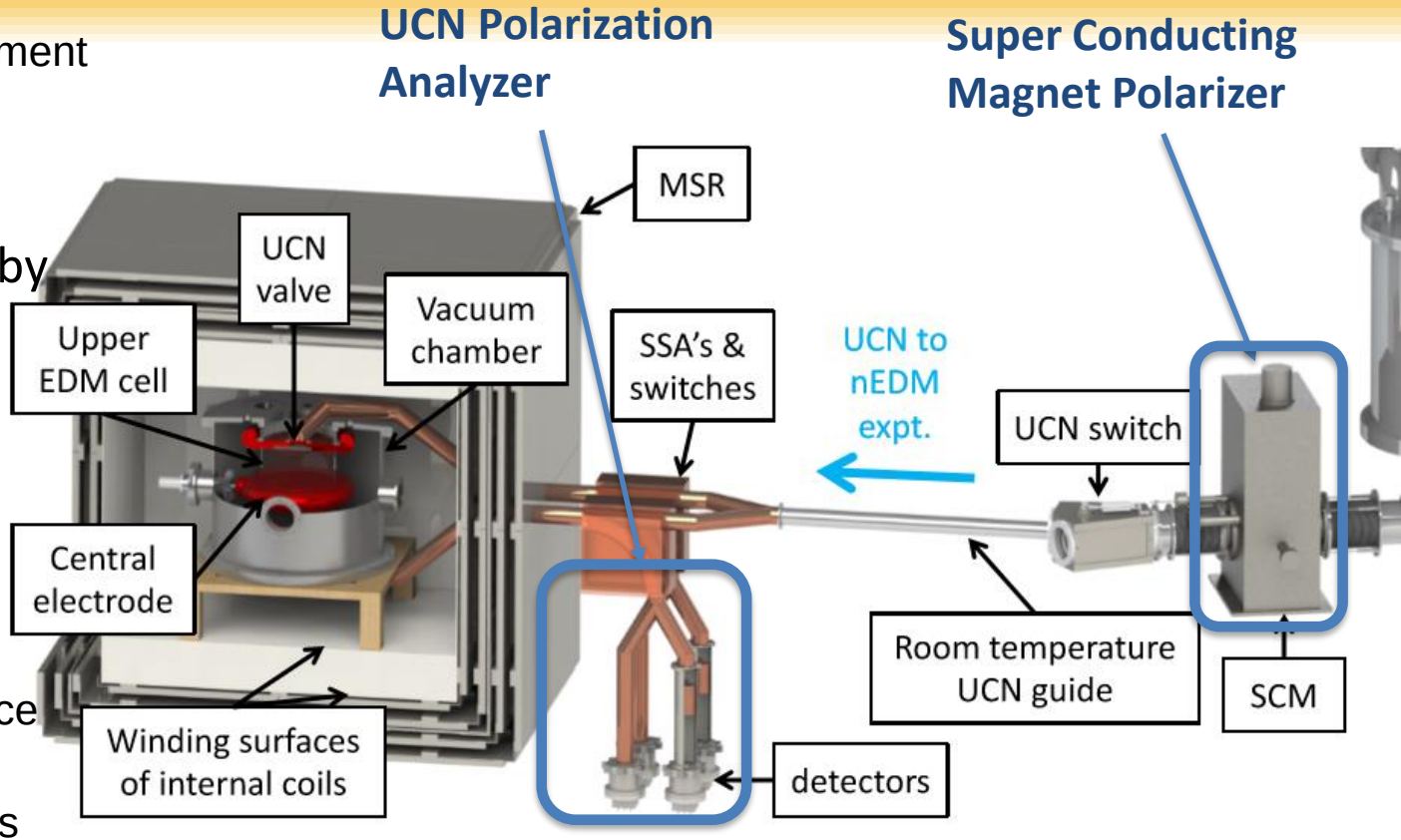
- Future nEDM measurement
- Uncertainty of the experiment is given by

$$\sigma_n \cong \frac{\hbar}{2\alpha T E \sqrt{N}}$$

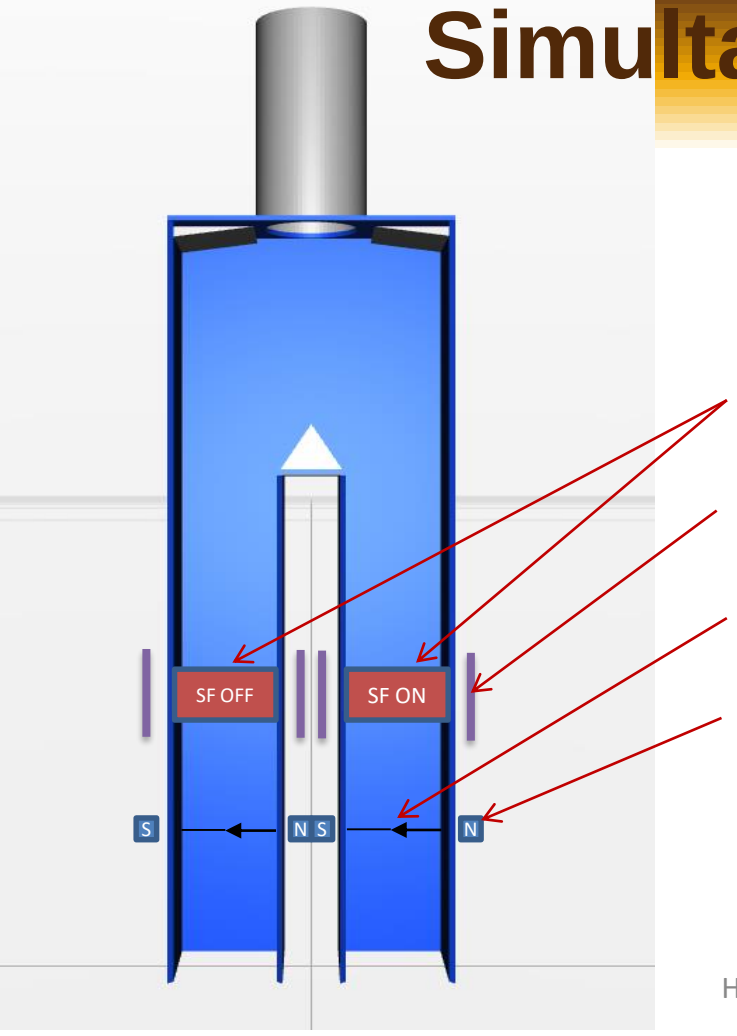
- Polarization measure

$$\alpha = \frac{N_+ - N_-}{N_+ + N_-}$$

- nEDM experiments place limits on beyond the standard model theories



Simultaneous Spin Analyzer



Spin Flippers

RF Shield

Iron Foil

Magnets
& Return Yoke

- Error from the experiment is given by $\sigma_n \cong \frac{\hbar}{2\alpha T E \sqrt{N}}$
- The simultaneous spin analyzer system increases total counts N and α by reducing time in storage[1,2]

1) Afach et al. Eur. Phys. J. A51 (2015)
2) Helaine, PhD. Thesis, Université de Cean Basse-Normandie

Polarizing Foils and SCM

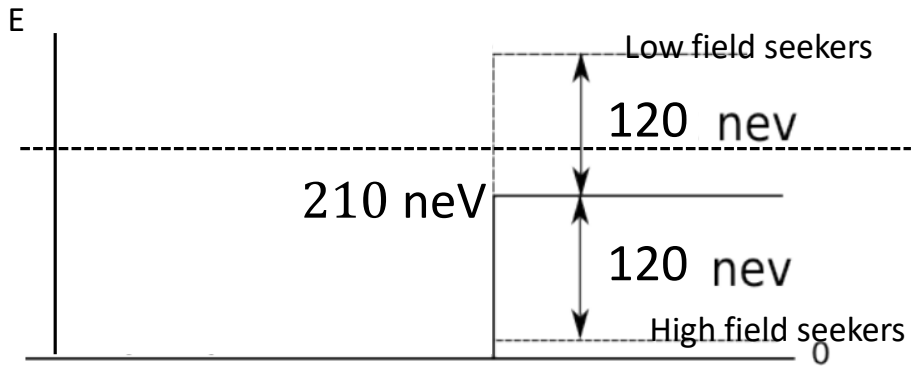
$$V_{F,eff} = V_{F,Fe} \pm 60\ \text{neV/T} \cdot \text{B}$$

Magnetic field changes potential due to spins

Thin iron foils saturate magnetization

- Have internal field 2 T

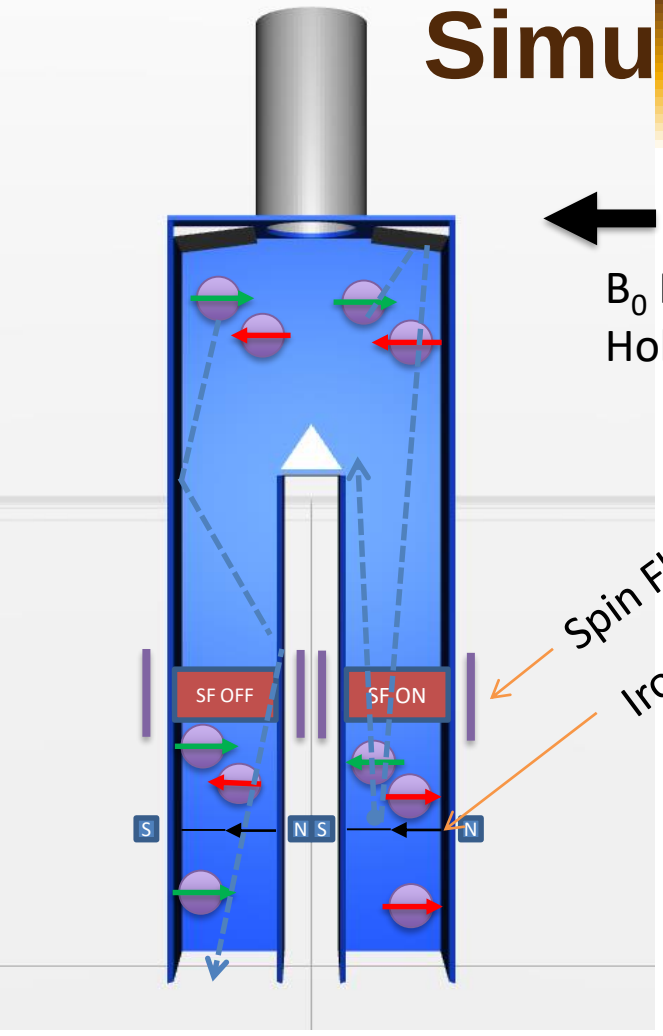
UCN K. E.



One Polarization state will be let through, the other will be reflected

Super Conducting Magnet provides large enough B field to polarize

Simultaneous Spin Analyzer



B_0 Magnetic Holding field

Spin Flippers

Iron Foil

- UCN's polarization track magnetic field as long as the fields direction doesn't change fast
  - Adiabatic Slow Passage
  - Spin and B_0 always point in same direction

Initial spin +1/2 in green

Initial spin -1/2 in red

- With the right spin state they are let through the foil, while left spin states are blocked

Neutron Spin Flipper - AFP

- Adiabatic Fast Passage

-Adiabatic in the Rotating Frame

$$\gamma_n B_1^2 \gg v_n \nabla_z B_0$$

Adiabatic parameter

$$k = \frac{\gamma_n B_1^2}{v_n \nabla_z B_0}$$

B_1 = 100 μT ← Spin flipper coil magnetic field

$\nabla_z B_0$ = 280 μT/m ← Holding field gradient measured

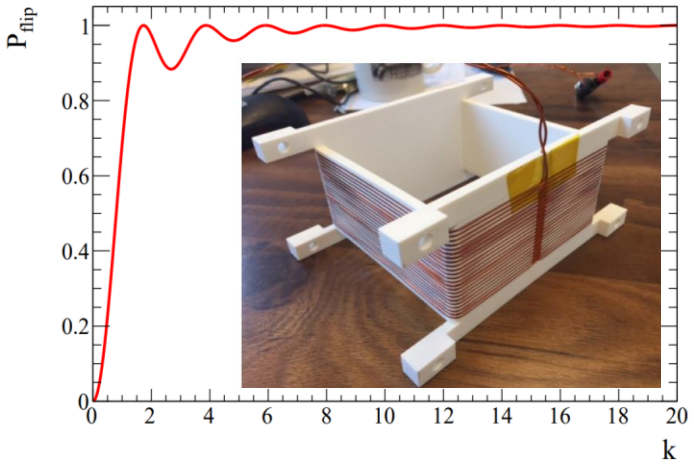
v_n = 10 m/s ← Neutron velocity: worse case

γ_n = 1.832 x 10^8 $s^{-1}T^{-1}$ ← Constant

$k = 654$

Probability of spin flip

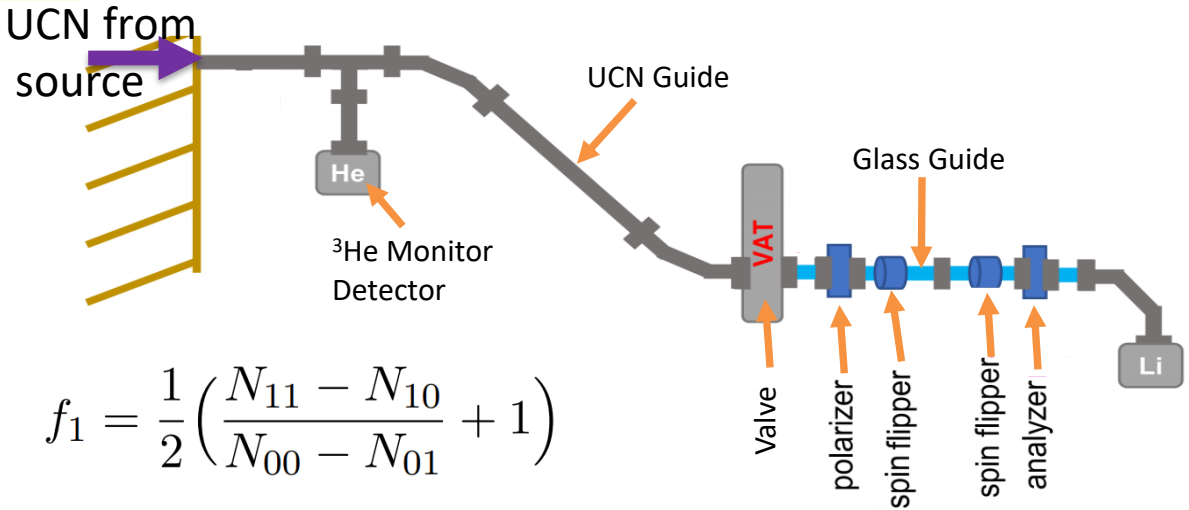
$$P_{flip} = 1 - \frac{\sin^2\left(\pi\sqrt{1+k}/2\right)}{1+k^2}$$

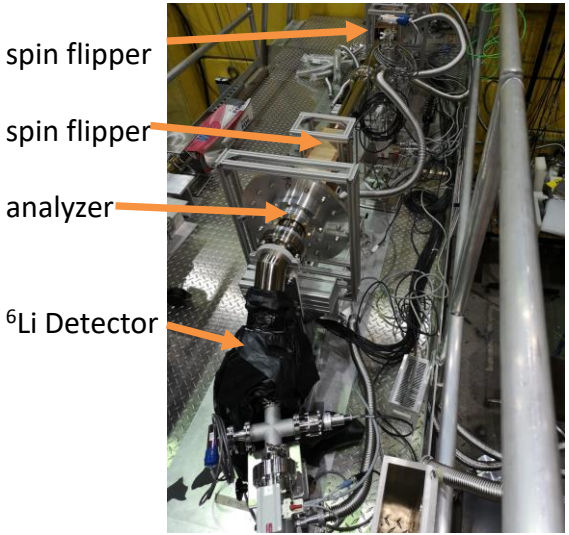


$$\omega = \frac{\gamma_n B_0}{2\pi} = 8.2 \text{ kHz}$$

7.6 kHz experimentally measured

Analyzer and Spin Flipper Experiment





$$f_1 = \frac{1}{2}\left(\frac{N_{11} - N_{10}}{N_{00} - N_{01}} + 1\right)$$

$$f_2 = \frac{1}{2}\left(\frac{N_{11} - N_{01}}{N_{00} - N_{10}} + 1\right)$$

$$p_1 = \frac{N_{00} - N_{10}}{N_{00} + N_{10}}$$

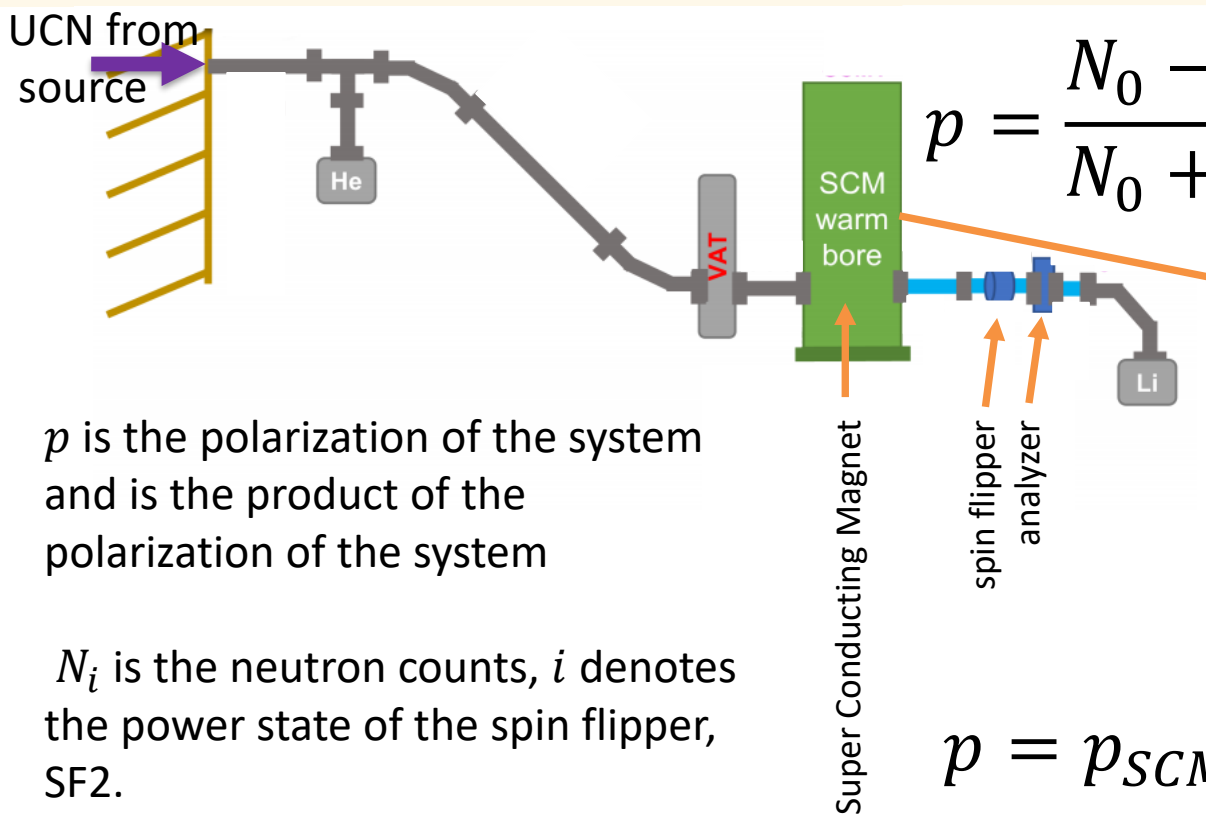
$$p_2 = \frac{N_{00} - N_{01}}{N_{00} + N_{01}}$$

f_i is the spin flipping efficiency of $i = 1$ or 2

N_{nm} is the neutron counts

n denotes the power state of the first spin flipper, m the second spin flipper,with $n, m = 0$ (off) or 1 (on).

Super Conducting Magnet Polarization



$$p = \frac{N_0 - N_1}{N_0 + N_1}$$

p is the polarization of the system and is the product of the polarization of the system

N_i is the neutron counts, i denotes the power state of the spin flipper, SF2.

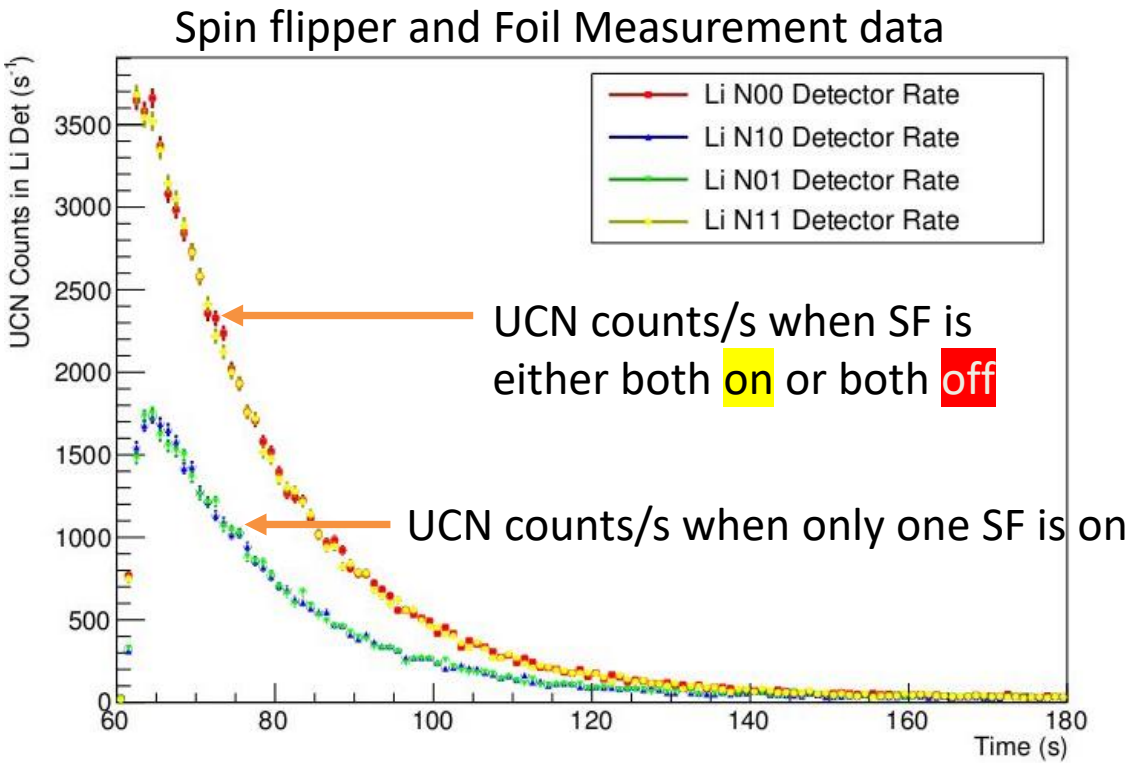
$\mathrm{i} = 0$ (off) or 1 (on)

$$p = p_{SCM} \cdot p_A$$

Raw Data

Time before 60 s includes the UCN source irradiation and pre-storage

Time = 60 s the valve to the experiment opens



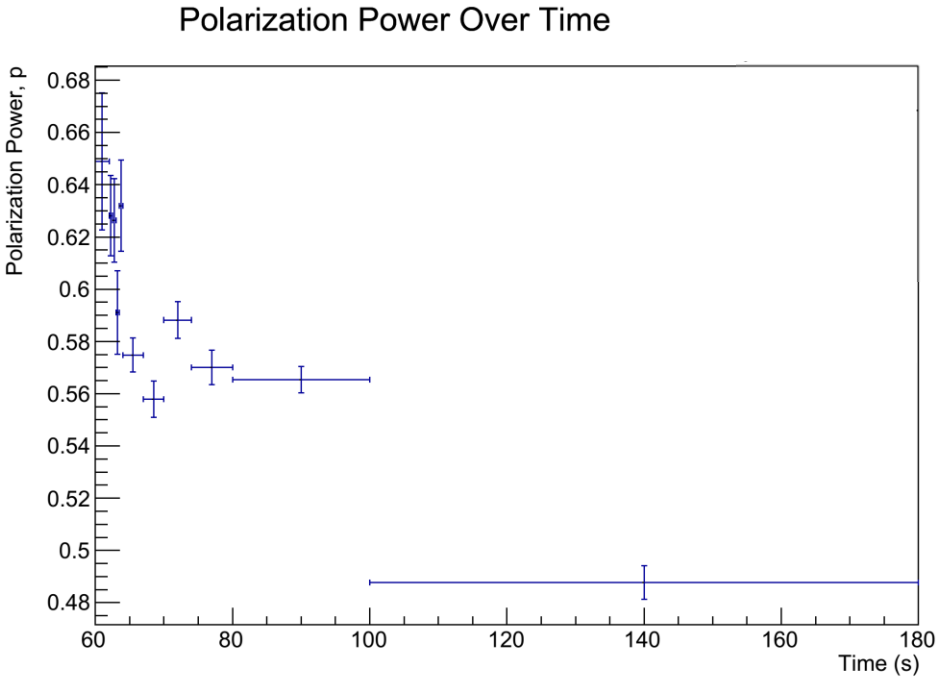
Preliminary Measurement

- Polarizing foil* $p_A = 60 \pm 2\ \%$
- Spin flipper efficiency* is $f_{1,2} = 100 \pm 2\ \%$
- Polarizing power* of the super conductor measurement $p_{SCM} = 55 \pm 5\ \%$

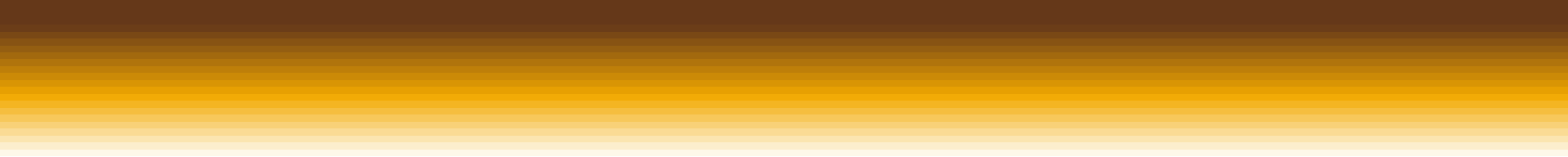
* Systematic effects have not been looked at

Polarizing foil and SCM should be much higher (80-100 %). PENTrack, a UCN Monte Carlo simulation is under way to understand this further.

Analyzer Foil's Polarization vs Time



- Depolarizing with time suggests a surface that depolarizes UCNs in the guide



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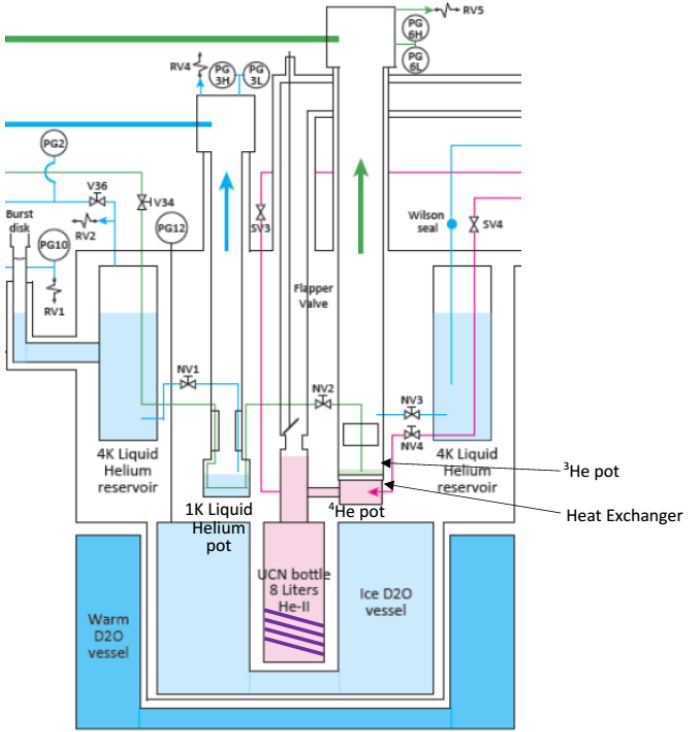
Question time

POLARIZATION MEASUREMENT OF UCN

UCN Production



- Proton Spallation on Tungsten target produces neutrons
- Down-scattered to ultracold regime

Ramsey Method Sequence for nEDM measurement

$$P(\uparrow;\downarrow) = P(\omega_{RF}, T, B_o, B_1)$$