The Neutron Electric Dipole Moment Experiment at Oak Ridge National Laboratory

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Talk Outline

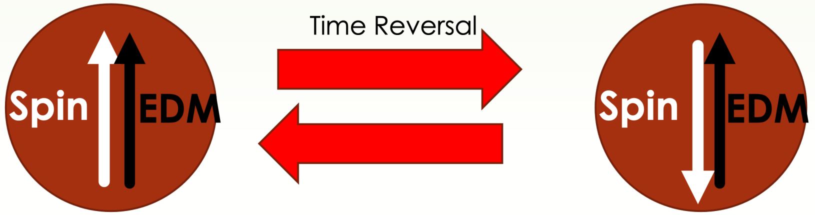
- nEDM Motivation
- Outline of an nEDM Measurement
- Neutron production for the nEDM@SNS Experiment
- nEDM@SNS Precession Measurement
- Known Systematic Effects
- Summary

Neutron Electric Dipole Moment (nEDM) Motivation

- Nonrelativistically, an electric dipole moment, $\vec{d}$, can be defined by

$$H = -(\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E})$$

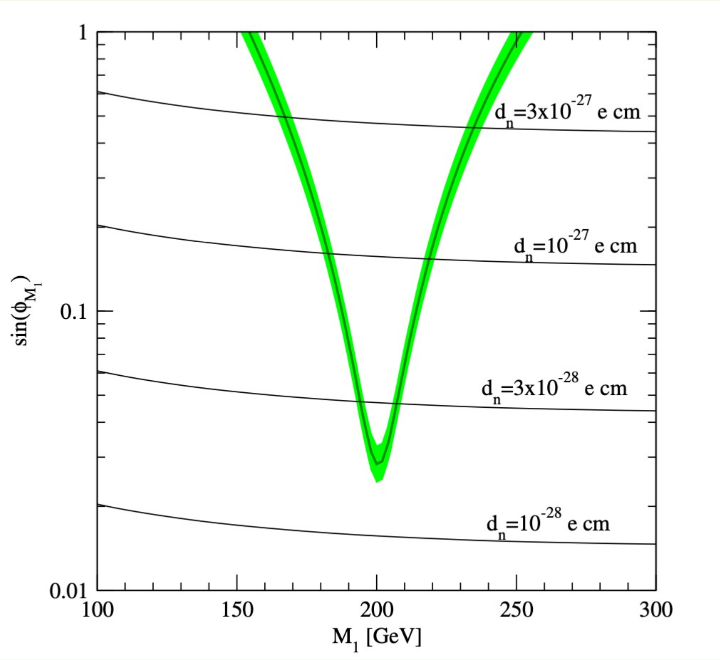
- Nonzero Permanent Electric Dipole Moments directly probe CP violation



- CP violation in the SM is not sufficient to be consistent with the observed matter anti-matter asymmetry

- Measuring the Neutron EDM is a strategic choice experimentally

Example of nEDM constraints. MSSM parameters from the baryon asymmetry:



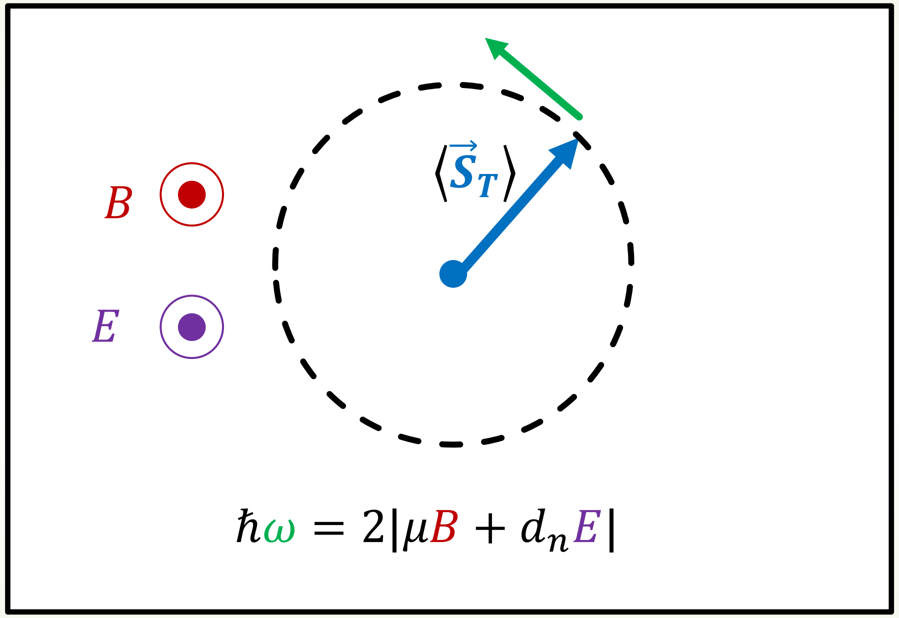
Li, Profumo, and Ramsey-Musolf, 2009

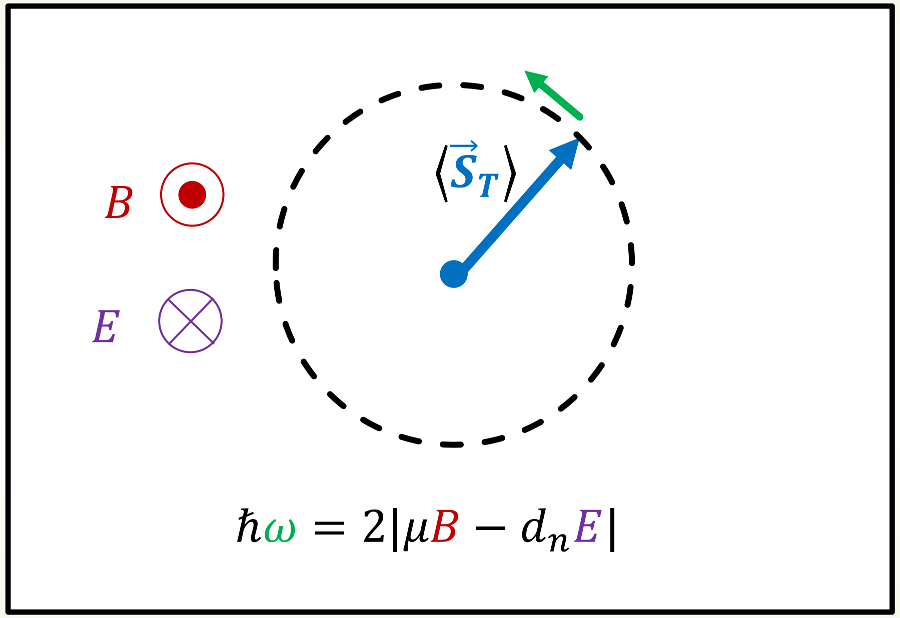
Standard Model Prediction	Current Bound	Target Precision of nEDM@SNS
$d_n \sim 1\times10^{-32}\ \mathrm{e} \cdot \mathrm{cm}$	$d_n < 1\times10^{-26}\ \mathrm{e} \cdot \mathrm{cm}$	$d_n < 2 - 3\times10^{-28}\ \mathrm{e} \cdot \mathrm{cm}$

Outline of an nEDM Measurement

- uses basic nuclear magnetic resonance (NMR) techniques.

Nonrelativistic Hamiltonian: $H = -\frac{\vec{S}}{|S|} \cdot (\mu B + d_n E)$





$$d_n = \frac{\hbar \Delta\omega}{4E} \Rightarrow \delta d_n \geq \frac{\hbar}{4ET\sqrt{N}}$$

Experimental focus is to minimize $\boldsymbol{\delta d_n}$

(picture assumes d_n>0)

Neutron Production for nEDM@SNS Experiment

- Ultra Cold Neutrons (UCNs) are defined as having speeds ≤ 8 m/s (or energies $\leq 3\times10^{-7}$ eV)

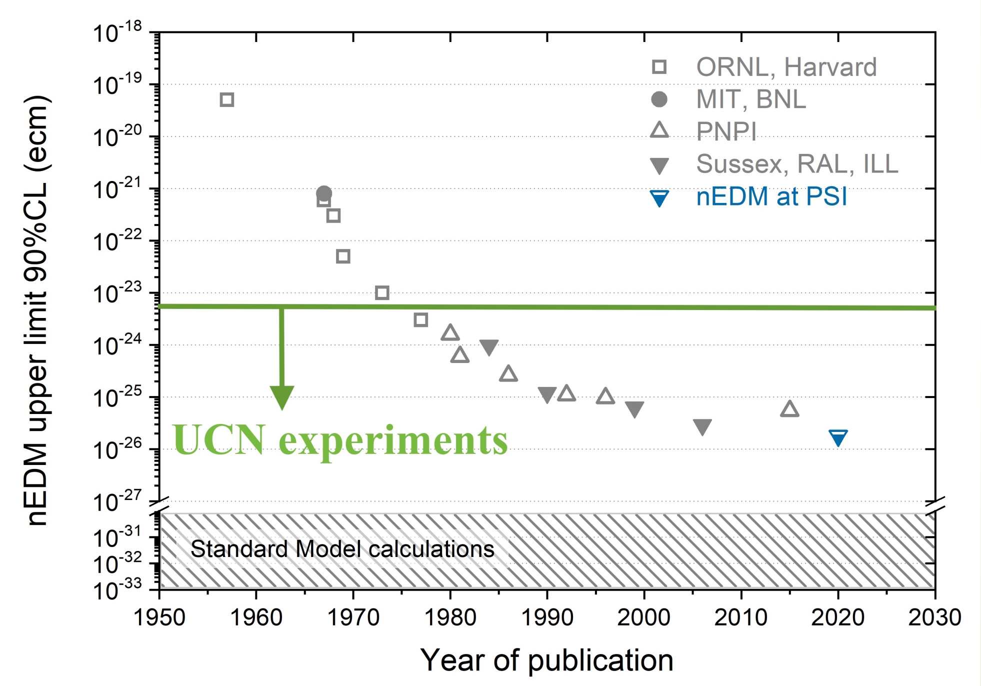
- UCNs are completely reflected by many materials

- nEDM@SNS will measure UCNs produced by down scattering cold neutrons in a superfluid bath at 450 mK.

- UCNs **remain** in the superfluid bath until lost to beta decay, cell wall losses, up scattering, or 3He absorption .

$$\frac{1}{\tau_{UCN}} = \frac{1}{\tau_\beta} + \frac{1}{\tau_{walls}} + \frac{1}{\tau_{up}} + \frac{1}{\tau_{3He}}$$

- Estimated to achieve 170 UCNs/cc

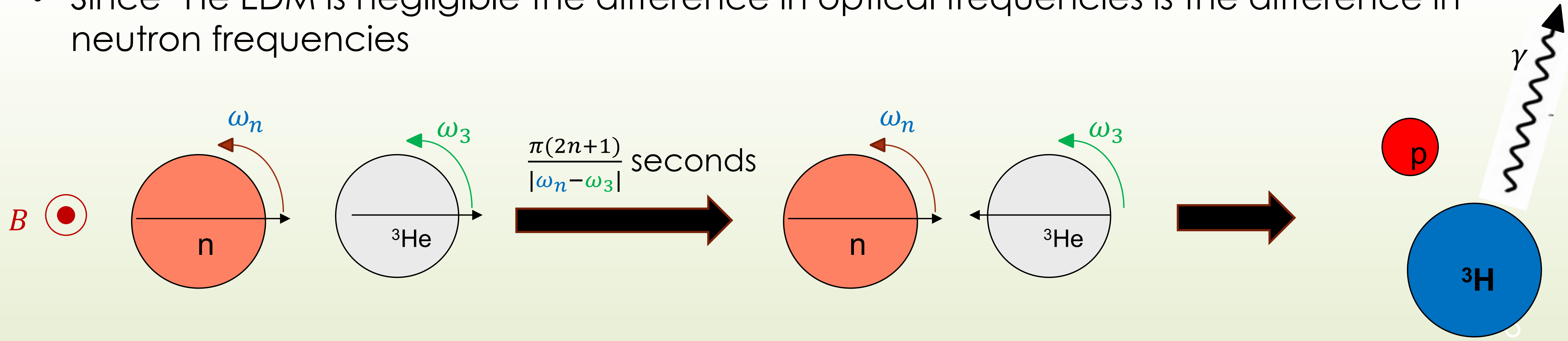


(image adapted from Wikipedia)

nEDM@SNS Experiment Precession Measurement

To measure $\Delta\omega$ (with the neutrons still in the superfluid!):

- Spin polarized ^3He is added to the superfluid bath with the concentration, $x_3 = \frac{n_3}{n_4+n_3} = 10^{-10}$
- During precession, the reaction products $n + {}^3He \rightarrow p + {}^3H + 764$ keV scintillate
- Reaction cross section maximized for spins antiparallel, minimized for spins parallel (min $\lesssim$1% of max).
- Since ^3He EDM is negligible the difference in optical frequencies is the difference in neutron frequencies



Some *Known* Systematic Effects

- Magnetic Field Stability
  - For target sensitivity, require coherent (with the electric field) fluctuations smaller than $\delta B \leq 10^{-16}$ T
- Motional Magnetic Field

$$\vec{B}_v \simeq -\frac{\vec{v}}{c^2} \times \vec{E} \qquad \frac{v}{c} = 10^{-8} \Longrightarrow \delta B \sim 10^{-10}\ \text{T}$$

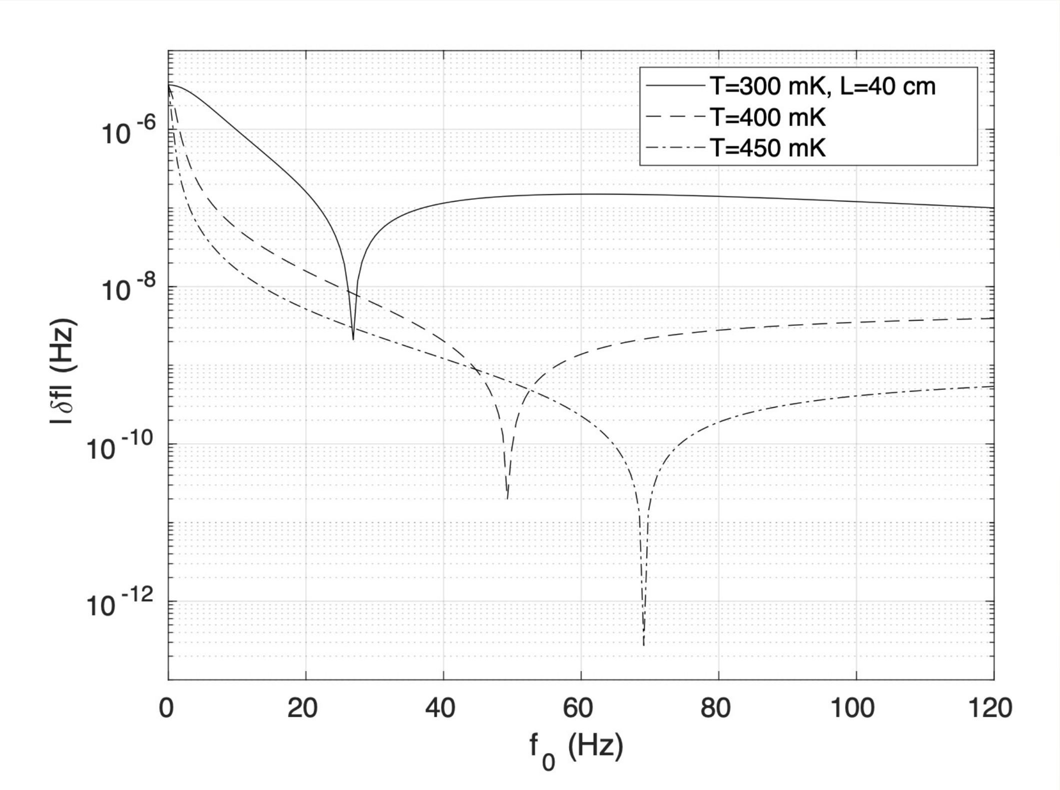
- Bloch-Siegert induced false EDM effect (also called geometric phase)

$$\delta\omega = \frac{\gamma^2 B_1^2}{2\,(\omega_0 - \omega_r)}$$

Example assuming simple circular motion

$$B_1^2 = \left|\vec{B}_v + \vec{B}_r\right|^2 \quad \Longrightarrow \quad \delta\omega = -\frac{\gamma^2 \left(\frac{\partial B_z}{\partial z}\right) \frac{E}{c^2} \omega_r R}{2\,(\omega_0 - \omega_r)}.$$

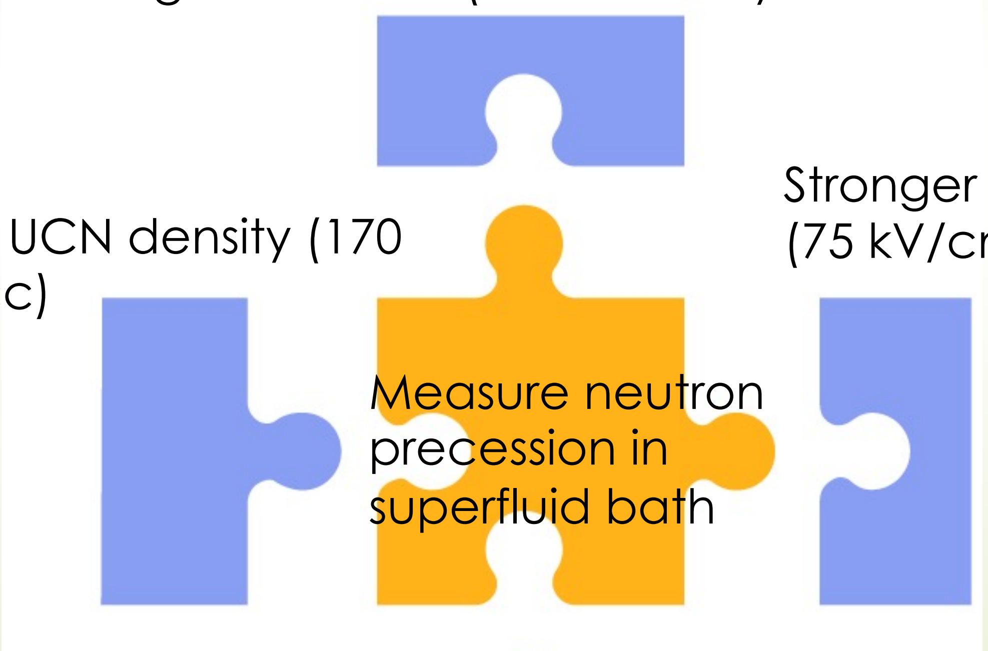
False EDM effect for the ^{3}He



(C.M. Swank, A.K. Petukhov and R. Golub *Phys. Rev.* **A 93** (2016) 062703.)

Summary

- The nEDM is sensitive to CP violation and is thus of interest to BSM physics
- The nEDM@SNS aims to improve the sensitivity current sensitivity limit by 1 to 2 orders of magnitude



A disadvantage: Cryogenics!