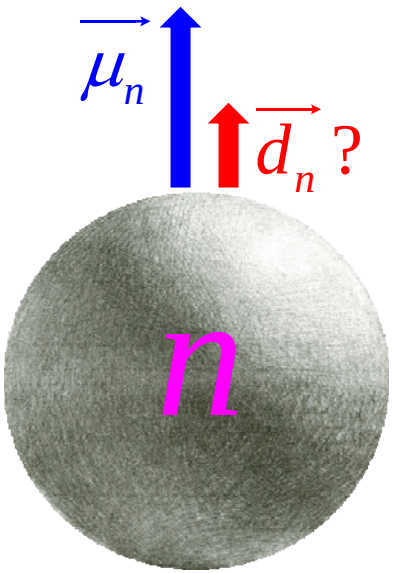
^{3}He Relaxation Time Measurements At 330 mK for the Neutron Electric Dipole Moment (nEDM) Experiment

40th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics



Q. Ye, H. Gao, W. Zheng
Duke University

R. Golub, P. Huffman
NC State University

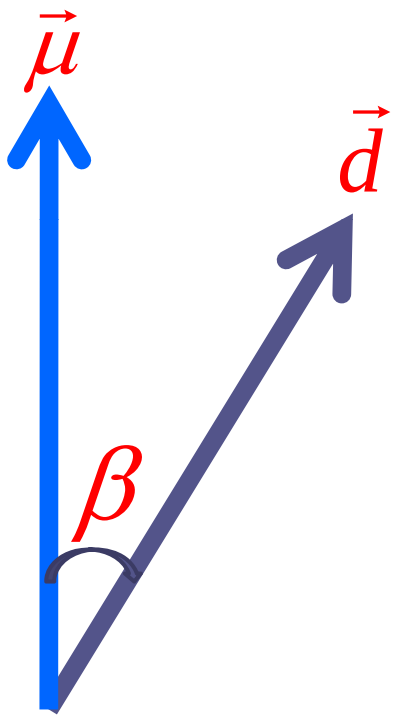
May 20, 2009

Outline

- Introduction
- Overview of the nEDM Experiment
- ^{3}He Relaxation Time Measurement & Preliminary Results
- Summary, Future Plans & Acknowledgement

Neutron Electric Dipole Moment

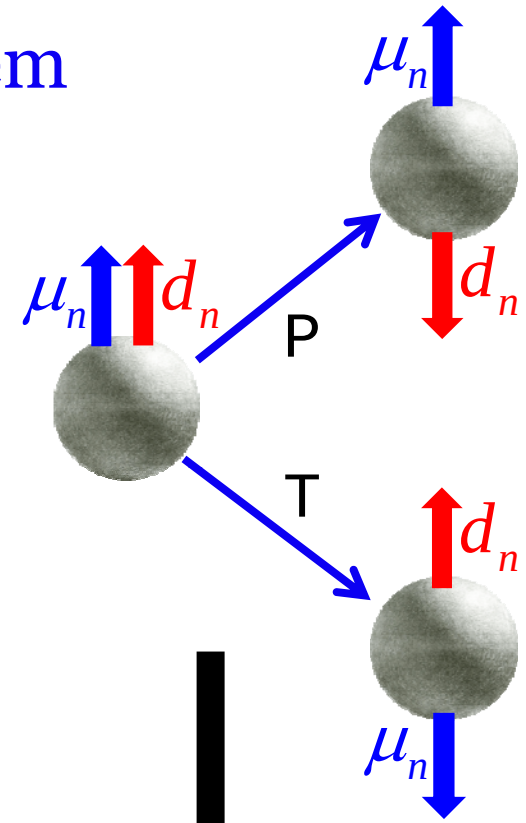
- Non-degenerate quantum system @ ground state



Requires additional quantum #
CONTRADICTION!

$$\beta = 0, \pi !$$

$$\vec{d} = \alpha \vec{\mu}$$



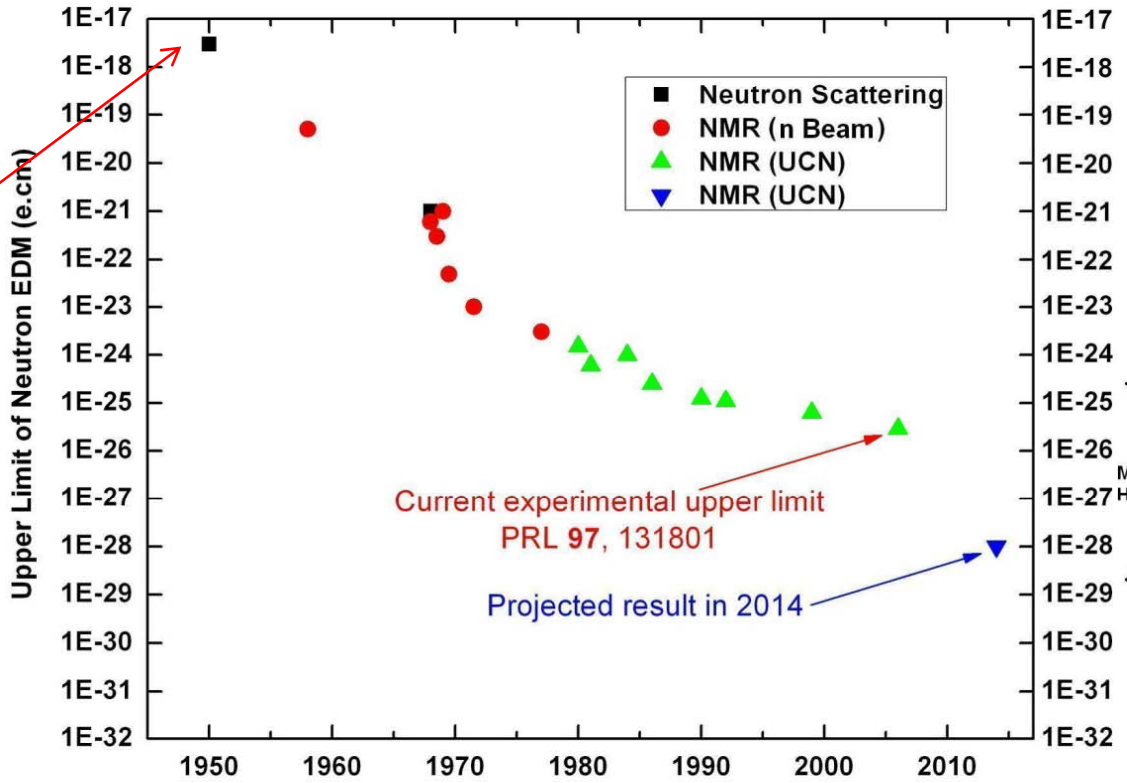
$d_n \neq 0 \rightarrow$ P, T violation!

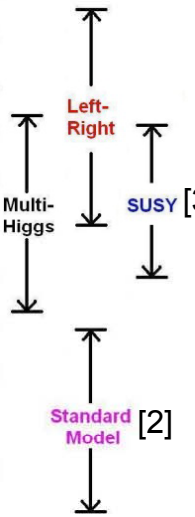
[1] I. B. Khriplovich and S. K. Lamoreaux. CP Violation Without Strangeness. Springer, 2004.

Neutron EDM Physics Motivation

- Direct T violation <-> CP violation (CPT theorem)
- Physics Beyond the Standard Model

1950, Smith, Purcell and Ramsey[1]





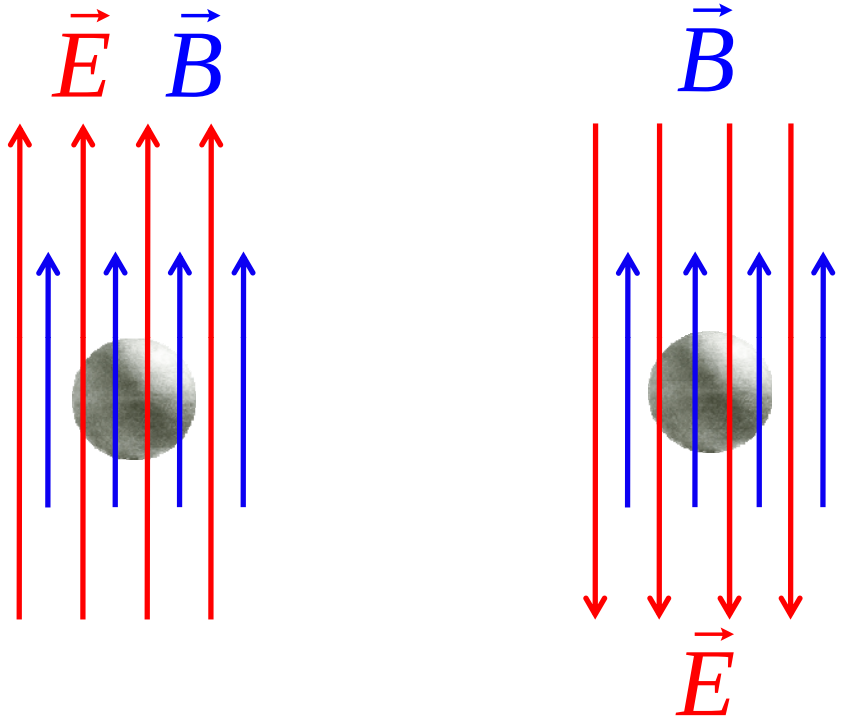
- Baryon Asymmetry of the Universe.

New Physics!!!
New sources of CP violation?

[1] E. M. Purcell and N. F. Ramsey. Phys. Rev., 78:807, 1950.
[2] B. McKellar et al., Phys. Lett. B, 197:556, 1987.
[3] S. Abel et al., Nucl. Phys. B, 606: 151, 2001
[4] M. Pospelov, A. Ritz, Annals of Physics 318: 119, 2005

nEDM Measurement Principle

$$H = -(\mu_n \hat{s} \cdot \vec{B} + d_n \hat{s} \cdot \vec{E})$$



$$\Delta\nu = 4 d_n E_0 / h$$

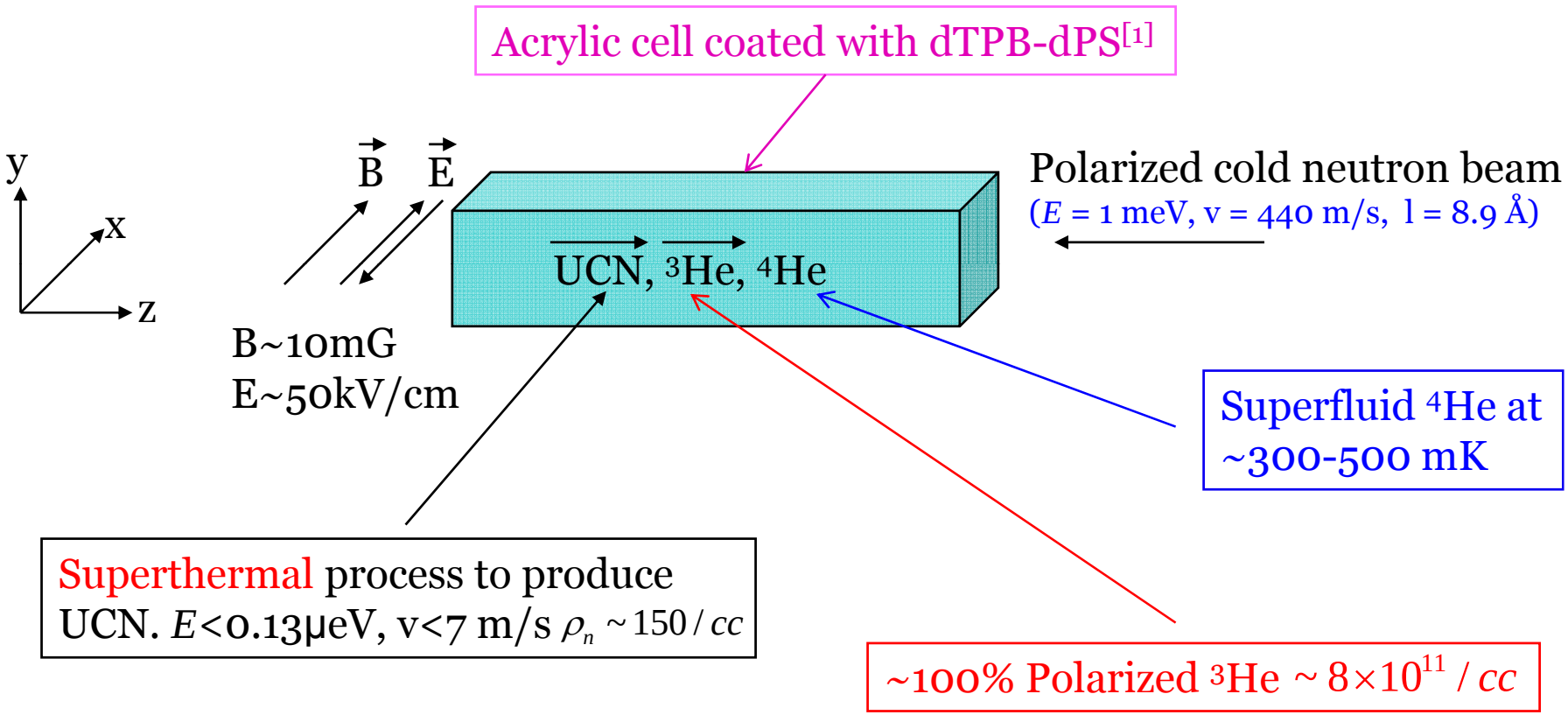
$$\begin{cases} B_0 = 10mG \\ E_0 = 50kV/cm \\ d_n = 4\times10^{-28} e\cdot cm \end{cases} \rightarrow \begin{cases} \nu_0 = 29.2Hz \\ \Delta\nu = 0.019\mu Hz \end{cases}$$

Extremely difficult to measure!

$$\nu_n = \frac{-(2\mu_n B_0 + 2 d_n E_0)}{h} \qquad \nu_n = \frac{-(2\mu_n B_0 - 2 d_n E_0)}{h}$$

Measurement technique

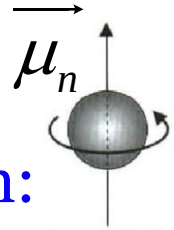
- Neutron in an external $\vec{B}$ and $\vec{E}$ field $\Delta\nu = -4d_n E_0 / h$



[1] deuterated polystyrene doped with the deuterated organic fluor 1,1,4,4-tetraphenyl buta-1,3-diene (dTPB-dPS)

Neutron frequency ν_n measurement

- Magnetic moments
- Spin Dependent reaction:



$$\frac{\mu_{3He}}{\mu_n} = 1.11$$

^{3}He EDM highly suppressed[1]

$$\vec{n} + \overrightarrow{^3He} \rightarrow p + t + 764keV \begin{cases} \sigma_{parallel} \sim 2\times10^4 b \\ \sigma_{anti-parallel} \sim 4\times10^6 b \end{cases} (UCN, v < 7.6m/s)$$

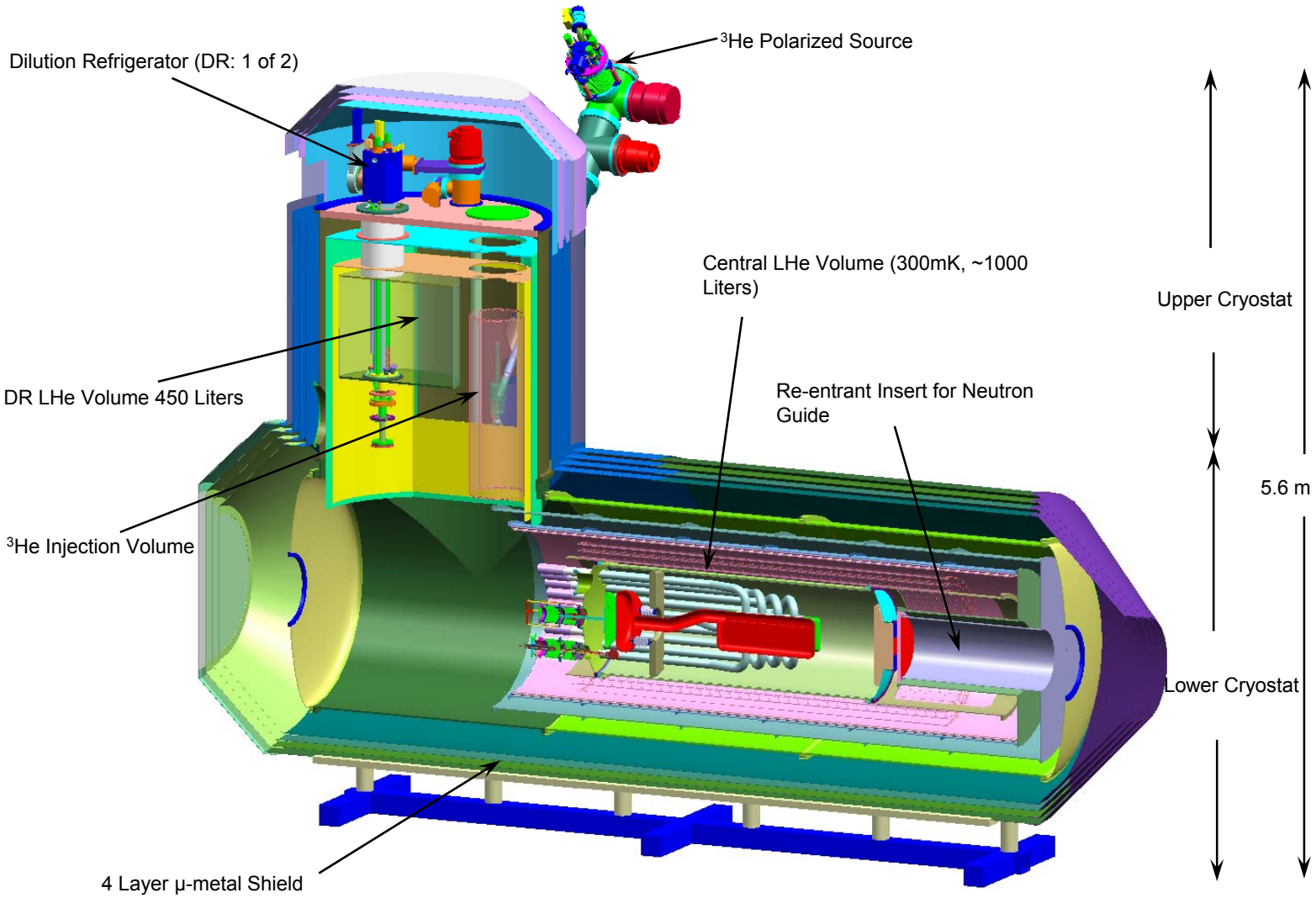
- Scintillation light wavelength (80 nm) shifted[2] → ~430 nm (dTPB-dPS)
- Scintillation Rate:

Monitored using SQUID[3]

$$\Phi(t) = \Phi_{bg} + Ne^{-t\frac{1}{\tau_{ucn}}}\{\frac{1}{\tau_\beta} + \frac{1}{\tau_{3He}}[1 - P_{3He}(t)P_n(t)\cos(2\pi(\nu_{3He} - \nu_n)t + \phi)]\}$$

[1] L. I. Schiff, Phys. Rev. 132, 2194 (1963); Quantum Mechanics, third edition (New York: McGraw-Hill, 1968)
[2] W. M. Burton and B.A. Powell, Appl. Opt. 12, 87 (1973). [3] Superconducting Quantum Interference Device

nEDM experiment conceptual design



Role of ^{3}He in nEDM experiment

- Spin dependent reaction

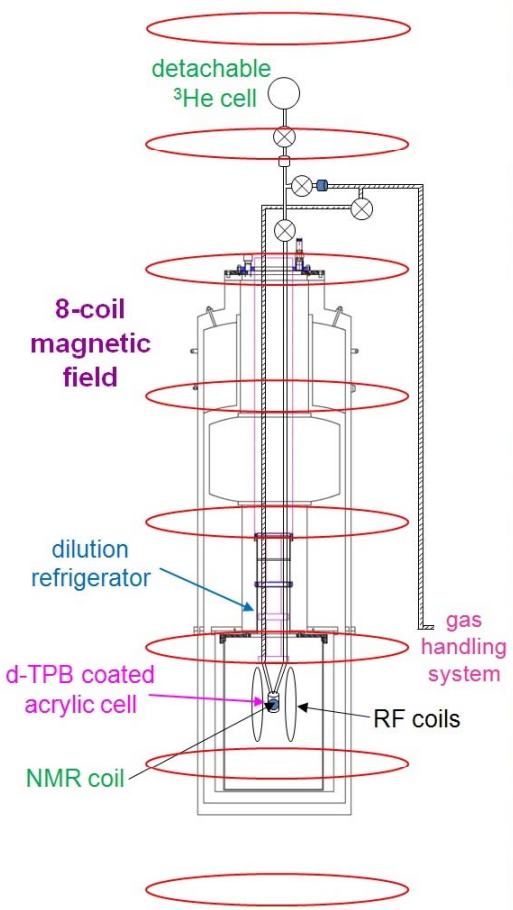
$$\vec{n} + \overrightarrow{^3He} \rightarrow p + t + 764keV$$

- Co-magnetometer using SQUID $B_0 = -\frac{h\nu_{3He}}{2\mu_{3He}}$

- Polarized ^{3}He needs to have a long relaxation time in the dTPB-dPS coated acrylic cell ~10^4 s or longer at ~300-500 mK[1] >> neutron storage time

[1] The EDM Collaboration. A New Search for the Neutron Electric Dipole Moment, Funding Pre-proposal, 2002.

^{3}He depolarization study under nEDM surface condition and temperature



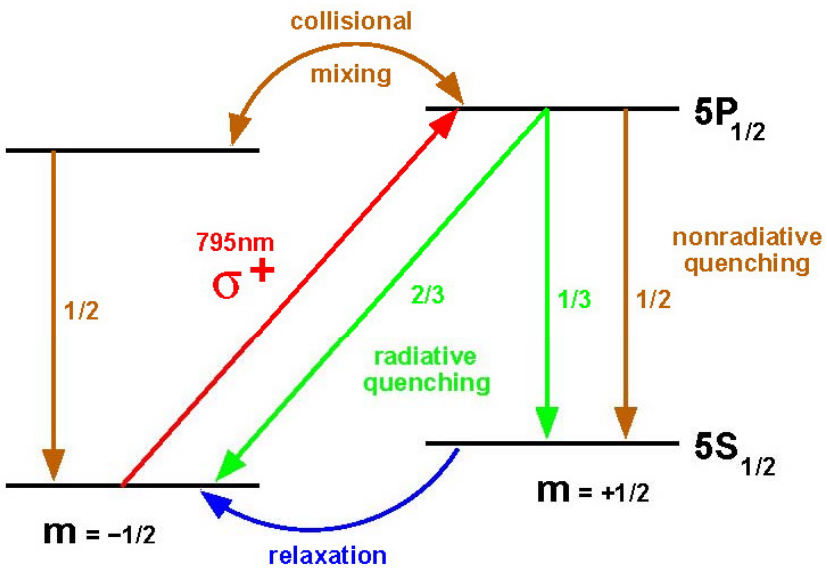
Q. Ye, H. Gao, W. Zheng
Duke University

F. Dubose, R. Golub, P. Huffman
E. Korobkina, C. Swank
NC State University

D. Dutta
Mississippi State University

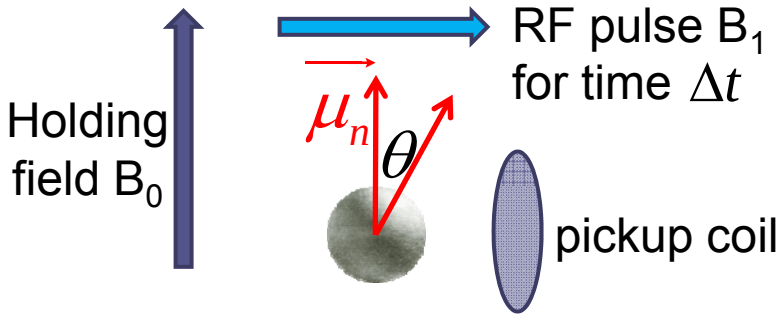
Experimental techniques – SEOP & NMR-FID[3]

- Rb Optical Pumping[1]
  - Polarize Rb outer shell electron



- Spin Exchange[2]
  - Spin exchange between Rb electrons ←→ ^{3}He nuclei

- Free Induction Decay



- Tipping angle

$$\theta = \gamma B_1 \Delta t$$

- Tip the same angle (<3^0) every five minutes

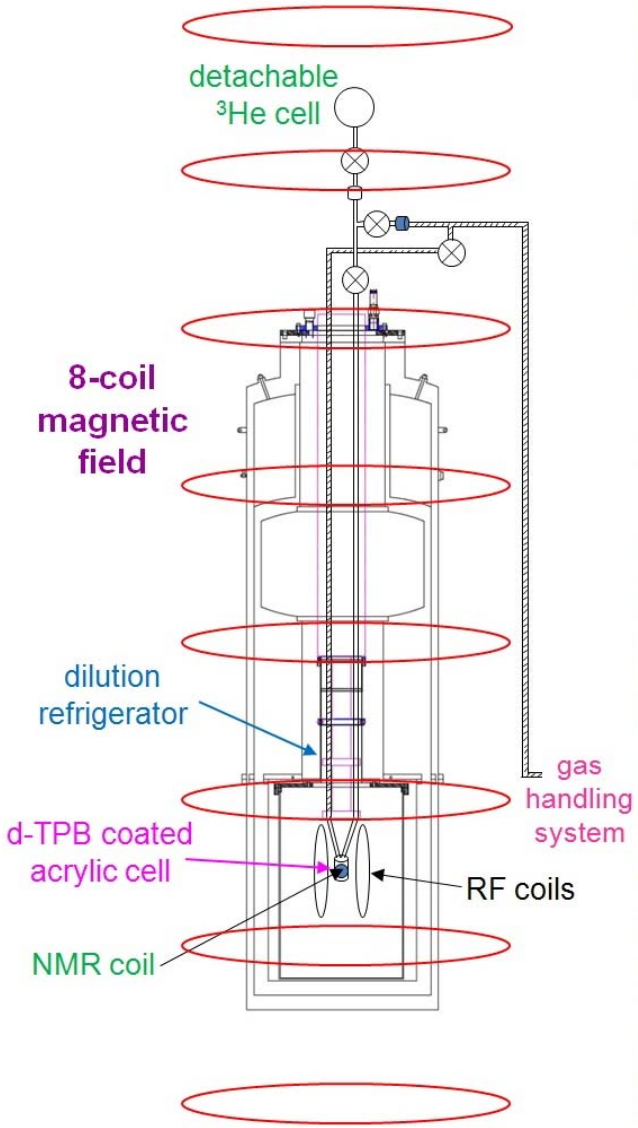
$$A = A_0 e^{-t/T_1}$$

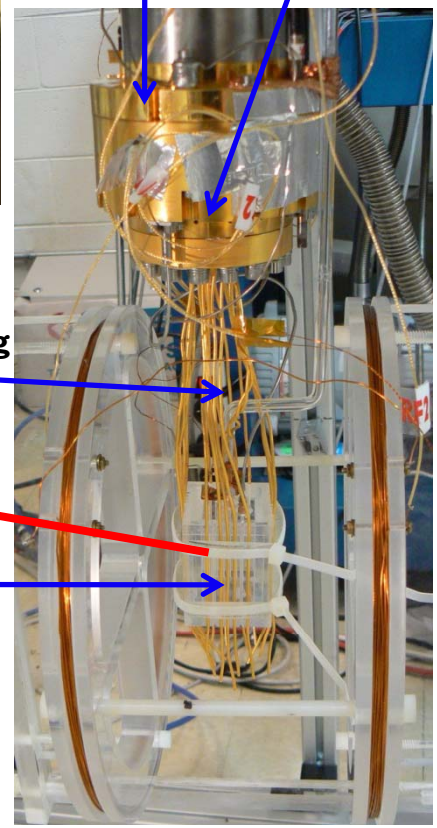
^{3}He longitudinal relaxation time

[1] W. Happer. Rev. Mod. Phys., 44:169, 1972. [2] T. Walker and W. Happer. Rev. Mod. Phys., 69:629, 1997.
[3] A. Abragam. Principles of Nuclear Magnetism. Oxford University Press, Oxford, UK, 1961.

330 mK experimental apparatus

Duke University, TUNL

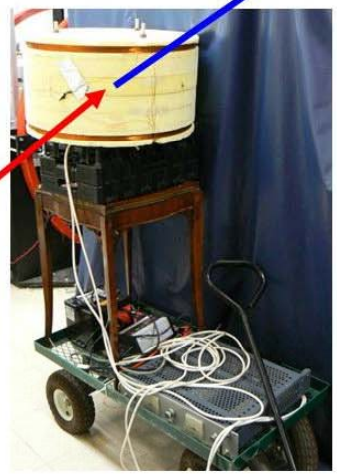




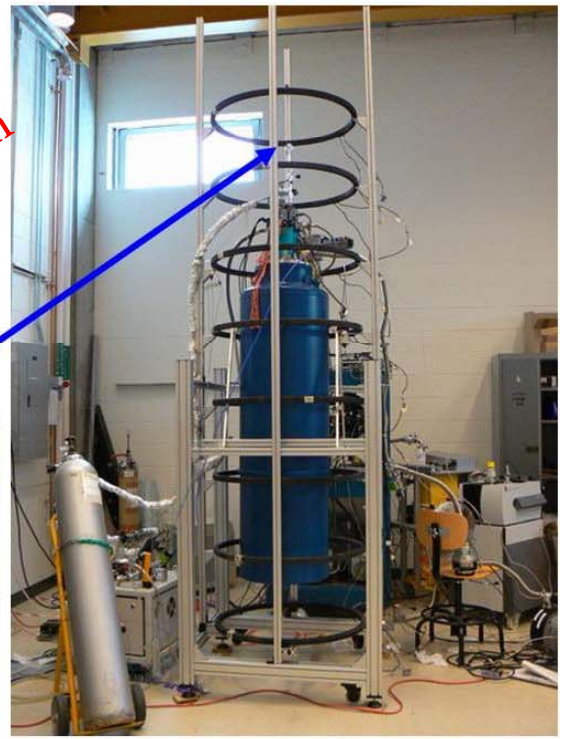
Experimental procedure

- Cool down -> 330mK
- Fill the acrylic cell with superfluid ^{4}He
- Polarize ^{3}He

Bring over to the top of the 8-coil system



Physics building

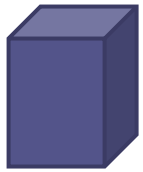


French Family Science Center
FFSC 1127

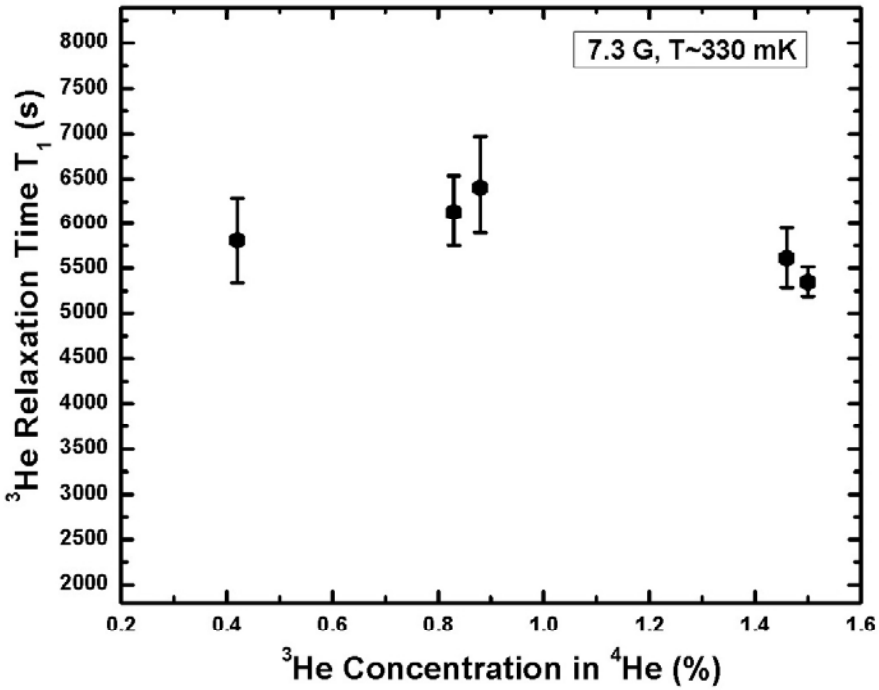
- Let ^{3}He into the acrylic cell
- Start T_1 measurements

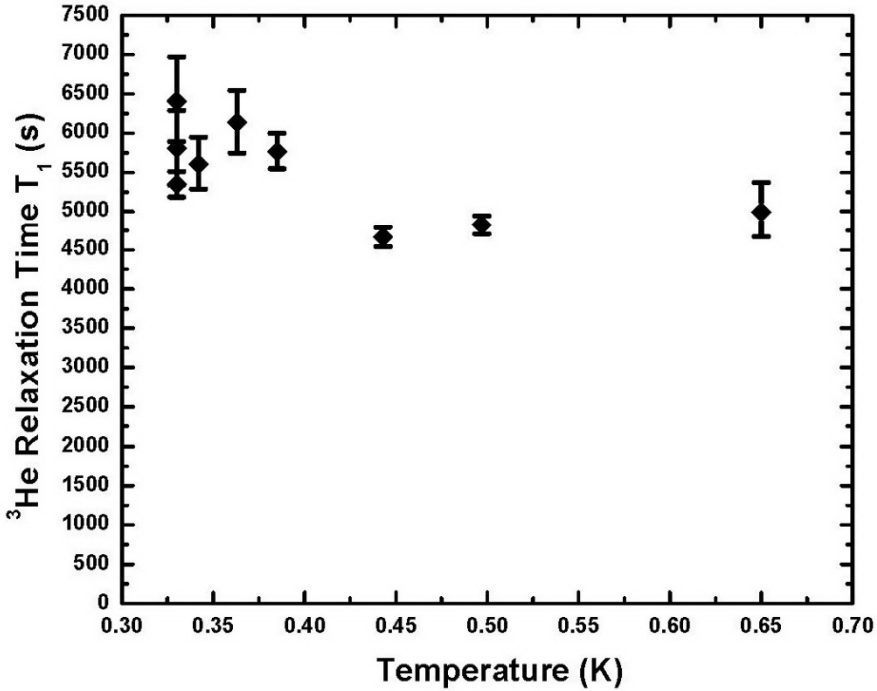
[1] Q. Ye *et al.*, submitted to PRL, 2009.

Preliminary Data



cell full of superfluid ^{4}He





Relaxation effects from dipole-dipole interaction and B-field gradients are small compared to the wall effect.

^{3}He T_1 does not change much in the χ ranging from 0.42% to 1.5% at 0.33 K, nor with the temperature from 0.33 K to 0.65 K.

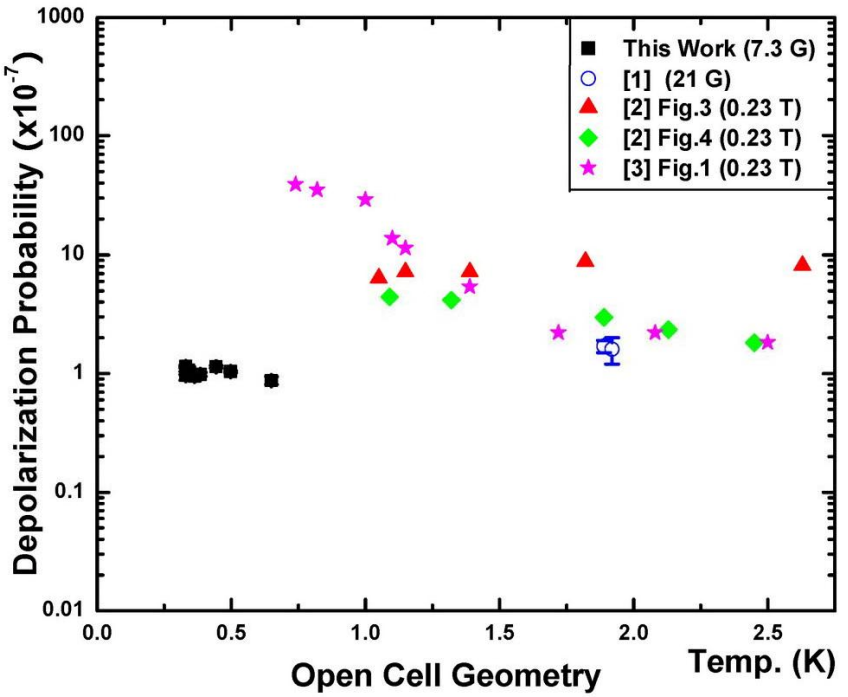
[1] Q. Ye *et al.*, submitted to PRL, 2009.

Depolarization probability P_d

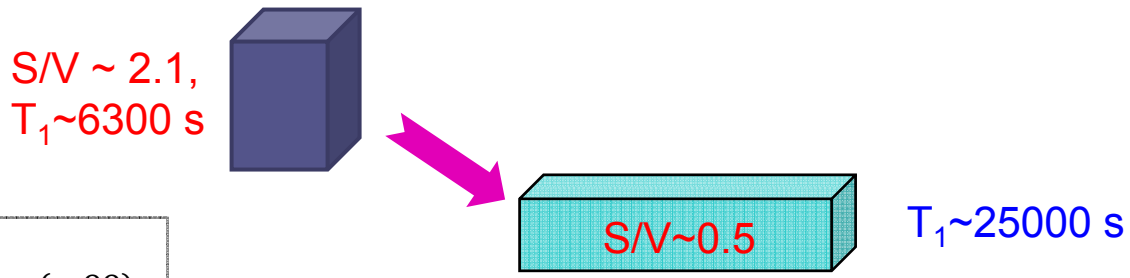
$$\frac{1}{T_1} = \frac{1}{4}\bar{v} \cdot P_d \frac{S}{V}$$

$$P_d = \frac{4}{\bar{v} \cdot T_1 \cdot (S/V)}$$

- d-TPB coated acrylic surface outperformed glass surfaces with various coatings in the open geometry systems[4]



^{3}He in vapor, ^{4}He film covered solid-H_2 coating on glass



[1] Q. Ye et al., Phys. Rev. A, 77, 053408 (2008)
[2] C.P. Lusher et al., J. of Low Temp. Phys. 72, 25 (1988).
[3] C.P. Lusher et al., J. of Low Temp. Phys. 72, 71 (1988).
[4] Q. Ye *et al.*, submitted to PRL, 2009.

Summary

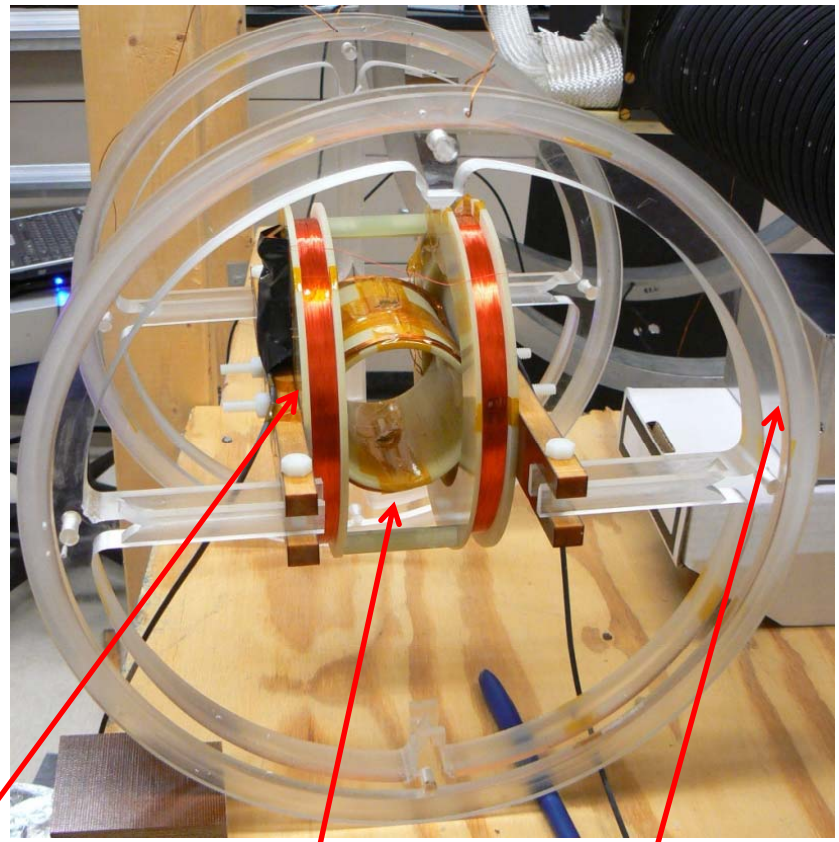
- nEDM experiment's status
  - CD1 received in 2007
  - On track for CD2 review this year

- The measured ^{3}He relaxation time under nEDM surface condition and temperature is sufficient for the experiment.

nEDM ground "breaking" on Feb. 6, 2009 in SNS

Future Plans

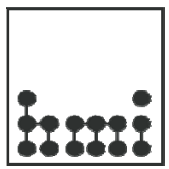
- Add gradient coils to 330 mK test setup to study the geometric phase effect [1] .
- Add pulsed NMR system / SQUID to measure low concentrations of ^{3}He in superfluid ^{4}He → imaging ^{3}He
- More R&D…



[1] A. L. Barabanov, R. Golub, and S. K. Lamoreaux. arXiv:nucl-ex/0607020, 2009

EDM Collaborating Institutions

Los Alamos
National Laboratory



OAK RIDGE
National Laboratory

Acknowledgement

- School of Arts and Science of Duke University
- U.S. DOE contract number DE-FG0203ER41231
- Los Alamos National Laboratory
- Hahn Meitner Institute of Berlin
- NC Sate University