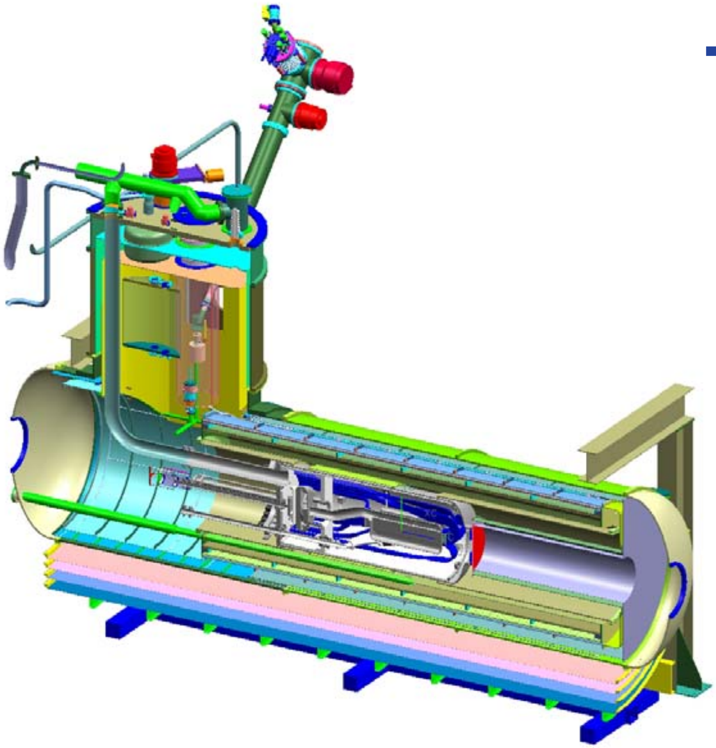


The nEDM Project

Martin Cooper

Co-spokesperson, CPM

Los Alamos National Laboratory

NSAC Meeting

Crystal City, VA

August 21, 2008

nEDM Collaboration

R. Alarcon, S. Balascuta, L. Baron-Palos
Arizona State University, Tempe, AZ, USA
D. Budker, A. Park
University of California at Berkeley, Berkeley, CA 94720, USA
G. Seidel
Brown University, Providence, RI 02912, USA
A. Kokarkar, V. Logashenko, J. Miller, L. Roberts
Boston University, Boston, MA 02215, USA
J. Boissevain, R. Carr, B. Filippone, R. McKeown, M. Mendenhall, R. Schmid
California Institute of Technology, Pasadena, CA 91125, USA
M. Ahmed, W. Chen, H. Gao, X. Qian, Q. Ye, W.Z. Zheng, X. F. Zhu, X. Zong
Duke University, Durham NC 27708, USA
F. Mezei
Hahn-Meitner Institut, D-14109 Berlin, Germany
C.-Y. Liu, J. Long, H.-O. Meyer, M. Snow
Indiana University, Bloomington, IN 47405, USA
L. Bartoszek, D. Beck, P.. Chu, A. Esler, J.-C. Peng, S. Williamson, J. Yoder
University of Illinois, Urbana-Champaign, IL 61801, USA
C. Crawford, T. Gorringe, W. Korsch, B. Plaster
University of Kentucky, Lexington KY 40506, USA

B. Bourque, S. Clayton, M. Cooper, M. Espy, R. Hennings-Yeoman, T. Ito, A. Matlachov, C. Mauger, E. Olivas, J. Ramsey, I. Savukov, W. Sondheim, S. Stanislaus, S. Tajima, J. Torgerson, P. Volegov
Los Alamos National Laboratory, Los Alamos, NM 87545, USA
E. Beise, H. Breuer
University of Maryland, College Park, MD 20742, USA
K. Dow, D. Hassel, E. Ihloff, J. Kelsey, R. Milner, R. Redwine, C. Vidal
Massachusetts Institute of Technology, Cambridge, MA 02139, USA
J. Dunne, D. Dutta
Mississippi State University, Starkville, MS 39762, USA
F. Dubose, R. Golub, C. Gould, D. Haase, P. Huffman, E. Korobkina, C. Swank, A. Young
North Carolina State University, Raleigh, NC 27695, USA
V. Cianciolo, S. Penttila
Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
M. Hayden
Simon-Fraser University, Burnaby, BC, Canada V5A 1S6
G. Greene
The University of Tennessee, Knoxville, TN 37996, USA
S. Lamoreaux, D. McKinsey, A. Sushkov
Yale University, New Haven, CT 06520, USA

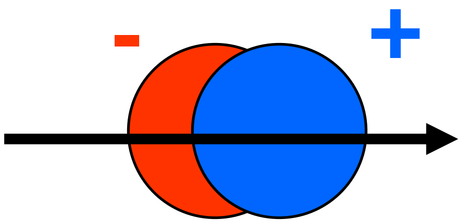
Outline

- Introduction to nEDM
- Collaboration Foci

The Permanent EDM of the Neutron

- A permanent EDM $\vec{d}$

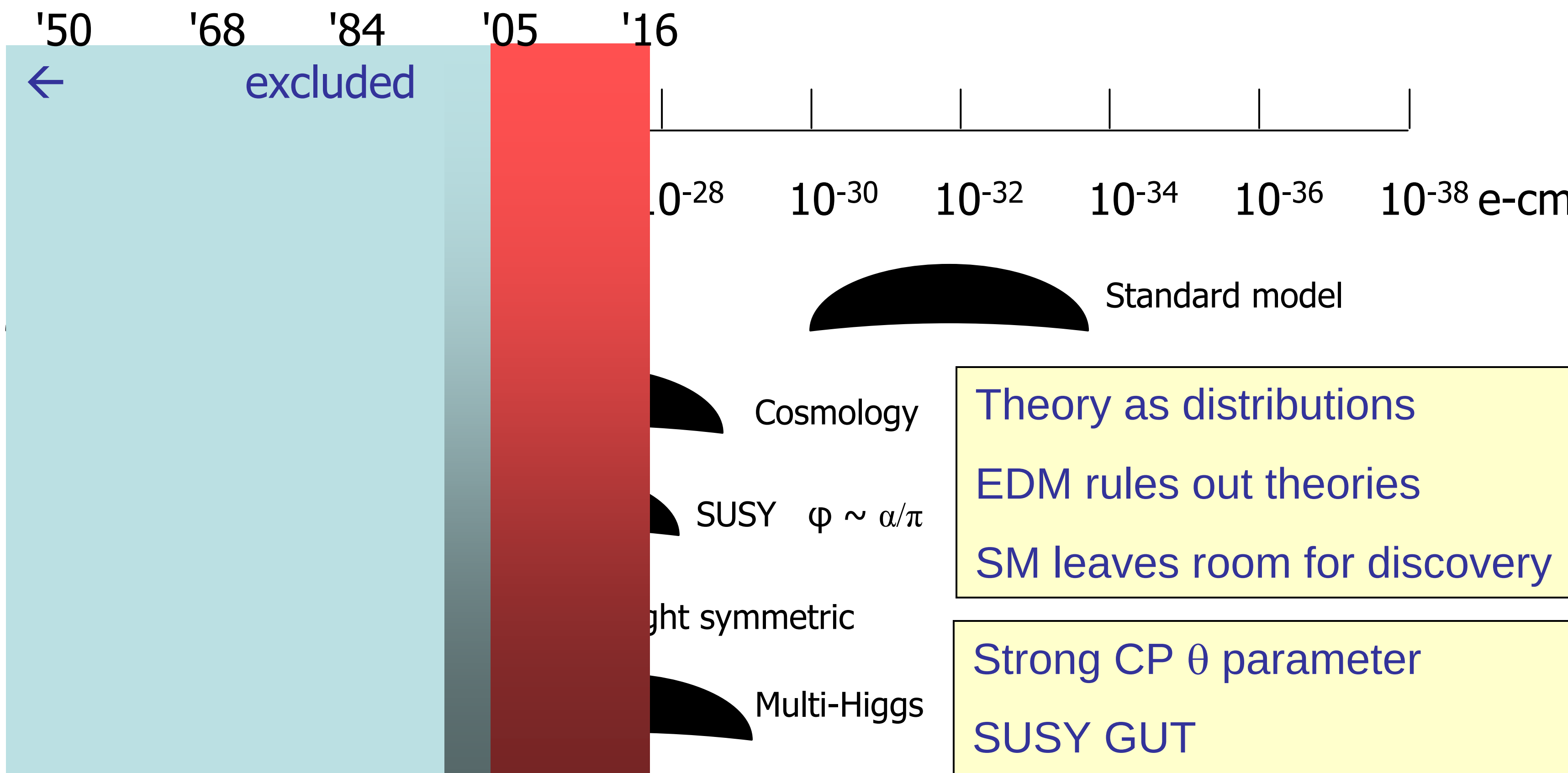
$\vec{d} \bullet \vec{E}$



s = 1/2

- The current value is < 3 x 10^{-26} e•cm (90% C.L.)
- We hope to obtain roughly < 2 x 10^{-28} e•cm with UCN in superfluid He

Theory and Experiment



Theory as distributions

EDM rules out theories

SM leaves room for discovery

Strong CP θ parameter

SUSY GUT

Electro-weak Baryogenesis

An EDM could be seen

Results interesting after LHC

Status of EDM Measurements (e-cm)

Fundamental Particles

n	ILL	$\|d_n\|$	$< 1.2 \times 10^{-25}$
	PNPI	$\|d_n\|$	$< 1.1 \times 10^{-25}$
	ILL (^{199}Hg)	$\|d_n\|$	$< 3.0 \times 10^{-26}$
	ILL (No E)	$\|d_n\|$	$<$ (1) $\times 10^{-27}$
	PSI	$\|d_n\|$	$<$ (1) $\times 10^{-27}$
	SNS (^{3}He)	$\|d_n\|$	$<$ (2) $\times 10^{-28}$
p		$\|d_p\|$	$< 10^{-22}$
Λ	$\Lambda \to p\pi^-$ assym.	$\|d_\Lambda\|$	$< 1.5 \times 10^{-16}$
e	g-2	$\|d_e\|$	$< 4 \times 10^{-16}$
ν	reactor exp.	$\|d_\nu F_3\|$	$< 2 \times 10^{-20}$
μ	g-2	$\|d_\mu\|$	$< 7 \times 10^{-19}$
		$\|d_\mu\|$	$< 10^{-24}$
τ	$\Gamma(Z \to \tau^+\tau^-)$	$\|d_\tau\|$	$< 4.5 \times 10^{-18}$
d	BNL	$\|d_d\|$	$<$ (10^{-27})

Paramagnetic Atoms

H	Lamb shift			$\|d_e\| < 2 \times 10^{-13}$
Fe^{+3}	$d_{3/2}$			$\|d_e\| < 2 \times 10^{-22}$
Rb	5s	$\|d_a\|$	$< 1.2 \times 10^{-23}$	$\|d_e\| < 5 \times 10^{-25}$
Cs	6s	$\|d_a\|$	$< 1.3 \times 10^{-23}$	$\|d_e\| < 1 \times 10^{-25}$
Tl	$5p_{1/2}$	$\|d_a\|$	$< 1 \times 10^{-24}$	$\|d_e\| < 2 \times 10^{-27}$

Diamagnetic Atoms

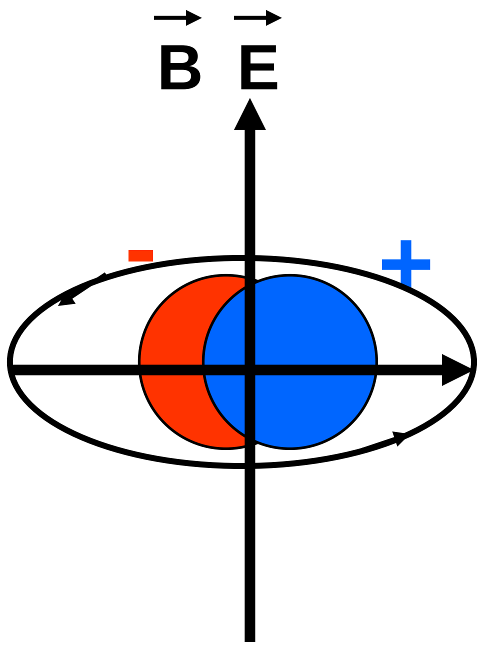
^{129}Xe	Wash.	$\|d_a\|$	$< 2 \times 10^{-26}$	$\|d_n\| < 2 \times 10^{-23}$
^{199}Hg	Wash.	$\|d_a\|$	$< 2 \times 10^{-28}$	$\|d_n\| < 2 \times 10^{-26}$
^{225}Ra	ANL	$\|d_a\|$	$<$ (10^{-26})	$\|d_n\| <$ (10^{-27})
^{225}Ra	ANL	$\|d_a\|$	$<$ (10^{-28})	$\|d_n\| <$ (10^{-29})

Polar Molecules

YF	Sussex	$\|d_e\| < 4 \times 10^{-25}$ (10^{-28})
PbO	Yale	$\|d_e\| <$ (10^{-30})
GGG	IU	$\|d_e\| <$ (10^{-30})

Blue numbers are forecasts

The Basic Technique



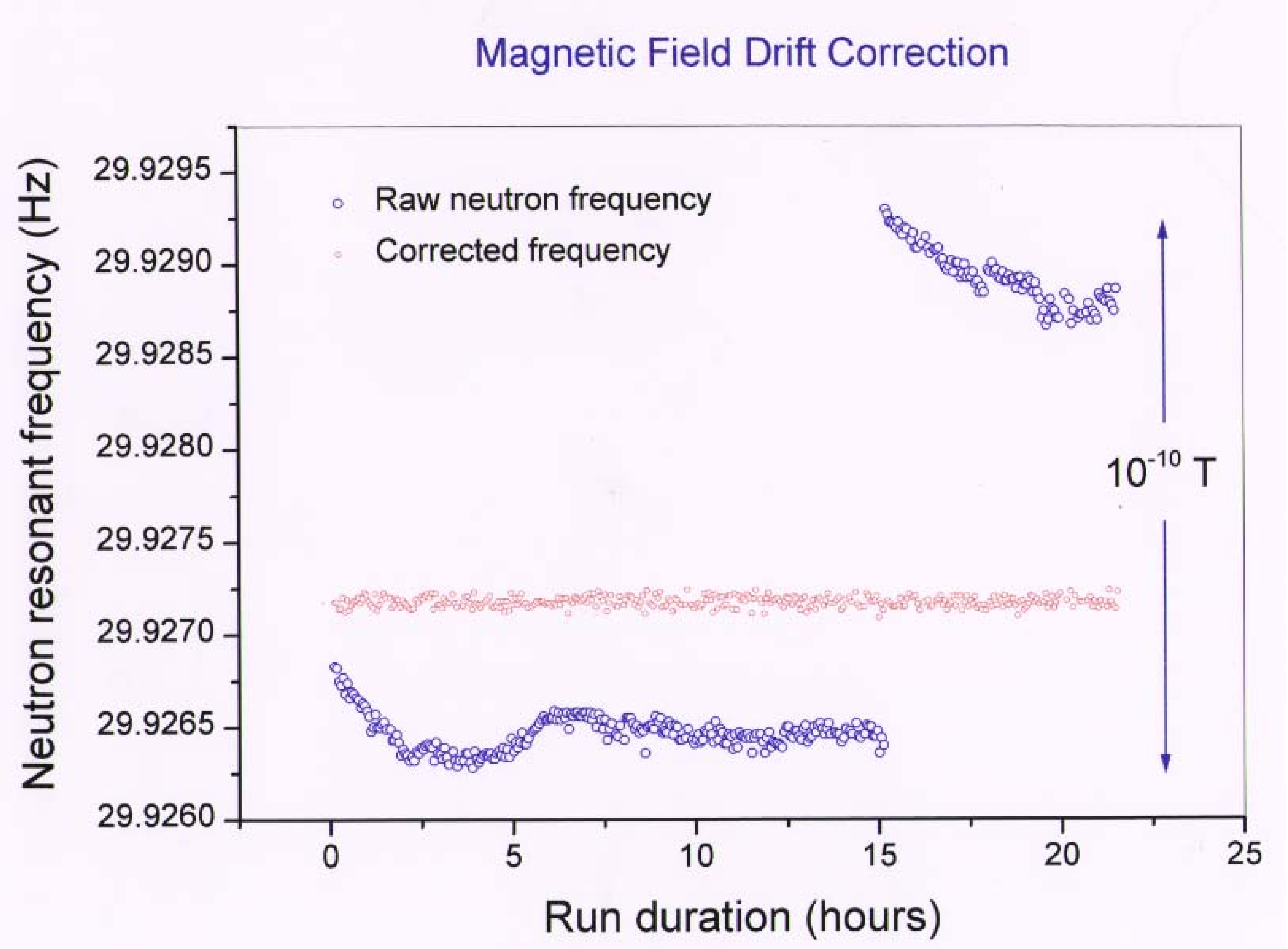
Look for a precession frequency ω_d

s = 1/2 dipole moment d_n

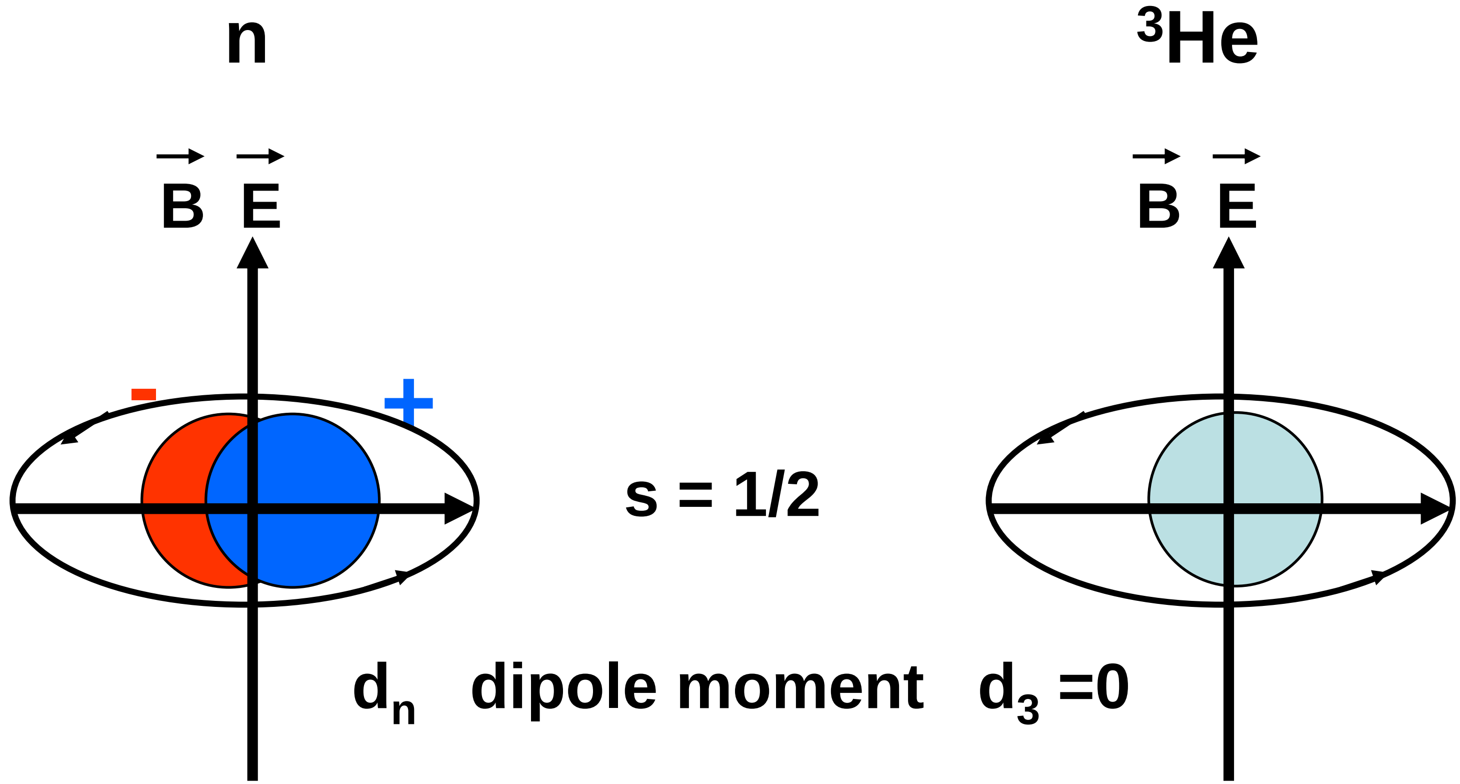
Figure of Merit for EDM Experiments ~ $E\sqrt{N\tau}$ $\rightarrow$ **125**

E $\rightarrow$ 5E $\tau \rightarrow 5\tau$ N $\rightarrow$ 125 N

The Need for a Co-magnetometer



^{3}He Magnetometry



Look for a difference in precession frequency $\omega_n - \omega_3 \pm \omega_d$ dependent on E and corrected for temporal changes in ω_3

Cryogenic ^{3}He co-magnetometer is the principal reason the nEDM Collaboration believes its experiment has more promise

^{3}He-Dopant as an Analyzer

$^3\vec{He} + \vec{n} \rightarrow t + p$ $\sigma(\text{parallel}) < 10^2$ b

$\sigma(\text{opposite}) \sim 10^4$ b

UCN loss rate ~

$1-\vec{p}_3 \bullet \vec{p}_n = 1-p_3 p_n \cos(\gamma_n-\gamma_3)B_0 t$

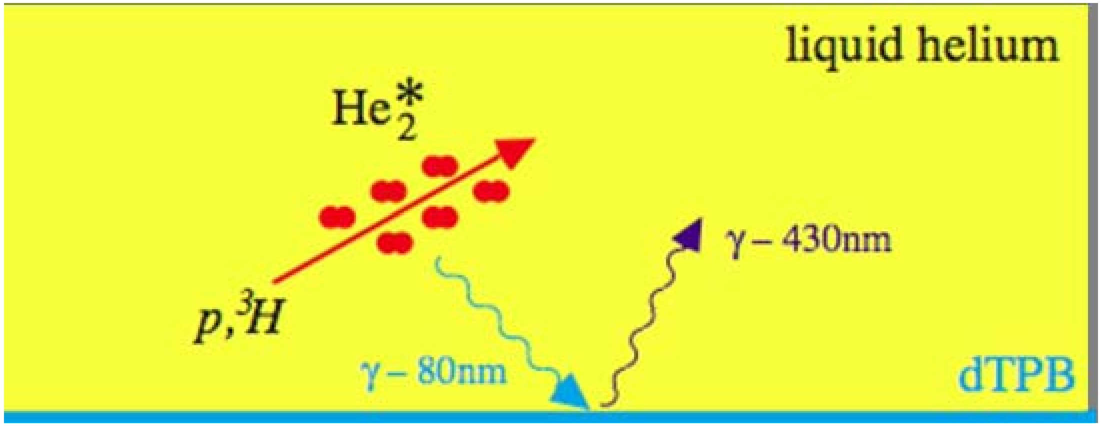
$|\gamma_n-\gamma_3| = |\gamma_n|/10$

^{3}He concentration must be adjusted to keep the lifetime τ reasonable for a given value of the ^{3}He polarization.

The proper value for the fractional concentration x = Atoms-^{3}He/Atoms-^{4}He ~ 10^{-10}.

^{4}He as a Detector

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



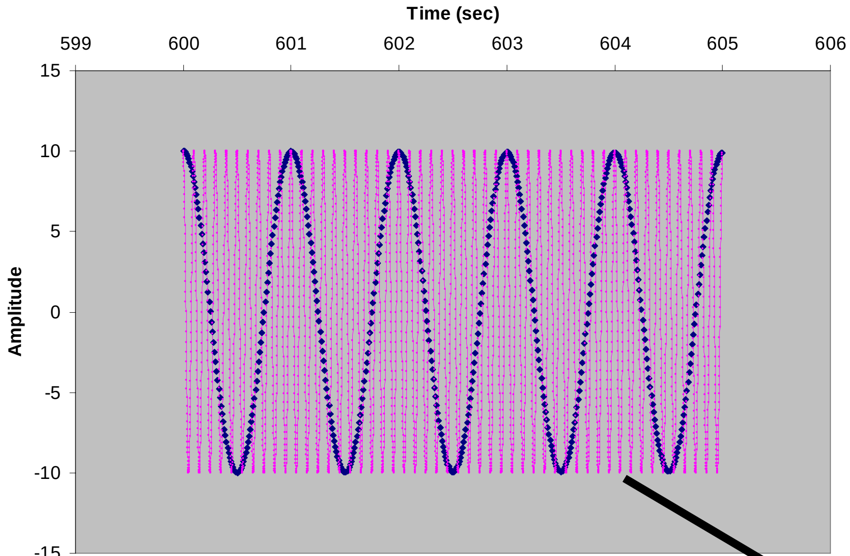
t + p share 764 keV of kinetic energy.

The emitted light (~3 photons/keV) is in the XUV ~ 80 nm.

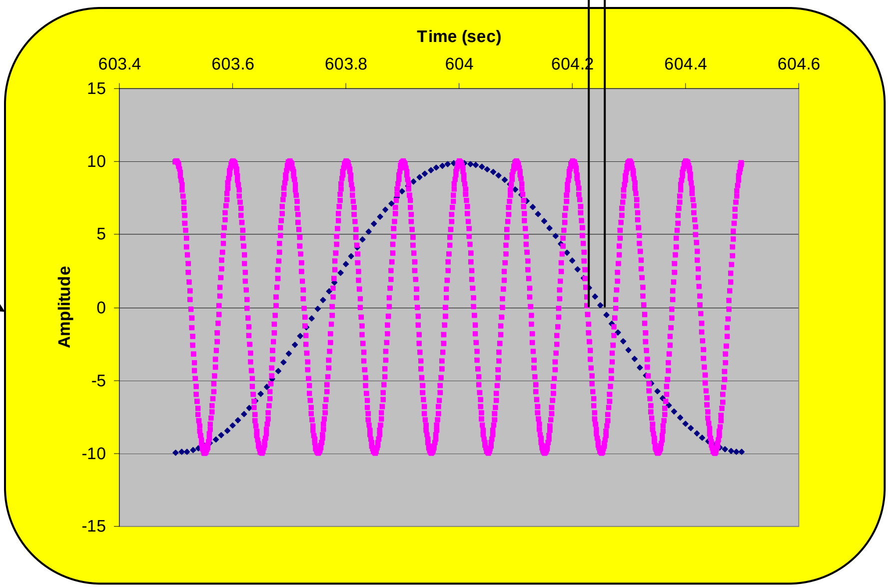
A wavelength shifter (TPB) is used to change it to the blue, where it can be reflected and detected.

The walls and the wavelength shifter must be made of materials that do not absorb or depolarize neutrons or 3He.

The Signal



~ d_nE



^{3}He(n,p)t Scintillation Light

$\nu \sim (\gamma_3 - \gamma_n)$

SQUID $\nu \sim \gamma_3$

Sensitivity

The Basic Equation

Light Response

$$\Phi(t) = \Phi_B(t) + Ne^{-\Gamma_{ave}t}\left[\frac{1}{\tau_\beta} + \frac{1}{\tau_3}\left[1 - P_n P_3 e^{-\Gamma_p t}\cos(2\pi f_\gamma t + \phi)\right]\right]$$

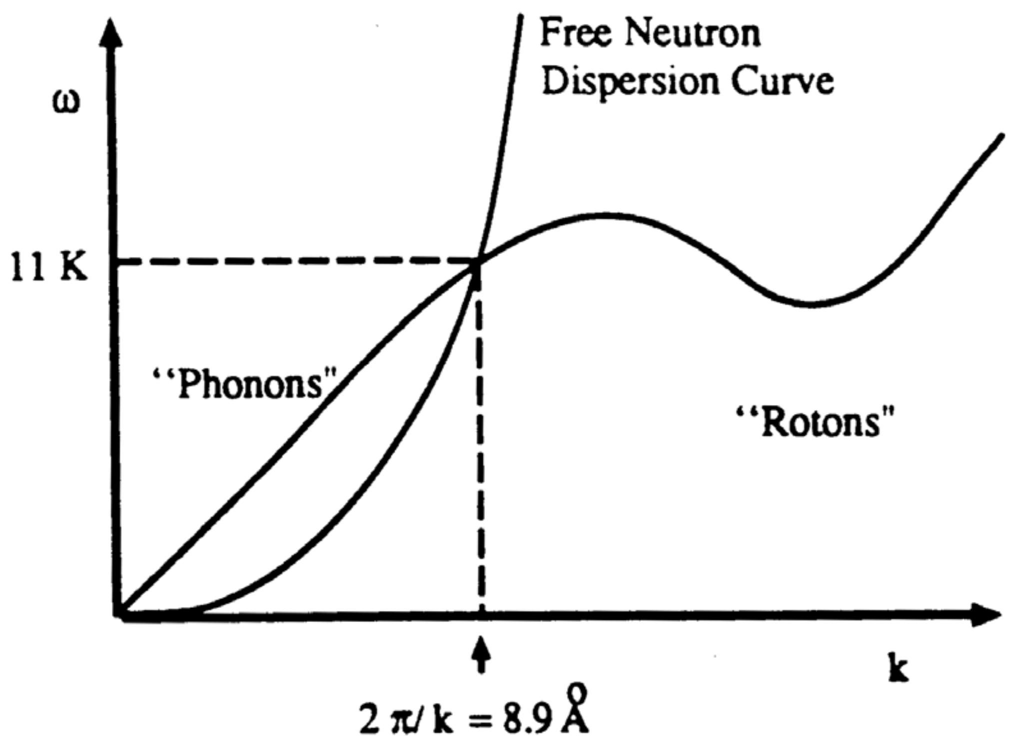
$$\Gamma_{ave} = \frac{1}{\tau_\beta} + \frac{1}{\tau_3} + \frac{1}{\tau_{cell}}$$

Determine f_γ and δf_γ

Change in f_γ with E measures the EDM

δf_γ determines the sensitivity

Superthermal Source of UCN

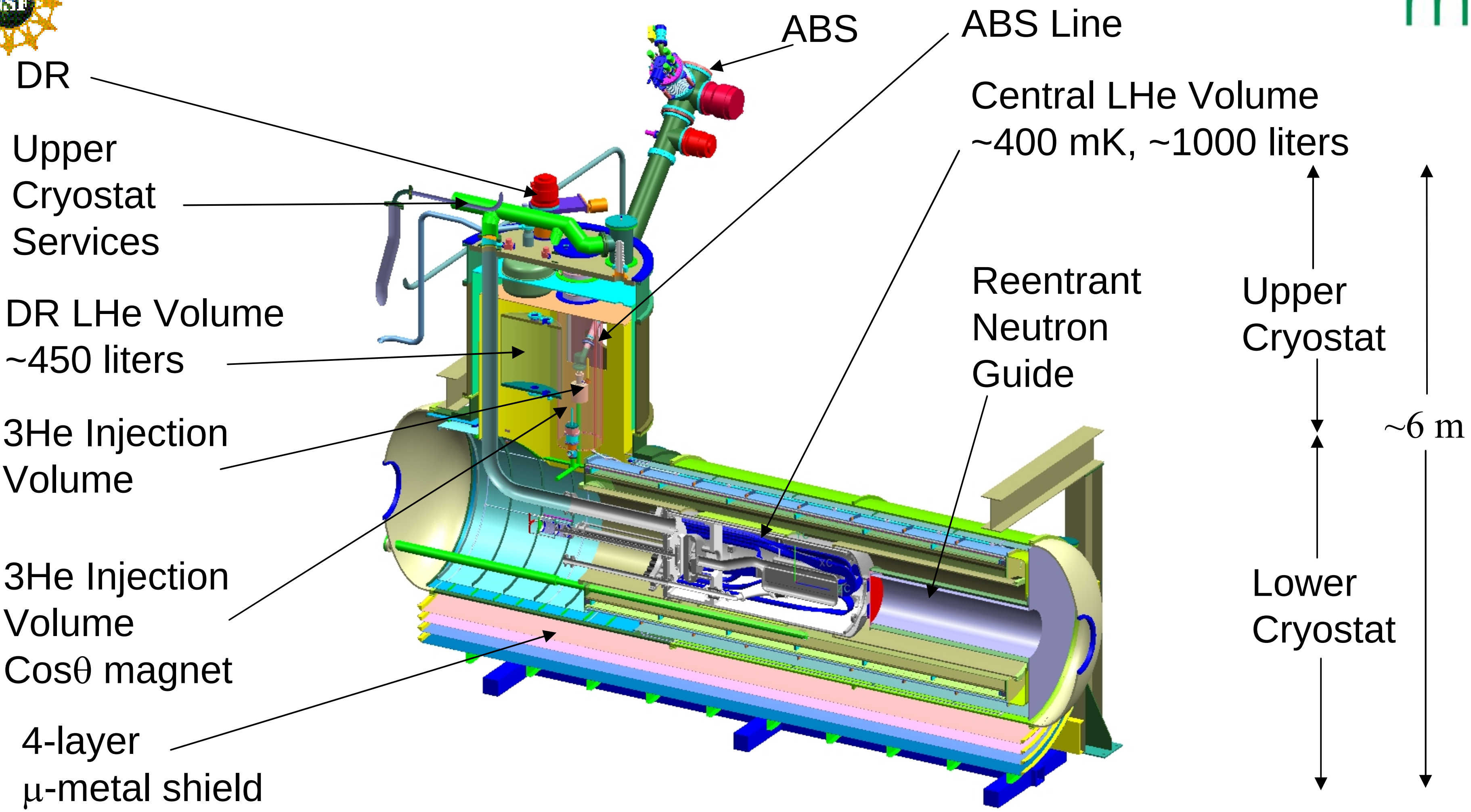


U_w = 200 neV
U_{LHe} = 20 neV

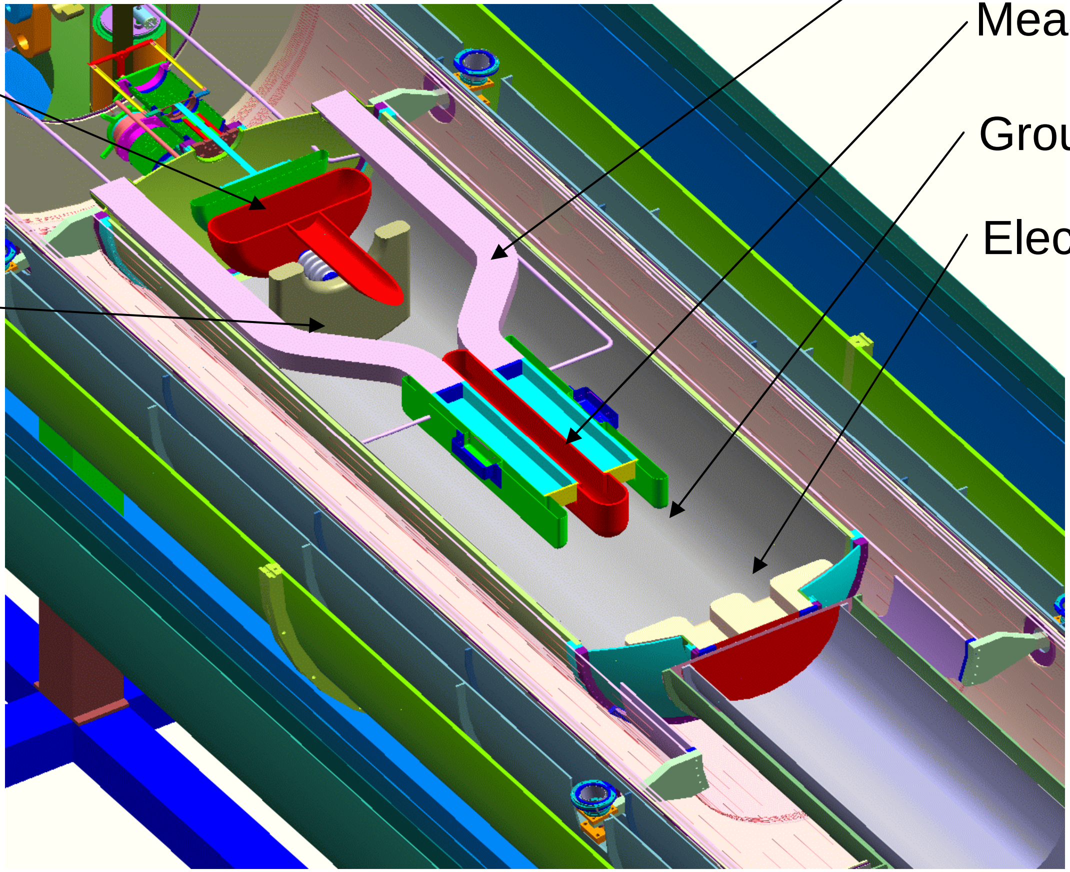
Quasi two-level system with single phonon upscattering suppressed by a large Boltzman factor.

$\tau_{up} \sim 100\ T^{-7}$ from 2-phonon upscattering

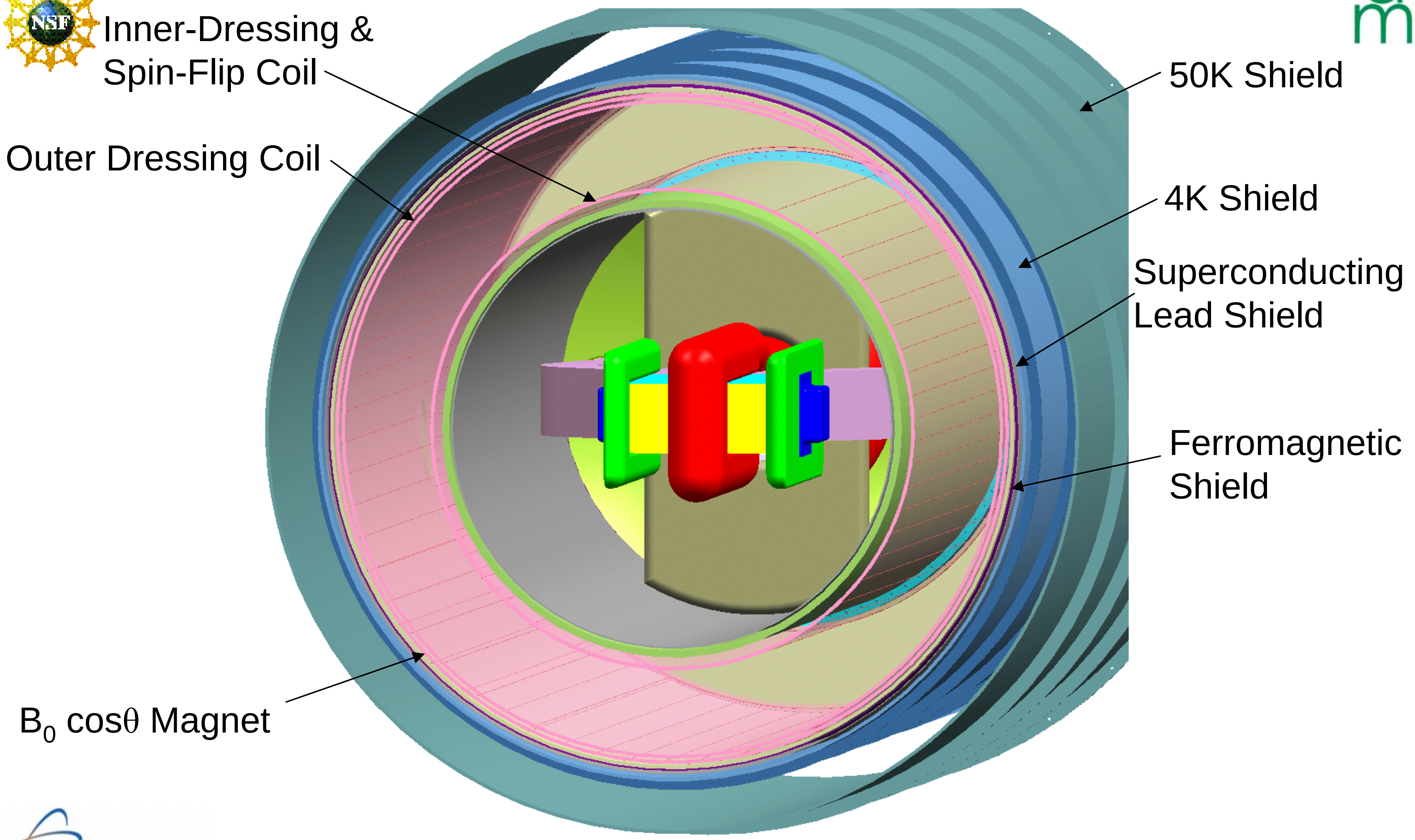
EDM Experiment - Vertical Section View



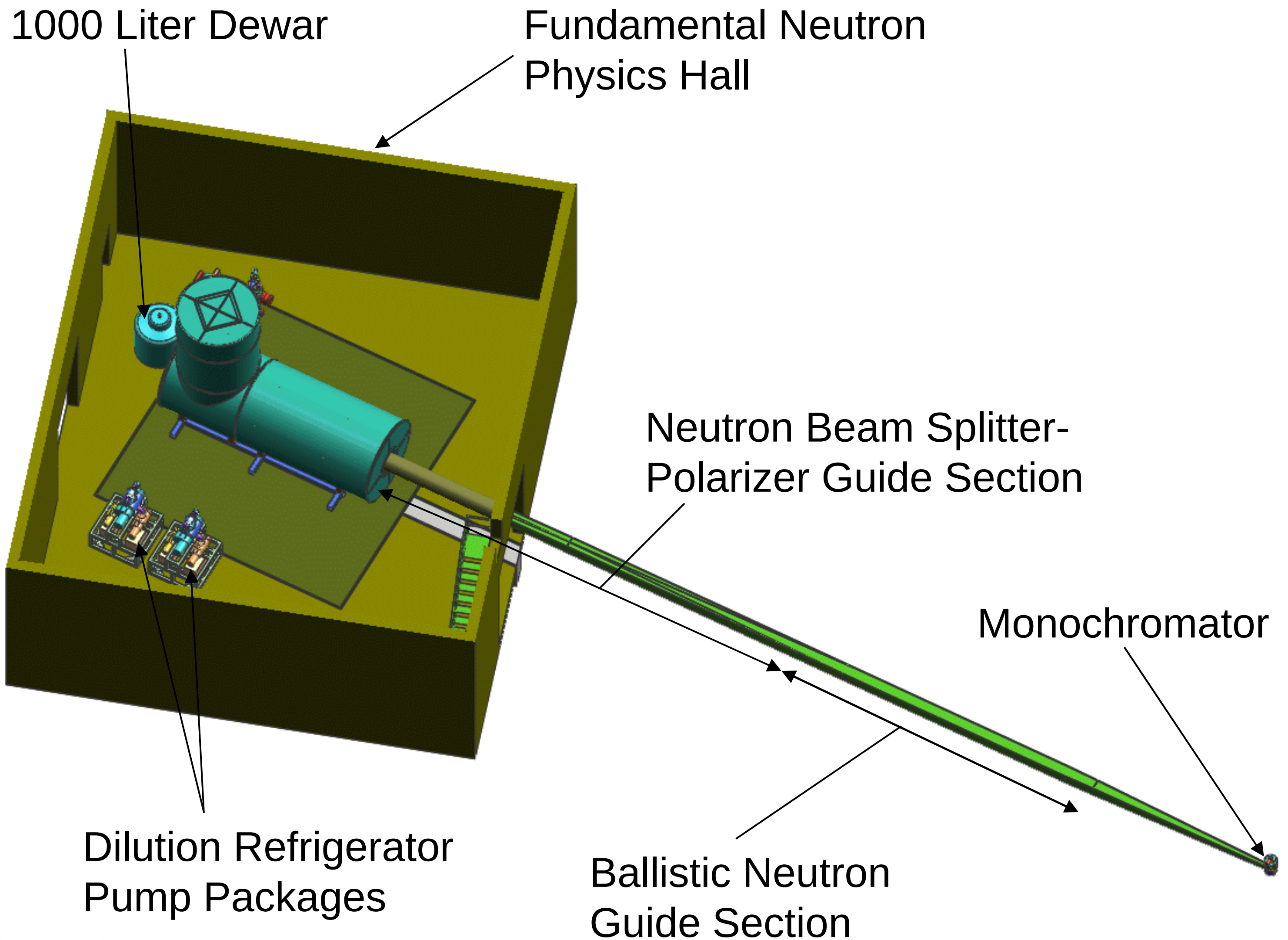
EDM Experiment - Horiz. Section View



Coil and Shield Nesting



Neutron Guide



Outline

- Introduction to nEDM
- Collaboration Foci

Collaboration Foci

- Technical Feasibility
- Preliminary Engineering
- Project Management

R&D Risks

Table 1. R&D Status Arranged by Risk on August 13, 2007

High Risk	
^{3}He relaxation time	First measurements made
Light collection	Test apparatus under construction – on schedule
Valve material	Vespel identified as a promising candidate
HV studies to 500 mK	Waiting on the dual-use cryostat
^{4}He evaporative purification	Test apparatus under construction – on schedule
^{3}He injection	Test apparatus under construction – on schedule but will be delayed by the dual-use cryostat
Medium Risk	
Scintillation in an electric field	To be done with the HV studies at 500 mK
Full valve test	Test apparatus under construction – on schedule
Geometric phase	A follow-on measurement to the ^{3}He relaxation
Magnetic uniformity	Uniformity improving with each iteration
Leakage currents on coated acrylic	Uncoated acrylic acceptable – Coated tests to be done with the HV studies at 500 mK
SQUID's observe ^{3}He S/N	S/N very close to what is needed
SQUID's & micro-discharges	Requires more work
Neutron storage time	Delayed by the UCN source
Low Risk	
PMT Operation at 4 K	Ordinary tubes show the expected behavior – coated photocathode measurements to commence
^{3}He tri-coil construction	Nearly ready to ship by industry
HV studies to 1.8 K	Work complete with improved results
Electrode material selection	Postponed as lower priority for 3 months
Laser induced fluorescence	Abandoned as not main stream
Slow controls	Postponed to 2008 as non-critical

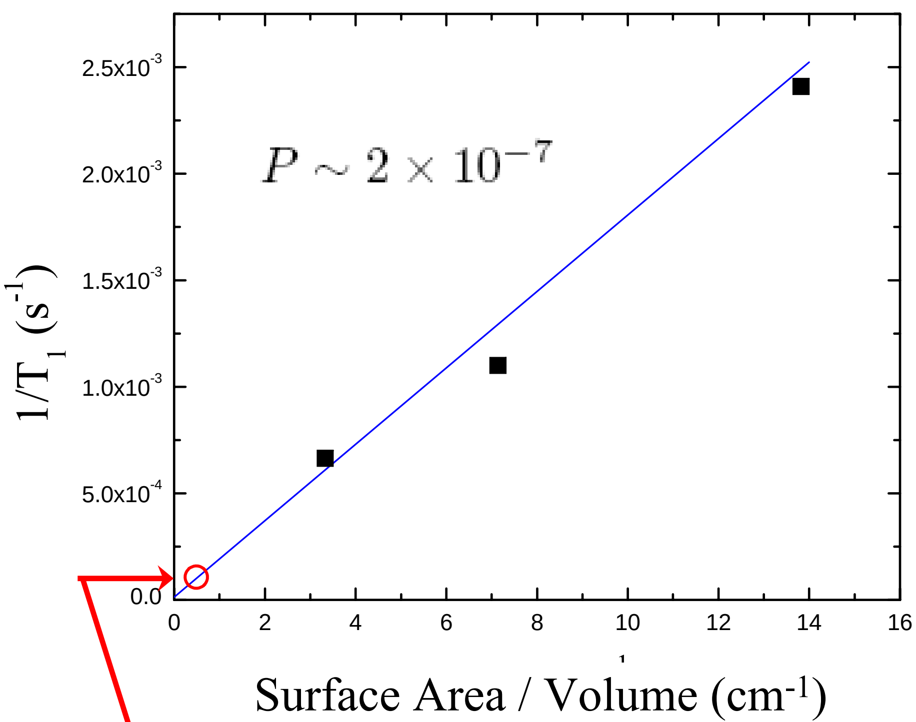
R&D Risks Updated

Table 2. R&D Status Arranged by Risk on July 18, 2008

High Risk	
HV studies to 500 mK	Waiting on the dual-use cryostat – New and very encouraging results in a small cryostat at 1.8 K
Medium Risk	
^{3}He Transport	Simulations – advanced state – experimental confirmation needed
Light collection	Propagation test successful, data under analysis
^{3}He injection	Test apparatus under construction with several capabilities demonstrated – on schedule but will be delayed by the dual-use cryostat
Scintillation in an electric field	To be done with the HV studies at 500 mK
Leakage currents on coated acrylic	Uncoated acrylic acceptable – Coated tests to be done with the HV studies at 500 mK
SQUID's & micro-discharges	Requires more work
Neutron storage time	300 s measured at 150 K - Work postponed
Low Risk	
Valve material	Vespel operates for 10,000 cycles – depolarization needs study
Full valve test	Under rebuild with Torlon but just engineering
Magnetic uniformity	Uniformity improving with each iteration
^{3}He relaxation time	First measurements complete - favorable result
^{4}He evaporative purification	Replaced by known McClintock method
Geometric phase	Analytic solution minimizes need for measurement
PMT Operation at 4 K	Ordinary tubes show the expected behavior – coated photocathode works well at 8 K
SQUID's observe ^{3}He S/N	S/N exceeds specifications by a factor of 5
Electrode material selection	Postponed as lower priority until after CD-2

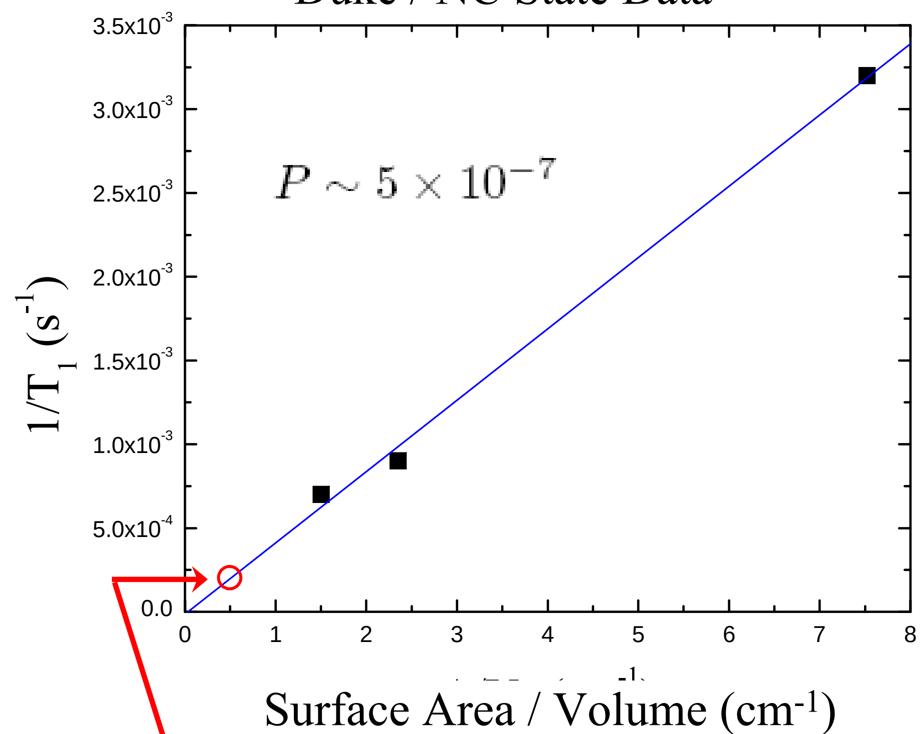
^{3}He-Spin Relaxation

Reanalyzed
UIUC Data



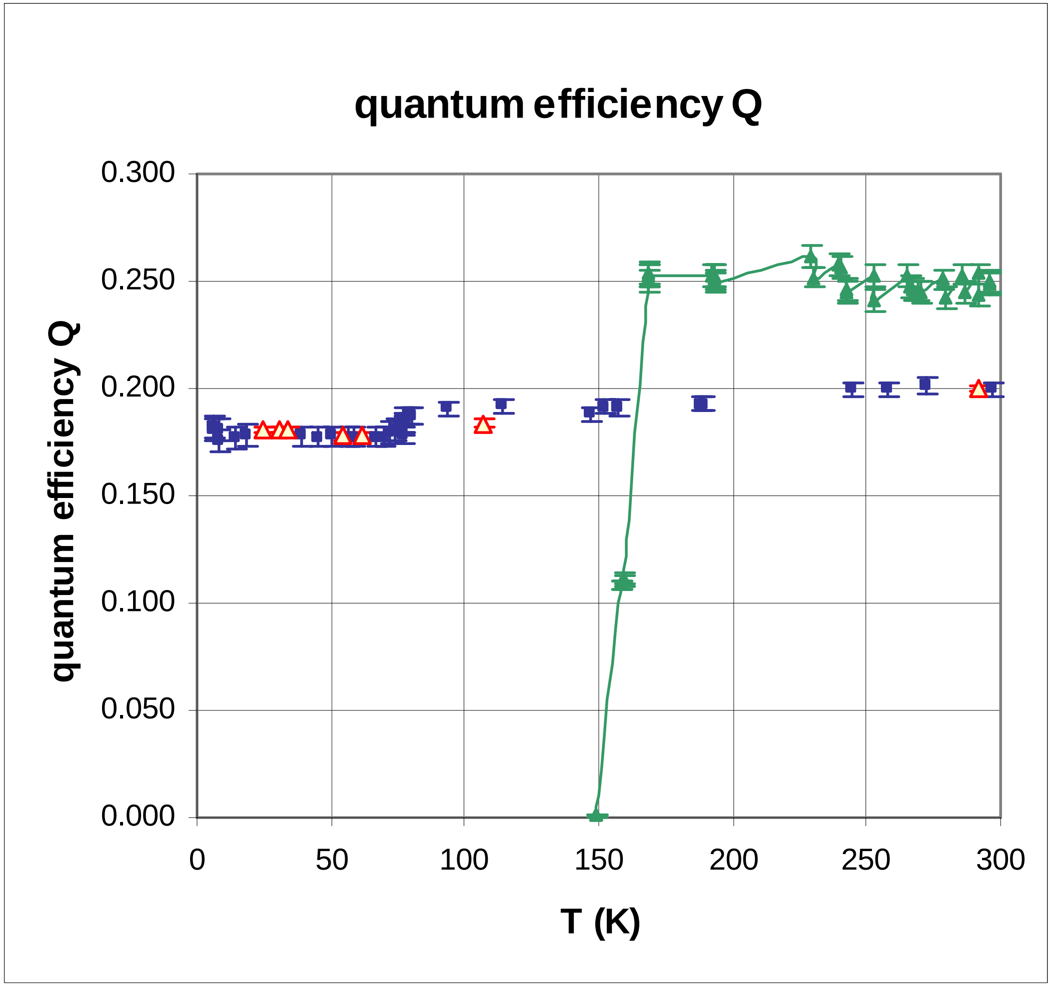
$$T_1^{nEDM} \sim 1.1 \times 10^4 \text{ s}$$

Reanalyzed
Duke / NC State Data



$$T_1^{nEDM} \sim 4.7 \times 10^3 \text{ s}$$

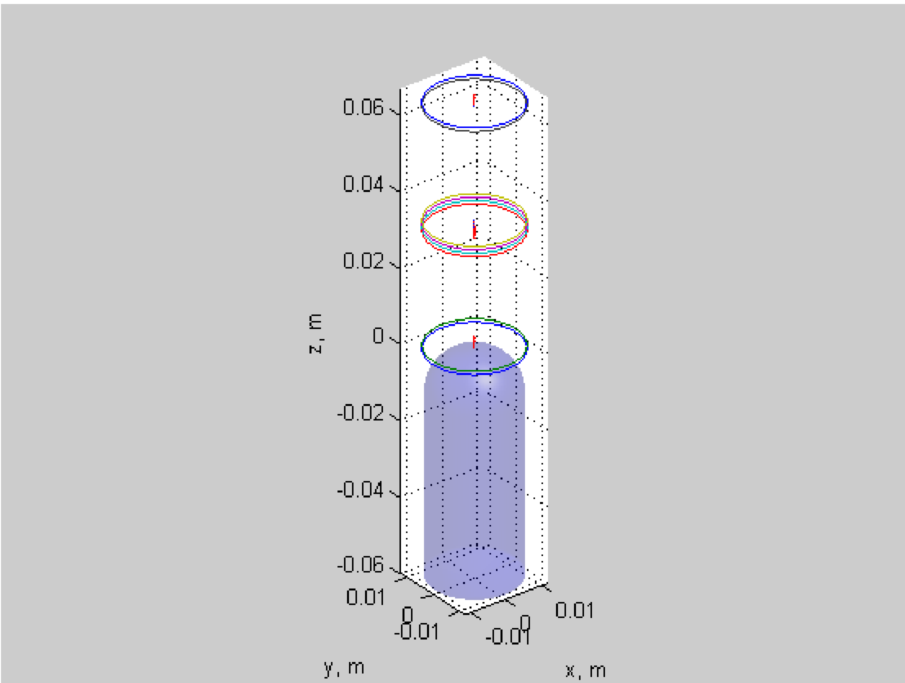
PMT at 8 K

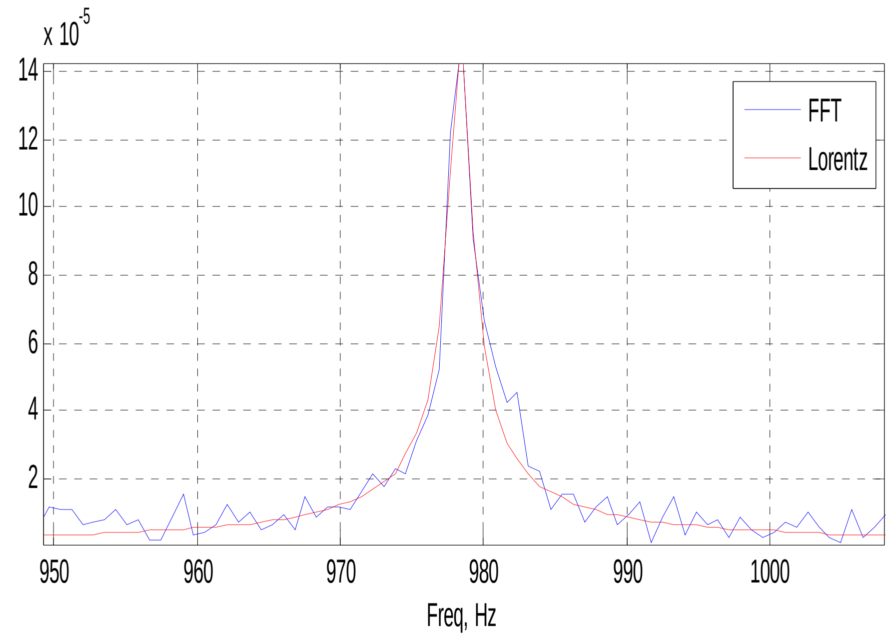


normal PM

Pt underlay

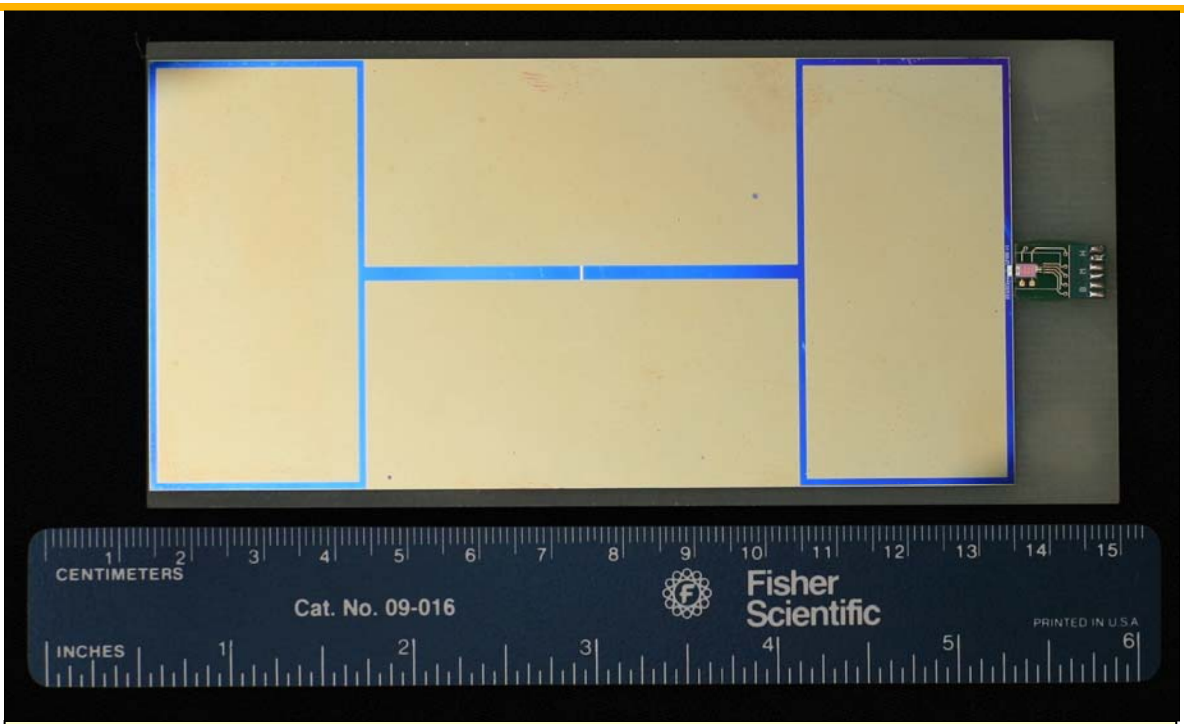
SQUID Signal-to-Noise





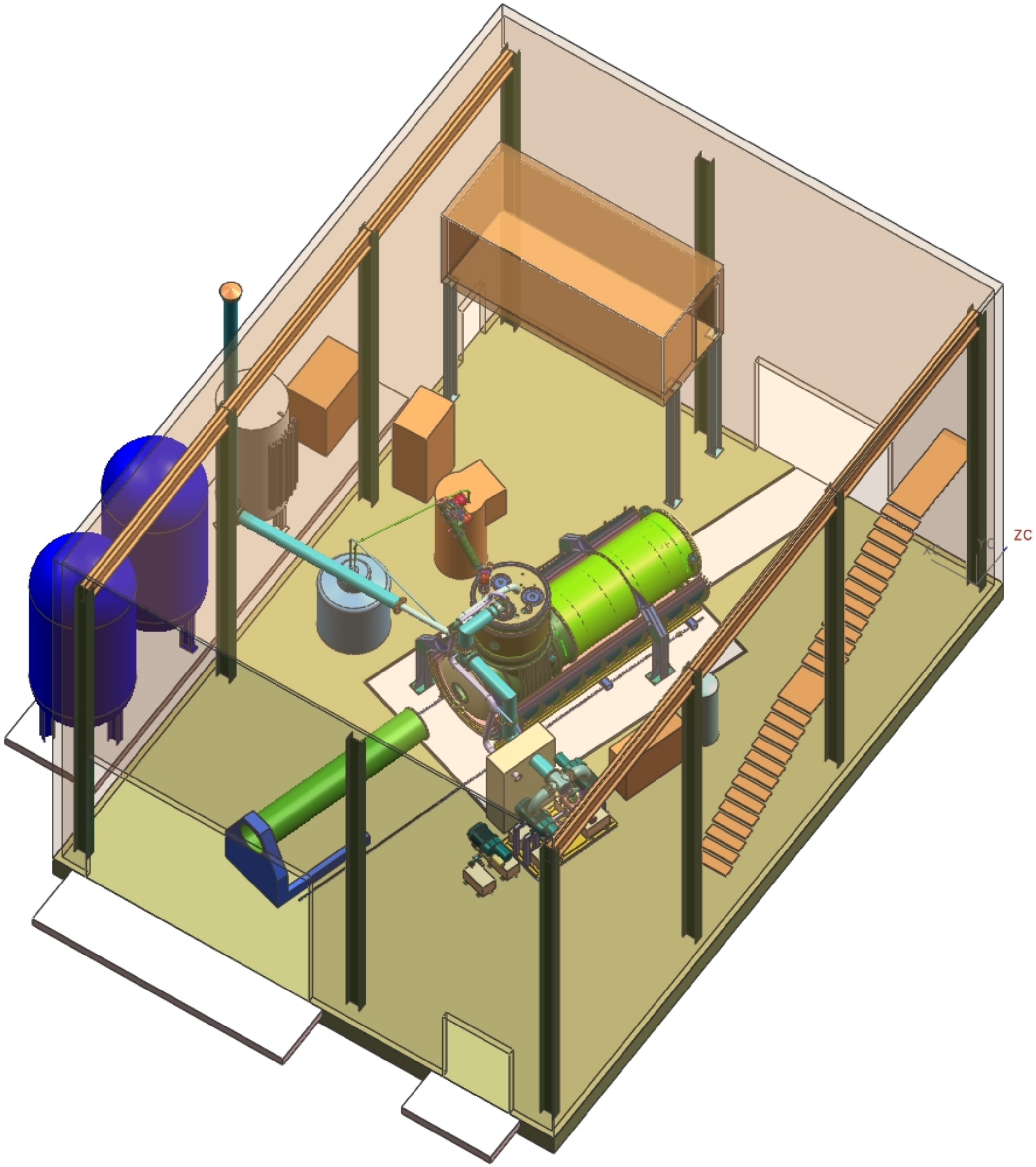
Requirement to match the statistical error from 3He(n,p)t = 26 μHz
Extrapolation to an 8 gradiometer system and 500 s = 1.2 μHz

SQUID Gradiometer

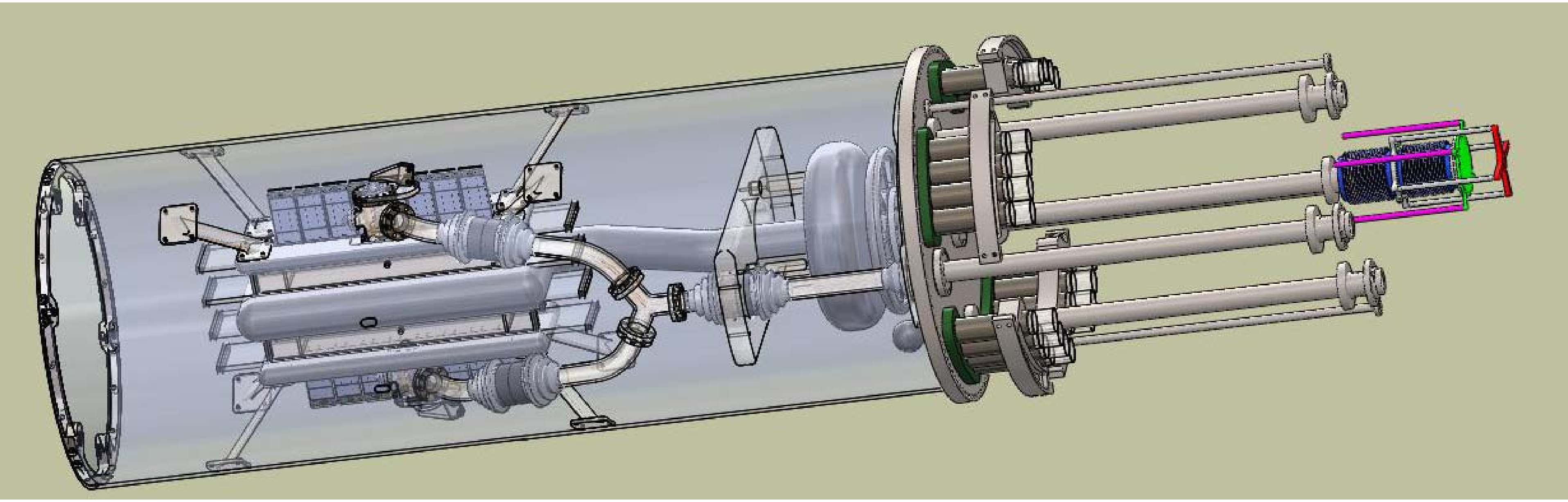


- Tested by LANL SQUID team
- Manufactured by SBIR Grantee, Robin Cantor of Star Electronics
- For common mode noise suppression like vibrations

Engineering the FnPB UCN Hall



Engineering the Central Detector



Funding

- Total DOE funding = $11,795k
- Total NSF funding = $7,450

Schedule

- Feb 2007 Conceptual Design Approved
- Feb 2009 Technical Feasibility, Preliminary Engineering, Cost and Schedule Baseline Approved
- Aug 2009 Construction Approved
- Jan 2010 Beneficial Occupancy of FnPB UCN Building
- Oct 2015 nEDM Project Completed
- 2018 First Published Results @ few $\times 10^{-27}$ e•cm
- 2020 nEDM Experiment Completed and Published @ few $\times 10^{-28}$ e•cm