LA-UR- 10-07050

Approved for public release; distribution is unlimited.

Title: The Search for a Neutron EDM at the SNS

Author(s): Takeyasu Ito

Intended for: PSI 2010 Workshop

Los Alamos
NATIONAL LABORATORY
EST. 1943

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Form 836 (7/06)

Search for a neutron EDM at SNS

Takeyasu Ito
Los Alamos National Laboratory
for the nEDM collaboration

The nEDM Collaboration is developing an experiment to run at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory to search for the neutron electric dipole moment (EDM) with a sensitivity of $< 10^{-27}$ e cm based on the scheme proposed by Golub and Lamoreaux. The collaboration has been working on a various R&D experiments to establish the technical feasibility of the experiment and to guide the design of the apparatus. The collaboration has also been working towards finalizing the engineering of the experimental apparatus. In this talk, the principle of the experiment and the status of the project will be presented.

The Search for a Neutron EDM at the SNS

Takeyasu Ito
Los Alamos National Laboratory

for the nEDM Collaboration

PSI2010 Workshop
October 14, 2010
Paul Scherrer Institut

Outline

- Overview of the experimental approach
- Design of the experiment
  - Engineering design
- Status of the experiment
  - Technical developments
  - Projected sensitivity
  - Schedule

The nEDM Collaboration

R. Alarcon, S. Balascuta, L. Baron-Palos

Arizona State University

G. Seidel

Brown University, Providence

A. Kolarkar, E. Hazen, V. Logashenko, J. Miller, L. Roberts

Boston University

D. Budker, A. Park

University of California at Berkeley

J. Boissevain, R. Carr, B. Filippone, M. Mendenhall,

A. Perez Galvan, R. Schmid

California Institute of Technology

M. Ahmed, M. Busch, P. Cao, H. Gao, X. Qian, G. Swift, Q. Ye, W.Z. Zheng

Duke University

L. Bartoszek, D. Beck, P. Chu, C. Daurer, J.-C. Peng, S. Williamson, J. Yoder

University of Illinois Urbana-Champaign

C.-Y. Liu, J. Long, H.-O. Meyer, M. Snow

Indiana University

C. Crawford, T. Gorringe, W. Korsch, E. Martin, S. Malkowski, B. Plaster, H. Yan

University of Kentucky

S. Clayton, M. Cooper, M. Espy, C. Griffith, R. Hennings-Yeoman, T. Ito, M. Makela, A. Matlachov, E. Olivas, J. Ramsey, S. Ramahan, I. Savukov, W. Sondheim, J. Torgerson, P. Volegov

Los Alamos National Laboratory

E. Beise, H. Breuer

University of Maryland

K. Dow, D. Hasell, E. Ihloff, J. Kelsey, R. Milner, R. Redwine, J. Seele, E. Tsentalovich, C. Vidal

Massachusetts Institute of Technology

D. Dutta, E. Leggett,

Mississippi State University

R. Golub, C. Gould, D. Haase, A. Hawari, P. Huffman, D. Kendellen, E. Korobkina, C. Swank, A. Young

North Carolina State University

R. Allen, V. Cianciolo, P. Mueller, S., Penttila, W. Yao,

Oak Ridge National Laboratory

M. Hayden

Simon-Fraser University

G. Greene, N. Fomlin

The University of Tennessee

S. Stanislaus

Valparaiso University

S. Baeβler

The University of Virginia

S. Lamoreaux, D. McKinsey, A. Sushkov

Yale University

nEDM Experiment Overview

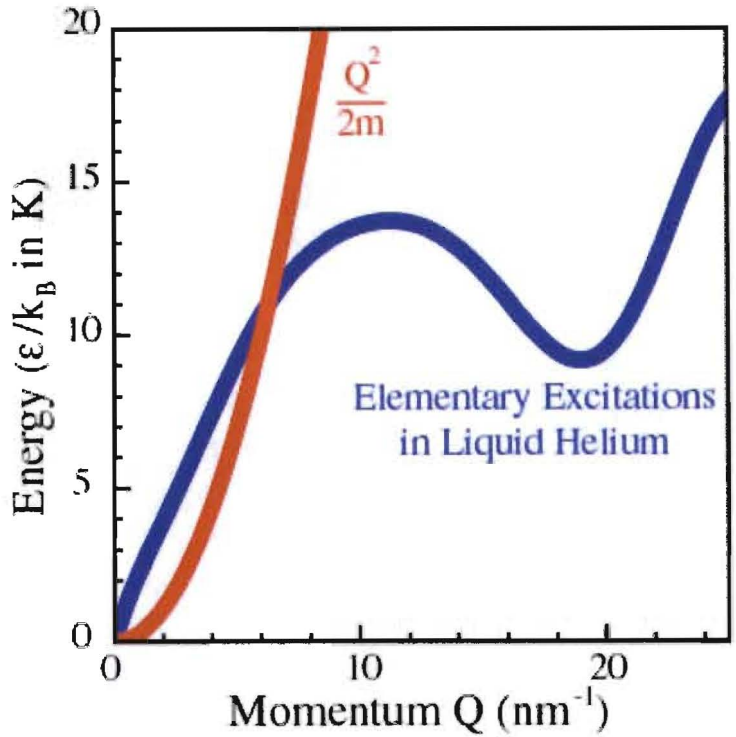
Experimental Concept:
Golub& Lamoreaux, PHYSICS REPORTS 237,1,1994

- In situ production of UCN from 8.9 A cold neutron beam via superthermal process
- ^{3}He comagnetometer
- Use ^{3}He as spin analyzer for the neutron
- Two complementary approaches to the measurement
  - Free precession method
    - Use SQUID magnetometer to measure the ^{3}He precession frequency
  - Dressed spin method
    - Apply RF to tune the effective gyromagnetic ratio of the neutron and ^{3}He
- Projected sensitivity: $d_n < 8 \times 10^{-28}$ e cm (90% CL)

nEDM Experimental Approach
UCN Production

R.Golub and J.M.Pendlebury, Phys.Lett.A **62**,337,(77)

- 8.9 Å cold neutrons get down-scattered in superfluid ^{4}He by exciting elementary excitation
- Up-scattering process is suppressed by a large Boltzman factor
- No nuclear absorption



- Expect a production of ~ 0.3 UCN/cc/s
- With a 500 second lifetime, ρ_{UCN}~150/cc and N_{UCN}~1.2x10^6 for an 8 liter volume

nEDM Experimental Approach

3He as comagnetomer and spin analzer

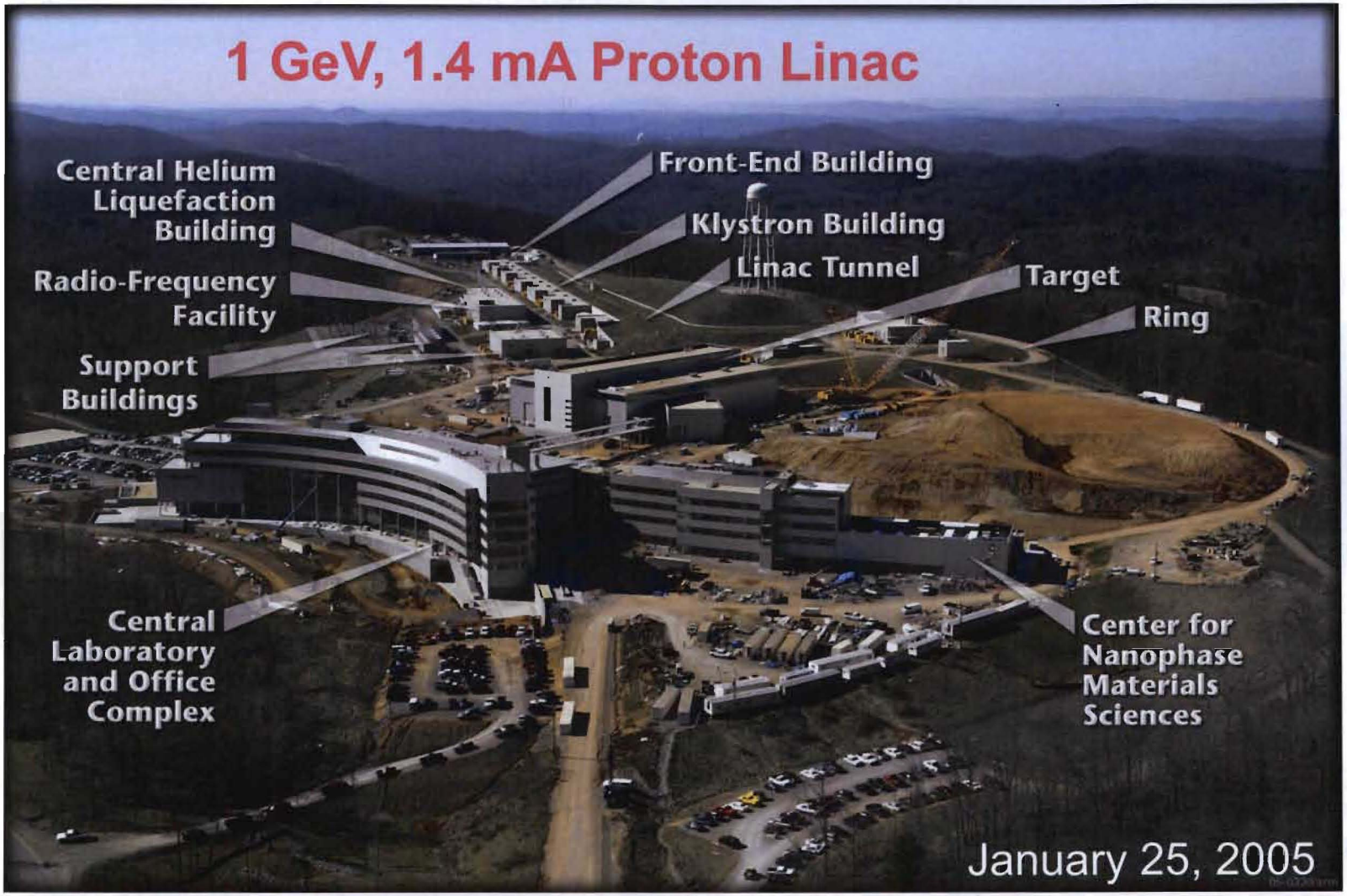
- ^{3}He gyromagnetic ratio larger than neutron's by ~ 10%
- Neutron absorption on ^{3}He highly spin dependent
- Rate of neutron loss due to absorption on ^{3}He

$$\propto 1 - \left| p_3 p_n \cos\left[(\omega_3 - \omega_n) t \right] \right|$$

- Reaction product of n+^{3}He→p+t generates UV (~80 nm) scintillation light in SF ^{4}He

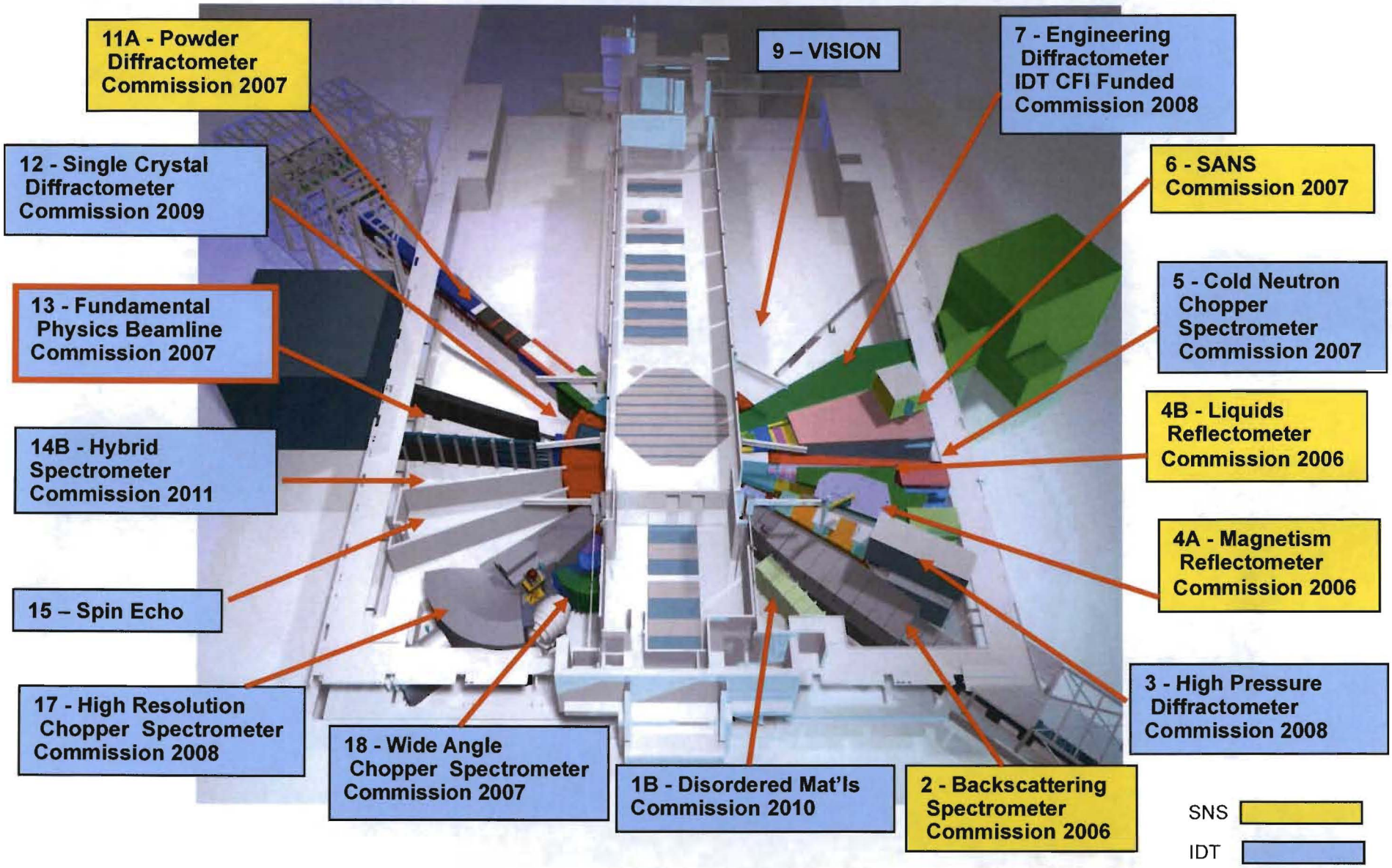
Spin dependent neutron-^{3}He absorption reaction provides a measurement of the difference of the neutron precession frequency and the ^{3}He precession frequency

Spallation Neutron Source (SNS) at ORNL

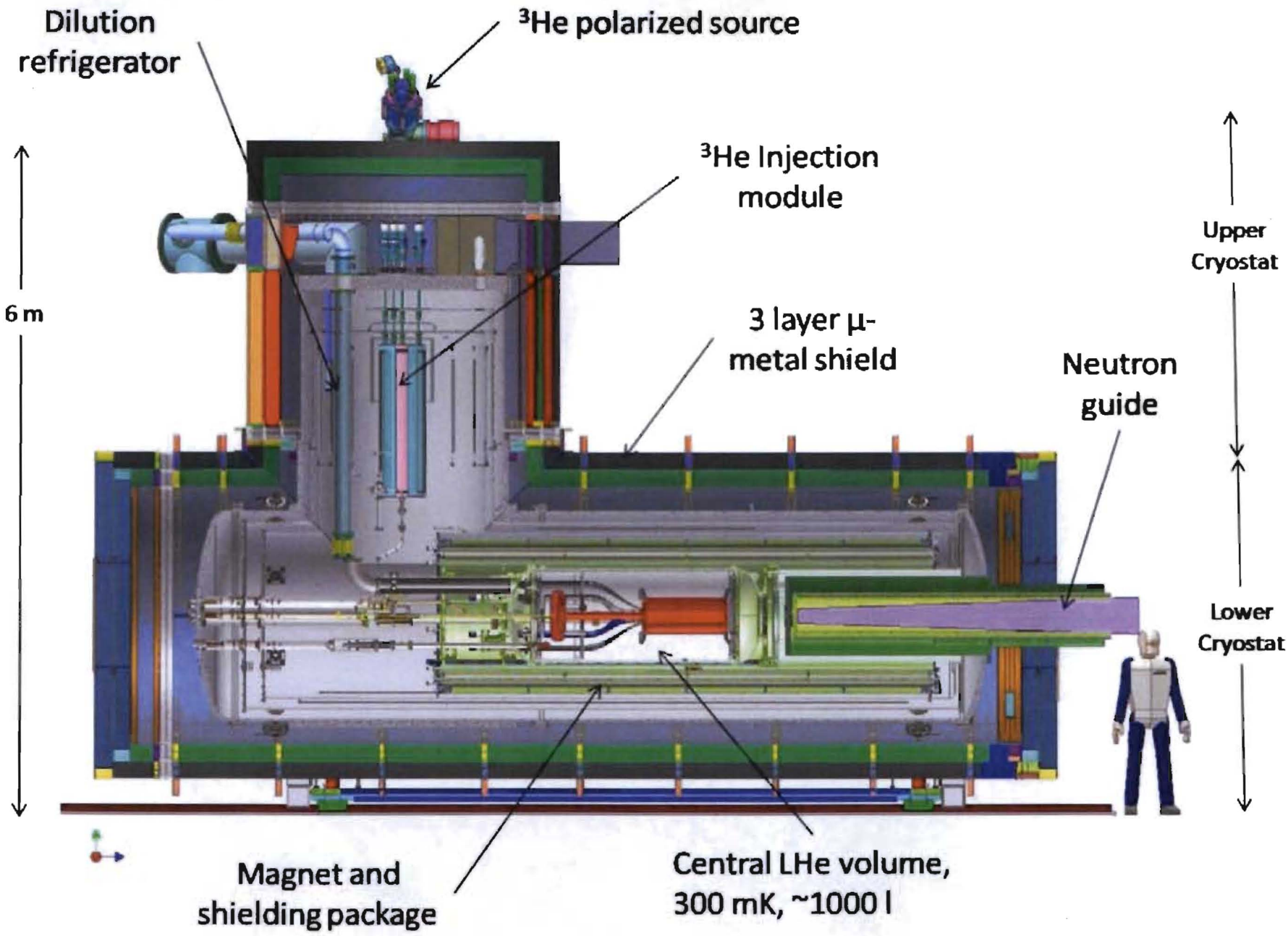


- SNS construction completed: 2006
- SNS Total Project Cost: 1.411B$

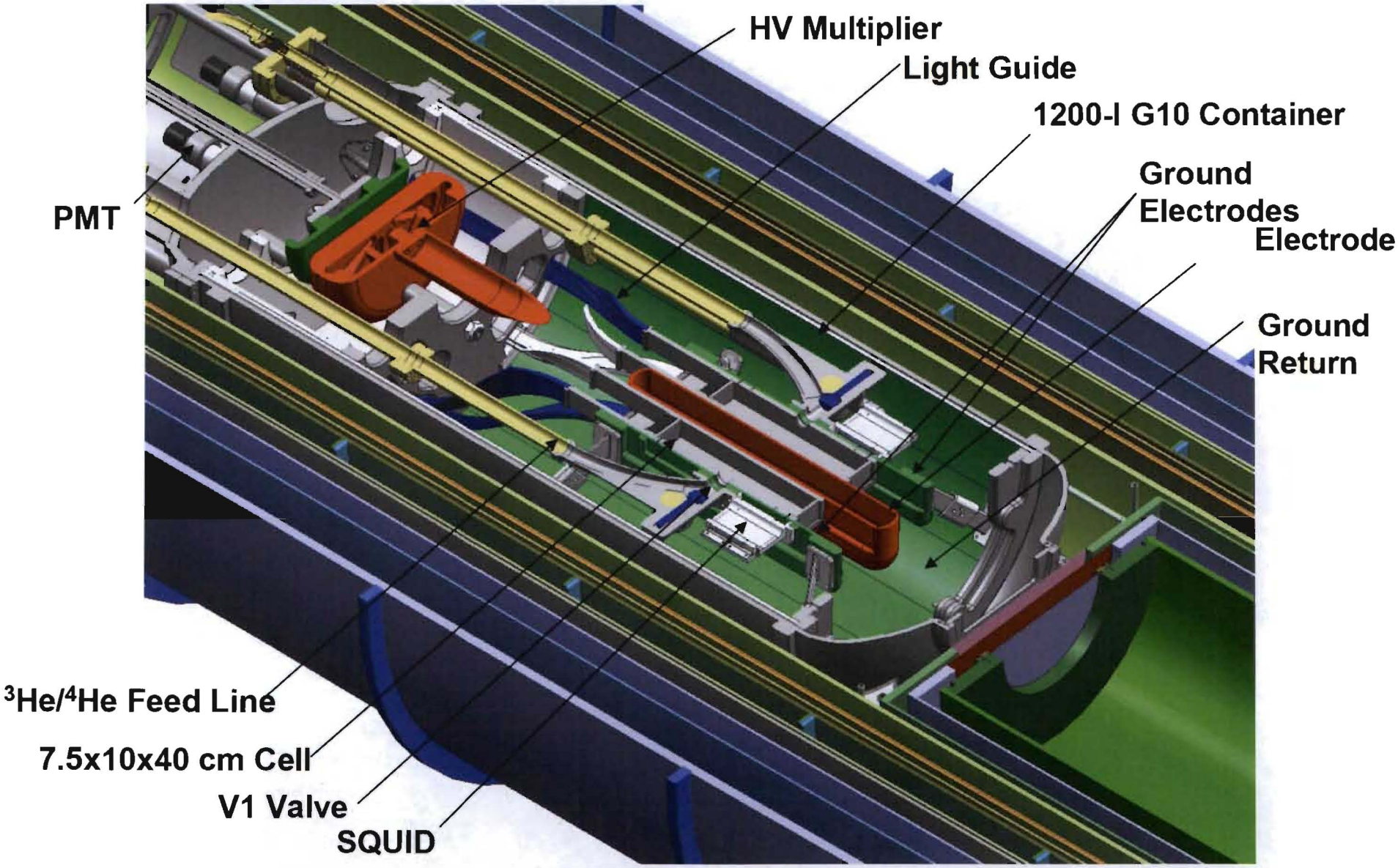
SNS Target Hall



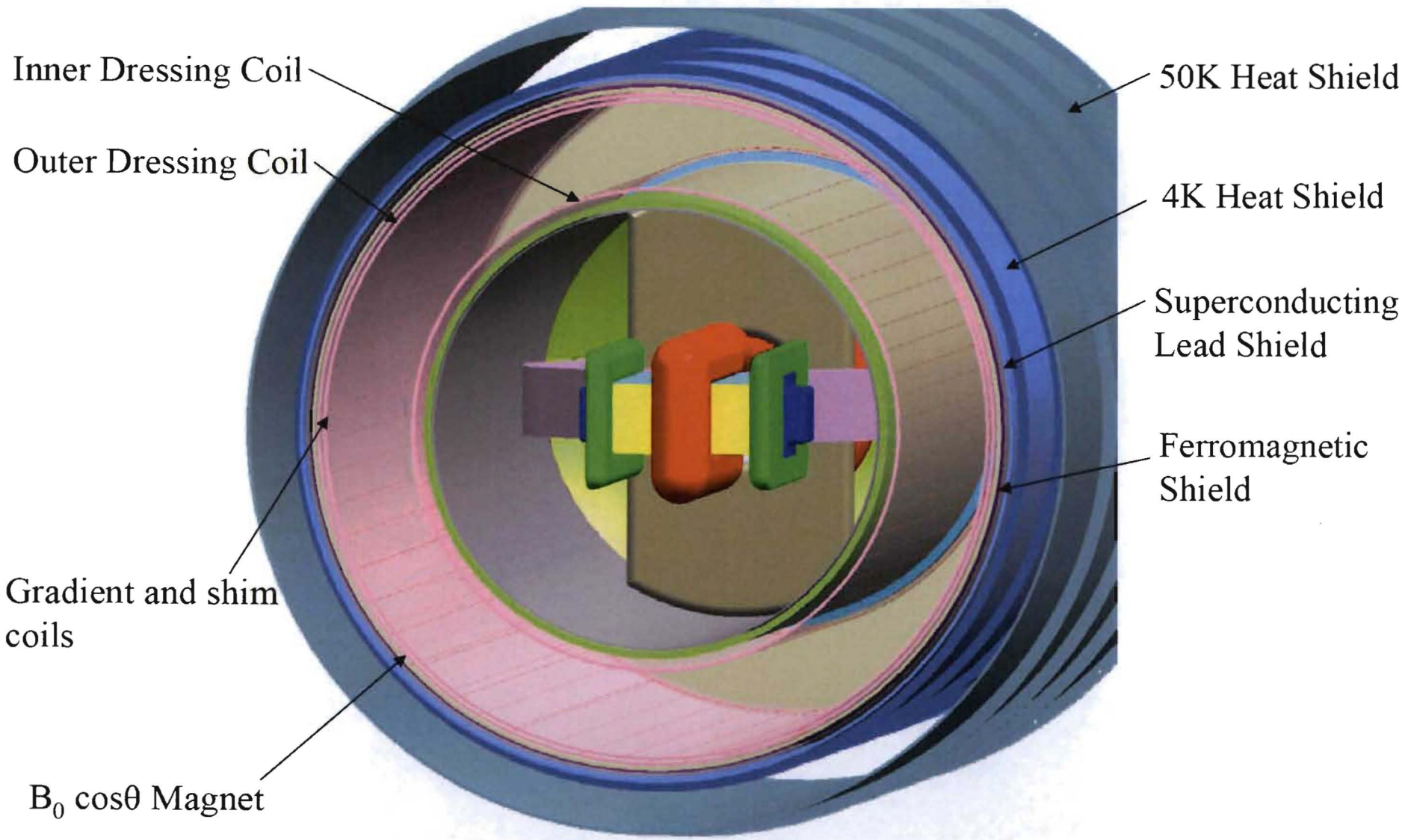
EDM Experiment Schematic



Central Detector System



Magnet System



Technical challenges

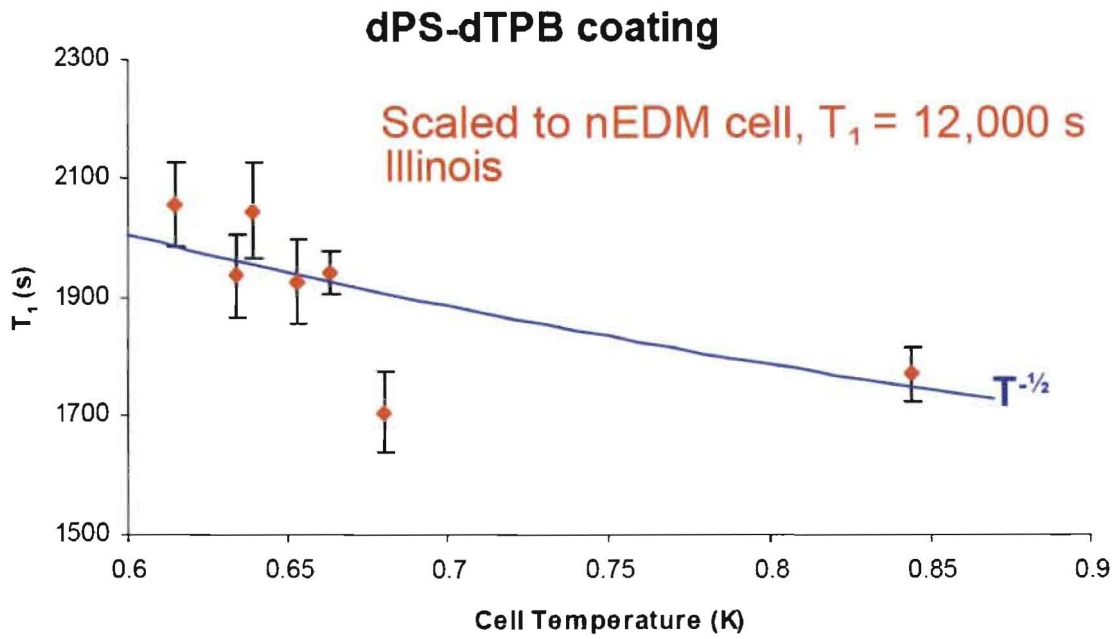
- Progress towards development of an experiment
  - Central detector module @ 0.3 –0.45K
  - Magnet module @ 4K
  - Dressing field RF induces eddy currents in conductors (big headache at 0.4K)
  - Superconductors distort B-fields
  - SQUIDs can be killed by HV sparks
  - Materials of cell and 3He transport must maintain neutron & 3He polarization

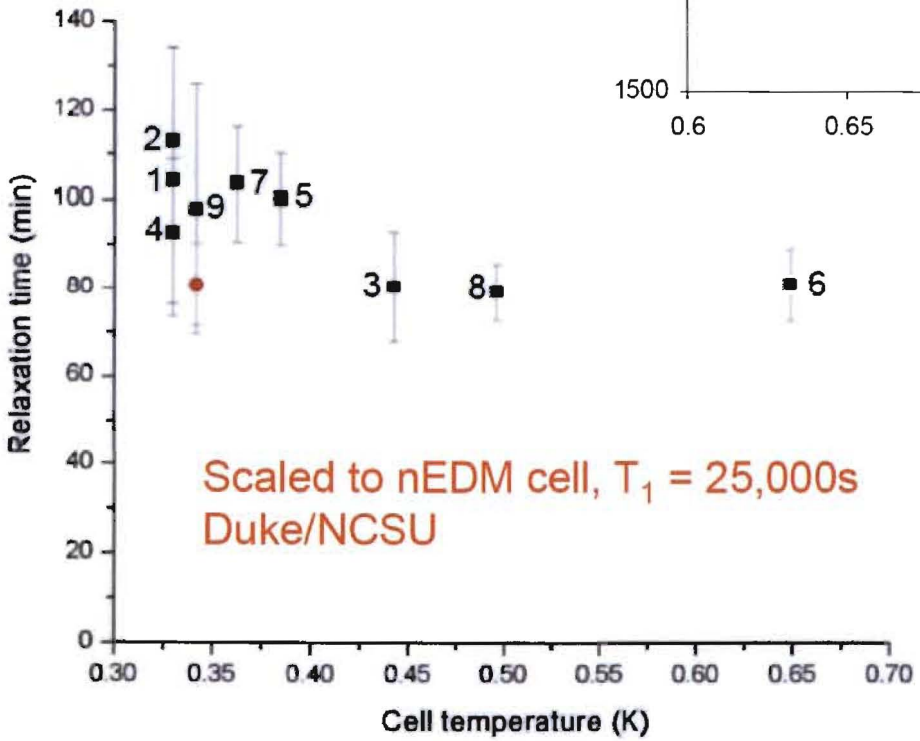
Technical Developments

- Polarized 3He Atomic Beam Source tested
- Relaxation time of 3He on deuteratedpolystyrene walls (doped withdTPB) measured
- Progress towards HV tests at low temperature
- SuperfluidHe valves tested
- Magnetic field uniformity measured
- HV dependence of scintillation light production measured

Polarized ^{3}He wall relaxation

Need T_1 > 10,000s



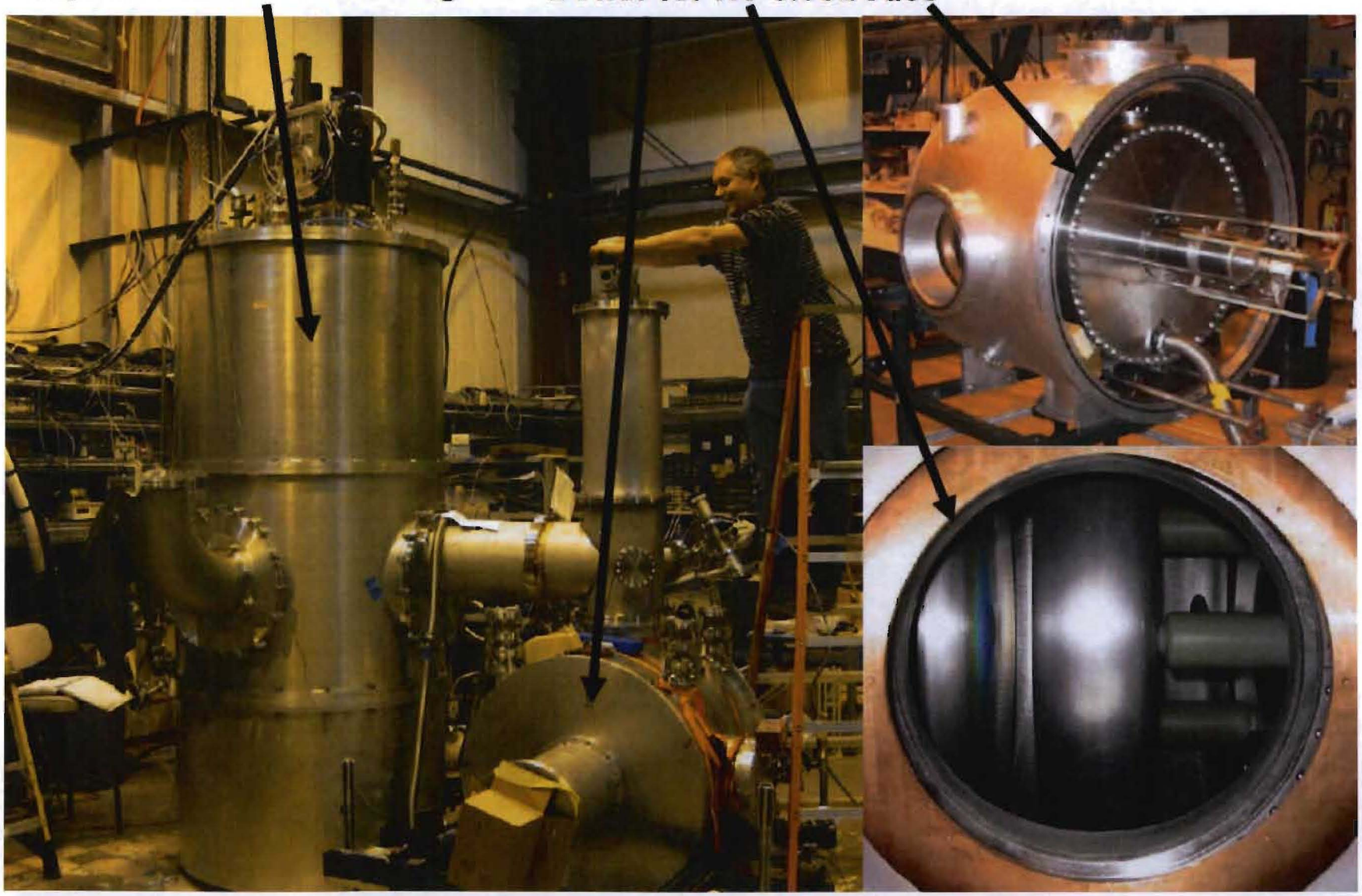


Cryogenic non-metalic superfluild valves

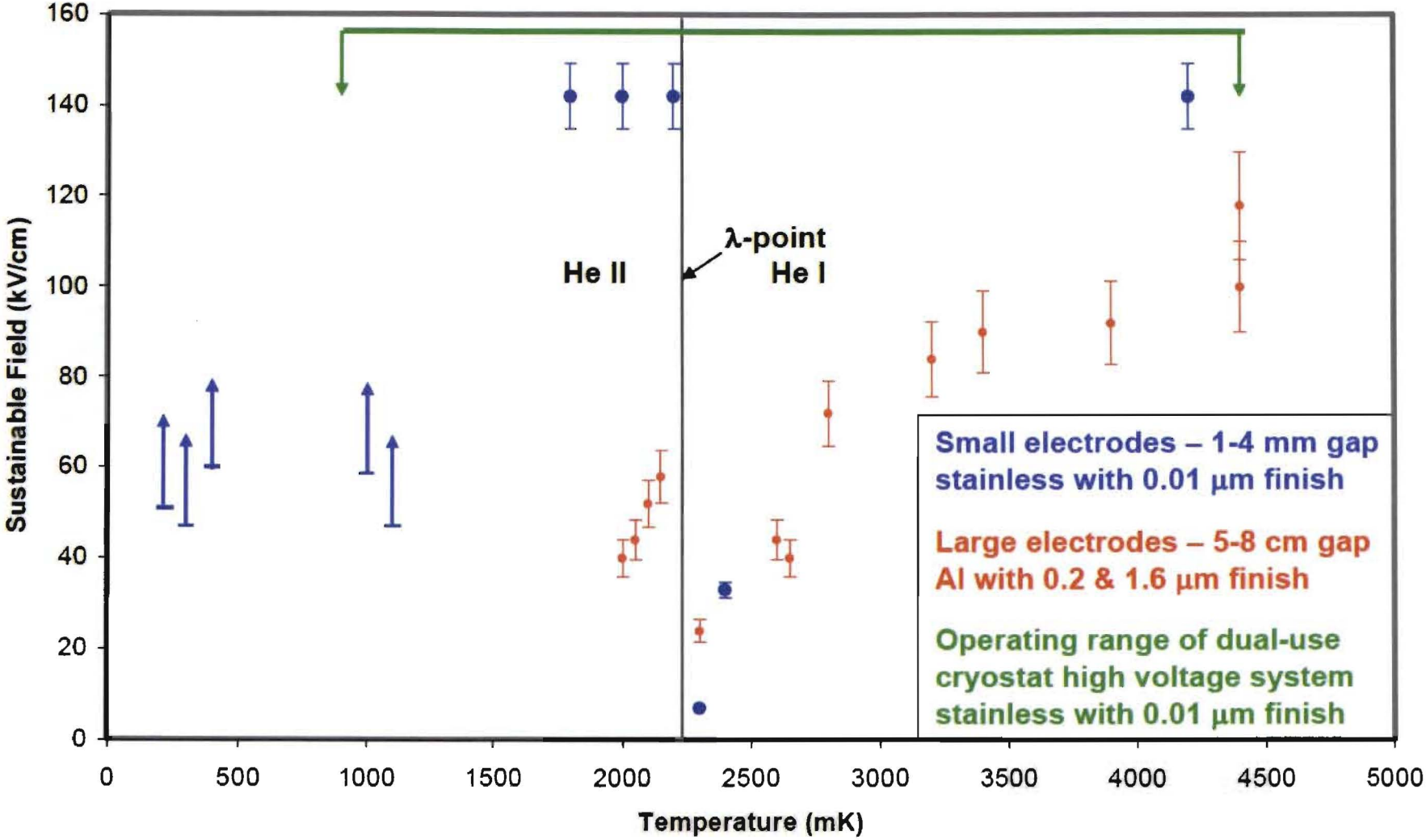
thermoplastics

- Valve body made from Torlon
- Valve boot & seal made from Vespel
- Tested for 10,000 cycles sealing superfluid He at 1.7K

HV test stand

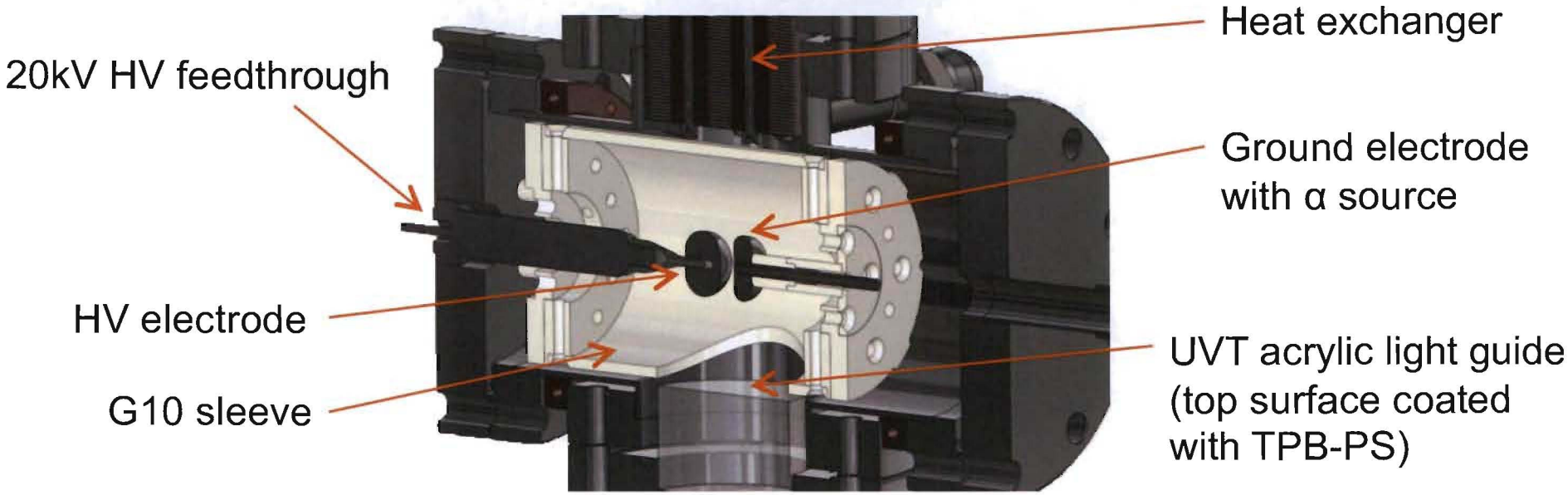


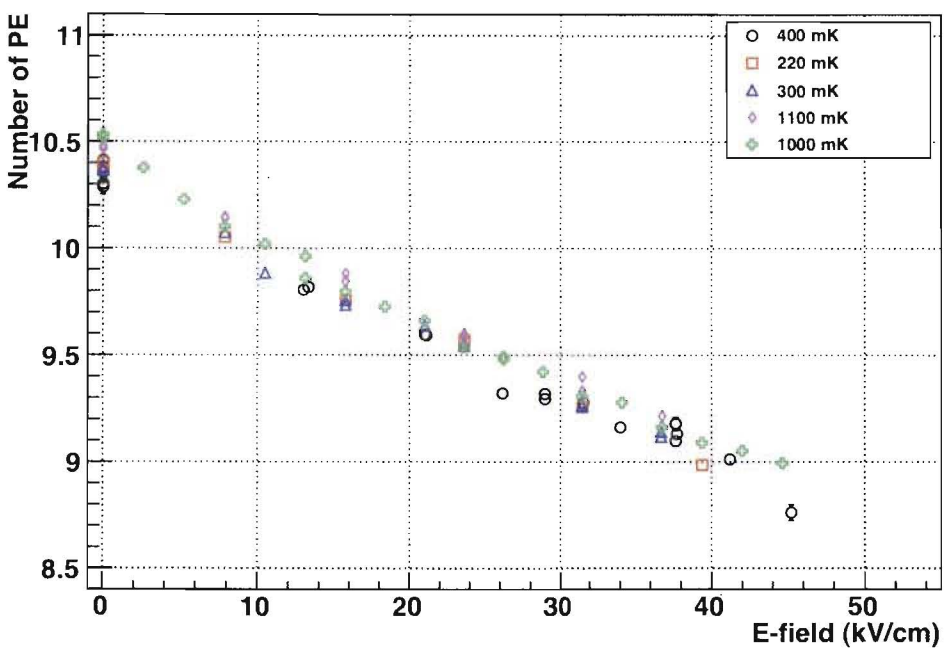
Status of HV tests



To Do List: Confirm small scale studies (~1cm electrodes with ~ few mm gap) with large electrodes and large gaps

Liquid helium scintillation in an electric field[8]





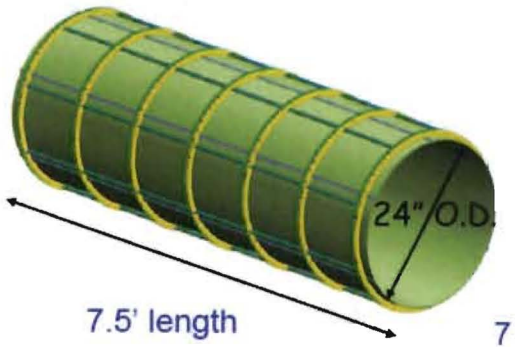
- Liquid helium scintillation intensity was measured using an α source as a function of the electric field strength up to ~ 45 kV/cm for temperatures between 0.2-1.1 K.
- Scintillation intensity reduces by ~ 15% at 50 kV/cm.

Magnet development

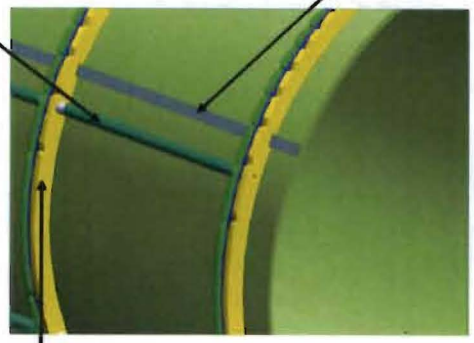
Nylon/G10 spacers match thermal contraction of Nb/Ti-Cu wire

Rings slide in slots on acrylic tube

acrylic tube

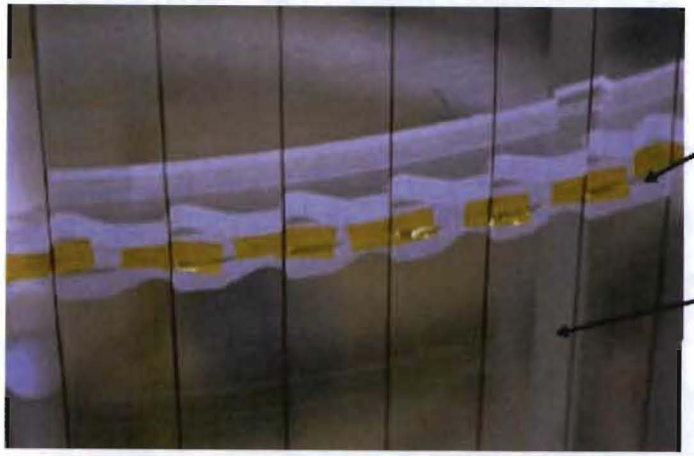


7.5' length



7 × 3-ring-sets of wire locators

defines wire radius

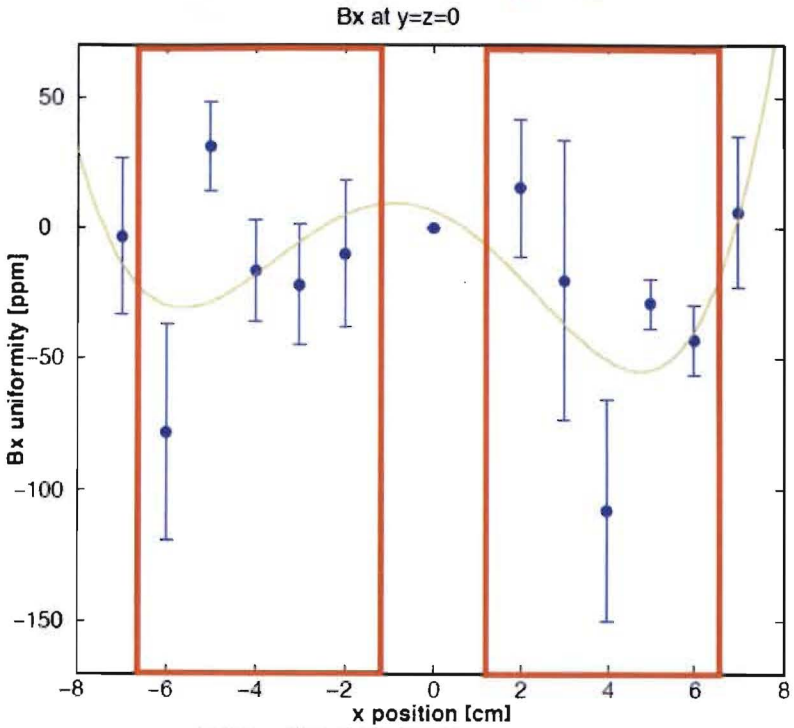


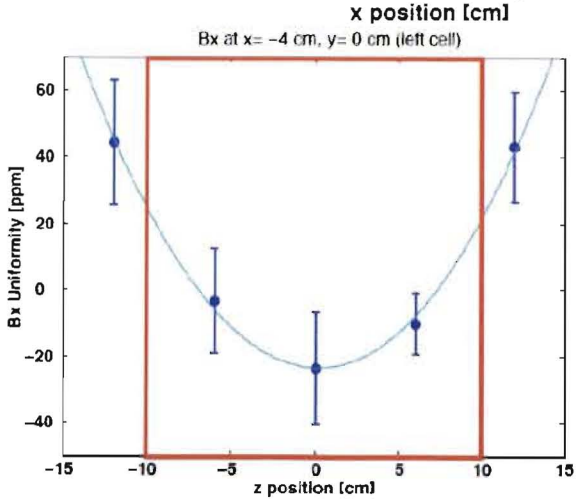
3-ring set

Nylon/G10 spacer stand-off rods

Spring-loaded wire tensioners

Measured gradientes extrapolated to the nEDM geometry





	Volume averaged gradients Measured at 0.9 gauss	
Scaled gradients	(Left cell)	(Right cell)
$dB_x/dx)/B_0$	< 5 ppm/cm	< 9 ppm/cm
$dB_y/dy)/B_0$	< 5 ppm/cm	< 5 ppm/cm
$dB_z/dz)/B_0$	-6 ± 1 ppm/cm	6 ± 1 ppm/cm

- **Gives false EDM due to geometric phase < 2 x 10^{-28} e-cm**
- **Need to match these values at 4K and low B-field and with full scale magnet**

Projected sensitivity

- Statistical sensitivity limited by neutron density in storage cells
  - Given by 8.9 A neutron flux
- Free precession measured by scintillation light from neutron capture on ^{3}He
- Back ground in the scintillation signal (neutron β decay etc) also contributes to worsening the statistical sensitivity
- Optimizing measurement cycle (T_{fill}, T_{meas}, ρ_{He3}) gives a shot noise limit of

$$\delta d_n < 8 \times 10^{-28} e \cdot \mathrm{cm}\ (90\%\ \mathrm{C.L.})$$

  in 300 live days
- Similar sensitivity in the dressed spin method

Systematic uncertainties

Systematic errors include

- Additional noise beyond counting statistics that reduce the sensitivity
  - e.g. uncompensated B-field fluctuation
- False EDM signals (effects that mimic the EDM signal)
  - E-field correlated effects –e.g. leakage currents
    - Measure and reduce artificial correlations (e.g. EDM that changes sign with direction of B, use of 2 cell
  - Physics issues –geometric phase
    - Careful design of apparatus

Systematic effects (projected)

Source	Systematic error (e cm)	Comments
Linear vxE (geometric phase effect)	$< 2 \times 10^{-28}$	Uniformity of B_0
Quadratic vxE	$< 0.5 \times 10^{-28}$	E-field reversal to 1%
Pseudomagnetic field effects	$< 1 \times 10^{-28}$	$\pi/2$ pulse, comparing two cells
Gravitational offsets	$< 0.1 \times 10^{-28}$	With 1 nA leakage currents
Leakage currents	$< 1 \times 10^{-28}$	< 1 nA
Miscellaneous	$< 1 \times 10^{-28}$	

Geometric phase effect

- Significantly different effects for neutron vs ^{3}He
  - Neutron has $\omega_0 >> \omega_T$ (ω_T is cell traversal frequency) and is largely independent of cell geometry
    - Can use previous analysis of geometric phase
      Pendlebury et al Phys Rev A 032102 (2004)
  - ^{3}He has $\omega_0 << \omega_T$ and is sensitive to cell geometry
    - Depends on diffusion time to walls (geometry & temperature)
    - False EDM in rectangular geometry:
      Golub,Swank & Lamoreaux arXiv:0810.5378
- Effect depends on Magnetic Field gradients

B_0 along x-direction

$$d_f = \frac{J\hbar}{E}\Delta\omega = \frac{J\hbar\gamma^2 L_z^2}{2c^2}\left[\left\langle\frac{\partial B_z}{dz}\right\rangle_V \psi_z(\omega_0) + \left\langle\frac{\partial B_y}{dy}\right\rangle_V \left(\frac{L_y^2}{L_z^2}\right)\psi_y(\omega_0)\right]$$

$\psi_z(\omega_0)$ is related to the velocity autocorrelation function

Schedule

- Critical Decision 2 (CD2): xxx/2011
  - Cost and schedule baselined
- CD3: xxx/2011
  - Final engineering design and drawings completed
- Start construction 2011-2012
- Start cryogenic testing: 2013
- Install subsystems into the experiment: 2014-2016
- Start commissioning: 2017

More than just the sensitivity….

- The "known" systematic effects are part of the experimental design
- Tackling the unknown effects requires unique handles in the experiment that can be varied
- The significance of a non-zero result requires multiple approaches to unforeseen systematics
- nEDM@ SNS is unique in its use of a polarized 3He co-magnetometer, characterization of geometric phase effects via temperature variation, as well as the dressed-spin capability

Comparison with other neutron EDM experiments

	CryoEDM1	CryoEDM2	PSIEDM1	PSIEDM2	SNSEDM
$\Delta\omega$ via accumulated phase in n polarization	Y	Y	Y	Y	N
$\Delta\omega$ via light oscillation in ^{3}He capture	N	N	N	N	Y
Co-magnetometer	N	N	Y	Y/N	Y
Superconducting B-shield	Y	Y	N	N	Y
Dressed spin technique	N	N	N	N	Y
Horizontal B field	Y	Y	N	N	Y
Multiple EDM cells	N	Y	N	Y	Y

Summary

- Neutron EDM experiment at SNS is underway.
- An experiment at the SNS can incorporate powerful and novel techniques to provide significant scientific reach in the search for a neutron EDM