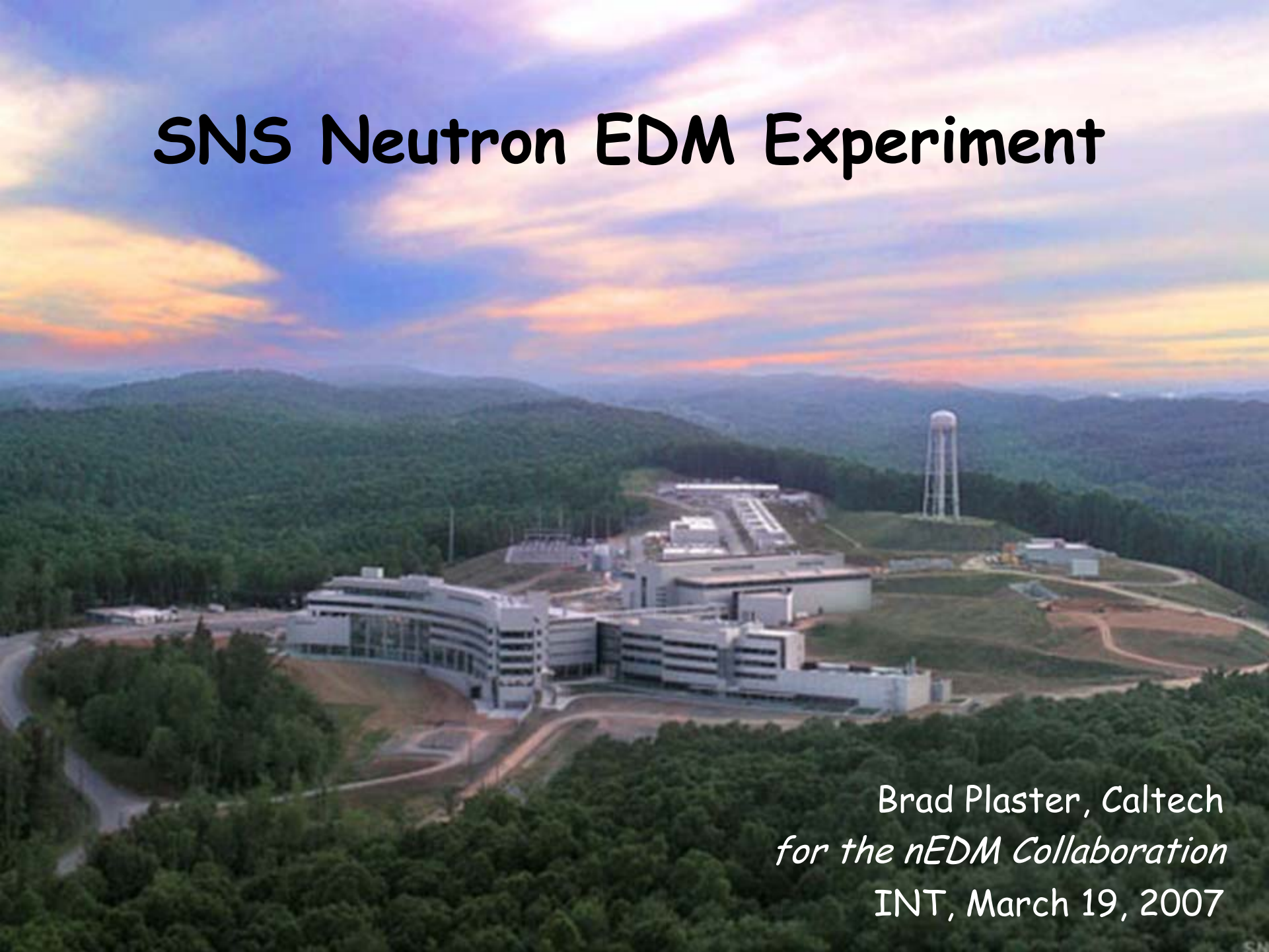


# SNS Neutron EDM Experiment

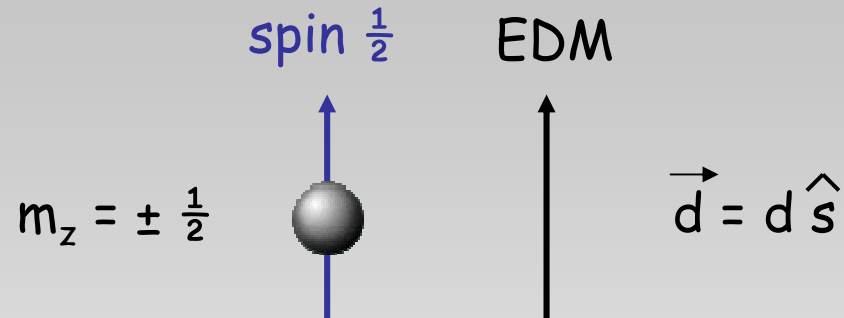


Brad Plaster, Caltech  
*for the nEDM Collaboration*  
INT, March 19, 2007

# T-violating EDMs

Electric dipole moment

$$\vec{d} = \sum e_i \vec{r}_i$$

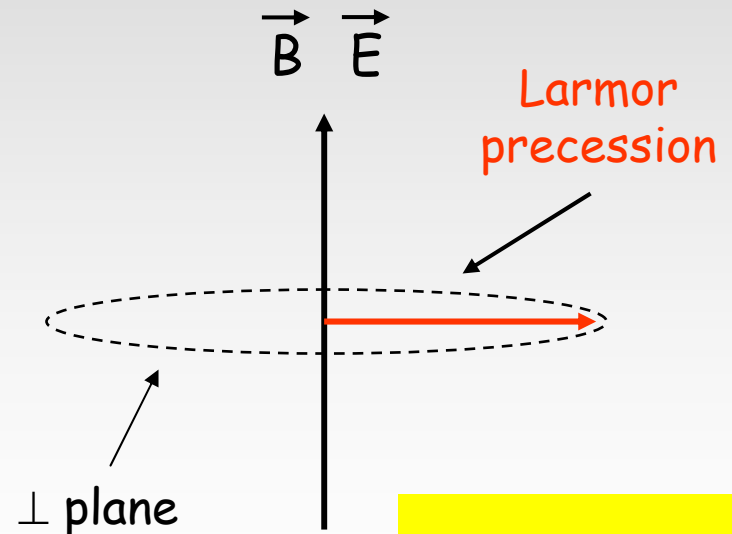


Non-relativistic Hamiltonian

$$\mathcal{H} = -2(\vec{\mu} \cdot \vec{B} \pm \vec{d} \cdot \vec{E}) = h\nu$$

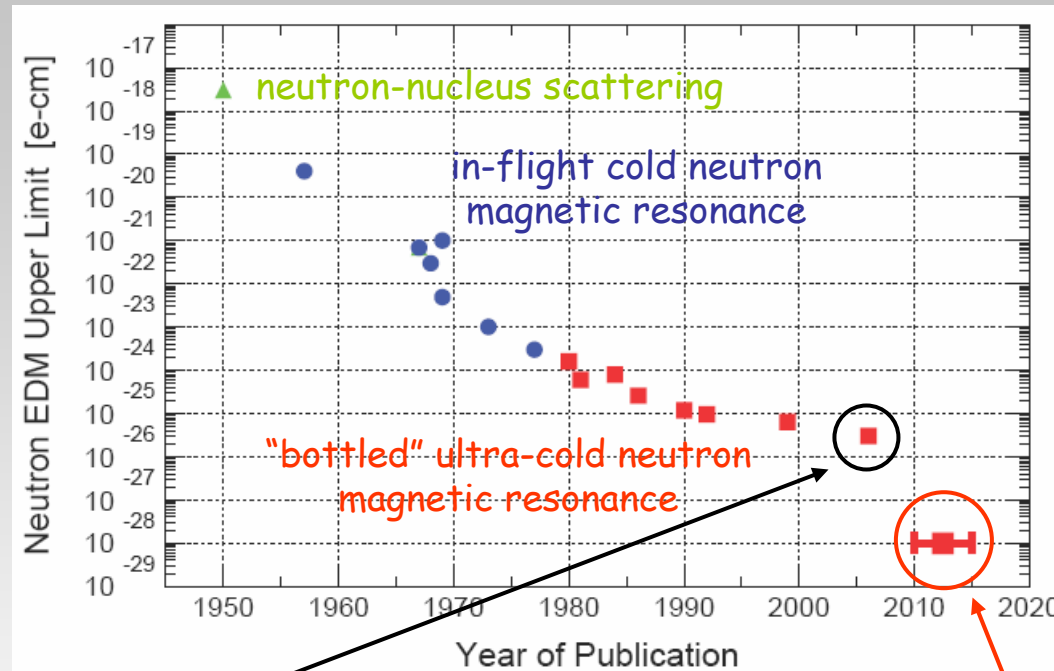
P- and T-  
Conserving

P- and T-  
Violating



$$\nu_{\uparrow\uparrow} \neq \nu_{\uparrow\downarrow}$$

# Status of neutron EDM searches



Current Limit

$$|d_n| < 2.9 \times 10^{-26} \text{ e-cm}$$

Institut Laue-Langevin

[ PRL 97, 131801 (2006) ]

SNS Search  $\rightarrow 10^{-28} \text{ e-cm}$

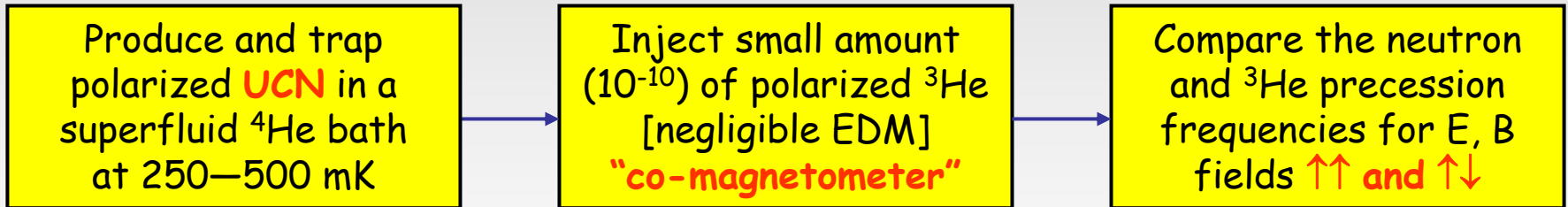
Increased Figure-of-Merit  
Reduced Systematics

# Overview of SNS experiment

- Experiment to be staged at new Spallation Neutron Source (SNS) at Oak Ridge National Laboratory
  - 1 GeV proton beam on liquid Hg target
  - ✓ Beamline #13 [FNPB]:  
Fundamental Neutron Physics Beamline



*First neutrons produced April 28, 2006*



$$B = 10 \text{ mGauss}$$

$$\nu_0 = 29.2 \text{ Hz}$$

$$E = 50 \text{ kV/cm}$$

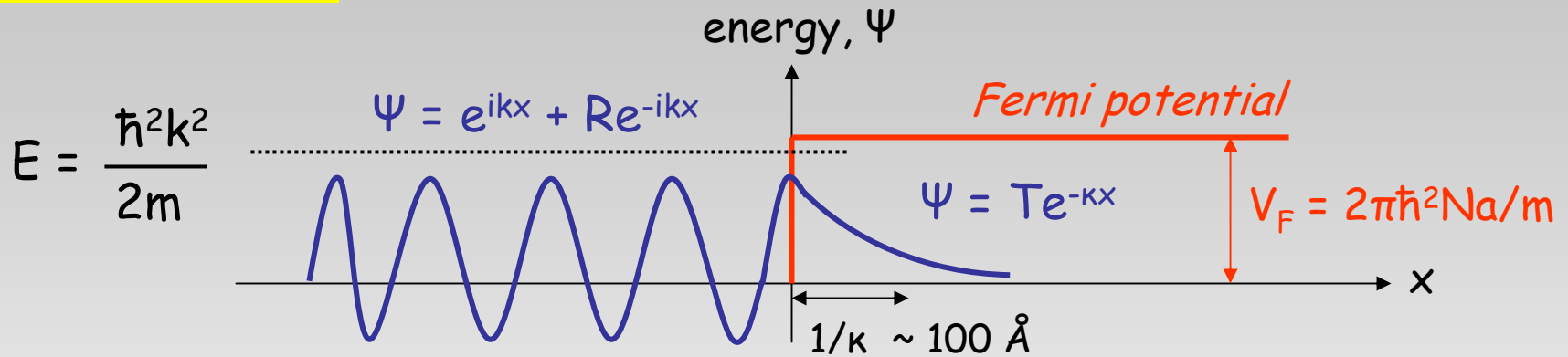
$$\text{if } d_n = 5 \times 10^{-28} \text{ e-cm}$$

$$\Delta\nu_n = 1.2 \times 10^{-8} \text{ Hz}$$

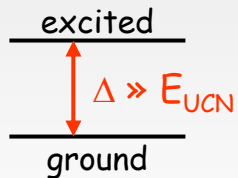
$$\Delta\nu_3 = 0$$

# Superthermal UCN source

UCN:  $v < 7 \text{ m/s}$



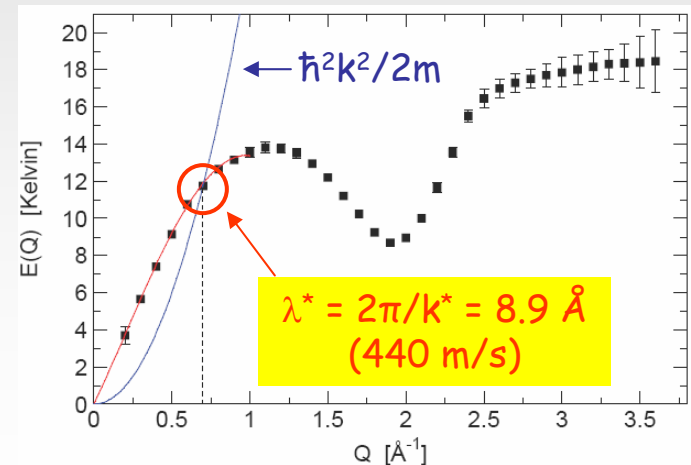
- UCNs produced via a "superthermal process" in superfluid  $^4\text{He}$



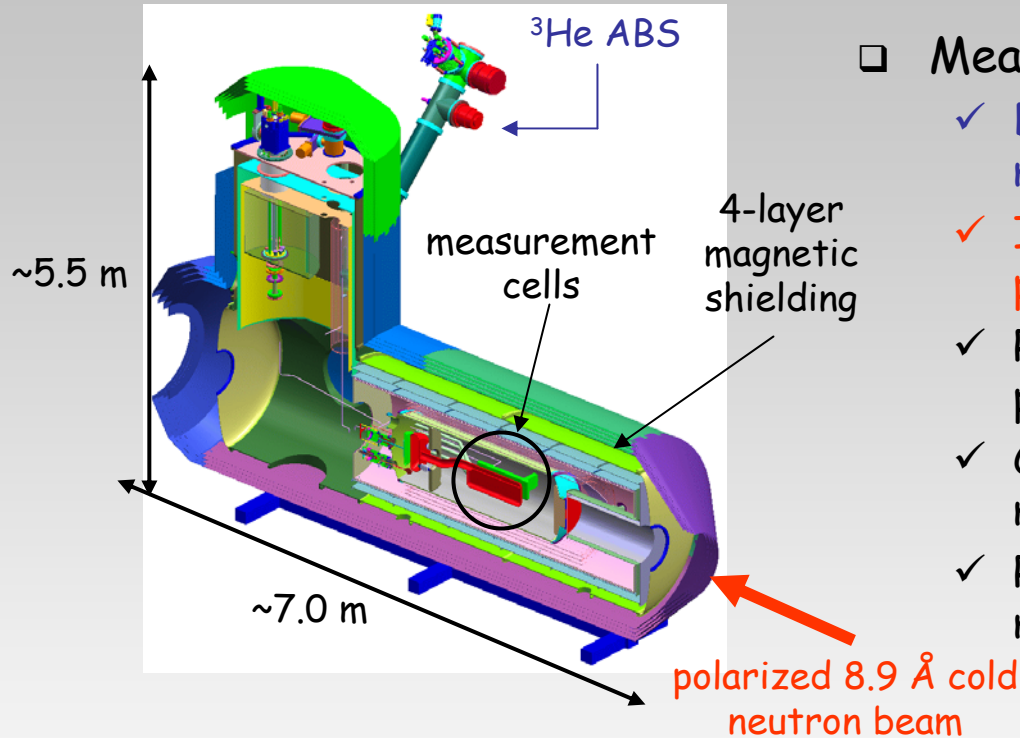
$$E_{\text{UCN}} \sigma_{\text{UP}} = (E_{\text{UCN}} + \Delta) e^{-\Delta/kT} \sigma_{\text{DOWN}}$$

- In superfluid  $^4\text{He}$ , if  $\hbar^2 k^2/2m = E(Q)$ , recoil phonon will carry away nearly all of the incident neutron's energy

Superfluid  $^4\text{He}$  dispersion curve



# Experiment conceptual design



## Measurement cycle

- ✓ Diffuse polarized  $^3\text{He}$  into the measurement cells
- ✓ **Illuminate measurement cells with polarized  $8.9 \text{ \AA}$  cold neutron beam**
- ✓ Rotate neutron and  $^3\text{He}$  spins into plane  $\perp$  to B-field via " $\pi/2$  pulse"
- ✓ Conduct precession frequency measurements
- ✓ Remove (depolarized)  $^3\text{He}$  from measurement cells

repeat

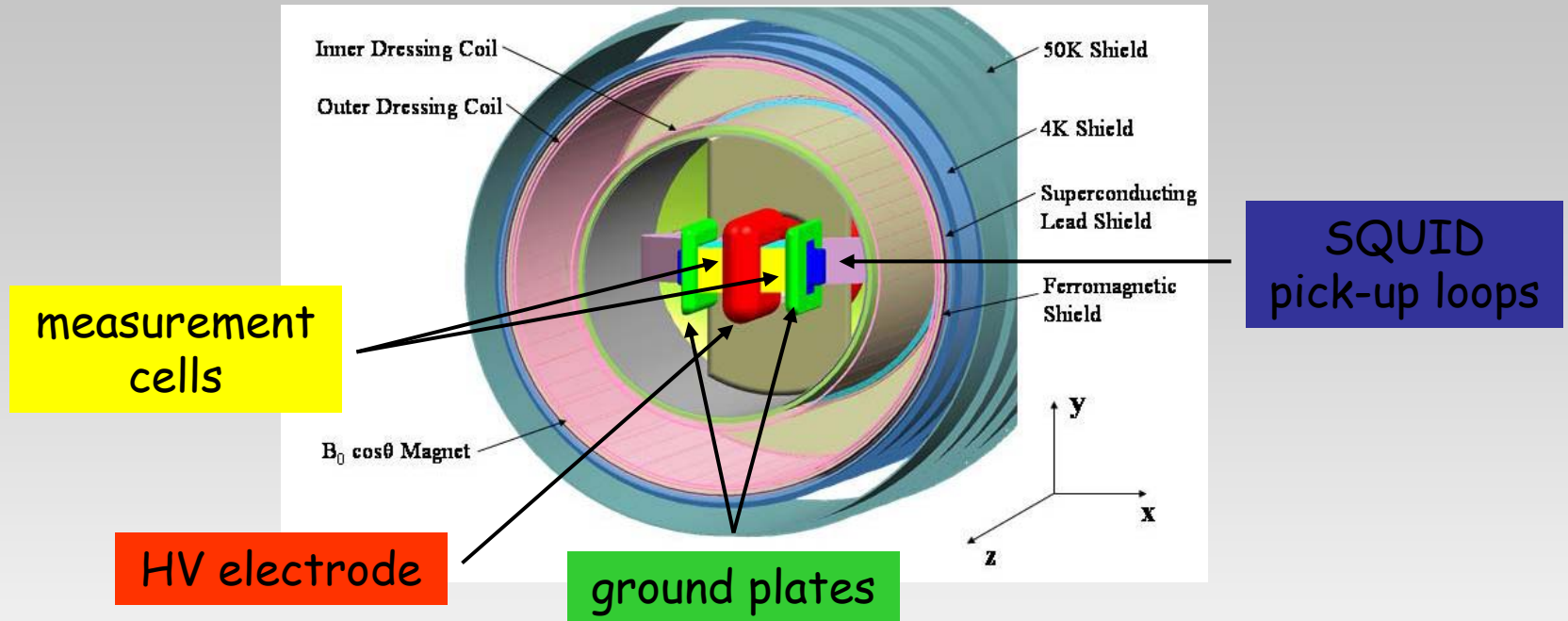
## Measurement cells

- ✓ Filled with 0.5 K superfluid  $^4\text{He}$
- ✓ Coated with deuterated-TPB ( $V_F \sim 165 \text{ neV}$ , speeds  $< 5.5 \text{ m/s}$ )

Sandwiched between the high-voltage electrode and 2 ground plates

Simultaneous  $\uparrow\uparrow$  and  $\uparrow\downarrow$  measurements

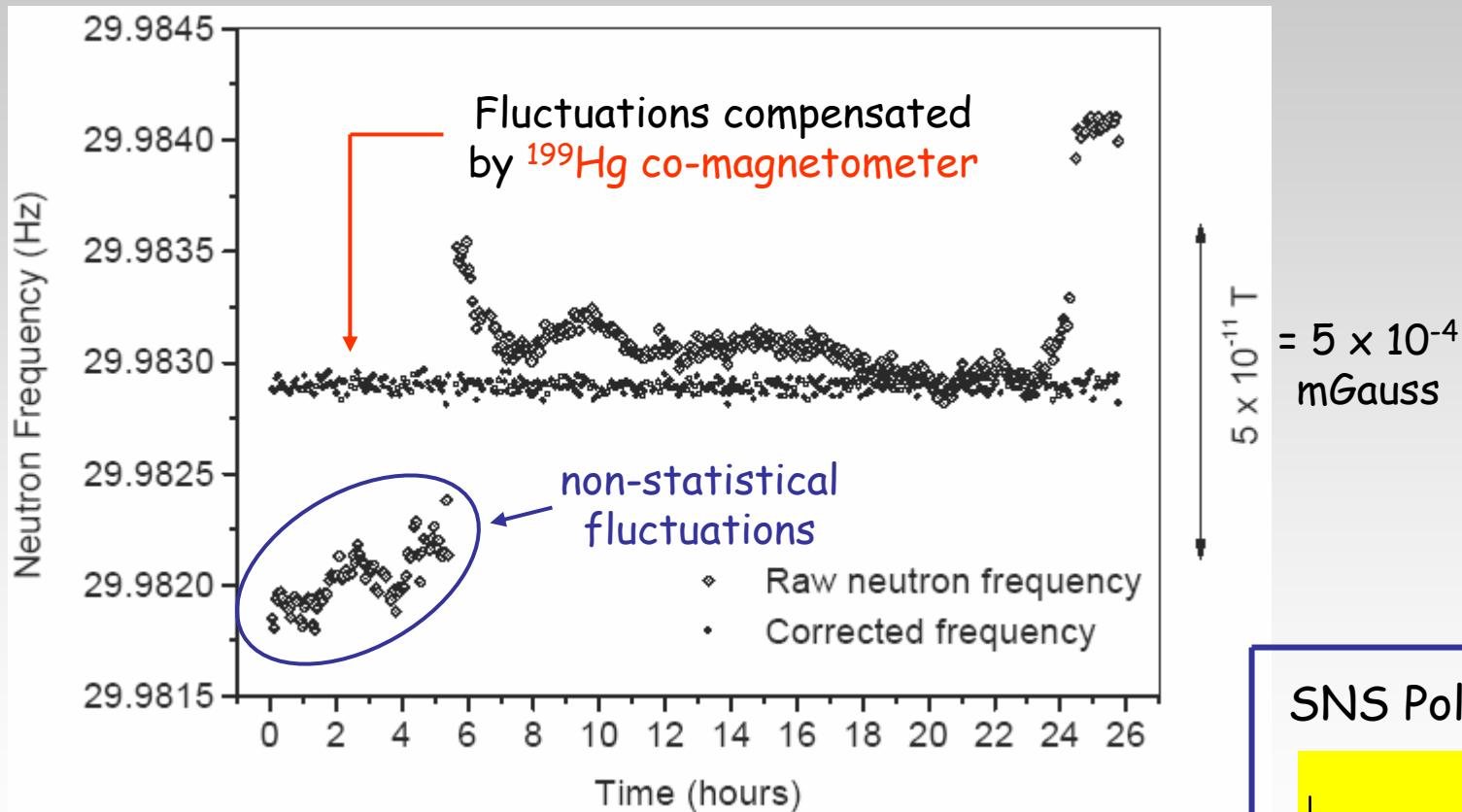
# Measurement cell region



- ❑ Problem: Temporal B-field variations induce  $v_n$  fluctuations
  - ❑ Solution: Polarized  $^3\text{He}$  "co-magnetometer"
    - ✓ Negligible EDM;  $^{199}\text{Hg}$  EDM  $< 2 \times 10^{-28}$  e-cm
    - ✓ Pick up magnetization from precessing  $^3\text{He}$  dipoles with SQUIDS
- Magnetic induction expected at SQUID pick-up loop:  
 $\sim 10^{-10}$  Gauss

# Magnetometry

## ILL experiment $\nu_n$ measurements



[from P.G. Harris *et al.*, PRL 82, 902 (1999)]

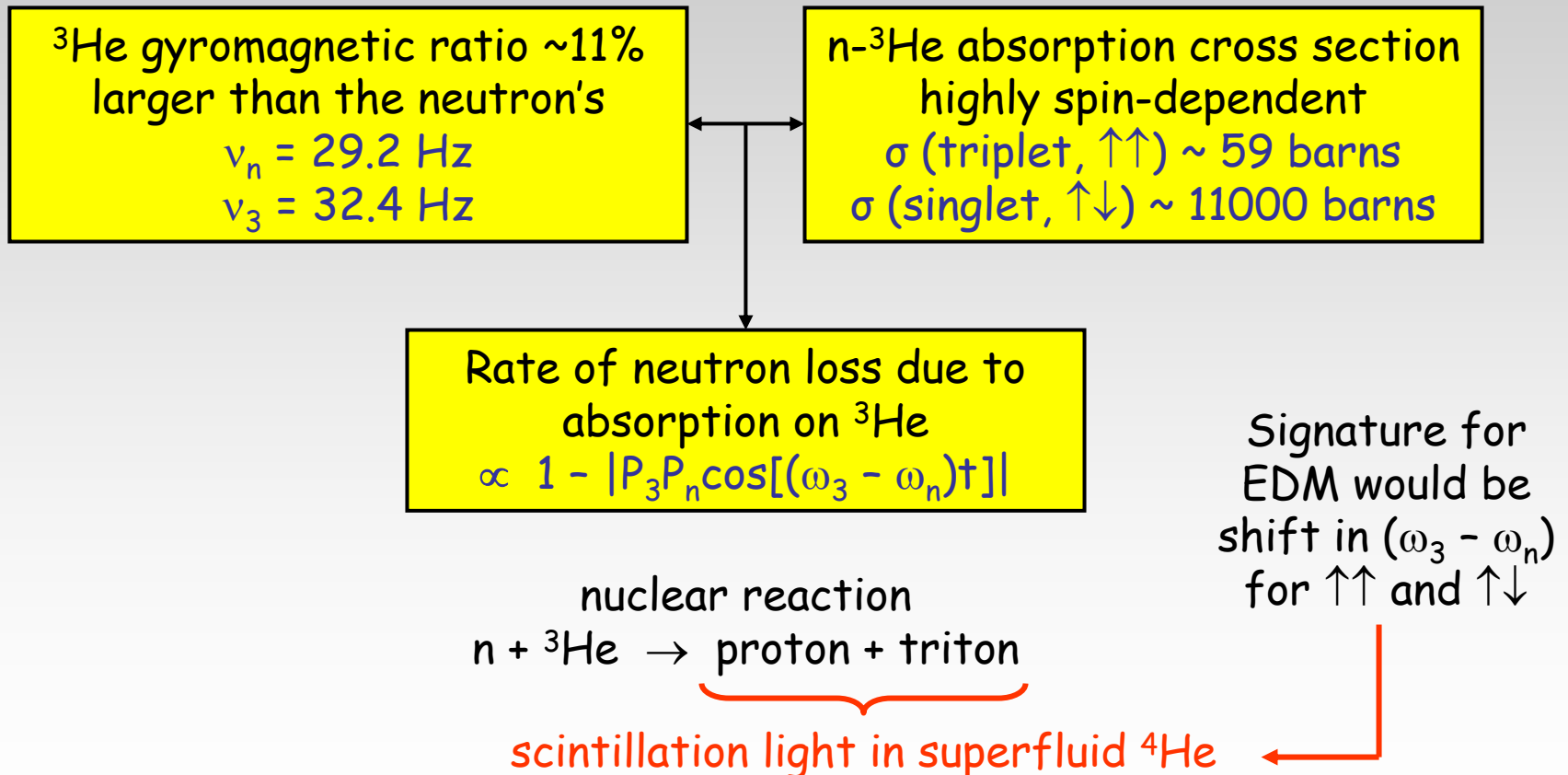
SNS Polarized  $^3\text{He}$

$$|\gamma_3 - \gamma_n| \approx \frac{|\gamma_n|}{10}$$

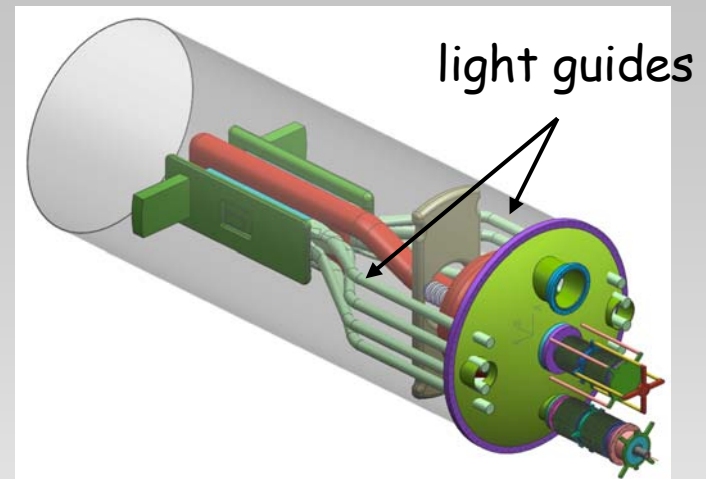
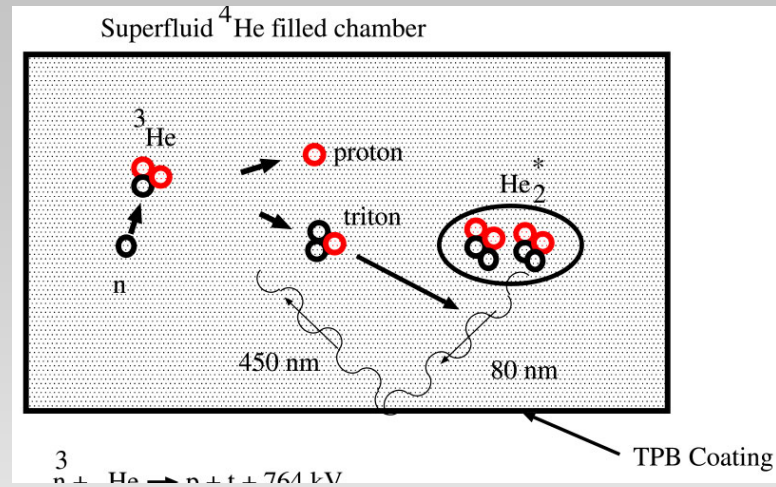


# Precession frequency measurement

- $^3\text{He}$  also serves as the **analyzer** for the measurement of the neutron precession frequency



# Signal and light collection



- **Signal:** proton + triton generate scintillation light in superfluid  $^4\text{He}$  (excited He molecules decay by emitting ultraviolet light)
  - ✓ Prompt pulse (time  $< 20$  ns) from decay of singlet molecules
  - ✓ Afterpulsing from destructive interactions of triplet molecules
  - ✓ Wavelength-shifted to visible with measurement cell wall coatings
- **Background:** electrons [  $\beta$ -decay or Compton-scattered  $\gamma$ -rays ]
  - ✓ Afterpulsing expected to be more intense for  $p + T$  than for  $\beta$

# Expected sensitivity

---

Figure of Merit

[ storage experiment]

$$|\vec{E}| \sqrt{N_{UCN} T_m}$$

Parameter	SNS	ILL [ $10^{-26}$ ]
Electric field	50 kV/cm	10 kV/cm
N (number of UCN)	$1 \times 10^6$	$1.5 \times 10^4$
$T_m$ (measurement time)	500 s	130 s
Figure-of-Merit	$\sim 100$	1

---

# Systematic uncertainties

- $^3\text{He}$  “co-magnetometer” should suppress most of the “usual” systematics associated with EDM experiments
  - Leakage currents associated with E-field reversal, etc.
- “Fundamental” systematic effects: differences in effective magnetic fields experienced by UCN and  $^3\text{He}$ 
  - Limiting factor for ILL experiment which we are addressing are false EDMs from “geometric phases”
  - Field gradients induce off-axis field components
  - Particle rest-frame “ $\mathbf{v} \times \mathbf{E}$ ” fields

$$\vec{B}_v = \frac{\vec{E} \times \vec{v}}{c^2}$$

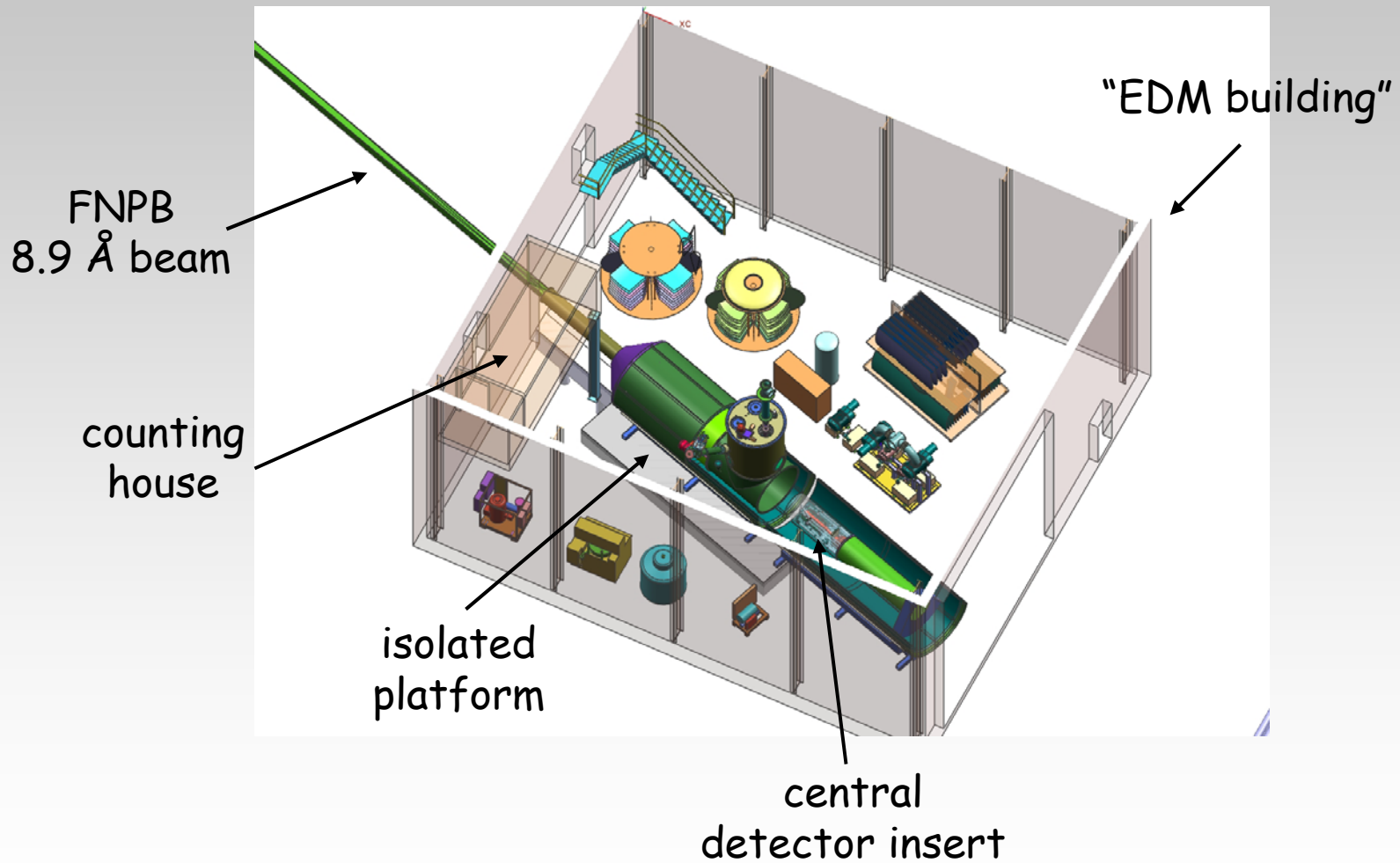


$$\begin{array}{l} \partial B_z / \partial z \neq 0 \\ \nabla \cdot \mathbf{B} = 0 \\ \hline B_r = -[(\partial B_z / \partial z) / 2] \vec{r} \end{array}$$

Does NOT  
average away  
see B. Filippone

# Setup at SNS

---



# Collaboration and timeline

---

- Large collaboration assembled with backgrounds in nucl-ex, hep-ex, low-temp cond-mat, AMO

Arizona State, UC-Berkeley, Boston University, Caltech, Duke, HMI, Indiana, Illinois, Kentucky, LANL, Maryland, MIT, Mississippi State, North Carolina State, ORNL, Simon Fraser, Tennessee, Yale

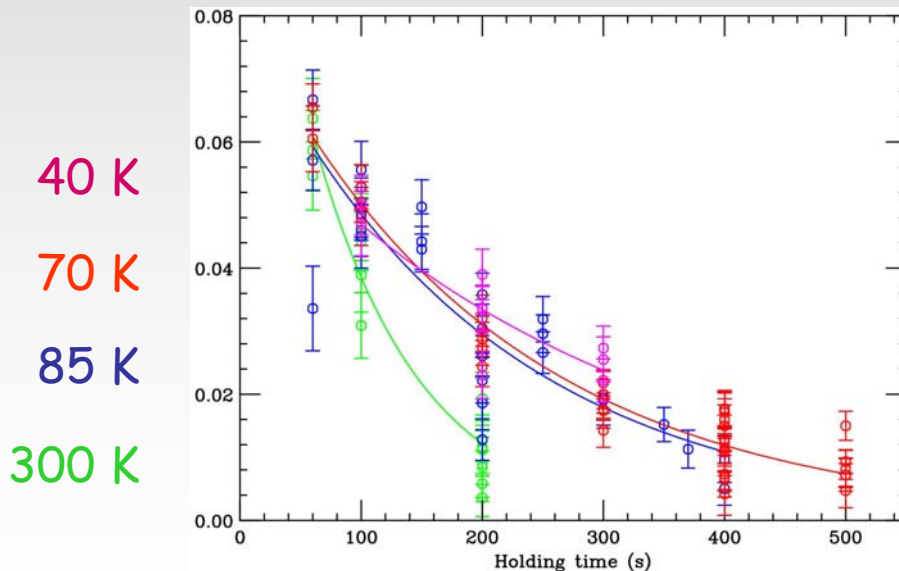
[ Spokespersons: Martin Cooper (LANL) and Steve Lamoreaux (Yale) ]

---

- Anticipated schedule
    - ✓ DOE "CD-0" granted November 2005
    - ✓ DOE "CD-1" granted February 2007
    - ✓ R&D through end of CY 2007
    - ✓ "CD-2" review early 2008
    - ✓ **Begin commissioning components of apparatus at SNS ~ 2013**
-

# R&D studies

- Examples of some of the on-going R&D activities
  - ✓ Neutron storage time in acrylic cell coated w/ deuterated polystyrene
  - ✓ High-voltage studies in superfluid  $^4\text{He}$  environment
  - ✓ Magnetic field studies [modeling gradients, geometric phase, etc.]
  - ✓ Modeling/testing of the central detector system [light transport]
  - ✓ Modeling of the  $8.9\text{\AA}$  neutron beamline



Preliminary Results  
from Neutron Storage  
Time Run Using UCN  
Source at LANSCE

LANL: T.M. Ito *et al.*

# Summary

---

- ✓ Neutron EDM search at SNS holds potential for improvement to level of  $10^{-28}$  e-cm
  - ✓ Collaboration currently refining the conceptual design of the apparatus and completing R&D studies
  - ✓ Experiment between DOE CD-1 and CD-2 stages
  - ✓ Commissioning of apparatus components on SNS floor expected to commence ~2013
-