The Search for a Neutron Electric Dipole Moment

• Science of Electric Dipole Moments (EDM)
• Status of neutron EDM searches
• nEDM experiment at SNS
  – Technical challenges & progress
  – Construction/Funding challenges & status
• Worldwide efforts for neutron EDM
How big is the neutron EDM?

If \( l \sim 0.1 r_n \),

\[ d_n \sim 1 \times 10^{-14} \text{ e-cm} \]

But experiment says \( d_n < 3 \times 10^{-26} \text{ e-cm} \)
Neutron EDM & Electron Scattering

- Neutron EM current:

\[
\langle n | J_{\mu}^{EM} | n \rangle = \bar{u}_N \left[ F_1(q^2)\gamma_{\mu} + \frac{F_2(q^2)}{2M_N} \sigma_{\mu\nu}q_\nu + F_A(q^2)(iq^2\gamma_{\mu}\gamma_5 - 2M_N q_\mu\gamma_5) + \frac{F_3(q^2)}{2M_N} \gamma_5\sigma_{\mu\nu}q_\nu \right] u_N
\]

- \( P&T \) even

- \( P \) odd

- \( P&T \) odd

- \( F_3 \) related to neutron EDM:

\[
d_n = \lim_{q^2 \to 0} \frac{F_3(q^2)}{2M_N}
\]

- Also related to Transversity!

\[
\delta q = \int_0^1 dx \left[ h_1(x) - \bar{h}_1(x) \right]
\]

\[
d_n = \sum_q d_q \delta q
\]

Transversity distribution = spin distribution of quarks carrying momentum fraction - \( x \) - of the total momentum of a transversely polarized nucleon
nEDM Violates Time-Reversal Symmetry

- Since neutron has no distinguishable partner, EDM violates Time-Reversal Symmetry
Primary Motivation for EDM Searches

• Particle EDMs violate Time-Reversal Symmetry and Charge-Parity (CP) Symmetry

• Can be a window to new physics beyond the Standard Model (even beyond Large Hadron Collider)
  – Since they are Very small in Standard Model

• May shed light on why the Universe is not symmetric in amount of Matter vs Antimatter
  – Sakharov Criteria: Proton decay, non-equilibrium phase & new CP violation
Origin of elementary EDMs

- Standard Model EDMs are due to CP violation in the quark weak mixing matrix CKM (e.g. the $K^0/B^0$-system) but...
  - $e^-$ and quark EDM's are zero in 1$^{\text{st}}$ & 2$^{\text{nd}}$ order
  - Need at least three loops to get EDM's (electron actually requires 4 loops!)
- Thus EDM's are VERY small in standard model

Neutron EDM in Standard Model is $\sim 10^{-32}$ e-cm ($\sim 10^{-19}$ e-fm)

Experimental neutron limit: $< 3 \times 10^{-26}$ e-cm
Is there a "natural" source for new CP violation & EDMs?

• New physics (e.g. SuperSymmetry = SUSY) often has additional CP violating phases in added couplings
  - New phases: \( \phi_{CP} \) should be \( \sim 1 \) (why not?)

• Contribution to EDMs depends on masses of new particles
  \[ d_n \sim 10^{-24} \text{ e-cm} \times \sin \phi_{CP} (1 \text{ TeV}/M_{\text{SUSY}})^2 \]

Note: experimental limit: \( d_n < 0.03 \times 10^{-24} \text{ e-cm} \)
Impact of non-zero EDM

• Must be new Physics

• Sharply constrains models beyond the Standard Model (especially with LHC data)

New nEDM at $3 \times 10^{-28}$ e-cm moves limits off graph

McKeen, Pospelov & Ritz
hep-ph 1303.1172

Heavy sfermions $> 50$ TeV
1 TeV gauginos
Present EDM Limits
Origin of Hadronic EDMs

- Hadronic (strongly interacting particles) EDMs are from
  - $\theta_{\text{QCD}}$ (an allowed term in QCD)
  - or from the quarks and gluons themselves

\[
\mathcal{L}_{\text{eff}} = \frac{g_s^2}{32\pi^2} \, \bar{\theta} \, G^a_{\mu\nu} \tilde{G}^{\mu\nu,a} + \frac{1}{3} \, w \, f^{abc} G^a_{\mu\nu} \tilde{G}^{\nu\beta,b} G^c_{\beta} \mu,c \\
- \frac{i}{2} \sum_{i=e,u,d,s} d_i \bar{\psi}_i (F^c \sigma) \gamma_5 \psi - \frac{i}{2} \sum_{i=u,d,s} \bar{d}_i \bar{\psi}_i g_s (G^c \sigma) \gamma_5 \psi + \cdots
\]

- $e^{-}$, quark EDM
- Quark color EDM (chromo-EDM)
Particle EDM Zoo

- Paramagnetic atoms and polar molecules are very sensitive to $d_e$
- Diamagnetic atoms are sensitive to quark “chromo-“EDM $(\text{gluon+photon}) = \tilde{d}_q$ and $\Theta_{\text{QCD}}$
- Neutron and proton sensitive to $\tilde{d}_q$, $d_q$ & $\Theta_{\text{QCD}}$

Observation or lack thereof in one system does not predict results for other systems
## Relative EDM Sensitivities

<table>
<thead>
<tr>
<th>System</th>
<th>Dependence</th>
<th>Present Limit (e-cm)</th>
<th>Future (e-cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n)</td>
<td>(d_n \sim (3 \times 10^{-16}) \theta_{\text{QCD}} + 0.7(d_d - \frac{1}{4}d_u) + 0.6e(\tilde{d}_d + \frac{1}{2}\tilde{d}_u))</td>
<td>(&lt;3 \times 10^{-26})</td>
<td>(10^{-28})</td>
</tr>
<tr>
<td>(^{199}\text{Hg})</td>
<td>(d_{\text{Hg}} \sim (0.001 \times 10^{-16}) \theta_{\text{QCD}} - 0.006e(\tilde{d}_d - \tilde{d}_u))</td>
<td>(&lt;3 \times 10^{-29})</td>
<td>(10^{-29}(?))</td>
</tr>
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</table>
Searches for a Neutron EDM

  - Neutron Scattering
  - Searching for Parity Violation
  - Pioneered Neutron Beam Magnetic Resonance
nEDM Sensitivity “Moore’s Law”

Neutron EDM Experimental Limit (e cm)

10^{-20} 10^{-25} 10^{-30}


Future neutron EDM
What is the precision in an EDM measurement?

$$\mathcal{E} = \hbar \omega = \vec{d} \cdot \vec{E}$$

Uncertainty in d:

$$\sigma_d \sim \frac{\Delta \mathcal{E}}{|\vec{E}|}$$

Using Uncertainty Principle:

$$\Delta \mathcal{E} \Delta t \sim \hbar$$

Precise energy measurement requires long individual measurement time, giving

$$\sigma_d \sim \frac{\Delta \mathcal{E}}{|\vec{E}|} \sim \frac{\hbar}{|\vec{E}|T_m}$$

Can improve with counting statistics

$$\propto \frac{1}{\sqrt{N}}$$

Coherence effect
How to Measure an EDM

1. Inject polarized particle
2. Rotate spin by \( \pi/2 \)
3. Flip E-field direction
4. Measure frequency shift

\[ \nu = \frac{2 \mu \cdot \vec{B} \pm 2 \vec{d} \cdot \vec{E}}{h} \]

- Small change in B obscures measurement of \( d \)
  - thus larger B requires smaller fractional control of B
  - large \( <\Delta B^2> \) can give short spin-coherence time \( T_2 \)
  - but smaller B leads to larger geometric phase systematics

Must know B very well
Best Neutron Limit: ILL-Grenoble neutron EDM Experiment

Harris et al. Phys. Rev. Lett. 82, 904 (1999)

Trapped Ultra-Cold Neutrons (UCN) with $N_{UCN} = 0.5$ UCN/cc

4-layer Magnetic Shield

$|E| = 5 - 10$ kV/cm

100 sec storage time

$\sigma_d < 3 \times 10^{-26}$ e cm
To further improve sensitivity need new techniques

• Enhance number of stored neutrons
  - \( \sqrt{N} \) improvement - LHe at < 1K can do this

• Increase Electric field
  - Linear improvement - LHe as dielectric could help

• Minimize key systematic effects
  - Highly uniform B-field to minimize systematics
  - Can try superconducting B-shield
  - Co-magnetometer could be essential
    • Measure B-field averaged over neutron volume
Technologies for nEDM (new, SNS)

• UCN (or beam for crystal exps)
  – $\text{SD}_2$, Superfluid $^4\text{He}$

• HV - the bigger the better
  – Vacuum, $\text{LHe}$, Crystal

• Magnetic Shielding
  – Room temperature and Cryogenic

• Magnetometers
  – Atomic & others: $^{199}\text{Hg}$, $^3\text{He}$, $^{129}\text{Xe}$, $^{133}\text{Cs}$, SQUIDs, neutrons
  – Co-magnetometers are most effective
nEDM COLLABORATION

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*Yale University*
Spallation Neutron Source (SNS) at ORNL

1 GeV proton beam with 1.4 MW on spallation target
SNS nEDM Experiment


- Production of ultracold neutrons (UCN) within the apparatus
  - *high UCN density and long storage times*

- Liquid He as a high voltage insulator (along with CryoEDM)
  - *high electric fields*

- Use of a $^3$He co-magnetometer and superconducting shield
  - *Control of magnetic field systematics*

- Use $n-^3$He capture $\rightarrow$ light to measure neutron precession frequency
  - two techniques:
    - *free precession*
    - *dressed spin techniques*

  **100x improvement over existing limit**

- Sensitivity estimate: $d_n \sim 3-5 \times 10^{-28}$ e·cm (90% CL after 3 yrs)
Previous experiments used Ramsey Technique

- So-called separated-oscillatory field technique
  - Measure neutron “survivors” how many $n \uparrow$ vs. $n \downarrow$
Alternative to Ramsey technique is direct measurement of frequency

- via spin-dependent neutron capture on polarized $^3$He
- capture rate, measured via scintillation in LHe, oscillates at $n$-$^3$He beat frequency

Measure neutron “casualties”

$N$ (counts/0.03 sec)
SNS Measurement cycle

1. Load collection volume with polarized $^3$He atoms
2. Transfer polarized $^3$He atoms into the measurement cell
3. Illuminate measurement cell with polarized cold neutrons to produce polarized UCN
4. Apply a $\pi/2$ pulse to rotate spins perpendicular to $B_0$
5. Measure precession frequency
6. Remove reduced polarization $^3$He atoms from measurement cell
7. Flip E-field & go to 1.

$^3$He functions as “co-magnetometer” since $d_{^3He} \ll d_n$ due to $e^-\text{screening}$
Can also take advantage of “Dressed” Spins

Add a non-resonant AC B-Field

Use of two measurement techniques provides critical cross-check of EDM result with different systematics

Can match effective precession frequency of n & $^3$He about $B_0$

Video = Ping-Han Chu
**Example of future Neutron EDM Sensitivity**

<table>
<thead>
<tr>
<th></th>
<th>ILL published</th>
<th>EDM @ SNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{UCN}$</td>
<td>$1.3 \times 10^4$</td>
<td>$4 \times 10^5$</td>
</tr>
<tr>
<td>$</td>
<td>E</td>
<td>, (kV/cm)$</td>
</tr>
<tr>
<td>$T_m , (s)$</td>
<td>$130$</td>
<td>$1000$</td>
</tr>
<tr>
<td>$m , (cycles/day)$</td>
<td>$270$</td>
<td>$25$</td>
</tr>
<tr>
<td>$\sigma_d , (e$-cm$/day)$</td>
<td>$3 \times 10^{-25}$</td>
<td>$3.5 \times 10^{-27}$</td>
</tr>
</tbody>
</table>

$\sigma_d \approx \frac{\hbar}{|E| T_m \sqrt{mN_{UCN}}}$

- $N_{UCN}$: Neutron Capture Rate
- $|E|$: Electric Field
- $T_m$: Measurement Time
- $m$: Number of Cycles per Day
- $\sigma_d$: EDM Sensitivity

**Improve Sens.**
- $N_{UCN}$: $x \times 5.5$
- $|E|$: $x \times 7$
- $T_m$: $x \times 2.3$
- $m$: $x \sim 90$
nEDM Components

- Dilution refrigerator
- $^3$He polarized source
- $^3$He Injection module (Transport & purify $^3$He)
- 3 layer μ-metal shield
- Neutron guide
- Upper Cryostat
- Lower Cryostat
- Magnet and shielding package
- Central LHe volume, (HV, Light collection, SQUIDS) 300 mK, \(~1000\ l\)

+ offline test facility at NCSU research reactor
Some Technical Challenges:
(“it’s just engineering” 😊)

- Non-conducting central volume: RF heating & magnetic Johnson noise
- Polarized $^3$He friendly: maximize $T_2$
- Polarized n friendly: maximize $T_2$
- UCN friendly: maximize $T_m$
- Purify 4He: ppt compared to ppm (natural)
- 1200L SF LHe at 0.3 K: no leaks
- High E-field: ~ 80 kV/cm
- No E-breakdown: SQUID survival
- Ambient B-field suppression: 10-5 for SQUIDS & systematics
- Uniform B-fields: ppm level
- All above approved for Ops at National Lab!
# Projected systematic uncertainties

<table>
<thead>
<tr>
<th>Error Source</th>
<th>Systematic uncertainty (e-cm)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear vxE (geometric phase)</td>
<td>$&lt; 2 \times 10^{-28}$</td>
<td>Uniformity of $B_0$ field</td>
</tr>
<tr>
<td>Quadratic vxE</td>
<td>$&lt; 0.5 \times 10^{-28}$</td>
<td>E-field reversal to $&lt;1%$</td>
</tr>
<tr>
<td>Pseudomagnetic Field Effects</td>
<td>$&lt; 1 \times 10^{-28}$</td>
<td>$\pi/2$ pulse, comparing 2 cells</td>
</tr>
<tr>
<td>Gravitational offset</td>
<td>$&lt; 0.2 \times 10^{-28}$</td>
<td>With E-field dependent gradients $&lt; 0.3\text{nG/cm}$</td>
</tr>
<tr>
<td>Heat from leakage currents</td>
<td>$&lt; 1.5 \times 10^{-28}$</td>
<td>$&lt; 1 \text{ pA}$</td>
</tr>
<tr>
<td>vxE rotational n flow</td>
<td>$&lt; 1 \times 10^{-28}$</td>
<td>E-field uniformity $&lt; 0.5%$</td>
</tr>
<tr>
<td>E-field stability</td>
<td>$&lt; 1 \times 10^{-28}$</td>
<td>$\Delta E/E &lt; 0.1%$</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>$&lt; 1 \times 10^{-28}$</td>
<td>Other vxE, wall losses</td>
</tr>
</tbody>
</table>

**Statistical sensitivity:** $3 - 5 \times 10^{-28}$ e-cm @ 90% CL in 3 calendar years
Status of nEDM @ SNS

• NSAC Review of Fundamental Physics with Neutrons (1/12)
  – nEDM is highest priority of sub-field
  – nEDM should focus on Critical R&D for 2 yrs
    • Several key elements need to be demonstrated
  – “Equipment Project” (MIE) stopped 3/12
  – Funded via R&D (2012/2013)
    • Reviewed every 4 months via external Technical Review Committee (managed by ORNL)
  – Full DOE review 12/13

Thanks Chris Keith/JLAB!!
DOE Review (12/13)

• Key Technical milestones largely met
  – High Electric Fields
  – Uniform Magnetic Fields
  – $^3$He transport uncertainties reduced
  – Other advances
HV in Nov. 2011

3-4 mm gap, most of data taken at SVP

$E_{\text{max}}$ or $E_{\text{breakdown}}$ (kV/cm)

$1.6 \text{ K}$

$P_\lambda$

$4 \text{ K}$

$nEDM \text{ Goal}$

Pressure (torr)
Medium-scale HV system
HV in Nov. 2013

T = 0.4 K

nEDM Goal
Next Steps for HV

• Previous studies used electropolished SS
• Will soon test coated PMMA electrodes

Carbon nano-particle coating on PMMA
Cryogenic Magnets and Magnetic Shielding

½ - Scale Cosθ Coil

Superconducting Pb B-Shield

Cryostat

Automated B-mapping system
**Recent Magnetic Performance**

- **With Pb Shield in Superconducting state:**
  - Can reproducibly measure gradients $< 0.2 \ \mu G/cm$ ($< 2 \ \text{nT/m}$)
  - Pb Shield increases B-shielding $> x 100$
  - Present gradients limit false EDM effect (uncorrected) to $< 4 \times 10^{-28} \ \text{e-cm}$
    - comparable to statistical sensitivity goal
DOE Review (12/13)

• Collaboration proposes a 4-yr “Demonstration” phase (Critical Component Demonstration – CCD)
  – Continue as R&D project to build high-fidelity, full-scale “prototypes” of most difficult subsystems
Recent Status & Future

• 4-yr NSF proposal for CCD approved ~6.5M$
• Anticipate 4-yr DOE Funding for CCD ~7M$
• Continuation of external Technical Review Committee
• Developing “inch-pebbles” (i.e. NOT “milestones”) to monitor progress over CCD
• Would complete construction “after” CCD over ~ 2 yrs with more conventional systems
• Commissioning underway by 2019-2020
### CCD Goal:
Reduce Risk and Uncertainty
“Do the Hard Stuff First”

#### Status of Components Now

<table>
<thead>
<tr>
<th>Component</th>
<th>Current TRL</th>
<th>Cost Risk</th>
<th>Schedule Risk</th>
<th>Technical Risk</th>
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<tr>
<td>2.01. Neutronics: Neutron Guide Vacuum Window Material (DOE)</td>
<td>3</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td>2.02. Neutronics / He3 Services: Spin Transport Magnets (DOE, NSF)</td>
<td>4</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td>2.03. Cryogenics: Helium Insulation Volume and Seals (DOE)</td>
<td>3-4</td>
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<td>2.04. He3 Services: Dilution Refrigerator (NSF)</td>
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<td>2.09. Central Detector System: Light Collection, E-field Monitor (DOE)</td>
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<td>2.10. Central Detector System: UCN Storage (DOE)</td>
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CCD Goal:
Reduce Risk and Uncertainty
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Status of Components after CCD

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Yes, we have an Org. Chart

**Internal Technical Committee**
Bob Golub, co-chair  
Paul Huffman, co-chair

**R&D Manager**
Vince Cianciolo  
Paul Huffman (deputy)

**Spokesperson**
Brad Filippone

**Collaboration Board**
Bob Redwine, chair

**NSF Co-Pi’s**
Brad Filippone  
Doug Beck

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**CCD Activity Leaders**

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- 2.02 Spin Transport Magnets, **Chris Crawford**
- 2.03 Helium Insulation Volume and Seals, **David Haase**
- 2.04 Dilution Refrigerator, **Weijun Yao**
- 2.05 Injection System, **Steve Williamson**
- 2.06 Purification System, **Steve Williamson**
- 2.07 Coil Package, **Brad Filippone**
- 2.08 B-field Monitor, **Brad Plaster**
- 2.09 Light Collection, E-field Monitor, **Vince Cianciolo**
- 2.10 UCN Storage, **Kent Leung**
- 2.11 High Voltage, **Takeyasu Ito**
- 2.12 V1 Valve, **Takeyasu Ito**
- 2.13 SQUIDs, Grounding and Shielding, **Steve Clayton**
- 2.14 PULSTAR Systematic Error and Spin Dressing Test Cryostat, **Katerina Korobkina**
- 2.15 Assembly and Commissioning, **Vince Cianciolo**
Worldwide nEDM Searches
<table>
<thead>
<tr>
<th>Experiment</th>
<th>UCN source</th>
<th>cell</th>
<th>Measurement techniques</th>
<th>$\sigma_d$ Goal (10^{-28} e-cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILL - CryoEDM</td>
<td>Superfluid $^4$He</td>
<td>$^4$He</td>
<td>Cryo HV, SuperCond., Ramsey technique, external SQUID mag.</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>ILL-PNPI</td>
<td>ILL turbine PNPI/Solid D$_2$</td>
<td>Vac.</td>
<td>Ramsey technique for $\omega$ E=0 cell for magnetometer</td>
<td>Phase1&lt;100 &lt; 10</td>
</tr>
<tr>
<td>ILL Crystal</td>
<td>Cold n Beam</td>
<td>solid</td>
<td>Crystal Diffraction Non-Centrosymmetric crystal</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>PSI EDM</td>
<td>Solid D$_2$</td>
<td>Vac.</td>
<td>Ramsey for $\omega$, external Cs &amp; $^3$He, Hg co-magnetom. Xe or Hg comagnetometer</td>
<td>Phase1 ~ 50 Phase 2 &lt; 5</td>
</tr>
<tr>
<td>Munich FRMII</td>
<td>Solid D$_2$</td>
<td>Vac.</td>
<td>Room Temp., Hg Co-mag., also external Cs mag.</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>RCNP/TRIUMF</td>
<td>Superfluid $^4$He</td>
<td>Vac.</td>
<td>Small vol., Xe co-mag. @ RCNP Then move to TRIUMF</td>
<td>&lt; 50 &lt; 5</td>
</tr>
<tr>
<td>SNS EDM</td>
<td>Superfluid $^4$He</td>
<td>$^4$He</td>
<td>Cryo-HV, $^3$He capture for $\omega$, $^3$He co-mag. with SQUIDS &amp; dressed spins, supercond.</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>JPARC</td>
<td>Solid D$_2$</td>
<td>Vac.</td>
<td>Under Development</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>JPARC</td>
<td>Solid D$_2$</td>
<td>Solid</td>
<td>Crystal Diffraction Non-Centrosymmetric crystal</td>
<td>&lt; 10?</td>
</tr>
<tr>
<td>LANL</td>
<td>Solid D$_2$</td>
<td>Vac.</td>
<td>R &amp; D</td>
<td>~ 30</td>
</tr>
</tbody>
</table>
Why so many exps??

- Science remains compelling even with LHC data

If the U.S. is to remain a leader, additional new investments by the nuclear science funding agencies will be necessary over the next 5-10 years aimed at realizing the program outlined in Table II-1. These investments include construction of at least one tonne scale neutrinoless double beta decay detector, construction of a high sensitivity neutron EDM experiment, construction of detectors for the PVES program at Jefferson Lab.

Among the most powerful probes of new physics that does not conserve CP are the electric dipole moments (edm’s) of the neutron, electron and proton. Searches for the edm’s of neutrons and electrons are already sensitive to contributions from new particle masses at the 10–100 TeV scale, with substantial improvements in reach expected over the next decade. A new direct neutron edm experiment is planned at Oak Ridge National Laboratory.

NSAC LRP Implementation 2013

- Exciting opportunities for new/existing facilities
  - New = FRMII, JPARC, SNS; Existing = ILL, PSI, TRIUMF
Comparison of advanced, high sensitivity experiments

Table 2: Comparison of capabilities for nEDM searches. The last five items marked with an * denote a systematics advantage.

<table>
<thead>
<tr>
<th>Capability</th>
<th>Cryo1</th>
<th>Cryo2</th>
<th>PSI1</th>
<th>PSI2</th>
<th>SNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \omega$ via accumulated phase in $n$ polarization</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>$\Delta \omega$ via light oscillation in $^3$He capture</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Horizontal B-field</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>*Comagnetometer</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>*Superconducting B-shield</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>*Dressed Spin Technique</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>*Multiple EDM cells</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>*Temperature Dependence of Geometric phase effect</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
</tbody>
</table>

nEDM @ SNS has unique systematics advantages
Summary

• Importance of greatly improved neutron EDM sensitivity is recognized worldwide

• A number of exciting technologies are being developed to extend the neutron EDM sensitivity by two orders-of-magnitude

• nEDM @ SNS is world leading in sensitivity and systematic error control