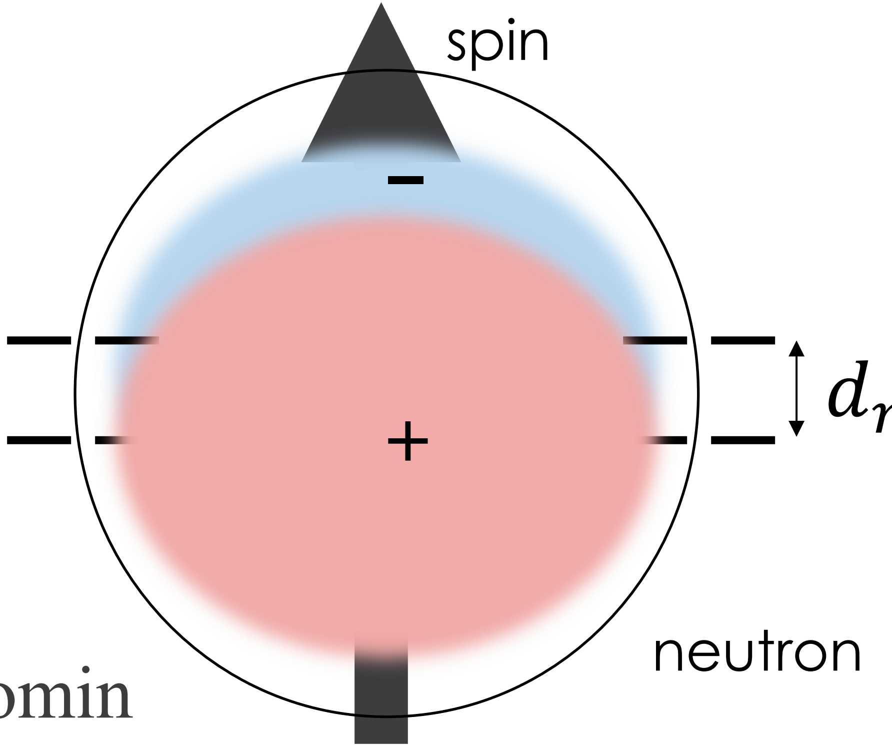
Looking For New Sources of CP Violation



Nadia Fomin

The Last Hug

Why Corned Beef Sandwiches — And The Rest Of The Universe — Exist

National Public Radio (NPR)
Joe Palca
May 25, 2019 8:20 AM ET

https://www.npr.org/2019/05/25/723215836/why-corned-beef-sandwiches-and-the-rest-of-the-universe-exist

WHAT'S THE MATTER WITH THE UNIVERSE?

WHERE'S THE ANTIMATTER?

WHAT WE EXPECT

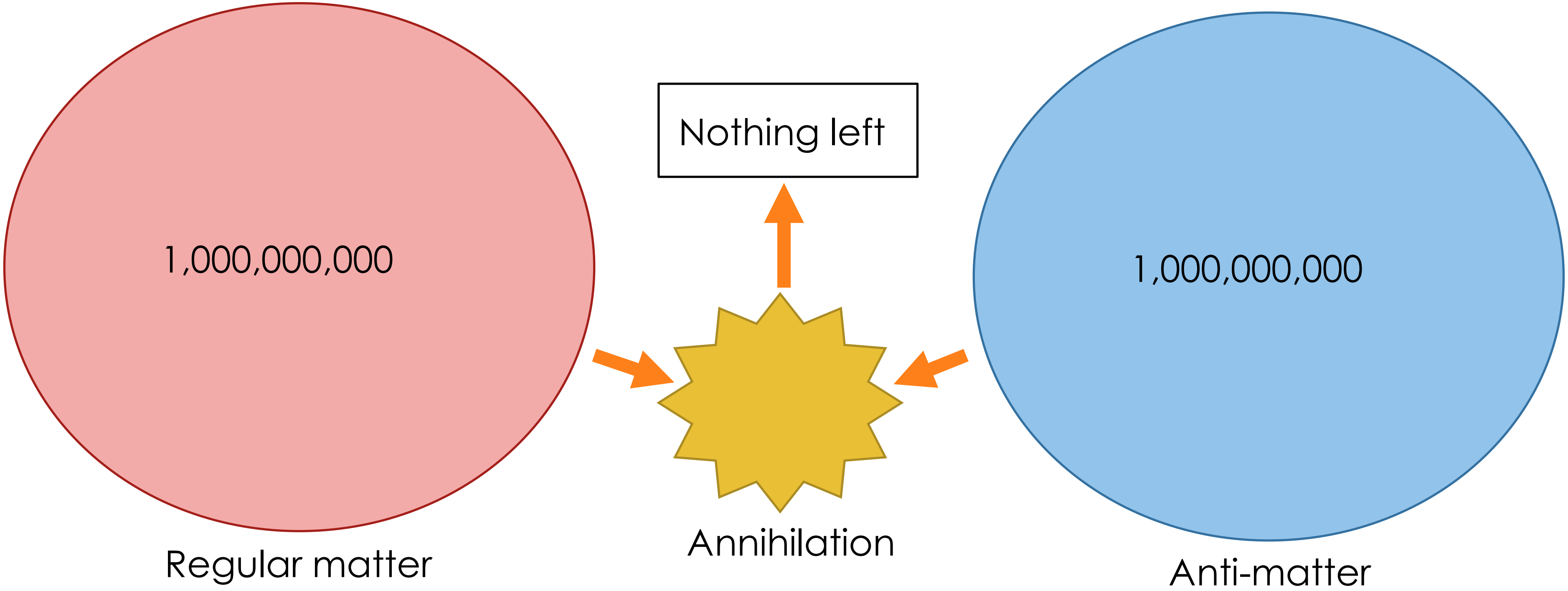
1,000,000,000

Regular matter

1,000,000,000

Anti-matter

WHAT WE EXPECT



WHAT WE OBSERVE

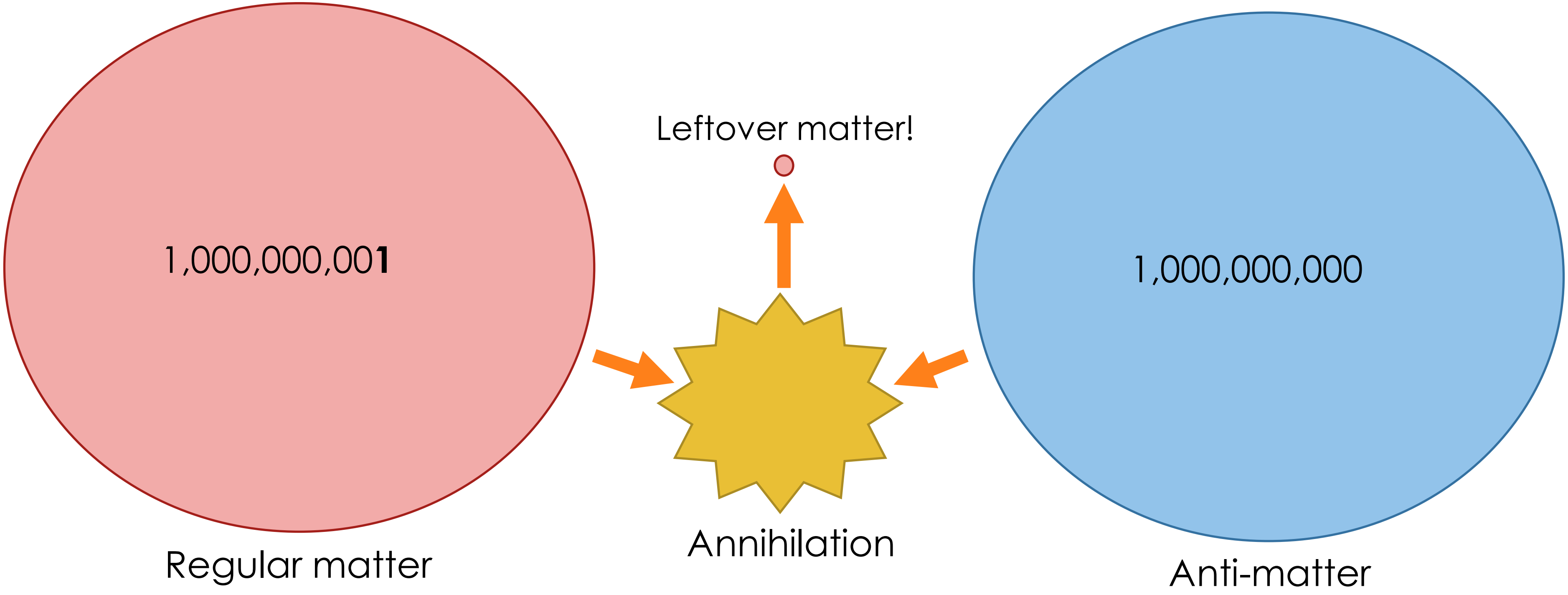
1,000,000,00**1**

Regular matter

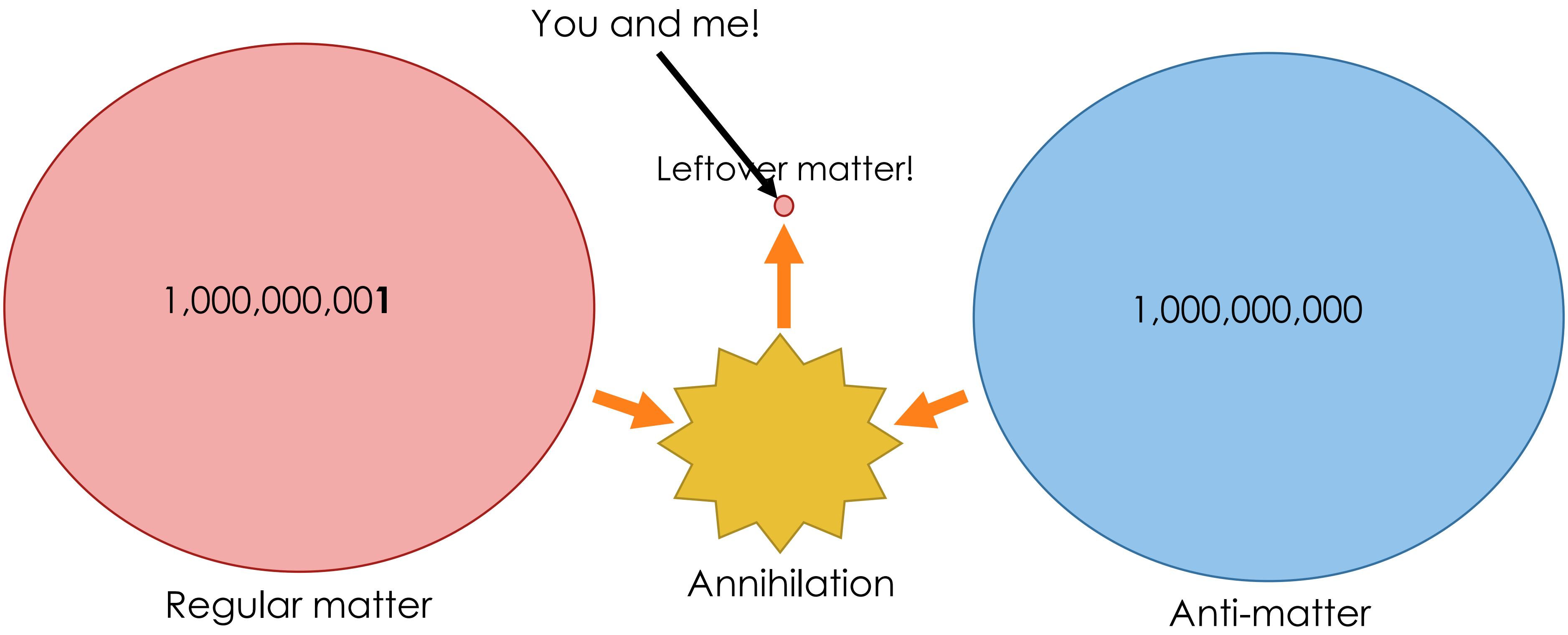
1,000,000,000

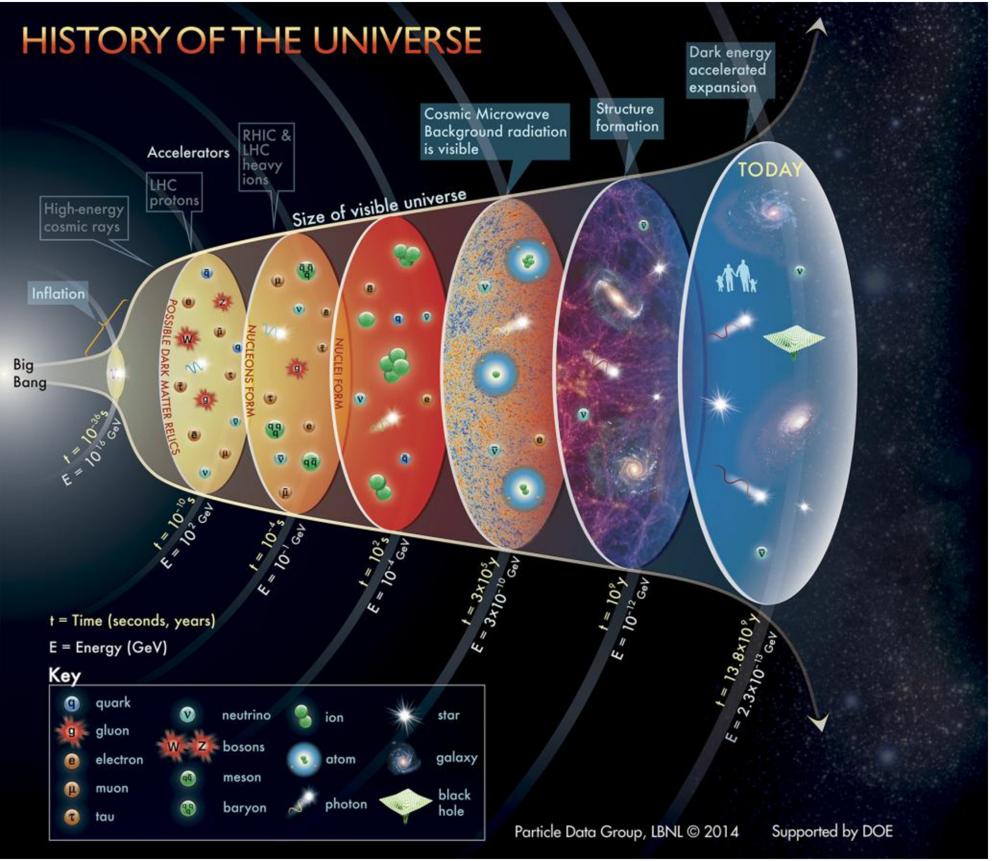
Anti-matter

WHAT WE OBSERVE



WHAT WE OBSERVE





What happened?

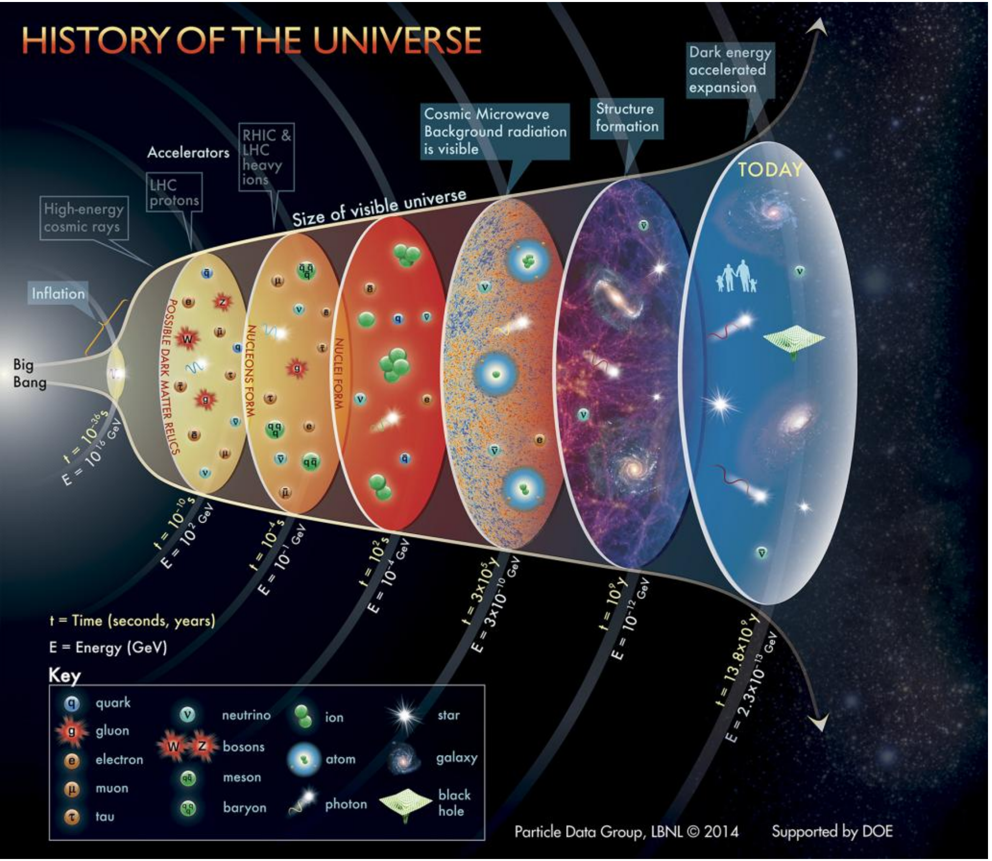
Matter-antimatter asymmetry parameter:

$$\frac{N_{Baryons}}{N_\gamma} \approx 10^{-10}$$

Sakharov conditions:

1. Baryon number violating process
2. CP violation
3. Universe moves away form thermal equilibrium

Sakharov, Soviet Physics Uspekhi. 34 (1967)



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Not enough CP violation has been observed!

Sakharov, Soviet Physics Uspekhi. 34 (1967

Symmetry Violation and EDMs

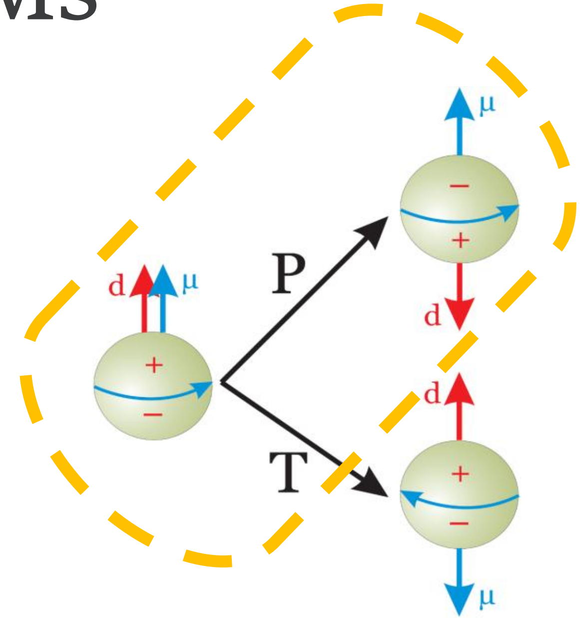
Electric Dipole Moment (EDM):

$$\vec{d} = \int \vec{r}\rho(r)d\vec{r} = \int \vec{r}|\psi(r)|^2 d\vec{r}$$

If parity is conserved:

$$\hat{P}\psi(r) = \psi(-r) = \pm\psi(r)$$

And EDM is zero



For a composite system, EDM is the first moment of the charge distribution. The parity symmetry, i.e., the particle wavefunction is symmetric about its mass center, requires that the EDM should be zero.

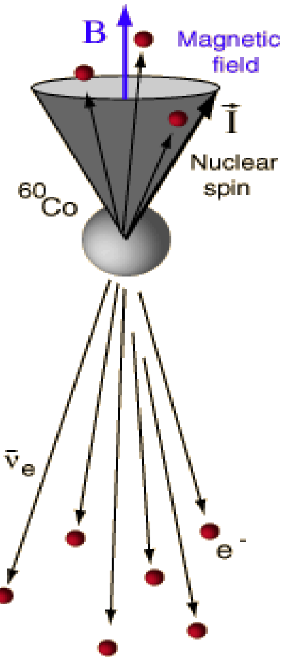
Parity Violation Exists

"Parity Violation"

Beta emission is preferentially in the direction opposite the nuclear spin, in violation of conservation of parity.

Wu, 1957

$^{60}Co \rightarrow {}^{60}Ni + e^{-} + \bar{\nu}_e$

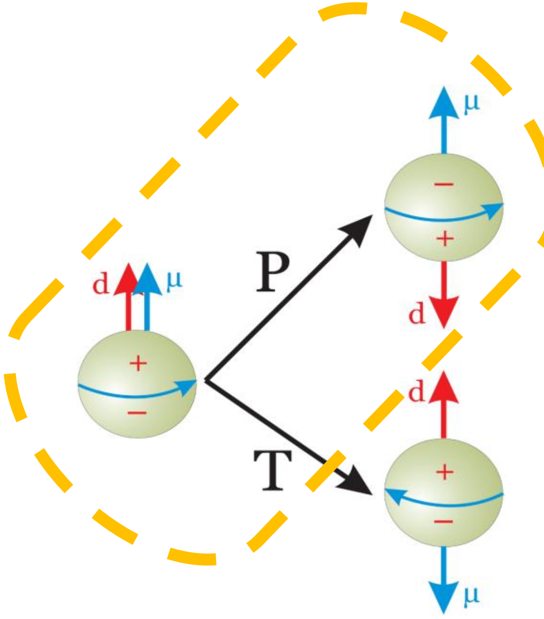


- Lee and Yang suggest it in 1956
- Chien-Shiung "Madame" Wu and collaborators observe it in 1957
- Cobalt nuclei were cooled so that putting them in magnetic field "polarized" them.
- For parity conservation, electron emission probability should be 50/50 with/against direction of nuclear spin
- Observation→ preferred direction opposite nuclear spin
- Eventually showed that neutrinos are left-handed: intrinsic spin is opposite of velocity direction

With Parity Violation comes non-zero nEDM

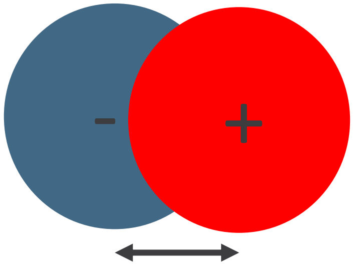
- For a fundamental particle with spin, the EDM, if exists, has to align with the direction of its spin, since the spin is the only vector in the system.

- Vectors pointing along other directions would average out to zero as the particle "spins"



Electric Dipole Moments

- Permanent asymmetry in the internal charge density distribution.
- The Wigner-Eckart theorem:- For spin-1/2 particle, under isotropic space, all tensors of the same rank (e.g. μ_m,d_e & $\vec{\sigma}$) are proportional each other.



- Under the application of static B and E field, the interaction Hamiltonian becomes:

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

Different from EDMs of electrically polarized atoms and molecules, which are caused by the presence of degenerate ground state mixing!

- Under Parity and Time Reversal:

$$PH = -(\vec{\mu_n} \cdot \vec{B} - \vec{d_n} \cdot (-\vec{E})) \neq H$$

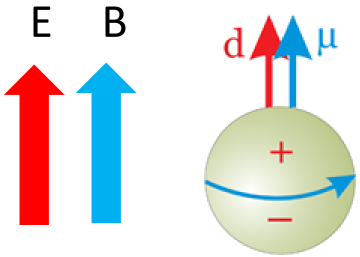
$$TH = -((-\vec{\mu}_n) \cdot (-\vec{B}) - (-\vec{d}_n) \cdot \vec{E}) \neq H$$

- We have P, T and CP (from CPT theorem) symmetry violations

Same story but with pictures

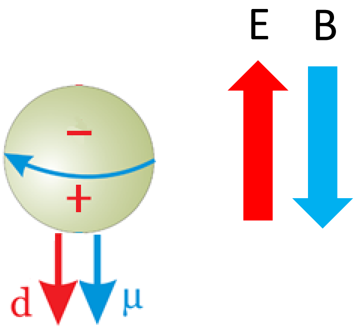
Fundamental particles don't have degenerate ground state, so $\vec{d} = d\hat{J}$.

We start with the ground state of:



T

$$\vec{d} = d\hat{J}$$



$$\varepsilon_{1/2} = dE + \left(\frac{1}{2}\frac{h}{2m}\right)B$$

$$\varepsilon_{1/2} = \underbrace{-dE}_{\text{T-odd}} + \underbrace{\left(-\frac{1}{2}\frac{h}{2m}\right)(-B)}_{\text{T-even}} \quad \Rightarrow [H,T] \neq 0$$

The ground state is not a T eigenstate!

The Hamiltonian violates T symmetry.

The physics must violate the time-reversal symmetry, in order for the EDM and the spin to co-exist.

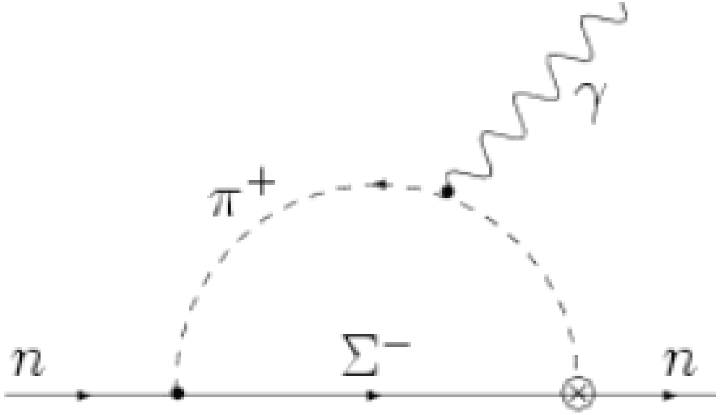
Looking for CP violation in nEDMs

- **Electroweak sector:**
  - CP violation arises from complex phases in the CKM matrix
  - SM estimates $|d_n| \approx 10^{-32} e \cdot cm$

- **Strong sector:**
  - Allowed term in QCD Lagrangian that does not vanish

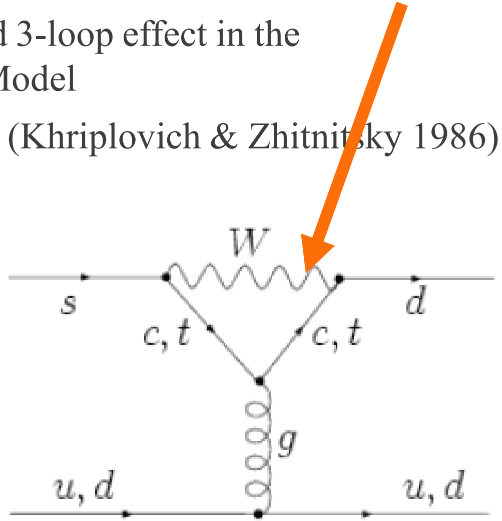
$$\mathcal{L}_{\bar{\theta}} = -\frac{\alpha_s}{16\pi^2}\bar{\theta} Tr(G^{\mu\nu}\bar{G}_{\mu\nu})$$

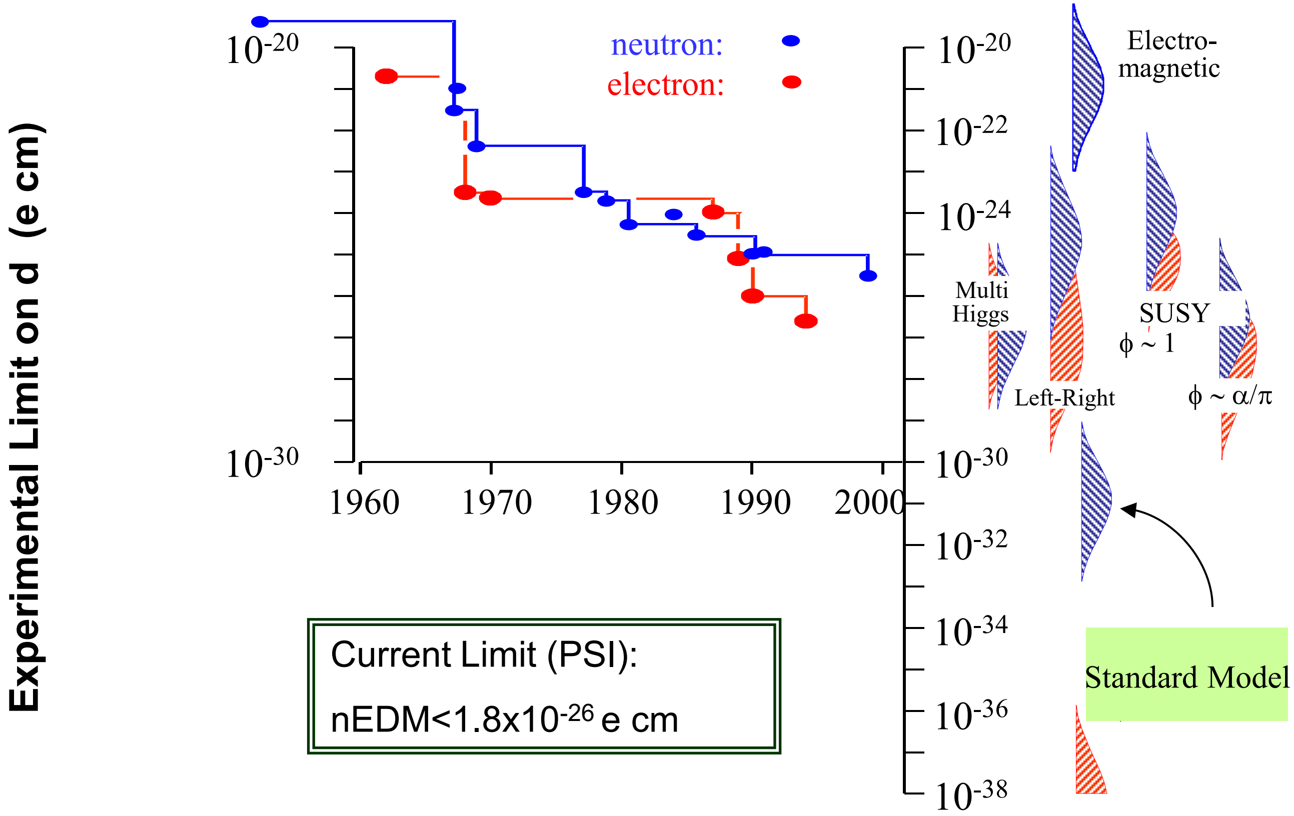
  - At LE, it can be reduced to a CP-odd quark current.
  - The resulting EDM is about a thousandth of the size of the nucleon, with a theta phase on the order one.
  - The results of null EDM requires that the theta-term to be some arbitrary small value, and thus the Strong CP problem
    - Could be solved by a new gauge field that couples to gluons similarly → Axion



Suppressed 3-loop effect in the Standard Model

$d_n \sim 10^{-32}$ e-cm (Khriplovich & Zhitnitsky 1986)





Current Limit (PSI):

nEDM<1.8×10^{-26} e cm

We love EDMs because:

Theorists

1. Essentially free of SM "background" (CKM)*

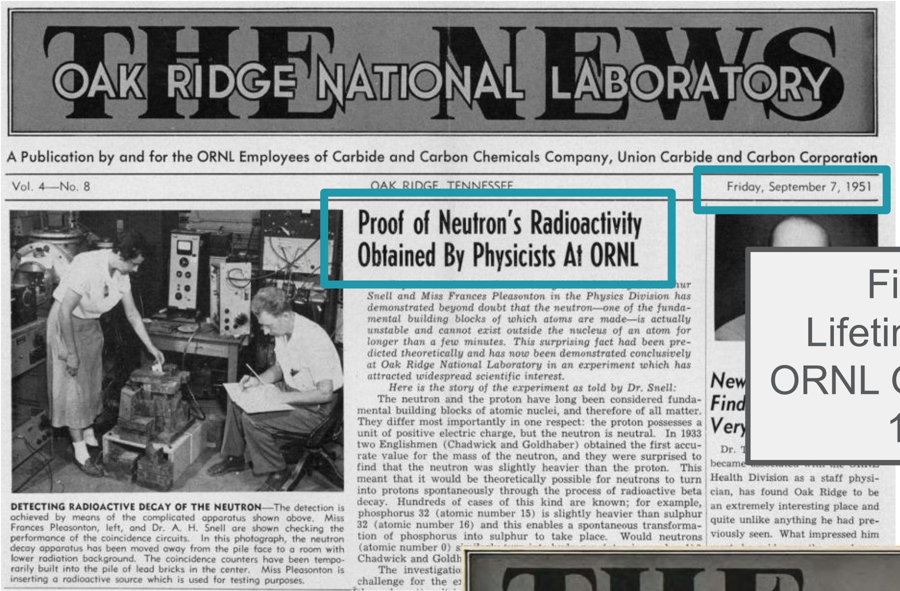
2. Probe very high-scales (Λ~10-100 TeV)

$$d_n \propto \frac{m_q}{\Lambda^2} e\,\phi_{CP}$$

3. Probe key ingredient for baryogenesis (CPV in SM is insufficient)

* Observation would signal new physics or a tiny QCD θ-term ($< 10^{-10}$).
Multiple measurements can disentangle the two effects

Slide from Vincenzo Cirigliano



First Neutron
Lifetime Experiment
ORNL Graphite Reactor
1948-1951

The measurement was motivated by a conversation between Ramsey and Rabi to test the parity conservation. Their measurement at Oak

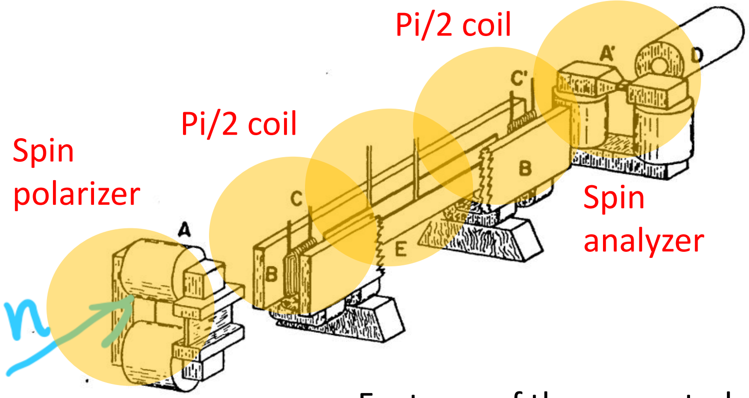
Ridge got a null result, supporting parity conservation, so they did not bother to publish the result.

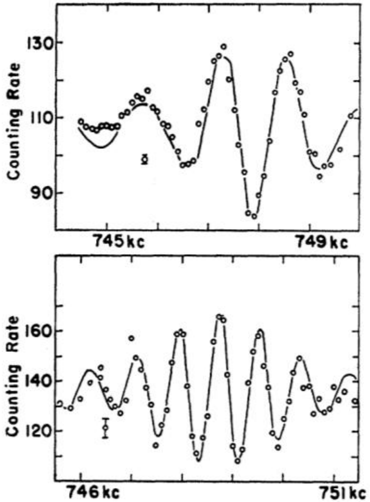
First Neutron
EDM Experiment
ORNL Graphite Reactor
c.1950

Archival documents courtesy
V. Cianciolo & T. Gawn

A particular arrangement that is more advantageous in many cases is one in which the oscillating field is confined to a small region at the beginning of the space in which the energy levels are being studied and to another small region at the end, there being no oscillating field in between.

-- N. Ramsey (1950)



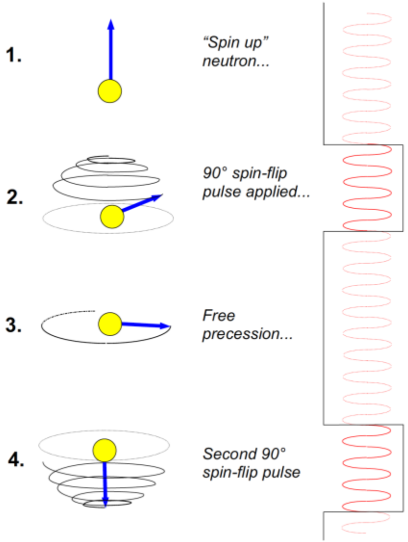


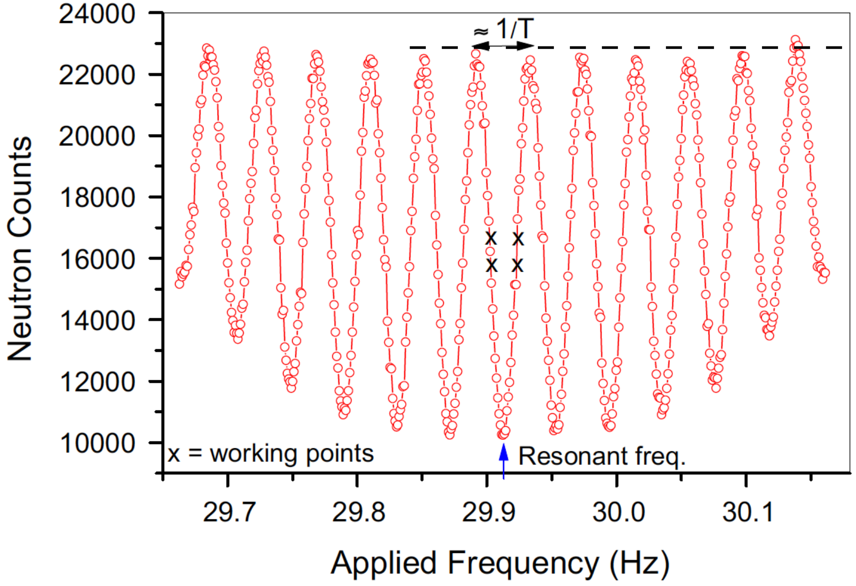
Features of the separated oscillatory fields:

1. Narrow fringes
2. Not sensitive to the field uniformity.

Ramsey's method of separated oscillatory fields with UCN ushers in modern nEDM measurements

Nobel Prize in Physics in 1989 "for the invention of the separated oscillatory fields method and its use in the hydrogen maser and other atomic clocks"



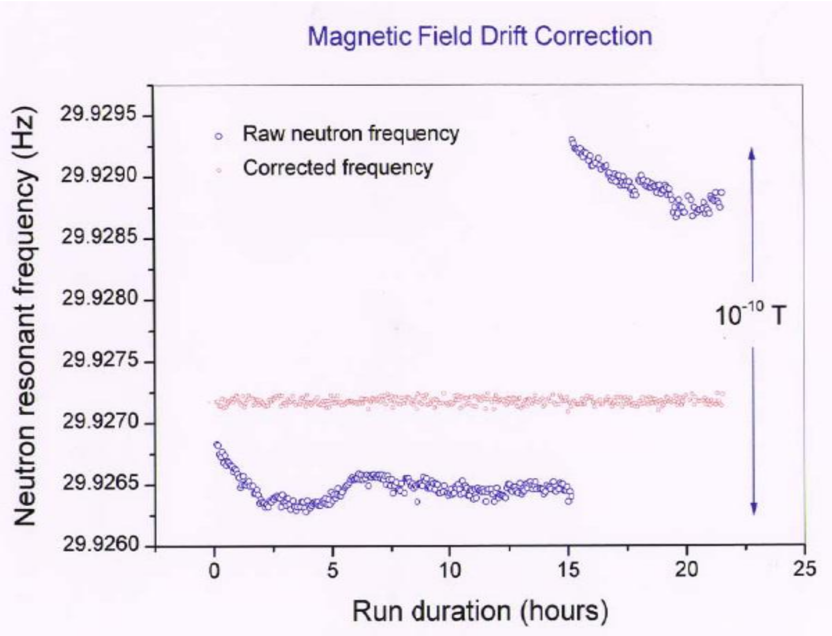


"Co-magnetometer" for B-field fluctuations

$$H = -\left(\mu\vec{B} + d_n\vec{E}\right)\cdot\frac{\vec{S}}{|S|}$$

A B field of 2 fT would cause a 0.1 μHz shift in frequency, equivalent to a EDM signal of 10^{-26} e·cm in a 10kV/cm field.
A "co-magnetometer"

Uniformly samples the B Field, faster than its relaxation time.

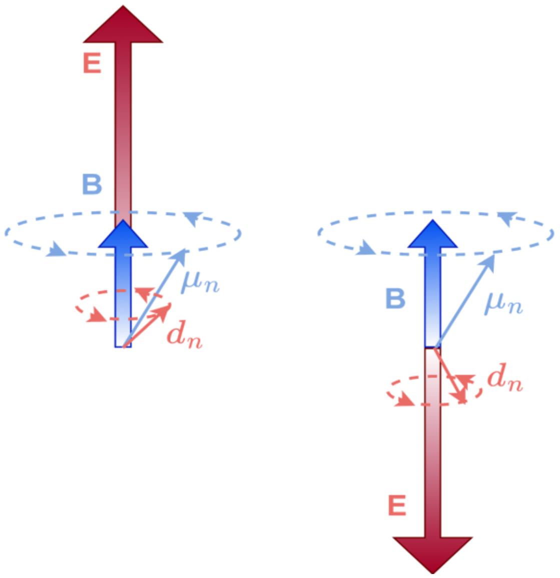


Polarized ^{199}Hg atoms; EDM of ^{199}Hg < 10^{-29} e-cm (measured)

How to Measure an EDM

- Particles of interest are placed in a uniform magnetic field perpendicular to their spin.
  - Spins precess at their Larmor frequency: $f = -\frac{2}{h}(\overrightarrow{\mu_B} \cdot \vec{B})$
- Apply a strong electric field parallel to $\vec{B}$…
- Flip the relative direction of $\vec{B}$ and $\vec{E}$…
- Look for a frequency shift proportional to E: $\Delta f = 4\mu_E E/h$
  - For $\mu_E = 10^{-28}$e·cm and $E = 75$kV/cm,

    $\Delta f \sim 7.5$ nHz.



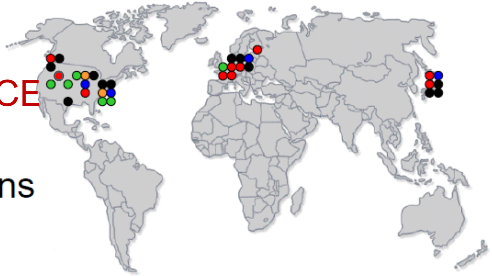
$$\delta d_n = \frac{\hbar}{2\sqrt{2}\alpha E T_{free}\sqrt{N}}$$

Slide courtesy of V. Cianciolo

EDMs Worldwide

Rough estimate of numbers of researchers, in total ~500 (with some overlap)

- Neutrons ~200
  - @ILL
  - @ILL,@PNPI
  - @PSI
  - @FRM-2
  - @RCNP,@TRIUMF
  - @SNS
  - @J-PARC
  - @LANSCE
- Molecules ~50
  - YbF@Imperial
  - PbO@Yale
  - ThO@Harvard
  - HfF+@JILA
  - WC@UMich
  - PbF@Oklahoma
- Atoms ~100
  - Hg@UWash
  - Xe@Princeton
  - Xe@TokyoTech
  - Xe@TUM
  - Xe@Mainz
  - Cs@Penn
  - Cs@Texas
  - Fr@RCNP/CYRIC
  - Rn@TRIUMF
  - Ra@ANL
  - Ra@KVI
  - Yb@Kyoto



- Ions-Muons ~200
  - @BNL
  - @FZJ
  - @FNAL
  - @JPARC
- Solids ~10
  - GGG@Indiana
  - ferroelectrics@Yale

K. Kirch, Proceedings CIPANP 2012
http://nedm.web.psi.ch/EDM-world-wide/

2019 EDM Limits: Comparing Physics Sensitivity

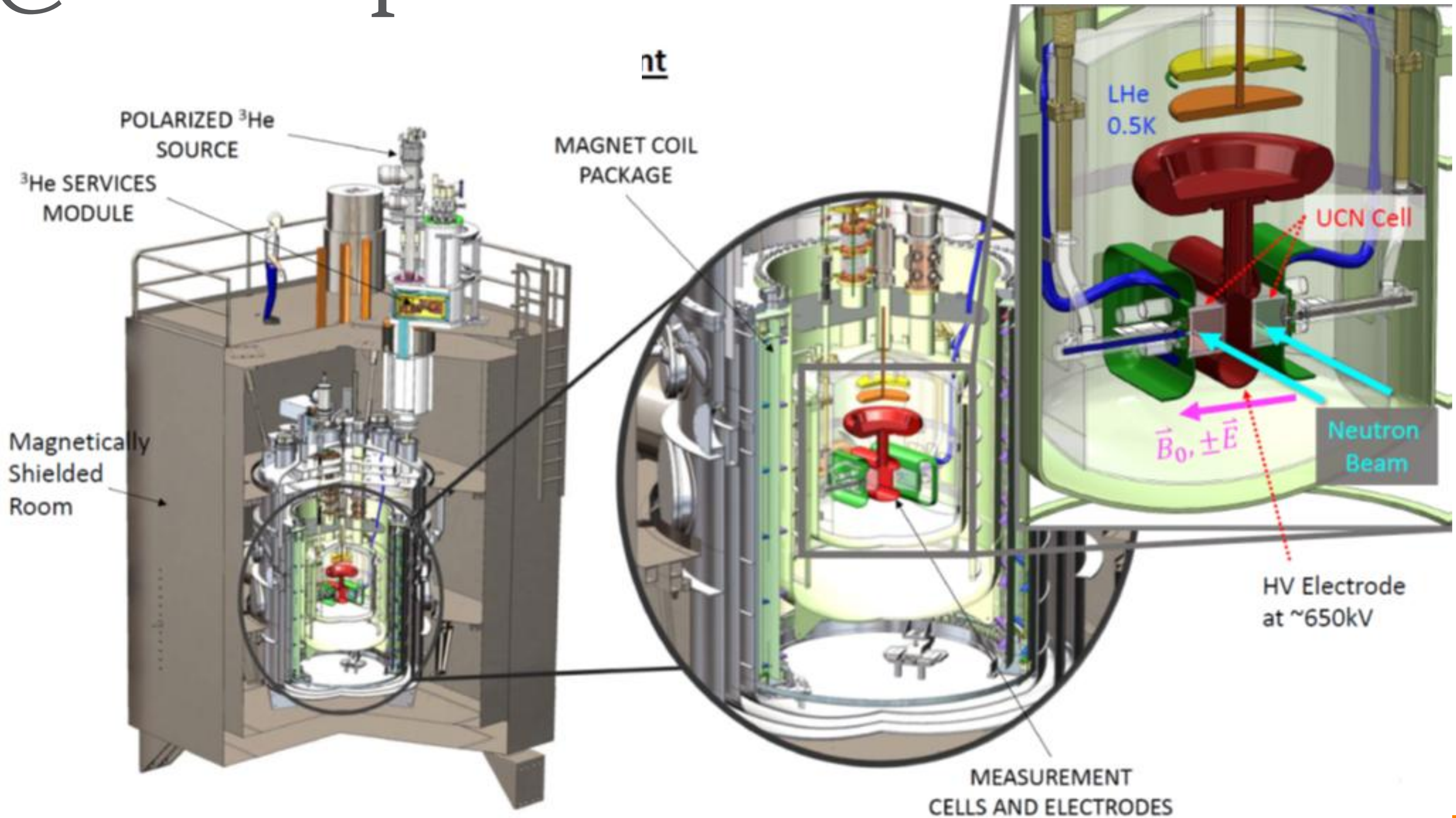
T.E. Chupp, P. Fierlinger, M. Ramsey-Musolf, JTS, RMP 91:015001 & Nature 562:355 (2018) & PRA 100:022505 (2019)

System	Best Limit (2σ) 1E-28 *e* cm	SM estimate 1E-28 *e* cm	Method (Location)
Electron	0.11	$\sim 10^{-10}$	cold ThO beam (Harvard/Yale)
Muon	1.8×10^{9}	$\sim 10^{-8}$	g-2 (BNL)
Neutron	360	$\sim 10^{-4}$	UCN in bottle (ILL)
Nucleus	**0.074**	$\mathbf{\sim 10^{-7}}$	**Hg atoms in cell (UW-Seattle)**

Nuclear	Best Limit (2σ) 1E-28 *e* cm	Long Term Goal	Goal on "Hg scale"	Method (Location)
Hg-199	0.074	0.010	0.010	Hg atoms in cell (UW)
Xe-129	15	0.001	0.010	Xe/He in cell (Mainz)
Ra-225	140000	1.000	0.001	Ra atoms in a laser trap (ANL/MSU/USTC)

nEDM@SNS Experiment

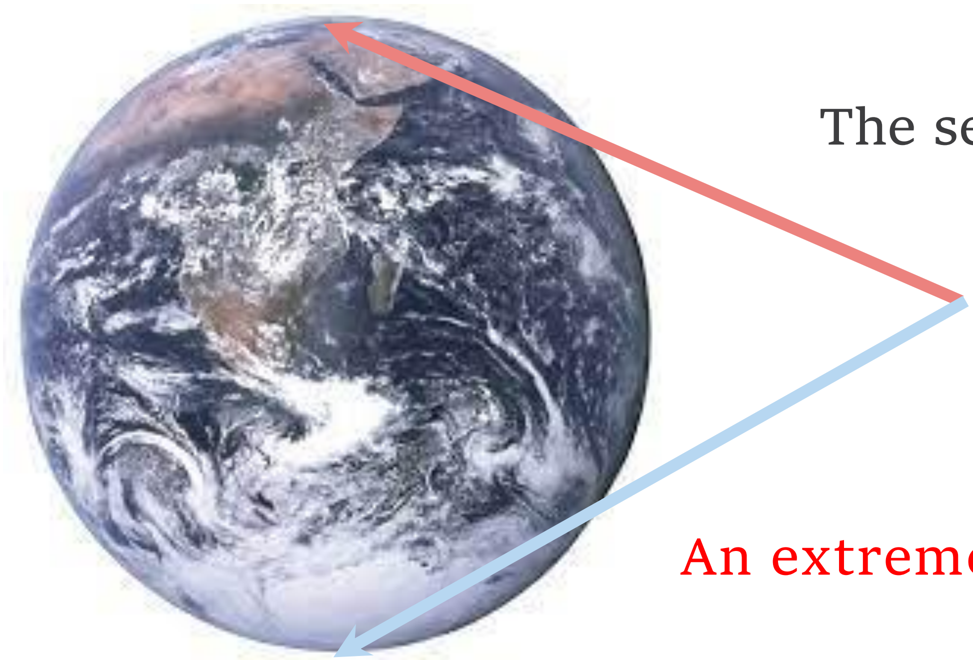
Sensitivity : $|d_n| \approx 10^{-28}\ e \cdot cm$



To put this into perspective…

Sensitivity : $|d_n| \approx 10^{-28}\ e \cdot cm$

If a neutron were the size of the earth…



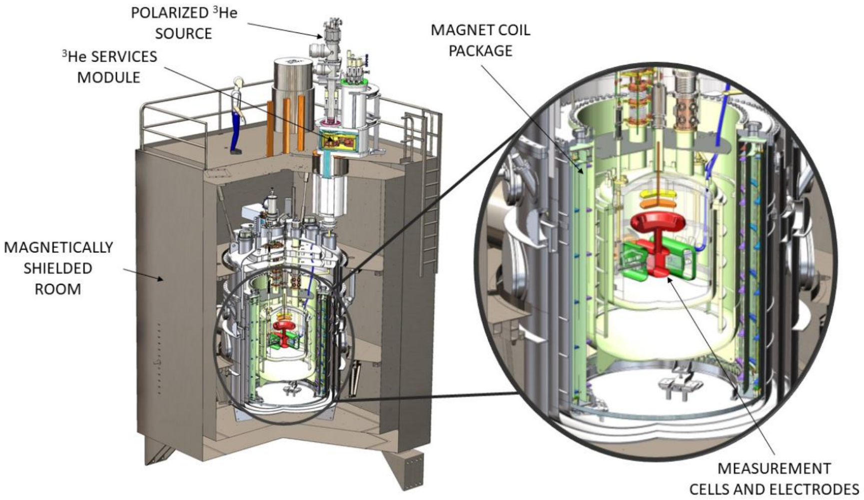
The separation in charge is only

$$1\ \mu m$$

An extremely precise measurement!

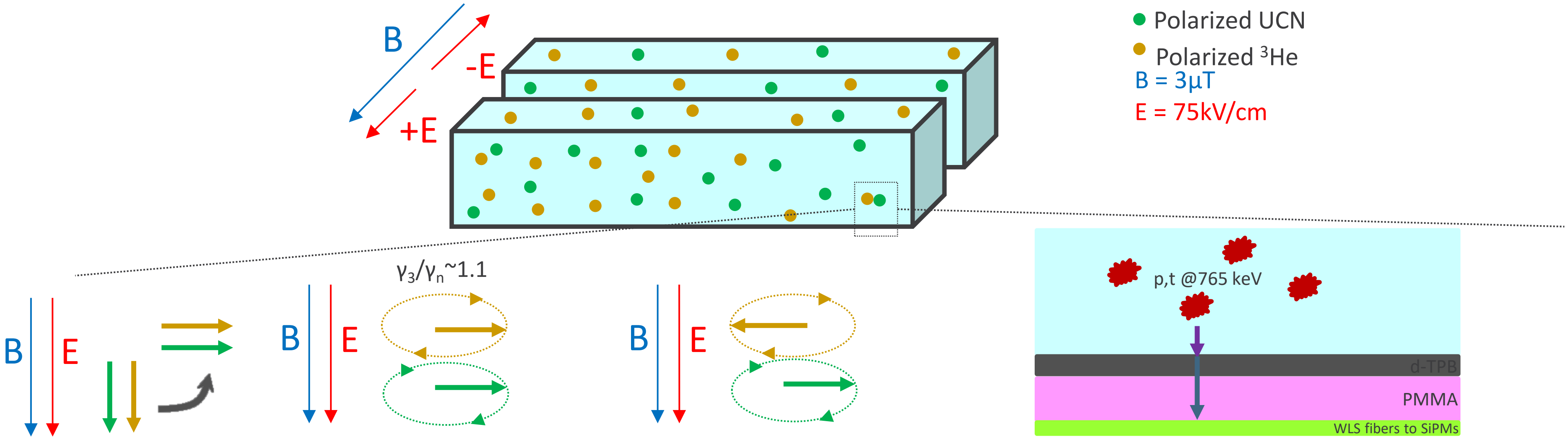
SNS@nEDM experiment

- Plans to measure $|d_n| \approx 10^{-28}\ e \cdot cm$
  - Current limit is $|d_n| < 1.8 \times 10^{-26}\ e \cdot cm$
- Measure d_n by neutron capture rate with polarized ^{3}He
- Uses ^{4}He to produce a high density of Ultra Cold Neutrons (UCNs)
  - Energies < 165 neV or velocity of 5 m/s
- UCNs can be contained for long periods of time
- An array of SQUID sensors for precision measurement/control over magnetic fields.



nEDM@SNS measurement cycle

Let the polarized UCN and polarized ^{3}He precess and collect scintillation signal from the n-^{3}He capture reaction at the beat frequency.



Apply a π/2 pulse.

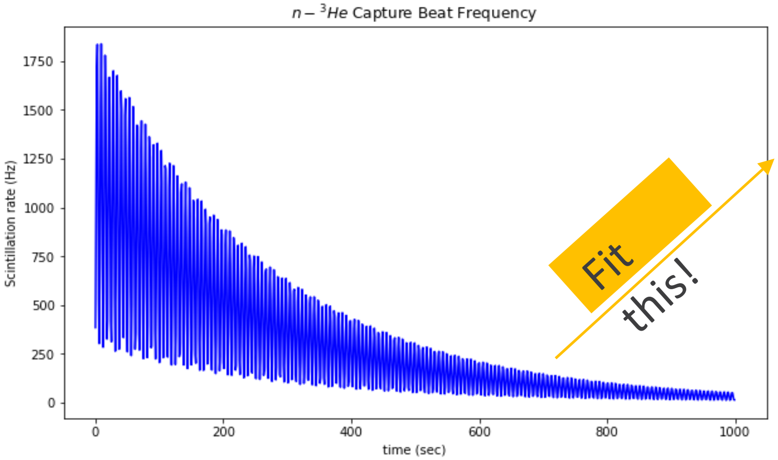
n-^{3}He absorption reaction: n+^{3}He→p+t
$\sigma_{\uparrow\downarrow}$~ 800 kbarns and $\sigma_{\uparrow\uparrow}$ ~ 0 barns

Decay products excite SF ^{4}He which scintillates. (80nm UV)

Scintillation $\propto 1 - |P_n P_3[\cos(\omega_{n3})\, t]|$

Free Precession Method

From scintillation rate, we can extract the n-^{3}He precession frequency, ω_{n3} , for both cells.



Fit this!

$$\frac{1}{\tau_{UCN}} = \frac{1}{\tau_{up}} + \frac{1}{\tau_{walls}} + \frac{1}{\tau_\beta} + \frac{1}{\tau_3}$$

$$\dot{N}(t) = \frac{\epsilon_\beta N_0}{\tau_\beta} e^{-t/\tau_{UCN}} + \frac{\epsilon_3 N_0}{\bar{\tau}_3}\left[1 - P_n P_3 \cos(\omega_{n3} t + \phi)\right] e^{-t/\tau_{UCN}} + \dot{N}_{BKGD}$$

$$\omega_{n3} = (\gamma_n - \gamma_3) B_0 \pm \frac{2 d_n E}{\hbar}$$

$$\omega_n = \omega_{n3} - \omega_3$$

SQUIDS

Cell 1 (+E) $\omega_{n+} = \mu_n B_0 + d_n E_0$

Cell 2 (-E) $\omega_{n-} = \mu_n B_0 - d_n E_0$

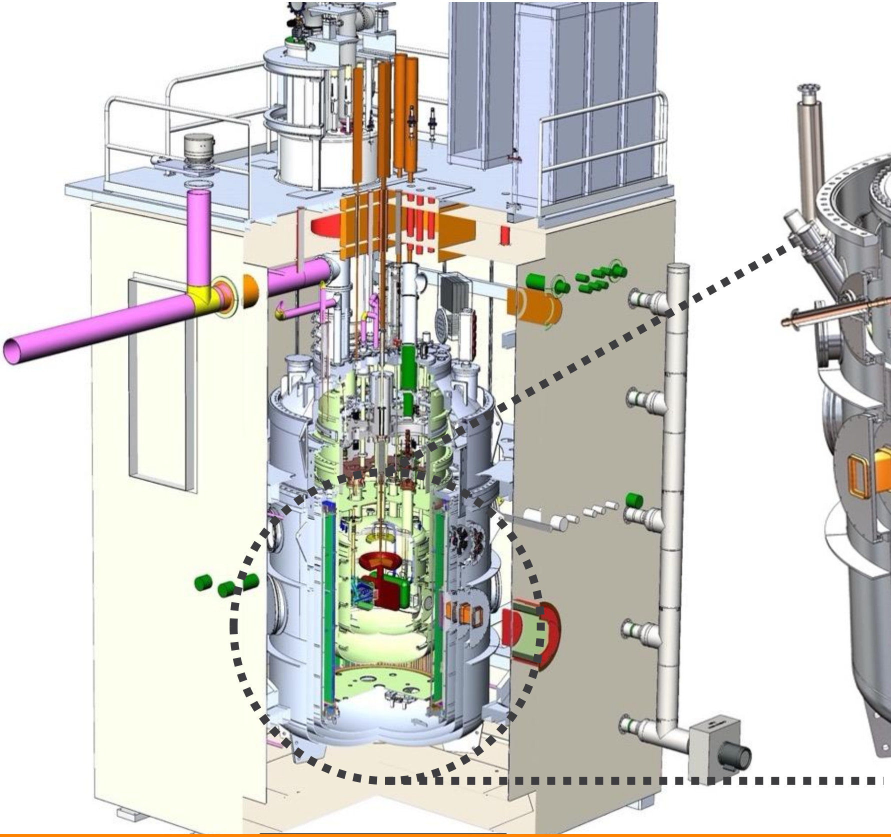
$$\Delta\omega_n = \omega_{n+} - \omega_{n-} = \frac{d_n E_0}{\hbar}$$

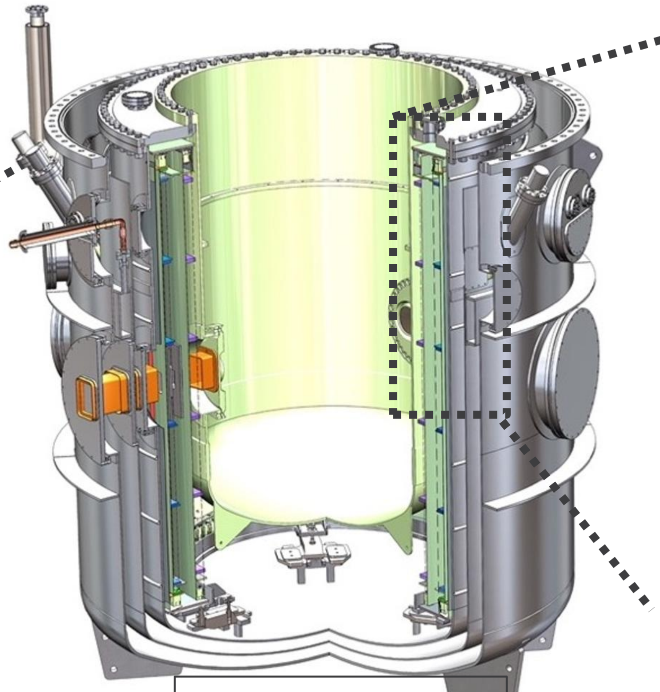
300 live days (~3 years)

$$\sigma_{d_n} = 3.3 \times 10^{-28} e \cdot cm$$

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Magnetic Shield Enclosure and Cryogenic Magnet





nEDM@SNS Cryomagnet Package

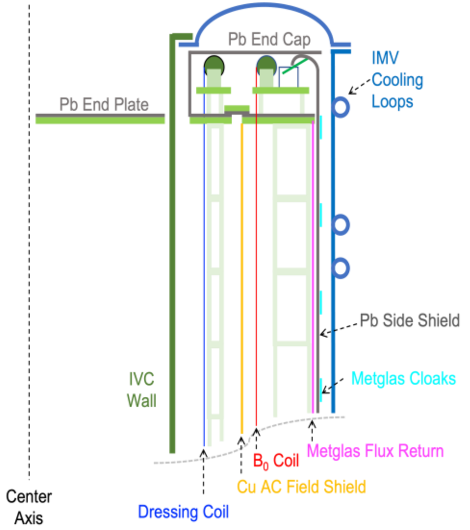
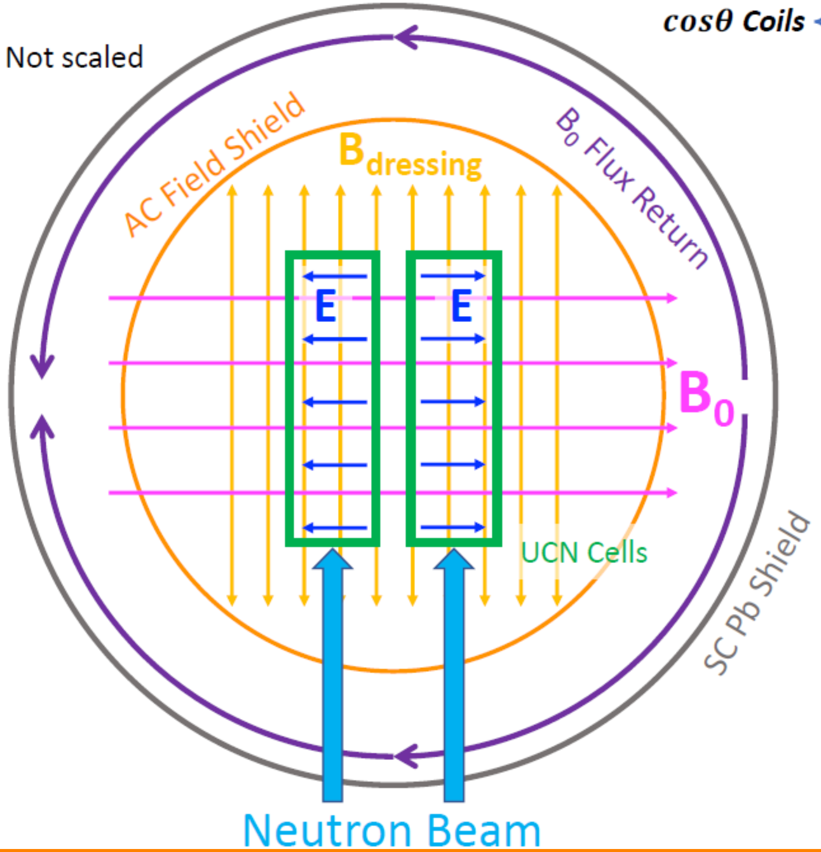


Illustration of the Magnetic Fields



cosθ Coils

B_0 Coil: (Superconducting Cu-clad NbTi wire)

- 30 mG and uniformity of 3 ppm/cm
- uniformity is crucial for the transverse coherence time T_2 of UCN and helium-3

Dressing Coil: (Superconducting Ti/Pb Solder Wire)

- AC field < 0.5 G and uniformity of 45 ppm/cm
- also used as $\pi/2$ spin flip

Superconducting Pb Shield:

Further shield the ambient environmental magnetic fields and stabilize the magnetic drifts over the measurement time

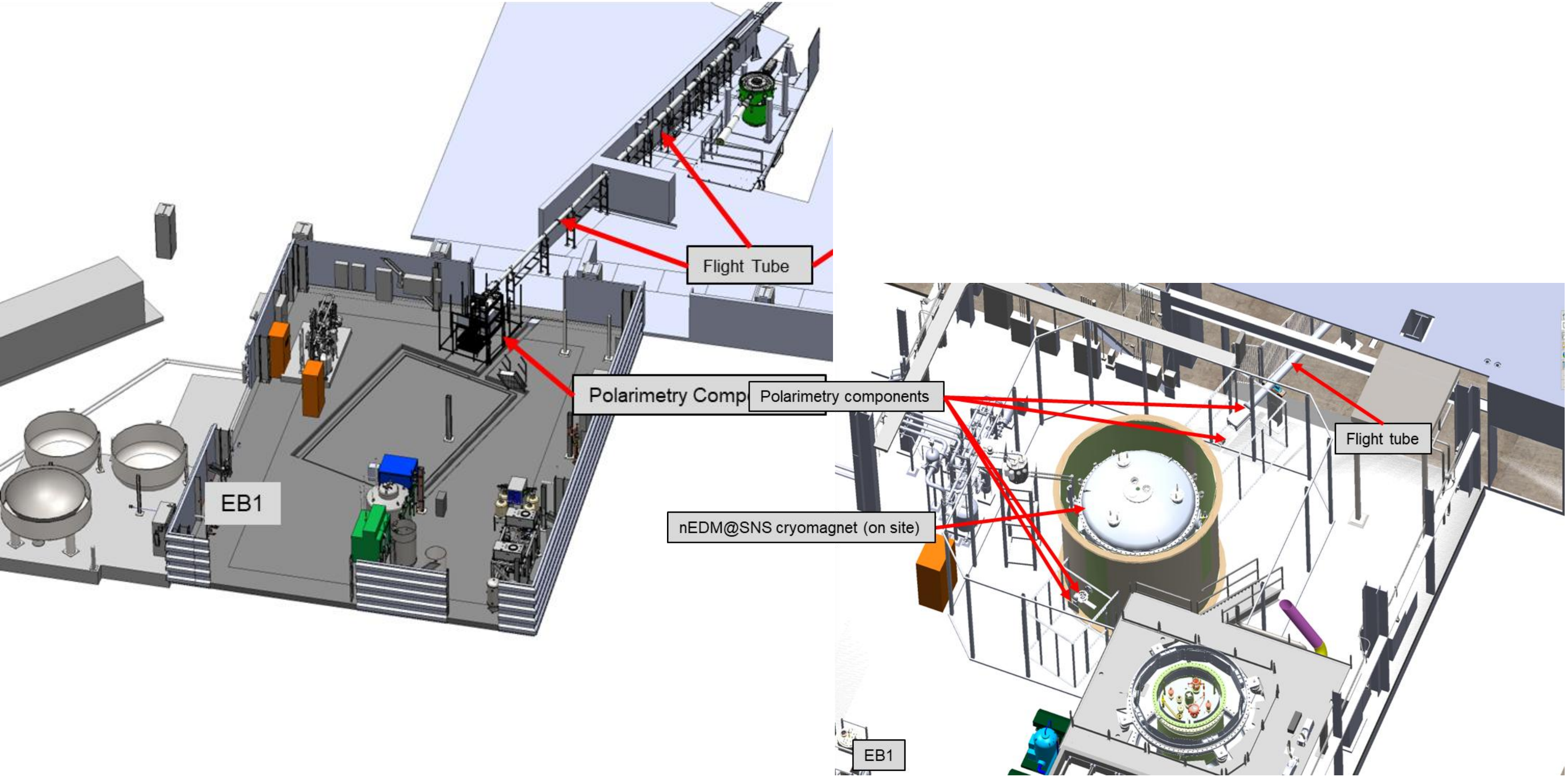
B_0 Flux Return:

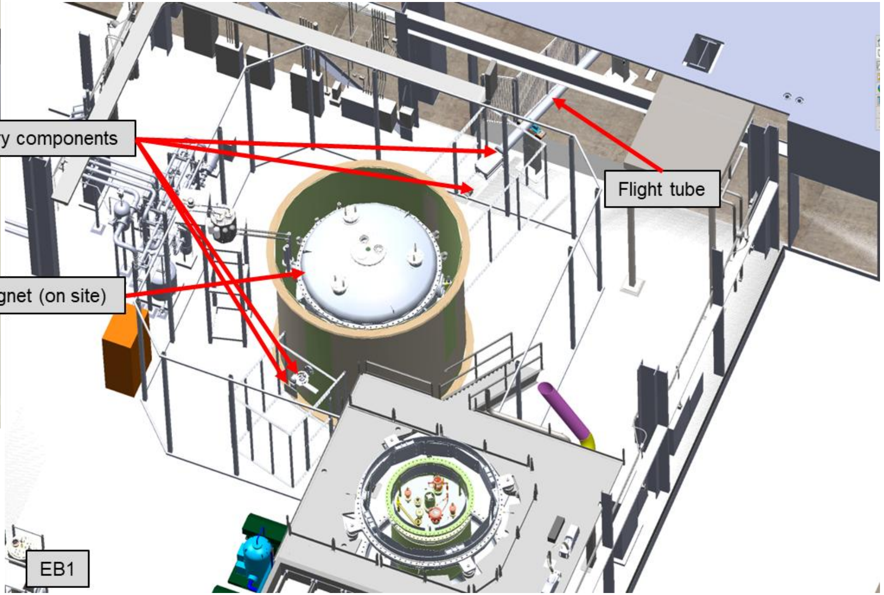
Metglas 2826M, location accuracy < 1 mm

improve field uniformity, mitigating the effect of errors in wire placement and reducing field distortions due to the cylindrical superconducting shield just outside of this shield

AC Field Shield:

A copper film shields the Metlas from heating of the dressing field


Flight Tube
Polarimetry Comp
EB1
Polarimetry components
Flight tube
nEDM@SNS cryomagnet (on site)
EB1


Polarimetry components
Flight tube
nEDM@SNS cryomagnet (on site)
EB1

Department of Energy
Office of Science
Washington, DC 20585

Dr. Cynthia Jenks
Associate Laboratory Director for Physical Scien
Oak Ridge National Laboratory
1 Bethel Valley Road
Oak Ridge, TN 37830

November 6, 2023

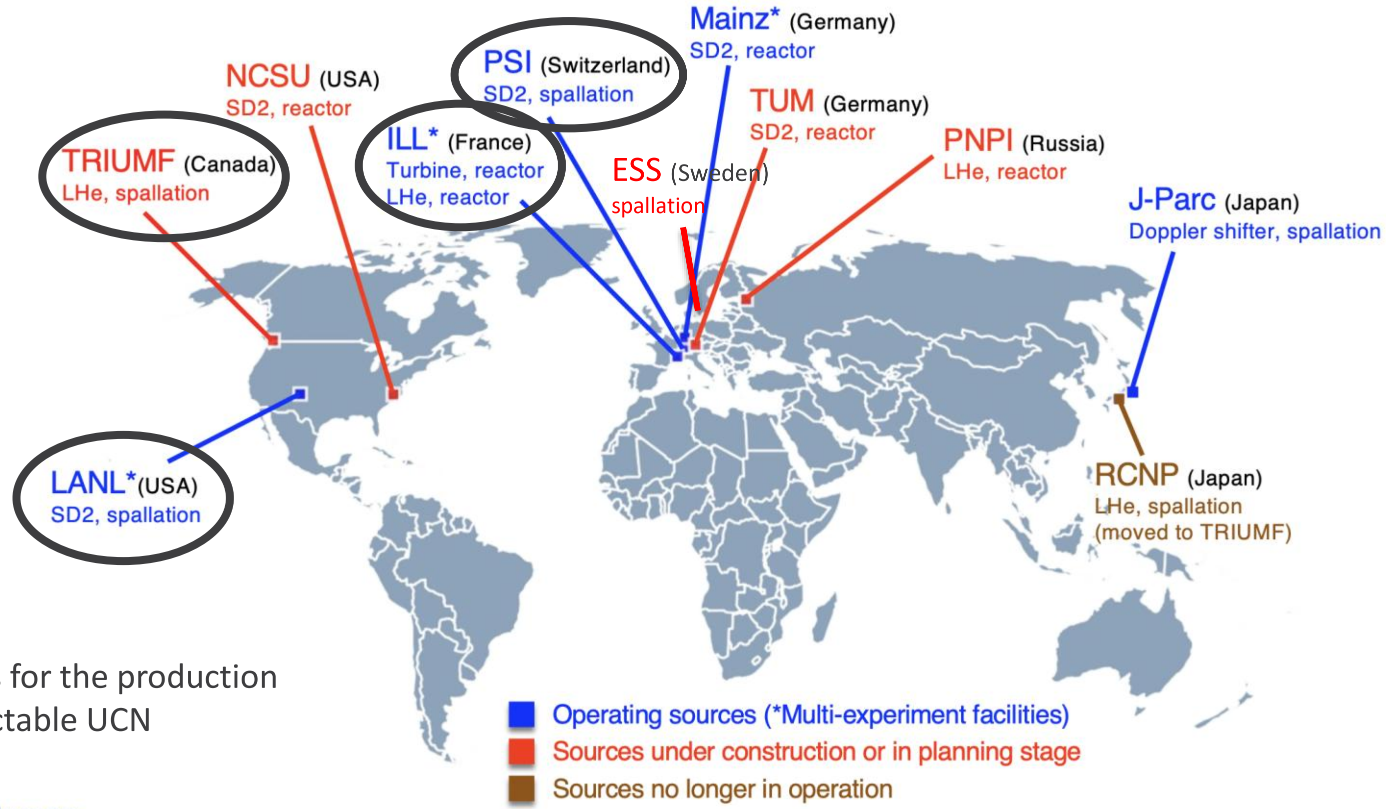
Stated plainly, despite overcoming a number of impressive technical challenges over the years, and in some cases developing entirely new technical solutions which have value on their own, DOE NP and NSF conclude there remains sufficiently large uncertainty in the cost, schedule, and technical risk to a successful completion of this activity that continued expenditure of cost and effort that would require sacrificing support in other areas is not justified. This decision was reached with due consideration for the impact it may have on the fundamental symmetries research community and the goal of making the world's best measurement of the neutron's electric dipole moment. I ask that you please work diligently with the respective program managers so that together we can implement an orderly ramp down of ongoing nEDM@SNS activities, allowing for any exposed staff to make a smooth transition. I also ask that those collaborators receiving a copy of this letter communicate this decision to all personnel involved in the experiment.

Sincerely,

Timothy J. Hallman
Digitally signed by Timothy J. Hallman
Date: 2023.11.09 13:03:10 -05'00'

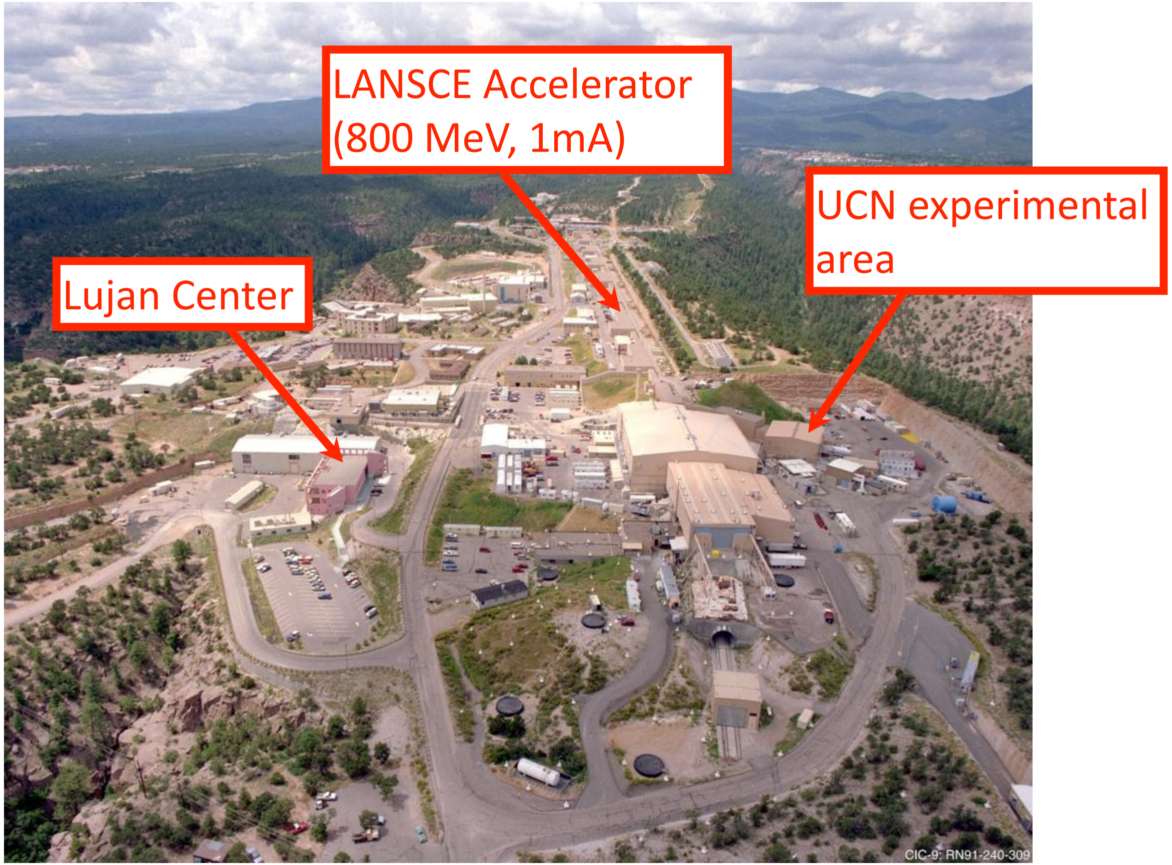
Timothy Hallman
Associate Director
Office of Nuclear Physics

Ultracold neutron sources in the world

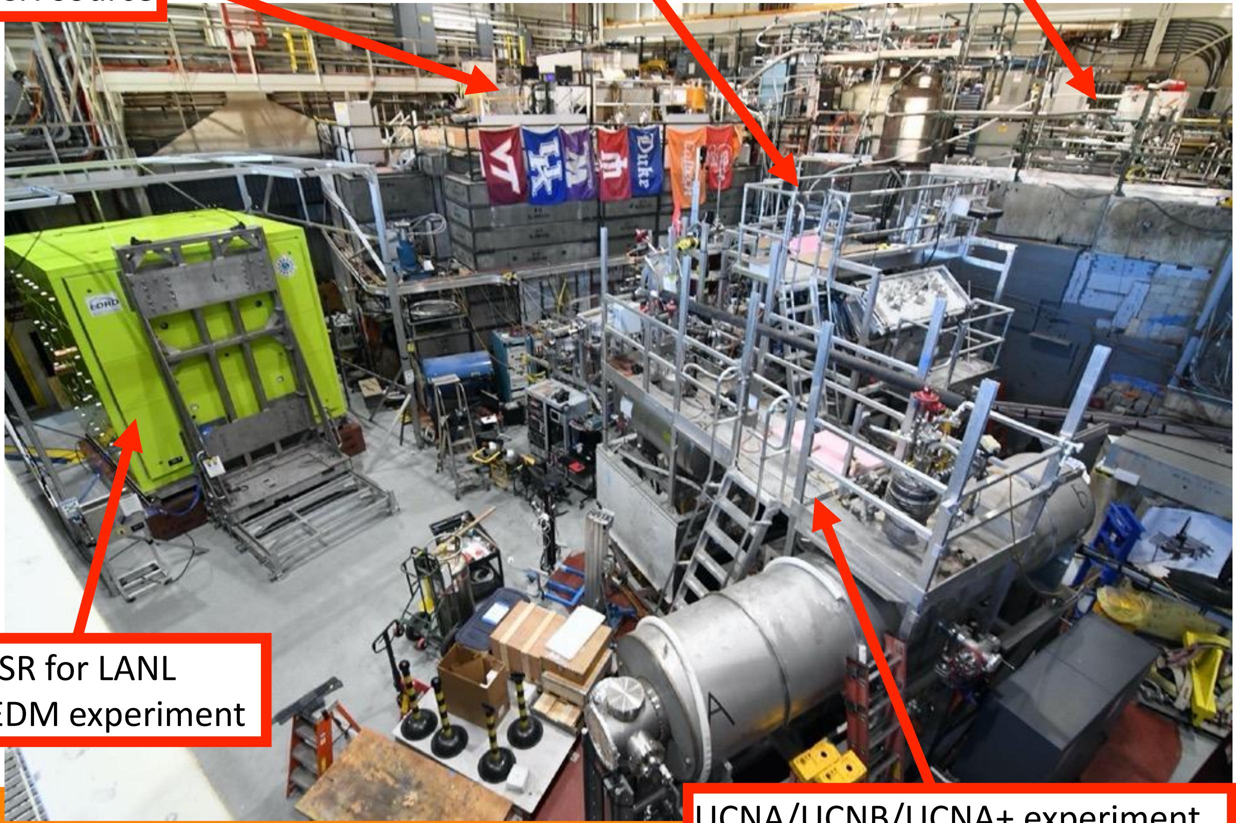


Facilities for the production of extractable UCN

Los Alamos Neutron Science Center



LANL UCN Experimental Hall



LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

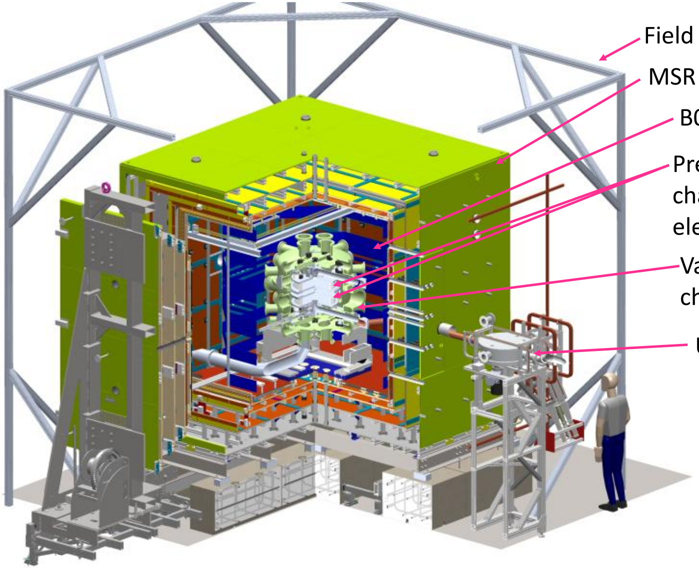
U.S. DEPARTMENT OF ENERGY | Office of Science

NSF

THE GLENN T. SEABORG INSTITUTE

LANL nEDM experiment

- Goal sensitivity:
  - $\boldsymbol{\delta d_n = 2 \times 10^{-27} e} \cdot \mathrm{cm}$
- Key features
  - Ramsey's separated oscillatory field method
  - Demonstrated UCN density*
  - Simultaneous spin analysis
  - Large MSR
    - 4 layers of mu-metal + 1 layer of RF shield
    - Outer dimension: 3.5 m x 3.5 m x 3.5 m
    - Inner dimension: 2.4 m x 2.4 m x 2.4 m
  - Double precession chamber
  - Magnetometry
    - 199Hg comagnetometer
    - 199Hg external magnetometer
    - OPMs



Estimated statistical sensitivity of an nEDM experiment

Parameters	Values
E(kV/cm)	12.0
N(per cell)	39,100
T_{free} (s)	180
T_{duty} (s)	300
α	0.8
σ/day/cell (10^{-26} e-cm)	5.7
σ/day (10^{-26} e-cm) (for double cell)	4.0
σ/year (10^{-27} e-cm) (for double cell)	2.1
90% C.L./year (10^{-27} e-cm) (for double cell)	3.4

$$\delta d_n = \frac{\hbar}{2\alpha T E \sqrt{N}}$$

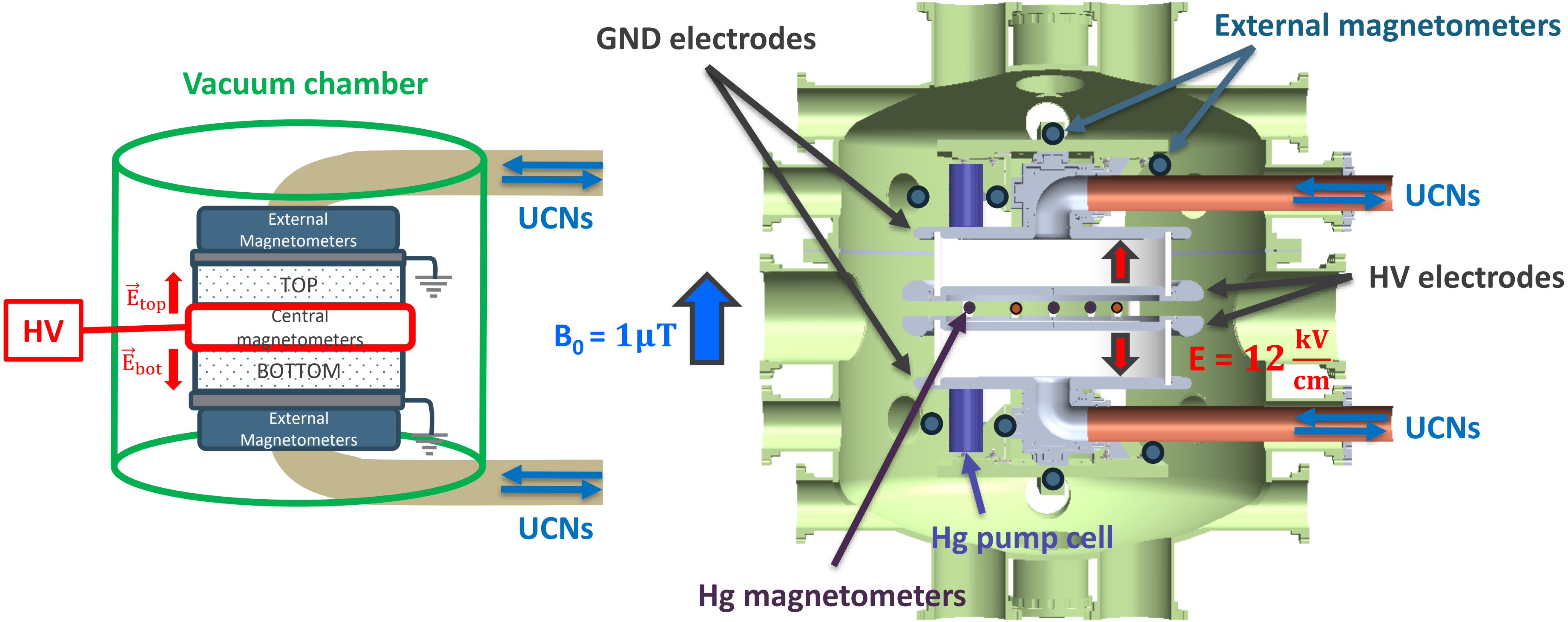
This estimate is based on the following:

- 50 cm diameter cell
- The estimate for E, T_{free}, T_{duty}, and α is based on what has been achieved by other experiments.
- The estimate for N is based on the actual detected number of UCN from our fill and dump measurement at a holding time of 180 s [1]. Further improvements have been achieved (new switcher and new detector) [2].

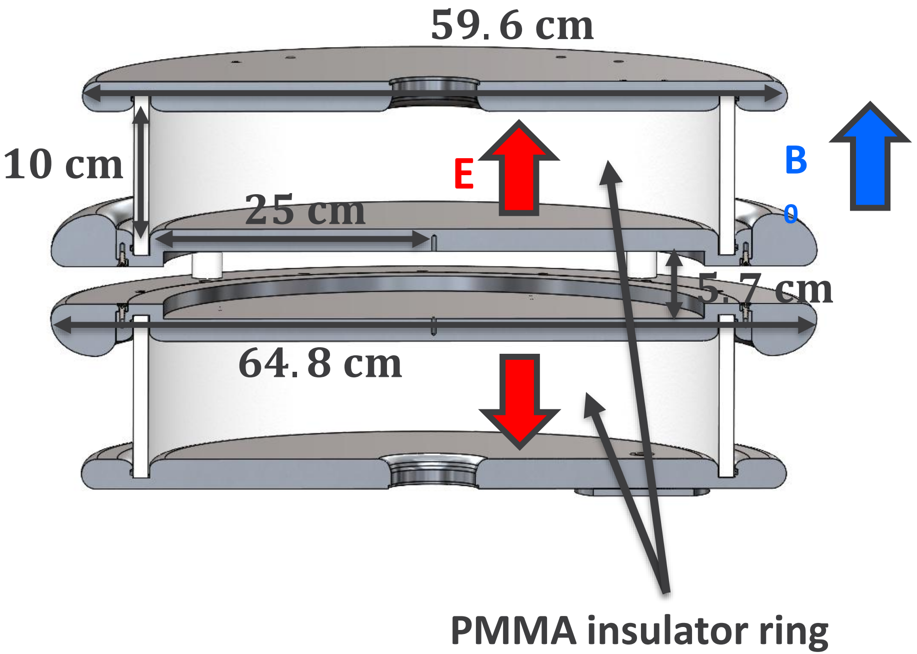
* "year" = 365 live days. In practice, it will take 5 calendar years to achieve this with 50% data taking efficiency and nominal LANSCE accelerator operation schedule

[1] T. M. Ito, et al., Phys. Rev C 97, 012501 (R) (2018)
[2] D. K.-T. Wong, et al., NIMA 1050, 168105 (2023)

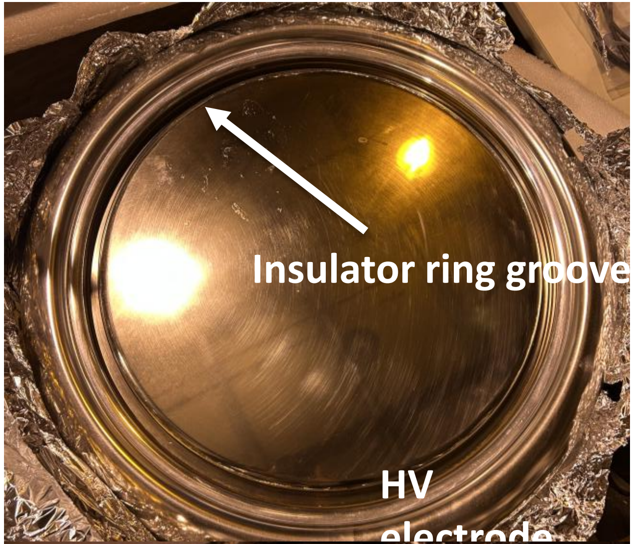
Precession chambers



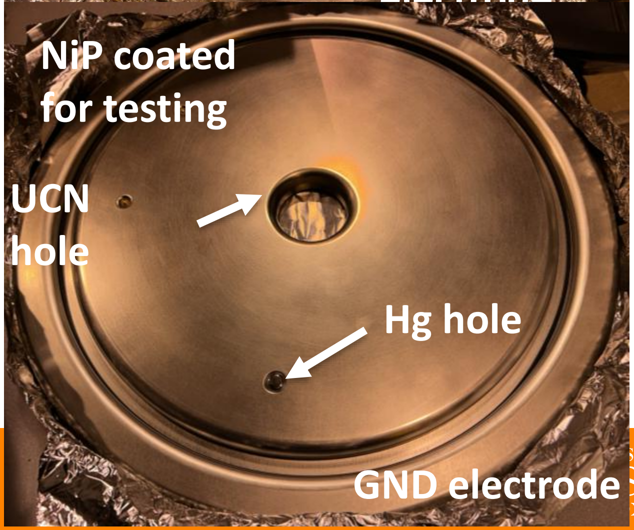
Electrodes



59.6 cm
10 cm
25 cm
E
B
0
5.7 cm
64.8 cm
PMMA insulator ring



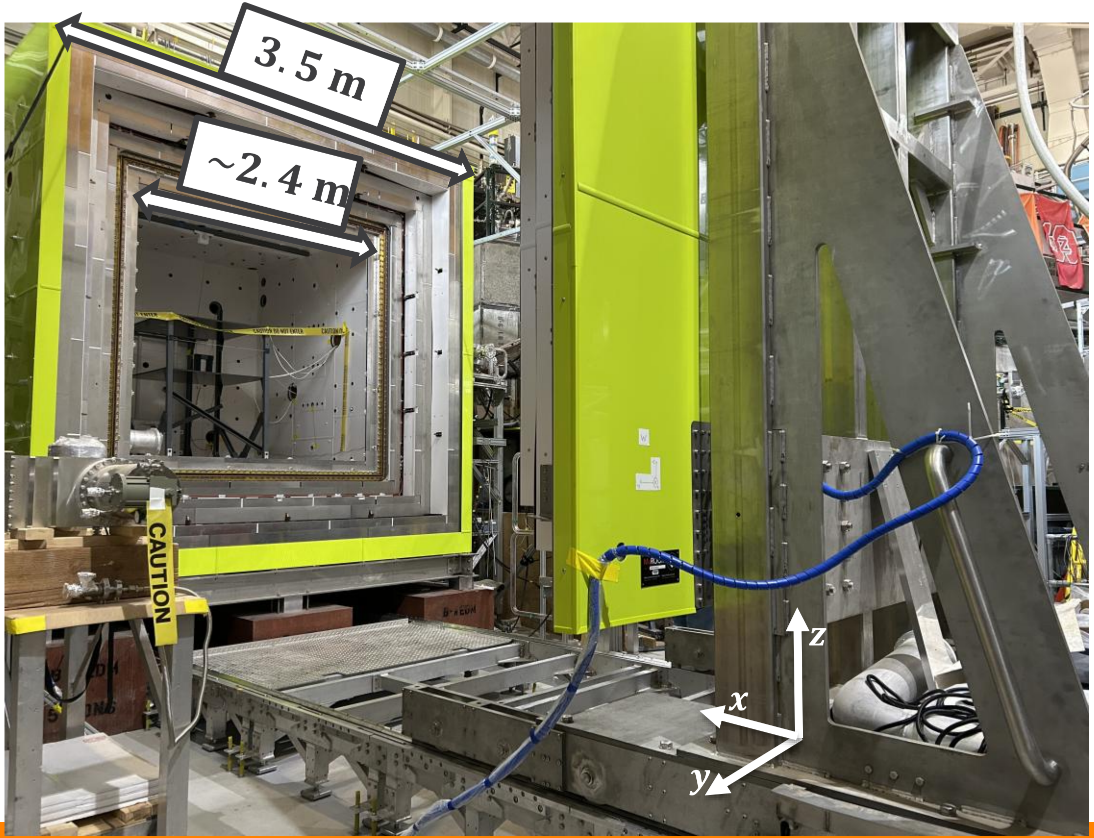
Insulator ring groove
HV electrode



NiP coated for testing
UCN hole
Hg hole
GND electrode

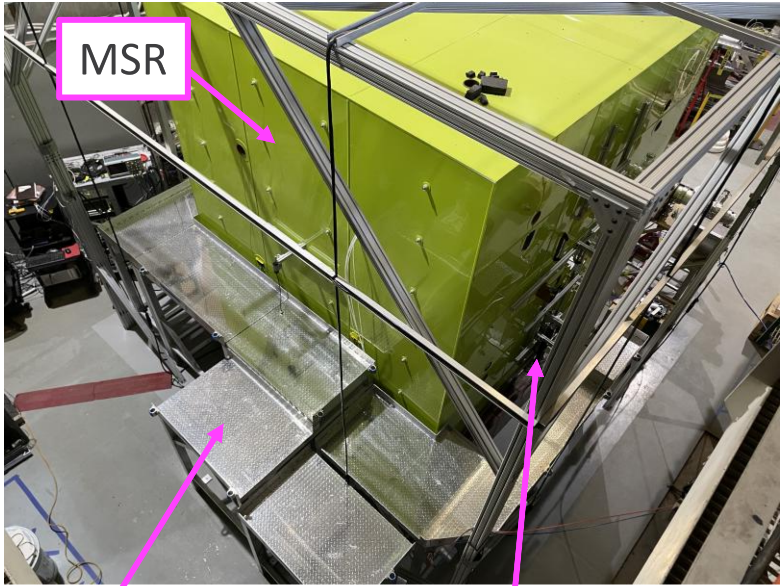
Magnetically shielded room (MSR)

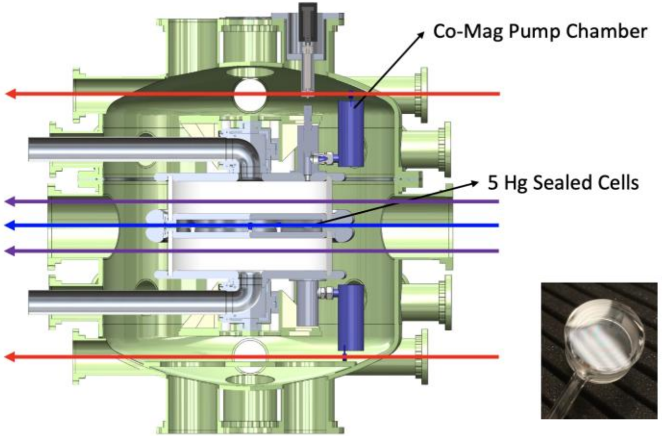
- 4 cubic layers of MuMetal and 1 layer of copper for RF shield
- Shielding factor of 10^4 at 0.01 Hz
- Residual field < 500 pT
- MSR performance aligns with the requirements

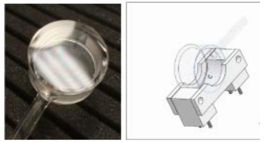


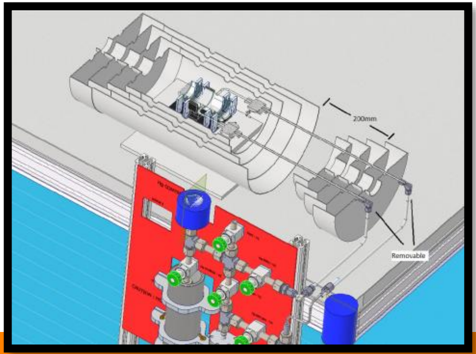
^{199}Hg (co)magnetometer

Successful platform installation









Development work in progress at U. Washington.

To be installed in the experiment in early 2026.

LANL nEDM Schedule

Now – June 2025: Maintenance Period

- Continued Magnetic Field Characterization (MSR, B0, STC, etc.)
- Scanning parts for magnetic impurity
- Assemble the Apparatus: UCN Storage Cells, HV, OPM, etc.
- Infrastructure Improvements

June – December 2025: Engineering Run

- Spin Transport Through MSR, Simultaneous Spin Analyzers, etc.
- Commission the Apparatus: UCN Storage Cells, HV, OPM, etc.

January – June 2026: Maintenance Period

- Install ^{199}Hg Co-Magnetometer

June – December 2026

- Commission ^{199}Hg Co-Magnetometer
- Initial Physics Run

LANL nEDM collaboration

Arizona State University

R. Alarcon, G. Velez Bustamante, S. Clymer, L. Domer

Los Alamos National Laboratory

T. Bowles, S. Clayton, C. Cude-Woods, A. Fratangelo, T. Ito, M. Makela, C. Morris, C. O'Shaughnessy, N. Phan, T. Sandborn, T. Schaub, I. Smythe, W. Uhrich

University of Illinois, Urbana-Champaign

Y. Chen, C.-Y. Liu, K. Zine, K. Young

Indiana University

M. Luxnat, G. Vasser, M. Snow

University of Kentucky

P. Adhikari, R. McDonald, R. Bhattarai, P. Palamure, B. Plaster, A. Tewsley-Booth

Massachusetts Institute of Technology

P. Hohan Murthy

University of Michigan

T. Chupp, F. Hills

East Tennessee State University

R. Pattie

Tennessee Tech

A. Reid, A. Holley

Valparaiso University

A. Koch, S. Stanislaus

University of Washington

T. Bowles, B. Heckel

Yale University

Steve Lamoreaux

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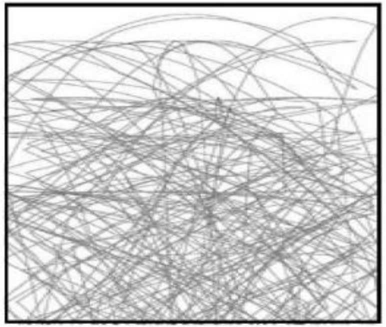
Simply the best.....so far

The search for the neutron EDM

Neutrons reflected for all incidence angles: UCNs

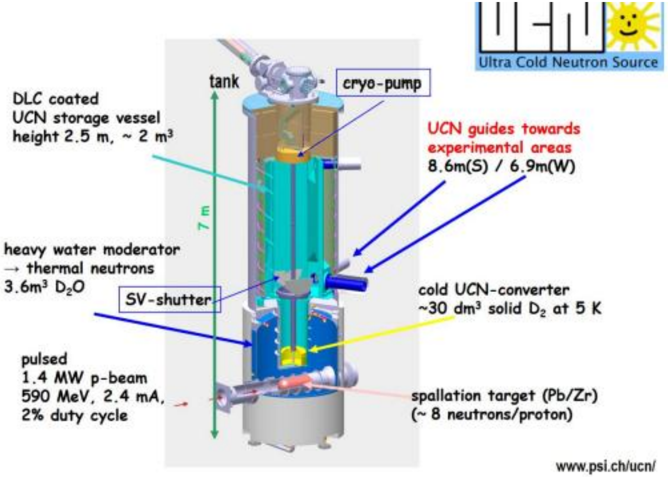


$\lambda_n \approx 800$ Å;

$v_n \approx 5$ m/s;

$T_n \approx 2$ mK ;

$E_n \approx 130$ neV



1. Did this experiment use Ramsey’s Method?
2. Were polarized or unpolarized neutrons used?
3. How good was the UCN density in the precession chamber?
4. How did this experiment control for B-field drifts?
5. Which systematic effect is described in most detail
6. What special measure(s) were taken to convince the community everything is accounted for?
7. How do you interpret eq.7 and the sentence below it?
8. What is the physics impact of the result?

A different way to look for T symmetry violation (but also with neutrons)

Three scientific goals of NOPTREX: Why Do It?

(1) Search for P-odd/T-odd NN interaction

-Discover new source of P-odd/T-odd interaction

(2) Search for P-even/T-odd NN interaction

-Discover new source of P-even/T-odd interaction

-Aid scientific interpretation of P-odd/T-odd electric dipole moment (EDM) searches

(3) Understand P violation in heavy nuclei

-Quantify weak matrix element in heavy nuclei

-Compare with statistical theory of P-odd N-A

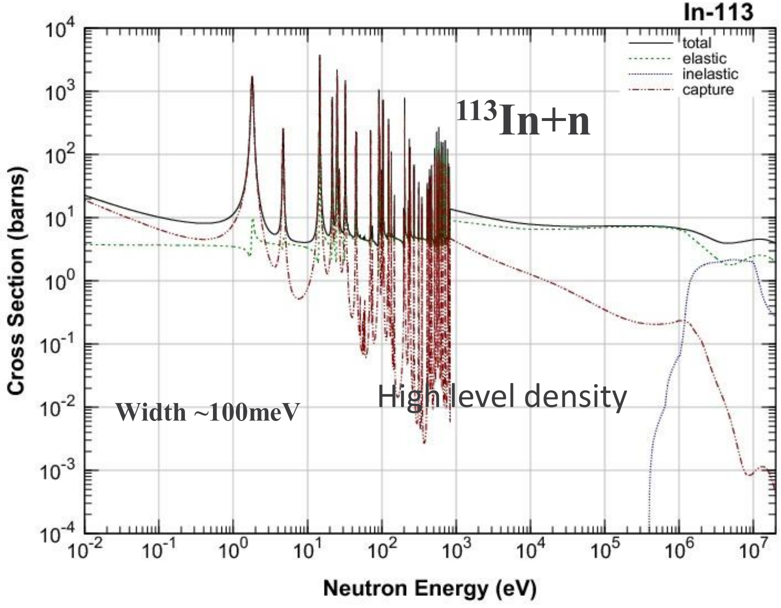
-Success bolsters confidence in (1) and (2)

Neutron-Nucleus Resonances

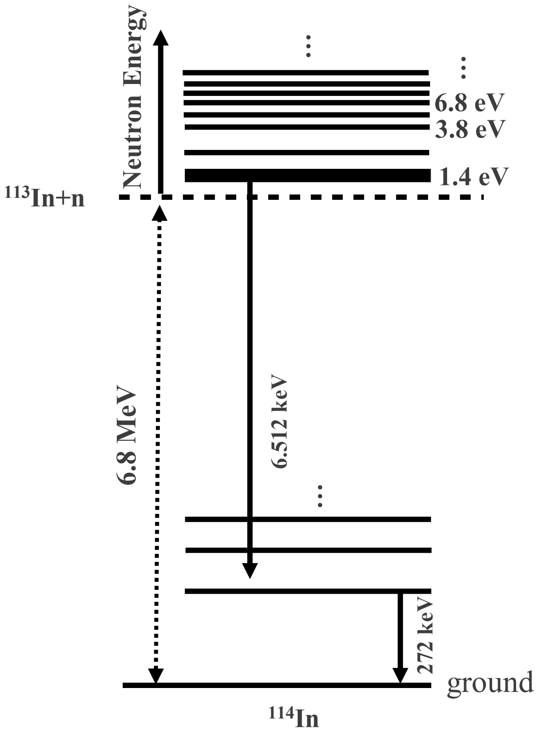
dense set of resonances just above neutron separation energy

mainly L=0 resonances, but lots of L=1 resonances

P-odd or P-odd/T-odd can mix L=0 and L=1 states
P-even/T-odd can mix different L=1 states



High level density

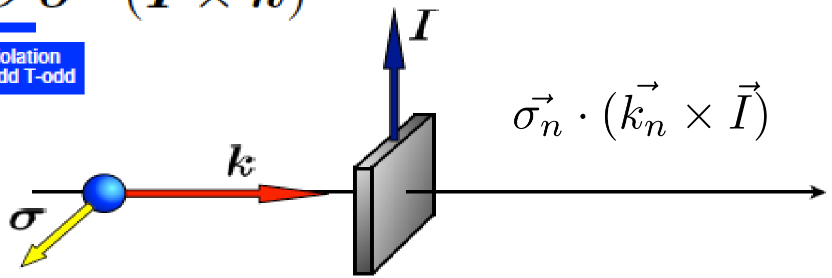


Forward Scattering Ampliltude

$$f = A' + B'\boldsymbol{\sigma}\cdot\hat{\boldsymbol{I}} + C'\boldsymbol{\sigma}\cdot\hat{\boldsymbol{k}} + D'\boldsymbol{\sigma}\cdot(\hat{\boldsymbol{I}}\times\hat{\boldsymbol{k}})$$

- A': Spin Independent, P-even T-even
- B': Spin Dependent, P-even T-even
- C': P-violation, P-odd T-even
- D': T-violation, P-odd T-odd

$$\vec{\sigma}_n\cdot(\vec{k}_n\times\vec{I})$$



$$|s\rangle \quad |p\rangle \quad |p_{1/2}\rangle \quad |p_{3/2}\rangle$$

$$J_s E_s \Gamma_s \Gamma_s^n \quad J_p E_p \Gamma_p \Gamma_p^n \quad \Gamma_{p,1/2}^n \quad \Gamma_{p,3/2}^n \quad \langle W\rangle$$

The enhancement of P-odd/T-odd amplitude on p-wave resonance (σ.[K X I]) is (almost) the same as for P-odd amplitude (σ.K). Factor is now measured!

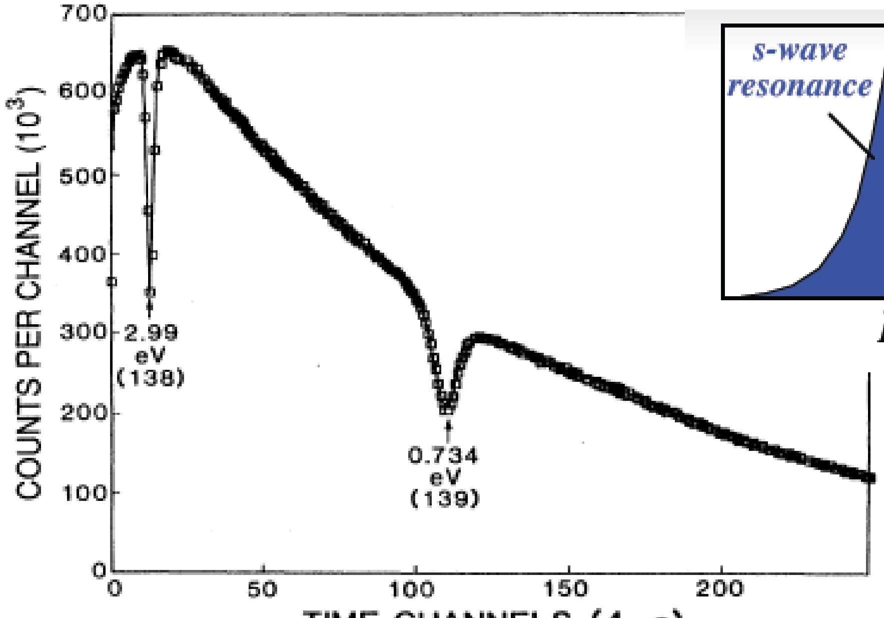
Experimental observable: ratio of P-odd/T-odd to P-odd amplitudes

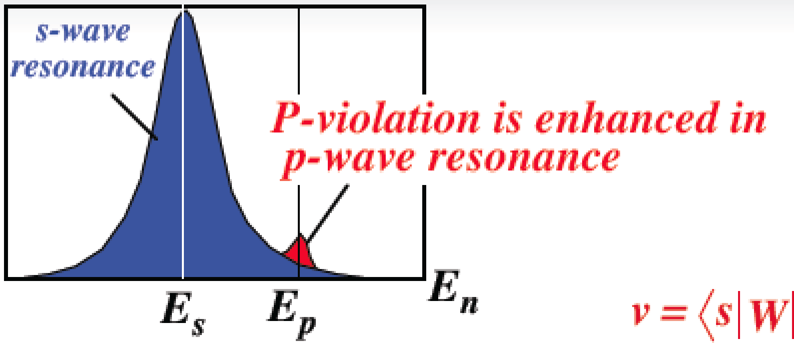
$$\lambda_{PT} = \frac{\delta\sigma_{PT}}{\delta\sigma_P}$$

λ can be measured with a statistical uncertainty of ~1 10^{-6} in 10^7 sec at MW-class spallation neutron sources. Ratio (T-odd amplitude in nucleon/strong amplitude)~10^{-13}. Statistical sensitivity up to 100X better than present neutron EDM limit.

Forward scattering neutron optics limit is null test for T (no "final state effects")

Parity Violation in n+ ^{139}La at 0.734 eV $\Delta\sigma/\sigma=10\%$
Standard Model P Violation Amplified by ~10^6 !





$$v = \langle s|W|p\rangle$$

Also 10^3 amplification of P-even/T-odd asymmetry. Needs polarized eV neutron transmission through tensor-aligned target of ^{127}I. Cryogenic R&D+ relevant (n, gamma) spectroscopy in progress

Idea is to use the observed enhancement of PV to search for a P-odd/T-odd asymmetry.

Phase 1 of NOPTREX approved at JPARC! Polarized ^{139}La target in progress

Outlook

- A EDM violates both the Parity (P) and the Time-reversal (T) symmetries.

- A null EDM will rule out electroweak baryogenesis in minimal supersymmetric models, and tightly constrain model-independent analyses of P and T violation. If no EDM is discovered, the null EDM results will push the limits on the mass scale for new T violation physics above 100 TeV, and it will provide the best probe of CP violation in the Higgs sector, exceeding the energy reach of the Large Hadron Collider.

- On the other hand, discovery of a nonzero nEDM at this level would reveal a completely new source of T violation (and thus CP violation), contributing to the development of a unified theory of the fundamental forces of nature. In many scenarios, successful baryogenesis leads to strict lower bounds on the nEDM within the reach of the ongoing EDM experiments.