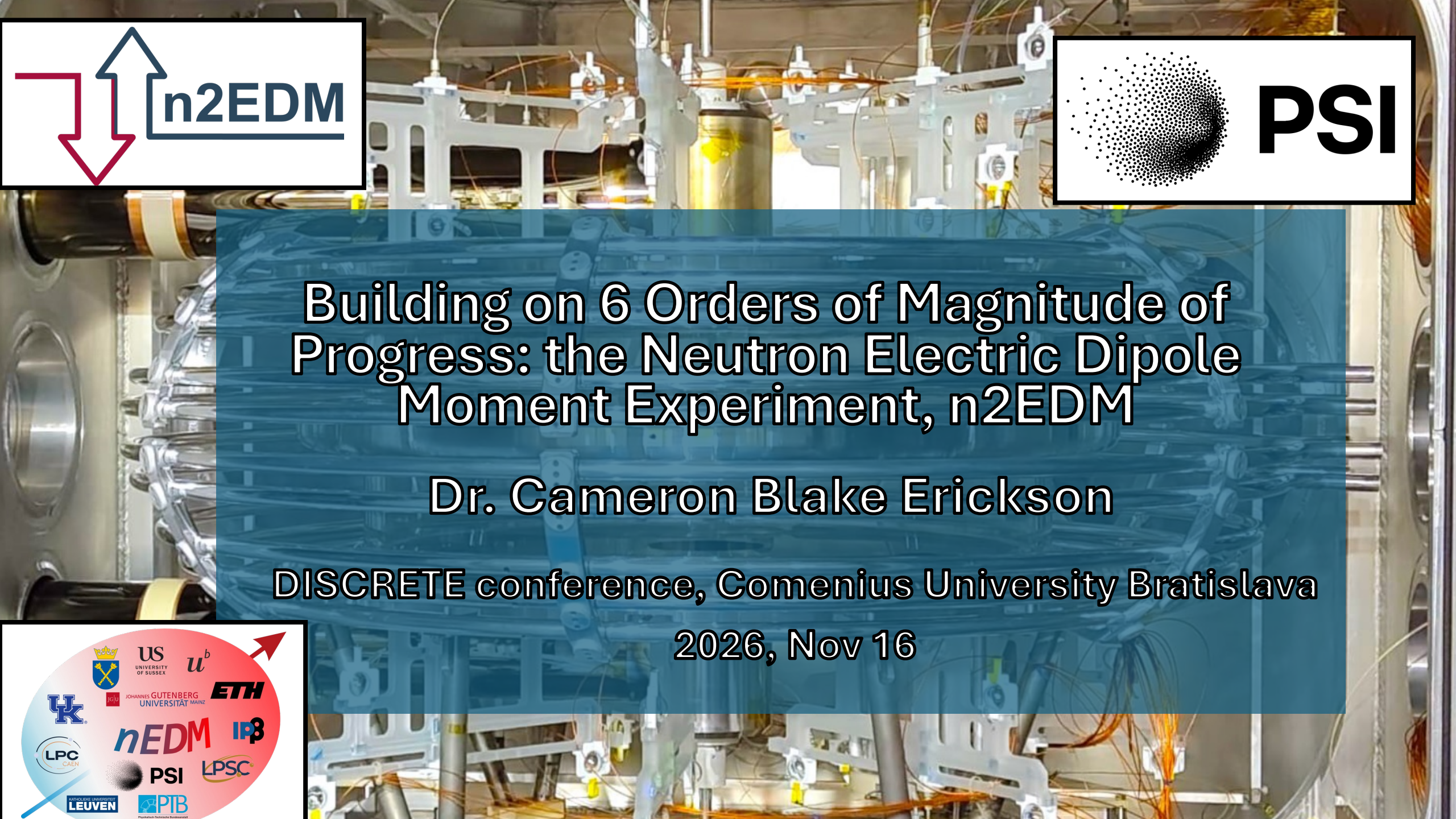


Building on 6 Orders of Magnitude of Progress: the Neutron Electric Dipole Moment Experiment, n2EDM

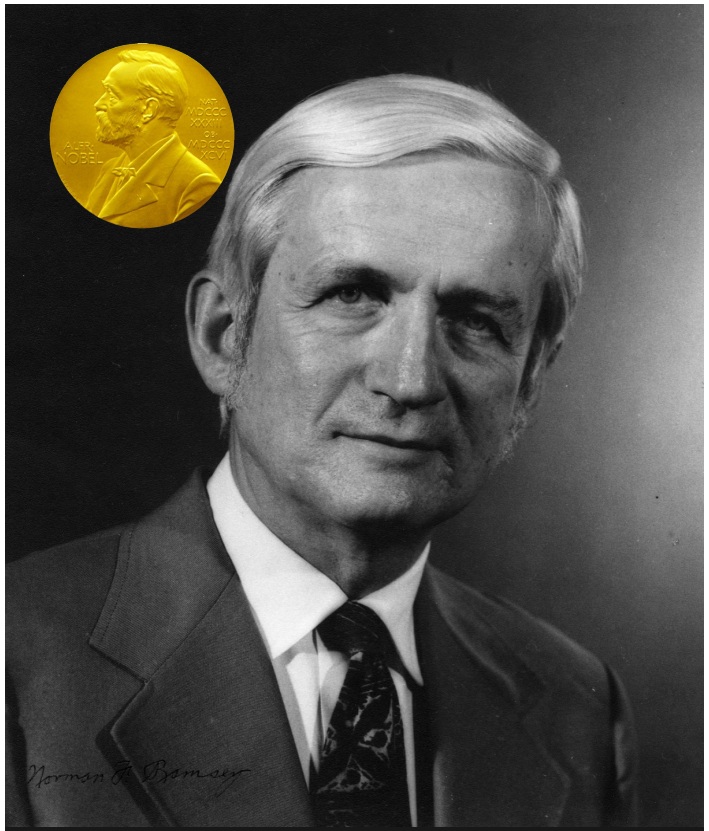
Dr. Cameron Blake Erickson

DISCRETE conference, Comenius University Bratislava

2026, Nov 16

A Quote of A Quote on Electric Dipole Moments (EDMs)

> “The non-observation of any EDM has ruled out more speculative theories than any other known experimental approach.”
>
> ~ 1999 Norman Ramsey*



Norman Ramsey

1989 Nobe Prize in Physics

*Breit Centennial Symposium, Yale (1999), quoted in the CERN Physics Beyond Colliders BSM Working Group report (2019).

“Intrinsic” or “Permanent” Electric Dipole Moments

- Ramsy’s quote applies to ”*intrinsic*” EDM’s, $\mathbf{d}$, defined by a fixed proportionality to a system’ s angular momentum $\boldsymbol{J}$:

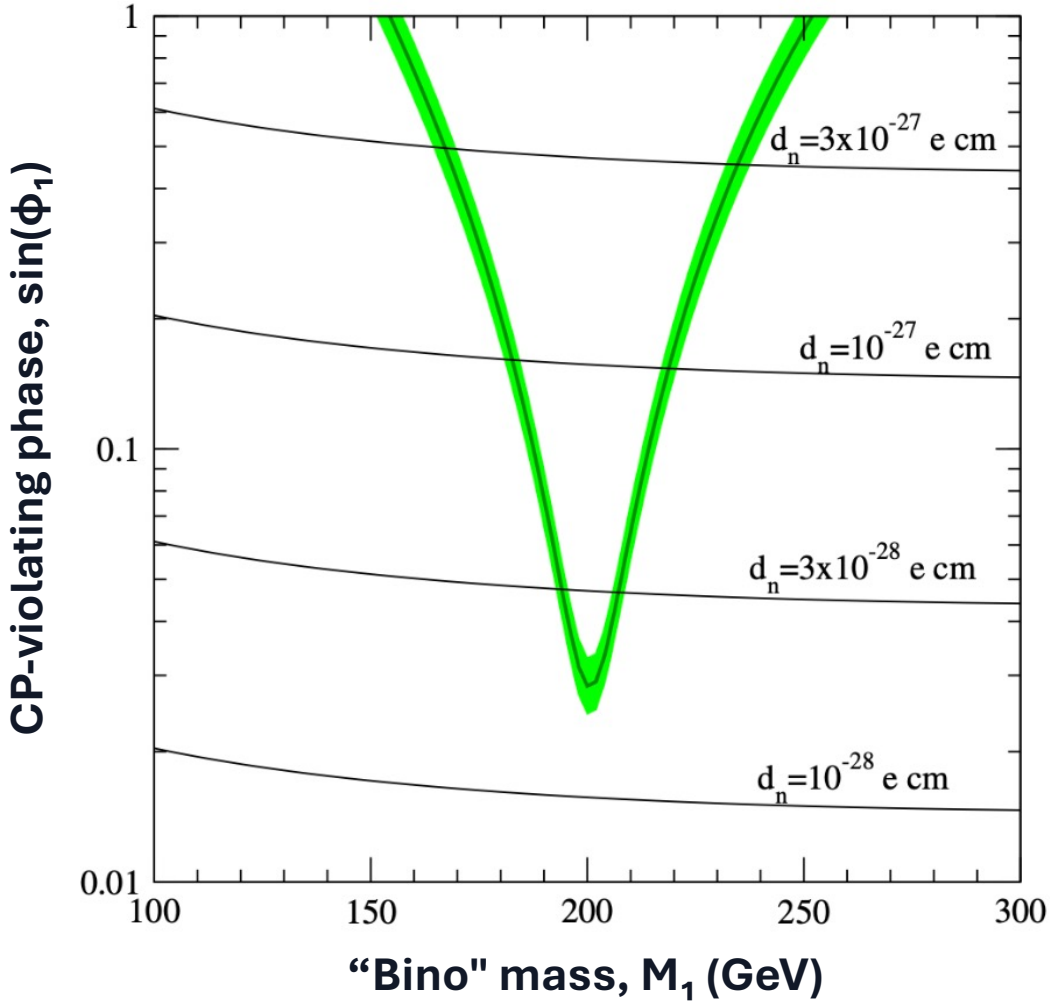
$$\mathbf{d} \propto \mathbf{J}$$

- Intrinsic EDM’s violate CP and T symmetry. For a low energy Hamiltonian:

$$H_{\mathrm{EDM}} = -\mathbf{d} \cdot \mathbf{E} \xrightarrow{\mathrm{CP}} +\mathbf{d} \cdot \mathbf{E}$$

EDM's Heavily Constrain Theories

Example: Toy constraints from the Minimal Supersymmetric Standard Model (MSSM)



Green band

Consistent with observed baryon asymmetry, η.

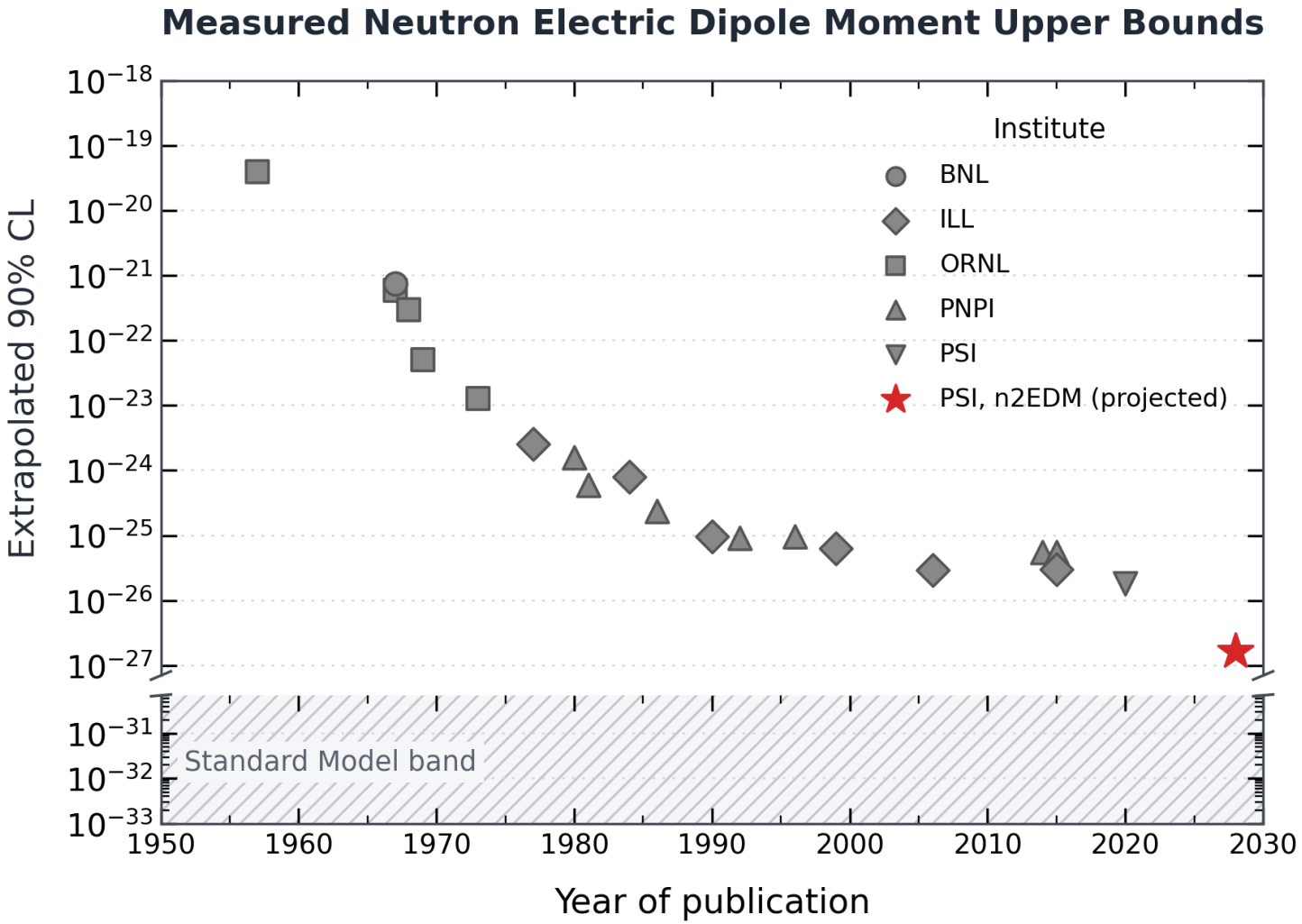
Predicted neutron EDM (e·cm)

At fixed bino mass, the predicted EDM increases with $\sin(\phi_1)$.

- Increased CP violation predicts increased d_n
- Minimum d_n compatible with these constraints is 10^4 times larger than the Standard Model Prediction

Li, Profumo & Ramsey-Musolf (2009), Fig. 3

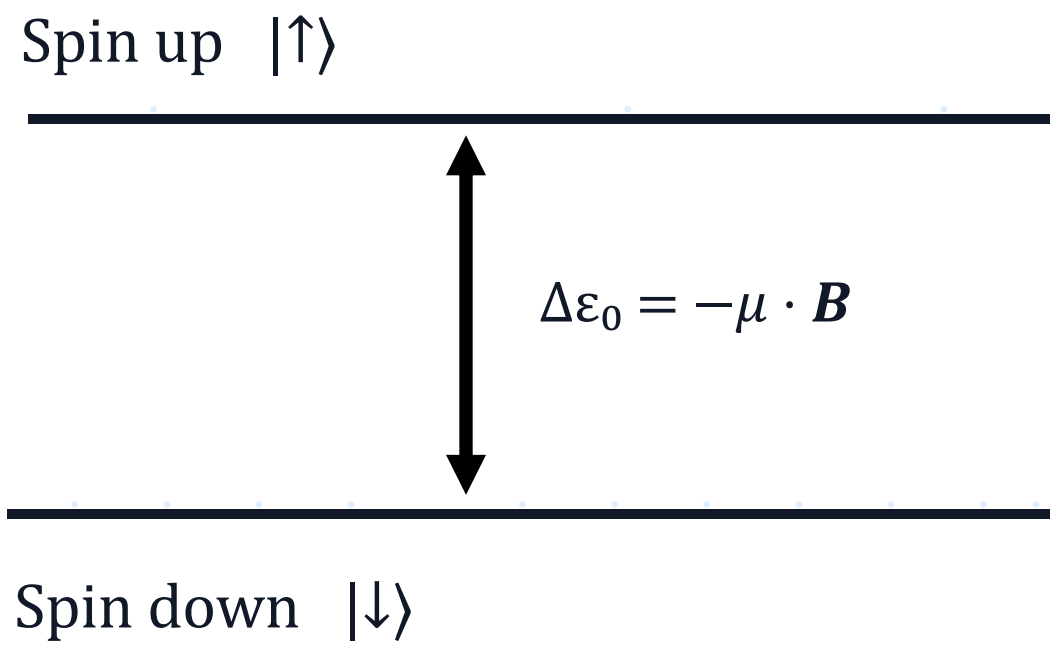
The 6 Decade Search for the Neutron Electric Dipole Moment (nEDM)



- Despite extensive searches in particles, atoms, and molecules, no nonzero intrinsic EDM has been observed.
- The neutron is a long lived, neutral system – well suited for EDM measurement
- The n2EDM experiment at PSI plans aims to achieve a record sensitivity of ~ **1×10^{-27} e·cm**

Basic Sketch of an nEDM Measurement

1.) Prepare an ensemble of neutrons with a known spin polarization (recall $\mathbf{d} \propto \boldsymbol{S}$) along the holding magnetic field $\boldsymbol{B}$

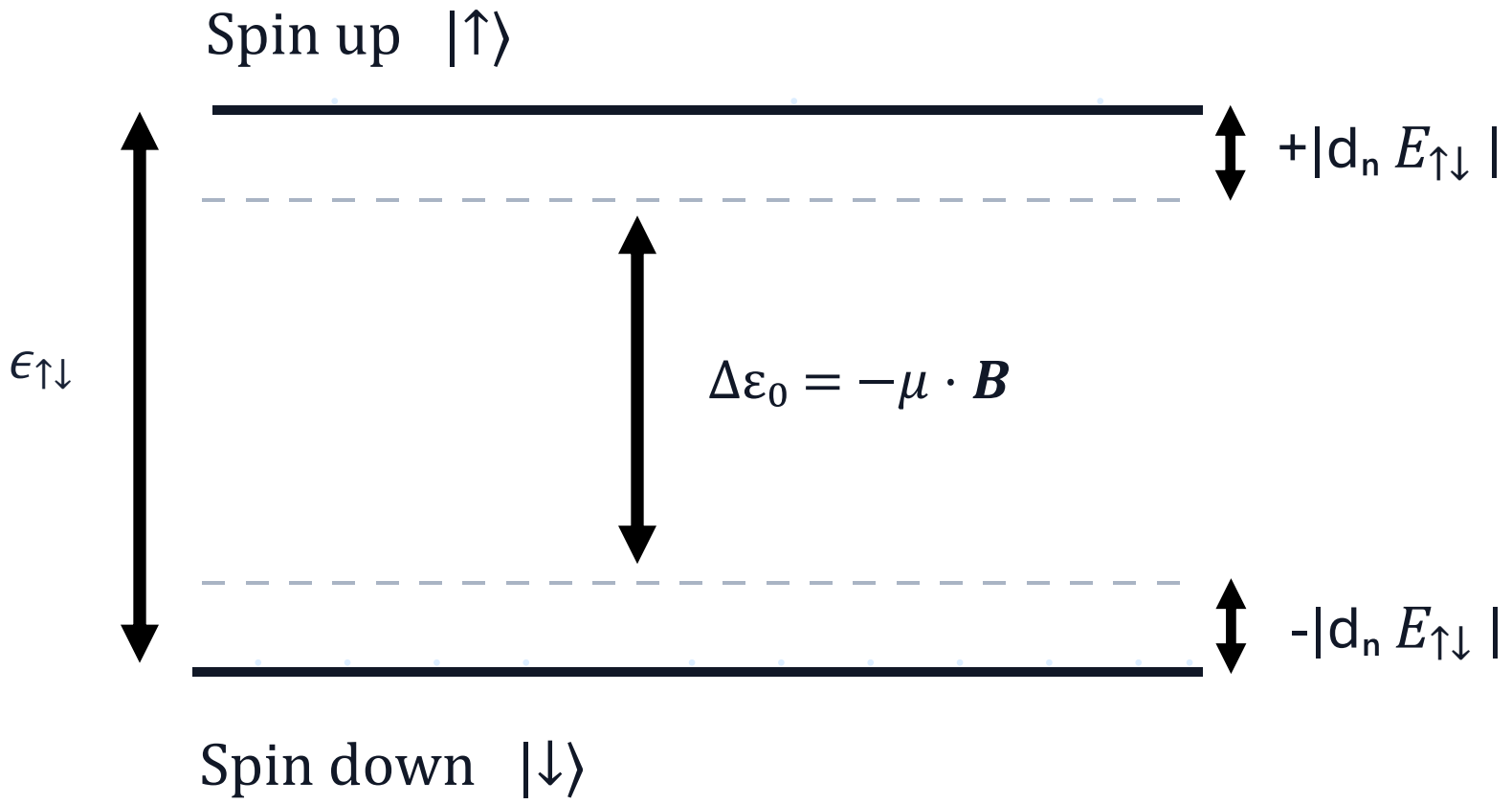


For the neturon's magnetic moment μ

(for illustration we assume a positive electric dipole)

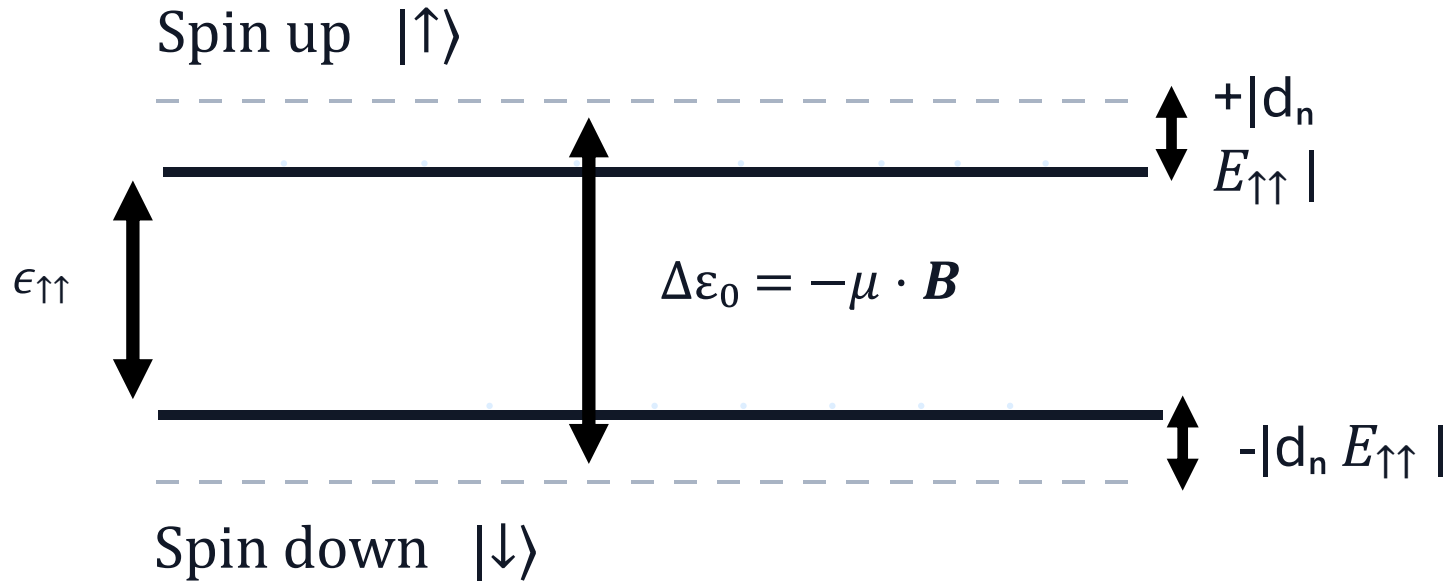
Basic Sketch of an nEDM Measurement

2.) Apply a known electric field antiparallel $E_{\uparrow\downarrow}$ the axis of spin quantization (the magnetic field) and measure the splitting



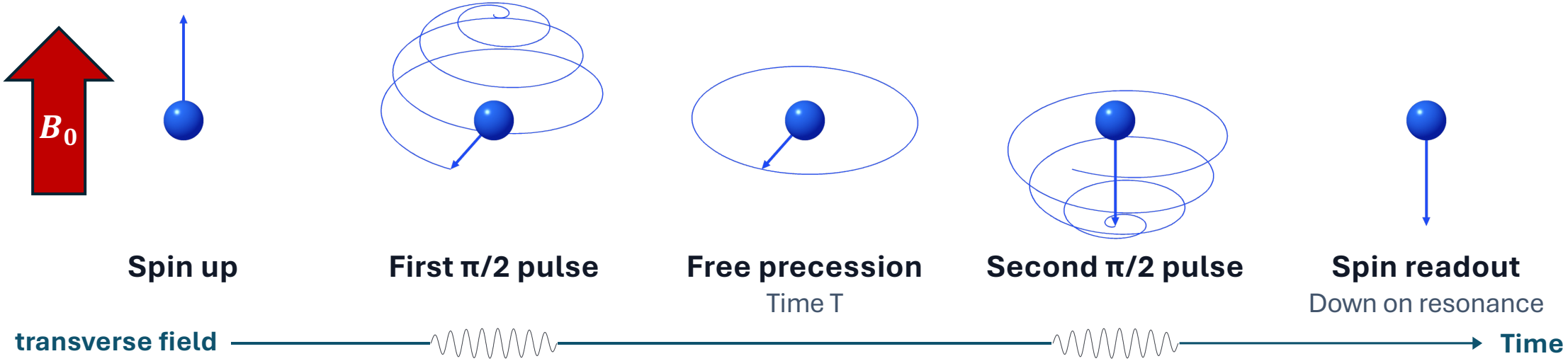
Basic Sketch of an nEDM Measurement

5.) CAREFULLY hold $\boldsymbol{B}$ constant and do the same with $E_{\uparrow\uparrow}$

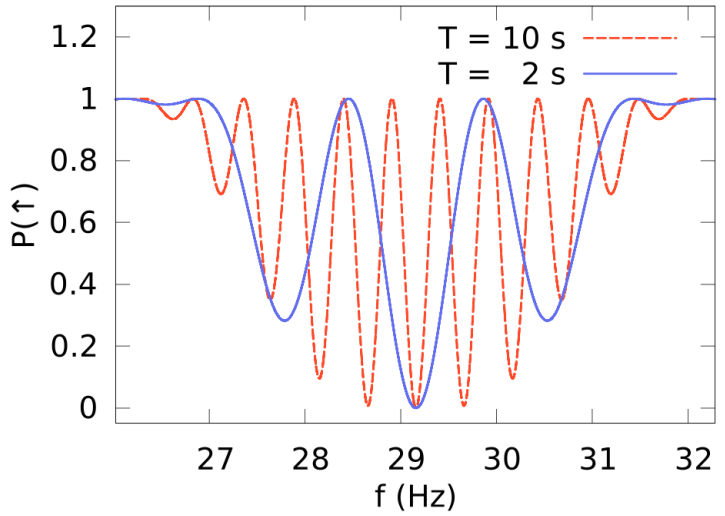


6.) Extract the nEDM by computing $\epsilon_{\uparrow\downarrow} - \epsilon_{\uparrow\uparrow} = 4d_n E_{\uparrow\uparrow}$

nEDM NMR Spectroscopy: Ramsey's Method



- Two short magnetic field pulses separated by a free precession time T
- Scanning the applied frequency allows for a fit of the resonance



Key Challenges of an nEDM Experiment

- Statistics

$$\sigma(d_n) = \frac{\hbar}{2\alpha E T \sqrt{N}}$$

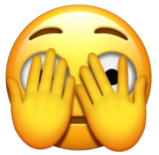
→ Maximize electric field strength E, precession time T, neutron polarization α and statistics N

- Systematics

$$H = -\frac{2}{\hbar}\,\mathbf{S}\cdot(\mu_n\mathbf{B} + d_n\mathbf{E})$$

→ Control magnetic field $\boldsymbol{B}$ *experienced* by the neutrons

For n2EDM target parameters: $\frac{\sigma_{d_n} E}{\mu_n B} \sim 10^{-10}$



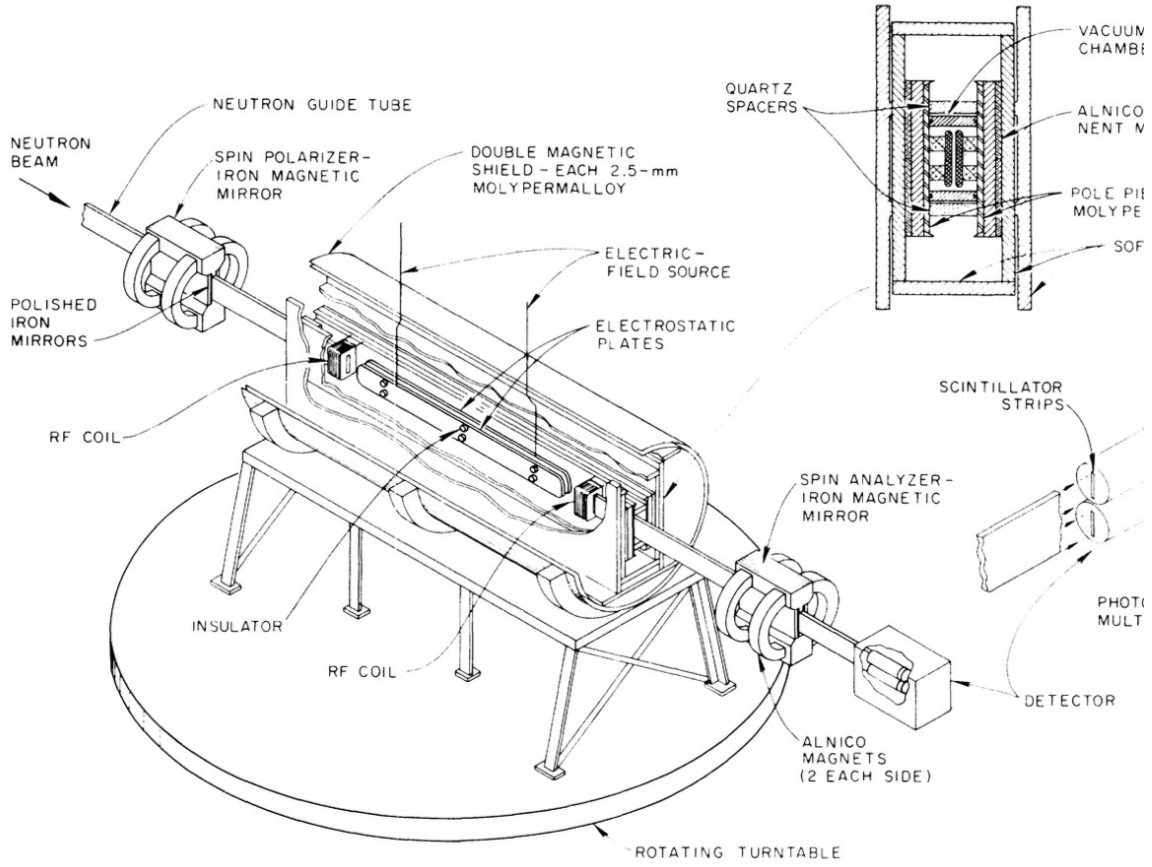
Systematics Limited: The Last "Beam" nEDM Measurement ,1977

- Neutron beam with speeds ~154 m/s, precession time of $T \sim 0.01$ sec

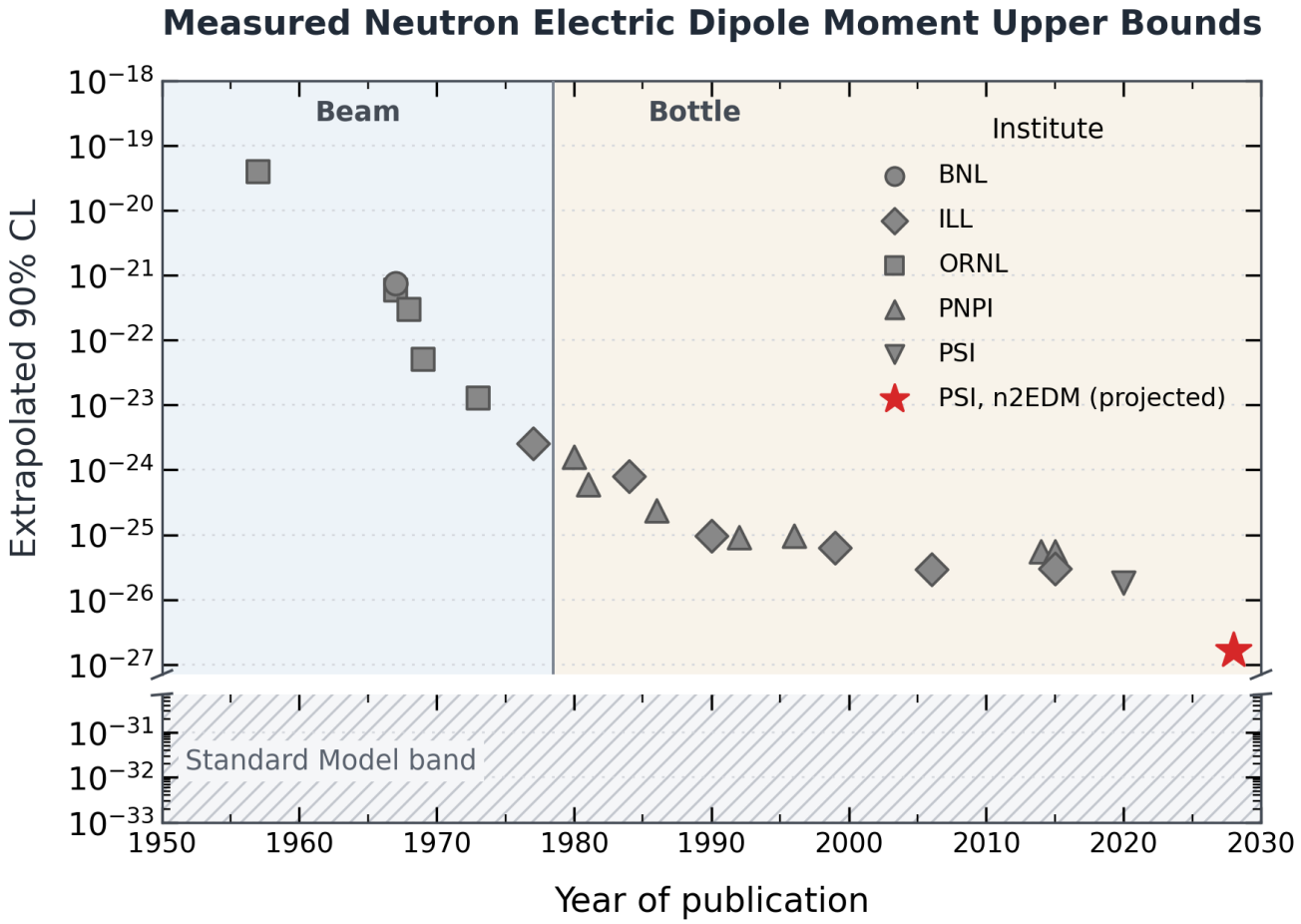
- Ultimately limited by systematics caused by the "motional field"

$$\mathbf{B}_{\mathrm{mot}} = \frac{\mathbf{E} \times \mathbf{v}}{c^2}$$

- Apparatus mounted on a gun turret to rotate 180 degrees to study $\boldsymbol{v} \rightarrow -\boldsymbol{v}$



Improving Systematics: Beam to Bottle Measurements

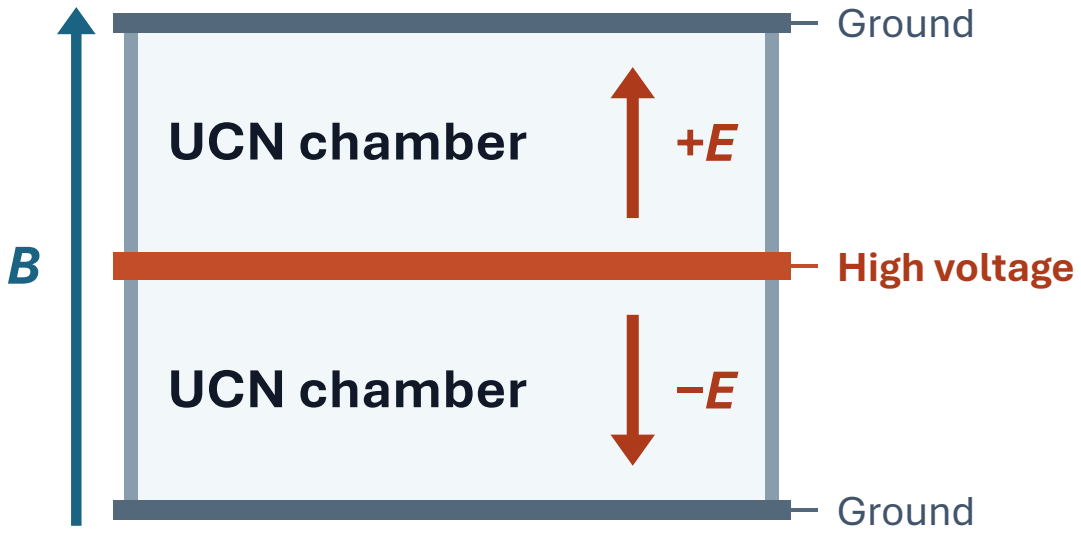


- Ultra cold neutrons (UCNs) are created by down scattering neutrons in a refrigerated "converter"
- UCNs move slow enough ($|v| < 8$ m/s) to be reflected at all angles for some materials
  --> they can be bottled like a gas!
- Excellent because $T \sim 100$ sec and $\langle v \rangle = 0$

Two different strategies to control UCN systematics

Double chamber

PNPI in Gatchina, USSR/Russia

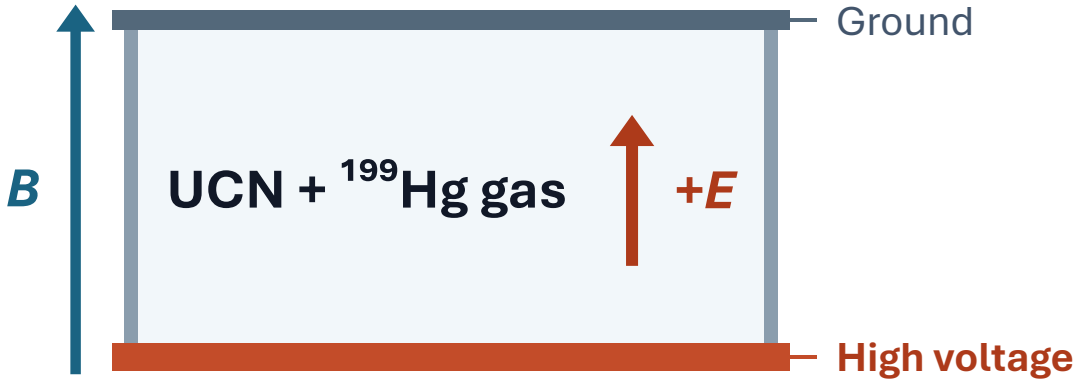


Compare chambers with opposite E

Shared B fluctuations cancel in the difference.

Mercury comagnetometer

ILL in Grenoble France, later PSI in Villigen Switzerland

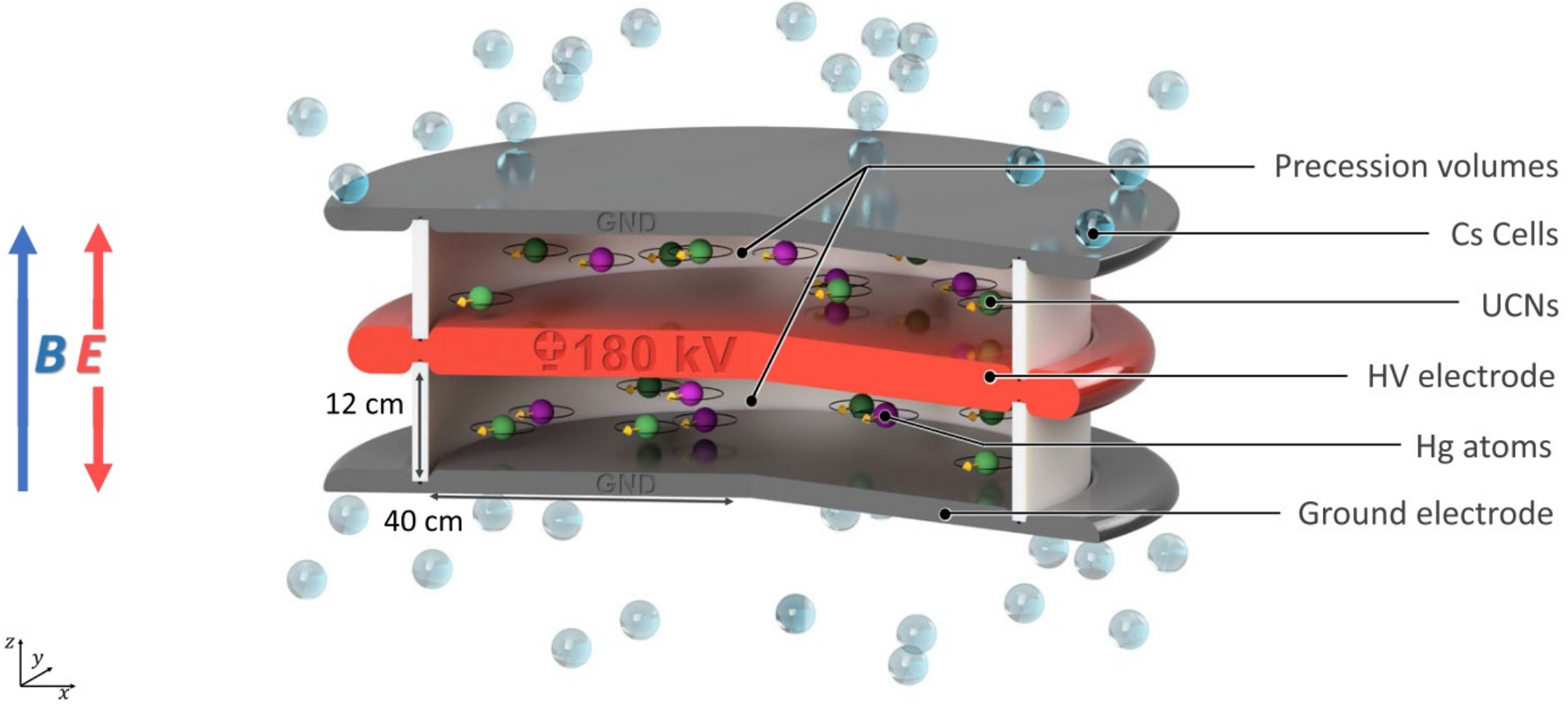


Measure B in the neutron chamber

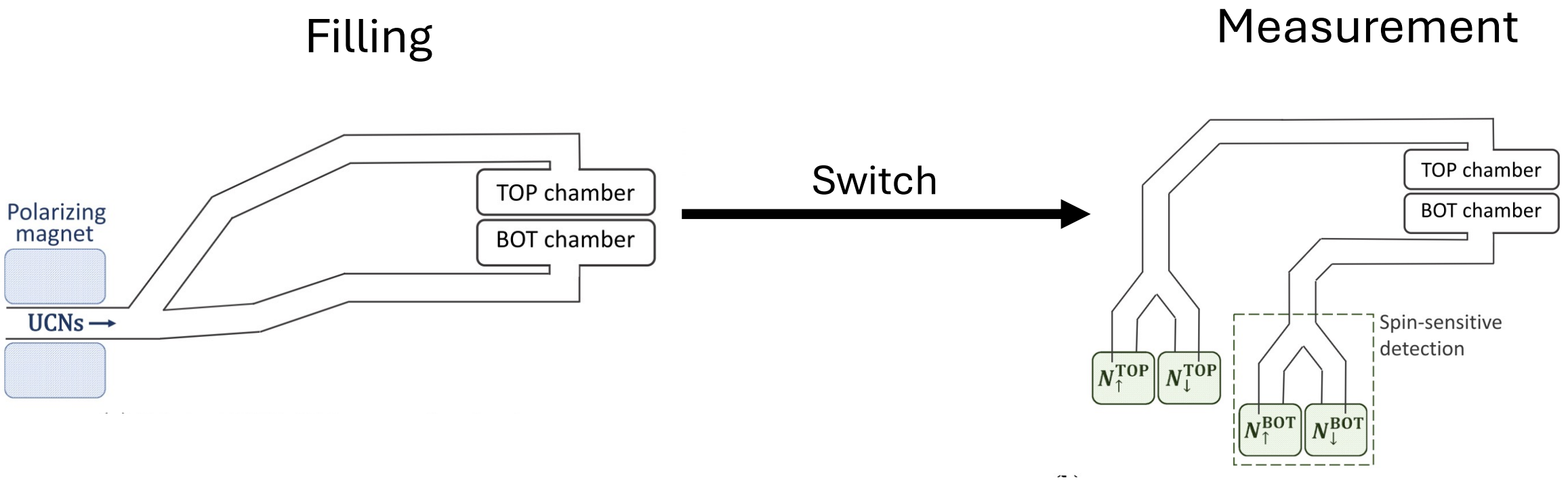
Track ^{199}Hg spin precession optically.

Both experiments eventually employed external Cesium atomic magnetometers

n2EDM: First Double Chamber + ^{199}Hg Comagnetometer

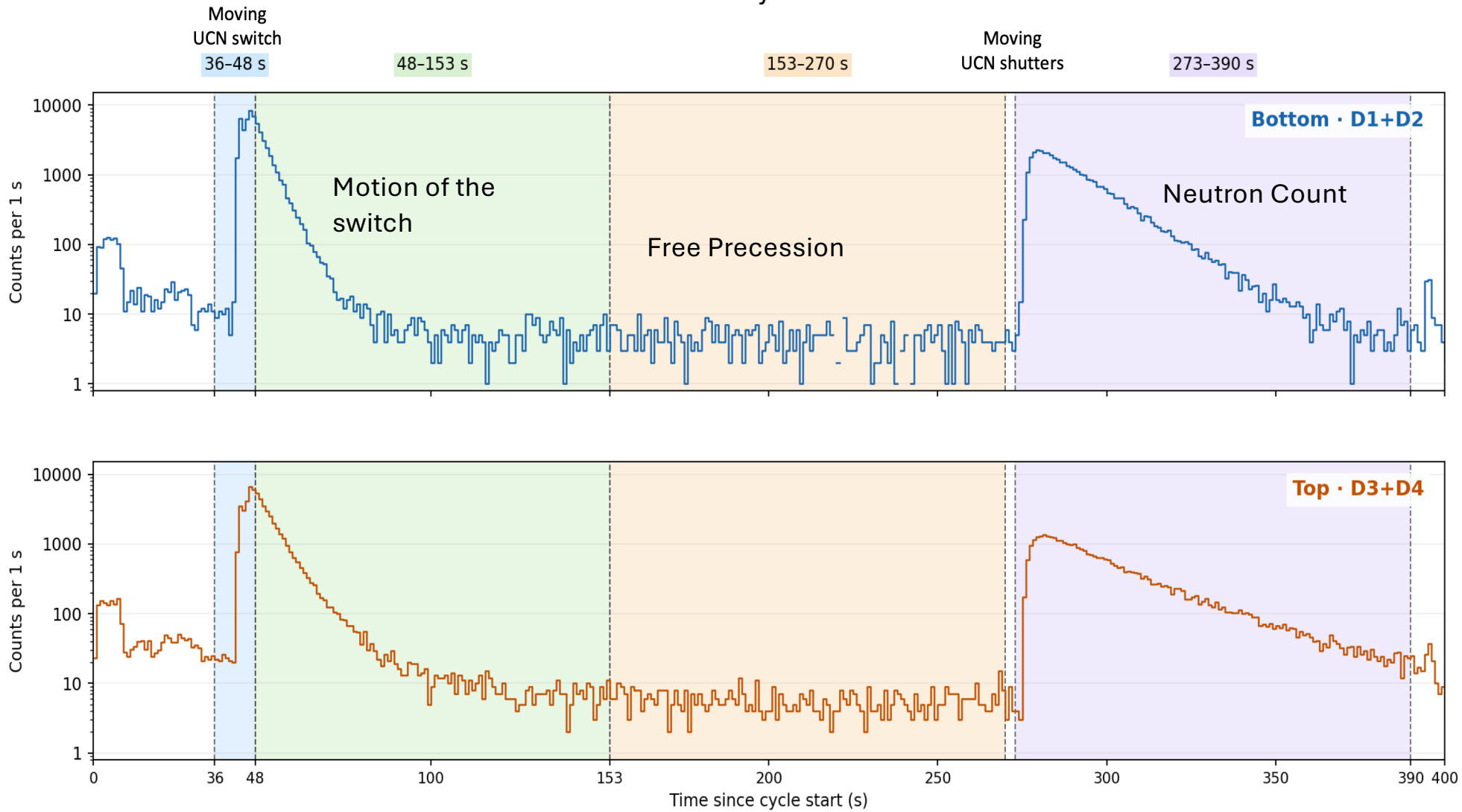


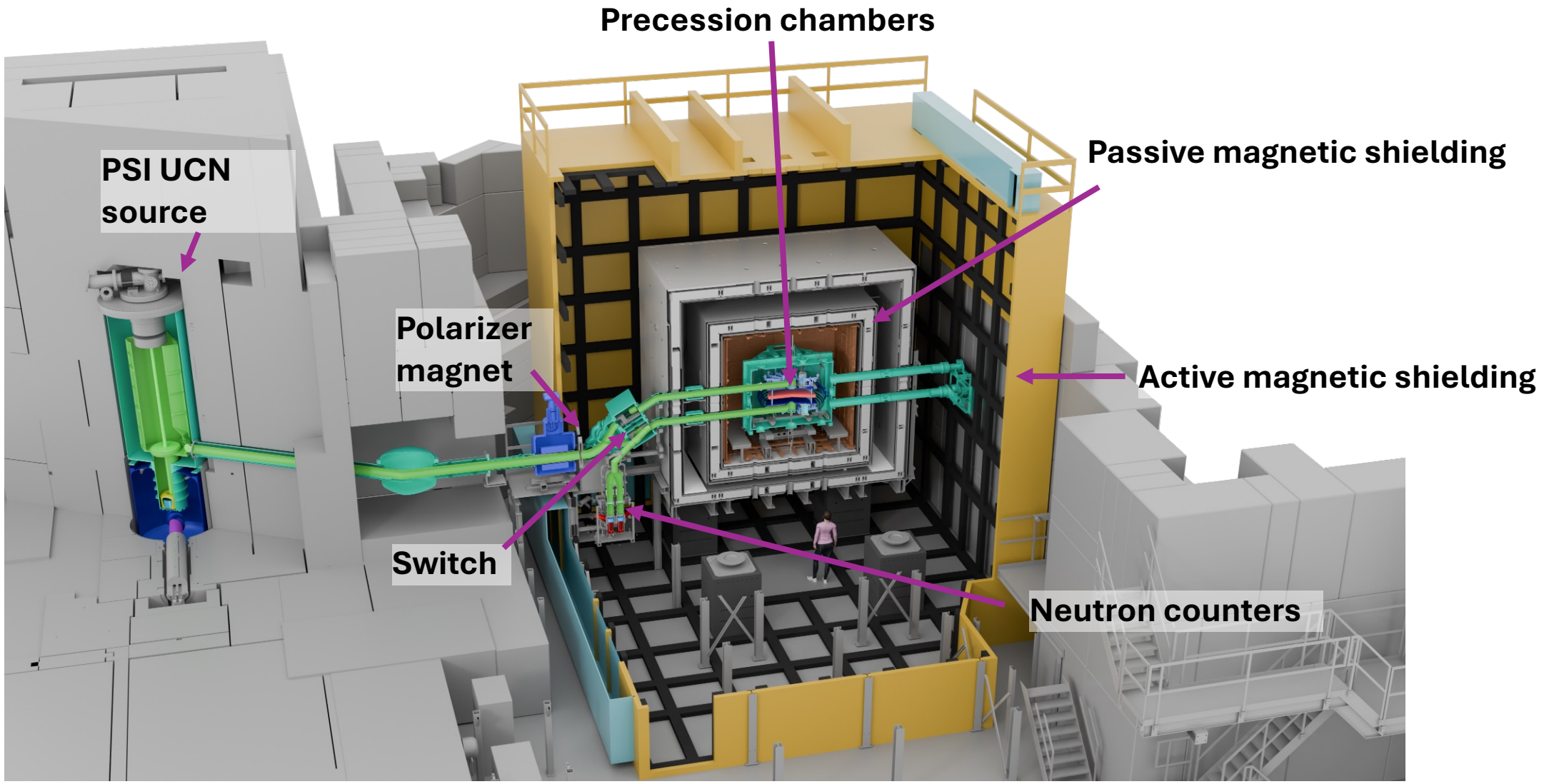
n2EDM UCN Plumbing



Livecount spectrum and integration windows – example cycle

Run 10262 · cycle 44



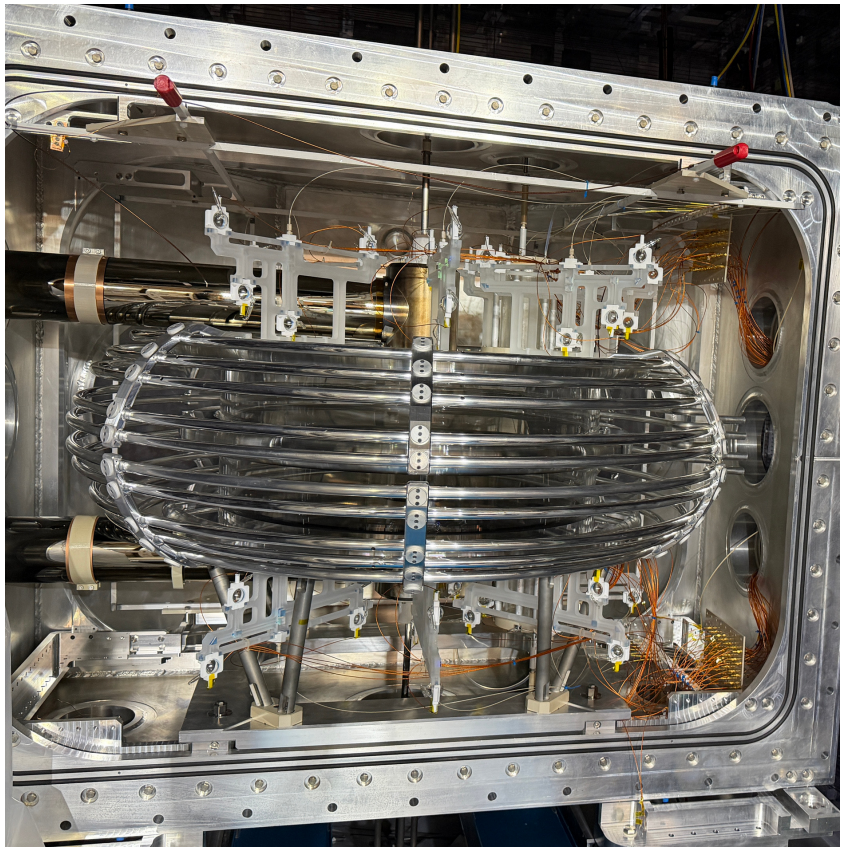

Precession chambers
PSI UCN source
Passive magnetic shielding
Polarizer magnet
Active magnetic shielding
Switch
Neutron counters

n2EDM status

Parameter	Design goal	Demonstrated
Neutrons counted after 225 s	76,800	**120,000**
Electric field	15 kV/cm	**6 kV/cm**
Neutron polarization α	0.8	**0.86**
Comagnetometer sensitivity	20 fT	**≈15 fT**
Cs array sensor count	112	**56**
Cs sensor statistical precision	< 5 pT	**< 1 pT**
All systems running together	Yes	**Sometimes**

World record daily sensitivity

$\sigma(d_n) \approx \mathbf{7.7 \times 10^{-26}}$ e cm/day



Systematics studies in progress