New Results from a Search for the EDM of ^{199}Hg

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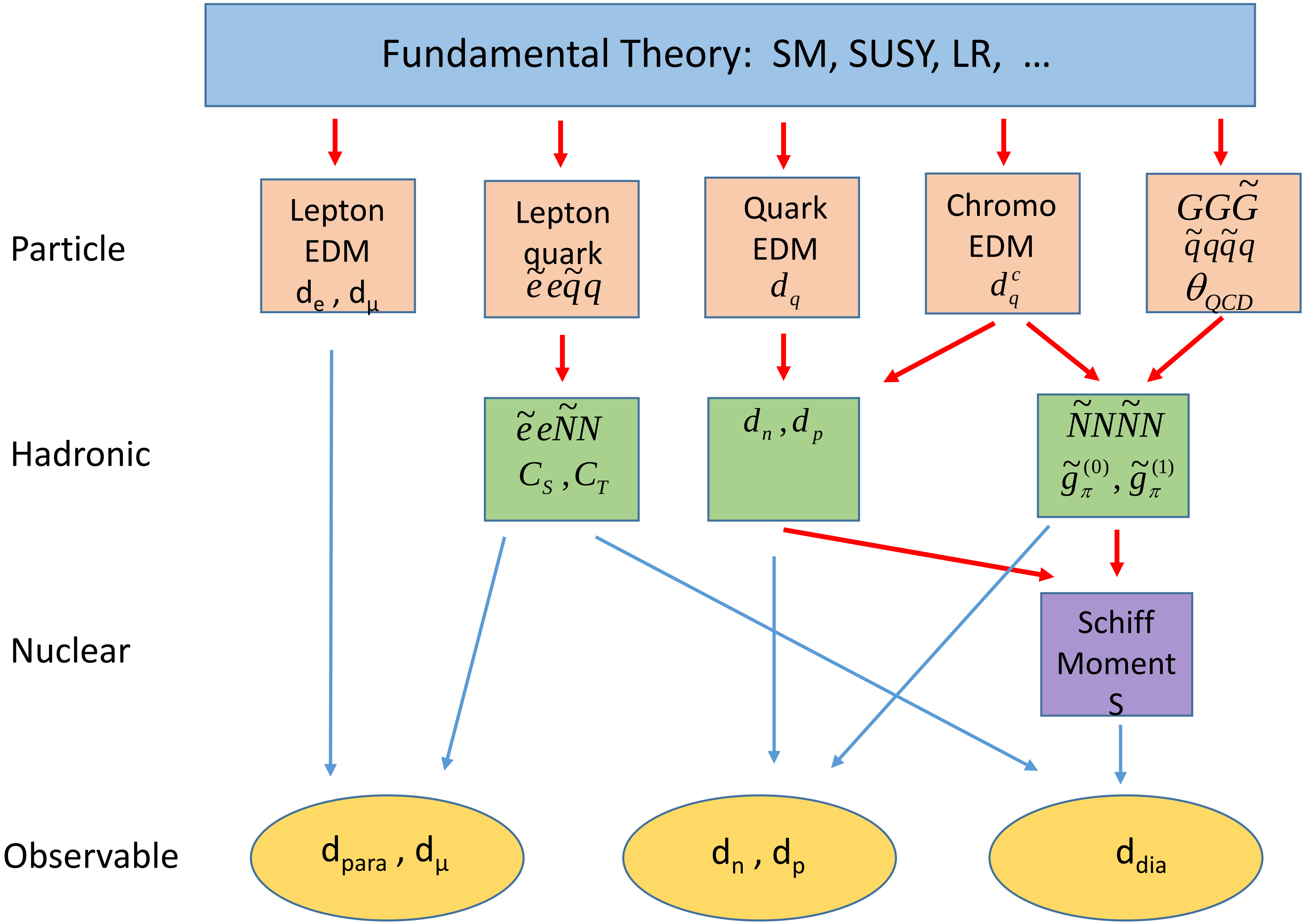
Partial List of EDM Experiments

Leptonic EDMs		Hadronic EDMs	
Cs (trapped)	Penn St.	n (UCN)	SNS
Cs (trapped)	U. Texas	n (UCN)	ILL-PNPI
Cs (fountain)	LBNL	n (UCN)	PSI
^{210}Fr (trapped)	Cyric	n (UCN)	KEK-Triumph
		n (UCN)	Munich
YbF (beam)	Imperial College	p (ring)	BNL
HfF+ (trapped)	JILA	d (ring)	COSY
ThO (beam)	Harvard-Yale		
PbF (trapped)	U. Oklahoma	^{129}Xe (liquid)	Princeton
WC (beam)	U. Michigan	^{129}Xe (cell)	GUMainz
		^{129}Xe (cell)	TUMunich
GGG (solid)	Indiana	^{129}Xe (cell)	Tokyo Inst. Tech.
		^{199}Hg (cell)	Seattle
muon (ring)	J-PARC	^{223}Rn (trapped)	TRIUMF
		^{225}Ra (trapped)	Argonne
		^{225}Ra (trapped)	KVI



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The Team

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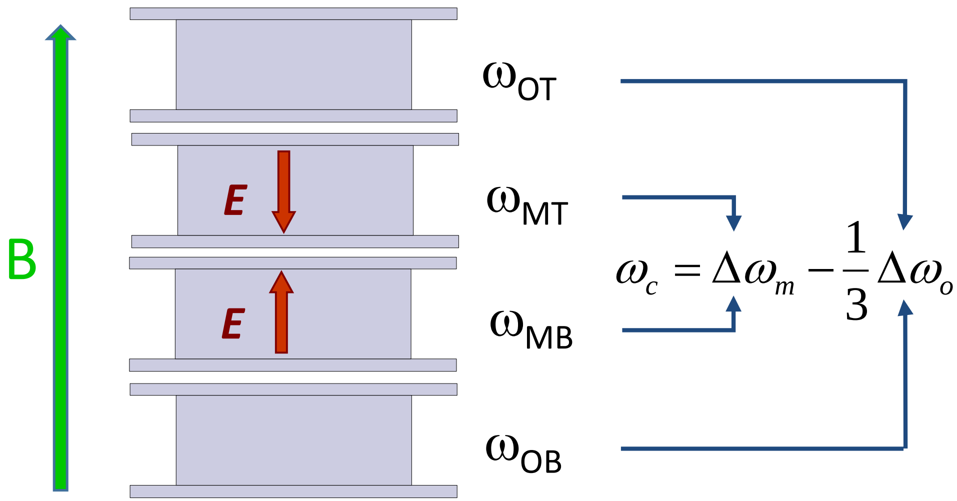
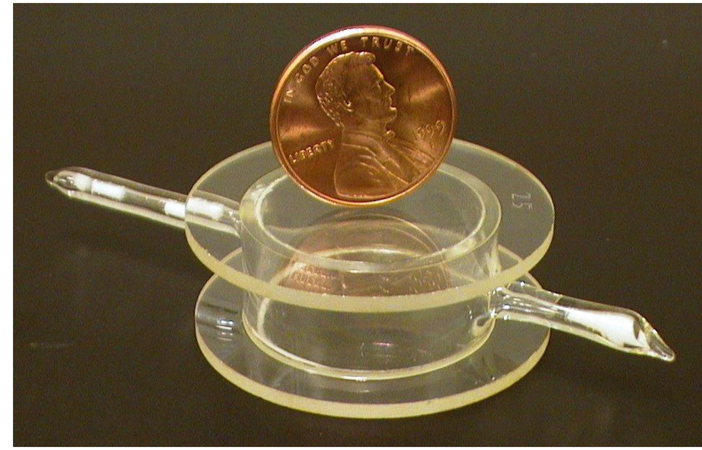
Current EDM Experiment

$$H = -(\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E})$$

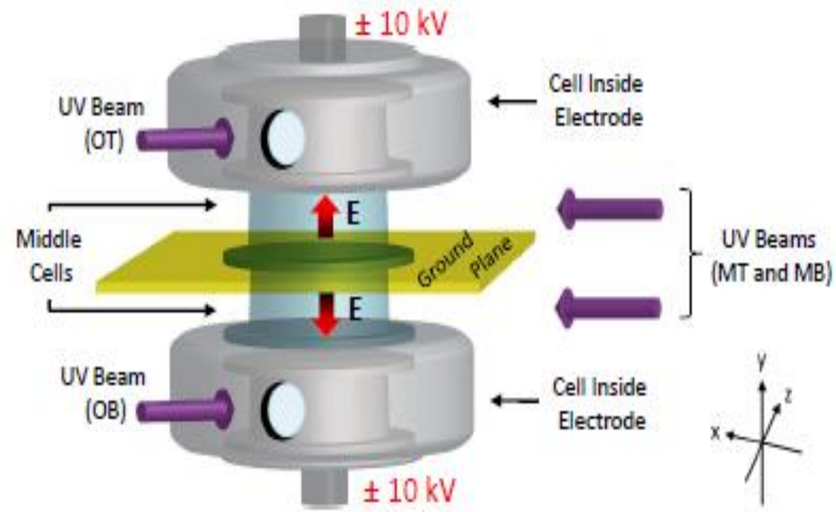




T_2 Spin Relaxation: 300 - 600 sec

$$\omega_c = \frac{\mu}{\hbar}\left(-\frac{8}{3}\frac{\partial^3 B}{\partial z^3}\Delta z^3\right) + \frac{4dE}{\hbar}$$

Cancels up to 2nd order gradient noise
Same EDM sensitivity as Middle Difference



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Cell Holding Vessel

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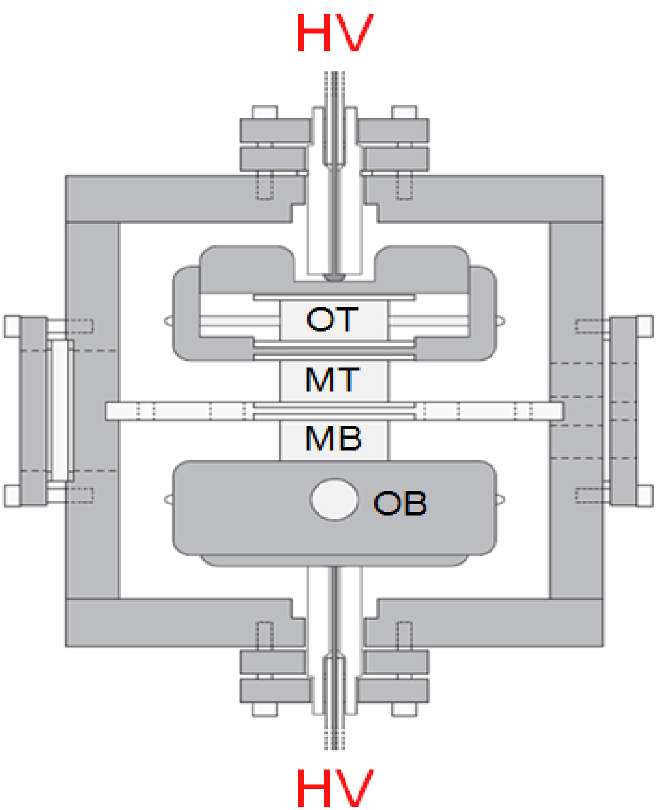
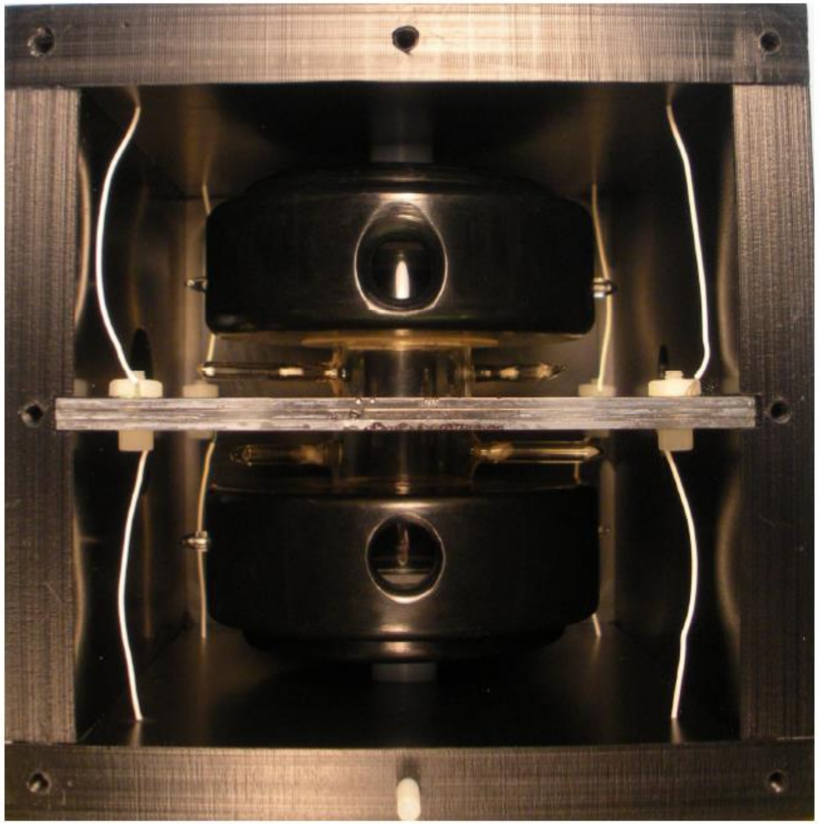
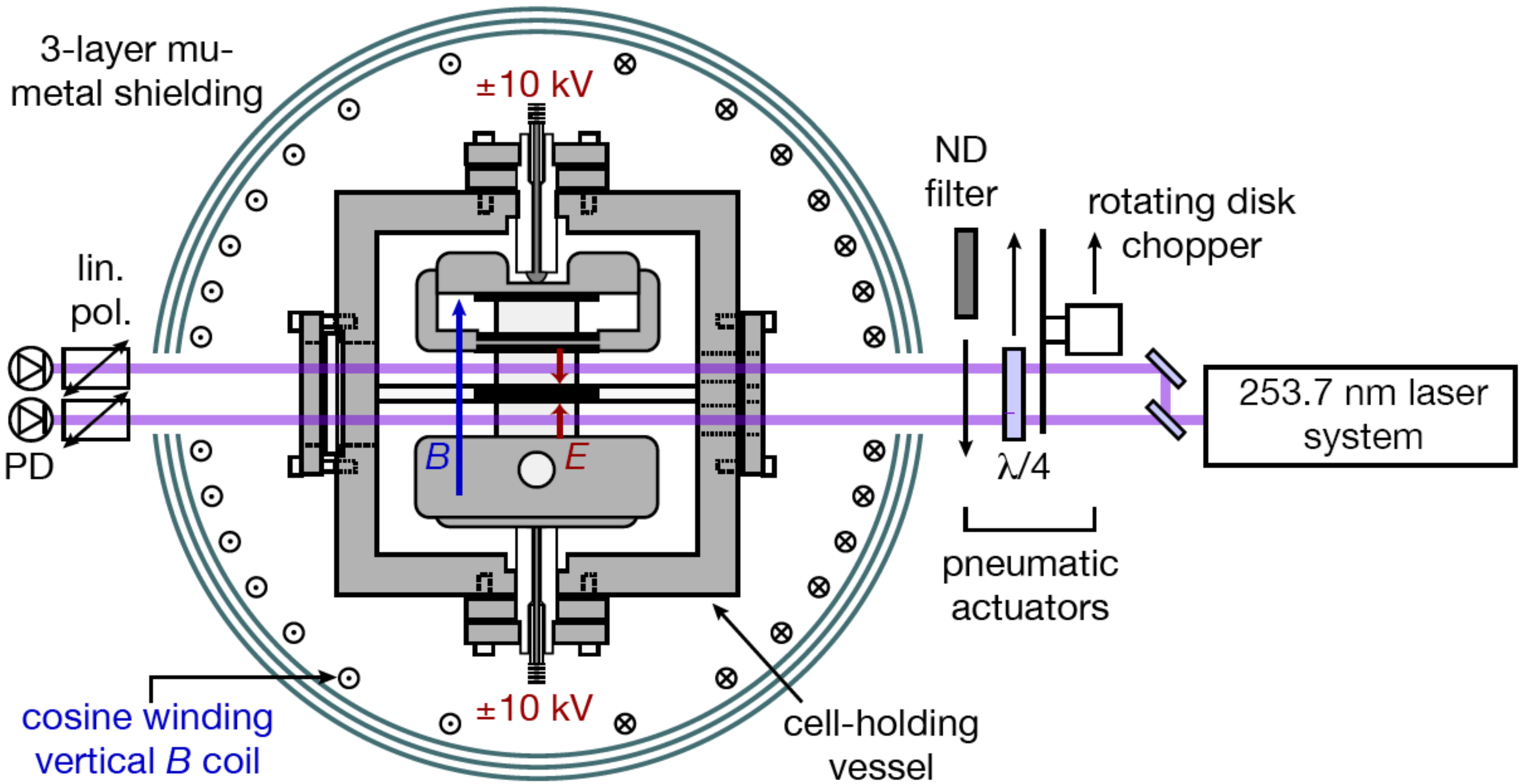
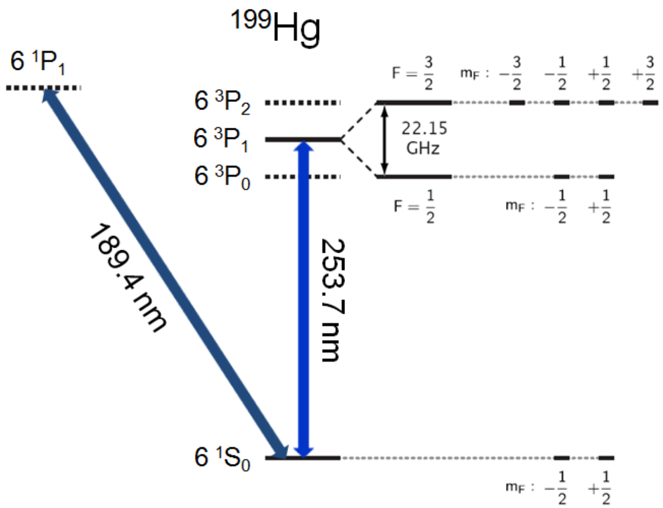


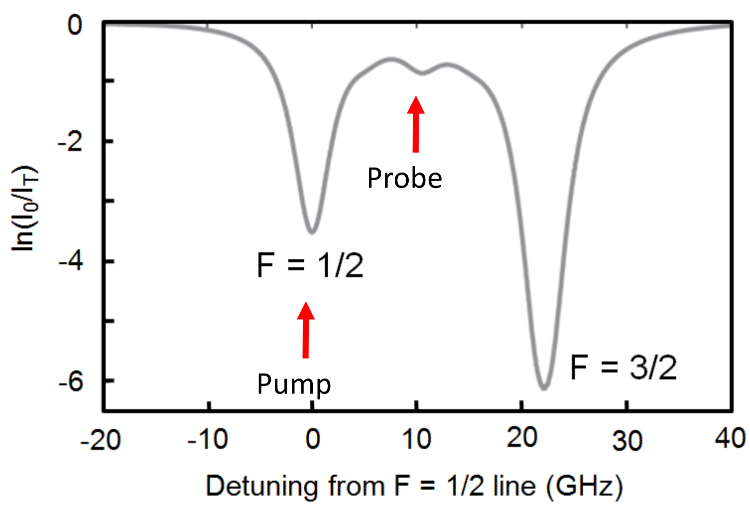


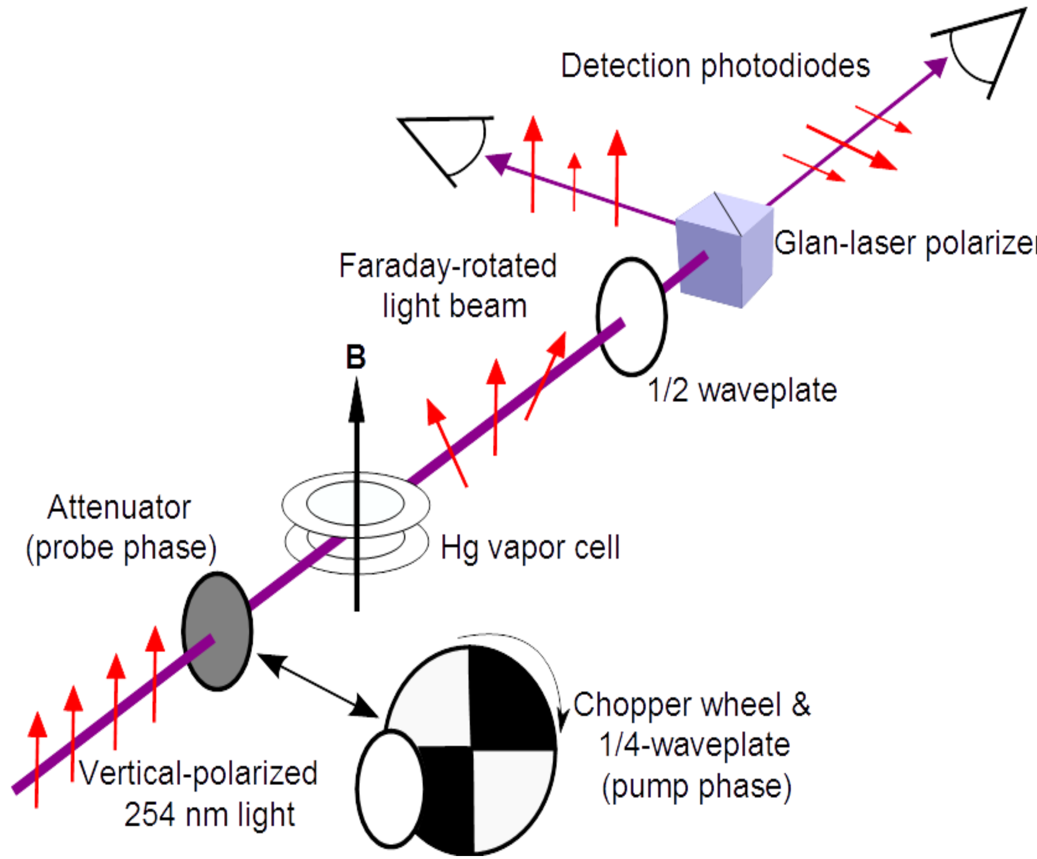
Schematic Overview



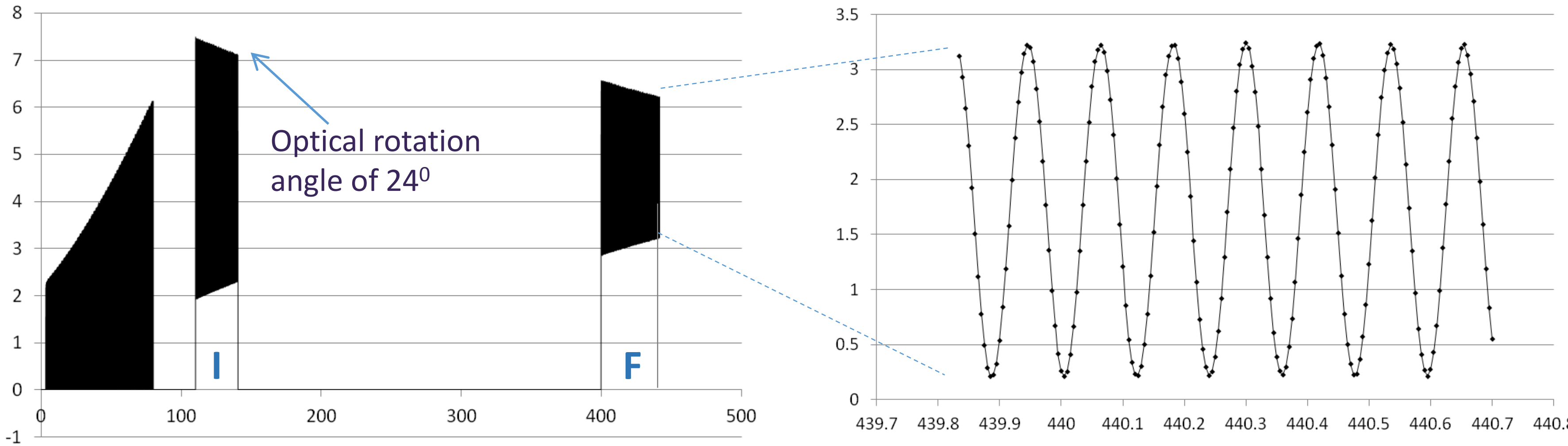
Faraday Rotation Detection







Precession in the Dark



Photodiode signal (V) vs. time (seconds)

We extract the precession phase φ_F at the start of the F (final) period and the precession phase φ_I at the end of the I (initial) period.

$$\omega_{Dark} = (\varphi_F - \varphi_I)/T_{Dark}$$

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Digital Phase Analysis

For neighboring cells, a and b, we want to extract

$$\Delta\omega_{ab} = \omega_a - \omega_b = [(\phi_a - \phi_b)_F - (\phi_a - \phi_b)_I]/T_{Dark}$$

To do so, we multiply the signals from neighboring cells.

$$\textit{From} \quad \underline{S(t_n) = Ae^{-t_n/\tau}\sin(\omega t_n + \phi)} \quad \textit{and}$$

$$N^2(t_n) = S^2(t_n) - S(t_n - \pi/2\omega)\cdot S(t_n + \pi/2\omega) = A^2 e^{-2t_n/\tau}$$

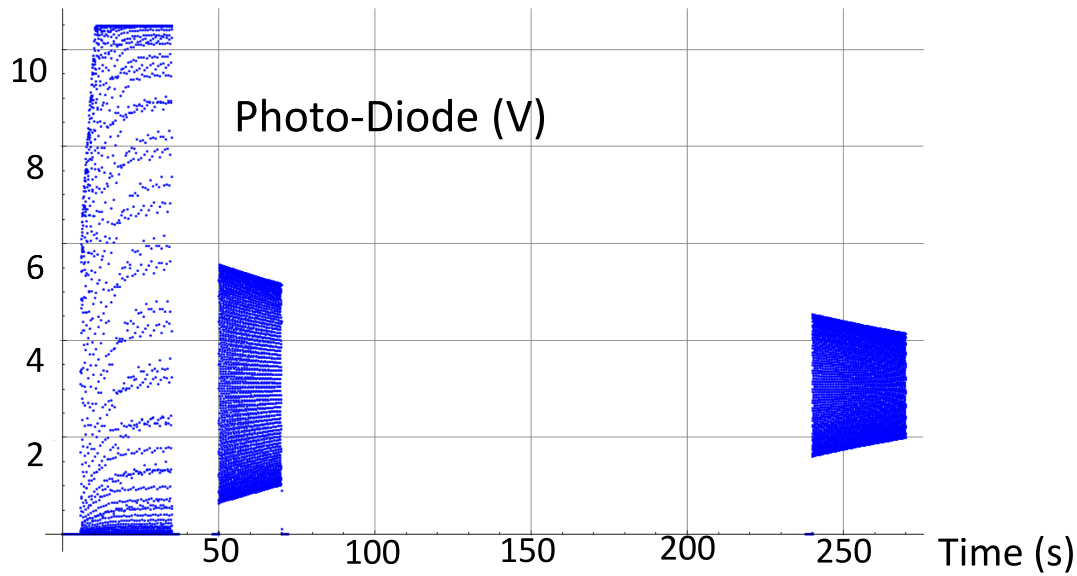
$$\textit{we get} \quad \bar{S}(t_n) = S(t_n)/N(t_n) = \sin(\omega t_n + \phi) \quad \textit{and}$$

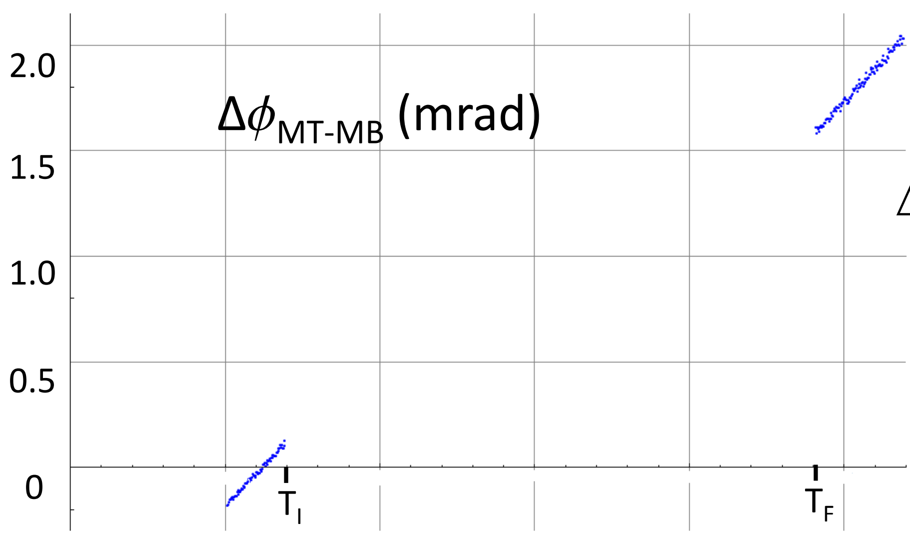
$$\bar{C}(t_n) = [\bar{S}(t_n + \pi/2\omega) - \bar{S}(t_n - \pi/2\omega)]/2 = \cos(\omega t_n + \phi)$$

$$\textit{Finally} \quad \bar{S}^a(t_n)\cdot\bar{C}^b(t_n) - \bar{C}^a(t_n)\cdot\bar{S}^b(t_n) = \sin(\Delta\omega_{ab}t_n + \Delta\phi_{ab})$$

$$\approx \Delta\omega_{ab}t_n + \Delta\phi_{ab}$$

Phase Data

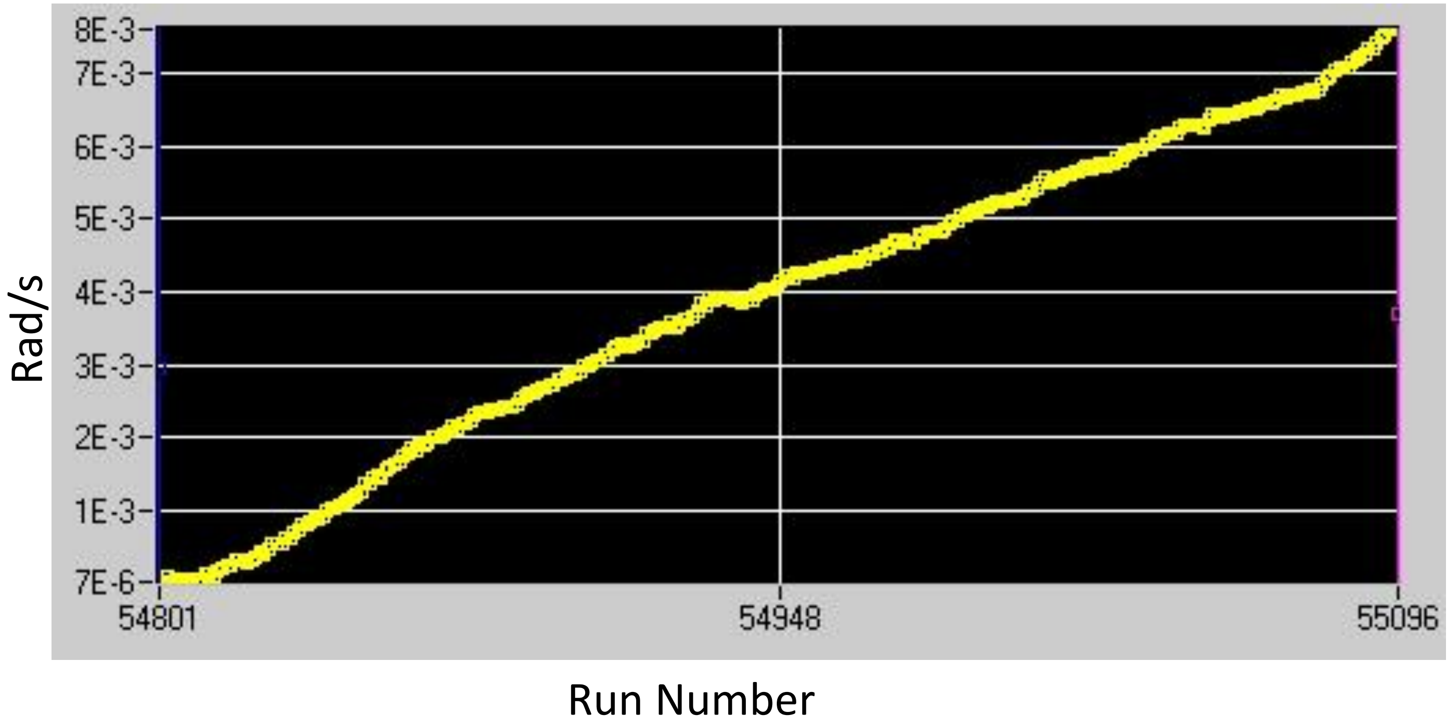




$$\Delta\omega_{Dark} = \frac{\Delta\phi(F) - \Delta\phi(I)}{T_F - T_I}$$

System Performance

Average angular frequency relative to first scan



This corresponds to a drift of ~1 μGauss/day

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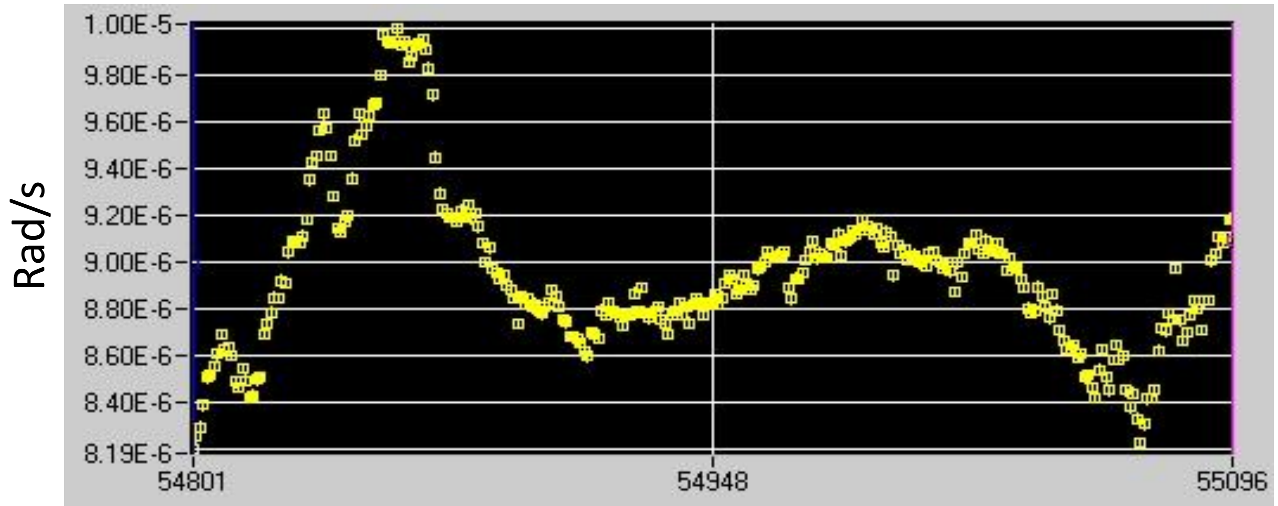
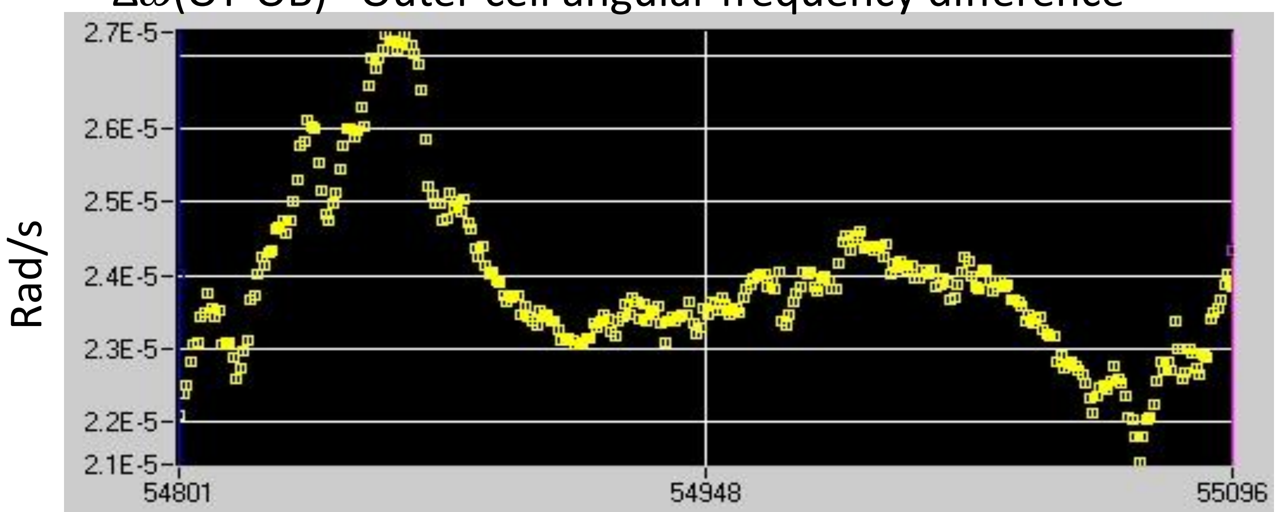
For the same run:

Δω(MT-MB)   Middle cell angular frequency difference

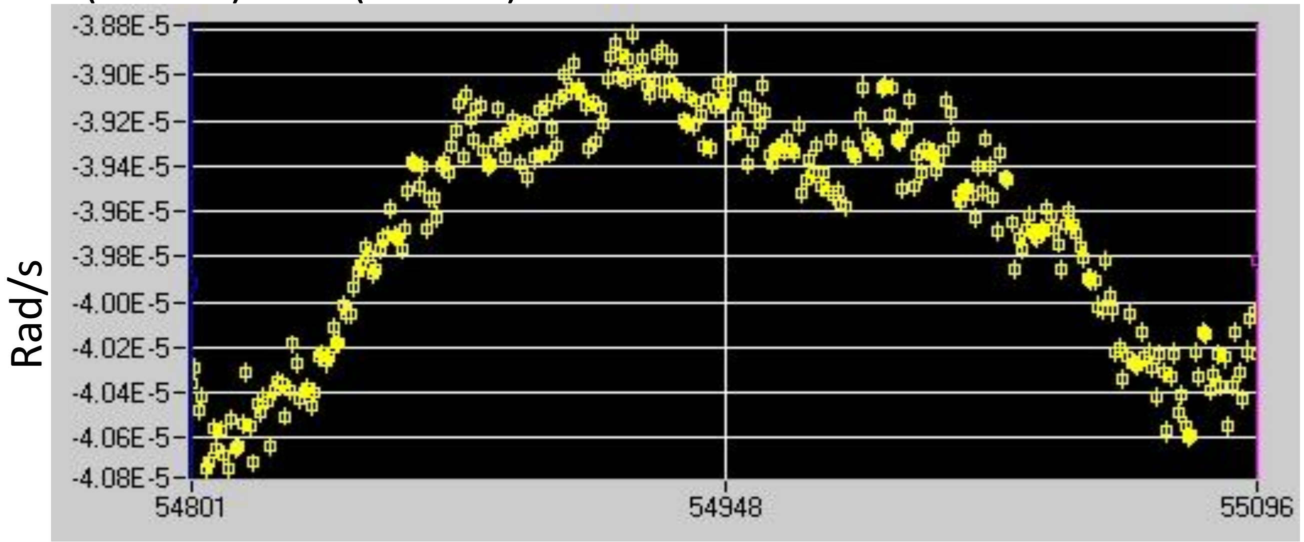


0.3 nG/day

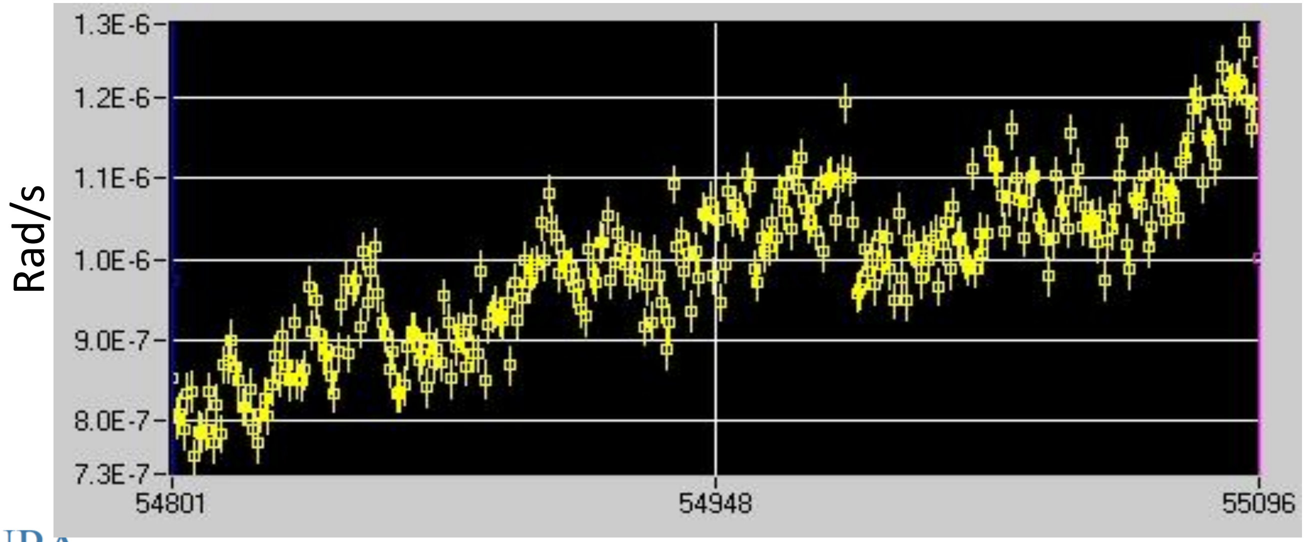
Δω(OT-OB)   Outer cell angular frequency difference



Δω(OT-MT) + Δω(OB-MB)   Quadratic field drift channel



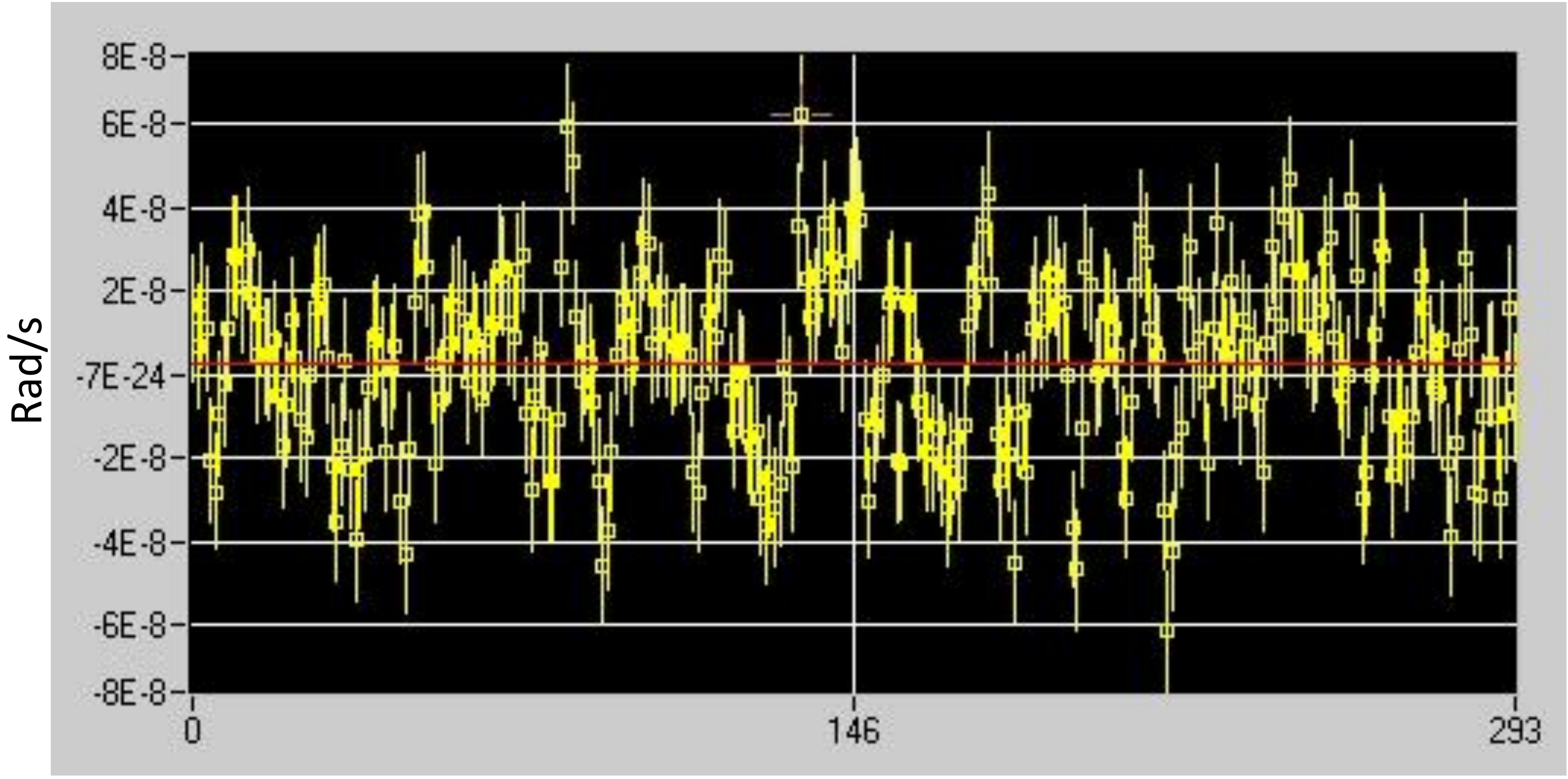
$\Delta\omega_C$ EDM sensitive frequency combination



80 pG/day

One day EDM signal

$$\omega_{edm}(n) = (-1)^n\,[\Delta\omega_C(n\text{-}1) - 2\,\Delta\omega_C(n) + \Delta\omega_C(n+1)]/4$$



ω_{edm} = xx ± 2.0 × 10^{-9} rad/s, a factor of 4 improvement over 2009

(3.5 × 10^{-29} e-cm/day for 10kV runs)

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Data Sequences

EDM data is taken in ``sequences''. Each sequence comprises:

- A defined set of cell orientations and ordering in the vessel
- Equal number of day long runs at 6kV and 10kV
- Equal number of runs with normal and reversed magnetic fields
- Equal number of runs with fast and slow high voltage ramp rates
- Typically 16 -20 runs total

285 edm data runs were taken, spread across 12 sequences.

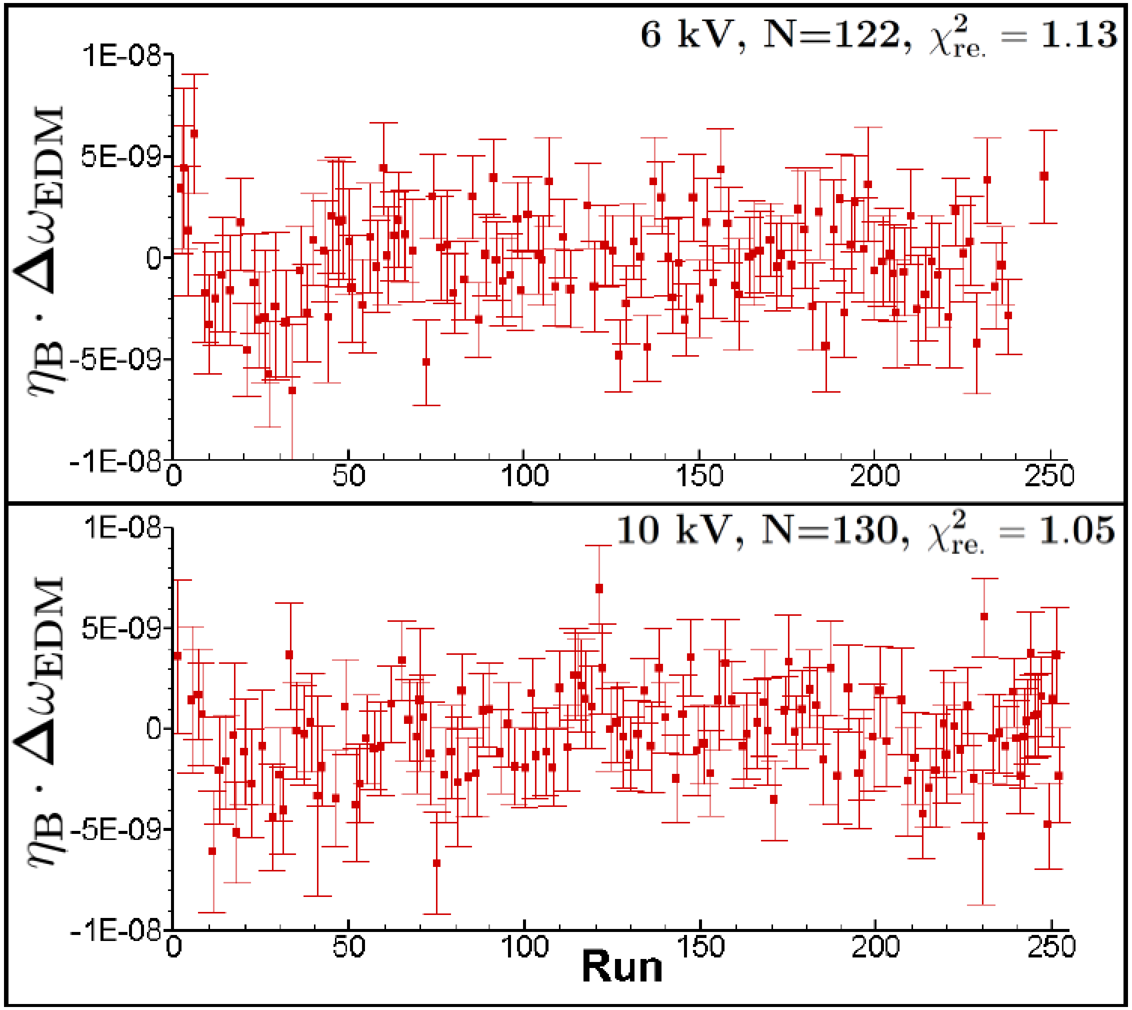
63 non-edm runs were taken to investigate a systematic error that was observed, an HV correlated frequency shift between the outer cells.

32 edm data runs were removed on the basis that:

$$\omega_{OT} - \omega_{OB} > 2.0\sigma \quad or \quad 2.0\times10^{-8}\, s^{-1}$$

Final EDM Data Set

$$d_{Hg} = (2.20 \pm 2.75_{stat} \pm 1.59_{sys}) \times 10^{-30} e \cdot cm$$



$$|d_{Hg}| < 7.5 \times 10^{-30} e \cdot cm$$

at 95% C.L.

(B. Graner, et al, PRL 116, 161601, 2016)

$$d_n < 1.6 \times 10^{-26} e \cdot cm$$

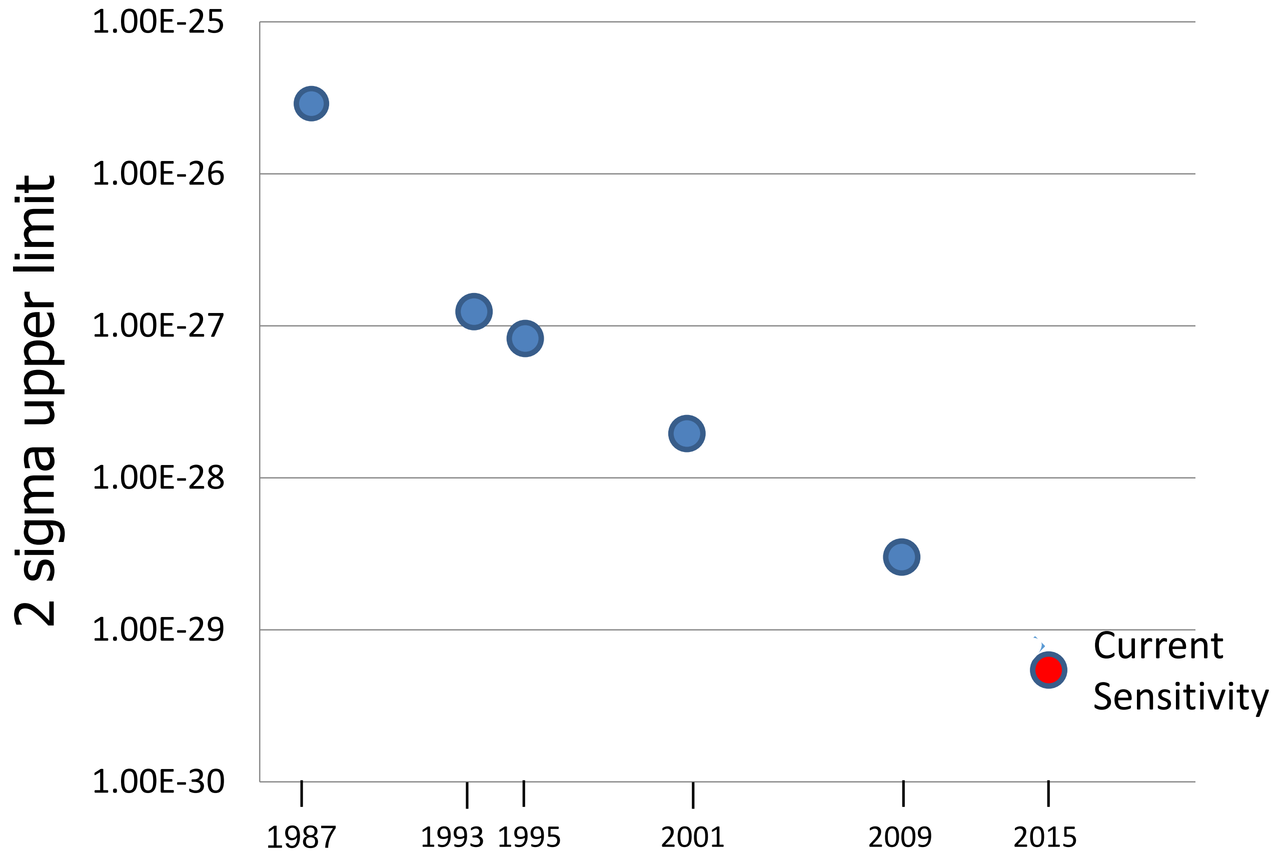
$$d_p < 2.0 \times 10^{-25} e \cdot cm$$

$$\Theta_{QCD} < 8.6 \times 10^{-11}$$

$$C_T < 1.5 \times 10^{-10}$$

$$\tilde{d}_u - \tilde{d}_d < 5.8 \times 10^{-27} cm$$

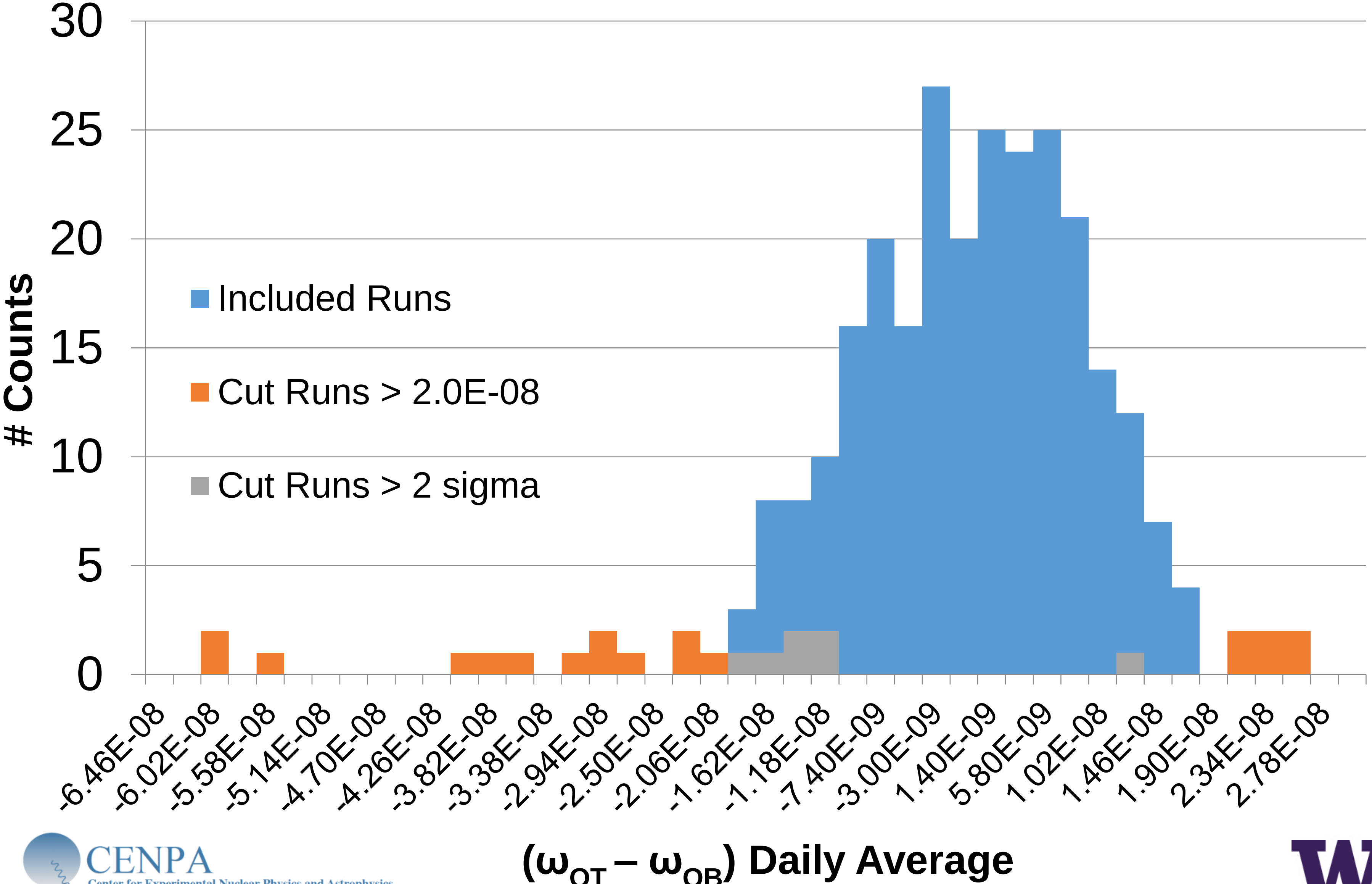
History of ^{199}Hg EDM results



Systematic Error Budget

Source	Error (10^{-31} e cm)
Axial Cell Motion	12.6
Leakage Currents	5.02
Radial Cell Motion	3.36
E^2 effects	3.04
Parameter Correlations	2.33
v x **E B** fields	2.29
Charging Currents	1.83
Geometric Phase	0.06
Quadrature sum	**14.8**

$(\omega_{OT} - \omega_{OB})$ Histogram



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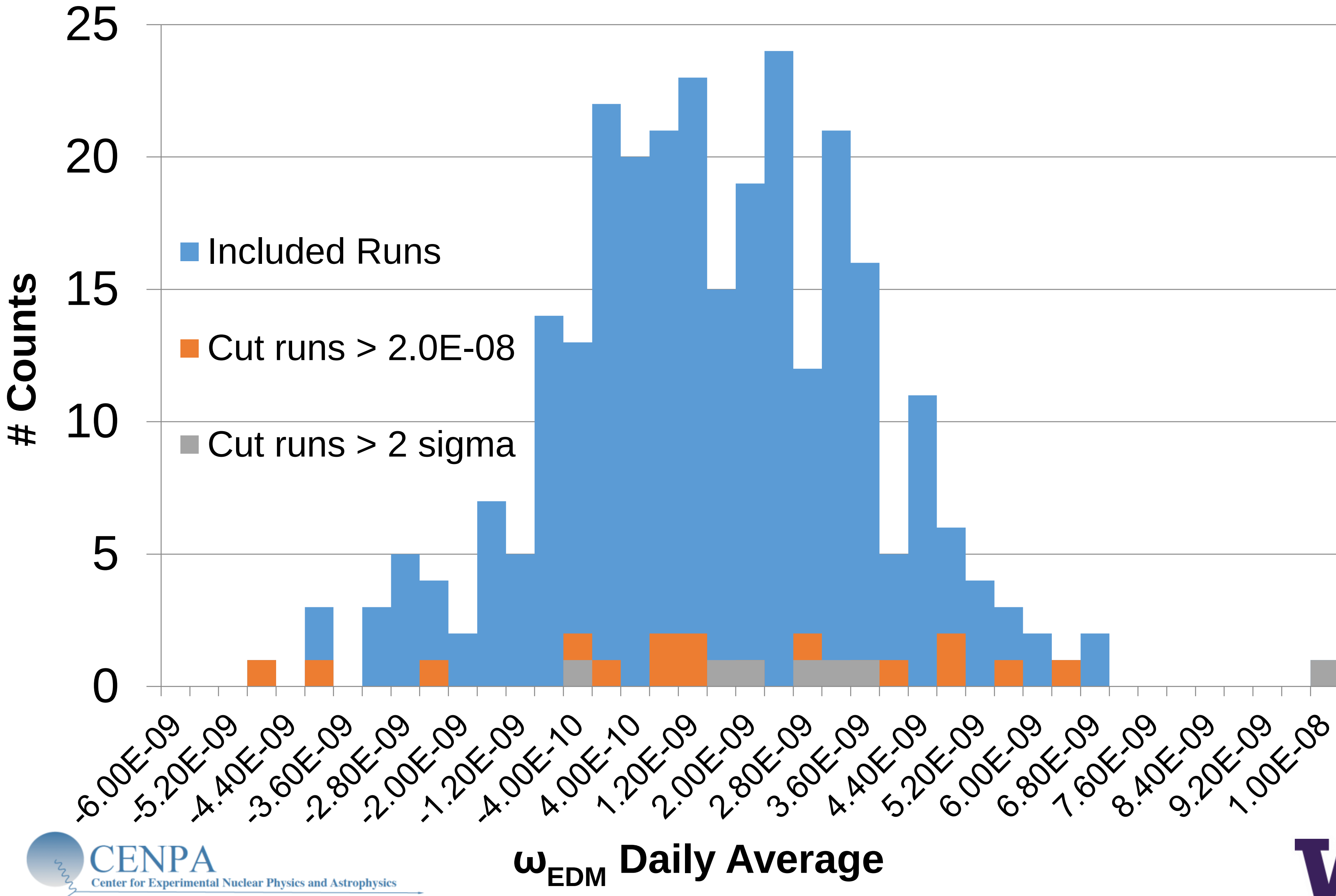
EDM Result Bias



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Axial cell motion

Outer cell motion as small as 100 nm in the known magnetic field gradients would account for the observed signals.

By comparing the set of excluded data (32 cut runs + 63 systematic runs) to the EDM runs, we determined the feedthrough of the cell motion onto the edm signal:

$$\frac{\eta_{\mathbf{B}} \cdot (\Delta\omega_{EDM}^{ex.} - \Delta\omega_{EDM})}{\eta_{\mathbf{B}} \cdot (\Delta\omega_{OT-OB}^{ex.} - \Delta\omega_{OT-OB})} = (1.6 \pm 5.7) \times 10^{-2}$$

An obvious solution to reducing this systematic in future work is to reduce the magnetic field gradients.

Summary and Outlook

We have completed a new measurement of the EDM of ^{199}Hg. Our result represents a factor of 4 increase in sensitivity over our previous experiment.

We have constructed new, shorter vapor cells allowing a 10% increase in the applied electric field strength.

We have installed a new innermost magnetic shield and are in the process of measuring and reducing the magnetic field gradients.

If we can identify the source of the excess noise that we see in our frequency difference measurements, a factor of 2-3 improvement in sensitivity is possible with the existing apparatus.