Comparison of Frozen Spin type EDM search methods

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Considered methods

- BNL Frozen Spin
- I.Koop's Spin Wheel
- Frequency Domain Method

BNL FS

- Observation of the vertical polarization component[1]
  $\Delta P_V \approx P \cdot \omega_{EDM} \cdot t$
- Cross section asymmetry $\varepsilon_{LR} \approx 5 \cdot 10^{-6}$ for smallest practical values of (horizontal plane) ω_{MDM}[2]
- Challenging task for polarimetry[3]

[1] D. Anastassopoulos et al., *AGS Proposal: Search for a permanent electric dipole moment of the deuteron nucleus at the* 10^{-29} $e \cdot cm$ *level.* p. 9.

[2] Ibid., p. 18.

[3] Mane, "Spin Wheel", p. 6.

BNL FS

Systematics

- Only known first-order systematic effect pertaining to the spin dynamics is the existence of $\langle E_V \rangle \neq 0$[4]
- Error frequency $\omega_{syst} \approx \frac{\mu \langle E_V \rangle}{\beta c \gamma^2}$ changes sign when reversing the beam circulation direction (CW/CCW)[5]
- However, at practical values of element alignment error, $\omega_{syst} \gg \omega_{EDM}$, hence $P_V = P \frac{\omega_{EDM}}{\omega} \sin(\omega t + \Theta_0) \not\approx P \omega_{EDM} t$

* Since it's a Phase Domain method, it's vulnerable to the geometric phase error[6]

[4] D. Anastassopoulos et al., *AGS Proposal: Search for a permanent electric dipole moment of the deuteron nucleus at the* 10^{-29} *$e \cdot cm$ level.* p. 10.

[5] Ibid., p. 11.

[6] V. Anastassopoulos et al., *A Storage Ring Experiment to Detect a Proton Electric Dipole Moment*, p. 6.

Geometric phase error

- Caused by the non-commutativity of rotations
- In "Frequency Domain Logic" it means the absence of a definite orientation of the spin precession axis (SPA)

* Call that the *3D Frozen Spin* state

FS-type methodology

Conditions of success

- One must always have a definite direction of the SPA
- Frequency (not phase) must be measured

These conditions are satisfied by two methods:

- Spin Wheel
- Frequency Domain

Spin Wheel

The Spin Wheel is great; it satisfies both success conditions.

- Apply a radial magnetic field of strength B_x sufficient to turn the spin vector about the $\hat{x}$-axis with a frequency of 1 Hz
- $\omega_{B_X} \parallel \omega_{EDM}$ hence $\omega_{net} \propto \omega_{EDM} + \omega_{B_X}$[7]
- EDM effect $\hat{\omega}_{EDM} = \frac{1}{2}\left[\omega_{net}(+B_X) + \omega_{net}(-B_X)\right]$
- Value of B_X is calibrated by measuring the vertical orbit splitting

[7] Mane, "Spin Wheel", p. 6.

Spin Wheel

The good, the bad, the ugly

- Higher polarization growth rate greatly simplifies the task for polarimetry
- Magnetic field calibration by means of orbit split measurements seems unfeasible
- Element misalignment-induced error is not accounted for:

$$
\begin{aligned}
\hat{\omega}_{EDM} &= \frac{1}{2}\left(\omega_{EDM} + \cancel{\omega_{B_X}} + \omega_{mis} + \omega_{EDM} - \cancel{\omega_{B_X}} + \omega_{mis}\right) \\
&= \omega_{EDM} + \omega_{mis}
\end{aligned}
$$

Frequency domain method

This methodology has been developed specifically to deal with misalignment error.

- No reason to apply an external B-field; misalignment B_X-field provides a sufficiently fast wheel
- The FS condition ensures that $\omega_{net} \propto \omega_{EDM} + \omega_{mis}$
- The same EDM estimator $\hat{\omega}_{EDM} = \frac{\omega_{net}(+B_X)+\omega_{net}(-B_X)}{2}$
- To flip the sign of B_X one must reverse the guide field polarity (CW/CCW comeback)
- The value of B_X is calibrated via horizontal plane precession frequency