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

As seen by the authors

- ▶ 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 · cm level.* p. 9.
[2]Ibid., p. 18.
[3]Mane, "Spin Wheel", p. 6.

- ▶ 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 growth occurs mostly due to the MDM

- * 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 · 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

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[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:

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

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