An Active Spin Tune Feedback System for the Cooler Synchrotron (COSY)
Nonzero electric dipole moment (EDM) of elementary particles violates CP-Symmetry

\[ H = -\mu \sigma \cdot B - d \sigma \cdot E \]

\[ \mathcal{T} : H = -\mu \sigma \cdot B + d \sigma \cdot E \]

\[ \mathcal{P} : H = -\mu \sigma \cdot B + d \sigma \cdot E \]

- Standard Model prediction: $10^{-32}$ to $10^{-31} \text{ e cm}$
- New physics?
EDM Measurements in Storage Rings

\[ \frac{dS}{dt} = d \times E^* + \mu \times B^* \]

- Different methods proposed, E-field, B-field, combined
- Signal is build-up of vertical polarization
- COSY is a magnetic storage ring
Spin in Magnetic Storage Rings

- Spin rotates rapidly (120 kHz) around vertical axis
- Define spin tune $\nu_s \approx \gamma G$: spin rotations per turn
- EDM causes small up-down-oscillation of spin, no useful signal
- Need Wien filter in phase with spin over 1000 s, $\Delta f/f < 10^{-10}$
Spin tune can be measured to a precision of $O(10^{-8})$ in 2 s (PRL 115, 094801 (2015))

Wien filter not available, use solenoid

COSY accelerator frequency is adjusted

This changes the spin tune and the time at which the beam arrives at the detector
Feedback System - II

- $f_{\text{COSY}} \approx 750 \text{ kHz}$, $f_{\text{spin}} \approx 120 \text{ kHz}$ and $f_{\text{sol}} \approx 871 \text{ kHz}$:

- $\frac{|\Delta \phi|}{\Delta T} = 7.7 \frac{\text{rad}}{\text{Hz s}} \Delta f_{\text{COSY}}$

- Frequency can be adjusted in steps of 3.7 mHz corresponding to $\Delta \phi / \Delta T \approx \pm 30 \text{ mrad/s}$
Phase Over One Cycle

- Without feedback: relative phase drifts
- With feedback: relative phase fixed over cycle
- Stable within $\sigma = 12^\circ$
Confirm that phase is fixed
Solenoid is switched back on with active feedback system
Polarization tilted into vertical direction at a speed proportional to $\sin \phi$

Vertical Spin Build-Up - I
Vertical Spin Build-Up - II

- Examine angle $\alpha = \arctan \left( \frac{p_v}{p_H} \right)$
- **Blue**: positive initial polarization, **Red**: negative
- Increases at roughly constant rate
- Feedback stops when spin is vertical

$\phi_{\text{set}} = 0.50 \pi$

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Horizontal Spin Build-Up - III

- Slope of build-up has expected sinusoidal shape
- Independent from initial polarization
- Confirms that the feedback system works
Conclusion

- Successfully tested spin feedback system
- Confirmed by direct measurement of relative phase and vertical build-up experiments
- Phase stable within $\sigma = 12^\circ$
- Will be used with RF Wien Filter in precursor experiments