Spin Feedback System at COSY

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Outline

Electric Dipole Moments

Spin Manipulation

Feedback System

Validation Using Vertical Spin Build-Up

Wien Filter Method
Electric Dipoles and Fundamental Symmetries

- 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 $10^{-31}$ e cm

- New physics?
Measurement Principle

- \( \frac{dS}{dt} = d \times E^* + \mu \times B^* \)
- Different methods proposed: E-field, B-field, combined
- Pictured: E-field only
- Signal is build-up of vertical polarization
Cooler Synchrotron - COSY

- From 300 MeV/c to 3300 MeV/c, protons or deuterons
- Circumference: 184 m
- Magnetic ring elements only
- To be used for EDM precursor experiments
Spin Precession

- Vertical magnetic field
- Vertical polarization is stable
- Horizontal polarization precesses
- Coherence time at COSY: $\approx 1000 \text{ s}$
Spin Manipulation

- Spin can be rotated by RF devices
- Comparable to NMR
- Frequency must be on resonance
- Solenoid rotates spin around beam axis (z), Wien filter around y-axis
Spin Resonance

- Resonance: Fixed phase relation between field and spin
- Spin precesses each turn
- Magnetic RF field must match this
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Why Feedback?

- Feedback system fixes phase between spin precession and solenoid frequency
- Need spin in phase with RF over 1000 s
- Would mean, $\Delta f/f < 10^{-10}$ if 80% drop in signal is accepted
- Solution: Adjust accelerator frequency to keep the spin phase fixed
Feedback System

- Measure polarimeter events, COSY frequency and solenoid frequency using one time reference
- Measure phase difference between spin and solenoid
- Adjust COSY accelerator frequency to change the phase
- Tested with solenoid, Wien filter planned
Polarimetry

- Polarized beam causes asymmetry in count rate of elastic events
- Scattering angle $9^\circ$ to $13^\circ$
- Measure asymmetry, e.g. $\frac{N_L - N_R}{N_L + N_R}$
- Horizontal polarization precesses faster than detector rate
Calculating Spin tune and In-Plane Polarization

- Spin tune \( \nu_s = \frac{f_{\text{spin}}}{f_{\text{COSY}}} \approx G\gamma \approx 0.16 \)
- Problem: only one detector event every 24 spin revolutions
- Solution: use time information to map all events to one period
- Spin tune can be measured to a precision of \( O(10^{-8}) \) in 2 s (PRL 115, 094801 (2015))
Relative phase:
\[ \phi = 2\pi f_{\text{sol}} T - 2\pi \nu_s f_{\text{COSY}} T = 2\pi n \left( \frac{f_{\text{sol}}}{f_{\text{COSY}}} - \nu_s \right) \]

- \( f_{\text{COSY}} \approx 750 \text{ kHz} \), \( f_{\text{spin}} \approx 120 \text{ kHz} \) 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

- Top: relative phase drifts without feedback
- Center: relative phase fixed over cycle with feedback
- Bottom: corrections to frequency
- Stable within $\sigma = 12^\circ$
Feedback in Spin Flip

- Spin rotation depends on relative phase $\phi$
- Maximum field when spin is parallel to beam: no effect
- Maximum field when spin is perpendicular to beam: maximum effect
- Use feedback to set relative phase
- Equivalently: Choose where spin points when RF field is at maximum
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- Maximum field when spin is **perpendicular** to beam: maximum effect.
- Use feedback to set relative phase.
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Vertical Spin Build-Up - I

- Confirm that phase is fixed
- Solenoid is switched back on with active feedback system
- Polarization tilted into vertical direction at a speed proportional to $\sin \phi$
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
Vertical Spin Build-Up - III

- Slope of build-up has expected sinusoidal shape
- Independent from initial polarization
- Confirms that the feedback system works
EDM in Magnetic Rings

- Spin rotates rapidly (120 kHz) around vertical axis
- EDM causes small up-down-oscillation of spin, no macroscopic build-up
- Limit for muon EDM measured this way
- Not suitable for hadrons: \( G_\mu \approx 10^{-3}, \ G_\rho \approx 1.79 \), proportional to precession frequency
Wien Filter Method

- Radio frequency Wien filter rotates spin
- Causes net build-up of vertical polarization

\[ \vec{E}^* = \vec{v} \times \vec{B} \]
Wien Filter

- Wien filter: E- and B-fields with zero Lorentz force
- No influence on trajectory at design velocity
- RF field: spin rotates about axis of magnetic field
- $f_{\text{filter}} = f_{\text{COSY}} + f_{\text{spin}}$
Wien Filter Signal

- Top: vertical polarization without Wien filter
- Bottom: the same with Wien filter
- Broad band from rapid oscillation
- Source: PhD thesis M. Rosenthal
RF Wien Filter at COSY

- Frequency 100 kHz to 2 MHz
- Rotatable 90° about beam axis
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
- Phase Locking the Spin Precession in a Storage Ring, Publication: Phys. Rev. Lett. 119, 014801