Spin Feedback System at COSY

21.7.2016 | Nils Hempelmann |

Outline

Electric Dipole Moments

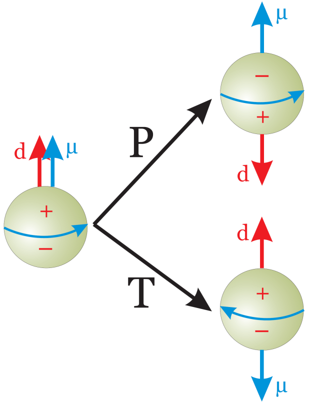
Spin Manipulation

Feedback System

Validation Using Vertical Spin Build-Up

Wien Filter Method

Electric Dipoles and Fundamental Symmetries

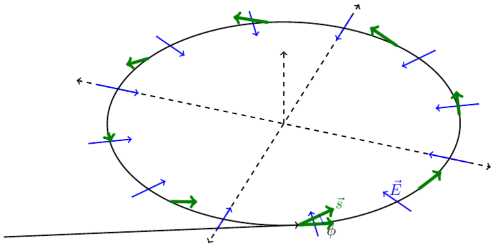


- Nonzero electric dipole moment (EDM) of elementary particles violates CP-Symmetry

$$H = -\mu\boldsymbol{\sigma}\cdot\boldsymbol{B} - d\boldsymbol{\sigma}\cdot\boldsymbol{E}$$
$$\mathcal{T}: H = -\mu\boldsymbol{\sigma}\cdot\boldsymbol{B} + d\boldsymbol{\sigma}\cdot\boldsymbol{E}$$
$$\mathcal{P}: H = -\mu\boldsymbol{\sigma}\cdot\boldsymbol{B} + d\boldsymbol{\sigma}\cdot\boldsymbol{E}$$

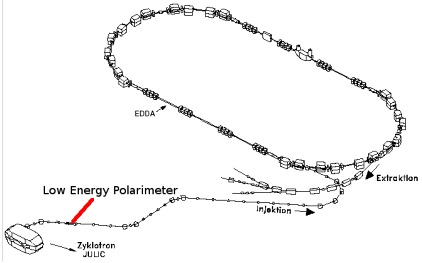
- Standard Model prediction: 10^{-32} to $10^{-31}\ \mathrm{e\,cm}$
- New physics?

Measurement Principle



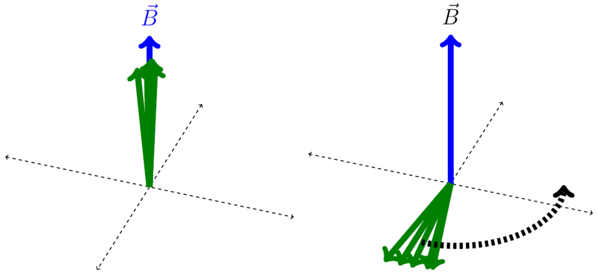
- $\frac{d\mathbf{S}}{dt} = \mathbf{d} \times \mathbf{E}^* + \mu \times \mathbf{B}^*$
- Different methods proposed: E-field, B-field, combined
- Pictured: E-field only
- Signal is build-up of vertical polarization

Cooler Synchrotron - COSY



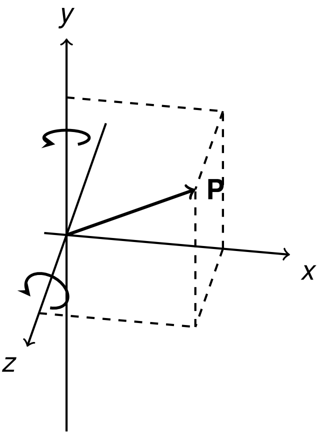
- From 300 MeV/c to 3300 MeV/c, protons or deuterons
- Circumference: 184 m
- Magnetic ring elements only
- To be used for EDM precursor experiments

Spin Precession



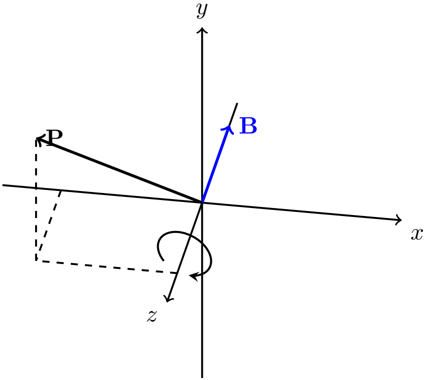
- Vertical magnetic field
- Vertical polarization is stable
- Horizontal polarization precesses
- Coherence time at COSY: $\approx$1000 s

Spin Manipulation



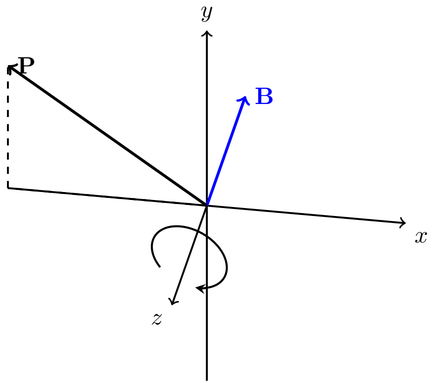
- Spin can be rotated by RF devices
- Comparable to NMR
- Frequency must be on resonance
- Solenoid rotates spin around beam axis (z), Wien filter around y-axis

Spin Resonance



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

Spin Resonance



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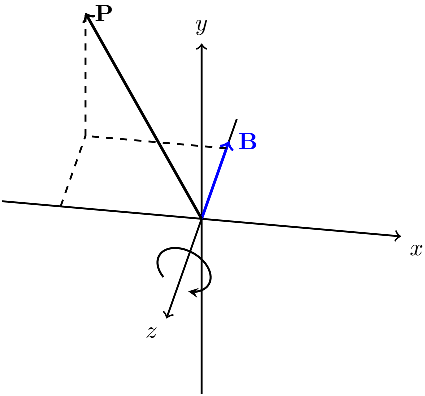

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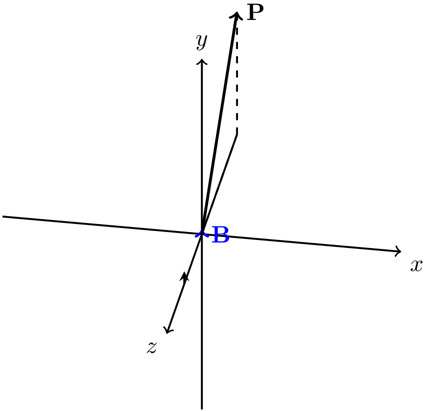

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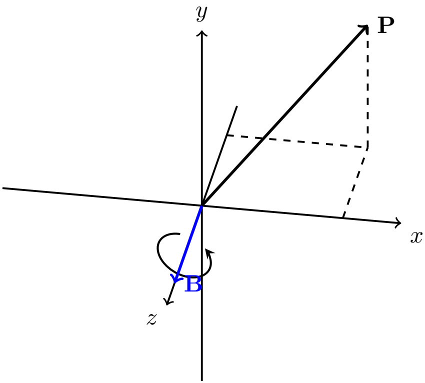

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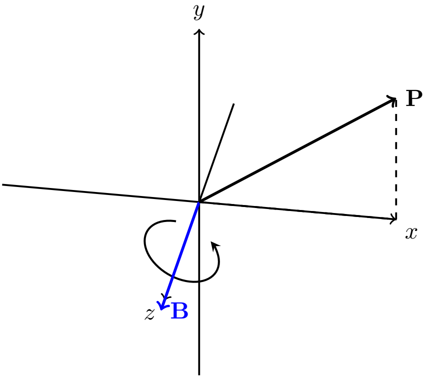

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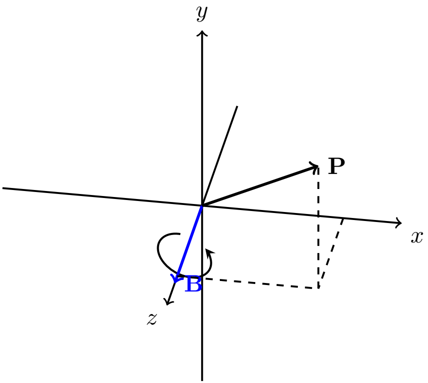

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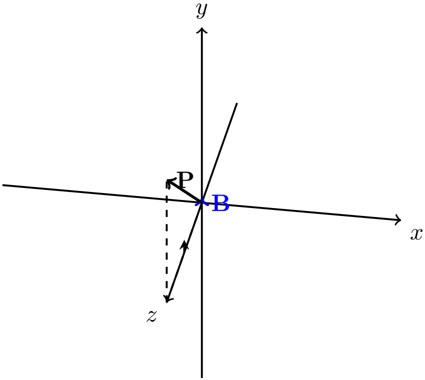

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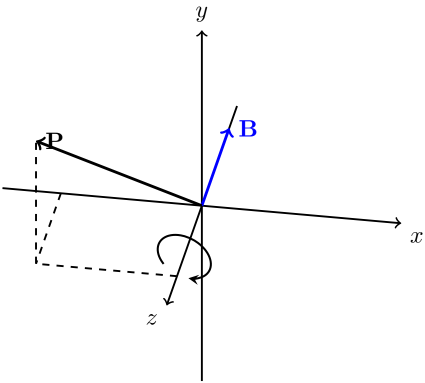

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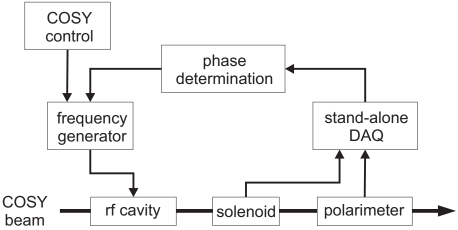
Why Feedback?

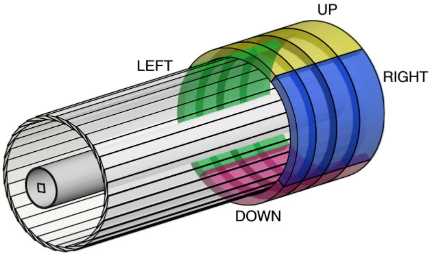
- Feedback system fixes phase between spin precession and solenoid frequency
- Need spin in phase with RF over 1000 s
- Would mean, $\Delta f / f < 10^{-10}$ if 80% drop in signal is accepted
- Solution: Adjust accelerator frequency to keep the spin phase fixed

Feedback System



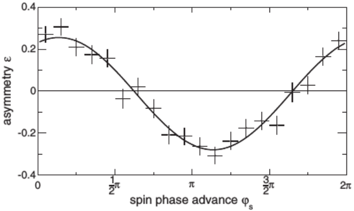
- Measure polarimeter events, COSY frequency and solenoid frequency using one time reference
- Measure phase difference between spin and solenoid
- Adjust COSY accelerator frequency to change the phase
- Tested with solenoid, Wien filter planned

Polarimetry



- Polarized beam causes asymmetry in count rate of elastic events
- Scattering angle 9° to 13°
- 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

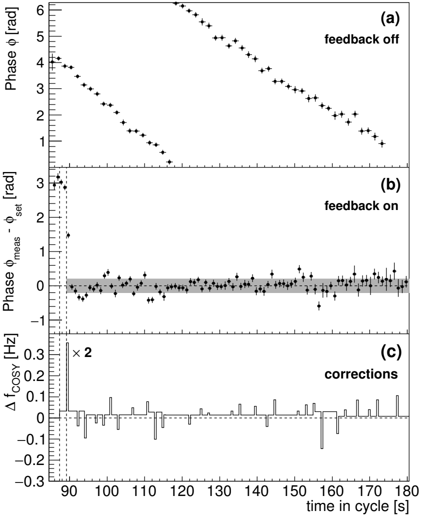


- Spin tune $\nu_s = \frac{f_{\mathrm{spin}}}{f_{\mathrm{COSY}}} \approx G\gamma \approx 0.16$
- Problem: only one detector event every 24 spin revolutions
- Solution: use time information to map all events to one period
- Spin tune can be measured to a precision of $\mathcal{O}(10^{-8})$ in 2 s (PRL 115, 094801 (2015))

Phase and COSY Frequency

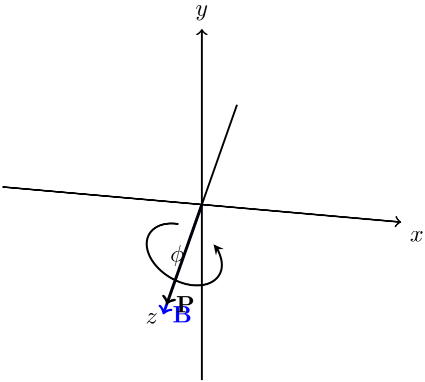
- Relative phase:
  $\phi = 2\pi f_{\mathrm{sol}} T - 2\pi \nu_s f_{\mathrm{COSY}} T = 2\pi n \left(\frac{f_{\mathrm{sol}}}{f_{\mathrm{COSY}}} - \nu_s \right)$
- $f_{\mathrm{COSY}} \approx 750\,\mathrm{kHz}$, $f_{\mathrm{spin}} \approx 120\,\mathrm{kHz}$ and $f_{\mathrm{sol}} \approx 871\,\mathrm{kHz}$:
- $\frac{|\Delta\phi|}{\Delta T} = 7.7 \frac{\mathrm{rad}}{\mathrm{Hz\,s}} \Delta f_{\mathrm{COSY}}$
- Frequency can be adjusted in steps of 3.7 mHz corresponding to $\Delta\phi / \Delta T \approx \pm 30\,\mathrm{mrad/s}$

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 ϕ
- 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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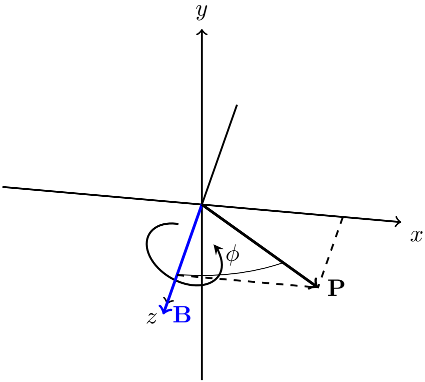

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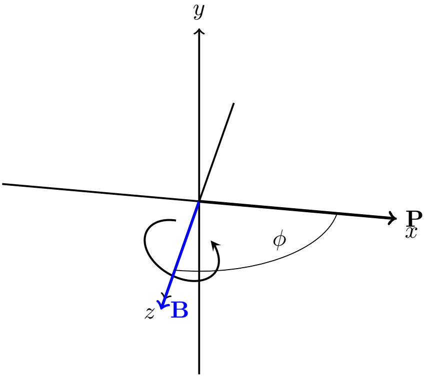

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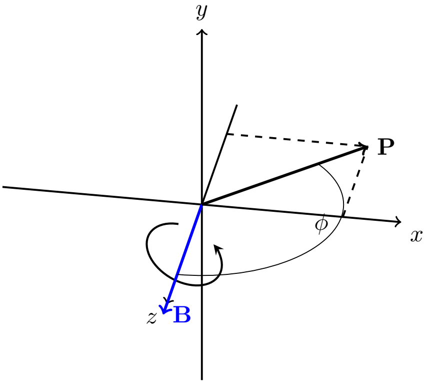

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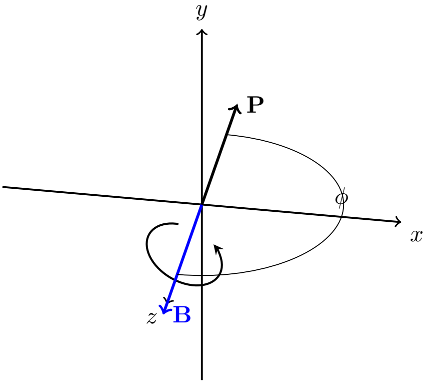

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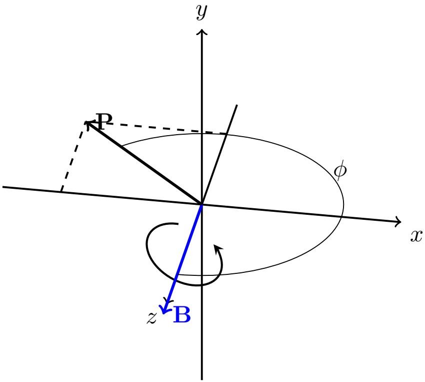

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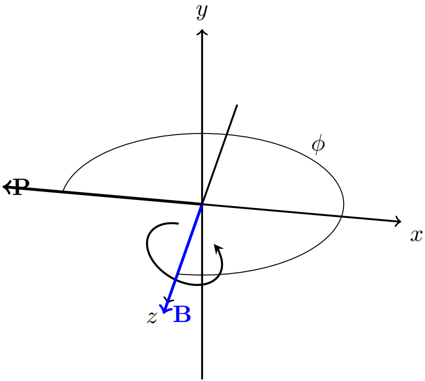

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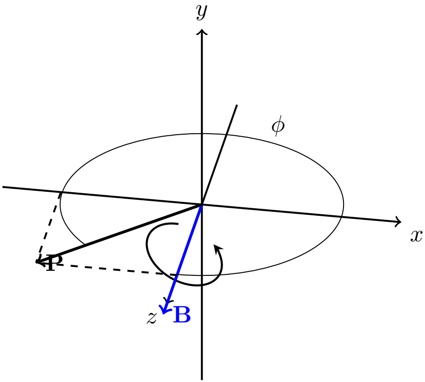

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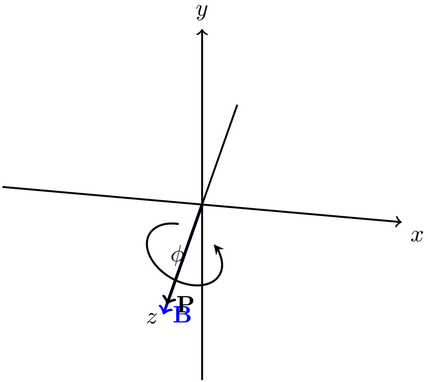

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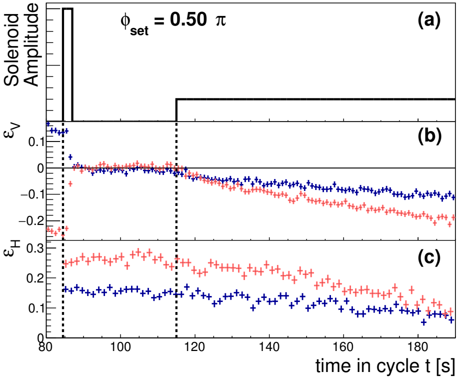
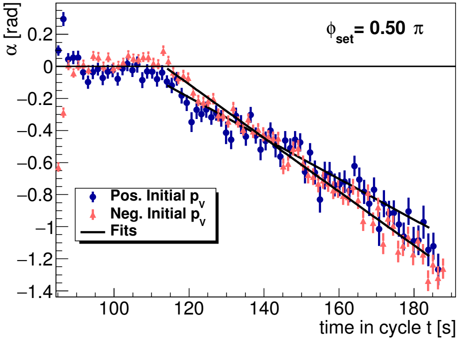
Vertical Spin Build-Up - I



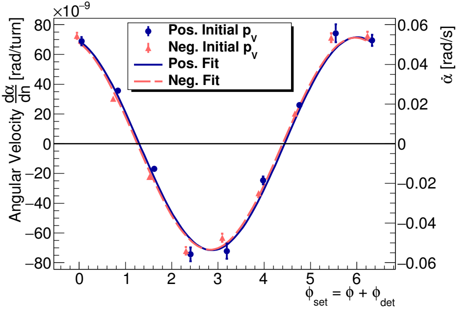
- Confirm that phase is fixed
- Solenoid is switched back on with active feedback system
- Polarization tilted into vertical direction at a speed proportional to sin ϕ

Vertical Spin Build-Up - II



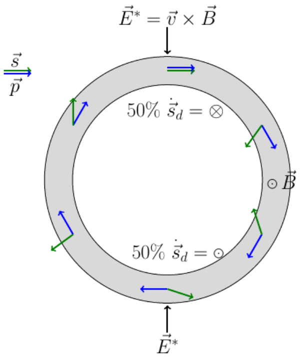
- Examine angle $\alpha = \arctan\left(\frac{p_V}{p_H}\right)$
- Blue: positive initial polarization, Red: negative
- Increases at roughly constant rate
- Feedback stops when spin is vertical

Vertical Spin Build-Up - III



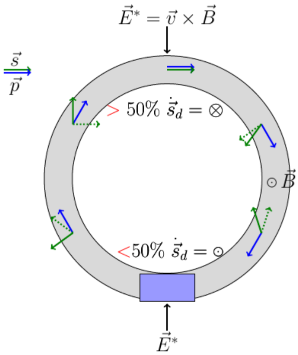
- Slope of build-up has expected sinusoidal shape
- Independent from initial polarization
- Confirms that the feedback system works

EDM in Magnetic Rings



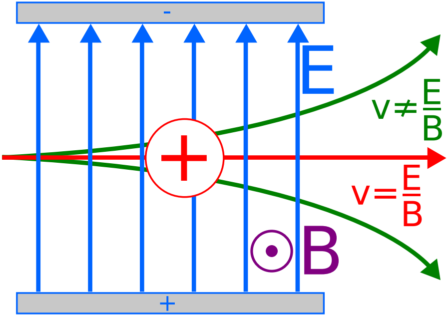
- Spin rotates rapidly (120 kHz) around vertical axis
- EDM causes small up-down-oscillation of spin, no macroscopic build-up
- Limit for muon EDM measured this way
- Not suitable for hadrons: $G_\mu \approx 10^{-3}$, $G_p \approx 1.79$, proportional to precession frequency

Wien Filter Method



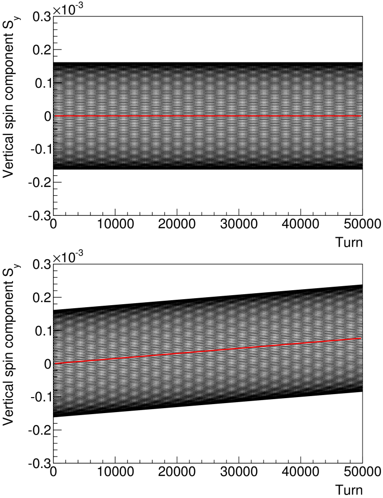
- Radio frequency Wien filter rotates spin
- Causes net build-up of vertical polarization

Wien Filter



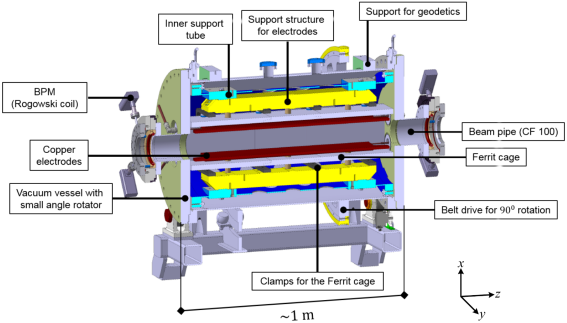
- Wien filter: E- and B-fields with zero Lorentz force
- No influence on trajectory at design velocity
- RF field: spin rotates about axis of magnetic field
- $f_{\text{filter}} = f_{\text{COSY}} + f_{\text{spin}}$

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